CALICE ECAL Meeting

8th June 2009

Analysis of pion showers in the ECAL from CERN Oct 2007 Data

– Update –

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University of Cambridge

Summary of data and MC simulations

- Reconstructed data

2007 data from CERN
v0406 reconstruction

Run330641 – 8GeV -ve Pion

Run330332 – 10GeV -ve Pion

Run330645 – 12GeV -ve Pion

Run330328 – 15GeV -ve Pion

Run330326 – 20GeV -ve Pion

Run331298 – 30GeV +ve Pion

- GEANT4 simulations used

Mokka version 6.7.p03.calice

with physics lists...

LHEP

QGSP_BERT

QGSC_BERT

QGS_BIC

FTFP_BERT

FTF_BIC

(recommended by G4 authors)

Summary of physics lists

List of models with their energy range for pions within physics lists

LHEP

- G4LEPion 0 – 55 GeV
- G4HEPion 25GeV – 100TeV

FTFP_BERT

- Bertini Cascade 0 – 5GeV
- FTFP 4GeV – 100TeV

FTF_BIC

- Binary Cascade 0 – 5 GeV
- G4LEPion 10GeV – 50GeV
- FTFB 4GeV – 100TeV

QGSC_BERT

- Bertini Cascade 0 – 9GeV
- QGSC 6GeV – 100TeV

QGSP_BERT

- Bertini Cascade 0 – 9.9GeV
- G4LEPion 9.5GeV – 25GeV
- QGSP 12GeV – 100TeV

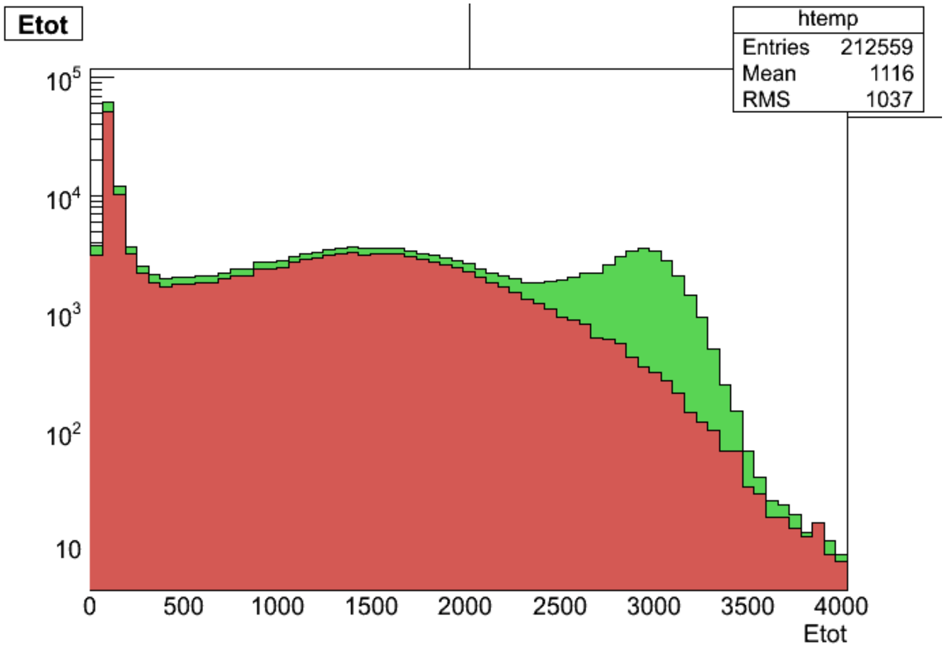
QGS_BIC

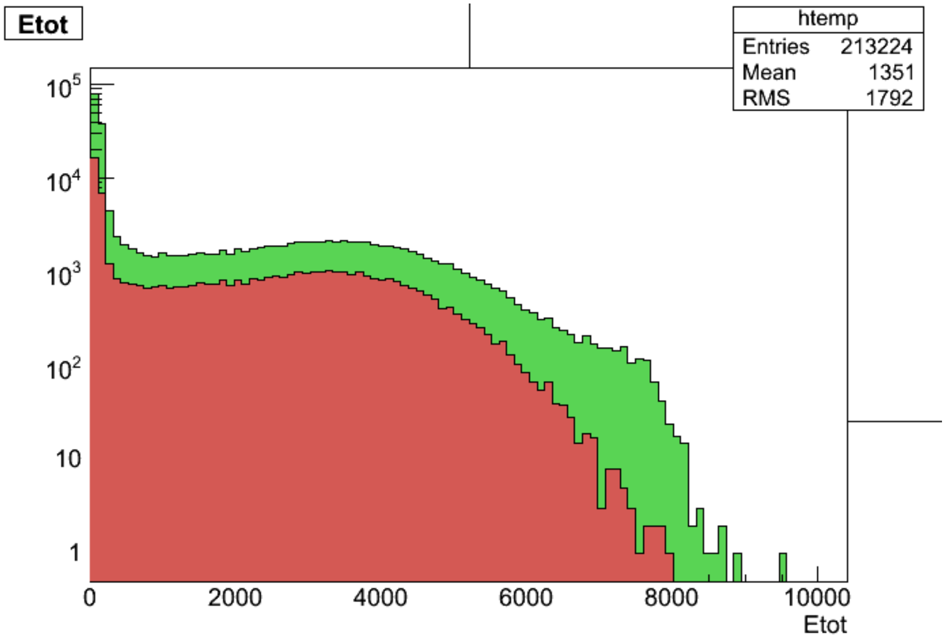
- Binary Cascade 0 – 1.3 GeV
- G4LEPion 1.2GeV – 25GeV
- QGSB 12GeV – 100TeV

Most overlaps and changes in models used occur between 8 - 30GeV

Event Selection

- Electron/proton events distinguished using signal from the Cerenkov gas chamber.



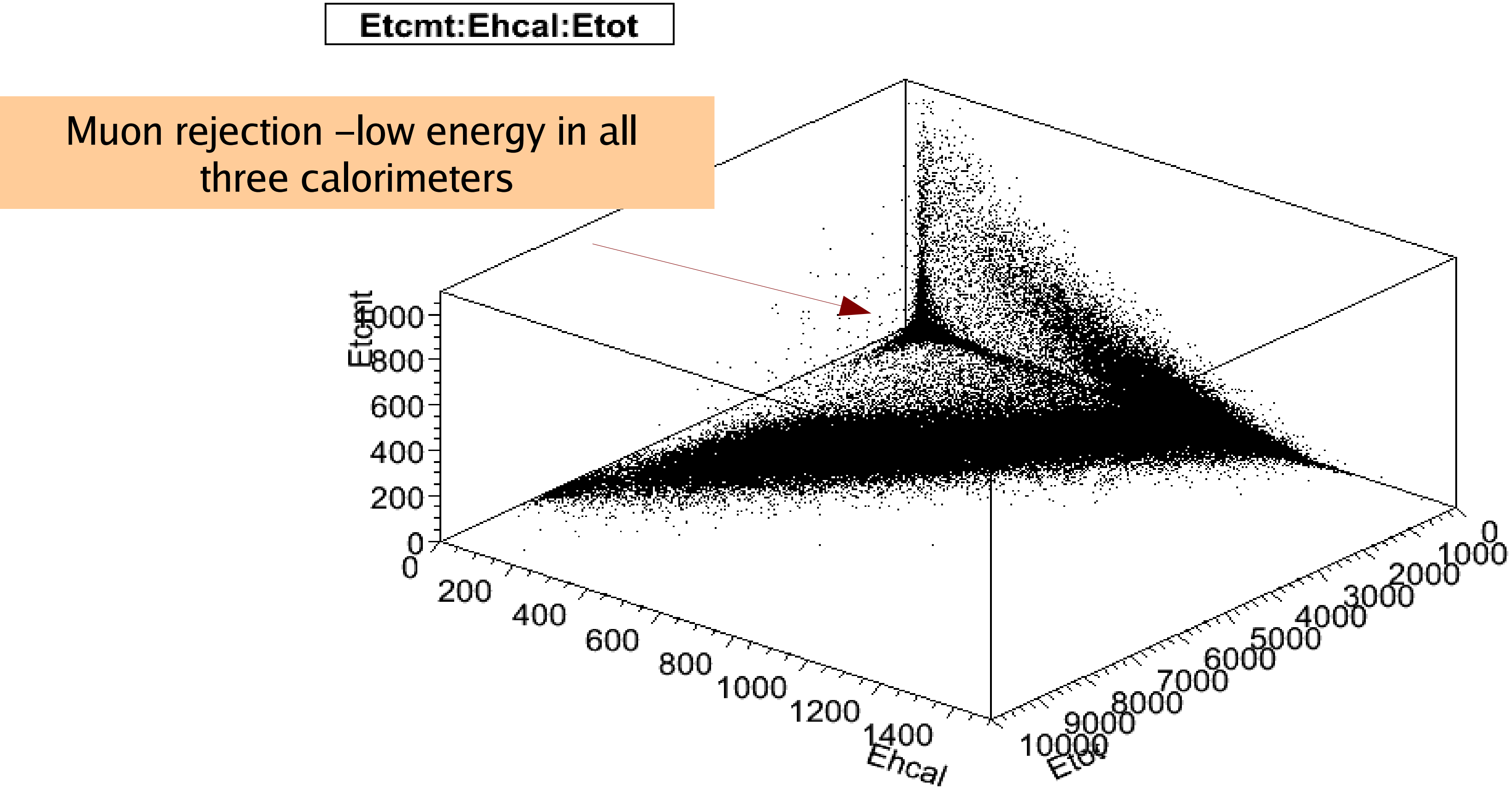


π^- runs : demand Cerenkov **off (red)** to remove e^- (8,10,12,15,and 20GeV)

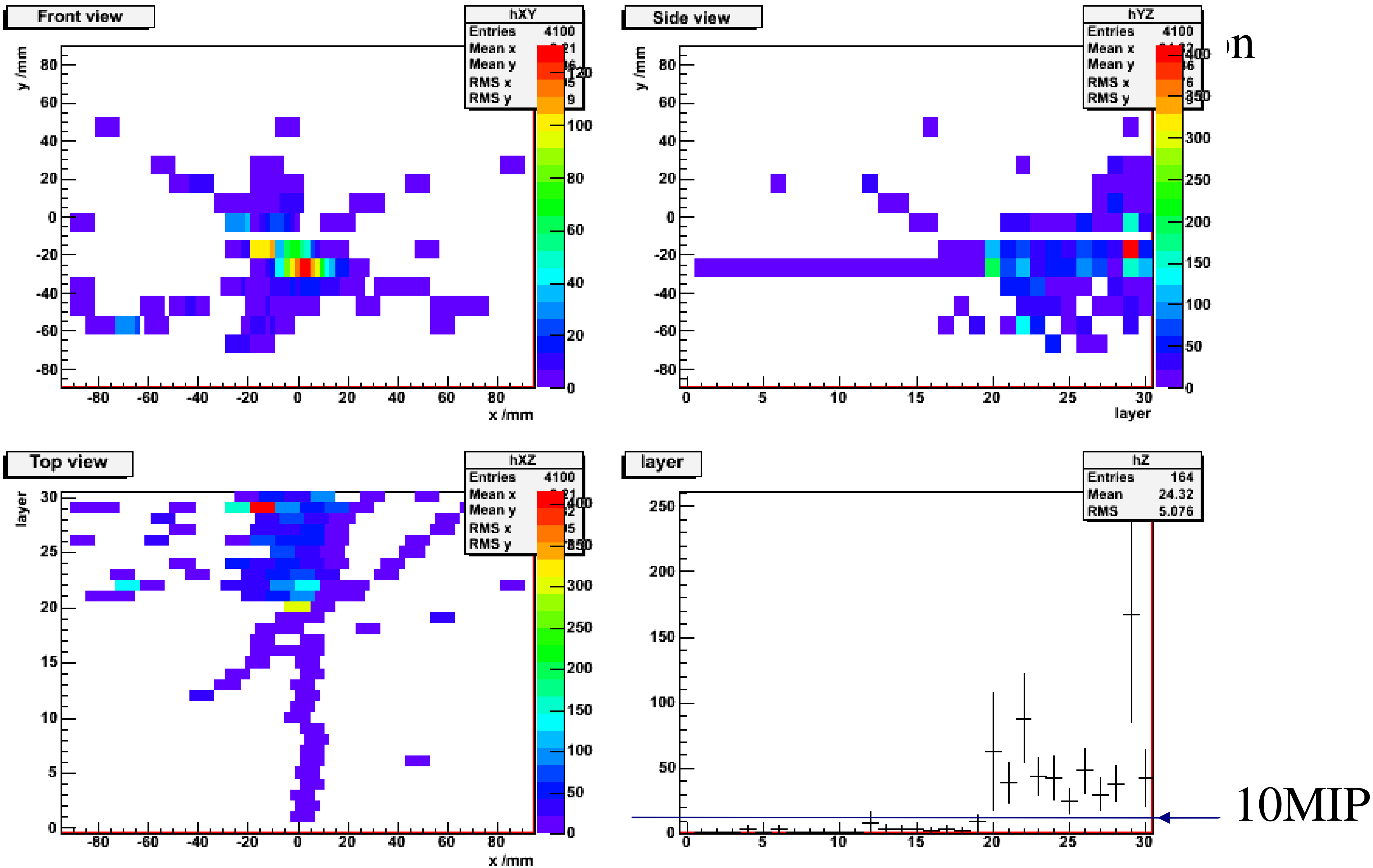
π^+ runs : demand Cerenkov **on (green)** to remove p (only 30GeV)

Event Selection

- Muon events are distinguished from the rest by comparing the data and pure muon MC simulation, looking at distribution of energy deposited in ECAL, HCAL and TCMT.



First interaction layer – Algorithm

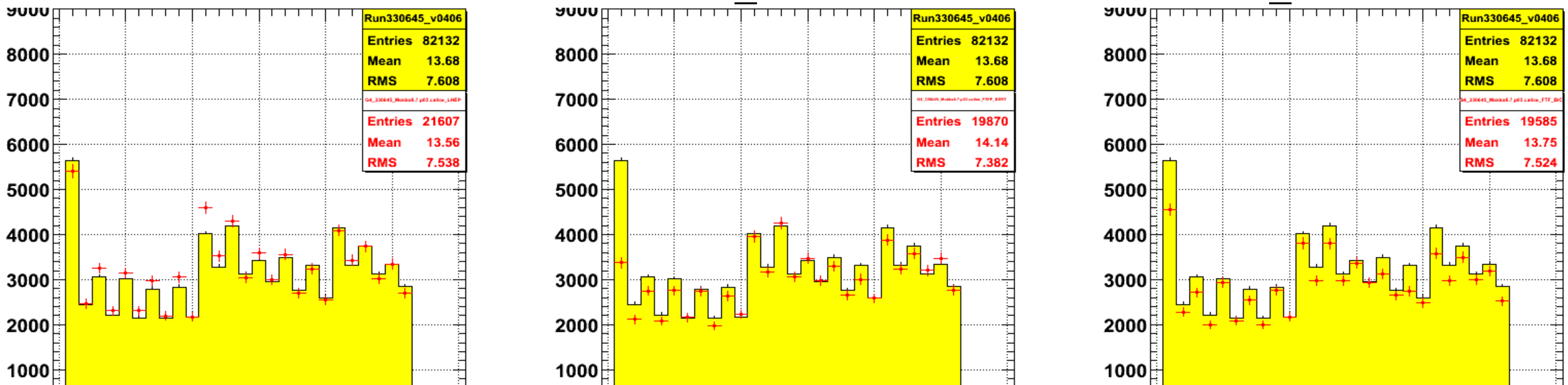


Identify the first layer which 3 layers out of 4 consecutive layers >10MIPs

First Interaction Layer – -12GeV

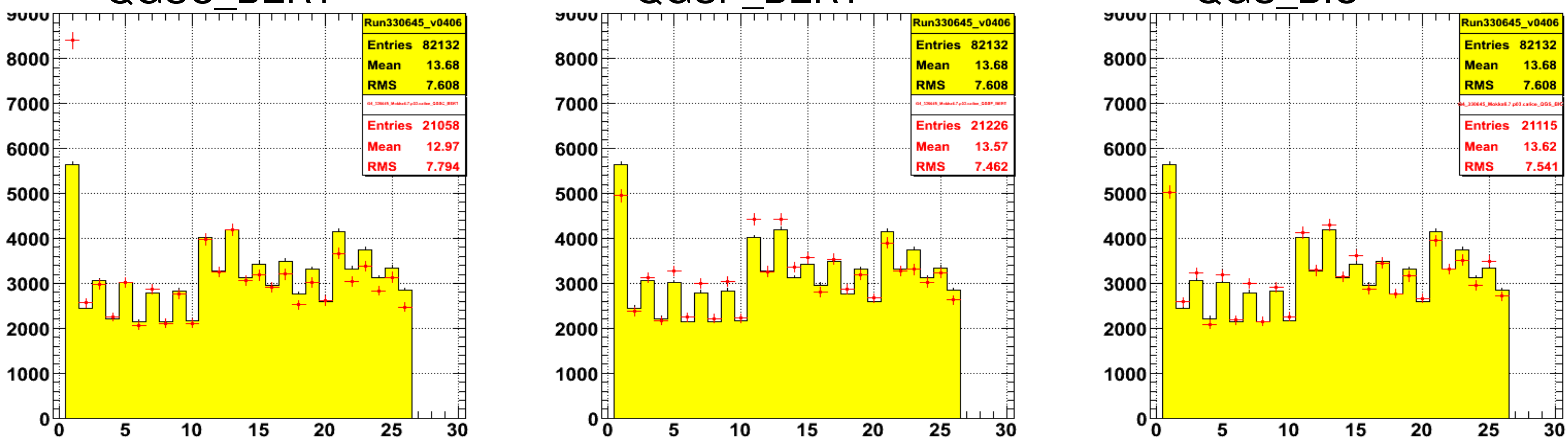
(normalised to number of events)

LHEP FTFP_BERT FTF_BIC



Most significant difference between physicslists in layer 1.
- upstream showering -> cut events where interaction layer =1

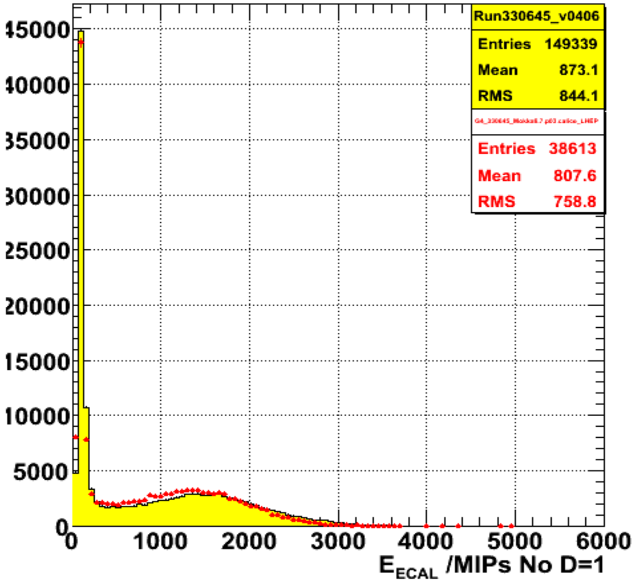
QGSC_BERT QGSP_BERT QGS_BIC



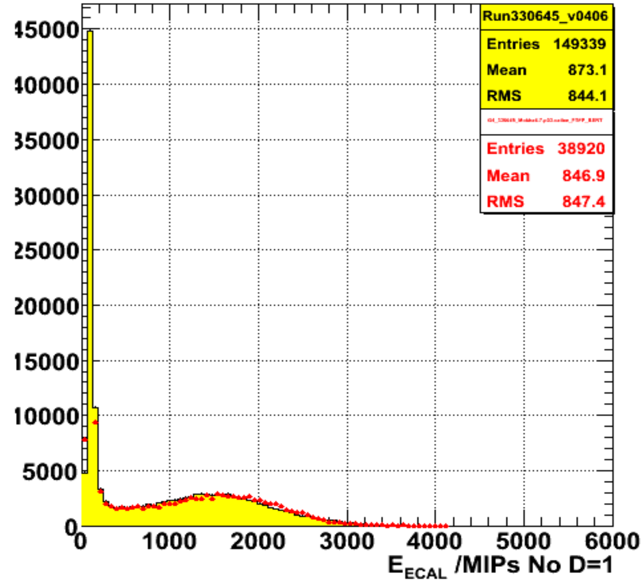
Total Energy Dissipated in ECAL – -12GeV

(Normalised to number of events)

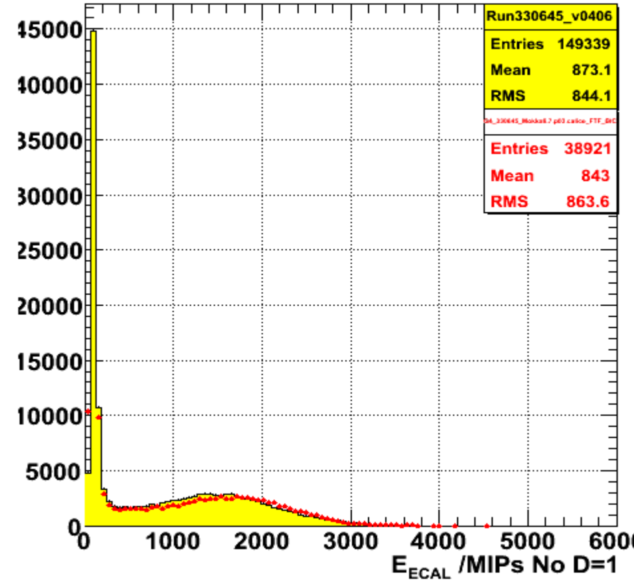
LHEP



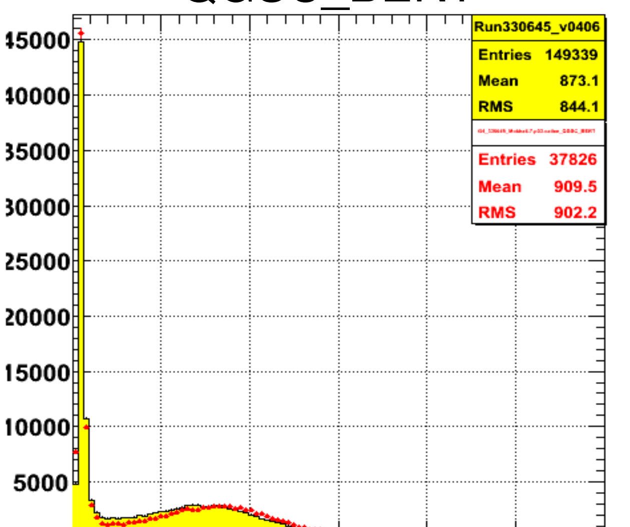
FTFP_BERT



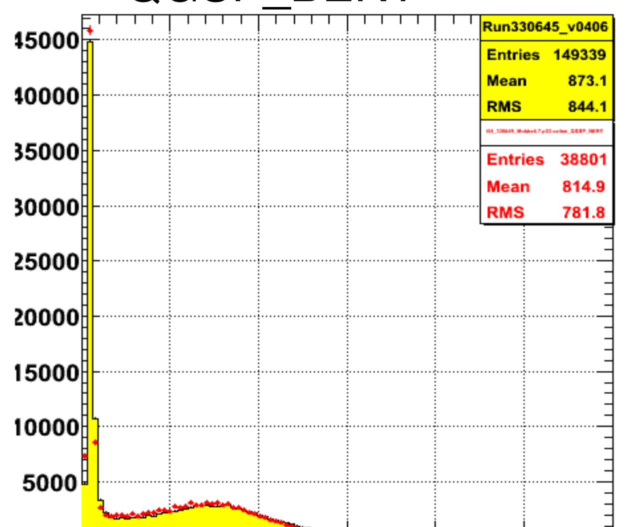
FTF_BIC



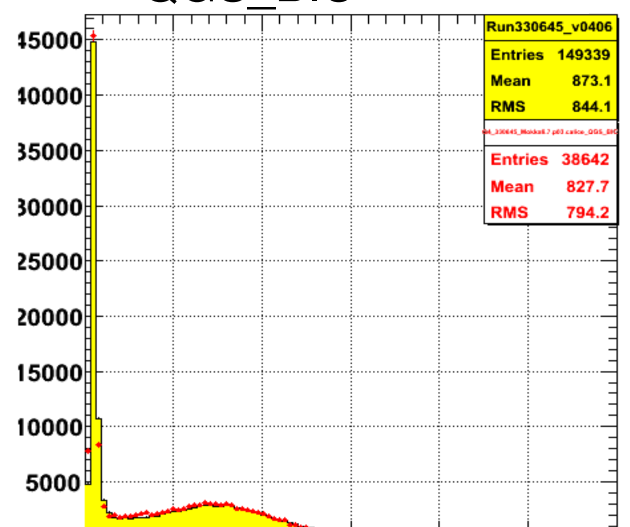
QGSC_BERT



QGSP_BERT



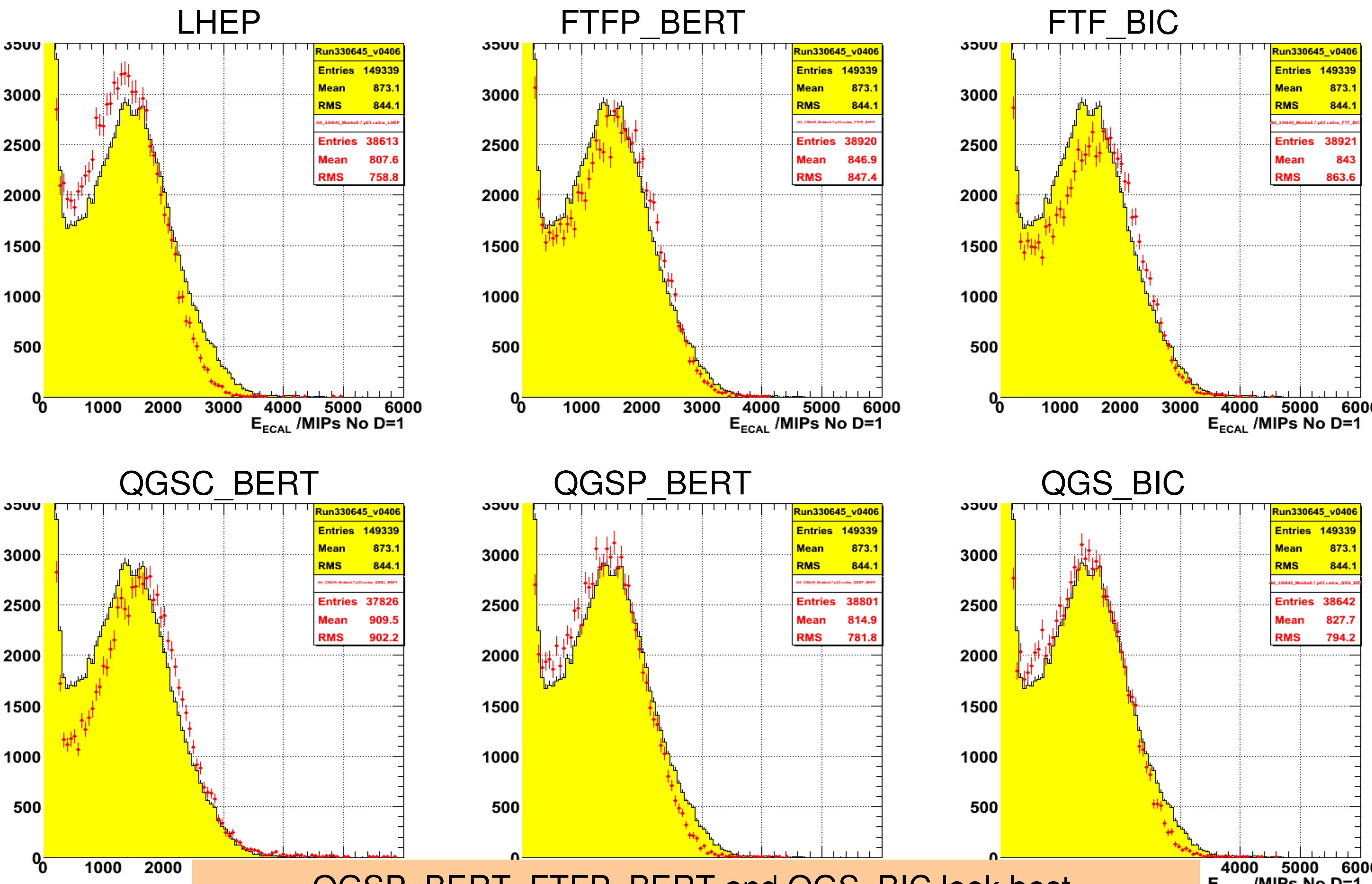
QGS_BIC



Low energy non-interacting peak well simulated, but not very interesting

Total Energy Dissipated in ECAL – -12GeV

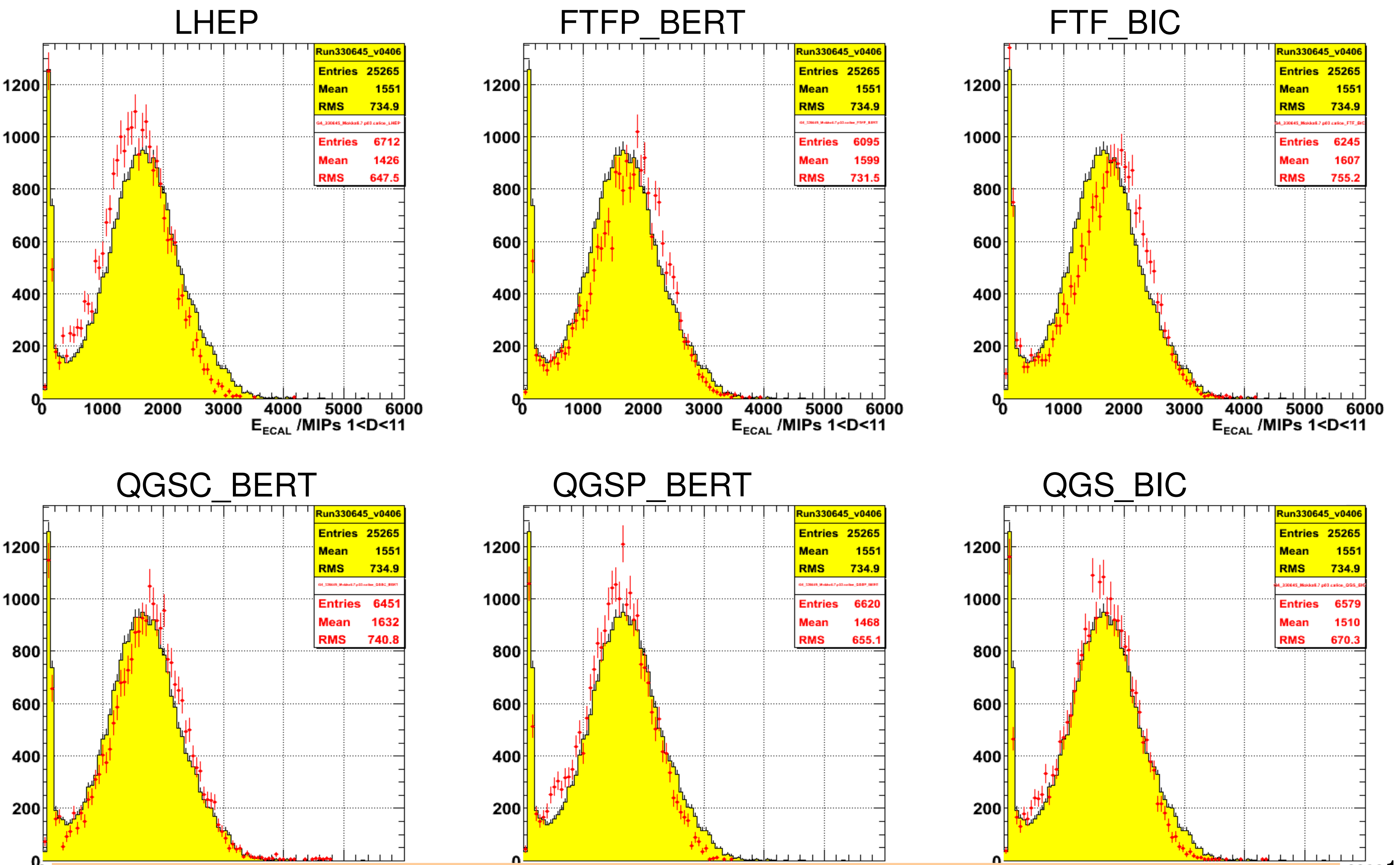
(Normalised to number of events) (zoomed)



QGSP_BERT, FTFP_BERT and QGS_BIC look best.

Total Energy Dissipated in ECAL – -12GeV

(Normalised to number of events) (1< interaction layer <11)

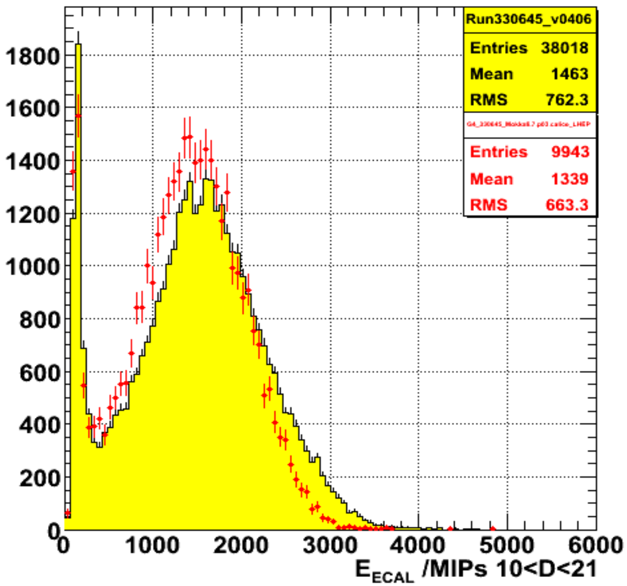


Low energy peak is almost entirely eliminated. None perfect, but QGS models preferred

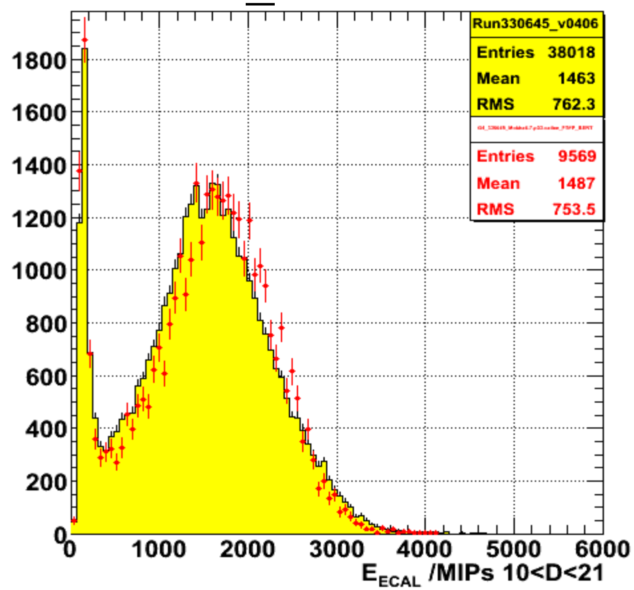
Total Energy Dissipated in ECAL – -12GeV

(Normalised to number of events) (10< interaction layer <21)

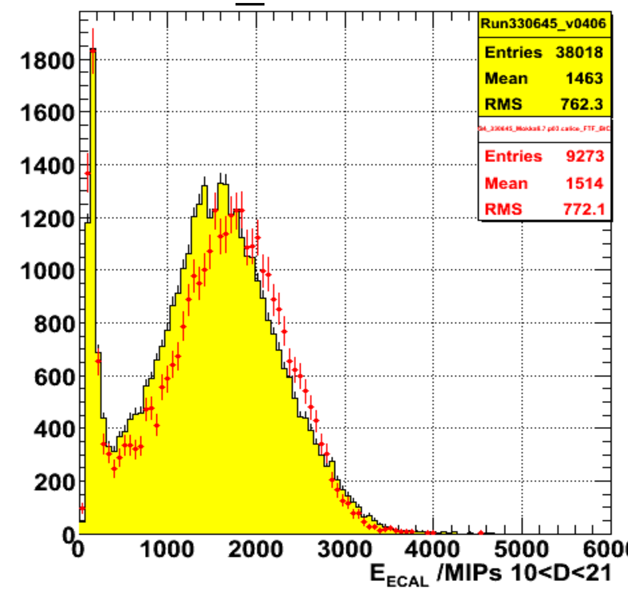
LHEP



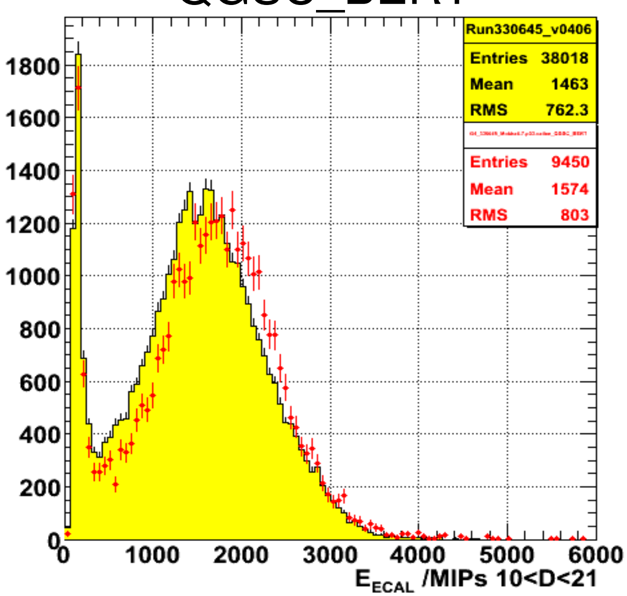
FTFP_BERT



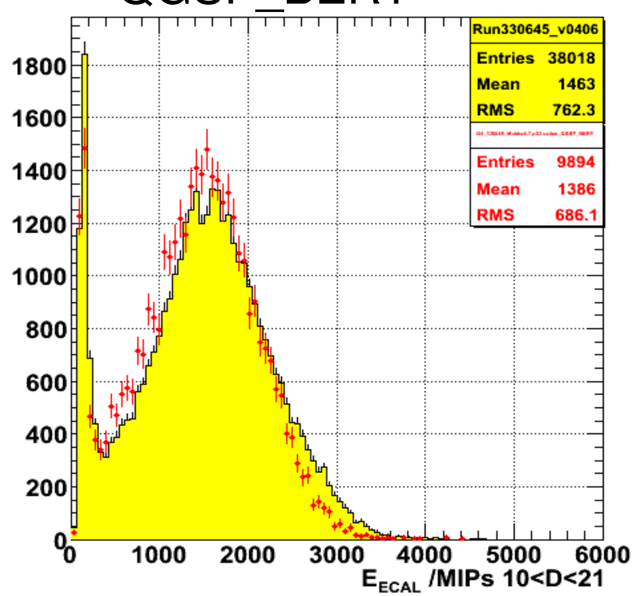
FTF_BIC



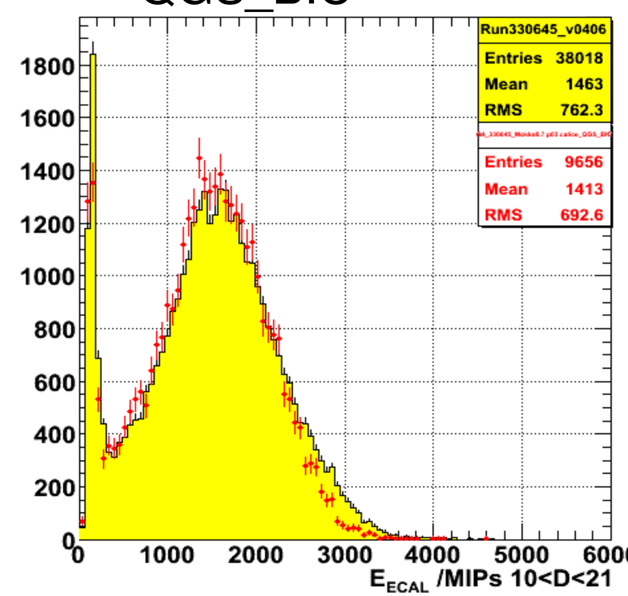
QGSC_BERT



QGSP_BERT



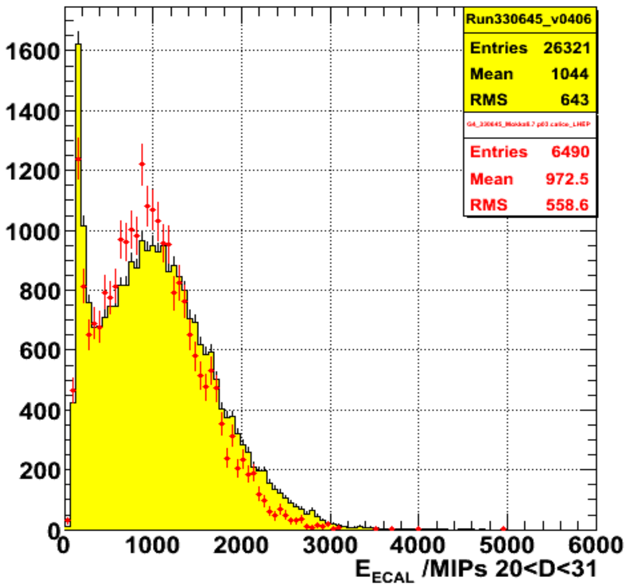
QGS_BIC



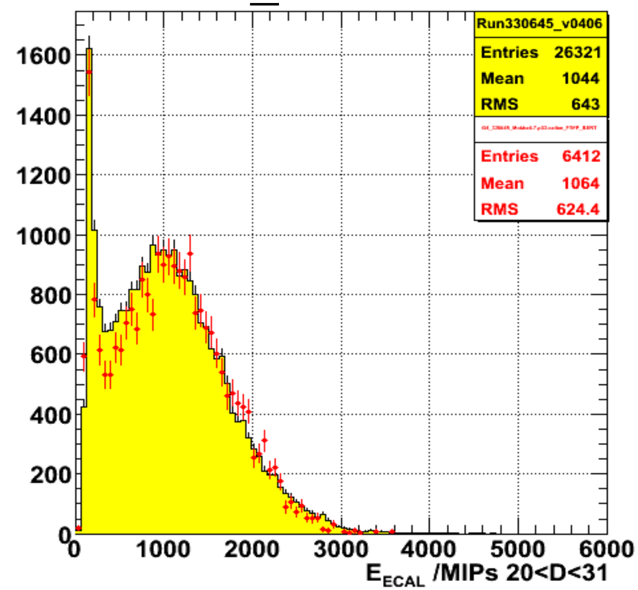
Total Energy Dissipated in ECAL – -12GeV

(Normalised to number of events) (20< interaction layer <31)

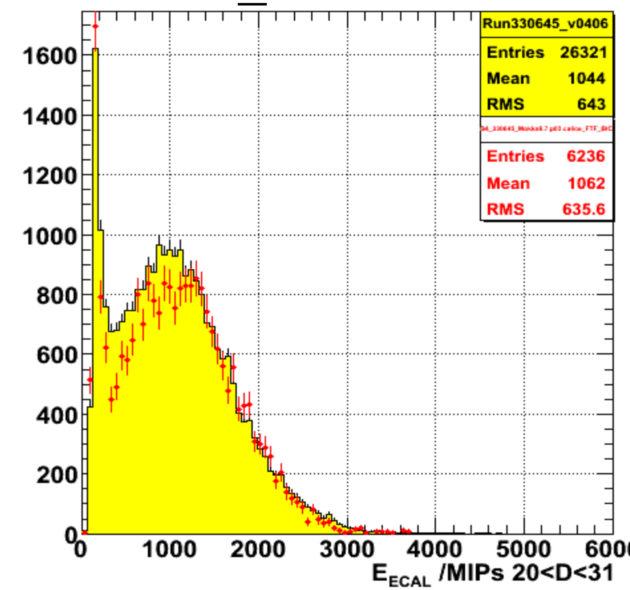
LHEP



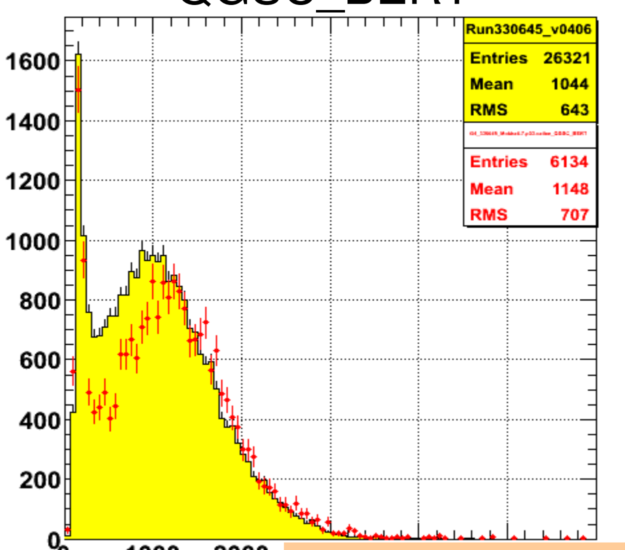
FTFP_BERT



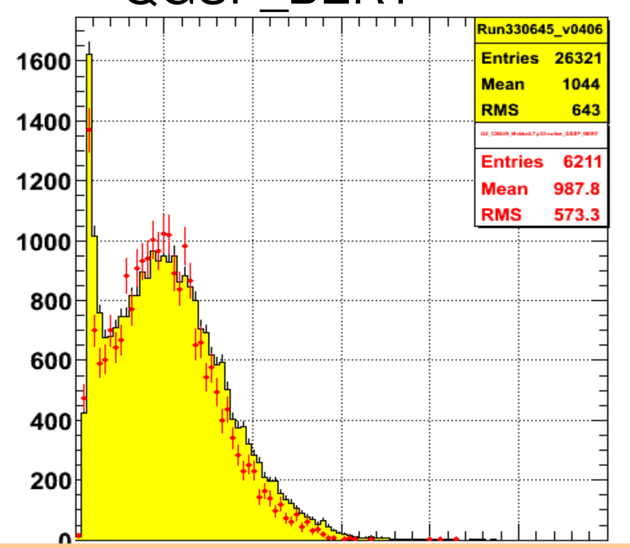
FTF_BIC



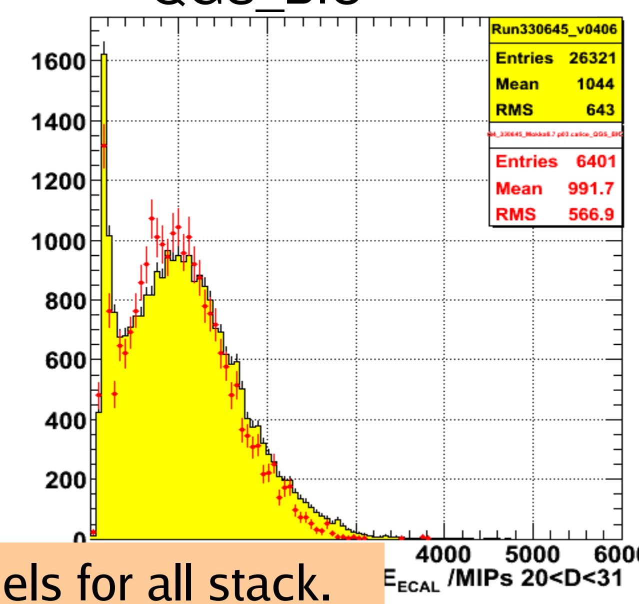
QGSC_BERT



QGSP_BERT



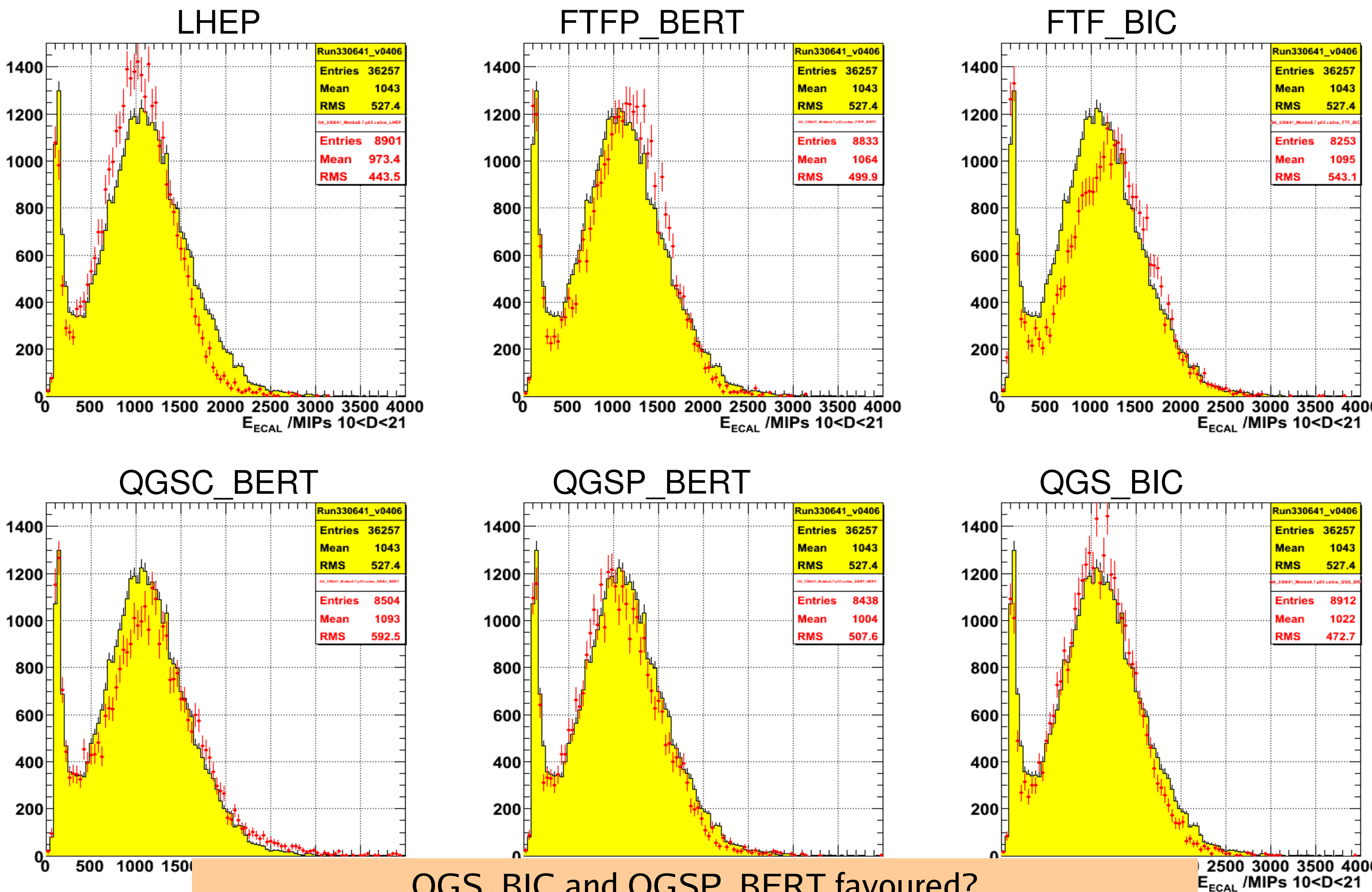
QGS_BIC



Similar level of agreement between data and models for all stack.

Total Energy Dissipated in ECAL – -8GeV

(Normalised to number of events) (10< interaction layer <21)

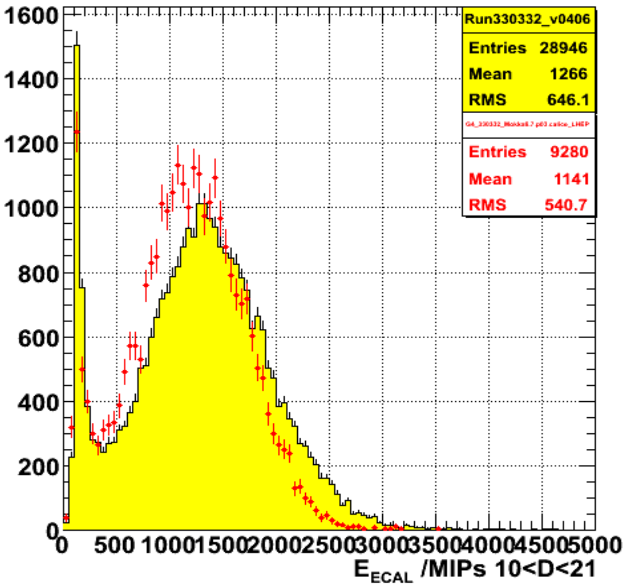


QGS_BIC and QGSP_BERT favoured?

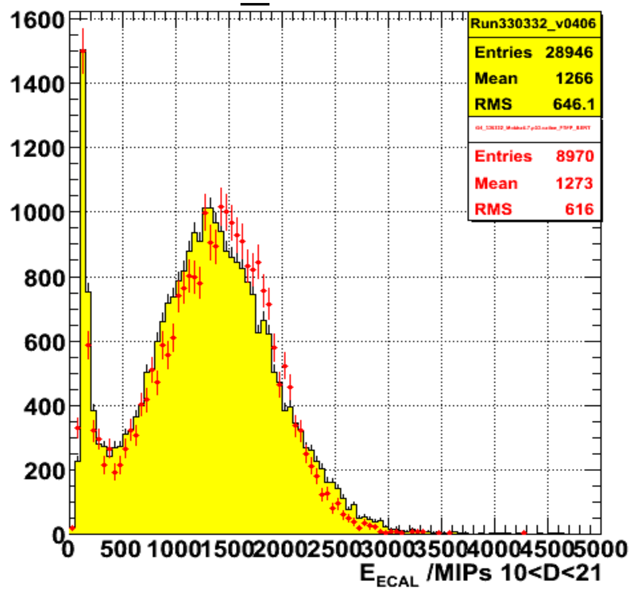
Total Energy Dissipated in ECAL – -10GeV

(Normalised to number of events) (10< interaction layer <21)

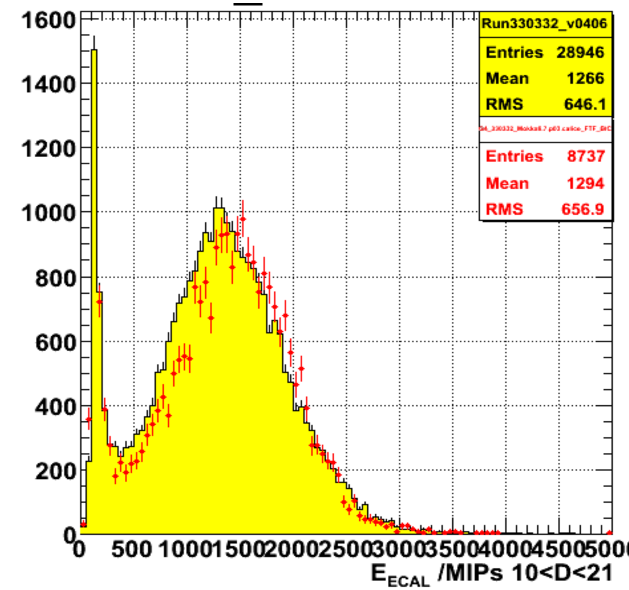
LHEP



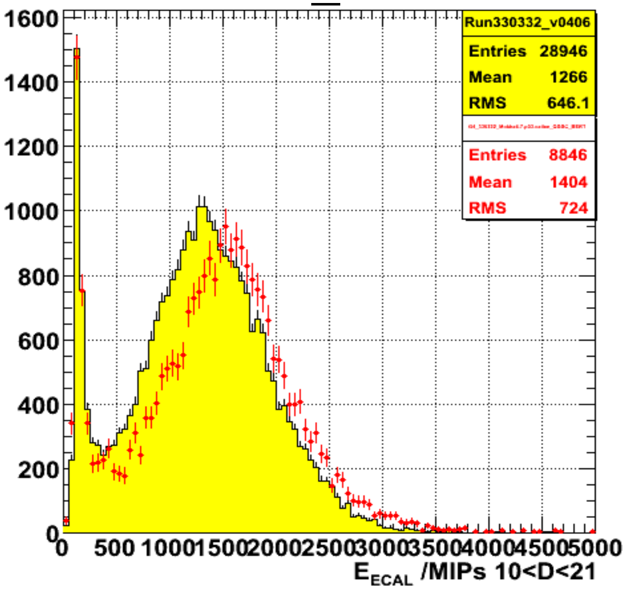
FTFP_BERT



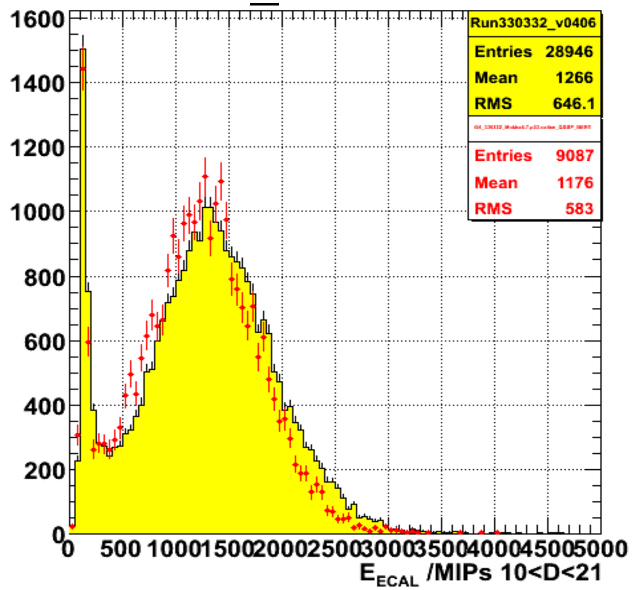
FTF_BIC



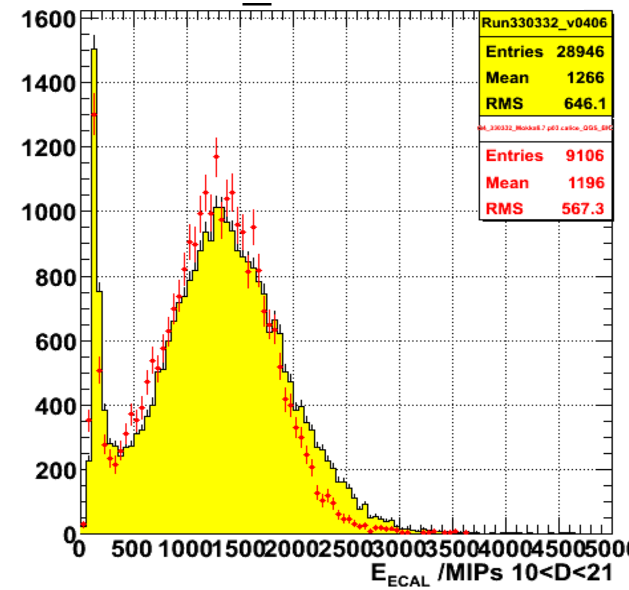
QGSC_BERT



QGSP_BERT

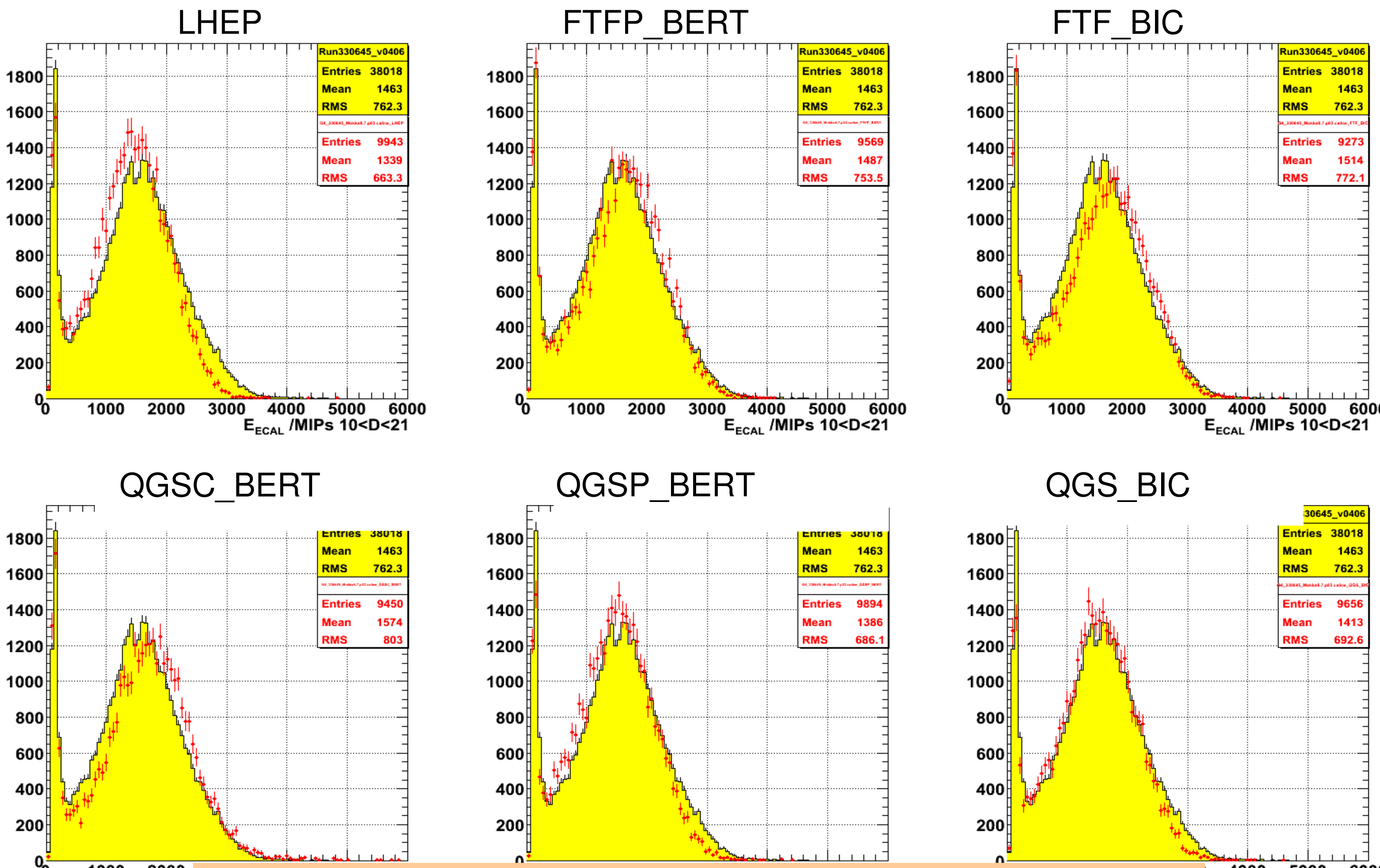


QGS_BIC



Total Energy Dissipated in ECAL – -12GeV

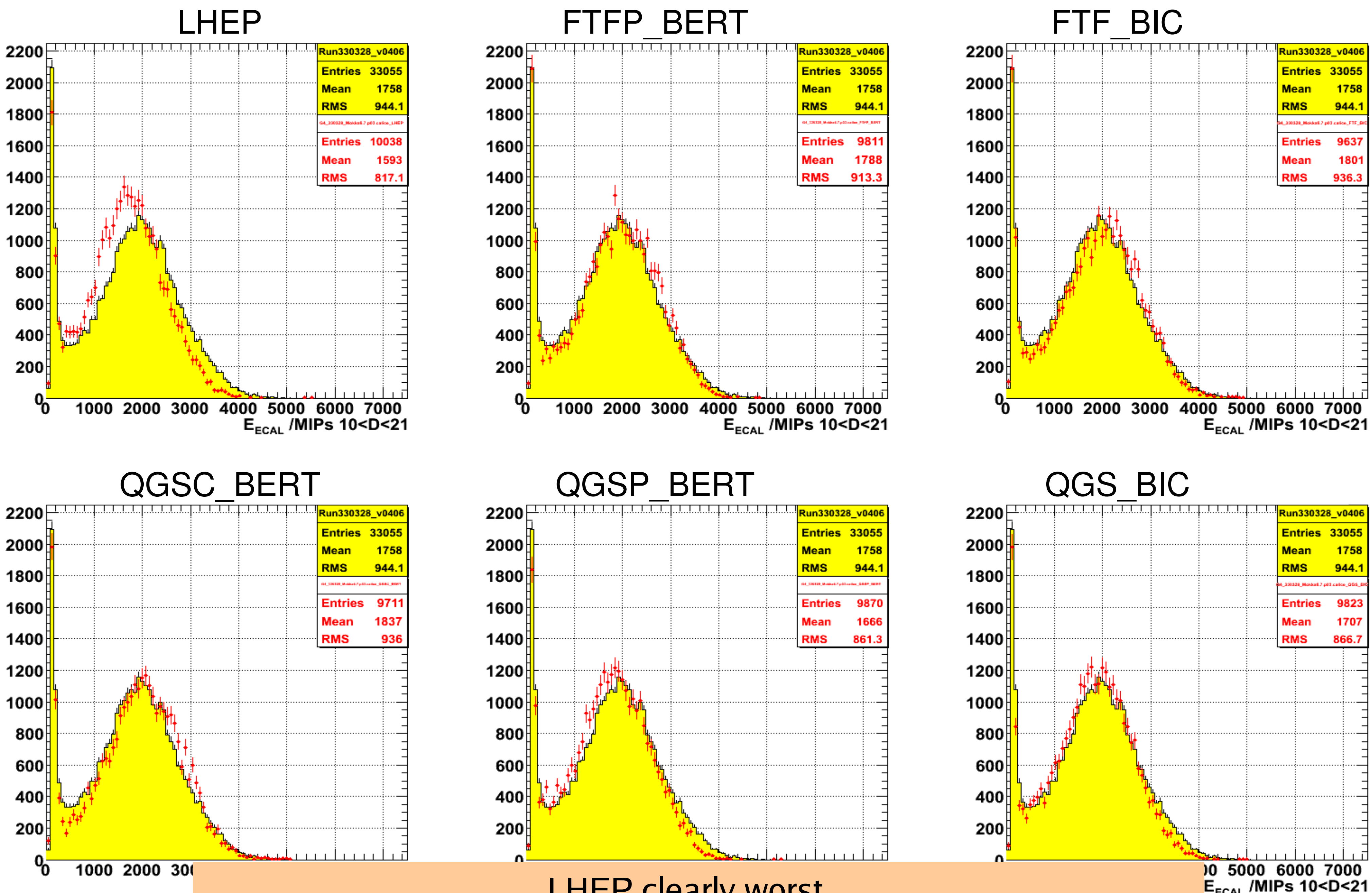
(Normalised to number of events) (10< interaction layer <21)



Same plot as previous one. Shown for completeness

Total Energy Dissipated in ECAL – -15GeV

(Normalised to number of events) (10< interaction layer <21)

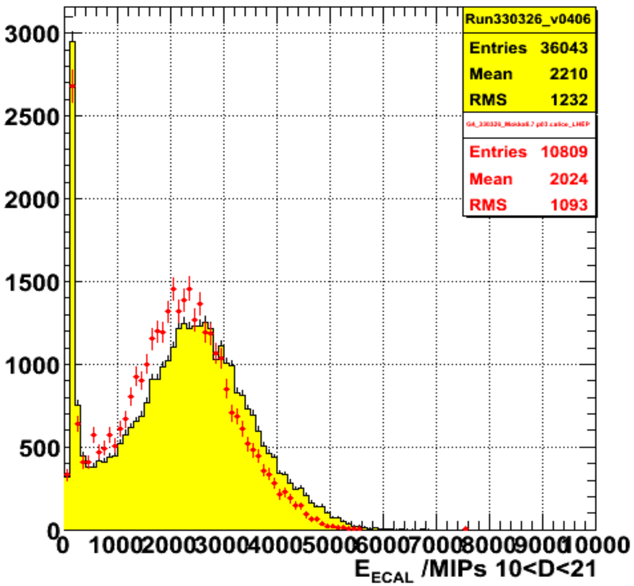


LHEP clearly worst.

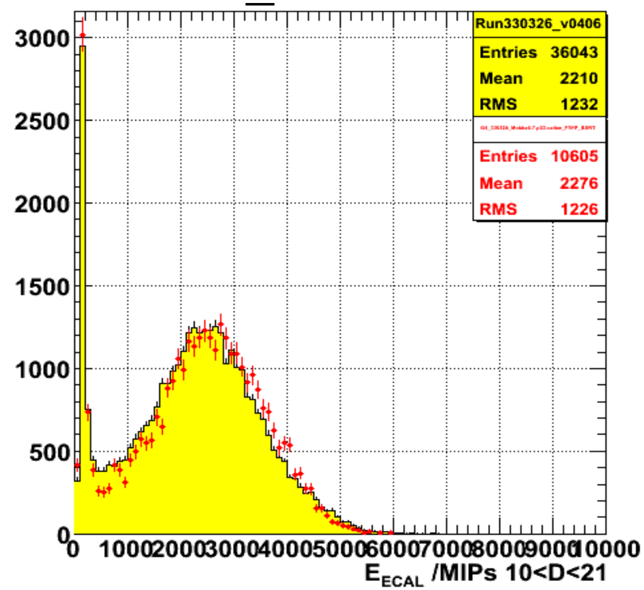
Total Energy Dissipated in ECAL – -20GeV

(Normalised to number of events) (10< interaction layer <21)

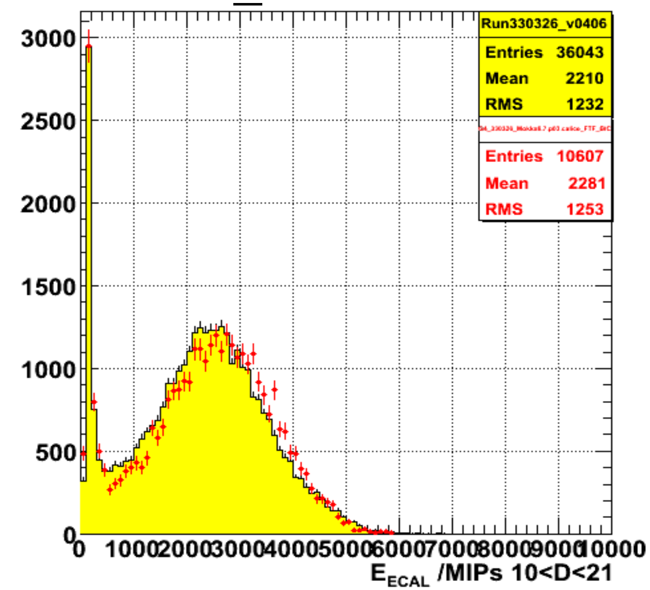
LHEP



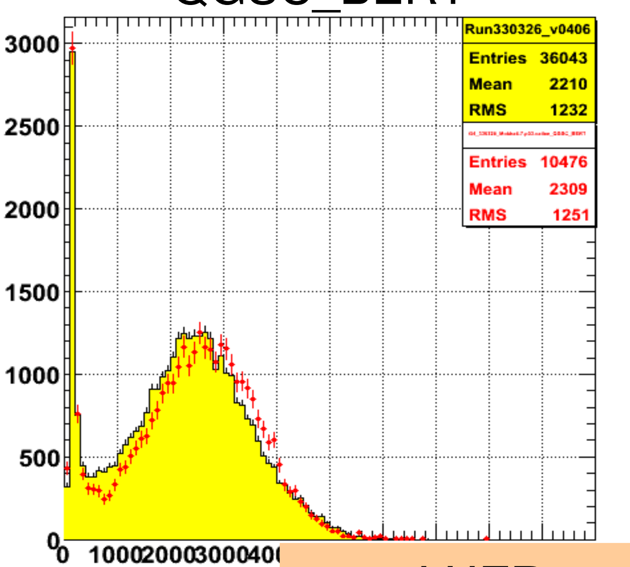
FTFP_BERT



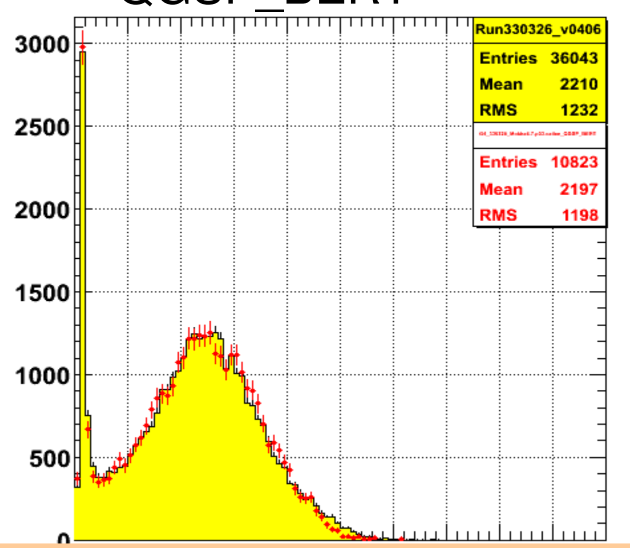
FTF_BIC



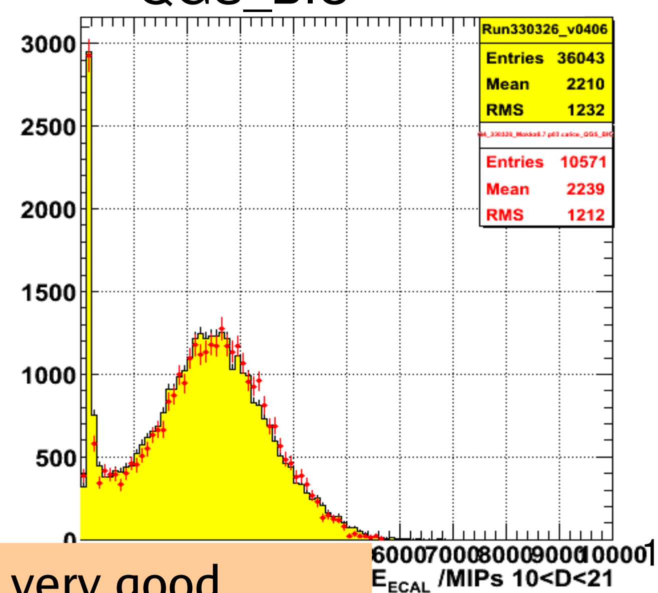
QGSC_BERT



QGSP_BERT



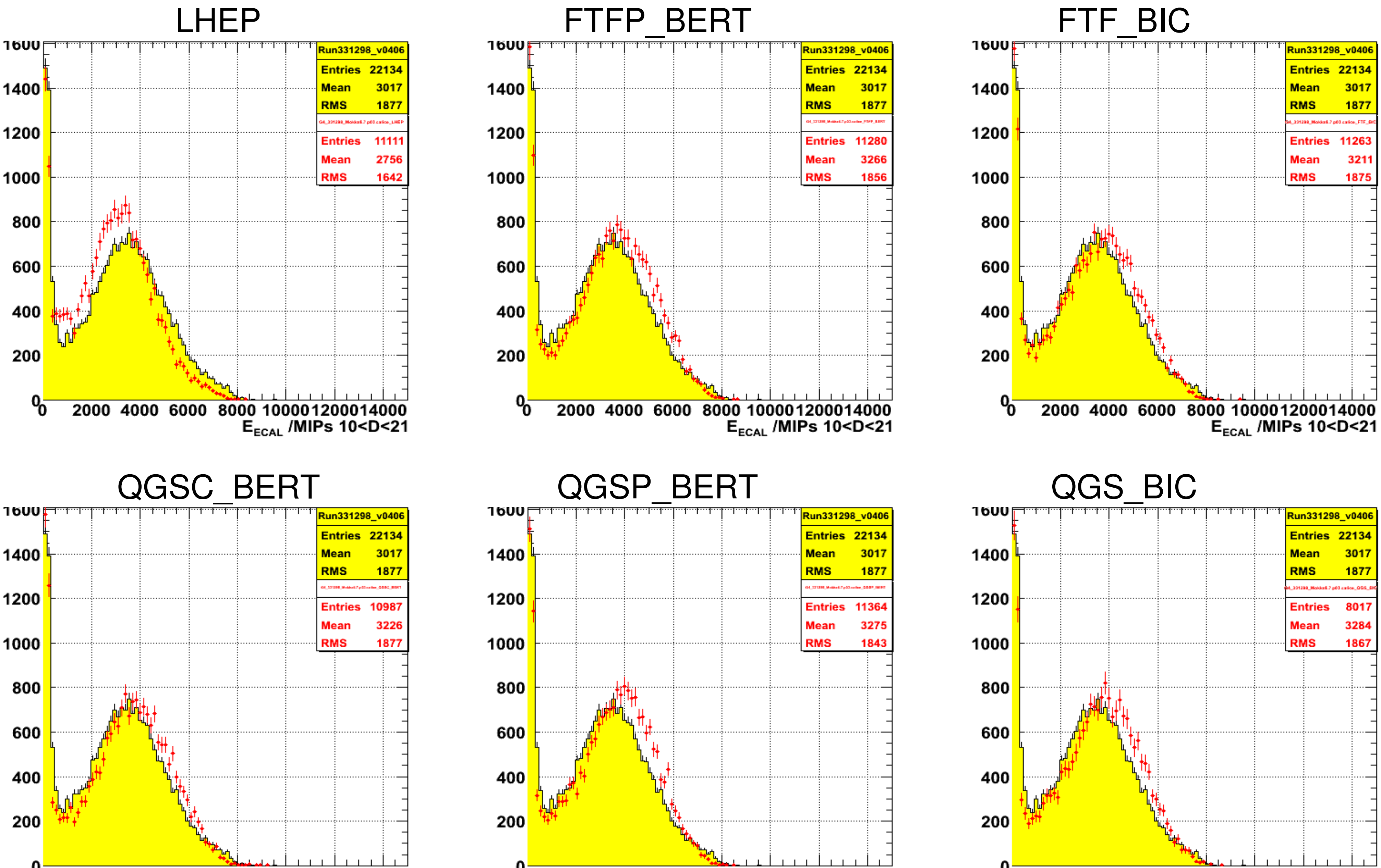
QGS_BIC



LHEP worst. QGSP_BERT and QGS_BIC are very good.

Total Energy Dissipated in ECAL – +30GeV

(Normalised to number of events) (10< interaction layer <21)

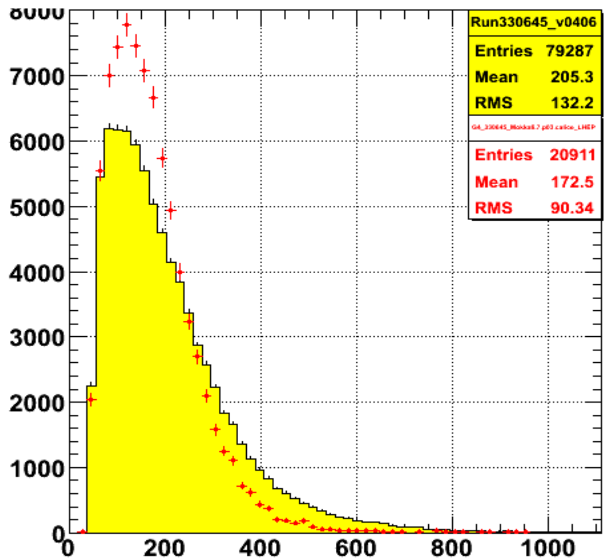


All MC much worse. Overall QGSP_BERT and QGS_BIC shows best agreement

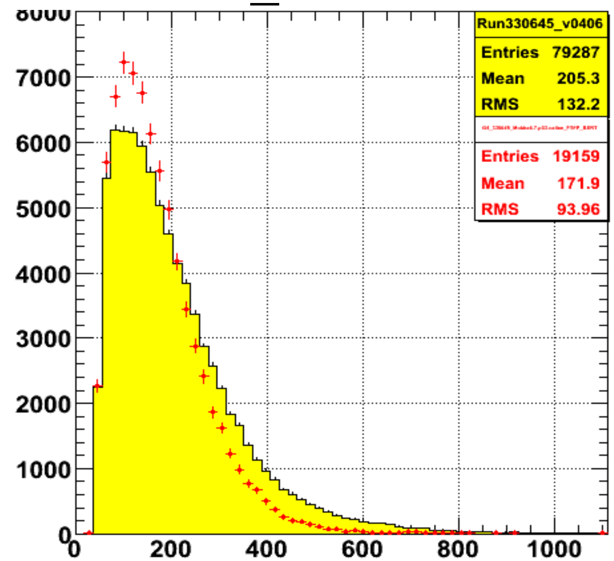
Shower energies (first 5 layers) – -12GeV

(normalised to number of events)

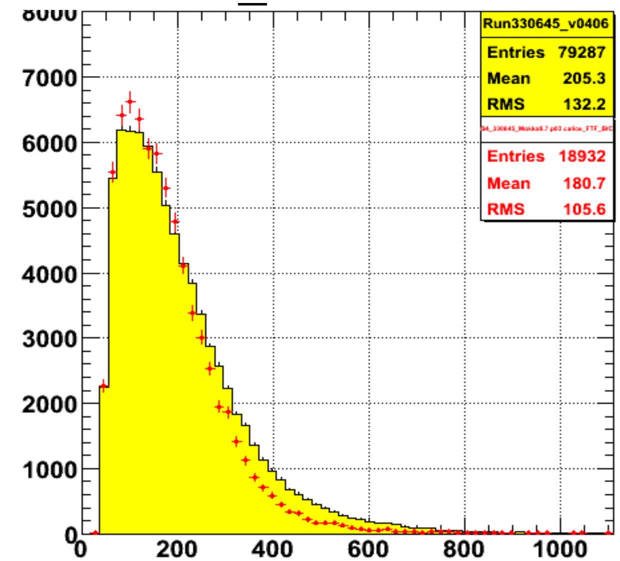
LHEP



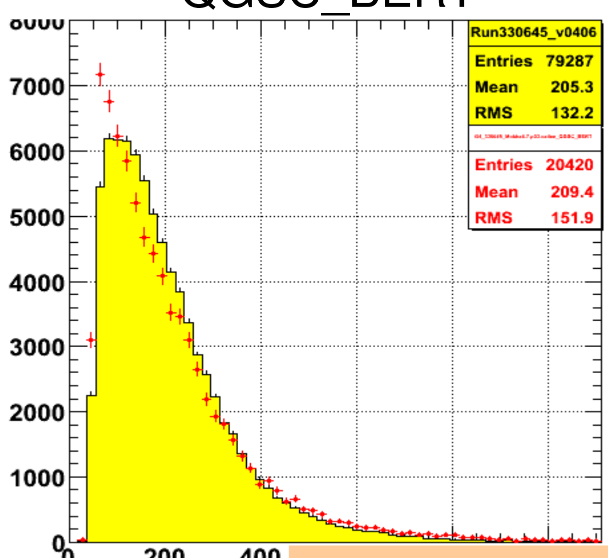
FTFP_BERT



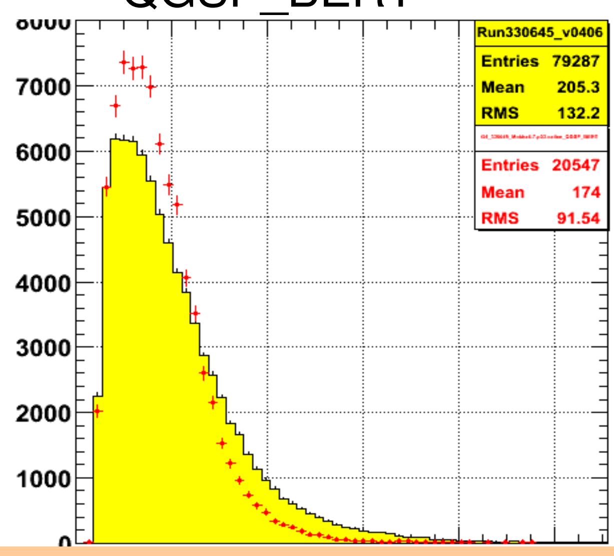
FTF_BIC



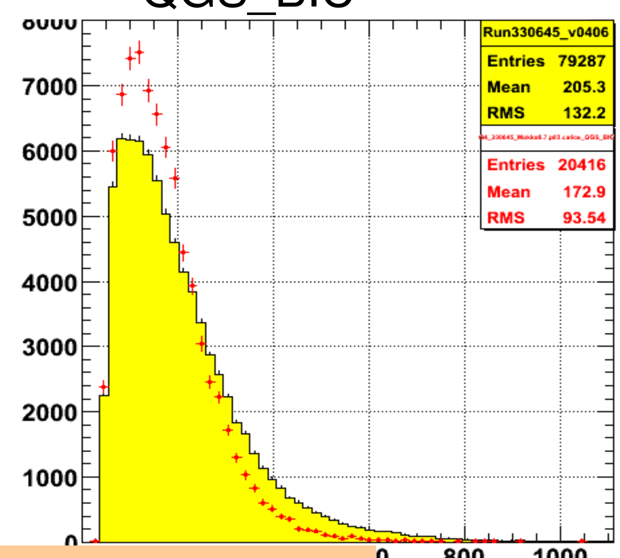
QGSC_BERT



QGSP_BERT



QGS_BIC

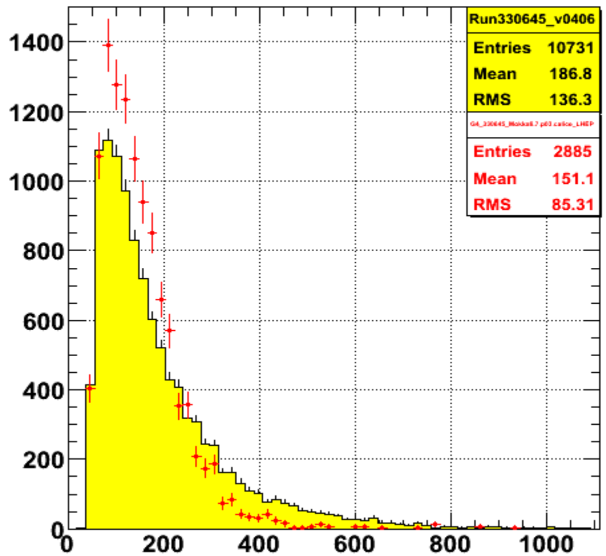


All models discrepant No tungsten thickness weight been applied.

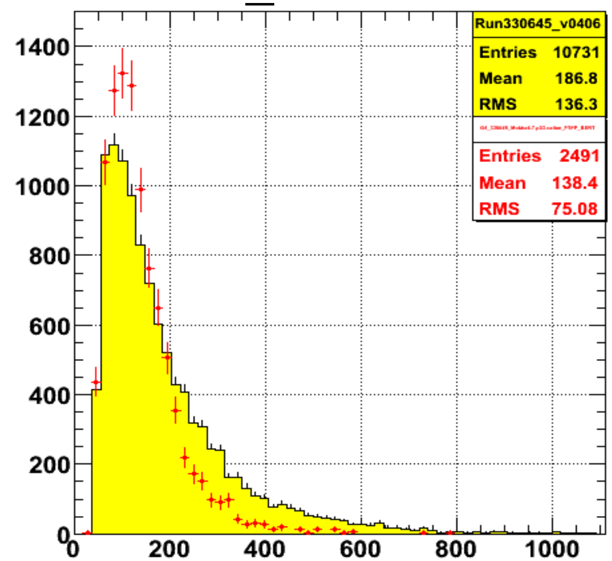
Shower energies (first 5 layers) – -12GeV

(normalised to number of events) (1< interaction layer <6)

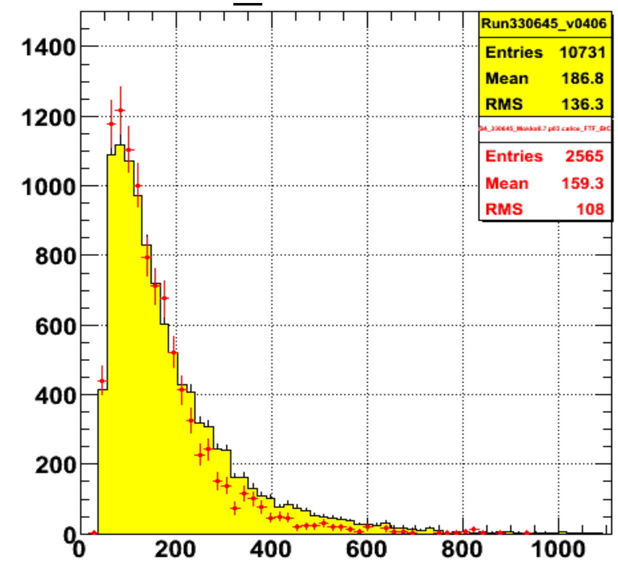
LHEP



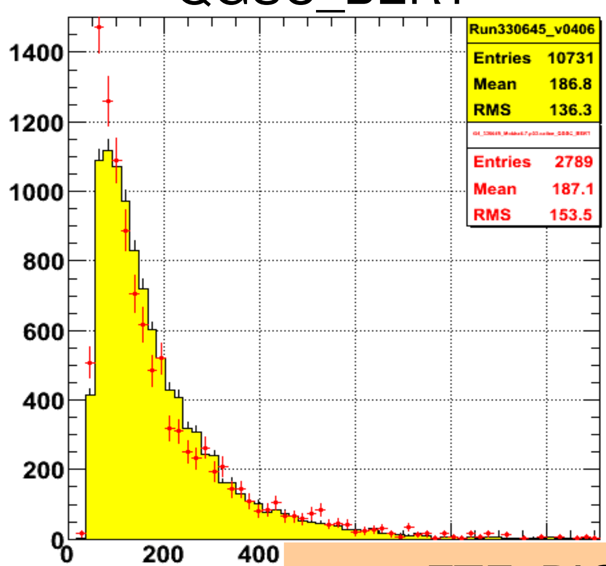
FTFP_BERT



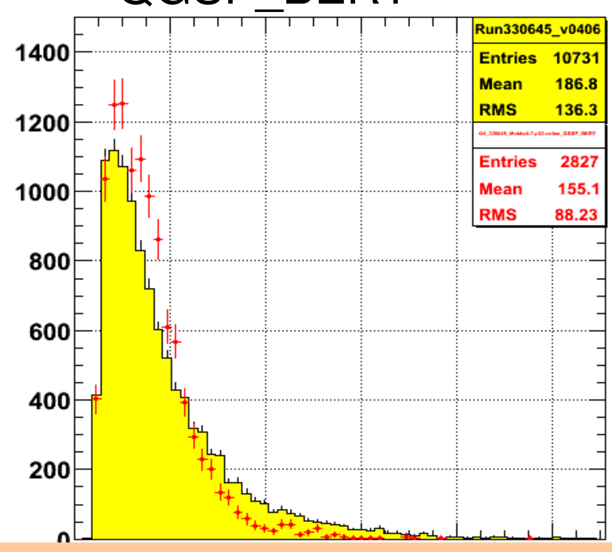
FTF_BIC



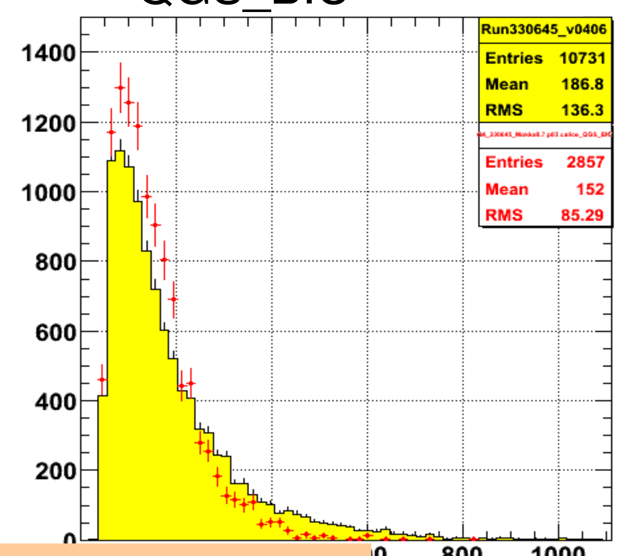
QGSC_BERT



QGSP_BERT



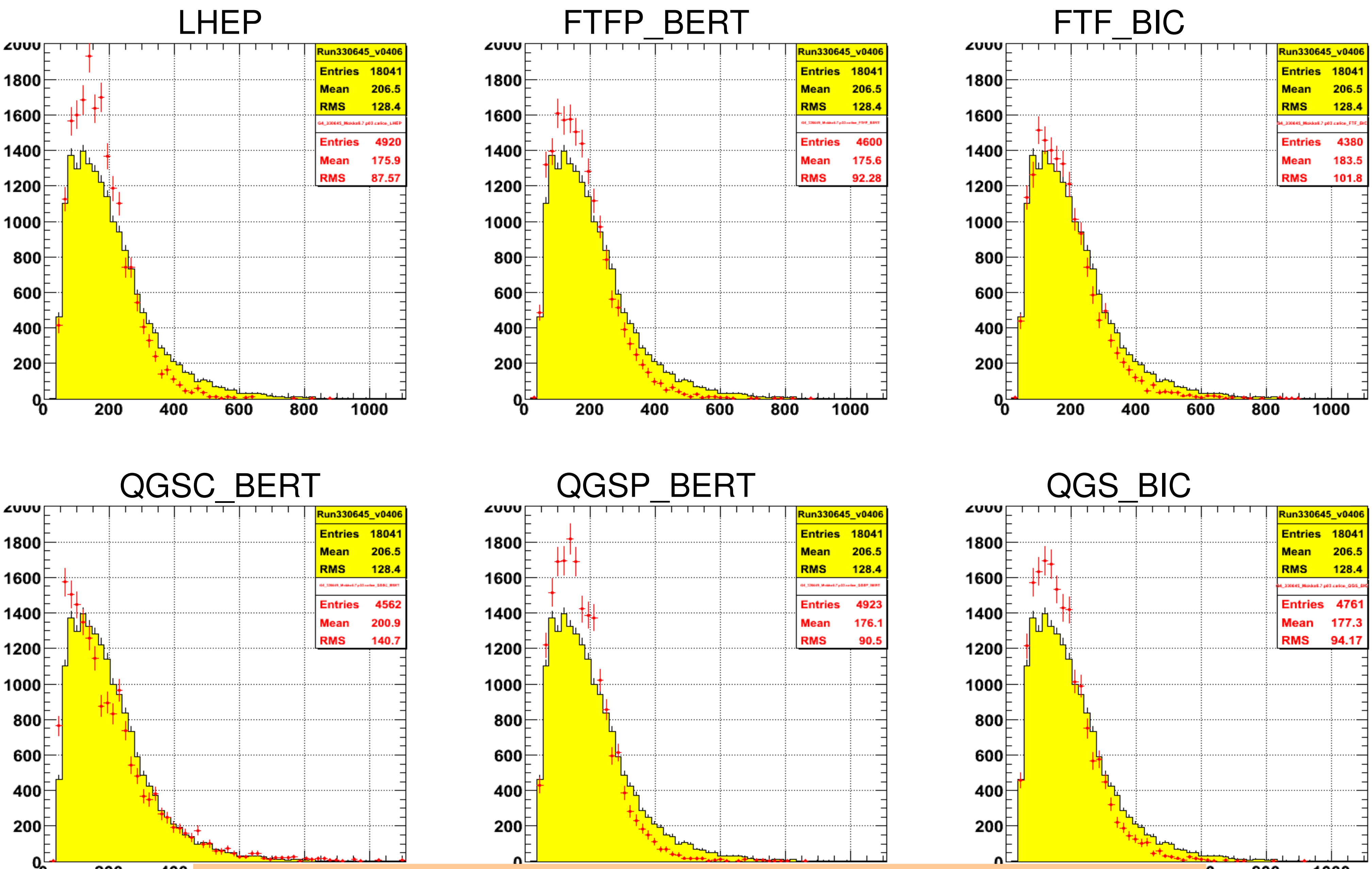
QGS_BIC



FTF_BIC best? QGSC shows good tail, but not the peak

Shower energies (first 5 layers) – -12GeV

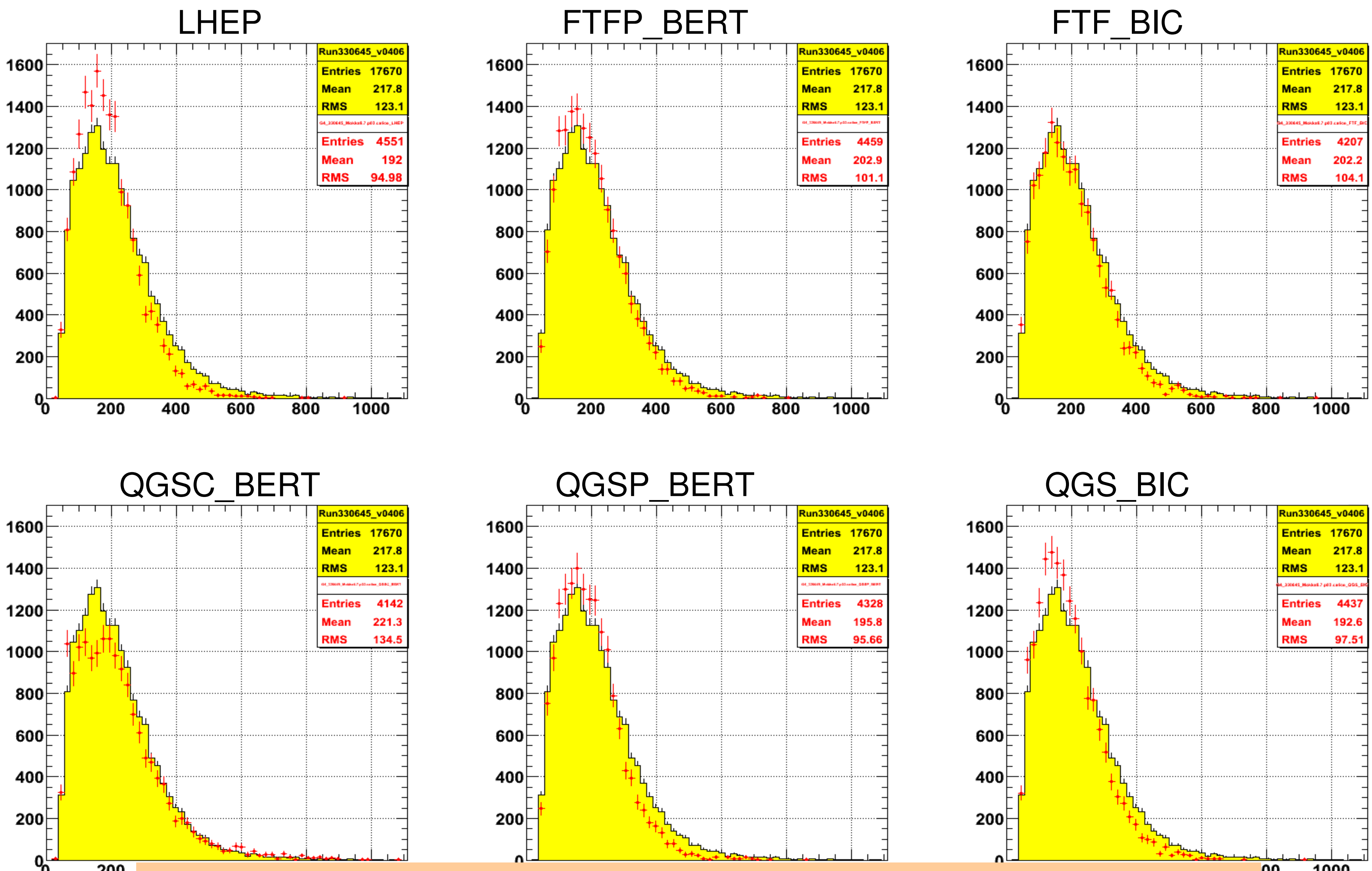
(normalised to number of events) (10< interaction layer <16)



FTF_BIC and QGSC_BERT still the best

Shower energies (first 5 layers) – -12GeV

(normalised to number of events) (20< interaction layer <26)

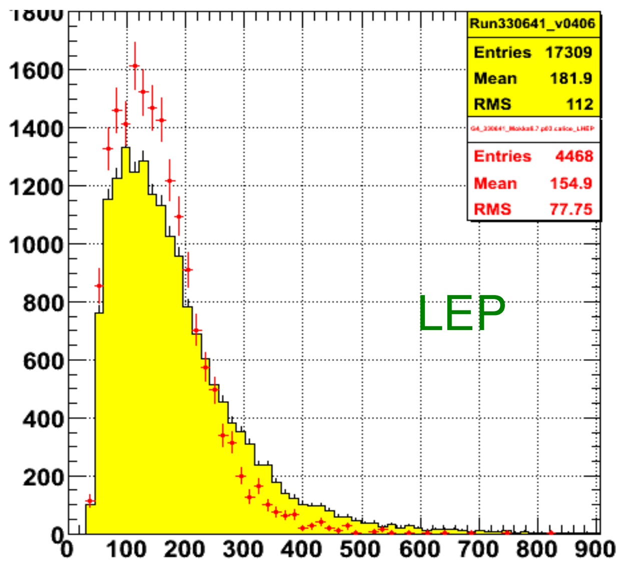


FTFs shows good agreement. QGSC_BERT predicts tail well. LHEP worst?

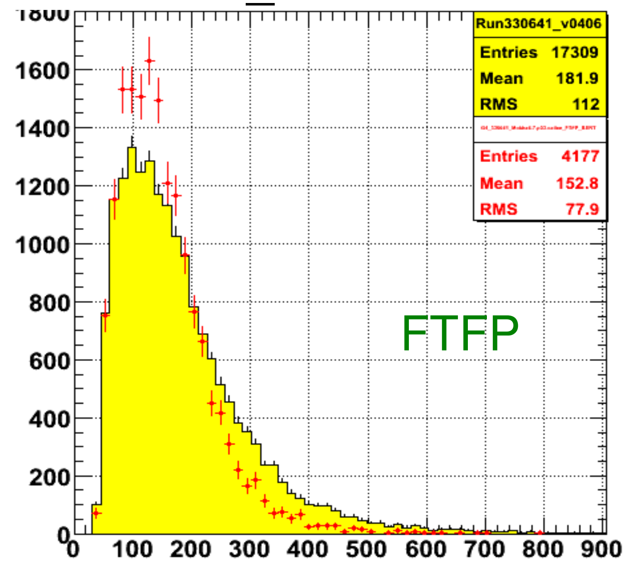
Shower energies (first 5 layers) – -8GeV

(normalised to number of events) (10< interaction layer <16)

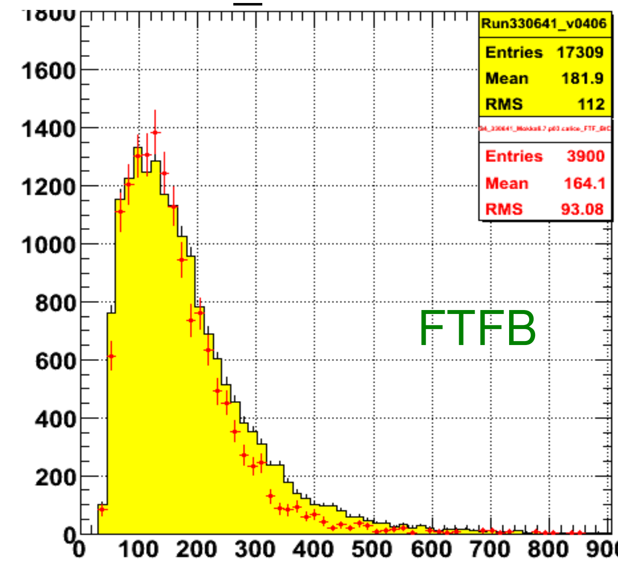
LHEP



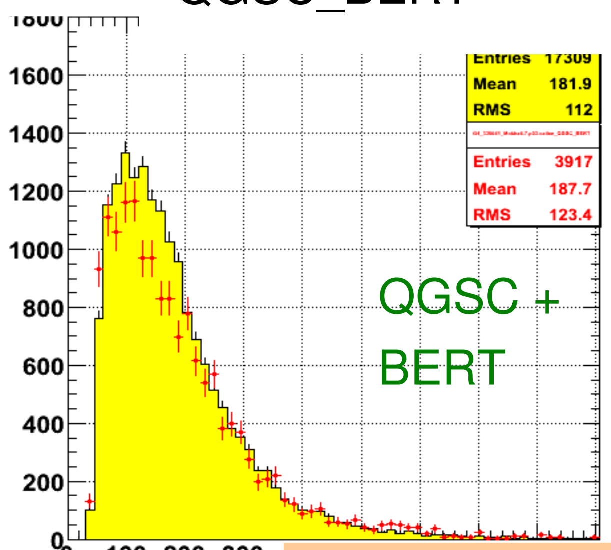
FTFP_BERT



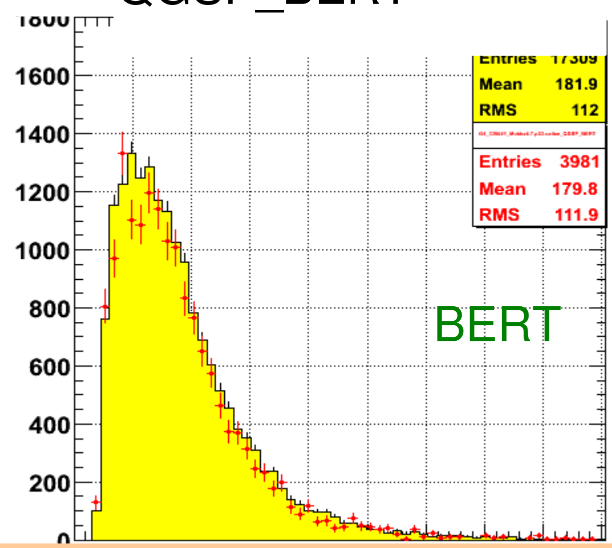
FTF_BIC



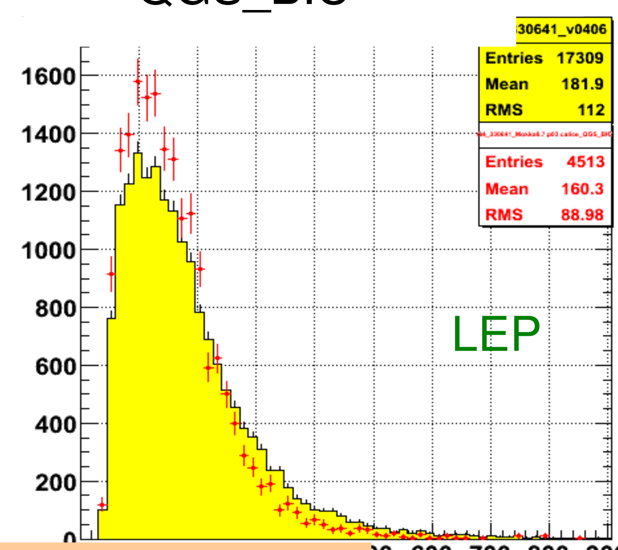
QGSC_BERT



QGSP_BERT



QGS_BIC

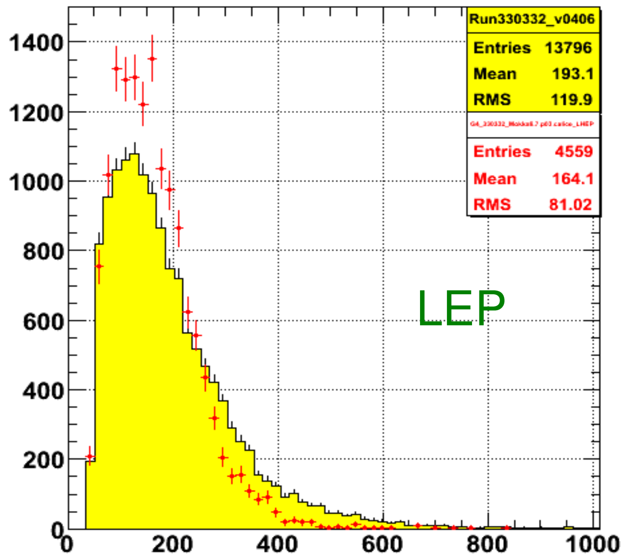


BERT gives good tails? FTFB best at predicting peak.

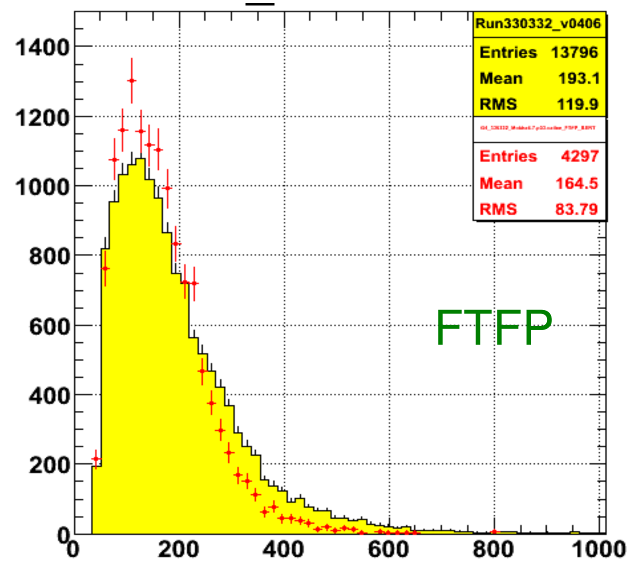
Shower energies (first 5 layers) – -10GeV

(normalised to number of events) (10< interaction layer <16)

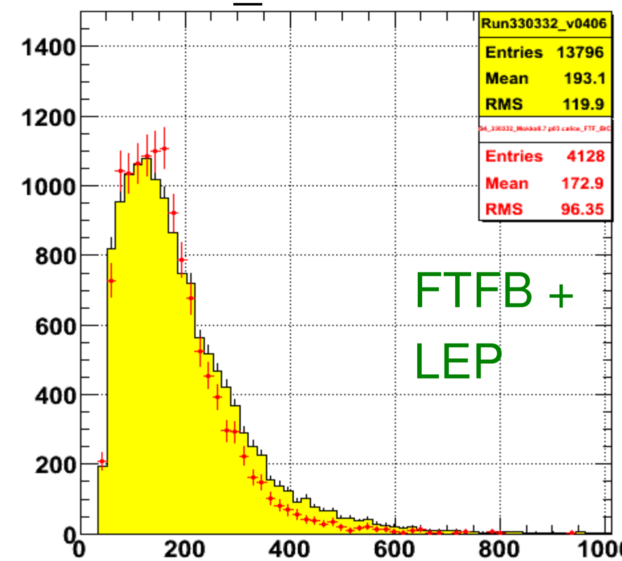
LHEP



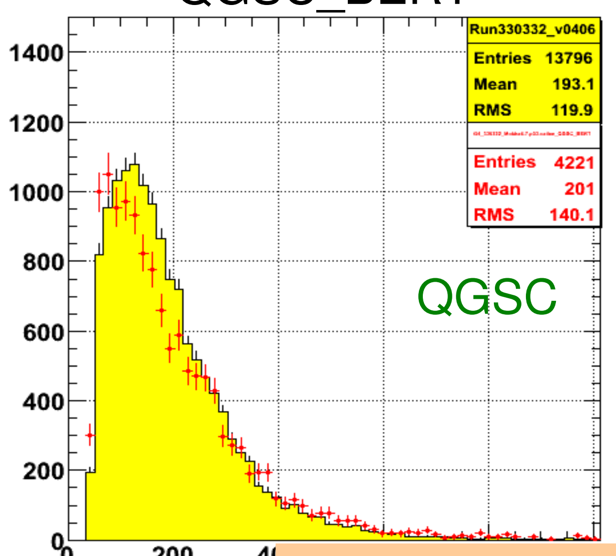
FTFP_BERT



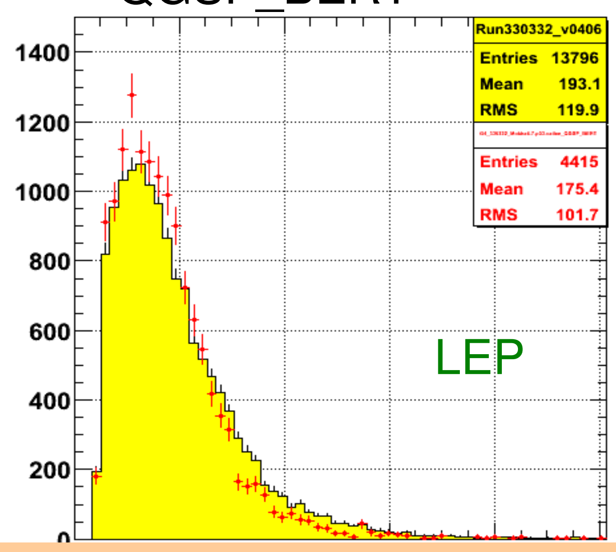
FTF_BIC



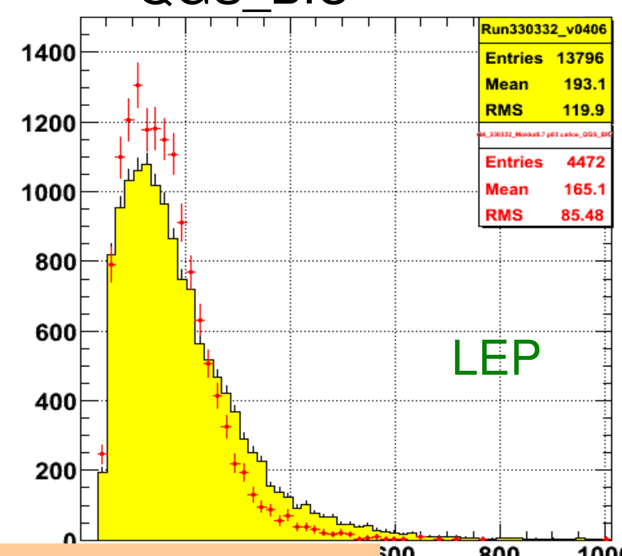
QGSC_BERT



QGSP_BERT



QGS_BIC

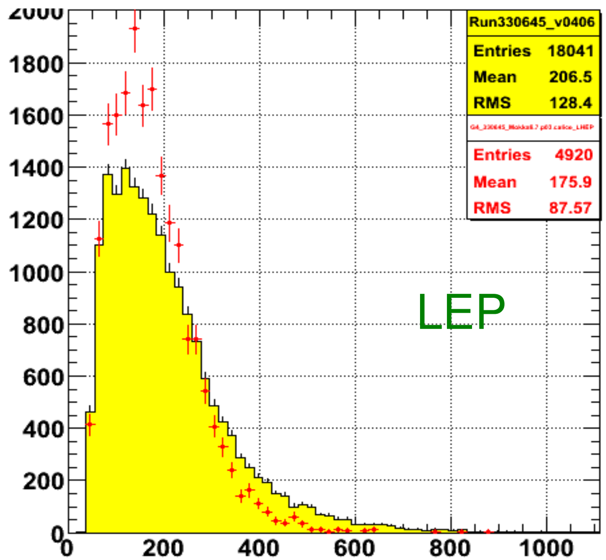


Significant difference in physicslists with LEP. QGSC gives good tail.

Shower energies (first 5 layers) – -12GeV

(normalised to number of events) (10< interaction layer <16)

LHEP



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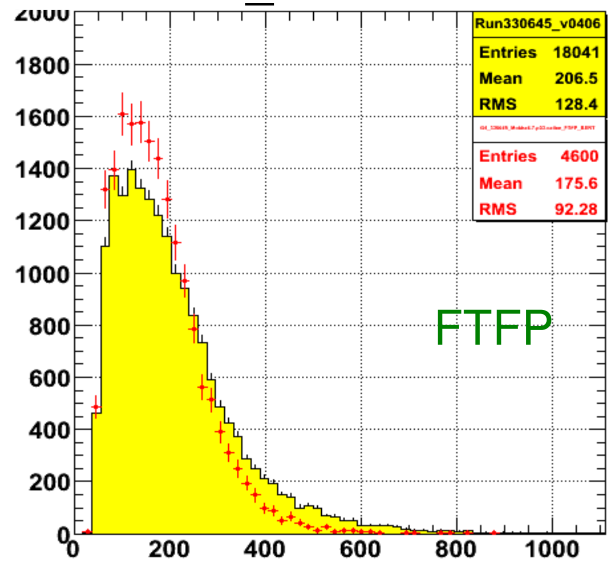

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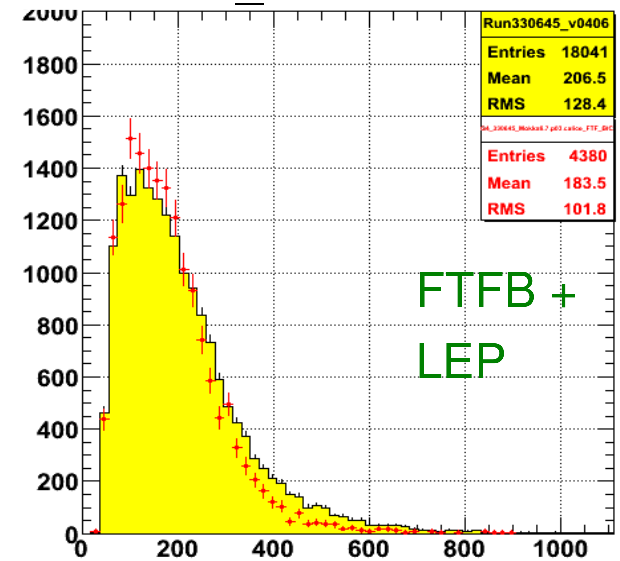
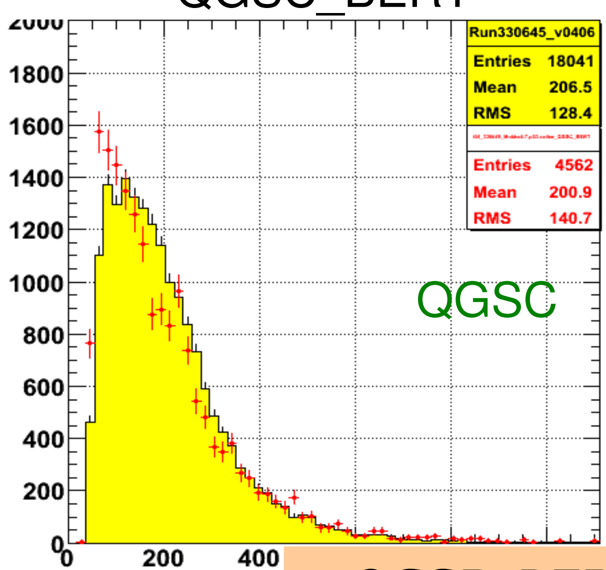
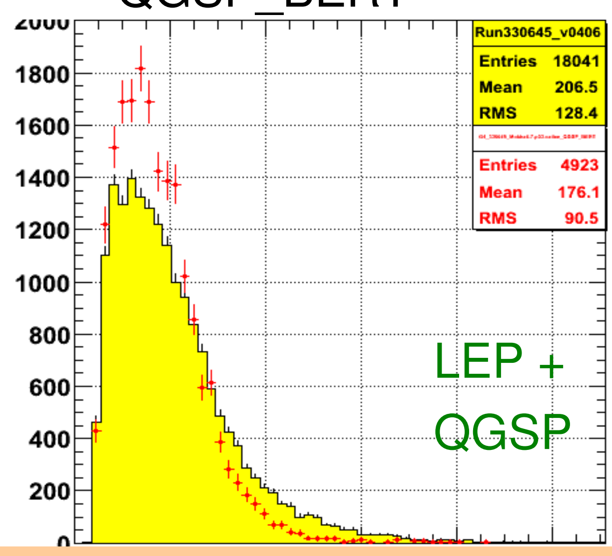


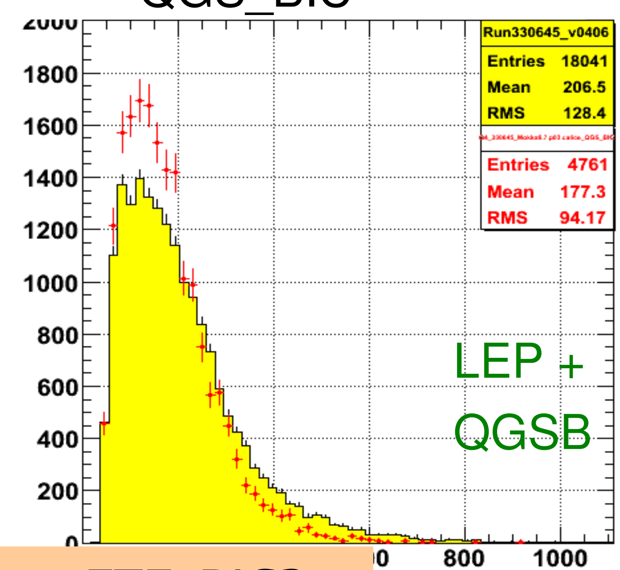
QGSC_BERT



QGSP_BERT



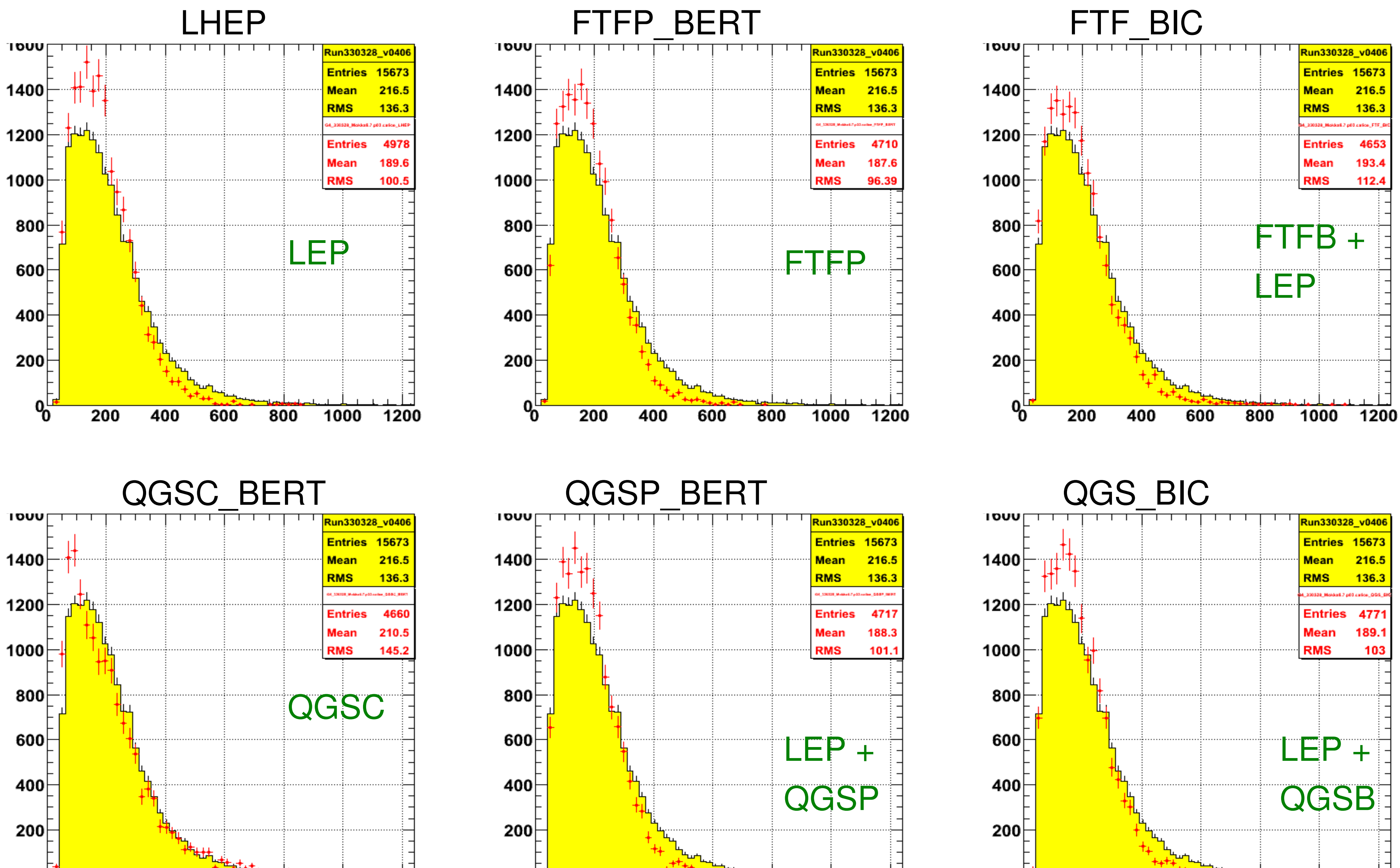
QGS_BIC



QGSP_BERT gets worse. QGSC_BERT better than FTF_BIC?

Shower energies (first 5 layers) – -15GeV

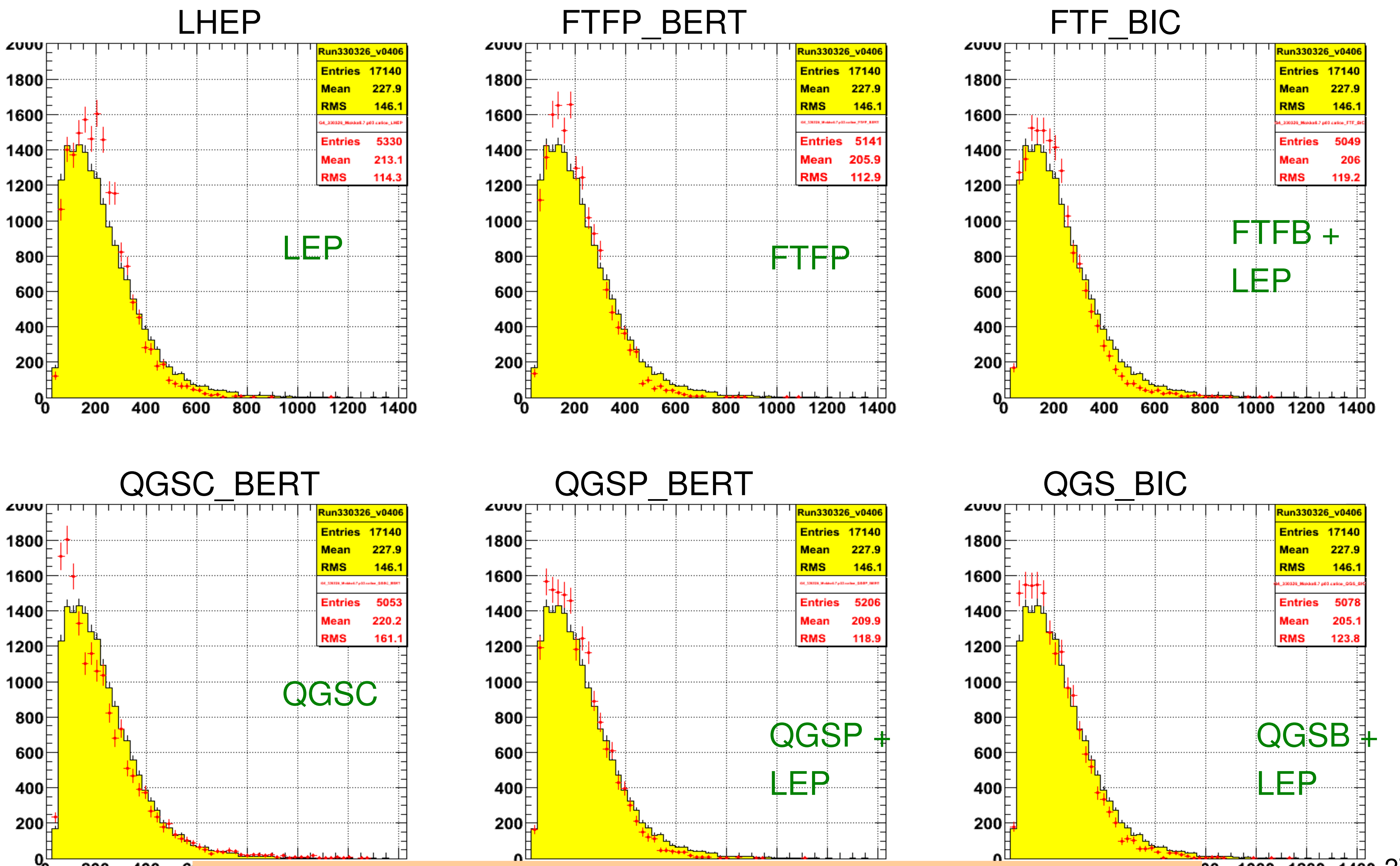
(normalised to number of events) (10< interaction layer <16)



QGSC_BERT and FTF_BIC. But their peak shapes are clearly different

Shower energies (first 5 layers) – -20GeV

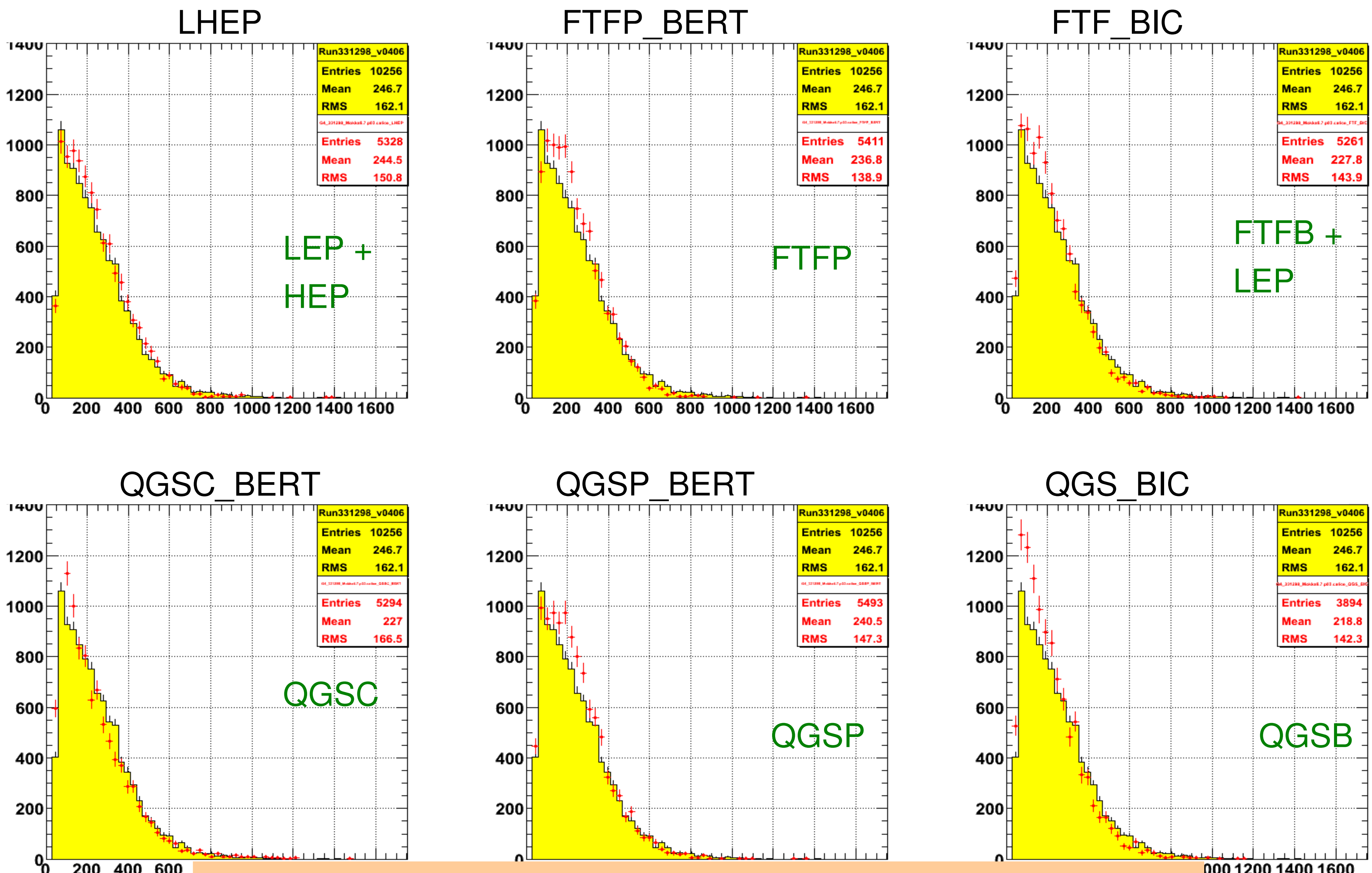
(normalised to number of events) (10< interaction layer <16)



Suddenly tails of all physicslists are better.

Shower energies (first 5 layers) – +30GeV

(normalised to number of events) (10< interaction layer <16)

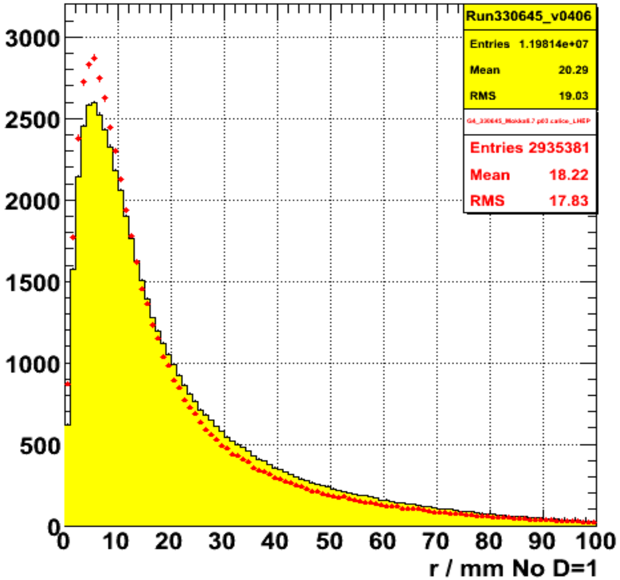


All shows reasonable agreement. QGS_BIC worst on the peak.

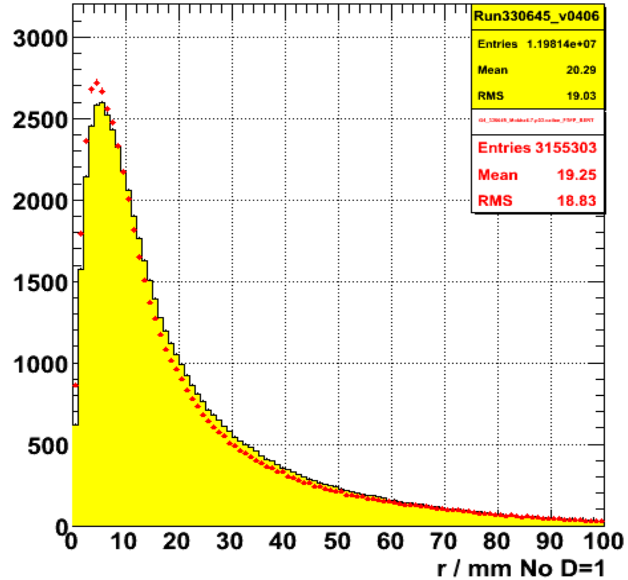
Transverse energy distribution – -12GeV

(Normalised to number of hits)

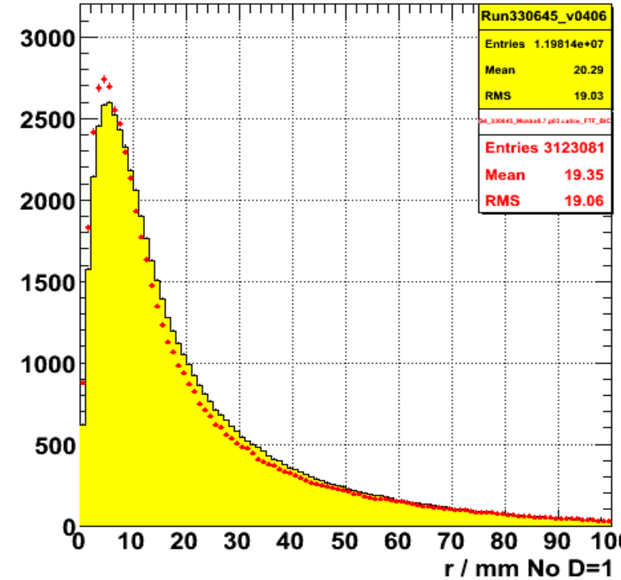
LHEP



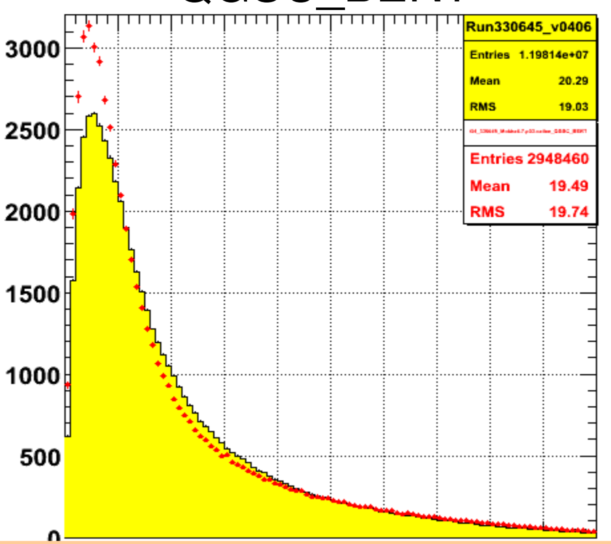
FTFP_BERT



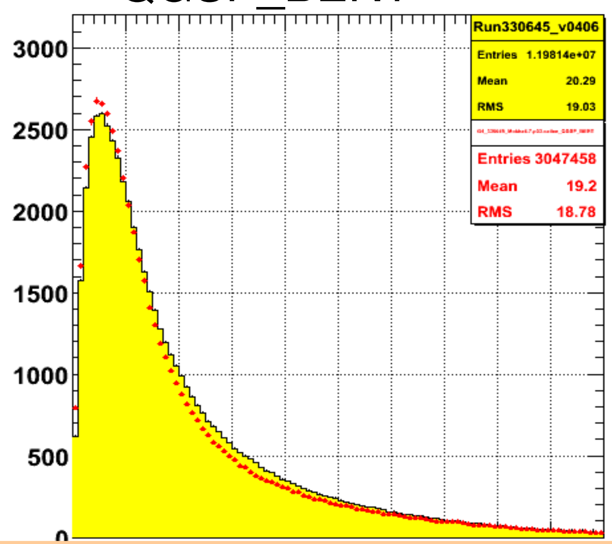
FTF_BIC



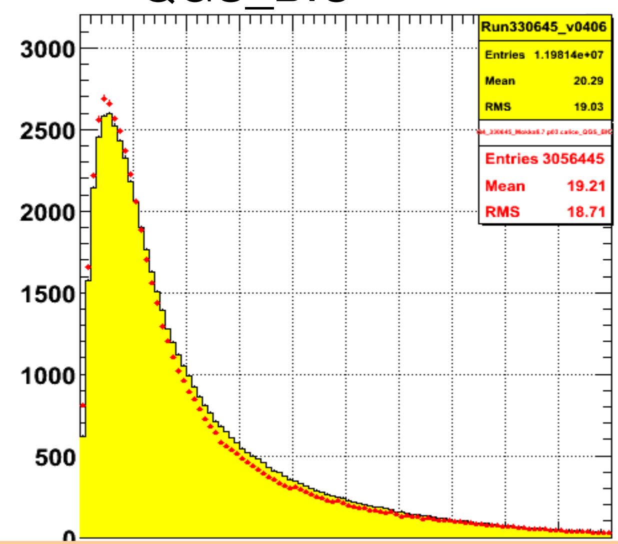
QGSC_BERT



QGSP_BERT



QGS_BIC

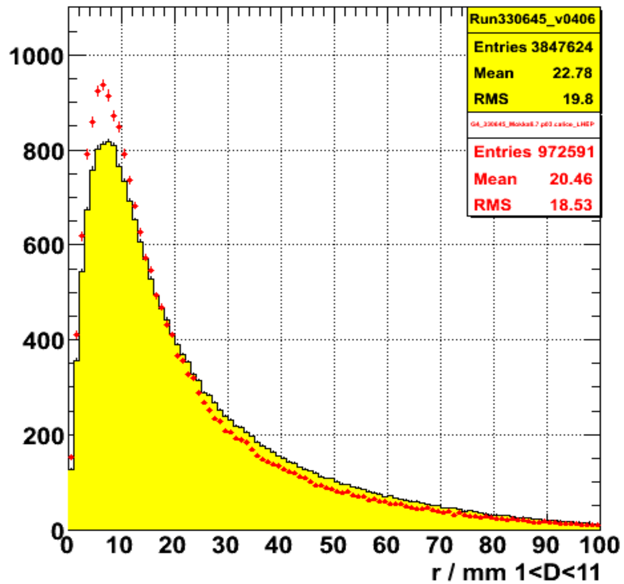


All physics lists predict narrower shower. QGSP_BERT and QGS_BIC agrees well on the peak

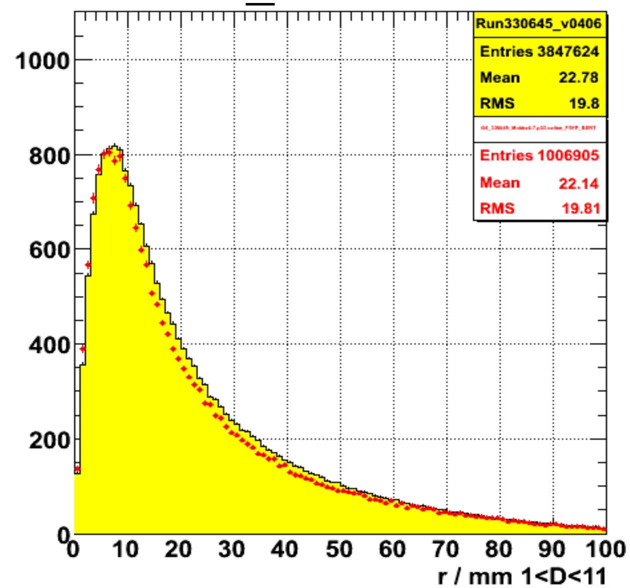
Transverse energy distribution – -12GeV

(Normalised to number of hits) (1< interaction layer <11)

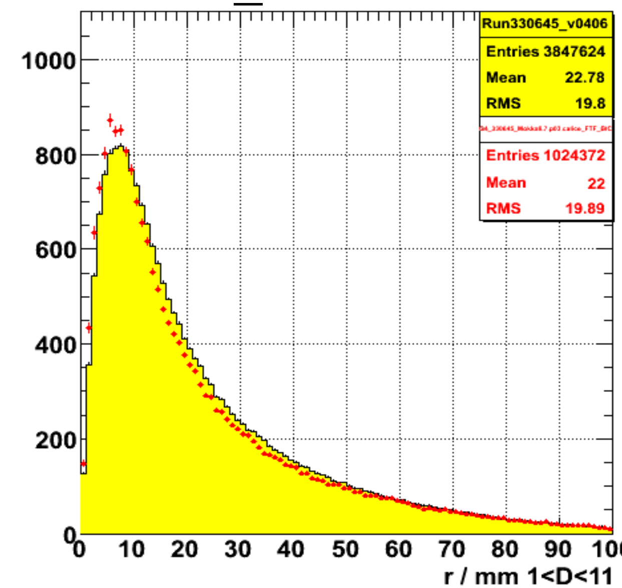
LHEP



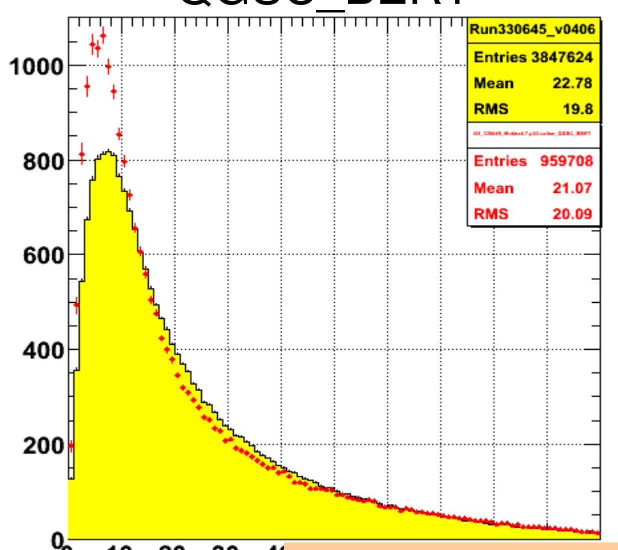
FTFP_BERT



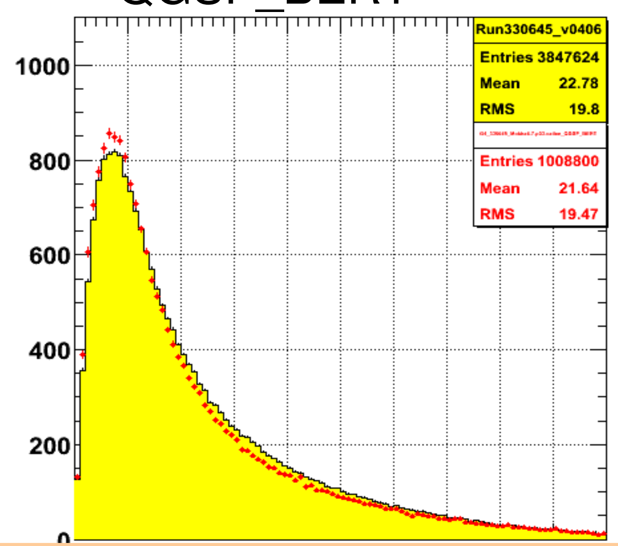
FTF_BIC



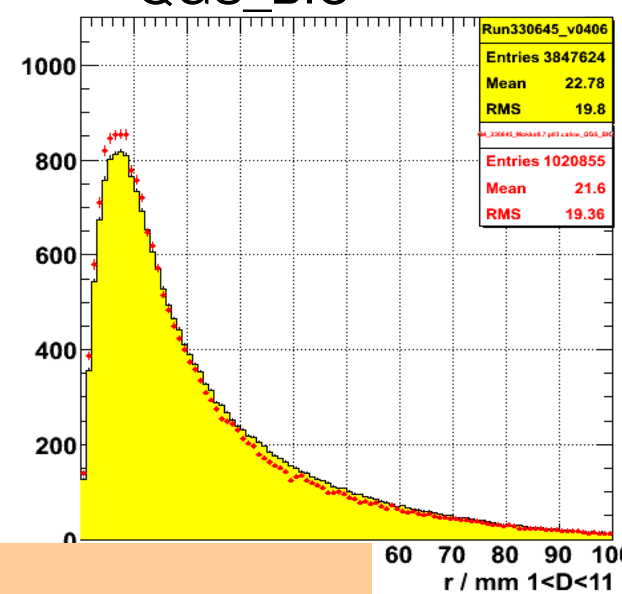
QGSC_BERT



QGSP_BERT



QGS_BIC

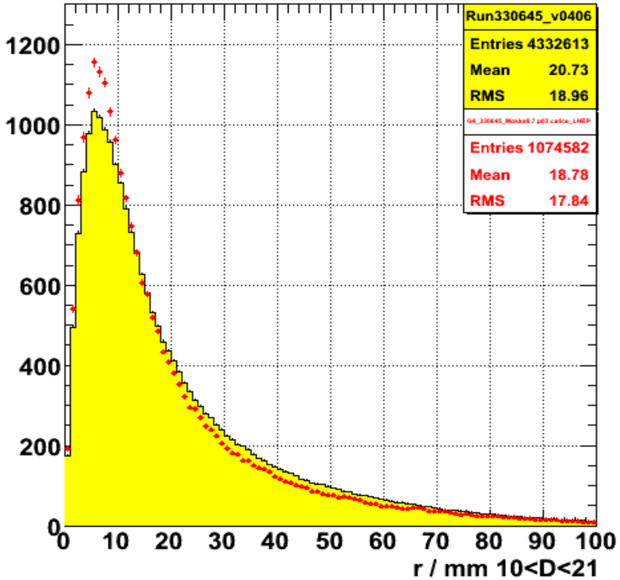


LHEP and QGSC_BERT worst.

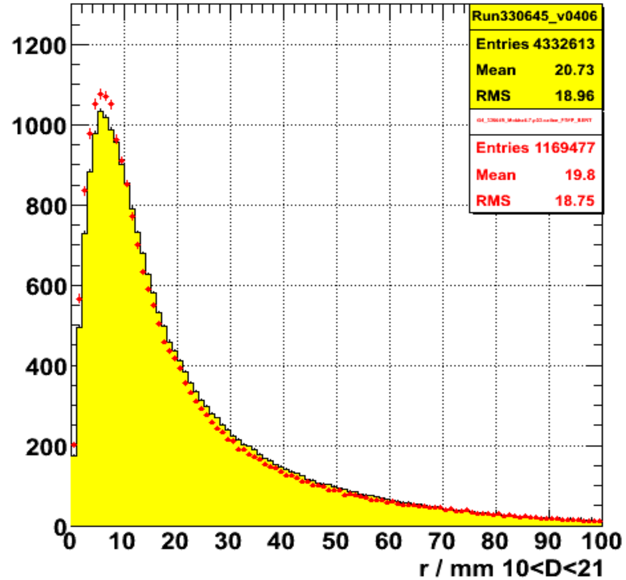
Transverse energy distribution – -12GeV

(Normalised to number of hits) (10< interaction layer <21)

LHEP



FTFP_BERT



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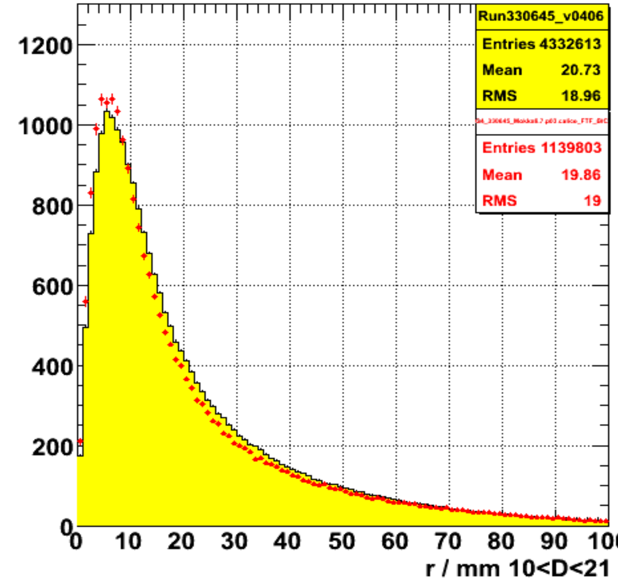
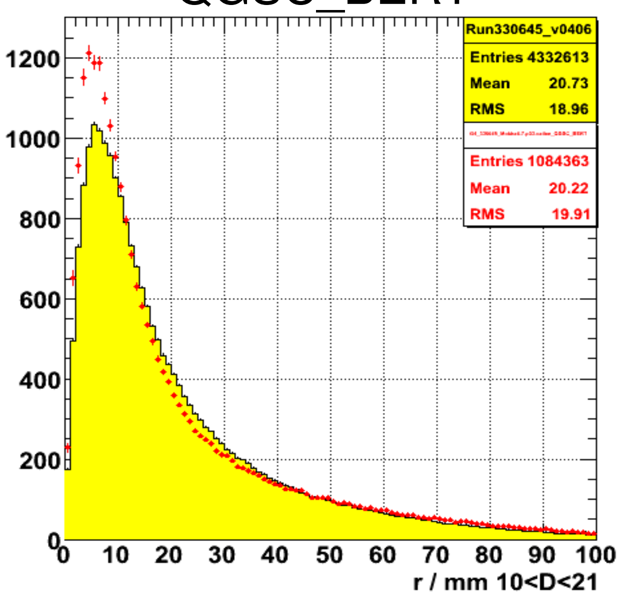
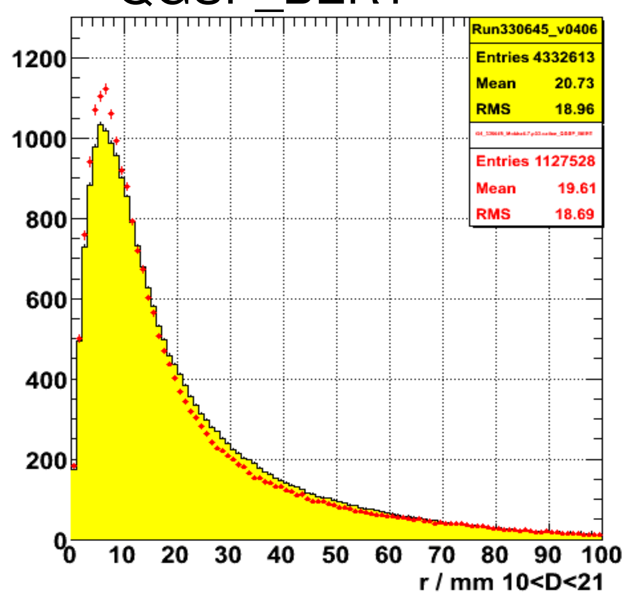


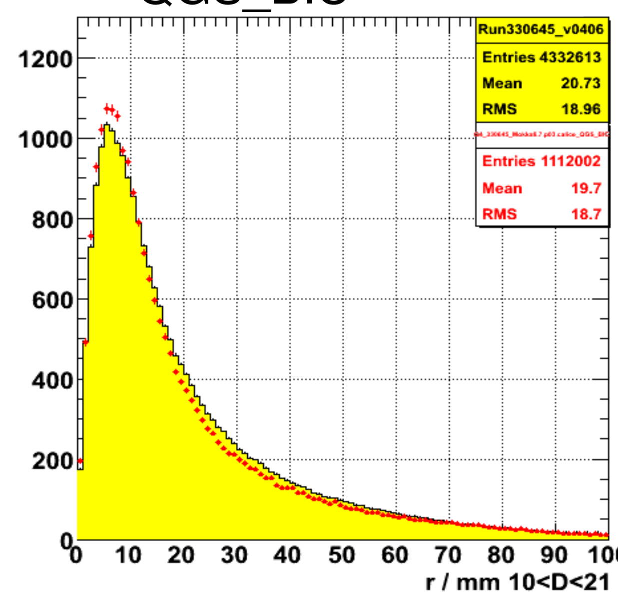
QGSC_BERT



QGSP_BERT

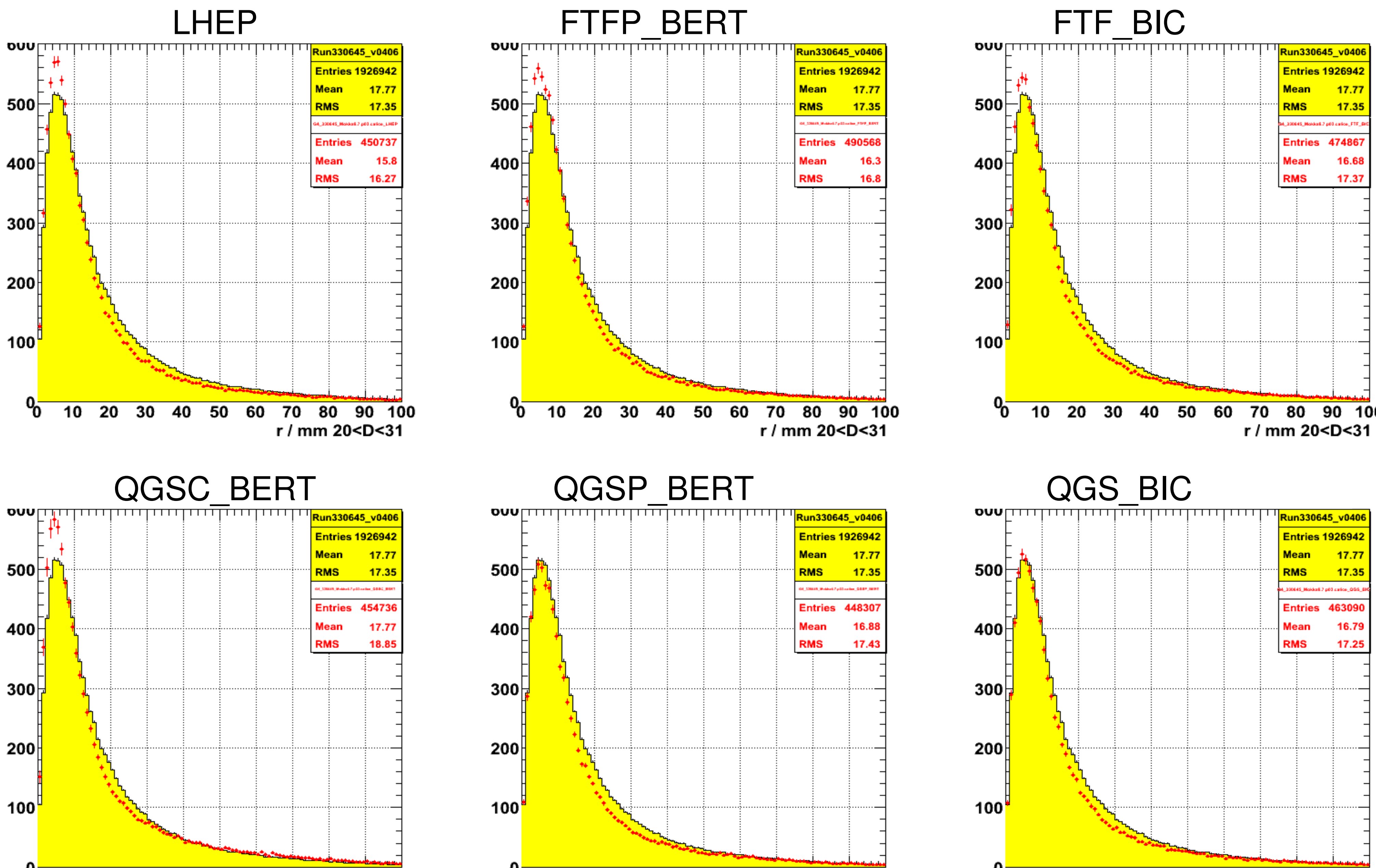


QGS_BIC



Transverse energy distribution – -12GeV

(Normalised to number of hits) (20< interaction layer <31)

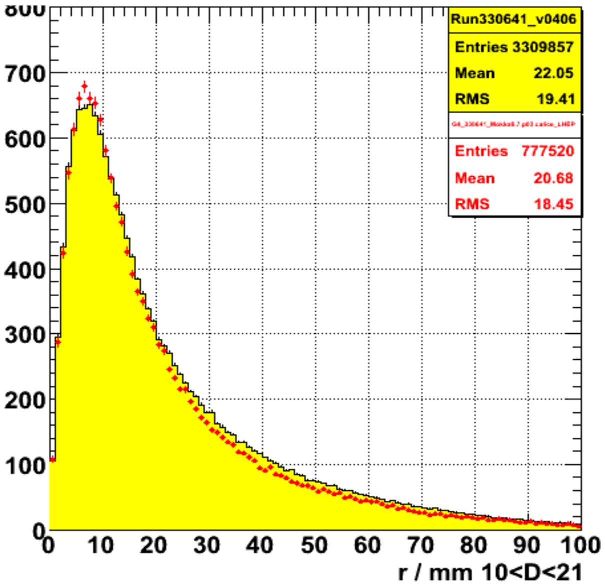


Shower narrowing with depth shown with all physicslists.

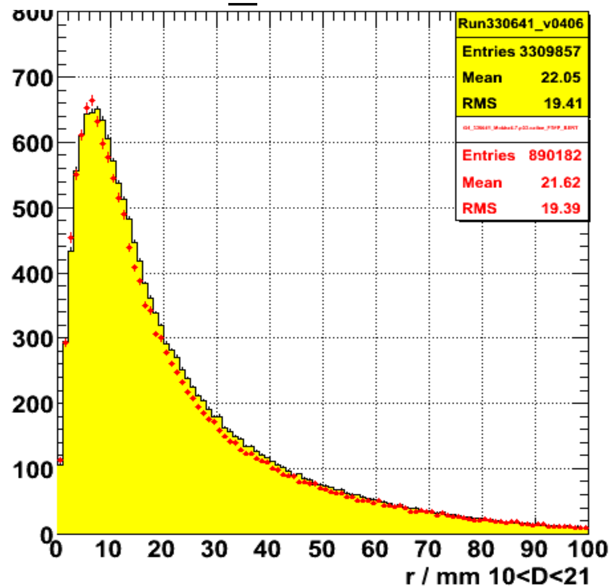
Transverse energy distribution – -8GeV

(Normalised to number of hits) (10< interaction layer <21)

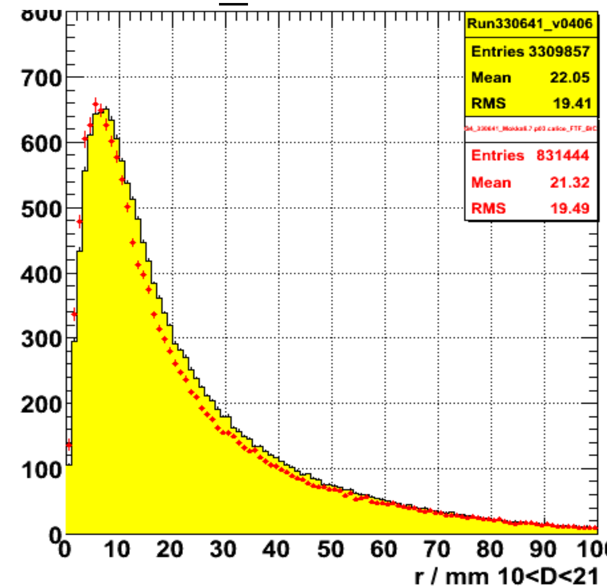
LHEP



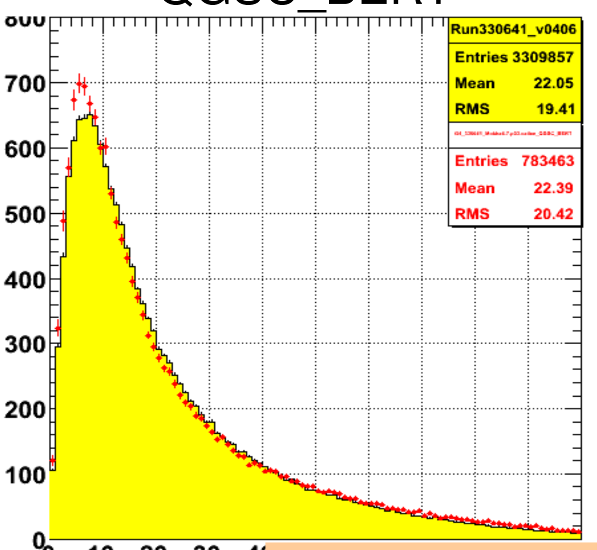
FTFP_BERT



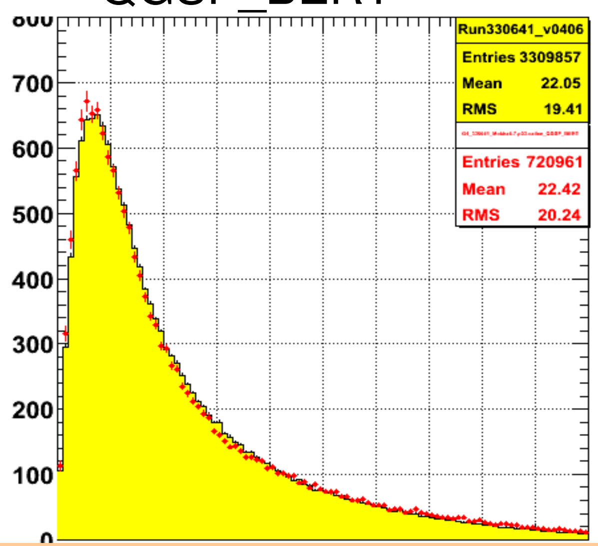
FTF_BIC



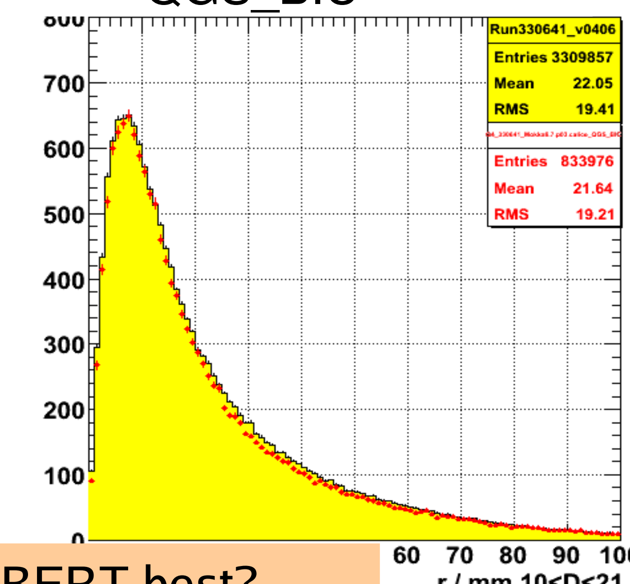
QGSC_BERT



QGSP_BERT



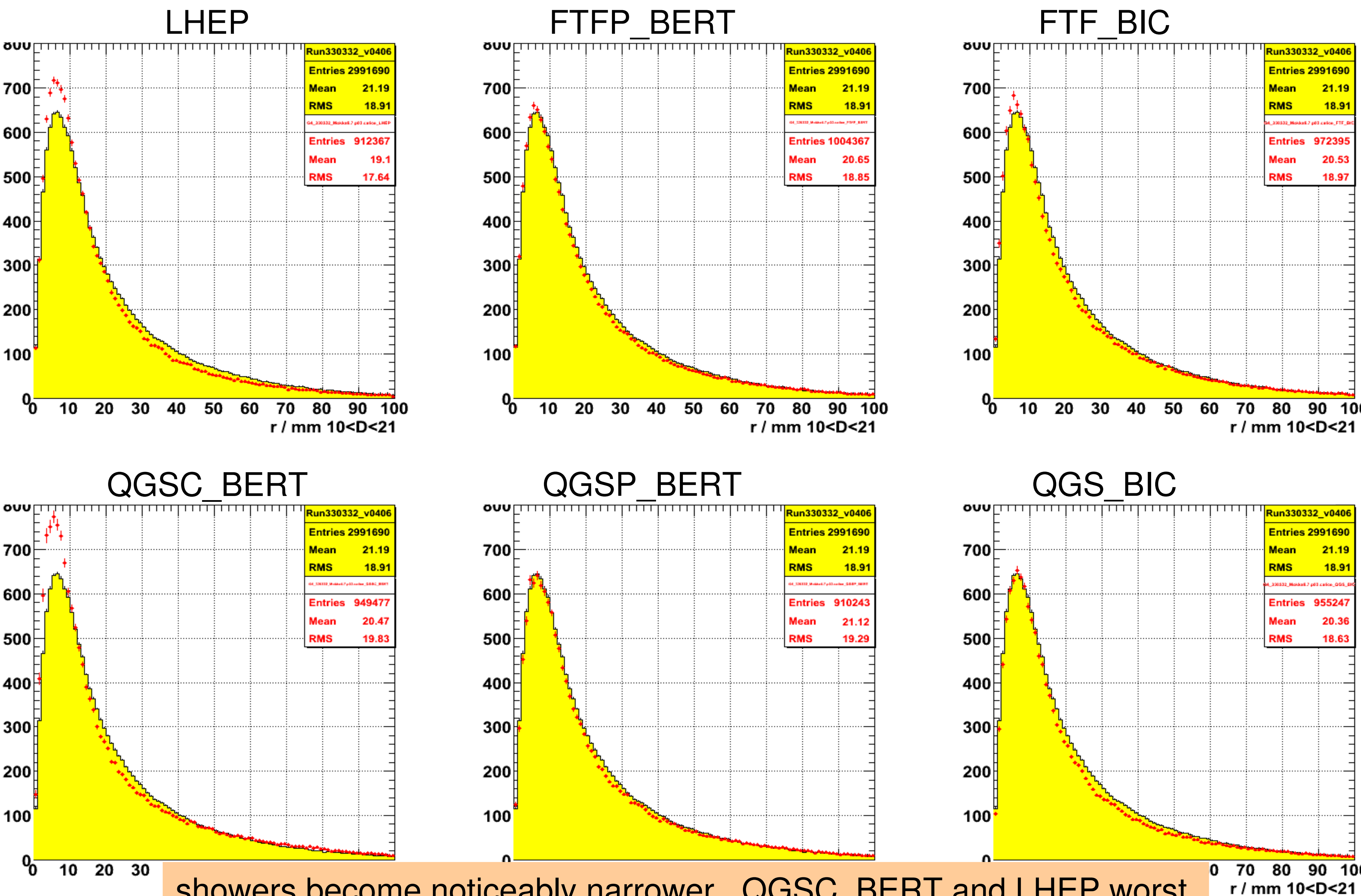
QGS_BIC



QGSs show good agreements on tail. QGSP_BERT best?

Transverse energy distribution – -10GeV

(Normalised to number of hits) (10< interaction layer <21)

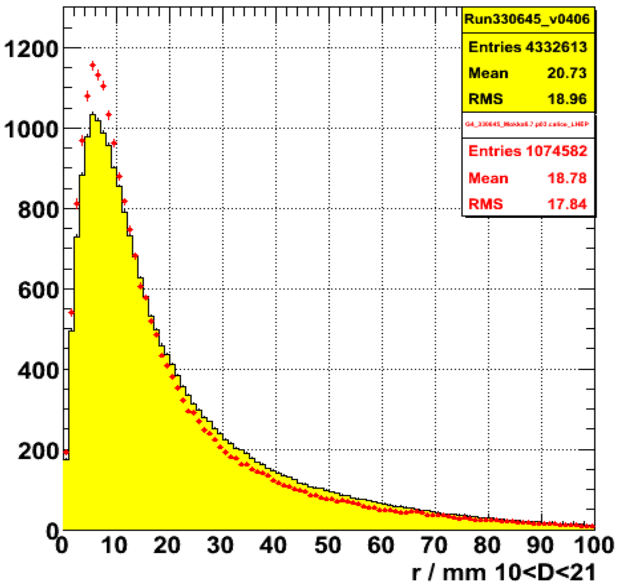


showers become noticeably narrower. QGSC_BERT and LHEP worst.

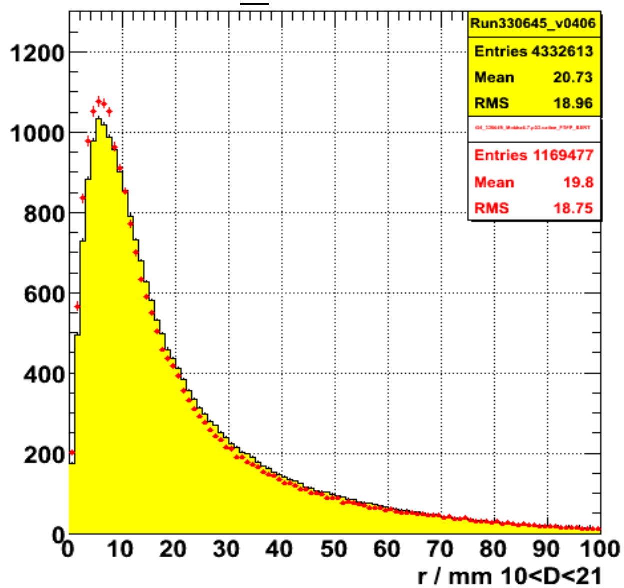
Transverse energy distribution – -12GeV

(Normalised to number of hits) (10< interaction layer <21)

LHEP



FTFP_BERT



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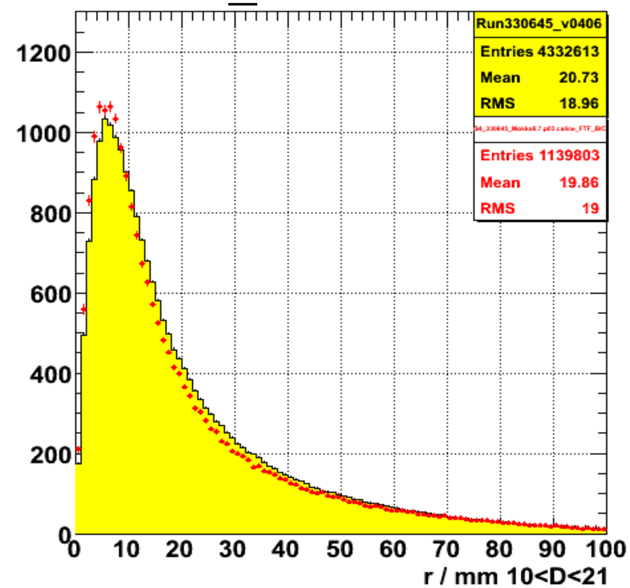
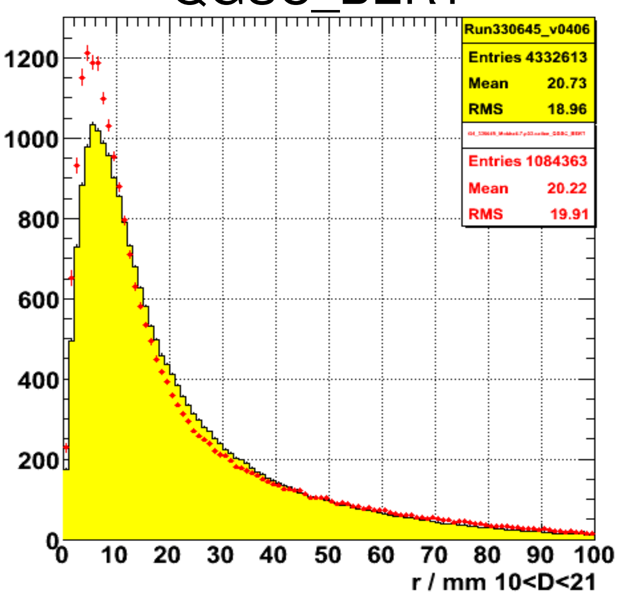
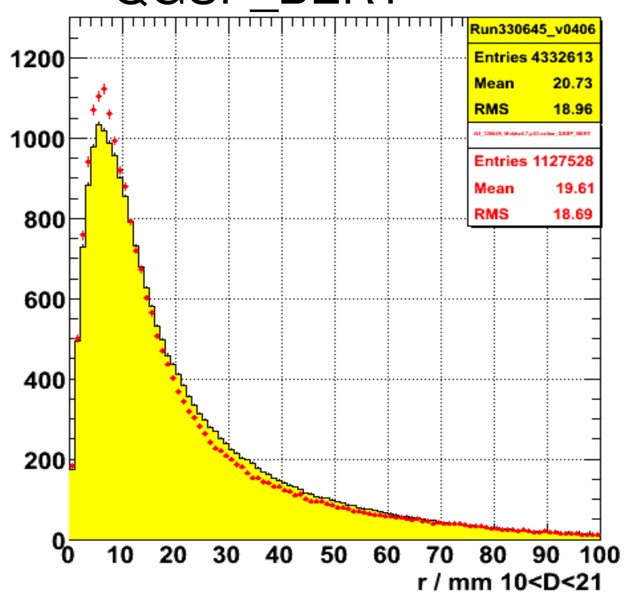


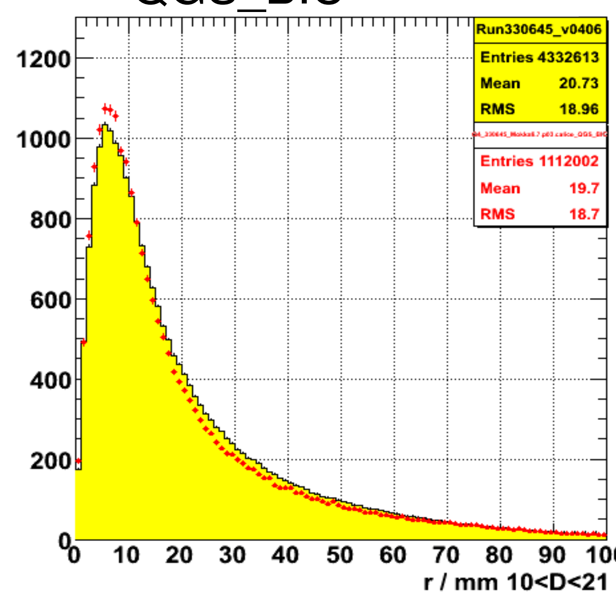
QGSC_BERT



QGSP_BERT



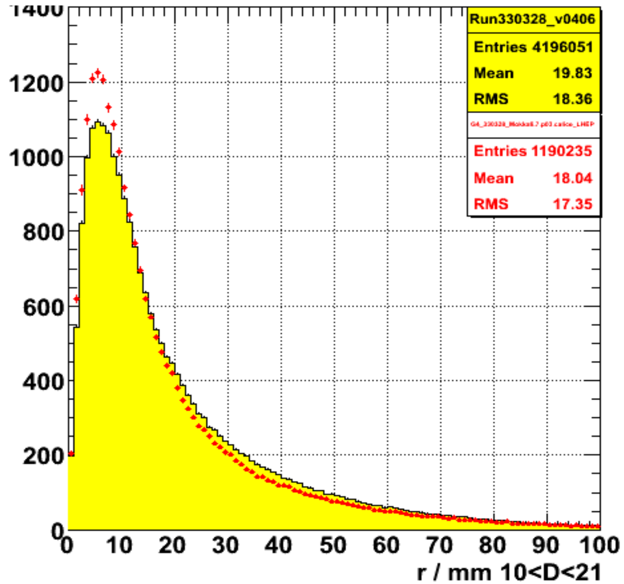
QGS_BIC



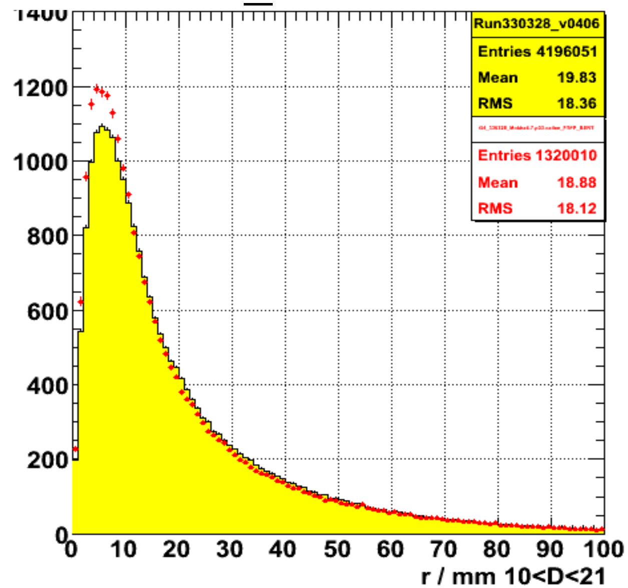
Transverse energy distribution – -15GeV

(Normalised to number of hits) (10< interaction layer <21)

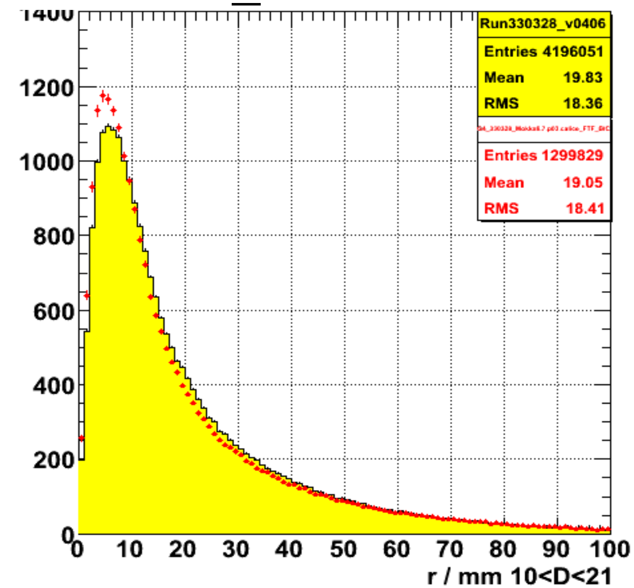
LHEP



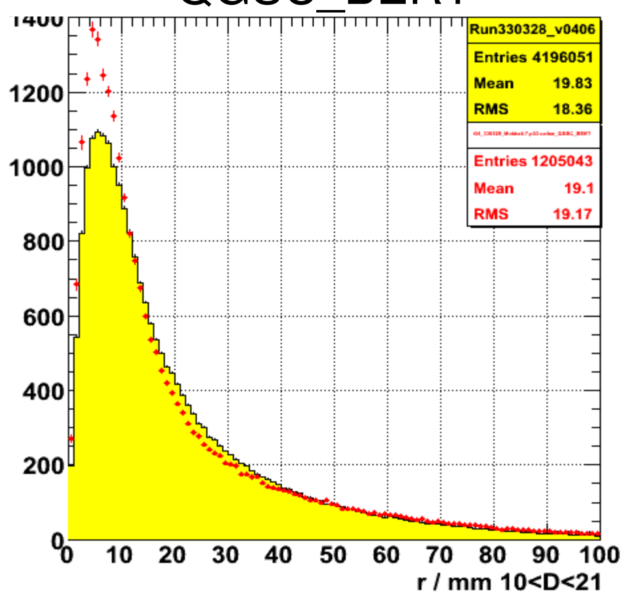
FTFP_BERT



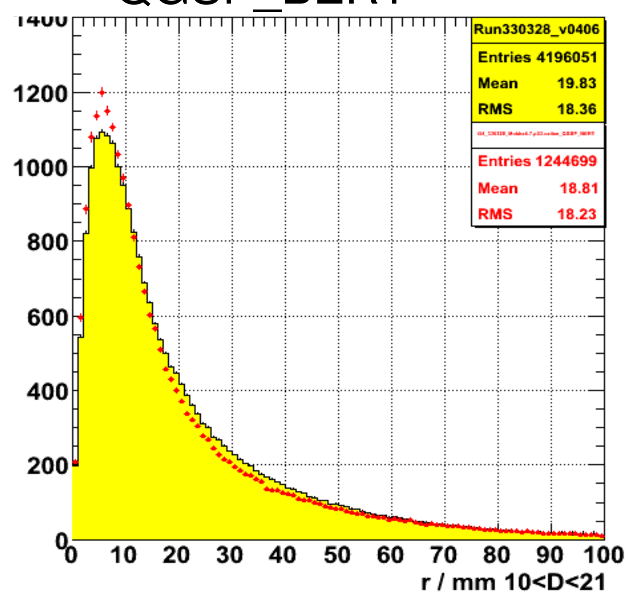
FTF_BIC



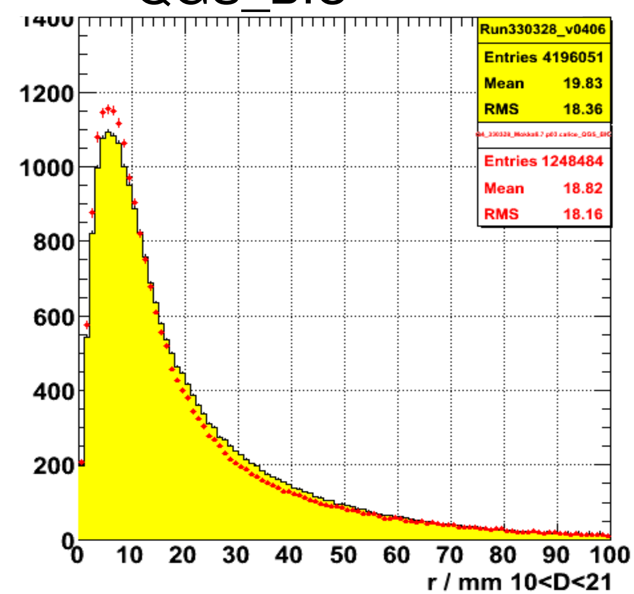
QGSC_BERT



QGSP_BERT



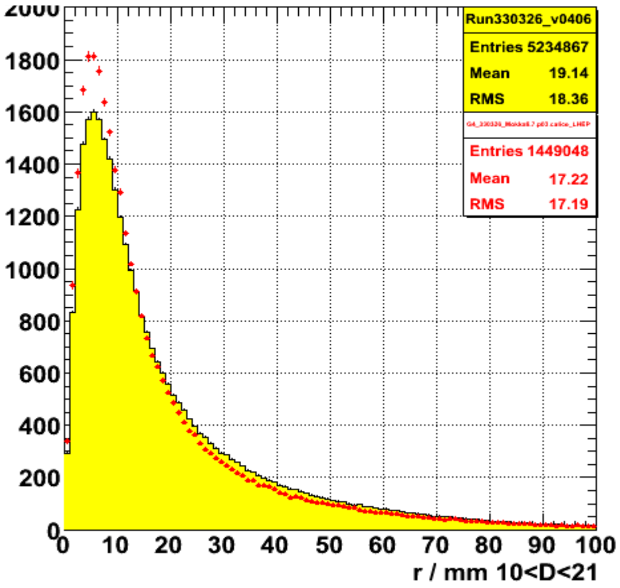
QGS_BIC



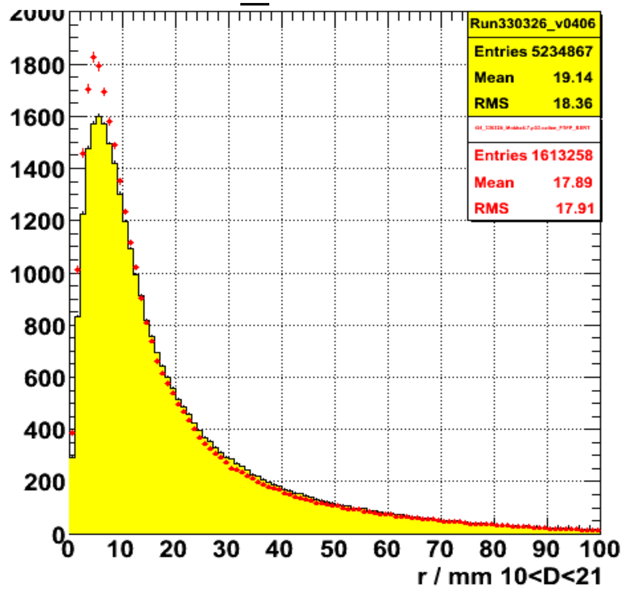
Transverse energy distribution – -20GeV

(Normalised to number of hits) (10< interaction layer <21)

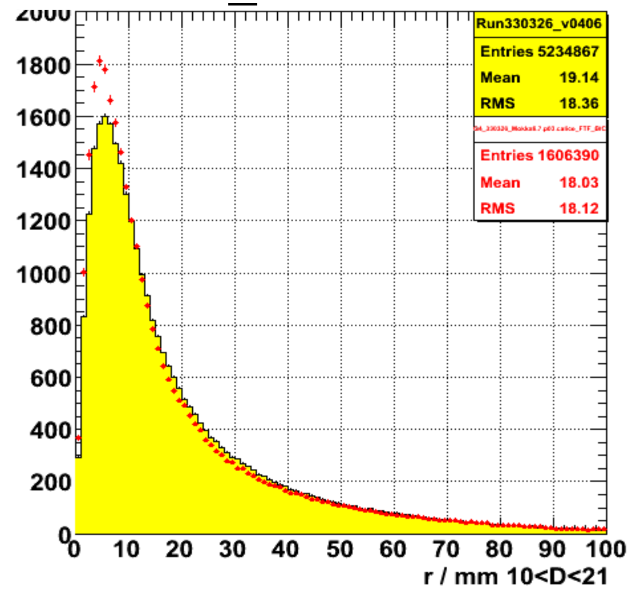
LHEP



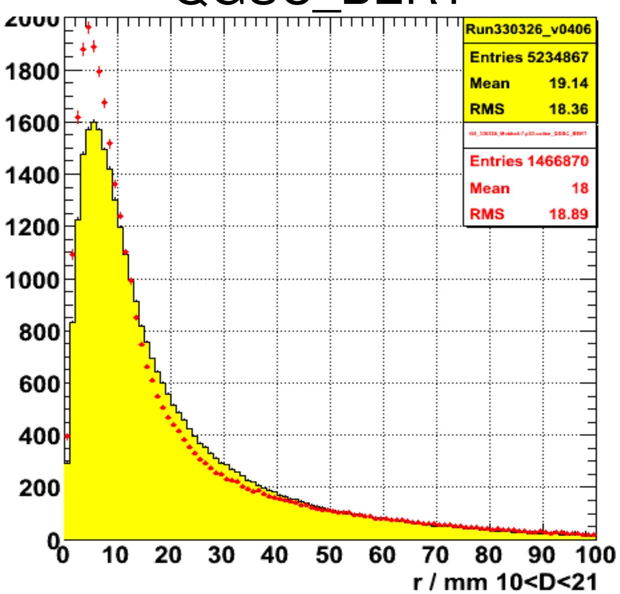
FTFP_BERT



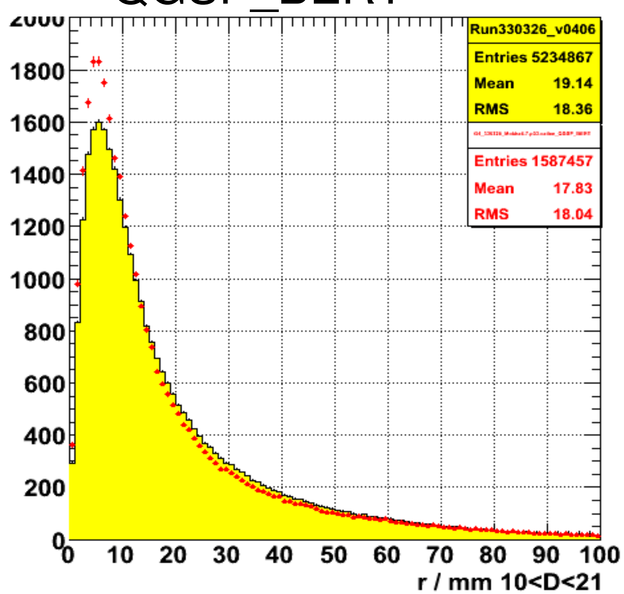
FTF_BIC



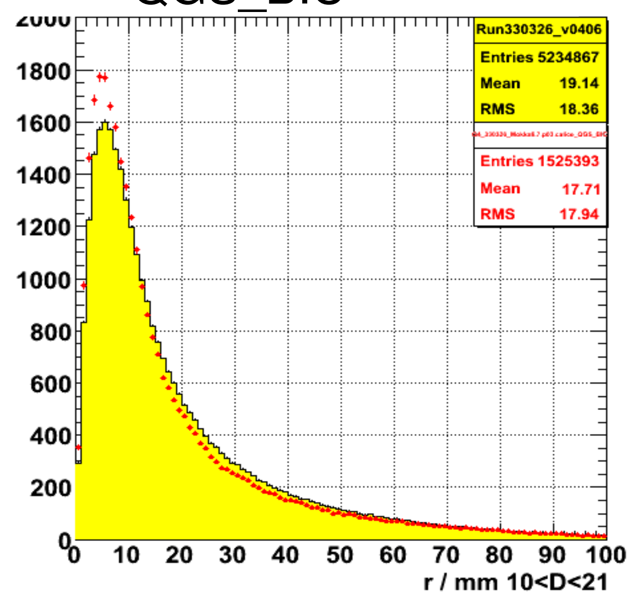
QGSC_BERT



QGSP_BERT

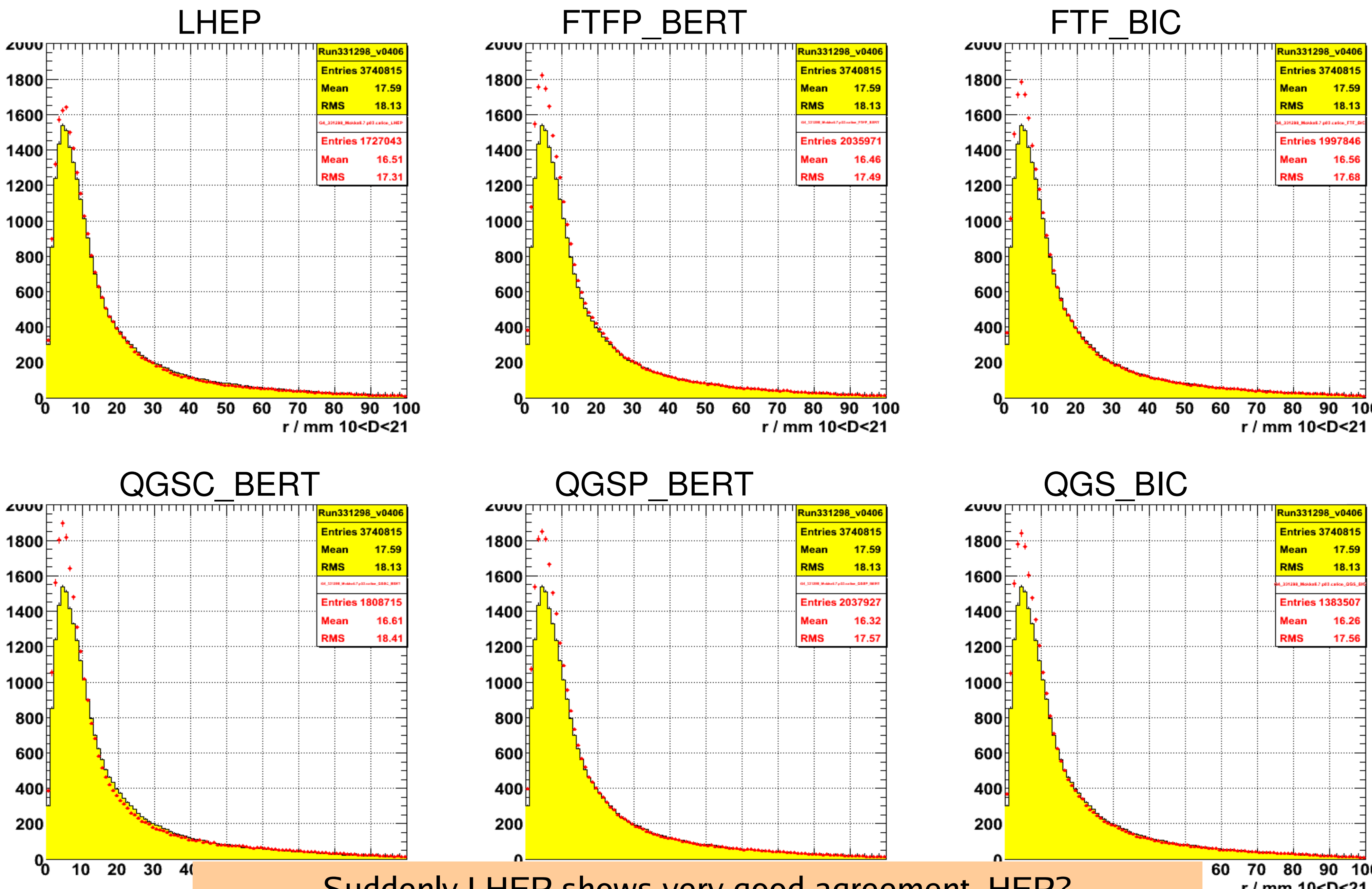


QGS_BIC



Transverse energy distribution – +30GeV

(Normalised to number of hits) (10< interaction layer <21)



Suddenly LHEP shows very good agreement. HEP?

Summary

- Total energy in ECAL – No physics list fits all the data. Difficult to interpret, because of the use of different models at different energies within the physics list.

  –> Motivates looking at observables which focus on primary interaction properties, such as:

- Energy in first 5 layers after the first interaction – BERT looks good at 8 GeV, several models are quite good at 30GeV, but none of them is really good in the 10-15 GeV region. QGSC best here?

  Probably wise to look at energy levels below 8GeV, 4GeV for example to see the effect of Binary Cascade model (BIC) which is turned on above 5 GeV for both QGS_BIC and FTF_BIC.

- Transverse Energy distribution – all physics lists tend to be narrower than the data (by few % in mean)

THE END

Simple mathematical model of first interaction layer

- Probability of interaction by particular material

$$p_m \propto w/l$$

w = width of the material

l = interaction length

- , Prob. of interaction by particular layer i

$$p_i = \Sigma(p_m)$$

summed over all material between the (i)th silicon and the previous silicon

- Probability of interaction at a particular layer i

$$P_i = p_i \prod_n (1-p_n)$$

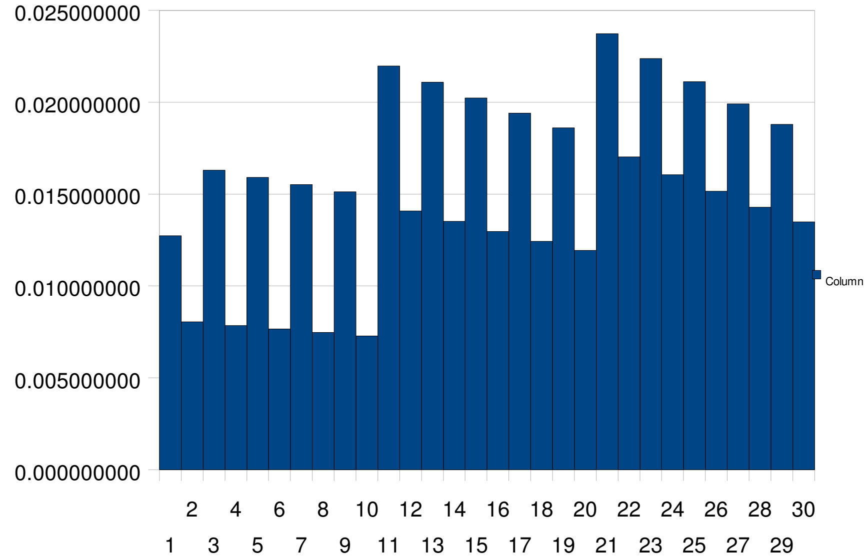
for all n in the range $0 < n < i$

.... does not include back scattering at the moment. Will be introduced later

Simple mathematical model of first interaction layer

- There is one variable, which is a proportionality constant for p_m. (0.6 is used)

- Following values for w and l of different materials are used (material = w/l).



Aluminium	= (0.1 / 388.8);
Air	= (0.575/ 701.1);
PCB	= (2.64 / 483.4);
Silicon	= (0.525/ 456);
Tungsten	= (1.4 / 103.1);
Cfib_epox	= (0.3 / 546)

Simple mathematical model of first interaction layer

- Adding backscattering

  after the interaction, particles can scatter backwards to add systematic error to true first interaction layer.

- Add a variable "backscattering probability" (value used is 0.27)

Backscattering angle is not necessarily zero relative to ECAL, hence backscattered particles are likely to deposit energy earlier.

, Higher proportionality constant for backscattered particles than input beam particles(3 is used).

- New $P_i = p_i \prod(1-p_n) + \Sigma_l(p^b_i \prod(1-p^b_m))$

  p^b = probability of interaction by backscattering

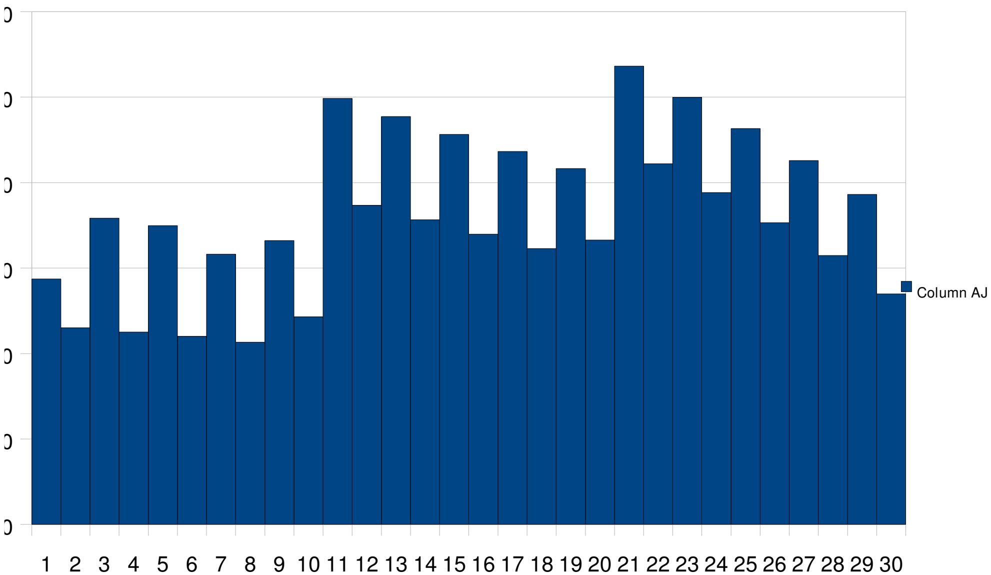
  $i < m < l$

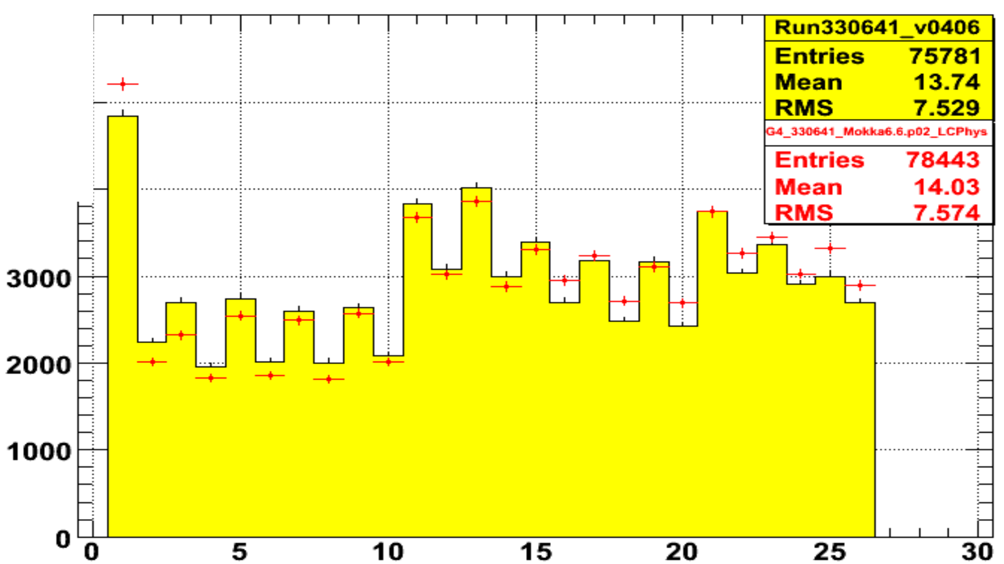
  $i < l < 31$

Simple mathematical model of first interaction layer

- Most characteristic common in all energy are reproduced.
- Followings are not reproduced;

1. Large bin in 1st layer
2. Slightly smaller bin in 11th layer
3. From 21st layer, amplitude of oscillation gradually decreases

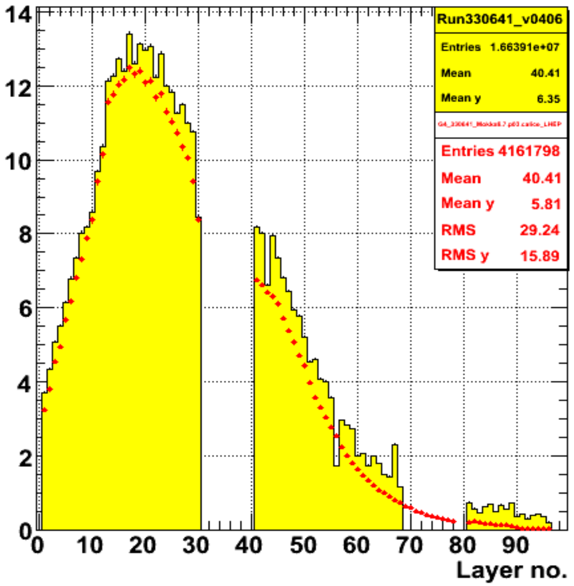




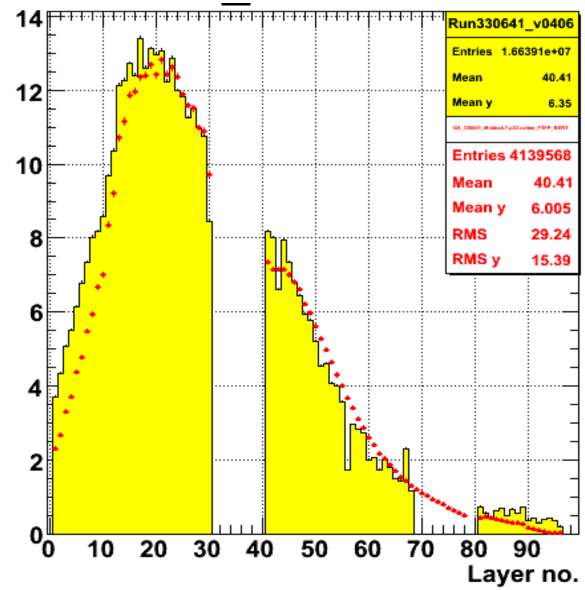
Longitudinal energy distribution – -8GeV

(TProfile – average taken at every bin hence not normalised)

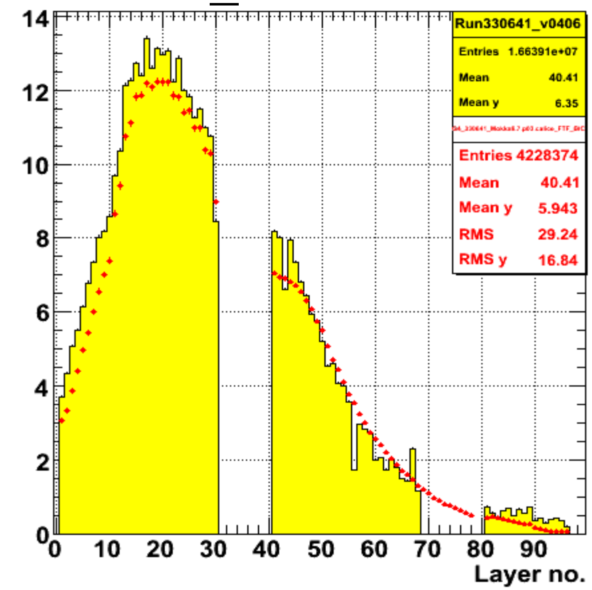
LHEP



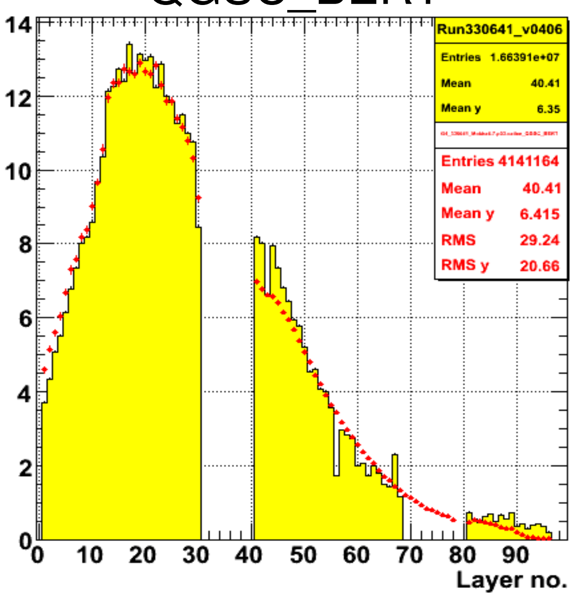
FTFP_BERT



FTF_BIC



QGSC_BERT



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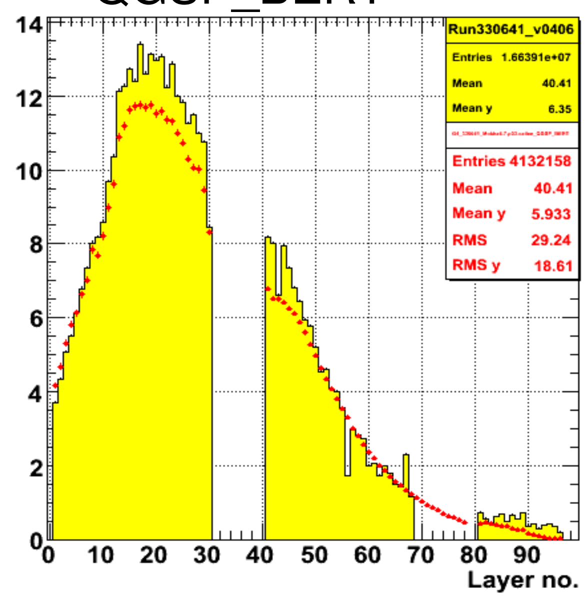
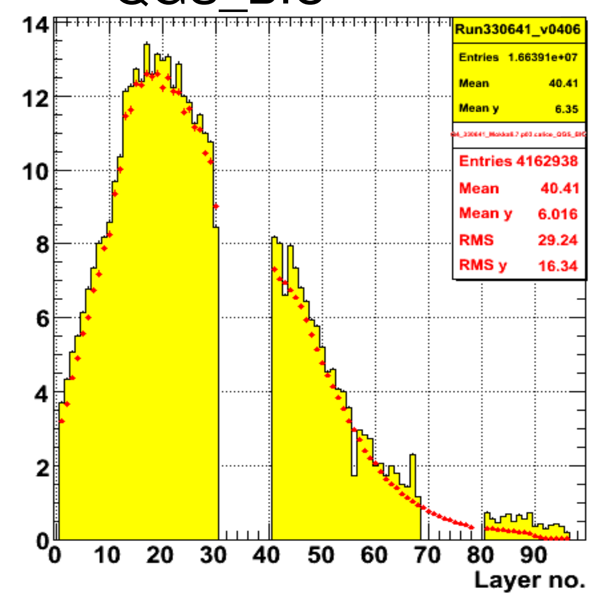


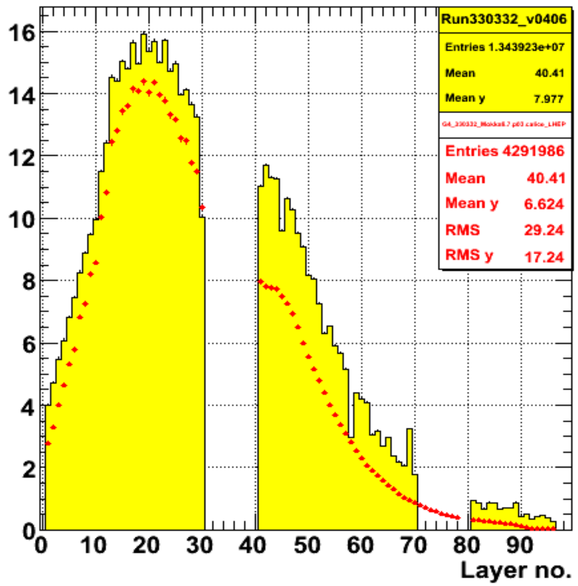
QGS_BIC



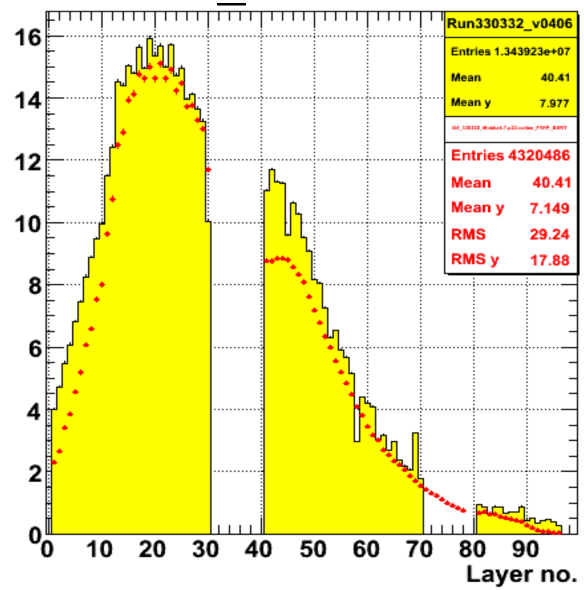
Longitudinal energy distribution – -10GeV

(TProfile – average taken at every bin hence not normalised)

LHEP



FTFP_BERT



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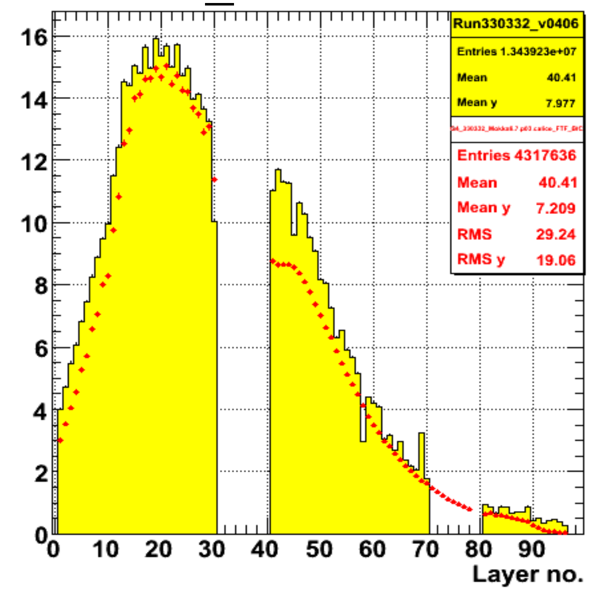
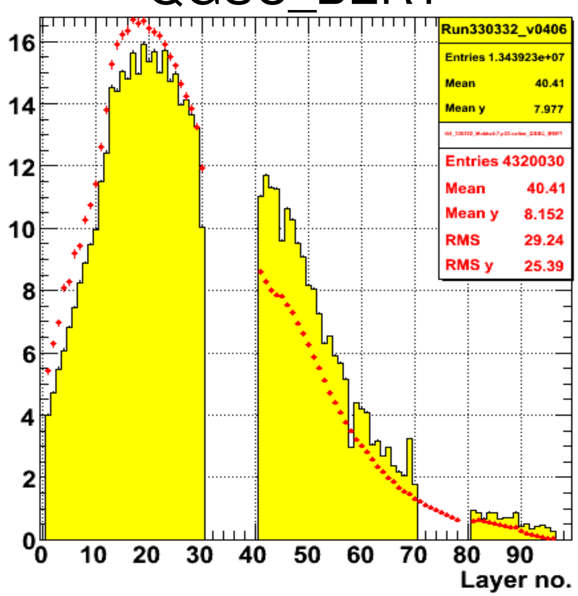


QGSC_BERT



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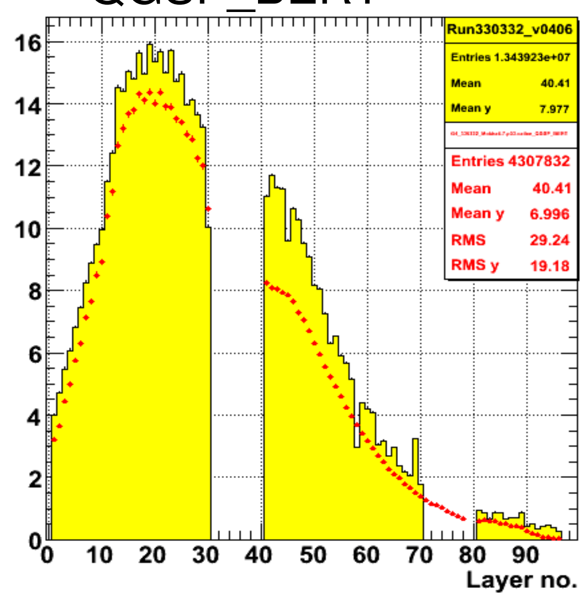

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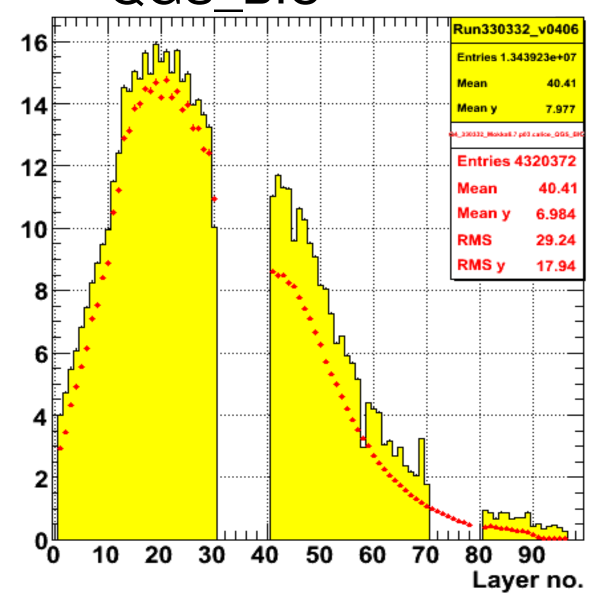
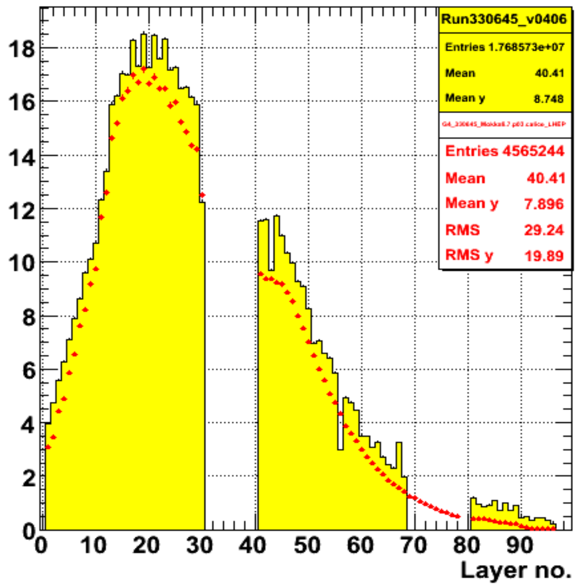


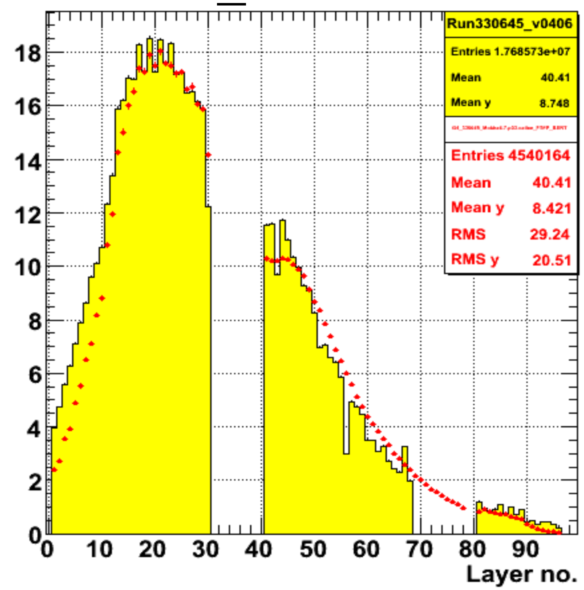
Longitudinal energy distribution – -12GeV

(TProfile – average taken at every bin hence not normalised)

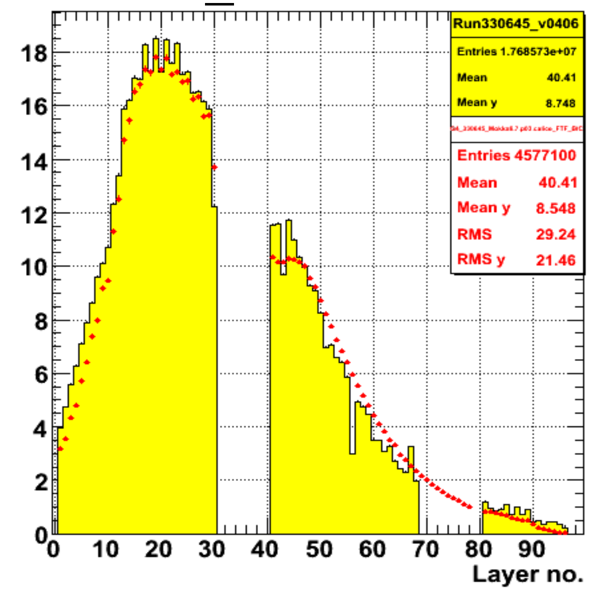
LHEP



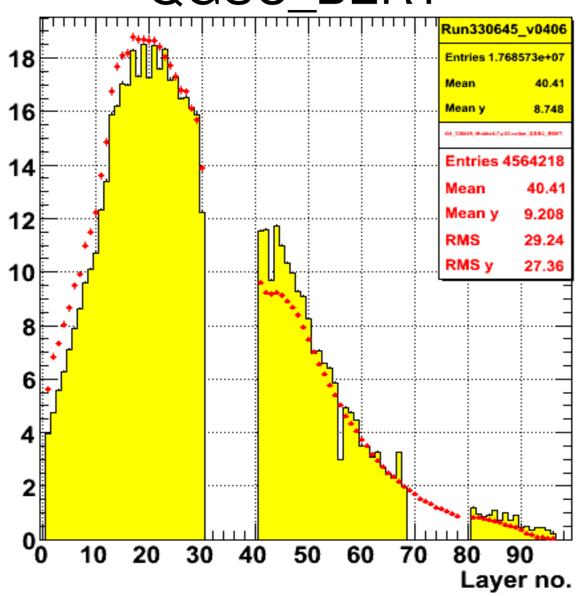
FTFP_BERT



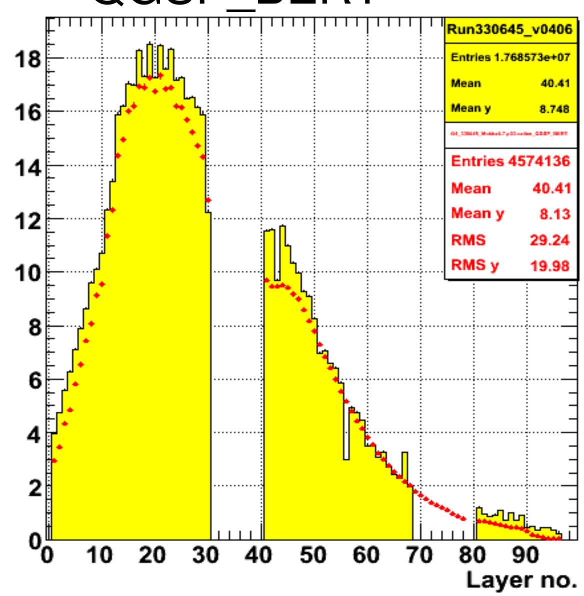
FTF_BIC



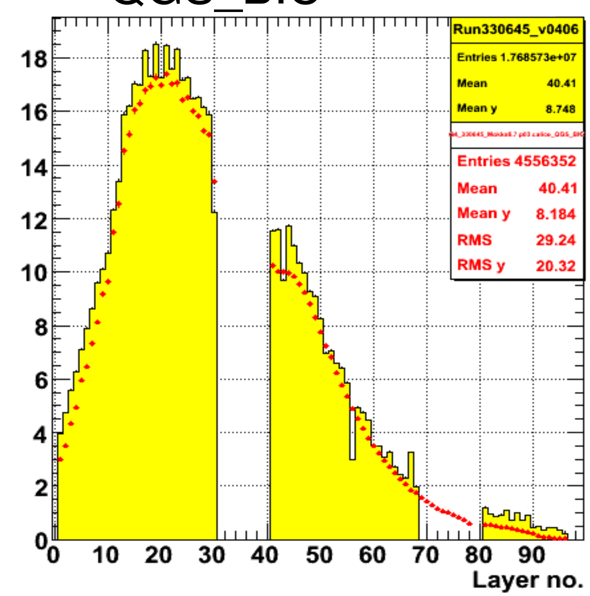
QGSC_BERT



QGSP_BERT



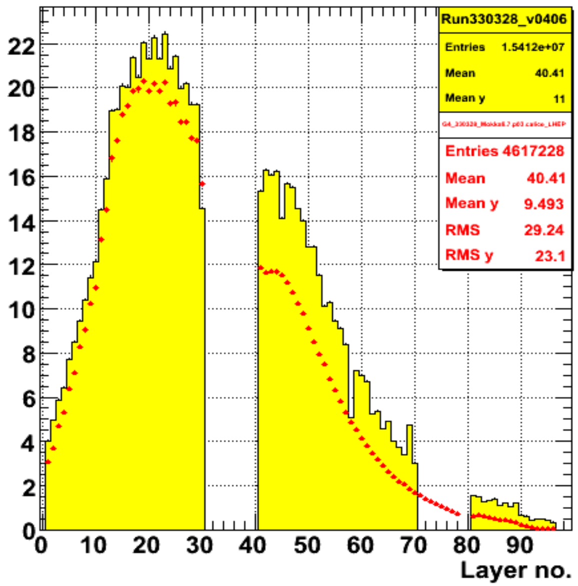
QGS_BIC



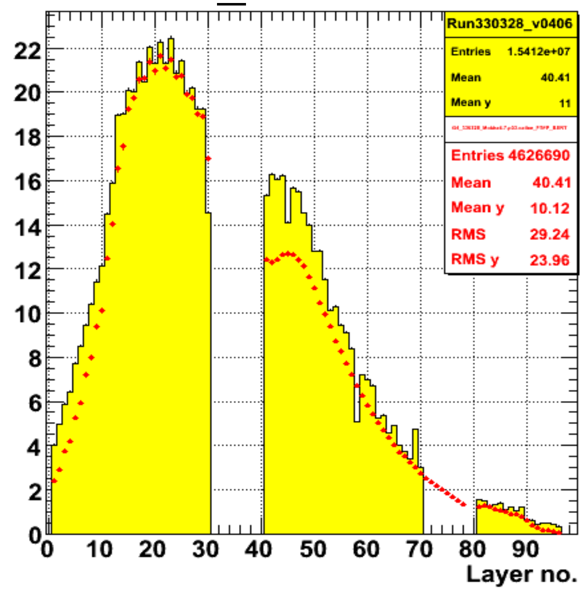
Longitudinal energy distribution – -15GeV

(TProfile – average taken at every bin hence not normalised)

LHEP



FTFP_BERT



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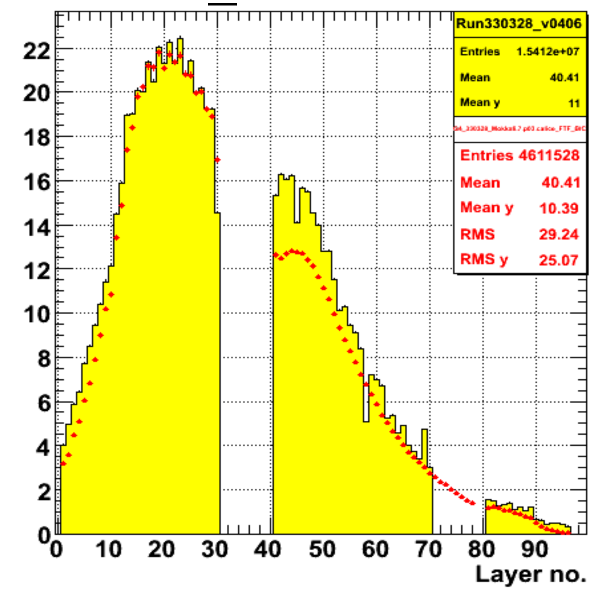

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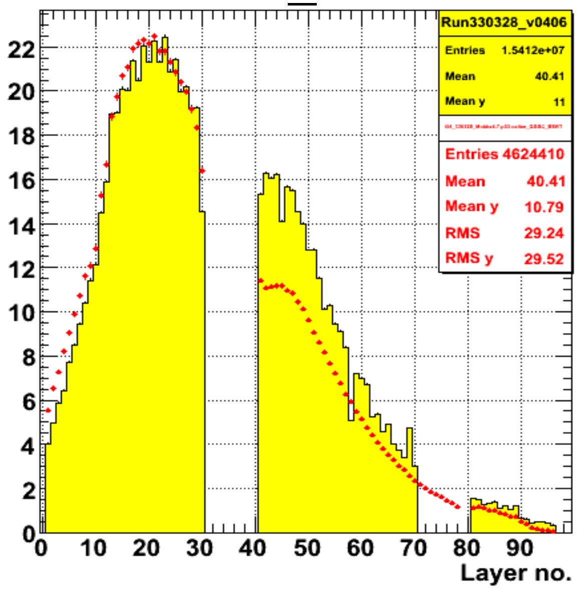
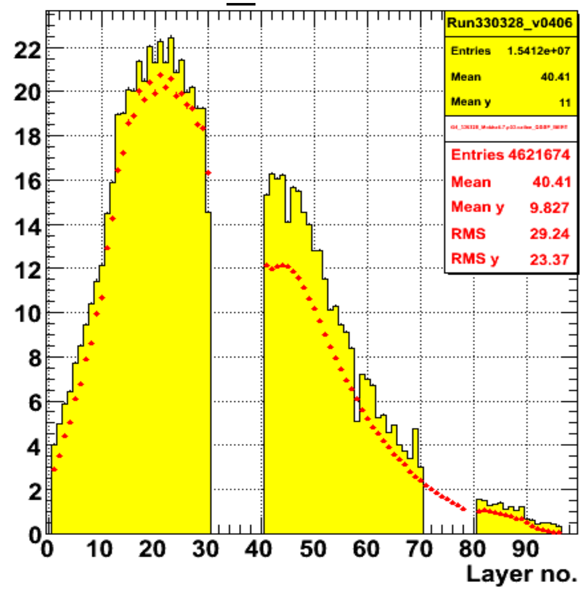


QGSP_BERT



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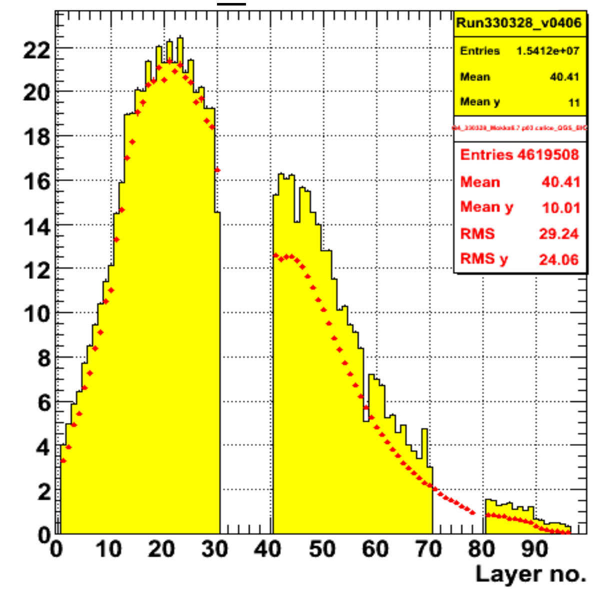
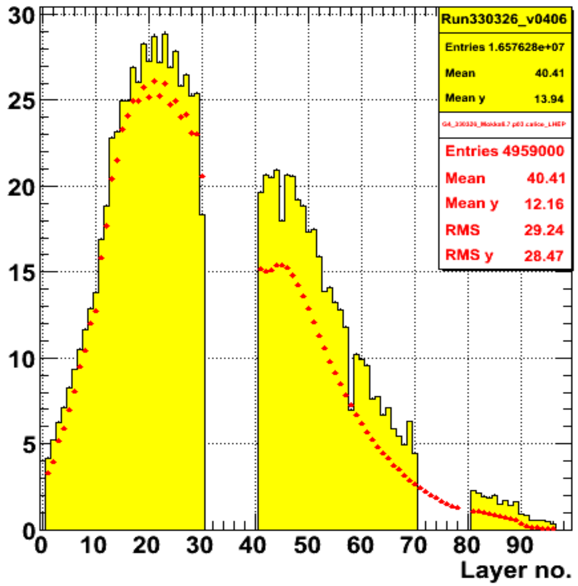


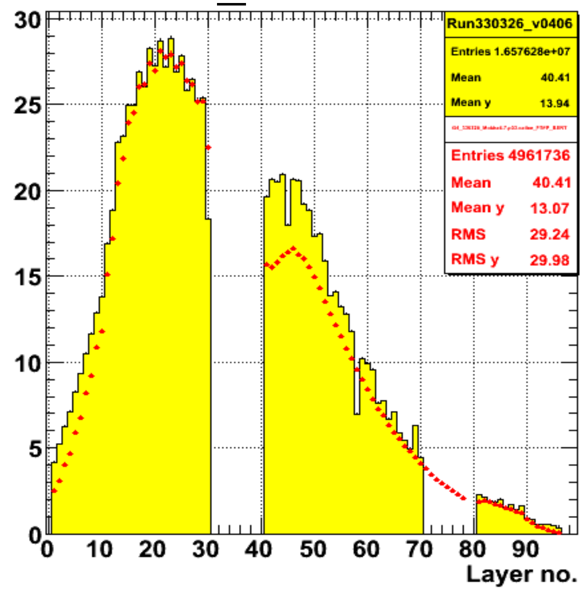
Longitudinal energy distribution – -20GeV

(TProfile – average taken at every bin hence not normalised)

LHEP



FTFP_BERT



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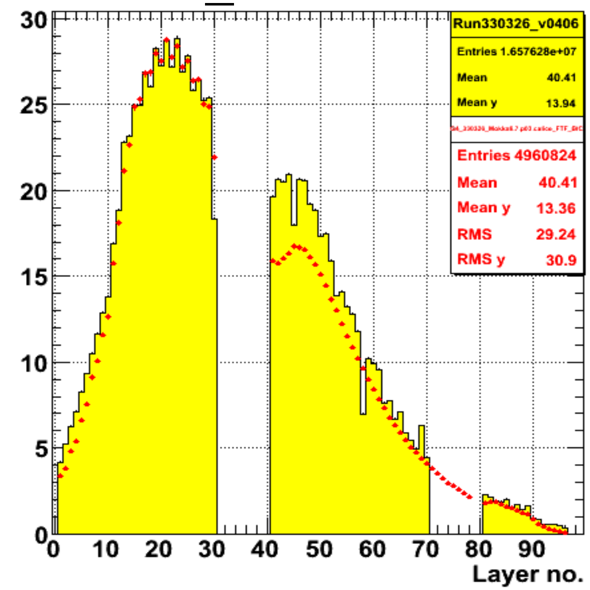

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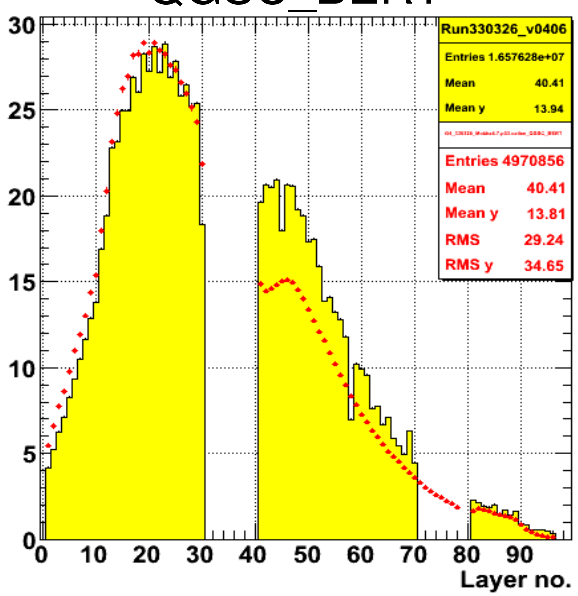
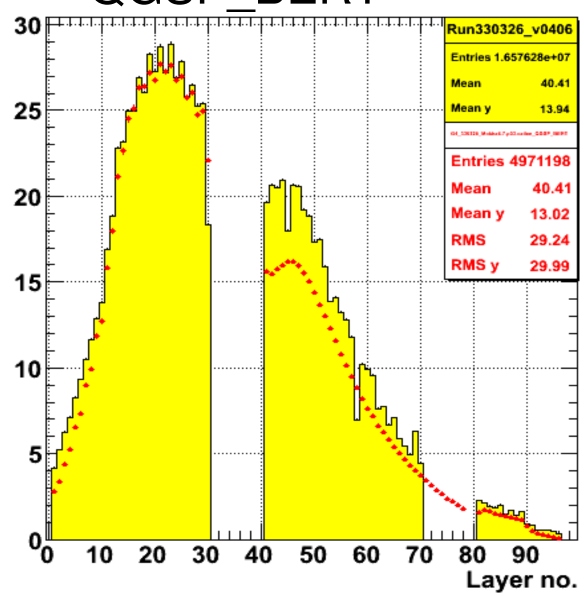
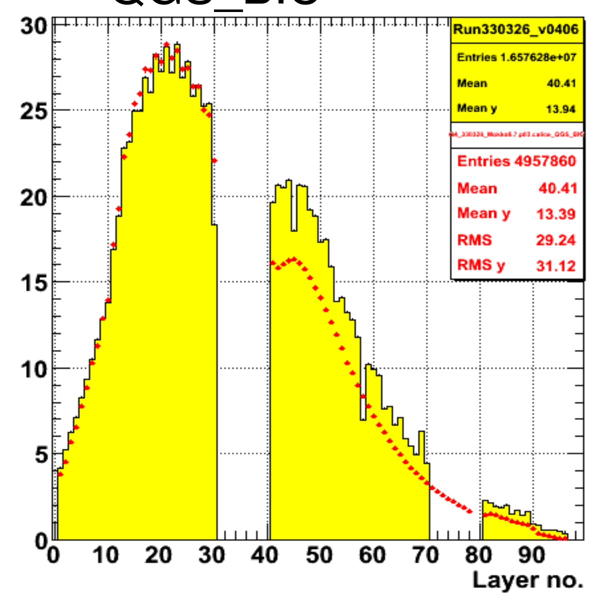


QGSP_BERT

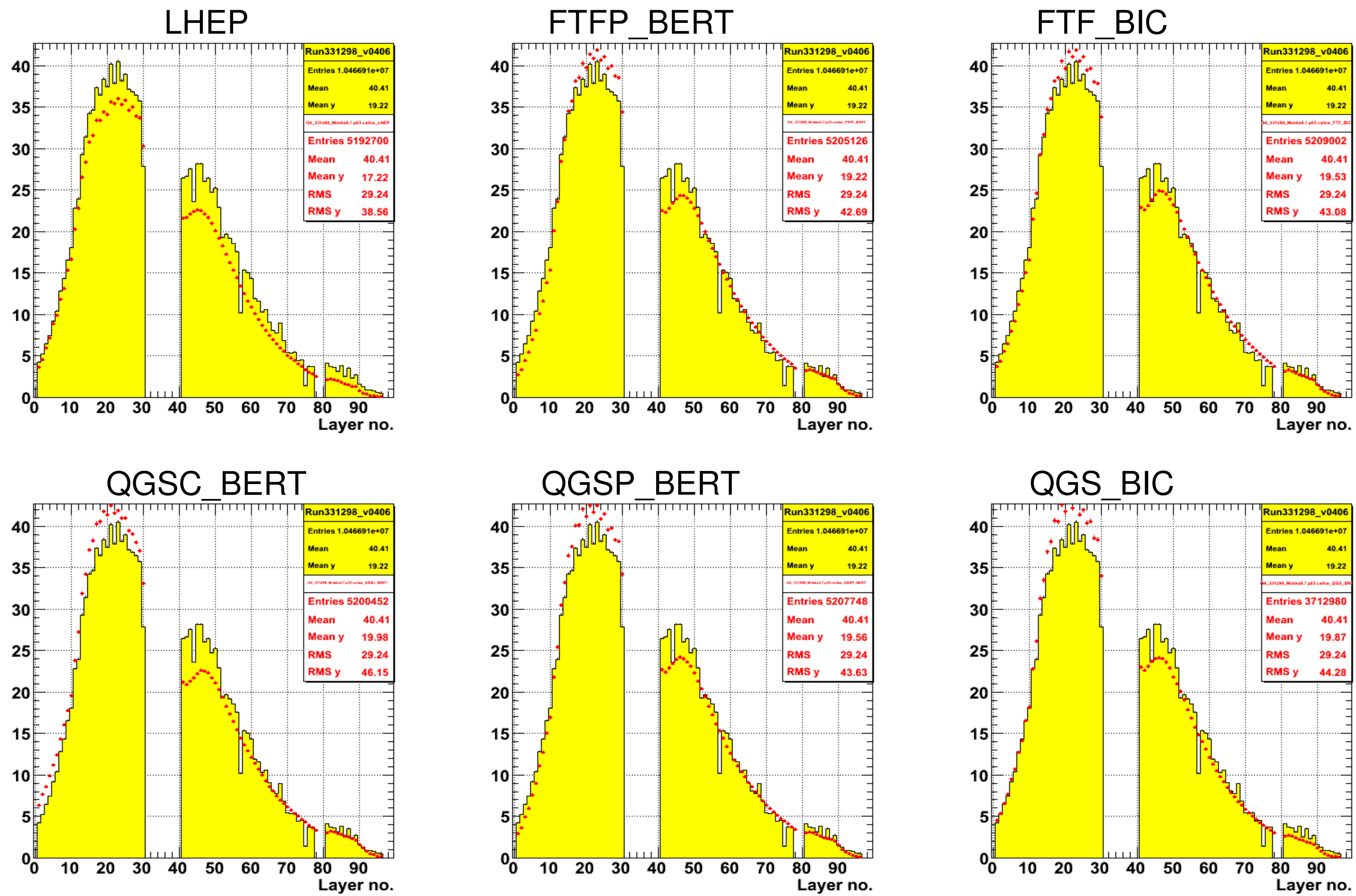


QGS_BIC



Longitudinal energy distribution – +30GeV

(TProfile – average taken at every bin hence not normalised)



First Interaction layer using depth/X0

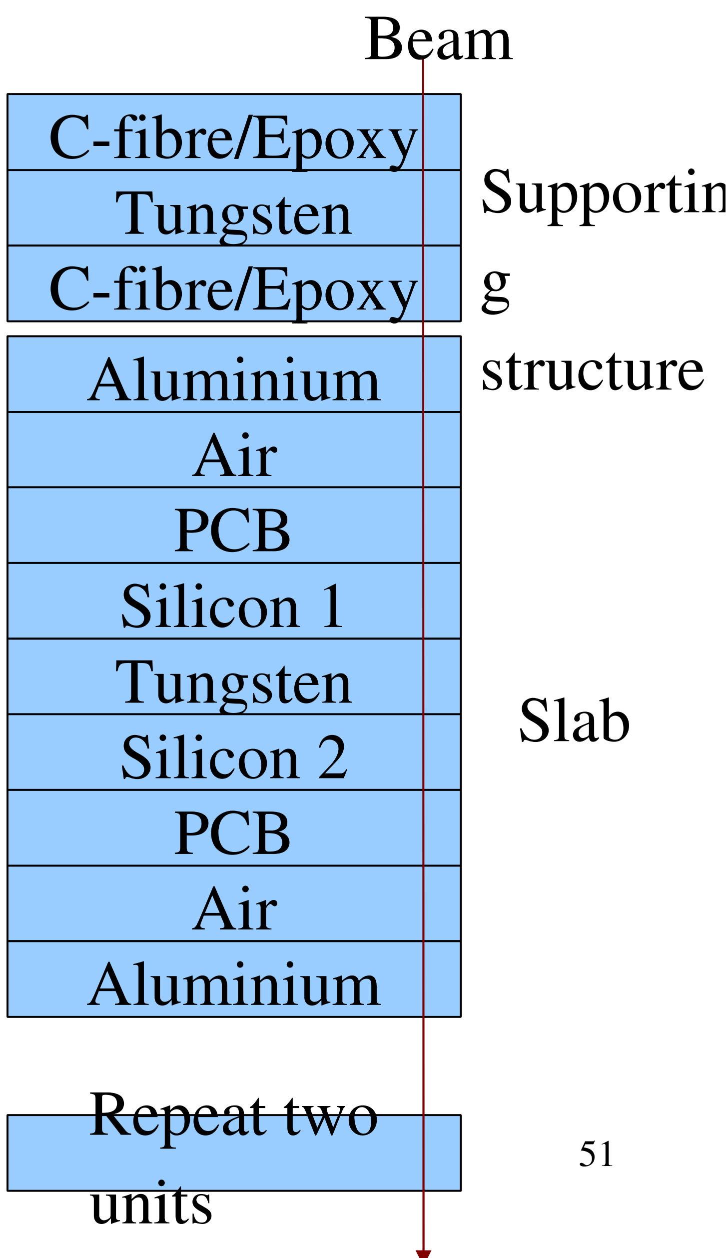
Attempt to obtain simple exponential decay for the first interaction layer

For every silicon layer, calculated amount of material previous to such layer in a consistent way.

W_X = sum of (depth of material / interaction length of material) before 'x'th silicon

first interaction layer against W_x is plotted with weight $1/(W_X - W_{X-1})$

used following interaction length and depth values.



Overview of GEANT4 simulations

- QGSP
  - Quark Gluon-String with Precompound
  - Precompound (P) calls nuclear de-excitation routine
  - 12GeV – 50TeV (QGS)
- BERT
  - BERTini cascade
  - Unique evaporation model to de-excite the remnant nucleus
  - Up to ~10GeV
- LCPhys
  - Linear Collider Physics list by Dennis Wright (SLAC)
  - "best-guess selection of EM and hadronic physics processes for LC detector"
- LHEP
  - Low and High Energy Parametrized
  - Fast, parametrized model based on GHEISHA
  - Average Energy and Momentum