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Hadronic Shower Shape studies in Geant4

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Outline

- Motivation
- Goal
- Strategy
- Simplified calorimeters
- Comparisons between Physics Lists
- Contribution of different particle types
- Summary of the studies done so far
- Prospects
- Conclusions

For details see the note: CERN-LCGAPP-2007-02

http://lcgapp.cern.ch/project/docs/noteShowerShapes.ps

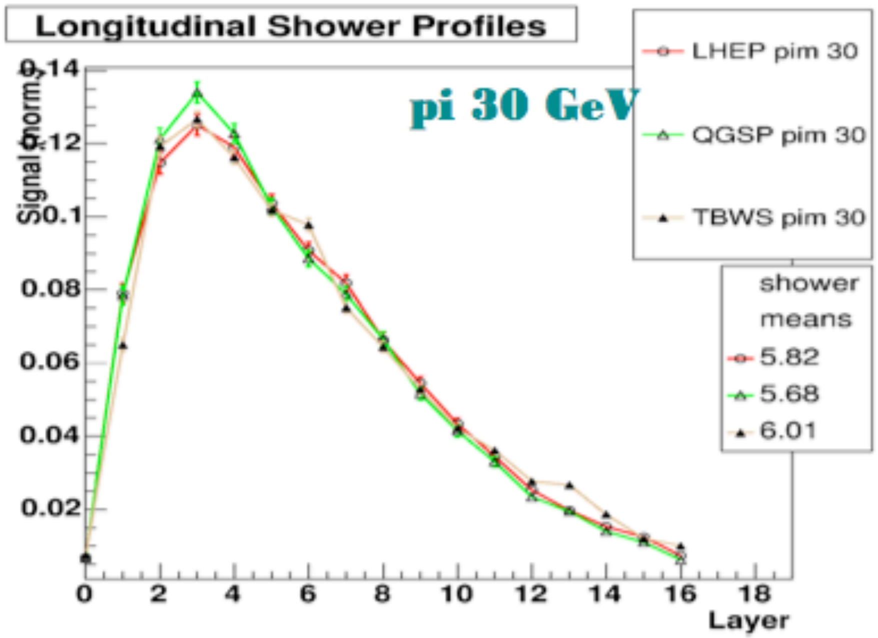
Motivation

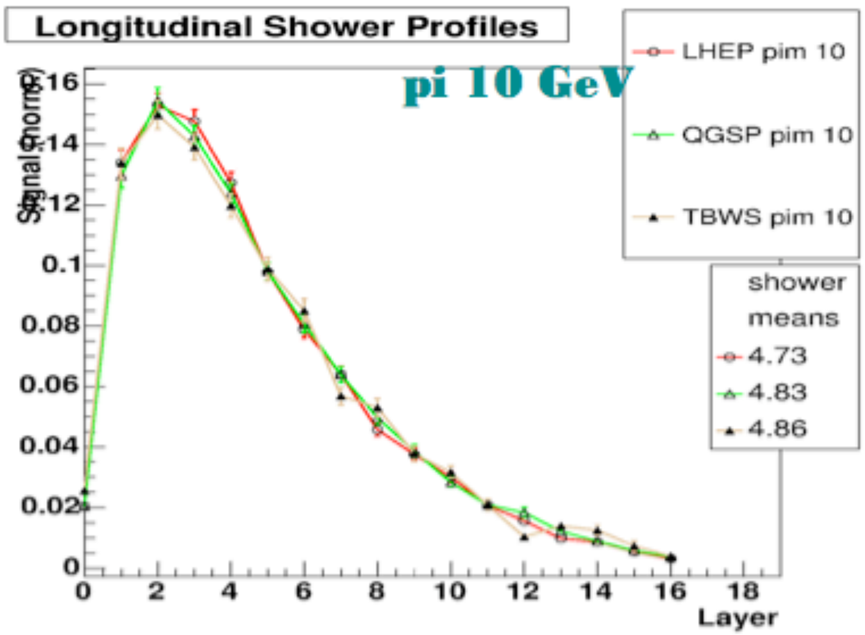
From comparisons between data from calorimeter test-beams of LHC experiments (ATLAS HEC, ATLAS TileCal, CMS HCAL) with Geant4 simulations with LHEP and QGSP Physics Lists, it has been concluded that:

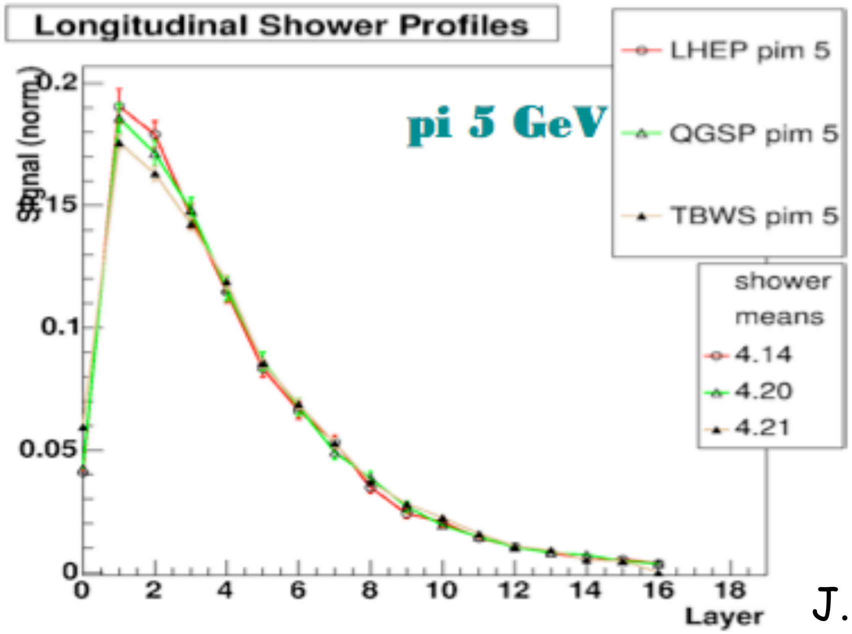
- σ_E/E is described well by LHEP and even better by QGSP;
- e/π is described quite well by LHEP and even better by QGSP;
- hadronic shower shapes are shorter and narrower than data for QGSP, whereas LHEP looks better.

QGSP and LHEP are similar at low and intermediate beam energies: good agreement with data for CMS, but not for ATLAS ! ?

CMS HCAL 2004 test-beam







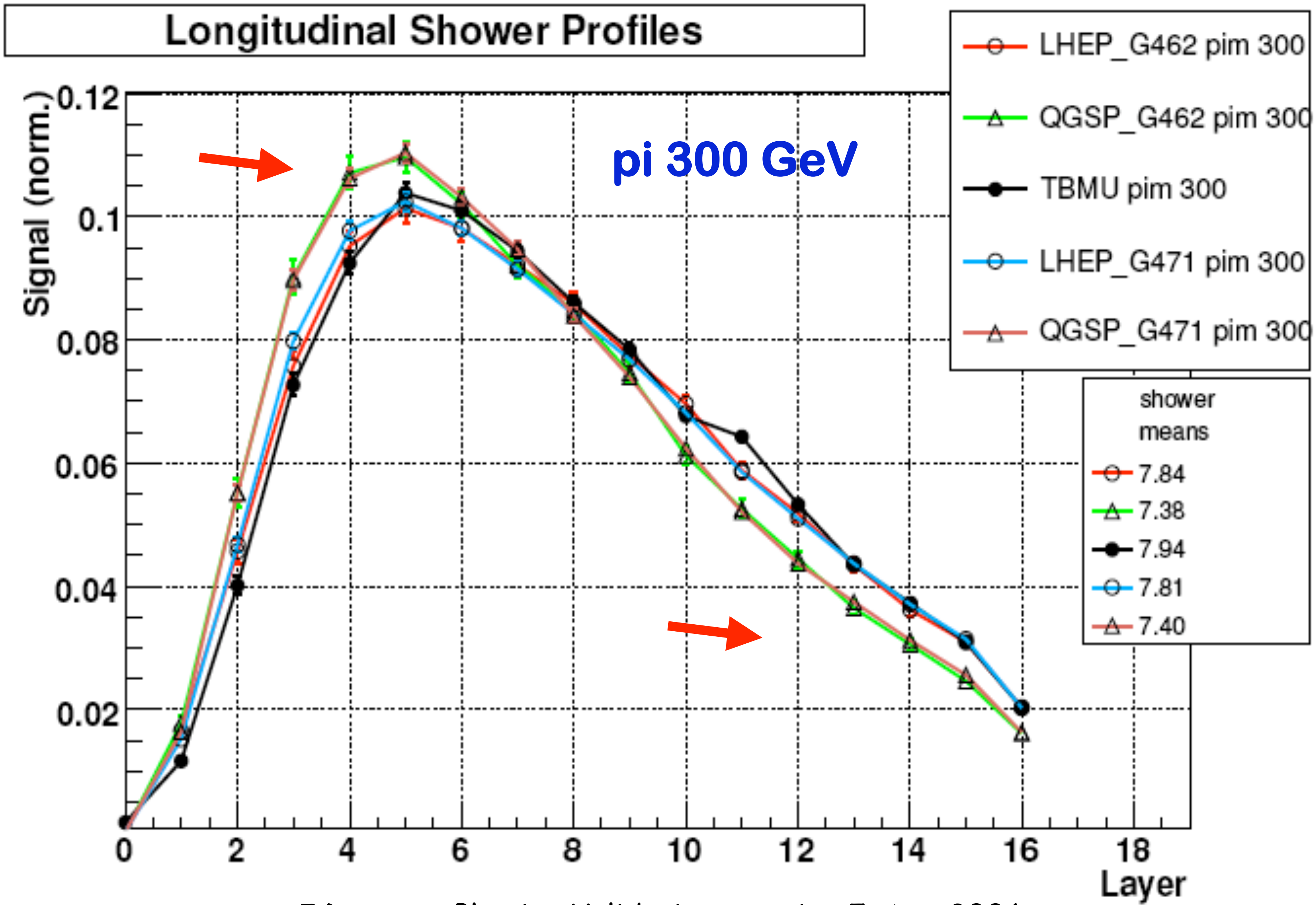
Geant4 version 6.2.p02

LHEP and QGSP show good agreement with test beam data at low and intermediate energies

J.Damgov, Physics Validation meeting 5-Apr-2006

A.R

CMS HCAL 2004 test-beam



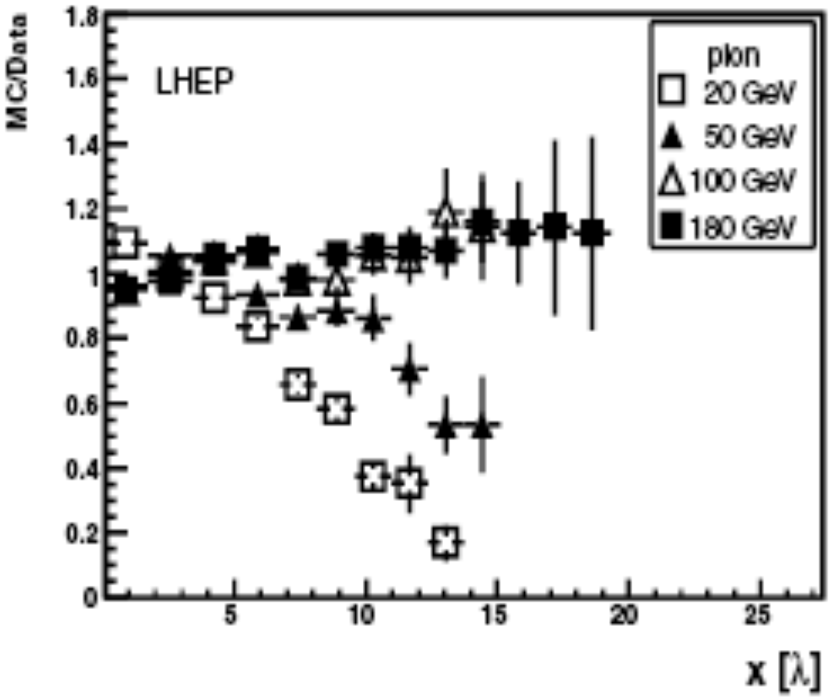
J.Damgov, Physics Validation meeting 5-Apr-2006

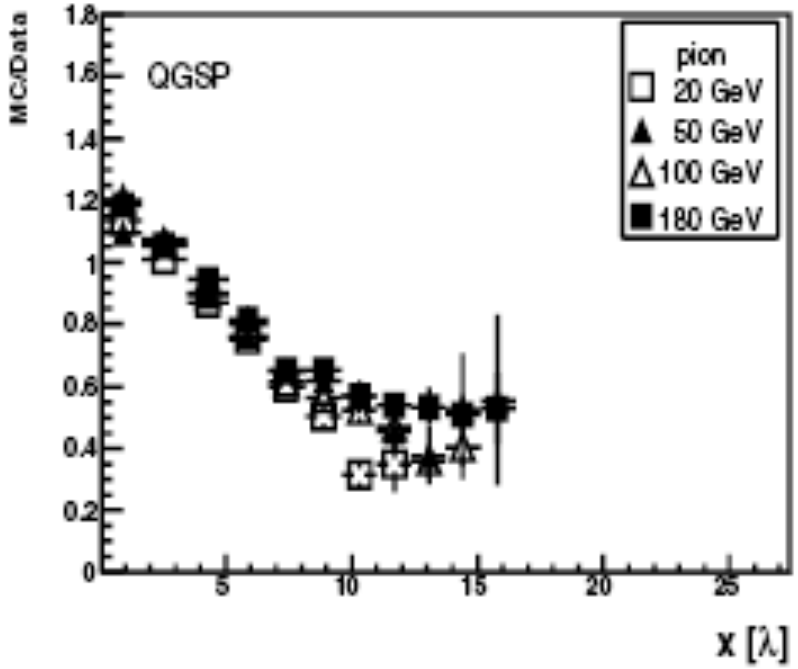
A.Ribon, April-2007

ATLAS TileCal 2002 test-beam @90° incidence

longitudinal profile

MC (G4 7.1.p01a) / Data vs penetration depth in λ



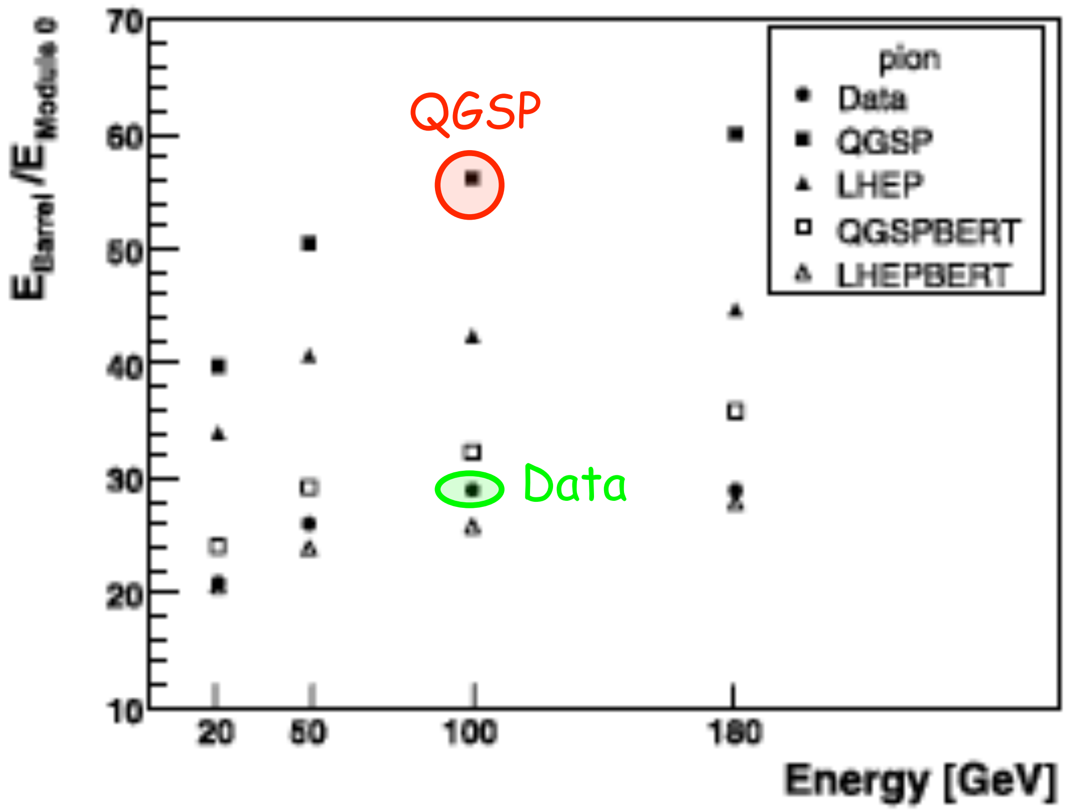


M.Simonyan, Physics Validation meeting 20-Sep-2006

ATLAS TileCal 2002 test-beam @90° incidence

lateral profile

G4 7.1.p01a E_{barrel} / $E_{module\ 0}$



M.Simonyan, Physics Validation meeting 20-Sep-2006

Goal and Strategy

The goal is to understand the impact of the various physics processes on the development of hadronic showers, in order to improve the longitudinal (and lateral) shower profiles.

To tackle this complex problem we use two complementary approaches:

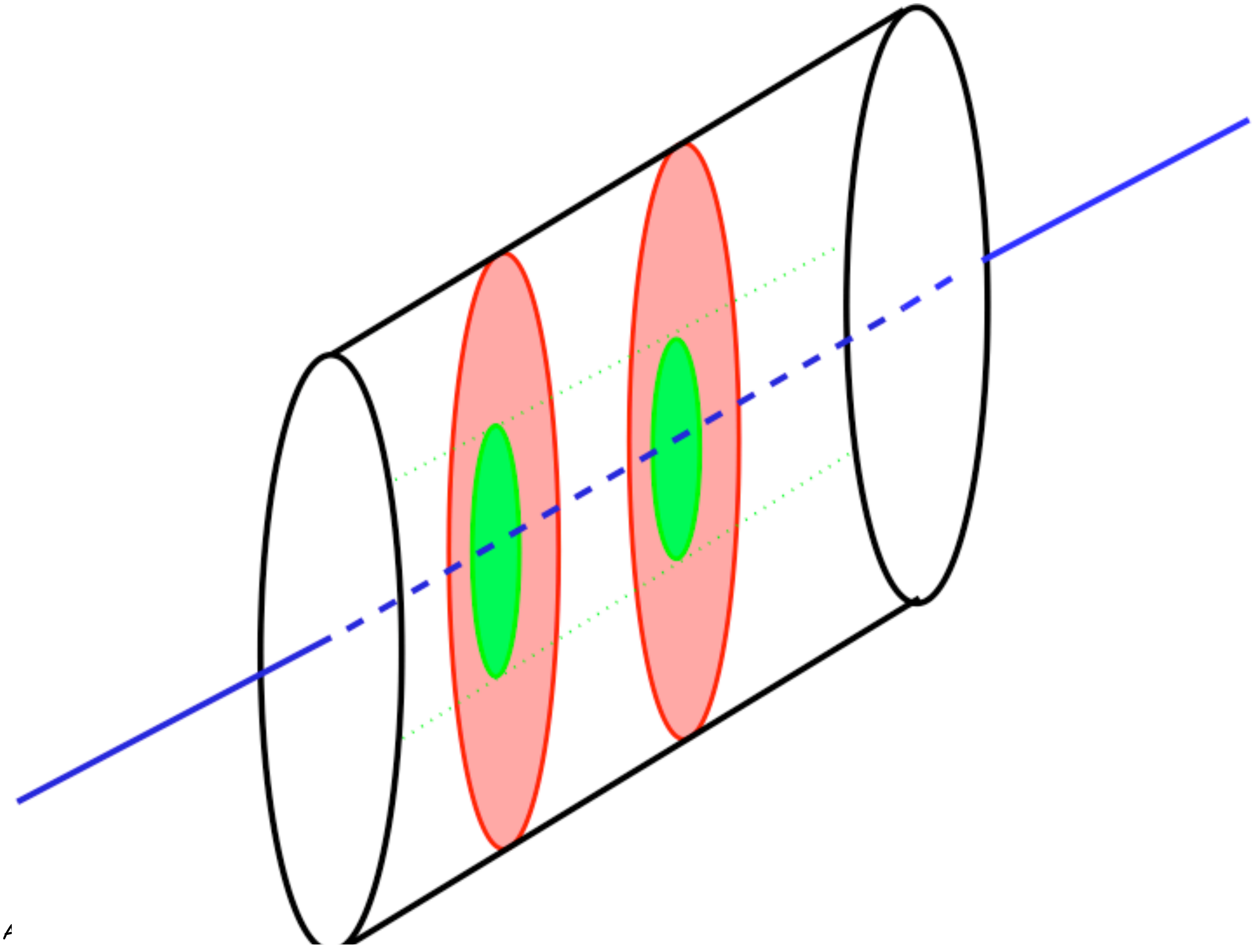
1. "microscopic" : study single physics processes, using thin-target data;
2. "macroscopic" : monitor the observables of a sampling calorimeter set-up to compare different physics simulations.

This talk covers only 2) : other presentations will discuss in detail 1).

Simplified Calorimeter setup

Ultimately, the LHC calorimeter test-beam data will validate any improvement in the hadronic shower shapes.
However, it is useful to compare different physics simulations, between themselves without real data, in simplified calorimeter set-ups:

- to avoid to repeat, each time, long and laborious analyses, which can be done (currently) only by the experimentalists;
- to control variables which are not measurable;
- to decouple pure physics effects from instrumental details (beam composition, beam profile, complex geometry, Birks effects, noise, cross-talk, digitization, and reconstruction).



“Observables”

- total energy deposit in all active layers
- total energy deposit in the whole calorimeter
- energy deposit in each active layer
  (longitudinal shower profile)
- energy deposit in each ring (i.e. radial bin)
  (lateral shower profile)
- - average number of steps and tracks per event;
  - average track and step length;
  - average number and Ekin of exiting tracks;
  - kinetic energy spectra of tracks entering some
    active layers;

  each of these is done for different particle types
  and also for all particle tracks;
  - contributions to the visible energy and shower
    shapes for different particle types.

Comparing different Physics Lists: Summary

- Adding cascade models (Bertini, Binary) to QGSP the hadronic showers get longer and wider;
- Adding a precise transport of low-energy neutrons (HP) does not affect the bulk of the hadronic showers but contribute to larger tails;
- The parametrized physics list (LHEP) has a reduced, longer and wider EM component, a harder spectrum of high-energy $\pi^{\pm}$, and more 100 MeV - 1 GeV neutrons;
- Arbitrarily increasing the diffraction component in QGS produces longer showers.

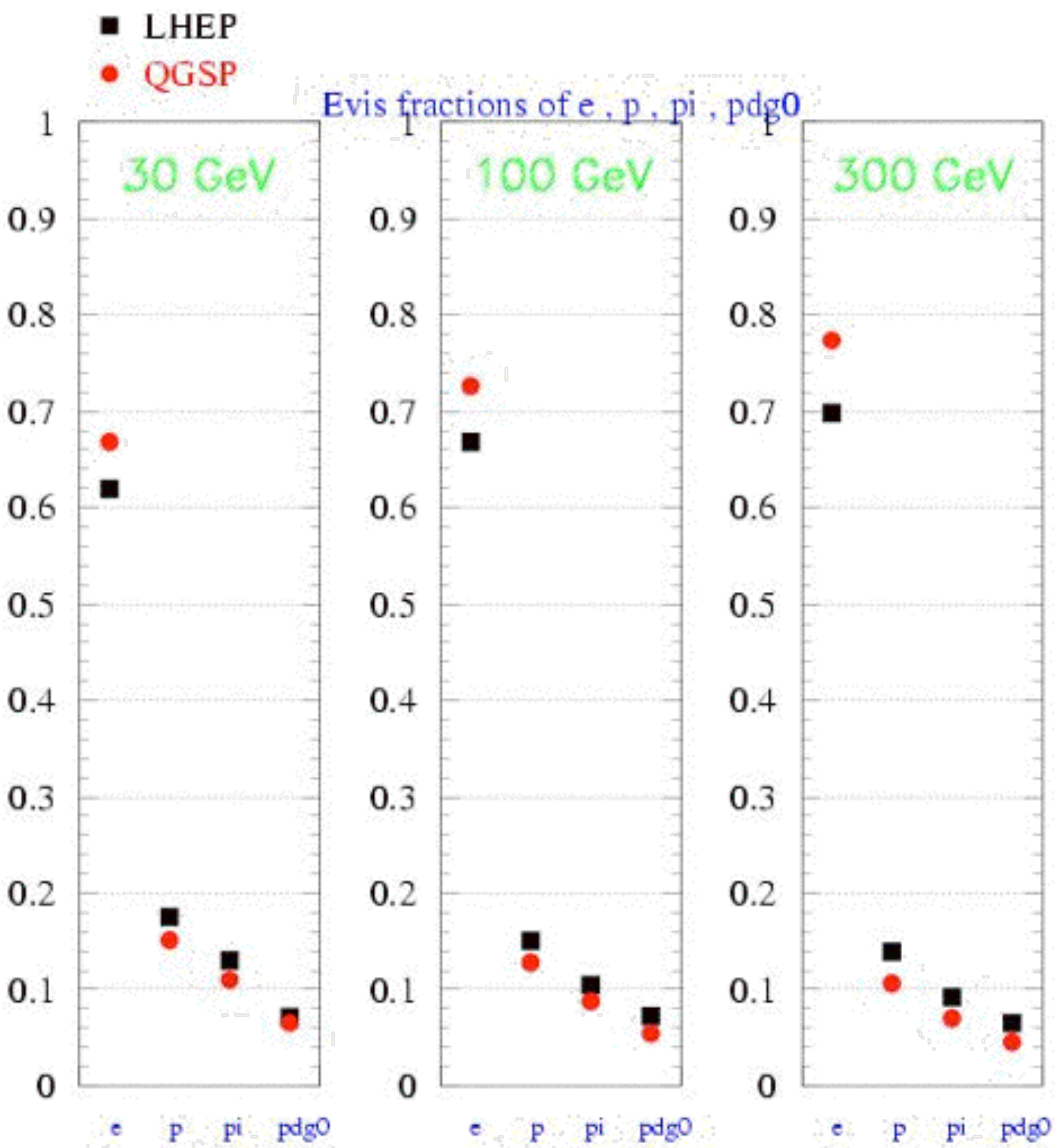
Particle contributions

- We want to study how much different particle types contribute to the visible energy, and their shower shape (longitudinal and transverse).

- We consider the following particle types:
  - **e** : e^-/e^+
  - **p** : p/pbar
  - **pi** : π^+/π^-
  - **pdg0** : nuclei (and neutrons)

NB) The contribution of kaons and muons is negligible (<1%).

We consider always a primary beam of π^- .



Alberto R
CERN/PH

Some observations

- The relative contribution to the visible energy per particle type is: $e \gg p > \pi > n$
  and the electron dominance grows as the beam energy increases.

- For both longitudinal and lateral shower shapes
  $e \ll \pi < n < p$

- Comparing QGSP with respect to LHEP :
  - QGSP has larger electron contribution, especially for higher beam energies;
  - QGSP has shorter and narrower electron shape;
  - QGSP has similar shapes for the others.

Work done up to now

- Look at various thin-target benchmarks
- Revision of hadronic elastic scattering
- Revision of cross-sections
- Study of neutron production and transportation

- Study of hadronic showers, looking at all the physics variables that we think are relevant, using simplified calorimeters.

Main lessons & prospects

- Quasi-elastic is accounted in the inelastic cross-section, but was not part of String models (QGS and FTF), which implied to overestimate the deep-inelastic component. We are now including a model of quasi-elastic and validating it on data.
- Diffraction is a key element for the longitudinal development of hadronic showers. We need to validate/tune/improve the current implementation using thin-target benchmarks.
  A revised Fritiof (FTF) model looks promising...
- Low Energy Parametrized (LEP) model for $\pi^{\pm}$ $(k^{\pm}) \leq 10$ GeV , used in all Physics Lists (but QGSP_BERT), needs to be improved or replaced.

Conclusions

- QGSP produces hadronic showers which are too short and narrow. We are working to understand and improve the hadronic shower shapes.
- The best Physics Lists we can offer in version 8.2 for applications that rely on a good description of hadronic shower shapes are LHEP, QGSP_BERT.
- Written a report to document where we stand with our understanding of hadronic showers.
- We are working on: thin-target tests; improving models; revising cross-sections.
- The most promising work items are: **quasi-elastic** & **diffraction** and treatment of $\pi^{\pm}$ ($k^{\pm}$) $\leq$ 10 GeV .