



Calibrating the sPHENIX Hadronic Calorimeter with Cosmic Ray Muons

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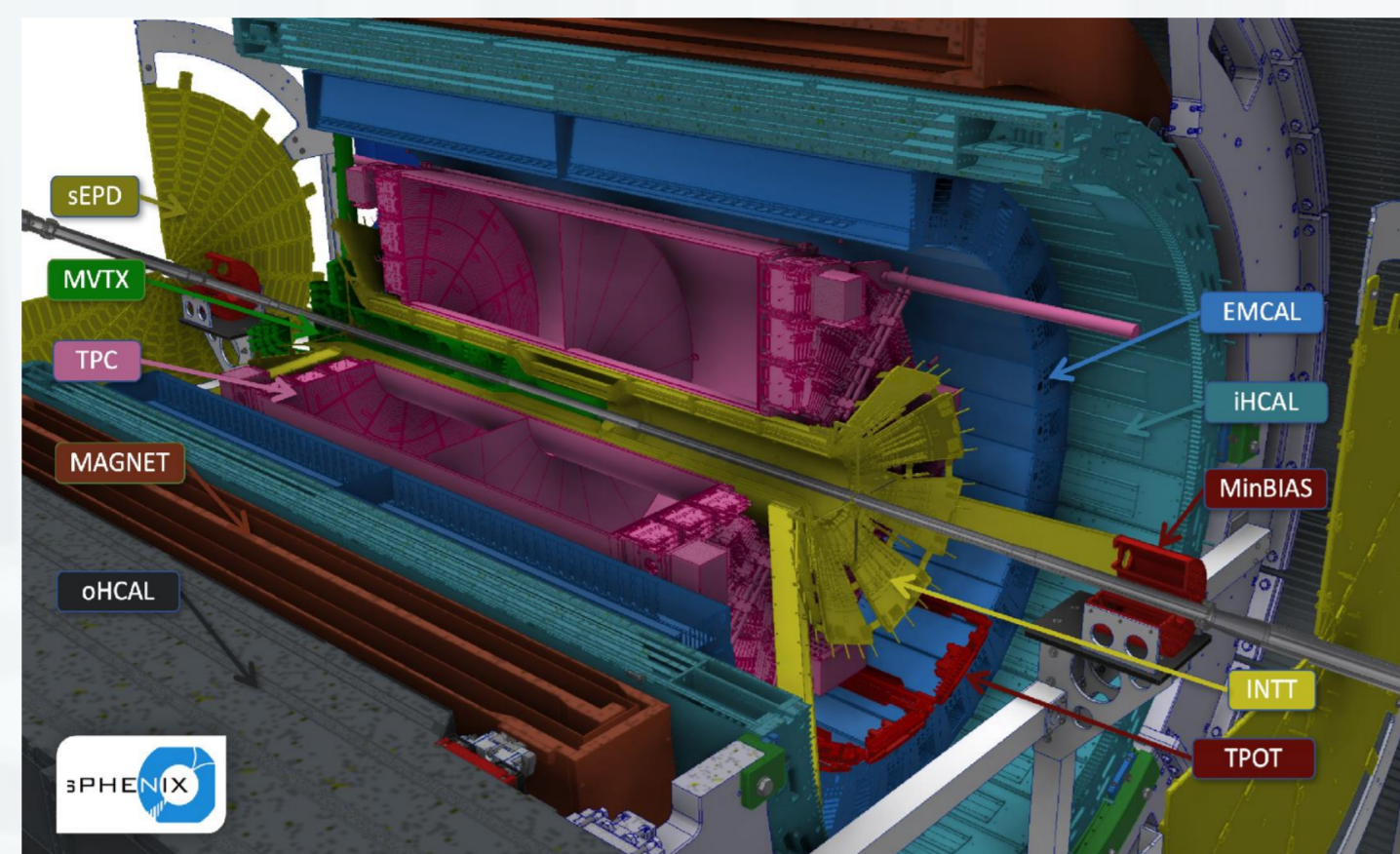


Abstract

The sPHENIX detector at BNL's Relativistic Heavy Ion Collider (RHIC) contains two layers of hadronic calorimeters (HCal). The outer HCal is the outermost layer located outside the solenoid coil, and the inner HCal is positioned between the solenoid magnet and the Electromagnetic Calorimeter. The sPHENIX program, aimed at achieving precise jet measurements and analyzing the microscopic properties of the strongly interacting quark-gluon plasma, requires a well-calibrated energy scale for the calorimeters.

A method utilizing in-situ measurements of energy deposits from cosmic ray muons is developed to perform a comprehensive tower-by-tower absolute calibration at the electromagnetic scale, with the absolute scale being determined from comparisons to Geant4 simulations of the cosmic muon flux.

A quality assurance test using the pre-installation relative calibrations and overall energy scale is used to validate the simulation and verify the feasibility of this cosmic calibration.

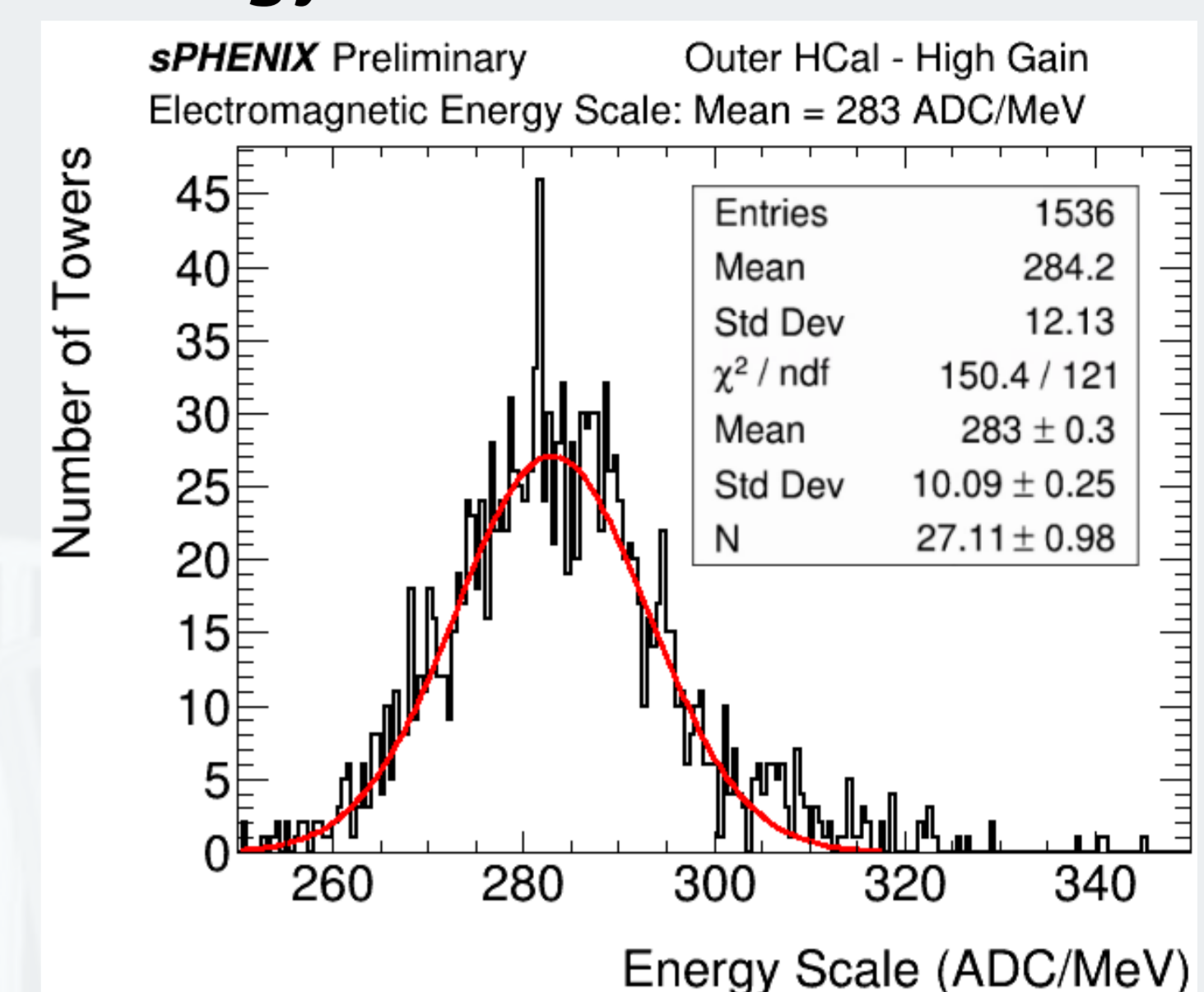


Electromagnetic Energy Scale

The energy scale will be used as a factor to convert the raw ADC readout of each tower to the energy deposited inside the tower of the particles. The determination of the electromagnetic energy scale is done with the two MPV data sets. The ratio of the in-situ MPV and simulated MPV determines the energy scale for that tower:

$$\text{Energy Scale} = \frac{MPV_{in-situ}}{MPV_{sim}}$$

The resulting factor from each tower is collected to form the right figure. A Gaussian fit applied to these data gives a general energy scale for the high gain mode outer HCal: 283 ± 0.3 ADC/MeV.



Data Processing and Selection

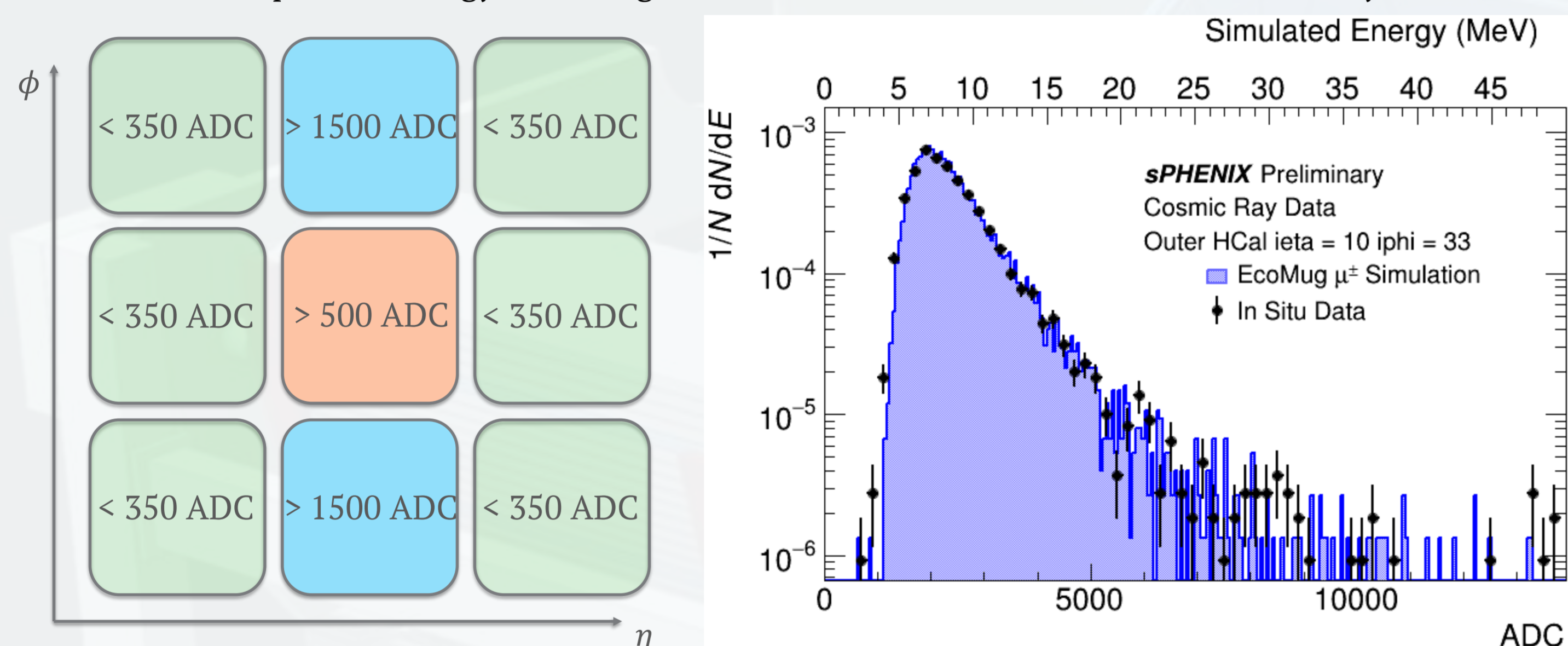
The raw cosmic ADC signals are triggered with sPHENIX cosmic trigger (Poster 497 Daniel Lis, 501 Shuhang Li) and initially undergo first-order relative calibration, derived from the pre-installation cosmic test, which results from the cosmic muons traversing all tiles in the tower. This factor primarily eliminates most of the performance differences between towers, except for the differences attributed to tile shapes (η dependence) and temperature variations in the sPHENIX interaction region (time dependence).

Then, to get the tower's energy distribution deposited by the cosmic muon, offline cuts are applied, which are designed to select cosmic muons that traverse all tiles within a tower, maintaining an approximately perpendicular trajectory to the detector barrel's radius:

Minimum Energy Cut: To eliminate noise, the target tower must have a minimum of 500 ADC counts.

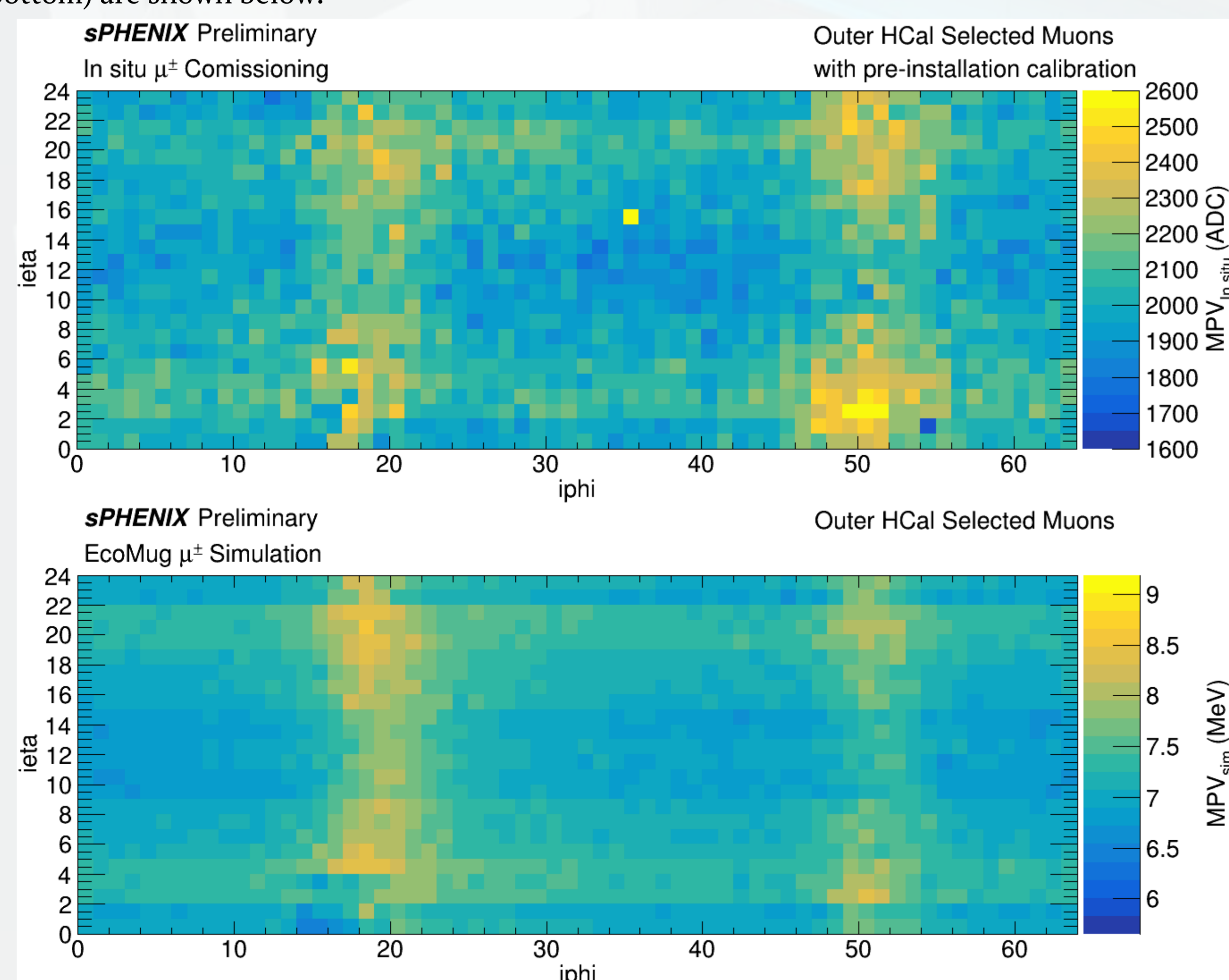
Vertical Cut: The two towers vertically above and below the target tower (ϕ direction) should each have a minimum of 1500 ADC counts. This cut establishes coincidence ensuring that the selected muons pass through all three towers, and that the muon traverses the entirety of the target tower.

Adjacent Veto Cut: The six adjacent towers surrounding the target tower and the two vertically oriented towers should not possess energy exceeding 350 ADC. This restriction ensures the verticality of the muon.



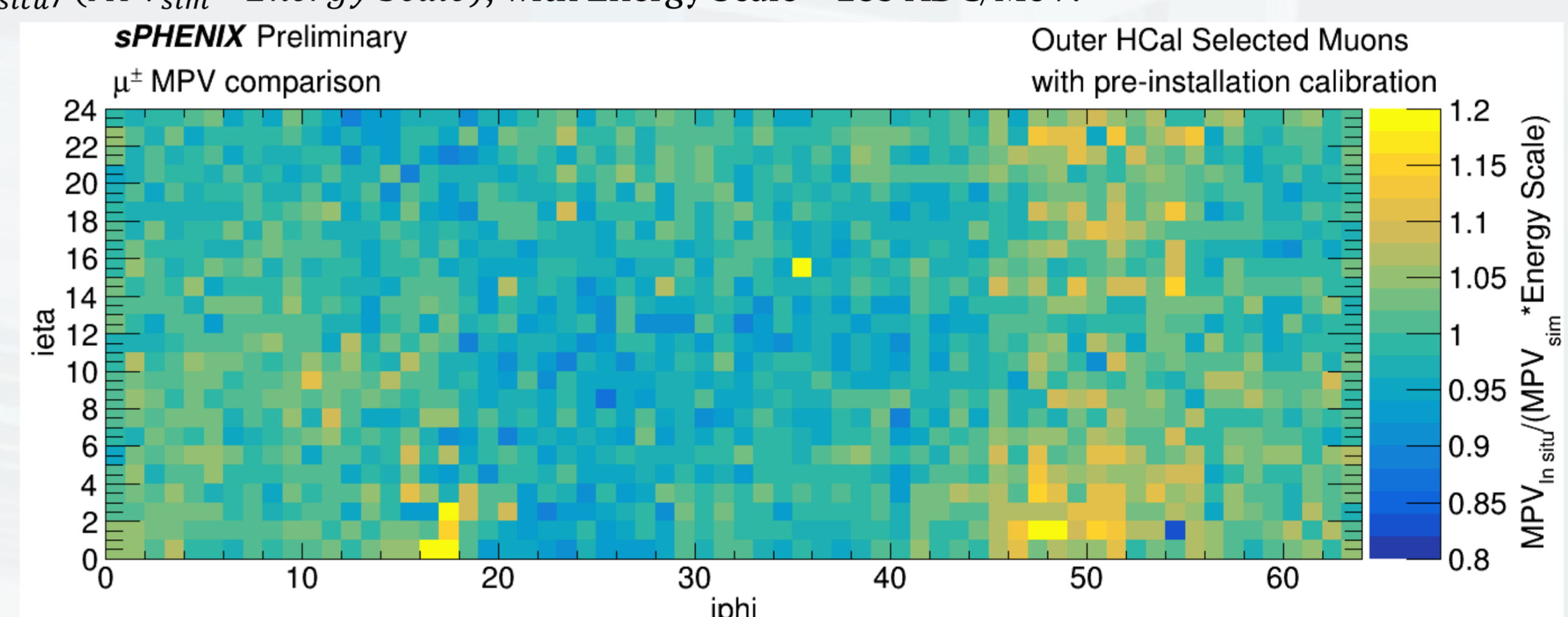
Most Probable Value Distribution

The key parameter is the Most Probable Value (MPV) for distribution of energies for such muons. A Gamma function fit is then applied to each tower's energy distribution, thereby obtaining the MPV for each tower. The 2D distribution of the MPV for each oHCal towers' sPHENIX in situ selected cosmic muon's energy spectrum with pre-installation calibration applied (top) and simulated result (bottom) are shown below.

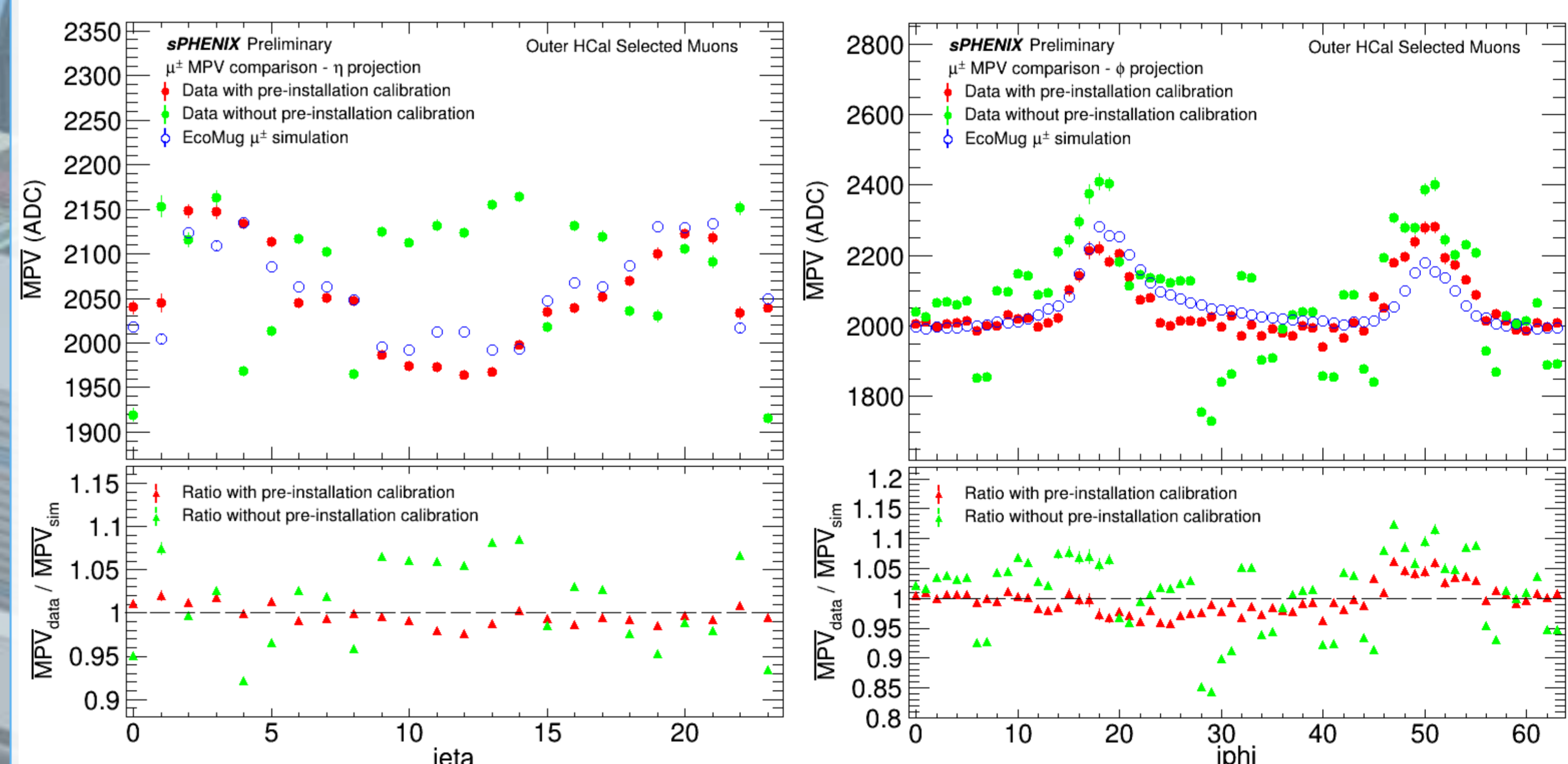


Simulation Validation

A quality assurance test is essential to validate if our simulation is realistic. The 2D distribution of MPV comparison between oHCal towers' sPHENIX in situ selected cosmic muon's energy spectrum with pre-installation calibration applied and the simulation result is shown. The comparison is done with function: $MPV_{in-situ}/(MPV_{sim} * \text{Energy Scale})$, with Energy Scale = 283 ADC/MeV.



The detailed information is shown in the η and ϕ projection comparison between sPHENIX in situ data with and without pre-installation calibration applied and simulated cosmic data. In the upper figure, the dots are the mean MPV value of the towers within the same ieta or iphi slice. And for the simulated mean MPV, it times the Energy Scale, 283 ADC/MeV for comparison. The dots in the lower figure are the comparison obtained from $MPV_{in-situ}/(MPV_{sim} * \text{Energy Scale})$.



The η projection comparison distribution with pre-installation calibration applied shows a significant concordance between the sPHENIX in situ cosmic data set and the corresponding simulation set. The discrepancy in the majority of the data is 2% or less.

In the ϕ projection comparison distribution with pre-installation calibration applied, a pronounced peak emerges around iphi ~ 50, presenting a difference of approximately 6-7%. This discrepancy can be ascribed to the temperature differential between the upper and lower regions of the detector, with a variation of around 1-2°C observed, with the top part warmer and the lower part cooler, with higher temperatures producing lower gains.

The result without pre-installation calibration applied shows much larger discrepancy that is about 10%. The pre-installation calibration dramatically decrease the discrepancy from 10% to less than 5%. And now, the new calibration will eliminate the final discrepancy.

Summary

The sPHENIX in-situ cosmic muon calibration method's reliability is confirmed through the comparison analysis. The calibration factor that will be used is gain from the ratio between raw sPHENIX and the simulated in-situ cosmic muon directly. To maintain calibration accuracy, continuous temperature monitoring and regular cosmic runs are essential and will be done by the shift crews. Further investigations will focus on addressing and understanding the remaining variance.

Acknowledgements

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