sPHENIX Hadronic Calorimeter Cosmic Muon Calibrations

Hanpu Jiang, Shuhang Li, Emma McLaughlin, Blair Seidlitz, Bill Zajc

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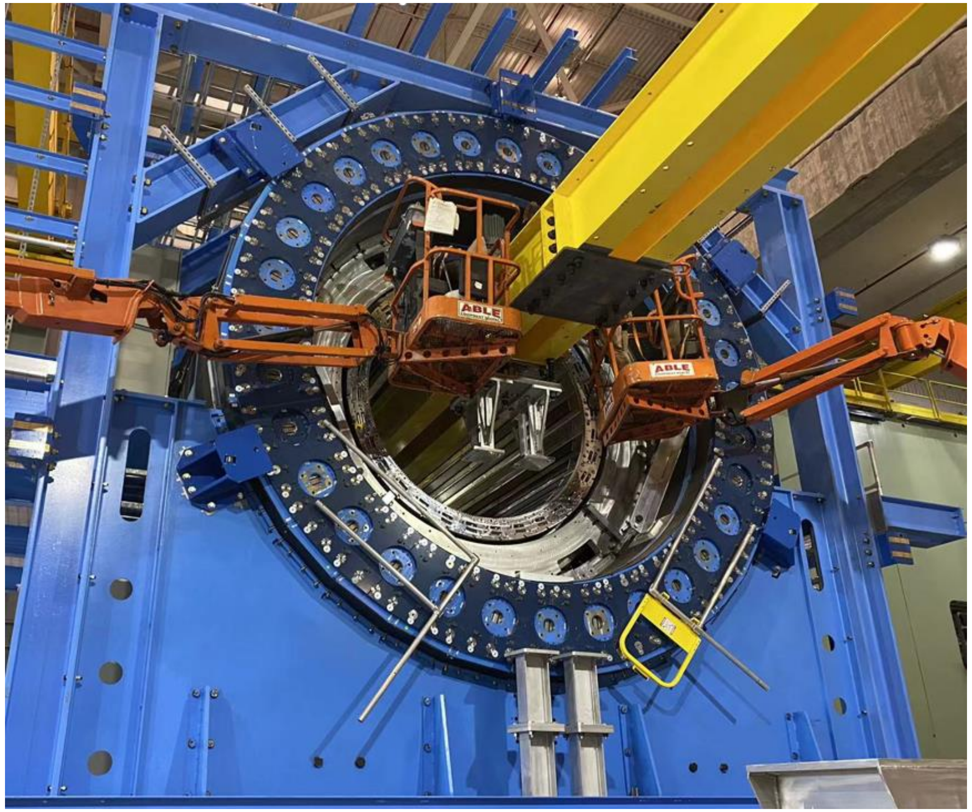
DNP Meeting, Oct 29, 2022

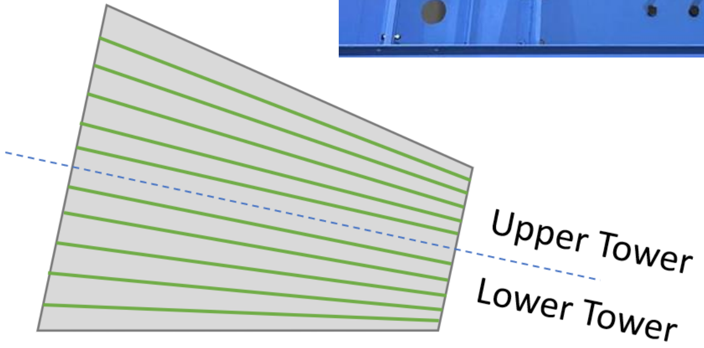
sPHENIX

Columbia University
In the City of New York

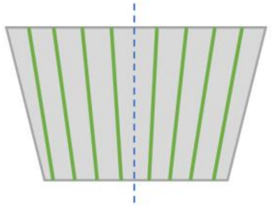
Hadronic Calorimeter (HCal) Geometry

· 32 sectors for both outer HCal (oHCal) and inner Hcal (iHCal).
· One oHCal sector has 10 scintillator slots. An iHCal sector has 8 scintillator slots.
· Each slot is filled with 24 tiles along z. Tiles have different sizes and shapes to be projective in η.
· 48 towers in one sector. One tower has 5 or 4 tiles. There are two lines of towers in one sector.
· A silicon photomultiplier (SiPM) is installed on each tile. All 5 or 4 tiles' SiPMs in the same one tower are read out together.



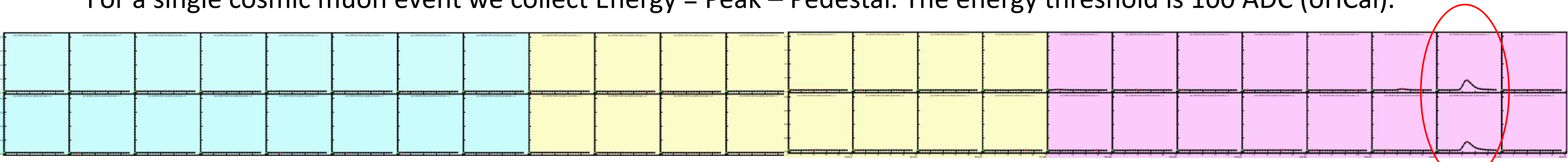


Test orientation for outer HCal


Test orientation for inner HCal

Cosmic Muons Data Collection

For a single cosmic muon event we collect Energy = Peak – Pedestal. The energy threshold is 100 ADC (oHCal).

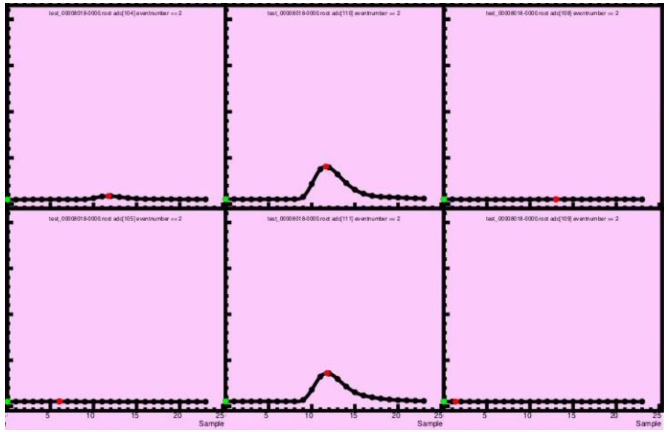


↑South end North end↑

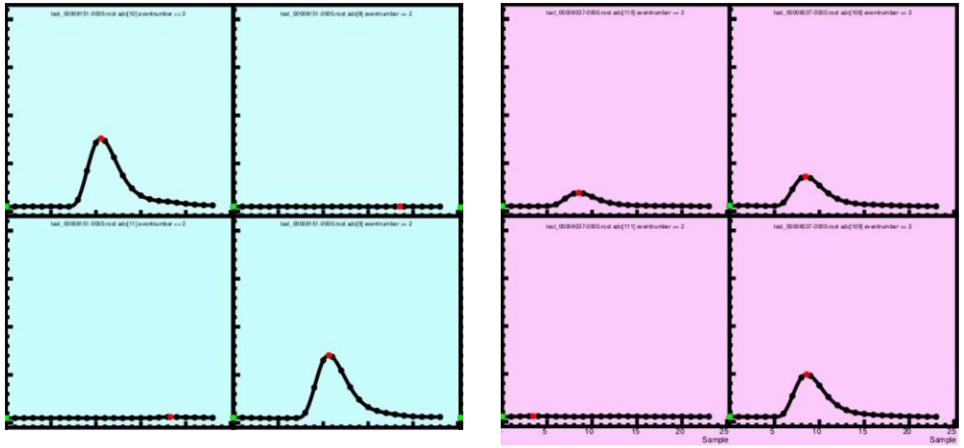
Events cut:

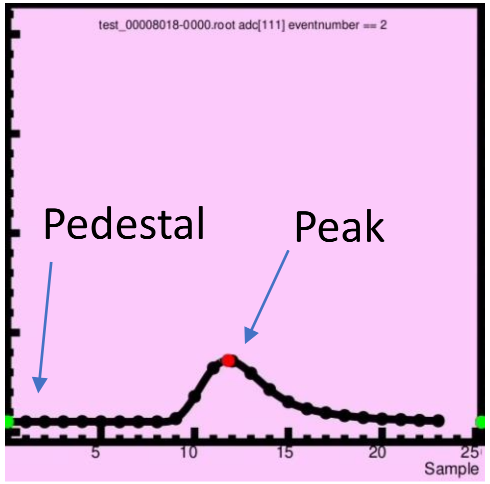
1. Vertical tower cut: the vertical two-towers pair both have signals.
2. Neighboring tower cut: the 4 neighboring towers have no signal.
3. Energy difference cut (iHCal only): signal is not smaller than vertical pair tower's signal – 150 ADC.

Good event:



Bad events:





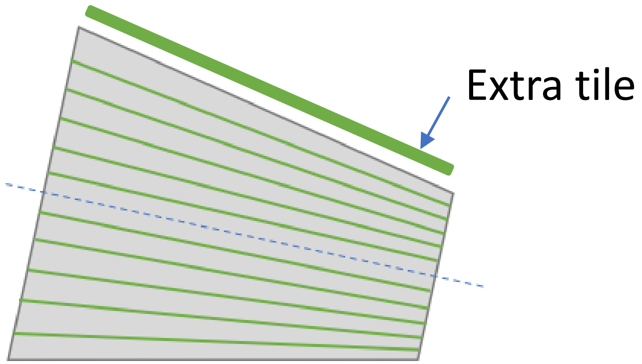
Note: all results are from a test stand using the beam test electronics, not the production ADC's

Events Cut Results

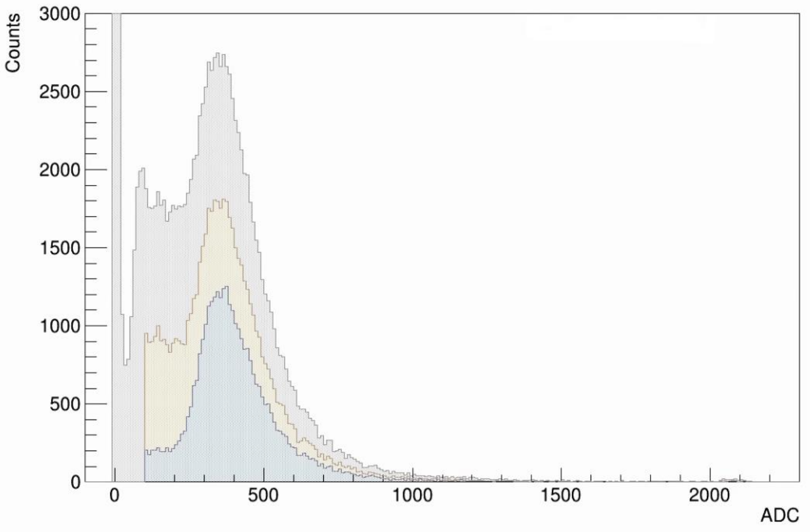
· One-hour cosmic run for oHCal and iHCal.
12 one-hour runs for iHCal. Add 12 runs together to get enough events.

· 3-tower cut to verify the cut:
Place an extra tile beside a particular tower and use this tile and the tower on the other side to get coincidence.

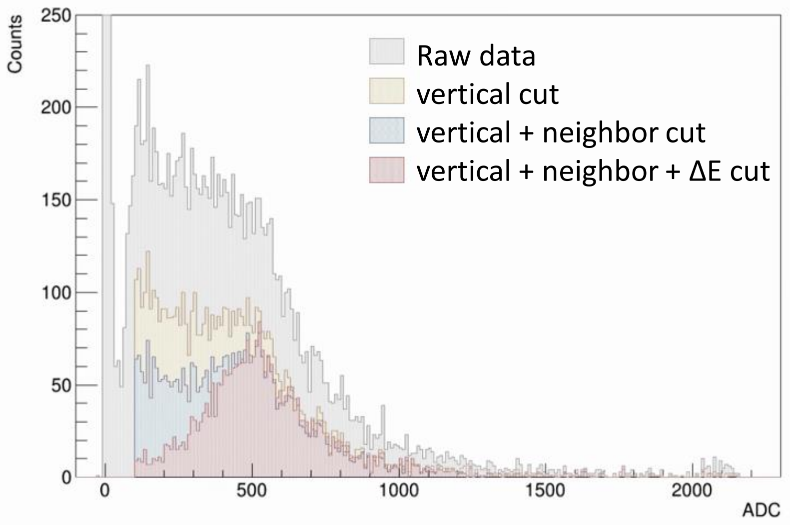
· The peak after 3-tower cut and is very similar with our cut. (< 1%)



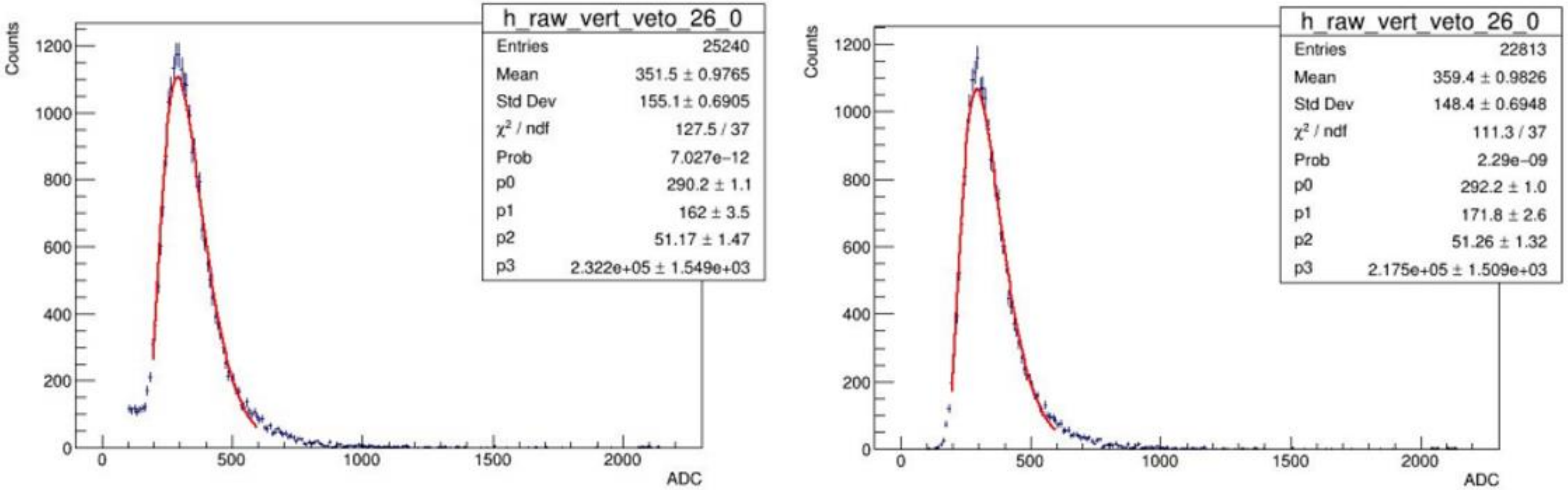
3-tower test orientation



oHCal cut result (1 hour).



iHCal cut result (1 hour).



The same tower after vertical + neighhor cut & after 3-tower cut. (oHCal)

Fitting the towers' deposited energy distribution

Peak finder algorithm:

1) Rebin the original histogram (Width: 10 ADC → 20 ADC).
2) Do function Smooth() twice.
3) Use peak finder (TSpectrum()) to find the peaks.
4) Find the highest peak within the range 100 ~ 1800.

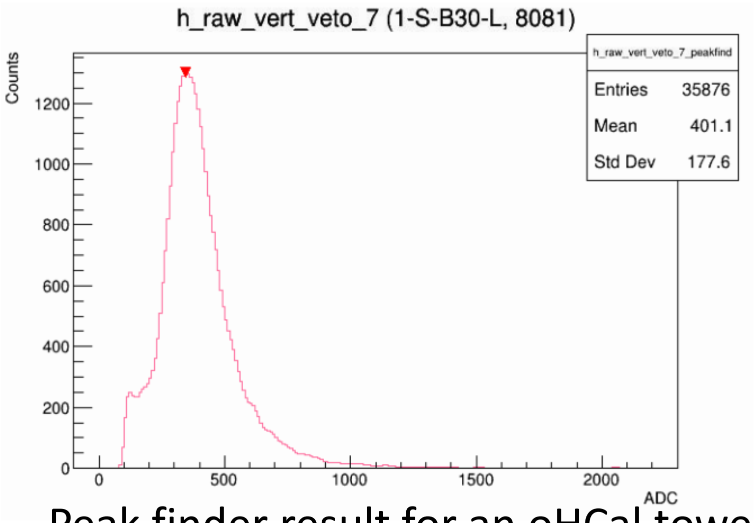
Peak fitting:

1) Fit with Gamma function + Linear function.
2) Using GetMaximum() algorithm to get the maximum of the whole function.
3) For oHCal: Only fitting the peak range between peak-finder's result – 50 ~ peak-finder's result + 200. For iHCal, the range is similar, but alternates corresponding to the rough peak.

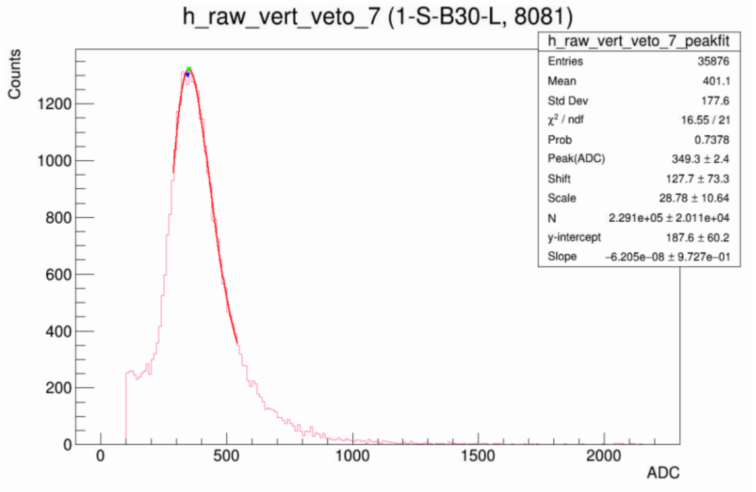
Gamma function:

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

→ Get the most probable value (MPV) from the fitting ---- this is our calibration object from cosmic ray.



Peak finder result for an oHCal tower



Peak fitting result for an oHCal tower

Performance Ratio (PR) correction on the tower's MPV

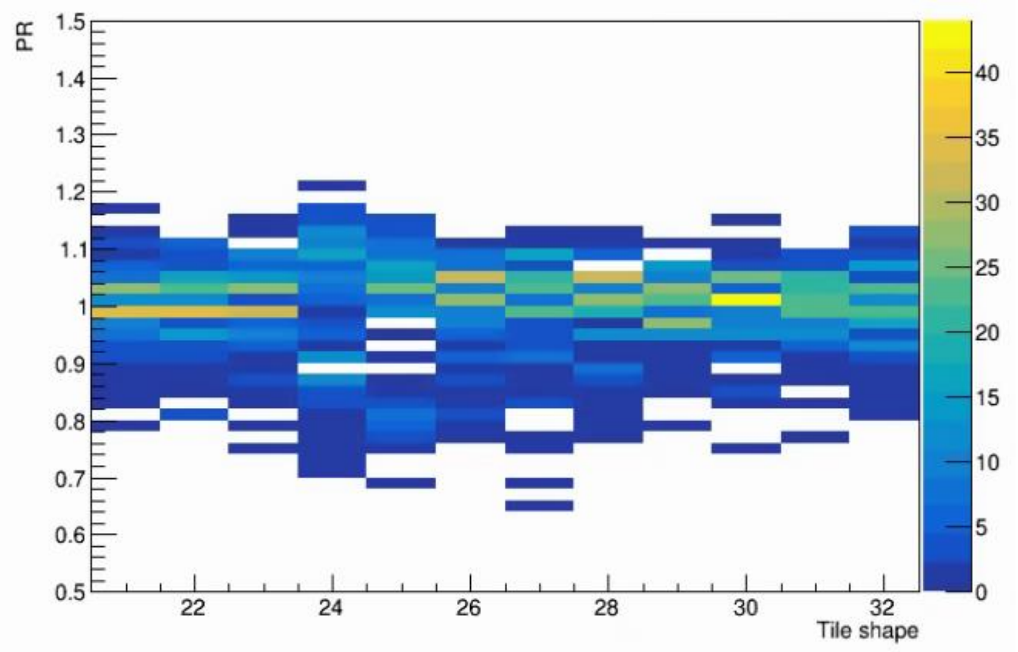
Performance Ratio Correction:

· With the same tile shape, the tiles have different performance. The PR is measured separately for each tile shapes. (measured by GSU)

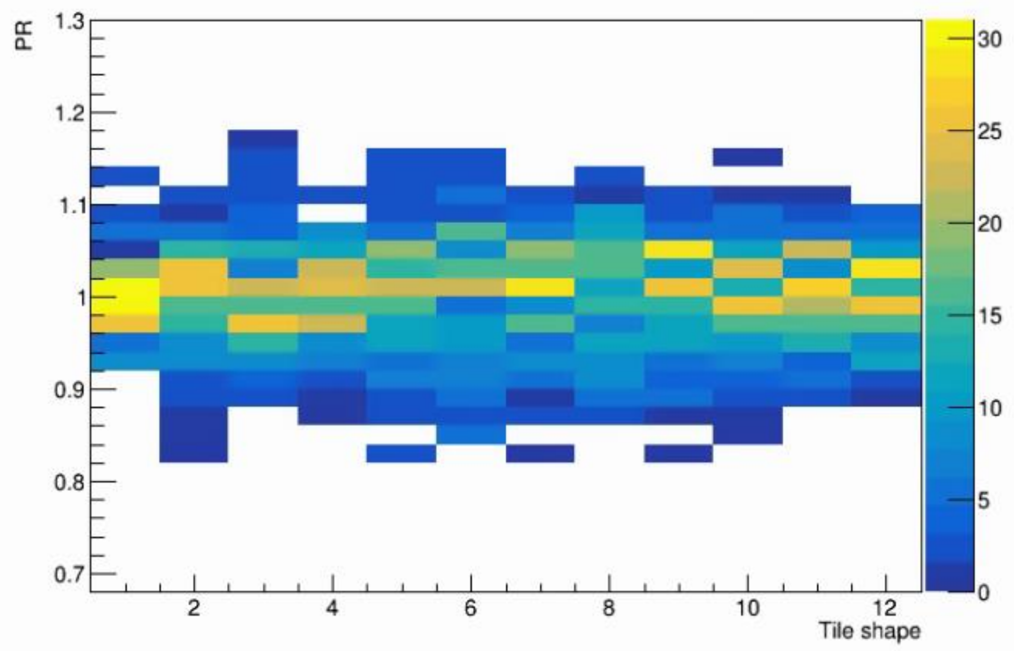
· Each tile's PR is the ratio of measured output to the expected output.

· Tower's PR is mean value of the tiles in it. For most of the towers, their tiles have similar PR.

$$MPV_{PR\ corrected} = \frac{MPV_{Raw}}{PR}$$



oHCal PR distribution for each tile shape



iHCal PR distribution for each tile shape

Temperature correction on the tower's MPV

Temperature Correction:
· The SiPMs have different performances at different temperatures. Higher temperature intend to give a lower result. We take 26 Celsius as a standard to do the correction.
· Temperatures of each tower are output at the beginning and the end of each one-hour run. We use the mean temperature of these two output and of all 48 towers to do the correction.

For oHCal, Temperature performance ratio (TPR) = 1 – (Temperature - 26) * α

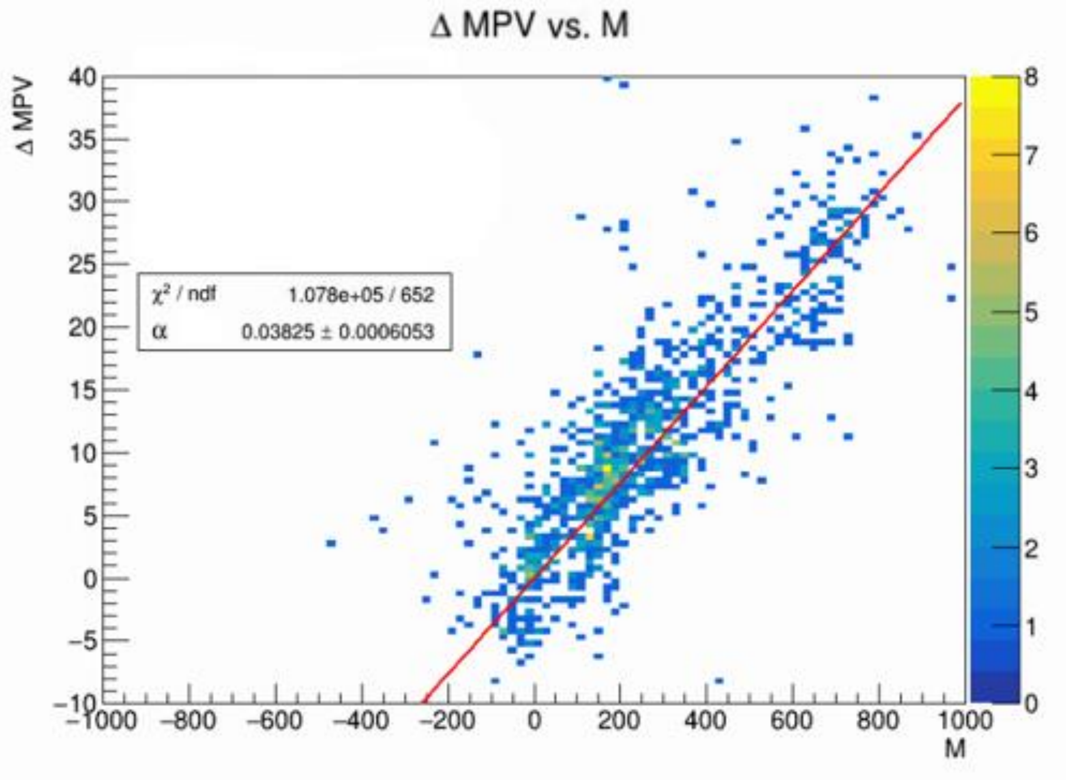
$$MPV_{Temp\ corrected} = \frac{MPV_{Raw}}{TPR}$$

To get the parameter α, use two runs for the same sector, and use the difference to get it.

$$MPV = MPV_r \cdot [1 - \alpha(T - 26)]$$

$$\underbrace{MPV_1 - MPV_2}_{\Delta MPV} = \alpha \cdot \underbrace{[MPV_1(T_2 - 26) - MPV_2(T_1 - 26)]}_{M}$$

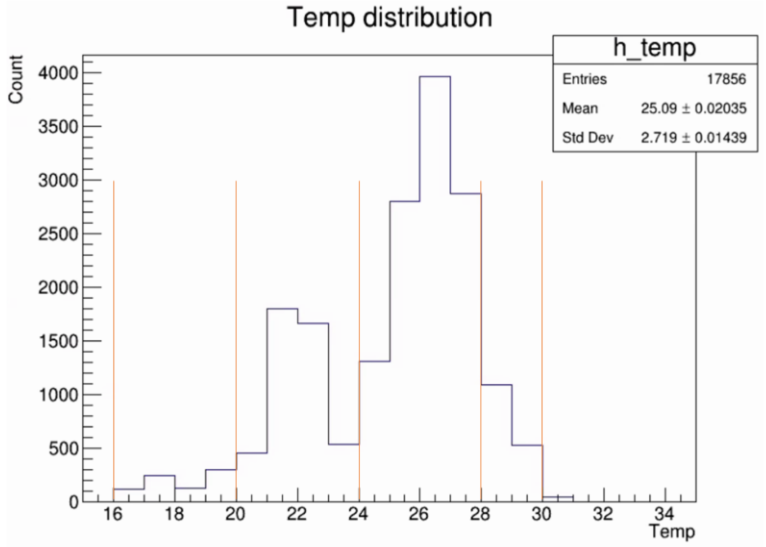
oHCal: α = 3.83%



Temperature correction on the tower's MPV

For iHCal, the temperature range is much larger, from 16°C to 31°C, and the parameter α is actually different with different temperature. And because iHCal doesn't have enough events in one-hour runs, we use mean to get α.

$$Mean = Mean_r \cdot \left[1 - \alpha_{(T)}(T - 26)\right]$$



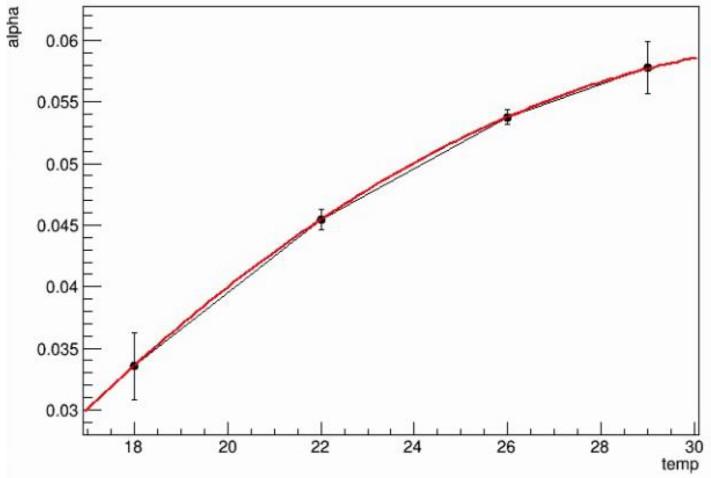
The changing tendency of the parameter α.

α = -0.000111 * T ^2 + 0.00740 * T – 0.0637

So, the temperature correction for iHCal is:

$$TPR = 1 - \int_{26}^{T} (-0.000111x^2 + 0.00740x - 0.0637)dx$$

$$MPV_{Temp\ corrected} = \frac{MPV_{Raw}}{TPR}$$



And for iHCal, the temperature correction is done before adding them together and the fitting.

Sectors’ Mean MPV distribution

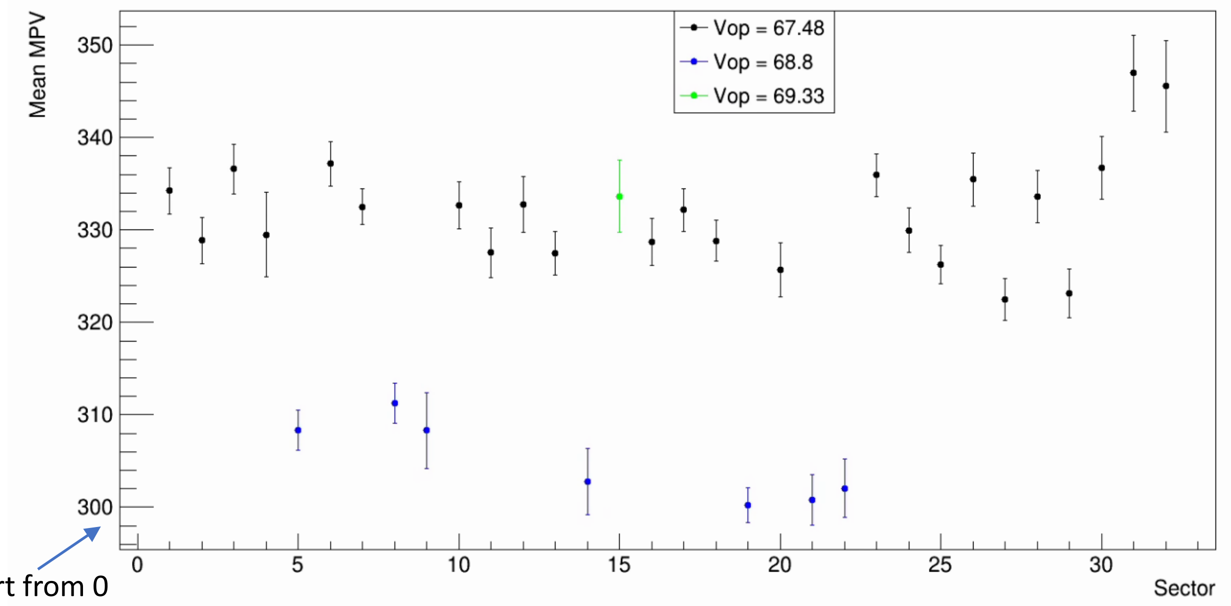
The mean of the all 48 towers’ MPV in each sector are shown in this distribution. The x-axis is the sector number from 1 to 32. The y-axis is the mean MPV which doesn't start from zero. This distribution shows the general performance of each sector. (Error bar is RMS / Sqrt{#Tower}.)

For iHCal, there are two points for each sector that the left one means the south part, and the right one means the north part.

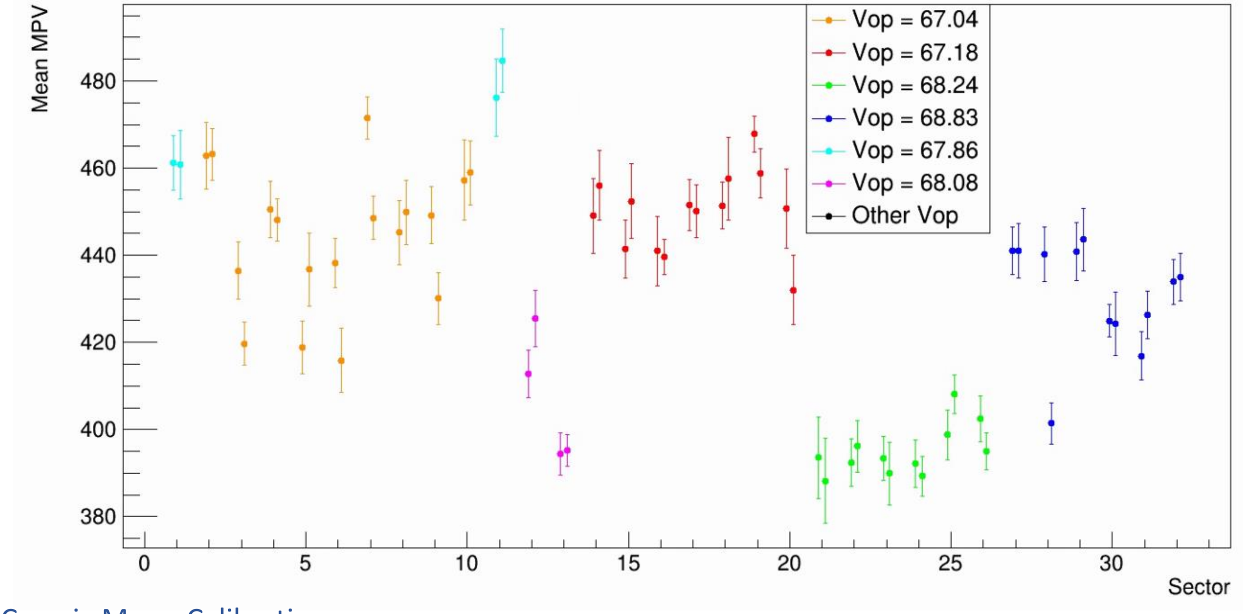
Sectors 30 ~ 32 in oHCal are chimney sectors that have smaller size to leave space for the magnet.

Sectors’ mean MPVs are separated into different groups by their operating voltage. (2 main groups in oHCal, 6 groups in iHCal).

May apply bias voltages to bring them back to the same level.



Not start from 0



Summary

· We used a set of event cuts to efficiently select muon events.

· We developed a reliable fitting method to get peak position.

· With GSU group's measurement, we did the performance ratio correction.

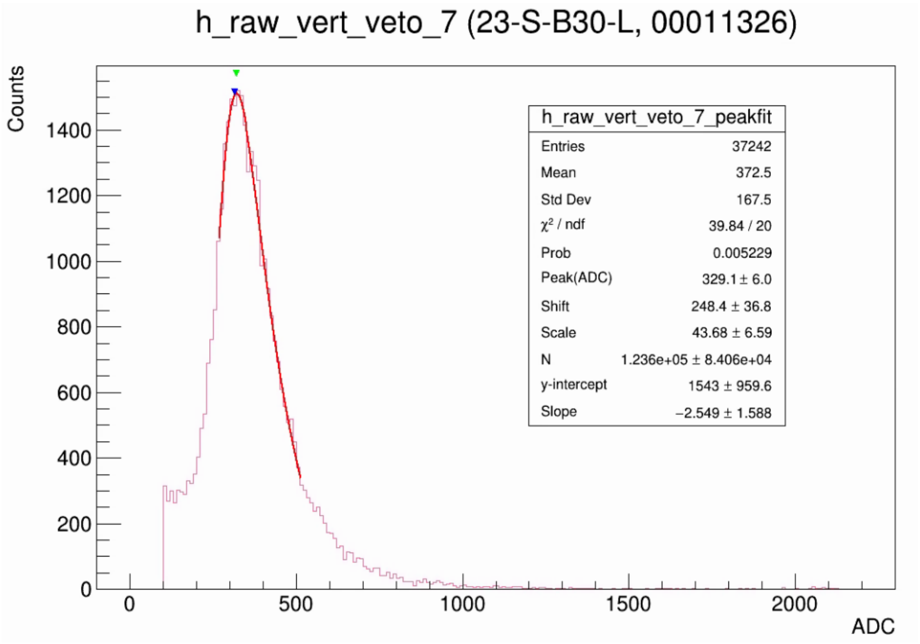
· We figured out the suitable temperature correction method to eliminated the influence of temperature.

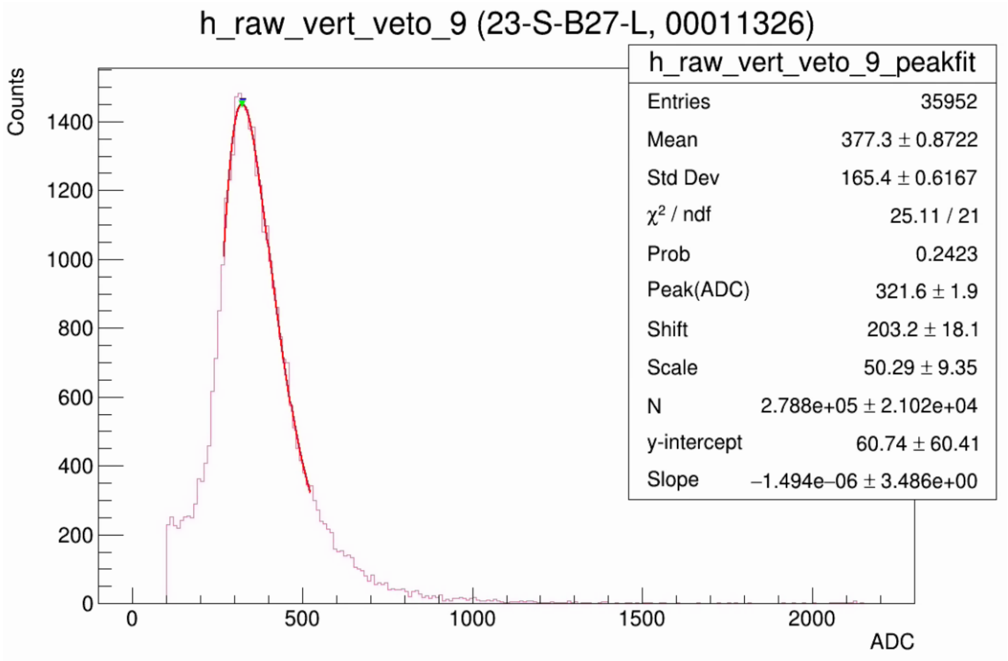
· The cosmic calibration results will give reference for the online monitoring. (what's the subject for the next talk)

· All the sectors of both inner & outer HCal are tested and every channel works well!

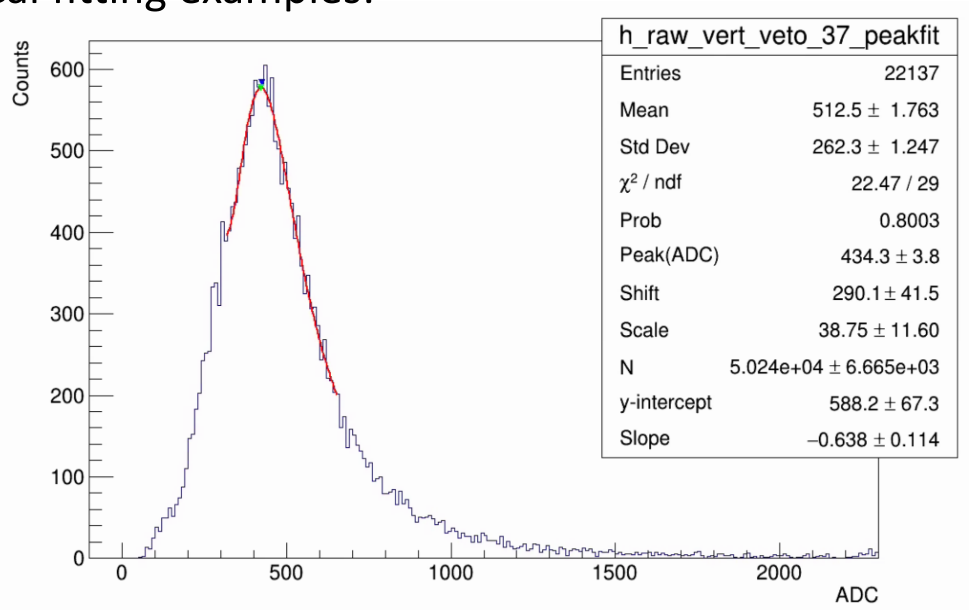
Backup

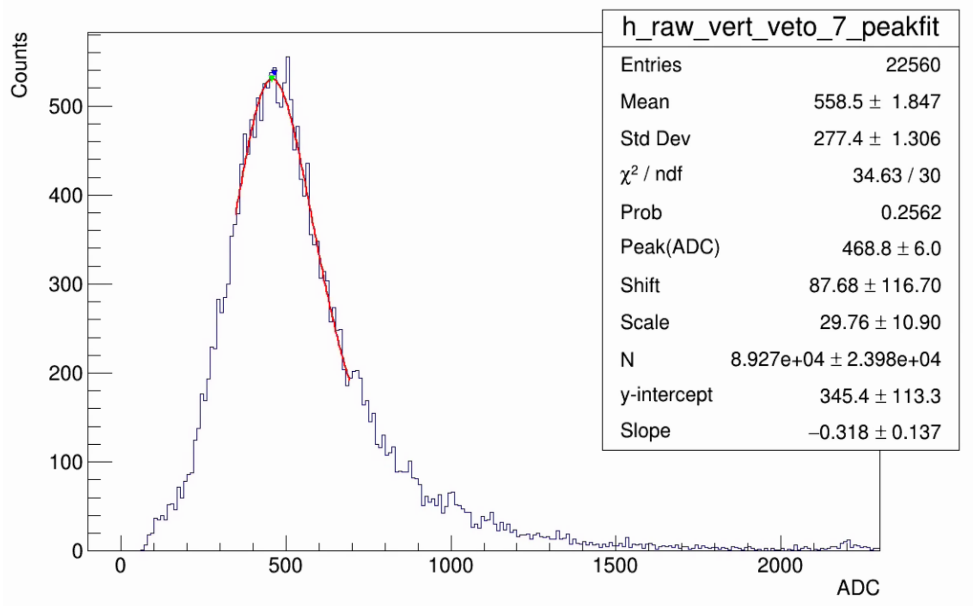
oHCal fitting examples:



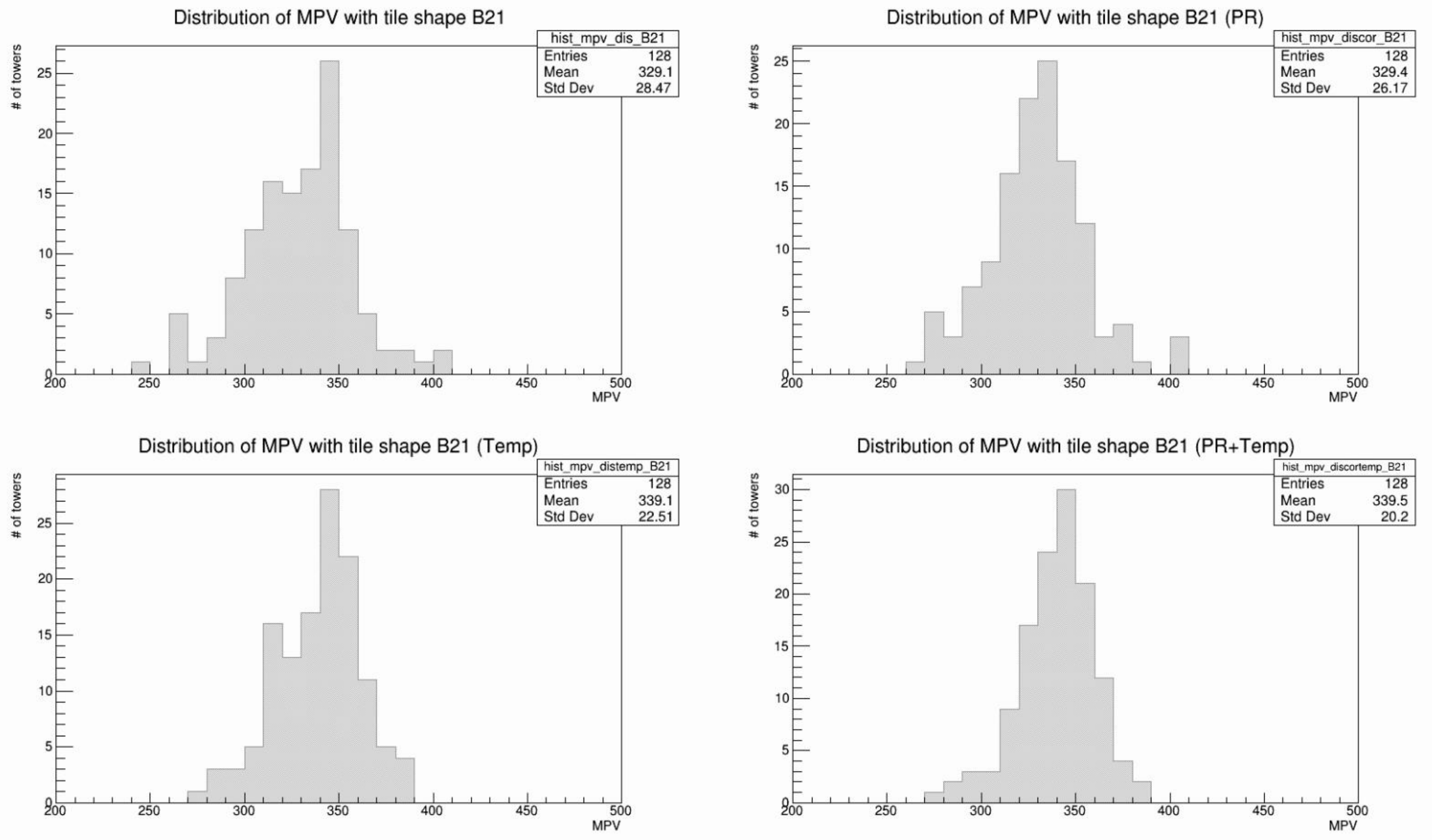


iHCal fitting examples:

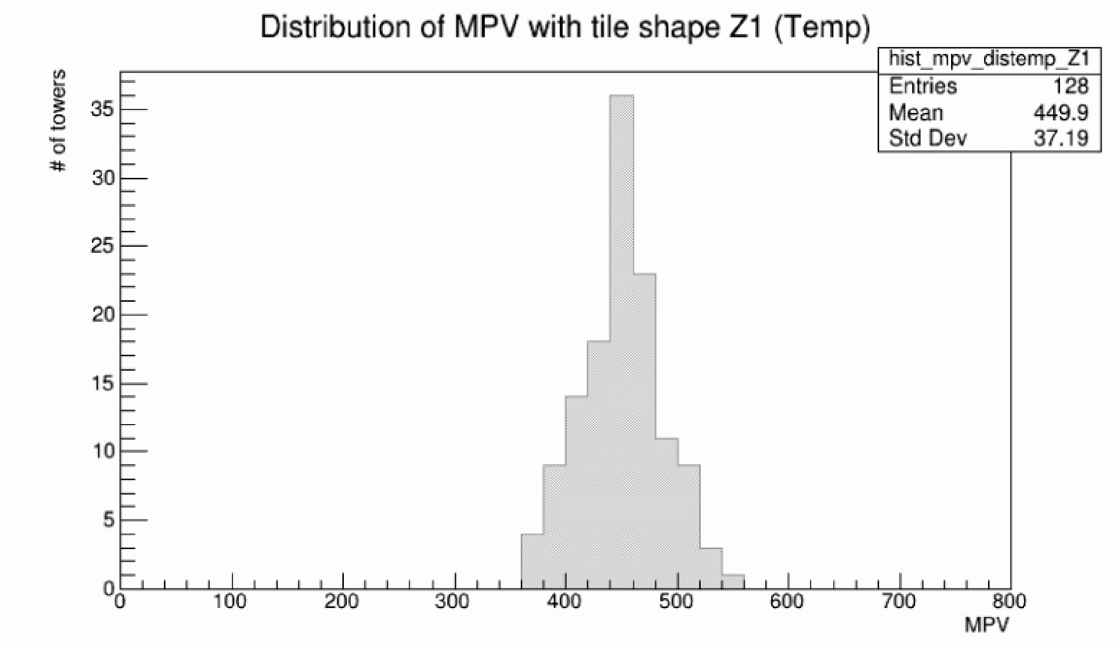


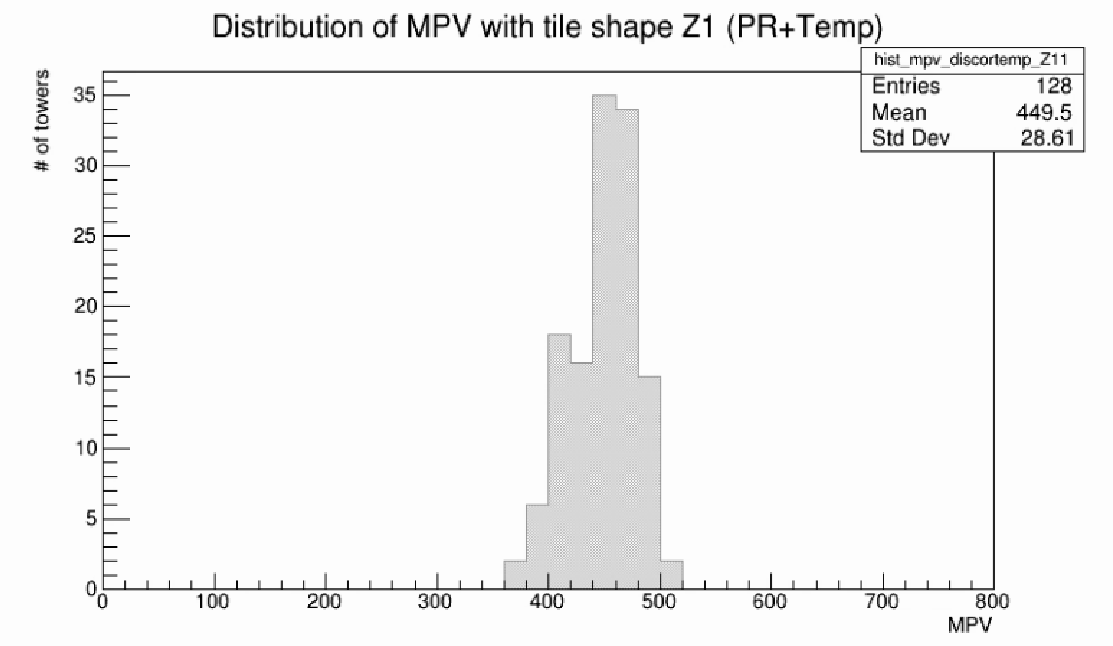


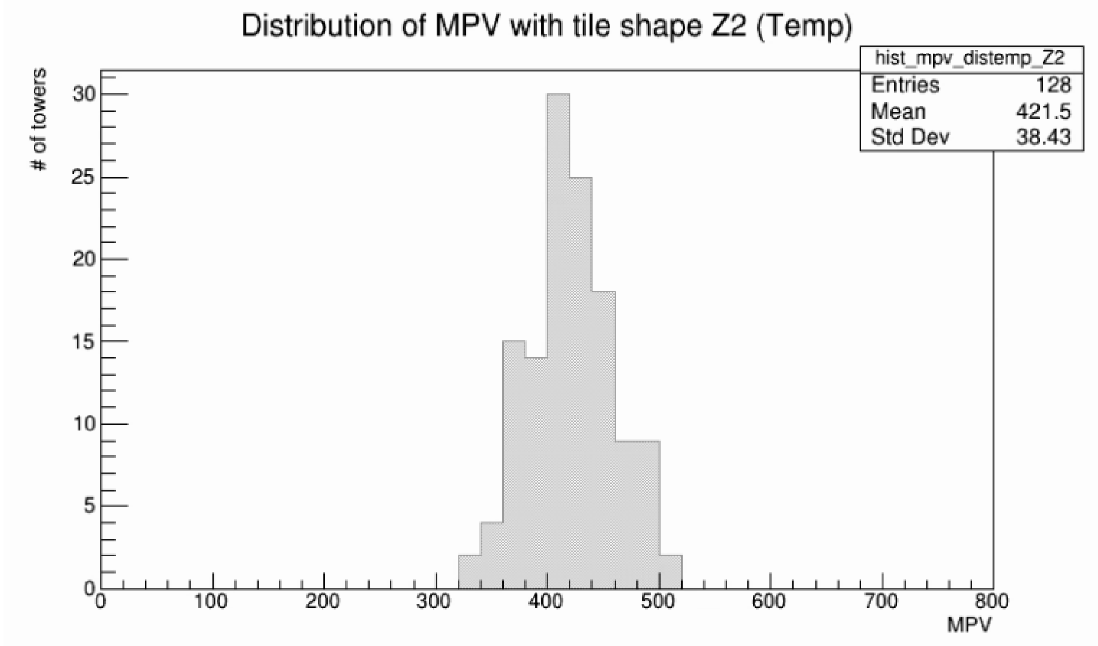
Distribution of all towers' MPV in oHCal with tile shape B21

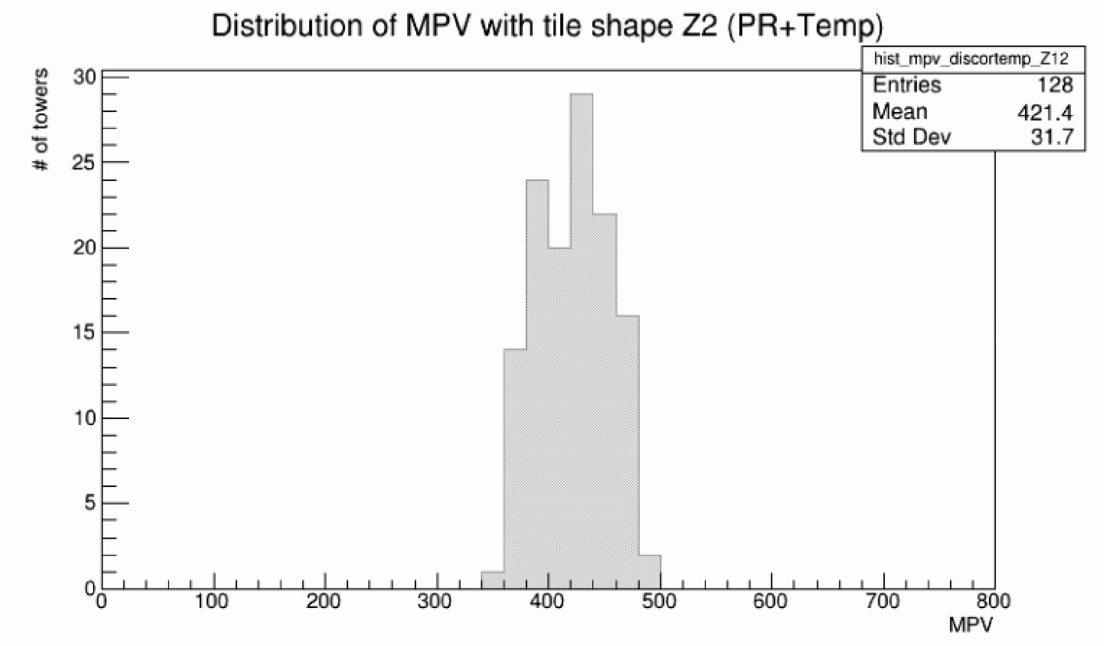


Distribution of all towers' MPV in iHCal with tile shape Z1 & Z2

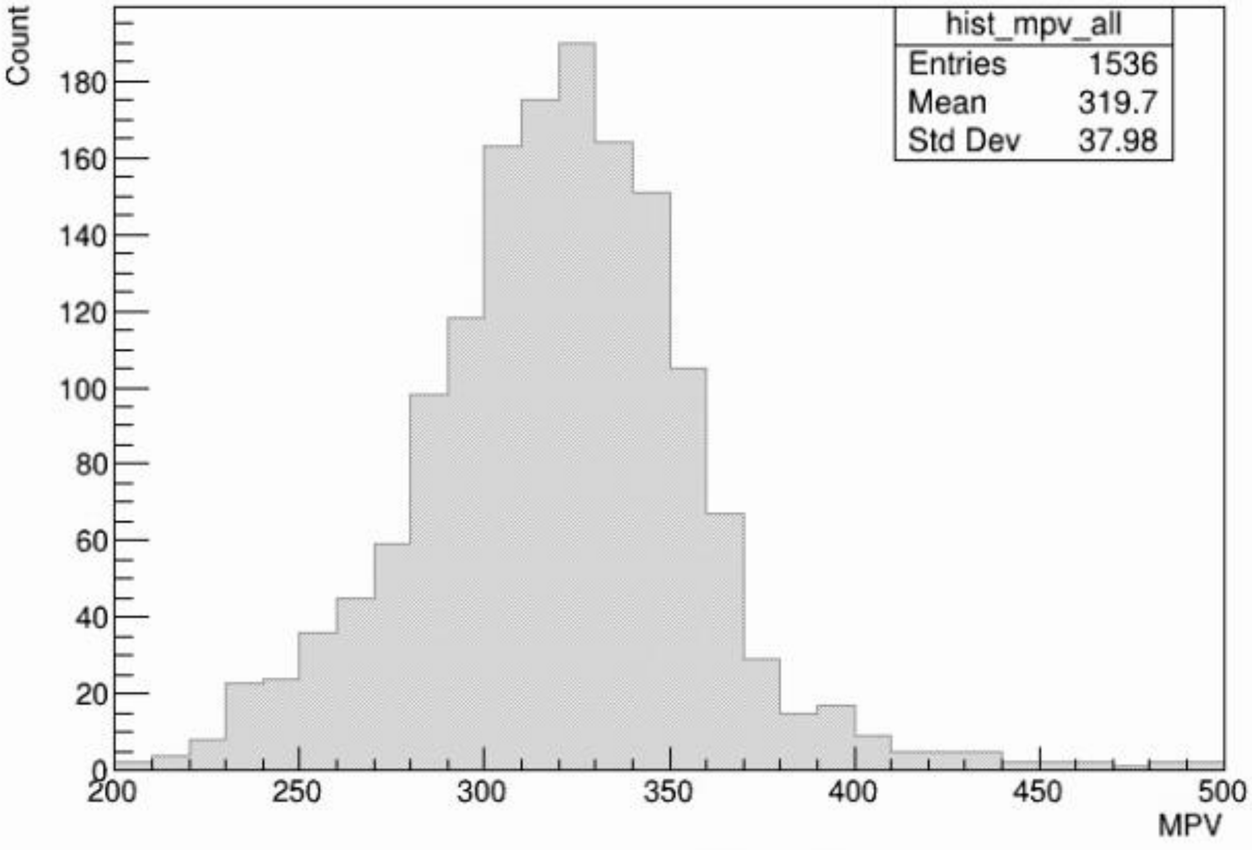


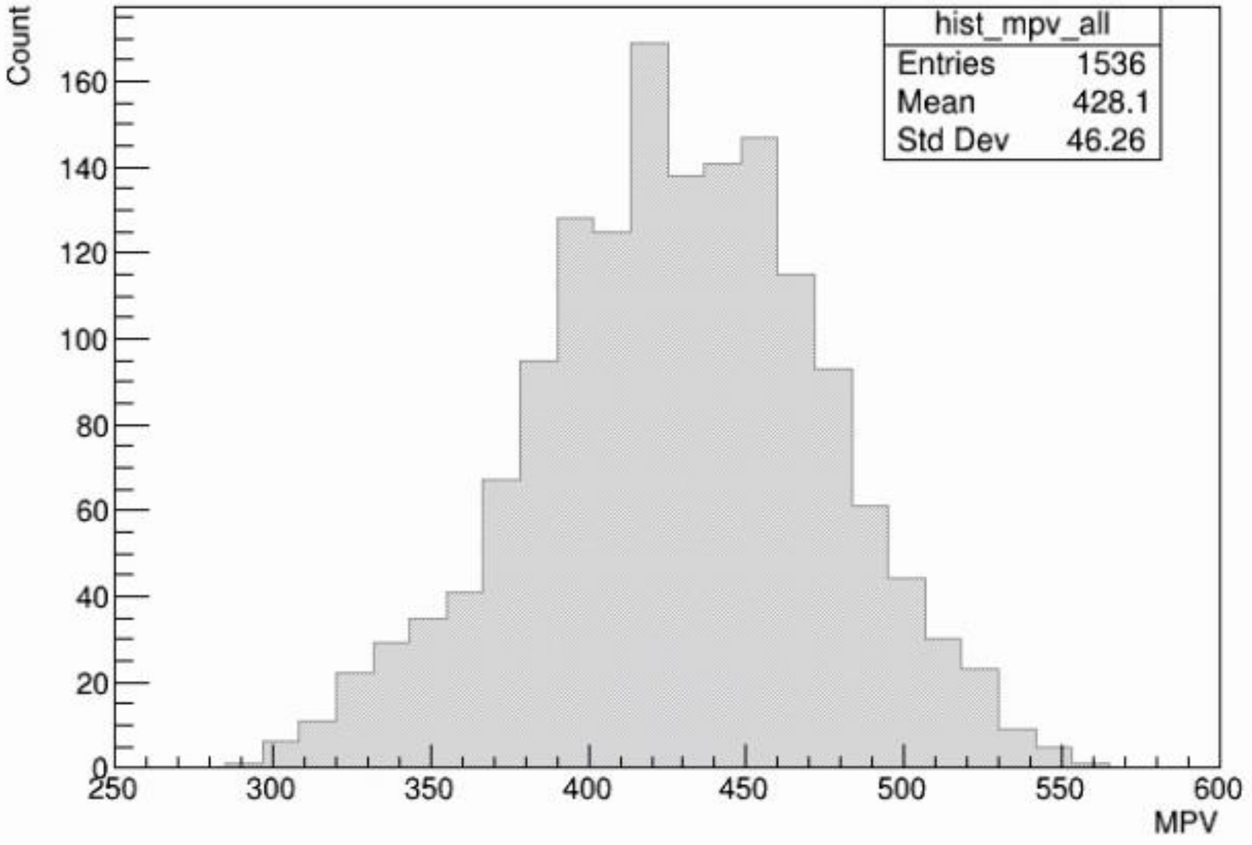


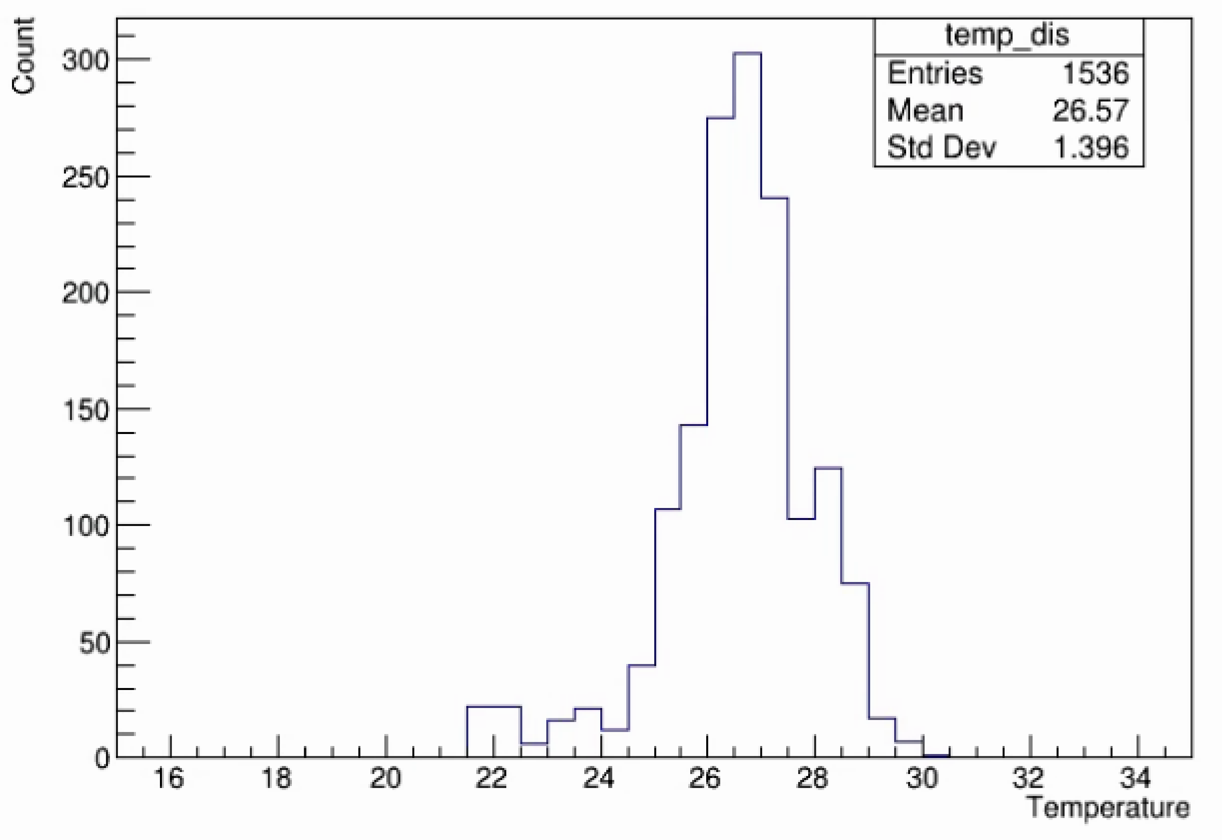




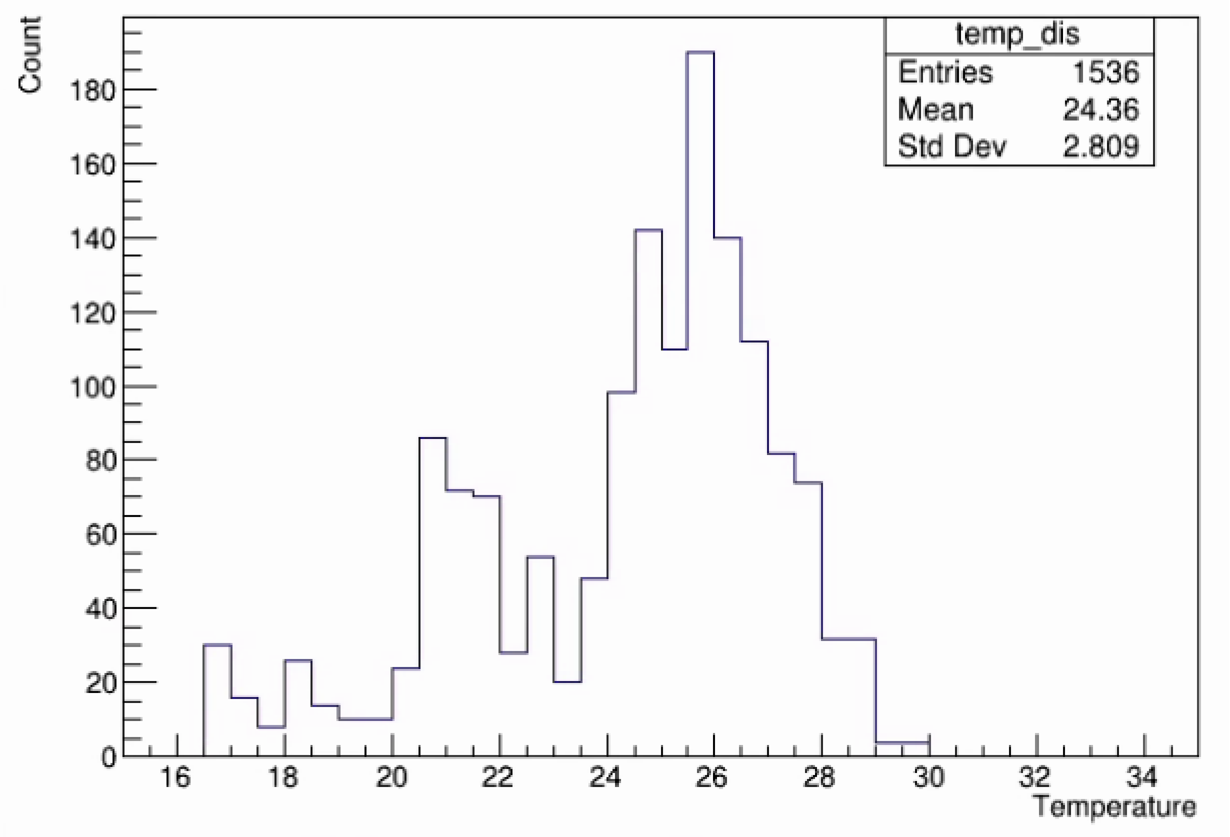
Distribution of all towers' MPV in oHCal and iHCal.







oHCal tower's temperature distribution



iHCal tower's temperature distribution

Error Calculation:

For run-by-run temperature correction, the corrected MPV only need the PR correction in calculation.

$$MPV_{corrected} = \frac{MPV_{raw}}{PR}$$

Error propagation:

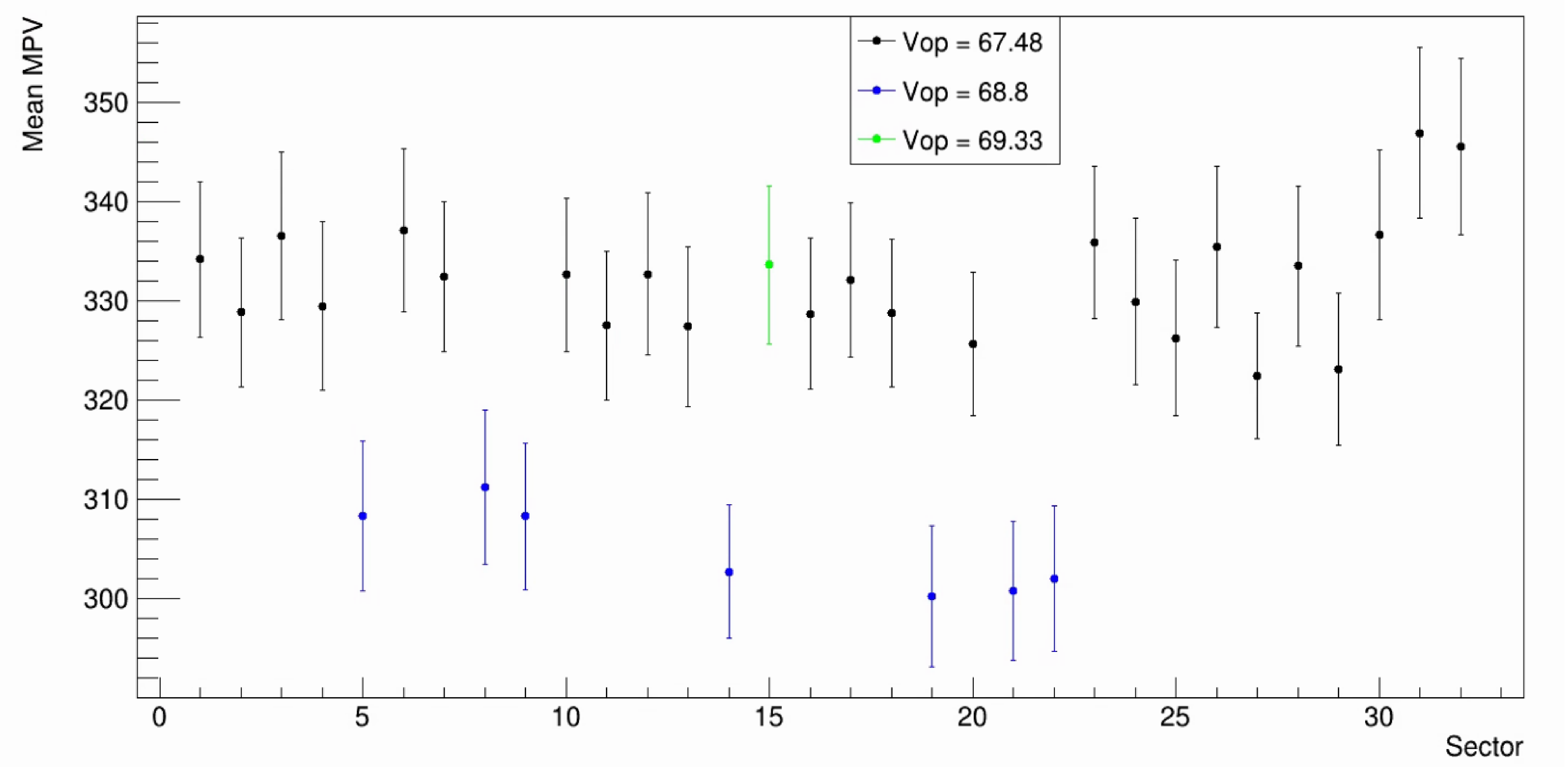
$$\delta MPV_{corrected} = MPV_{corrected} * \sqrt{\left(\frac{\delta MPV_{raw}}{MPV_{raw}}\right)^2 + \left(\frac{\delta PR}{PR}\right)^2}$$

with $\delta PR = 0.01$.

Note:

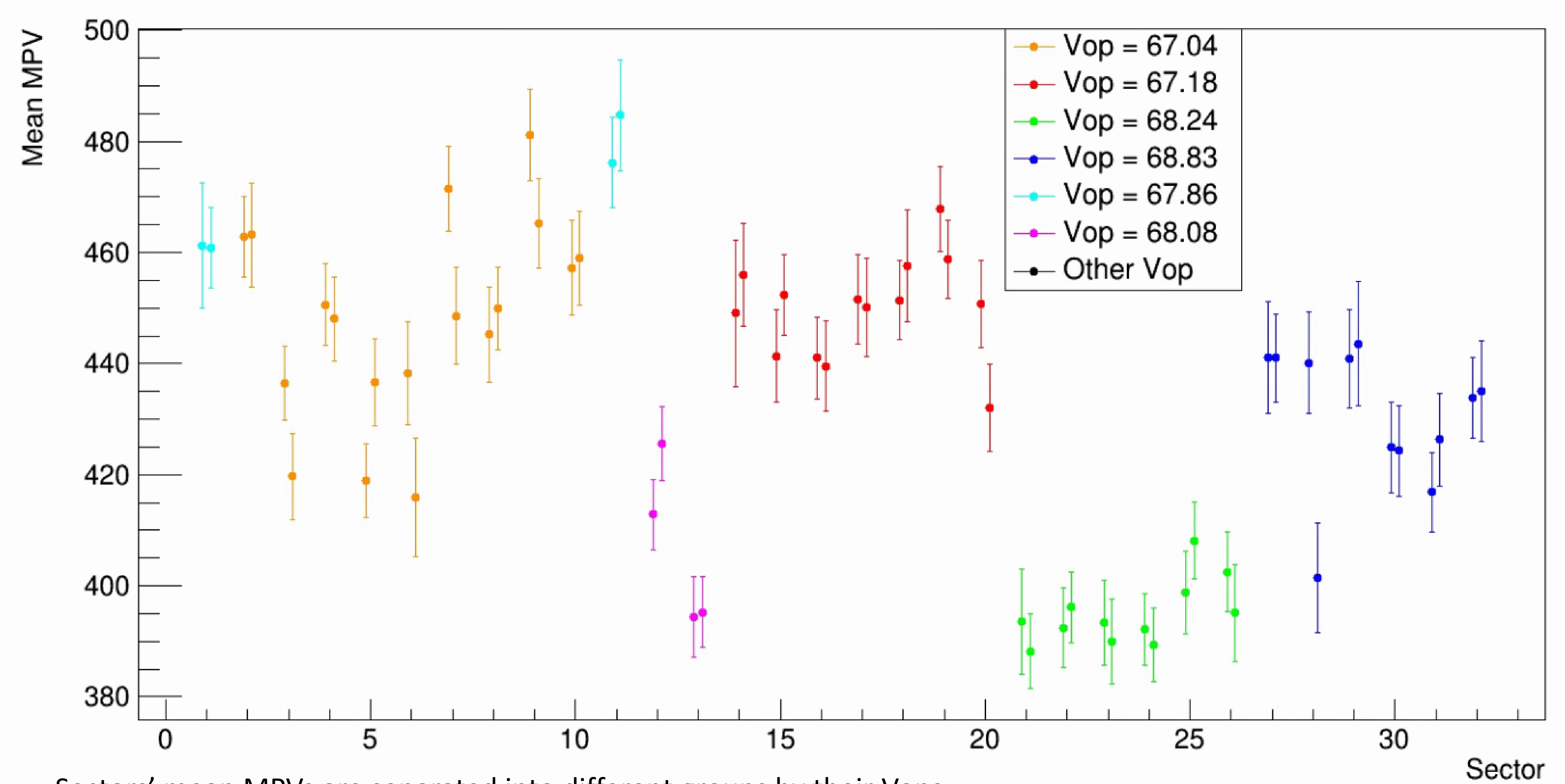
1. I use the error of Gamma function's peak from the fitting instead of the peak of Gamma function + linear function's peak, which is find by using GetMaximumX().
2. Do not involve the temperature error.

Sectors' Mean MPV distribution for oHCal: (error bar is the error propagation results with the errors of PR, temperature, and fitting.)



Sectors' mean MPVs are separated into different groups by their Vops.

Sectors' Mean MPV distribution for iHCal: (error bar is the error propagation results with the errors of PR, and fitting.) There are two points for each sector that the left one means the south part, and the right one means the north part.



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