Status of W-DHCAL Analysis

Christian Grefe (CERN), Thibault Frisson (CERN)

on behalf of the CALICE collaboration and the CLIC physics and detector study (CLICdp)

14. May 2014
Americas Workshop on Linear Colliders 2014, Fermilab

Outline

1. Introduction
2. Calibration
3. Digitization (RPCSim)
4. Summary and Outlook

Outline

1 Introduction

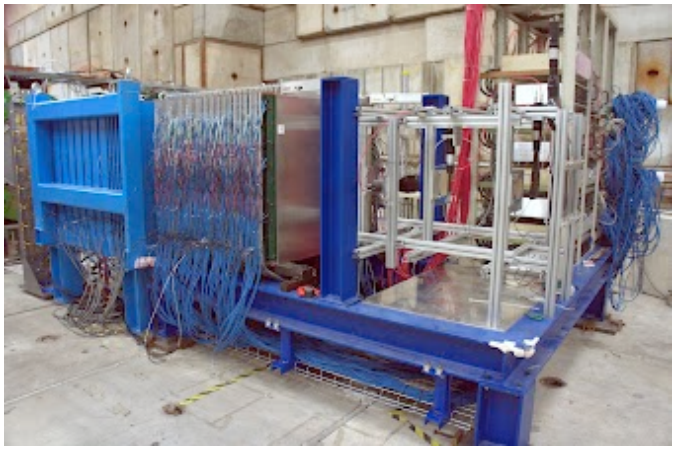
2 Calibration

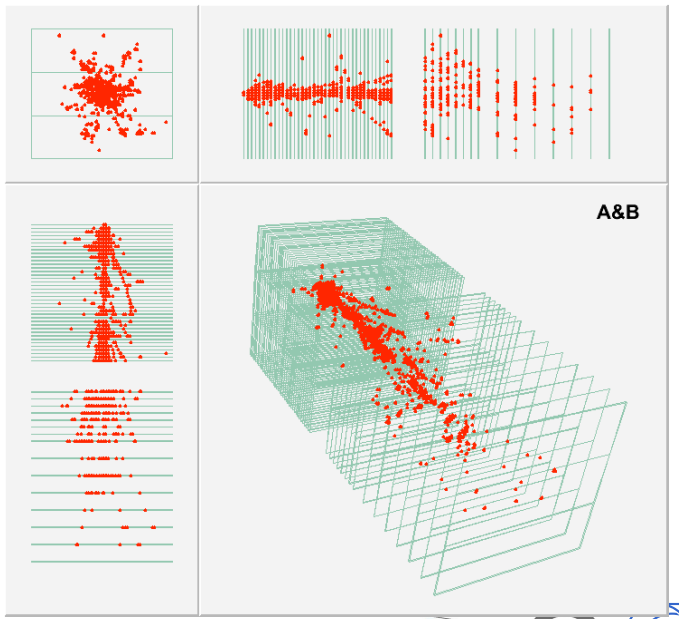
3 Digitization (RPCSim)

4 Summary and Outlook

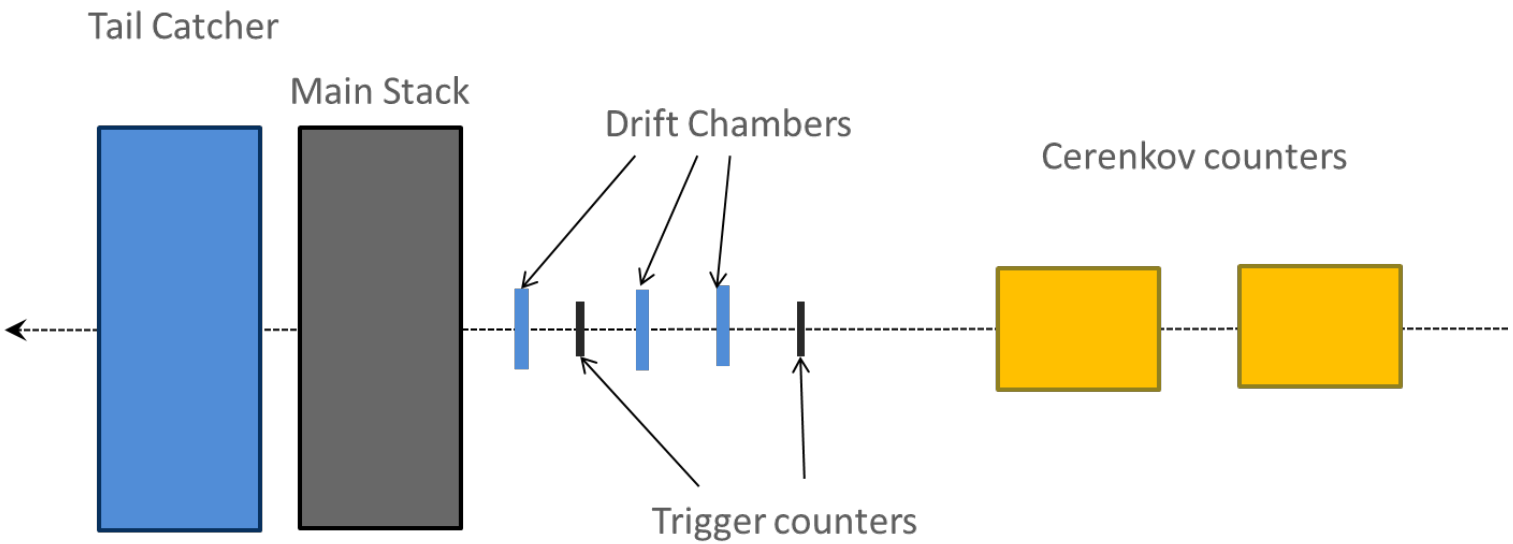
Data Taking at CERN (2012)

- 54 RPC layers:
  39 with tungsten absorber (main stack),
  15 with steel absorber (tail catcher)
- Each layer instrumented with 96×96
  $1 \times 1\,\mathrm{cm}^2$ pads $\Rightarrow \sim 500000$ channels
- PS (1–10 GeV): 1 run period of 2 weeks
- SPS (10–300 GeV): $2 + 1 + 1$ weeks
- Dedicated μ and high rate runs
- In total ~ 30 million events recorded





Data Taking at CERN (2012)



- 39 layers W-DHCAL + 15 layers Fe-DHCAL
- $10 \times 10\,\mathrm{cm}^2$ scintillator triggers ($30 \times 30\,\mathrm{cm}^2$ for dedicated muon runs)
- Three wire chambers $\Rightarrow$ beam profile
- Two Cerenkov counters $\Rightarrow$ particle identification

Outline

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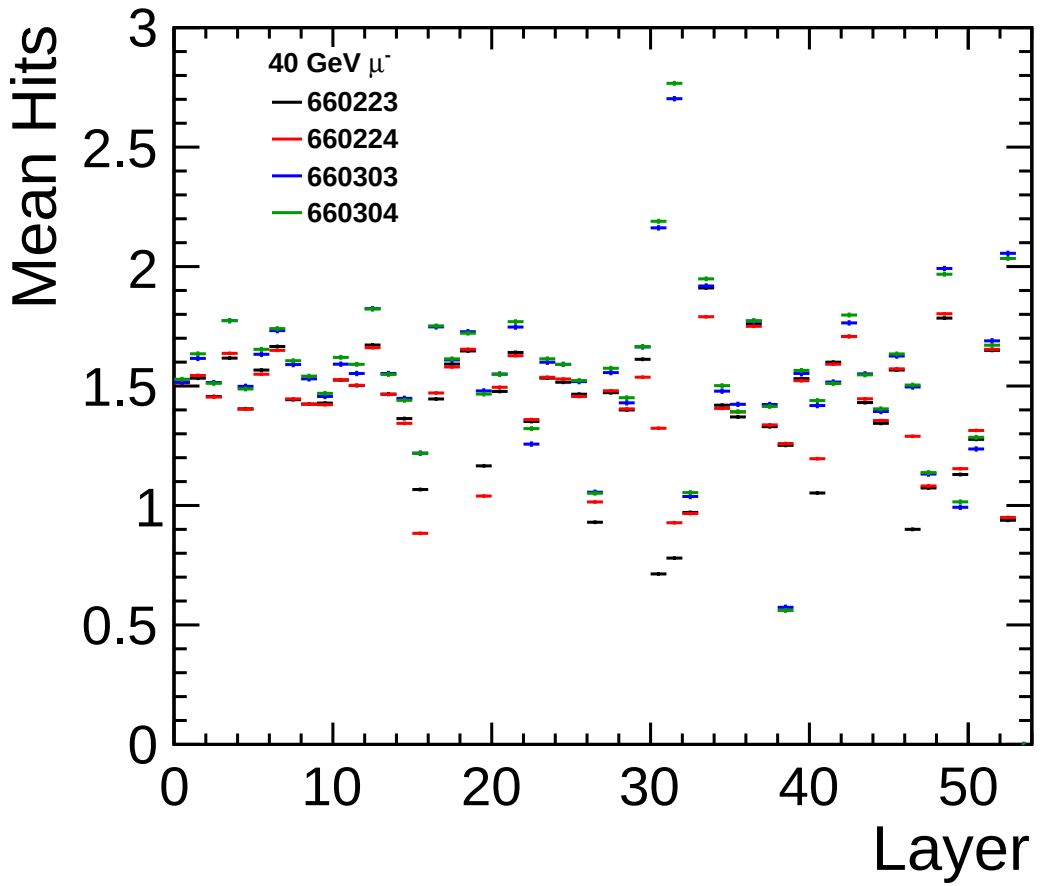
2 Calibration

3 Digitization (RPCSim)

4 Summary and Outlook

Goal of Calibration

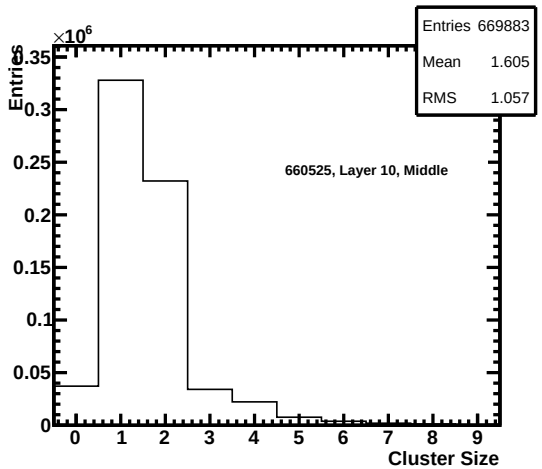
- DHCAL only measures number of hits
  $\Rightarrow$ control efficiency (ϵ) and multiplicity (μ)
- Depends on temperature, pressure, voltage, ...
- Remove **layer-to-layer** and **run-to-run** fluctuations
- Determine nominal efficiency (ϵ_0) and multiplicity (μ_0) for digitization tuning

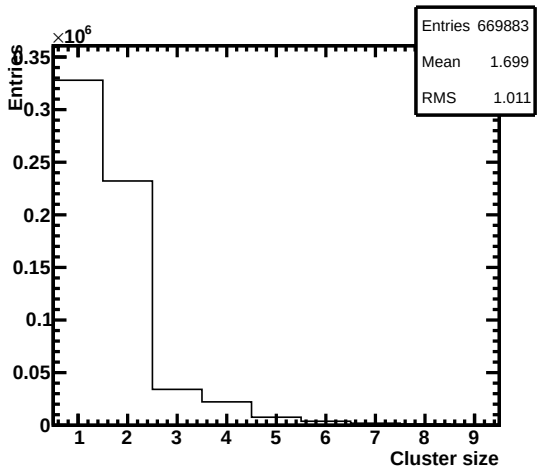


Determination of Efficiency and Multiplicity

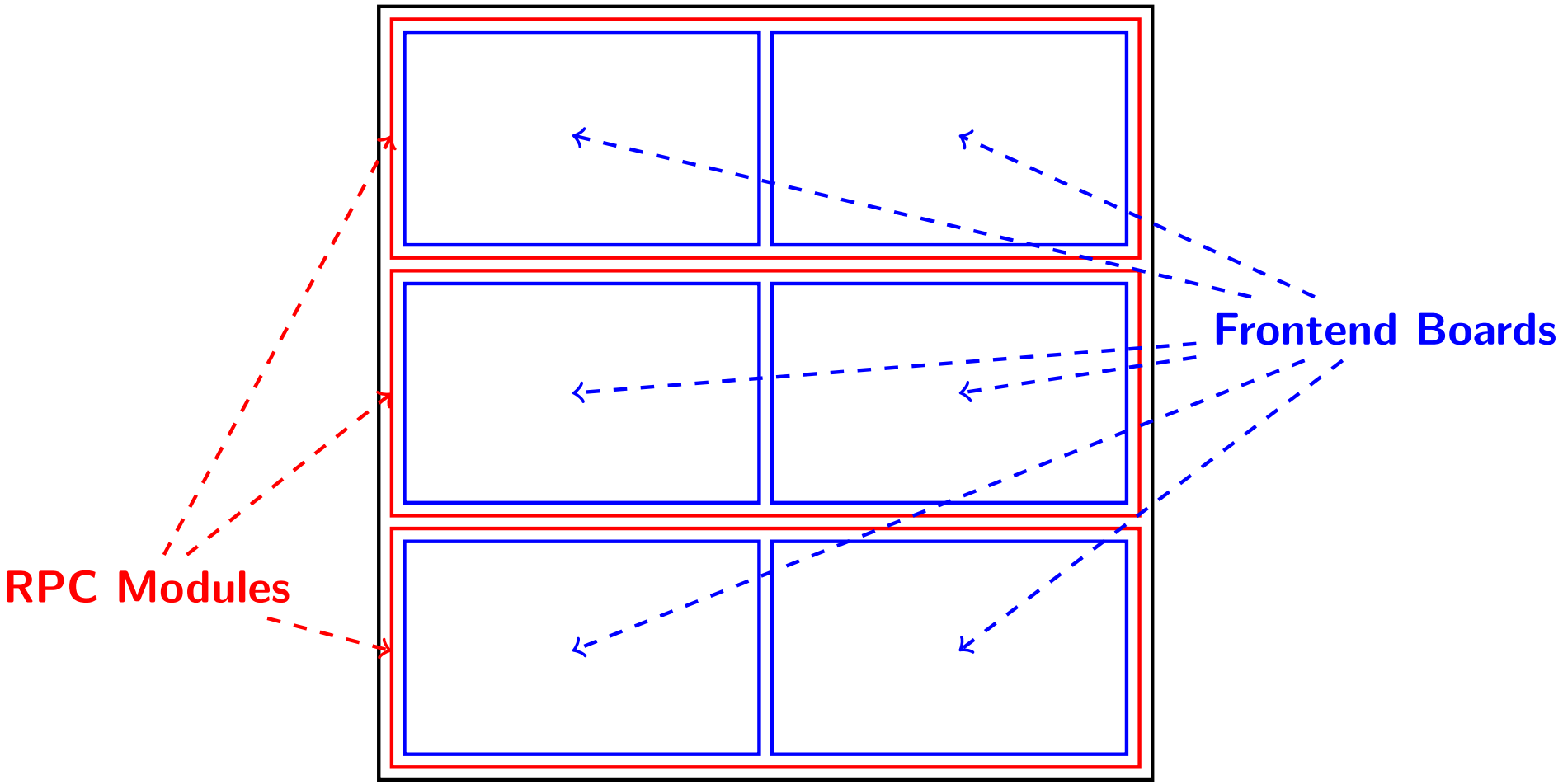
- Lose **pre-selection for muon events** based on number of active layers (> 30) and total number of hits (< 150)
- For each layer of interest **find mip stub candidates** in neighboring layers (± 3 layers, min 4 valid clusters)
- Only use clusters with 3 or less hits for mip stub candidates
- **Straight line fit** to identify intersection with layer of interest, χ^2 cut to validate mip stub
- Determine if cluster exists in layer of interest within 20 mm of intersection

- Efficiency: fraction of events with cluster found (left)
- Multiplicity: mean cluster size for events with cluster found (right)



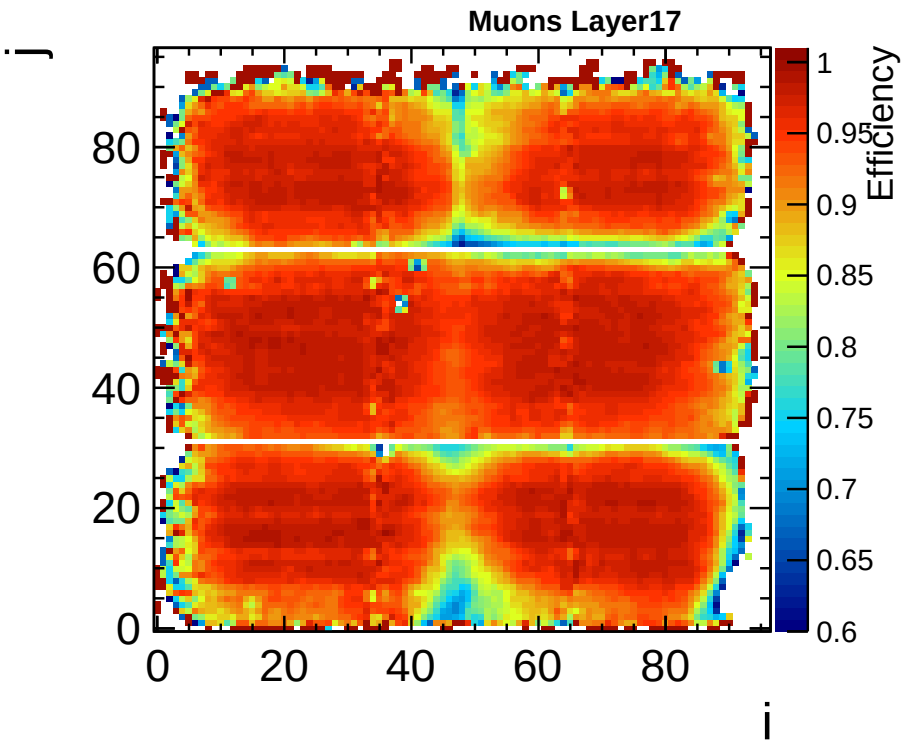


Layout of one DHCAL Layer

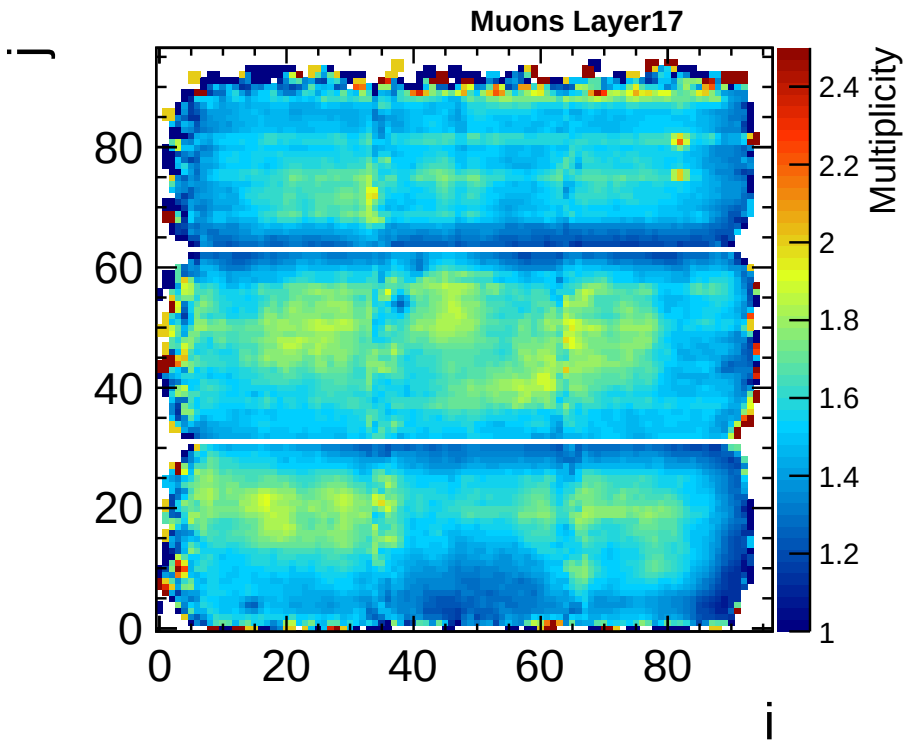


- 3 RPC modules per layer
- 2 fronted boards per RPC module

Efficiency

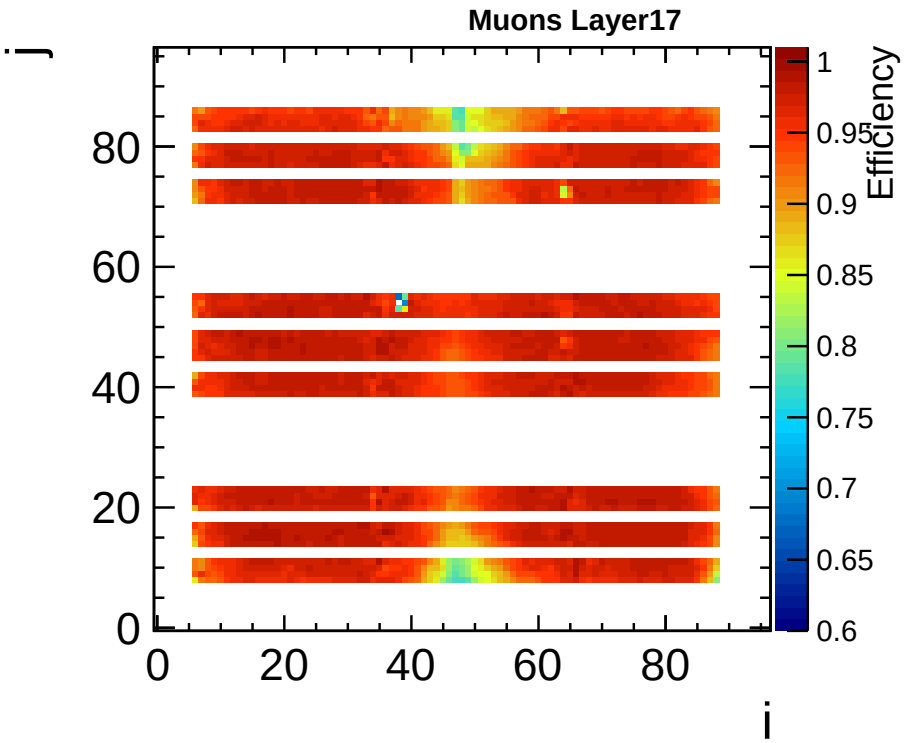


Multiplicity

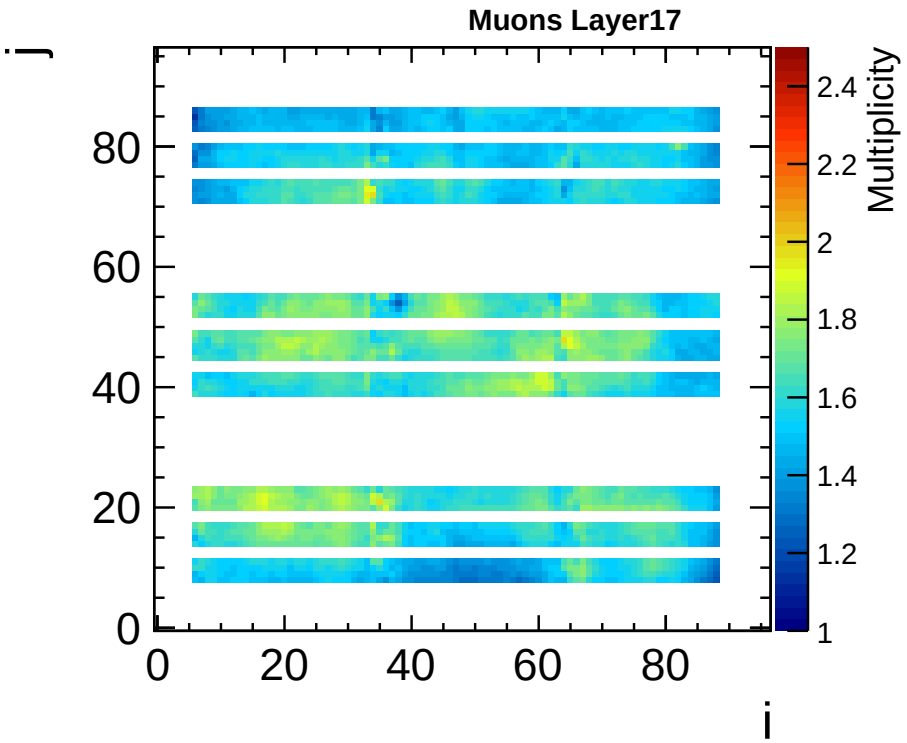


- Combine 18 muon runs taken with $30 \times 30\,\mathrm{cm}^2$ triggers at 9 positions
- More than 500k events at each trigger position
  $\Rightarrow$ allows to extract **local efficiencies and multiplicities for each pad**
- Beam runs only allow to extract efficiency and multiplicity for central region
  $\Rightarrow 10 \times 10\,\mathrm{cm}^2$ trigger with narrow beam spot
- Average: $\epsilon_0 = 87.1\%$, $\mu_0 = 1.55$ (**Raw**)

Efficiency

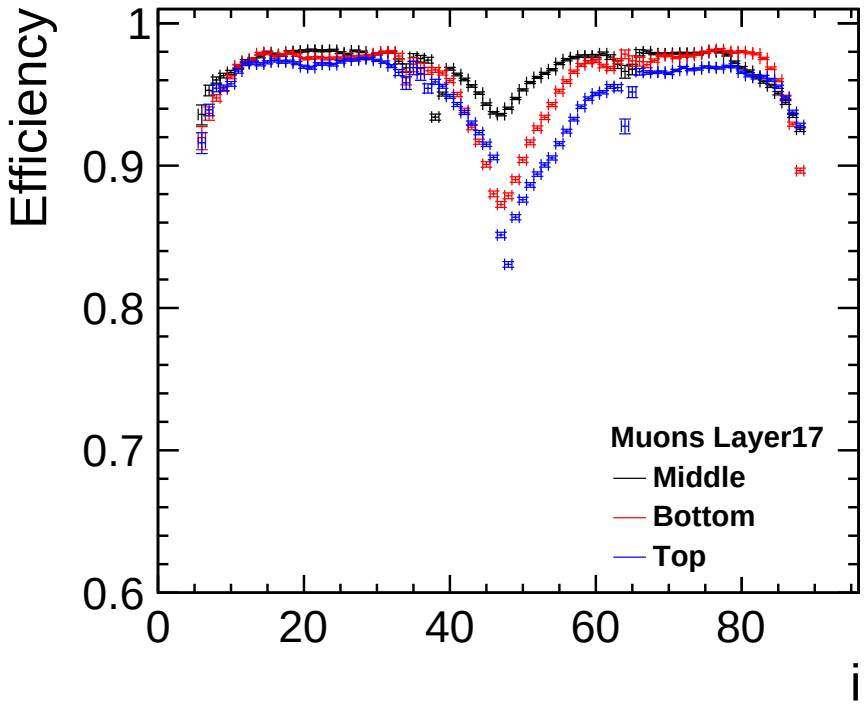


Multiplicity

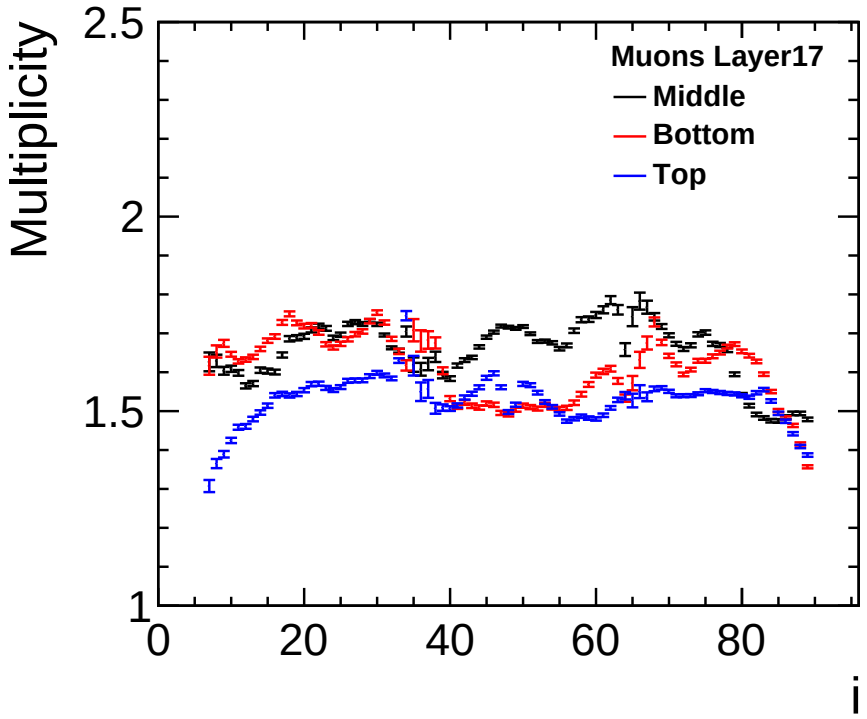


- Determine nominal values in clean regions to tune digitization
- Remove module boundaries and fishing lines
  - Effect of fishing lines included in GEANT4 through material
  - Module boundaries effect added in digitization
    $\Rightarrow$ lower effective charge depending on position
- Average: $\epsilon_0 = 94.6\%$, $\mu_0 = 1.61$ (**Cleaned**)

Efficiency

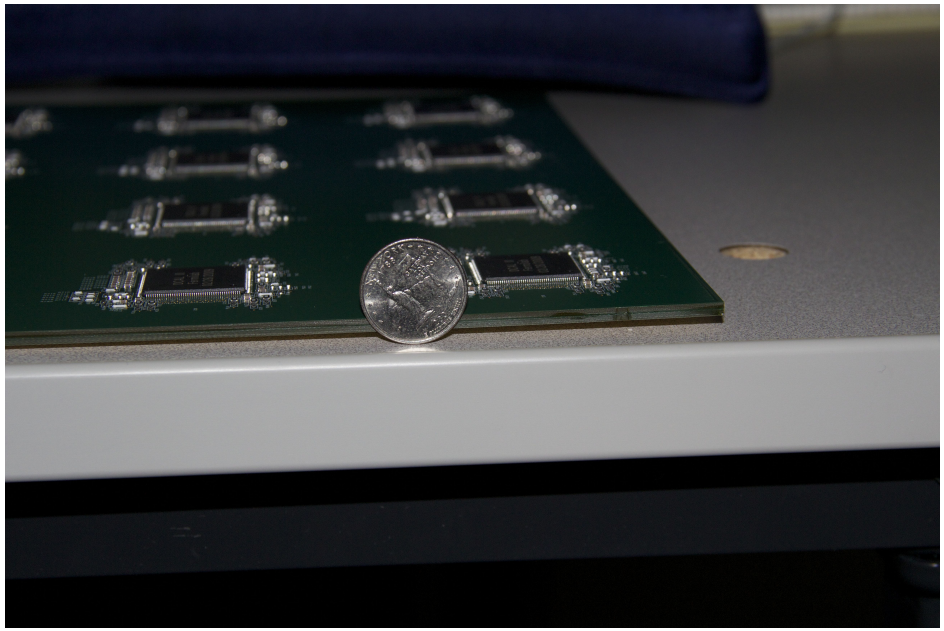


Multiplicity



- Average efficiency and multiplicity for each module depending on i / x
- Drop of efficiency in the centre of each module ⇒ **not visible in Fe-DHCAL**
- Multiplicity not affected in a similar fashion

Warping of Frontend Boards

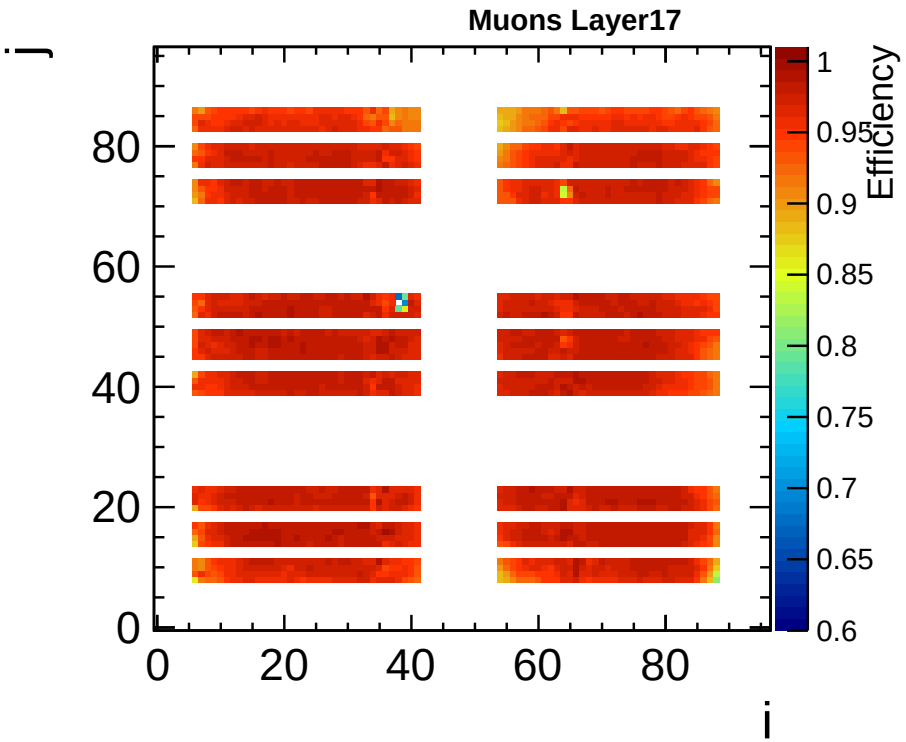




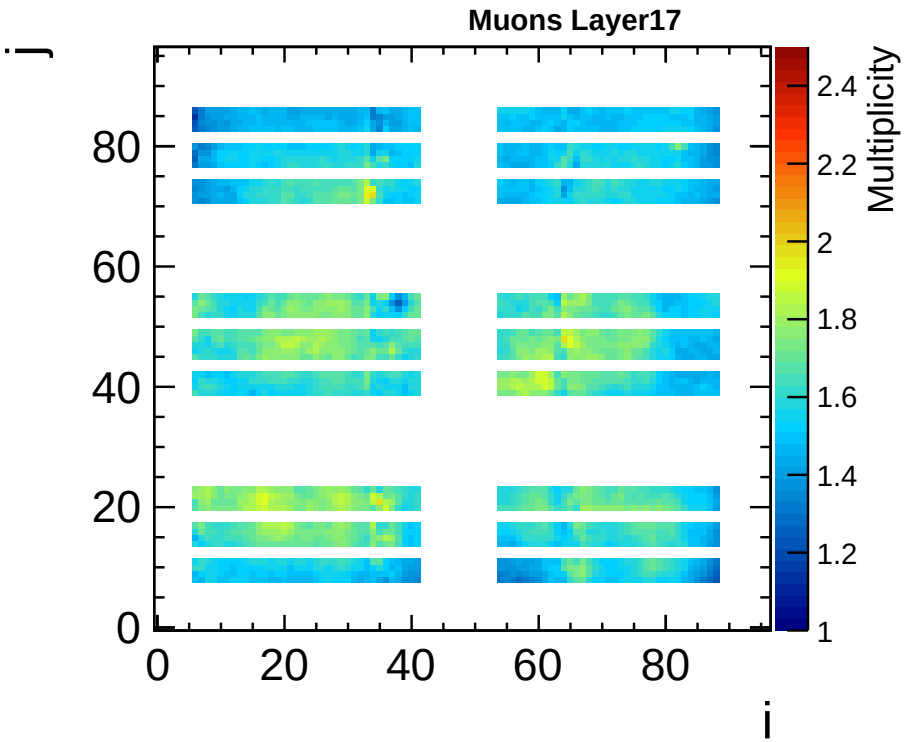
Dime for size reference

- Opened several modules to investigate cause of efficiency drop
- Front end board pressed down on left side ⇒ **significantly warped** boards
- Boards used to be perfectly flat, effect developed over time
- Similar warping observed for boards in lab that were never operated in beam

Efficiency



Multiplicity



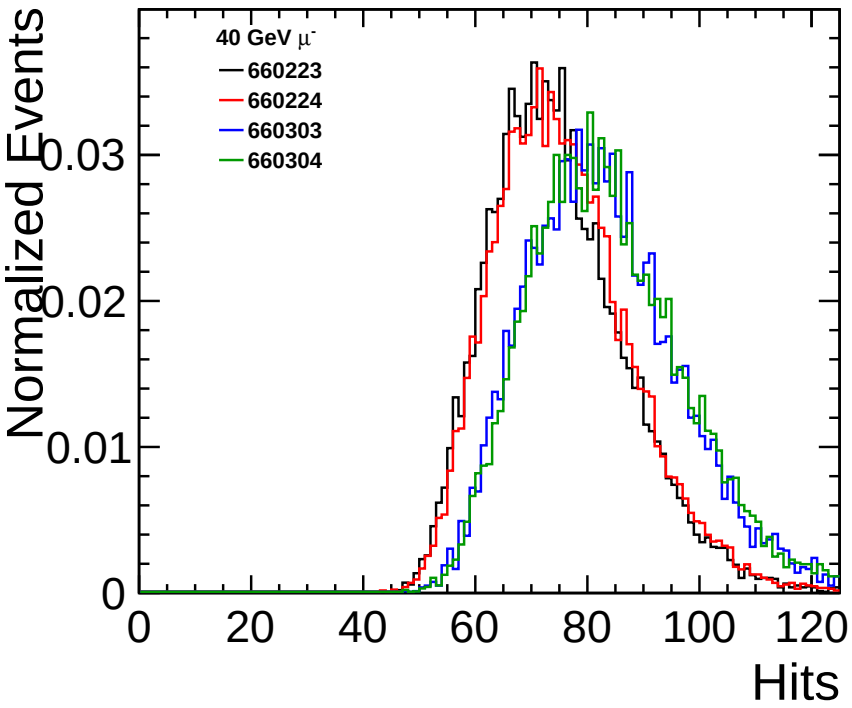
- Remove frontend board boundaries for final cleaning
- These are the regions used for tuning of digitization
- Average: $\epsilon_0 = 95.3\%$, $\mu_0 = 1.61$ (**Fully Cleaned**)

Calibration Procedure

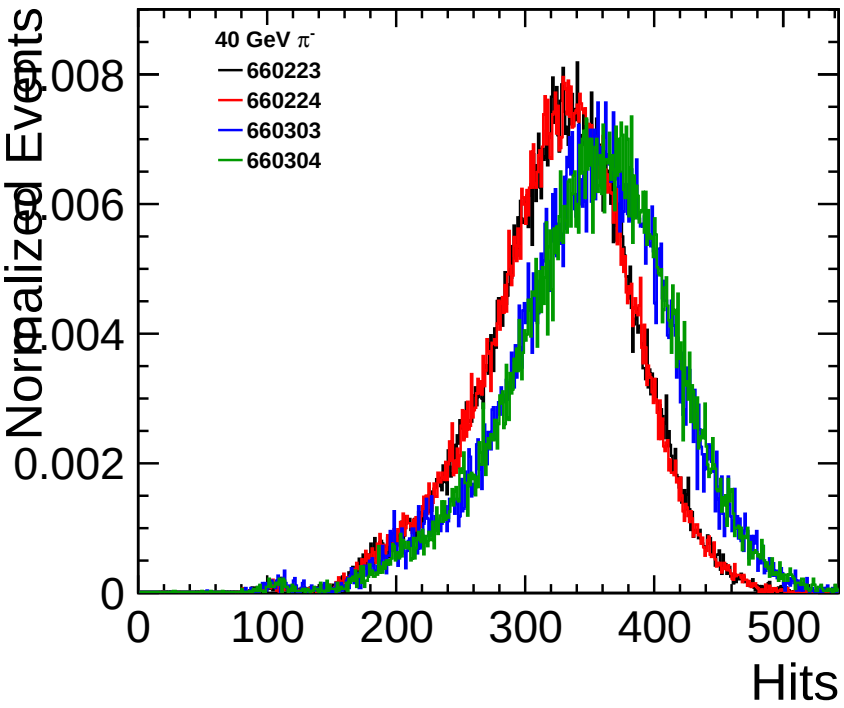
- Correct each hit for its local efficiency and multiplicity to nominal values:
$$N^{\text{calibrated}} = \sum_i^N \frac{\mu_0\ \epsilon_0}{\mu_i\ \epsilon_i}$$
- μ_0 and ϵ_0 are determined from the respective regions in the muon runs
- μ_i and ϵ_i are determined for each module if possible (more than 100 entries)
$\Rightarrow$ works well only for central module
- Use cleaned regions $\rightarrow$ "cleaned calibration" (**averages over central dip**)
- Use fully cleaned regions $\rightarrow$ "fully cleaned calibration" (**ignores central dip**)

Response at 40 GeV

Muons



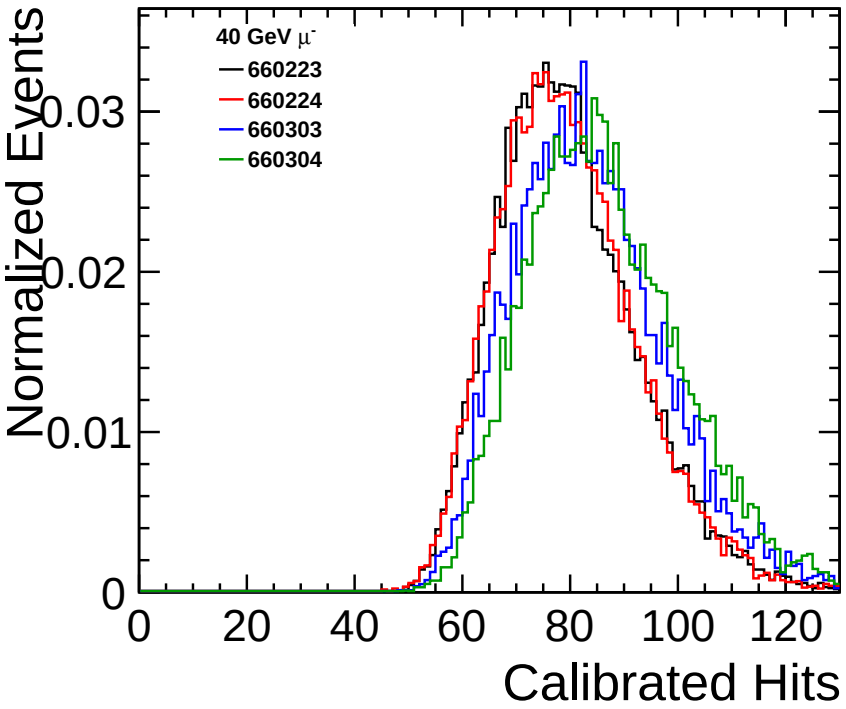
Pions



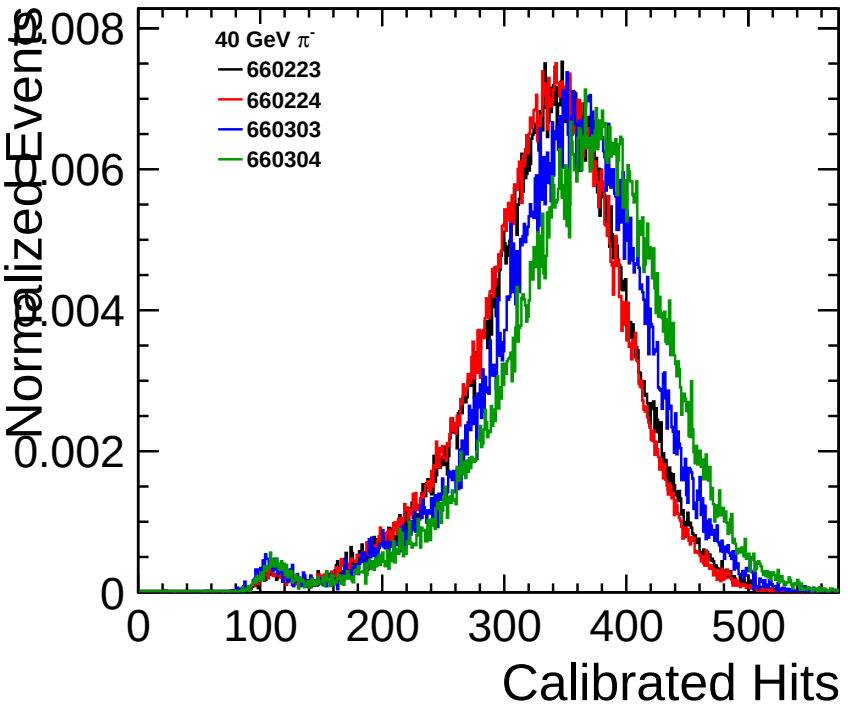
- 2 sets of runs taken at same beam momentum and significantly different temperature and pressure conditions
- Allows to quantify impact of the calibration

Response at 40 GeV - Fully Cleaned Calibration

Muons



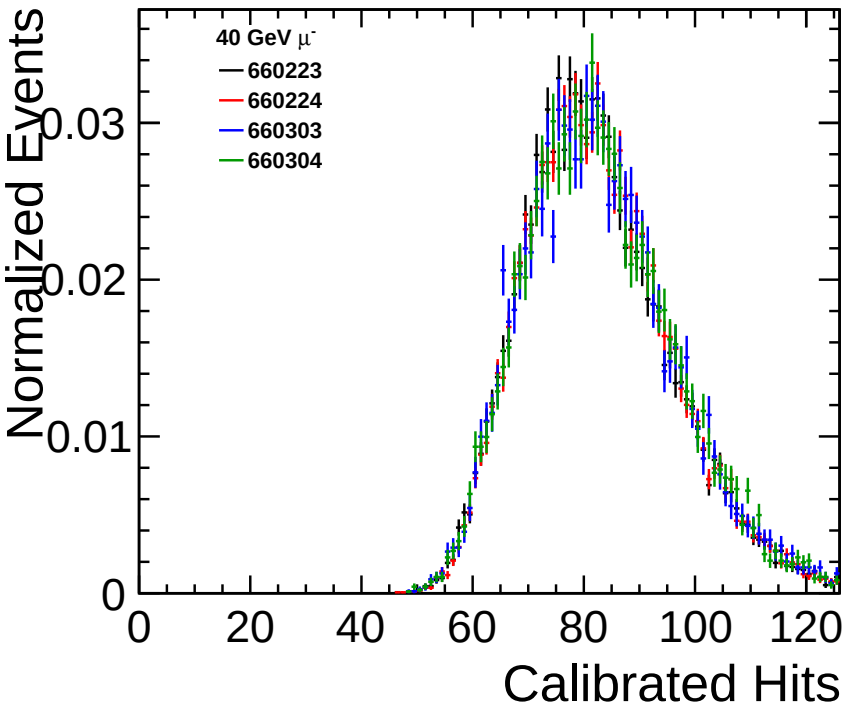
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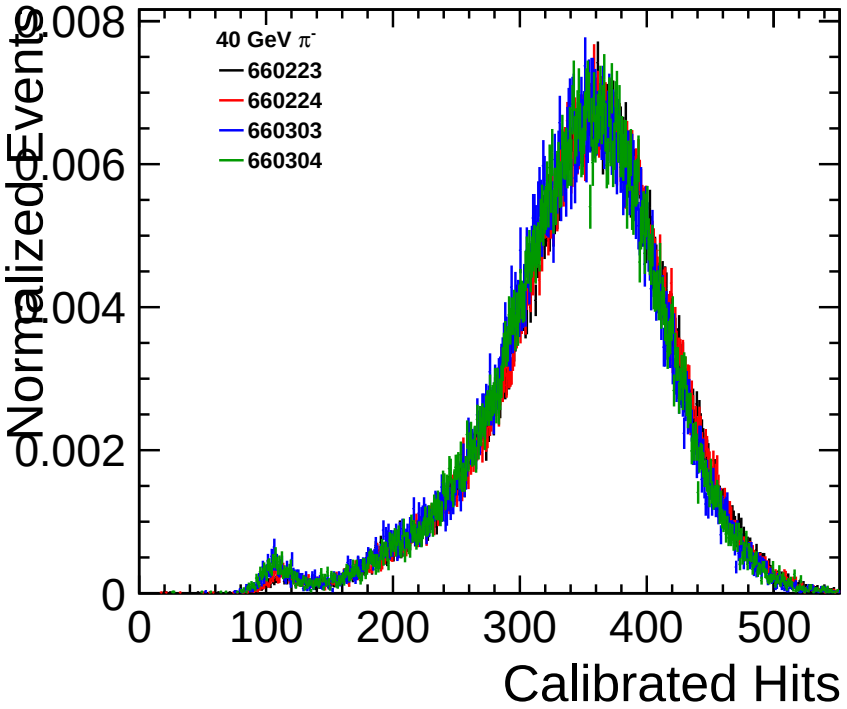
- Calibration improves the agreement but still slightly different response
- Dip in central region is present in data but not accounted for in calibration

Response at 40 GeV - Cleaned Calibration

Muons



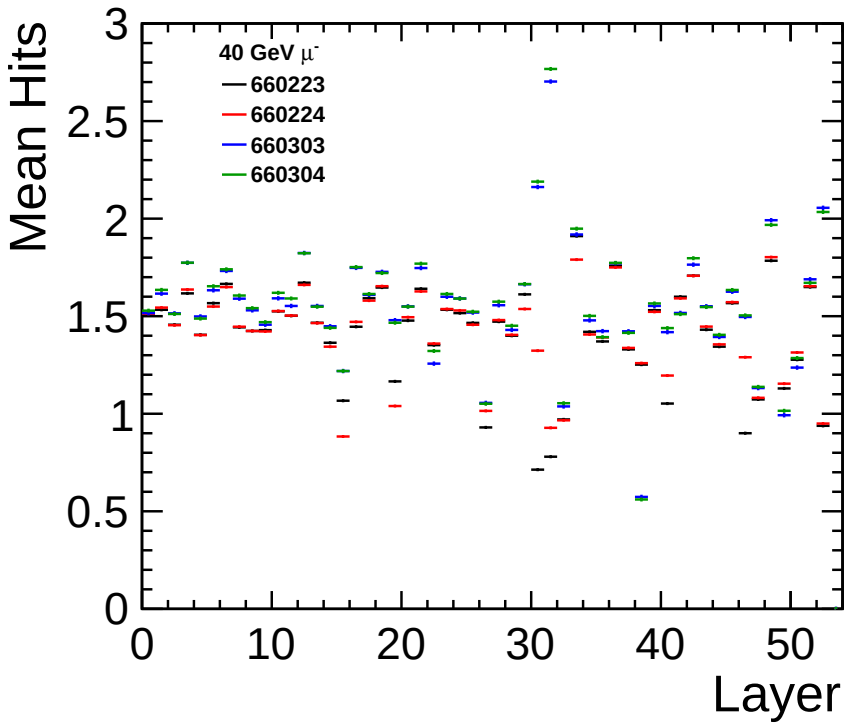
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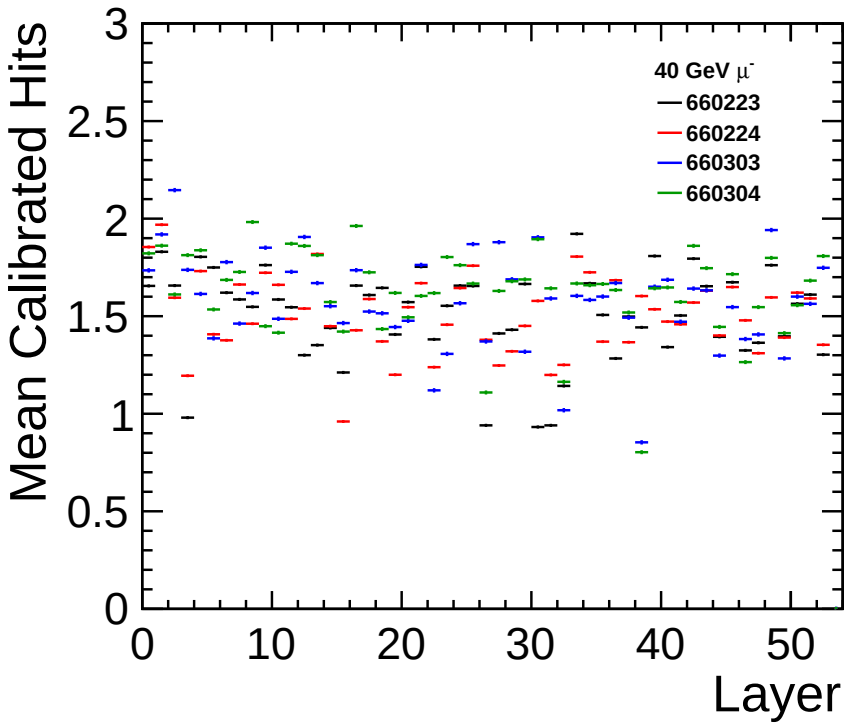
- Including the central region in the calibration gives best results
- Extracted calibration and data is weighted by local beam profile
- Most hits end up in the region with reduced efficiency
  $\Rightarrow$ **important to describe efficiency in centre well**

Longitudinal Profiles (40 GeV Muons)

Uncalibrated



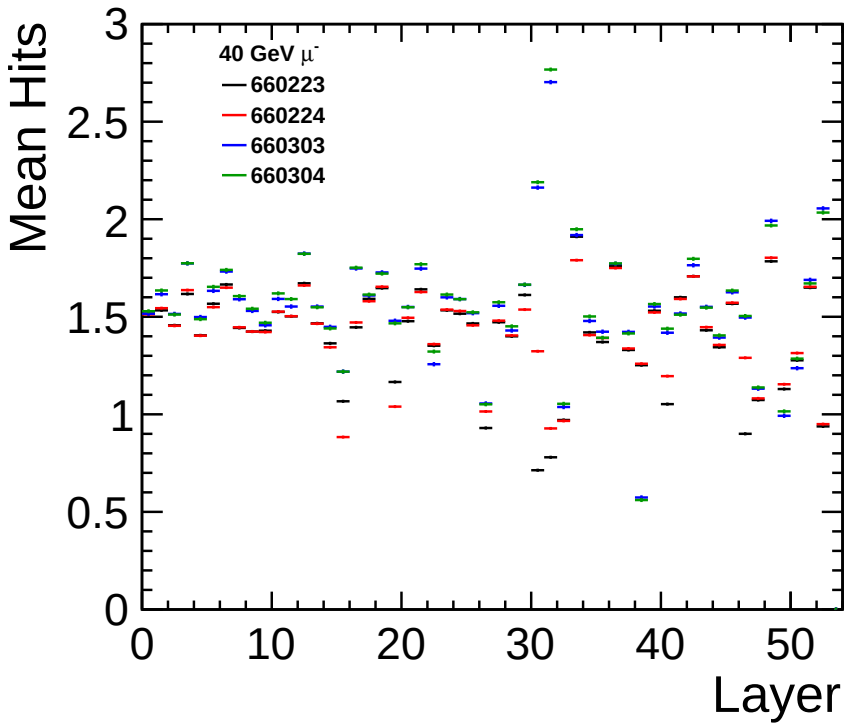
Fully Cleaned



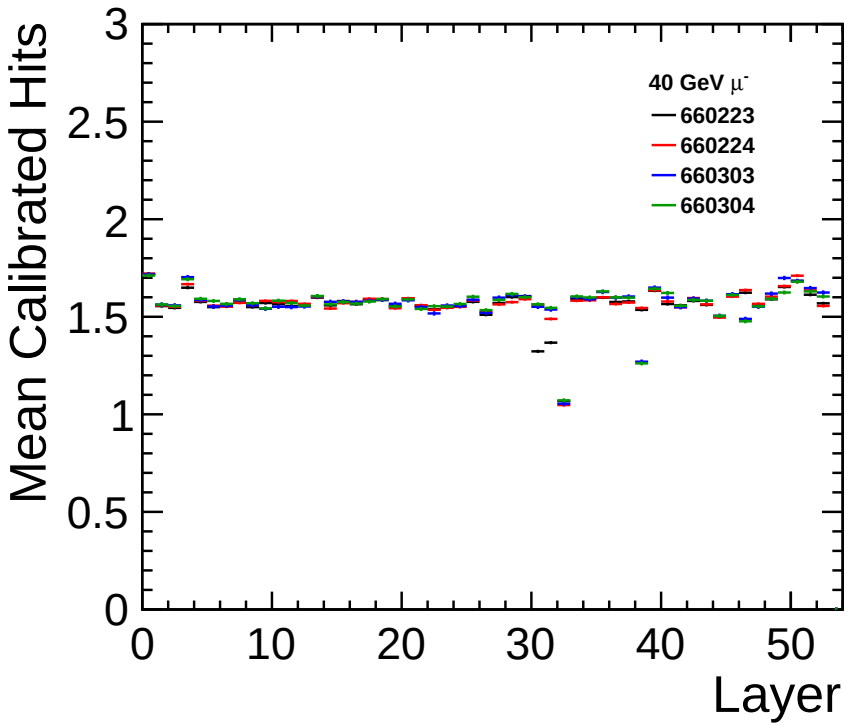
- Fully cleaned calibration not sensitive to response in most relevant region
- Limited statistics in fully cleaned regions ⇒ additional fluctuations

Longitudinal Profiles (40 GeV Muons)

Uncalibrated



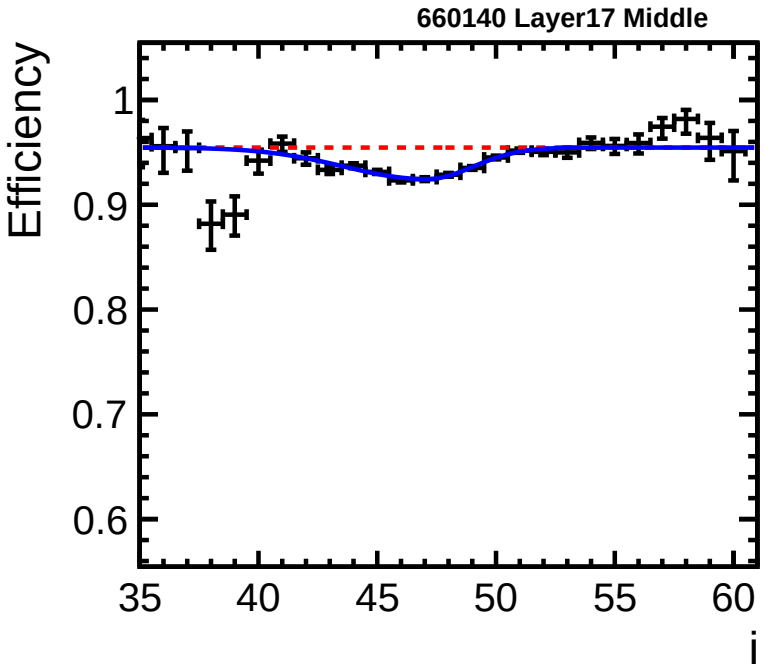
Cleaned

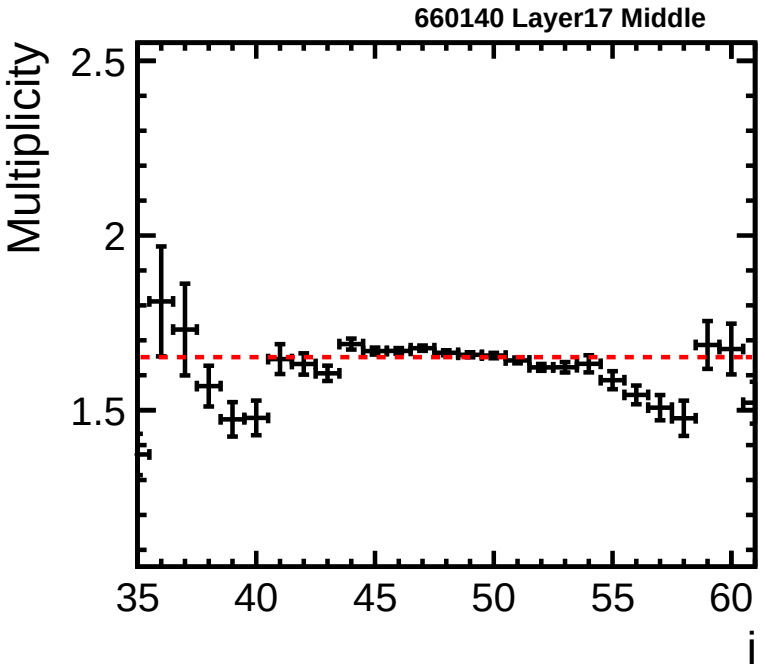


- Excellent correction of layer-to-layer fluctuations when including centre
- Some difficulties for layers with large correction factors

Local Calibration

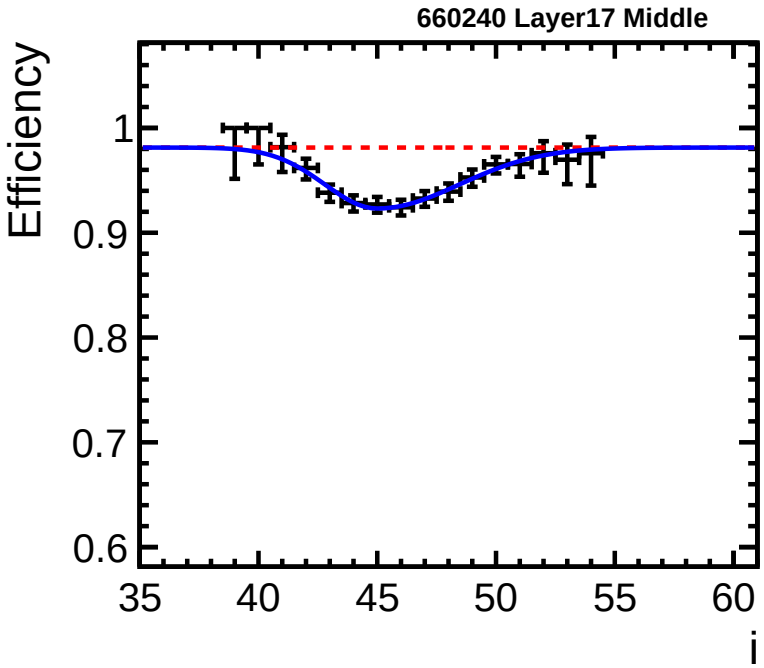
- Most runs have sufficient statistics to extract local efficiency for central i-bins
- Cleaned calibration remains as default for each module and layer
- Extract sidebands as fit to flat + asymmetric Gaussian distribution
  $\Rightarrow$ flat component determines module calibration if fit succeeds
- All i-bins with efficient uncertainty below 5% use local efficiency (95% CL)
- Single multiplicity value determined as mean value over module

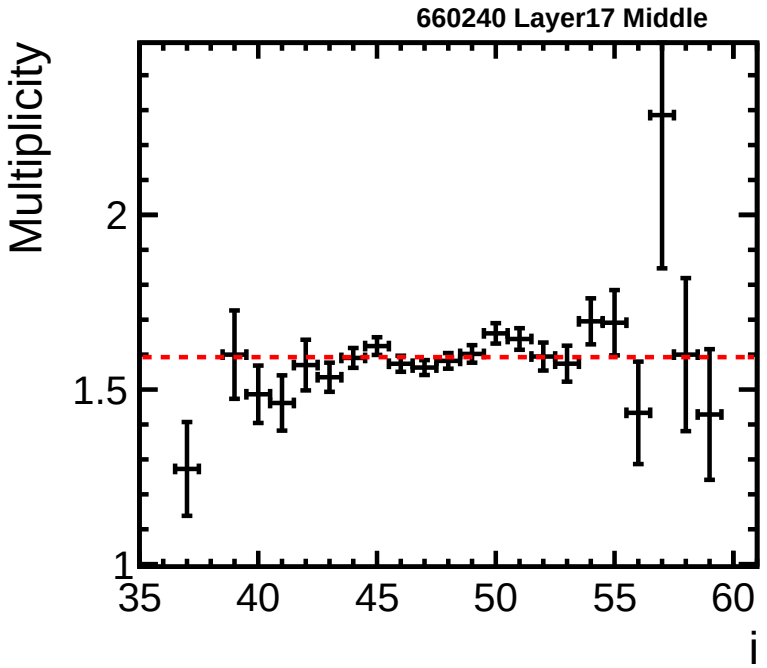




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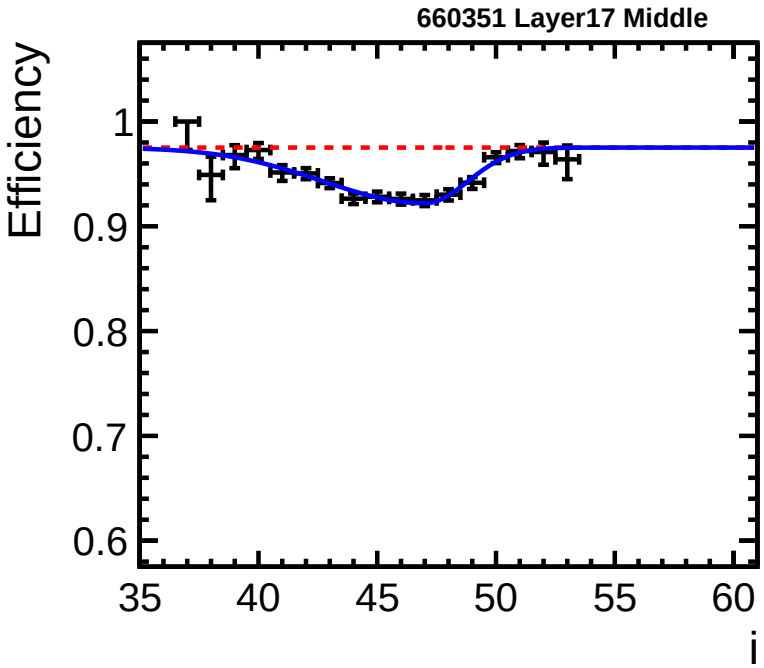
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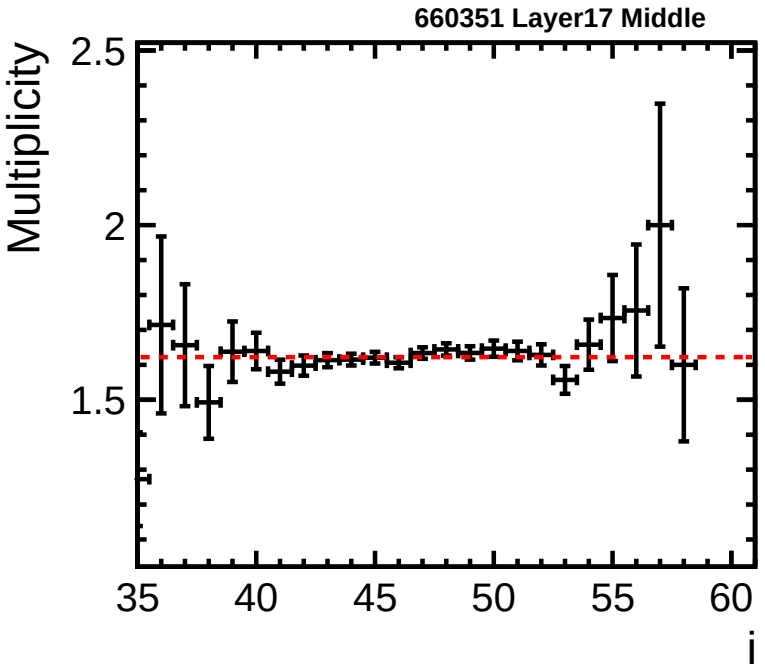




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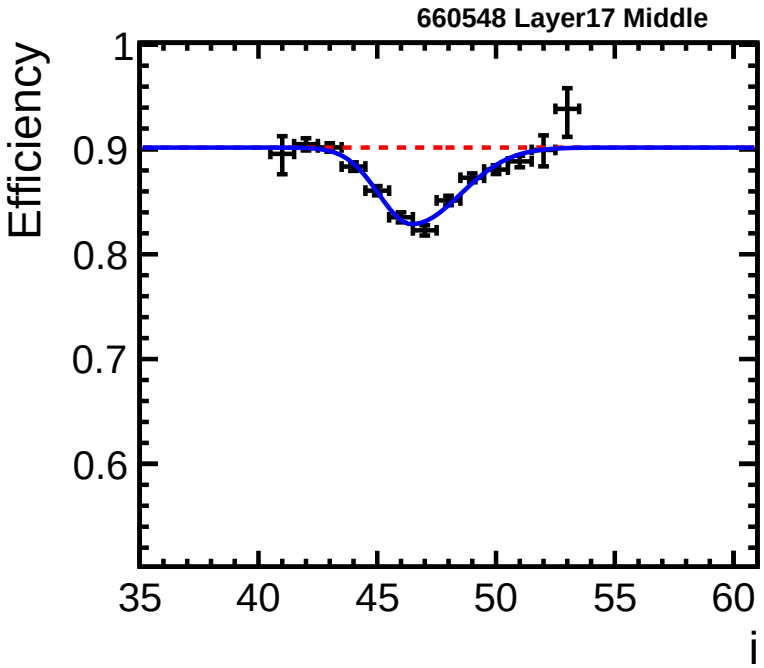
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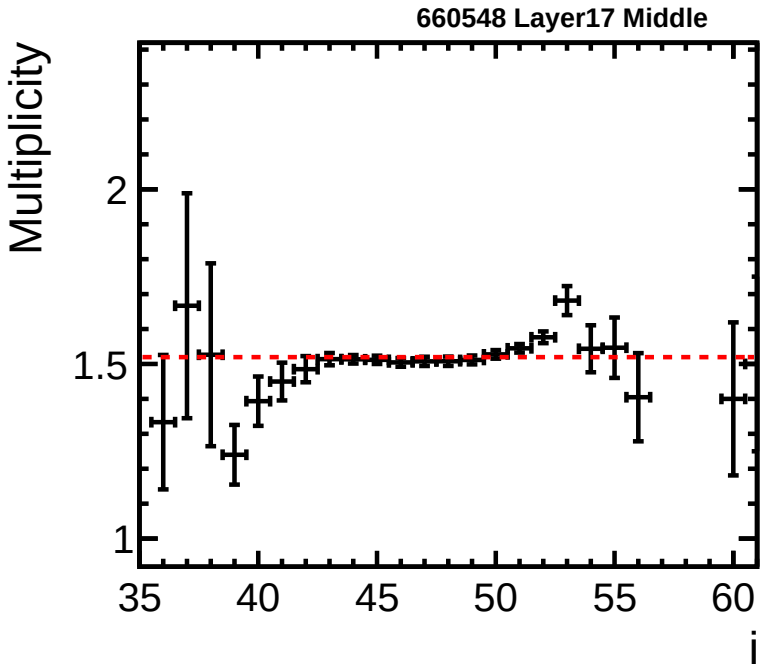




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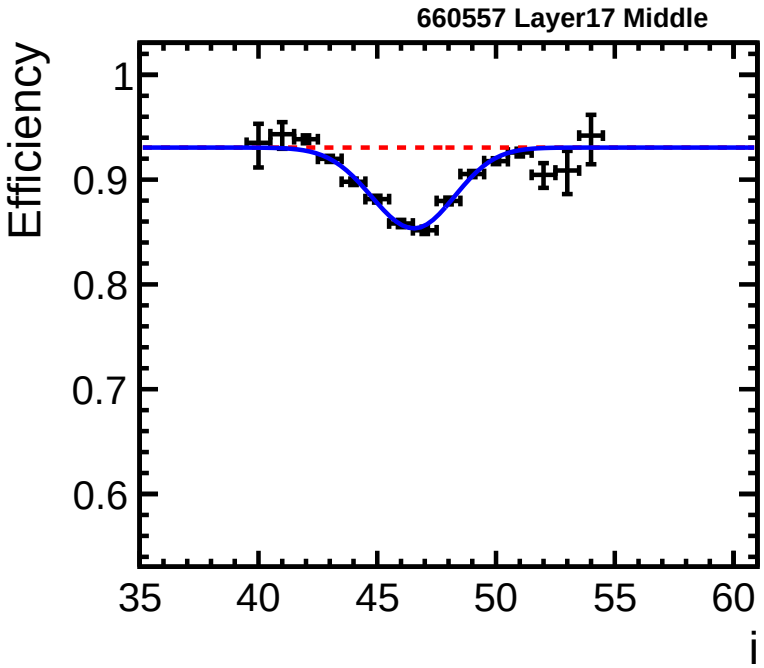
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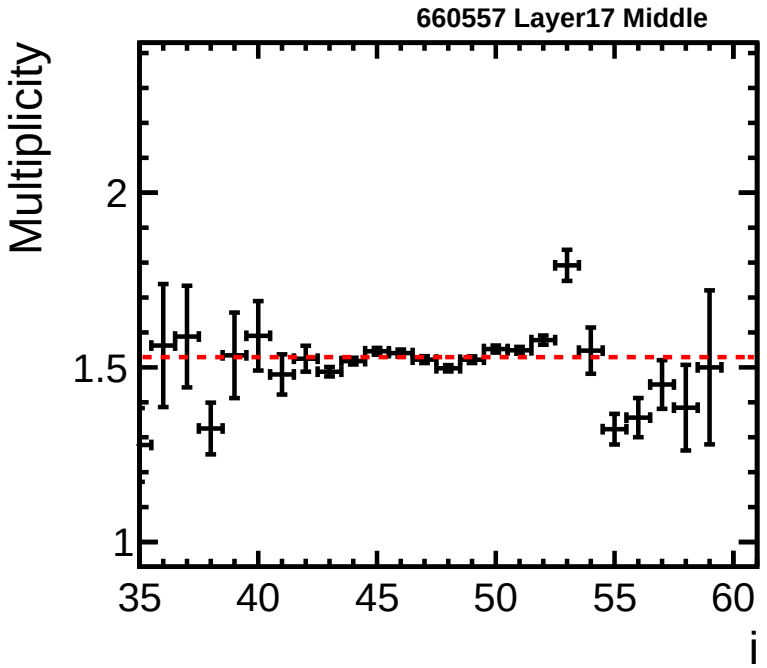




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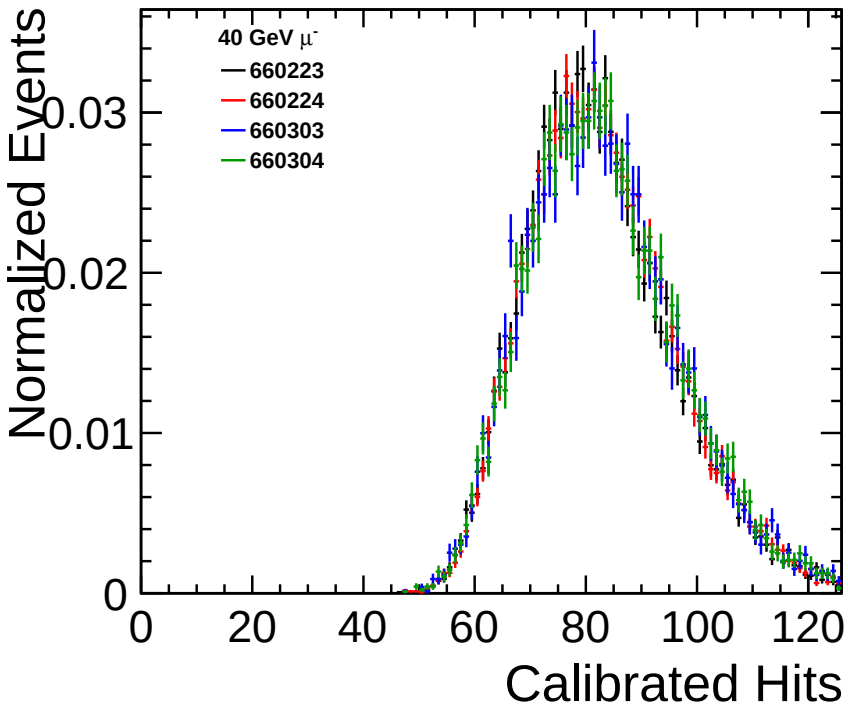
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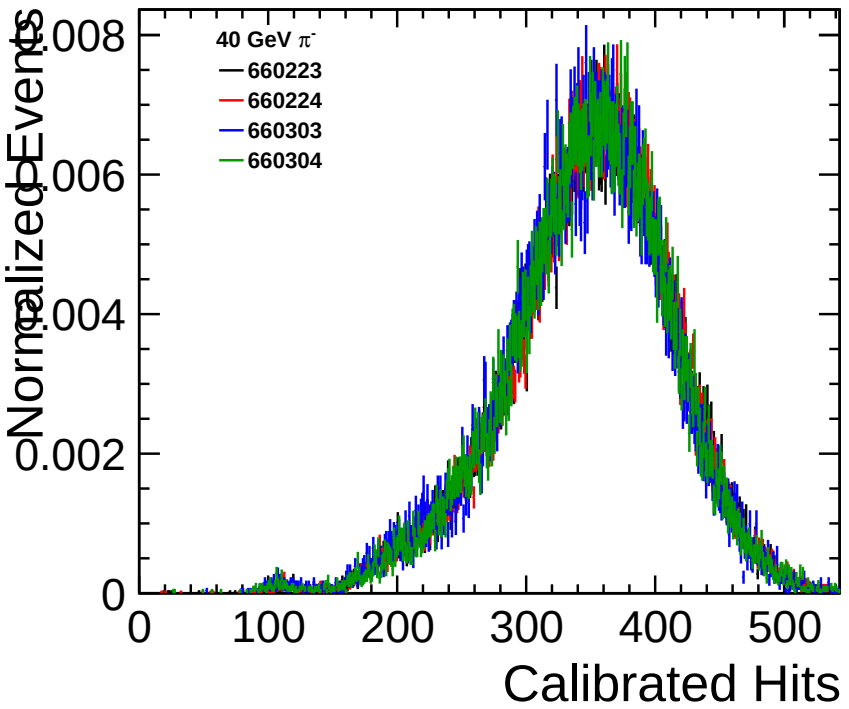


Response at 40 GeV - Local Calibration

Muons



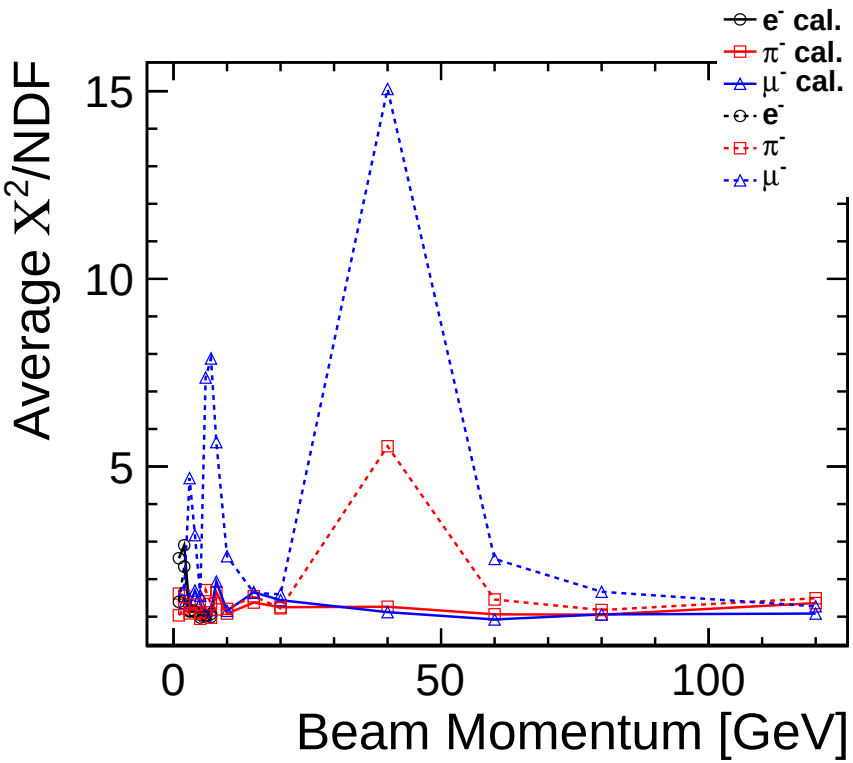
Pions



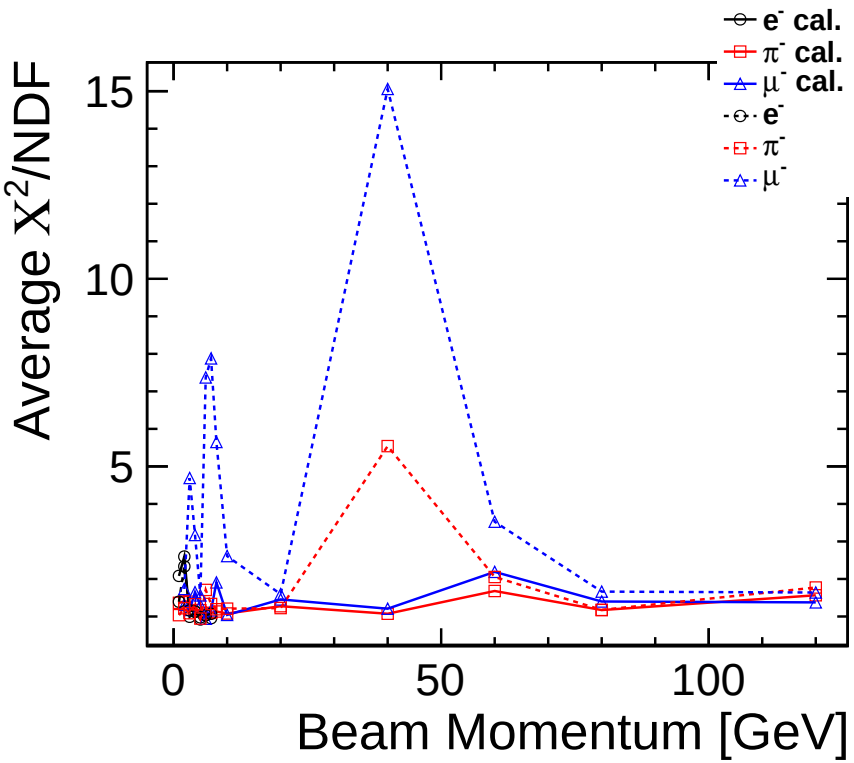
- Local calibration scheme normalizes responses similar to cleaned calibration

Calibration Quality

Cleaned Calibration



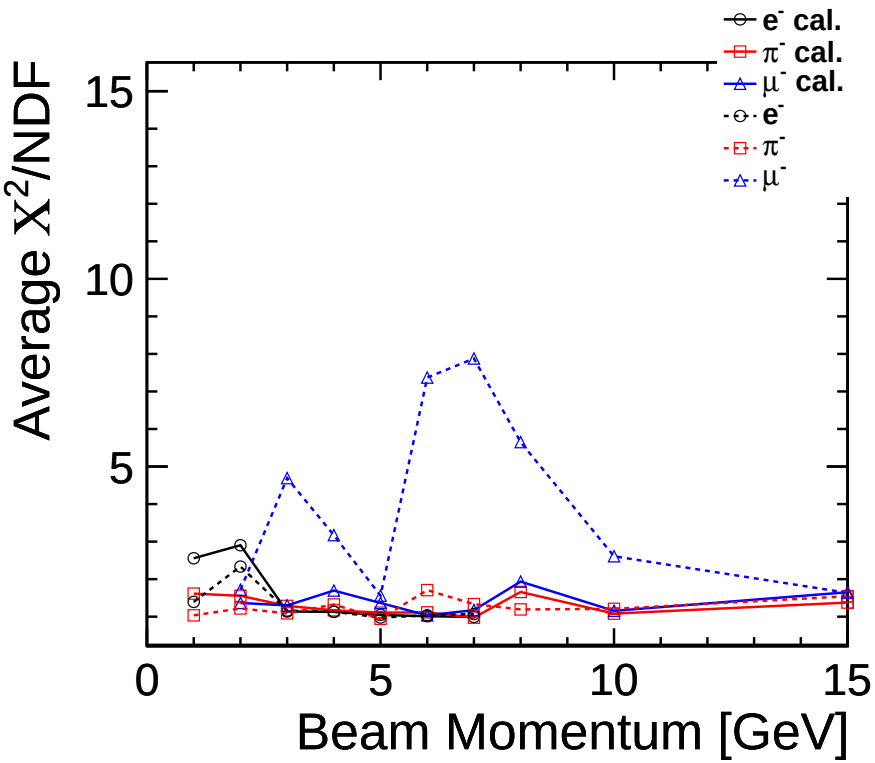
Local Calibration



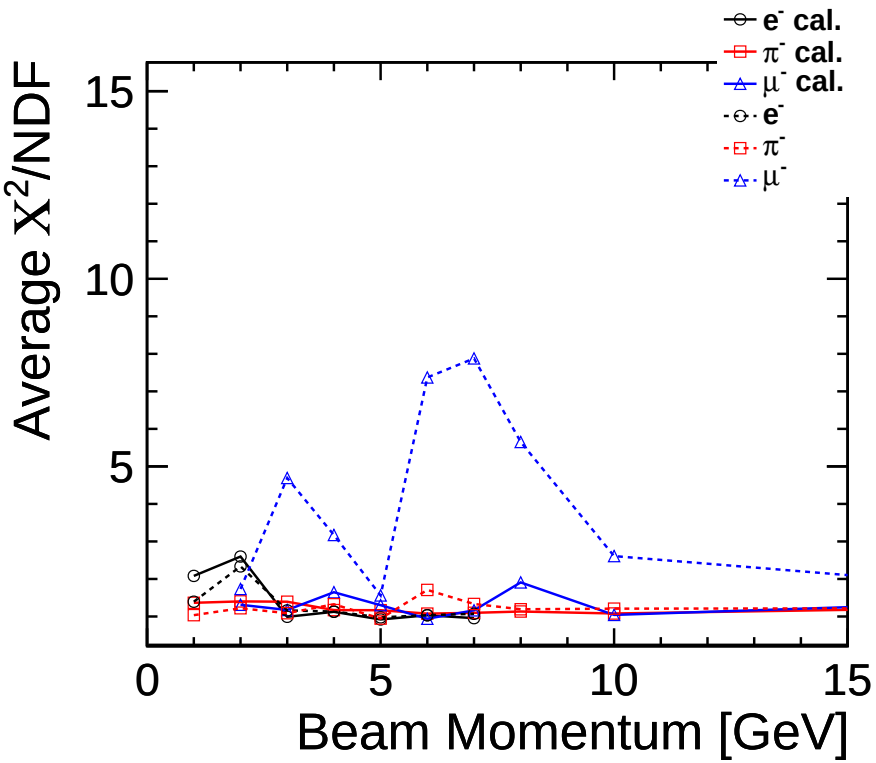
- Calculate χ^2 between all response histograms of all beam momenta
- Both calibrations look very good: χ^2/NDF close to 1 for all points

Calibration Quality

Cleaned Calibration



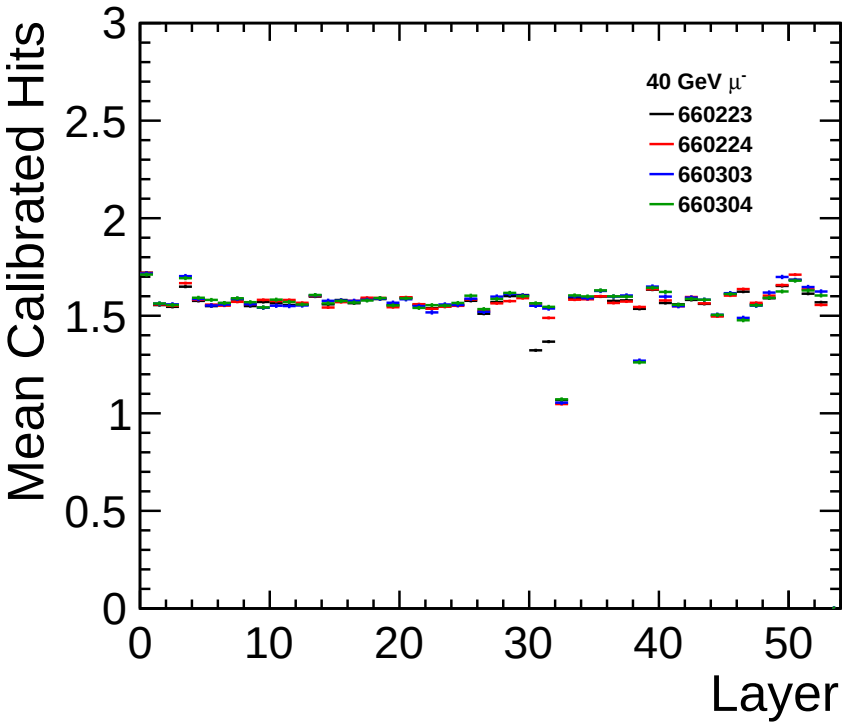
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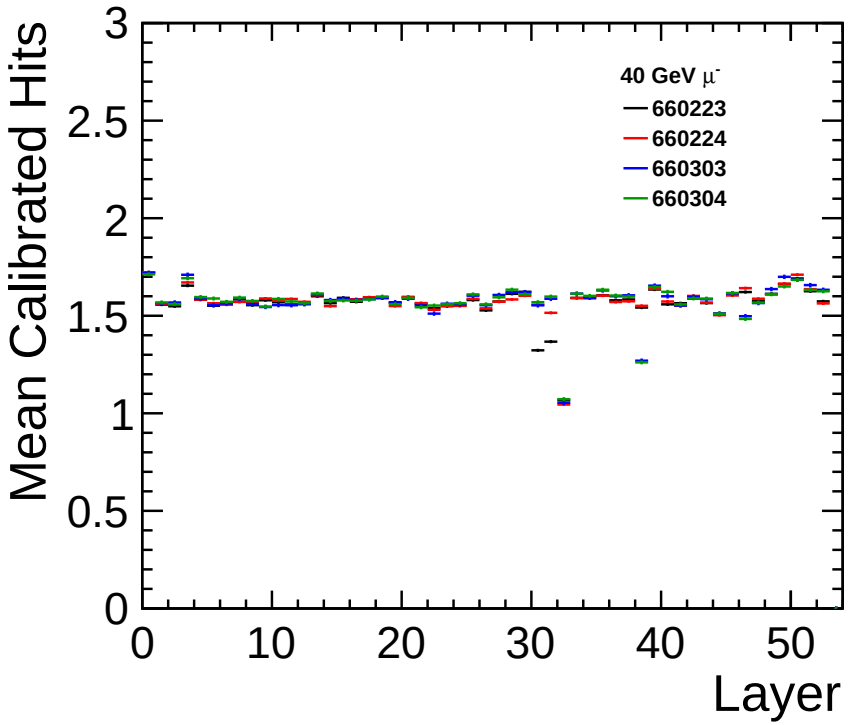
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Longitudinal Profiles (40 GeV Muons)

Cleaned Calibration



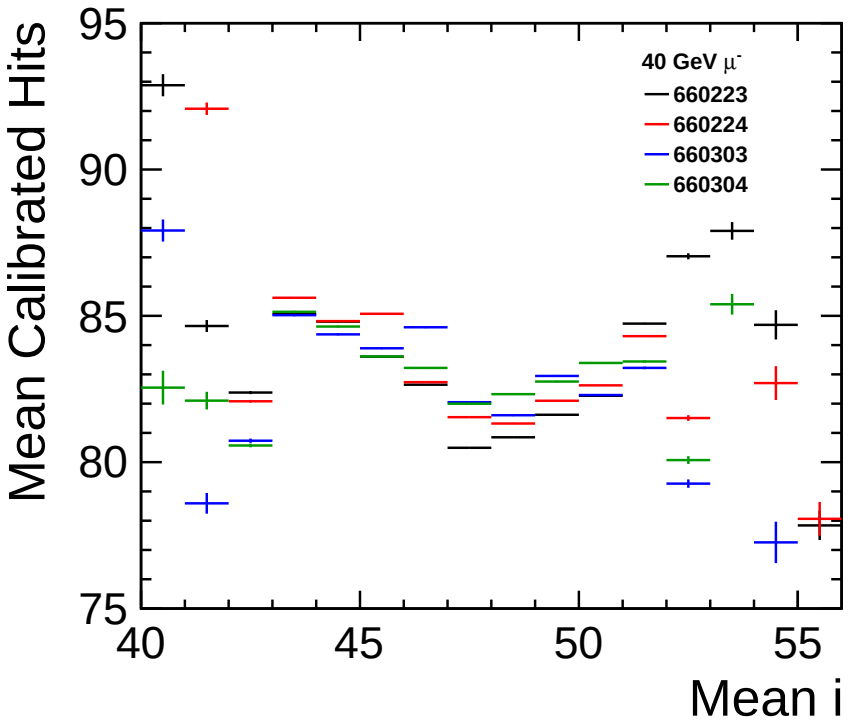
Local Calibration



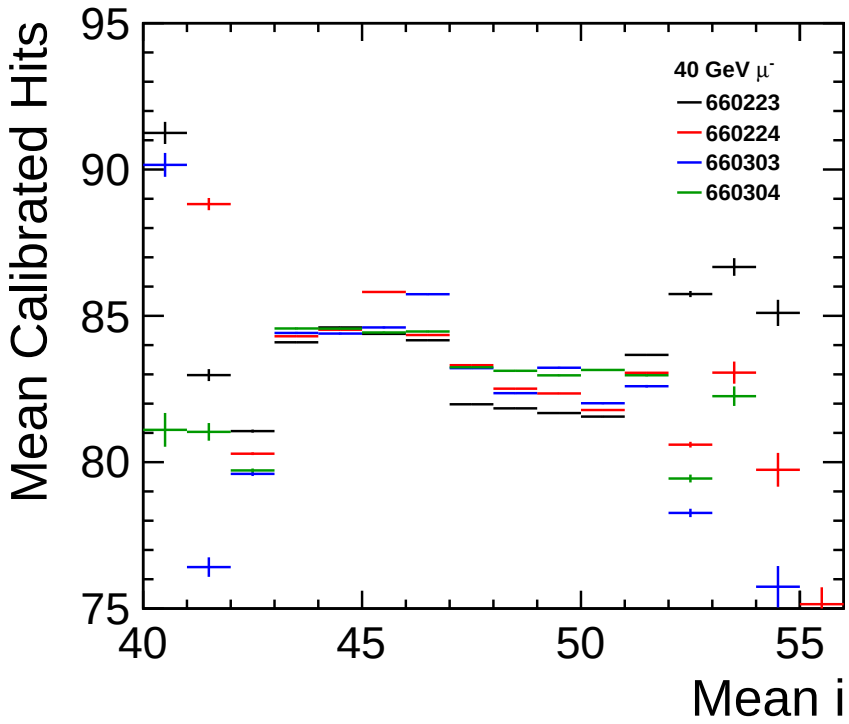
- Almost indistinguishable performance in correcting layer-to-layer fluctuations

Horizontal Dependence of Muon Response (40 GeV)

Cleaned Calibration

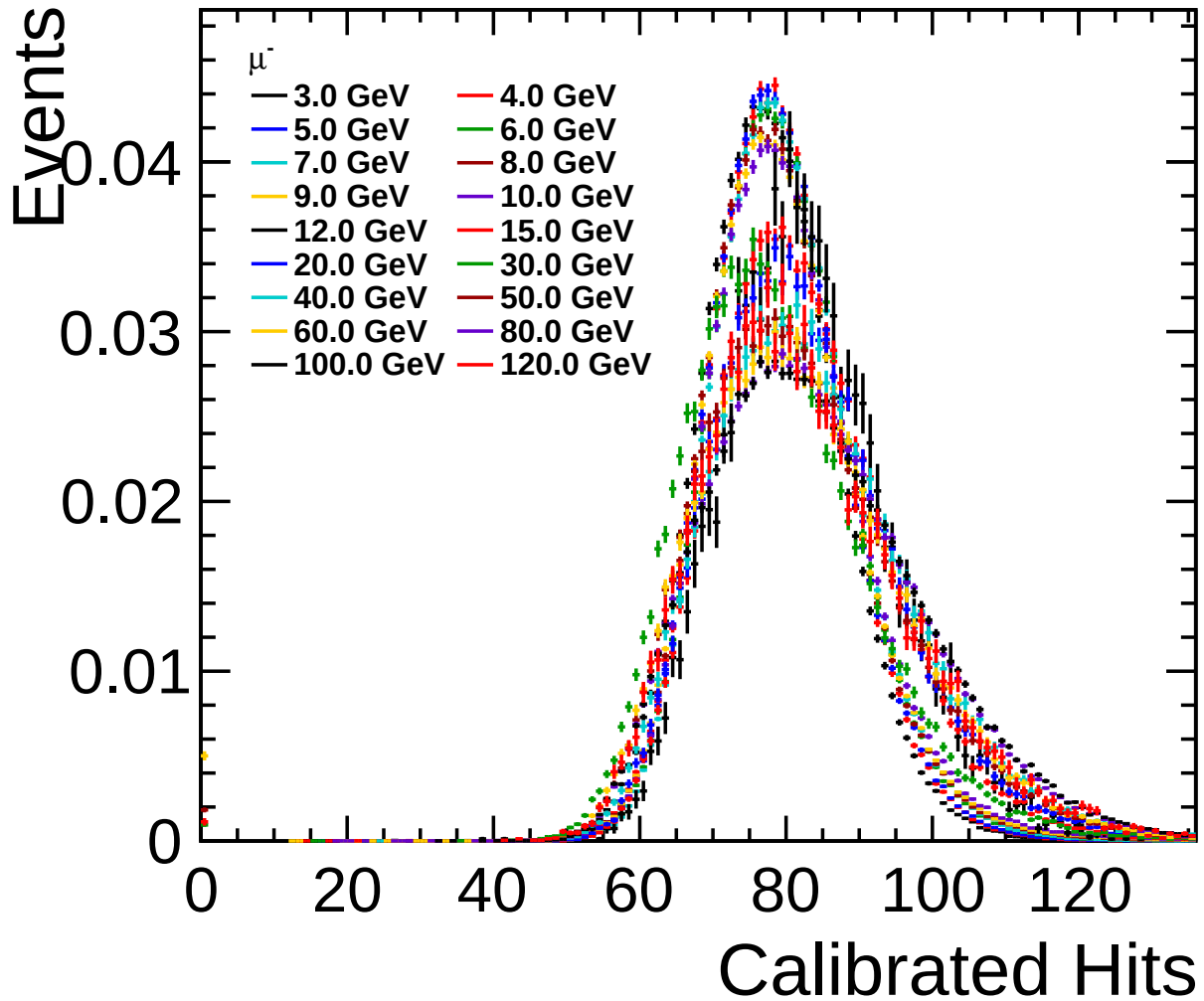


Local Calibration

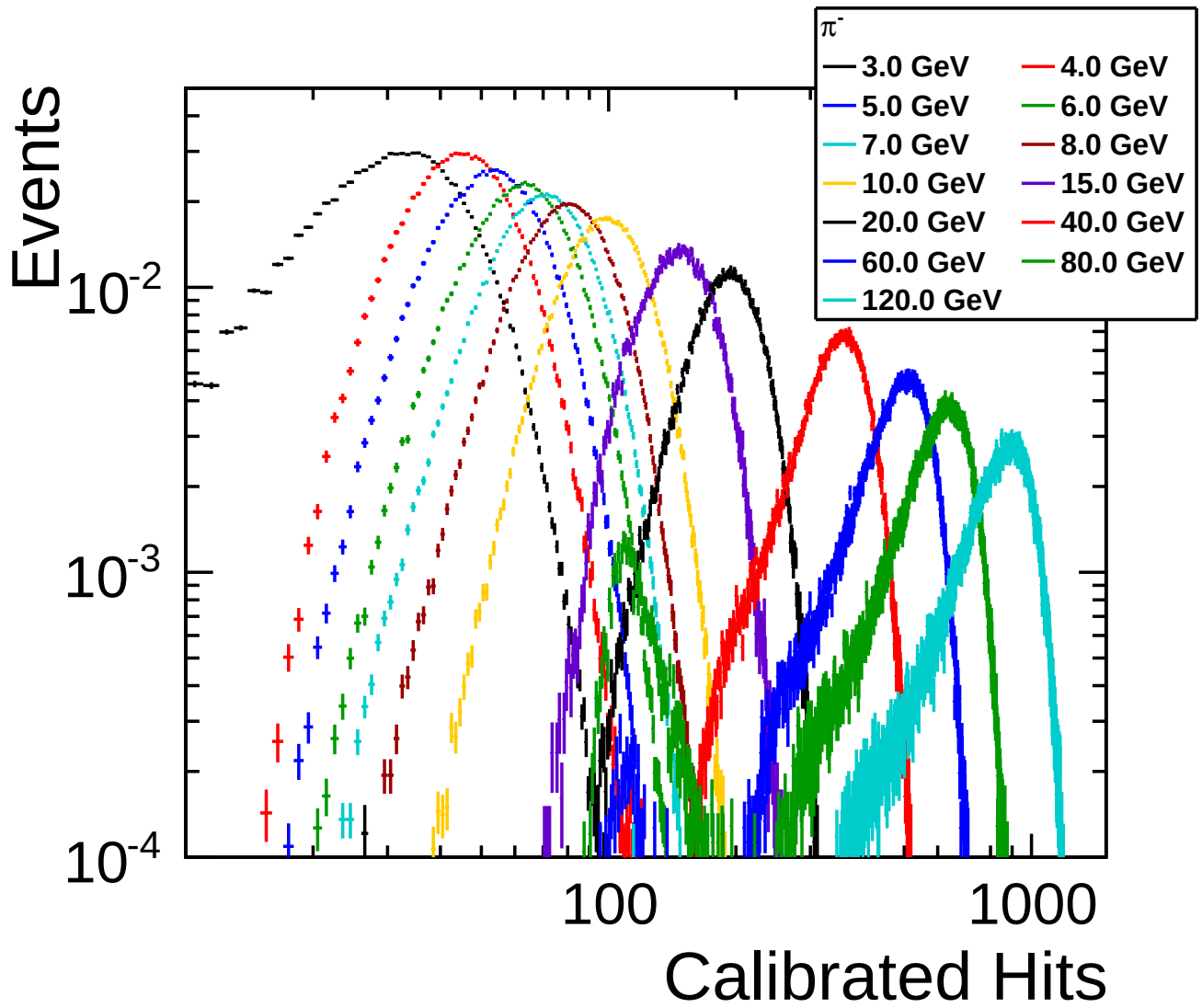


- Cleaned calibration does not remove horizontal dependence in response
- Local calibration removes dip in response
- Use local calibration scheme as default

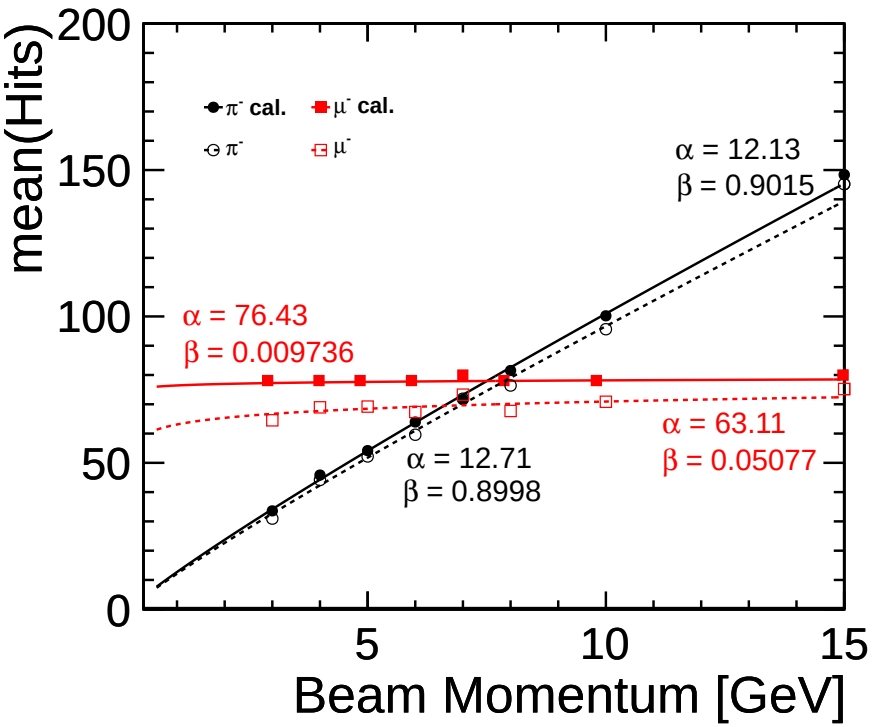
Muon Response (Local Calibration)

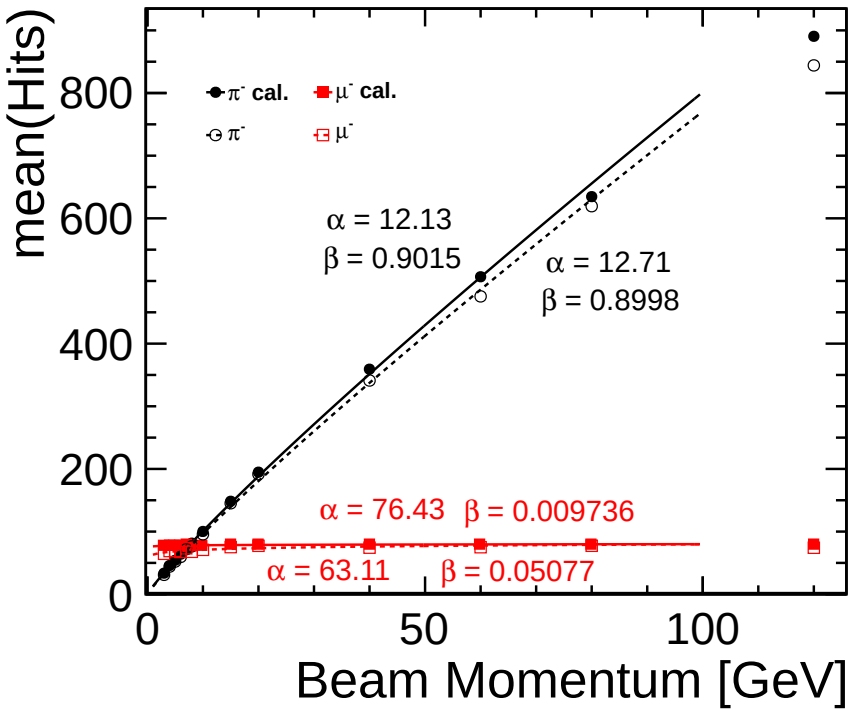


Pion Response (Local Calibration)



Linearity (Preliminary)





- Parametrize using $N = \alpha E^{\beta}$

Outline

1 Introduction

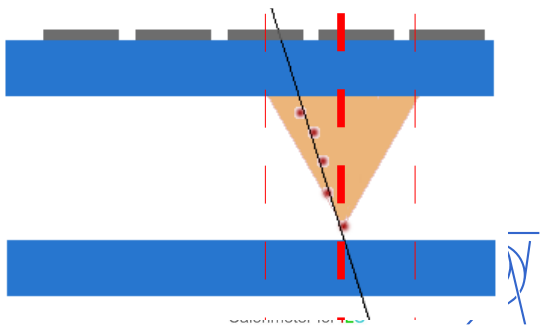
2 Calibration

3 Digitization (RPCSim)

4 Summary and Outlook

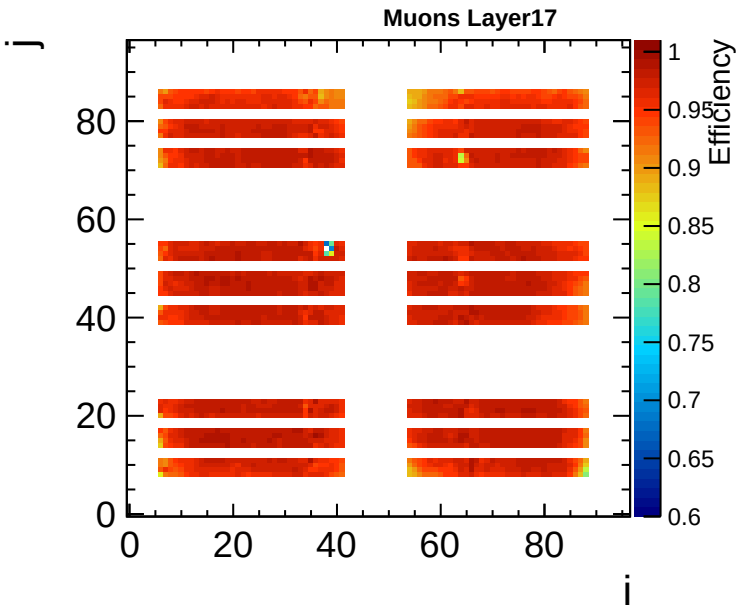
RPCSim (Marlin Version)

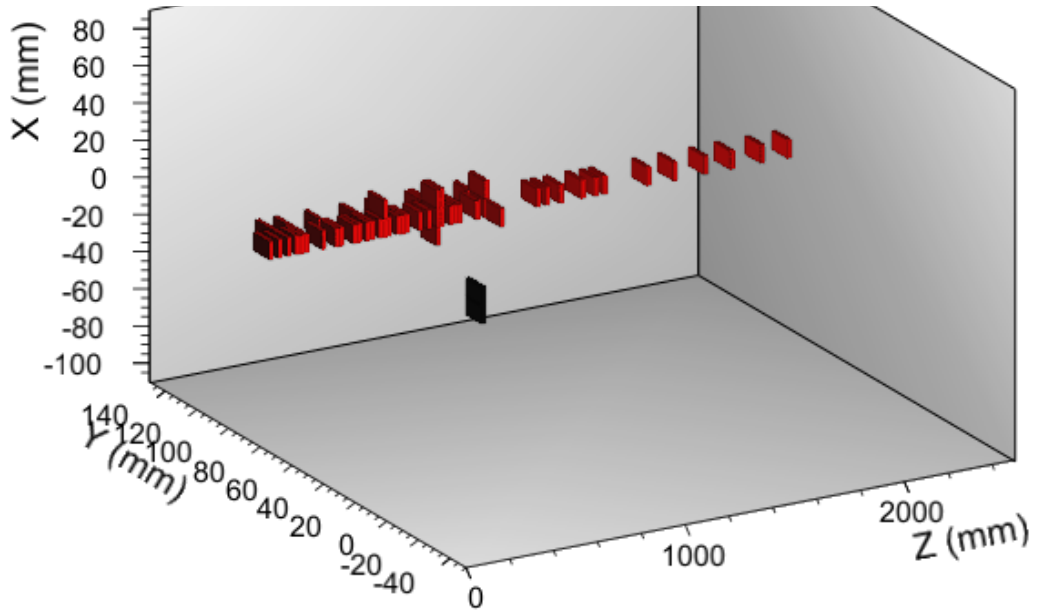
- Use all charge deposits generated by GEANT4 stored in SimCalorimeterHits
- Only allow one avalanche within distance cut d_{cut}, ignore other charge deposits
- Randomly generate total charge for each remaining deposit
  $\Rightarrow$ based on data from RPC with analog readout
- Correct generated charge by offset Q_0
- Lower effective total charge depending on distance to module boundary
- Spread charge according to model and collect charge on pads
  $\Rightarrow$ uses lookup from pre-calculated Monte Carlo integration
  - RPCSim3 (double exponential): $f(r) = Re^{-r/s_1} + (1-R)e^{-r/s_2}$
  - RPCSim4 (exponential): $f(r) = Re^{-r/s}$
  - RPCSim5 (double Gaussian): $f(r) = Re^{-r^2/(2{\sigma_1}^2)} + (1-R)e^{-r^2/(2{\sigma_2}^2)}$
  - RPCSim6: $f(r) = \left(A + r^2\right)^{-3/2}$
- Create CalorimeterHit for each pad over threshold t



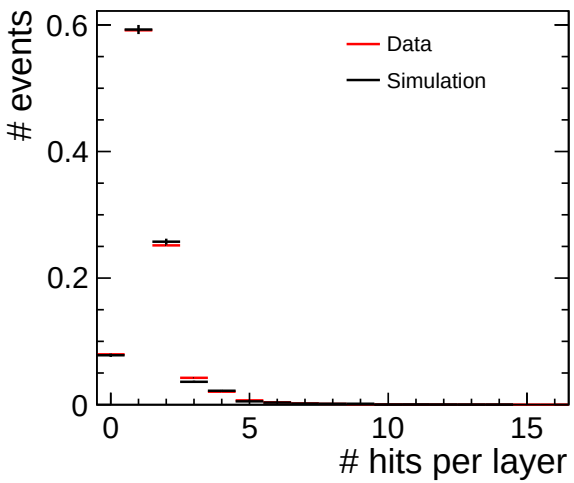
Tuning of the Digitization with Muons

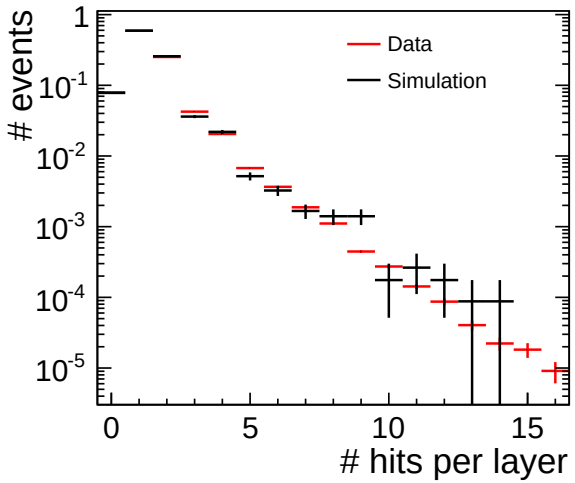
- Use fully cleaned regions from muon run (660357) as target
- Muon Monte Carlo with a Gaussian spread similar to angular spread in data
- Remove cells from both data sets which have been identified as dead in data
- Pre-select clean muon events using Hough transform $\Rightarrow$ remove other hits
- Digitize data with varying Q_0, t and charge spread parameters
- Response from MiPs not sensitive to d_{cut}
- Compare hits / layer distributions for Monte Carlo and data and minimize χ^2

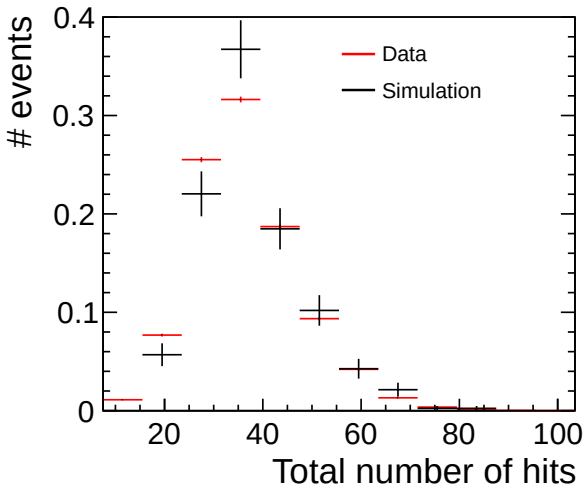




Preliminary Tuning (RPCSim3)

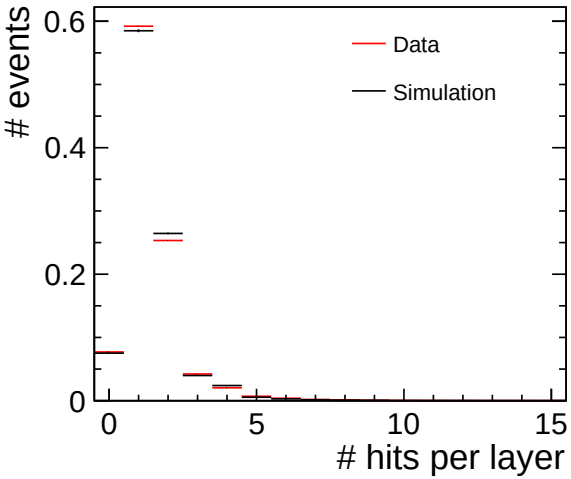


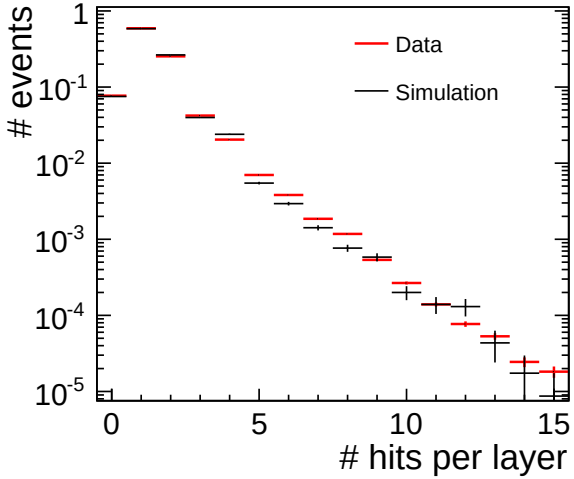


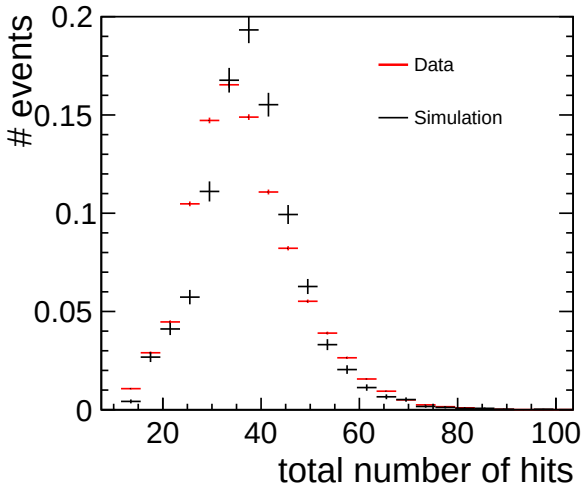


- Very good description of peak **and** tail
- $Q_0 = 0.15\,\text{pC},\ t = 0.34\,\text{pC},\ d_{\text{cut}} = 1.8\,\text{mm}$
- $R = 0.2,\ S_1 = 0.1\,\text{mm},\ S_2 = 2\,\text{mm}$
- Discrepancies for distribution of total hits $\Rightarrow$ Removal of large number of cells requires a very careful reproduction of beam profile in Monte Carlo
- Only use main stack hits after layer 5

Preliminary Tuning (RPCSim5)







- Good description of peak **and** tail
- $Q_0 = 0.175\,\text{pC},\ t = 0.275\,\text{pC},\ d_{\text{cut}} = 1.8\,\text{mm}$
- $R = 0.25,\ \sigma_1 = 0.2\,\text{mm},\ \sigma_2 = 3.25\,\text{mm}$
- Discrepancies for distribution of total hits $\Rightarrow$ Removal of large number of cells requires a very careful reproduction of beam profile in Monte Carlo
- Only use main stack hits after layer 5

Outline

1 Introduction

2 Calibration

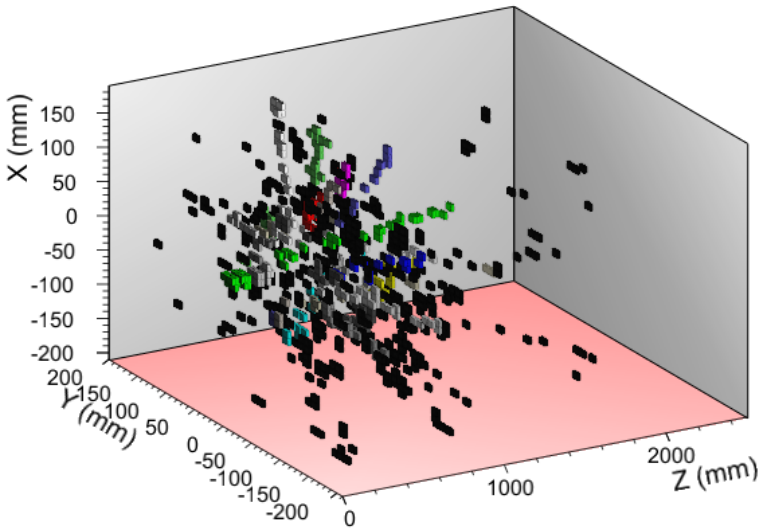
3 Digitization (RPCSim)

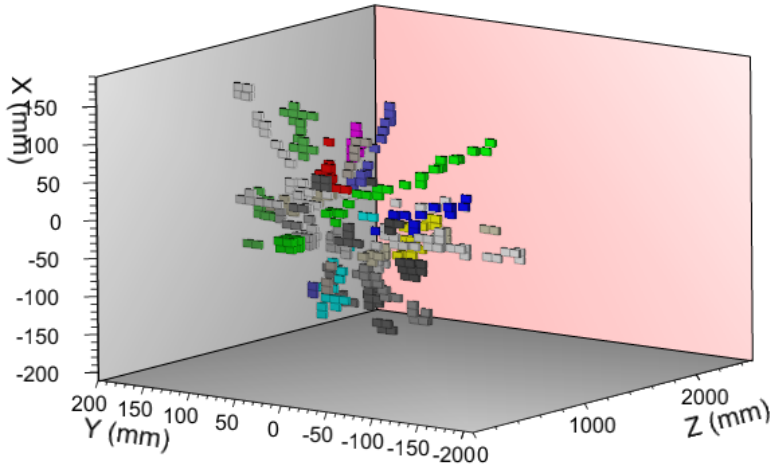
4 Summary and Outlook

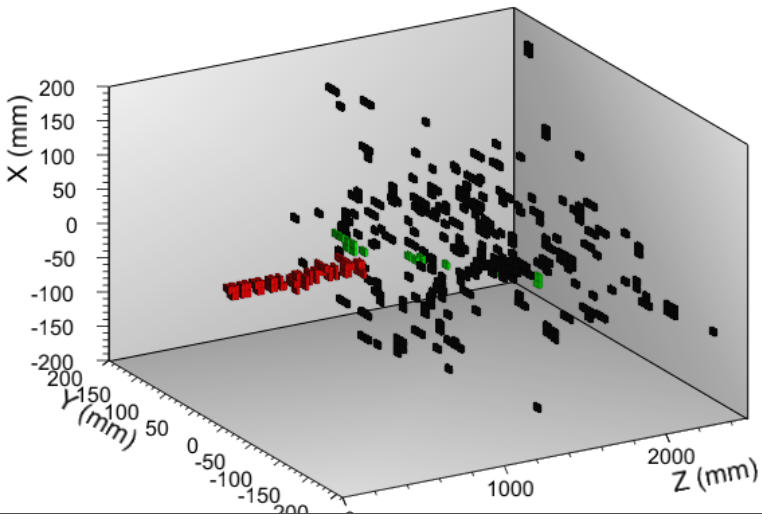
Summary and Outlook

- W-DHCAL data needs to be corrected for run and layer conditions
- Multiplicities and efficiencies can be determined for each run from muons
- Large efficiency drop in centre of modules (not present in Fe-DHCAL data)
  $\rightarrow$ different for each layer and run
- Developed local calibration scheme to normalize data
- RPCSim implemented as Marlin processor
- Hough transform based track finding implemented in Marlin
  $\rightarrow$ muon identification and study of shower structure
- Very promising preliminary results from digitization tuning with muons
- Additional work on Monte Carlo needed to understand some details

Bonus: Hough Transform







- Implemented Marlin processor to find tracks using Hough transform
- Identify sub-structure in showers
- Identify kinks in muon events