Pion and proton shower profiles measured with ATLAS Tile Calorimeter

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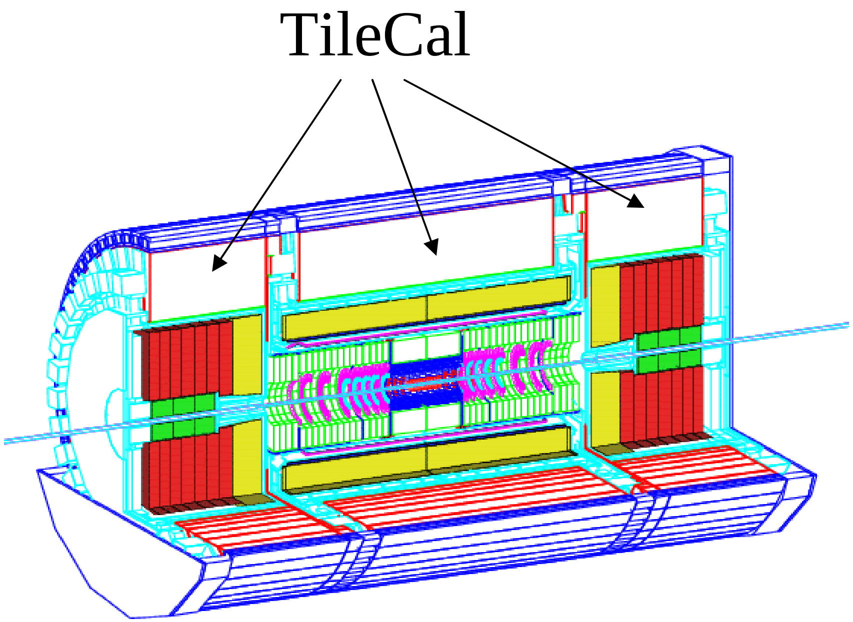
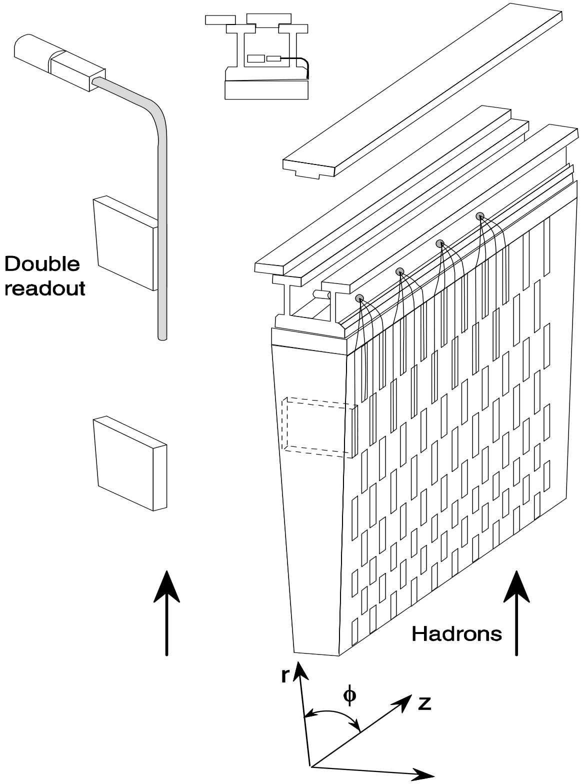
Outline

- Tile Calorimeter, test beam setup.
- Simulation tools.
- Particle identification.
- Pion and proton longitudinal shower profiles.
    MC and data comparison.
- Lateral spread.
    MC and data comparison.
- Conclusion.

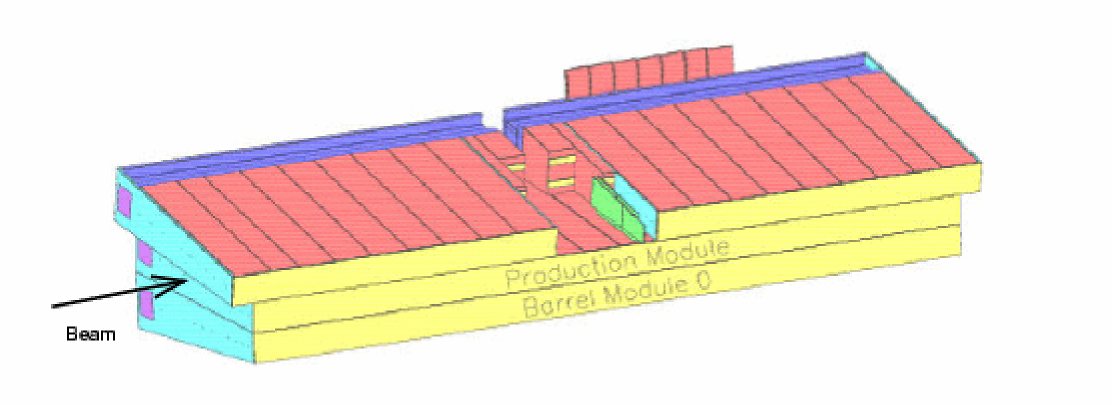
ATLAS Tile Calorimeter

- Iron/scintillator sampling calorimeter with WLS readout.
- Scintillating tiles are placed perpendicular to the colliding beams.





Test beam setup



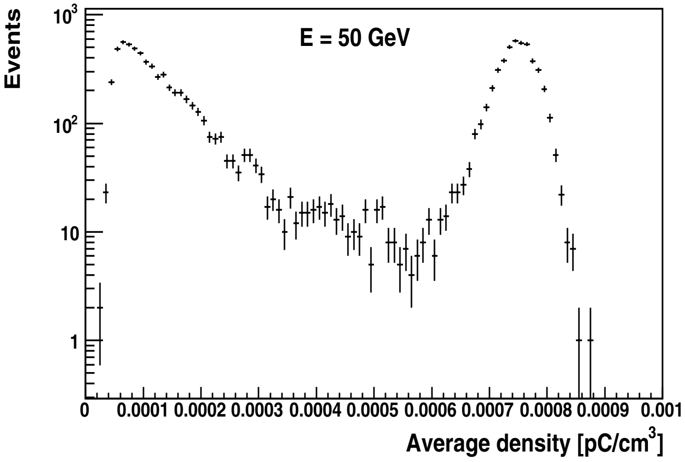
- Beam hits the modules of the detector from the side, perpendicular to the tiles (90 degree run).
- More than 25 nuclear interaction length deep calorimeter.
- Beam hits the center of Barrel module placed in the middle.
- The Extended Barrel modules have different cell geometry and there is a gap between two of them. For these reasons they are not used in this analysis. The response of bottom module is multiplied by factor 2.

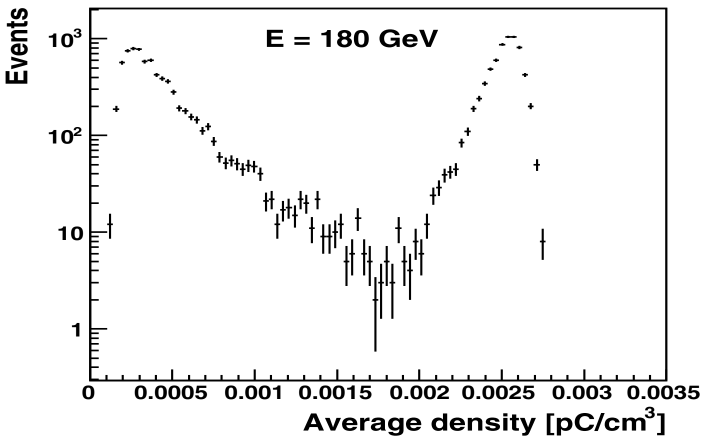
Simulation tools

- Simulation and digitization with ATLAS framework Athena 12.0.1.
- Geant4.7.1.patch01.atlas03.
- Being different from the "plain" geant4-07-01-patch-01 in:
  - Fix in G4ExcitedStringDecay
  - Fix in G4PropagatorInField. Solves some tracking problems with strict parameters.
  - Fix in G4LCapture. Solves the ghost photon problem.
  - Fix in G4QGSMSplitableHadron.cc.
- Hadronic physics models used:
  - LHEP_GN 2.5
  - QGSP_GN 2.6
  - LHEP_BERT 1.1
  - QGSP_BERT 1.2

Electron identification

- Set threshold to be equal to the 1 % of total measured signal in calorimeter.
- Take all the cells above the threshold and calculate average energy density (energy/volume).
- Systematic uncertainty on the longitudinal shower profile coming from this cut is 4%.



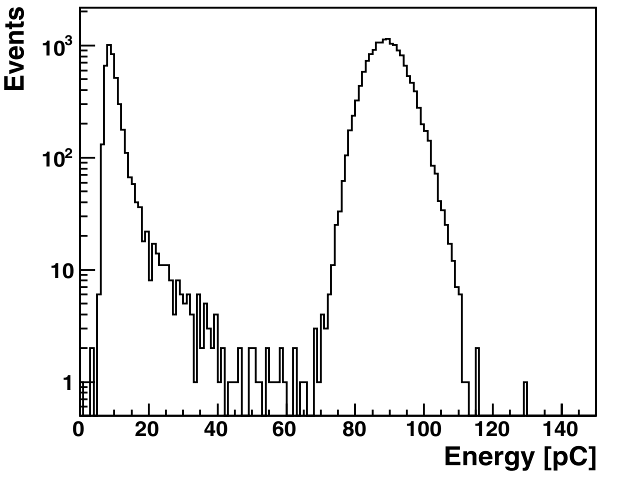


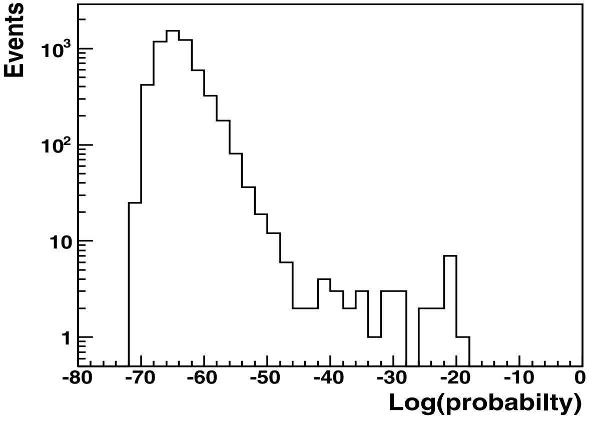
Muon identification

- The overwhelming fraction of muons is rejected using a cut on the total energy deposited in the calorimeter.
- However, the cut does not allow to identify muons with large energy deposition, especially important at the end of hadronic shower.
- Geant4 simulation is used to identify the events :

  Using muon simulation results, calculate probability of having given energy deposition in the given layer.

  The likelihood of the event being muon is obtained by multiplying probabilities calculated for all layers.
- Systematic uncertainty on the longitudinal shower profile coming from this cut is smaller than statistic errors.

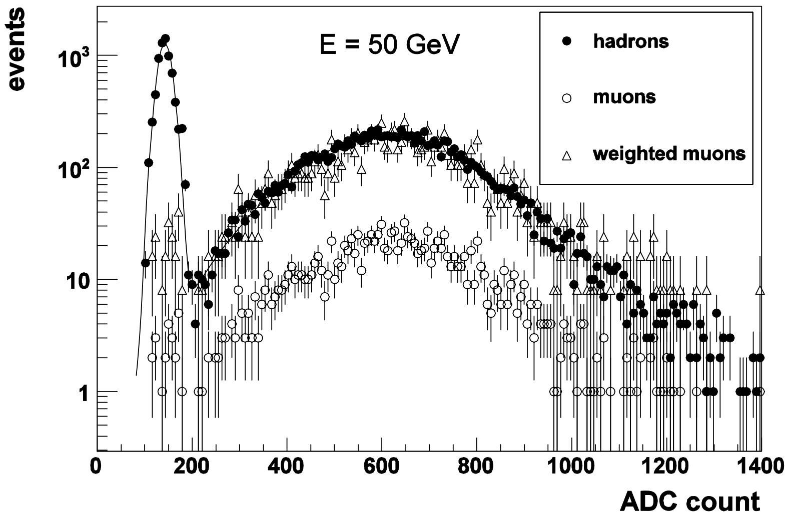




Pion/proton discrimination

- Cherenkov counter is used for pion/proton discrimination.
- Proton contamination in the sample of pions is evaluated using Gaussian fit of proton distribution.
- Muons are used to evaluate pion contamination in the sample of protons.
- Since pion-muon mass difference is small in comparison with pion-proton one, their Cherenkov signal distribution is similar to the pions.
- Muons are selected using calorimeter information.

- Weight muons distribution to fit pions distribution in the high signal region where only pions are present.
- Use weighted muon distribution to calculate pion contamination in the proton sample.



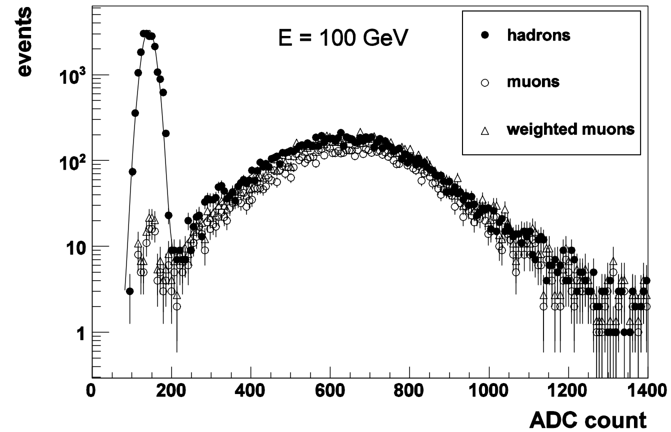
Pion/proton discrimination

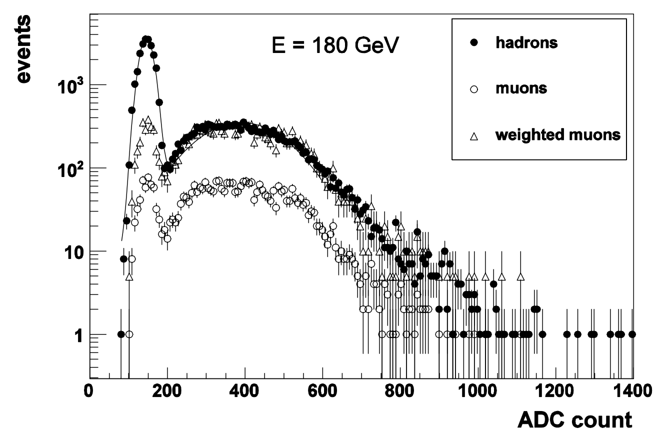
- At 180 GeV Cherenkov counter the efficiency to pions is noticeably less than 100 %.
- Pion contamination in the sample of protons:

  50 GeV 2.8 ± 0.6%,

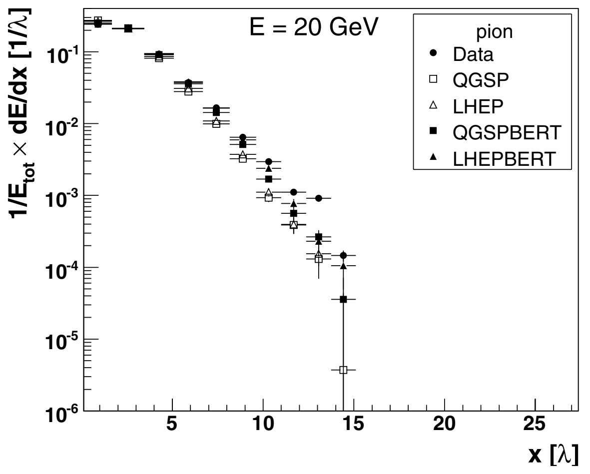
  100 GeV 0.74 ± 0.07%

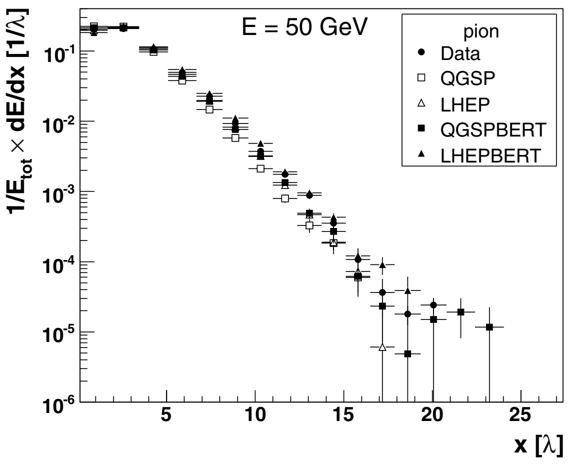
  180 GeV 12.7 ± 0.6%
- At 20 GeV negative beam was available.
- Proton contamination in the sample of pions is negligible at all energies.
- We correct 180 GeV proton shower profile for pion contamination.
- Electron and muon contamination in the sample of protons is less that in the sample of pions since Cherenkov counter rejects most of them.

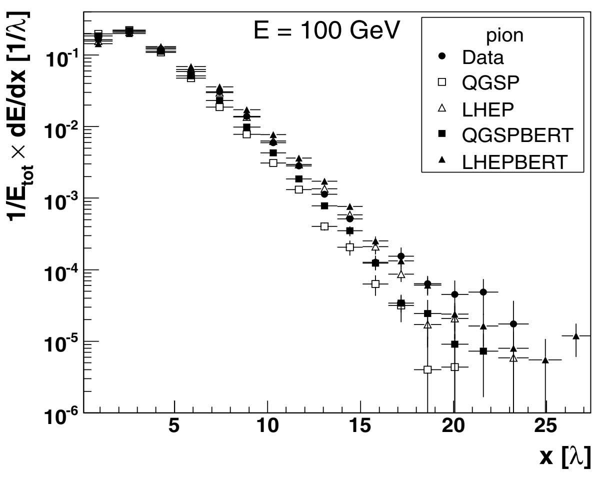


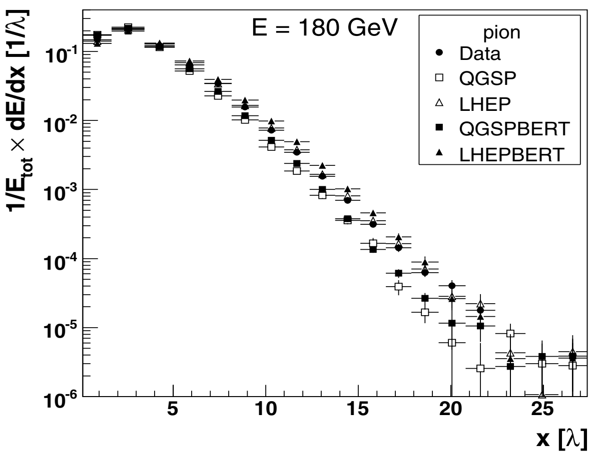


Pion longitudinal shower profile



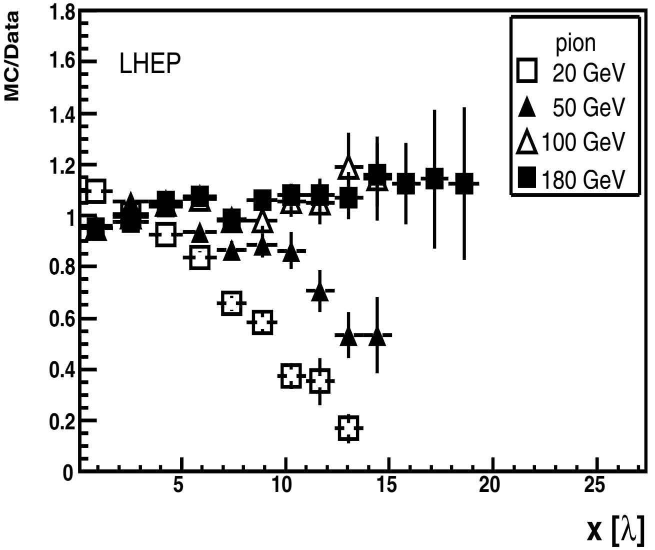




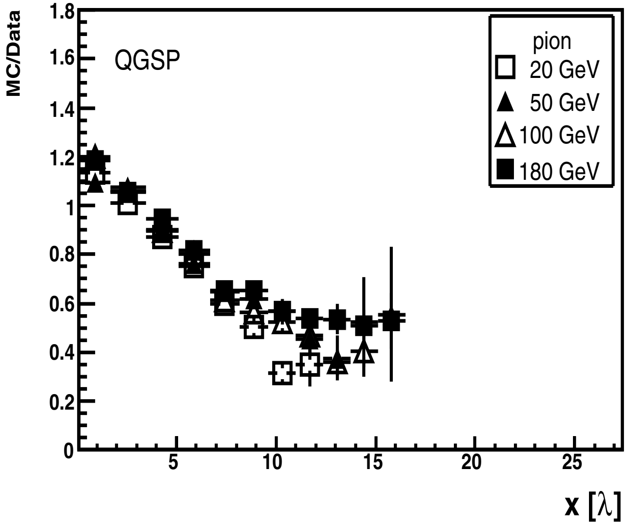


MC and Data comparison

Good description at high energies.

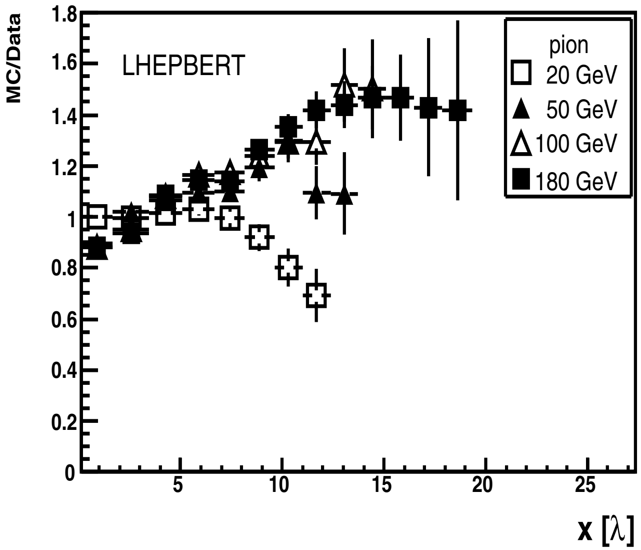


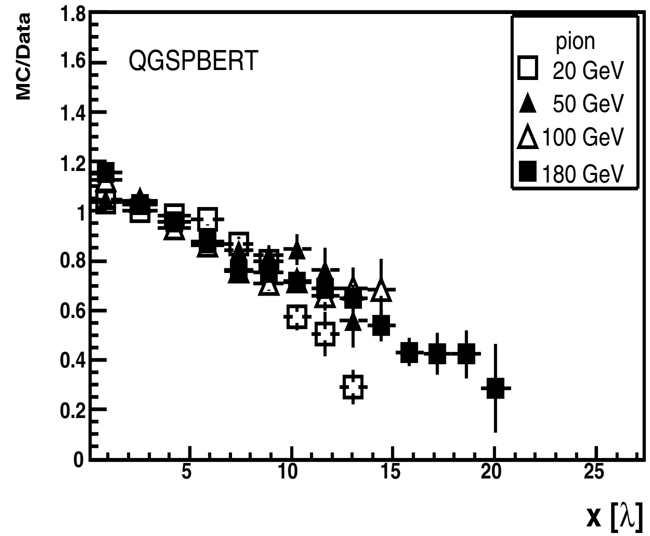
Showers are too short.



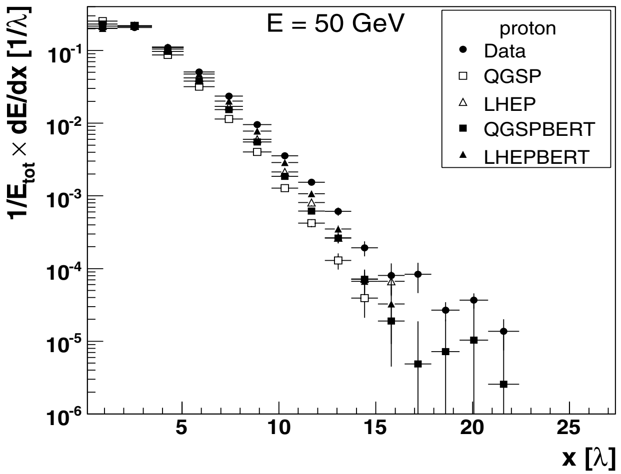
MC and Data comparison

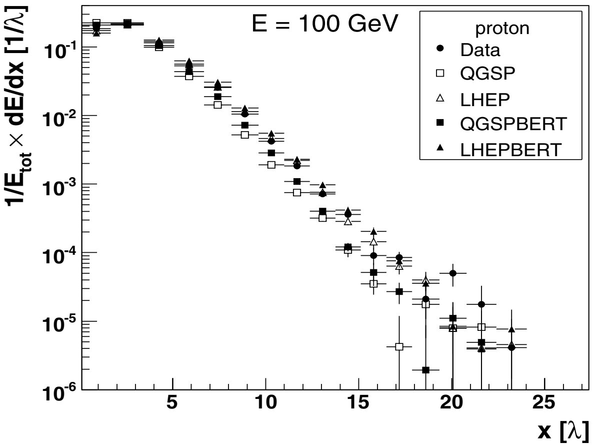
Bertini model makes showers longer.

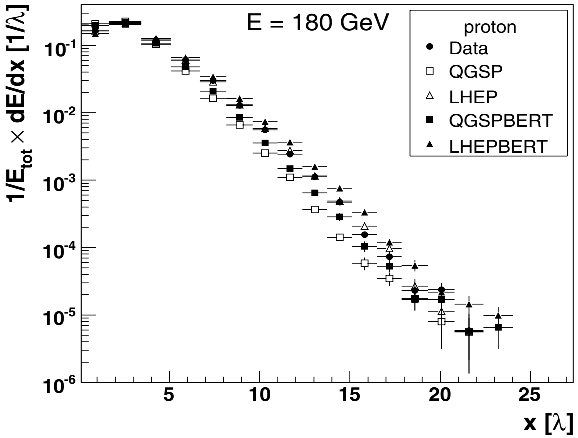




Proton longitudinal shower profile







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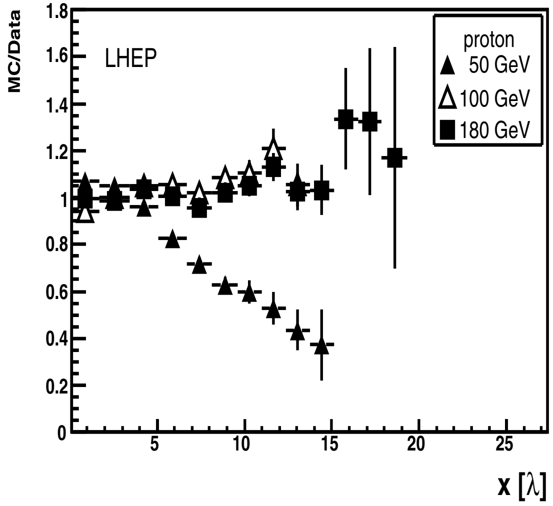
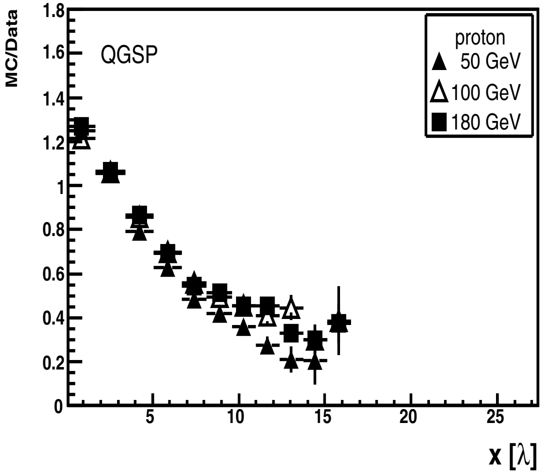


Showers are too short.



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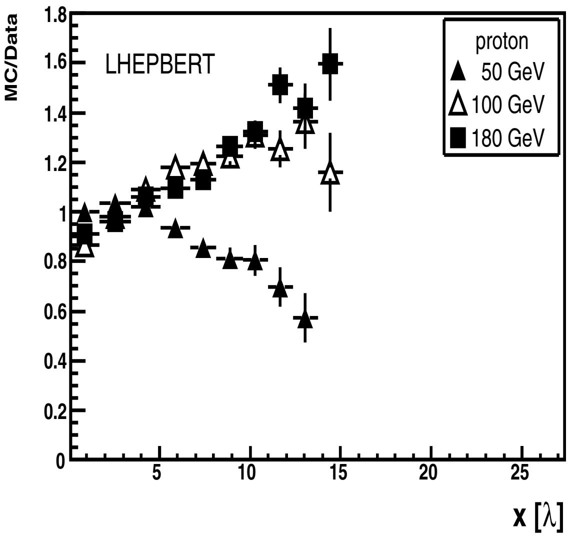
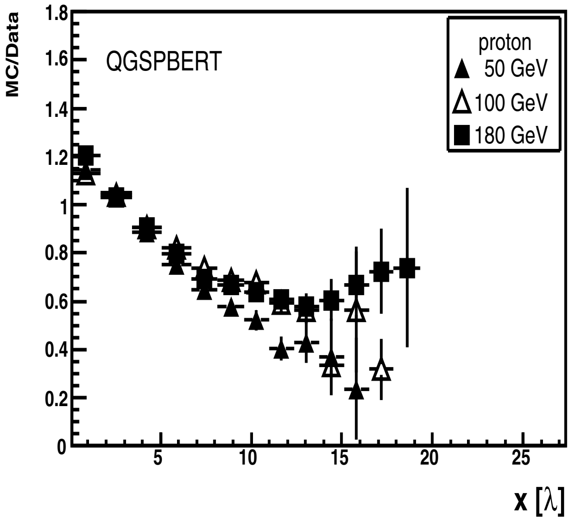


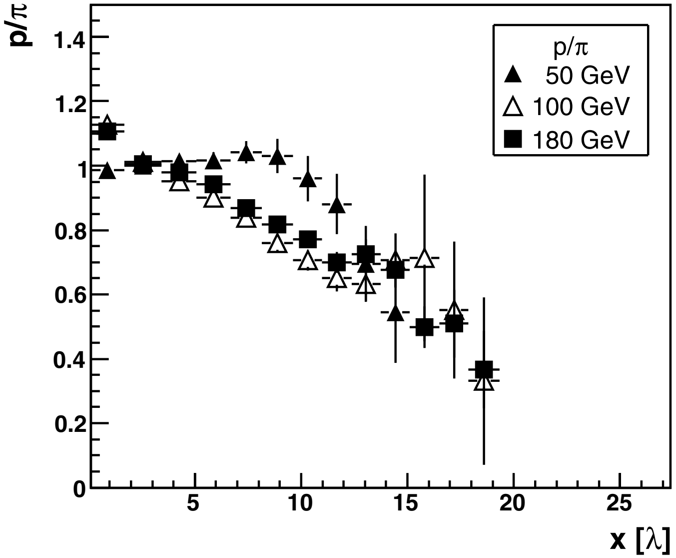


Pion and proton shower profile comparison

1. Proton-nucleus interaction cross-section is larger than pion-nucleus one by about 20%. Protons start showering earlier than pions.
2. Electromagnetic fraction of hadronic shower is larger in case of pions and it is mainly concentrated in the beginning of shower.

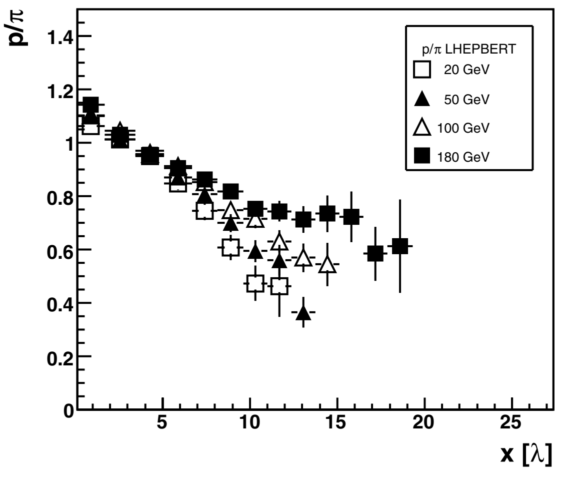
The first effect is dominant at high energies.

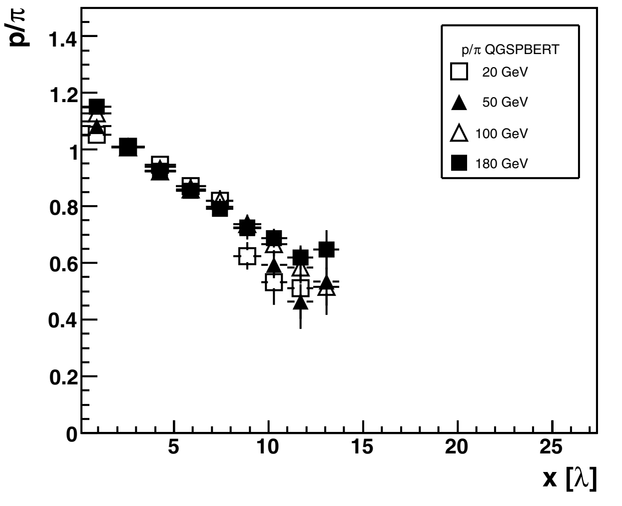
At 50 GeV the effects are compensating each other.



Pion and proton shower profile comparison

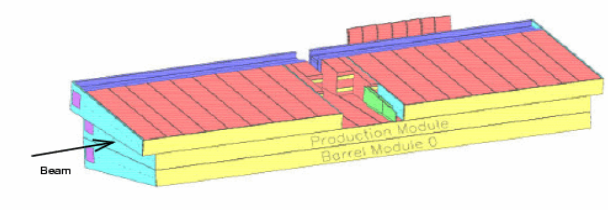
- Geant4 is able to predict general behavior of the ratio, but not compensation at 50 GeV.

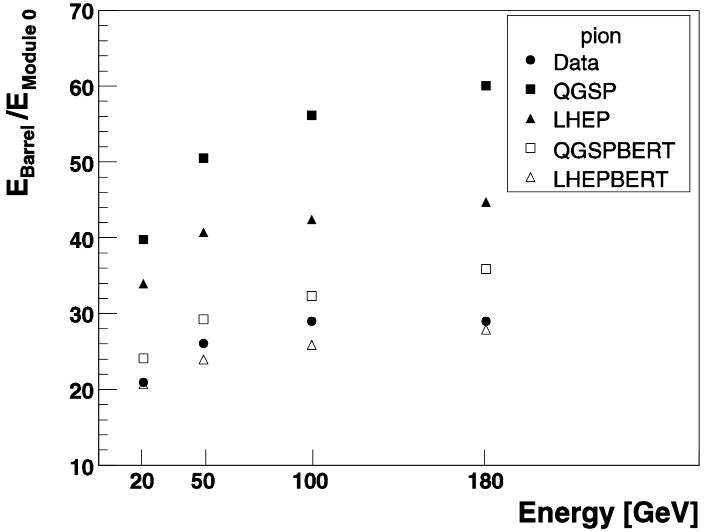


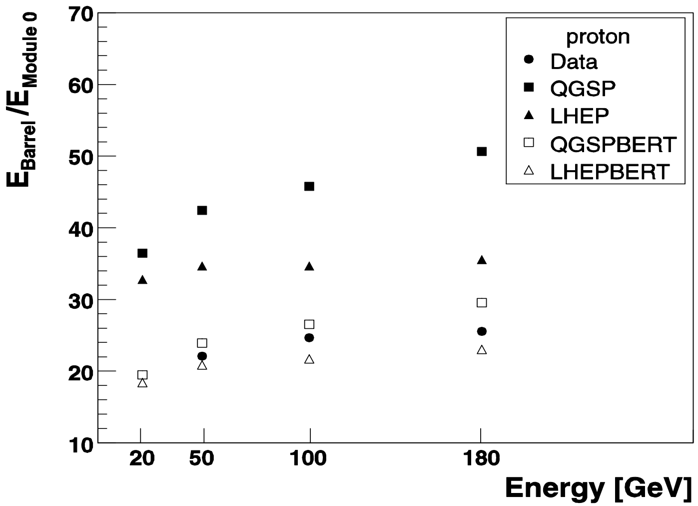


Lateral spread

- Ratio of the energies deposited in the module where beam hits and in the bottom module.
- In case of QGSP and LHEP showers are too narrow.
- With Bertini model the ratio is quite well described.



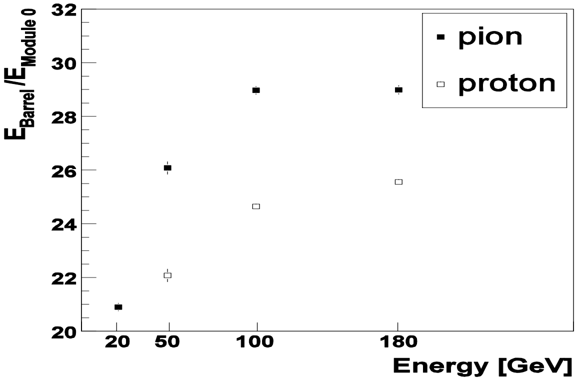




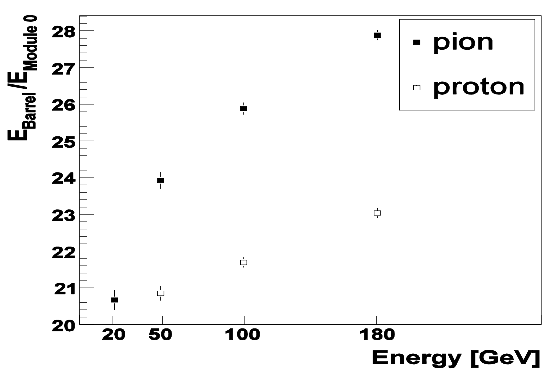
Pion and proton shower lateral spread comparison

- Pion induced showers are narrower than proton ones.

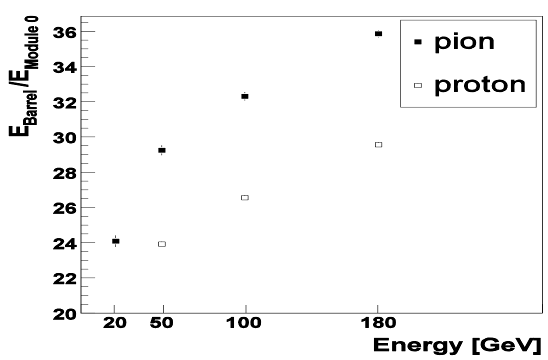
- Large electromagnetic fraction of pion induced showers is concentrated near the shower axis.



LHEPBERT



QGSPBERT



Conclusion

- Measured pion and proton induced shower longitudinal profiles are compared with Geant4 predictions using several hadronic physics models.
- LHEP quite well describes the longitudinal shower profile at high energies and predicts short showers at low energies both in case of pions and protons.
- QGSP predicts very short showers at all energies both for pions and protons. Slightly better agreement with the data was found adding Bertini model.
- Bertini intra-nuclear cascade model makes showers longer.
- Both QGSP and LHEP predict narrow showers in case of pions and protons.
- With Bertini model quite a good agreement of lateral spread was found between data and MC both for pions and protons.
- Geant4 in general is able to predict the ratio of longitudinal shower profiles induced by pion and proton as well as narrowness of pion showers.