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

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- We study the properties of pion showers in the ECAL
- ECAL length ~1λ_{abs} $\Rightarrow$ incomplete showers, but this does allow us to focus on the initial interaction (cleaner?). Will contain the e/m component of the primary interaction.
- Compare with GEANT models, including new physics lists in the β-release of Geant4.9.3
- Complements the AHCAL work. Allows us to study interactions in Tungsten.
- Main focus on energies ~8-20 GeV – important for ILC jets and also main problem region for modelling.

Summary of data and MC simulations

- Reconstructed data

2007 data from CERN

with v0406 reconstruction

Run330641 – 8GeV π^-

Run330332 – 10GeV π^-

Run330645 – 12GeV π^-

Run330328 – 15GeV π^-

Run330326 – 20GeV π^-

Run331298 – 30GeV π^+

- GEANT4 simulations

Mokka version 6.8.p01.calice
GEANT 4.9.2.p01
with physics lists...

LHEP
QGSP_BERT
QGSC_BERT
QGS_BIC
FTFP_BERT
FTF_BIC

(as recommended by G4 authors)

and new in GEANT4.9.3.b01

QGSC_QGSC
QGSC_CHIPS
QGSC_FTFP_BERT
FTFP_BERT_TRV

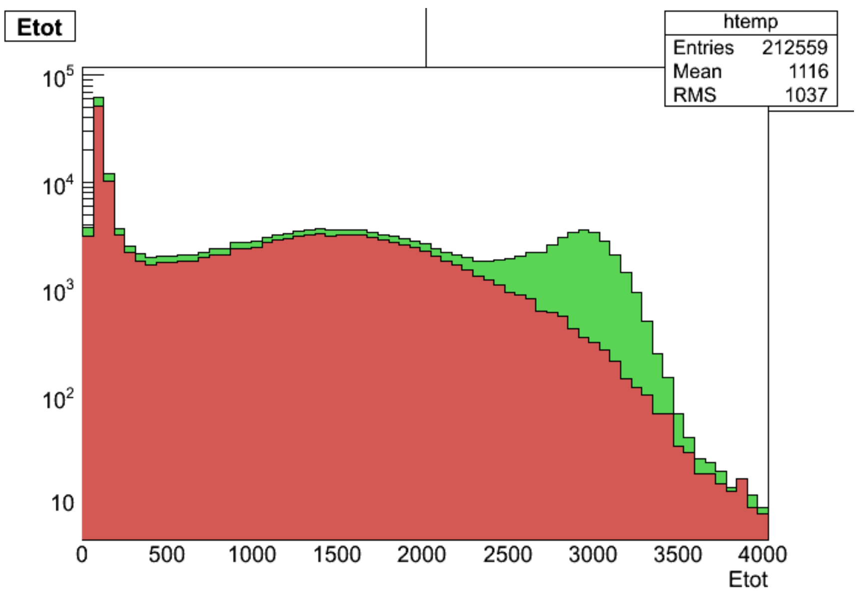
Models used in Physics Lists (for $\pi^{\pm}$)

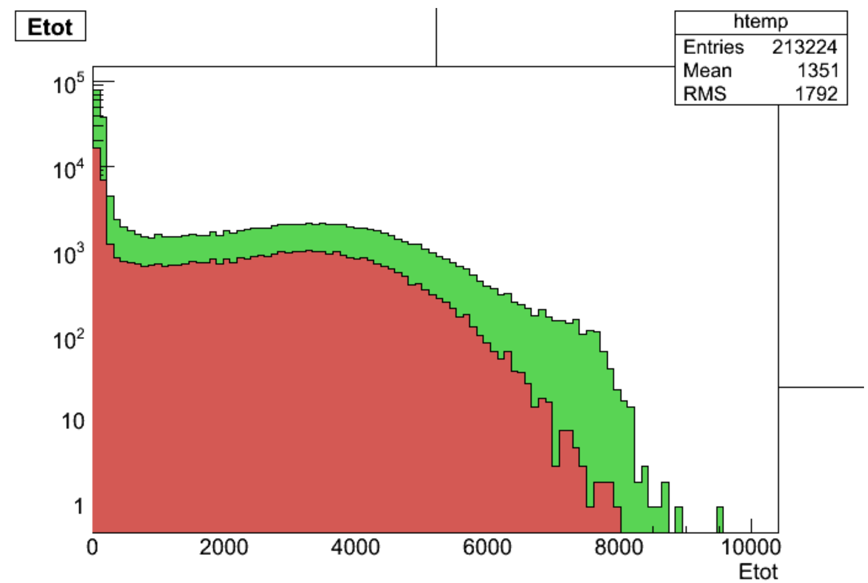
- LHEP LEP (<55); HEP (>25)
- QGSP_BERT BERT (<9.9); LEP (9.5-25); QGSP (>12)
- *QGSP_FTFP_BERT* BERT (<8); FTFP (6-25); QGSP (>12)
- QGS_BIC BIC (<1.3); LEP (1.2-25); QGSB (>12)
- QGSC_BERT BERT (<9); QGSC (>6)
- *QGSC_CHIPS* QGSC_CHIPS (∀ energies) "energyflow i/f to CHIPS"
- *QGSC_QGSC* QGSC (∀ energies) "multisoft i/f to CHIPS"
- FTFP_BERT BERT (<5); FTFP (>4)
- *FTFP_BERT_TRV* BERT (<8); FTFP (>6)
- FTF_BIC BIC (<5); FTFB (>4)

- n.b. Ranges overlap to provide smooth transitions between models. Energies in GeV
- Prerelease lists in *italics.*

Event Selection I

- Electron/proton events reduced using signal from the Cerenkov.
- (Still Kaon contribution?)





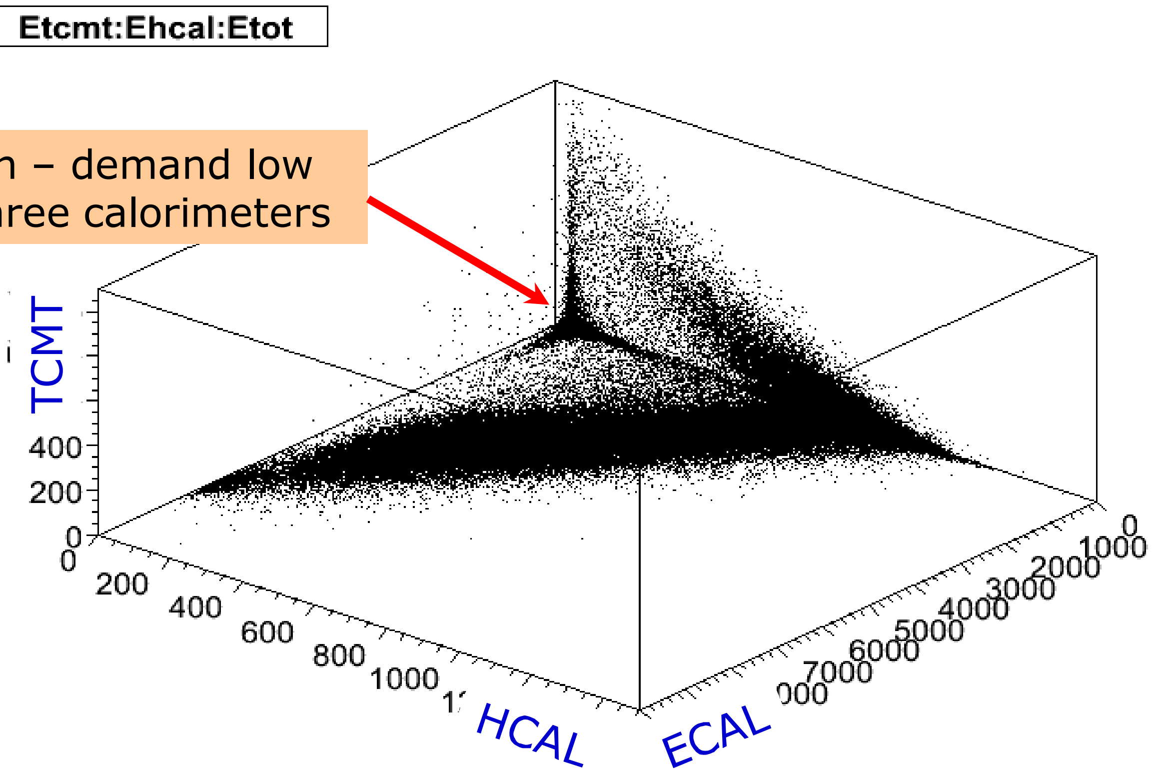
π^- runs : demand Cerenkov **off (red)** to remove e^- (8,10,12,15,and 20GeV)

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

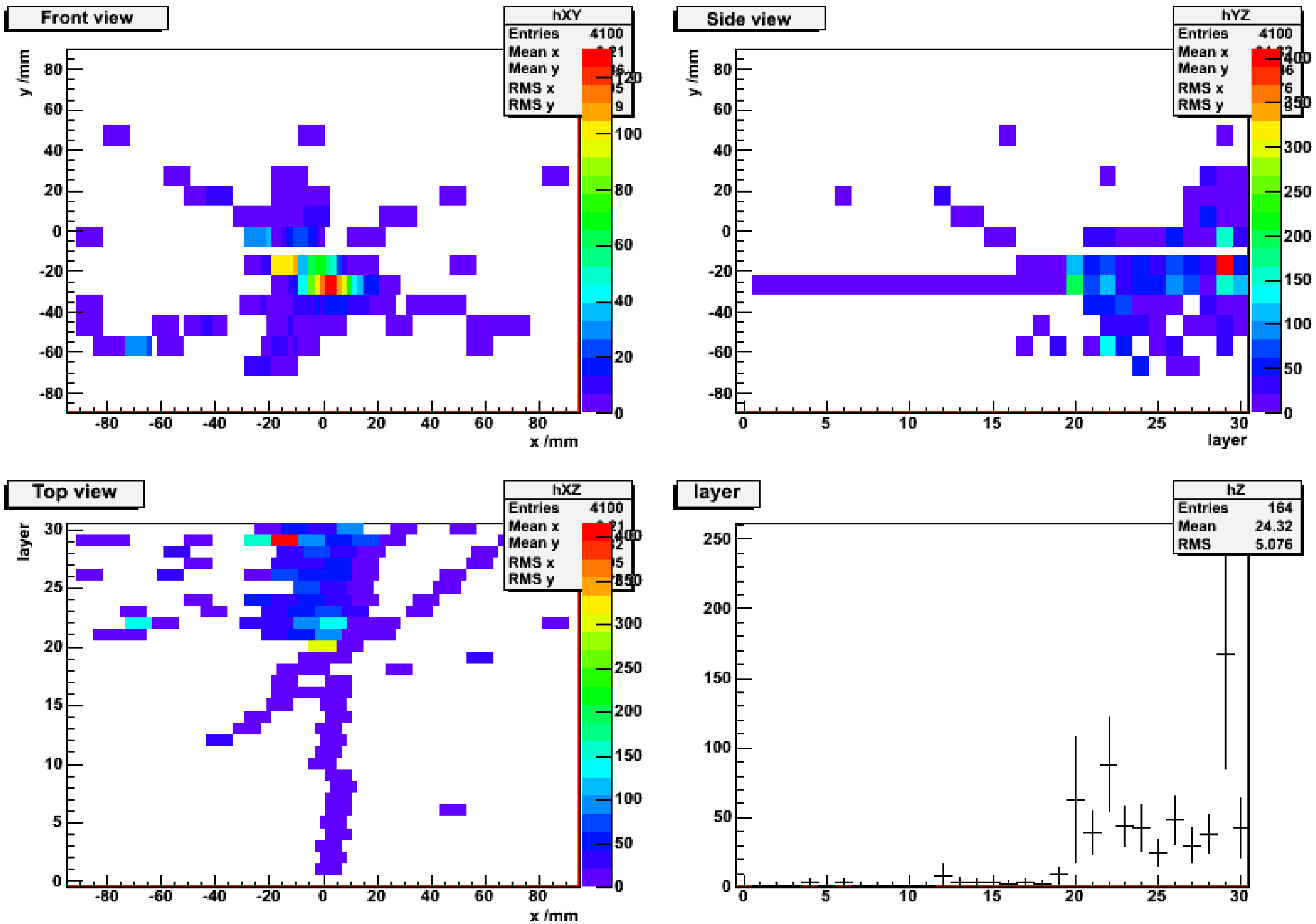
Event Selection II

- 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.

Muon rejection – demand low energy in all three calorimeters



Identify first interaction layer

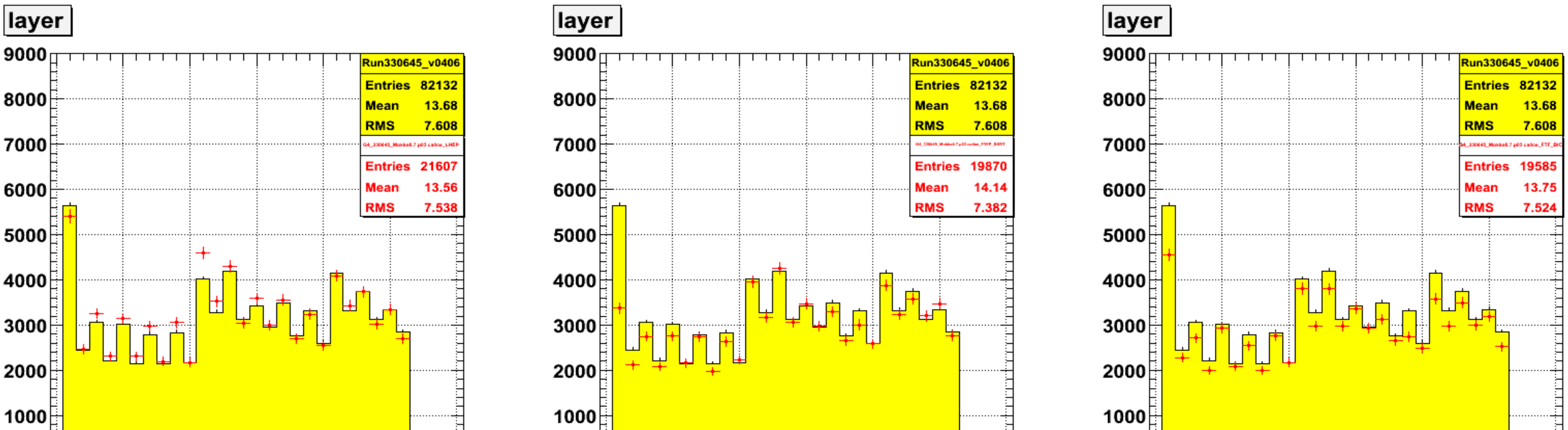


Identify the first layer at which 3 out of 4 consecutive layers >10MIPs

Very simple, but after extensive scanning, seems to work as well as any more sophisticated procedure.

First Interaction Layer – -12GeV

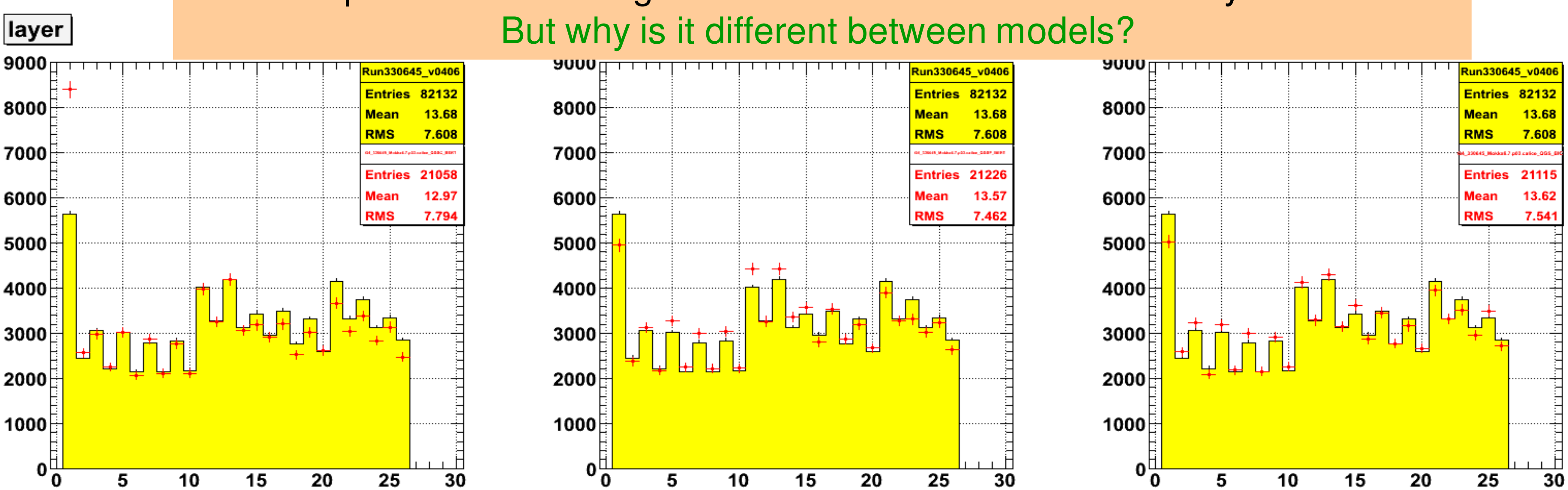
(normalised to number of events)



6 physics lists. Most significant difference between physics lists is in layer 1.

Upstream showering ?⇒ cut events where interaction layer =1

But why is it different between models?

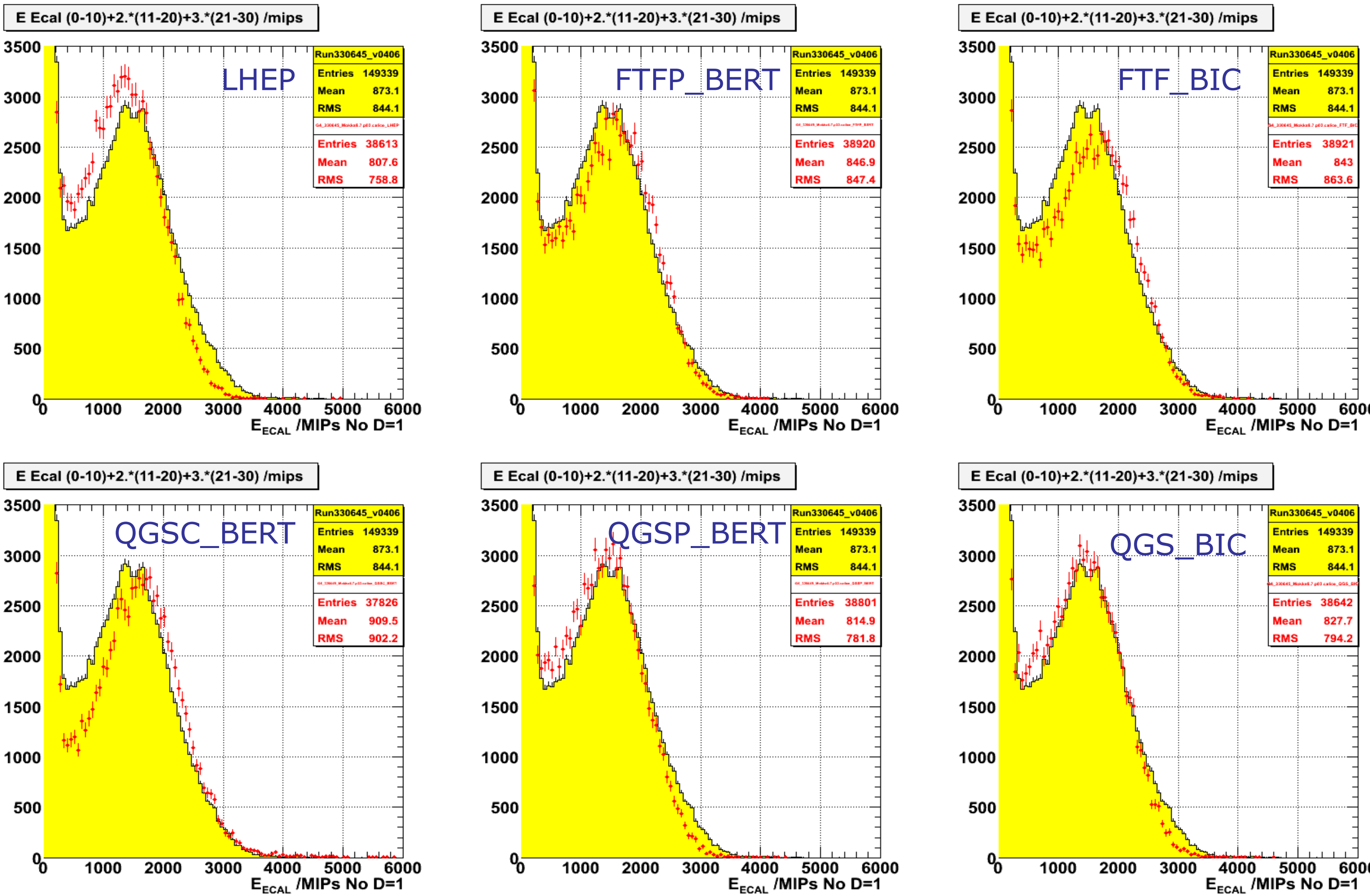


Total ECAL energy

- First set of plots are total ECAL energy (simple 1:2:3 stack weighting for sampling fraction).
- Compare data to MC normalised to total no. of events
- Large low energy peak is seen (non-interacting pions + residual muons). The size of this is well modelled (i.e. x-sections are basically OK), but otherwise not very interesting – suppressed.
- Since shower is incompletely absorbed, and the sampling is non-uniform, we are combining lots of different distributions. Hence maybe more useful to look at total energy in ECAL where the interaction layer is restricted to a limited part of the calorimeter.

Total Energy Dissipated in ECAL: -12GeV

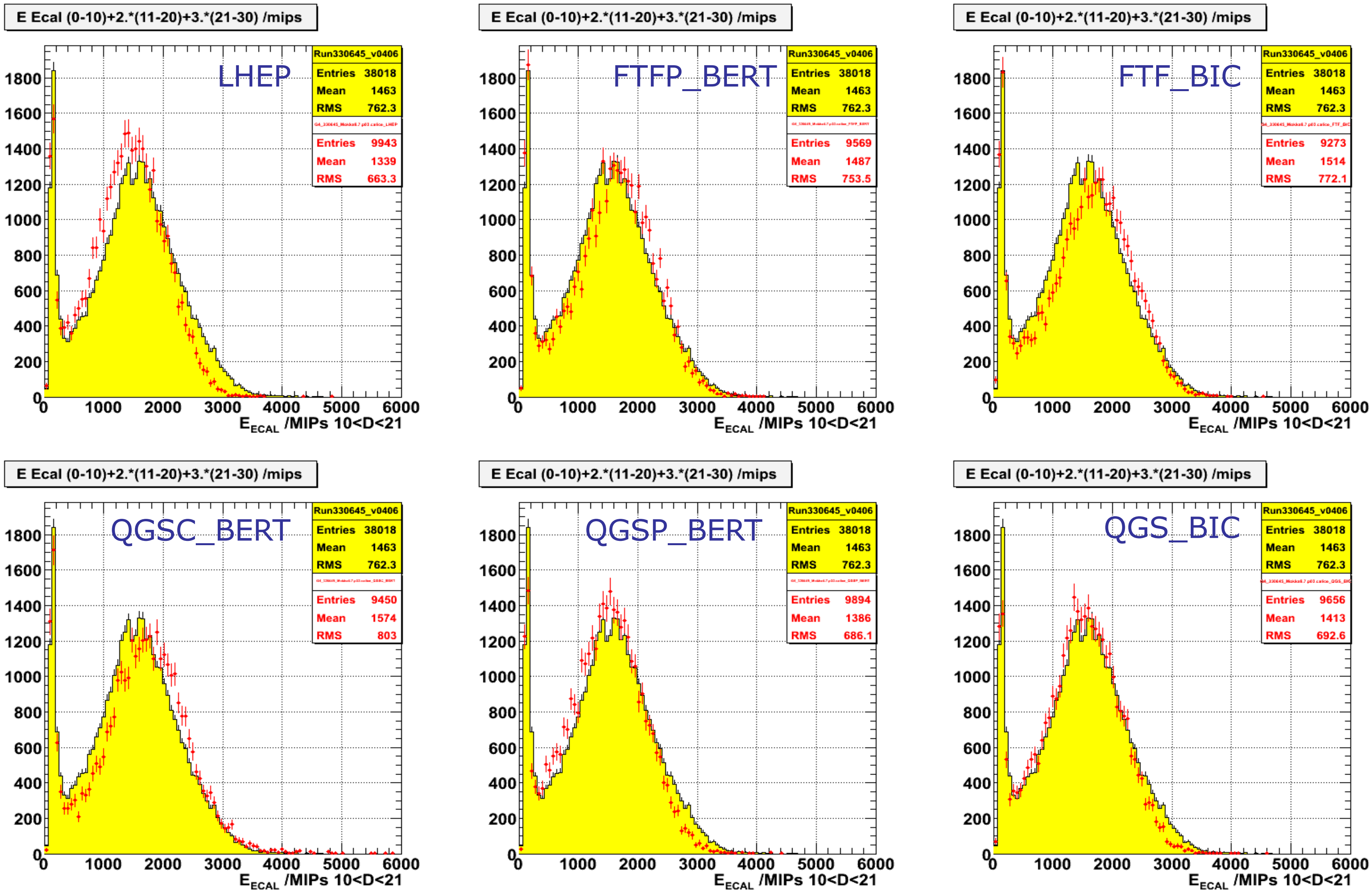
Data (yellow) c.f. MC (red) (Normalised to number of events)



QGSP_BERT, FTFP_BERT and QGS_BIC look best. None perfect.

Total Energy Dissipated in ECAL: -12GeV

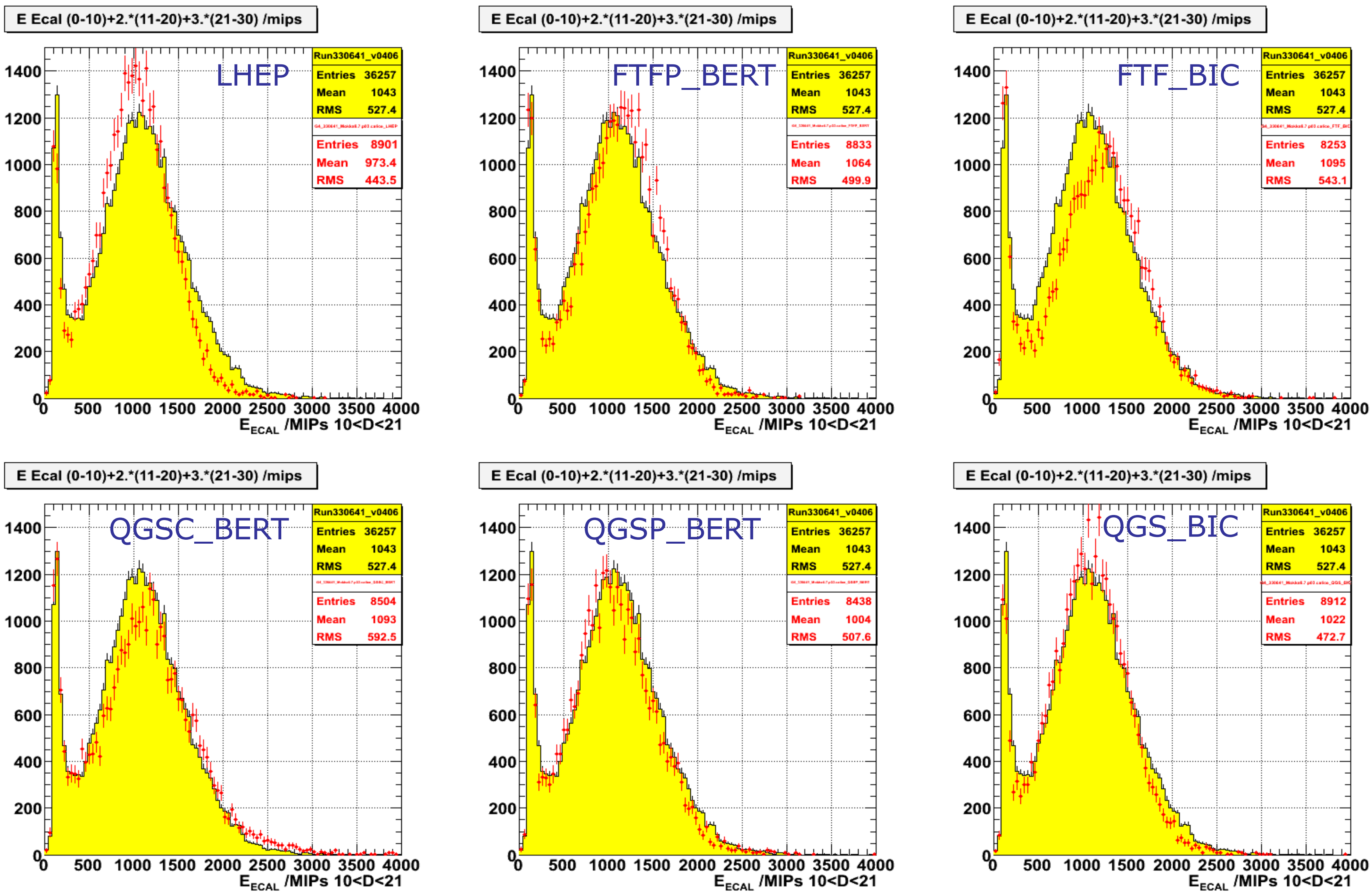
(Normalised to number of events) (10< interaction layer <21)



Similar conclusions

Total Energy Dissipated in ECAL: -8GeV

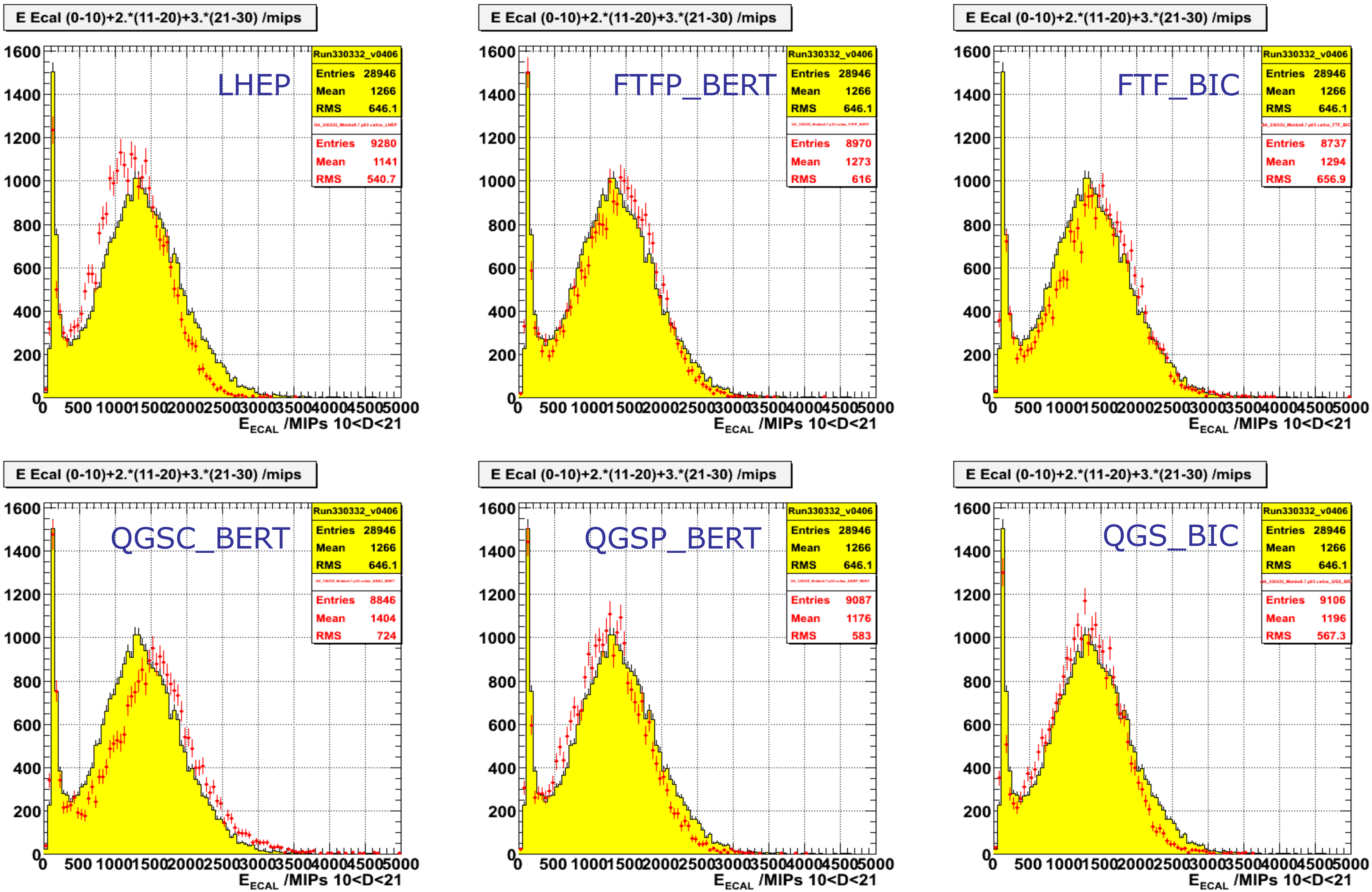
(Normalised to number of events) (10< interaction layer <21)



QGS_BIC and QGSP_BERT favoured?

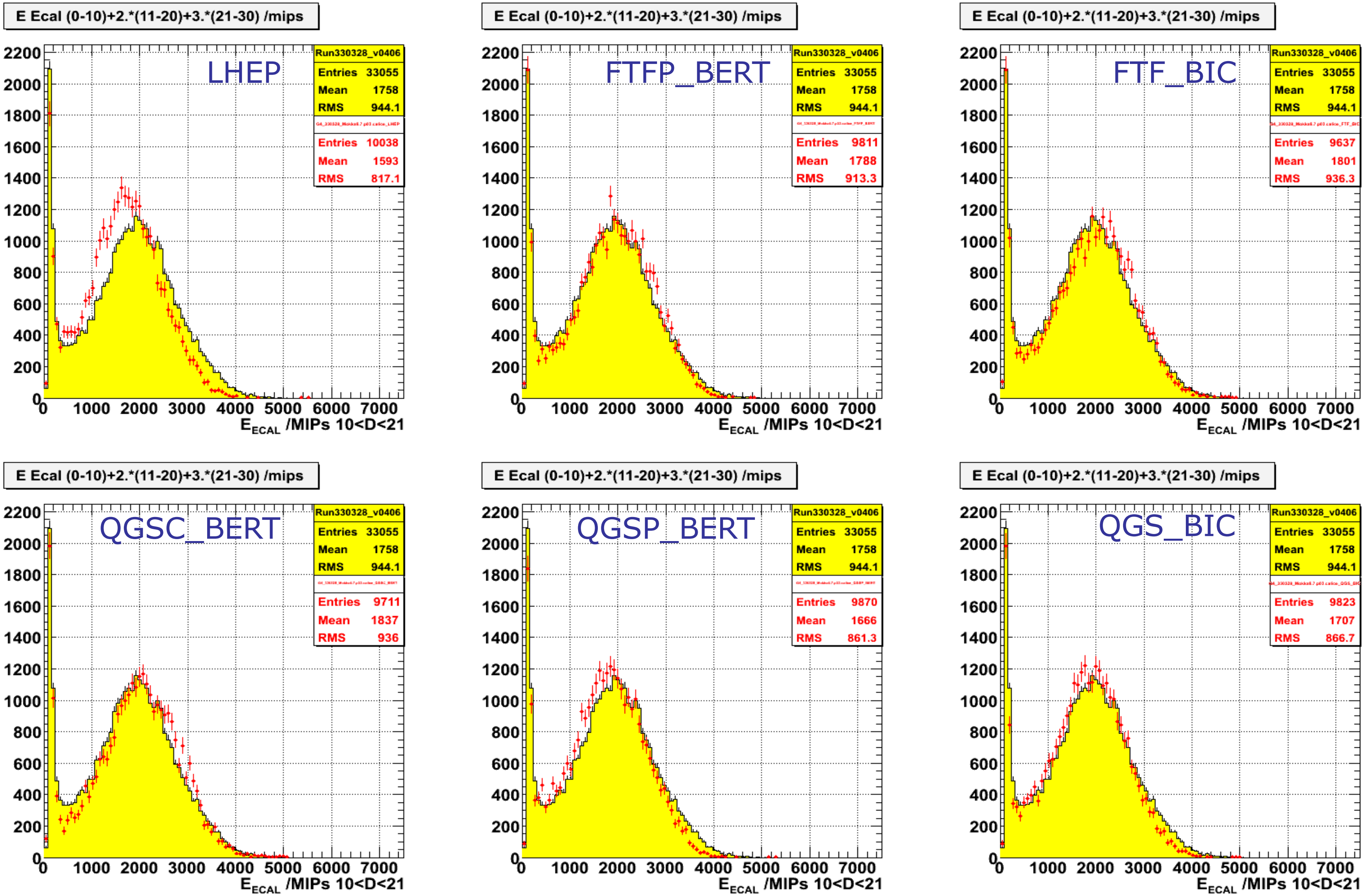
Total Energy Dissipated in ECAL: -10GeV

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



Total Energy Dissipated in ECAL: -15GeV

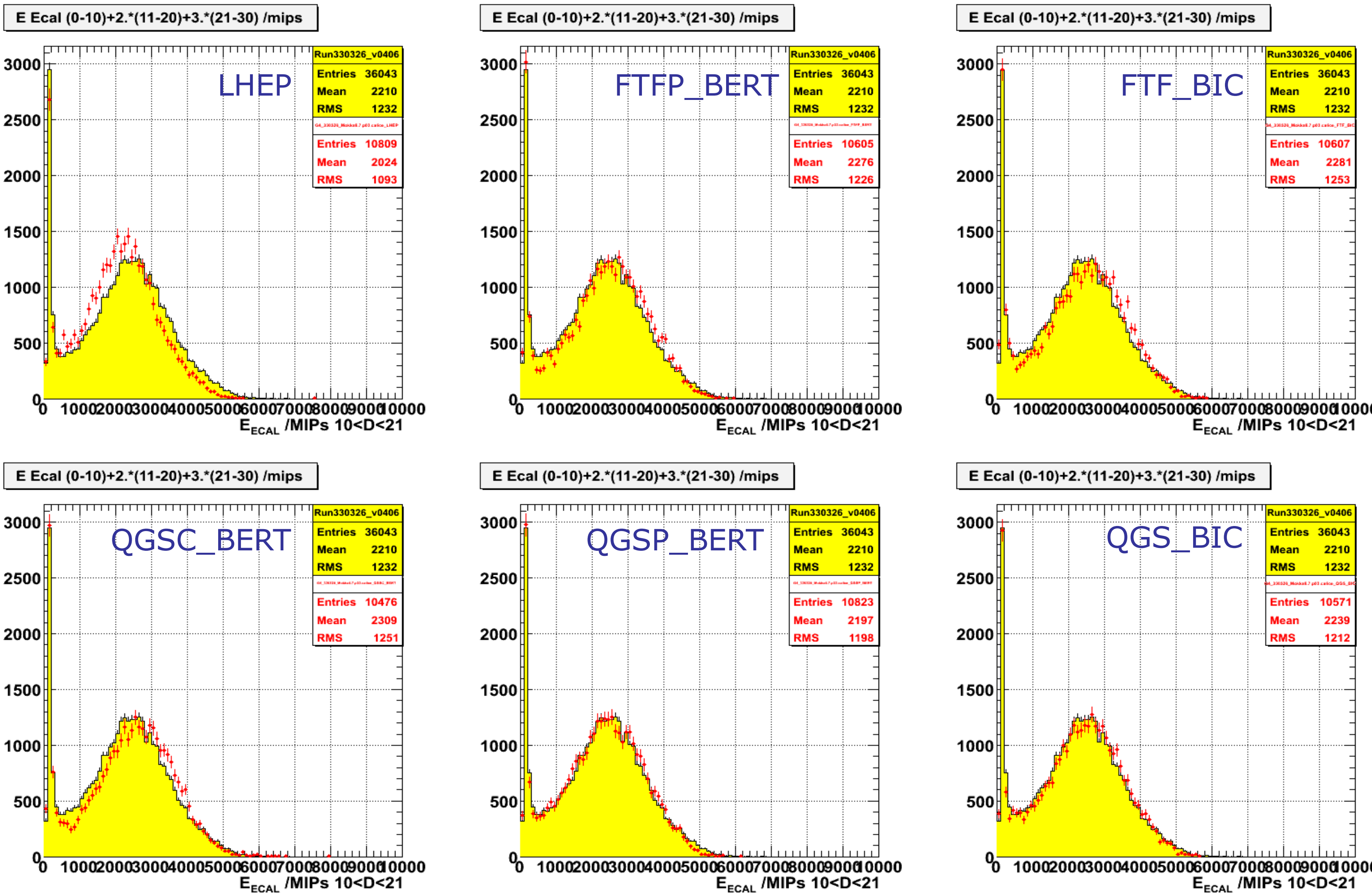
(Normalised to number of events) (10< interaction layer <21)



LHEP clearly worst

Total Energy Dissipated in ECAL: -20GeV

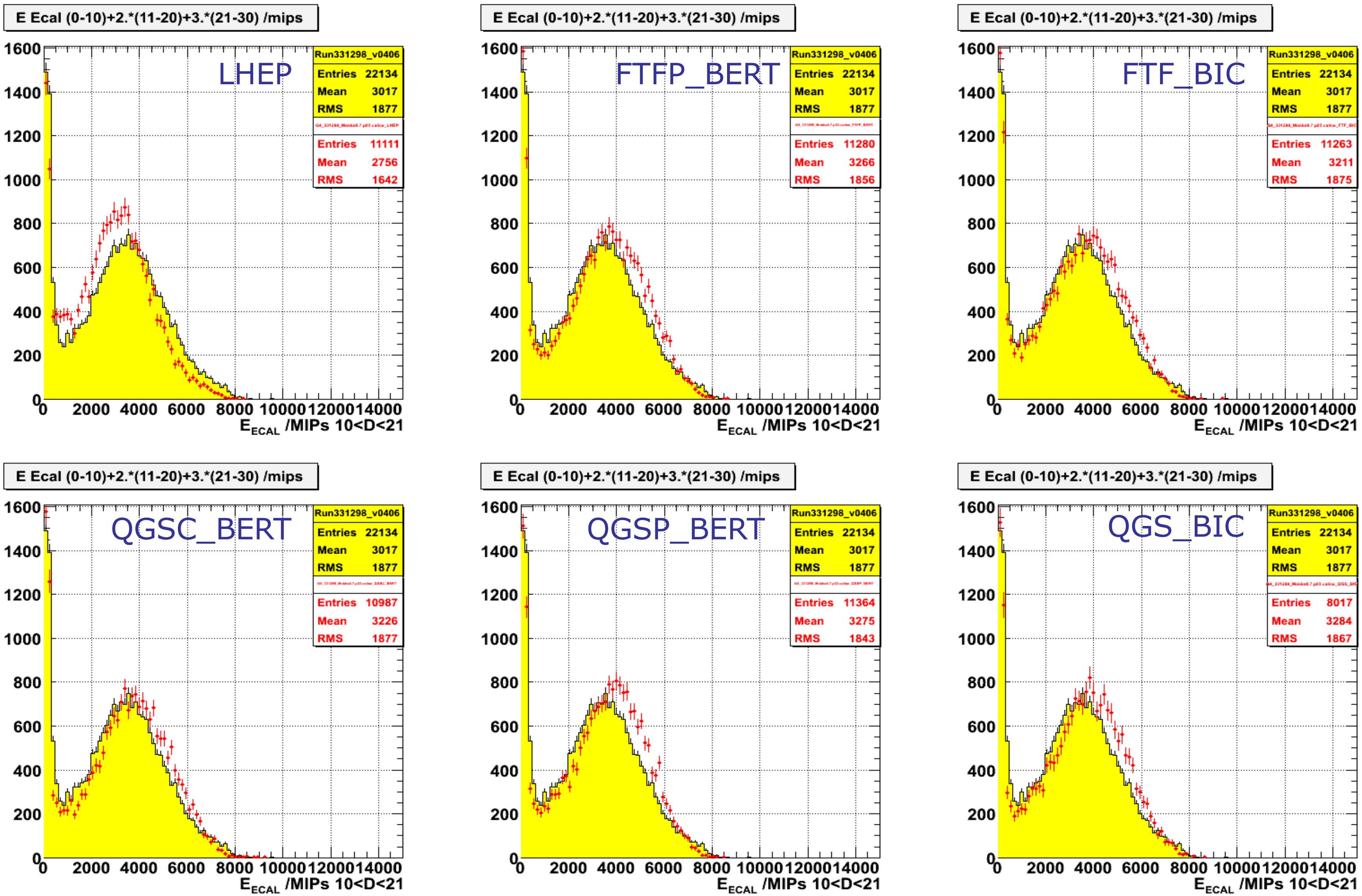
(Normalised to number of events) (10< interaction layer <21)



LHEP clearly worst

Total Energy Dissipated in ECAL: +30GeV

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

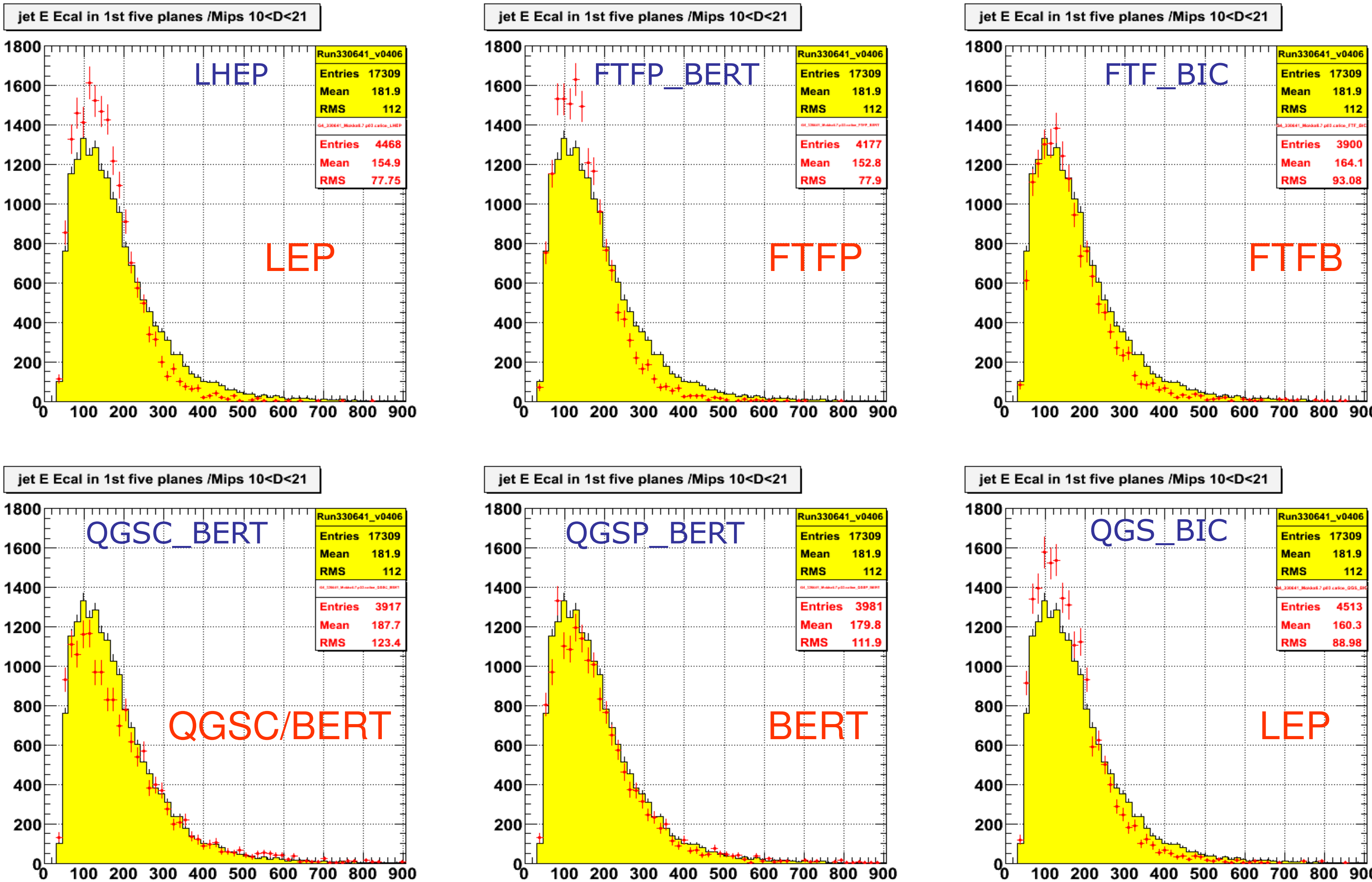


All relatively poor

Initial shower energy

- Next plots show ECAL energy in first 5 layers after interaction point.
- Aim is to provide some measure of the particles produced in the primary interaction at the ~full beam energy.
- Therefore can label plots by the interaction model(s) which are being invoked by each physics list at the beam energy (marked in red below).
- Because of unequal sampling it makes sense to restrict data to a small range of interaction layers. We used 11-15 (first half of second stack).

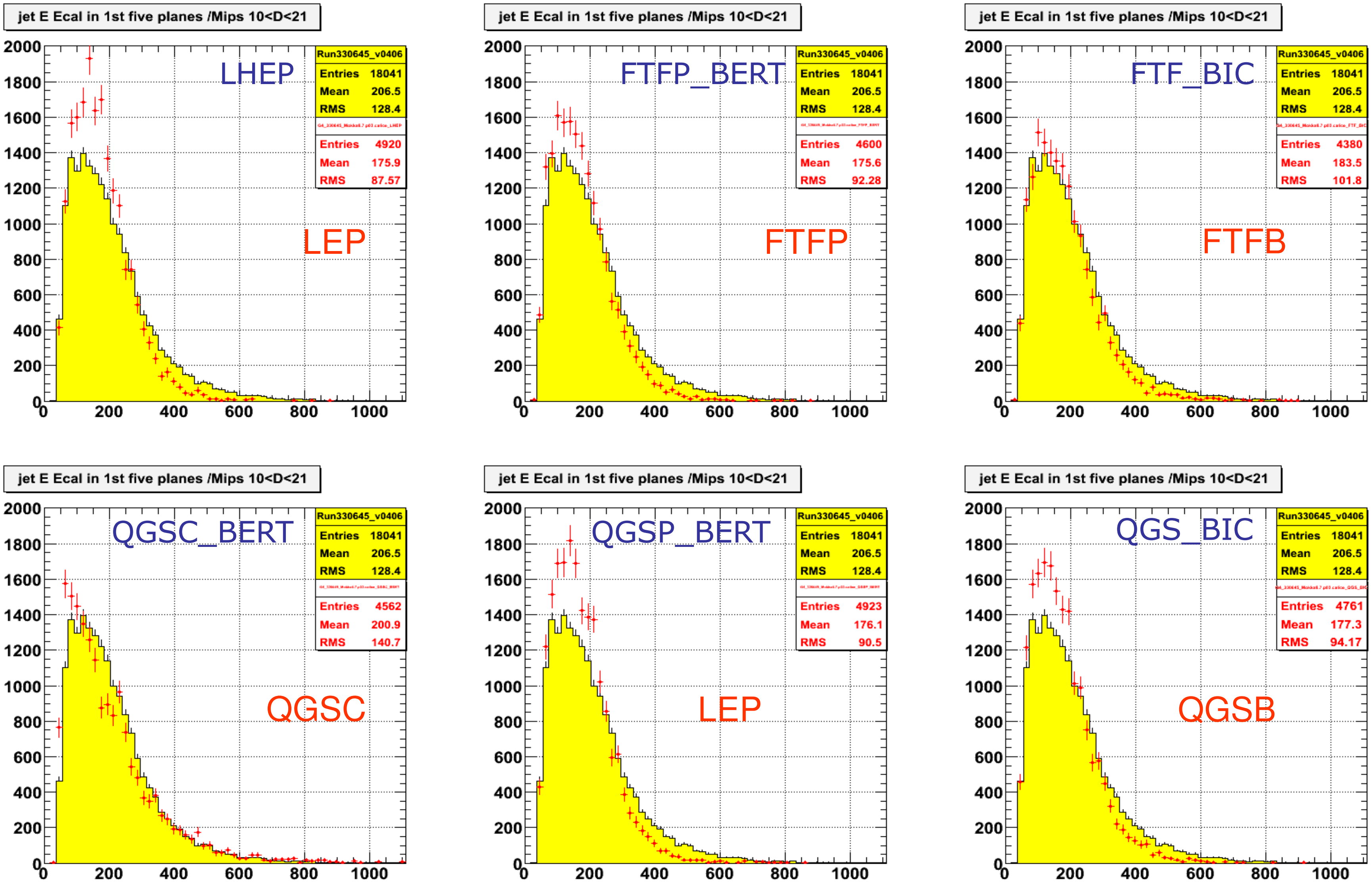
Shower energy (5 layers after interaction): -8GeV
(normalised to number of events) (10< interaction layer <16)



BERT gives good tails. FTFB best at predicting peak?

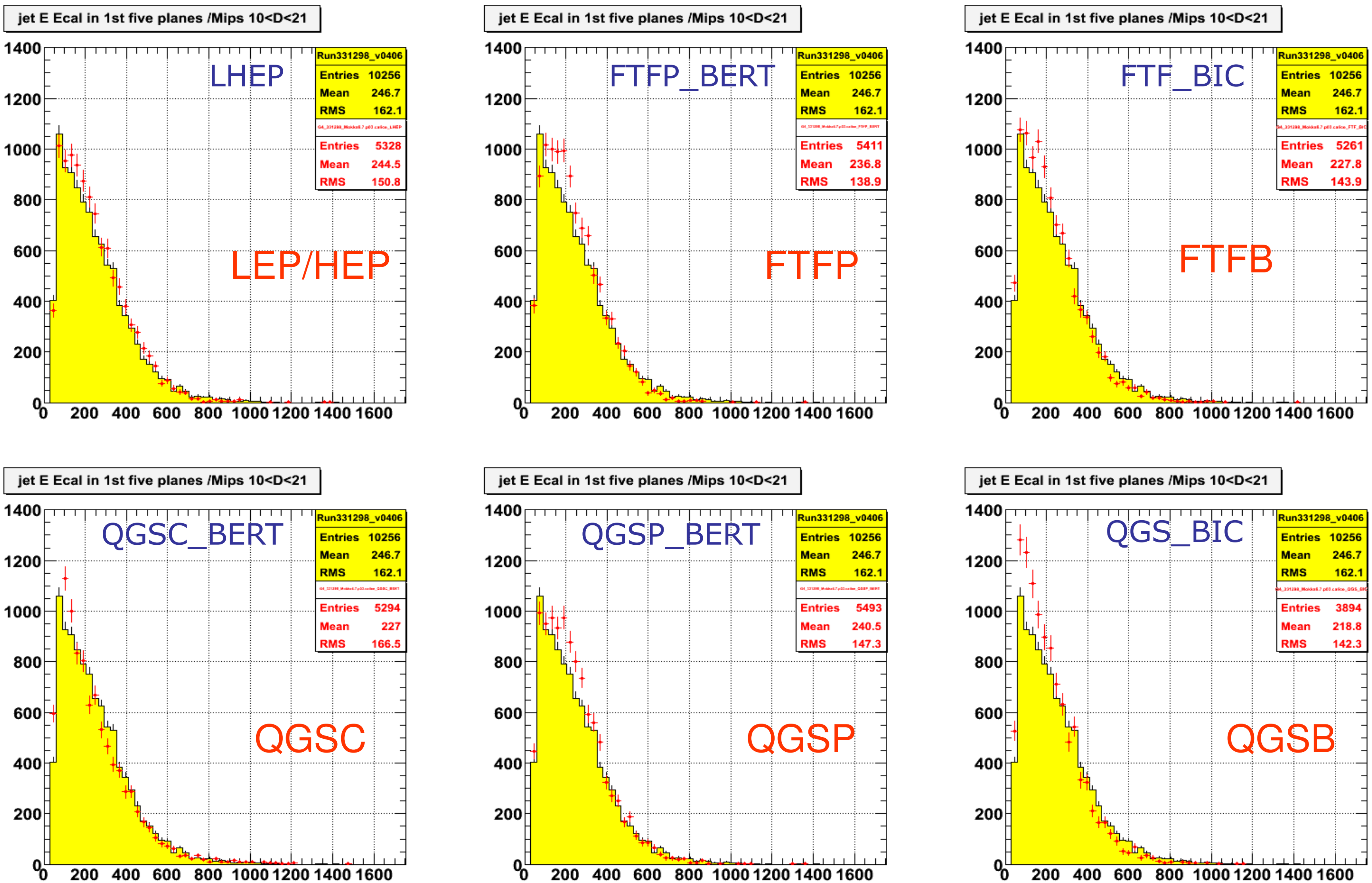
Shower energy (5 layers after interaction): -12GeV

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



Significant difference in physics lists using LEP @ 12 GeV. QGSC gives good tail.

Shower energy (5 layers after interaction): +30GeV
(normalised to number of events) (10< interaction layer <16)



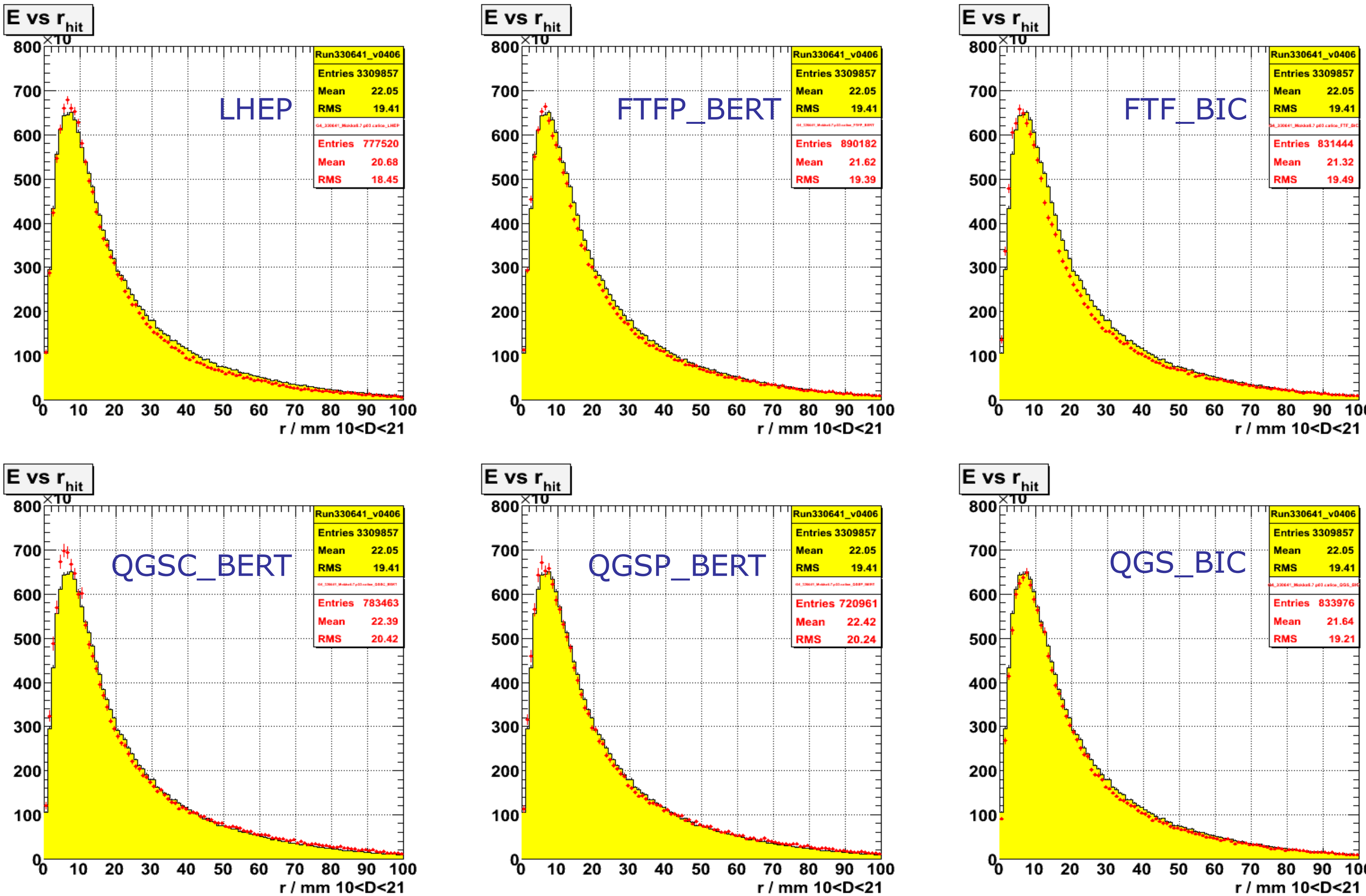
All show reasonable agreement. QGS_BIC worst on the peak.

Transverse profiles

- Next measure transverse profiles.
- Histogram hit radius (w.r.t. shower barycentre).
- Weighted by energy; no weighting for sampling fraction.
- As before, makes sense to restrict range of interaction layers.

Transverse energy distribution: -8GeV

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

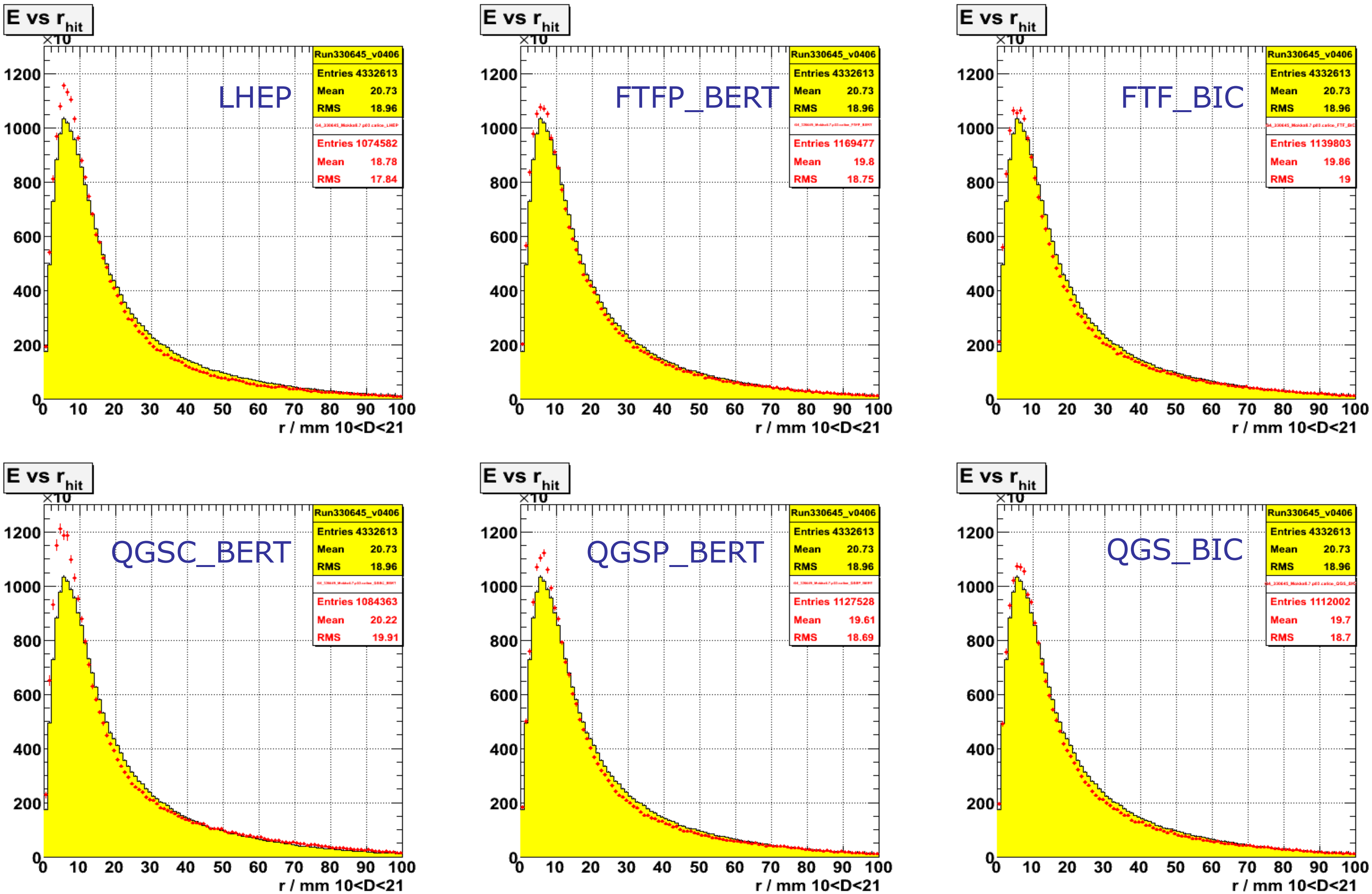


Calice Me

QGS models show good agreement in tail. QGSP_BERT best?

Transverse energy distribution: -12GeV

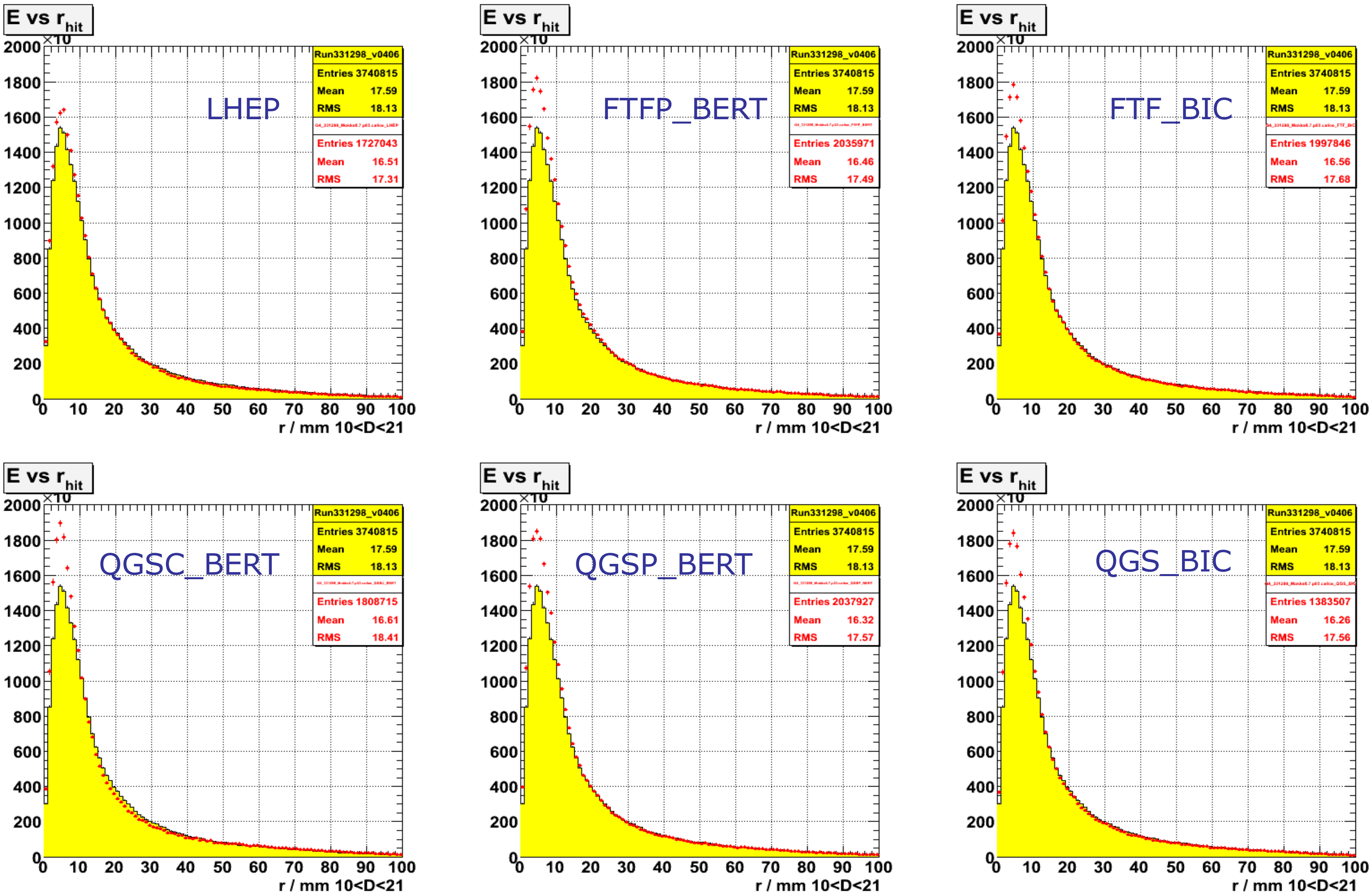
(Normalised to number of hits) (10< interaction layer <21)



Most models slightly narrow. But not too bad.

Transverse energy distribution: +30GeV

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



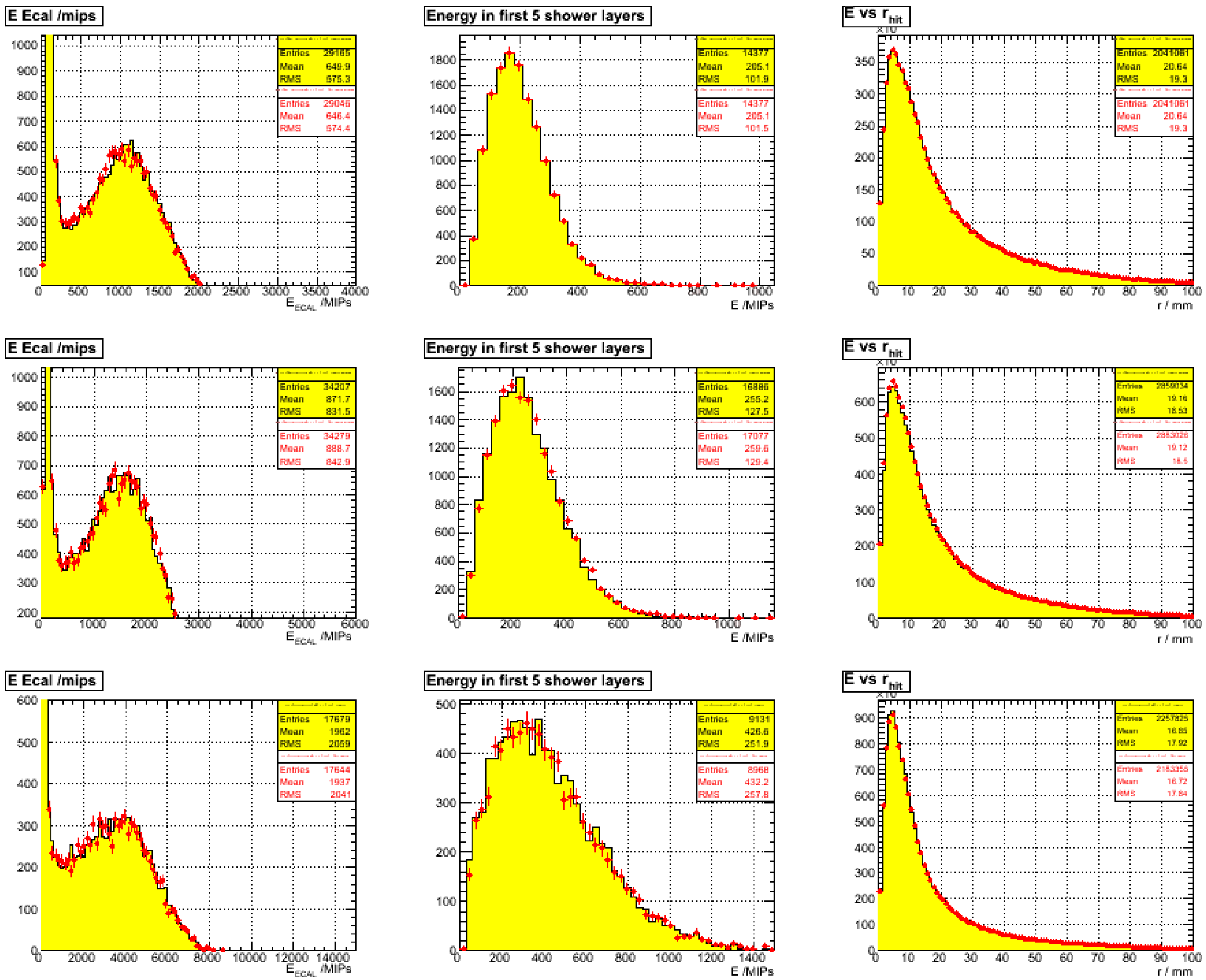
Suddenly LHEP shows very good agreement – better than the string models.

New Physics Lists – FTFP_BERT_TRV (yellow) c.f. FTFP_BERT (red)

8 GeV

12 GeV

30 GeV



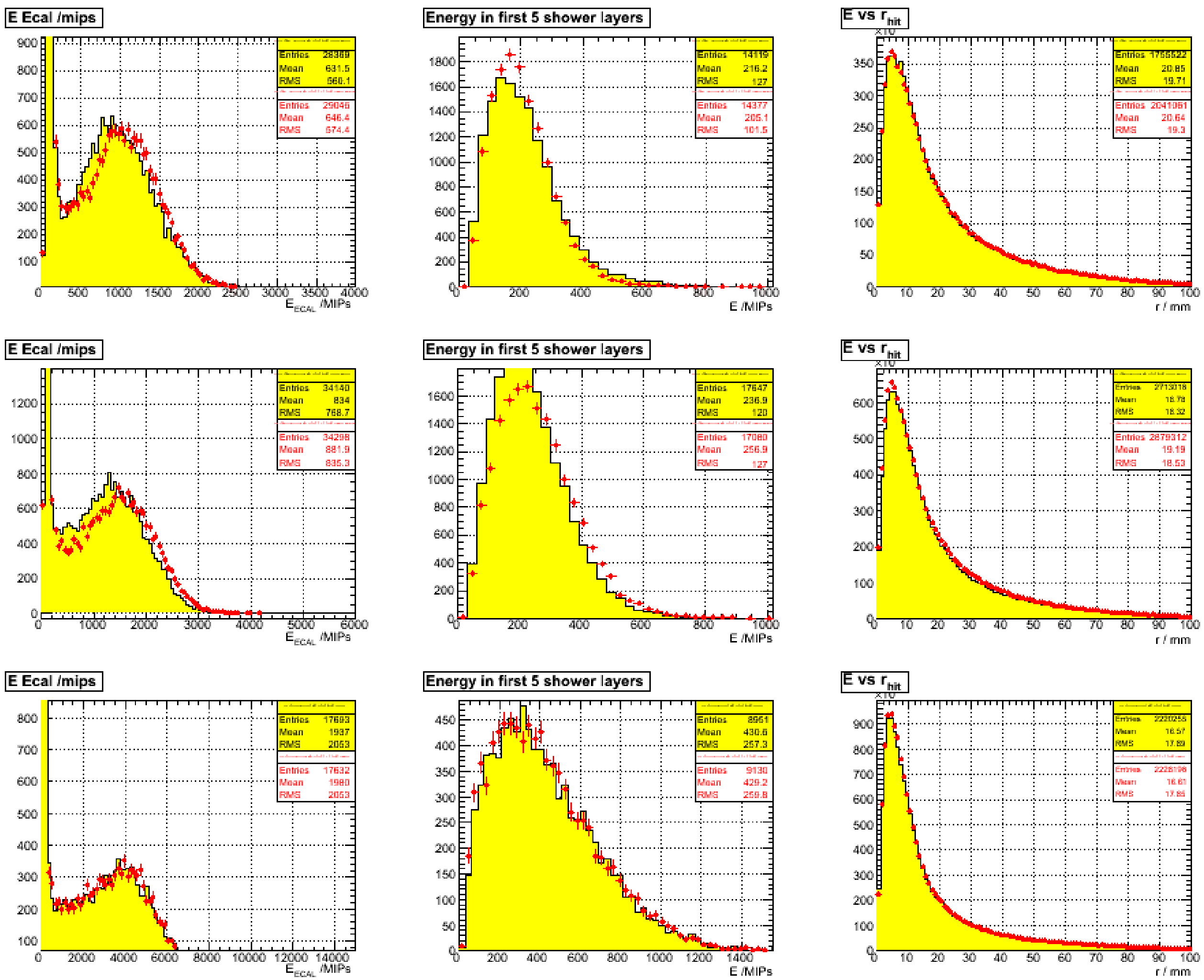
Little difference at these energies, as expected.
Using FTFP for the primary interaction in both cases

New Physics Lists – QGSP_FTFP_BERT (yellow) c.f. QGSP_BERT (red)

8 GeV

12 GeV

30 GeV



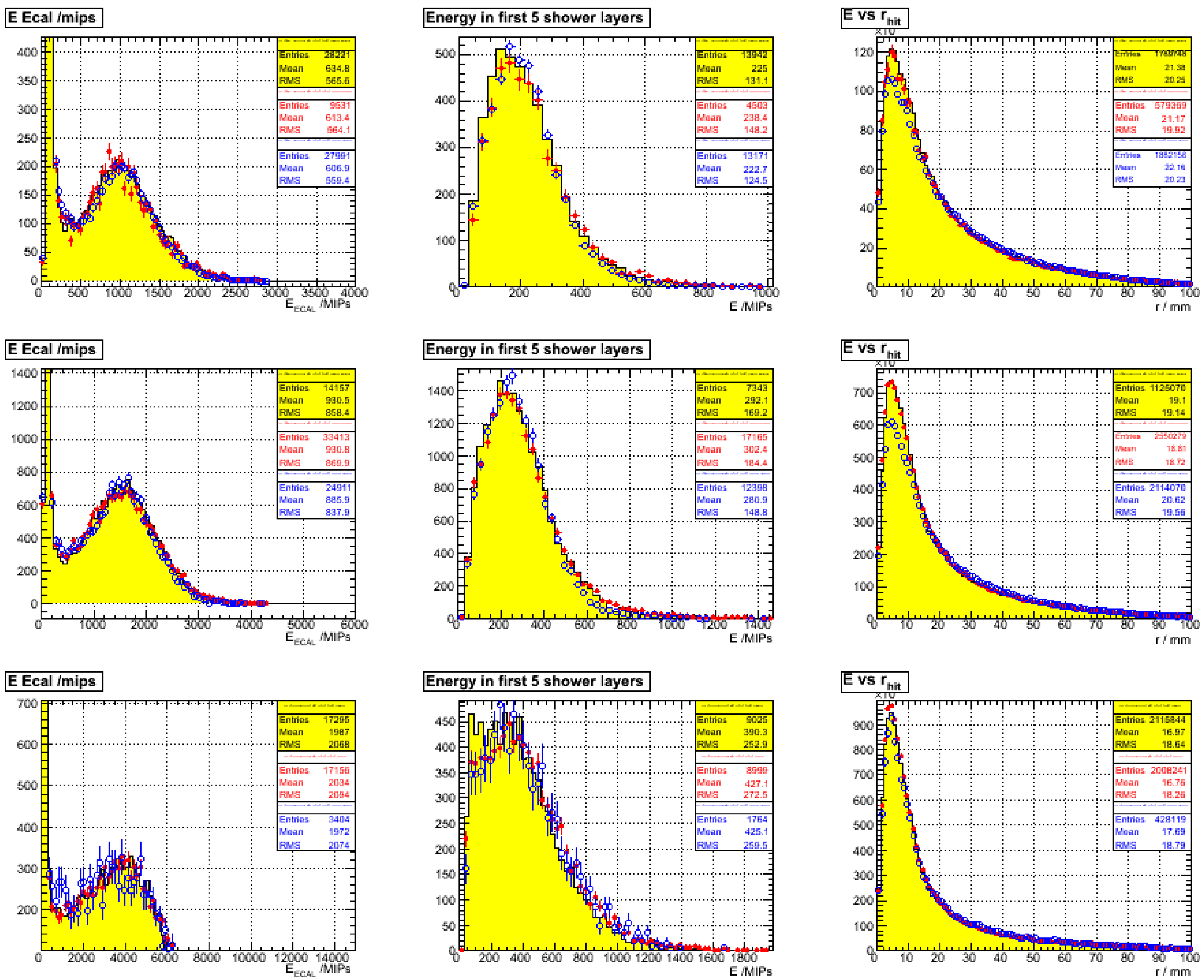
Different at 8 and 12 GeV – looks much like FTFP_BERT, because FTFP used for primary interaction. No change at 30 GeV. All as expected

New QGSC Lists – _BERT (yellow) _QGSC (red) _CHIPS (blue)

8 GeV

12 GeV

30 GeV



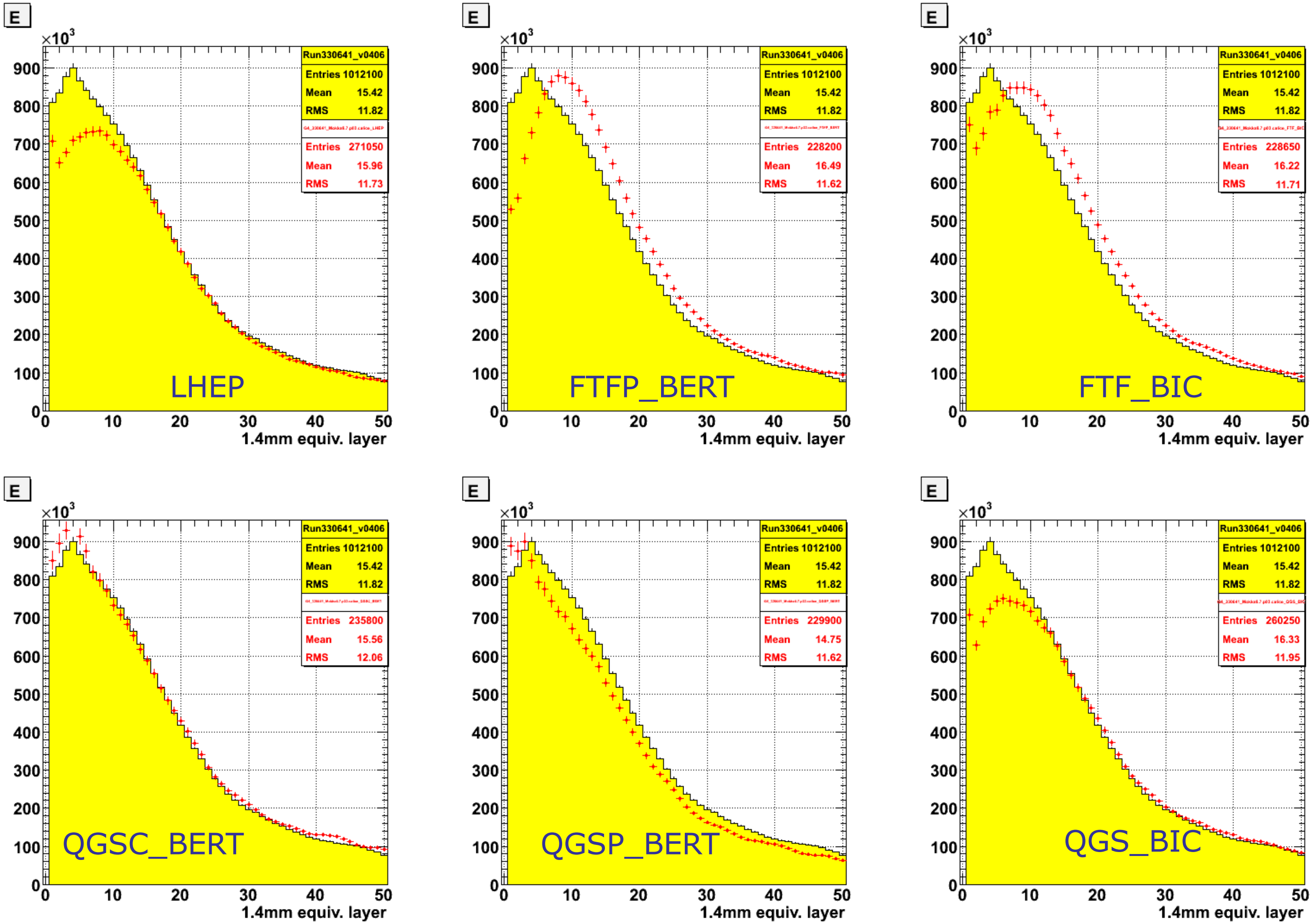
Some differences seen, e.g. in 5-layer energy, and transverse profile. Worth pursuing?

Longitudinal shower profiles

- Measure longitudinal shower profiles w.r.t. interaction point.
- Handle non-uniform sampling of ECAL by working with 1.4mm-equivalent layers of Tungsten. So, samples in the 2.4mm (4.2mm) stacks get entered twice (thrice) – with some interpolation to place energy in fictitious intermediate layers.
- Restrict interaction layer to be in first stack, so we can examine at least the first 50 1.4mm-equivalent layers of the shower (almost 1 λ_{abs}; ~20 X_0)
- Work in Progress Attempt to perform fits to these profiles, taking two or (usually) three terms of the form

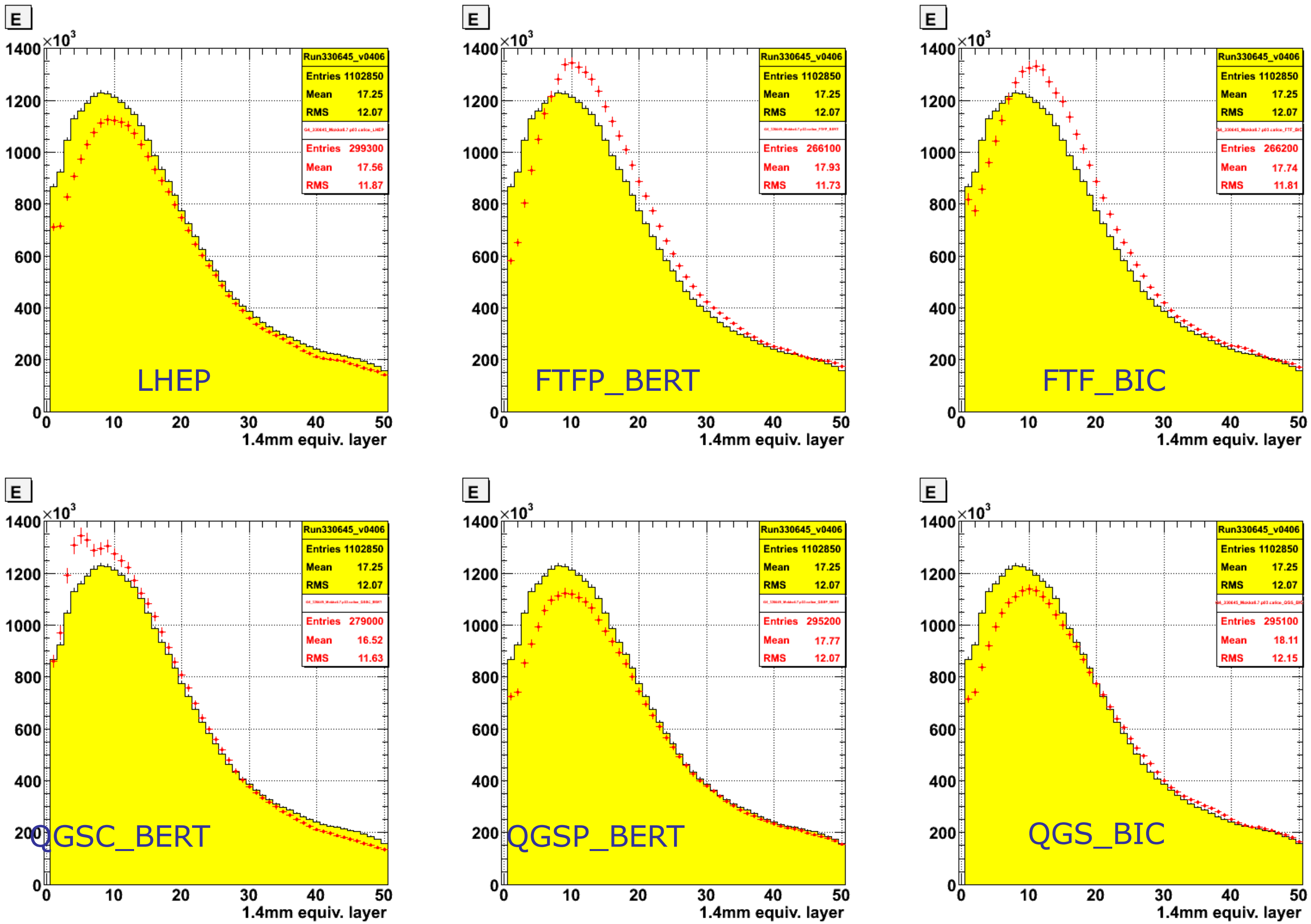
$$\sum_i A_i t^{\alpha_i} \exp(-\beta_i t)$$

Longitudinal profile : -8 GeV



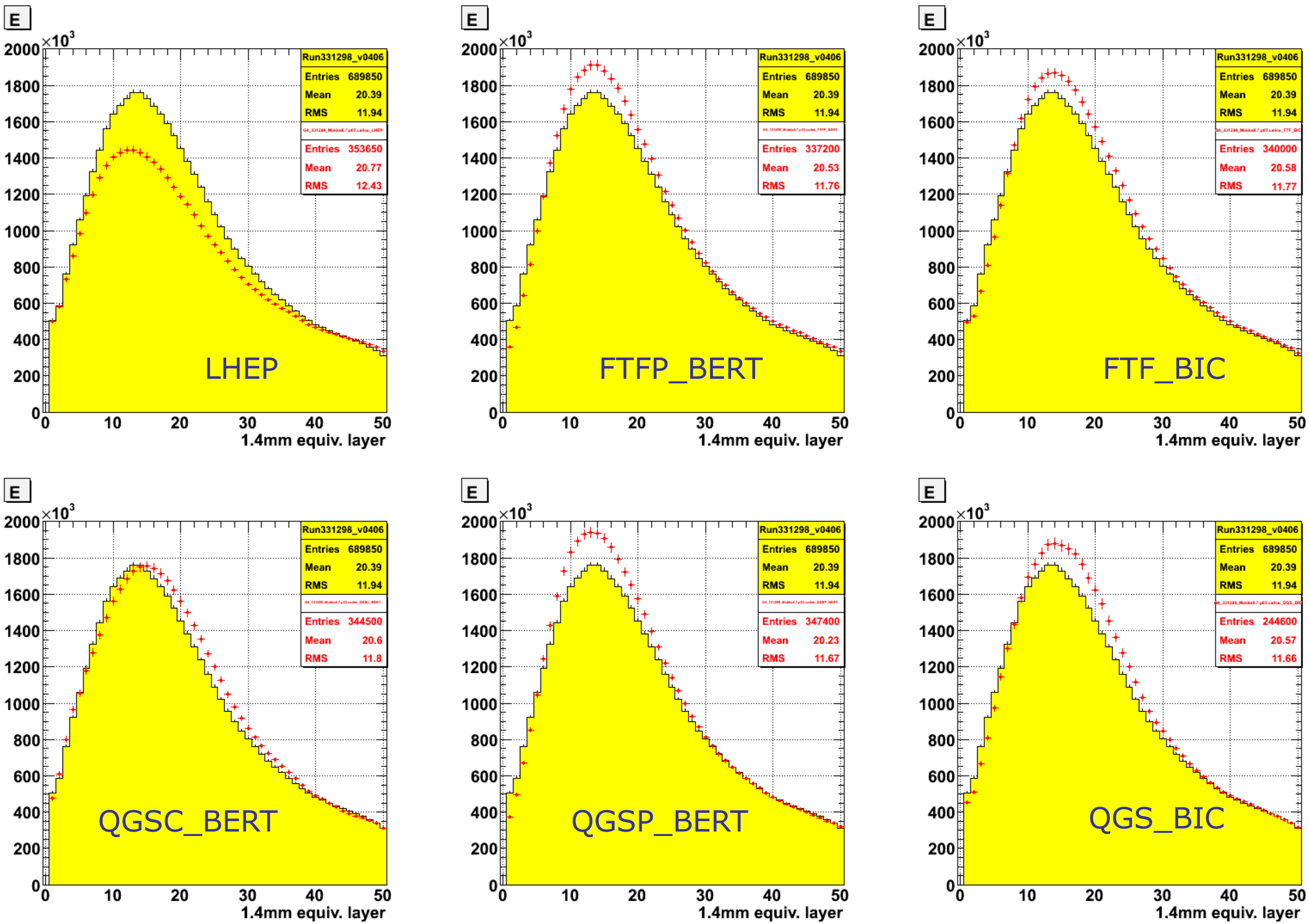
Significant differences. QGSC_BERT comes closest to data

Longitudinal profile : -12GeV



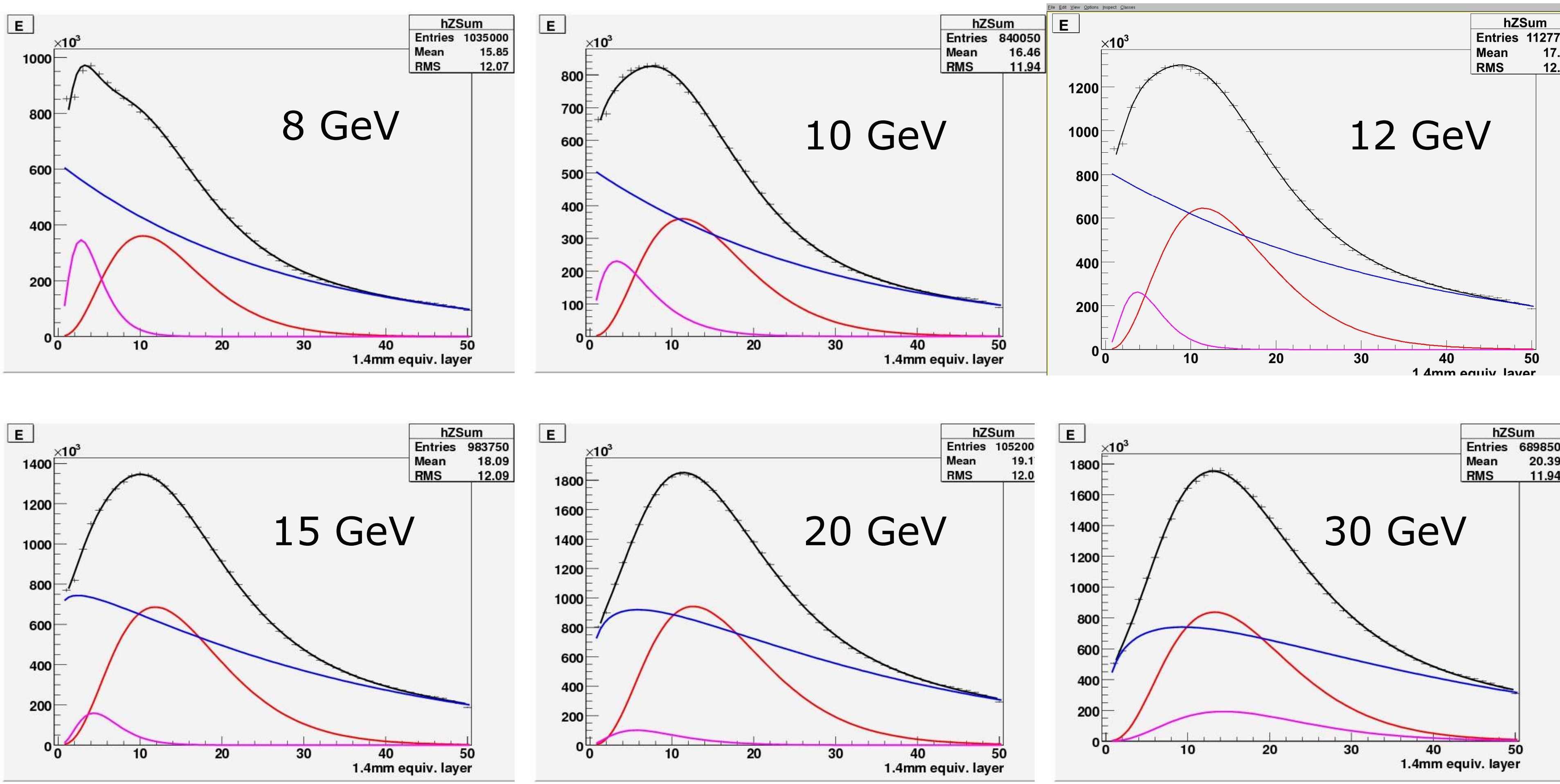
None of the models is particularly good.

Longitudinal profile : +30 GeV



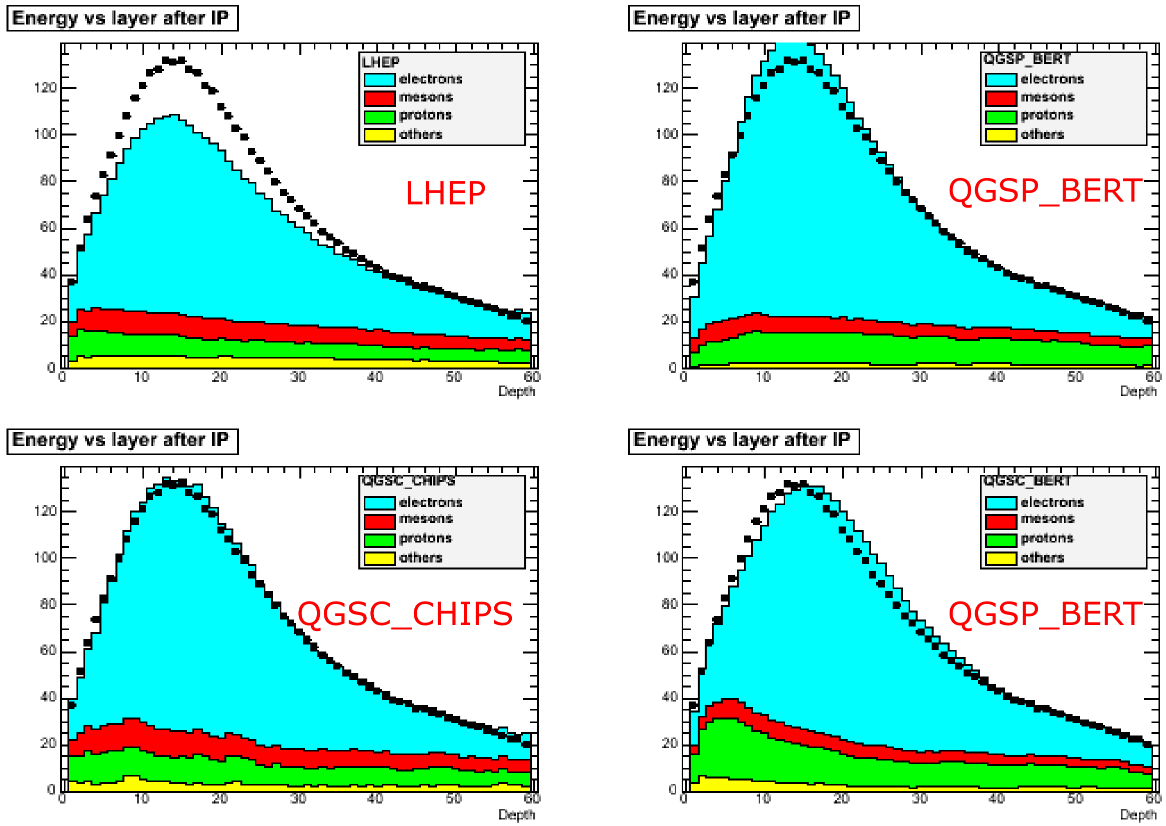
Again, none of the models is particularly good. QGSC_BERT best?

Fits to profiles



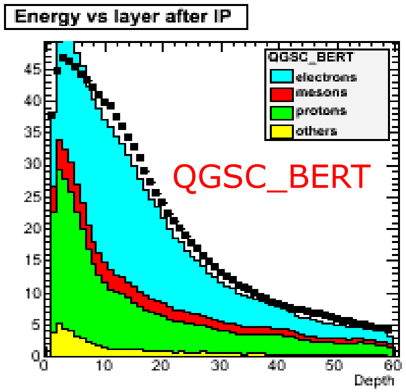
Red component can probably be largely ascribed to the photon contribution
Blue – penetrating – pions and other MIP-like hadrons?
Magenta? Definitely needed @ lower energies; not at 30 GeV. Nuclear fragments?

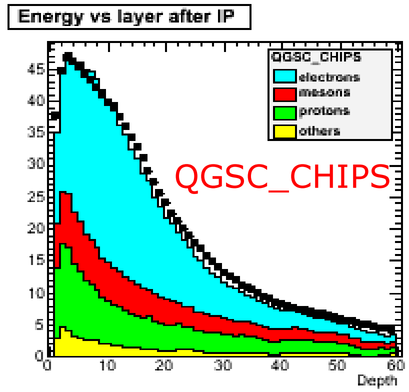
Longitudinal Shower profile composition @ 30 GeV

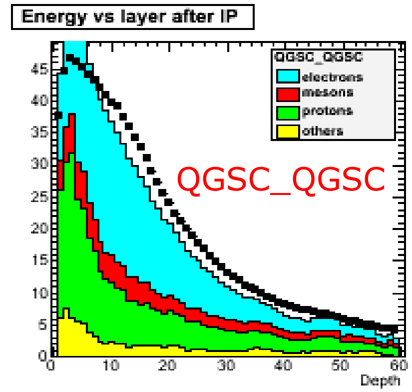


- Use detailed tracking in Mokka to decompose the hit energies into electrons (including δ-rays), "mesons" ($\pi^{\pm}$, $K^{\pm}$, $\mu^{\pm}$), protons and others (e.g. heavier nuclear fragments)
- Electrons dominate. Mesons contribute surprisingly little. Suggests a two-component fit would work well at 30 GeV.

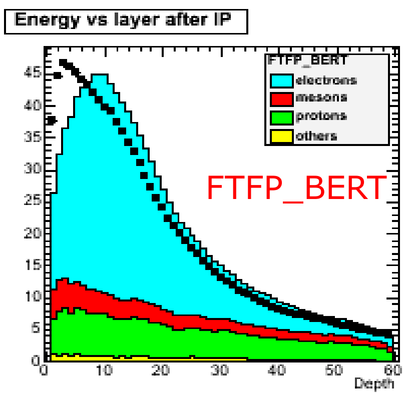
Longitudinal Shower profile composition @ 8 GeV

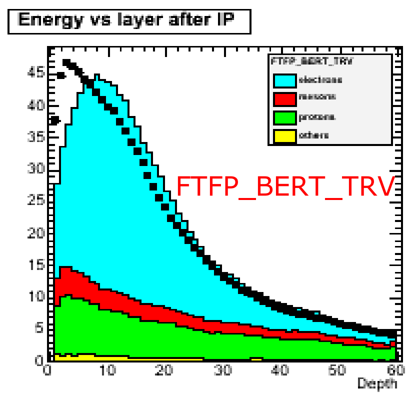


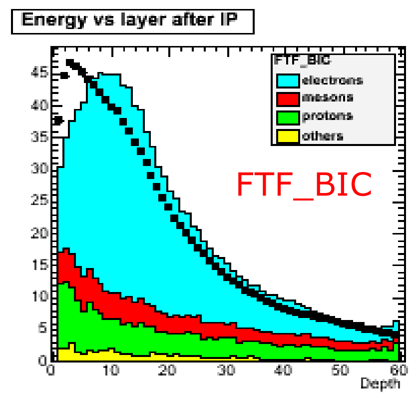


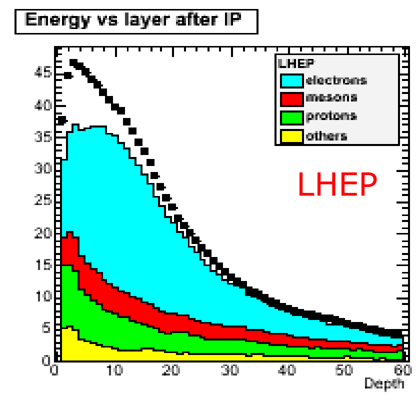


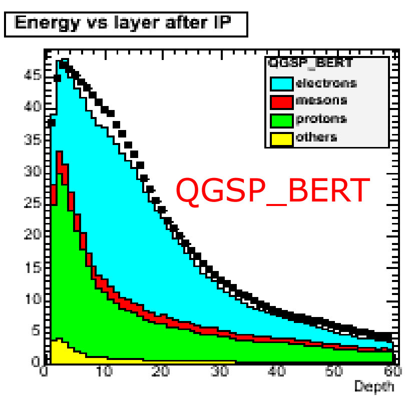
Big differences between models, especially in terms of the very short range proton component

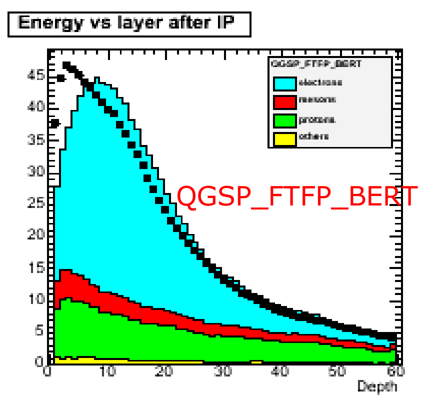


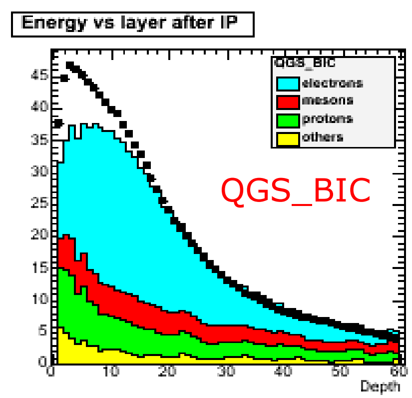






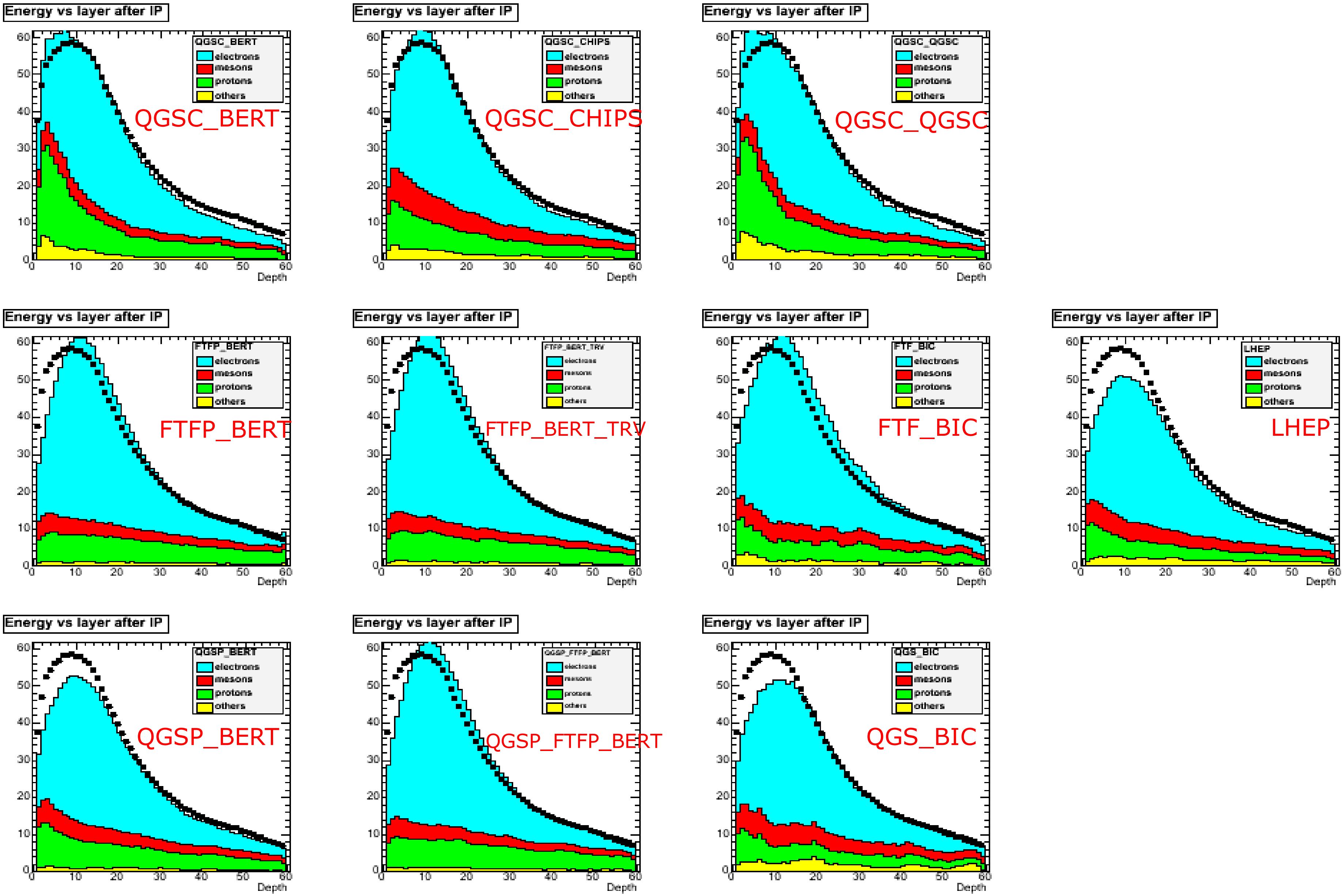




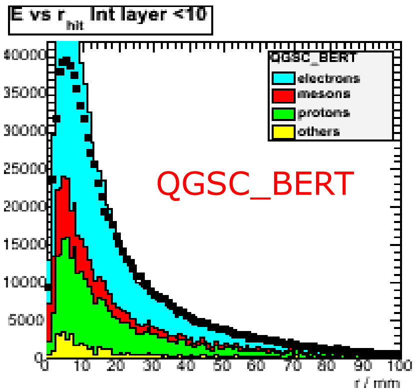


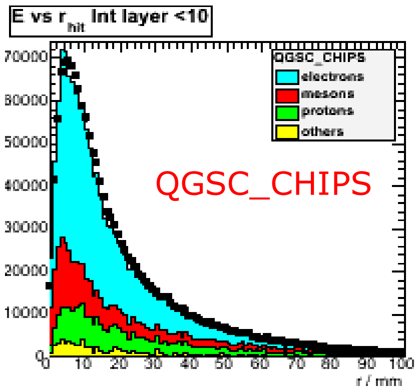
QGSC_CHIPS looks interesting?

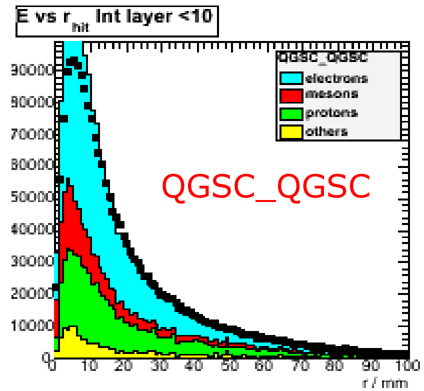
Longitudinal Shower profile composition @ 12 GeV

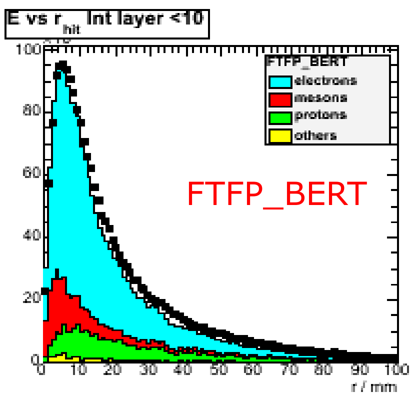


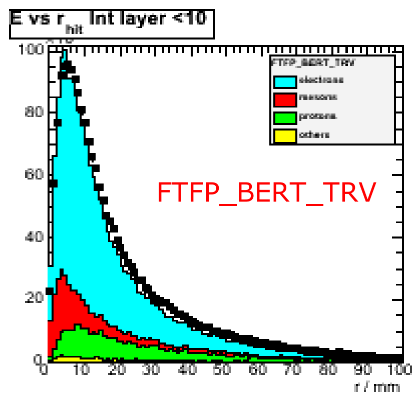
Transverse Shower profile composition @ 12 GeV

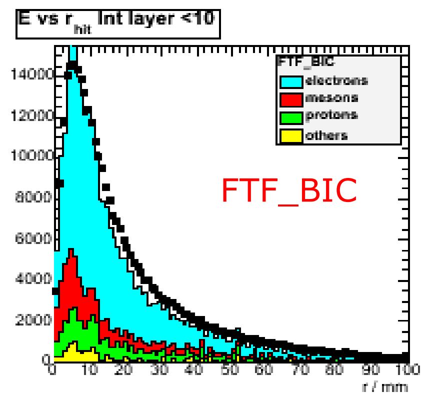


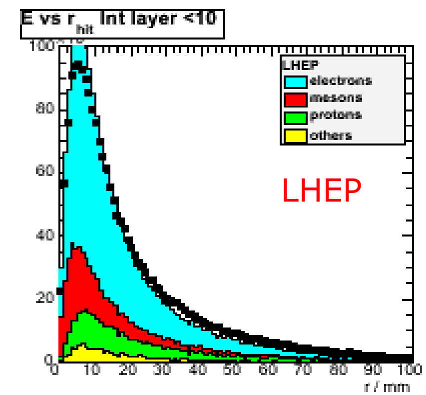


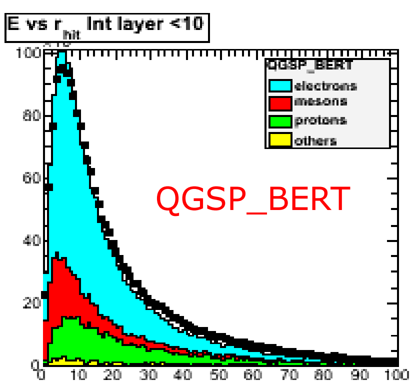


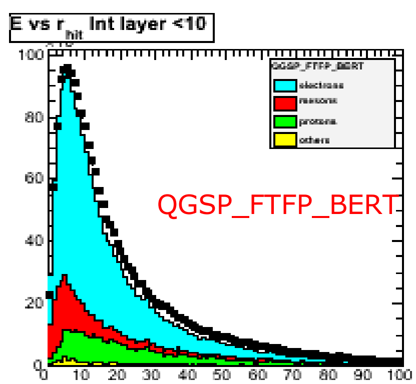


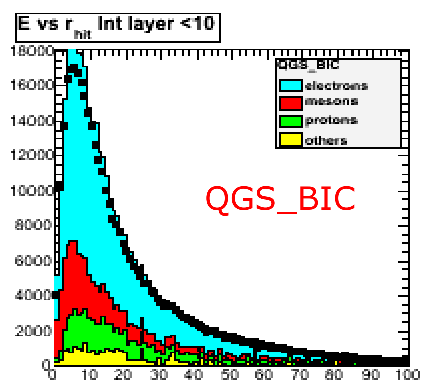












Not much discrimination between shower components, nor between models.

Summary

- The ECAL does have significant sensitivity to hadronic models.
- Although showers not contained, it allows one to probe features of the primary interaction.
- Focussing on the intermediate energy region, (8-15 GeV) crucial for ILC jets, yet where models are uncertain.
- Main problem is too much information – hard to distil clear conclusions.
- No physics list is perfect.
- Longitudinal profile shows promise as a way of partially disentangling the shower composition.
- The new list QGSC_CHIPS (in Geant4.9.3 β version) looks potentially promising, in the variables studied here.