Calorimeter calibration and related data production in the 2023 run

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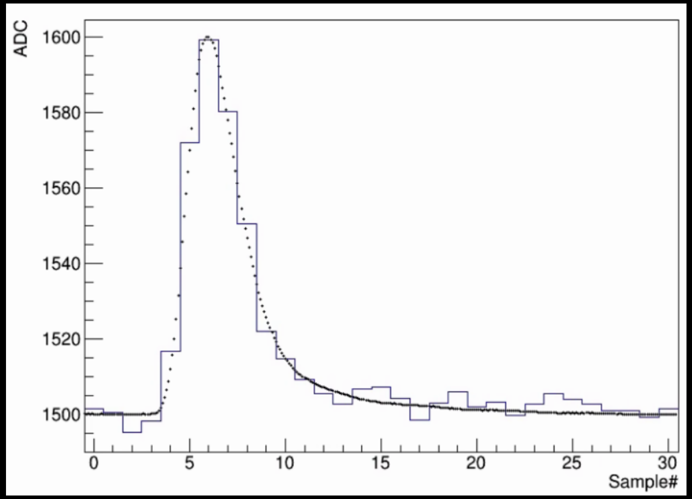
Collaboration Mtg: DeC. 4th, 2023

overview

- **Calibrations**
  - Cosmic muon calibration of HCals
  - Pi0 and “tower slope” of the EMCal
  - Software implementation
- **Hardware relevant studies**
  - Understanding pathological calorimeter data
  - Software solutions
- **State of calorimeter simulations**
  - Noise simulation
  - Photon energy scale and resolution
- **Calorimeter data preparation**

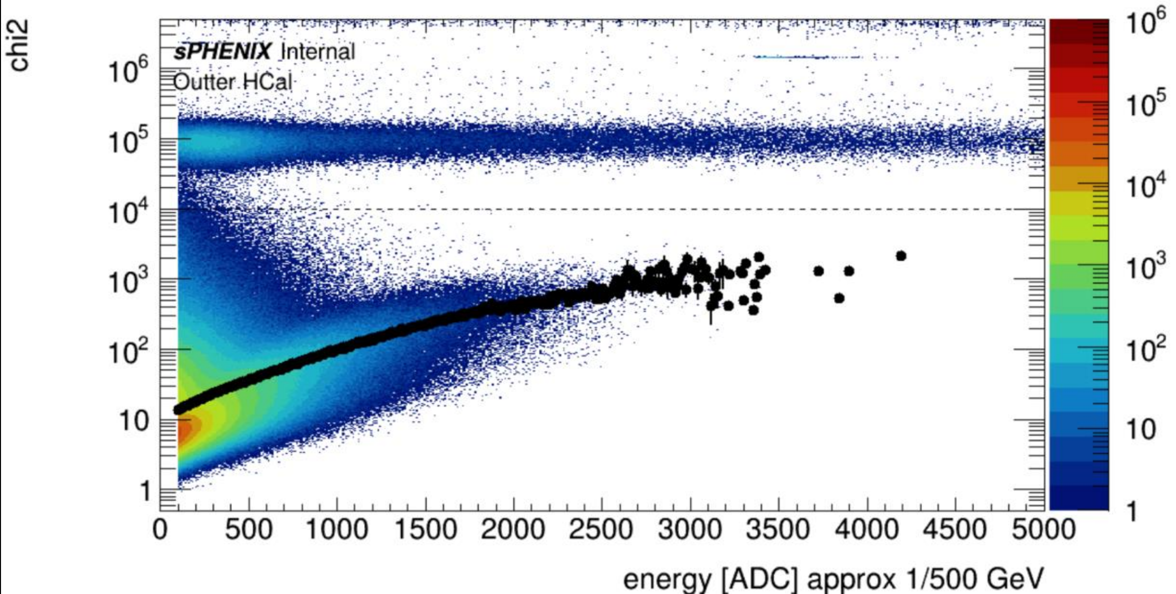
Signal processing

- **Same raw data processing in the Hcals and EMCal**
- **Raw data for 2023**
  - 31 14-bit samples per a channel, digitized 6x beam clock
- **Signals are fit with template waveform**
  - The saved output of the fit is
    - Amplitude (floating point ADC max of the waveform)
    - peak time (saved in integer milli-sample precision)
    - pedestal - float point precision
    - Least-squares difference between the fit and waveform data divided by number of degrees of freedom
  - We currently fit 16 samples (not well studied but no large degradation in performance for 12 samples)



Template fit performance

- **Chi2 vs. ADC with beam template.**
  - Noise levels in the HCals are at the level of 2-5 ADC, which indicates low energy signals are consistent with a good template description.
  - Towers can have distorted waveforms for an entire run (example at chi2=1e6)
  - Some towers have distorted ~1% of the time
- **Both cases of problematic towers are caught by a Chi2 cut**
- **The other calorimeters look very similar**
- **Computing speed**
  - To fit all channels is several seconds per an event
  - This can be speed up by an order of magnitude by software zero suppression.



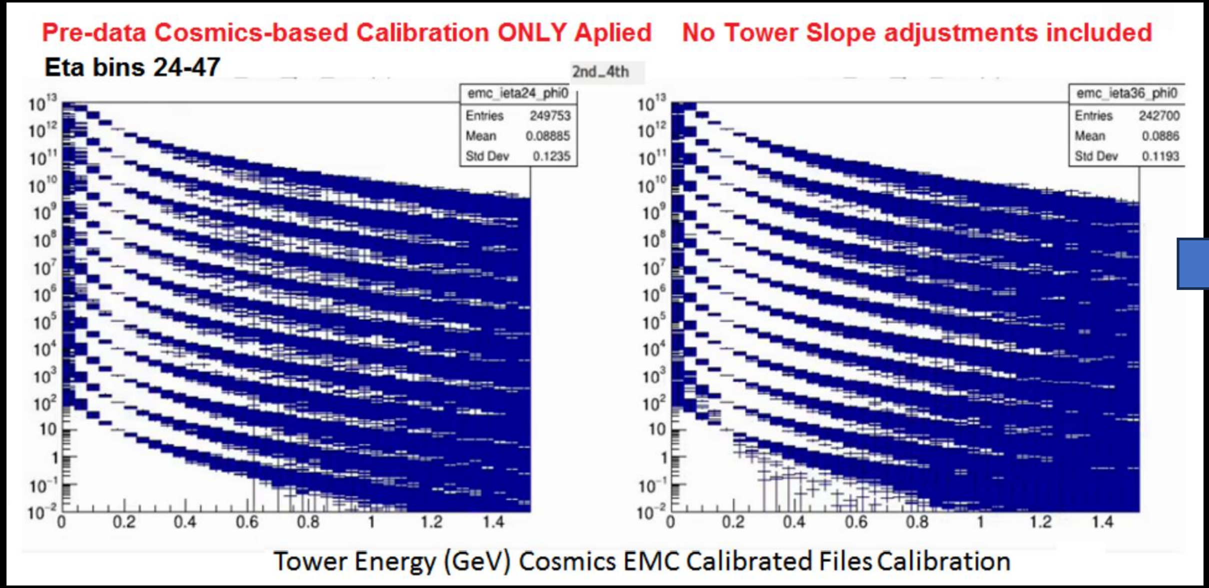
EMCal calibration

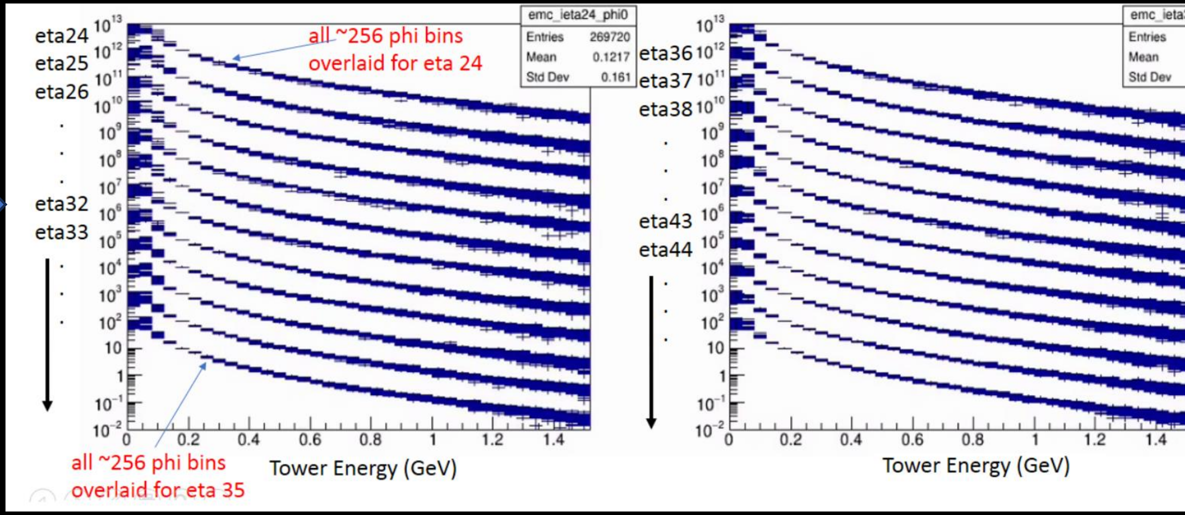
- **The EMCal calibration is factorized into two dimensions, η and φ**
- **Φ dimension: The tower slope method**
  - Azimuthal symmetry is assumed in the tower energy spectra, up to a gain factor.
  - The slope (dN_{twr}/dE) is a function of E and thus a spectra can be fit with another to find the **relative** gain factor.
  - All towers with the same η are fit with the φ-integrated spectra yielding a relative calibration for all towers with the same η acceptance
- ***η* dimension: pi0 mass spectra, binned in the leading tower *η* of the leading cluster**
  - The pi0 mass peak is extracted via a fit and the ratio of this with a target mass is the calibration factor.
  - Because the mass is a product of many calibration factors an iterative approach is to used.
  - The result is an absolute data-driven calibration in the η dimension.
  - The mass target is arbitrary at this point and is commented later.

Tower slope method

- **Fit a particular *η*-φ with a template(E*gain) where the template is the sum of towers spectra for the particular *η***
  - Fit range E=[0.12,0.7] GeV
- **Need to improve QA on fits and extracted coefficients**

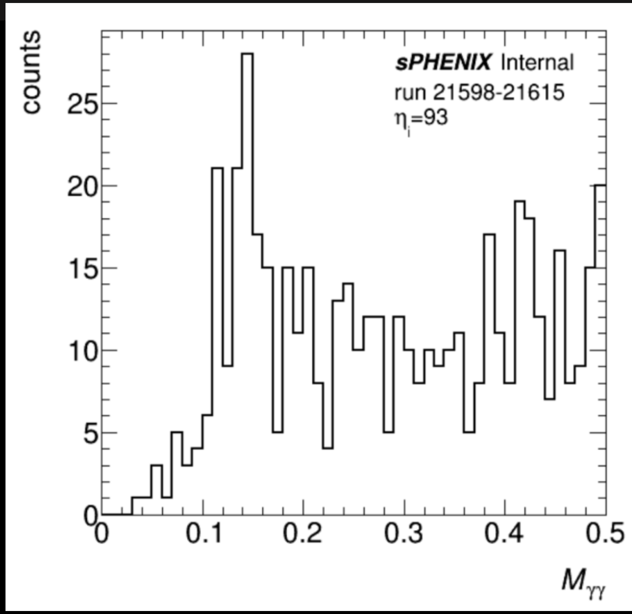
Justin Ohio U

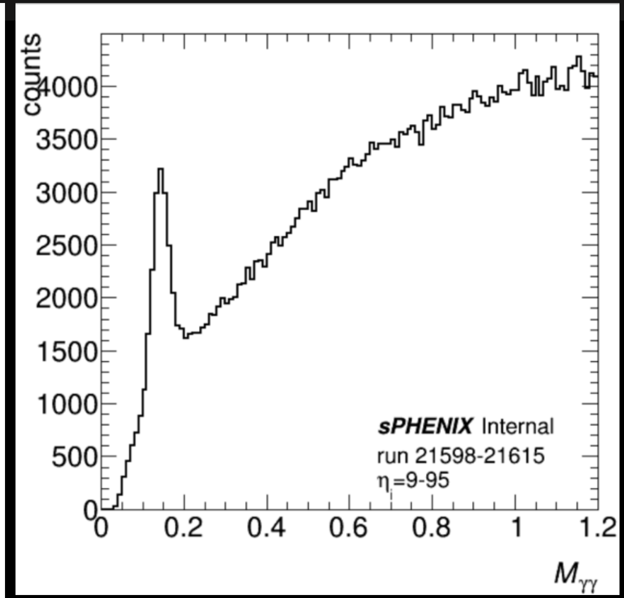


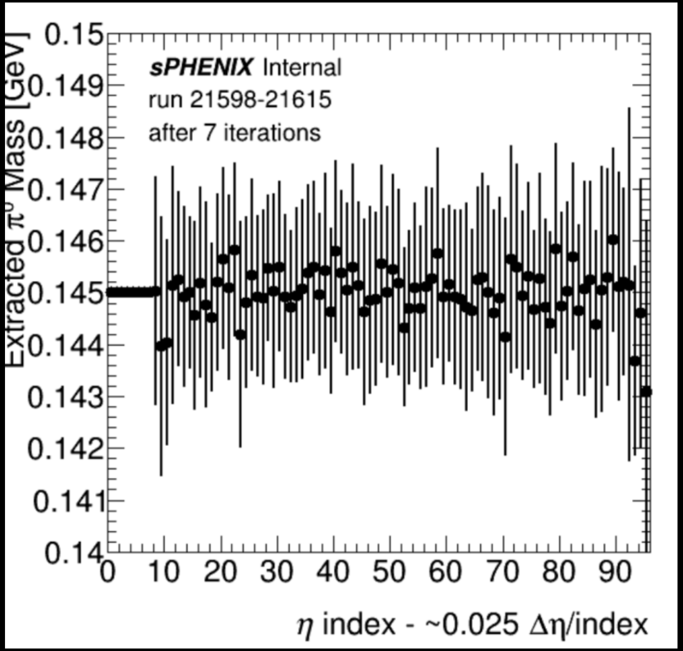


Pi0 calibration

- **Example: 2.1M events**
  - Runs: 21598, 21609, 21608, 21599, 21616, 21615
- **Speed: non-parallelized**
  - Tower slope 5 hours
  - Pi0 10 iterations: 24 hours (parallelized 2h)
- **Cuts**
  - $p_{T1} > 1.3 + 1.4 * (N_{clus}-30)/200$
  - $p_{T2} > 0.4 + 1.4 * (N_{clus}-30)/200$
  - Only add p_T for $N_{clus} > 30$
  - $\Delta R < 1.1$
  - Asym < 0.6
- **3% peak error! This means there is an additional 3% relative uncertainty/smearing due to calibrations which is not expected to improve**

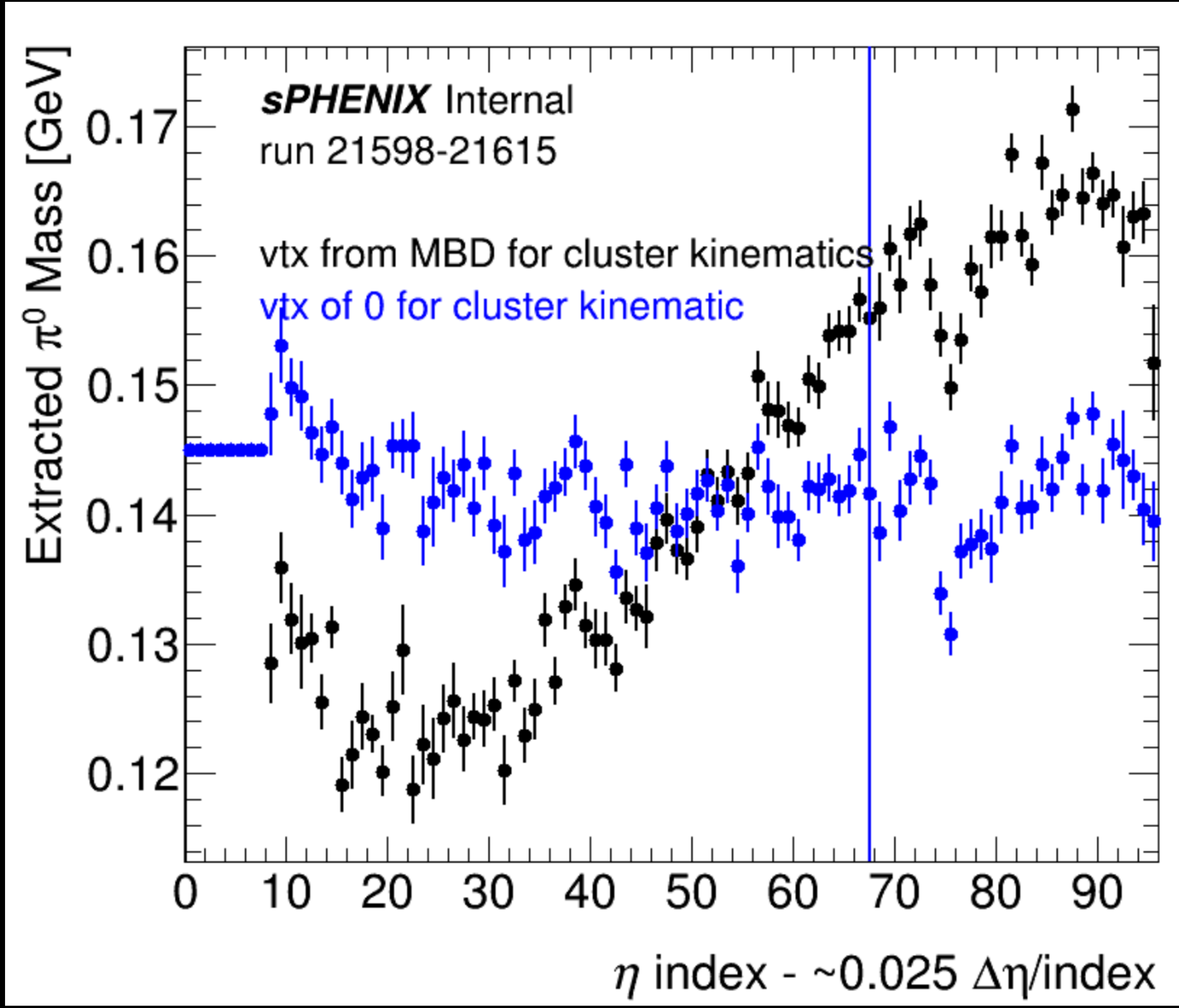






η asymmetry in current calibration

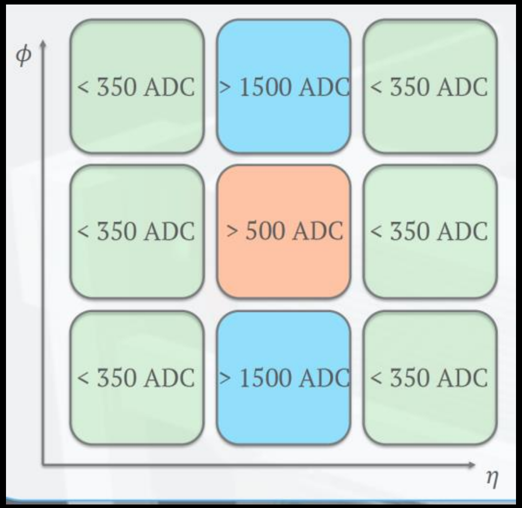
- It has been presented in PC meetings of an obvious asymmetry in EMCal tower energies.
- This mis-calibration arose from the unavailability of a proper vertex at the time of the QM calibration (the current used in DSTs)
- A default value of 0 was used which biased the extracted pi0 mass
- Right: he pi0 mass extracted by the same clusters (detector eta/phi and E) but a different vtx used to assign the physics eta

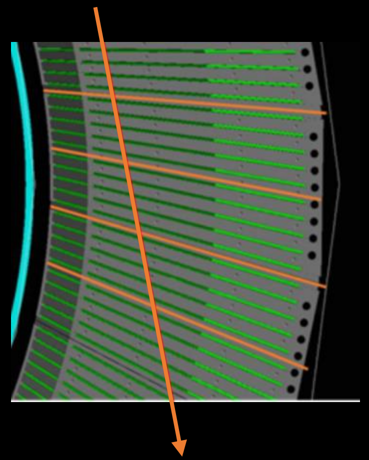


HCal cosmic muon calibration overview

- **The calibration for both the inner and outer HCals is derived by comparing energy deposits from cosmic muons between data and MC**
- **Data is collected with single trigger tower threshold trigger with calorimeters in high gain mode**
  - Unprescaled rates of 5-20 kHz
- **MC: We use a dedicated MC generator called [EcoMug]**
- **Offline signal criteria is applied to select muons with a long path length, passing through all tiles in a tower, seen on the right.**

[Hanpu, Shuhang, Columbia]



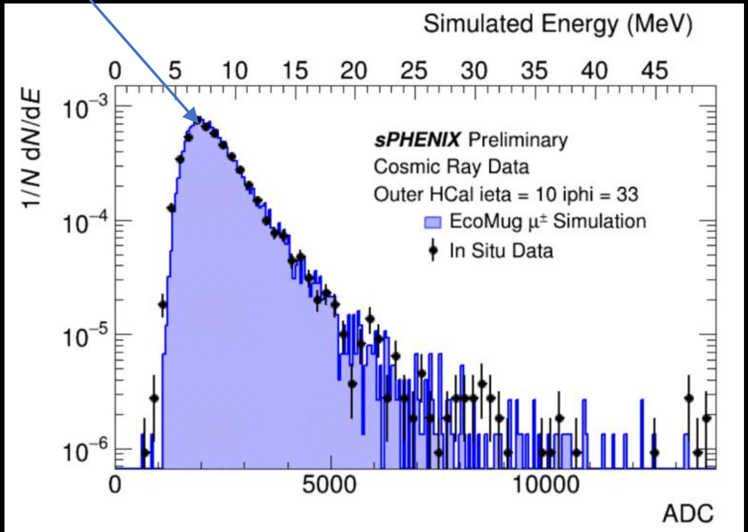


HCal cosmic muon calibration results

- **The distribution is characterized with a fit and the peak position is used for calibration.**
- **The ADC is compared to the simulated light yield from the scintillator.**
- **The calibration factor is then scaled by the high-low gain ratio and by the MC-derived pion sampling fraction**
  - Said another way, the calibration matches data-MC MIPs scintillator energy of a particular kinematics/species and uses the MC to translate that into energy deposited in scintillator +absorber by beam-like particles.
- **Bellow are the comparison of η-φ cosmic MPV in data (left) and MC (right)**
  - Pre-installation calibrations already applied to data
  - Top sPHENIX iphi=15-16

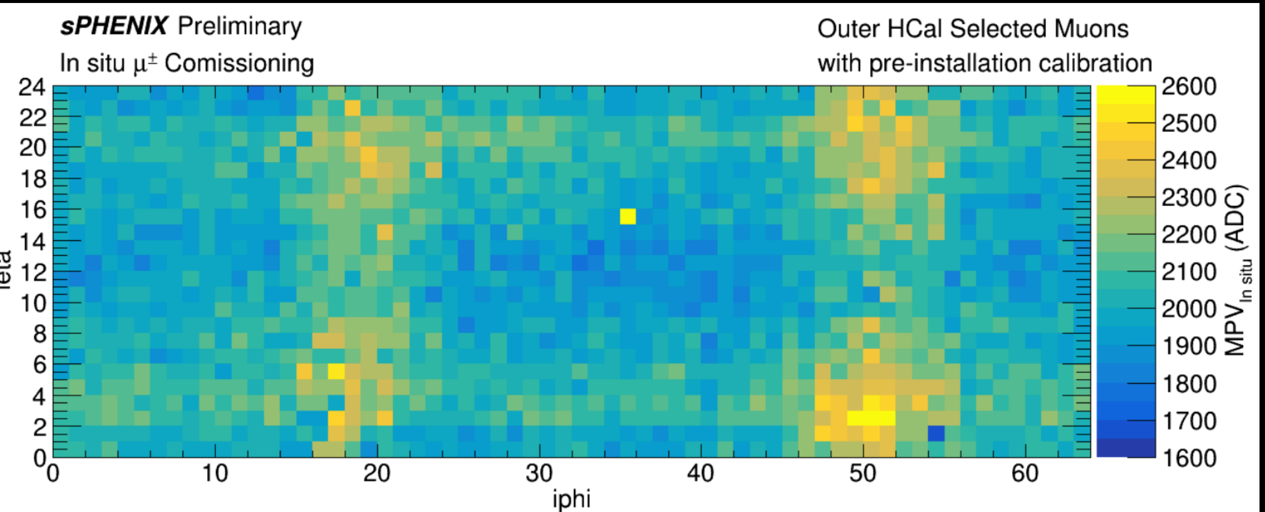
"MPV"

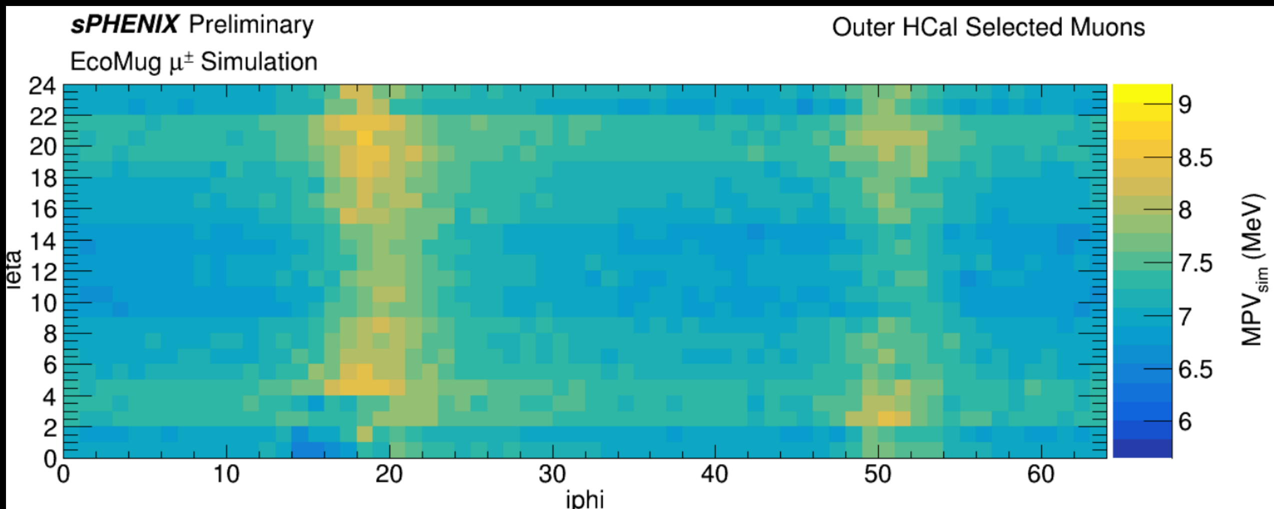
simulator light yield



ADC in high gain

Hanpu, Shuhang, Columbia





Current status of calibration

Hcal cosmics

- Analysis is on git sPHENIX-Collaboration/analysis/HCalCosmicCalib
- Working on updating the calibration with cosmics taken during the months of beam data-taking which will account for changes in pulse fitting – expected in the coming weeks
- Now comparing to official sphenix cosmics simulation
  - CreateFileList.pl -type 22 DST_CALO_CLUSTER -run 11
- Exploring dependence on muon trajectory

EMCal calibration

- Analysis is on git sPHENIX-Collaboration/macros/calibrations/calo/calib_nov23
- Original calibration for QM was done without vertex info which caused issues
- Automated fully PR'ed process has been implemented and new results are expected to be available in the next weeks

What is in the DSTs

➢Raw and calibrated TowerInfov2 objects

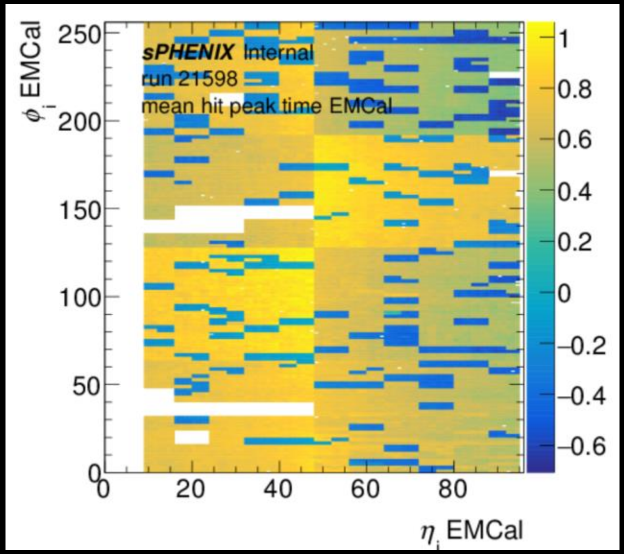
- Data fields
  - Amplitude (floating point ADC max of the waveform)
  - peak time (saved in integer milli-sample precision)
  - pedestal - float point precision
  - Least-squares difference between the fit and waveform data divided by number of degrees of freedom
- Status fields
  - get_isBadChi2: if the chi2 is above 1e4 for that event
  - get_isHot: all towers with isBadChi2 > 5% of hits during the run
  - get_isBadTime: set to true is the event/tower has a peak time greater than 2 (1) from that runs hit time mean for the HCal (EMCal).
  - get_isGood: if all the above are false, will return true
- No modification of data fields (all masking is done but users using status bits)

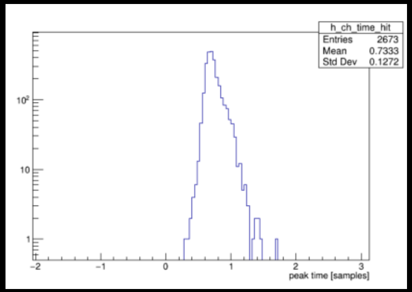
➢EMCal clusters created with a photon template

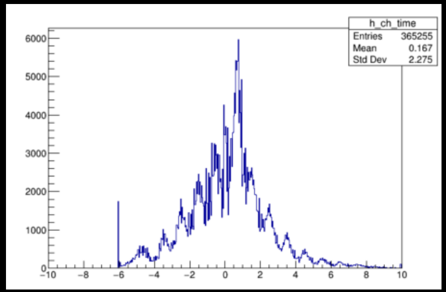
- Clustered with towers which have no quality cuts
- No hot cluster removal right now

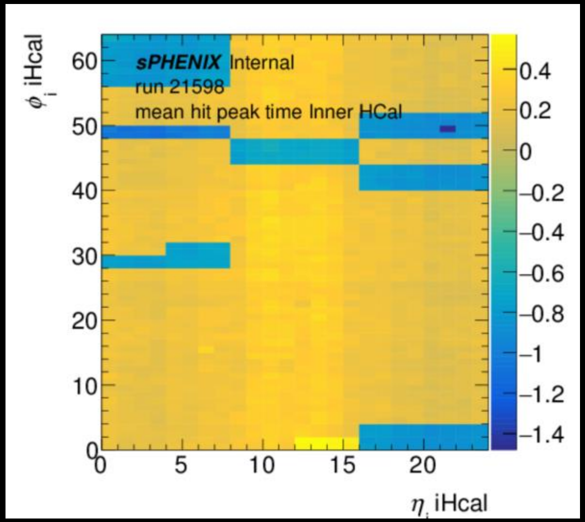
Timing cuts

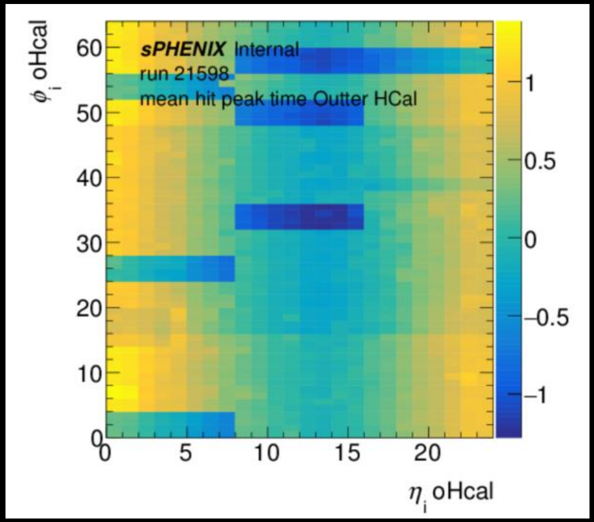
- **Left: mean EMCal time for hit (> 0.5 GeV)**
  - There is effect of a rounding error when detector is timed in due to disagreement of FPGA time and GTM (experts can confirm)
- **Middle: single EMCal channel (ieta=20 iphi=62) timing distribution for hists (top) all events (bottom)**
- **Right: inner and outer mean channel time**





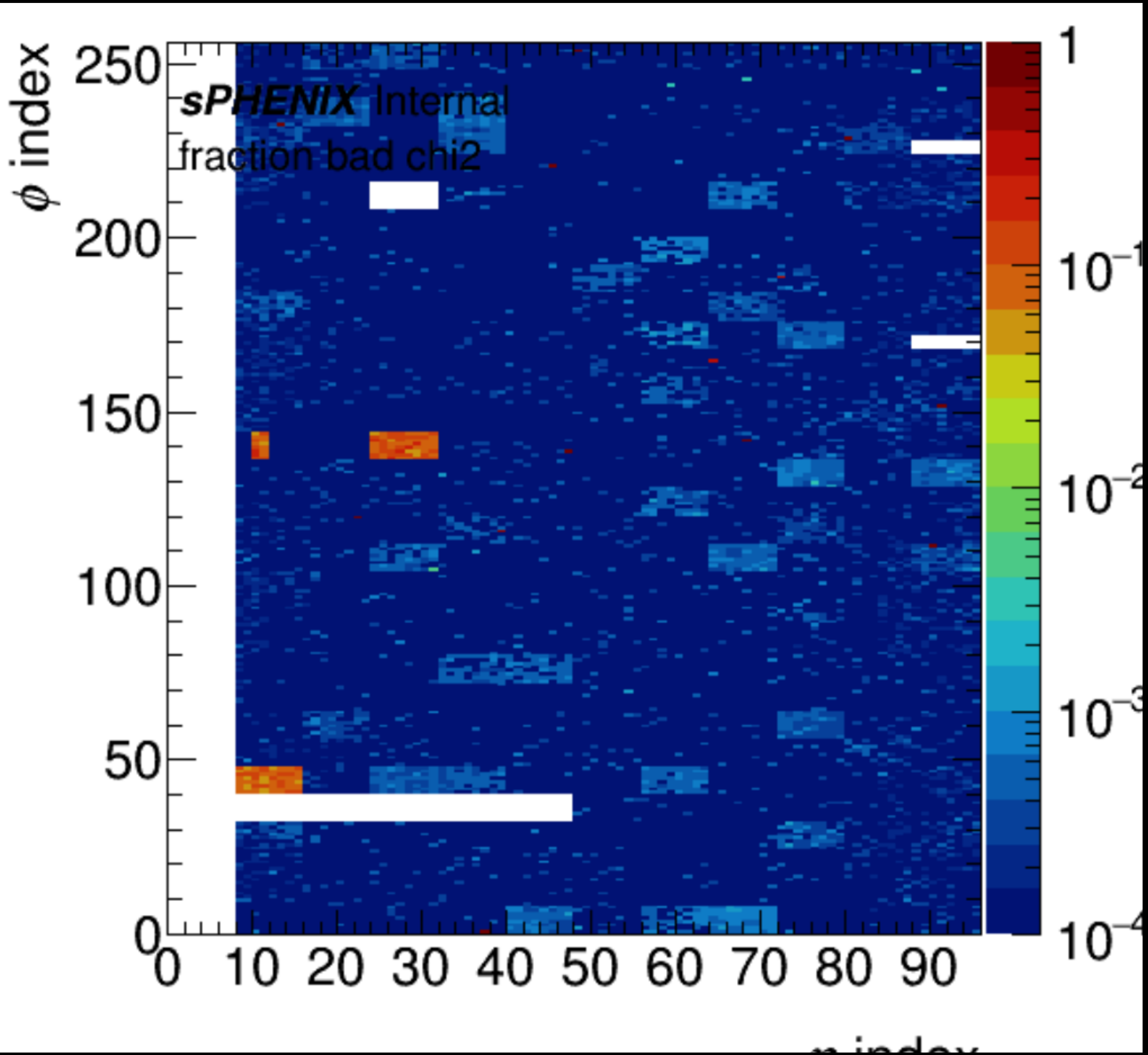






Bad chi2 values

- Right: fraction of hits that have a bad chi2 value
- > 5% is considered a hot tower
- Bad towers are easily determined by this metric
- Emma has found towers with noisy bits that lead to bad chi2s at the 1-5% of events (hard to see in this plot)



Identifying pathological tower behavior

- **Hot towers were initially identified statistically**
  - Inordinately large average energy or number of hits
- **The underlying pathological behaviors were identified in both EMCal and HCal**
  - Towers with jumbled bits for an entire run
  - Towers with sometimes rare single bit flips
  - Appears read-out related
- **Developed event-by-event identification strategy**
  - Pulses are fit with template waveforms, which is used to generate a very poor goodness-of-fit metric for jumbled/flipped bits
  - coresoftware was updated to calculate this and save it to tower objects
- **Passed information to hardware experts for possibly identifying hardware or operational solutions**

Examples of pathological towers

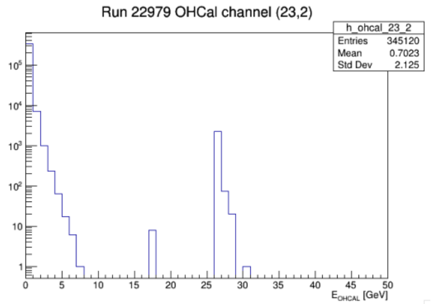
Pedestal data: Pedro Nieto-Marin Iowa State

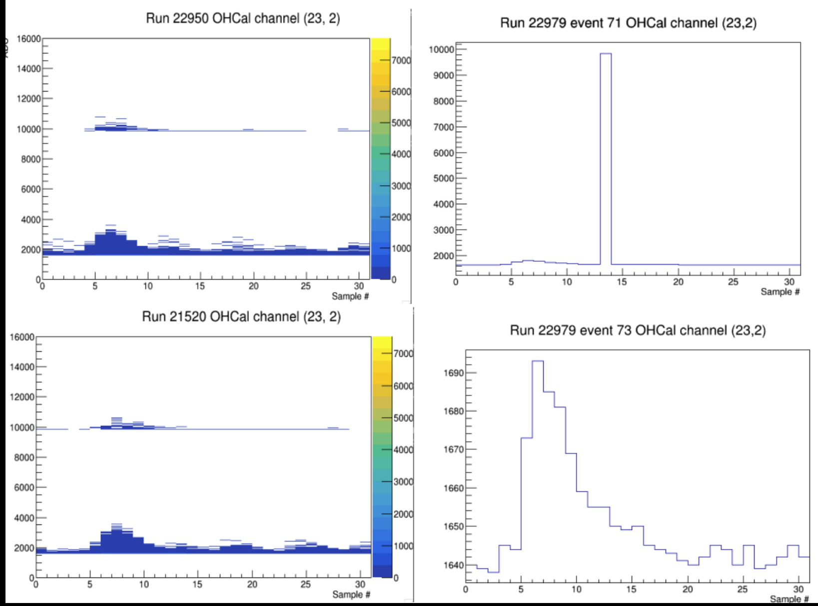
General summary

Run number	Subsystems Included	Number of bad channels (RMS>30)	$< RMS > \pm\sigma_{RMS}$
21518	EMCal, HCal, ZDC, MBD, Ll1, Gl1	74	11.9635 ± 3.75301
21520	EMCal, HCal, ZDC, MBD, Ll1, Gl1	141	12.1037 ± 4.15951
21598	EMCal, HCal, ZDC, MBD, Ll1, Gl1	10	12.0316 ± 3.70411
21599	EMCal, HCal, ZDC, MBD, Ll1, Gl1	7	12.0461 ± 3.70546
21615	EMCal, HCal, ZDC, MBD, Ll1, Gl1	6	12.056 ± 3.69148
21796	EMCal, HCal, ZDC, MBD, Ll1, Gl1	11	12.2218 ± 3.72039
21813	7/8 of EMCal, HCal, ZDC, MBD, Ll1, Gl1	77	12.0275 ± 3.77564
21889	7/8 of EMCal, HCal, ZDC, MBD, Ll1, Gl1	74	12.053 ± 3.71444
21891	7/8 of EMCal, HCal, ZDC, MBD, Ll1, Gl1	13	12.0946 ± 3.71661
22949	5/8 of EMCal, HCal, MBD, ZDC, Ll1	72	12.6984 ± 3.72108
22950	5/8 of EMCal, HCal, MBD, ZDC, Ll1	73	12.6266 ± 3.70581
22951	5/8 of EMCal, HCal, MBD, ZDC, Ll1	79	12.657 ± 3.6937
22979	5/8 of EMCal, HCal, MBD, ZDC, Ll1	70	12.6904 ± 3.69699
22982	5/8 of EMCal, HCal, MBD, ZDC, Ll1	71	12.7552 ± 3.77643

Emma McLaughlin: Beam data studies

- Case 2: Hot towers that occasionally have a spike in their waveform: (12 towers of total 46 towers, 12 runs of 15 total runs)
  This only has been noticed in the OHCal channel (23, 2) so far but is flagged as a hot tower for 12 of the 15 production runs
  We have also seen this tower as hot while taking cosmics with the OHCal trigger
  Frequency in run where channel is marked as hot: 0.6%
  in run where channel is not marked as hot + timing cuts: 0.1%



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htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 1000
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 2000
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 3000
event 3388 eventnumber 3388 energy 25.7266 eta 23 phi 2
event 3699 eventnumber 3699 energy 25.8698 eta 23 phi 2
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 4000
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 5000
event 5678 eventnumber 5678 energy 25.6257 eta 23 phi 2
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 6000
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 7000
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event 9664 eventnumber 9664 energy 26.3233 eta 23 phi 2
event 9722 eventnumber 9722 energy 25.9246 eta 23 phi 2
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event 10672 eventnumber 10672 energy 25.9136 eta 23 phi 2
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htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 11000
event 11112 eventnumber 11112 energy 26.013 eta 23 phi 2
event 11364 eventnumber 11364 energy 26.3312 eta 23 phi 2
event 11724 eventnumber 11724 energy 25.8468 eta 23 phi 2
event 11955 eventnumber 11955 energy 25.9185 eta 23 phi 2
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event 12423 eventnumber 12423 energy 25.9722 eta 23 phi 2
event 12891 eventnumber 12891 energy 26.0647 eta 23 phi 2
htJetCalos::process_event(PHCompositeNode *topNode) Processing Event 13000
htJetCalos::EndRun(const int runnumber) Ending Run for Run 21598
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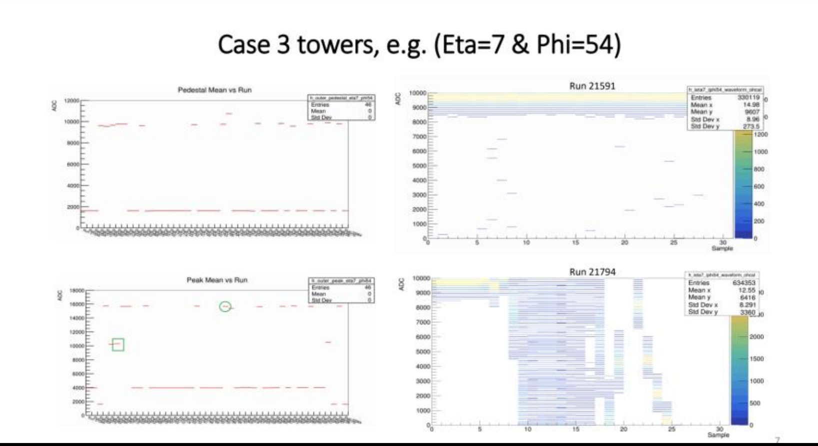
Munir Daradkeh: Hcal LED studies which show the same effects



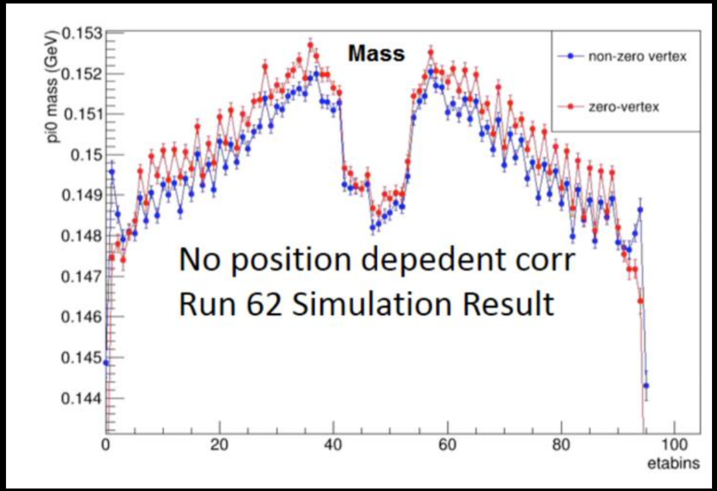
State of MC

- **The philosophy leading up to QM and, depending on person power, the strategy in the future is to calibrate to the existing MC, this way previous truth-reco physics definitions stay the same, such as the JES.**
- **There are some additions that need to be made, given what was learned from run 23**
  - The noise in the simulation is 1 ADC, this is a large underestimate and is channel dependent
  - Run 23 conditions such as live towers
- **Additionally, there are current features of the MC that make it complex to calibrate to.**
  - Pi0 mass has a nontrivial eta-phi dependence
  - Inaccurate intrinsic or noise related resolution leads systematic effects

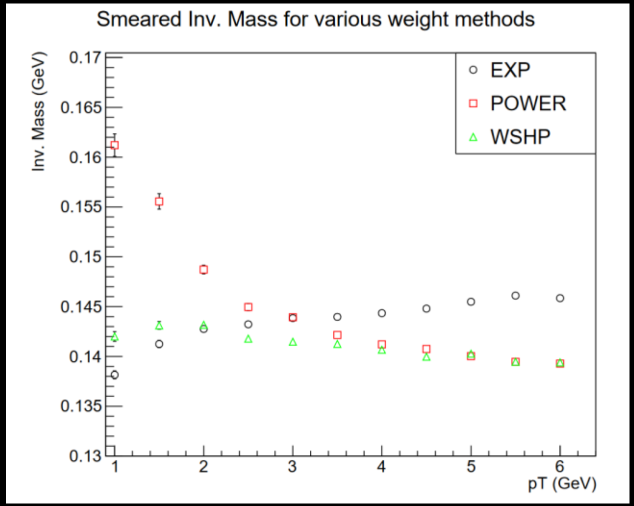
EMCal

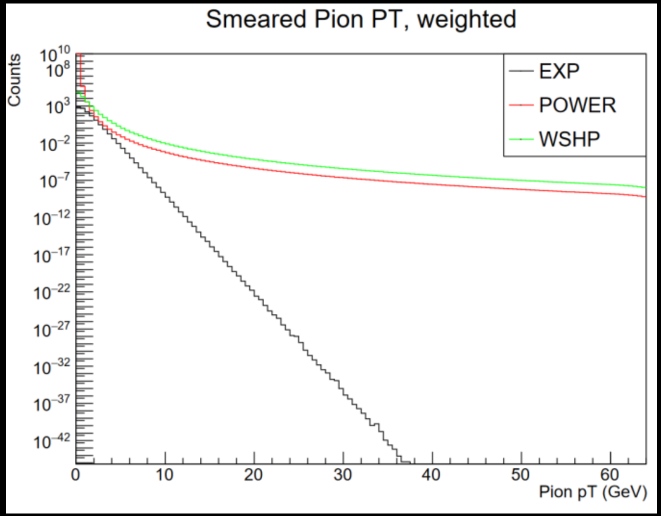
- **As previously said the current calibration calibrates to an arbitrary pi0 mass**
- **The correct pi0 mass depends on**
  - What the mass is in MC
  - Account for any difference in data and MC
- **We need to measure the resolution in data and compare it to MC.**
  - Any discrepancy need to be propagated to the MC or account for it in the calibration
    - For example, a lower resolution produces a large observed pi0 mass given a falling pT spectrum
- **Need to finish up single photon energy closure in MC i.e. finalize Position dependent correction**
- **Left: pi0 mass in HIJING without position dependent correction**
- **Right: example of truth studies of resolution effects on pi0 mass**

Sijan + Justin



Nikhil Kumar





Thanks!

EMCal calibrations 24

- **1B a day**
- **1.4 s budget Calorimeter processing**
- **This takes 10s of seconds in the current setup**
- **Plan is to go from prdf -> raw towers only once**
  - This is a necessity given computing resources
- **It is the case that we did not collect enough statistics in 23 to rehearse the planned 24 calibration strategy although the 23 approach is of similar complexity.**

- **Will we take 1B events in commissioning to "rehearse" EMCal Calibration?**

Useful

- Group disk space
  /sphenix/tg/tg01/commissioning/CaloCalibWG/
- Software twiki

HCal 2024

- When watch shifts start, have shifters take cosmics once a day (for an hour or so) to establish and test a reliable routine.
- During beam time, take cosmics during down time.