Validation of Geant4 Simulation of CMS Calorimeters with Test-Beam data.

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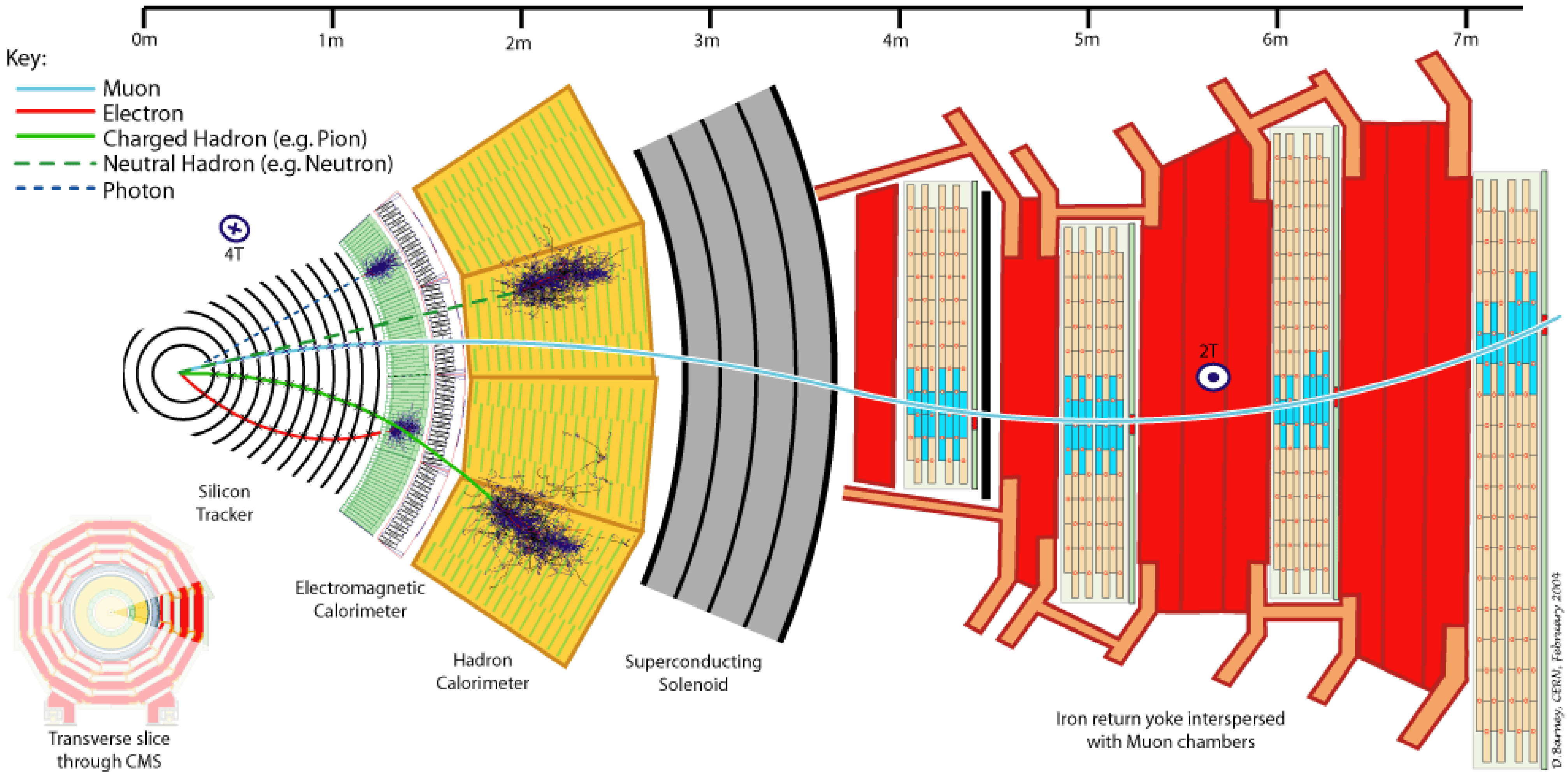
- Introduction
- CMS detector and the TestBeam 2006 Setup
- CMS Calorimeter Simulation and comparison with TestBeam Results
- Conclusions

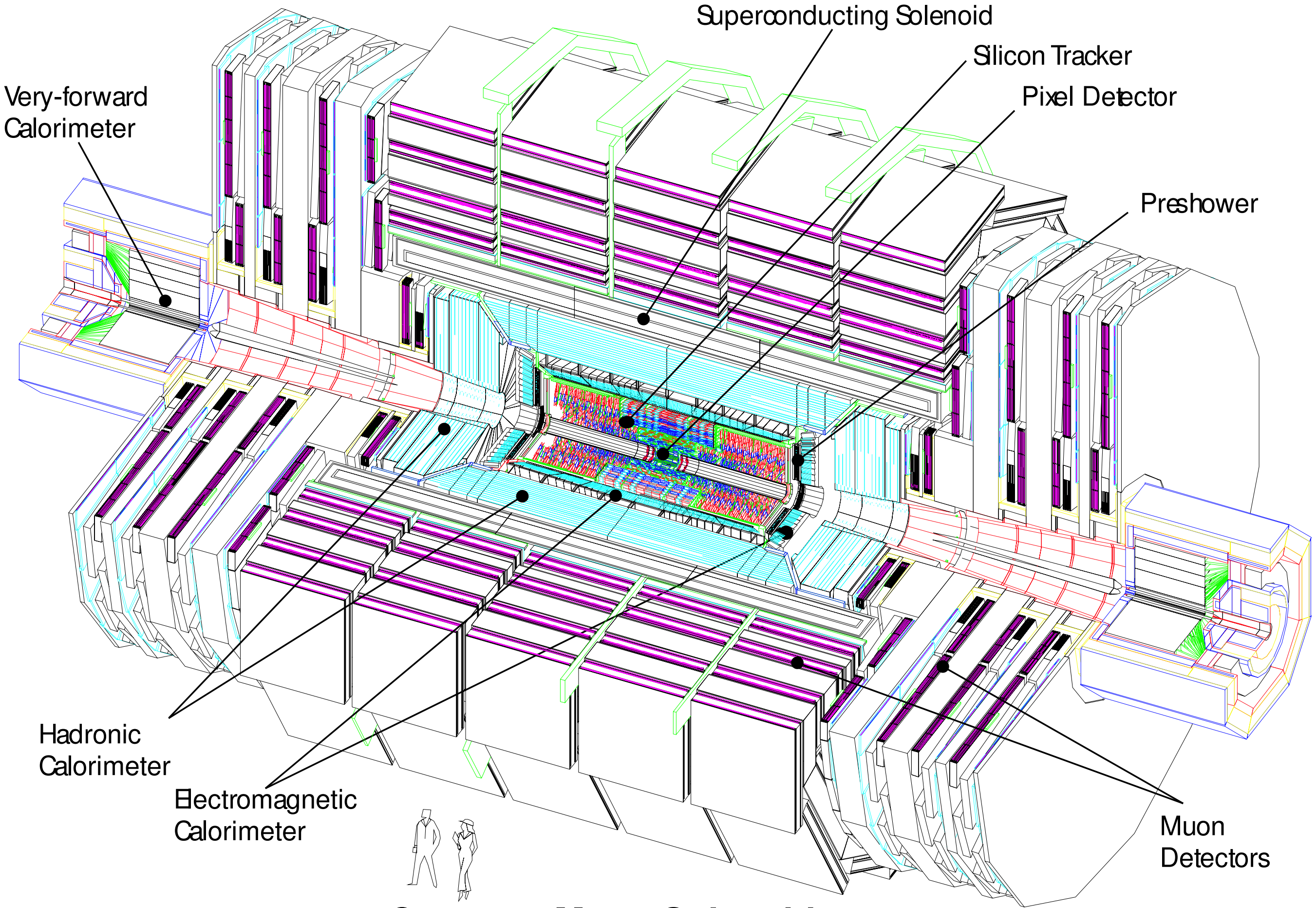
Simulation of hadron showers is both difficult and expensive.

- expensive - in terms of CPU power. Calorimeter shower simulation is the single biggest consumer of CPU time in the full detector simulation.
- difficult - in terms of complexity and uncertainties of underlying physics processes spanning from particle to nuclear physics, and impossible to cover in one single physics model.

Many LEP experiments used detailed simulation of hadron showers. Experiments at the Tevatron (being initially more of a discovery machine, rather than precision one) did not.

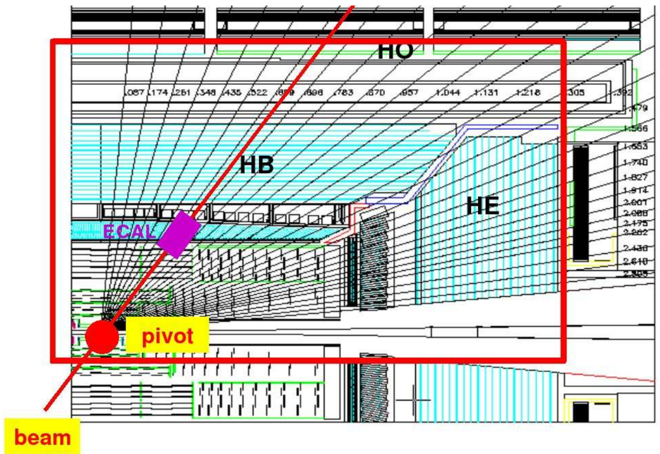
CMS experiment, with the help of the Geant4 team, wants to do better. In tight collaboration with G4, and using the data from 2004 and 2006 TestBeams at H2 on SPS, we are trying to identify, understand and resolve the discrepancies between the simulated and observed behavior of CMS calorimeters.


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D.Barney, CERN, February 2004



Compact Muon Solenoid

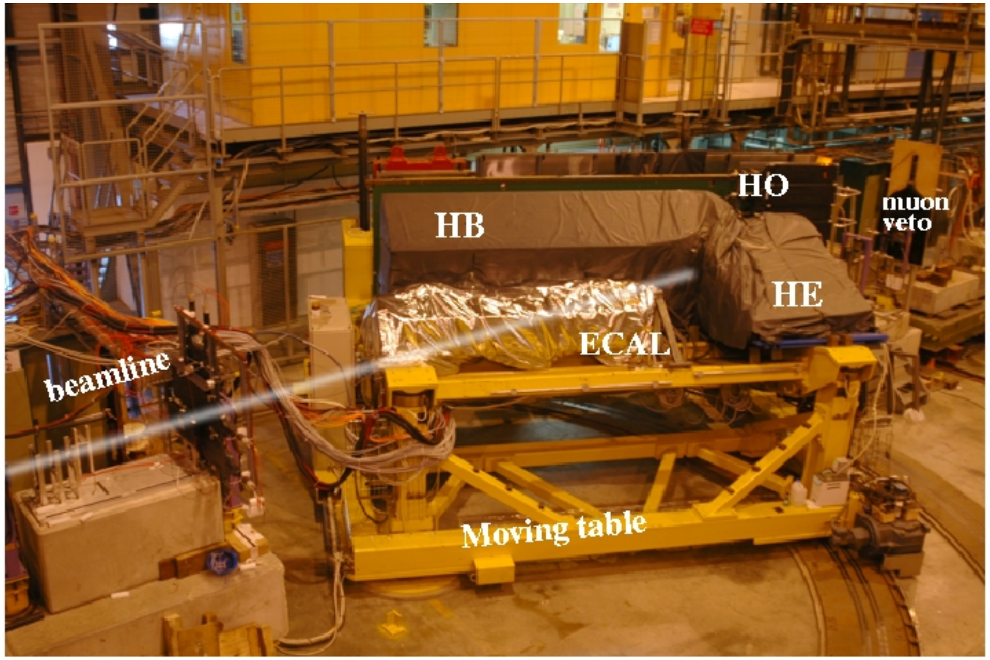
HCAL = Hadronic Calorimeter - sampling scintillator/brass
ECAL = Electromagnetic Calorimeter - homogeneous crystal ($PbWO_4$)
HB = HCAL Barrel
HE = HCAL EndCap
HO = HCAL Outer

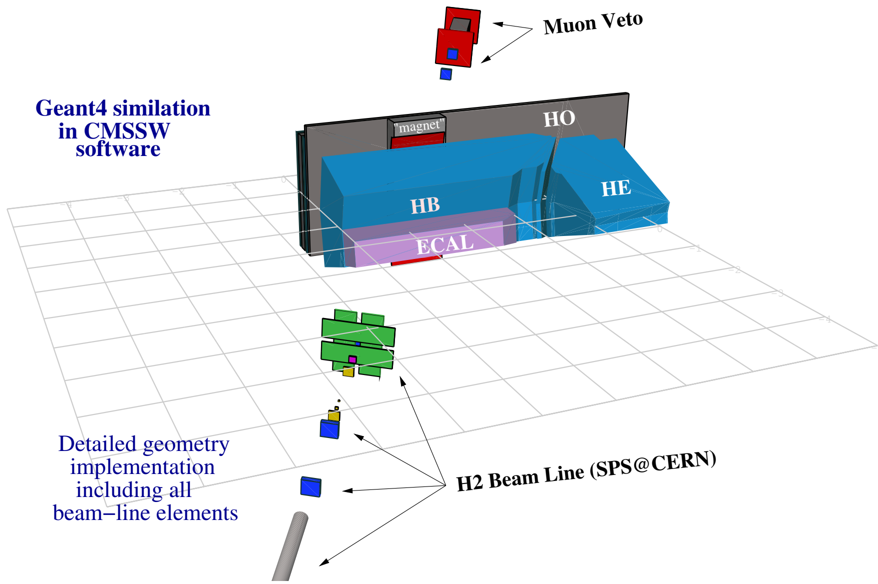


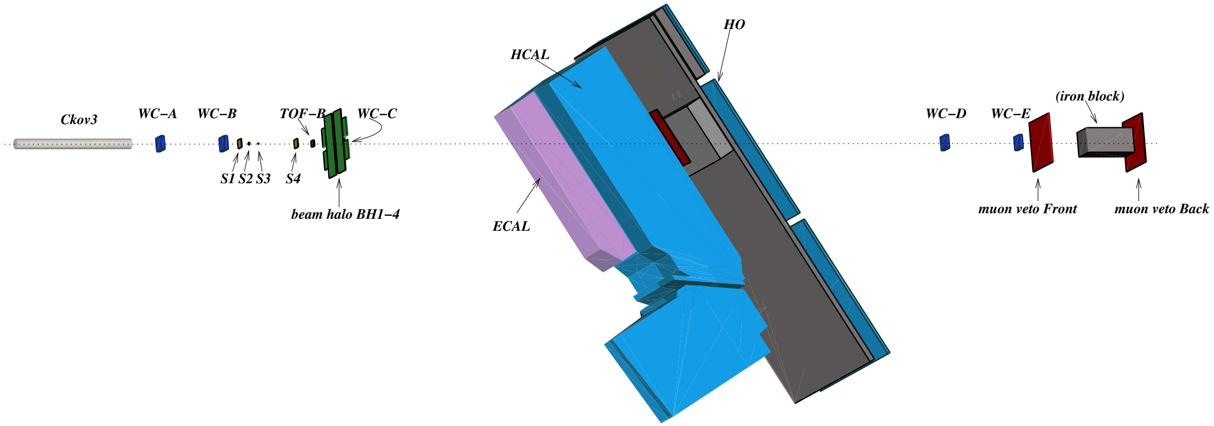
Calorimetric systems present on the Testbeam table.

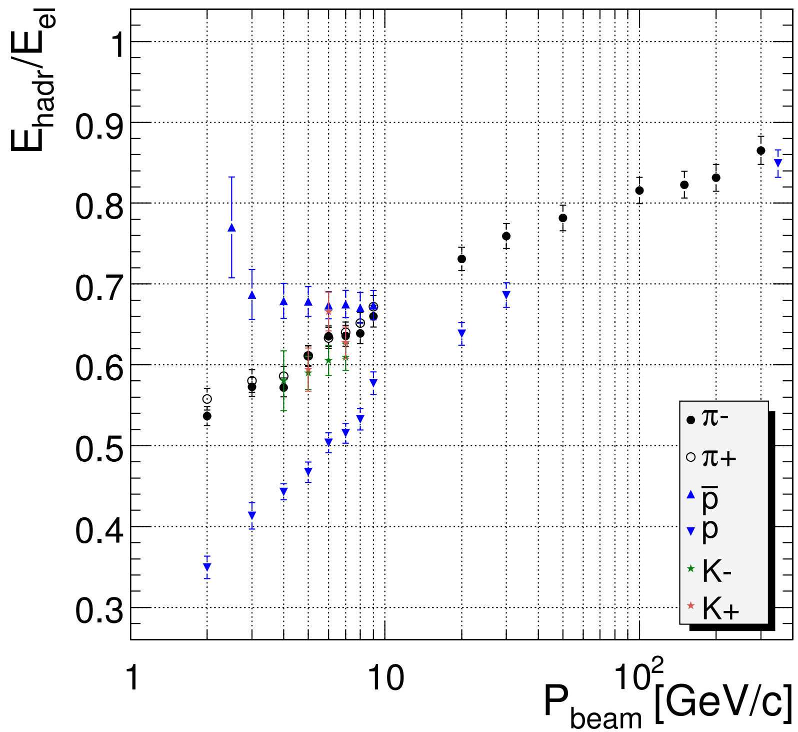
Pivot point corresponds to interaction point in CMS.

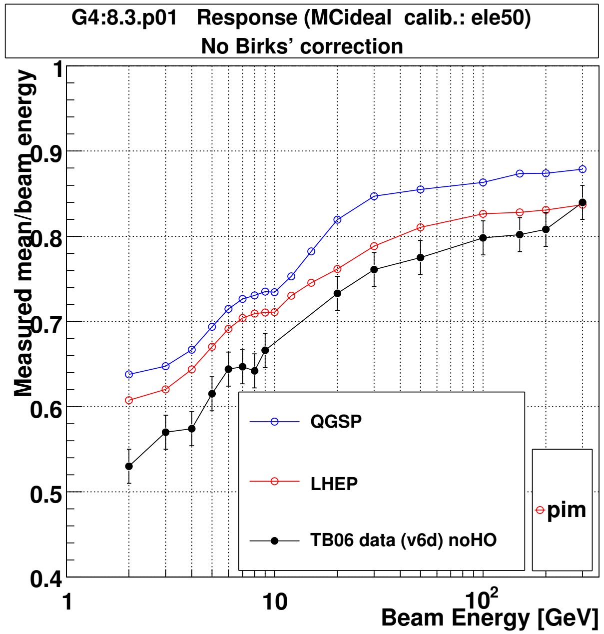
Testbeam 2006 setup... ...MonteCarlo geometry... ...and main result

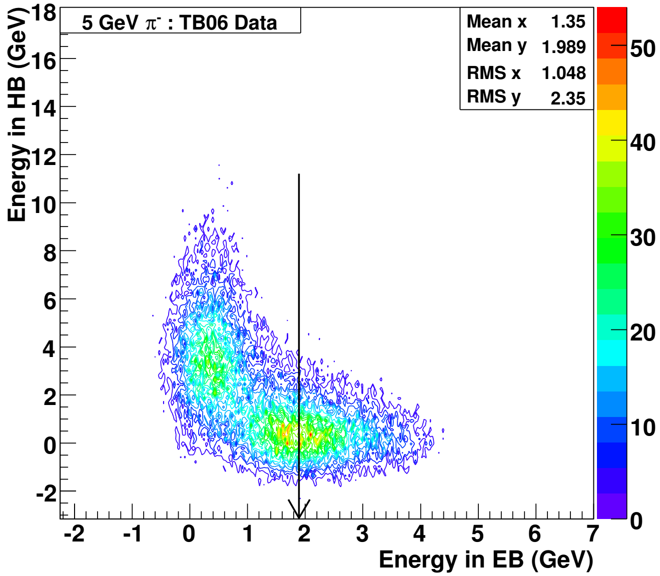


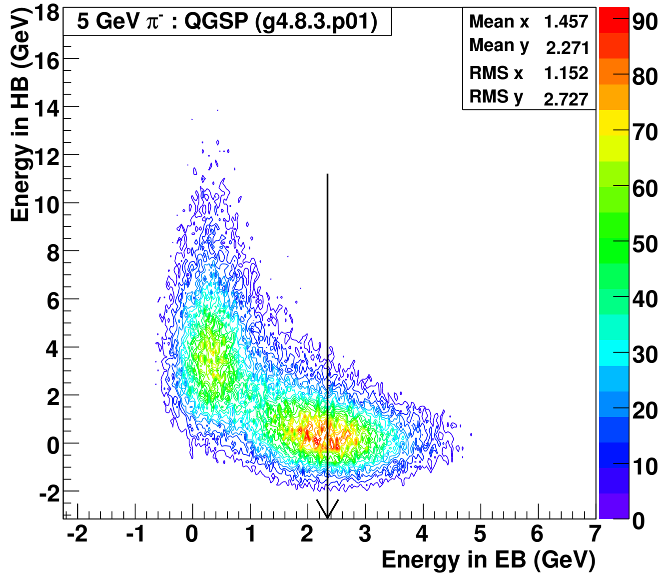


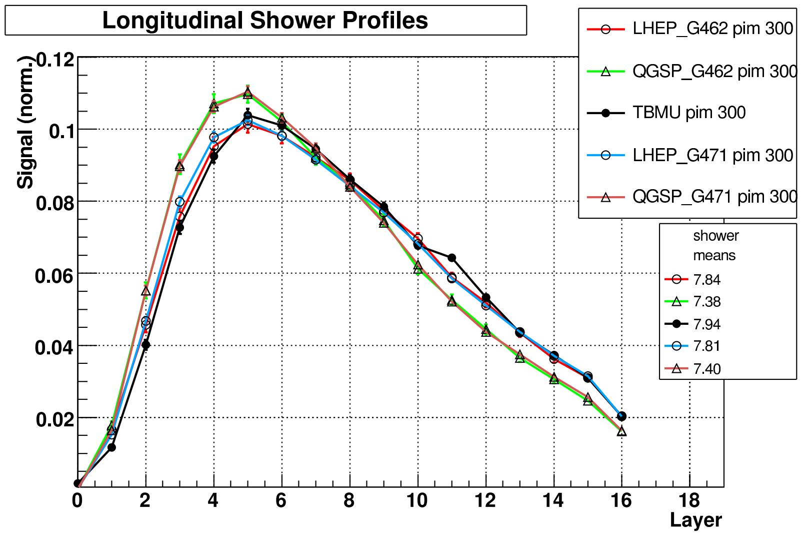








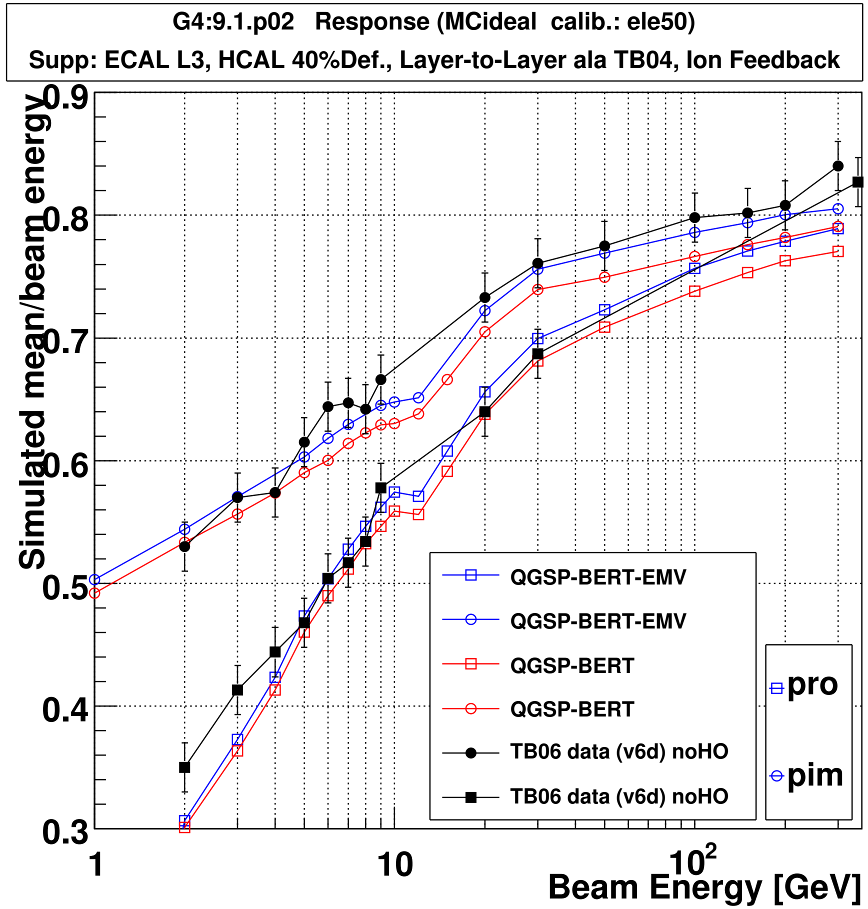




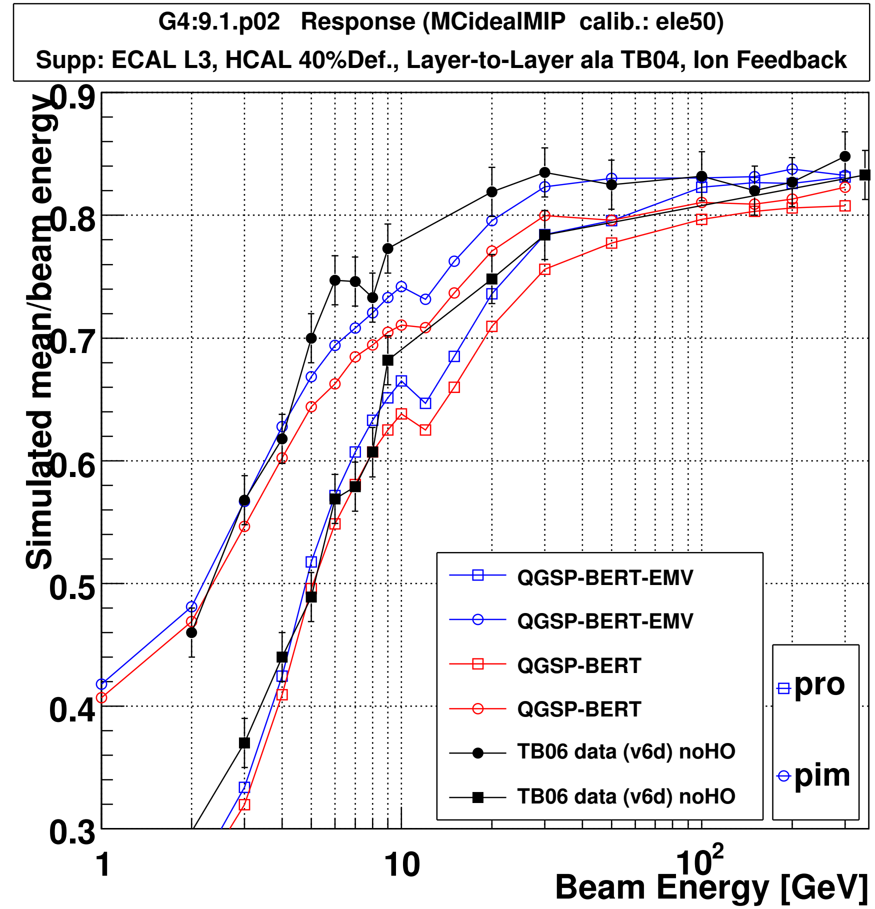
- Pion response in MonteCarlo was higher than measured in TB for both parametrized (LHEP) and model-based (QGSP) physics lists in all versions of G4 used;
- Showers were longer than measured in TB for G4 versions 6.2 and 7.1

- Take into account scintillation saturation effect (Birks' law)
  - optimize Birks' constants for HCAL scintillators and $PbWO_4$ crystals.
  - make sure electromagnetic showers are not affected by the saturation effect.
- Use new physics list: QGSP-BERT
  - Bertini cascade replacing the LEP model below 10GeV improves the response at low energies
- Feed results back to Geant4, resulting in a new and improved version of the toolkit - G4.9.1.p02
  - improved Bertini cascade code, including now Coulomb barrier in the de-excitation process
  - better treatment of quasi-elastic scattering for high energy region of QGS model.
  - changes in LHEP model for improved p_T distribution of hadrons from strange baryon reactions.
  - inclusion of electromagnetic interactions for long-lived charged hadrons with c and b quarks.

ECAL + HCAL

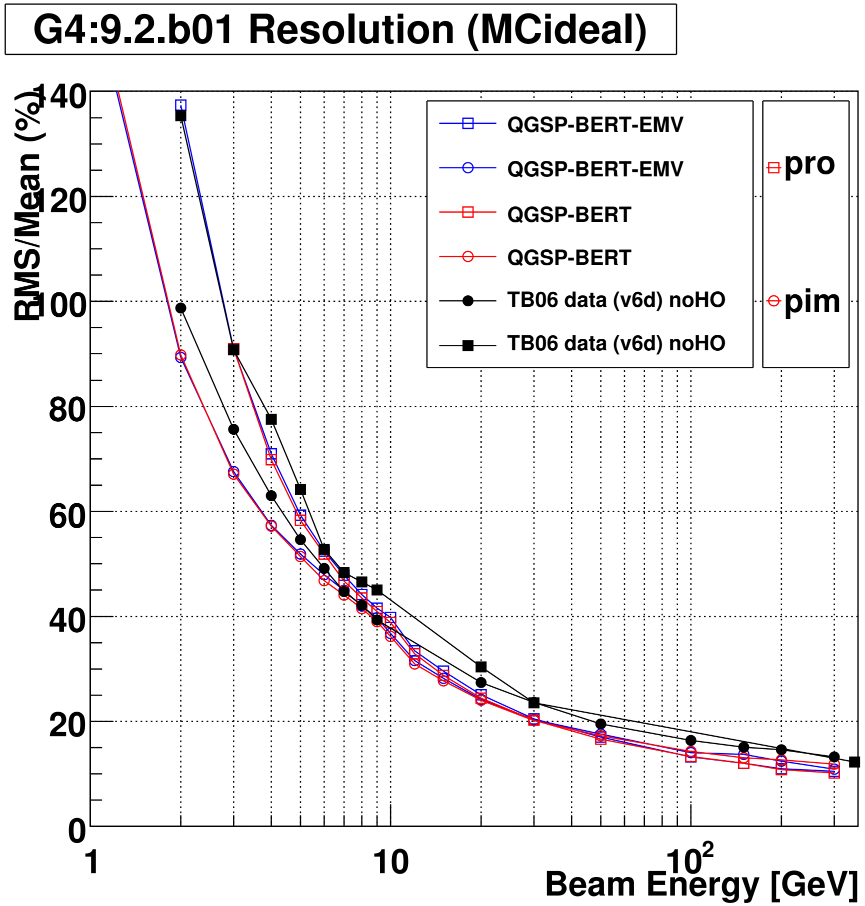


HCAL alone (MIP in ECAL)

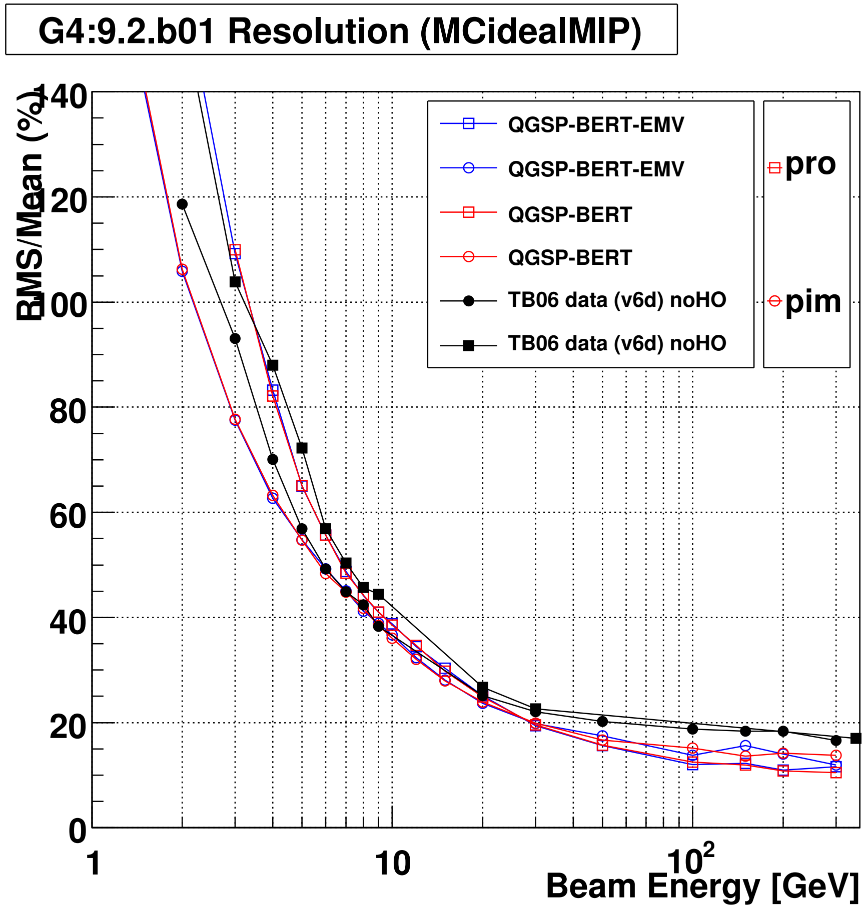


Rather good agreement of linearity of response in both cases for the QGSP-BERT-EMV physics list

ECAL + HCAL

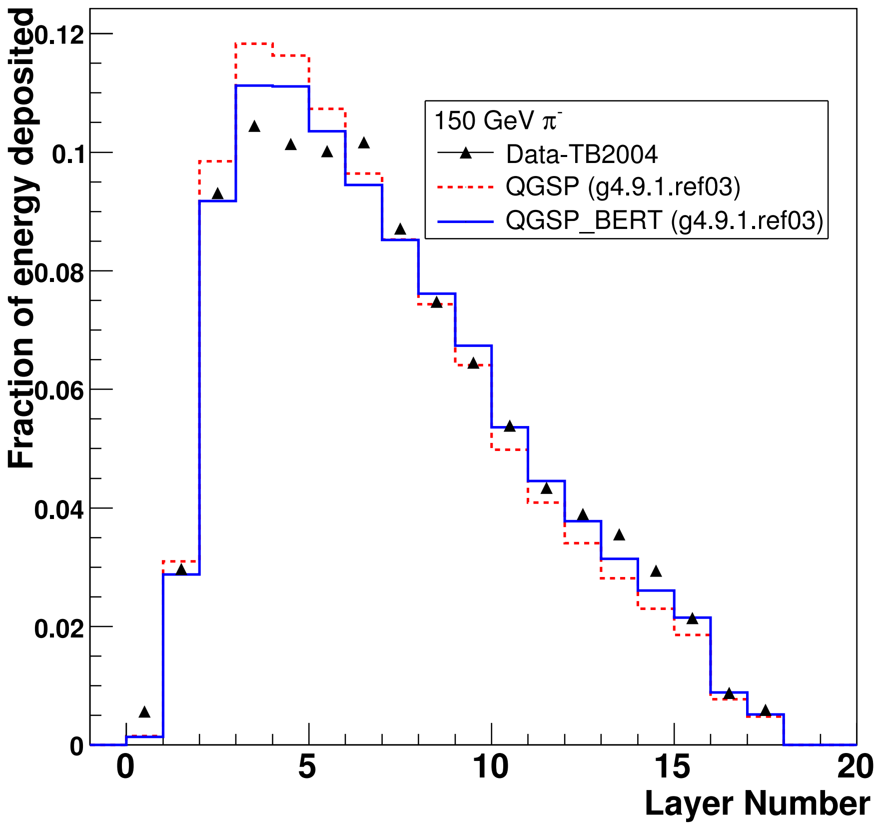


HCAL alone (MIP in ECAL)

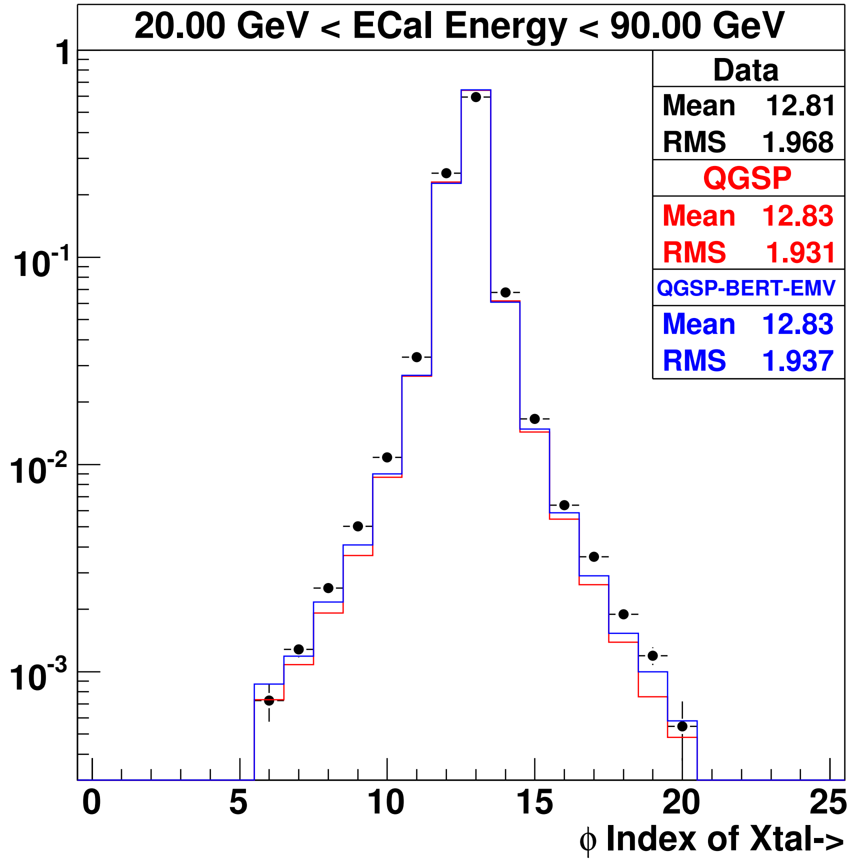


Resolution is better than measured in both cases.

Longitudinal



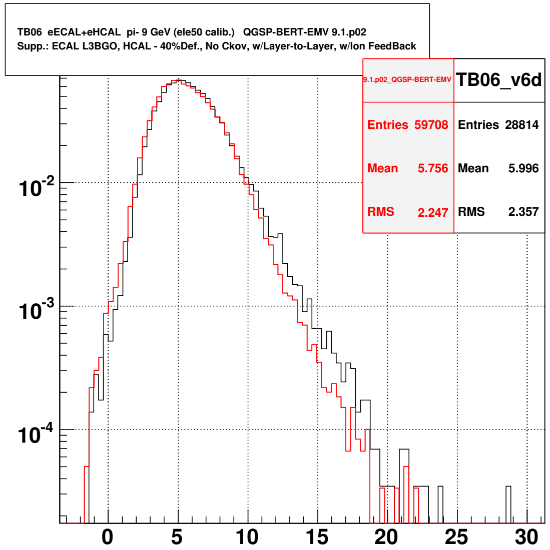
Transverse

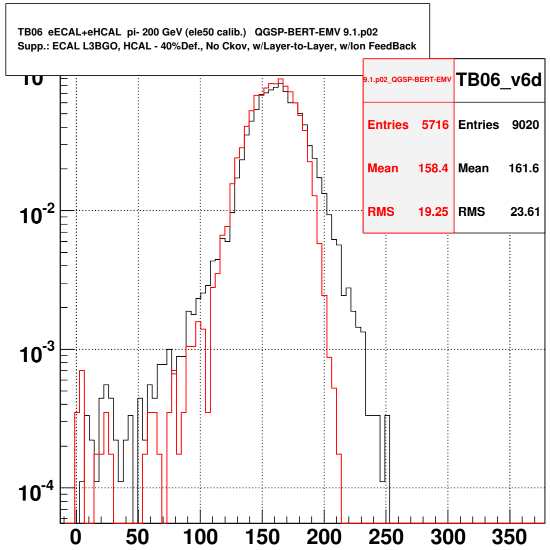


Shower profiles are reproduced better by the QGSP-BERT model.

Width of total reconstructed energy distribution:

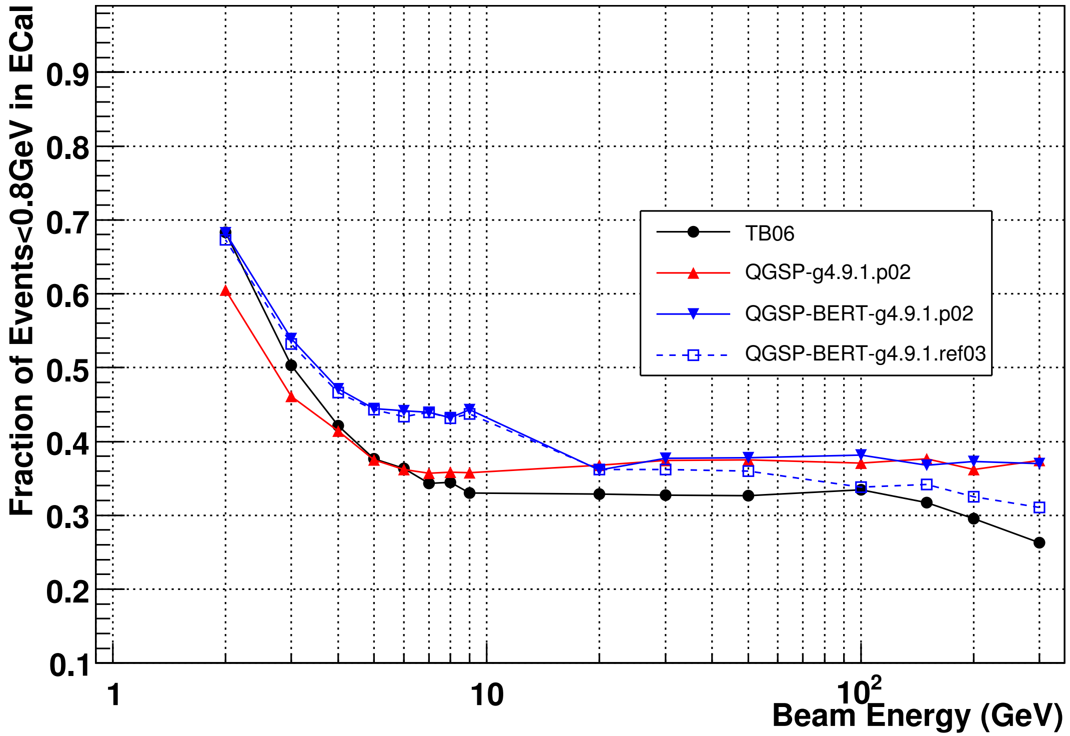
narrower in simulation than in testbeam for high energy hadrons





Fraction of pion MIP-like events in ECAL: Bertini cascade disagrees with TB data

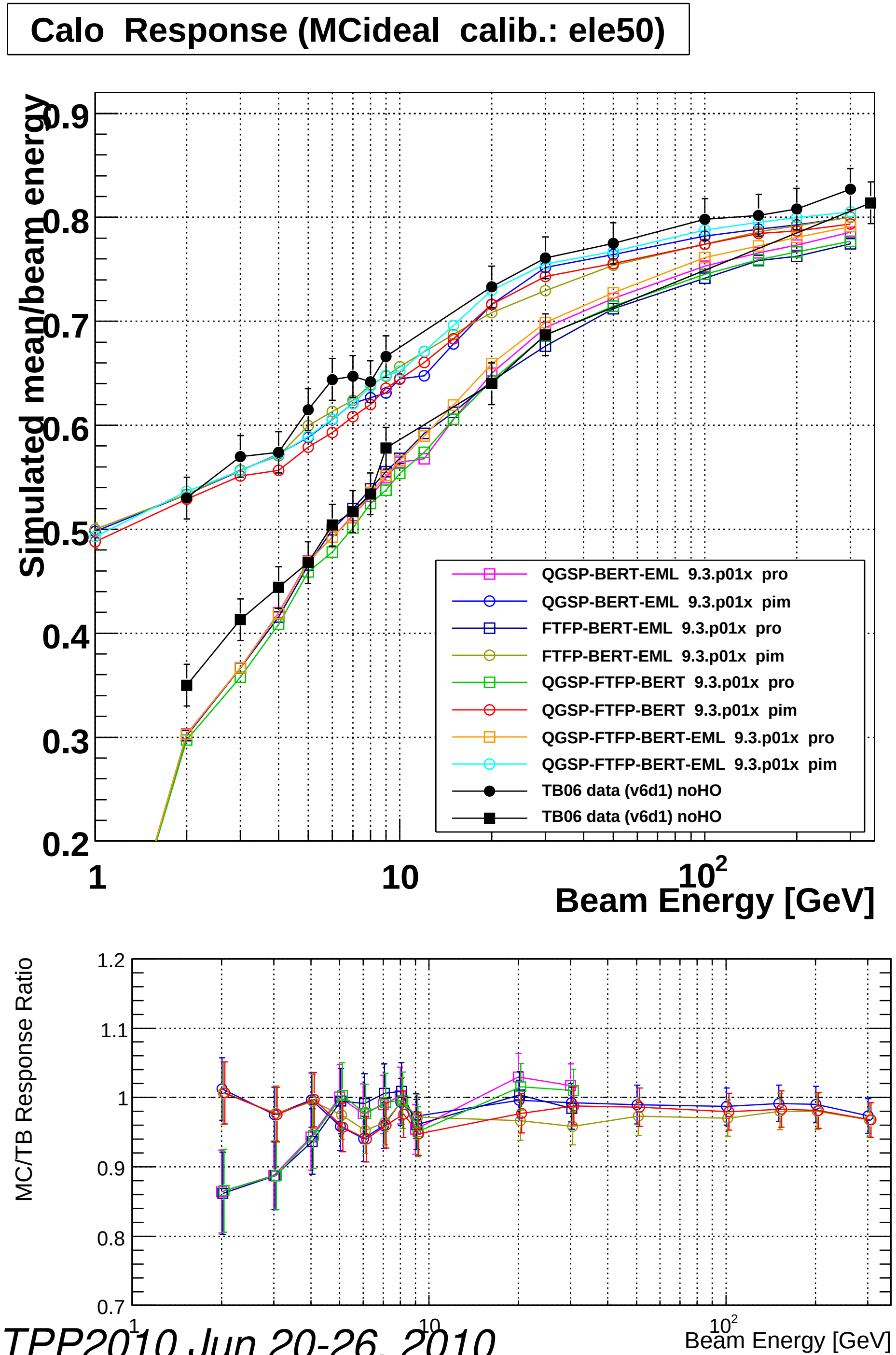
(N.B. inclusion of pion bremsstrahlung in newer versions of G4)

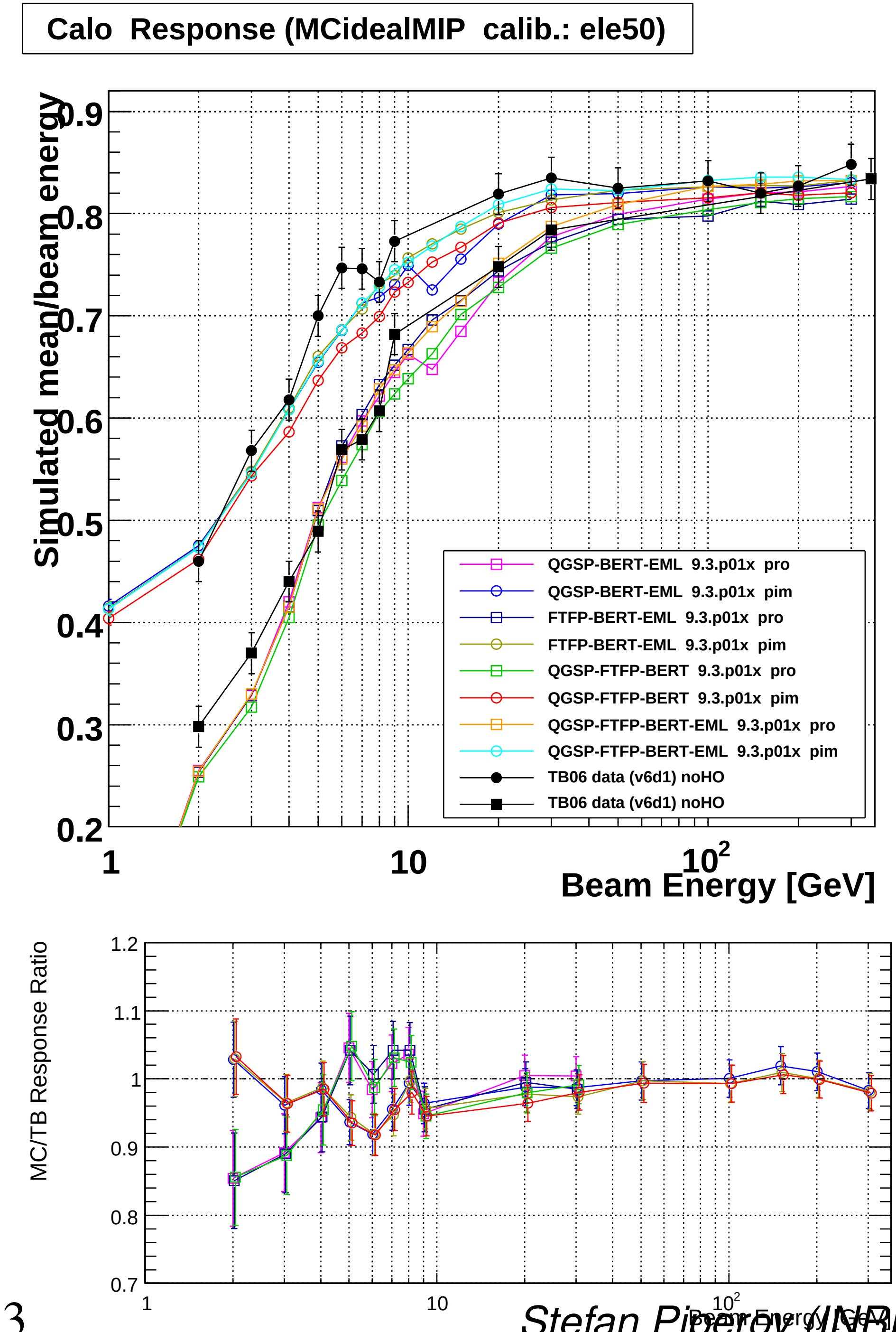


Following the success of the initial improvements, many new Geant4 versions were tested against the TestBeam data – with many (new) physics lists – and fed back into the simulation, in orther to improve it further.

- Over 20 Geant4 versions were tested altogether. Starting with G4.6.2 and testing currently G4.9.3.ref05 in preparation of the release of Geant4.9.4 this year.
- Over 20 Physics Lists based on:
  - LHEP - Low and High Energy Parametrized list.
  - QGS - Quark-Gluon String model.
  - FTF - FRITJOF model.
  - CHIPS - Chiral Invariant Phase Space model.
  - BERT - Bertini Cascade.
  - BIC - Binary Cascade.
  - EMV and EML - Enhanced Multiple-scatteing models.

This is how the activity turned into a Validation Process for Geant4.


Calo Response (MCideal calib.: ele50)
Simulated mean/beam energy
Beam Energy [GeV]
QGSP-BERT-EML 9.3.p01x pro
QGSP-BERT-EML 9.3.p01x pim
FTFP-BERT-EML 9.3.p01x pro
FTFP-BERT-EML 9.3.p01x pim
QGSP-FTFP-BERT 9.3.p01x pro
QGSP-FTFP-BERT 9.3.p01x pim
QGSP-FTFP-BERT-EML 9.3.p01x pro
QGSP-FTFP-BERT-EML 9.3.p01x pim
TB06 data (v6d1) noHO
TB06 data (v6d1) noHO
MC/TB Response Ratio


Calo Response (MCidealMIP calib.: ele50)
Simulated mean/beam energy
Beam Energy [GeV]
QGSP-BERT-EML 9.3.p01x pro
QGSP-BERT-EML 9.3.p01x pim
FTFP-BERT-EML 9.3.p01x pro
FTFP-BERT-EML 9.3.p01x pim
QGSP-FTFP-BERT 9.3.p01x pro
QGSP-FTFP-BERT 9.3.p01x pim
QGSP-FTFP-BERT-EML 9.3.p01x pro
QGSP-FTFP-BERT-EML 9.3.p01x pim
TB06 data (v6d1) noHO
TB06 data (v6d1) noHO
MC/TB Response Ratio

- CMS wants to have good detailed hadron shower simulation, validated by testbeam results.

- Early comparisons showed discrepancies in linearity of response and shower shapes.

- Implementation of Birks' law for scintillator saturation, and a new physics list (QGSP-BERT-EMV) improved agreement significantly.

- Feeding back the comparison results to the Geant4 collaboration resulted in newer versions and physics lists giving even better agreement with TestBeam data, and made this process a Validation activity.

- The collaboration with Geant4 team continues and we expect even more improvements in next releases.