sPHENIX EMCal Calibration Methods

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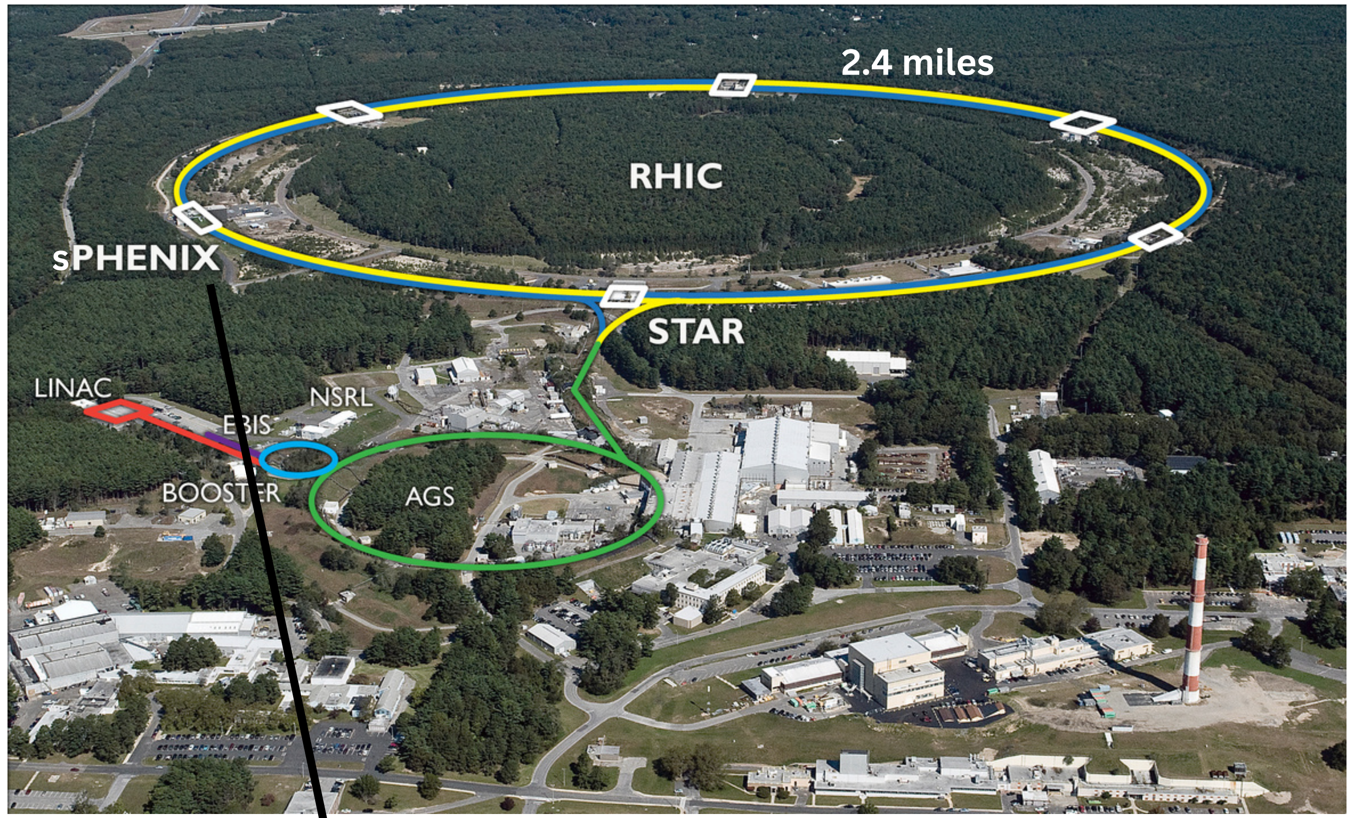
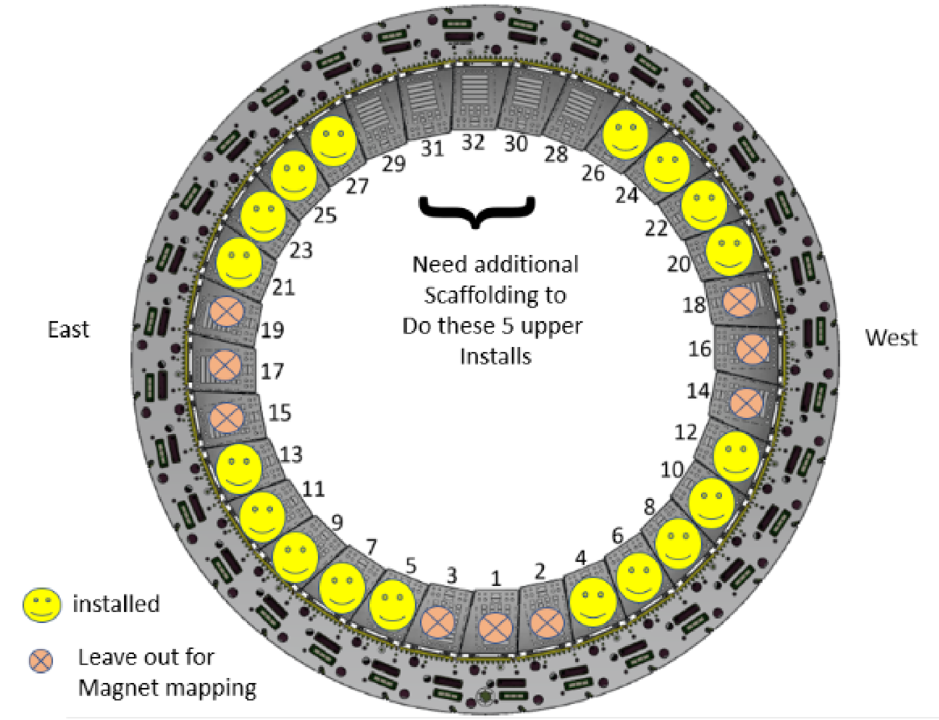
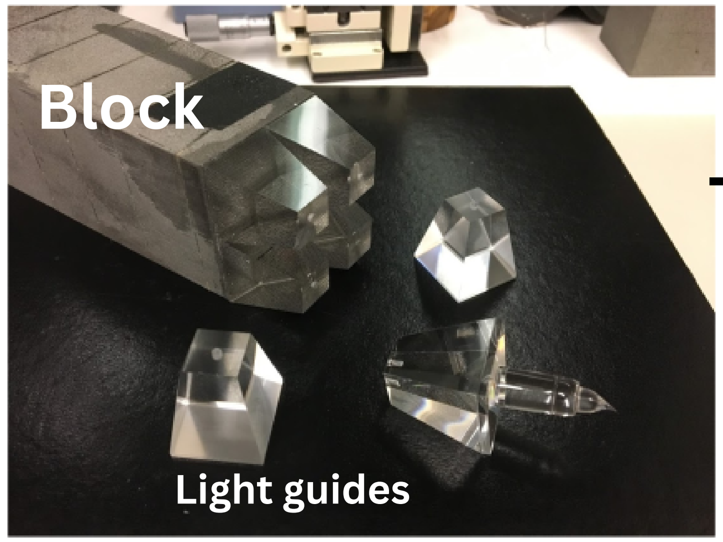
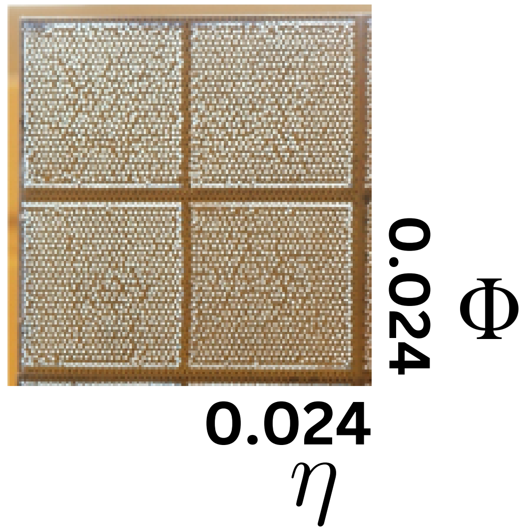


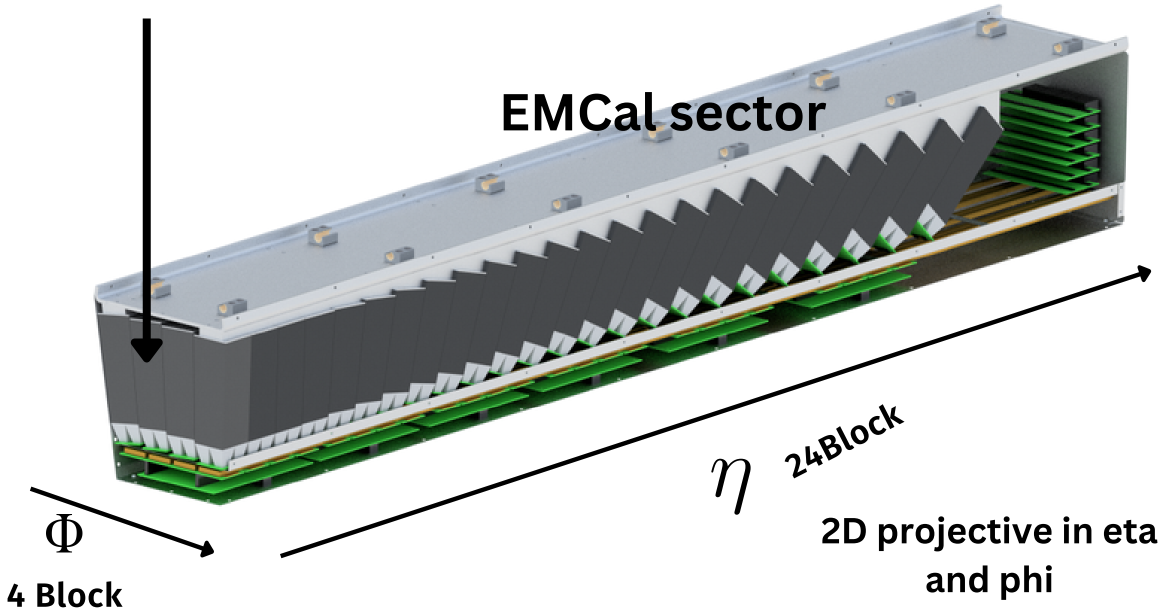
EMCal Sector Installations



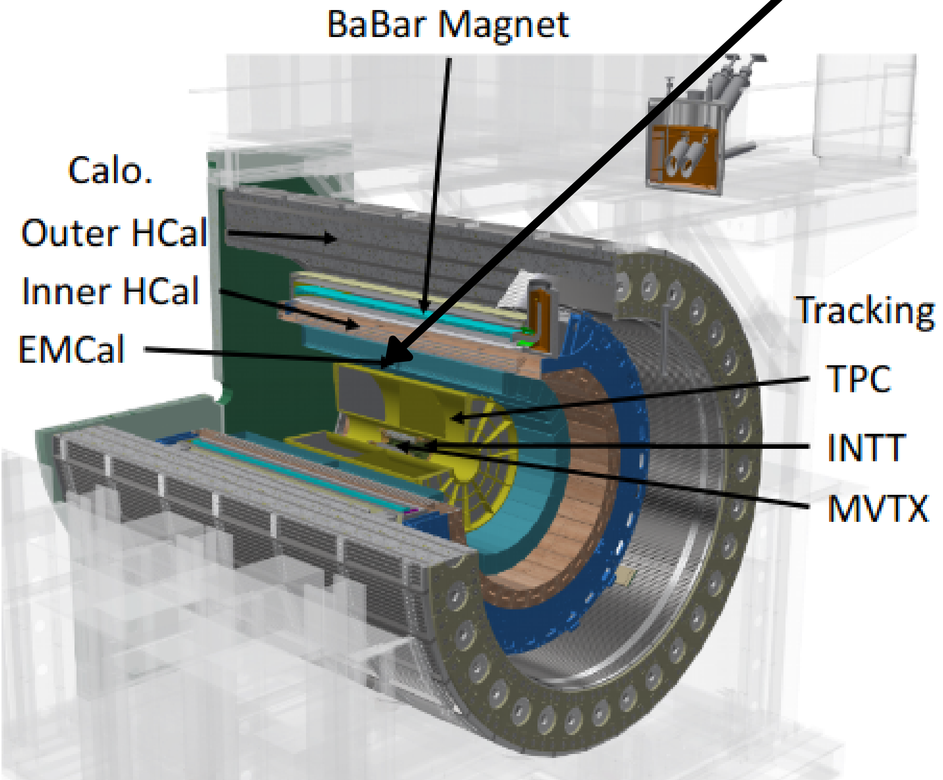
Block (4 towers)

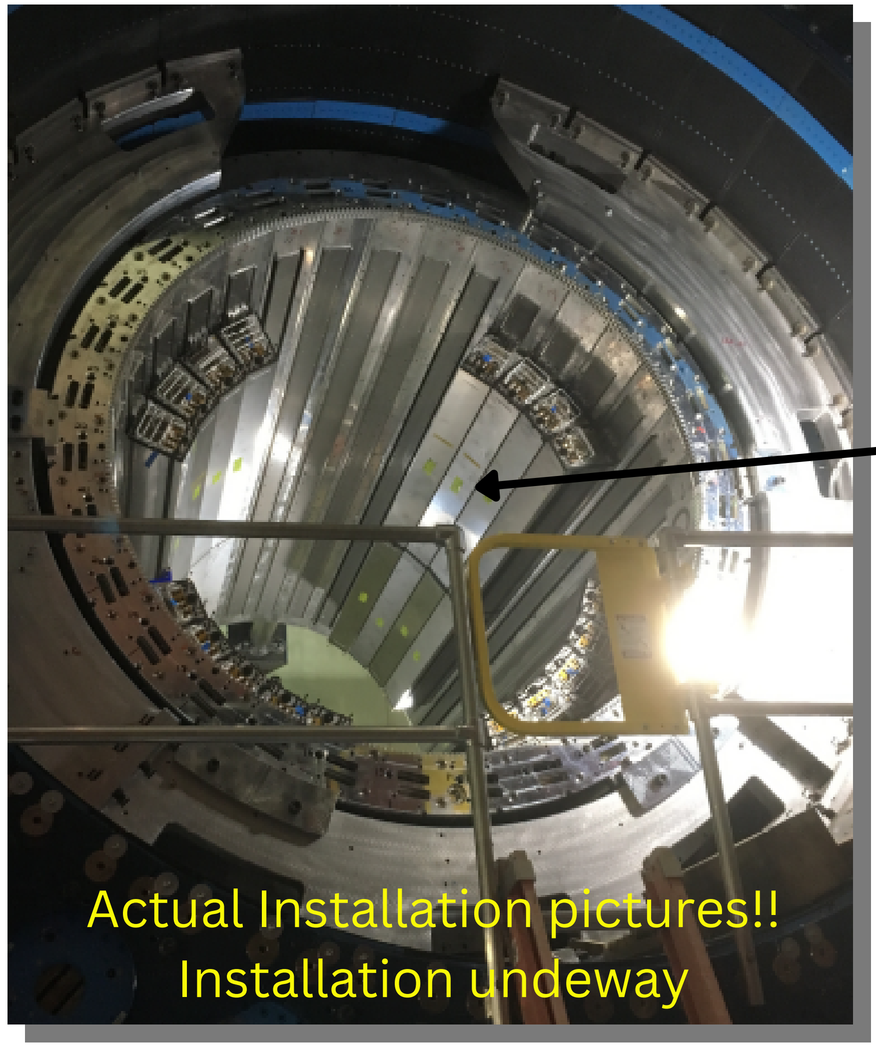




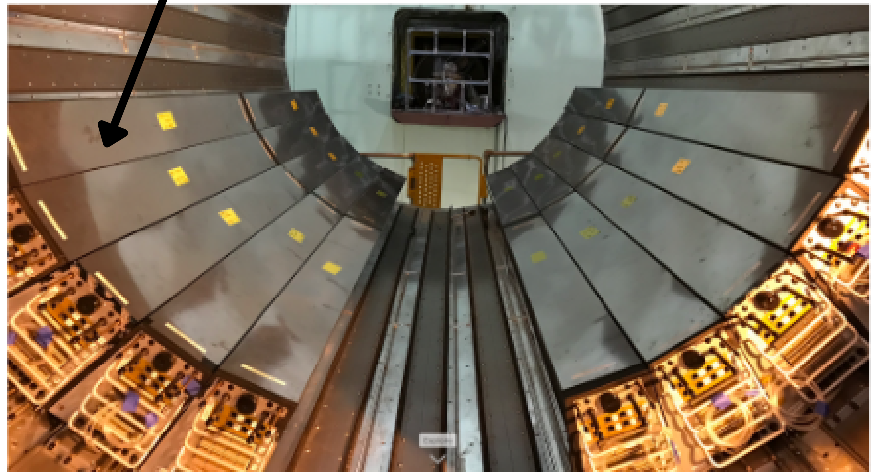


sPHENIX detector





EMCal Sectors



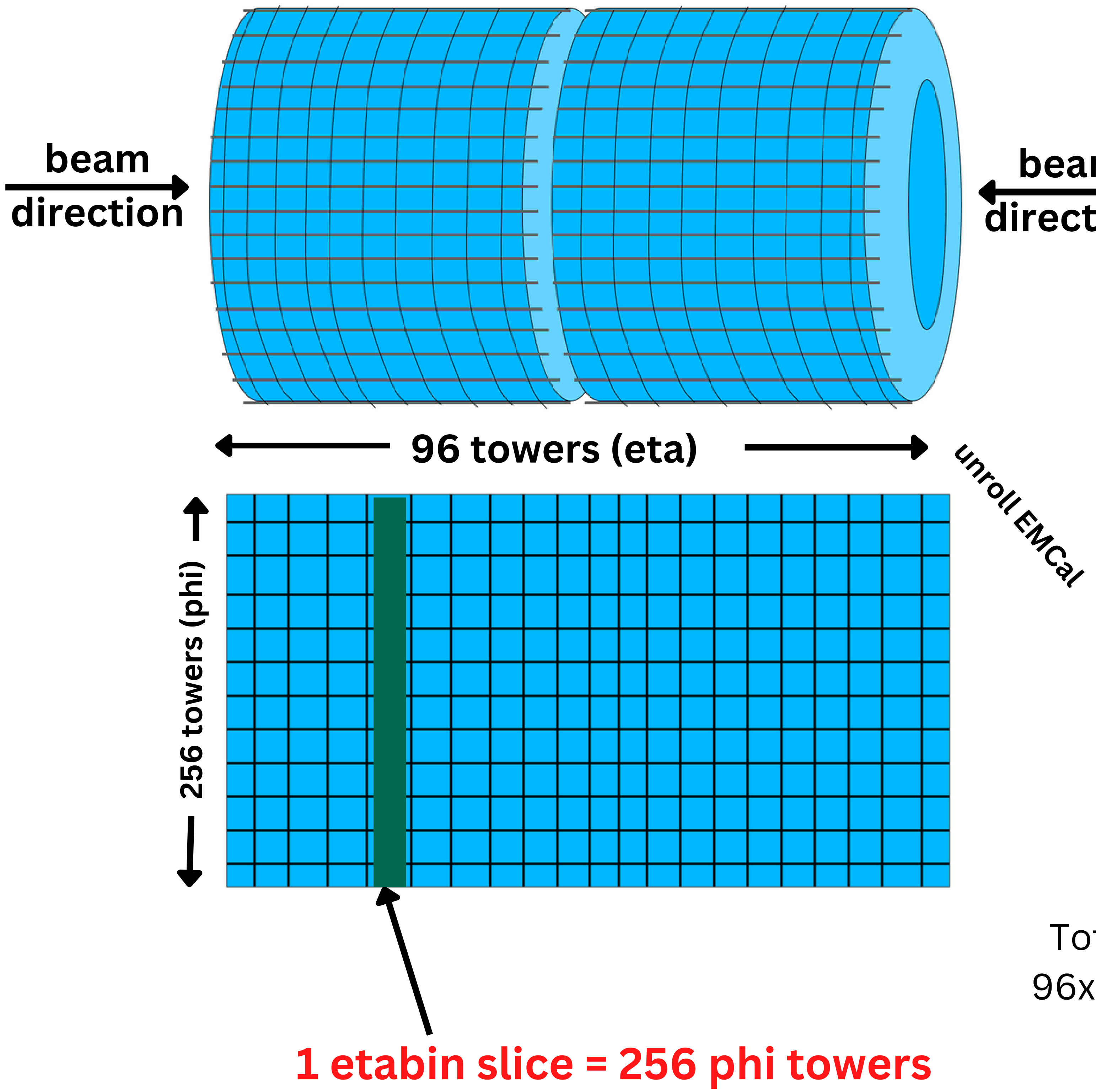
Introduction to sPHENIX EMCal geometry

sPHENIX EMCal geometry

sPHENIX EMCal specifications

- 0.024×0.024 in η and ϕ
- $|\eta| \leq 1.1$
- 2π azimuthal acceptances
- $13\%/\sqrt{E}$ energy resolution of EMCal
- trigger rate 15 kHz
- magnetic field 1.4 T

Illustration only (Not in Scale)



Total towers:
96x256=24,576

Calibration Methods of EMCal/HCals

Relative Calibration

Flattening corrections for uniformity over time and channel number

- Minimum Ionizing Particle (MIP) Calibration (tower-based) - cosmic muons
  - pre-install cosmic calibration completed
- Tower-Slope method (data-driven) Justin Bryan OU
- LED - Hardware based system

Absolute Calibration

Overall EM Scale of whole EMCal

- pi0 tower-by-tower method Shyam Chauhan OU
- Electron (E/p) method
- Eta meson --> 2gamma at high energy

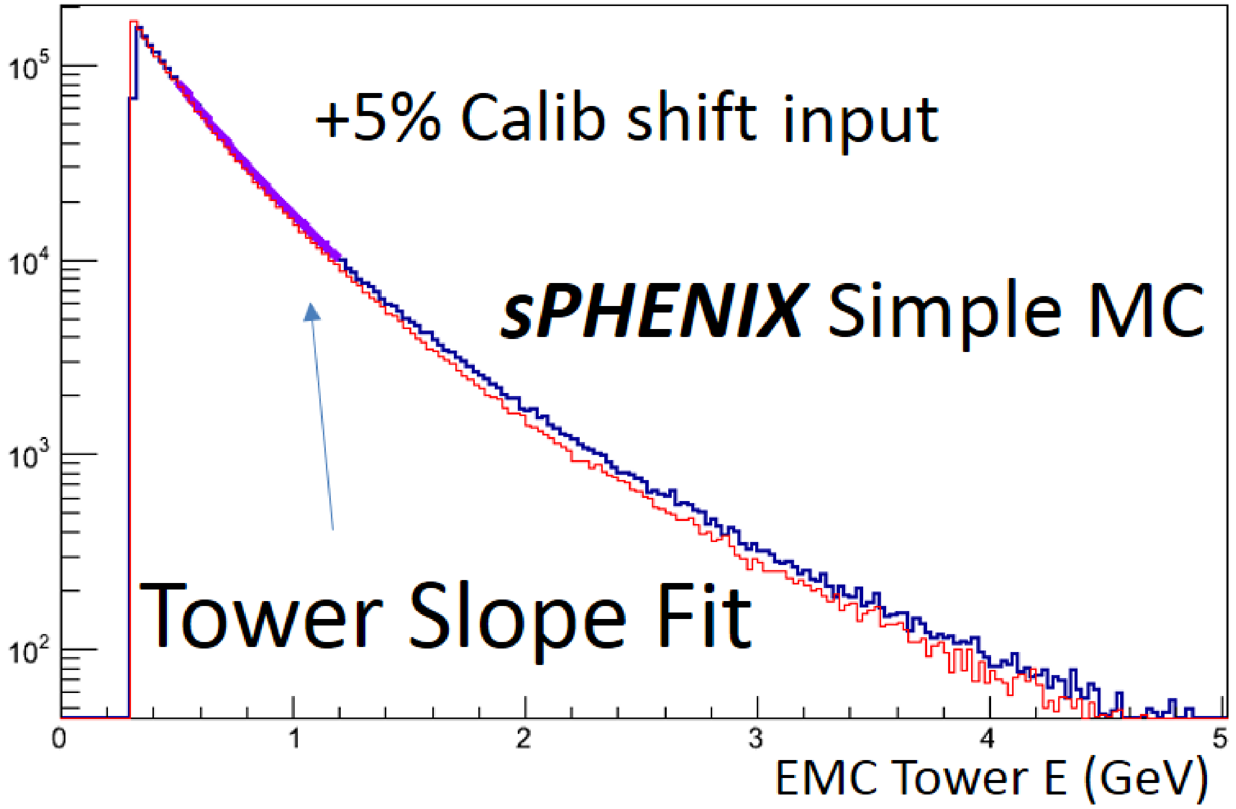
gamma , electron (shower based) calibration methods

TOWER BASED METHODS

Multiple redundant and complementary methods!

SHOWER/CLUSTER BASED METHODS

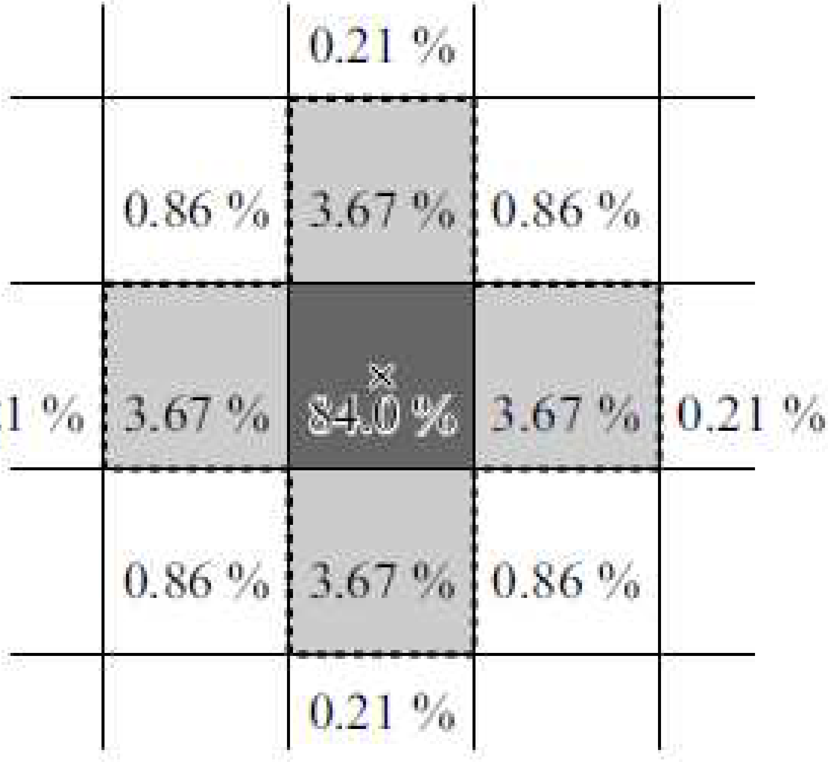
EMCal Tower E Distribution



- Channel/Tower based calibration methods Based on single tower energy response Example: Tower slope method
- Fit slope of individual tower energy spectra compare slope at later time to test for and extract gain drift
- shift = new_slope/old_slope

$$E_j = \sum_{i_{tower}} g_{ij} \mathrm{ADC}_i$$

gij is the correction factor, j is for each test particle

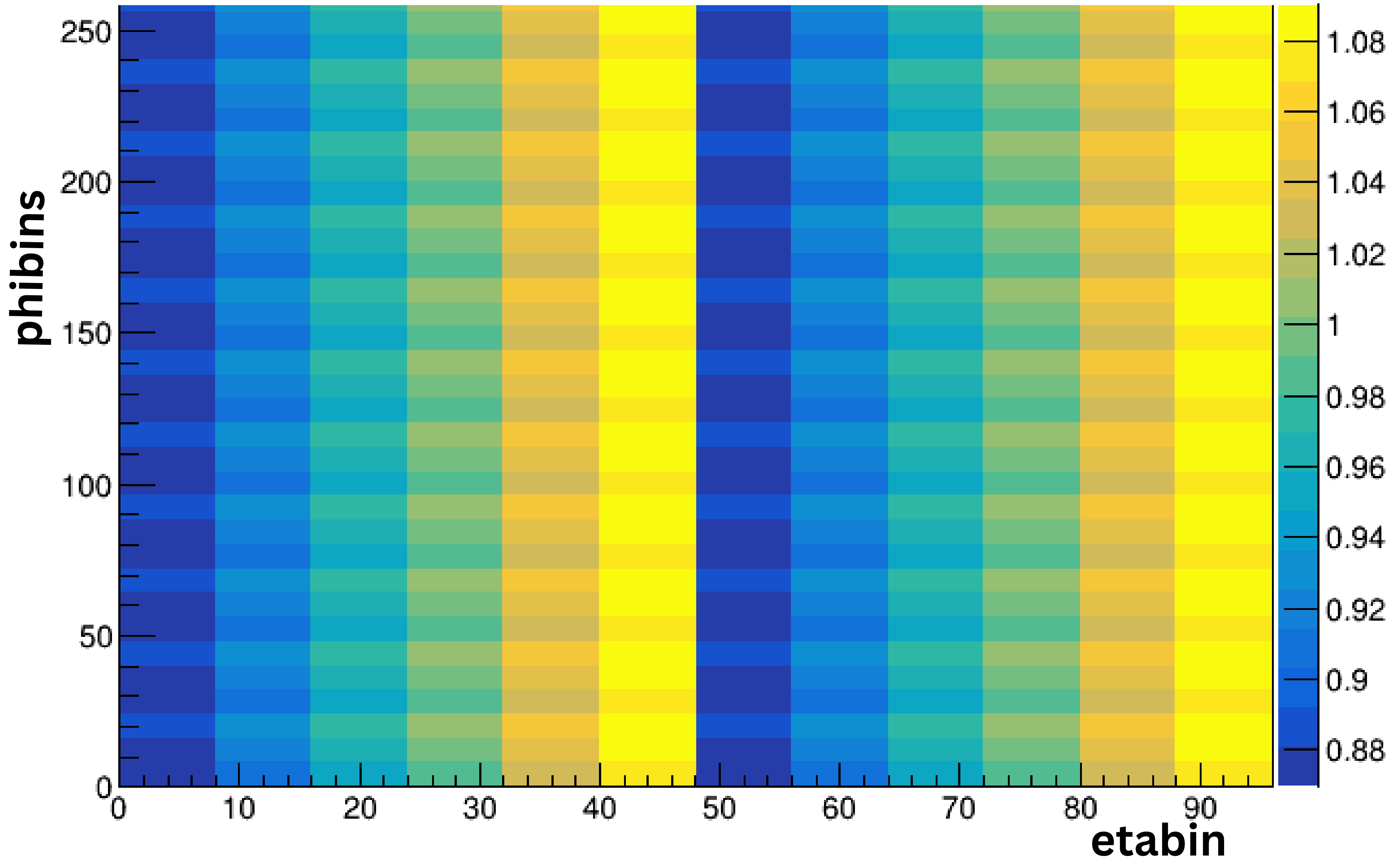


shower energy distributed among towers
Need UNFOLDING of individual tower contributions

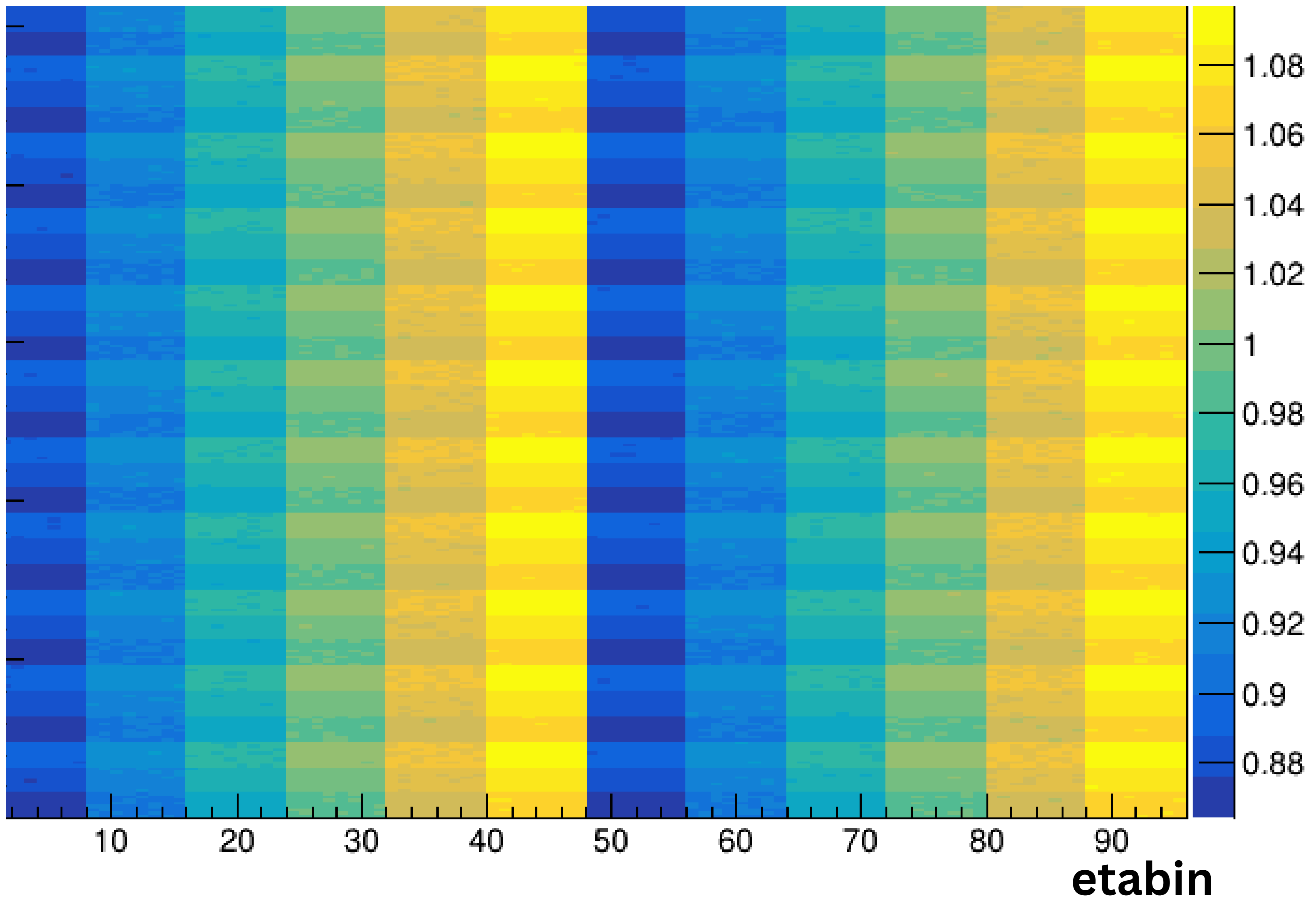
Example: EMCal Tower-Slope method / Calibrations

- **sPHENIX-developed new method: uses data-driven spectral shape to detect gain drift in one data sample relative to reference data sample and extract shift parameter**
- **Basic method demonstrated - final characterization of systematics underway**
- **Same method also used for sPHENIX HCals**

Input De-calibration Shifts

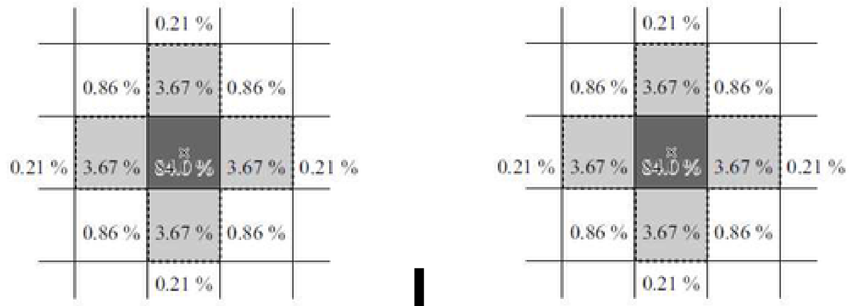


Recovered Shifts



Iterative pi0 tower-by-tower method

$$\pi^0 \rightarrow \gamma\gamma$$



bin by max energy tower of each cluster

(Re)calculate inv. mass

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

cluster pairs from combinatorics form bkg

fill histogram with inv. mass at cluster max tower location

perform fit (Gaus+Pol2)

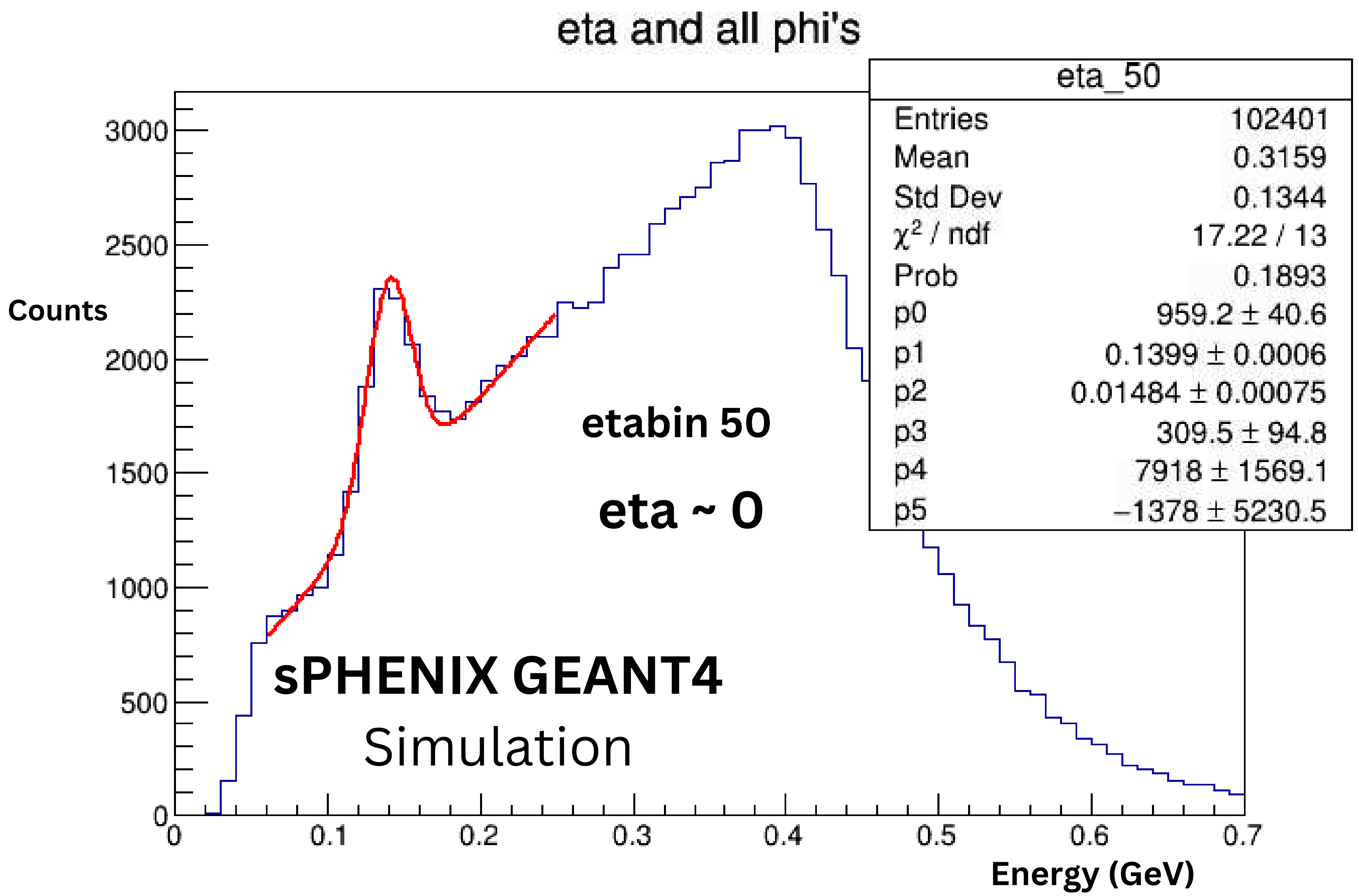
obtain fit parameters i.e. mean

calculate correction factor i.e. (fit mean)/0.135

multiply tower Es with correction factor

until convergence

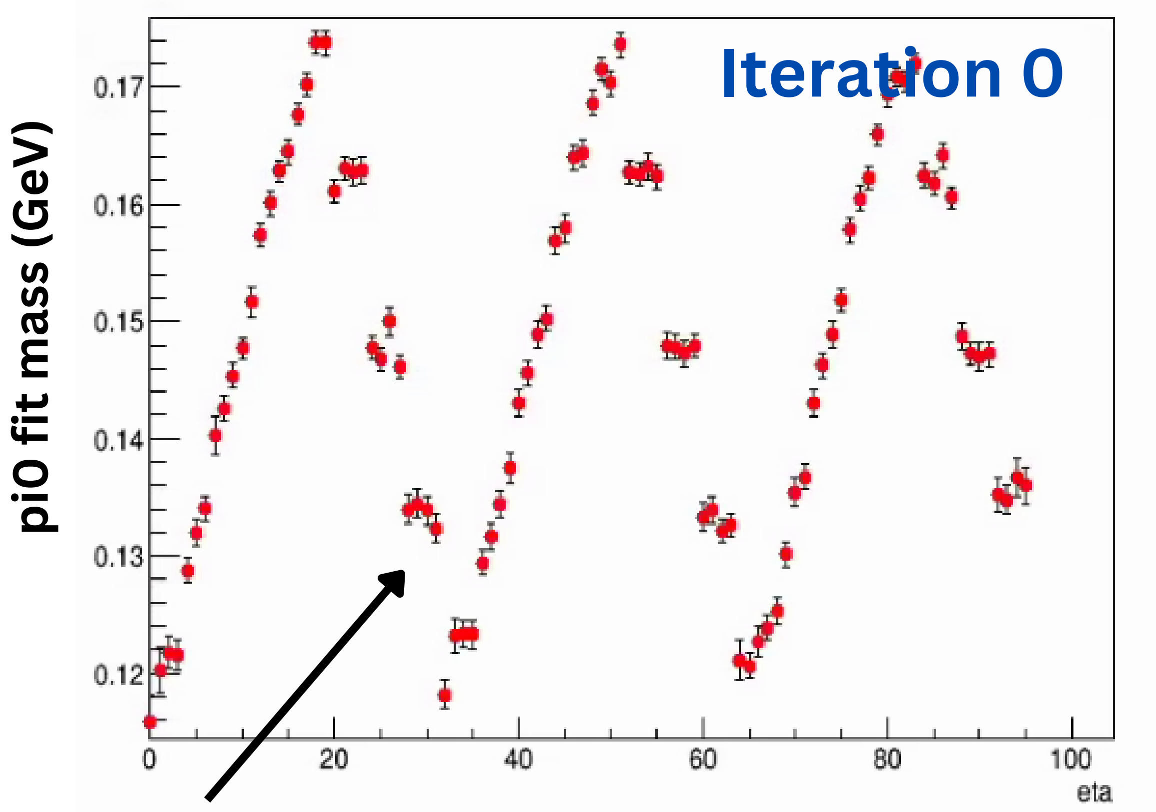
example fit of one etabin (slice)

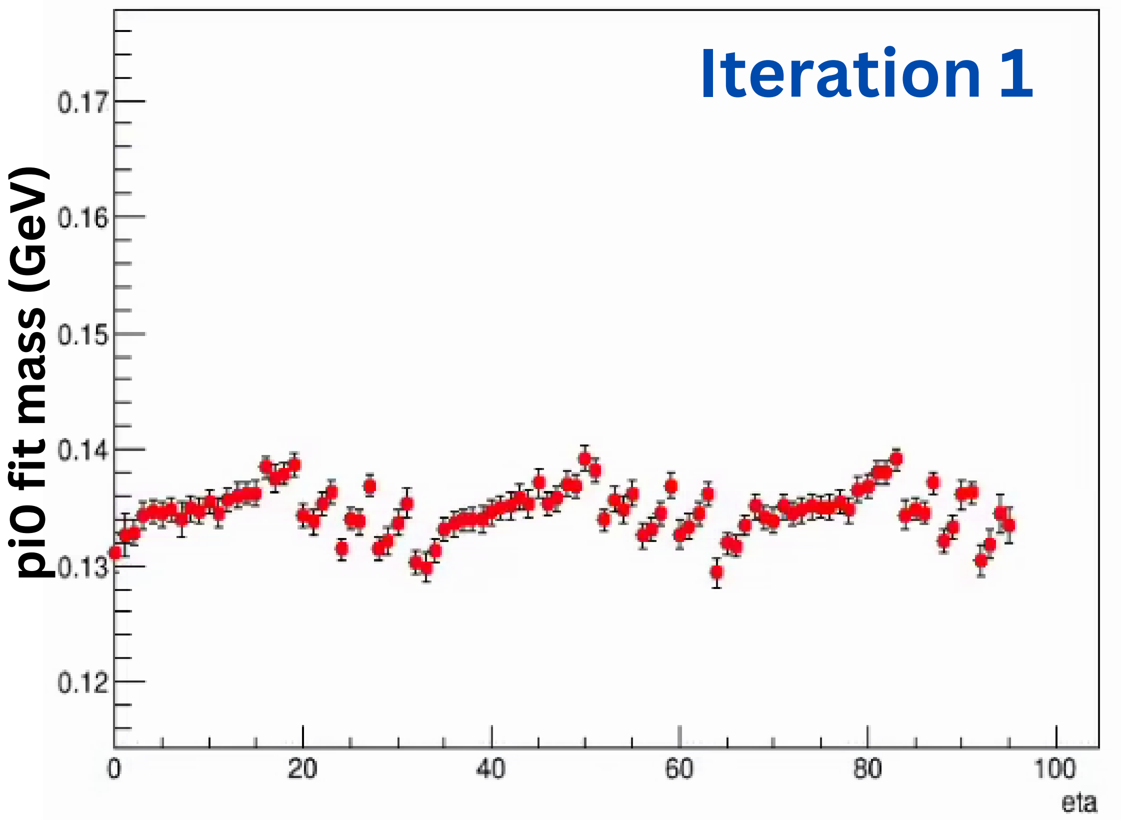


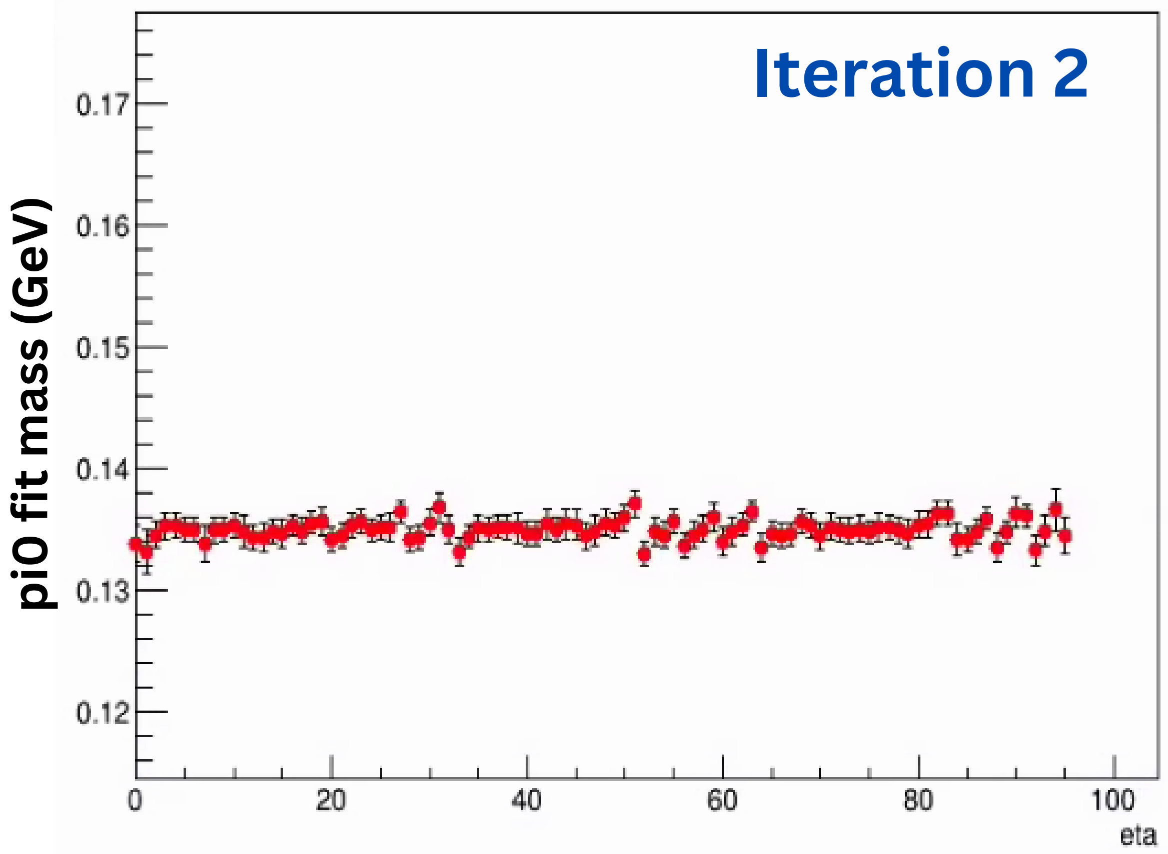
data from AuAu peripheral collisions

Pi0 method: Calibrations of all 96 etabin (slices)

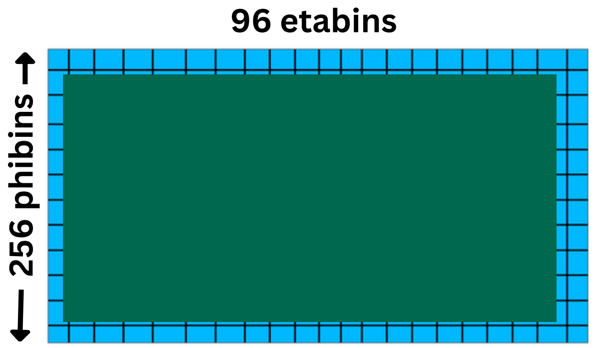
Iterative unfolding with only eta dependence (1D decal pattern)

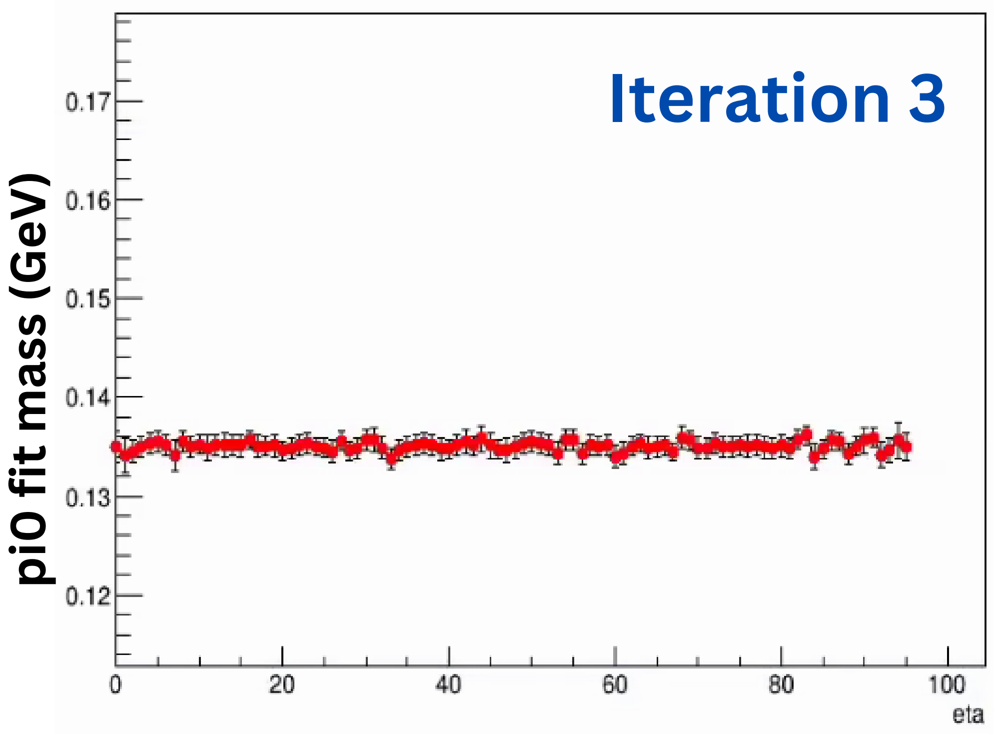


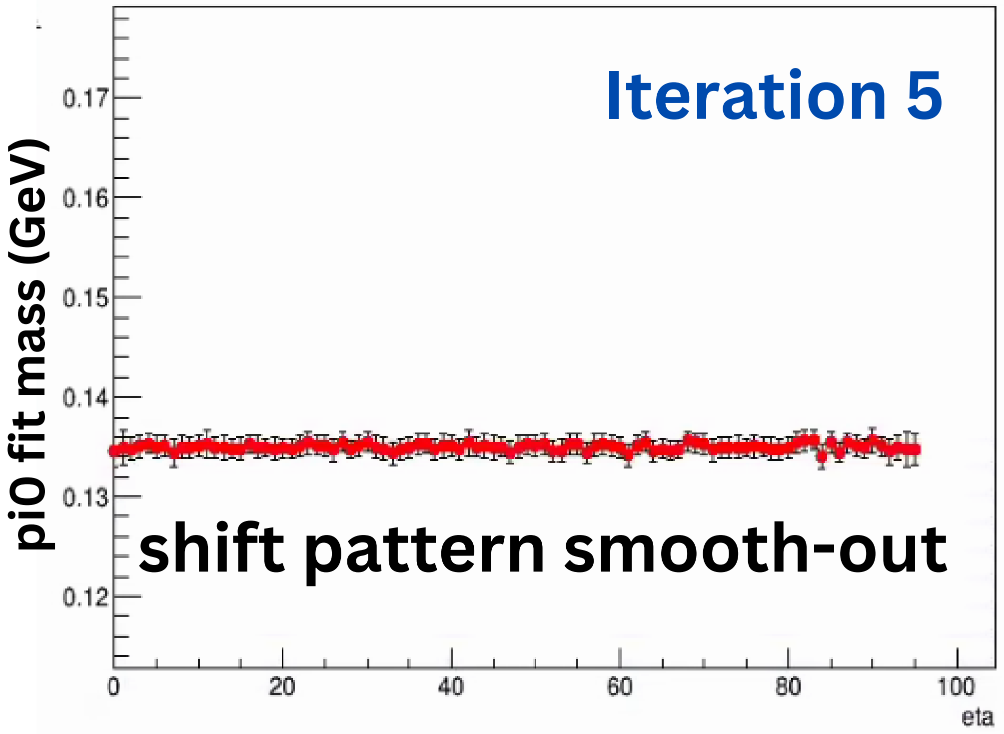




Input de-calibration shift pattern







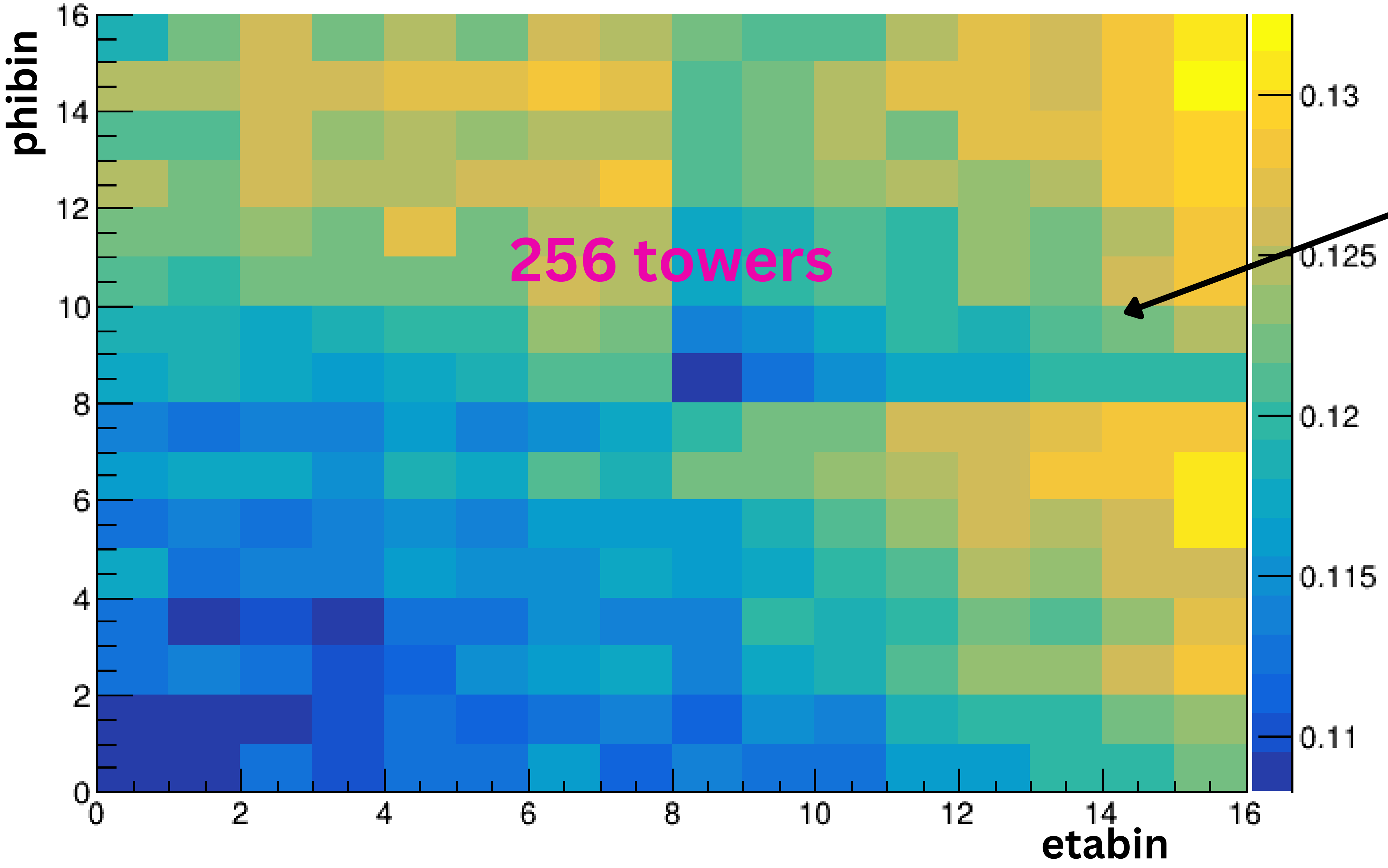
By Iteration 5 calibration corrections successfully fix problematic input de-calibration!

piO T.b.T. - Tower Level Eta, Phi

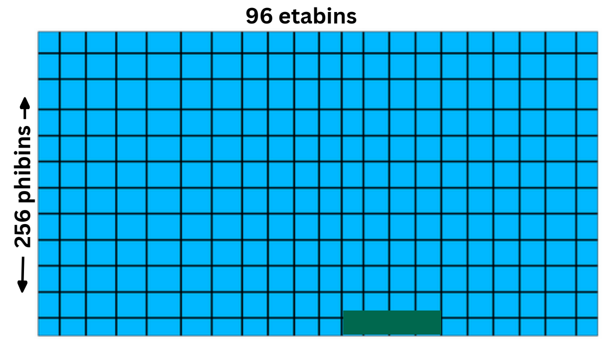
Full method: unfolding with eta and phi dependence (2D decal pattern)

- sPHENIX Mock Data Challenge 2 : 40 M HIJING (simulation) events
- Only enough for Tower by Tower test of small (16x16 tower) region
  - combined statistics from many regions across detector
- higher statistics tests of full 24k tower are underway using pi0's embedded into HIJING
- Real Data analysis will use ~1-3 Billion Peripheral events

z-values are tower mass from fit mean



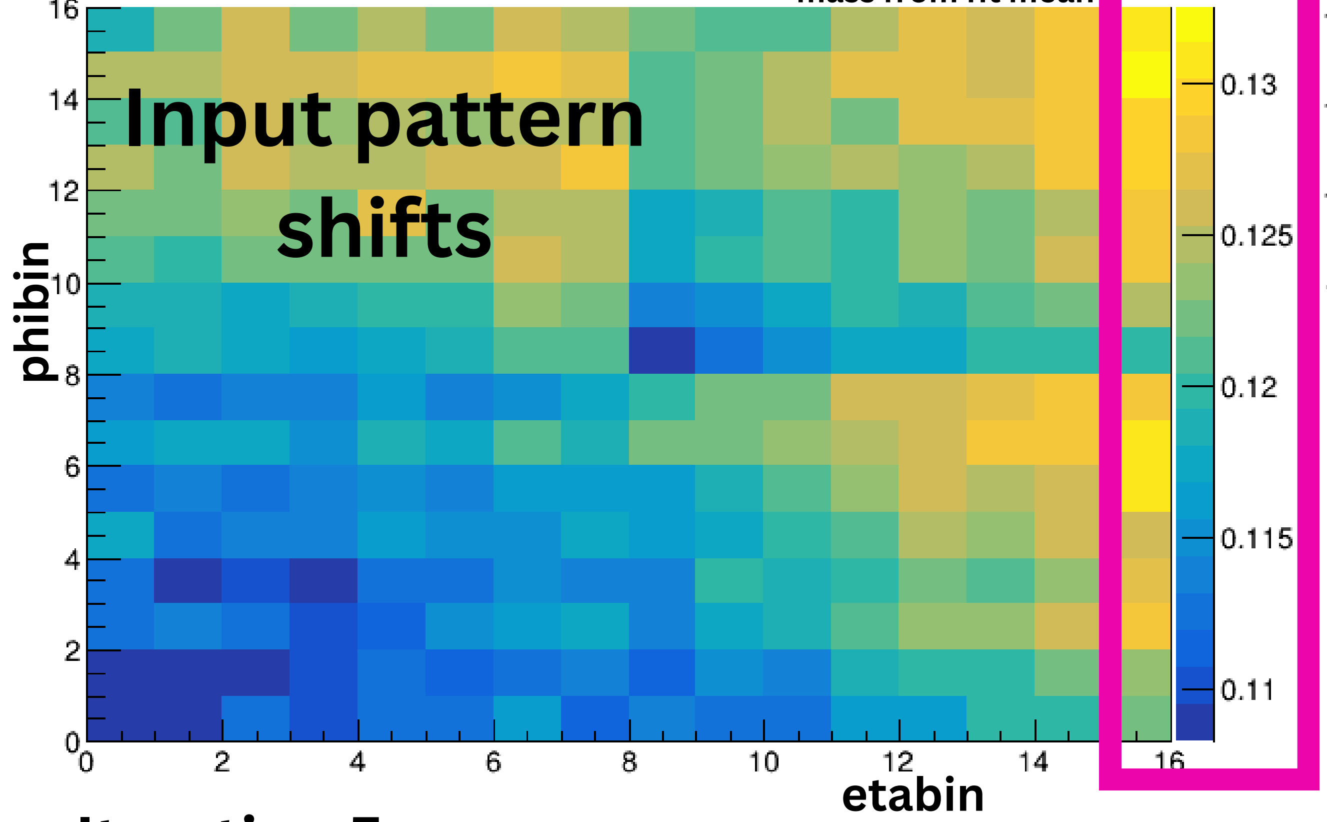
complete EMCal geomerty



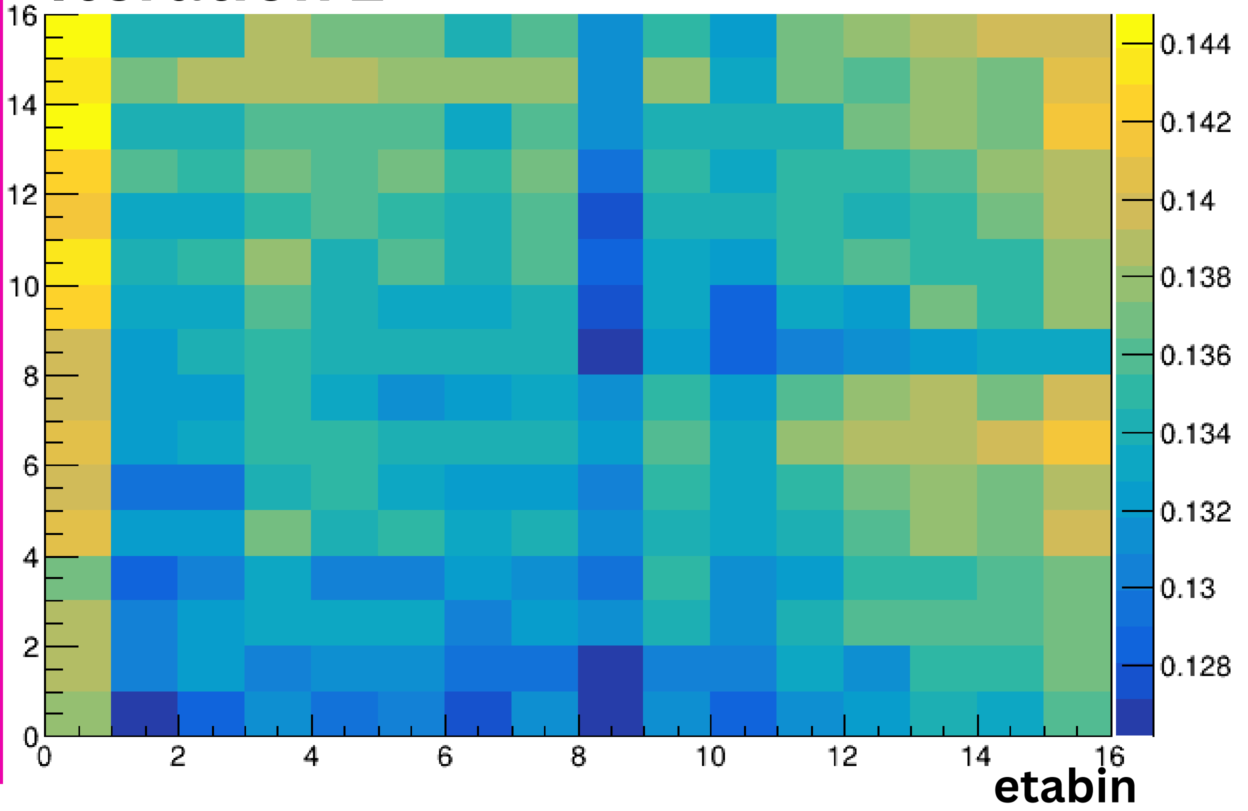
16x16 region

16x16 2D Eta-Phi Unfolding pi0-tbt Calibration

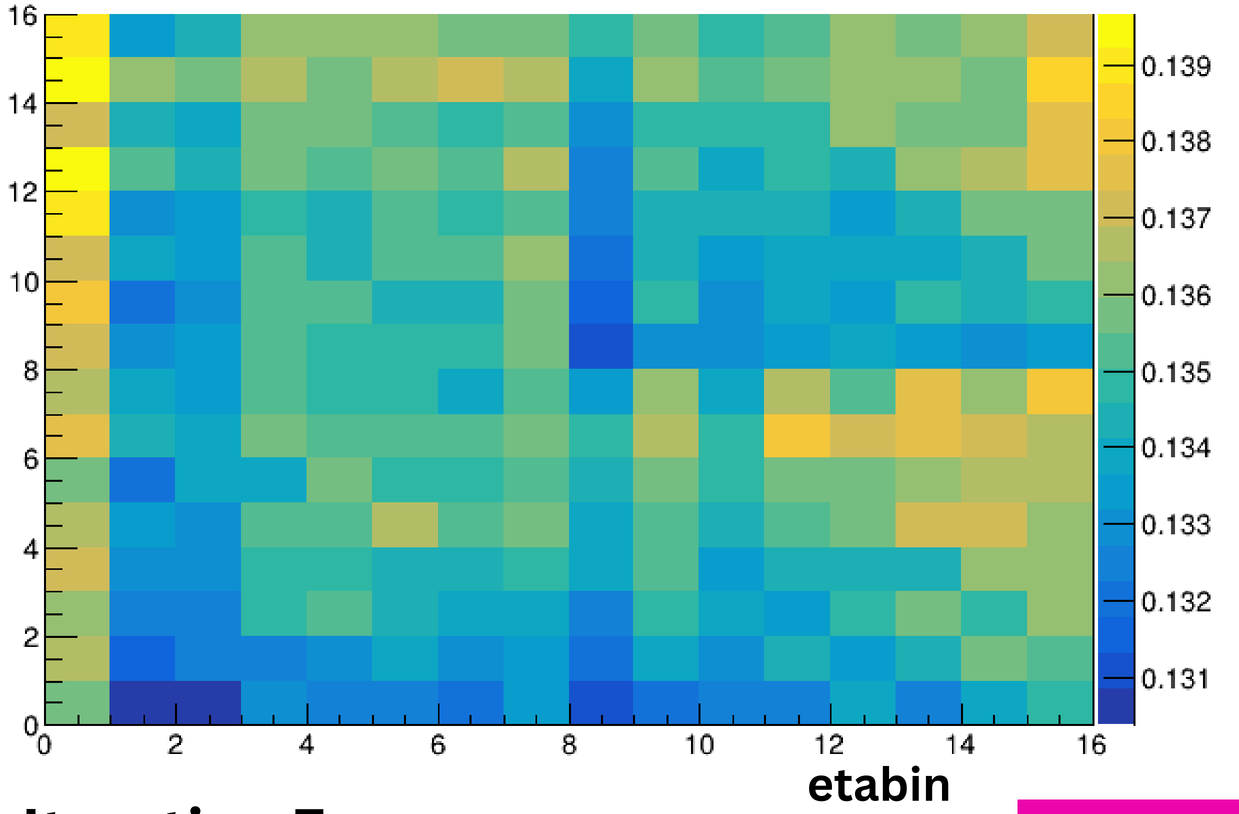
Iteration 0



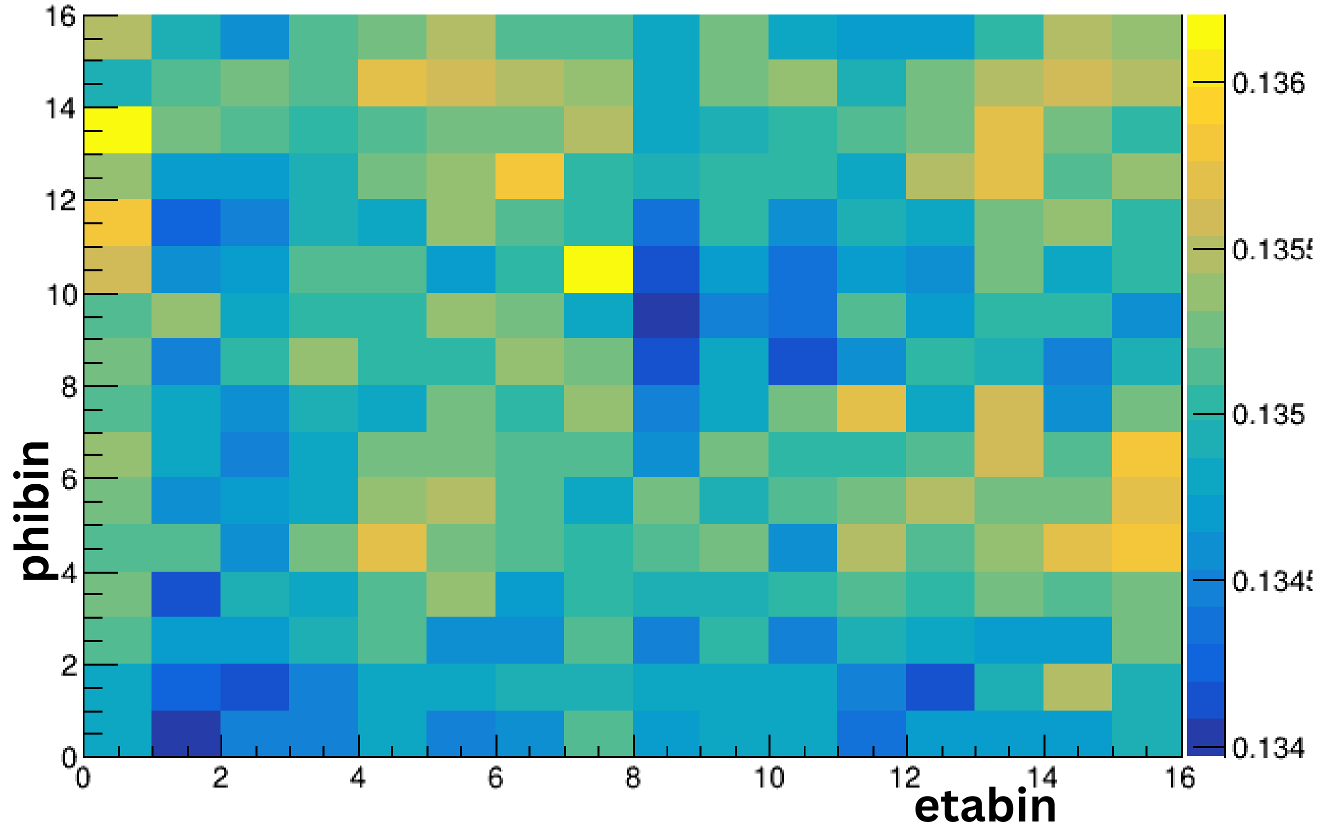
Iteration 1



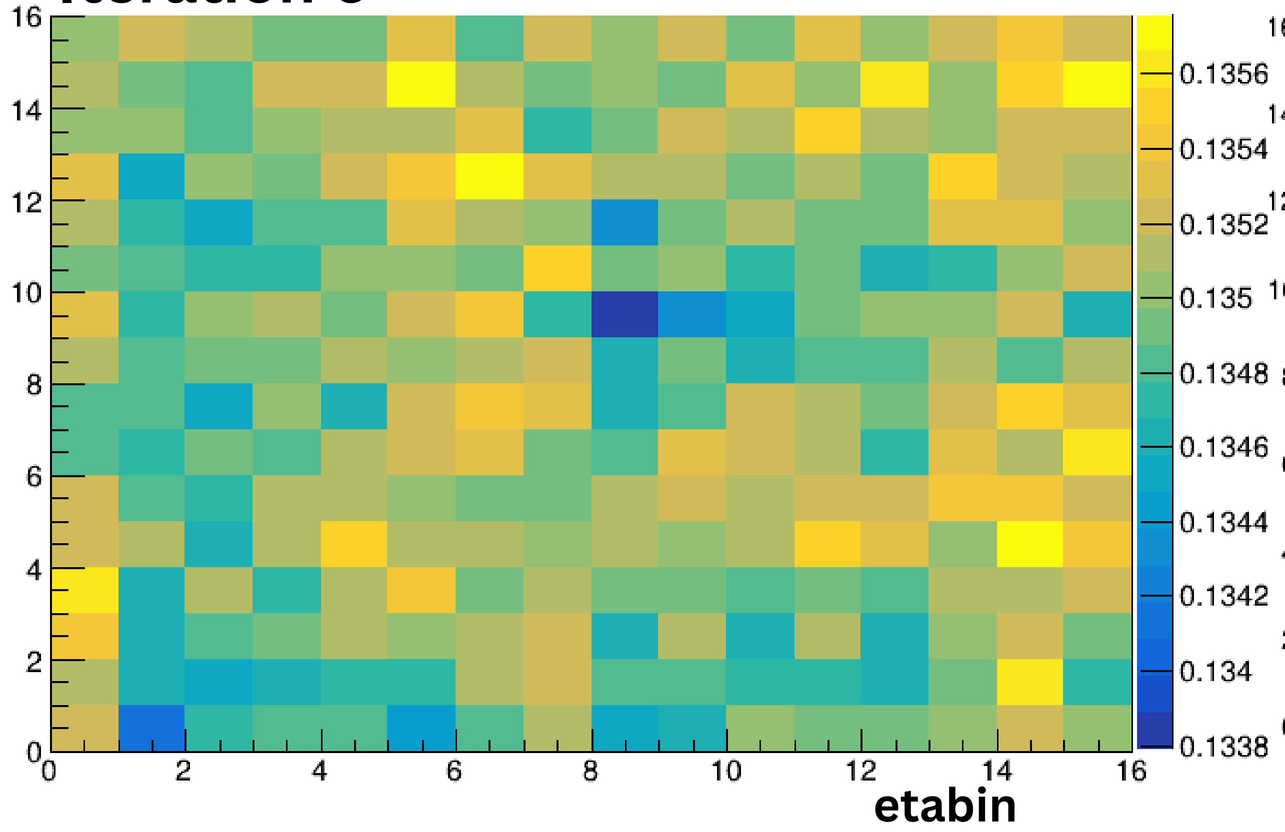
Iteration 2



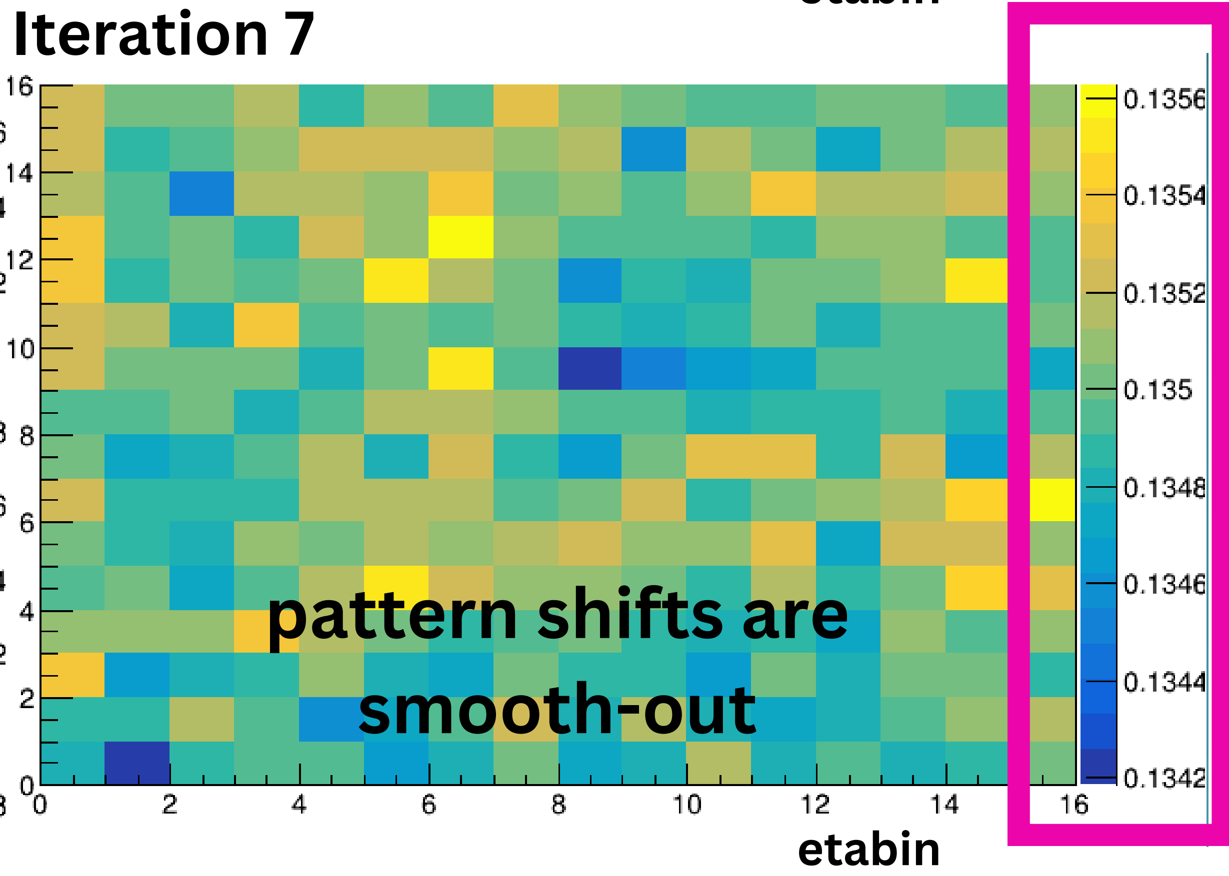
Iteration 5



Iteration 6



Iteration 7

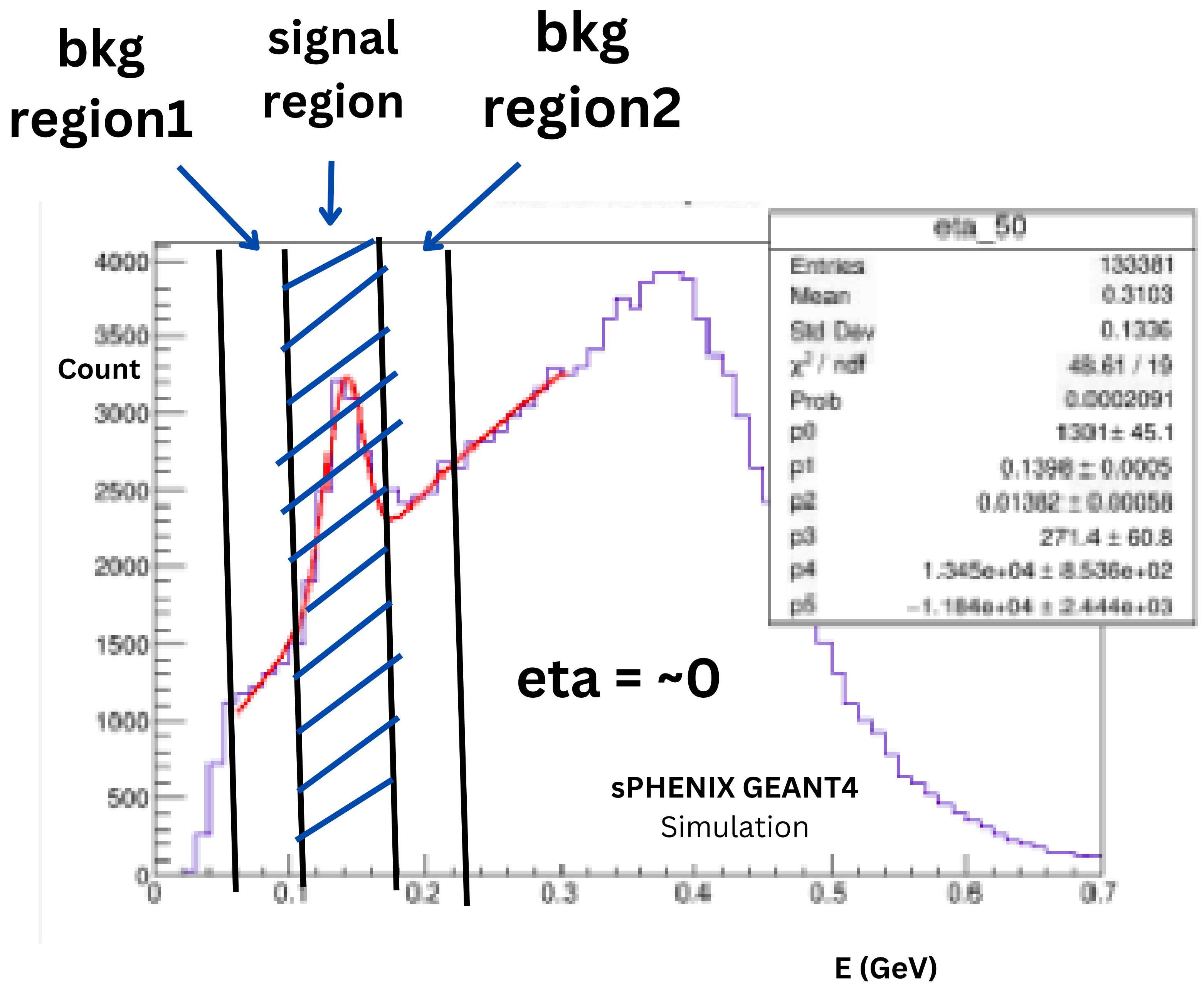


Optimal Pi0 Photon pT Cuts Study

How many minimum events do we need to perform Pi0 Calibration in order to get better statistical precision + fit reliability?

Goals in picking optimal energy/pT region for pi0's

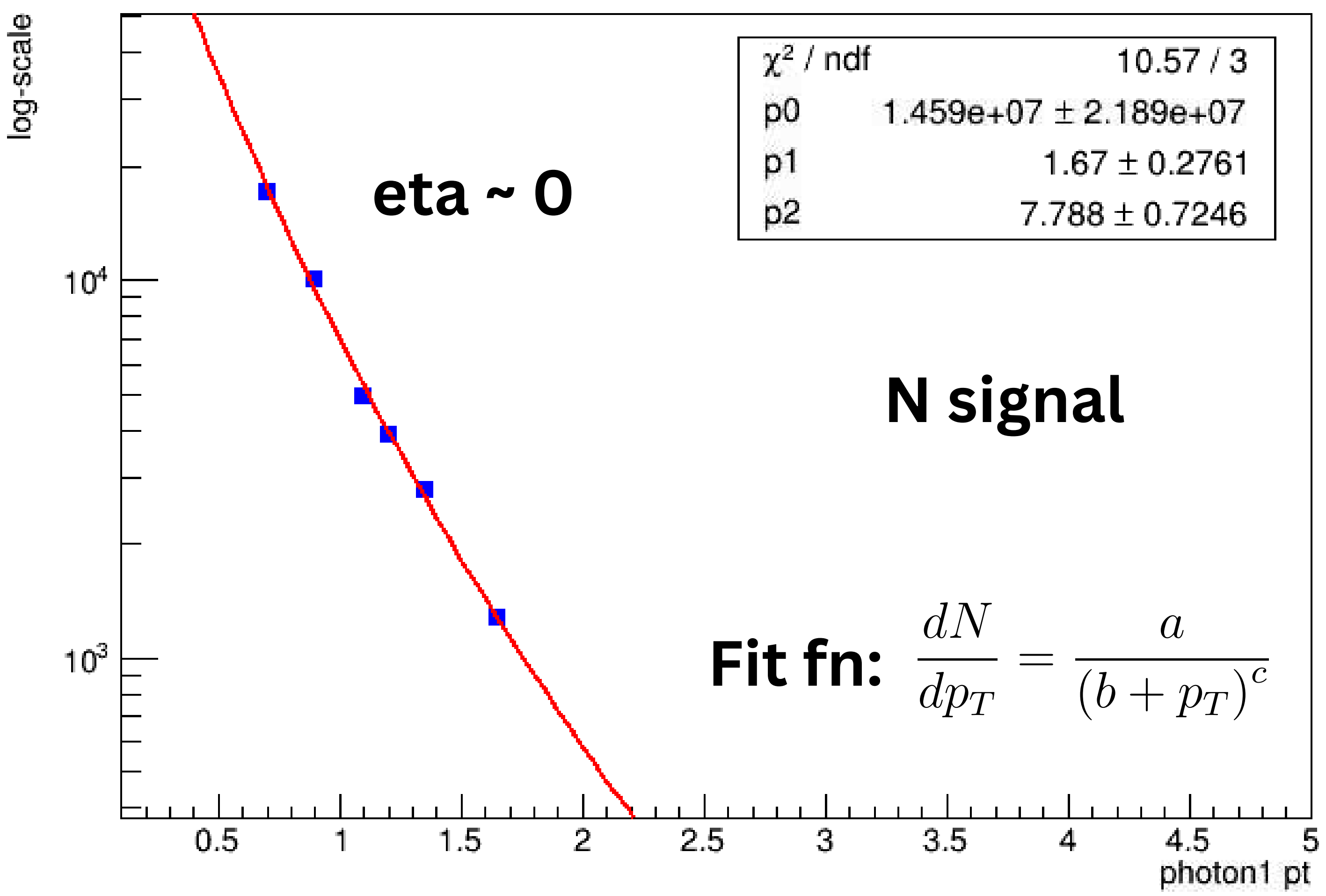
- **peak fitting robustness, minimizing human intervention to perform fit with good S/B ratio**
  - drives cut towards higher pT photons
- **maximize statistical precision per event by lowering relative statistical error on fit mass value**
  - drives cuts to lower pT photons
- **we should find optimal pT of the photons in the interplay between above two conditions**
- **Relative statistical error vs. photon pT cut depends on increasing yield of signal but also under-peak background for lower pT**
  - Fitting at very low pt becomes bkg level very high
  - prefer simple estimator function of rel stat err to extrapolate

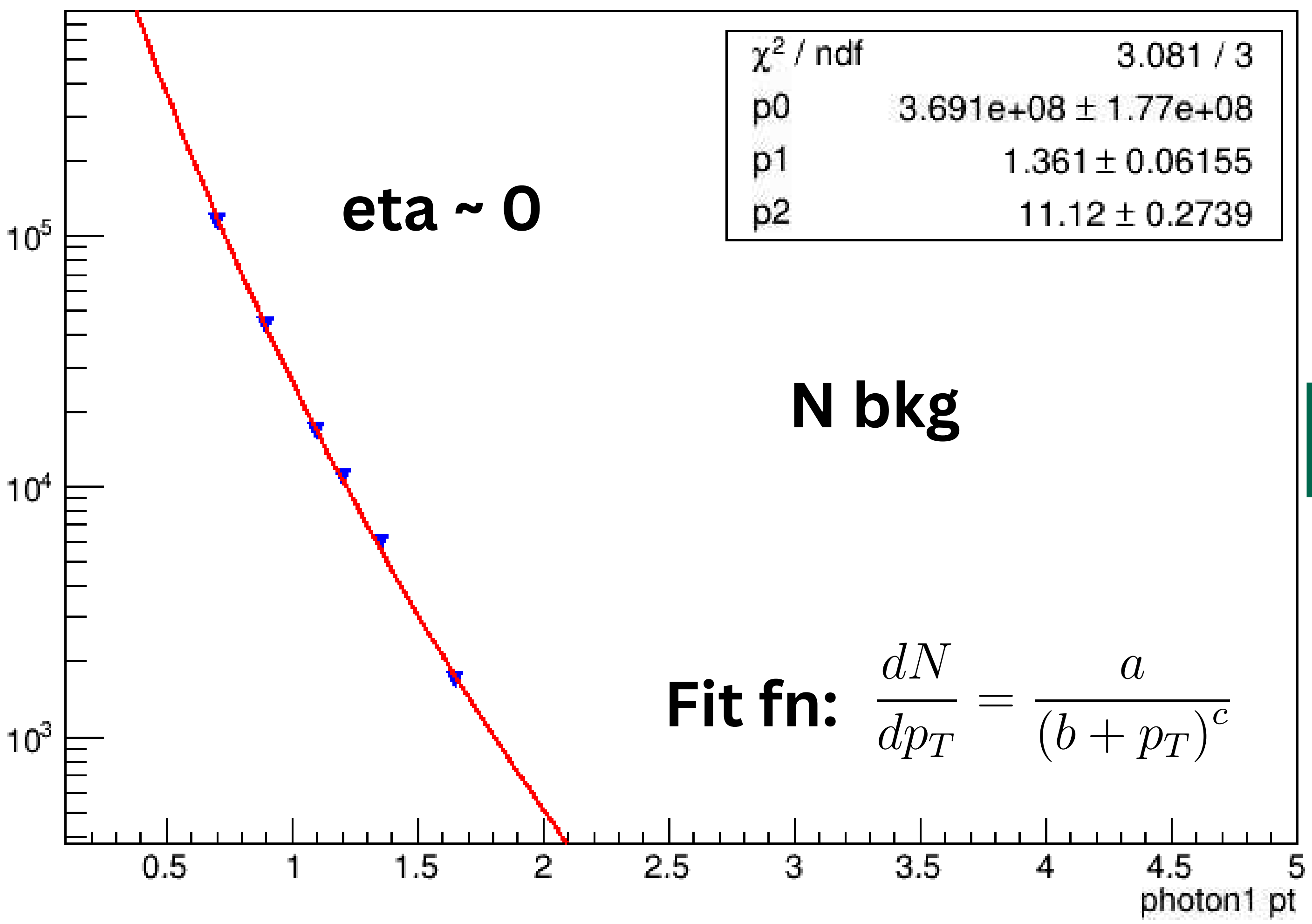


Optimal Pi0 Photon pT Cuts Study

- **Estimated dependence of error for ALL photon cut pT values from finite sampling of measured points**
  - Measure spectra and error for 6 photon pT values: (0.7, 0.9, 1.1, 1.2, 1.35, 1.65)
- **Fit the signal (S) and bkg (B) points with modified power-law function to extrapolate to all photon pT**
- **S/B Stat relative error:** Estimator form from known function [1]

$$\frac{dN}{dp_T} = \frac{a}{(b+p_T)^c}$$





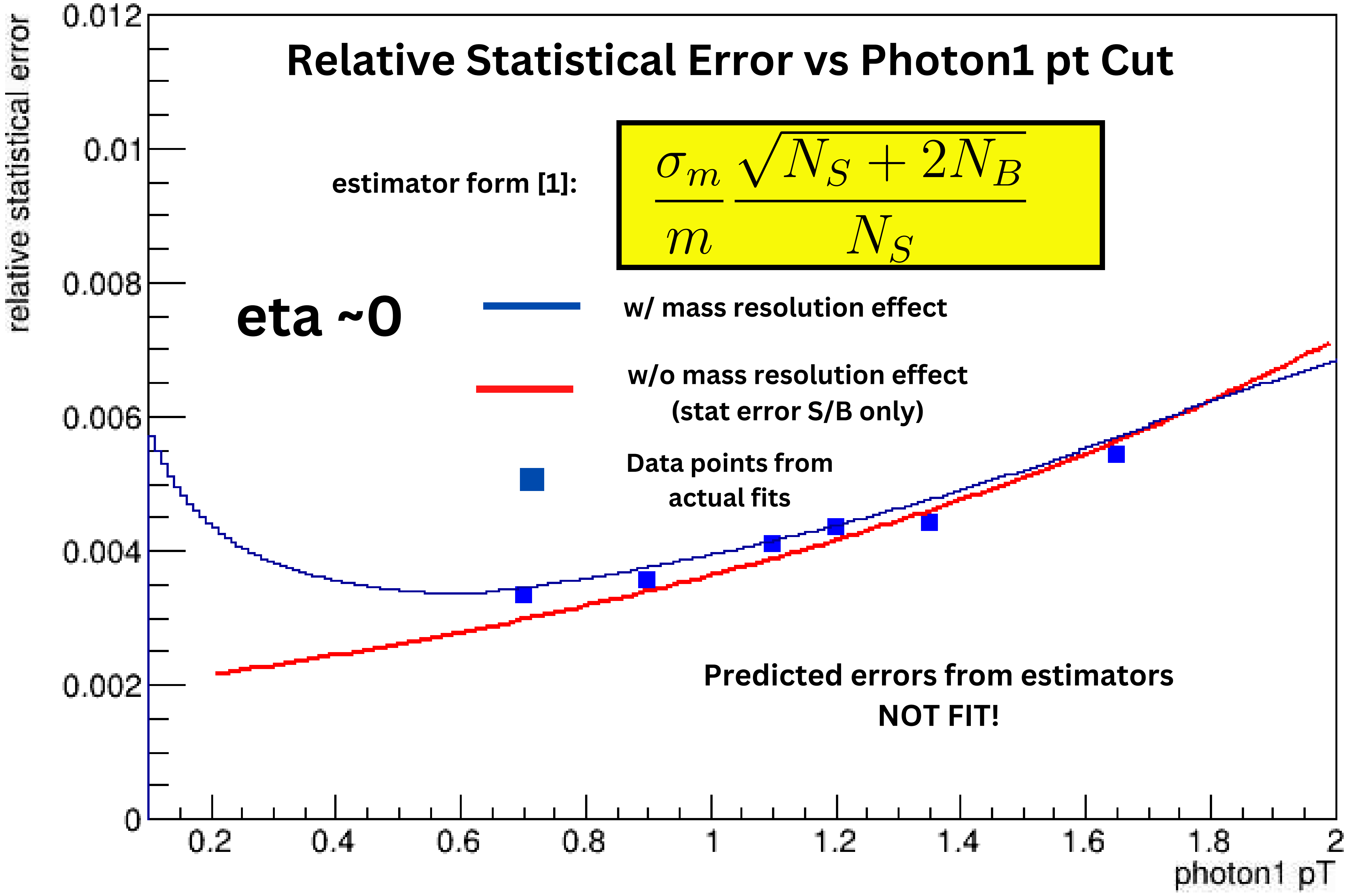
Estimator fn as a function of p_T^γ

$$\frac{\sigma_m}{m} \frac{\sqrt{N_S(p_T^\gamma) + 2N_B(p_T^\gamma)}}{N_S(p_T^\gamma)}$$

[1] Christian K. Boesing, PHENIX thesis: http:://zenodo.org/record/4267413

Optimal Pi0 Photon pT Cuts Study

- Relative statistical error decreases with decreasing pT
  - but at slow rate
- By including mass resolution, we see very shallow minimum around 0.6
- Better fit reliability at higher pT outweighs small loss in statistical precision
  - fit reliability study ongoing
- Simple estimation techniques work well!



[1] Christian K. Boesing PHENIX thesis: http:://zenodo.org/record/4267413

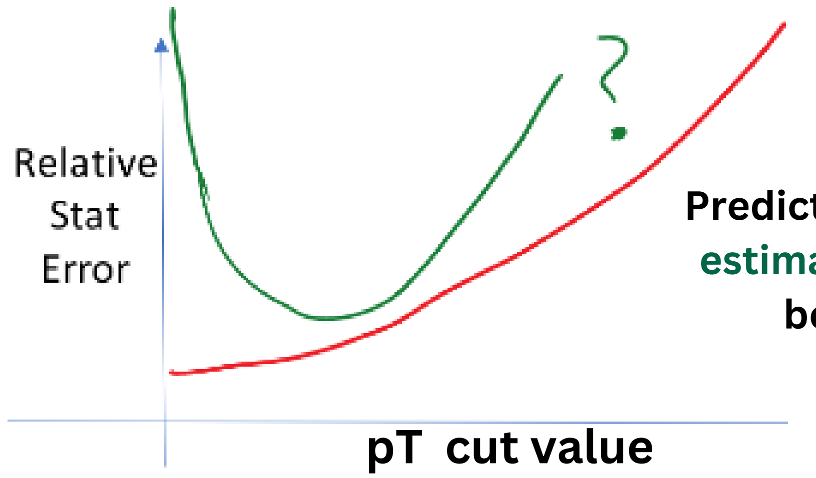
Summary & Outlook

- Preparations for imminent sPHENIX data taking underway including EMCal calibrations and development
- EMCal Calibrations framework include a variety of hardware-based systems and of data-driven probes including:
  - Tower based energy gain tracing accomplished from tower energy spectral shape modifications
  - EM-Shower-based Tower by Tower Pi0 Calibration

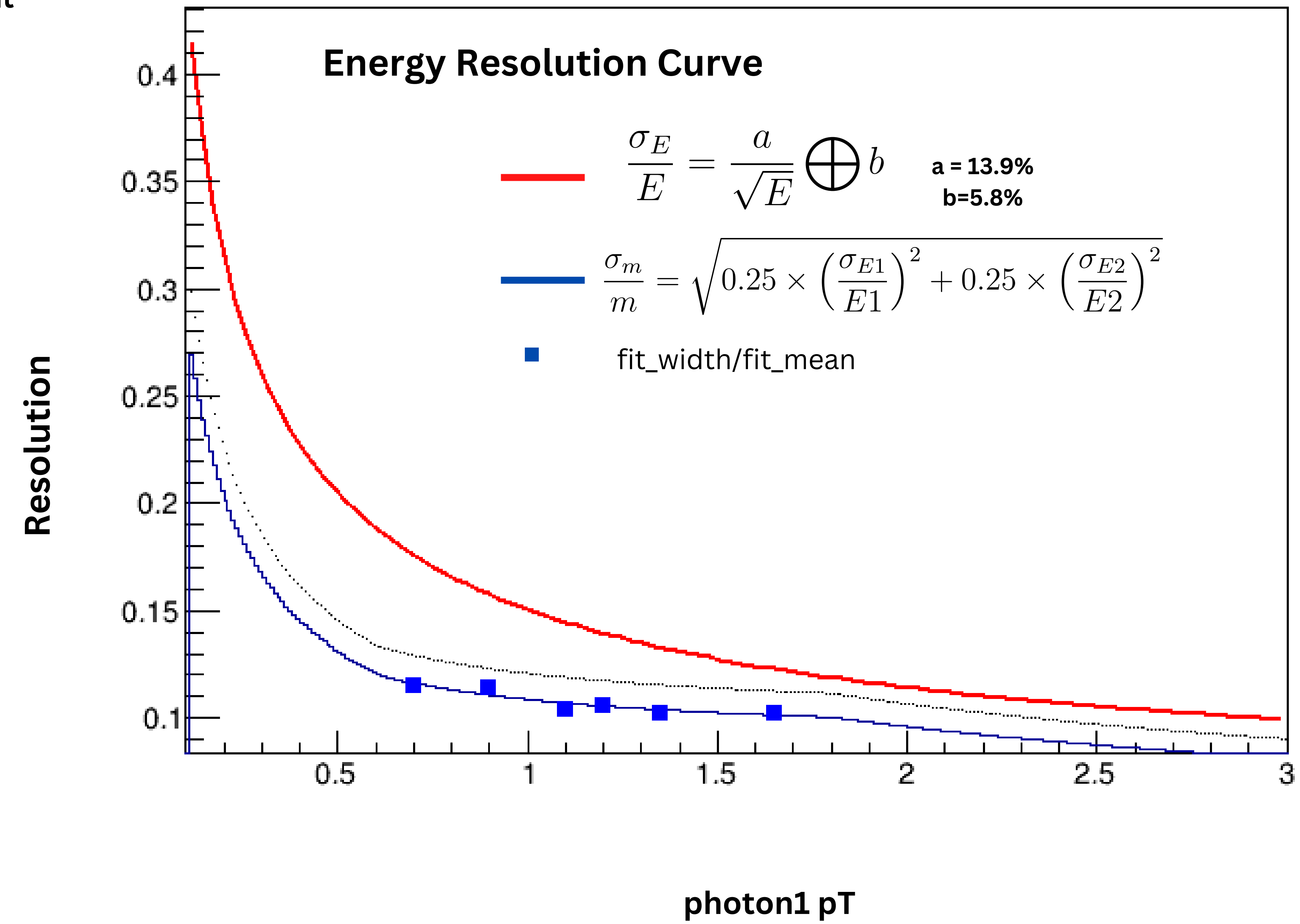
- Iterative Pi0 Tower by Tower method convergence behavior and cut optimization studied
  - Statistical precision sufficient in wide 0.6-~1.2 photon pT cut region
  - Mass peak fitting reliability will determine exact cut values chosen within this pT region.
- Simple estimation methods for calculating and extrapolating expected statistical precision of peak fitting in the presence of combinatoric background and calorimeter energy resolution work well!

Backup

Optimal Photon pT Cuts: Mass resolution



Predicting of how estimator might behave

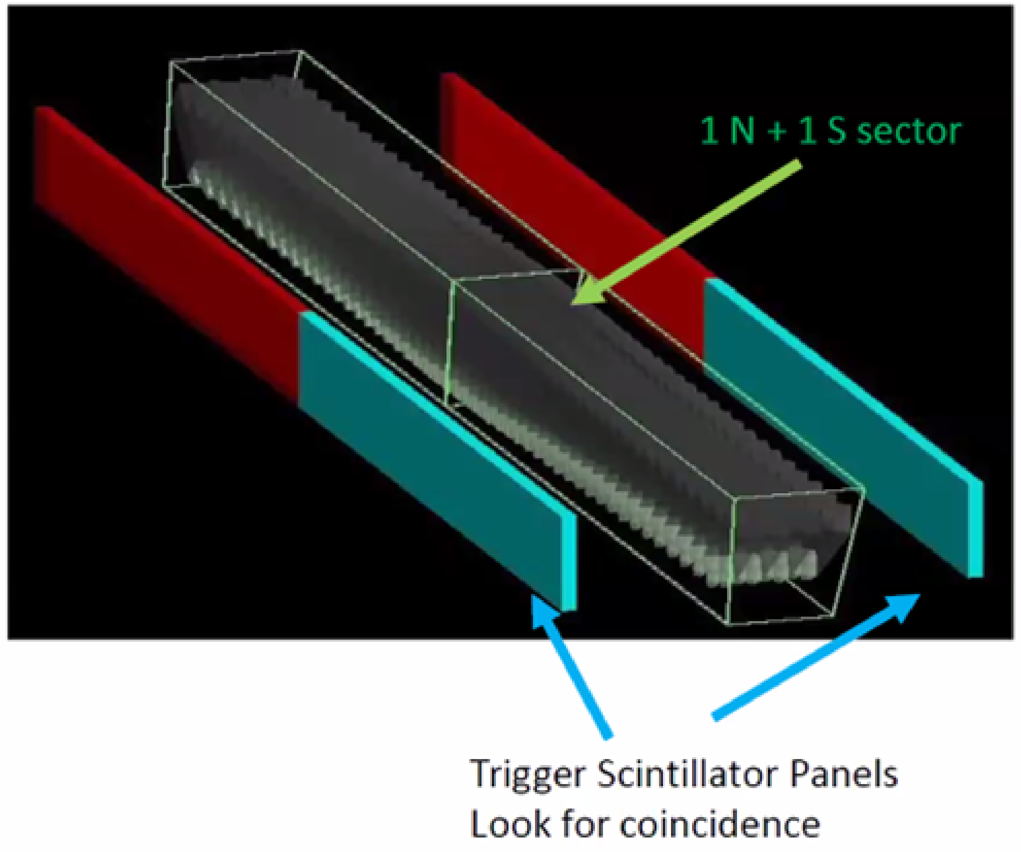


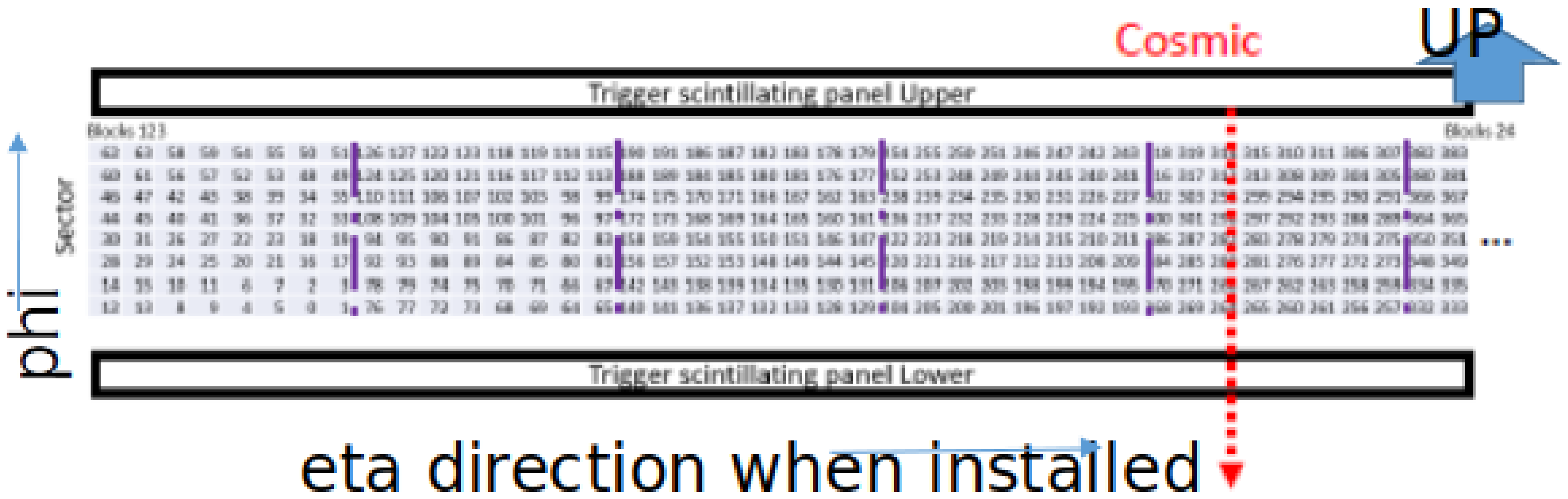
Choose etabin, take six different photon1 pT cuts (0.7, 0.9, 1.1, 1.2, 1.35, 1.65), estimate S and B integral counts for various pseudo rapidity values

Cosmics testing/Calibration: EMCal

- Each EMCal sector tested after fabrication/construction completion
- Convenient test geometry in rotated direction – detector phi direction tower rows pointed vertically, select cosmic MIPs through -rows
- Determination of individual channel characteristics (variations in fiber quality/density light transmission, etc) to create initial set of tower by tower gain corrections for initial uniformity
- Full set of characterization constants complete

calibration of channel by channel



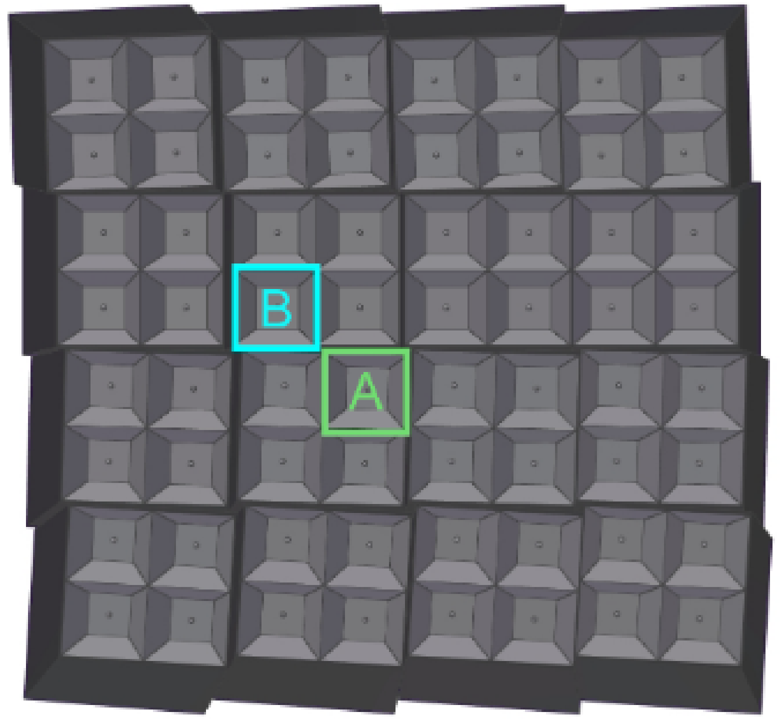


Test Beam Simulation and Data Performing Calibrations and studying EMCal energy responses

Ref:

Design and Beam Test Results for the 2D Projective sPHENIX Electromagnetic Calorimeter Prototype

C.A. Aidala, S. Altaf, R. Belmont, S. Boose, D. Cacace, M. Connors, E. Desmond, J. Frantz, E.A. Gamez, N. Grau, J.S. Haggerty, A. Hodges, J. Huang, Y. Kim, M.D. Lenz, W. Lenz, N.A. Lewis, E.J. Mannel, J.D. Osborn, D.V. Perepelitsa, M. Phipps, R. Pisani, S. Polizzo, A. Pun, M.L. Purschke, C. Riedl, T. Rinn, A.C. Romero Hernandez, M. Sarsour, Z. Shi, A.M. Sickles, C. Smith, S. Stoll, X. Sun, E. Thorsland, F. Vassalli, X. Wang, C.L. Woody



EMCal Prototype to perform test

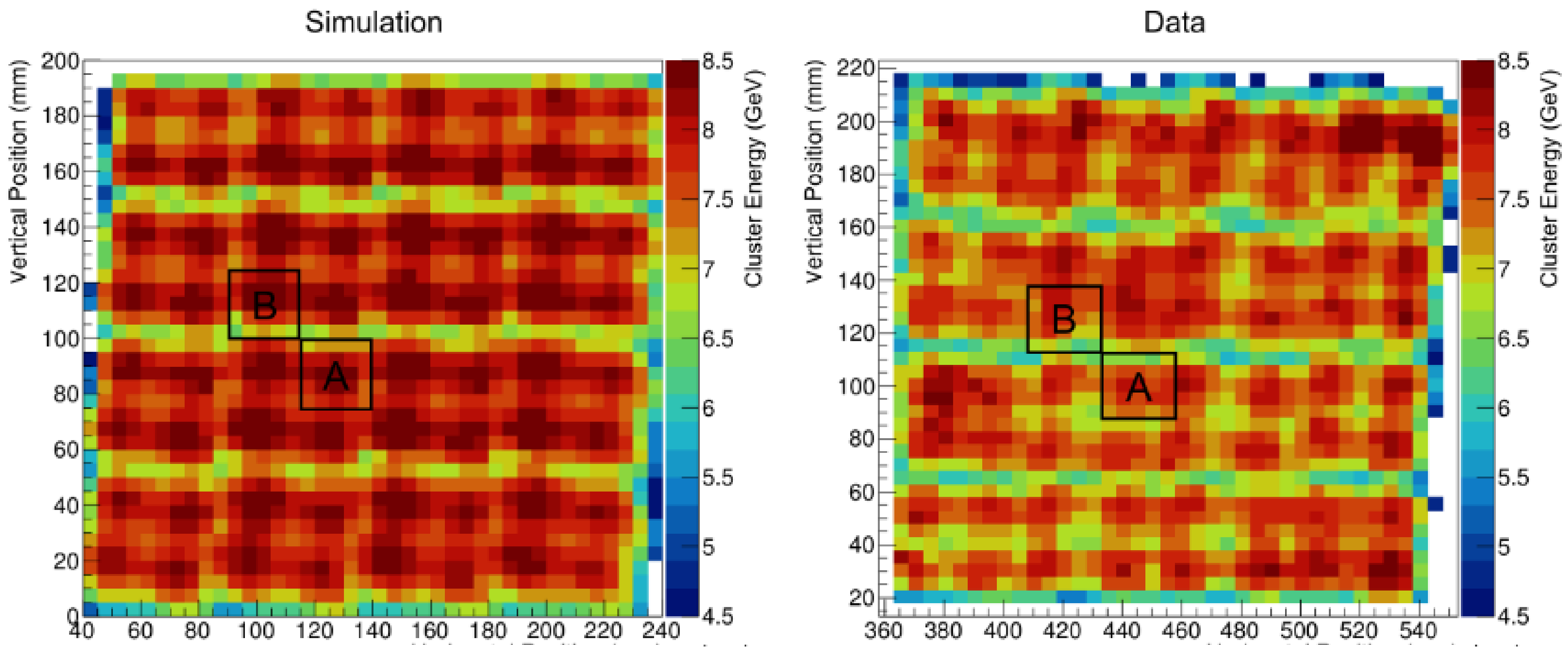


Fig. 6. Cluster Energy vs. Position for simulations (left panel) and data (right panel). The results correspond to an input energy of 8 GeV. Towers A and B are shown in black squares.

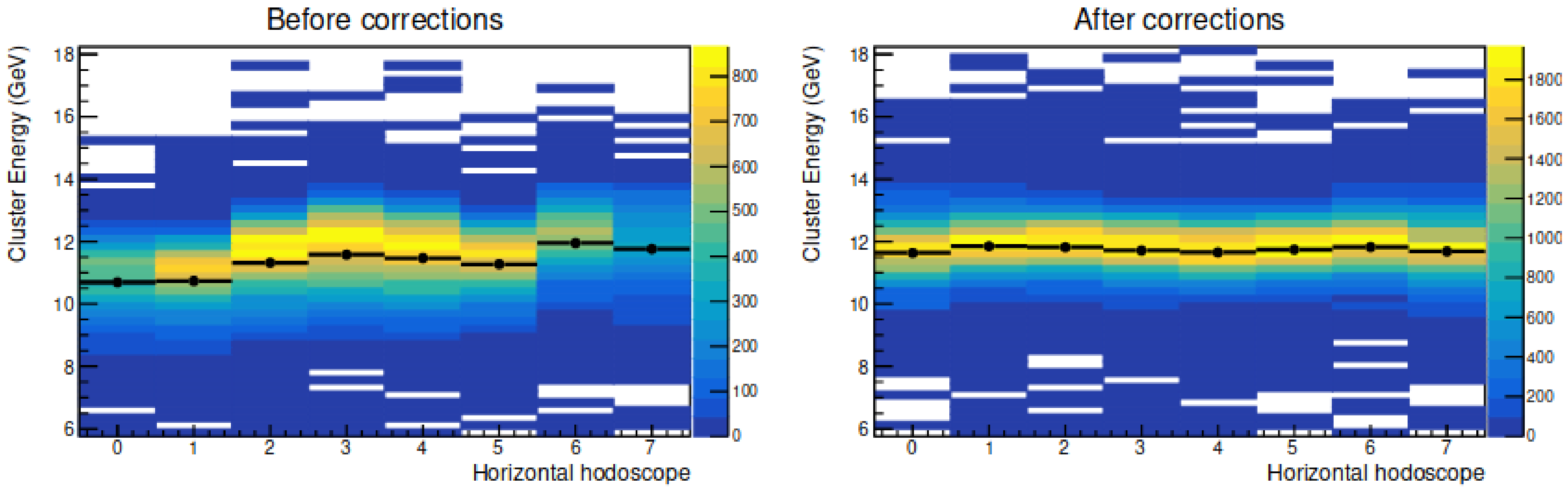
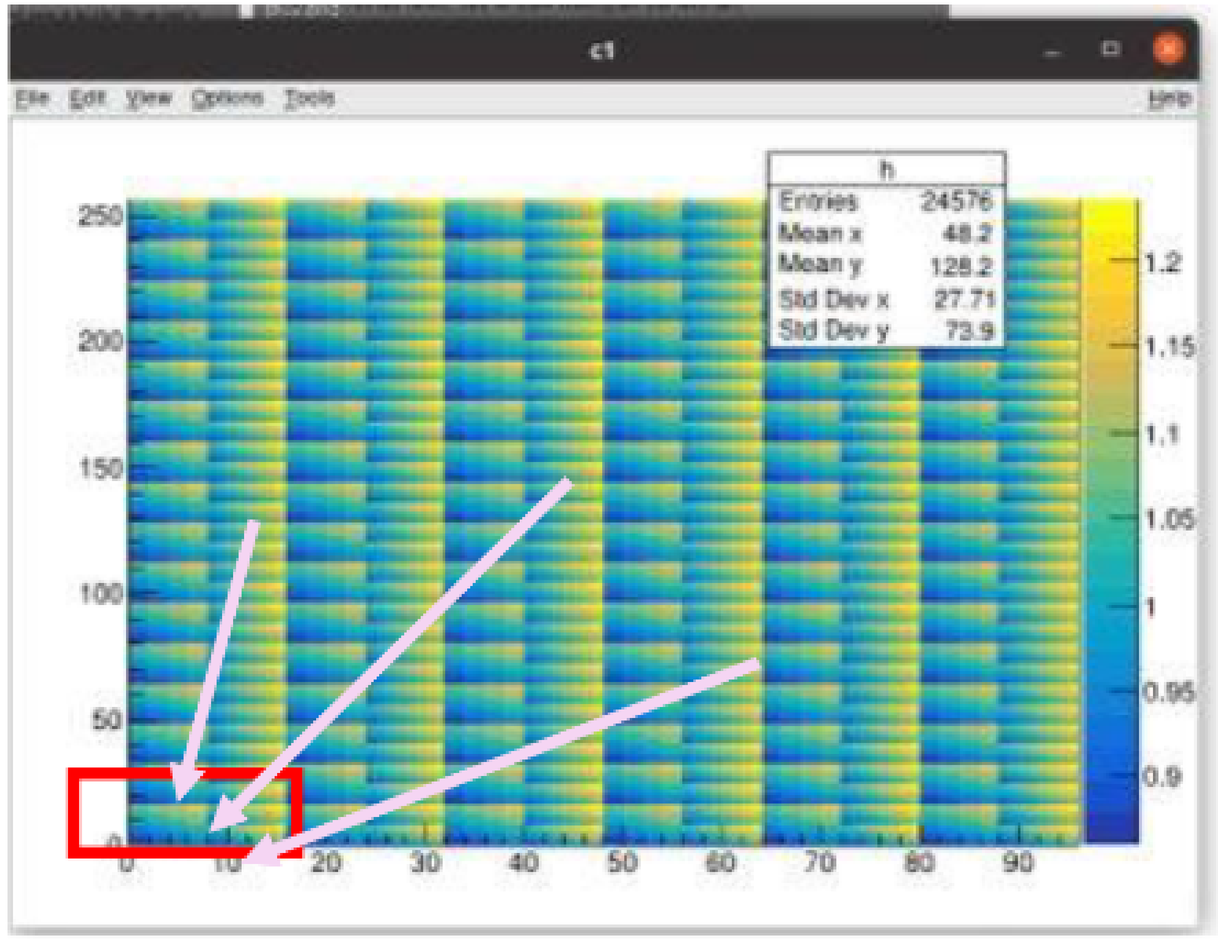


Fig. 7. Cluster Energy vs. Horizontal Hodoscope Position before (left panel) and after (right panel) applying the hodoscope-based position dependent correction and the beam profile correction. The color scale represents the number of events, while the black points correspond to the mean of the energy distributions for each hodoscope position. The data corresponds to a 12 GeV beam centered at Tower A.

Calibration of EMCal (1etabin, 1phibin i.e. tower level)

- make a single decalibration shift pattern for 2D eta-phi in 16x16 unit, repeat same pattern across EMCal
- perform iteration as usual, but only on 16x16 unit (256 towers) because of added statistics in the red area fit won't fail

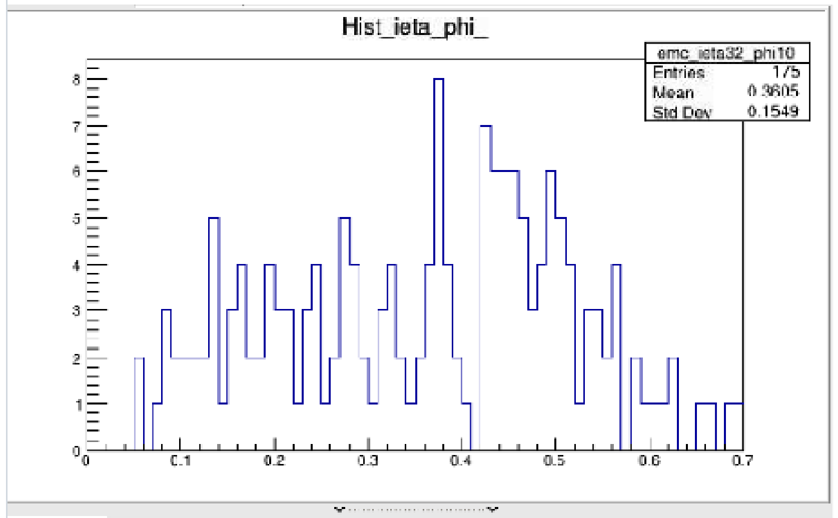
256/16 = 16 pattern instances along phi



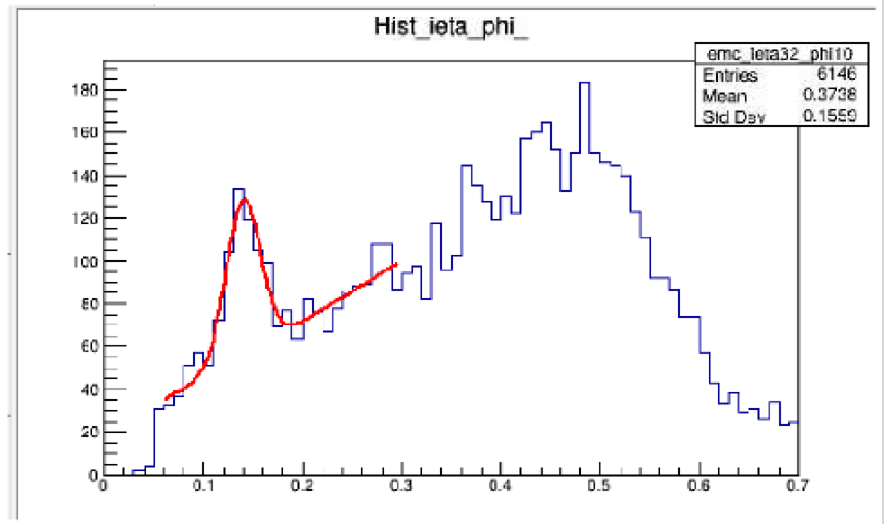
96/16 = 6 pattern instances along eta

Total statistical increase for each of the 16x16 tower unit
= times number of instances -->
6x16 = 96 times

Example: eta0_phi10 tower ~8M total events



Single tower from all MDC 2 events statistics

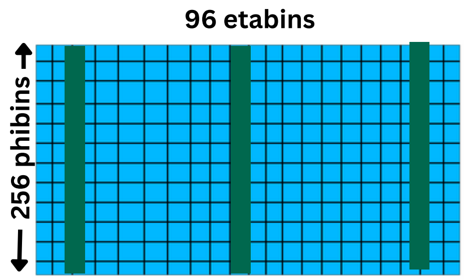


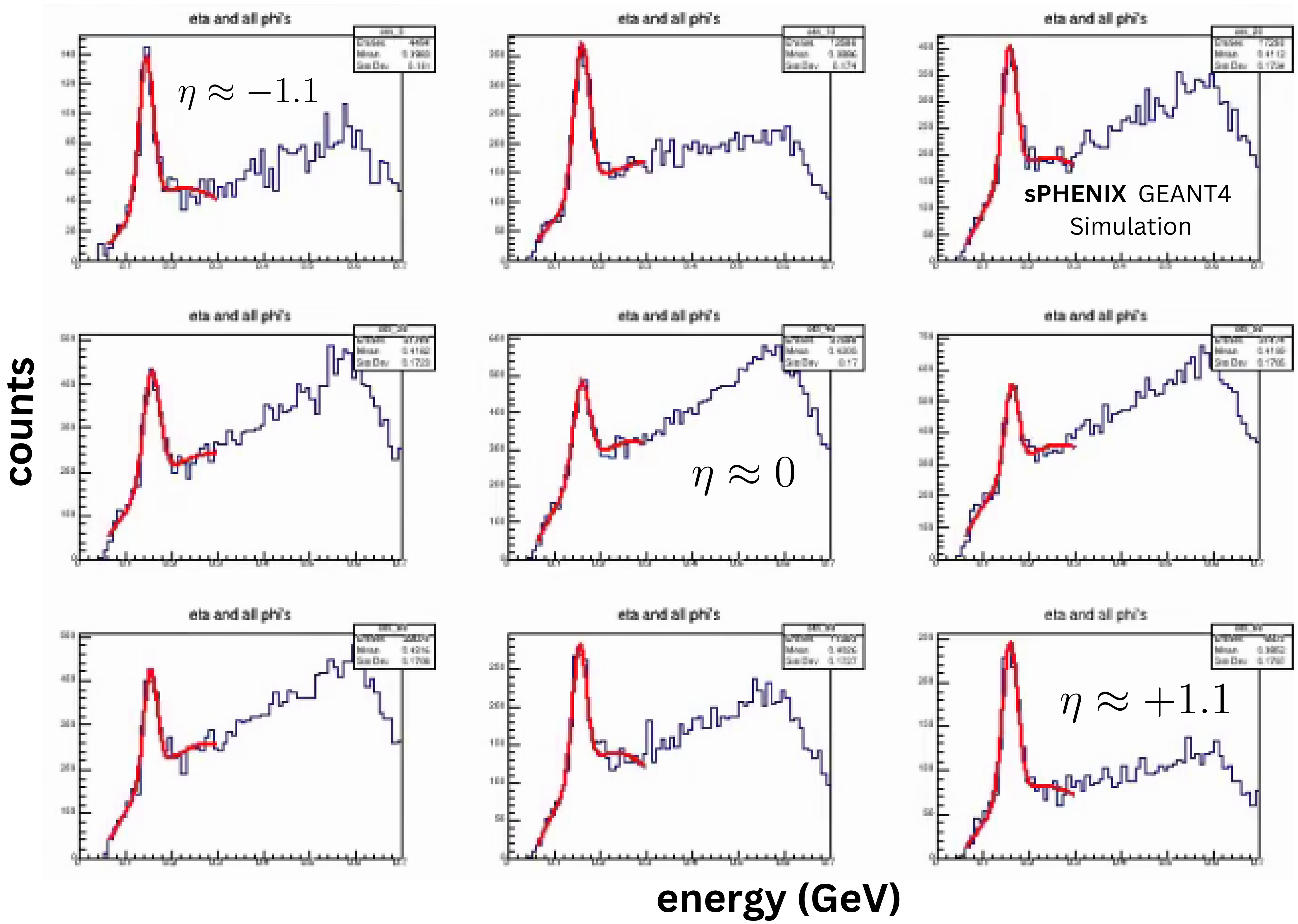
Same tower location with combined 96 times statistics

pi0 tbt - etabin slices level calibrations

- **Initial test of method performed with sPHENIX GEANT4 Simulation Sample**
  - **Preliminary pi0,photon cuts**

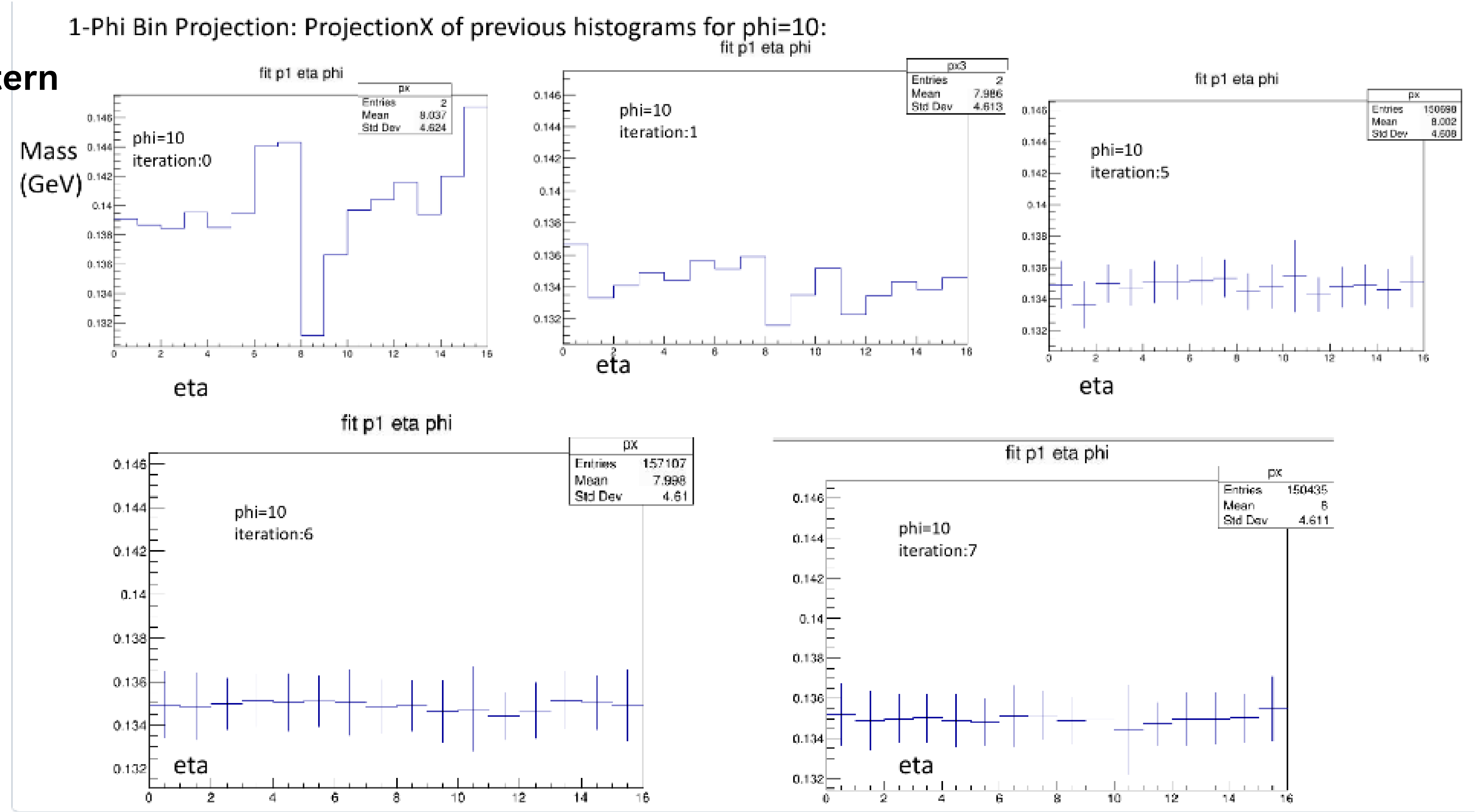
- **~small eta dependence of S/B visible**





(phibin-10) projection of previous slide histograms

Input shift pattern



shift pattern smooth-out