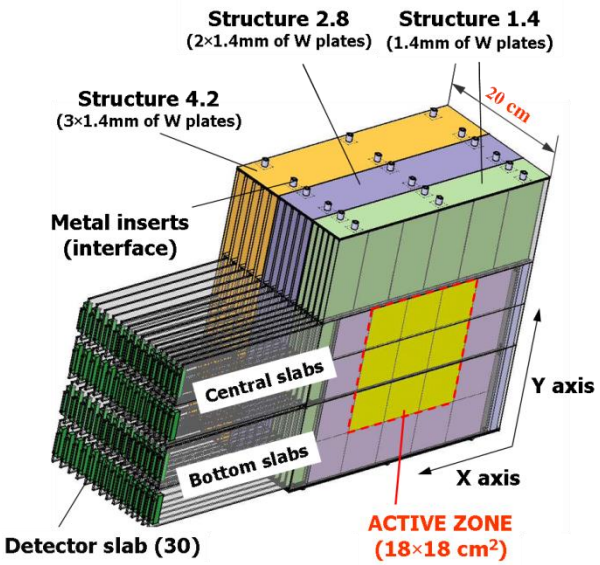
Interactions of pions in the Si-W ECAL prototype

Towards a paper

Naomi van der Kolk

Introduction

- Publication of CALICE Analysis Note CAN-025:
  Study the interactions of π^- in the Si-W ECAL at low energies (2 – 10 GeV) and compare various Monte Carlo Models (physics lists) to this data
- The analysis has been revised again and the manuscript for a publication has been submitted to the editorial board



Revisions since previous CALICE meeting at Annecy

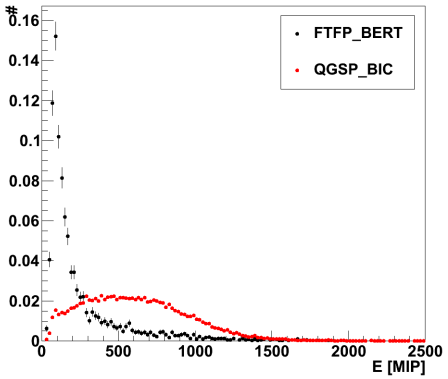
- Changed from Geant4 v9.3 to v9.6
- Improved the cut on multi particle events
  - Cut on the number of hits in the TCMT, very efficient against $\pi^-+\mu^-$ (~99%), a little less against $\pi^-+\pi^-$ (~80%)
- Corrected the data for contamination due to electrons and multi particle events
  - Calculated the correction based on FTFP_BERT and QGSP_BERT, the difference is part of the systematic error
- Added figures of mean and standard deviations on the radial and longitudinal shower observables.

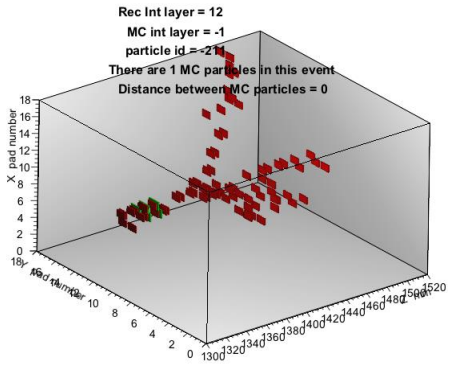
Change in Geant4 version

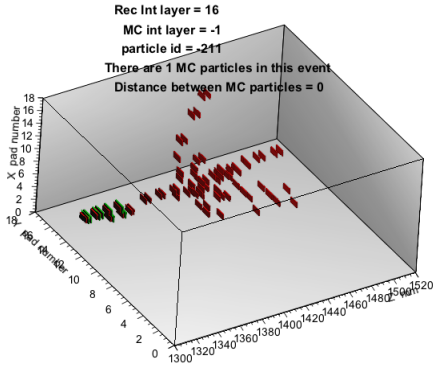
- Updated the analysis to from Geant4 v9.3 to v9.6p01. (Big thanks to Mathias Götze)
- Recommended physics lists:
  - QGSP_BERT
  - FTFP_BERT and FTFP_BERT_HP
  - QGSP_BIC
  - QBBC
- Two issues have come up where there was a large difference with the previous version, related to QGSP_BIC and FTFP_BERT

QGSP_BIC: MC particle endpoint

- A very high contamination with non-interacting events in QGSP_BIC
  - 13 – 35% compared to 3% for other physics lists
- Contaminating events look like interacting events (energy deposition, visual)



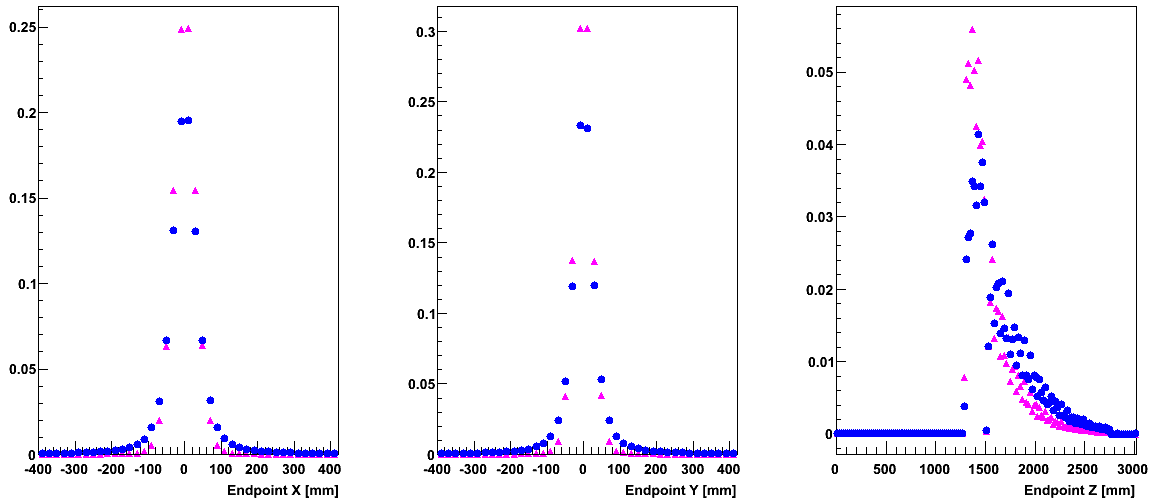




QGSP_BIC MC particle endpoint

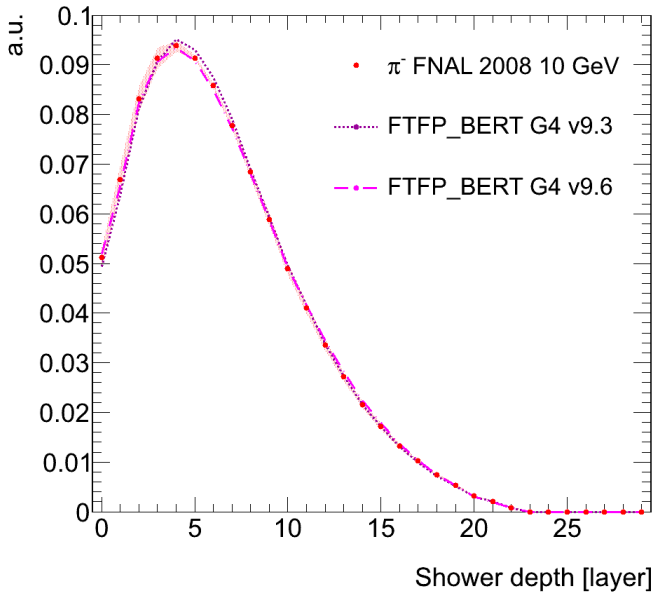
- The endpoint of the MC particle has changed wrt the previous version and is different from other physics lists
- The G4 process “PionMinusInelastic” leads to the endpoint of a MC particle for the other physics lists but not always for LEP based lists.
- We cannot use this list at low energies!

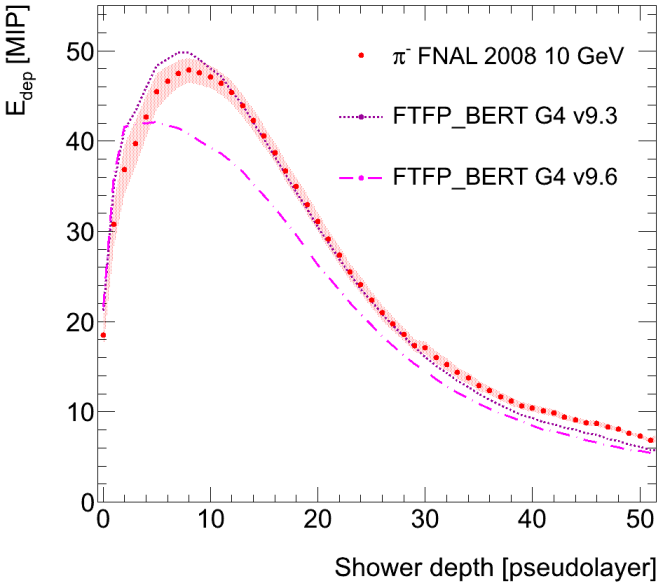
QGSP_BIC
FTFP_BERT



FTFP_BERT energy deposition

- The Fritiof model has been modified extensively, tuned to mostly scintillator data
- The energy deposition has changed between the versions, but not the hit density
- Related to the sensitive material?
  - *Shower development of particles with momenta from 1 to 10 GeV in the CALICE Scintillator-Tungsten HCAL, JINST 9 P01004 (2014) (A. Lucaci-Timoce)*





New Results
As in the paper draft

Selecting interacting events

- Interactions are found based on two criteria:
  - Absolute energy increase
  - Relative energy increase
- Especially at low beam energies the second criterion is very important

E (GeV)	Fraction found by absolute energy criterion	Additional fraction found by relative energy criterion
2	0.35	0.25
4	0.61	0.16
6	0.74	0.11
8	0.80	0.08
10	0.83	0.07

Interaction finding efficiency

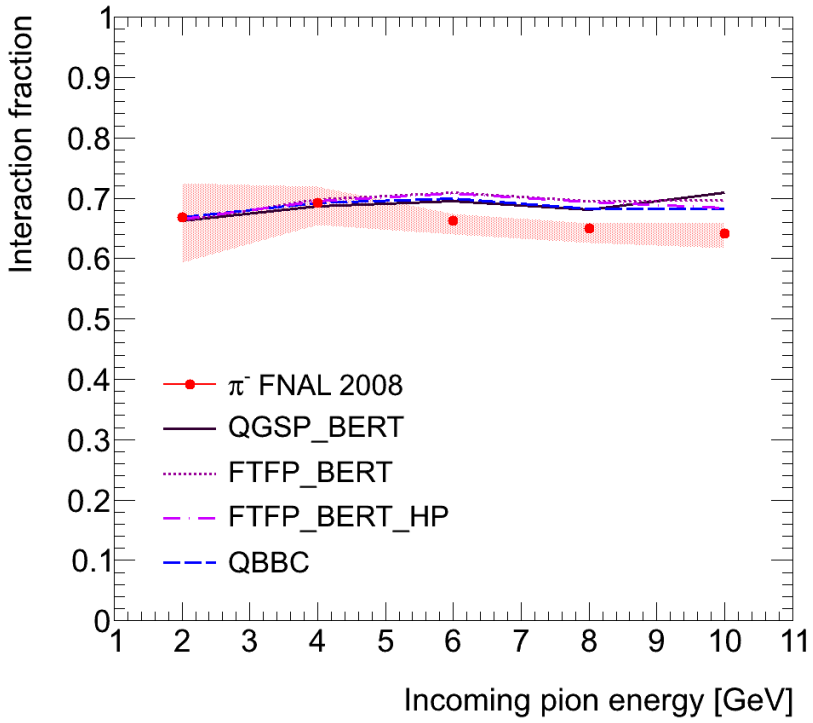
The fraction of all true interacting events that is classified as interacting
It depends on the MC physics list, especially at low energy,
the Bertini/Fritiof based models have the lowest efficiency

Physics list	2 GeV	4 GeV	6 GeV	8 GeV	10 GeV
QGSP_BERT	0.59	0.77	0.83	0.86	0.88
FTFP_BERT	0.60	0.77	0.85	0.88	0.90
FTFP_BERT_HP	0.58	0.77	0.85	0.88	0.90
QBBC	0.60	0.78	0.84	0.87	0.89

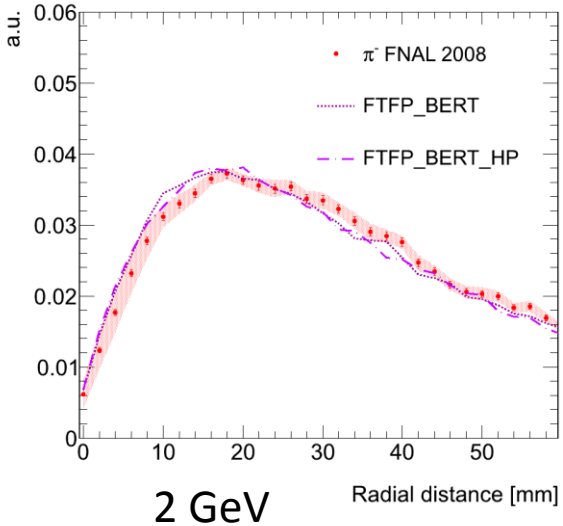
Contamination = fraction of all events classified as interacting that is non-interacting, it is about 0.03 independent of energy

Interaction fraction

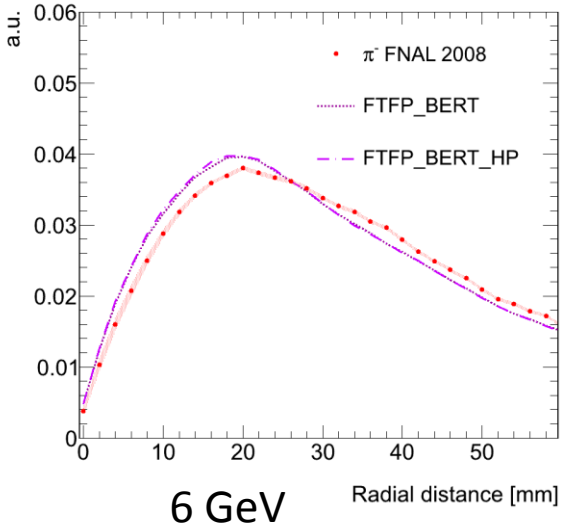
- The fraction of interacting events corrected with the interaction finding efficiency
- For data the efficiency of FTFP_BERT is used
- Correction of the data for electron and multi-particle event contamination
- Systematic error based on varying the selection variables , non-interacting events and uncertainty in the correction factor.
- The interaction fraction is consistent with the ECAL material budget and approximately independent of energy



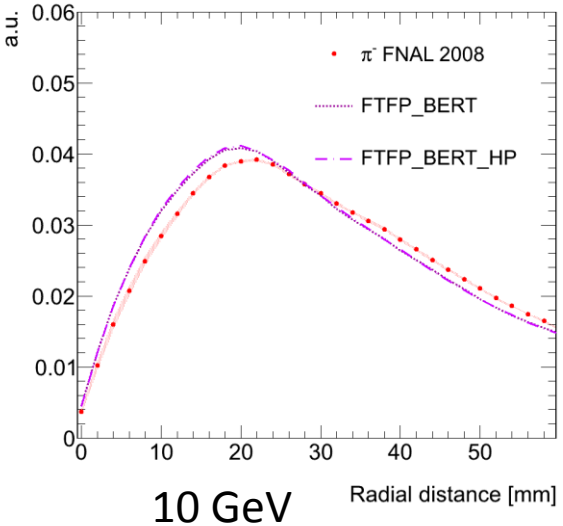
Radial hit distribution



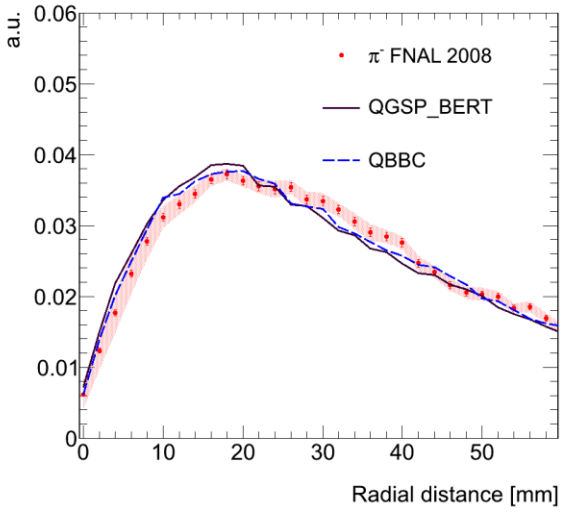
2 GeV

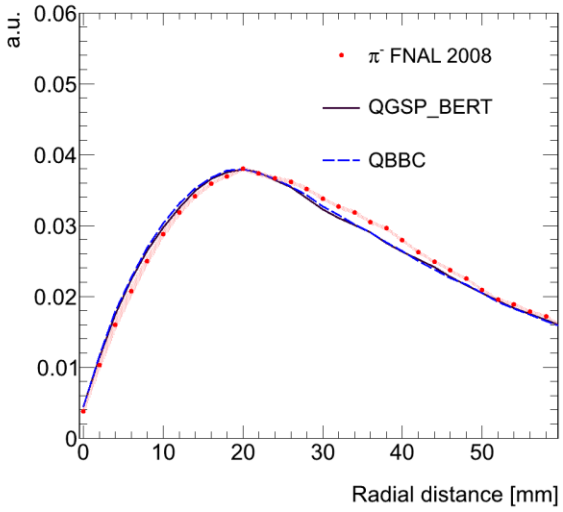


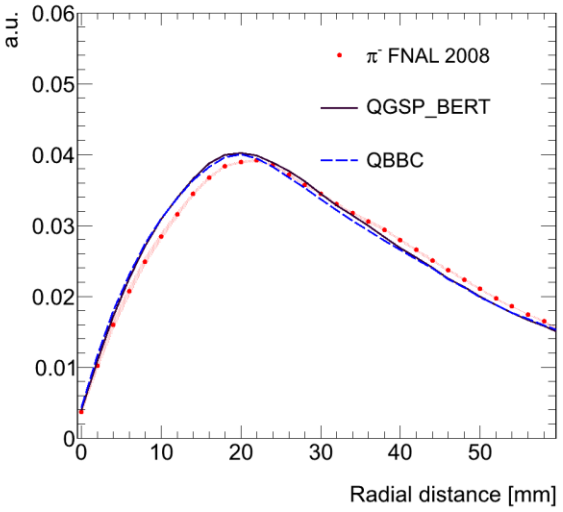
6 GeV



10 GeV

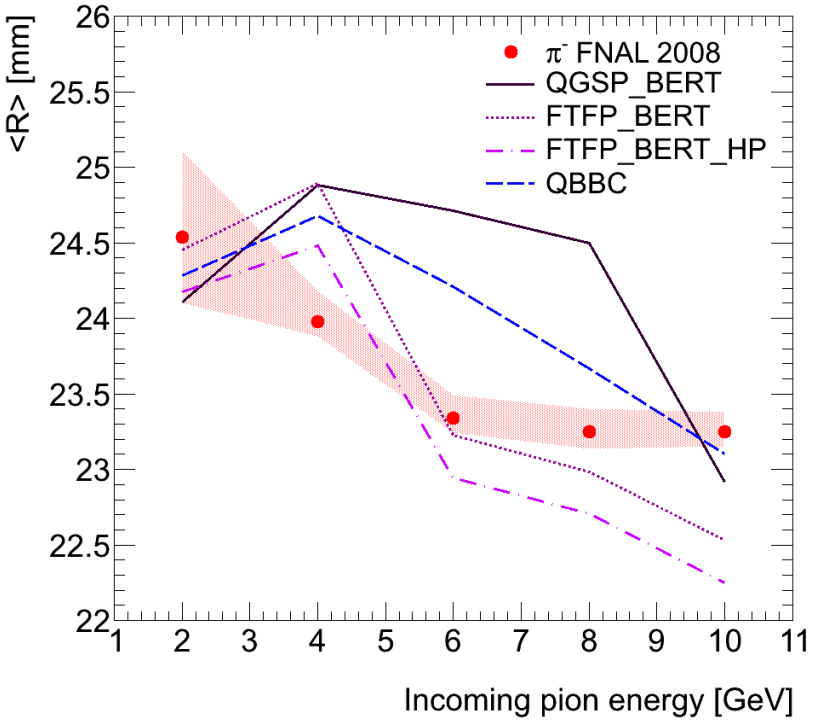


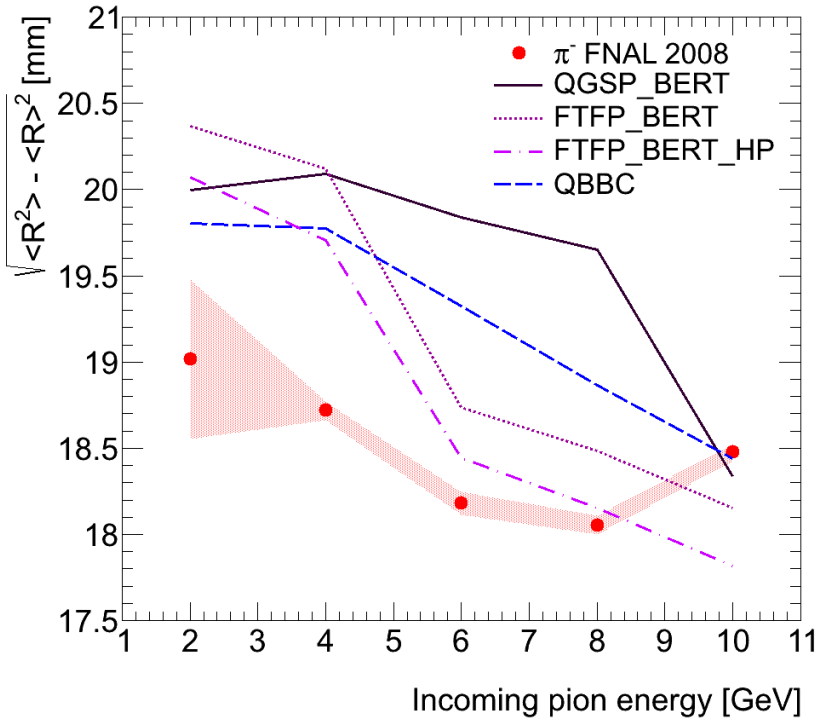




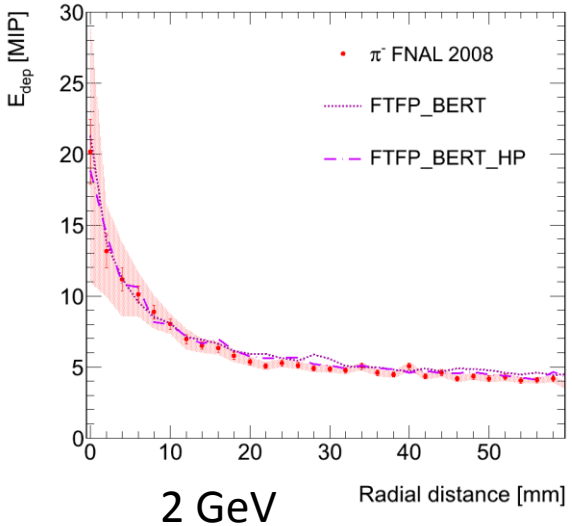
Radial hit distribution

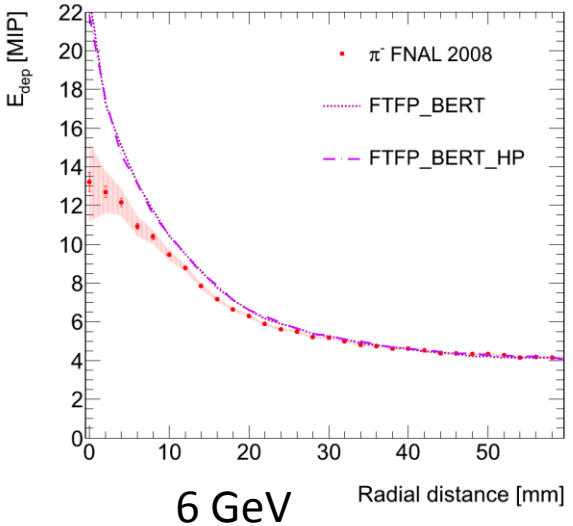
MC close to the data (within 10%), but details are not reproduced
Clear transition visible for FTFP_BERT between Bertini Cascade (2,4 GeV) and Fritiof string model (6, 8, 10 GeV)

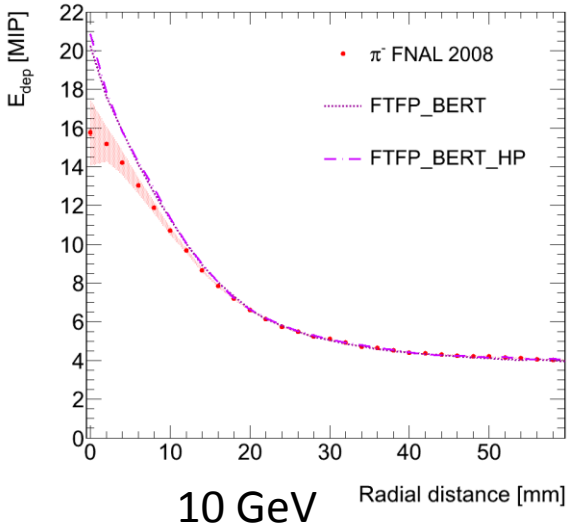




Radial energy profile



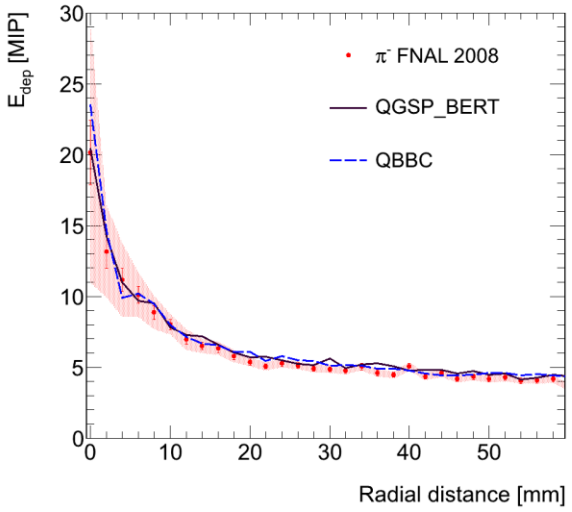


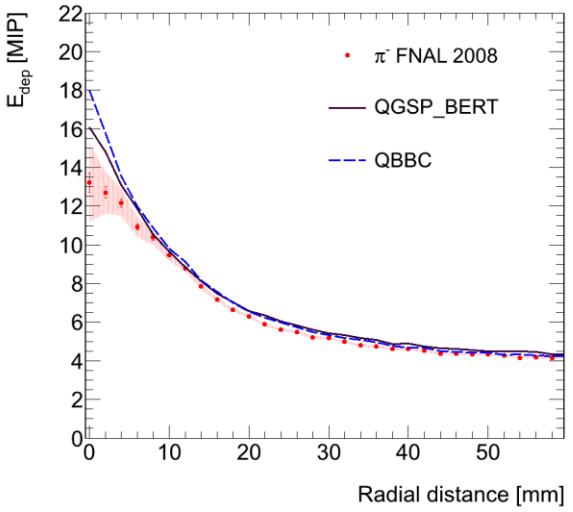


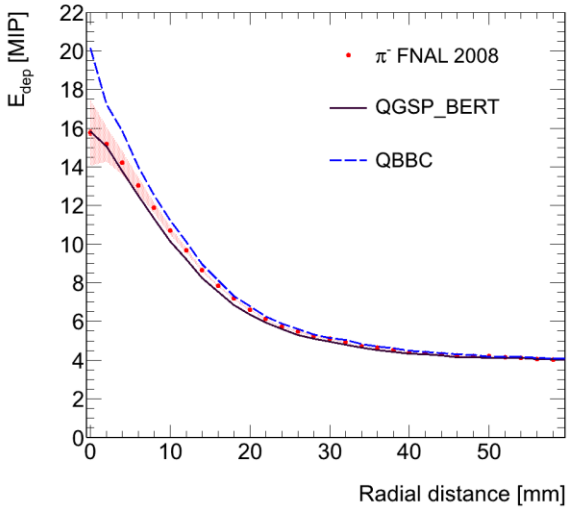
2 GeV

6 GeV

10 GeV

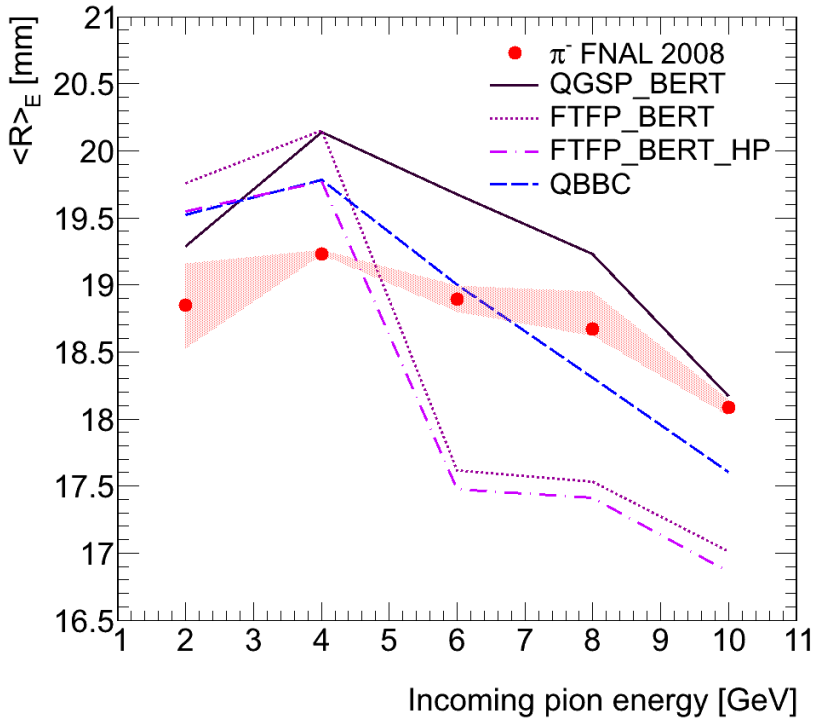


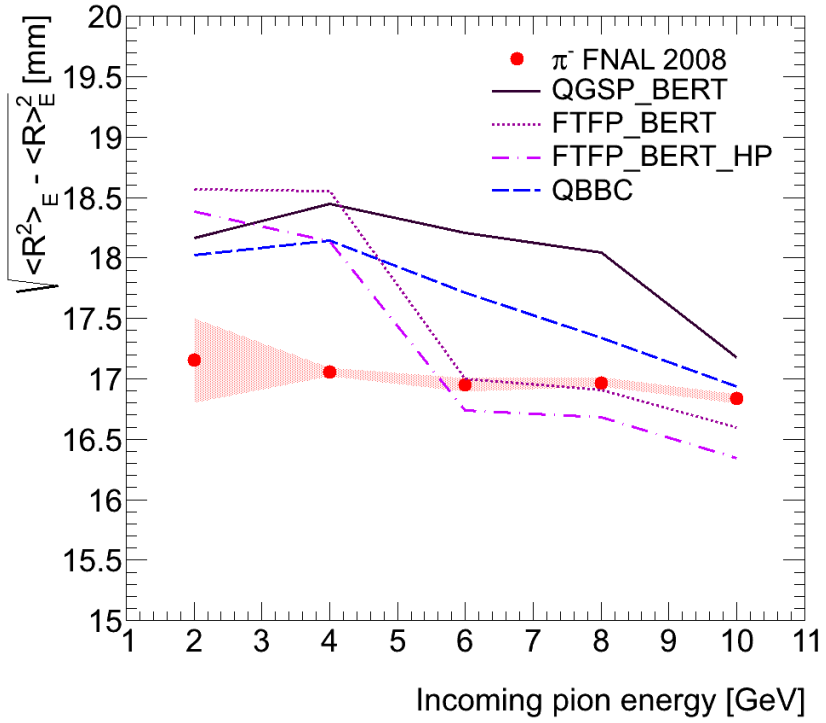




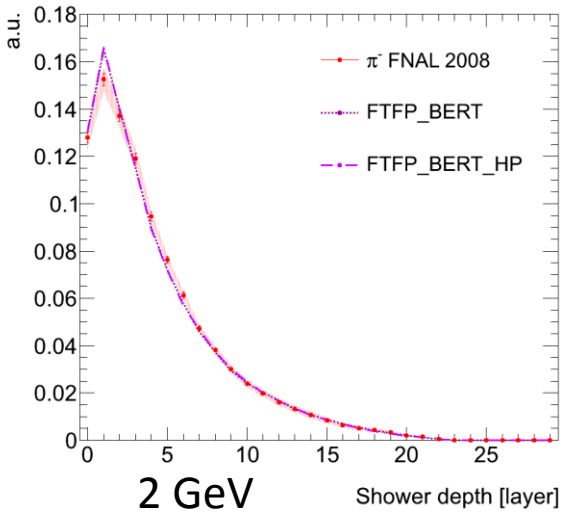
Radial energy profile

MC close to the data (within 10%), but details are not reproduced
Clear transition visible for FTFP_BERT between Bertini Cascade (2,4 GeV) and Fritiof string model (6, 8, 10 GeV)
Too much energy deposited near the shower axis

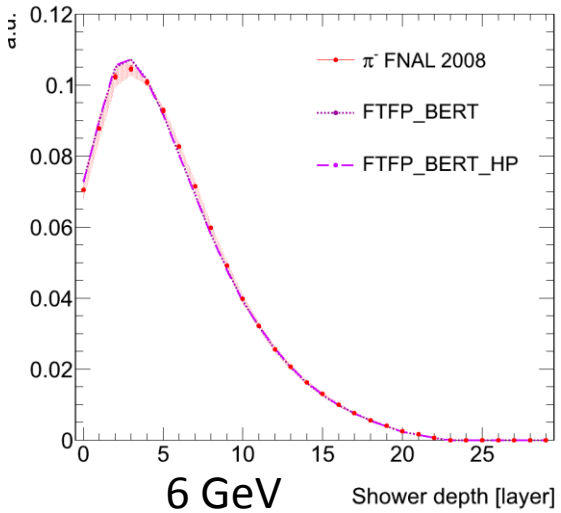




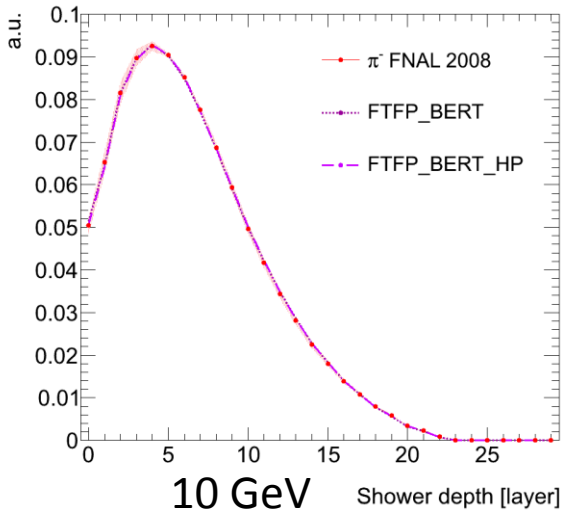
Longitudinal hit density



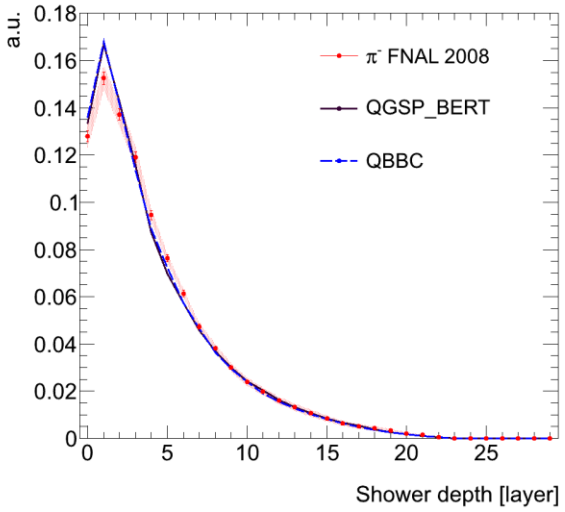
2 GeV

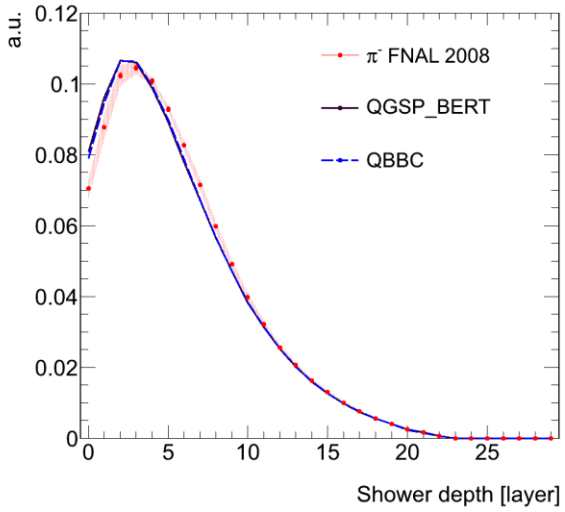


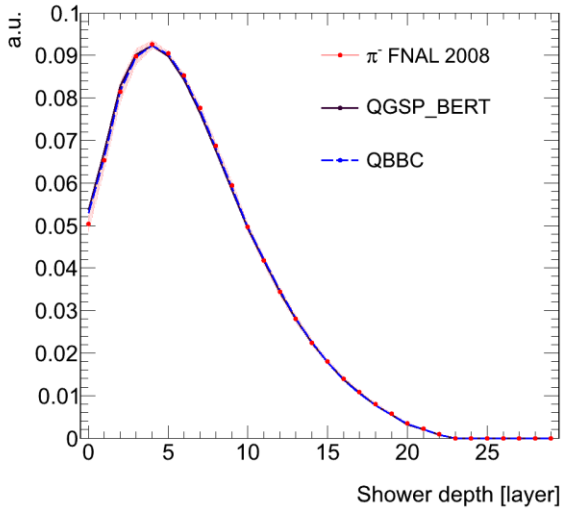
6 GeV



10 GeV

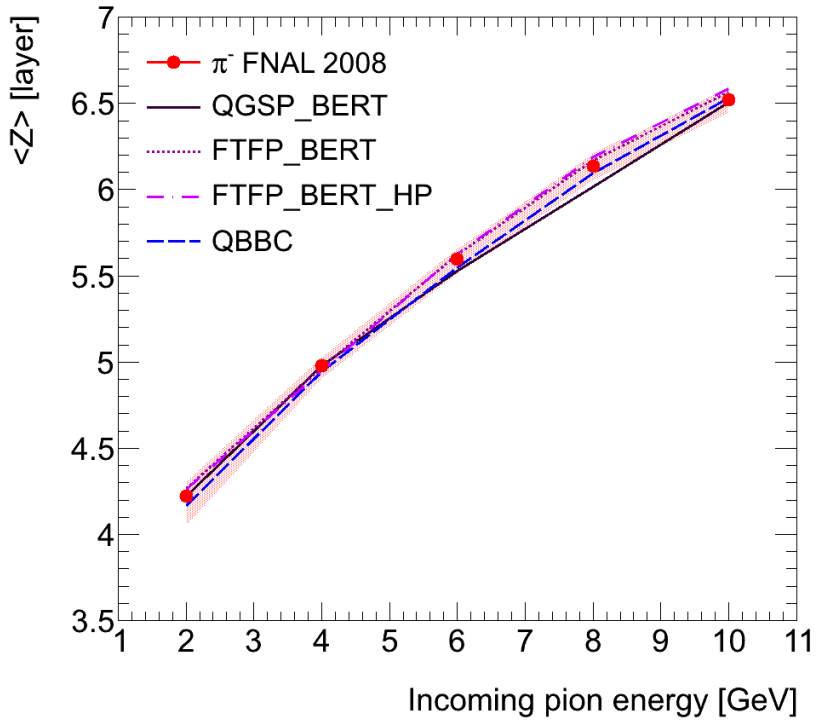


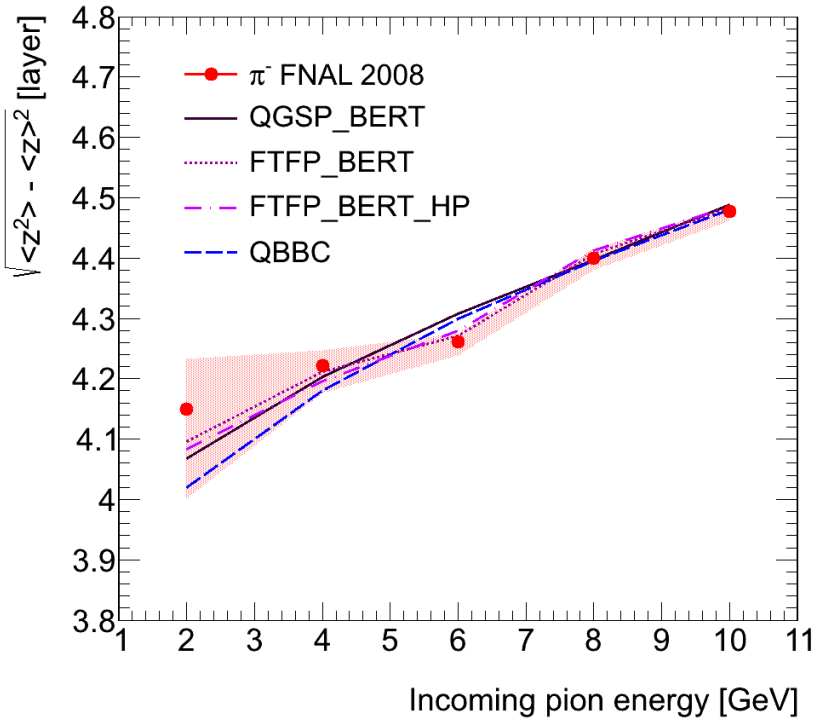




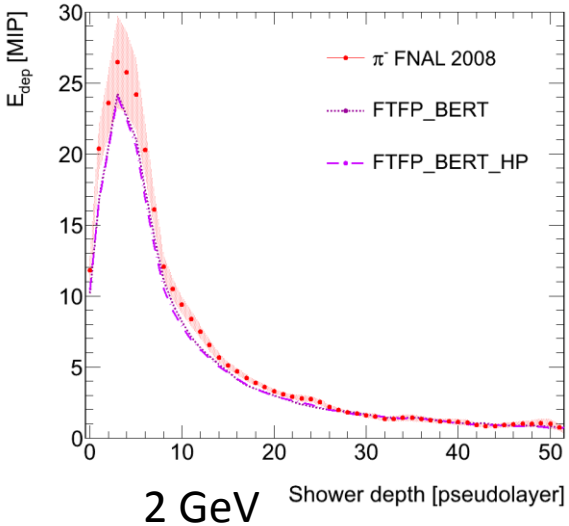
Longitudinal hit density

MC reproduces very well the longitudinal hit density

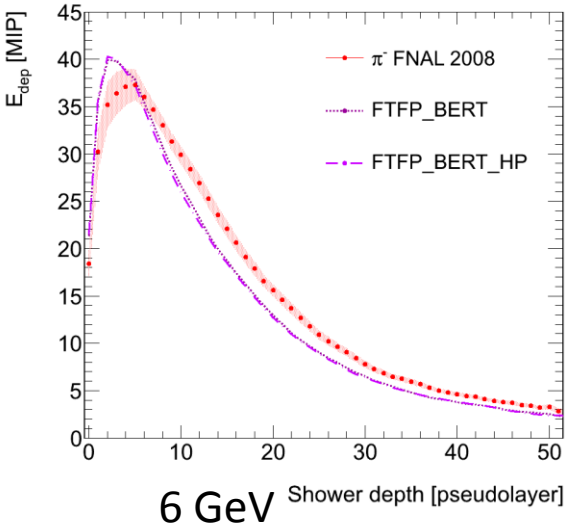




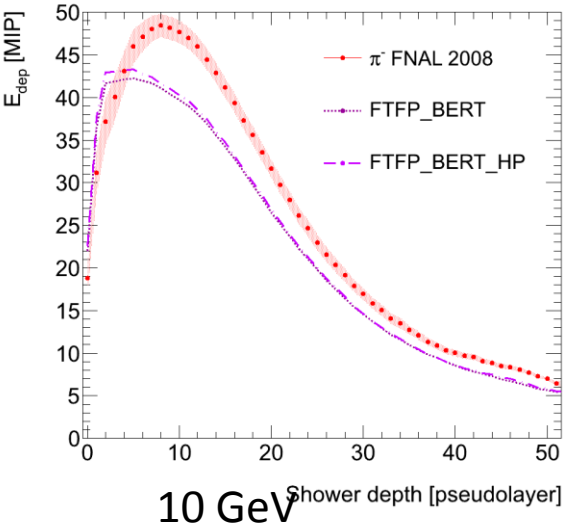
Longitudinal energy profile



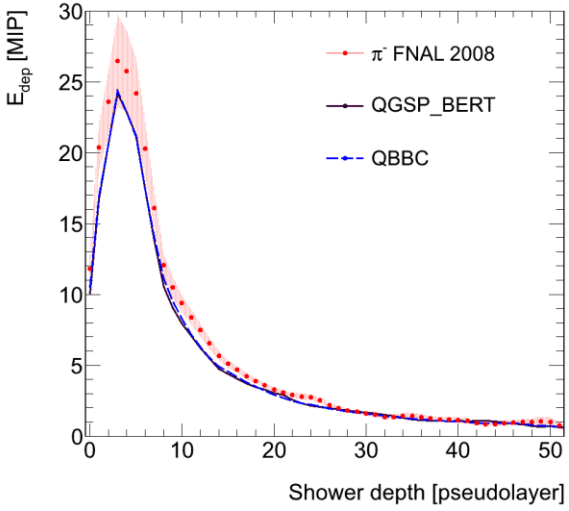
2 GeV

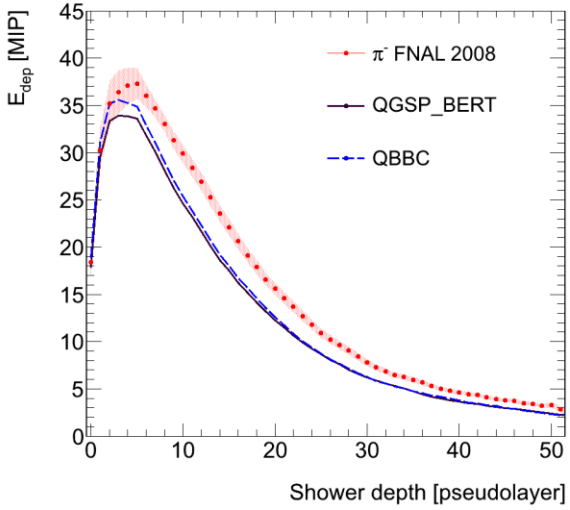


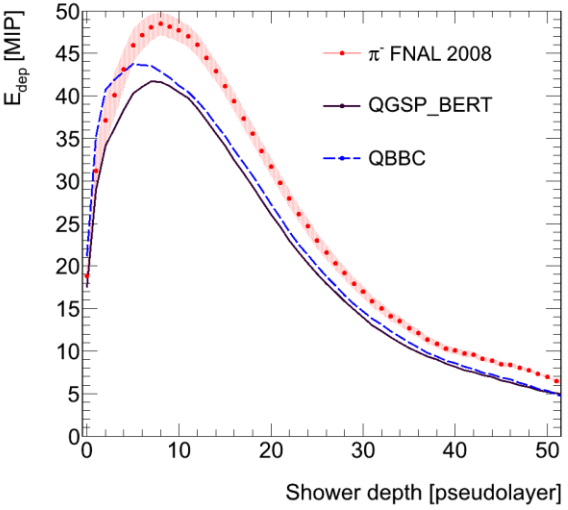
6 GeV



10 GeV

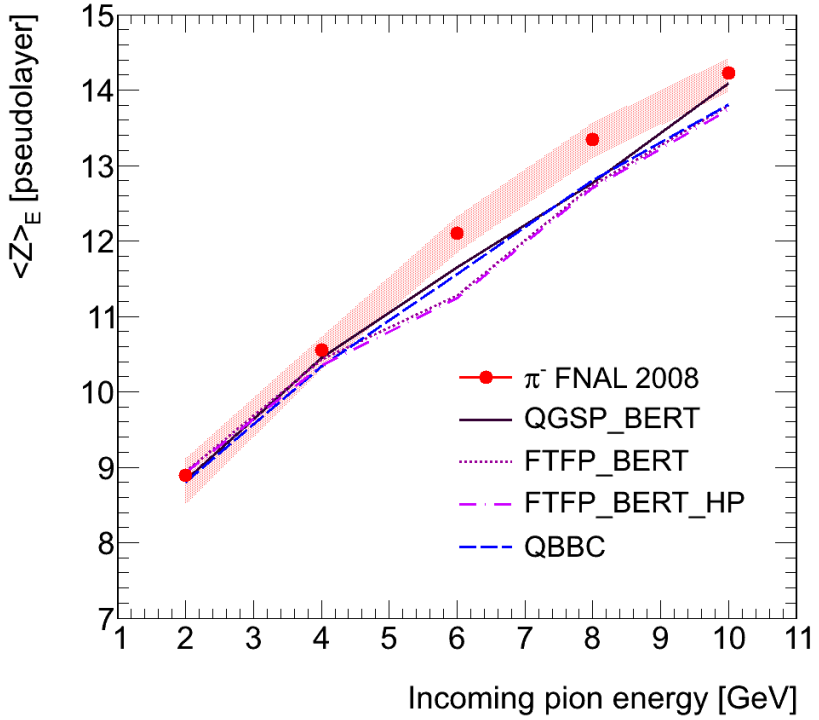


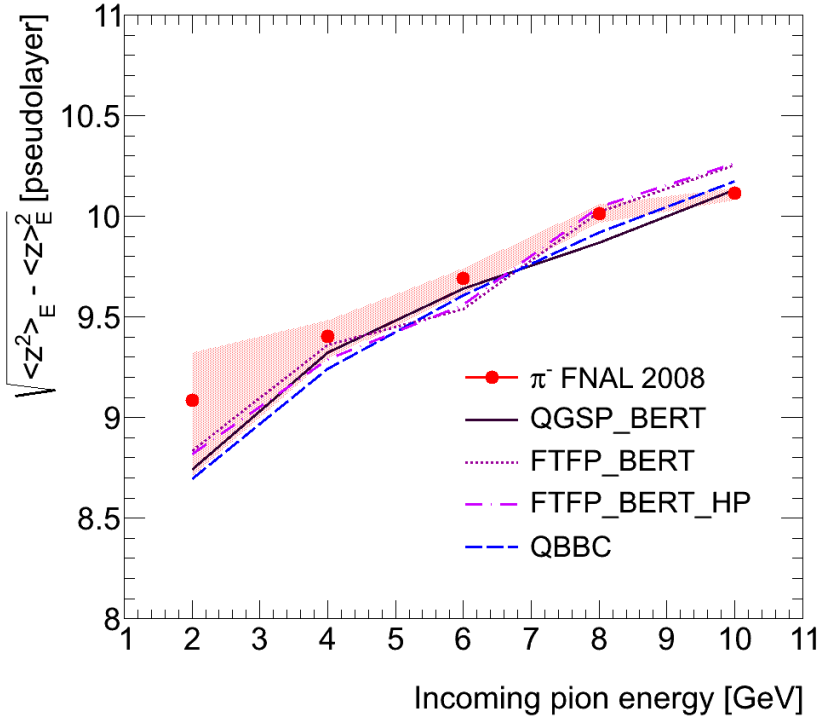




Longitudinal energy profiel

MC underestimates the energy deposition
The description gets worse with energy
Too much energy is deposited close to the interaction region
In the mean and std. dev. This effect is washed out





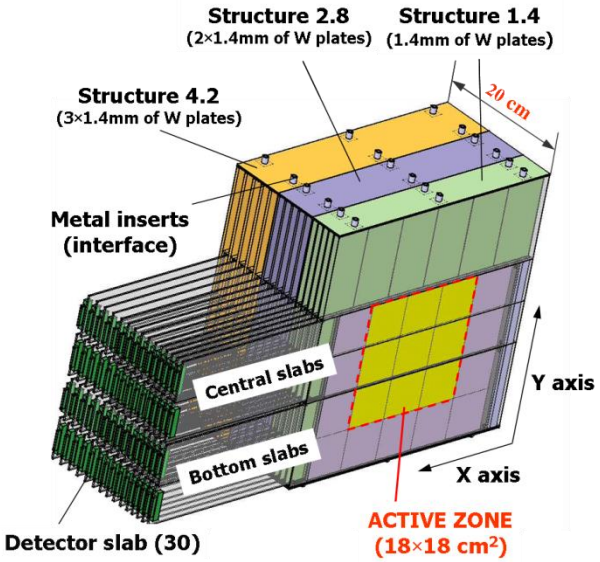
Summary

- Testbeams of pions at 2, 4, 6, 8 and 10 GeV were studied with the Si-W ECAL prototype
- Interacting events were identified using two criteria; absolute energy and relative energy increase
- The second is important especially at low beam energies
- Data and MC were compared in the interaction fraction, radial and longitudinal shower distributions
  - The radial distributions are sensitive to the MC models
- Changing the Geant4 version has caused a large delay, but has made the paper more interesting
- Broadly the MC are close to the data (within 10%), but details are not reproduced.
- The main discrepency is in the energy deposition, which is too close to the shower axis and interaction layer
- The data from the Si-W ECAL is very precise and allows to discriminate between MC models on a very fine scale

Backup:
Analysis details

Analysis setup (backup)

- Event sample:
  - Si-W ECAL physics prototype
  - 2008 FNAL test beam of π^- at 2, 4, 6, 8 and 10 GeV
  - Matching Monte Carlo
    (physics lists: FTFP_BERT, FTFP_BERT_HP, QGSP_BERT, QBBC)
- Event cuts:
  - correct trigger, minimum number of hits (25), hits in correct region of ECAL (centre), minimum hit energy (0.6 mip), no noisy layers, muon rejection, electron rejection (based on found interaction layer > 6), multiple particle event rejection
- Sample size:
  - 500 k MC events (accepted 25 k – 300 k)
  - 150 k – 700 k data events (accepted 20 k – 450 k)



Selection criteria (backup)

- Interacting (inelastic hadronic interaction)
  - Absolute energy increase

    $E_i > E_{cut}$ && $E_{i+1} > E_{cut}$ && $E_{i+2} > E_{cut}$
  - Relative energy increase

    $F=(E_i+E_{i+1})/(E_{i-1}+E_{i-2}) > F_{cut}$ &&

    $F' = (E_{i+1}+E_{i+2})/(E_{i-1}+E_{i-2}) > F_{cut}$ &&

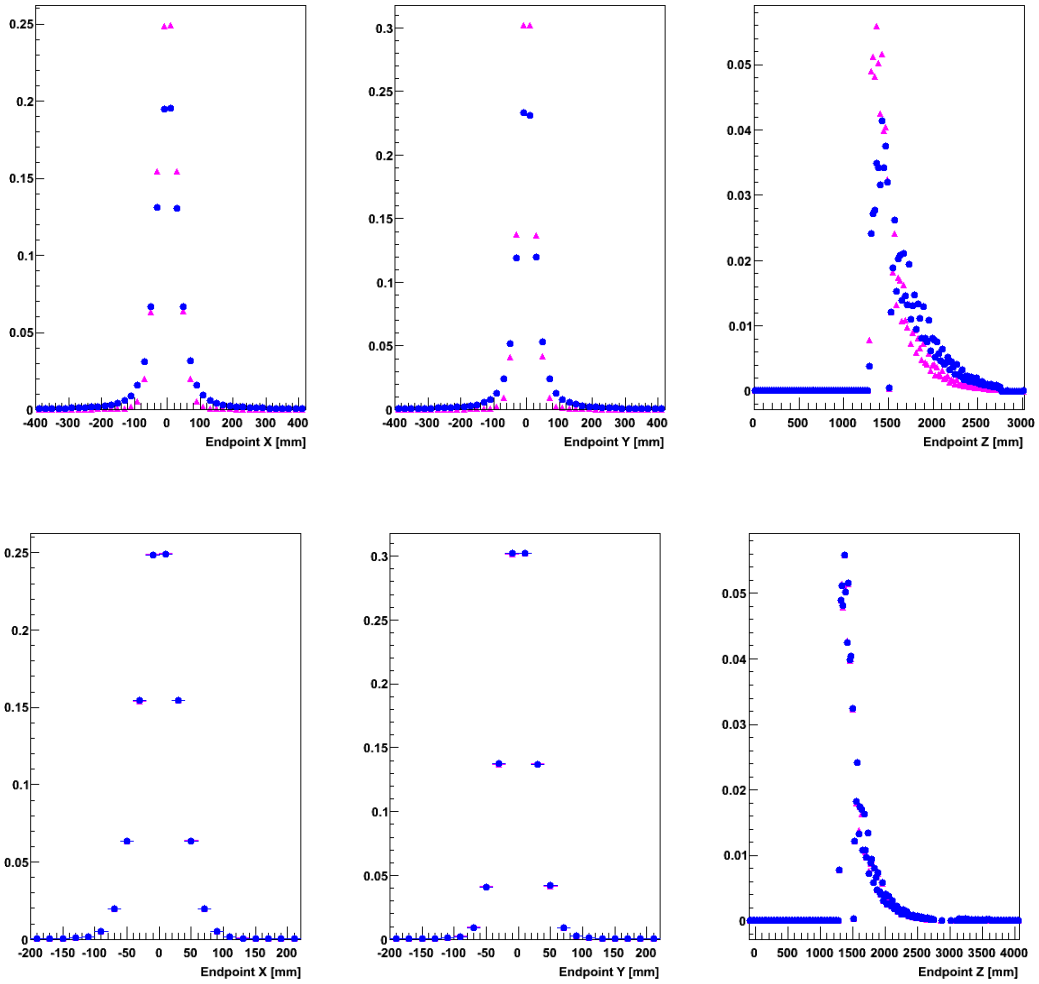
    $E_{aroundi} > 0.5E_i$

Contaminations (backup)

- Muons: negligible at all energies
- Multi-particle events: 5%
- Electrons: 10% - 0%
- Non-interacting events: 3%

Backup:
QGSP_BIC

MC particle endpoint @ 8GeV



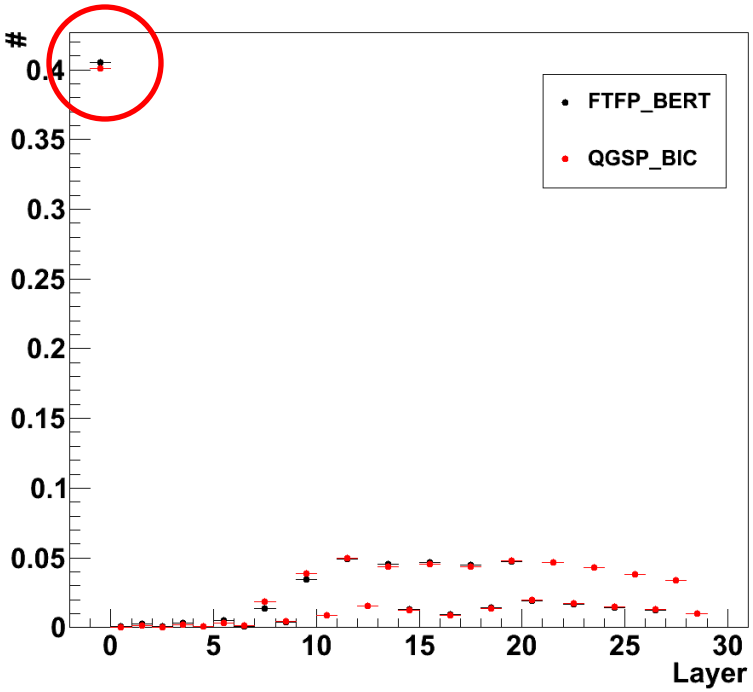
Geant4 v9.6p01

QGSP_BIC
FTFP_BERT

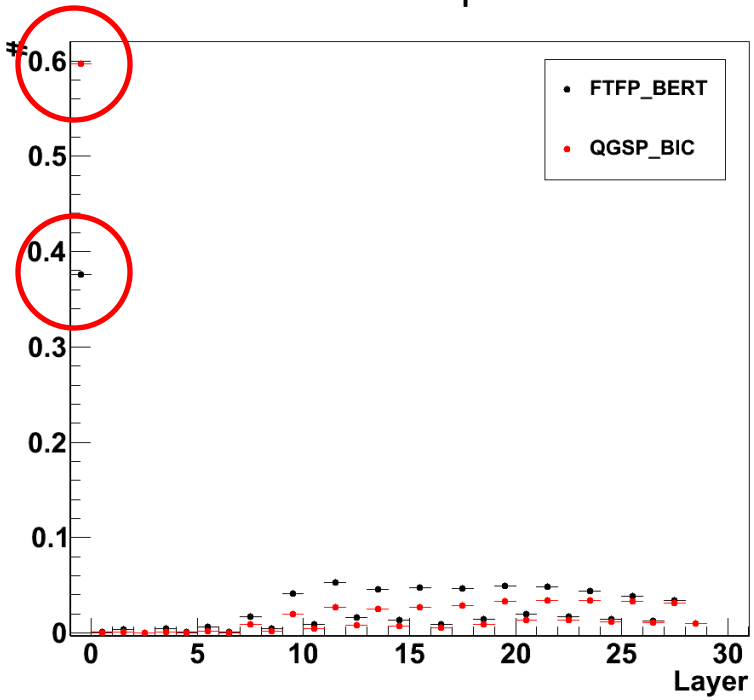
Geant4 v9.3

MC end layer distribution

Geant4 v9.3



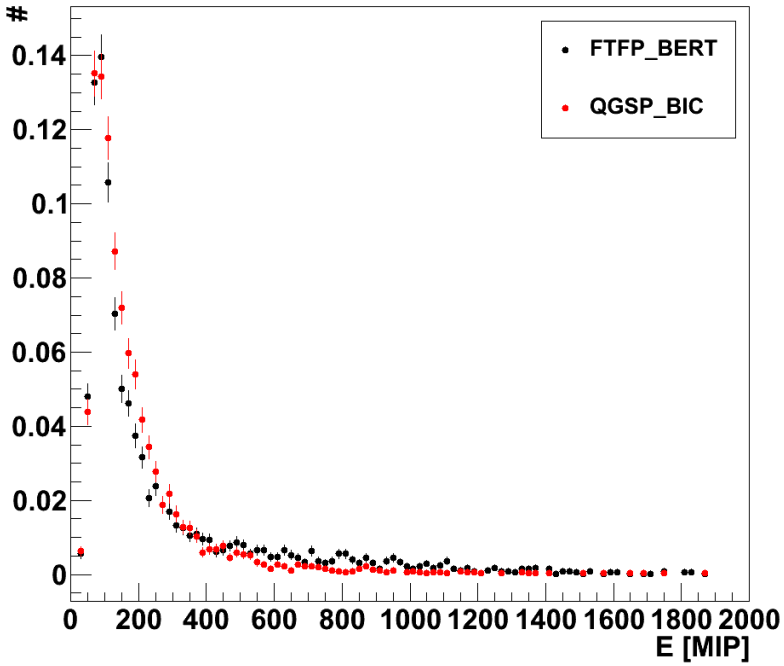
Geant4 v9.6p01



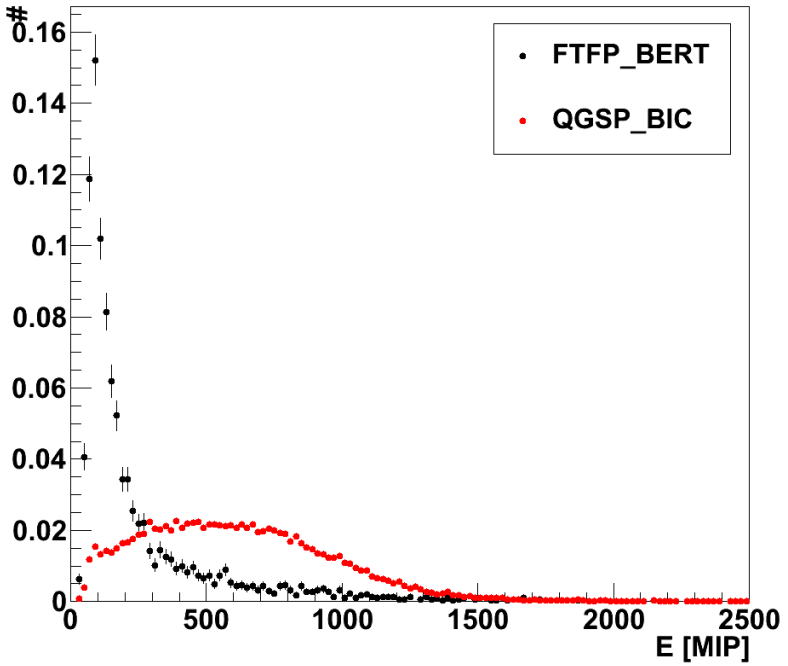
Much more events with an endpoint outside the ECAL for QGSP_BIC in v9.6p01

Total deposited energy by contaminating events

Geant4 v9.3



Geant4 v9.6p01

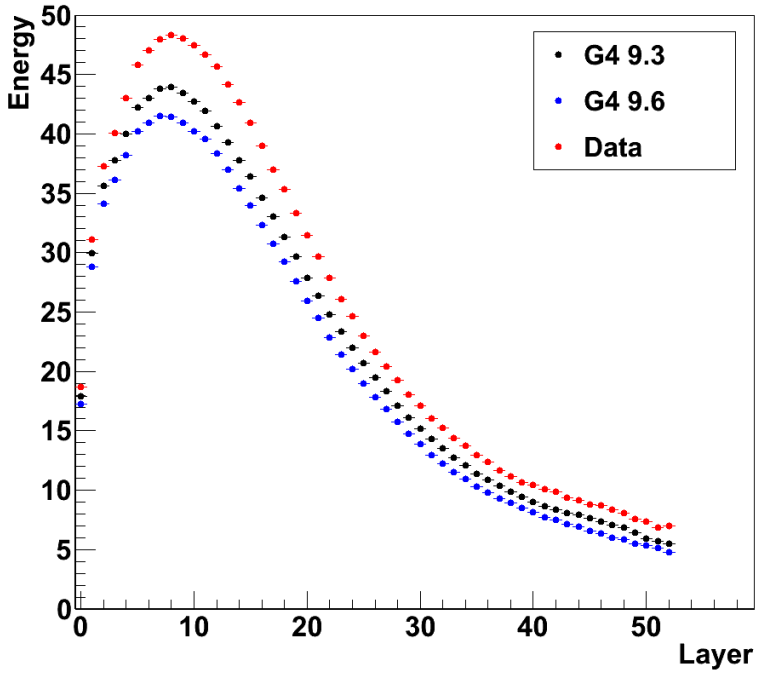


Backup:
FTFP_BERT

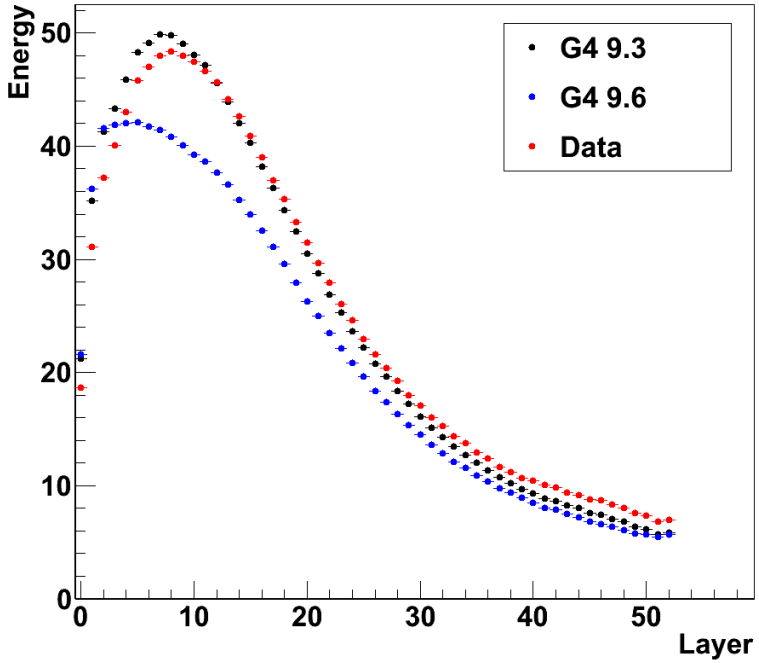
Change in energy deposition @ 10 GeV

The change with Geant 4 version is much more pronounced in FTFP_BERT

QGSP_BERT



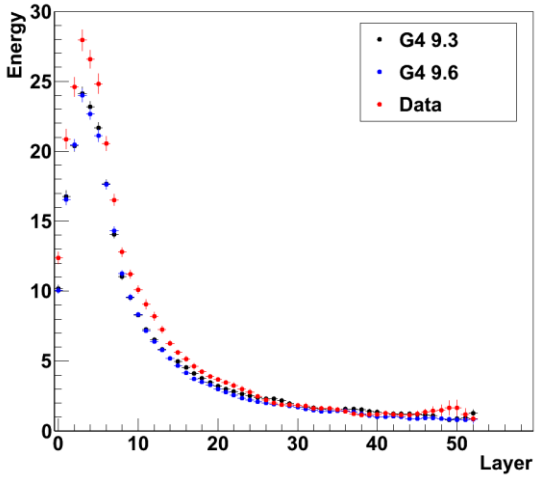
FTFP_BERT



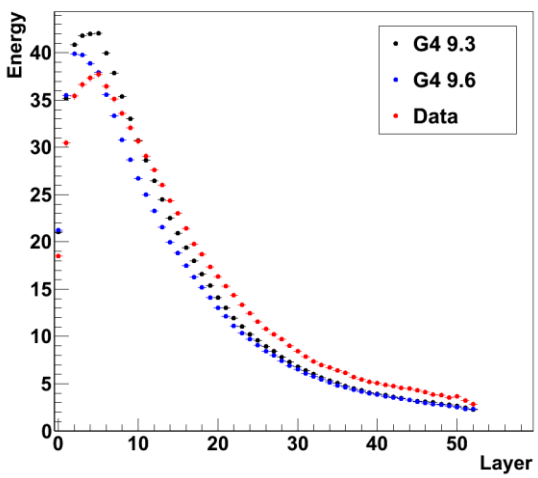
Change in energy deposition

The change with Geant 4 version increases with energy in FTFP_BERT

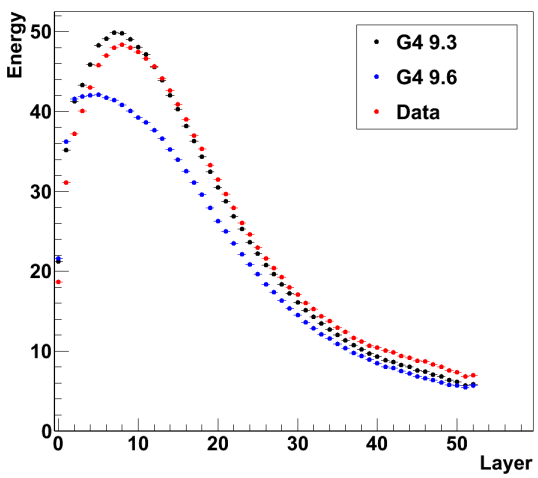
2 GeV



6 GeV



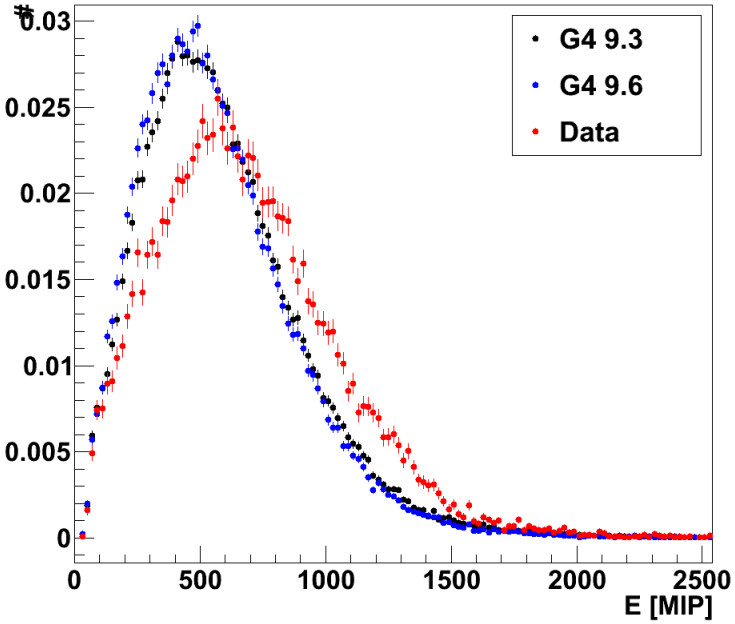
10 GeV



Change in total deposited energy @ 10 GeV

The change with Geant 4 version is much more pronounced in FTFP_BERT

QGSP_BERT



FTFP_BERT