0.0.1 Heavy Gas Čerenkov Detector

A charged particle traveling faster than the speed of light in the medium will create an electromagnetic disturbance in the medium. The radiation emitted by this process is called Čerenkov radiation after its discoverer.

Čerenkov radiation is conically distributed about the trajectory of the particle, with an angle given by

$$\cos\theta = \frac{1}{\beta n}$$

where the index of refraction $n = c/u$ and $\beta = v/c$, with c the speed of light in vacuum, u the speed of light in the medium, and v the speed of the particle.

The index of refraction allows one to control the threshold particle velocity $v_T = u = c/n$ below which there is no Čerenkov light produced, and above which there is Čerenkov light produced. For a gas, the quantity $n - 1$ is proportional to the pressure, so adjusting the pressure of the gas allows one to select the threshold velocity. Adjusting the threshold velocity then allows one to select particles of different mass. Given the same momentum, two particles of different mass will have different velocity. Therefore, a Čerenkov detector can be tuned, for instance, to distinguish electrons from pions.

The SHMS Heavy Gas Čerenkov detector consists of a large cylindrical tank, with outer flange diameter of 1.88 m or 74 inch, and bolt to bolt length of 1.3 m or 51.1 inch. The detector contains four mirrors which focus light onto four 5 inch Hamamatsu R1584 photo multiplier tubes (PMTs), as shown in Fig 1.

The main detector cylinder is made of a 0.5 inch thick T6061-T6 Aluminum sheet with radius of 1.725 m or 67.9 inch. Both circular ends have been covered with 0.04 inch thick 2024-T4 Aluminum windows. These windows were hydrostatically formed (and hence tested) at a pressure of 45 PSI.In addition, the windows were hydrostatically tested at a pressure of 60 PSI. The tank itself was helium leak checked and is leak free on a scale of 10^{-8} Atm-cm^3/s. HGC detector configuration only allows sub atmospheric pressure operation, thus under no circumstance the detector pressure shall exceed 1 Atm. Each of the aluminum windows are sandwiched between the detector vessel and a thick aluminum flange. All three components are clamped with stainless steel bolts with washers and silicon bronze nuts. Installation torque for each bolt is specified to be 26 lb·ft.

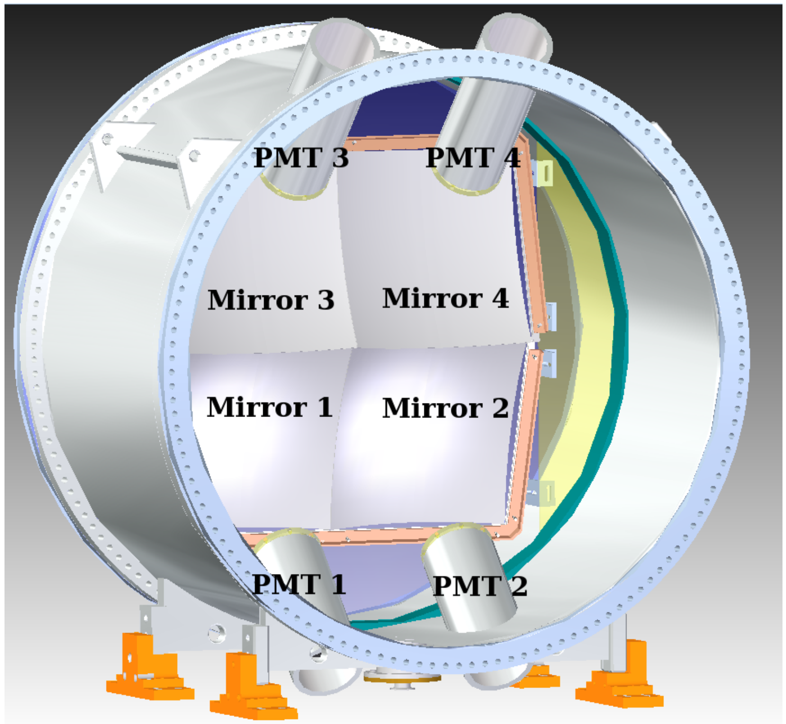


Figure 1: CAD Drawing of SHMS HGC detector.

The HGC tank is mounted on the detector rails using a three point alignment scheme. The rails are easily capable of supporting the weight of the tank without deformation. The gas handling system for the tank is designed to enable the tank to be filled with gas suitable for the experiment. Typically this would be C_4F_8O (C_4F_{10}), or CO2, at the desired operating pressure which is 0.2-1 Atm. Detector operating pressure must not exceed 1 Atm.

The system consists of a dual-bottle gas manifold for the production gas and a third single-bottle manifold for a purge gas (nitrogen or CO2). The bottle rack is at floor height welded to the SHMS detector carriage under the stairs on the large angle side.

A diagram of the gas circuit is reproduced in Fig. 2. Each gas bottle has its own regulator, and all should be set to a nominal 40 psig. The ultimate gas pressure delivered to the gas panel in the SHMS hut is limited to less than 14 psig by a pressure regulator at the manifold output set to 12–13 psi and protected by a 14 psi popoff valve.

The gas flows through a 14X molecular sieve located on the SHMS de-

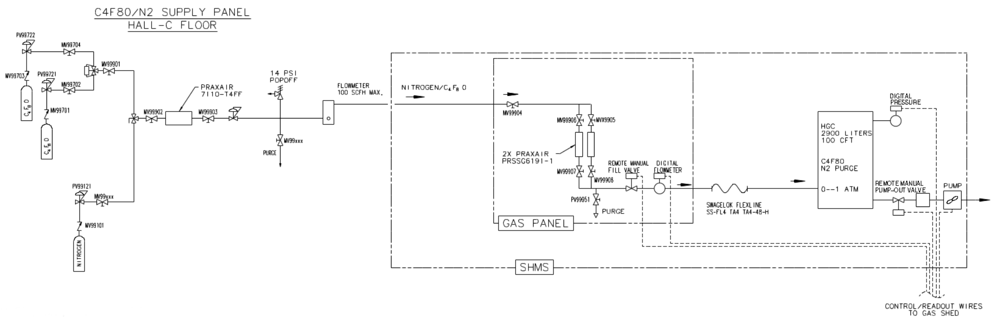


Figure 2: CAD Drawing of SHMS HGC gas system (excerpt from JLab Drawing 67165-00100).

tector gas panel in the detector hut to hedge against contamination and is delivered to the tank through a fill valve. A digital flow-meter monitors and logs the gas being delivered, and a digital pressure gauge records the pressure in the tank. Communication between the digital pressure gauge and digital fill valve limits the final pressure in the tank. A 1 psig popoff valve protects the tank from unintended overpressure due to misconfiguration or equipment failure.

Before filling, the tank is first cleaned by executing several pump and purge cycles. The oil-free pump that used to evacuate the tank is located on a platform welded directly beneath the HGC tank and can be controlled both locally or remotely. The fill valve is verified to be closed (it's normal state), the pump engaged, and the pump-out valve opened. Pressure in the tank can be monitored both locally and remotely via the digital pressure gauge.

The mirrors in the HGC may require adjustment for optimal focusing on the PMT faces. Small adjustment to the mirror position cannot be done while the detector is mounted. The adjustment to mirror position can only be performed when the detector vessel is in the horizontal position with both aluminum windows completely removed. While the HGC is mounted, up to 1 cm adjustment to PMT position can be made by repositioning the plastic eccentric PMT holders. This adjustment should only be done by personnel who completely understand the design of the PMT mounting assembly.

PMTs From Fig 1, there are four aluminum sleeves welded onto the detector cylinder, where each sleeve hosts one PMT assembly. Note that the

PMT #	Serial #	Voltage
1	LA0274	2132
2	LA0272	1967
3	LA0273	1926
4	LA0271	2013

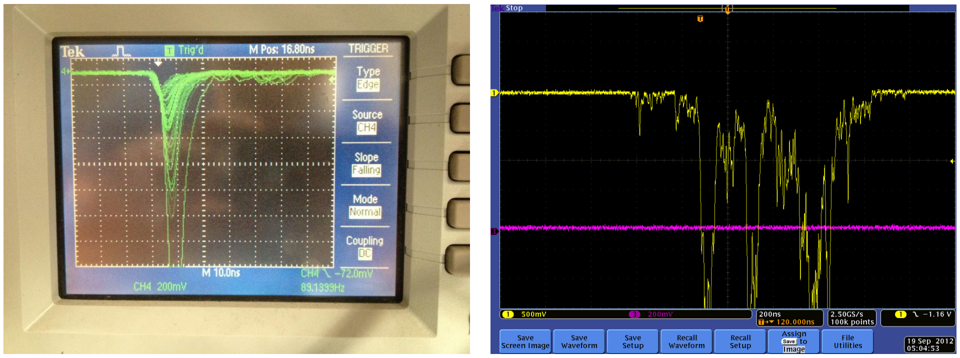
Table 1: Serial number and initial recommended operating voltage for each PMT.

PMT assembly is outside of the vessel enclosure, viewing the Čerenkov radiation through a quartz viewport. The inner end of each sleeve is installed with a quartz window that provides vacuum seal. The rounded face of each Hamamatsu R1584 PMT is glued to a custom flat-head quartz adapter. The PMT and quartz adapter is pressed against the viewport, held in position via spring pressure. The contacting optical surfaces are coupled with a thin layer of UV-transparent silicon grease. A spring lock-in mechanism (open end of the sleeve) is used to provide mechanical pressure to ensure good contact between optical surfaces and a customized rubber cone is used to provide a seal against light leaks.

The SHMS HGC 5 inch PMTs use **negative** HV. The PMT photo-cathode is powered using high negative voltage and the mu-metal shield is grounded, so there is a 2000 V potential difference between the PMT and the shield. Note that the Aerogel and Noble Gas Čerenkov detectors use PMT bases that are designed for positive HV, therefore one must only use labeled HV cables for HGC. The HV is supplied by one pod of the *CAEN* power supply. The safe PMTs operating voltages are between 1500 and 2400 V. For the initial commissioning stage, the operation voltages should not exceed 2200 V. The serial number and initial recommended operating voltages for each PMT are listed in Table 1. At the recommended voltage, the expected average pulse height for a PMT signal should be $\sim$400 mV and rates $\sim$100 Hz.

Fig 3a shows an example of regular signal from a R1584 PMT; Fig 3b shows an example of discharging signal indicating a breach of electrical insulation between the photo-cathode and mu-metal shield. The discharging signals have very distinctive characteristics since they are relatively large pulses (>5 Volts) that are >100 ns long.

At the time of installation, extensive tests were performed for all four



(a) Regular Signal (b) Discharge

Figure 3: (a) shows example of regular PMT signal; (b) shows a discharged signal.

PMTs and confirmed no discharge at 2000 Volts. Once discharging signal is observed, one should carefully monitor the rate as well as report the incidence immediately. The primary suspect for causing discharge pulse is a possible electric insulation breach between the photo tube and mu-metal shield. Further diagnose would require complete removal of the PMT assembly from the aluminum sleeve while all four PMTs are switched off. Electric insulation that covers the inner edge of mu-metal shield cylinder must be carefully inspected. Once the location of discharge is identified, it is recommended to seal the suspect area with few layers kapton tape.

Operation Procedures The SHMS Heavy Gas Čerenkov Detector operates either as an π/κ or e/π discriminator. Figures 4 and 5 indicates suggested gas pressure vs. Čerenkov threshold for various particles and SHMS momentum settings. C_4F_8O and C_4F_{10} are functionally equivalent gases in this role. See references [1] and [2] for more detailed studies.

The nomenclature used in the description of these operation procedures refers to the gas system diagram in Figure 2.

π/κ **Procedures** This mode of operation typically requires the tank to be filled with C_4F_8O (C_4F_{10}) at pressures varying from 0.2 to 1 Atm (absolute). The detector is pumped down to 1 millitorr, then refilled with C_4F_8O (C_4F_{10}) gas.

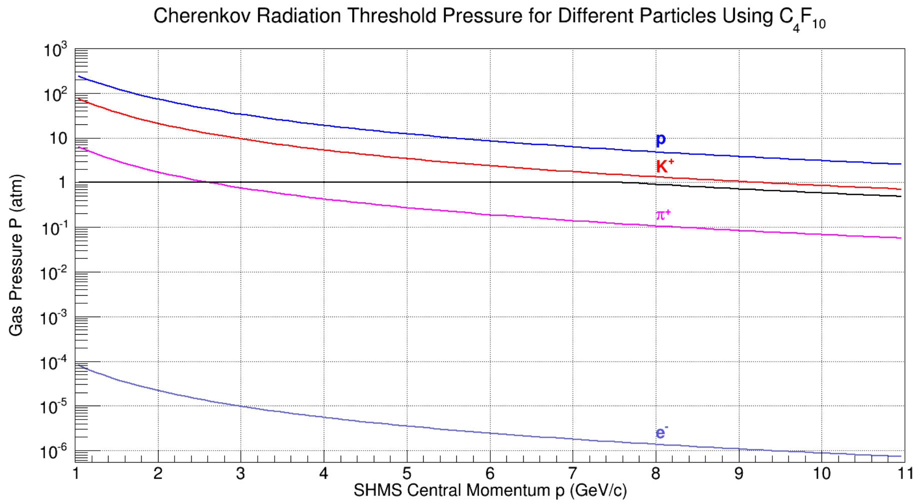


Figure 4: Gas Pressure vs. Particle Momentum. The black curve represents the suggested gas pressure of the HGC detector for good π/κ separation. The colored curves represent the Cherenkov threshold pressure for different particles. C_4F_8O performs equivalently to C_4F_{10} in this context.

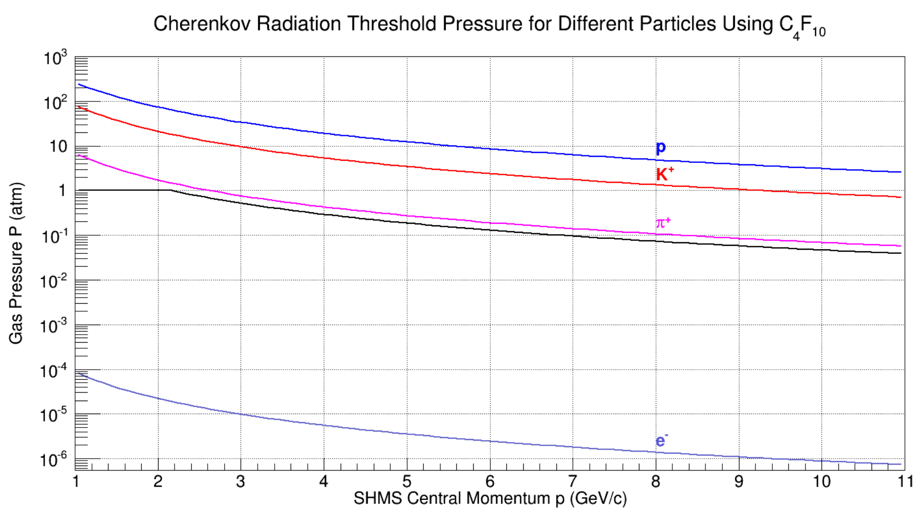


Figure 5: Gas Pressure vs. Particle Momentum. The black curve represents the suggested gas pressure of the HGC detector for good e/π separation. The colored curves represent the Cherenkov threshold pressure for different particles. C_4F_8O performs equivalently to C_4F_{10} in this context.

Because the operating pressure is slightly subatmospheric, a pump and fill procedure is employed.

1. Initial Prep
   (a) Ensure that the HGC Remote Fill Valve is CLOSED.
   (b) If you will changing the radiator gas, then ensure Valve **MV9902** is also CLOSED. This is the main cut-off valve downstream of the 3-way valve on the supply gas panel under the stairs on the SHMS carriage.
   (c) Rotate the 3-way valve to connect the radiator gas you require to the downstream system.
   (d) Leave the cut-off valve closed for now.
2. The tank is now ready to be evacuated.
   (a) Turn ON the pump. (This pump is oil-free and does not require a trap.)
   (b) Very *slowly* open the HGC Remote Pump-out Valve. Since this valve connects the pump line to the detector volume, the pump will work hard. Meter this valve so that the pump is never under extreme stress. It will take approximately 20 minutes to pump down the tank.
   (c) Monitor the HGC Digital Pressure readback and close the HGC Remote Pump-out Valve when you have reached $\approx 110^{-3}$ Torr.
   (d) CLOSE the HGC Remote Pump-out Valve.
   (e) Turn OFF the pump.
   (f) Monitor the HGC Digital Pressure readback for a few moments and ensure it is stable!
3. The tank can now be filled.
   (a) If required due to Step 1b, *slowly* open the cut-off valve on the gas supply manifold under the SHMS stairs. Monitor the flow-meter on the same panel and ensure that you do **NOT** see any flow beyond that needed to pressurize the lines to the distribution panel in the SHMS detector hut.

(b) Slowly open the HGC Remote Fill Valve and monitor the Digital Flowmeter *and* Digital pressure readbacks. A reasonable flow is 20 cfpm.

(c) Monitor the HGC Digital Pressure readback and close the HGC Remote Fill Valve when you have reached the desired operating pressure.

(d) CLOSE the HGC Remote Fill Valve.

(e) If the tank will remain at this pressure for an extended period (*i.e.* over a week, then CLOSE the main cutoff valve at the supply panel under the SHMS carriage stairs (**MV9902**).

The fill should take approximately 30 minutes. The detector should NEVER be left unattended during a fill. Frequently check the pressure in the tank and be aware when the pressure is near to one atmosphere. **DO NOT let the pressure exceed one atmosphere under any circumstances; doing so risks damage to all of the equipment and personnel in the detector hut.**

Bibliography

[1] Simulations for π/κ separation for the shms heavy gas cherenkov detector. URL `https://hallcweb.jlab.org/doc-private/ShowDocument?docid=804`.

[2] Simulations for e/π separation for the shms heavy gas cherenkov detector. URL `https://hallcweb.jlab.org/doc-private/ShowDocument?docid=803`.