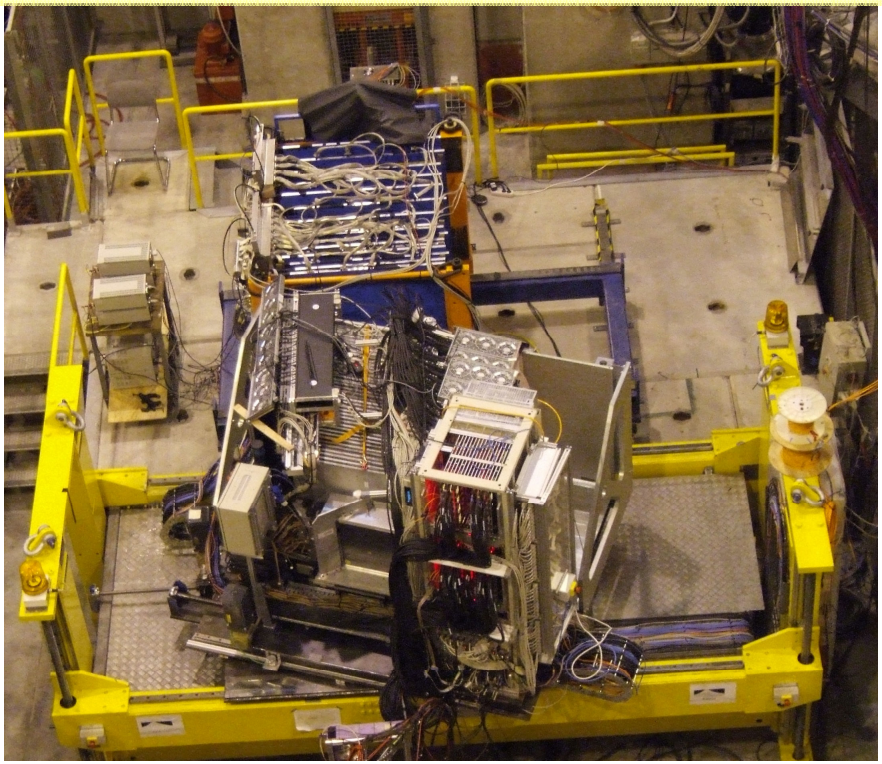
Pion showers in the CALICE Si-W ECAL

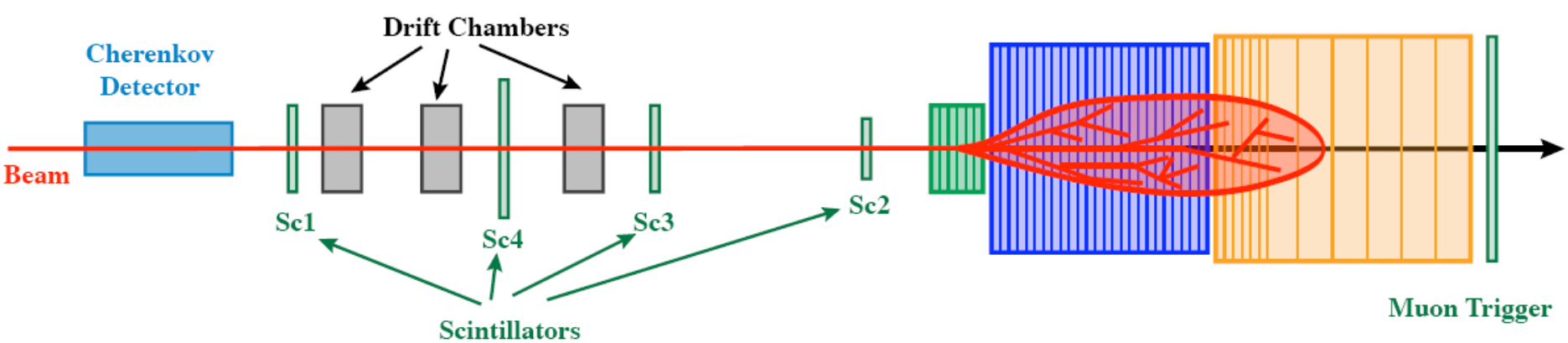
David Ward

- Outline CALICE detector + test beam
- Briefly mention e^- tests
- Mainly discuss measurements of hadronic showers

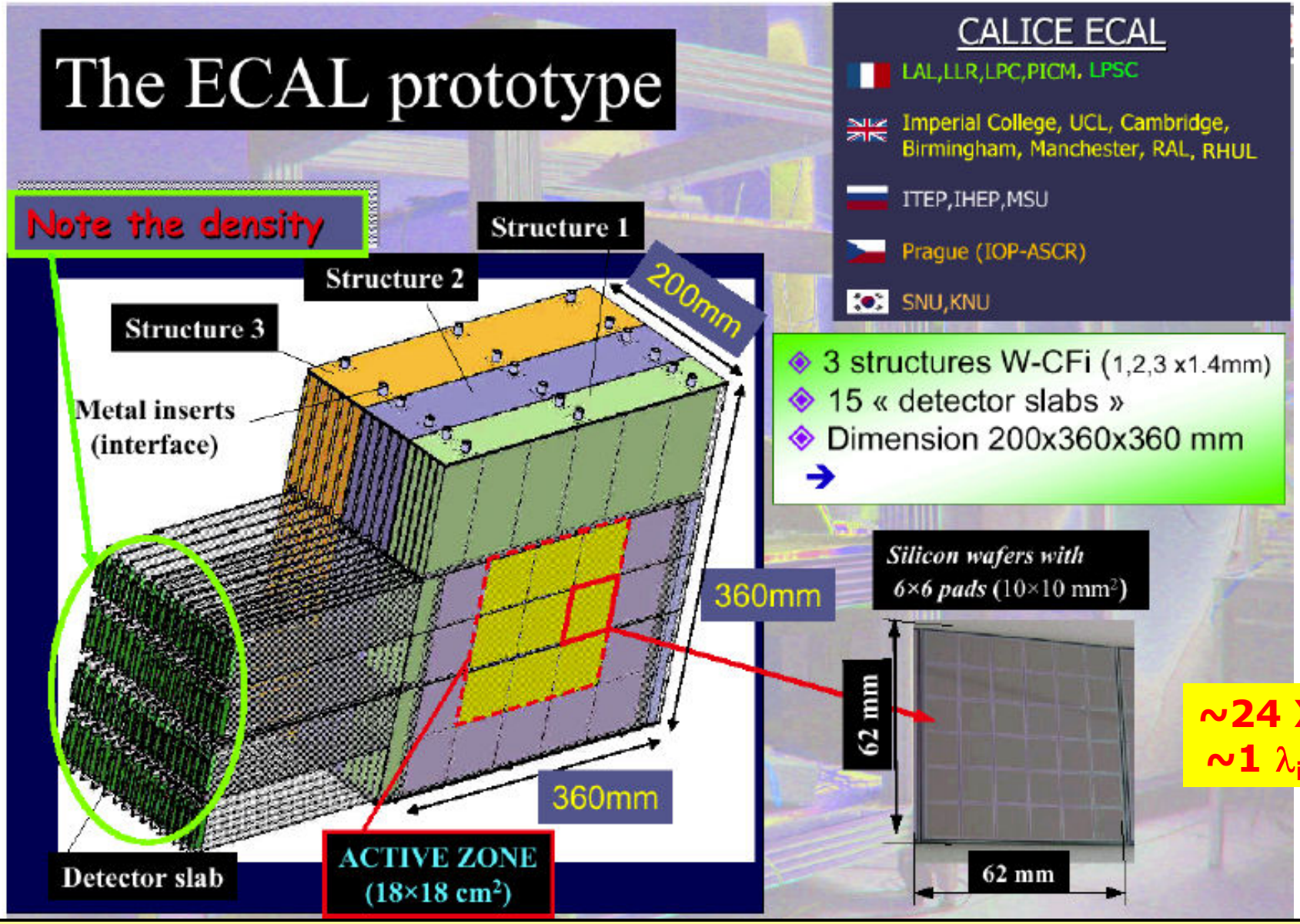
CALICE test beams

- **CALICE – highly granular calorimeters; motivated by particle flow approach to jet reconstruction**
- **Main beam tests, using π, μ, e beams:**
- **2006-7**
  - **SiW ECAL + AHCAL + TCMT @ CERN**
- 2007
  - Small DHCAL test @ Fermilab
- 2008
  - SiW ECAL + AHCAL + TCMT @ Fermilab
- 2009
  - Scint-W ECAL + AHCAL + TCMT @ Fermilab
  - Standalone RPC and Micromegas tests @ CERN

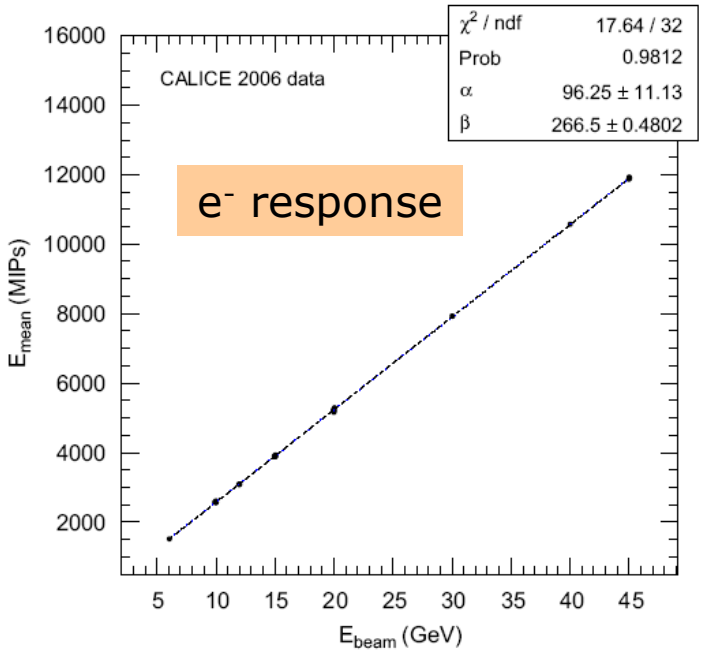


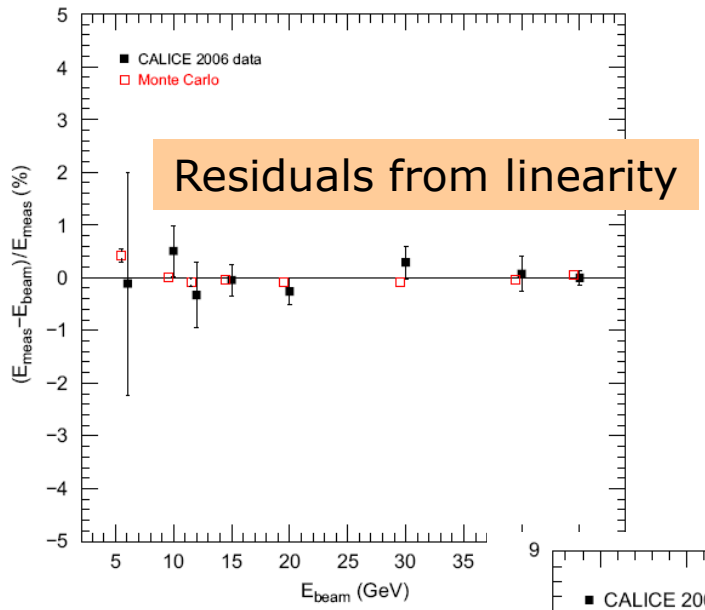


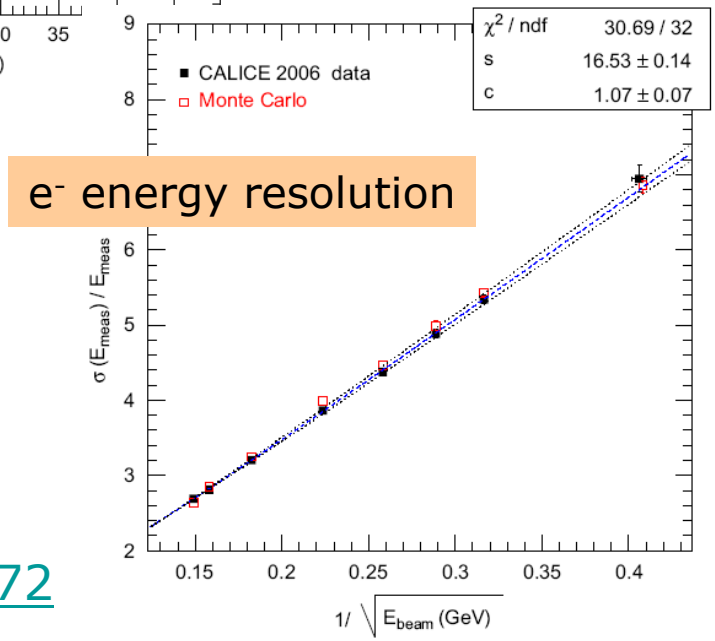
SiW ECAL


The ECAL prototype
Note the density
Structure 1
Structure 2
Structure 3
Metal inserts
(interface)
200mm
360mm
360mm
Detector slab
ACTIVE ZONE
(18×18 cm²)
CALICE ECAL
LAL,LLR,LPC,PICM, LPSC
Imperial College, UCL, Cambridge,
Birmingham, Manchester, RAL, RHUL
ITEP,IHEP,MSU
Prague (IOP-ASCR)
SNU,KNU
3 structures W-CFi (1,2,3 x1.4mm)
15 « detector slabs »
Dimension 200x360x360 mm
Silicon wafers with
6×6 pads (10×10 mm²)
62 mm
62 mm
~24 X0
~1 λint

SiW ECAL electron results





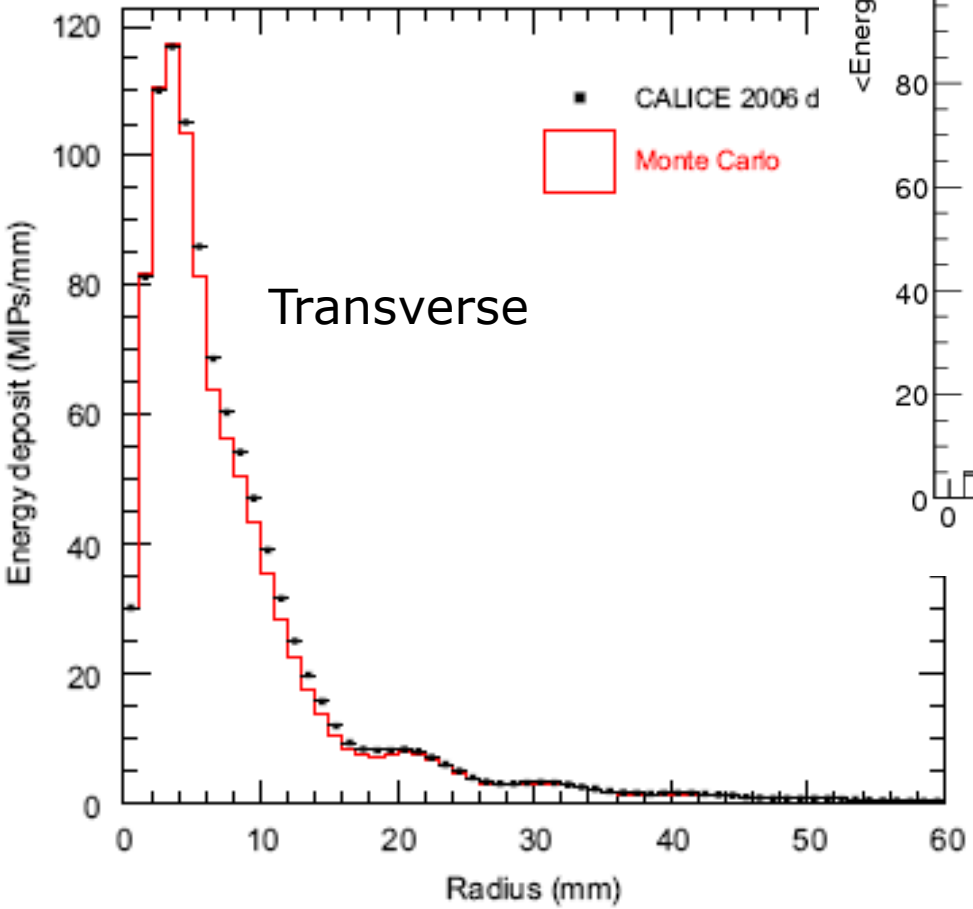


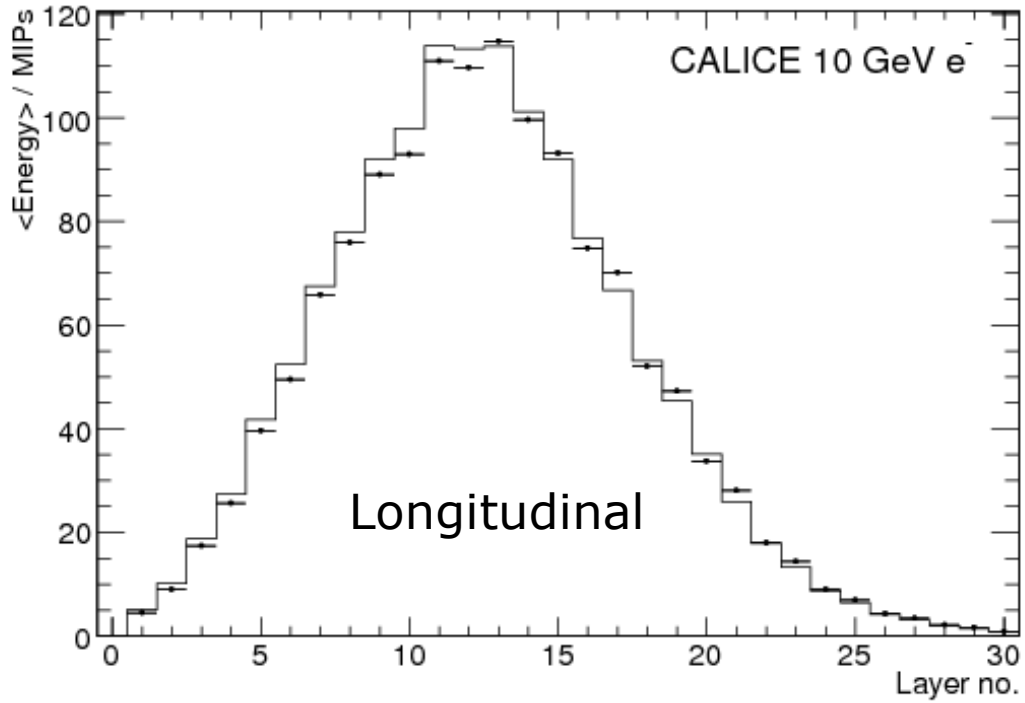
Linearity of response is good to ~1% (though small offset from zero in test beam setup; largely simulated)

Energy resolution: $16.5\%/\sqrt{E} \oplus 1.1\%$
Well modelled by Monte Carlo

NIM A608 (2009) 372

Shower profiles for e⁻





Generally well modelled by GEANT4

Pion beam data and MC simulations

- Reconstructed data
- 2007 data from CERN
- 8 energies used

  Run330641 – 8GeV π^-

  Run330332 – 10GeV π^-

  Run330645 – 12GeV π^-

  Run330328 – 15GeV π^-

  Run330326 – 20GeV π^-

  Run331298 – 30GeV π^+

  Run331286 – 50GeV π^+

  Run331324 – 80GeV π^+
- Calibrated using muons $\rightarrow$

  energies in MIPs
- Cuts to remove muons, electrons, protons.

- GEANT4 simulations

  GEANT 4.9.3
  with physics lists...

  QGSP_BERT

  QGSP_BERT_TRV

  QGSP_FTFP_BERT

  QGS_BIC

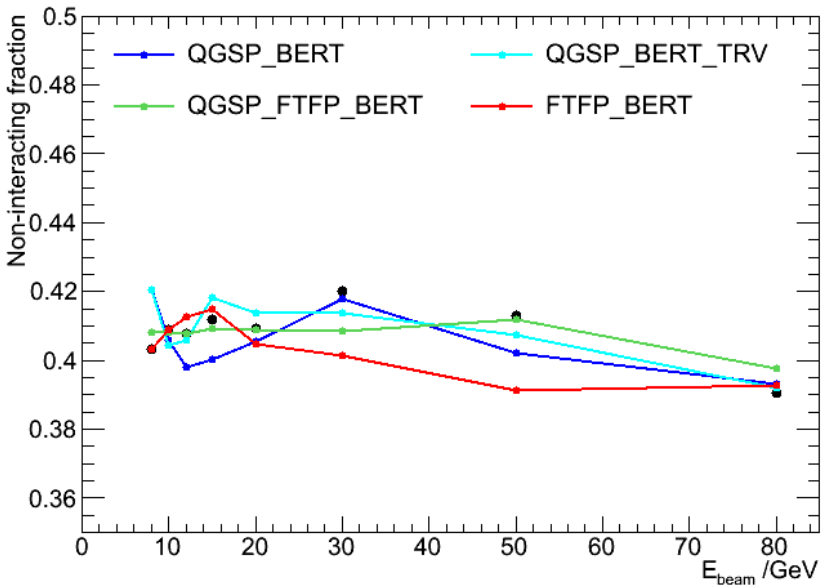
  QGSP_BIC

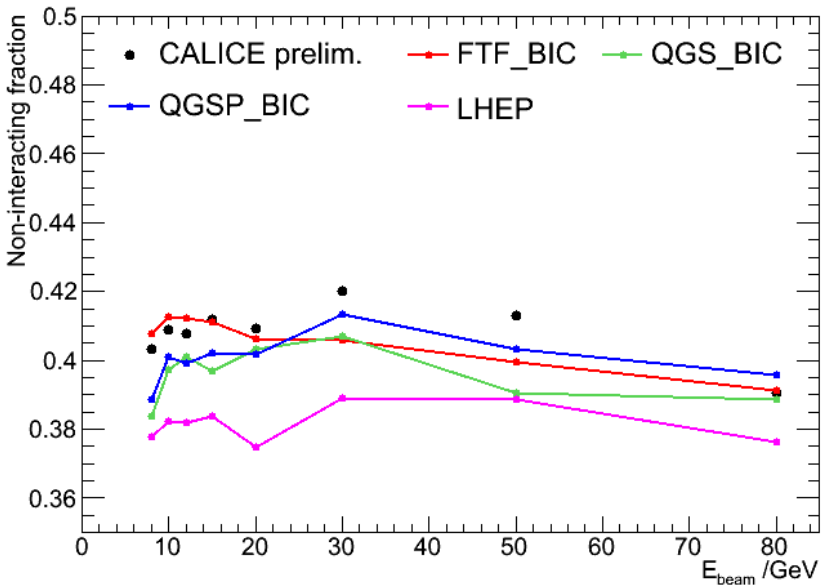
  FTFP_BERT

  FTF_BIC

  LHEP

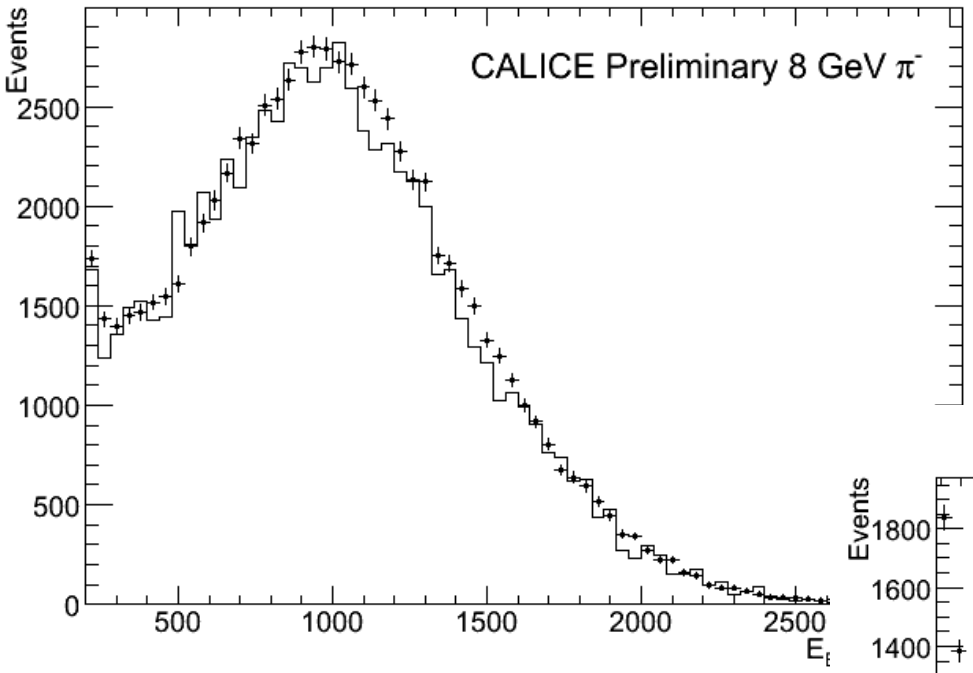
Fraction of non-interacting pions





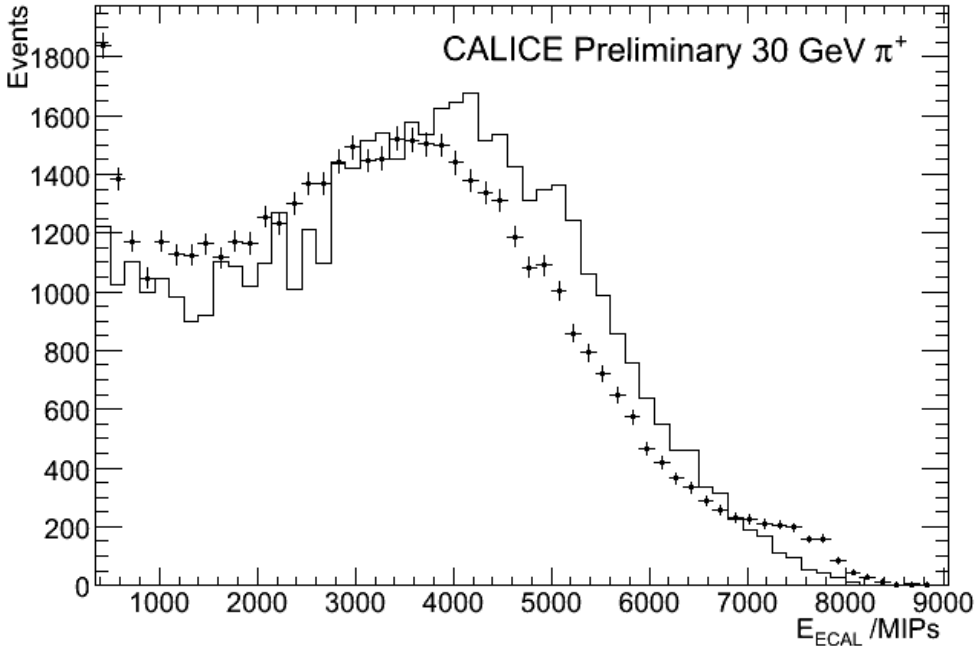
- Roughly half of pions start to shower in the ECAL (~$1\lambda_{int}$)
- "Non-interacting" : < 100 MIPs deposited in the ECAL
- Quite well modelled (~1-2%) by most physics lists – serves as a check of cross-sections on (mainly) tungsten.

Total ECAL energy



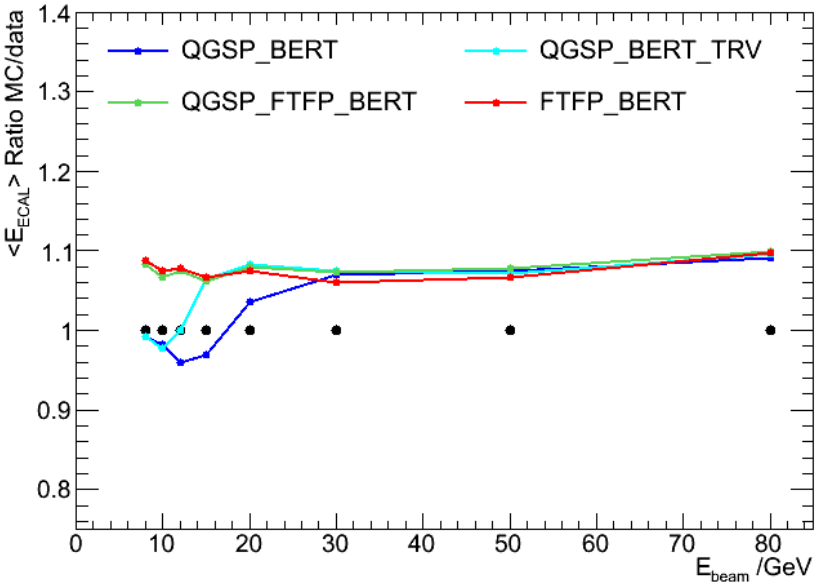
Pions which did interact. Only part of their energy is deposited in the ECAL.

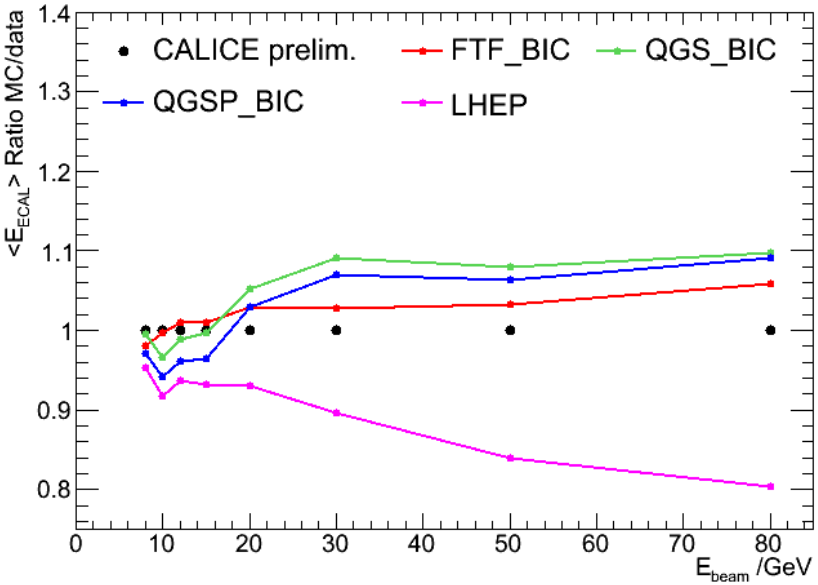
Compare data (points) with QGSP_BERT simulation



Mean energy in ECAL

Plot ratio of Monte Carlo / Data vs pion energy
for all eight physics lists

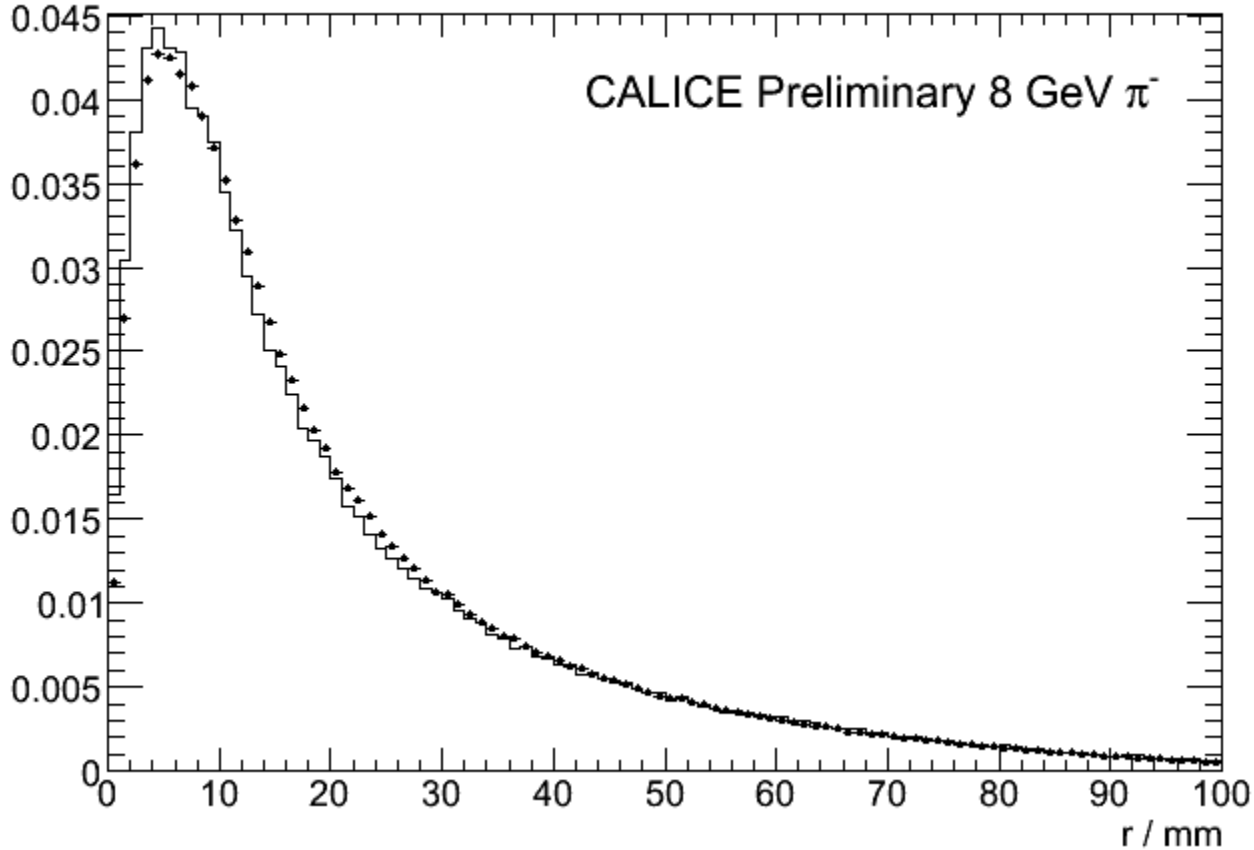




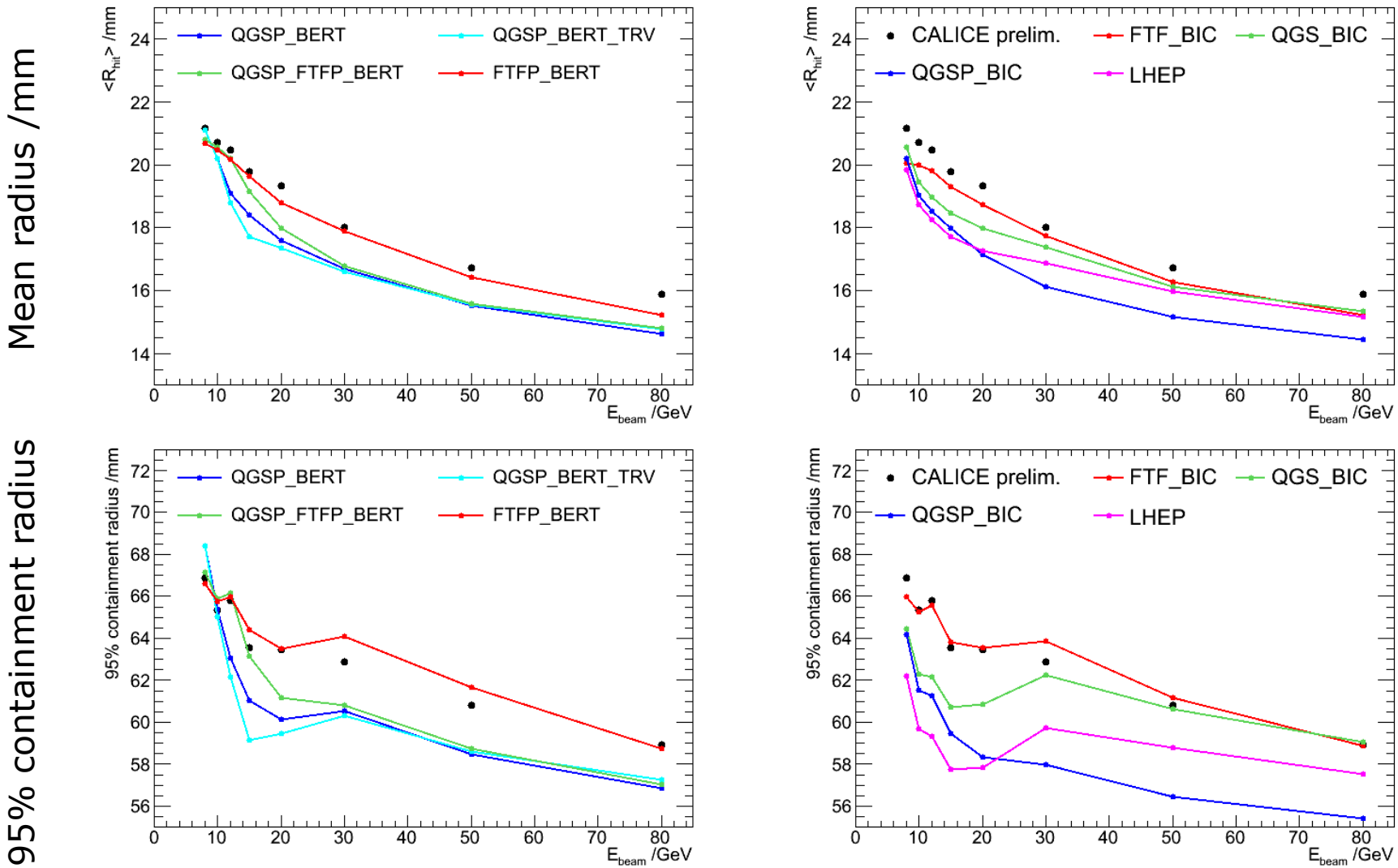
All except LHEP lie within 10% of data
Several models are good at ~ 8 GeV
FTF_BIC probably closest to data overall

Transverse shower profile

Radius of hit computed w.r.t. the shower centroid in (x,y)
Plot the energy-weighted radial distribution
Data (points) c.f. QGSP_BERT.

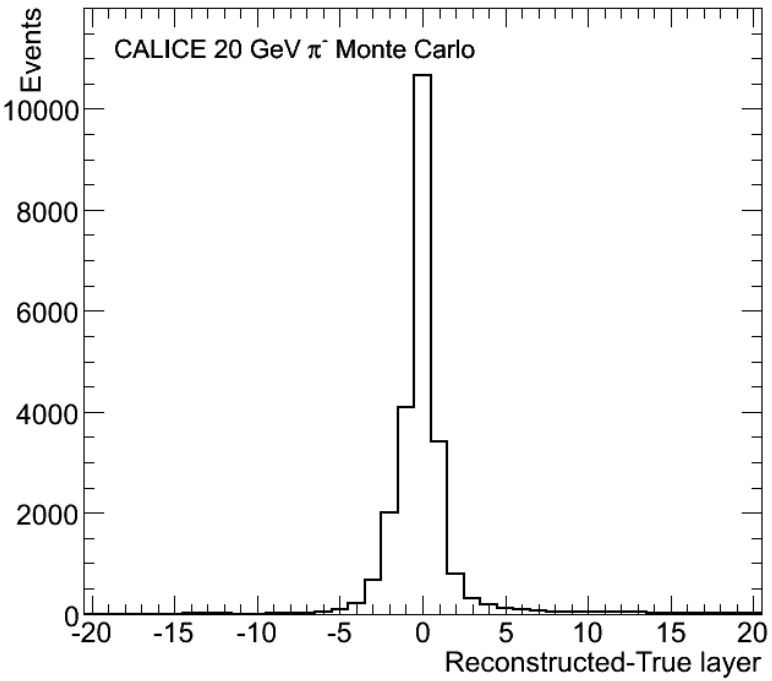


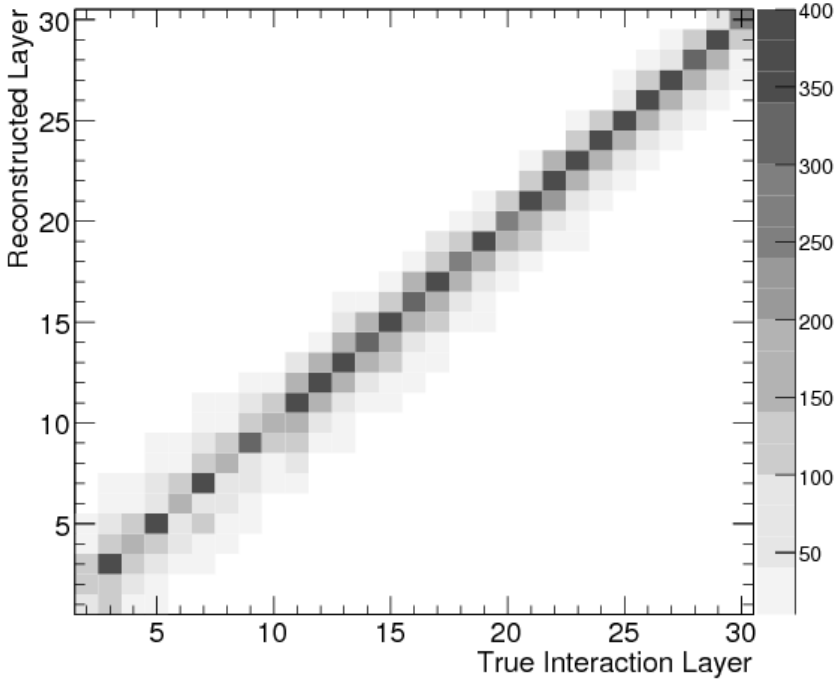
Mean shower radius; 95% containment



Most models lie below data (showers too narrow by ~10%). FTFP_BERT, FTF_BIC best

Identify shower starting point

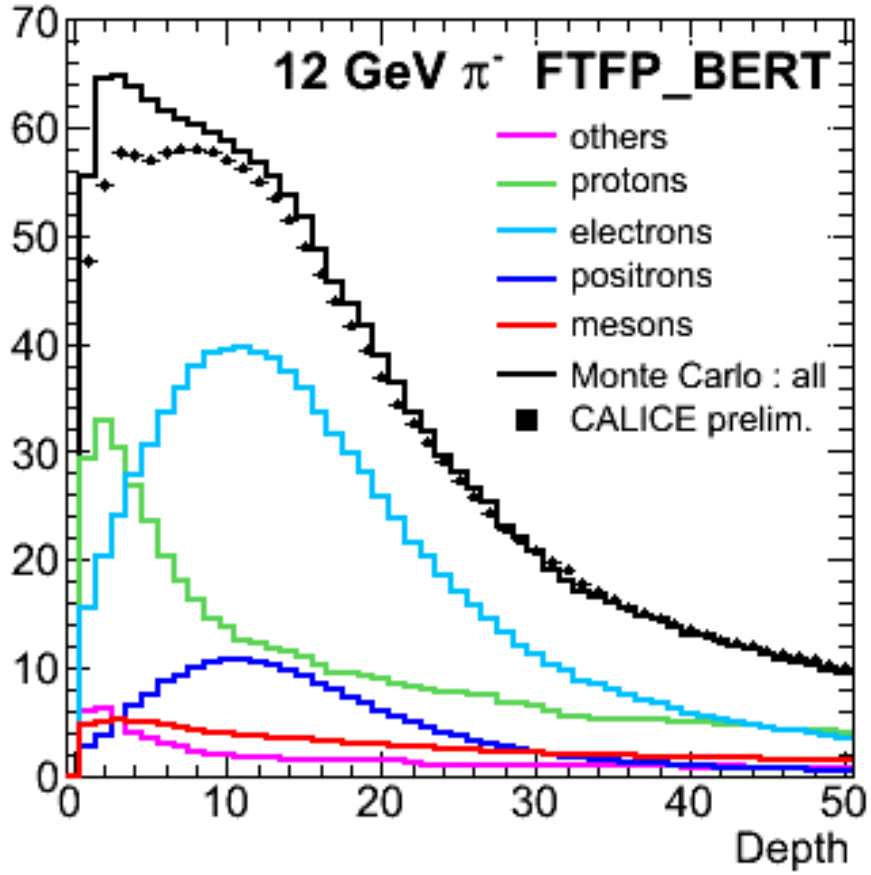




Simple algorithm – excluding isolated hits, find the first ECAL layer with >10 MIPs, so long as two out of the following three also >10 MIPs
Usually correct to within ±1 layer

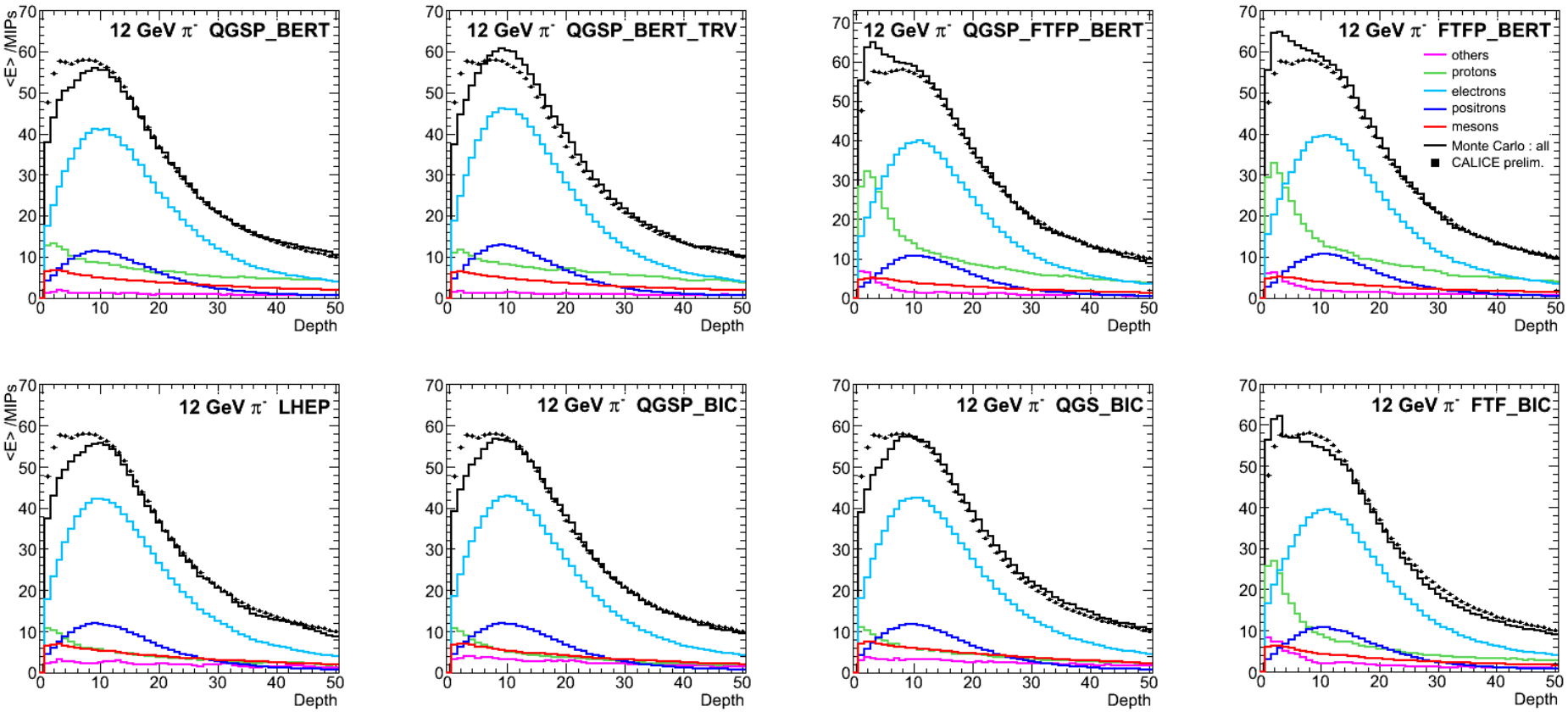
Longitudinal Shower Profile

- Want to deconvolve the distribution of paticle interaction points from the (more interesting) intrinsic shower shape.
- Use the interaction point as calculated above, and measure MIPs/layer thereafter.
- In MC can use truth info to separate contributions from different species.
- $e^{\pm}$ peak after ~10-15 layers, as expected
- "mesons" show long profile
- Protons show a short-range component (nuclear fragments) as well as longer



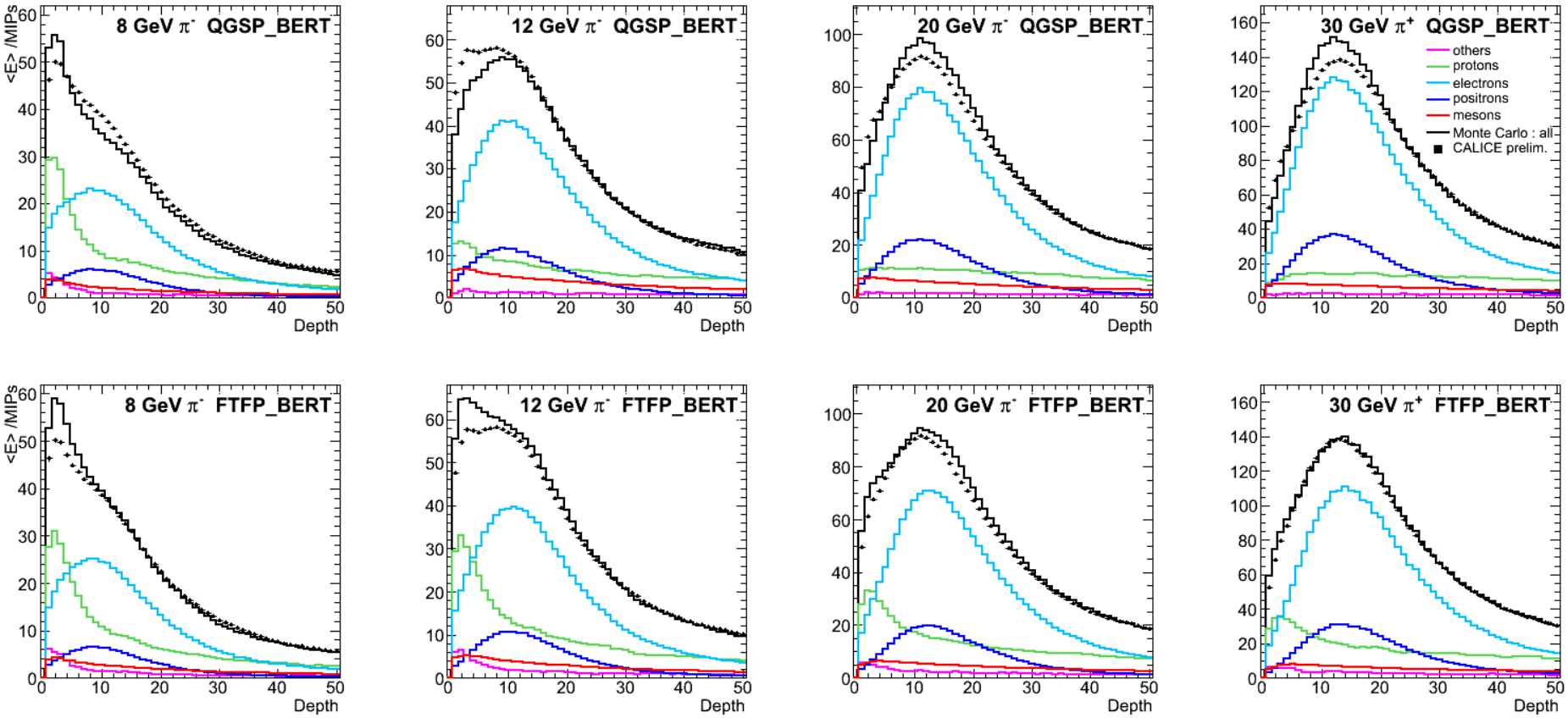
This model, at this energy, seems to overestimate the nuclear fragments

12 GeV compared with eight physics lists



Significant differences between models;
most obviously in regard to the proton contribution
No model is perfect.

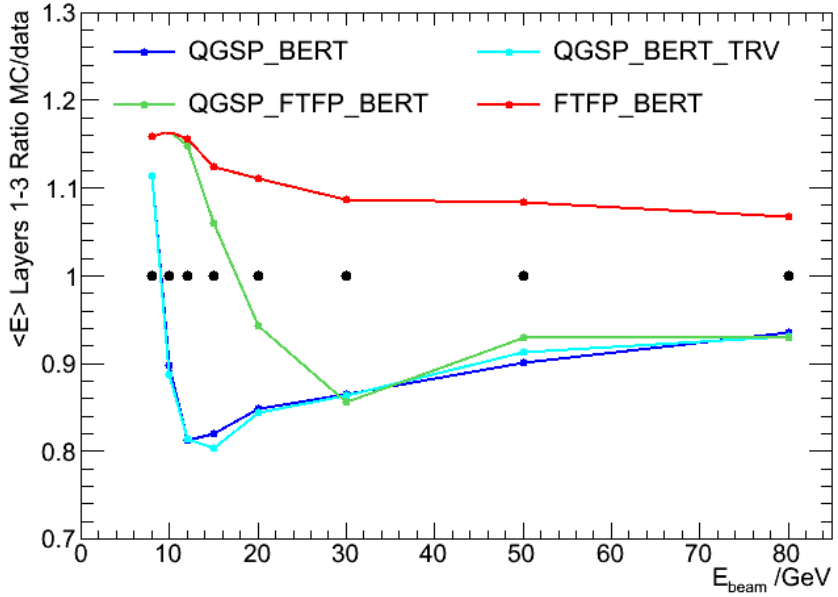
Two physics lists @ four typical energies

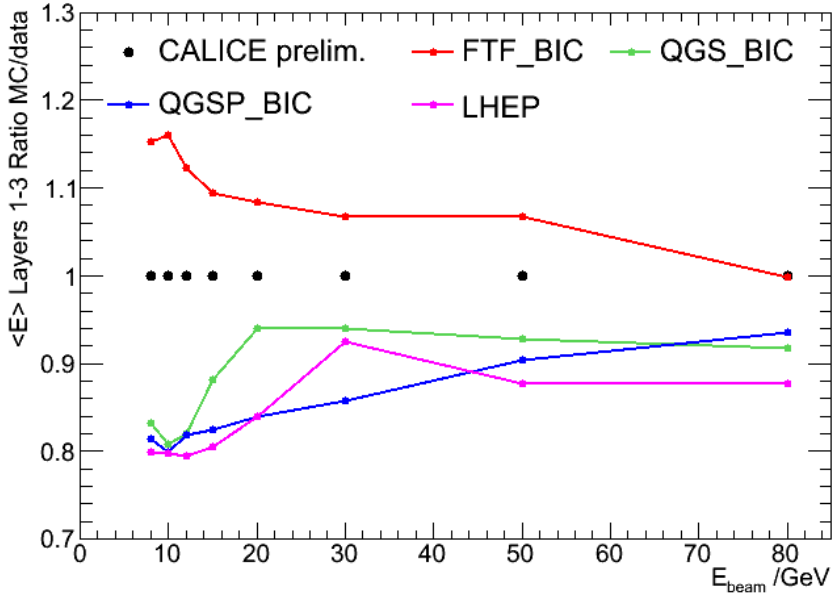


Try to summarise the situation by examining three ranges of depth dominated by different shower components…

Energy in layers 1-3

Ratio Monte Carlo / Data
Region dominated by nuclear fragments

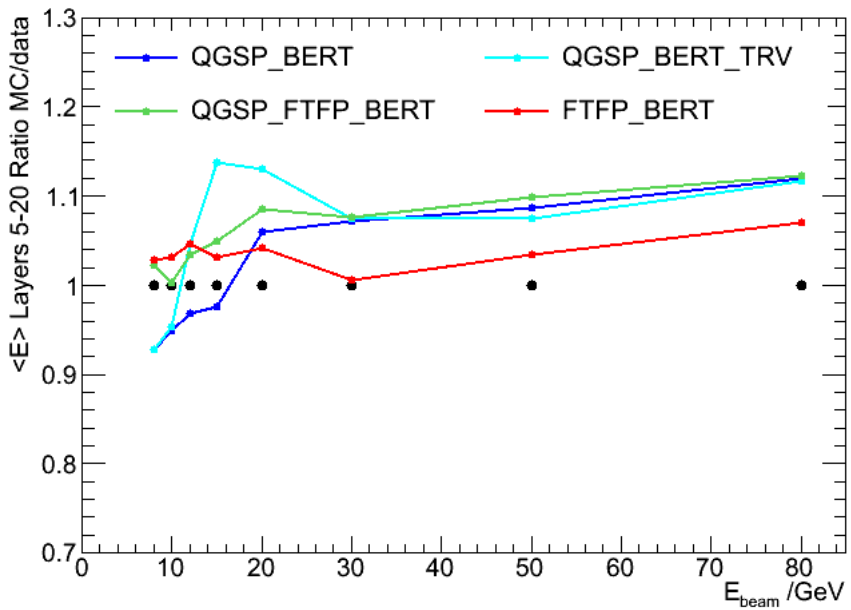


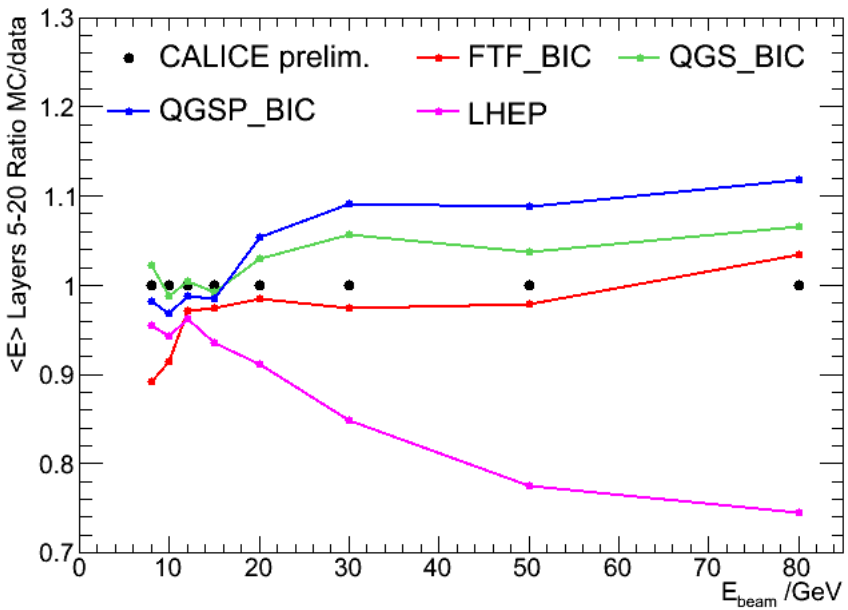


FTFP_BERT and FTF_BIC systematically overestimate the data
So do the BERTINI-based physics lists at 8 GeV
Other models lie below data
Discrepancies at the ~20% level

Layers 5-20

Ratio Monte Carlo / Data
Region dominated by electromagnetic component

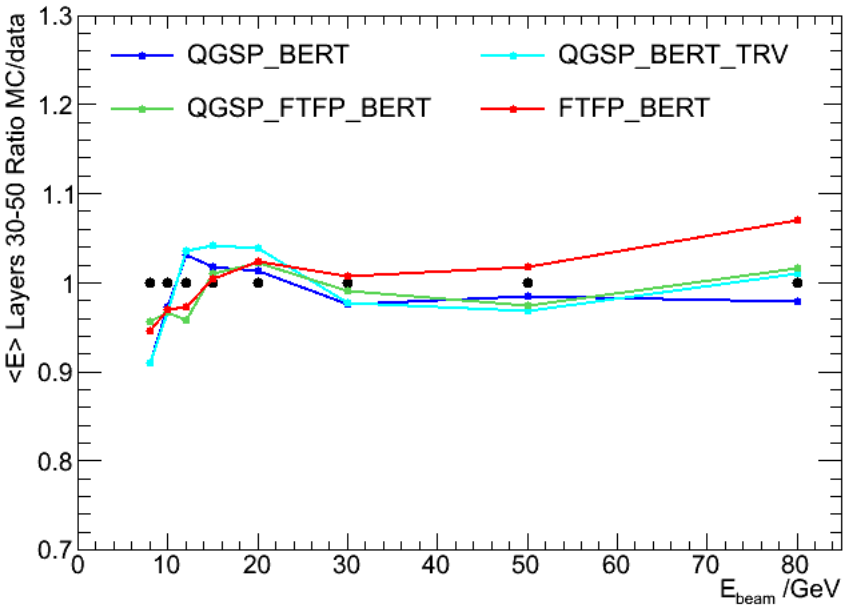


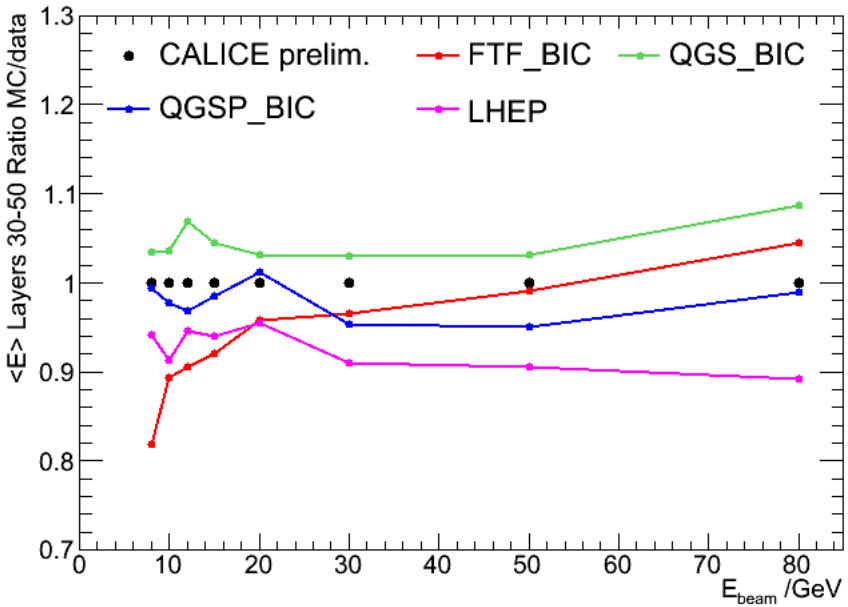


LHEP systematically low
FTFP_BERT and FTF_BIC seem to be closest to data above 20 GeV

Layers 30-50

Ratio Monte Carlo / Data
Tail region - dominated by long-range hadrons





Most physics lists are within 10%

Other physics lists studied

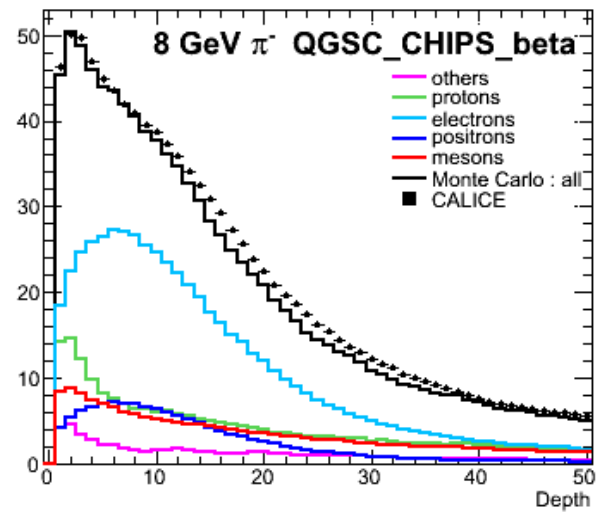
- FTFP_BERT_TRV
  - Not significantly different from FTFP_BERT in our data.
- QGSP_BERT_HP
  - The high precision neutron tracking does not have a significant effect on the response of our ECAL.
- CHIPS-based models
  - These seem interesting.
  - Studied QGSC_BERT, QGSC_CHIPS and QGSC_QGSC in GEANT4.9.3.b01 β-release. QGSC_CHIPS was very promising, and probably gave the best overall description of our data.
  - Studied the same three lists, and CHIPS alone, in the released GEANT4.9.3. Performance was very poor – too much energy into low energy protons. We believe this is understood, and we will be interested to evaluate updated versions.

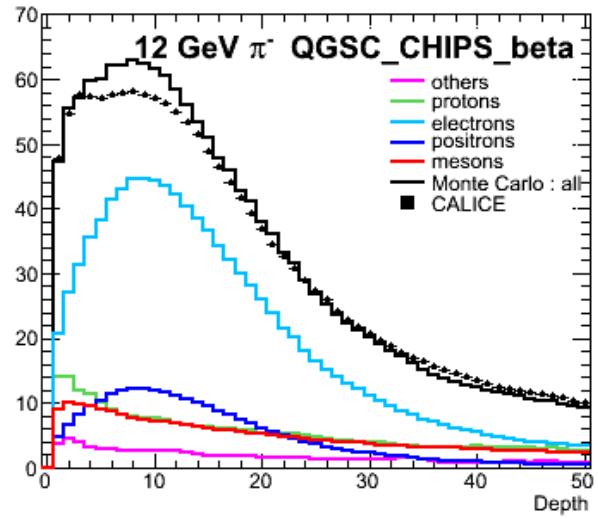
Summary

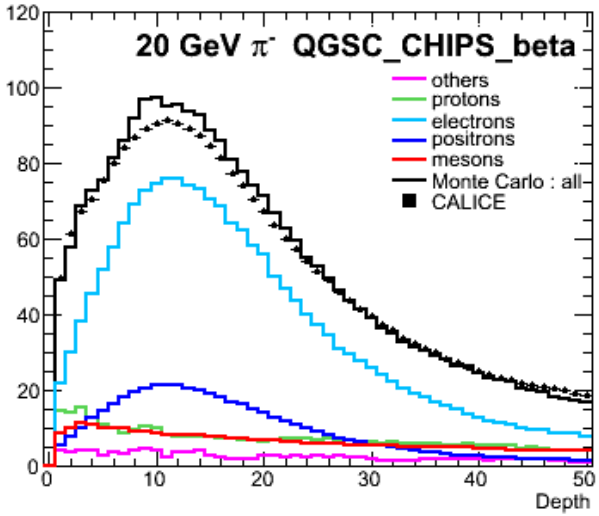
- CALICE Si-W ECAL is clearly too small to contain hadronic showers.
- But its high granularity, and small X_0/\lambda_{int} allow us to make some detailed observations of the shower substructure just after the primary interaction. Also provides information about interactions in Tungsten.
- Looked at the energy deposited in the ECAL, the transverse and longitudinal shower profiles.
- Longitudinal profile of the shower w.r.t. the initial interaction seems particularly useful.
- Most of the physics lists studied give a reasonable description of the data, to the 10-20% level.
- Since the changes to the FTF model in GEANT4.9.3, the physics lists FTFP_BERT and FTF_BIC seem slightly favoured, especially in terms of the transverse shower width, and also the longitudinal profile.

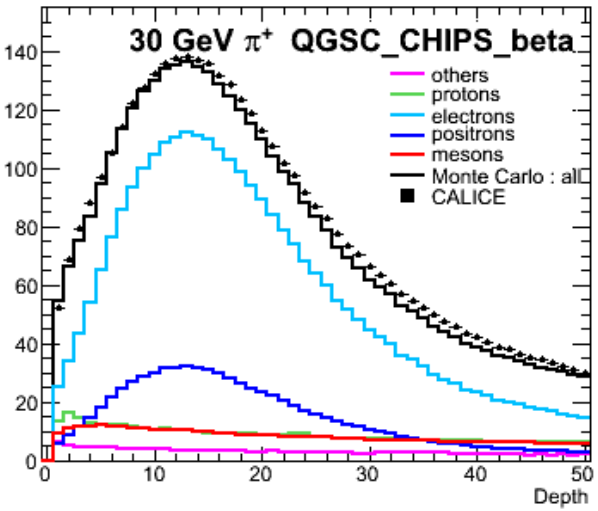
Backup

QGSC_CHIPS from GEANT4.3.b01

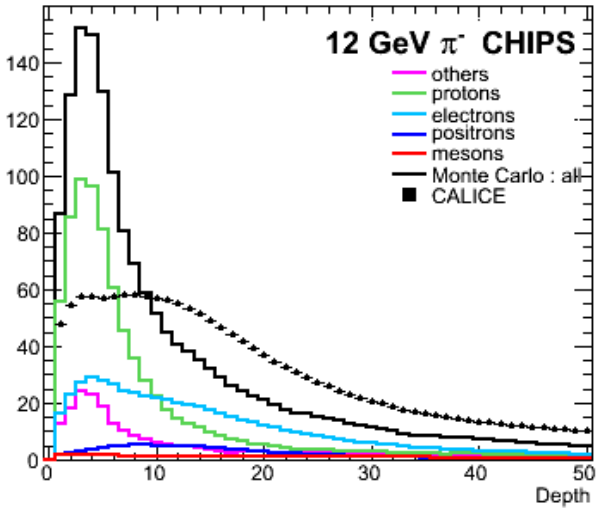


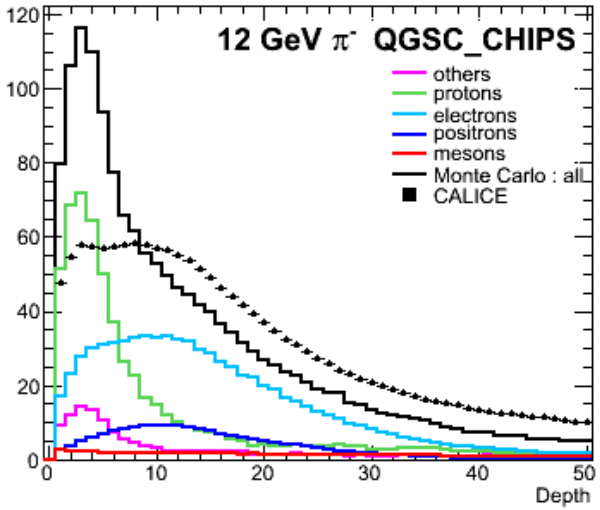


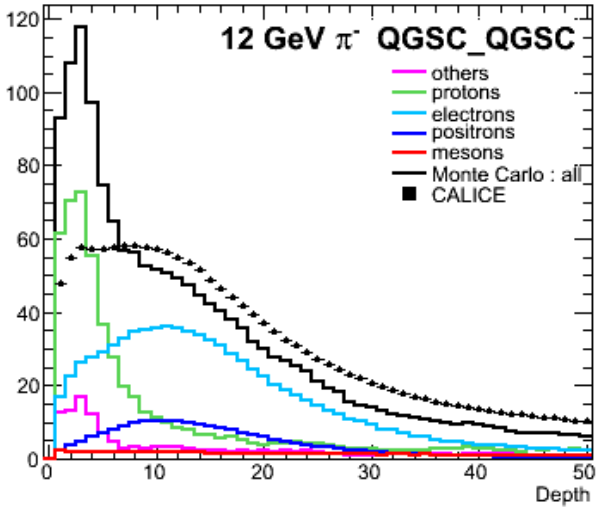


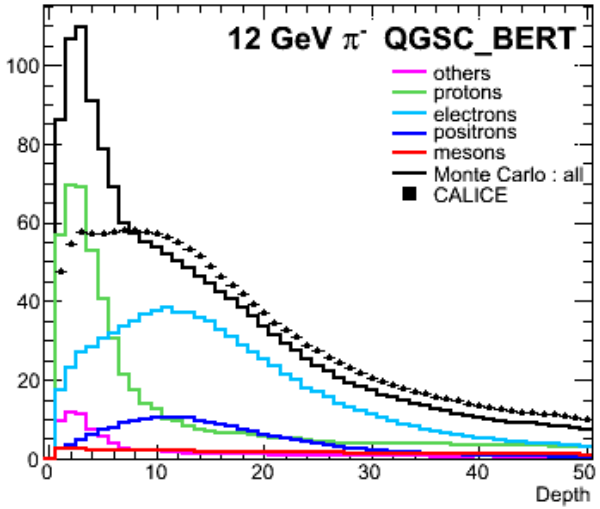


CHIPS models in GEANT4.9.3









CHIPS models in GEANT4.9.3