Hadronic Calorimeter Cosmic Muon Calibrations

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1 Introduction

The sPHENIX experiment has two layers of hadronic calorimeter (HCal). The outer HCal (OHCal) is outside the solenoid coil, and the inner HCal (IHCal) is inside the magnet. For both OHCal and IHCal, there are 32 sectors in azimuth. Mechanically, an OHCal sector has 10 scintillator slots extending along the z-axis. For the IHCal, there are 8 slots. Each sector is divided into two azimuthal segments, each subtending $\Delta\phi \approx 0.1$. Each scintillator slot is instrumented with 24 "tiles" of varying sizes to provide segmentation in the longitudinal direction of $\Delta\eta \approx 0.1$. The different sizes and shapes are designed to make each tower projective in the η direction. A mechanical sector therefore contains 2 (ϕ-segmentation) $\times$ 24 (η segmentation) = 48 towers, with each tower containing 4 tiles (IHCal) or 5 tiles (OHCal). An analog sum of the light from the tiles in each tower is presented to a Hammamatsu Silicon Photomultuplier (SiPM). The SiPM output pulse passes through a pre-amp/shaper and is then digitized.

Figure 1: Schematic drawing showing the location of the calorimeters in the sPHENIX experiment.
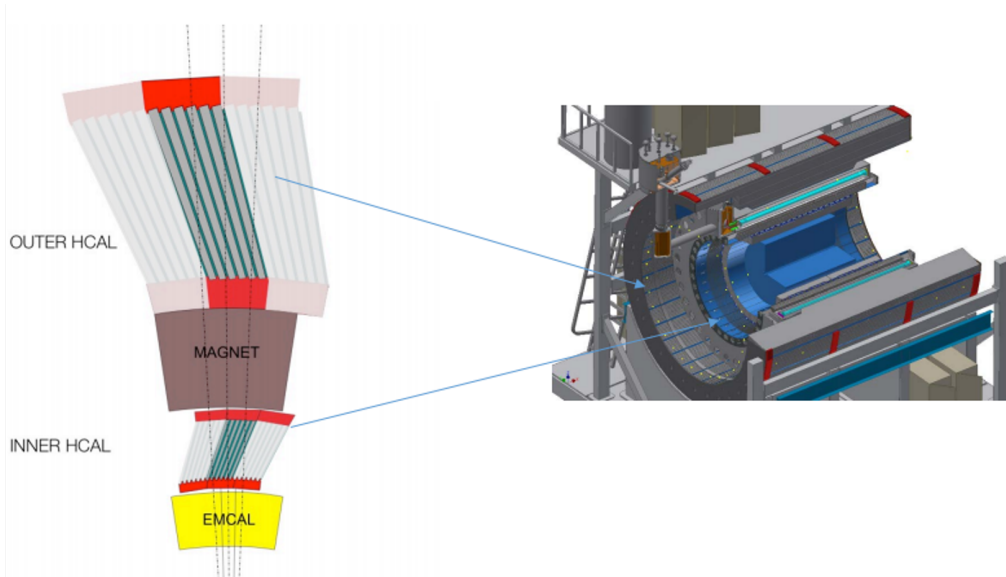

This note concentrates on calibration for the HCal using cosmic muons. We collect the energy deposits of muon particles passing through the sectors, and select events where the muons pass through all tiles in a tower. Our primary diagnostic is the Most Probably Value (MPV) for the ADC distributions for such events. The MPV's are then subjected to corrections for temperature and the Performance Ratio (PR) of the tiles in each tower.

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Figure 2: Assembled sectors are shown in Building 912 at Brookhaven. The segmentation of each physical assembly is $2(z) \times 24(\eta)$.

(a) A typical fit used to determine the Most Probable Value of the pedestal-subtracted ADC distribution for cosmic ray muons in an HCal sector
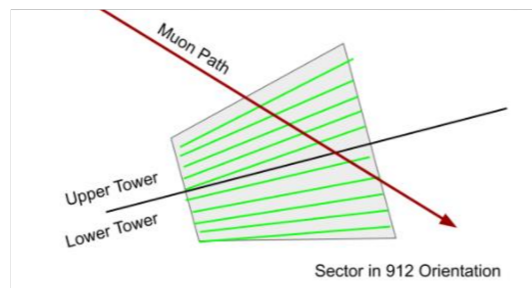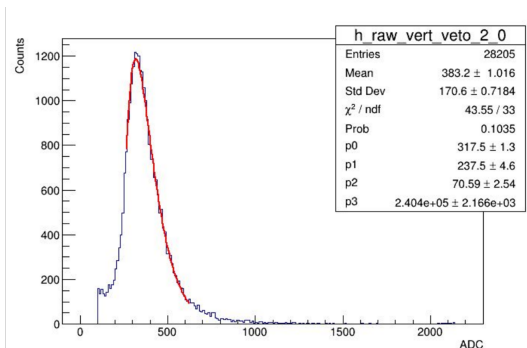
(b) Schematic illustration of cosmic ray muon paths leading to the "platform" structure seen for ADC values below ~ 200.

Figure 3: Features of the sPHENIX HCal cosmic ray muon triggering and testing.

2   Signal Collection and Events Selection

To perform the cosmic muon calibration for the OHCal the assembled sector is oriented as shown in Figure 2 so that the tiles are roughly horizontal (the "Building 912" orientation. In this case we have a row of upper towers and a row of lower towers, and vertical muons would pass through all tiles in a tower. For the IHCal, the sector is roughly 90 degrees from the Building 912 orientation so there is a row of left towers and a row of right towers. The tiles in this configuration are roughly vertical, which requires a nearly horizontal muon to pass through all the tiles in a tower.

A single cosmic muon event is shown in Fig.4, which is for the OHCal in the Building 912 orientation, where we see the muon penetrating the penultimate column. We can see the detailed signal in the first figure of Figure5, which shows the waveform of the ADC output, which samples at 6x the 9.4 MHz RHIC beam clock. The ADC value that is used in subsequent studies is the peak waveform value minus the pedestal, with the pedestal determined from the average value of the first three samples.

To obtain a well-defined calibration signal, we use cuts to select muons with a direction roughly perpendicular to the plane of the scintillator tiles. For the OHCal, we first require that both towers in a vertical direction have signal so so that events like the third panel shown in Figure5 will be rejected. In order to eliminate muon directions that pass partially through neighboring towers, we require that
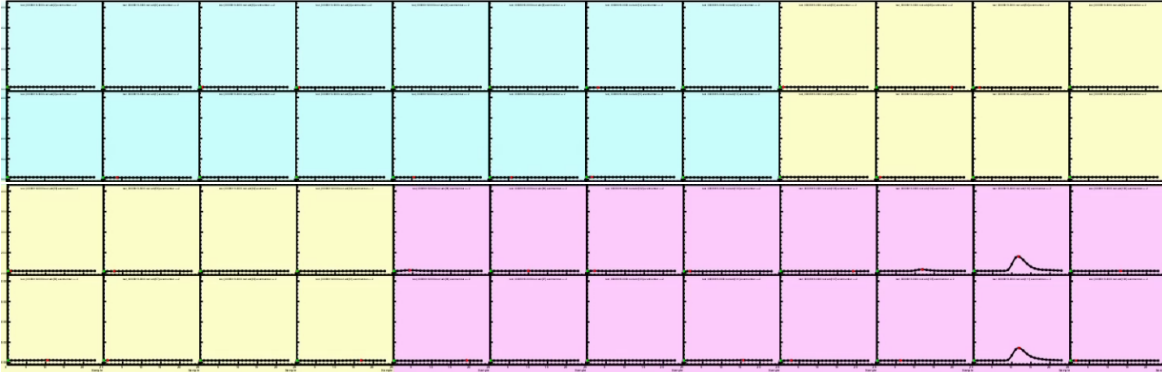
Figure 4: The signals from 48 towers in a sector for one hit are shown at the same time. The 48 towers are shown in two lines. The blue towers are the south part; the yellow towers are the middle part; and the red towers are the north part.

the 4 neighboring tower have no signal. Events like the fourth panel shown in Figure5 will be rejected by this cut. These two cuts are sufficient for the OHCal, because its orientation is ideal for dominantly vertical muons. However, for the IHCal, where tests were made for sectors rotated roughly 90 degrees from the OHCal orientation, we needed an additional cut to ensure that the muon goes through all tiles in the tower. The extra cut is the energy difference cut that requires a tower to have a signal not smaller than its vertical pair tower's signal minus 150 ADC.

The results after the cut we applied are shown in Figure6. The left one is the distribution of oHCal, and the right one is for iHCal. After the cuts we applied, we can see the peaks are shown up. And because one hour cosmic run with iHCal has a small entry, so, we usually do 12 one hour cosmic runs for each iHCal sector, and then add them together to do the calibration. And to ensure that our cut works well and select the right peak we want. So, we also did some 3 tower tests to check it. The 3 tower cut is that we place an extra tile beside a particular tower, and use this tile and the tower on the other side to get coincidence. So, we can get the muon that goes through the whole tower. Here is an example for the 3 tower test of oHCal in Fig.7, the left one is the distribution after our cut, and the right one is the 3 tower cut. Because the peak positions are very similar after these cuts that the difference is smaller than 1%. So, we believe our cut works well.
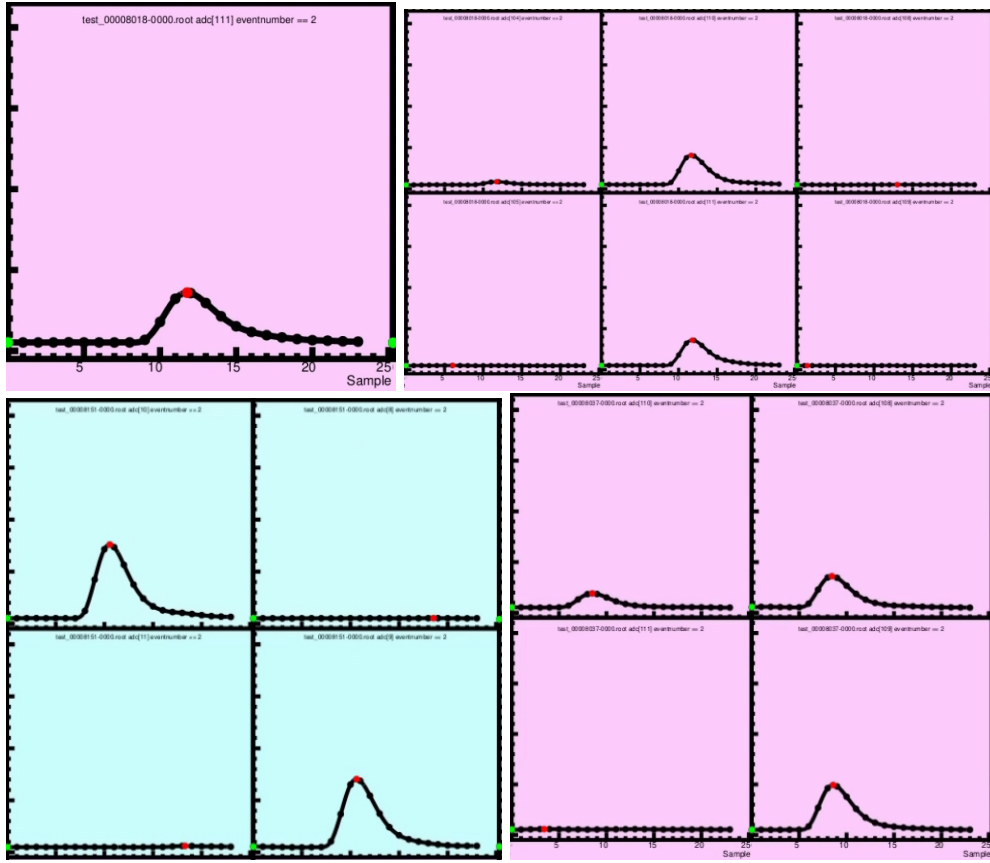
Figure 5: The first figure is an example of the waveform in a single tower. The second figure is an example of a good event that would pass all cuts. The third and fourth figures are examples of bad events.
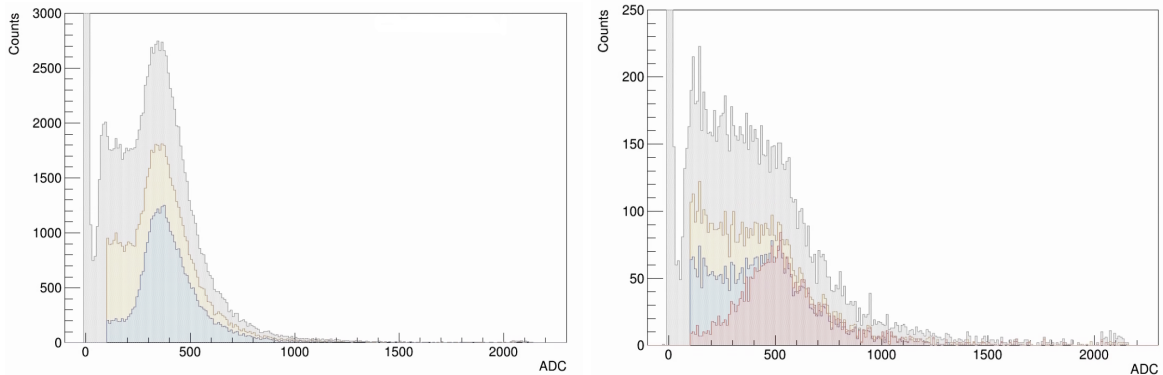

Figure 6: The left figure is the distribution of one hour cosmic run with oHCal, and the right figure is one hour cosmic run with iHCal. The grey distribution is the raw data. The yellow distribution is after the vertical tower cut. The blue distribution is after the neighboring tower cut. The red distribution is after the energy difference cut.
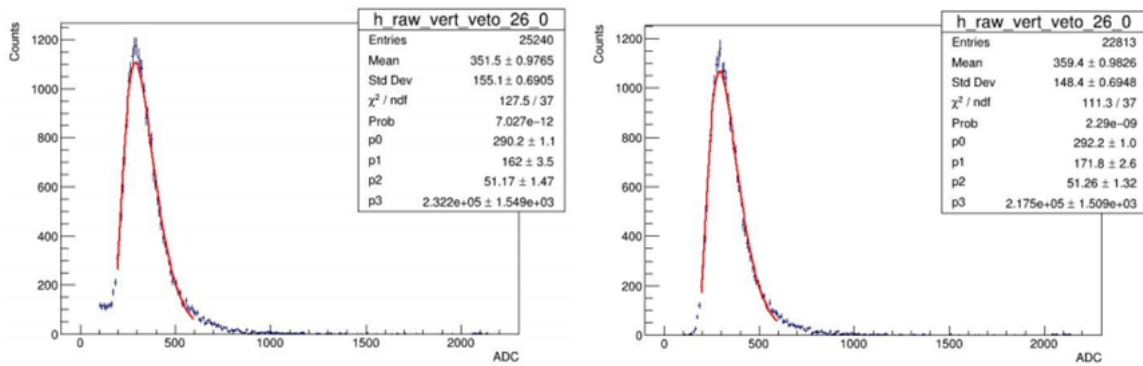
Figure 7: This is an example based on the oHCal. The left figure is the distribution after vertical and neighboring tower cuts. The right figure is the distribution after 3 tower cut. The parameter p0 is the peak position of the fitting.
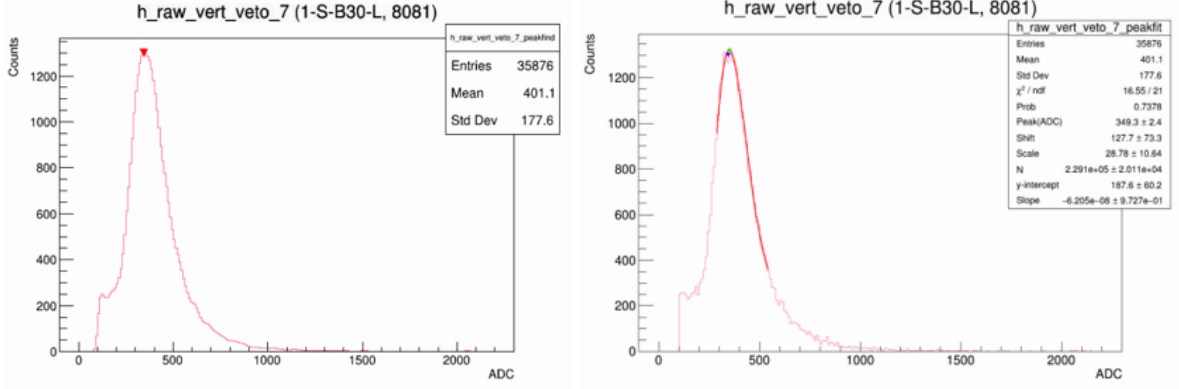
3 Peak Fitting

Figure 8: This is an example based on an oHCal tower's one hour run. The left figure peak finder's result. The right figure is the fitting result.

After collecting the events and applying the cuts, we get the reliable distribution with obvious peak that refers to the muons energy deposit which passes the whole tower. To find the accurate MPV value, we first use the peak finder algorithm to find the rough peak position, and then based on this results, we use the Gamma function plus the linear function (func1) to fit the range around the rough peak position to get the precise peak. This is our goal of fitting and it's our calibration object with the cosmic ray. In the fitting function 1, we change the form of Gamma function to get the mode value of Gamma function directly, instead of getting the shape parameter. Parameter m is the mode of Gamma function. Parameter u is the shifting of the Gamma distribution along x-axis. Parameter θ is the scale of Gamma function. And there is a linear function $ax + b$ following the Gamma function.

$$f(x) = \frac{N \left(\frac{x-u}{\theta}\right)^{\frac{m-u}{\theta}} e^{-\frac{x-u}{\theta}}}{\left(\frac{m-u}{\theta}\right)! \theta} + ax + b \tag{1}$$

Before the fitting, firstly, we apply the peak finder algorithm that is based on the TSpectrum function. We rebin the original histogram to make the bin width is 20 ADC, and do smooth function twice to prepare for the peak finder. And then use the TSpectrum peak finder the get the highest peak between 100 and 1800 ADC. The left figure in Fig.8 is an example of the peak finder's result for oHCal.

Then we can fit the distribution around the peak finder's result. We use the function in Equation 1 to fit the original distribution, then use the GetMaximum algorithm to get the maximum of the whole function as our MPV. The fitting is only applied to the range around the peak, between the peak finder's result minus 50 ADC and plus 200 ADC, instead of the whole distribution. The fitting result is shown in the right figure in Figure 8.

4 Corrections on the MPV

Since the MPV is influenced by some factors. We mainly applied two corrections on the MPV. The first one is the PR correction. Because the tiles have different performance even with the same tile shape. PR correction is applied to eliminated this difference within the same tile shape (measured by people from GSU). Each tile's PR is given as the ratio of measured output to the expected output. We use the mean value of the tiles in the tower as the tower's PR to do the PR correction with Equation 2.

$$MPV_{PR-corrected} = \frac{MPV_{Raw}}{PR} \tag{2}$$

After PR correction, with the same tile shape, the towers are hoped to have the same performance. But because the PR is measured for each tile shape separately, this correction just eliminates the

performance difference of the towers that have the same tile shapes. We will apply more effort to eliminate the difference between different tile shapes.

Then, because the SiPMs have different performances at different temperatures that higher temperature intends to give a lower result. We hope to apply a temperature correction as a linear relationship and take 26 degree as a standard to do the correction, with Equation 3.

$$TPR = 1 - \alpha * (T - 26) \tag{3}$$

And then, we applied a similar equation to do the temperature correction with Equation 4.

$$MPV_{TPR-corrected} = \frac{MPV_{Raw}}{TPR} \tag{4}$$

The parameter α is the difference of MPV with 1 degree temperature difference. To get the parameter α, we need several runs for the same sector, and use the difference between these runs to get it. In Eqn.5, if we have two runs, we can use the relationship between δm and M, which represents the terms after α, to get α, as shown in Figure 9. For oHCal, m is the MPV, while for iHCal, m is the mean, because there are not enough events for an iHCal's one-hour run. We can use mean to get this relationship can reduce the influence of fluctuations. The temperature data is measured by the thermometer attached to the pre amp board of each tower, and is output at the beginning and the end of each one hour run. We use the mean value of these two data. And for each one-hour run, we use directly the temperature of each tower for oHCal, and we use the mean temperature of the all towers to be the data we use for iHCal. As a result, we can get the parameter α that 3.8% for oHCal. However, for iHCal, the parameter α is not stable.

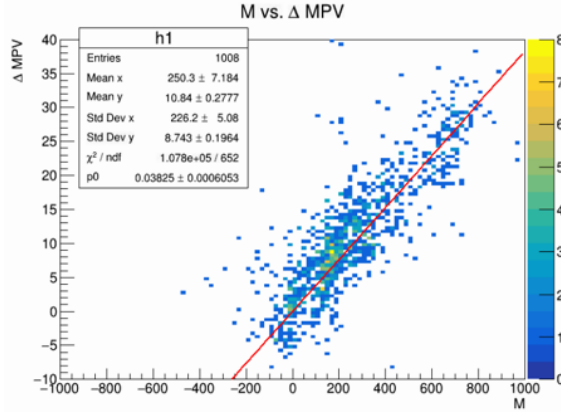$$m_1 - m_2 = \alpha * [m_1(t_2 - 26) - m_2(t_1 - 26)] \tag{5}$$

Figure 9: This is the relationship between δm and M for oHCal.

The temperatures of each tower in iHCal runs have a large distribution from 16 degree to 32 degree, as shown in Figure 10. To eliminate the influence of the difference of parameter α in different temperature range, we try to get the α with the method shown in Equation 5 with different temperature separately.

The polynomial fitting of the alpha distribution gives that $\alpha_{(T)} = -0.0001108T^2 + 0.007398T - 0.06369$. Based on this expression, we applied the temperature correction to iHCal with Eqn.6.

$$TPR = 1 - \int_{26}^{T} (-0.0001108x^2 + 0.007398x - 0.06369) dx \tag{6}$$
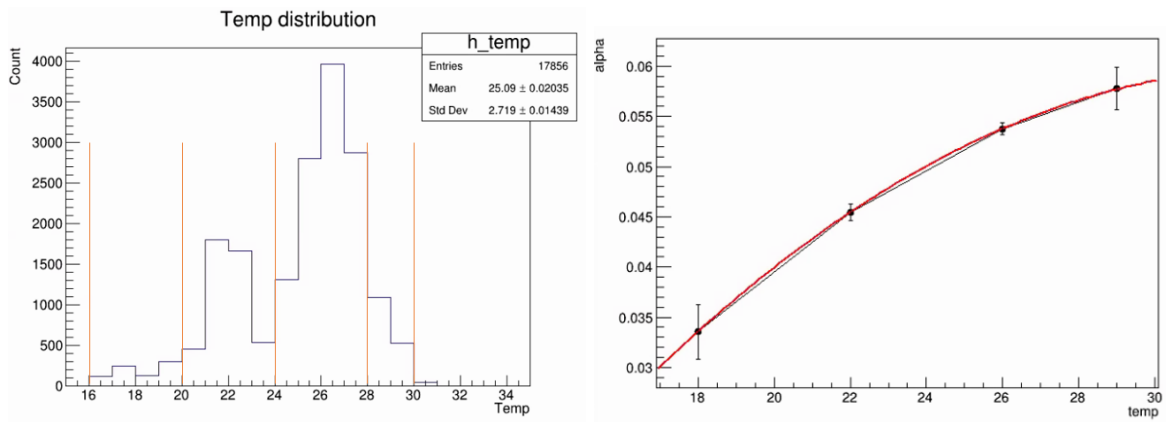
Figure 10: The temperature distribution and temperature range we use to get $\alpha_{(T)}$ (left), and the α distribution (right).

For oHCal, we apply the temperature correction after we get the MPV. But for inner HCal, because we use 12 one hour runs, and in order to eliminate the influence of temperature change during these 12 hours, we apply the temperature correction before we add them together.

5 Results

After finding the MPV and applying the corrections, we can now get some comprehensive results after we did cosmic runs for all sectors. Figure 11 is all towers' MPV in the outer HCal with tile shape B21, which are the towers at the middle of the sector. We can see how do our correction influences the tower's MPV distribution. The corrections reduce the standard deviation of the distribution.
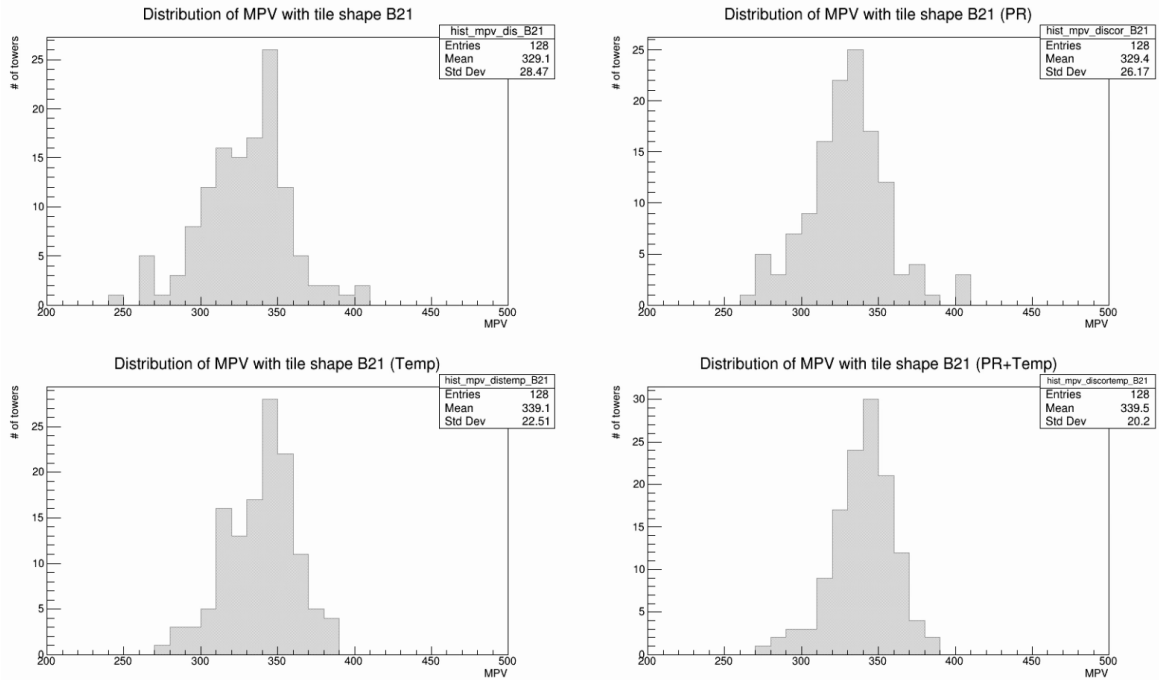

Figure 11: This is the tower's MPV distribution with tile shape B21. The upper left figure is raw distribution, and the upper right figure is data after PR correction. The lower left is data after temperature correction only. And the lower right is the final distribution after both corrections.

For the inner HCal, there are similar figures in Figure 12 of the towers with tile shape Z1 and Z2, which are the tower at the middle of the sector and besides it. Because for inner HCal, we do the temperature correction before we add them together and the fitting, so the MPV is temperature corrected. And then we apply the PR correction to get the final results directly. And from these two figures, we can see the MPV difference between different tile shapes. For Z1, the mean is 450, but for Z2, it's 420. If we add all different tile shapes' MPV distribution together as shown in Fig.13. We can see the distribution's width is much larger. The main reason is caused by the difference between different tile shape. It requires more corrections based on the mean value of different tile shape to eliminate.

Another important result is the sectors' mean MPV distribution. The distribution of oHCal is shown in Fig.14. The x-axis is the sector number from 1 to 32. And y-axis is the mean of the 48 towers' MPV in the sector, with the error bar equal the RMS of 48 tower's MPV divided by the square root of the number of towers. And we can see that there is a problem, that the mean MPV are separated into 2 different groups. The reason should be that they have 2 different operating voltage of SiPMs. In some sense, the Vop doesn't do their job. But within the Vop group, the distribution has a small RMS.

This kind of separation is also shown in the inner HCal mean MPV distribution as well. For iHCal, to reduce the influence of tile shape differences, we split one sector into north part and south part, as shown in Fig.15. There are two points for each sector that the left one means the south part that involve 14 towers with tile shape Z5 to Z11, and the right one means the north part that also involve 14 towers with the same tile shapes. We can see very clear several different Vop groups with different level mean MPV. This is one of the main problem we are currently dealing with and trying to eliminate. Maybe we will change the Vop for these sectors to bring them back to the same level.
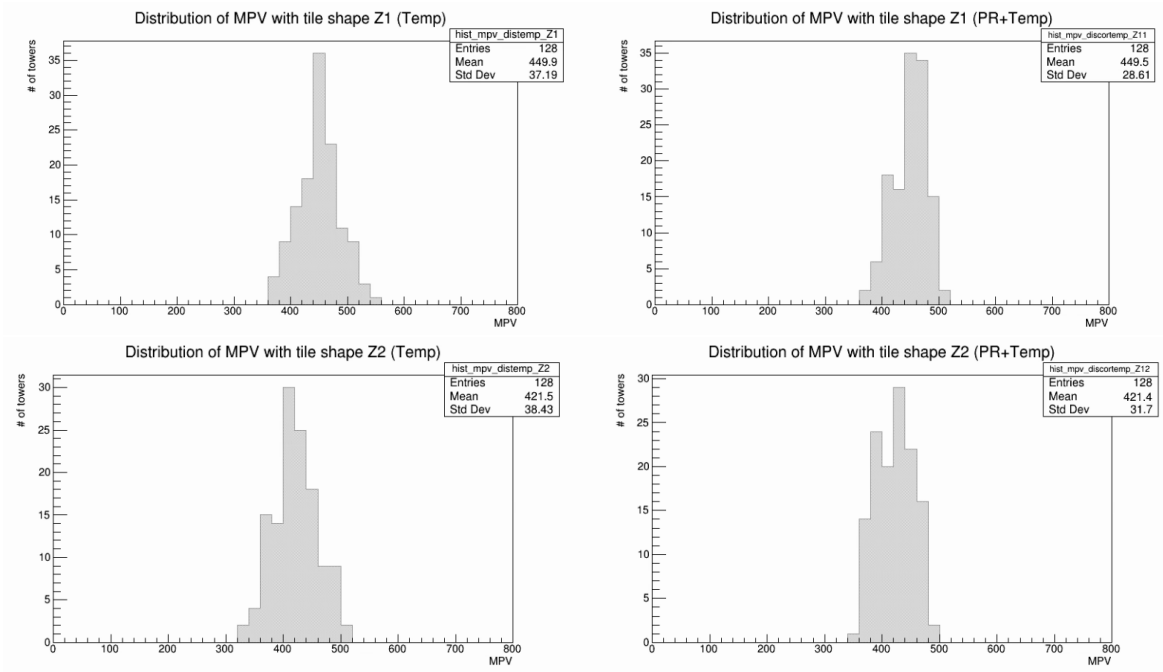
Figure 12: The upper figure is the tower's MPV distribution with tile shape Z1. The lower figure is about the towers with tile shape Z2. The left figures are raw distribution, which are temperature corrected. And the right figures are data after PR correction.

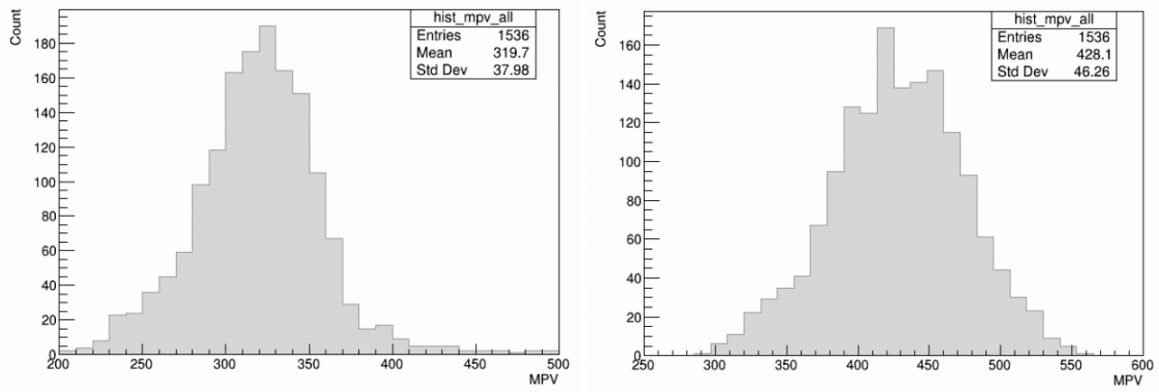In Fig.16 and 17, there are detailed tower's MPV distribution for all sectors.

Figure 13: These are the all towers' MPV distribution of oHCal (left) and iHCal (right) after all corrections.
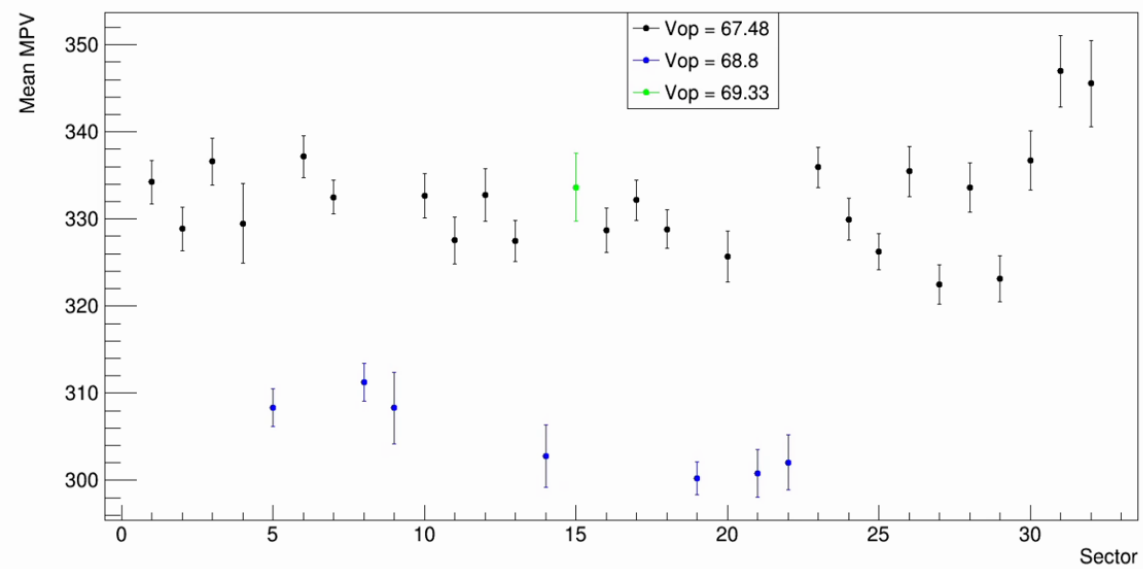

Figure 14: The distribution of oHCal sectors' mean MPV. For oHCal sector 30 ∼ 32, they are the chimney sectors whose south side are half size.
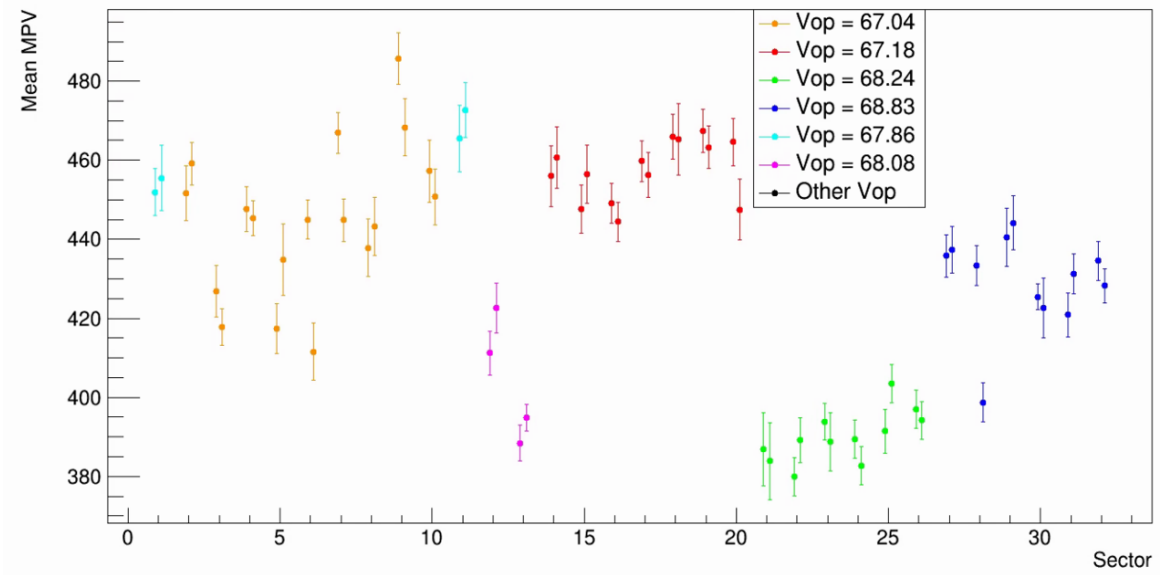
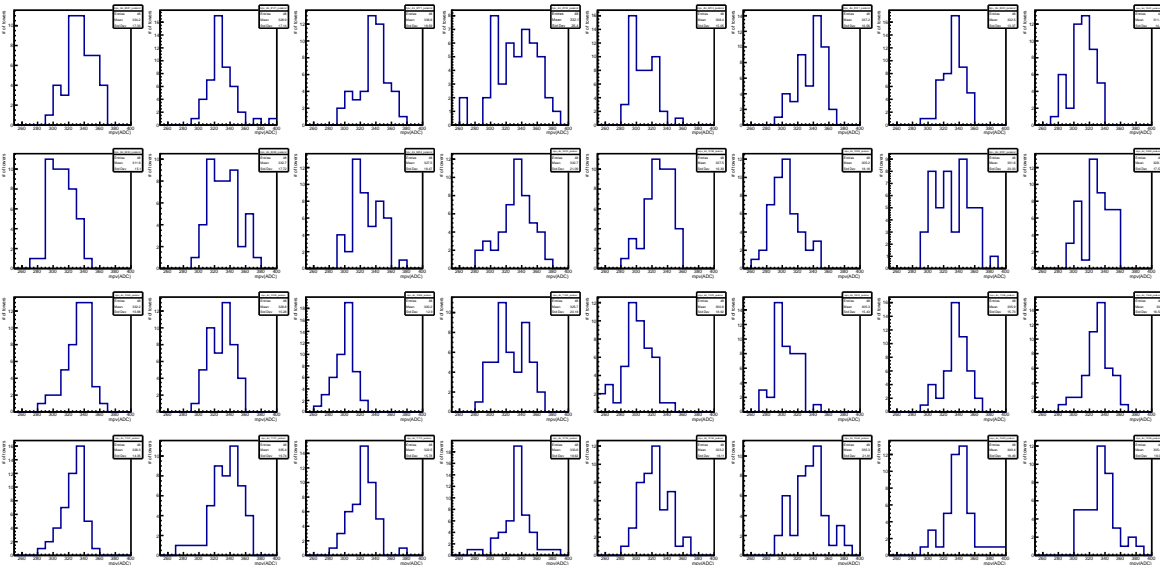Figure 15: The distribution of iHCal sectors' mean MPV.

Figure 16: The distribution of each tower's MPV in 32 oHCal sectors. Start from sector 1 to 32.
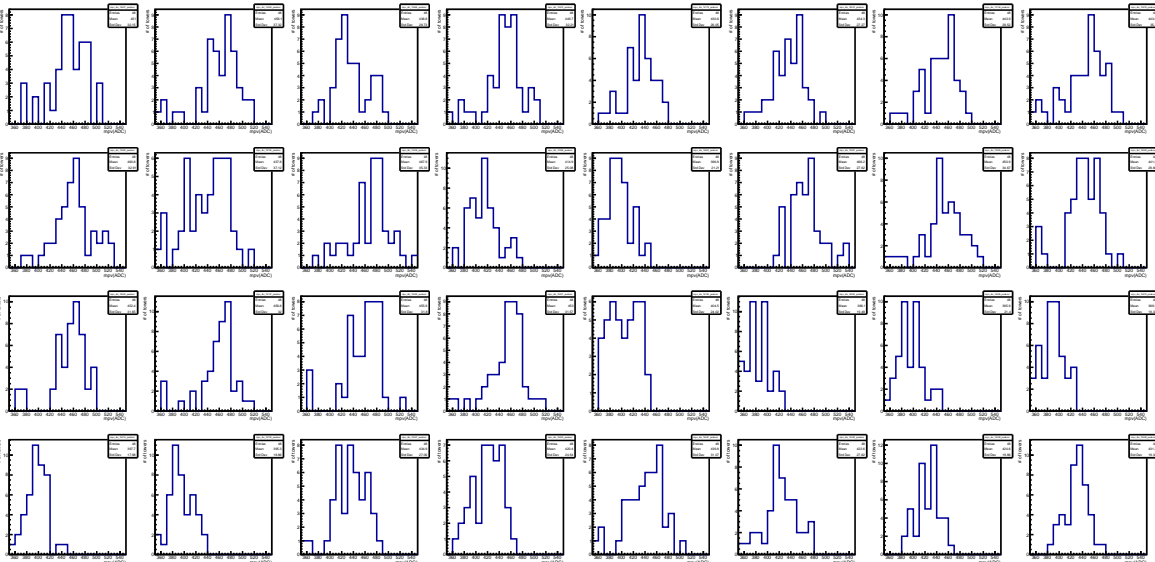
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Figure 17: The distribution of each tower's MPV in 32 iHCal sectors. Start from sector 1 to 32.

6 Code

The raw data is save as prdf files in /sphenix/data/data02/sphenix/hcal/912/. The cosmic data is saved in cosmic/ and LED data is saved in test/. Each run is named with its run number, and the information of the runs are recorded in elog https://sphenix-intra.sdcc.bnl.gov/WWW/elog/HCAL/. And for the detailed setting of the runs, there are log files with the run number. To do the analysis, we need firstly convert the prdf files into ROOT files with the script shucknew.sh in the direction /sphenix/data/data02/sphenix/hcal/sectortest/macro/. The result will be put into /sphenix/data/-data02/sphenix/hcal/sectortest/root/. And then, we can use the script makeCosmicsHistos.sh to apply cut and build histogram for each tower in oHCal. The results are stored in /sphenix/data/-data02/sphenix/hcal/sectortest/histos/. For iHCal, I did the cut and temperature correction together in my own direction /sphenix/u/hj2552/fitting/iHCal_new/temp_mean/. You can run the makeand-fitcosmics.sh in each sector by hand. Or you can run the script run.sh directly for all sectors.

After we get the distribution, we can do the fitting and output the results. The data and results for the oHCal is in /sphenix/u/hj2552/fitting/newvolt, and for the iHCal, the current version we thought to be the best is in /sphenix/u/hj2552/fitting/iHCal_new/temp_mean/. The fitting and analysis code is cosmicstestfit.C. Please run it as root -l -q -b cosmicstestfit.C. There are some general results in peakfitting_summary.root.

The temperature data is stored in /sphenix/u/hj2552/fitting/temp. The PR data for oHCal is in /sphenix/u/hj2552/fitting/PR_new/pr_tower_nor.txt. And the PR data for iHCal is in the direction /sphenix/u/hj2552/fitting/PR_iHCal/pr_tower_nor.txt.

Acknowledgments