Lateral Profiles of Hadron-Induced Showers in the AHCAL

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Outline

Data Selection

Monte Carlo Tuning

Results: Shower Energy

Results: Lateral Energy Profiles

Results: Fractional Energy Deposition

Results: Shower Radius

Summary and Outlook

Data Selection

- π^- beam data from CERN 2007 data taking period
- Runs 330327 (18 GeV): combined ECAL/HCAL/TCMT data taking
- Events selected with triggers
  - BEAM (SPILL + Scintillator coincidence) & SPILL data (real data only):
  - SKIP calibration/pedestal data
- HCAL energy cut: $E > 0.5$ MIP
- Discard events with Nr. of firing ECAL cells SiPM > 50

  $\Longrightarrow$ get rid of showers starting already in ECAL
- Discard events with Nr. of firing SiPM < 150 in HCAL

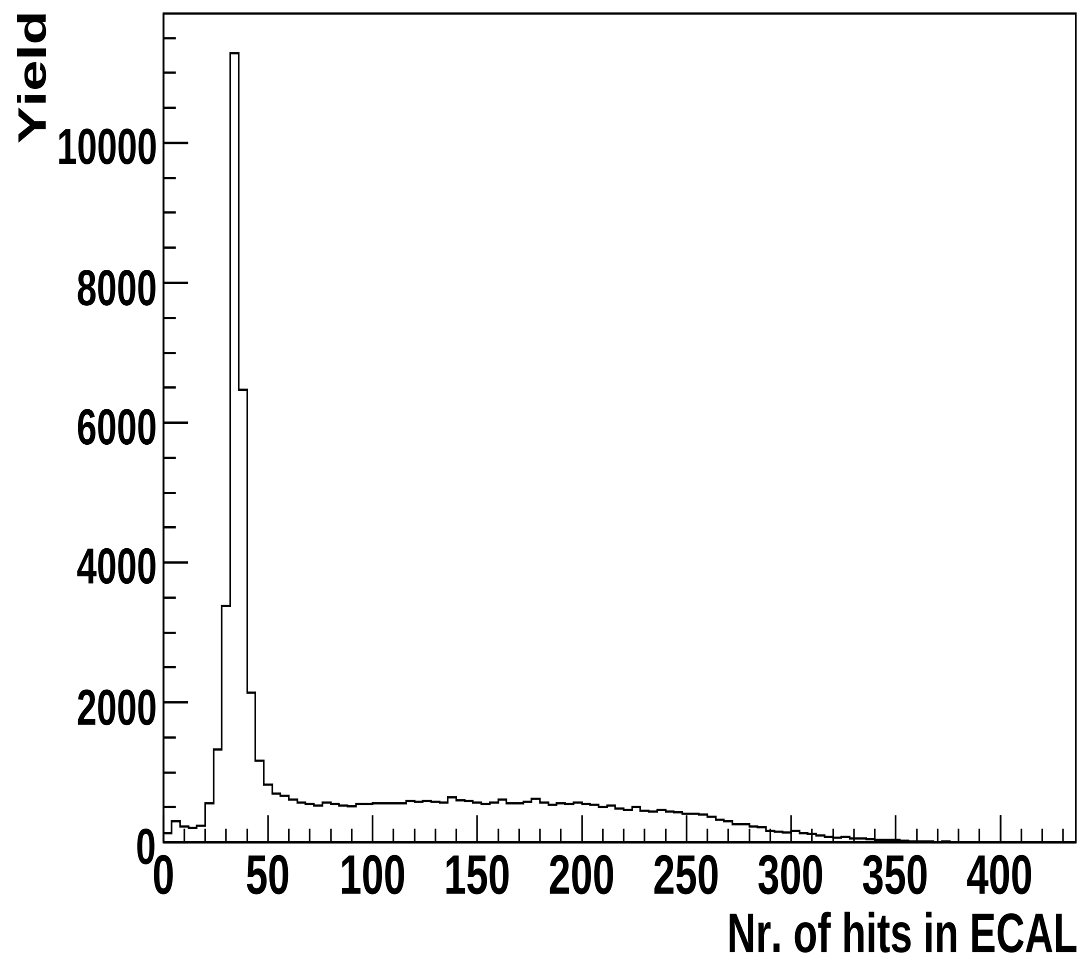
  $\Longrightarrow$ select shower events
- NOTE: no energy deposited in TCMT used sofar

  $\Longrightarrow$ This analysis focuses on showers only in AHCAL
- Latest calibration used in data (temperature correction included)
- Latest calibration/digitisation used in Monte Carlo
- Same cuts used in both data and Monte Carlo

Data Selection: MIP in ECAL

Skip event if Nr. of hits in ECAL > 50

$\Rightarrow$ **meant to clean sample from showers already starting in ECAL**

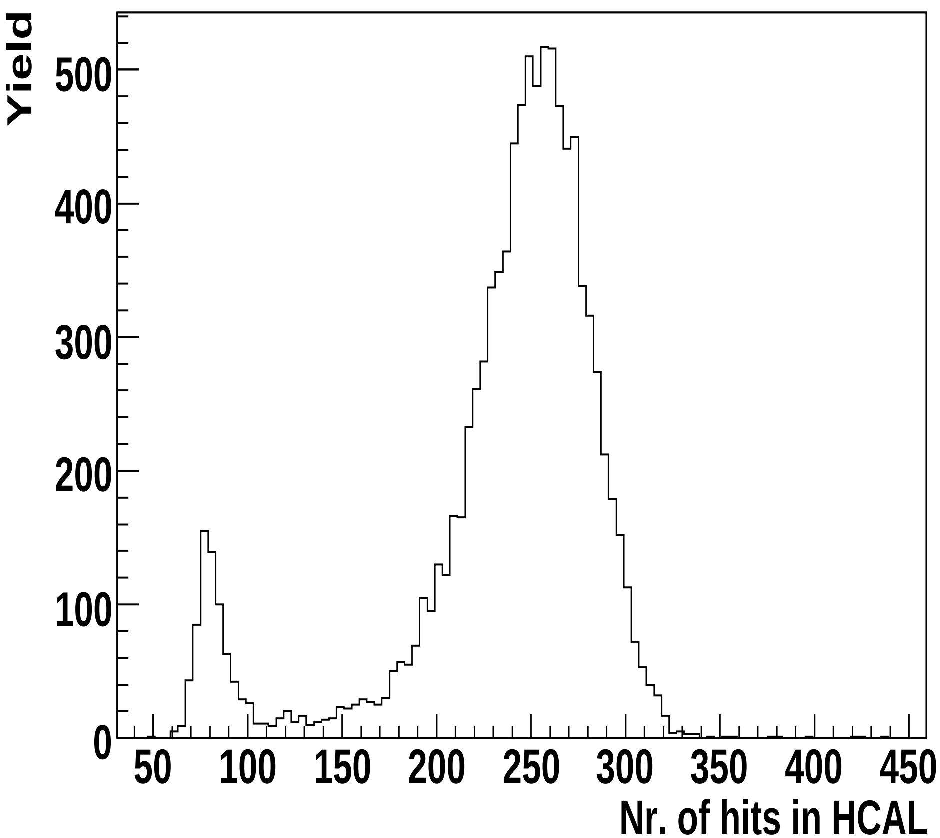


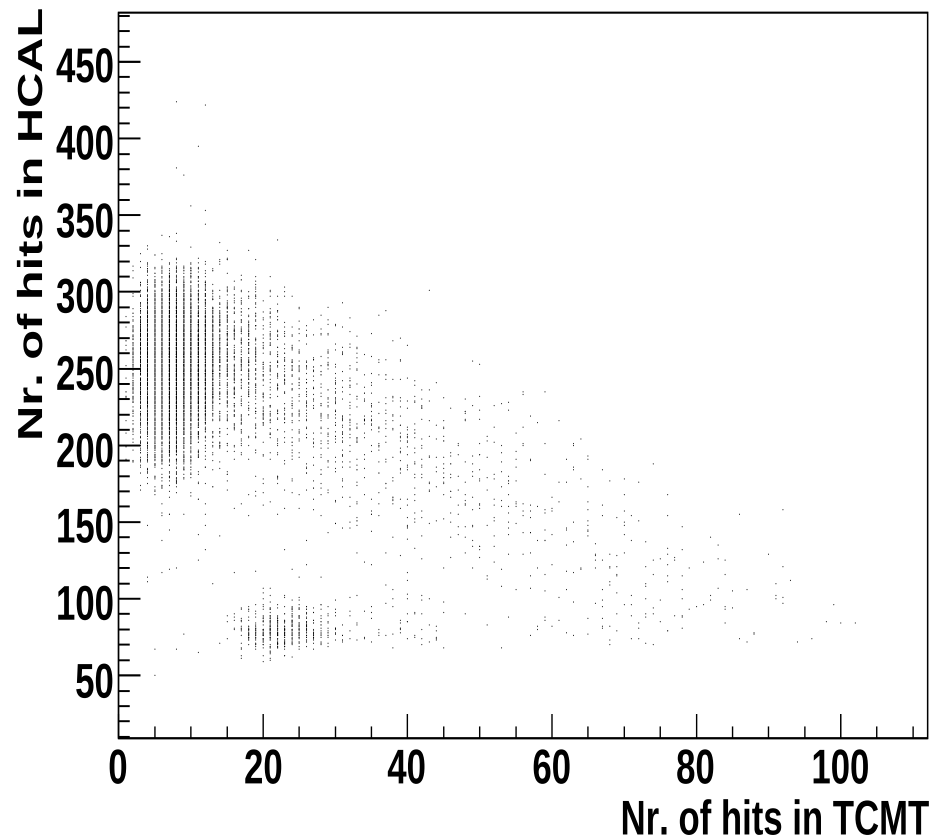
Data Selection: Showers in HCAL

Select event if Nr. of hits in HCAL > 150

$\Rightarrow$ **meant to select shower events only**

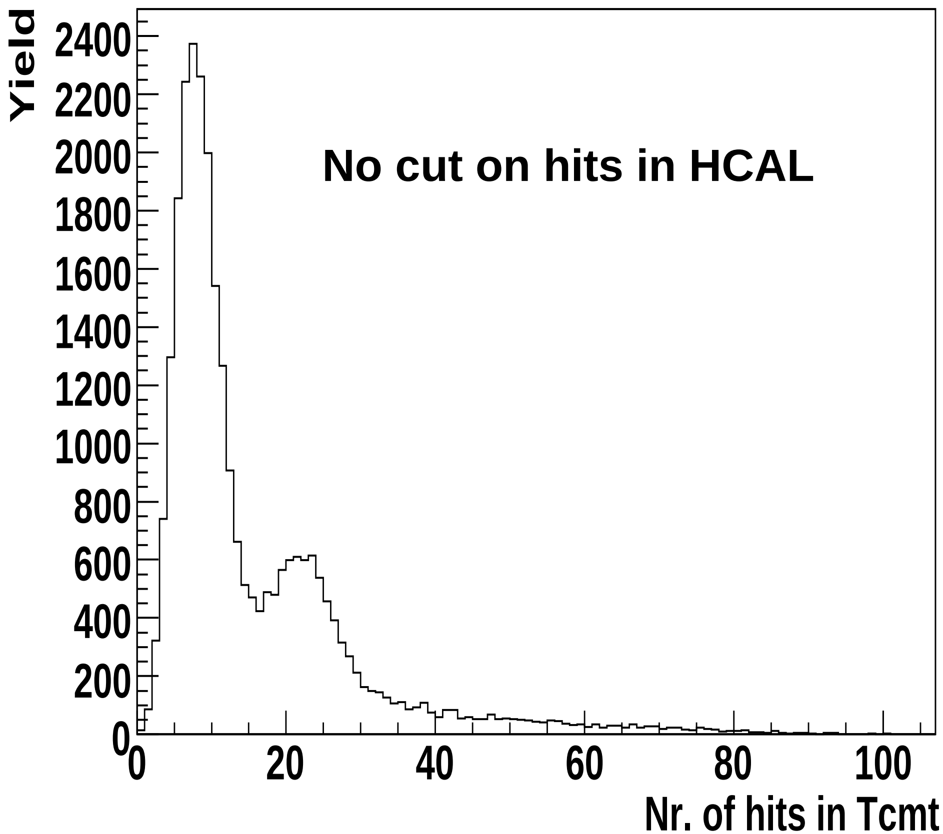
$\Rightarrow$ **cut applied after cut on ECAL hits**

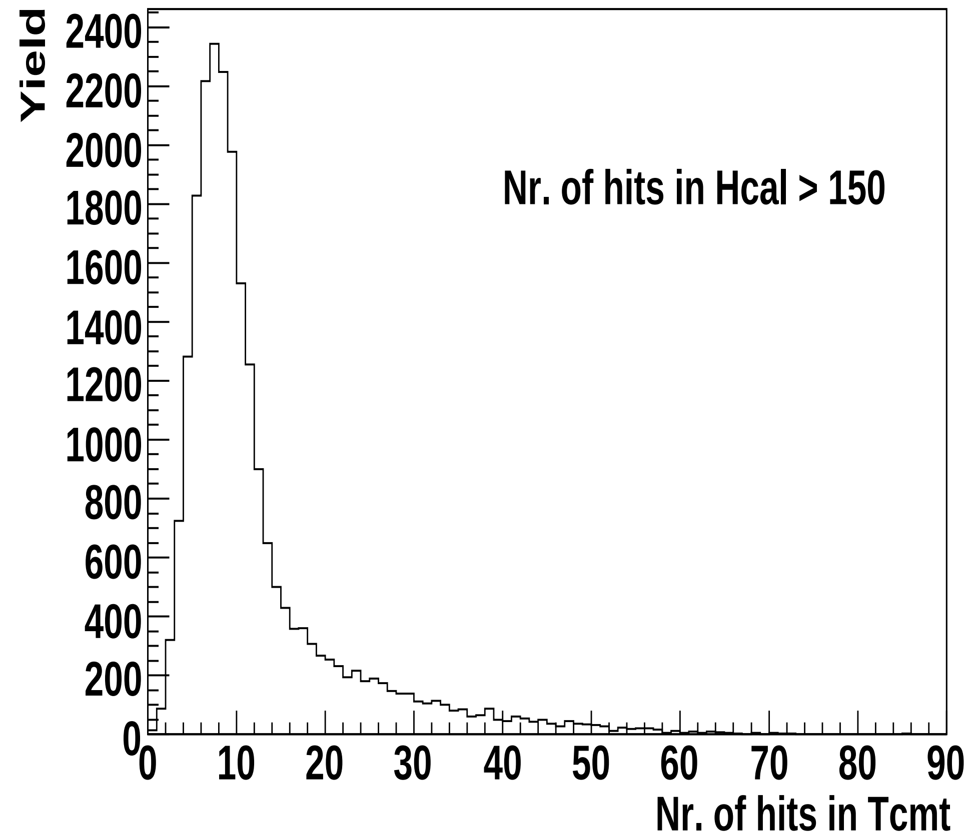




Data Selection: μ-contamination

μ-contamination removed after applying shower cut in HCAL





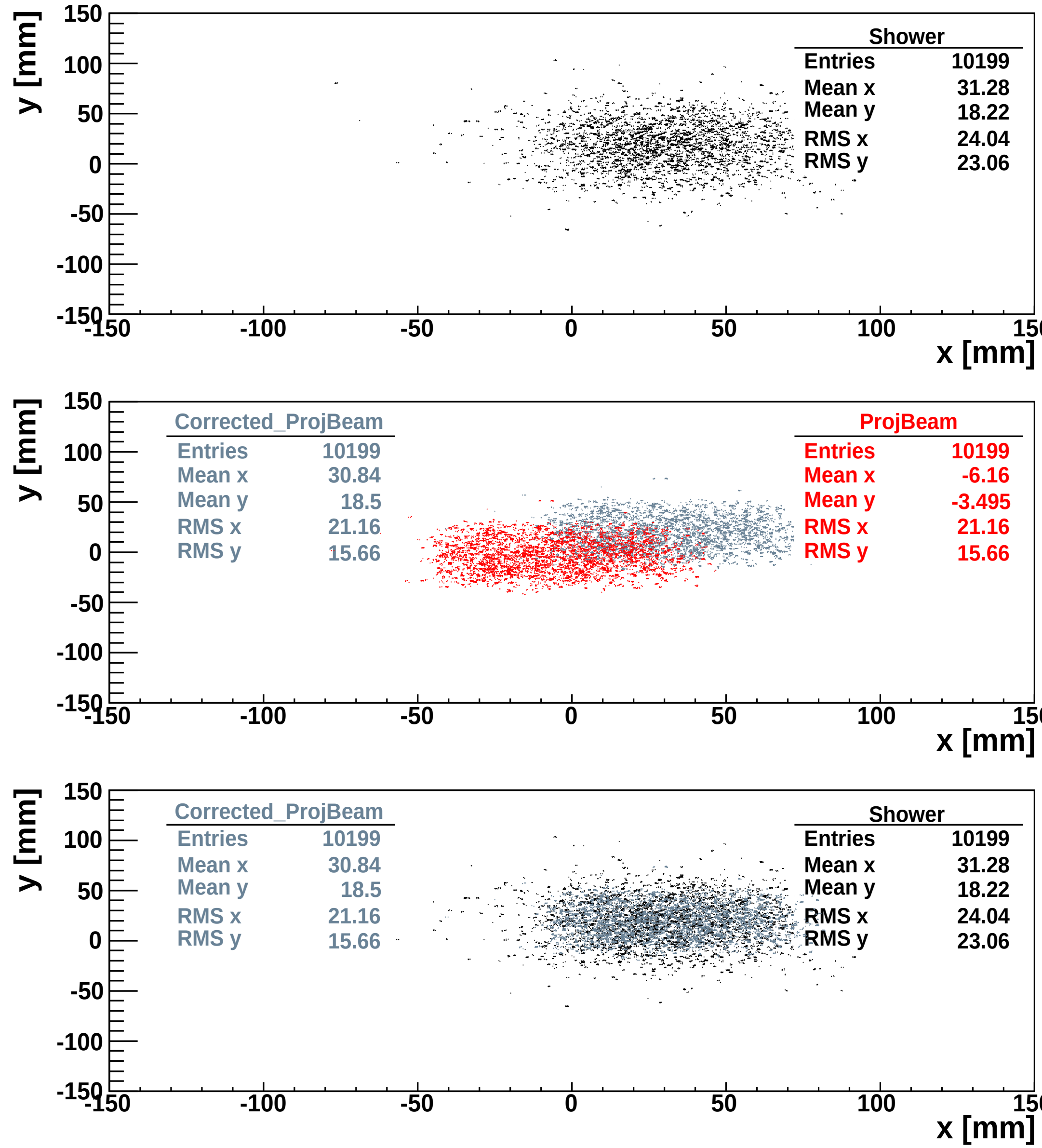
NOTE: on top of this, additional conservative cut applied: Discard event if

— a) $0 <$ Nr. of hits in TCMT layer ≤ 3

— b) at least 15 (out of 16) TCMT layers fullfill a)

Monte Carlo Tuning

- **Beam width given by data:**
  profiles in chamber DC3
- **Beam mean given by data:**
  showers COGs in HCAL
- **Beam gun located in front of DC3**



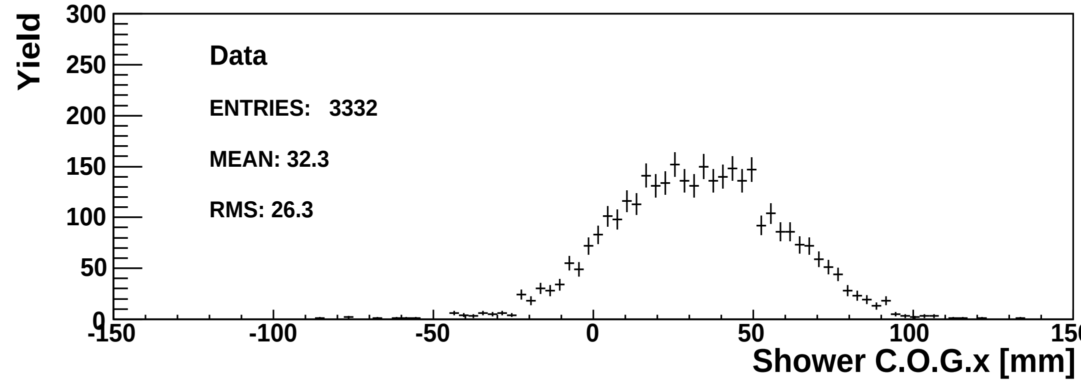
Monte Carlo Tuning

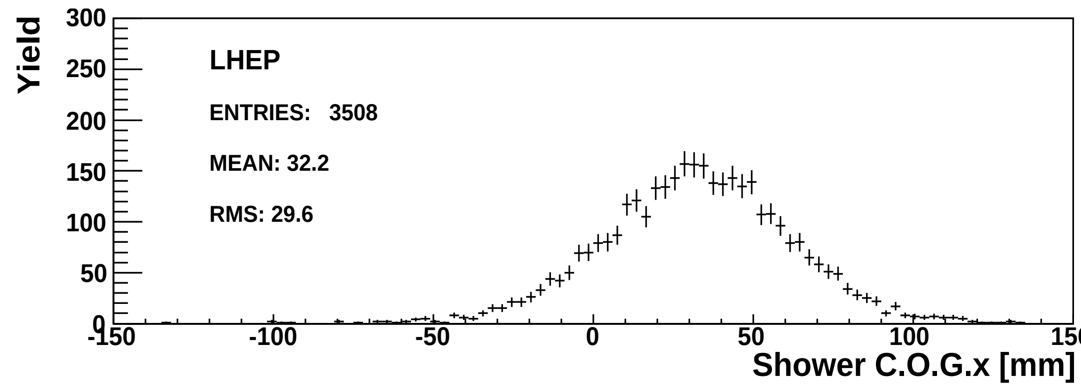
- No disalignment in MC

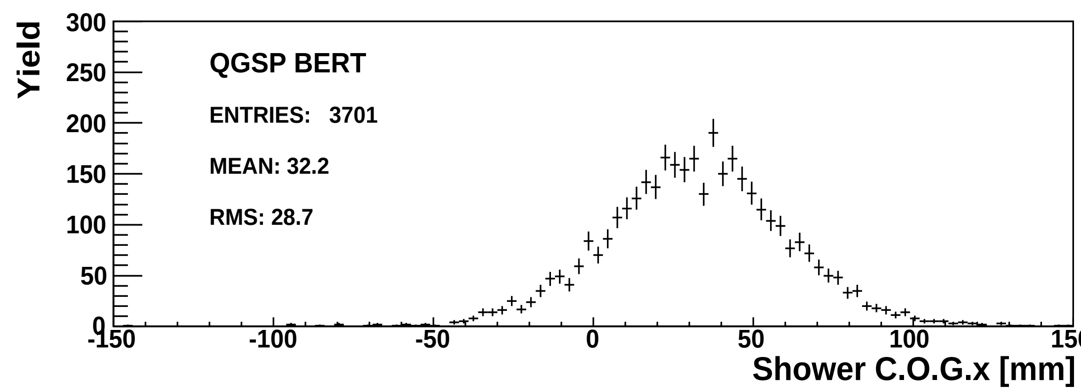
- Simulation done with larger chambers: $300 X 300$ mm^2

  $\Rightarrow$ otherwise beam partially cut due to linearity cut in chambers

- Running conditions reproduced







Results

Hadron Shower Energy

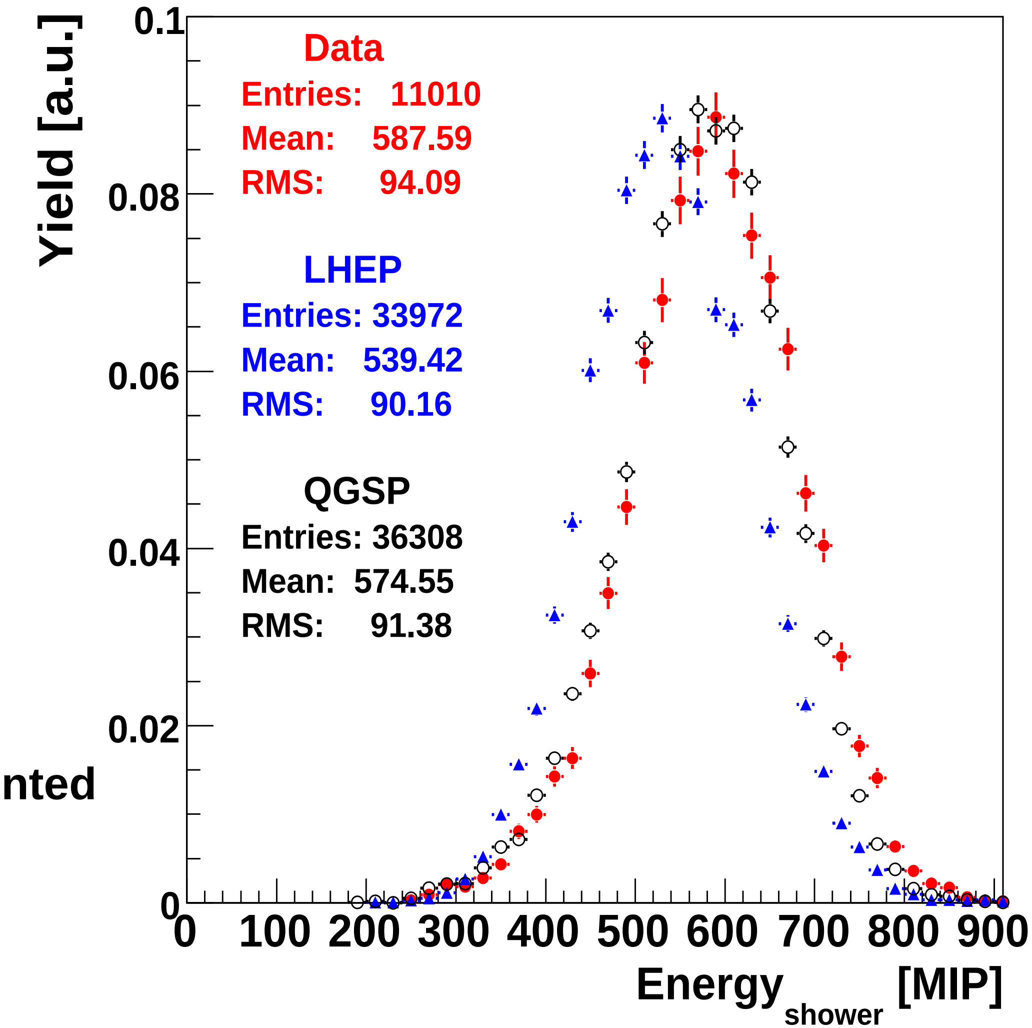
Data - Monte Carlo Comparison

Shower Deposited Energy

- **Models predict different amount of energy deposition**

Comparison with test-beam data is crucial to reduce large models uncertainties

NOTE: energy-related results presented in MIP units in this analysis



Results

Lateral Energy Profiles

Analysis Strategy

- Shower reconstructed wrt reconstructed incident track axis
- For each shower event, energy in i-tile localised (after alignment) according to

$$\rho_i = \sqrt{(x_i - x_{track})^2 + (y_i - y_{track})^2}$$

$x_i/y_i \longrightarrow$ **tile-center coordinates**

$x_{track}/y_{track} \longrightarrow$ **track impact point coordinates**

Analysis Strategy

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$x_i/y_i \longrightarrow$ **tile-center coordinates**

$x_{track}/y_{track} \longrightarrow$ **track impact point coordinates**

- Tile coordinate is fixed while secondary shower track may be everywhere in tile
- Circumvent this geometrical bias assuming uniform distrib. probability for hit in tile

$$x_i \longrightarrow x_i + \Delta x$$

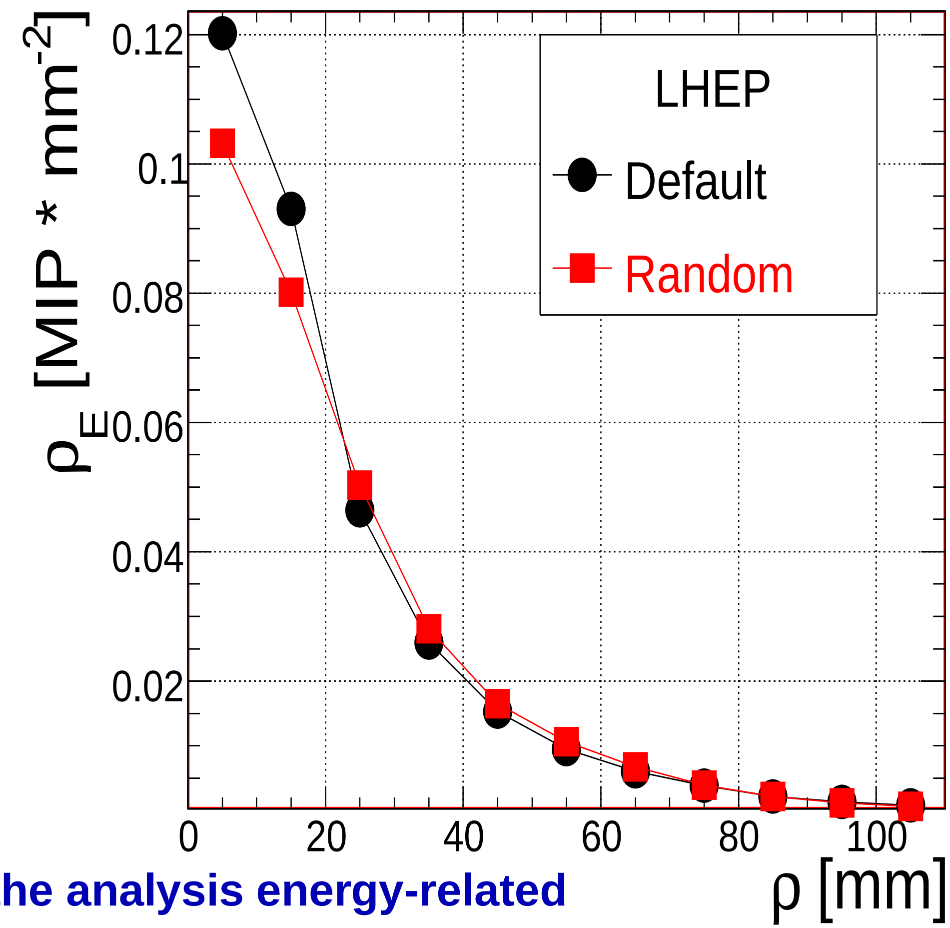
$$\Delta x = \textit{\textbf{Uniform\_Random\_Generator}}(x_i - \textit{\textbf{cellSize}}/2., x_i + \textit{\textbf{cellSize}}/2.)$$

...and similarly for y_i

Analysis Strategy

- **Effects of randomisation procedure for hit-coordinates (Monte Carlo simulation)**

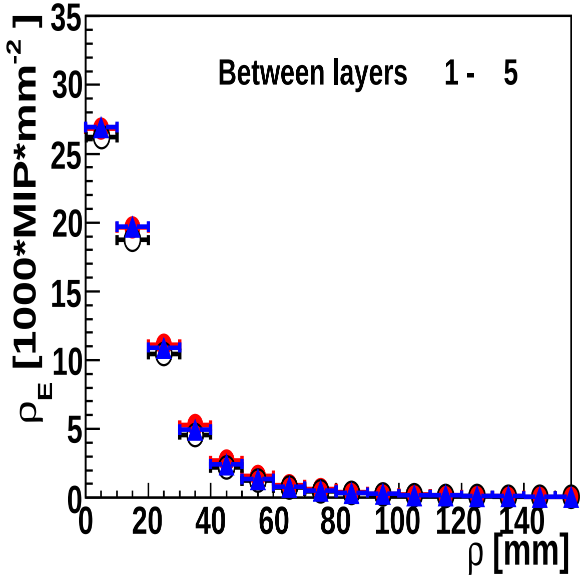
As expected, procedure induces smoothness of measured profiles

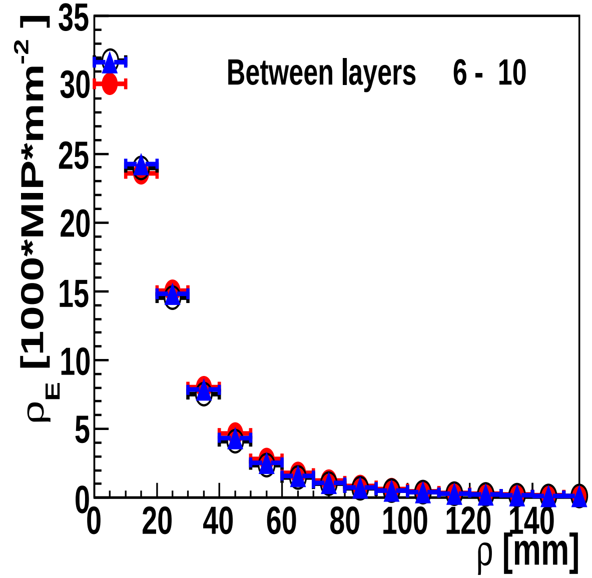


NOTE: Random procedure applied in the analysis energy-related results (data and Monte Carlo) presented in this work

Data - Monte Carlo Comparison

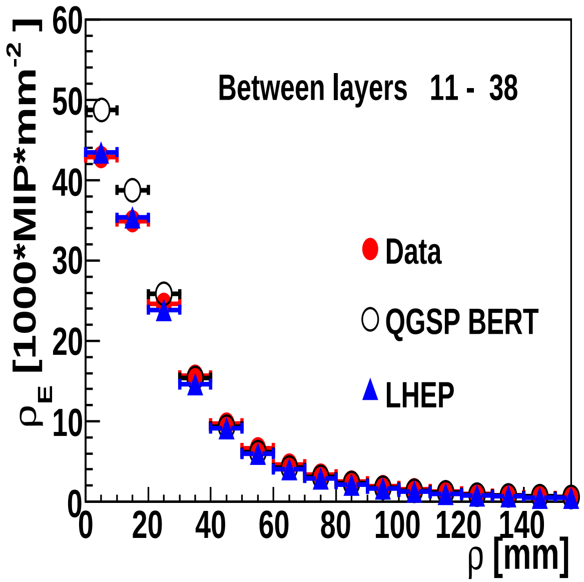
Lateral Energy Density





Better agreement

LHEP-Data in shower core



MC models can be compared

with data for longitudinal

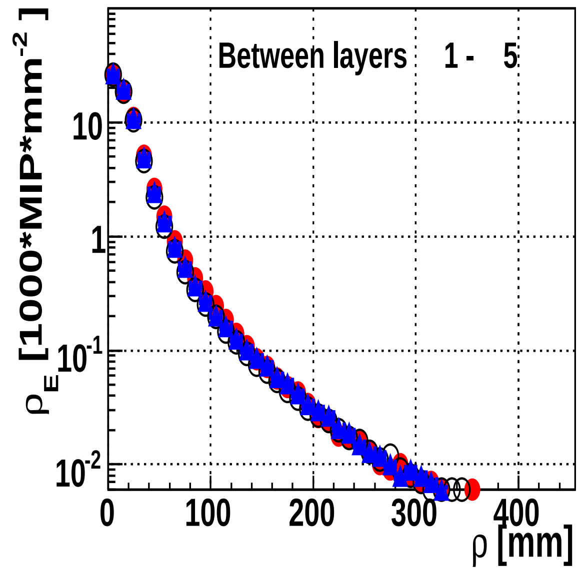
sections of showers

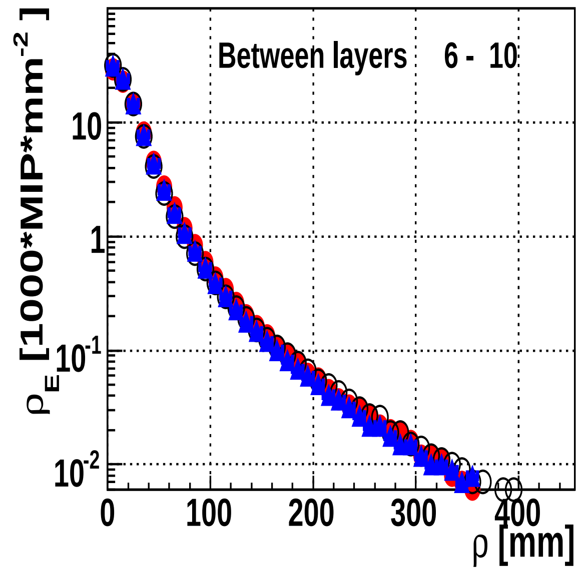
where different interactions

type might dominate

Data - Monte Carlo Comparison

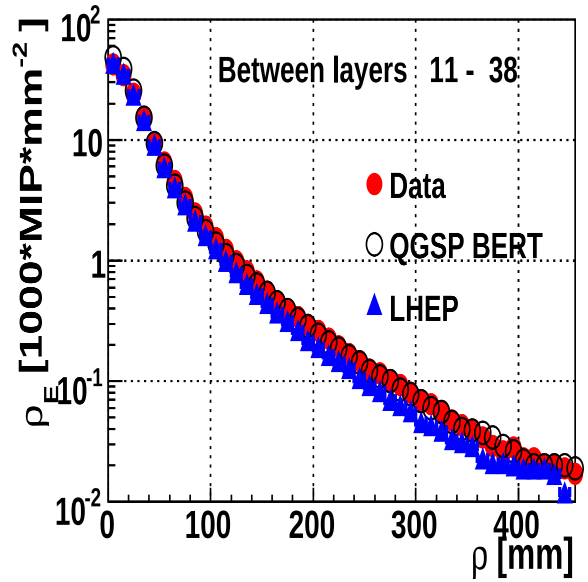
Lateral Energy Density





Better agreement

QGSP-Data in shower tail



MC models can be compared

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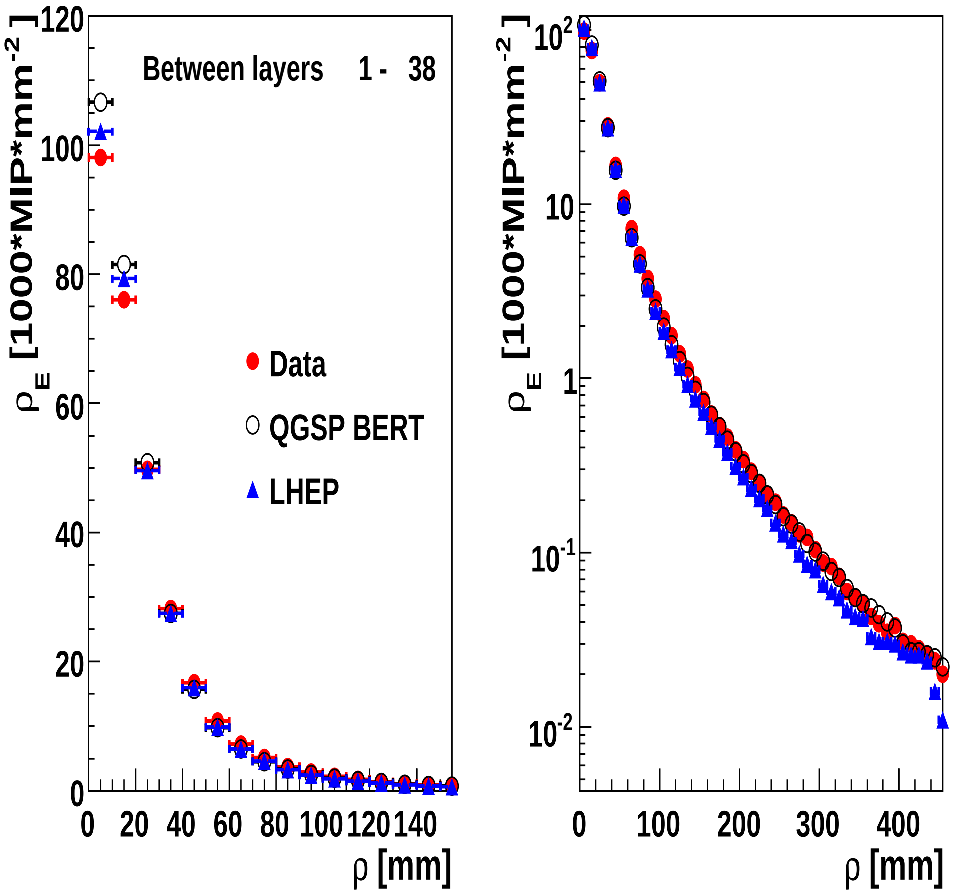
Data - Monte Carlo Comparison

Lateral Energy Density: Effects from different deposited shower energy in models

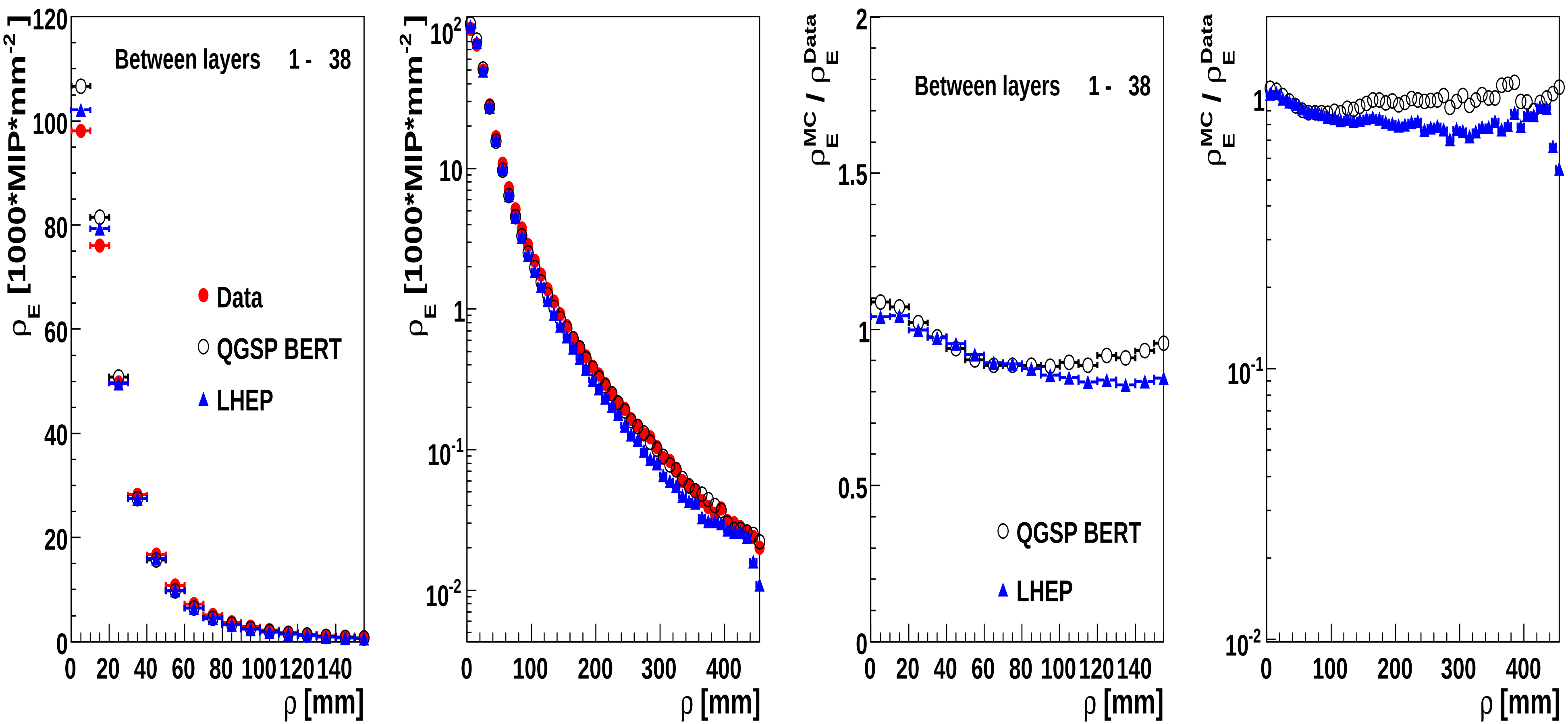
- ***Investigate shower energy deposition in whole HCAL***



Data - Monte Carlo Comparison

Lateral Energy Density: Effects from different deposited shower energy in models

- ***Investigate shower energy deposition in whole HCAL***
- ***Normalise MC bin by bin to data energy content***



Results

Lateral Fractional Energy Deposition in Hadron Showers

Data - Monte Carlo Comparison

Fractional Energy Deposition

- Calculated in every bin ρ_i via

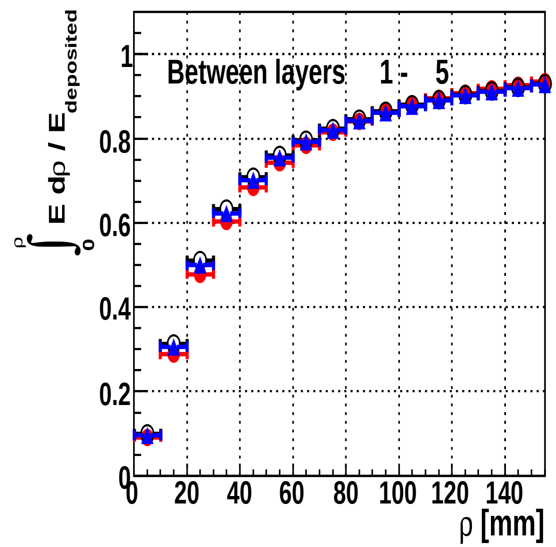
  energy integration from lowest

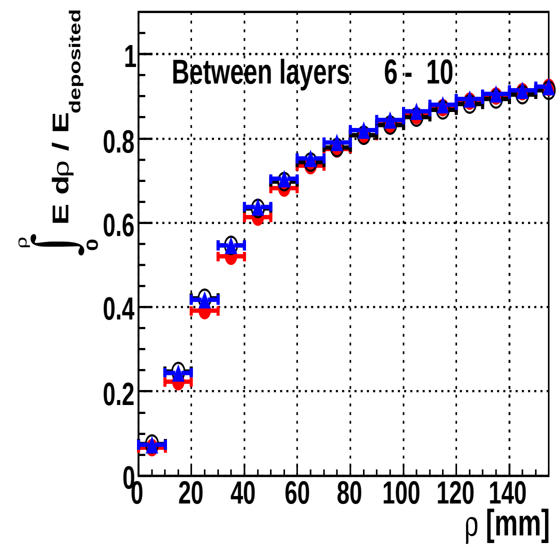
  bin up to ρ_i bin

  Then, normalise to total energy

  reconstructed in calo sector

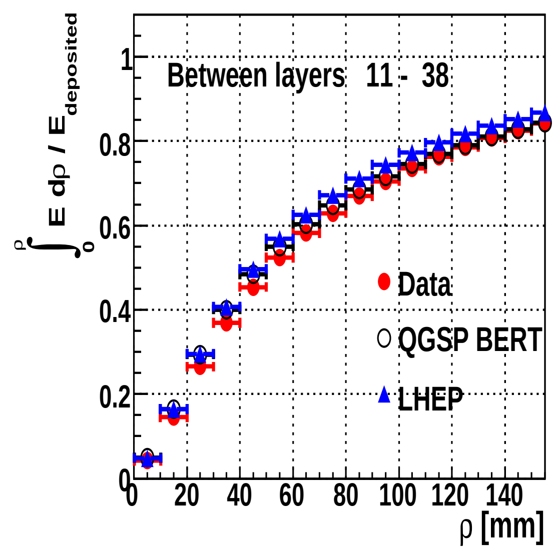
Showers Core:





Similar conclusions as for

energy density might be drawn



MC models can be compared

with data for longitudinal

sections of showers

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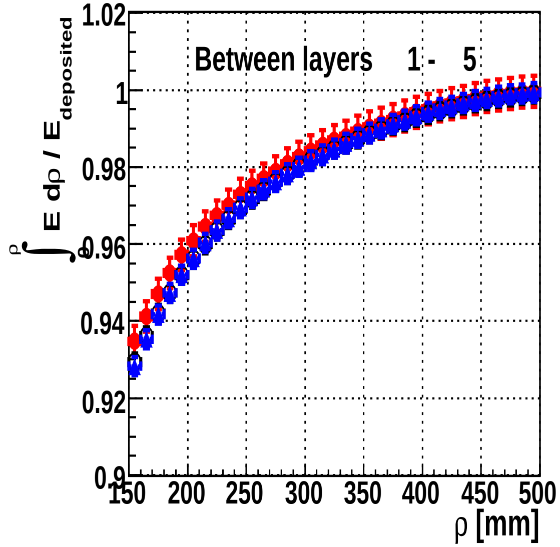
Data - Monte Carlo Comparison

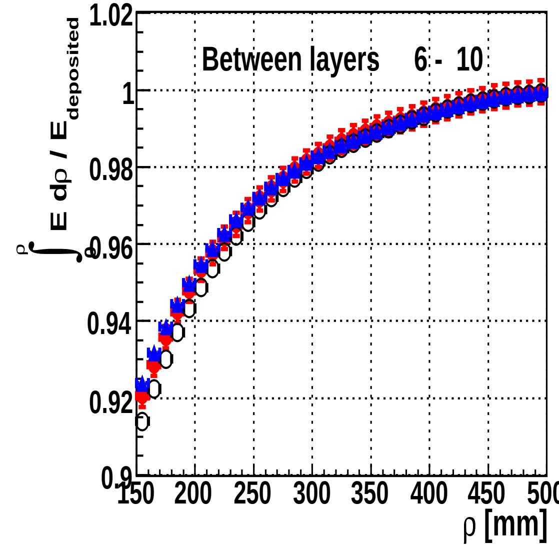
Fractional Energy Deposition

- **Calculated in every bin ρ_i via energy integration from lowest bin up to ρ_i bin**

  Then, normalise to total energy reconstructed in calo sector

Shower Tail:





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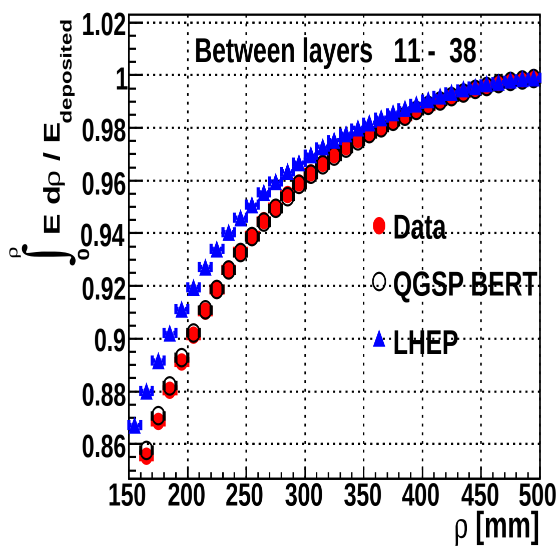


MC models can be compared with data for longitudinal sections of showers where different interactions type might dominate

NOTE: statistical uncertainties are correlated

Results

Hadron Shower Radius

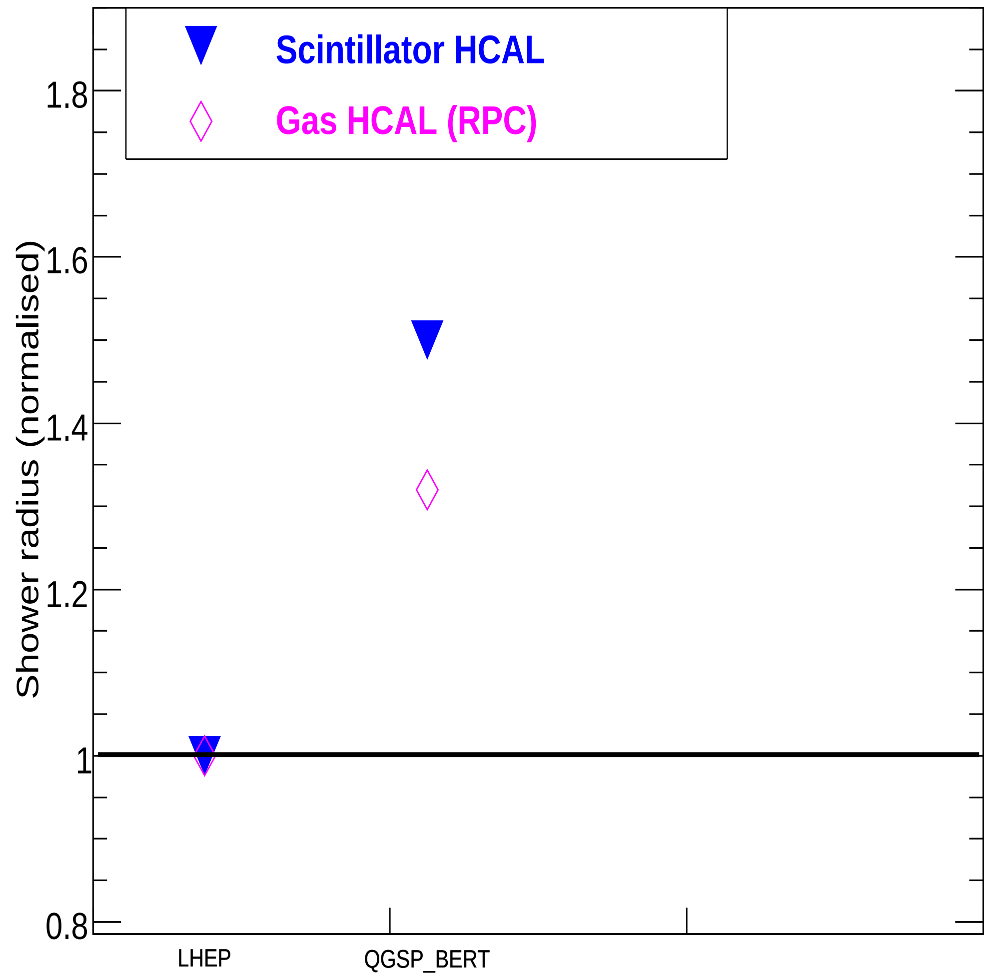
Data - Monte Carlo Comparison

Shower radius distribution

- Available MC show large variations of quantitites describing hadron showers, and for different hadronic calorimeter scenario

Effects appear to be sizable: Investigation with real data needed

(Adapted from G. Mavromanolakis and D. Ward arXiv:physics/0409040; 10 GeV π)



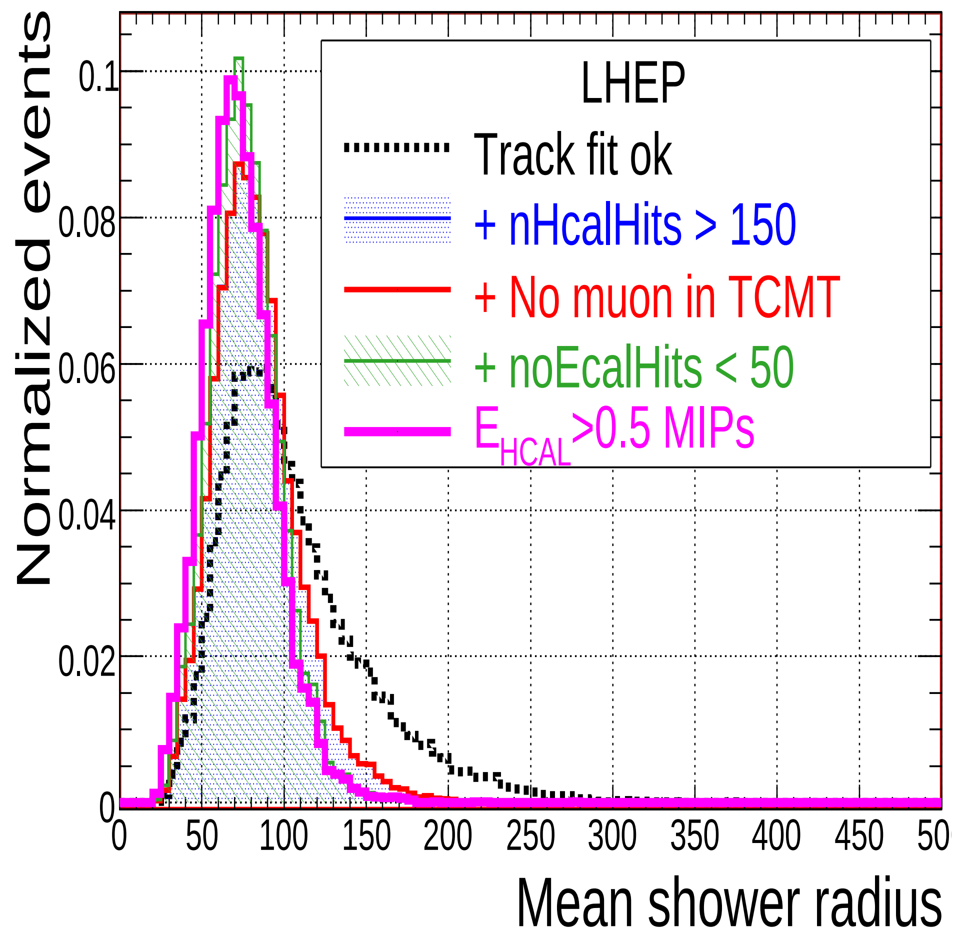
Data - Monte Carlo Comparison

Shower radius distribution

- **Effects of analysis cuts on reconstructed shower radius distribution investigated to possibly compare with other simulations**

Stronger effects from selecting shower events:

uniform noise hits contribution to ditribution becomes negligible in events with > 150 firing cells



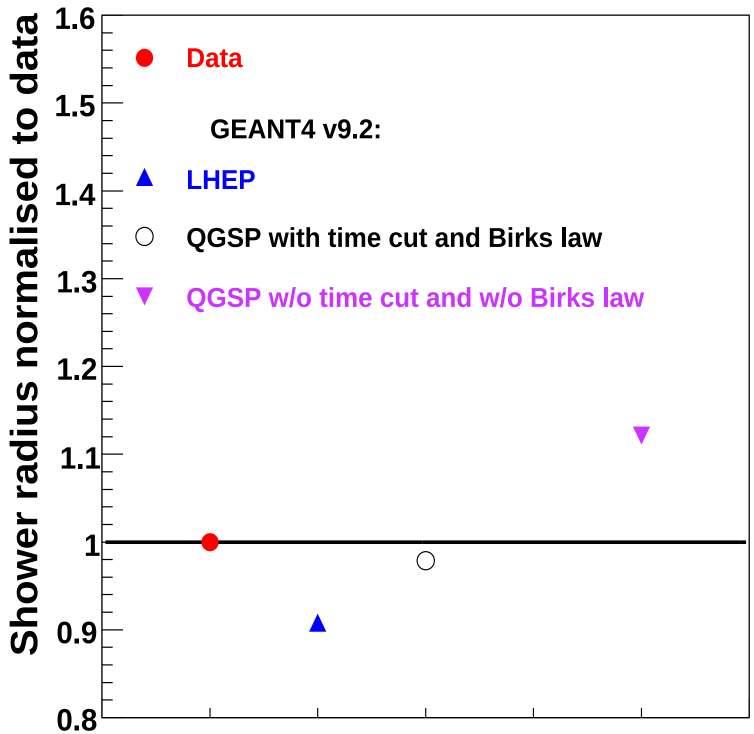
Data - Monte Carlo Comparison

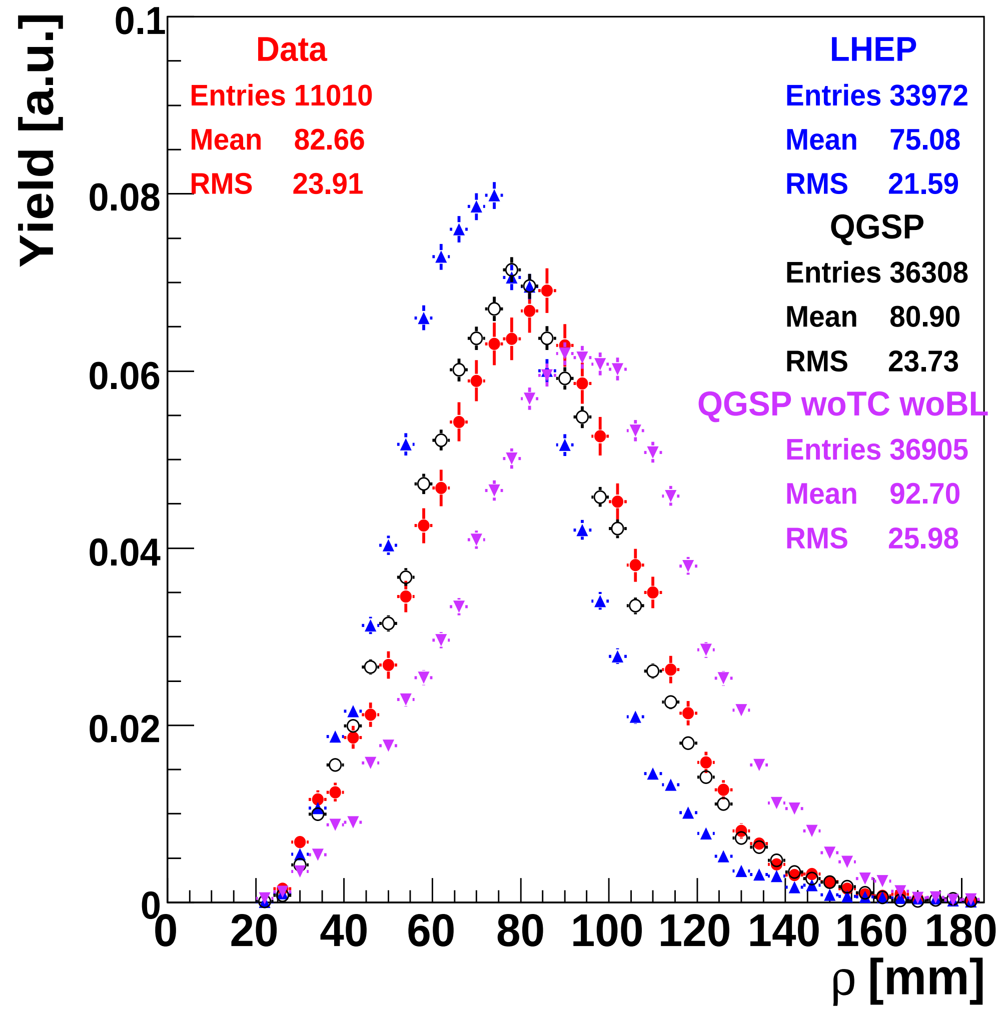
Shower radius distribution

LHEP/QGSP BERT $\Rightarrow$ no/with neutrons

- **WO detector effects also QGSP BERT is sizably off**

  $\Rightarrow$ Including Birks Law and time cut, it describes better the data





Data - Monte Carlo Comparison

<u>Shower radius distribution</u>

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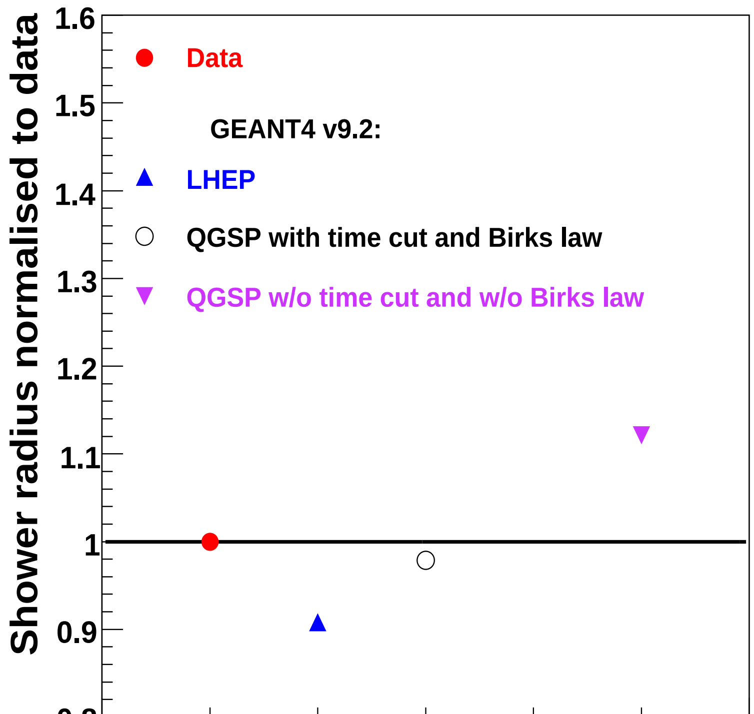
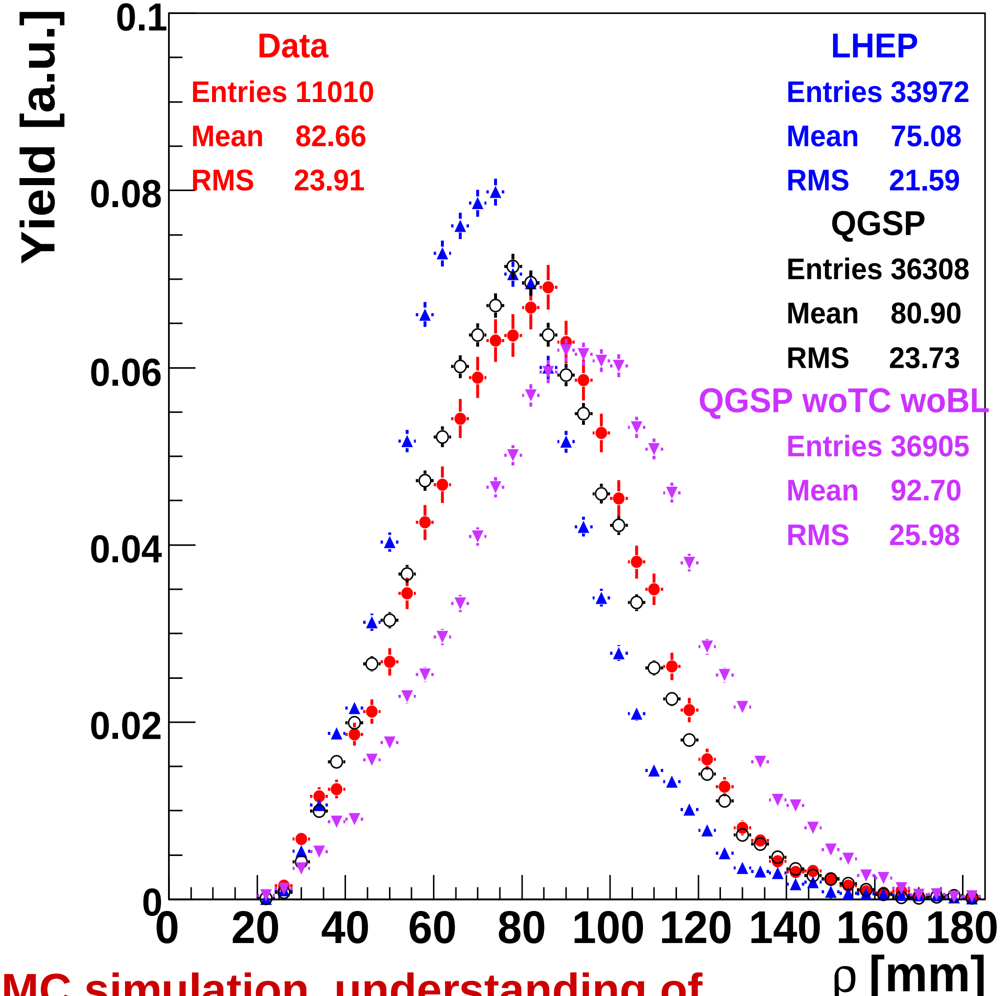




For MC simulation, understanding of detector effects is crucial!

Summary and Outlook

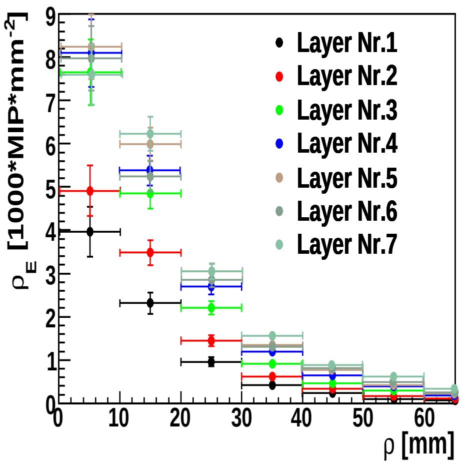
- Lateral hadron shower investigated with high granularity CALICE AHCAL
- Analysis procedure presented: data selection/analysis algorithm
- Monte Carlo tuning to real data presented
- Results proposed:
  - Shower Energy
  - Fractional energy
  - Lateral Energy Profiles
  - Shower radius
- Analysis focused in comparing MC models (LHEP & QGSP BERT) to data
  - Simulation improved after inclusion of detector effects
  - Within current calib/digit, QGSP BERT (LHEP) better matches profile tail (core)
- As further steps (next note):
  - Evaluate systematical uncertainties
  - Extract different contributions in shower development
  - Analysis different test-beam energy (particle type) data
  - Analysis with respect to start of shower

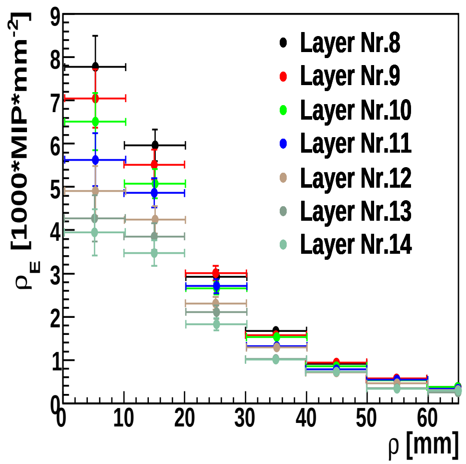
Backup Slides

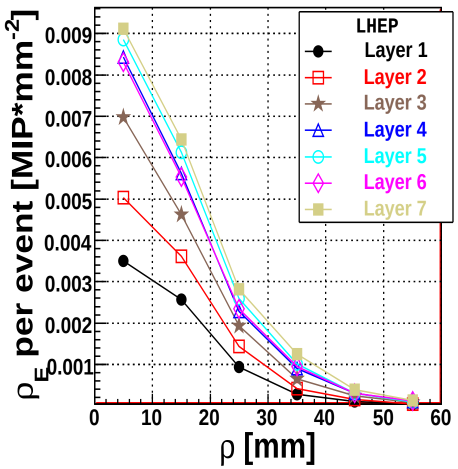
MC Cross-Check: Lateral Profiles

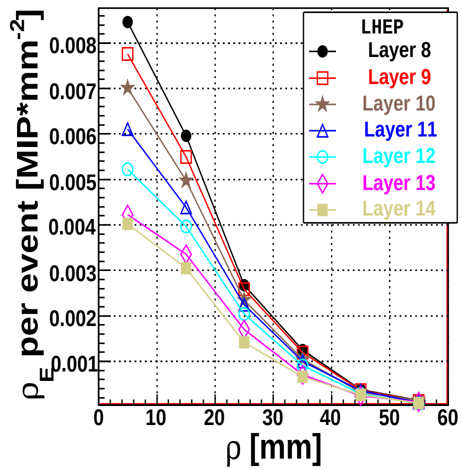
Riccardo (10K events) | Angela (all statistics)

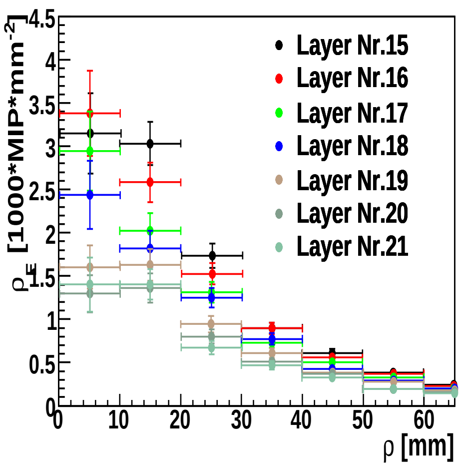
LHEP

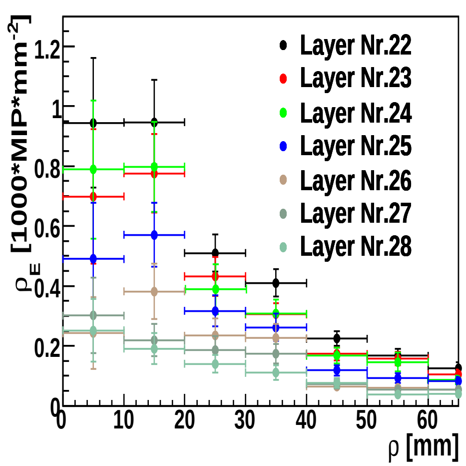


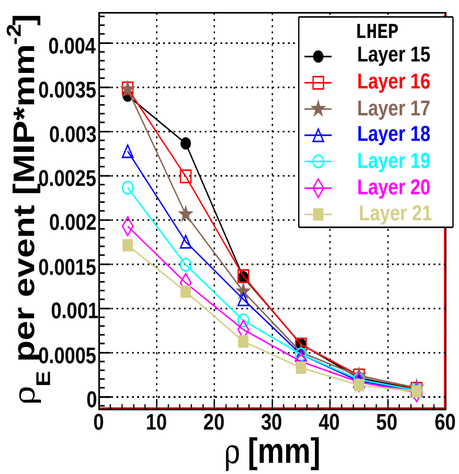


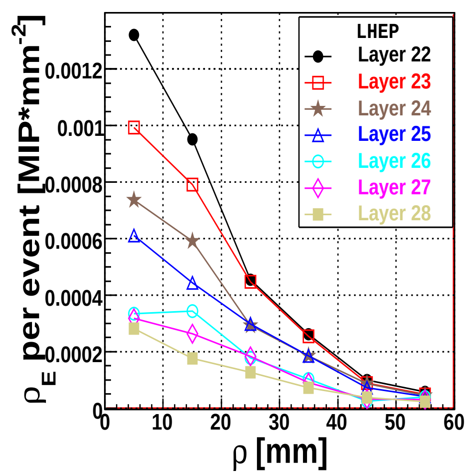












MC Cross-Check: Lateral Profiles

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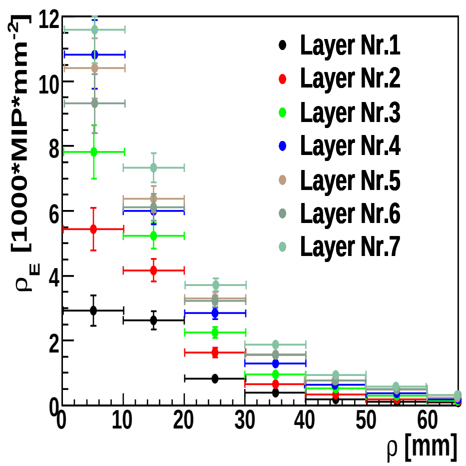
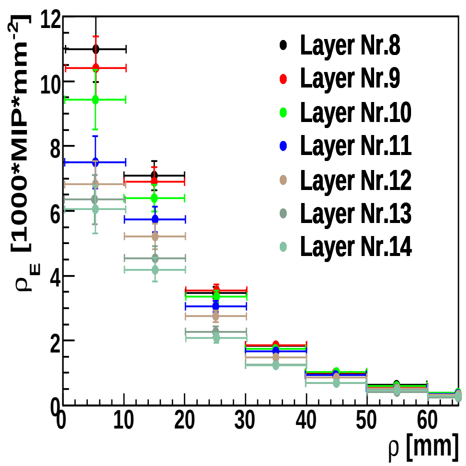
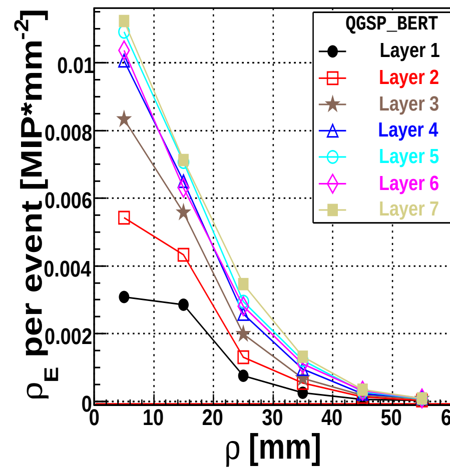
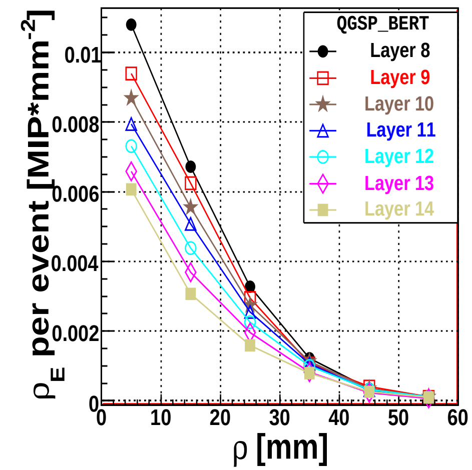
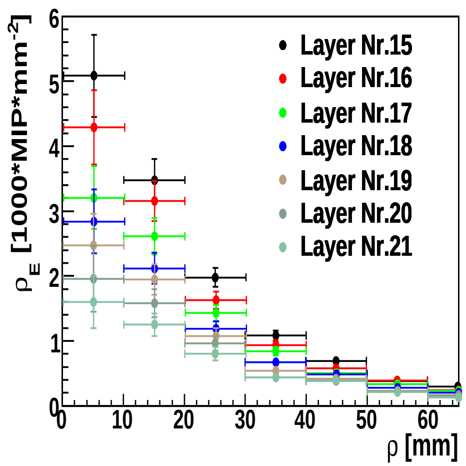
QGSP BERT

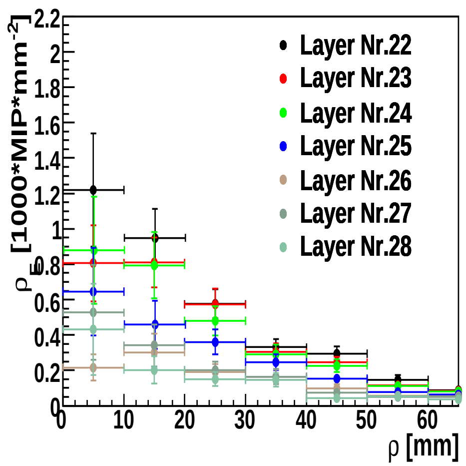


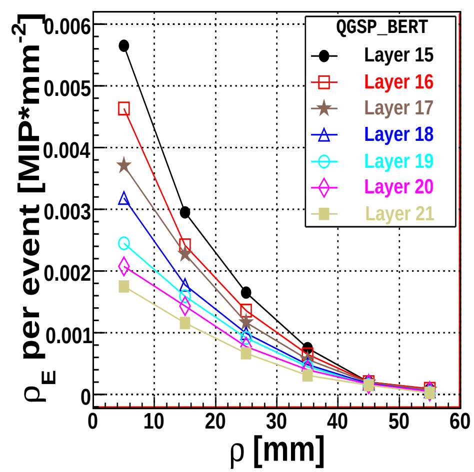


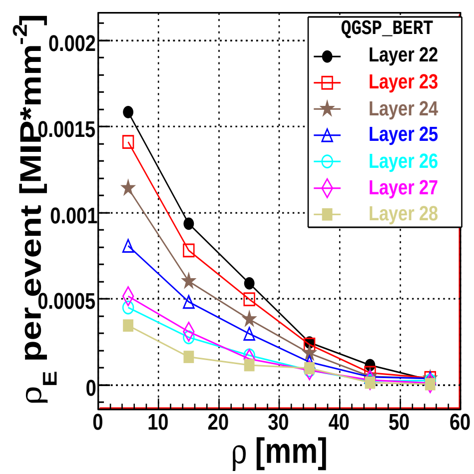








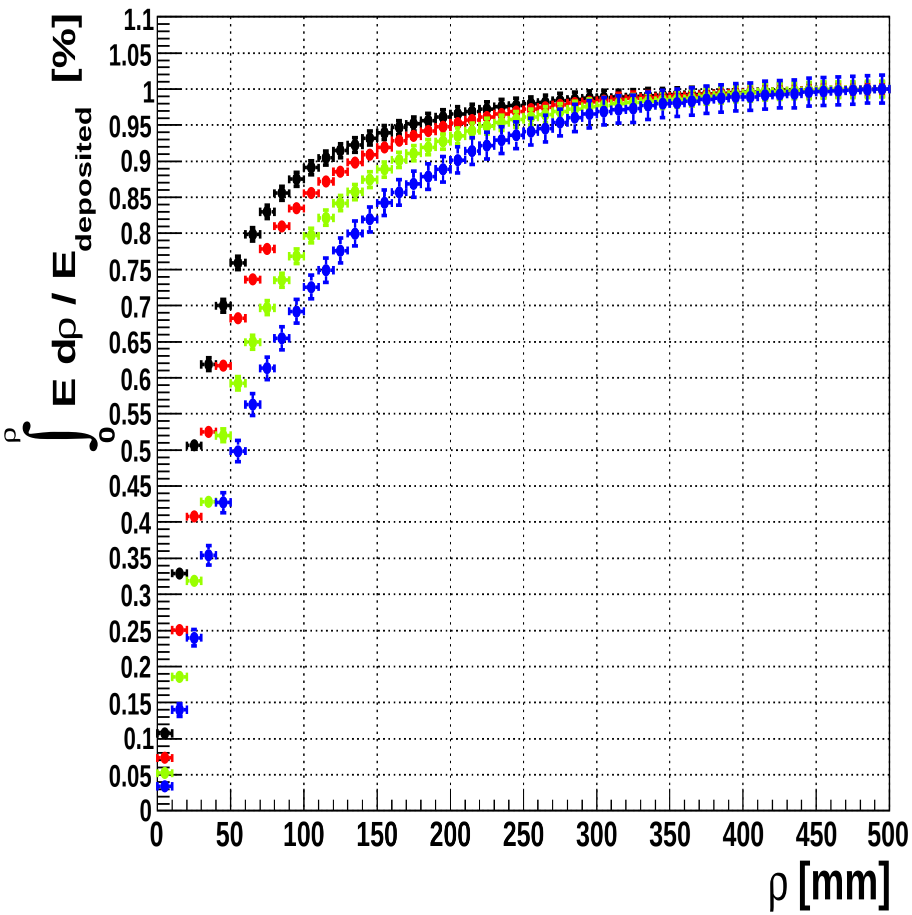


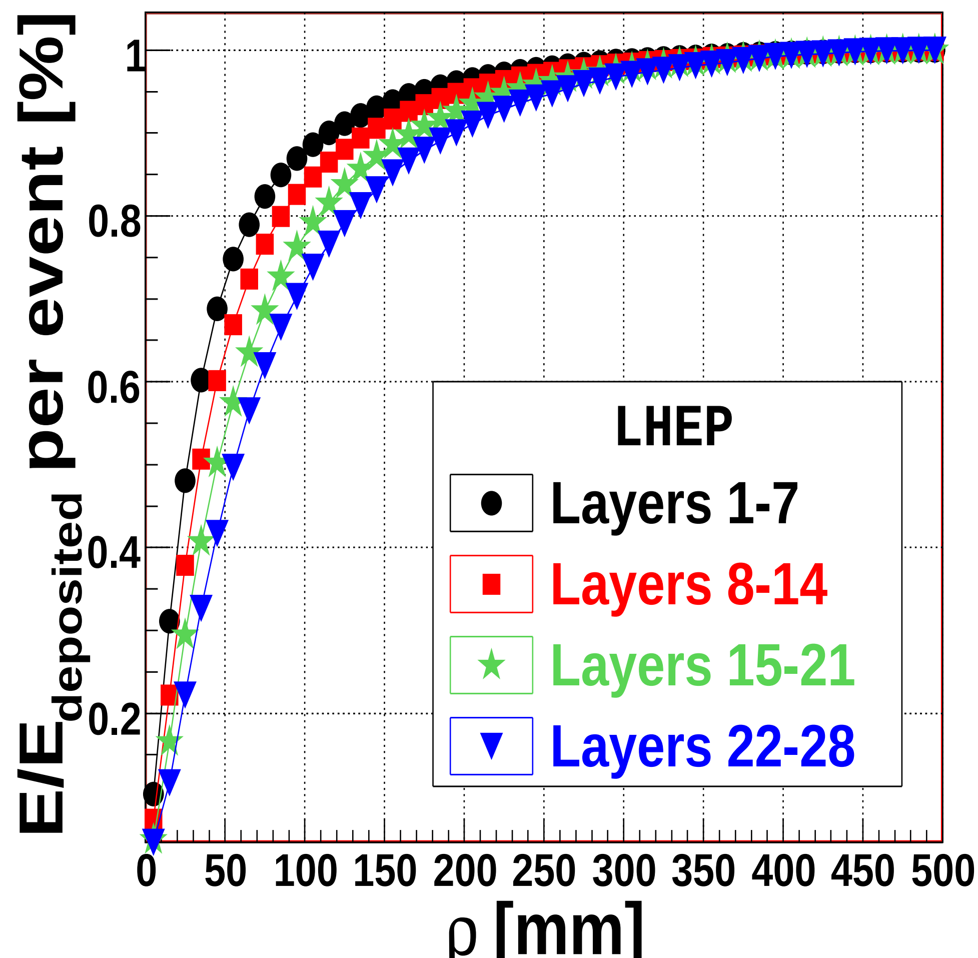


MC Cross-Check: Fractional Energy

Riccardo (10K events) | **Angela (all statistics)**

LHEP





MC Cross-Check: Fractional Energy

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QGSP