Validation Using CMS Data

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Geant4 Collaboration Meeting

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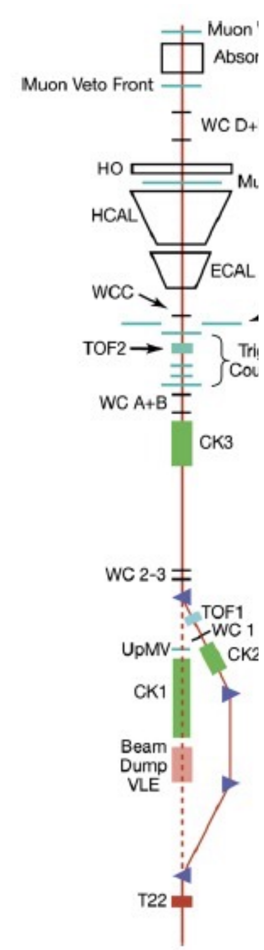
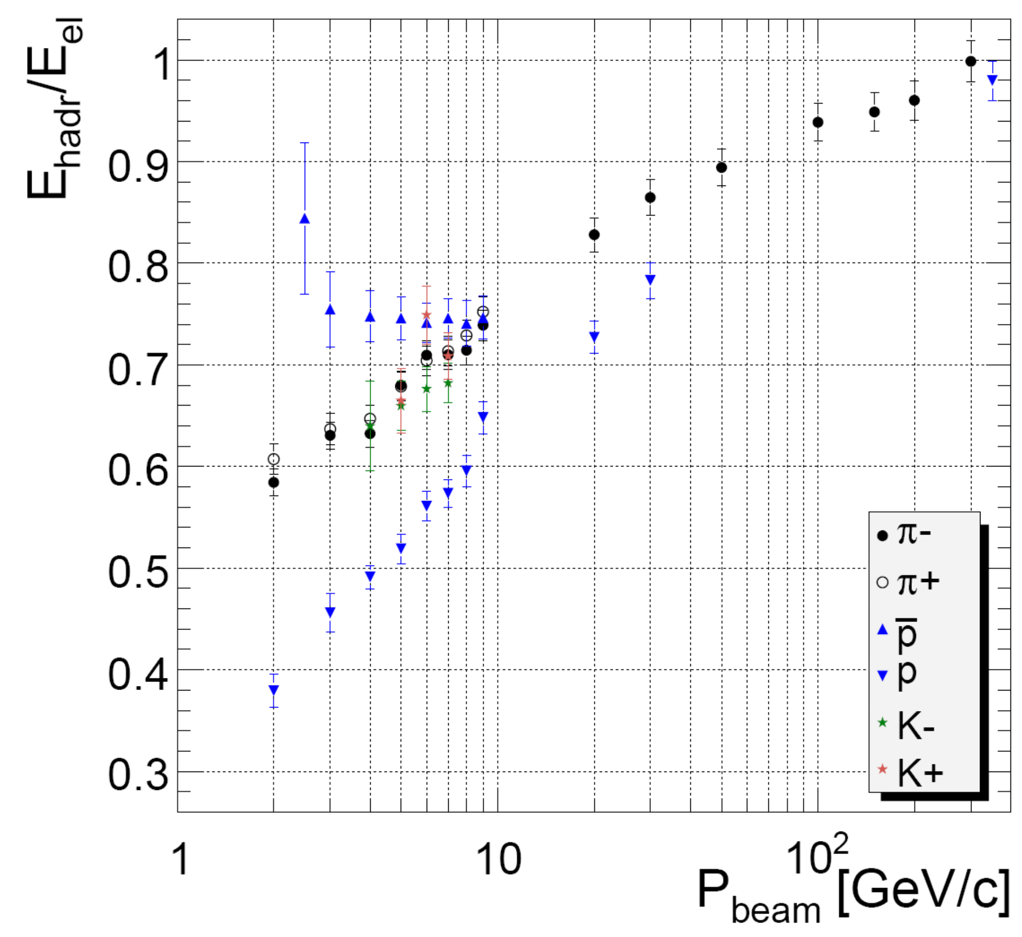
Introduction

- CMS Simulation application is based on Geant4
  - Current version in production 10.4.p03
  - Future version 10.6 and a step to that 10.5.ref08
- Adaptation of a new Geant4 version or a new Physics List requires validation of the model predictions with some from the existing data
- The current validation results are intended for the version id Geant4.10.6 (due in December 2019)
- The validation is carried out using 2 sources of data:
  - 2006 test beam with CMS calorimeter prototypes (hadron beams of different types and different energies)
  - Collision data from the CMS experiment utilizing zero bias or minimum bias triggers from low luminosity runs

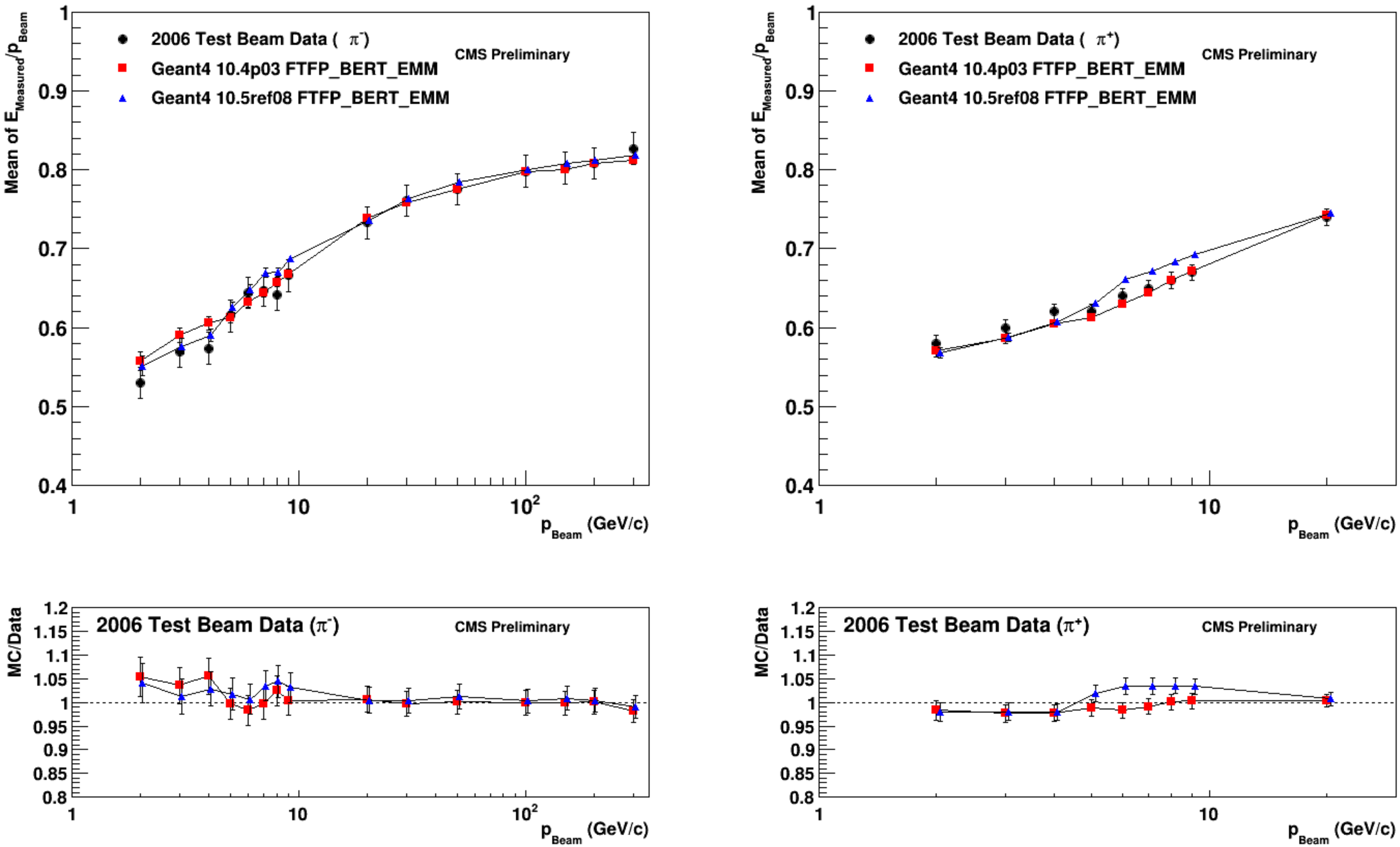
2006 TestBeam Data

- CMS collected data with prototype of Hadron Calorimeter Barrel and a supermodule of the barrel Electromagnetic Calorimeter in the H2 test beam area at CERN during 2006.
- Special action was taken to go to low energy hadron beam down to 1 GeV using a secondary target
- The analysis utilized particle identification using data from TOF counters and Cherenkov detectors up to energy of 9 GeV
- The results consist of mean energy response (measured as the ratio of the total energy in the calorimeter to the beam momentum) as a function of beam momentum for different beam types and also the energy distribution for particles of a given type at a given momentum (all particles or particles which do not undergo inelastic interactions in Electromagnetic Calorimeter)
- Results from this test beam were published (EPJ C60, 2009, 359) and used in many comparisons presented in earlier conference



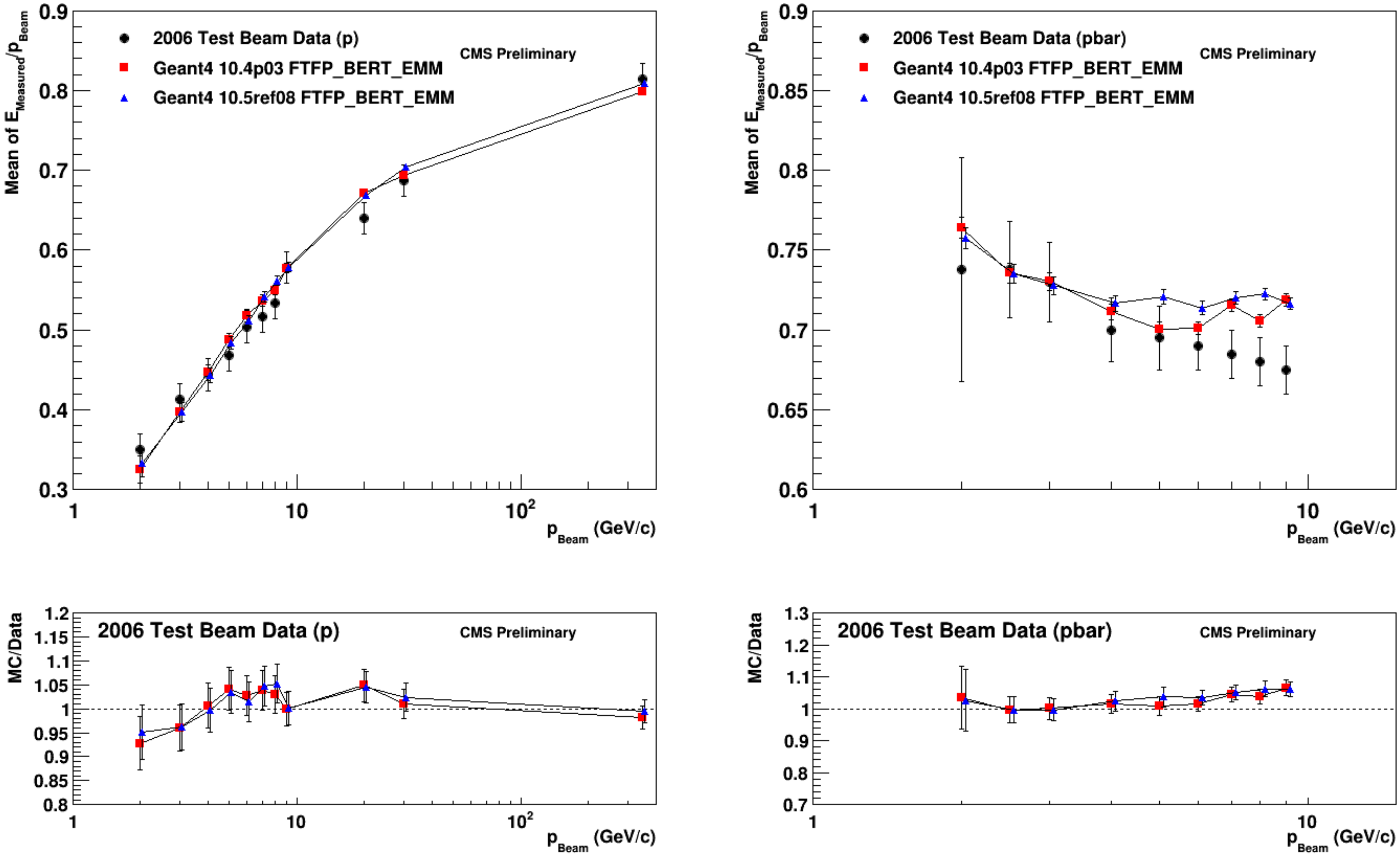


Mean response with pions



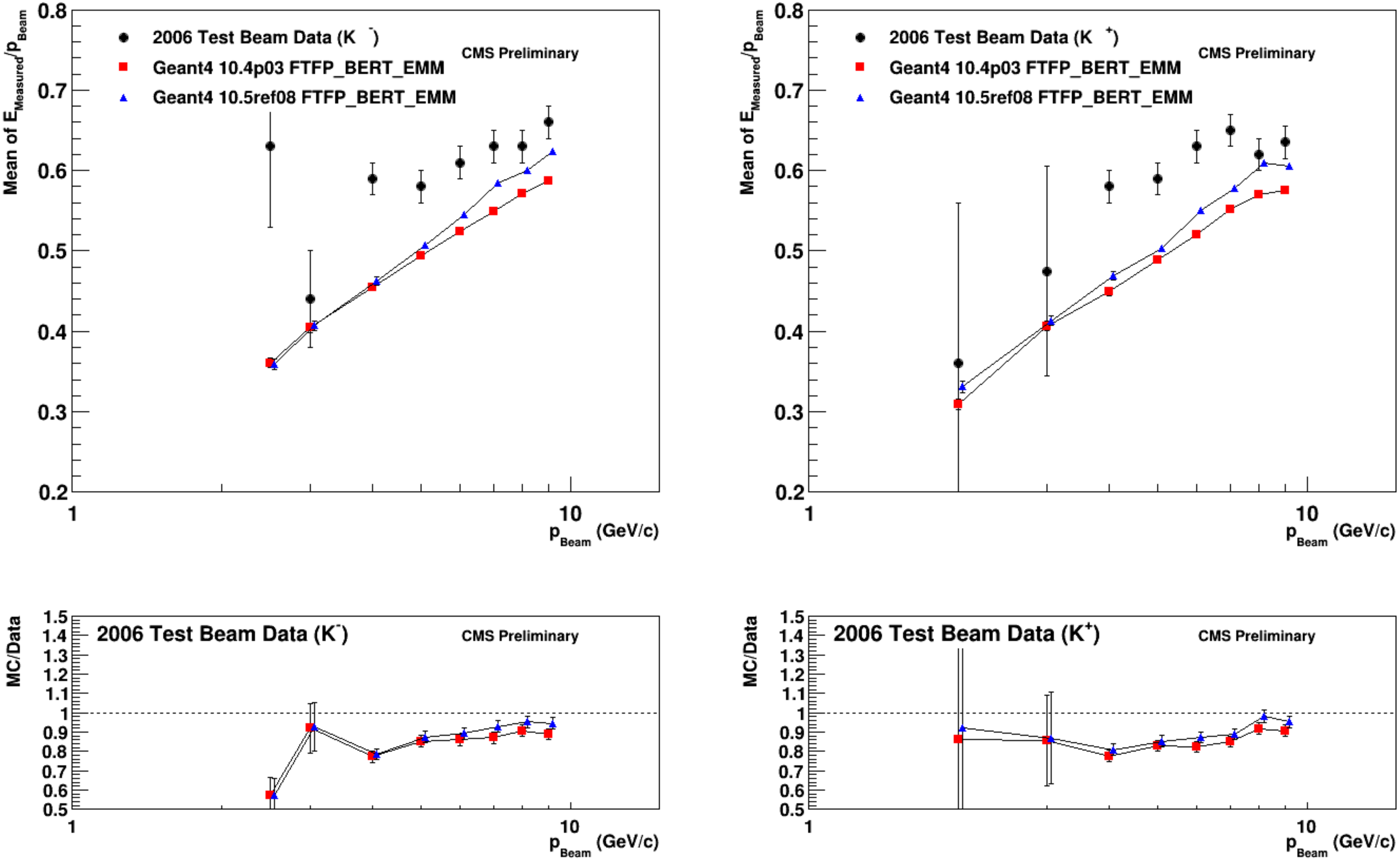
- Level of agreement is good for negative pions and is getting slightly worse for positive pions in the new Geant4 version

Mean response with protons/antiprotons



- Level of agreement remains good for protons and is slightly worse for anti-protons in 10.5.ref08

Mean Response for kaons



- Level of agreement is not good and remains unchanged with Geant4 versions

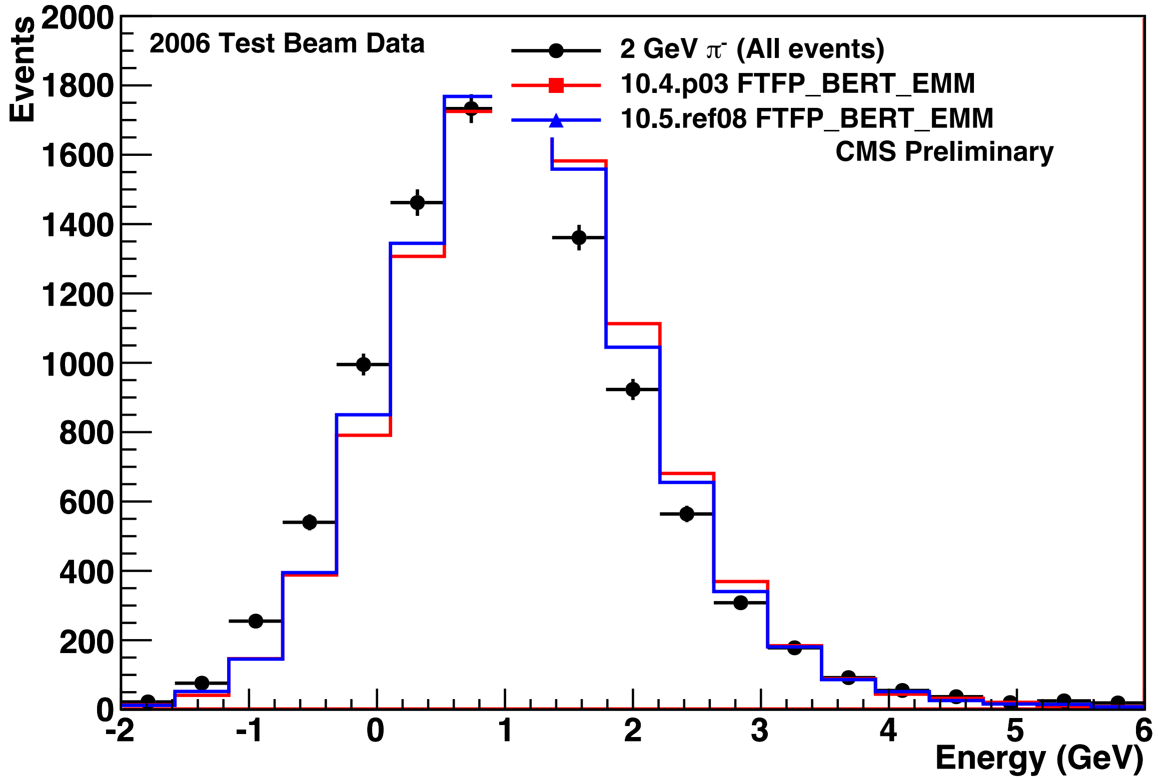
Summary from Mean Response

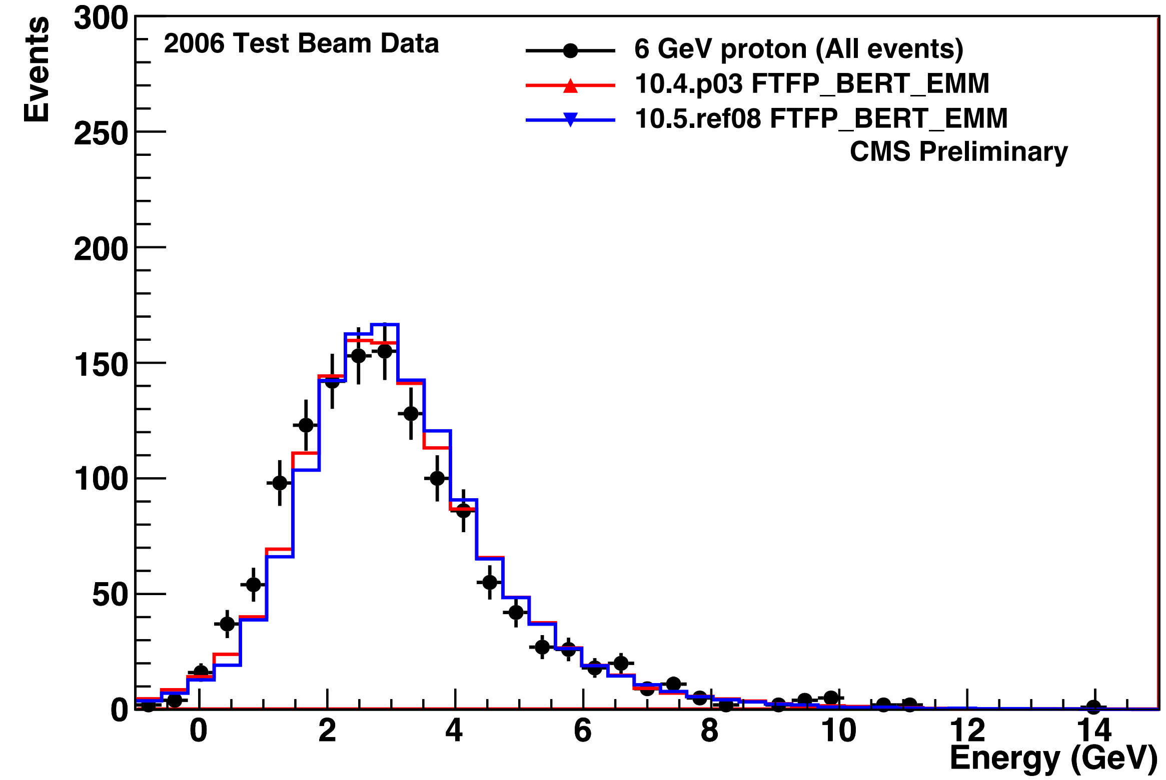
χ^2/d.o.f. between data and Monte Carlo

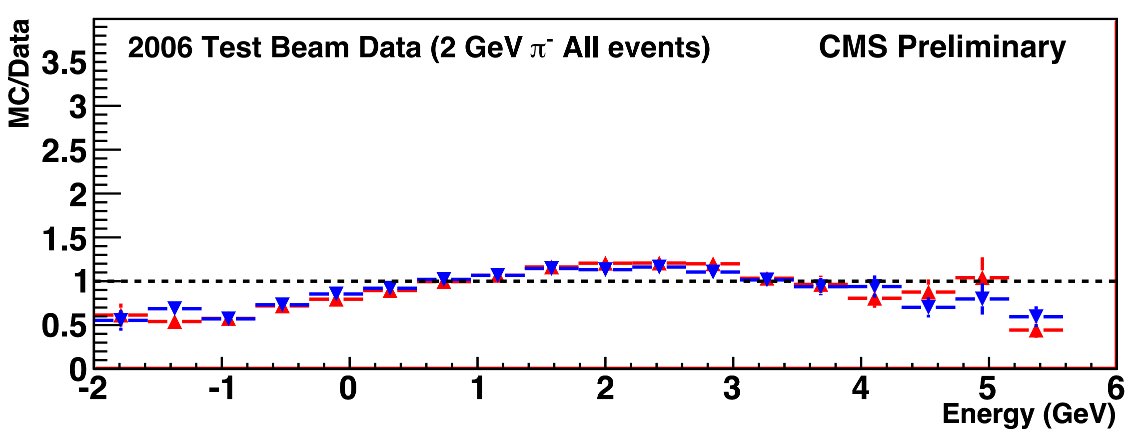
	negative pions	positive pions	negative kaons	positive kaons	protons	anti-protons
G4 10.4.p03 FTFP_BERT_EMM	0.45	0.73	26.2	26.8	0.80	1.79
G4 10.5.ref08 FTFP_BERT_EMM	0.46	2.67	17.3	15.0	0.77	2.77

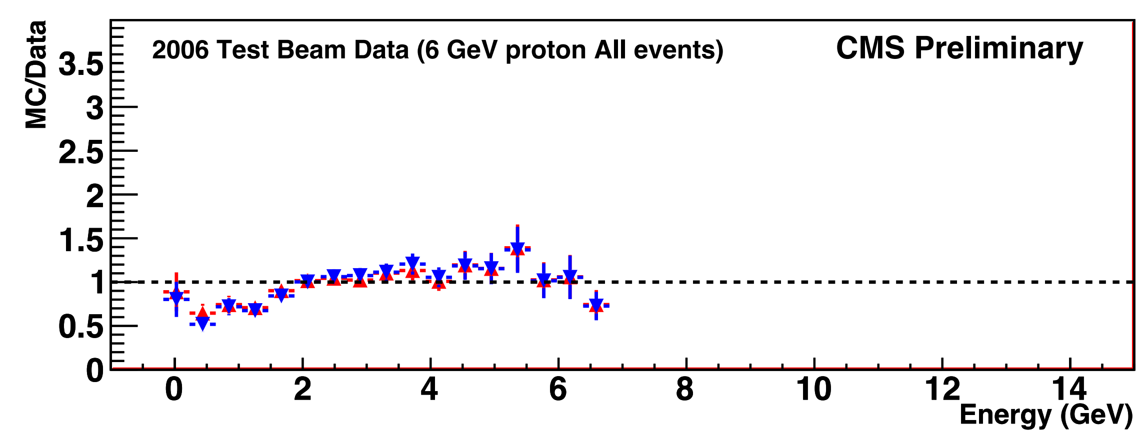
- The predictions from 10.5.ref08 show some improvement for kaons, some deterioration for positive pions and anti-protons, and acceptable agreement for negative pions and protons
- pp collisions at high energies produce mostly pions. So one expects to have a reasonable agreement between data and MC with the cuurent physics list in the Geant4 version 10.5.ref08

Energy for negative pions and protons



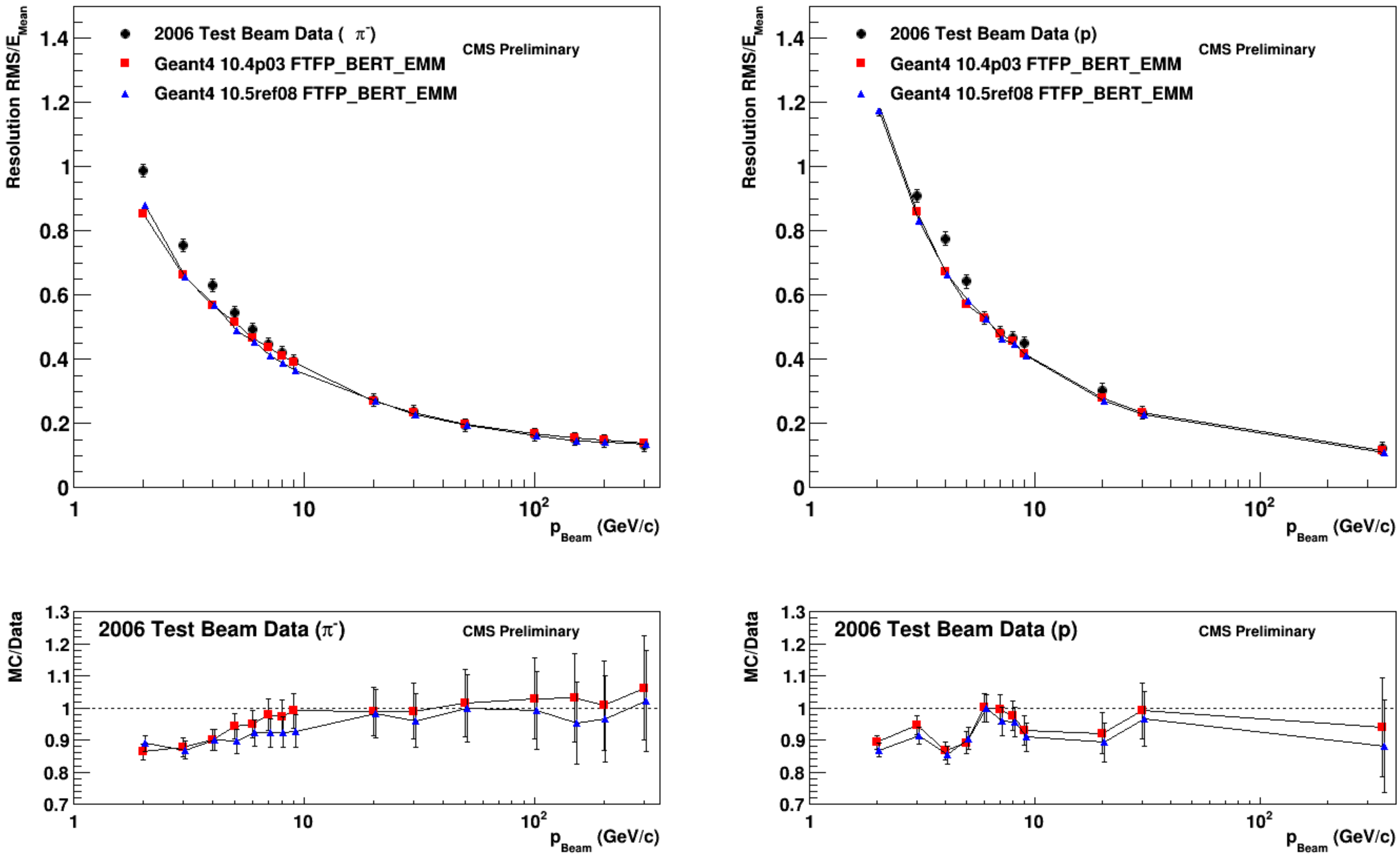






- Energy spectrum in the data is slightly broader for pions while the agreement between data and MC is better for protons

Energy Resolutions



- Monte Carlo predictions show better energy resolution than the data for low energy pions

Isolated Charged Particles

- Compare ratio of calorimeter energy measurement to track momentum for isolated charged hadrons between pp collision data from CMS and MC

- Select good charged tracks reaching the calorimeter surface

- Impose isolation of these charged particles
  - propagate track to calorimeter surface and study momentum of tracks (selected with looser criteria) reaching ECAL (HCAL) within a matrix of 31x31 (7x7) around the impact point of the selected track for charge isolation
  - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for neutral isolation

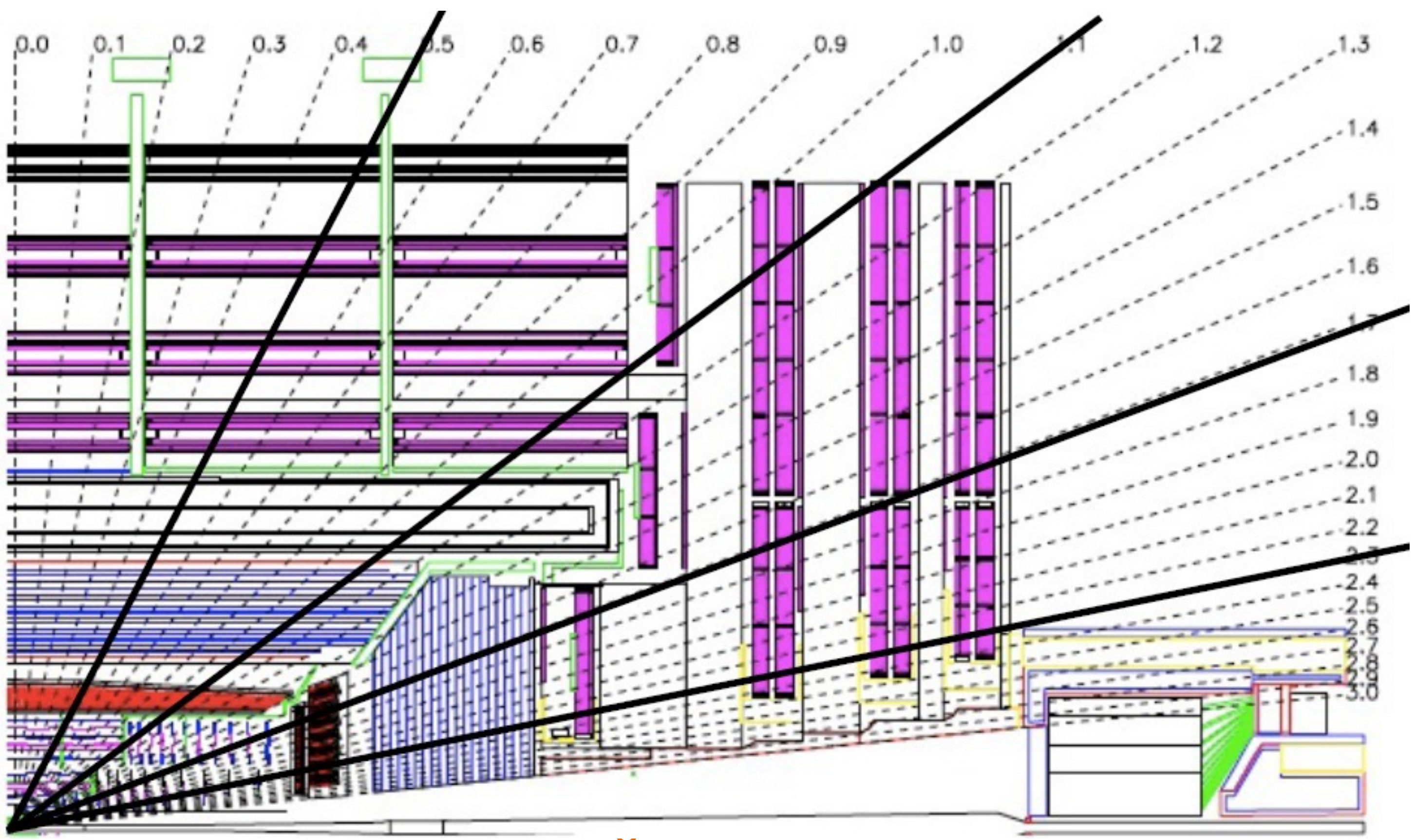
- Two versions of NxN matrix are defined for ECAL and HCAL
  - ECAL uses 7x7 or 11x11 matrix
  - HCAL uses 3x3 or 5x5 matrix

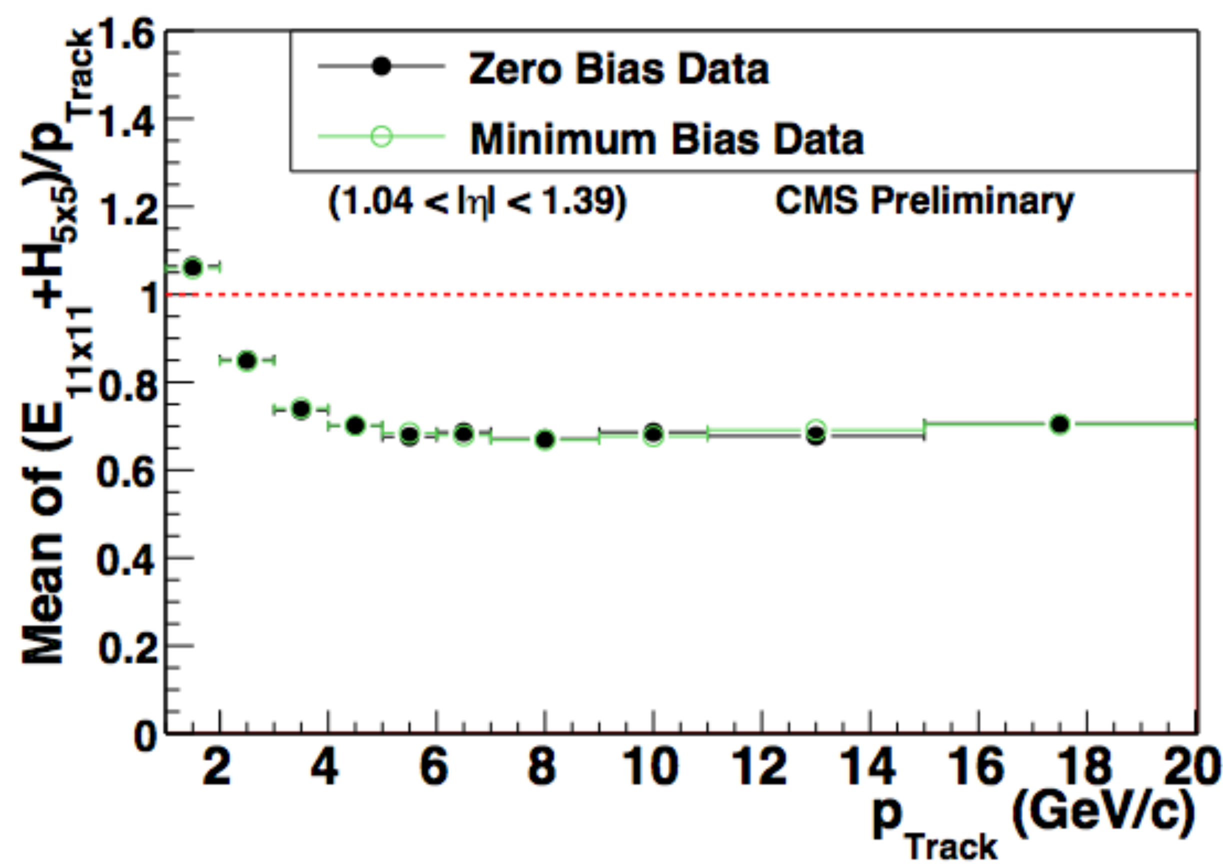
- The methodology was developed using 7 TeV data (PAS: JME-10-008) and analysis of the 2016 low pileup data plus the comparisons with earlier Geant4 model predictions were presented in the last two CHEP conferences.

Data and MC Sets Used

- For Data: Use low luminosity runs taken during 2016B run period:
  - Zero Bias trigger
  - Minimum Bias trigger

  Two data sets show similar distributions and they are combined
- For Monte Carlo:
  - Generate events using single particle generator producing a known mixture of pions (70%), kaons (15%), protons (15%) and their anti-particles with a flat energy distribution between 1 and 20 GeV
  - Generate 100k events with Physics List FTFP_BERT_EMM for Geant4 versions 10.4.p03 and 10.5.ref08

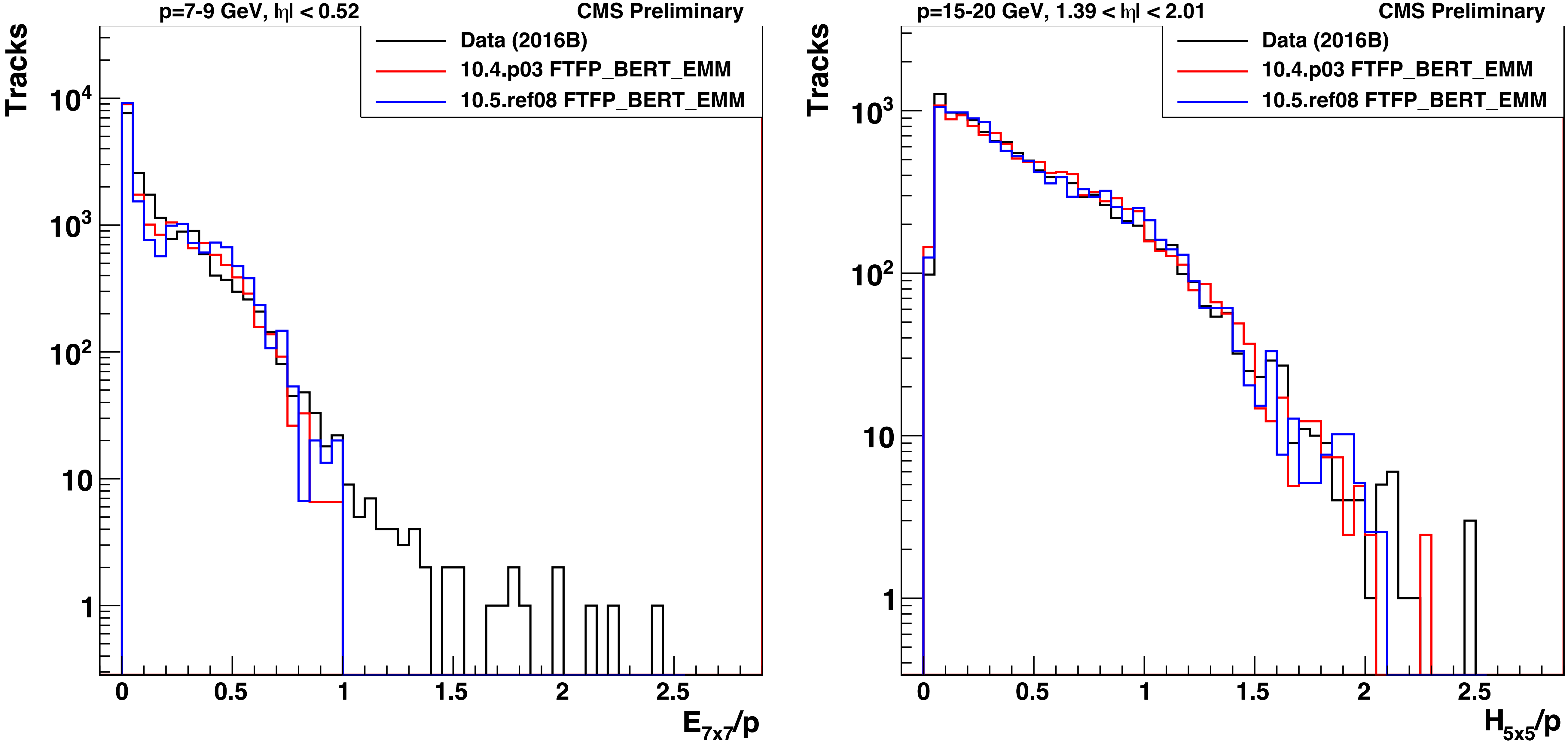




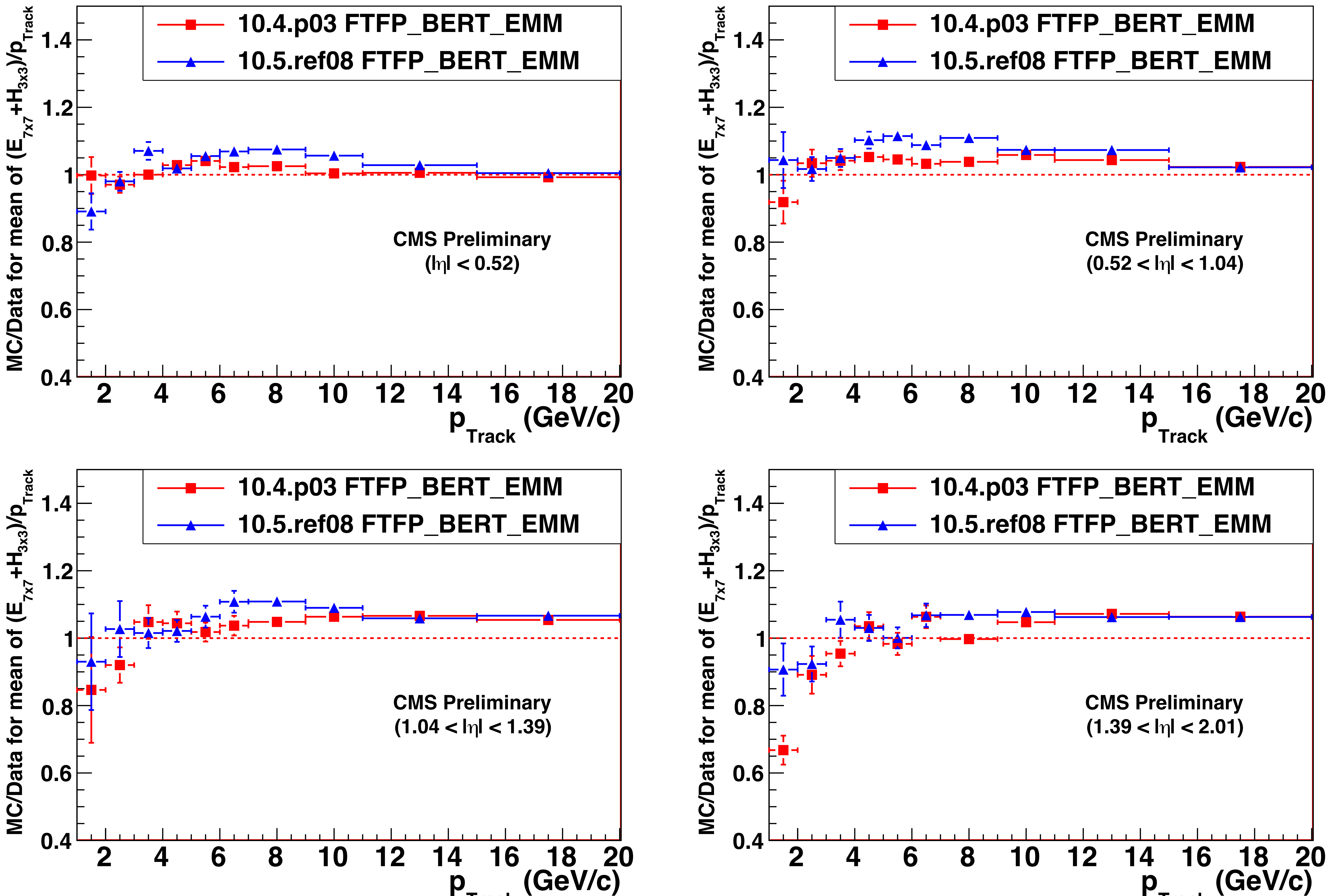
Energy in ECAL and HCAL

Narrow Matrix (ECAL) 7-9 GeV

Wide Matrix (HCAL) 15-20 GeV

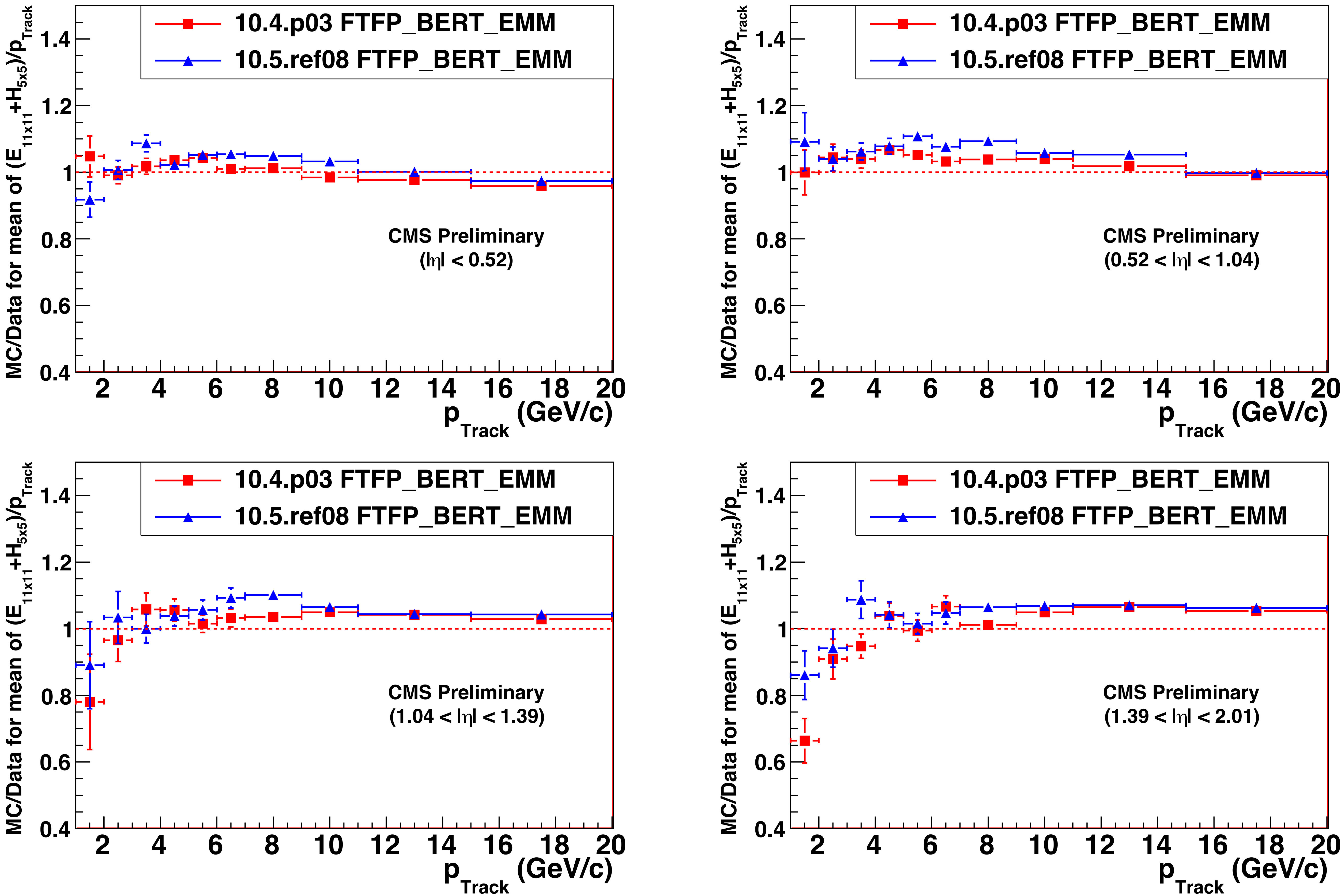


Combined Calorimeter Energy Ratio (Narrow Matrix)



Level of agreement is better in the Geant4 version 10.4.p03

Combined Calorimeter Energy Ratio (Wide Matrix)



10.4.p03 provides better agreement

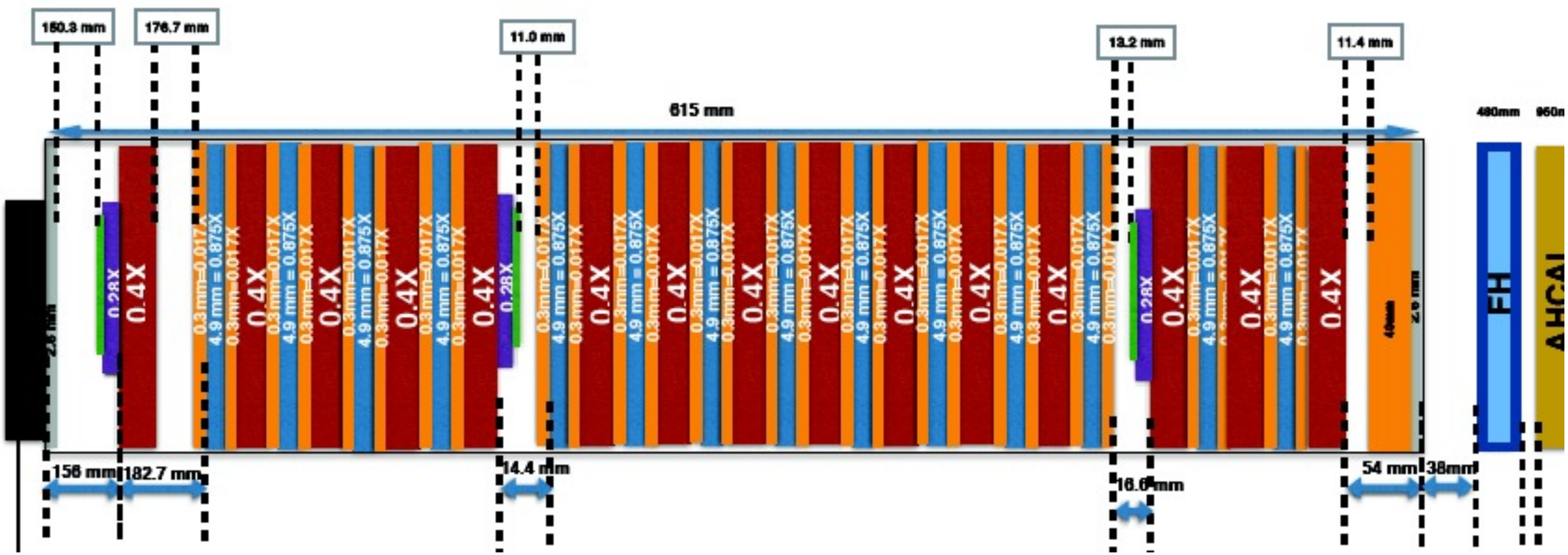
Level of Agreement

- The level of agreement between data and MC is between 3 to 7% depending on the region of the detector as well as the physics list used

	$(E_{7x7}+H_{3x3})/p$ 10.4.p03	$(E_{7x7}+H_{3x3})/p$ 10.5.ref08	$(E_{11x11}+H_{5x5})/p$ 10.4.p03	$(E_{11x11}+H_{5x5})/p$ 10.5.ref08
Barrel 1	(1.6±0.4)%	(4.7±0.4)%	(2.1±0.4)%	(3.2±0.4)%
Barrel 2	(4.0±0.4)%	(6.9±0.4)%	(2.8±0.4)%	(5.5±0.4)%
Transition	(5.3±0.5)%	(6.6±0.5)%	(3.6±0.5)%	(5.1±0.5)%
Endcap	(5.5±0.5)%	(5.9±0.5)%	(5.0±0.5)%	(6.0±0.5)%

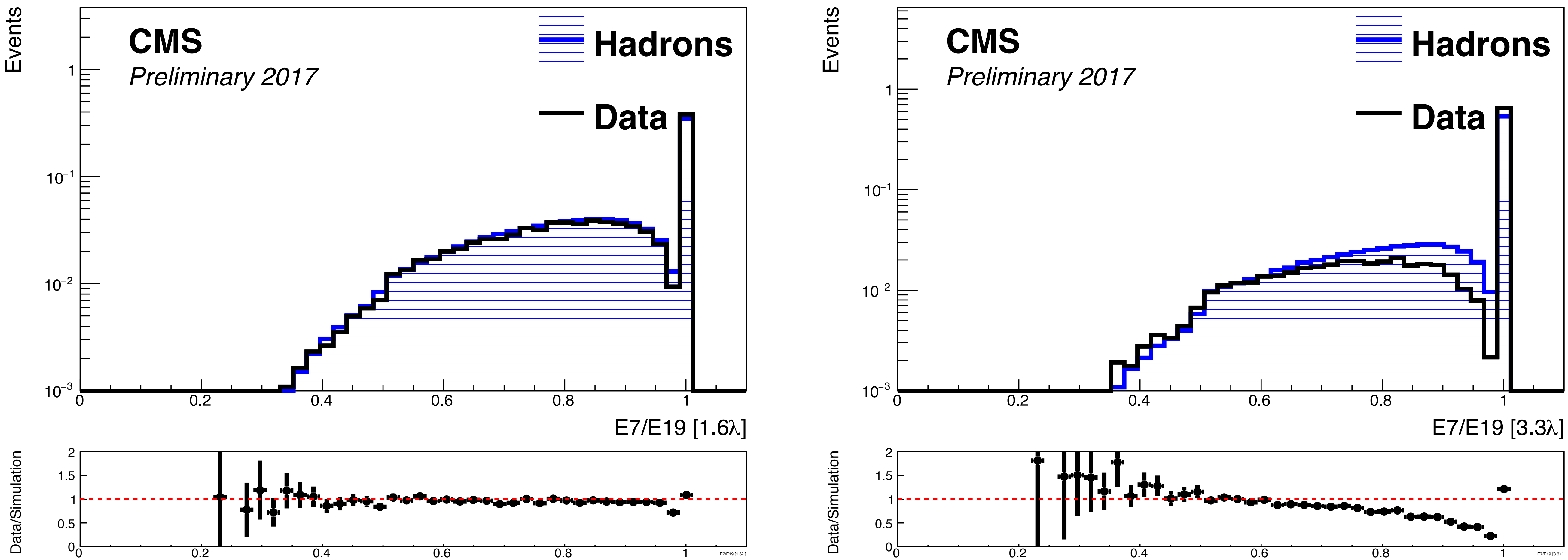
Summary & Outlook

- CMS has compared predictions from the physics list FTFP_BERT_EMM from two Geant4 versions with data
- Test beam data with identified particle types are used as one source of validation while isolated charged particles from collision data are used as a second source
- There is a good agreement between data and Monte Carlo for the physics list FTFP_BERT_EMM to be used by CMS for its future event production using Geant4 version 10.6 tested using its predecessor 10.5.ref08
- CMS foresees to continue validation of physics within Geant4



July 2017 setup with high granularity calorimeter prototype in CERN test beam

Summary & Outlook



- Compare lateral shower profile of 200 GeV pions at various depths in the calorimeter
- Use the physics list FTFP_BERT_EMM with Geant4.10.2.p02
- Recent data sets exist with a more complete setup and comparisons under way with a more recent version of Geant4 and a physic list with better adopted EM physics

Backups

Geant4 in CMS

- CMS used the physics lists in the past for its Monte Carlo production
  - QGSP_FTFP_BERT_EML (with Geant4 versions 9.4.p02, 9.6.p02)

- CMS moved to a new Geant4 version in mutli-threaded mode for the run2 operation
  - QGSP_FTFP_BERT_EML (with Geant4 versions 10.0.p02)

- CMS moved to a new physics list for its production during 2017
  - FTFP_BERT_EMM (with Geant4 version 10.2.p02)

- CMS is using a newer version of Geant4 for ultra-legacy production
  - FTFP_BERT_EMM (with Geant4 version 10.4.p03)

- The list FTFP_BERT uses FTFP and Bertini Cascade models and in version 10.0.p02:
  - Bertini Cascade valid at ≤ 5 GeV
  - FTFP valid at ≥ 4 GeV
- The list FTFP_BERT evolved in version 10.4.p03:
  - Bertini Cascade valid at ≤ 12 GeV
  - FTFP valid at ≥ 3 GeV
- The list FTFP_BERT evolved in version 10.5.ref08:
  - Bertini Cascade valid at ≤ 6 GeV
  - FTFP valid at ≥ 3 GeV

- EMM specify the physics models for electromagnetic processes
  - EMM uses the default multiple scattering model for HCAL

2006 TestBeam Analysis

- Measurements consist of mean energy response (ratio of the total energy in the calorimeter to the beam momentum) as a function of beam momentum for different beam types and also the energy distribution for particles of a given type at a given momentum
- Events are simulated only till the simulation hit level (including saturation effect as in Birk's law)
- Effect of electronics and detector noise is taken care of by adding Gaussian noise separately for ECAL and HCAL
  - RMS_{ECAL} = 0.362 GeV
  - RMS_{HCAL} = 0.640 GeV
- The detector components in the beam line are described in the simulation package and the cuts which are used for data analysis are also used for analyzing the Monte Carlo Sample
- Exclude hits in the outer hadron calorimeter and use a time cut of 100 ns
- Energy in the calorimeter is summed up around the beam spot
  - 7x7 matrix of crystals for ECAL
  - 3x3 towers for HCAL
- 50 GeV electrons are used for defining energy scales of ECAL as well as HCAL. Energy is measured as
  - $E_{vis} = E_{ECAL} * f_{ECAL} + E_{HCAL} * f_{HCAL}$
  - f_{ECAL} = 1.01, f_{HCAL} ~105 (for FTFP_BERT_EMM Physics List)