Testing Hadronic Interaction Models using a Highly Granular Silicon-Tungsten Calorimeter

Interactions of pions in the CALICE Si-W ECAL prototype

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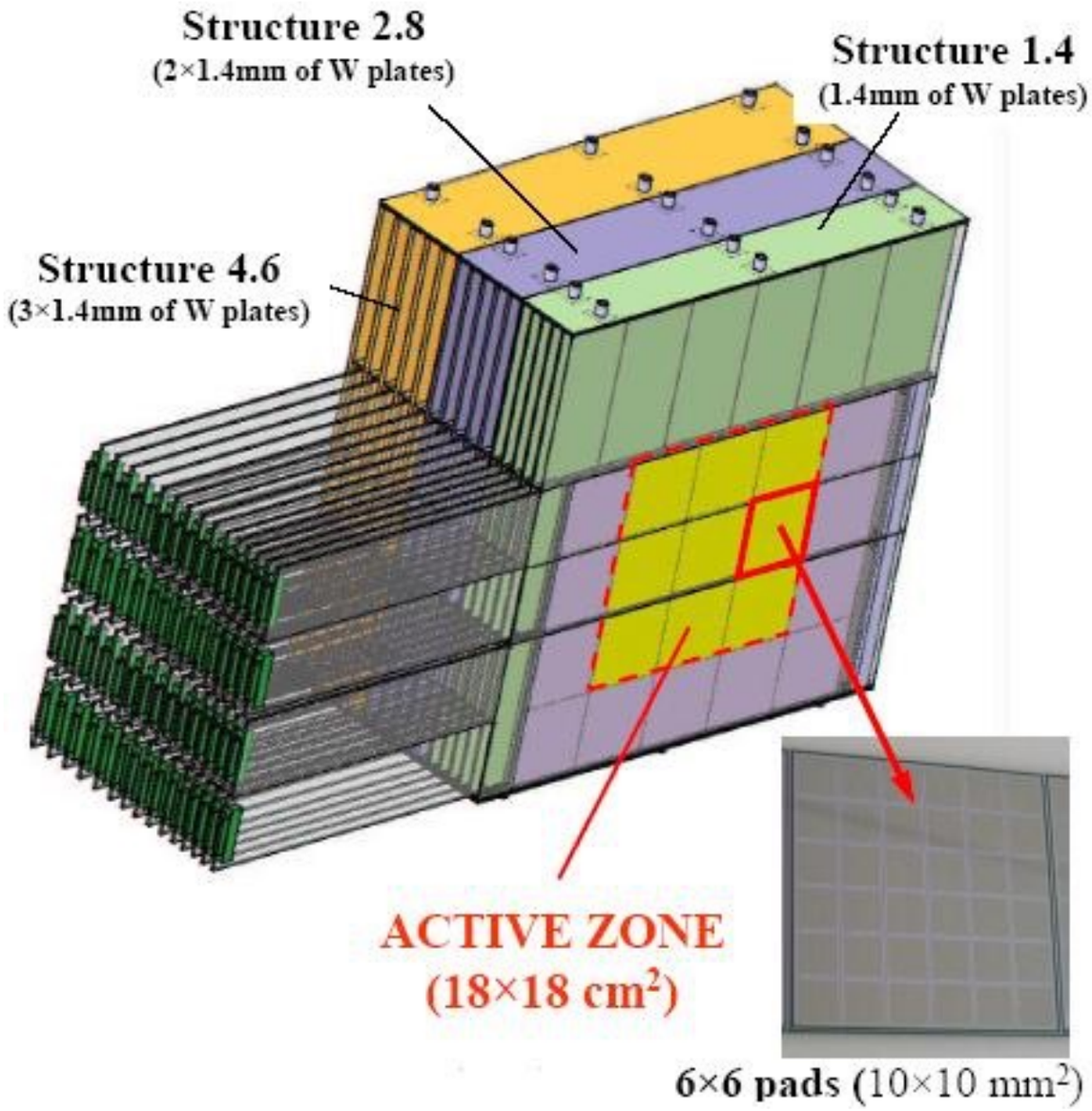
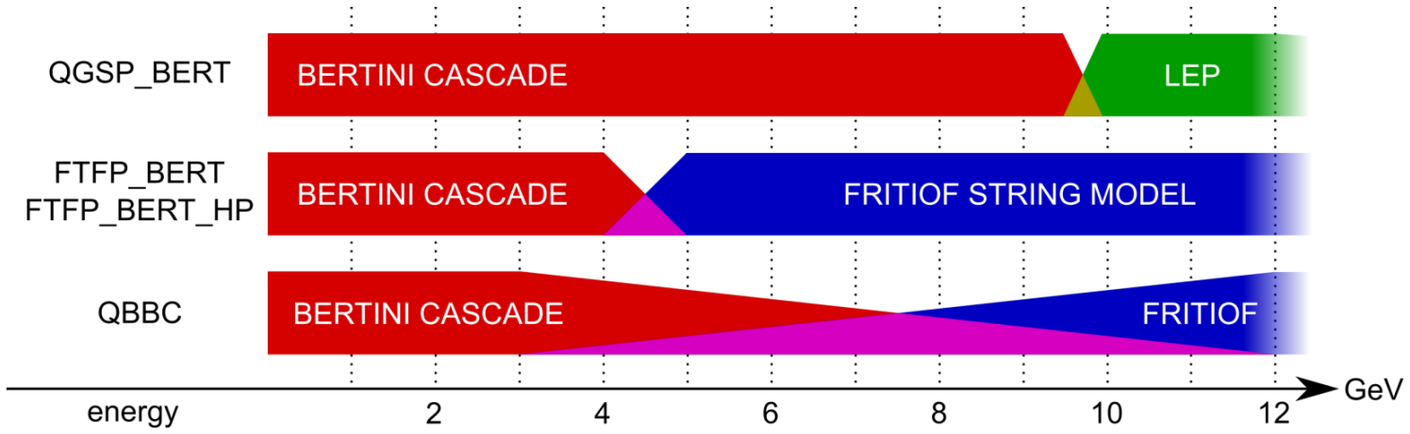
Si-W ECAL Prototype

- CALICE Si-W ECAL physics prototype
  - 30 layers, 3 modules of 10 layers with increasing W thickness
  - 24 X_0, ~1 λ_I
  - Active area of 18x18 cm^2, pixel size 1x1 cm^2
- More than half of the hadrons will interact in the Si-W ECAL
- Detailed view of the primary interactions of hadrons



Analysis of Pion Test Beam Data

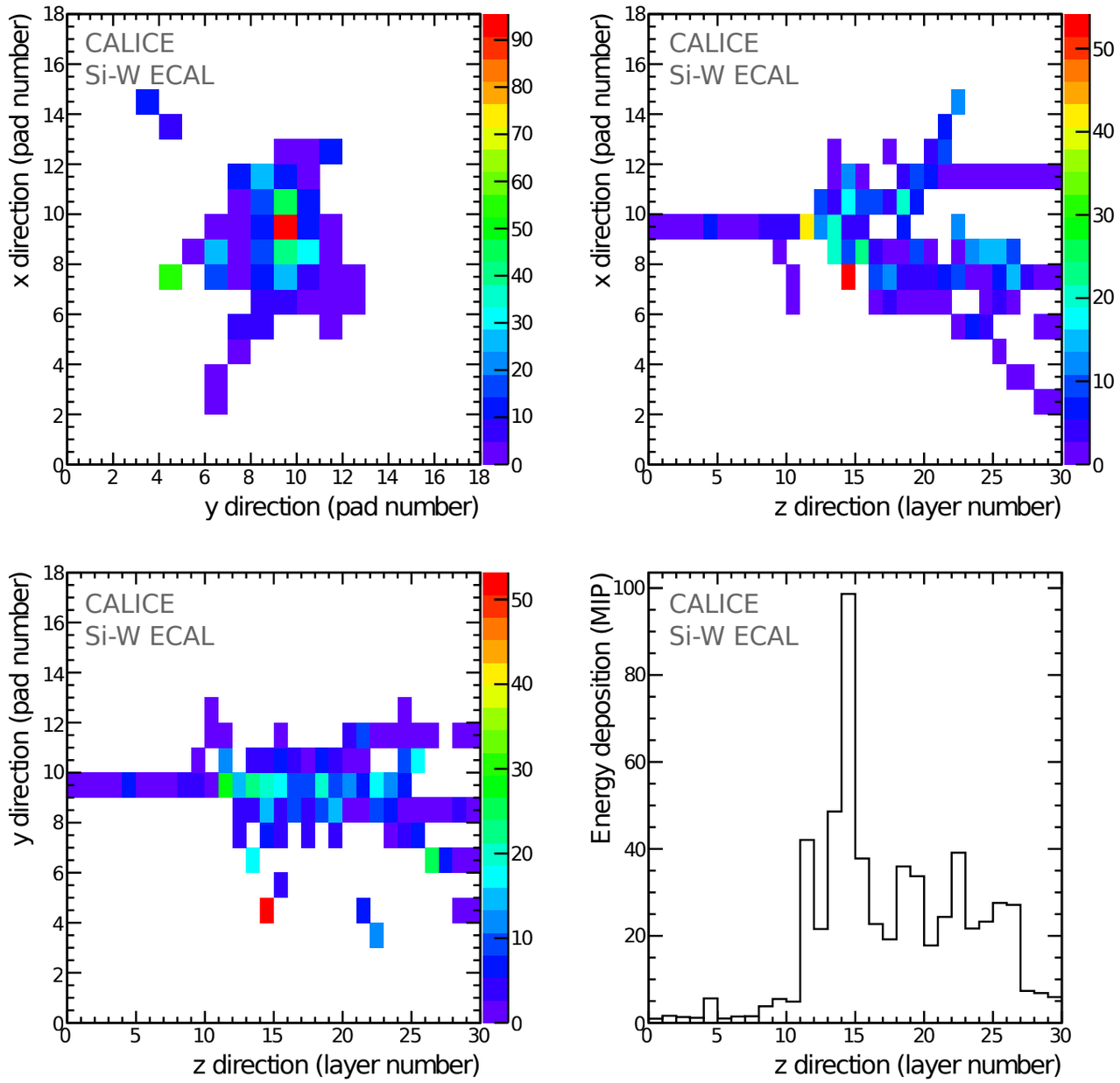
- Test beam data recorded at FNAL in 2008 of π^- at 2, 4, 6, 8, and 10 GeV
- Study interactions in terms of shower observables;
  radial and longitudinal distributions
- Compare predictions of simulations (Geant4 9.6p01) to the data in order to help improve the simulation models



- Interesting energy range:
  - energy range of the majority of changed pions and other hadrons within high energy jets
  - Transition region of models in Geant4 physics lists
- arXiv: 1411.7215 (submitted to NIM A)

Interacting Events

- Interaction of a 10 GeV pion in the Si-W ECAL
- Energy increase at the primary interaction



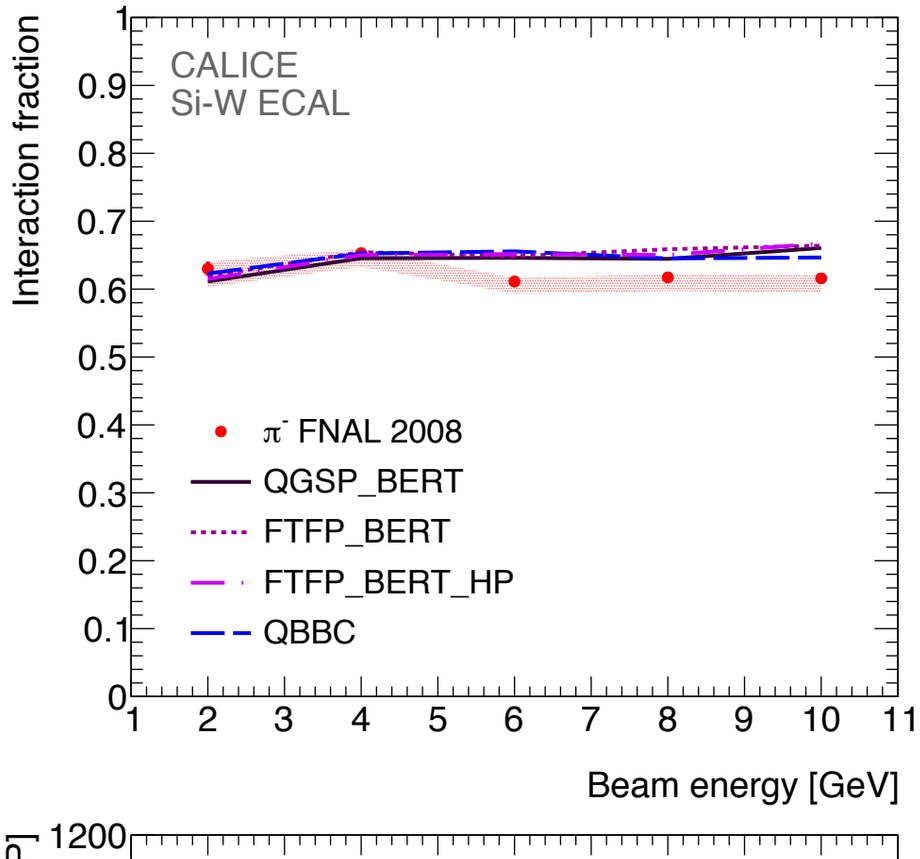
Selecting Interacting Events

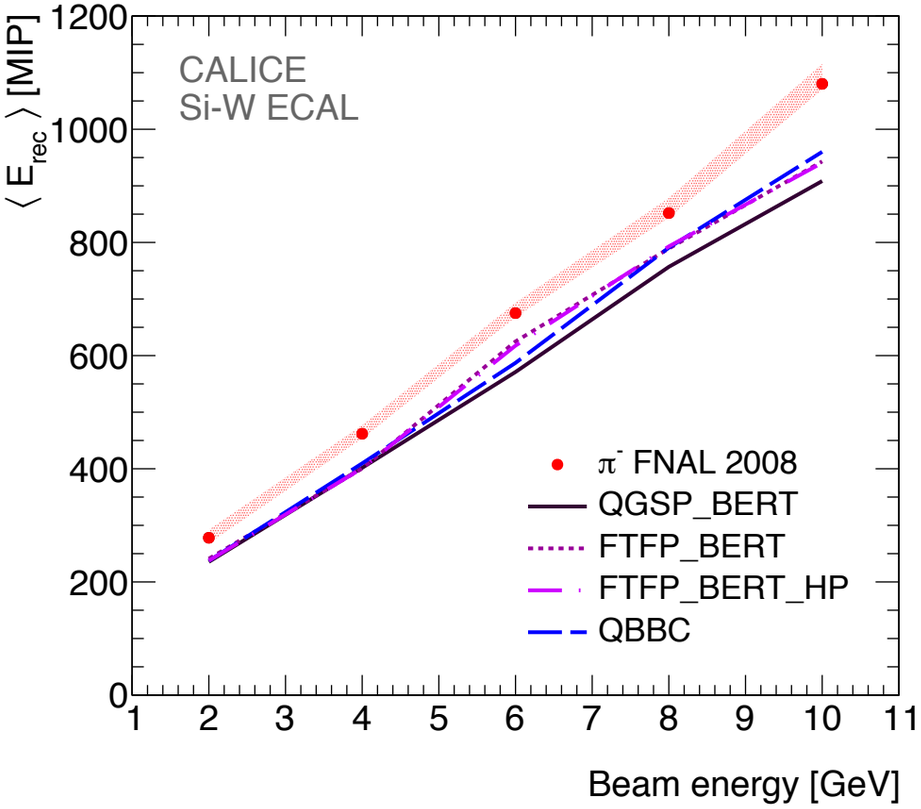
- Interacting events are found based on two criteria:
    - Absolute energy increase
    - Relative energy increase
- Especially at low energies the second criterion is important
- The efficiency is approximately the same for all physics lists
- Contamination with non-interacting events is between 2.4% and 3.7%

E(GeV)	Fraction found by absolute energy criterion	Additional fraction found by relative energy criterion	Total efficiency
2	0.35	0.25	0.60
4	0.67	0.14	0.81
6	0.84	0.07	0.91
8	0.88	0.04	0.92
10	0.90	0.03	0.93

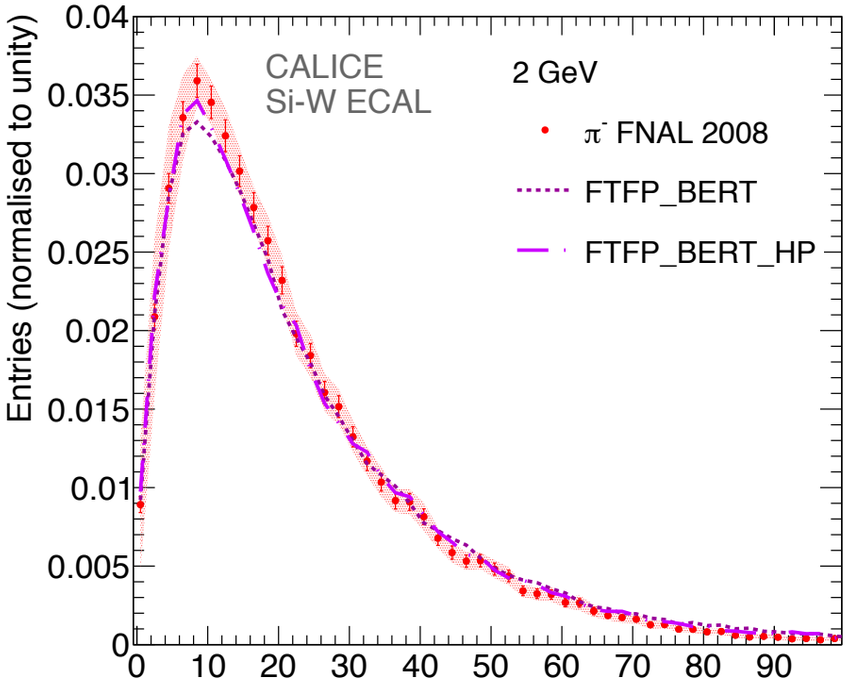
Interaction Fraction and Shower Energy

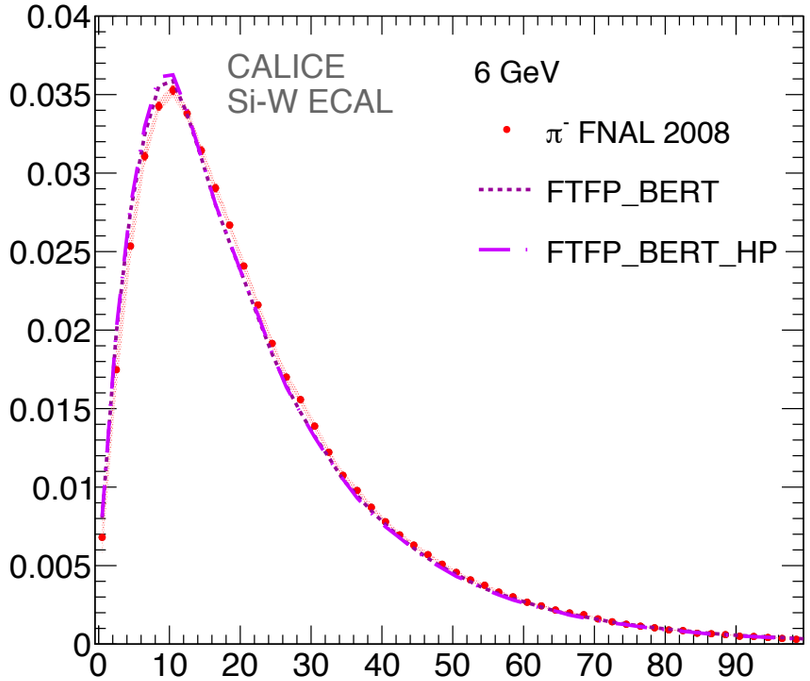
- The fraction of interacting events corrected with the interaction finding efficiency
- The interaction fraction is consistent with the Si-W ECAL material budget and approximately independent of energy
- The total shower energy is underestimated in the MC

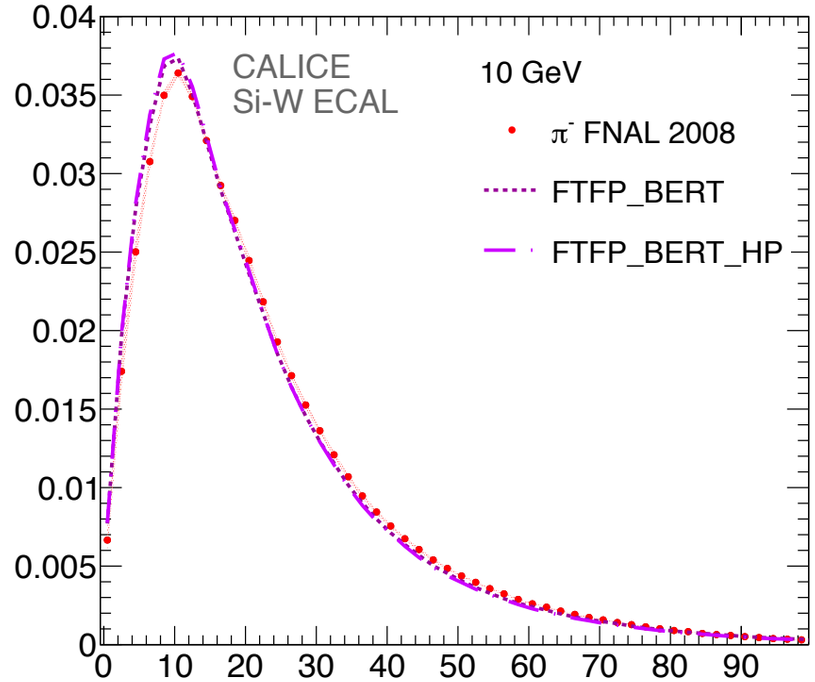




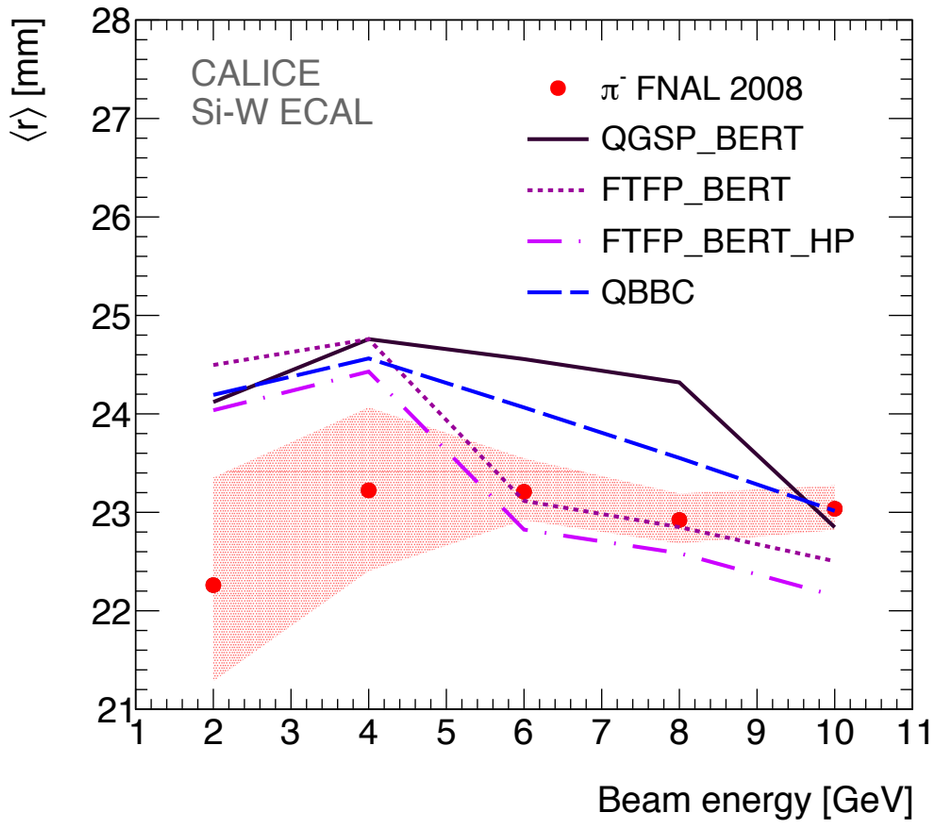
Radial Hit Distribution



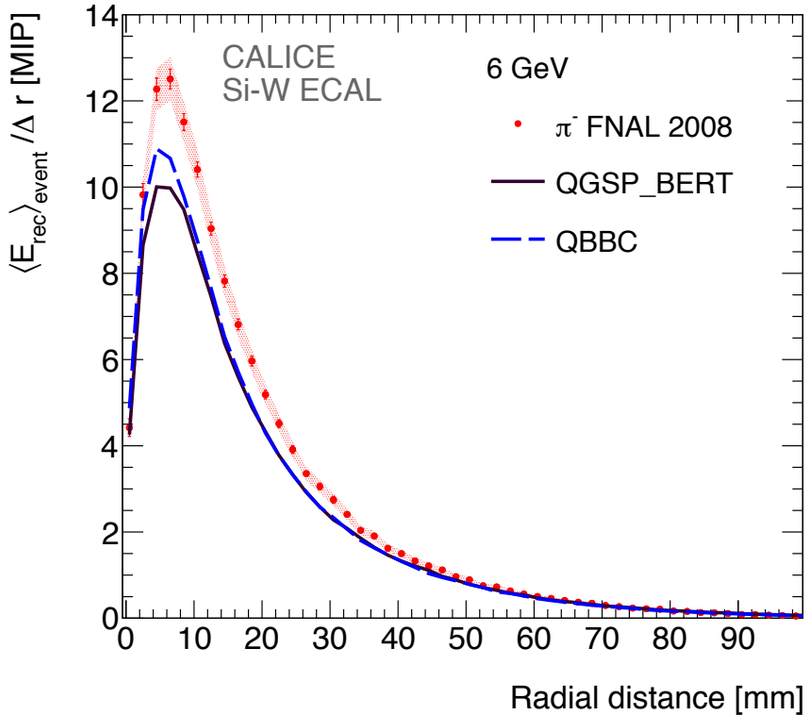


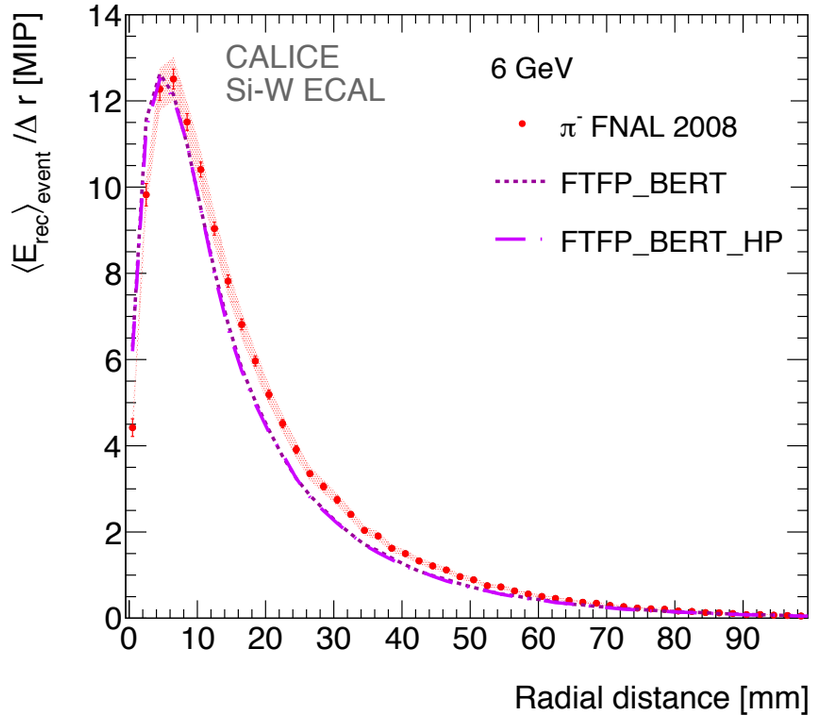


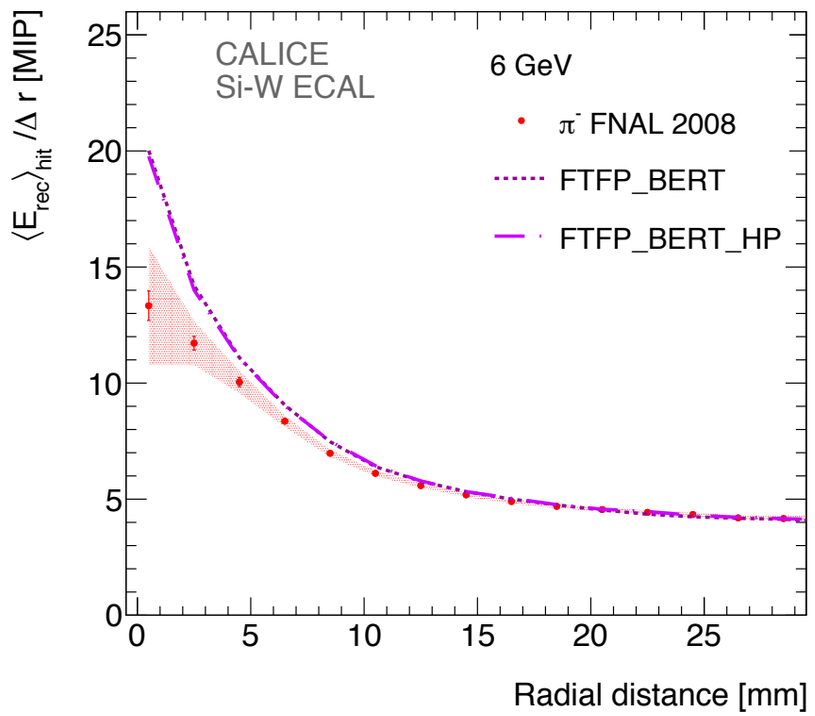
- MC close to the data, but too wide showers
- Mean radial distance constant within 5%
- MC sensitive to model transitions



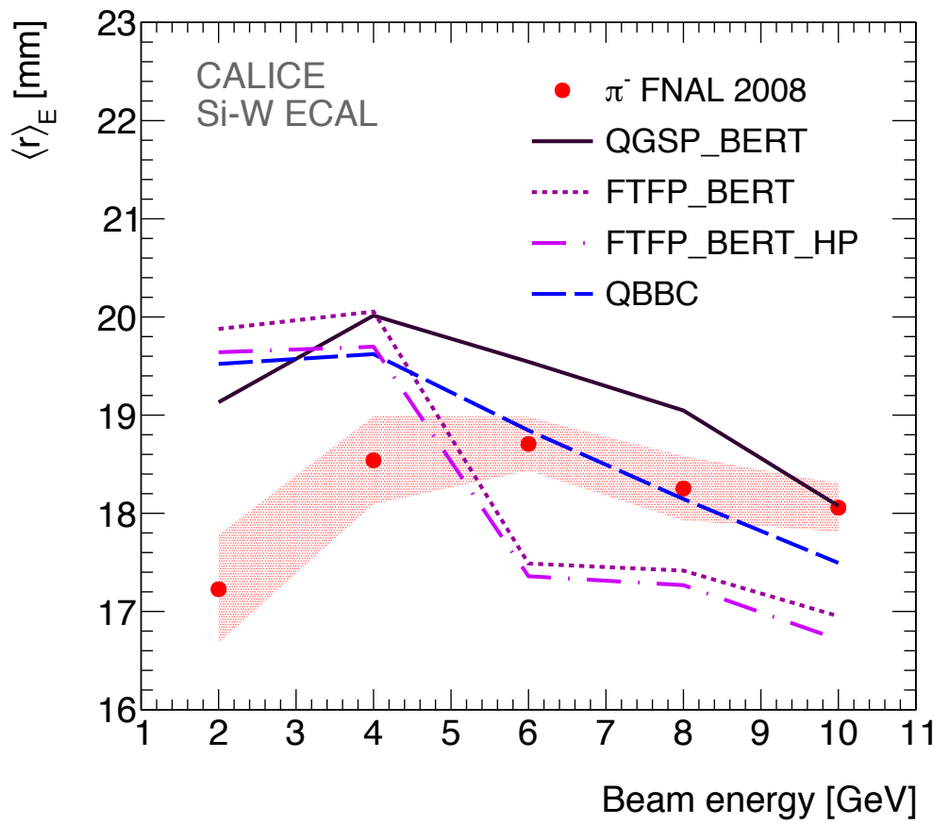
Radial Energy Profile



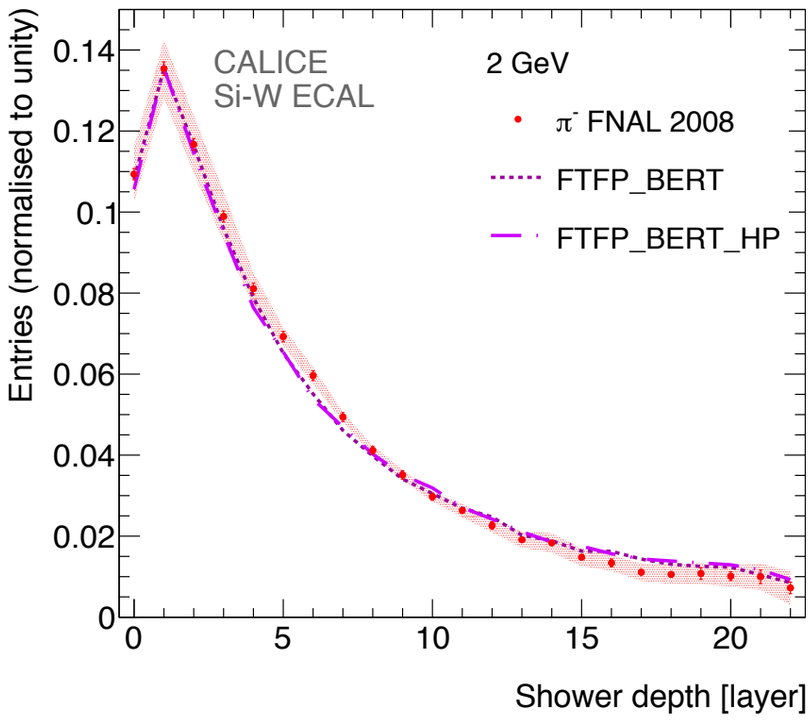


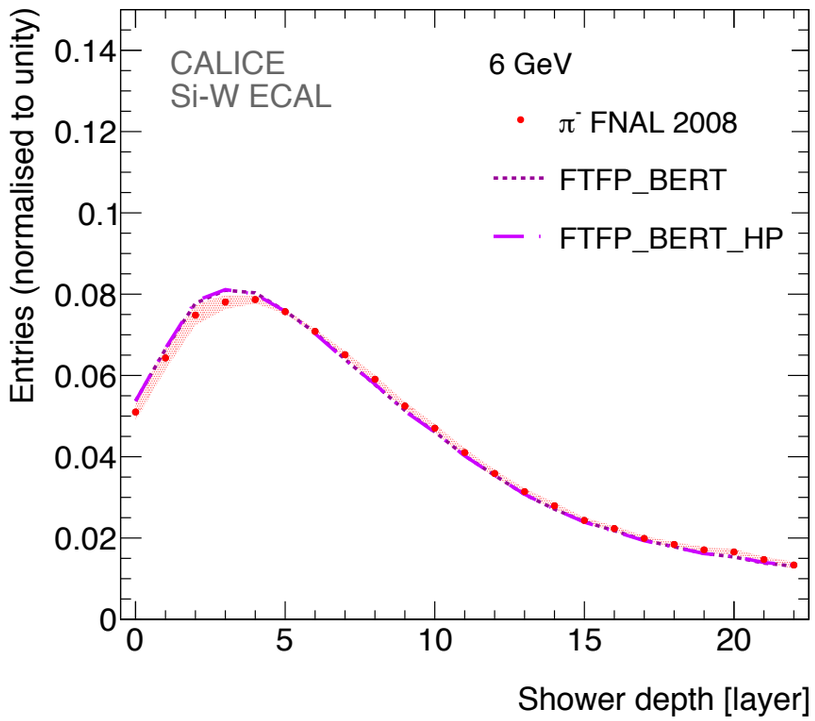


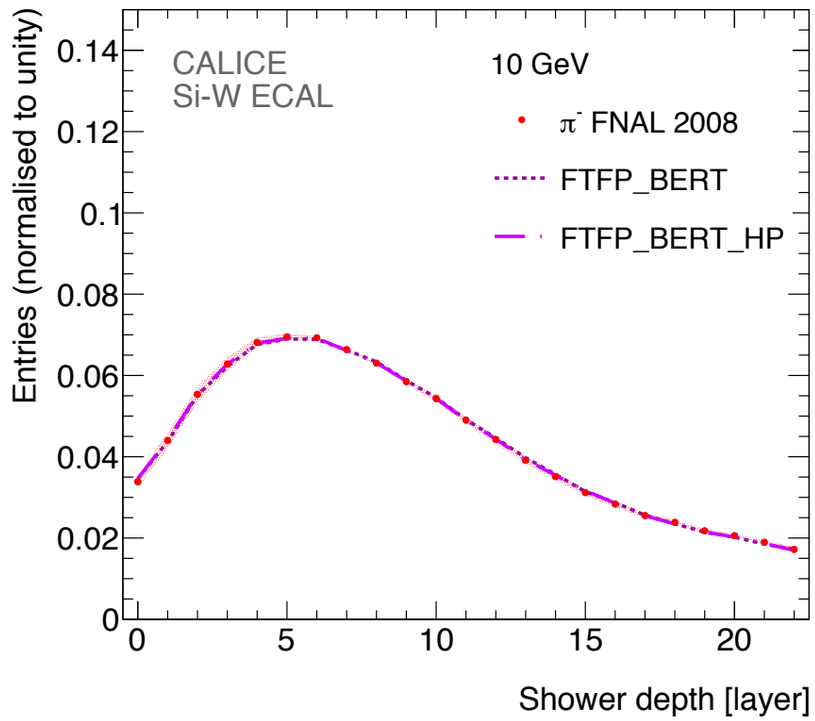
- MC close to data, but not enough energy overall and too much energy near the shower axis in the Fritiof String model
- Clear transition between models



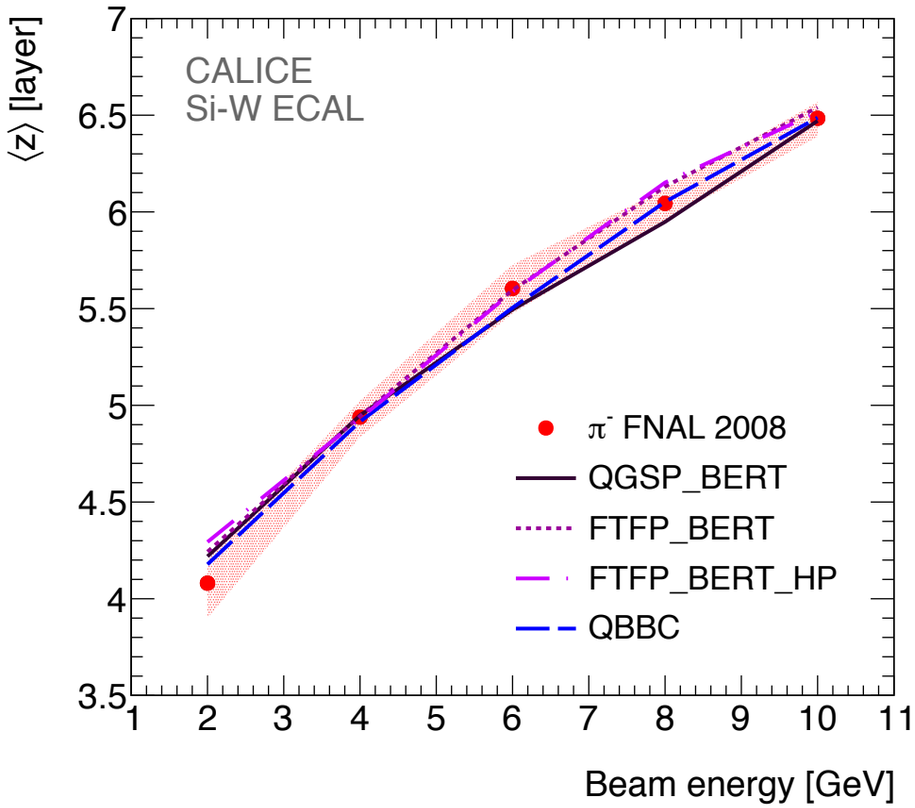
Longitudinal Hit Density



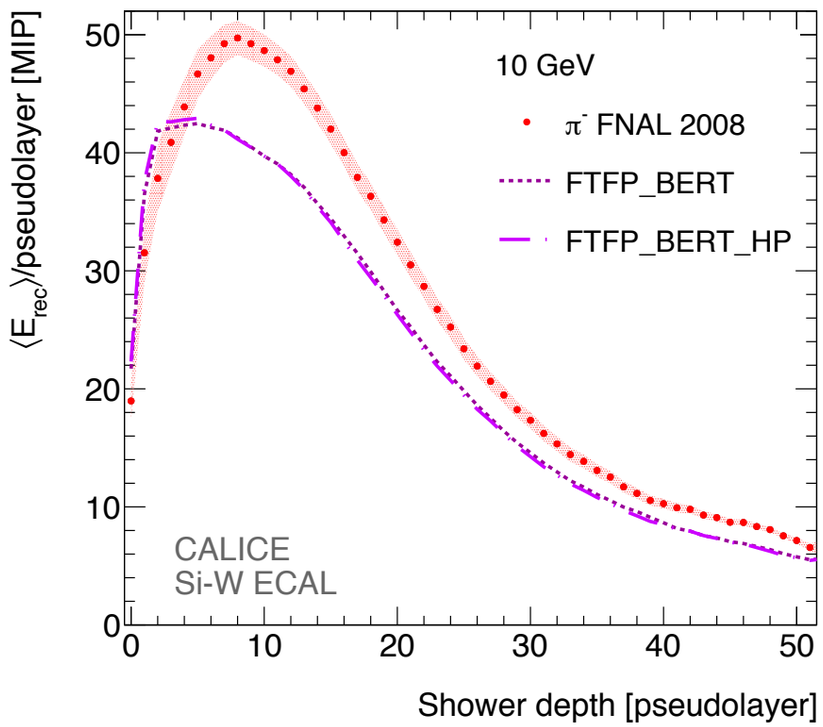


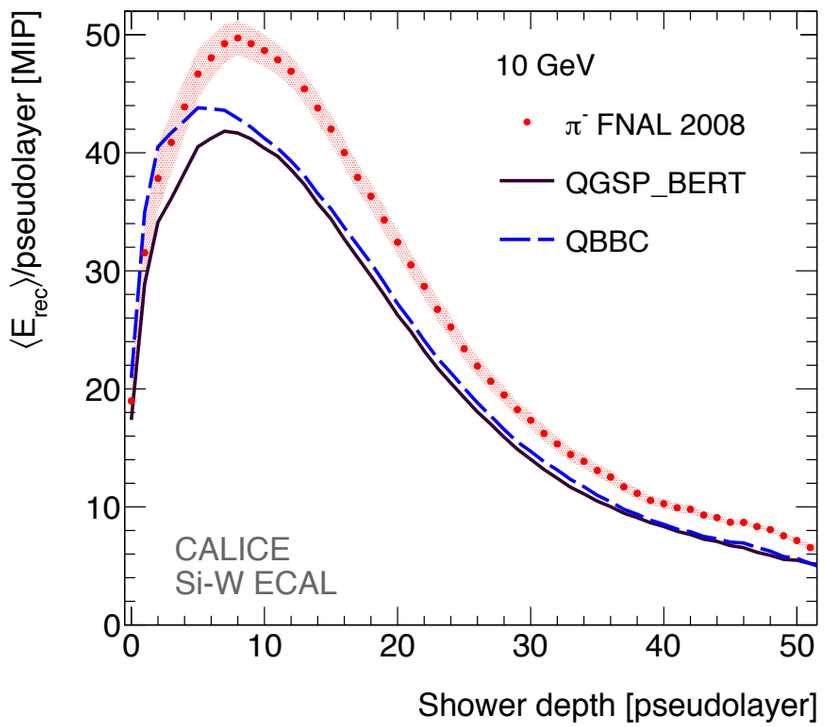


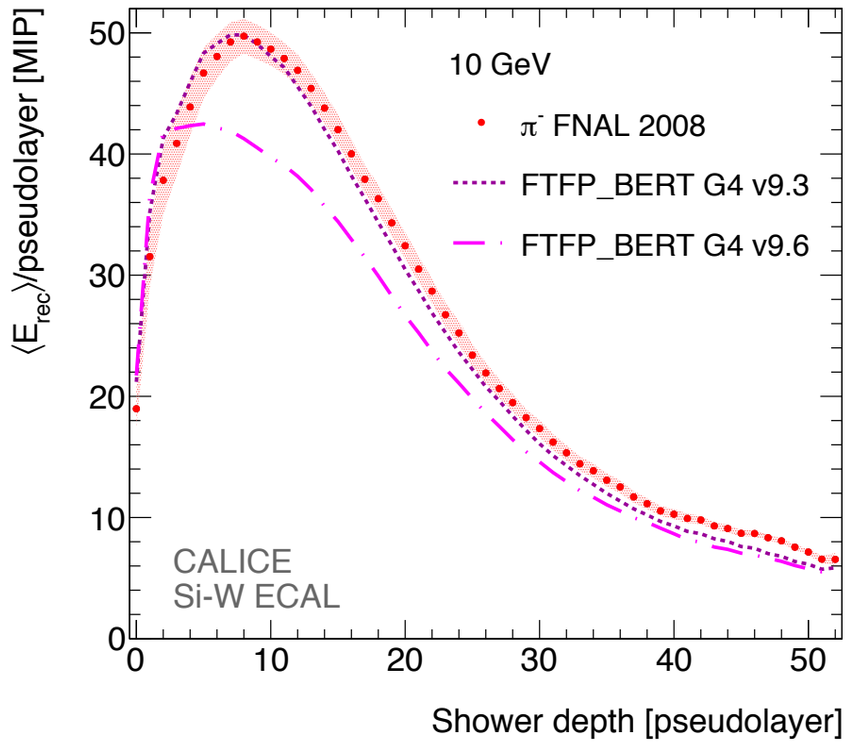
- MC reproduces the data well



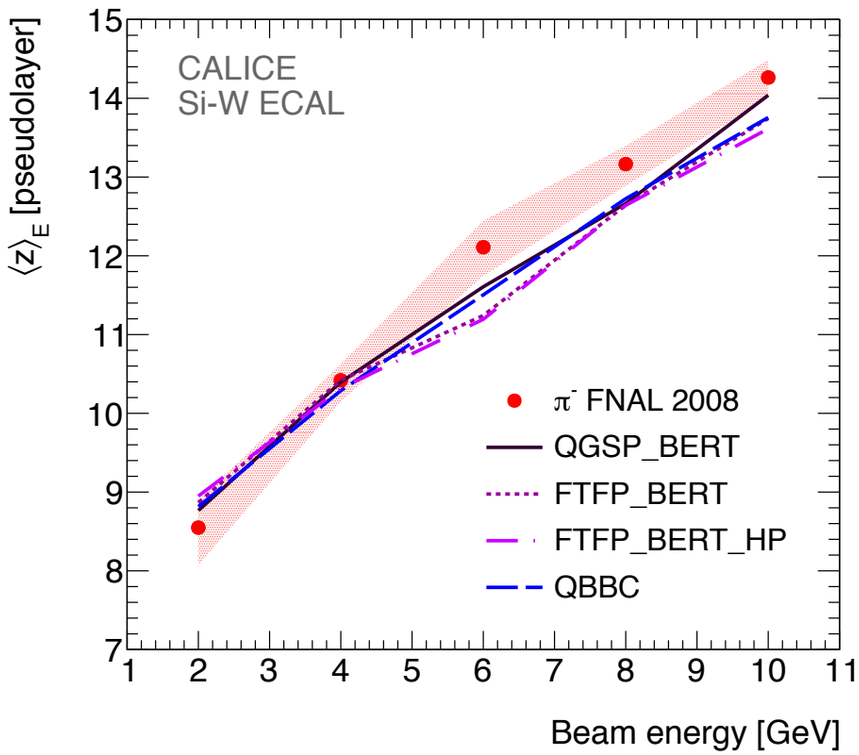
Longitudinal Energy Profile







- MC underestimates the energy deposition
- Too much energy deposited close to the interaction region by the Fritiof model
- Large change in FTFP_BERT between G4 versions
- No energy mismatch for scintillator HCAL observed
- Bug in G4 v9.6, should be solved in v10.1



Summary and Conclusion

- Test beam data 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
  - Overall the MC are close to the data (within 20%), but details are not reproduced.
  - The main discrepancy is in the energy deposition, which is too low and too close to the shower axis and interaction layer for the Fritiof model
  - The reduced energy is caused by a reduced number of hits in the MC
  - The data from the Si-W ECAL is very precise and allows to discriminate between MC models on a very fine scale

Questions?

Back-up: Event Selection

- Event sample:
  - Si-W ECAL physics prototype
  - 2008 FNAL test beam of π^- at 2, 4, 6, 8, 10 GeV
  - Matching MC: QGSP_BERT, FTFP_BERT, FTFP_BERT_HP, QBBC
- Event cuts:
  - Physics trigger, Cherenkov trigger
  - minimum number of hits (25)
  - hits in correct region of the Si-W 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 13 k – 180 k)
  - – 150 k – 700 k data events (accepted 8 k – 154 k)

Backup: Contamination

- The FNAL test beam at low energies consists mostly of electrons, also muons are present and sometimes events are recorded with multiple incoming particles.

- These contaminations are removed to obtain a clean pion sample. The data is corrected for the residual contaminations (based on MC studies).

- Muons are removed virtually 100% and their residual contamination is negligible.

- The residual contamination with multi-particle events is estimated to be between 8.2% at 2 GeV and 1.5% at 10 GeV.

- The residual contamination with electrons is estimated to be 3% at 2 GeV and it is negligible at 10 GeV.

Backup: Interaction Selection Criteria

- Interacting events (inelastic hadronic interaction)
  - Absolute energy increase
    - $E_i > E_{cut}$ && $E_{i+1} > E_{cut}$ && $E_{i+2} > E_{cut}$
  - Relative energy increase
    - $F = (E_i + E_{i+1}) / (E_{i-1} + E_{i-2}) > F_{cut}$ &&
    - $F' = (E_{i+1} + E_{i+2}) / (E_{i-1} + E_{i-2}) > F_{cut}$ &&
    - $E_{around,i} > 0.5\ E_i$