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Status of Hadronic Shower Shape studies in Geant4

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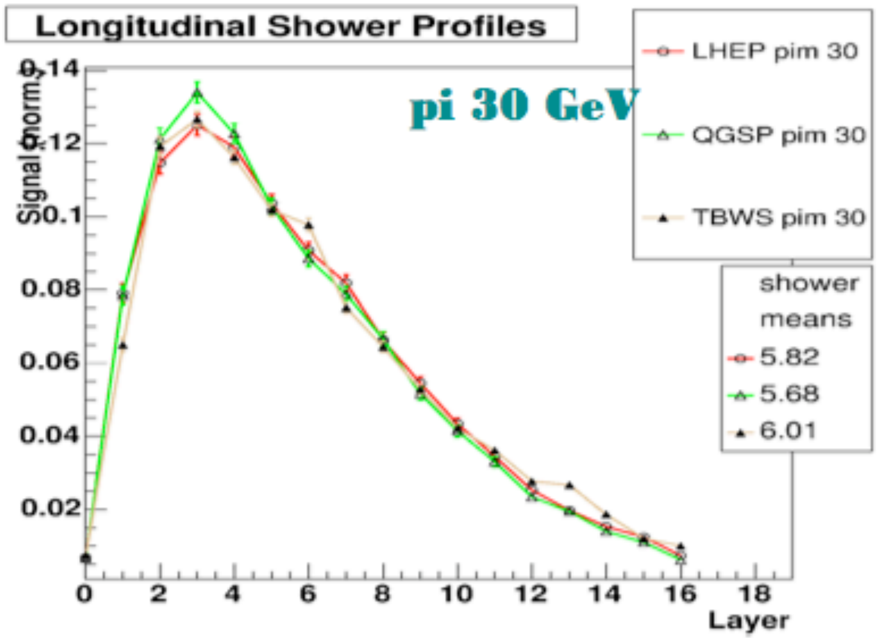
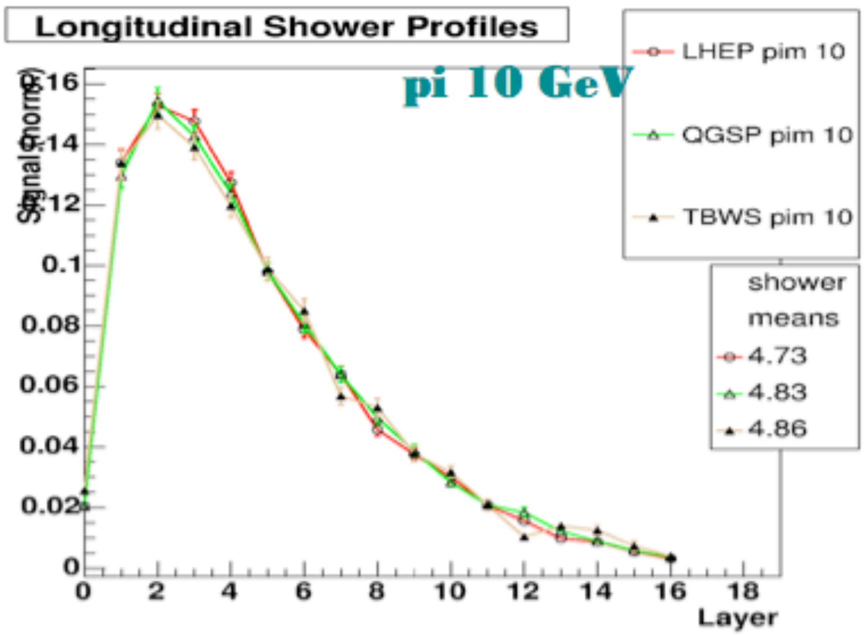
Motivation

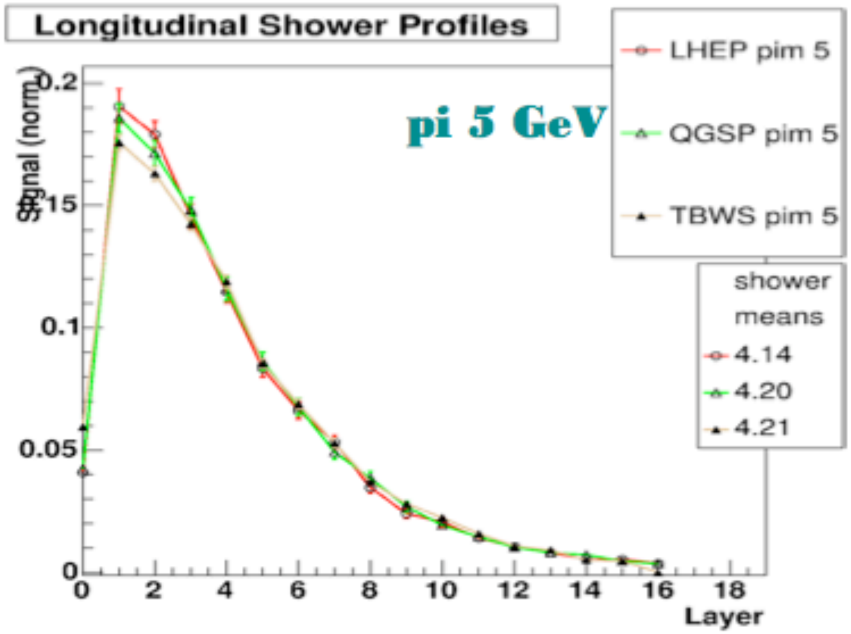
From comparisons between data from calorimeter test-beams of LHC experiments (ATLAS HEC, ATLAS TileCal, CMS HCAL) with Geant4 simulations with LHEP and QGSP Physics Lists, it has been concluded that:

- σ_E/E is described well by LHEP and even better by QGSP;
- e/π is described very 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



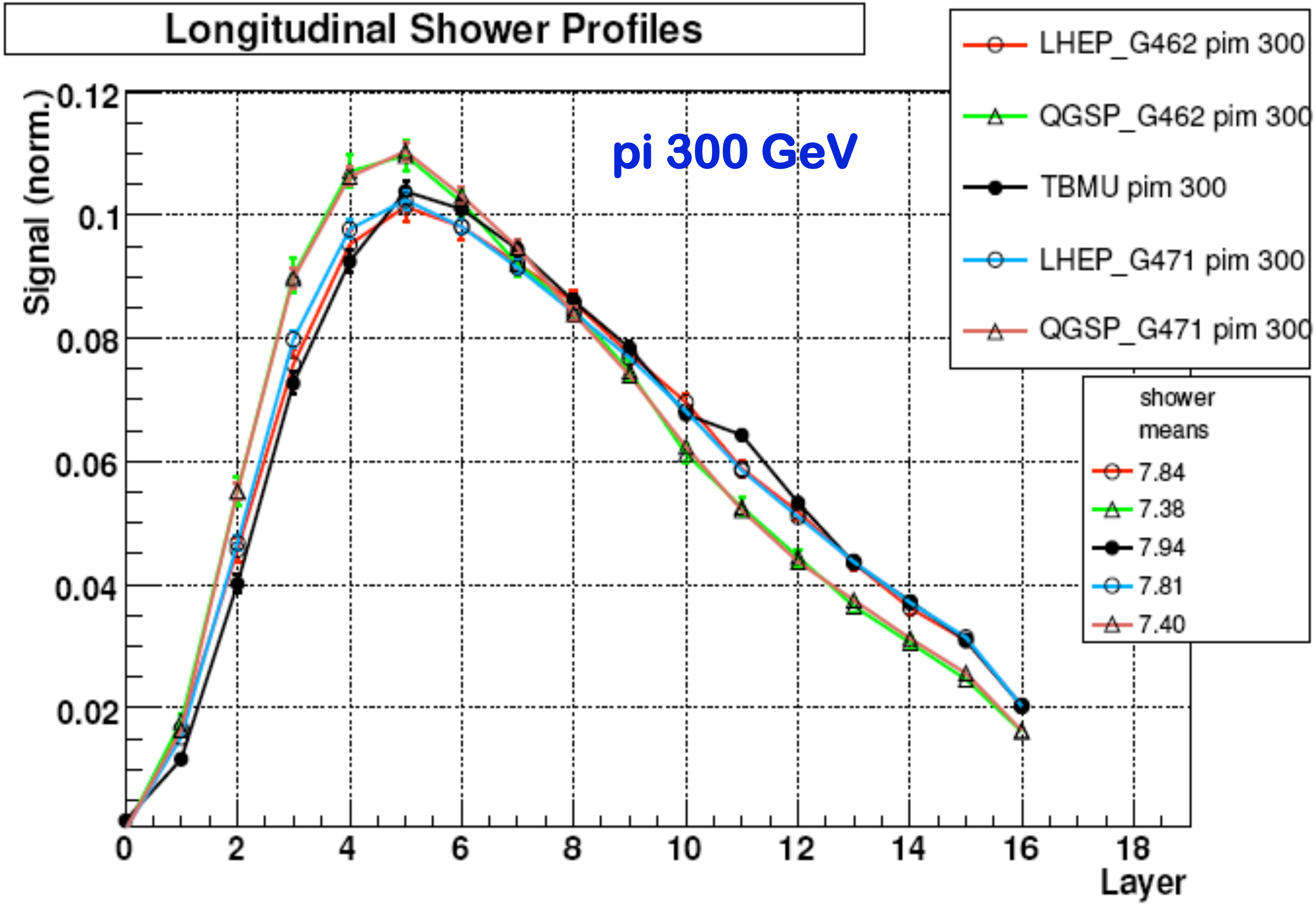




LHEP and QGSP show good agreement with test beam data at low and intermediate energies

A.R

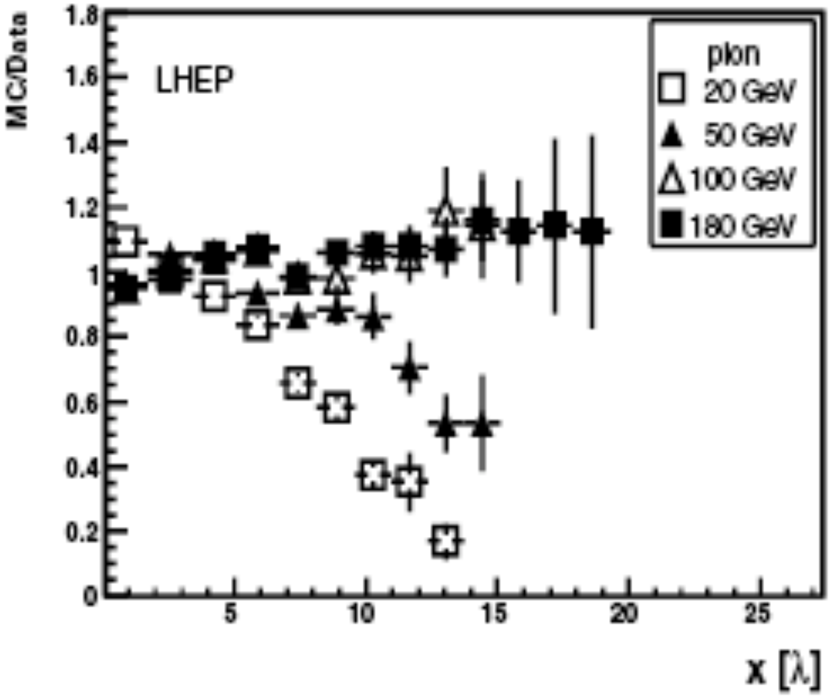
CMS HCAL 2004 test-beam

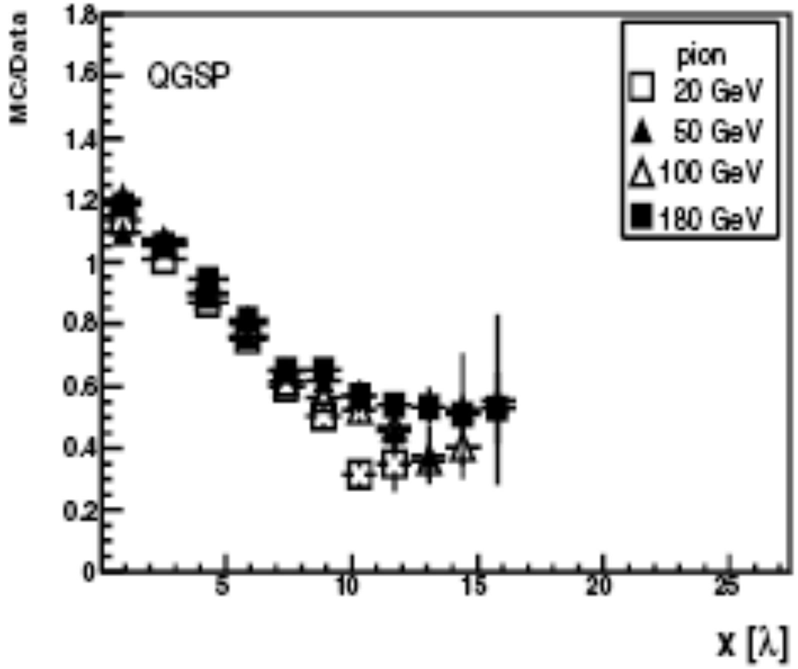


A.Ribon, 31-Jan-2007

ATLAS TileCal 2002 test-beam @90° incidence

longitudinal profile

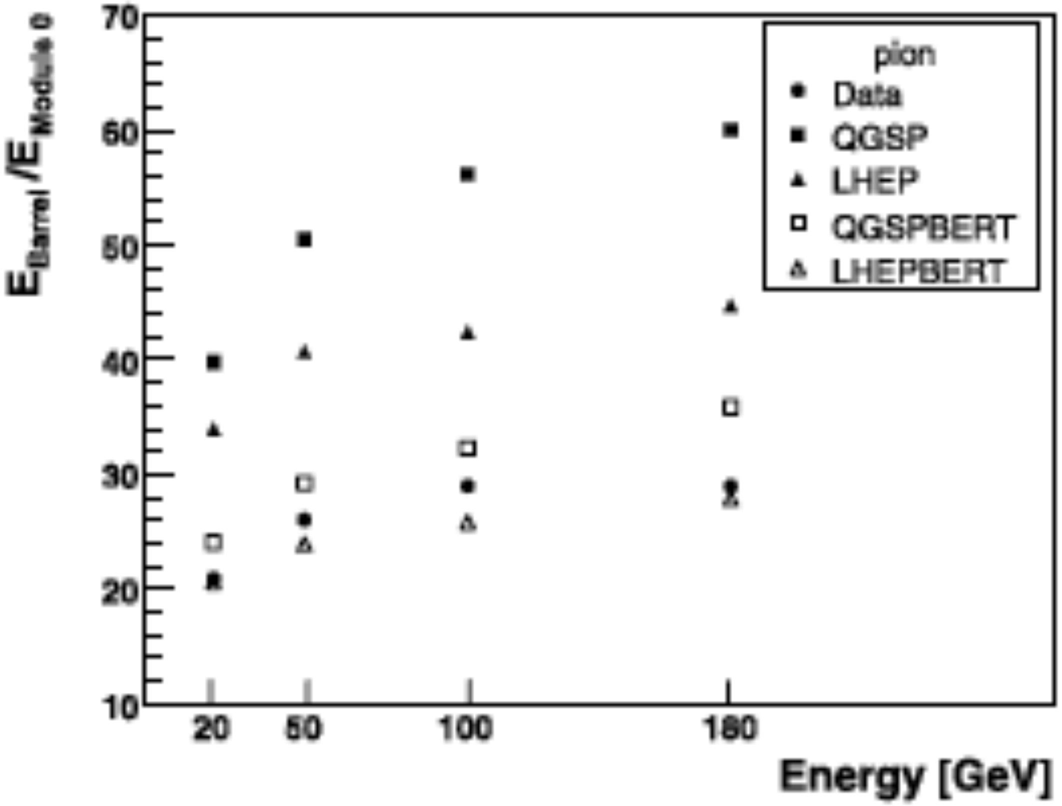




M.Simonyan, Physics Validation meeting 20-Sep-2006

ATLAS TileCal 2002 test-beam @90° incidence

lateral profile



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:

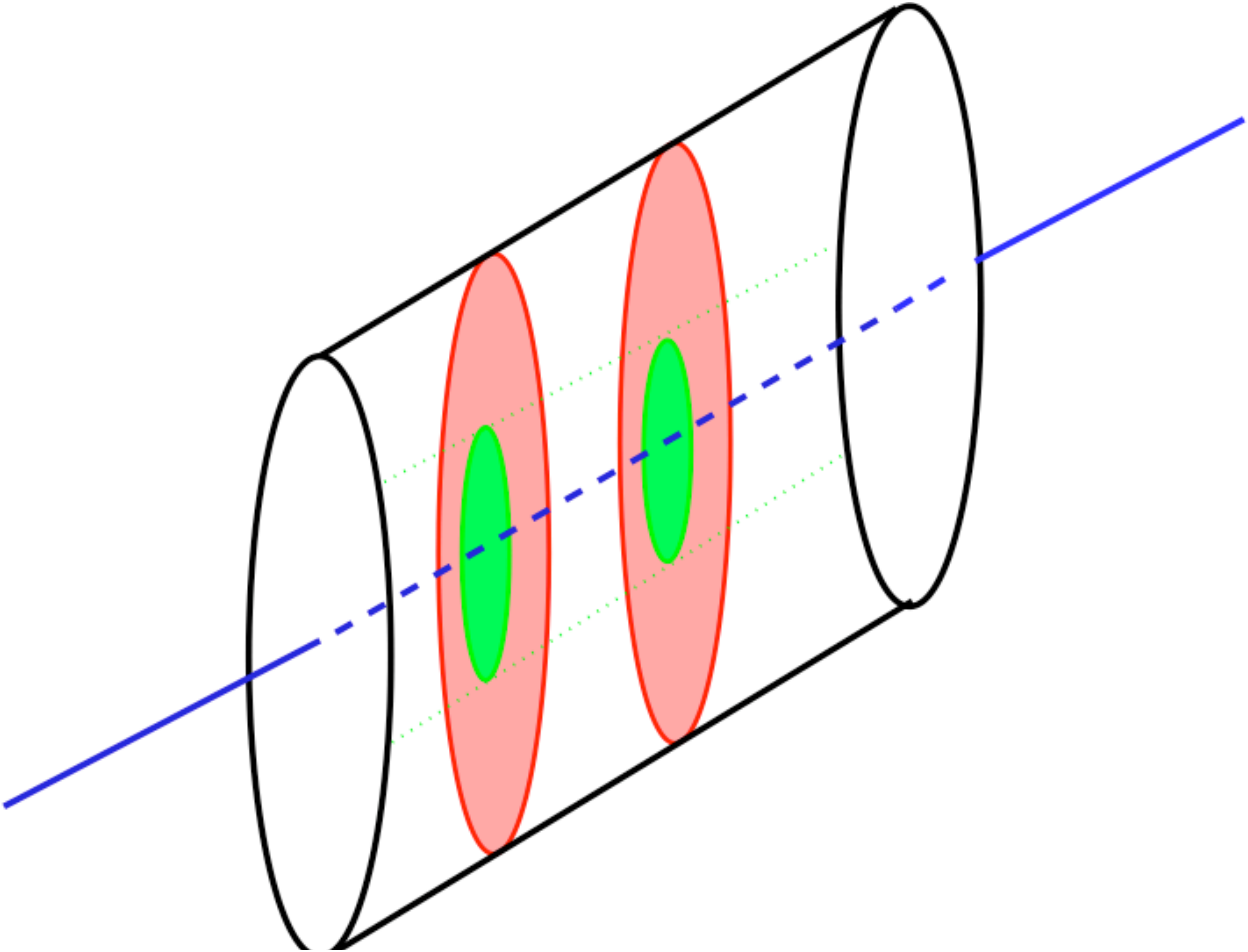
1. "microscopic" : study single physics processes, using thin-target data;
2. "macroscopic" : monitor the observables of a sampling calorimeter setup to compare different physics simulations.

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 setups:

- to avoid to repeat, each time, long and laborious analyses, which can be done (currently) only by the experimentalists;
- to look to many other variables, even not measurable, but still interesting;
- to decouple pure physics effects from instrumental details (beam composition, beam profile, complex geometry, 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

- Adding cascade models (Bertini, Binary) the hadronic showers get longer and wider;
- Adding a precise transportation 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;
- Enhancing (by hand) the diffraction component in QGS produces longer showers.

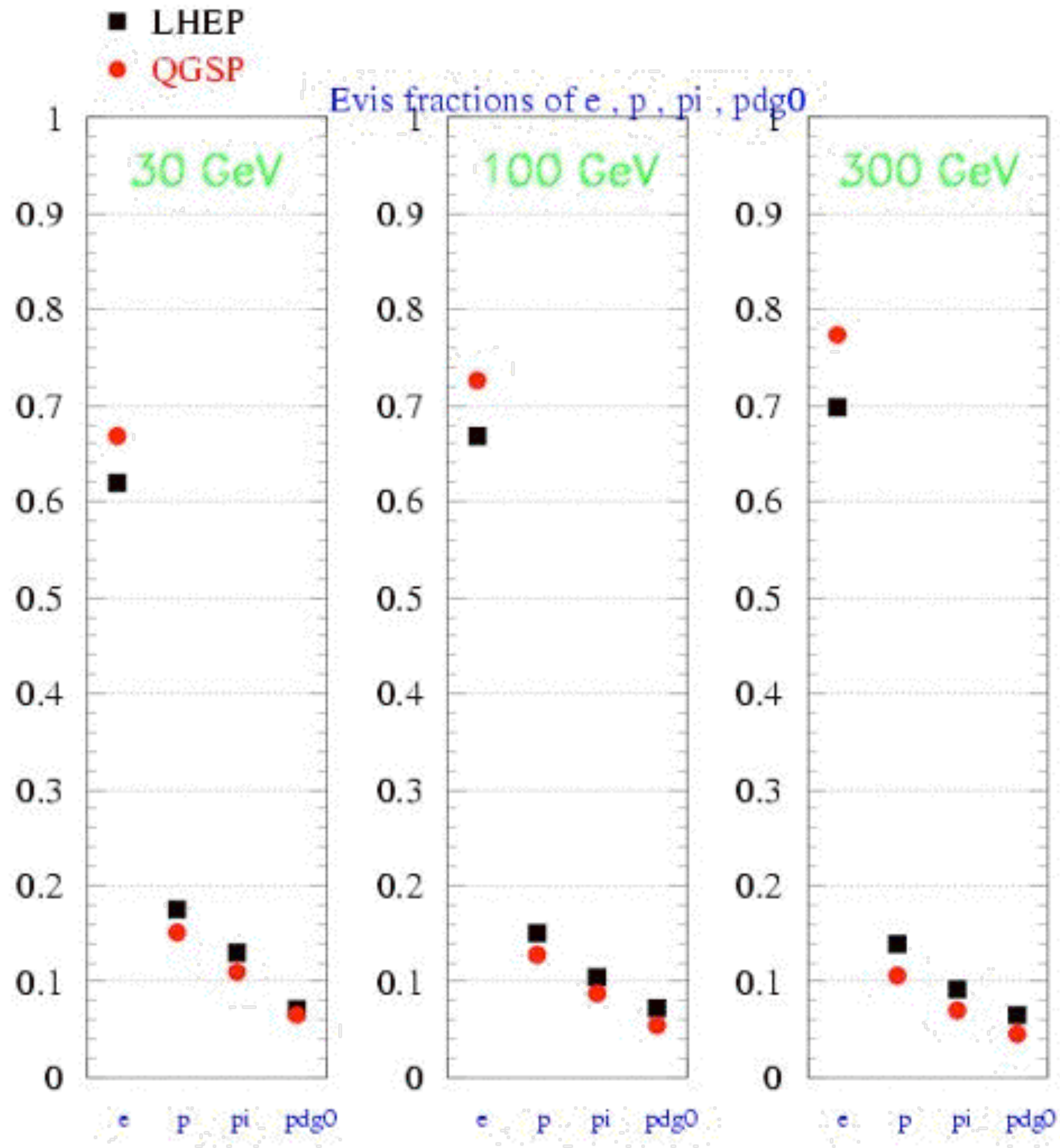
Particle contributions

- We want to study how much different particle types contribute to the visible energy, and which is shower shape (longitudinal and transverse) for each of them.

- We consider the following particle types
  1. e^-/e^+
  2. p/pbar
  3. π^+/π^-
  4. nuclei (and neutrons)

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

  We consider always a primary beam of π^- .



Alberto F
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.

Status at the Geant4 workshop (Oct 06)

- 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.

News in the last 3 months

- On going work on thin-target tests, hadronic elastic scattering, cross-sections, and neutron production and transportation.
- Some comparisons with Fluka.
- Identified 2 useful data-set for benchmarking diffraction: SPY (450 GeV/c p on Be), and HELIOS (450 GeV/c p on Be, Al, W).
- Improvements in the FTF (Fritiof) model in G4.
- Tried out the wrapper of Fortran INCL+ABLA.
- Some study of the effects of $\pi^{\pm}$, $k^{\pm}$ < 10 GeV.
- Started to write a LCG note.

Effects of $\pi^{\pm}$, $k^{\pm}$ below 10 GeV

- The motivation was to understand why all Physics Lists, with the only exception of QGSP_BERT, have a high fraction of total π^0 produced, ≈ 46%
- It is LEP that produced such high fraction of π^0 (this over-production below 10 GeV compensates for the under-production at high energies).
- LEP is used for $\pi^{\pm}$, $k^{\pm}$ below 10 GeV in all Physics Lists, except QGSP_BERT which uses the Bertini model instead.
- Replacing LEP with a better model, at least for $\pi^{\pm}$, $k^{\pm}$ below 10 GeV, would improve the shower shapes (also for this reason QGSP_BERT is the current best one).

Conclusions

- The problem of the shower shapes in Geant4 is around since about 3 years, but only in the last 9 months it is our top priority.
- The best Physics List we can offer at the moment for applications that rely on a good description of hadronic shower shapes is QGSP_BERT.
- We are writing 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.
- Two of the most promising work items are diffraction and treatment of $\pi^{\pm}$, $k^{\pm} \leq 10$ GeV .