Interactions of Pions in the Si-W ECAL prototype

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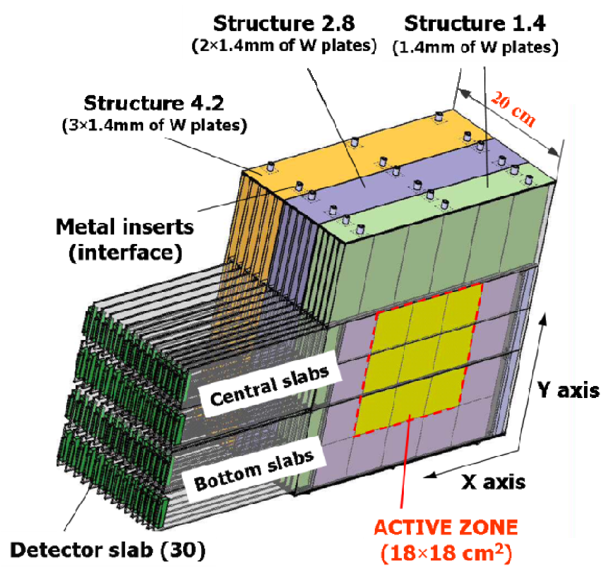
Physique des 2 Infinis et des Origines

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Introduction

- Study the interactions of π^- in the Si-W ECAL physics prototype at low energies (2 – 10 GeV) and compare various Monte Carlo Models (physics lists) to this data



Analysis setup

- Event sample:
  - Si-W ECAL physics prototype
  - 2008 FNAL test beam of π^- at 2, 4, 6, 8 and 10 GeV
  - Matching Monte Carlo (physics lists: FTFP_BERT, FTFP_BERT_HP, QGSP_BERT, QGSP_BIC, QBBC)
- Event cuts:
  - correct trigger, minimum number of hits (25), hits in correct region of 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 25 k – 300 k)
  - 150 k – 700 k data events (accepted 20 k – 450 k)

Event Classification

- Classify events as interacting or non-interacting
  - The absolute and relative energy increase in subsequent layers defines the interaction point
- We will refine the event classification with machine learning techniques (more independent criteria) in future

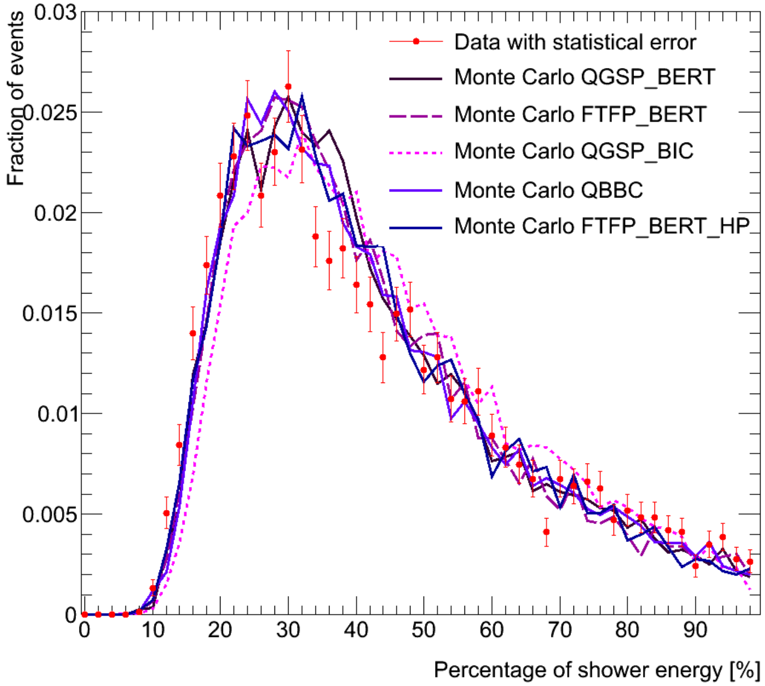
Event Classification (2)

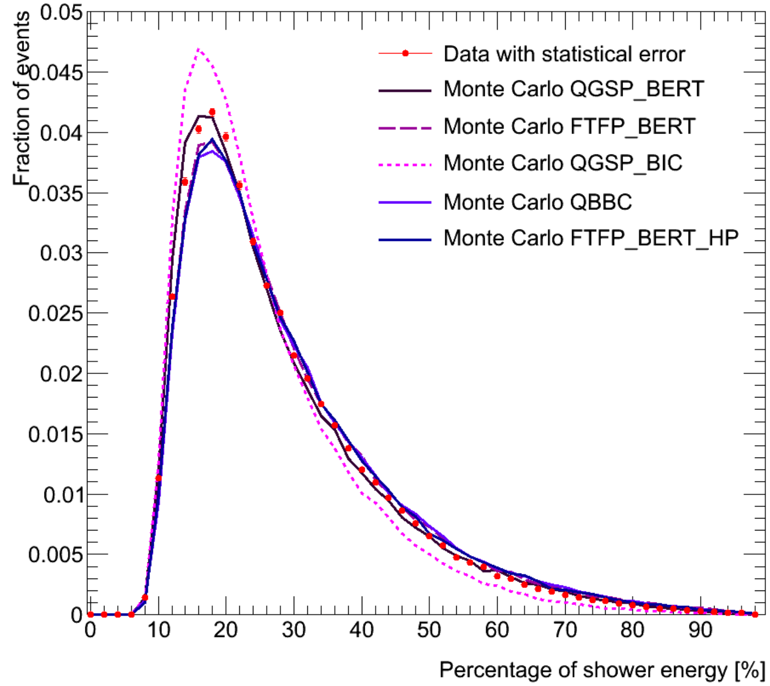
- Interactions are found based on two criteria:
  - Absolute energy increase
  - Relative energy increase
- Especially at low beam energies the second criterion is very important

E (GeV)	Fraction found by absolute energy criterion	Additional fraction found by relative energy criterion
2	0.35	0.26
4	0.61	0.16
6	0.75	0.11
8	0.80	0.08
10	0.83	0.07

High energy fraction in a single layer

The relative energy increase criterion selects also events with a strong local energy increase. These kind of events are not negligible at low beam energy.





At 2 GeV 20.3% (MC: 18.3 – 21.8%) of events have more than 60% of the energy deposited in a single layer. At 10 GeV this is 4.4% (MC: 2.6 – 5.8%).

Interaction layer

- The efficiency to find the interaction close to the real interaction layer:
  within one layer η(±1),
  within 2 layers η(±2)
- Model FTFP_BERT (other models give similar efficiencies)

E (GeV)	η(±1)	η(±2)
2	0.48	0.50
4	0.62	0.66
6	0.73	0.76
8	0.76	0.80
10	0.79	0.82

Interaction finding efficiency

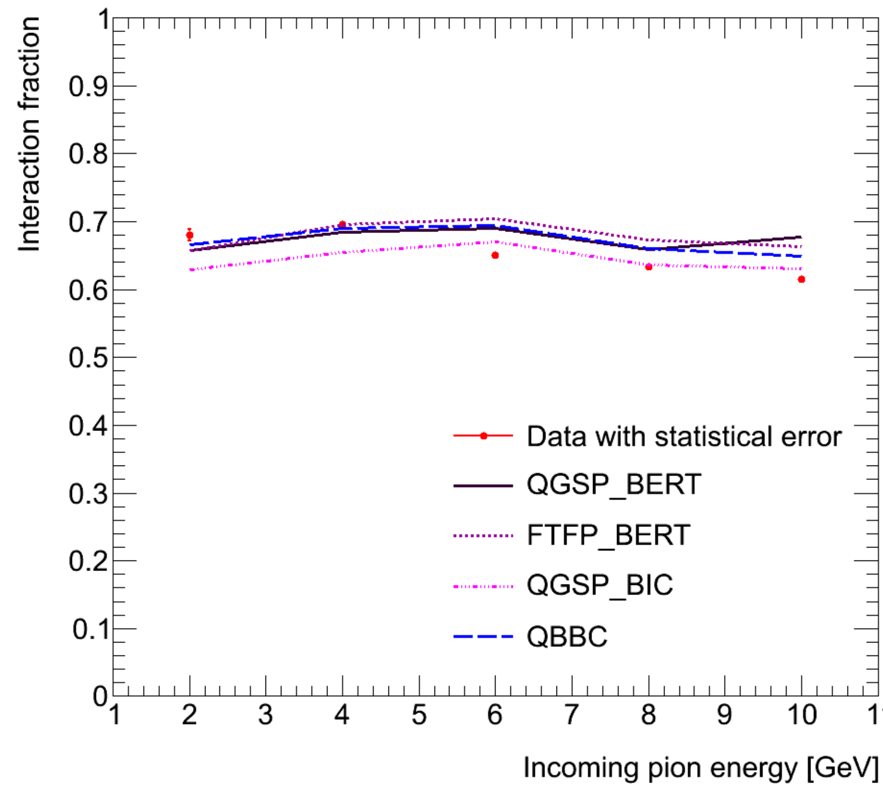
The fraction of all true interacting events that is classified as interacting
It depends on the MC physics list. Especially at low energy QGSP_BIC has a much higher efficiency compared to the others.

Physics list	2 GeV	4 GeV	6 GeV	8 GeV	10 GeV
QGSP_BERT	0.60	0.77	0.83	0.86	0.88
FTFP_BERT	0.60	0.77	0.85	0.88	0.90
FTFP_BERT_HP	0.59	0.77	0.85	0.88	0.90
QBBC	0.60	0.78	0.84	0.87	0.89
QGSP_BIC	0.73	0.86	0.91	0.93	0.94

Contamination = fraction of all events classified as interacting that is non-interacting, it is approximately 0.03 independent of energy, except for QGSP_BIC where it is between 13% at 2 GeV and 33% at 10 GeV!

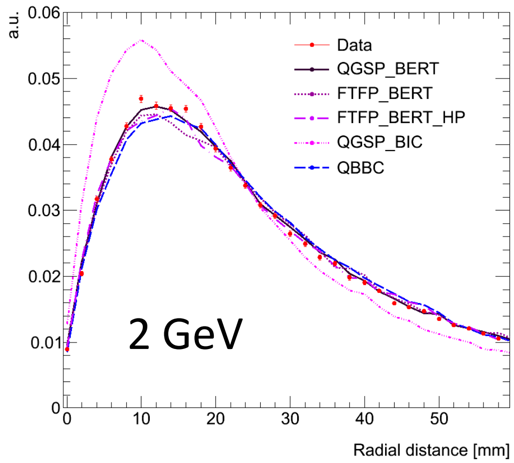
Interaction fraction

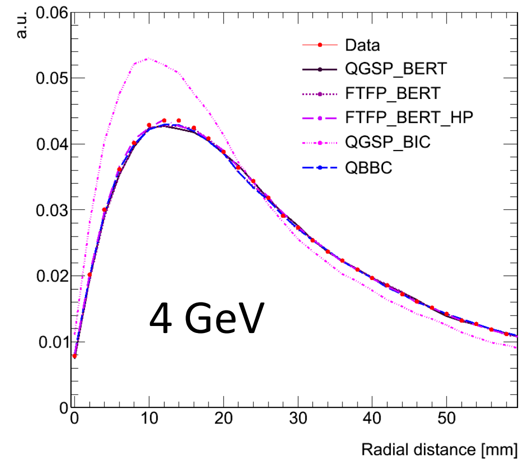
- The fraction of interacting events corrected with the interaction finding efficiency
- For data the efficiency of FTFP_BERT is used
- Systematic error:
  - Electrons and muons,
  - multi-particle events,
  - non-interacting events,
  - variation in selection variables,
  - unknown efficiency
- The interaction fraction is consistent with the ECAL material budget and approximately independent of energy

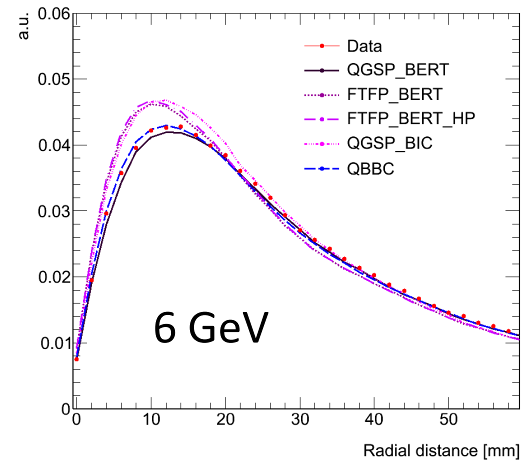


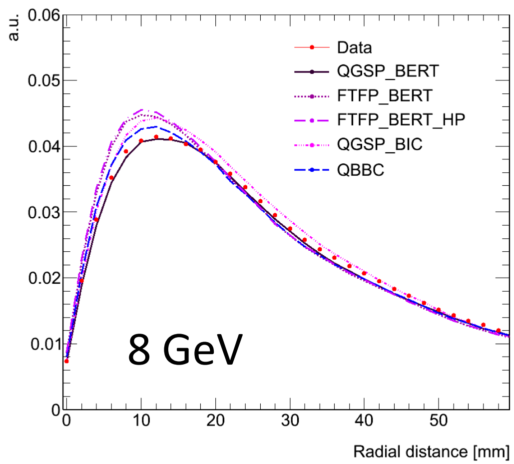
Radial distributions

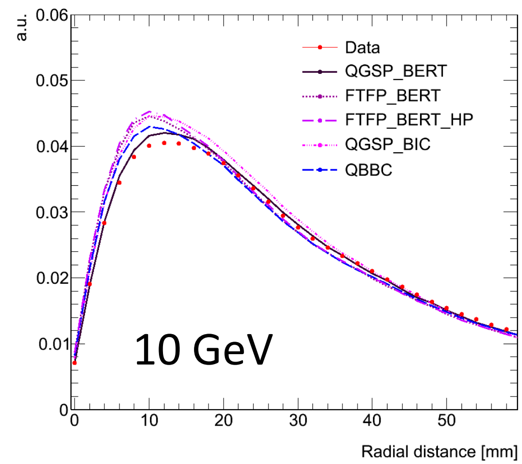
Radial distance of hits





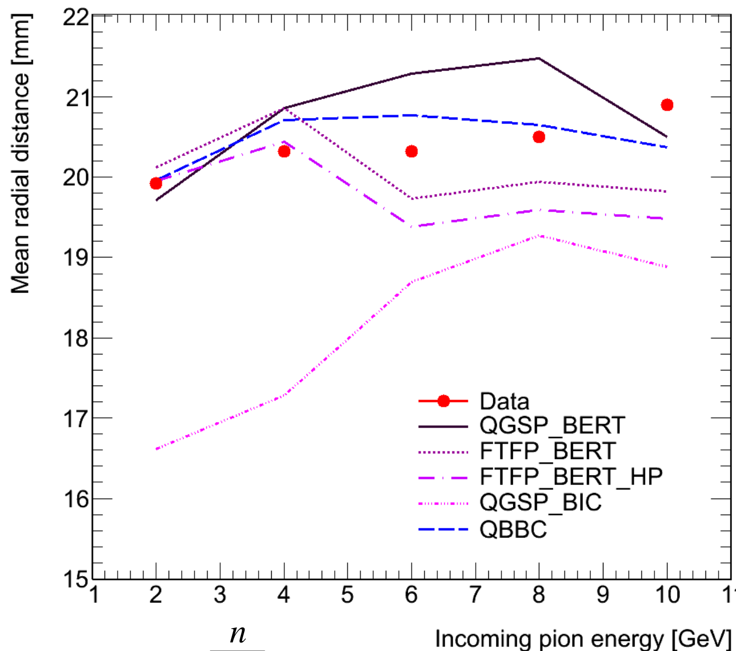


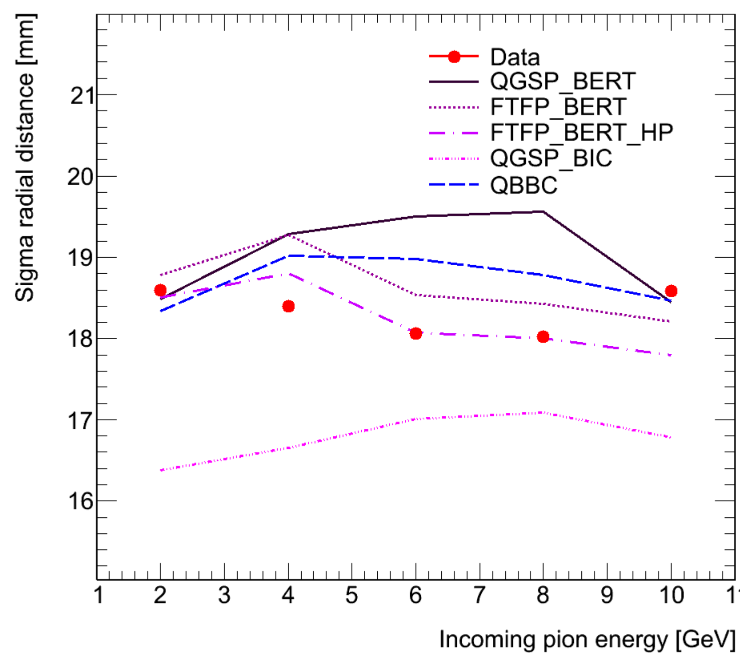




At low energy QGSP_BIC overestimates at low r, at higher energies more models overestimate.

Radial distance of hits mean and sigma vs energy



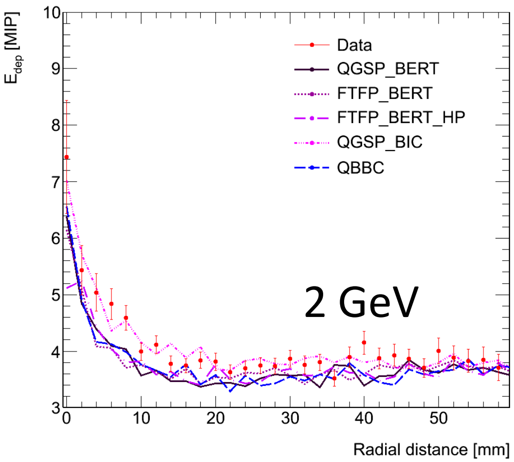


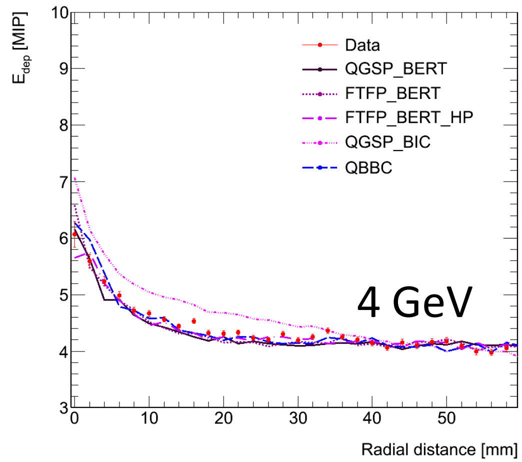
$$\langle r \rangle = \frac{\sum_{i}^{n} r_i}{n}$$

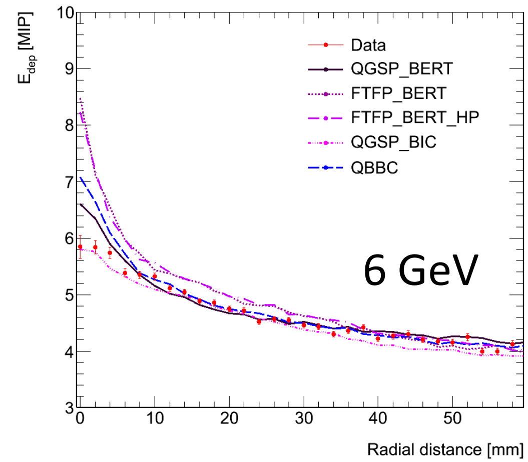
Clear transition between 4 and 6 GeV for FTFP_BERT. QGSP_BIC underestimates.

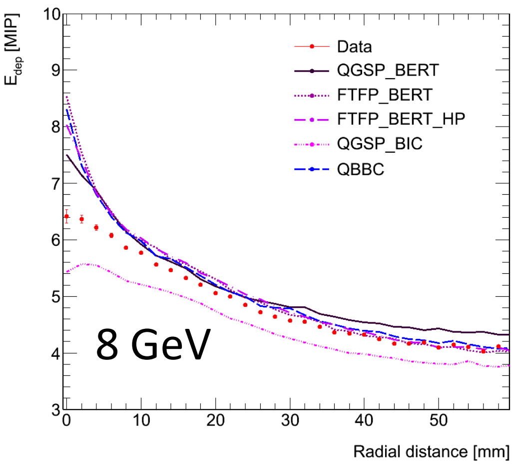
$$\sigma = \sqrt{\langle r^2 \rangle - \langle r \rangle^2}$$

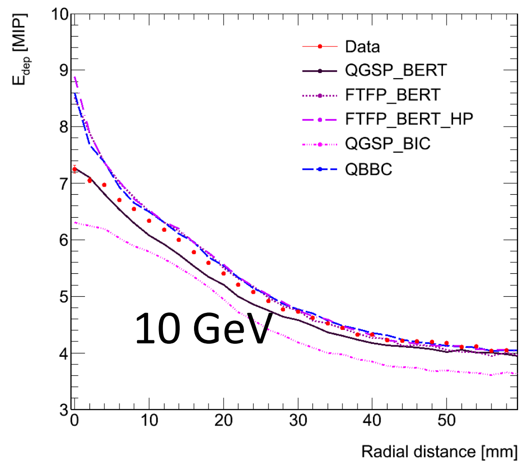
Radial energy profile





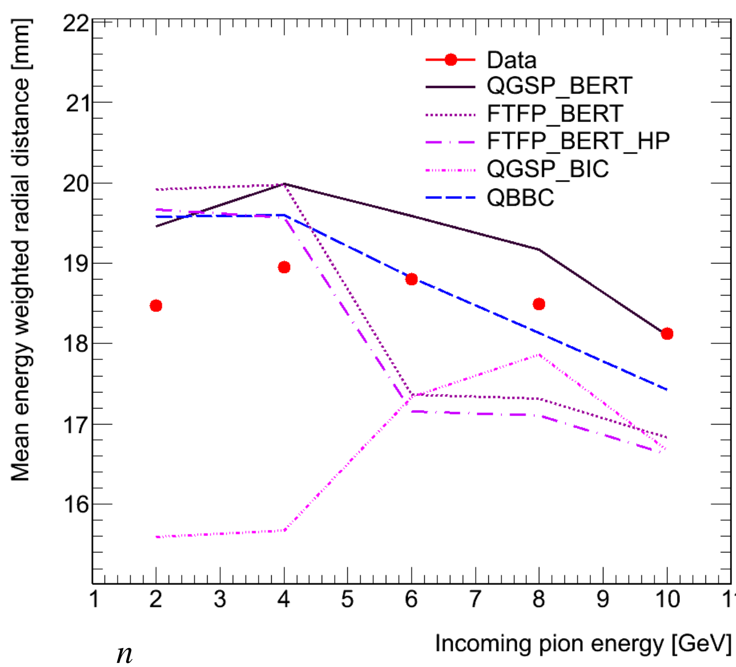


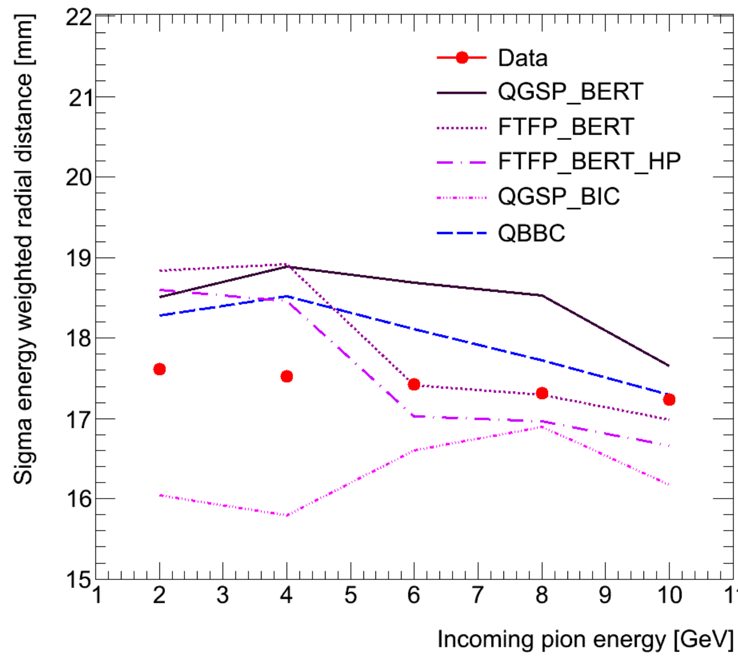




Better fit at low energy. At high energy most models overestimate at small r.

Mean shower radius and sigma





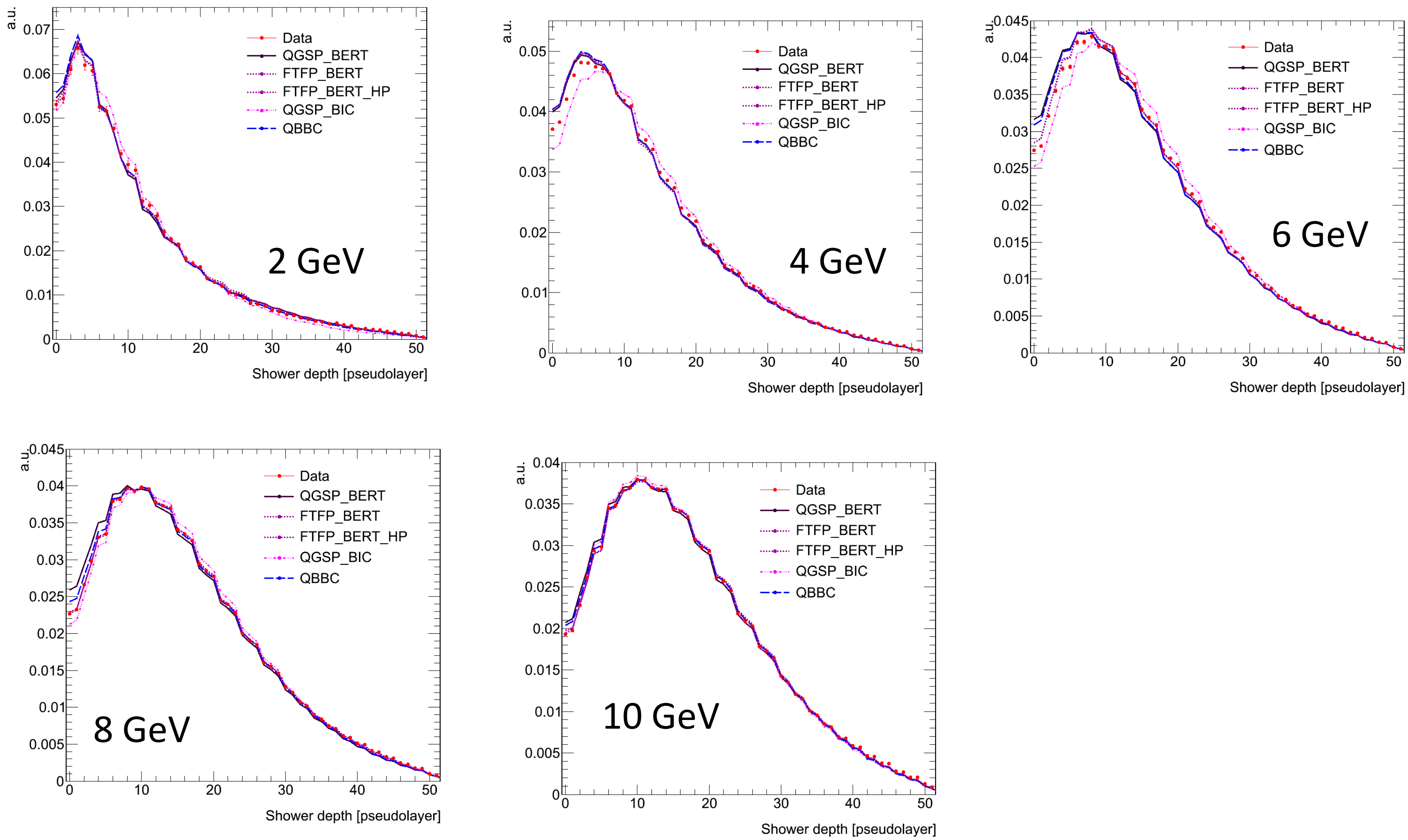
$$\langle r \rangle_E = \frac{\sum_i^n E_i r_i}{\sum_i^n E_i}$$

Clear transition between 4 and 6 GeV for some models. QGSP_BIC underestimates. Others overestimate at low energy

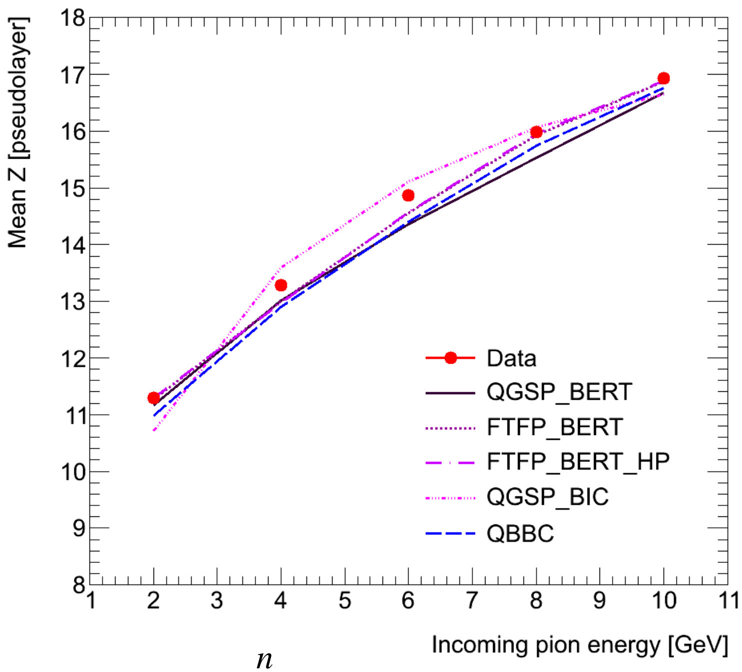
$$\sigma_E = \sqrt{\langle r^2 \rangle_E - \langle r \rangle_E^2}$$

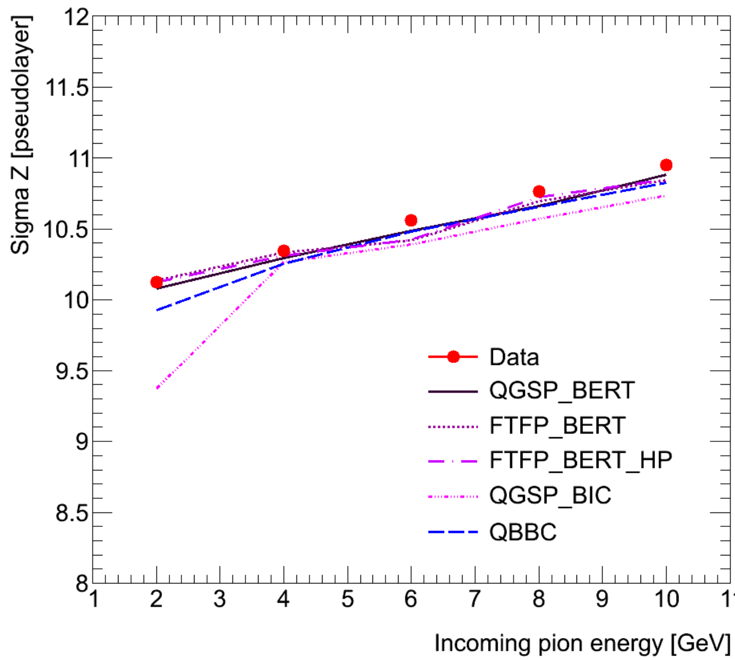
Longitudinal distributions

Z (layernumber)



Mean Z and sigma Z

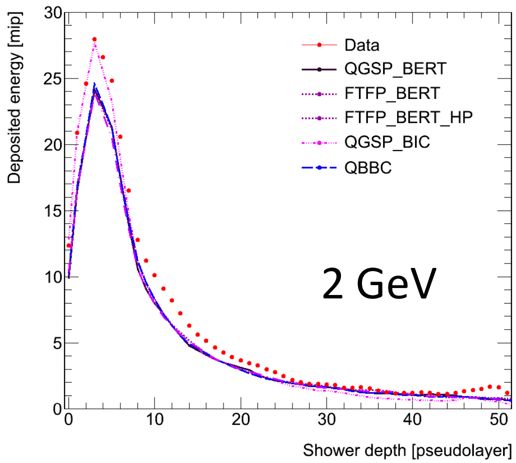


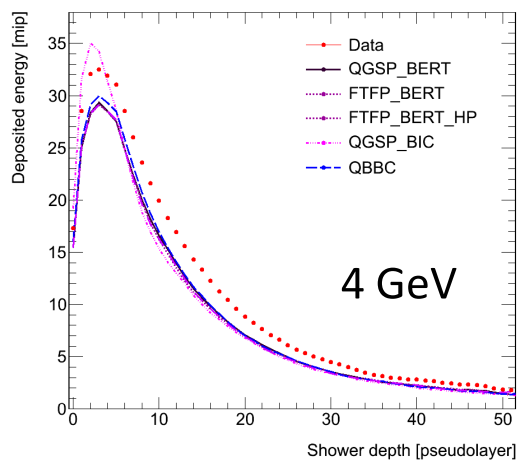


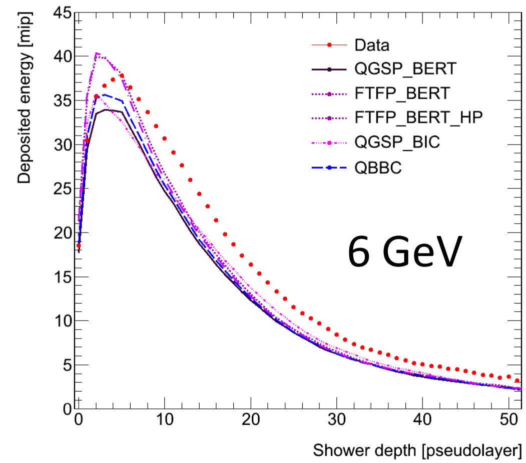
$$\langle z \rangle = \frac{\sum_i^n z_i}{n}$$

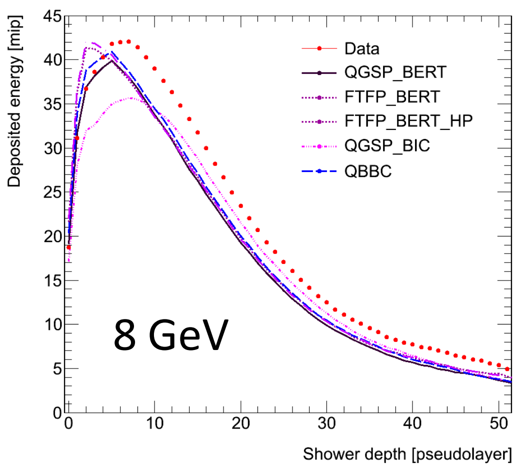
$$\sigma = \sqrt{\langle z^2 \rangle - \langle z \rangle^2}$$

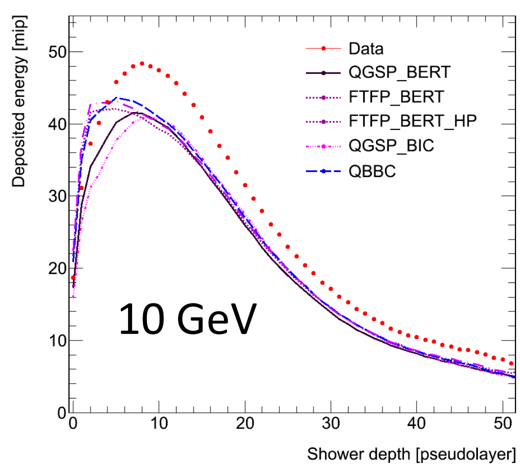
Longitudinal energy profile





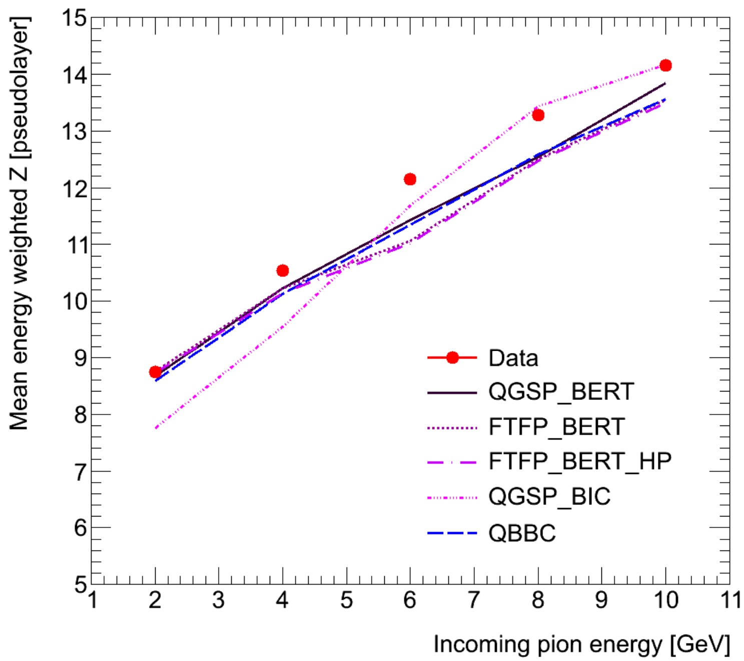


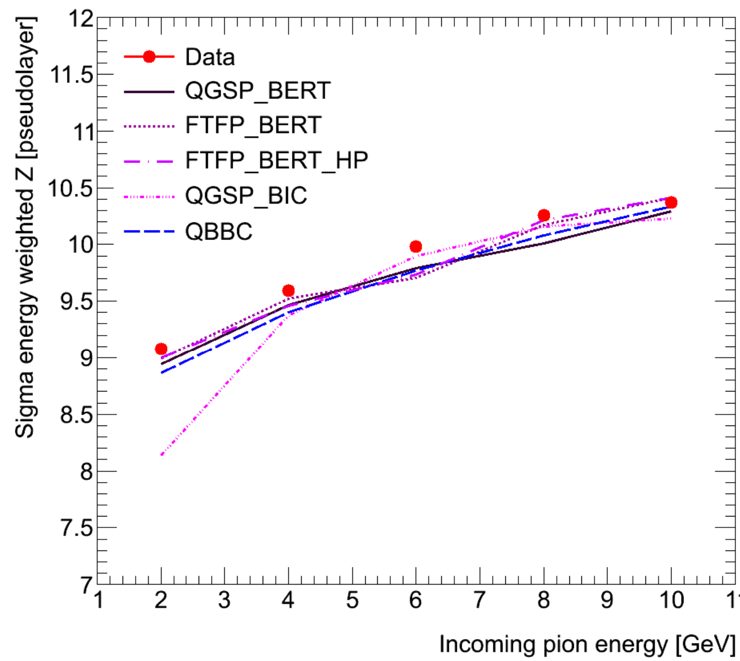




The data is not well described by the MC

Mean longitudinal position and sigma



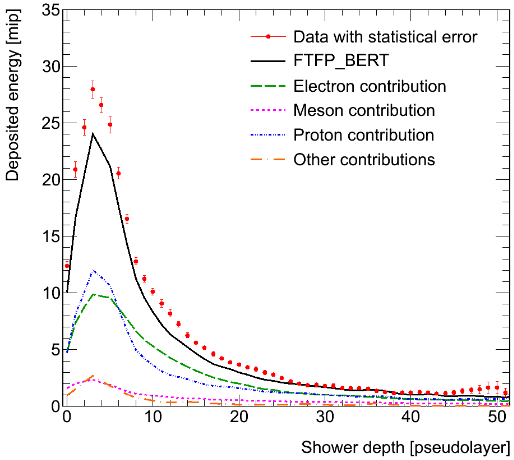


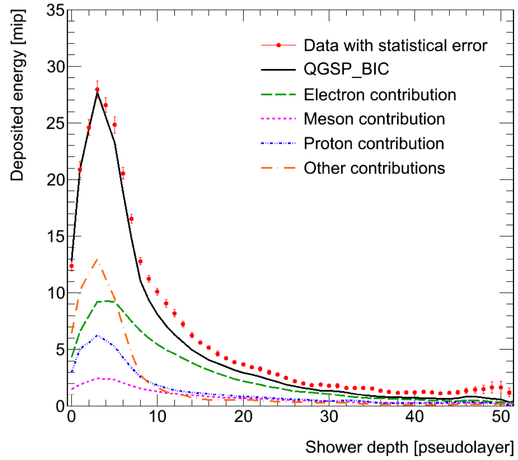
$$\langle z \rangle_E = \frac{\sum_i^n E_i z_i}{\sum_i^n E_i}$$

$$\sigma_E = \sqrt{\langle z^2 \rangle_E - \langle z \rangle_E^2}$$

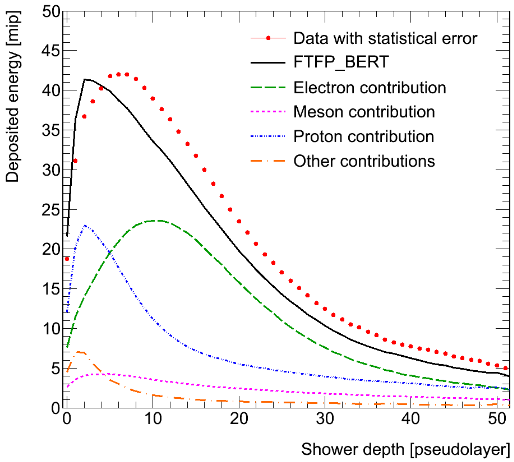
MC contributions to the Longitudinal energy profile

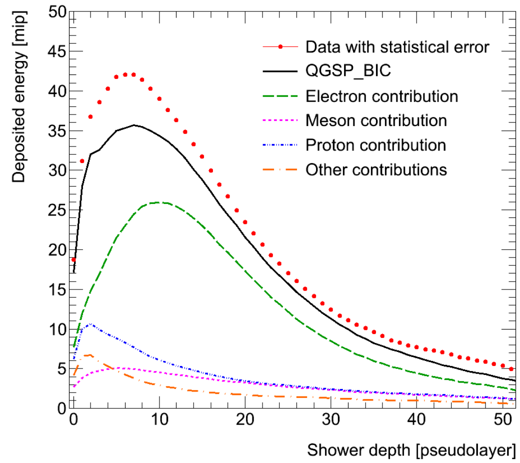
2 GeV





8 GeV





Summary

- Testbeams 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, shower radius and longitudinal energy profile

Selection criteria (backup)

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

Contaminations (backup)

- Muons: 2% - 1% (2 GeV – 10 GeV)
- Multi-particle events: 13% - 2%
- Electrons: 3% - 0%
- Non-interacting events: 3% - 5%