CMS HCAL test-beam validation of Geant4

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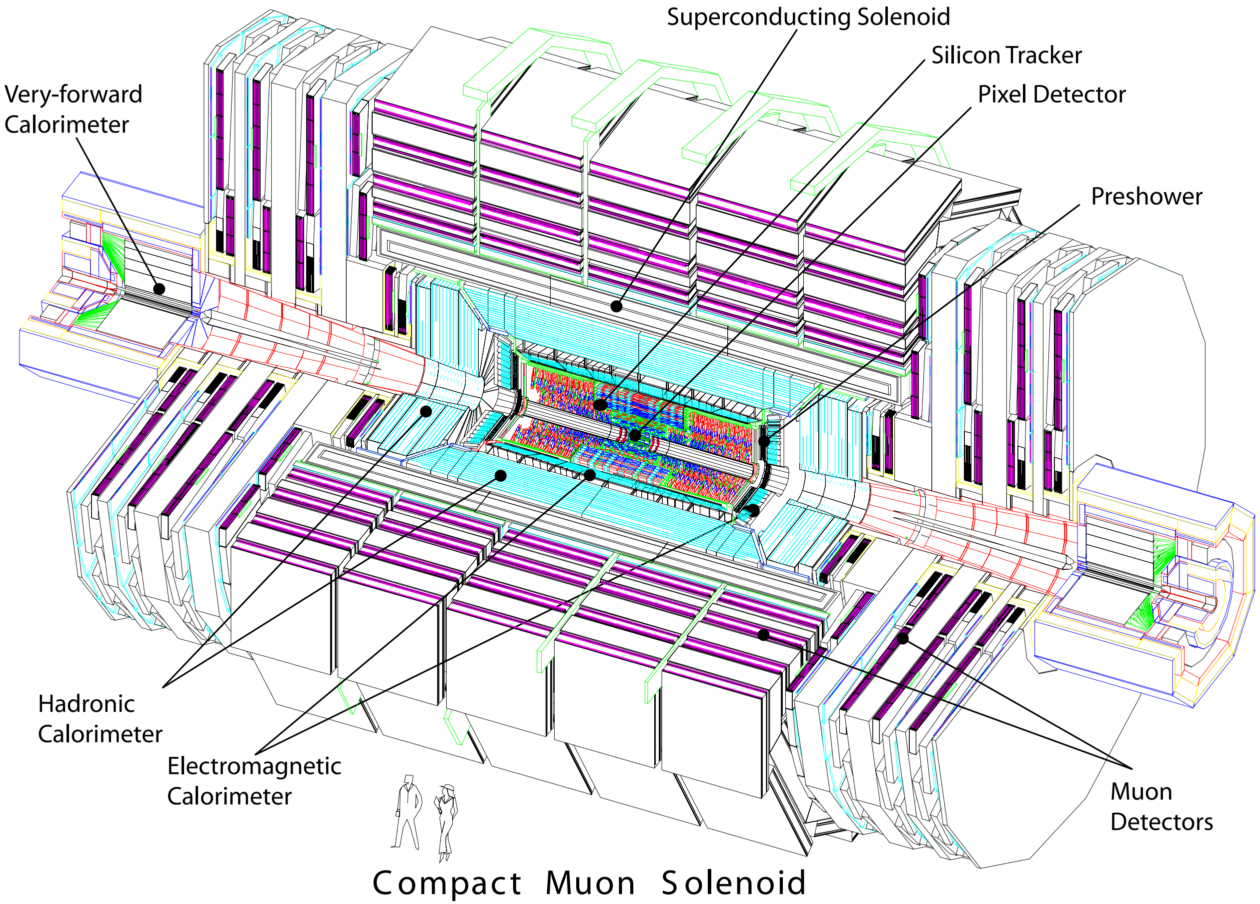
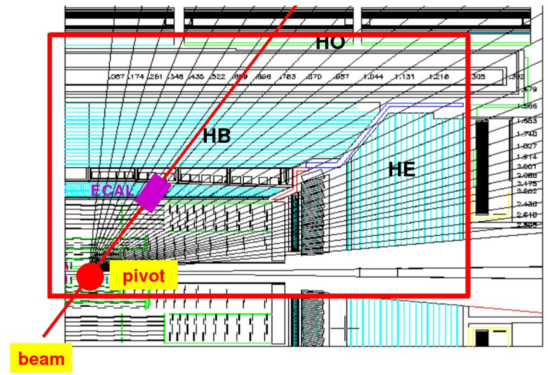
- CMS TestBeam 2004 Setup
- Understanding TB04 data: Main difficulties
- TB04 Results and Comparison with MC simulation
- Simulation with various Geant4 versions
- Plans - CMS TestBeam 2006
- Conclusions

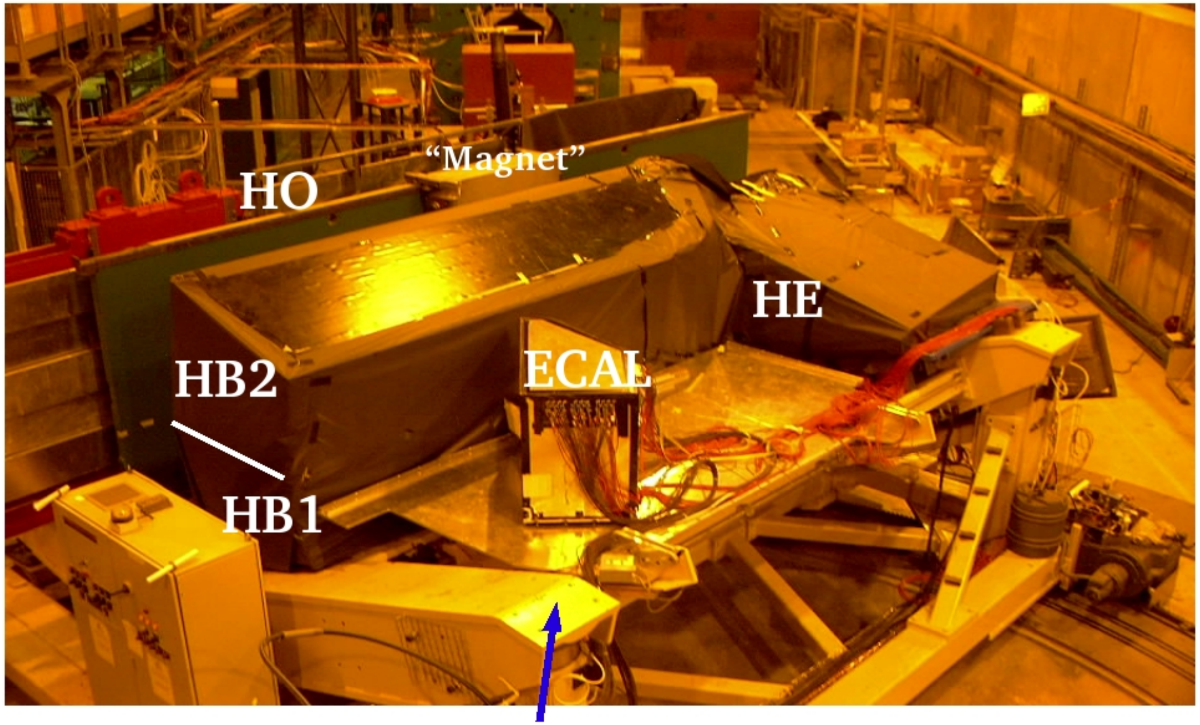




Calorimetric systems present on the Testbeam 2004 table. Pivot point corresponds to interaction point in CMS. ECAL is only a prototype matrix of 7x7 crystals. HCAL Barrel modules are production wedges readout with real front-end electronics.

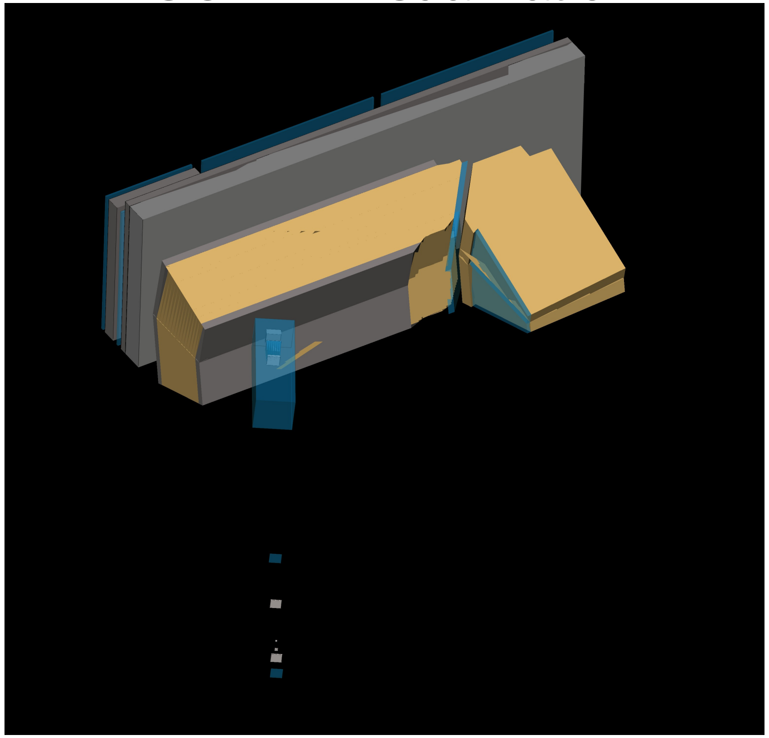
The Very Forward Calorimeter was present in the Testbeam setup, but is not included in the current study.

Photo of testbeam area



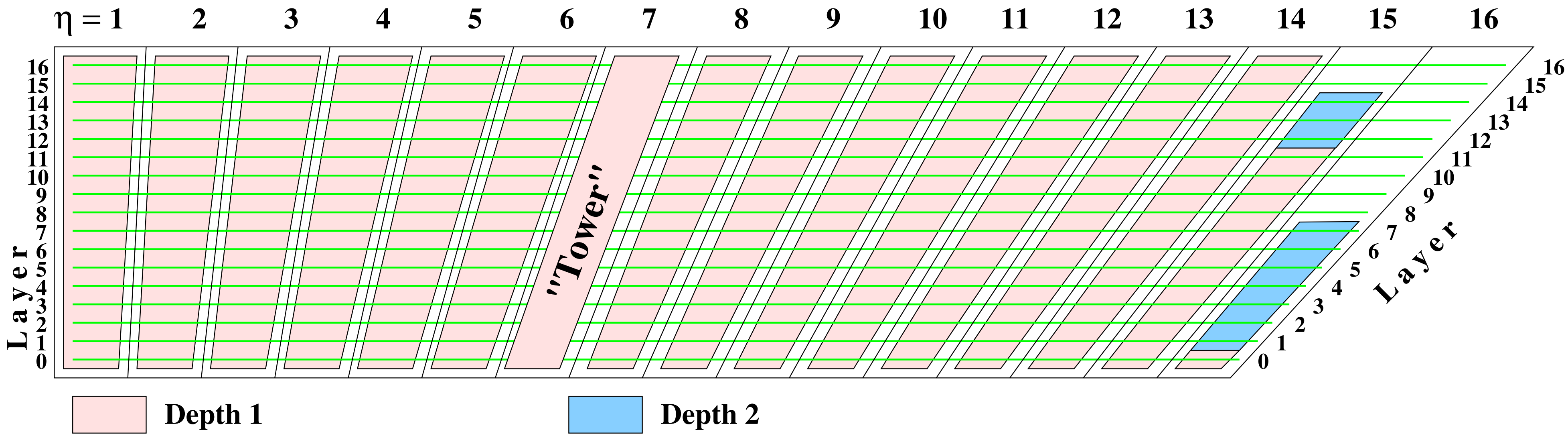
Beam from SPS.

IGUANA visualization

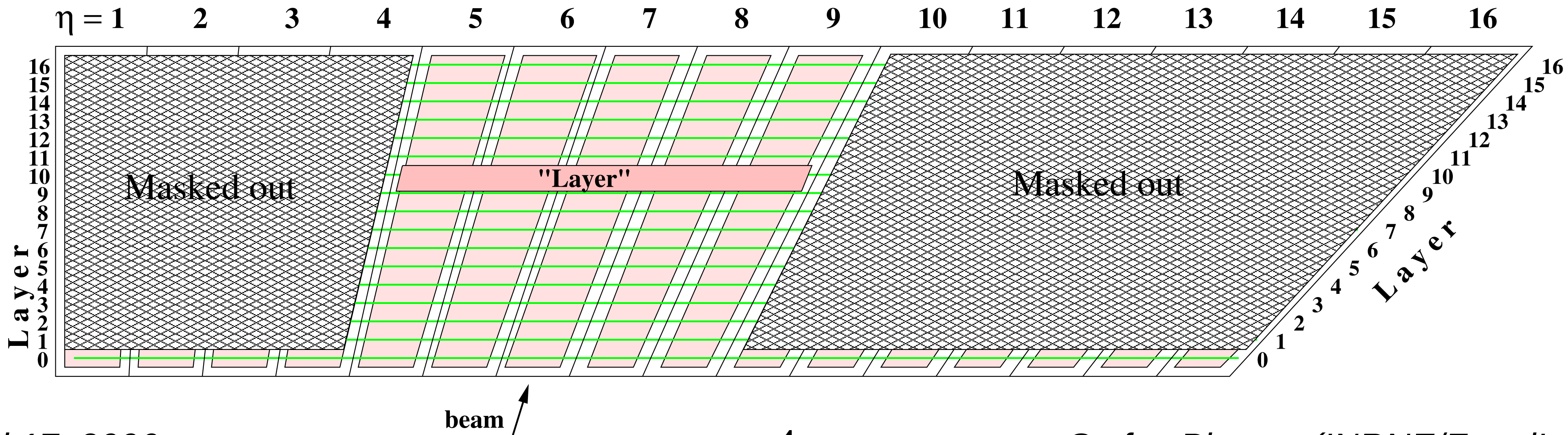


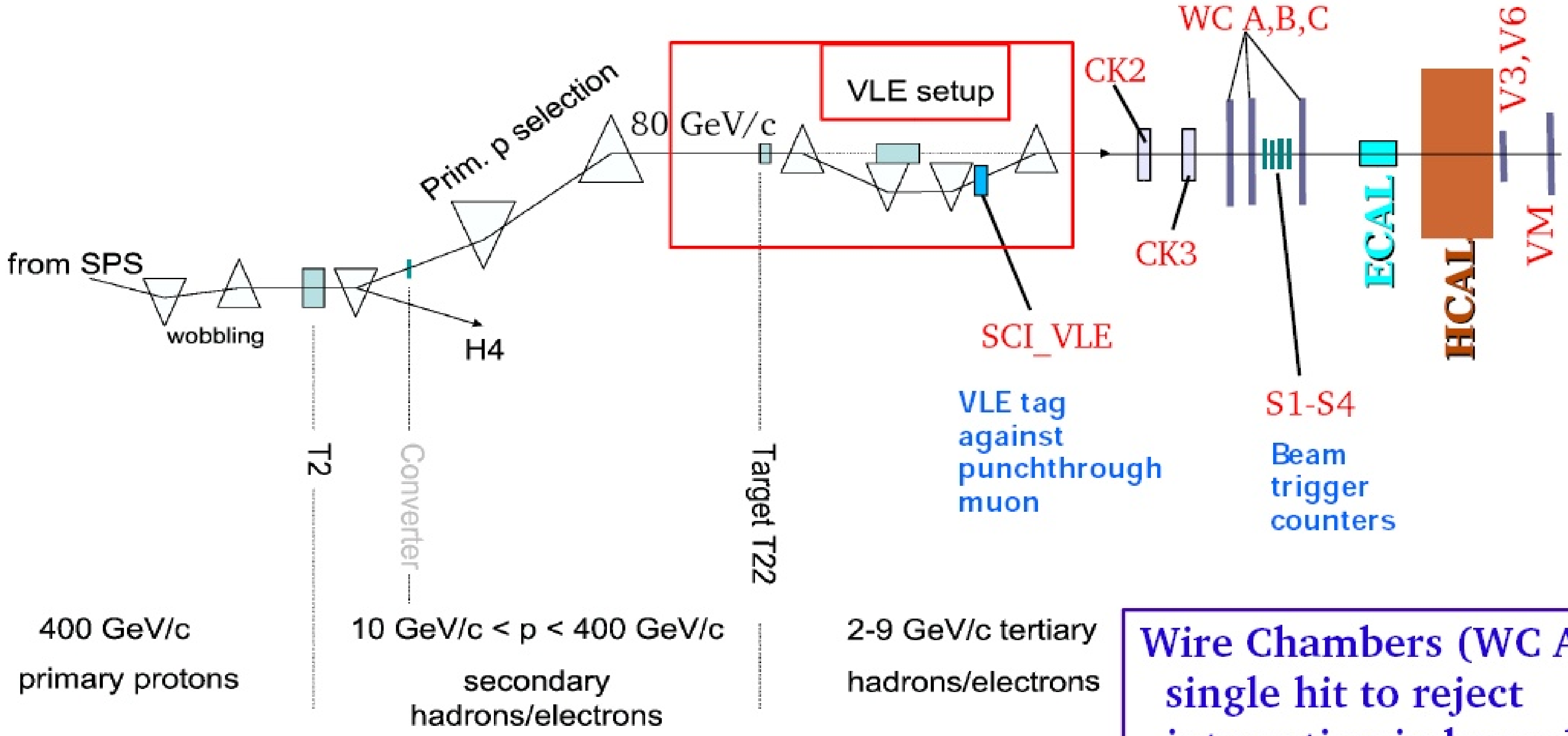
Moving table allows beam to be sent into arbitrary eta/phi tower of HCAL.
ECAL crystals always stay in the beam.

HB1: tower−wise readout – normal, as in CMS



HB2: Layer−wise readout – for longitudinal shower profile studies





Wire Chambers (WC A,B,C):
single hit to reject
interaction in beam line

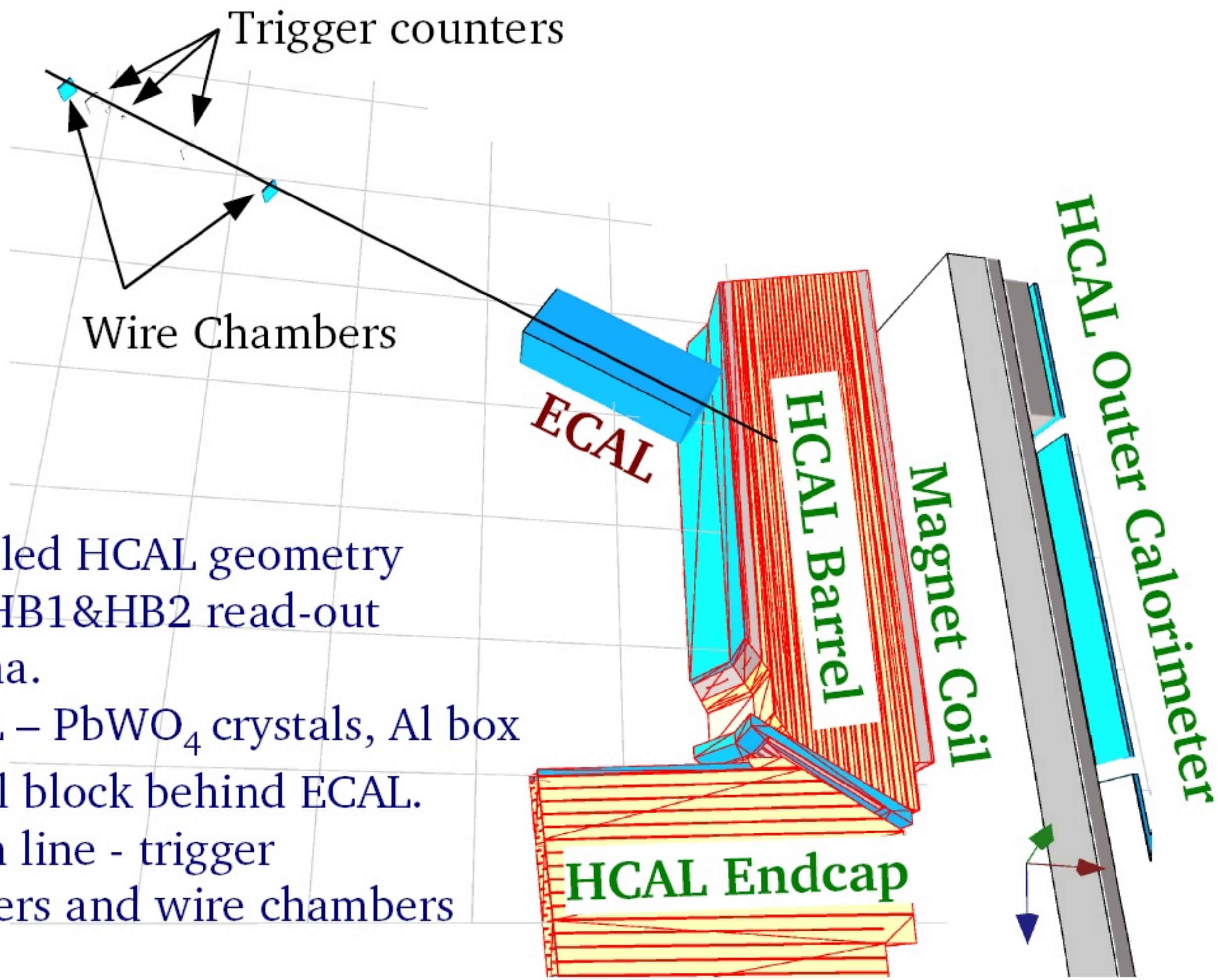
Available beam tunes:
- pions 2-300 GeV
- muons 80/150 GeV
- electrons 9-100 GeV

P-ID:
- Cerenkov counter (CK2) - electron
- Cerenkov counter (CK3) - pion / kaon / proton
- Scintillators (V3, V6, VM) – muon tagging

Main simulation tool: OSCAR_3_7_0

– uses G4.6.2_p02

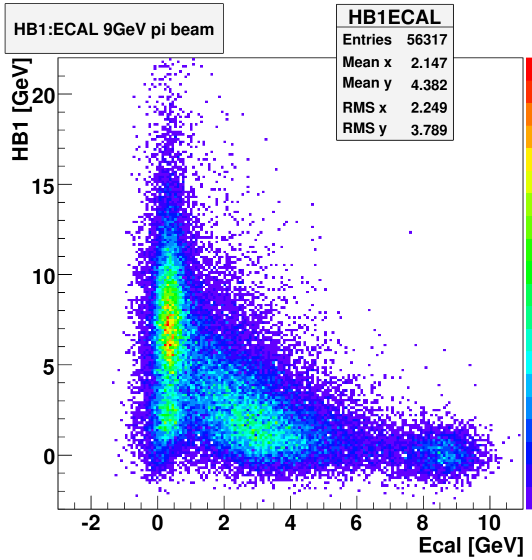
– physics lists: LHEP-3.7,QGSP-2.8,QGSC-2.9,FTFP-2.8 (Pack.-2.5)



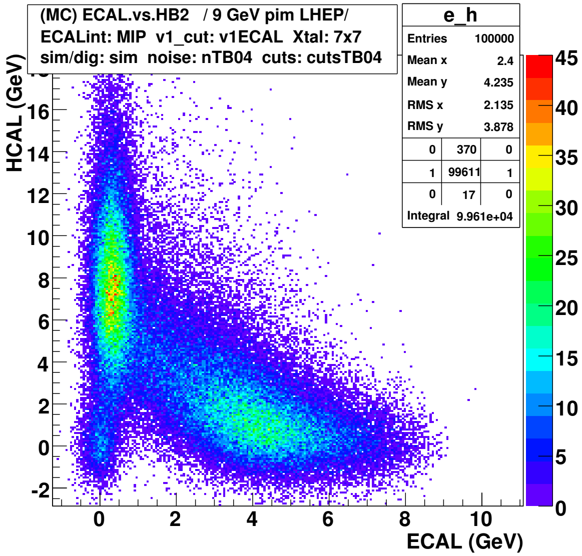
- Detailed HCAL geometry with HB1&HB2 read-out schema.
- ECAL – $PbWO_4$ crystals, Al box and Al block behind ECAL.
- Beam line - trigger counters and wire chambers

HCAL signal vs. ECAL signal - the ”banana” plot

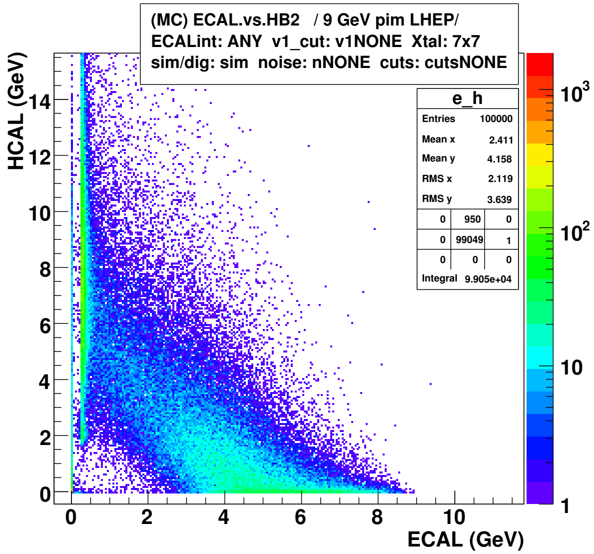
TestBeam data



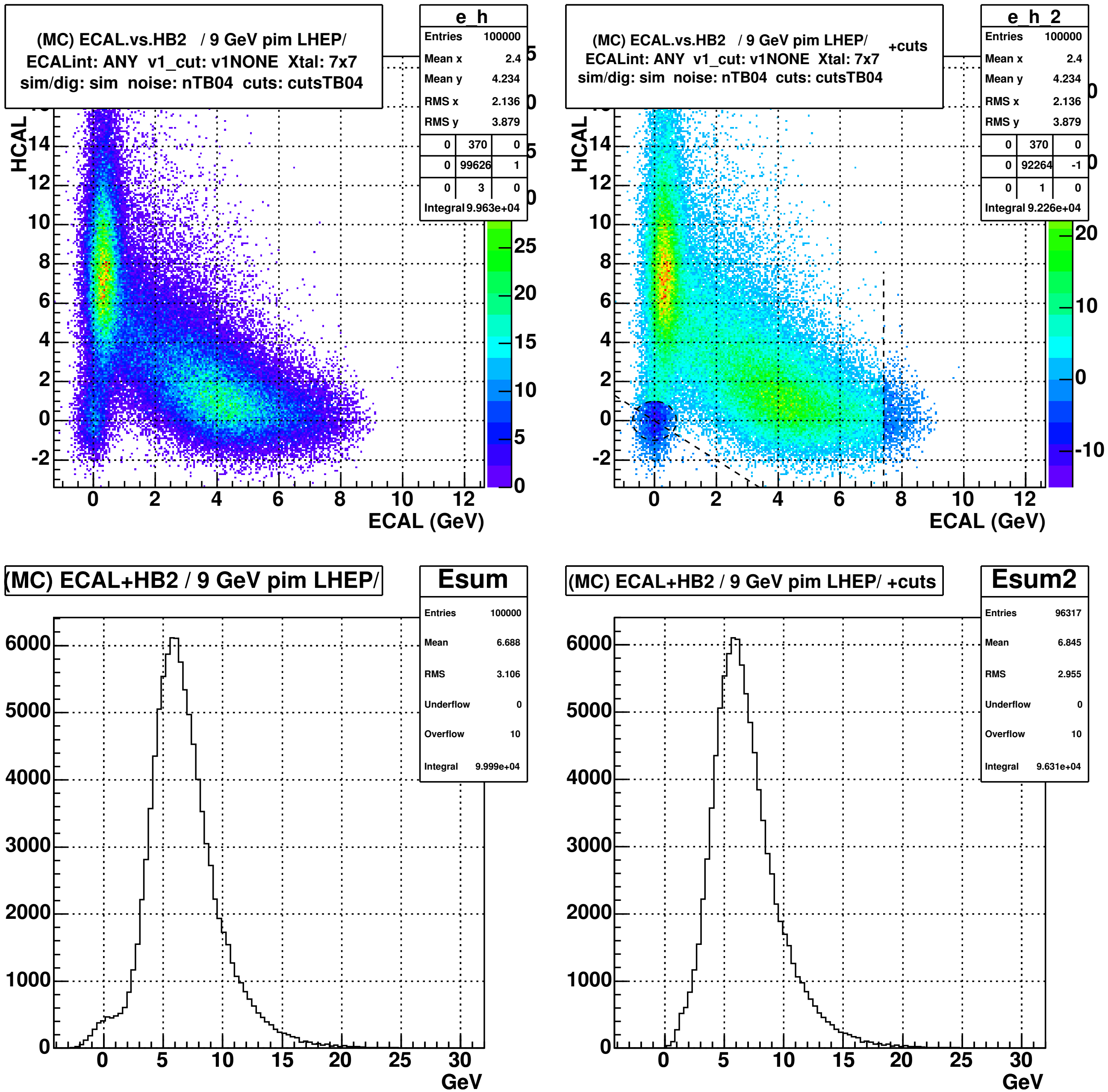
MonteCarlo with noise



MonteCarlo w/o noise

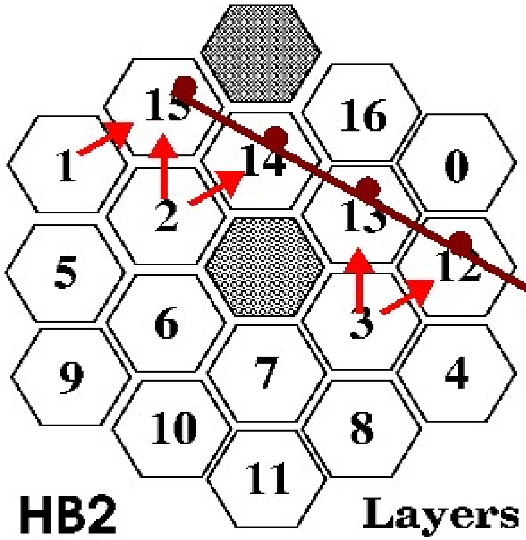


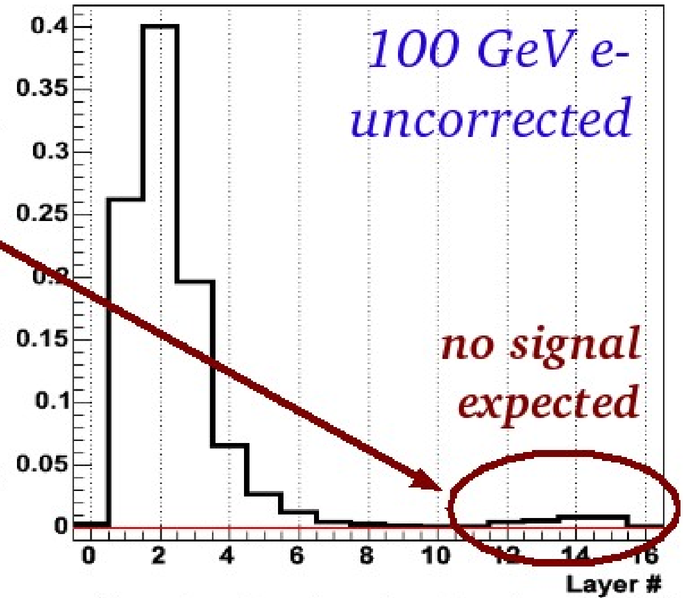
- electron contamination in pion beam
- interactions in beamline
- muons from pion decay

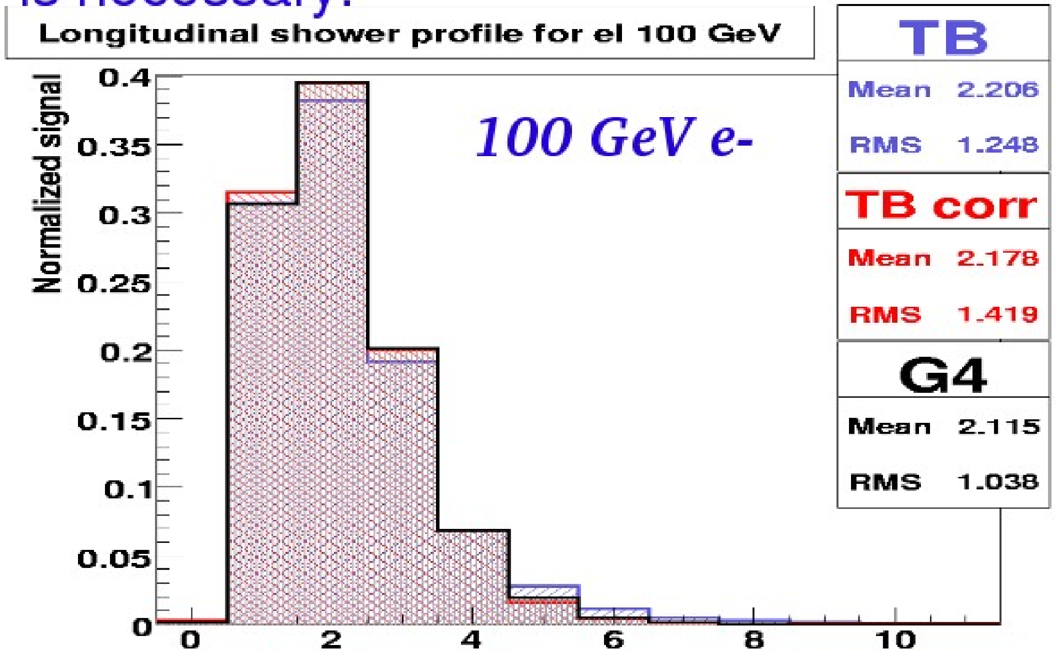


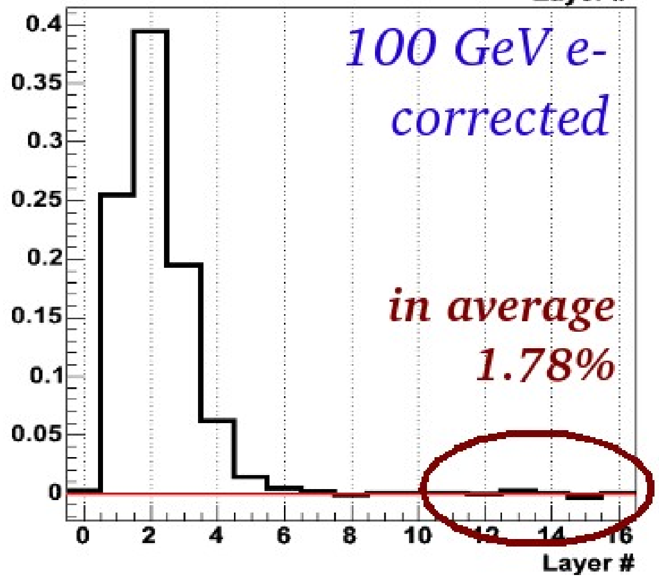
Caloimeter-based cuts are necessary to clean up the beam-interracted particles. These introduce systematic errors, but are the only way to enable comparison with the TB data.

In the test beam environment there is no magnetic field to compensate the cross-talk – correction is necessary.







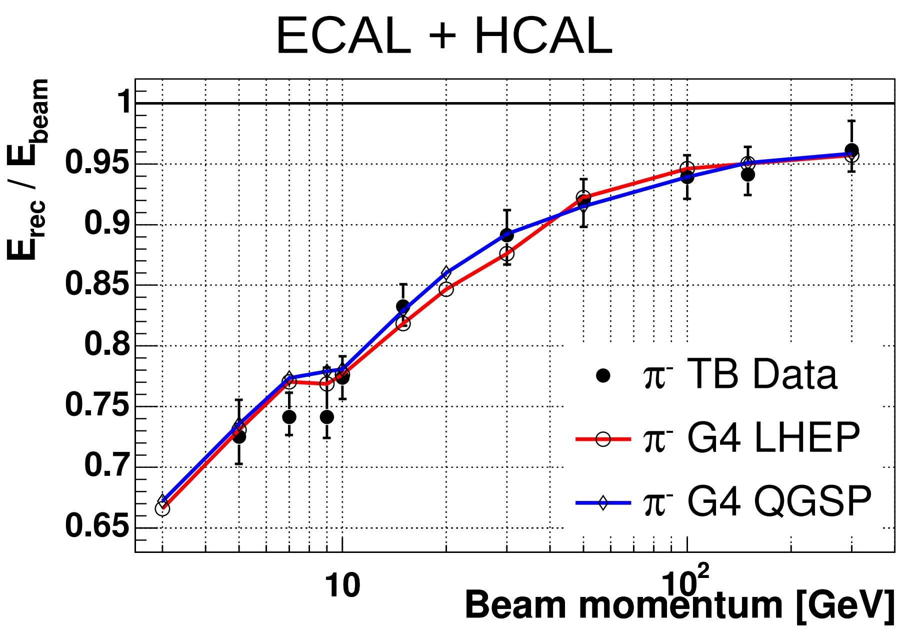


Data

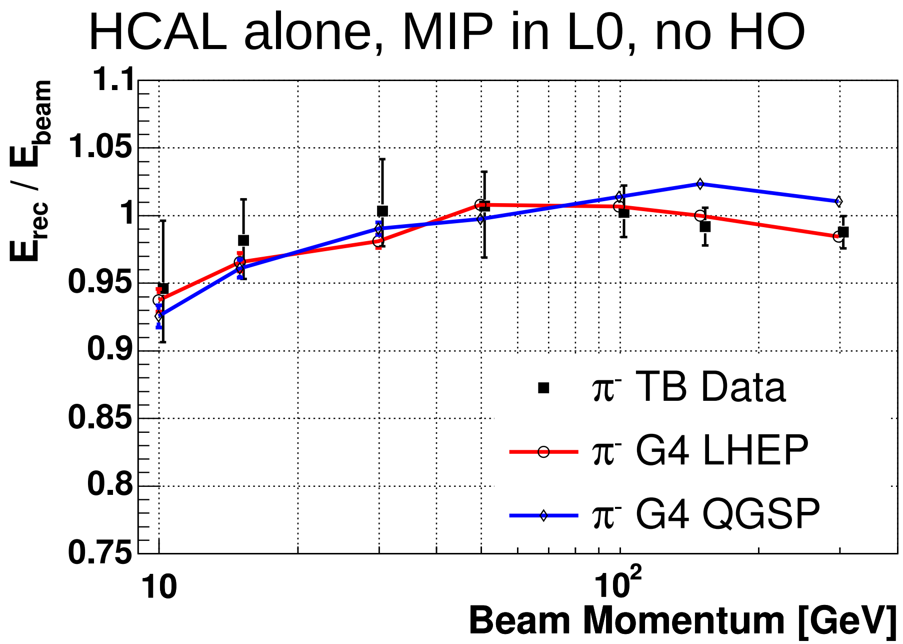
- Very Low Energies (VLE)
  - 2,3,5,7,9 GeV mainly $\pi^{\pm}$ beam
  - with/without ECAL
  - HB1/HB2
  - Full particle identification
- Medium Energies (MED)
  - 10,15,20 GeV $e^{\pm}$, $\pi^{\pm}$ beam
  - with/without ECAL
  - HB1/HB2
  - Partial particle identification
- High Energies (HIGH)
  - 30,50,100,150,300 GeV $e^{\pm}$, $\pi^{\pm}$, p beam
  - with/without ECAL
  - HB1/HB2

Simulation

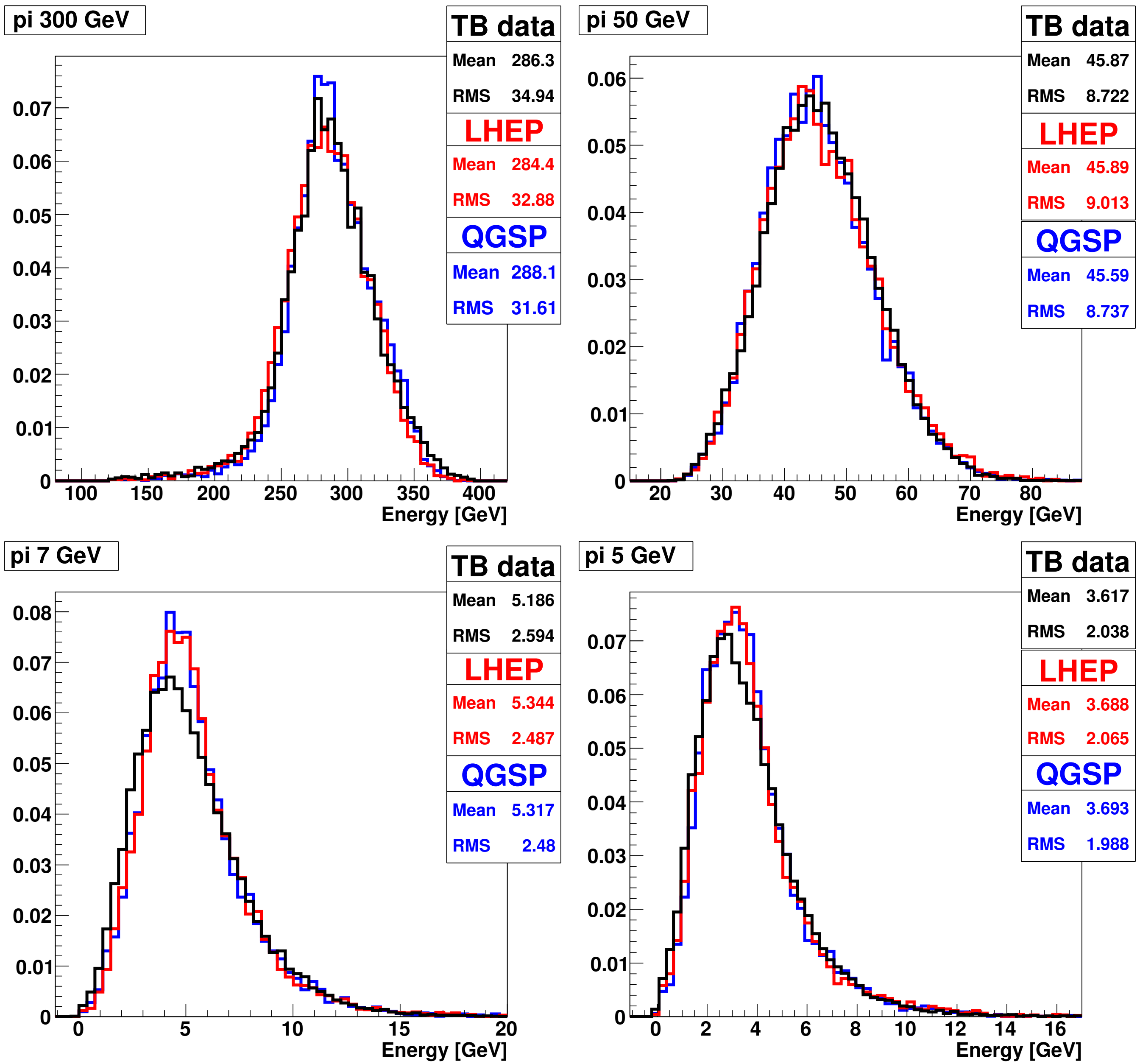
- Very Low Energies (VLE)
  - 2,3,5,7,9 GeV $e^{\pm}$, $\pi^{\pm}$, p, $K^{\pm}$ beam
  - with/without ECAL
  - HB2
- Medium Energies (MED)
  - 10,15,20 GeV $e^{\pm}$, $\pi^{\pm}$, p, $K^{\pm}$ beam
  - with/without ECAL
  - HB2
- High Energies (HIGH)
  - 30,50,100,150,300 GeV $e^{\pm}$, $\pi^{\pm}$, p, $K^{\pm}$ beam
  - with/without ECAL
  - HB2



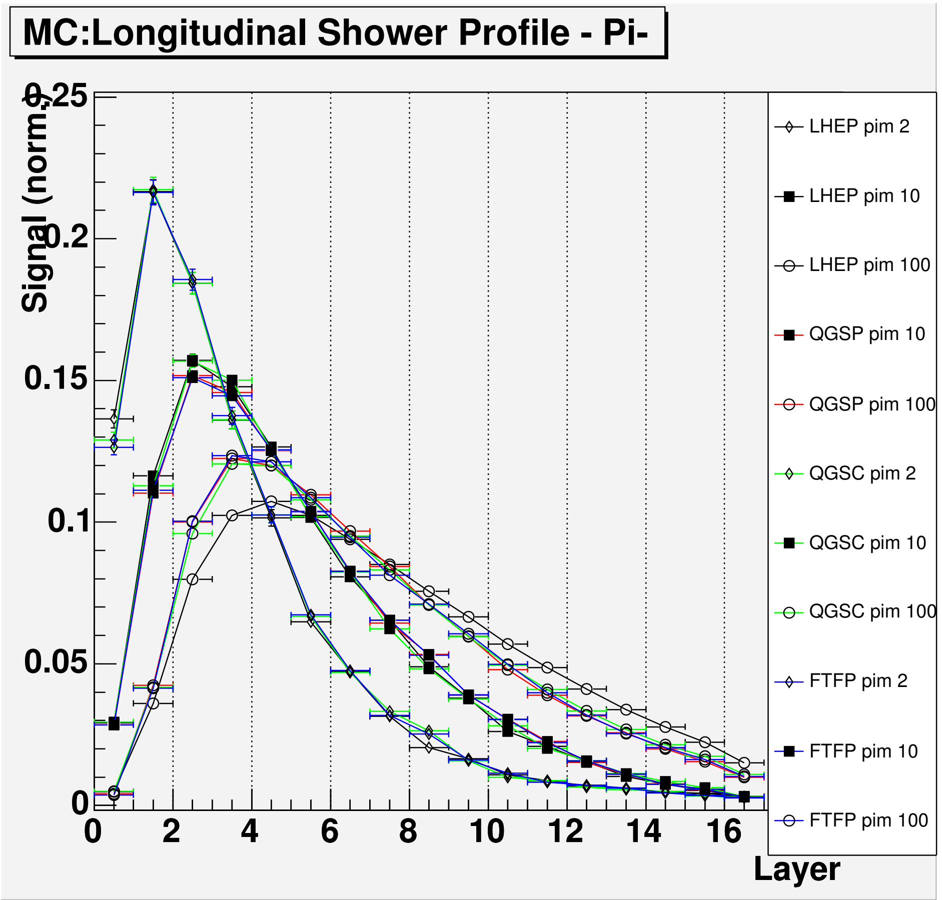
The combined system is simulated correctly by both physics lists. The slight non-linearity around 7GeV is still to be understood.

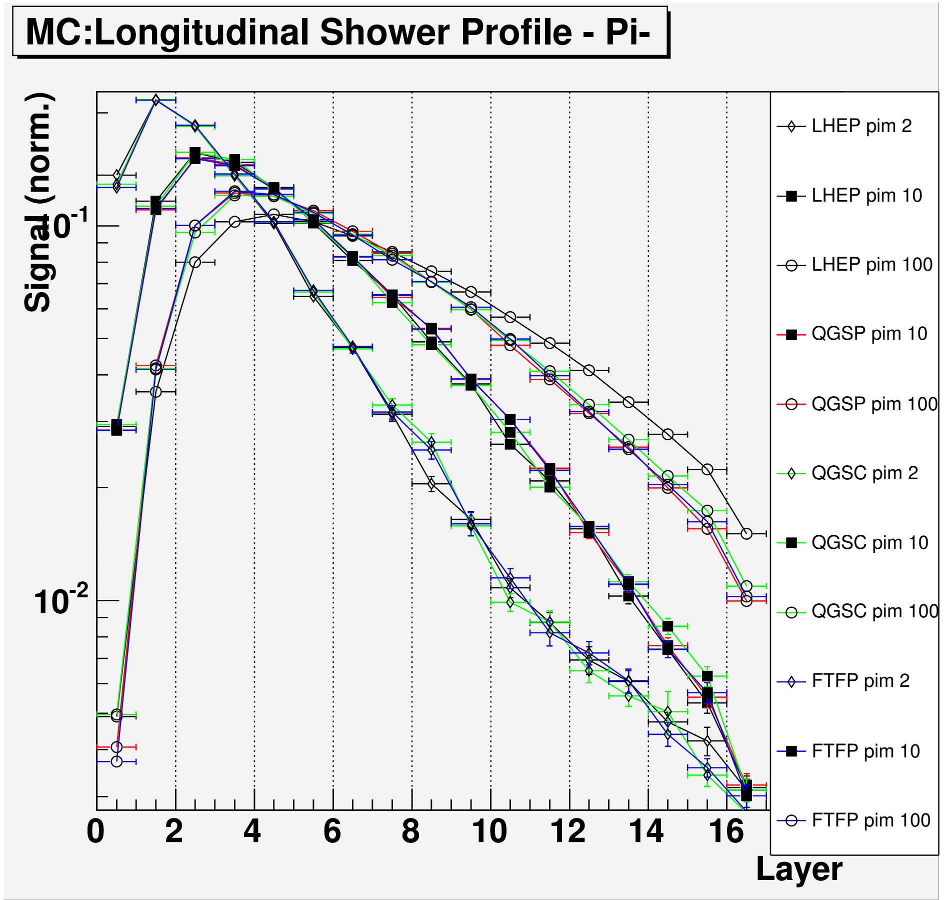


QGSP predicts more signal (=less leakage) at highest energies, most likely due to the shorter showers. (see later)

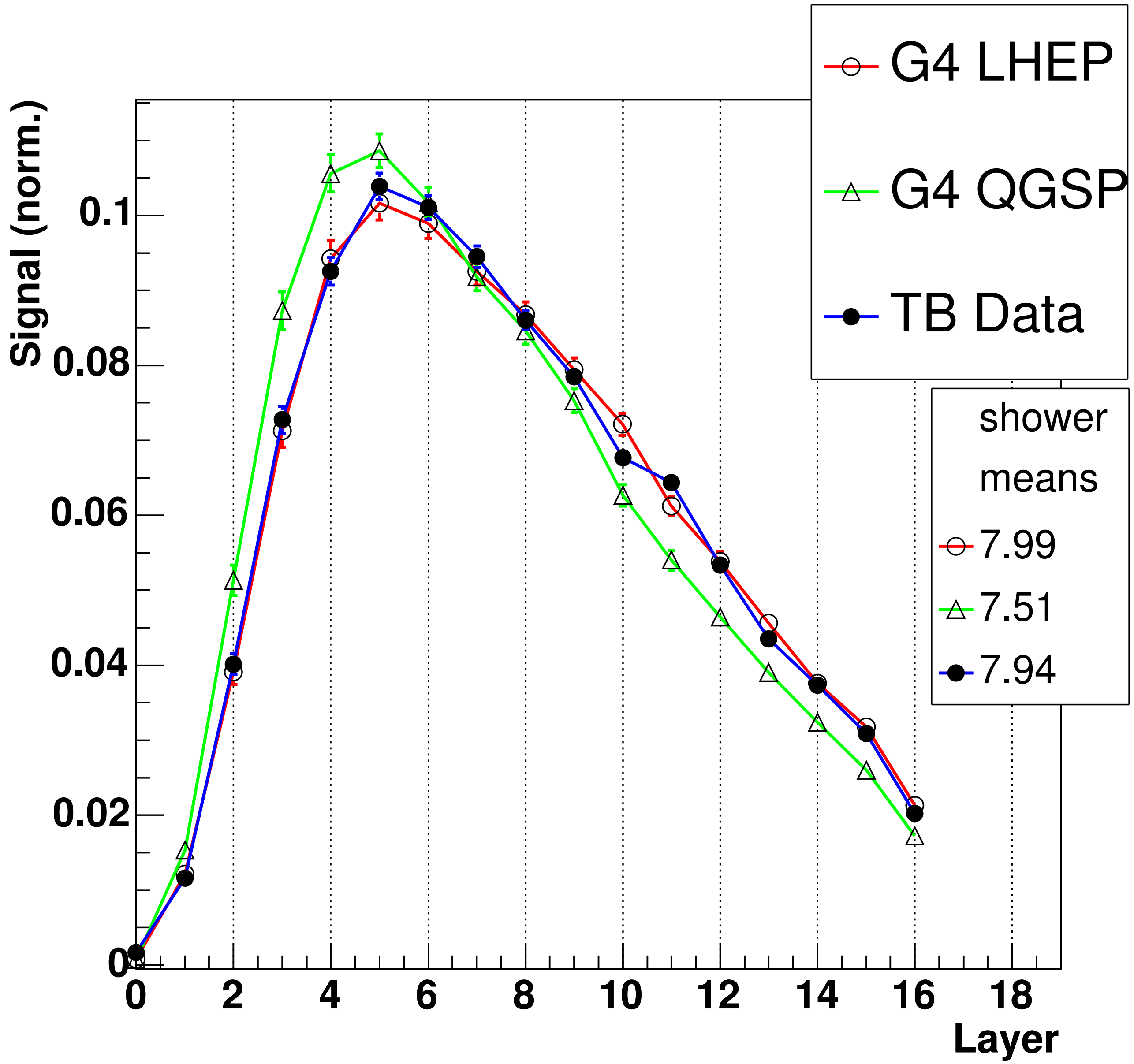


Good agreement with data.





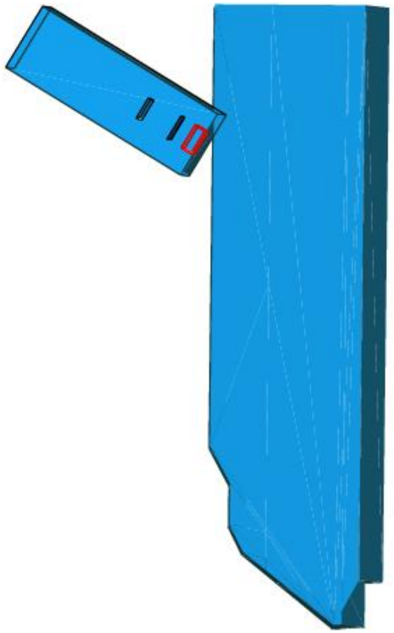
Early MC simulations showed that the parametrized physics list (LHEP) predicts different shower profiles than the calculated models (QGSP, QGSC, FTFP). So we were curious what the test-beam data will look like.



Data seems to agree better with LHEP list. QGSP predicts shorter showers, better contained in the calorimeter.

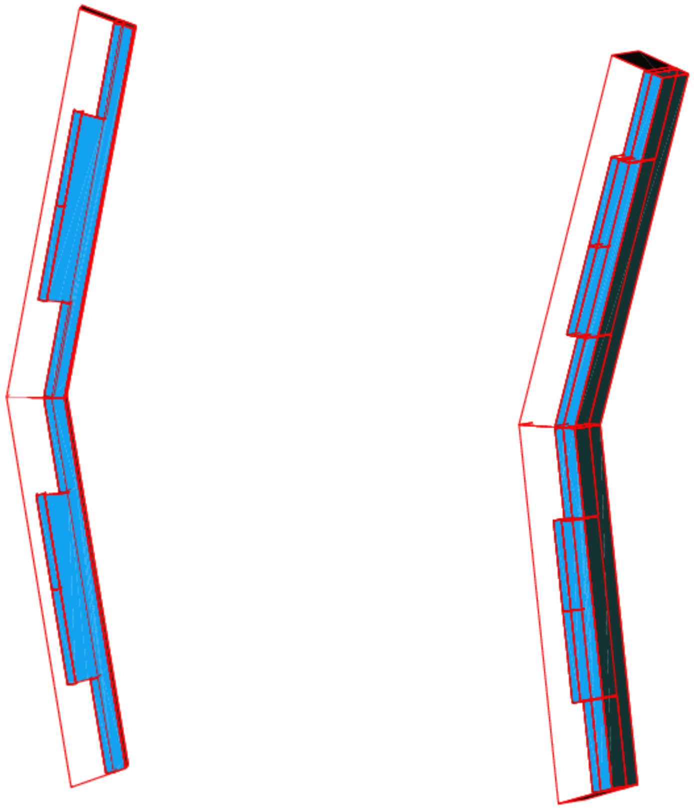
300 GeV pions, leaving MIP in ECAL and L0.

The misplaced Al-block



error in placement logic

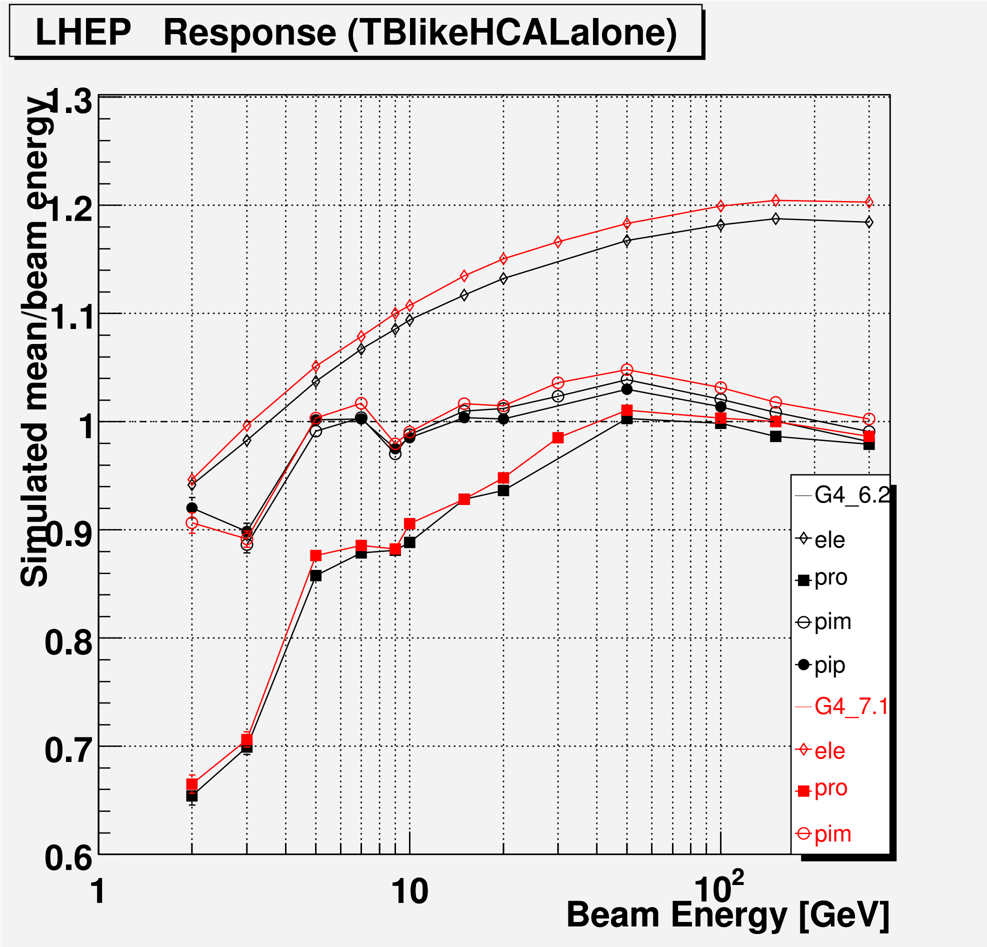
Wrong L0-absorber thickness

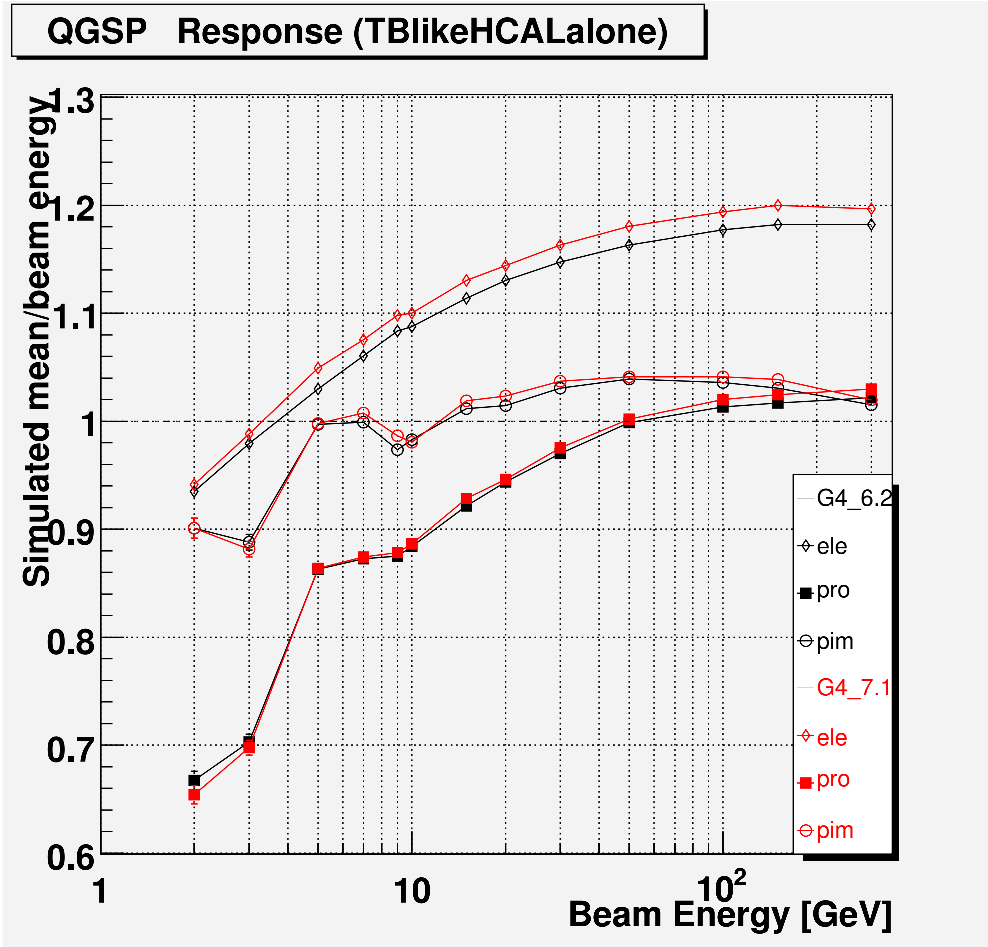


TestBeam specific issue

- 4.6.2_p2 - our production version in TB2004
- 4.7.1 - last G4 version in the ”old” framework, and first in the ”new” (CMSSW). Probably our ”production” version for TB2006.
- 4.8.0 - test version in preparation. Hopefully usable for parallel TB2006 simulations/validations.

G4.7.1 - linearity of response (preliminary)





G4.7.1 shows overall more visible energy for all interactions and does not affect the e/pi ratio.

- real production ECAL supermodule

- better beam particle ID - hopefully cleaner beam, therefore no need for calorimeter-based cuts.

- use the Test-beam simulation for validation of newer releases of G4 and OSCAR producer inside CMSSW.

- CMS HCAL measured in TB2004 agrees quite well with the predictions of Geant4.
- parametrized physics list shows better agreement with data.
- QGSP predicts shorter showers, resulting in difference in predicted response at high energies.