Validation of Geant4 Physics Using 1996 CMS HCal Test Beam Data

Outline

- Test Beam Setup
- Simulation
- Comparison for HCal alone data
- Comparison for ECal + HCal data
- Conclusions

October 7-8, 2004

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Test Beam Setup

The test beam detector module has two components:

- Hadron calorimeter with alternate layers of absorber and plastic scintillator

  28 scintillator plates mostly of 4 mm thickness with absorber of varying thickness in-between
- Electromagnetic calorimeter consisting of 49 lead tungstate crystals.

Data taking conditions:

- Each scintillator layer is read out independently using PMT and the crystals are equipped with APD
- Data are taken with three geometrical configuration: with, without and inverted ECal in front
- Use electron and π beams of energy between 10 and 300 GeV ($+$ 225 GeV μ beam for calibration)
- Magnetic field between 0 and 3 Tesla with direction parallel to the face of the scintillator plates - (HCal Barrel configuration)

Simulation

- Use GEANT 4.5.2.p02 with the Test Beam description in a stand-alone vesrion
  - The absorber layers are made of a special type of Brass
  - All Monte Carlo event samples are generated using the physics list of version PACK 2.3:
    - LHEP version 3.6
    - QGSP version 2.7
    - QGSC version 2.8
    - FTFP version 2.7
  - Cutoff of 700 μm used on range of particles

- Also generate event samples using GEANT 3.21 with GHEISHA. Choose 100 KeV cutoffs for photon, electron, charged hadrons and 10 KeV cutoff for neutrons.

- Simulate inhomogeneity in light collection in the crystals along its length using the efficiency curve
- Noise studied from data and added to individual channels
- For tracking in B-field use a supplied map providing profile of field strength along the beam direction. The peak value is changed for different runs.

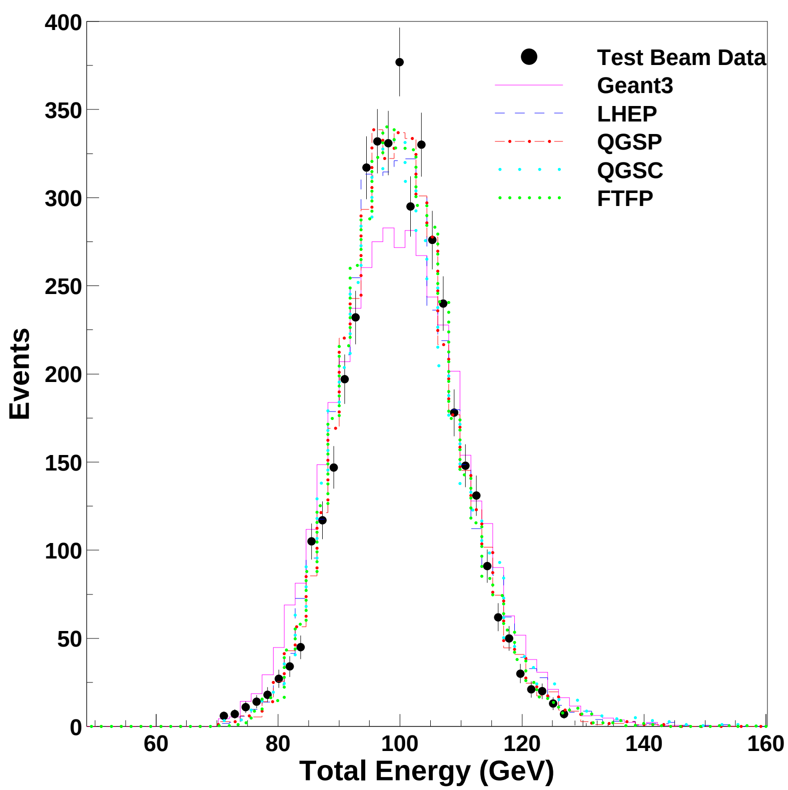
☞ Energy measurement done in data and Monte Carlo samples by the same method

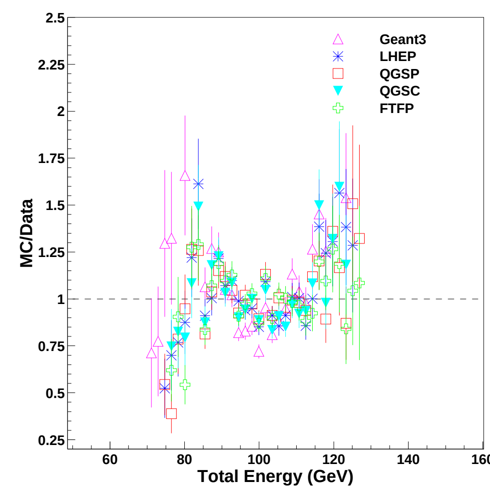
- Calibrate each channel using μ sample
- For a configuration with HCal alone:
  - Convert energy deposits in terms of MIPs
  - Weigh the energy deposit in each layer by the absorber thickness in front
  - Normalise to beam energy using 100 GeV pion data
- For a configuration with ECal and HCal together:
  - Fix the scale of the ECal using high energy electron data
  - Calibrate the energy deposit in the HCal using the same method as before and get the HCal scale by normalising with 100 GeV pion data

HCal alone data

100 GeV π sample has been used to obtain the energy scale factor

	σ (GeV)	RMS (GeV)
Data	8.9±0.1	9.1±0.1
LHEP	9.3±0.1	9.9±0.1
QGSP	9.0±0.1	9.3±0.1
QGSC	9.3±0.1	10.7±0.1
FTFP	8.8±0.1	9.4±0.1
Geant3	10.2±0.1	10.7±0.1

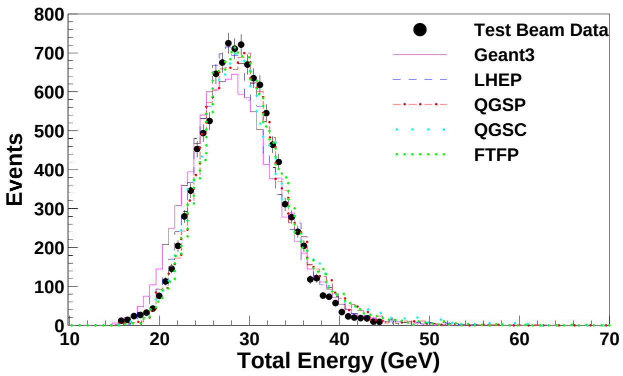




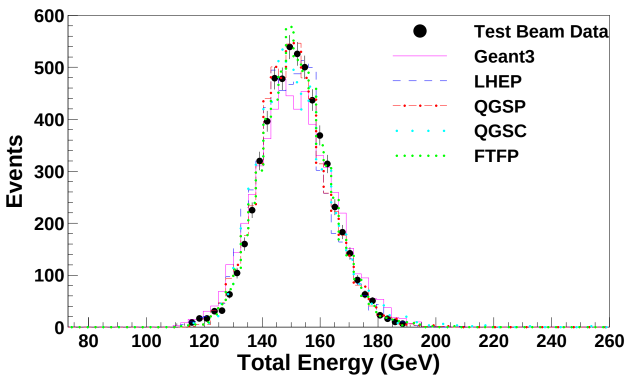
Geant4 models (particularly QGSP, FTFP) provide good description of energy resolution

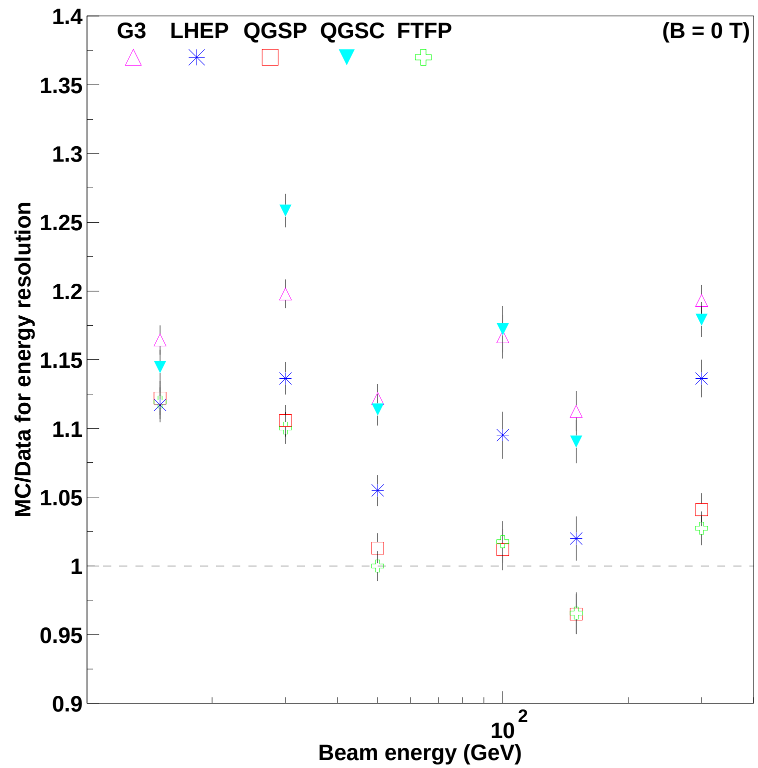
Energy resolution:

30 GeV



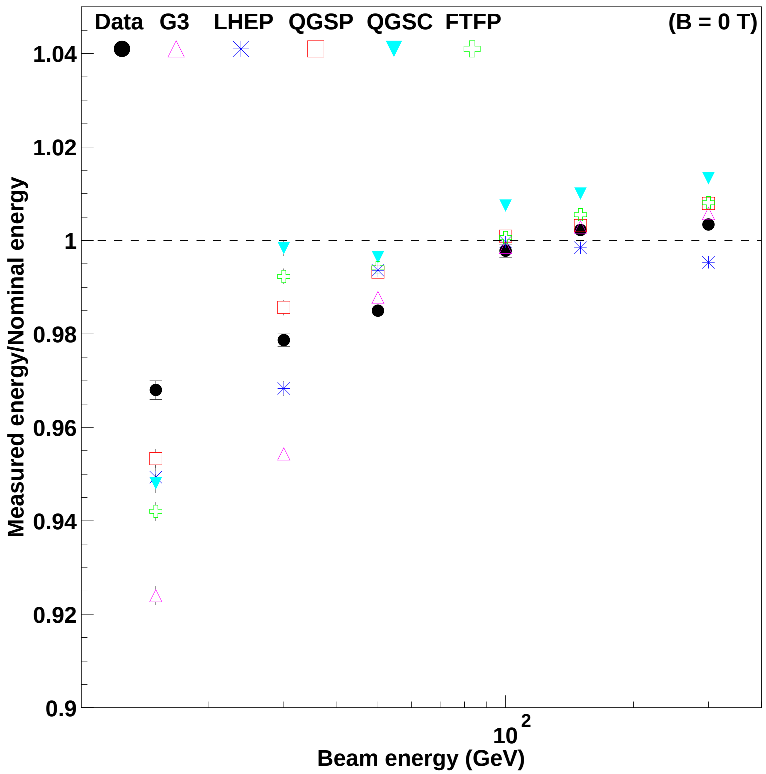
150 GeV

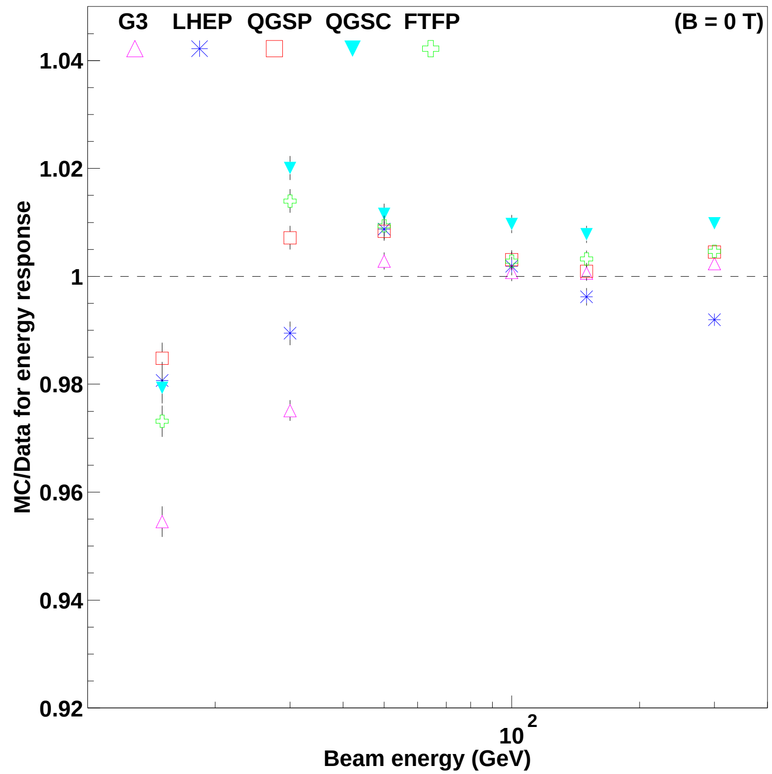




- ❑ Monte Carlo models show longer non-Gaussian tails especially at lower beam energies
- ❑ Energy resolution at high energy is well explained by QGSP, FTFP models

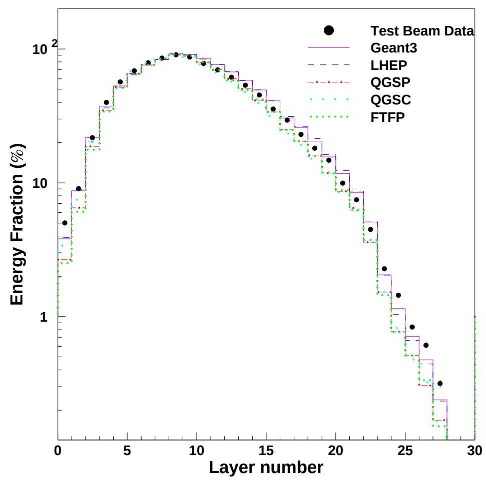
Energy response:

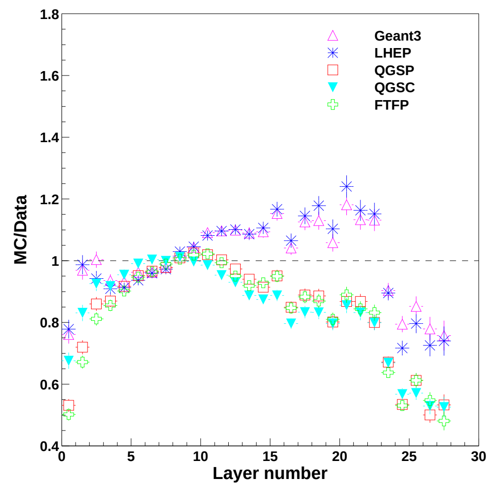


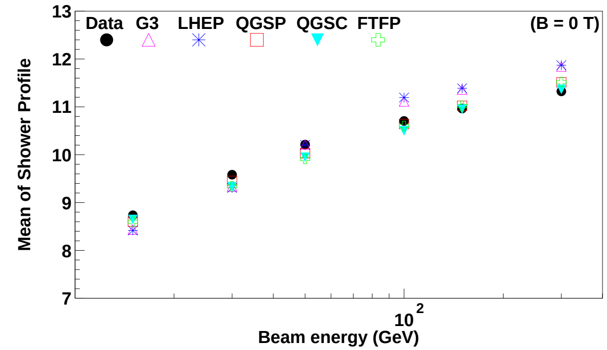


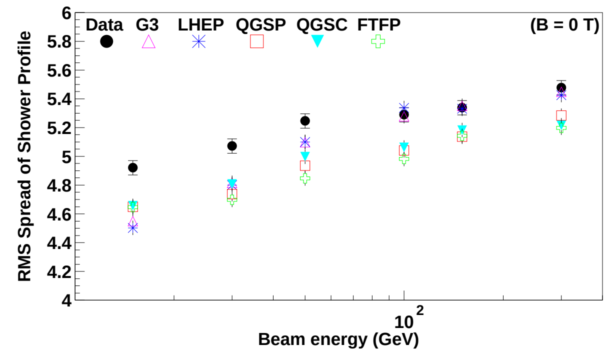
- ❑ Nonlinearity in the energy response increases at lower energies
- ❑ Agreement with different Geant4 models is rather good (within 2%)

Longitudinal Shower Profile:







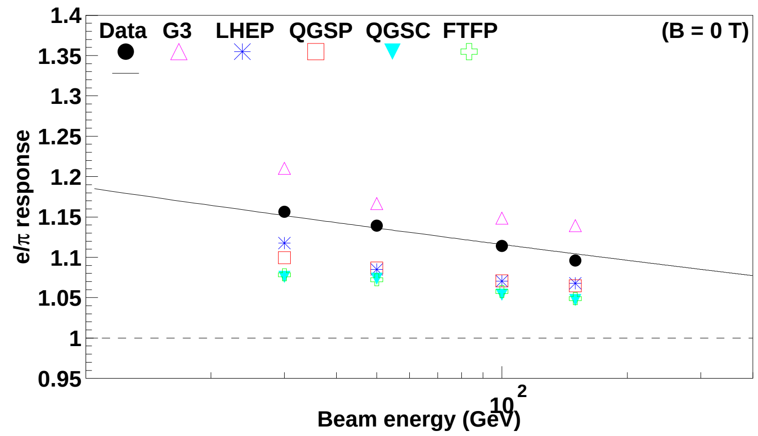


- At 100 Gev, data lie between predictions from LHEP and QGSP
- Mean of the shower profile distributions increases with energy for data and MC – better agreement with microscopic models
- Width in the shower profile spectrum is much larger in the data at low energies – better agreement with parametrised models

e/h:

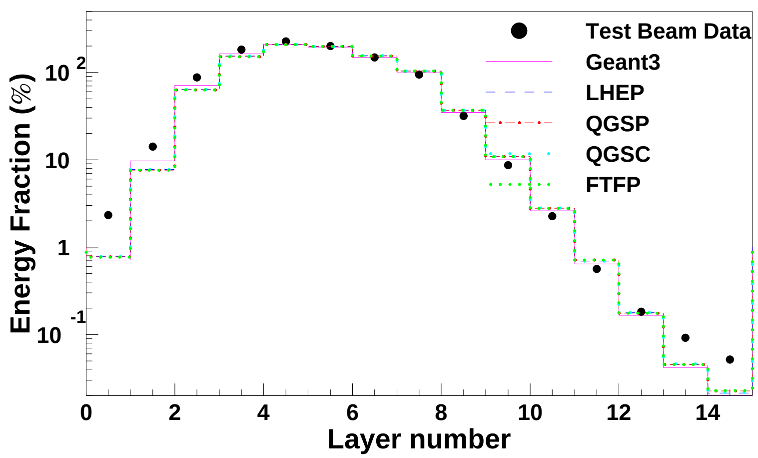
Measure electron energy with the same scale factor as for $\pi \Rightarrow e/\pi$ ratio

	at 100 GeV	at 50 GeV
Data	1.119 ± 0.001	1.143 ± 0.001
LHEP	1.070 ± 0.001	1.086 ± 0.001
QGSP	1.071 ± 0.001	1.088 ± 0.001
QGSC	1.054 ± 0.001	1.074 ± 0.001
FTFP	1.058 ± 0.001	1.073 ± 0.001
Geant3	1.148 ± 0.001	1.167 ± 0.001



✧ e/h decreases with energy

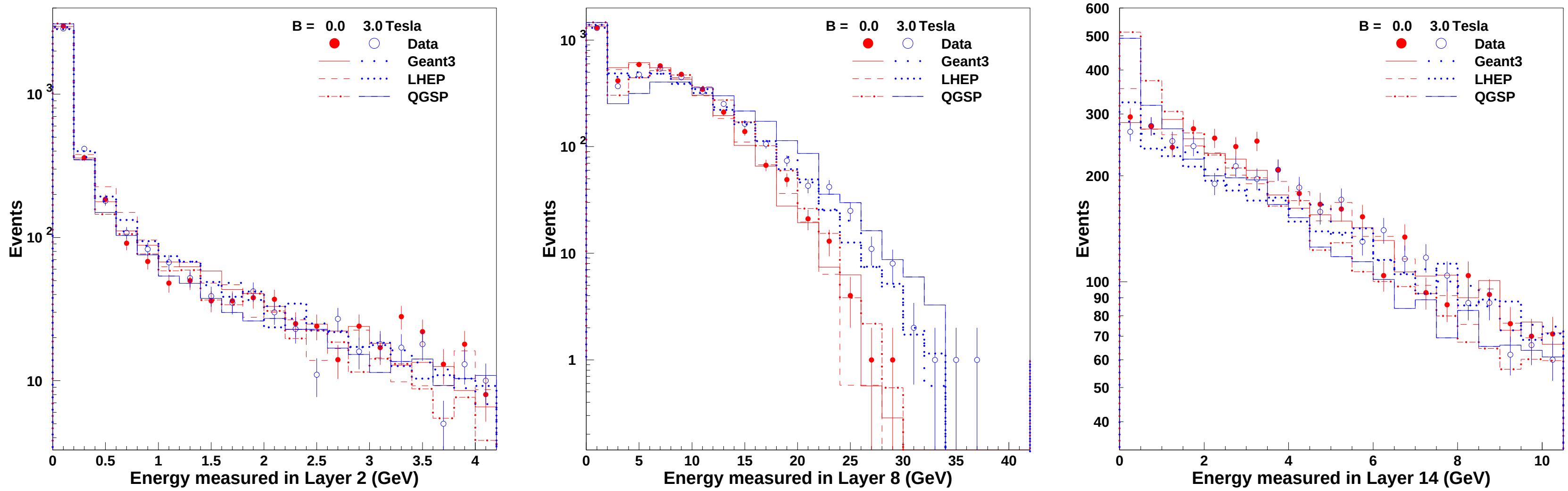
✧ Geant4(Geant3) differ by $-4\%(+3\%)$



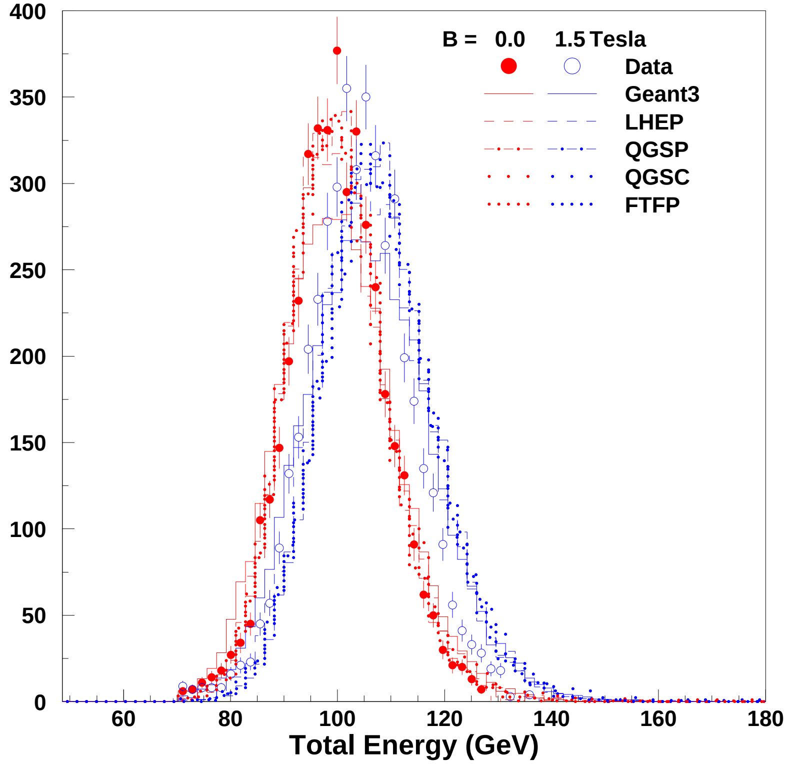
Longitudinal shower profile:

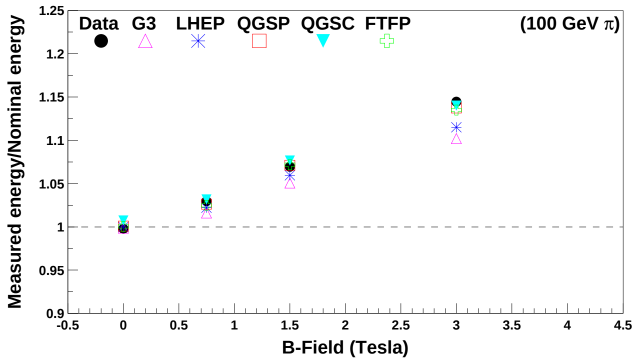
- More energy deposit in layers 1 and 2 in case of real data
- Longer tails in the shower in case of real data

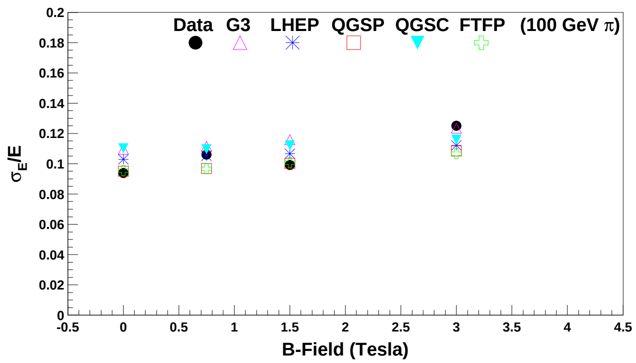
B Field effect:



- B-field results no substantial difference in energy deposit pattern at the beginning or the end of shower
- There is a substantial gain in layers $5-10$





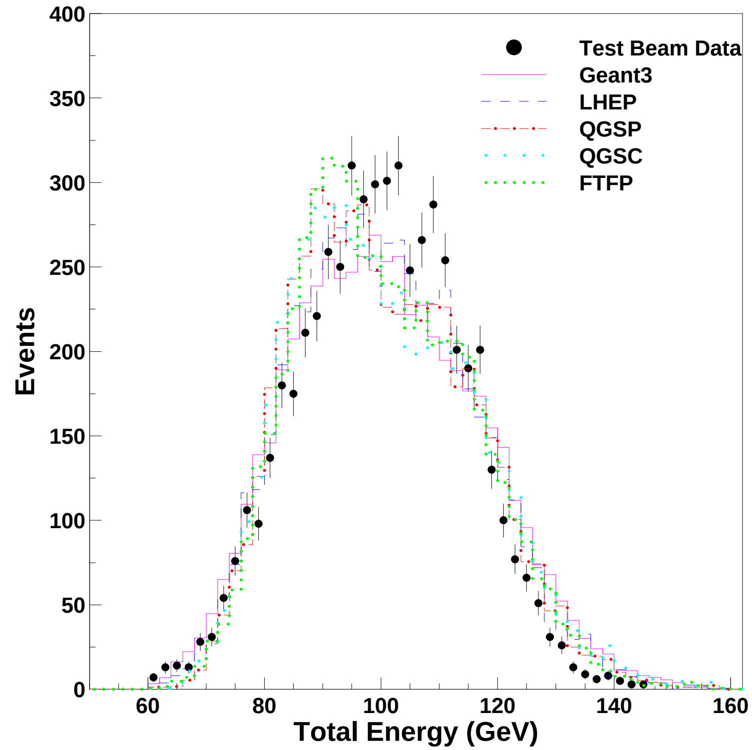


- B = 3.0T results $\sim 10\%$ increase in response for pions and $\sim 20\%$ increase for electrons
- Increase in response is explained by the simulation models
- Shower profile in data is between QGSP and LHEP

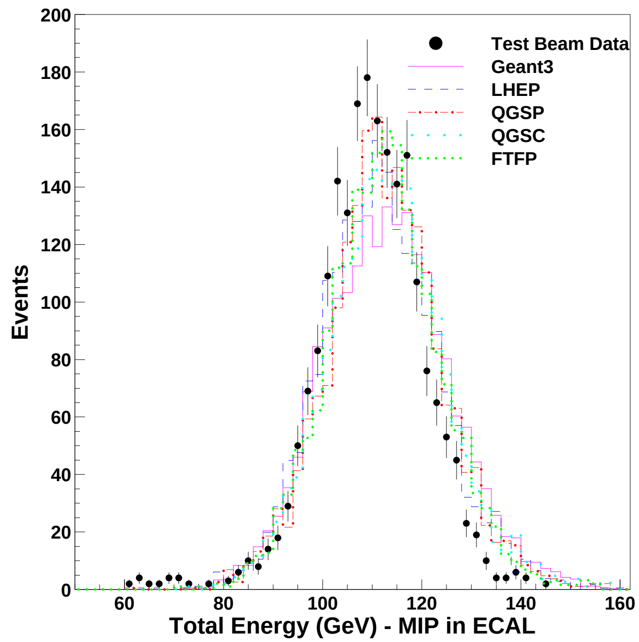
ECal + HCal data

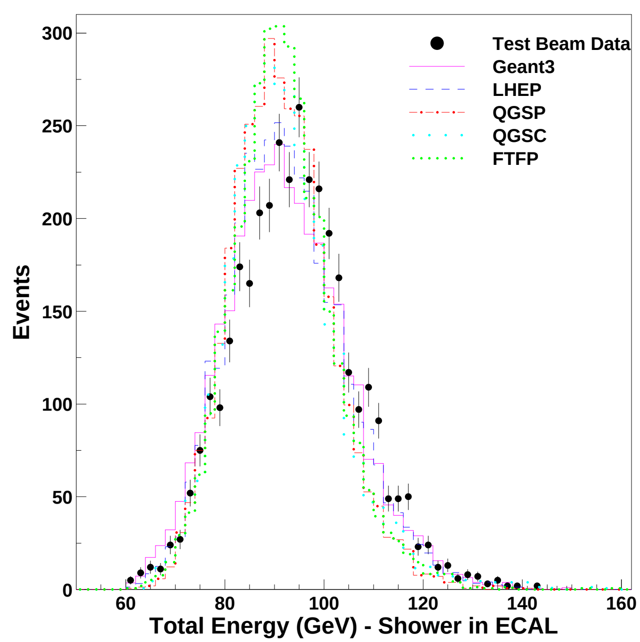
With 100 GeV π^- in the combined setup

	σ (GeV)	RMS (GeV)
Data	14.0±0.1	14.1±0.1
LHEP	14.6±0.1	15.1±0.1
QGSP	14.2±0.1	15.0±0.1
QGSC	14.8±0.1	16.1±0.1
FTFP	14.2±0.1	14.8±0.1
Geant3	15.9±0.1	16.0±0.1



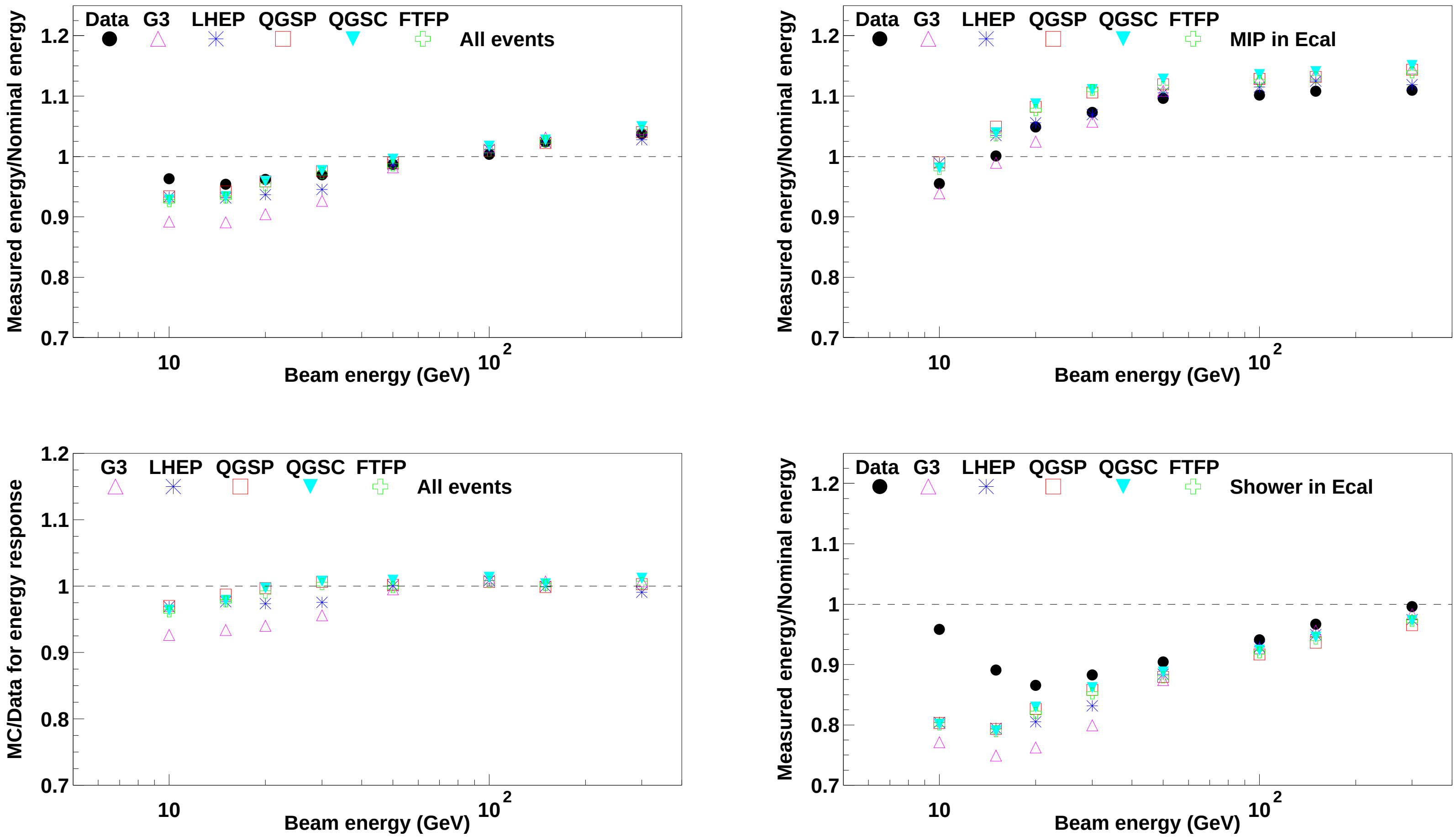
Worsening in resolution is due to non-matching e/h between ECal and HCal





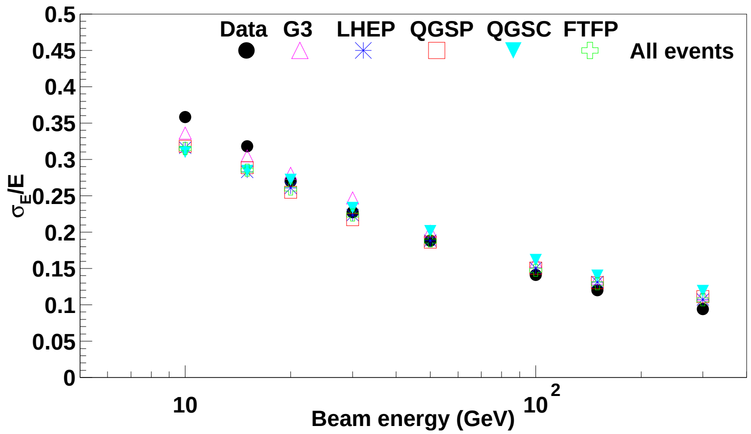
	MIP in ECal		Shower in ECal	
	Peak (GeV)	σ (GeV)	Peak (GeV)	σ (GeV)
Data	110.2±0.2	9.7±0.2	93.8±0.2	11.9±0.2
LHEP	111.5±0.2	11.3±0.1	92.4±0.2	11.4±0.1
QGSP	112.5±0.2	11.3±0.1	91.4±0.1	9.5±0.1
QGSC	112.5±0.2	11.5±0.2	91.1±0.1	9.8±0.1
FTFP	112.3±0.2	11.1±0.1	91.4±0.1	9.6±0.1
Geant3	112.9±0.2	12.3±0.1	92.2±0.1	12.0±0.1

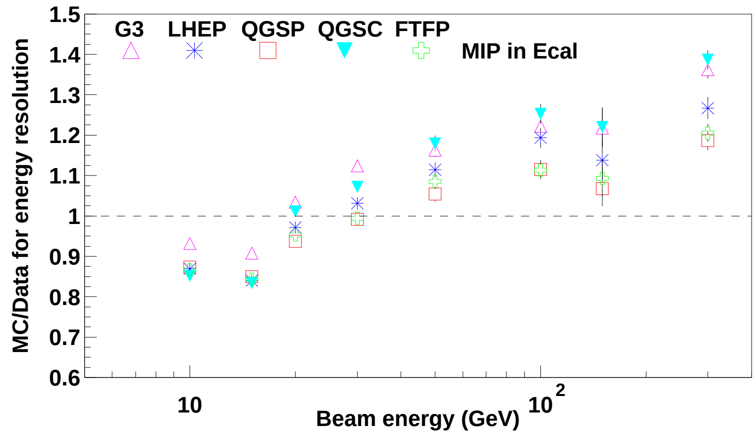
Energy response:

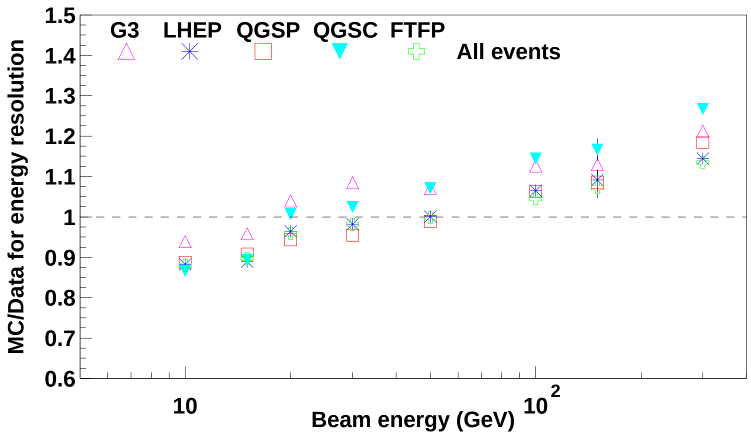


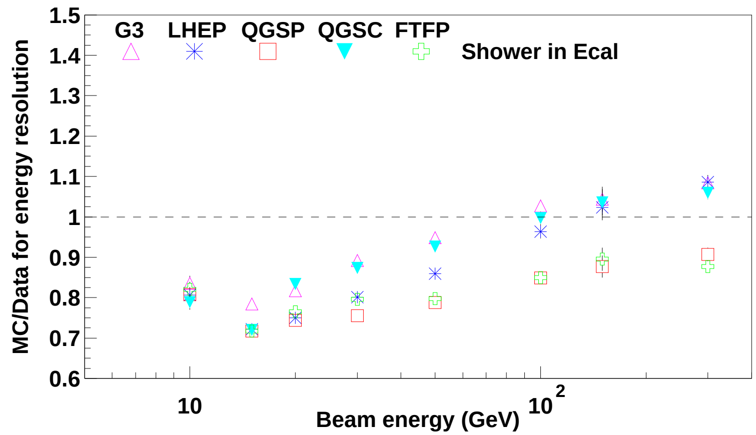
- ❑ Non-linearity in response is reasonably reproduced by the models
- ❑ Larger discrepancy is in the sample which starts showering in ECal

Energy resolution:



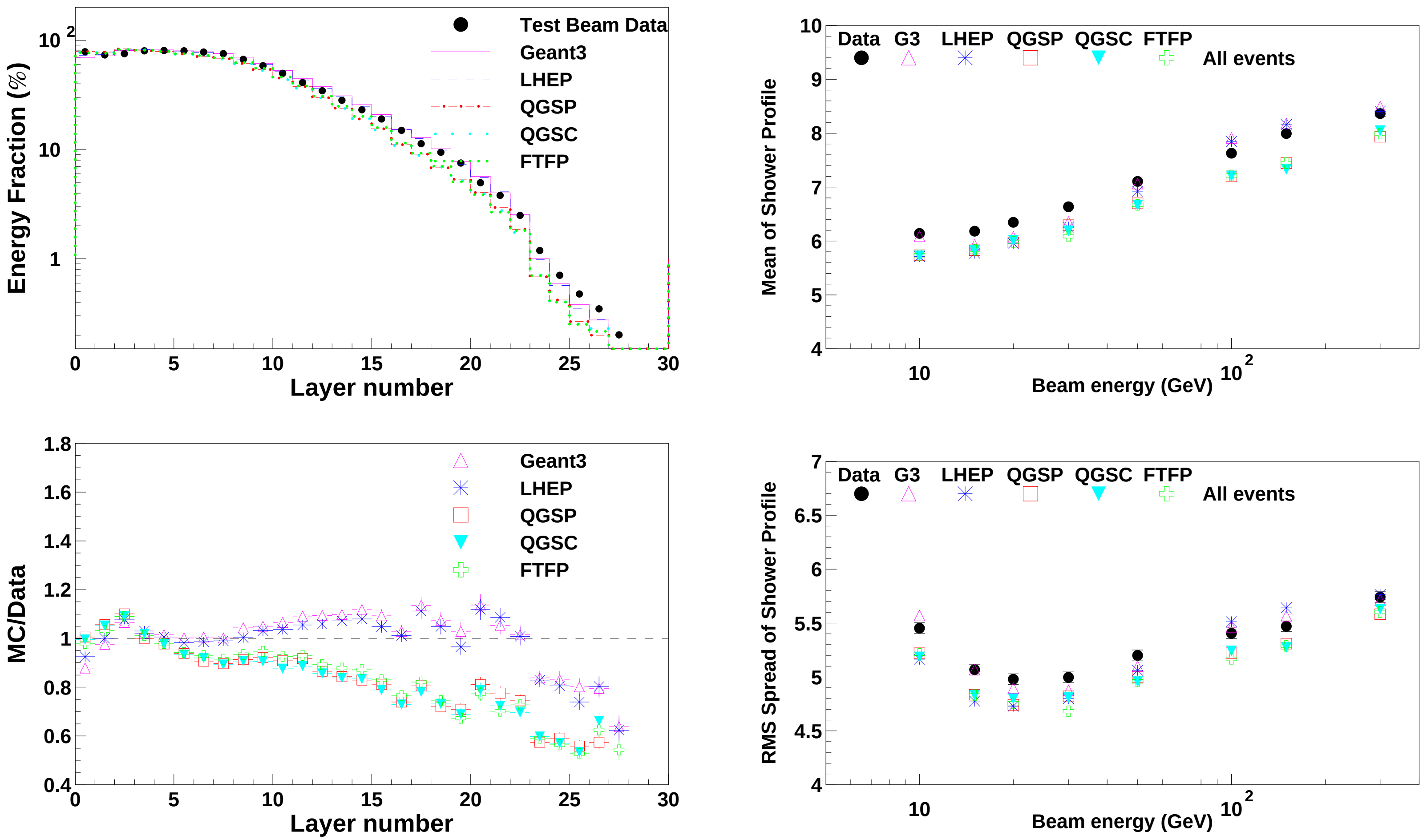






- Energy resolution is described within 10%
- Discrepancy is larger in the sample which starts showering in ECal

Longitudinal shower profile:



- ❑ Difference between data and Monte Carlo reduces at higher energies
- ❑ Parametrised models are in better agreement

Conclusions

A detailed comparison is performed between 1996 CMS HCal test beam data and different models in Geant4 for hadron shower

- Energy response of the calorimeters (HCal stand-alone or ECal and HCal) to pion beam is well explained (better than 5%)
- Microscopic models QGSP, FTFP explain energy resolution for pions in HCal alone setup at energies above 50 GeV. The agreement worsens to 15% at lower energies.
- The agreement is worse for the combined setup and the difference is $\sim 20\%$ if the shower starts in ECal.
- The peak position of longitudinal shower profile for pions are better explained by the microscopic models while the widths are in better agreement with the parametrised models.
- e/π ratio in the data are within 5% of the model predictions and lie between the predictions of Geant4 (lower) and Geant3.
- Enhancement in the response due to magnetic field is well reproduced by the models for pion as well as electron beams.