Interactions of pions in the CALICE Si-W ECAL prototype

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Introduction

The primary physics goals at future high energy lepton colliders require the precise measurement of the energy of hadron jets. Particle Flow Algorithms (PFA) are promising for achieving a jet energy resolution of 3-4% for jets in the energy range of 50 GeV to 500 GeV [1,2]. The PFA approach aims to reconstruct all particles in the final state of the e+e- collision. This requires highly segmented calorimeters to disentangle the contribution from showers created by different types of particle within a jet, i.e., photons and hadrons. The CALICE collaboration [3] designs, constructs and operates prototypes of calorimeters dedicated to the application of particle flow algorithms.

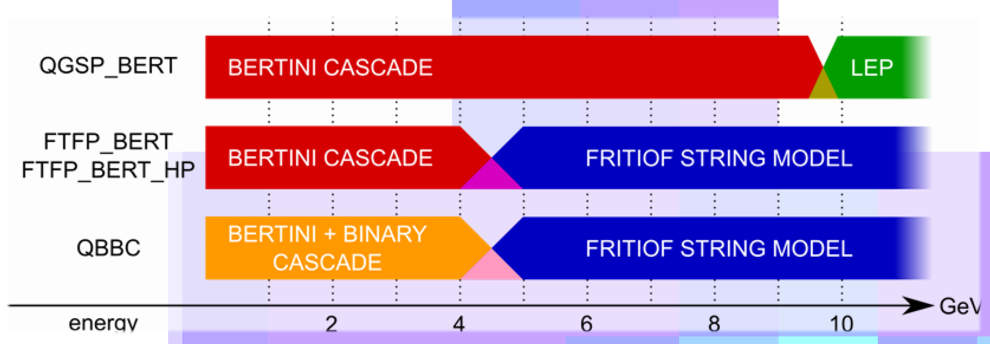
In this study a highly granular silicon tungsten electromagnetic calorimeter prototype is used to study hadronic showers and test Monte Carlo models in the energy range between 2 and 10 GeV.

Monte Carlo modeling

To optimise PFAs the interactions of hadrons must be modelled reliably in Monte Carlo simulations and the detector response to hadrons must be well understood. In view of this, highly granular calorimeter prototypes provide a unique means to test and further develop models of hadronic cascades.

Due to the complicated nature of hadronic interactions a precise description of hadronic showers in simulations is difficult to achieve. In GEANT4 [4] several phenomenological models are available.

These models are combined into physics lists where they are applied in a specific energy range. Four of these physics lists have been studied in comparison to the data.

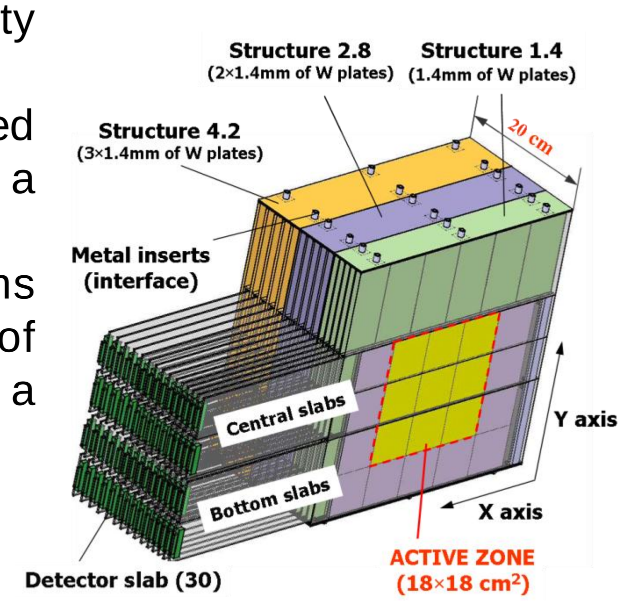


The Silicon-Tungsten Electromagnetic Calorimeter prototype

The prototype consists of a sandwich structure of 30 layers of silicon and tungsten. It has a high granularity due to the segmented Si wafers with 1x1 cm^2 pixels.

The active zone is 18x18 cm^2. The prototype is divided into 3 modules of 10 layers, where each module has a different tungsten thickness.

The total thickness accounts for 24 radiation lengths and 1 interaction length. This means more than half of the hadrons traversing the prototype will have a primary interaction within its volume.



Interaction fraction and interaction finding efficiency

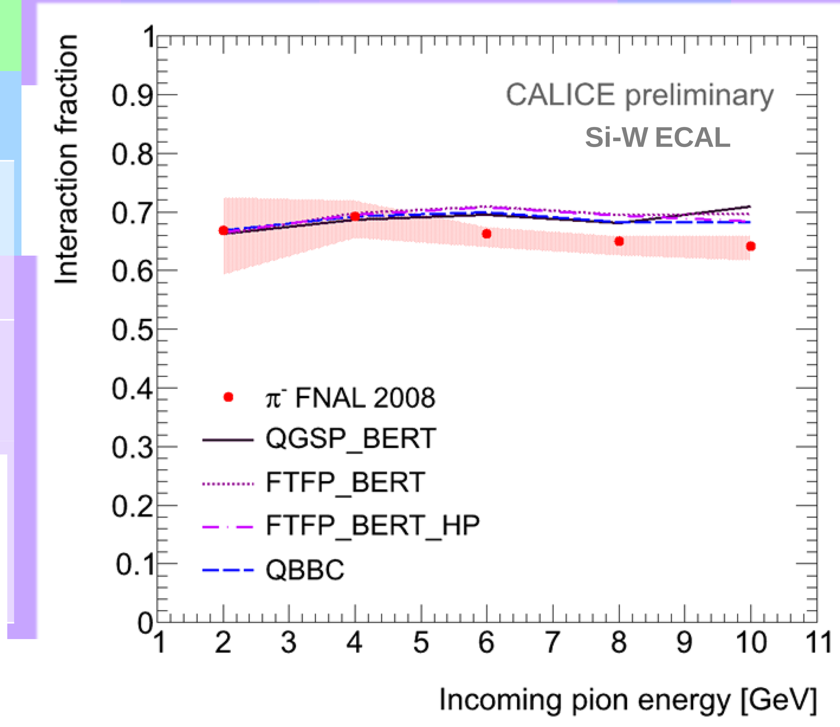
Interacting events are identified based on the deposited energy in the calorimeters layers.

There are two cuts, one based on the absolute energy increase and the other on the relative energy increase:

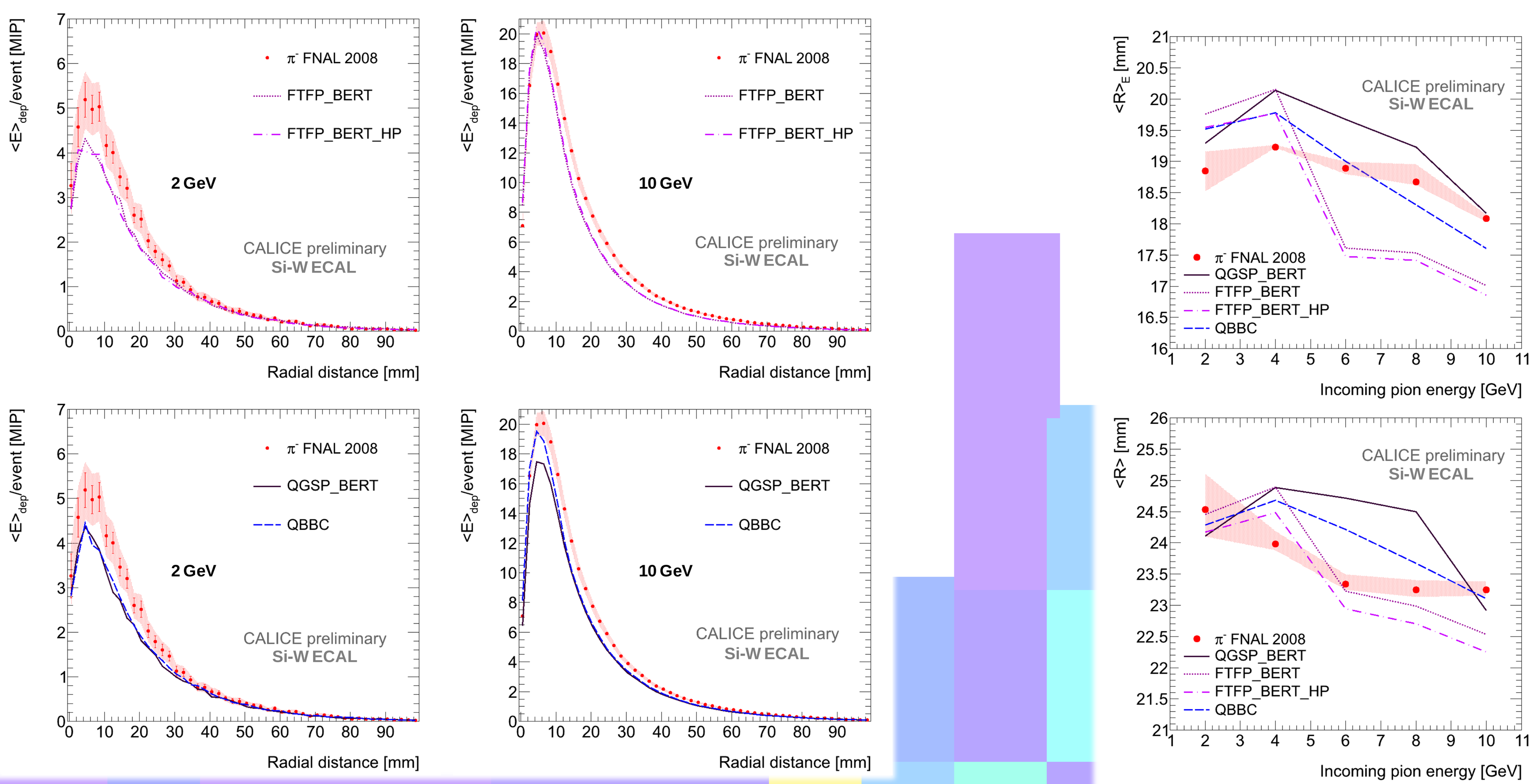
1) $E_i > E_{cut}$ && $E_{i+1} > E_{cut}$ && $E_{i+2} > E_{cut}$
2) $(E_i+E_{i+1}) / (E_{i-1} + E_{i-2}) > F_{cut}$ && $(E_{i+1}+E_{i+2}) / (E_{i-1} + E_{i-2}) > F_{cut}$

The second criterion is important at low energies.

E (GeV)	Fraction found by absolute energy criterion	Additional fraction found by relative energy criterion	Interaction finding efficiency
2	0.35	0.25	0.60
4	0.61	0.16	0.77
6	0.74	0.11	0.85
8	0.80	0.08	0.88
10	0.83	0.07	0.90

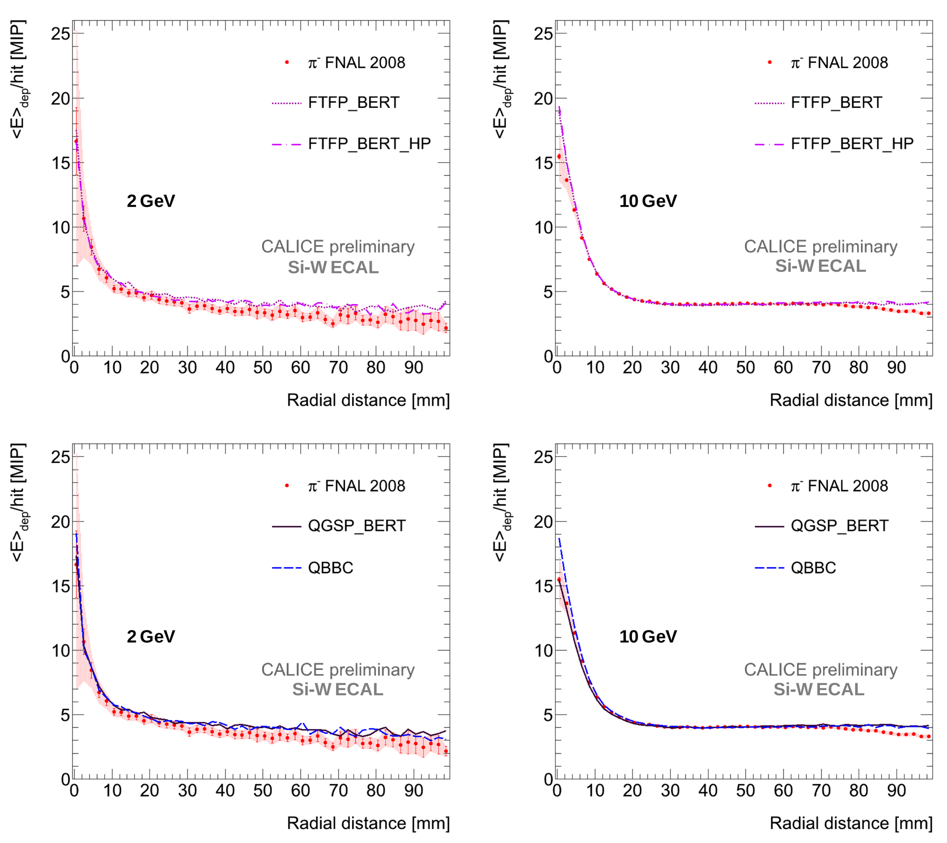


Radial energy profile



The radial distributions are sensitive to the model transitions in FTFP_BERT as can be clearly seen in the mean radial distance as a function of energy.

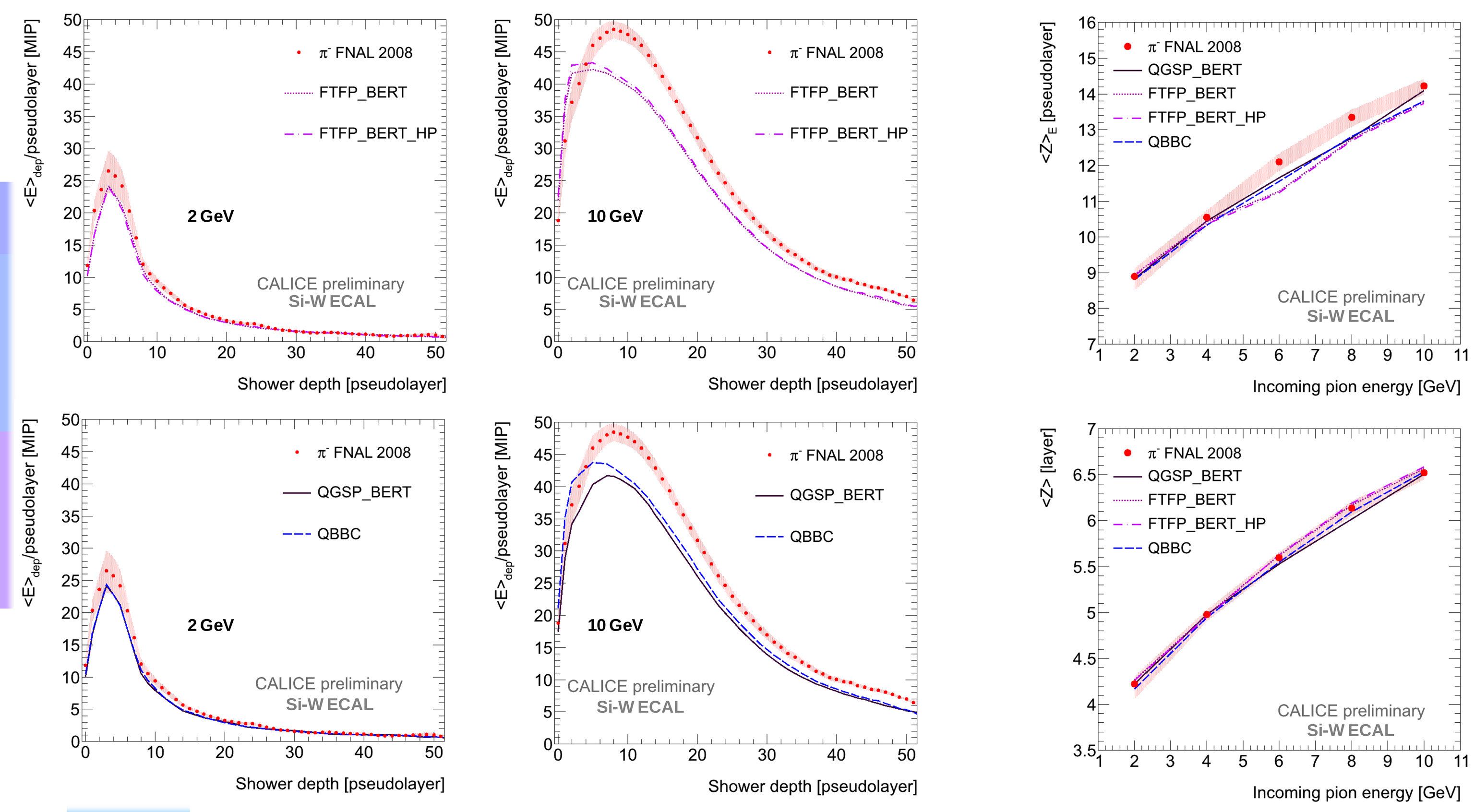
Mean hit energy



The overall energy deposition per event is underestimated by all physics lists. At the same time too much of the energy is deposited in the hits near the shower axis at higher energies by all physics lists except QGSP_BERT.

The radial hit distribution is reasonably well modeled.

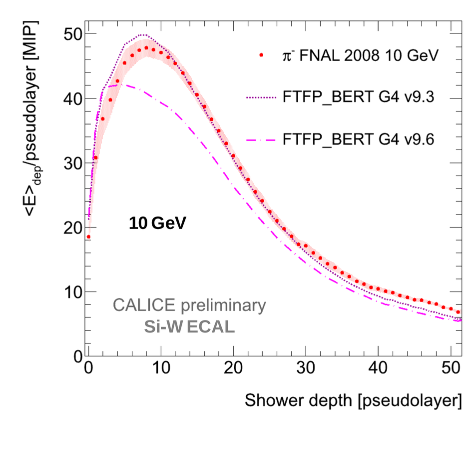
Longitudinal energy profile



The overall energy deposition is underestimated by all physics lists, while too much energy is deposited near the interaction point.

The longitudinal hit distribution is very well reproduced by simulations.

Recent tuning of the Fritiof string model based on scintillator data causes the discrepancy between data and Monte Carlo.



Conclusions

Interactions of pions in the Si-W ECAL can be found with an efficiency between 60% and 90%, using two energy based criteria.

The data recorded with the Si-W ECAL has such high precision that it can distinguish between predictions from simulations of different physics lists in Geant4 at a very detailed level.

The Monte Carlo predictions are mostly within 10% of the data.

In general too little energy is deposited in the detector and especially the Fritiof string models deposits too much energy near the interaction region.

[1] J.C. Brient and H. Videau, eConf C010630 (2001) E3047, arXiv:hep-ex/0202004
[2] M.A. Thomson, Nucl. Instrum. Meth. A611(2009) 25-40, arXiv:0907.3577
[3] The CALICE Collaboration website https://twiki.cern.ch/CALICE
[4] The GEANT4 Collaboration, Nucl. Instrum. Meth. A506 (2003) 250-303