Validation of Physics Models of Geant4 using data from CMS Experiment

Overview

- Introduction
- Validation using test beam data
- Validation using collision data
- Summary

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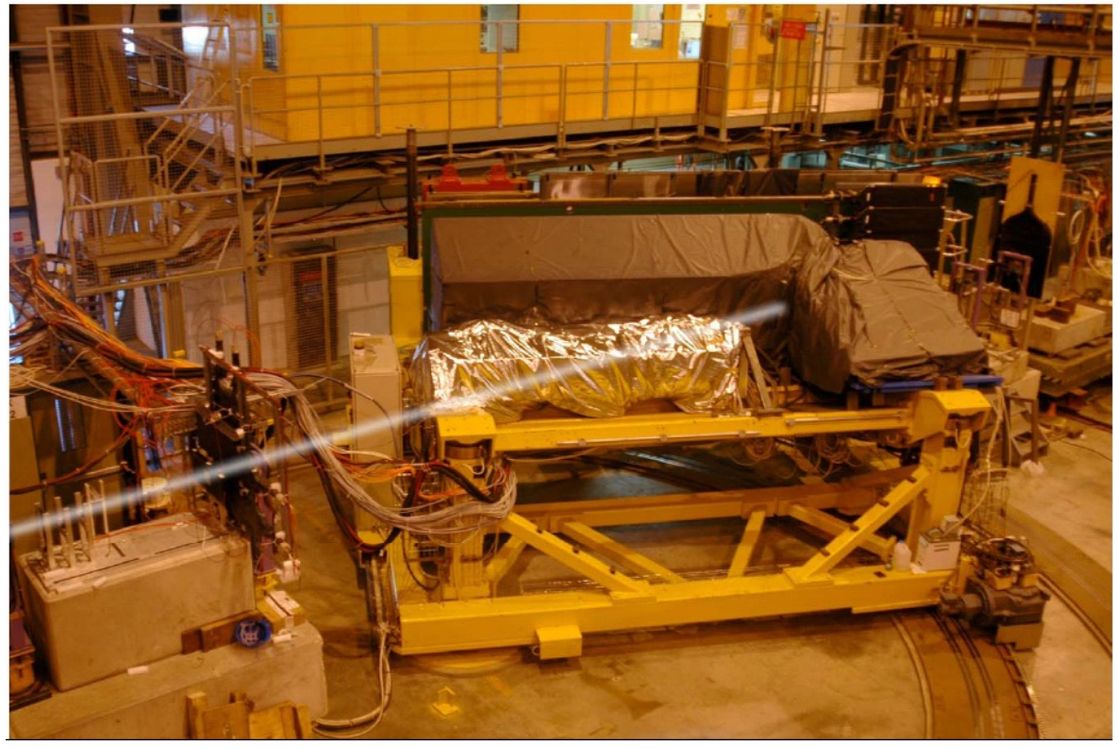
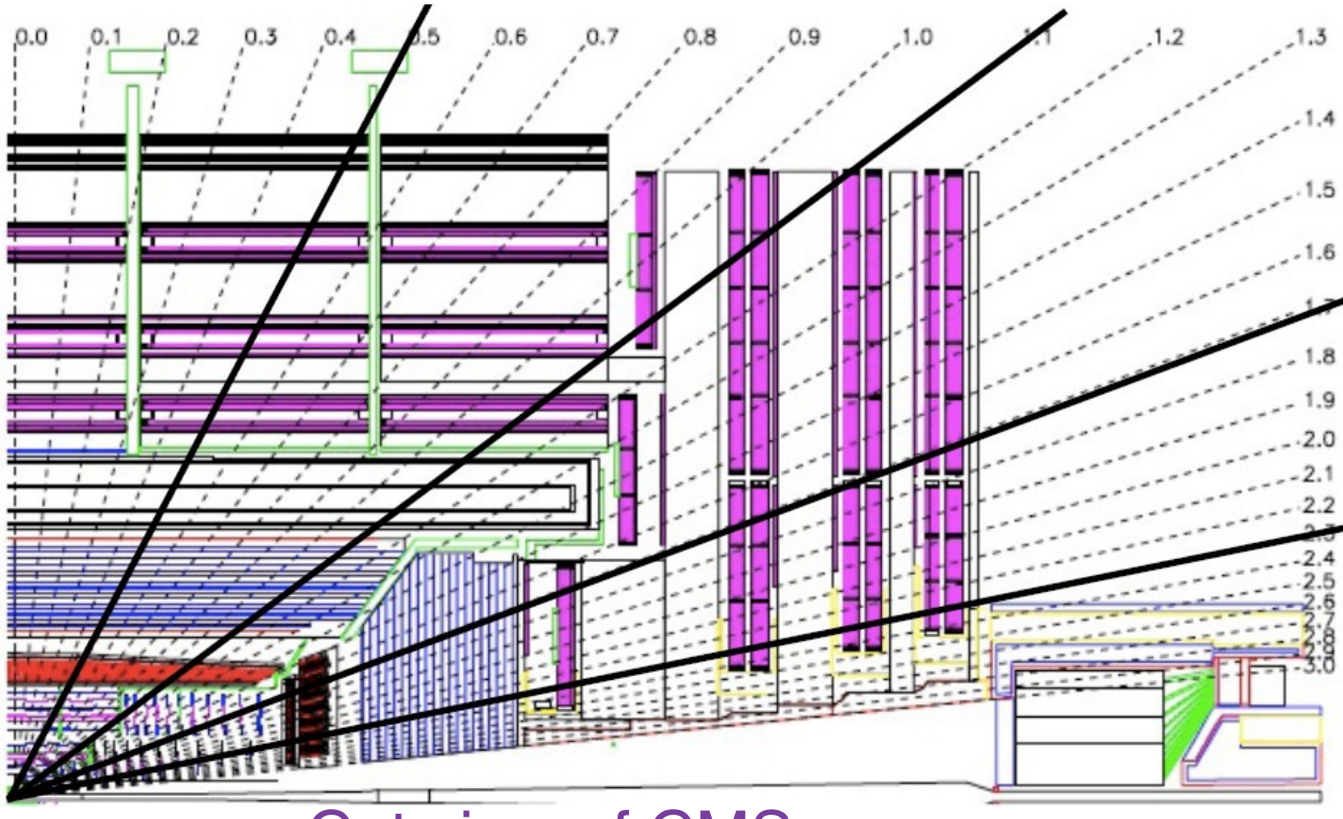
(on behalf of CMS Collaboration)

Introduction

- CMS Simulation application is based on Geant4
  - started with version 9.3.p01 for early data from LHC run 1
  - used version 10.0.p02 for data from 2015-16.
- The physics of Geant4 are monitored continuously using data during these transitions. There are 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



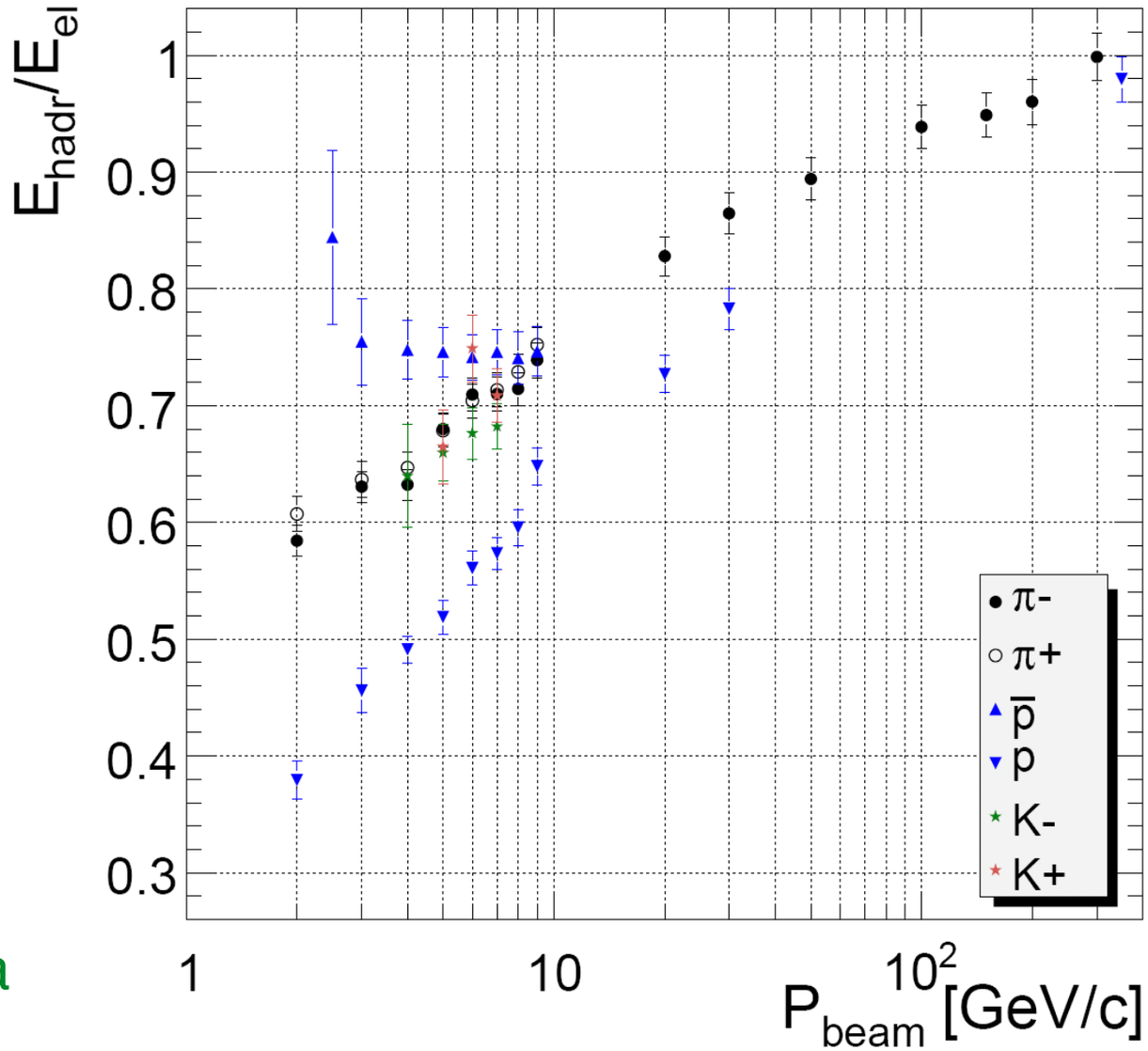
2006 H2 TestBeam



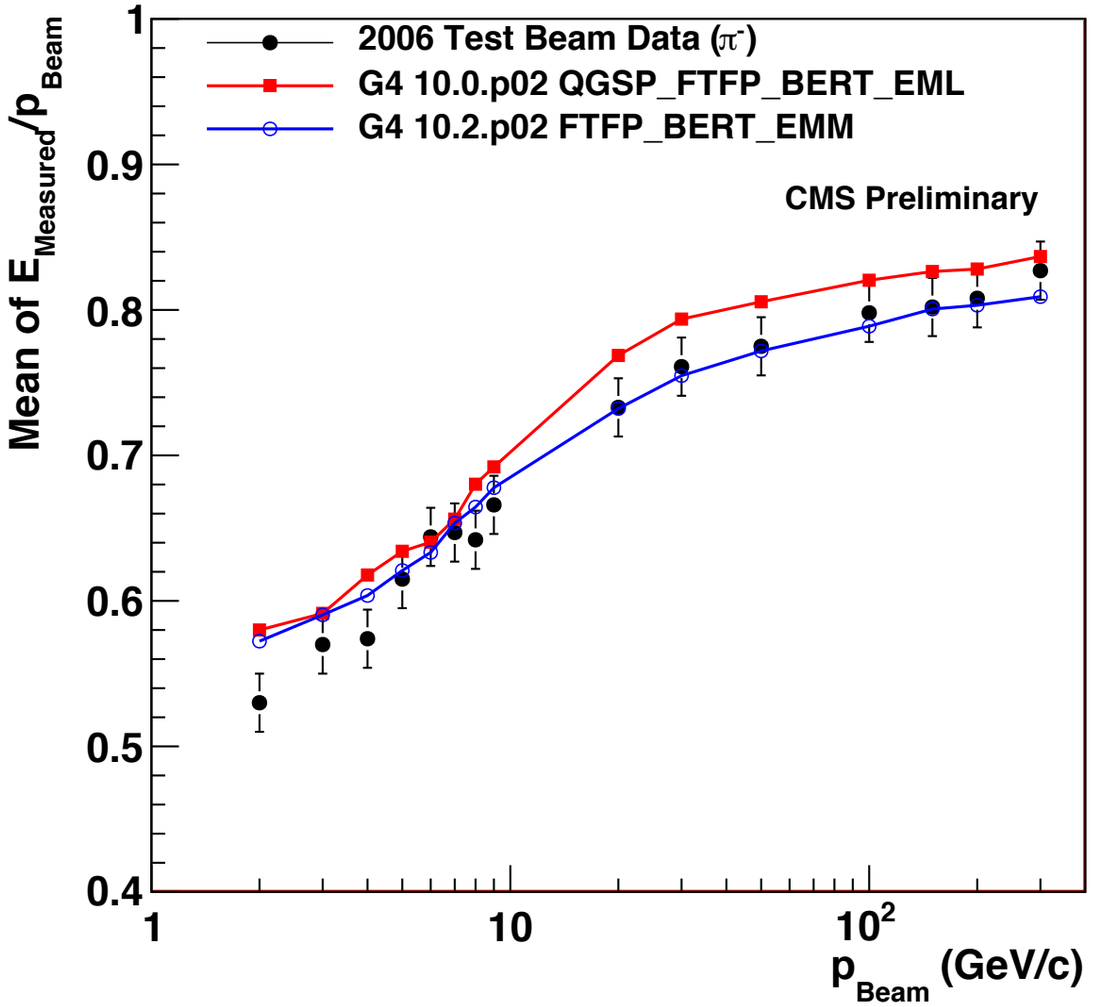
Cut view of CMS

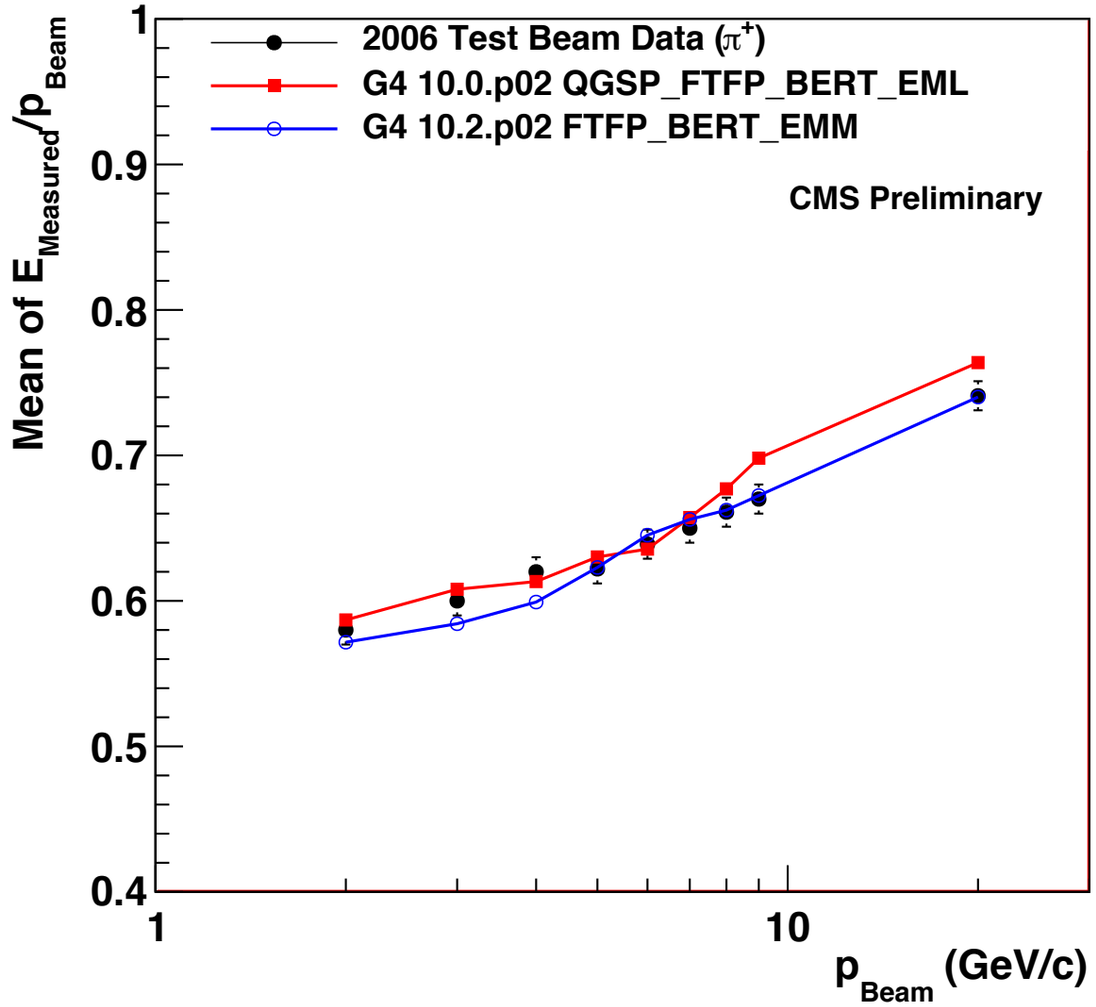
2006 TestBeam Data

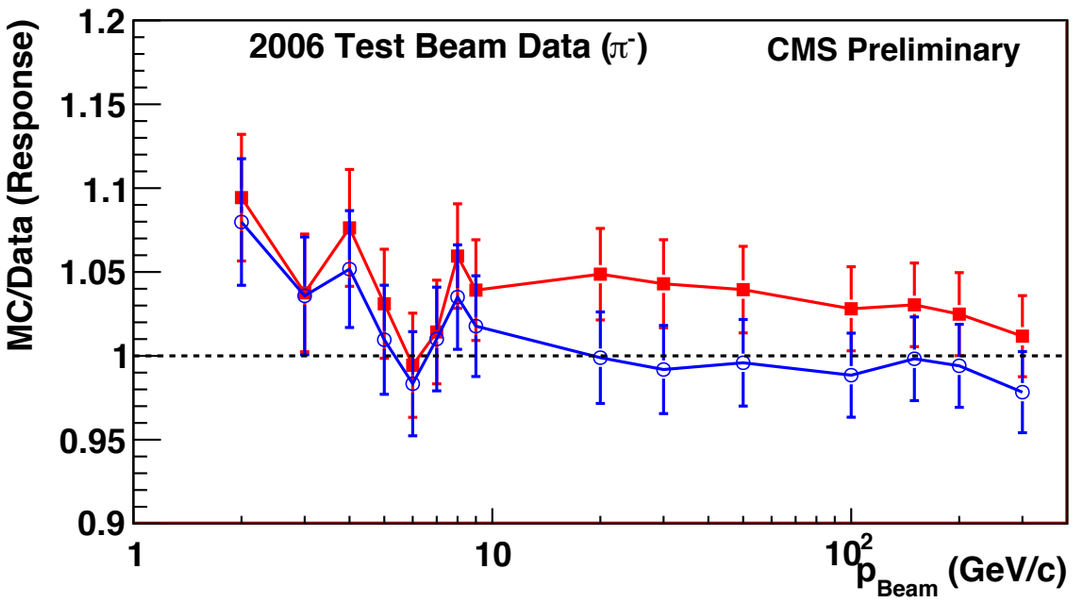
- CMS collected data with prototype of barrel HCAL and barrel ECAL super-module in the H2 test beam area at CERN during 2006.
- Special action was taken to go for low energy (down to 1 GeV) hadron beam using a secondary target
- Beam particle identification utilized data from Cherenkov and TOF detectors
- The results 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

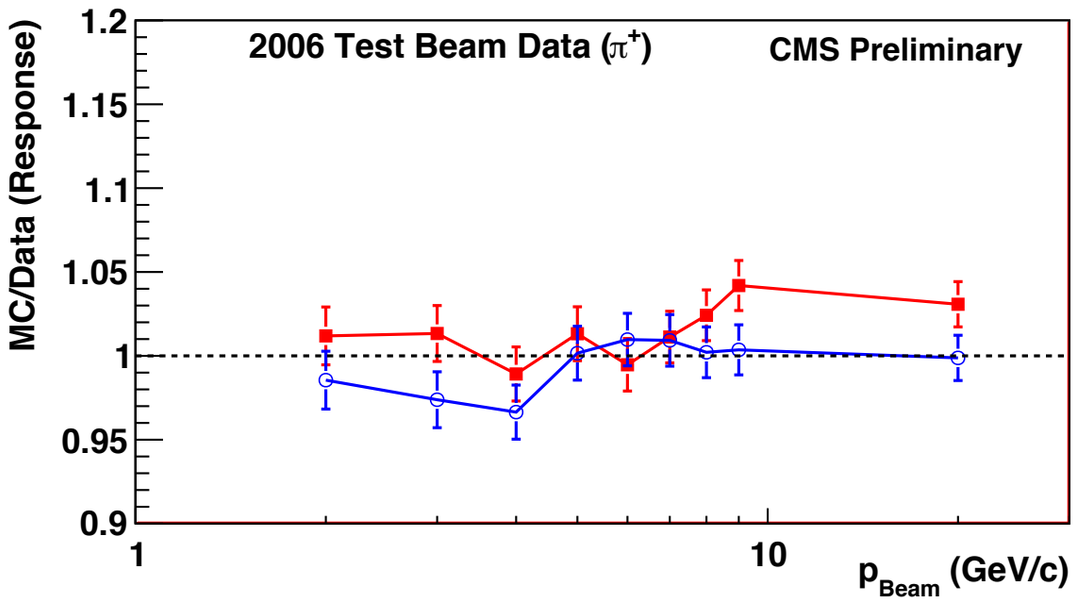


Mean response with pions

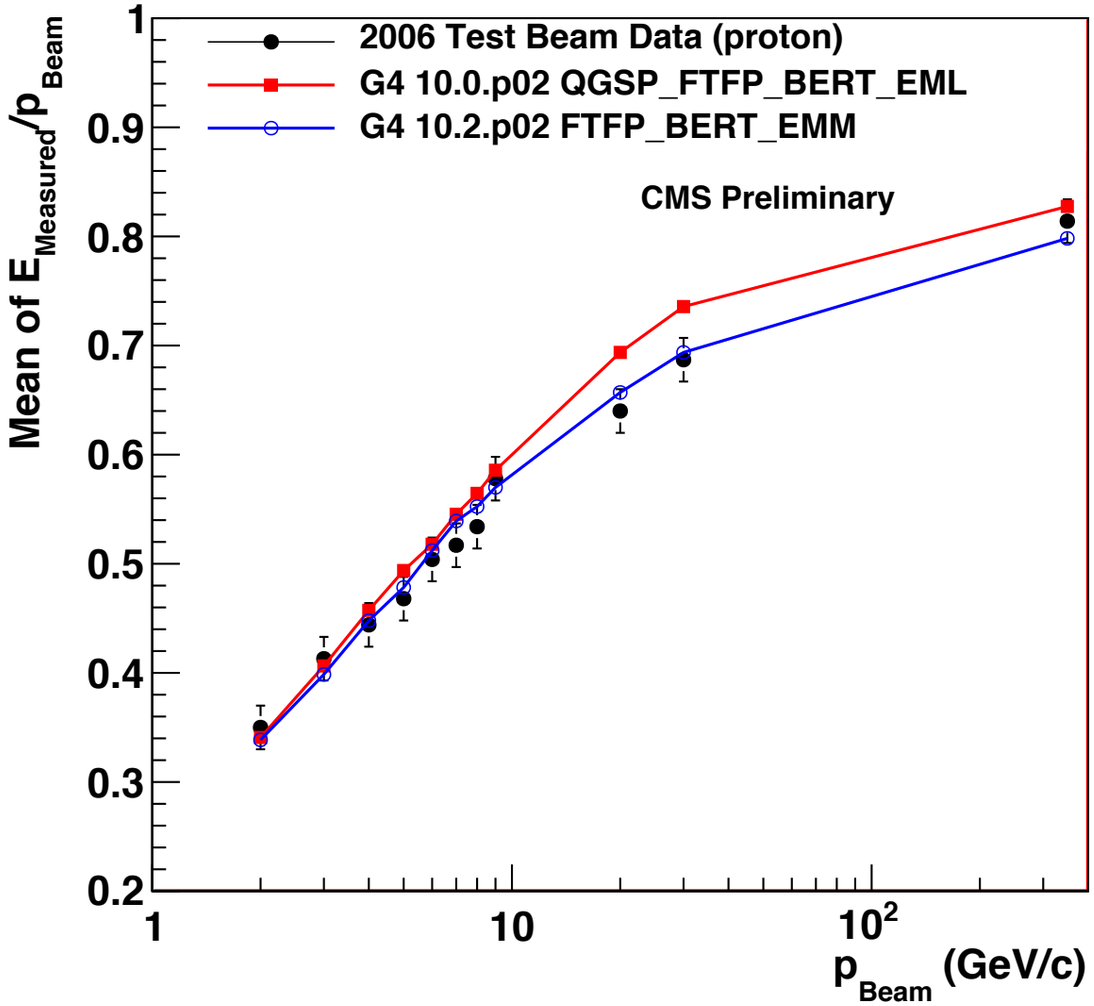


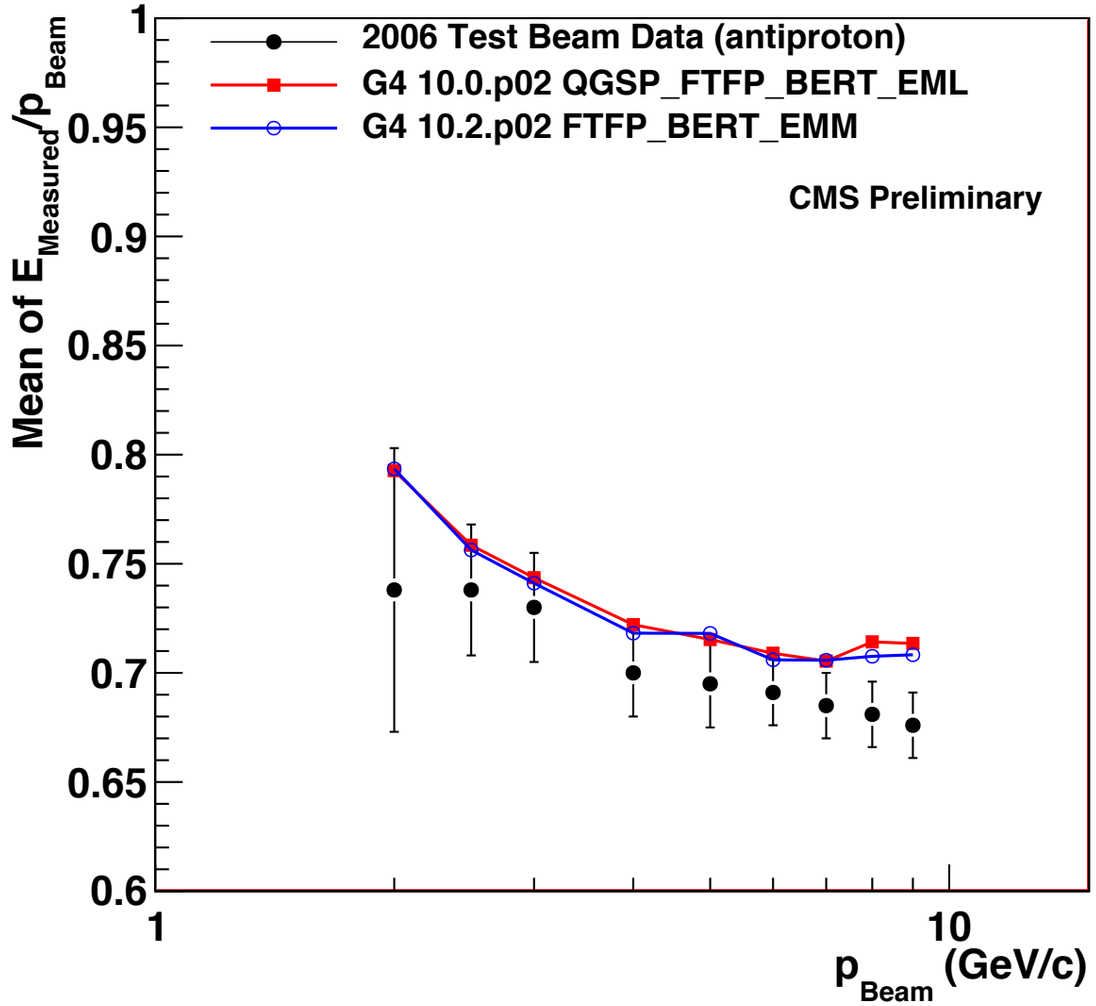


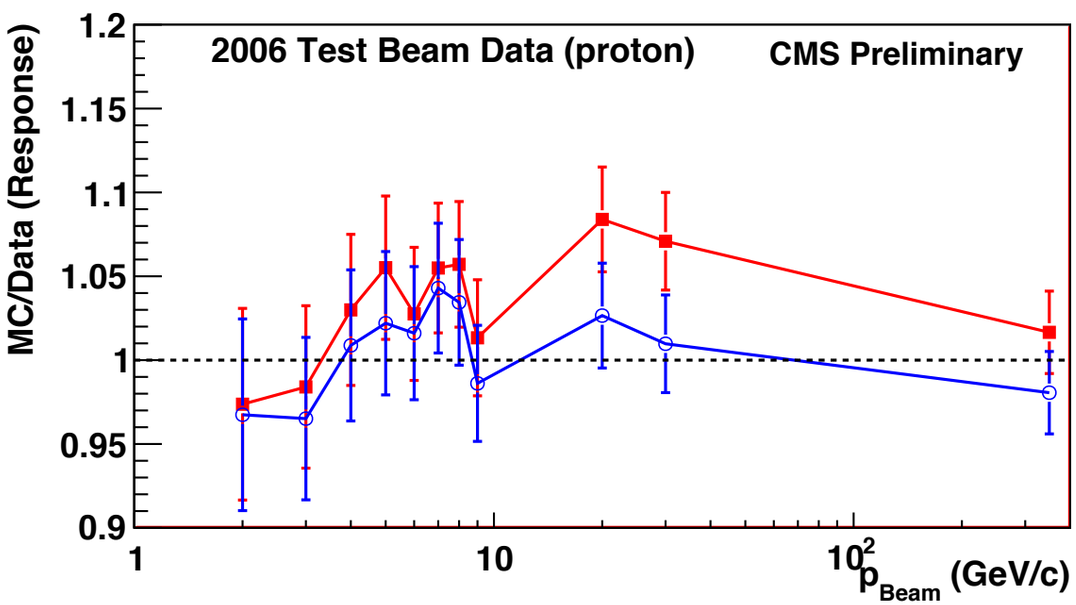


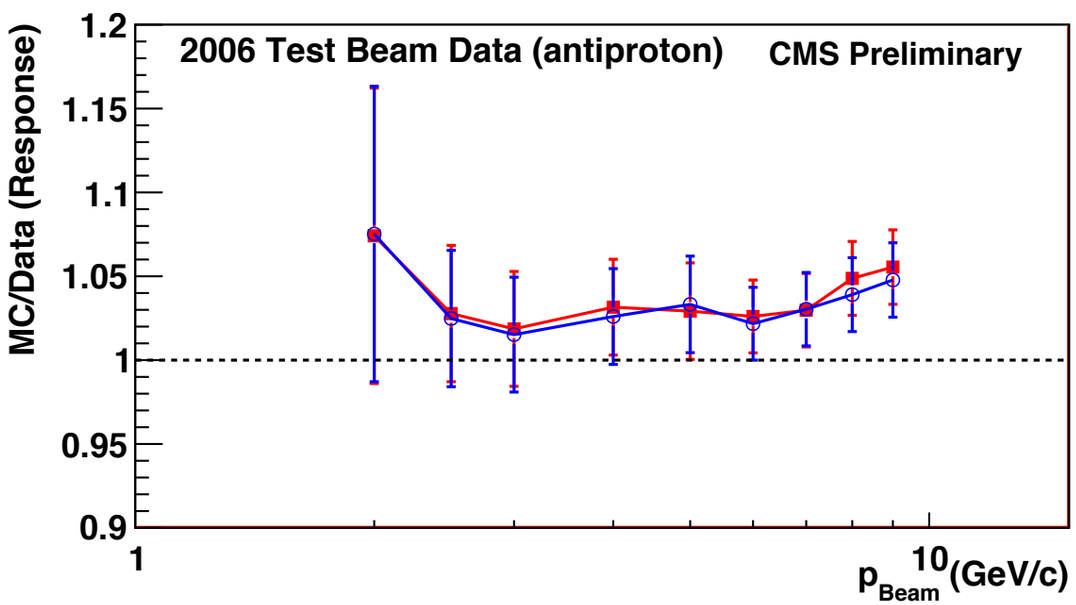


Mean response with protons/antiprotons









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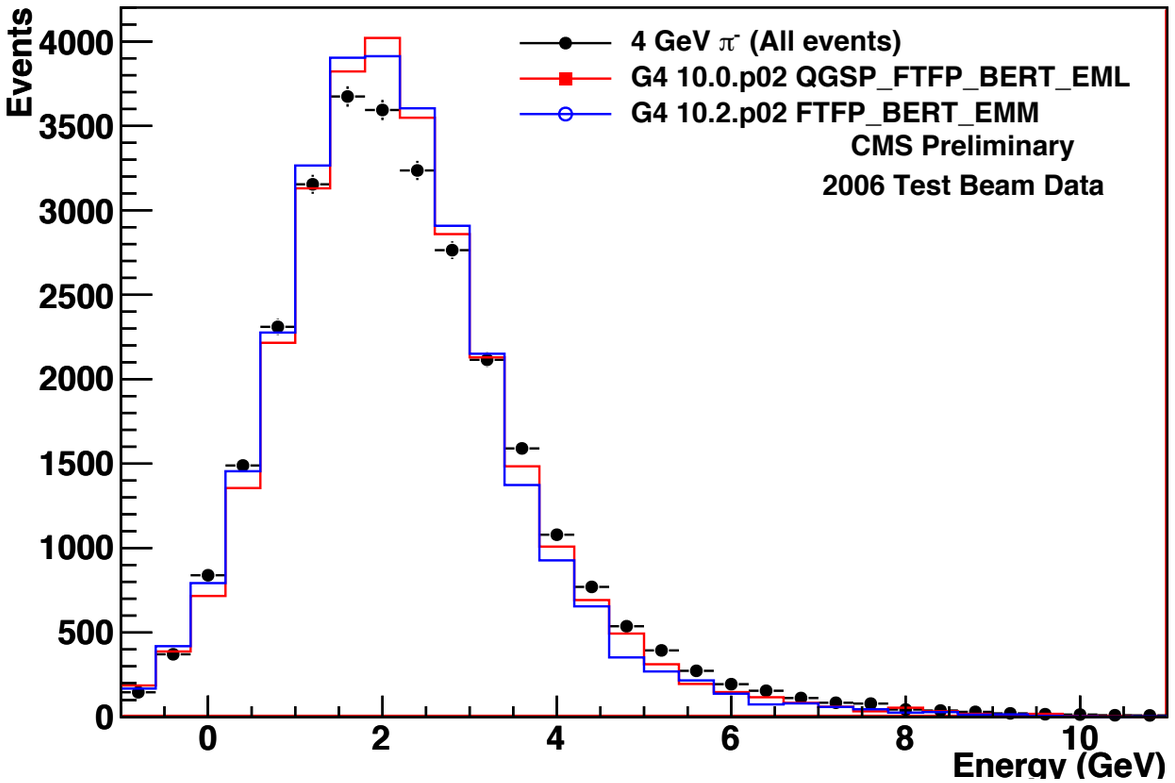
Summary from Mean Response

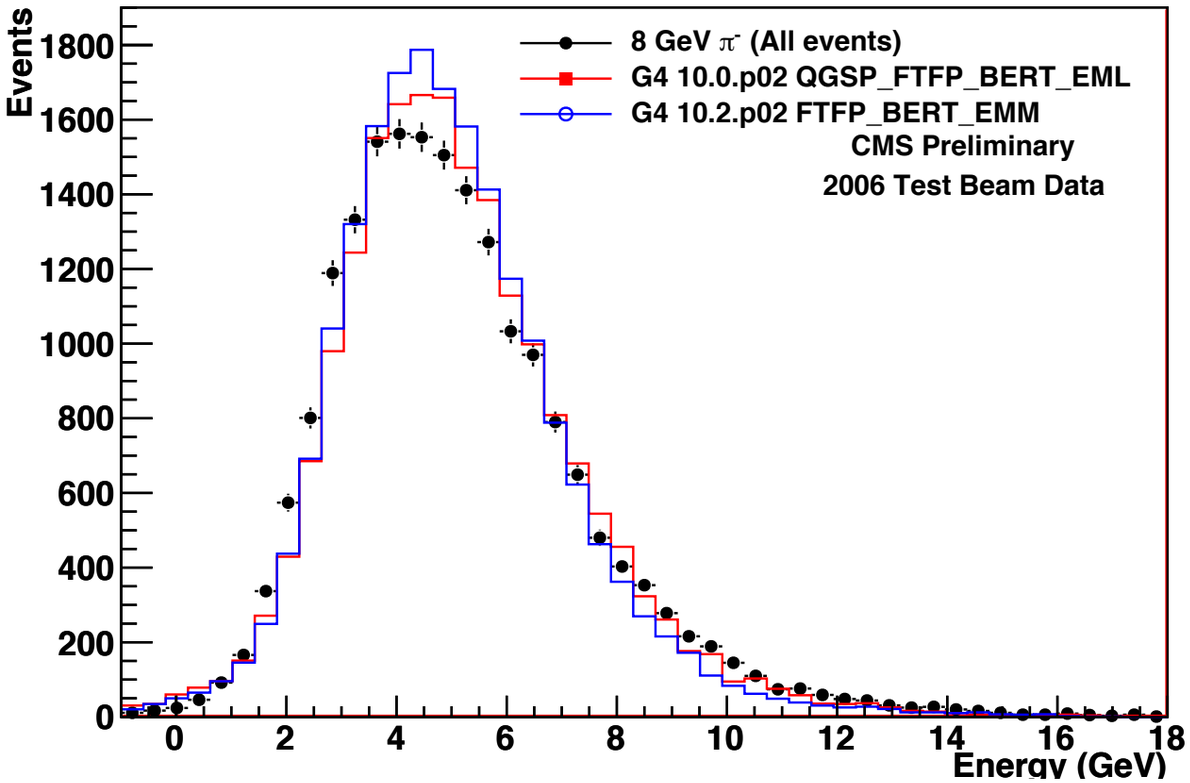
Mean Level of Disagreement between Data and MC

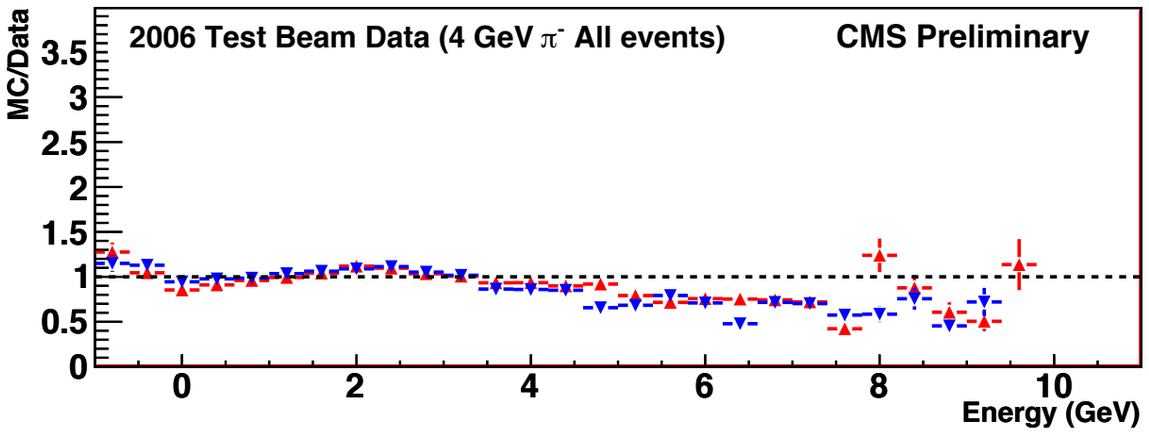
	negative pions	positive pions	protons	anti-protons
G410.0.p02 QGSP_FTFP_BERT_EML	(3.6±0.6)%	(1.9±0.5)%	(4.3±1.0)%	(3.5±0.8)%
G4 10.2.p02 FTFP_BERT_EMM	(1.8±0.7)%	(1.0±0.5)%	(2.2±1.1)%	(3.1±0.8)%

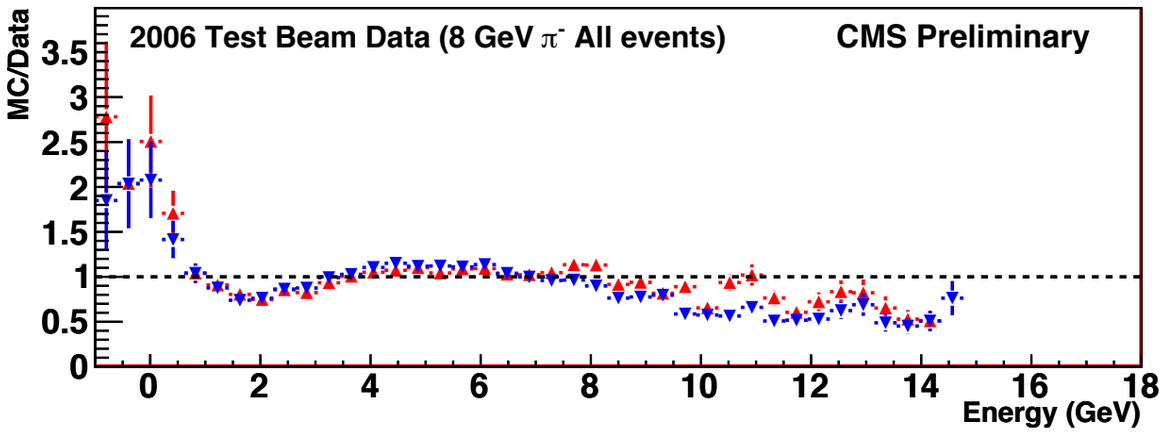
- The level of agreement between data and MC improve in the new model for pions, protons and anti-protons
- pp collisions at high energies produce mostly pions. So one expects to have a better agreement between data and MC with the new physics list in the Geant4 version 10.2.p02

Energy for negative pions (All)



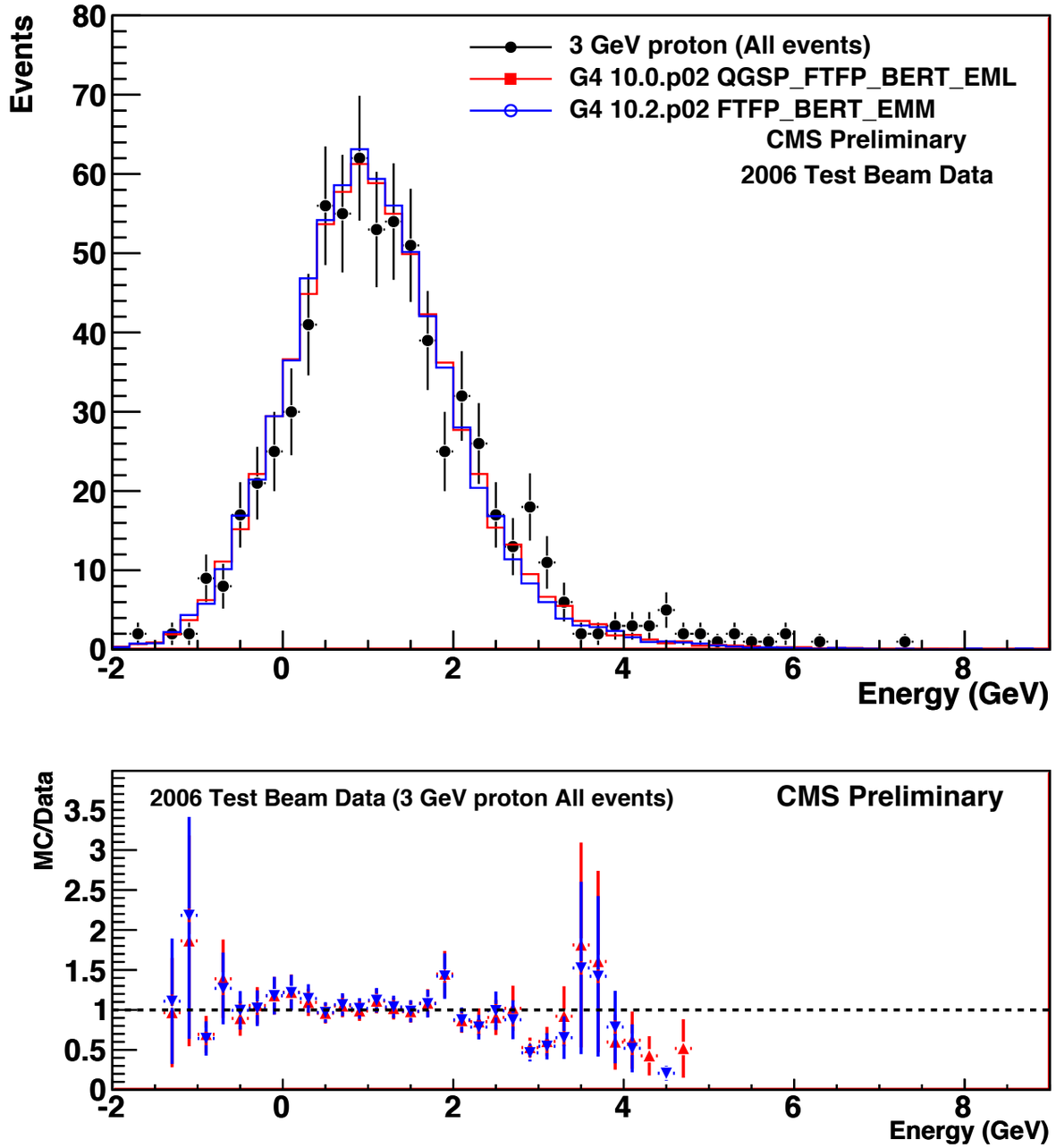


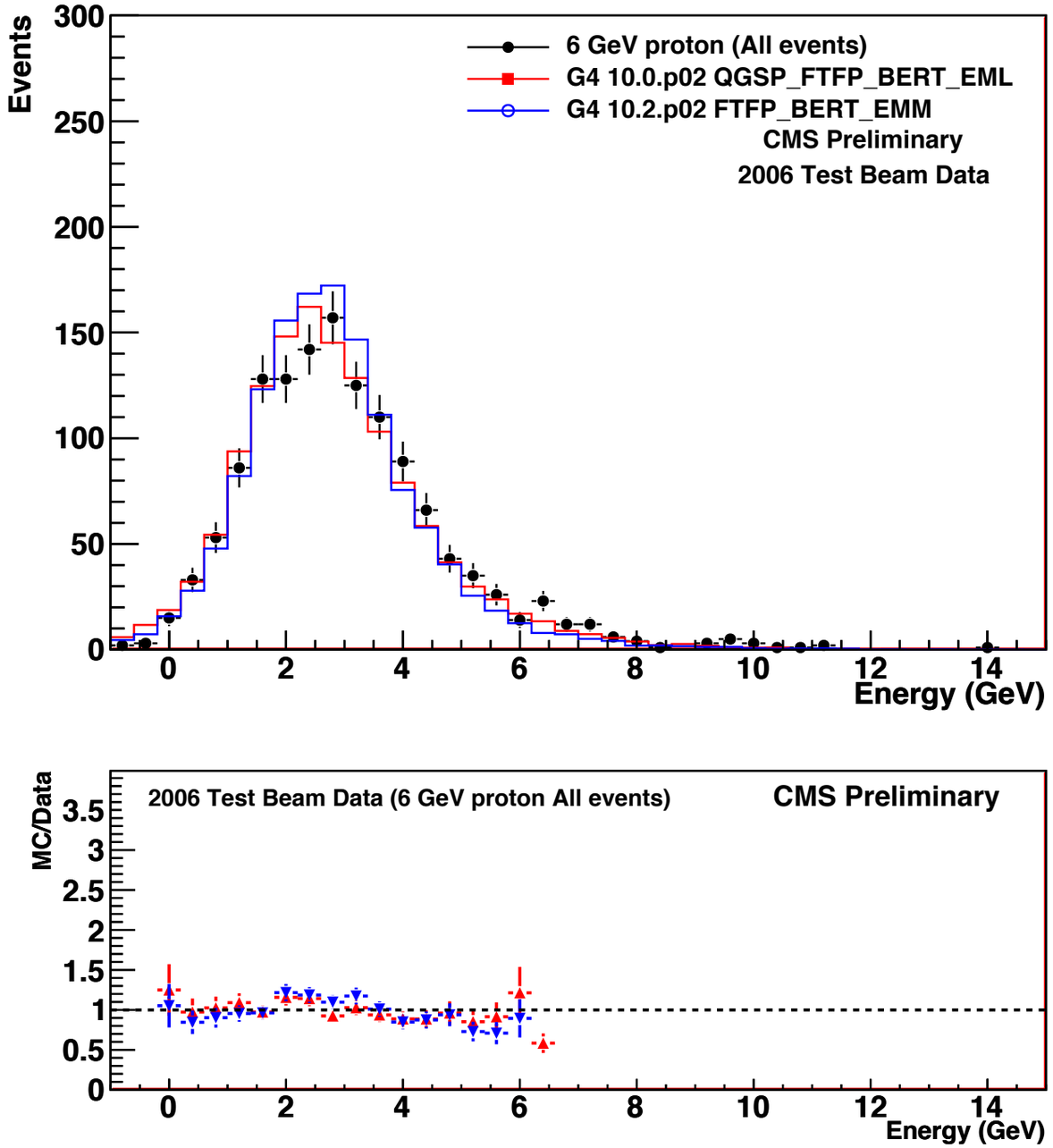




- Total energy measured for negative pion beams of 4 GeV/c and 8 GeV/c
- Fairly good agreement (better than 8% on average) observed in the energy distribution with the data having a slightly longer tail than the MC

Energy for Protons (all)





- Energy distribution for protons at 3 and 6 GeV/c
- Both versions of Monte Carlo provide a decent (within 10% on average) description of the data

Isolated Charged Particles

- Compare ratio of calorimeter energy measurement to track momentum for isolated charged hadrons between data and MC
- Select good charged tracks
  - $p_T > 1$ GeV
  - Chi-square/d.o.f. < 5
  - # of layers crossed > 8
  - fractional error on p < 0.1
  - no missed hits in inner/outer layers
  - originates close to primary vertex (< 0.2 mm in x-y and r-z planes)
  - reach the HCAL 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
  - study energy deposited in an annular region in ECAL (HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices for neutral isolation
- Final cuts
  - no other track in the isolation region
  - energy cut of 2 GeV for neutral isolation
  - no additional good primary vertex in the event (to avoid PU effect)

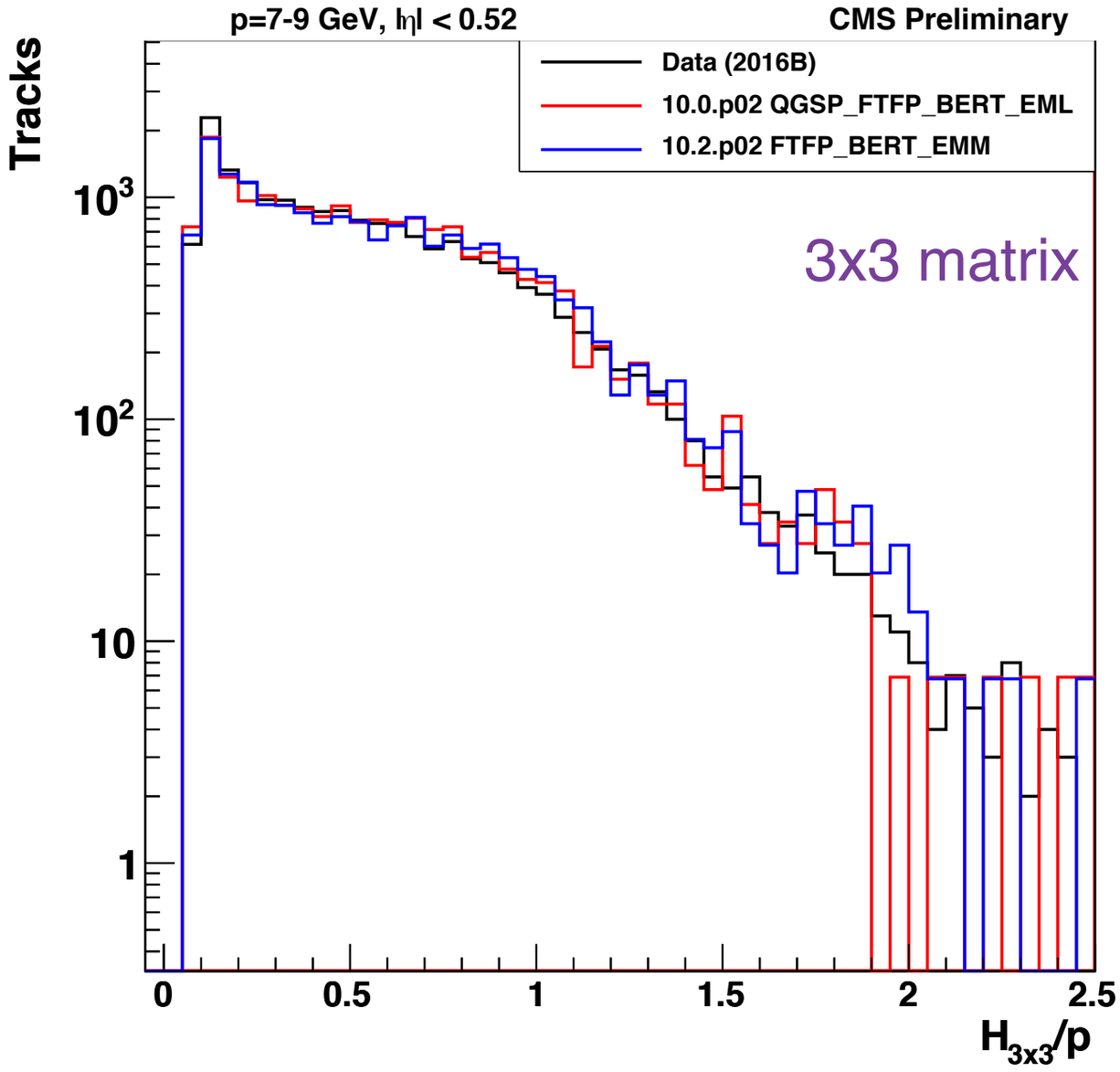
Data Sets Used

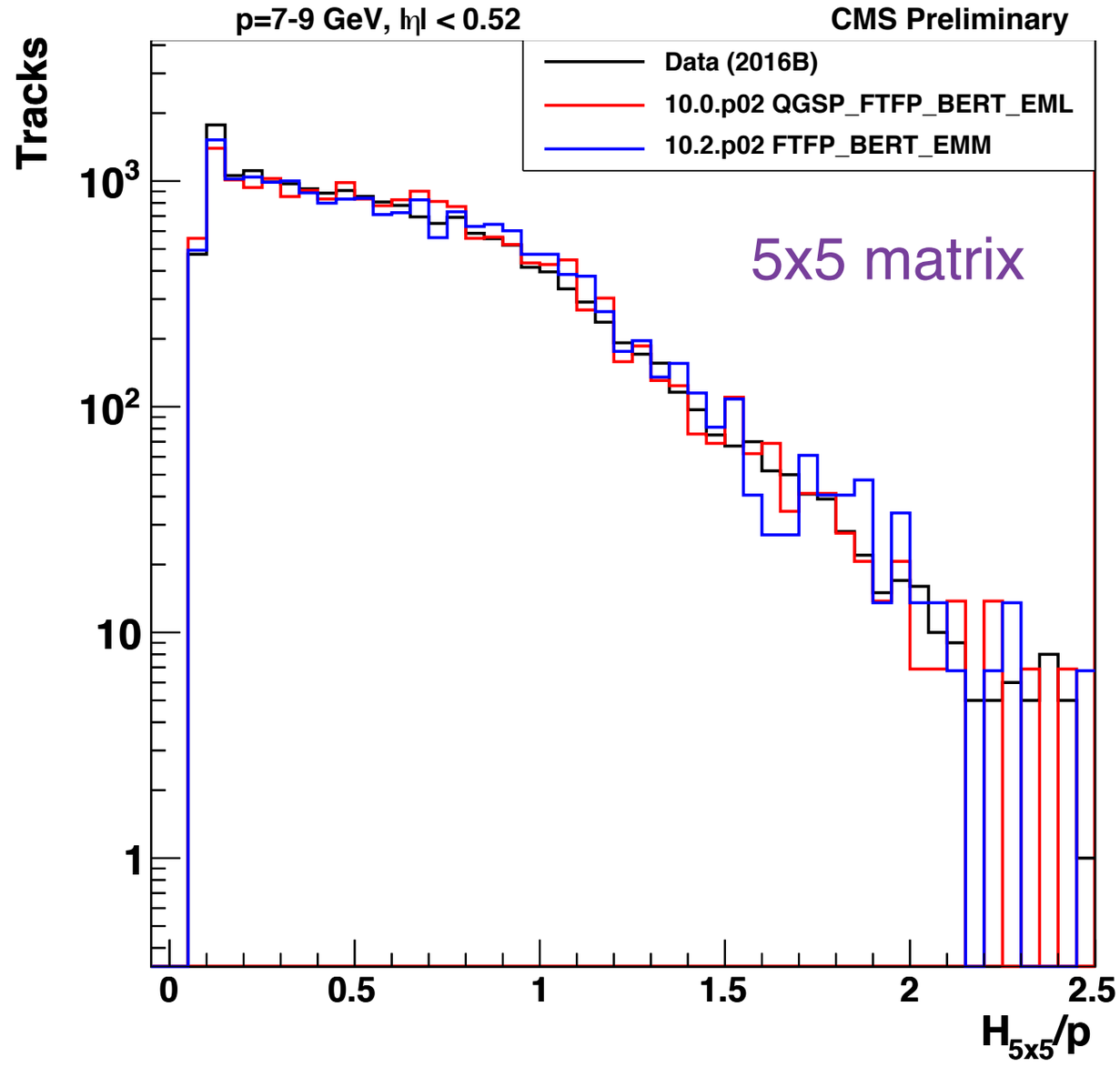
- For Data: Use low luminosity runs taken during 2016B run period:
  - Zero Bias trigger
  - Minimum Bias trigger

  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 (16%), protons (14%) and their anti-particles with a flat energy distribution between 1 and 20 GeV
  - Generate 100k events with Physics List QGSP_FTFP_BERT_EML for Geant4 version 10.0.p02 and with the list FTFP_BERT_EMM for Geant4 version 10.2.p02

- Combine energy measurements from a matrix of NxN cells around the cell hit by the extrapolated track to the calorimeter surface
- Compare energy measured in the calorimeter (scaled by particle momentum) in four regions (two in the barrel, one in the endcap and one in the transition region)

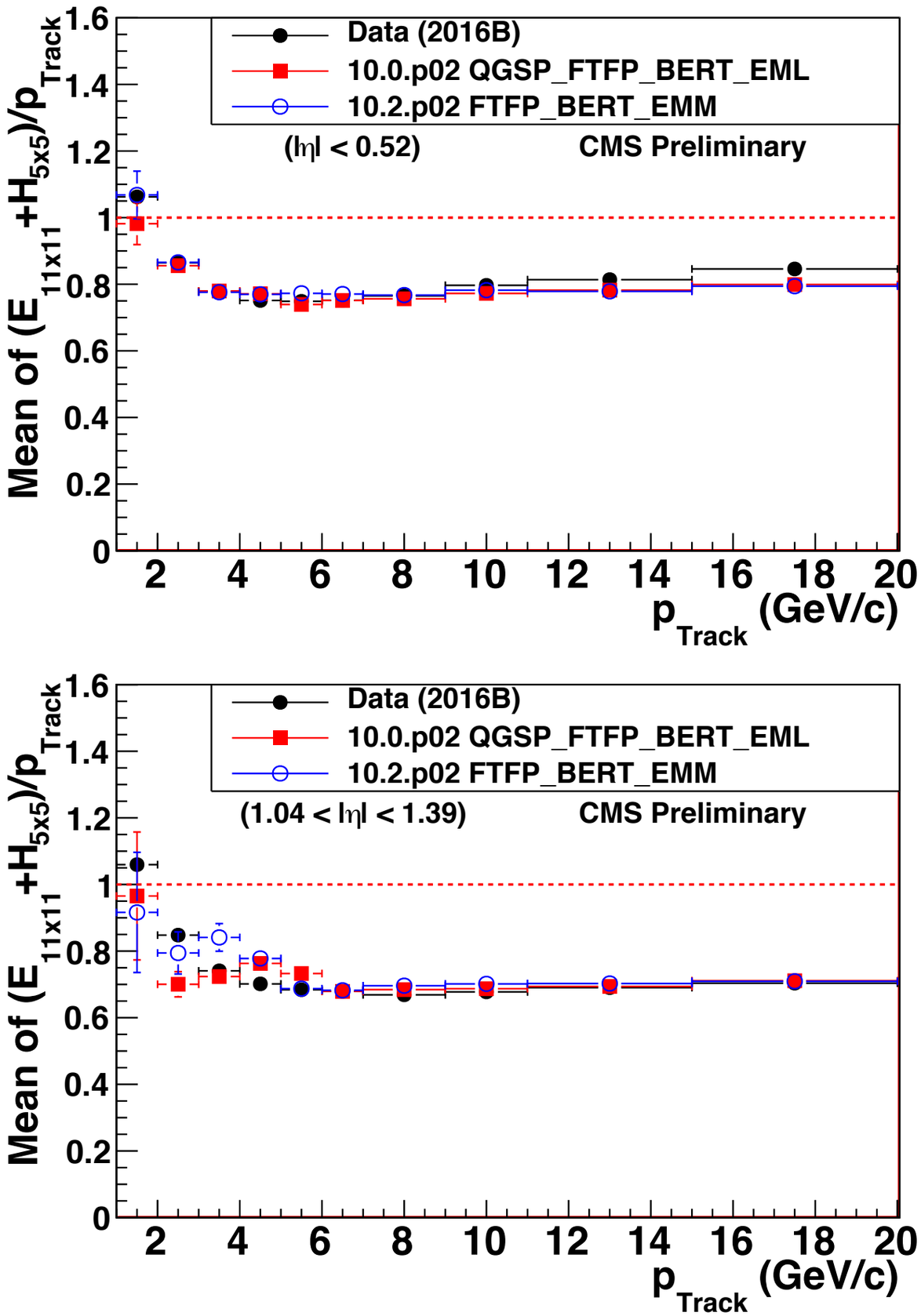
Energy in HCAL

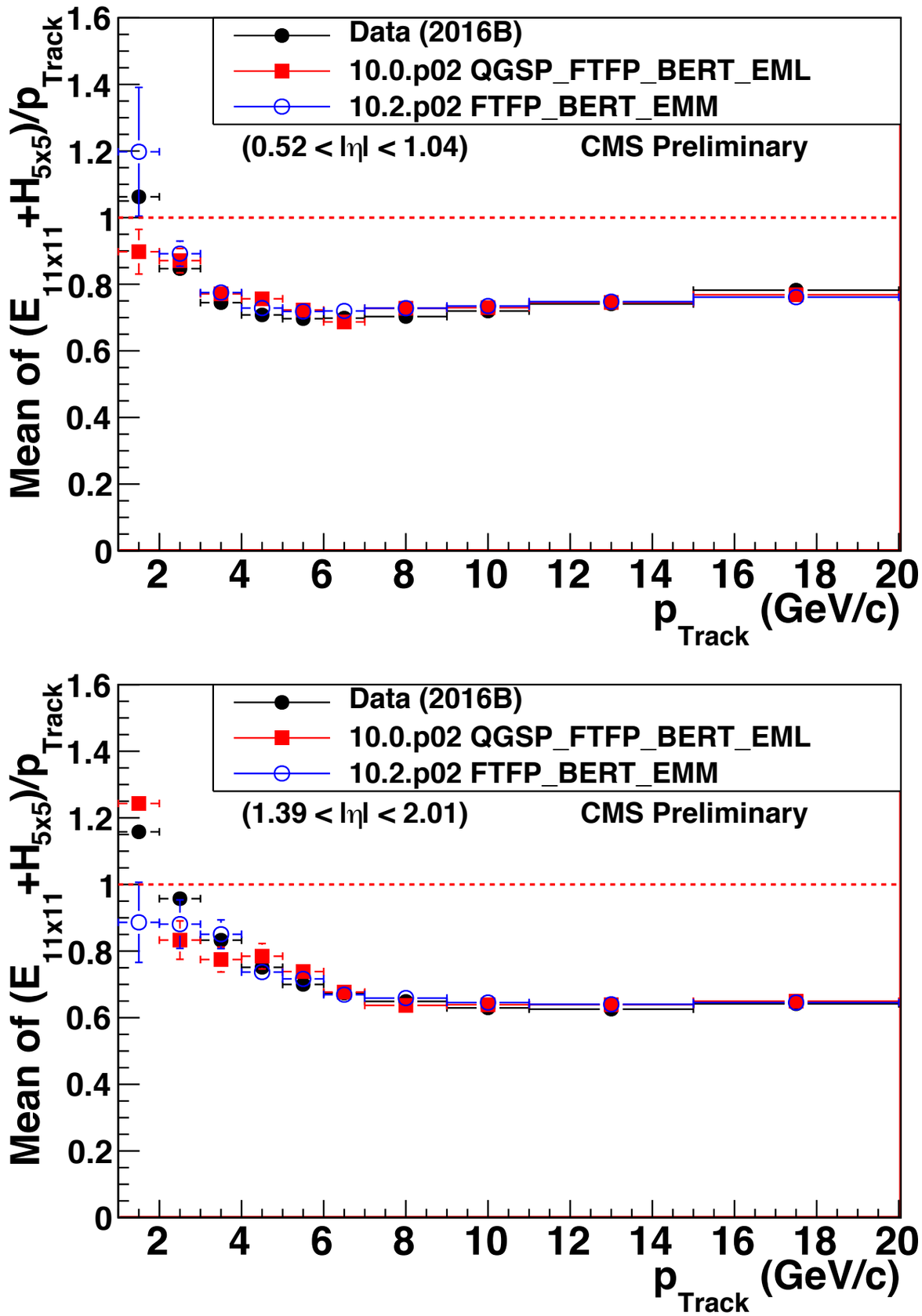




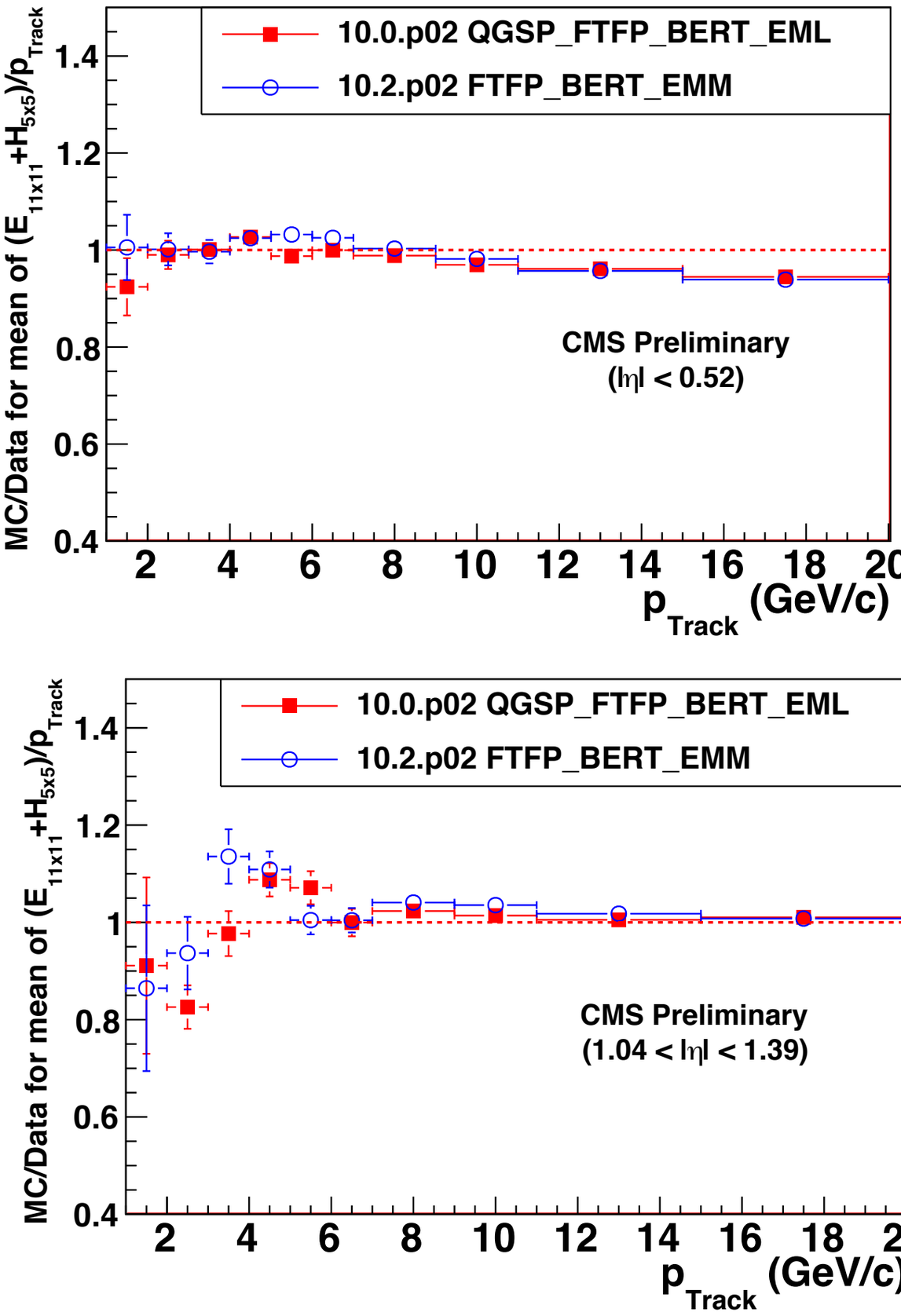
- Two versions of NxN matrix are defined for ECAL and HCAL
  - ECAL uses 7x7 or 11x11 matrix
  - HCAL uses 3x3 or 5x5 matrix

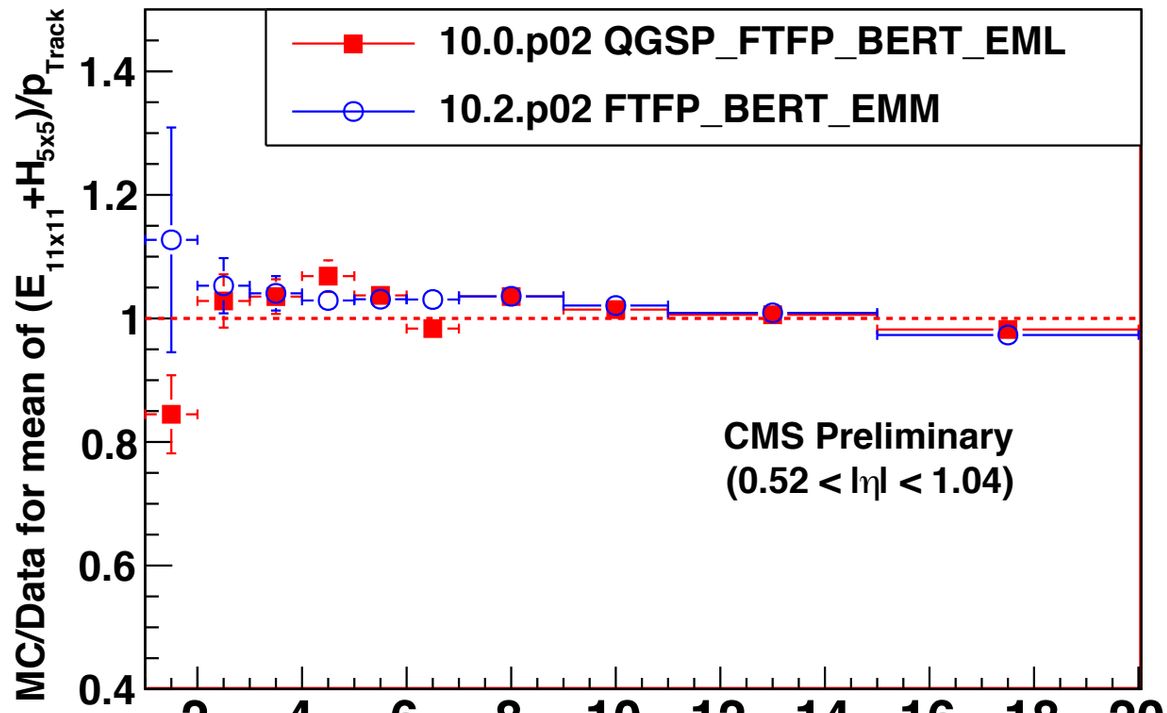
Combined Calorimeter Energy

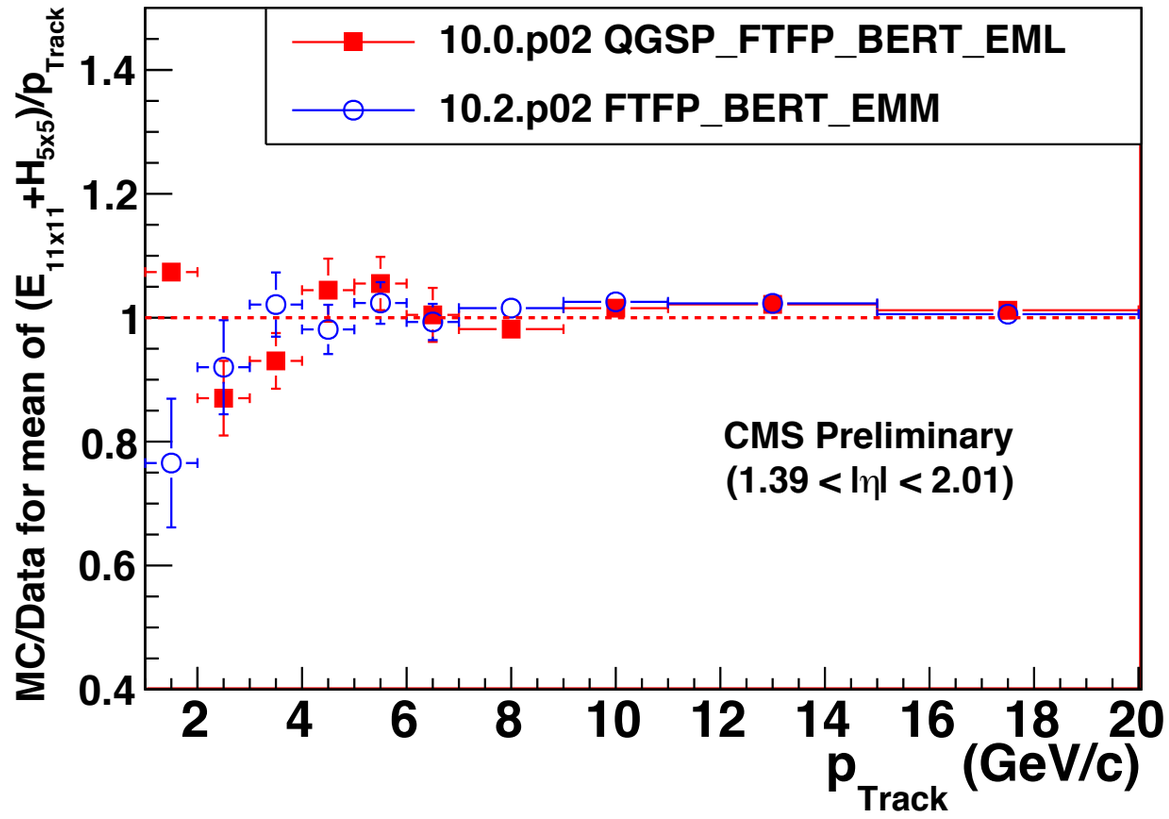




Combined Calorimeter Energy







Level of Agreement

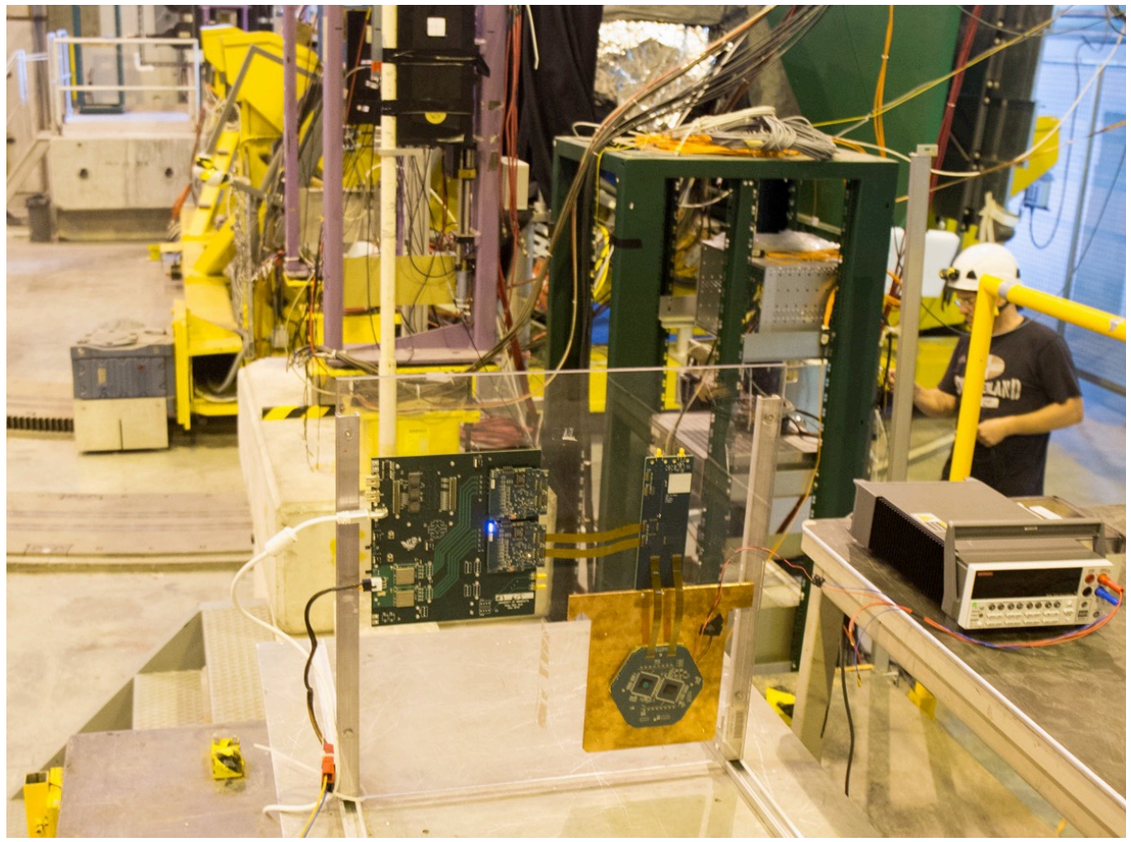
- The level of disagreement between data and MC is between 2 to 5% depending on the region of the detector as well as the physics list used

Mean Level of Disagreement between Data and MC

	$(E_{7x7}+H_{3x3})/p$ 10.0.p02	$(E_{7x7}+H_{3x3})/p$ 10.2.p02	$(E_{11x11}+H_{5x5})/p$ 10.0.p02	$(E_{11x11}+H_{5x5})/p$ 10.2.p02
Barrel 1	(1.1±0.4)%	(2.4±0.4)%	(2.5±0.4)%	(2.6±0.4)%
Barrel 2	(3.4±0.4)%	(3.6±0.4)%	(1.9±0.4)%	(2.2±0.4)%
Transition	(3.7±0.5)%	(4.9±0.5)%	(1.6±0.5)%	(2.2±0.5)%
Endcap	(1.1±0.3)%	(4.1±0.5)%	(4.7±0.4)%	(1.6±0.5)%

Summary

- CMS has compared predictions from two physics lists 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 new version of physics list (FTFP_BERT_EMM) to be used by CMS for its future event production using Geant4 version 10.2.p02
- CMS foresees to continue validation of physics within Geant4

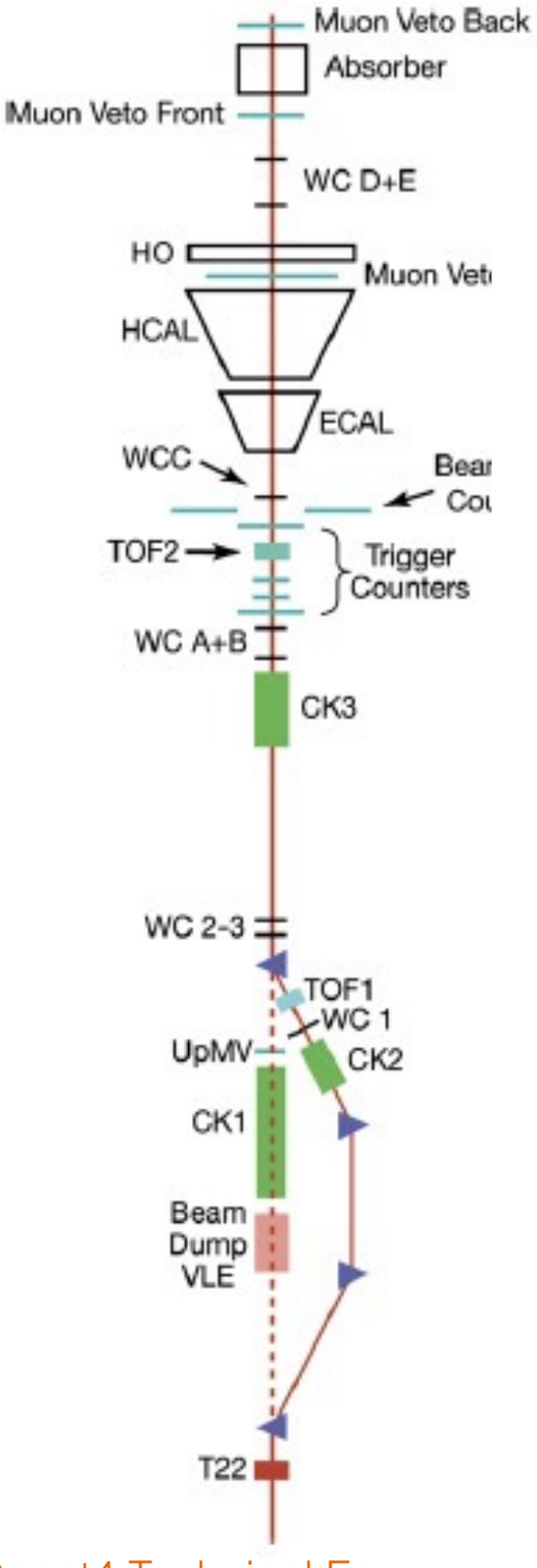
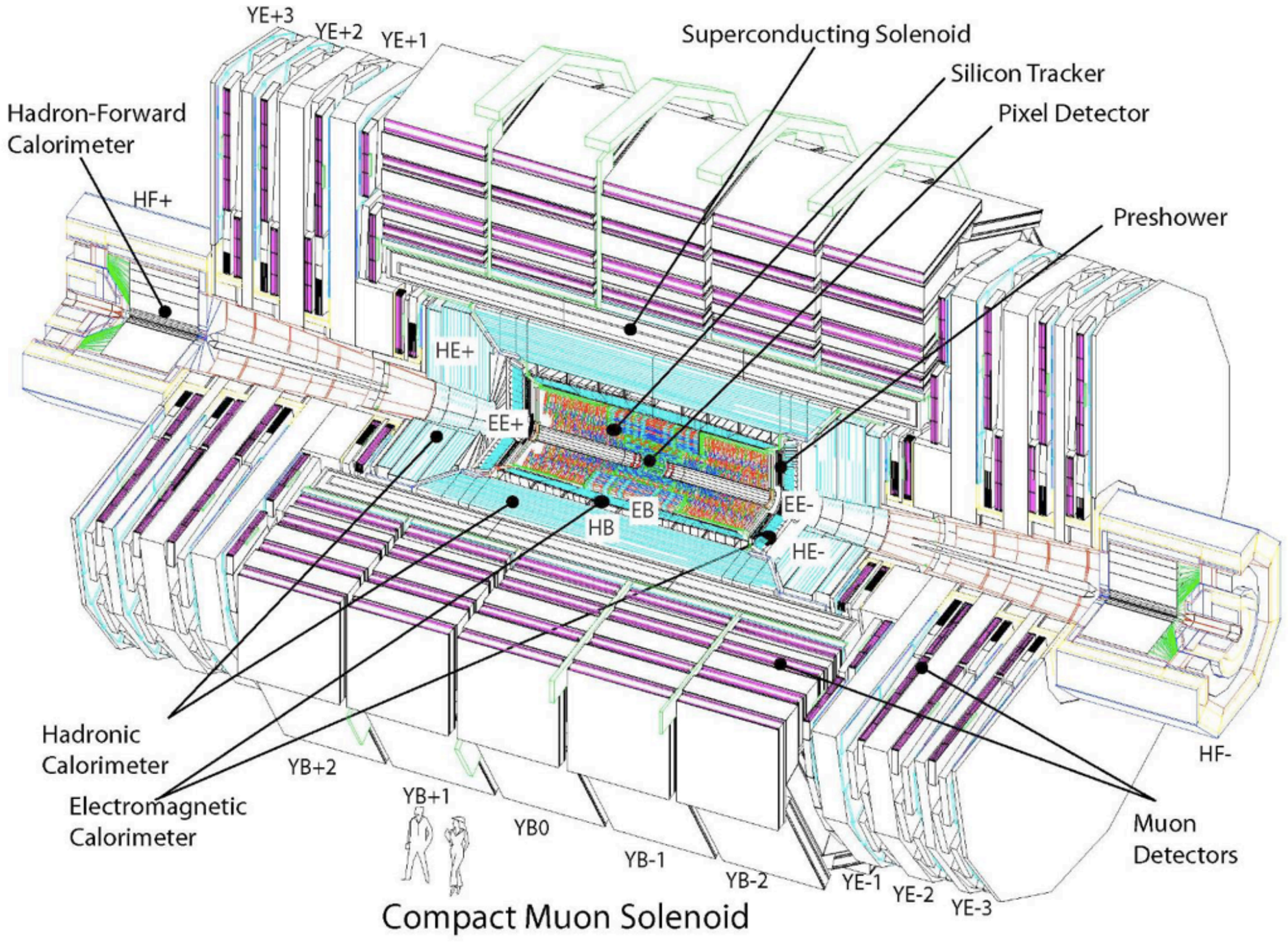


Setup with high granularity calorimeter prototype in CERN and FNAL testbeds

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 multithreading mode from beginning of Run2 (2015)
  - QGSP_FTFP_BERT_EML (with Geant4 version 10.0.p02)
- CMS plans to move to a new physics list for its production plan for 2017
  - FTFP_BERT_EMM (with Geant4 version 10.2.p02)
- FTFP_BERT is the recommended physics list from Geant4 collaboration [J.Allison et al., NIM A506 (2003) 250; NIM A835 (2016) 186]

- The list QGSP_FTFP_BERT combines QGSP, FTFP, Bertini Cascade models for π/K/p/n with a fixed validity region:
  - Bertini Cascade valid at ≤ 8 GeV
  - FTFP valid between 6 and 25 GeV
  - QGSP valid at ≥ 12 GeV
- The list FTFP_BERT uses FTFP and Bertini Cascade models:
  - Bertini Cascade valid at ≤ 5 GeV
  - FTFP valid at ≥ 4 GeV
- EML, EMM specify the physics models for electromagnetic processes
  - EML utilizes simplified multiple scattering model for all detectors
  - EMM uses the default multiple scattering model for HCAL and the simplified one for other detectors (handling of multiple scattering is critical for sampling calorimeters)

Beam Line and Detectors