Status of W-DHCAL Analysis

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

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CLICdp Collaboration Meeting

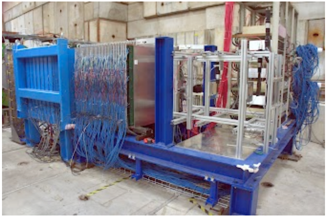
Outline

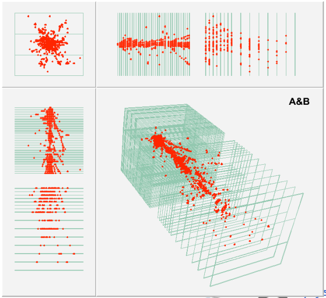
1. Introduction
2. Calibration
3. Simulation and Digitization (RPCSim)
4. Summary and Outlook

Outline

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 $\sim$ 30 million events recorded





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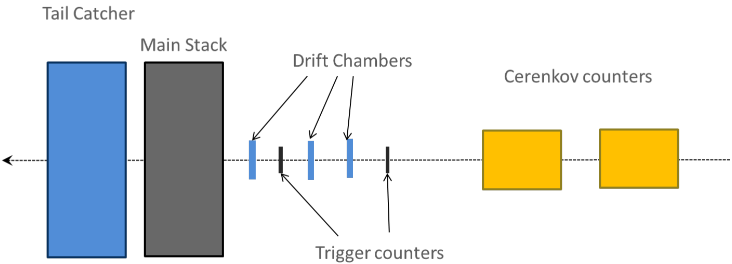
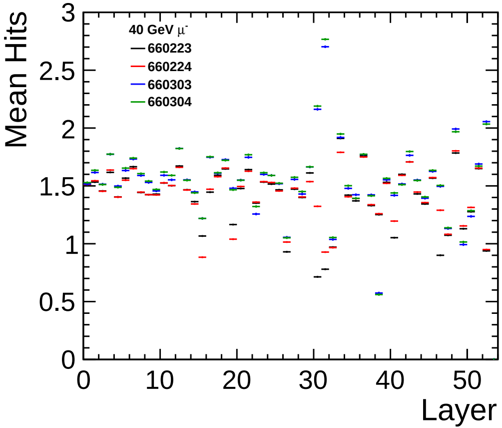


- 39 layers W-DHCAL + 15 layers Fe-DHCAL
- $10 \times 10\,\mathrm{cm}^2$ scintillator triggers ($30 \times 30\,\mathrm{cm}^2$ for dedicated muon runs)
- Three wire chambers ⇒ beam profile
- Two Cerenkov counters ⇒ particle identification

Outline

Goal of Calibration

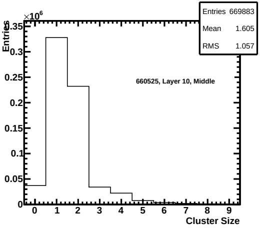
- DHCAL only measures number of hits $\Rightarrow$ control efficiency (ϵ) and multiplicity (μ)
- Depends on temperature, pressure, voltage, ...
- Remove **layer-to-layer** and **run-to-run** fluctuations
- Determine nominal efficiency (ϵ_0) and multiplicity (μ_0) for digitization tuning

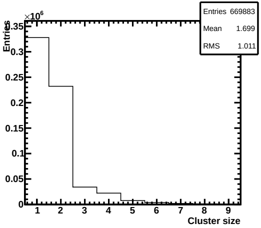


Determination of Efficiency and Multiplicity

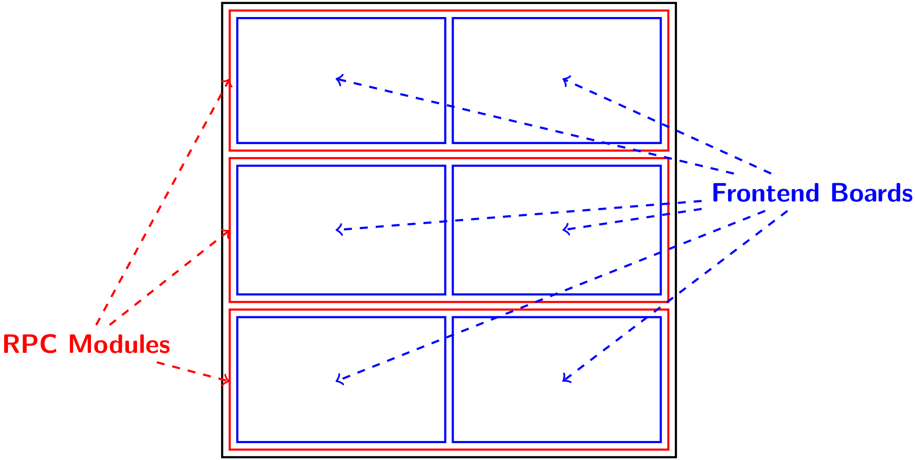
- Lose **pre-selection for muon events** based on number of active layers (> 30) and total number of hits (< 150)
- For each layer of interest **find mip stub candidates** in neighboring layers (± 3 layers, min 4 valid clusters)
- Only use clusters with 3 or less hits for mip stub candidates
- **Straight 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)



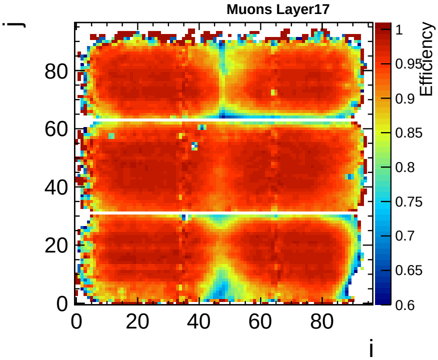


Layout of one DHCAL Layer

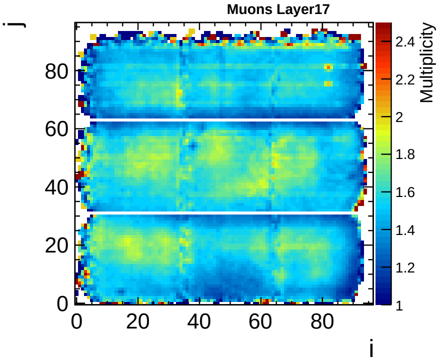


- 3 RPC modules per layer
- 2 fronted boards per RPC module

Efficiency

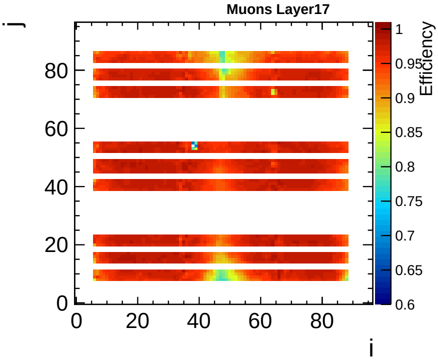


Multiplicity

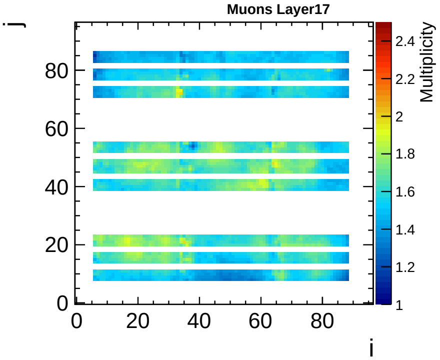


- Combine 18 muon runs taken with $30 \times 30\,\mathrm{cm}^2$ triggers at 9 positions
- More than 500k events at each trigger position
  $\Rightarrow$ allows to extract **local efficiencies and multiplicities for each pad**
- Beam runs only allow to extract efficiency and multiplicity for central region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

Efficiency

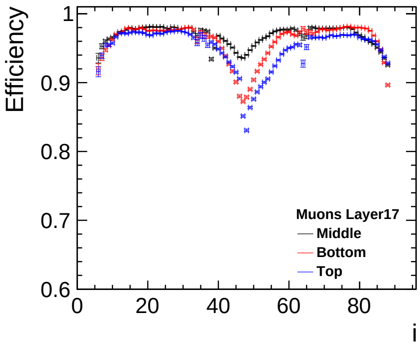


Multiplicity

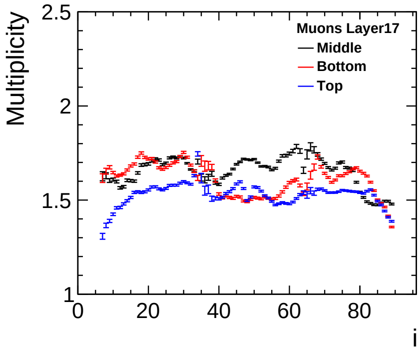


- Determine nominal values in clean regions to tune digitization
- Remove module boundaries and fishing lines
  - Effect of fishing lines included in GEANT4 through material
  - Module boundaries effect added in digitization
    $\Rightarrow$ lower effective charge depending on position
- Average: $\epsilon_0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

Efficiency

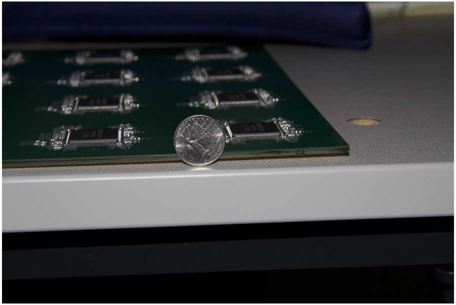


Multiplicity



- 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

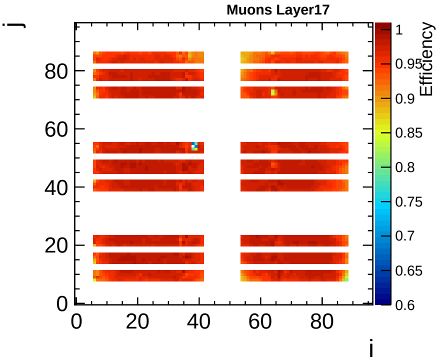
Warping of Frontend Boards



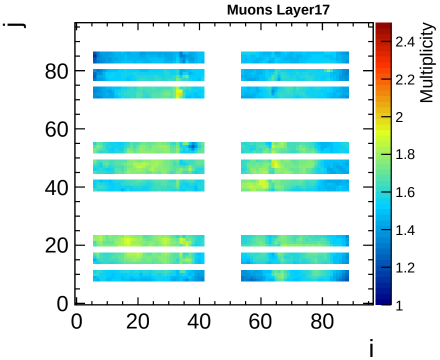
Dime for size reference

- 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



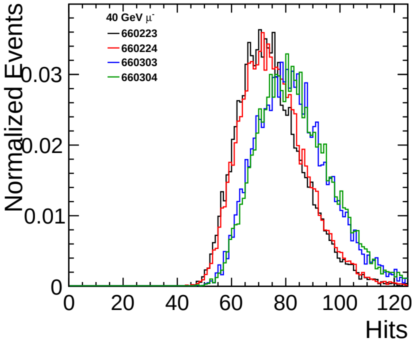
- Remove frontend board boundaries for final cleaning
- These are the regions used for tuning of digitization
- Average: $\epsilon_0 = 95.3\%$, $\mu_0 = 1.61$ (**Fully Cleaned**)

Calibration Procedure

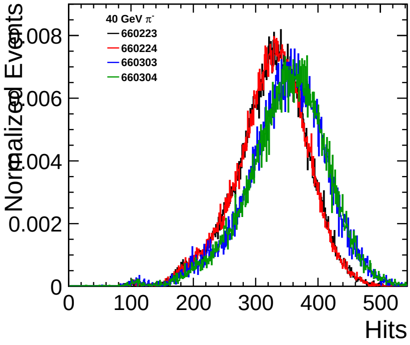
- Correct each hit for its local efficiency and multiplicity to nominal values:
$$N^{\text{calibrated}} = \sum_i^N \frac{\mu_0 \ \epsilon_0}{\mu_i \ \epsilon_i}$$
- μ_0 and ϵ_0 are determined from the respective regions in the muon runs
- μ_i and ϵ_i are determined for each module if possible (more than 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



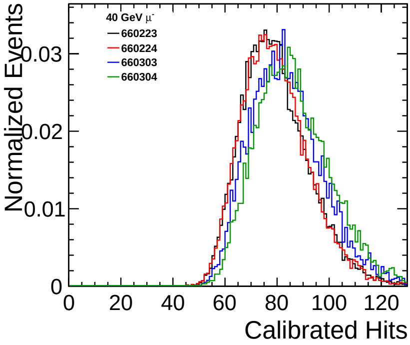
Pions



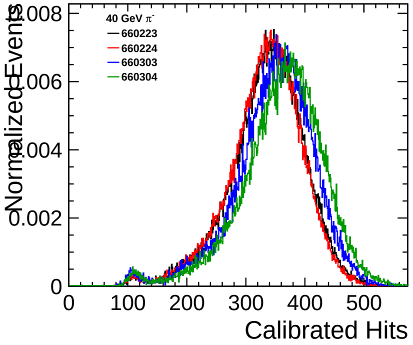
- 2 sets of runs taken at same beam momentum and significantly different temperature and pressure conditions
- Allows to quantify impact of the calibration

Response at 40 GeV - Fully Cleaned Calibration

Muons



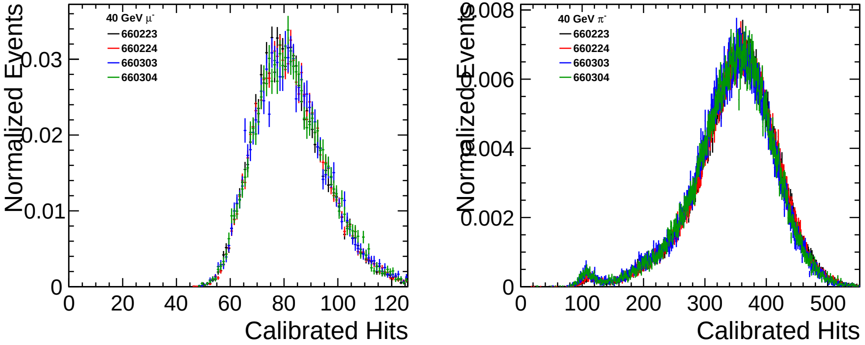
Pions



- 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

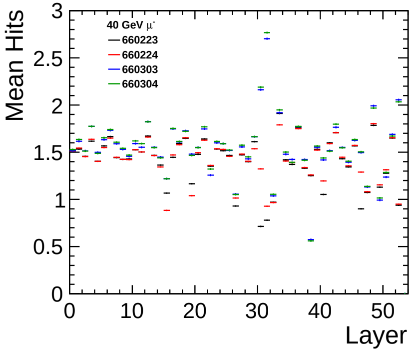
Muons **Pions**



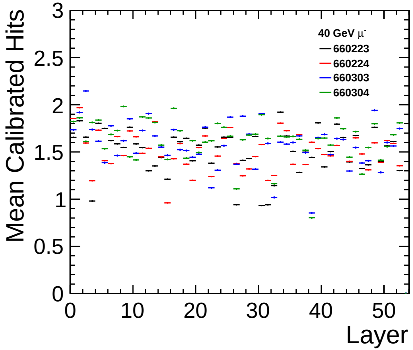
- Including the central region in the calibration gives best results
- Extracted calibration and data is weighted by local beam profile
- Most hits end up in the region with reduced efficiency
  $\Rightarrow$ **important to describe efficiency in centre well**

Longitudinal Profiles (40 GeV Muons)

Uncalibrated



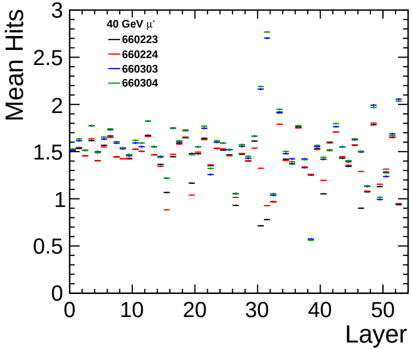
Fully Cleaned



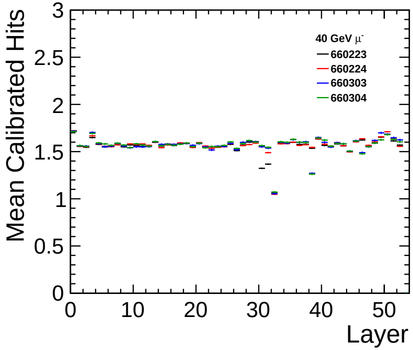
- Fully cleaned calibration not sensitive to response in most relevant region
- Limited statistics in fully cleaned regions ⇒ additional fluctuations

Longitudinal Profiles (40 GeV Muons)

Uncalibrated



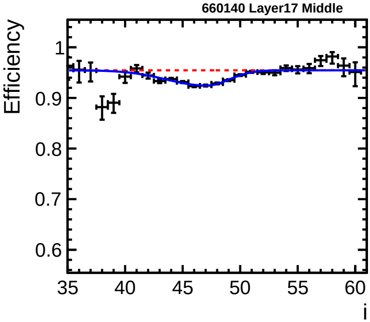
Cleaned

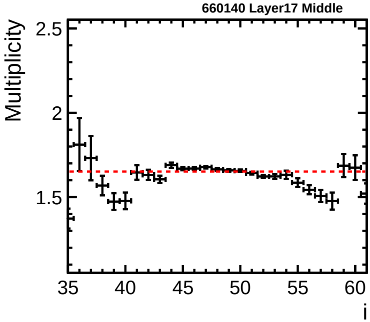


- Excellent correction of layer-to-layer fluctuations when including centre
- Some difficulties for layers with large correction factors

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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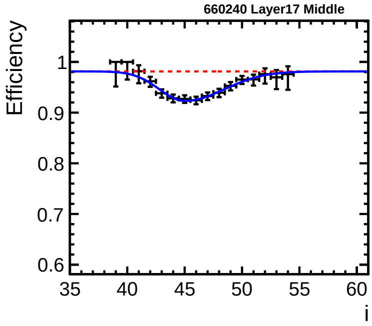

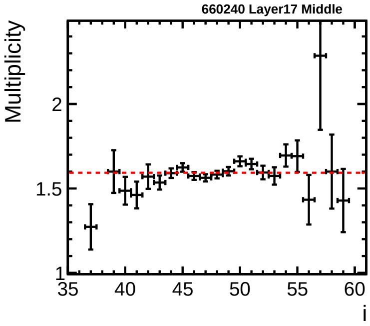

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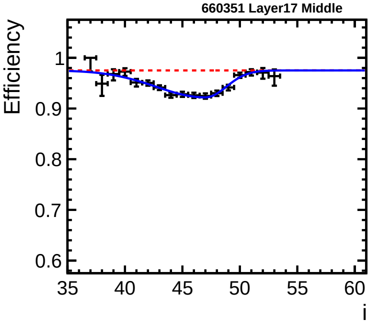

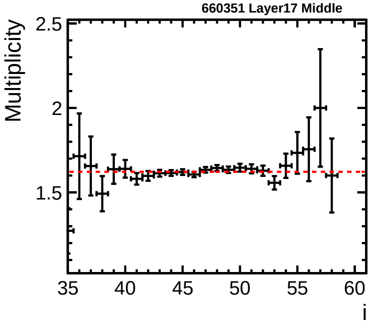

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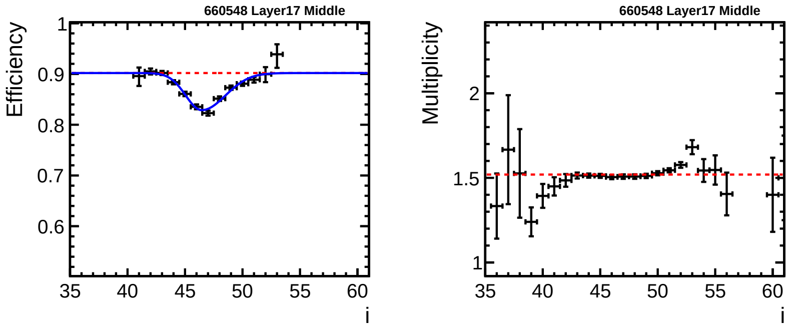

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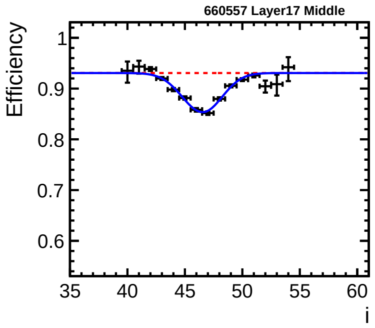
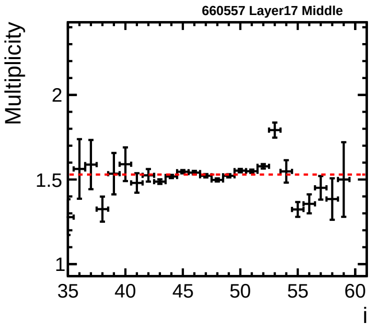
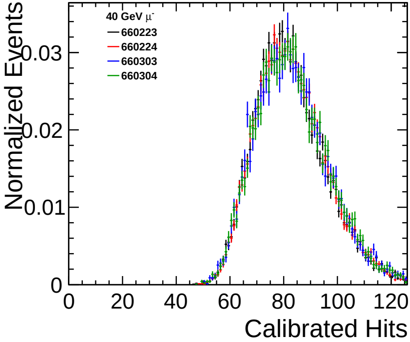




Response at 40 GeV - Local Calibration

Muons



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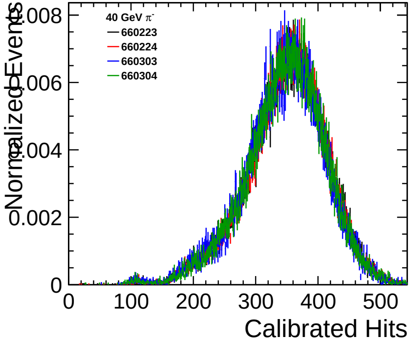
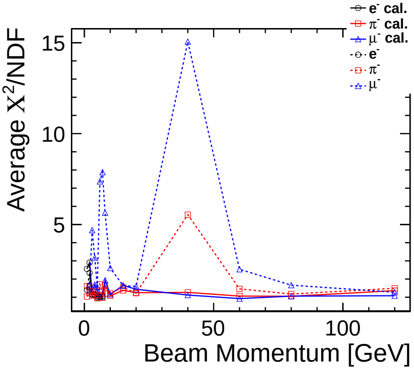


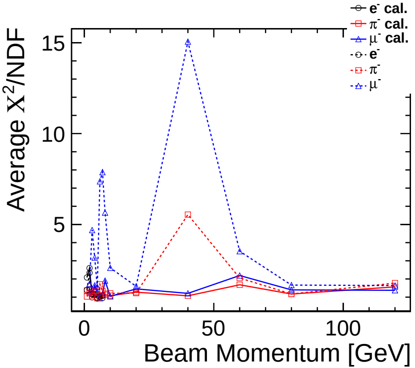
- Local calibration scheme normalizes responses similar to cleaned calibration

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

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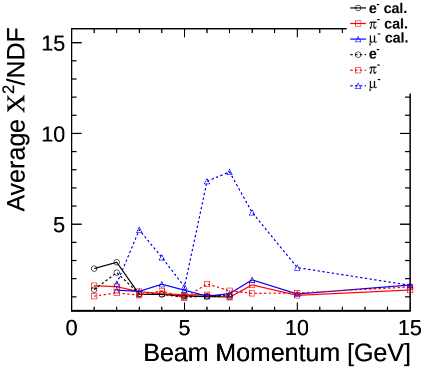

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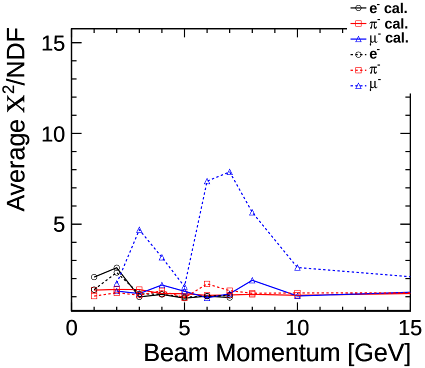

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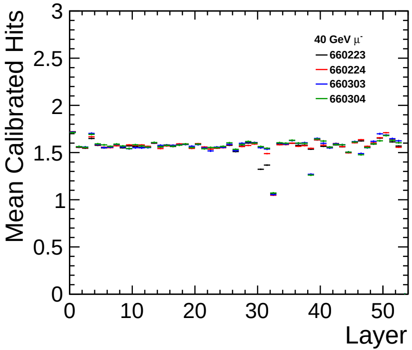
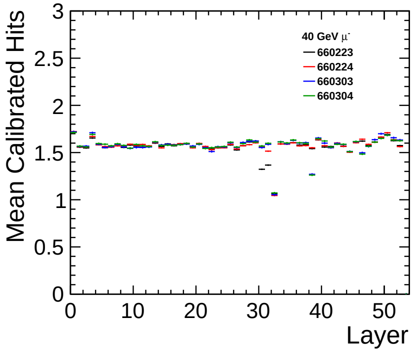
Longitudinal Profiles (40 GeV Muons)

Cleaned Calibration



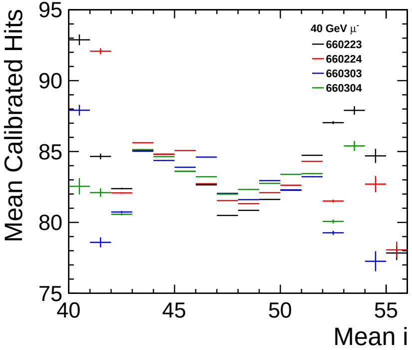
Local Calibration

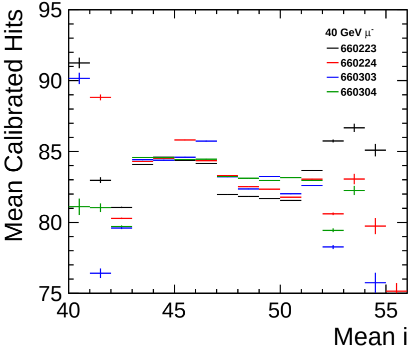


- Almost indistinguishable performance in correcting layer-to-layer fluctuations

Horizontal Dependence of Muon Response (40 GeV)

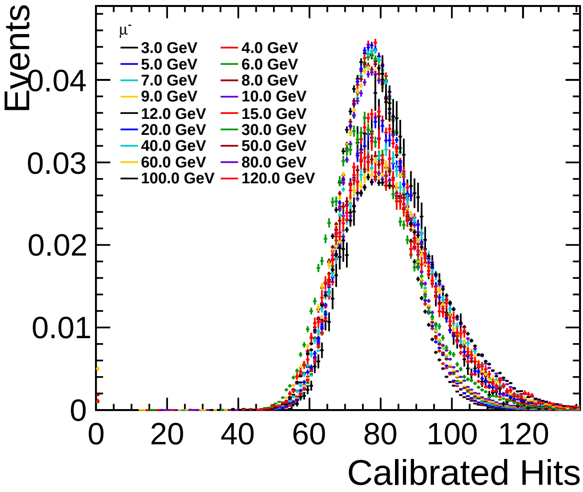
Cleaned Calibration **Local Calibration**



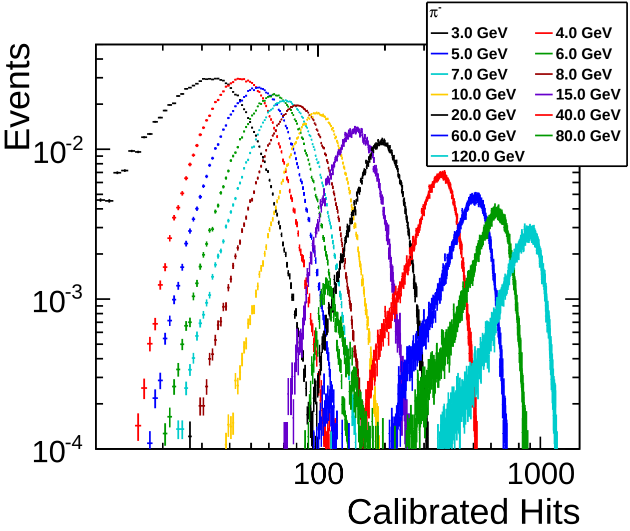


- Cleaned calibration does not remove horizontal dependence in response
- Local calibration removes dip in response
- Use local calibration scheme as default

Muon Response (Local Calibration)

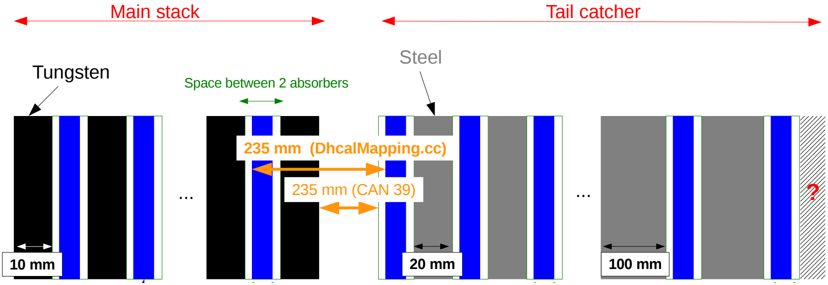


Pion Response (Local Calibration)



Outline

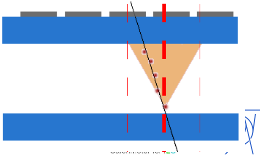
Geant4 Model of Test Beam Setup



- Re-use model of beam line instrumentation and absorber structure for main stack and tail catcher from CALICE analog HCAL test beam
- Replace active layers with implementation of RPC cassettes from Fe-DHCAL test beam
- Remaining tasks:
  - Verification of all distances and sizes
  - Fix remaining overlaps

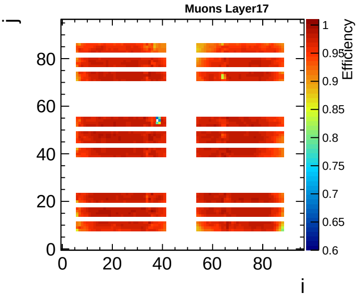
RPCSim (Marlin Version)

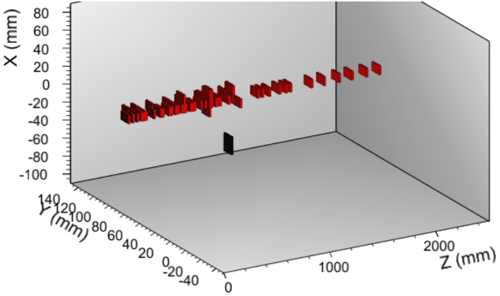
- Use all charge deposits generated by GEANT4 stored in SimCalorimeterHits
- Only allow one avalanche within distance cut d_{cut}, ignore other charge deposits
- Randomly generate total charge for each remaining deposit
  ⇒ based on data from RPC with analog readout
- Correct generated charge by offset Q_0
- Lower effective total charge depending on distance to module boundary
- Spread charge according to model and collect charge on pads
  ⇒ 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



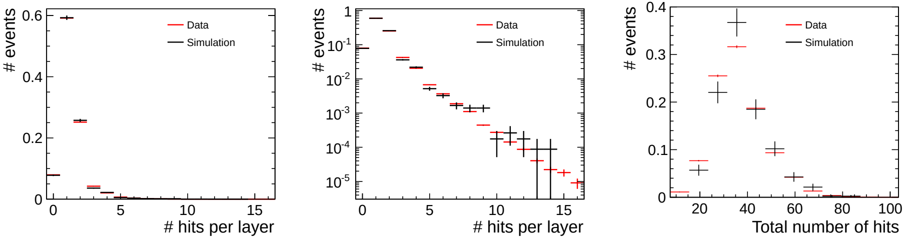
Tuning of the Digitization with Muons

- 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 ⇒ 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



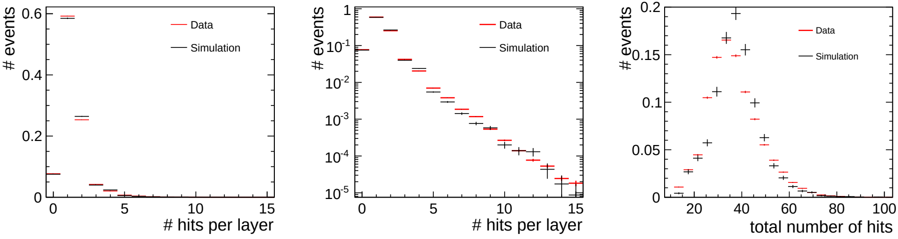


Preliminary Tuning (RPCSim3)



- 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
- $Q_0 = 0.175\,\mathrm{pC}$, $t = 0.275\,\mathrm{pC}$, $d_{\mathrm{cut}} = 1.8\,\mathrm{mm}$
- $R = 0.25$, $\sigma_1 = 0.2\,\mathrm{mm}$, $\sigma_2 = 3.25\,\mathrm{mm}$
- 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

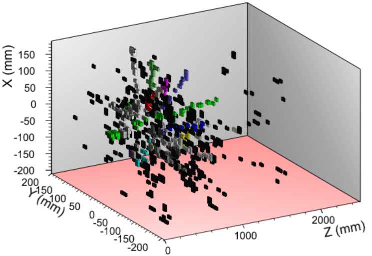
Summary

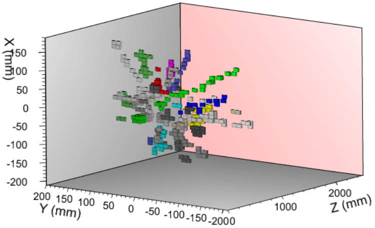
- W-DHCAL data needs to be corrected for run and layer conditions
- Multiplicities and efficiencies can be determined for each run from muons
- Large efficiency drop in centre of modules (not present in Fe-DHCAL data)
  $\rightarrow$ different for each layer and run
- Developed local calibration scheme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

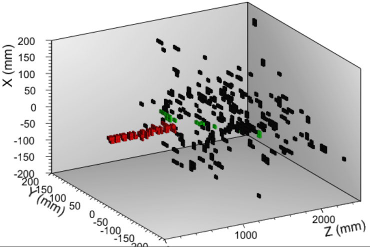
Outlook

- Finalize simulation model
- Use beam profiles extracted from data in simulation
- Optimize particle selection cuts for high purity
- Comparison of GEANT4 models and test beam data
  - Response: linearity and resolution
  - Longitudinal shower profile
  - Lateral shower profile
  - Track multiplicity in the shower
  - ...
- **Excellent opportunities for student projects**

Bonus: Hough Transform







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