



Validation of Hadron Shower Simulation using data from H2 TB Setup of CMS Calorimeter

Outline

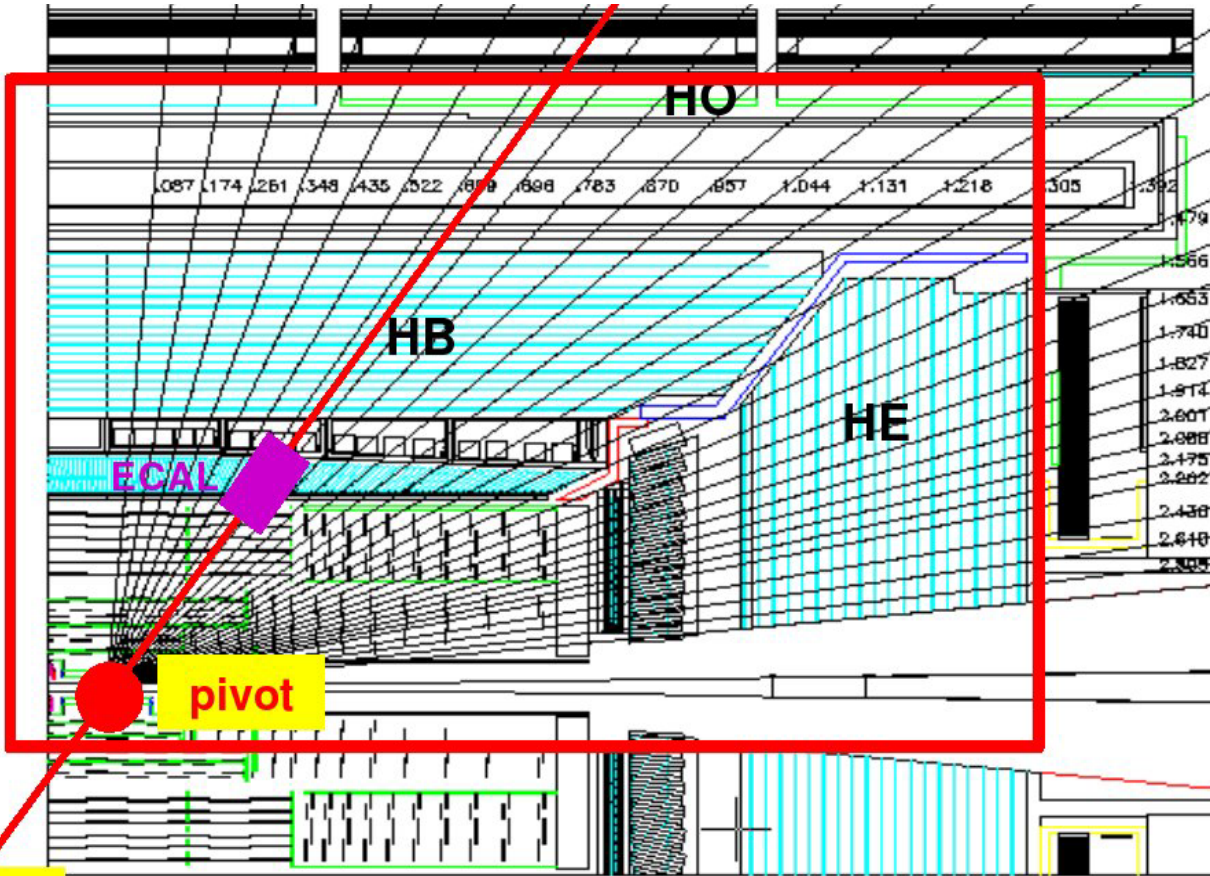
- ❑ TB Setup and Data
- ❑ Monte Carlo samples
- ❑ Mean energy response
- ❑ Energy resolution
- ❑ Fraction of MIP events in ECAL
- ❑ Summary

LCG Validation Meeting
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H2 Test Beam Setup



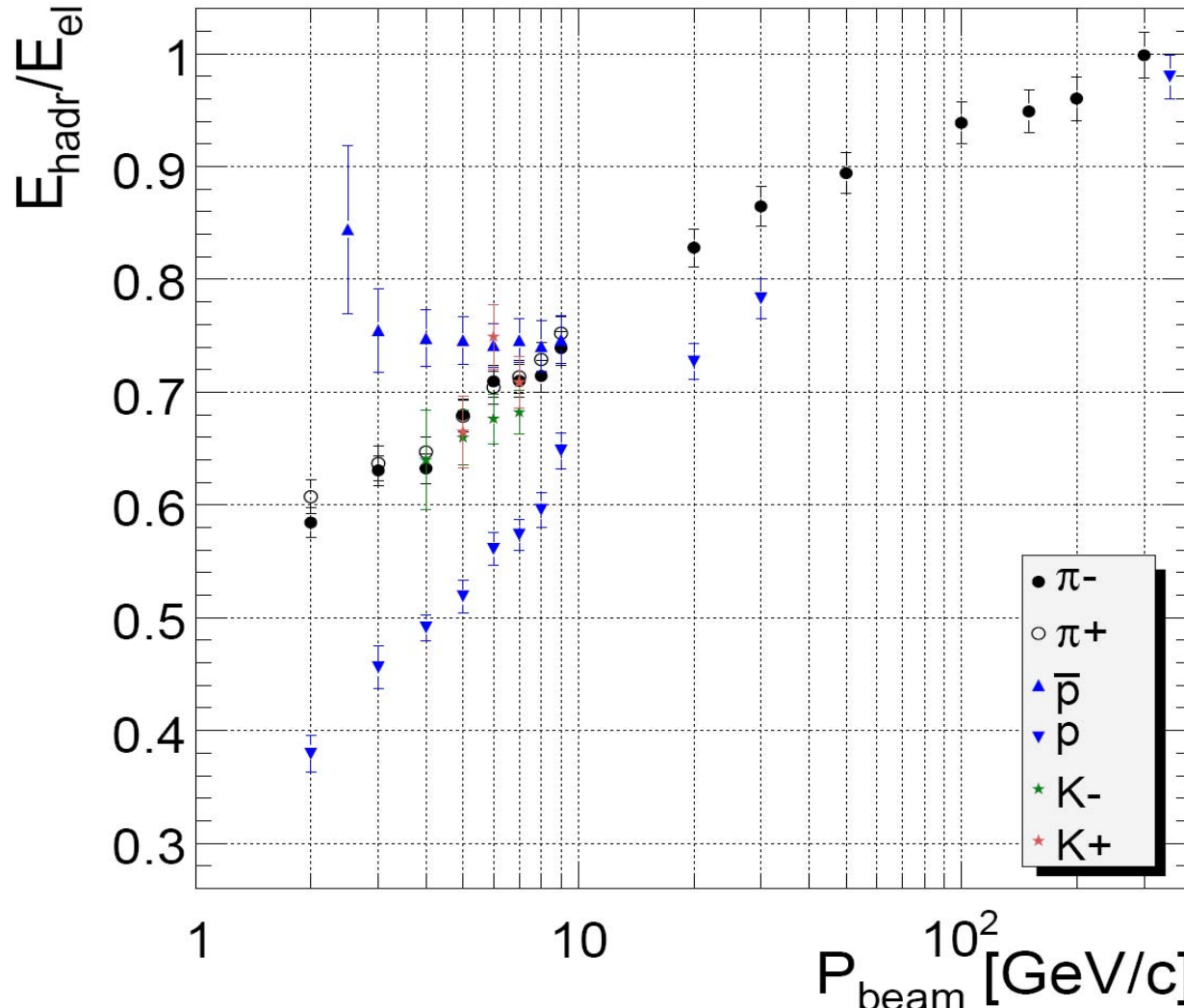
Slice of CMS calorimeter
 Pivot point corresponds to interaction point in CMS.
 ECAL is a matrix of 7x7 crystals in the 2004 run and a barrel super-module during 2006.
 HB modules are production wedges read out with real front-end electronics

ECAL = Electromagnetic Calorimeter
 HB = HCAL Barrel
 HE = HCAL Endcap
 HO = HCAL Outer

Number of beam counters to veto interactions in beam line and unwanted beams to the calorimeter



Test Beam Data



2006 TB Data from HB1

2-350 GeV/c

- ❑ Positive and negative beams of momenta 1 – 350 GeV/c
- ❑ Beams are cleaned from beam-line interaction and wrong type
- ❑ Particle ID for $p < 10$ GeV/c



Monte Carlo Simulation



- ❑ Use mostly 4.9.1.ref08 version of Geant4
- ❑ In addition use the correction of Coulomb barrier in Bertini cascade model
- ❑ Physics Lists considered: QGSP_BERT, FTFP_BERT, FTF_BIC, QGSP_BERT_NOLEP, QGSB_BERT_NOLEP
- ❑ Two different variation of NOLEP is used:
 - QGSP(QGSB) extended down to 8.5 GeV from 12 GeV: NOLEP1
 - Bertini extended up to 14 GeV from 9.9 GeV: NOLEP2



Treatment to the simulated sample



- ❑ Calibrate energy deposits in ECAL (~ 1.02) and HCAL (~ 104) using $50 \text{ GeV}/c$ electrons for each of the physics lists
- ❑ Take care of layer to layer variation in energy calibration from the wire source calibration data
- ❑ Introduce noise for ECAL ($\sim 50 \text{ MeV}/\text{crystal}$) and HCAL ($\sim 200 \text{ MeV}/\text{tower}$) as measured in the data sample
- ❑ Additional noise factor due to ion feed back in the HPD (obtained from the data)
- ❑ Apply the same beam cleaning cuts as done to the data

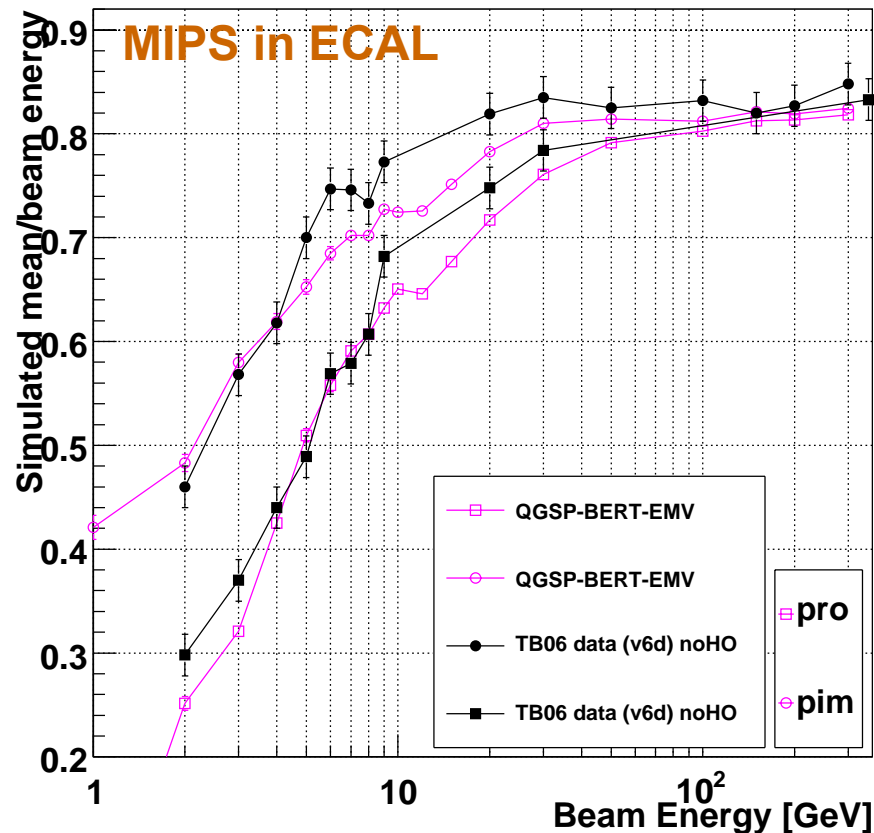
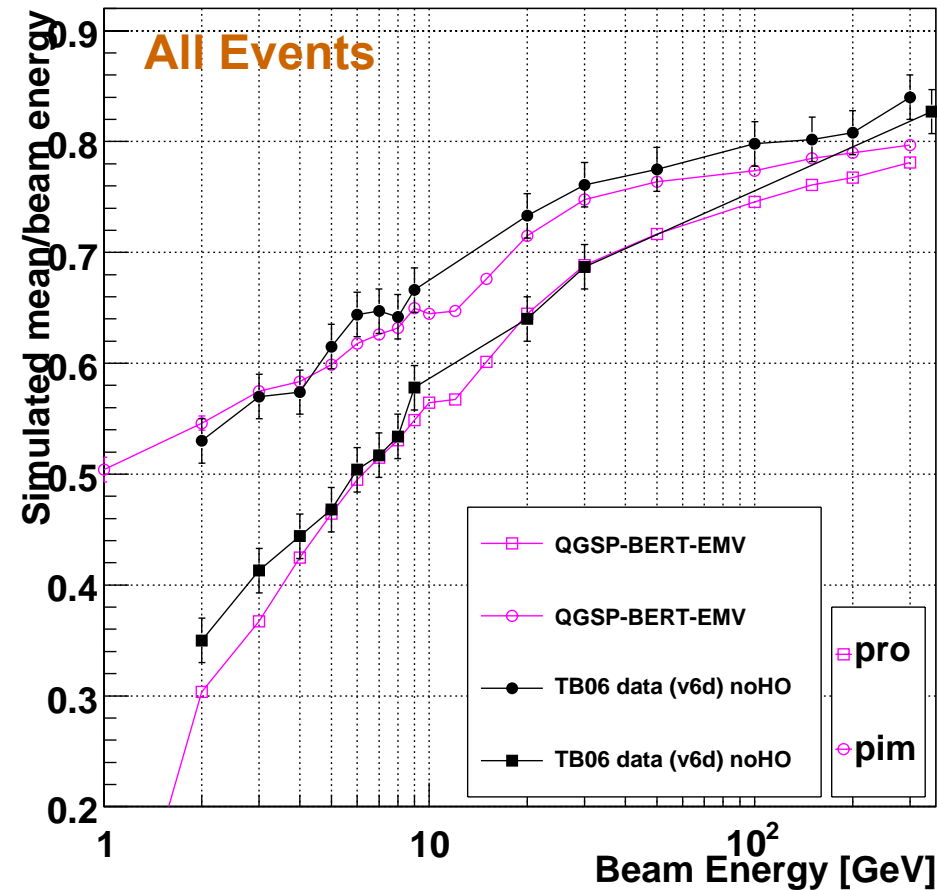


Mean response for QGSP_BERT_EMV



G4:9.1.ref08Bertini Response (MCideal calib.: ele50)

G4:9.1.ref08Bertini Response (MCidealMIP calib.: ele50)



- Reasonable agreement for the combined data.
- Systematic lower prediction with MIP's in ECAL for $E > 10$ GeV
- Shows two kinks in energy evolution around 9 & 15 GeV

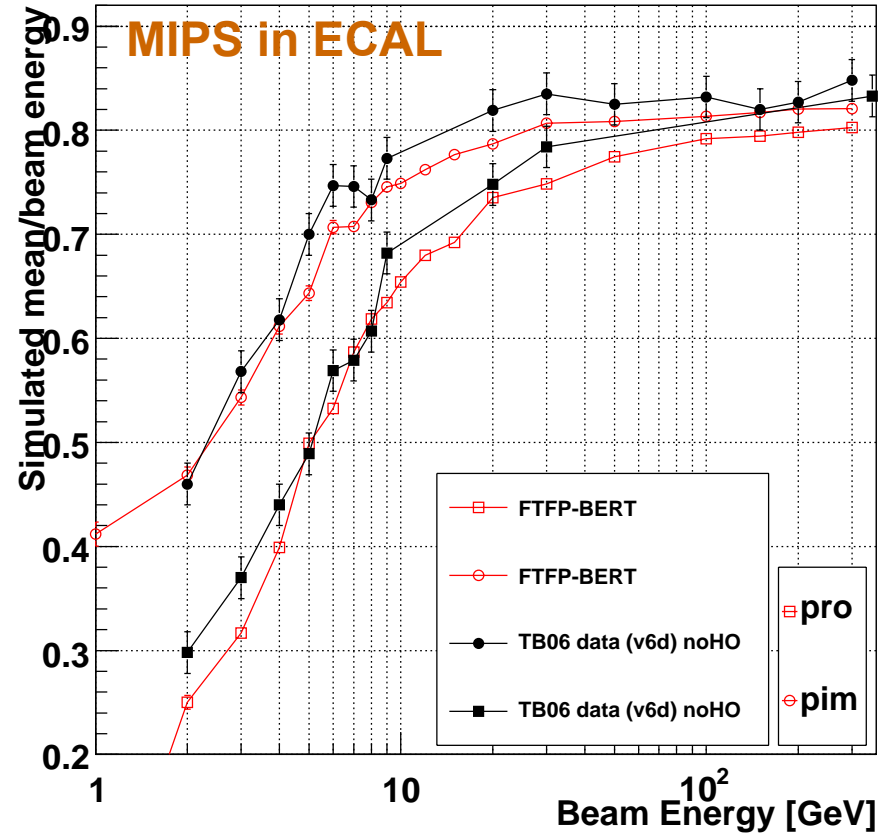
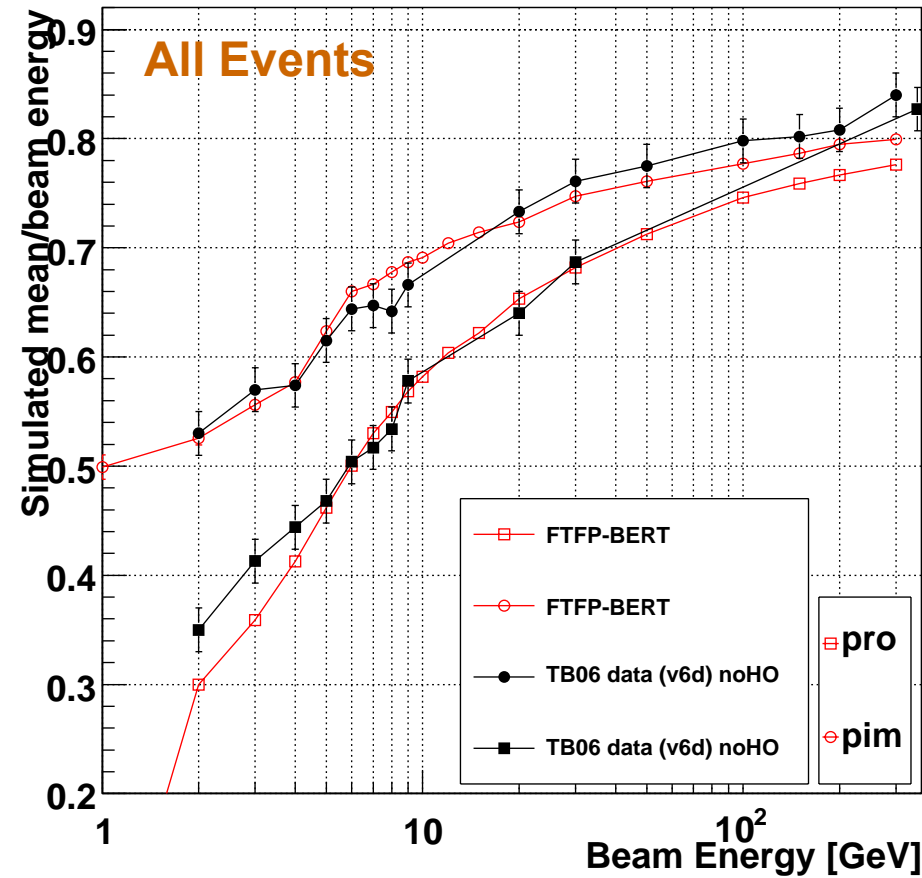


Mean response for FTFP_BERT



G4:9.1.ref08Bertini Response (MCideal calib.: ele50)

G4:9.1.ref08Bertini Response (MCidealMIP calib.: ele50)



Agreement better with FTFP_BERT

Discontinuity only around 6 GeV

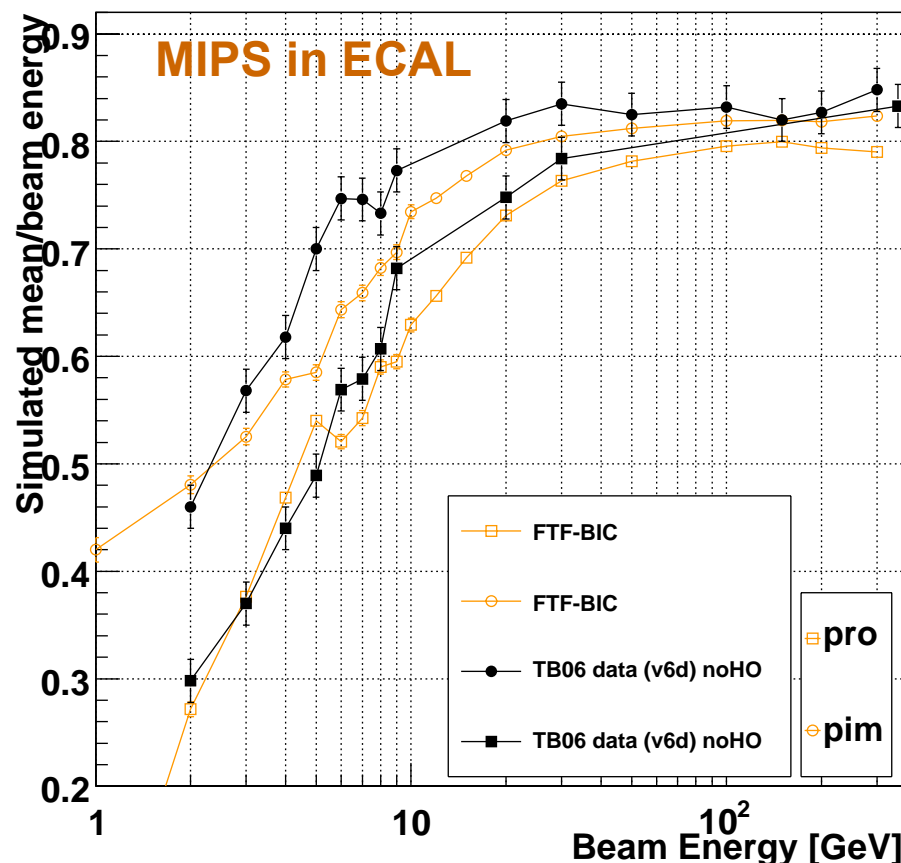
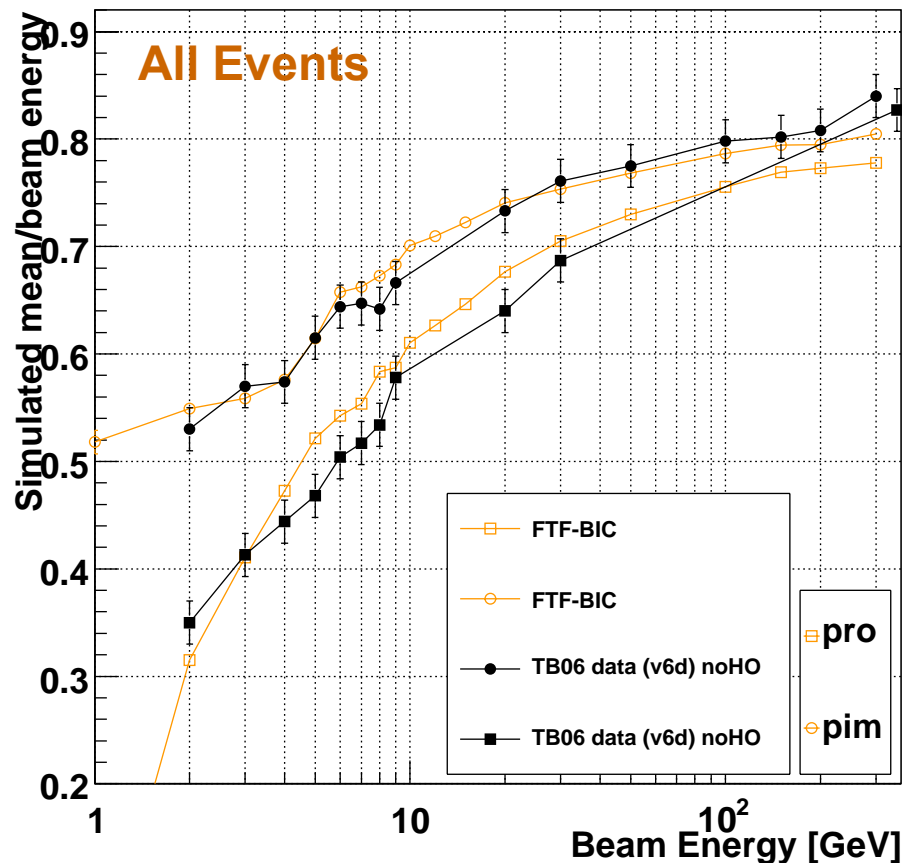


Mean response for FTF_BIC



G4:9.1.ref08Bertini Response (MCideal calib.: ele50)

G4:9.1.ref08Bertini Response (MCidealMIP calib.: ele50)



- ❑ Larger discontinuity with MIP in ECAL around 5 GeV
- ❑ Agreement at the same level as QGSP_BERT

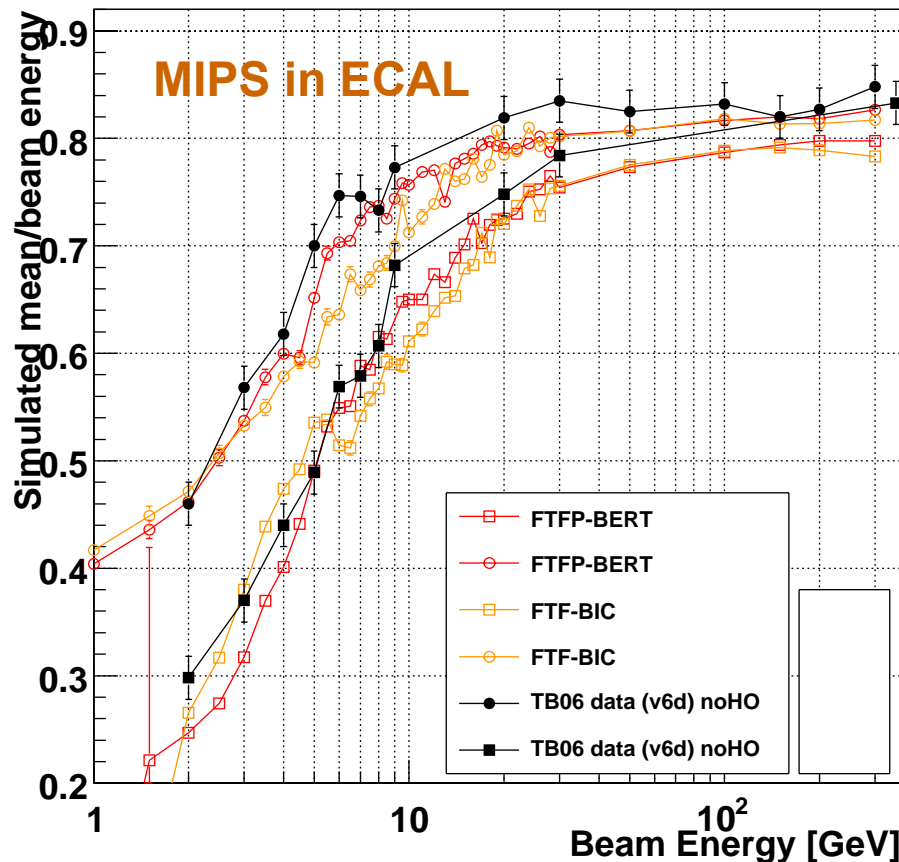
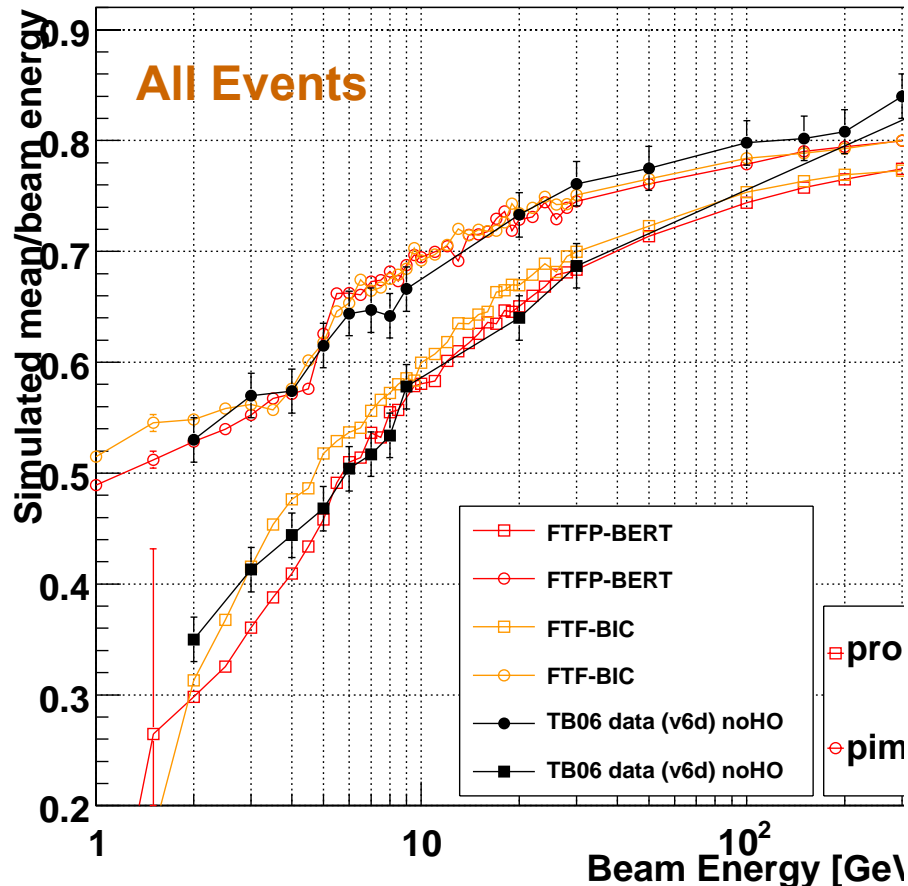


Mean response for FTF_BIC/FTFP_BERT



G4:9.2.b01 Response (MCideal calib.: ele50)

G4:9.2.b01 Response (MCidealMIP calib.: ele50)



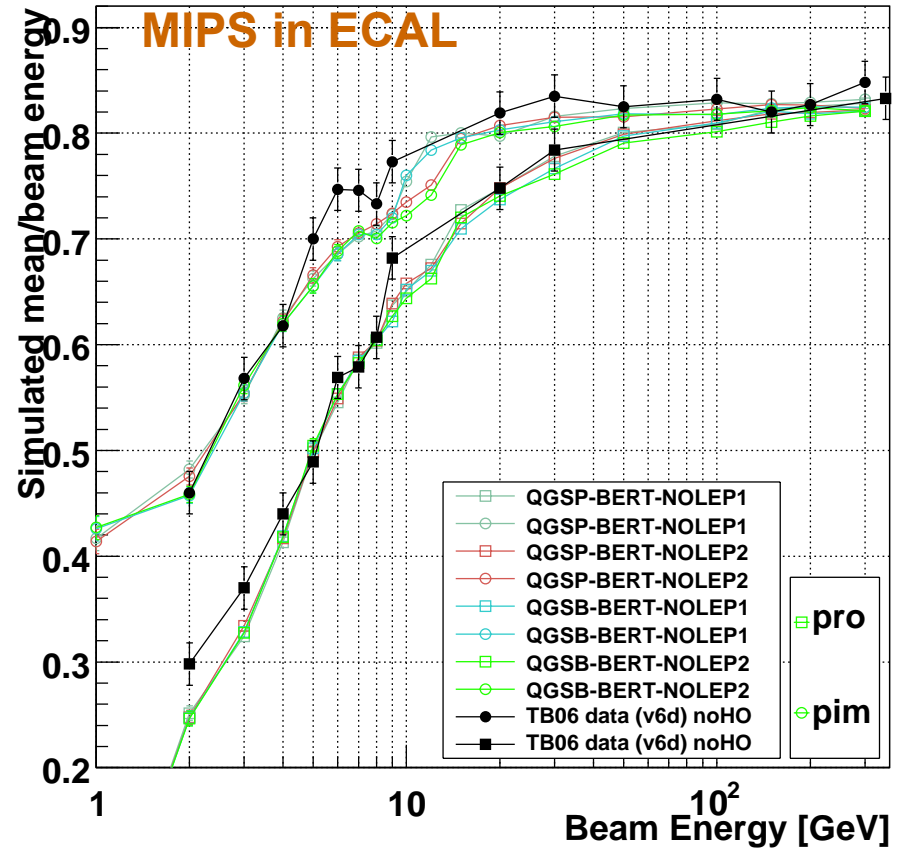
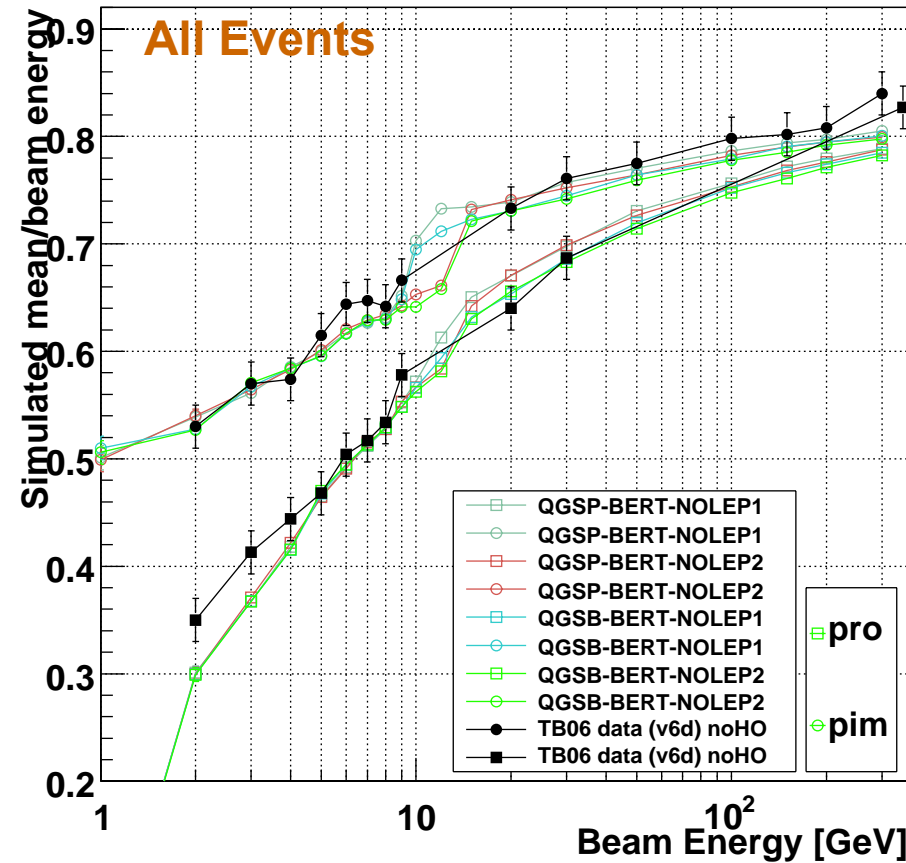
Finer scan shows structure only around 5 GeV



Mean response for QGSP(B)_BERT_NOLEP

G4:9.1.ref08Bertini Response (MCideal calib.: ele50)

G4:9.1.ref08Bertini Response (MCidealMIP calib.: ele50)



□ Discontinuity still exists either around 10 GeV (NOLEP1) or 15 GeV (NOLEP2)

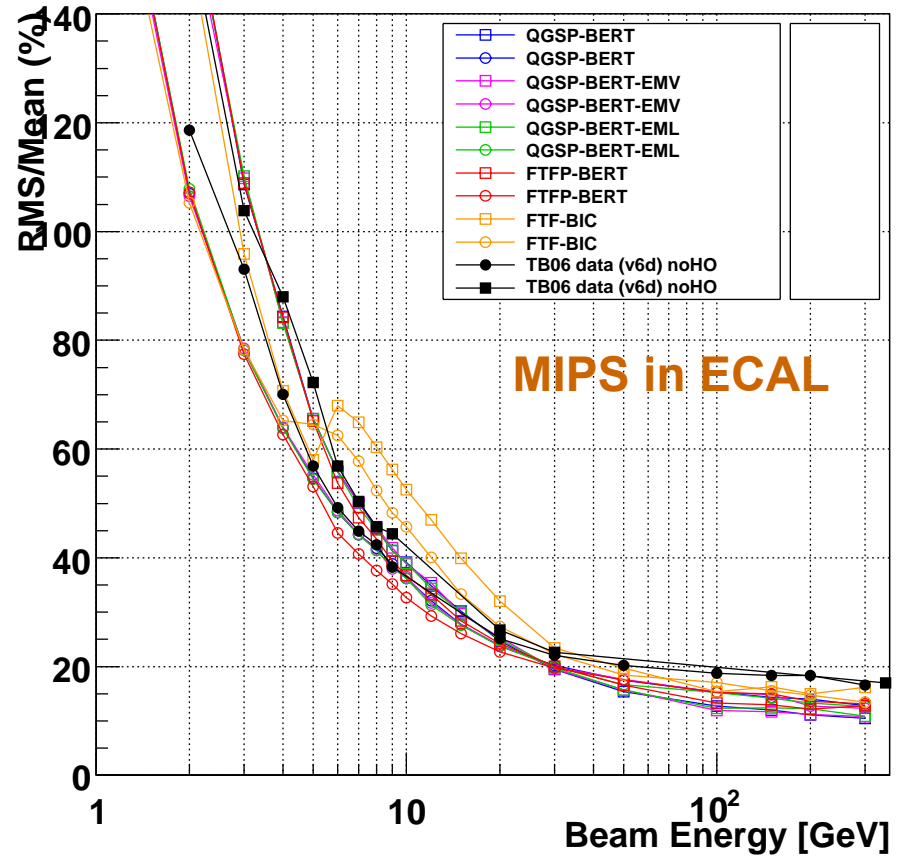
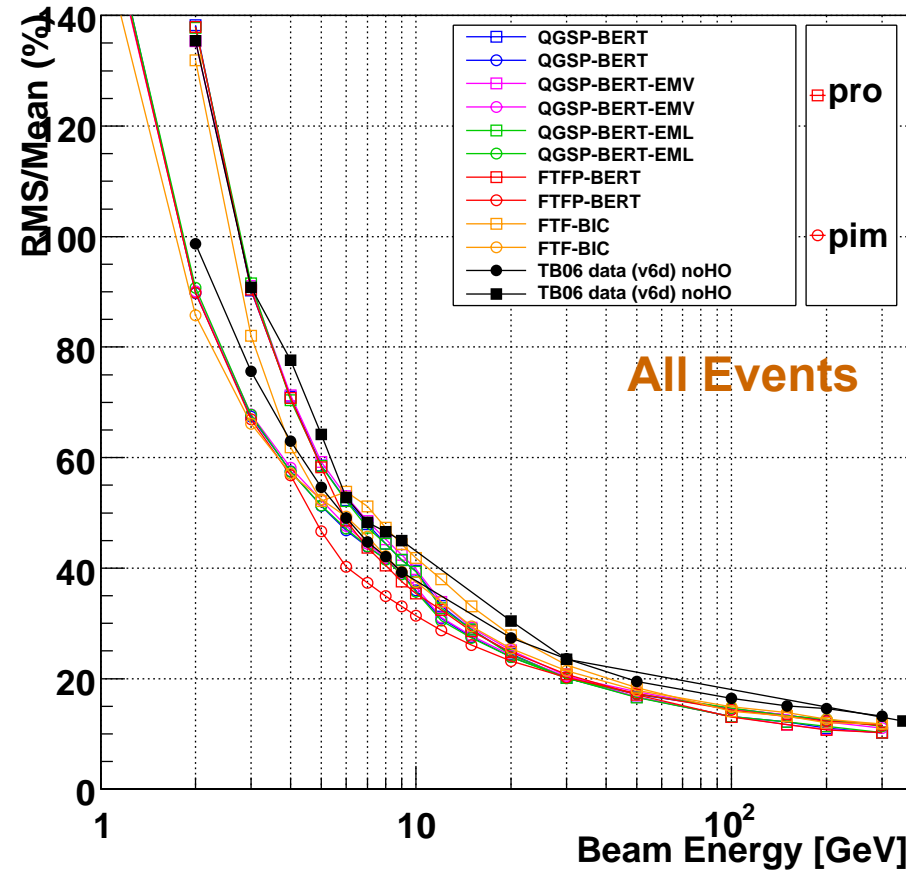


Energy Resolution for QGSP_BERT's



G4:9.2.b02 Resolution (MCideal)

G4:9.2.b02 Resolution (MCidealMIP)



- FTFP_BERT gives much better energy resolution over the entire energy region
- FTF_BIC shows discontinuities around 5 GeV
- MC predicts better energy resolution at high energies (with MIP in ECAL)

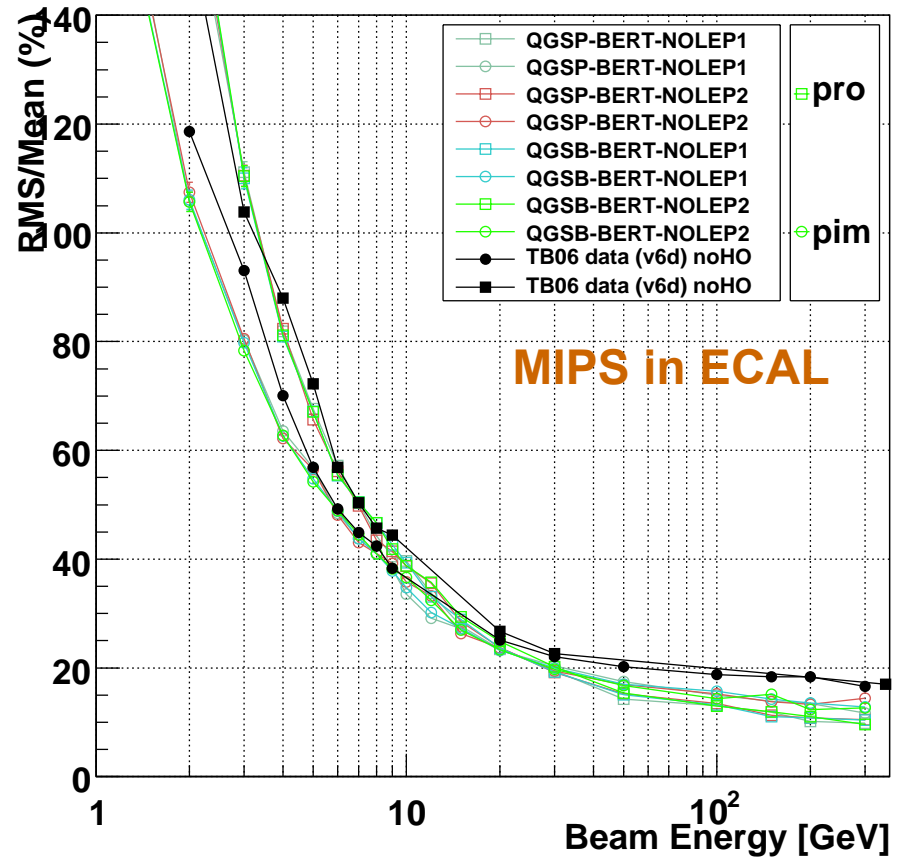
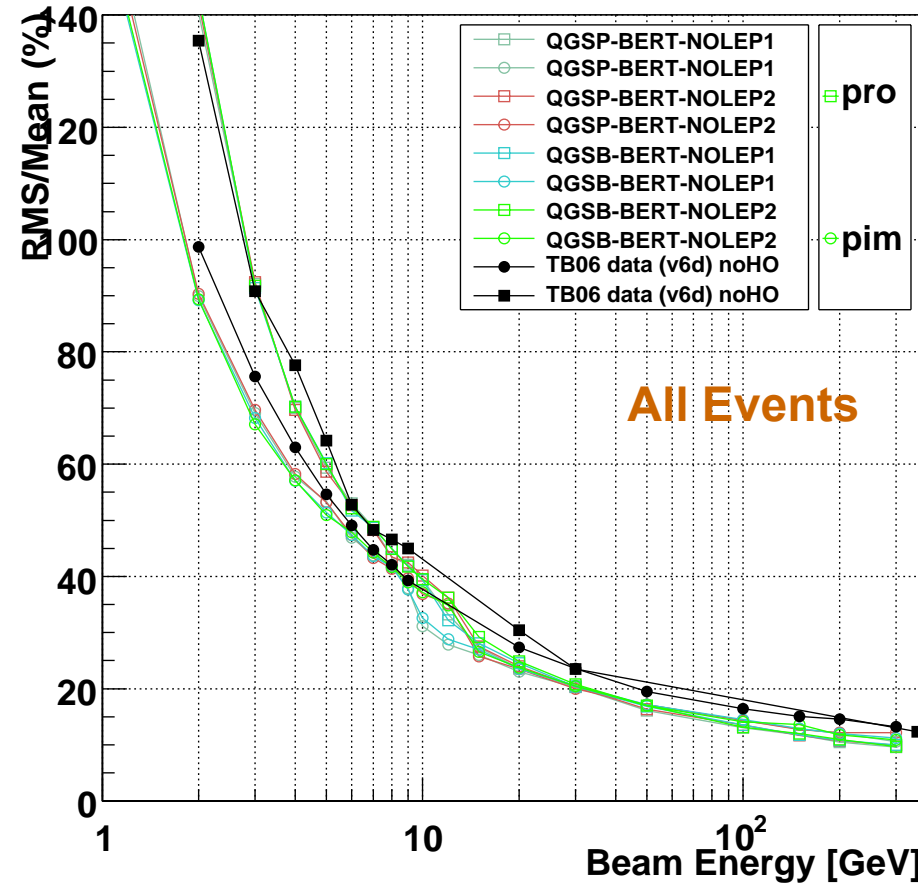


Energy Resolution for QGSP(B)_BERT_NOLEP



G4:9.1.ref08Bertini Resolution (MCideal)

G4:9.1.ref08Bertini Resolution (MCidealMIP)



NOLEP models show discontinuity around 10 GeV

The disagreement at high energies persists

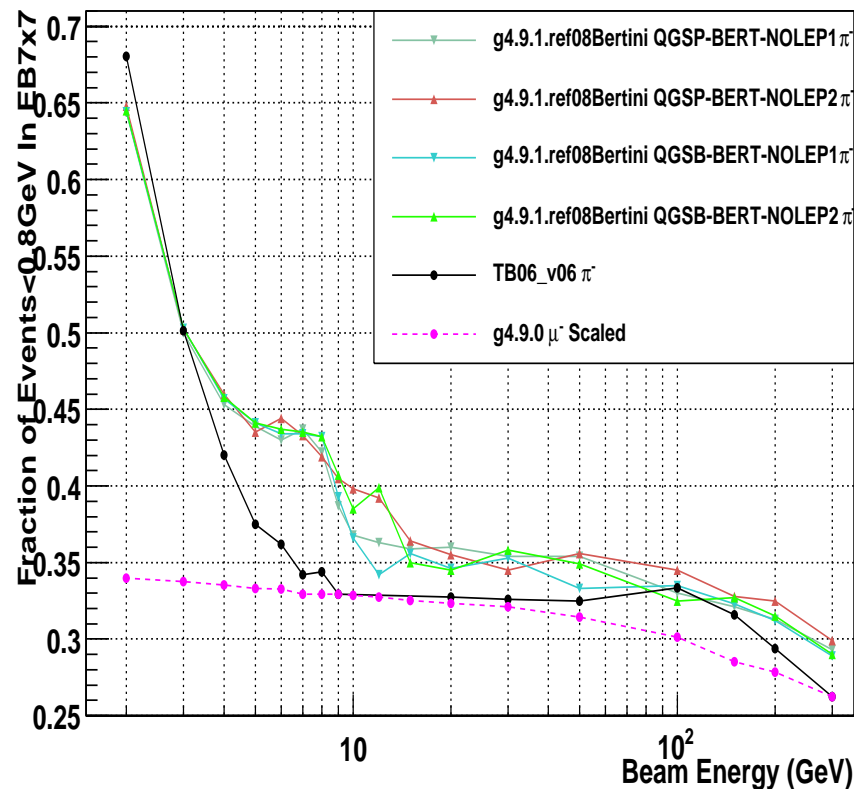
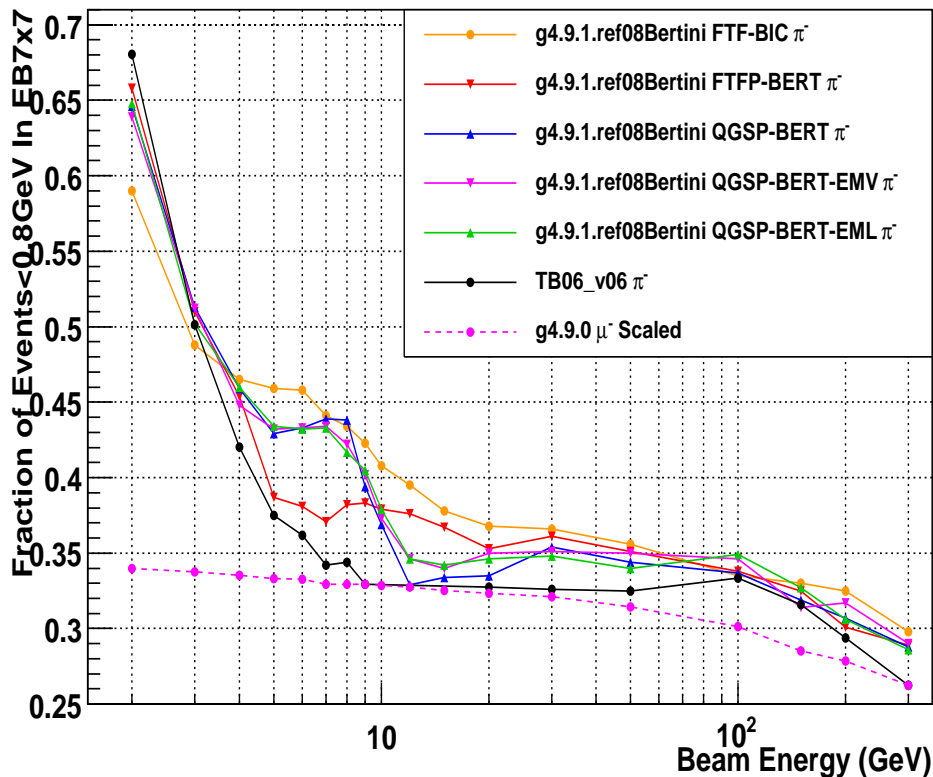


Fraction of MIP like events in ECAL



MIP fraction G4.9.1.ref08Bertini (old lists)

MIP fraction G4.9.1.ref08Bertini (new lists)



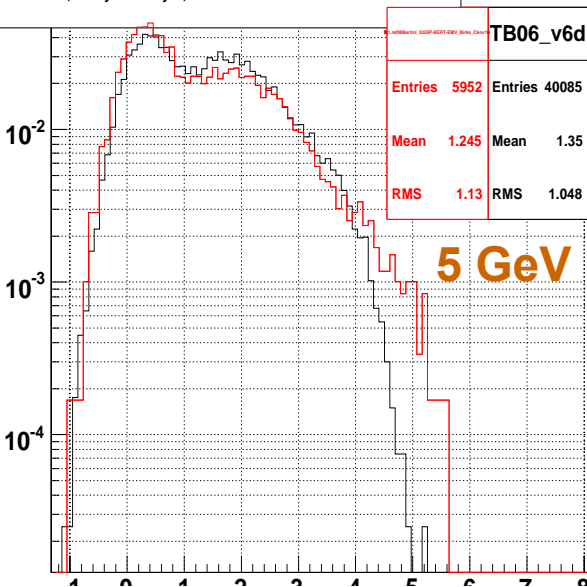
- ❑ Decrease in the MIP rate at high energies is explained with hadron bremsstrahlung in Monte Carlo
- ❑ QGS+Bertini predicts a much larger MIP fraction at 5-9 GeV
- ❑ FTFP_BERT provides the best agreement with the data



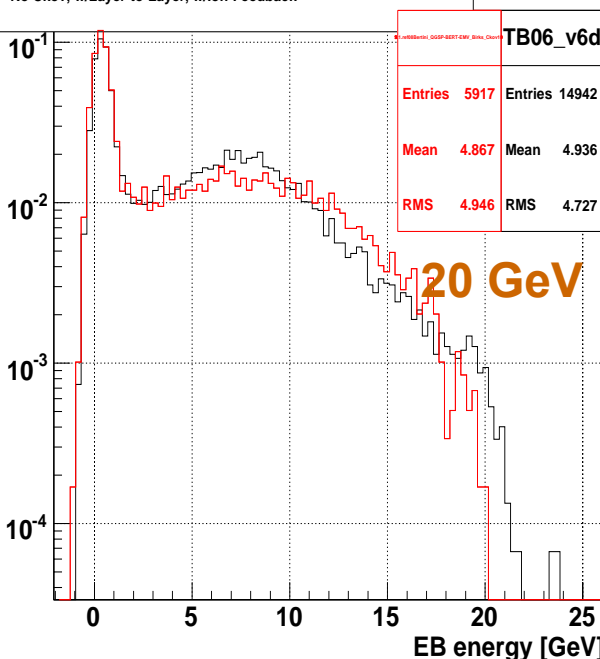
Energy measured in ECAL



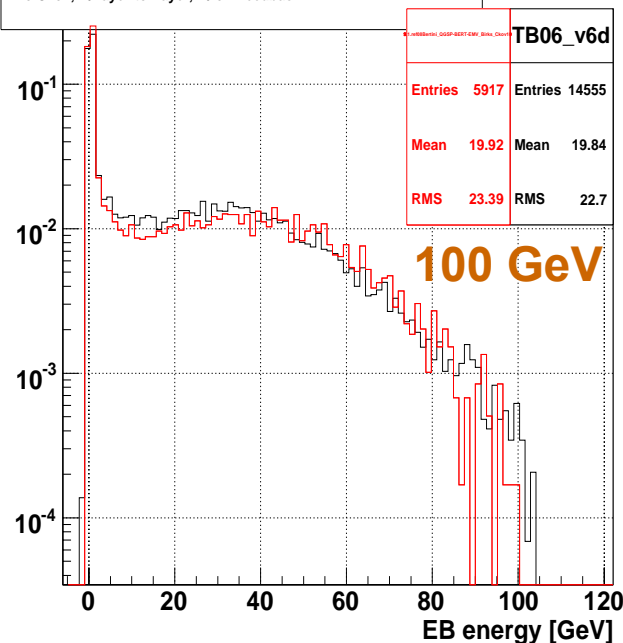
eCal: 5GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



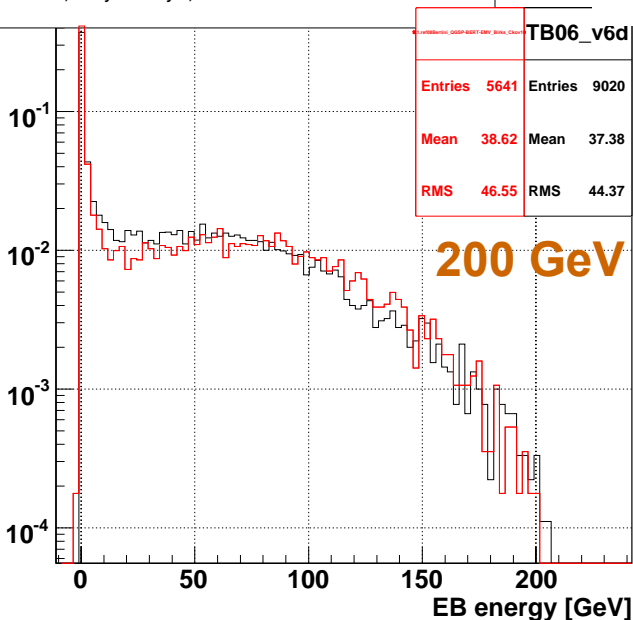
eCal: 20GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



eCal: 100GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



eCal: 200GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



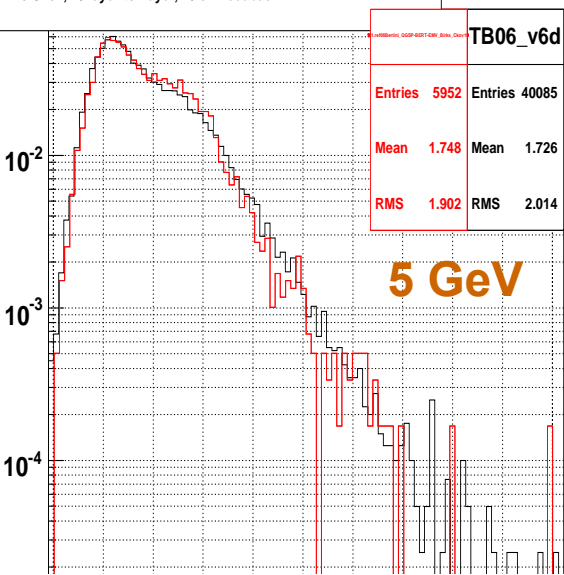
- ❑ Good agreement between data and MC at high energies
- ❑ Broader energy distribution in MC at low energies
- ❑ Worse agreement at intermediate energies
- ❑ True for all physics lists



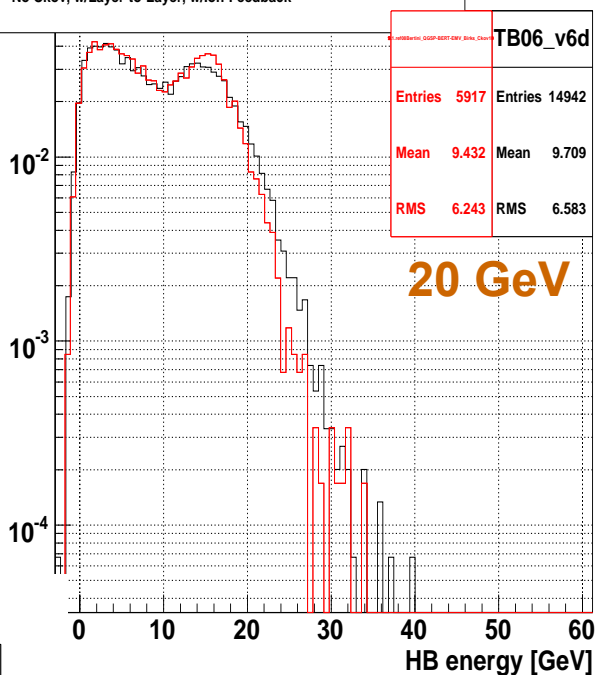
Energy measured in HCAL



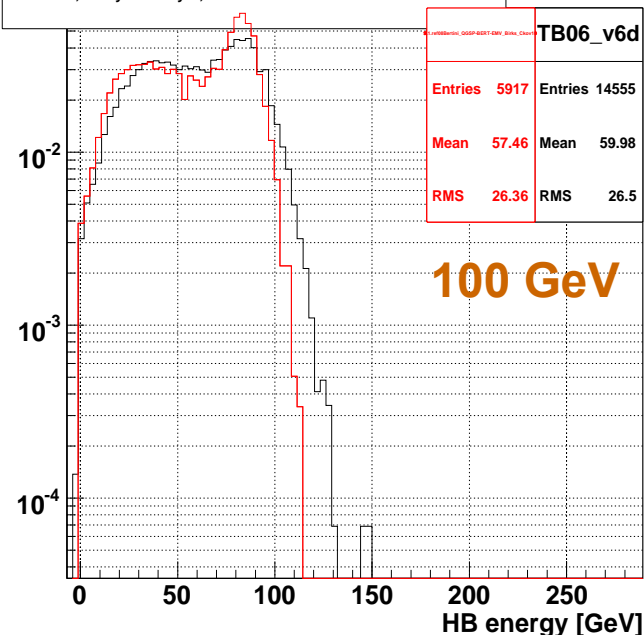
eHcal: 5GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/lon-Feedback



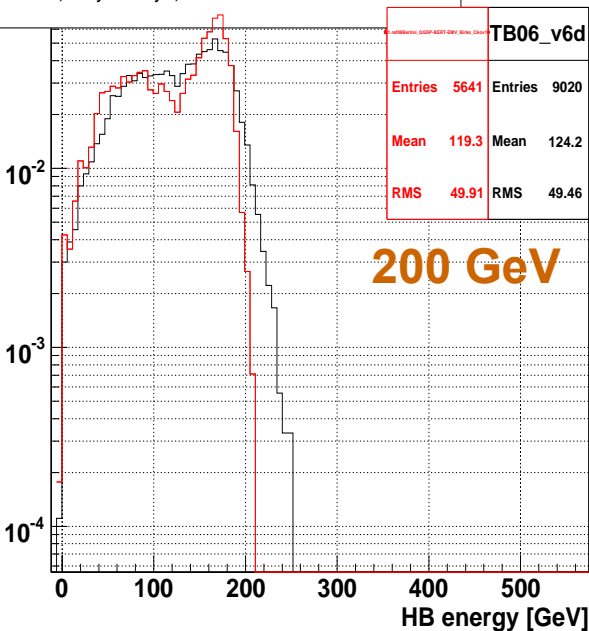
eHcal: 20GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/lon-Feedback



eHcal: 100GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/lon-Feedback



eHcal: 200GeV pim TB06_v6d vs QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/lon-Feedback



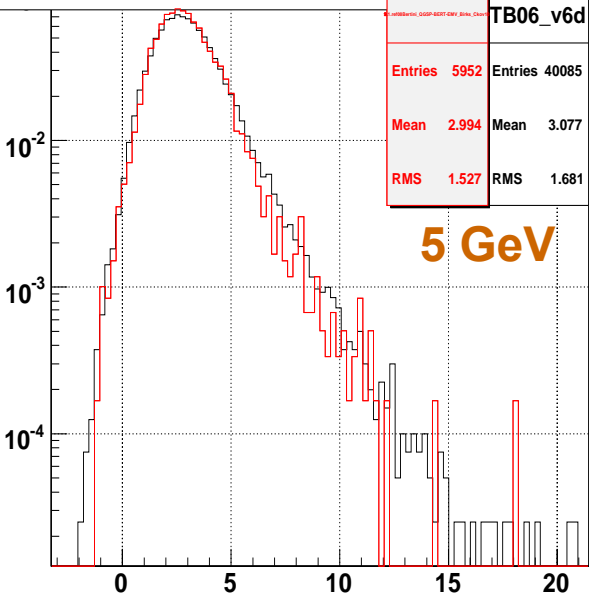
- Good agreement at low energies
- MC energy spectrum has a sharper cut off on the high energy side compared to the data



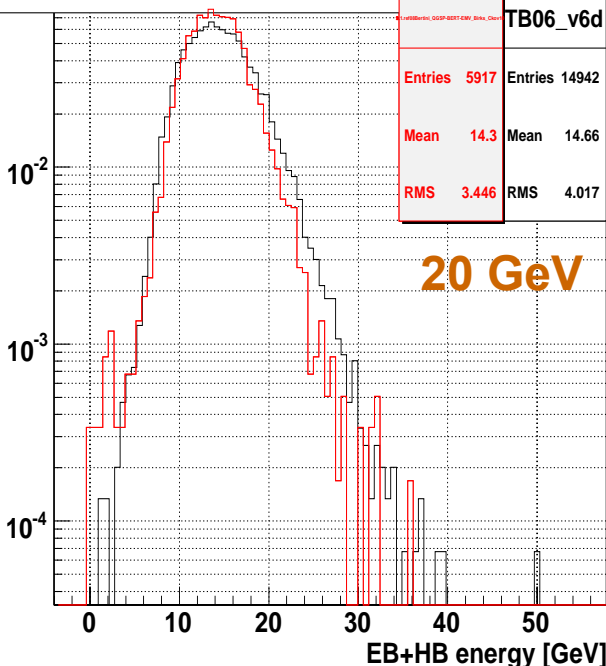
Energy measured in the Calorimeter



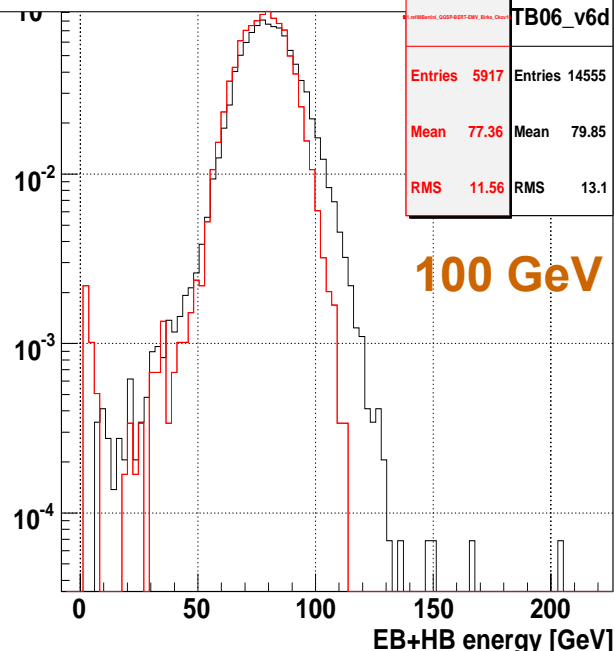
TB06 eECAL+eHCAL pi- 5 GeV (ele50 calib.) QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



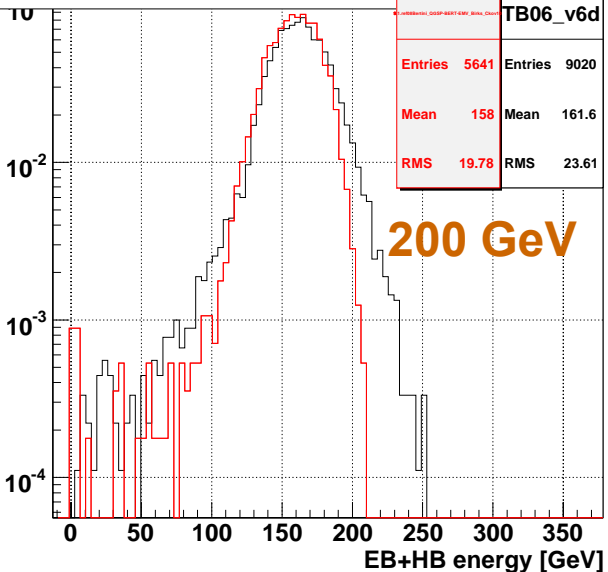
TB06 eECAL+eHCAL pi- 20 GeV (ele50 calib.) QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



TB06 eECAL+eHCAL pi- 100 GeV (ele50 calib.) QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



TB06 eECAL+eHCAL pi- 200 GeV (ele50 calib.) QGSP-BERT-EMV 9.1.ref08Bertini
No Ckov, w/Layer-to-Layer, w/Ion-Feedback



- ❑ Main disagreement is at higher energies
- ❑ The difference is more visible for events with MIP like signal in ECAL



Summary



- ❑ The physics list **FTFP_BERT** provides the best agreement for mean energy response for pions and protons.
- ❑ Reasonable agreement is also seen with **QGSP_BERT** and some of its variations.
- ❑ Smooth energy dependence is a major concern. Even removing **LEP** from the physics list does not give rise to the smooth energy dependence.
- ❑ Energy response at high energies shows a sharper cut off on the high energy side resulting better energy resolution in the MC than in the data.
- ❑ MIP fraction is larger for the Monte Carlo samples in the energy region **5-10 GeV** (hopefully the new correction in **Bertini** will help)

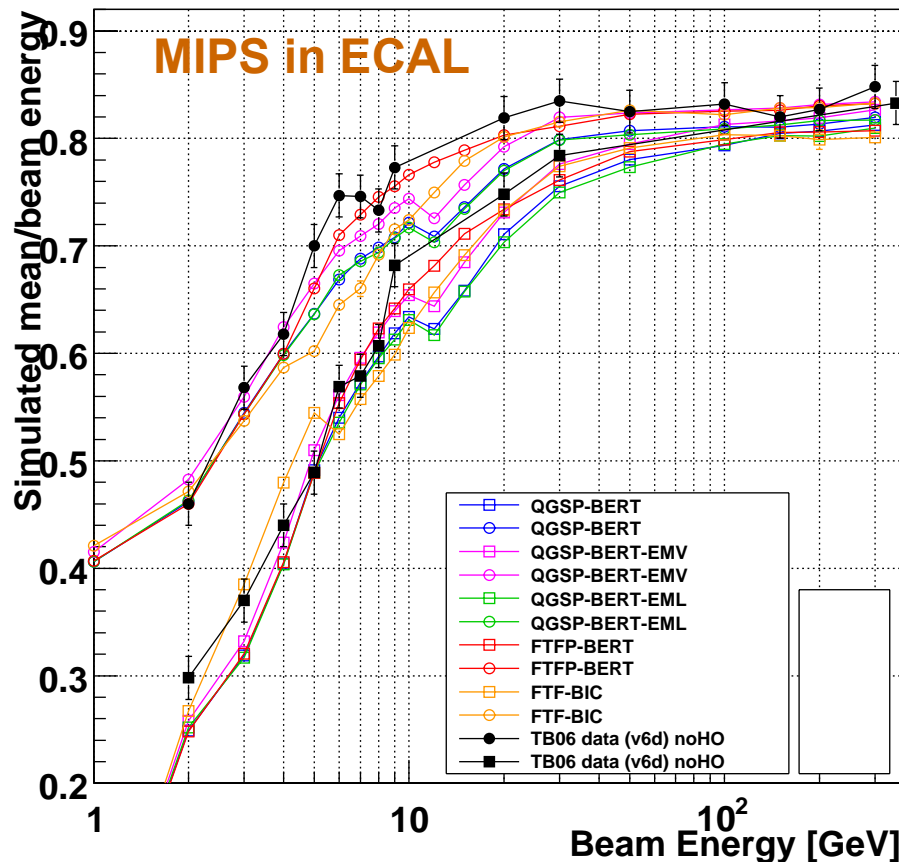
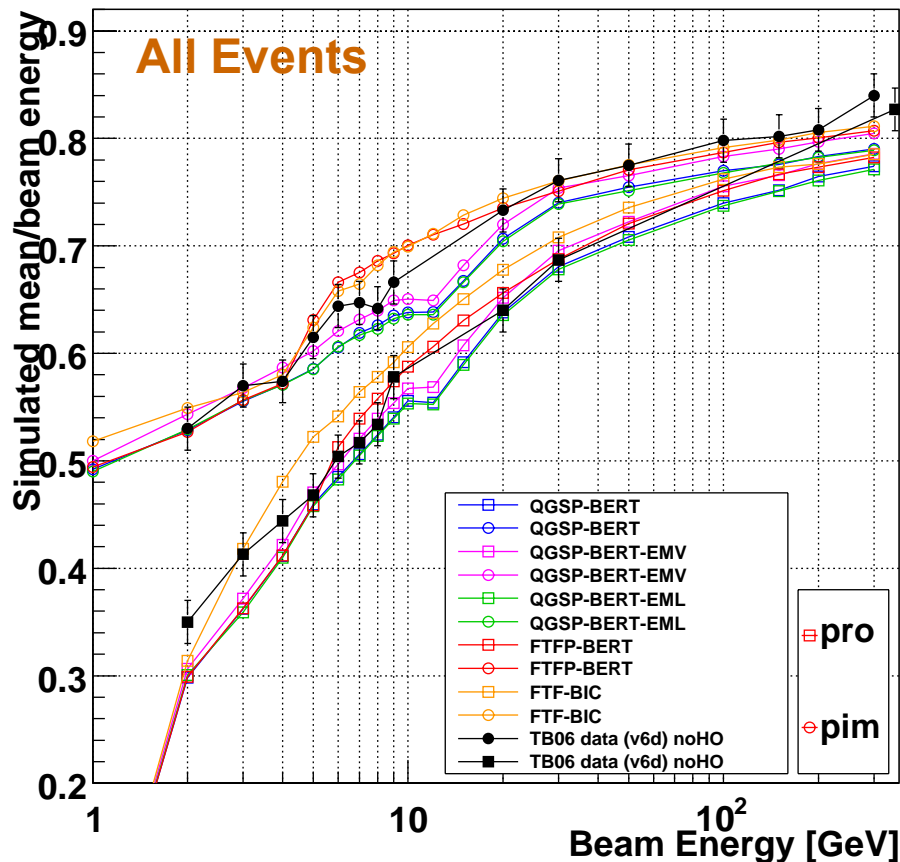


Mean response for QGSP_BERT's



G4:9.2.b02 Response (MCideal calib.: ele50)

G4:9.2.b02 Response (MCidealMIP calib.: ele50)

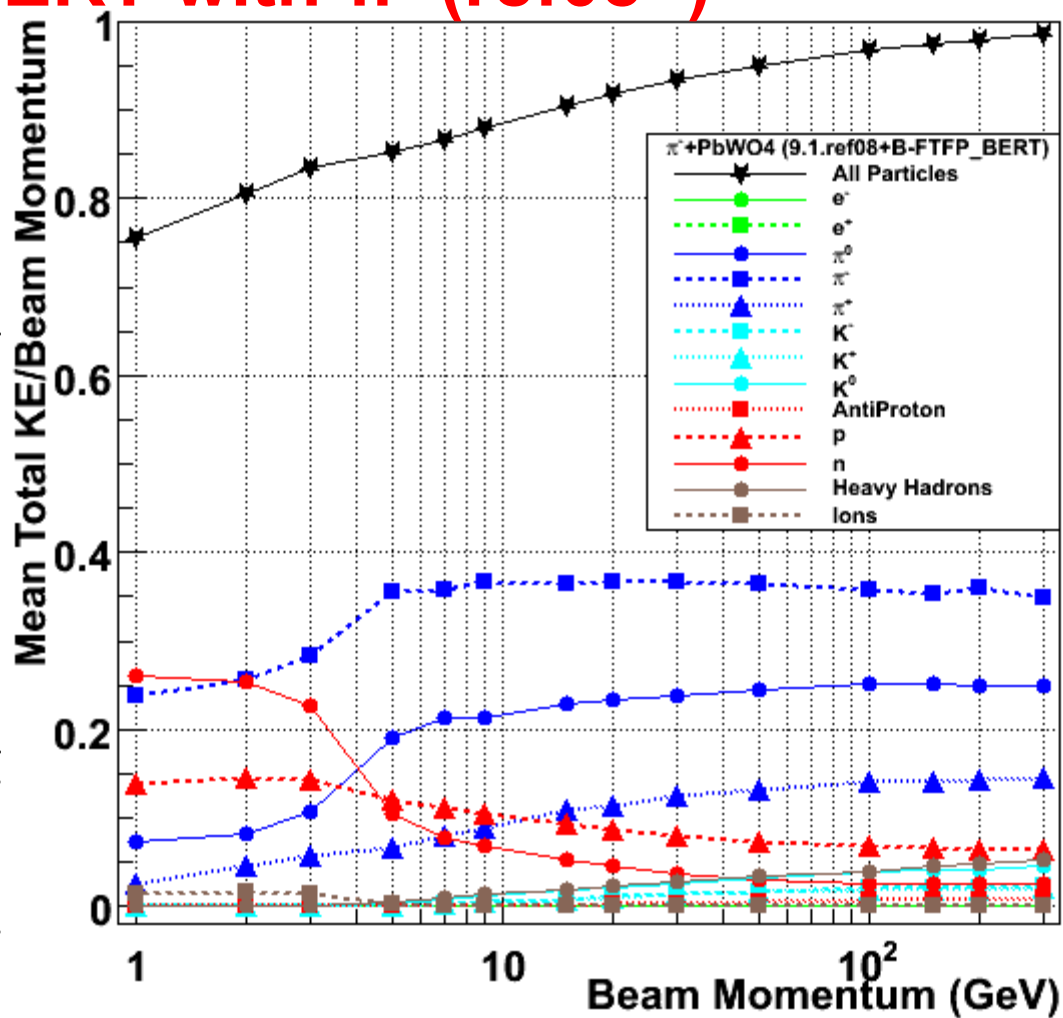
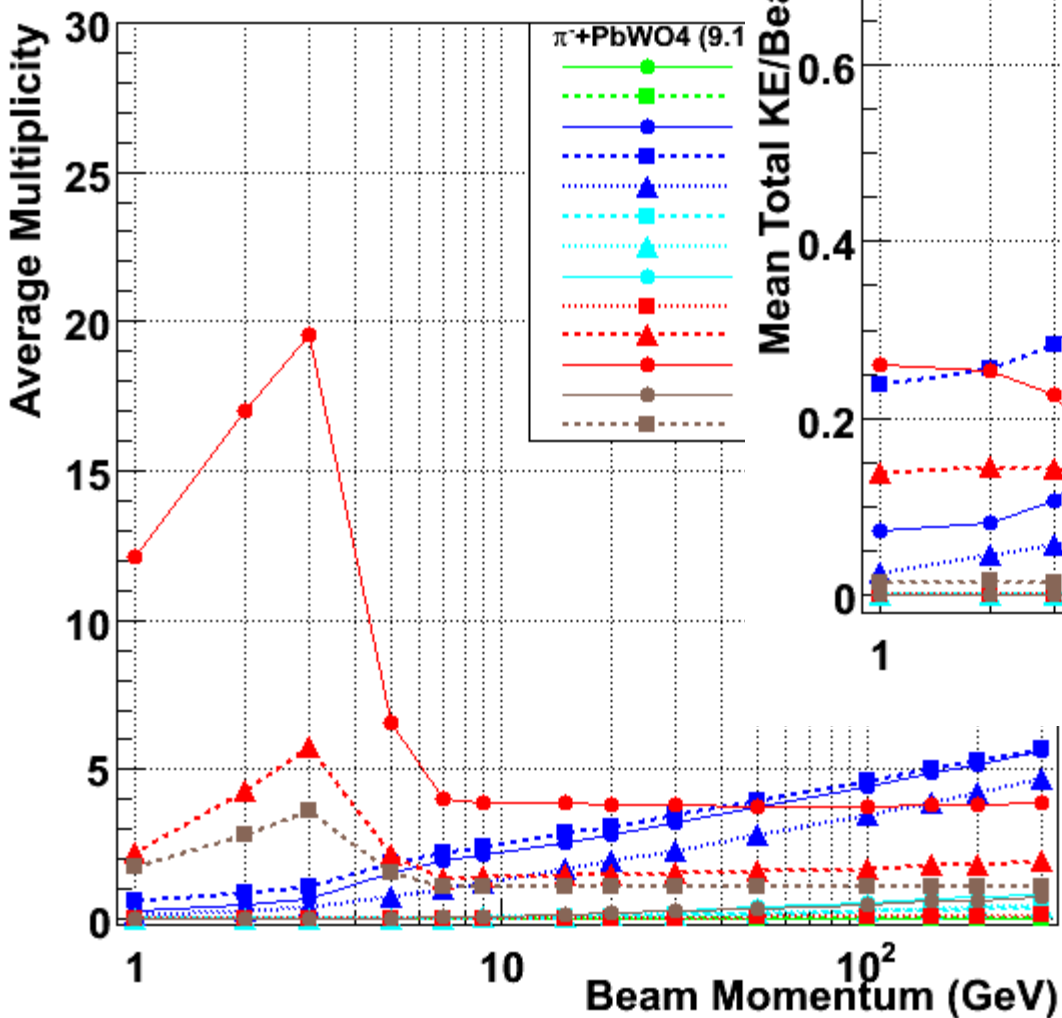


FTFP_BERT gives the best description for energy response

Most physics lists show clear discontinuities

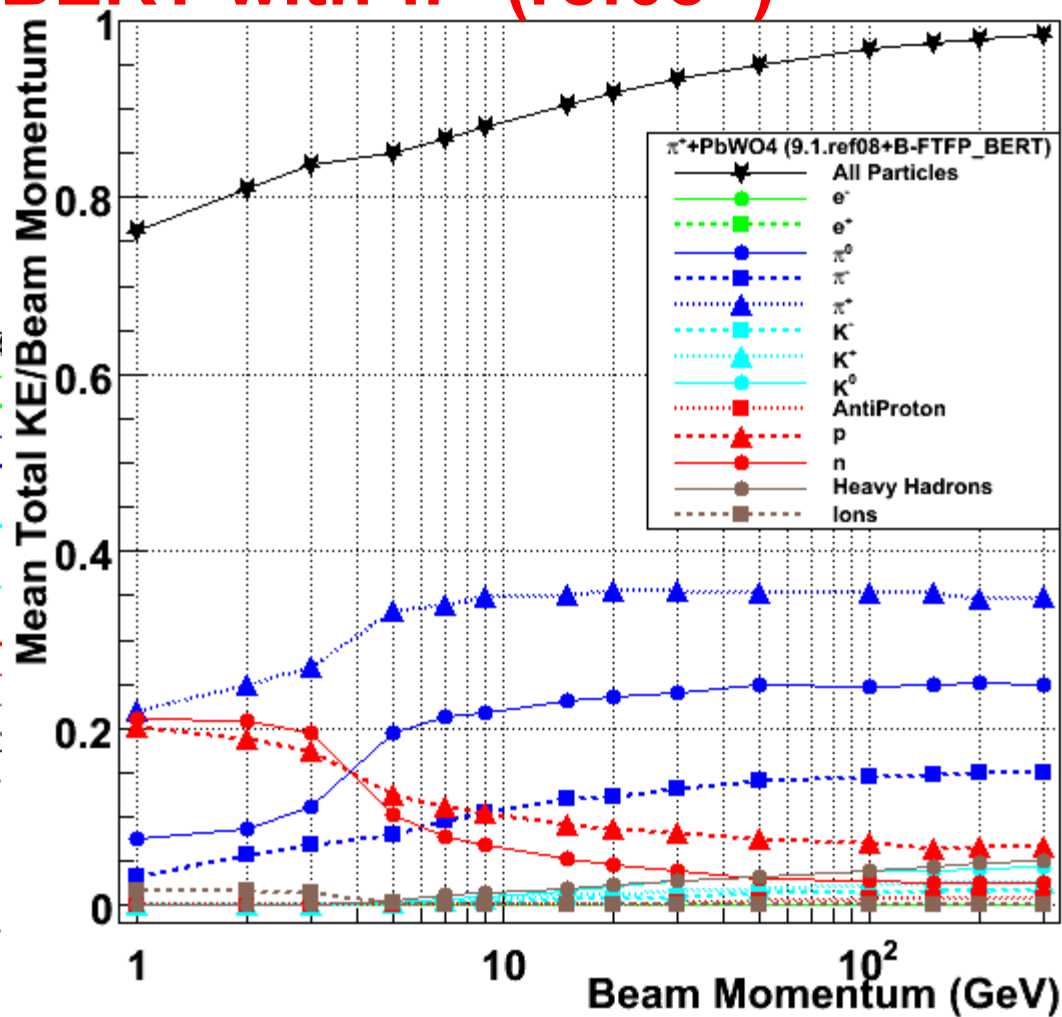
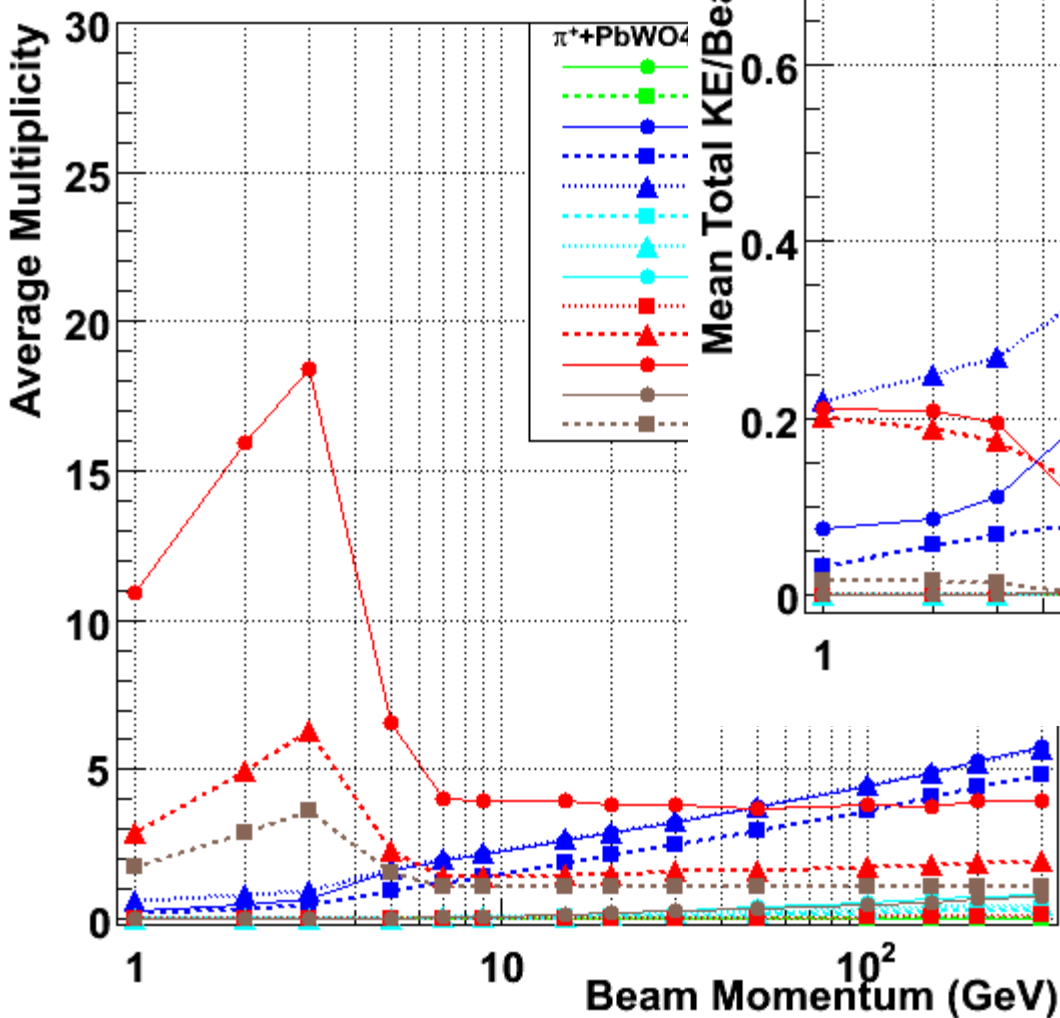


FTFP_BERT with π^- (ref08+)



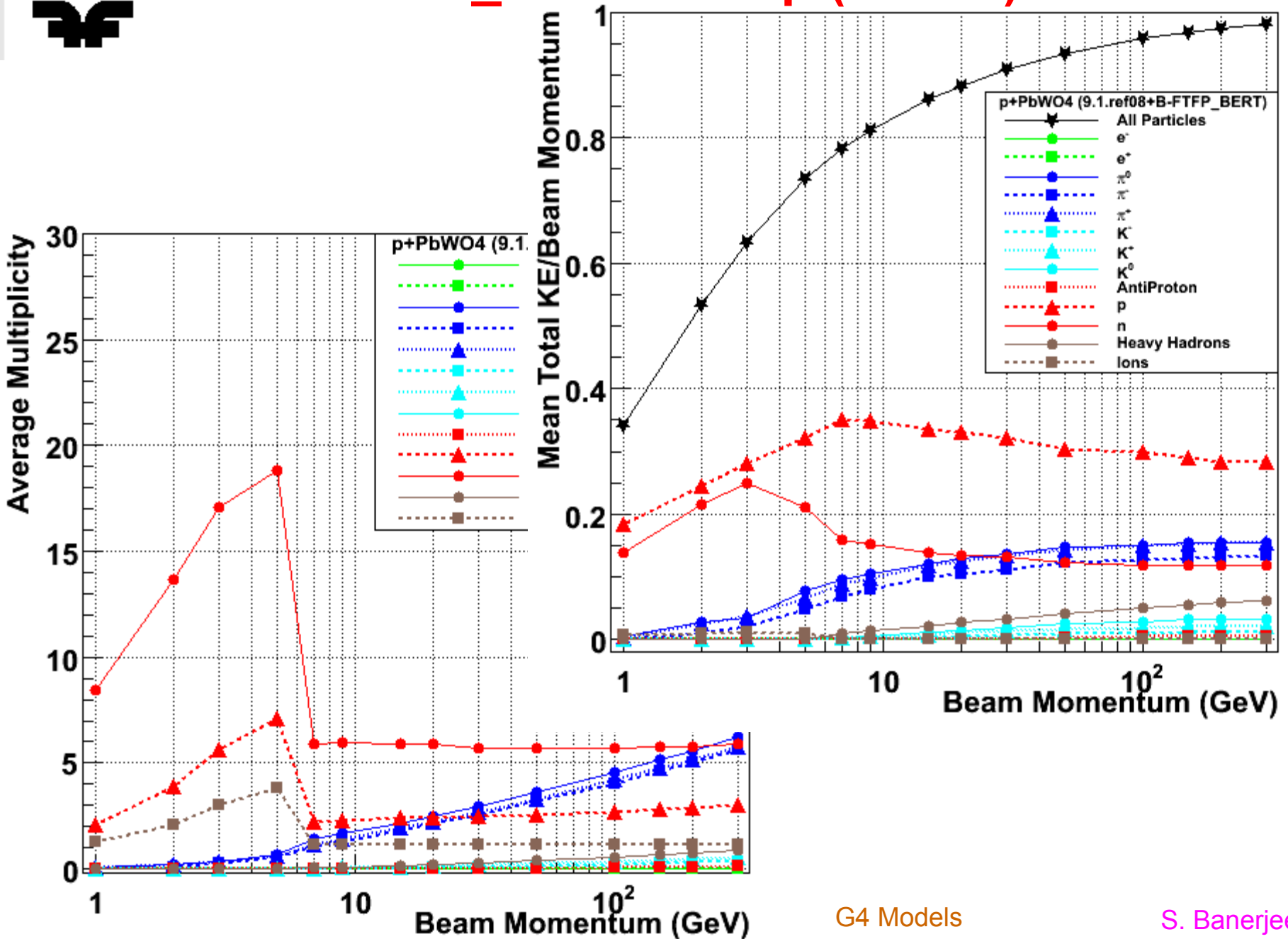


FTFP_BERT with π^+ (ref08+)



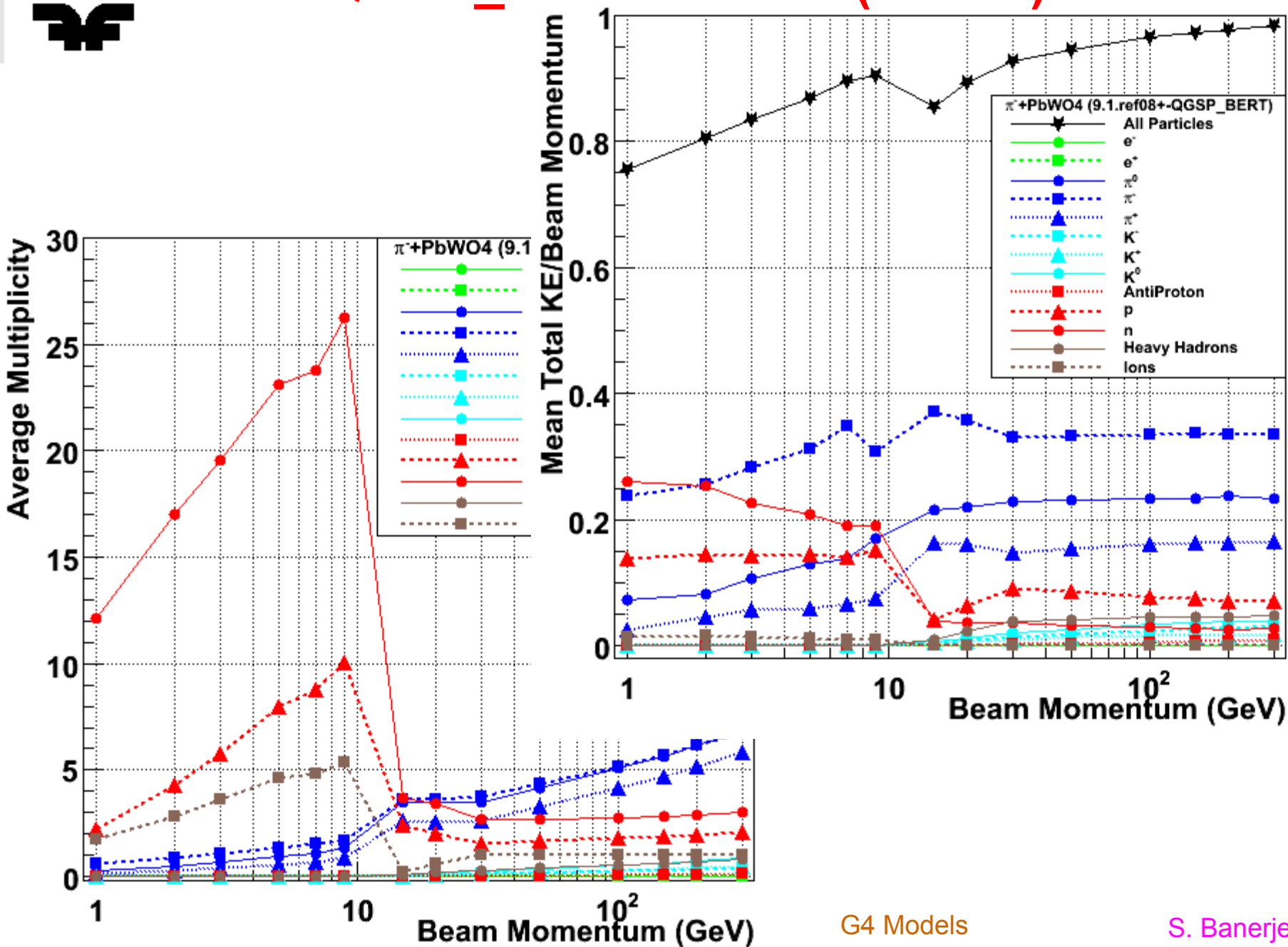


FTFP_BERT with p (ref08+)



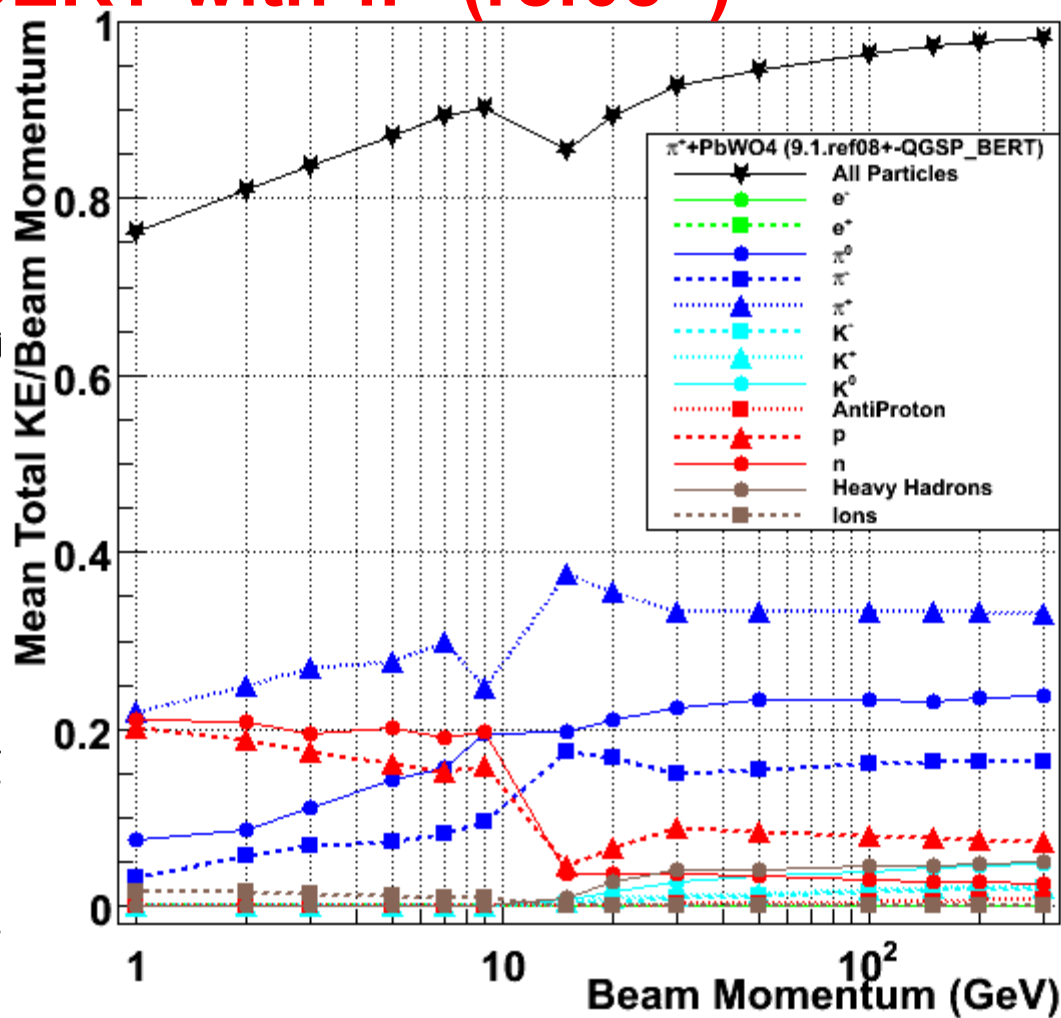
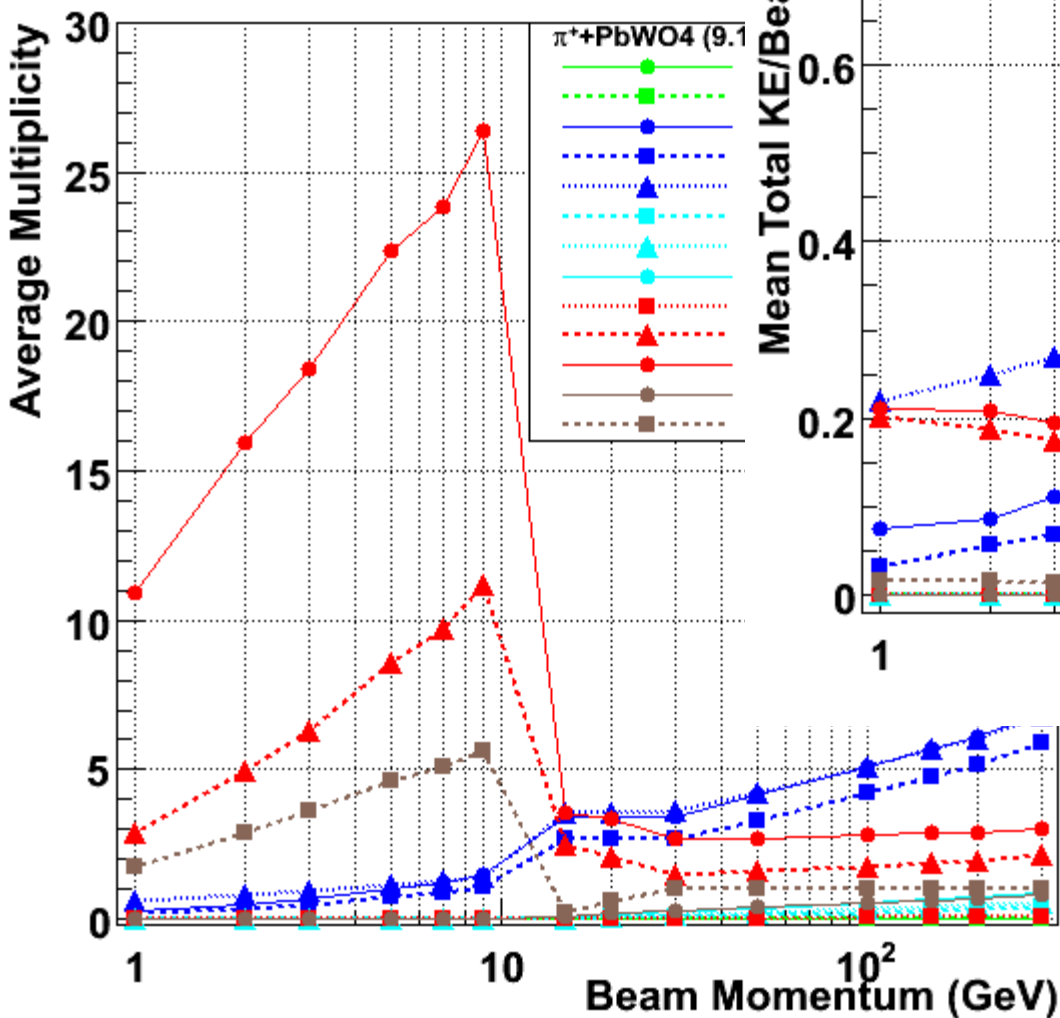


QGSP_BERT with π^- (ref08+)



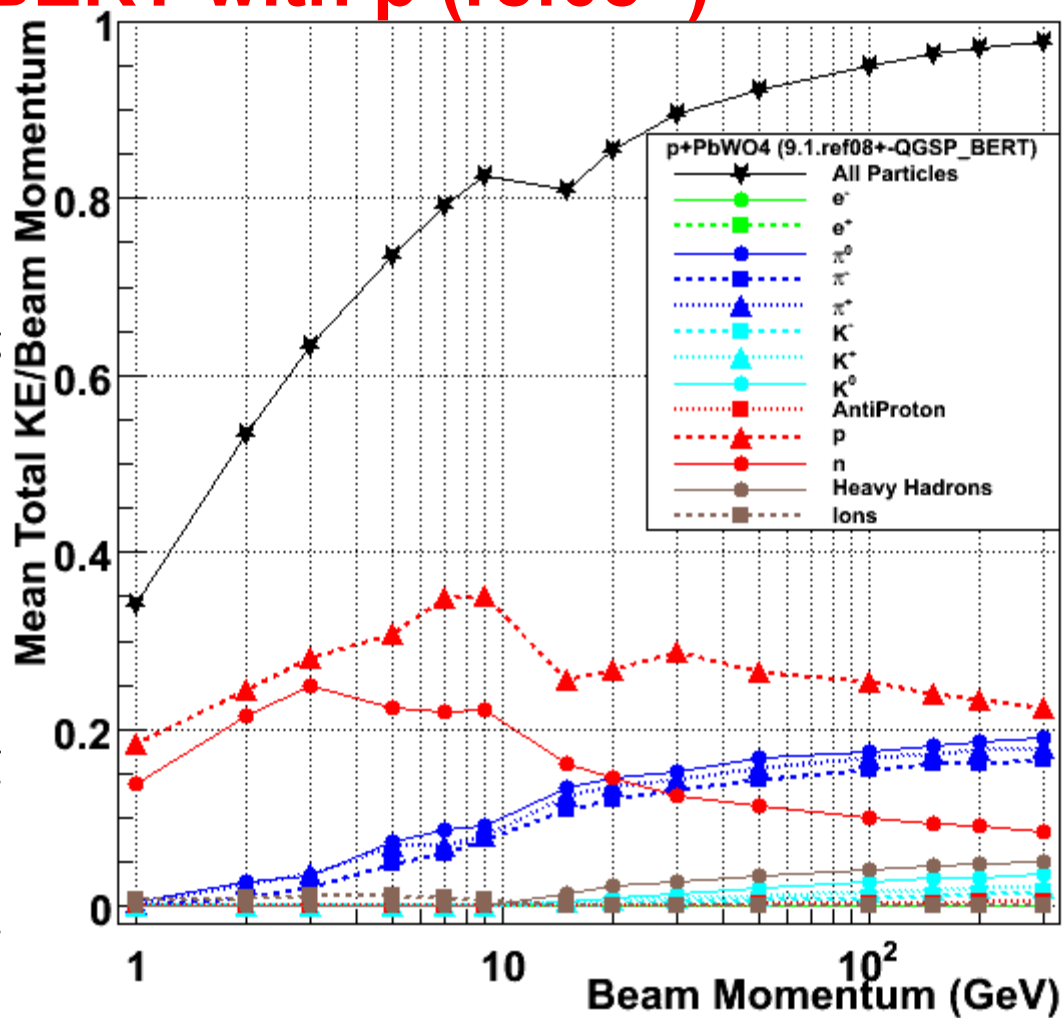
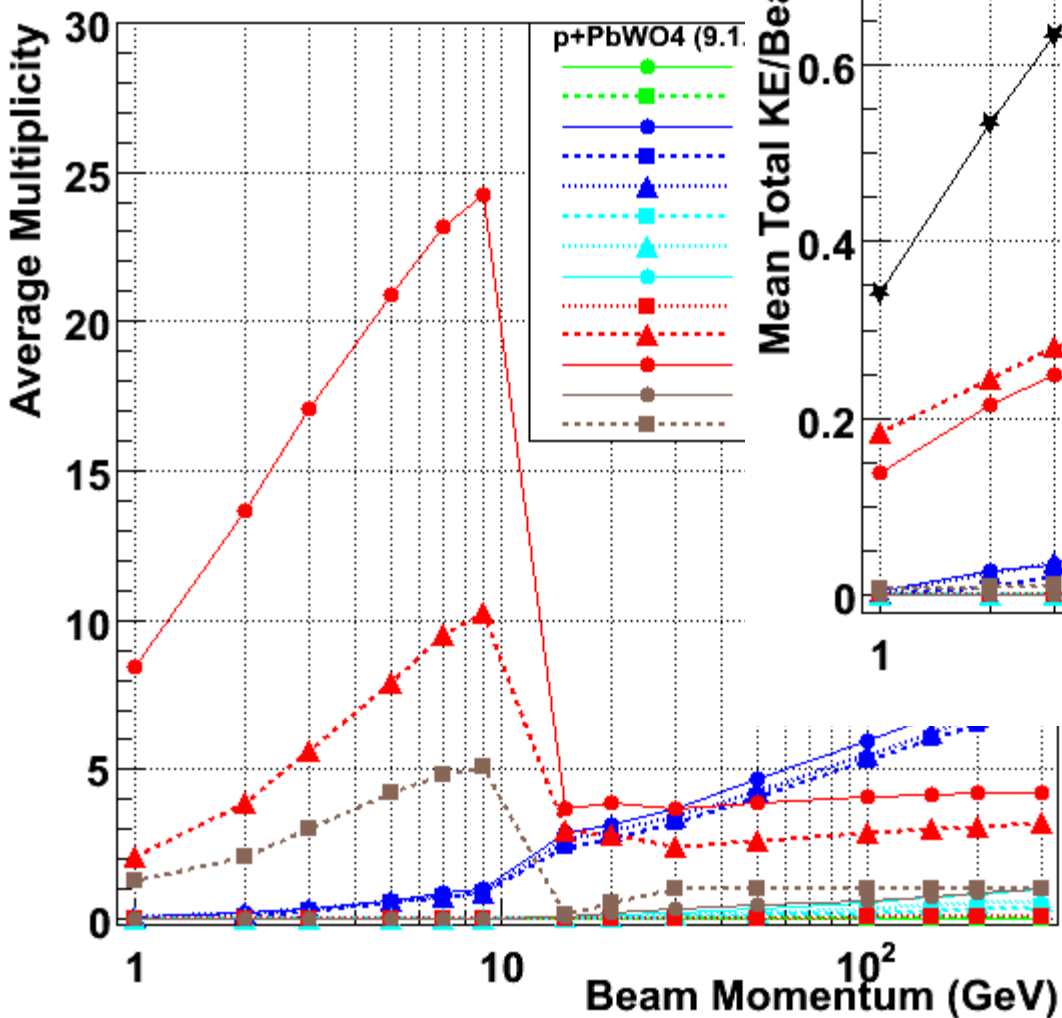


QGSP_BERT with π^+ (ref08+)



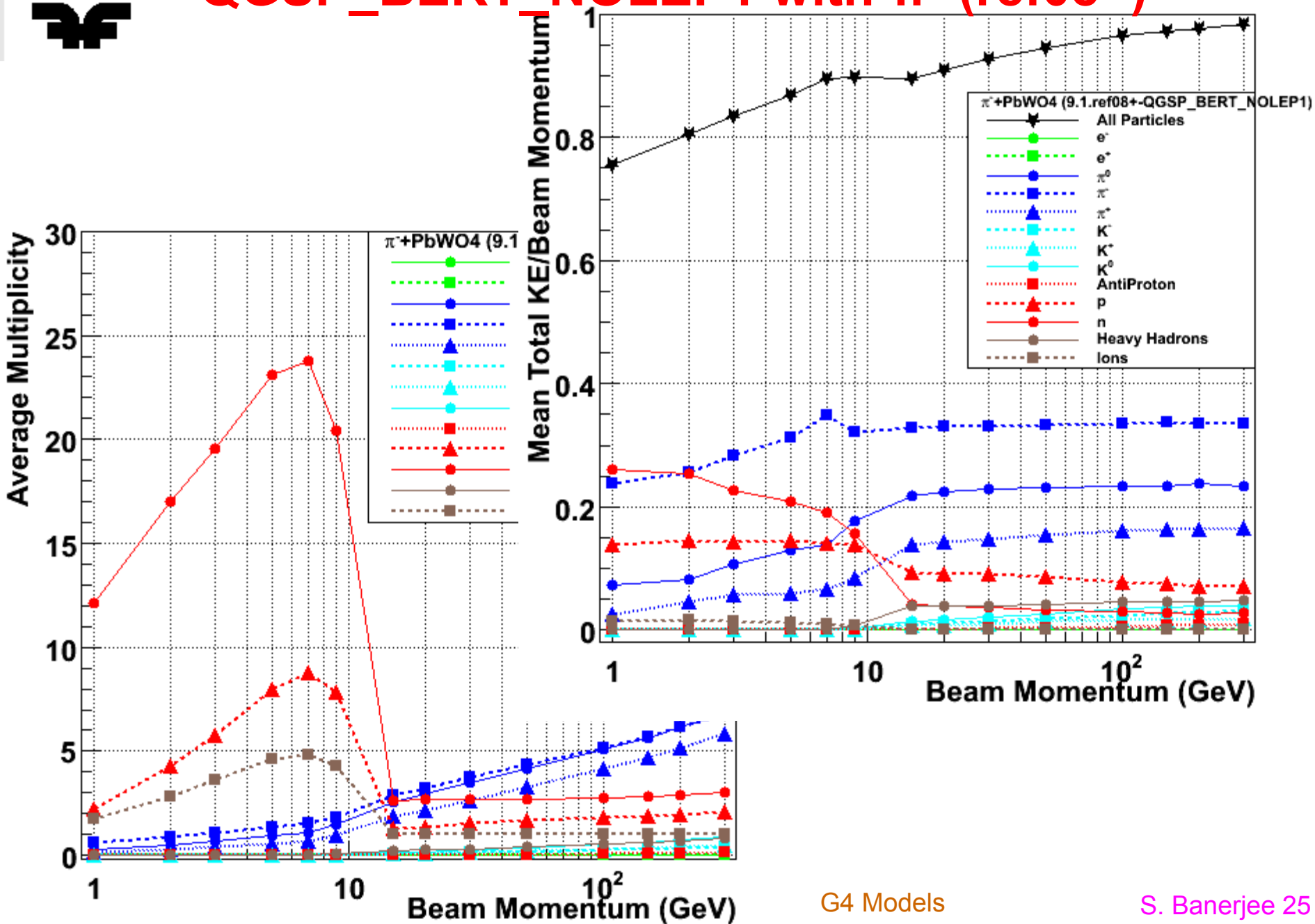


QGSP_BERT with p (ref08+)



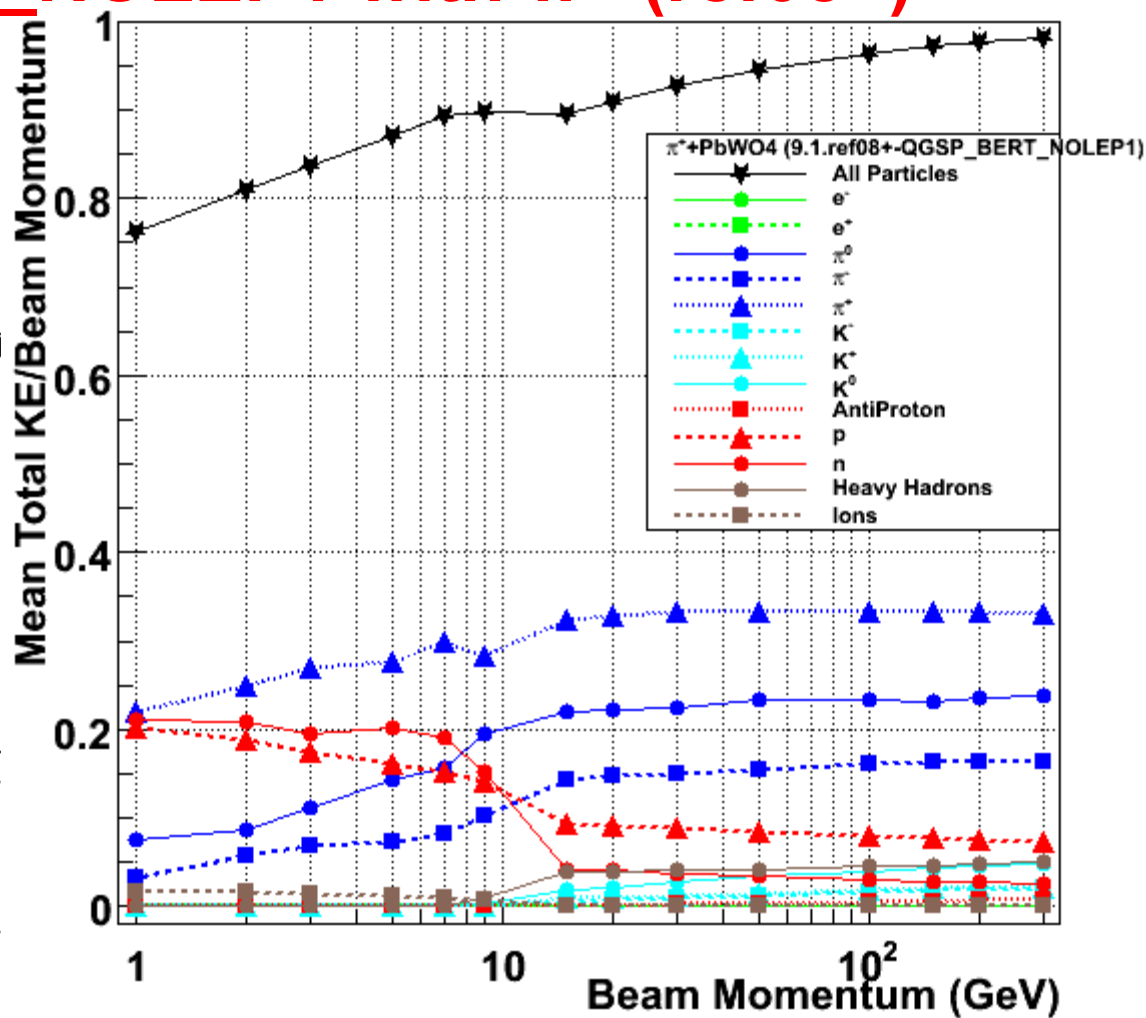
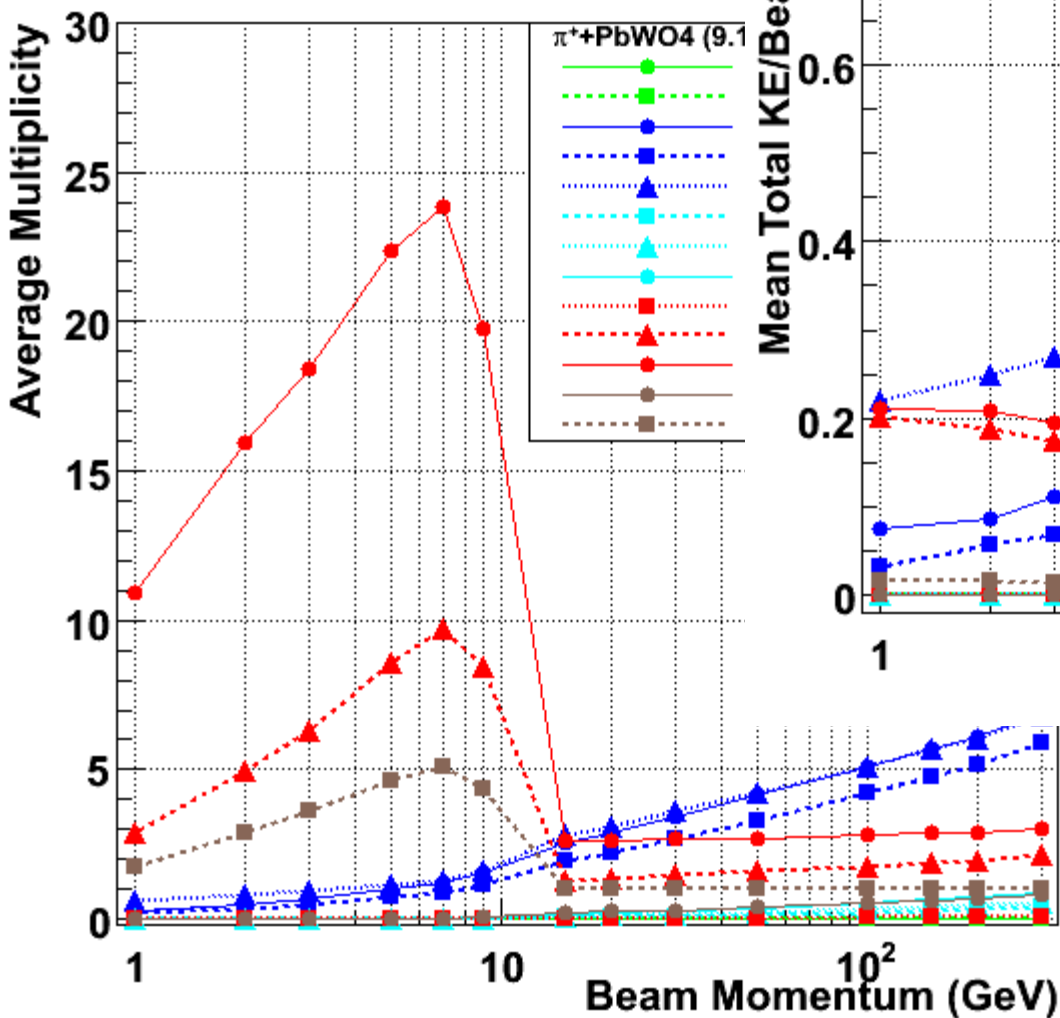


QGSP_BERT_NOLEP1 with π^- (ref08+)



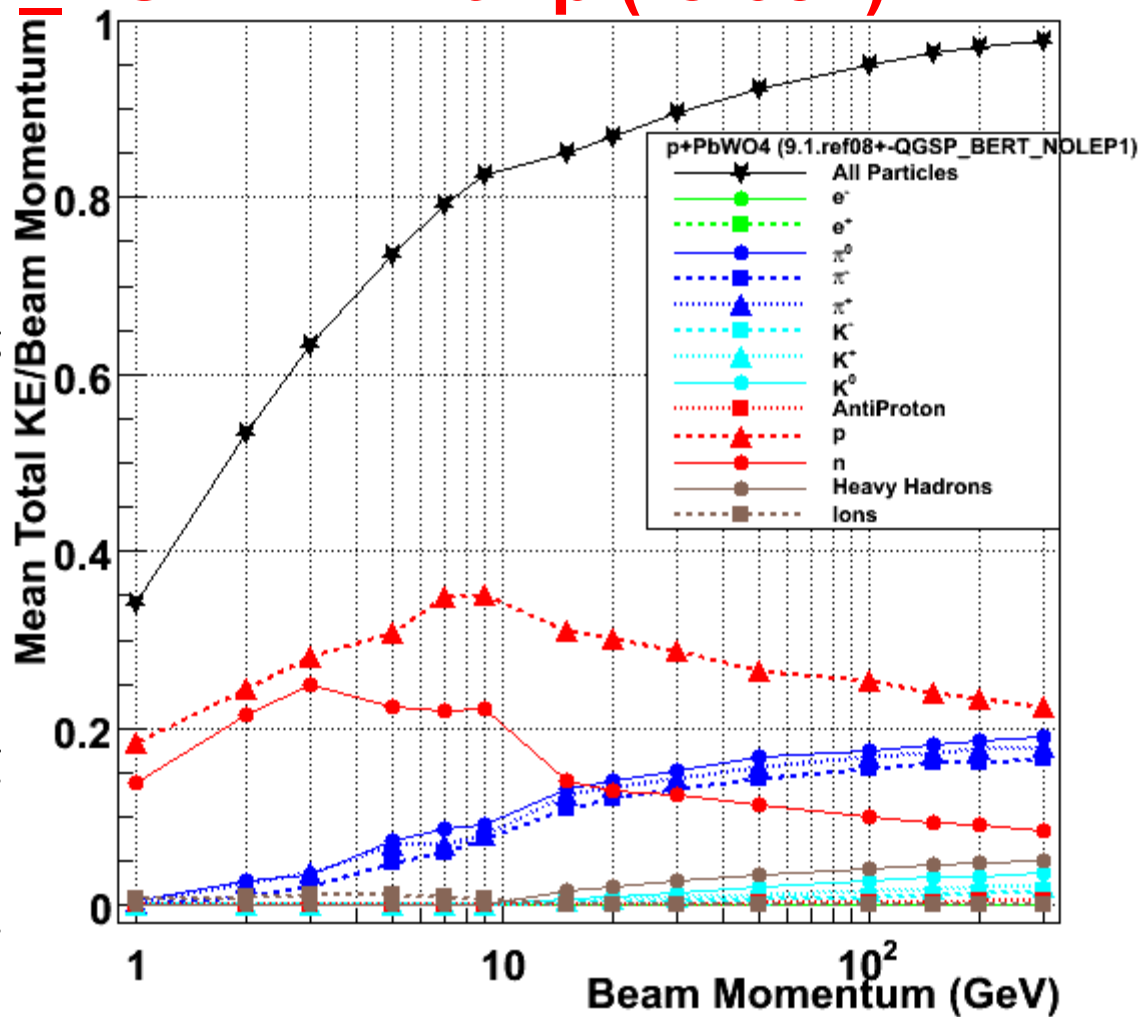
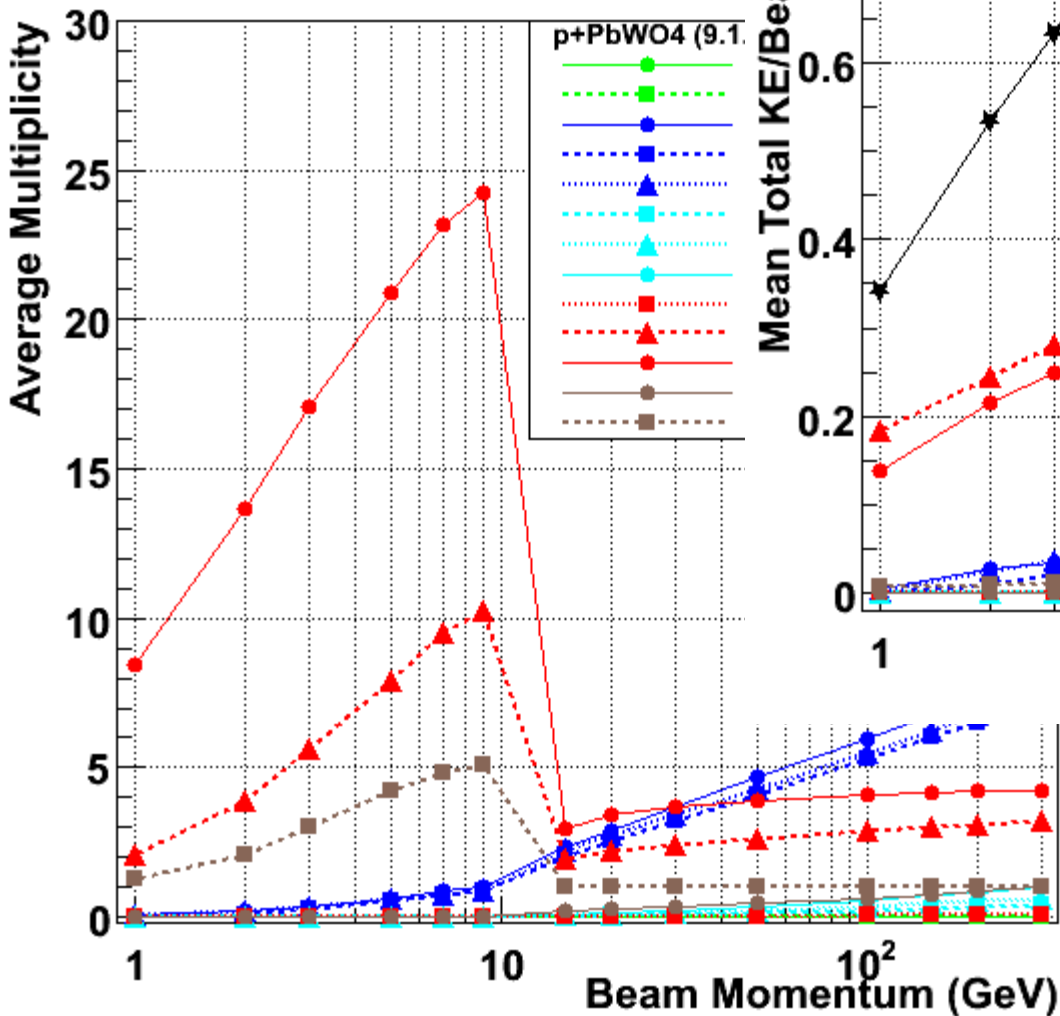


QGSP_BERT_NOLEP1 with π^+ (ref08+)



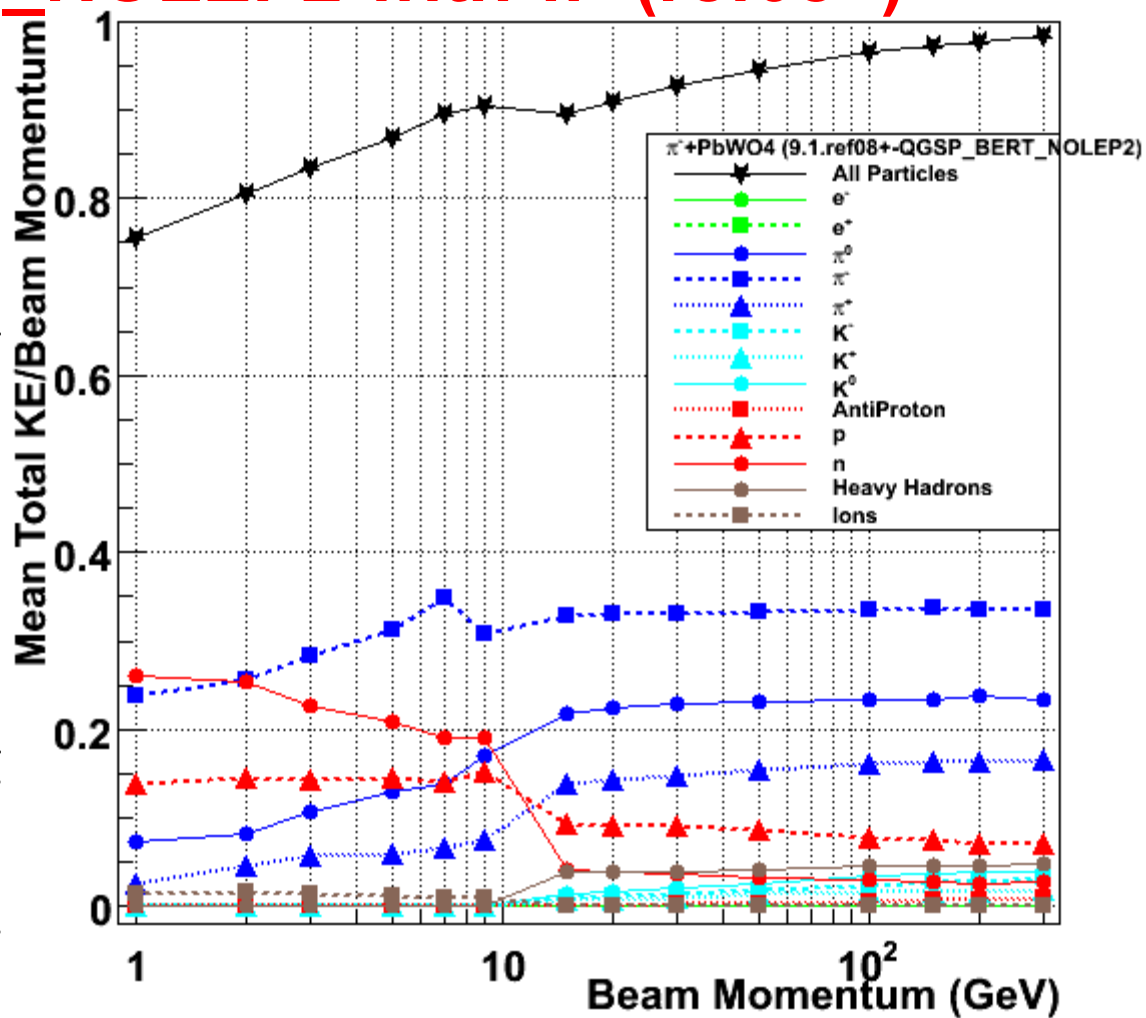
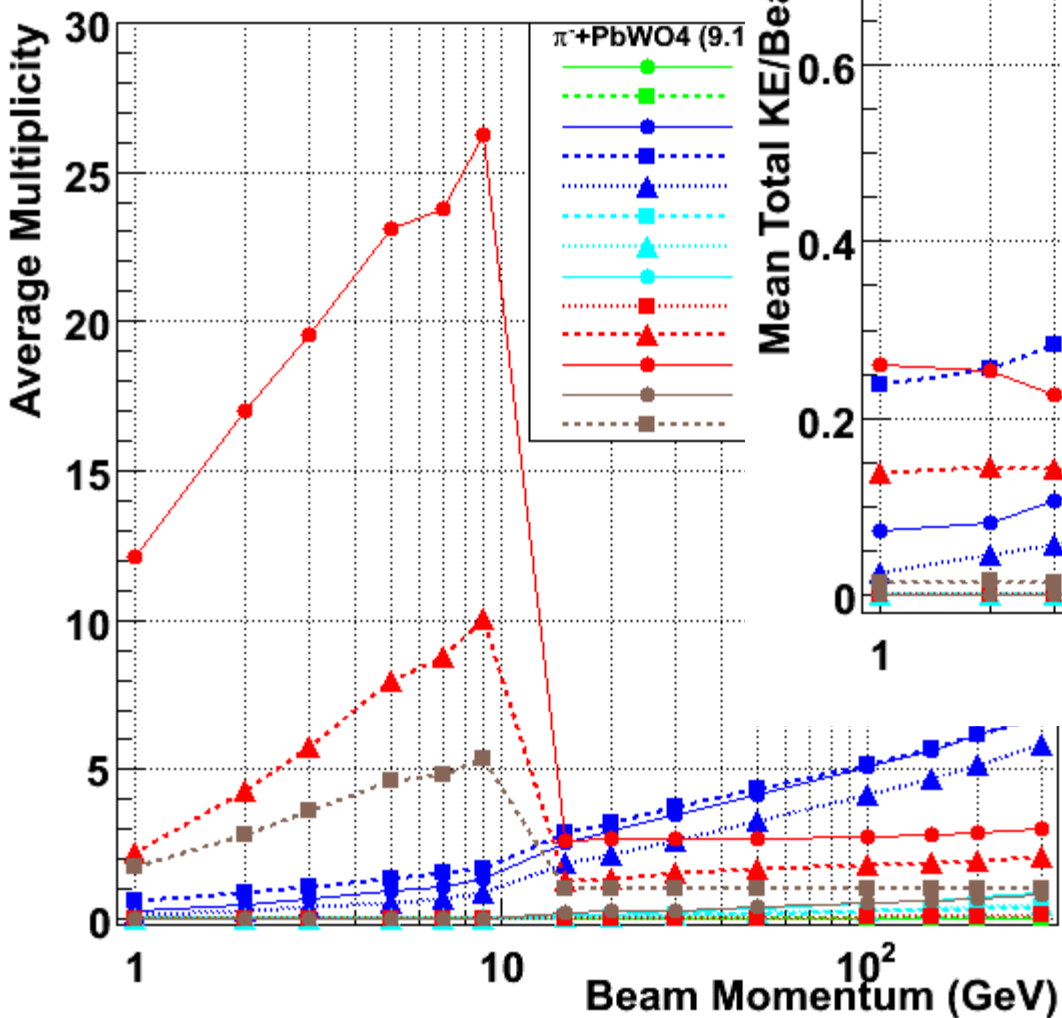


QGSP_BERT_NOLEP1 with p (ref08+)



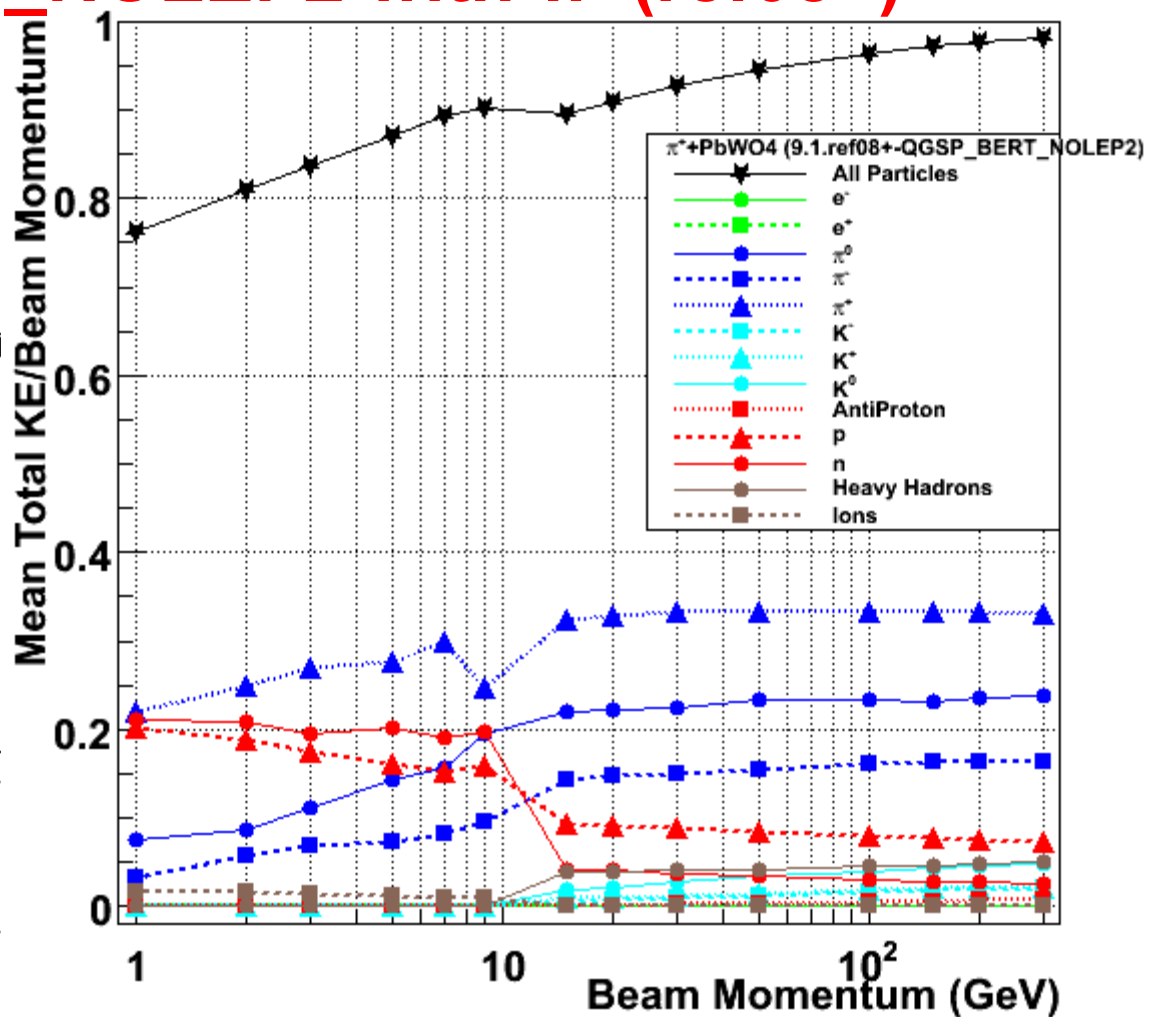
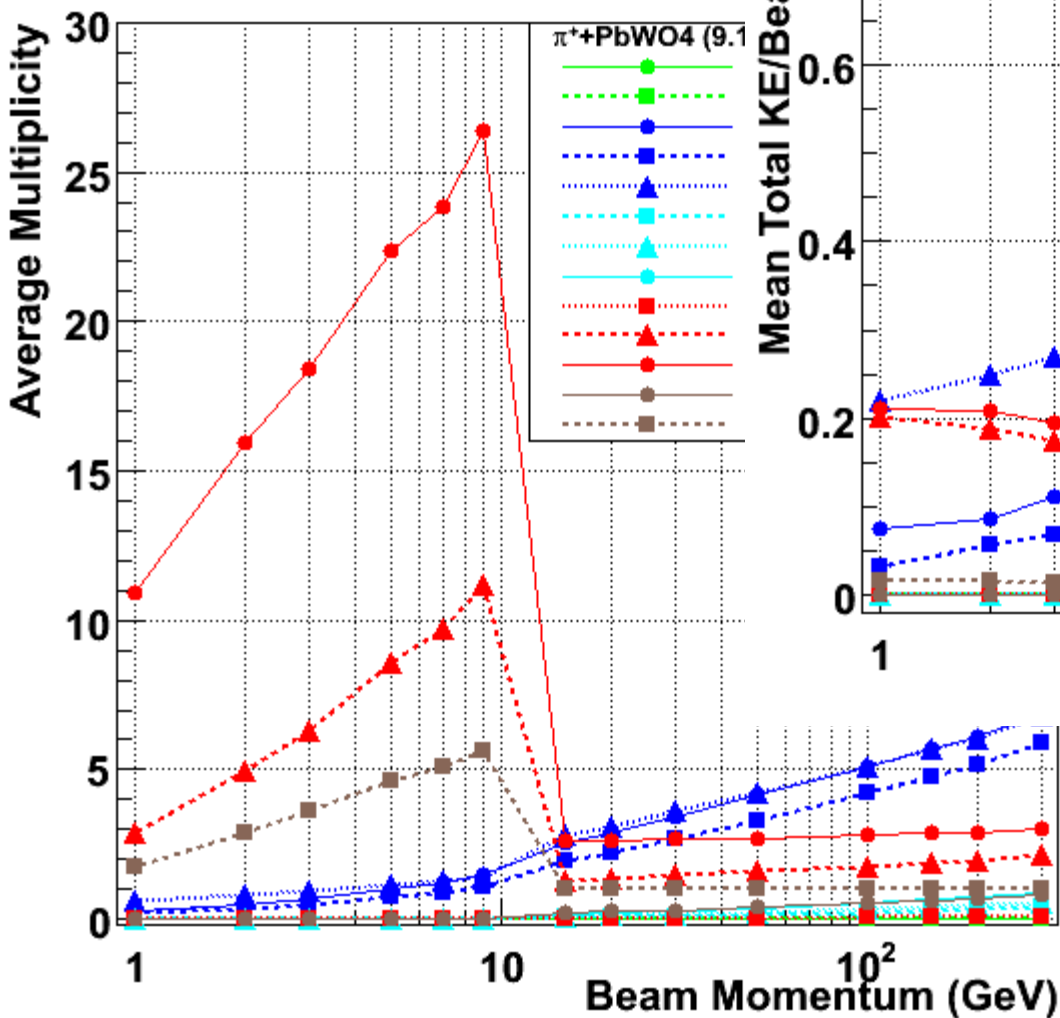


QGSP_BERT_NOLEP2 with π^- (ref08+)



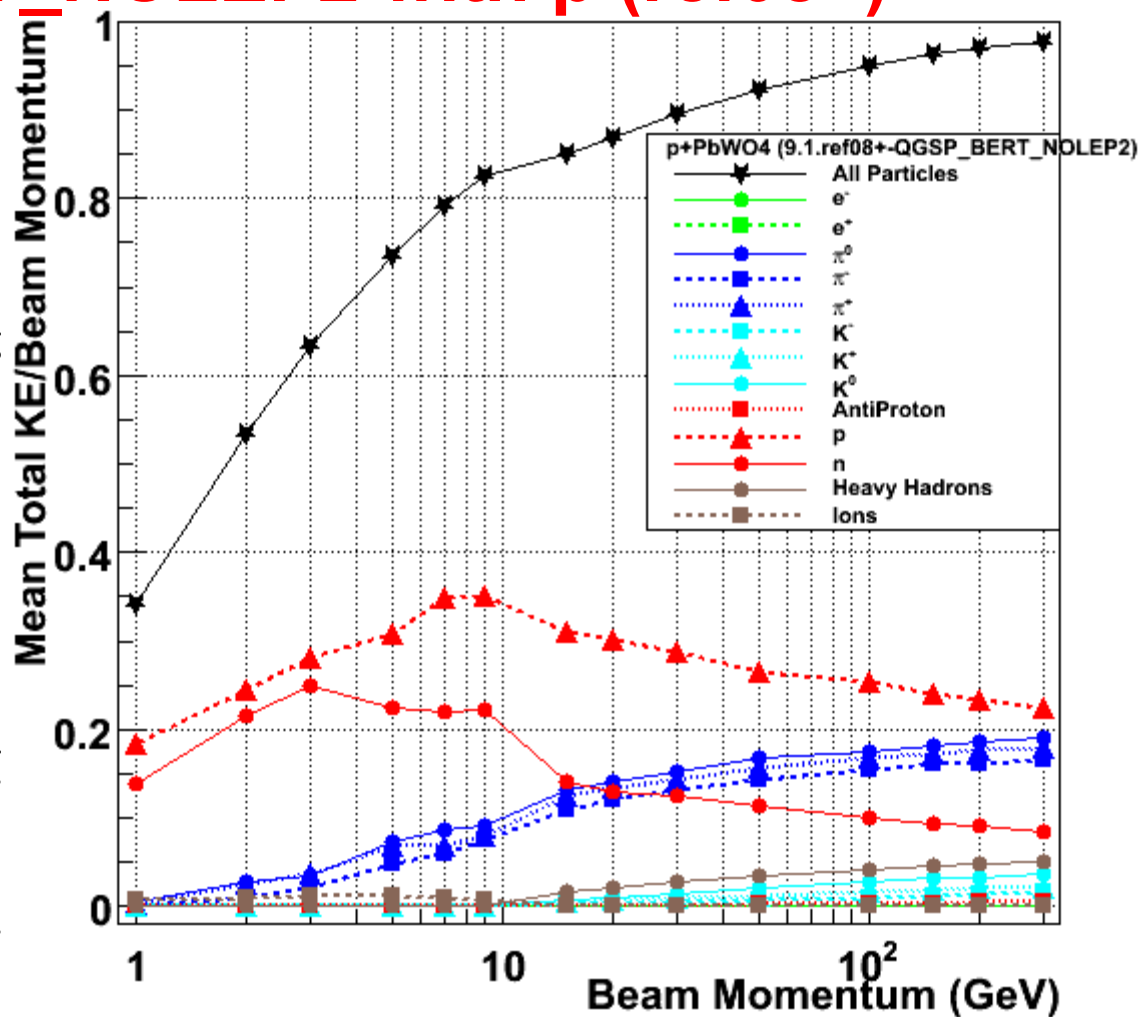
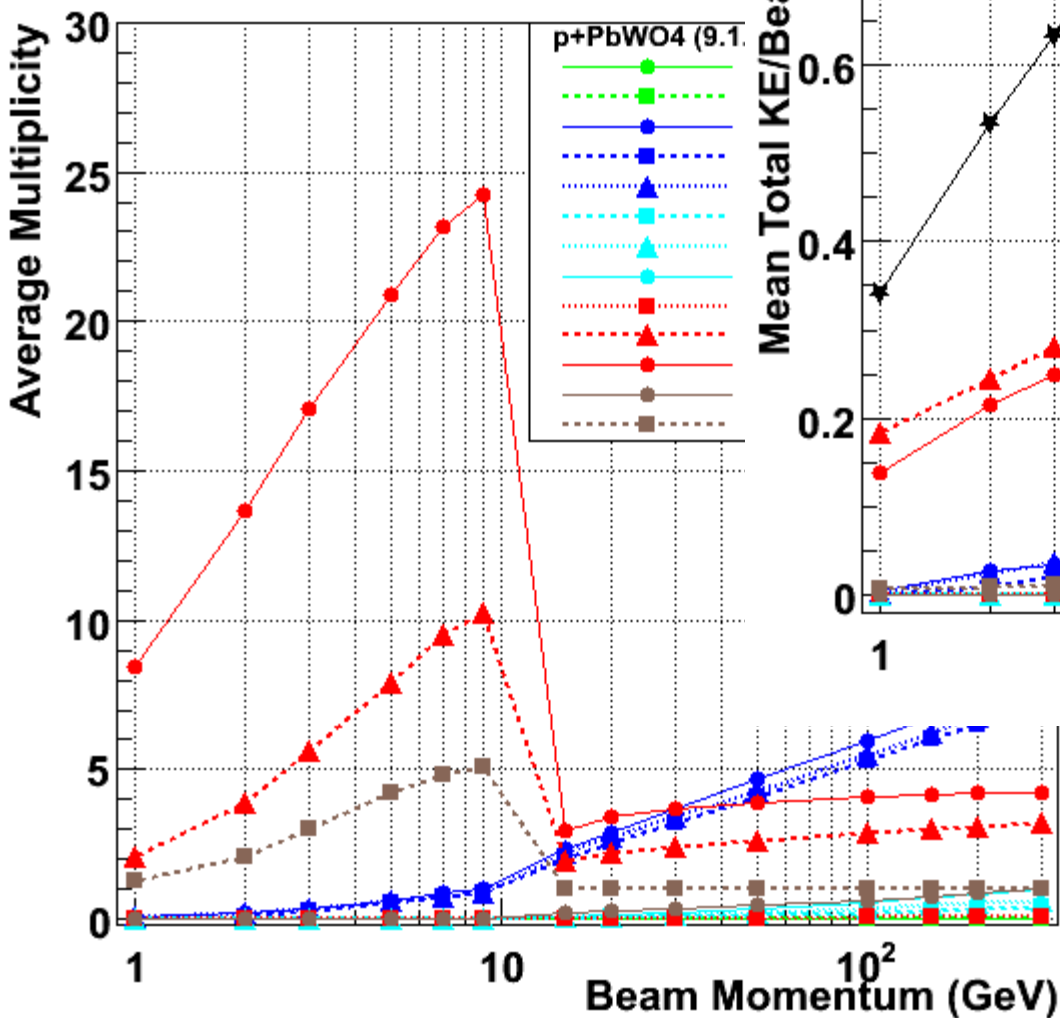


QGSP_BERT_NOLEP2 with π^+ (ref08+)



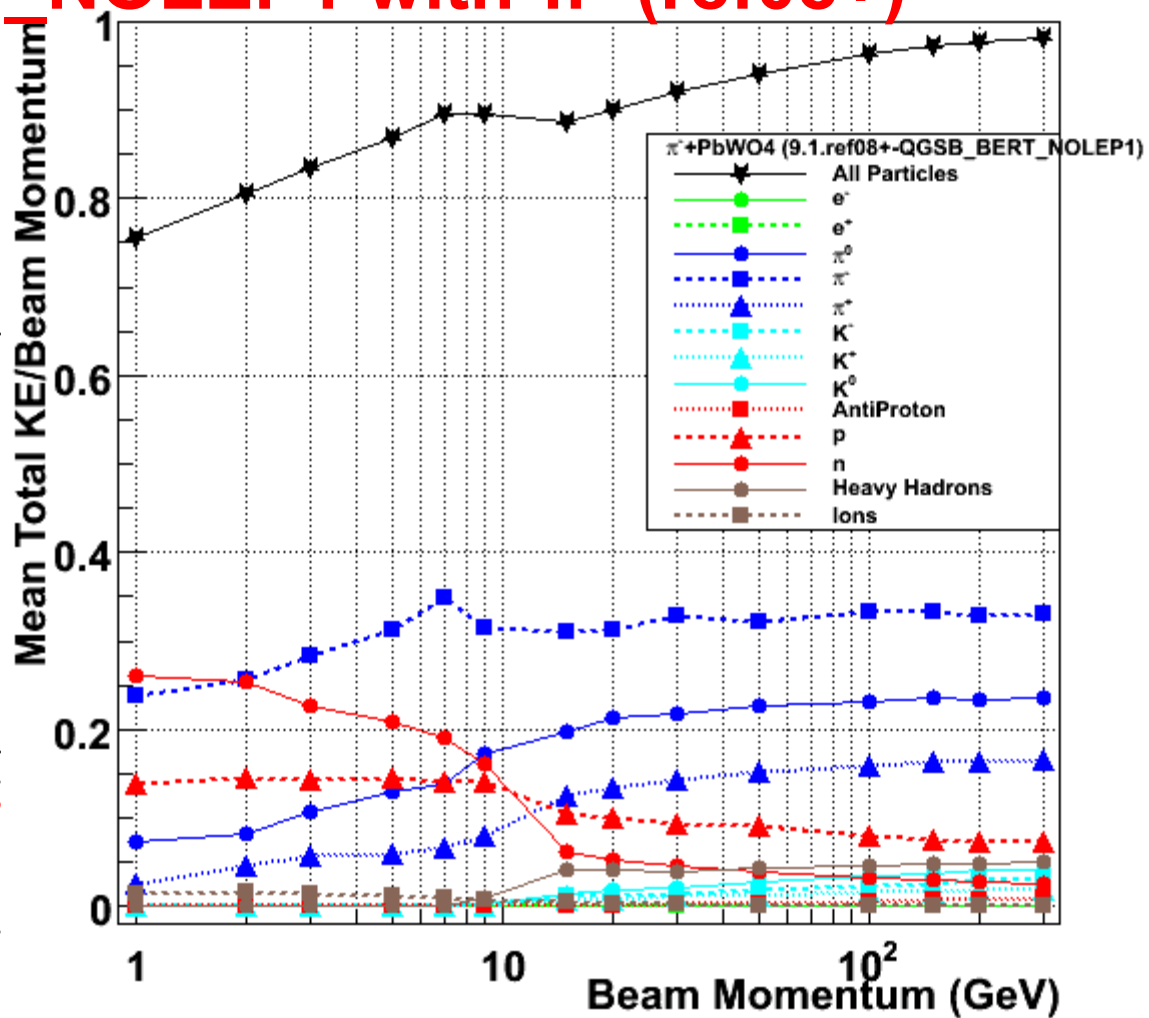
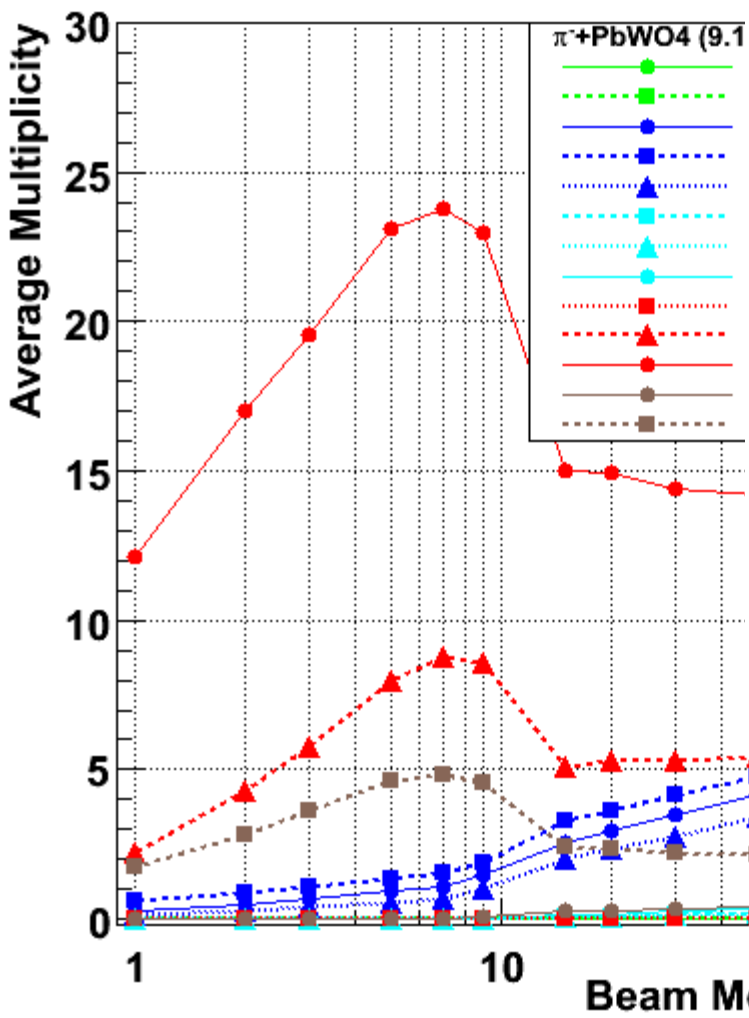


QGSP_BERT_NOLEP2 with p (ref08+)



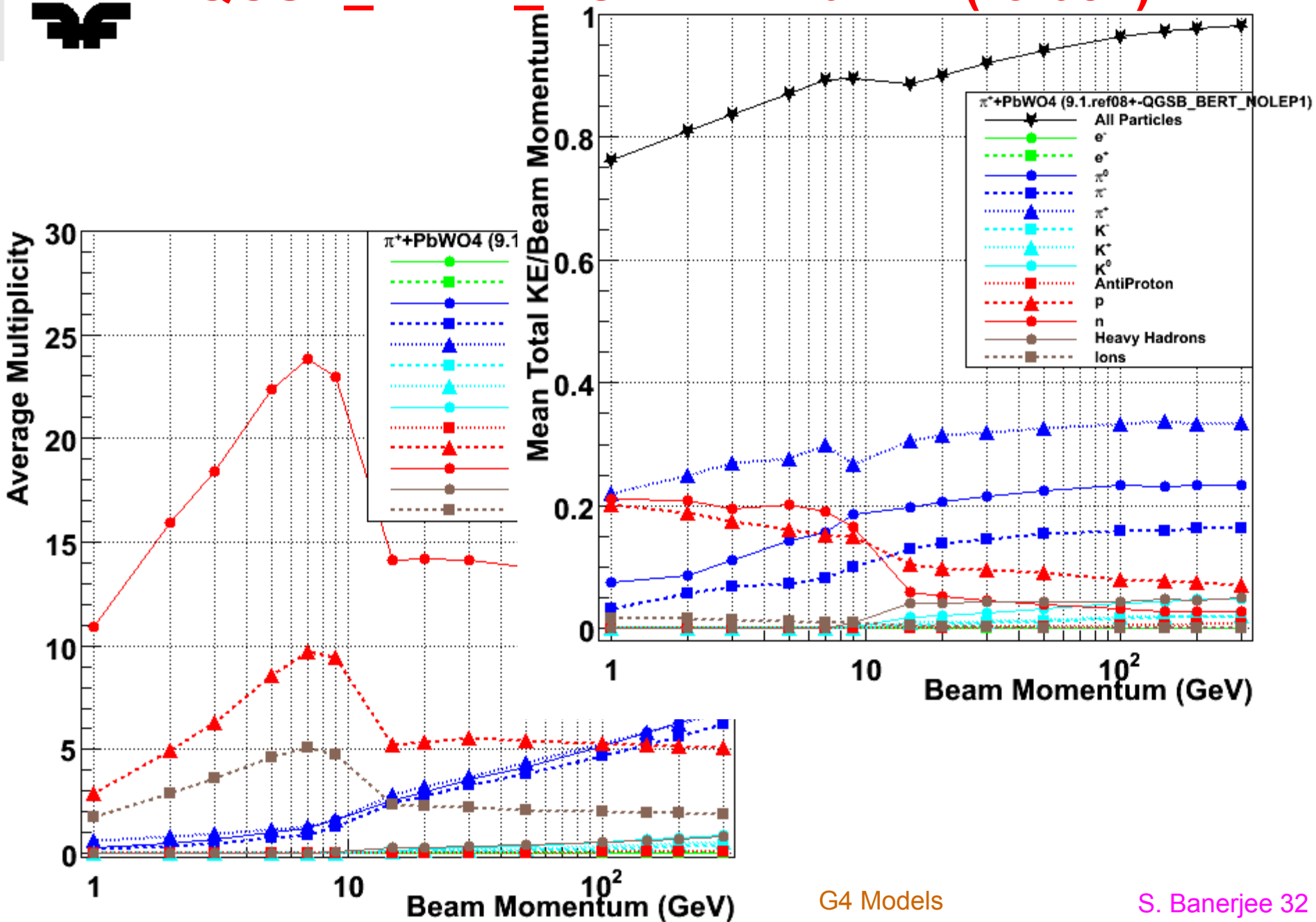


QGSB_BERT_NOLEP1 with π^- (ref08+)





QGSB_BERT_NOLEP1 with π^+ (ref08+)





QGSB_BERT_NOLEP1 with p (ref08+)

