Simulation of 96 Test Beam Setup with Geant4

Outline

- Test Beam Setup
- Data and Simulation
- Energy Measurement
- Comparison of HCal alone data
- Comparison of ECal + HCal data
- Effect of B-Field
- Outlook

Sunanda Banerjee
CERN/TIFR

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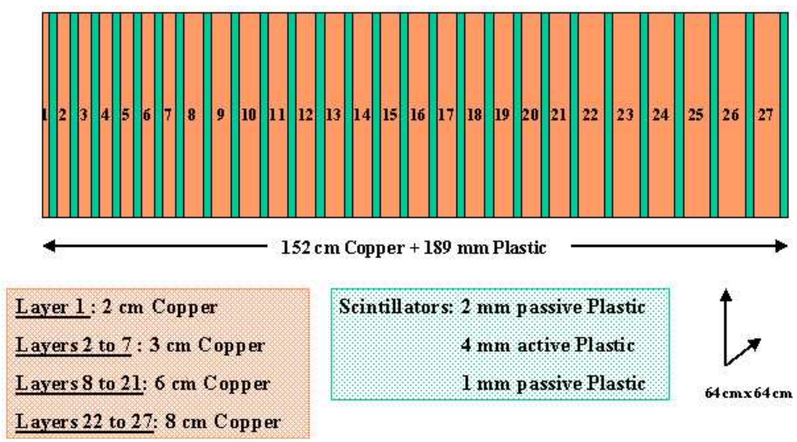
Test Beam Setup



The test beam detector module has two components:

- Hadron calorimeter with alternate layers of copper absorber and plastic scintillators
  28 scintillator plates mostly of 4 mm thickness with absorbers of varying thickness in-between
- Electromagnetic calorimeter consisting of 49 lead tungstate crystals.

- Data taken with three geometrical configuration: with, without and inverted ECal in front
- Direction of magnetic field parallel to the face of the scintillator plates - (HCal Barrel configuration)

Data and Simulation

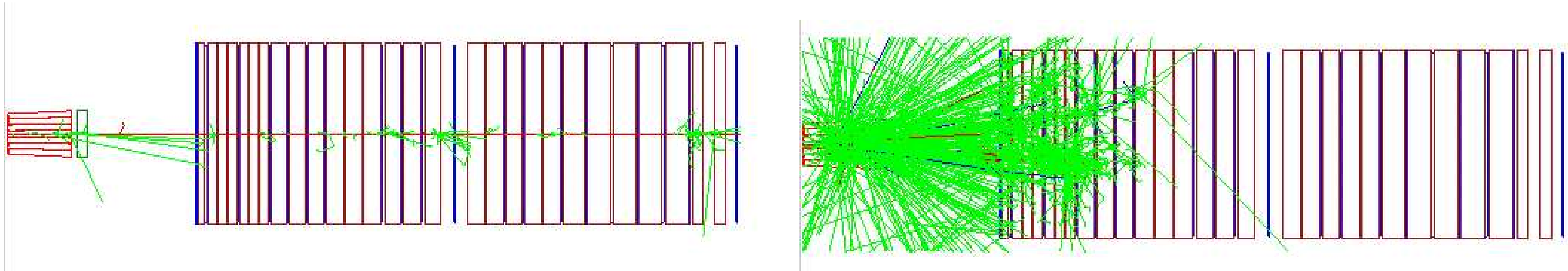
- Each scintillator layer of HCal was equipped with WLS fibres and has been readout independently using PMT with negligible noise
- The crystals are equipped with APD with approximate gain of 50 but with substantial electronic noise per channel ($\sim$ 30 MeV)

Data were collected with

- different detector configurations
- different types of beam
  - μ beam of 225 GeV (for calibration)
  - π beam with energies between 10 to 300 GeV
  - electron beam with energies between 10 to 300 GeV
- varying magnetic field with field values of 0, 0.75, 1.5, 3 tesla

Typically $\geq$ 10000 events were taken for each setup

☛ Use GEANT 4.5.2 with the Test Beam description given as one of the advance examples



Use four different physics lists provided for hadronic physics:

- LHEP (parametrised models for inelastic scattering)
- QGSP (a quark gluon string model and a pre-equilibrium decay model with an evaporation phase to model the behaviour of the nucleus)
- QGSC (QGSP for the initial reaction and with a chiral invariant phase-space decay)
- FTFP (diffractive string excitation model similar to that in Fritjof and the Lund fragmentation functions)

and a cutoff of 700 μm used on range of particles

5000−10000 events have been generated with

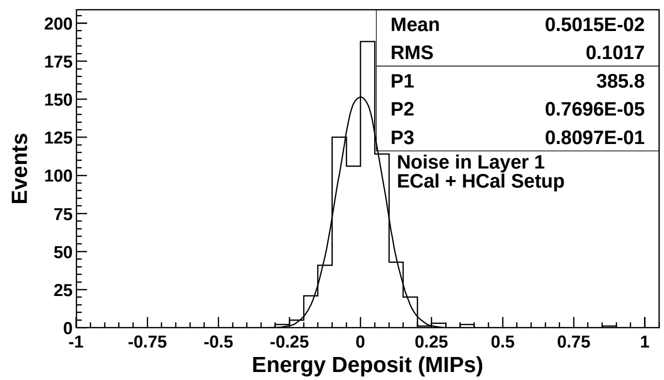
- beams of
  - 225 GeV muons
  - 10 to 100 GeV pions
  - 10 to 100 GeV electrons
- magnetic field of 0.0 and 3.0 tesla
- configurations with and without ECal

☛ Use GEANT 3.21 with GHEISHA package to simulate hadron showers. Choose 100 KeV cutoffs for photon, electron, charged hadrons and 10 KeV cutoff for neutrons

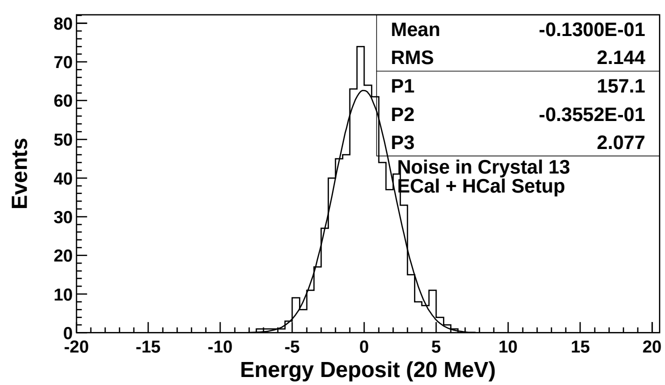
5000−20000 events have been generated with similar conditions

Noise studied from data and added to individual channels:

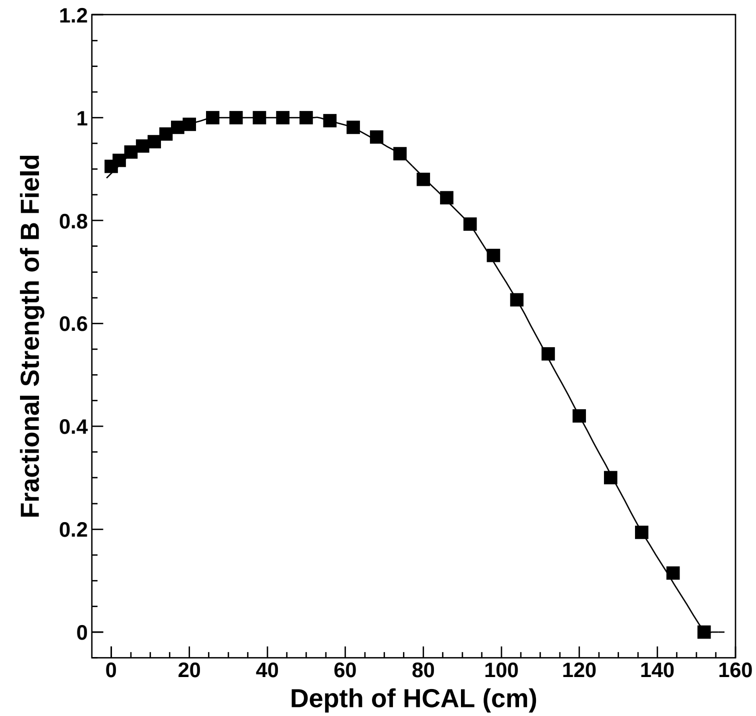
HCal



ECal



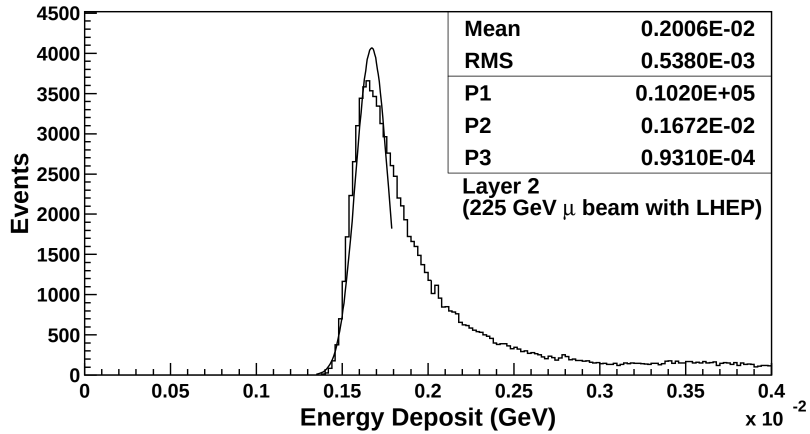
Profile of the field strength along the beam direction from the edge of HCal

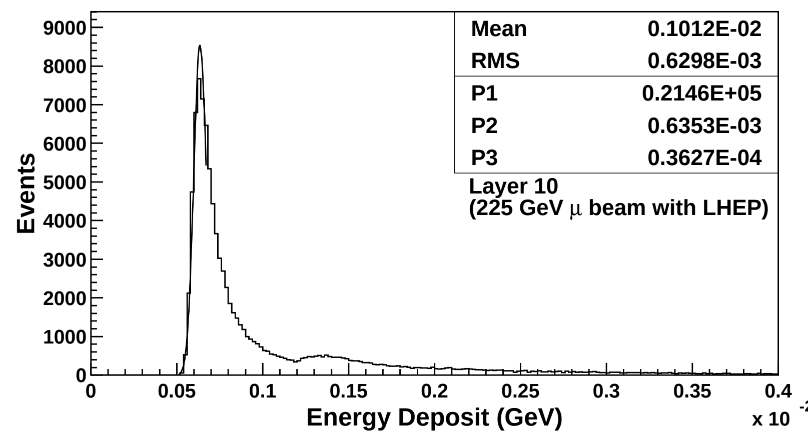


Peak value is changed for different run conditions

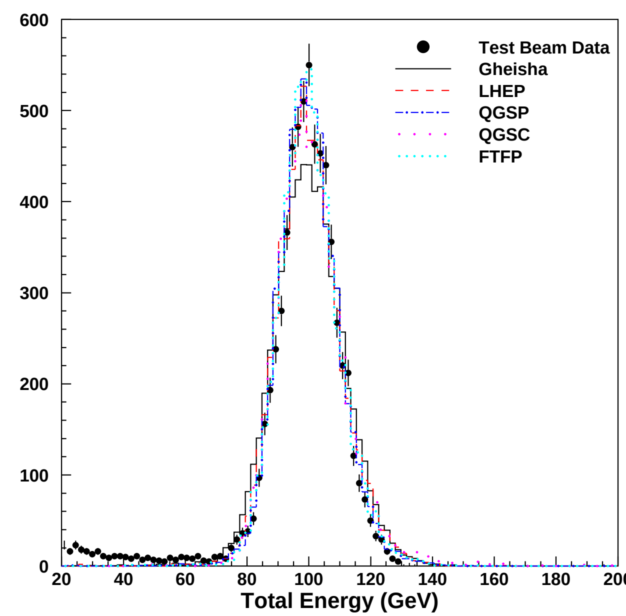
Energy Measurement

Calibrate each channel using μ sample (for data as well as simulation)

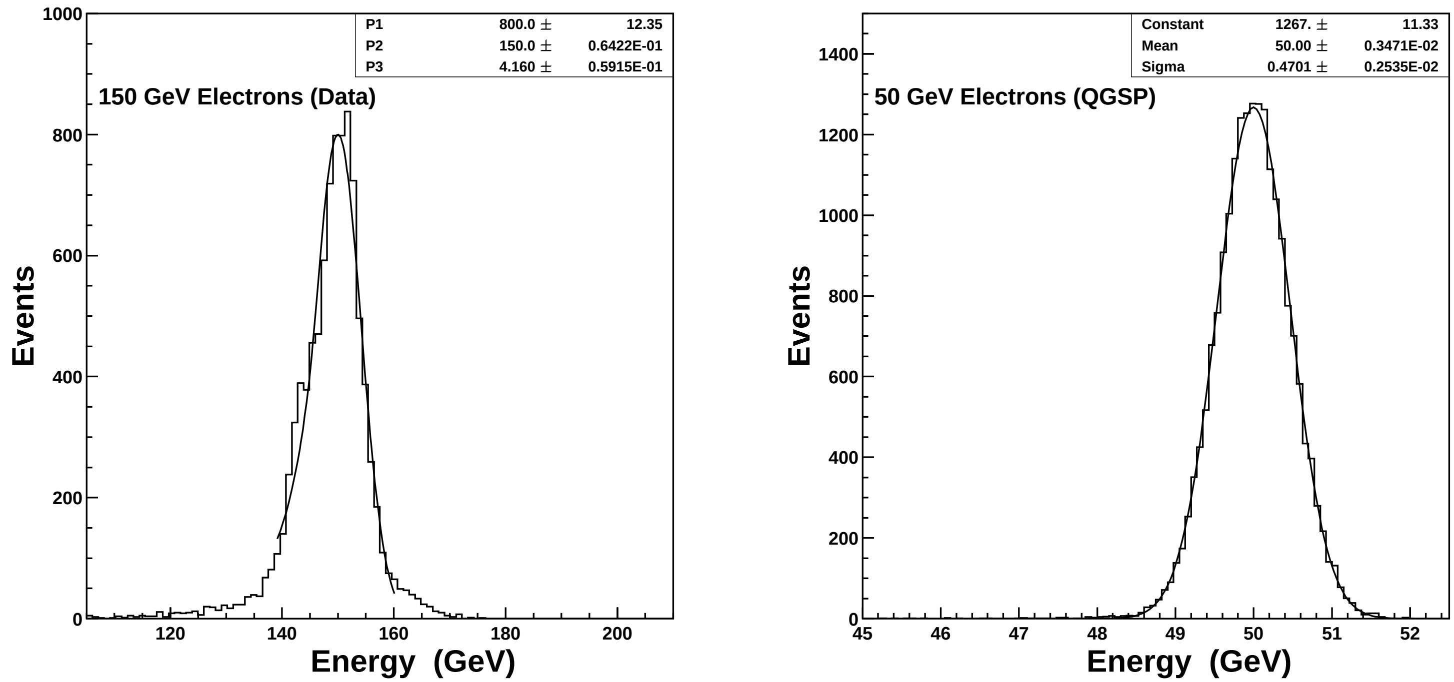




- For a configuration with HCal alone:
  - Convert energy deposits in terms of MIPs
  - Weigh the energy deposit in each layer by the absorber thickness in front
  - Normalise to beam energy using 100 GeV pion data



- For a configuration with ECal and HCal together:
  - Fix the scale of the electromagnetic calorimeter using electron data at high energies



  - Calibrate the energy deposit in the hadron calorimeter using the same method as before and normalise the hadron calorimeter scale with 100 GeV pion data

❑ Can improve the energy measurement by re-weighting energy deposits in different parts of HCal

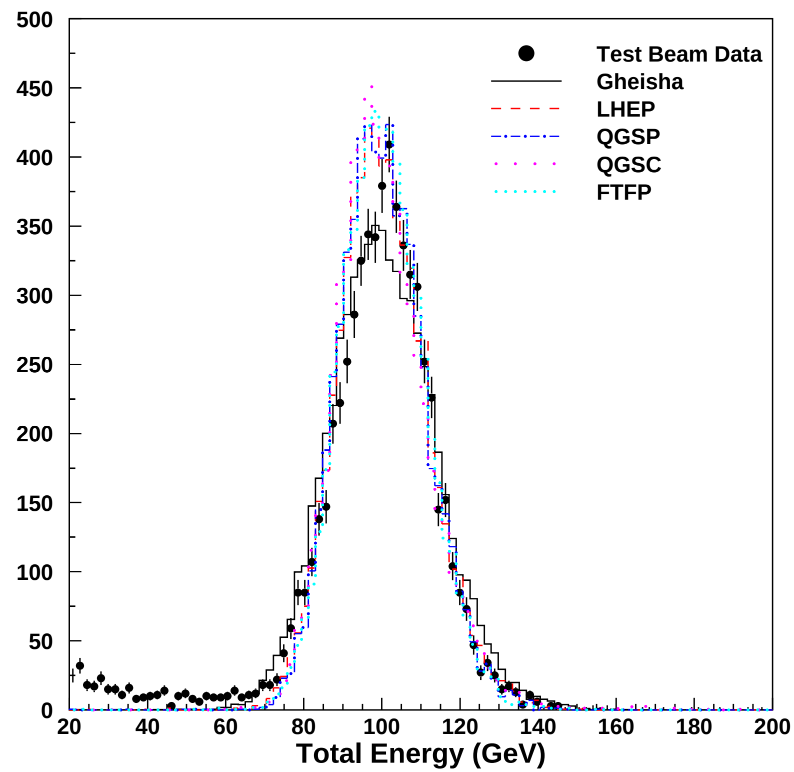
Total Energy = ECal + $w_1.H_1$ + $w_2.H_2$ + $w_3.H_3$

H_1= Energy deposit in the layer 1
(compensates high e/π of ECal)

H_2= $\Sigma_{i=2}^{i=18}$ ($\mathrm{E_{Deposit}}$ in layer i)
(simulates Hadron Barrel)

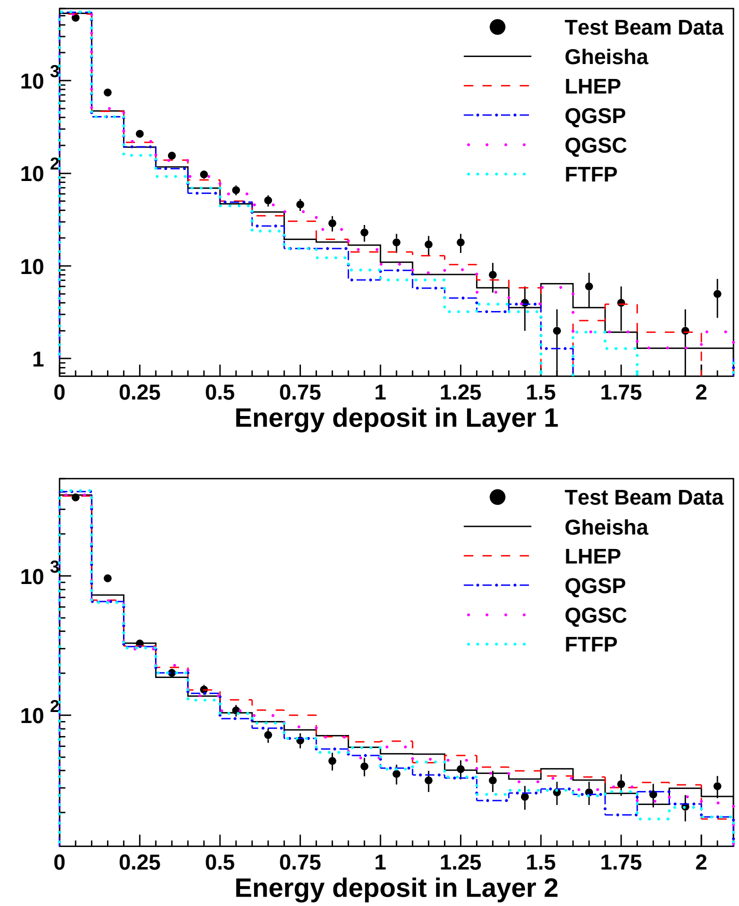
H_3= $\Sigma_{i=19}^{i=28}$ ($\mathrm{E_{Deposit}}$ in layer i)
(simulates energy leakage)

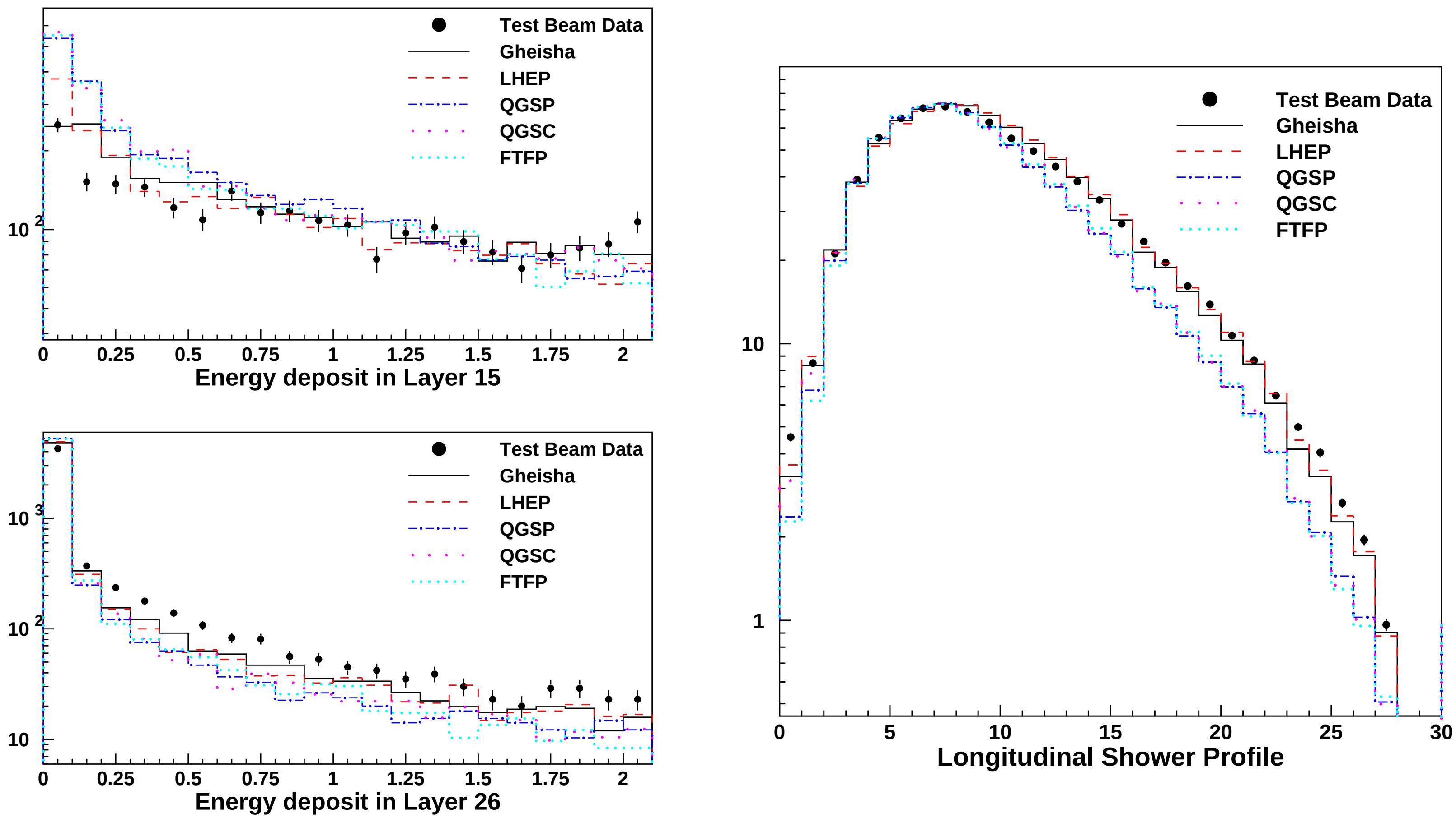
w_1, w_2, w_3 evaluated by minimising energy resolution for 100 GeV pions and constraining the mean value to the incident beam energy



HCal alone data

	Peak (GeV)	σ (GeV)
Data	100.0±0.1	9.1±0.1
LHEP	100.0±0.1	9.9±0.1
QGSP	100.0±0.1	9.2±0.1
QGSC	100.0±0.1	9.5±0.1
FTFP	100.0±0.1	9.2±0.1
Geant3	100.0±0.1	10.8±0.1



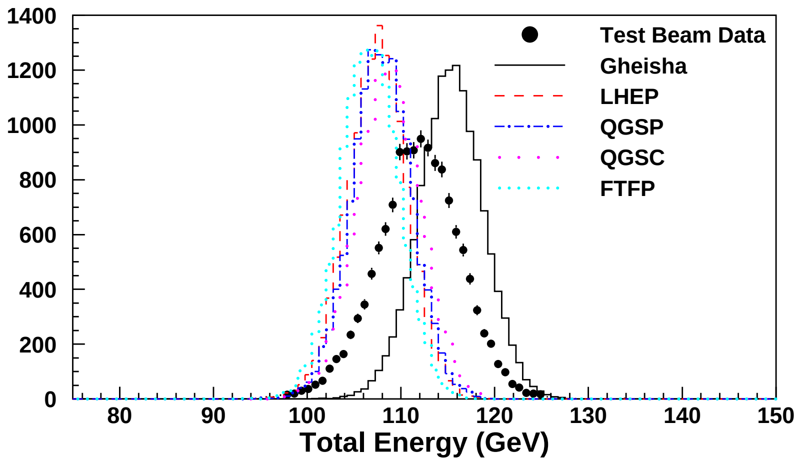


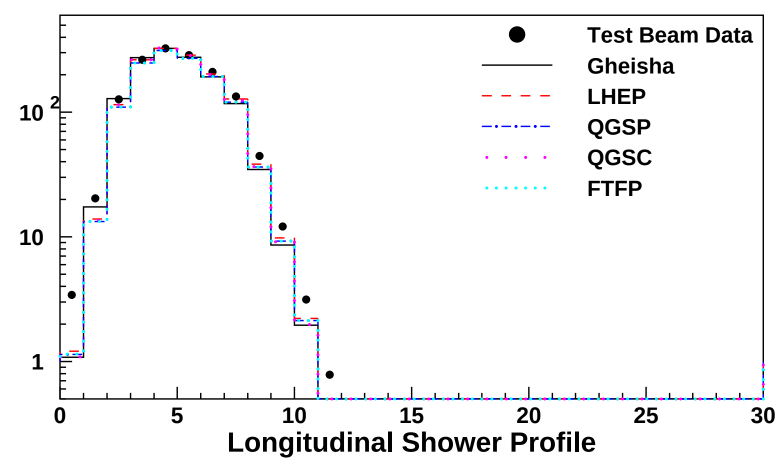
Longitudinal shower profile looks better for LHEP and Geant3

Measure electron energy with the same scale factor as for pions ⇒ e/h ratio

e/h ratio in HCal is $\sim$ 3% higher in Geant3 while it is 3-5% smaller in the different models of Geant4

	Peak (GeV)	σ (GeV)
Data	111.9±0.03	4.41±0.03
LHEP	107.5±0.02	3.16±0.02
QGSP	108.0±0.03	3.17±0.02
QGSC	106.8±0.03	3.15±0.03
FTFP	106.7±0.03	3.13±0.02
Geant3	115.3±0.03	3.46±0.02



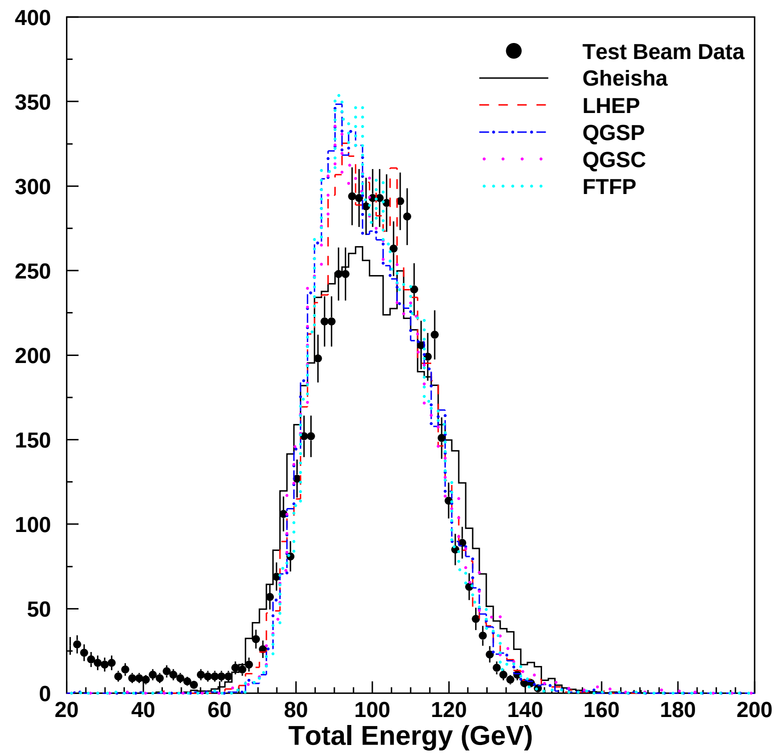


- ❑ More energy deposit in layers 1 and 2 in case of real data
- ❑ Longer tails in the shower in case of real data

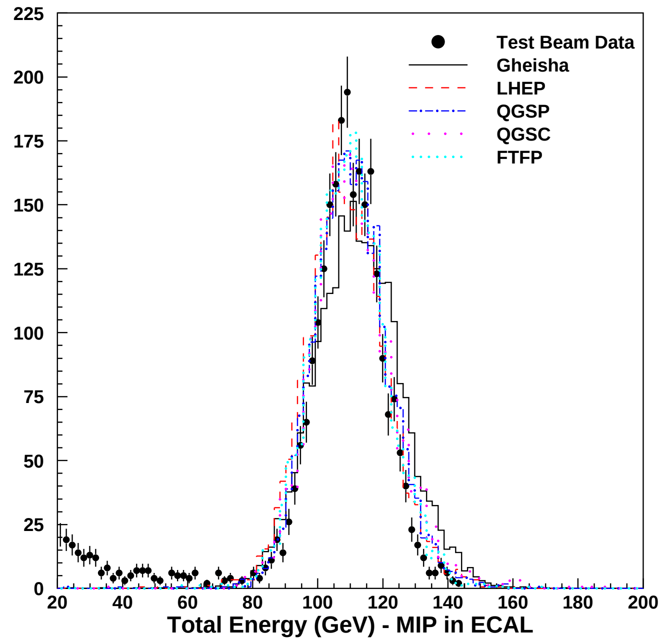
ECal + HCal data

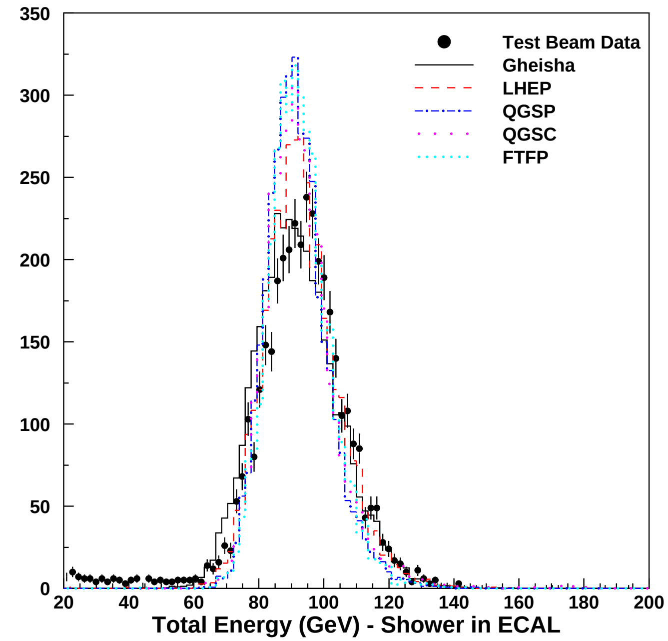
With 100 GeV π^- in the combined setup

	Peak (GeV)	σ (GeV)
Data	100.2±0.2	14.2±0.2
LHEP	100.0±0.2	14.0±0.1
QGSP	100.0±0.2	13.4±0.1
QGSC	100.1±0.2	13.4±0.1
FTFP	100.1±0.2	13.0±0.1
Geant3	100.0±0.2	17.4±0.2



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

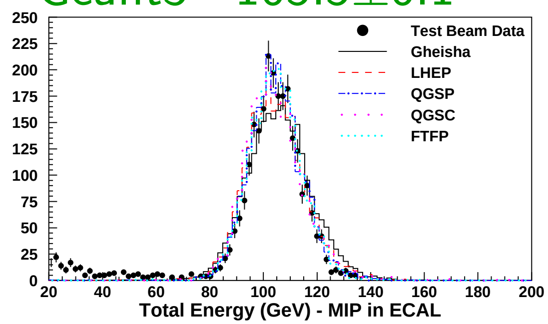


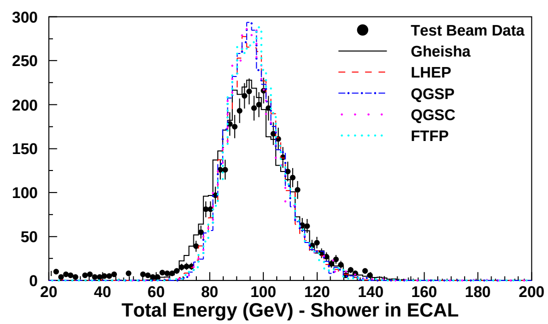


	MIP in ECal		Shower in ECal	
	Peak (GeV)	σ (GeV)	Peak (GeV)	σ (GeV)
Data	109.7±0.2	9.8±0.2	93.6±0.2	11.9±0.2
LHEP	108.6±0.2	11.5±0.2	92.6±0.1	10.8±0.1
QGSP	110.0±0.2	10.9±0.1	91.3±0.1	8.7±0.1
QGSC	109.8±0.2	11.1±0.2	91.7±0.1	9.1±0.1
FTFP	109.4±0.2	10.8±0.1	92.0±0.1	8.8±0.1
Geant3	111.9±0.2	12.7±0.1	91.1±0.1	12.8±0.1

Re-weighting layer 1 moves the peaks of the two samples closer

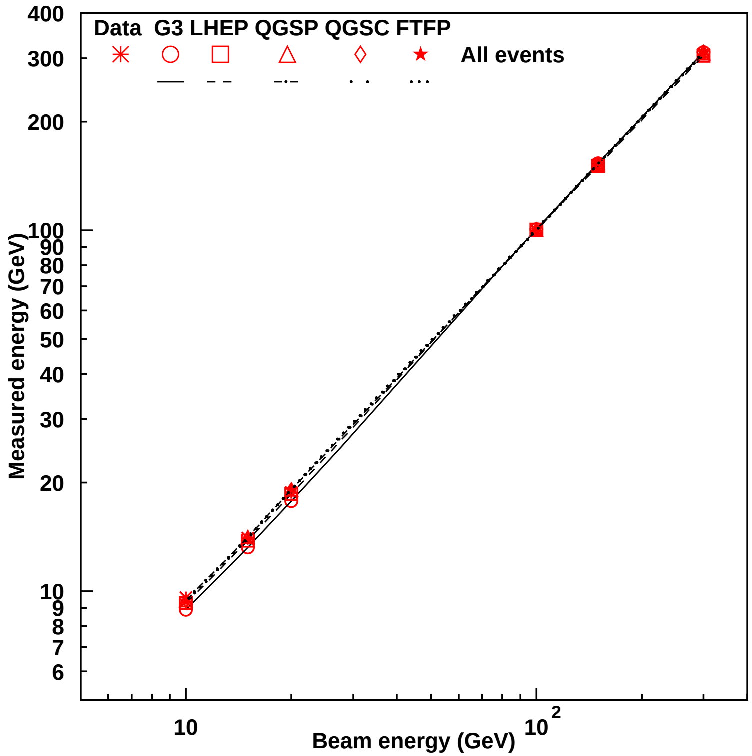
	MIP in ECal		Shower in ECal	
	Peak (GeV)	σ (GeV)	Peak (GeV)	σ (GeV)
Data	104.4±0.2	9.0±0.1	97.3±0.2	12.2±0.2
LHEP	104.3±0.2	10.3±0.1	96.5±0.2	10.2±0.1
QGSP	104.4±0.2	9.5±0.1	96.5±0.2	9.7±0.1
QGSC	103.7±0.2	9.7±0.1	96.2±0.2	9.7±0.1
FTFP	104.5±0.2	9.4±0.1	96.8±0.2	9.8±0.1
Geant3	105.5±0.1	11.2±0.1	95.4±0.1	13.0±0.1

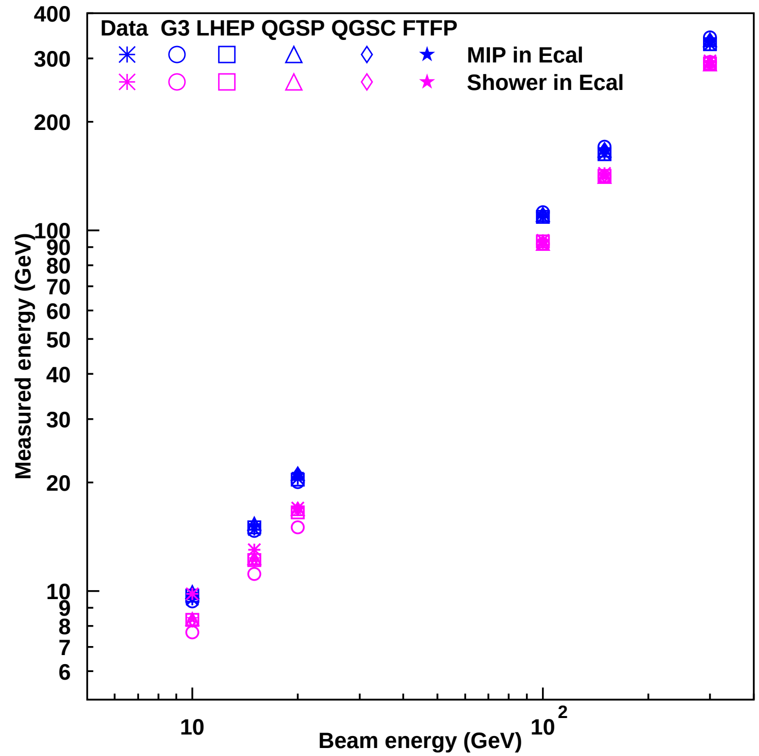




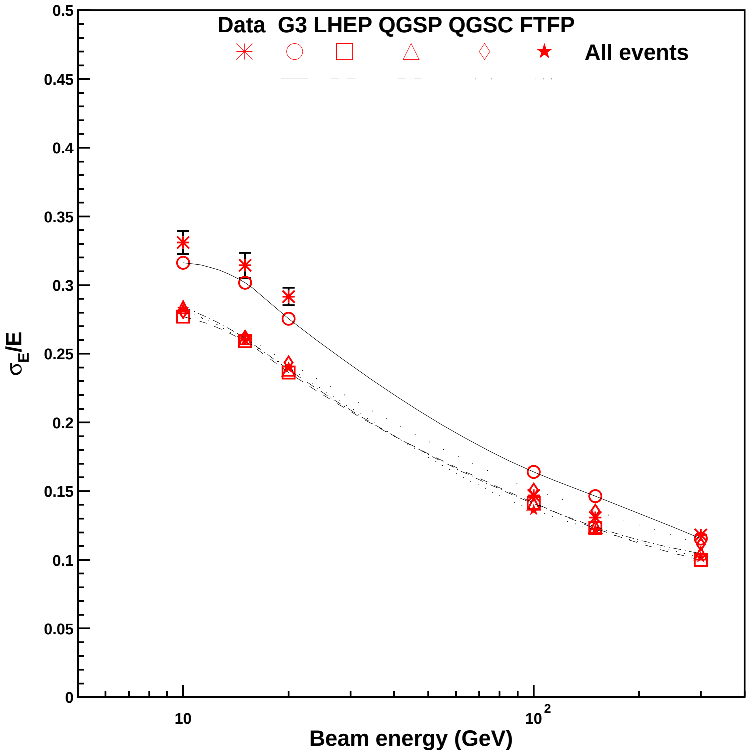
This improves the overall resolution

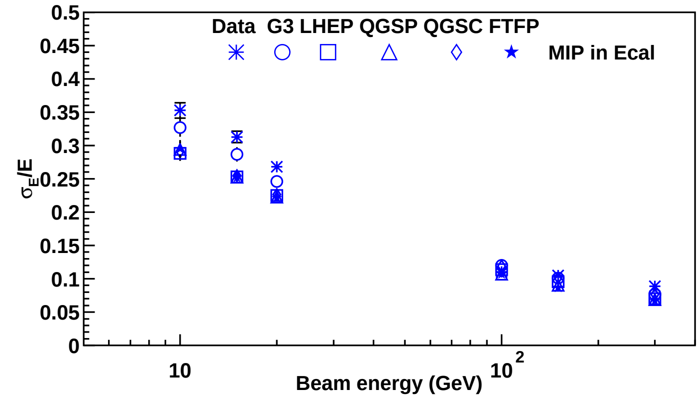
	σ (GeV)
Data	11.7±0.1
LHEP	11.1±0.1
QGSP	10.5±0.1
QGSC	10.6±0.1
FTFP	10.5±0.1
Geant3	13.2±0.1

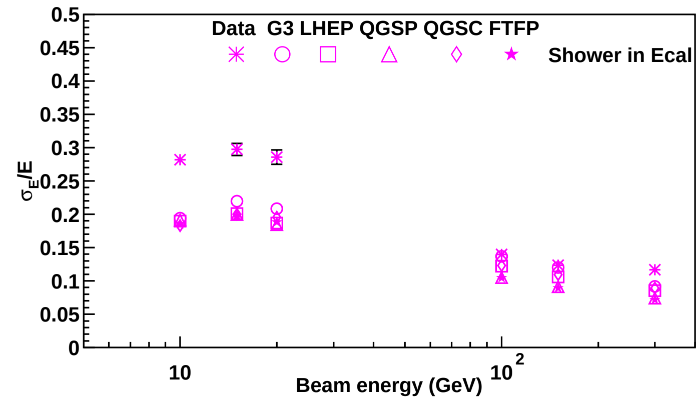




- Non-linearity in the response with energy is reasonably well reproduced by the different models inside Geant4
- The remaining discrepency is there in the sample which starts showering in the electromagnetic calorimeter

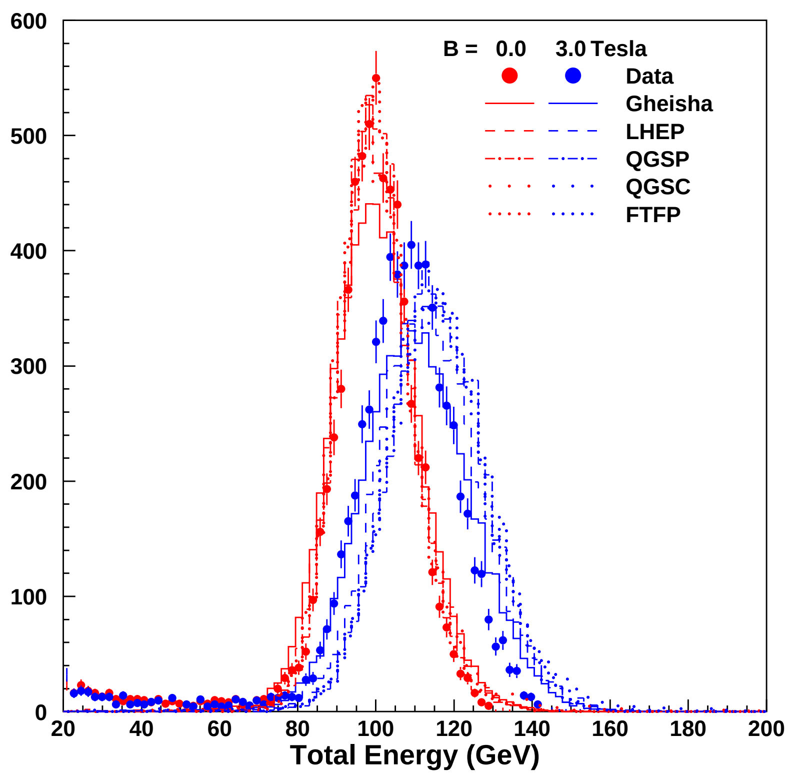


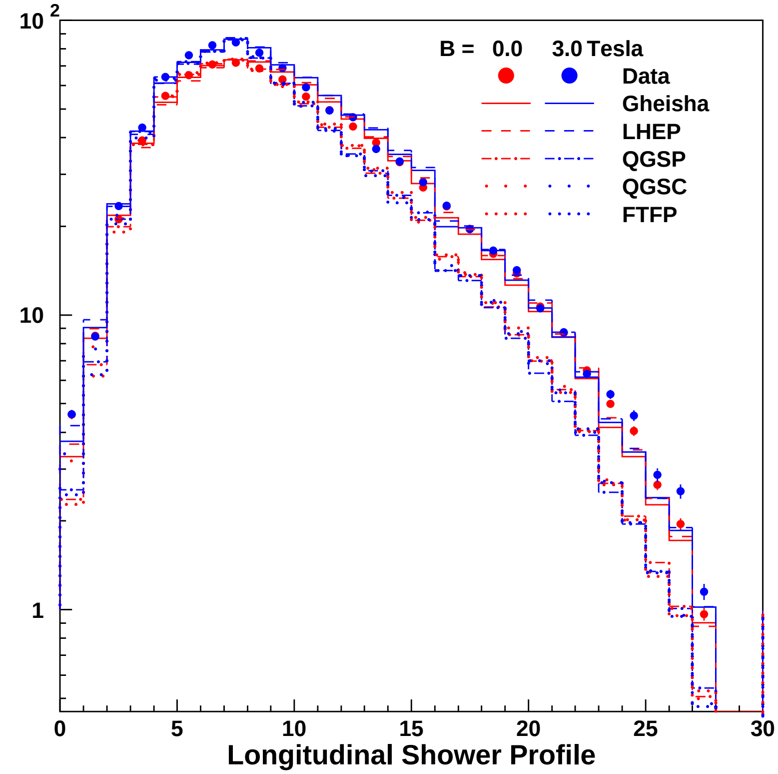




- Energy resolution is well described at high energies
- The discrepancy at lower energies is more in the sample which starts showering in ECal

HCal data in Magnetic Field

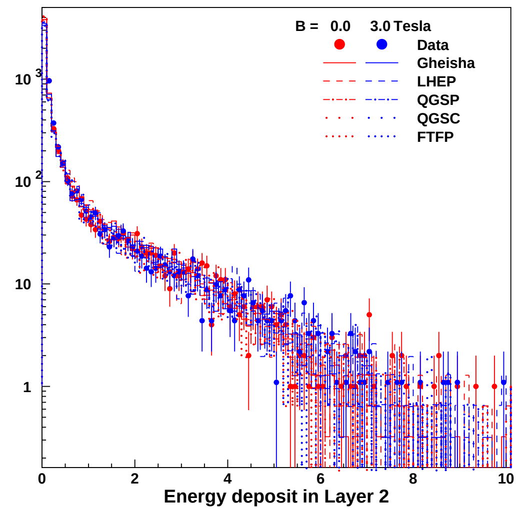


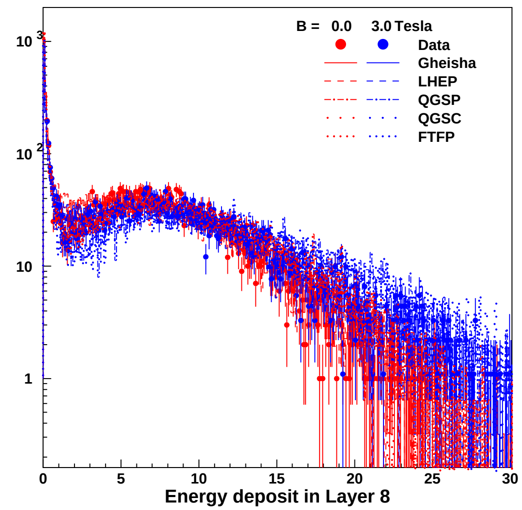


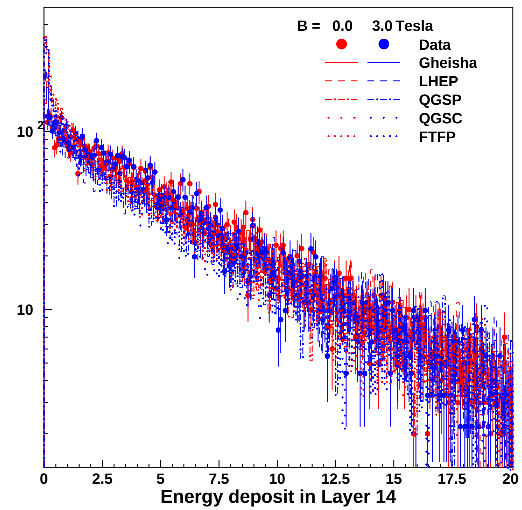
- 3 Tesla B-field results increase in response in the HCal with substantial gain in layers 5-11
- Simulation models also predict an increase in the response

Measured energy of 100 Gev π with 3T Field

	Peak (GeV)	σ (GeV)
Data	108.3±0.2	11.3±0.1
LHEP	113.1±0.2	12.4±0.1
QGSP	115.1±0.2	11.8±0.1
QGSC	115.2±0.2	12.0±0.2
FTFP	115.0±0.2	11.8±0.2
Geant3	110.2±0.1	13.0±0.1







Outlook

- Update to the latest versions of the hadronic model as suggested by HPW
- Look at data with different beam energies for HCAL alone setup
- Look into more samples with magnetic field on
- Complete the work at the earliest possible time