SHMS Nobel Gas Cherenkovs Calibration Analysis

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1 Nobel Gas Cherenkovs

Cherenkov counter is wildly used as a tool for particle identification in nuclear and particle physics. When a charged particle travels faster than the speed of light in a medium, it will emit cherenkov light [1]. Thus for incident charged particles' momentum be fixed by a magnetic spectrometer, the Cherenkov counter with appropriate choice of medium will separate particles that travel faster than the speed of light from particles that travel slower than the speed of light in that medium [2]. Photomultiplier tubes (PMT) are used to convert the received Cherenkov light signals into electrical pulses, so that the resulting photoelectrons could be counted and recorded [1].

After the 12 Gev upgrade at JLab, the SHMS in Hall C will analyze momenta up to 11 GeV/c at scattering angles from 5.5 to 40.0 degrees [2]. Under these kinematic regions, the pion background rate is much greater than the scattered electron rate which the ratio of pion rate over electron rate is more than 1000:1 [2]. Therefore, as an important part of the detector package, the Cherenkov counter combined with magnetic spectrometer and shower counter will separate the scattered electrons from strong pion background [2].

For Cherenkov radiation, we have equation:

$$cos\theta_c = \frac{1}{\beta n} \tag{1}$$

Where n is the index of refraction of the medium, β is the incident particles velocity and θ_c represents the Cherenkov angle [1]. Then the condition for emittion of Cherenkov radiation is when $cos\theta_c < 1$ which is equivalent to:

$$n > \frac{1}{\beta} \tag{2}$$

In order to separate electron from pion, the medium of Cherenkov counter is choose to satisfy:

$$\frac{1}{\beta_{e^-,min}} < n < \frac{1}{\beta_{\pi,max}} \tag{3}$$

So that all the scattered electrons will emit Cherenkov light while all the pions will produce no radiation directly [2]. The Argon/Neon nobel gas mixture will have appropriate index of refraction that satisfy Eq. 3 for SHMS momentum range around one atmosphere pressure [2]. Thus a Nobel Gas Cherenkov (NGC) detector is designed to identify scattered electrons and supress the pion background for SHMS [2].

The current Nobel Gas Cherenkovs (NGC) intalled in SHMS contains four mirrors and each of them focusing the Cherenkov light to the corresponding PMTs. The left panel of Figure 1 shows the geometry of the NGC detector, while the right panel illustrates the detection of Cherenkovphotons radiated by a single electron [2].

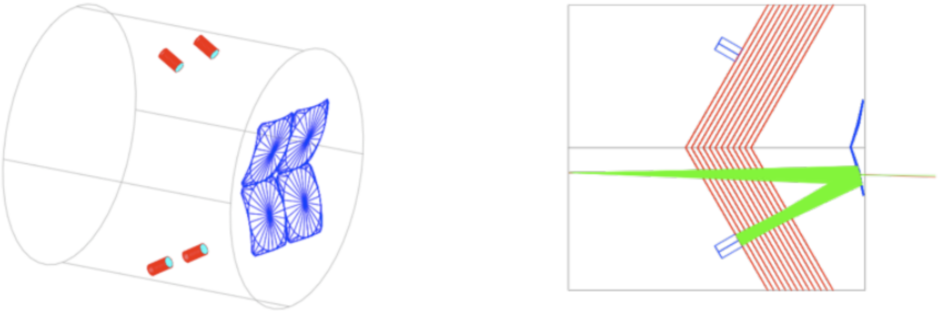


Figure 1: Left: The geometry of the SHMS Noble Gas Cerenkov. Four mirrors which placed at one end of the 2.5 m long tank, focusing Cherenkov light to the corrseponding PMTs placed at the other end of the tank [2]. Right: Side view of the NGC apparatus for detection of Cherenkovphotons radiated by a single electron, The red lines represents virtual planes where the positions of the photons are recorded [2].

2 Calibration Analysis

In SHMS replay root files, the calibration is already implemented for number of photoelectrons (NPE) produced by each PMT. According to Ambrose and Huber, the calibration is determined using quadrant and tracks-fired strategies [3]. The quadrant strategy use post-replay processing to isolate the single photoelectron peak (SPE) in PMT pulse integral ADC, while the traks-fired strategy use the inherent cuts in hcana to isolate SPE [3]. After the determination of SPE, the calibration is done by:

$$NPE = \frac{ADC_{\text{PMT}}}{ADC_{\text{SPE}}} \tag{4}$$

In this paper, we aimed to analyze the calibrated NPE data and test the quality of above calibrations. We use the root software and SHMS run 2732 to 2744 data to do the analysis [4]. Since the four PMTs in NGC receive Cherenkov light from four mirrors, we could track matching the NPE data from each PMT into its corresponding quardent in xy mirror plane. The track matching follows:

$$x_{\text{NGC}} = x_{\text{Focal Plane}} + \theta * z_{\text{NGC}} \tag{5}$$

$$y_{\text{NGC}} = y_{\text{Focal Plane}} + \phi * z_{\text{NGC}} \tag{6}$$

Where θ, ϕ are angles for tracks deviate from z-axis in x, y direction respectively [3]. For both θ, ϕ be small angle, we use small angle approximation to get Eq. 5 and Eq. 6.

$z_{\mathrm{NGC}} = -89.1\mathrm{cm}$ is the z position of NGC relative to the focal plane. Once we get xy position in the mirror plane of NGC for all events, we could make a histrogam of NPE on mirror plane by setting the corresponding NPE number as weight for each event. From Figure 2, we observe that NPE produced by PMT0 lies mainly on the first quarant of xy mirror plane. Similiarly, NPE produced by PMT1, PMT2 and PMT3 lies on fourth, second and third quarant respectively.

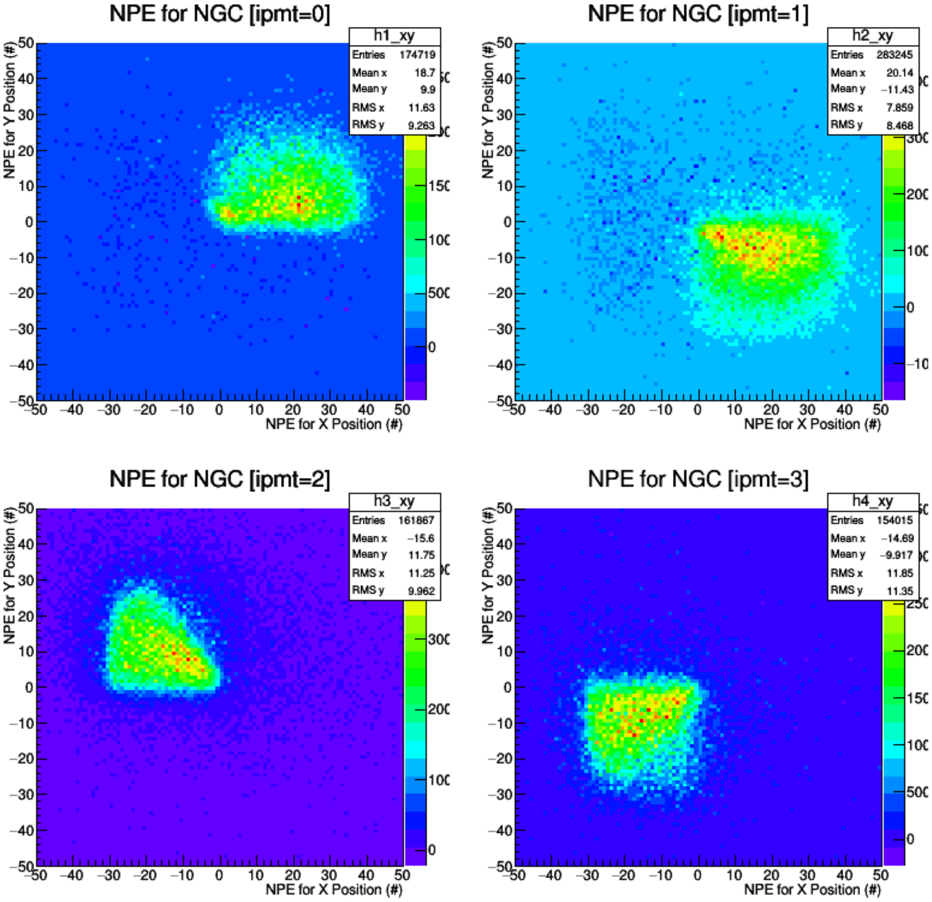


Figure 2: Histogram of NPE on xy mirror plane of NGC for four PMTs. All the histrogams contain $100 * 100$ bins with both x-axis and y-axis range $[-50, 50]$.

2.1 Average NPE

In this anaysis, the Beta cut and shower/preshower cut are applied to all track matching results from Eq. 5 and Eq. 6 for each PMT. The Beta cut used is: $|\beta - 1.0| < 0.2$, see Figure 3.

For shower/preshower cut, since the central momentum p for SHMS has 10% to 15% deviation, we make preshower/p vs shower/p plots to have a more proper acceptance of events, see left panel of Figure 4. Then we apply Beat cut, goodAdcPulseTime cut ($|\mathrm{goodAdcPulseTime} - 50.0| < 10.0$) and goodAdcTdcDiffTime cut $|\mathrm{goodAdcTdcDiffTime} + 20.0| <$

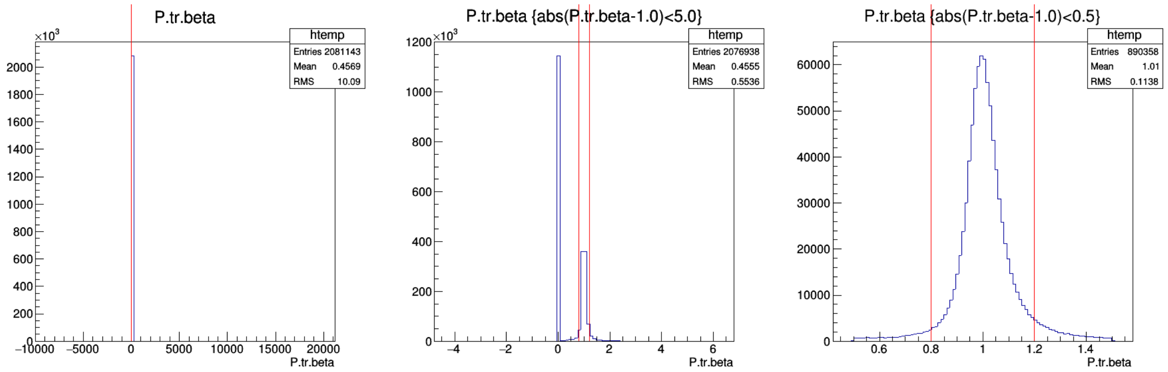


Figure 3: Illustration of Beta cut $|\beta - 1.0| < 0.2$, the red lines indicate where the cut is applied.

10.0) to have a better view of the region of electrons, see center and right panel of Figure 4. Then, we used three lines to make a 2D cut to select region of electrons, see Figure 5.

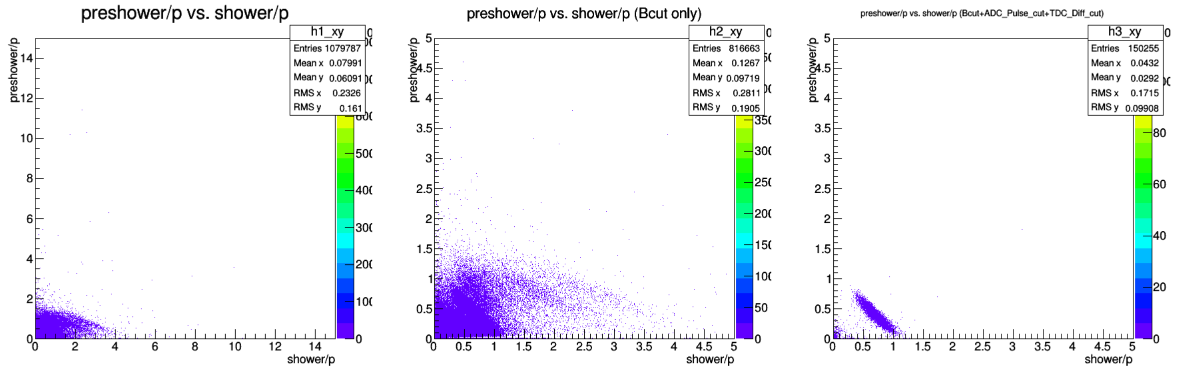


Figure 4: Plot of preshower/p vs shower/p which is used to separate electrons from pions. Left: no cut. Center: only Beta cut. Right: Beta cut + goodAdcPulseTime cut + goodAdcTdcDiffTime cut.

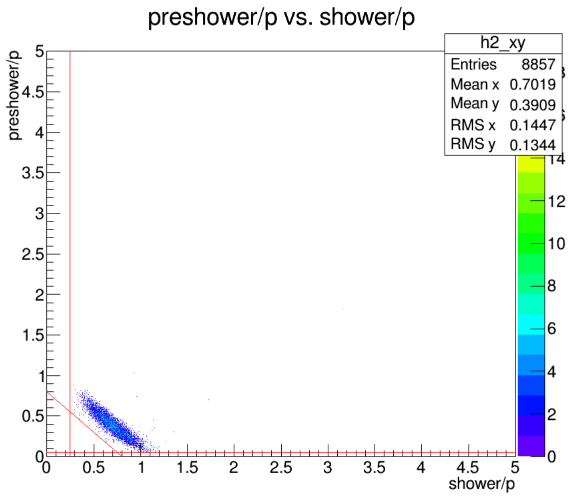
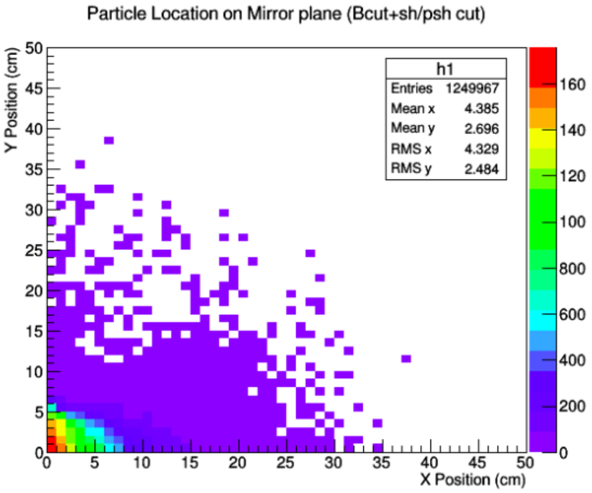


Figure 5: Plot of shower/preshower cut, the three rad lines indicate the 2D cut to select the electrons.



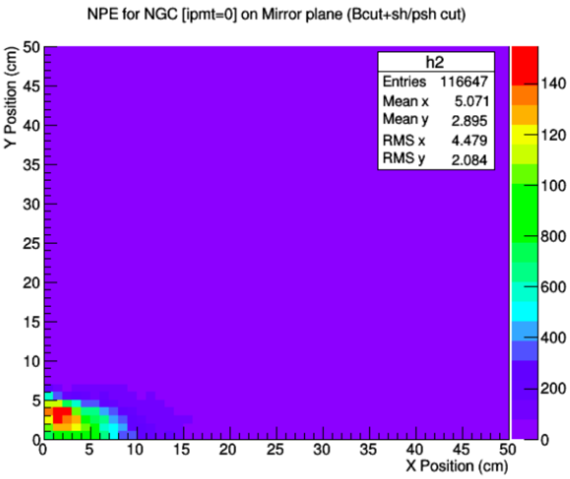


Figure 6: Event tracking histogram under Beta cut and shower/preshower cut (h_1) for PMT0. h_1 for the other PMTs are similiar.

Figure 7: NPE histogram on xy mirror plane under Beta cut and shower/preshower cut (h_2) for PMT0. h_2 for the other PMTs are similiar.

After applying the Beta cut and shower/preshower cut to track matching results, for each PMT, we make the event tracking histograms (h_1) with bin content be the number of events fall in the bin area on mirror plane and the weight of each event be 1 ($w = 1$), see Figure 6. Then based on h_1 histograms, we make a new set of histograms (h_2) by changing the weight from $w = 1$ to $w = NPE$ for the corresponding NPE value for each event. Then the result bin content for h_2 becomes number of events $*$ NPE, see Figure 7. Therefore, based on the bin content for h_1 and h_2, we compute the average NPE for each bin by taking the ratio of h_2 to h_1:

$$< \text{NPE} >= \frac{\text{NPE} * \#\text{event}}{\#\text{event}} \rightarrow h_3 = \frac{h_2}{h_1} \tag{7}$$

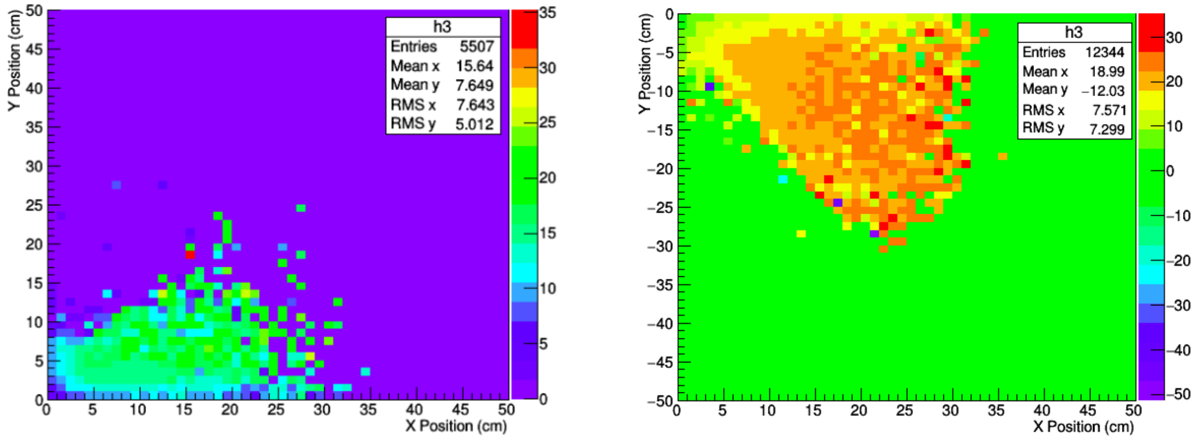
Here h_3 represents the set of histrogams which shows the average NPE on mirror plane, see Figure 8.

2.2 Efficiency Map

We define the efficiency, η, to be how many electrons are correctly selected for a cut on NPE [3]. Then the efficiencies are computed by taking the ratio of particles selected with the NGC cut (N_2), divided by the clean electron cut (N_1) which are particles selected without the NGC cut:

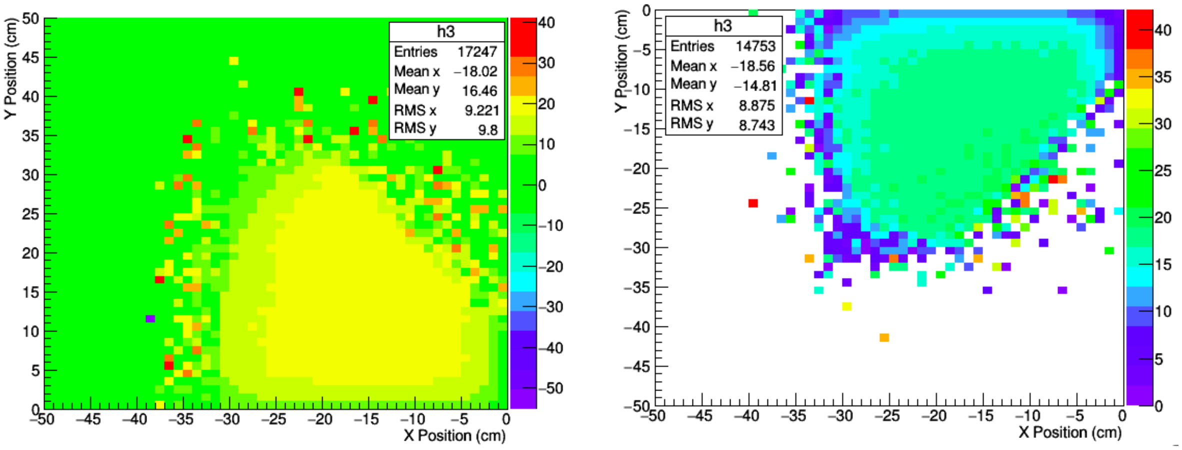
$$\eta = \frac{[\text{Particle ID}][\text{Beta}][\text{Cherenkov}]}{[ParticleID][Beta]} \rightarrow \eta = \frac{N_2}{N_1} \tag{8}$$

Where [Particle ID] is the shower/preshower cut and [Beta] is the Beta cut described in section 2.1. [Cherenkov] is the NGC NPE cut: NPE> 0. In section 2.1, we already obtained the N_1 values which is the clean electron cut histograms h_1. Then we created a new set of histograms h_4 for N_1 by appling NGC cut to h_1, see Figure 9. Then the efficiency histrogams h_5 are created by: $h_5 = \frac{h_4}{h_1}$, see Figure 10. Since N_1, N_2 are both



(a) PMT0

(b) PMT1



(c) PMT2

(d) PMT3

Figure 8: Histograms of average NPE (h_3) for all four PMTs.

integers, we will have error in the calculation of efficiency for the fraction part of N_2 values are rounded to the nearest integer. Therefore, the modified efficiency and the corresponding error are considered in two cases:
Case 1: $N_1 = N_2$

$$\begin{aligned} \eta &= \frac{N_1 - 0.25}{N_1} \\ \delta_1(\eta) &= 0 \\ \delta_2(\eta) &= \frac{0.25}{N_1} \end{aligned} \tag{9}$$

Case 2: $N_1 > N_2$

$$\begin{aligned} \eta &= \frac{N_2}{N_1} \\ \delta_1(\eta) &= \frac{\sqrt{N_2\left(1 - \frac{N_2}{N_1}\right)}}{N_1} \\ \delta_2(\eta) &= \frac{0.5}{N_1} \end{aligned} \tag{10}$$

Then the total error for efficiency is given by:

$$\delta_{\text{tot}}(\eta) = \sqrt{{\delta_1}^2 + {\delta_2}^2} \tag{11}$$

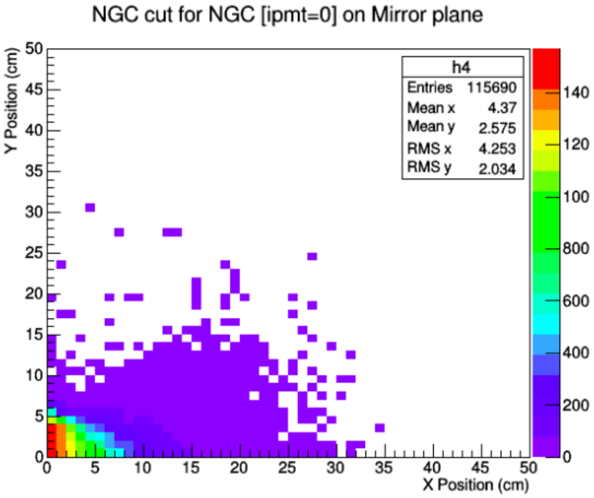
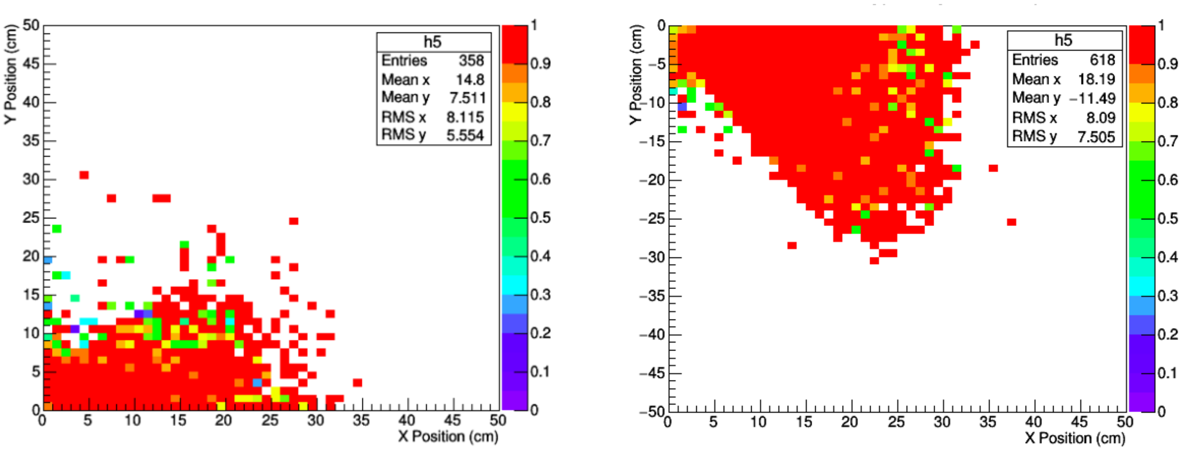


Figure 9: Event tracking histogram under Beta cut, shower/preshower cut and NGC cut (h_4) for PMT0. h_4 for the other PMTs are similiar.

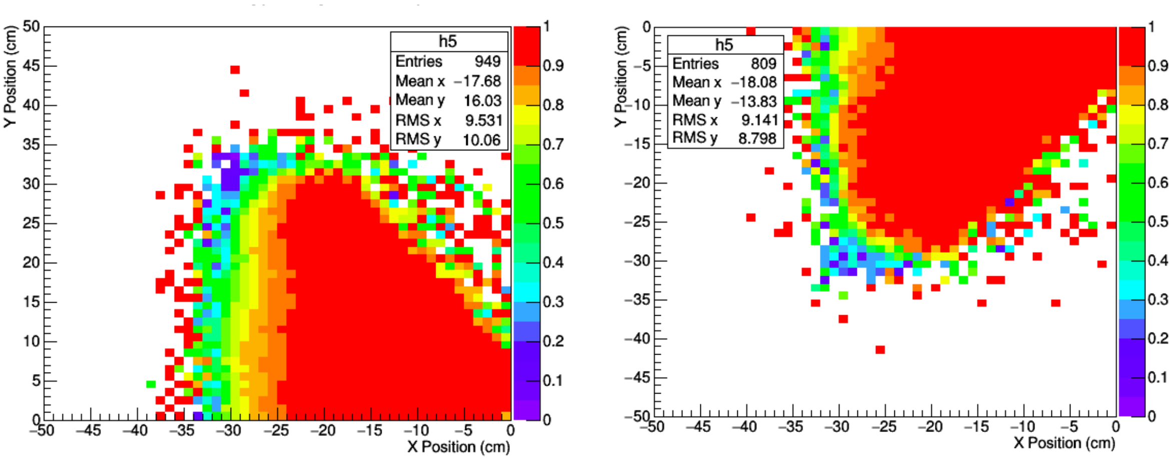
2.3 Efficiency vs. <NPE>

Once we get the average NPE (h_3) and the efficiency map (h_5), we could correlate the bin content of h_3 and h_4 to get η(<NPE>) for every bins in xy mirror plane. Then we



(a) PMT0

(b) PMT1



(c) PMT2

(d) PMT3

Figure 10: Histograms of efficiency map (h_5) for all four PMTs.

plot η vs. <NPE> with <NPE> be x-axis and η be y-axis. In order to have a better resolution on <NPE>, we divide the <NPE> axis (x-axis) into ceil(10$*$ <NPE>$_{max}$) number of bins and caluclate the average value as well as average error of η(<NPE>) located in each <NPE> bins, see Figure 11. Theoretically, the η(<NPE>) obey poisson distribution:

$$\eta = 1 - e^{-\lambda \text{<NPE>}} \tag{12}$$

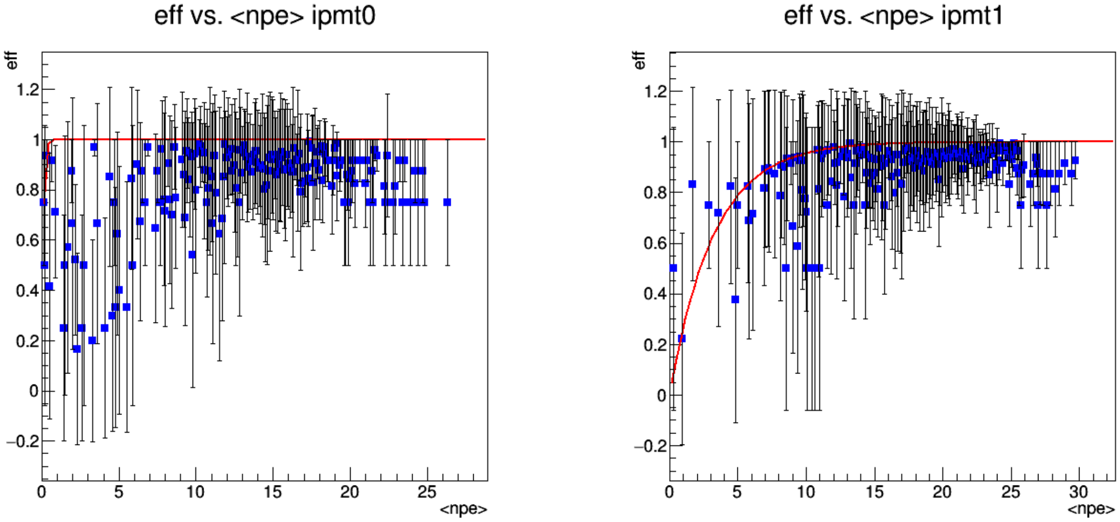
Where the constant $\lambda = 1$ in theory. Thus, we could test the calibration of <NPE> by fitting η(<NPE>) with Eq. 12 which λ is the only fitting parameter to see whether the fitted λ is close to the theroetical value 1. According to the fit given by root software, we get the red fit curves in Figure 11, and we obtain the λ values and their errors for each PMT, see Table 1.

Table 1: Fitting parameter λ and corresponding errors for all four PMTs.

PMT	λ	Error
0	9.47150e+00	3.47087e+00
1	3.11849e-01	3.00086e-02
2	1.03719e+00	1.07404e-01
3	1.91089e-01	2.01292e-02

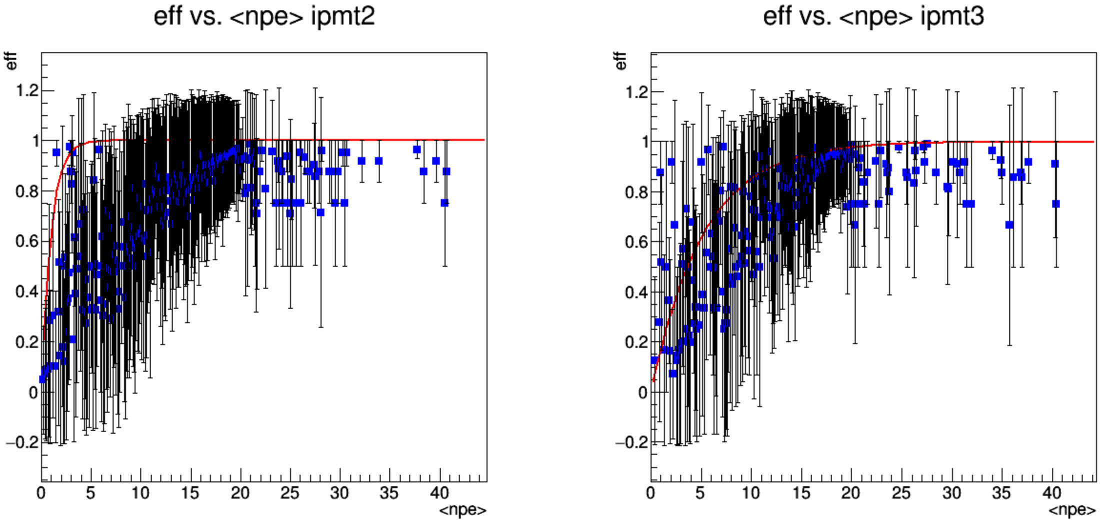
3 Conclusion

According to the results in Figure 11, we need to combine the weighted statistical error with systematic error (from interger values of N_1 and N_2) correcely to reduce the error bars on efficienty data for higher statistics. This may change the fitting parameter results for λ in Table 1. If $\lambda \approx 1$, this suggests that the origional calibration of NPE in the SHMS replay root files for NGC obeys the poisson distribution and it is done correctly. If λ is not close to 1 within $\pm 2\sigma$ of error, this suggests that the origional calibration of NPE is not done correctly. However, more statistics from more SHMS run data are needed to confirm our analysis result.



(a) PMT0

(b) PMT1



(c) PMT2

(d) PMT3

Figure 11: Plots of efficiency vs. <NPE> for all four PMTs.

Reference

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