W-DHCAL Test Beam Analysis

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CLIC Detector and Physics Collaboration Meeting

1. October 2013

Outline

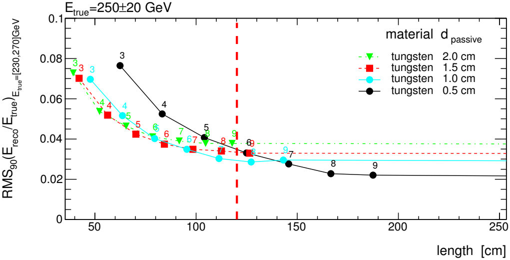
Why Tungsten?

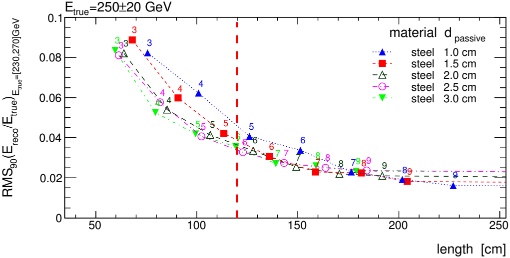
- Calorimeters have to be inside coil to avoid large dead areas
- Coil size limited by cost and feasibility
- Make optimal use of the available space
- Sampling calorimeter with reasonably small gap for active layer
  - Assume 5 mm plastic scintillator + 1.5 mm for readout
- Test various (simplified) calorimeter geometries
  - Absorber materials: steel, tungsten
  - Absorber thickness: 5–30 mm

Material	X_0 [cm]	λ_I [cm]
Steel	1.73	16.9
Tungsten	0.37	10.2

P. Speckmayer, C.G. - LCD-Note-2010-001

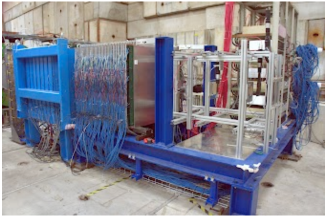
- Fit resolution to determine sampling and constant term
  $\sigma(E)/E = \frac{s}{\sqrt{E}} \oplus c$
- Steel has better intrinsic resolution
- Steel leakage dominated up to 1.5 m HCal depth
- For limited calorimeter depth ($\sim 1.2\,\mathrm{m}$) tungsten performs better
- Optimal sampling with tungsten absorber thickness around 10 mm
- Corresponds to a total depth of 7.5 λ_I

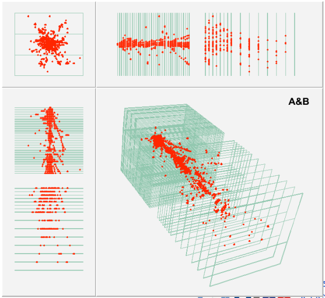




Data Taking at CERN (2012)

- 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





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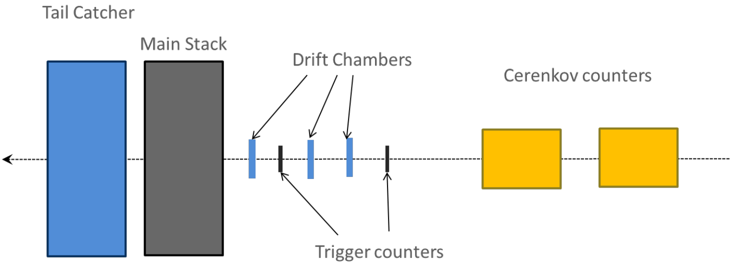


- 39 layers W-DHCAL + 15 layers Fe-DHCAL
- $10 \times 10\,\text{cm}^2$ scintillator triggers ($30 \times 30\,\text{cm}^2$ for dedicated muon runs)
- Three wire chambers $\Rightarrow$ beam profile
- Two Cerenkov counters $\Rightarrow$ particle identification

1. Introduction
2. Wire Chamber Data
3. Data Quality
4. Calibration
5. Summary and Outlook

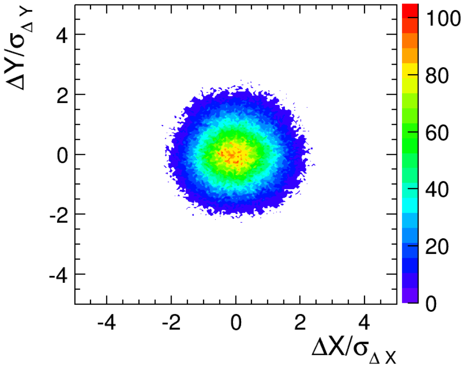
Wire Chamber Data

- Precise position measurements from delay wire chambers (SPS only)
- Use slope calibration obtained during AHCAL running
- Can be used for seeding in event reconstruction and to determine beam profile for each run for Monte Carlo
- Relative position from survey or from data itself

William Nash (Boston University) - LCD-Note-2013-009

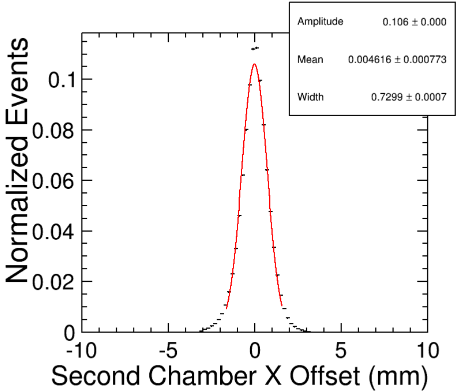
Relative Position (Wire Chamber to W-DHCAL)

- Reconstruct tracks from wire chamber hits and calorimeter hits in muon events
- Relative offset obtained by comparing extrapolated x and y position in the first HCAL layer



Point Resolution and Efficiency

- Use straight line through two layers to obtain resolution of third layer: consistent result for all layers $\sigma_x \approx 0.6\,\mathrm{mm}$, $\sigma_y \approx 0.52\,\mathrm{mm}$
- Layer Efficiencies ≈ 96%, total efficiency: 87.2%



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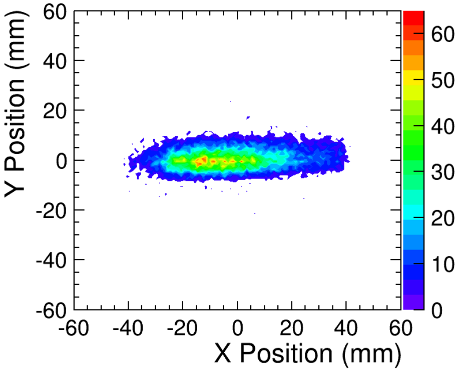
Beam Profile (300 GeV)

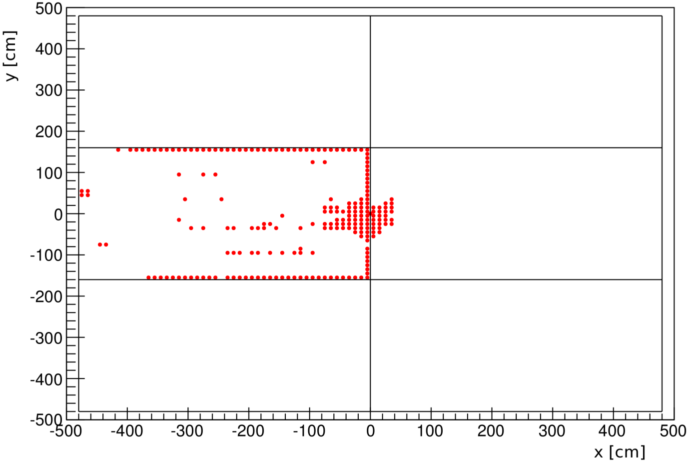


- One histogram per run (SPS only)
- Used as input for Monte Carlo simulation

William Nash (Boston University)

Data Quality Issues

- Box events
- Dead RPC modules
- Dead and oversensitive chips
- Oversensitive cells
- Dead cells



Helga Holmestad (CERN, University of Oslo)

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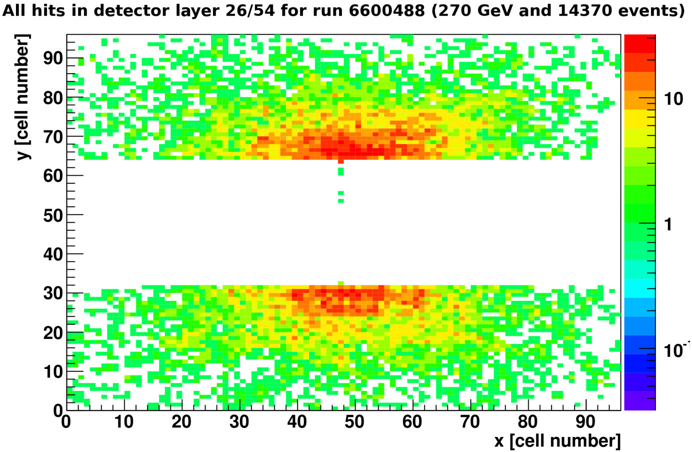

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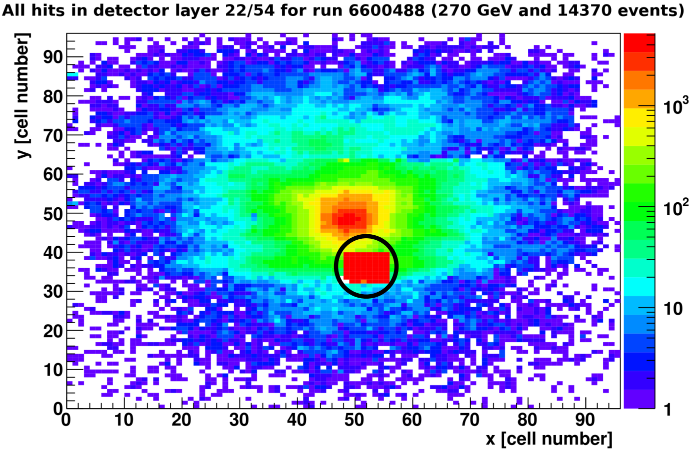

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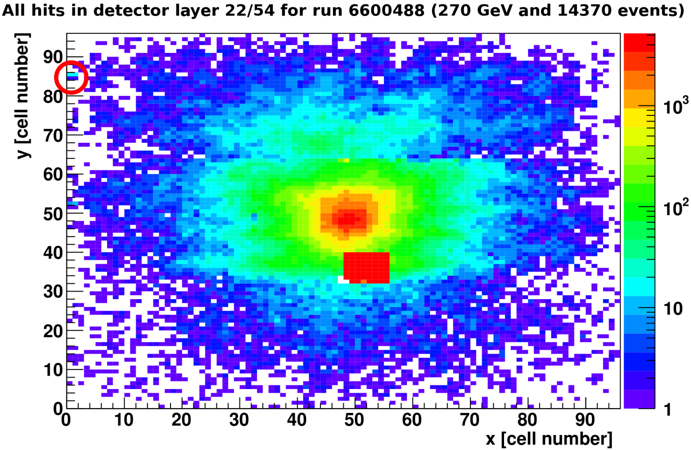

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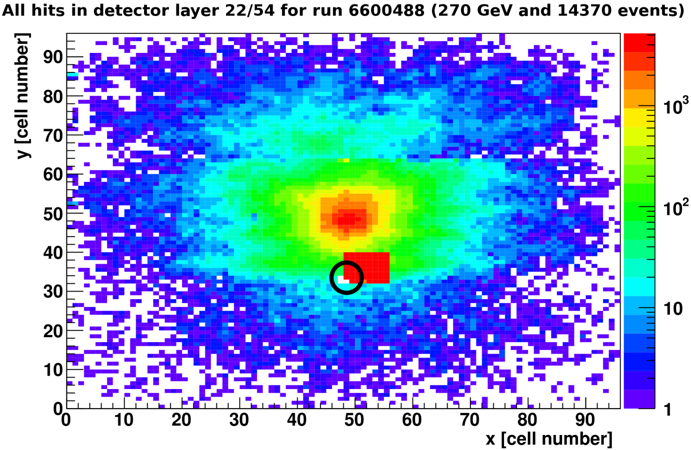

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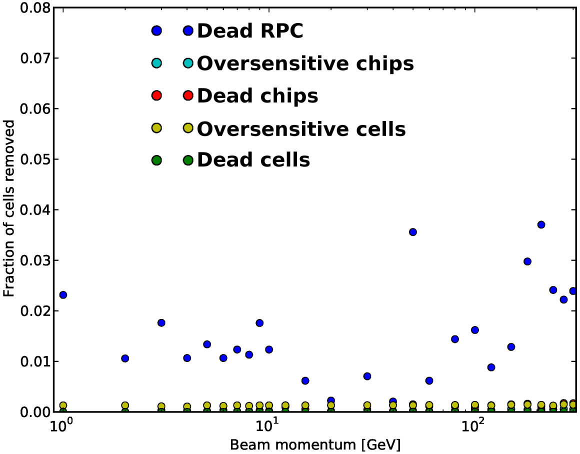
Cleaning Procedure

- Ignore duplicate hits → event based
- Remove out of time hits: only accept bins -19 to -17 → event based
- Algorithm to identify dead and noisy regions by looking for large steps (loose) → run based
- Identify and reject box events by looking for patterns along module boundaries → event based
- Re-run algorithm to identify dead and noisy regions (tight) → run based

Fraction of Cells Removed



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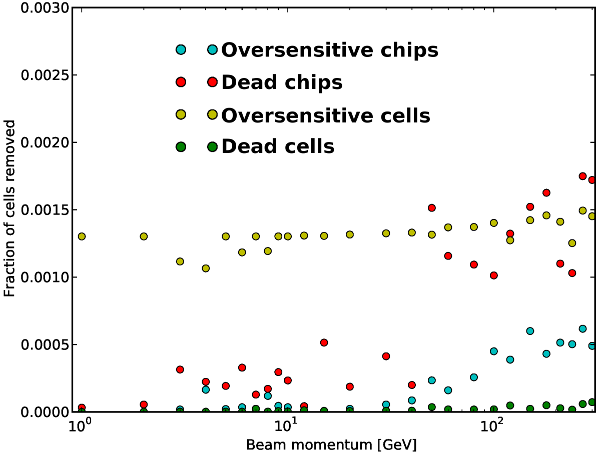

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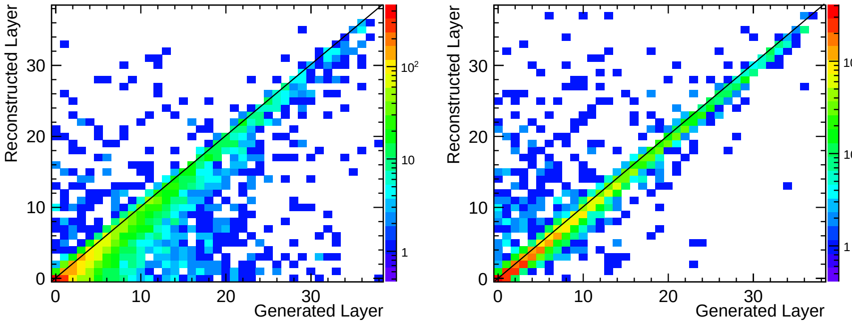
Interaction Layer Definition

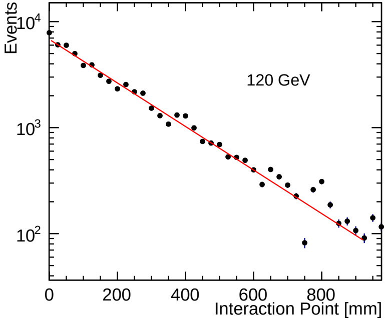
- Old definition: minimum of 3 hits in two consecutive layers
- New definition of interaction layer based on a three layer hit average
- Require increase of factor 2 and minimum average of 4
- Assume 3 hits in each "layer before stack" to allow identification in first layer

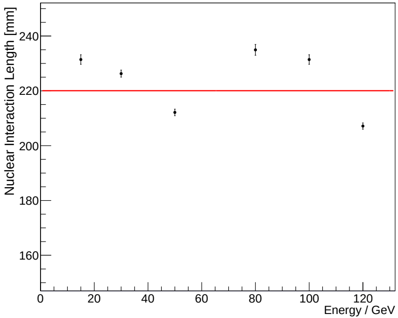


Christian Reichelt (Technical University of Denmark)

Interaction Layer Definition

- Verified in data and MC that the interaction layer follows exponential drop
- Interaction length extracted from exponential fit as expected

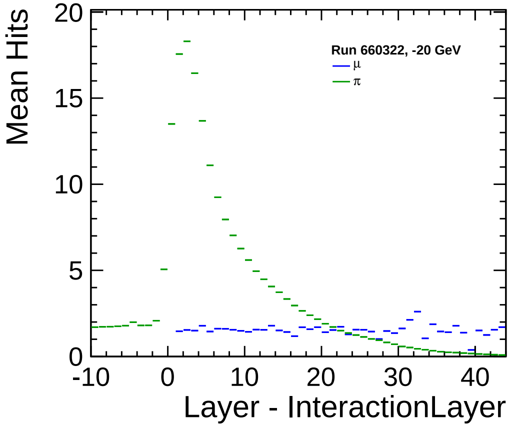




Christian Reichelt (Technical University of Denmark)

Why Calibrate?

- DHCAL only measures number of hits
- Multiplicity μ and efficiency ϵ depend on many factors
  - Temperature
  - Pressure
  - Voltage
  - ...
- Temperature stabilized by tent and AC



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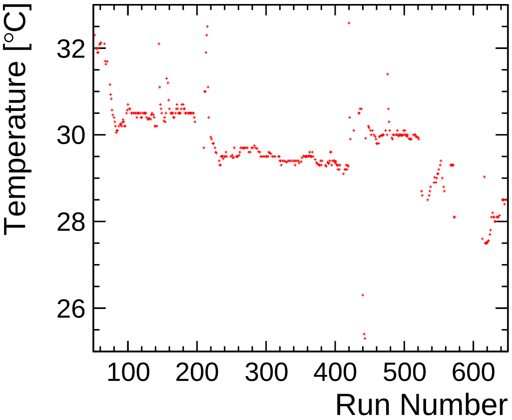

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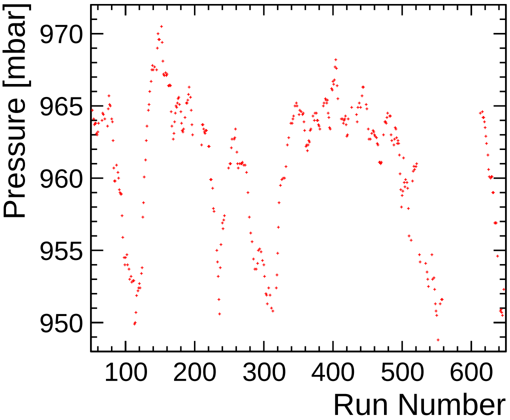
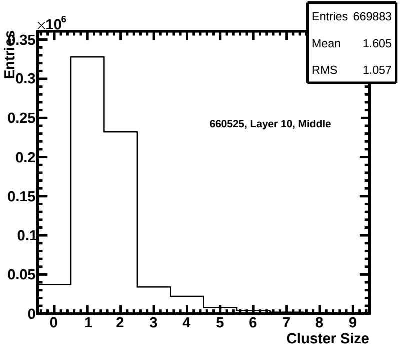
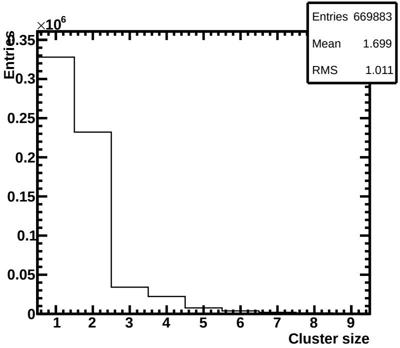


Determination of Efficiency and Multiplicity

- Lose pre-selection for muon events based on number of active layers (> 30) and total number of hits (< 150)
- For each layer finds mip stub candidate in neighboring layers (± 3 layers, min 4 valid clusters)
- Only use clusters with 3 or less hits
- Straight line fit to verify mip stub and identify intersection with layer of interest
- Determine if nearby cluster exists in layer of interest
- Efficiency ϵ: fraction of events with cluster found
- Multiplicity μ: mean cluster size for events with cluster found
- Ignore if intersection is a module border or has been identified as dead or noisy

Example Histogram



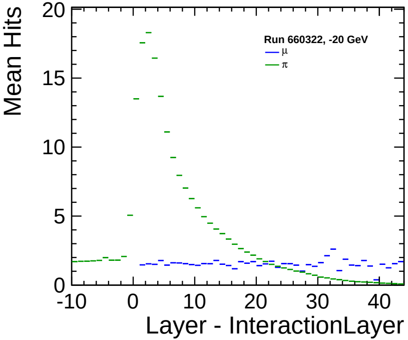


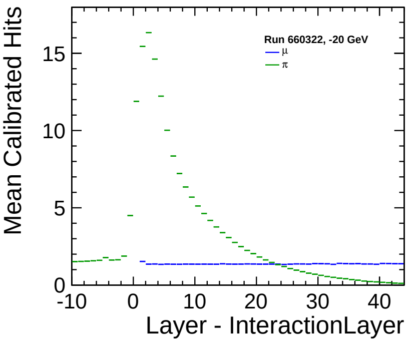
- Extract efficiency as $(N_{\text{total}} - N_0)/N_{\text{total}}$
- Extract multiplicity as mean excluding bin 0
- Determined for each module in each layer

Calibration Procedure

- Correct each hit for its local efficiency and multiplicity to nominal values:
$$N_{\text{hits}}^{\text{calibrated}} = \alpha \sum_i^N \frac{\mu_0 \ \epsilon_0}{\mu_i \ \epsilon_i}$$
- μ_i and ϵ_i are determined for each module in each layer from muons within the run: works well only for central module
- Could use temperature and pressure dependence to correct for run conditions and use single calibration set $\Rightarrow$ need to remove voltage dependence
- μ_0 and ϵ_0 are the nominal values, determined as average from all modules and layers in all dedicated muon runs:
$$\mu_0 \approx 1.63, \ \epsilon_0 \approx 81\%$$

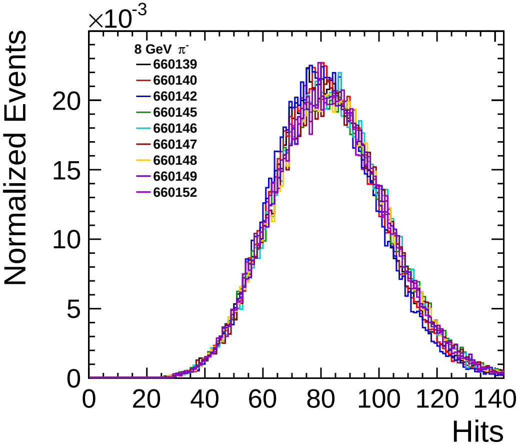
Longitudinal Shower Profiles (20 GeV)





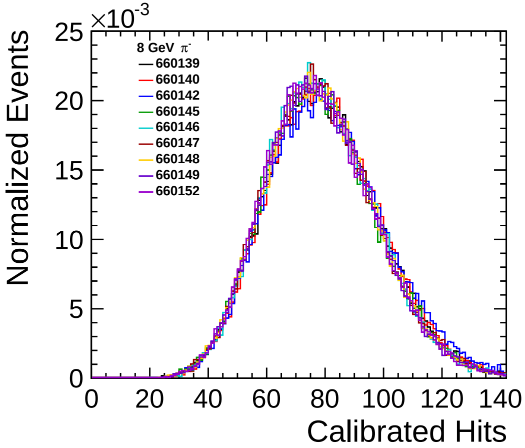
- Layer-to-layer fluctuations are effectively removed

Total Number of Hits (8 GeV Pions)



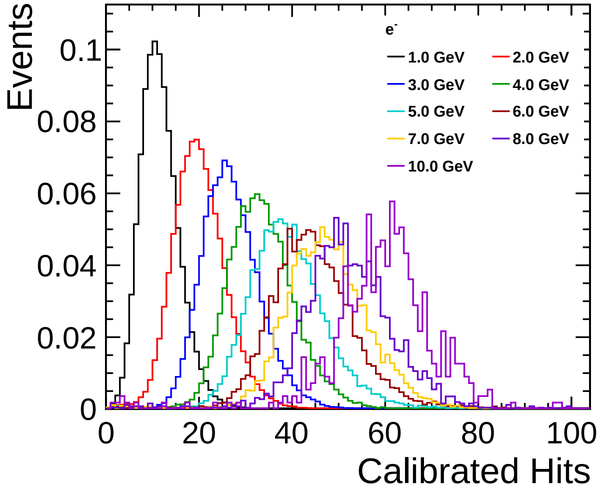
- Run-to-run fluctuations removed

Total Number of Hits (8 GeV Pions)

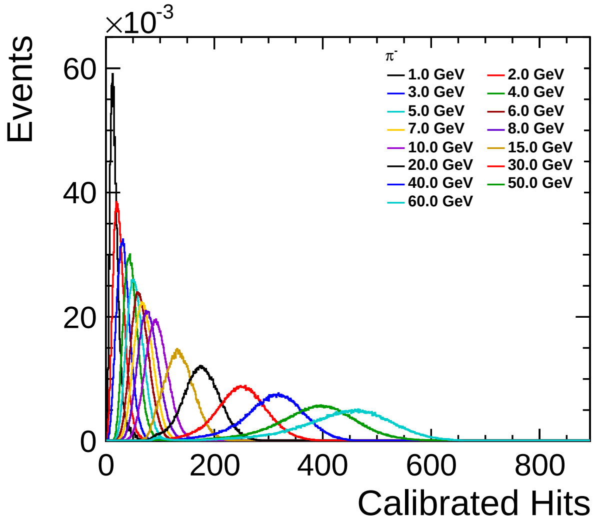


- Run-to-run fluctuations removed

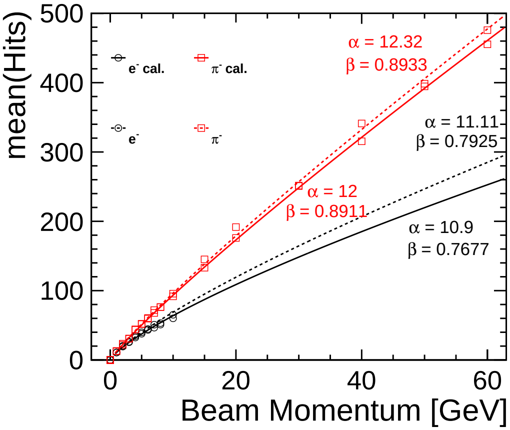
Total Number of Hits (Electrons)



Total Number of Hits (Pions)



Linearity



- Parametrization: $N_{\text{hits}} = \alpha\ E^{\beta}$

Summary and Outlook

- High quality wire chamber data for external particle position and direction
- Procedures to clean data dead and noisy cells
  $\rightarrow$ some effects still need to be understood
- Hit multiplicity and efficiency depend on temperature, pressure and voltage
- Layer calibration to eliminate these fluctuations
  $\rightarrow$ needs further improvement to properly treat inefficient regions

Next Steps

- Finalize Mokka model including beam line instrumentation
- Include beam profile and particle angles from wire chamber data in simulation
- Tune digitization model with muon and electron data $\rightarrow$ prediction for pions
- Add local density based calibration
  $\rightarrow$ need to treat MIPs different then showers
- Improve particle identification using Monte Carlo