Hall A Møller Polarimeter

1 Purpose and Layout

The Hall A polarimeter is used to measure the polarization of the beam being delivered to Hall A.\textsuperscript{1} This document provides an overview of the instrument and its operation as well as making the operators of this instrument aware of the hazards that this device presents. The system consists of (see Fig.1),

• A magnetized ferromagnetic foil placed in the beam path. The foil acts as a polarized electron target and it can be selected from a set of four different foils. A pair of Helmholtz coils ($\sim 0.03T$) magnetizes the in-beam foil. The foils are located 17.5 m upstream from the nominal pivot point of the Hall A High Resolution Spectrometers.

• A magnetic spectrometer system consisting of four quadrupole magnets and a dipole magnet. The spectrometer focuses the electrons scattered in a particular kinematic range onto the Møller detector package.

• A detector package and its associated shielding house.

• Two stand-alone data acquisition systems.

• An off-line analysis software package to extract the beam polarization. Roughly, the beam polarization is calculated by taking the difference in the counting rates of two different beam helicity samples.

2 Principles of Operation

The cross-section (\(\sigma\)) for Møller scattering \(e^- + e^- \rightarrow e^- + e^-\) depends on the beam and target polarizations \(p^{beam}\) and \(p^{target}\) as:

\[
\sigma \propto 1 + \sum_{i=X,Y,Z} (A_{ii} \cdot p_{i}^{targ} \cdot p_{i}^{beam})
\]

where \(i = X, Y, Z\) defines the projections of the polarizations. The analyzing powers \(A_{ii}\) depend on the scattering angle in the Center-of-Mass (CM) frame \(\theta_{CM}\). Assuming that the beam direction is along the Z-axis and that the scattering happens in the ZX plane of a right-handed Cartesian reference frame, then:

\[
A_{ZZ} = -\frac{\sin^2 \theta_{CM} \cdot (7 + \cos^2 \theta_{CM})}{(3 + \cos^2 \theta_{CM})^2},
\]

\textsuperscript{1}(Home page: http://hallaweb.jlab.org/equipment/moller/)
$A_{XX} = -\frac{\sin^4 \theta_{CM}}{(3 + \cos^2 \theta_{CM})^2},$

$A_{YY} = -A_{XX}$

$A_{ZZ}$ is called the longitudinal analyzing power while $A_{XX}$ and $A_{YY}$ are referred to as the transverse analyzing powers. The analyzing powers do not depend on the beam energy and they reach their maximum values when $\theta_{CM} = 90^\circ$,

$A_{ZZ}^{\text{max}} = 7/9,$

$A_{XX}^{\text{max}} = A_{YY}^{\text{max}} = A_{ZZ}^{\text{max}}/7$

The main purpose of the polarimeter is to measure the longitudinal component of the beam po-
polarization. The Møller polarimeter of Hall A detects pairs of scattered electrons in a range of $75^\circ < \theta_{CM} < 105^\circ$ with an average analyzing power of about $< A_{ZZ} > = 0.76$.

The target consists of a thin magnetically saturated ferromagnetic foil. In such a material, about 2 electrons per atom can be polarized yielding an average electron polarization of about 8% for the foil. The foil is magnetized ($\mathcal{P}_{foil}$) along its surface and it makes an angle $\theta_{targ}$ of 20° with the beam in the vertical plane (see Fig. 3 and Chapter 3.2). The effective target polarization ($\mathcal{P}_{target}$) is,

$$\mathcal{P}_{target} = \mathcal{P}_{foil} \cdot \cos \theta_{targ}$$

$\mathcal{P}_{foil}$ is determined from special magnetization measurements of the foil samples.

The scattered electron pairs pass through a magnetic spectrometer which selects particles in a particular kinematic region. Two electrons are detected with a two-arm detector system and the coincidence counting rate of the two arms is measured. The beam longitudinal polarization is then calculated as:

$$\mathcal{P}_Z^{beam} = \frac{N_+ - N_-}{N_+ + N_-} \cdot \frac{1}{\mathcal{P}_{target} \cdot < A_{ZZ} >}$$

where $N_+$ and $N_-$ are the measured counting rates with two opposite mutual orientation of the beam and target polarizations, while $< A_{ZZ} >$ is obtained using Monte-Carlo calculation of the Møller spectrometer acceptance.

3 Description of Components

3.1 Polarimeter Control

Control of the Møller polarimeter is divided into two separate sections,

- The operators in the Machine Control Center (MCC) have sole control over target motion and currents settings of the quadrupoles & dipole that make up the magnetic spectrometer of the polarimeter. To access the Graphical User Interface (GUI) screens used for control of the polarimeter,
  - Launch NewTools application located in any of the Hall A control computers.
  - Select EDM (OPS) - it opens a new window labeled Accelerator Main Menu
  - On the new screen, the left-button under the “Hall A” brings-up a drop-down menu. Select Hall A Møller Polarimeter Control. Fig. 2 shows the final screen.

- The user has control over target polarization. See section 3.2.
Figure 2: The Møller MEDM MCC control screen.
3.2 Polarized Electron Target

The Møller Polarized Electron Target is located on the beam line 17.5 m upstream of the main Hall A physics target. The target consists of:

- A sliding rail which contains 5 ferromagnetic foils, stretched at 20° to the beam in the vertical plane. The rail can move the target foils across the beam in two projections.
- An air-core magnet consisting of two coils coaxial with the beam, used to magnetize the target foils.

The rail with 5 foils is shown in Fig. 3 while the foils characteristics are given in Table 1. Fig. 4 shows the target chamber, the beam pipe, Helmholtz coils and other elements. The target rail can be moved horizontally, placing different foils into the beam. The whole target holder can also be moved along another rail, tilted at 20° to the beam, as the foils are tilted. This allows to scan the beam along the foil. Both motions put no material in the beam, apart from the thin foils, and can be carried out while the beam is on. The MCC operator must “mask” the Møller target motion before performing any target motion. Authorized Hall A personnel (see section 6) are also allowed to move the target. Such operation requires MCC to grant “channel access” to iochla for the duration of the measurements.
Table 1: The target foils’ parameters. “SM” stands for a Supermendur alloy. The polarization are quoted for a 16 A current in the coils. Target# 1 is an old target, used before 2005, installed for cross-calibration.

Two closed-circuit TV cameras, located in the Hall A Counting House, are used to observe the target motion. One camera looks from the side and shows a scale measuring the longitudinal position of the target. At the central (default) position, the scale shows 31 mm. The second camera shows the horizontal position of the target rail. At the empty (default) position the scale is centered about a mark “20”.

The target is magnetically saturated using two external, water cooled, Helmholtz coils, providing a field of about 350 Gs along the beam axis at the target center. The coils are turned on by the Møller CODA [1] script, during the data taking. Its polarity is reversed for each new run of data taking (one run typically takes 2-3 min).

Data Acquisition “dead time” typically limits the beam current that can be used to perform a beam polarization measurement to about 1.0\(\mu\)A while localized beam heating of the iron foils (which causes some loss of target polarization) would limit the beam currents to less than 2\(\mu\)A.

Møller target position interlocks, used to indicate when the various targets are properly located in the beam path, are routed to the Fast ShutDown (FSD) system of the accelerator. Fig. 5 shows the crate which controls the signals. The Møller FSD crate is located in Hall A rack 02. Target control is via EPICS (ref) Input & Output Controller (IOC) IOCHLA. The master section of this IOC is located in the corridor leading to Hall A, in the bottom of rack 1H75L05 (see Fig. 6). The slave crate with the field wirings is located in Hall A rack 02 below the Møller FSD crates (see Fig. 5).

### 3.3 Spectrometer Description

The Møller polarimeter spectrometer consists of four quadrupole magnets and one dipole magnet. Fig. 7 shows a side view of the spectrometer,

- quadrupole MQM1H02A (white color, there is no label on the yoke);
- quadrupole MQM1H02 (red color, on the yoke labeled PATSY);
- quadrupole MQO1H03 (blue color, on the yoke labeled TESSA);
Figure 4: The Møller target area. The beam direction is from right to left side of the picture.

- quadrupole MQO1H03A (blue color, on the yoke labeled FELICIA)
- dipole MMA1H01 (on the yoke marked as University of Kentucky).

All of these magnetic elements are controlled by MCC operators since they can steer the beam.

The spectrometer accepts electrons scattered close to the horizontal plane (see Fig.1). The acceptance in the azimuthal angle is limited by a collimator in front of the dipole magnet, while the detector vertical size and the magnetic field in the dipole magnet limit the acceptance in the scattering angle $\theta_{CM}$.

The electrons have to pass through the beam pipe in the region of the quads, through the collimator in front of the dipole magnet, with a slit of 0-4 cm high, through two vertical slits in the dipole, about 2 cm wide, positioned at $\pm 4$ cm from the beam. These slits are terminated with vacuum tight windows at the end of the dipole. The dipole deflects the scattered electrons down, towards the detector. The detector, consisting of 2 arms - 2 vertical columns - is positioned such that electrons, scattered at $\theta_{CM} = 90^\circ$ pass close to its center. This acceptance is about $76 < \theta_{CM} < 104^\circ$. At beam energies below 1 GeV the vertical slits in the dipole limit the acceptance to about $83 < \theta_{CM} < 97^\circ$. 
Energy range of the spectrometer is 0.8 GeV ÷ 11.0 GeV. For a given beam energy there is an optimal setting of the currents in these 5 magnets. Typically, the dipole magnet should be turned on only for the Møller measurements.

3.4 Detector

The Møller polarimeter detector is located in the shielding box downstream of the dipole and consists of two identical modules placed symmetrically about a vertical plane containing the beam axis, thus enabling coincidence measurements (see Fig. 8). Each part of the detector includes:

- An aperture detector consists of four scintillators with light guides and Hamamatsu R4124 (13 mm diameter) photomultiplier tubes connected to each segment. Size of the aperture assembled detector is 31cm×4cm×3.6cm.

- A spaghetti lead - scintillating fiber calorimeter\(^2\), consisting of 2 blocks

\(^2\)before summer 2002 a lead glass calorimeter consisting of 4 8×8×30 cm\(^3\) was used. It lost a big fraction of the
9×15×30 cm³, each separated into 2 channels equipped with Photonis XP2282B (2 inch) photomultiplier tubes. Thus, each of the vertical detectors is segmented into 4 calorimeter channels.

The HV crate is located in the Hall A rack 15 (see Fig. 9) and is connected to a portserver hatsv5, port 3. HV for the various calorimeter blocks is tuned in order to align the Møller peak position at a ADC channel 300 for each module.

3.5 Electronics

The electronics, used for Møller polarimetry, is located in several crates in the Hall (racks 12, 14, 15):

1. VME, board computer hallavme5 - for DAQ;
2. CAMAC - for the trigger and data handling;
3. NIM - for the trigger and data handling;

amplitude due to the radiation damage and deterioration of the optical contact.
Figure 7: The Møller spectrometer. The target is located at the right side of the photograph.

Figure 8: The Møller detector in the shielding box. The aperture detector on the face of the lead-scintillating fiber calorimeter is not shown.
Figure 9: The Møller HV crate (LeCroy1458) and part of the Møller DAQ (crate below HV crate).
4. LeCroy 1450 - HV crate, slots 5 and 6 (calorimeter and aperture detector).

The photograph on Fig. 10 shows (from left to right) the DAQ crates in rack 14, power supplies for the Møller spectrometer quadrupole magnets in rack 13 and FADC DAQ crates in rack 12. Rack 14 from the top to bottom: crate with delay lines (blue), two Møller target Helmholtz coils power supplies. Crate below the power supplies is the VME DAQ crate and Helmholtz coils control, the next one is the CAMAC crate and the bottom one is the NIM crate.

One can connect to the CPU boards and the HV crate via a portserver:

1. hallavme5 - hatsv5 port 4;
2. LeCroy 1450 - hatsv5 port 3.

3.6 DAQ

Two data acquisition (DAQ) systems in are used. The original DAQ\(^3\) is based on CODA [1] and runs on adaql2. The database server for CODA is running on adaql1. A more recent DAQ system, still undergoing evaluation, is based on Flash Analogue-to-Digital Converters (FADC) in VME format. This system runs on the hamoller computer and it uses Portserver hatsv12 port 5 to connect to the VME modules. Data is stored on hamoller:/data1/raw/. The FADC DAQ electronics is located in the Hall rack 12 (see Fig. 11).

3.7 Slow Control

The Helmholtz coils are controlled via a script starting automatically at the beginning of each CODA run. The polarity of the current in the coils is reversed at every new run.

The HV, the electronics settings and the collimator position are controlled from a Java program with a GUI\(^4\).

Procedure to start the slow control task,

- Login to adaql1 as moller;
- adaql1> cd Java/msetting/
- adaql1> ./mpc ← it starts the slow control task.

It may take about a minute to start all the components and read out the proper data from the electronic crates. The slow control GUI is presented on Fig. 12. The components are:

- EPICS [2] Monitor: these EPICS variables are stored for every DAQ run

\(^3\) (More details in: http://hallaweb.jlab.org/equipment/moller/guide1.2_linux.html)
\(^4\) (More details in http://hallaweb.jlab.org/equipment/moller/slow_mpc.html)
Figure 10: Møller electronics, located in the Hall, at the right side of the beam line. From left to right: the DAQ crates in rack 14, power supplies for the Møler spectrometer quadrupole magnets in rack 13 and FADC DAQ crates in rack 12.
Figure 11: The Møller FADC crates.
– **Detector Settings** is used to set up the thresholds, delays etc.
– **High Voltage Control** for the photomultiplier tubes
– **Motor Control** to move the collimator
– **Target Monitor** information on the target position, magnets etc.

High voltage can be changed or turned on/off using the HV GUI window (Fig. 13), where the first eight channels belong to the calorimeter and the other eight channels belong to the aperture counters. The settings of the CAMAC electronics used to select the trigger and control DAQ are controlled using the Detector Setting window (Fig. 14):

– **Delay line** - the delays for the calorimeter and aperture counter signals;
– **LedDiscriminator** - discriminator thresholds for the calorimeter and the counters
– **PLU Module** - settings of the logical unit

The collimator width can be changed using **Motor Control** window (Fig. 15).

### 4 Operating Procedure

The procedure includes general steps as follows:

- “Non-invasive” preparations - start the appropriate computer processes, turn on the HV and learn the magnet settings needed;
- “Invasive” preparations: beam tuning with the regular magnet settings, loading the Møller settings, beam tuning, if necessary, installing the Møller target;
- Detector check/tuning;
- Measurements;
- Restoring the regular settings.
The “non-invasive” preparations can be done without disturbing the running program in the Hall. It is reasonable to perform these preparations before starting the “invasive” part.

In more details, the “invasive” procedure looks as follows:

- Remove the main target;
- Load the Møller settings in the magnets, keep the dipole off;
- Tune the beam position with any convenient beam current;
- Turn on the Møller dipole;
- Check the beam position;
- Tune the beam to \( \sim 0.5\) µA for Møller measurements;
- Pull in the Møller target, using the TV camera to make sure the foil is at the window center;
- Make at least two CODA runs in order to use both coil polarities;

4.1 Initialization

In order to control the operations, several terminal sessions of the `moller` account must be opened on `adaql1`,... The data analysis and some initial calculations are done using a PAW [3] session on `adaql1`:

![Figure 13: HV control GUI window.](image)
Figure 14: Detector setting GUI window.

- Login to adaql1 as moller;
- adaql1> cd paw/analysis, start PAW (type paw), select Workstation type 3.

Check that the portserver connections are available:

- Try telnet hatsv5 2003 and telnet hatsv5 2004;
- If a connection is refused - clean it up, by connecting telnet hatsv5 as root and typing kill 3 or kill 4, see instructions in ∼adaq/doc/portserver.doc.

Slow control:

- Login to adaql1 as moller;
- Start the slow control (see section 3.7);
Figure 15: GUI window to control the dipole collimator size (and also the slide, which is not relevant here).

- Load the regular settings and the appropriate HV.

CODA runs on adaql1:

- Login to adaql1 as moller, make two sessions;
- adaql2> kcoda - clean up the old coda;
- Reset the VME board hallavme5 by: telnet hatsv5 2004, -> reboot;
- adaql2> start_coda - start CODA;
- Click Connect and select the configuration beam_pol;
- Click Download to download the program into the VME board.

4.2 Initial Beam Tune

Typically, the Møller measurements are taken during the regular Hall A running, when the beam has been tuned for this running. However, the Møller measurements require a different magnetic setting. At least the dipole magnet has to be turned on. This magnet slightly deflects the beam downward. The deflection at the main target could be 2-8 mm, depending on the beam energy. It is, therefore, useful to tune the beam position before the dipole is turned on. It can be done before the magnets are set to the Møller mode. The requirements for straight beam are:

- On BPM IPM1H01 (in front of the Møller target) $|X| < 0.1$ mm, $|Y| < 0.1$ mm.
- On BPM IPM1H04 (downstream of the Møller detector) $|X| < 0.1$ mm, $|Y| < 0.1$ mm.

These requirements should be given to MCC.
4.3 The Magnet Settings
The proper Møller magnets (quads and dipole) settings for the given beam energy have to be provided to MCC by the Møller polarimeter team. The beam must be turned off when the magnets are being tuned.

4.4 Final Beam Tune
The beam parameters for Møller measurements are:

- beam currents between $\sim 0.5 \mu A$ and $< 2 \mu A$;
- the beam current should be reduced mainly by closing the “slit” in the injector (not by the laser attenuator), in order to reduce the effect of current leak-through from the other halls.

4.5 Target Motion
The procedure is as follows:

- Ask the MCC to mask the main target (cryotarget or whatever) motion and remove the main target, then ask the MCC to unmask the motion;
- Ask the MCC to mask the Møller target motion;
- Move to target to the position needed (say, 4) using the MEDM screen (see Fig. 2). Check that the target is close to the center of the window in the TV camera screen.

4.6 Detector Tuning and Checking
The goal is to check that the detector is working, that the counting rates are normal and that the Møller peaks are located at about ADC channel 300 for all the calorimeter blocks.

A. Data taking with CODA

1. Take a RUN for about 20k events. Let us assume the run number is 9911.

B. Data analysis with PAW

1. `PAW> exec run run=9911`: build an NTUPLE and attach it to the PAW session;
2. `PAW> exec lg_spectra icut=60 run=9911`: look at the ADC distributions. The peaks should be at about ADC channel 300 for all 8 modules. If the peaks are off - try to adjust the HV (do not go beyond 1990V).

C. Check of the background

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5A reasonable accuracy in the magnets settings is about 1-2%. 

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1. Raise the thresholds to 240 mV of the channels 1 and 2 of the discriminator, using the slow control window (see section 3.7);
2. Take a run of about 20k events, say run=9915;
3. \texttt{PAW> exec lg\_spectra icut=60 cut=11 run=9915}: look at the ADC distributions. The peaks should be at about ADC channel 300 for all 8 modules. The histograms 9 and 10 present the sums of the left and right arms. The histogram 11 (sum of both arms) should contain a clean peak at about channel 600;
4. \texttt{PAW> exec asymu run=9915}: polarization analysis should provide a reasonable number. Check the scaler rates per second. The counting rates in each arm should not exceed 600kHz. If they are higher ask the MCC to reduce the beam current.

4.7 Polarization Measurement

1. Take an even (say, 2) number of runs of data, each run of about 20-30 k events (30 k at $E_{\text{beam}} < 2$ GeV).
2. Analyze the data
   1. \texttt{PAW> exec run run=Run\_Number and}
   2. \texttt{PAW> exec asymu run=Run\_Number, for each RUN,}

4.8 Polarization Measurement with FADC

ROOT[4] based analyzer is used to process data from FADC DAQ. Data analysis is performed on \texttt{hamoller} computer under “a-onl” account. One should go to directory \texttt{moller\moller\fadc-18Feb2011} and type command:
\texttt{a-onl> source root\_setup\_sh}
Move into the analysis directory:
\texttt{a-onl> cd onlana}
To replay a new run (<Run\_Number>) and generate a new .root file:
\texttt{a-onl> analyzer}
In analyzer terminal type:
\texttt{ROOT> replay\_test(< Run\_Number >)}
To analyse run (< Nevents > is number of events to analyze, -1 - all events) type:
\texttt{ROOT> t = T(< Run\_Number >)}
\texttt{ROOT> t-> Loop(< Nevents >)}
Few graphic windows will be pop up and calculated asymmetries are printed in analyzer terminal.
5 Safety Assessment

5.1 Magnets

Particular care must be taken in working in the vicinity of the magnetic elements of the polarimeter as they can have large currents running in them. The quadrupole magnets and the leads for the dipole magnet are protected with Plexiglas shields. Removal of these shields requires following JLab’s “Lock out / Tag out” procedure and ESH&Q rules. Concurrence from the Hall A work Coordinator must be obtained before proceeding with such work.

As with all elements of the polarimeter which can affect the beamline, the magnets are controlled by MCC. There is a light panel “MAGNET ON” (see Fig. 16) which indicates the status of the Møller polarimeter magnets (quadrupole magnets MQM1H02A, MQM1H02, MQO1H03, MQO1H03A and dipole magnet MMA1H01). The light panel is placed on the top of Møller magnets plastic shielding box and lighting when any one of the Møller magnets is energized.

Figure 16: “MAGNET ON” light panel on the top of the Møller spectrometer shielding guard.

The power supply (62 V, 500 A rating) for the dipole is located in the Beam Switch yard Building (Building 98). The maximum current for the dipole is 450A. The power supplies for quadrupoles MQM1H02, MQO1H03 and MQO1H03A (40 V, 330 A rating) are located in Hall A electronics.
rack 13 (see Fig. 10). The power supply for quadrupole MQM1H02A is located behind the Hall A electronics rucks (see Fig. 17). The status of the quadrupole power supplies is on the checklist for closing up Hall A.

Figure 17: Power supply for the Møller quadrupole magnet MQM1H02A locates in the Hall A.

5.2 Vacuum System

One must be careful in working near the downstream side of the dipole magnet, as there are two 2 by 16 cm, 4 mil thick titanium windows. The windows are partially protected by a lead collimator downstream of the dipole. Only members of the Møller polarimeter group should work in this area. If work is done on the collimators, the appropriate ear and eye protection should be used.

5.3 High Voltage

There are 16 photomultiplier tubes within the detector shielding hut, with a maximum voltage of 3000 V. The detector is serviced by sliding it back on movable rails. The high voltage must be turned off during any detector movement. Only members of the Møller group should move the detector.
5.4 Target

To avoid damage to the Møller target, the target should not be in the beam if the beam current is greater than 5 $\mu$A. The experimenters are responsible for ensuring that the Møller target is removed from the beam for regular running and that its position is unmasked.

6 Authorized Personnel

The list of the presently authorized personnel is given in Table 2. Other individuals must notify and receive permission from the contact person (see Table 2) before adding their names to the above list.

<table>
<thead>
<tr>
<th>Name</th>
<th>Dept.</th>
<th>Ext.</th>
<th>e-mail</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Javier Gomez</td>
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</tr>
<tr>
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<td></td>
</tr>
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<td></td>
</tr>
</tbody>
</table>

Table 2: Moller Polarimeter: authorized personnel.

References


