Hadronic Performance

Outline

- Introduction
- Thin target comparisons
  - BNL pA data at 14.6 GeV
  - MIPP pA data at 56-120 GeV
- Collision data from LHC

Sunanda Banerjee

Introduction (I)

- Three hadronic models are used extensively in explaining LHC data:
  - Bertini cascade model at low energies
  - FTF model at intermediate to high energies
  - QGS model at high energies
- While QGS model development has been static over past few years, continuous development has been happening to Bertini-cascade and FTF models
- Also hadronic cross sections are getting improved over years
- test47 package has been developed to validate intermediate to medium-high energy hadronic models using data from ITEP, BNL and MIPP experiments

Introduction (II)

- Cross section packages are improved for every reference release during this year (geant4.9.6 version)
  - Mainly technical and optimization work in view of multi-threading
  - Some progress on cross sections for anti-particles and ions
- Several improvements has happened to Bertini cascade model and the changes are well documented
  - Technical changes for MT and numerical precision
  - Interface modification for momentum and angular distributions
  - Improvement and extension of angular distribution description
  - Some new data on cross sections used in this model
  - Changes in the de-excitation model
  - Addition of a new N-body phase space
- Some improvements also happen to FTF
  - Introducing nucleus-nucleus collision
  - Improvement of annihilation at rest
  - New parameterization of the cross sections
  - Technical changes in view of multi-threading

Introduction (III)

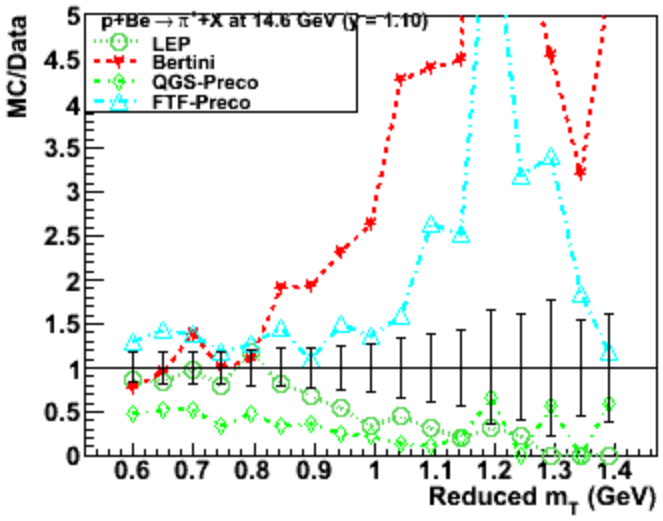
- Four models tested in 9.6.ref05, ref06, ref07 and ref08 for data at 14.6 GeV/c
  - LEP, Bertini, QGSP, FTFP
- Also looked into evolution of two of these models with time
  - Seven versions of Bertini cascade code are tried
    - As in 9.3.p01, 9.3.ref06, 9.4.ref00, 9.5.ref00, 9.6.ref05, 9.6.ref06, 9.6.ref08
  - Seven versions of FTFP model
    - As in 9.3.p01, 9.3.ref06, 9.4.ref00, 9.5.ref00, 9.6.ref05, 9.6.ref06, 9.6.ref08
- Three models tested in 9.6.ref05, ref06, ref07 and ref08 for MIPP data
  - HEP, QGSP, FTFP
- Also looked into evolution of these three models with time
  - 9.4.ref09. 9.5.ref00, 9.5.ref02, 9.6.b01, 9.6.ref00, 9.6.ref04, 9.6.ref05, 9.6.ref07, 9.6.ref08
- Physics list QGSP_FTFP_BERT_EML is compared with CMS collision data using 9.5.p02

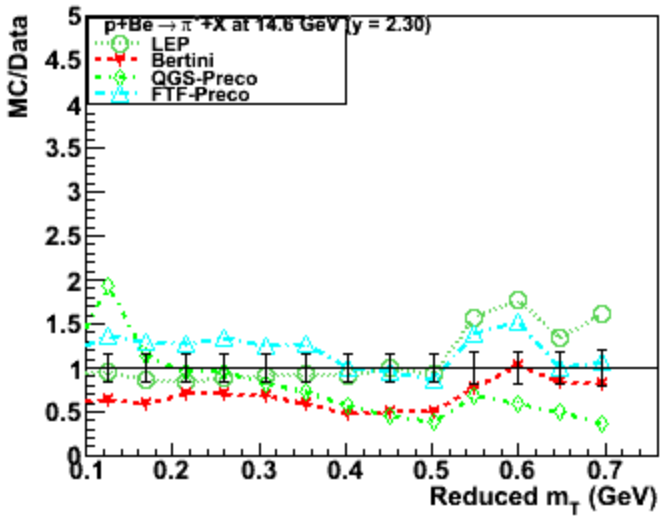
BNL Data

- Data set from BNL E-802: T. Abbott et al. (Phys. Rev. D45, 3906)
- Inclusive $\pi^{\pm}$, $K^{\pm}$ and proton production from p beams at 14.6 GeV/c on a variety of nuclear targets (Be … Au)
- Data quality: statistical error 5-30%; systematic uncertainty 10-15%
- Targets studied Be, Al, Cu, Au for all the final states available
- For calculation of invariant cross sections in the BNL data constant bin width of ($\Delta y = \pm 0.1$) is used.

π^+ in pA Interactions at 14.6 GeV/c

9.6.ref08

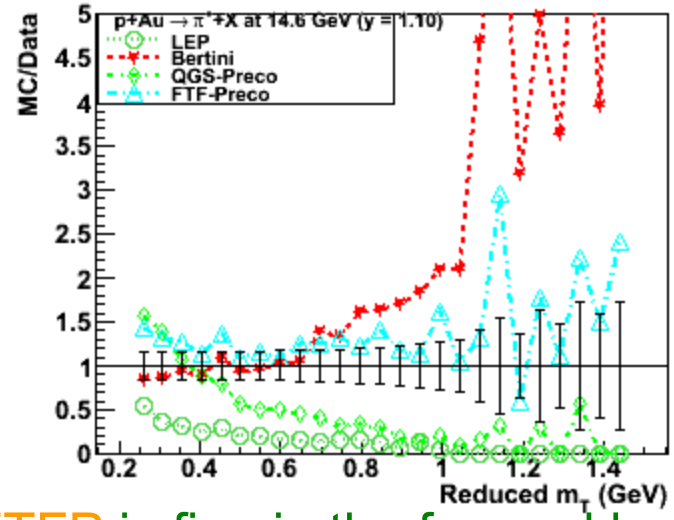


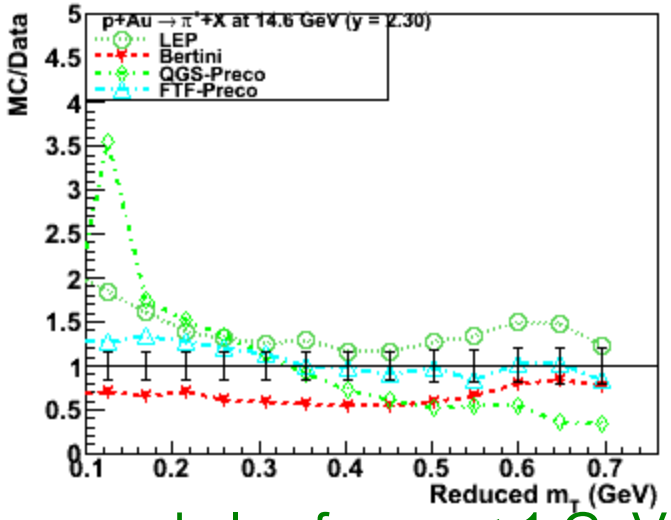


Be

y = 1.1

y = 2.3



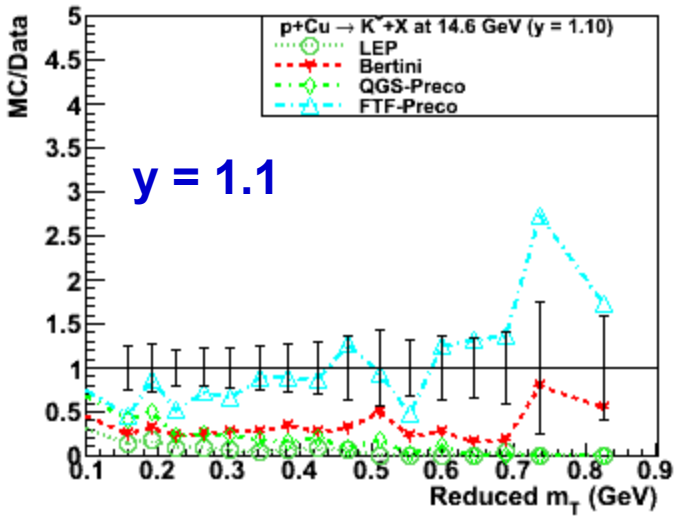


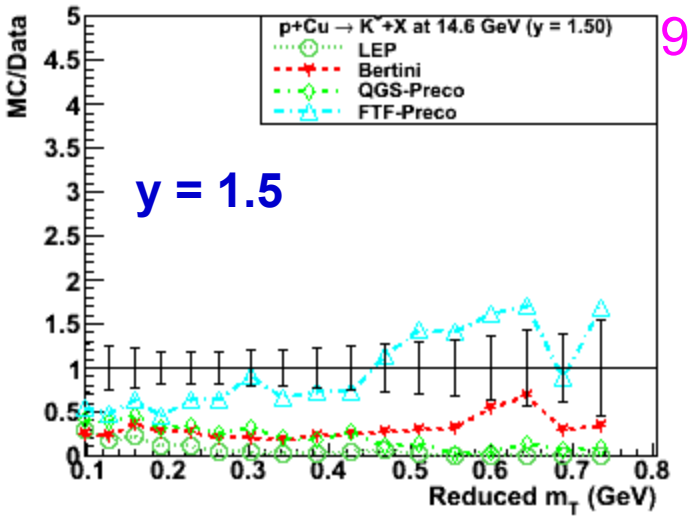
Au

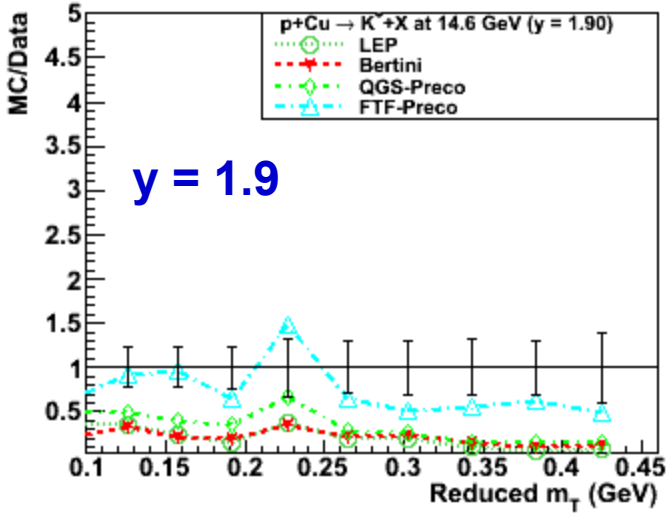
FTFP is fine in the forward hemisphere and also for m_T < 1 GeV (backward). Bertini has issues: more in the backward hemispehre

K^+ in pCu Interactions at 14.6 GeV/c

9.6.ref07



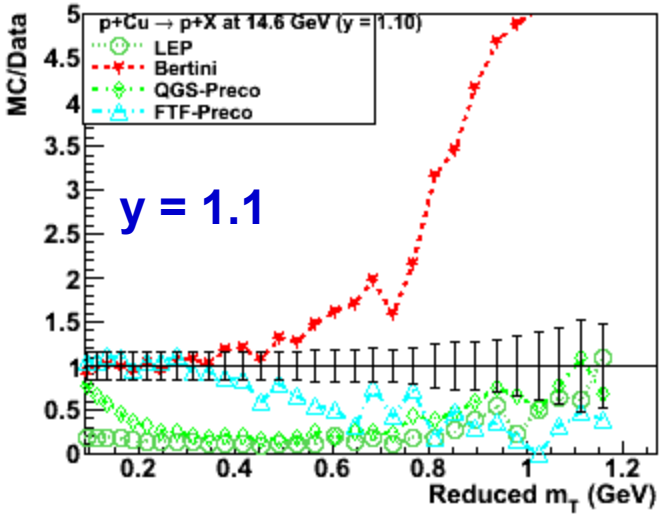


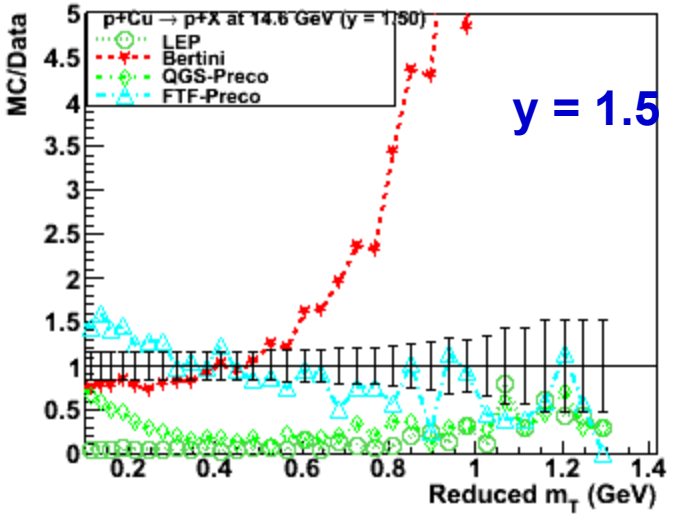


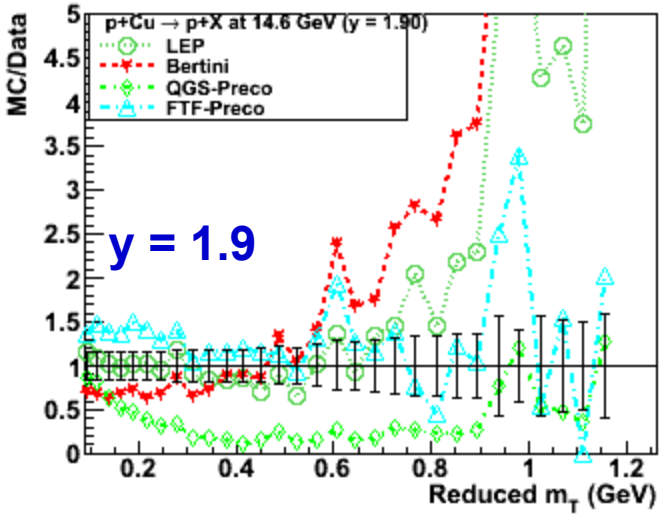
- All models other than FTFP under-estimates the predicted cross section by a large amount

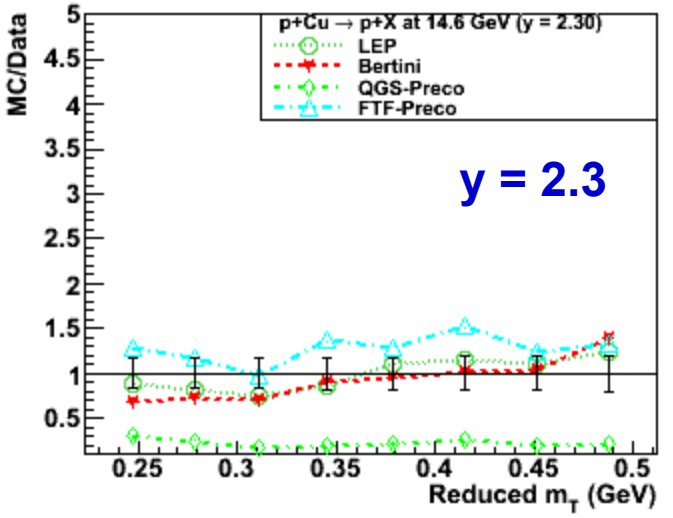
p in pCu Interactions at 14.6 GeV/c

9.6.ref06









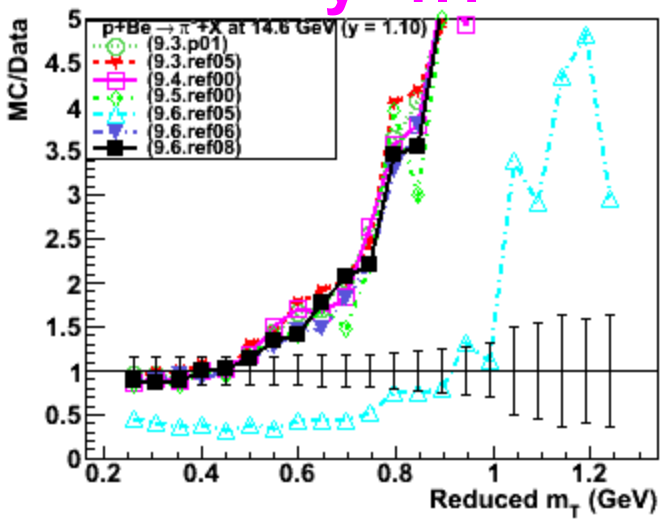
- FTFP provides the best predictions

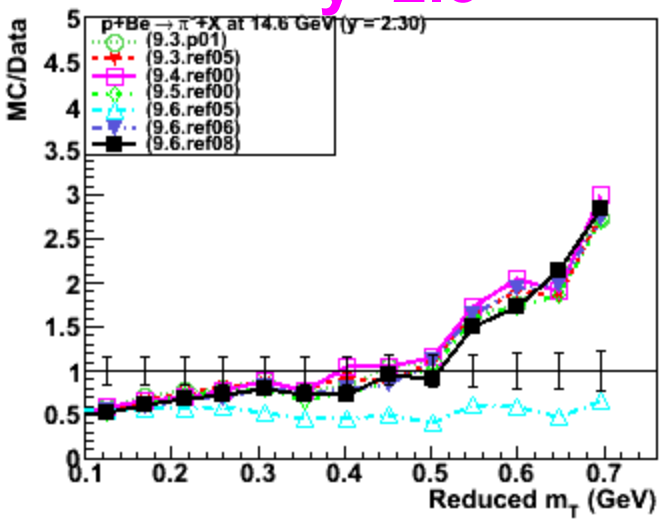
$p + A \rightarrow \pi^- + X$ at 14.6 GeV/c (Bertini)

y=1.1

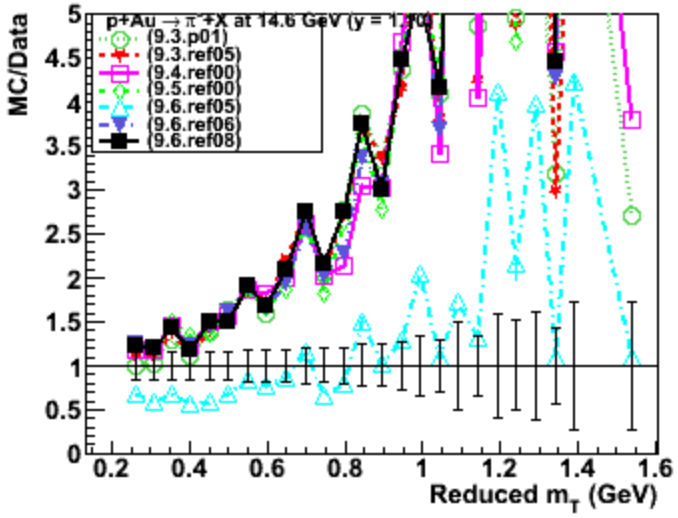
y=2.3

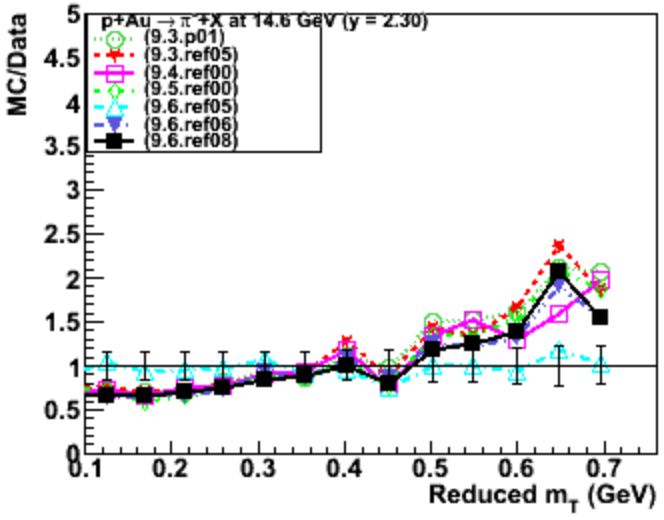
Be





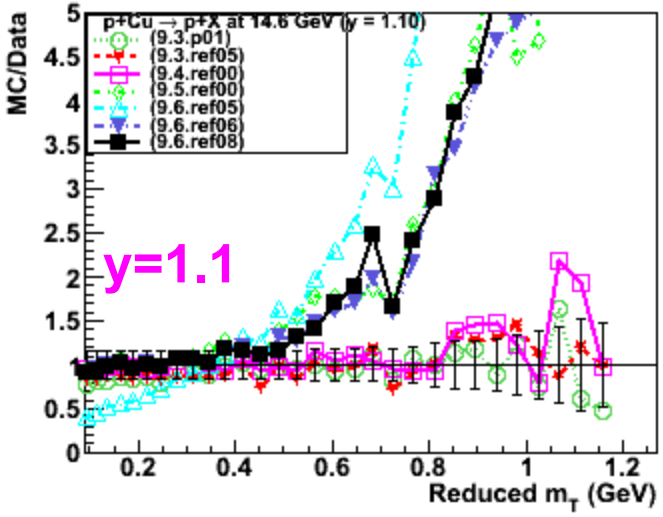
Au

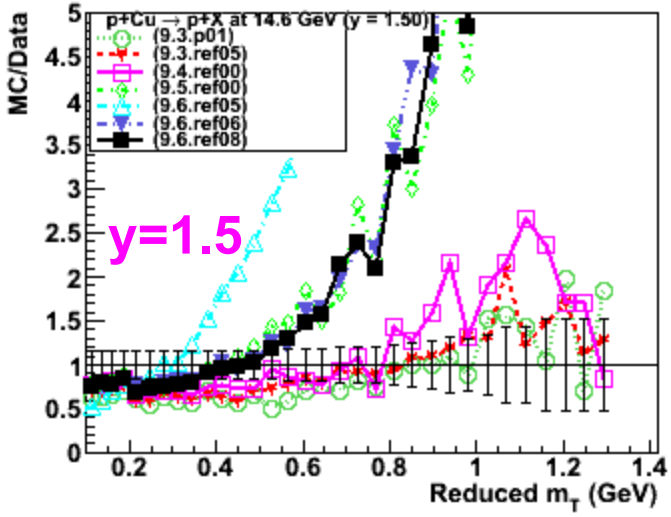


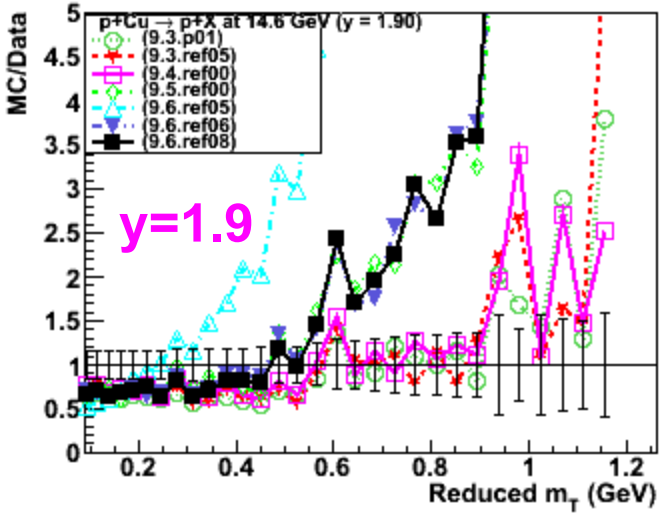


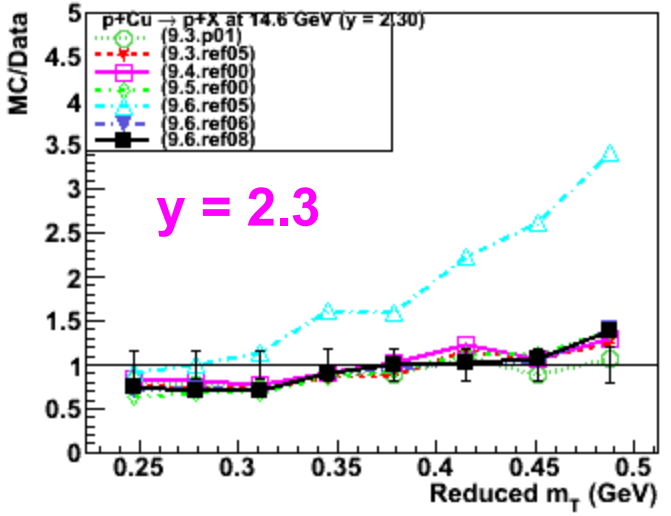
There was a significant deterioration in the description in 9.6.ref05.
This was recovered in subsequent Bertini cascade code

p + Cu → p + X at 14.6 GeV/c (Bertini)





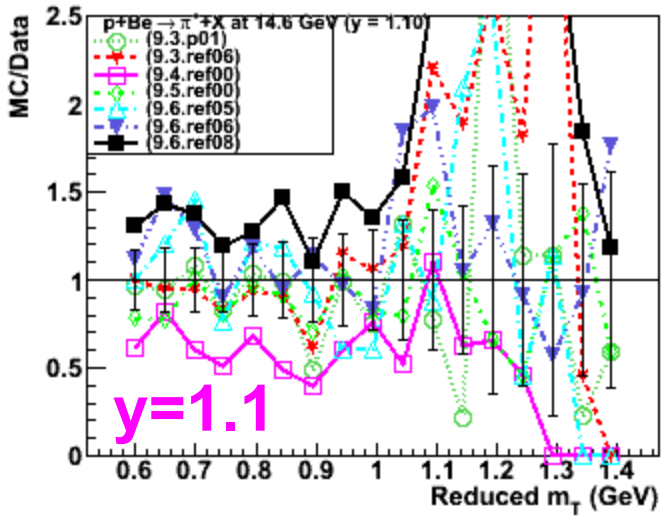


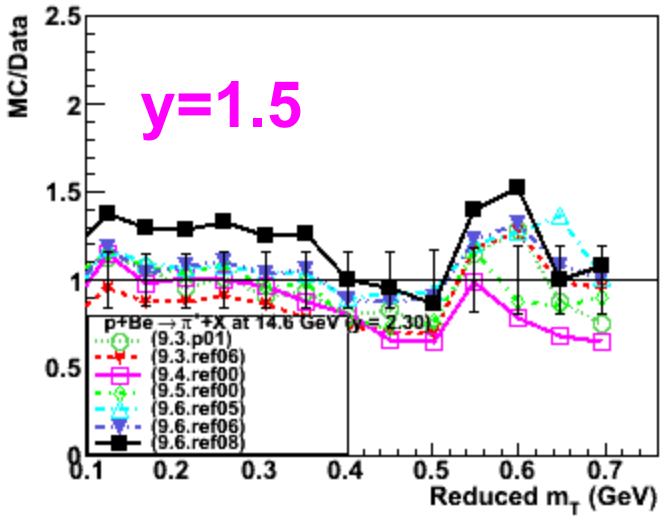


Agreement used to be better till 9.4.ref00. Version 9.6.ref05 was different

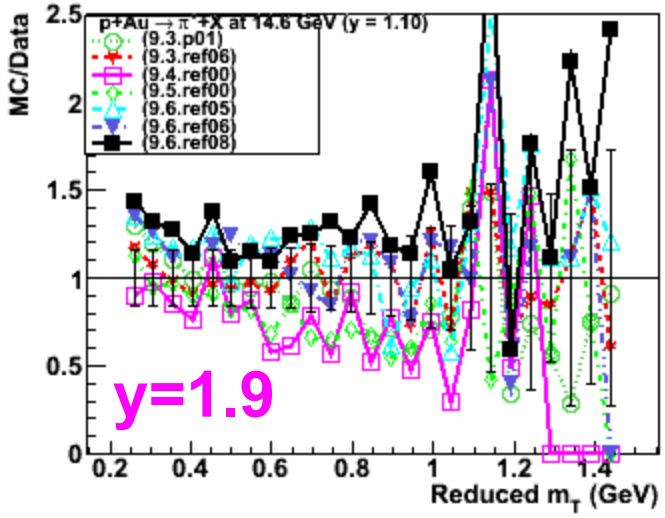
p + A → π⁺ + X at 14.6 GeV/c (FTFP)

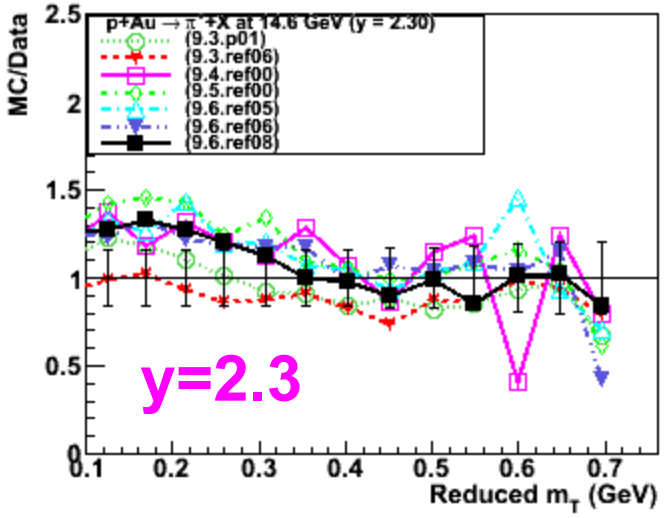
Be





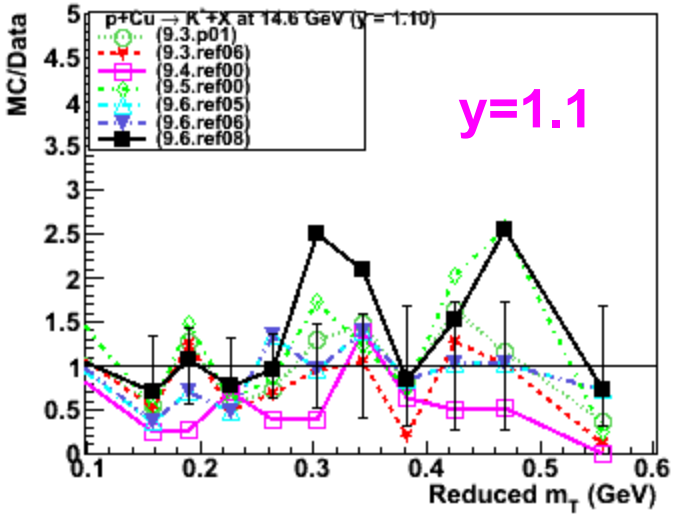
Au

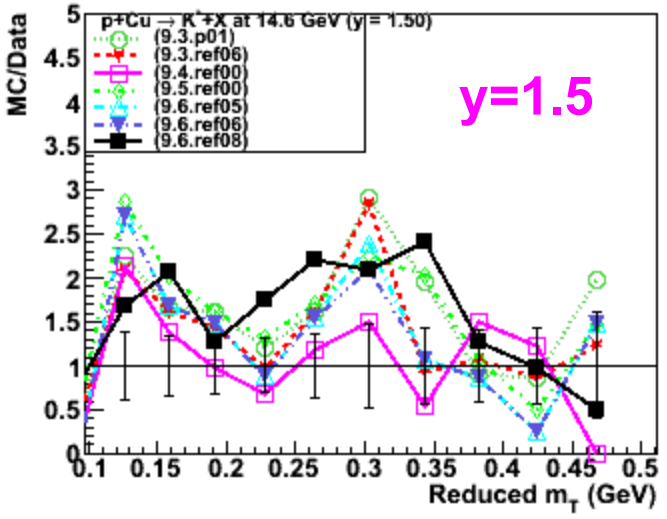


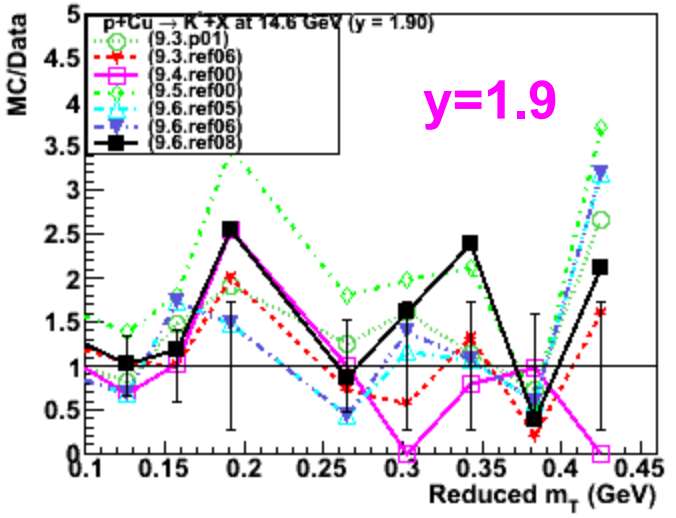


The last changes (ref07/ref08) in FTF model did not improve the agreement

p + Cu → K^+ + X at 14.6 GeV/c (FTFP)







Maximum deviation is within a factor of 2.

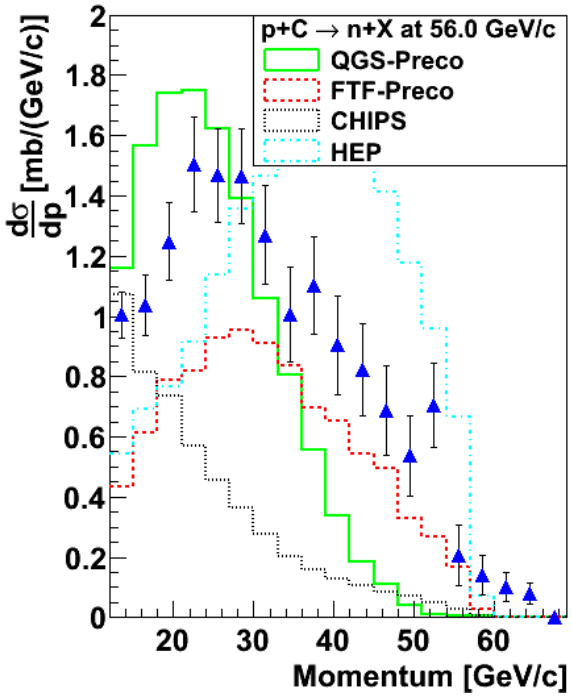
Data from MIPP Experiment

- The MIPP experiment has two spectrometers with TPC, drift + proportional chambers and a particle identification system using dE/dx, TOF and Cerenkov detectors. Two calorimeters (electromagnetic and hadron) further downstream detect photons and neutral hadrons:

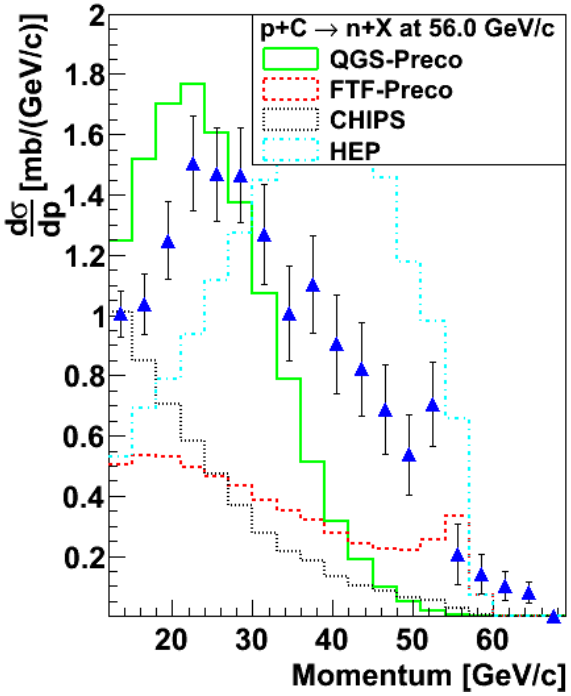
  T.S.Nigmanov et al. Phys. Rev. D83 (2011) 012002
- Targets used: Hydrogen, Beryllium, Carbon, Bismuth, Uranium.
- Projectile: proton beam at: 58, 59, 84 and 120 GeV/c. Beam momentum and impact point at the target are measured using an upstream spectrometer.
- Neutrons are detected in the hadron calorimeter and its energy is measured by subtracting energies of charged particles within the geometric acceptance of calorimeter.
- Background is large for low energy neutrons and inefficiency of triggering and selecting neutron events is large for high energy neutrons. So there is a low energy threshold for the data set and corrections are made due to these effects. Systematic uncertainties are dominated by these effects.
- For calculation of invariant cross sections, finite target size, beam orientation, acceptance cut of the detector, beam momentum spread, etc. are taken into account.

pC→nX at 56 GeV/c (p_{LAB} distribution)

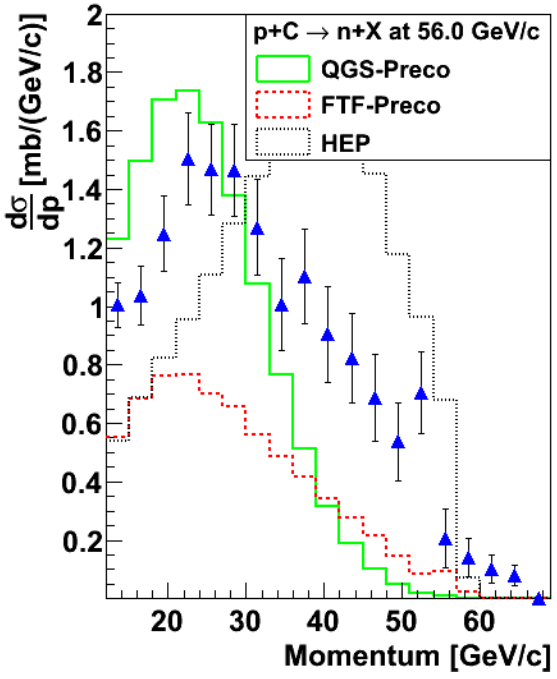
9.4.p01



9.5.ref00



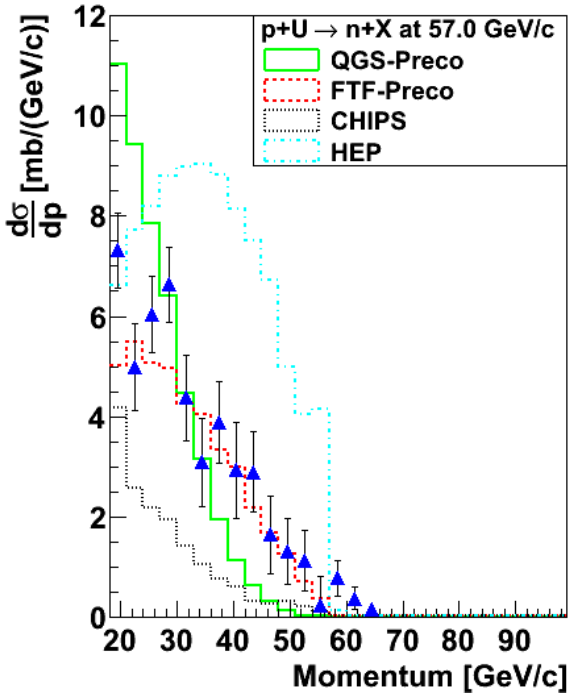
9.6.ref08



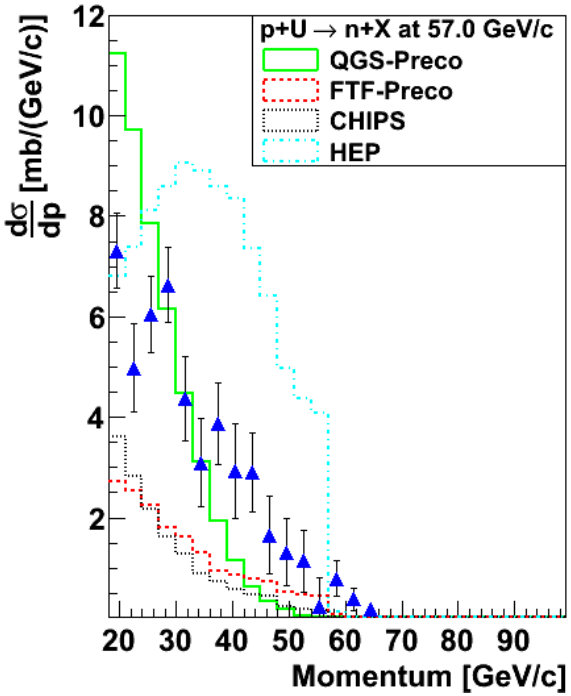
- Only FTFP used to provide good description of high momentum data in version 9.4.p01
- Predictions from FTFP have improved from versions 9.5 to 9.6

pU→nX at 57 GeV/c (p_{LAB} distribution)

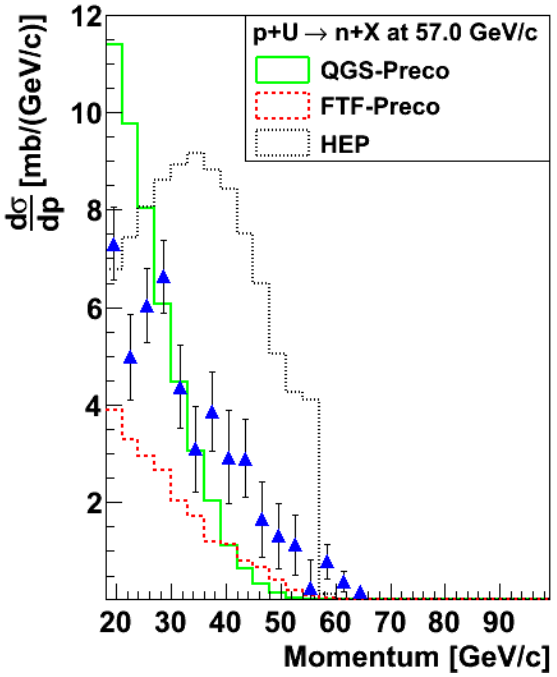
9.4.p01



9.5.ref00



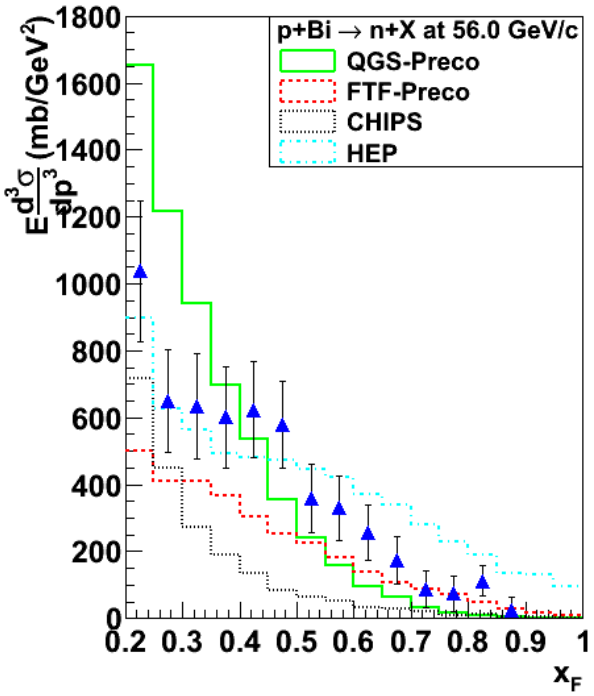
9.6.ref08



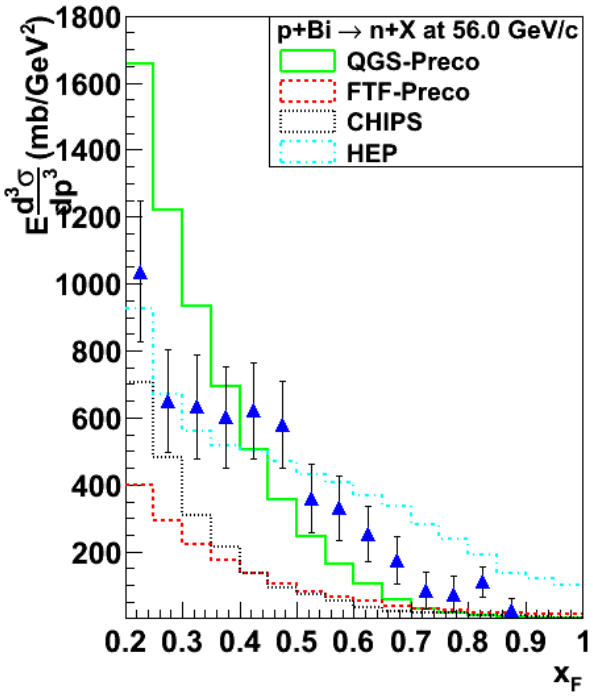
- Predictions from FTFP have moved much closer to the data in the new version as compared to in version 9.5.ref00

pBi→nX at 56 GeV/c (x_F distribution)

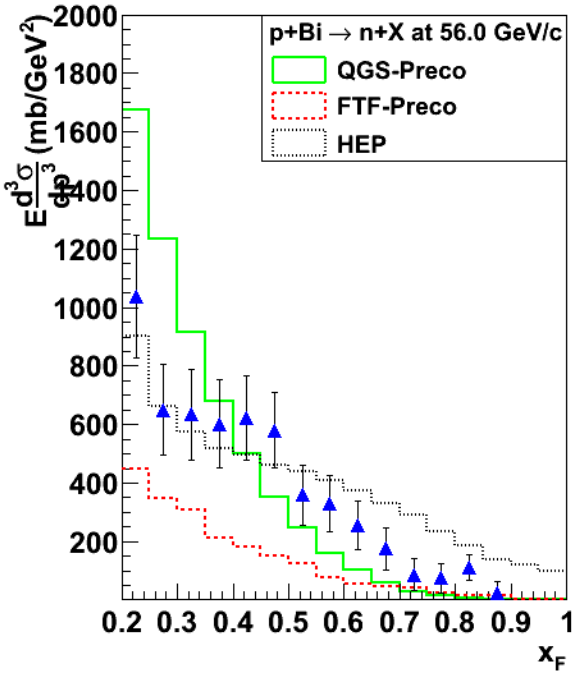
9.4.p01



9.5.ref00



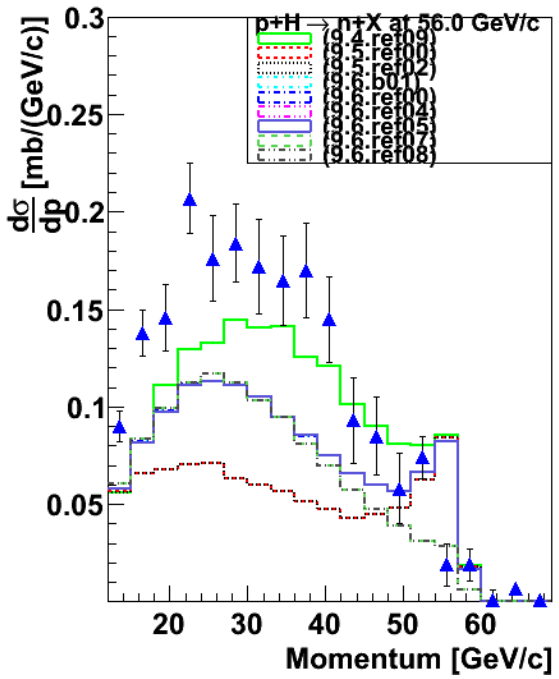
9.6.ref08



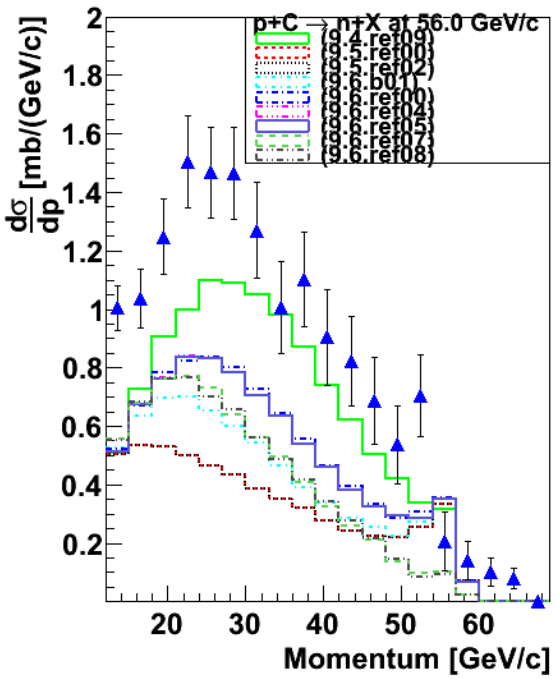
- Predictions for x_F distribution for FTFP model have increased by ~25% and have moved closer to the data

pA→nX at 56 GeV/c (p_{LAB} distribution)

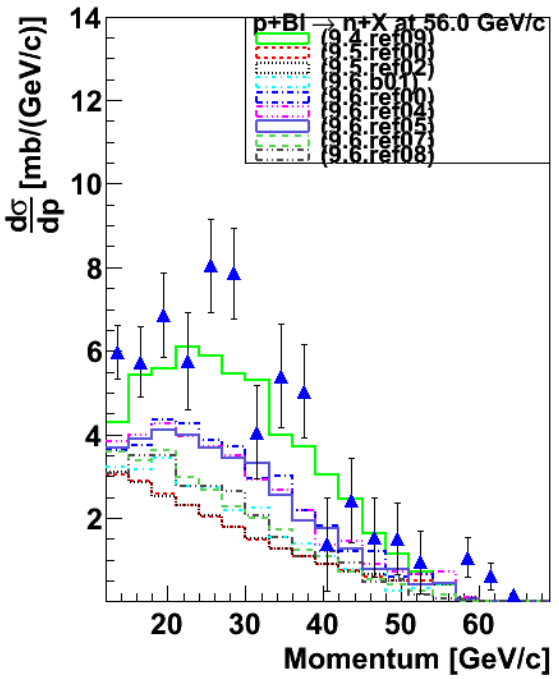
H



C



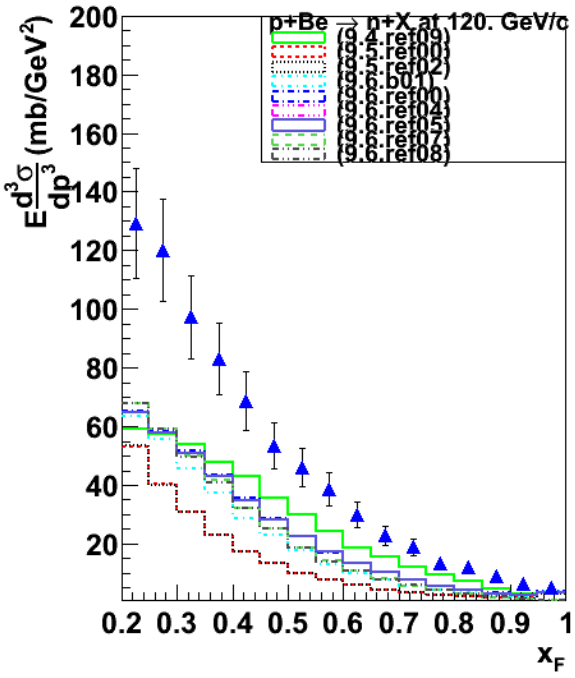
Bi



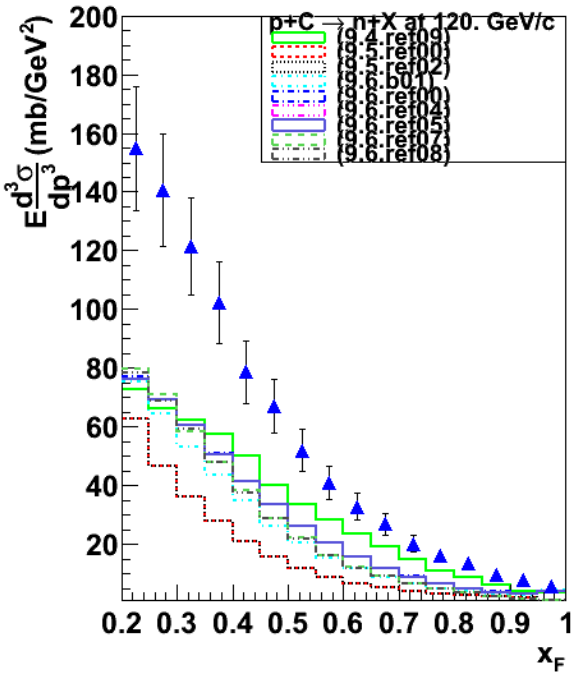
- Predictions for QGSP and HEPAR have been very stable
- Predictions from FTFP used to be very close to the data till 9.4.ref09. It went bad and now have come back close to the data since 9.6.ref00. In the last 2 versions (9.6.ref07 and 9.6.ref08), agreement has deteriorated for heavier nuclei.

pA→nX at 120 GeV/c (x_F distribution)

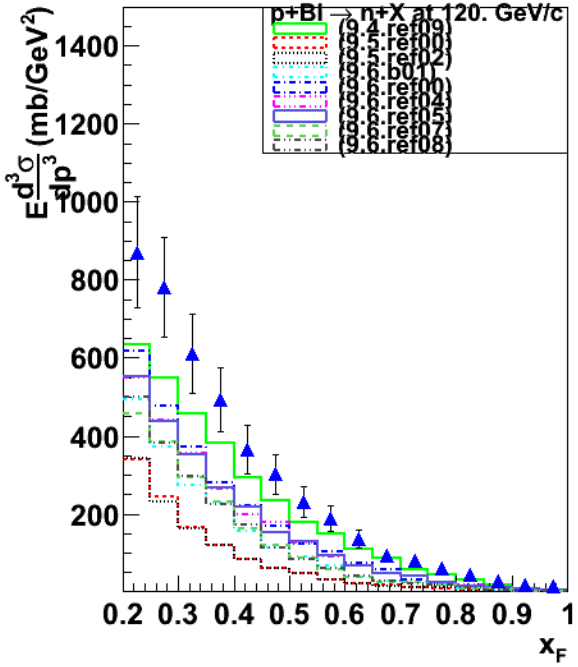
Be



C



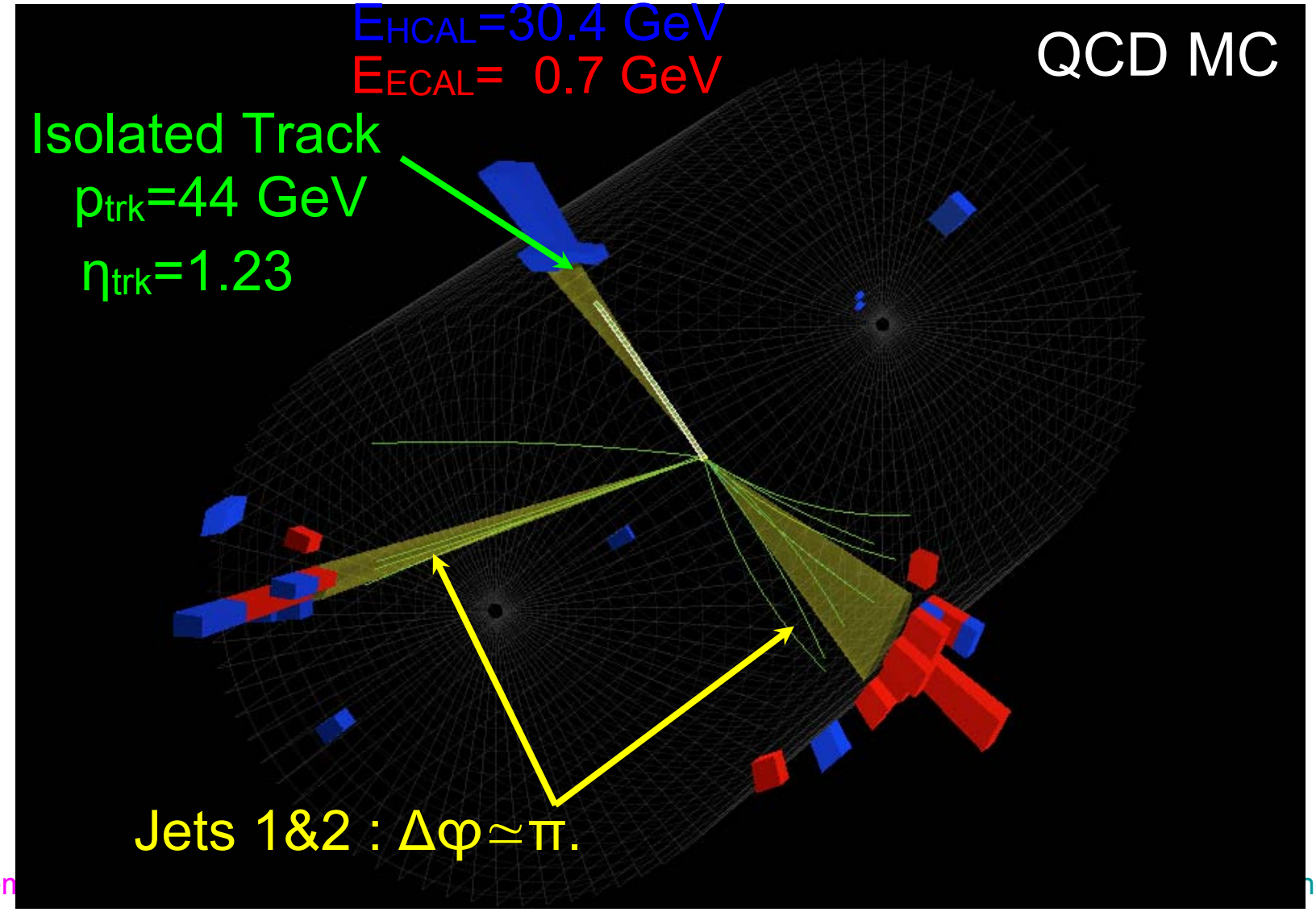
Bi



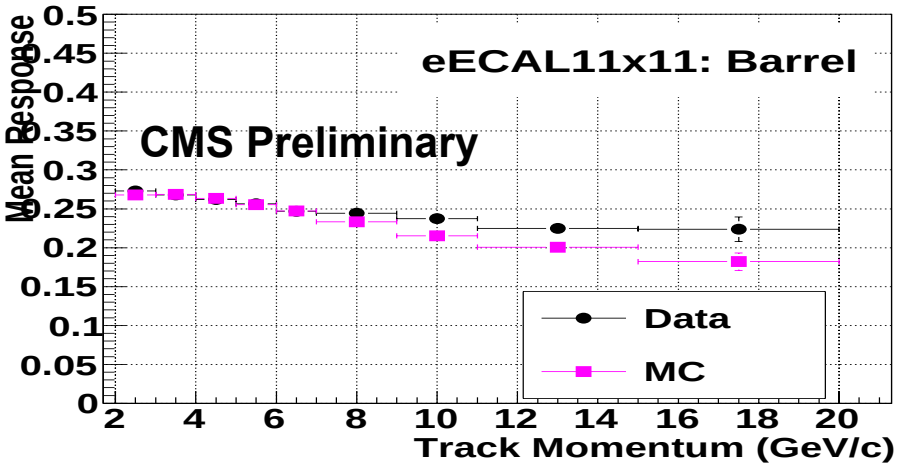
- Predictions from FTFP have the right shape and they move closer to the data since 9.5.ref00 (predictions from the last two reference versions are moving in the wrong direction). The other 2 models (QGSP and HEP) have been stable with time.

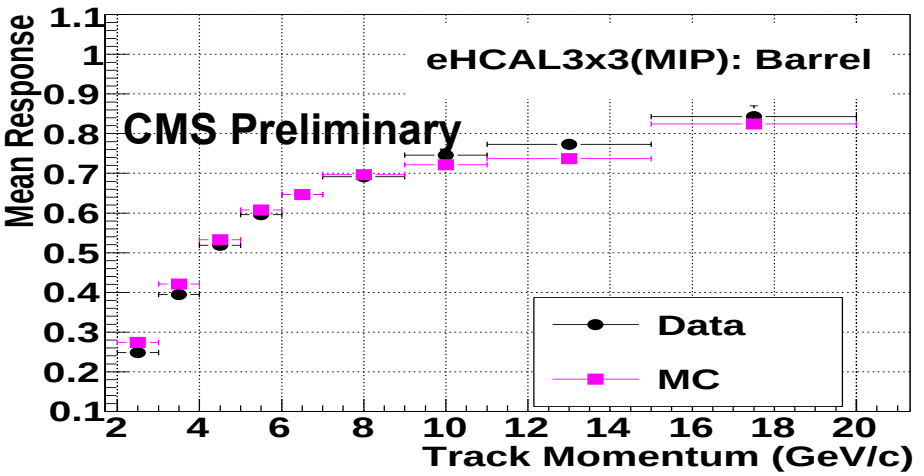
Use of Collision Data

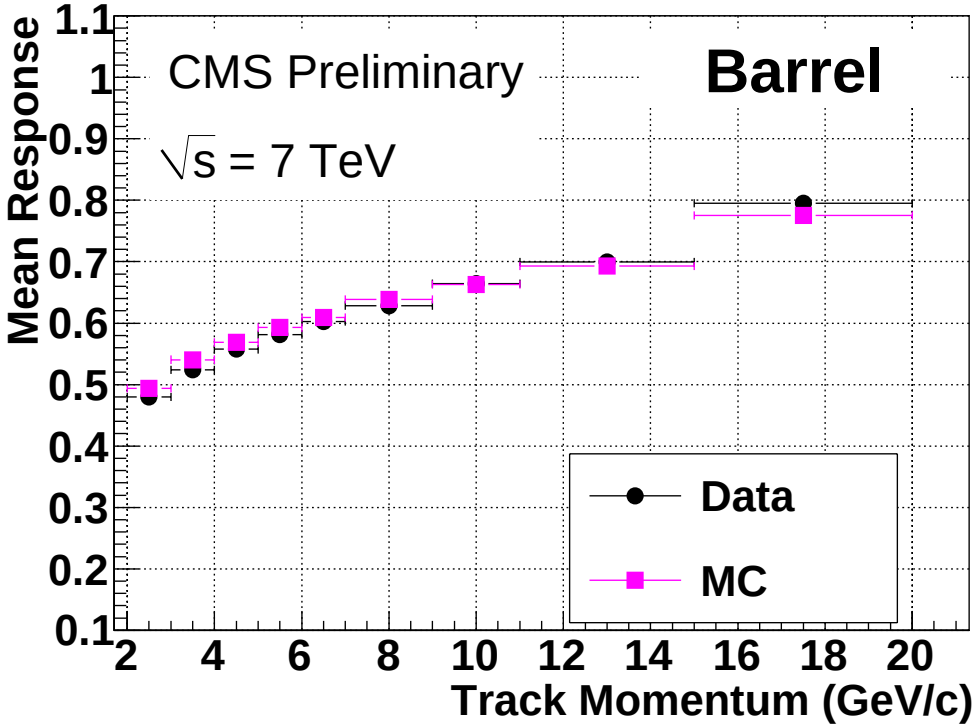
Use isolated charged particles from CMS data from 2010 run and compare with predictions from Geant4.9.3.p01 (QGSP_BERT_EML)

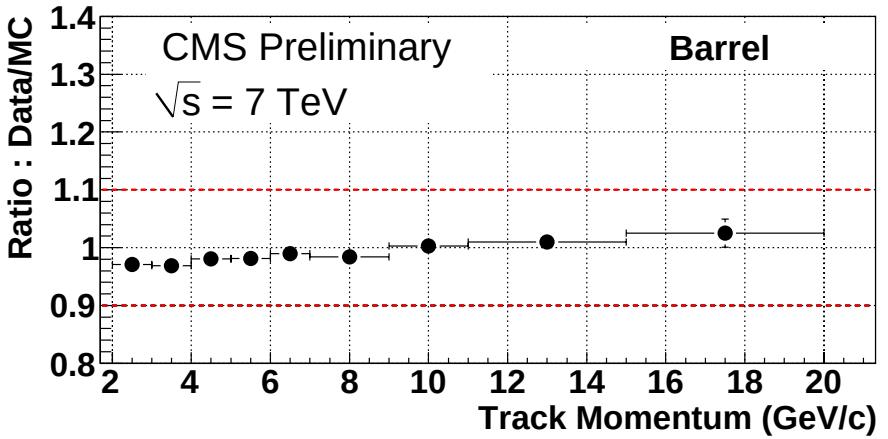


Early comparison (barrel region)





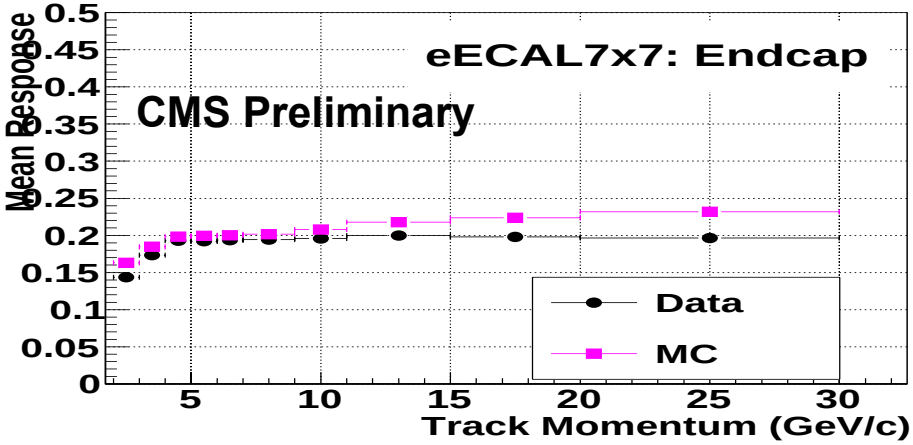


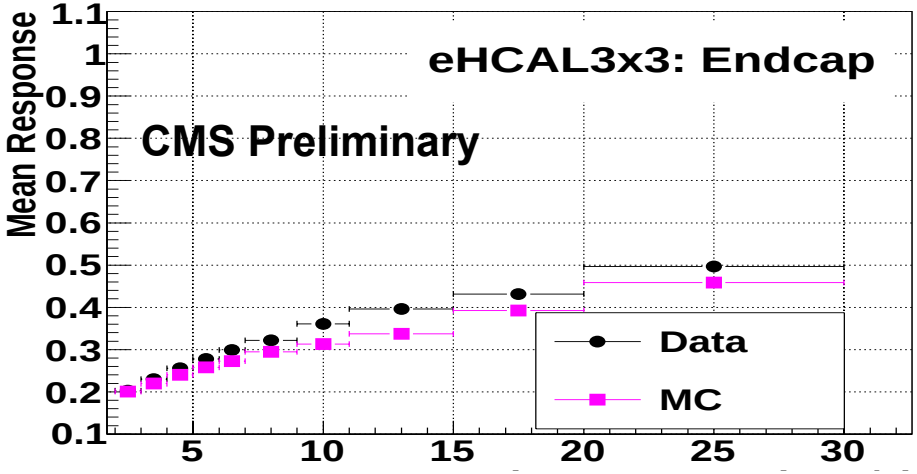


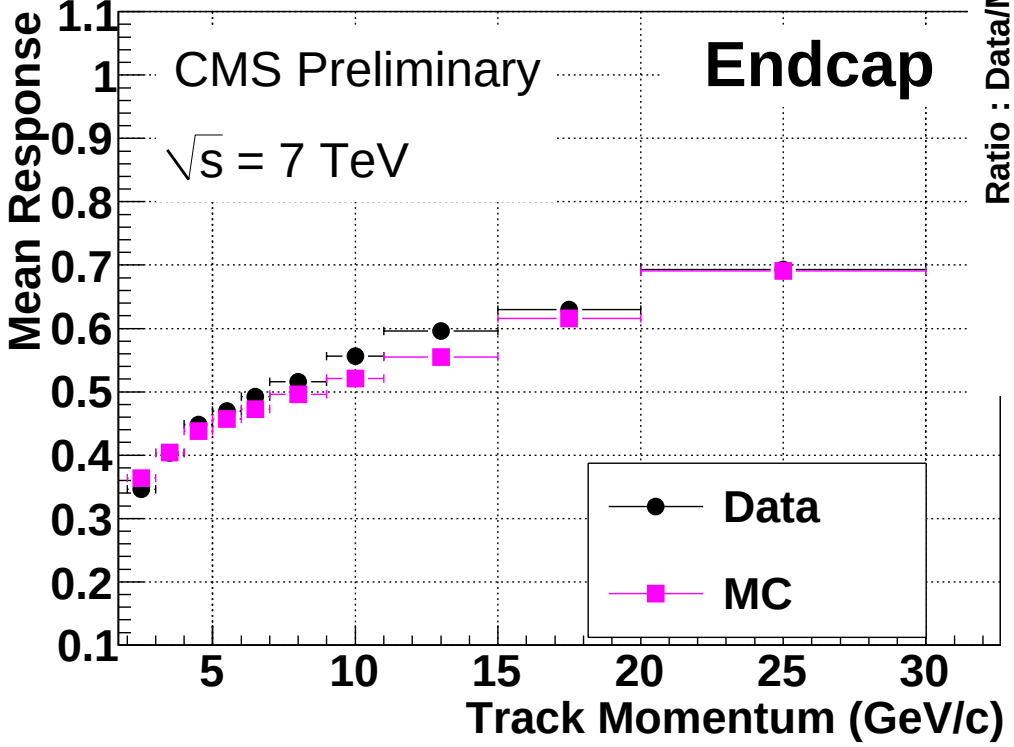
- Significant statistics is available for particles with momentum below 20 GeV/c
- Data/MC agreement was better than ±3% between 2-20 GeV/c

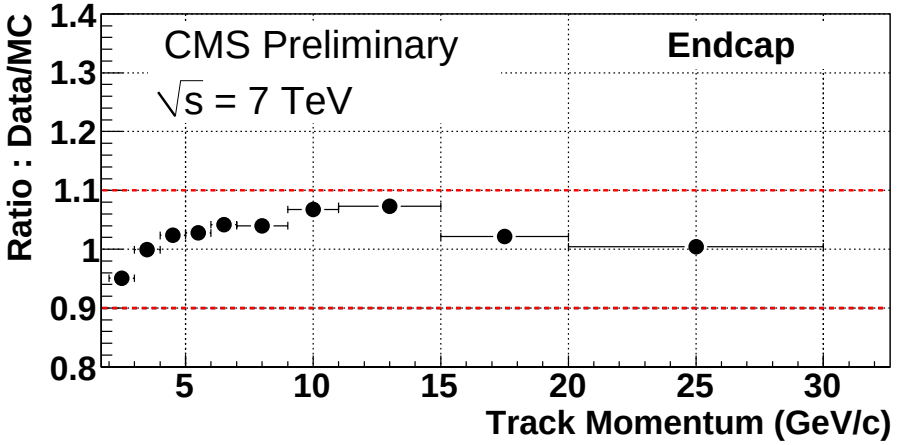
rmance

Early comparison (endcap region)









- Agreement in overall response is still within ±5%
- The source of discrepancy was due to scale factor in HCAL which was corrected during 2011

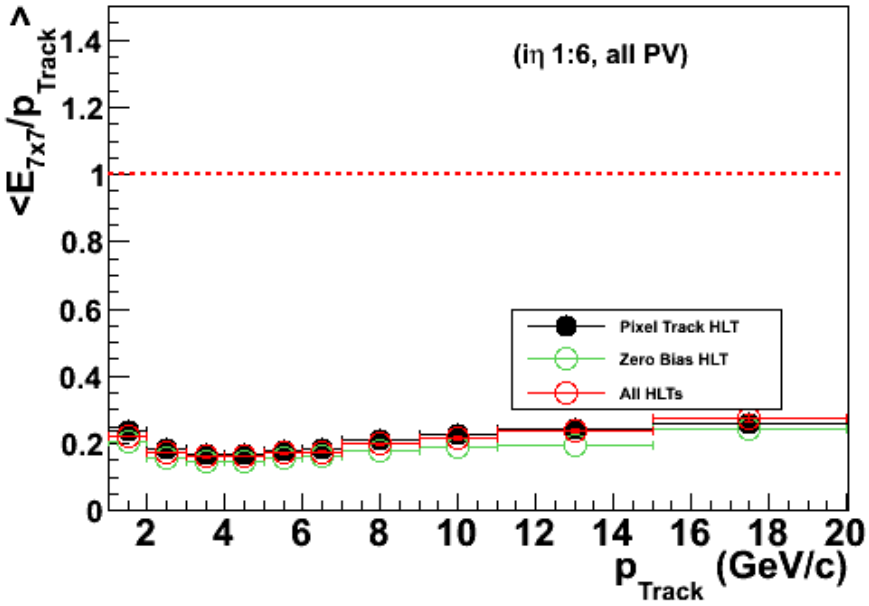
New data for validation

- An older version of Geant4 (9.3.p01) and an older physics list (QGSP_BERT_EML) was validated with the 2010 data
- 2010 minimum bias trigger events provided a very good data set of clean events which can be used for that validation work
- However these data sets cannot be used for validating more modern version of Geant4 or physics list
- During 2012, some low luminosity runs were recorded. However they do not have as clean an environment as the 2010 data. Also minimum bias trigger was not present during these runs.
- A new venture has started to utilize these data sets to validate Geant4 physics lists to be used by CMS

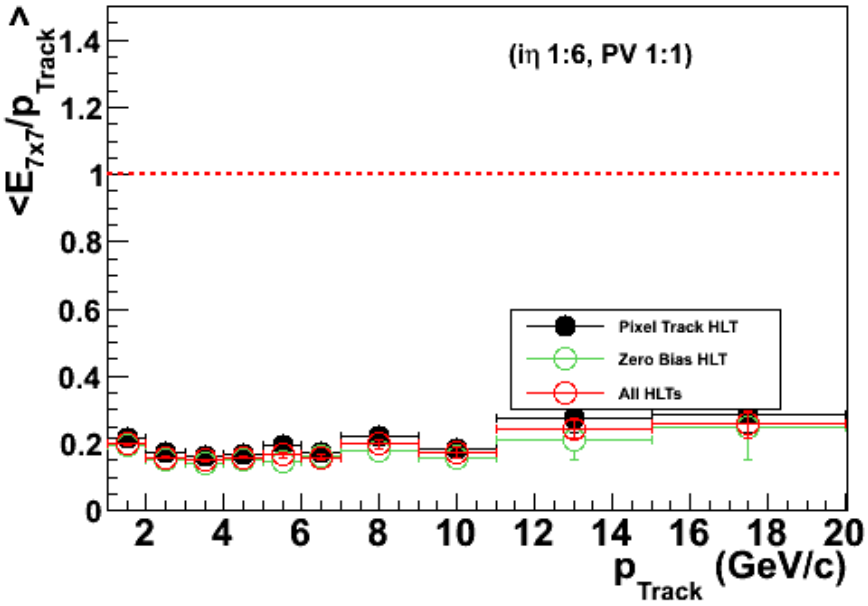
Method of Analysis

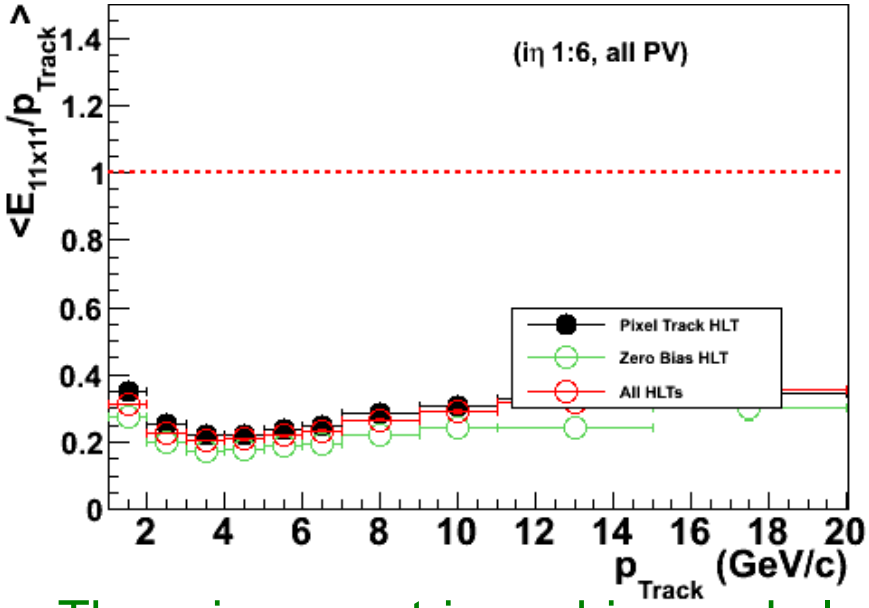
- Select well reconstructed tracks not interacting within the tracker, originating close to the primary vertex and reaching the HCAL surface
- Use old studies to decide on isolation criteria
  - Propagate track to calorimeter surface and study momentum of tracks (selected with a looser criteria) reaching ECAL(HCAL) within a matrix of 31x31 (7x7) around the impact point of the selected track
    - No other charged particle should be within the isolated zone
  - Study the energy deposited in an annular region in ECAL(HCAL) between 15x15 and 11x11 (7x7 and 5x5) matrices
    - Energy in the isolation region should be below a threshold decided by the noise level in the calorimeter
- Measure the response as the energy measured by the calorimeter in a matrix of NxN surrounding the impact point scaled to the track momentum

ECAL response for |η| < 0.52

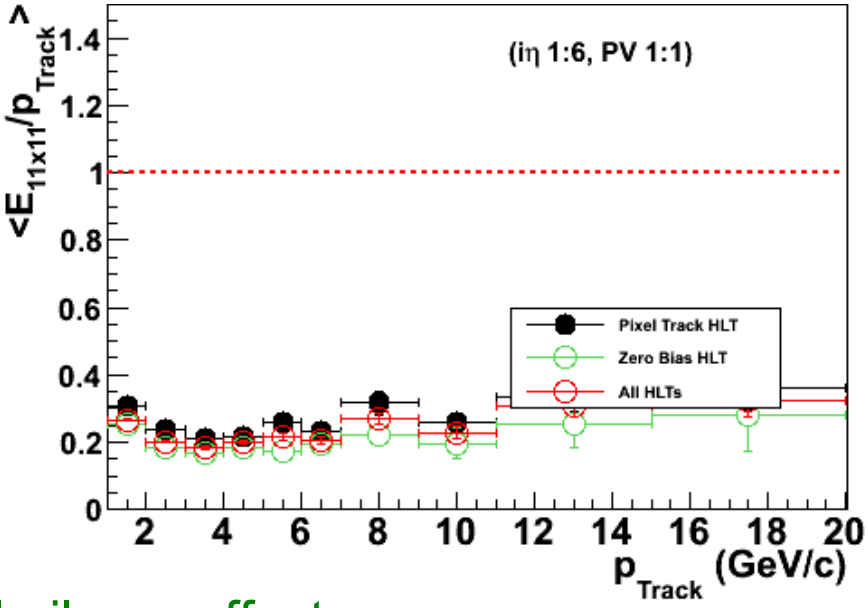


7x7



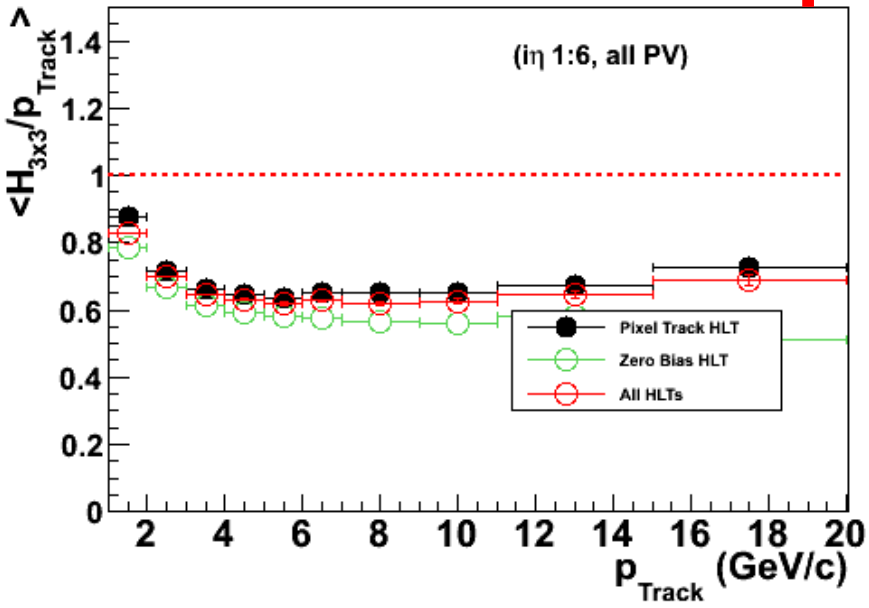


11x11

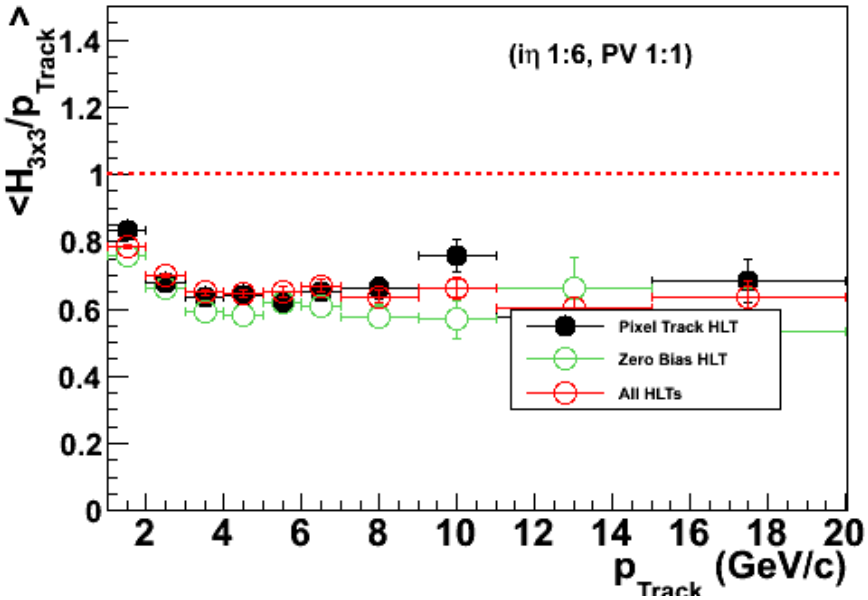


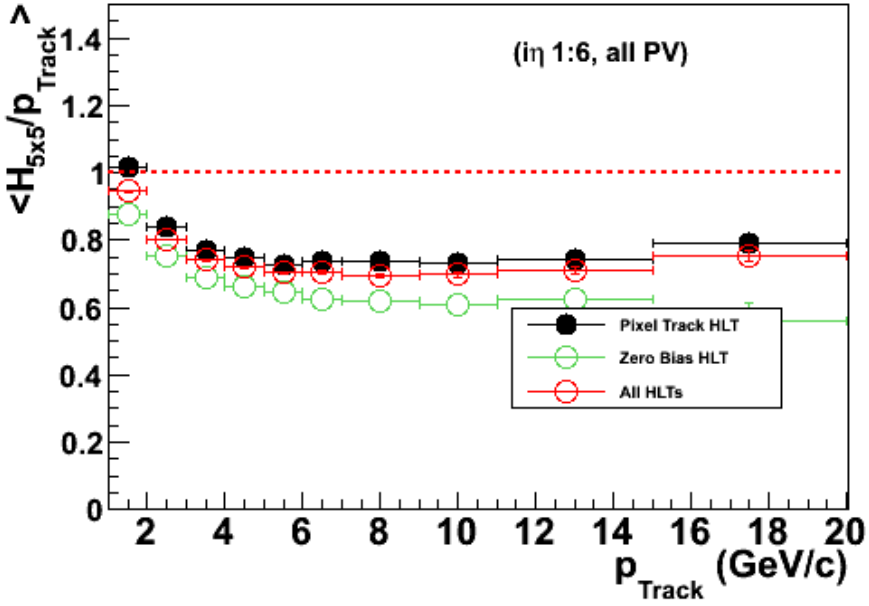
There is some trigger bias and also small pile-up effect.

HCAL response for |η| < 0.52

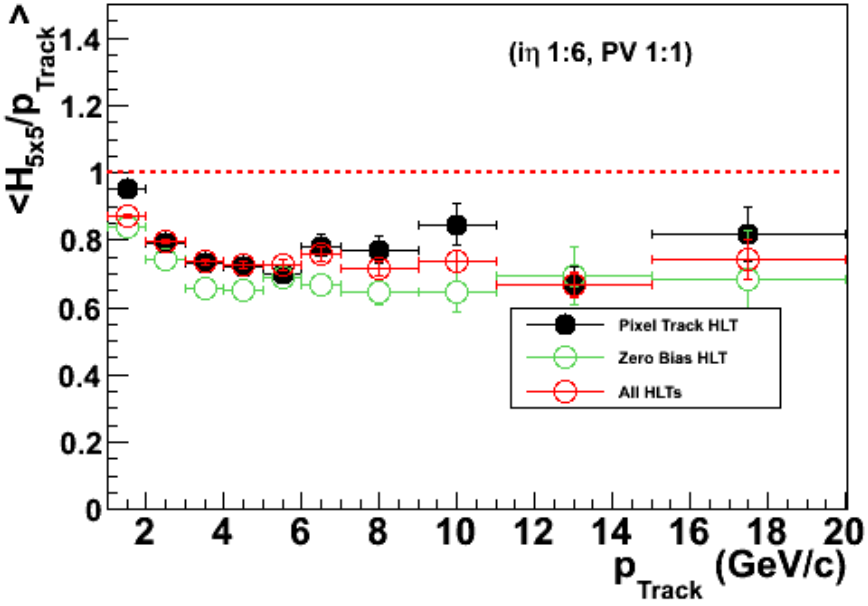


3x3





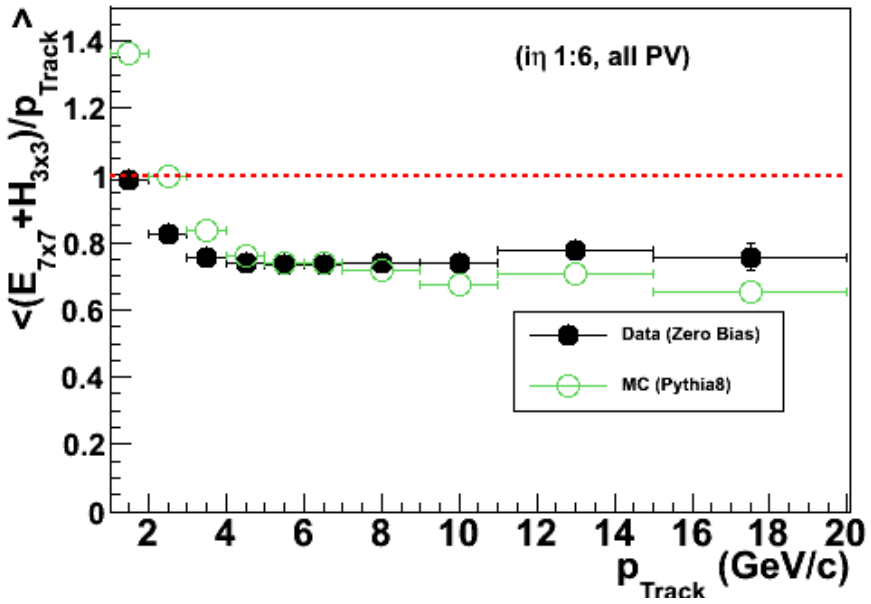
5x5



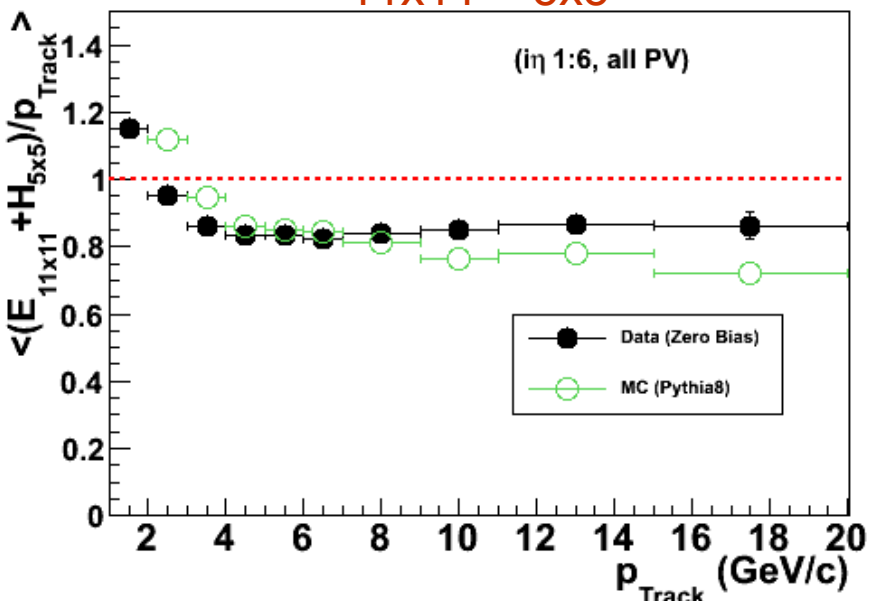
The effect becomes larger with larger signal zone size

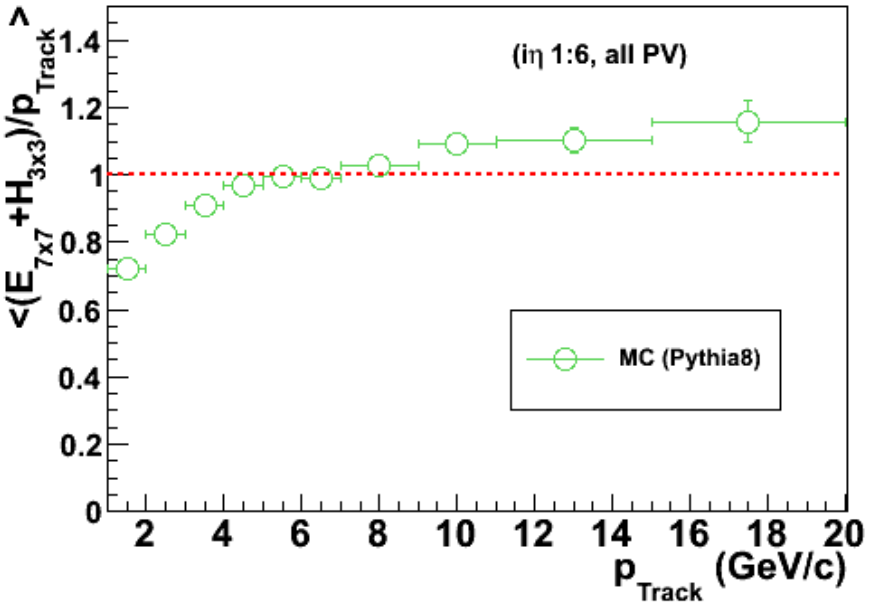
Calorimeter response for |η| < 0.52

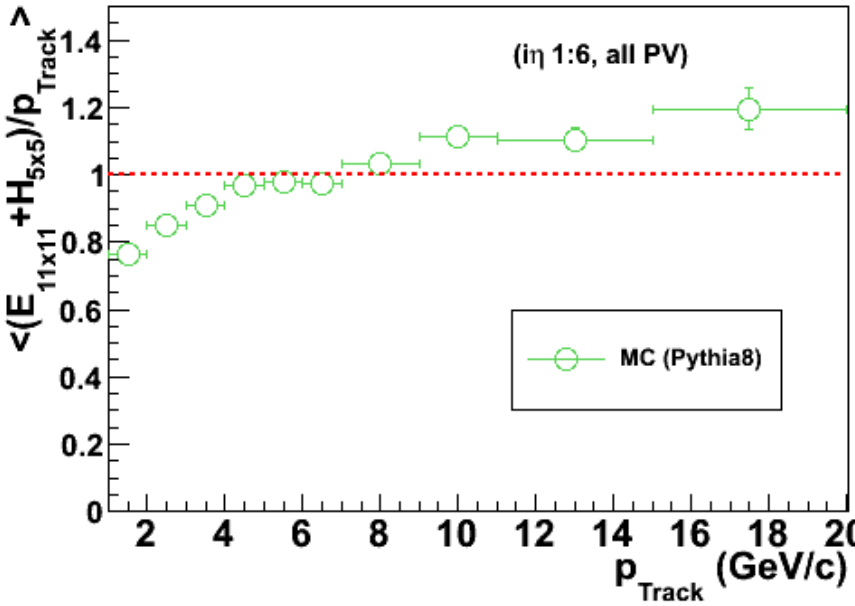
7x7 + 3x3



11x11 + 5x5

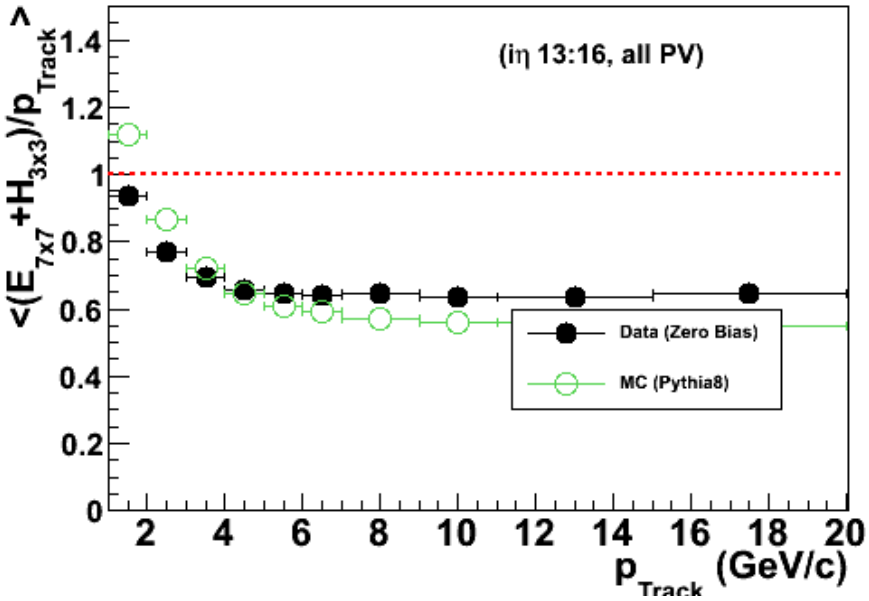


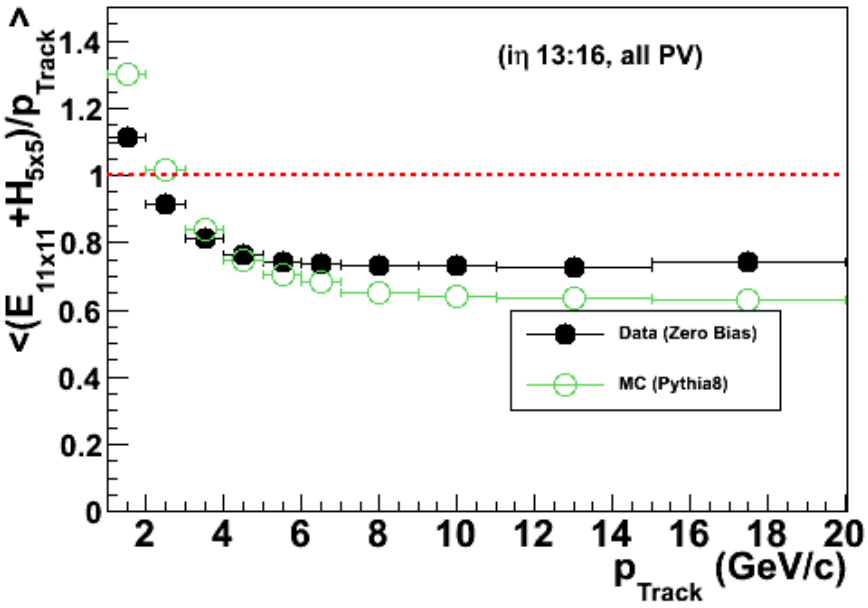


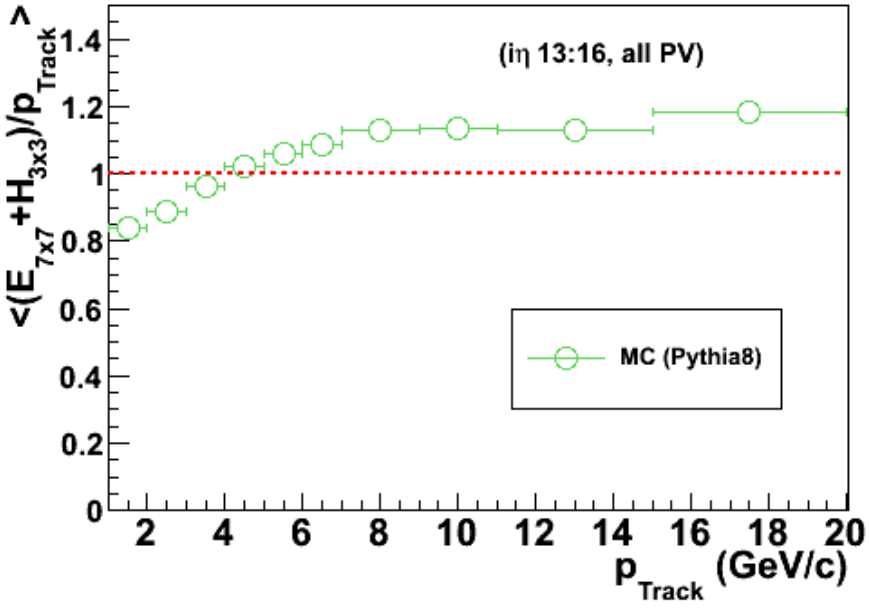


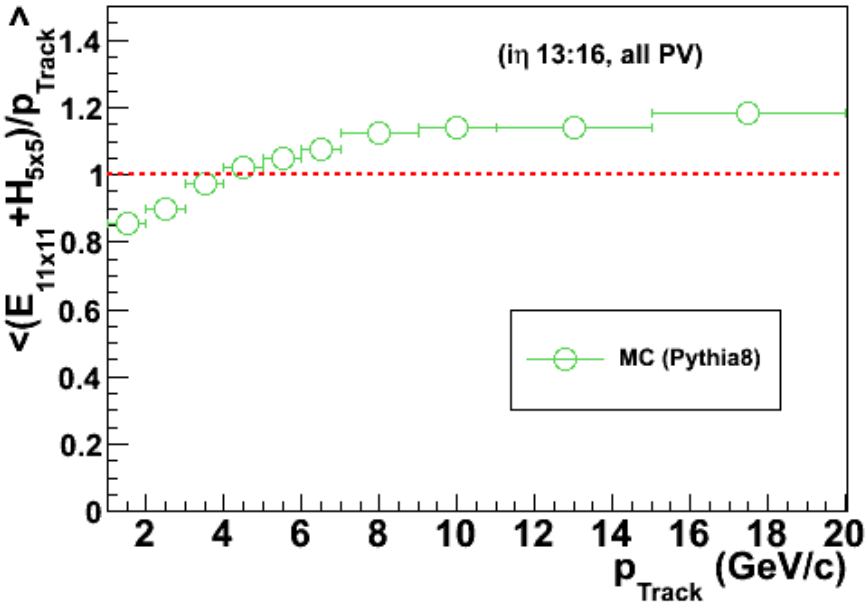
Perfor

Calorimeter response for |η| = 1.04: 1.39









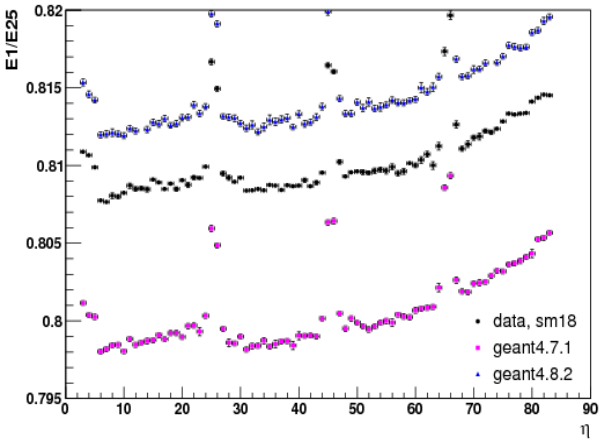
Observations

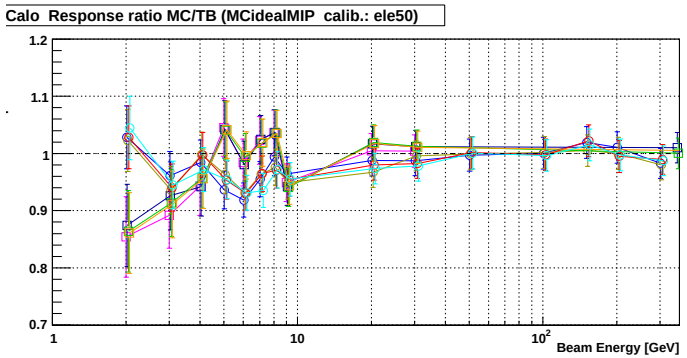
- The predictions of Bertini cascade model have fluctuated recently (9.6.ref05). While more recent versions (9.6.ref07, 9.6.ref08) are in better agreement, earlier versions (e.g. 9.4.ref00) used to describe some of the data better.
- Comparison with BNL data does not show very large deviations with the new version of the FTFP model. Recent changes (post 9.5.ref02) for FTFP have made the predictions getting closer to the data. Since 9.6.ref06, the changes are going away from the data (for E904 as well as MIPP).
- An attempt to utilize low pileup runs with zero bias triggers from LHC collision data in validating Geant4 physics lists for energy below 20 GeV. However this validation critically depends on the detector noise modeling.

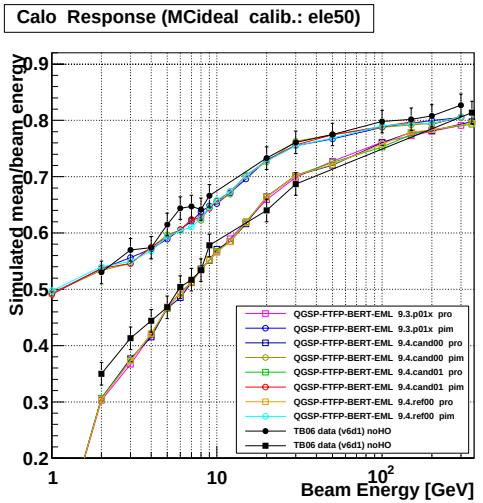
Back Up

Test Beam Data

- Geant4 used within CMS simulation package was tuned to data taken by CMS collaboration
  - Early tuning utilized test beam data taken with real detector modules or prototypes at the SPS beam area
    - Measure energy response, energy resolution, lateral shower profile, energy containment and leakage for electrons at different energies in H4 test beam area to ECAL super-modules
    - Measure energy response, energy resolution, shower shapes, energy sharing between ECAL and HCAL using electron, muon and hadron beams at different energies in H2 test beam area to a combined calorimeter system







Hadronic Performance