Tests of GEANT4 using the CALICE Si-W ECAL

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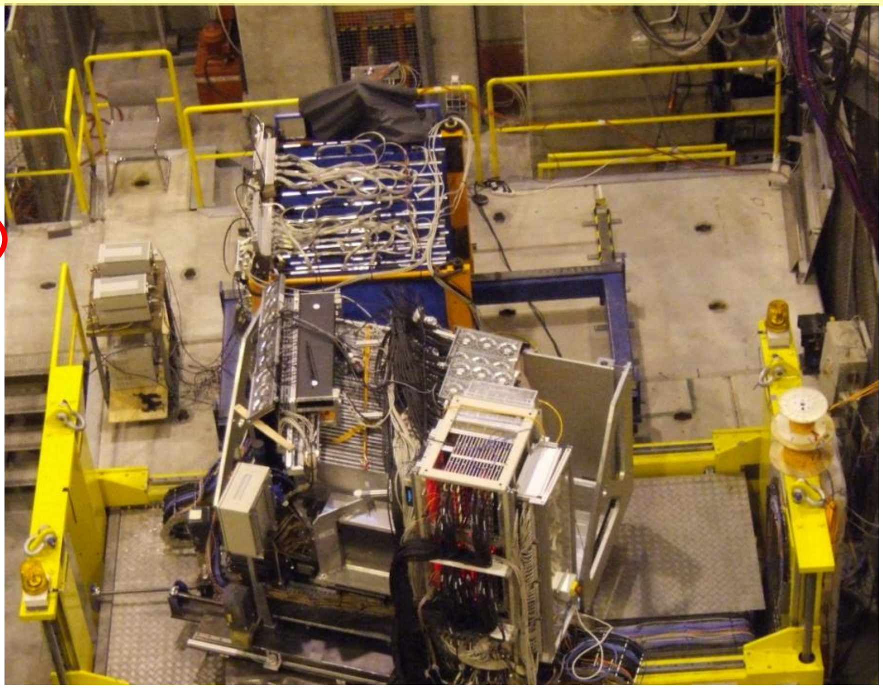
- Discuss measurements of electromagnetic and (mainly) hadronic showers + comparison with GEANT4 simulations
  - Study of e/m showers reported previously – serves as a check of our understanding of the detectors.
  - The ECAL is $\sim 1\lambda_{int}$ in depth $\Rightarrow$ ~50% of hadrons start to shower in the ECAL. Need to understand the ECAL response.
  - Fine granularity of the ECAL permits some interesting measurements of hadronic shower properties in Tungsten.

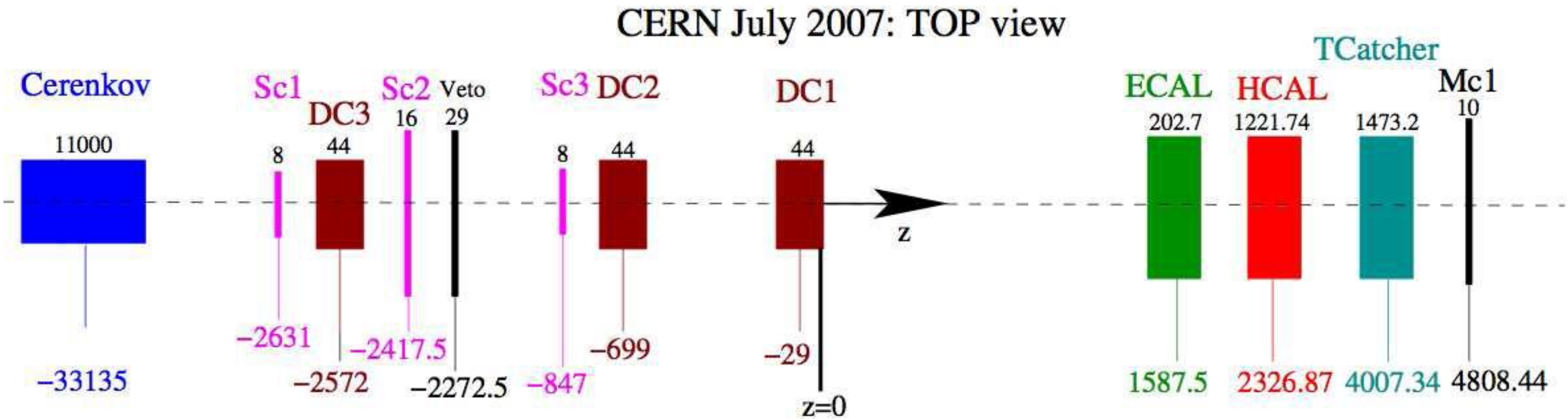
CALICE

- CALICE ~300 people/53 groups/17 countries
- Various projects aimed towards aspects of highly segmented calorimetry for a future Linear Collider detector, motivated by Particle Flow.
- Given focus by common test beams, combining ECAL/HCAL/tail catcher (TCMT); common DAQ/analysis.
- First round – small "physics prototypes"
  - Evaluate technologies; identify problem areas.
  - Validate Monte Carlo simulations, especially for hadronic showers, so that results can feed into full detector simulations.
  - Still sizeable systems with ~20K channels.
- Second phase – "technological prototypes" (mainly under aegis of EUDET).
  - More realistic technological solutions; module dimensions etc.
  - e.g. minimise thickness of sensitive layers; power pulsing.
- Will discuss some results of physics prototypes today.

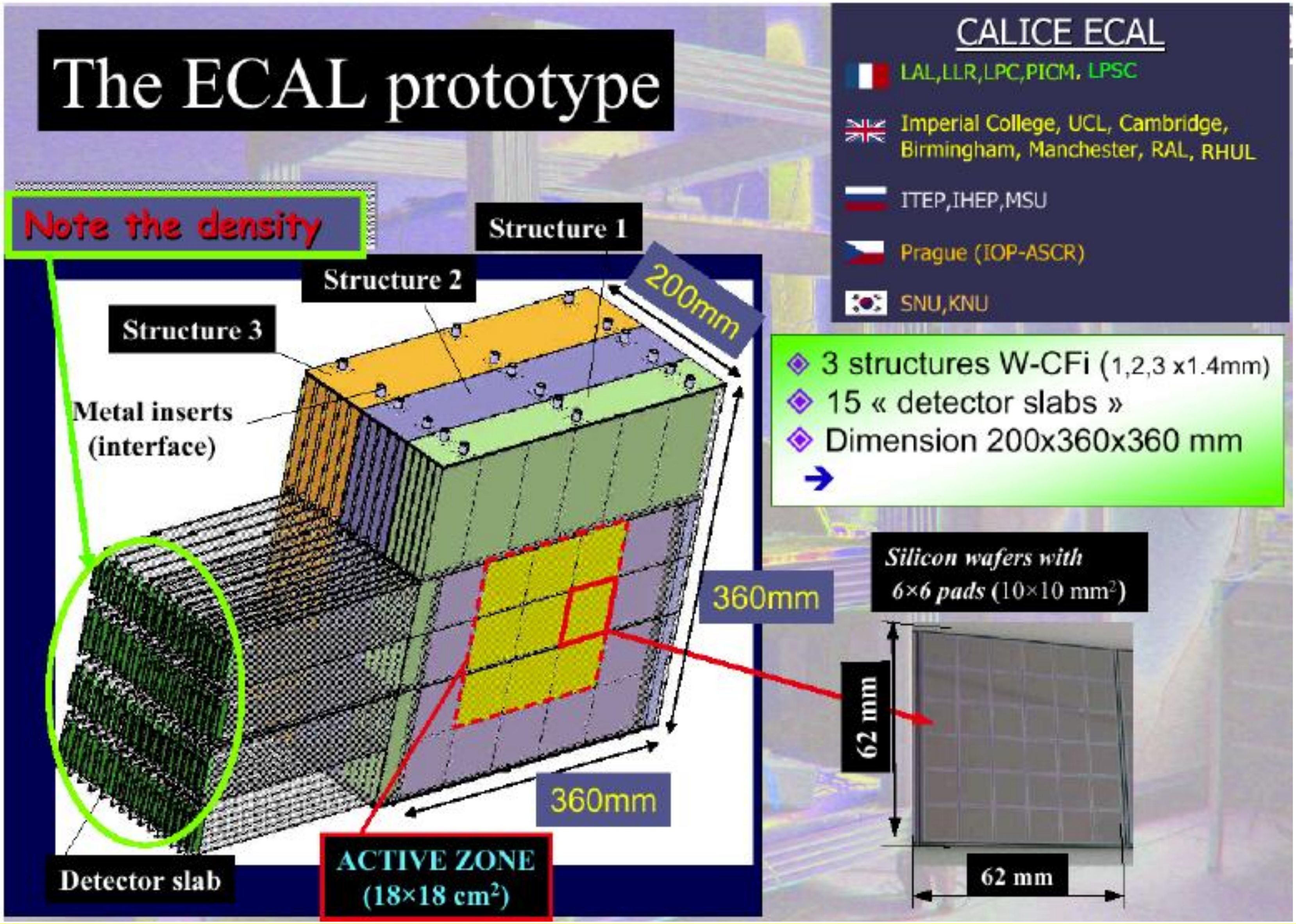
CALICE test beams

- Main beam tests, using π, μ, e beams:
- 2006-7 SiW ECAL + AHCAL + TCMT @ CERN
- 2008 SiW ECAL + AHCAL + TCMT @ Fermilab
- 2008-9 Scint-W ECAL + AHCAL + TCMT @ Fermilab
- 2010 DHCAL + TCMT @ Fermilab
- 2010 W HCAL @ CERN





SiW ECAL

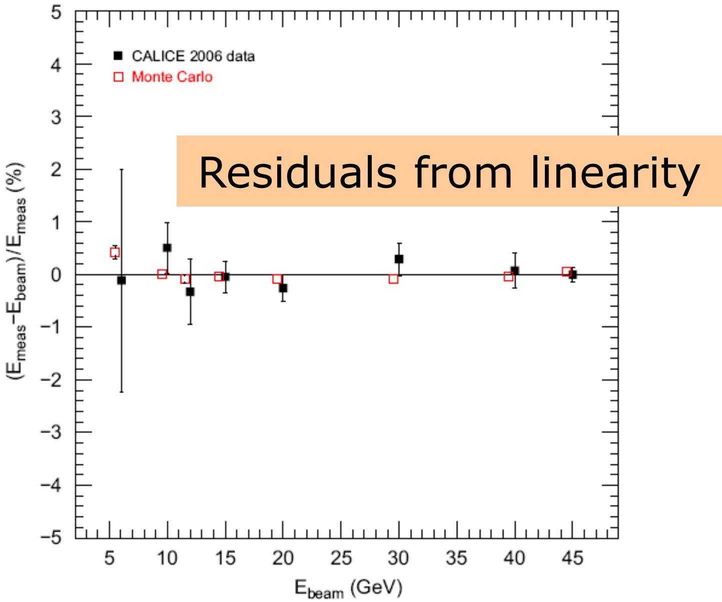


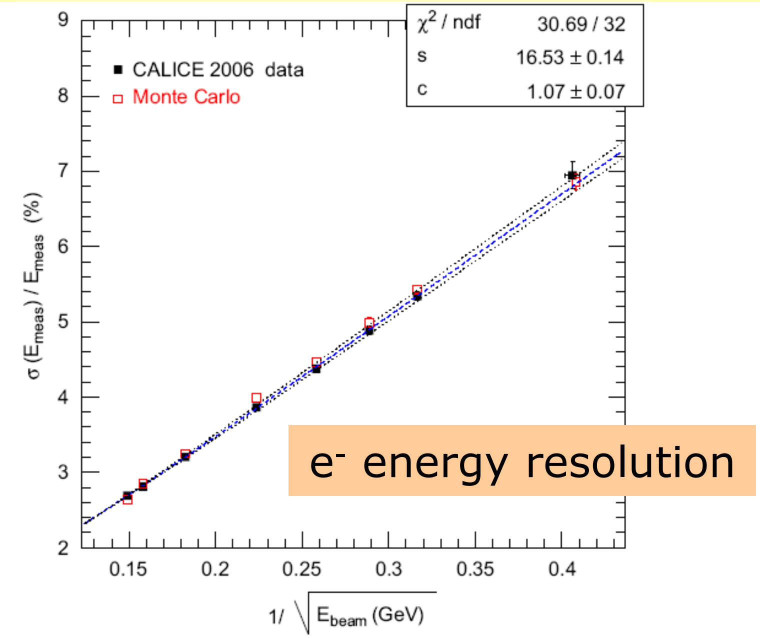
The ECAL prototype
CALICE ECAL
LAL,LLR,LPC,PICM, LPSC
Imperial College, UCL, Cambridge, Birmingham, Manchester, RAL, RHUL
ITEP,IHEP,MSU
Prague (IOP-ASCR)
SNU,KNU
Note the density
Structure 1
Structure 2
Structure 3
200mm
Metal inserts (interface)
3 structures W-CFi (1,2,3 x1.4mm)
15 « detector slabs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

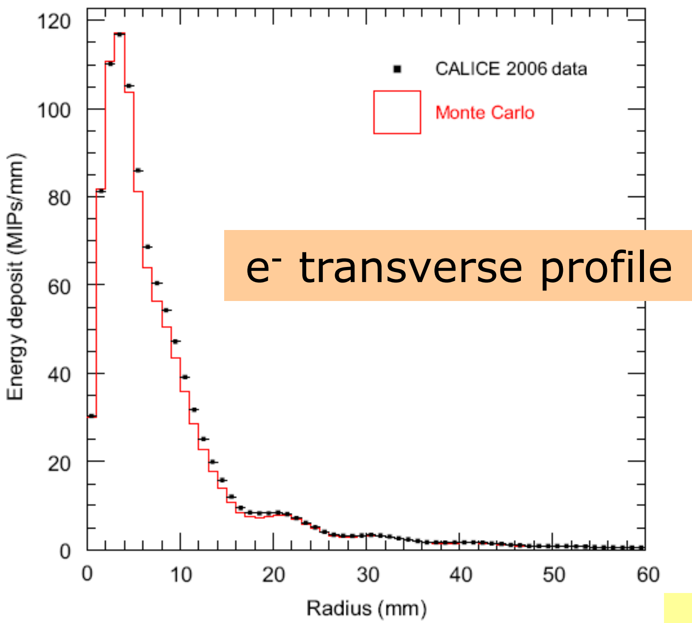
Data used

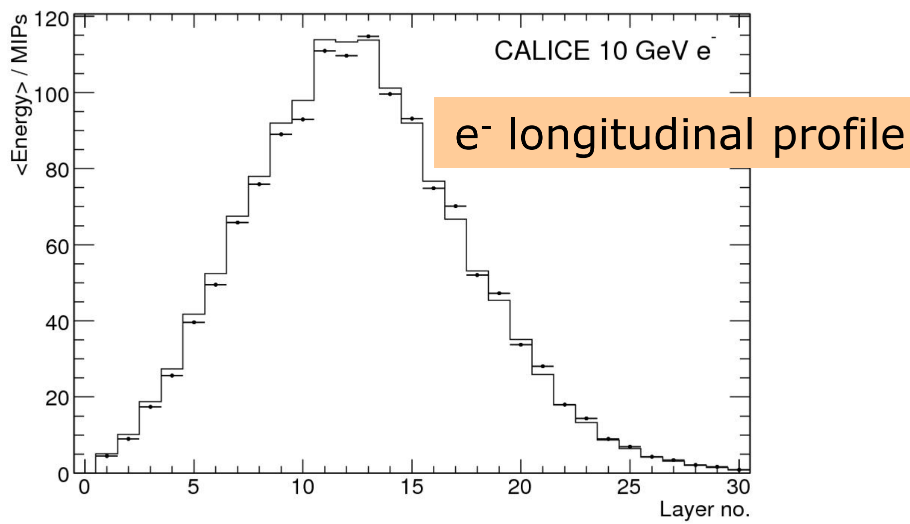
- Based on the 2007 CERN test beam running.
- π^- beams @ 8, 10, 12, 15, 20 GeV
  - Čerenkov used to remove e^- background
- π^+ beams @ 30, 50, 80 GeV
  - Čerenkov used to remove proton background
- Muons identified by low energy in all three calorimeters, and rejected.
- Simulations using GEANT4.9.3 (December 2009) with eight hadronic physics lists
  - QGSP_BERT
  - QGSP_BERT_TRV
  - QGSP_FTFP_BERT
  - QGSP_BIC
  - QGS_BIC
  - FTF_BIC
  - FTFP_BERT
  - LHEP
- Comparisons made at detector level. Energies in units of MIPs (minimum ionising particle (i.e. muon) equivalents).

Some electron results



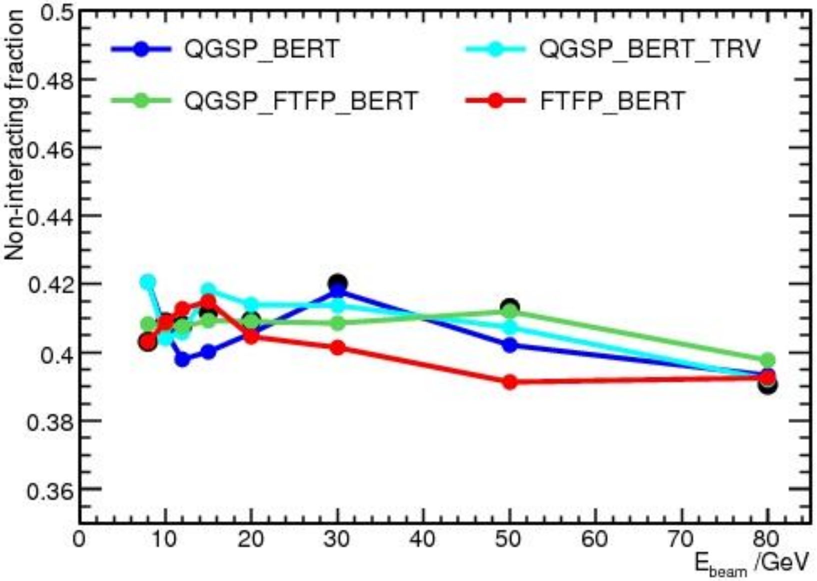


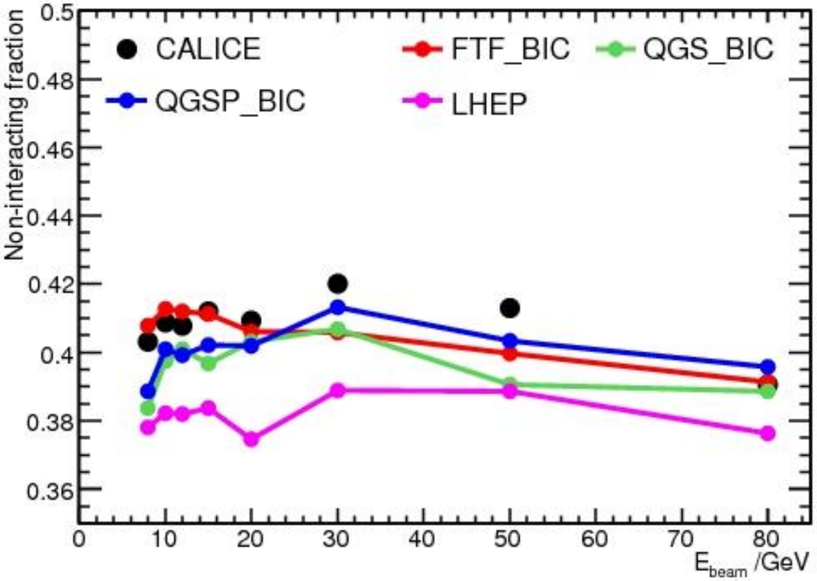




Probability of not interacting in ECAL

As identified through MIP-like energy deposition in ECAL



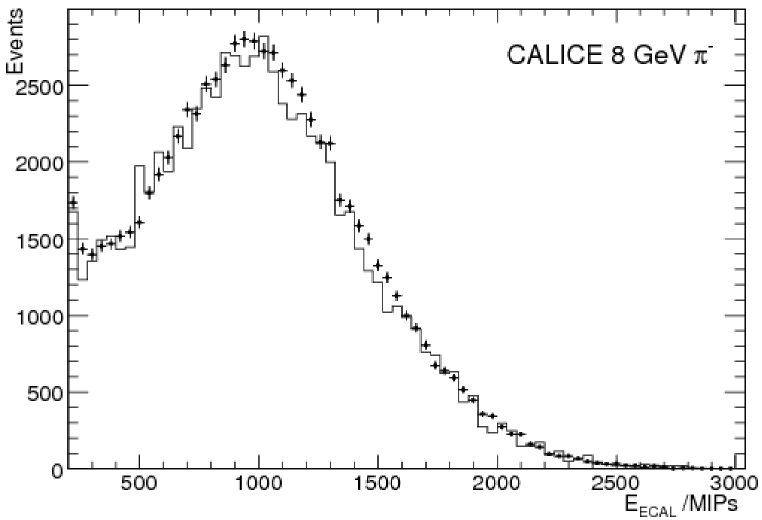


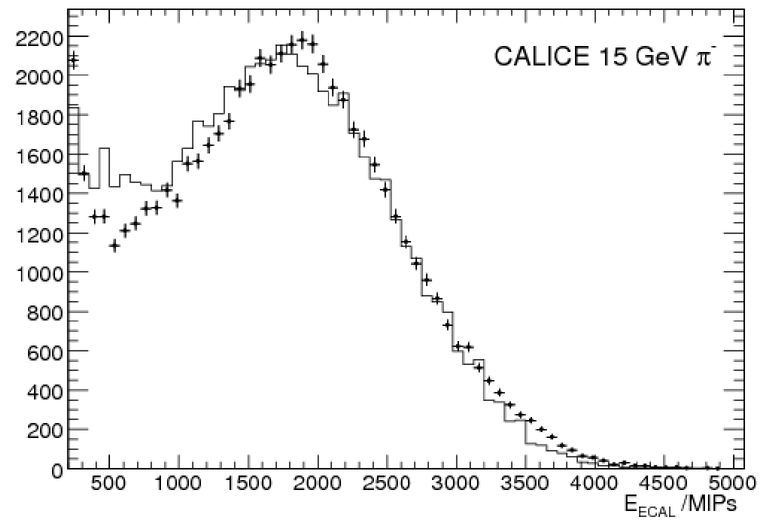
Serves as a test of the GEANT4 cross-sections on Tungsten

Most physics lists within 1-2% of data

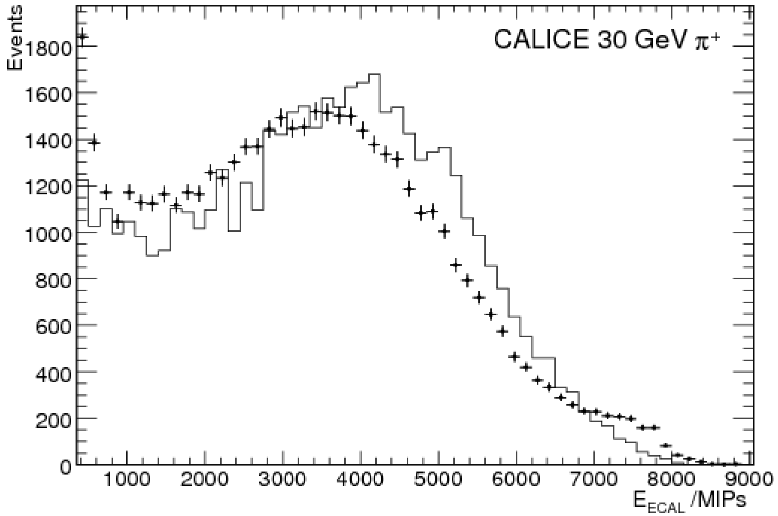
Most conspicuous outlier is LHEP

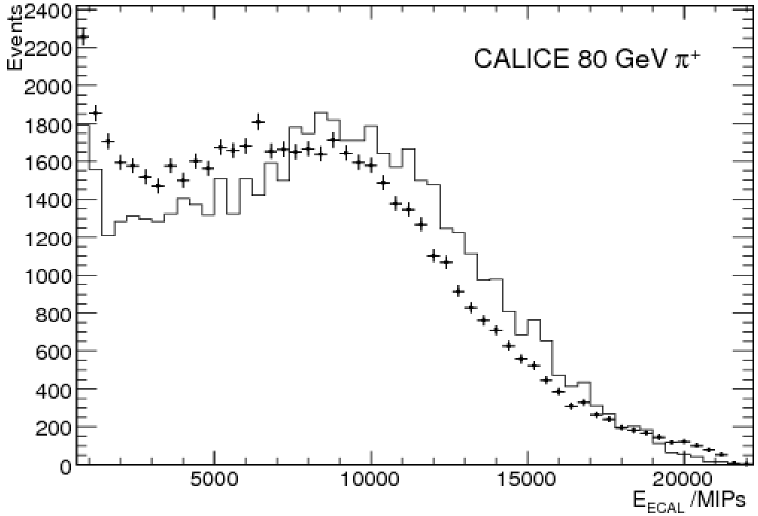
Energy in ECAL (QGSP_BERT physics list)





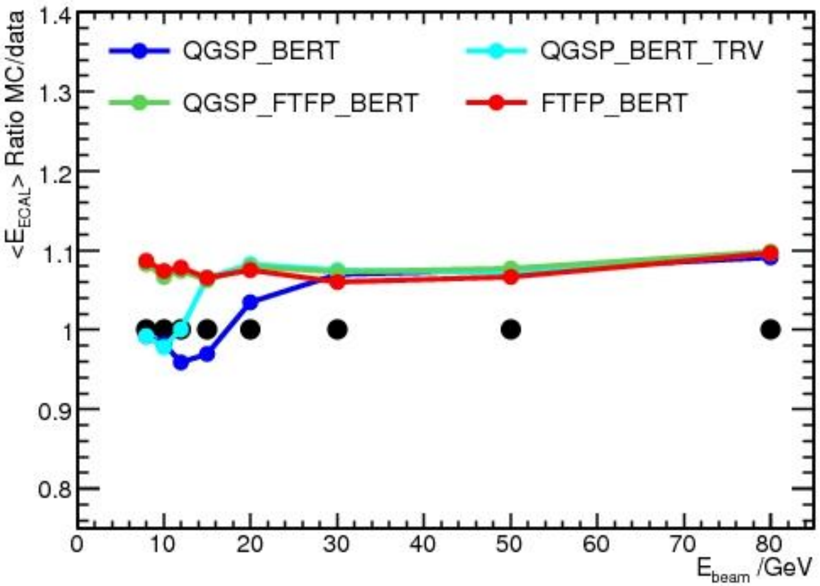
This model looks good at 8 GeV (BERT); less so at high energy (QGS)

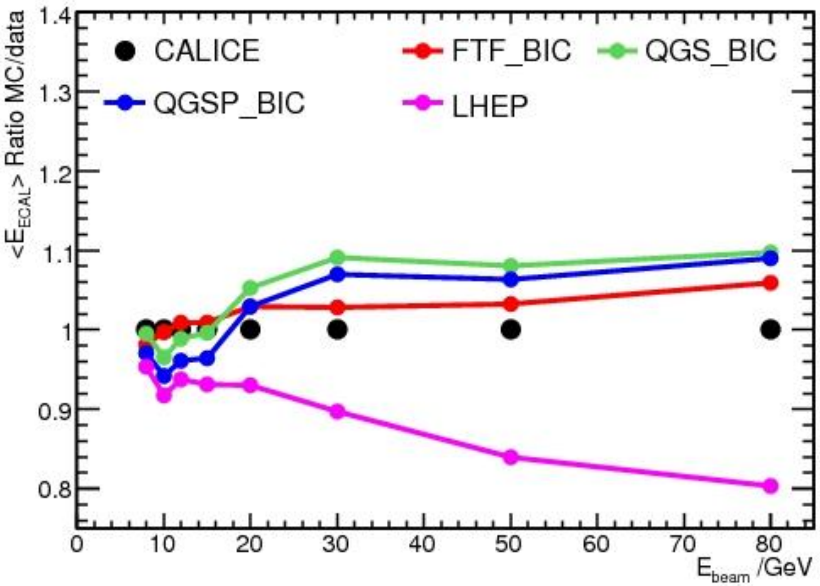




Energy deposited in ECAL

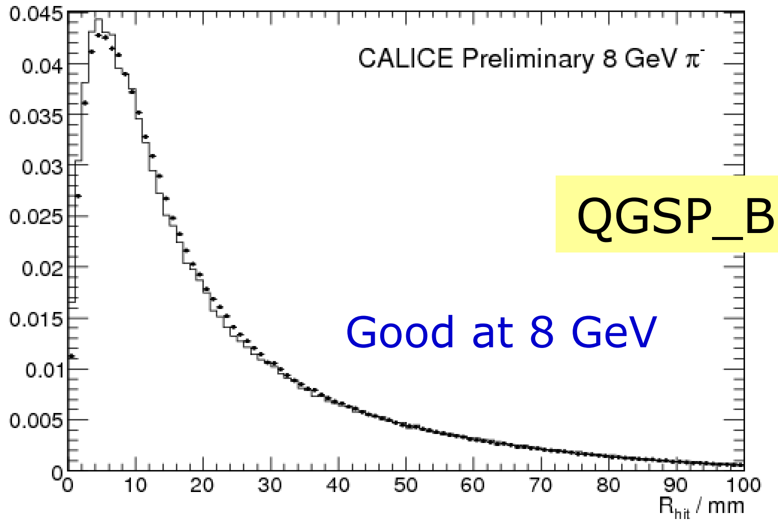
Show trend of <E(MC)>/<E(Data)> vs beam energy

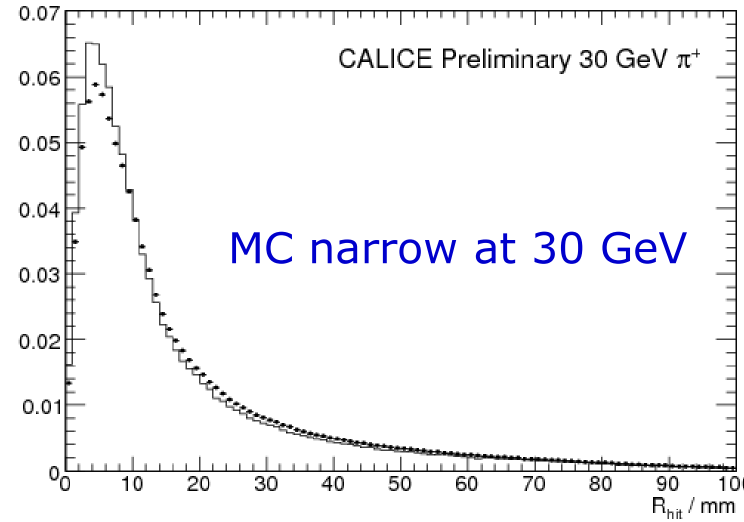




- Steps seen as Geant4 makes transitions between models
- Most models lie within 10% of data
- Closest overall seems to be FTF_BIC
- LHEP is a striking outlier, diverging significantly at high energies

Transverse shower profile

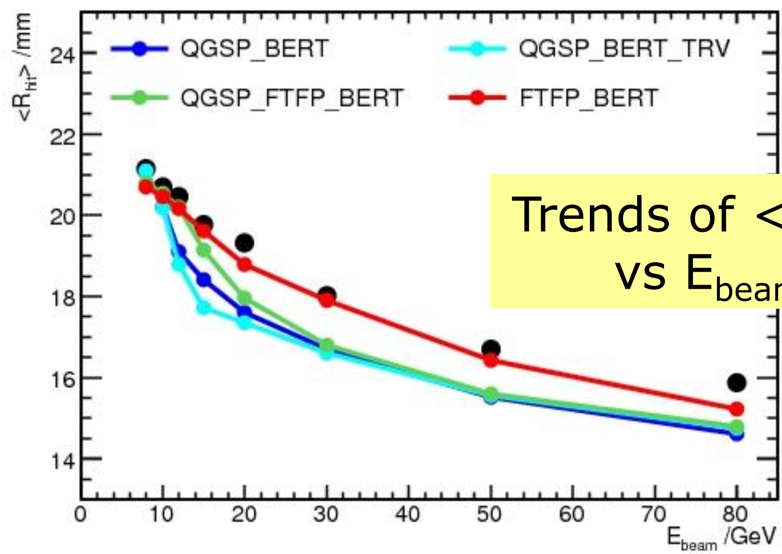


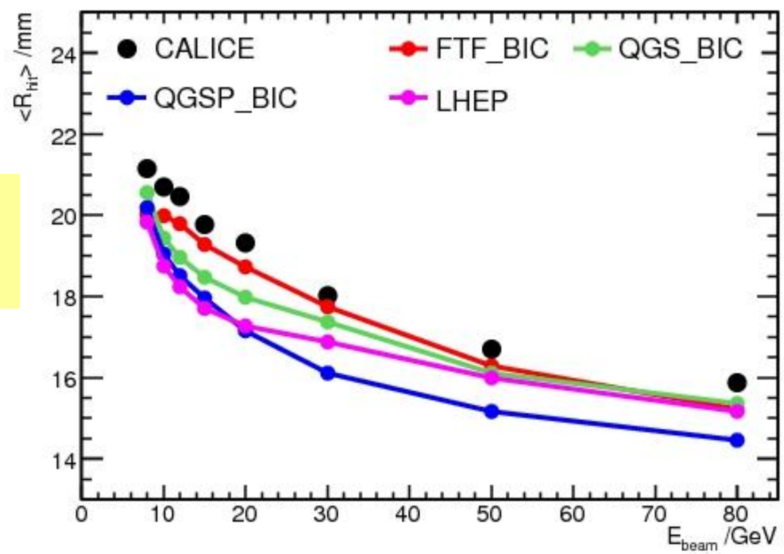


QGSP_BERT

Good at 8 GeV

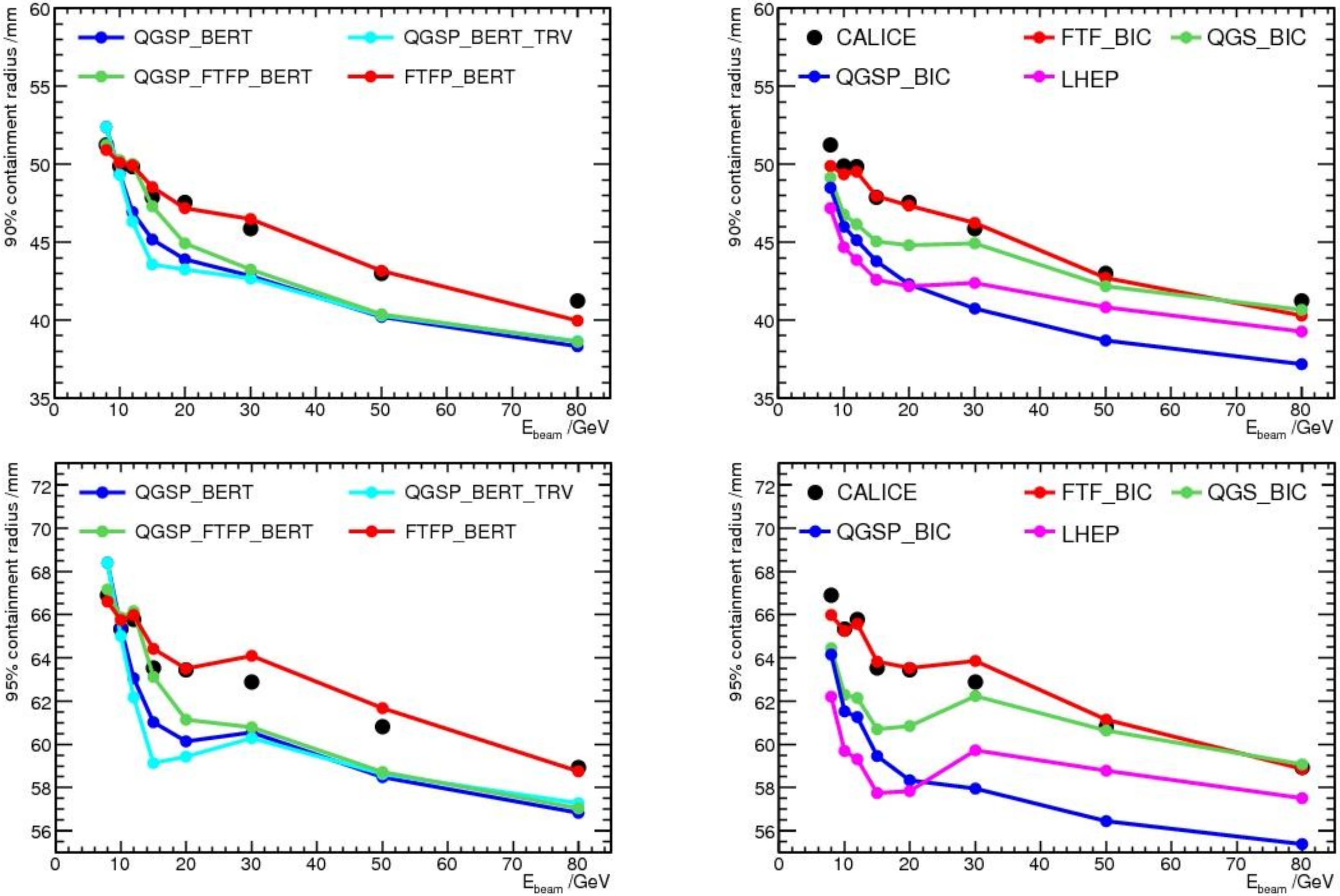
MC narrow at 30 GeV





Trends of $\langle R_{hit} \rangle$ vs E_{beam}

Tails of transverse profiles



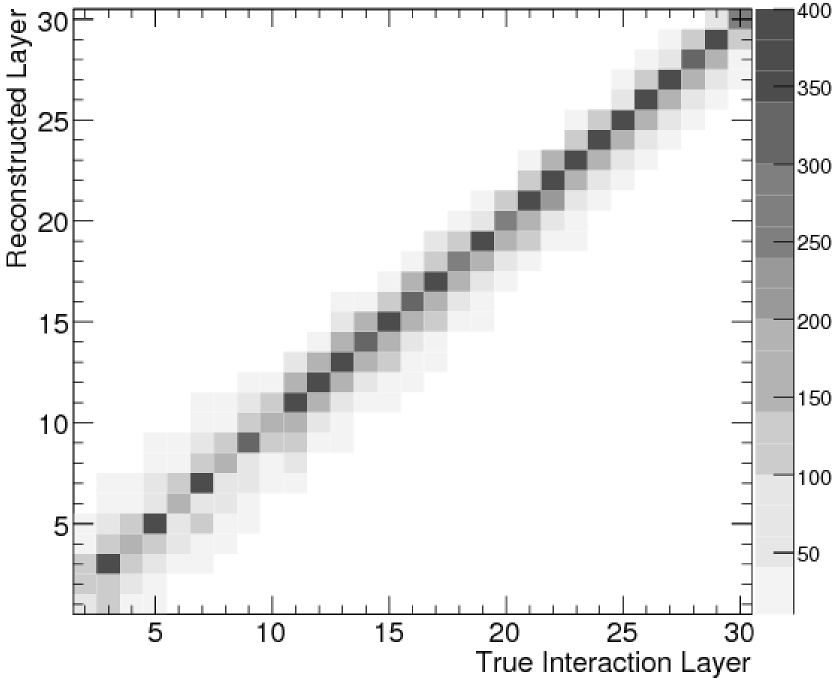
Radius to confine 90% of shower energy

or 95%

Most models underestimate shower width at high energies. FTF lists fit data best

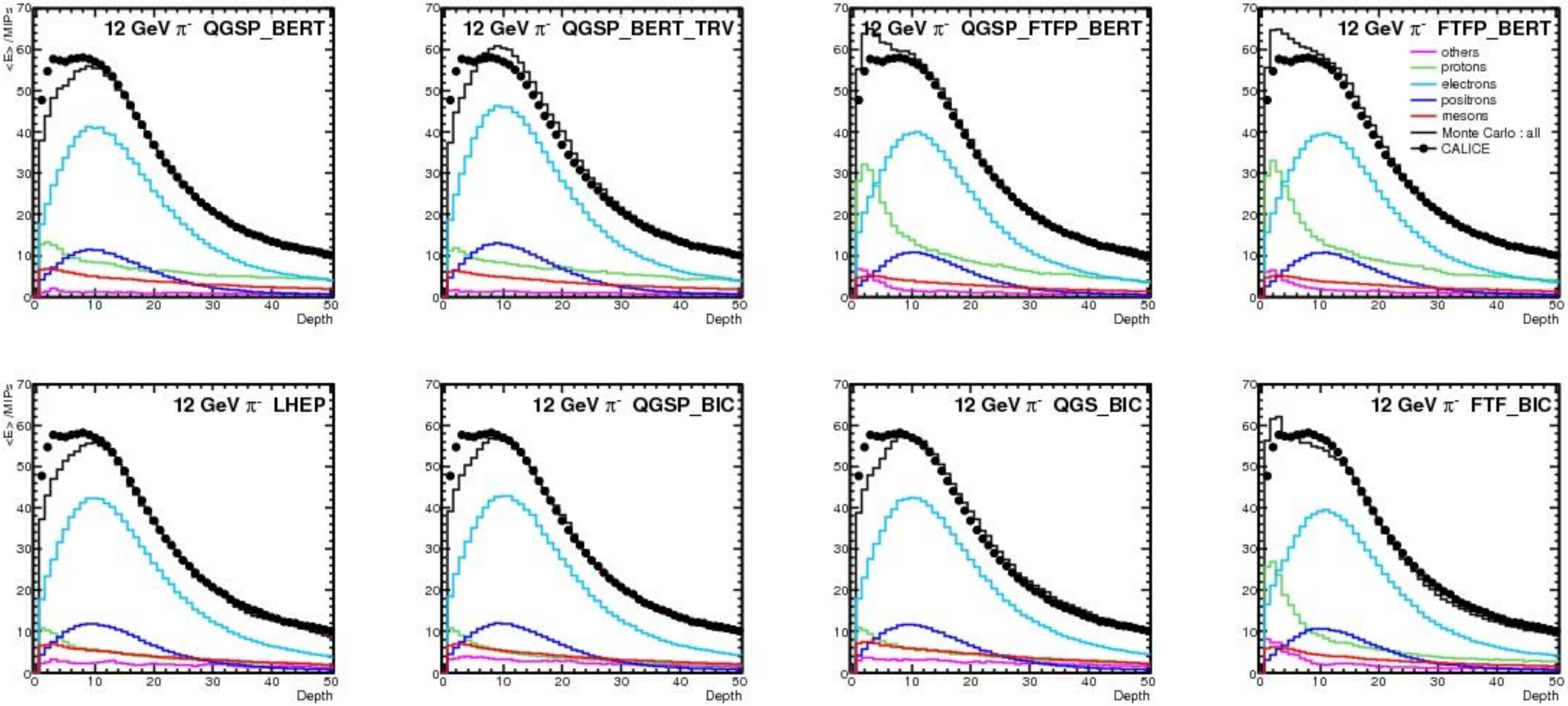
Longitudinal shower profile

- The observed longitudinal shower development reflects a convolution of the distribution of shower starting points with the true shower shape.
- High granularity allows us to identify the shower start to within ± 1 layer typically.
- Can then measure shower longitudinal development w.r.t. this point.
- Restrict to showers starting in first 10 layers of ECAL, so that almost 1 λ_{int} in the ECAL is available to develop the shower. And $\sim 20X_0$ so that photons in initial interaction can shower fully.



Shower profiles w.r.t. interaction point

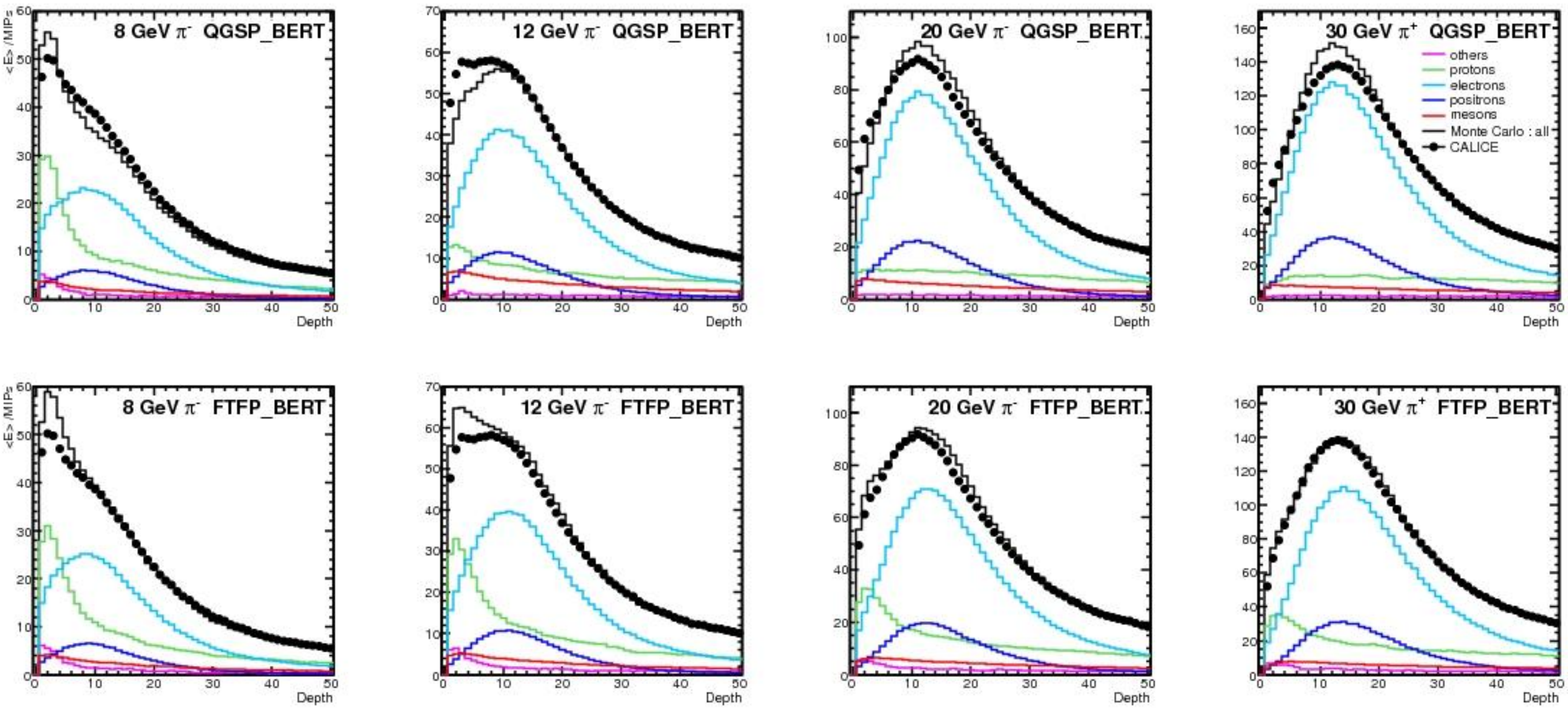
12 GeV data compared to all 8 physics lists



In simulation, can record hit energies associated with each particle species.
Note that "mesons" (π, μ, K), $e^{\pm}$ and protons have distinctive shower profiles.
None completely fits the data.

Shower profiles w.r.t. interaction point

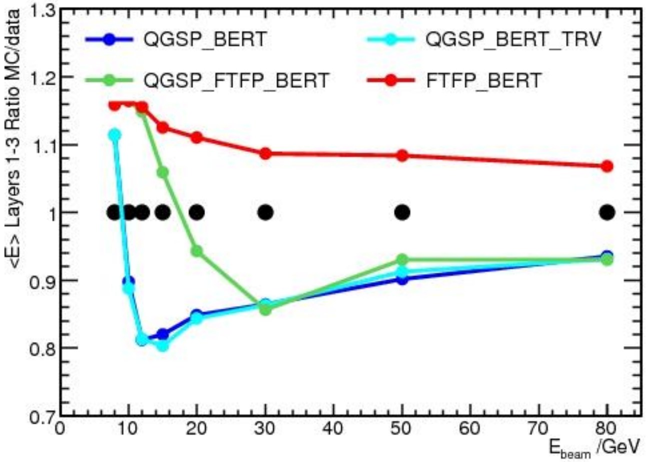
Compare two physics lists at 4 energies

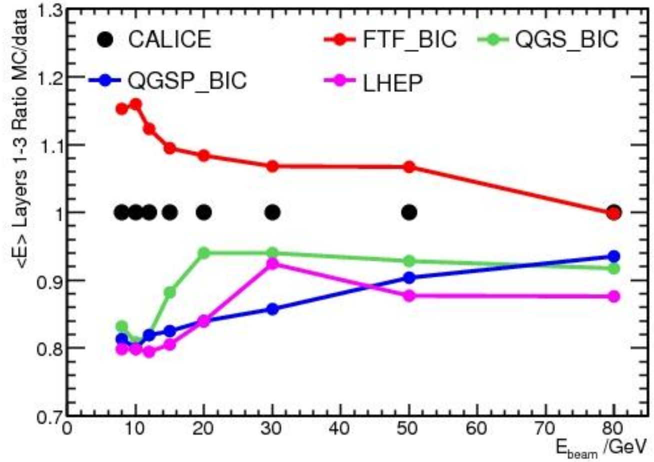


Three main components can be observed:

- Short range component (mainly protons; nuclear spallation products)
- Electromagnetic component
- Longer range components; mesons + MIP-like protons

Focus on different regions of the shower:

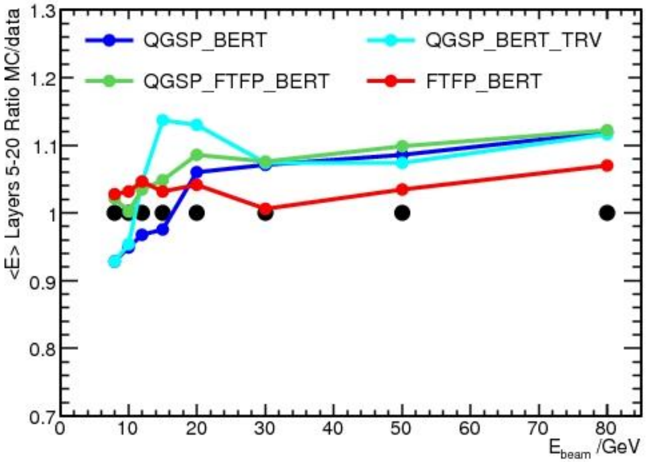


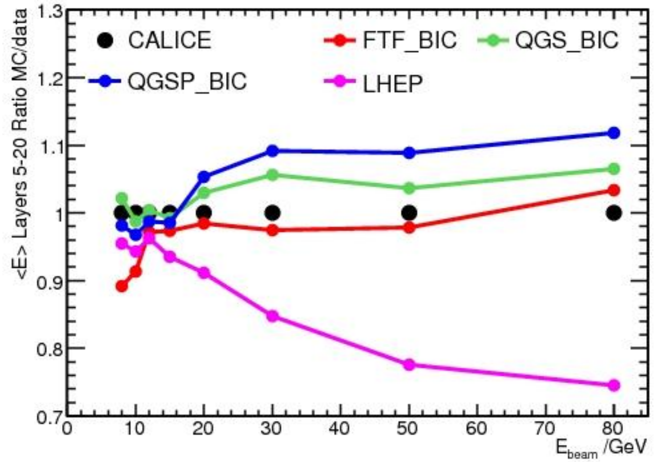


Layers 1-3

Nuclear fragments

No physics list is really successful





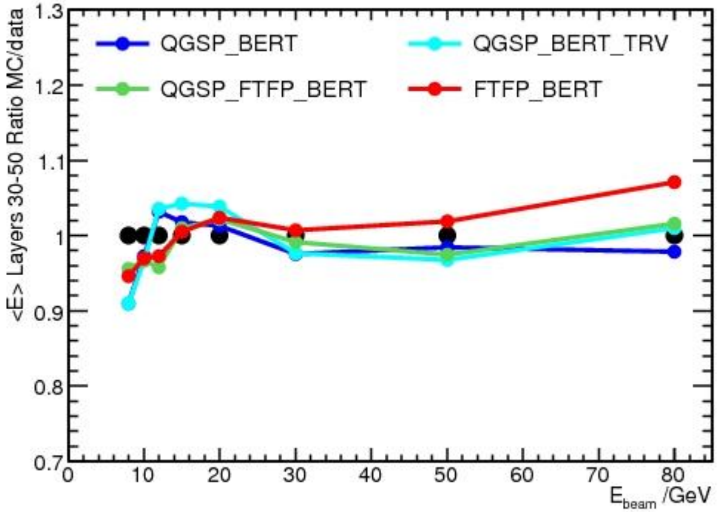
Layers 5-20

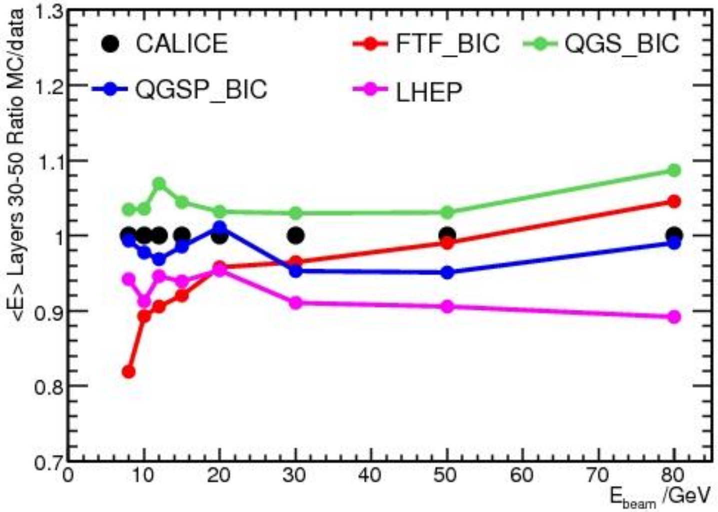
Electromagnetic

FTF lists seem best

LHEP fails badly

… continued …





Layers 30-50

Mainly hadron dominated

Most models within ~10% of data

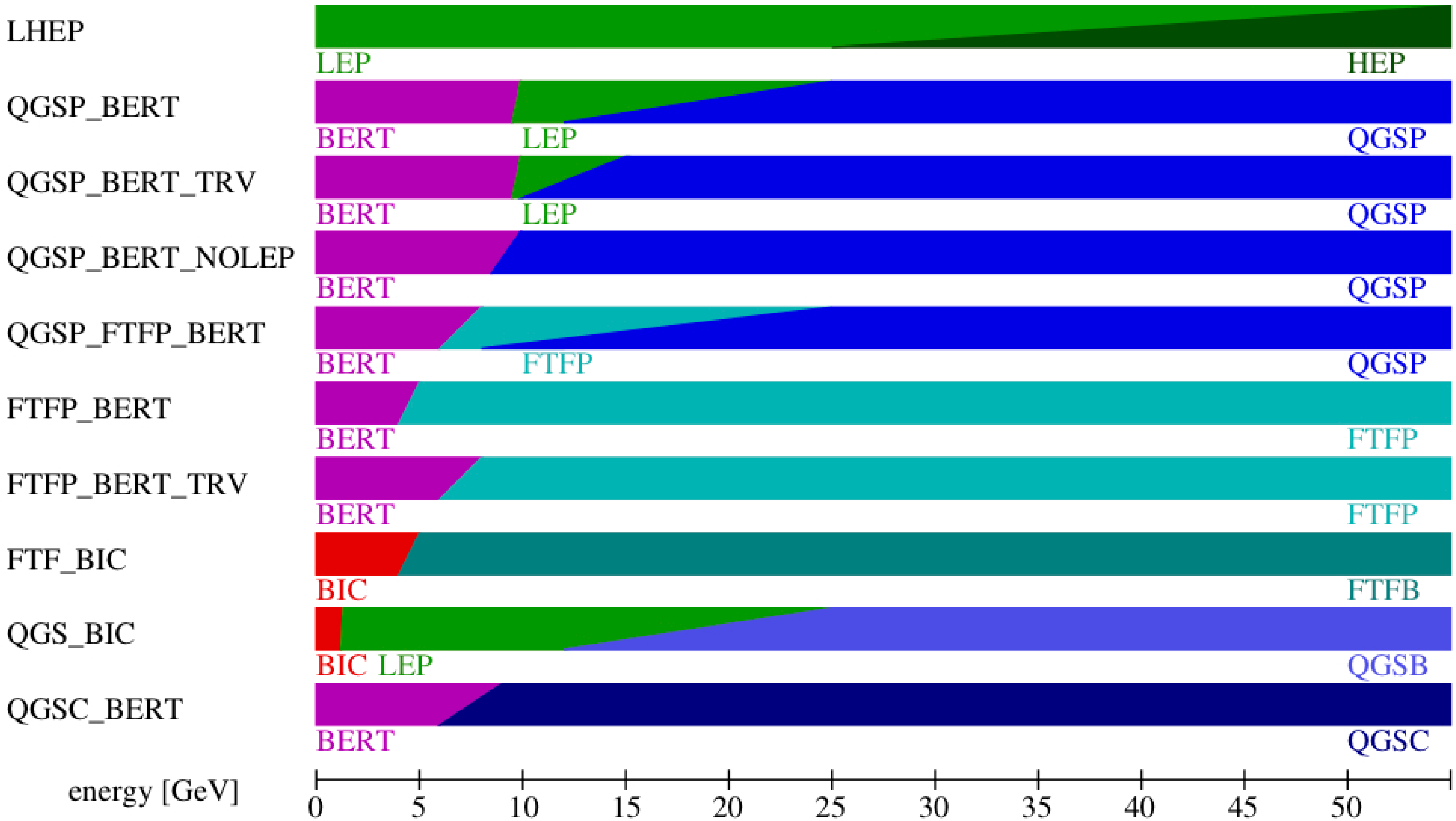
QGSP models slightly favoured

Summary

- Use of the CALICE ECAL to study the early stages of hadronic showers has some interesting advantages for testing Monte Carlo models:
  - Can study interactions on Tungsten
  - Fine longitudinal granularity $\Rightarrow$ can identify shower start well
  - Fine segmentation $\Rightarrow$ charged spallation products can traverse several layers of W, compared to ~1 layer of Fe in our HCAL
  - Large λ_{int}/X_0 (~29 for W c.f. ~10 for Fe) means e/m component can develop rapidly compared to hadronic.
- Main findings from comparing with eight physics lists in GEANT4.9.3
  - LHEP stands out as the least successful.
  - Total energy not a very useful discriminator.
  - Most lists underestimate transverse shower shape, especially at higher energies. FTF (Fritjof)-based models seem best here.
  - Longitudinal shower profiles allow some disentangling of components of shower. Mild preference for FTF lists, but none is perfect.
- Lower energy pions from FNAL in 2008 will soon provide interesting complementary information

Backup slides

Physics lists in GEANT4.9.3



All are hybrids of several models; random selection between alternatives in the transition region in order to smooth behaviour.