Hadron Showers
in the CALICE AHCAL

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Outline

- PFLOW and imaging calorimeter
- AHCAL prototype and e.m. validation
- Track segments and multiplicity
- Identification of shower start point
- Longitudinal hadron shower profiles
- Shower radius and leakage
- Summary

PFlow and Imaging Calorimeter

- Measure each particle type in the detector subsystem that provides the best resolution

$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1 \left(\frac{E}{100}\right)^{+0.3} \%$$

Resolution | Tracking | Leakage | Confusion

Tracker

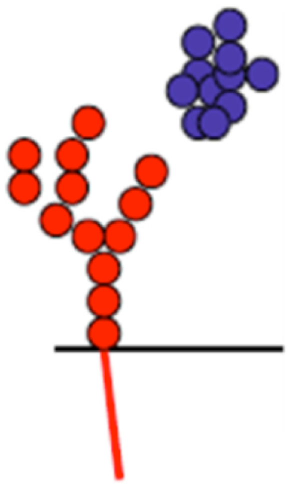
- charged hadrons
- electrons
- muons

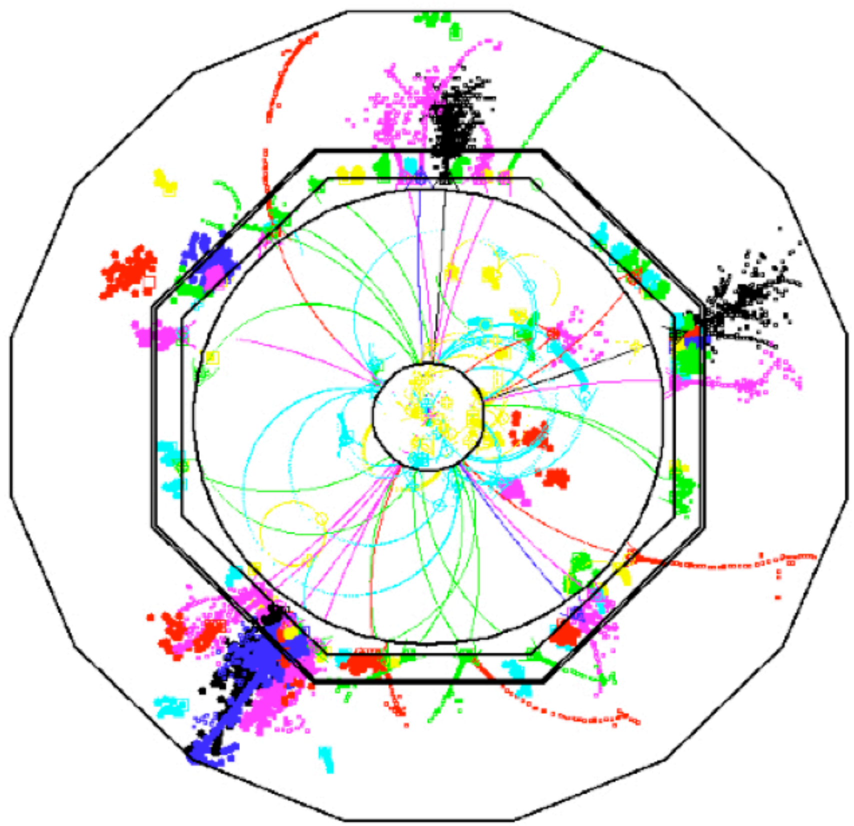
Electromagnetic Calorimeter

- photons
- π^0

Hadronic Calorimeter

- long-lived neutral hadrons





- Optimization of HCAL geometry => 3x3 cm^2 tiles

Particle Flow Performance

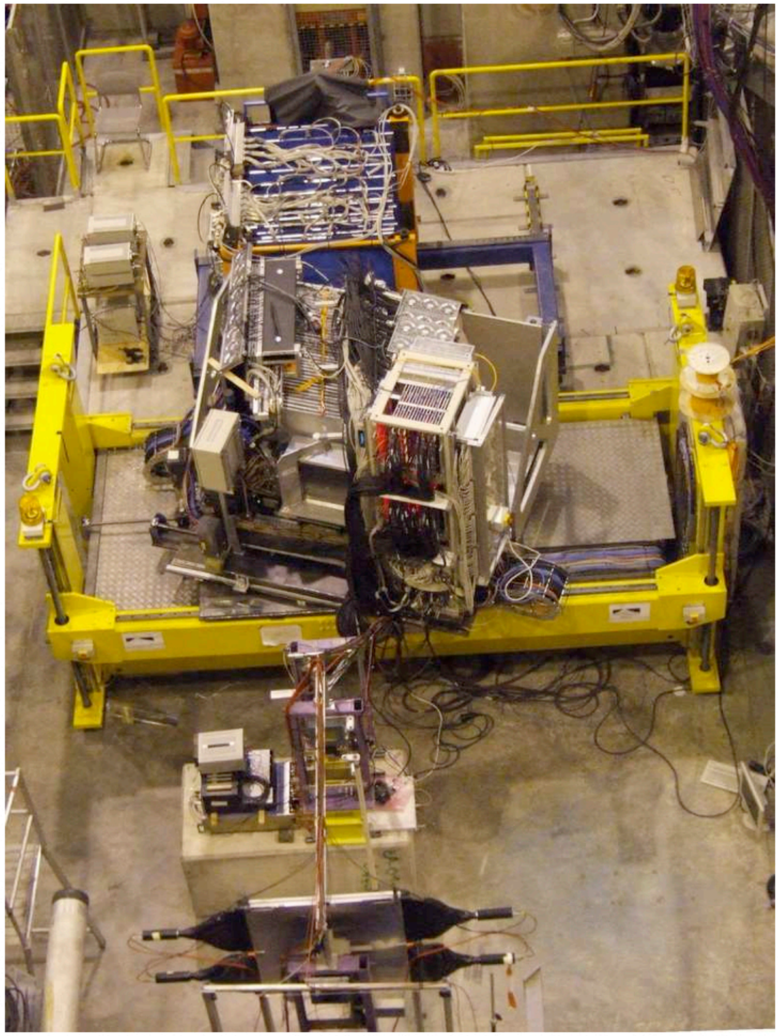
- The performance of PandoraPFA algorithm with ILD detector concept is studied
- using MC samples ~10 000 $Z \rightarrow uds$, E_Z = 91.2, 200, 360 and 500 GeV.

Jet Energy	$rms_{90}(E_j)/E_j$
45 GeV	$(3.74 \pm 0.05)\%$
100 GeV	$(2.92 \pm 0.04)\%$
180 GeV	$(3.00 \pm 0.04)\%$
250 GeV	$(3.11 \pm 0.05)\%$

- Physics list compared: LCPhys, QGSP_BERT, QGS_BIC, FTFP_BERT, LHEP
- Within 4% in agreement on the obtained Jet Energy Resolution

CALICE Test-beam

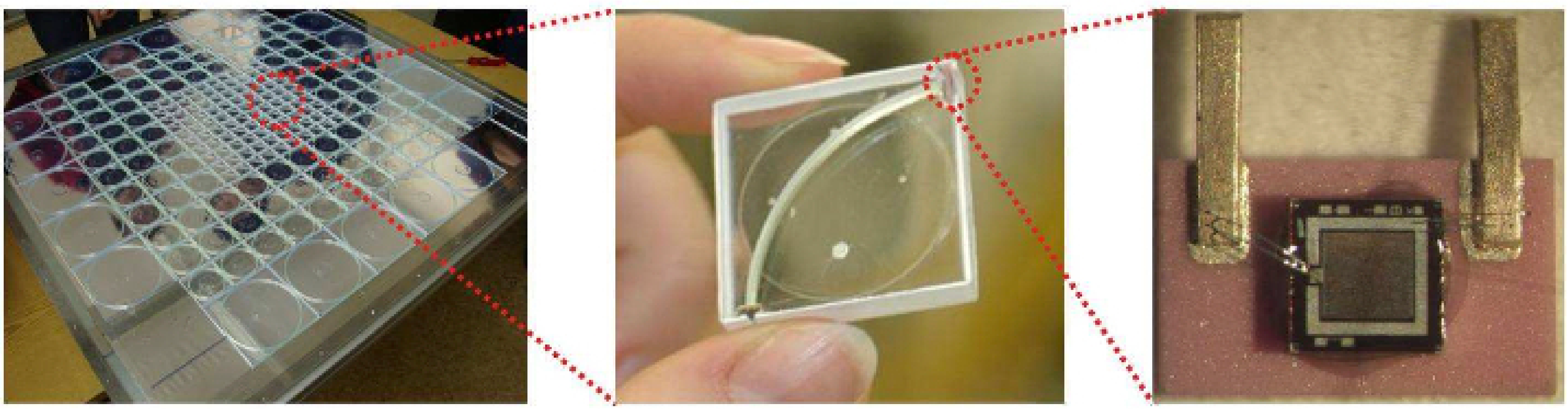
- CALCIE collaboration is preparing/performing large scale test-beam
- A comprehensive set of data has been collected with the AHCAL
- Comparison with simulated data



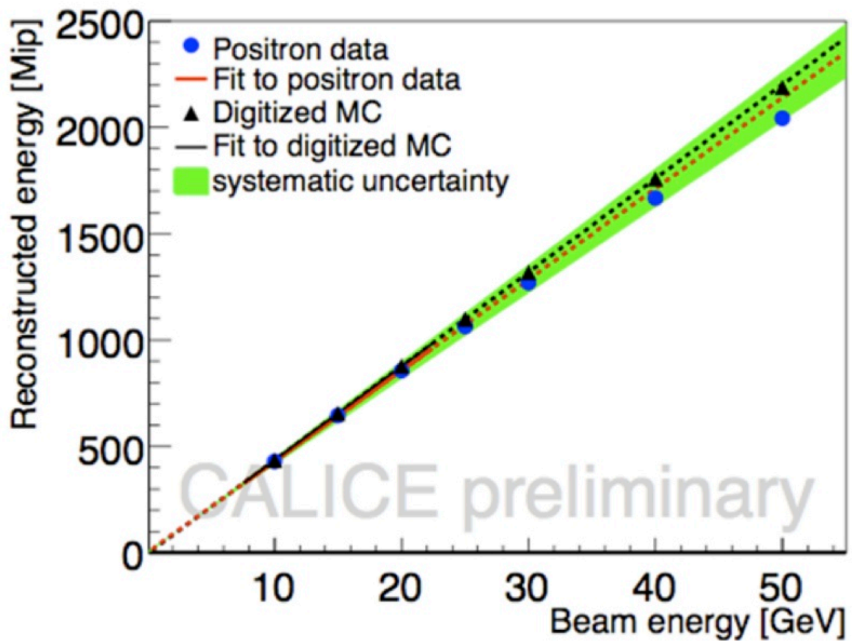
Highly Granular AHCAL Prototype

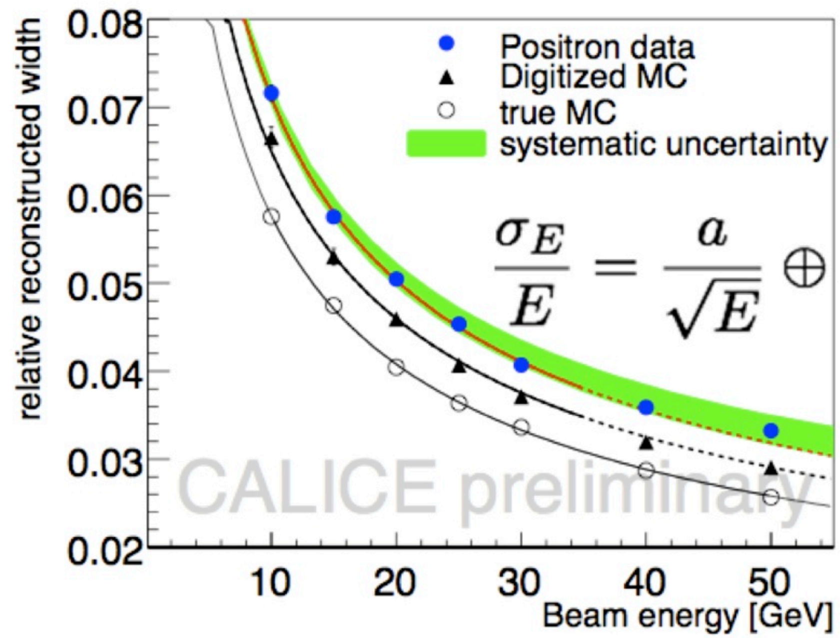
AHCAL size	~1m^3
materials	Steel -Scintillator
layers	38
interaction length	5.3λ_I
x-y	scannable
impact angle	0-30 deg

channels	7608
cell size (cm^2)	3x3 to 12x12
light yield	~13 pixel/MIP
S/N	~10



Validation with e.m. Showers





- Use positron data, no ECAL in front, to validate detector understanding and calibration
- Simulation includes p.e. statistics, SiPM non-linearity, electronic noise, light cross talk between tiles

- Non-linearity < 4% @ 50 GeV
- Stochastic:
  data: a = 22.5 ± 0.1 (stat) ± 0.4 (syst) [%/√E]
  MC: a = 20.4 ± 0.2 (stat) [%/√E]
- Constant term:
  data: b = 0 ± 0.1 (stat) ± 0.1 (syst) [%/√E]
  MC: b = 0 ± 0.6 (stat) [%/√E]
- c fixed to ~ 60MeV (pedestal event)

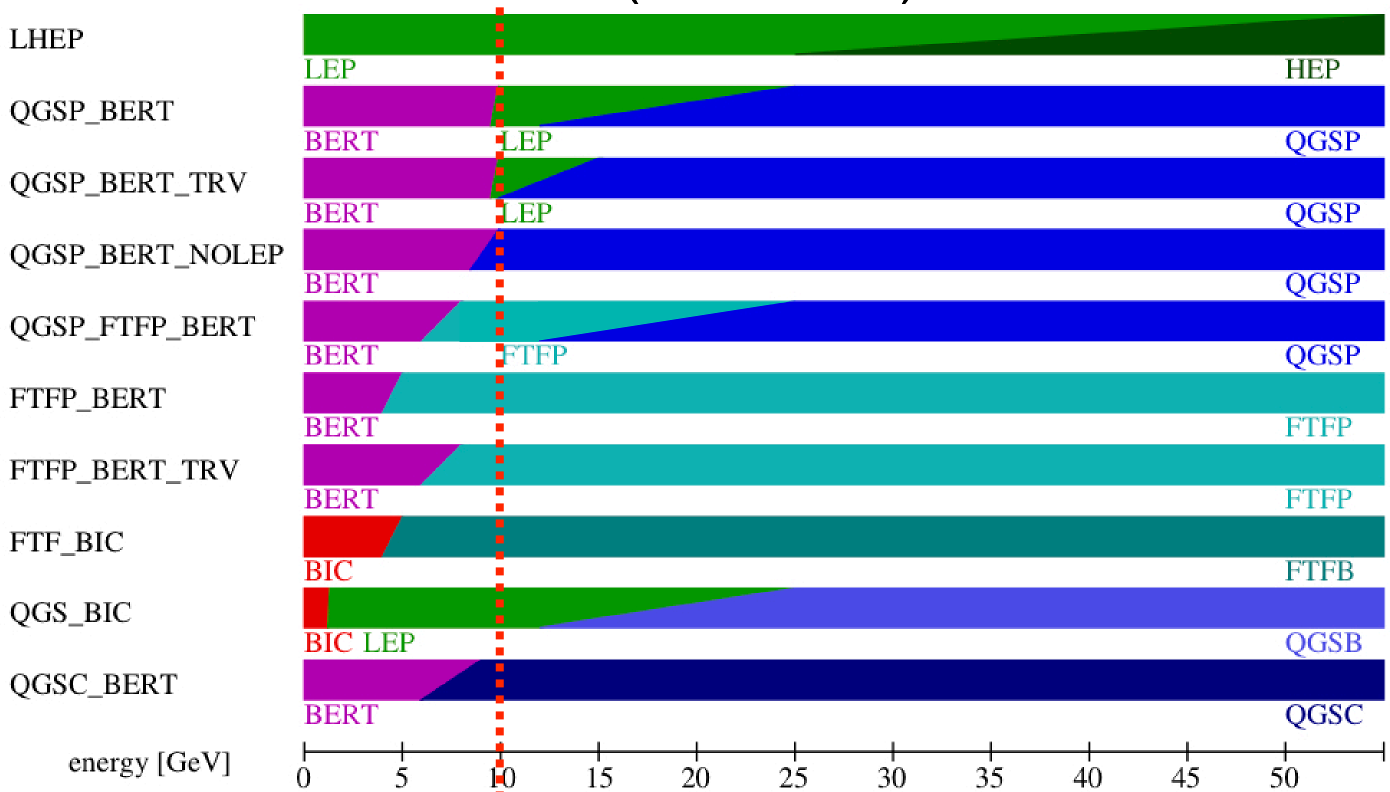
Composition of Physics Lists

- Geant 4.9.3 final version (12/2009)

outdates →

preferred by LHC test beam data →

transition →



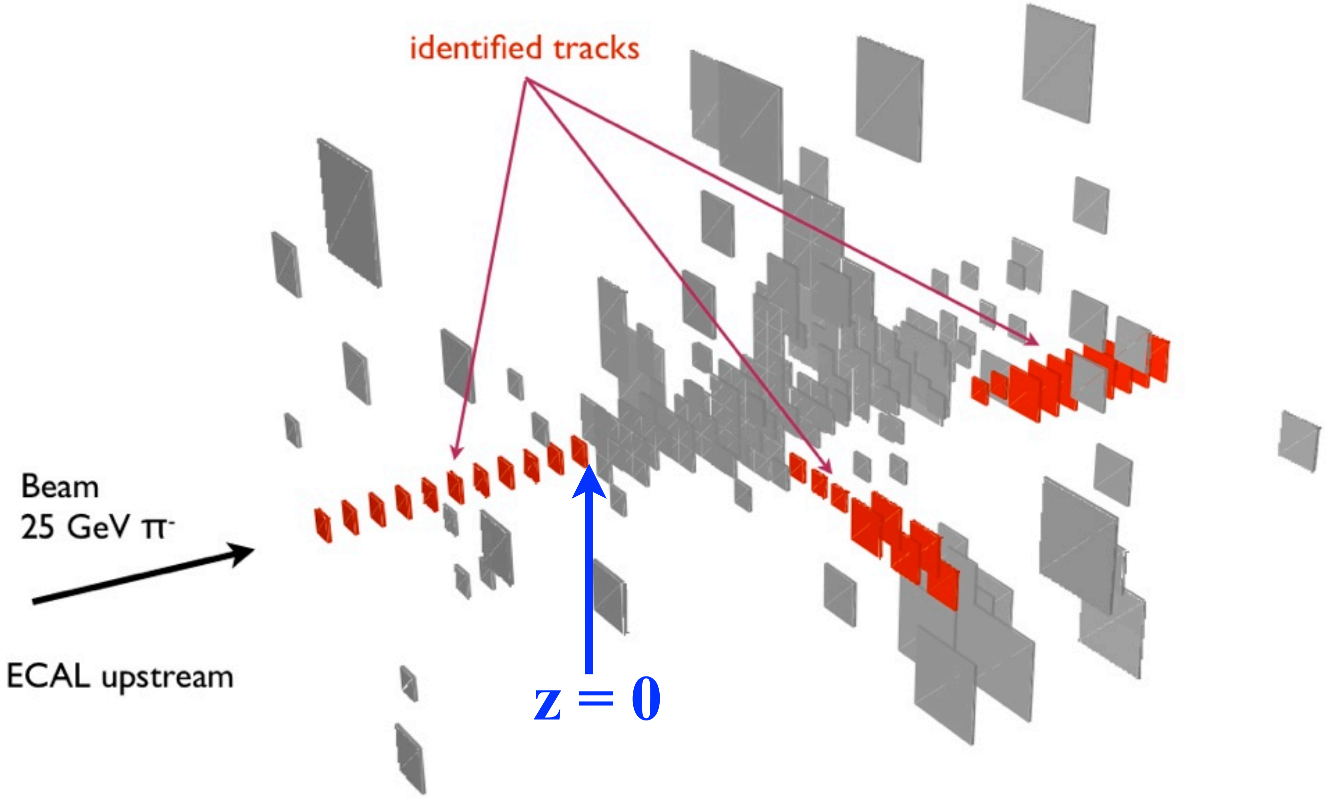
10 GeV

80 GeV

CHIPS: Recently the model was extended such that it can be used over the full energy range. a promising new approach, but not yet tuned.

- Composition of the Geant4 physics lists for pions.
- All physics lists combine at least two models.
- The energy range up to 55 GeV is displayed here.

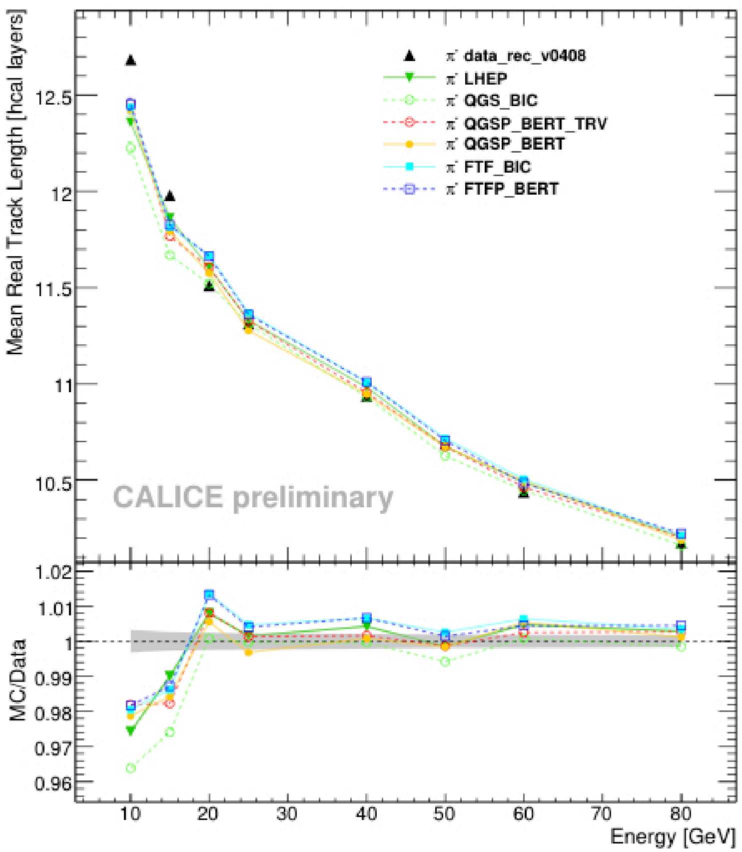
Identification of Track Segments



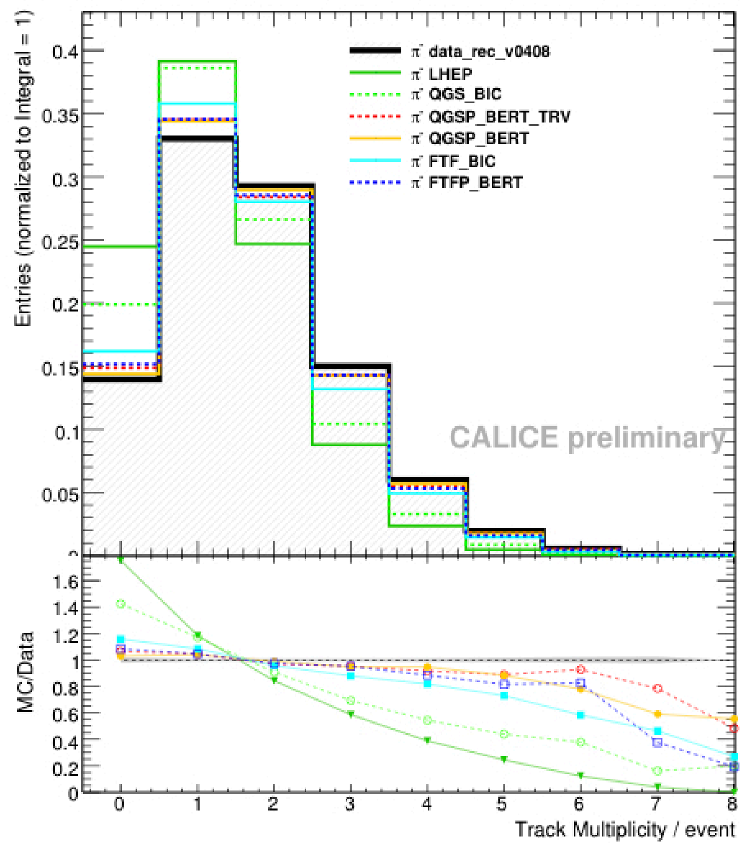
- The high granularity of the calorimeter allows detailed 3D studies of the substructure of hadron showers
  - Minimum ionizing track segments can be identified
  - Strong support particle flow algorithm

Shower fine structure

Mean Track Length



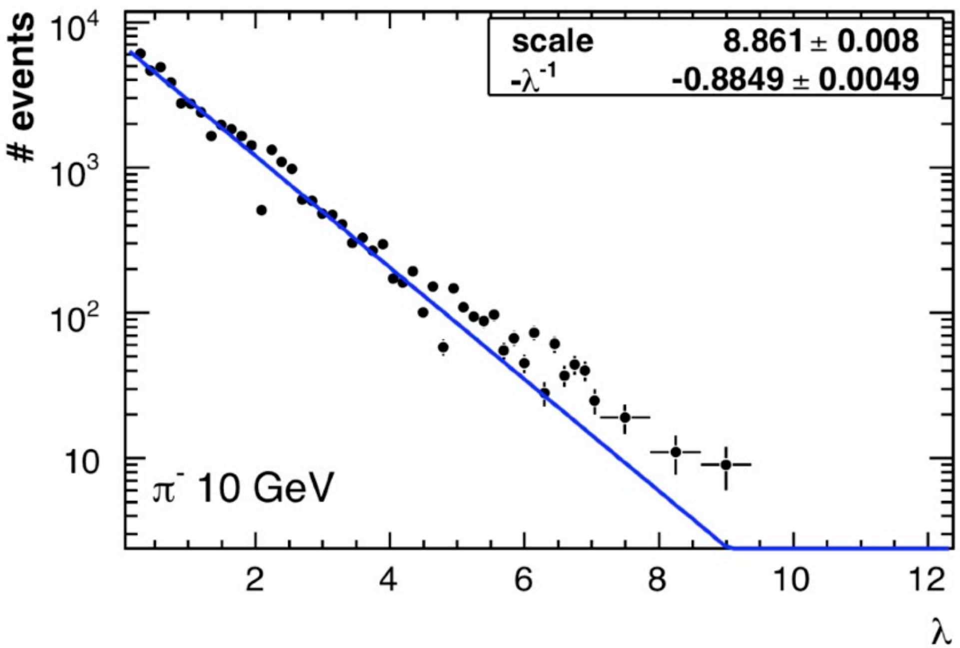
Track Multiplicity



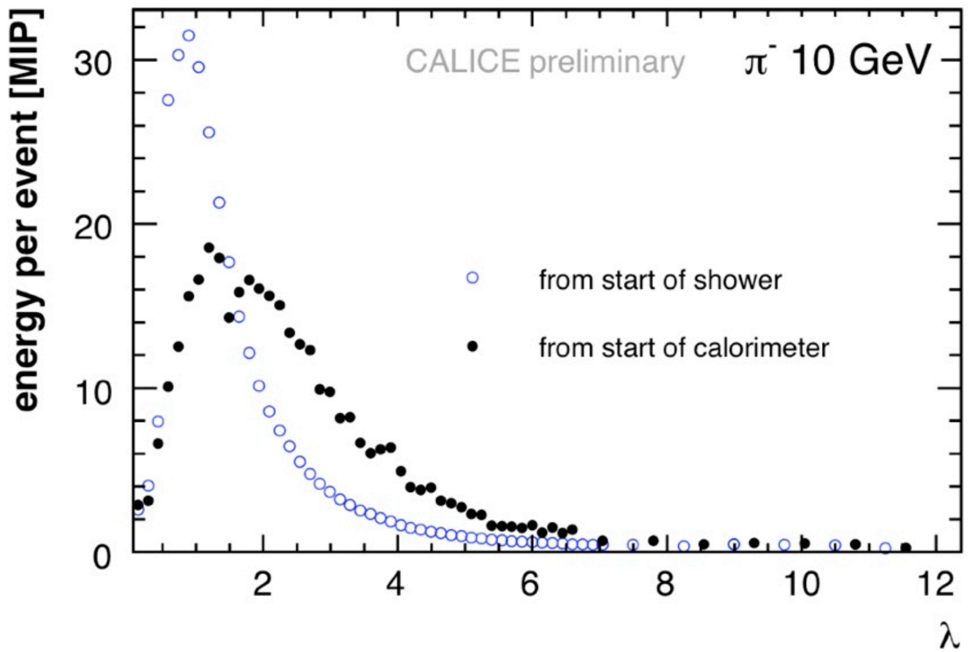
- Track segments in hadronic showers are a powerful tool to check models
- Too short tracks in all models, E < 20 GeV
- Too low multiplicity for LHEP and QGS_BIC

Position of Shower Start

Position of shower start



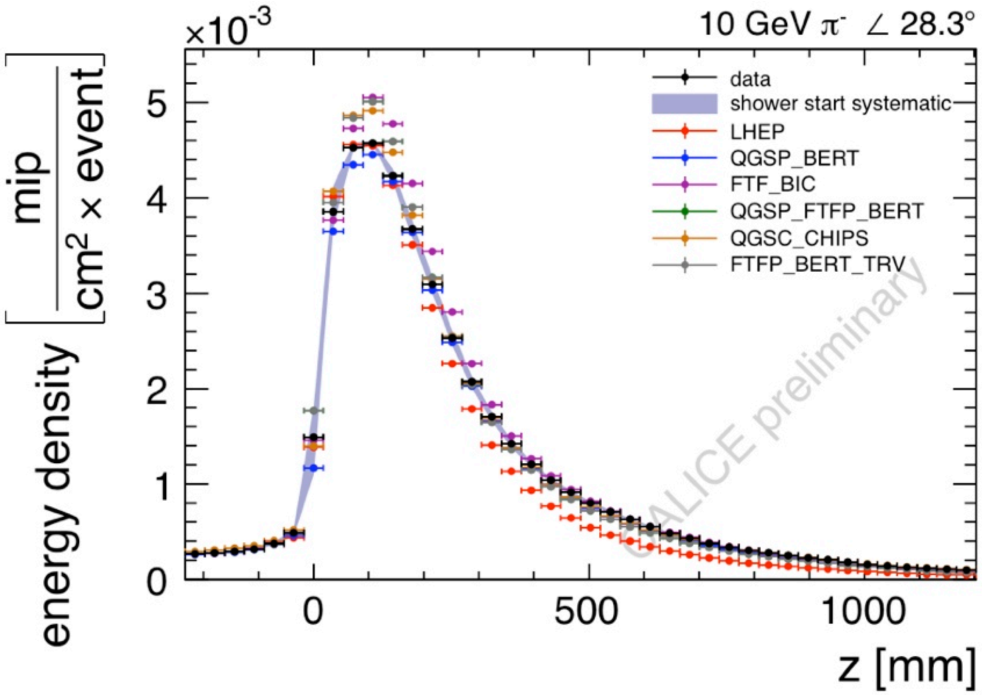
Longitudinal shower profile

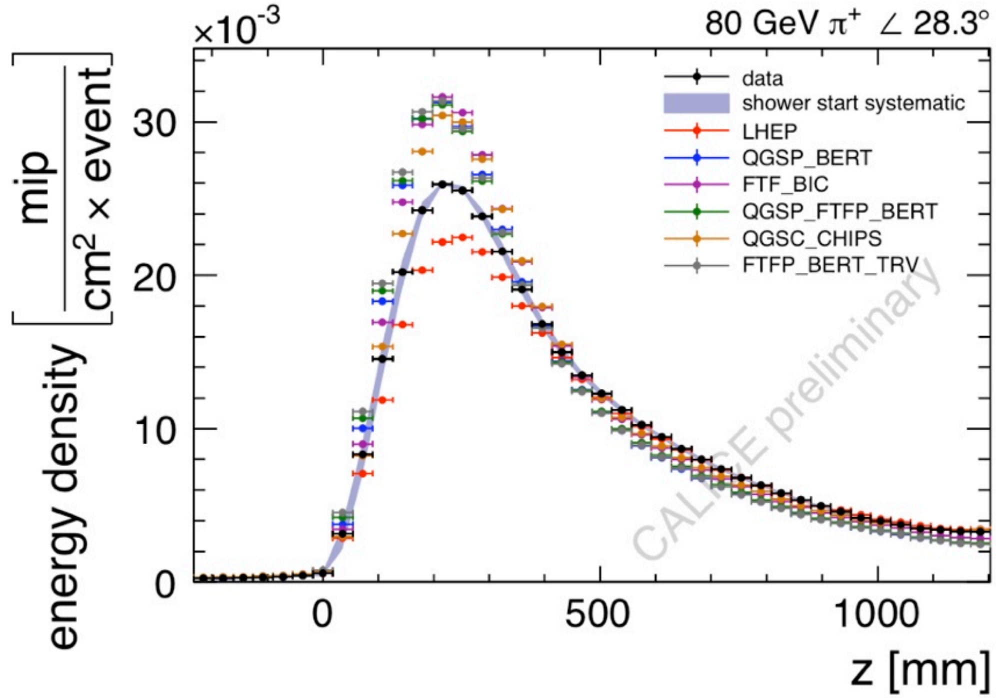


- Developed a method to identify the first hadron interaction
- Position of shower start in the calorimeter as a function of the number of interaction lengths
- Method allows to measure longitudinal profile without fluctuations in first interaction

Longitudinal Shower Profile

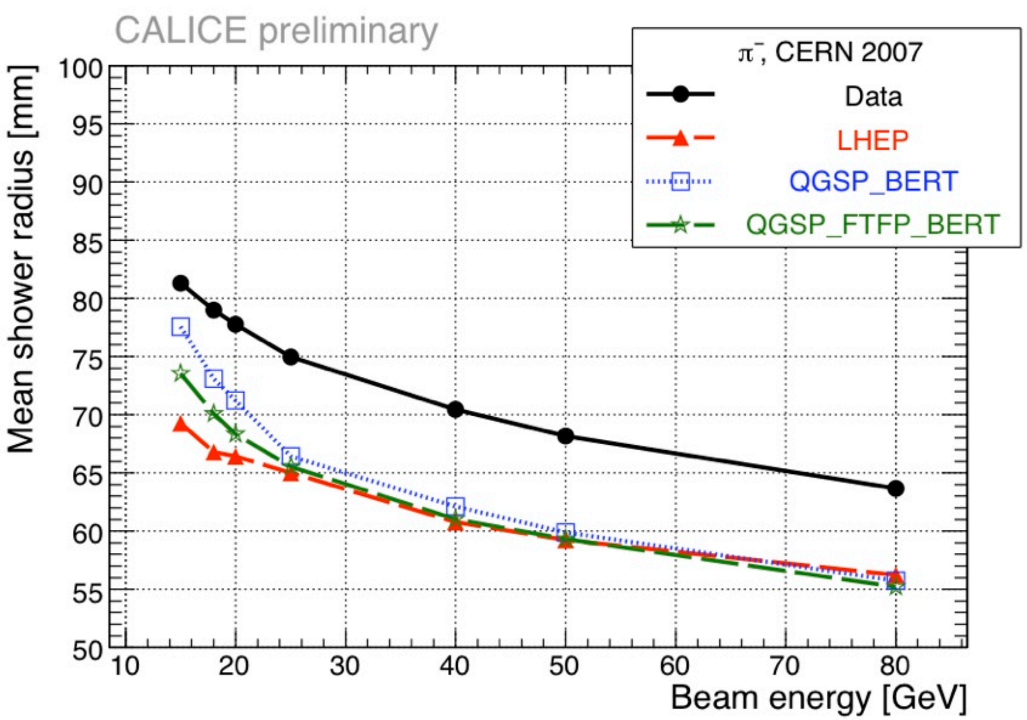
z = 0, first identified nuclear interaction point

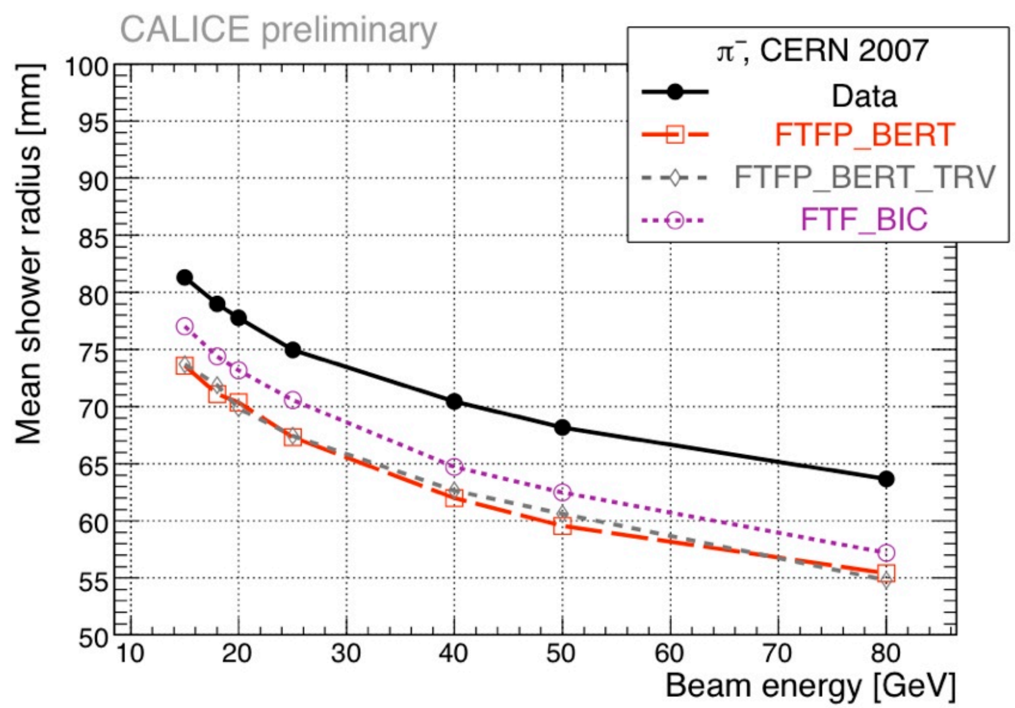




- Increased sensitivity with longitudinal shower profile from first nuclear interaction point, fluctuation ± 1Layer.
- Agreement between data and simulation around 20%
- Most model predict too short showers at high energy

Mean Shower radius





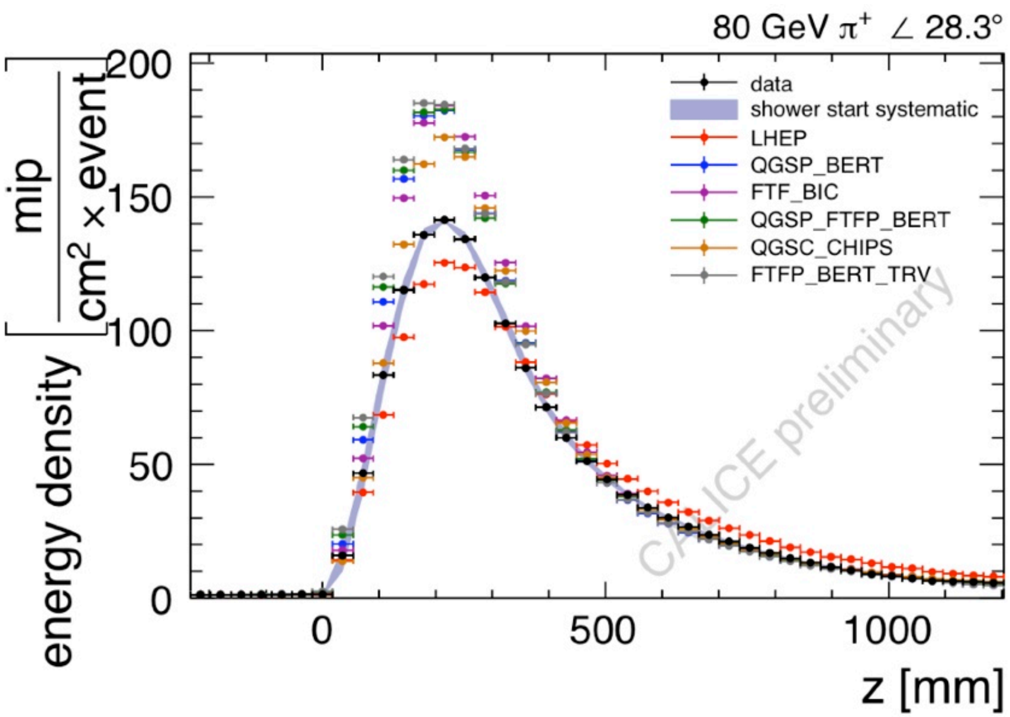
- Shower radius: distance between hit and shower axis weighted with energy

$$\langle R \rangle_{event} = \frac{\sum_i E_i \cdot R_i}{\sum_i E_i}$$

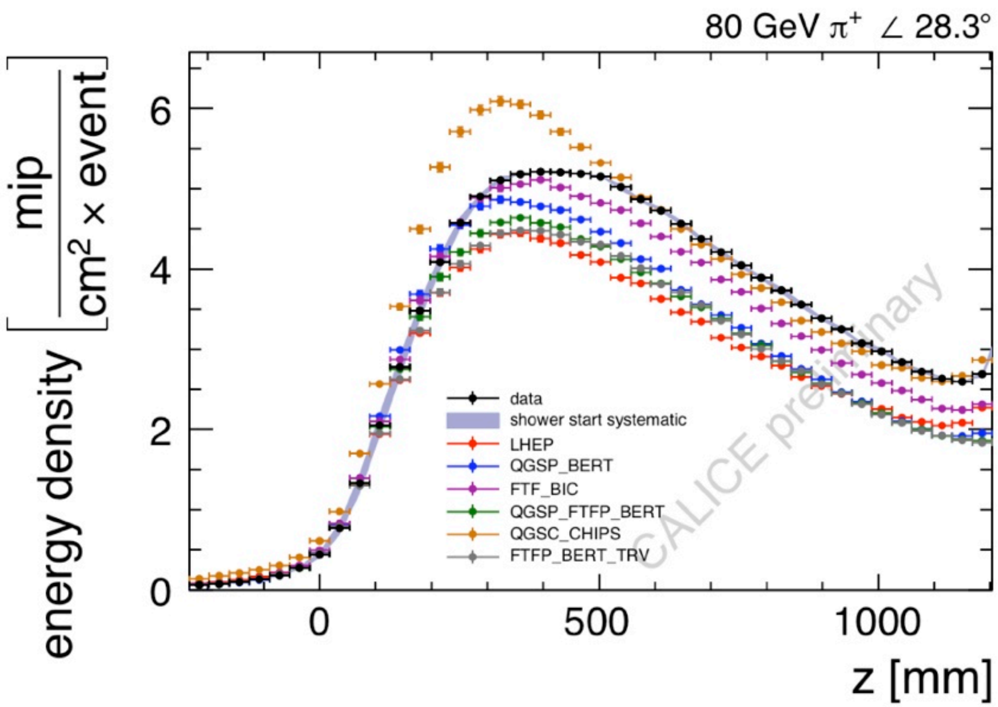
- Showers become narrow with increasing energy
- MC models predict narrower showers than in data

Longitudinal Shower Profile

0 ≤ R < 60 mm



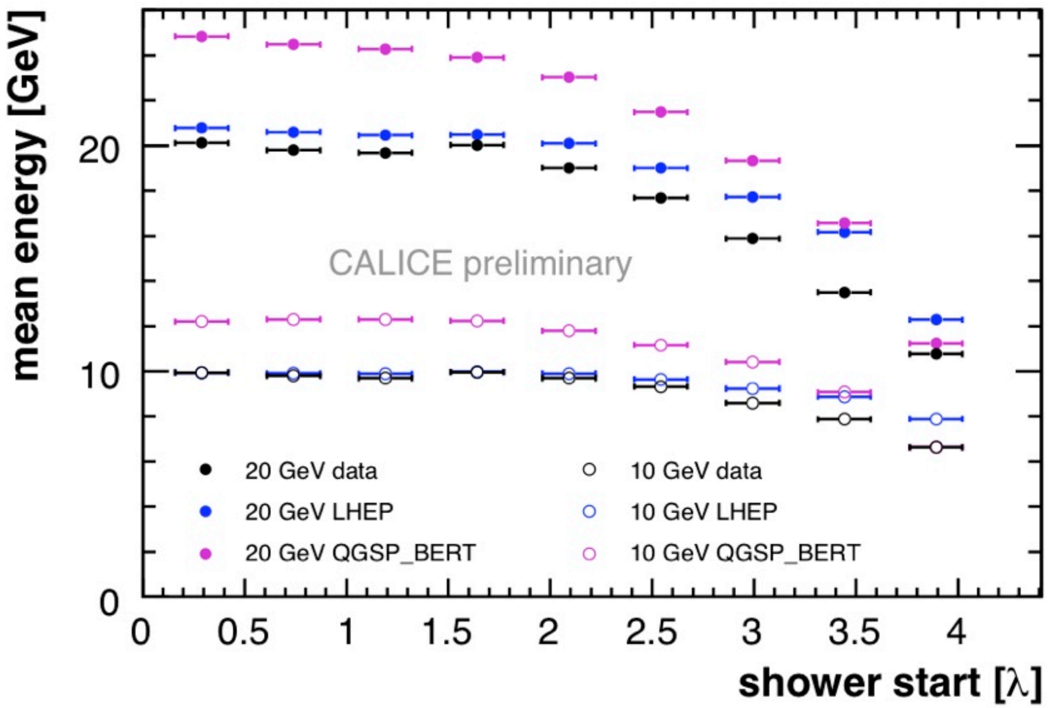
120 ≤ R < 180 mm

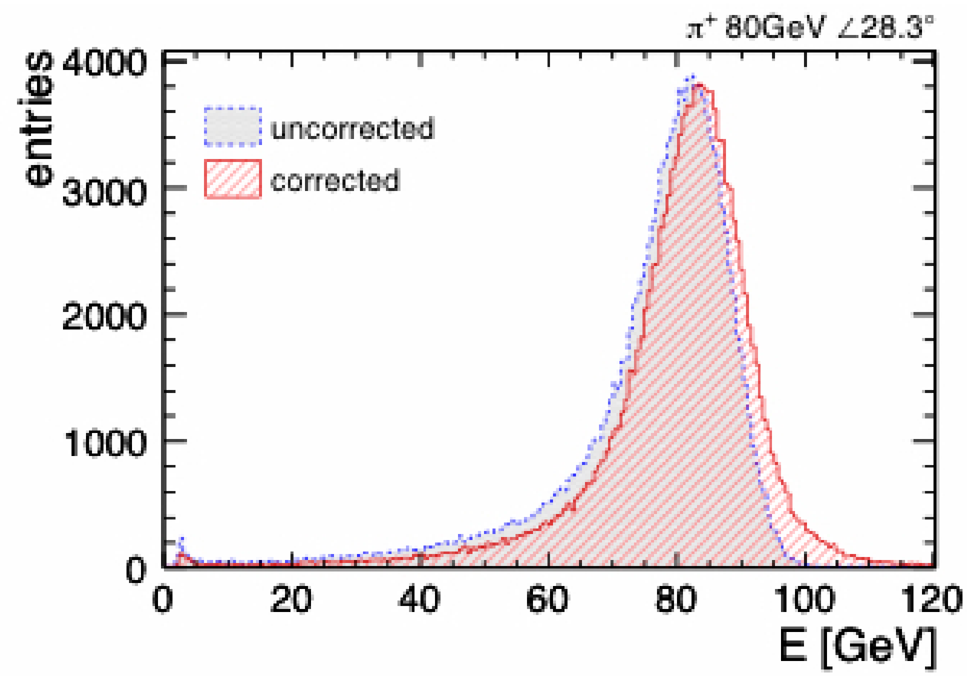


- Shower core, reflect the e.m. shower information
  - overshoot stronger
- Larger radius, reflect the neutron information
  - string models less deviations

Leakage

- Leakage depends on:
  - beam energy
  - shower starting position
- Reconstructed energy decreases and resolution worsens





- Mean energy corrected
- Resolution improved

Summary

- AHCAL Prototype - Testing the Concept
  - Operation of a 8000 channels system
  - Calibration established
  - Systematics established
- AHCAL Prototype - New Tool for Hadron Shower Physics
  - Developed method to identify the first hadron interaction
  - Developed method to estimate and correct longitudinal leakage
  - Confronted several simulation models with data
- The tungsten HCAL data will come soon
  - WHCAL pions test beam start on November 2010
  - Allow new comparisons of simulation models with data