UPDATED SHMS HGC CALIBRATION CODE

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1 Heavy Gas Cherenkov (HGC) Detector

The HGC detector of the Super High Momentum Spectrometer (SHMS) is used for the separation of charged π/K. The HGC detector utilises four photomultiplier tubes (PMTs) to collect Cherenkov light. When charged particles pass through the detector with velocity greater than the velocity of light in the gas medium then they produce a cone of Cherenkov light. This Cherenkov light reflects from the four mirror quadrants inside the HGC tank and is then collected by the PMTs [1]. A layout of the HGC detector and its four mirror quadrants is shown in figure 1 [1]. The purpose of the calibration is to produce a reliable translation from the raw FADC channel (charge in pC) to the physically accurate number of photoelectrons (NPE). This can be achieved by isolating the single photoelectron (SPE) peak to generate a calibration.
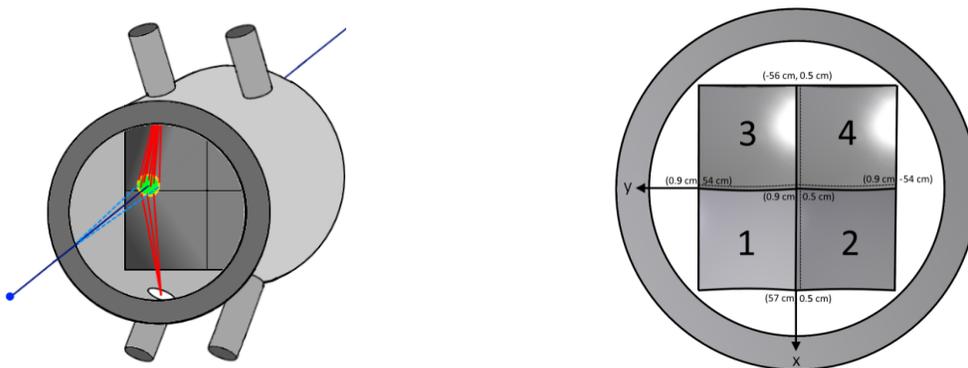

Figure 1: A layout of the HCG detector (left) and its four mirror quadrants (right) used in the HGC detector. A cone of Cherenkov light is reflected from four mirror quadrants and collected by the four PMTs (as shown in left figure) of HGC detector.

2 Calibration code

The calibration code is available to download from Github [2]. The calibration scripts makes use of the TProof class in root to process the data [3]. The preliminary testing of the calibration code has been done with the Kaon LT experimental data and is showing promising results. Typically, a single run from the Kaon LT experiment does not have sufficient statistics to generate a reliable calibration, thus tests have generally been conducted by chaining together sets of 2-3 runs. The construction of the HGC is similar to the Noble Gas Cherenkov (NGC) detector. As such, with some adjustments to the HGC calibration code, it should be relatively straightforward to convert it to a code capable of calibrating the NGC.

2.1 Running the code

This package of the calibration code consists of three scripts, calibration.C, calibration.h and run_cal.C. These three scripts are available in the /hallc_replay/CALIBRATION/shms_hgcer_calib directory for the use of fellow collaborators. The code can be used after completing the following steps :-

- Users should update their hallc_replay and ensure that they have the latest version of the repository from Gitbhub.

- Navigate to the CALIBRATION/shms_hgcer_calib directory.

- Create a new directory with the name of Calibration_plots for output files

- The calibration is carried out via execution of the run_cal.C root macro.

The pathing is set up for our environment on the farm but people should modify/add their own environment to the block around Line147 of the run_cal.C macro in this folder.

- It is highly recommend you execute the script without displaying any graphics (run in batch mode)

- This script requires between 4 and 13 arguments

- For example, the script can be executed via

    - root -l -b -q 'run_cal.C("RunPrefix", NumEvents, nRuns, RunNumber1, RunNumber2, RunNumber3,....., RunNumber10)'

- RunPrefix The prefix to the replayed rootfile you wish to run, e.g if your files are Coin_Replay_#RUNNUMBER_#NUMEVENTS.root, the prefix would be Coin_Replay, omit the trailing _ before the runnumber

- NumEvents The number of events per run (must all be equal), e.g. if you ran all events, enter -1 here

- nRuns Number of runs you want to chain together and attempt to calibrate over, the script can handle 1-10 runs - ONLY enter 1, 2, 3, ...10 here

- **RunNumber1** The run number for the first run you want to add to the chain

If you entered 2, 3, ..., 10 for nRuns, you will also need to specify RunNumber2, RunNumber3, ..., RunNumber10

- **RunNumber2** The run number for the second run you want to add to the chain

- **RunNumber3** The run number for the third run you want to add to the chain

- ....

- **RunNumber10** The run number for the tenth run you want to add to the chain

As an example of running the script, suppose you want to analyse Coin_Replay_5555_-1.root, Coin_Replay_5556_-1.root and Coin_Replay_5557_-1.root. Execute in the calibration code directory,

- **root** -l -b -q '**run_cal.C**("Coin_Replay", -1, 3, 5555, 5556, 5557)'

Note: Sometimes you may need to hit the enter key twice.

2.2 Output files

The code has been written in such a way that all of the calibration plots are produced on a single pdf file. This output pdf file will be saved in the Calibration_plots directory after the successful execution of the calibration code. The name of the output pdf file is depend upon the run(s) used for the calibration. If the calibration is executed on a single root file (without chaining two or more root files) then the name of the output pdf file is of the form Calibration_plots_Run.pdf. If a root file does not have sufficient statistics to generate a reliable calibration then chaining of several root files will be required and in this case, the output pdf file name is of the form Calibration_plots_1stRun_LastRun.pdf.

The code produces two text output files for the calibration parameters. These two files are also saved in the same directory as the pdf file. Again their names also depend upon the run(s) used for the calibration, for a single root file, it is phgcer_calib_run.param and phgcer_calib_err_run.param while for more than one root file, the output text files names would be phgcer_calib_1stRun_LastRun.param and phgcer_calib_err_1stRun_LastRun.param. The first (name in blue) output text file is formatted as required for the HGC calibration parameter input in hcana. The second (name in red) output text file contains further information on the calibration parameters that can be utilised in other studies (as will be explained in the report).

2.3 Timing cuts

The calibration of the HGC detector is strongly depend upon the timing cuts used in the calibration script. If users do not get reasonable calibration parameters after they run the calibration code then the first step they should take is to check the timing cuts. The relevant

lines in the code are located in the calibration.C script in the block starting at line number 168. The code has been designed to handle the timing cuts on each individual PMT.

A demonstration of placing the timing cuts on each PMT is shown in figure 2, where the red regions have been selected out from the full timing information (shown in blue) as the good timing information for each PMT. If users do not place these cuts correctly then they will not get reasonable calibration parameters.
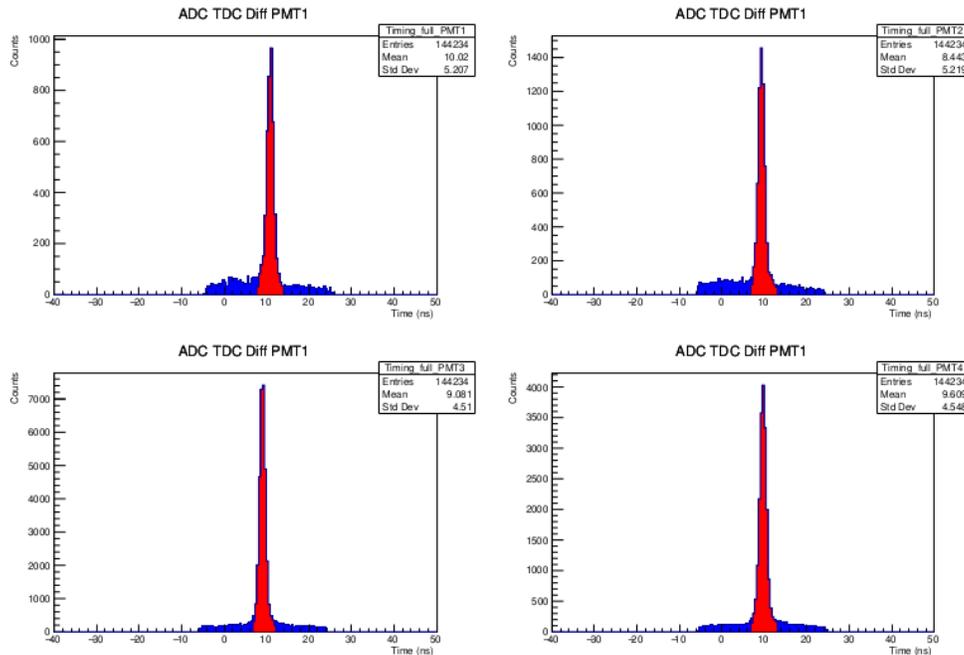

Figure 2: The timing information for each individual PMT. Blue regions are the timing information without placing the cuts . Red regions are the good timing information for each PMT.

3 Interpreting the calibration

In this report, the output details of the calibration plots and parameters are given from a calibrated set of the three run numbers 6918, 6919 and 6920. This set is taken from the 4.9 GeV beam energy run plan (Nov/Dec 2018) of the Kaon LT experiment. As mentioned in Section 1, the HGC detector uses four PMTs to collect Cherenkov light produced by charged particles (pi/K...) passing through the detector volume. Each PMT of the HGC detector can receive Cherenkov light from the four mirror quadrants and this Cherenkov light is used to calibrate each PMT. For a given PMT, we can examine the distribution of light from each mirror quadrant individually. As such, we can draw four distributions for each PMT as a histogram, four PMTs with four distributions means 16 total histograms. To produce a calibration, the SPE peak in each histogram is sufficient. It is the most intense peak and easy to isolate with high precision (in most cases). However, for a PMT focusing on its own mirror quadrant (PMT 1 focusing on mirror 1, PMT 2 focusing on mirror 2 and

so on) receives too much light which makes it extremely difficult to isolate the SPE peak, therefore the calibration algorithm does not consider their histograms for the calibration.

The procedure of obtaining the first set of calibration parameters is that the remaining three histograms of each PMT are fitted with a function, f(x) (shown in figure 3 in red). f(x) is the sum of two Gaussian functions. The code has been written to check the number of events at the peaks and the χ^2 of the fit to determine whether the fit is acceptable or not. By default, the χ^2 condition for a good fit is $0.5 < \chi^2 < 10$ and the max events at the first peak is > 40. Users can adjust these two statements in the calibration.C script in the block starting at line number 534. In figure 3 all three quadrants have satisfied these two conditions, that is why the calibration algorithm declared "Good fit" (text shown in green) for all three quadrants. If any of them did not satisfy the conditions then the calibration algorithm would have printed "Bad fit" in this text box instead. The SPE peak mean (and error on the mean) of any "Good fit" quadrants are used to calculate an error weighted average for each PMT. This error weighted average is the first set of calibration parameters. In figure 3 the other two functions, black and green, are the individual Gaussian functions
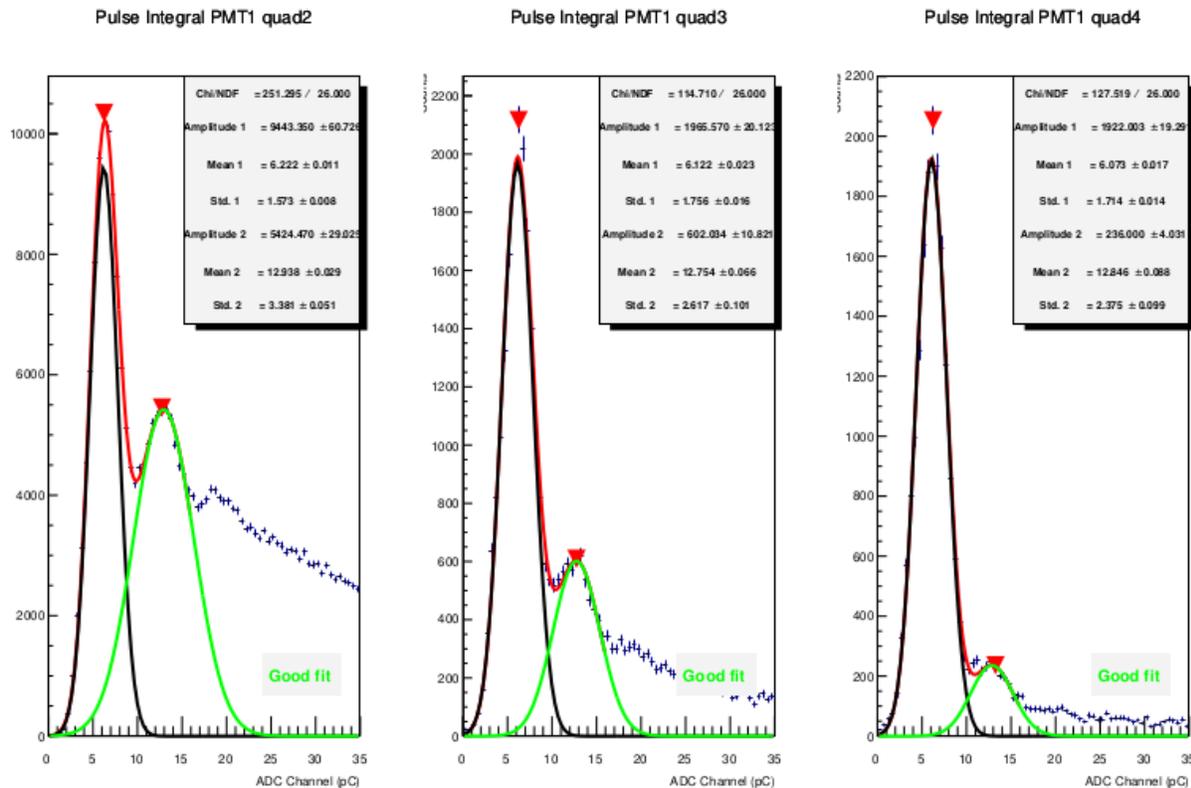

Figure 3: The separated photoelectron peaks fitted with the sum of two Gaussian for PMT1.

drawn from f(x).

To check the quality of the first set of calibration parameters and generate another set of calibration parameters for each PMT, a further study is conducted. A new histogram is

created to store the full calibrated spectrum for each PMT. This is done by filling a new histogram bin-by-bin with the previous histogram data for each PMT and scaled by the first set of calibration parameters. Mathematically, the new bin content is given by

$$b_i' = \frac{b_i}{\overline{\mu}},$$

where b_i' and b_i are the ith bins of the calibrated and uncalibrated spectra respectively and $\overline{\mu}$ is the error weighted average calculated previously for each PMT. This new histogram of the full distribution of Cherenkov light is then fitted with a new function, g(x), which is the sum of four Gaussian and two Poissonian functions (shown in figure 4 in yellow). In figure 4 all of the other functions are the individual functions drawn from g(x). This is the next step of the calibration algorithm and from this work we will also have a another set of calibration parameters for each PMT. The procedure of generating another set of calibration parameters is that the calibration algorithm takes the mean of the first photoelectron peak from the full distribution of Cherenkov light and multiplies it with the previously obtained calibration parameter (see line968 in calibration.C file) for each PMT.

Scaled ADC spectra for PMT1

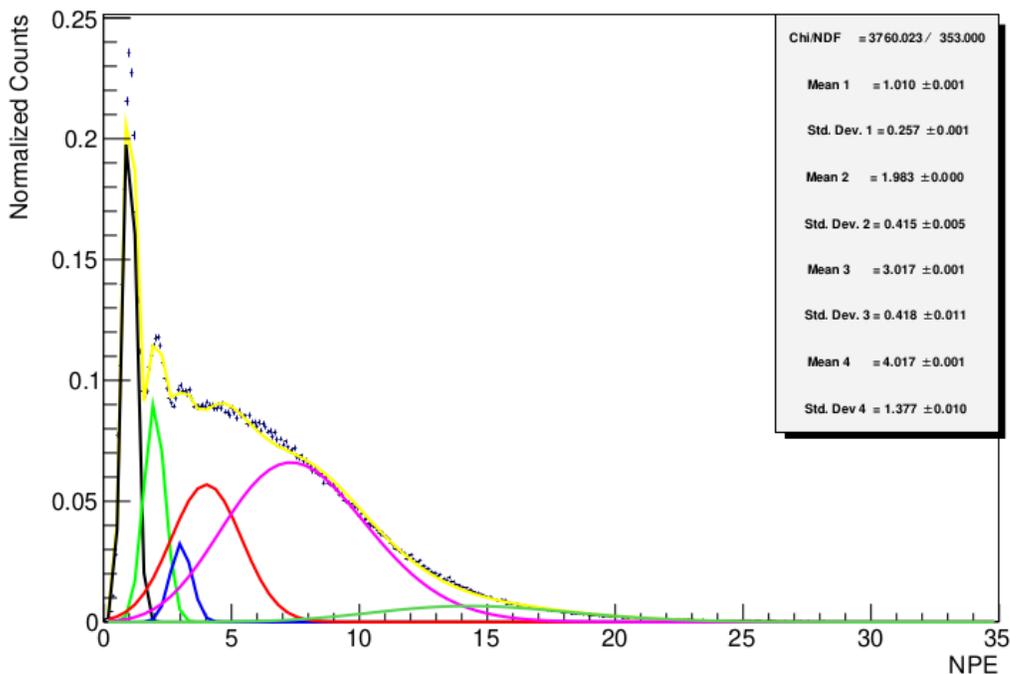|	
Chi/NDF	= 3760.023 / 353.000
Mean 1	= 1.010 ± 0.001
Std. Dev. 1	= 0.257 ± 0.001
Mean 2	= 1.983 ± 0.000
Std. Dev. 2	= 0.415 ± 0.005
Mean 3	= 3.017 ± 0.001
Std. Dev. 3	= 0.418 ± 0.011
Mean 4	= 4.017 ± 0.001
Std. Dev 4	= 1.377 ± 0.010

Figure 4: The full distribution of Cherenkov light scaled with the previously obtained calibration parameter for PMT 1.

In the full distribution of Cherenkov light, the initial few photoelectron peaks are easy to distinguish which we can see when you zoom in the plot as in figure 5.
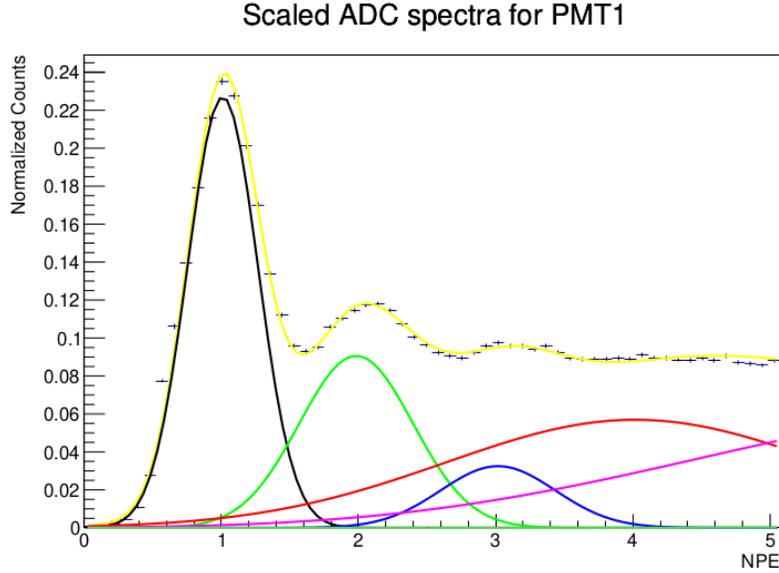
Figure 5: The zoomed (0- 5 NPE) version of the full distribution of Cherenkov light scaled with the previously obtained calibration parameter for PMT 1.

The last part of the calibration work is checking the linear spacing of the initial three photoelectron peaks. This is depicted in figure 6, where three photoelectron peaks are fitted with two linear functions. In the first linear function, the intercept variable is fixed at zero (shown in red) whereas in the second linear function, the intercept variable is a free parameter (shown in black).
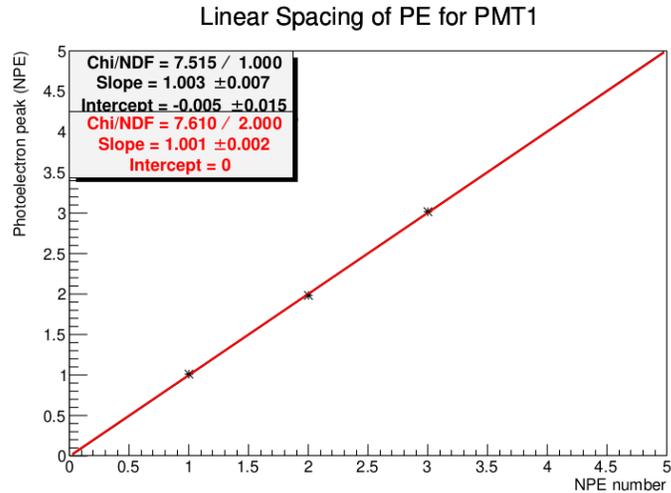

Figure 6: The plot of the linear spacing of the PE from the 1st, 2nd and 3rd Gaussian peaks for PMT 1. The plot has been fitted with two functions (black and red), the resulting fit parameters can be seen in the statistics box in the top left of the plot.

4 Conclusions

The calibration algorithm produces two sets of calibration parameters for each PMT. The first (file name in blue in the output files section) text output file of the calibration parameters contains the final calibration parameters (error weighted average from the two sets) only. The second (file name in red in the output files section) text output file is created to study the parameters in more detail, for example by checking their consistency over time throughout an experiment. In this file, there are three sections (two sections for the two sets of calibration parameters and last section for the error weighted average) of the calibration parameters (each parameter is produced with its error). From the analysis of Kaon LT and Pion LT experimental data, there was no indication that one set was more consistent than the other. Therefore our group has decided to just take the error weighted average from the two sets of calibration parameters and use this as the final calibration parameters for each PMT. Users can carry out their own studies to examine the consistency of the calibration parameters with the information included in the second output file. If users find that one set is more consistent than other then they should use that set as the final calibration parameters. They can edit the code to save that set of the calibration parameters as the final calibration parameters in the first text output file for each PMT. Otherwise, the error weighted average from the two sets of calibration parameters is an ideal solution. This is also what is used by default in the first output text file.

In table 1, there is a comparison of the new calibration parameters (from both sets and error weighted average) to the original parameters that we were used in our online analysis.

PMT No	Cal Par	Cal Par from Quality work	Error Weighted Ave	Old Par
1	6.17 ± 0.008	6.237 ± 0.011	6.19 ± 0.006	6.26
2	6.82 ± 0.010	6.839 ± 0.013	6.82 ± 0.007	7.30
3	5.36 ± 0.013	5.384 ± 0.015	5.37 ± 0.009	5.85
4	6.86 ± 0.039	6.893 ± 0.045	6.87 ± 0.029	6.98

Table 1: The comparison of the new calibration parameters and their error weighted average to the old calibration parameter values. The new calibration parameters are produced from a calibrated set of the three run numbers (6918, 6919 and 6920).

The new calibration parameters in table 1 has been obtained from a calibrated set of the three run numbers (6918, 6919 and 6920). As we can see that there are significant changes in the new calibration parameters as compared to the old ones. The parameter for PMT 1 is shifted 11.67 σ. PMT 2 & 3 the parameters are shifted 68.57 σ and 53.33 σ respectively. While the parameter for PMT 4 is shifted 3.79 σ. The new calibration algorithm is very transparent to understand the quality of the calibration parameters. Users can find more plots and discussions of the new calibration algorithm in the slides of the talk which is presented by the author in the hallc commissioning analysis meetings on Oct 29, 2020.

References

[1] George Ryan Ambrose, M.Sc. Thesis (2019), Blinded by the Light: Commissioning of the Hall C SHMS Heavy Gas Cherenkov Detector. Master's thesis, University of Regina.

[2] Vijay Kumar, KaonLT Collaboration, https://github.com/JeffersonLab/hallc_replay/tree/master/CALIBRATION/shms_hgcer_calib Accessed, Oct 20, 2020

[3] ROOT @ cern, https://d35c7d8c.web.cern.ch/developing-tselector Accessed, Jul 30, 2020.