Calibration of CMS HCAL

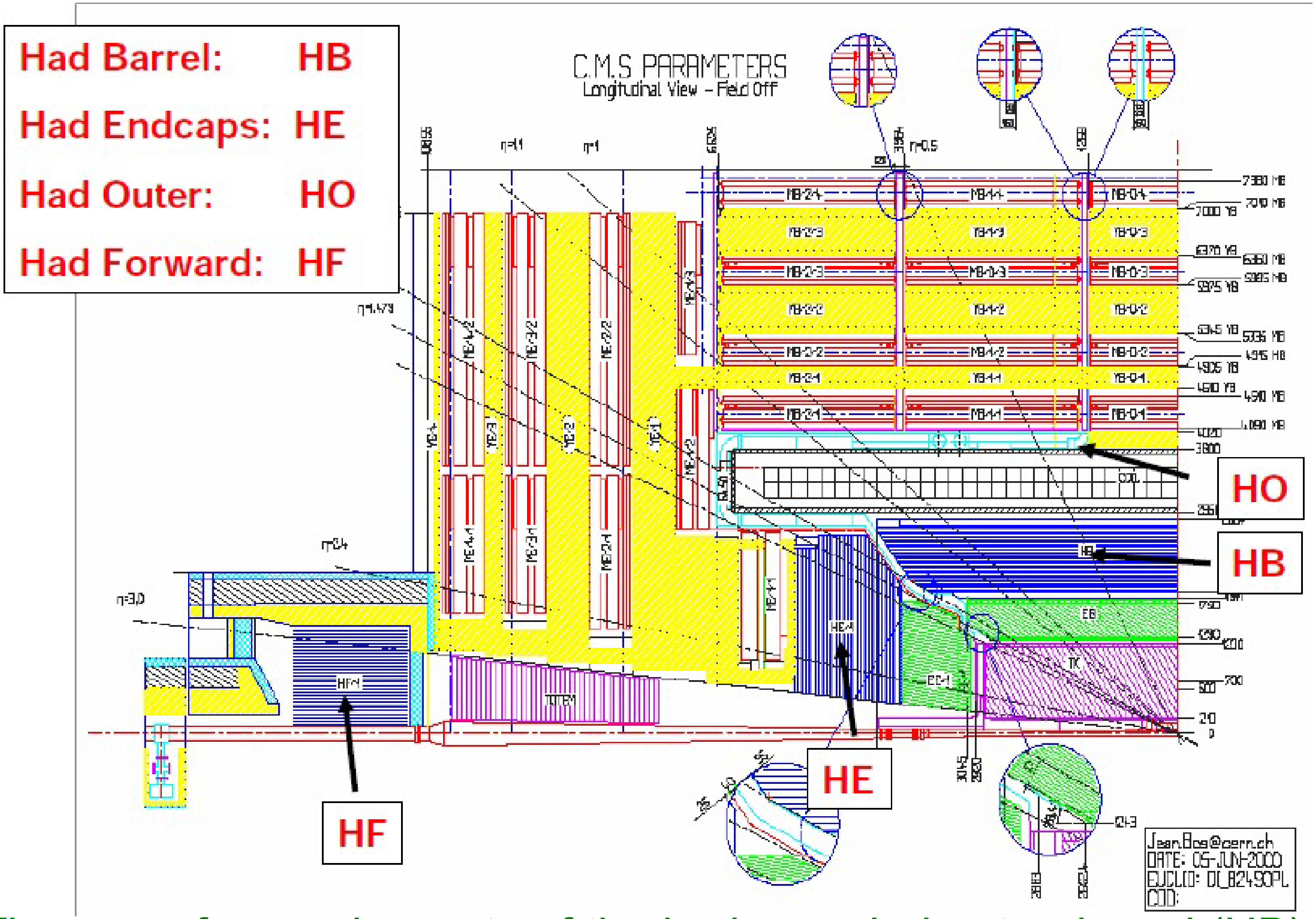
Outline

- CMS Hadron Calorimeter
  - Energy measurement in HCAL
- Calibration of HCAL
  - Calibration during construction
  - Determination of absolute scale factor (test beam)
  - Calibration system built-in to modules
  - Calibration using collision data
    - Relative Calibration using NZS data
    - Relative Calibration using Muon Signal
    - Absolute Calibration

June 2018

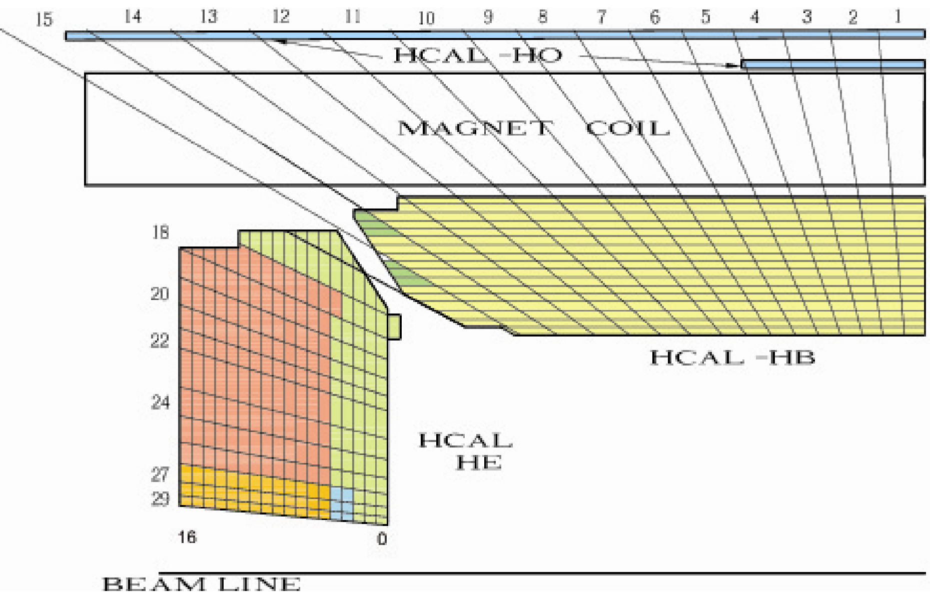
Sunanda Banerjee

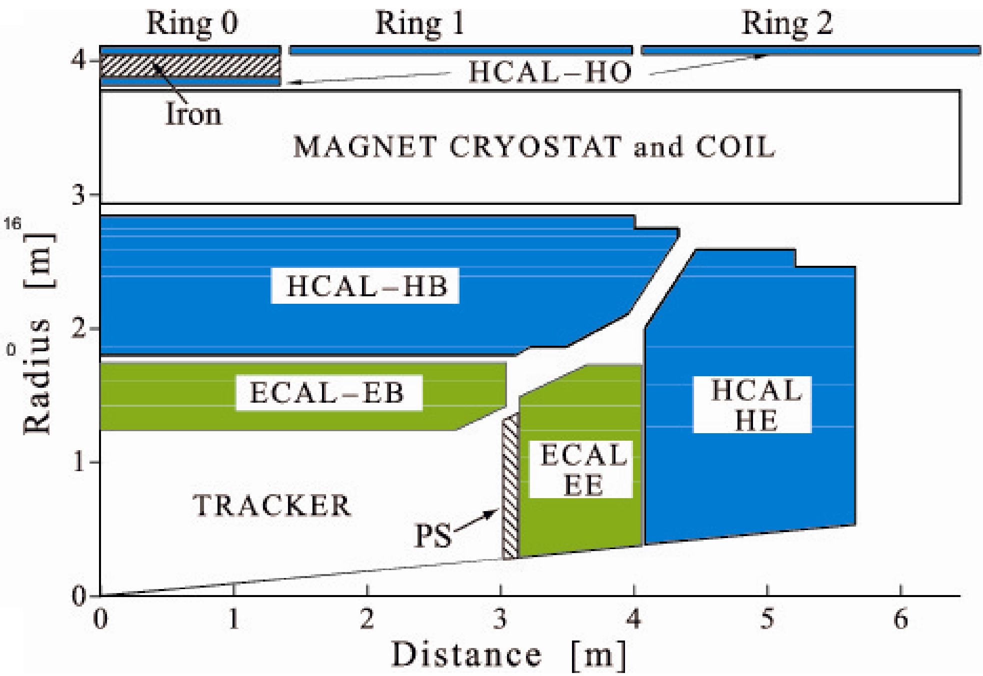
CMS Detector



- There are four major parts of the hadron calorimeter: barrel (HB), endcap (HE), outer barrel (HO) and forward (HF)

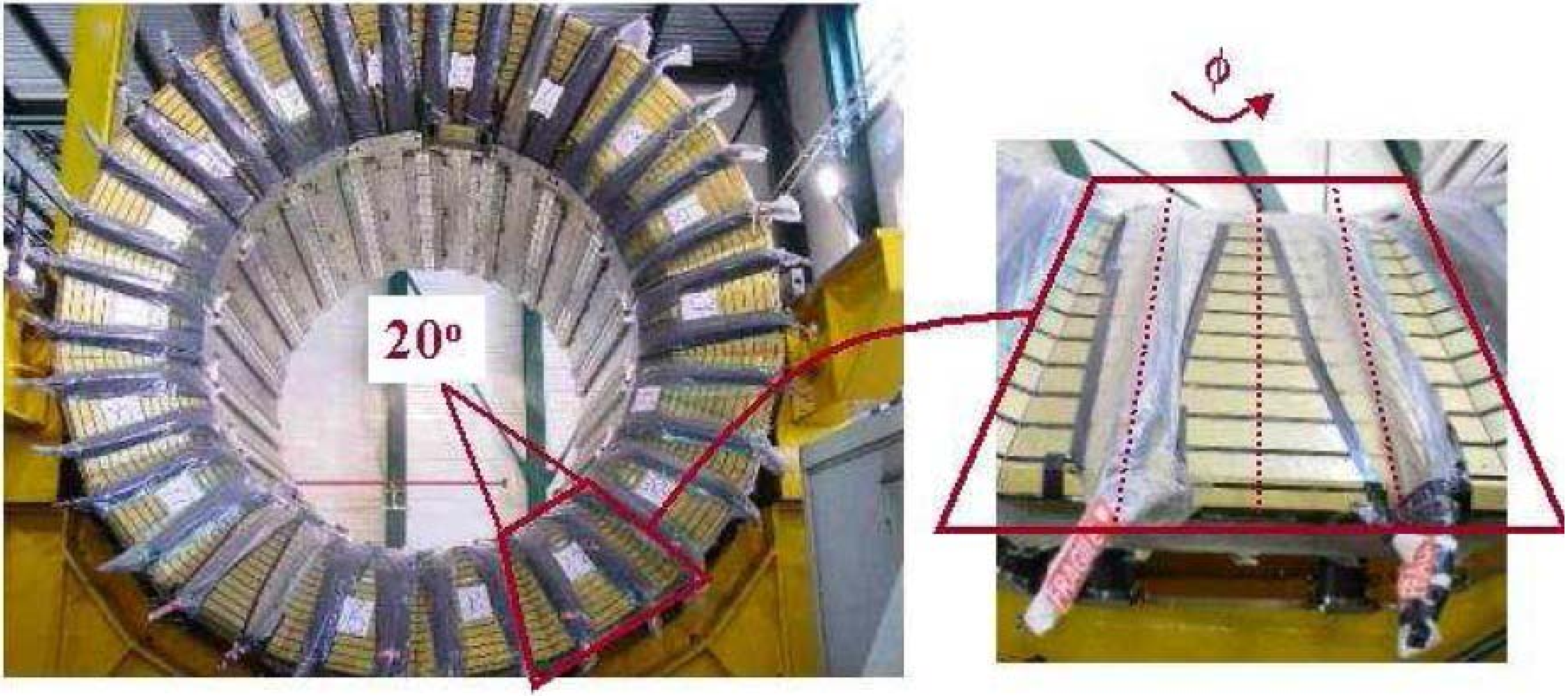
Hadon Calorimeter





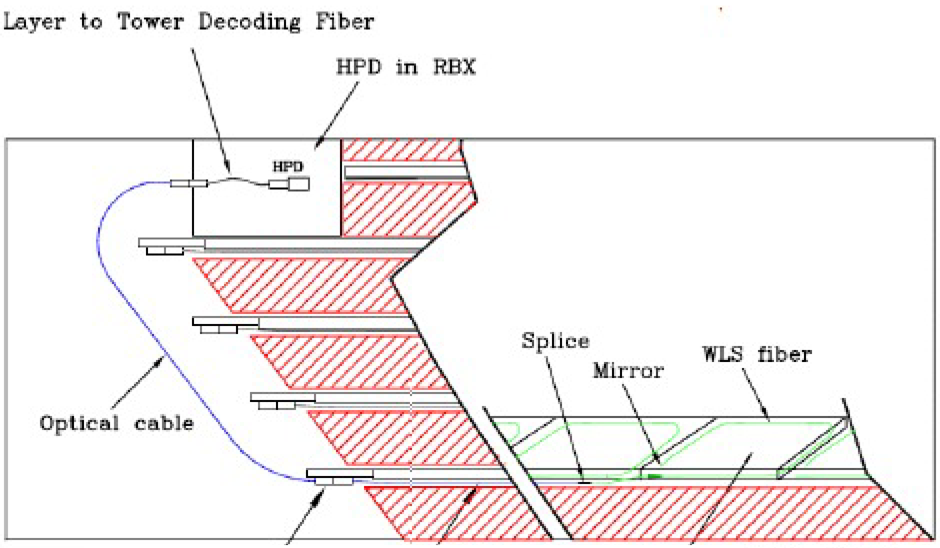
- Except for HF, the hadron calorimeter is preceded by ECAL made out of lead tungstate crystals
- HCAL (except HF) is mainly brass absorber with plastic scintillator
- The read out of HCAL utilizes pointing geometry in a tower like structure and are identified by η, φ and depth index
  - HB covers |η| < 1.39; HO covers |η| < 1.26
  - HE covers 1.31 < |η| < 3.0; HF covers 2.87 < |η| < 5.0

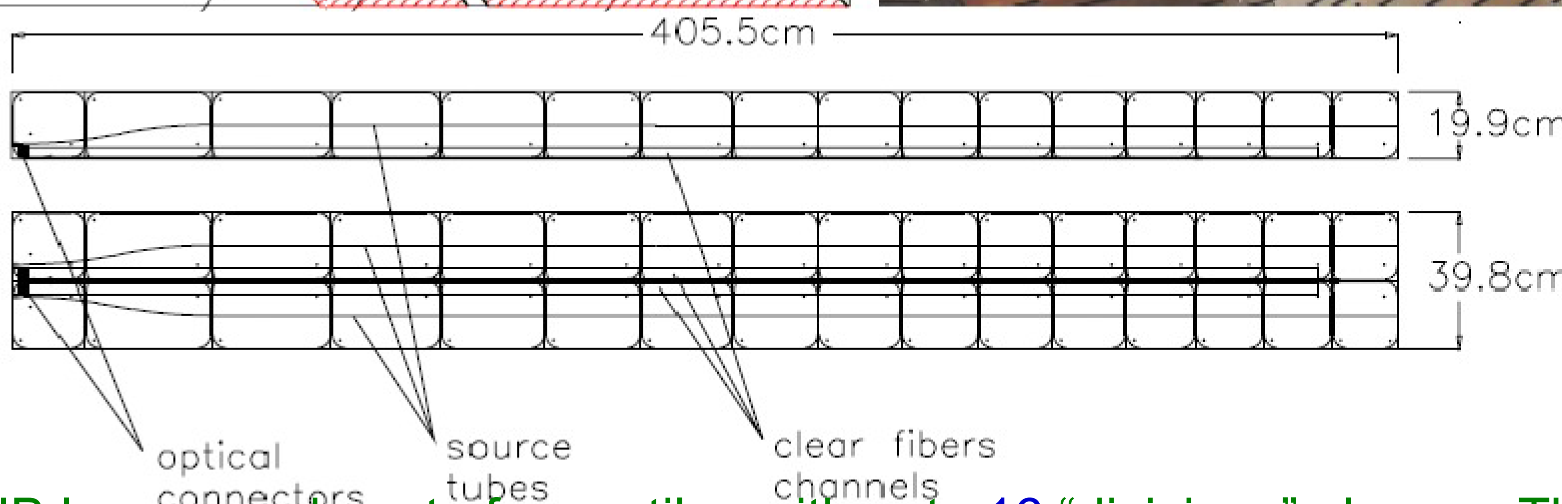
HCAL Barrel (HB)



- There are 18x2 wedges each covering 20º in φ
- Each wedge has 17 layers of scintillators: the front and back ones are 9 mm thick while the rest are 3.7 mm thick
- The front one also has larger light output per MeV energy deposit and is read out with an optical filter to reduce the light o/p

HB



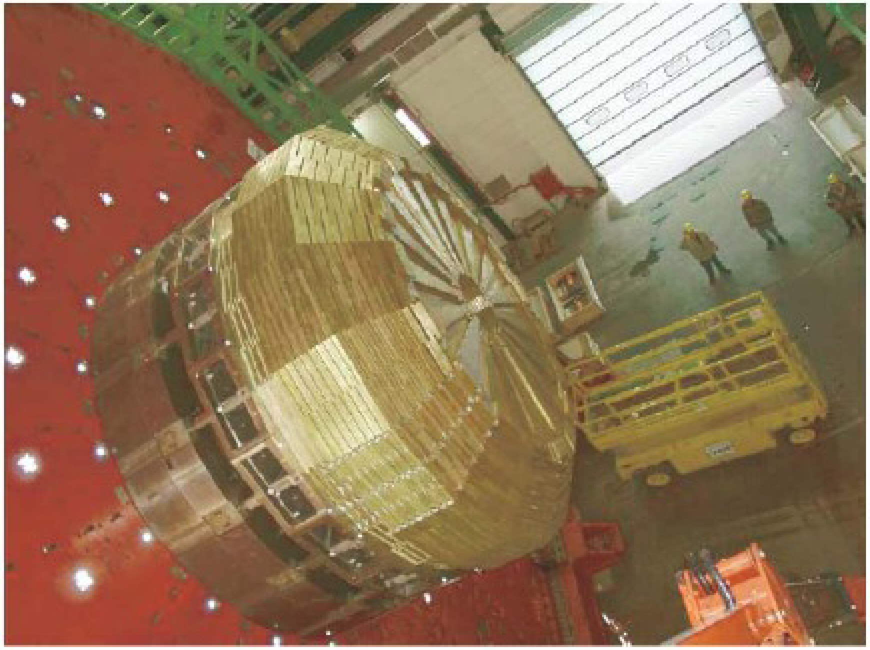


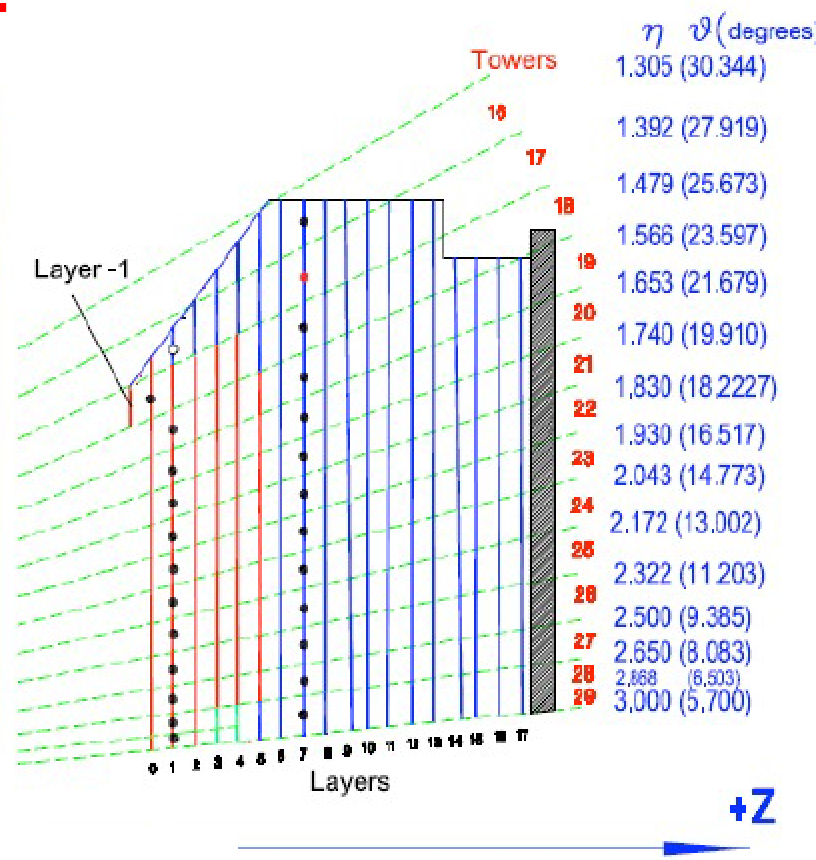
- HB layers made out of megatiles with upto 16 “divisions” along η. The two central φ-sectors make a wider tile while the two side ones are put radially forward and a megatile covers one φ-sector being read out using HPD’s

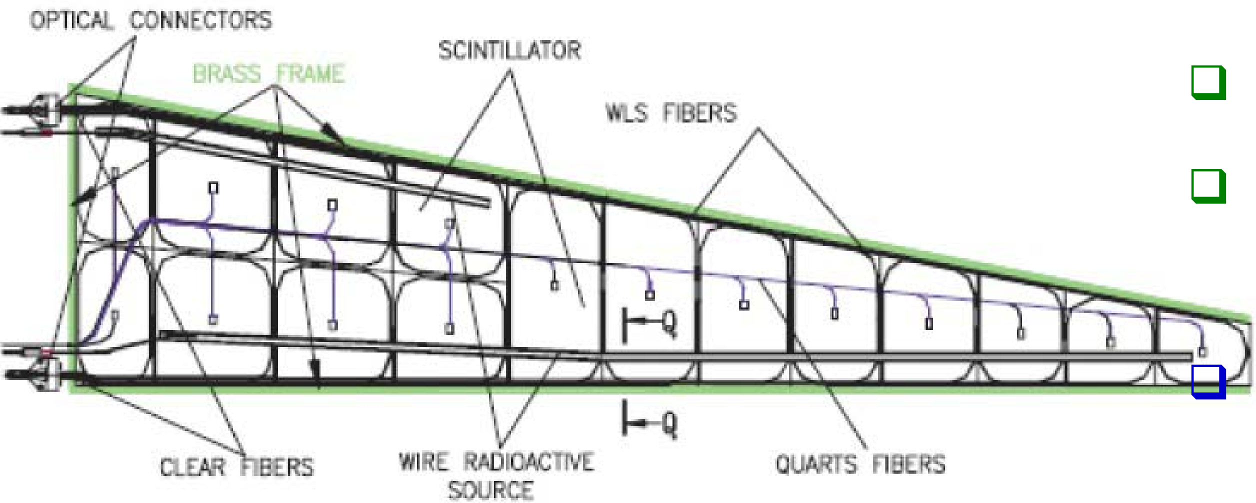
HCAL Endcap (HE)

- Endcap hadron calorimeter also has 20º segmentation along φ with each sector having two half sectors staggered along z
- It has a nose-like structure with a short scintillator tile (corresponding to $|i\eta|$ = 18
- There are 18 layers along z with the front layer having 9 mm thick scintillator and the remaining ones with 3.7 mm thick scintillators
- The front layer used to have a neutral density filter like barrel which is removed for the 2018 data taking

HE



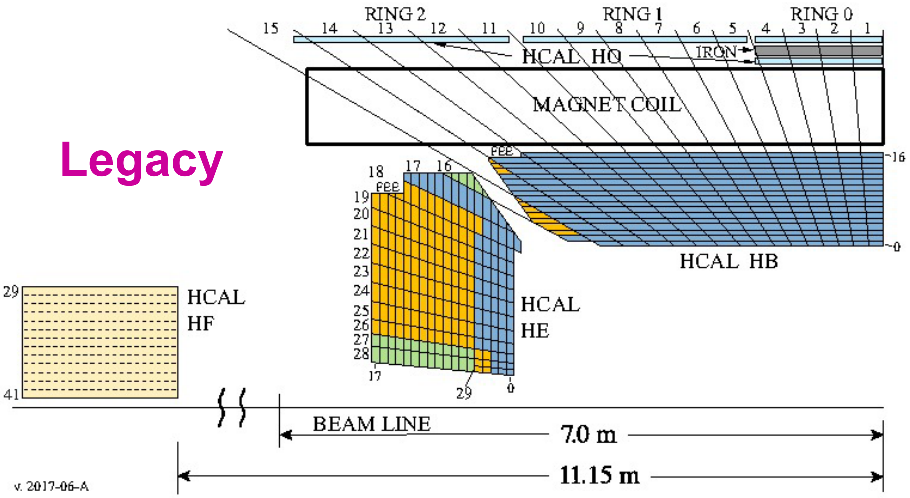




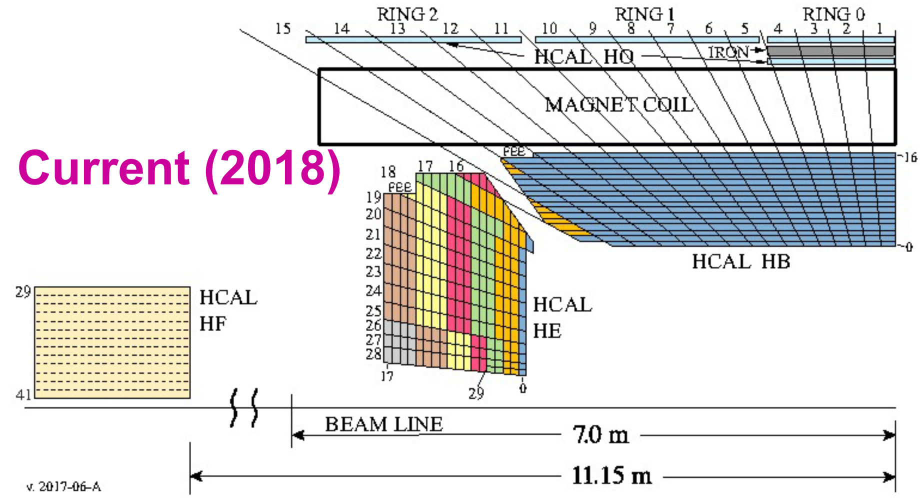
- Beyond |iη|=20, φ-width is 10°, otherwise it is 5°
- For |iη|>17 there were 2 depth segments (now 5:6) and for last 3 (4) iη values, it is 3 (7)
- Readout changed from HPD to SiPM

Layer Grouping of HB/HE

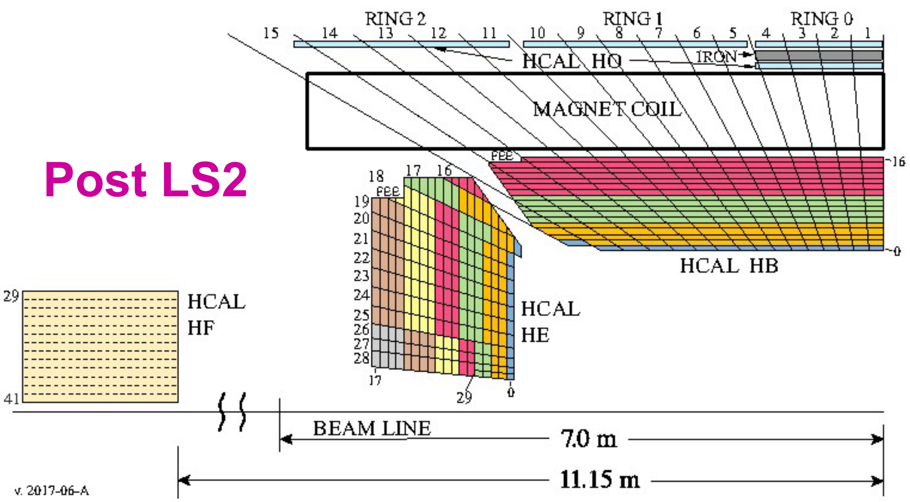
Legacy



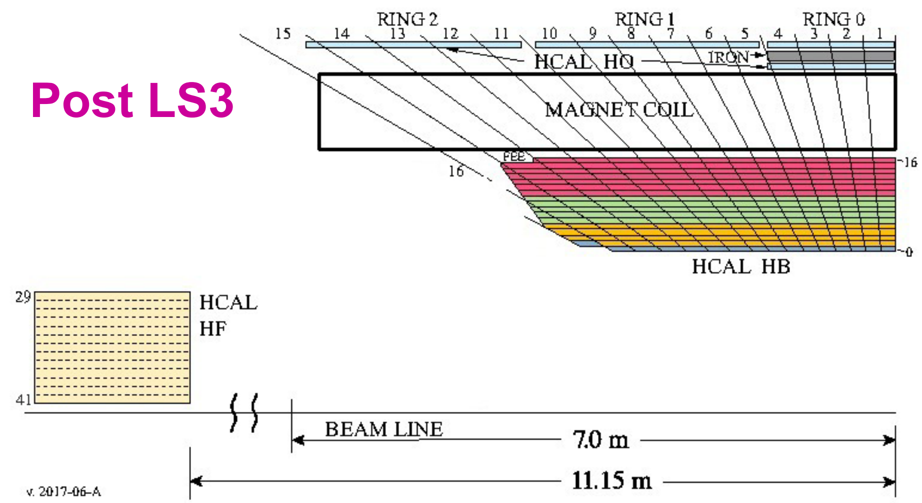
Current (2018)



Post LS2

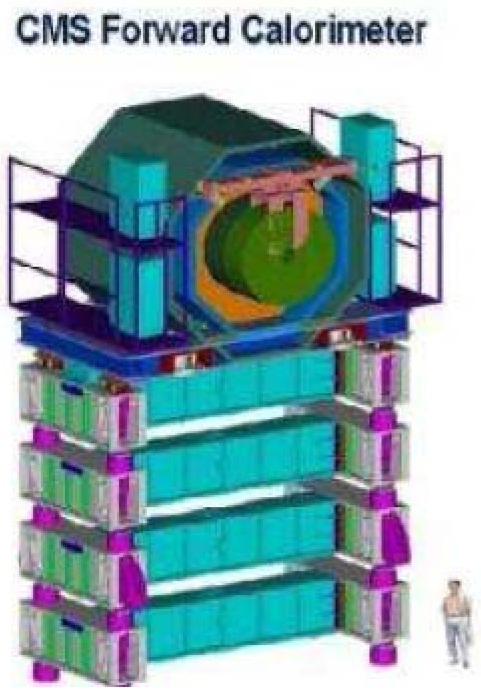


Post LS3



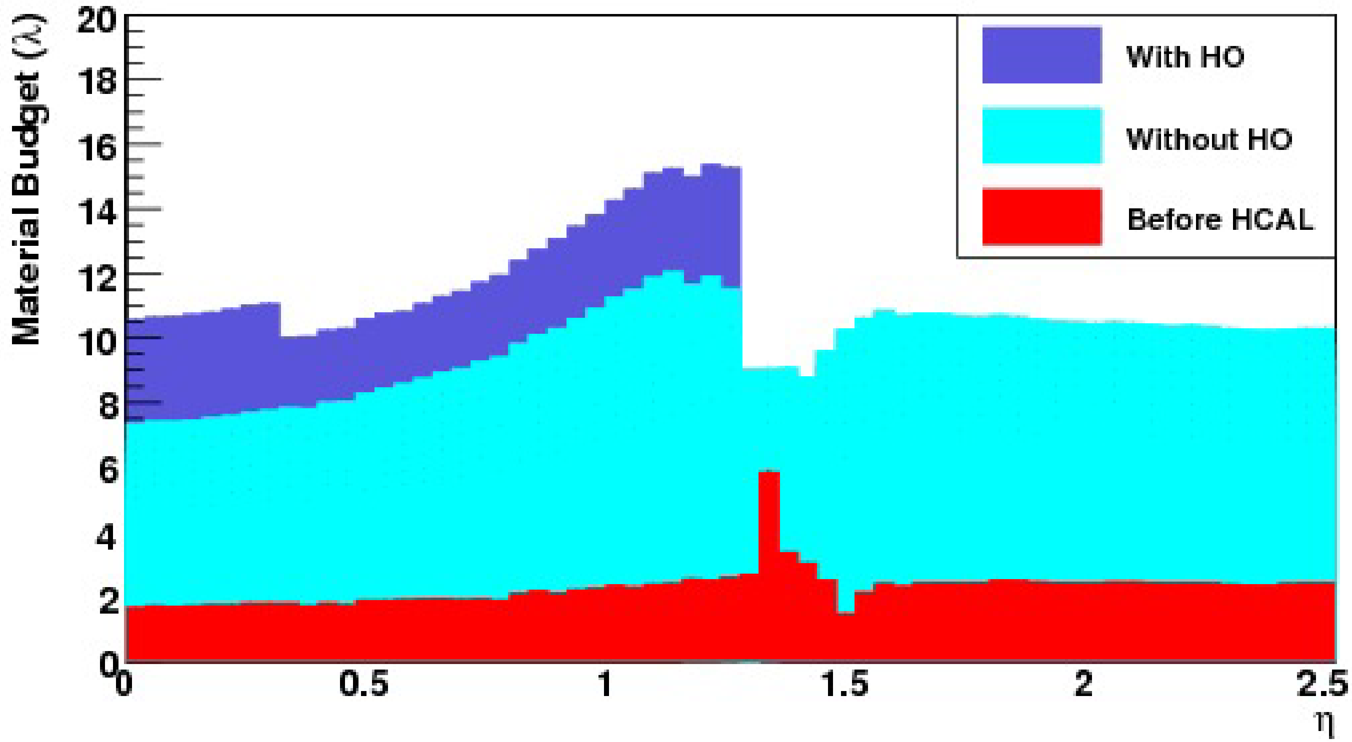
- ❑ Layer grouping of HB/HE has changed with time (depending on readout scheme)

HCAL Forward (HF)



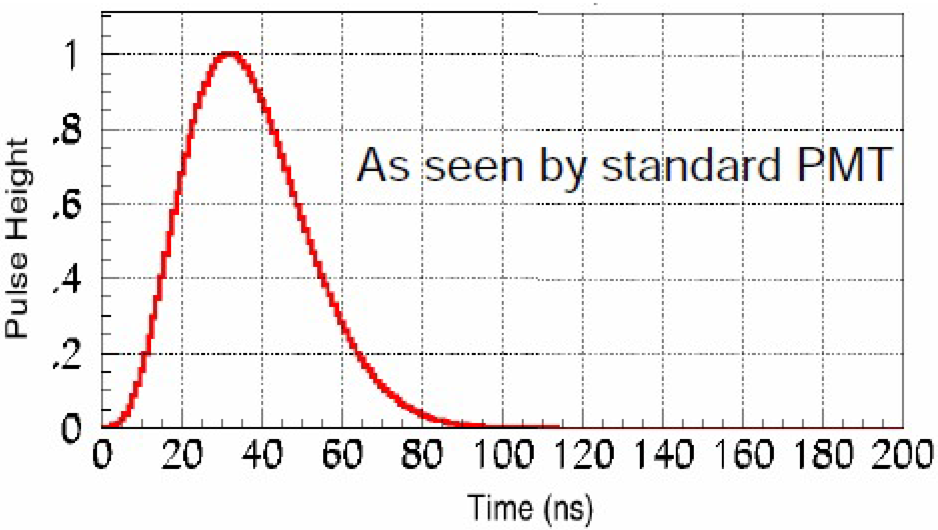
- HF is a combined electromagnetic and hadron calorimeter and is positioned in a more hostile radiation zone
- It utilizes Cerenkov radiation in quartz fibres within steel absorbers. The fibres run parallel to the beam direction and are grouped in r (cylindrical) and φ giving approximate (η,φ) segmentation.
- There are two types of fibres differing in length (1650|1430 mm) to capture light from all or only hadronic showers.

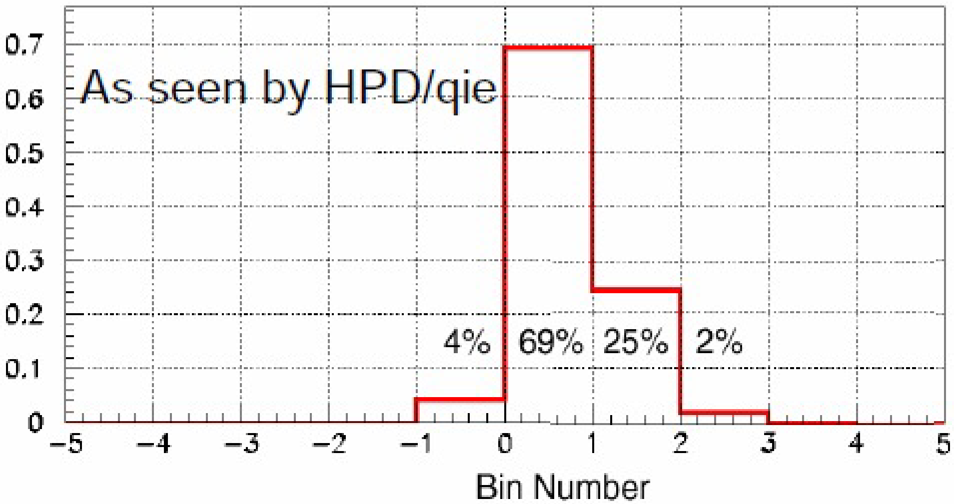
Shower Containment



- To contain hadronic showers of sufficient high energy, one requires typically 10 interaction lengths of absorber material
- Because of finite size of the magnet aperture, HB needs to be supplemented by layers of absorber outside the coil

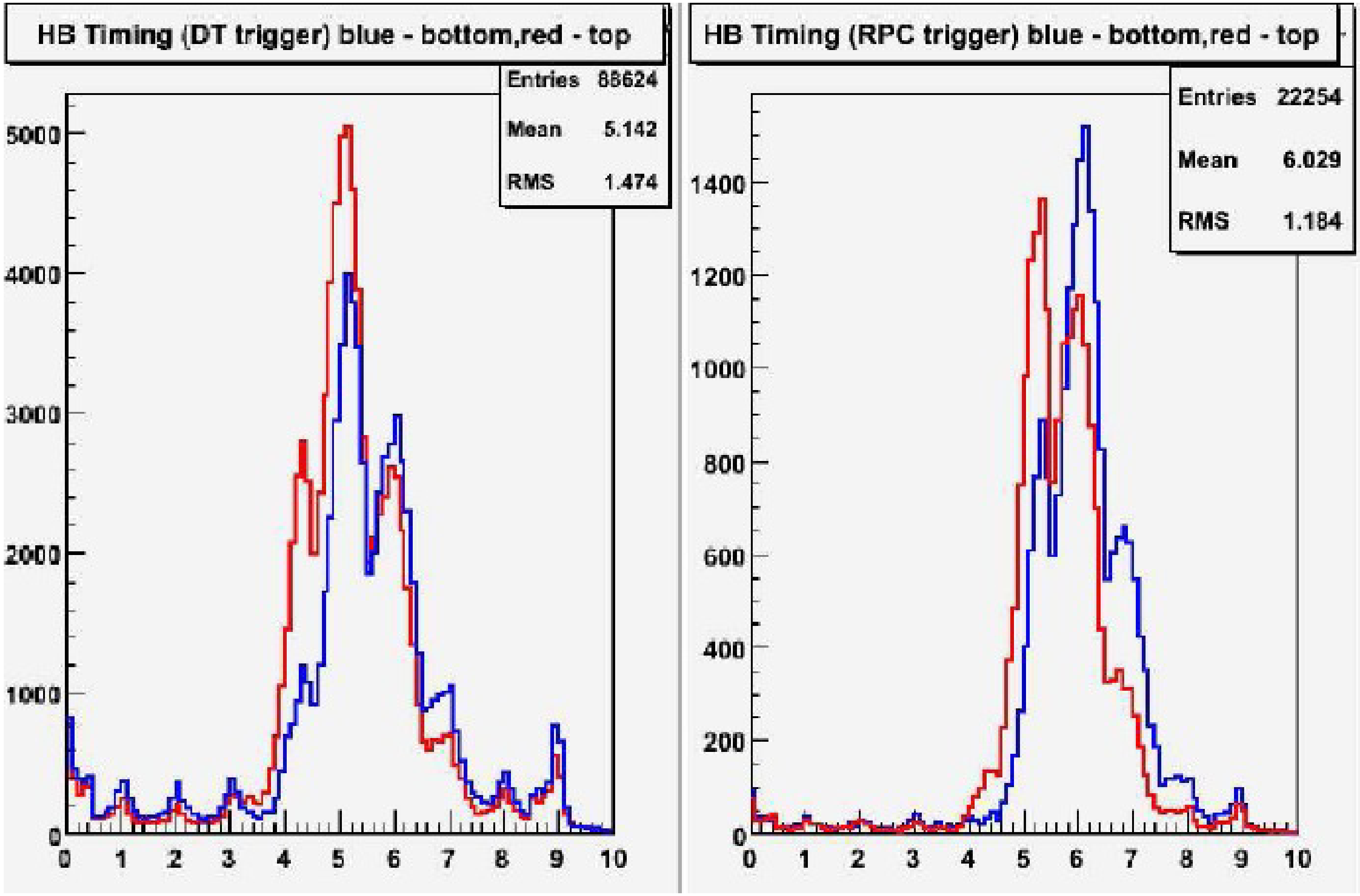
Pulse Shape





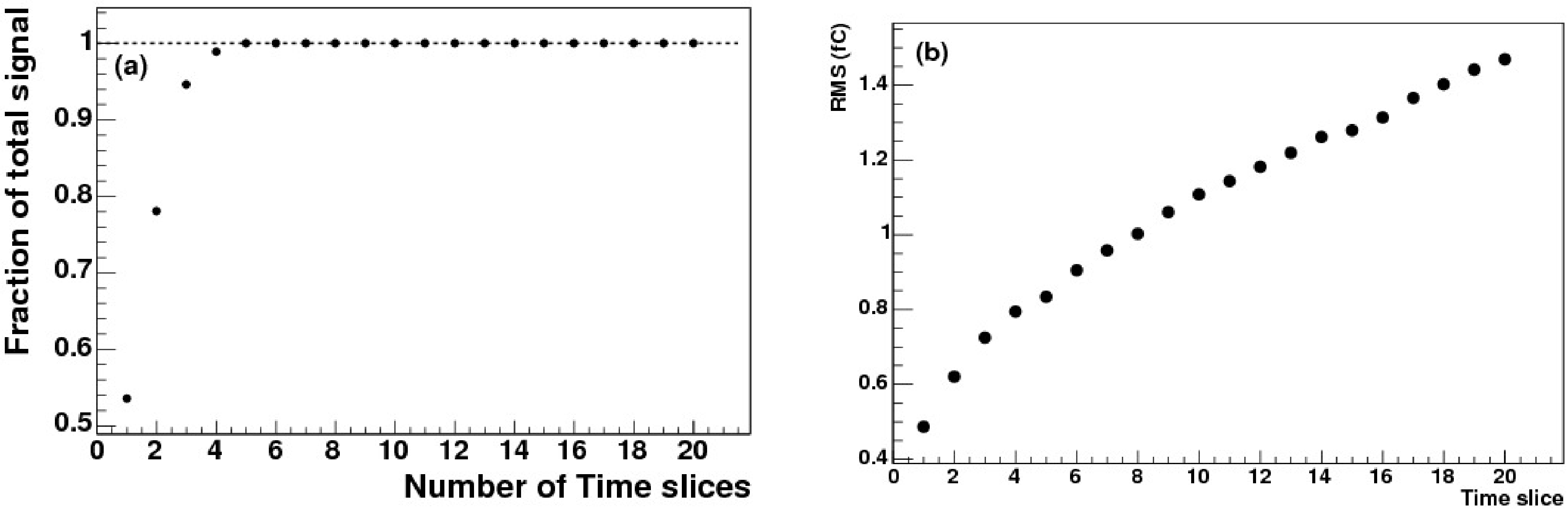
- Signal from HB/HE/HO has a typical width of 100 ns. The charge is integrated in 25 ns time window by a QIE (8 or 11) from the HPD or SiPM
- Need 4 time slices to measure the full energy.
- Read 10 time slices with time slice 4 aligned with the LHC clock so that the first 4 time slices measure the noise and the next 4 measure the signal
- Signal in HF is much faster. The signal is mostly contained in one time slice if the phase is well adjusted. This property is used to suppress noise due to anomalous hits

Time Synchronization



- Time synchronization and phase tuning is very crucial
- This is done during the extended Cosmic runs during 2006-2008 with zero magnetic field (CRUZET) and timing measurement fro HCAL and DT/RPC are matched

Time Slices used for Energy Measurement

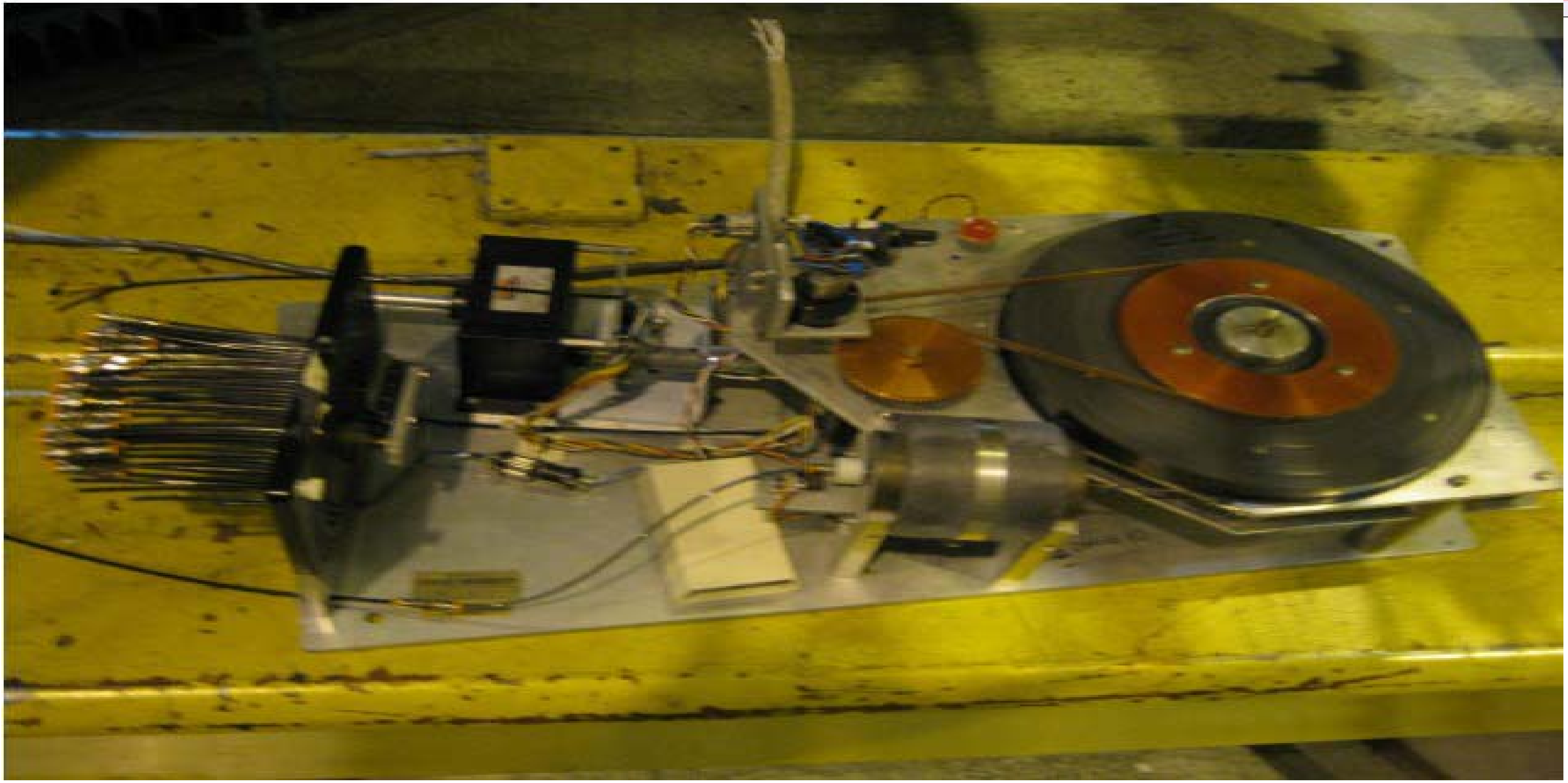


- Number of time slices to be used need optimization in view of
  - Fluctuation of the signal
  - Noise in the detector
  - Out of time pileup
- For the early runs 4 time slices were used. For 2012, two slices are used (with average containment correction) and now just one slice

Calibration of HCAL

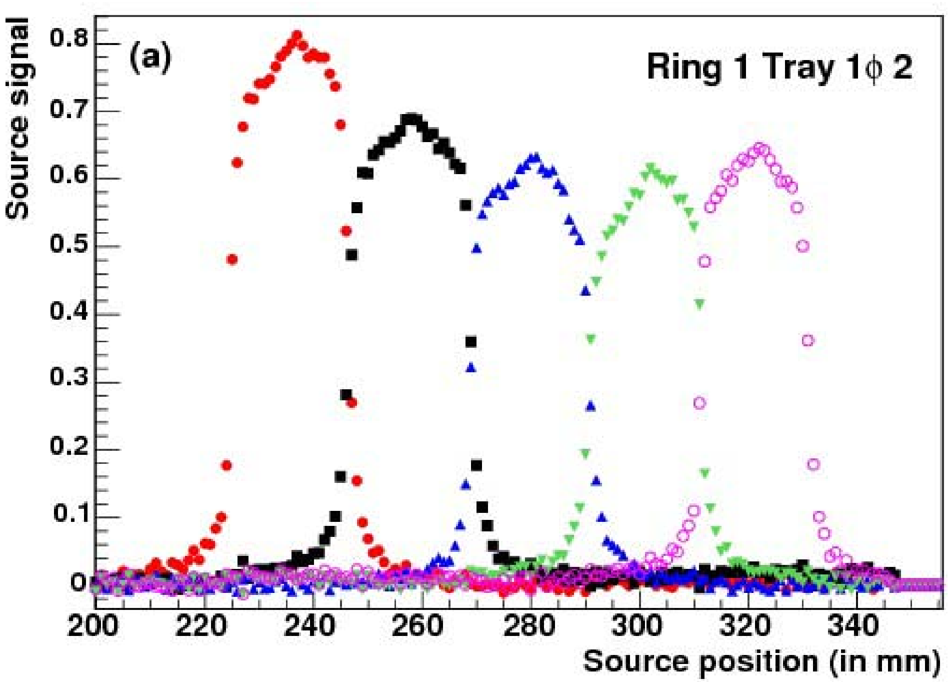
- The calibration of HCAL can be divided into 3 stages:
  - At the time of construction and commissioning
    - Radioactive wire source calibration
    - Use dedicate test beam to find absolute scale
  - Use built-in calibration system to monitor the readout
    - Use LED to monitor the readout electronics
    - Use Laser runs to monitor readout electronics and some selective layers
  - Use collision data
    - Relative calibration (φ-symmetry)
    - Relative calibration (use muons for HO and HB/HE)
    - Absolute calibration (isolated hadrons)
    - Use Z decaying to electron-pair (only for HF)
    - Use jet balancing with jet/γ (used for jet calibration)

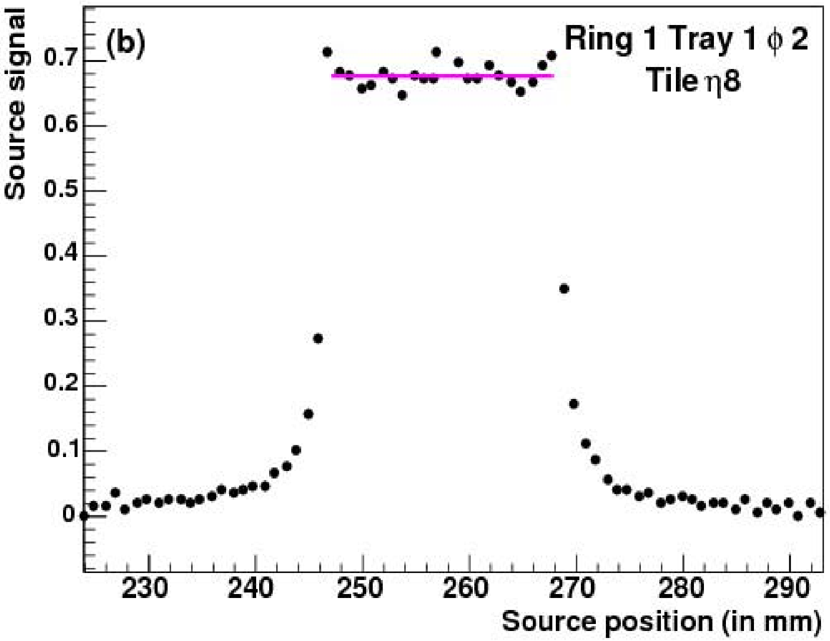
Wire Source Calibration



- 3 mCi radioactive source (^{137}Cs) mounted on the tip of a stainless steel wire which is moved using a computer-controlled motor
- This wire can be inserted in a stainless steel tube mounted on the mega-tile. These measurements are available only during the long shut down periods (YETS and LS)

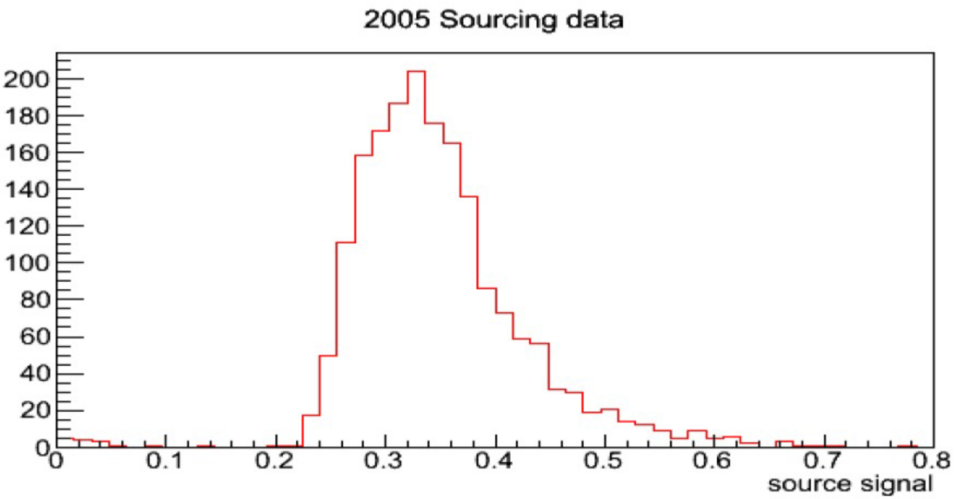
Sourcing done during commisioning

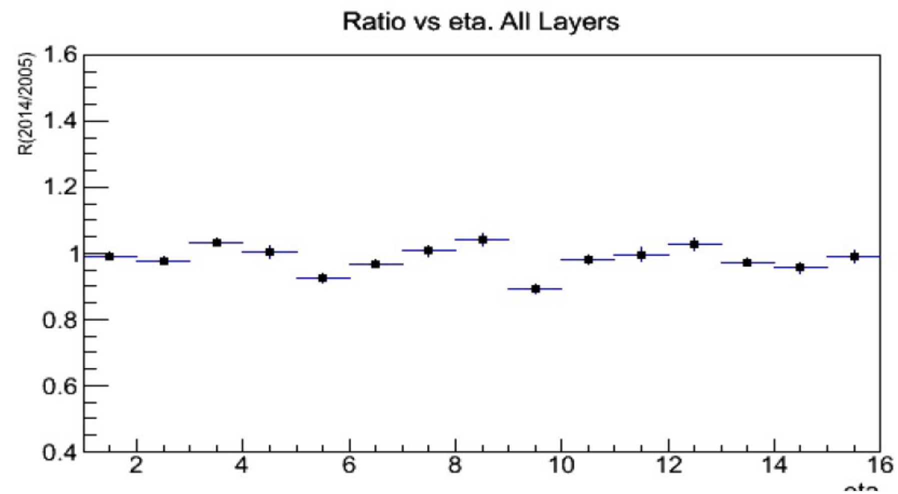


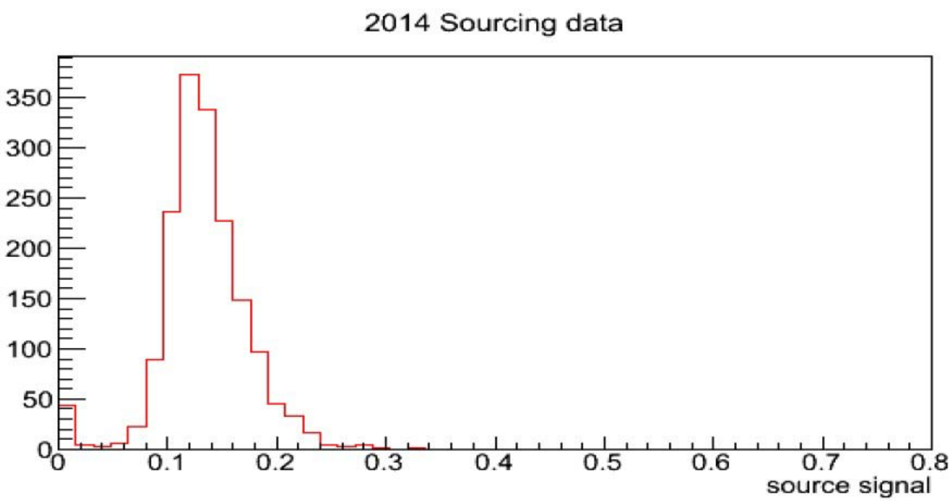


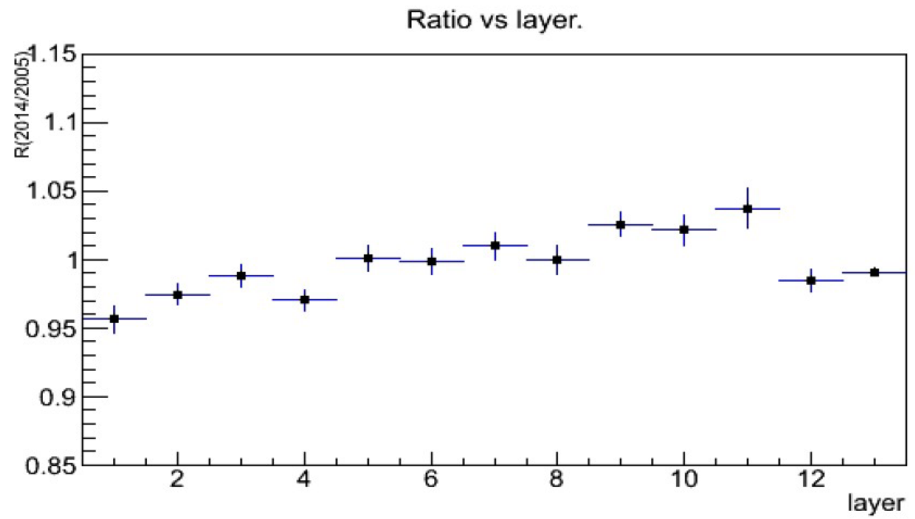
- The high level of event rate causes a DC which is recorded before integrating with the readout system or read out using the standard readout scheme after complete integration
- The wire is moved with a constant speed and the time determines the wire length which is a measure of the position in the mega-tile
- Correct for the edge effect in a given tile and fit the plateau with p_o parameterization

Sourcing during LS1





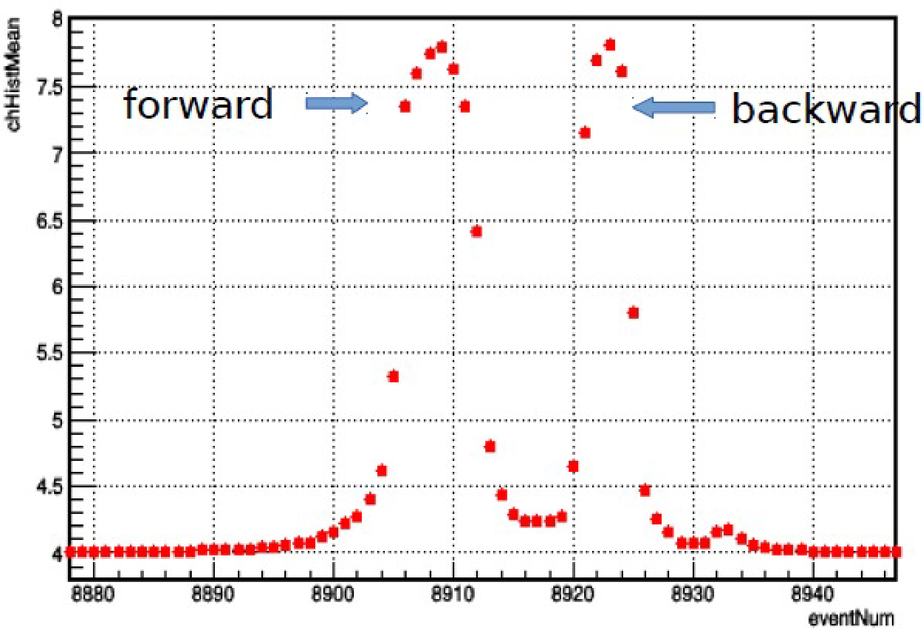


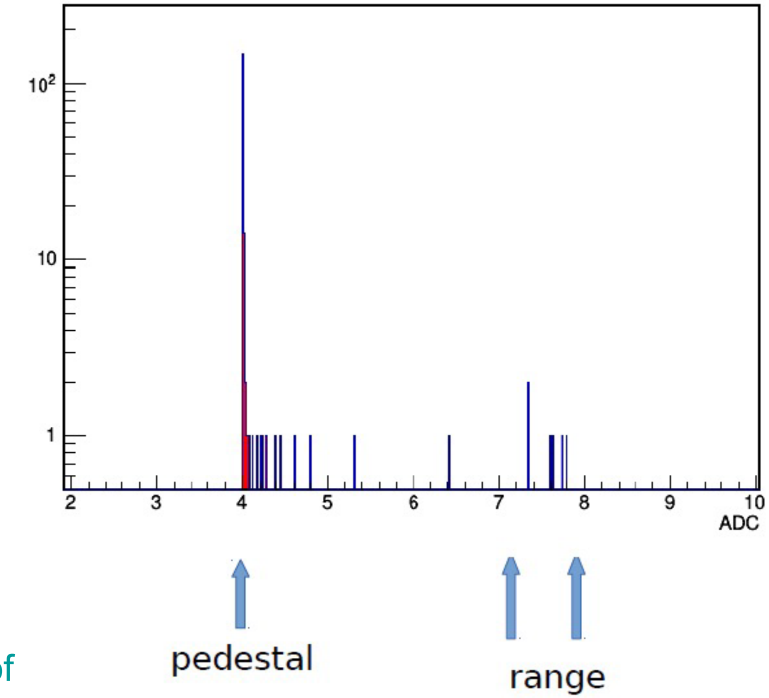


- Source measurements done for HB during 2005 and 2014. There is a net reduction primarily due to HPD gain drifts
- Only the front scintillator layers show some degradation. No net η dependent effect is observed

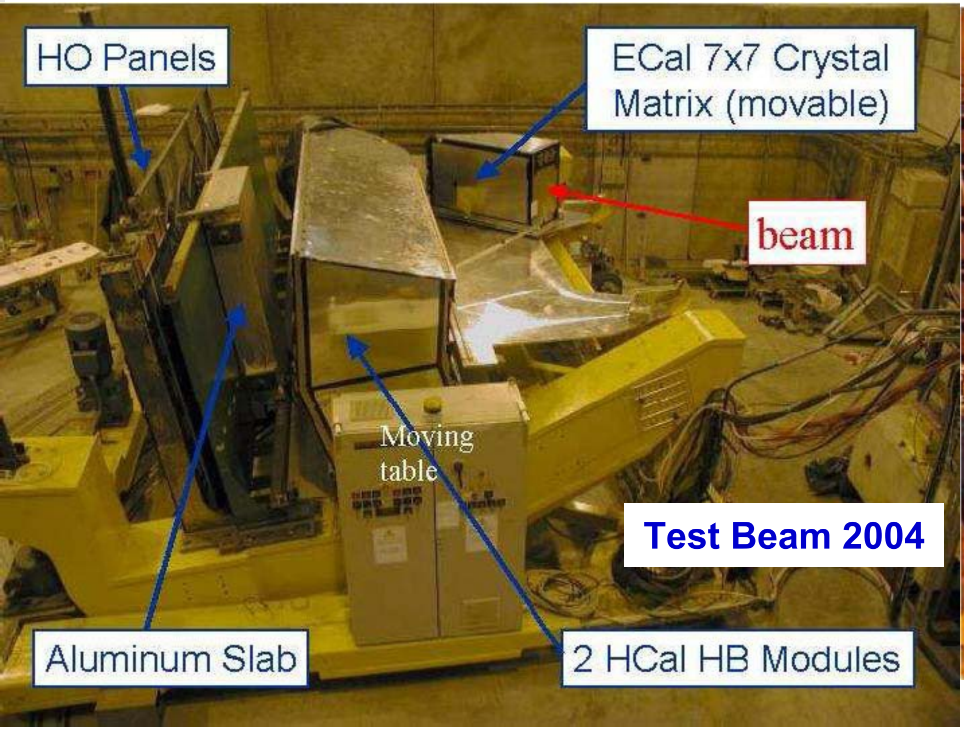
Sourcing During Upgrade

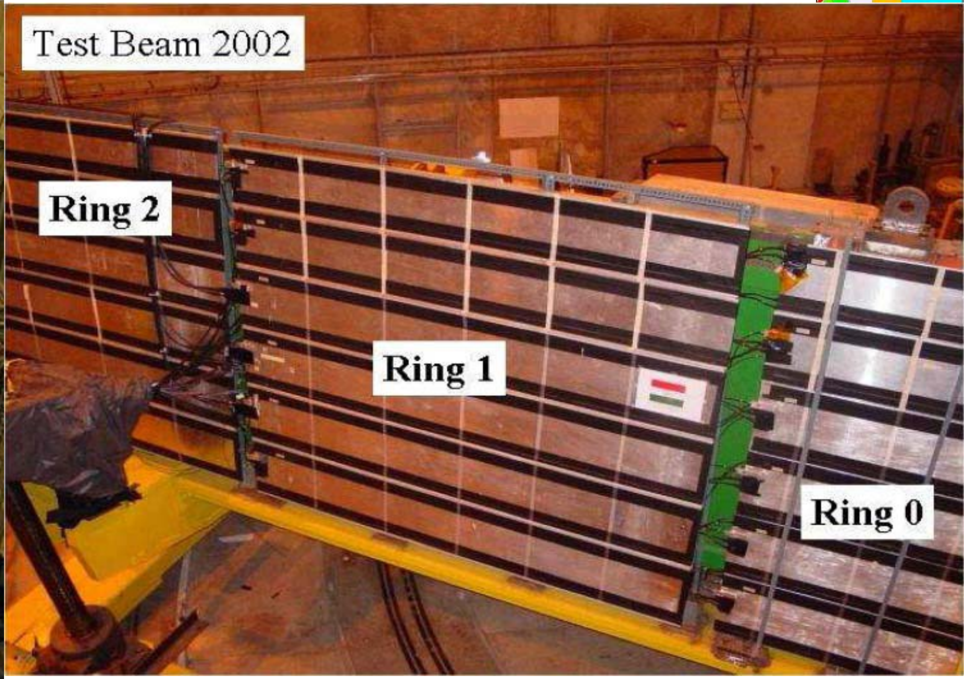
- Whenever the detector is upgraded the first step is to redo sourcing
- During 2016-17 EYETS, one of the readout box of HE (HEP17) was replaced with new phototransducer (SiPM instead of HPD) and also new readout electronics. This required wire-sourcing
- During 2017-18 YETS, all HE RBX's will use SiPM and QIE11. Also number of readout channels will increase by a large factor (~3)
  - Read out while the wire moves in and out (take average)
  - Pedestal corresponds to bin with maximum # of entries
  - Bin with maximum signal value → Signal + Pedestal





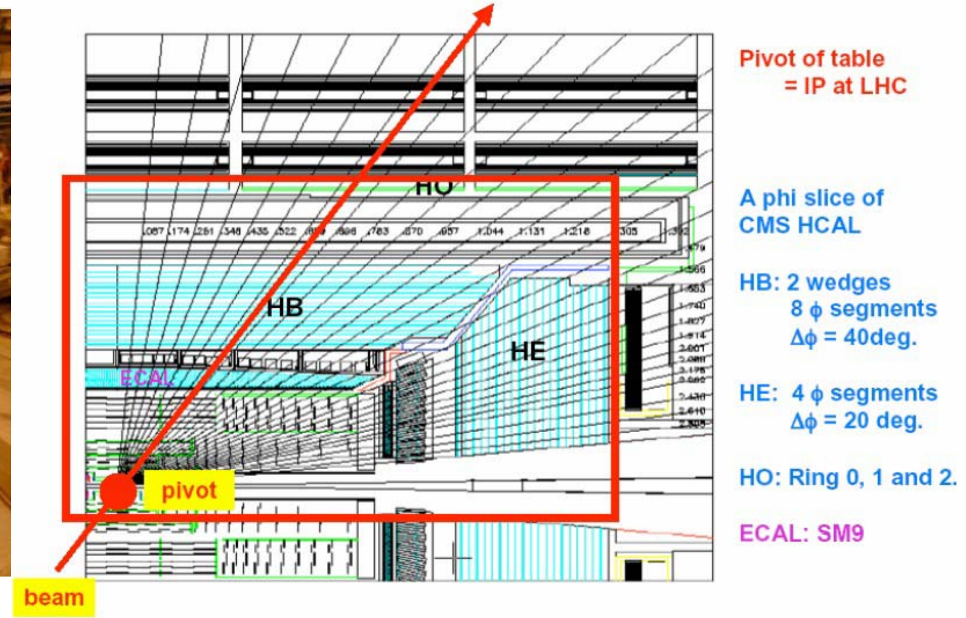
H2 Test Beam





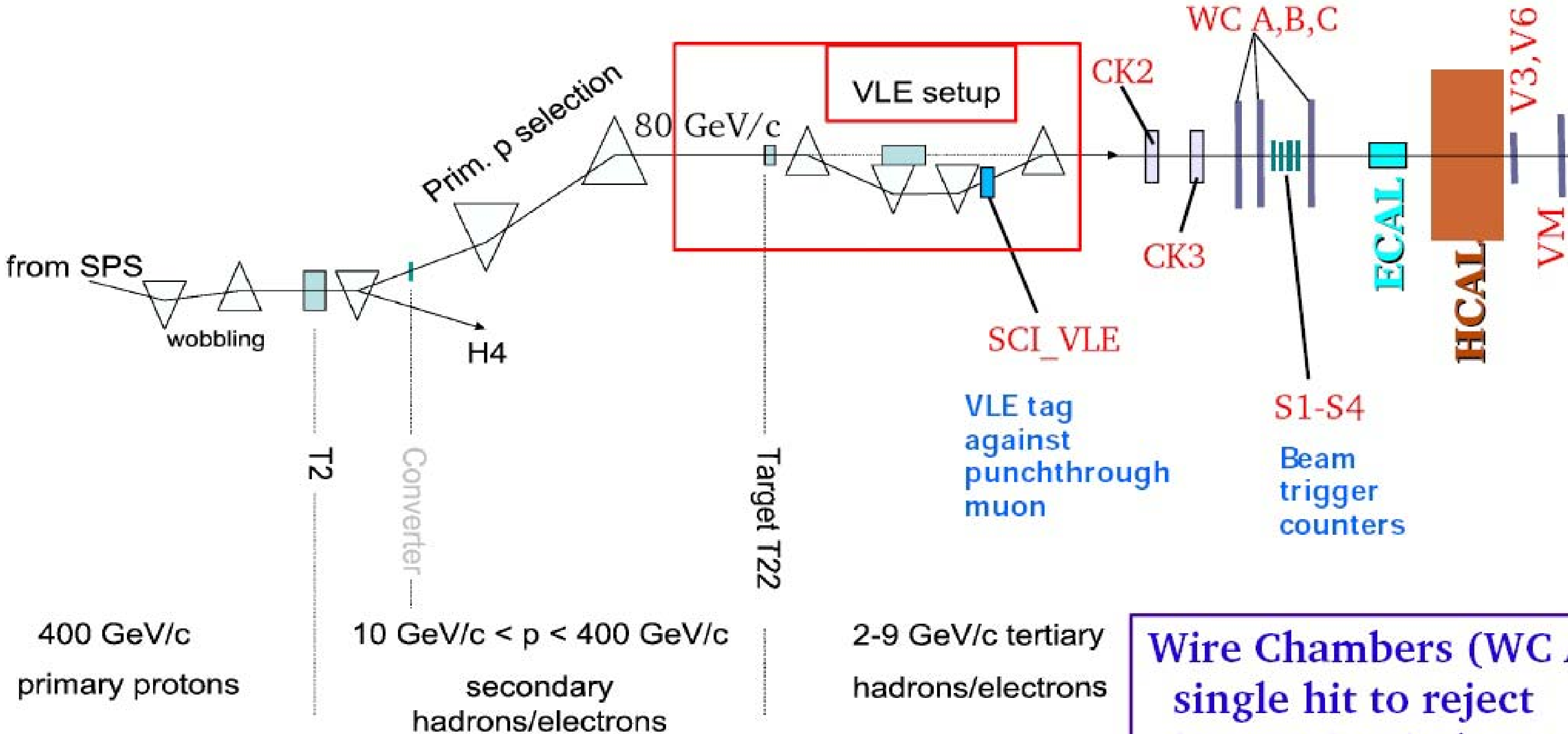
- There has been a very intense test beam activity starting from 1995 using the H2 beam line of the SPS with positive and negative hadron beams between 20 and 300 GeV and also dedicated electron and muon beams
- The early runs used hanging tile structure with varying thickness of absorbers and could employ magnetic field with HB/HE orientation and having strength up to 3 Tesla

Test Beam Setups



- There was a 7x7 $PbWO_4$ crystal (first generation) array during the first runs which was replaced by a new 7x7 $PbWO_4$ crystal array in 2002 and finally a real EB super-module during 2006
- From 1999 onward a turn table was commissioned to rotate the modules around a pivot point so that beam can point to a given iη,iφ tower and also 2 realistic HB wedge, 1 HE wedge and 6 trays of HO (½ R0,R1,R2)
- Earlier test beams used PMT and later replaced by realistic readout system
- The 2007 setup had super crystal and a layer mimicking the preshower

Test Beams



Wire Chambers (WC A,B,C):
single hit to reject interaction in beam line

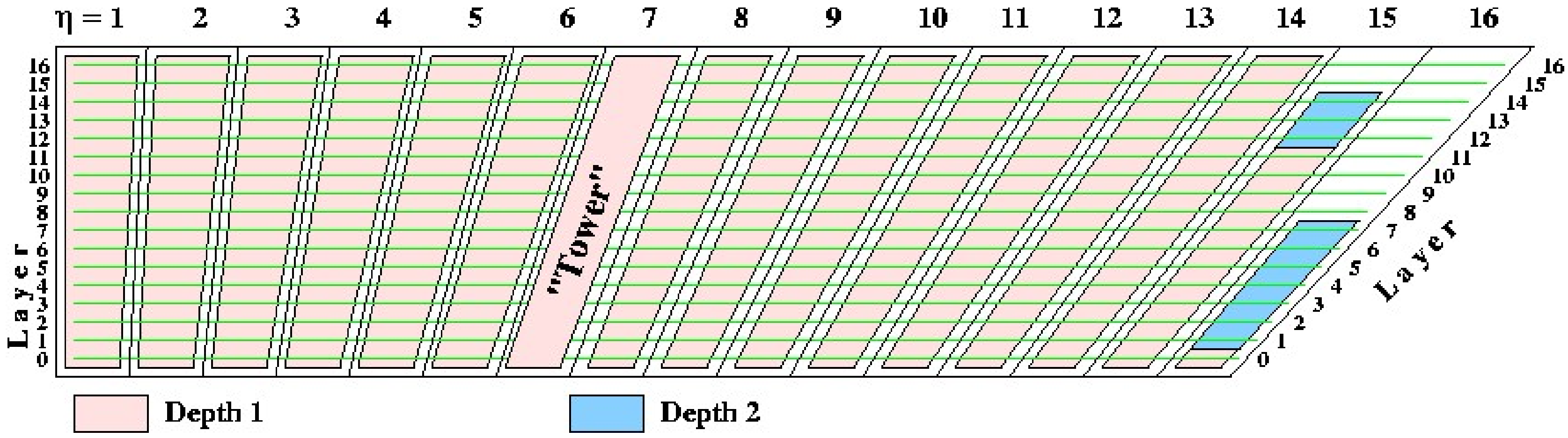
Available beam tunes:
- pions 2-300 GeV
- muons 80/150 GeV
- electrons 9-100 GeV

P-ID:
- Cerenkov counter (CK2) - electron
- Cerenkov counter (CK3) - pion / kaon / proton
- Scintillators (V3, V6, VM) – muon tagging

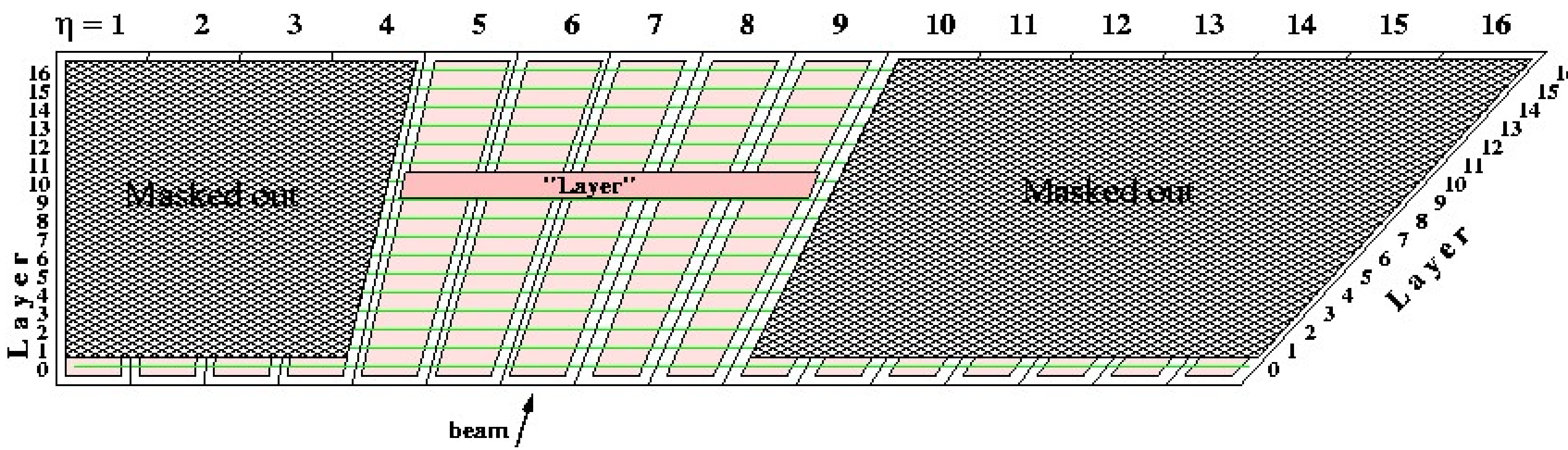
- VLE setup was available only from 2006 onward to get hadron beams with energy below 20 GeV

HB Readout Schemes

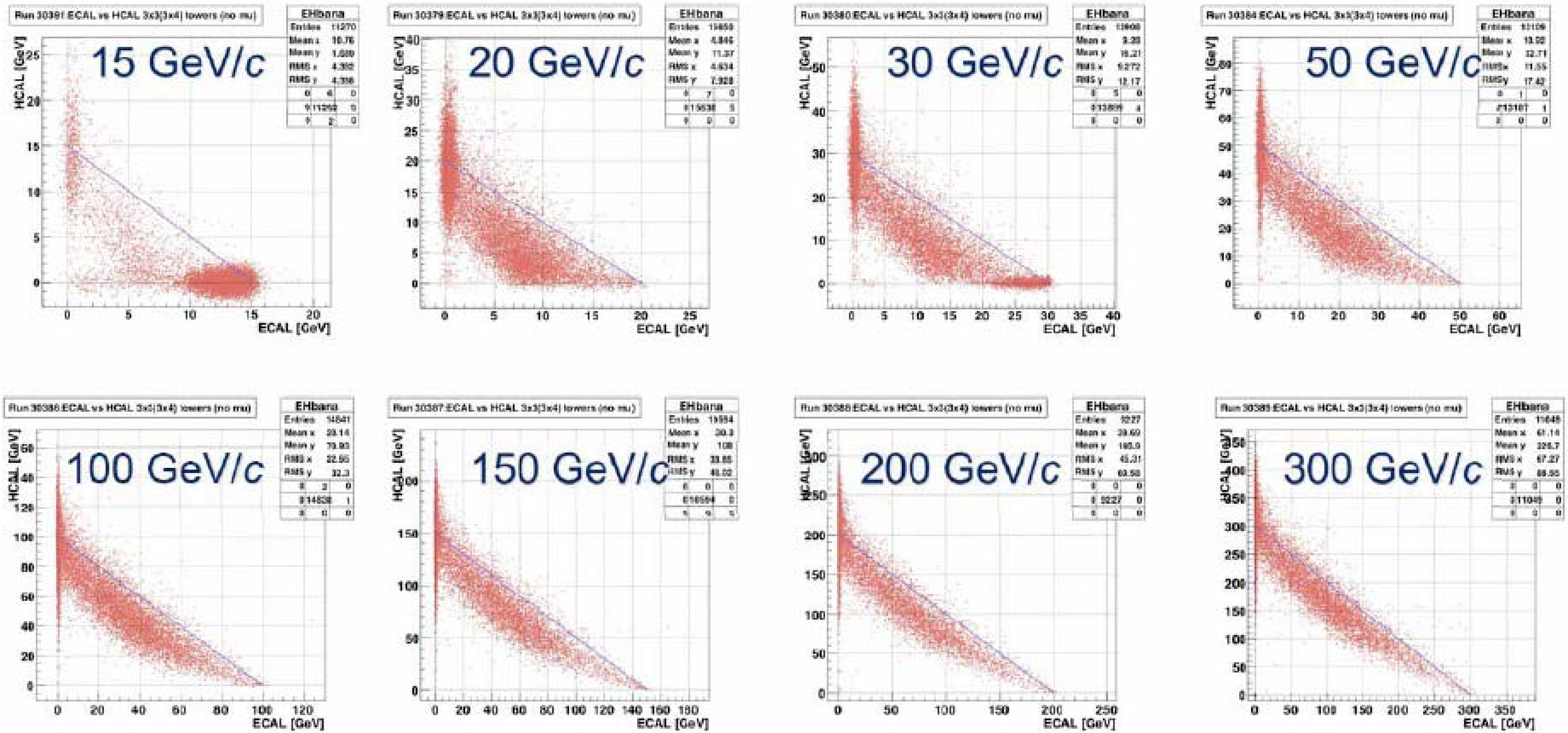
HB1: tower–wise readout – normal, as in CMS



HB2: Layer–wise readout – for longitudinal shower profile studies

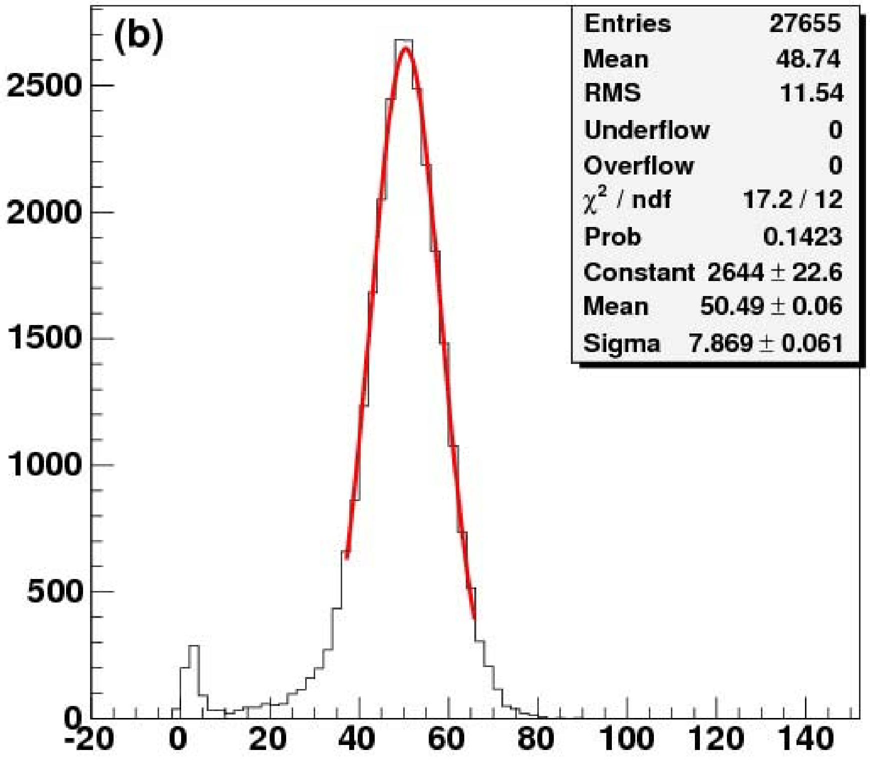


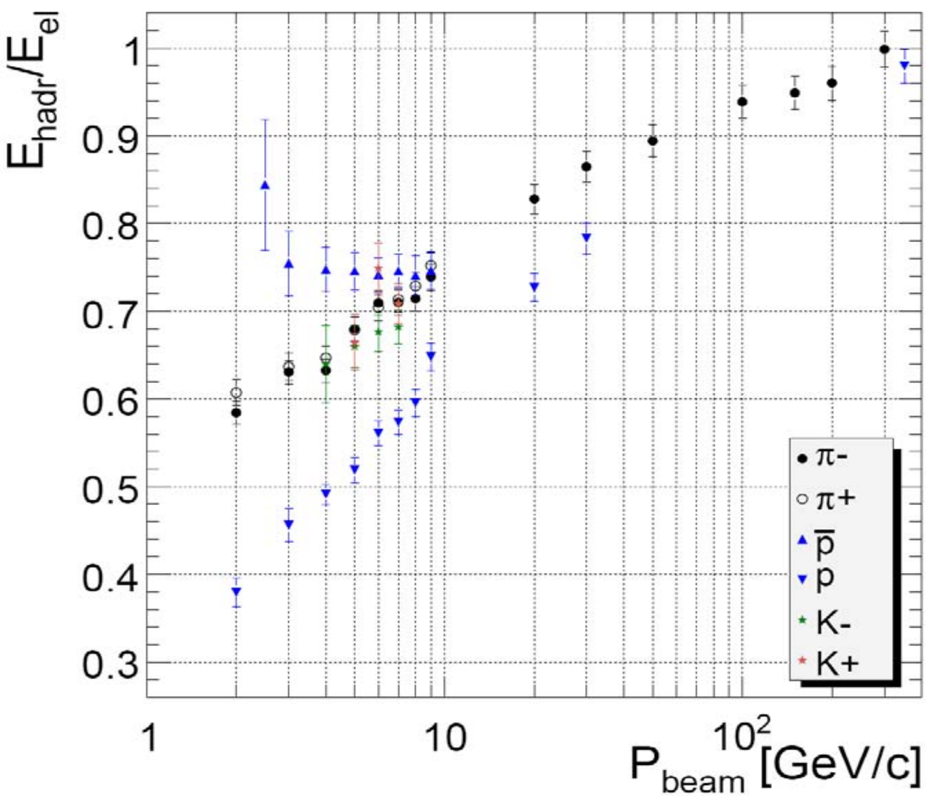
- Two configurations for HB was used: tower structure as in real setup and individual layer readout to study longitudinal shower profile



- ❑ Calibrate the ECAL and HCAL using electron beams at 50 GeV
- ❑ Look at the energy profile in HCAL vs ECAL ⟶ Banana shape
- ❑ Study energy profile when the hadrons do not interact within ECAL

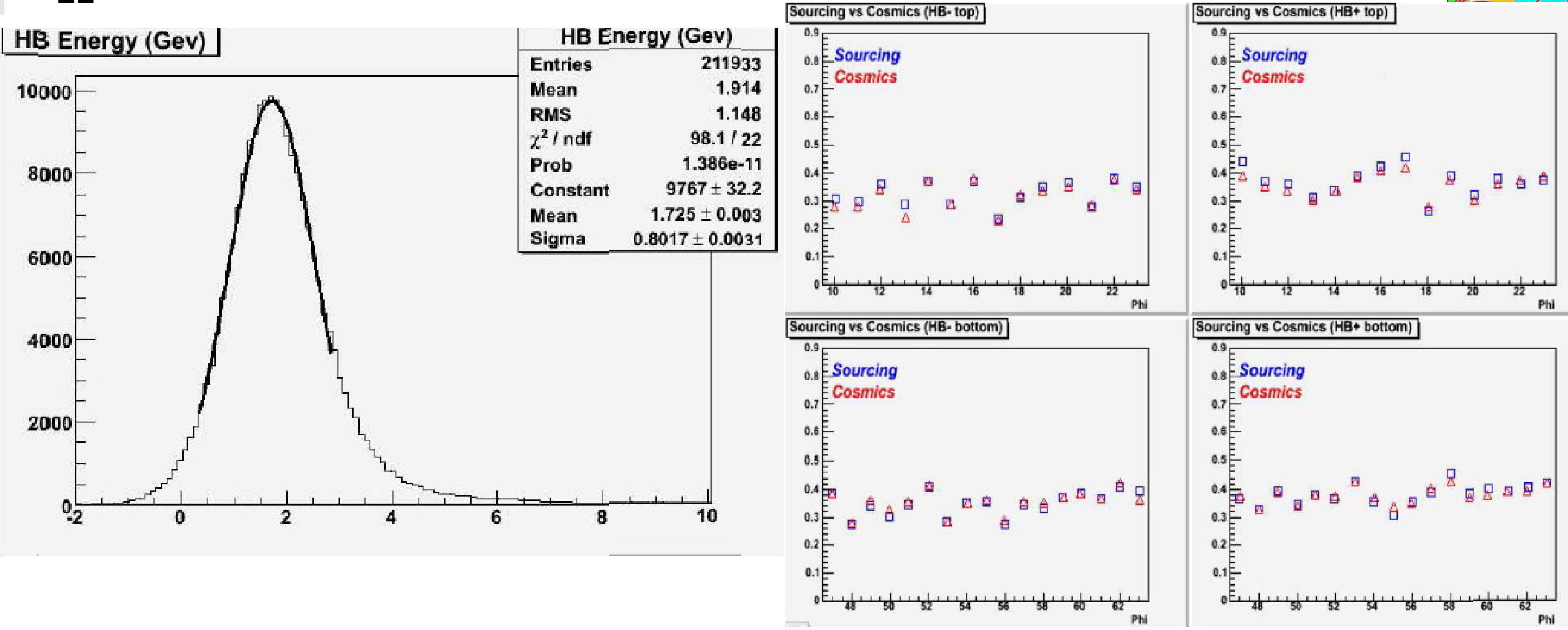
Energy Scale





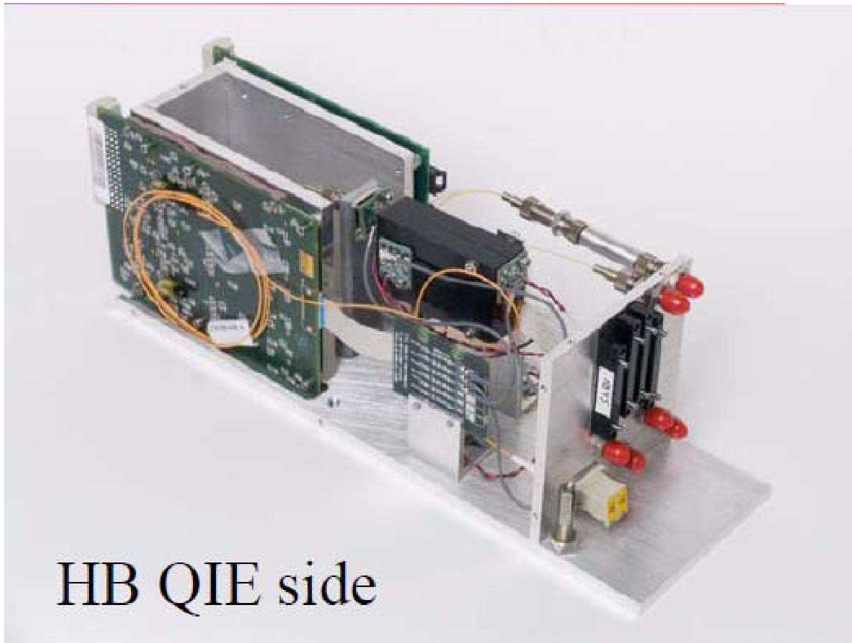
- Fit the energy profile with a Gaussian to get the mean energy and find a scale factor to match the energy to beam energy
- The calorimeter system is strongly non-linear and there is also some particle type dependence
- Choose 50 GeV π^- beam to make the final energy scale

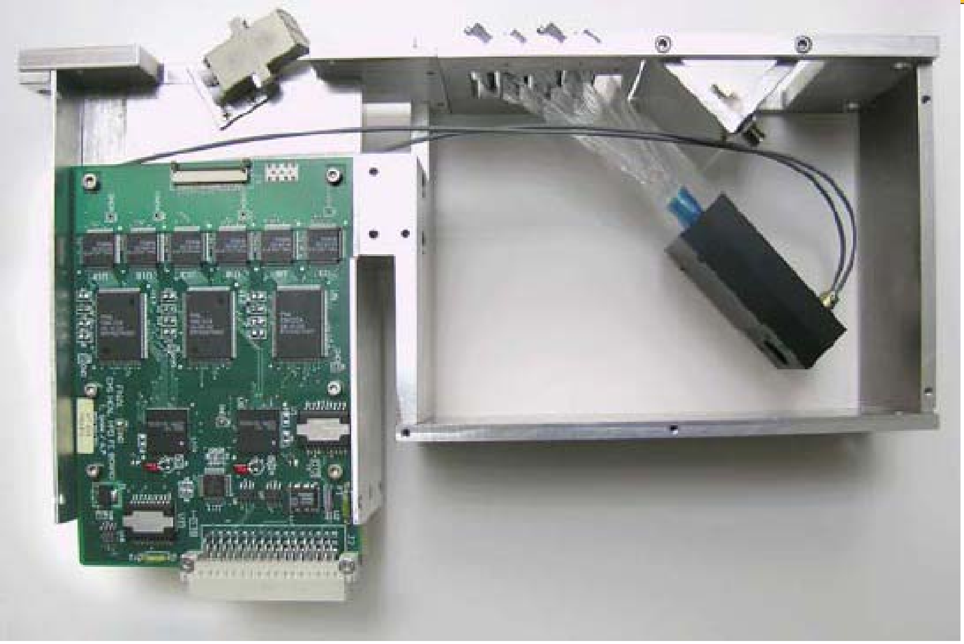
Pre-Commissioning Runs



- Energy scale was verified prior to commissioning runs using Cosmic data and splashes of the LHC beams
- Good agreement is observed between Cosmic and Sourcing data

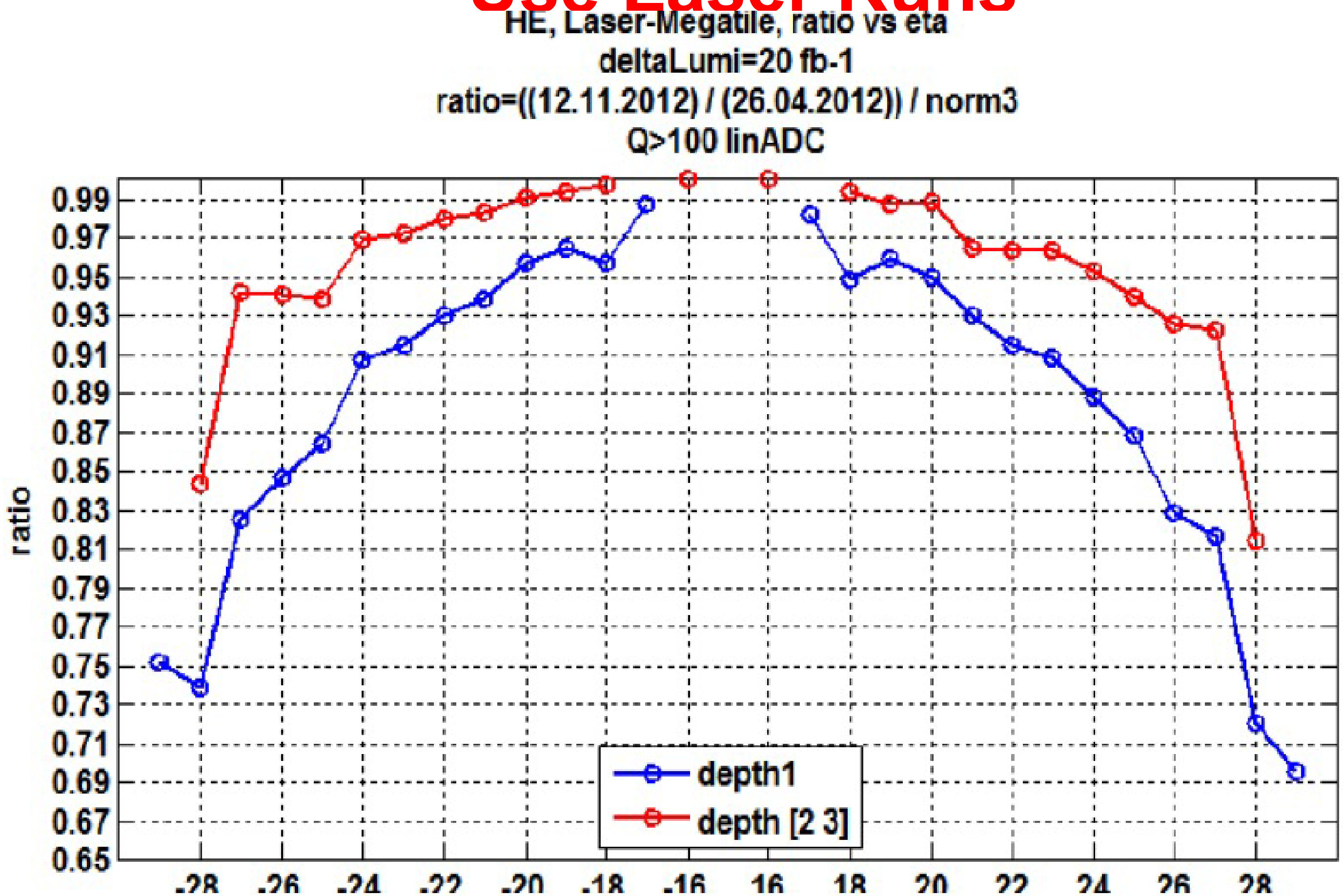
Calibration Modules





- One quartz fibre per φ-segment bring in a pulse from a nitrogen laser system. It is fanned out to every tile by 200 μm quartz fibre.
- In decoder box both the laser and the LED are used to excite Y11 wave shifter. From the wave shifter, quartz fibre feed each pixel of the photo-detector.
- Laser pulse also excites scintillator of a particular layer so each tower receives a signal.

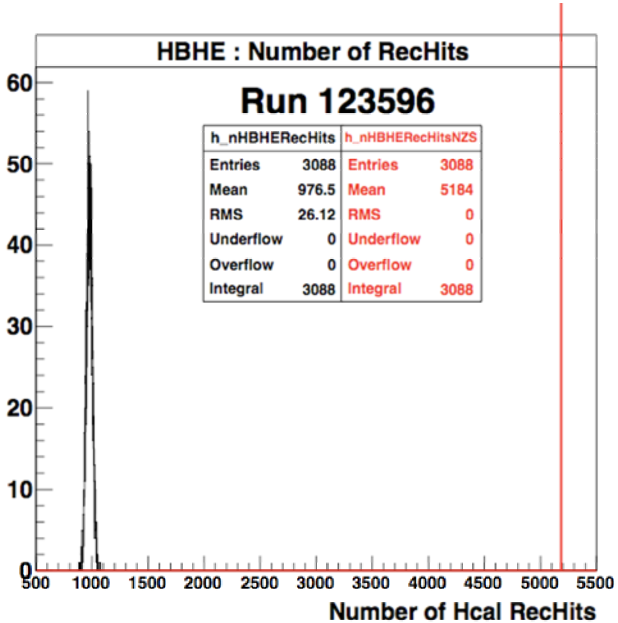
Use Laser Runs

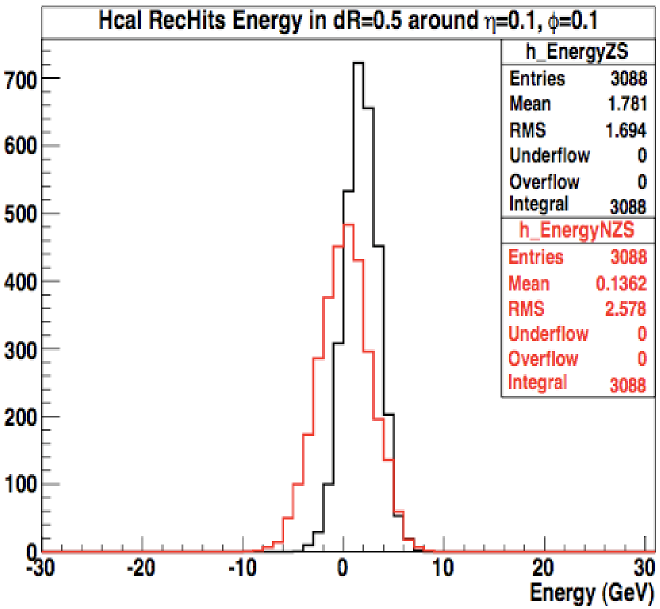


- There is degradation of the HPD as well as radiation damage of the scinitllator+wave shifter fibres, The two can be dis-entangled.
- L1 trigger needs some calibration results presented in the form of look-up table (LUT) which takes care of gain variation as well as absolute calibration

Zero Suppression in HCAL readout

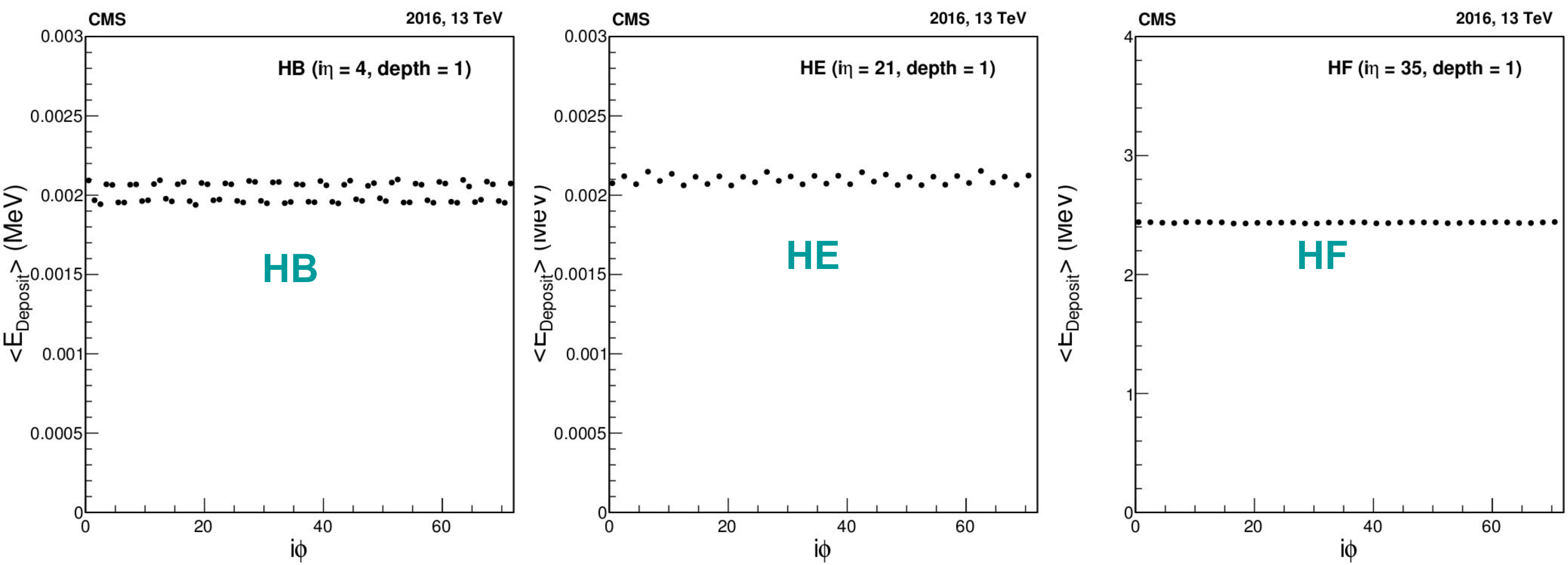
- Zero suppression in HCAL makes a significant bias to the mean energy response of low energy particles. This necessitates NZS HCAL events to determine single particle response for particles of energy below 10 GeV.
- Every 4096th L1Accept is taken with NZS HCAL and two HLT paths with selection on specific L1Triggers feed HcalNZS primary dataset.
- At reconstruction time, every HCAL Digi is flagged with an information if it would have been ZeroSuppressed online or not → ZsMark&Pass.
- By default, all the Digis which are marked as "ZsMark&Pass" are dropped and corresponding RecHits are not made. All the higher level processing (HLT etc) should be same whether the HCAL channels are ZS or NZS.





φ Symmetry in HCAL

- Though the detectors are made in symmetric modules, the support structure made some staggering between alternate layers
- This has created small asymmetry – this is ignored for inter-channel calibration



φ-Symmetry

- Taking advantage of the azimuthal symmetry of the detector, inter-calibration is performed by comparing the average energy deposit in a calorimeter cell to the mean of the average energy distributions in the entire η-ring (cells same iη).

- There are two possible approaches to obtain correction coefficients using minimum bias events and the azimuthal symmetry of HCAL:

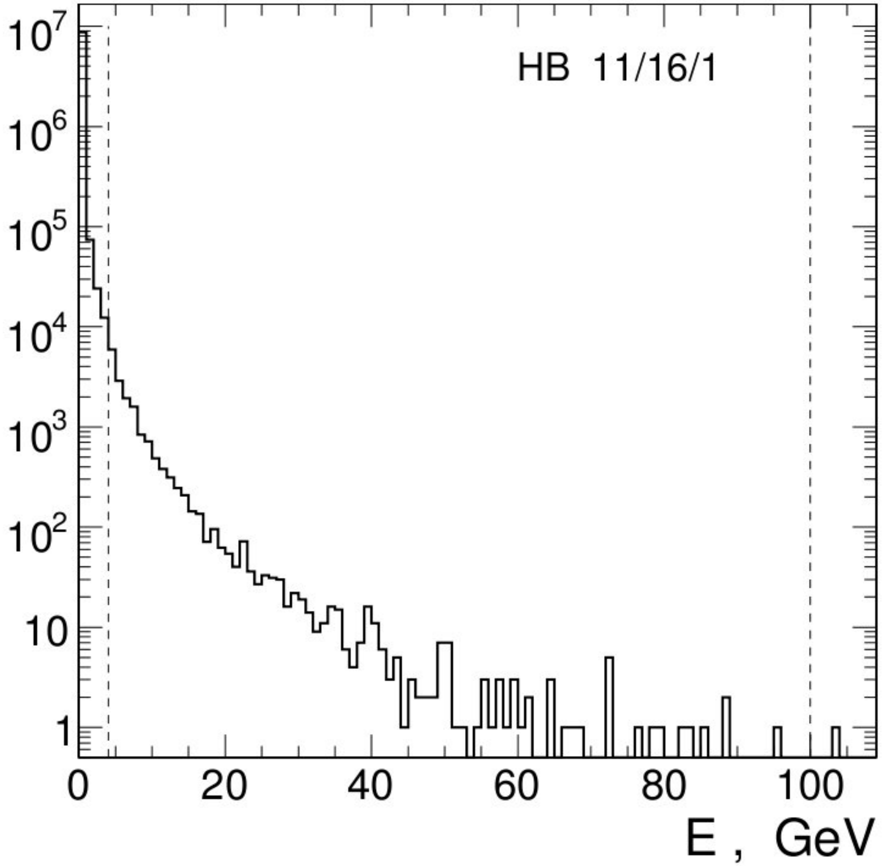
  - Direct comparison of the mean deposited energy in the cells after noise subtraction. The uncertainty on the estimation of coefficients is dominated by uncertainty on the noise estimation. Need very large samples for better precision.

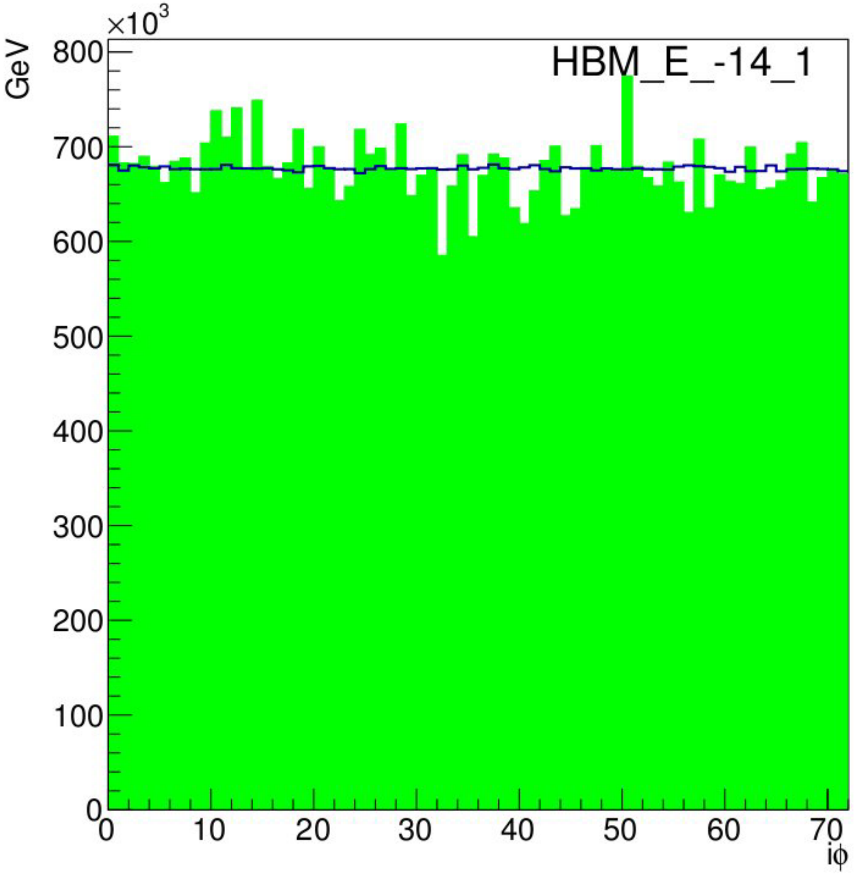
$$Corr_{i\eta,i\varphi} = \frac{\langle E_{i\eta,i\varphi} \rangle}{\left({}^{1}\!/\!{}_{N_{i\varphi}} \times \sum_{N_{i\varphi}} \langle E_{i\eta,i\varphi} \rangle \right)}$$

$N_{i\varphi}$ is the number of HCAL cells in an iη ring and $\langle E_{i\eta,i\varphi} \rangle$ is the mean energy deposition in the HCAL cell.

Iterative Approach

- In the first approach, all events triggered by non-HCAL signals are considered
- Hits in certain energy region are considered to avoid noise
- Hit energy is re-calculated with the correction factors in a given iteration and the process is repeated till it converges





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φ-Symmetry

- The second approach relies on noise removal through subtracting the variance of noise from the variance in the measured energy. This method requires substantially smaller samples but it is still sensitive to the noise level in a channel. For noisier channels we need larger statistics.

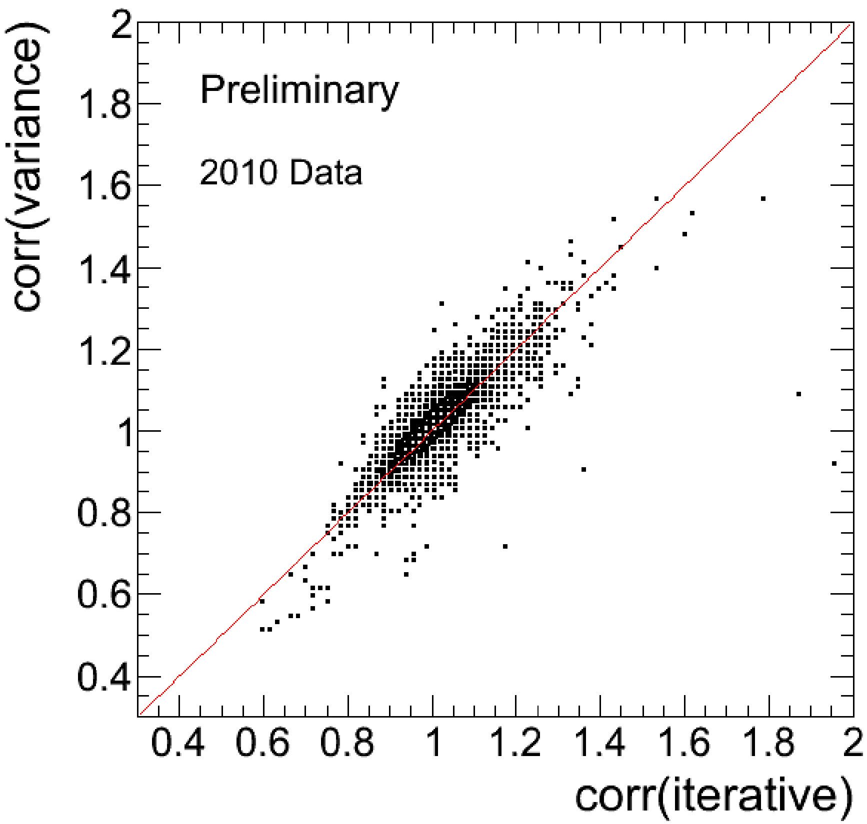
$$Corr_{i\eta,i\phi} = \sqrt{\left\langle \Delta^2 R_{i\eta,i\phi} \right\rangle \Big/ \left(1/N(i\eta) \times \sum_{N_{i\phi}} \left\langle \Delta^2 R_{i\eta,i\phi} \right\rangle \right)}$$

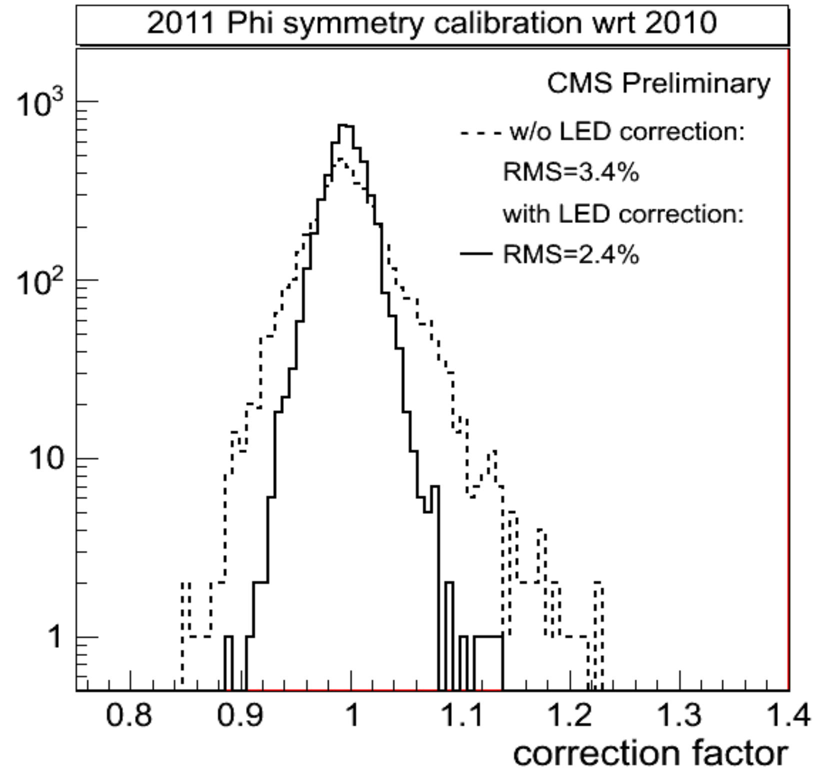
where

$$\Delta^2 R_{i\eta,i\phi} = \left\langle \Delta^2 \left(E^{signal}_{i\eta,i\phi} \right) + \Delta^2 \left(E^{noise}_{i\eta,i\phi} \right) \right\rangle - \left\langle \Delta^2 \left(E^{noise}_{i\eta,i\phi} \right) \right\rangle$$

- Due to the small expected signal and the requirement of no correlation between signal and noise, the calibration data has to be collected with no zero suppression (NZS) of the HCAL readouts.
- A special HcalNZS stream is used to collect a fraction of all Level 1 accepts events for calibration needs.

Earlier Calibration



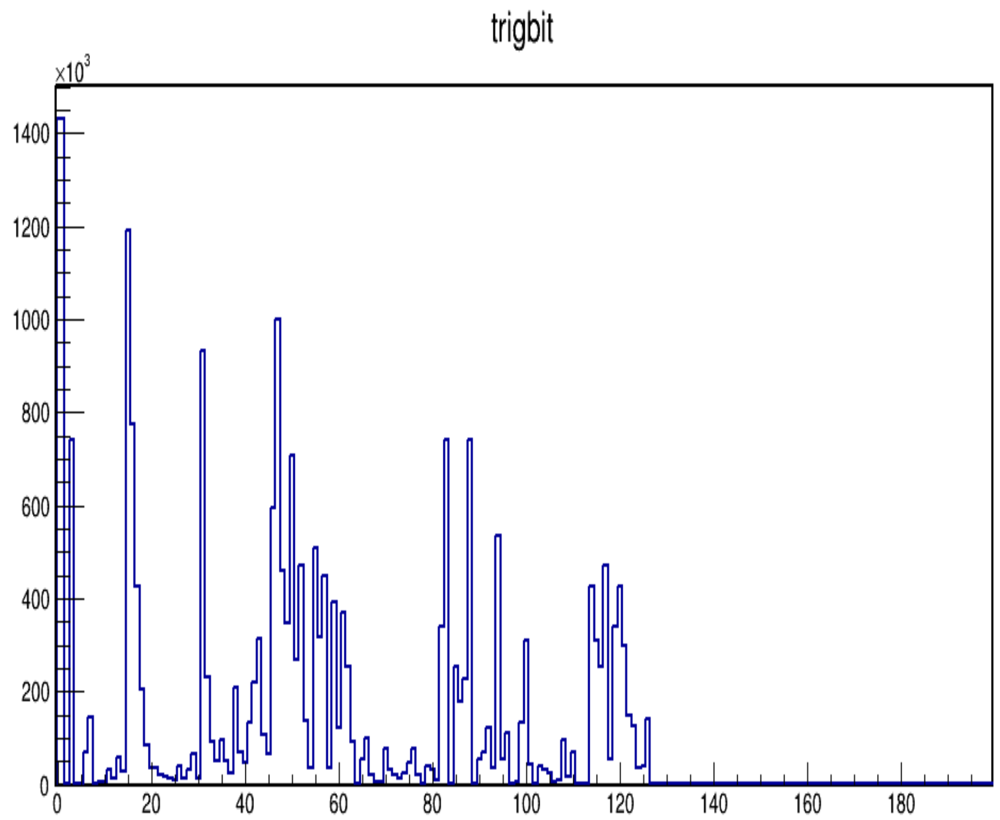


- ❑ Results from the two methods agree quite well
- ❑ Use of LED monitoring data is very useful in improving the resolution

Optimization of Triggers

- One important aspect is to find which triggers among all the L1A will be useful for this study
  - Decide on the basis of statistical uncertainty

NZS sample used:
/HcalNZS/Run2012C-v1/RAW



Useful Triggers

- Common (for iη 1, 5, 14, 24) fired nonHCAL L1 trigger names with stat. error < 0.15 :

L1_ZeroBias (bit 0)

L1_ZeroBias_Instance1 (bit 1)

L1_SingleEG7 (bit 31)

L1_SingleEG5 (bit 47)

L1_SingleEG18er (bit 48)

L1_SingleEG22 (bit 49)

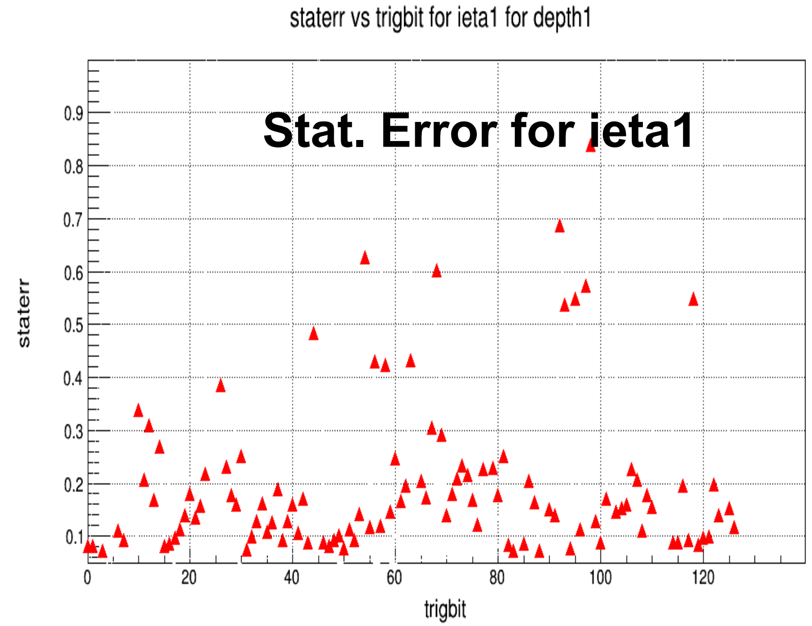
L1_SingleEG12 (bit 50)

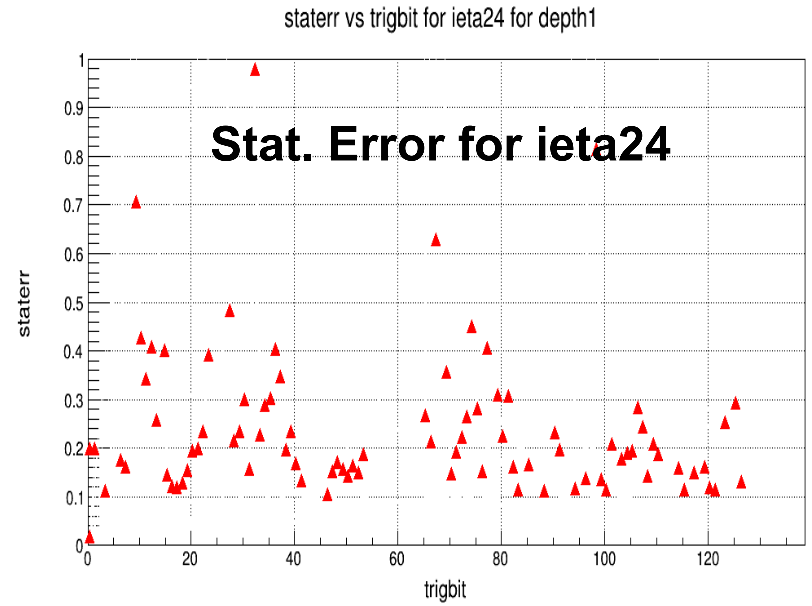
L1_SingleEG20 (bit 52)

L1_DoubleEG5 (bit 82)

L1_SingleEG20_RomanPotsOR (bit 117)

L1_DoubleEG5_RomanPotsOR (bit 119)





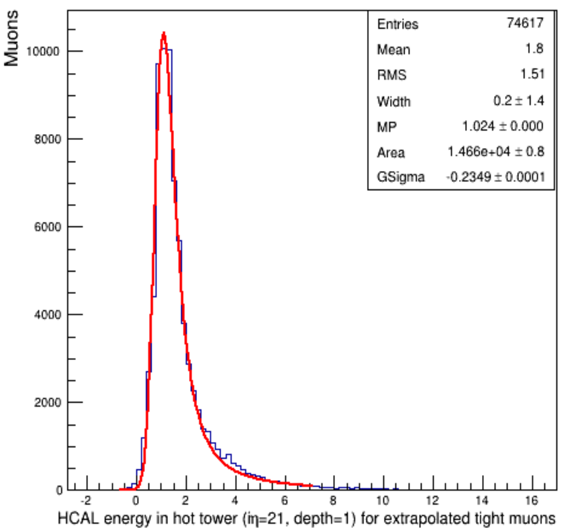
Studied with the L1 menu for Run2

Study Using Muons

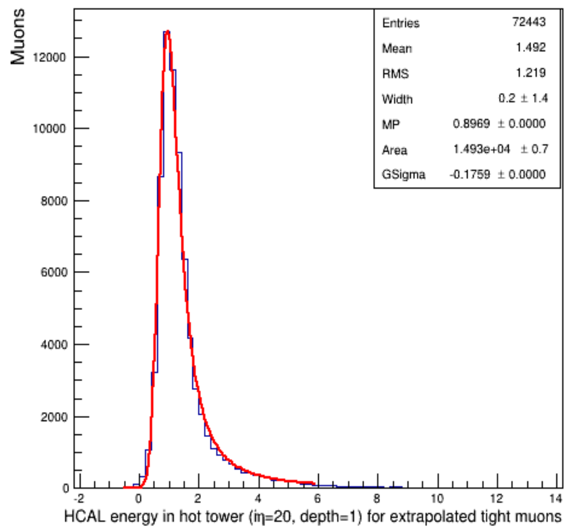
- Propagate well measured muon tracks to the surface of ECAL and HCAL.
  - Particle Flow and Global Muon.
  - Muon $p_T > 20$ GeV.
  - χ^2/ndof of the global-muon track < 10.
  - At least one muon chamber hit included in the global-muon track fit.
  - Muon segments in at least two muon stations.
  - $d_{xy} < 2$ mm wrt the primary vertex.
  - $d_z < 5$ mm wrt primary vertex.
  - Number of pixel hits > 0.
  - Cut on number of tracker layers with hits > 5.
- Measure energy deposited in 1x1 cell around the impact point of track in HCAL as a signal.
- These 1x1 cells are required to be the highest energetic (hotCells) in 3x3 cells.
- Fit the energy distribution to a Gaussian-Landau function to get the most probable value for each iη and depth

Energy Deposition in HB/HE layers

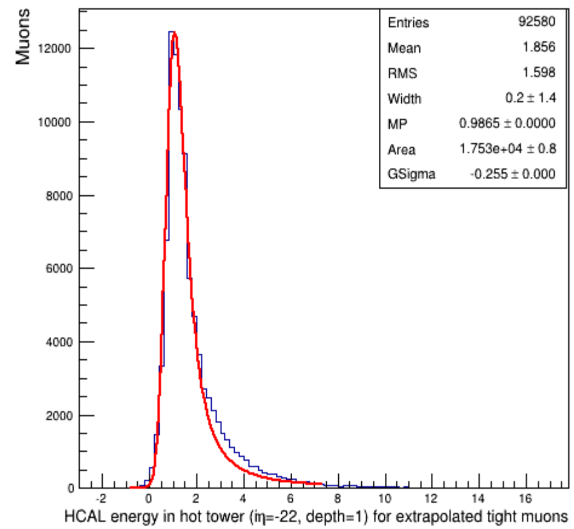
- Use SingleMu datasets from 2012 data
- The dataset is divided into luminosity blocks of 0.5-1 fb^{-1}
- Energy deposition distributions show landau tail.



(iη,dep) (21,1)

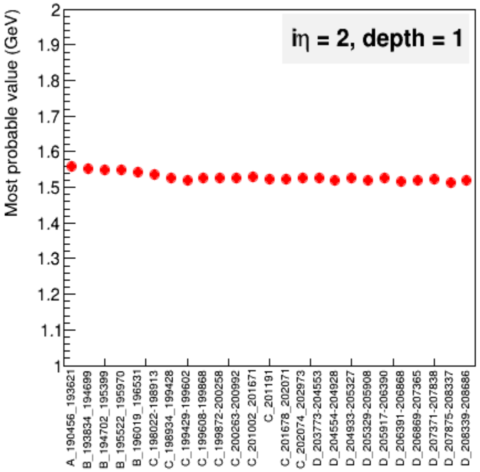


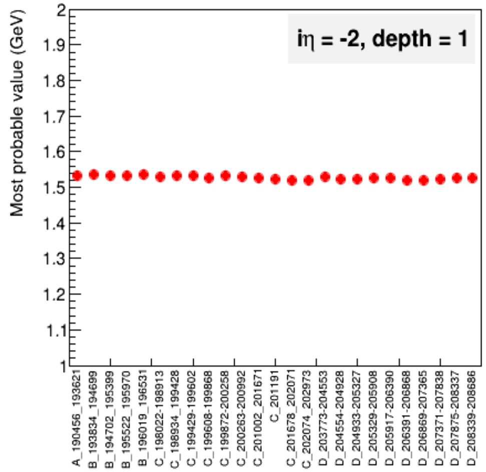
(iη,dep) (20,1)



(iη,dep) (-22,1)

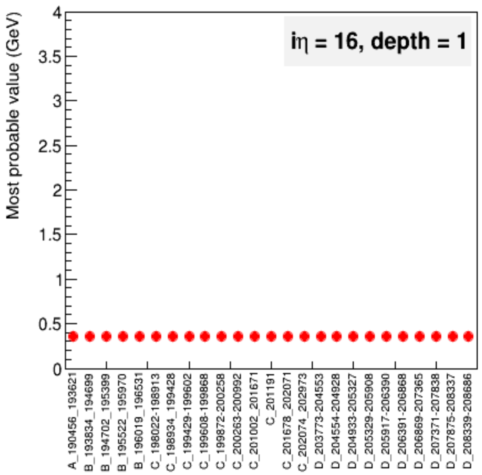
HB Layers

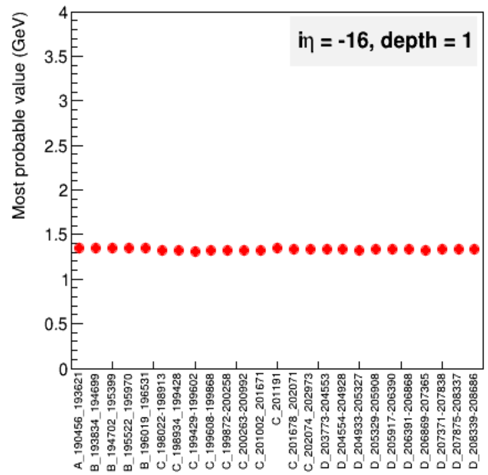




Variation of energy with Run-Numbers (|iη|,depth) = (2 , 1)

(energy deposition remains same)

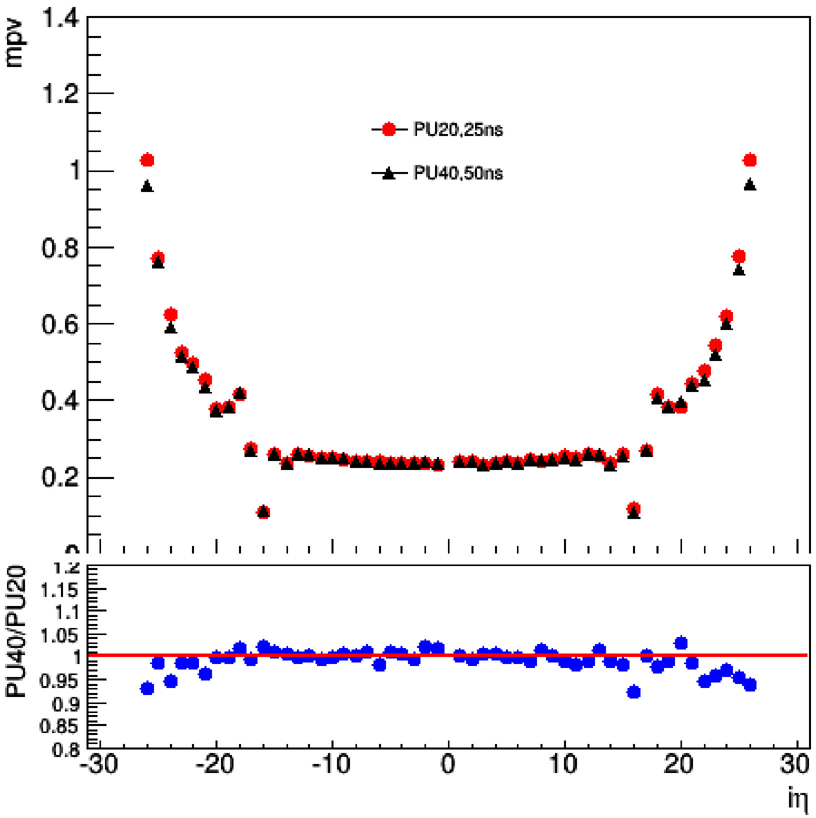


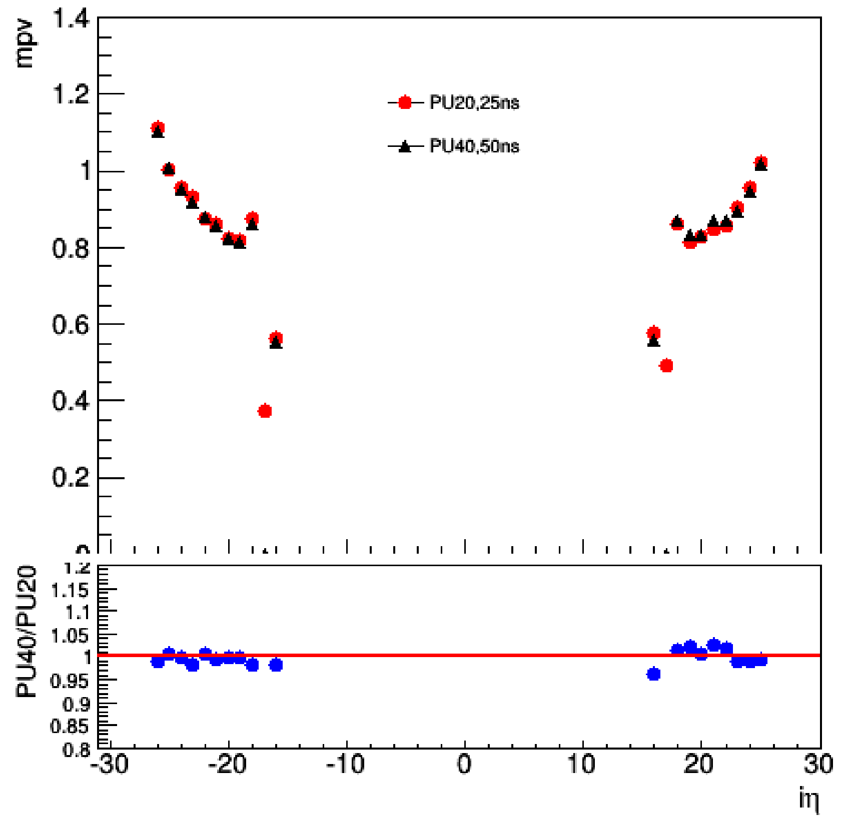


Variation of energy with Run-Numbers (|iη|,depth) = (16 , 1)

(energy deposition remains same)

Sensitivity to Pile-Up

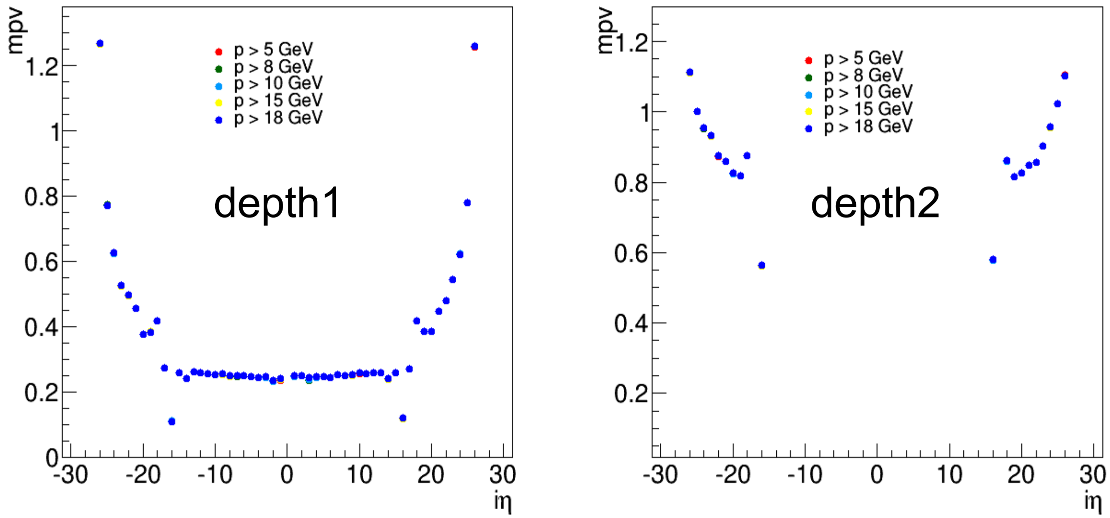




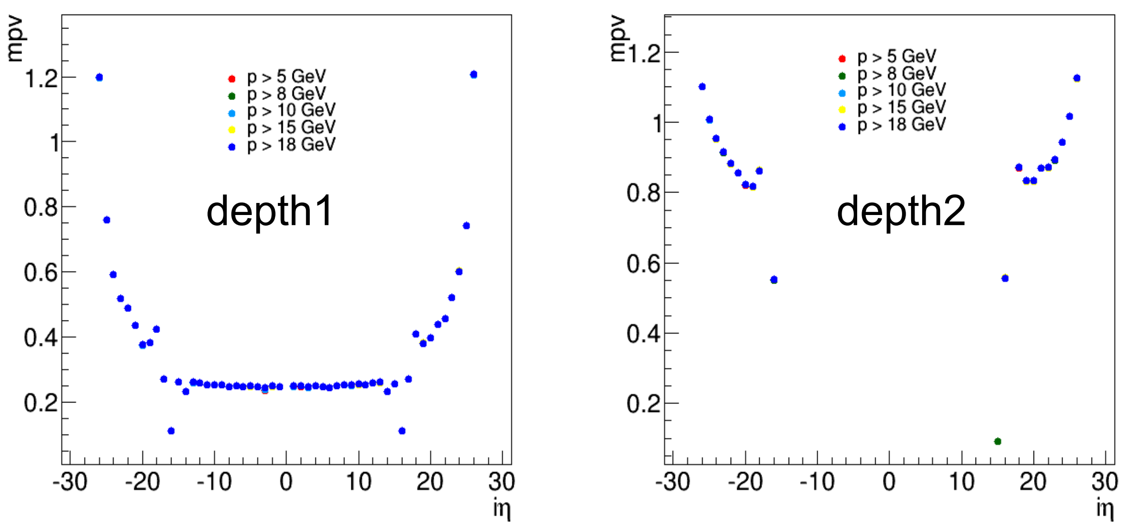
- Use two Drell Yan Monte Carlo data sets for Run 2 scenario (PU20 @ 25ns and PU40 @ 50ns)
- Variation of most probable value of energy deposited (path-length corrected) in a particular iη. The energy deposition remains nearly same for both scenarios
- However with higher pileup condition shows significant dependence

Momentum dependence

PU20 @ 25ns Bx



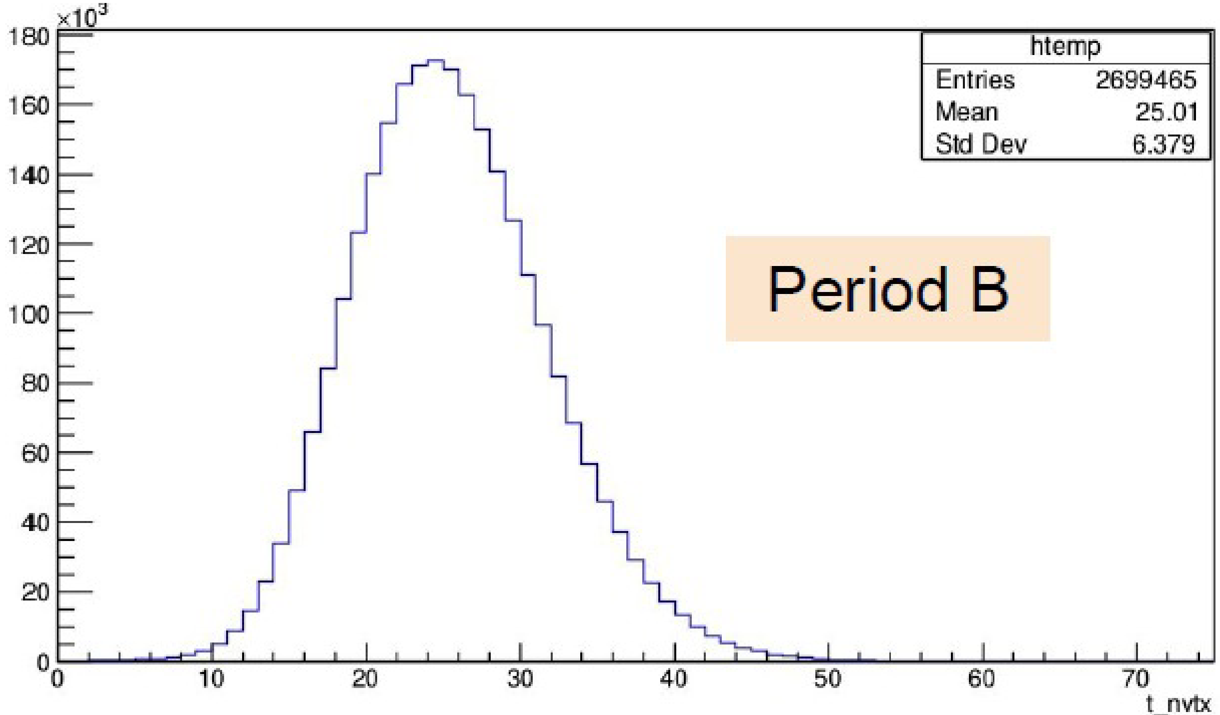
PU40 @ 50ns Bx



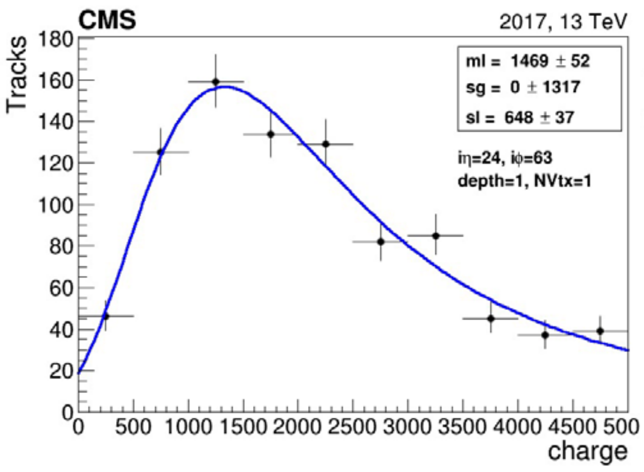
- Variation of most probable value of energy with iη for different p bins (p > 5,8,10,15,18 GeV)
- Energy deposited per path-length remains same for all momentum bins

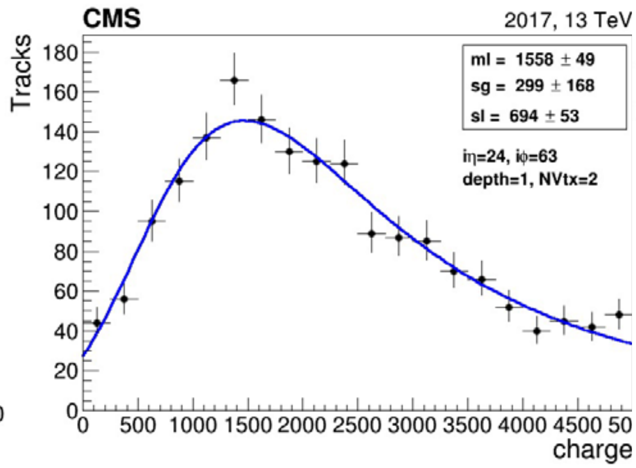
New Look into Muon Signal

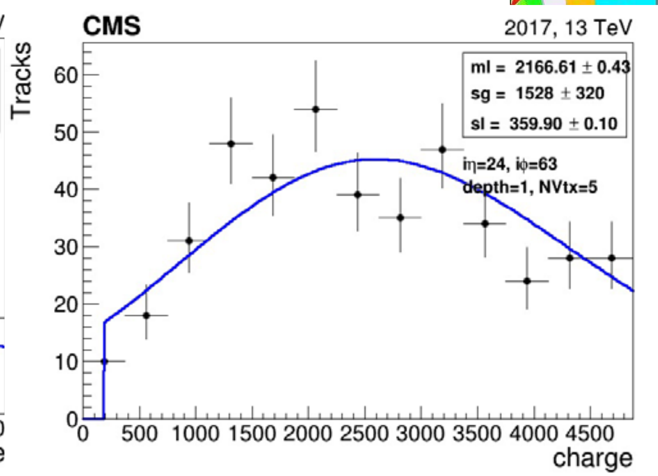
- Pile-up makes some impact on the signal
- This is more prominent in the endcap and in the front layers
- With finer depth segments in HEP17 it was possible to take a look into this
- During 2018, mean # of primary vertex (a measure of PU) increased from 25 in Period B to 38 in Period F.
- So it is worthwhile to take a look into this



Correction due to Pile Up

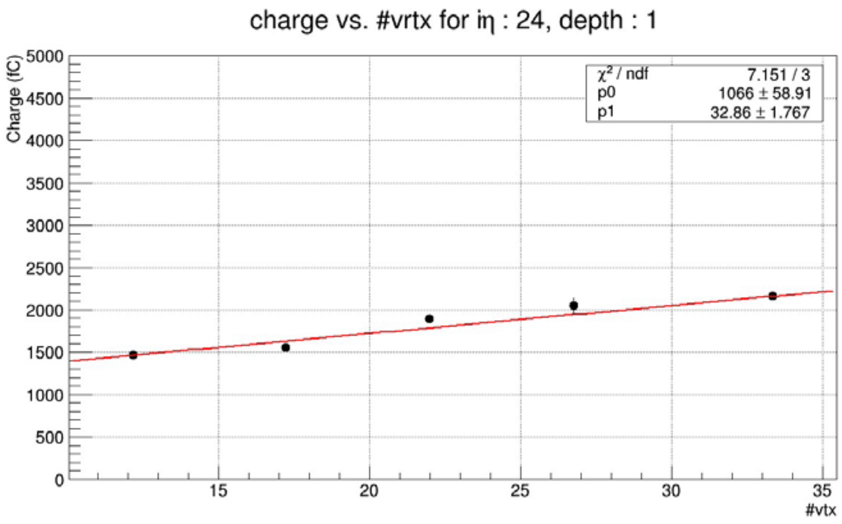






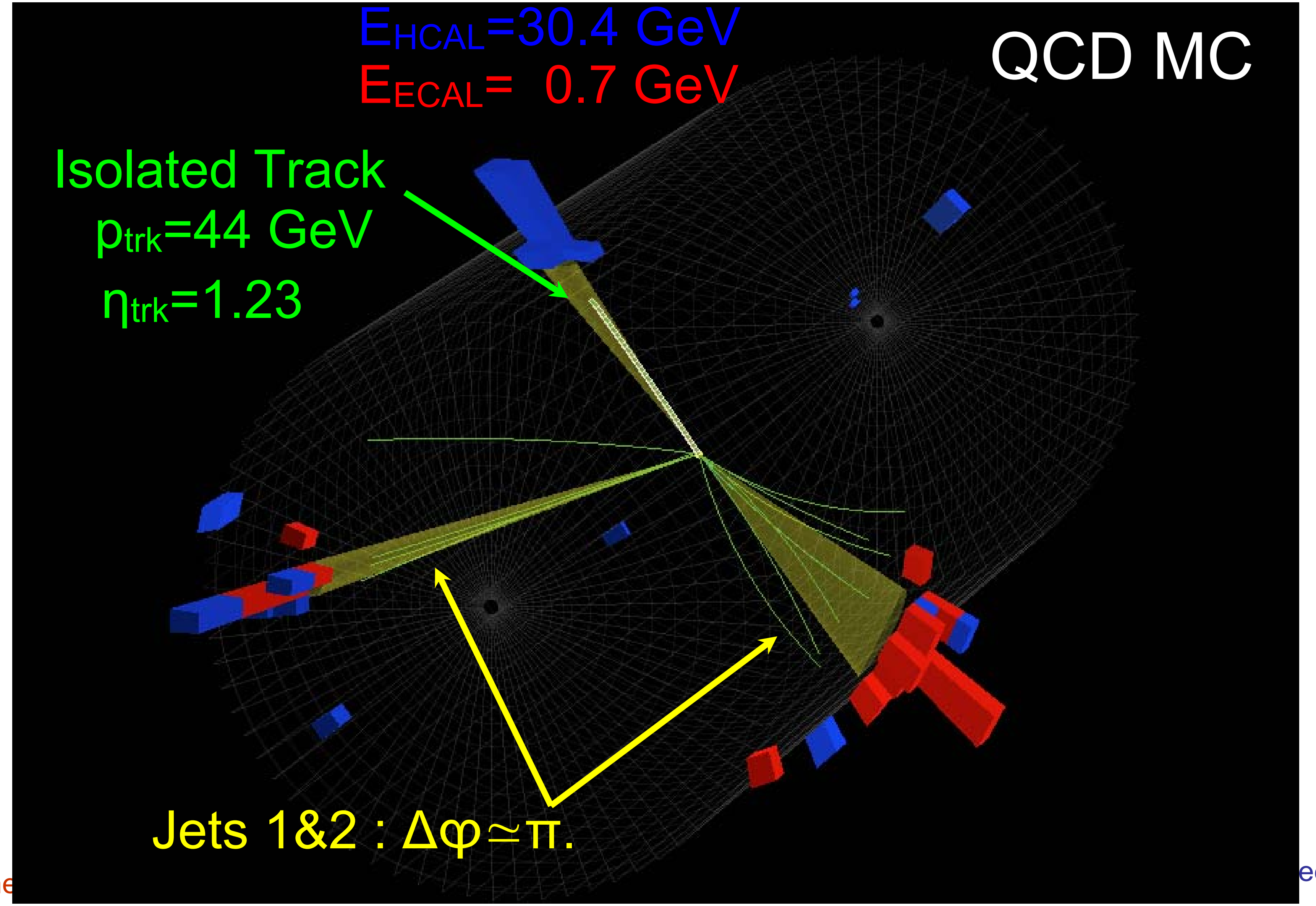
Charge distriution due to muon in iη=24 depth=1 in different bins of N_{vtx}

- The peak position shifts as a function of # of vertex
- Extrapolate MPV to N_{vtx} = 1 giving PU corrected value



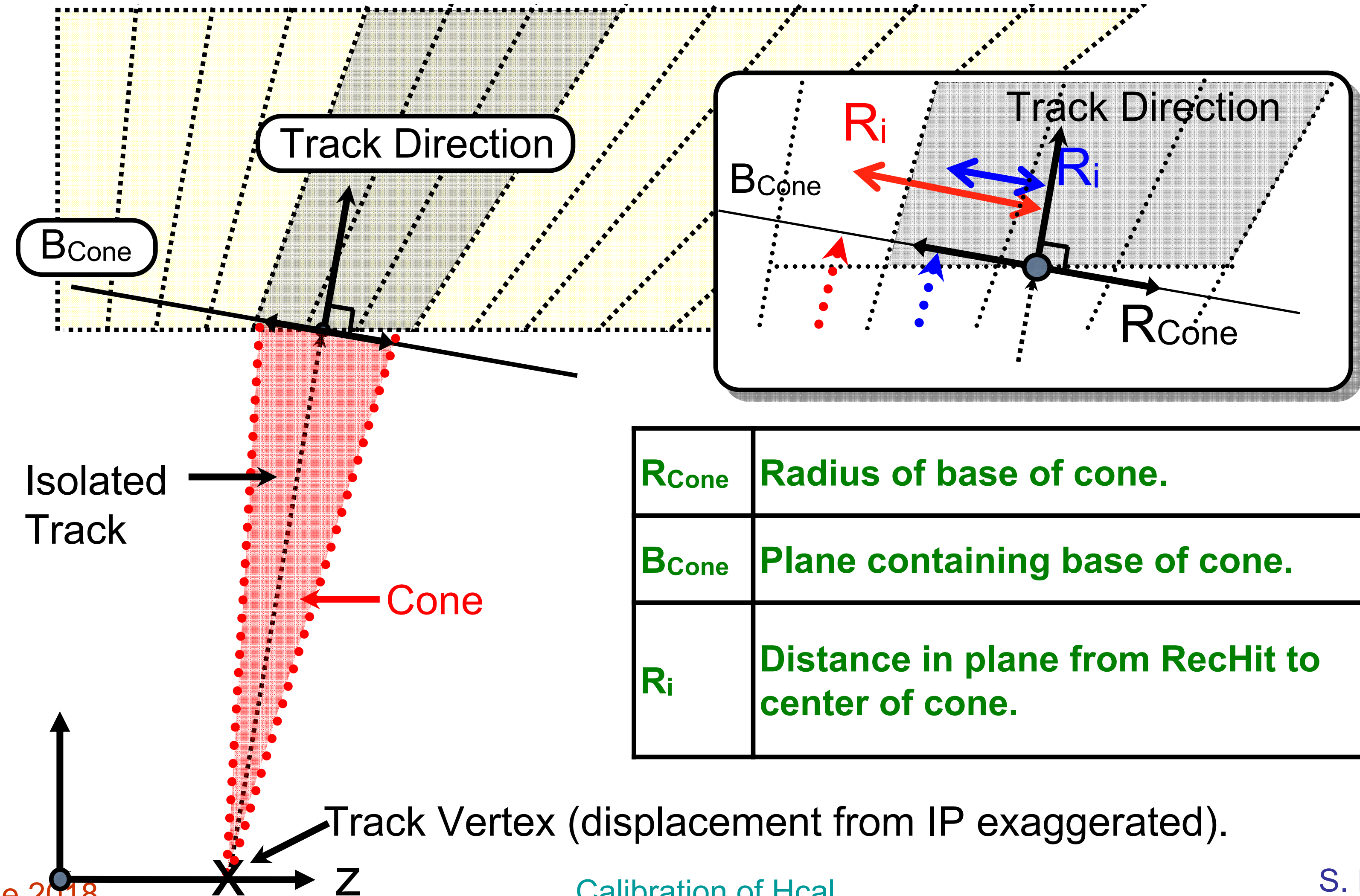
Use of Isolated Charged Hadrons

Use isolated charged particles from LHC collision data:



Selection of High Energy Tracks

- Cone algorithm: Include i^{th} RecHit if $R_i < R_{Cone}$.
- Now implemented in Analyzer.



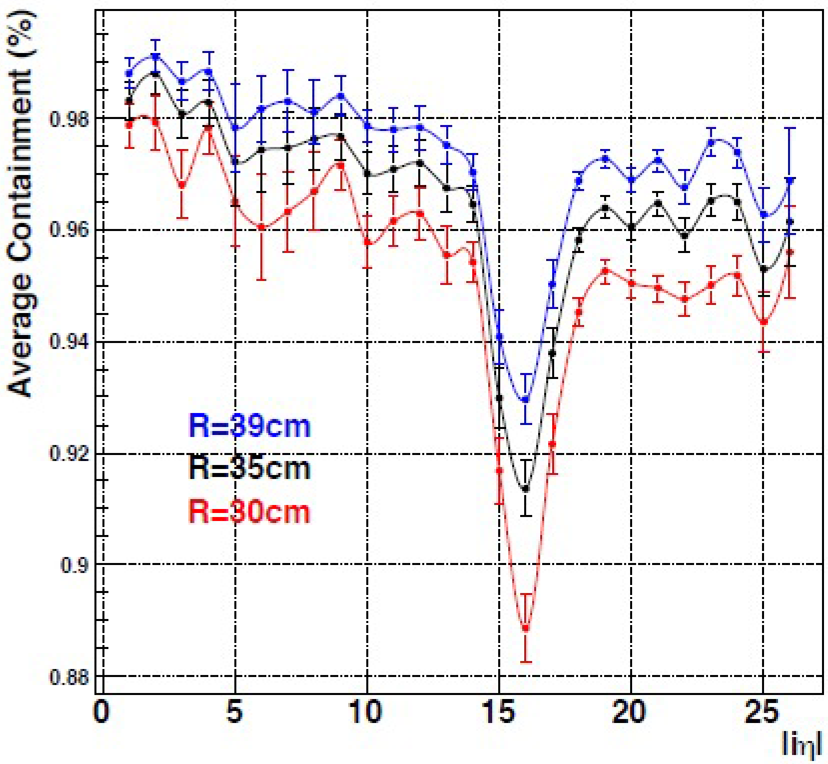
R_{Cone}	**Radius of base of cone.**
B_{Cone}	**Plane containing base of cone.**
R_i	**Distance in plane from RecHit to center of cone.**

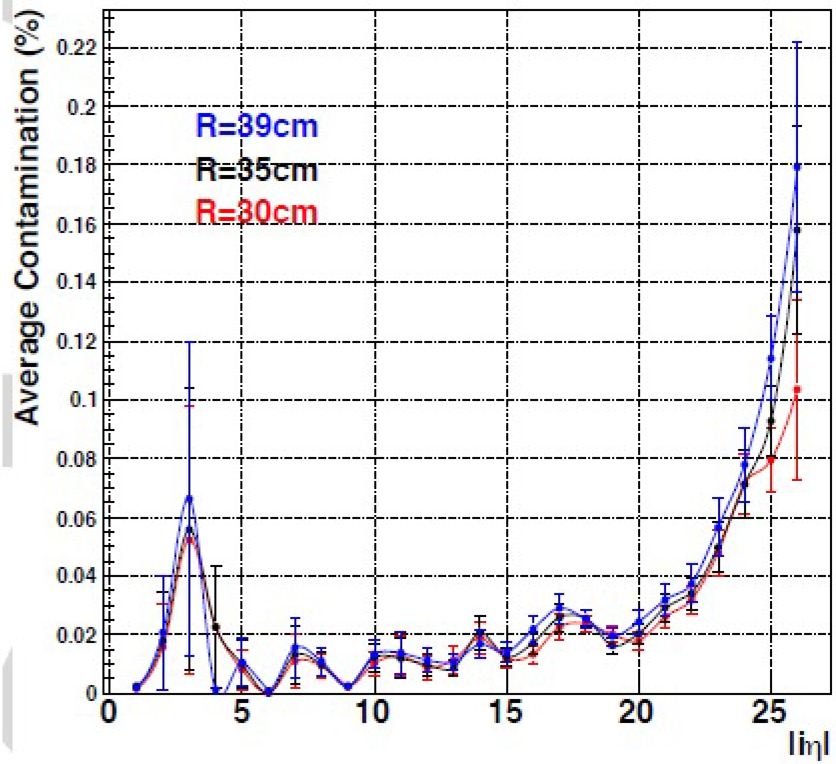
Selection Criteria

Motivation	Cut
Track Quality	highPurity tag, # tracker layers with hit > 8, Track reaches Hcal (p_T > ~1 GeV)
Track Momentum	40 < p < 60 GeV
MIP in Ecal	0.001 < (E in 3x3 Ecal Cluster) < 0.8 GeV
Charge Isolation	No highPurity tracks with p > 2 GeV && No tracks crossing > 4 layers with p > 2 GeV in isolation radius.
Neutral Isolation	Energy in isolation ECAL annulus below threshold.
HLT	Passes HLT_IsoTrackHB/HE
Distance From Lead Jet	ΔR from lead jet > 1.2

- $R_{iso} = R_{Cluster} + 28.9$ cm.
- E_{Ecal} threshold scales with area of isolation region.

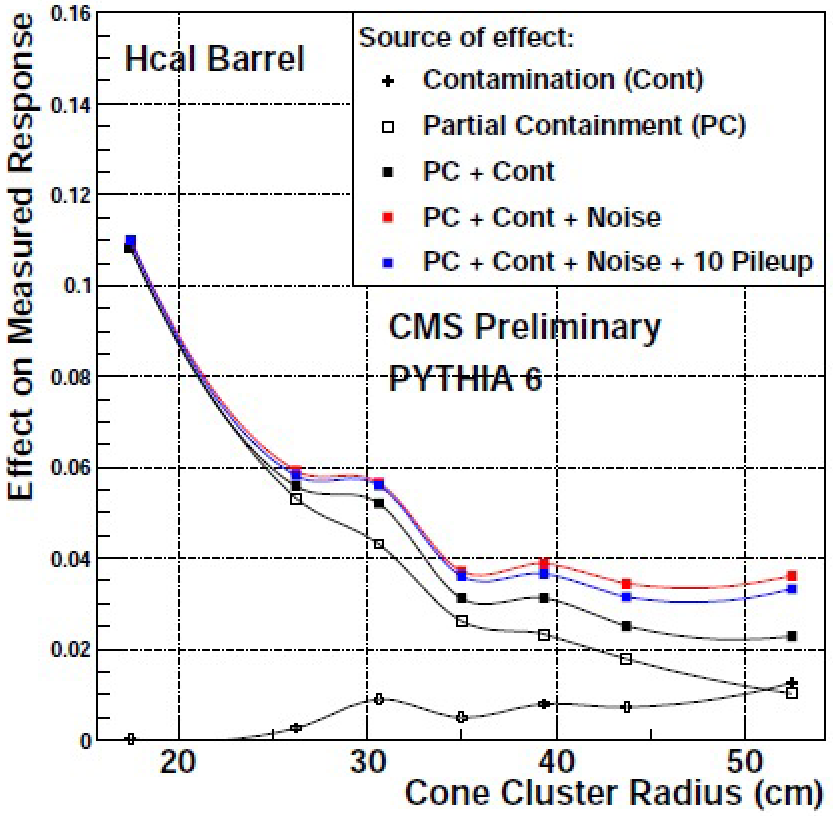
Optimization of cone size

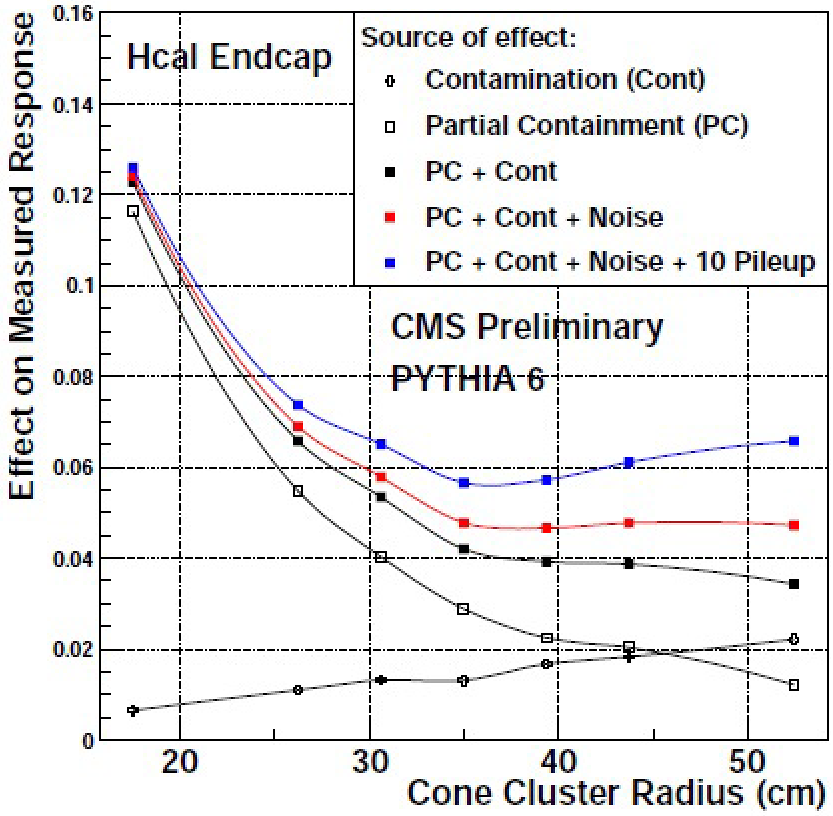




- Propagate charged particles to the HCAL surface
- Measure energy in a cone around the track direction
- Optimize the cone size to maximize containment and minimize contamination

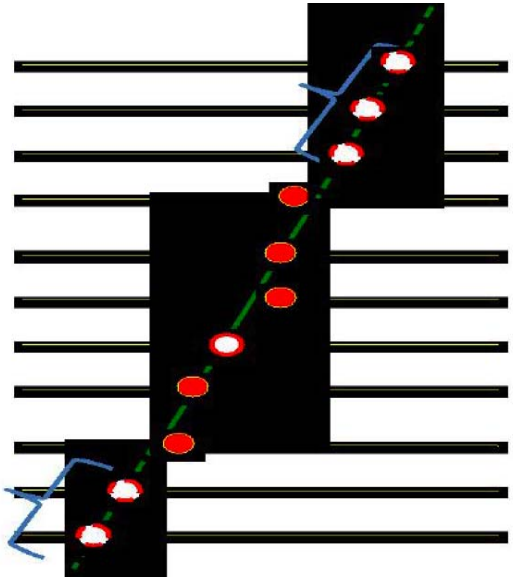
Systematic Uncertainty





- Systematic effect studied with different running condition
- The optimized cone size is used in the final calibration process

2012 Data



- Selection of good charged tracks
  - – p_T > 10 GeV/c
  - – Chi-square < 5.0
  - – Number of layers crossed > 8
  - – $\Delta p/p < 0.1$
  - – No missed hits in inner/outer layers
  - – Track should originate close to primary vertex
  - – Track should reach the HCAL surface
- Track isolation
  - – Propagate the track to the HCAL surface and find the highest momentum track within a cone of 63.9 cm around the impact point. If this is > 2 GeV, reject the track.
  - – Measure energy in the ECAL within a cone of 14 cm around the impact point of the track on the ECAL surface. Cut is < 1 GeV.
  - – Should be away from the L1 object in a cone of $\Delta R = 1$.

2012 IsoTrack Calibration

- Match the Reco::tracks with trigger objects.
- Study the statistics after successive cuts.

	# Tracks(HB)	Efficiency	# Tracks (HE)	Efficiency
Level 3	936,902		1440681	
Good Tracks	211,375 (878,747)	0.229 (0.014)	159,078 (1,861,508)	0.112 (0.016)
Charge Isol.	109,984 (28,865)	0.520 (0.033)	47,178 (47,223)	0.297 (0.035)
MIP Cut	17,171 (5,123)	0.156 (0.178)	8,048 (8,114)	0.171 (0.172)
Mom. Cut	12,728 (536)	0.741 (0.105)	6,927 (1,136)	0.861 (0.175)
L1 Assoc.	8,632 (182)	0.678 (0.340)	6,432 (162)	0.929 (0.143)

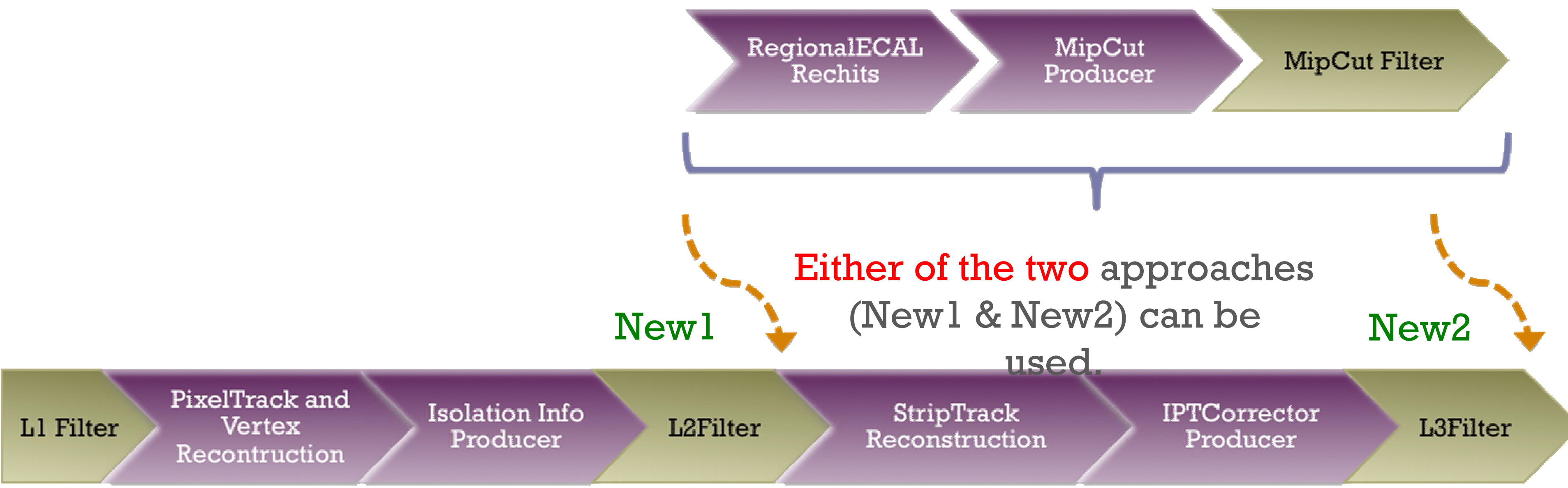
Statistics is insufficient for carrying out HCAL calibration.

Isolated Track HLT Paths

- Calibration of HCAL using isolated tracks is done using the data collected by dedicated isotrack triggers (HLT_isotrack_HB & HLT_isotrack_HE).
- Reconstruct tracks and propagate them to HCAL surface to examine isolation from charged particles
- Use Pixel Tracks at L2 level and strip reconstructed tracks at L3 level.
  - L2Filter : energy>12 GeV, ChargeIsol <2 GeV
  - L3Filter : energy>38 GeV, ChargeIsol <2 GeV, Δp_T > 5 GeV(L1)
  - Radius of cone for cluster measurement = 40 cms

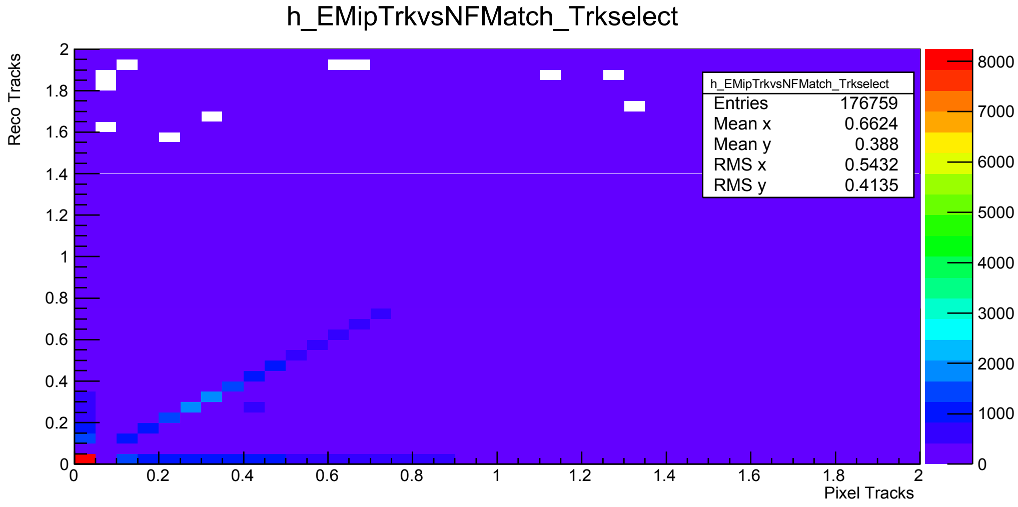
Possible Improvement to HLT

- Scenario 1 (Improved): A change in the coding of hltIsolPixelTrackProd (the producer just before L2 filter) to make it faster.
- Scenario 2 (New1): Add the Mip Cut filter just after L2 filter.
- Scenario 3 (New2): Add the Mip Cut filter just after L3 filter

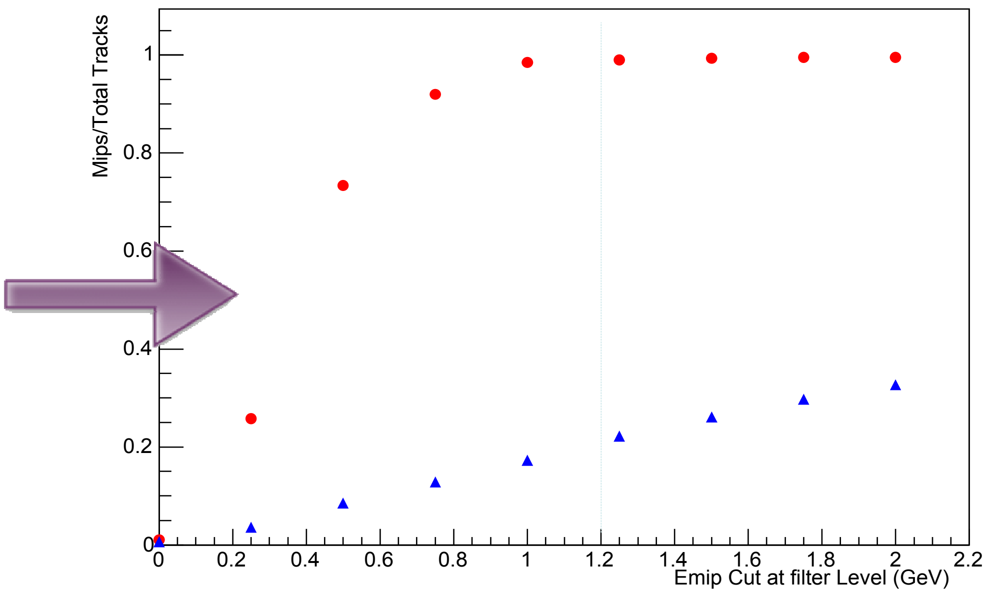


Optimizing Mip Cut at HLT

- ❑E_mip calculated at PixelTracks level is correlated to the E_mip at reco::track level.
- ❑The cut of E_mip for Pixel tracks is 2 GeV.

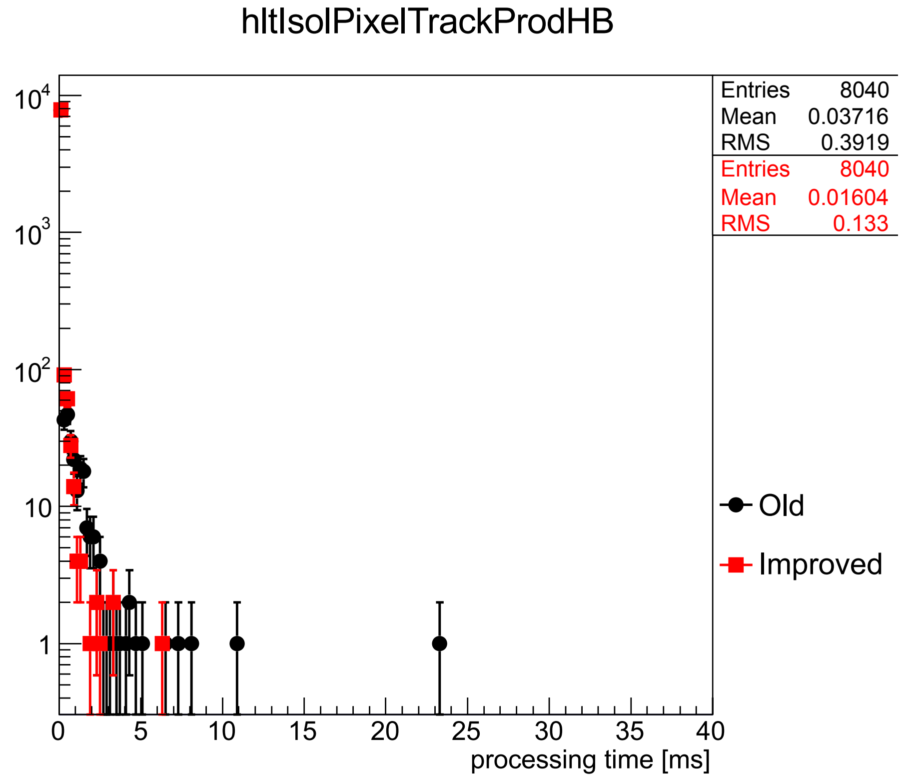


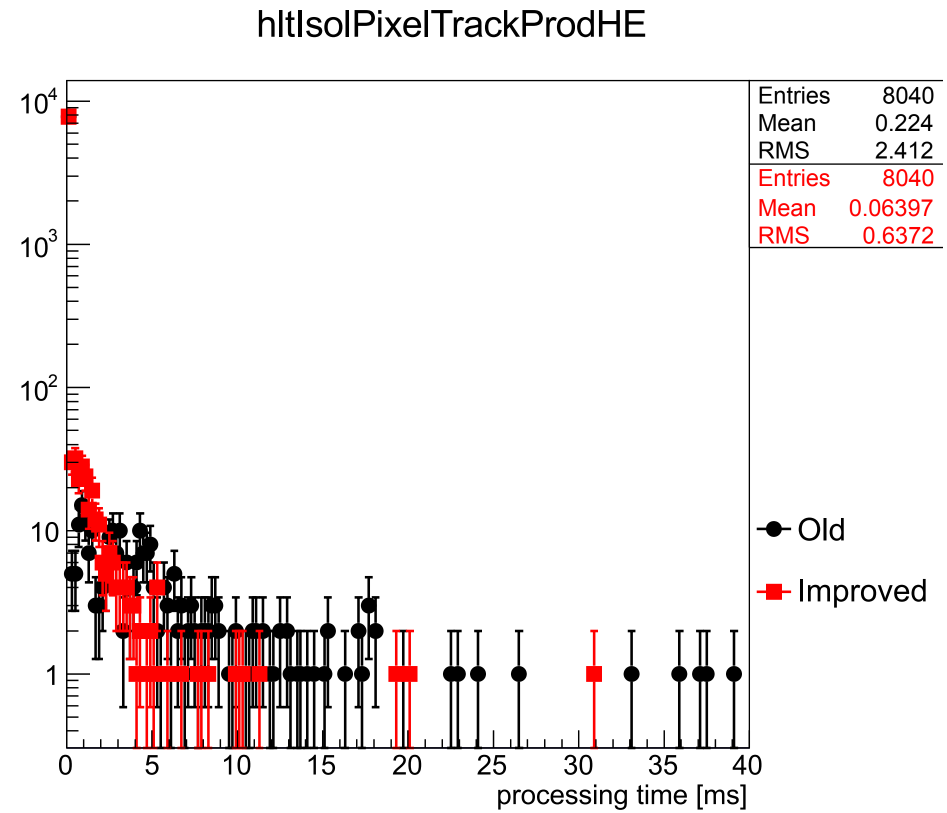
- ❑A Cut of ~1.2 GeV will remove large fraction of the bad tracks without deteriorating the efficiency.



Processing Time

Modified the producer before L2Filter to gain in time.





There is a tail in the timing plot (more for HE). This tail is investigated and is due to large number of PixelTracks. These events do not eventually provide any good isolated tracks at the offline stage. A simple filter can be made to remove this tail

Final calibration

- L3 Method: Iterative approach to find calibration constants for HB and HE readout channels.
- In every iteration, multiplicative factors are calculated by using all the isolated tracks in the sample as below

$$c_i^{(m+1)} = c_i^{(m)} \left(1 + \frac{\sum_j w_{ij}^{(m)} \cdot (p_j / E_j^{(m)} - 1)}{\sum_j w_{ij}^{(m)}} \right)$$

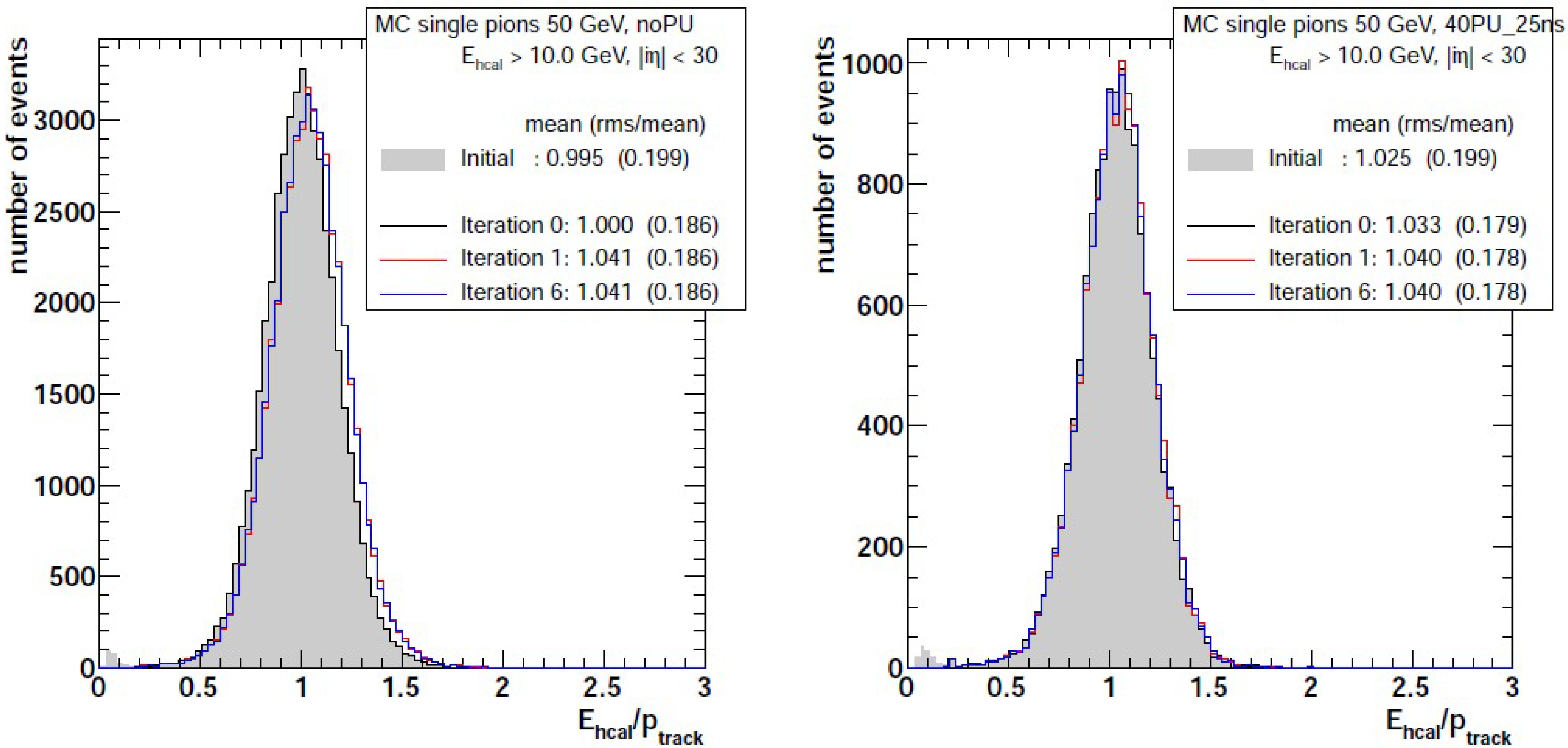
or

$$c_i^{(m+1)} = c_i^{(m)} \left(1 - \frac{\sum_j w_{ij}^{(m)} \cdot (E_j^{(m)} / p_j - 1)}{\sum_j w_{ij}^{(m)}} \right)$$

where $w_{ij}^{(m)} = \frac{e_{ij}^{(m)}}{E_j^{(m)}}$, and $E_j^{(m)} = \sum_i e_{ij}^{(m)}$

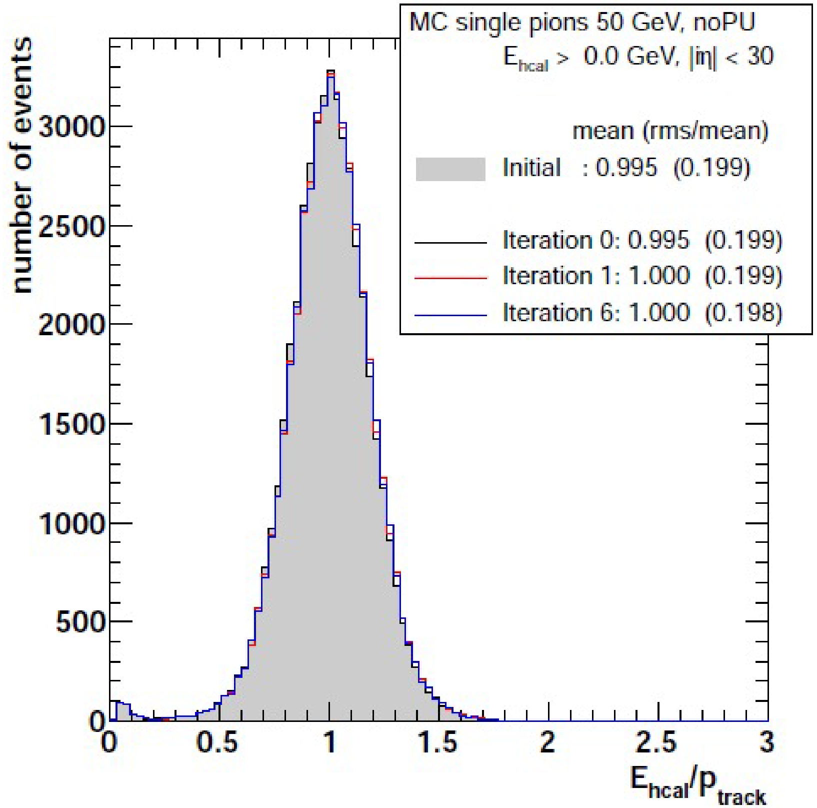
- The calibration constants converge after a number of iterations.
- Root tuple is created with information of track momentum, energy deposits and the corresponding DetId's in the cone for good isolated tracks
- The macro to carry out this iterative procedure is being written and it is being debugged

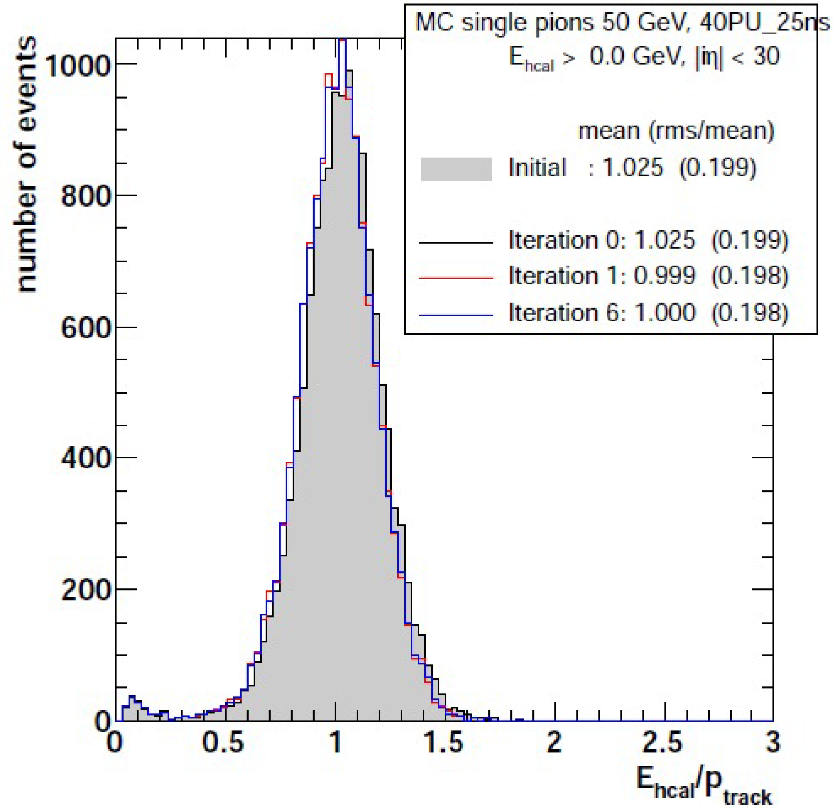
Single Particle (Method 1)



- Use single particle MC (π^- at 50 GeV) with two PU scenario
- Results converge within 5 iterations but there is a systematic shift of 4% irrespective of PU condition

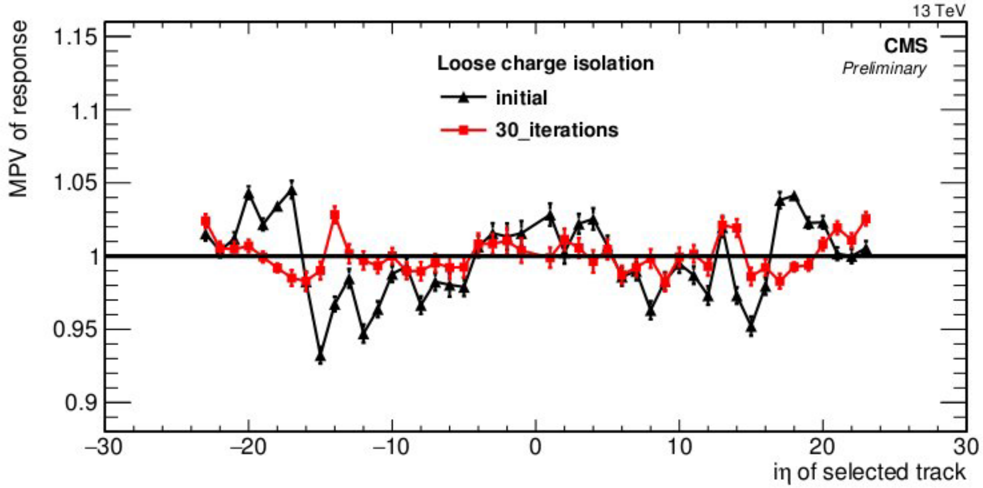
Single Particle (Method 2)



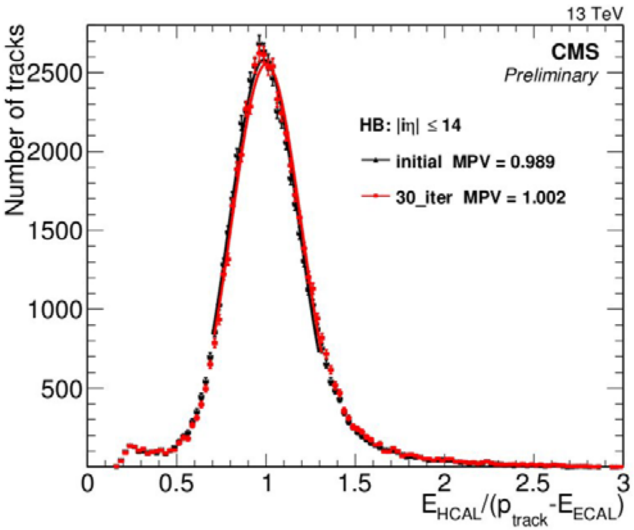


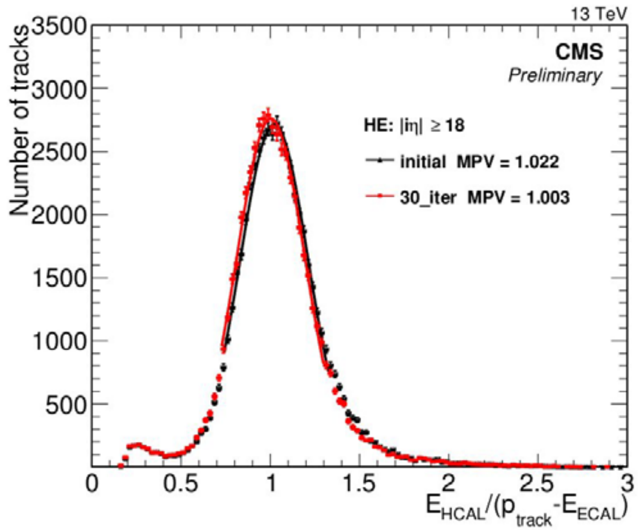
- Again convergence is good
- There is no systematic shift in the correction factor
- There is no dependency on PU condition

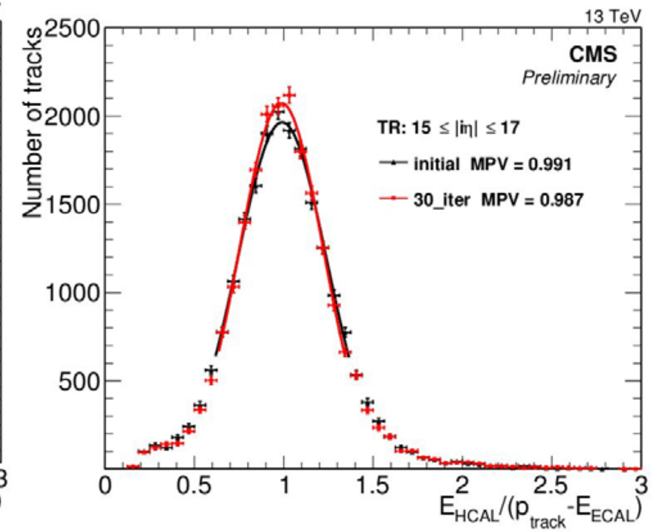
2016 Data



- Data collected during 2016 are used with loose isolation selection and PU correction to derive the scale corrections
- Corrected response gives MPV close to 1 within quoted accuracy

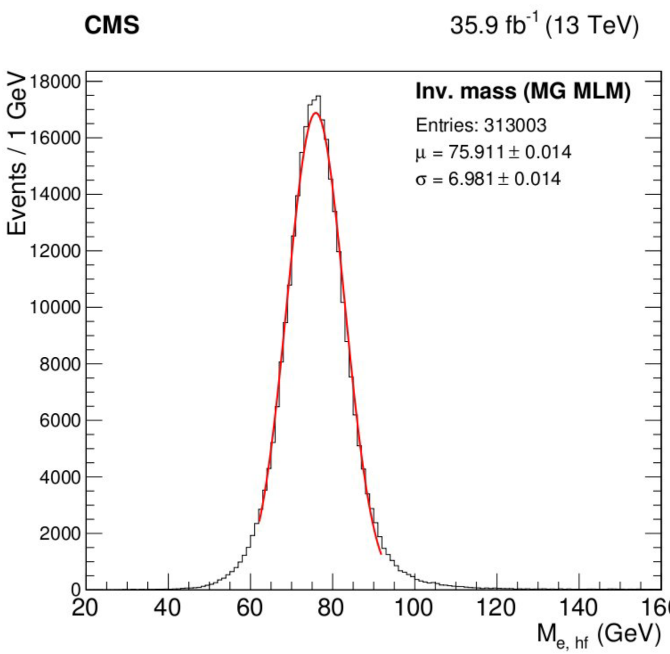


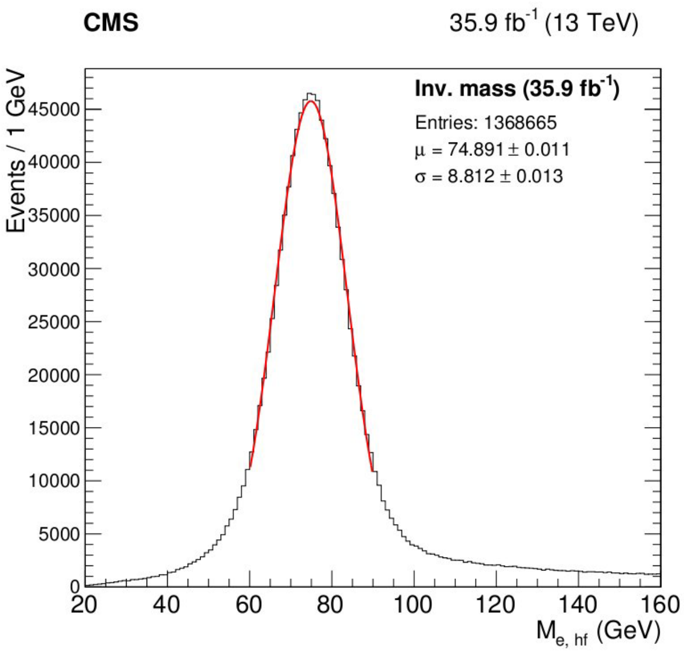




Energy Scale of HF

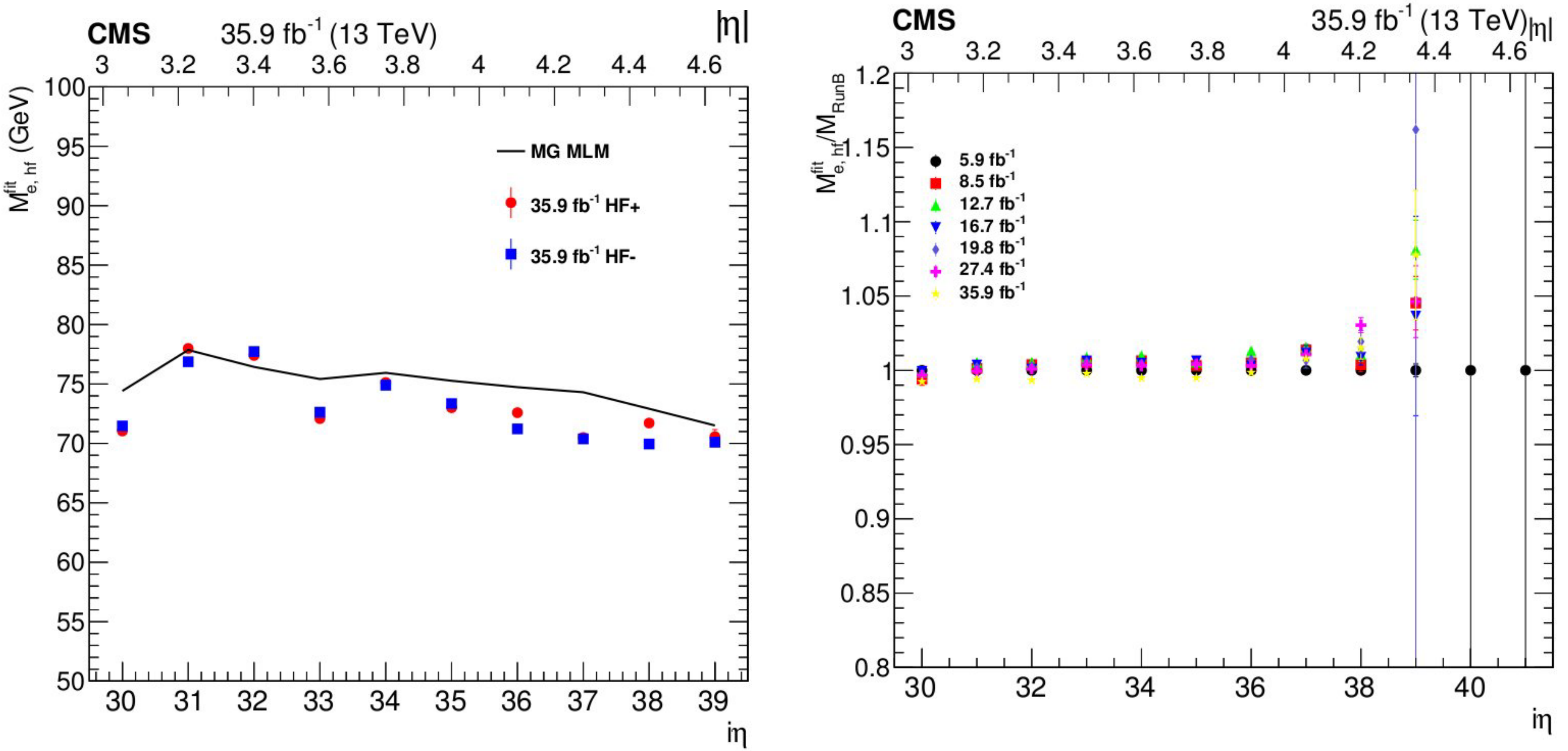
- Use the decay mode $Z \rightarrow e^+e^-$ to calibrate the long fibers of HF
- Let one of the electrons going to ECAL where the energy and direction of the electron is measured with high accuracy while the other comes to HF
- Constrain the effective mass to Z mass





- Both data and MC shows measured Z-mass below nominal mass due to absent correction of using only long fiber energy & clustering effect

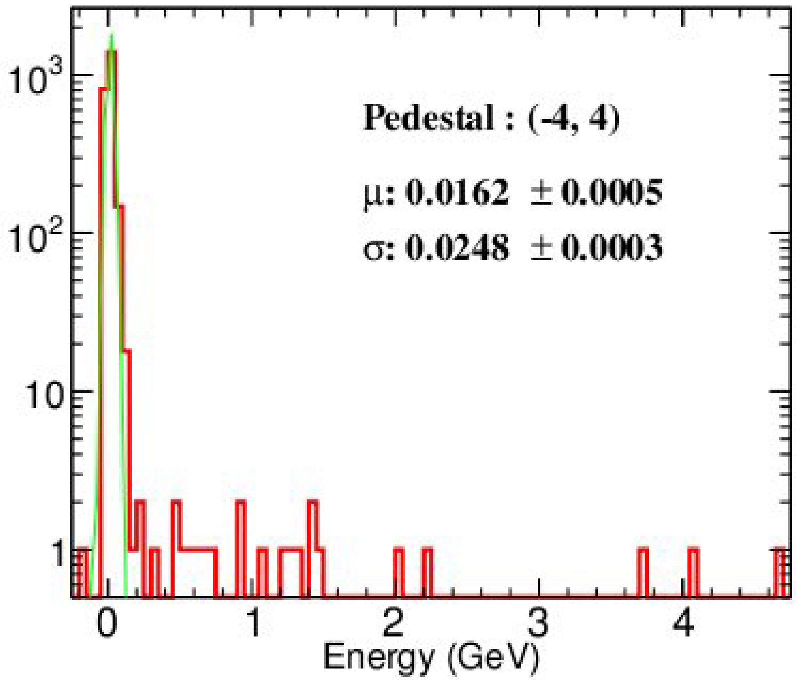
HF Energy Scale during 2016

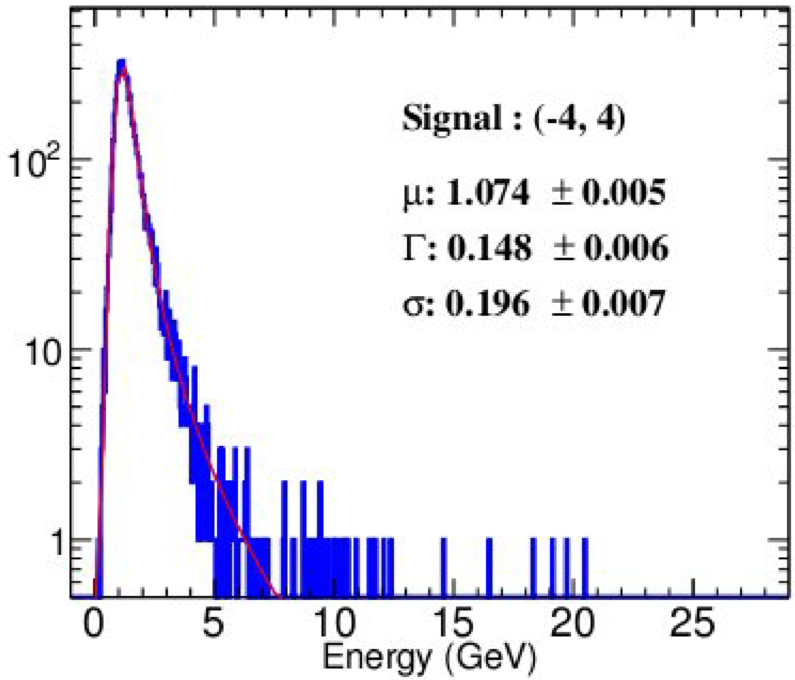


- ❑ Energy scale is the same for HF+ and HF-
- ❑ Energy scale has to be adjusted for towers in the range iη range 33:38
- ❑ Energy scale stable in different run periods

Inter-calibration of HO

- Inter-calibration of HO channels make use of muons from the collision data
- Identified muons are extrapolated to the HO surface to identify the tower to be studied
- Energy distribution is fitted with Gaussian for background events and Gaussian convoluted Landau for signal events
- MPV's are used for inter-calibration



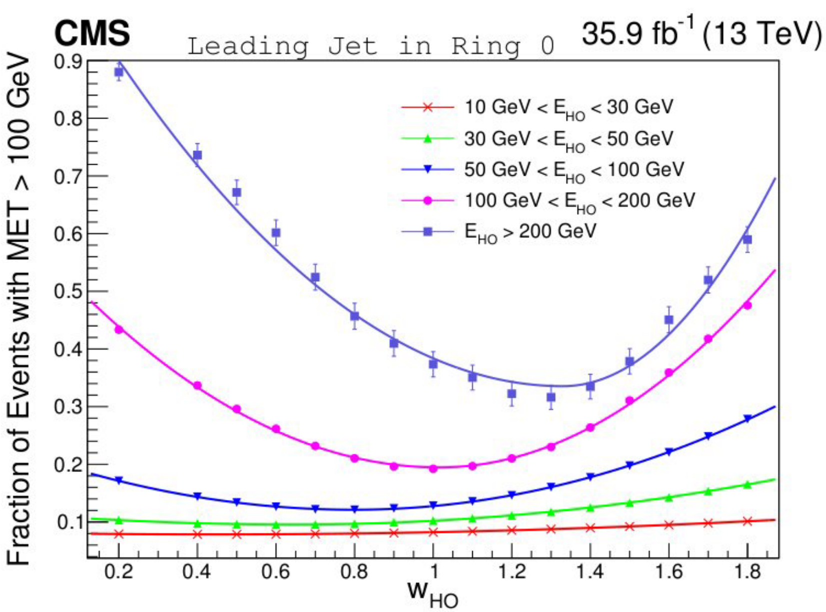


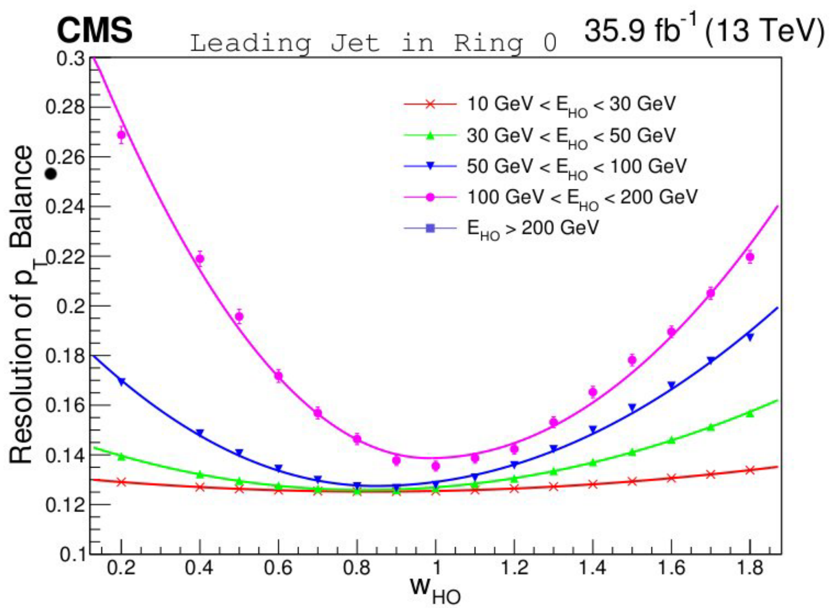
Energy Scale for HO

- Energy of a jet in the barrel region is measured from energy measured in ECAL, HB and HO

$$E_{Jet} = E_{ECAL} + w_{HCAL} \times (E_{HB} + w_{HO} \times E_{HO})$$

- The relative weight wHO of energy measured in the HO is derived
  - Minimizing mean MET or fraction of events with large MET
  - Balancing di-jets by minimizing $\frac{(p_T^1 - p_T^2)}{< p_T >}$





Preparation Phase

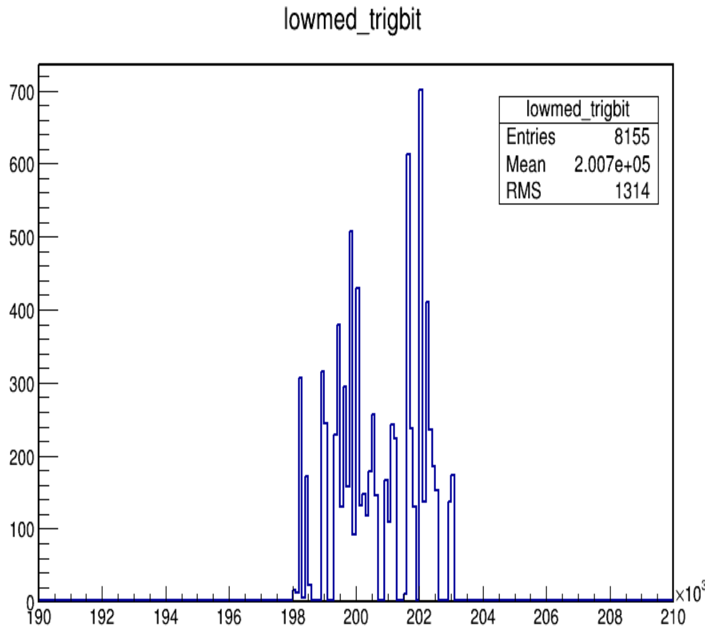
- ❑ Utilize dedicated special runs
  - – Pedestal runs to evaluate noise
  - – LED, Laser runs to monitor readout units as well as study radiation damage effect
- ❑ Use collision data with default or dedicated trigger
  - – Separate the data into several primary data sets
  - – If reconstructed hits are needed take specific action
    - ❖ select events of interest
    - ❖ keep only the collecttions needed for calibration
  - – If reconstructed hits are not needed can work with (mini)AOD
- ❑ For all calibration processes
  - – Make specific ROOT tree's for the analysis

AlCaReco

Back Up

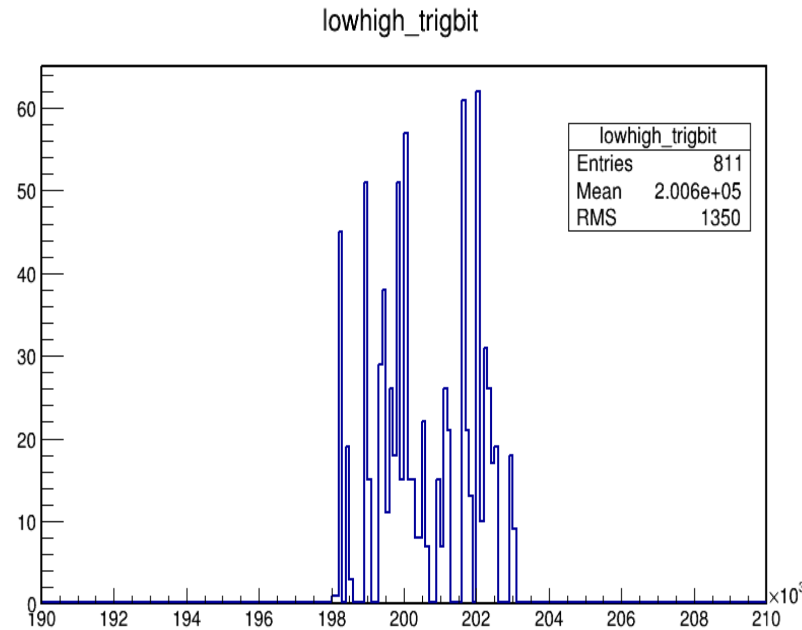
Choice of triggers

- Three L1 fired non HCAL trigger bits are selected with
  - low stat. error (bit 31, L1_SingleEG7)
  - medium stat. error (bit 44, L1_DoubleMu_10_Open)
  - high stat. error (bit 9 , name : L1_TripleMu0).

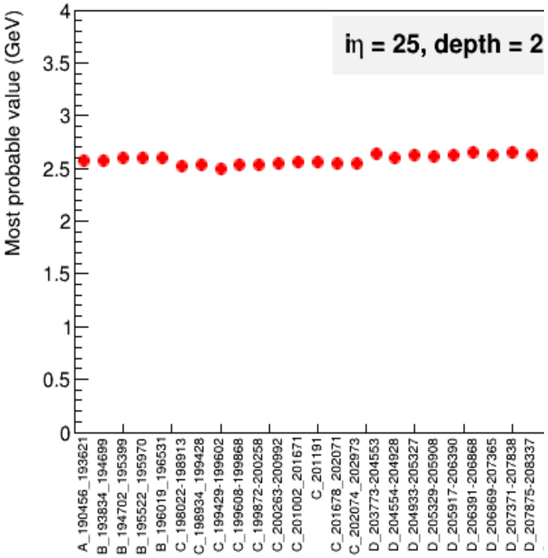


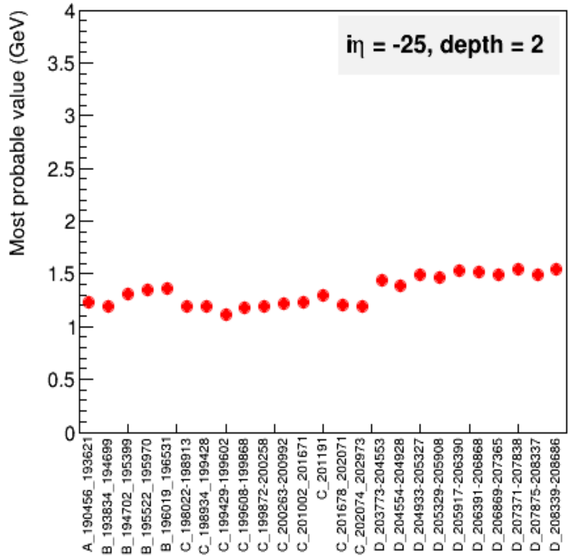
- Corresponding fired number of events, overlapped by any of these two bits's events are observed.

Fired Events by low error bit: 932432
Fired Events by med error bit: 107129
Fired Events by high error bit: 7074
Fired Events by med/high bits : 5666



HE Layers





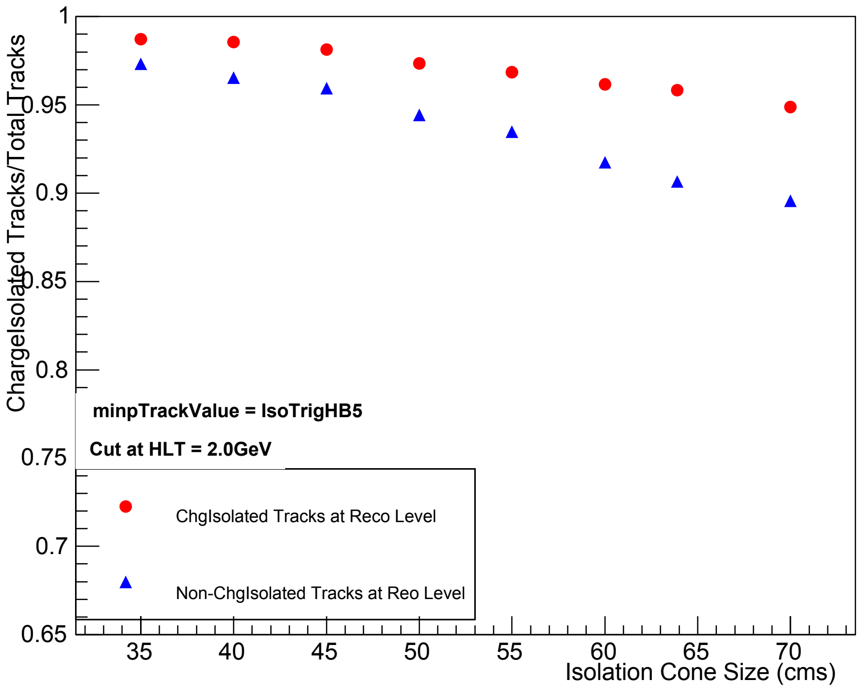
Variation of energy with Run-Numbers (|iη|,depth) = (25 , 2)

(energy deposition remains same)

- Energy deposition is nearly constant for HB layers
- Fluctuations in energy observed mostly for HE layers

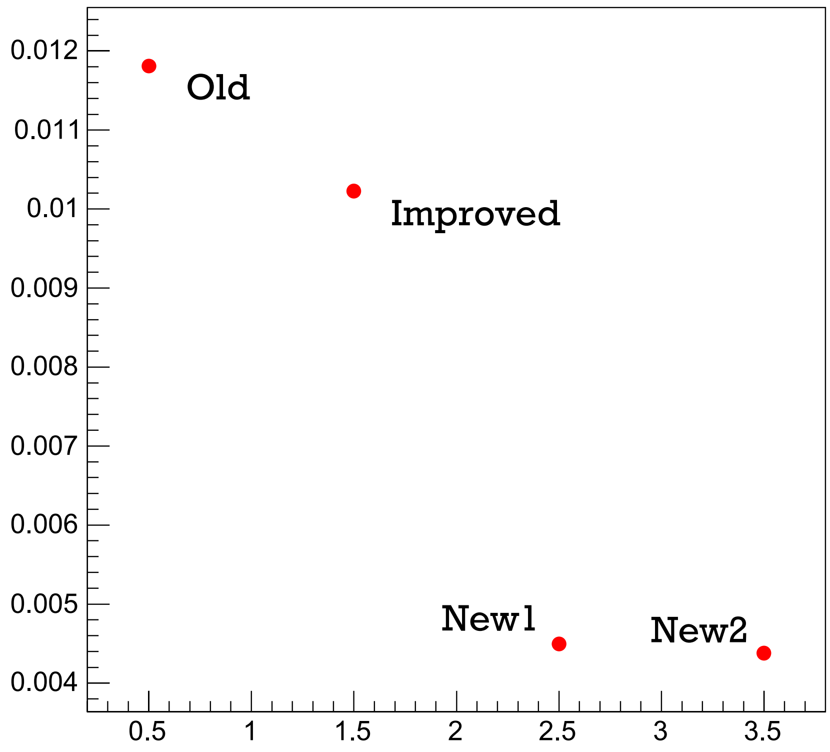
Optimizing Charge Isolation at HLT

- Currently Isolation cone size of 40 cm is used at HLT level and 63.9 cm is used for offline analysis.
- Offline cut of 2 GeV on highest momentum track reaching HCAL within the isolation cone is used.
- Current value of charge isolation cut at HLT is 5 GeV
- Decreasing the cut value from 5 GeV to 2 GeV reduces the fraction of good as well as bad tracks selected at HLT
- This value need not be changed

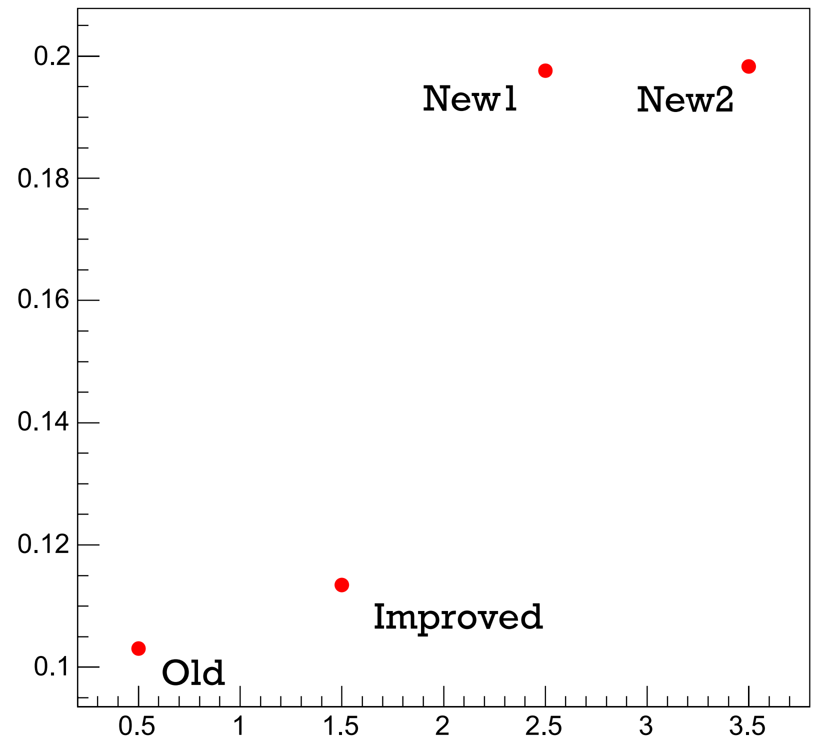


HLT Rate and usefulness of events selected

Fraction of Events selected by HLT

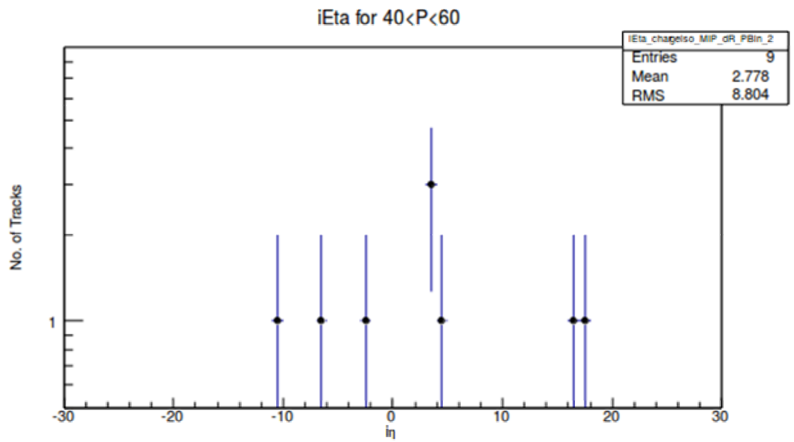


Fraction of Useful events selected

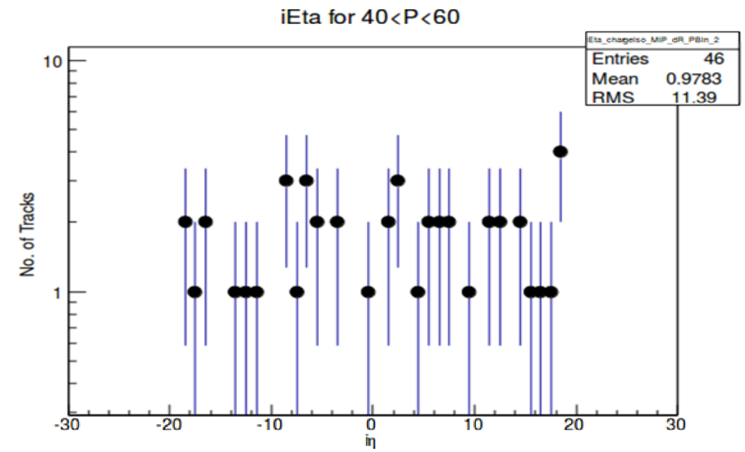


Isolated Tracks in Run 2012D

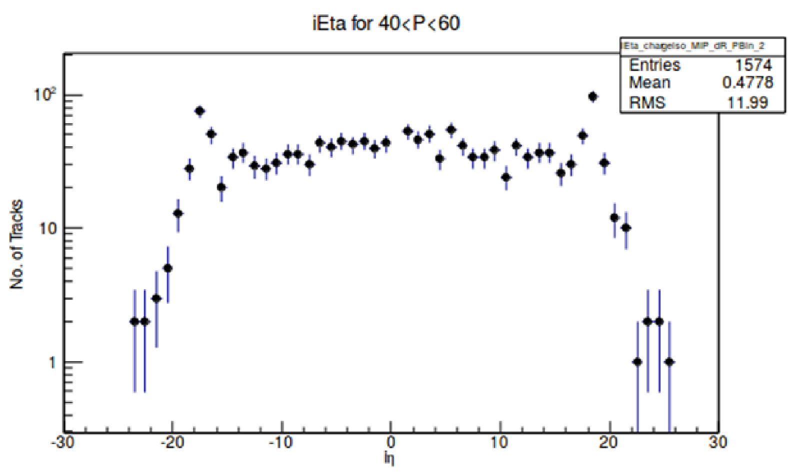
HLT_PFJet140



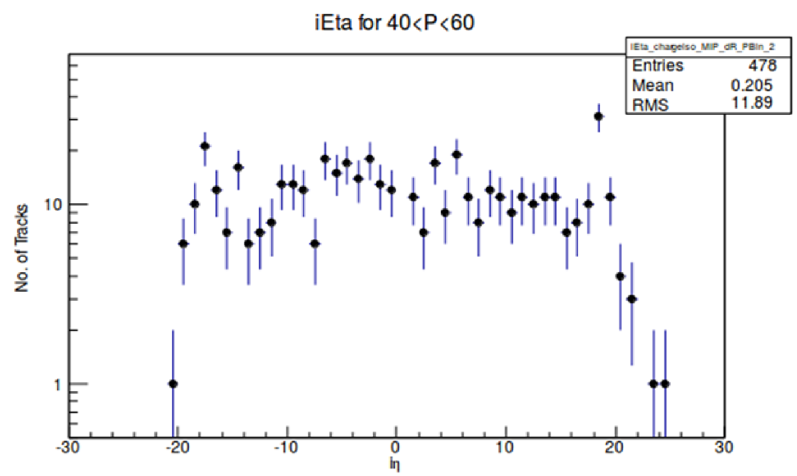
HLT_PFJet200



HLT_PFJet320



HLT_PFJet400

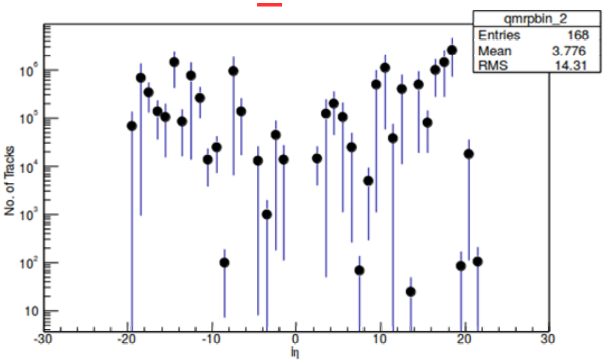


Look at single jet triggers in the entire data sets: **HLT_PFJet40, HLT_PFJet80_v, HLT_PFJet140, HLT_PFJet200, HLT_PFJet320, HLT_PFJet400**

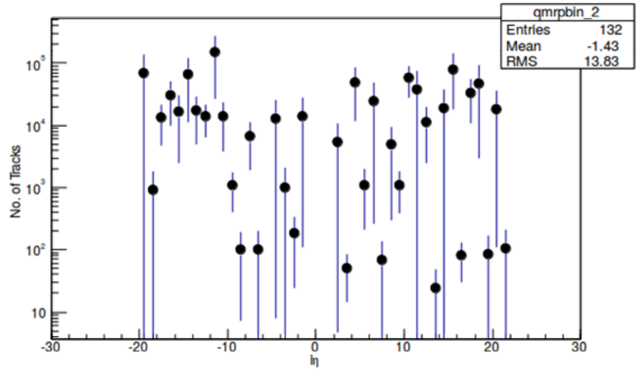
Isolated Tracks in QCD MC

All the HLTs are unprescaled in this sample
Normalized for integrated luminosity of 1 fb^{-1}.

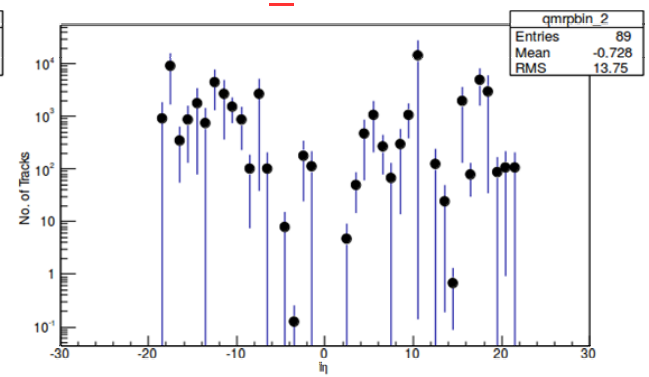
HLT_PFJet40



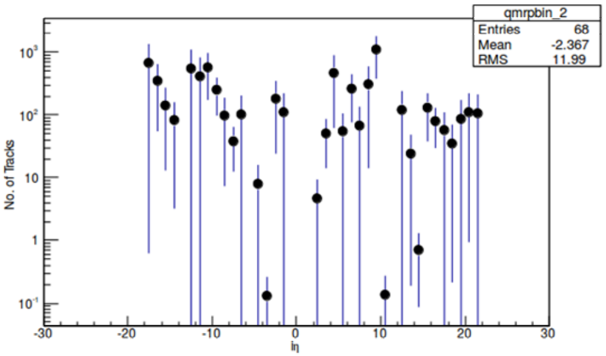
HLT_PFJet80



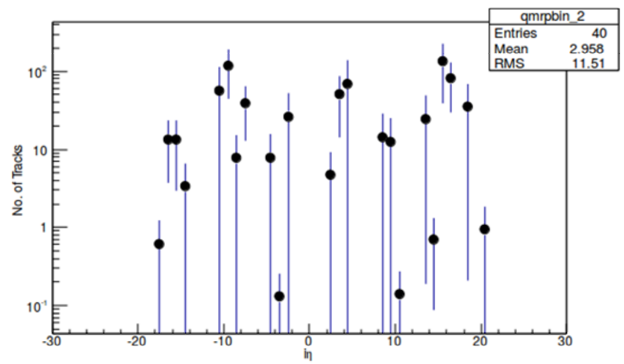
HLT_PFJet140



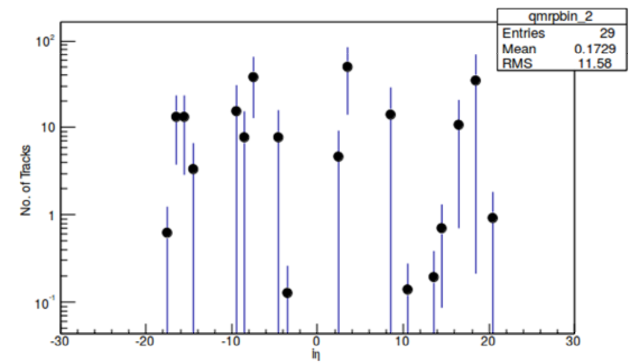
HLT_PFJet200



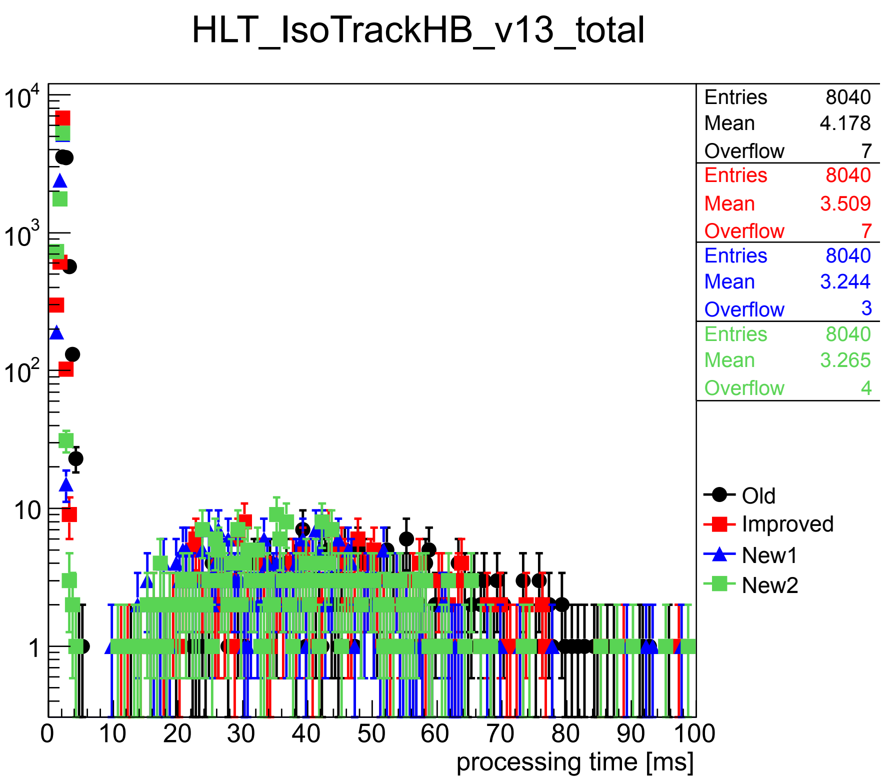
HLT_PFJet320

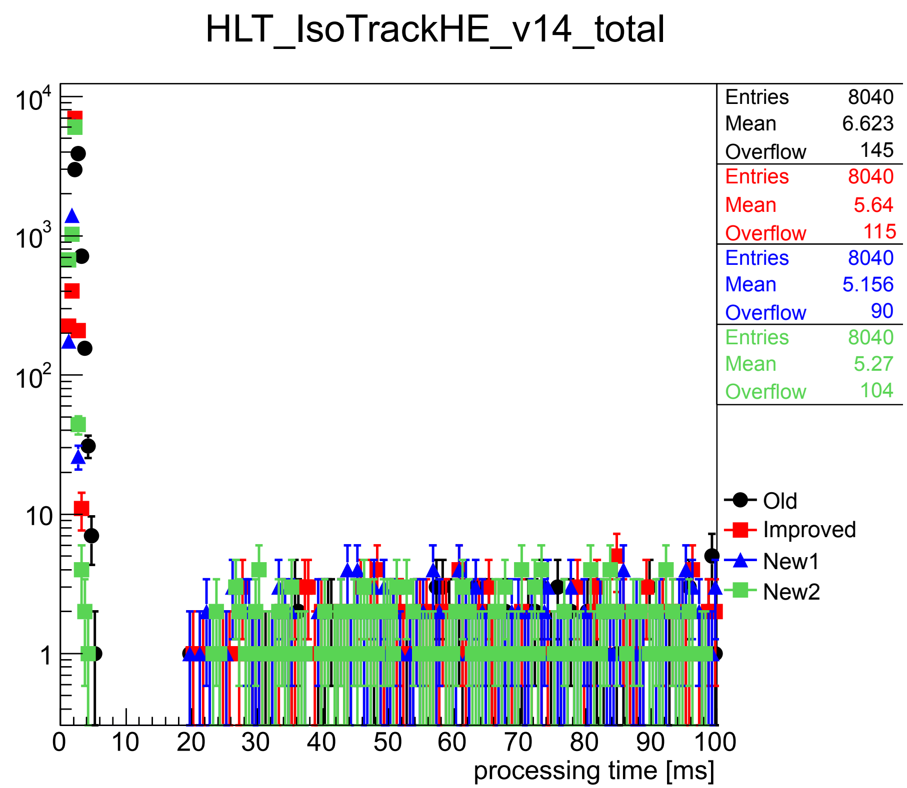


HLT_PFJet400



Total time taken



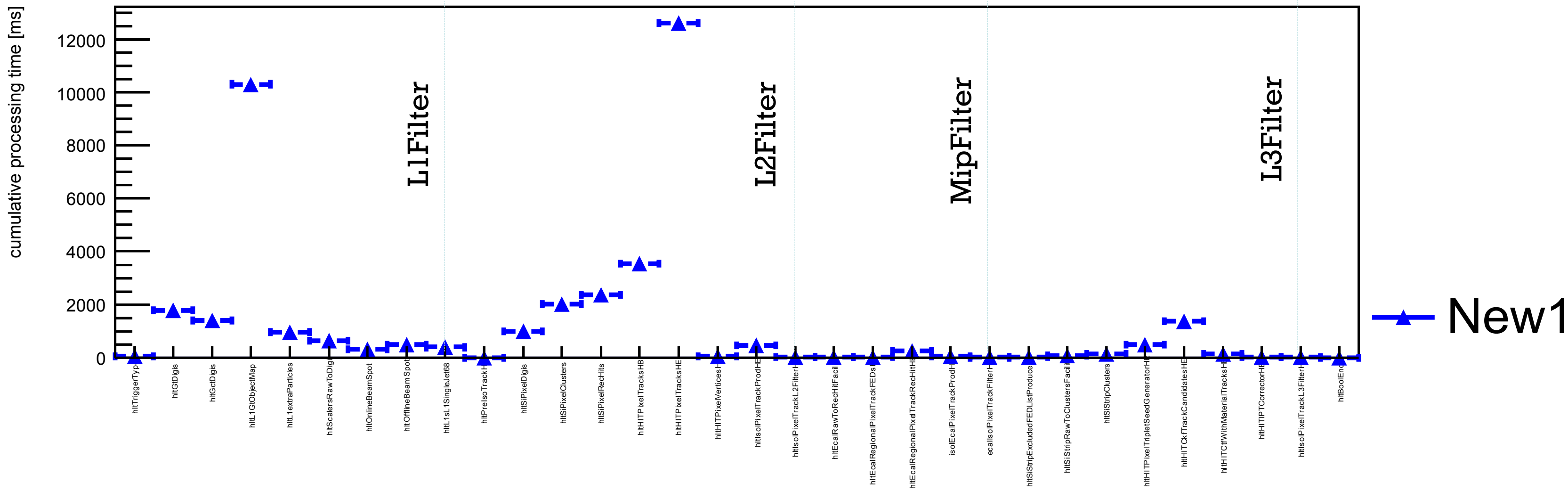


- There is convincing reduction in time taken by the HLT path.
- Average time taken is the smallest for New1 scenario

Timing : New1

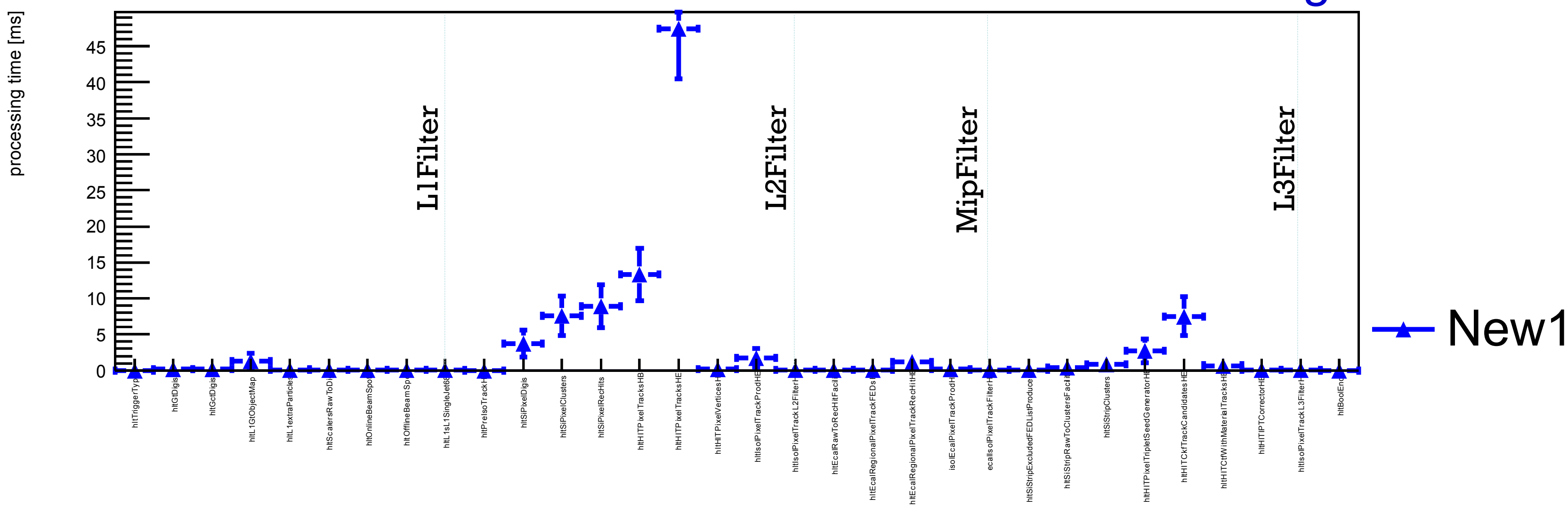
HLT_IsoTrackHE_v14_module_active

Cumulative Time



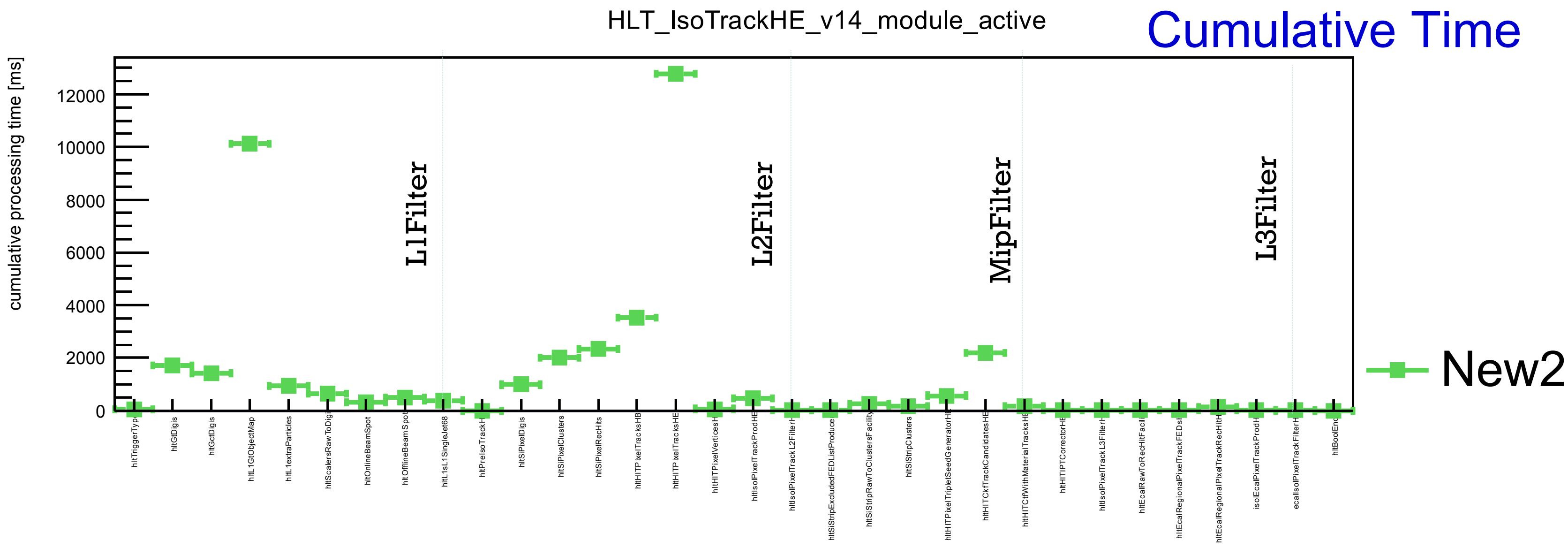
HLT_IsoTrackHE_v14_module_running

Average Time

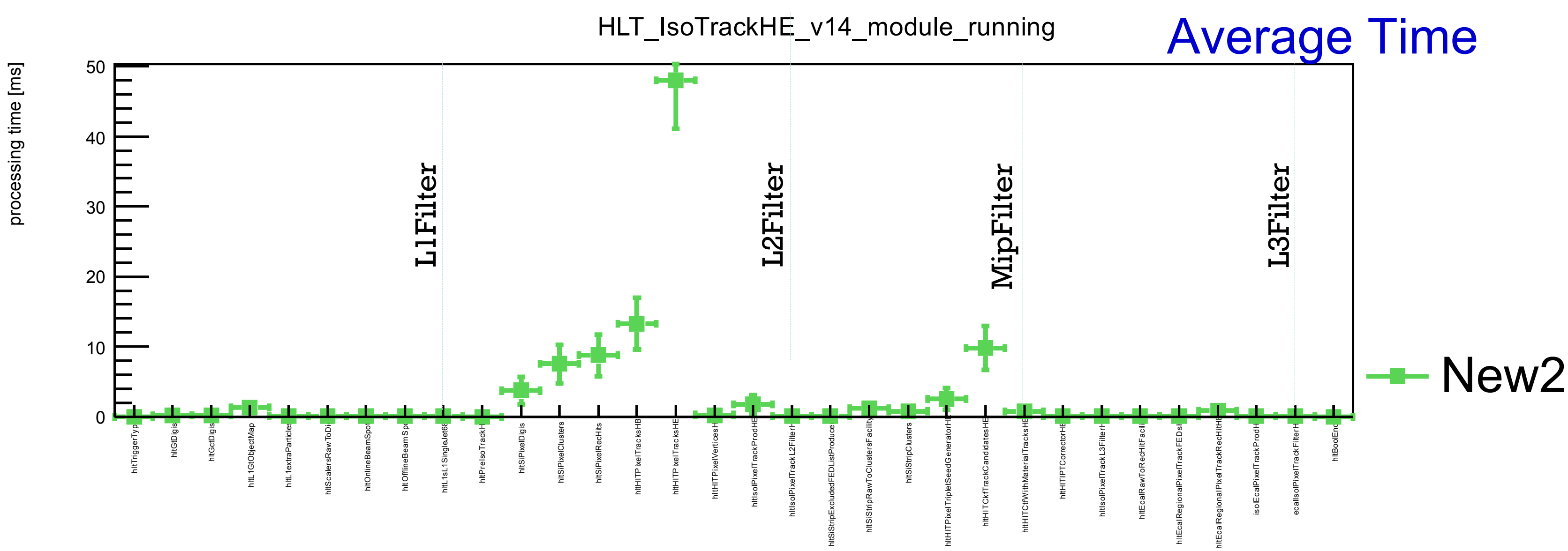


Timing : New2

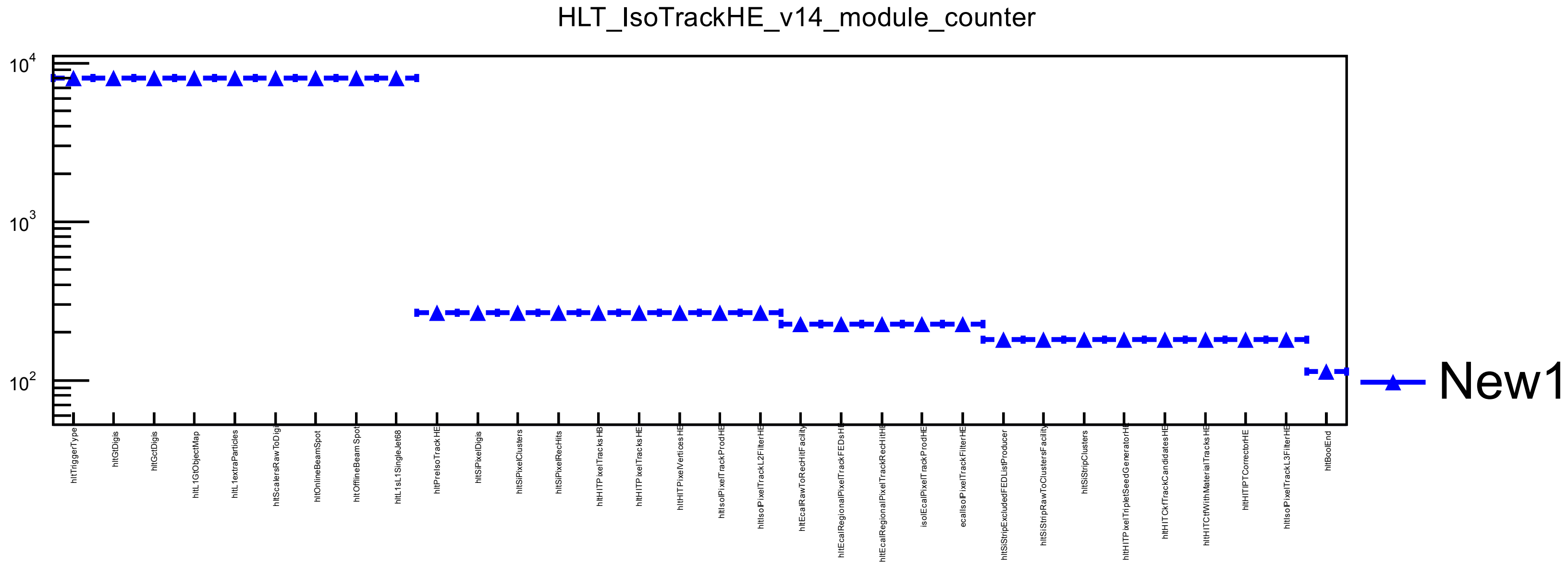
Cumulative Time

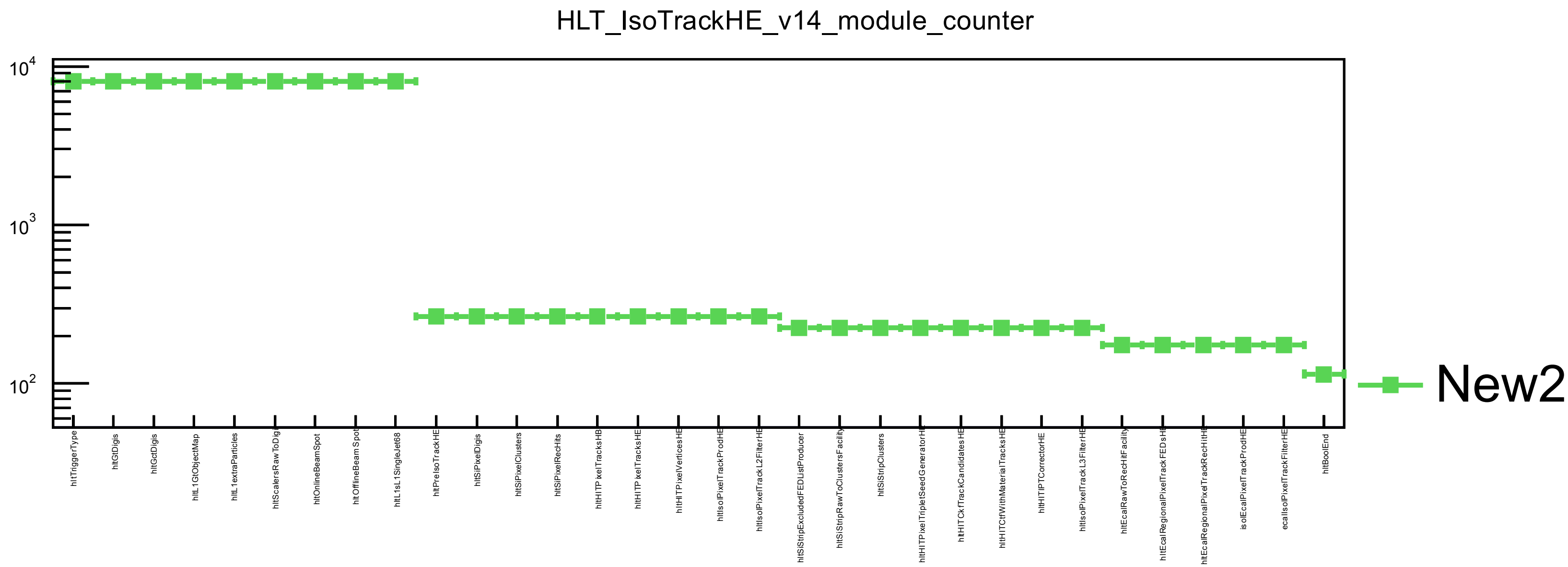


Average Time



Event Counter





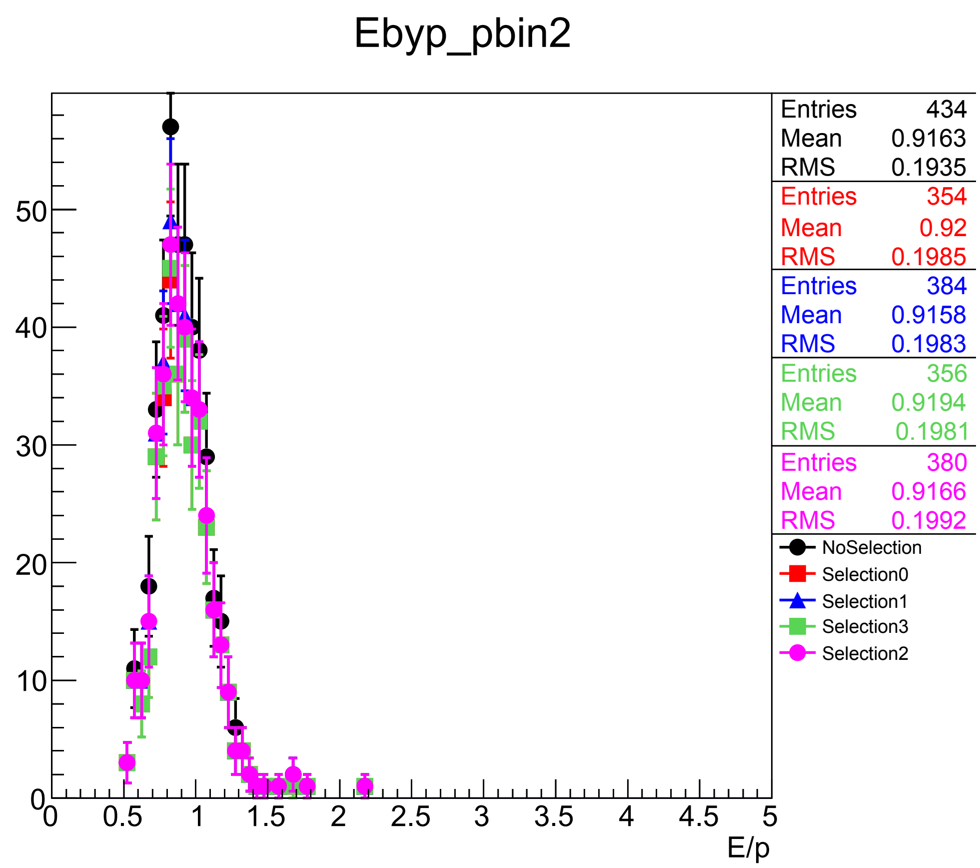
Enlarge data set (track quality criteria)

- Selection of good charged tracks (Selection0)
  - p_T > 10 GeV/c
  - Chi-square < 5.0
  - Number of layers crossed > 8
  - $\Delta p/p$ < 0.1
  - No missed hits in inner/outer layers
  - Track should originate close to primary vertex: |dxy|<0.2, |dz|<5.0
  - Track should reach the HCAL surface
- Selection1
  - 2 inner missing hits and 2 outer missing hits allowed
  - PV Cuts : |dxy|<10, |dz|<100
- Selection2
  - 2 inner missing hits and 2 outer missing hits allowed
- Selection3
  - PV Cuts : |dxy|<10, |dz|<100

Selection on Track Quality

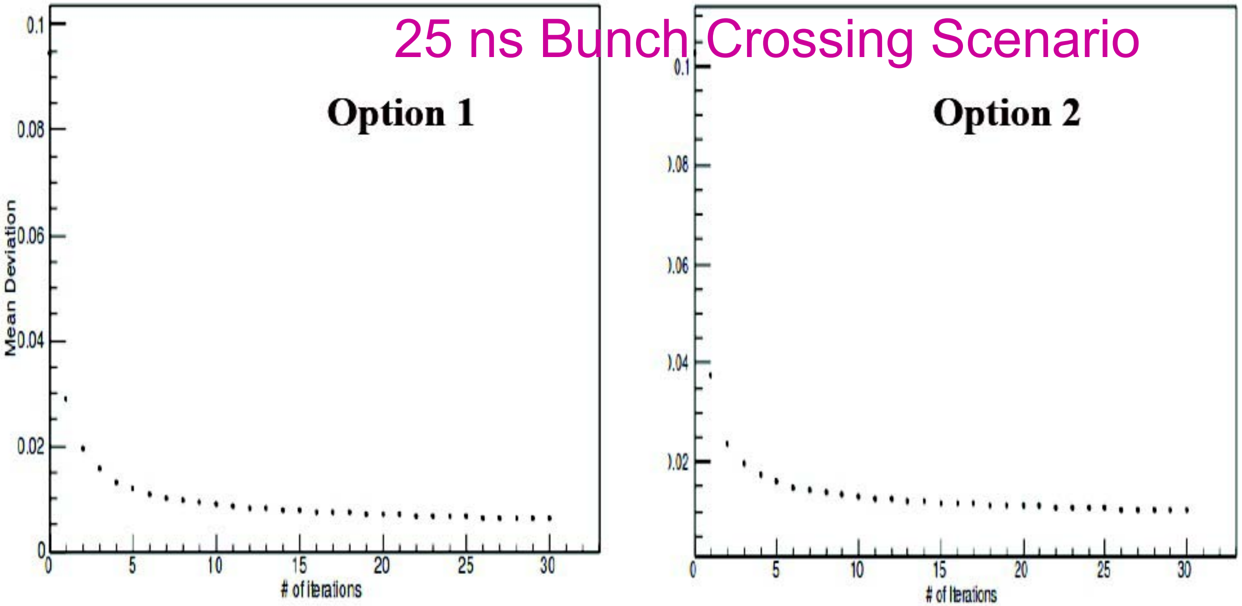
- The mean response remains almost the same by relaxing cuts on
  - dxy and dz - Proximity to PV
  - Inner and Outer Missing hits
- Statistics improves by ~8%.

P: 40-60 GeV

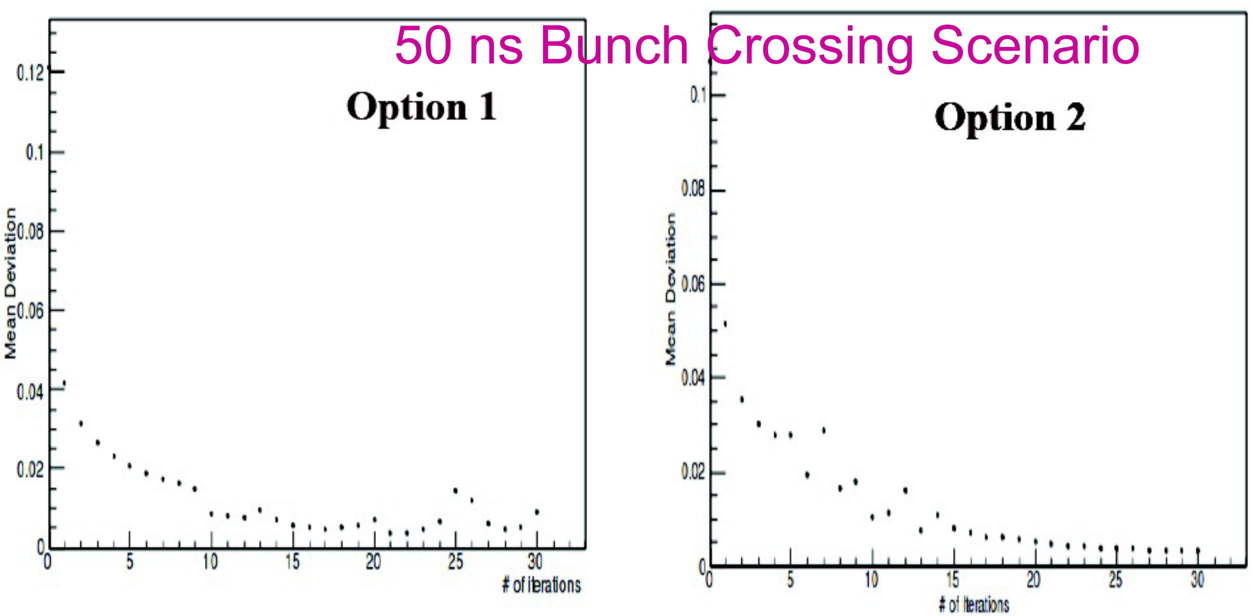


QCD MC Sample

25 ns Bunch Crossing Scenario



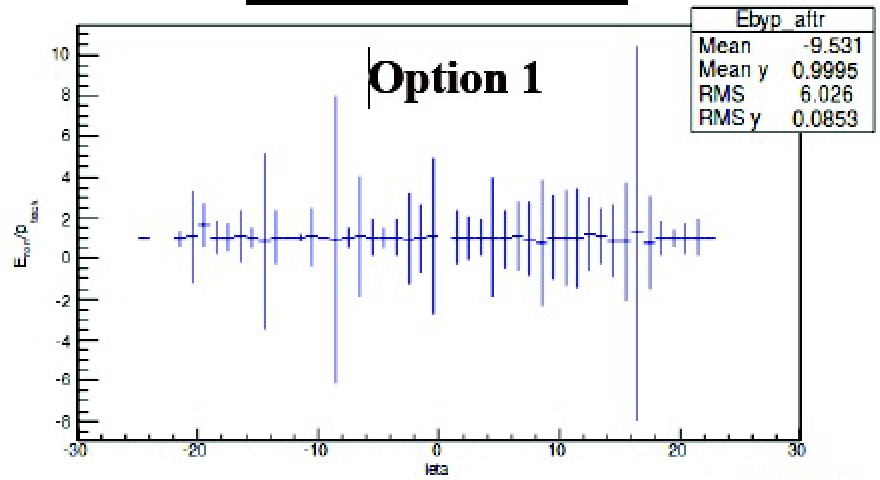
50 ns Bunch Crossing Scenario



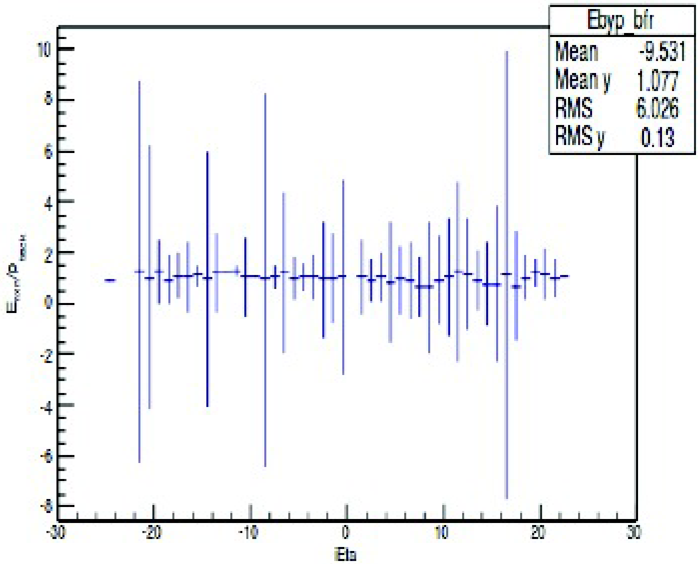
- For low PU condition both options have good convergence
- For high PU condition the second option converges better

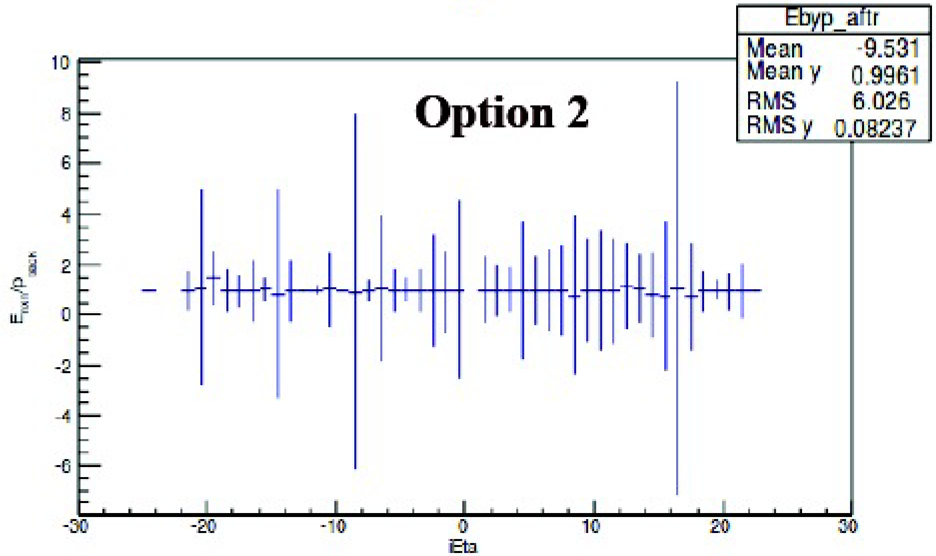
QCD MC sample

31st iteration



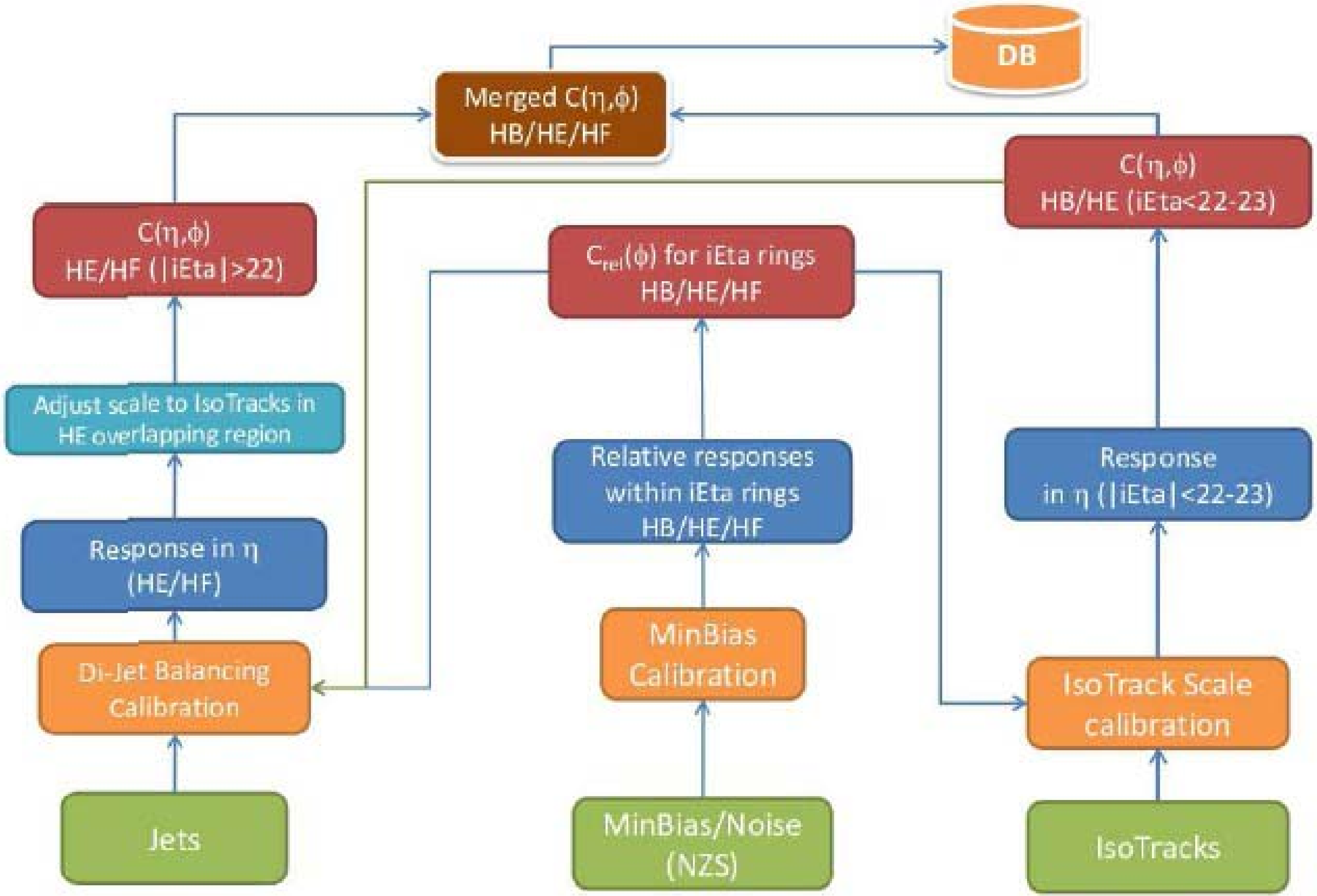
1st iteration





- ❑ No systematic effect is observed in the final E/p measurement

Calibration Workflow



- ❑ Did not cover several aspects: di-jet, γ-jet balancing for HB/HE,