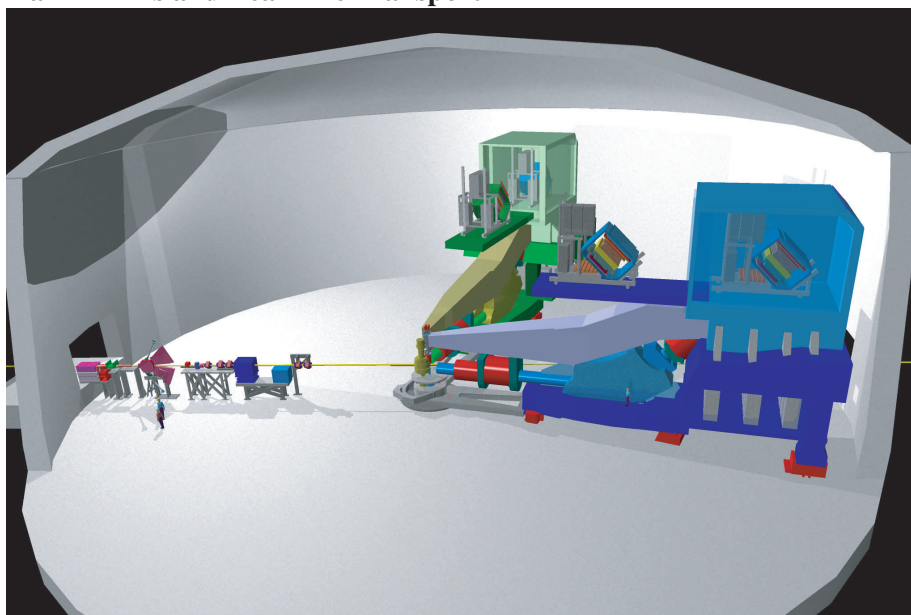


2017 Version: Jefferson Lab Hall A Standard Equipment Manual

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Hall A Arms and Beamline Transport



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The Hall A Collaboration

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August 16, 2018

¹Thomas Jefferson National Accelerator Facility

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Part I

Hall A Standard Equipment Manual

Chapter 1

Introduction ¹

1.1 Technical Information About this Document

*This is a PDF document with hyper-references. Browsing is helped by the “bookmark” menu at the left side of the **acroread** or **xpdf** window. The objects like citations, figures, tables etc. are hyper-marked. One can “click” on a reference to an object and jump to the page with this object. Jumping back can be done using the right mouse button (**acroread**) or the left arrow button at the bottom of the window (**xpdf**). External references to the Web are also “clickable”. In order to use them, make sure that your PDF browser is configured to work with a Web browser (use the button “Preferences” in **acroread**, or provide and edit the file `~/xpdfrc` for **xpdf**). One should open a Web browser window and afterward one may use the WWW-links from the PDF browser. Finally, the PDF browsers allow to search for a given pattern in the whole document.*

The areas of text, dedicated to safety issues, are marked by red color throughout this document. Sometimes only the titles of the appropriate sections are marked. Also, red margin bars mark the beginnings of these areas.

*L^AT_EX (more specifically, **pdflatex**) is used to produce this document. The document source was originally kept in CVS [1] format but has now moved to the Jefferson Lab github repository [2] with a full copy stored on the Hall A’s web pages [3].*

This document can be printed, but it is best used on-line.

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1.2 The Purpose of this Document

This document contains the following information concerning the Hall A “base equipment”:

- general overview;
- safety assessment;
- technical overview;
- operating procedures;
- performance information.

Although reading of this document is not explicitly required, the other documents refer to it, as far as safe operations of the base Hall A equipment are concerned.

The operating procedures are intended to provide shift personnel with the information they need to understand, at least at a rudimentary level, the function of the various subsystems in the end-station. It should also aid in determining if the equipment is performing properly and provide instructions for what to do in the case of malfunctions. This document does not necessary give a complete comprehensive reference to each subsystem, but at least provides a guide for the shift personnel. When appropriate, other references are indicated for the user who requires more information.

This document includes some information on this matter in order to help the shift workers to check up the equipment.

1.3 Hall A Overview

The design purpose of Hall A is to study electron scattering on nuclei and nucleons at high luminosity of up to $5 \cdot 10^{38} \text{ cm}^{-2}\text{s}^{-1}$ with high momentum resolution. The $(e, e'p)$ reaction is often utilized. The spectrometers must have high resolution to be able to isolate the different reaction channels in nuclei.

The basic lay-out of Hall A is shown in Fig. 1.1, demonstrating the Hall dimensions. A CAD-drawn 3-dimensional view of the Hall is given on the scalable picture on the [cover](#) page.

The beam line transports the CEBAF electron beam, in the energy and current ranges of 0.4 - 11.0 GeV and 0.1 - 120 μA to the target at the Hall center. Various types of targets have been used, including liquid hydrogen and polarized ^3He gas. Secondary particles are detected with the two High Resolution Spectrometers (HRS). Both of these devices provide a momentum resolution of better than 2×10^{-4} and a horizontal angular resolution of better than 2 mrad at a design maximum central momentum of 4 GeV/ c . The rest of the beam is transported to the high power water cooled beam dump.

The present base instrumentation in Hall A has been used with great success for experiments which require high luminosity and high resolution in momentum and/or angle for at least one of the reaction products.

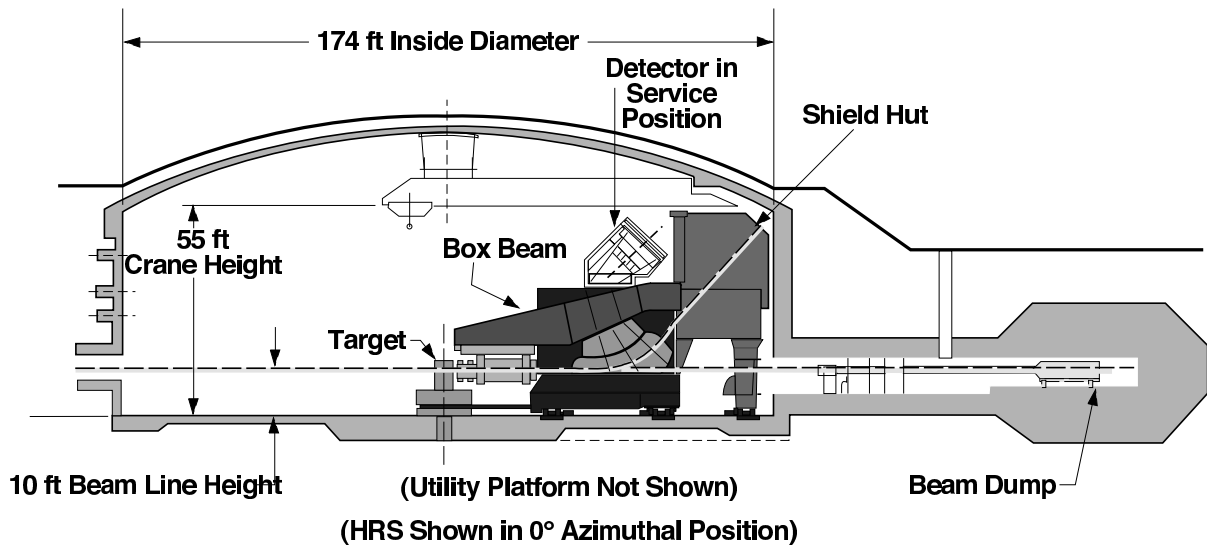


Figure 1.1: Schematic cross section of Hall A with one of the HRS spectrometers in the (fictitious) 0° position.

Part II
Beamline

Chapter 2

General Description ¹

2.1 Introduction

The control and measurement equipment along the Hall A beamline consists of various elements necessary to transport beam with the required specifications onto the reaction target and the dump and to simultaneously measure the properties of the beam relevant to the successful implementation of the physics program in Hall A.

The resolution and accuracy requirements in Hall A are such that special attention is paid to the following:

1. Determination of the incident beam energy;
2. Control of the beam position, direction, emittance and stability;
3. Determination of the beam current;
4. Determination of the beam polarization.

A schematic of the Hall A line starting at the shield wall is shown on Fig. 2.1, 2.2 and 2.3.

2.1.1 The Beam Entrance Channel

The beam entrance channel consists of 63.5 mm inner diameter stainless steel tubing connected with conflat flanges. Through magnets the inner diameter of the tubing is restricted to 25.4 mm. Each section has a roughing port and is pumped with an ion pump. The pressure is about 10^{-6} Torr. There are several sections along the beamline where users interface their equipment. Their individual systems are tested leak tight (to $\leq 10^{-9}$ Atm cm^3/sec).

2.1.2 The Beam Optics Channel

These consist of dipoles, quadrupoles, sextupoles, and beam correctors with their standard girders and stands. Starting from the beam switch yard, there are eight dipoles

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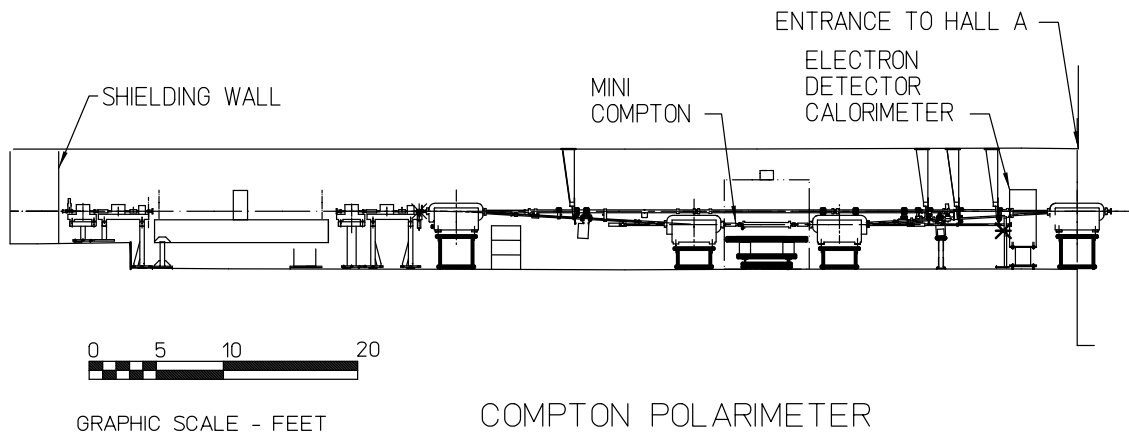


Figure 2.1: Schematic of the Hall A beamline starting at the shield wall to end of alcove.

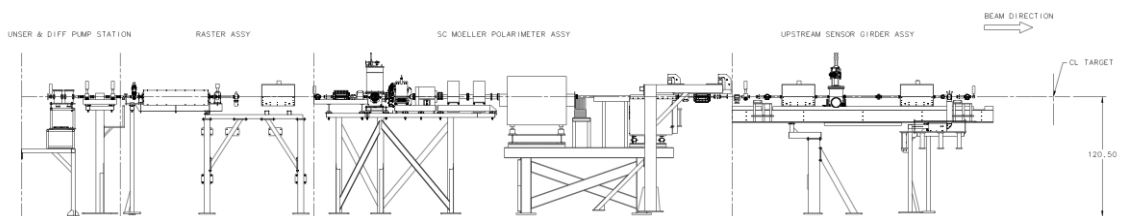


Figure 2.2: Schematic of the Hall A beamline from the end of the alcove to the target chamber. This image has been updated to show the new larger raster system as well as the new Moller magnets.

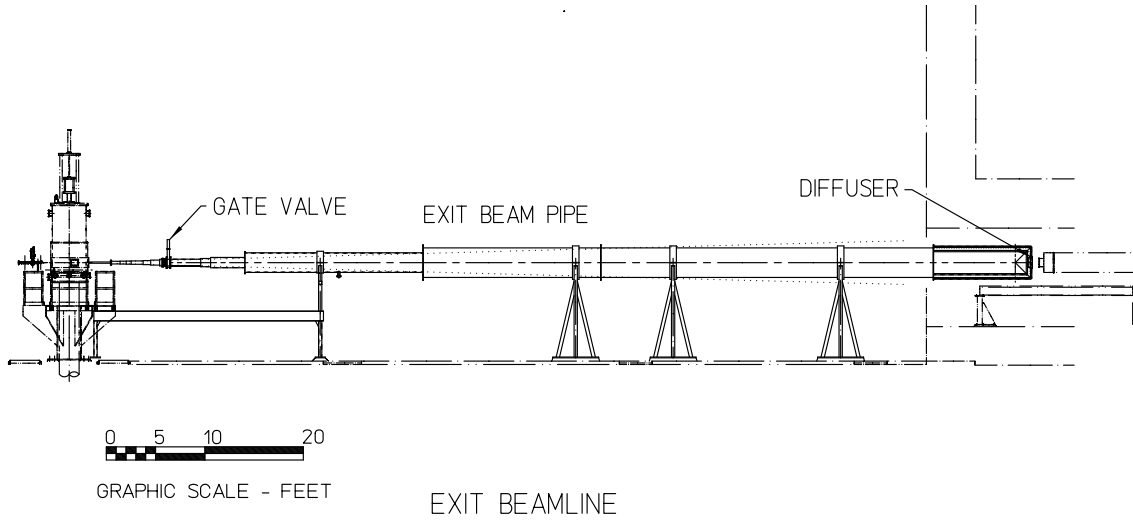


Figure 2.3: Schematic of the Hall A beamline from the target chamber to the dump diffuser.

in the arc section which (along with five other smaller beam deflectors) bend the beam 37.5 degrees into the hall. Each dipole has a quadrupole and a pair of steering magnets (correctors) associated with it. After the shield wall at the entrance to the tunnel into the hall the beam is essentially undeflected onto the target and into the dump.

The beamline optics elements are designed to deliver various optical tunes of the beam on to the physics target as well as simultaneously deliver various optical tunes at other locations along the beamline. These requirements are listed in Tables 2.1 and 2.2. For the basic beamline we are able to deliver beam onto the hall A target in the achromatic mode.

Mode	Spot Size $4 \cdot \sigma_{x,y}$	Dispersion η	Position Stability	Size Stability
Achromat	$140 \mu\text{m}$	0	$50 \mu\text{m}$	$50 \mu\text{m}$
Dispersive	$\propto \eta \delta$	4m to 12m	$50 \mu\text{m}$	$50 \mu\text{m}$
Defocussed	0 to 3mm	0	$\pm 10\%$	$\pm 10\%$

Table 2.1: Line A Optics and Beam Requirements at Target

Build dispersion in arc section with all magnetic elements except dipoles turned off.

²Destructive measurements.

³Build dispersion in arc section with all magnetic elements except dipoles turned off.

Mode	Spot Size $4 \cdot \sigma_{x,y}$	Dispersion η	Position Stability	Size Stability
Energy-eP ²	$>100\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Moller Pol. ²	$>250\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Compton Pol.	$>80\mu\text{m}$	0	$50\mu\text{m}$	$50\mu\text{m}$
Energy-arc ^{2 3}		15m	$50\mu\text{m}$	$50\mu\text{m}$

Table 2.2: Line A Optics and Beam Requirements at Other Locations.

2.1.3 Beam Diagnostic Elements

These consist of beam position monitors (BPMs), beam current monitors, wire scanners (superharps) and beam loss monitors. The wire scanners are fabricated by Saclay (French collaboration) and four have been installed along the beamline, two before the arc section and two after the arc section. They are essential for the beam energy determination by the arc method. Another two wire scanners are installed on the bench just before the target to determine the beam position and direction of the beam at the target point with high precision and also measure the emittance of the incident beam. They are also used to absolutely calibrate the two associated beam position monitors located in front of the target.

To determine the position and the direction of the beam on the experimental target point, two Beam Position Monitors (BPMs) are located at distances 7.524 m (IPM1H03A) and 1.286 m (IPM1H03B) upstream of the target position. The BPMs consist of a 4-wire antenna array of open ended thin wire striplines tuned to the fundamental RF frequency of 1.497 GHz of the beam [4]. The standard difference-over-sum technique is then used [5] to determine the relative position of the beam to within 100 microns for currents above $1\mu\text{A}$. The absolute position of the BPMs can be calibrated with respect to the scanners (superharps) which are located adjacent to each of the BPMs (IHA1H03A at 7.353 m and IHA1H03B at 1.122 m upstream of the target). The schematic of the readout electronics is shown in Figure 2.4. The position information from the BPMs can be recorded in three different ways:

1. The averaged position over 0.3 seconds is logged into the EPICS [6] database (1 Hz updating frequency) and injected into the datastream every 3-4 seconds, unsynchronized but with an reference timestamp. From these values we can consider that we know the average position of the beam calculated in the EPICS coordinate system which is left handed.

2. Approximately once a shift (or more often if requested by the experimenters) a B-scope procedure [7] can be performed using the same EPICS electronics which then gives the peak-to-peak variation of the beam.

3. Event-by-event information from the BPMs are recorded in the CODA datastream from each of the 8 BPM antennas (2x4) from which the position of the beam can be reconstructed. However, these raw values belong to a parallel electronics chain whose constants have to be retrieved by calibrations to the EPICS or scanner data.

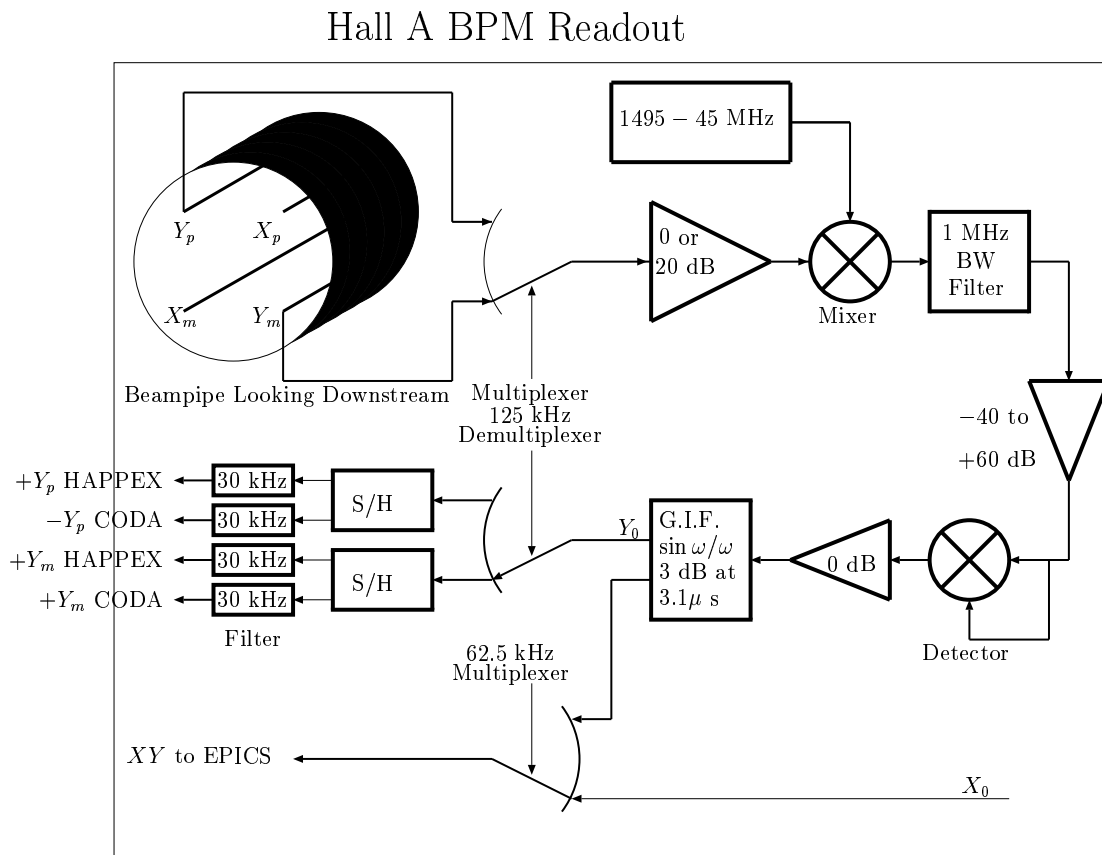


Figure 2.4: Schematic of the BPM readout electronics

2.1.4 Beam Exit Channel

After the target vacuum chamber, which was built by the University of Virginia, there is an exit beam pipe which transfers the scattered beam onto the dump tunnel under vacuum. This exit beam pipe is made of a thin walled aluminum spiral corrugated pipe of welded construction. The largest diameter is 36 inches with a 0.164 inches wall thickness and the smallest diameter is 6 inches with a 0.042 inches wall thickness. The whole assembly is rather light (approximately 800 kg) and is supported by H shaped adjustable stands. To prevent possible linear collapse of the larger diameter sections under vacuum load, four aluminum channels of total cross-sectional area of 3" are welded to its side. A vacuum of 10^{-5} Torr is maintained with a turbomolecular pump. The exit face of this pipe has a 12" port and is connected to the diffuser with a Beryllium window.

2.2 Machine/Beamline protection system

The MPS [8] system is composed of the Fast Shutdown System (FSD), Beam Loss Monitor (BLM), and gun control system.

The FSD system is a network of permissive signals which terminate at the electron gun and chopper 1. The permissive to the gun and chopper 1 may be inhibited by any device connected to an FSD mode. Devices connected to the FSD system include vacuum valves, RF systems, Beam loss systems, beam current monitors, beam dumps, and particular to Hall A, the target motion mechanism and the raster (value and derivative).

The gun control system includes software program which monitors beam operating conditions and the state of the FSD and BLM systems. the program will warn the operators if a potential for beam damage exists. Potential for damage exists when running high average current beam, when FSD nodes are masked and when the beam power approaches the operating envelope limits for a specific beam dump.

2.3 Safety Information

The beamline in the Hall provides the interface between the CEBAF accelerator and the experimental hall. All work on the beamline must be coordinated with both physics division and accelerator division; in order to ensure safe and reliable transport of the electron beam to the dump.

2.3.1 Hazards

Along the beamline these various hazards can be found. These include radiation areas, vacuum windows, high voltage, and magnetic fields.

2.3.2 Mitigations

All magnets (dipoles, quadrupoles, sextupoles, beam correctors) and beam diagnostic devices (BPMs, scanners, Beam Loss Monitor, viewers) necessary for the transport of the beam are controlled by Machine Control Center (MCC) through EPICS [6], except for special elements which are addressed in the subsequent sections. The detailed safety operational procedures for the Hall A beamline should be essentially the same as the one for the CEBAF machine and beamline.

Personnel who need to work near or around the beamline should keep in mind the potential hazards:

- Radiation “Hot Spots” - marked by ARM or RadCon personnel,
- Vacuum in the beam line tubes and other vessels,
- Thin windowed vacuum enclosures (e.g. the scattering chamber),
- Electric power hazards in vicinity of the magnets,
- Magnetic field hazards in vicinity of the magnets, and
- Conventional hazards (fall hazard, crane hazard etc.).

These hazards are noted by signs and the most hazardous areas along the beamline are roped off to restrict access when operational. In particular, the scattering chamber, with its large volume and thin windows requires hearing protection once it has been evacuated. Signs are posted by RadCon for any hot spots along the beamline and RadCon must be notified before work is done in a posted area.

Some magnets, as the Møller spectrometer elements, are covered with plastic sheets for electric safety. Any access to these magnets requires the “Lock and Tag” procedure [9] and the appropriate training, including the equipment-specific one.

Additional safety information is available in the following documents:

- EH&S Manual [9];
- PSS Description Document [10]
- Accelerator Operations Directive [11];

2.3.3 Responsible Personnel

Since the beamline requires both accelerator and physics personnel to maintain and operate and it is very important that both groups stay in contact that any work on the Hall A beamline is coordinated.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
<i>Hall A Physicists</i>					
Douglas Higinbotham	Hall-A	7851		doug@jlab.org	<i>1st Contact</i>
Robert Michaels	Hall-A	7410		rom@jlab.org	<i>2nd Contact</i>
<i>Liaisons from Accelerator Division</i>					
Hari Areti	Accel.	7187		areti@jlab.org	..to Physics
Yves Roblin	Accel.	7105		roblin@jlab.org	..to Hall-A

Table 2.3: Beamline physics division and accelerator division points-of-contact.

Chapter 3

Beam Current Measurement ¹

The Beam Current Monitor (BCM) is designed for stable, low noise, non-intercepting beam current measurements. It consists of an Unser monitor, two rf cavities, the electronics and a data acquisition system. The cavities and the Unser monitor are enclosed in a box to improve magnetic shielding and temperature stabilization. The box is located 25 m upstream of the target. You can recognize it as a grey object on the stands, about 2 m downstream from where the beam enters the hall.

The DC 200 down-converters and the Unser front end electronics are located in Hall A. The temperature controller, the Unser back end electronics and its calibration current source, cavity's RF unit (housing the RMS-to-DC converter board) and all multi-meters, VME crate and computers are located in Hall A control room.

3.0.1 System Layout

The schematic diagram of the BCM system is presented in Fig. 3.1.

The Unser monitor is a Parametric Current Transformer designed for non-destructive beam current measurement and providing an absolute reference. The monitor is calibrated by passing a known current through a wire inside the beam pipe and has a nominal output of 4 mV/ μ A. It requires extensive magnetic shielding and temperature stabilization to reduce noise and zero drift. As the Unser monitor's output signal drifts significantly on a time scale of several minutes, it cannot be used to continuously monitor the beam current. However, this drift is measured during the calibration runs (by taking a zero current reading) and removed in calibrating the cavities. The more stable cavities are then used to determine the beam current and charge for each run. We also use the OLO2 Cavity Monitor and the Faraday Cup 2 at the Injector section to provide an absolute reference during calibration runs.

The two resonant rf cavity monitors on either side of the Unser Monitor are stainless steel cylindrical high Q (~ 3000) waveguides which are tuned to the frequency of the beam (1.497 GHz) resulting in voltage levels at their outputs which are proportional to the beam current. Each of the rf output signals from the two cavities are split into two

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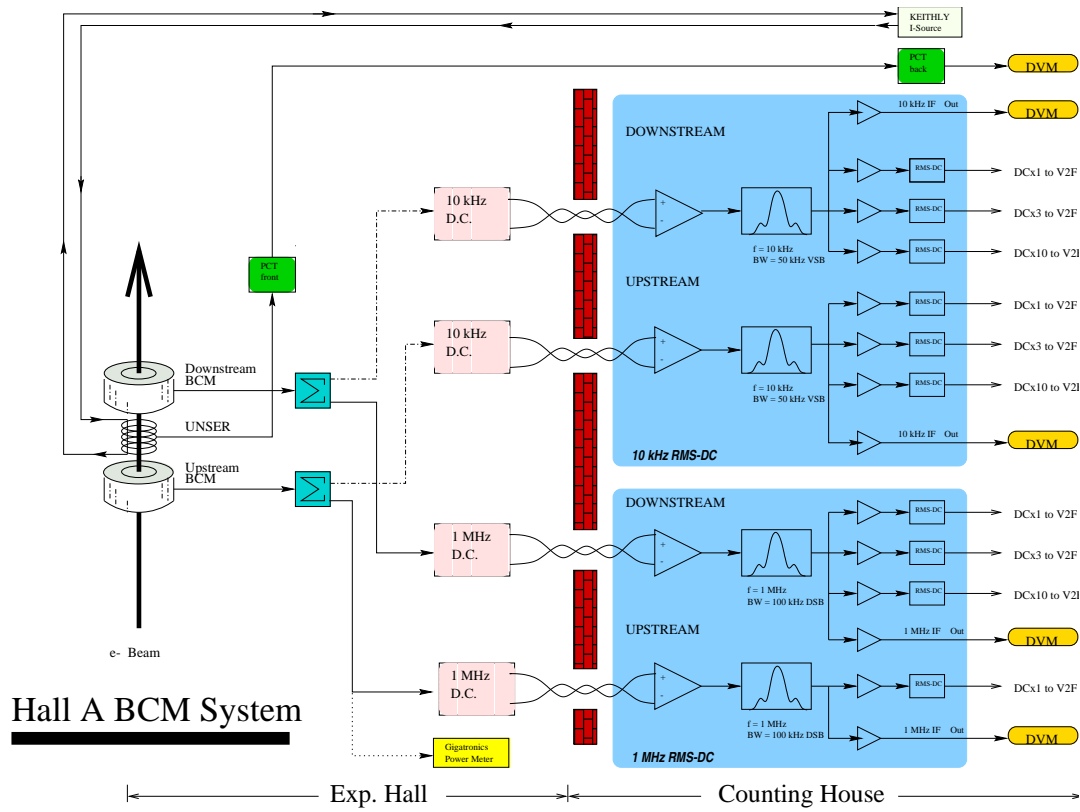


Figure 3.1: Schematic of the Hall A beam current measurement system.

parts. One part of the signal is converted to 10 kHz signals (by the “downconverters”) and fed into an RMS-to-DC converter board consisting of a 50 kHz bandpass filter to eliminate noise, amplified and split to two sets of outputs, which after further processing are recorded in the data stream. These two paths to the data stream (leading to the sampled and integrated data) will now be described. (The other part of the split signal is downconverted to 1 MHz signals and represents the old system (pre Jan 99). Only the HAPPEX collaboration presently uses these signals.)

For the sampled (or EPICS [6] or Slow) data, one of the amplifier outputs is sent to a high precision digital AC voltmeter (HP 3458A). Each second this device provides a digital output which represents the RMS average of the input signal during that second. The resulting number is proportional to the beam charge accumulated during the corresponding second (or, equivalently, the average beam current for that second). Signals from both cavity’s multi-meters, as well as from the multi-meter connected to the Unser, are transported through GPIB ports to the HAC computer where they are recorded every 1 to 2 seconds via the data-logging process which is described in the calibration procedure. They are also sent through EPICS to CODA and the data stream where they are recorded at quasi-regular intervals, typically every two to five seconds.

For the integrated (or VTOF or Fast) data, the other amplifier output is sent to an RMS-to-DC converter which produces an analog DC voltage level. This level drives a Voltage-To-Frequency (VTOF) converter whose output frequency is proportional to the input DC voltage level. These signals are then fed to Fastbus scalers and are finally injected into the data stream along with the other scaler information. These scalers simply accumulate during the run, resulting in a number which is proportional to the time integrated voltage level and therefore more accurately represents the true integral of the current and hence the total beam charge. The regular RMS to DC output is linear for currents from about 5 μA to somewhere well above 200 μA . Since it is non-linear at the lower currents, we have introduced a set of amplifiers with differing gains (x3 and x10) allowing the non-linear region to be extended to lower currents at the expense of saturation at the very high currents. Hence there are 3 signals coming from each BCM (Up_{x1}, Up_{x3}, Up_{x10}, Dn_{x1}, Dn_{x3}, Dn_{x10}). All 6 signals are fed to scaler inputs of each spectrometer (E-arm and H-arm) . Hence we have a redundancy of 12 scaler outputs for determining the charge during a run. During calibration runs we calibrate each of these scaler outputs.

In coordination with the Hall A run coordinator, ll Hall A members are authorized to take BCM calibration data using the Standard Non-Invasive Hall A BCM Calibration Procedure which is maintained in the accelerator document database and it is executed by operates. The extended calibration procedures involving the Faraday Cup 2 and the OLO2 monitor at the Injector are presently performed by accelerator operations though a knowledgeable physicist needs to be present either in the operations room and/or the counting house to ensure that the data is recorded and verified as being correct.

3.0.2 Hazards and Mitigations

As operators perform the calibration procedures there is no hazard to Hall A personnel in performing a beam current measurement.

3.0.3 Responsible Personnel

System responsible personnel are shown in Table 3.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Douglas Higinbotham	Hall-A	7851		doug@jlab.org	<i>Contact</i>
John Musson	Hall-A	7441		musson@jlab.org	Accel. expert

Table 3.1: Beam Current Monitor: authorized personnel

Chapter 4

Target Chamber ¹ ²

The cryo-targets and the waterfall targets (see Sec. 6) are contained in a special target chamber which is a large evacuated multistaged can. So far, three chambers have been designed:

1. a chamber used up to 2003;
2. a chamber designed for use with septum magnets, starting in 2003;
3. a chamber designed for use with the BigBite spectrometer.

Here, chamber 1 is described. Chambers 2 and 3 are only different in size and slightly in shape. The safety considerations fully apply to chambers 2 and 3. The chamber was designed to isolate the beam line vacuum from each HRS so that each HRS could rotate around the target without vacuum coupling and without jeopardizing certain desired kinematic and acceptance specifications of both high resolution spectrometers needed for approved experiments. It was also designed to simultaneously contain a liquid or gas target and an array of water cooled thin metallic foils, both remotely controlled and also be adaptable for the waterfall target. The desired kinematic specifications that were considered included momentum and energy resolution in both arms, angular range of spectrometers, angular acceptance, and luminosity. The chamber vacuum is isolated from the HRS by using thin aluminum foils.

The target chamber is designed so that each spectrometer will have continuous coverage in the standard tune from $\theta_{min} = 12.54^\circ$ to $\theta_{max} = 165^\circ$. The aluminum window is 6 *in* high and 0.016 *in* thick made of 5052 H34 aluminum foil. The foil forms regularly spaced vertical ridges when placed under load. The window had an inter-ridge spacing of 3 inches. If the window is treated as a collection of smaller rectangular windows which have the full vertical height of 6 inches and the inter-ridge spacing as a width, then stress formulas predict that the 0.016 *in* material would reach ultimate stress at a pressure higher than 35 PSID (for both over-pressure and under-pressure). There is a gate valve between the scattering chamber and the beam entrance (exit) pipe. Both valves will be closed automatically in the event that the chamber vacuum begins to rise and an FSD

¹ CVS revision Id: tgtcham.tex,v 1.11 2005/04/04 22:27:25 gen Exp

²Authors: ?? ??@jlab.org

will be caused (this is done via a relay output of the scattering chamber vacuum gauge). If either valve is closed an FSD will result.

The target chamber is supported by a 24 *in* diameter pivot post secured in concrete, rising about 93.6 *in* above the Hall A cement floor. The Hall A target chamber consists of an aluminum middle ring, a stainless steel base ring, each with a 41.0 *in* inner diameter, and a stainless steel cylindrical top hat with 40 *in* inner diameter to enclose the cryotarget and secure the cryogenic connections.

When the scattering chamber is under vacuum, there is a potential danger of window rupture. The loud noise from the rupture could hurt one's ears if not protected. Therefore when the chamber is under vacuum, protective covers are put on if possible. These must be taken off for data taking. For restricted access, the protective cover is required to be on when the chamber is under vacuum. Before switching from controlled access to restricted access, the protective cover is required to be installed. Anytime that the scattering chamber is under vacuum, the pivot area is enclosed in a rope or tape barrier and a warning sign is posted. Hearing protection is required in the enclosed area.

The aluminum ring with an outer diameter of 45.0 *in* and wall thickness 2.0 *in* is necessary for a sturdy support structure and to permit machining of the outside surface to accommodate the flanges for fixed and sliding seals mounted on opposite sides of the ring that vacuum connect the chamber to each HRS. The height of the aluminum ring shown is 36.0 *in*, which is designed to accommodate the mounting flanges. The stainless steel base ring is 11.50 *in* in height with one pump-out 6 *in* diameter port and with seven 4 *in* viewing and electrical feed-through ports. The base ring will also contain support mechanisms for the solid target ladder assembly, a rotisserie for collimating slits, radiators, and magnetic fingers for removing the solid target vacuum-lock can. The total height of the top ring, middle ring, and base ring is 93.81 *in*. This length is partly determined by our desire to include with the cryogenic extended target a solid target vertical ladder secured in an inverted hat through a hole in the base of the chamber.

The base ring includes an end plate through which the inverted hat will be adapted to fit into the large vertical pipe serving as the pivot post for the Hall A spectrometers.

The stainless steel cylindrical top hat has 40.0 *in* inner diameter, and is 0.375 *in* thick and 46.31 *in* high , which is necessary to permit the cryotarget to be withdrawn and to make space available to expose the solid targets to the electron beam.

The 200 μA electron beam, focused to a $\sim 0.1 \text{ mm} \times 0.1 \text{ mm}$ spot and rastered ± 5 mm horizontally or vertically on the target, enters through a oval hole in the middle ring which is 2.06 *in* wide and exits through a 1.81 *in* hole connected to the exit pipe.

4.1 Target Chamber - Spectrometer Coupling

The aluminum middle ring will support a flange on each side for each high resolution spectrometer. Four flanges will be available: Two flanges will contain a 6 *in* window opening which will be covered with a thin foil (e.g., 10 mil aluminum) . These two flanges will be used for experiments utilizing extended targets that do not require optimum momentum resolution. The other two flanges will have two fixed ports (with a 8 *in* \times 6

in opening) which will be mainly used for calibration of the spectrometers . Fixed ports are centered at 16.11° and 45° for one flange and at 16.11° and 90° for the second flange.

For a point beam on target a vertical opening in the walls of the chamber of height $57.15 \text{ cm} \times 0.065 \times 2 = 7.43 \text{ cm}$ is required so that the scattered beam is within the full acceptance of the spectrometer. If the beam is rastered on target $\pm 0.5 \text{ cm}$ in the vertical direction, then the opening in the outer side of the chamber must be at least 8.5 cm for full acceptance.

From consideration of the angular range of the spectrometers in the standard tune, the scattered beam acceptance envelope, the effects of an extended gas target on acceptance, and the effects of a rastered beam $\pm 5 \text{ mm}$ on acceptance, the target chamber requires a window of at least 8.5 cm high in the aluminum ring extending from 6.33° (2.48 in) from the beam exit point to 8.83° (3.47 in) from the beam entrance point on one side and a similar window on the other side of the beam. For future considerations (e.g., using a third arm or sliding seal) the width of the window on the middle ring was actually constructed to be 17.78 cm (7 in).

4.2 Stress Analysis of the Middle Ring

Since the middle ring has an extensive cut across the midplane on both sides as well as entrance and exit holes and loaded with about $25,000 \text{ lbs}$, calculations of the stresses and deformation of the midplane support area of the middle ring and deflection of the window opening were made using the finite element analysis code ANSYS . The work was conducted by a graduate student in the Department of Civil Engineering at the University of Virginia and a REU student. A scaled down model of the middle ring was constructed and then tested by applying forces to it using the Materials Testing Service of the Department of Transportation at the University. ANSYS was first checked by comparing calculations of the test model deflections to the actual data. Agreement was within $\pm 10\%$. Results of ANSYS for the target chamber showed that the maximum deflection of the opening of the window in the middle ring varied from 0.007 in to 0.015 in depending on how the middle ring was loaded. This was decided to be a safe limit. In the final design, several movable 7 in long, 2 in diameter aluminum support rods are placed in the window for added support. In addition, flanges defining the ports and coupling to the spectrometers can be added, giving additional support to the middle ring. Compressional stresses, calculated using ANSYS assuming the middle ring was attached to the top hat and loaded with $25,000 \text{ lbs}$, were less than 3000 psi almost everywhere. However, stresses over small areas rose to levels 6000 psi near the entrance and exit holes. These calculations indicated that we did not exceed the safety limit of $15,000 \text{ psi}$ for aluminum. A simple model calculation shown in Appendix A gives the result 1434 psi , which represents some average value over the midplane contact area.

4.3 Vacuum Pumping System

The vacuum in the target chamber is maintained by an Alcatel (880 l/s) turbomolecular vacuum pump. The pump is connected to a 6 *in* port in the stainless steel ring between $130^\circ \leq \theta_p \leq 180^\circ$. The vacuum pump is fastened to a horizontal pipe connected to the chamber. The vacuum pressure in the chamber is about 10^{-5} mm. An additional Alcatel pump connected to an 8 *in* port should be added to obtain lower vacuum. Both pumps may be isolated from the target chamber using gate valves which are remotely operated from the vacuum control rack and interlocked to the FSD system.

A 2 *in* all metal gate valve is located between the entrance flange to the chamber and the beam profile monitor. An additional gate valve is located 2 m downstream of the target chamber to isolate the chamber from the exit beam pipe.

4.4 Safety Assessment

The scattering chamber is typically a low maintenance item but it is a vacuum system and hence problems may occur. The day to day operations of the cryogenic targets are managed by the Hall A Staff while major maintenance operations are handled by the Cryogenic Target Group (Physics Division). Occasionally the cryogenic targets experience difficulties due to failures of the End Station Refrigerator which supplies the coolant. In these cases the Cryogenics Group of the Accelerator Division should be contacted.

The target chamber may pose several hazards:

1. **Rupture of vacuum windows.** This hazard is mitigated by lexan guards on the vacuum windows, installed by the hall technicians either at the beginning of a “restricted access” period or during “control access”, in case an access to the target chamber area is needed. Installation and removal of the guards is included in the technician’s checklists. When the chamber is under vacuum, it is mandatory to use ear protection in the chamber vicinity. The appropriate signs must be installed by the technicians.
2. **Induced radioactivity.** The RADCON surveyor measures the level of induced radiation as a part of the general survey and may declare the target area as “High Radiation Area”, installing a rope protection around [13].

Some other safety issues are discussed in the cryo-target chapter (see Sec. 7.2).

4.5 Authorized Personnel

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-A	W.B.			<i>Contact</i>
Jessie Butler	Hall-A	5544		jbutler@jlab.org	Target group
Dave Meekins	Physics	5434		meekins@jlab.org	
Jian-Ping Chen	Hall-A	7413		jpchen@jlab.org	

Table 4.1: Target chamber: authorized personnel. “W.B.” stands for the white board in the counting house.

Chapter 5

Arc Energy Measurement ¹

In order to determine the integral field of the eight dipoles that lead to Hall A, and in turn determine the beam energy, a ninth dipole wired in series with the rest is located in a special shed near the hall A counting house.

The ARC energy measurement is under EPICS [6] control through a MEDM [14] display. Two independent control systems are used: the beam bend angle measurement through the arc ("scanners") and the field integral of the arc ("integral"). To measure the energy:

- perform several angle measurements
- perform an integral measurement
- analyze the integral measurement and note the value of the arc field integral
- analyze the angle measurements, average the results (proposed by the software), then ask for the energy calculation, enter the above arc field integral and you will get the beam energy computed from the average angle.

5.1 Summary of ARC operations

Six scanners of the same type, called "ARC scanner" and labeled from scanner #1 to #6, are installed on the Hall-A beamline. Scanners #1 to #4 are used for the ARC energy measurement and they are located on the Hall-A arc: #1 [1HA1C07A] and #2 [1HA1C07B] just upstream of the arc, in the BSY, and #3 [1HA1C18A] and #4 [1HA1C18B] in the Hall-A tunnel, just upstream the Compton polarimeter. Scanners #5 [1HA1H03A] and #6 [1HA1H03B] are located between the Moller and the target to control the beam geometry on the target and their use will not be discussed here.

Procedure for running a harp scan is described elsewhere²

¹Authors: D. Higinbotham doug@jlab.org

² Harp scan procedure http://halloweb.jlab.org/equipment/beam/harp_halla/harp.html.

Each scanner has a motor/ball-screw/shaft-encoder/vacuum-penetrator system moving accurately a set of 3 tungsten wires through the beam. Each time a wire crosses the beam a PMT located a few meters downstream records a signal due to the electromagnetic shower induced by the beam in the wire. Both forward and backward passes are recorded. The motion is a horizontal translation and, for a forward pass:

- the translation is from beam left to beam right,
- the two first wire crossing the beam are at 45deg from the vertical,
- the third wire, which is the only important for the ARC energy measurement, is vertical.

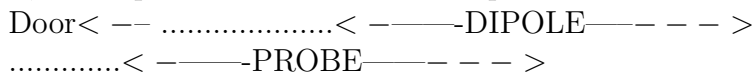
Recording, during the scan, the scanner position and the PMT output voltage allows us to determine the beam position at each scanner location. Then, using calibration data not detailed here, we deduce the net beam bend angle through the arc. This result measured in dispersive arc tuning, along with the field integral of the arc dipoles, provides an accurate determination of the beam energy.

5.2 Summary of field integral

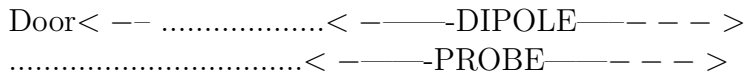
The purpose is to measure absolutely the straight field integral of a "BA" 3m long dipole, called the "9th dipole" and located in the "Dipole Shed". It is of the same type as the 8 arc dipoles and is powered in series with them.

The ARC integral setup is basically made of a 3m long plate (the "probe") which is able to move inside the 9th dipole gap along the beam axis and carrying two field measurement devices: a pair of pick-up coils connected in series and a set of NMR probes. The coils are on both ends of the probe and the NMRs close to the center.

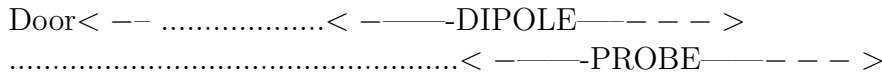
-at the "upstream" probe position, the "downstream" coil is close to the dipole center, the "upstream" is outside the dipole and the NMRs at one end of the dipole:



-at the "central" probe position, each coil is at one end of the 3m long dipole and the NMRs close to the dipole center:



-at the "downstream" probe position, the "upstream" coil is close to the dipole center, the "downstream" is outside the dipole and the NMRs at one end of the dipole:



We call upstream the position where the probe is the closest to the shed access door. Among the 3 above positions, the only one where the NMR can lock on the dipole field is the central one as in the extreme position of the probe, the field homogeneity is not sufficient. The probe position is controlled by a linear encoder. The Z axis refers to the "beam" direction, increasing from upstream to downstream. We use three kinds of "Z":

- Zm to locate a point inside the magnet. The dipole center is at Zm=0 and the yoke ends at +/-1500.mm

-Zp to locate a point inside the probe. The probe center is at Zp=0. Each of the 4 NMR probes has a Zp given in the file "magnet.dir". At a temperature of 21C, the coils are at Zp=+-1519.815mm (from magnet.dir)

-Zd to refer to a displacement of the probe w.r.t. the dipole. Zd=0 refers to the upstream (home) position of the probe. The integral measurement is performed from Zd=0.000mm (1st PDI trigger) to Zd=3199.000mm (last PDI trigger), for forward pass. Zd is given by the display (at the top of the rack) or by the master screen ("OUT").

The relationship between Zm, Zp and Zd is:

$$Zd - Zm + Zp = C$$

where C is a constant given in magnet.dir (C=1604.000 nomin.). Example of use: to have the probe center at the dipole center, one must set Zd=1604.000mm (set Zm=0 and Zp=0 in the above formula, and solve for Zd)

The integral measurement sequence is the following:

-from the current position (a priori arbitrary) move the probe upstream, up to a limit (optic) switch.

-move downstream by a few mm to cross the encoder index (encoder initialization)

-move to the central position to measure the central field by NMR, the system checks if the NMR locks and if the reading is stable, it will be the "before" field

-move back to upstream position

-move to downstream position while integrating the flux through the coil system, this measurement will be called the "forward" integral (duration ~ 7s)

-move back to upstream position while integrating the flux through the coil system, this measurement will be called the "backward" integral (duration ~7s)

-move to the central position to measure the central field by NMR, the system checks if the NMR locks and if the reading is stable, it will be the "after" field.

In addition to the central field, 4 probe temperatures, a local excitation current measurement, the setting of the dipoles P.S, the readback of the dipoles P.S and the probe position at NMR measurement time are recorded "before" and "after".

To perform an integral field measurement:

1-check if the system works (see "details on integral system check" below)

2-run the above integral sequence (see "details on integral run" below)

3-fix the error(s) if any (see "details on integral errors" below)

4-save the data in a file (see "details on integral data save" below)

5-analyze the data

5.3 Details on integral run

To run the integral measurement sequence, call the [arc.integral.adl](#) medm screen, then:

-push "start" to start the full sequence

-look at the results displayed:

-after the "before" NMR measurement: the "before" data set

-after the "forward" integral pass: the forward velocity profile and the forward voltage-after-gain profile

- after the "backward" integral pass: the backward velocity profile and the backward voltage-after-gain profile
- after the "after" NMR measurement: the "after" data set
- if "BAD NMR" or "PDI saturation" flags are set, or if something is obviously wrong in the data or plots, call expert.
- data are ready to be saved (see "Details on integral data save" below)

5.4 Details on temperatures

The AC system of the shed is made of two cooling units, a heating unit and a controller connected to two temperature sensors : one located in the shed and one located in the BSY. This system is programmed in such a way that the temperature of the shed follows the BSY temperature within $\pm 2\text{C}$. The BSY temperature can be anywhere in the 18C to 35C range, regardless of the season. The BSY temperature and the shed temperature are given (in F) by a display panel located close to the workstation, on the wall. The AC system can be set in manual control by turning from "auto" to "manual" a set of switches controlling the cooling units and the heater unit. These switch boxes are located on the shed wall. If the shed temperature is above 34.4C (94F), call the crew chief (the electronics can be damaged) and cool down the shed in manual AC mode. The 4 temperature sensors of the probe are labeled Tx+z+ , Tx+z- , Tx-z+ , Tx-z- depending on their position w.r.t. the frame.

Both "x+" sensors are on the probe edge which is inside the dipole gap and both "x-" sensors on the opposite edge which is outside the dipole gap. Both "z-" sensors are at $1/4$ of the long dimension of the probe and both $z+$ at $3/4$ of this length. The average of the 4 temperatures is used by the analysis program to correct the coil distance from the thermal expansion of the probe, so it is important to make sure that the 4 sensors are working well. The user can just make sure that the temperatures displayed in [arc-master.adl](#) or recorded in [arc-integral.adl](#) are realistic. In [arc-integral.adl](#) they are given in the order: Tx+z- , Tx+z+ , Tx-z- , Tx-z+ Tx-z- and Tx-z+ should be close to the shed temperature. Tx+z- and Tx+z+ depend on the probe position, as the gap (iron yoke) is warmer than the shed and the dipole coil (at both ends of the dipole) is warmer than the iron yoke. For a probe in a central position for more than about one hour, the Tx+z- and Tx+z+ sensors should give the yoke temperature, i.e the shed temperature plus 0. to 5C , depending on the current, LCW temperature and the magnet/shed temperature history. The 4 temperatures are also displayed inside the shed, on the electronics rack. These values are digitized by separate ADCs, so they may differ from the remote values by $\sim 0.1\text{C}$.

5.5 Safety Information

5.5.1 Hazards

The ninth dipole presents a magnetic field hazards as well as the mapper creating a mechanical hazard as it moves. Very high currents are also present in the magnet.

5.5.2 Mitigations

The ARC energy system's dipole magnet and motion system is located in a locked shed with access limited to authorized persons which are listed in the standard equipment manual. To be added to the list, contact Douglas Higinbotham. The standard operation mode of the integral measurement setup is the remote mode, through the network, from the counting house.

Name (first,last)	Dept.	Call [12]		e-mail	Comment	
		Tel	Pager			
<i>Hall A Personnel</i>						
Douglas Higinbotham	Hall-A	7851		doug@jlab.org	<i>Contact</i>	
<i>Accelerator Personnel</i>						
Michael Tiefenback	Hall-A	7430		tiefen@jlab.org		
Yves Roblin	Accel.	7105		roblin@jlab.org		
Rick Gonzales	Hall-A	7198		gonzales@jlab.org		
Bill Merz	Hall-A	5836		merz@jlab.org		
Mark Augustine	Hall-A	7103		augustin@jlab.org		
Hari Areti	Accel.	7187		areti@jlab.org		
Pete Francis	Hall-A	7528		francis@jlab.org		
Scott Higgins	Hall-A	7411		higgins@jlab.org		
David Seidman	Hall-A	7054		seidman@jlab.org		
Ron Lauze	Hall-A	7186		lauze@jlab.org		
Tony Day	Hall-A					
Christopher Curtis	Hall-A	7086		curtis@jlab.org		Alignment group
<i>CEA - Saclay experts</i>						
Pascal Vernin	CEA	OFF		vernin@jlab.org		
Christian Veyssi�re	CEA	9704 [15]		cveyssiere@Cea.Fr		
Francois Gougnaud	CEA					
Jacques Marroncle	CEA					

Table 5.1: Arc Energy Measurement: authorized personnel

5.5.3 Responsible Personnel

The arc requires both accelerator and physics personnel to maintain and operate. It is very important that both groups stay in contact and that any work on the system be

coordinated between the two groups. Therefore, this system has both a physics division and accelerator division point of contact.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Douglas Higinbotham	Hall-A	7851		doug@jlab.org	Physics Contact
Rick Gonzales	Hall-A	7198		gonzales@jlab.org	Accelerator Contact

Table 5.2: Beamline physics division and accelerator division points-of-contact.

Part III

Targets

Chapter 6

Overview ¹

Several types of mutually exclusive target systems have been used in Hall A, including:

1. a system of cryo-targets and solid targets;
2. a waterfall target;
3. a target of polarized gaseous ^3He .

The set of cryogenic targets currently operates with liquid hydrogen, liquid deuterium and gaseous helium 3 or helium 4 as target materials. A variety of solid targets are also provided; BeO, Carbon and Aluminum are typical but other self supporting materials are available if need arises. The combination of cryogenic targets and a few solid targets is the standard configuration.

A waterfall target was used during the commissioning of the hall spectrometers and for hypernuclear experiments. This system also requires a special installation.

In addition, there is a large program based on polarized ^3He . This is a special installation and hence is not available at the same time as the cryogenic target system.

The target(s) presently in use are discussed in the following chapters.

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Chapter 7

Cryogenic Target System ¹

7.1 Procedure for Normal Running of the Hall A Cryogenic Targets

This procedure provides guidelines for the everyday running of the Hall A cryogenic targets.

7.1.1 Introduction

The Hall A cryotarget system allows for multiple configurations depending on the requirements of the experiment(s). In the standard configuration, the system has three separate target loops. One of these loops contains low pressure ⁴He gas with pressure up to 32 psia. The other two loops are usually used for liquid hydrogen and deuterium targets. Each loop can have one or two target cells which is again dependent experiment requirements. Below the loops, solid targets, such as carbon foils can be added.

A short version of the cryotarget target control system user manual is available at http://hallaweb.jlab.org/equipment/targets/cryotargets/Halla_tgt.html. An updated User's Guide to the Hall A Cryotarget is available at https://polweb.jlab.org/guides/atarg/ATARG_MAN.html. Other useful information for cryotarget operators is also available at the above web sites.

During the normal operation, the hydrogen and/or deuterium targets shall have already been liquefied and are in a stable state of about 2 to 3 degrees sub-cooled liquid (19K for hydrogen and 22K for deuterium). The normal operating conditions of the targets are given in Table 7.1. Also listed in Table 7.1 are the freezing and boiling temperatures. These parameters should be reasonably stable (temperature to ± 0.1 K, pressure to ± 1 psi) provided that the End Station Refrigerator (ESR) is stable. The temperature is controlled by a software PID loop with a high power heater (up to 1500 Watts). The PID loops read the output of one of the temperature sensors and adjust the power in the high power heater appropriately. The control loop functions extremely well

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Target	Temperature ($^{\circ}K$)	Pressure (PSIA)	Freezing T ($^{\circ}K$)	Boiling T ($^{\circ}K$)
H ₂	19	25	13.86	22.24
D ₂	22	22	18.73	25.13

Table 7.1: Normal operation conditions of the cryo-target cells

and the temperature fluctuations with steady beam are typically measured in hundredths of degrees. The PID control loop also monitors the electron beam current to keep the target temperature stable by compensating for this heat load during unstable beam situations.

Graphical User Interface

The principal interface with the target is through the Graphical User Interface (GUI), of the control system. Every target operator shall be familiar with the use of the target GUI.

7.1.2 Alarm Handler

It is *mandatory* to have an alarm handler, ALH, running at all times when the target has been cooled-down. Further, it is *mandatory* that the alarm handler be visible in all work spaces on the target control computer. Even though the target safety is ultimately insured by mechanical measures, the alarm handler can save you lots of time, grief and potentially prevent problems with data. The ALH will alarm if any of its parameters goes out of normal range. Servicing the alarm is the responsibility of the target operator. At high beam current, the ALH will usually alarm when the beam goes from on to off or from off to on, since the temperature change is out of normal range. The ALH can also repeatedly alarm if there are noisy analog channels. **If the AH alarms repeatedly or the cause of the alarm is not clear, the target operator should contact the on-call target expert.**

7.1.3 Target Motion and Fast Raster

The target motion is interlocked with the machine Fast Shut Down (FSD) system. Therefore, it is *mandatory* that operators call MCC so that they can remove beam from the Hall and mask our FSD node *before* using *any* target motion mechanism. In the case of Gmp experiment, a separate pointing target is planned to be inside the scattering chamber. This target will be manually positioned by a target group expert. The cryotarget motion control will be disabled, while the pointing target is in position, by power lockout.

When full power beam with tiny beam spot hit the cryotarget, there is a danger that the beam can melt the target cell. The fast raster is used to prevent this from happening. Every time when moving the cryotarget into beam position, the target operator *must*

check to make sure that the faster raster is on and has a reasonable size for beam current above 5 μA .

7.1.4 Cryogenic Consumption

The ESR is not a bottomless reservoir of helium coolant. Every effort should be made to keep our consumption within reasonable bounds. This means that heater overheads should be tens and not hundreds of Watts and that loops which will be dormant for extended periods should be powered down as much as possible. If you feel that the cryogenic consumption is too high (or have received complaints from another ESR user) and are uncertain about the appropriate action contact the on-call target expert.

7.1.5 Checklist

The Hall A target experts and the JLab target group tracks the state of the target. To facilitate this task the target checklist *must be logged in the Elog and the charts and the main target page screen captured at least once per shift.*

7.1.6 Target Operators

One individual on each shift is responsible for target operations. This individual is the dedicated target operator. To become a certified target operator, one must be trained by one of the target experts and to sit one shift with an already certified target operator. The training usually takes place in the Hall A counting house and consists of a guided walk through of the control system and procedures for handling off normal events.

The target operator must read this document, the Safety Assessment Document for the Hall A Cryogenic Targets, and the short version of the GUI manual. The target operator shall be familiar with the GUI system and be able to handle the normal target loop operation, the cryostat operation and the target motion. He/she shall also be able to deal with the GUI crash, the IOC crash and the usual alarms.

After the target operator's training, if he/she feels comfortable with the normal operation of the cryotargets, he/she should sign his/her name on the target operator authorization list, which is maintained in the counting house by the target controls, indicating that he/she has read this procedure and has been trained. The target expert who trained him/her should inform the Hall A staff who is responsible for the cryotarget system (J. P. Chen).

The following table contains the names of the currently recognized target experts (who have worked on the Hall A cryotarget system and have extensive knowledge of the system) and their pager numbers

A cryotarget expert will be on call all the time when a cryotarget is in cooled state. An on-call cryotarget-expert list will be posted in the Hall A Counting House.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
<i>Hall A Physicists</i>					
Jian-Ping Chen	Hall-A	7413		jpchen@jlab.org	cell:218-0722
<i>JLab Cryo-Target Group</i>					
Dave Meekins	Physics	5434		meekins@jlab.org	cell:968-9076
Christopher Keith	Physics	5878		ckeith@jlab.org	cell:746-9277

Table 7.2: Cryo target: experts and authorized personnel, with their phone numbers

7.2 Safety Assessment

7.2.1 Hazards

The cryogenic hydrogen and deuterium targets present a number of potential hazards, such as the fire/explosion hazard of the flammable gas as well as the hazards connected with the vacuum vessel and the of handling cryogenic liquids (ODH and high pressure).

7.2.2 Mitigations

Flammable Gas Hydrogen and deuterium are colorless, odorless gases and hence not easily detected by human senses. Hydrogen air mixtures are flammable over a large range of relative concentrations from 4 % to 75 % H₂ by volume. Detonation can occur with very low energy input, less than 10% of that required by mixtures of air and gasoline. At temperatures above 23K hydrogen gas is lighter than (STP) air and hence will rise. At atmospheric pressure, the ignition temperature is approximately 811K but air H₂ mixtures at pressures of 0.2 to 0.5 Atm can be ignited at temperatures as low as 610K. Hydrogen mixtures burn with a colorless flame [16].

The total volume of hydrogen in the target is approximately 5.4 *l*. The volume changes between the liquid state and gas at STP by a factor of about 850. Thus filling the target would require about 4500 STP *l* of hydrogen. The hydrogen target is connected to a 1,000 Gallon (about 3,800 *l*) recovery tank. The normal running condition for hydrogen is 25 psia. Thus, the total amount of hydrogen in the system is about 11000 STP *l*. A similar volume of deuterium will be required. In addition to this volume, one hydrogen and one deuterium bottle will be kept in the Hall in order to fill and pump/purge the targets. These bottles will be placed in a gas rack behind the gas panels. The large storage tanks are located outside the Hall at the rear of the counting house.

The basic idea behind safe handling of any flammable or explosive gas is to eliminate oxygen (required for burning) and to prevent exposure to any energy source that could cause ignition. In the Hall A environment, the most likely source of oxygen is of course the atmosphere and the most likely ignition sources are from electrical equipment. Oxygen is removed from the internal volumes of the system by pumping and purging the system. Extensive procedures reviewed by an independent expert are used to perform this task. This task shall only be performed by system experts.

There are three flammable gas detectors installed (one on top of the target, one each on top of the hydrogen and deuterium gas panels) to provide early detection of hydrogen/deuterium leaks. These detectors are sensitive (and calibrated) over the range from 0 to 50% Lower Explosive Limit (LEL) of hydrogen. The electro-chemical sensors were manufactured by Crowcon Detection Instruments LTD and the readout (four channels) was purchased from CEA Instruments, Inc. (The Gas Master Four System). The readout unit provides two alarm levels per channel. The low level alarm is tripped at 20% of LEL while 40% of LEL activates the high level alarm. Each channel has a relay output for both low and high level alarm states and there is also a set of common relays for both alarm levels (these common relays respond to the logic of the sensor inputs).

Electrical Installation Hall A contains a significant amount of electrical equipment and almost all of it could serve as an ignition source in the presence of an explosive oxygen and hydrogen mixture. Extensive efforts have been made to minimize the dangers from the equipment that is most likely to come into contact with hydrogen gas. Electrical equipment considered to be in close contact with hydrogen meets the requirements of NFPA 2 Hydrogen Technologies Code and/or NFPA 55 Compressed Gases and Cryogenic Fluids Code as well as NFPA 497. Equipment not meeting these Code requirements is isolated during off normal events by either valve isolation (vacuum turbopumps) or by electrical power trip.

A pressure switch, installed on the scattering chamber, will trip when the vacuum in the scattering chamber is greater than 1 torr (i.e. during an isolation vacuum loss event). This switch de-energizes the following systems: vacuum gauge power, fan motor power, and heater power supplies. The switch also forces pneumatically actuated gate valves to close isolating the turbo pumps.

There are a number of electrically powered devices associated with the target gas handling system. All the pressure transducers in the system are approved for use in a hydrogen atmosphere. The solenoid valves on the gas panels are explosion-proof and have been disabled. The readouts for the pressure transducers are mounted in the target control equipment racks man meters from the gas panels. All the pressure transducers have 4-20 mA outputs.

In addition to the electrical devices in the gas handling system, there are a number of devices inside of or mounted on the scattering chamber.

All the devices which are in the scattering chamber must have their power delivered to them by wires in vacuum. The insulation of these wires must be radiation resistant, so Kapton and glass fiber tubing insulation has been used where applicable.

The following electrical items are in close proximity to or are actually in the hydrogen system.

Axial Circulation Fan The fans which circulate the hydrogen in the target are AC induction motors and therefore contain no brushes and are practically immune to sparking. The three phase power for these fans is delivered to them by 18 gauge stranded copper wire with Kapton insulation. The maximum current that the fans

draw is 5 A for a maximum power consumption of 200 W when pumping liquid hydrogen/deuterium. The current and voltage drawn by the fans is monitored by the control system.

Fan Motor Tachometer The fans have a tachometer which consist of a coil that views the flux change caused by a permanent magnet attached to the motor rotor. The tachometer signals are carried on 22 gauge stranded wire with Kapton insulation. This is a low power signal. The control system monitors the frequency of the fans.

High Power Heater There is a high-power heater in the pipe of the loop. The maximum power available is 1500 W. The current and voltage supplied to this heater are monitored by the control system and there is a software power maximum enforced on the power setting of this heater. Internal vacuum connections to the heaters are made with 18 gauge stranded wire with Kapton insulation.

Resistive temperature sensors There are six resistive temperature sensors immersed in each target loop. These resistors provide temperature measurements of the target fluid. The temperature controllers that read them use a current of less than 30 μ A to excite them (they are excited with a constant voltage which for our resistors is on the order of 30 mV). The resistors are connected to the outside world with quad strand 36 gauge phosphor bronze wire with Formvar insulation.

Target Lifter An AC servo motor provides the power to lift the target ladder. This motor is powered by three phase 208 V power and is equipped with fail safe brakes (the brakes are **released** by a loss of 24 V DC control voltage) and 50 to 1 gear reducers. On power up, there is a delay relay that ensures that the motors are always energized before the brakes are released.

Vacuum Pumps The scattering chamber is evacuated by two Leybold 1000 l/s turbo pumps that are backed by a Leybold 65 cfm mechanical pump. The turbo pumps are powered by 120 V AC power while the backing pump requires three phase 208 V AC power. The turbo pumps are isolated during an insulating vacuum failure event by the use of automatic gate valves. The motors on the backing pumps are induction motors and approved for use in this environment. (The JLab fire protection engineer has reviewed this issue). An identical mechanical pump is used in the pump and purge system of the gas panels. Both the scattering chamber backing pump and the pump and purge system's mechanical pump exhaust to the vent line.

Vacuum Gauges The chamber vacuum is monitored by an HP cold cathode gauge. This gauge is not rated for hydrogen service and is therefore isolated from the scattering chamber vacuum during an insulating vacuum loss event by automatic gate valve. This gauge has a maximum operating voltage of 4000 V and a maximum current of 133 μ A. The pressure at the entrance to the roughing pump is measured by a convectron gauge.

Gas Handling System The most important aspect of hydrogen safety is to minimize the possibility of explosive mixtures of hydrogen and oxygen occurring. Therefore the gas handling system has been made of stainless steel components (wherever possible) and as many junctions as possible have been welded. Flanged connections are made with metal seals where possible. Reasonable measures have been implemented to ensure that the system pressure does not fall near or below atmospheric pressure.

The pressure in the gas handling system is monitored in numerous places. Most importantly, the absolute pressure of the target is viewed by two pressure transducers, one on the fill line, PT127 for H₂ and PT136 for D₂, and one on the return line, PT131 for H₂ and PT140 for D₂. These pressures are also measured by manual gauges. The fill line gauges are PI126 for H₂ and PI135 for D₂. The return line gauges are designated PI130, H₂ and PI139, D₂. The gas tanks are viewed with both pressure transducers (PT133 for hydrogen and PT142 for deuterium) and pressure gauges (PI123 for hydrogen and PI112 for deuterium).

If the pressures significantly deviate either from one another or from the normal operating pressure, the target operator shall call the target-expert-on-call. When they differ from one another, it often is due to a failure of one (or more) of the pressure transducers. If more than one deviates significantly from the normal operating pressure, it could be due to temperature change or could be a more serious situation (i.e. a leak in the system).

The target system is considered by JLab to be a “Pressure System”. Thus, the design and construction of the system must meet the requirements of the the most applicable ASME pressure code. The Codes of Record for the system are ASME Boiler and Pressure Vessel Code Section VIII Division 1 and ASME B31.3 Process Piping Code. These Codes have conservative safety allowances. The system was not originally designed or constructed to these Codes, however all alterations of the system are in compliance. Further the relief system has been modified to meet these Code requirements. All currently used cells and cell blocks also meet the requirements of the B31.3 Code. The large volume storage tanks located outside the Hall also meet the requirements of the ASME Boiler and Pressure Code and bear an ASME nameplate. These tanks are inspected on a regular basis and currently (or will by time of operation) meet the National Board Inspection Code requirements.

Target Cells The target cells themselves represent the most likely failure point in the hydrogen system. The outer wall is made of 0.006 *in* thick aluminum. The entrance and exit windows are thinner, but no less than 0.004 *in*. There is one 15 *cm* long cell bolted on to each cell block. The cell has an outer diameter of 3 inches. The upstream windows are connected to 0.8 *in* diameter tubes with flanges which are also bolted on to the cell block. A vertical flow diverter plays a role to make the coolant flow in vertical direction to help remove the beam heating more effectively. The cell and cell block components have been pressure tested hydro-statically to meet the requirements of the ASME B31.3 2008 Process Piping Code. The design pressure of the current cell is 100 psi.

Pressure Relief The gas handling and controls systems have been designed to prevent excessive pressure build up in the system in order to protect the target cells from rupture. It has been determined that the worst case pressure load will arise from an insulating vacuum loss. The calculation of this load was reviewed by a JLab Design Authority not associated with the target group. The estimated relief load is 350 scfm of hydrogen. The primary relief path is 2 inch Sch 10s pipe connected to the recovery tank. There is a separate relief valve on the fill side of the target, CRV30 for H₂ and CRV59 for D₂. This valve is not capable of handling the entire relief load from an insulating vacuum loss event so overpressure protection of the system (on each loop) is provided by an ASME relief valve which meets the requirements of the Code. The capacity of this relief is 1100 scfm for hydrogen. The relief valves exhaust to the Hall A hydrogen vent line. This line is 2 inch Sch 10s IPS stainless steel pipe ~150 ft. long. The vent line is continuously purged with 1 psig of He gas from the House Helium supply. The scattering chamber and pump/purge vacuum pumps are also exhausted to this line. Thus any vented target gas is placed in an inert environment until it is released outside of Hall A. Additionally, each gas tank has one relief valve as required by Code.

The scattering chamber provides secondary containment in the event of a cell rupture. Therefore, the scattering chamber itself has a 1 psig relief (check valve), VRV01 and a 4 psig rupture disk. Thus, the scattering chamber internal pressure will not exceed 5 psig. This relief path is also exhausted to the hydrogen vent line. A series of valves and controls allow for the safe removal and exhaust of hydrogen from the scattering chamber should a cell burst.

Scattering Chamber Vacuum The scattering chamber will be leak checked before service but, the possibility of vacuum loss cannot be eliminated. A conservative calculation estimating the relief load on the relief system of each loop has been performed. This calculation was performed as part of Code and JLab policy requirements and was reviewed by an independent JLab Design Authority. This calculation (TGT-CALC-301-010) has been filed in the Hall A Cryotarget pressure system directory PS-TGT-XX-026. In summary, this calculation conservatively indicates that the relief path and safety devices limit the maximum developed pressure in the cell to less than the 120 psi for all credible overpressure conditions as required by ASME B31.3 322.6.3.

Temperature Regulation This is really more an issue of target stability than one of safety. However, a target with a carefully regulated temperature will presumably not undergo worrisome pressure changes.

Each target contains six quality temperature measurements with resistive temperature sensors. The temperature regulation is performed by a software PID control of a high power heater using one of the quality temperature measurements as input to the loop. This is a three parameter control loop (Proportional, Integral and Differential Control or PID). The PID loop also compensates for the beam heat load during beam trip and recovery incidents. This is not a true regulation but rather one for one replacement of the beam load should the beam disappear for whatever reason. The beam load is

calculated from the target length, the beam current as read from a current monitor and the target material.

Excursions of the target temperature outside acceptable limits will cause the control system to take action. Finally the redundancy of temperature measurements can be used by the control system to pick up the failure of a sensor or its readout channel. A more complete discussion of target temperature regulation is available in Reference [17].

Target Freezing Solid hydrogen is more dense than the liquid phase, so freezing does not endanger the mechanical integrity of a closed system. The chief hazard is that relief routes out of the system will become clogged with hydrogen ice, making the behavior of the system during a warm-up unpredictable. For this reason, the relief route bypasses the heat exchanger and should not freeze during any credible scenario.

The coolant flow through the three target heat exchangers is connected in parallel for the three target loops. The entire target system will be operated so that it represents a constant heat load on the ESR. For instance, the ESR will deliver a constant mass flow of helium cryogen at a constant temperature, about 15 K, and the coolant will be returned at an approximately constant but higher temperature, usually about 20 K. The targets are temperature regulated by IOC heater PID loop.

In the unlikely event that the target temperature drops too low, an alarm will sound and the target operator shall turn down the corresponding J-T valve(s) or apply auxiliary heater power. Target temperature can fall after IOC reboot. After the reboot the high power heater will be reset to zero before going back to PID control. Although the time the high power heater is zero is short (for about 1 minute), the temperature will drop. To prevent this from happening, an auxiliary heater is used in parallel to the regular heater. During an IOC reboot, the auxiliary heater supply will replace the main supply to keep the temperature from dropping unacceptably. Since 2008, the IOC has been relocated to the entry labyrinth where the radiation exposure has been minimized. As a result the frequency of IOC reboots has dramatically decreased.

ODH The total volume of the targets is relatively small, with the entire scattering chamber containing only 9,000 STP l of target gas when all three targets are full. As the scattering chamber is located in the middle of Hall A (i.e. not in a confined area) and the total Hall A volume is 40,000 m^3 , the ODH hazard is minimal.

Controls The target controls have been implemented with the EPICS [6] control system and with hardware very similar to that employed by the accelerator. The basic control functions reside on a VME based single board computer or IOC. The graphical interfaces to the control system use a PC, and also require the Hall A Hewlett Packard, HP, computer for control (HAC) to be present as well. Power failures will result in a loss of computer control. As a result of such a failure the target heat exchanger may freeze and the remainder of the target may vent through the relief path. The beam will also be tripped during such a failure. There is thus, little chance of damage or danger

from the system. During a power failure, the target operator shall call the target-on-call immediately.

The principal functions that the control system performs are:

Pressure/Temperature Monitoring The pressure and temperature are monitored at various places in the system and alarm states are generated if a sensor returns a value that is outside defined limits.

Target Lifter The target lifting mechanism is controlled by the computer. This allows one to place the desired target in the beam. Limit switches and hard stops are installed to ensure the target cannot move outside the allowable range.

7.2.3 Checklist

Checklist for pre-hall-closing:

- Target has completed cool-down, at least one loop has liquid hydrogen with temperature stable at 19K, pressure stable at around 25 psi.
- High power heater in PID control for the hydrogen loop.
- Loop fan (pump) has been set to non zero value (20-75 Hz) for the hydrogen loop.
- Coolant (ESR) flow and inlet temperature are stable.
- All unused loops are filled with over 1 atm gauge of helium gas.
- Scattering chamber vacuum is normal (below 10^{-5}).
- target in “Empty” position for beam tuning.
- Alarm handler is on and all alarm limits are set.
- No constant alarms caused by abnormal conditions.
- Target-on-call name is written on the whiteboard.

7.2.4 Responsible Personnel

The principle contacts for the cryogenic targets are listed in table 7.3. Every shift must have a trained target operator whenever the cryogenic targets contain liquid. These operators are trained by one of the “experts” listed in the table and certified by J.P. Chen, Silviu Covrig, or Greg Smith.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
<i>Hall A Technicians</i>					
Tech-on-Call	Hall-A	W.B.			Vacuum
Jessie Butler	Hall-A	5544		jbutler@jlab.org	Vacuum
<i>Hall A Physicists</i>					
Cryotarg-on-Call	Hall-A	W.B.			Cryotarget
Jian-Ping Chen	Hall-A	7413		jpchen@jlab.org	Cryotarget
Greg Smith	Hall-C	5405		smithg@jlab.org	Cryotarget
Silviu Covrig	Hall-C	6410		covrig@jlab.org	Cryotarget
<i>JLab Cryo-Target Group</i>					
Dave Meekins	Physics	5434		meekins@jlab.org	
Christopher Keith	Physics	5878		ckeith@jlab.org	
<i>Central Helium Liquefier (CHL) Experts</i>					
Cryo-on-Call	via-MCC	7048			ESR
CHL-group	Cryo	7405			ESR

Table 7.3: Cryo target: authorized personnel and contacts. “W.B.” stands for the white board in Counting House.

Part IV

Magnetic Spectrometers

Chapter 8

Hall A Vacuum System

1

The Hall A vacuum system consists of 5 separate but interconnected subsystems. The largest is designed to supply the Hall A HRS (see Chapter 9) with a self contained 5×10^{-6} Torr vacuum that enables both spectrometers to be pumped down from atmospheric pressure. in a few hours. The target vacuum system is designed to maintain 1×10^{-6} Torr in order to minimize contamination and provide an insulating vacuum for the cryo target. Rough insulating vacuum for the 4 superconducting magnets is provided by a 360 *cfm* Roots type blower that can be connected to each magnet. The beam line vacuum is maintained by 1 ℓ/s ion pump system used in the accelerator ring and a small turbo pump located near the target. The final subsystem is a differential pumping station located near the target exit port.

8.1 HRS Vacuum System

The HRS vacuum system is shown in Figure 8.1. Vacuum for the HRS is supplied by an Alcatel 880 ℓ/s Turbo pump backed by a Balzers 360 *cfm* Roots type Blower. This Blower, via a special manifold, also supplies the roughing vacuum to the HRS at the Dipole Inlet Transition. The first Turbo is mounted on the lower side of the Dipole entrance transition. The roughing port is also located on this transition, on the top side. The upper turbo is located on the lower side of the window transition.

Vacuum readouts and interlock outputs are supplied by five (5) HPS series 421 Cold Cathode gauges and seven (7) series 275 Mini-Convectron gauges. In addition to these there will also be a Fisons Micromass 386 RGA head installed in the system for diagnostic purposes. Most of this instrumentation will be located on the Turbo pump manifold (for detailed information see Figure 8.1).

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on each respective spectrometer on the gantry platform. Selective equipment will also be controllable from the Hall A counting house.

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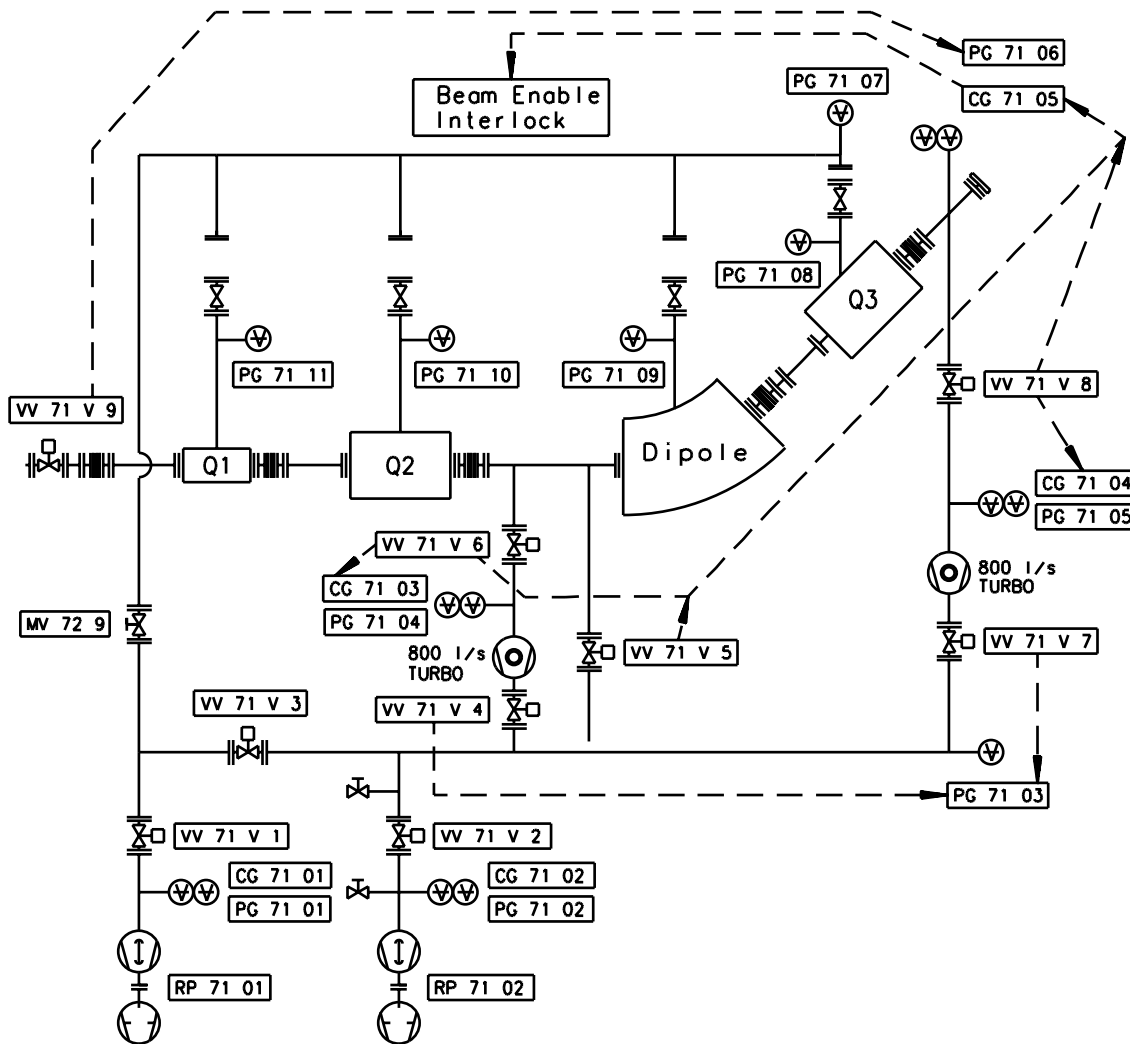


Figure 8.1: HRS vacuum system.

Chamber

The HRS vacuum chamber consists of an associated vacuum window, a sieve slit and Q1 transition, Q1 to Q2 transition, Spool section, Dipole transition, Dipole to Q3 transition, and the Q3 to exit window assembly. The spectrometer vacuum is contained by a 0.007 inch kapton window at the entrance and a 0.004 inch titanium window at the exit.

8.2 Target Vacuum System

Vacuum for the target chamber is supplied by an Alcatell 880 ℓ/s Turbo pump backed by an Alcatell 21 *cfm* 2 stage vane pump. The Turbo is mounted on the lower ring of the Target Chamber to one side so as not to interfere with the Target Chamber windows.

The same instrumentation is used here as on the spectrometer.

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on the access Balcony. Selective equipment will also be controllable from the Hall A counting house.

8.3 Magnet Vacuum System

Vacuum for the magnet insulating vacuum is provided by the Cryo pumping effects of each individual magnet.

All controls for the Magnets are manual as we expect no problem after initial pump down.

The insulating vacuum for each magnet is self contained within the magnet.

8.4 Beam Line Vacuum System

Vacuum for the entrance beam line is supplied by 65 ℓ/s Balzers turbo pumps, the first of which is located on the E P chamber, and the second located 3 *m* upstream of the target chamber. Both turbos are equipped with a HPS 7 Series 275 mini Convectron gauge and a HPS series 421 Cold Cathode gauge located near the balcony.

Vacuum readouts and relay outputs for interlocks are supplied by HPS series 421 Cold Cathode gauges. In addition to these there will also be Convectron gauges. Most of this instrumentation will be located on the Turbo pump manifold.

Powered valves, instrumentation and pumps will be controlled and powered at the Vacuum System equipment rack located on the Balcony. Selective equipment will also be monitored from the Hall A counting house. All control is by Accelerator in the MCC.

8.5 Beam Exit Vacuum System

Vacuum for the target chamber is supplied by an Alcatell 880 ℓ/s Turbo pump backed by an Alcatell 21 *cfm* 2 stage vane pump which maintains a 1×10^{-4} vacuum on the exit beam pipe.

Between the target chamber and the exit beam pipe there is a 0.007 inch kapton window that has a 0.0375 inch hole in it at the beam spot. This window acts as a differential pumping station.

Also between the target chamber and the exit beam pipe is an 8 inch air actuated gate valve that is operated from the MCC.

Vacuum readouts and interlocks outputs are supplied by an HPS 7 Series 275 mini Convectron and an HPS series 421 Cold Cathode gauge which are located near the balcony.

Controls are interlocked to the beam.

The chamber is made of a low mass aluminum corrugated vacuum tube of 1 *m* diameter.

At the exit point of the exit beam pipe is a beam diffuser that consists of 2.025 inch beryllium windows with a water filled cavity between them for cooling. The water is circulated through the cavity by a water cooling system located on the Hall floor, and is interlocked through the FSD system with 2 flow switches, one on the supply and one on the return line.

Due to high radiation levels at the exit beam pipe all seals in this area are metal.

8.6 Safety Information

8.6.1 Hazards

Hazards associated with the vacuum system are due to rapid decompression in case of a window failure. Loud noise can cause hearing loss.

8.6.2 Mitigations

To mitigate the hazard, all personnel in the vicinity of the large chamber with a window are required to wear ear protection when the chamber is under vacuum. Warning signs must be posted at the area.

The scattering chamber is equipped with a large 0.016" thick aluminum window that allows the spectrometers to swing from 12.5° to 165° on the left side and 12.5° to 140° on the right side. In order to protect this window when the Hall is open, lexan window guards are installed.

At the inlet of the sieve slit a 8" diameter 7 mil kapton window is provided to separate the target chamber from the spectrometers. Finally, under the HRS detectors, a 4 mil titanium window is provided.

Additionally, all vacuum vessels and piping are designed as pressure vessels.

8.6.3 Responsible Personnel

The authorized personnel is shown in Table 8.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-A	W.B.			<i>Contact</i>
Jessie Butler	Hall-A	5544		jbutler@jlab.org	

Table 8.1: Vacuum in Hall A: authorized personnel. “W.B.” stands for the white board in the counting house.

Chapter 9

High Resolution Spectrometers (HRS)

1

9.1 Overview

The Hall A spectrometers are designed to perform high resolution and high accuracy nuclear physics experiments. An absolute cross section accuracy of up to $\sim 1\%$ is required by the physics program planned in the Hall, which implies $\sim 10^{-4}$ accuracy in the determination of particle momenta and ~ 0.1 mr in the knowledge of the scattering angle.

A layout of the 4 GeV/c High Resolution Electron Spectrometer is shown on Figures 9.2 and 9.1. Its main design characteristics are given in the attached table. The spectrometer has a vertical bending plane and 45° bending angle. The QQDQ design includes four independent superconducting magnets, three current-dominated $\cos 2\theta$ quadrupoles and one iron-dominated dipole with superconducting racetrack coils. The second and third quadrupoles of each spectrometer have sufficiently similar field requirements that they are of identical design and construction. The overall optical length, from target to focal plane, is 23.4 m. Optically, the HRHS is essentially identical to HRES. In fact the two spectrometers can be used interchangeably to detect either positively or negatively charged particles as needed by any particular experiment. They are now commonly referred to as “The Left Arm” and “The Right Arms” rather than “Hadron” and “Electron”

The support structure includes all system elements which bear the weight of the various spectrometer components and preserve their spatial relationship as required for 45° vertical bending optics.

The alignment and positioning system includes all the elements which measure and adjust the spatial relationship. The support structure consists of the fabricated steel

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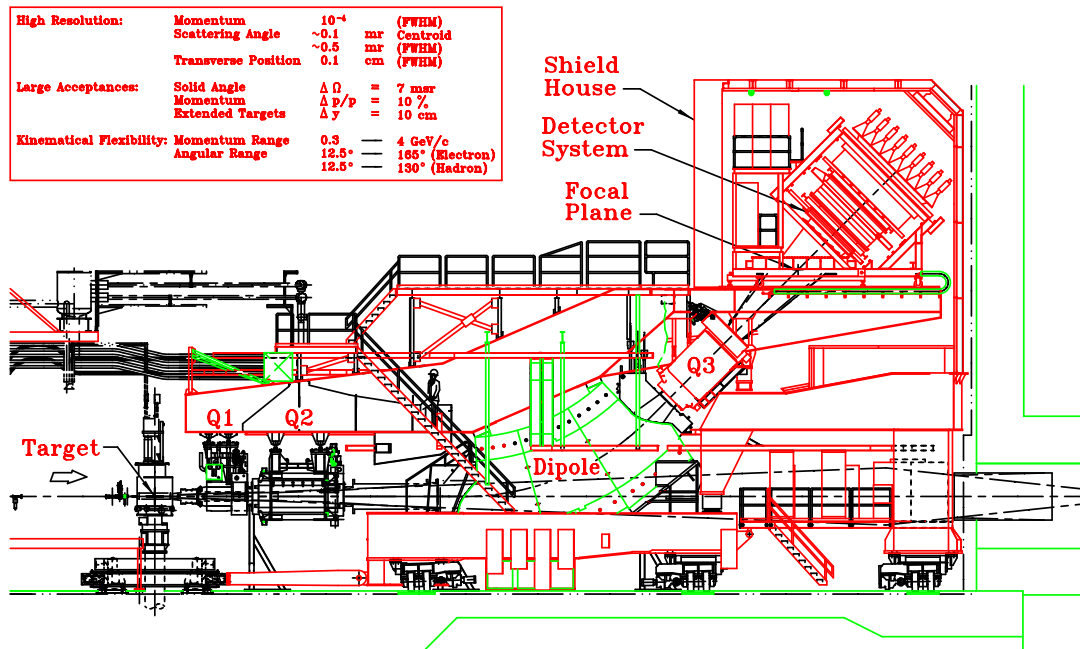


Figure 9.1: A side view of the Hall A HRS spectrometer.

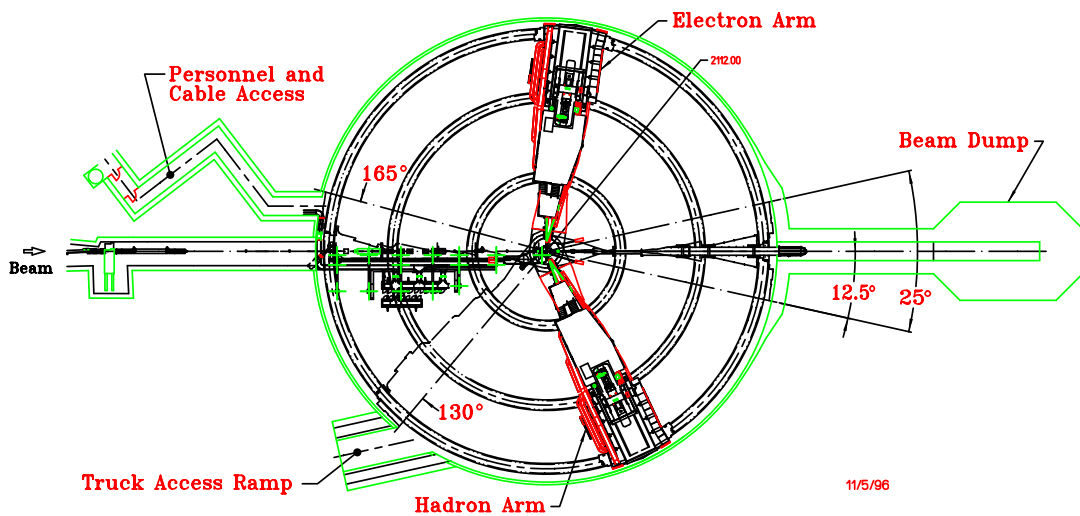


Figure 9.2: A bird's eye view of the Hall A end-station at TJNAF.

components which support the magnets, detector, shield house and associated equipment. It is composed of the box beam, which supports the outer elements in fixed relative position atop the dipole; the dipole support bracket, upon which the dipole rests on the jacks; the cradle, upon which the dipole rests through the vertical positioning system, VPS; and a portion of the shield house load through the inboard legs of the gantry; the gantry, which supports the shield house and the magnet power supplies; and the bogies, which support the cradle-gantry assembly and roll on the floor plates and provide the driving power to move the two spectrometer arms.

The detector package (described in detail in Chapter 11) is supported on the box beam and is surrounded by the shield house. It must perform two functions, tracking and particle identification, PID. The most important capability of focusing spectrometers is measuring precisely the momenta and entrance orientations of the tracks. Momentum resolution of 10^{-4} is obtainable, consistent with the resolution of the incident beam.

The actual configuration of the detector package varies from experiment to experiment. The description given here is only an example of what is possible.

A particle traversing the detector stack (Figure 9.3) encounters two sets of horizontally mounted, vertical drift wire chambers (x,y) with two planes of 368 wires in each chamber. The track resolution is $\sim 100 \mu\text{m}$. From the chamber information both positions and angles in the dispersive and transverse directions can be determined. The information from these chambers is the principal input of the tracking algorithms.

The chambers are followed by a scintillator hodoscope plane designated S1. This plastic scintillator array provides the timing reference for the drift chambers, and is also used in trigger formation and in combination with a second hodoscope pair it can provide time of flight particle identification. These scintillators can also be used to perform crude tracking.

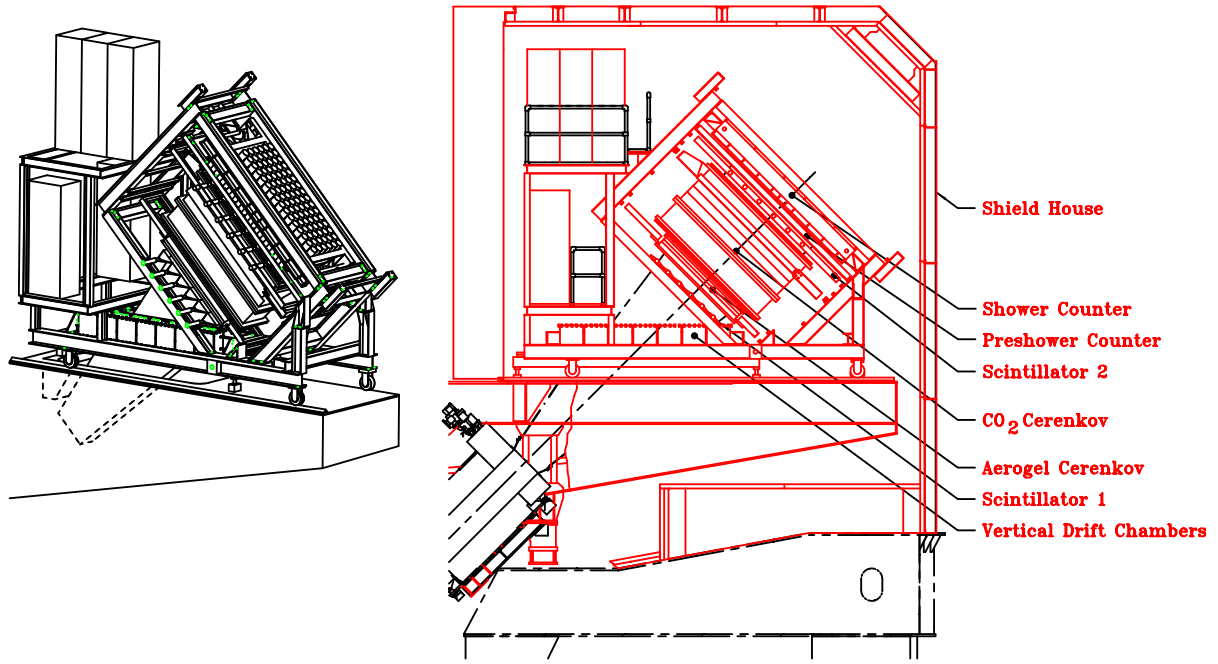
The next element encountered by a particle is a gas threshold Cherenkov detector. This is used for particle identification. This gas threshold Cherenkov detector can be swapped against an Aerogel detector, with a similar function.

The second hodoscope plane, S2, is located directly behind the gas Cherenkov. Its function is essentially the same as that of S1. In the hadron spectrometer an option exists to have this hodoscope pair be preceded by a third chamber, to improve tracking. Each of the two spectrometers have gas and Aerogel Cherenkov detectors which can be used when they are in electron detection mode.

The final elements in the detector stack on HRSE are the pre-shower and the total-absorber lead glass shower calorimeter. This is used for energy determination and PID.

The hadron detector is shown schematically in Figure 9.4. It consists of two sets of (x,y) vertical drift wire chambers identical to those of the electron arm. The remaining part of the detection system is used to define the level 1 trigger, as well as for particle identification and timing. It consists of two minimally segmented planes of scintillation counters equipped with photomultipliers at both ends, and it includes Cherenkov counters (gas CO₂ and Aerogel).

In addition, a proton polarimeter is installed in the back of the detector package to measure the polarization of the proton using a segmented carbon analyzer up to 60



11/7/96

Figure 9.3: The electron spectrometer detector stack.

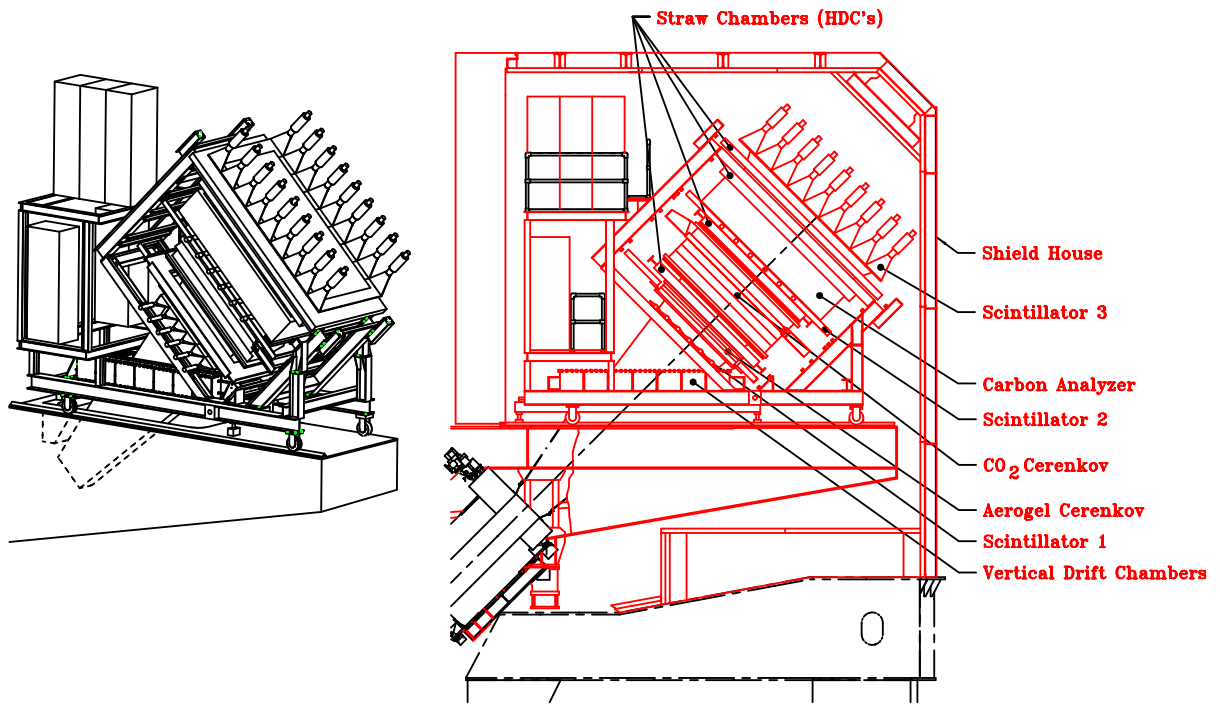


Figure 9.4: The hadron spectrometer detector stack.

cm in thickness to allow measurements over a wide range of proton energies. A pair of front and a pair of rear straw tube wire chambers determine the incident and scattered angles, respectively. The polarimeter detectors are dimensioned to accept a 20° cone of scattered protons.

Several support systems are necessary in addition to the basic components mentioned above. They include gas supply systems for the wire chambers, high voltage supplies, readout electronics, a second level trigger, software for data analysis and testing, and a remotely controllable mechanical system.

For each spectrometer, all detectors are mounted on a single rigid support frame along with their associated electronics. The trigger electronics are located on the support frame, next to the detectors.

To reduce the resolution degrading effects of multiple scattering, the entire interior of the spectrometer from the collimator box to the detector hut is a vacuum vessel. The ends of this evacuated volume are capped by relatively thin vacuum windows.

9.2 Safety Information

9.2.1 Hazards

The spectrometers have associated vacuum, electrical, cryogenic and magnet systems all of which can be extremely dangerous due to the size and stored energy in the systems. Hazards of rotating the spectrometers as well as the particle detectors that get placed inside the detector hut of the spectrometer are covered in detail in following sections.

9.2.2 Mitigations

The vacuum systems associated with the spectrometers are essentially pressure vessels and care should be exercised so as not to puncture the windows. During hall maintenance, covers are placed over the windows to help mitigate accidentally hitting a window.

The magnets themselves are installed inside cryostats. These vessels are exposed to high pressures and are therefore equipped with safety relief valves and burst discs.

The hydraulic system originally intended to operate the vertical positioning system (VPS) and the horizontal positioning system (HPS) has been dismantled, after problems were encountered during the initial attempted operation of the system so this is no longer a hazard.

The cryogenic system operates at an elevated pressure at 4K. One must guard against cold burns and take the normal precautions with pressure vessels when operating this system. Only authorized personnel are permitted to install and take out U-tubes.

The magnets have a great deal of stored energy as they are large inductors. Always make sure people are clear of them and that the dump resistor is attached to the magnet.

9.3 The Magnets of HRS

Each HRS is composed of three superconducting quadrupole magnets, Q1, Q2, and Q3, and one superconducting dipole magnet. The large quadrupoles were manufactured for JLab by SIEMENS, the small quadrupole by SACLAY, while the dipole was built for JLab by WANG NMR. The quadrupole magnets are referred to as Q1, Q2, and Q3, where a particle first traverses Q1, then Q2 and the dipole magnet and finally traverses Q3.

The magnet system is followed by a large steel and concrete detector hut, in which all detector elements reside. Most of the detector elements have been built by universities involved in the Hall A physics program.

The HRS magnet system is the cornerstone of the Hall A activities. Many of the experiments approved in Hall A center on physics at high resolution and other short-range phenomena, and rely on a spectrometer able to momentum analyze charged particles up to very high momenta. The design value for the maximum momentum accessible to the HRS magnet system is 4 GeV/c.

9.3.1 Magnets and Power Supplies

The HRS magnet's are all superconducting and hence their coils must be maintained at cryogenic temperatures during operations. The LHe required by the magnets is supplied by the End Station Refrigerator, ESR.

All the HRS magnets cryogenic services are supplied through the overhead cryogenic lines. The distribution network begins at the distribution box over the pivot. This box is connected to the rest of the network via the flexible transfer lines over the pivot. The network is adjacent to the upstairs catwalk of the HRS.

Cryogenic information about each magnet is available on the control screens in the counting house, one for each magnet. Normally during run periods the control screens are sent upstairs to the Hall A counting house and information on all the HRS magnets is available on the HRS control screen located in the center of the main console. The control of all magnets is described in a following Section.

The power supplies for the magnets are located on the gantry balcony adjacent to the magnets. The supplies are all cooled with low conductivity water (LCW).

Under no circumstances should any panel of any magnet power supply be opened by someone other than authorized personnel due to the shock hazard. This hazard is mitigated by signs and protective panels. There are also signs posted listing the dangers of high magnetic fields.

A control interface for the power supplies is available through the HRS control screen in the Hall A counting house.

9.3.2 Quadrupole Magnets

The quadrupoles provide some of the focusing properties of the spectrometer and to a large extent its acceptance. Operating limits imposed on the quads are as follows: 1850A for Q2 and Q3 and 3250A for Q1.

All three quadrupoles for the HRS spectrometer are warm iron superconducting magnets. The soft iron around the superconducting coil enhances the field at the coil center and reduces stray fields. The basic parameters for the first quadrupole, Q1, are an effective length of about 0.9 m, useful aperture of 0.3 m and a field gradient of 9.5 T/m. To achieve the lowest possible angle setting of the HRS spectrometer (with respect to the beam line) the incident electron beam passes through a notch in the outer yoke of Q1 when the spectrometer is at its smallest angle of 12.5° . The other two quadrupoles, Q2 and Q3, are essentially identical with an effective (magnetic) length of about 1.8 meter, a useful aperture of 0.6 m and a field gradient of 3.5 T/m.

The maximum operating currents (assuming a 4 GeV/c momentum particle) for the quadrupoles are about 3000 A, 1700 A, and 1600 A, for Q1, Q2, and Q3, respectively. This will render pole field values of 1.2, 1.0, and 1.0 T, respectively. The energy stored in the quadrupole fields is sufficient to cause an unrecoverable quench if all the energy stored is dumped into the magnets. Therefore a quench protection circuit is incorporated. However, a quench can only happen if the cryomagnets have a helium level below the coil 60% during operation.

The operating current to the Q1 quadrupole coils is provided by Danfysik System 8000 power supplies, which can operate up to 3500 A current and 5 V. The power supplies will be cooled with a combined maximum water flow of 45 liters per minute.

In addition to the main quadrupole windings, all quadrupoles have multipole windings. To further optimize focusing properties of the HRS magnet system, it was intended to operate including some of these multipole trim coils in order to reduce higher order aberrations. The operating current for these multipole corrections would be small, only (the multipole corrections are typically less than 2% of the main quadrupole field), of order 50 A. Since the sextupoles were inadvertently installed rotated 90° from their correct orientation, these trim coils are now considered useless and there are at present no plans to use them.

9.3.3 Cryogenic Procedures

The cryogenics control is handled by the JLab Cryogenics Group. The cryo control coordinator can be reached at the CHL (x7405) or by calling the MCC.

9.3.4 Dipole Magnet

The dipole, by virtue of its field index, provides both dispersion and focusing. The present operations envelope states that the supply for the left HRS dipole may not be operated at a current above 1800 A (4.4 GeV/c). The supply for the right HRS dipole may not be operated above 1200 A (3.2 GeV/c), due to complications caused by an internal short.

The dipole for the HRS spectrometer is a superconducting, cryo-stable magnet. Its basic parameters are an effective length of about 6.6 *m*, a bend radius of 8.4 *m*, and a gap width of 25 *cm*. It is configured to achieve a 45 degree bending angle for 4 GeV/*c* momentum particles at a central field excitation of 1.6 T. For the HRS dipole to reach 1.6 T an operating current of about 1500 A is required.

The dipole has been designed to achieve cryostability up to a field of 2 T, and this property has been extensively tested up to a field of 1.6 T. The cryostable coils are equipped with an energy removal circuit to cover the possibility of an unrecoverable quench. However, this can only happen if the helium level drops below the coil during operation. The current to the coils will be provided by a Dynapower Corporation power supply, which can operate up to 2000 A and 10 V. This power supply is located on the gantry beside the dipole, and will be cooled with a maximum water flow of 35 liters per minute. The total water flow needed to cool the 4 power supplies for the HRS magnet system (dipole and quadrupoles) amounts to 80 liters per minute, with a supply pressure of cooling water for Hall A of 100 psi.

9.4 Operation of the HRS Magnets

9.4.1 Introduction

This is an abbreviated operating manual for the HRS superconducting magnets specifically designed for Hall A experimenters. It provides instructions for setting currents, invoking NMR field regulation and general system monitoring. Curious readers are directed to the references for more in-depth operating instructions and other technical manuals. Copies of the following supporting documents are available in the Hall A Control Room and through the Hall A webpage (see Table 9.1).

References	
WANG NMR Dipole	User Manual
Dynapower	Instruction Manual
Appendix	NMR Tesla meter
Appendix	NMR Field Regulation
Siemens/Fug	Q2/Q3 Magnet Instrumentation and Power Supplies
Saclay/Danfysik	Q1 Power Supply Manual
TOSP	HRS Dipole
TOSP	HRS Quadrupole Q1
TOSP	HRS Quadrupole Q2, Q3
HRS	SC Dipole Magnet Safety Review Vol. 2
HRS	SC Quad Safety Review Vol. 1

Table 9.1: HRS Magnets: extra manuals available in Hall A Control Room.

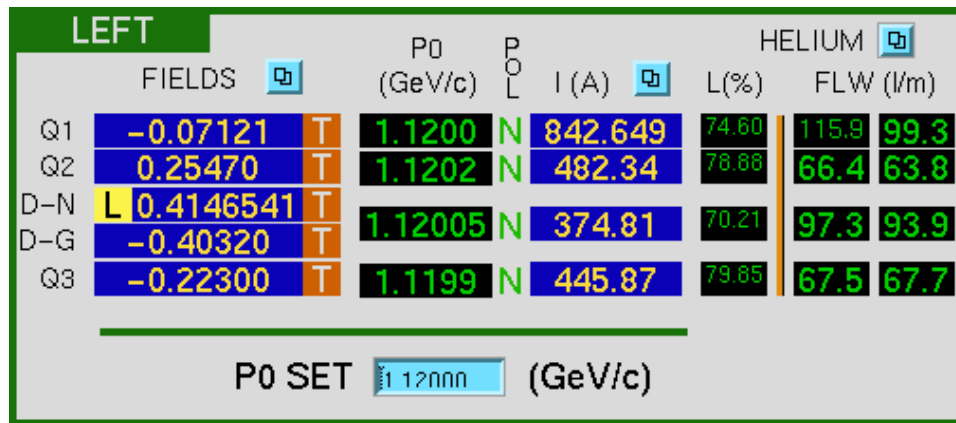


Figure 9.5: A part of “Hall A General Tools” screen, used for HRS (left) magnets control.

9.4.2 Simple HRS Setting (Autopilot Mode)

The magnets are controlled remotely using EPICS [6] and MEDM [14] GUI, provided that everything is working and power supplies are turned on and ready to go. The appropriate interface runs on the computer `hacsbc2` (see Section 20.9). On the “Hall A General Tools” control screen, in the upper left, there is a rectangular box for each spectrometer (see Figure 9.5).

This box displays a brief summary of the status of the spectrometer magnets and their cryogenic systems. The blue fields (with white numbers) give readbacks of the magnetic fields and currents in each magnet. The black fields also give readbacks, however in this case if the text appears green those parameters are OK while if they are red then that parameter is out of tolerance and may indicate a fault condition. For example if the helium level goes below a certain point the magnet will be automatically turned off. In some cases it may be desirable to monitor certain critical quantities on a strip chart (e.g. magnet settings). A strip chart tool is available for this purpose from the bottom of the “EOS Menu” button in the “MyMenu” window.

To set the spectrometers for a given value of central momentum (P0) type the desired P0 value into the light blue P0 SET box and hit return. The magnets will be automatically set to the correct values. All green numbers in the P0 column indicates that the desired field or current settings have been reached.

Caution: Regarding the dipoles, in general it’s a bad idea to assume that at the first instant that the P0 display turns green that the desired field has been reached and you can start taking data. Stable field is in general not achieved for from 15 to 30 minutes after reaching the nominal desired field. This settling time depends on the magnet (the right dipole is slower than the left dipole) and the magnitude of the field change (small changes settle faster than big changes). Experimenters are advised to observe both the field reading and current reading on the magnet in question and verify that things are stable to their satisfaction before proceeding.

9.4.3 Powering Up Dipole Magnets:

Use these instructions to recover from loss of a magnet due to a fault (e.g. He level or lead flow fault). The order of actions matters.

(Contact Tech-On-Call if anything behaves funny or things don't respond as expected. Sometimes after a trip an access to the Hall is required to reset things).

1. Wait for Iout=0 (you can't and don't want to do anything while the magnet is in emergency fast dump mode.)
2. While waiting, make a log entry re the fault. Give details such as time, coincident activities, and nature of the fault.
3. Make sure the fault is cleared. (e.g. He level and flow rates returned to normal values and stable)
4. In the HRS Right (Left) Dipole Systems' control panel:
 - (a) Press RESET (verify that all faults are cleared in the middle column)
 - (b) Press ON (Display will indicate Power Supply ON and Magnet ENGAGED)

Power supply and magnet are ready to go. From here you can return to "Autopilot Mode" (see Section 9.4.2).

9.4.4 Starting Q1 Power Supply:

Do this when a fault causes the power supply to shut off. Wait for fault to clear (watch He levels).

1. Push POWER OFF/RESET (check all faults cleared)
2. Select desired polarity
3. Push POWER ON
4. Type in Setpoint (Amps) (light blue field) or re-enter P0 in Autopilot Mode.

9.4.5 Starting Q2/3 Power Supply:

Do this when a fault causes the power supply to shut off. Wait for cause of fault to clear (watch He levels).

1. Push RESET
2. Select desired polarity
3. Push ON
4. Type in Current Set (light blue field) or re-enter P0 in Autopilot Mode.

9.4.6 Responsible Personnel

In the event that problems arise during operation of the magnets, qualified personnel should be notified (see Table 9.2). This includes any prolonged or serious problem with the source of magnet cryogenics (the ESR). On weekends and after hours there will be a designated individual on call for magnet services. Any member of the Hall A technical staff is qualified to deal with unusual magnet situations but in the event of serious problems the technician on call should be contacted.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-A	W.B.			<i>Contact</i>
Ed Folts	Hall-A	7857	Web	folts@jlab.org	
Jack Segal	Hall-A	7242		segal@jlab.org	
Heidi Fansler	Hall-A	6915	Web	fansler@jlab.org	
Jessie Butler	Hall-A	5544		jbutler@jlab.org	
Andrew Lumanog	Hall-A	7459	327-5523	andrewl@jlab.org	
Jason Glorioso	Hall-A	6258	831-8713	glorioso@jlab.org	
Mahlon Long	Hall-A	6436	770-5562	mlong@jlab.org	

Table 9.2: List of HRS responsible personnel where “W.B.” stands for the white board in the counting house.

Chapter 10

Spectrometer Rotation

Since each HRS weighs in excess of 1,000 tons it is very important that all safety precautions are carefully adhered to. The good news is they move very slowly (a few degrees/min maximum), BUT 1,000 tons moving even very slowly is hard to stop.

10.0.7 Hazards

Hazards include:

- Knocking items over.
- The wheels crushing things (including fingers and toes) on the floor in the path of the spectrometer
- Damaging the beamline or other equipment on the floor if one goes to too small or too large an angle, or if it just gets pushed around inadvertently.
- Tearing out of cables etc. physically attached to the superstructure

10.0.8 Mitigations

Hazard mitigations:

- Guards on either side of the wheels prevent items from getting under them.
- Large pins in the floor to stop the spectrometer rotated beyond the needed angular range.
- Blinking lights on the spectrometers indicating they are in motion or that motion is possible (controls engaged etc.)
- During a running experiment the run coordinator and work coordinator should know in advance of any moves. Moves at any other time must be cleared with the Hall work coordinator before implementation.

- Careful inspection of the intended path to make sure it is clear. This is part of the pre-run checklist performed by the technical staff prior to closing the Hall and a remote camera allows shift worker to inspect the area.
- Any motion that takes a spectrometer inside 14 degrees or outside X degrees (X being specified in the pre-run checklist and noted on the whiteboard during a run) must be supervised by a trained Hall A technician.

Remote Procedure for a shift worker:

- Make sure the move is part of the approved runplan (if in doubt, check with the run coordinator).
- Check that the pre-run checklist has been completed and note and comply with any possible limitations to spectrometer motion (if there is a conflict inform the Run Coordinator and do not initiate any move until the conflict is cleared).
- Visually inspect the Hall using the closed circuit TV cameras to verify that there are no obstructions.
- If people are in the Hall wait until they leave (during a Controlled Access MCC keeps track of people in the Hall). (Maybe we could soften this to "Inform EVERYONE in the Hall of the move".)
- Activate the spectrometer motion controls (see the Wiki and below) and move to the desired angle.
- Deactivate the controls (brakes on, power off, etc.)
- Update the spectrometer position information on the Hall A Controls screen
- Make a halog entry indicating you've moved the spectrometer including from what angle to what new angle.

Procedure for a non-run associated move in the Hall:

- Inform the work coordinator of the planned move
- Perform a careful visual inspection to verify that the path is clear
- Check to make sure there are no temporary connections to the spectrometer (wires etc.) that could be damaged during the move.
- Inform everyone in the Hall of the move and check with them re 3.
- Activate the spectrometer motion controls (see the Wiki and below) verify that the warning lights are on and move to the desired angle.
- Deactivate the controls (brakes on, power off, etc.).

The full procedure for moving the spectrometer follows and can also be found on the Hall A wiki.

On hacsbc2, click the red "tool box" icon on the linux taskbar, as above. Choose bogies_SetSpec so that you can determine the angle and vernier setting for the spectrometer. Enter the spectrometer (L or R), and the angle, and you will get two options for the floor mark and the vernier. Generally choose the vernier closer to zero. Center the cameras on the desire vernier using the Move+/Move- buttons on the Hall A General Tools screen. The TV monitors for these cameras are on the middle shelf, in rack CH01A05.

Choose bogies_Left (or bogies_Right) in the tool box to bring up the bogies control screen. Click PSM enable and wait a few seconds for PSM OK to read YES. Click DM enable and wait a few seconds for DM OK to read YES. Make sure the velocity is set to 0 and the direction is CW or CCW as desired. Click on Brake Release and wait for Brakes OK to read YES.

Click on ClampRelease, set the velocity to 700. Once you see the spectrometer start to move in the floor angle camera - you cannot see the spectrometer move in the Hall overview camera, as it only moves a few degrees per minute at maximum speed. For the left arm, to move to a larger angle, the direction should be CCW, while for the right arm CW moves the spectrometer to larger angle. The direction of the spectrometer is reversed by using a negative rpm. Watch the spectrometer motion on the cameras. When you are getting close to the desired angle, slow down to about 300 rpm. To stop, click on the Clamp Release button and the Brake button. Disable DM and PSM, and disconnect to close the GUI. Read off the floor angle mark and vernier, and input the values into the appropriate fields in the Alignment section of the Hall A General Tools GUI.

10.0.9 Responsible Personnel

Following the experimental run plan, as posted in the counting house by the run coordinator, shift workers are allowed to rotate the HRS following guidelines of the standard equipment manual. In the event of a problem getting the spectrometers to rotate the run coordinator should notified. If the run coordinator is unable to solve the problem, and with the run coordinators concurrence, qualified personnel should be notified to repair the problem (see Table 10.1). On weekends and after hours please only use the tech-on-call number. It should be noted that for experiments that are using thick targets at high current, it is not uncommon that the produced radiation will cause the motion system to require a hard reset.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Tech-on-Call	Hall-A	W.B.			<i>Contact</i>
Ed Folts	Hall-A	7857	Web	folts@jlab.org	
Jack Segal	Hall-A	7242		segal@jlab.org	
Heidi Fansler	Hall-A	6915	Web	fansler@jlab.org	
Jessie Butler	Hall-A	5544		jbutler@jlab.org	
Andrew Lumanog	Hall-A	7459	327-5523	andrewl@jlab.org	
Jason Glorioso	Hall-A	6258	831-8713	glorioso@jlab.org	
Mahlon Long	Hall-A	6436	770-5562	mlong@jlab.org	

Table 10.1: List of HRS responsible personnel where “W.B.” stands for the white board in the counting house.

10.1 Field Monitoring ^{1 2}

The field-monitoring controls are available using the main HRS screen (see Figure 9.5). The dipoles’ field is measured using NMR Teslameters and field probes.

10.1.1 Dipole Field Monitoring Electron Arm

Basic Setup

Each spectrometer dipole magnet is equipped with a Metrolab PT 4025 NMR Teslameter, several field probes, and multiplexers (to allow switching between the probes). Details of the operation and theory of operation for the Teslameter can be found in its user manual, a copy of which is available in the the counting house. The basic layout is shown in Figure 10.1

The ”Gap Probes” (Group 0 in the controls) are located in two groups of three; one group on the low field side of the gap and the other on the high field side of the gap. The groups of three are made up of one each of the manufacturer’s type 3, 4 & 5 probes, designed to cover different field ranges (see Table 10.2). The six “Purcell Gap Probes” (Group 1 in the controls) are located in the Purcell gap of the magnet and consists of two each of the above types. *Note: Since the fall of 1998 the multiplexer-multiplexer in both arms, MUX 2032, has been removed and hence the “Purcell Gap Probes” are currently unavailable. There are no plans to re-install this multiplexer.*

The ”Gap Probes” are equipped with coils which provide a field gradient that cancels out the field gradient of the magnet in the vicinity of the probe. These gradient compensating coils are part of a simple circuit that is completely independent of the Teslameter. The basic circuit for the compensating coils is shown in Figure 10.2

The following graphs (see Figures 10.3 and 10.4), can be used to determine optimum values for the compensating coil control voltage. It should be noted that the setting of

¹ CVS revision Id: nmr-1999.tex,v 1.4 2003/12/17 03:59:48 gen Exp

²Authors: J.LeRose lerose@jlab.org

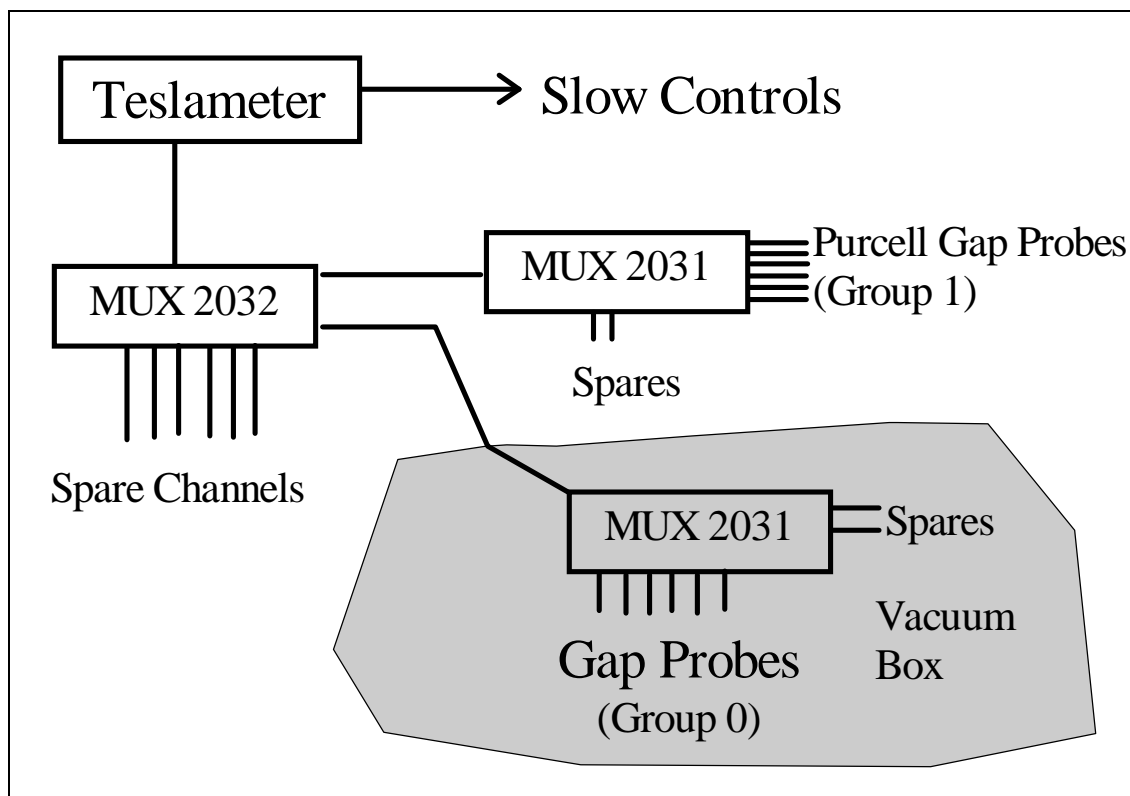


Figure 10.1: Basic layout of NMR system

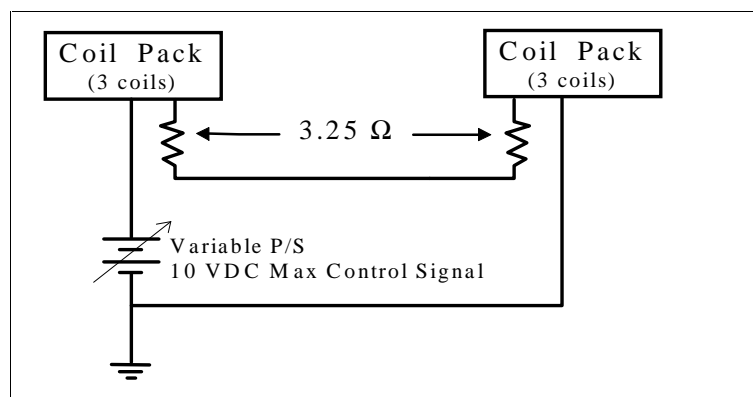


Figure 10.2: Gradient Compensating Circuit.

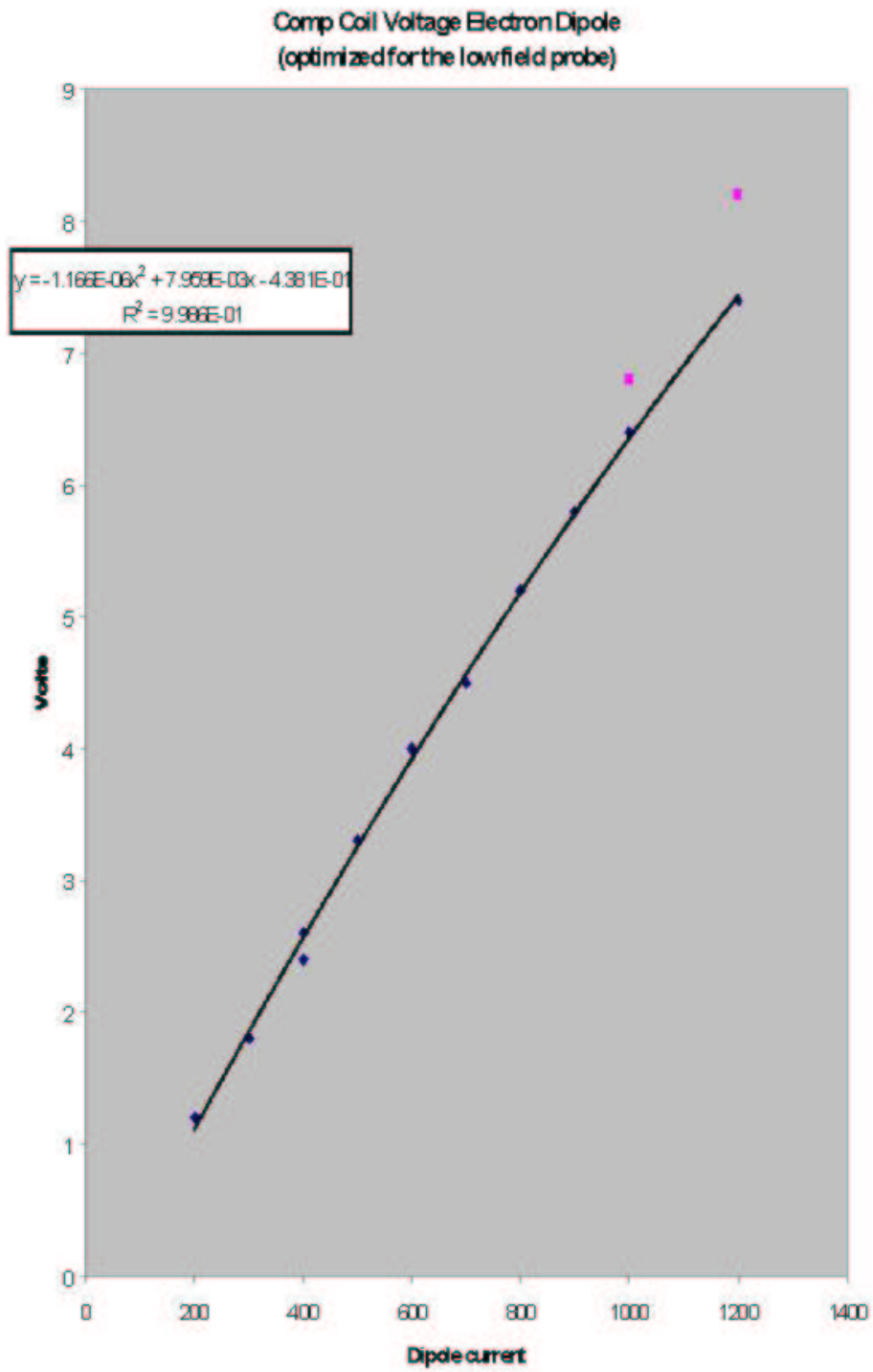


Figure 10.3: Control Voltage calibration for the Left Dipole.

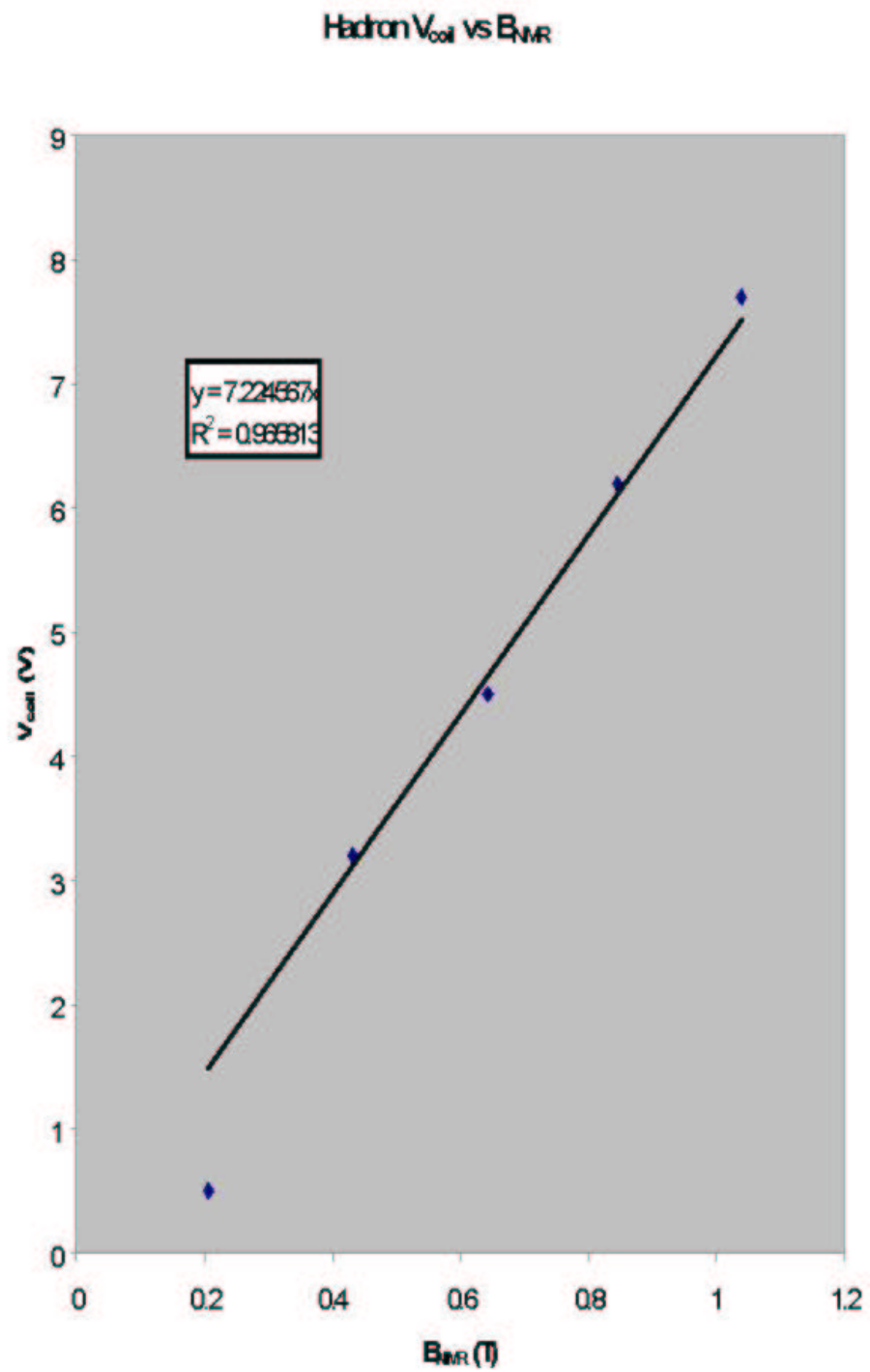
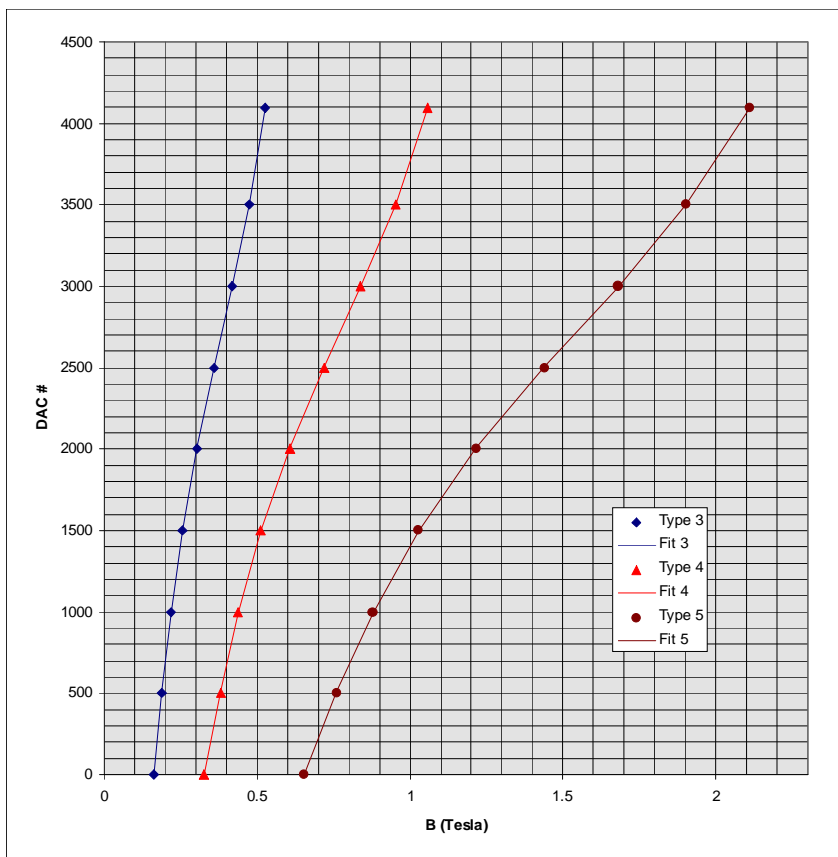


Figure 10.4: Control Voltage calibration for the Right Dipole.



$$DAC = C_0 + C_1 \cdot B + C_2 \cdot B^2 + C_3 \cdot B^3$$

Probe type	C ₀	C ₁	C ₂	C ₃	Group 0 Probes	Group 1 Probes
3	-5157.04	45026.48	-95678.57	82559.35	0,3	
4	-5157.39	22514.30	-23920.73	10320.28	1,4	
5	-5156.74	11255.70	-5979.12	1289.79	2,5	

Figure 10.5: DAC Calibration for manual operation of NMR probes.

Probe Type	Field Range (T)
3	0.17 - 0.52
4	0.35 - 1.05
5	0.70 - 2.10

Table 10.2: Dipole NMR probe field ranges

the compensating coil current is not very critical in most cases. In general if you're within 10% of the correct value everything should work fine.

10.1.2 NMR Operating Procedure

When running in Autopilot mode (see: Simple Spectrometer Field Setting) the compensating coil voltage is set automatically and the probe appropriate for the field desired is selected. The gaussmeter is placed in SEARCH Mode and the dipole power supply software regulator is turned on. In this case the dipole current is adjusted to achieve the desired field. The user should just stand back and let it work. What follows are instructions for using the NMR gaussmeter in situations where Autopilot doesn't work or some special supplemental measurements are required.

In principle it is possible to make the field measurements using the SEARCH mode in the Teslameter. In this mode you select a probe and the meter explores the whole field range of the probe until it finds and "locks" on the resonant signal indicating that it has a field measurement. A "lock" is indicated on the controls display by an "L" to the left of the field values. This has the advantage of simplicity but in practice can be time consuming and doesn't always work. The problem being, in situations where there is a lot of noise mixed in with the signal, the circuitry has problems distinguishing the signal from the noise and gets lost before it ever finds a lock. The problem is exacerbated when the field being measured is at the high end of the probe's range. In this case the search starts at the low end and keeps getting hung up on the noise and never gets to the field range of interest. The solution to this problem is to tell the device approximately what field it's looking for and use the AUTO mode to find the lock. In the procedure below that is what we will be doing.

In any case, for "gap probes" (group 0) you must energize and adjust the gradient compensating coils for the field ranges to be measured before trying to make a measurement.

For studies involving 10% changes in the field settings the compensating coil current can be set once and left alone.

Recommended Procedure:(turn the **SOFTWARE REGULATOR OFF** for all non-autopilot field measurements)

For group 0 probes set compensating coils appropriately (see figures).

Put the meter in MANUAL mode with SEARCH OFF

Select a probe **and** polarity (**Group 0: Probes 0, 1, 2 negative; Probes 3, 4, 5 positive**)

Type in the appropriate DAC number for the field range being measured (see below)

Select AUTO and wait for a lock (indicating a valid field reading)

Verify that you have a good lock by checking the oscilloscope for a clear resonant signal.

If you have problems see the table listing problems and possible solutions.

Selecting DAC Number

In selecting the DAC number to use for the field of interest use either the graph in Figure 10.5 or the polynomial at the bottom of the same figure.

Problems and Solutions

Symptom	Diagnosis and Cure
Weird numbers on displays, controls for all magnets fouled up	Need to reboot. See instructions below.
NMR Teslameter does not respond to commands and display shows all zeros.	Meter's communications are somehow hung up. Push RESET .
Will not lock	Very high noise level makes resonance hard to find. Search for the resonance manually by adjusting the DAC in manual mode until you see the resonant signal. (It helps if you know what field you expect so you'll know where to look).
You find resonance manually but still can't get a lock	Check probe polarity. Try decreasing and increasing DAC number by 1. Optimize signal by adjusting compensating coils.
Can't find resonance manually	Try a different probe. Use readings from other probes to tell you where to look for the resonance with the probe that's giving you trouble. Make sure compensating coils are energized properly. Make sure magnet is on.

Table 10.3: NMR: Problems and solutions

Problems	Explanation	Action
NMR not locked but current is changing in the right direction	Normal operation for large field changes	Wait. (see above)
NMR locked but current going in the wrong direction.	Normal operation.	Wait.
NMR locked but field not correct and current not changing	Field regulation is disabled or software is confused.	Check that field regulation is enabled. Enter desired field value or one very near the desired value again.
NMR field display freezes. (Usually but not always shows -#.0000000)	NMR Gaussmeter is not communicating with software.	Push RESET .

Table 10.4: NMR troubleshooting

10.1.3 Authorized Personnel

The individuals shown in Table 10.5 are responsible for NMR operation problems.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Javier Gomez	Hall-A	7498		gomez@jlab.org	<i>Contact</i>
John LeRose	Hall-A	7624		lerose@jlab.org	

Table 10.5: NMR: authorized personnel.

10.2 Collimators and Sieve Slits ^{3 4}

Both spectrometers have front-end devices for calibrating the optical properties of the spectrometers. These are known as the collimator boxes. These boxes are positioned between the scattering chamber and the first quadrupoles (Q1). Each box is carefully aligned and rigidly attached to the entrance flange of the Q1 of the respective spectrometer. The boxes are part of the vacuum system of the spectrometer.

Inside each box a ladder is mounted which is guided by a linear bearing and moved up and down by a ball screw. On this ladder 3 positions are available to insert collimators. Below this ladder a special valve is mounted that can isolate the vacuum in the spectrometer from the target system. This valve should be activated when it is moved in front of the holes connecting the box with spectrometer and target chamber. A schematic view of the collimator box is shown in Fig. 10.6.

Vacuum requirement is 10^{-6} Torr. The material for the box is aluminum. It is possible to open one side of the box so that collimators can be exchanged. The reproducibility of collimator positions after moving the ladder and/or after replacing a collimator is better than 0.1 mm in horizontal and vertical direction. The dimensions of the box are roughly height=175 cm, width=35 cm and depth=15 cm. The tolerance in the dimension of the 7 msr collimator hole is ± 0.5 mm in each direction. The tolerance in the position of each of the sieve-slit holes is ± 0.1 mm in each direction.

A typical sieve slit collimator (shown in Fig. 10.7) consists of a plate of roughly 14 cm x 20 cm containing 49 holes positioned in a regular 7x7 pattern. This slit is made out of 5 mm thick tungsten. The holes have a diameter of 2 mm except for the central one and one positioned off-diagonal which have a diameter of 4 mm. The horizontal distance between the holes is 12.5 mm while the vertical distance is 25.0 mm.

To get the latest information on the dimensions and locations of the collimators see the Hall A homepage on the web⁵.

10.2.1 Safety Assessment

The collimator boxes form part of the vacuum system for each spectrometer. All hazards identified in the spectrometer vacuum section apply to the collimator box as well.

In addition, safe access to the top of the collimator boxes is needed during manual operation of the box as outlined below. Due to the proximity of the collimator boxes to the scattering chamber, and Q1 quadrupoles, all necessary safety precautions with regards to vacuum windows, electrical power cables, cryogenic transfer lines, and high magnetic field should be taken. A radiological survey and appropriate RADCON designated procedures must be followed when dealing with sieves and collimators.

³ CVS revision Id: slit.tex,v 1.7 2008/04/01 16:52:31 leroose Exp

⁴ Authors: J.LeRose lerose@jlab.org

⁵ <http://halloweb.jlab.org/>

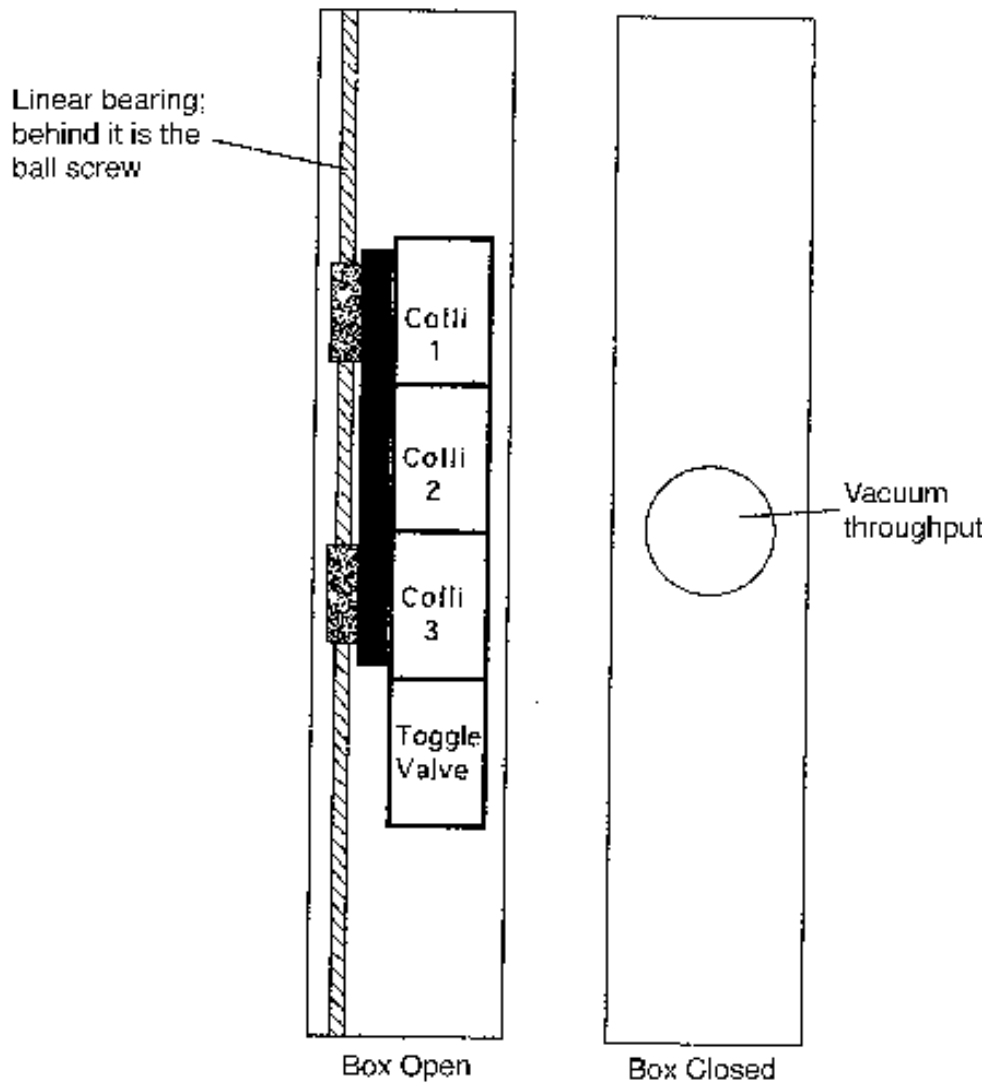


Figure 10.6: Schematic layout of the collimator box.

Sieve Slit

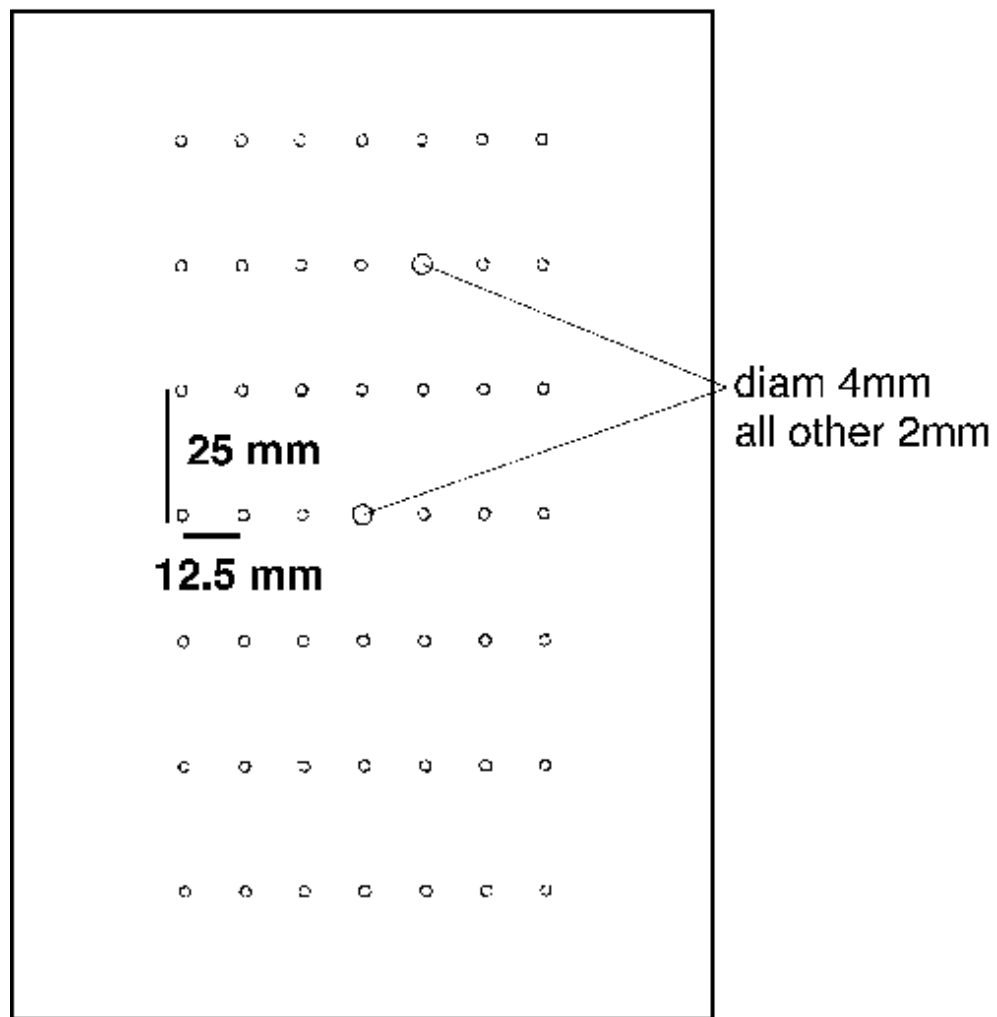


Figure 10.7: Sieve slit collimator for optics calibration.

10.2.2 Operating Procedure

Slit position is changed remotely from the standard Hall A control screen.

10.2.3 Authorized Personnel

The authorized personnel is shown in table 10.6.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Jessie Butler	Hall-A	5544		jbutler@jlab.org	Mechanics and vacuum
Javier Gomez	Hall-A	7498		gomez@jlab.org	Controls

Table 10.6: Collimator: authorized personnel.

10.3 Spectrometer Alignment ^{6 7}

At present, the systems implemented to determine the alignment of each spectrometer (roll, vertical angle/pointing and horizontal angle/pointing) without the help of the Accelerator Division Survey group are limited to roll, vertical angle and horizontal angle. All alignment information is displayed in the “ALIGNMENT” mosaic of the “Hall A General Tools” EDM screen (see Fig. 20.4) (“EOS Menu” -- > “EDM (HLA Main)” -- > “Hall A Main Menu” -- > “Tools”).

A bi-axial inclinometer is used to determine the roll and vertical angle (also known as pitch) of each spectrometer. These inclinometers are attached to the back of the dipoles at the power supply platform level. The raw inclinometer measurements, in Volts, are displayed as “Tilt X” and “Tilt Y”. The inclinometer temperature is also given (“Tilt T”), in degree Celsius. From these values, the “ROLL” and “PITCH” values are calculated. Agreement between the inclinometer readings and survey measurements are better than ± 0.1 mrad over all presently available history.

The horizontal spectrometer angle is determined from floor marks set in place by the survey group. Floor marks have been placed every 0.5° covering the useful range of both spectrometers. There are two concentric rings of floor marks in the hall. We will concentrate in the inner ring which covers the angular range of both spectrometers. The outer ring is similar. The inner-ring floor marks are located at a distance of ~ 10 m from the target center. A ruler attached to each spectrometer dipole runs over the floor marks and it acts as a vernier to interpolate between marks. The location of a given floor mark on the ruler can be viewed from the Hall A Counting House through a TV camera (labeled “Front Camera”). The camera is able to move along the length of the ruler so that any parallax effect can be eliminated. The camera motion is controlled from the “Tools” screen through two push buttons (“FRONT CAMERA” - “MOVE +” and “MOVE -”). Two fields in the “ALIGNMENT” mosaic (“Flr Mrk” and “Vernier”) allow to input the values read from the TV monitor. The effective spectrometer angle is then calculated and displayed as “Angle”. The application “HRS Floor Marks” calculates the floor mark and vernier value to which the spectrometer should be set to obtain a given angle. Spectrometer horizontal angle surveys and floor mark determinations agree to ± 0.2 mrad.

⁶ CVS revision Id: AlignmentOps.tex,v 1.8 2003/12/17 03:59:48 gen Exp

⁷ Authors: J.Gomez gomez@jlab.org

10.3.1 Authorized Personnel

The authorized personnel is shown in table 10.7.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Javier Gomez	Hall-A	7498		gomez@jlab.org	<i>Contact</i>

Table 10.7: HRS alignment: authorized personnel.

Part V
Particle Detectors

Chapter 11

Overview ¹

11.1 Overview of the Detector Package

The detector packages of the two spectrometers are designed to perform various functions in the characterization of charged particles passing through the spectrometer. These include: providing a trigger to activate the data-acquisition electronics, collecting tracking information (position and direction), precise timing for time-of-flight measurements and coincidence determination, and identification of the scattered particles. The scintillators provide the timing information, as well as the main trigger. The particle identification is obtained from a variety of Cherenkov type detectors (aerogel and gas) and lead-glass shower counters. A pair of VDCs provide tracking information. The main part of the detector package in the two spectrometers (trigger scintillators and VDCs) is identical; the arrangement of particle-identification detectors differs slightly. The HRS-L can be equipped with a focal-plane polarimeter to determine the polarization of detected protons. The focal-plane-polarimeter operates for proton momenta up to 3 GeV/ c with a figure-of-merit of 0.03. The side view of the detector stacks are shown in Fig. 11.1.

The optics of the HRS spectrometers, results in a narrow distribution of particle trajectories in the transverse direction, leading to an aspect ratio of the beam envelope of about 20:1 at the beginning of the detector package and 4:1 at the end.

The detector package and all data-acquisition (DAQ) electronics are located inside a Shield Hut (SH) to protect against radiation. The SH is also equipped with air conditioning and fire suppression systems. The individual detectors are installed on a retractable frame, so that they can be moved out of the SH for repair or reconfiguration. The DAQ electronics are mounted on the same frame.

The concept of the VDCs fits well into the scheme of a spectrometer with a small acceptance, allowing a simple tracking analysis algorithm and high efficiency, because multiple tracks are rare. The VDCs are bolted to an aluminum frame which slides on Thomson rails attached to the box beam. Each VDC can be removed from its SH for repair using these Thomson rails. The position of each VDC relative to the box beam can be reproduced to within 100 μm .

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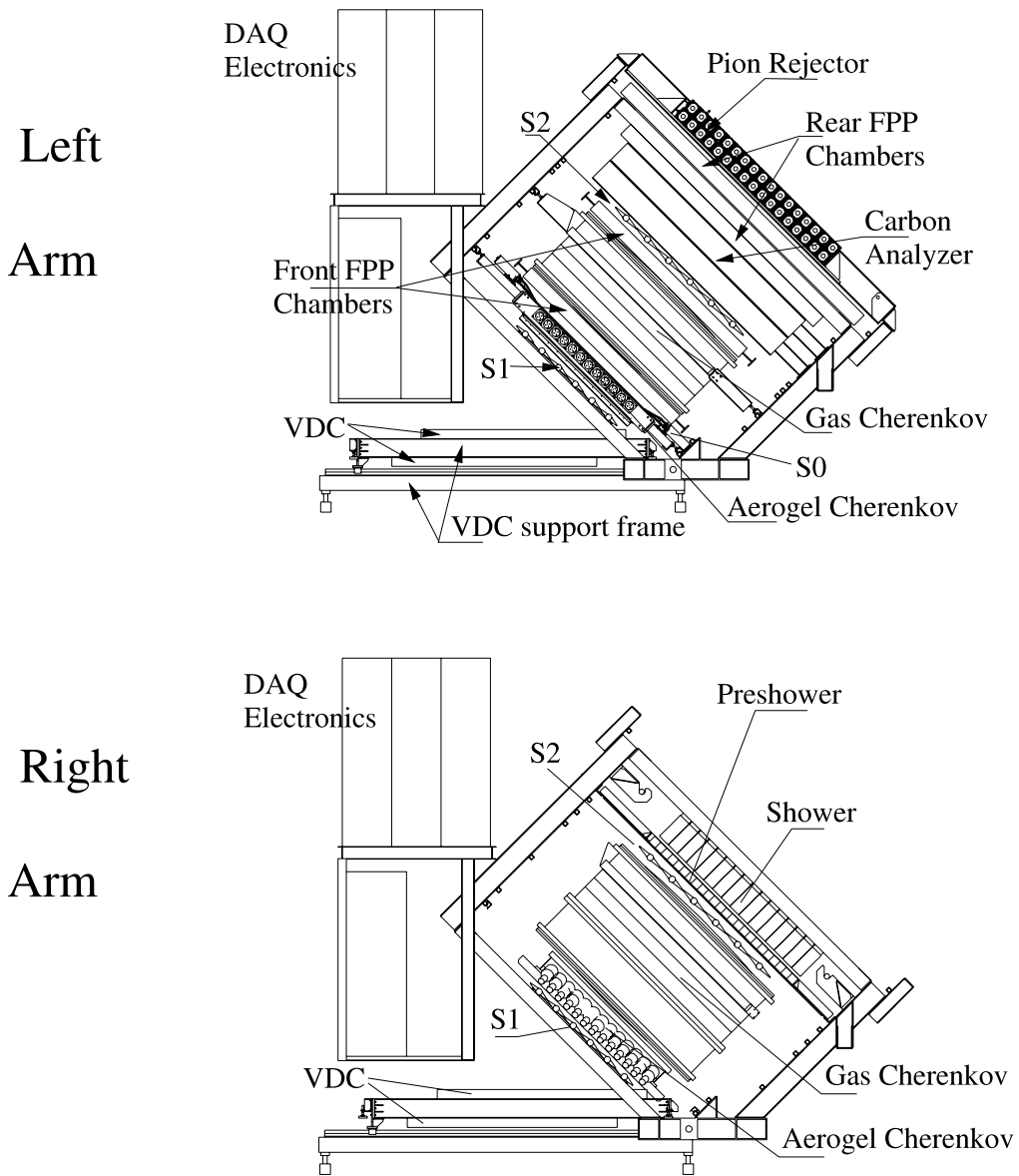


Figure 11.1: The side view of the detector stacks.

There are two primary trigger scintillator planes (S1 and S2), separated by a distance of about 2 m. The long path from the target to the HRS focal plane (25 m) allows accurate particle identification via time-of-flight in coincidence experiments if the accidental rate is low. After correcting for differences in trajectory lengths, a TOF resolution of $\sigma_T \sim 0.5$ ns is obtained. The time-of-flight between the S1 and S2 planes is also used to measure the speed of particles β , with a resolution of 7% (σ).

A gas Cherenkov detector filled with CO₂ at atmospheric pressure is mounted between the trigger scintillator planes S1 and S2. The detector allows an electron identification with 99% efficiency and has a threshold for pions at 4.8 GeV/ c . For electrons, the gas Cherenkov detector in the HRS-R has about twelve photoelectrons. In the HRS-L, the gas Cherenkov detector in its standard configuration has a pathlength of 80 cm, yielding seven photoelectrons on average. The total amount of material in the particle path is about 1.4% X_0 .

Two layers of shower detectors are installed in each HRS. The blocks in both layers in the HRS-L and in the first layer in the HRS-R are oriented perpendicular to the particle tracks. In the second layer of the HRS-R, the blocks are parallel to the tracks. The front layer in the HRS-R is composed of 48 lead glass blocks, 10 cm by 10 cm by 35 cm. The second layer is composed of 80 lead glass blocks, 15 cm by 15 cm by 35 cm each. The front layer in the HRS-L is composed of 34 lead glass blocks, of dimensions 15 cm by 15 cm by 35 cm. Some blocks are shorter - 30 cm instead of 35 cm. The second layer is composed of 34 similar blocks. Because of its reduced thickness, the resolution in the HRS-L is not as good as that of the shower detector in the HRS-R. The combination of the gas Cherenkov and shower detectors provides a pion suppression factor of $2 \cdot 10^5$ above 2 GeV/ c , with a 98% efficiency for electron selection in the HRS-R.

There are three aerogel Cherenkov counters available, with various indices of refraction, which can be installed in either spectrometer and allow the clean separation of pions, kaons and protons over the full momentum range of the HRS spectrometers. The first counter (AM) contains hygroscopic aerogel with an index of refraction of 1.03 and a thickness of 9 cm. The aerogel is continuously flushed with dry CO₂ gas. It is viewed by 26 PMTs (Burle 8854). For high-energy electrons the average number of photo-electrons is about 7.3.

The next two counters (A1 and A2) are diffusion-type aerogel counters. A1 has 24 PMTs (Burle 8854). The 9 cm thick aerogel radiator used in A1 has an index of refraction of 1.015, with a threshold of 2.84 (0.803) GeV/ c for kaons (pions). The average number of photo-electrons for GeV electrons in A1 is $\simeq 8$. The A2 counter has 26 PMTs (XP4572B1 made by Photonis). The aerogel in A2 has an index of refraction of 1.055, giving a threshold of 2.84 (0.415) GeV/ c for protons (pions). The thickness of the aerogel radiator in A2 is 5 cm, producing an average number of about 30 photo-electrons for GeV electrons.

11.2 Geometry of the Detector Packages

Tables 11.1 and 11.2 give geometry information for the Left arm and Right arm detector packages. The values in the tables indicate the position of the central point of the detector. The origin of coordinate system (0,0,0) is located at the intersection of the mid-plane of the spectrometer and the nominal focal plane (\sim middle of the Bottom VDC). The configurations can be modified to meet experimental needs, for example the short gas Cherenkov counter can be made longer to increase the pion rejection, the two aerogel counters can be installed on one spectrometer, an additional CH2 analyzer for FPP can be added and so on. The locations of the VDC, S1, and shower detectors are fixed, but some of the other detectors can be moved.

detector	location actual	location IDEAS model	width X	width Y	BEAM X(+)	X(-)	ENVELOPE Y
VDC1*	0		1942	271	843	- 824	+/- 57
VDC2*	572		1942	271	932	- 911	+/- 85
S1	1311	1321	1718	356	696	-1022	+/- 163
AERO	1646		199	414	709	- 888	+/- 182
GAS	2535		2200	650	886	-1110	+/- 279
S2	3358	3378	2197	540	897	-1124	+/- 285
preSHOW	3502	3546	2400	700	925	-1158	+/- 301
SHOW2	3780	3912	2400	900	964	-1207	+/- 322

Table 11.1: Locations of the detectors on Right Arm in mm.

detector	location actual	location IDEAS model	width X	width Y	BEAM X(+)	X(-)	ENVELOPE Y
VDC1*		0	1942	271	843	- 824	+/- 57
VDC2*		500	1942	271	932	- 911	+/- 85
S1		1287	1760	360	675	- 845	+/- 163
AERO		1617	1872	414	709	- 888	+/- 182
SC1		1837	1780	480	738	- 924	+/- 198
GAS		2409	2200	650	857	-1073	+/- 263
SC2		2952	2080	640	865	-1083	+/- 268
S2		3141	2220	640	877	-1099	+/- 274
Analyzer		3495	2190	680	916	-1147	+/- 296
SC3		3907	2540	1000	1099	-1343	+/- 457
SC4		4264	3170	1500	1382	-1645	+/- 705

Table 11.2: Locations of the detectors on Left Arm in mm.

Chapter 12

Trigger Scintillator Counters

1

12.1 Overview

In the standard detector configuration each HRS has two trigger scintillator planes, S1 and S2. The paddles in each plane are arranged to provide segmentation along the detector-x direction. An additional un-segmented scintillator plane, S0, can optionally be inserted into the detector stack for experiments that require a high hadron trigger efficiency. Fast signals from these planes are used to form the trigger, as well as providing timing information useful for particle identification. Typically a coincidence between two-or-more scintillator planes is used to form the trigger, and through different combinations the triggering efficiency of each plane can be measured.

The S1 scintillator plane consists of six paddles, each with an active area of 29.5 cm by 35.5 cm. The counters are made of 5 mm thick BICRON 408 plastic scintillator and use multi-strip adiabatic light guides which end in a long cylindrical spool. There is an inlet for optical fiber mounted on the side of the cylindrical light guide. Each paddle is viewed by a 2" photo multiplier tube (Burle 8575) on each end. The S1 paddles are installed at a small angle to the S1-plane and overlap by 10 mm. The detectors are clamped to the detector frame through an additional A1 channel, and supported from the PMT housings. Figure 12.1 shows the mounting scheme for S1. Signals from the PMTs are sent to NIM modules on the second level of the shielding hut for processing.

The S2 plane (also called S2m) consists of sixteen bars mounted on a steel frame, as shown in Figure 12.2. The bars are made a fast plastic scintillator (EJ-230) with dimensions of 17 inches by 5.5 inches by 2 inches thick. Since the S2 detector is located after the tracking and PID detectors in the HRS, the extra material does not compromise the particle detection while providing a greater photon yield for an improved timing resolution as compared to S1. The bars are individually wrapped with 25 μ m of mylar and 50 μ m of black tedlar. The bars do not overlap, but are pressed together by a

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Figure 12.1: S1 mounting

force 60 lbs to minimize the dead area between adjacent bars. Trapezoidal lucite light guides on both ends couple the bar to 2" photo multiplier tubes (Photonis XP2282B). S2 is assembled on a sub-frame mounted on rails in the detector frame. The bars are supported by two thin aluminum honeycomb panels placed over the scintillators, leaving the PMTs and bases accessible for servicing. On the frame are mounted analog splitters and threshold discriminators for the initial signal processing.

The optional S0 plane is made of 10 mm thick BICRON 408 plastic scintillator with an active area 170 cm long by 25 cm wide. This area is covered by a single paddle, viewed from each end by 3" PMTs (XP4312B). The signals from these PMTs are sent to NIM modules on the second level of the shielding hut for processing.

12.2 PMT regime and time resolution

High energy electrons passing perpendicular to the S1 detector plane yield about 400-500 photons at the photo cathode of each PMT. In a fresh PMT this leads to 80-100 photo electrons. On the HRS the discriminators have a threshold of 45 mV and a typical PMT has gain $3 * 10^6$. The HV for a fresh PMT should be in the range -1800 to -2000 V. Based on PMT pulse rise time (2.8 ns) and photo electron statistics the time resolution for the counter is about $\sigma_t \approx 0.2ns$. The propagation time of the light inside the detector is about 10 ns, which needs to be corrected by using track position information.

Due to its thicker cross-section, the initial photon yield in S2 is larger than in S1. With cosmic rays around 900 photo electrons per PMT were observed. To match the gains, the HV on the PMTs were adjusted, and set between -1700 and -2000 V. The signals

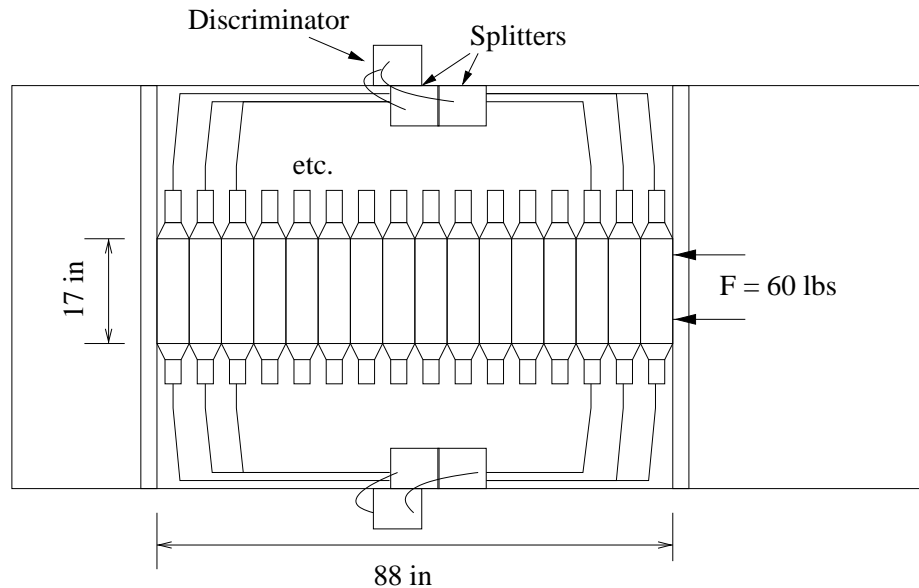


Figure 12.2: The layout on the frame of the S2 paddles and electronics.

from each PMT are sent to a passive 90/10% splitter, with the greater and lesser portions sent to the on-frame discriminator and Fastbus ADCs, respectively. The discriminator is a Phillips-Scientific model 706 with the threshold set at 10mV. Both NIM outputs are used on each channel, with one line as input for the trigger-logic and the other going to a TDC after passing through a NIM-ECL converter and a delay of some 880ns. The average resulting timing resolution for a single PMT was measured to be better than $\sigma_{pmt} < 150ps$.

The geometry of S0 counter limits its timing resolution. In 1999 the resolution was measured to be $\sigma_t \approx .2ns$.

LeCroy HV 1460 modules are used to supply HV power for the trigger counters. The HV can be controlled from a VT100 terminal connected through a terminal server or through the EPICS [6] system based on the HAC computer. Current HV settings for the trigger counters should be found from a printout of the EPICS control in the last experimental logbook.

Figures 12.3 and 12.4 give examples which are included for guidance only. The settings used in the plots may be not correct.

12.3 PMT operation monitoring

There are two ways to monitor PMT/detector performance. The first is based on a scaler display program which provides information about PMT counting rates and coincidence counting rates. A large variation of the rates between paddles is an indication of a possible

Right Arm Top									
HV/OFF HV/ON	S2 11-16 L/R	S1 1-6 L/R	Slot 4 Preshower	Slot 5 Preshower	Slot 7 Preshower	Slot 8 Preshower	S2 1-10 Right	S2 1-10 Left	Gas Cerenkov
Ch 0	-1601	-2001	-1044	-1060	-851	-1083	-1601	-1601	-2558
Ch 1	-1600	-2002	-1146	-1148	-1090	-1081	-1601	-1601	-2592
Ch 2	-1601	-2101	-1098	-1067	-990	-1071	-1601	-1601	-2551
Ch 3	-1601	-1970	-1063	-1077	-1074	-1102	-1602	-1601	-2547
Ch 4	-1601	-2033	-1081	-1161	-1067	-1086	-1598	-1600	-2395
Ch 5	-1599	-2201	-1112	-1108	-1024	-1011	-1599	-1601	-2530
Ch 6	-1601	-2051	-1112	-1083	-1172	-1093	-1598	-1600	-2327
Ch 7	-1600	-1977	-1192	-1072	-1101	-1067	-1600	-1600	-2459
Ch 8	-1601	-2073	-1024	-1063	-1028	-1094	-1602	-1601	-2616
Ch 9	-1601	-1951	-1102	-1075	-1107	-1065	-1599	-1600	-2528
Ch 10	-1601	-2001	-1125	-1108	-1089	-1065	-13	-14	-16
Ch 11	-1601	-2152	-974	-1054	-1109	-1151	-18	-23	-25

Figure 12.3: EPICS HV HRSR summary screen.

LeCroy 1461 High Voltage Card																	
Mainframe Id: 2		Ranges: Set V: 0->3000 V or 0->-3000 V															
Card No: 1		RU SET: 50->2000 V/s					VDZ SET: 0->30 V					TCURR SET: -2550->-10 or 10->2550 uA					
		RDN SET: 50->2000 V/s					CDZ SET: 0->10 uA										
CHANNEL	ENGAGE	MEAS V	DEMAND V	SET V	MEA CURR	TRIP CURR	TCURR SET	STATUS	RAMP UP	RU SET	RAMP DN	RDN SET	VOLT DZ	VOZ SET	CURR DZ	CDZ SET	HV LIMIT
Ch. 0	off	-2	-1200	-1200	-2	-2550	-2550	0	55	55	496	496	2	1	1	1	-3120
Ch. 1	off	-2	-1200	-1200	-1	-2550	-2550	0	55	55	495	495	2	1	1	1	-3120
Ch. 2	off	-2	-2201	-2201	-1	-2550	-2550	0	56	56	508	507	2	1	1	1	-3120
Ch. 3	off	-2	-2200	-2200	-2	-2550	-2550	0	56	56	508	507	2	1	1	1	-3120
Ch. 4	off	-2	-2200	-2200	-2	-2550	-2550	0	55	54	494	494	2	1	1	1	-3120
Ch. 5	off	-4	-1963	-1963	-2	-2550	-2550	0	56	56	506	506	2	1	1	1	-3120
Ch. 6	off	-3	-550	-550	-1	-2550	-2550	0	56	56	507	506	2	1	1	1	-3120
Ch. 7	off	-2	-1200	-1200	-1	-2550	-2550	0	55	55	499	498	2	1	1	1	-3120
Ch. 8	off	-3	-1039	-1039	-2	-2550	-2550	0	56	56	504	503	2	1	1	1	-3120
Ch. 9	off	-1	-1027	-1027	-1	-2550	-2550	0	56	56	505	504	2	1	1	1	-3120
Ch. 10	off	-1133	-2000	-2000	-510	-2550	-2550	3	57	56	509	508	2	1	1	1	-3120
Ch. 11	off	-1	-1200	-1200	-1	-2550	-2550	0	56	55	501	500	2	1	1	1	-3120

Figure 12.4: HV screen for a single card.

problem. The second technique is to track the average amplitudes of each PMT for good track events after a complete event reconstruction. For high efficiency of the trigger it is important to keep the average amplitude for the S1 PMTs above 600 channels. Due to the passive splitting, the S2 amplitudes should be expected to be only about 50 channels above the pedestal.

12.4 Measures to Protect the PMTs from Helium

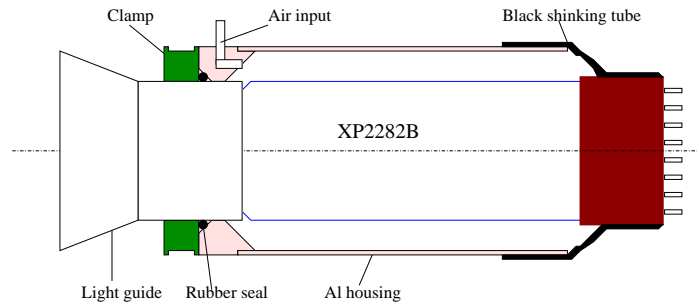


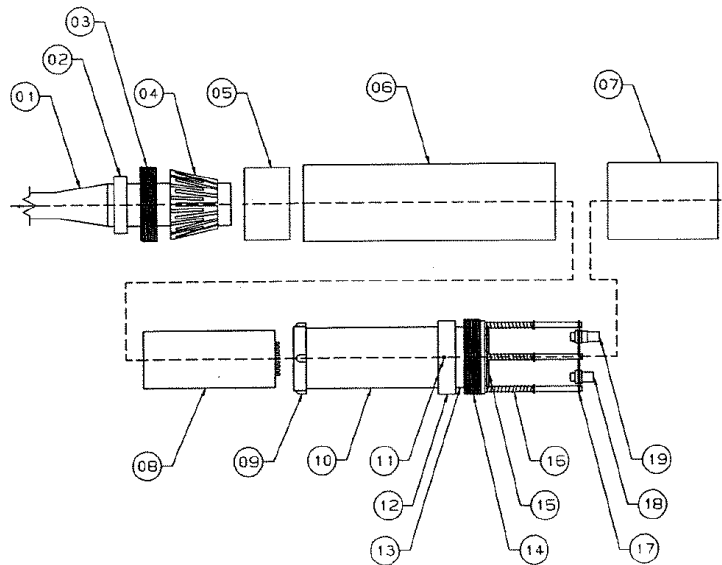
Figure 12.5: Details of the PMT Housing for S2.

There has been found in the past large He concentrations in Hall A, which can lead to a dramatic reduction in the PMT lifetime. To mitigate this problem, each PMT for S0, S1 and S2 is enclosed in a hermetic housing. Air from outdoors is supplied to the housing at a slight over-pressure. Figure 12.5 shows a schematic of the housings used for the S2 PMTs.

12.5 2" PMT Bases for S1 Trigger Counters

A schematic diagram of the 2" PMT Base is shown in Figure 12.6. The Base consists of three main components. These are the front tubular housing (06), which encloses the PMT, part of the scintillator counter's light guide (01), and the mu-metal shield (10). The actual base with the socket and the dynode chain is a separate part, actually an assembly of parts (09-19). The rear tubular housing (07) completes the assembly and encloses the dynode chain and wiring. The three main sections join at the coupling nut (14), which threads partly inside the front tubular housing, while the rear tubular housing threads on the remaining part.

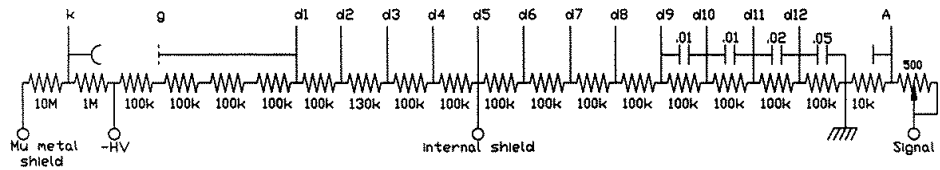
The PMT and the electronic amplification components are mounted on a P.C. board (15) which is enclosed in an aluminum Faraday cage. This assures rigidity and protection from stray RF fields. The mu-metal shield is at cathode potential to minimize the dark current due to capacitive discharge in the photo cathode glass window.



2 inch PMT Base Assembly

Figure 12.6: The 2" PMT base used in S1 trigger scintillators.

BURLE 8575 PHOTOMULTIPLIER TUBE DYNODE CHAIN



- All resistors: .6 Watt Metal Film.
- All Capacitors > 200 V.
- Values in microfarads.

UNIVERSITY of REGINA	
Faculty of Science Electronics Shop	
Title: Burle 8854 P.M. Tube Dynode Chain	
Date: 17/Dec/90	Page: 1 of 1
Notes: version 1. With matching pot.	
File: 8575.dwg	

Figure 12.7: The 2" PMT base used in the S1 trigger scintillators.

The Electronic Amplification Chain The arrangement of the resistor dynode chain is shown in Figure 12.7. The cathode is connected to the mu-metal shield through a 10 M Ω resistor, in addition to the 1 M Ω resistor between the cathode and the negative HV. The dynode chain incorporates an adjustable potentiometer (0-500 Ω) to allow a match between the PMT and the external load, in order to eliminate after-pulse ringing. This potentiometer should be adjusted at first to 250 Ω and then make fine adjustments as needed by observing the anode pulses on the oscilloscope for critical matching. It is not advisable to do the adjustments with HV on. Instead, the process should be done with HV off; remove the rear tubular housing, adjust the potentiometer, replace the rear housing, and then turn the HV on again. Iterate until the matching is accomplished. In addition to the obvious safety concerns, one does not want to remove the light sealing rear housing from an active PMT and induce a large light leak which could destroy the PMT. The bases have been extensively tested under beam conditions. They have several safety related features but these cannot protect anyone who is bent on violating operating procedures and common sense. They allow the removal of the PMT/Base assembly, for repairs of the electronics or replacement of a PMT, without decoupling the housing and collets from the light guide. Thus, replacement of PMTs can be done in minutes without the need to remove the scintillator counters from their subframes.

12.6 Safety Assessment

12.6.1 Hazards

The personnel hazard with these devices is the high voltage. This same hazard can damage the equipment if the voltage is left on when a tube is exposed to room lighting.

12.6.2 Mitigations

The bases on the phototubes are high voltage devices and the high voltage channel must be turned off and the SHV cable removed before handling.

The maximum (negative) voltage for both the PMTs and dynode chain is 3 kV. In actual use, however, there should be no need to exceed the 1.8–2.1 kV operating parameters, since both PMTs and dynode chain have high gain. Nevertheless, the bases are high voltage devices and care should be exercised during handling and setup. The external aluminum parts, the front and rear housing, and the back plate (17), are all grounded via the ground of the BNC (18) and SHV (19) connectors. Since the back plate is connected to the coupling nut via the three steel posts, the front plate is also grounded via the coupling nut and the back plate. Common sense, however, dictates that the bases are not to be handled while under high voltage, even when multiple grounding connections are provided.

The mu-metal shield is also under high voltage, since it is connected to the cathode. Electrical isolation between the mu-metal shield and the front tubular housing is assured by the high dielectric retainer ring (12) and the plastic insulator (09) at the free end of

the mu-metal shield. The air gap between the mu-metal shield and the front tubular housing is 6 mm, thus the breakdown value (18 kV) far exceeds the maximum 3.0 kV of the PMT.

In the event that the mu-metal shield is inserted without the plastic insulator ring, or someone decides to operate the base without the outside housings, the 11 M Ω resistors between the -HV and the mu-metal shield will restrict the current flow through the mu-metal shield (and the person's hands) to less than 0.2 mA with 2.1 kV on the base.

12.6.3 Responsible Personnel

The individuals responsible for the operation of the trigger counters are shown in Table 12.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	<i>Contact</i>
Jack Segal	Hall-A	7242		segal@jlab.org	

Table 12.1: Trigger counters responsible personnel.

Chapter 13

The Hall A Gas System

1

13.1 Overview

The Hall A detector gas systems are located in the Hall A Gas Shed alongside of the truck ramp for Hall A. The gas cylinders in use are along the outside of the Gas Shed in a fenced area. There are racks next to the Gas Shed for storage of full gas cylinders. On the other side of the truck ramp there are racks for storage of both full and empty cylinders. Hall A currently uses ethane, argon, ethanol, carbon dioxide, methane, and nitrogen. Details of these systems can be found in the Hall A Gas Systems (HAGS) manual. A copy of the current manual is in Counting Room A and on the Hall A web page.

Four systems are supplied from two cylinders of Coleman grade CO₂. One system is for the gas Cherenkov counters in the HRS detector arrays. One system is for flushing the mirror aerogel Cherenkov counter in the HRS detector arrays. One system is for the gas Cherenkov counters in the (e,p) setup in the beamline. One system is for the FPP straw tube wire chambers. Argon and carbon dioxide for the FPP straw tube wire chambers are mixed inside the Gas Shed.

Three systems are supplied from two cylinders of UHP grade argon. One system is for the VDC wire chambers of both arms. Argon and ethane for the VDC wire chambers are mixed inside the Gas Shed and bubbled through ethyl alcohol. One system is for the FPP straw tube wire chambers. Argon and carbon dioxide for the FPP straw tube wire chambers are mixed inside the Gas Shed. One system is for flushing clean, inert gas through the RICH detector wire chamber.

One system is supplied from two cylinders of Chemically Pure grade ethane. This is for the VDC wire chambers of both arms. Argon and ethane for the VDC wire chambers are mixed inside the Gas Shed and bubbled through ethyl alcohol.

Two systems are supplied from two cylinders of UHP grade nitrogen. One system is

¹Authors: J.Segal segal@jlab.org

used to provide pressurized gas for the automatic cylinder switch-overs in the systems. One system is used to flush impurities from the RICH detector freon reservoir.

One system is supplied from two cylinders of UHP grade methane. The system is for the wire chamber of the RICH detector.

Jack(John) Segal - pager and phone are both extension 7242

Hall A Technician on call

13.2 Safety Information

13.2.1 Hazards

Some of the gases that are used are flammable. Also, the gas bottles are under high pressure and can become missiles.

13.2.2 Mitigations

The bottles are located in a gas shed with the bottles secured so that they can not fall.

In Counting Room A there are two alarm panels associated with the gas systems for the detectors. They are located on the far left end of the control console, mounted one above the other. The upper panel is a Gas Master flammable gas monitoring system. The lower panel is a gas systems status indicator. The Gas Master system will go into alarm if elevated levels of flammable gas are present in either of the Detector Shielding Huts or the Gas Shed. The gas systems status will alarm if any of a number of faults are detected in the Hall A Wire-chamber Gas System. The LED for the specific fault will turn red to indicate which fault caused the alarm. Response to an alarm should be to contact the personnel listed below.

13.2.3 Responsible Personnel

Maintenance of the gas systems is routinely performed by the Hall A technical staff. Shift personnel are not expected to be responsible for maintaining the detector gas systems (see Table 13.1 for the names of persons to be contacted in case of problems).

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Tech-on-Call Jack Segal	Hall-A Hall-A	W.B. 7242		segal@jlab.org	<i>Contact</i>

Table 13.1: Responsible personnel for detector gas system.

Chapter 14

Vertical Drift Chambers

1

14.1 Overview

The High Resolution Spectrometer Vertical Drift Chambers provide a precise ($\pm 125 \mu\text{m}$) measurement of the position and angle of incidence of both recoil electrons (in the HRSe) and knockout protons (in the HRSh) at the respective spectrometer focal planes. This information may be combined with the knowledge of the spectrometer optics to determine the position and angle of the particles in the target.

Each Hall A spectrometer boasts its own VDC detector package. These packages are located on permanent rails mounted on the spectrometer decks in the shielding huts above the outrun windows but beneath the space frames. The packages consist of two VDCs, and are identical in all aspects. The VDCs have been constructed without guard wires. Each VDC is composed of two wire planes in a standard UV configuration - the wires of each plane are oriented at 90° to one another, and each plane is oriented at 45° with respect to the nominal particle trajectories (see Figures 14.1,14.2).

Operation of the Hall A drift chambers requires the application of both High Voltage (HV) across the chambers themselves and Low Voltage (LV) across the preamp/disc cards, which are mounted on the sides of the VDCs, within the confines of the protective aluminum Faraday cage. The chamber gas is a combination of argon (Ar) and flammable ethane (C_2H_6) which is bubbled through alcohol. Gas is routed from bottles located in the Hall A gas supply shed to gas supply control panels located on the main level of the space frames in the detector huts.

As charged particles pass through the chamber gas in the VDCs, they produce ionization. This ionization drifts along the electric field lines defined by the high voltage planes and the signal wires. Ionization is collected in the form of analog pulses on the signal wires. The pulses are then amplified, discriminated and used to start multihit TDCs, which are subsequently stopped by the overall event trigger. The TDCs are read

¹Authors: J.Segal segal@jlab.org

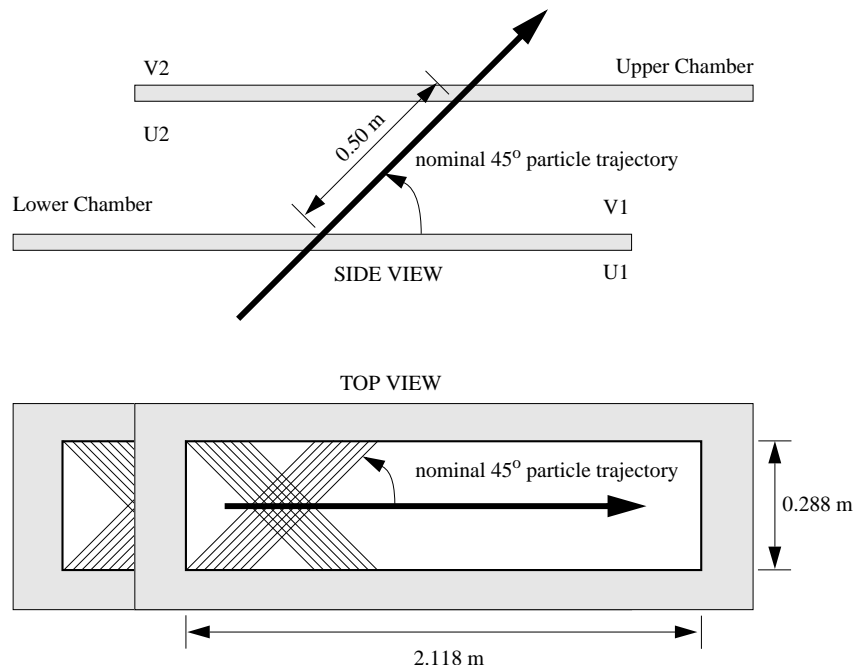


Figure 14.1: Relative VDC geometry

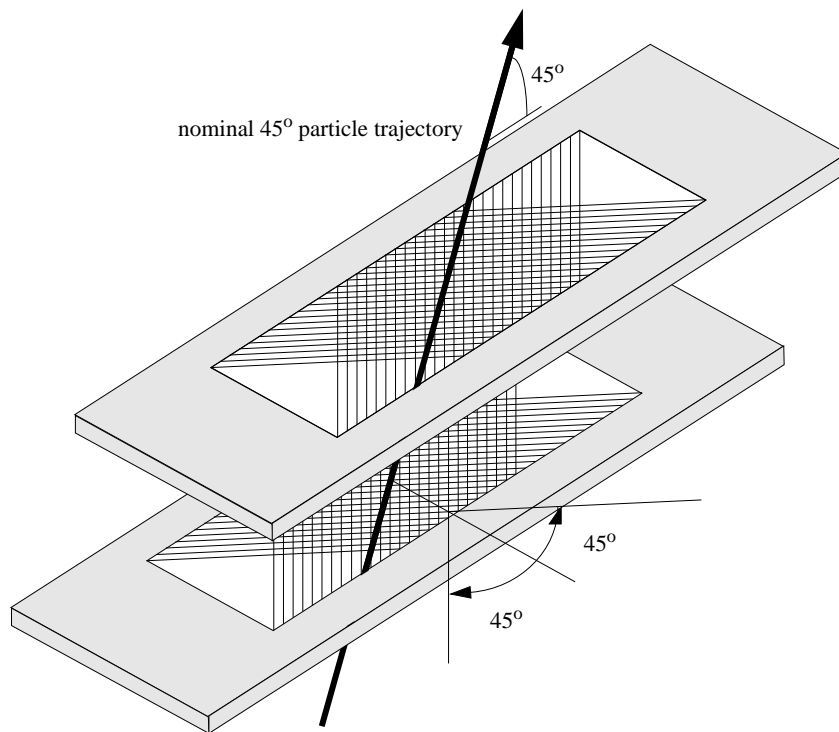


Figure 14.2: Relative VDC geometry

out by the CODA [18] acquisition software. In-depth data analysis requires the offline software (see Sec. 23.1).

14.2 Operating Procedure

Gas Flow Operating Procedures Chamber gas is delivered to a given VDC detector package via HAGS, the Hall A Gas System. Complete details of this system are presented elsewhere in this manual.

Each VDC detector package consists of two VDCs connected in parallel (see Figure 14.3). All gas connections are made using Polyflo™ tubing and Jefferson Lab specified connectors. Gas enters the chamber assembly after bypassing an overpressure bubbler containing 15 mm of (edible) mineral oil. Gas is exhausted from the VDC package through a second bubbler containing 5 mm of mineral oil. Each chamber has a volume of approximately 30 ℓ and is operated slightly above atmospheric pressure. Standard flow rate set points are clearly labeled next to the control panel flow meters. The gas flow through the chambers may be independently varied and is typically set to 7 ℓ/hr. A typical chamber leakage rate measured against the 5-mm mineral oil load is ≤ 3 ℓ/hr. The flow rate of 7 ℓ/hr when combined with the leak rate of ≤ 3 ℓ/hr ensures a complete exchange of gas in the chambers roughly every 8 hours. When a bottle is nearly empty (say 90%), it should be changed since the quality of the gas at the bottom tends to be low. Gas bottles may only be changed by authorized personnel.

The status of the gas handling system should be monitored carefully every shift. Manual logging is not required as the system status is constantly logged via EPICS [6]. Any substantial deviation from the median parameters can result in a change in the operational parameters of the VDCs and should be immediately investigated. If at all possible, gas flow should be continuously maintained, even in no-beam time periods. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition. Further, it is critical that gas flow has been maintained for 24 hours prior to any power up.

Power Supplies and Electronics Procedures The power supplies and readout electronics associated with the HRS VDCs are all commercially designed. The reader is directed towards the manuals made available by the manufacturer for the detailed information not provided here.

A Bertan 377N HV power supply, modified to allow a remote reset, provides -4.00 kV nominal to each of three HV planes in a given VDC detector package via a 10 MΩ Hammond splitter box (see Figure 14.2). The power supply is located in the detector hut in a NIM bin on the upper level of the space frame. This unit may be controlled either manually or remotely via the EPICS control software, and also provides a monitor of the current drawn (nominally 70 nA) by the VDCs to which it is attached. Connections from the power supply to the Hammond splitter box, as well as from the Hammond splitter box to the VDCs are made using standard SHV connectors on red RG-59/U cable good

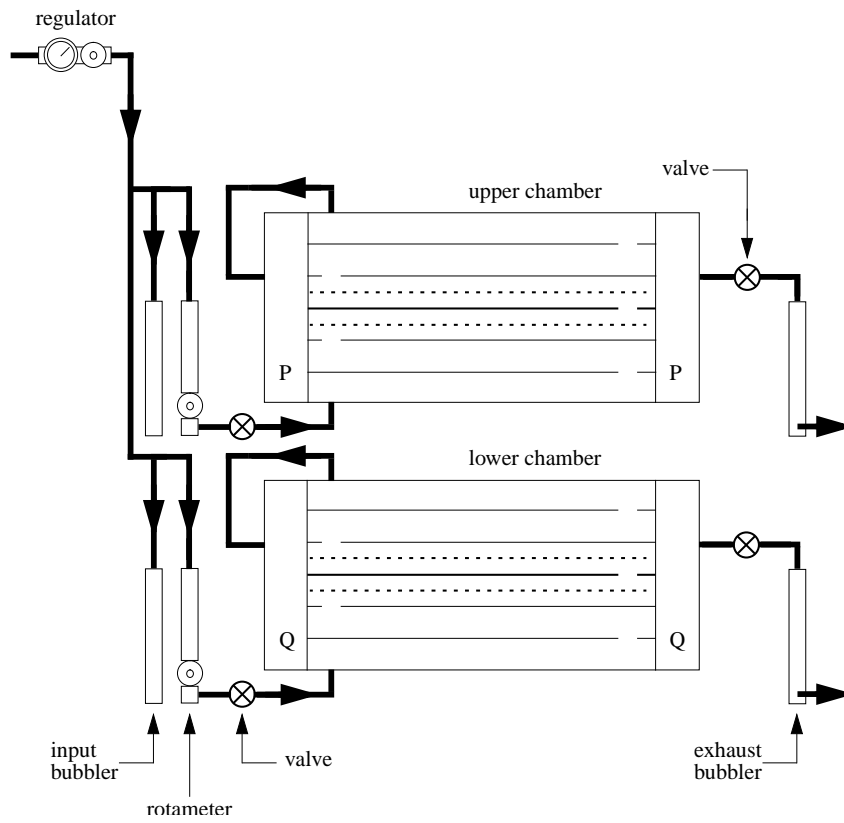


Figure 14.3: Gas flow schematic

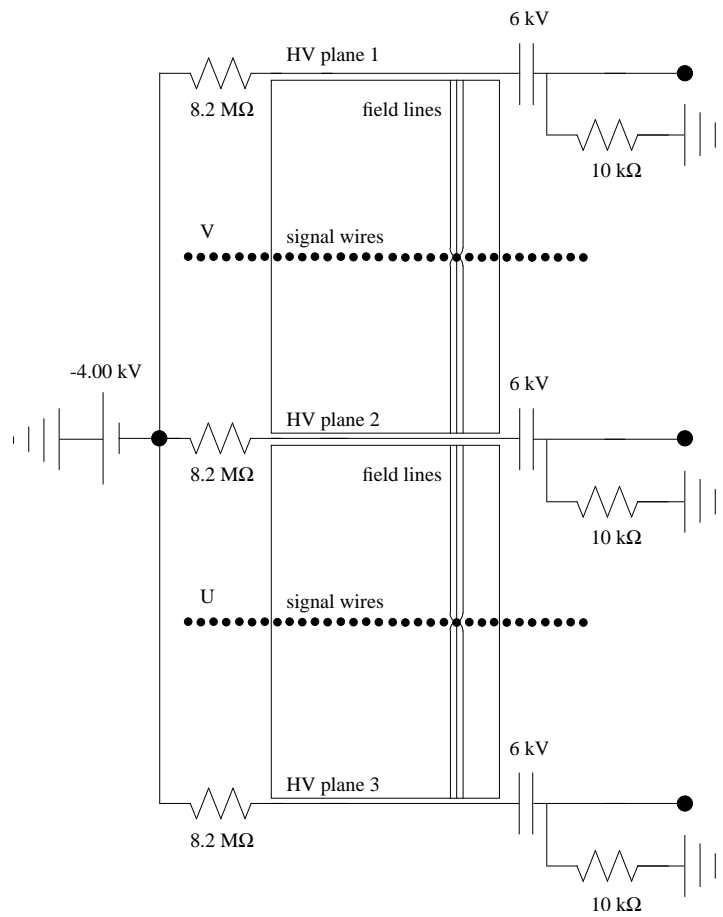


Figure 14.4: VDC overview.

to 5 kV.

The old LeCroy 2735DC pre-amp/discriminator cards used to instrument the chambers were replaced by the new MAD cards. MAD cards are powered with +5.0 V only, and the total current drawn from 92 cards is less than 15A. The signals from MAD cards are plugged into level-translator cards, before connecting to the FASTBUS readout. Level translator cards are powered with +5.0 V and -5.0 V with total current draw less than 10 A. These LV supplies are located in the detector hut on the main level of the space frame for the HRS_e and on the upper level of the space frame for the HRS_h . Complete connection schematics and instructions for making or breaking the connections are located on the aluminum Faraday cage protective plates covering the respective interface nodes between the power supplies and the VDCs.

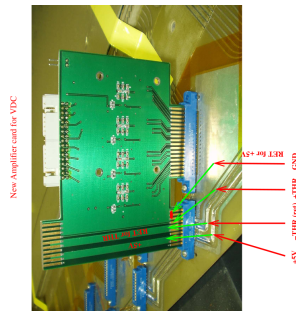


Figure 14.5: The new MAD card that is used as pre-amp/discriminator on VDC. It operates with +5.0 V



Figure 14.6: MAD cards on VDC



Figure 14.7: Power supply arrangement for MAD cards in the detector hut



Figure 14.8: Level translator arrangement in the detector hut

Each VDC wire plane consists of 400 $20\ \mu\text{m}$ ϕ , Au-plated tungsten wires. The first 16 wires on each end of the wire plane are connected to ground for field-shaping purposes. There are 368 wires per wire plane which act as signal wires. Thus, each spectrometer is instrumented with 1472 channels of LeCroy 1877 multihit Fastbus TDCs. These TDCs are located in a Kinetic Systems F050 Fastbus crate with a BiRa FB8189-4 power supply located on the main level of the spectrometer space frame in the detector hut. The connections between the pre-amp/discriminator cards mounted on the VDCs and the TDCs are made with 34-conductor twisted-pair cables. Clip-on ferrites are used to filter noise. A connection schematic is posted on the side of the rack holding the Fastbus crate on the space frame in the detector hut.

Power-up Procedure

1. ensure gas flow has been established in the chambers as previously outlined. If it has not, *STOP RIGHT HERE!* Gas flow must be well-established and steady-state *BEFORE* the HV may be enabled.
2. Ensure that all power supplies as well as the Fastbus crate are off and then connect the LV, HV, and TDC cables.
3. enable the LV. Set points are clearly labeled on the face of the power supplies. Note that they have overcurrent setpoints, and some fine adjustments over the first 30 minutes after a cold start power-up may be required. Appropriate LEDs should all be active on both the power supplies and the pre-amp/discriminator cards.
4. slowly (steps of no more than -300 V) ramp the HV to its nominal set point of -4.00 kV using either the manual or the remote controls. While the trip current is set to $10\ \mu\text{A}$, do not allow the chambers to draw more than $1\ \mu\text{A}$ during the ramping procedure or serious damage may result. If the power supply trips during the ramping procedure, you are moving too fast. Re-zero things and begin the procedure again. *NEVER USE THE AUTO-RESET FUNCTION.* If the power supply trips again, *STOP IMMEDIATELY AND INVESTIGATE.*
5. enable the Fastbus crate. Appropriate LEDs should all be active.

6. check for poor signal connections evidenced by hot wires (wires counting extremely fast) or dead wires (wires with no counts) using the histogramming software and cosmic rays. Remake any connections as necessary by first powering down the Fastbus crate.

If at all possible, the HV and LV power supplies should be left on continuously if and only if gas is available to the chamber. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition.

14.3 Handling Considerations

The VDCs are very delicate devices which are absolutely essential to the instrumentation of the Hall A spectrometers. Thus, extreme care must be exercised whenever they are moved or used.

- Before moving a VDC detector package, ensure that the protective plates are in position. Plates include tapped aluminum sheets to be bolted over the entrance and exit apertures, as well as aluminum sheets which slide in between the two chambers.
- Disconnect and reconnect all TDC cables with extreme care. The conductor pins are relatively fragile, and should one be broken off, repair will be *extremely* difficult.
- When initiating gas flow, pay strict attention to the feedback parameters. Overpressure may damage the chambers.
- Never attempt to apply HV to the chambers until gas flow conditions have reached steady-state.
- As the amount of heat generated by the pre-amp/discriminator cards is substantial, always make sure adequate cooling is provided before attempting to run. This cooling takes the form of four 12VDC fans mounted in the aluminum Faraday cage.
- When ramping the HV, never allow the chambers to draw more than 1 μA instantaneously. If they do, something is wrong!

14.4 Safety Assessment

14.4.1 Hazards

The following hazards are associated with the chambers:

The High Voltage System The Bertan 377N HV low current power supply provides a nominal -4.00 kV.

Explosive Gas The Ar C₂H₆ chamber gas is explosive and must be handled accordingly. Further, gas flow should be maintained for at least 24 hours prior to the enabling of HV.

High Pressure Gas Bottles The gas used in the chambers is supplied in high pressure (≥ 2000 psi) gas bottles. This confined high pressure gas represents a tremendous (potentially lethal) amount of stored energy.

14.4.2 Mitigations

For the HV, red HV RG-59/U cable good to 5 kV with standard SHV connectors is used to connect the power supply to a Hammond splitter box, and then to connect the splitter box to each of the three high voltage planes in a given VDC. A given chamber draws a current from 50–100 nA. Thus, when servicing the chambers, the HV for that element must be turned off and disconnected.

The high pressure gas bottles are stored far from the equipment in a controlled area as discussed in the Hall A gas handling section.

14.4.3 Responsible Personnel

The individuals responsible for the operation of the VDC are shown in Table 14.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Jack Segal	Hall-A	7242		segal@jlab.org	<i>Contact</i>
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	

Table 14.1: VDC responsible personnel.

Chapter 15

Gas Cherenkov Counters

¹

The Hall A gas Cherenkov detectors are filled with CO₂ at atmospheric pressure as delivered by the Hall A gas system described elsewhere. The Cherenkov does have photomultiplier tubes and thus high voltage.

A gas Cherenkov detector filled with CO₂ at atmospheric pressure is mounted between the trigger scintillator planes S1 and S2. The detector has an electron identification efficiency of 99% and a threshold for pions of 4.8 GeV/*c*. The detector has ten spherical mirrors with 80 cm focal length, each viewed by a PMT (ET Enterprises tube 9390KB); the light-weight mirrors were developed at INFN. The focusing of the Cherenkov ring onto a small area of the PMT photo-cathode leads to a high current-density near the anode. To prevent a non-linear PMT response, even in the case of few photoelectrons, requires a progressive HV divider. The length of the particle path in the gas radiator is 130 cm for the gas Cherenkov in the HRS-R, leading to an average of about twelve photoelectrons. In the HRS-L, the gas Cherenkov detector in its standard configuration has a path length of 80 cm, yielding seven photoelectrons on average. The total amount of material in the particle path is about 1.4% X_0 .

15.1 Concept of the design

Two similar threshold gas Cherenkov counters have been constructed as a part of the particle identification equipment to be included in the focal plane detector package of the High Resolution Spectrometers (HRS) in the TJNAF experimental Hall A (see Fig. 15.1). Each counter's housing is made of steel with thin entry and exit windows made of TedlarTM. Light-weight spherical mirrors have also been built, resulting in a very thin total thickness traversed by particles.

These two counters have identical sections but different lengths of the gas radiator, 80 cm for the left arm and 130 cm for the right arm. There is an additional section 50 cm long which can be attached to the short counter if needed. Each Cherenkov is made of 10

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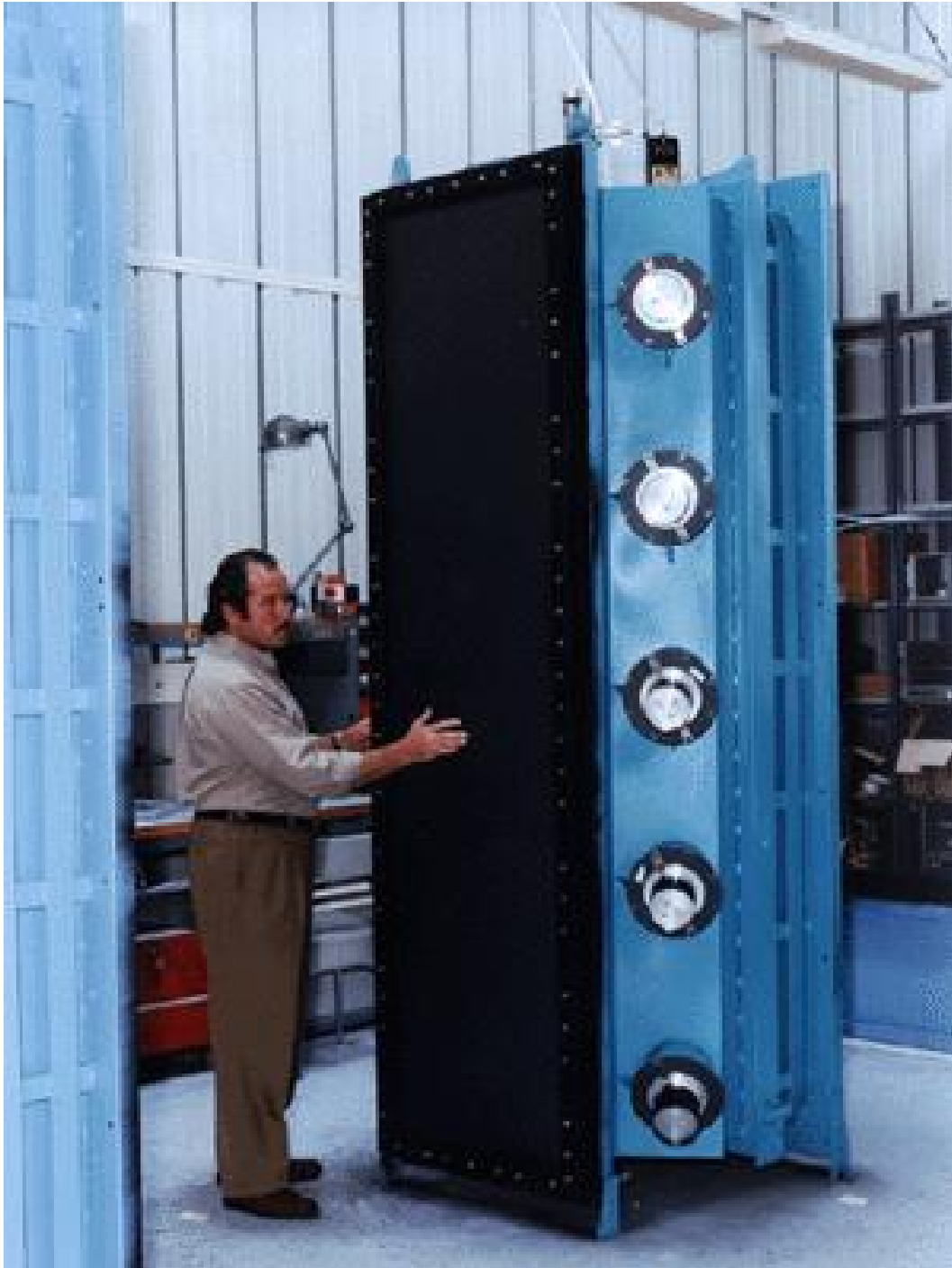


Figure 15.1: Gas Cherenkov counter.

tubes (PMT) and 10 spherical mirrors. Each mirror has a rectangular shape, the radius of a curvature of the reflective surface is 80 cm. The mirror is 1 cm thick, it is built of a very light honeycomb structure, which consists of the following materials: the MgF_2 layer, which protects the aluminum; the aluminum, which assures the reflectivity; the plexiglas, which assures a good surface; and a sandwich backing (carbon-epoxy, phenolic honey comb, carbon epoxy), which assures the rigidity of the mirror.

The 10 mirrors are placed just before the output window and are grouped in two columns of 5 mirrors. Each mirror reflects the light on a PMT placed at the side of the box. The mirrors of the same column are identical and the two columns are almost symmetrical. The positions and angles of the PMTs are not placed regularly, as like the mirrors, but were adjusted by an optical study in order to maximize the collection of light coming from the particular envelope of particles to be detected. The PMTs are fixed and mirrors orientation can be adjusted by hand.

The alignment procedure uses a small light source located about 820 cm from the mirror plane on the symmetry axis of the counter. The pictures in figs 15.2 and 15.3 show the image of the small light source on the PMT photo-cathodes during the mirror alignment procedure.

The five photomultiplier tubes are fixed to the two side walls. Each one is surrounded by high magnetic-permeability shielding (μ -metal). The fixing provides high voltage insulation between the PMT and the steel vessel. A set of optical fibers provides light pulses to each PMT for their calibration.

15.2 Safety Information

15.2.1 Hazards

This detector is operated under high voltage and makes use of a gas system.

15.2.2 Mitigations

The Cherenkov counter PMTs use high voltage. Care is required when handling any components of the counter and the body of the Cherenkov counter must be grounded. The maximum operating voltage on the PMTs is about -2,000 V, but nominally they are operated around -1,000 V. The voltage must be set to zero before the HV cable will be connected or disconnected from HV divider. The HV cables must be disconnected from all HV dividers before the replacement of any PMT on the gas Cherenkov counter.

The high voltage has to be adjusted in order to have the position of the photoelectron peak for each PMT at the same place, which is around 100 channels above the pedestal. For a good PMT the noise counting rate should not exceed 10 kHz. Past experience shows that PMTs need to be replaced on average every three years due to aging. Such a short life-time is about 3-4 times less than normal, due to He content in Hall A, which leads to a loss of the PMT's quantum efficiency.

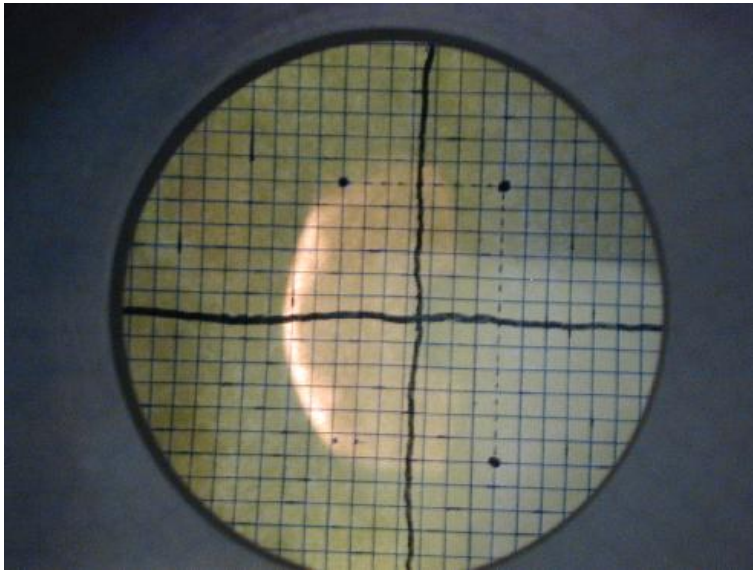


Figure 15.2: The image from the mirror #1 on the PMT photo-cathode.

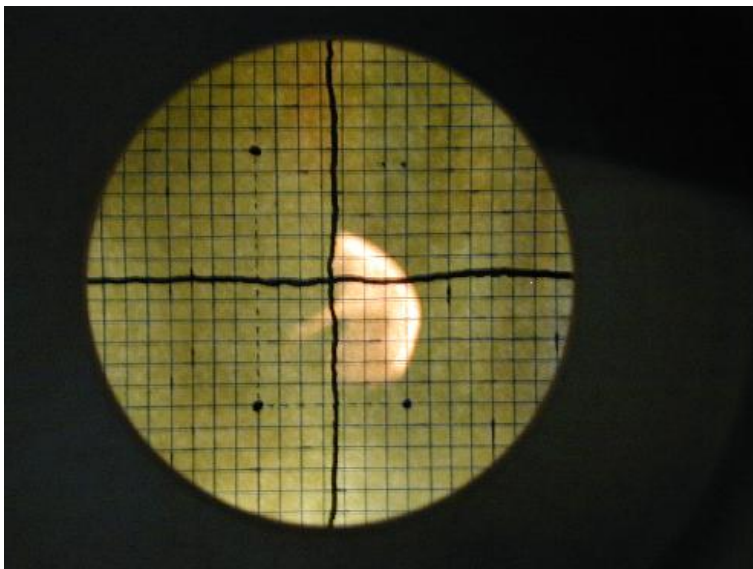


Figure 15.3: The image from the mirror #6 on the PMT photo-cathode.

Gas is supplied by the Hall A gas handling system and thus the gas bottles are outside the experimental hall and far from the equipment. The detector itself can not be over pressurized and the volume of gas is small.

15.2.3 Responsible Personnel

The individuals responsible for the operation of the gas Cherenkov counters are given in Table 15.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	<i>Contact</i>
Jack Segal	Hall-A	7242		segal@jlab.org	

Table 15.1: Gas-Cherenkov: authorized personnel.

Chapter 16

Electromagnetic Calorimeters ¹ ²

16.1 Purpose and Layout

Electromagnetic calorimeters, or shower detectors, provide very good particle identification (PID), separating electrons from hadrons or muons [19], [20]. The electron's energy is fully absorbed in a shower detector. For a typical shower detector thickness, about 20% of hadrons pass through it without interaction, releasing only the ionization energy. The other 80% interact strongly in the detector. Still, many particles carrying a large fraction of the initial energy escape from the detector. For electromagnetic showers, the energy-release density peaks at a detector depth of about 5 radiation lengths (the full detector depth is about 20 radiation lengths), while the energy release of other particles is more evenly distributed along the depth. Therefore, two factors are used for PID:

1. the ratio of the shower's energy to the particle's momentum;
2. the longitudinal shower profile.

The HRS spectrometers are equipped with 2-layer segmented shower detectors (see Fig. 16.1) built of lead glass.

A photo in Fig. 16.2 shows the HRS-R first layer (“pre-shower”) detector installed, while the second layer (“shower”) detector was removed.

The particle identification parameter R_{sh} is defined in Eq. 16.1 as:

$$R_{sh} = \frac{E_{tot}}{p} \times \frac{\ln(E_{presh})}{\ln(E_{ave})} \quad (16.1)$$

where E_{tot} is the total energy deposited in the shower detector, p the particle's momentum, E_{presh} the energy deposited in the front layer and E_{ave} the average energy deposited by an electron with momentum p .

¹ *CVS revision* Id: shower.tex,v 1.8 2008/04/28 15:51:05 gen Exp

²Original author: E.Chudakov gen@jlab.org

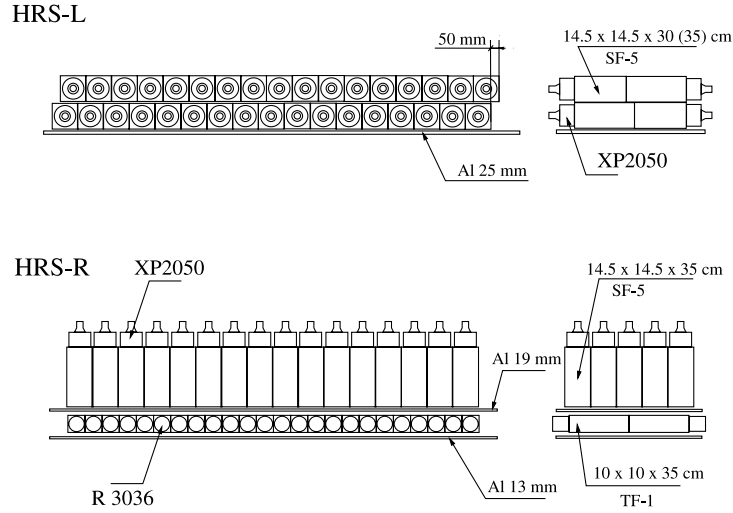


Figure 16.1: Schematic layout of part of the shower detectors in the HRS-L (top) and HRS-R (bottom). Particles enter from the bottom of the figure.

16.2 Description of Components

16.2.1 Detectors

The detector components are summarized in Table 16.1. Because of its reduced thickness,

HRS	layer	historic name	# of blocks	cols × rows	Sizes, cm			glass	PM type
					X	Y	Z		
L	1	pion rejector 1	34	2×17	14.7	35.0	14.7	SF5	XP3540B ^(c)
L	2	pion rejector 2	34	2×17	14.7	35.0	14.7	SF5	XP3540B ^(c)
R	1	pre-shower	48	2×24	10.0	35.0	10.0	TF1	XP5312B ^(b)
R	2	shower	75	5×15	15.0	15.0	32.5	SF5	XP3530B ^(a)

Table 16.1: The number and sizes of the lead glass blocks used in the shower detectors of the HRS. “X” denotes the dispersive plane of the HRS, while “Z” is along the average particle direction, perpendicular to the focal plane. Some of the large blocks are 30 cm long, instead of 35 cm. The photo-multiplier tubes were from: (a) - Photonis [21], a 130 mm tube, they have been replaced by (c) Photonis XP3540B [21]; (b) - Photonis [21]; (c) Photonis [21].

the resolution in the HRS-L is not as good as that of the shower detector in the HRS-R.

The High Voltage is controlled via EPICS [6] and the Hall A MEDM [14] (see Chapter 20). The MEDM windows and the voltages are shown in Figs. 16.3, 16.4 and 16.5.



Figure 16.2: HRS-R first layer (“pre-shower”) detector installed, while the second layer (“shower”) detector was removed.

Right Arm Top									
HV/OFF HV/ON	S1/S2 Left	S1/S2 Right	Slot 4 Preshower	Slot 5 Preshower	Slot 7 Preshower	Slot 8 Preshower	Aerogel Cerenkov	Aerogel Cerenkov	Gas Cerenkov
Ch 0	-2001	-2051	-1044	-1060	-852	-1083	-21	-20	-2401
Ch 1	-2000	-1977	-1147	-1148	-1090	-1081	-19	-19	-2427
Ch 2	-2101	-2071	-1098	-1067	-989	-1071	-18	-23	-2401
Ch 3	-1972	-1950	-1063	-1077	-1073	-1570	-16	-20	-2501
Ch 4	-2031	-2003	-1081	-1161	-1067	-1086	-18	-27	-2401
Ch 5	-2201	-2151	-1112	-1108	-1024	-1011	-20	-22	-2500
Ch 6	-2051	-1971	-1112	-1083	-1171	-1093	-20	-29	-2351
Ch 7	-1851	-1952	-1192	-1072	-1571	-1068	-21	-24	-2451
Ch 8	-1941	-2051	-1025	-1063	-1028	-1095	-18	-24	-2551
Ch 9	-1901	-2002	-1102	-1075	-1107	-1065	-19	-24	-2501
Ch 10	-2021	-2021	-1125	-1108	-1088	-1065	-20	-23	-16
Ch 11	-2101	-2022	-974	-1053	-1109	-1001	-18	-22	-25

Figure 16.3: HRS-R: HV, “top” crate - includes the “pre-shower”

The screenshot shows a software window titled 'chassis1.adl' with a sub-header 'Right Arm Bottom'. On the left, there are two buttons: 'HV/OFF' (highlighted in green) and 'HV/ON'. The main area contains a table with 12 channels (Ch 0 to Ch 11) and 11 columns of voltage settings. The columns are labeled: Slot 1 Shower, Slot 2 Shower, Slot 4 Shower, Slot 5 Shower, Slot 7 Shower, Slot 8 Shower, Slot 10 Shower, A2, A2, and A2.

Channel	Slot 1 Shower	Slot 2 Shower	Slot 4 Shower	Slot 5 Shower	Slot 7 Shower	Slot 8 Shower	Slot 10 Shower	A2	A2	A2
Ch 0	-1800	-1500	-1501	-1501	-1601	-1500	-1501	18	19	0
Ch 1	-1499	-1502	-1502	-1471	-1501	-1503	-1504	19	21	0
Ch 2	-1300	-1600	-1102	-1251	-1501	-1502	-1101	18	22	0
Ch 3	-1901	-1501	-1501	-1400	-1601	-1499	-1800	18	22	0
Ch 4	-1651	-1401	-1501	-1497	-1500	-1602	-1799	18	19	0
Ch 5	-1801	-1011	-1501	-1501	-1600	-1502	-1701	17	17	0
Ch 6	-1601	-951	-1501	-1101	-1601	-1502	-1602	20	18	0
Ch 7	-1552	-1402	-1501	-1101	-1502	-1900	-1410	19	19	0
Ch 8	-1499	-1421	-1452	-1501	-1501	-1801	-10	18	21	0
Ch 9	-1601	-1751	-1501	-1502	-1502	-1600	-21	19	20	0
Ch 10	-1501	-1450	-1281	-1501	-1601	-1801	-22	19	20	0
Ch 11	-1499	-1351	-1971	-1500	-1101	-1500	-22	19	17	0

Figure 16.4: HRS-R: HV, “bottom” crate - includes the “shower” detector.

The screenshot shows a software window titled 'chassis7.adl' with a sub-header 'Left Arm'. On the left, there are two buttons: 'HV/OFF' (highlighted in green) and 'HV/ON'. The main area contains a table with 12 channels (Ch 0 to Ch 11) and 14 columns of voltage settings. The columns are labeled: Sl/S2 Left, Sl/S2 Right, Gas Cerenkov, Pion Rejector, Pion Rejector, Pion Rejector, Slot 6 1461N, FPP HV, FPP HV, Pion Rejector, Pion Rejector, A1 Left, and A1 Right.

Channel	Sl/S2 Left	Sl/S2 Right	Gas Cerenkov	Pion Rejector	Pion Rejector	Pion Rejector	Slot 6 1461N	FPP HV	FPP HV	Pion Rejector	Pion Rejector	A1 Left	A1 Right
Ch 0	-1951	-2100	-2399	-1732	-1861	-1921	-1535	24	24	-2001	-1632	17	18
Ch 1	-2028	-2051	-2576	-1590	-1432	-1410	-1825	21	24	-2065	-1811	20	17
Ch 2	-2353	-2076	-2501	-1626	-1901	-1676	-1530	23	26	-1845	-1491	14	17
Ch 3	-2003	-2076	-2400	-1452	-1801	-1411	-1601			-1790	-2000	14	17
Ch 4	-2100	-2153	-2600	-1756	-2201	-1711	-1458			-1566	-1730	20	19
Ch 5	-2204	-1976	-2476	-1355	-1564	-1510	-1890			-1711	-1721	13	16
Ch 6	-2203	-2352	-2476	-1861	-1976	-1811	-1490			-1475	-1452	15	16
Ch 7	-2082	-2704	-2450	-1532	-1640	-1602	-1765			-1891	-1886	16	13
Ch 8	-2177	-2202	-13	-1611	-1355	-1852	-1451			-1572	-1967	19	1700
Ch 9	-2100	-2604	-20	-1422	-1532	-1701	-1856			-1730	-12	15	1901
Ch 10	-2192	-2251	-19	-1752	-1867	-1521	-1560			-1701	-19	17	17
Ch 11	-2082	-2052	-19	-1386	-1511	-1686	-2000			-1801	-20	22	16

Figure 16.5: HRS-L: HV, includes the “pion rejector”.

16.2.2 Electronics

The signals from PM tubes (see Table 16.1) are delivered via the 1 μ s delay lines to LeCroy ADC 1881M.

16.3 Safety Assessment

Before handling the HV bases on the detector stack:

1. Turn off the HV.
2. Make sure the HV can not be turned on remotely - turn off the HV crate, or put it in the “local” mode using the key at the front panel of the crate. . In order to ensure that the crate HV would not be turned on one can also turn off the power switch at the rear panel of the crate.

Keep in mind that each $15 \times 15 \times 35$ cm³ detector has a mass of about 35 kg.

16.4 Authorized Personnel

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	<i>Contact</i>
Jack Segal	Hall-A	7242		segal@jlab.org	

Table 16.2: Electromagnetic calorimeters (shower detectors) : authorized personnel.

Chapter 17

Aerogel Cherenkov Counters ¹

17.1 Overview

There are three aerogel Cherenkov counters available with various indices of refraction, which can be installed in either spectrometer and allow a clean separation of pions, kaons and protons over the full momentum range of the HRS spectrometers. The first counter (AM) contains hygroscopic aerogel² with a refraction index of 1.03 and a thickness of 9 cm. The aerogel is continuously flushed with dry CO₂ gas. It is viewed by 26 PMTs (Burle 8854 [22]).

For high-energy electrons the average number of photo-electrons is about 7.3 [23].

The next two counters (A1 and A2) are diffusion-type aerogel counters. A1 has 24 PMTs (Burle 8854). The 9 cm thick aerogel radiator used in A1 ³. has a refraction index of 1.015, giving a threshold of 2.84 (0.803) GeV/*c* for kaons (pions). The average number of photo-electrons for GeV electrons in A1 is $\simeq 8$ (see Fig. 17.1). The A2 counter has 26 PMTs (XP4572B1 from Photonis [21]). The aerogel in A2 also hydrophobic has a refraction index of 1.055, giving a threshold of 2.8 (0.415) GeV/*c* for protons (pions). The thickness of the aerogel radiator in A2 is 5 cm, producing an average number of about 30 photo-electrons for GeV electrons.

17.2 Mirror Aerogel Cherenkov Counter ^{4 5}

AM is a silica aerogel Cherenkov counter with a compact reflection mirror design, which was dictated by the available space (36.3 cm along the incident particle direction). In addition, the high singles rates expected in Hall A are better handled with segmented detectors covering the focal plane; this requires short pulse decay times. Even though the diffusion length in silica aerogel can be quite short for low λ light generated in the *SiO*₂

¹ Author: B. B. Wojtsekhowski bogdanw@jlab.org

² Airglass AB, BOX 150, 245 22 Staffanstorps, Sweden.

³ Matsushita Electric Works, www.mew.co.jp.

⁴ *CVS revision* Id: aerogel.tex,v 1.14 2005/04/04 22:27:25 gen Exp

⁵ Author: G.J. Lolos gjlolos@jlab.org

radiator [24], enough directionality remains in the visible λ region, where the selected PMTs have good quantum efficiency, to make light collection with mirrors an attractive and practical alternative.

An effective segmentation of the aerogel Cherenkov counter, matching the segmentation of the trigger scintillators, can be used to separate multiple tracks through the focal plane and will allow an additional element of selectivity and track sensitivity in the focal plane instrumentation. This means that specific sections of the focal plane can be physically disabled from the trigger if the experimental conditions require it. It will also provide the capability to identify and separate pions and protons traversing the focal plane trigger scintillators and the vertical drift chambers (VDCs) within the resolving time of the system (double hits). For example, in the off-line analysis, the aerogel counter PMT with the highest number of photoelectrons can be matched with the trigger counter and VDC information to identify the actual path of a pion, thus separating it from a simultaneously detected proton which has no Cherenkov signature. Such a capability of double hit resolution is not possible with diffusion Cherenkov counter designs, because the photon collection efficiency does not have a strong spatial correlation with the incident particle track within the aerogel material.

The segmentation, in addition to supplementing the information on the individual particle position along the focal plane, couples well with the desire to increase the active solid angle viewed by the PMTs in the counter. Although the photon detection probability is not as directly proportional to the solid angle covered by PMTs as in the case of a diffusion box, clearly the larger effective coverage leads to a higher probability that a photon will end up on a PMT. Given the divergence of the beam envelope incident on the aerogel and the diffusion of the light in the low λ region by the aerogel material, an increase in the area covered by PMTs results in an increase in the number of photons detected. As a result, a total of 26 PMTs are used in the counter, as shown in Fig. 17.2, with minimal spacing between their μ -metal shields (2.8 mm). The total area covered by the PMT photo-cathode windows comprises 72% of the area of the counter opposite the planar parabolic mirrors. A cross sectional schematic of the detector is shown in Fig. 17.3, clearly illustrating the planar parabolic design of the mirror surfaces and their relative orientation with respect to the PMTs, and the orientation of the counter relative to the central axis of the spectrometers.

The close spacing of the μ -metal shields creates dielectric breakdown problems. The μ -metal shields are at cathode potential (-2950 V) to avoid the capacitive discharge from a grounded μ -metal shield to the glass of the photo-cathode; discharges would contribute to the noise level in the PMT and adversely affect their performance at high operating voltages. This necessitates extra precautions in order to avoid dielectric breakdown between adjacent shields and between the shields and the aluminum structure of the counter, which is at ground potential. The solution was to wrap the outer surfaces of the μ -metal shields with a high dielectric value (12,000 V/mm), thin (0.254 mm) Teflon film⁶. In addition, the PMT housings consist of fiberglass-epoxy composites, with added inner and outer skins of 0.0254 mm thick Tedlar¹, with a further combined insulating

⁶DuPont Canada Inc., Box 2200, Streetsville, Mississauga, ON L5M 2H3, Canada.

value of 3,000 V . Such a combination of insulating materials eliminates any breakdown or small leakage current induced noise and simultaneously satisfies all safety requirements.

The final construction of the counter, described in this report, is built around the two sides of the main (PMT) section. Each section consists of two pieces of aircraft quality aluminum alloy, with stiffening aluminum rods formed integrally on the top and bottom. The openings for the PMT housings were machined on these structures using CNC milling machines to keep tolerances to fine levels. The double-walled structure, on both sides of the enclosure, further increases the rigidity of the exoskeleton by forming a second “outer” wall on each side - very similar in configuration to the inner one - and attached to the latter with cross-bolt braces. Each end plate is made out of the same aluminum alloy as the side walls, and also incorporates stiffening lips folded integrally to each plate, one at the top and one at the bottom. Each end plate has been provided with inlet and outlet gas line connections, which will be used to fill the counter enclosure with dry CO_2 gas to protect the silica aerogel from water vapor absorption.

All internal surfaces of the detector, except the planar parabolic mirrors are lined with aluminized mylar⁷ to increase the overall reflectivity of the counter. The mirrors are made of $45 \times 20.5cm^2$ molded surfaces, formed in one rigid structure. The rigidity is provided by two layers of carbon fiber epoxy composite backing, with a combined thickness of 0.28 mm , and a single sheet of mylar with thickness 0.127 mm . The special mylar material was obtained from exposed negative film used in the cartographic industry, and is of high smoothness and uniformity. One side was aluminized at CERN, while the other side remains in its exposed negative (black) state, further adding to the successive light penetration barriers into the enclosure.

The upper section of the counter containing the mirrors is mounted on its own aluminum sub-frame, which is bolted to the main frame that houses the PMTs. The light and gas sealing action is provided by continuous twin parallel rubber strips along the joint area, and by Tedlar film of 0.025 mm thickness covering the top of the outer planar parabolic area.

The third major component of the counter is a removable tray where the silica aerogel is placed. The tray occupies the bottom part of the counter and has inner dimensions of $195 \times 41cm^2$. It is formed by a frame with twin aluminum panels which secure the removable frame strung with fishing line in a criss-cross pattern to hold the aerogel panels in place. This “fish-net” frame is secured by screws and is easily removed without disturbing the aerogel panels or requiring re-stringing. The bottom of the tray is formed out of a single layer of carbon fiber epoxy skin (0.127 mm thick) and a layer of aluminized mylar of equal thickness. Externally, it is covered by a single layer of Tedlar film to assure integrity from light penetration; further environmental isolation is provided by two parallel strips of rubber gasket seals enclosing the circumference of the tray and containing the feed-through spacers for the retaining bolts. The tray is equipped with SMA-type fiber optic feed through connectors for the gain and timing monitor system, which utilizes fiber optic cables. Each fiber illuminates two adjacent PMTs, except for the last PMT on either side (13T and 13B in Fig. 17.2) which have their own dedicated

⁷National Metalizing, P.O. Box 5202, Princeton, NJ 08540, USA.

fiber. The light is generated in a gas plasma discharge unit⁸ and duplicates the spectrum expected from Cherenkov radiation. In addition, the fibers terminate beneath the silica aerogel; thus the light reaching the PMTs will have the absorption characteristics of real Cherenkov light produced in the aerogel radiator.

Due to the nature of Cherenkov detectors, where only a few photoelectrons (PEs) are emitted by the photo-cathodes in the PMTs, any extraneous light entering the enclosure is very troublesome. As a result of the small number of PEs expected, the PMTs operate either near to or at maximum high voltage, and thus at maximum gain. As such they can suffer damage if a sudden light leak develops. In testing we verified the extreme sensitivity to minute light leaks across the whole length of the structure because of the mirrored surfaces inside the enclosure. With 26 PMTs operating at maximum gain - and viewing, effectively, a giant mirror - sealing the enclosure against single photon penetration requires extra care during initial testing and operations.

The PMTs chosen for the counter were Burle model number 8854 with a 127 mm photo-cathode diameter⁹. The PMT amplification electronics have been described in Refs. [25, 26]. The dynode chain incorporated a 600 k Ω resistance between the cathode and first dynode instead of the nominal 300 k Ω . This generates a $V_{dyn} = 885V$ voltage drop across the cathode to dynode gap, thus increasing the photo-electron collection efficiency and peak to valley (P/V) ratio. This modification has proven successful in increasing the PE collection efficiency and the single PE resolution. The dynode amplification chain also incorporates a 11 M Ω resistor in series with the μ -metal shield to eliminate the possibility of electric shock through careless handling; this high impedance also limits the current drawn in the unlikely event of a complete dielectric breakdown between the shields and the aluminum parts of the detector. A schematic diagram of the electronic amplification chain is shown in Fig. 17.4.

The operation of the aerogel detector is discussed in Ref. [23].

17.3 Operating Procedure

Operating Voltage The operating voltage on the PMTs is -2,950 V. This is a near the maximum rated voltage and it has been shown to provide high efficiency, good P/V ratio, and long PMT life. The overall gain of the PMT is not at maximum, as measured by BURLE, since the dynode chain of the 13 dynodes (2nd dynode to 14th dynode) is kept at a -2,600 V equivalent with the original 300 k Ω resistor value between the cathode and 1st dynode. However, the gain is more than sufficient to separate single PEs from the pedestal on all ADCs we have used so far. It should not be necessary to increase the voltage above the recommended value.

⁸Optron Inc. 23206 S. Normandie Ave. #8, Torrance, CA 90502, USA.

⁹Burle Industries Inc., 1000 New Holland Ave., Lancaster, PA 17601, USA.

17.4 Handling Considerations

It is generally not advised to open up the counter if the persons involved are not thoroughly familiar with the assembly and specific component function. Routine operation does not require any hands on modifications to the detector, as long as the following operating principles are followed:

Installation and Removal of PMTs The replacement of a PMT or repairs of the electronic amplification chain can be accomplished by the removal of that specific PMT-Base combination. Turn the HV off on all PMTs and remove the rubber hood covering the base and housing interface region. Now remove the three small screws attaching the base to the integral housing. Note that the base can only be secured to the housing in one specific orientation.

Carefully slide out the base with the PMT and μ -metal shield mounted as one unit. Remove the elastomeric ring positioned between the PMT and the μ -metal shield. Loosen the nut securing the μ -metal shield to the base and carefully apply upward force on the shield while someone else is holding onto the base. This will remove the PMT and the μ -metal shield from the socket and base, respectively.

The replacement of the PMT requires experience because it has to be done with the μ -metal shield installed in, but not secured to, the base. The PMT pins need to be aligned with the socket pins in a specific geometry, thus the insertion has to be done by feel and experience. Once the PMT is inserted in the socket, the μ -metal shield is secured the base with the nut. Make sure the shield protrudes past the photo-cathode as much as the tapered design allows. Carefully insert the elastomeric ring between the PMT rim and the μ -metal shield. This ring supports the PMT and prevents it from sliding out of the pins during movement; it also helps seal the interior of the counter from the outside environment and reduces the CO_2 leakage rate. Reverse the process for installation.

Installation and Removal of the SiO_2 Tray **PLEASE NOTE:** The SiO_2 aerogel panels are extremely fragile and sensitive to water and chemical vapor. Do not handle with bare hands: use clean cotton, or another fabric type, gloves instead. Surgical gloves often are contaminated with lubricants and are not suitable for this purpose.

The tray is secured to the main section by hex bolts. The removal of the bolts results in the straightforward removal of the tray. There is minimum clearance between the tray walls and the main section; as a result, the tray has to be removed and installed in a uniform translation with respect to the main body. The frame supporting the fish net (or tennis racket) can be removed from the tray proper by removal of the two small screws in the middle of the tray walls; a tool (hook) is provided for this operation. The SiO_2 aerogel panels can now be removed or replaced. Reverse the procedure for installation. The securing bolts do not need to be tightened very much and, although spacers are inserted between the rubber strips to prevent damage, care and common sense should be exercised. Light and gas sealing is provided by the rubber strips - NOT by brute force.

WARNING: After each removal of any components of the counter, check for light

leaks before turning the HV on at operating values. Even a small light leak can destroy the PMTs if they are at -2,950 V! Check for light leaks with lights out, using a small portable light and a reduced voltage around -2,000 V.

17.5 Diffusion aerogel counters ¹⁰

For a reliable PID of kaons with momenta up to 2.84 GeV/ c an aerogel detector with a low refraction index of 1.015 (A1) was constructed. With a low index the light yield is expected to be less, a new design of the counter was evaluated and optimized. The result is an average number of 8 photo-electrons.

For the reliable positive identification of kaons and rejection of protons, a large number of photo-electrons is very important. The second diffusion aerogel counter (A2) was constructed with an aerogel index of refraction of 1.055. With only a 5 cm thickness of aerogel, almost 30 photo-electrons were collected. The large collection efficiency was achieved through several design considerations and use of different type of PMT - XP4572B.

Each detector consists of a tray for the aerogel radiator and a diffusion box which holds the PMTs. The surface of each box is covered with millipore paper. Hydrophobic aerogel was used for both detectors, however the boxes are gas tight so hygroscopic aerogel also can be used. The positive HV used in the detector allows the increase of the solid angle viewed by each PMT and as result the increase of the light collection efficiency. The PMTs don't have μ -metal shields because the magnetic field at the location of these detectors doesn't effect the light collection efficiency. The schematics of A1 and A2 are shown in figs 17.5 and 17.6.

The structure of the diffusion box is shown in Fig. 17.7. The picture was taken before installing the millipore paper.

Fig. 17.8 shows the view of the A1 counter from the inside. The semi-spherical photo-cathodes of the 8854 are on left and right sides. The white wires on the bottom were installed to prevent the motion of the aerogel blocks during detector transportation.

Fig. 17.1 shows performance characteristics of the A1 and A2 counters.

17.6 Safety Assessment

The PMTs are under high voltage and care is required when handling any components of the counter. As stated earlier on in this report, the insulating material between the μ -metal shield and the aluminum exoskeleton far exceeds the requirements dictated by the operating voltage. In addition, the 11 $M\Omega$ resistor between the μ -metal shield and the HV source restricts the current flow below the critical 1 mA level. The combination of Tedlar film, Plexiglas composites, and injection molded bases are all safe to handle but care should be exercised when handling the aluminum parts of the counter or touching

¹⁰Author: B. B. Wojtsekhowski bogdanw@jlab.org

the metal back plate of the base. It is strongly recommended to ground the aluminum exoskeleton of the counter, at several spots to a common ground with the HV and signal cable ground. This will further enhance safety and eliminate potential ground loops in the unlikely event of a slow, and otherwise difficult to diagnose, dielectric breakdown between the μ -metal shield and aluminum structure or aluminized mylar of the interior.

17.7 Authorized Personnel

The individuals responsible for the operation of the aerogel Cherenkov counters are given in Table 17.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	<i>Contact</i>
Jack Segal	Hall-A	7242		segal@jlab.org	

Table 17.1: Aerogel counters: authorized personnel.

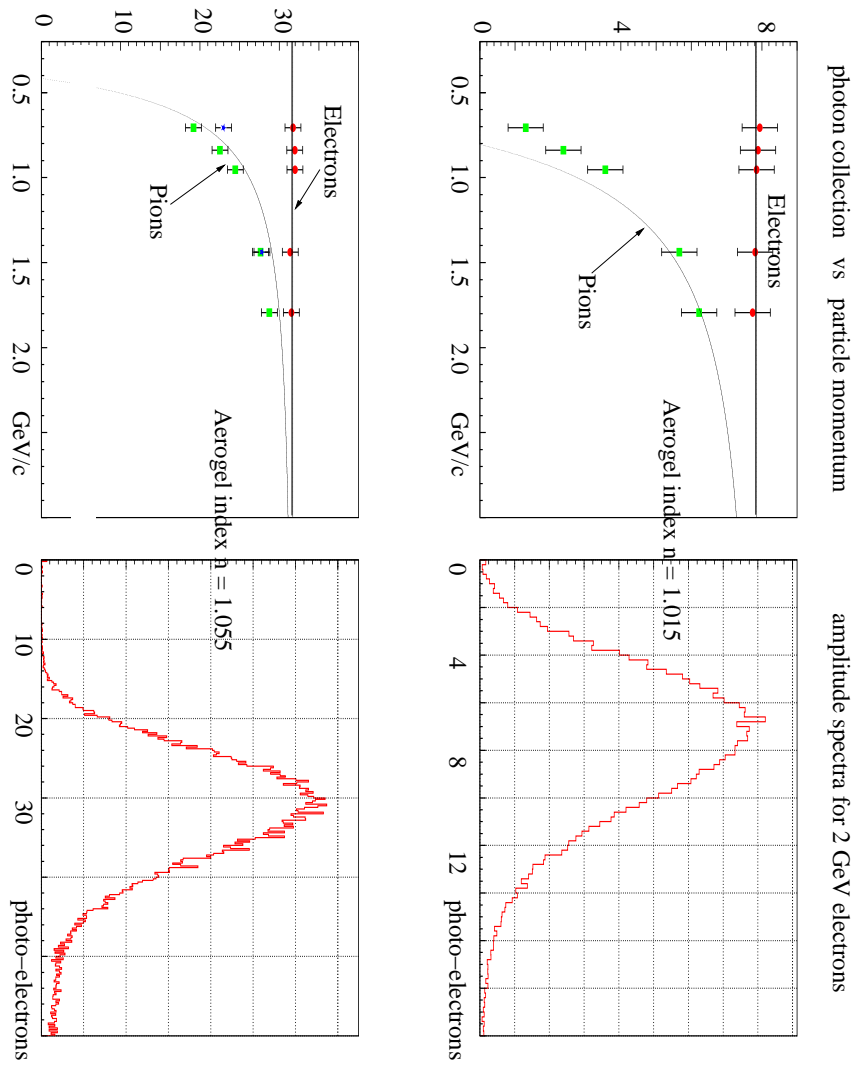


Figure 17.1: Number of photo-electrons in A1 and A2 vs particle momenta and the amplitude spectra.

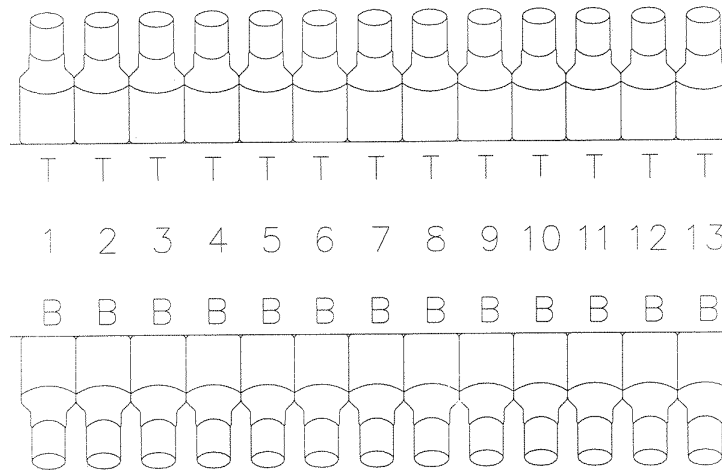


FIG. 1

Figure 17.2: Schematic diagram of the aerogel Cherenkov counter as viewed by the incoming particles. The numbers indicate the sections, 1 to 13, in the counter. Each section is viewed by two PMTs, one on the top (T) and one in the bottom (B). The labeling carries no significance other than identifying the PMTs during the testing phase, as described in the text.

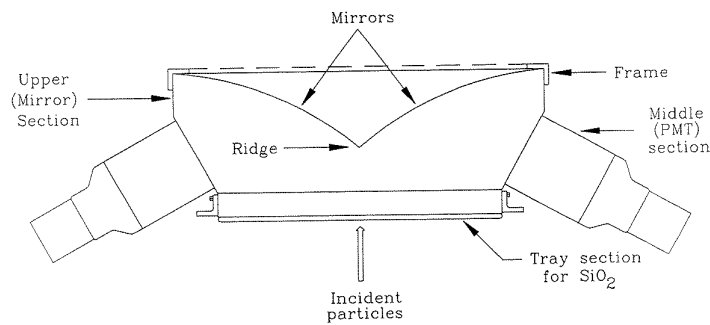
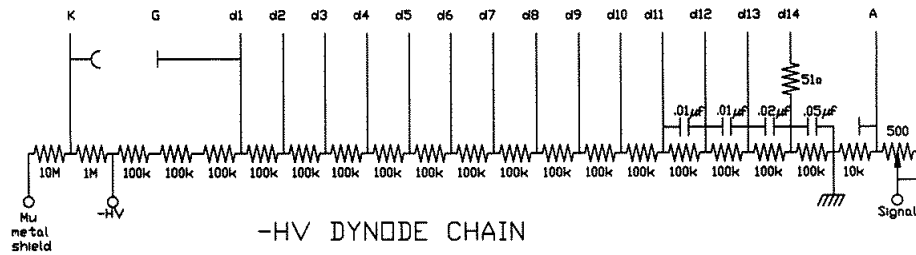


FIG. 2

Figure 17.3: Cross sectional drawing of the counter, along the particle direction, showing the planar parabolic nature of the mirrors and the geometry of the PMTs. The joint of the two mirror surfaces in the middle of the counter defines the mirror “ridge”.

BURLE 8854 PHOTOMULTIPLIER TUBE DYNODE CHAIN



- All resistors: .6 Watt Metal Film.
- All Capacitors > 200 V.
- Values in microfarads.

Figure 4

UNIVERSITY of REGINA	
Faculty of Science Electronics Shop	
Title: Burle 8854 P.M. Tube Dynode Chain	
Date: 17/Dec/90	Page: 1 of 1
Notes: -H.V. version 1. With matching pot.	
File: 8854.dwg	

Figure 17.4: Schematic diagram of the electronic amplification chain. The total resistance of $600\text{ k}\Omega$ between the cathode and the first dynode is shown as three $200\text{ k}\Omega$ resistors for sake of clarity. In the actual PC boards, the arrangement is of six resistors of $100\text{ k}\Omega$ each, in order to keep the voltage across each resistor low and avoid surface discharge between the closely packed resistors.

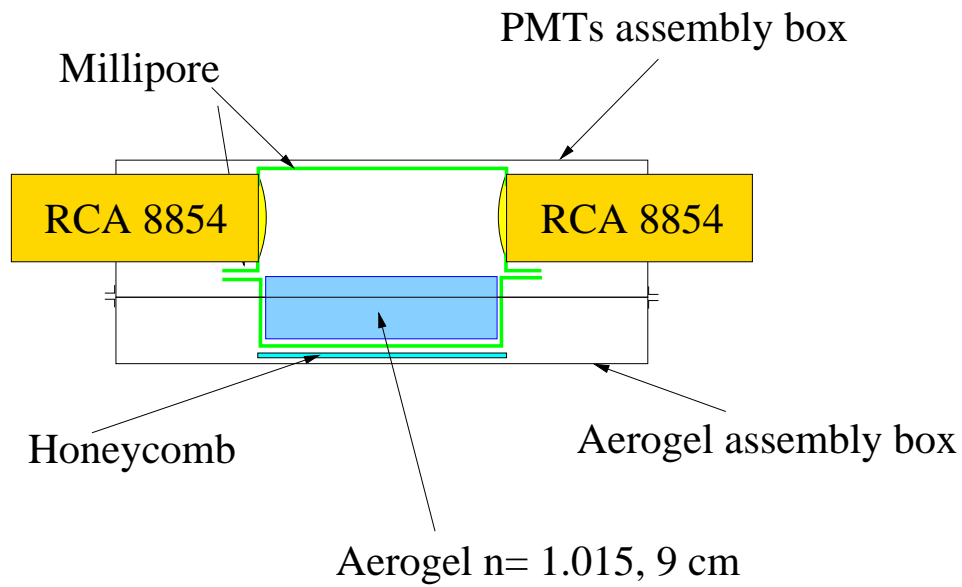


Figure 17.5: The scheme of A1 detector.

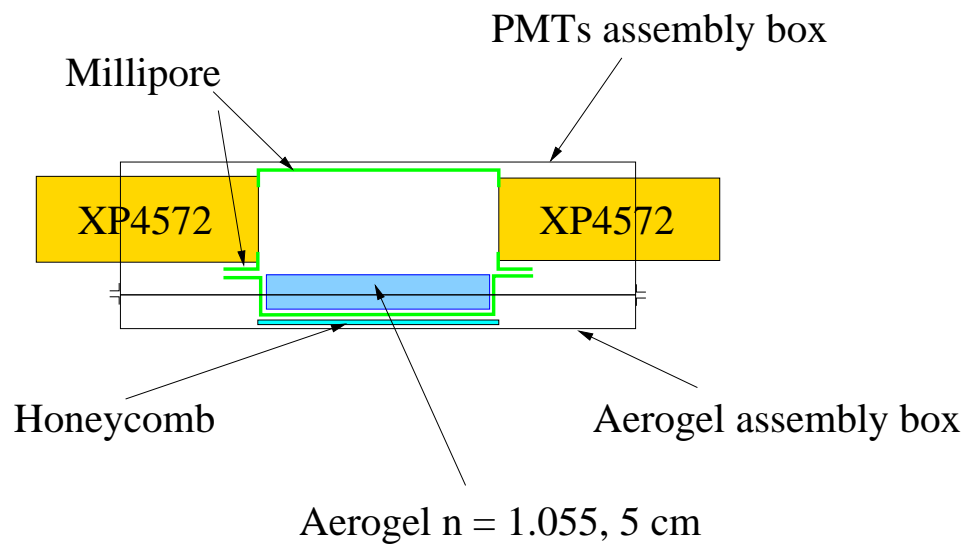


Figure 17.6: The scheme of A2 detector.

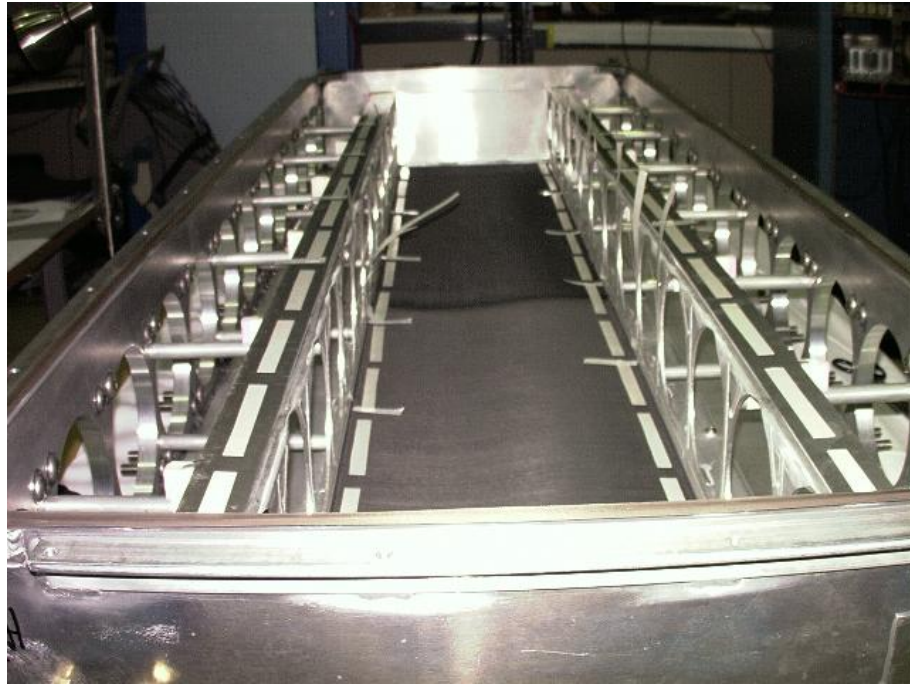


Figure 17.7: The diffusion box of A2 detector.



Figure 17.8: Aerogel A1 detector from inside of the diffusion box.

Chapter 18

The Focal Plane Polarimeter ¹ ²

18.1 Overview

The focal plane polarimeter measures the polarization of protons in the hadron spectrometer detector stack. When the protons pass through a carbon analyzer, the nuclear spin-orbit force leads to an azimuthal asymmetry in scattering from carbon nuclei, if the protons are polarized. The particle trajectories, in particular the scattering angles in the carbon, are determined by pairs of front and rear straw chambers, a type of drift chamber.

As shown in Figure 18.1, the front straw chambers are separated by about 114 cm, and are located before and after the gas Cherenkov detector. The second chamber is followed by scintillator 2, which is in turn followed by the polarimeter carbon analyzer. The rear chambers, chambers 3 and 4, are separated by 38 cm and are immediately behind the carbon analyzer.

The carbon analyzer consists of 5 carbon blocks. Each block is split in the middle so that it may be moved into or out of the proton paths, so that the total thickness of scattering carbon may be adjusted. The block thicknesses, from front to rear, are 9" (22.9cm), 6" (15.2cm), 3" (7.6cm), 1.5" (3.8cm), and 0.75" (1.9cm). The block positions are controlled through EPICS [6]; the controls may be reached through the Hall A / hadron spectrometer / detectors menus (see Fig. 20.4). Particles passing through the carbon analyzer can be absorbed in it.

The straw chamber planes are designated as X, U, and V planes. The central ray defines the z axis. X wires measure position along the dispersive direction. The UV coordinate system is created by a 45 degree rotation in the transverse plane of the XY coordinate system, with +U between the +X and +Y axes, and +V between the +Y and -X axes.

The straw chamber operation is described in the following paragraphs.

When a charged particle passes through the chamber in typical Jefferson Lab operating conditions, there will be about 30 primary ionizations of gas molecules. Positive high

¹ CVS revision Id: fpp.tex,v 1.7 2003/12/17 03:59:48 gen Exp

²Authors: S.Nanda nanda@jlab.org

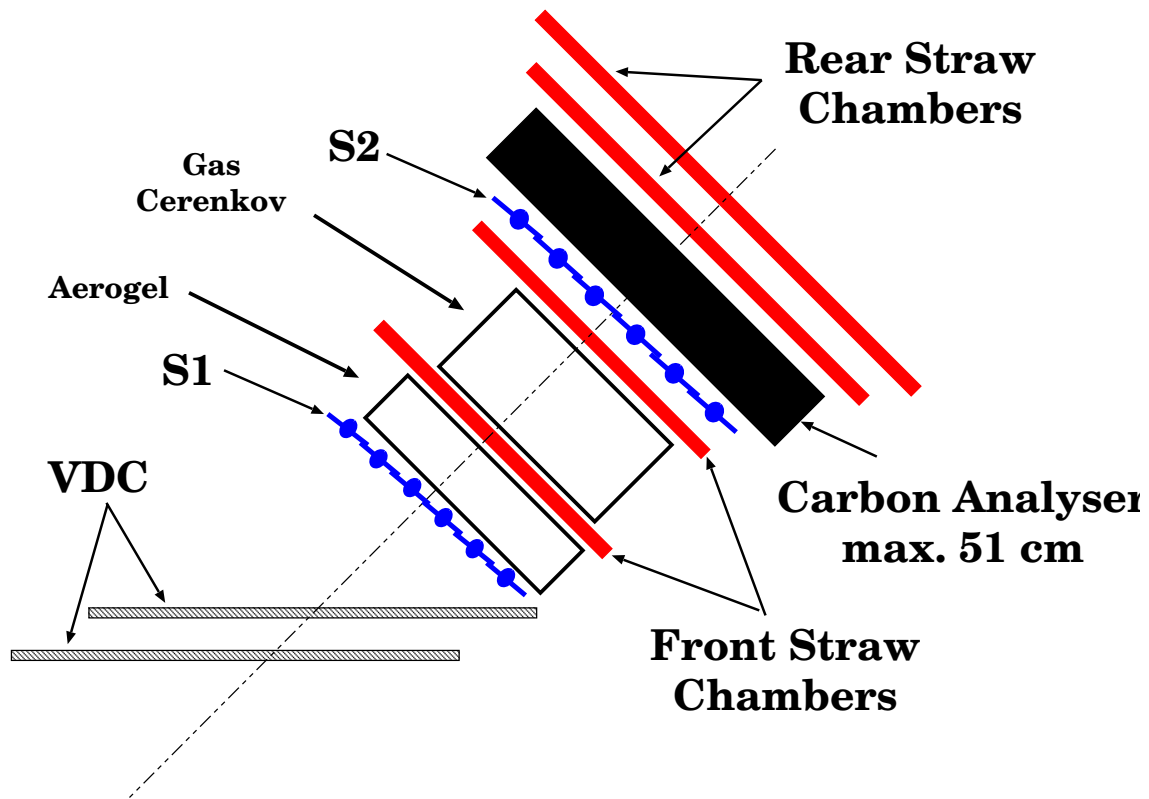


Figure 18.1: Schematic of the hadron detector stack.

voltage of about 1.8 - 1.9 kV is applied to the wire in the center of each straw. Electrons from the ionizations drift towards the wire. When the electrons get within about 100μ of the wire, the gain in energy between collisions with gas molecules is sufficient that gas molecules are further ionized in collisions. This leads to an *avalanche*, and a gain of about 10^5 per primary ionization under the conditions in which the FPP is run.

The movement of the positive and negative ions leads to a voltage drop on the wire, or equivalently to a negative analog signal. The analog signal is about 20 ns long, with a (negative) peak current of about $40 \mu\text{A}$, and propagates towards each end of the straw. At one end of each straw is a board that supplies high voltage (see Figure 18.2); impedance matching on this board, with a 1500 pF capacitor and a 370Ω resistor, reduces reflection of the signal.

The other end of each straw is connected to a readout board, that amplifies, discriminates, and multiplexes the input signals – (see Figures 18.3 and 18.4). At the readout end, the signal is “coupled to ground” through a 1500 pF capacitor followed by $310 + 50 \Omega$ resistors. In parallel with the 50Ω resistor are diodes to limit the signal size, preventing damage to the readout board circuitry. An amplifier samples the signal over the 50Ω resistor. The amp gain is about $-10 \text{ mV}/\mu\text{A}$, resulting in a +400 mV signal to a comparator. A threshold voltage input to the readout board is put over a voltage divider

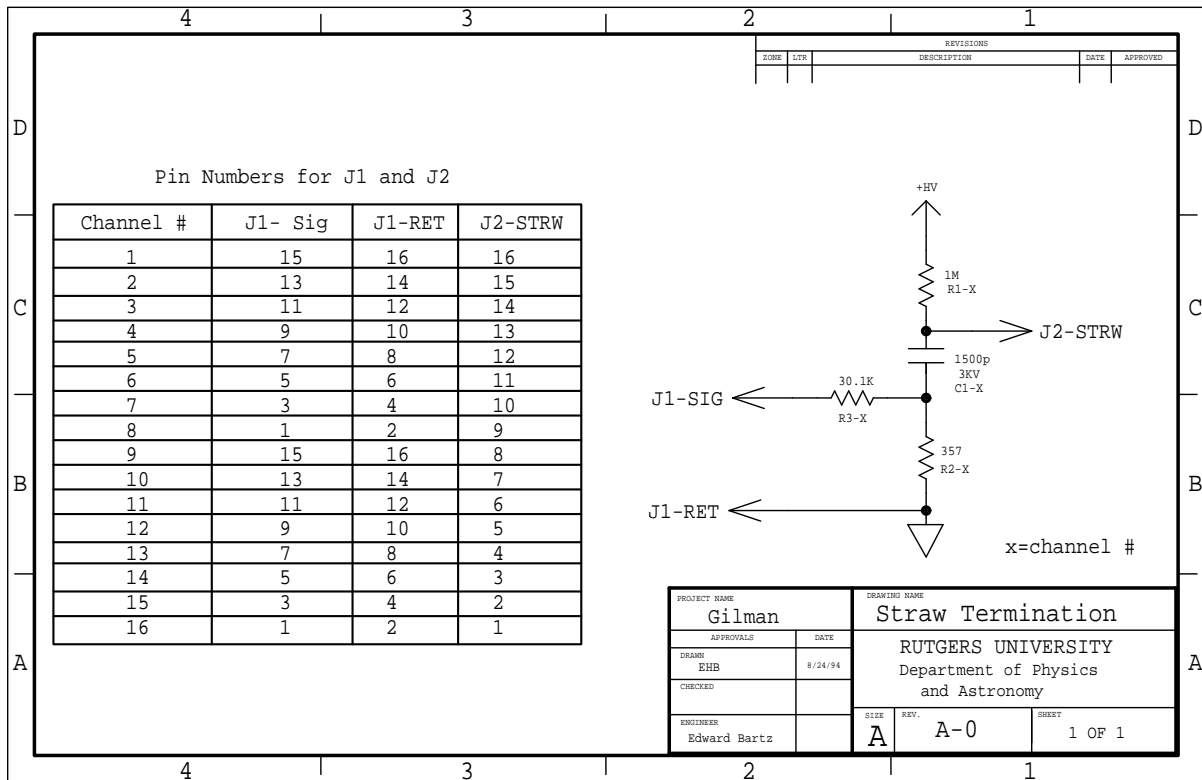


Figure 18.2: Circuit diagram for the high voltage / termination board.

consisting of $1500 + 10 \Omega$ resistors. For the typical 4 V threshold applied to the board, the comparator puts out a logical pulse when the 400 mV (peak) signal rises above the $4 \text{ V} / 151 = 26 \text{ mV}$ threshold. One-shots are then used to fix the width of the logical pulse for each channel – the one-shot width is fine tuned by the use of high precision resistors in an RC circuit; these resistors are mounted in sockets so as to be easily replaced if the need arises. An OR circuit then combines eight individual straw outputs into a single electronics channel.

Internally, within the Faraday cages, the high voltage is distributed to stacks of high voltage / test pulser boards, through which it is connected to each straw via a $1 \text{ M}\Omega$ 1/4 watt resistor.

The readout cards require a high-current low-voltage power supply and a low-current low-voltage power supply for a threshold level. The readout electronics are mounted on the chamber, shielded within Faraday cages. The high-current power supplies were built by the Rutgers University Department of Physics & Astronomy Electronics Shop. These supplies are set to provide sufficient current at $\pm 5 \text{ V}$ for the boards to which they are hooked up. No adjustments, except for turning the supplies on / off, should be needed in normal operation. There are voltage setting, current limiting, and overvoltage protection potentiometers within the boxes; adjustment information is given in the FPP logbooks.

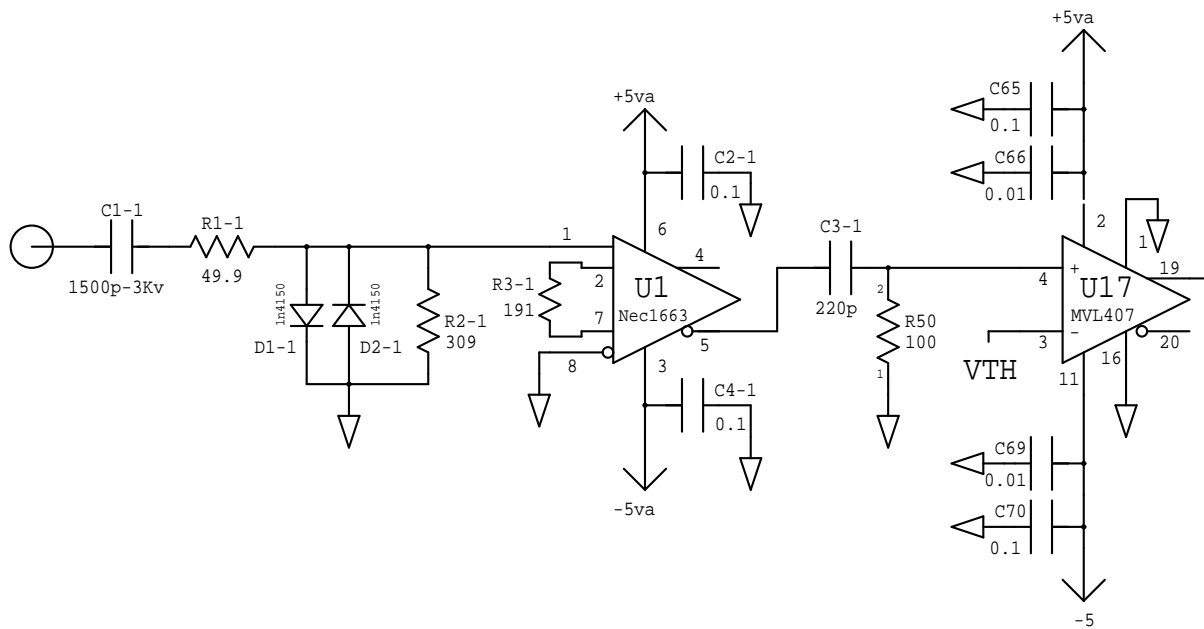


Figure 18.3: Circuit diagram for the amplifier / discriminator section of the readout board.

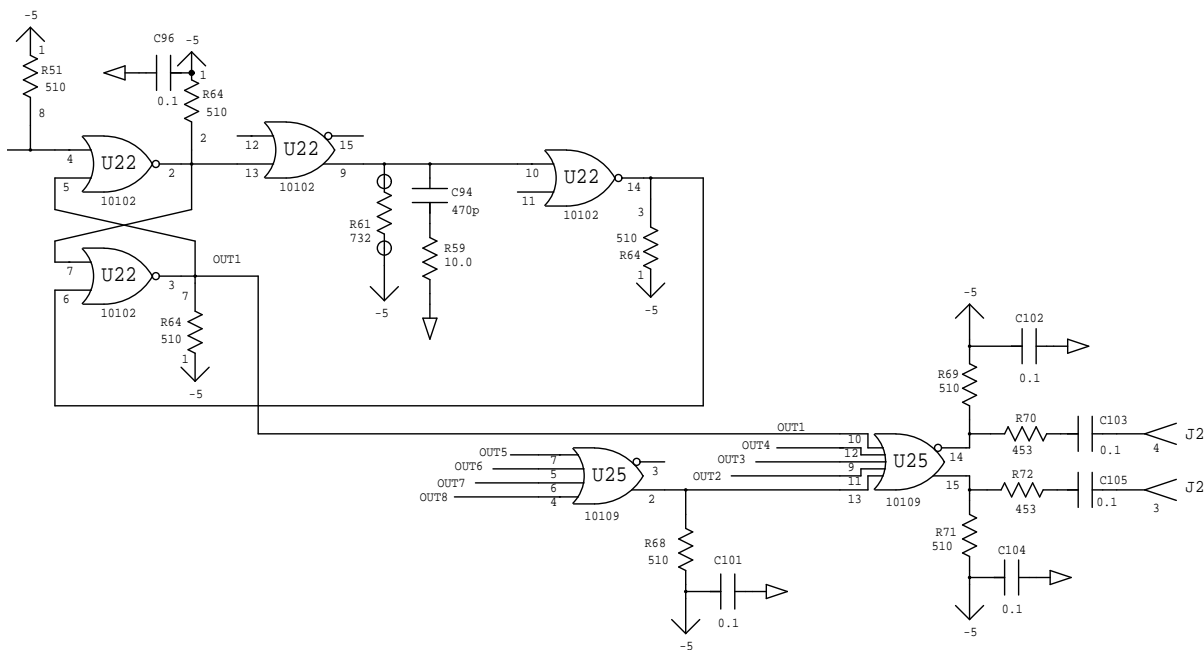


Figure 18.4: Circuit diagram for the logical / multiplexing section of the readout board.

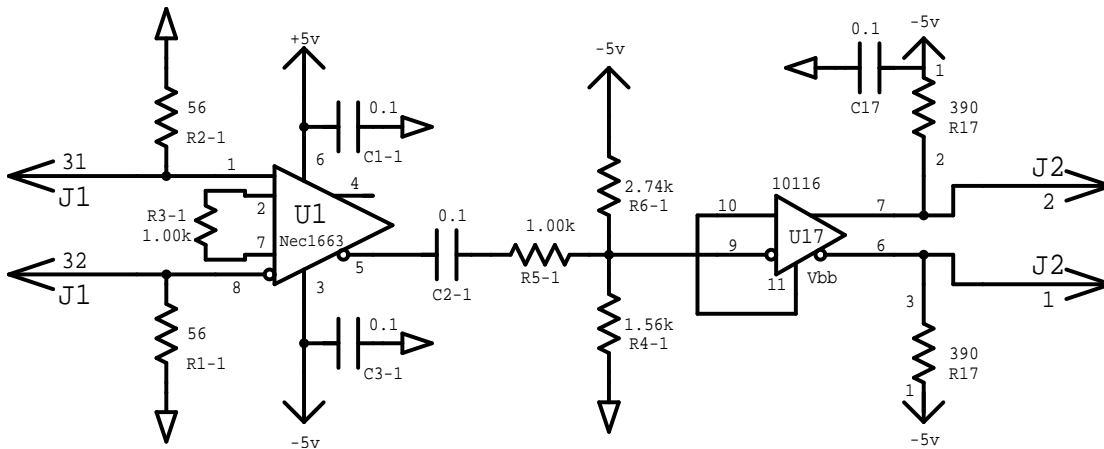


Figure 18.5: Circuit diagram for the level shifter / receiver board.

The low current supplies are *Hewlett-Packard* 6111A supplies. The 6111As can provide up to 1 A for voltage from 0 to 20 V. The supplies are currently hooked up through the rear panel to a DAC in the data acquisition panel; front panel controls on the supplies are disabled, except for the on/off switch. The voltage is controlled through an EPICS FPP threshold window, that is accessed through the Hall A / hadron spectrometer / detectors menus. The high-current supplies are not computer controlled. All supplies are mounted in the detector stack.

The multiplexed logical signals from the chambers have amplitudes smaller than ECL levels, to prevent noise at the chamber. These signals are fed to level shifter boards (see Figure 18.5), located in the FPP rack on the lower electronics level of the detector stack, on the beam right side. A high-current ± 5 V power supply for the level shifter boards is located at the bottom of the same rack. The boards convert the signals to ECL standard levels. The level shifter outputs are connected to the starts of *LeCroy* Model 1877 FASTBUS TDCs, located in the lower electronics level on the beam left side. The TDCs measure both leading and trailing edge times to allow demultiplexing. The TDCs are subsequently stopped by the overall event trigger, and are read out by the *CODA* acquisition software. The data are histogrammed online by the *DHIST* software. In-depth offline data analysis requires the *ESPACE* software.

The chamber gas is presently a combination of argon and ethane, about 63% and 37% by weight. The Hall A gas shed is outside next to the entrance of the Hall A truck ramp. Gas is routed from the Hall A gas shed mixing system to the gas panel located on the lower electronics level of the space frame, and subsequently to the FPP chambers. The gas system is shared with the VDCs. A detailed description of the system has been written by Howard Fenker³.

In addition, the chambers are outfitted with a test pulser capability. A pulse is

³http://www.jlab.org/Hall-A/document/HAWGS/HAWGS_OpMan.html

introduced into an 8 channel (16 wire) twisted pair cable on each chamber, which connects to the high voltage boards, at the opposite ends of each straw from the readout boards. The pulse is resistively coupled through a 20 k Ω resistor to the ground leg of a 1500 pF capacitor, and thence into the straws. After propagating through the straw, the pulse enters the readout board. A pulse of about 1 V amplitude in the twisted pair cable is sufficient to provide a few mV signal into the readout boards, resulting in a logical output signal. The system may be used to test the functionality of each readout channel and / or the continuity of the high voltage wire in each straw. The system currently is only implemented for manual operation, except that data may be read out through CODA. This procedure requires some familiarity with trigger logic and setup, should only be done by experts, and is not documented here.

18.2 Operating Procedure

Gas Flow Operating Procedures The chamber gas is mixed 63%-37% (by weight) Ar ethane. The gas is mixed in the Hall A gas shed which is located next to the entrance to the Hall A truck ramp. One needs key #8, which is located in a key box in the Hall A counting house, to get inside the shed where the gas mixing is done. The argon and ethane bottles which feed the gas mixing system are located outside the shed and can be exchanged when they are empty. The mixed gas is sent down into Hall A and to each of the detector huts. There are two each of argon and ethane bottles connected to the gas system and a Matheson 8590 controller switches between the two bottles when the gas pressure in the bottle drops below a certain level. At this point the one bottle can be replaced while the other is being used. The procedure for changing gas bottles is outlined below:

1. Warning: High pressure gas bottles contain significant stored energy and are potentially hazardous. Handling of gas bottles should be done only by qualified, trained personnel.
2. For smoothest operation, used gas bottles should be replaced before their internal pressure drops below the desired regulator output pressure.
3. Two possible cases exist in which a gas bottle needs to be replaced: only one empty gas bottle on a system or both bottles empty on a gas system.
4. For case 1 the sequence of steps is as follows:
 - (a) Check in the Hall A Gas Shed. If all bottles have sufficient pressure each of the Matheson 8590 controllers will have one green "RUN" LED lit and one yellow "READY" LED lit. A red "EMPTY" LED lit indicates a bottle with low pressure, the corresponding bottle needs to be replaced. If a red "EMPTY" LED is lit the central "ALARM" LED should also show red. Nothing further needs to be done here; go outside to the Gas Bottle Pad.

- (b) Visually verify that the corresponding pressure gauge on the flex line is showing a low pressure. A low pressure is not necessarily zero. Close the bottle valve for the empty bottle.
 - (c) Disconnect the empty bottle from the high-pressure flex-line. The in-line check-valves will prevent gas escaping from the manifold. Replace the bottle's cap, and move the empty bottle to the EMPTIES storage rack. Note that ethane bottle fittings, type CGA-350, have left-handed threads.
 - (d) Place a full bottle of gas in the on-line rack, remove the bottle cap, and connect the bottle to the flex-line.
 - (e) Open the new bottle's valve, check for leaks at the bottle fitting. The corresponding pressure gauge should now read full bottle pressure.
 - (f) The ALARM state of the Matheson 8590 controller should have automatically reset. Check inside the Hall A Gas Shed. Each controller should show a green "RUN" and yellow "READY" LED lit. If not, re-check the installation of the gas bottle.
5. For case 2 the sequence of steps is as follows:
- (a) Check in the Hall A Gas Shed. If all bottles have sufficient pressure each of the Matheson 8590 controllers will have one green "RUN" LED lit and one yellow "READY" LED lit. If a Matheson 8590 controller shows two red "EMPTY" LEDs lit and the central red "ALARM" LED lit, both bottles of the corresponding manifold need to be replaced. Nothing further needs to be done here, go outside to the Gas Bottle Pad.
 - (b) Follow steps 2. through 5., as detailed immediately above, for both bottles.
 - (c) The ALARM state of the Matheson 8590 controller should have automatically reset. Check inside the Hall A Gas Shed. Each controller should show two yellow "READY" LEDs lit. If not, re-check the installation of the gas bottle. Press either of the two buttons labeled "LEFT BANK" and "RIGHT BANK". The lit LED above the button you pressed will change from yellow "READY" to green "RUN". You will most likely need to reset the Low Supply Pressure shutdown at this point.

The four FPP straw chambers are connected in parallel to the gas system. (see Figure 18.6).

(The FPP chambers are also in parallel with the VDC chambers.) All gas connections are made using POLYFLOTM tubing and TJNAF-specified connectors. The chamber volumes range from approximately 120 to 220 ℓ . Gas pressure in the chambers is typically a few Torr above atmospheric pressure. The gas flow through the chambers may be independently varied and is typically set to 7 ℓ /hr, leading to a replacement of the chamber volumes about every 15 - 30 hours. Gas is exhausted from the FPP chambers through a bubbler containing < 1 mm of mineral oil. A typical chamber leakage rate at

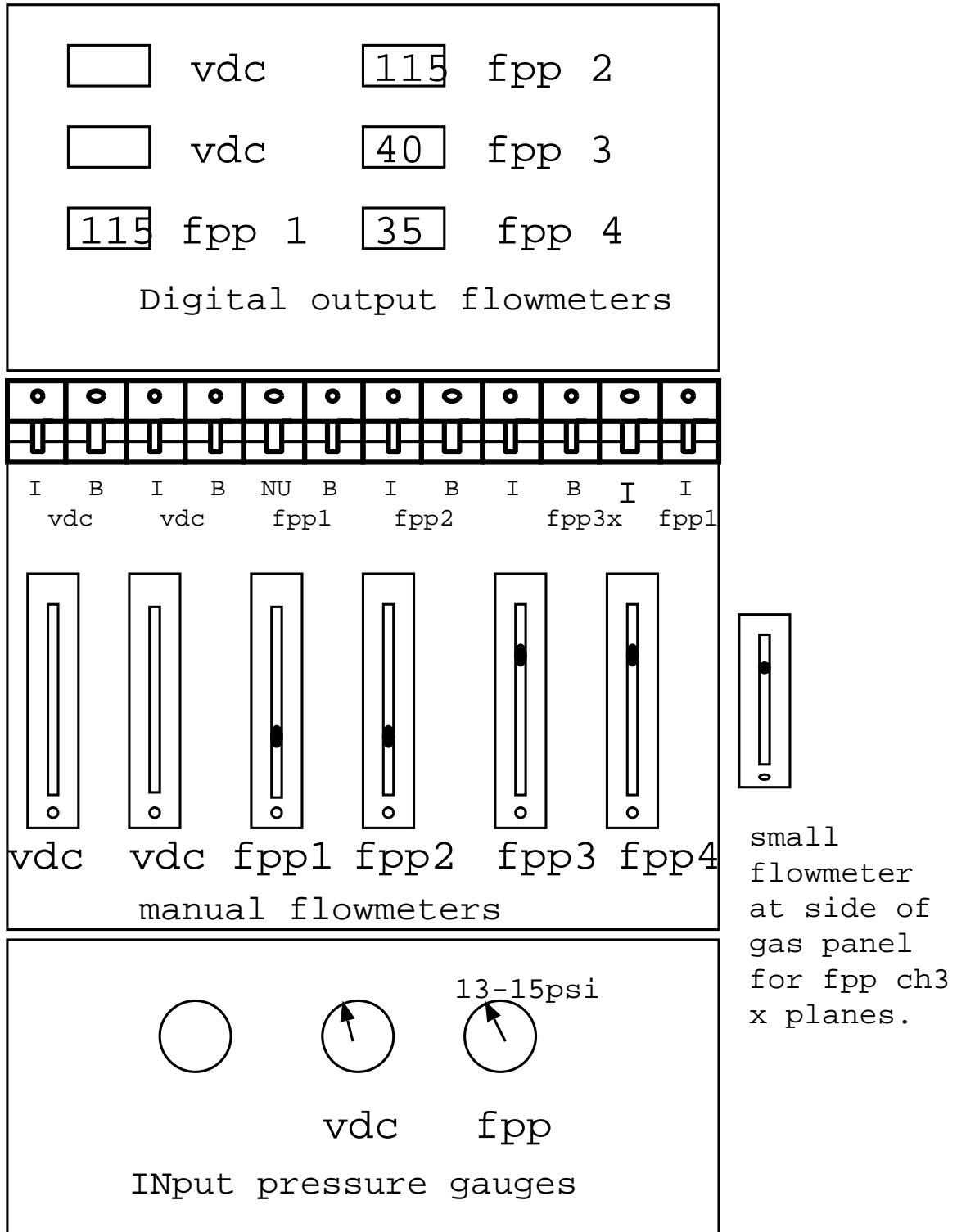


Figure 18.6: Drawing of the gas panel on the hadron detector stack.

this flow rate is 25 - 50 %. The flow rate of 7 ℓ /hr when combined with the leak rate of ≤ 3 ℓ /hr results in a complete exchange of gas in the chambers roughly every 1 - 2 days. At this level of consumption, a full gas bottle connected to the FPP system lasts approximately 10 days. When a bottle is nearing empty ($\approx 90\%$), it should be changed since there may be heavy contaminants in the gas. Gas bottles may only be changed by authorized personnel.

Gas-handling Procedures

1. Typically gas is continually flowing through the chambers. If at all possible, gas flow should be continuously maintained, even in no-beam time periods. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition. If the chambers are not being used in an experiment, the flowmeters for the front chambers are set to 20 and the flowmeters for the rear chambers are set to 60. When the chambers are used in an experiment the standard setting for the front chambers is 40 and for the rear chambers it is 105.
2. Gas pressure at the gas panel on the detector stack should be in the range 13 - 15 psi. With the large leakage rate of the FPP chambers, we typically run at near the limit of the capacity of the gas mixer to supply the gas flow demanded by the FPP and VDC chambers. Therefore it is possible to demand too much flow rate from the mixer. If the gas pressure drops below 13 psi drop the flow to the FPP chambers and contact Jack Segal or Howard Fenker to determine the cause and remedy for the situation.

The status of the gas handling system should be monitored carefully as well as logged at least once per 8-hour shift. Any substantial deviation from the median parameters indicates a change in the operational parameters of the FPP and should be immediately investigated.

Power Supplies and Electronics Procedures The power supplies and readout electronics associated with the FPP are a mixture of commercially purchased equipment and equipment designed and/or assembled with the Rutgers University Department of Physics & Astronomy Electronics Shop. The reader is directed towards the manuals made available by the manufacturer for the detailed information not provided here for the commercial equipment. For the Rutgers constructed equipment, further documentation is available on the web page⁴.

and through FPP notebooks (try for example contacting R. Gilman for notebooks maintained by Rutgers, CEBAF Center, phone 757.269.7011).

The LeCroy 1458 HV control crate houses the Lecroy 1469P modules which control the HV for the FPP chambers. The 1469P has 3 master HV channels and each master HV channel controls eight slave channels. In slot 7 of the 1458 is the 1469P module

⁴<http://www.jlab.org/~gilman/fpp-homepage.html>

which controls chamber 1 and chamber 2. In slot 8 of the 1458 is the 1469P module which controls chamber 3 and chamber 4. The individual slave channels can trip from high current faults or other trip faults, but all eight slave channels must be raised and lowered together by setting the master high voltage. The HV provides +1.8 - 1.9 kV nominal to each of the ≈ 5100 wires in the four FPP straw chambers. The power supply is located in the detector stack at the top of crate 6 in the upper electronics level. This unit is controlled through HAC13. Connections from the power supply to the chambers are made using standard SHV connectors mounted on red RG-59/U HV cable good to 5 kV.

The high-current low-voltage supply boxes were assembled by Rutgers University. They are designed to provide a maximum current of about 1.6 / 0.6 A at -5 / +5 V to each of the 318 readout cards on the four chambers. There are 63 / 63 / 90 / 102 cards on chambers 1 / 2 / 3 / 4. Typical operating currents are about two-thirds of this nominal maximum value. The +/-5 V power lines are independently fused to each card. Each of the eight supply boxes contains two or three power supplies, each rated for either 35 or 50 A. There are two power boxes for each chamber. Six boxes are located at the lower rear end of the detector stack. The second boxes for chambers 3 and 4 are located at the top of the detector stack, on an aluminum plate just off the upper electronics level. These power boxes are monitored through EPICS, but turned on/off through front panel switches.

Hewlett-Packard 6111A power supplies are used to provide typically 2 - 3 mA current per readout card. Each of the front and rear chambers have their own power supply. The front chambers thresholds are fused, to limit current drawn in case of a short on the board. The rear chamber cards use a 1.5 k Ω resistor external to the board to limit current drawn, in case of a short on the board. Board threshold circuitry also has a 1.5 k Ω to ground which with the external 1.5 k Ω makes a voltage divider. Therefore, the rear threshold supplies are typically set to a voltage which is a factor of two larger than the front threshold supplies to give the same threshold voltage at the readout board. Initial tests indicate that at least a 1.5 V threshold must be applied to the cards to prevent oscillations - this level will stop oscillations that arise when the voltage applied is reduced to about 1.0 V. In practice it has been found that the front chambers should be operated at 4 V and the rear at 7 V. Efficiency studies show that the chamber threshold could be raised by 50% with minor loss in efficiency. The HP supplies are also mounted in the hadron arm detector stack, on an aluminum panel located beneath the two upper high current supplies.

Each straw wire contains a 25 μm ϕ , Au-plated tungsten-rhenium wire. The number of wires per plane varies from 176 to 272. Wires are multiplexed 8 wires into one electronics channel, leading to a required 636 TDC channels. In practice a few extra channels are used, so that each 34 wire (16 differential signal channels plus one ground pair) twisted pair cable contains only signals from one of the four chambers. LeCroy 1877 multihit FASTBUS TDCs are used to measure the leading edge time and width of the pulses, to demultiplex the wire hit. Within each group of eight wires, the widths are set to about 25, 45, 35, 55, 90, 65, 105, and 75 ns. The TDCs are located in the upper

FASTBUS crate located on the lower electronics level of the spectrometer space frame in the detector hut. The FPP rack, containing level shifter cards, is located opposite the FASTBUS crates on the lower electronics level. It shifts signal sizes from the reduced ± 50 mV readout card output levels to ECL standard levels, for input to the TDCs. The connections between the readout cards and the level shifter cards, as well as between the level shifter cards and the TDCs, are made with 16-conductor twisted-pair cables. A wiremap, detailing the cabling, is posted on the side of the FPP rack.

Power-up Procedure

1. Ensure that gas flow has been established in the chambers as outlined in the previous section. If it has not, *STOP RIGHT HERE!* Gas flow must be well-established and steady-state *BEFORE* the HV may be enabled.
2. Ensure that all power supplies as well as the FASTBUS crate are off and the LV, HV, and TDC cables are connected.
3. Turn on the threshold and LV power supplies. Use EPICS to turn the threshold voltages up to correct values, about 4.0 V for front chambers 1 and 2, and 7 V for rear chambers 3 and 4.
4. Use HAC13 to turn up the chamber voltages. Standard values are 1875 V for front and rear chambers. It is probably best to raise the HV in 300V steps. After each step wait for the current to settle below 1 μA , then go up to the next level until 1875V is reached. Peak currents during turn-on should not exceed about 40 μA . A 10 V/s ramp rate leads to a leakage current of several μA . Trip levels should be set to 110 μA both for turning on HV and for normal operation, so that bad spills do not trip the chambers. Current should settle to about a μA or less within a few minutes. If the power supply trips during the ramping procedure, it is possible that you are moving too fast, or that some problem has developed with a chamber. Re-zero things and begin the procedure again. *NEVER USE THE AUTO-RESET FUNCTION.* If the power supply trips again, *STOP IMMEDIATELY AND INVESTIGATE.* *There is probably a problem and expert advice may be needed. Some detailed information, intended for experts debugging hardware problems, is available in the Rutgers web pages.*
5. Check for poor signal connections evidenced by hot wires (wires counting extremely fast) or dead wires (wires with no counts) using the histogramming software and cosmic rays. Be careful: apparent problems may result from bad demultiplexing rather than from poor signal connections. Remake any connections as necessary by first powering down the FASTBUS crate.

If at all possible, the HV and LV power supplies should be left on continuously if and only if gas is available to the chamber. This avoids time loss to reconditioning and maintains the desirable steady-state operating condition.

18.3 Carbon Doors

Four of the five doors operate remotely, the fifth needing further testing before it is certified reliable. The doors use the EPICS control system to activate and read back the various components.

Each layer of carbon doors has one relay board. Each board is identical in operation and there is one spare in the event one of them should fail. The global purpose of the relay board is as follows:

1. Turn on the 12V to power to rest of circuit board.
2. Set the polarity on the 90V used to power the motors.
3. Turn the 90V on.
4. Cut off the 90V to a motor if the appropriate limit switch is hit.
5. Read back the status of the limit switches.

The 12V used to power the circuit board runs through this relay and it is activated via an EPICS relay in VME crate 4 (hallasc4). Relay #1 turns on the 90V and it too is activated by an EPICS relay in VME crate 4. Relay #2 switches the polarity of the 90V being fed to the driving motors. When activated it reverses the polarity to the motors and it is controlled by a relay in VME crate 4. Relays #3 and #5 are activated by the inner limit switches of the carbon doors. When these switches are depressed the relay activates and the 90V is cut off. Relays #4 and #6 are activated by the outer limit switches of the carbon doors and like relays #3 and #5 cut off the 90V when activated. Relays #4 and #6 activate when opened rather than when depressed. It would be nice in the future to have relays #3 and #5 also activated by an open limit switch condition and deactivated when the switch is closed. This way the 12V could be off to one of the switches and the doors would stop moving. As it is now, a broken wire/short while the doors are closing could cause the doors to continue moving risking possible damage.

The status of the limit switches is readout via an ADC in VME crate 4. If the switches are closed a -4V is seen at the ADC input. This is effected via a voltage splitter of 3 k Ω - 6 k Ω resistors. The readouts are plugged in via telephone jacks (PJ4, PJ5, PJ6, and PJ7). A temporary fix has been put in place which sends the signals through a capacitor first to block voltage spikes going into the ADC. These voltage spikes caused the ADC to trip off-line which can only be fixed by resetting the VME crate.

The operation of the carbon doors is done via a GUI style control panel. This panel is located under the detector screen of the hadron arm (FPP Carbon Doors). The 3/4" carbon door has been disconnected at the 90V power supply and is not implemented in the software GUI. This door had what may have been some sliding problems. Since it may take a great deal of force to remove this door if it should jam, it will need to be tested so it can be removed easily if it should jam. The normal operating procedure with the GUI is to first make sure all the 90V power is off to each door (Blue switches), then

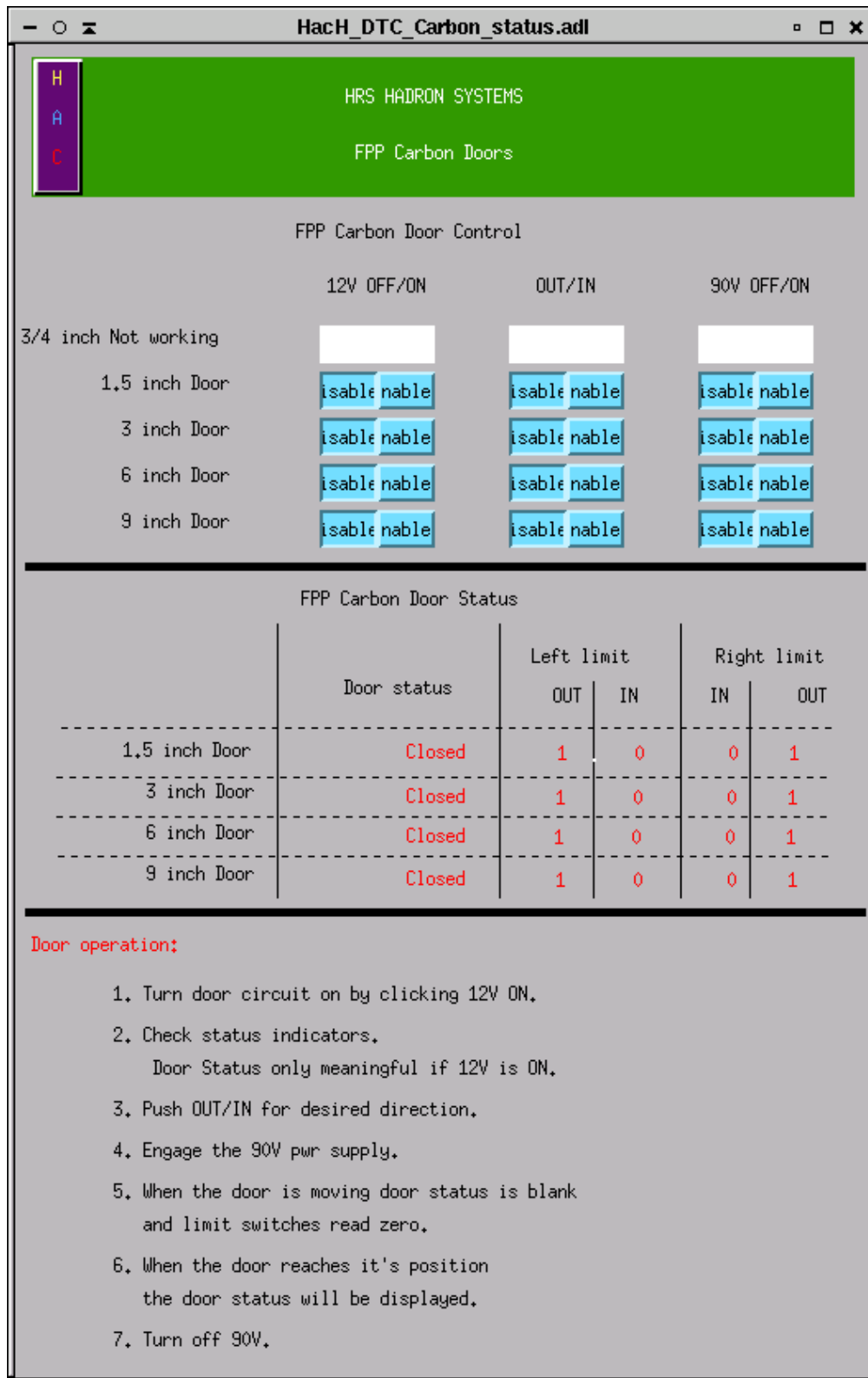


Figure 18.7: EPICS GUI for the carbon doors.

to turn on the 12V power to each door to see where it is located in the stack (in vs. out). If you wish to change the status of a door (in/out) then simply toggle the IN/OUT switch appropriately and turn on the 90V. It takes some time for the doors to move the entire range, so be patient. When the limit switches have been reached the appropriate indicators will light up. You should then turn the 90V off. The important aspect of this procedure is to make sure that you do not change the polarity of the 90V while the doors are moving. This place undue stress on the motors and the power supply as well.

18.4 Handling Considerations

The FPP straw chambers are very delicate devices which are absolutely essential to many Hall A physics experiments. Thus, extreme care must be taken whenever they are moved or used. Also, extreme care must be taken that other objects are not moved into them.

- Before moving a straw chamber, ensure that any protective plates are in position.
- Disconnect and reconnect all TDC, HV, and LV cables with care.
- When initiating gas flow, pay strict attention to the feedback parameters. Straw chambers are not very sensitive to overpressure of perhaps 50 - 100 Torr, but **the straw chambers can be easily destroyed by a few Torr underpressure.**
- Never attempt to apply HV to the chambers until gas flow conditions have reached steady-state.
- As the amount of heat generated by the pre-amp/discriminator cards is substantial, always make sure adequate cooling is provided before attempting to run. This is mostly ensured by making certain that the various cooling holes through the Faraday shields are not covered. The chambers have internally mounted fans where needed, which are powered up along with the readout cards.
- If the leakage current on the high voltage rises linearly with voltage, then a wire has broken and is shorted to ground!

18.5 Safety Assessment

The following potential hazards have been clearly identified.

The High Voltage System The LeCroy 1458 HV low current power supply provides a nominal +1.80 kV. Red HV RG-59/U cable good to 5 kV with standard SHV connectors is used to connect the power supply to the chambers. Each HV channel, of the 6 per chamber, typically will draw a few hundred nA.

The Low Voltage System LV power supplies are used for the pre-amp/discriminator/multiplexer cards. Each card requires up to 1.6 A at -5 V and 0.6 A at +5 V, plus a few mA threshold at 4 - 8 V.

High Pressure Gas Bottles The gas used in the chambers is supplied in high pressure (≥ 2000 psi) gas bottles. This confined high pressure gas represents a tremendous (potentially lethal) amount of stored energy.

18.6 Authorized Personnel

The individuals shown in Table 18.1 are responsible for chamber problems. Generally, the non Jefferson Lab people are responsible for FPP detector problems, whereas the Jefferson Lab people are responsible for more general data acquisition problems or, e.g., gas / voltage supplies shared with other systems.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Bogdan Wojtsekhowski	Hall-A	7191		bogdanw@jlab.org	<i>Contact</i>
Sirish Nanda	Hall-A	7176		nanda@jlab.org	
Jack Segal	Hall-A	7242		segal@jlab.org	

Table 18.1: FPP: authorized personnel.

Chapter 19

HRS Gas Supply System for Wire Detectors ^{1 2}

19.1 Overview

The detector systems in both HRS's (FPP and VDC) are expected to use a mixture of Argon and Ethane in roughly equal proportions, plus about 1% ethanol. The Argon and Ethane are supplied from high-pressure gas bottles. They are combined in the desired proportion by a mixing system and this mixture is passed through a bath of isopropyl alcohol which is maintained at a fixed temperature.

See Figure 19.1 for a schematic diagram of the gas supply / mixing system.

The gas mixture is delivered to gas distribution racks in the Hadron Spectrometer and the Electron Spectrometer. The transmission lines and the distribution plumbing have been designed as if the FPPs and VDCs were actually independent systems using different gas mixtures. This design was chosen in order to ease the expected transition to such a system in the future. Also supplied is a source of purge gas, currently pure argon. The distribution racks provide, for each detector, selection of either operating gas or purge gas, flow control and metering, overpressure relief to protect the detector components, exhaust flow measurement, and backflow prevention.

19.1.1 Bulk Gas Supply

The bulk gas supply consists of two bottles each of Argon, Ethane, and Carbon-Dioxide. Except for fittings which vary by type of gas the three supplies have identical plumbing. One bottle of each gas will be on-line during system operation while the second bottle serves as a ready reserve (connected to the manifold, but valved off). The two bottles are connected through check valves and manual valves to a high-pressure manifold. The pressure in this manifold is sensed by a pressure transducer whose signal is available to the slow-controls computer for monitoring. The pressure is also indicated locally by a

¹ CVS revision Id: gas-full.tex,v 1.4 2003/12/13 06:23:38 gen Exp

²Authors: J.Segal segal@jlab.org

mechanical pressure gauge attached to a two-stage regulator. A pressure regulator for each type of gas reduces the pressure to approximately 45 psig. This is the pressure at which gas is supplied to the gas shed. It may be monitored by the outlet pressure gauges (PG-021, -022, -023) on the pressure regulators and, inside the gas shed, on gauges PG-131, -132, -133. Prior to entering the shed the gas passes through manual valves (MV-031, -032, -033), Excess Flow Valves (XF-041, -042, -043), and Solenoid Valves (AV-051, -052, -053).

The Excess Flow Valves automatically close if the flow rate exceeds about 4 slpm at 45 psig. These valves must be manually reset after they trip. Refer to the section *Resetting a closed Excess Flow Valve* for this procedure. The solenoid valves are electrically operated (24 VDC) normally-closed valves. Power must be supplied to the solenoids in order for gas to flow. Valve power is supplied, when interlock conditions are satisfied, by the Gas Interlock System. Note that one of the required interlock conditions is that there be ample gas pressure *downstream* of the solenoid valves. System operators must use the manual "**Low Pressure Override**" pushbutton on the interlock panel (in the mixing room) in order to initially bring up the 45 psig supply pressure. The pushbutton circuit automatically re-arms after ample pressure is detected by the pressure switches (PS-111, -112, -113). These switches are located immediately above gauges PG-131, -132, and -133. Just below these gauges are overpressure relief valves (RV-121, -122, -123) which have been set to release if the supply pressure exceeds about 60 psig. After passing through check valves which prevent backstreaming the three gas supplies enter the mixing system.

19.2 Gas Mixing Station

The gas mixing system works by metering three gas supplies into a common mixing tank. The mixture is then bubbled through alcohol in a tank within a small refrigerator which has been modified for safe operation in a flammable gas system. Because the gas *flow*, not the pressure, is regulated by the metering system, pressure switches have been installed to monitor the mixer outlet pressure and provide feedback to the flow-control system. The mixing, bubbling, and pressure control systems are all built into the same relay rack. They are collectively referred to as the Gas Mixing Station. A flow diagram is shown in Figure 19.1

19.2.1 Mass Flow Control System

The flow rate of each component gas is controlled by a mass flow controller which delivers a constant mass of gas per unit time. (Tylan General model FC-280AV) The mass flow is independent of pressure, although a minimum differential pressure across the controller is required for proper operation. The valves are factory-calibrated for Nitrogen (N_2). The system controlling them is field-programmed to compensate for different gasses. Flow channel 1, currently assigned for CO_2 , has a mass flow controller calibrated to deliver a maximum of 100 sccm (standard cubic centimeters per minute) N_2 (74 sccm CO_2). Flow

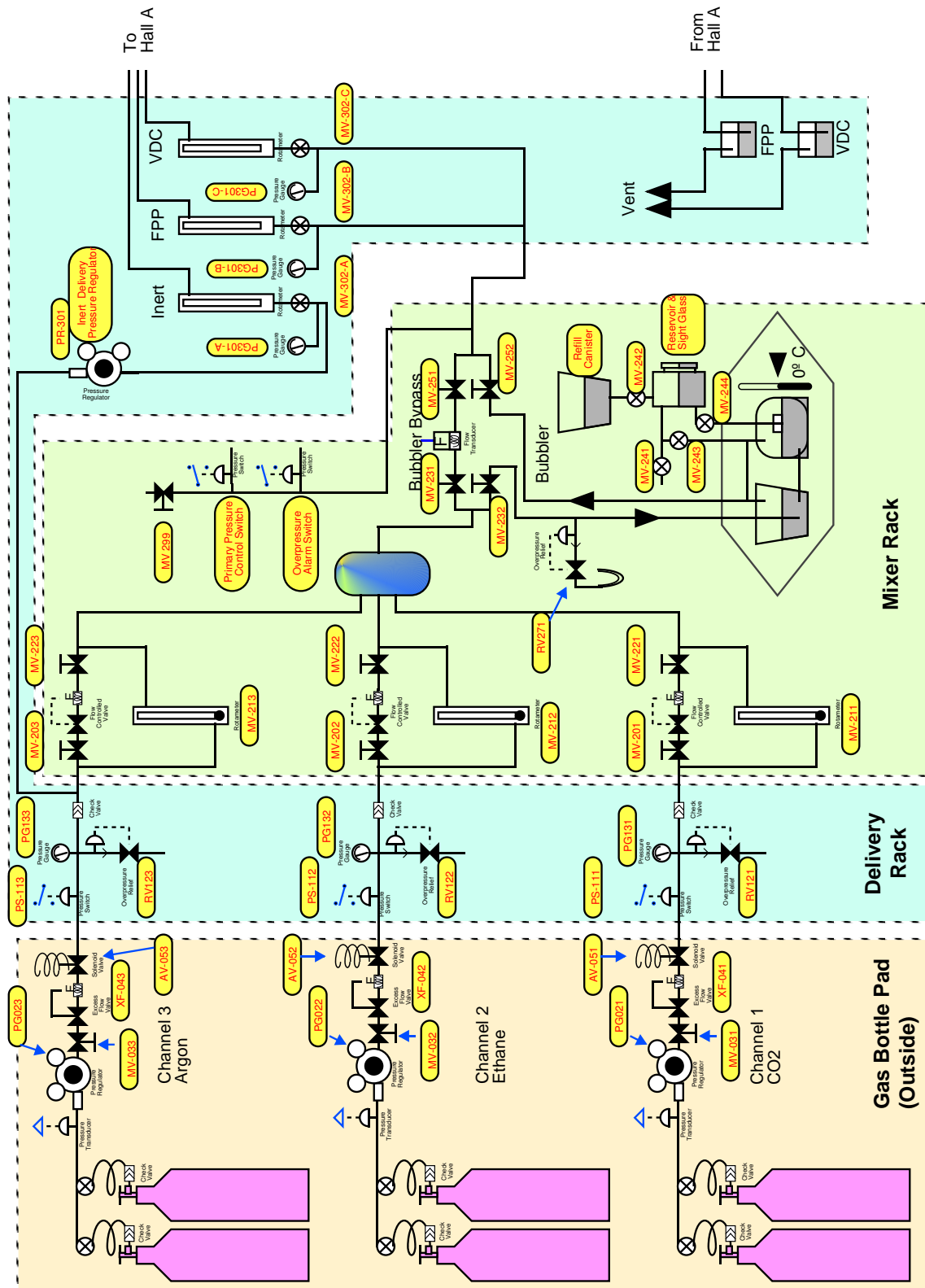


Figure 19.1: Shed Schematic Diagram

channels 2 and 3 have controllers with a full scale range of 1000 sccm N₂. With the calibration factors taken into account the maximum flows are 500 sccm Ethane (channel 2) and 1450 sccm Argon (channel 3). Manual valves (MV-201 & 221, etc.) are provided which allow one to bypass the mass flow controllers and use a needle-valve / rotameter set (MV-211, -212, -213) if desired. The needle valve must be closed during normal operation using the mass flow controllers.

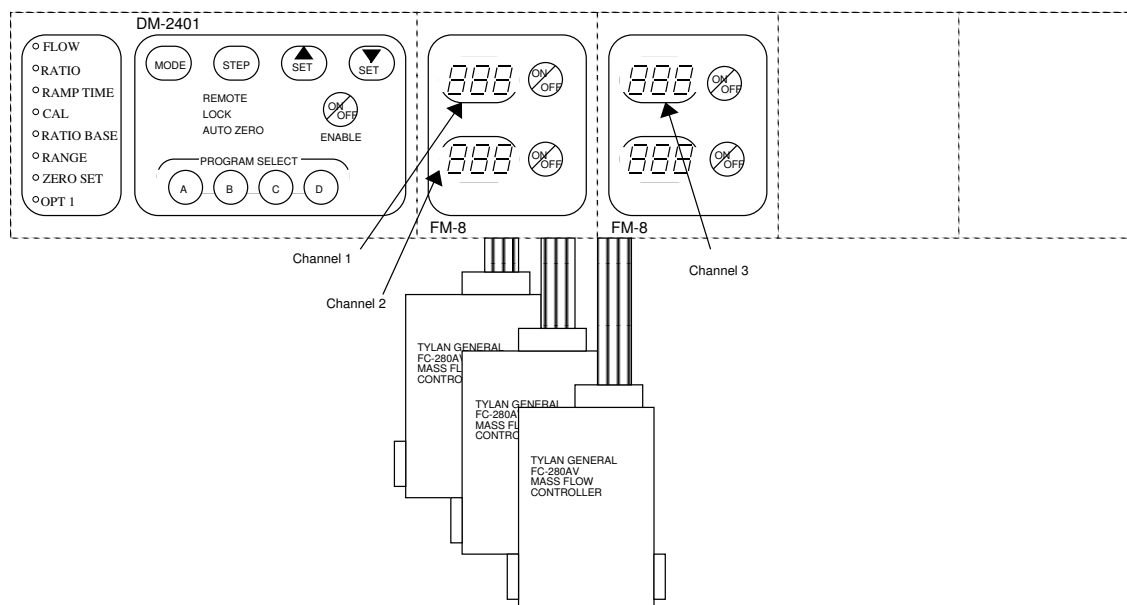


Figure 19.2: Block Diagram of Mass Flow Control System.

The mass flow valves are controlled by a Dynamass Flow Control System (Vacuum General, Inc. model DM-2401). This unit is outfitted with four flow-control channels (two model FM-8 two-channel modules) and could be upgraded to eight flow channels if desired. Refer Figure 19.2 for a diagram of this system. Currently HAWGS has only three of the four channels instrumented. The FM-8 receives a flow measurement from its associated flow controller, adjusts it by the calibration factor for the gas being used, and displays the result on the front panel. If the measured flow differs from the desired flow as set in the FM-8 by an operator, a correction signal is sent to adjust the valve in the flow controller. The DM-2401/FM-8 system allows the user to define up to four mixture/flow settings. Refer to the Dynamass System manual and to section 3.3.3 *Setting a Flow Rate* for more detail on operating the flow controllers.

The measured flows of the three component gasses are combined in a small blending tank in the back of the mixing station. The resulting mixture is delivered to the alcohol bubbler through a line which is teed to an overpressure relief valve (RV-271) set for 25 psig. This prevents overpressuring of the blending tank, the bubbler, or the delivery lines.

19.2.2 Alcohol Bubbler

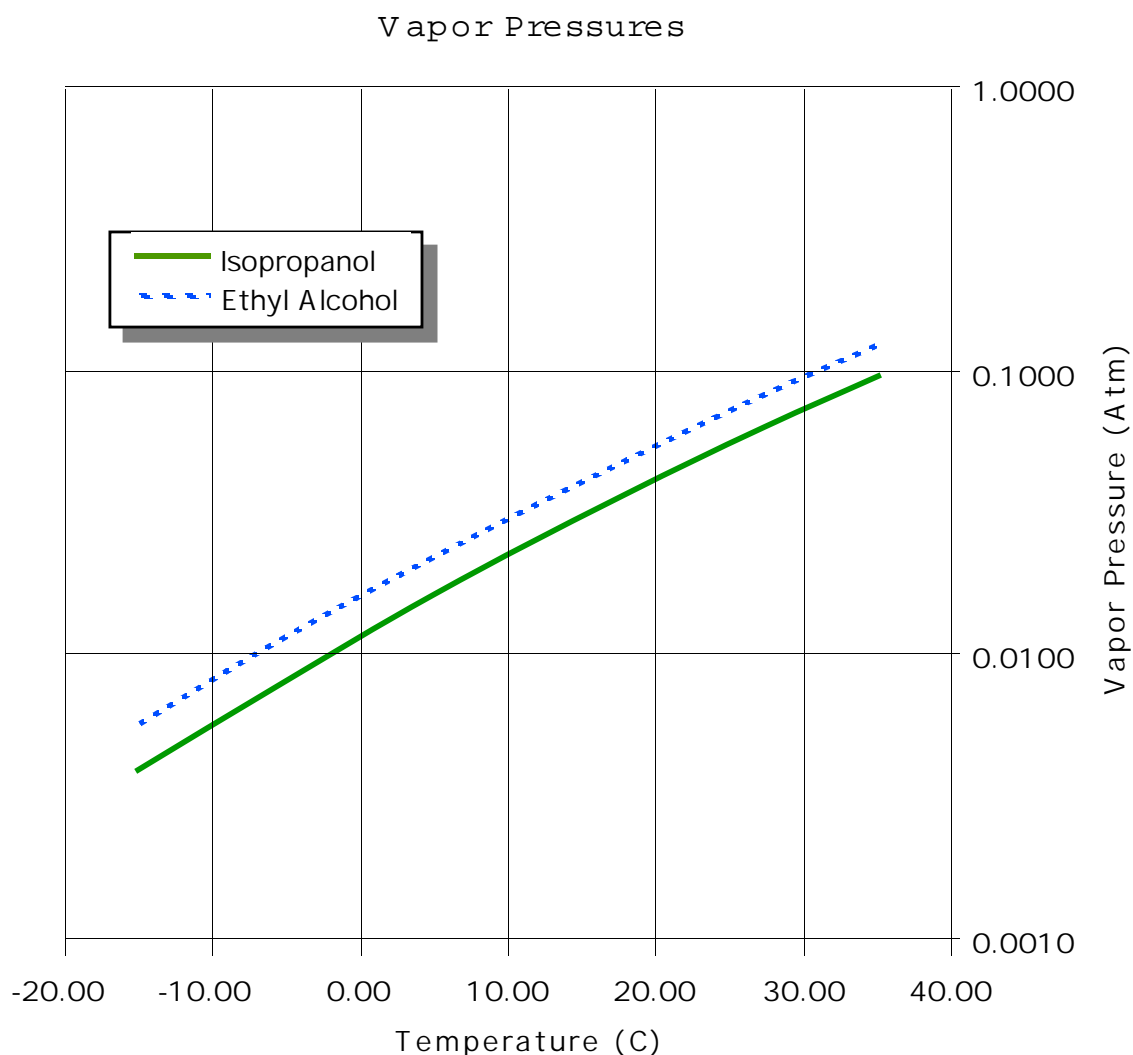


Figure 19.3: Vapor Pressures of Isopropyl and Ethyl Alcohols calculated using the CRC Handbook parameterization.

Because the interesting alcohols for use in wire chambers have a feeble vapor pressure at room temperature, it is not convenient to purchase bottled gas with alcohol already added. A practical means of adding alcohol vapor to a gas is to pass the gas through a reservoir of the liquid alcohol which is maintained at a specified temperature. At a given temperature, the vapor pressure of the alcohol may be known, and this vapor pressure represents directly the partial pressure of the vapor in the gas mixture. The vapor pressures of organic compounds may be calculated from information in the CRC Handbook of Chemistry and Physics, where it has been parameterized as

$$\text{Log}_{10}P = (-0.2185A/K) + B \quad (19.1)$$

where P is the pressure in Torr, K is the temperature in Kelvin, and A and B are parameters provided in the Handbook for a number of compounds. For isopropanol within the temperature range -26.1°C to $+232.0^{\circ}\text{C}$, the parameters given are $A=10063.5$ and $B=8.996156$. For Ethyl Alcohol the parameters are $A=9673.9$, $B=8.827392$.

At 0°C , for example, this formula gives the vapor pressure of isopropanol as 0.0115 Atm. (1 Atm. 760 Torr). If the gauge pressure of the bubbler gas + vapor is 1 atmosphere (2 Atm absolute pressure), as intended for Hall A, then the fraction of alcohol vapor, by partial pressure, is about 0.57%. Figure 19.3 shows the vapor pressures of these alcohols as a function of temperature.

Note that the bubbler temperature defines the vapor pressure and thus the dew point for the vapor in the gas. If the gas comes in contact with any surface which is colder than the dew point (the temperature of the bubbler) the alcohol vapor will condense on that surface. This is why it is important that all components of the gas system be maintained at a temperature above that of the alcohol bubbler. Because gas in the Hall A chambers is at about 1 atmosphere absolute pressure while that in the bubbler is at twice this pressure, the dew point for the gas in the chambers is lower than the bubbler temperature. The bubbler system consists of a refrigerator, a bubbler tank, a cold reservoir, a warm reservoir, and a fill tank. A float valve automatically maintains the liquid levels in the bubbler tank and the cold reservoir. Alcohol enters the bubbler tank only from the cold reservoir so that its temperature has already been established. The warm reservoir, sitting above the refrigerator, is equipped with a sight glass and serves as the main on-line alcohol storage vessel. When the level of liquid in this tank becomes low it must be manually refilled from commercially supplied bottles using the fill tank. The refrigerator used to maintain the alcohol bubbler temperature has been modified specifically to make it safe for containing flammable gasses and liquids.

Filling the alcohol reservoir is not trivial. Please refer to and carefully follow the procedure detailed in section 3.3.2 *Adding Alcohol*.

19.2.3 Delivery Pressure Control

Gas will be metered to each detector element through a needle valve. To achieve a constant flow through a needle valve a constant differential pressure must be maintained across it, so it is necessary to provide a fairly constant supply pressure out of the mixing station. This comes only at a price, as the mass flow controllers deliver a fixed *flow rate* regardless of pressure (within practical limits). If the detectors in Hall-A consume less gas than the mixer supplies, the pressure in the supply lines will increase. Similarly, if less gas is mixed than is consumed the pressure will decrease. To provide a usefully constant pressure of about 15 psig in the supply line, a pair of pressure switches has been installed in the mixing station outlet. The first of these, the **Primary Pressure Control Switch**, is set to open at 16 psig and close again at 14 psig or below. When the pressure is low this switch is closed and the Flow Control System is commanded to use the flow rates set into its PROGRAM C ("high flow"). When the **Primary Pressure Control Switch** opens, PROGRAM-D ("zero flow") is selected. By setting PROGRAM-C to provide just

a little more gas than required by the detectors, the supply pressure can be maintained at between 14 and 16 psig. with a cycle time of several minutes. This pressure variation will result in a flow rate variation of no more than about 15%, which should be of no consequence for the detectors.

A second pressure switch, the **Overpressure Alarm Switch**, is calibrated to open at 18 psig and re-close at 14 psig or below. If the delivery line pressure manages to exceed the 18 psig threshold it indicates a system failure of some sort and the gas interlock system is tripped by this switch. Manual operator intervention is then required to re-establish gas flow.

Pressure control of the inert gas supply, used to purge the detectors, is provided by a conventional single-stage regulator (PR-301) mounted inside the delivery rack. This regulator receives 45 psig inert gas (the same gas delivered to mixer flow channel 3) and provides 15 psig gas to the INERT supply line to Hall-A.

19.3 Gas Delivery into Hall A

Between the gas shed and the two Hall-A shield houses are several gas line runs of about 700 feet in length. These are shown schematically in Figure 19.4. Three gasses (inert, VDC, and FPP) are supplied to the Hadron Arm through 1/2-inch OD polyethylene tubing. Two similar tubes are teed into these near the beamline entrance to Hall-A and they supply VDC and inert gas to the Electron Arm shield house. The pressures in all of these lines is nominally 15 psig.

19.3.1 Distribution in the Shield Houses

Inside each shield house there is a gas distribution panel which controls the gas flows to the individual wire chambers in that detector stack. Figure 19.4 shows a diagram of the shield house gas systems.

Each gas supply is first filtered and fed to a visual pressure gauge (PG-401-A/B and PG- 501-A/B/C) so that the supply pressure can be locally verified. Inert gas (for purging detectors) and operating gas (either VDC or FPP gas) is manifolded to a series of three-way valves one for each detector flow circuit. These valves are labeled MV-411, -412 in the Electron Arm, and MV-511 MV-516 in the Hadron Arm.

The three-way valve associated with each detector may be used to select either operating or purge gas independently of the other detectors. The selected gas is supplied to the inlet of a needle-valve / rotameter combination (labels MV-42x and MV-52x) which is to be used to set and observe the gas flow to each detector. The rotameters are sized for reasonably accurate metering of 5 slph Argon-Ethane and purging at about ten times this rate. (Note that the gas mixer will supply a total of only 60 slph Argon-Ethane, limited by the capacity of the Ethane mass flow controller).

On its way from the rotameter to the detector the gas passes by an overpressure relief bubbler which is basically a manometer filled with mineral oil. The overpressure bubblers are set to release at a pressure greater than about 30 mm of water (~ 33 mm mineral

oil). This pressure is sufficient to allow purging at the desired rate. Gas returning from the detector passes through an electronic mass flow meter and through a low pressure oil bubbler. This bubbler prevents backstreaming of waste gas into the detectors. The flow meter reading is indicated locally on a LCD display and is available as an analog signal for connection to the slow controls computer. Note that these digital flowmeters are factory-calibrated for Nitrogen. To correct the readings for Argon multiply by 1.45; for Ethane multiply by 0.5; for CO₂ multiply by 0.74.

19.3.2 Waste Gas Collection and Venting

Gas coming from the chamber exhaust bubblers is collected in a manifold and routed back to the gas shed through a large (1-inch OD) polyethylene tube. There are separate manifolds and exhaust lines for the VDC and FPP systems. Back-pressure in the exhaust manifolds is monitored by PHOTOHELIC(*R*) pressure switches. If more than about 1-inch H₂O backpressure develops in an exhaust manifold the gas supply interlock system is tripped, turning off the gas supply at the solenoid valves outside the gas shed. The purpose of this particular interlock is to protect the detector windows from overpressure.

19.4 Authorized Personnel

The following personnel are responsible for problems concerning the gas system:

Howard Fenker -x7431

Jack Segal -x7242

19.5 Safety and Device Protection

There are a number of monitor points which provide signals to the gas interlock panel and which can cause the supply of gas to be interrupted. The primary purpose of this system is to facilitate the safe handling of a flammable gas. A secondary but equally important function is protection of the detector hardware. Finally, this system serves to help insure the integrity of the data collected by Hall A experiments by alerting the experimenters on shift if a condition arises which might affect the detector gas quality. The conditions monitored are 1) flammable gas leak detection, 2) low main supply pressure, 3) high delivery pressure, 4) high exhaust line pressure, 5) forced airflow in gas shed, 6) over-temperature in gas shed or a shield house, and 7) house fire alarm. The "Kill Gas" buttons in the counting room and in the gas shed also feed into this interlock system.

When a fault condition occurs, power to the solenoid valves controlling gas flow into the gas shed is turned off, closing the valves. An audible alarm sounds in both the gas shed and the counting room, and one or more red lights on the interlock panels in both locations indicate the specific fault detected. The audible alarm may be silenced by

1

Figure 19.4: Gas Distribution inside Hall-A.

pressing the "Alarm Override" button. Note that this does not restore gas flow or clear a fault.

After the fault is cleared it is necessary to activate the "Low Pressure Override" circuit by pressing the corresponding button on the interlock panel in the gas shed. This circuit temporarily disables the "Low Pressure" fault circuit, allowing the solenoid valves to open up and restore gas pressure to the inlet pressure switches. When pressure is restored this circuit automatically resets itself.

Note that the **Excess Flow Valves** will almost always trip immediately after the solenoid valves are re-opened. This is because of the sudden high flow rate which occurs when the pressure in the gas line downstream of a solenoid valve is low and the solenoid valve is opened with full inlet pressure. To reset the **Excess Flow Valves** refer to the section *Resetting a closed Excess Flow Valve*.

19.6 System Operation

19.6.1 Pre-Startup Checklist

Before initial use with a flammable gas or after a significant down-time the following checks should be made to insure the safety and integrity of the HAWGS:

1. Leak-Check the entire gas system using a safe gas such as Argon or Nitrogen.
2. Calibrate over-pressure relief valves: RV121, 122, 123 should release at 55-65 psig, RV271 must release at 20-25 psig).
3. Check calibration of Excess-Flow valves (should close at 4-5 slpm).
4. Check proper operation of each interlock circuit and that interlock system shuts off gas supply.
5. Measure the detectors leak rates and verify that each is below 7 slph (or current administrative limit - note that current physical limit is 500 sccm Ethane and 1450 sccm Argon based on flow controller full scales for N₂ and correction factors for Ethane and Argon).
6. Verify that flammable gas leak sensors are appropriately calibrated.

19.6.2 Startup Procedure

1. Close gas shed outlet valves MV-302-A, -B, -C to isolate the mixing/delivery system from the spectrometer detectors.
2. Activate the "Kill Gas" crash button. Interlock panel should alarm. Silence the alarm by pressing "Alarm Silence". Reset the Crash Button by pulling outward. If any fault conditions (red LED) other than "Low Pressure" and "Main Relay" are indicated, clear them by correcting the indicated fault.

3. Check alcohol supply and Bubbler temperature. Fill and/or adjust as necessary (see *Adding Alcohol*) .
4. Check that adequate supply bottles of appropriate gasses are attached to the high pressure supply manifolds and valve **one** bottle ON for each manifold.
5. Verify that all used main pressure regulators (outside) are set for 45-50 psig.
6. Select "Manual / Expert" pressure control using toggle switch on panel in rear of mixing station, behind flow controller. **Note that while in "Expert" mode there is no automatic delivery pressure control!** Overpressure is prevented only by the overpressure shutoff switch and the alcohol reservoir relief valve.
7. Verify that the Dynamass Flow Control System DM-2401 is in "Non-VG" mode by
 - Press PROGRAM SELECT pushbutton A.
 - Put the DM-2401 in NO-MODE mode (if it is not already) by pressing the MODE pushbutton until all LEDs in the column of LEDs on the left of the unit are off.
 - Simultaneously press and release PROGRAM SELECT buttons A and C.
 - Press the MODE pushbutton until the OPT 1 LED is lighted. Verify that the display for channel 4 reads all zeros.
 - Return the DM-2401 to NO-MODE.
8. Set Dynamass Flow-Control System to Program "D: Zero Flow" . Put the DM-2401 in "FLOW-MODE" and verify that all flow settings are at zero.
9. With the DM-2401 in "FLOW-MODE", set up flow program "C" to provide the desired mixture at about 10% higher total flow than the detectors are expected to consume.
10. Return the DM-2401 to "NO-MODE".
11. Select "Auto" pressure control using toggle switch on panel in rear of mixing station, behind flow controller.
12. Actuate the Low Pressure Override on interlock panel. "Main Relay" light should become green.
13. Set Excess-Flow Valves and Manual valves at regulators to full OPEN, wait about ten (10) seconds for supply lines to come up to pressure, then set all three Excess Flow Valves to AUTO SHUTOFF. - "Low-Pressure" interlock circuit should go to green during this step³.

14. Verify proper operation of flow/mix control system and outlet pressure regulation by observing flow rates on the mixer control and outlet pressure at the supply rack (pressure gauges 301B, -301C). If the alcohol bubbler loop is valved on it may take several minutes for its volume to fill with gas and come up to pressure. Be patient. When the pressure indicated on gauges PG301-B/C reaches about 15 psig the DM2401 system should cycle to flow program D. To bleed down the outlet pressure in order to cause the pressure loop to cycle, you may crack valve MV-299 (located in the rear of the mixer rack). When the pressure drops back to about 13 psig the control system should switch back to program C. Re-close valve MV-299 when tests are complete.
15. Check/Adjust the Purge gas pressure regulator (PR 301) to insure that the delivery pressure of the inert gas (taken from gas supply 3 - nominally Argon) is about 15 psig as registered on pressure gauge PG-301A.
16. Slowly open gas shed outlet valves MV-302-A, -B, -C to bring up the pressure in the supply lines to the spectrometers. After pressure has equalized open these three valves fully. Note that one or more **Excess Flow Valves** will trip (close) if the **total** gas flow through the three rotameters associated with these valves exceeds (roughly) 150 units (full scale on **one** rotameter).
17. At each of the Hadron and Electron shield house gas distribution racks, verify the presence of supply pressures (gauges PG401A,B and PG501A,B,C) and set gas selection valves and needle valves to desired gasses and flow rates for each chamber.

19.6.3 Normal Operation

19.6.4 Changing gas bottles

Warning: High pressure gas bottles contain significant stored energy and are potentially hazardous. Handling of gas bottles should be done only by qualified, trained personnel.

For smoothest operation, used gas bottles should be replaced before their internal pressure drops below the desired regulator output pressure.

The sequence of steps for replacing an empty gas bottle is as follows:

1. Make sure that the backup bottle is full, then open its bottle valve and its manifold valve. The in-line check-valves will prevent back-filling of the empty bottle. As a precaution, set the corresponding **Excess Flow Valve** to **OPEN/RESET**, wait ten seconds, then set the **Excess Flow Valve** back to **AUTO**.
2. Close both the bottle and manifold valves for the empty bottle.
3. Disconnect the empty bottle from the high-pressure flex-line, replace the bottles cap, and move the empty bottle to the EMPTIES storage rack. Note that ethane bottle fittings, type CGA-350, have left-handed threads.

4. Place a full bottle of gas in the on-line rack, remove the bottle cap, and connect the bottle to the flex-line.
5. Open the new bottles valve, check for leaks at the bottle fitting, then re-close the bottle valve.

19.6.5 Adding Alcohol

Warning: Never open gas flow into the alcohol bubbler without an outlet valve being open.

As long as the level in the **RESERVOIR** is such that some alcohol is visible in the sight glass the bubbler will be maintained at its normal fill. An effort should be made to prevent the **RESERVOIR** level from getting too low.

1. To fill the **RESERVOIR** close valves MV-243 and MV-244 to isolate the **RESERVOIR** from the pressure equalization line.
2. Open valve MV-241 to vent the **RESERVOIR**.
3. Remove the cover of the **REFILL CANISTER** and fill the canister with alcohol. Put the cover back on but do not seal it (if you seal the cover at this point the flow of alcohol out of the **REFILL CANISTER** will be impeded).
4. Open valve MV-242 to let the alcohol into the **RESERVOIR**. The liquid level can be monitored in the sight glass on the side of the **RESERVOIR**. Fill until the liquid level is near the top of the sight glass then close MV-242. **Do not overfill** (to or above the top of the sight glass).
5. Close valve MV-241, then open valves MV-243 and MV-244.
6. Seal the cover on the **REFILL CANISTER** to prevent contamination.

19.6.6 Setting a Flow Rate

The flow of each individual gas component, and therefore the final gas mixture, is controlled by the **Dynamass DM-2401 System**, the **FM-8 Flow/Ratio Modules**, and the **Tylan General FC-280 Mass Flow Controllers**. The **DM-2401** accepts and stores programs for the set of **FM-8's**. Each **FM-8** controls one or two **Mass Flow Controllers**.

To set or alter a flow rate:

1. Prevent the mixed-gas outlet pressure from exceeding its 18 psig interlock trip level by either a) closing valves MV-201,2,3, or b) insuring that the detectors are consuming a sufficient quantity of gas to prevent this overpressure from occurring during the time it takes you to perform steps 3-11, below.

2. Set the Auto/Expert pressure control switch (rear of mixer rack) to EXPERT.
3. Verify that the DM-2401 is in the NO-MODE mode, indicated by none of the LEDs in the column on the extreme left of the unit being illuminated. If necessary, press the MODE pushbutton until this condition is achieved.
4. Press program select button C and verify that the corresponding LED illuminates.
5. At the DM-2401 Keyboard module, press the MODE switch until the FLOW LED illuminates. The window value for channel 1 will begin to flash.
6. Select the channel you wish to alter by pressing the STEP button until the window value of the desired channel is flashing.
7. Press the UP or DOWN SET buttons to alter the value as desired. Legal flow values are 0.0-100.0 sccm for channel 1, 0-1000 sccm for channels 2 and 3.
8. If the Red ON LED for the desired channel (immediately to the right of the value window) is not lit, press the ON/OFF button for that channel to illuminate this LED.
9. Repeat steps 6-8 as necessary to program all desired gas flows.
10. Return the DM-2401 to NO-MODE as in step 3.
11. Return the Auto/Expert pressure control switch (rear of mixer rack) to AUTO.
12. Re-Open valves MV201, 202, 203, if closed in step 1.
13. Observe system flow and pressure control and verify that it is correct.

19.7 Troubleshooting : Things to Check

Each of the following monitor points must report a nominal condition to the gas interlock panel in order for the logic to be "made up" and for gas flow to be enabled:

Label	Meaning	Likely Remedy	Sensor
Low Pressure Note: <i>This channel will always indicate a fault after some other problem has caused the solenoid valves to close.</i>	The secondary pressure of one or more of the mixer inlet gas supplies has dropped below the 45 psi threshold.	<ul style="list-style-type: none"> • Check for a closed "Excess Flow" Valve, Remedy the cause, and reset the valve • Replace empty supply bottle. 	3 pressure switches located on the "Delivery Rack"
Gas Shed Airflow	Gas Shed Exhaust Fan (ceiling of "Isobutane Room') has failed.	Restore forced ventilation.	Vane Switch mounted just inside exhaust fan
Overtemp Gas Shed	Temperature in Gas Shed Too High (~110°F).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature. 	Klixon mounted in rack
Over-Pressure FPP Over-Pressure VDC Electron Over-Pressure VDC Hadron	VDC/FPP Exhaust manifold pressure at Hadron Or Electron Shield House Gas Rack	<ul style="list-style-type: none"> • Eliminate exhaust line blockage • Allow Hall-A atmospheric pressure to stabilize 	PHOTOHELIC ^(R) gauges on gas panels in shld houses
Gas Leak	Flammable gas detection system has sensed a leak	<ul style="list-style-type: none"> • Localize leak by referring to readings on GasMaster-4 system in Counting House • Fix Leak 	GASMASTER HydroCarbon Detector heads in Gas Shed and each Shield House.
Overtemp Electron	Temperature in Electron Shield House Too High (~110°F).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature 	Klixon mounted in gas rack in Electron Shield House
Overtemp Hadron	Temperature in Hadron Shield House Too High (~110°F).	<ul style="list-style-type: none"> • Take action to protect equipment. • Reduce temperature. 	Klixon mounted in gas rack in Hadron Shield House
Post-Bubbler Supply Overpressure	Gas pressure out of mixer/bubbler rack is >18 psi.	<ul style="list-style-type: none"> • Reset Dynamass Controller • If needed, vent excess pressure using MV-299 	Pressure switch in rear of Mixing Station (mixer/bubbler rack)

19.7.1 Resetting a closed Excess Flow Valve

Each Excess Flow Valve automatically closes if the flow rate through it exceeds about 4 slpm at 45 psig. The exact flow threshold varies somewhat depending upon the delivery pressure.

These valves must be manually reset after they trip. This is done by rotating the red handle 90° CW (to OPEN/RESET) and then 90° CCW (back to AUTO SHUTOFF.). It will be necessary to keep the valve in the OPEN/RESET position for about 10 seconds until nominal pressure builds up downstream. The excess flow valves must be returned to the AUTO SHUTOFF setting to insure system safety.

Restoring flow after a "Low Supply Pressure" shutdown

If the gas pressure in any enabled supply line to the mixer rack drops below about 40-45 psig, the interlock will sound an alarm and close all of the solenoid valves. This prevents the system from delivering a bad mixture to the detectors. After restoring the gas supply, for example, after replacing an empty gas cylinder, perform the following steps to restart the flow of gas.

1. Verify that no faults other than "Low Pressure" and "Main Relay" are indicated on the gas interlock panel.
2. Insure that all high-pressure manifolds are pressurized and that the secondary pressures indicated by the gauges above the bottles are at about 40-45 psig (normally these should not need adjustment).
3. Press the Low Pressure Override button on the interlock panel in the gas shed.
4. Reset all Excess Flow Valves by turning their handles to OPEN/RESET, waiting for about ten seconds, then returning their handles to AUTO SHUTOFF.
5. Verify that all faults are now cleared on the gas interlock panel.

19.7.2 Restarting flow after a power failure.

Normally the gas control system is protected from power outages by an uninterruptable power supply (UPS). If the system is nevertheless disturbed by a loss of power then perform the steps outlined in section 3.2, Startup Procedure.

19.8 Maintenance

19.8.1 Periodic Inspections

Anytime work is done on any part of the gas system, or there is an occurrence that could possibly have damaged the gas system, the system should be carefully inspected and checked for leaks.

The flammable gas detector heads and control system should be tested periodically for proper operation, in accordance with the manufacturer's recommendations and the TJNAF fire safety program.

Each sensor feeding the Gas Interlock Panel should be exercised at least annually for proper operation. The interlock system itself should be tested at the same time to insure that it interrupts the supply of gas when it is tripped.

The high-pressure manifold and bottle connections should be regularly checked for leaks and damage. In particular, the CO₂ system (CGA-320) uses plastic seals at the bottle connection which must be replaced periodically.

Flowmeter Calibration The Tylan General mass flow controllers (mass flow valves) require periodic cleaning and calibration (section 5.7, Tylan General Mass Flow Controller Instruction Manual). The first step in this process is to check the operation of the instruments and perform further work as necessary. This procedure should be planned and carried out whenever 1) there appears to be a problem with the operation of a flow controller, or 2) there is a lengthy break in the Hall-A program that would allow the gas system to be taken off-line for several weeks. If absolutely necessary the needle-valve/rotameter combinations plumbed in parallel with the mass flow controllers could be used to allow interim operation of the gas system while one or more flow controllers is removed for maintenance.

Part VI
Slow Controls

Chapter 20

Overview ¹

A distributed computer system based on the Experimental Physics and Industrial Control System (EPICS) [6] architecture monitors and commands the various Hall A systems. The basic components of the system are:

- Input/Output Controllers (IOCs) - VME systems containing single board computers (SBCs) and I/O modules (i.e analog-to-digital converters (ADCs), digital I/O and RS-232C interfaces). Each SBC executes the real-time operating system Vx-Works and the corresponding EPICS application (signal database and sequencers).
- Operator Interfaces (OPI) - Computers capable of executing EPICS tools to interact with the IOCs. The four most used tools in Hall A are (a) a Web-enabled version of the Motif-based Display Editor/Manager (MEDM) [14], (b) StripTool and, (c) a signal archiver. MEDM is the main interface used for monitoring and controlling both the hall and accelerator equipment. StripTool allows to monitor the behavior of one or more signals as a function of time. The signal archiver keeps a record of a selected set of signals.
- Boot Servers - IOCs load the various software components needed to perform their functions from these machines (i.e. operating system, signal database and controls algorithms).
- MEDM Servers - OPI computers obtain the framework of each MEDM screen from these machines.
- Local Area Network (LAN) - the communication path joining the IOCs, OPIs and various servers.

20.1 System's Components

Four Linux based computers are used as OPIs: [hacsb2](#) (Hall A counting house), [hacweb4](#) (101B), [hacweb2](#) (hall) and [hacweb3](#) (laptop - as needed). Two computers act as boot

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servers: [hacsbc2](#) and [hlasrv](#) (2nd-floor of counting house). [Hlasrv](#) also acts as MEDM server. The tasks assigned to the various IOCs are,

- [hallasc7](#) Right HRS motion control.
- [hallasc6](#) e-p energy measurement system.
- [hallasc18](#) Left HRS motion control.
- [iocha1](#) Arc energy measurement system - beam position and profile wire scanners.
- [iocha2](#) Arc energy measurement system - 9th magnet $f Bdl$ measurement.
- [iocha3](#) RICH counter.
- [iocha4](#) Electron detector stack - VDCs high voltage and discriminator thresholds, reset lines to various DAQ crates.
- [iocha5](#) Beam current monitors.
- [iocha11](#) Hadron detector stack - VDCs high voltage and discriminator thresholds, reset lines to various DAQ crates.
- [iocha14](#) Left HRS - Q2, Q3 and Dipole power supplies and cryogenics, magnetic field probes and, collimator.
- [iocha16](#) Right HRS - Q2, Q3 and Dipole power supplies and cryogenics, magnetic field probes and, collimator.
- [iocha17](#) Monitors supply of various gasses to tracking chambers.
- [iocha22](#) Electron detector stack - LeCroy high voltage supplies located at various points in the hall (i.e. beam-line and both electron and hadron detector stacks).
- [iocha26](#) Polarized ^3He target system.
- [iocha48](#) Left and Right HRS Q1 power supplies. BigBox power supply.
- [iocha49](#) Septum magnets.
- [iochawt1](#) Waterfall target system.
- [iocha33](#) Polarized ^3He target system (lasers).

20.2 Operating Procedures

Log into the Hall A control system through one of the computers [hacsbc2](#), [hacweb4](#), [hacweb2](#) or [hacweb3](#). The task bar has a “tool box” icon with a small arrow on top. Clicking on the arrow brings up a menu of applications. To start any of these applications, use the left mouse button to click on the application name. These applications can also be started from a terminal by just typing their name.

20.3 AlarmHandler

The “AlarmHandler” notifies the user when either a signal being monitored is outside some pre-defined limits or communication with the IOC in which the signal resides has been lost. “AlarmHandler” will only detect an abnormal signal condition if the signal is included in the application configuration file and, the corresponding IOC database record is set to produce an alarm condition. The application configuration file is `~/AlarmHandler/EXP/ALH-default.alhConfig` where *EXP* represents the running experiment number. A detail description of the operation and configuration of this application can be found in the Alarm Handler Users Guide.²

20.4 ArchiverViewer

This application allows to look at the history of many EPICS signals (but not all) distributed over the whole accelerator complex including the halls. “ArchiverViewer” is a shell script which simply calls MyaViewer, an interface to the EPICS channel archiver Mya. A FAQ and User’s Guide³ are available for those interested in using this tool. These documents can also be accessed through the “help” button at the top of the application.

20.5 bogies_LEFT and bogies_RIGHT

These applications are used to move the left and right HRS spectrometers to the desired angle. The applications are very similar so, we will use “bogies_RIGHT” as an example. Upon starting the “bogies_RIGHT” application, a screen labeled “RIGHT-HRS Bogies” will open as shown in Fig. 20.1.

Pressing the button labeled “Graph” in the top-left corner of “RIGHT-HRS Bogies” will open two more screens: one labeled “Strip Chart” and an associated, column like, signal selection screen (see Fig. 20.2). The signal selection screen allows to select the signals to be plotted in the Strip Chart screen. All signals are plotted with the same color. To highlight a given signal, use the plot legend located towards the right of the Strip Chart screen: clicking on the line next to the signal name will change its color in the main plot. The plot screens are likely to be more useful to the Hall A technical staff than to the shift personnel.

The application screens show the Motor Current Output (MCO) and Motor Velocity Output (MVO) for each of the four middle-ring (M1-M4) and four outer-ring (O1-O4) motors. Also shown are the status and request buttons for the Power Supply Module (PSM), Drive Modules (DM), brakes and, clamps. The clamp request button (“CLAMP RELEAS”) actually releases two interlock circuits (the Forward Amplifier Clamp or FAC and the Reverse Amplifier Clamp or RAC) so that the spectrometer is able to move in any direction (i.e. clockwise or counter-clockwise). It is worth to stress that the PSM,

²<http://www.aps.anl.gov/epics/extensions/alh/index.php>

³http://devweb.acc.jlab.org/controls_web/certified/MyaViewer/

Graph		Disconnect	
<input checked="" type="checkbox"/> PSM ENABLE	PSM OK	NO	YES/NC
<input checked="" type="checkbox"/> DM ENABLE	DM OK	NO	YES/NC
<input type="checkbox"/> BRAKE RELEASES	Brakes OK	NO	YES/NC
<input type="checkbox"/> CLAMP RELEASES	FAC OK	NO	YES/NC
	RAC OK	NO	YES/NC
MCO M1	0.74	Amps	
MCO M2	0.73	Amps	
MCO M3	0.76	Amps	
MCO M4	0.71	Amps	
MCO O1	0.34	Amps	
MCO O2	0.30	Amps	
MCO O3	0.27	Amps	
MCO O4	0.25	Amps	
MVO M1	5	RPM	
MVO M2	0	RPM	
MVO M3	0	RPM	
MVO M4	0	RPM	
MVO O1	0	RPM	
MVO O2	0	RPM	
MVO O3	0	RPM	
MVO O4	0	RPM	
VELOCITY SET	0	0	RPM
ILIM MIDDLE SET	5	5	Amps
ILIM OUTER SET	4	4	Amps
DIRECTION	CW	CW/CCW	

Figure 20.1: Right HRS motion control.

DM, brakes and clamps request buttons represent requests that the hardware interlock circuits may negate. This can be clearly seen in Fig. 20.1 which was taken with the electrical power to the PSM and DMs disabled for septum magnet installation in the central pivot area. Note that PSM and DM request buttons are selected (red color) yet the corresponding status fields show interlock incomplete status (“NO”).

To move the spectrometer, select the request buttons in descending order, starting with “PSM ENABLE” and ending with “CLAMP RELEASES”. After selecting a button, wait until the corresponding status changes to “YES”. If the status does not change, reboot the IOC using the green buttons located in the middle room of the counting house. If the failure persists, contact the Hall A on-call tech. After the clamps have been successfully released, enter a value in the “VELOCITY SET” field (see Fig. 20.1 - “RIGHT-HRS Bogies” screen). The sign of the velocity will determine the sense of spectrometer rotation. The sense of rotation is displayed by the field “DIRECTION”.

Safe operation of the spectrometer motion systems requires,

- Find out from the shift leader the administrative constraints imposed on spectrometer motion. These constraints are communicated by the Hall A technical staff to the run-coordinator. Moving the spectrometers while no experiment is taking place (for example, a maintenance period), must first be approved by the head of the Hall A technical staff (E. Folts) or the person designated by him.
- If the administrative constraints allow to move the spectrometers remotely, use the Hall A cameras to ensure there are no objects in the path of the spectrometers.
- Check that the floor marks are seen in the TV monitors.

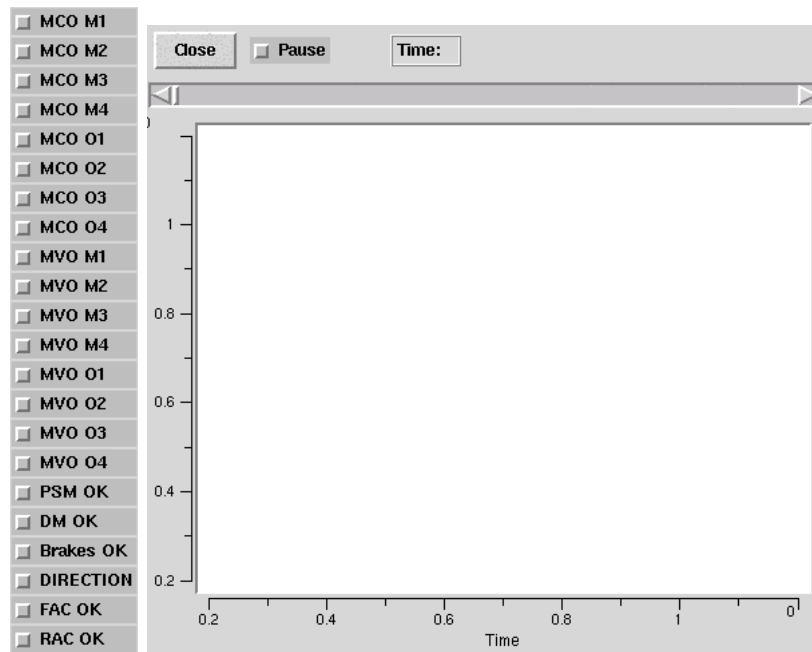


Figure 20.2: Right HRS motion control - additional options.

- Bring up the spectrometer motion application and go through the required steps to get the spectrometer moving. Look at the floor marks to ensure that the spectrometer is moving in the desired direction.
- While the spectrometer is moving, use the Hall A cameras to check that everything looks normal (for example, the cryogenic lines around the pivot). If something does not look right, de-selecting ANY of the interlocks (“PSM ENABLE”, ..., “CLAMP RELEAS”) will stop the spectrometer immediately.
- As the spectrometer approaches the desired floor mark, reduce the spectrometer speed. De-select the “CLAMP RELEAS” button to stop the spectrometer at the desired floor mark.
- De-select the remaining interlocks: “BRAKE RELEAS”, “DM ENABLE” and “PSM ENABLE”.
- Press the button labeled “Disconnect” to close the spectrometer motion application.

20.6 bogies_SetSpec

This application determines the floor mark and vernier readings required to set each spectrometer to a given angle. Its use is self-explanatory.

20.7 Menu_Accelerator

The “Menu_Accelerator” application brings up a web-version of Monticello, the root MEDM screen giving access to the various accelerator systems. Access to those systems is read-only mode except for some Hall A applications which are described elsewhere in this OSP. Not all the menus shown in this web-version of Monticello are operational because they still are linked to directory structures residing in specific Machine Control Center (MCC) computers.

20.8 Menu_ESR

This application brings up the End Station Refrigerator (ESR) menu. Access to all ESR systems is read-only mode. This application is typically used by the Hall A technical staff to monitor the hall cryogenics.



Figure 20.3: Hall A Main Control Screen.

20.9 Menu_HallA

This application brings up a menu giving access to all the EPICS based control systems in Hall A. (see Fig. 20.3). Using this window one can open the “Tools” window (see Fig. 20.4) containing many available functions for slow control of Hall A equipment.

20.10 StripTool

Strip Tool plots a real-time strip chart of the values of one or more signals. It is useful to monitor data trends. A detail description of the options and operation of this application can be found in the Strip Tool Users Guide⁴ with one difference; the version used by Hall A does not have a “print” function. To print a strip chart use the application “Snapshot” described below.

20.11 Snapshot

Snapshot refers to a KDE desktop application (ksnapshot) which allows to grab an image of either the whole screen or an individual window. The image can then be sent to a printer or stored on disk.

20.12 Troubleshooting Procedures

The status of most IOCs can be seen by opening the ‘Hall A Menu’ -- > ‘IOCs’. White entries means that the IOC is not responding which can be due to either the IOC not being used by the present experiment or it has failed. Rebooting of the IOCs is accomplished in several ways depending on the specific IOC. If the specific IOC can be rebooted through the Web, the url address is given next to it. The required user and password are posted in the Hall A Counting House. The remaining IOCs are rebooted through either the green buttons located in the middle room of the counting house or the crate resets screen “Hall A Menu” -- > “Tools” -- > “Crate Resets”.

If an IOC fails to reset and its name is “iocha..”, call MCC and request that the software on-call person be notified. If the name is “hallasc..” call J. Segal or J. Gomez.

20.12.1 Authorized Personnel

The authorized personnel is shown in table 20.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Jack Segal	Hall-A	7242		segal@jlab.org	
Javier Gomez	Hall-A	7498		gomez@jlab.org	

Table 20.1: Slow controls: authorized personnel.

⁴<http://www.aps.anl.gov/epics/extensions/StripTool/index.php>

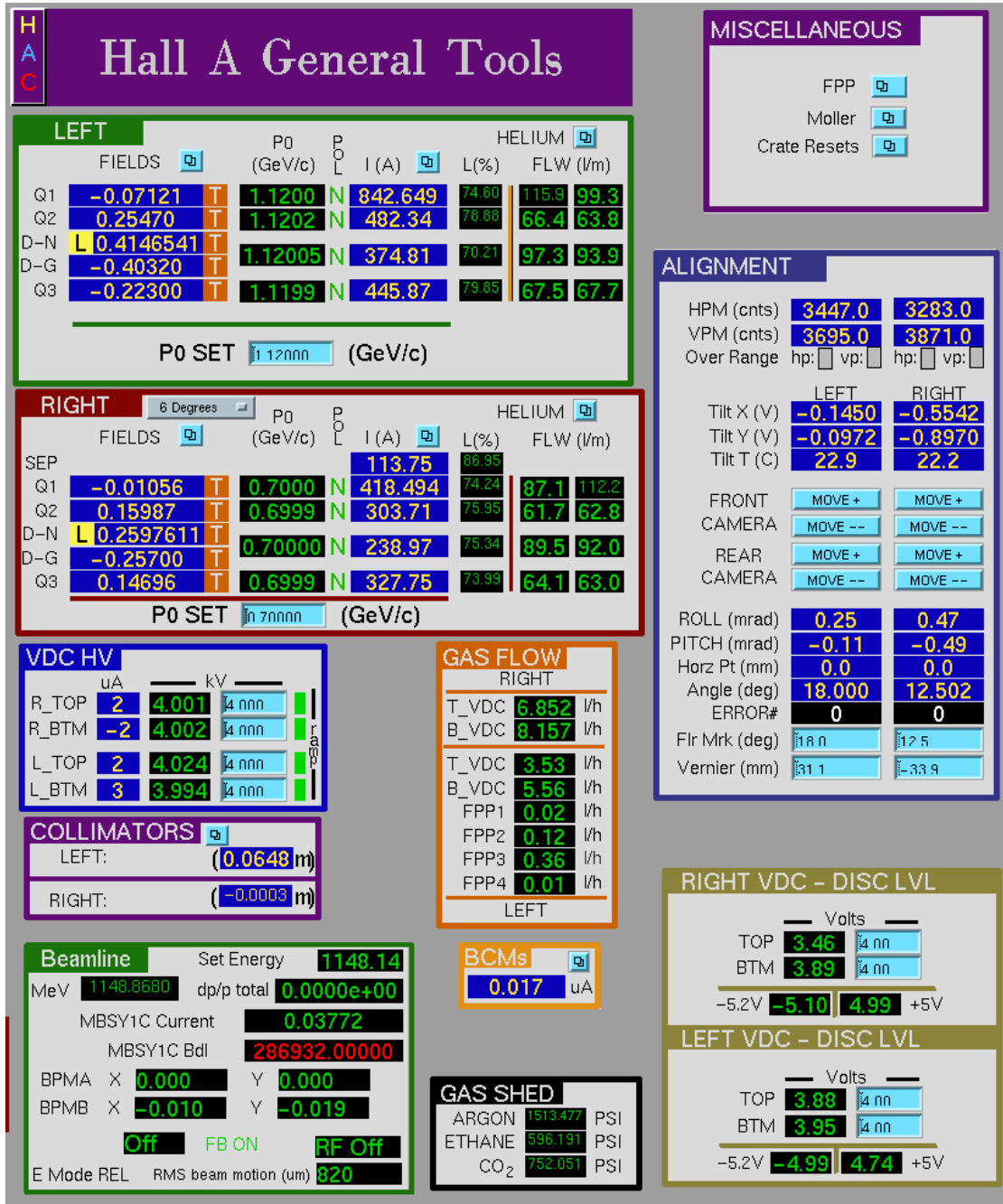


Figure 20.4: Hall A Tools Screen.

Part VII

Data Acquisition and Trigger

Chapter 21

Spectrometer Data Acquisition ¹

The Hall A data acquisition uses CODA [18] (CEBAF Online Data Acquisition), a toolkit developed at Jefferson Lab by the Data Acquisition Group. Up to date information about the Hall A DAQ is kept at ².

We typically run with three fastbus crates in each spectrometer, plus VME crates for scalers and Trigger supervisor. The fastbus modules are of the following types:

1. LeCroy model 1877S TDCs operating in common-stop with 0.5 nsec resolution for our drift chambers and straw chambers;
2. model 1875 TDCs operating in common-start with 0.1 nsec resolution or 0.05 nsec resolution depending on the setup, for our scintillators and trigger timing;
3. model 1881M ADCs for analog signals from scintillators, Cherenkov, and leadglass detectors.

In some run periods the beam position monitors and raster current were available in a VME system, but presently they are read out in fastbus.

The trigger supervisor is a custom-made module built by the data acquisition group. Its functions are to synchronize the readout crates, to administer the deadtime logic of the entire system, and to prescale various trigger inputs. We have two trigger supervisors, one in each spectrometer. This allows us to run the spectrometers independently if needed.

The public account `adaq` is normally used for running DAQ and `a-onl` is used for running other online software including the C++ analyzer Podd. On “`a-onl`” the directory tree of an experiment is `a-onl/$EXPERIMENT` which is organized in subdirectories of various tasks, such as scaler display, Podd, and other online codes, all of which will be described in sections below.

The trigger management software is run from the `atrig` account and is described in the Trigger chapter.

¹Authors: R.Michaels rom@jlab.org

²http://halloweb.jlab.org/equipment/daq/daq_trig.html

21.1 General Computer Information

In the counting room we have various computers for DAQ, analysis, and controls. The controls subnet is the responsibility of J. Gomez and is documented in another chapter. The DAQ computer's names are denoted by **adaqN**, where N is a number. **adaq1** and **l2** are Linux computers for running DAQ while **adaq3,4...** and higher are for analysis. A new computer has been installed and will be used for the Left HRS DAQ it is named **adaq1** we plan to have **adaq2** installed for Right HRS soon. The Linux PCs are administered mostly by Ole Hansen.

To reboot the Linux machines, first hit **Ctrl-Alt-F1** to switch to a text console, then hit **Ctrl-Alt-Del** to reboot. If power fails for a prolonged time, you must shutdown before the UPS fails.

21.2 DAQ checklist

Things to check before experiment starts

1. blaster test transfer rate
2. BPM cabling
3. BCM cabling
4. timestamp cabling
5. raster cabling
6. check portservers
7. check reset
8. check trigger latch is connected
9. helicity if needed
10. scalers
11. synchronization time stamp

21.3 Beginning of Experiment Checkout

This section describes the checkout of DAQ and trigger needed before an experiment can start.

1. First ensure that all the fastbus, VME, CAMAC, and NIM crates are powered on. They should boot up in a functional state, except for heavily loaded fastbus crates that sometimes lose their NVRAM. (If that happens, see notes in </adaqfs/halla/a-onl/doc/vmeram.doc>).
2. Make sure the HV is on for all detectors and that the values are normal.
3. Start the **xscaler** display following the instructions below and check that the rates from detectors are normal.
4. Startup **runcontrol** (CODA) using the directions below and start a run. With the trigger downloaded and the HV on, you are taking cosmic data, typically at a rate of 3 Hz per spectrometer. Examine the data using ESPACE or the C++ analyzer. Compare the plots and printouts to normal values.

21.4 Running CODA

This section describes how to run CODA for the spectrometer DAQ. There are two modes: (1) The most common is the “1-Trigger-Supervisor (1-TS)” mode which uses one trigger supervisor and is used for coincidence experiments; and (2) The “2-Trigger-Supervisor (2-TS)” mode which is used for running the two spectrometers independently.

The 1-TS mode can also handle single-arm triggers but is about 1/2 the aggregate speed of the 2-TS mode. When running the 2-TS mode, one uses the adaq account on **adaq12** or **adaq1** for one spectrometer and the adev account on **adaq11** or **adaq2** for the other spectrometer. The 1-TS mode normally uses the adaq account on **adaq12** or **adaq1** only. The information that follows refers to the adaq account, but the other account is quite similar.

Here is how to start and stop a run. Normally, when you come on shift, runcontrol will be running. If not, see the section on “Cold Start” below. To start and stop runs, push the buttons “Start Run” and “End Run” in the runcontrol GUI. To change configurations use the “Run Type” button. If you have been running you will first have to push the “Abort” button before you can change the run type. Typically the configurations you want are the following.

TWOSPECT – For running the two spectrometers in 1-TS mode.

PEDRUN – To do a pedestal run in 1-TS mode

RIGHTHRS – For R-arm in 2-TS mode

LEFTHRS – For L-arm in 2-TS mode

PEDRUNR – To do a pulser run for R-arm in 2-TS mode

PEDRUNL – To do a pulser run for L-arm in 2-TS mode

A note about pedestal runs. They have the exclusive purpose of obtaining pedestals used for pedestal suppression. For details about what is done and hints for getting pedestals for analysis (which does not want the PEDRUN result), see [/ped/README](#).

21.4.1 Some Frequently Asked Questions about DAQ

- *Q: Where is the data ?* Use a command “find_run 1745” to find where run 1745 has been written on disk and MSS. The data are first written to disks like [/adaql2/dataN](#), N=1,2,3...etc. Files are automatically split if they become bigger than a prescribed limit, the split files have suffixes .0,.1,.2...etc. Files are archived automatically to tape in the MSS tape silo. Two tape copies are made. Data are purged from disk automatically. Users should *never* attempt to copy, move, or erase data.
- *Q: How to adjust prescale factors ?* Edit the file [~/prescale/prescale.dat](#). One common problem is putting typographical errors here which then leads to no triggers getting accepted.
- *Q: What is the deadtime ?* The deadtime is displayed in the datamon window, which normally is running next to the runcontrol window, but if this window is not up, type [datamon](#) to bring it up. This window also shows the full-path-name of the file being written by CODA for the present run.
- *Q: Where are the crates ?* R-HRS has fastbus crates ROC1, ROC2, ROC7 on the lower level of the detector hut, and a 9U (tall) VME crate TS0 on the upper level. L-HRS has fastbus ROC3, ROC4, ROC8 and VME crate TS11.
- *Q: Why is the deadtime so high ? (and related)* Search for answers among the following. The standard lore is that 20% deadtime is tolerable, but you should ask your analysis team to decide. Sometimes people seeing large deadtimes have forgotten to observe that the beam is in pulsed mode. Another possibility is that the workstation is overloaded. The computer used for CODA should not be used for anything else. Do not attempt to read or write rapidly to the same physical disk to which CODA is writing. Sometimes it is observed that the workstation itself is very sluggish. This could be due to a foreign mounted disk having gone away, and there are other possible reasons. If a Cold Start of CODA doesn't solve the problem, you may try rebooting the workstation (see computer section). Also, if the event size changes substantially, e.g. due to VDC or FPP thresholds being turned off (a common mistake), the deadtime as a function of rate will change, especially in the regime of high rates.

21.4.2 Quick Resets

Problems with CODA can usually be solved with a simple reset. If not, try a Cold Start (see next section). Do not waste an hour of beam time on resets; if they fail, call an

expert. The expert claims he can restart CODA 90% of the time within 10 minutes.

If a ROC (ReadOut Controller, or crate) is hung up, reboot by going the workspace “Components” and typing `reboot`. If this doesn’t work, try pressing the reset button which is on the “Crate Resets” section of the Hall A General Tools EPICS [6] Gui. If this still fails for the FastBus crates there is a power cycle relay which can be activated with the EPICS button : Fastbus Power AC. Telnet back into the ROC to verify its alive. If all failed call an expert and most likely an access will be needed. Then press “Reset” in runcontrol, download and start a new run.

21.4.3 Cold Start of CODA

If CODA is not running, or if it gets hung up, you can do a cold start. Frequently a subset of these steps is sufficient to recover from a hangup, but it takes some experience to realize the minimum of steps that are necessary, so the simplest thing is to do them all, which takes a few minutes.

- Make sure the fastbus and VME crates are running. The crates are usually known by “ROCnumber-computer-(portserver-port)” where ROCnumber is the unique number for that ROC (ReadOut Controller, or crate), computer is the internet name and the portserver-port is the portserver IP and port# where to login. An example might be ROC4-hallasfi4-(hatsv4,port3) which is ROC4, a fastbus crate with IP `hallasfi4` attached to the portserver IP `hatsv4` at port 3. You would telnet in with the command “telnet hatsv4 2003”. You can check if the ROCs are up by looking on the Components work space at the telnet session (if it’s not logged, try to telnet in). If the ROCs don’t talk to runcontrol, you can type `reboot` at the arrow prompt (`→`). If you don’t get this arrow prompt, or if you can’t telnet in, the computer is hung up, so press the reset button in the “Crate Resets” GUI available from the EPICS screen for Hall A General Tools. After the ROC comes back (2 minutes), telnet back in to verify it’s up. On rare occasions it is necessary to power cycle the crate, which requires access.
- Start runcontrol and the other necessary processes by typing `startcod`. Note, `startcod` first cleans up old processes for you, so you don’t need to take care of that.
- In runcontrol, press the “Connect” button. Wait 5 seconds and press “Run Types”. After configure and before download, press the “Reset” button in the upper left corner. Choose the run type from the dialog box (see section on Running CODA for descriptions of run types).
- After you configure and download the Run Type, you can “Start Run” to start a new run.

21.4.4 Recovering from a Reboot of Workstation

If the workstation from which you are running CODA was rebooted, here is how to recover DAQ. Login as the relevant account, which is usually a-onl for 1-DAQ operation. Passwords for the online accounts should be available on a paper on the wall in the counting room, or ask the run coordinator. In the workspace for “Components” telnet into all the ROCs. If the x-terms windows are not available, type `setupxterms`. Start emacs for the prescale factors: `emacs /prescale/prescale.dat`. Make sure msqld is running in the process list; it is supposed to start when the computer boots. Then do a Cold Start (see section above).

21.5 Electronic Logbook and Beam Accounting

Two tools are available for logging information by the shift workers: (1) The Electronic Logbook “halog”, and (2) The Hall Beam–Time Accounting Table.

The electronic logbook is a web-based repository of logbook data. There are two ways to make entries: One can use the halog GUI (type `halog` and make your entry), or one may use a script to insert a file. Some data from EPICS and scalers, among other things, are inserted automatically into halog on each start-of-run and each end-of-run. These data also get written into files with the run number in their name in `/epics/runfiles`. Data appear on the web at a certain URL³. It is recommended that one software expert from the experiment be assigned to modify the logging scripts as he or she sees fit.

The Hall Beam–Time Accounting Table is the mechanism to summarize and record how the beam time in a shift was spent. The shift leader is responsible for submitting this table at the end of the shift. When submitted, the data are logged in a database and a summary is e-mailed to various people like the run coordinators and the hall leader. When you come on shift, the GUI is probably already running. If not, you may start it by logging onto `adaql1` as the `adaq` account and type “`bta`”. It is a fairly obvious GUI, but there is also some online help.

21.6 Port Servers

Portservers are devices on the network that allow access to RS232 ports (see Table 21.2). Here is how to connect from a computer: `telnet hatsv5 2011` will connect to the portserver at IP `hatsv5` and port 11. Note, the offset of 2000 is needed. For dealing with HV, it is best to use a Linux PC for which the keymap is F1 = PF1 and F2 = PF2.

If another person is connected to a certain port, you cannot connect. To bump off another user, login as root with password available from the paper posted on the wall of the counting room (or ask run coordinator) as follows `telnet hatsv5` as user = root. At the prompt, type `kill tty=4` to clear port 4, then `exit`. Now you can `telnet hatsv5 2004`.

³<http://www.jlab.org/~adaq/halog/html/logdir.html>

21.7 Authorized Personnel

The authorized personnel is shown in table 21.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Alexandre Camsonne	Hall-A	5064		camsonne@jlab.org	<i>Contact, first on call</i>
Robert Michaels	Hall-A	7410		rom@jlab.org	<i>Contact, second on call</i>
Ole Hansen	Hall-A	7627		ole@jlab.org	Computers

Table 21.1: DAQ: authorized personnel.

server IP	Port	Device
hatsv3	1	vt100 Dumb Terminal
hatsv3	2	ROC1 Lower Fastbus Crate
hatsv3	3	TS0 Trig. Super. VME Crate
hatsv3	4	R-arm Upper HV Crate
hatsv3	5	R-arm Lower HV Crate
hatsv3	8	ROC2 Upper Fastbus Crate
hatsv4	1	vt100 Dumb Terminal
hatsv4	2	ROC3 Lower Fastbus Crate
hatsv4	3	ROC4 Upper Fastbus Crate
hatsv4	5	HV Crate
hatsv4	6	RICH HV Crate
hatsv4	7	RICH VME Crate
hatsv4	14	TS1 Trig. Super. VME Crate
hatsv5	1	vt100 Dumb Terminal
hatsv5	2	e-P Crate 1
hatsv5	3	Moller 1
hatsv5	4	Moller 2
hatsv5	8	Compton ROC3
hatsv5	9	Compton ROC4
hatsv5	10	Compton ROC5
hatsv5	11	Beamline HV
hatsv5	12	e-P Crate 2
hatsv5	13	ARC Energy
hatsv5	14	ROC14 VME Crate
hatsv5	15	ROC15 VME Crate
hatsv12	5	Compton ROC1
hatsv12	6	Compton ROC2
hatsv15	-	2nd Floor Counting Room
hatsv9	4	Parity DAQ Crate

Table 21.2: Port Servers for DAQ

Chapter 22

Trigger Hardware and Software

1

22.1 Overview

Here we give a brief overview of the hall A trigger, including its hardware arrangement, the logic of the trigger, and the usage of the software control. Diagrams of the hardware layout are shown in accompanying figures.

Scintillators make the main trigger in each spectrometer arm. For coincidence experiments a coincidence is formed between the spectrometer arms. The main trigger is formed by requiring that scintillator planes S1 and S2 both fired (and both phototubes of the paddles that got a hit) in a simple overlap. To repeat, the trigger requires that one paddle in S1 and one in S2 both got a hit in both of their PMTs (4 PMTs total). The coincidence between spectrometers is formed in an overlap AND circuit. The Right Spectrometer singles triggers are called T1, the Left Spectrometer triggers are called T3, and the coincidence triggers are T5. Other triggers might be formed which require other detectors to measure the efficiency of the main trigger. The most important is T2 on R-arm and T4 on L-arm, whose definition has changed over time but typically require 2 out of 3 from among the S1, S2, and Cherenkov detectors (i.e. the "or" of S1 is used, etc).

The trigger design is quite flexible and it is relatively easy to add detectors to define new trigger types or to modify existing ones, so long as the detector is fast enough. The trigger supervisor also allows for the possibility of 2nd level triggers which could be used for a later decision.

22.2 Components

The trigger schematics is shown in Fig. 22.1 and 22.2.

¹Authors: R.Michaels rom@jlab.org

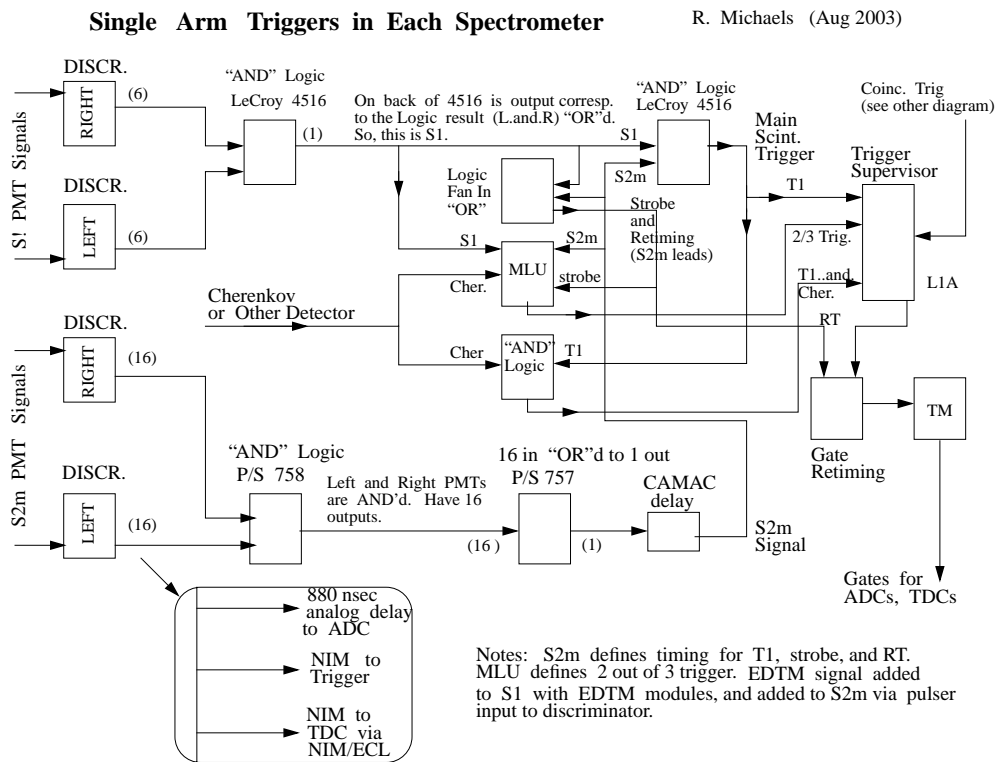


Figure 22.1: Single Arm Trigger Circuit.

Coincidence Trigger
 Electronics on Left Arm

R. Michaels (Aug 2003)

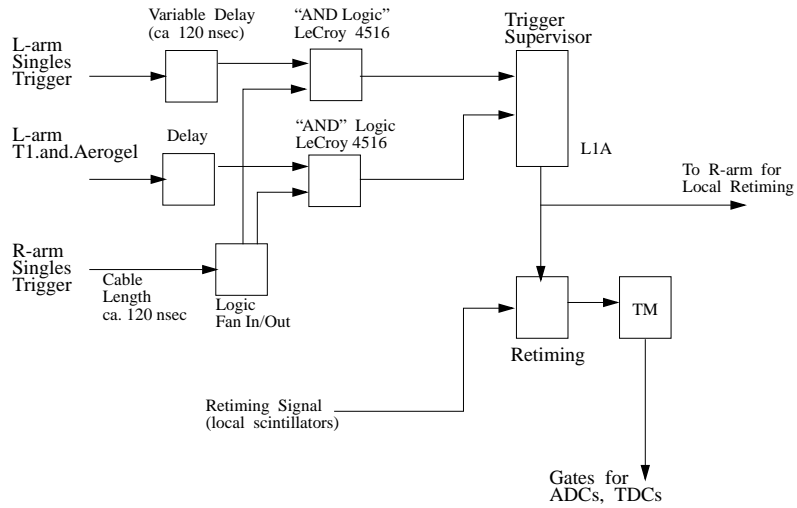


Figure 22.2: Coincidence Trigger Circuit.

Here we describe the software control of the CAMAC modules involved in the trigger. The software control was written by Tim Smith and Jeff Vieregg of MIT with some input from Bob Michaels. There are four types of modules that are controlled:

1. Discriminators;
2. Delay Units;
3. Memory Lookup Units;
4. AND/OR Modules.

Here are the instructions to download the trigger. First login to the ADAQ Linux box `adaql1` or `adaql2` (and no others) as `atrig` account. (E.g. `ssh adaql1 -l atrig`). The Run Coordinator should know the password. Type `trigsetup`. A self-explanatory graphical user interface pops up, where if you are in a coincidence experiment setup you must enter the momenta and particle ID's and then press "Download" and WAIT for it to finish and do not press `Ctrl-C`. However, for single arm running like Spin Duality or GDH, just press "Download" with the defaults, and WAIT for it to finish and do not press `Ctrl-C`. The user should look for suspicious error messages in the window from which `trigsetup` was launched, e.g. to check if connection to the crate is ok.

If individual modules need to be modified for test purposes etc. (e.g. to change thresholds), one may use the expert mode. Login to an ADAQ linux box as explained above, then type `trigsetup mapfile` where `mapfile` is the name of the trigger map file. Some examples of map files are in `/home/atrig/trigger`, see `trigger_left.map` and `trigger_right.map` for the left and right spectrometers respectively. These are default databases. One can modify each module on the fly, save the database, etc.

After you download, a record of what was sent is put into a file `/home/atrig/trigger/trigger.setup` which gets put automatically into the electronics log-book "halog". Also, whenever a CODA run is started, this file is inserted as a special event type 136 at the start of run. This will be the setup IF the download was successful. It is also interesting to know what is actually in CAMAC, but that can only be done in expert mode, and the delays cannot be read from CAMAC. The simplest way to be sure about what is in the trigger is to download again.

22.2.1 Authorized Personnel

The authorized personnel is shown in table 22.1.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Robert Michaels	Hall-A	7410		rom@jlab.org	<i>Contact</i>
Alexandre Camsonne	Hall-A	5064		camsonne@jlab.org	

Table 22.1: Trigger: authorized personnel.

Chapter 23

Online Analysis, Data Checks

¹

The following tools are available for checking data online.

23.0.2 Scaler Display and Scaler Events

Scaler rates and values are displayed using a ROOT based display called `xscaler`.

Normally this is already running on `adaq4` but if it is not running, login as `adaq` and go to the appropriate directory by typing “`goxscaler`”. Then type `./xscaler` there. The scalers are cleared at the beginning of each CODA run. Scalers are read out at approximately 0.5 Hz and injected into the CODA data-stream as event type 140. A file `scaler_history.dat` is maintained which is a complete history of scaler readings at the end of each run that ended normally. For 1-TS mode, this file is in `/adaqfs/halla/adaq/scaler`.

23.1 Analysis using C++ Analyzer

Podd is the main offline software package for analyzing Hall A experiments. This code is documented in a separate chapter but it is worth mentioning here in a list of essential tools for checking data online.

23.1.1 Responsible Personnel

The responsible personnel is shown in table 23.1.

¹Authors: R.Michaels rom@jlab.org A.Camsonne camsonne@jlab.org

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Ole Hansen	Hall-A	7627		ole@jlab.org	<i>Contact</i>
Robert Michaels	Hall-A	7410		rom@jlab.org	
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Table 23.1: Online analysis: authorized personnel.

Part VIII

Offline Analysis Software

Chapter 24

Podd (C++ Analyzer) ¹

The standard offline analysis software for Hall A data is “Podd” (a.k.a. the “C++ Analyzer”), an object-oriented C++ class package developed at Jefferson Lab by Hall A staff. Podd is based on the ROOT [27] programming framework, developed at CERN. All of ROOT’s analysis and visualization tools are available from within Podd, plus specialized classes for Hall A physics analysis. The current version of the Podd is 1.5.24. Detailed information about the software (downloads, documentation, etc.) can be found at

<http://hallaweb.jlab.org/podd/>.

Podd is modular and easily extensible. Individual analysis components are designed as plug-in modules that can be loaded dynamically from an analysis script or otherwise as needed. As a result, the scope of the data analysis is largely user-configurable. Only data from those spectrometers and detectors is analyzed, and only those physics calculations are carried out, that the user specifies. Configuration can occur at run time without any need for recompilation of the program.

Currently supported are the analysis of the Hall A HRS spectrometers, the beamline instrumentation, scaler and EPICS [6] slow control data, and beam helicity information. The event decoder is compatible with the CODA [18] event data format described in the section on Data Acquisition. Decoding of basic helicity information as well as a sophisticated algorithm for decoding and prediction of the G0 helicity sequence is possible. The following detectors can be used in either HRS spectrometer:

- Vertical Drift Chambers (VDCs)
- Scintillators (one or more paddles with up to two PMTs each)
- Cherenkov counters (arbitrary number of PMTs/mirrors, usable for both gas Cherenkovs and aerogels in each HRS)
- Shower counters (shower, preshower, pion rejectors with arbitrary organization in terms of rows and columns of blocks)
- Total shower counter (combination of a preshower and shower)

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The VDC code performs tracking in the focal plane and reconstruction to the target. The tracking algorithm has been shown to be accurate for events with one cluster per plane. Noisy events with higher cluster multiplicity and events with more than one good track in the focal plane may not be reconstructed correctly by the present version of the code, but work is in progress to make this type of analysis also reliable.

The scintillator, Cherenkov, and shower counter classes perform basic decoding, calibration (offset/pedestal subtraction, gain multiplication), and summing (for Cherenkovs) or cluster-finding (for showers) of hits. The cluster-finding algorithm of the shower class is basic and currently only capable of finding a single cluster per event. These classes are largely generic and should be able to accommodate most new detectors of the respective type, even with a different geometry and number of channels.

Several beamline apparatuses are available: a dummy beam (always at zero position and angle), an “unrastered” beam, and a “rastered” beam. BPM and raster detectors are implemented and can be analyzed to obtain the beam position on an event-by-event basis. The BPM code currently only supports standard ADCs (e.g. LeCroy), not the older Struck readout.

Plug-in libraries have been developed by users for the following equipment: the Big-Bite spectrometer (in several configurations), the neutron detector of the G_E^m experiment (E02-013), the focal-plane polarimeter (FPP) and the ring-imaging Cherenkov counter (RICH), which are optional detectors for the HRS, and the DVCS photon detector. Most of these libraries are available from the Podd web page cited above.

To carry out standard post-reconstruction calculations, the following so-called physics modules are available:

- Single-arm electron kinematics (Q^2 , ω etc.)
- Coincidence kinematics (missing energy etc.)
- Deuteron photodisintegration kinematics
- Single-arm elastic scattering kinematics from detected recoil particle
- Coincidence time
- Reaction point (vertex position) reconstruction
- Extended target tracking corrections for the HRS
- Energy loss corrections

There is no limit (other than machine resources) to the number of physics modules that can be configured for an analysis run. Identical modules can be added multiple times with different parameters. For example, one can calculate “electron kinematics” using both uncorrected and energy-loss corrected tracks in one analysis pass without modifying or recompiling any code. For experiments requiring specialized calculations of kinematics or any other quantities, writing a new physics module is the preferred approach.

The results of calculations performed by the various analysis modules (spectrometers, detectors, physics modules) are made available via so-called global variables. Global variables provide access to data via names (text strings). Scalars as well as fixed and

variable-size arrays are supported. The global variable names are used in the definition of the analysis output and of logicals.

Tests and cuts (“logicals”) can be defined dynamically at run time. They can be used for controlling the analysis flow, keeping statistics, pre-computing logical values to be included in the output, or applying cuts to histograms written to the output. If certain tests fail for a given event, further analysis of that event can be skipped, and the event is not written out. Such tests can be put at the end of all the major stages of the analysis. This allows making decisions about an event early in the analysis, improving performance. A summary of all test results is written to a file at the end of the analysis.

Data of interest can be histogrammed and/or written to a ROOT Tree in the output file. The contents of the output is defined dynamically at the beginning of the analysis. Both 1- and 2-dimensional histograms are supported. Histograms can be filled selectively using logical expressions (cuts).

Table 24.1 lists the analysis modules available in version 1.5.24 of Podd.

24.1 Running Podd

Precompiled binaries of the latest version of the Podd are installed on the Hall A counting house analysis machines (adaql1–10). To run Podd, log into any standard account on these computers, for example as `adaq`, and type

`analyzer`

As installed, Podd uses the default database in the location pointed to by the environment variable `DB_DIR`. The Hall A staff makes an effort to keep this database reasonably up-to-date for completed experiments. If you wish to analyze older data, the default database might work for you. However, if you wish to use a customized set of database files specific to your experiment (usually the case for the current experiment), you will need to re-define `DB_DIR` to point to the location of that database before starting the Podd. For details on the database, see Section 24.3.

The pre-installed Podd may not work if the `PATH` and/or `LD_LIBRARY_PATH` variables have been changed from the system defaults. If this is the case, you should correct the login script(s) of the problematic account. To restore the system defaults, you may execute one of the following commands:

```
For csh/tcsh shells:    source /adaqfs/apps/env/login.adaq
For bash shells:       source /adaqfs/apps/env/profile.adaq
```

If Podd is to be used outside of the Hall A counting house environment, it is currently necessary to build the program from source. A `tar` archive of the sources can be obtained from the following location

<http://hallaweb.jlab.org/podd/download>.

Class name	Description
Apparatuses	
THaHRS	HRS spectrometer (left or right) with VDC (“vdc”) and two scintillator planes (“s1”, “s2”).
THaIdealBeam	Dummy beam with zero position and angle.
THaRasteredBeam	Beam with raster
THaUnrasteredBeam	Beam without raster (for calibration)
THaDecData	Miscellaneous decoder raw data
Detectors	
THaVDC	VDC package for HRS
THaScintillator	generic scintillator
THaCherenkov	generic Cherenkov (gas or aerogel)
THaShower	generic shower counter
THaTotalShower	combination of preshower and shower
THaBPM	beam position monitor with standard ADCs
THaRaster	beam raster system
THaHelicity	beam helicity information (in-time or delayed)
Physics Modules	
THaReactionPoint	vertex position (intersection of spectrometer track with beam)
THaTwoarmVertex	vertex position (intersection of two spectrometer tracks)
THaAvgVertex	vertex position (average of reaction points from two spectrometers)
THaElectronKine	single-arm electron kinematics
THaPrimaryKine	single-arm kinematics for particle with arbitrary mass
THaSecondaryKine	coincidence kinematics
THaPhotoReaction	deuteron photodisintegration kinematics
THaSAProtonEP	elastic $A(e, A)e'$ kinematics from detected A
THaExtTarCor	extended target corrections
THaCoincTime	coincidence time calculation
THaS2CoincTime	coincidence time using S2 scintillator in HRS
THaGoldenTrack	selects Golden Track from multiple reconstructed tracks
THaDebugModule	prints values of global variables for each event and waits

Table 24.1: Analysis modules available in version 1.5.24 of Podd

24.2 Preparing Analysis of a New Experiment

Setting up offline analysis for a new experiment typically involves the following steps:

1. Determine the experimental configuration (spectrometers, detectors, beamline) to be analyzed and identify the corresponding analysis modules.
2. Create a database for the new experiment, using the start date of the data taking as the time-stamp for new new entries (see Section 24.3). At the minimum the database should contain up-to-date detector map entries for every detector and rough starting values for the spectrometer reconstruction matrix elements and VDC timing offsets. Often this information can be carried over from a previous experiment with only minor modifications. Also, enter any other calibrations and geometry data that are available, even if approximate.
3. In the database, create initial run database values. These are typically the starting beam energy and spectrometer momentum and angle settings. If the experiment is already completed, extract the history of these settings from logs and enter them into the database. These values affect the kinematics calculations; they are not important for detector checkout.
4. Determine which physics calculations are needed for the offline analysis and identify corresponding Physics Modules.
5. Identify desired output histograms and tree variables. Create an output definition file. The file `$ANALYZER/examples/output_example.def` contains most of the necessary documentation.
6. If desired, create a definition file for logicals. An example generating detailed VDC statistics is given in `$ANALYZER/examples/cuts_example.def`.
7. Write a CINT² script that sets up the configuration identified in Step 1 and the physics analysis decided on in Step 4. Often, a script from a previous experiment, or one of the examples in the directory `$ANALYZER/examples`, can serve as a guide. The script usually also locates raw data files, creates one or more `THaRun` objects, configures various options of the event loop object `THaAnalyzer`, and starts the replay. In particular, the names of the output file, the output definition file, and the logicals definition file must be given to `THaAnalyzer`.
8. Identify the plots that you wish to generate from the analysis results and write a script to create them. This may be part of the script created in the previous step. Note that there is no need to quit Podd and start a new session or another program after completion of the analysis; all of ROOT's visualization tools are available from within Podd.

²CINT is a C/C++ interpreter that acts as the interactive interface to ROOT and Podd.

24.3 Database Files and Directories

Version 1.5.24 of Podd uses simple ASCII text files to store database information. There is usually one file for each analysis module. The name of each file is composed as follows:

`db_apparatusname.detectorname.dat`

For example, a Cherenkov detector named “a1” which is part of the Left HRS spectrometer, named “L”, would be associated with a database file named `db_L.a1.dat`.

The “run database”, which contains global run-specific parameters such as beam energy and spectrometer momentum and angle settings, is stored in a special file named `db.run.dat`.

All of the above database files should be stored in a location that can be modified by the user, for instance in `~/DB`. **The environment variable `DB_DIR` must be defined to point to this top-level database directory.** Since database parameters change with time, database files are organized in time-dependent subdirectories within `$DB_DIR`. The name of each subdirectory has the form `YYYYMMDD`, where `YYYY`, `MM` and `DD` represent the year, month, and day, resp., of the date that is the start of the validity of the entries. Upon initialization, Podd locates the most appropriate time-dependent subdirectory based on the contents of `$DB_DIR` and the time-stamp of the run to be replayed. Often there is only one time-dependent subdirectory per experiment, but if significant changes occur during an experiment, it may be appropriate to create several directories. A finer division of time-dependent information can be provided by timestamps within each database file. This is especially true for the run database file which frequently will have many time-stamped sections.

For example, an experiment running in April and May of 2004 would create a database subdirectory `~/DB/20040401` and set `DB_DIR=~/DB`. Other files supporting the replay of this experiment would reside in an experiment-specific directory, usually `$EXPERIMENT`.

24.4 Program Design Overview

Spectrometers (and similar major installations) are abstracted in an Apparatus class hierarchy, while individual detectors belong to a Detector class hierarchy. Apparatuses are collections of detectors that are analyzed in a particular way. Specialized physics analysis, such as kinematics calculations, vertex determination, and energy loss corrections, can be done in Physics Modules. All three types of objects, Apparatuses, Detectors, and Physics Modules, are kept in lists that are processed during replay. In setting up the replay, it is up to the user which objects to place in the lists.

Both the Apparatus and the Detector class hierarchies, as well as the Physics Modules, inherit from a common base class, `THaAnalysisObject`. Physics Modules currently do not use a particular class hierarchy; all physics modules inherit from `THaPhysicsModule`, which in turn inherits from `THaAnalysisObject`.

The behavior of existing analysis modules can be modified or extended easily by using class inheritance. In such a case, the only code that needs to be written is the implementation of the new feature. For example, the standard Cherenkov detector class currently only calculates the total sum of ADC amplitudes. For a new type of Cherenkov counter, or to do a more sophisticated analysis of the standard Cherenkov detectors, one might want to calculate separate ADC sums for certain groups of PMTs. To do so, one would write a new class inheriting from the standard Cherenkov class, which could contain as little as one function, performing the additional calculations, and the corresponding data members. New types of detectors and even entire spectrometers, as well as new types of physics calculations, can be added similarly easily, again using class inheritance. No change to and no rebuilding of the core program is necessary to support such new modules.

24.4.1 Responsible Personnel

The responsible personnel shown in table 24.2.

Name (first,last)	Dept.	Call [12]		e-mail	Comment
		Tel	Pager		
Ole Hansen	Hall-A	7627		ole@jlab.org	<i>Contact</i>
Robert Michaels	Hall-A	7410		rom@jlab.org	
Alexandre Camsonne	Hall-A	5064		camsonne@jlab.org	

Table 24.2: Offline analysis: authorized personnel.

Part IX

BigBite Spectrometer

Chapter 25

BigBite Magnet ¹

25.1 Overview

The BigBite magnet, the key component to several Hall A approved experiments, was commissioned to 550 A under TOSP PHY-04-014 and subsequently to 800 A under TOSP PHY-05-015. The purpose of this document is to describe the hazards and safety procedures for operating this magnet. These procedures include running the magnet during an experiment and making field measurements. The BigBox power supply being used with BigBite was commissioned during Hall A experiment E99-114 (TSOP PHY-02-003) and this document presents the same procedures for safely operating the supply. This BigBite dipole magnet document is an update to the expired OSP PHY-05-001 and OSP PHY-08-002. under which the BigBite dipole was run for the past several years. This document does not attempt to describe the function or operation of the dipole or power supply.

25.2 Description of Magnet

Hall A BigBite experiments will make use of a large-acceptance dipole magnet to deflect charged particles into the various BigBite detector packages. The BigBox power supply will be used to energize this magnet. The power supply has previously been tested and was successfully used during the Hall A RCS experiment (E99-114). The control software of the supply runs from the HAC computer with the BigBox GUI. The first BigBite experiment (E01-015) ran the magnet at an excitation of 0.92 T which required 518 A with the maximum current limited to 550 A. Subsequently, after the successful completion of a high current commissioning under TOSP PHY-05-015, the limited was raised to 800 A.

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25.3 Authority and Responsibility

25.3.1 BigBox Power Supply

Only authorized personnel may enable the power supply as per the operating guidelines described in Section 25.7.1. To become authorized one must:

- Read and understand this document.
- Read and understand Chapter 6440 of the Jefferson Lab EH&S Manual on Static Magnet Fields.
- Complete JLab Lock and Tag Training (SAF104)
- Complete NFPA-70E Electrical Safety Training (SAF603)
- Complete training on power supply operation by authorized Hall A technical staff.
- Obtain an authorizing signature from the BigBite contact person, Douglas Higinbotham, on the attached signature sheet.

25.3.2 Energizing the BigBite Magnet

Once the BigBox power supply has been enabled, the BigBite magnet can either be controlled locally or with the BigBox GUI. Shift workers will only be allowed to control the magnet via the BigBox GUI and only after they have read and signed the COO of the experiment for which they are taking shift. One shall immediately turn off the magnet via the BigBox GUI or locally at the BigBox supply if someone unauthorized and/or unknown is seen entering the magnet area or any hazard, e.g. leaking low conductivity water, is identified.

25.3.3 Magnetic Field Measurements

With the written permission of the Hall A work coordinator, physics users may make field measurements of the area around the magnet. The guidelines for safely performing these measurements can be found in Section 25.7.3. During these measurements, the current to the magnet may be changed using the BigBox GUI. Once the measurements have been completed, authorized personnel secure the system as per Section 25.7.4.

25.4 Location of Equipment

All required equipment is located in Hall A. During operation, the BigBite magnet will be located near the pivot area and the BigBox power supply is located near the Hall A control racks.

25.5 Hazard Analysis

The hazards associated with the magnet and power supply are electrical, magnetic, and fire.

Electrical: The power supply has a maximum output current of 1050 A at a voltage of 250 V and thus presents a potentially lethal hazard. A hazard also arises from the power bus on the magnet itself.

Magnetic: The magnet produces a central field of 0.92 T at 518 A. As the magnet has a return yoke and a front field clamp, the external field is much smaller than the central field. Although the magnetic field is primarily confined to the magnet gap, fringe fields are strong enough to accelerate unsecured metal objects in the vicinity of the magnet. In addition these fields may present a particularly large hazard to individuals using a pacemaker. An additional hazard arises due to the close proximity of the magnet to the target area where an unsecured metal object could destroy the scattering chamber.

Fire: There exists a potential fire hazard with high current power supplies.

25.6 Hazard Mitigation

Electrical: Access to the power supply or magnet can only be made after following “Lockout/Tagout Procedures” as described in Chapter 6110 of the Jefferson Lab EH&S manual and the *Hall A power supply test and maintenance* safety procedure. When working on the power supply, the responsible people will follow the guidelines in the electrical safety chapter of the EH&S manual. Before being energized, the magnet’s exposed current bus must be covered to mitigate the shock hazard. The power supply bus must be covered and all doors secured. Also, to keep the current of the BigBite magnet within operational limits, the over-current circuit in the BigBox power supply should be set to no more than 800 A.

Magnetic: The possible presence of high magnetic fields will be indicated by standard Jefferson Lab signs and by a flashing beacon. The area surrounding the magnet will be roped off whenever it is possible that the magnet will be energized. The ropes will be at a distance from the magnet such that the fringe fields are less than 500 μT (5 G) at the maximum allowed current of 800 A. This should be roughly one meter, but should be checked as soon as possible once the magnet has been energized. Personnel with ferromagnetic implants and those wearing electronic medical devices are not allowed inside the roped off area. Due to the large magnet gap size, personnel working inside the roped-off area should be aware of the possible presence of a magnetic fringe field, as well as a high field in the magnet gap.

Fire: The magnet coils are protected from over-heating by Klixon devices installed on the magnet and interlocked to the power supply that will shut off the power supply in case of the coil over-heating.

25.7 Operating Guidelines

25.7.1 Testing the BigBite Magnet After Installation

Once the BigBite magnet has been installed and connected to the BigBox power supply, it should be tested to ensure that it is working properly.

- At least two qualified persons must be working on the task together.
- Rope off the area around the magnet.
- Install protective covers as needed over the target windows and the spectrometer sieve slit. Check with the Hall A work coordinator to ensure proper covers are used.
- Sweep the area inside the ropes for magnetic material. Make sure that the area is clean, and that no foreign objects are in or near the aperture of the magnet or the inside of the stay-clear zone. All such materials must be removed and placed outside of the ropes.
- Make sure all protective barricades, signs and beacons are in place to warn of possible exposure to magnetic and electrical hazards.
- Verify all covers on energized conductors on the magnet are securely in place.
- Verify all power supply doors and cabinets are closed and locked.
- Check that the cooling water is turned on. Valves on the magnet and on individual cooling paths must all be open.
- Verify that water flow is present. The flow switches on the supply and return lines must be open and the the supply pressure must be verified to be 50 psi greater than the return pressure.
- Turn on the flashing beacons.
- Remove the administrative lock on the power supply disconnect switch. Make sure the Jefferson Lab's Lockout/Tagout procedures, as described in Chapter 6110 of the Jefferson Lab EH&S manual are followed. Make sure your Lockout/Tagout training is up-to-date, you have been trained on the operation of the power supply and magnet and that you have been authorized by Douglas Higinbotham.
- Enable main power on the power supply and ramp output current at the rate of approximately 10 A per second to 50 A. Check that all controls and safety features are operational then continue to ramp at the rate of 10 A per second to the maximum current.
- Enter record of the successful test into a Hall A electronic log book.

25.7.2 Enabling the BigBite Magnet For Physics

- At least two persons must be working on the task together.
- Rope off the area around the magnet.
- Sweep the area inside the ropes for magnetic material. Make sure that the area is clean, and that no foreign objects are in or near the aperture of the magnet or the inside of the stay-clear zone. All such materials must be removed and placed outside of the ropes.
- Make sure all protective barricades, signs and beacons are in place to warn of possible exposure to magnetic and electrical hazards.
- Verify all covers on energized conductors on the magnet are securely in place.
- Verify all power supply doors and cabinets are closed and locked.
- Check that the cooling water is turned on. Valves on the magnet and on individual cooling paths must all be open.
- Verify that water flow is present — checking that the differential pressure is greater than 50 psi and look at flow switches (inlet pressure should be greater than 100 psi).
- Turn on the flashing beacons.
- Remove the administrative lock on the power supply disconnect switch. Make sure the Jefferson Lab’s Lockout/Tagout procedures, as described in Chapter 6110 of the Jefferson Lab EH&S manual are followed. Make sure your Lockout/Tagout training is up-to-date, you have been trained on the operation of the power supply and magnet and that you have been authorized by Douglas Higinbotham.
- Enable main power on the power supply and check the current can be set with the BigBox GUI by ramping the magnet to 50 A.
- Set the magnet to 0 A and submit a electronic log entry that magnet is ready and that Hall A shift workers now can control the magnet via the BigBox GUI.

25.7.3 Magnetic Field Measurements

With the Hall A work coordinator’s written authorization, a map of the magnet’s fringe field can be made. During magnetic field measurements, the covers should be on the scattering chamber. All work in the vicinity of the magnet must conform to the practice described in Chapter 6440 of the Jefferson Lab EH&S manual. In particular all workers must respect the limits shown in the table “exposure limits for static magnetic fields” of that chapter and reproduced below.

Ferromagnetic implant and electronic medical device wearers	Routine 8 Hour Average Routine Exposure Not Recommended	Maximum Allowable 0.5 mT (5 G) or as determined by a physician
Regular Employees	Whole Body: 60 mT (600 G) Limbs: 600 mT (6000 G)	Whole Body: 2 T (20,000 G) Limbs: 5 T (50,000 G)

The first field measurements should be made around the 1 meter perimeter to make sure the fringe is less than 5 G at this location. Measurements closer to the magnet and in the gap of the magnet can be made as long as the limits in the table are adhered to and a description of the planned measurement points has been presented to Douglas Higinbotham for approval. A hand-held Lake Shore field measurement device is available from Douglas Higinbotham for establishing the 5 G perimeter and making measurements to 0.1 G precision.

25.7.4 Turning Off The BigBox Supply

The magnet power supply should always be locked out when the magnet is not going to be used for any extended period.

- Ramp output current to zero and turn off main power at the power supply.
- Apply the administrative lock to the power supply.
- Turn off the flashing beacons.

25.7.5 Before Moving BigBite

Before moving the BigBite magnet (e.g. changing the angle of the spectrometer which must be done locally), the power supply must be turned off as per Section [25.7.4](#).

25.8 Authorized Personnel

Only Hall A technical staff are authorized to enable the main power supply and require proper electrical safety training. Shift workers are only allowed to control the BigBite power supply via a GUI.

Chapter 26

BigBite Rotation ¹

26.1 Overview

The BigBite system is rotated using either a hand operated or an electric wench. Rotation can only be done locally and needs to be done only after careful inspection that the nothing will be pulled or damaged by the rotation. This included not only the cables attached to BigBite, but also items around BigBite or that may have inadvertently been attached to BigBite. Care most also be taken to move the hundreds of cables that are connected between BigBite and the DAQ.

26.2 Location of Equipment

All required equipment is located in Hall A. During operation, the BigBite magnet will be located near the pivot area and the BigBox power supply is located near the Hall A control racks.

26.3 Hazard Analysis

The hazards associated with the rotation of BigBite include:

Hands During rotation, hands and/or figures could get caught in the wench chain.

Collisions During a rotation, it is possible for BigBite to collide with other items in the Hall. Along with collisions, items can also be pulled by BigBite.

DAQ Cables: There are several hundred cables that go between BigBite and the DAQ. These can easily be damaged during a BigBite rotation.

Electrical: The power supply has a maximum output current of 1050 A at a voltage of 250 V and thus presents a potentially lethal hazard. A hazard also arises from the power bus on the magnet itself.

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Magnetic: The magnet produces a central field of 0.92 T at 518 A. As the magnet has a return yoke and a front field clamp, the external field is much smaller than the central field. Although the magnetic field is primarily confined to the magnet gap, fringe fields are strong enough to accelerate unsecured metal objects in the vicinity of the magnet. In addition these fields may present a particularly large hazard to individuals using a pacemaker.

26.4 Hazard Mitigation

Hands During rotation, the operator of the wench shall keep their hands away from the wench during operation. The electric wench that we use has a several foot control cord on it, so one does not need to have their hands near the wench during operation.

Collisions

To avoid collisions of BigBite with other equipment, careful inspection much be made of the area. In particular, one needs to out only watch-out for items that BigBite it moving toward, but also check for items being pulled. In particular, watch out for items that may have inadvertently been attached to BigBite. Fig. 26.1 shows a real world example of a rope having been placed between BigBite and a pipe and not being found before a rotation.

Electrical: The BigBite magnet should be de-energized during rotations and workers should be mindful to watch that no cables are being damaged by the rotation. No one should be near the magnet's power bus during a rotation.

DAQ Cables: There are several hundred cables that go between BigBite and the DAQ. These need to be moved along with BigBite by hand and people need to take care that they are not damaged during the rotation.

Magnetic: The BigBite magnet should be de-energized during rotations.

26.5 Operating Guidelines

- At least two qualified persons must be working on the task together.
- Check area for any potential collisions or attachments.
- One person should be helping to move BigBite cables while the other is operating the wench.
- Enter record of the rotation into the Hall A electronic log book.

26.6 Authority and Responsibility

The wench may be operated by the Hall A technical staff and people who have been train by the staff on the use of the wench. Anyone who has completed the Hall A safety walk-through may act as an observer and help move the BigBite cables along.

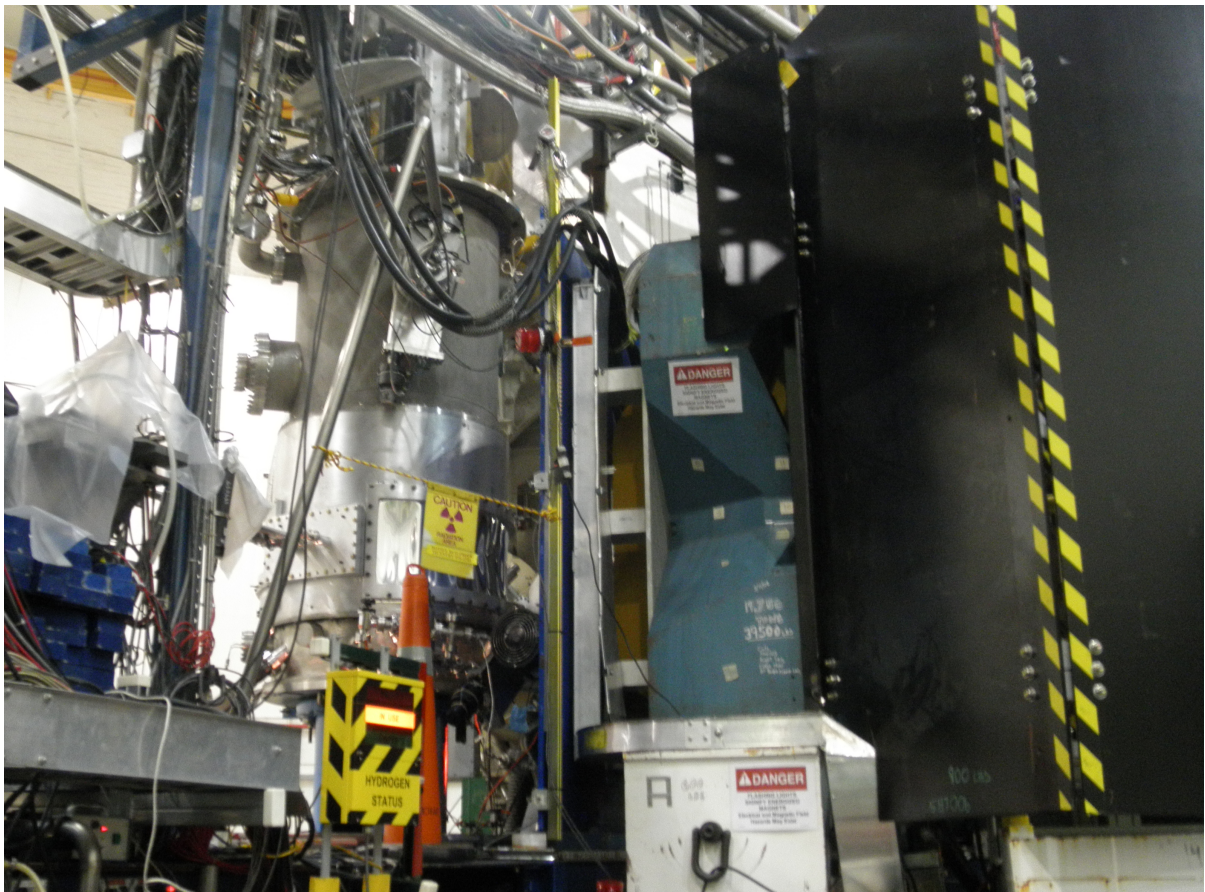


Figure 26.1: Photo of damage caused by failure to find a rope that had been attached between BigBite and a pipe.

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