SHMS Heavy Gas Cherenkov (HGC) Detector Calibration Plan

GH Draft: December 29, 2016

Abstract

This document presents a draft plan for the initial check-out and calibration steps for the SHMS Heavy Gas Cherenkov (HGC) Detector for the first year of operation. The obtained data will allow a detailed comparison between the obtained and predicted HGC characteristics, and provide an accurate indication on whether any mirror misalignments or other changes have occurred since the HGC was assembled at JLab in 2013. These calibrations will also provide important data for the HGC NIM paper planned to be written.

1 Initial HGC Configuration

1. Vessel filled with CO_2 at 1 atm.
2. PMT voltages set for constant gain $G = 5 \times 10^7$ according to Alex Fisher's report. [1]

PMT Pos.	R1584 PMT	Meas. Gain @ 2000 V	Manuf. Gain @ 2000 V	Exponent	Calc. HV $G = 5 \times 10^7$	Resolution Ratio	Manuf. Anode Dark Current
1 (LL)	LA0274	2.43	0.97	11.24 ± 0.32	-2132	3.57	90.0
2 (LR)	LA0272	5.94	3.60	10.36 ± 0.24	-1967	3.69	210.0
3 (UL)	LA0273	7.64	5.79	11.30 ± 0.19	-1926	3.74	120.0
4 (UR)	LA0271	4.63	3.20	11.23 ± 0.24	-2013	3.57	130.0

Table 1: Measured and Hamamatsu-reported PMT gains ($\times 10^7$) at 2000 V. 'Exponent' column is gain scaling exponent, n, where $\frac{Gain1}{Gain2} = \left(\frac{Voltage1}{Voltage2}\right)^n$. 'Resolution ratio' is single photoelectron peak (mean-pedestal)/width @ 2000 V. Anode dark current is in nA @ 2000 V.

3. According to the beam schedule, we assume 6.4 GeV, (up to) 20 μA beam, and according to the draft commissioning plan, the SHMS set to 3.0 GeV/c central momentum.

2 PMT Gain Matching

1. According to the draft commissioning plan, one of the first tasks will be an initial SHMS detector checkout with a defocused run, prior to any optics fine-tuning of the quadrupoles/optics. This is perfect for HV gain matching.
2. At the earliest opportunity, check that all HGC electronics signals (e.g. TDC inputs) are well-timed and any discriminator levels are appropriately set.

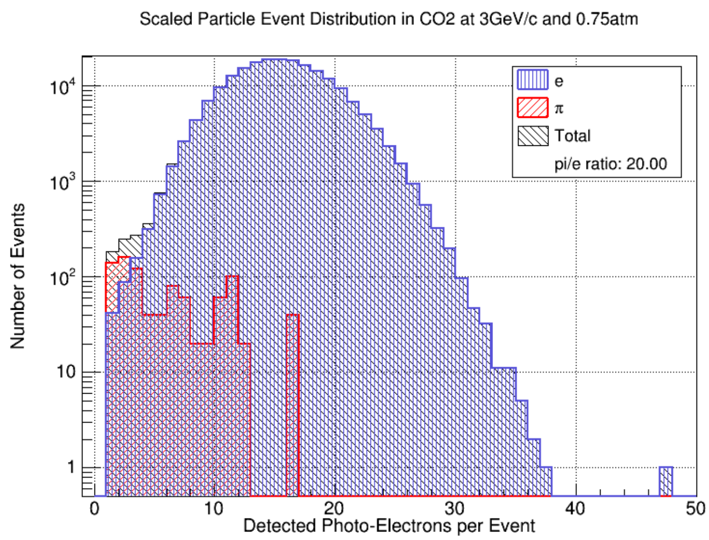

Figure 1: Simulated total detected photo-electron (p.e.) spectra for e^- and $\pi^\pm$ incident on the HGC with the SHMS set to a central momentum of 3 GeV/c and the focal plane uniformly illuminated. In this simulation, the HGC is filled with CO_2 at 0.75 atm. [We need to replace this with a figure corresponding to commissioning conditions.] See Ref. [2] for more information.

3. For a defocused run (i.e. the SHMS focal plane is reasonably uniformly illuminated), check the four PMT ADC spectra. Adjust the HV for each PMT so that the distributions for each are as similar as possible. Preferably, the ADC distribution should only cover about 50% of the maximum ADC-scale. As is shown in Fig. 1, the maximum p.e. is about 40 for commissioning conditions, while π for 0.95 atm C_4F_{10} and 7 GeV/c central momentum setting will give a maximum of about 95 p.e. [3]. The obtained ADC spectra will hopefully have a close resemblance to the simulated Fig. 1.

4. Completion of this step should be sufficient to satisfy the relevant Key Performance Parameters (KPP):

   (a) Detector running for 8 hours recording data from all subsystems.

   (b) Data showing relative timing of trigger, tracking, and particle identification detector subsystems.

   (c) Particle identification plots using signals from calorimetry and Cherenkov detectors.

3 PMT PhotoElectron Calibration

1. Some runs with low numbers of observed p.e. are required to obtain an accurate gain calibration of each PMT. This will allow the 1,2,3 p.e. peaks to stand out clearly and their positions accurately determined (Fig. 2).

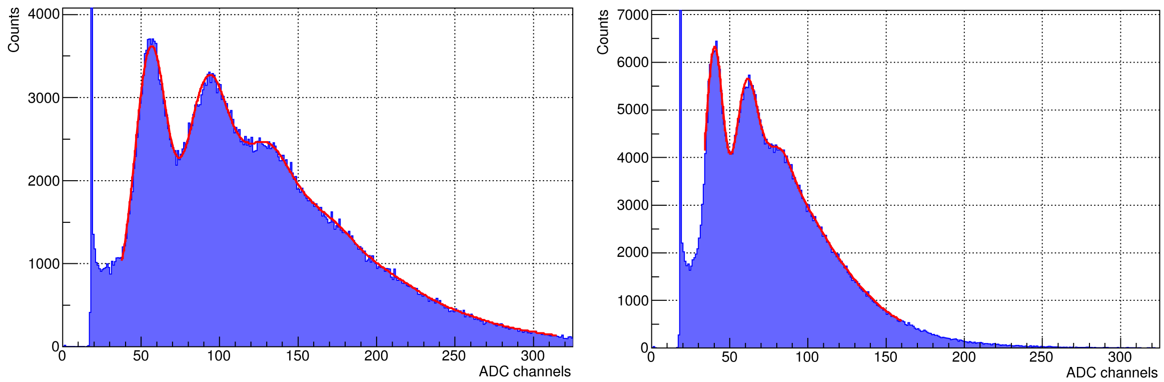

Figure 2: ADC spectra for PMT LA0271, **Left:** 2050 V, **Right:** 1950 V. The red curves represent a sum of 4-7 Gaussian distributions, whose widths are fixed to scale in proportion to the square root of the peak number. For more details, see Ref. [1].

2. Low numbers of p.e. can be accomplished in one of two ways:

   (a) If the SHMS optics commissioning plan includes a sweep of carbon elastics across the focal plane, runs can be selected where a given HGC mirror is not well-illuminated and these data used for the calibration.

   (b) Alternately, cuts can be placed on the drift chamber information to select events which illuminate a given HGC mirror. The mirrors not well-illuminated should yield the needed low p.e. spectra for those PMTs.

   After the calibrations are completed, the number of p.e. observed for each PMT can be compared to a simulation under the same conditions.

3. From the ADC conversion calibration, it should be possible to compute the mean number of electrons corresponding to a given ADC channel. A plot of the mean number of electrons at the anode versus the number of photoelectrons for the first 3 p.e. peaks should yield the gain of each PMT. If there is time to do this at more than one voltage, the Gain Exponent can also be determined. The computed Gain, Exponent and Resolution Ratios should be compared to those in Table 1. This will indicate whether any PMTs are in switched locations compared to the table.

4. Obtained calibration constants (valid for some range of run numbers) need to be uploaded to the online and offline analysis repositories for use by others.

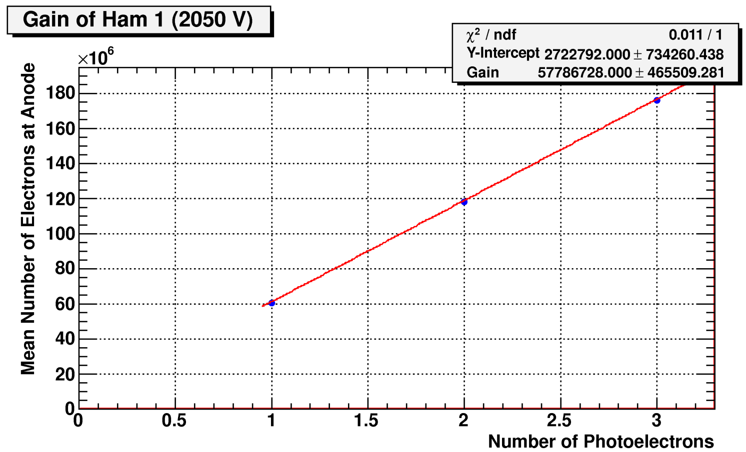

Figure 3: Plot of mean number of electrons at anode vs. number of photoelectrons for the first three peaks in Fig. 2. For more details, see Ref. [1].

4 Detection Efficiency

1. The average number of photoelectrons detected should be related to the particle detection efficiency via the standard equation [4]

$$Eff = \frac{CS}{S} = 1 - e^{-N_{pe}}, \tag{1}$$

where S is the number of focal plane hodoscope coincidences, and CS is the number of coincidences between the HGC and the focal plane hodoscopes. This relation should be checked, as a means of verifying the ADC calibration.

2. For incident electrons with the SHMS set at a central momentum of 3 GeV/c, and the HGC 0.75 atm CO_2, a cut at 4.5 p.e. should give an electron detection efficiency $> 99.7\%$, and a π^- detection efficiency of $< 0.3\%$ [2]. [This needs to be replaced with the numbers for commissioning conditions.]

3. As a second check, the shape of the calibrated ADC spectra for a large number of detected p.e. should be roughly consistent with a continuous distribution of the form

$$y = \frac{\mu^x e^{-\mu}}{\Gamma[x+1]} \tag{2}$$

where y is the number of counts/channel, x is the calibrated ADC value (in p.e.), μ is the mean of the Poisson distribution, and Γ is the gamma function (see Fig. 4).

4. Once these calibrations are complete, the position dependence of the p.e. output can be investigated using runs where the whole SHMS focal plane is uniformly illuminated. This will

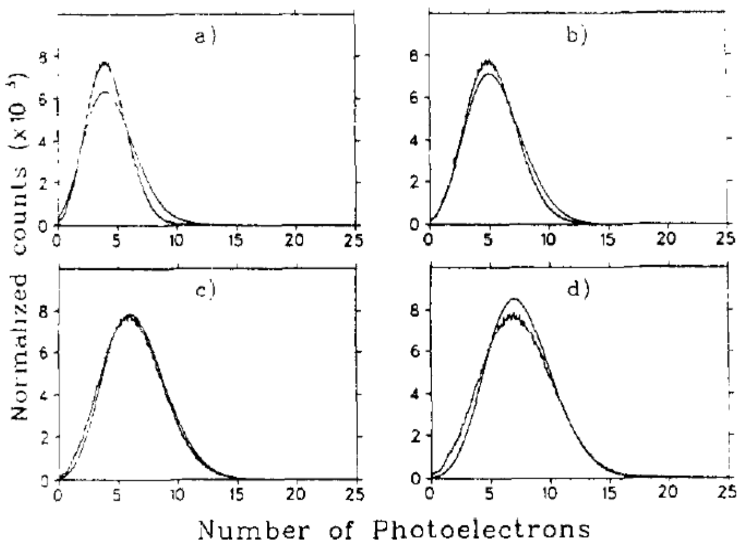

Fig. 9. The ADC spectrum of Fig. 7e, fit with Poisson distributions which assume different peak and average numbers of detected photoelectrons: (a) Peak = 4, $\mu = 4.5$, (b) Peak = 5, $\mu = 5.5$, (c) Peak = 6, $\mu = 6.5$, (d) Peak = 7, $\mu = 7.5$. It is clear that only (c) is an acceptable fit to the data.

Figure 4: Fits of Eqn. 2 to calibrated ADC spectra for the Hall A aerogel detector. For more details, see Ref. [4].

determine whether all four mirrors have been optimally aligned and whether there are any regions of low efficiency.

The position of the particle incident on the HGC can be computed from

$$
\begin{aligned}
X_{hgc} &= X_{fp} + (Z_{hgc} - Z_{fp})X' \\
Y_{hgc} &= Y_{fp} + (Z_{hgc} - Z_{fp})Y'
\end{aligned}
\tag{3}
$$

A spectrum of total p.e. versus (X_{hgc}, Y_{hgc}) should be compared to a simulation under the same conditions (see Fig. 5).

5 Later Calibrations

1. A second round of SHMS commissioning is scheduled for October with 2.2 and 6.4 GeV beam. The p.e. calibrations and efficiency scans should be repeated and checked for consistency with the earlier data.

2. The HGC is not planned to be filled with C_4F_{10} until after first phase of the commissioning experiments has been completed. This fill is expected to be done at the same time that the

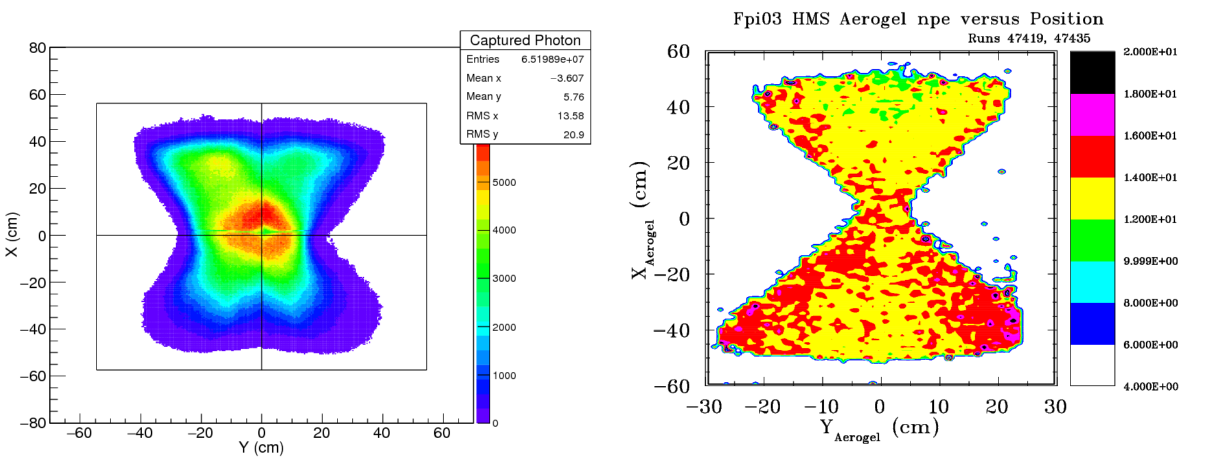

Figure 5: **Left:** Predicted p.e. pattern for π^+ with the SHMS set at a central momentum of 7 GeV/c and the HGC with 0.95 atm C_4F_{10}. [We need to replace this with a picture for initial commissioning conditions.] **Right:** Measured p.e. pattern for π^+ incident on the HMS aerogel detector at a central momentum of 3.336 GeV/c [5].

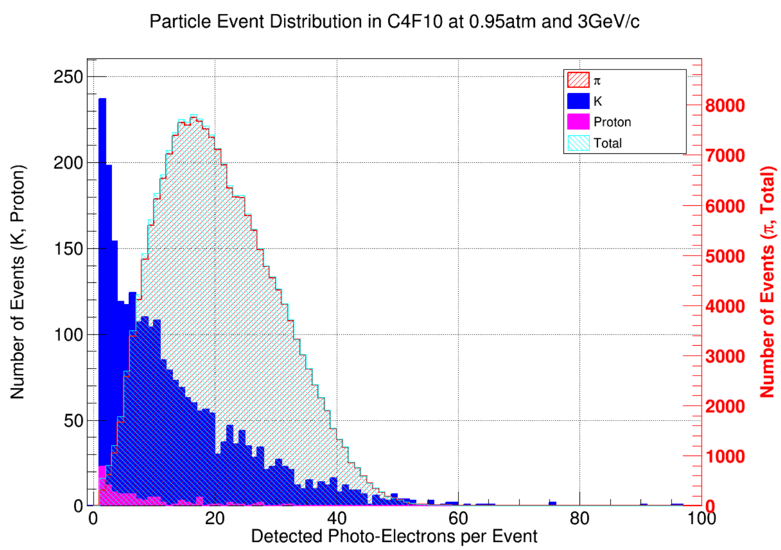

Figure 6: Simulated total detected photo-electron (p.e.) spectra for $\pi^\pm$ and $K^\pm$ incident on the HGC with the SHMS set to a central momentum of 3 GeV/c and the focal plane uniformly illuminated. In this simulation, the HGC is filled with C_4F_{10} at 0.95 atm. See Ref. [3] for more information.

small-angle beamline is installed. This will allow the π/K separation characteristics of the HGC to be properly determined, and compared to simulations (see Fig. 6).

3. After runs with a wide variety of SHMS momenta and particle types are obtained and cali-

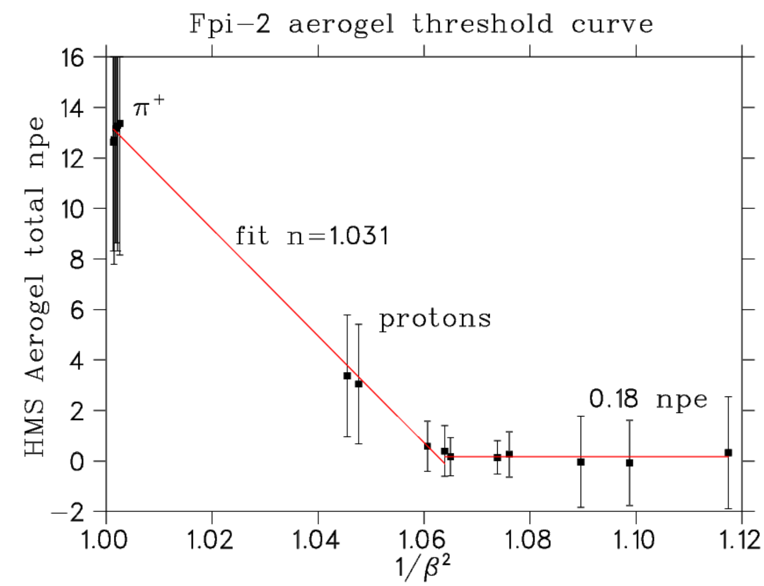

Figure 7: Measured p.e. for the HMS aerogel detector vs. $1/beta^2$ for π^+ and p. The p.e. slope above Cherenkov theshold gives the index of refraction. See Ref. [6] for more information.

brated, the index of refraction of the gas can be independently determined (see Fig. 7.)

References

[1] A. Fischer, "Performance Testing of 5 inch PMTs", Aug. 23, 2012, HallC-doc-738.

[2] M. Strugari, G.M. Huber, W. Li, "Simulations for e/π Separation for the SHMS Heavy Gas Cherenkov Detector", Aug. 15, 2016, HallC-doc-804

[3] M. Strugari, G.M. Huber, W. Li, "Simulations for π/K Separation for the SHMS Heavy Gas Cherenov Detector" Aug. 29, 2016, HallC-doc-803.

[4] L.C. Alexa, et al., Nucl. Instr. Meth. **A 365** 299 (1995).

[5] R. Asaturyan, et al., Nucl. Instr. Meth. **A 548** 365 (2005).

[6] G.M. Huber, "HMS Aerogel Cherenkov Calibration for Fpi-2", Feb. 26, 2004, HallC-doc-802.