SiW Electromagnetic Calorimeter

Testbeam results:
Position and angular resolution
Pion analysis

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Calorimeter R&D for ILC

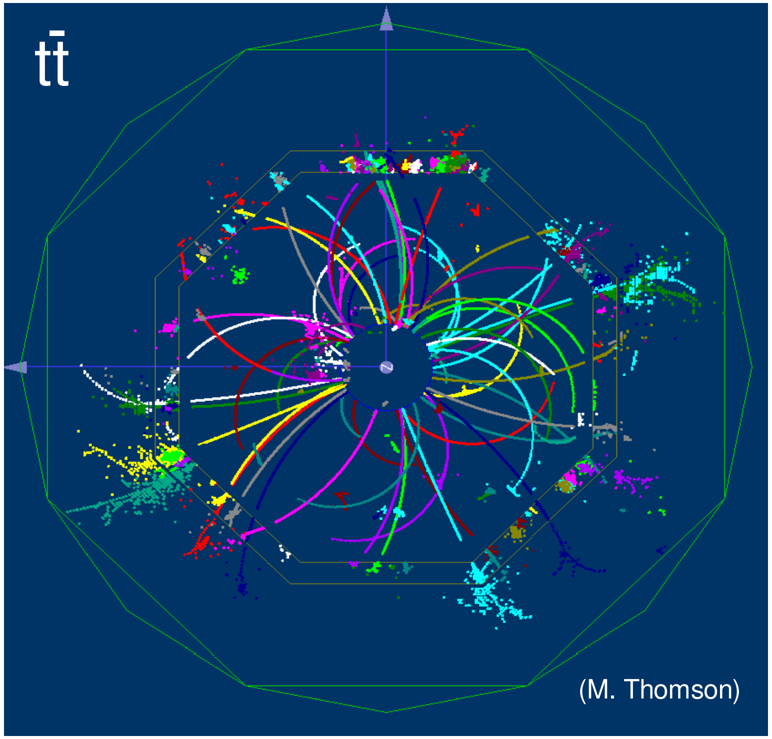
~336 physicists/engineers
57 Institutes
17 Countries
4 Continents

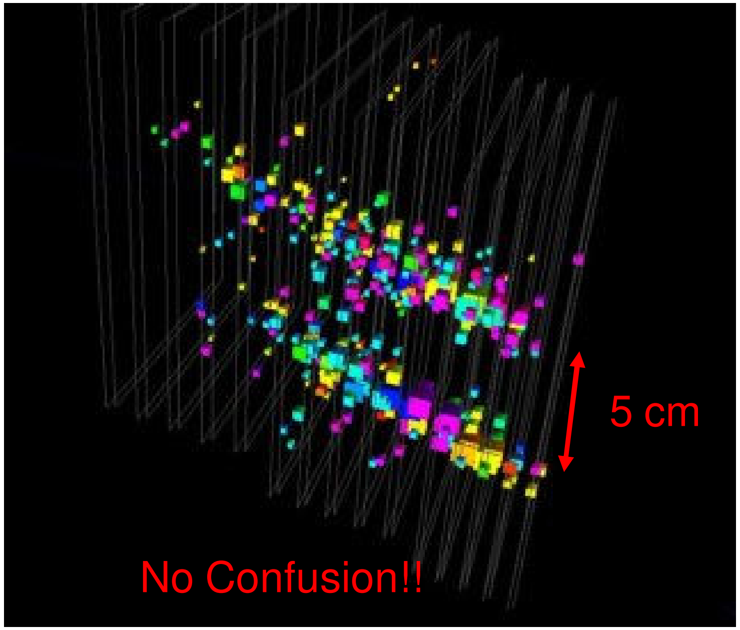
The goal

ILC goal:

The physics at the International Linear Collider will require good jet energy resolution which can be obtained with Particle Flow.

In order to reconstruct every particle a high segmentation is needed.



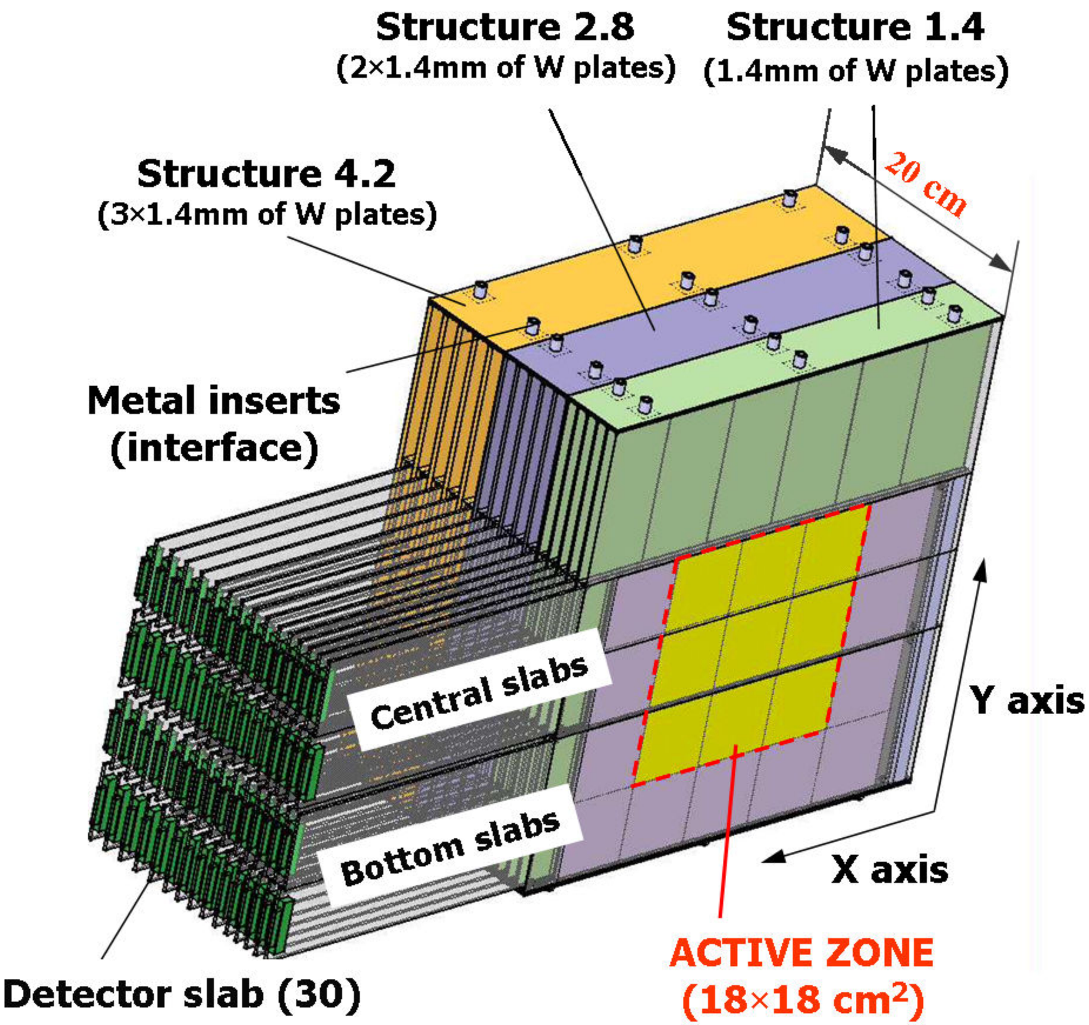


CALICE goal:

Several prototype calorimeters have been built to establish the technologies.

Data from testbeams will be used to tune clustering algorithms and validate existing MC models

SiW ECAL



Absorber material: Tungsten

Active material: Silicon wafers

1x1 cm^2 cells
6x6 cells in a wafer
3x3 wafers in a layer

30 layers of Tungsten:
- 10 x 1.4 mm (0.4 X_0)
- 10 x 2.8 mm (0.8 X_0)
- 10 x 4.2 mm (1.2 X_0)
  - ~24 X_0 total
  - ~1 λ_{int} total

Layers staggered along X

9720 channels

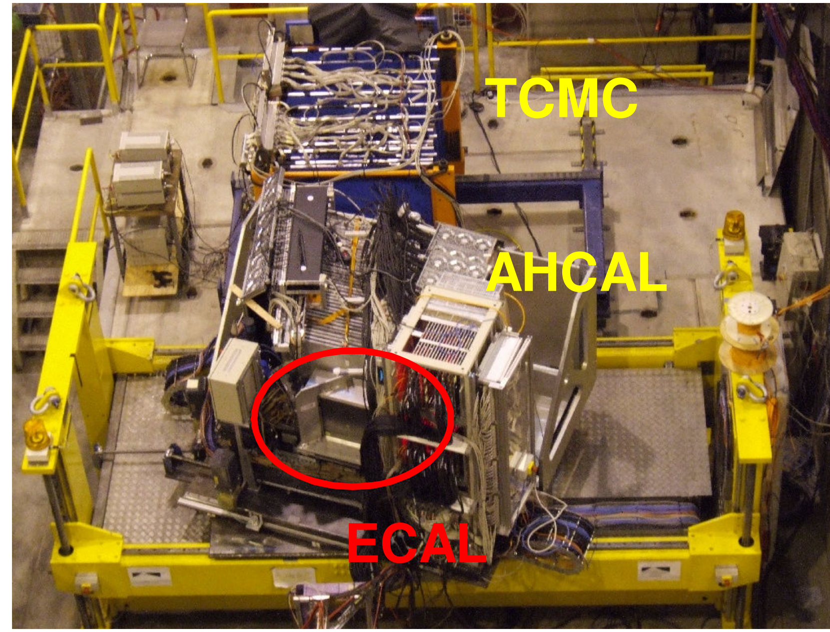
Testbeam program

ECAL Testbeam:

2006 at DESY and CERN (2/3 equipped)

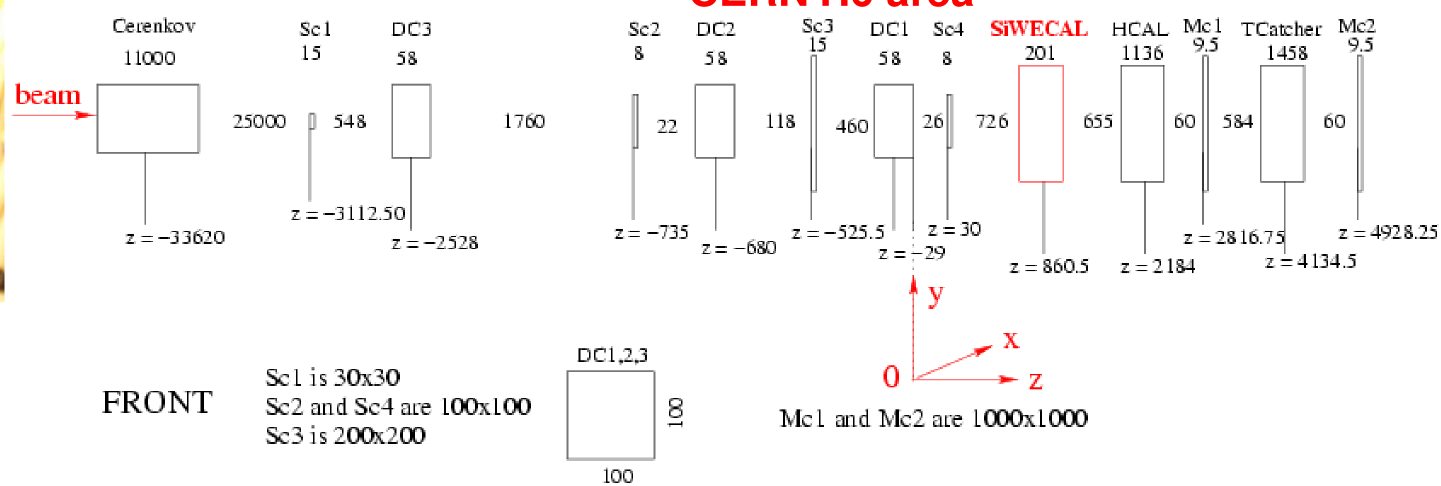
2007 at CERN (almost fully equipped)

2008 at FNAL (fully equipped)

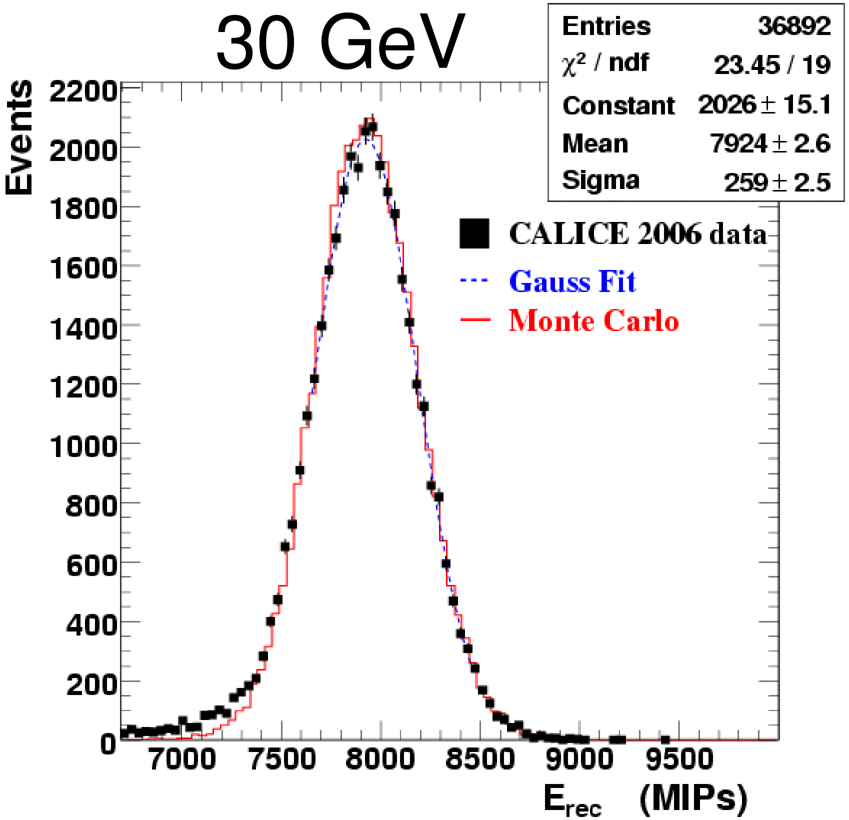


Slabs slit into alveolas

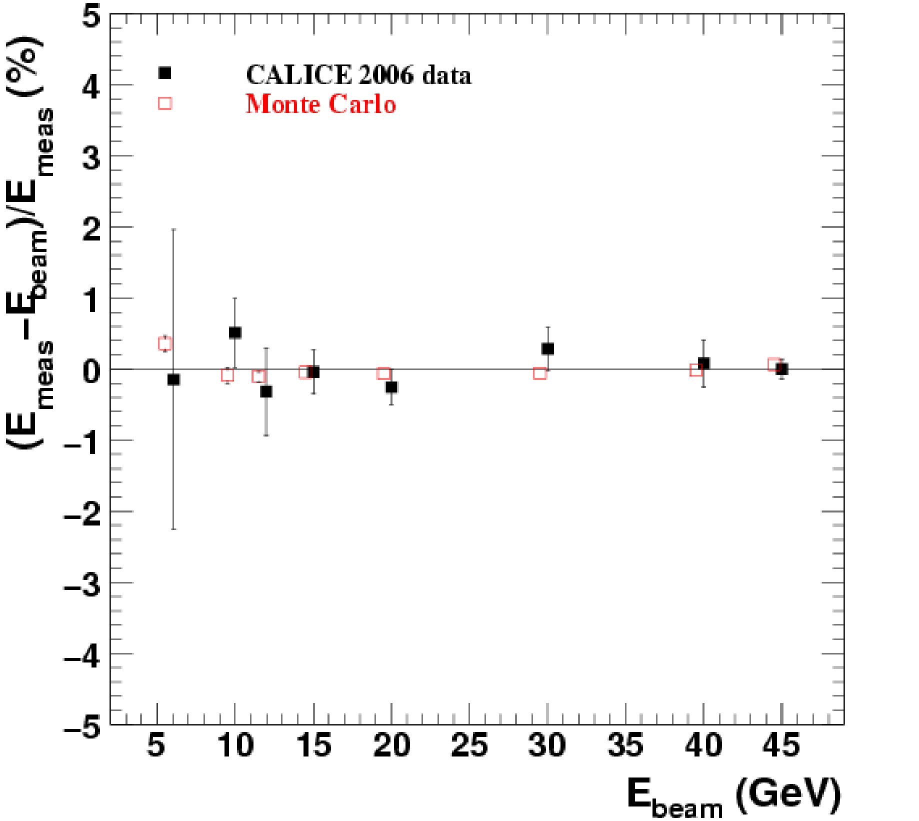
CERN H6 area



Electron energy resolution



$$\frac{\sigma E_{Meas}}{E_{Meas}} = \left(\frac{16.6 \pm 0.1}{\sqrt{E(GeV)}} \oplus (1.1 \pm 0.1) \right) \%$$

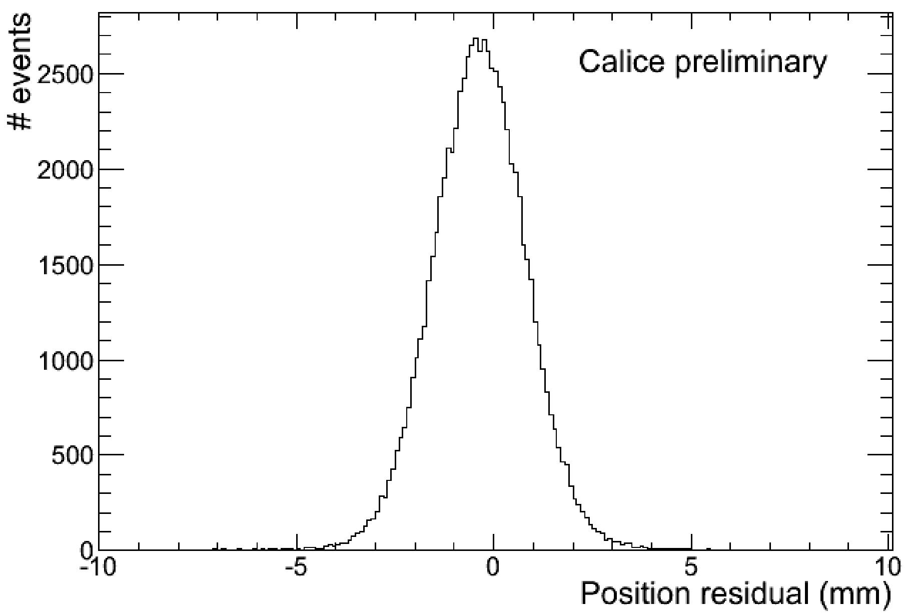


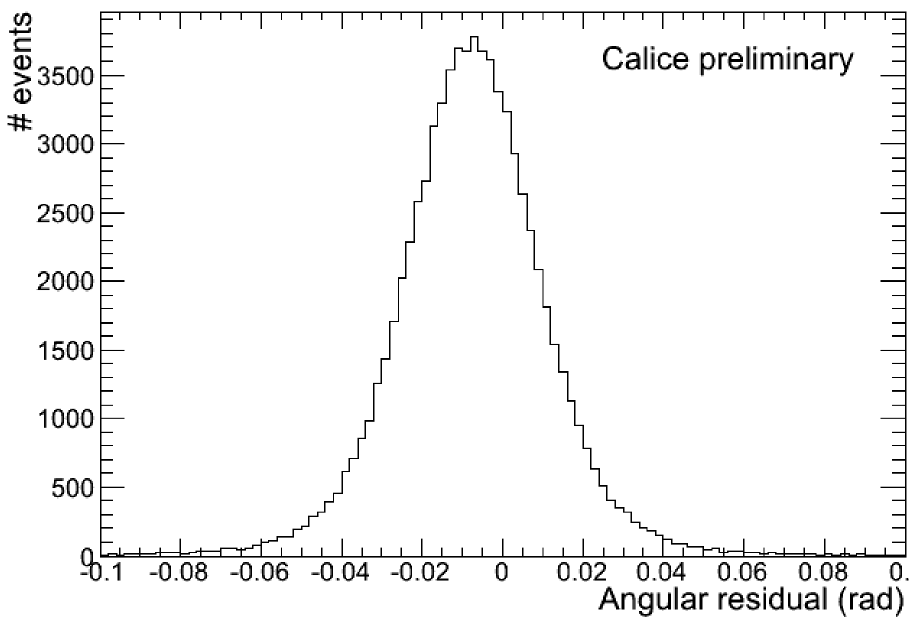
Good agreement between data end MC

Linear response within 1%

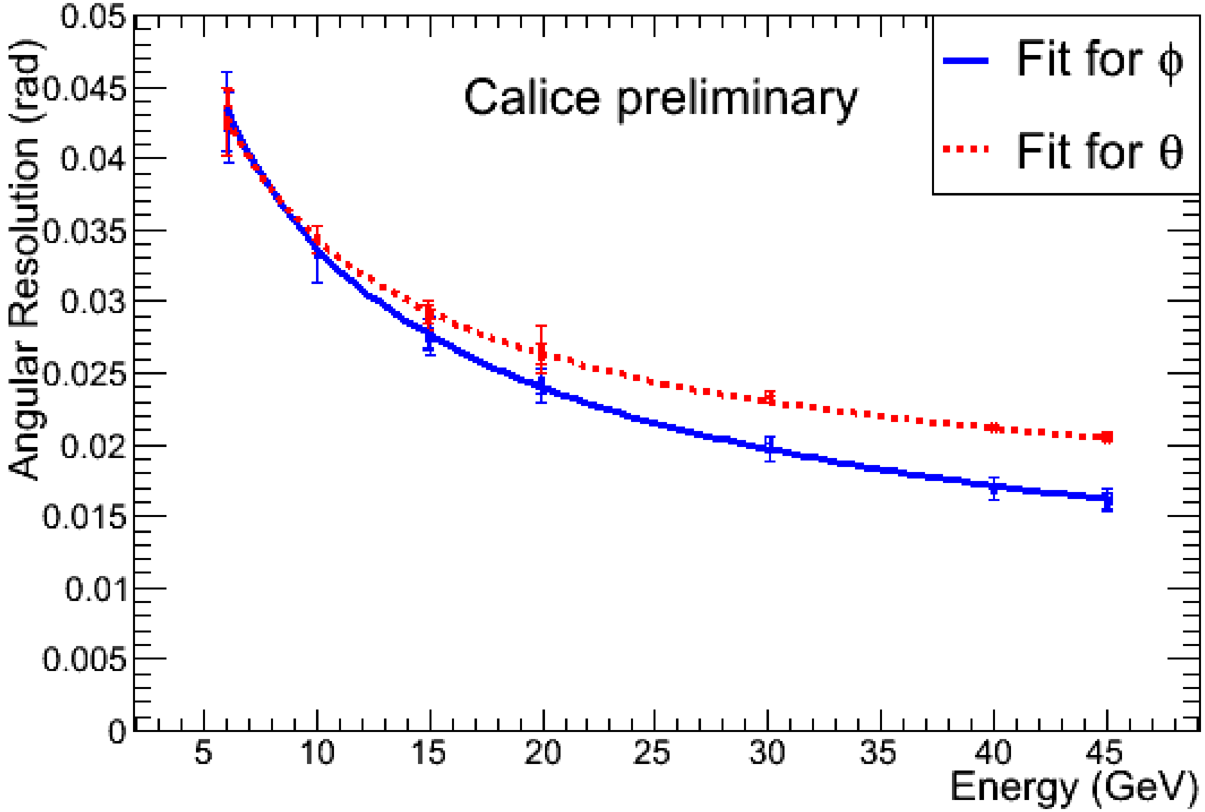
Definition

- For the position resolution the COG in x and y is compared with the track impact point
- The angle of impact is compared to the angle of the shower with respect to the x and y directions





Angular resolution



Fitted with:

$$\frac{p1}{\sqrt{E(GeV)}} \oplus p0$$

Φ, angle respect to X:

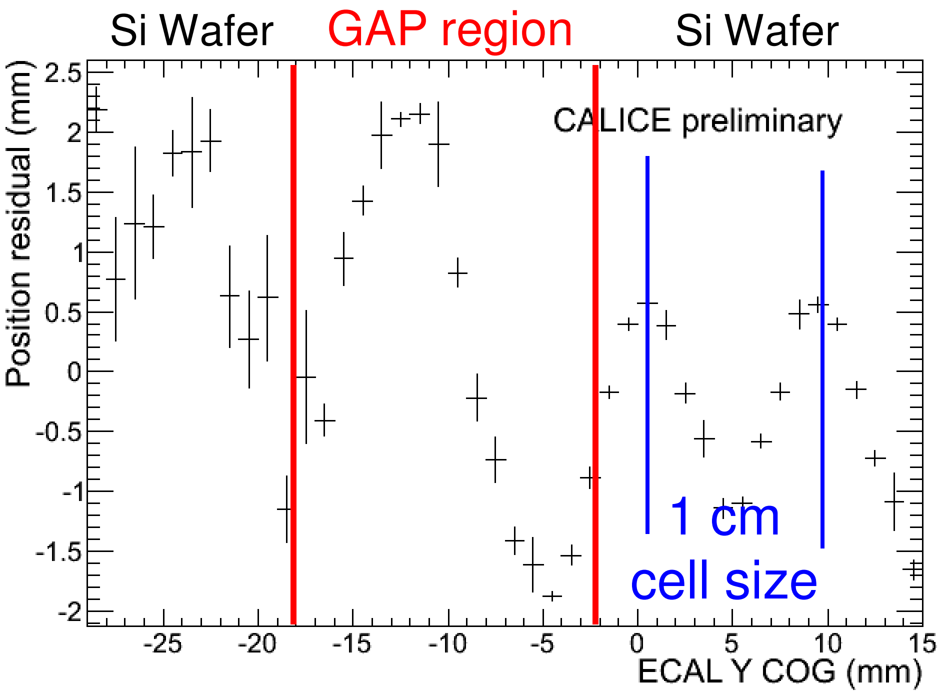
$$\left(\frac{106 \pm 2}{\sqrt{E(GeV)}} \oplus (4 \pm 1)\right) mrad$$

θ, angle respect to Y:

$$\left(\frac{100 \pm 2}{\sqrt{E(GeV)}} \oplus (14 \pm 1)\right) mrad$$

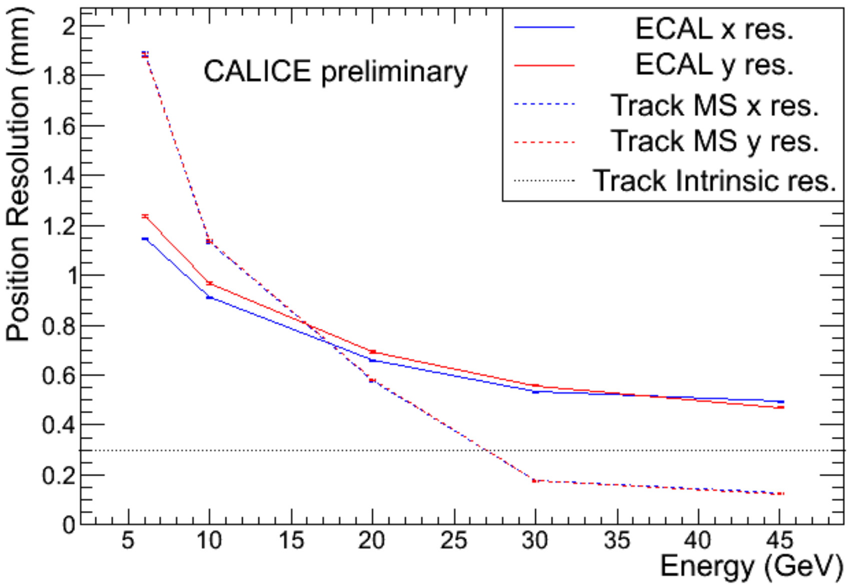
Angular resolution along X better than along Y thanks to the staggering

Position resolution

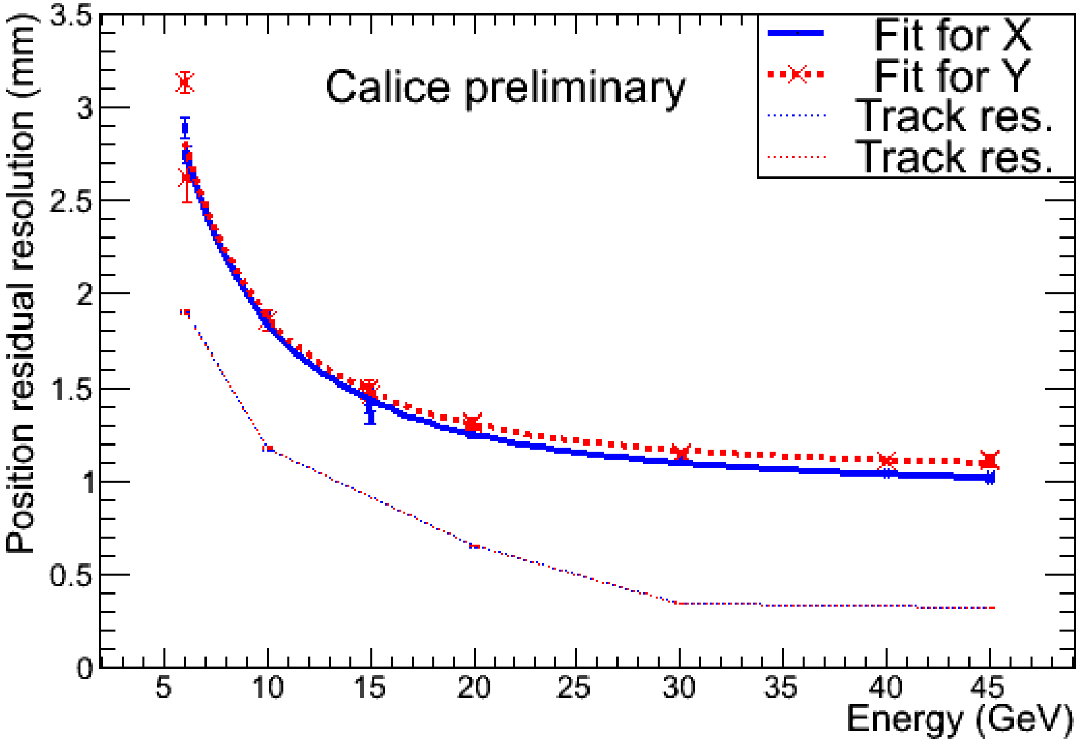


Need to correct for S-curve effect due to cell structure of ECAL

ECAL resolution estimated from MC is smaller than multiple scattering: need good estimate of tracking resolution at low energy



Position resolution



Fitted with:

$$\frac{p2}{E(GeV)} \oplus \frac{p1}{\sqrt{E(GeV)}} \oplus p0$$

Along X:

$$\left(\frac{15.3 \pm 0.5}{E(GeV)} \oplus \frac{1.4 \pm 0.6}{\sqrt{E(GeV)}} \oplus (0.94 \pm 0.02)\right) mm$$

Along Y:

$$\left(\frac{15.7 \pm 0.2}{E(GeV)} \oplus \frac{0 \pm 0.4}{\sqrt{E(GeV)}} \oplus (1.04 \pm 0.01)\right) mm$$

This is an upper limit, need to subtract track resolution estimated from MC that has to be validated

Pion interaction in ECAL

Calorimeter for ILC

Pions are identified if all following conditions are true:

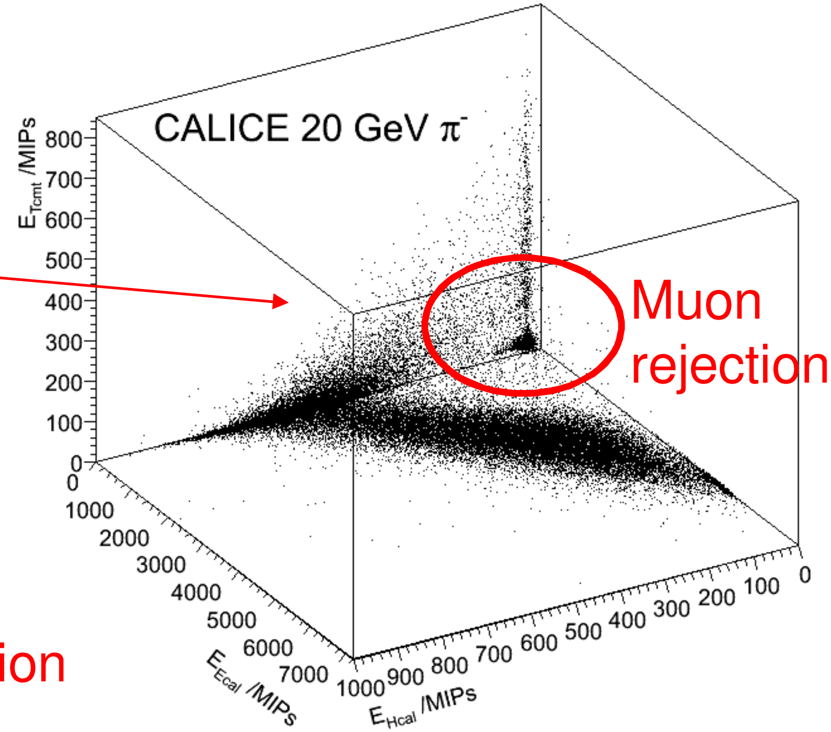
- MIPs in ECAL > 300
- MIPs in HCAL > 100
- MIPs in TCMT > 50
- MIPs in first two ECAL layers < 50
- Cherenkov is:
  - off for π^-
  - on for π^+
- Total energy in calorimeters < 1.5 peak value

Muon rejection

Electron rejection

Proton rejection

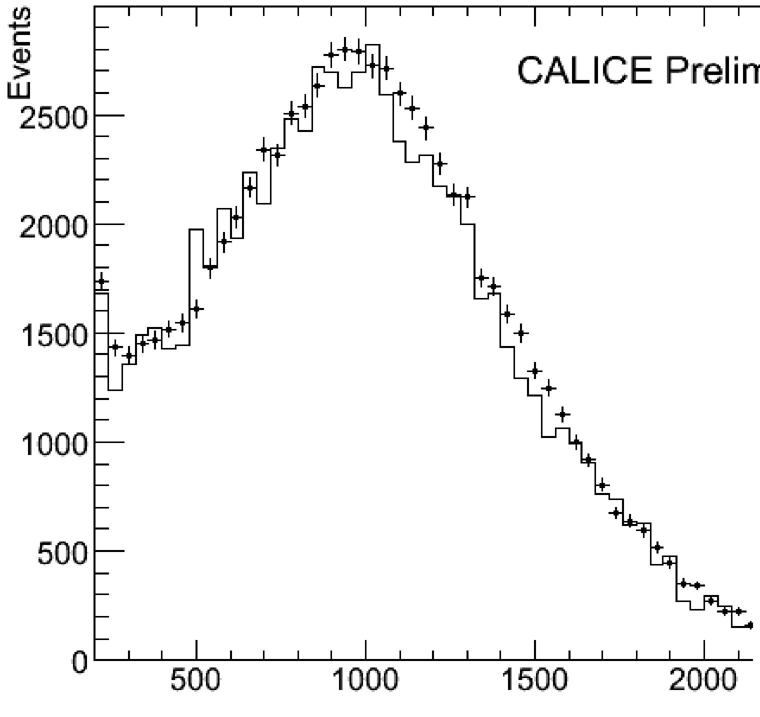
Double particle rejection



8 GeV pion

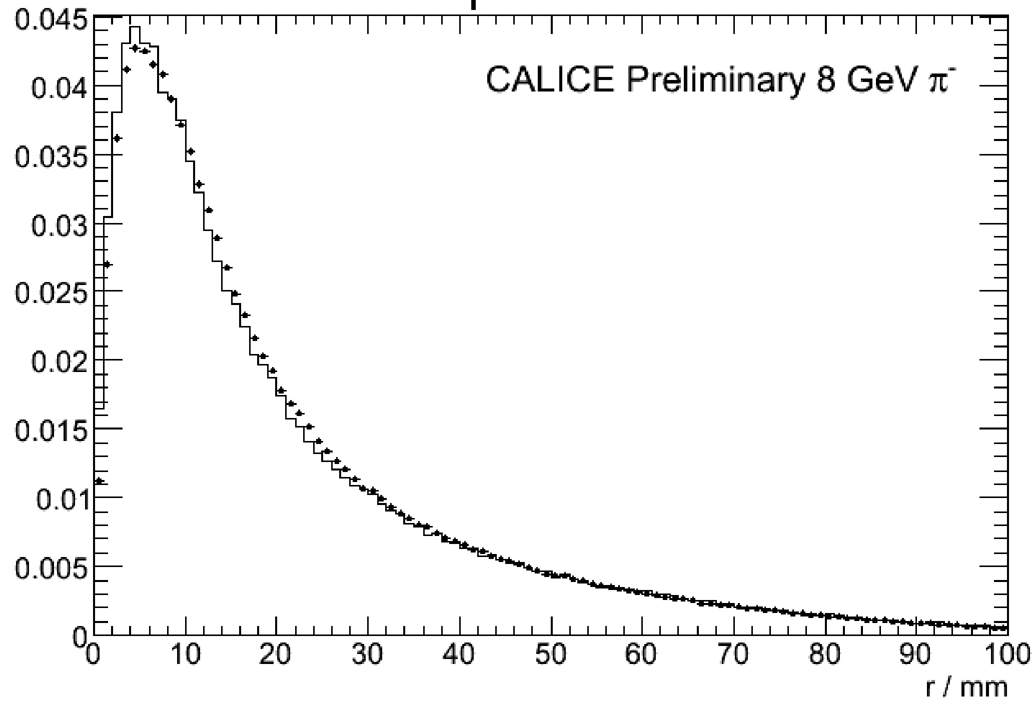
Compared for several Physics Lists

Total energy deposited in ECAL



QGSP_BERT_TRV
FTF_BIC
QGSP_BIC
QGS_BIC

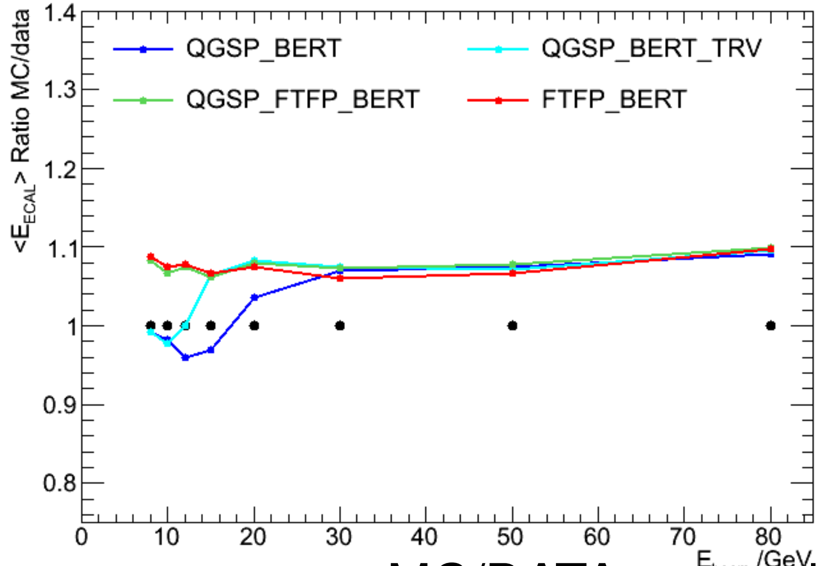
Lateral shower profile

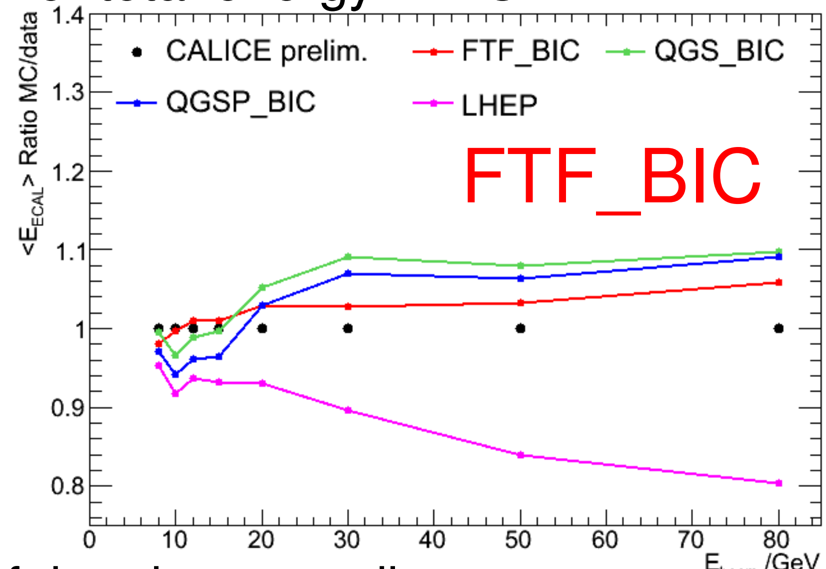


LHEP
QGSP_BERT
QGSP_FTFP_BERT
FTFP_BERT

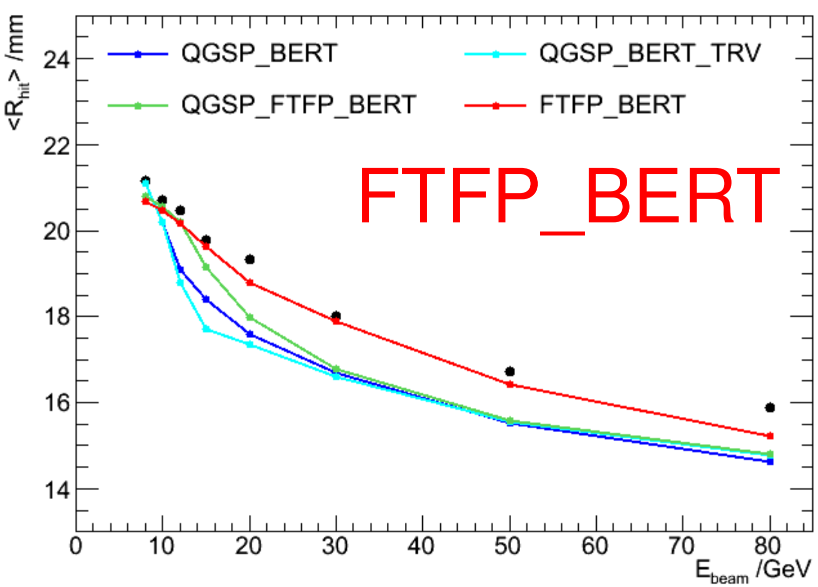
Comparison MC/DATA

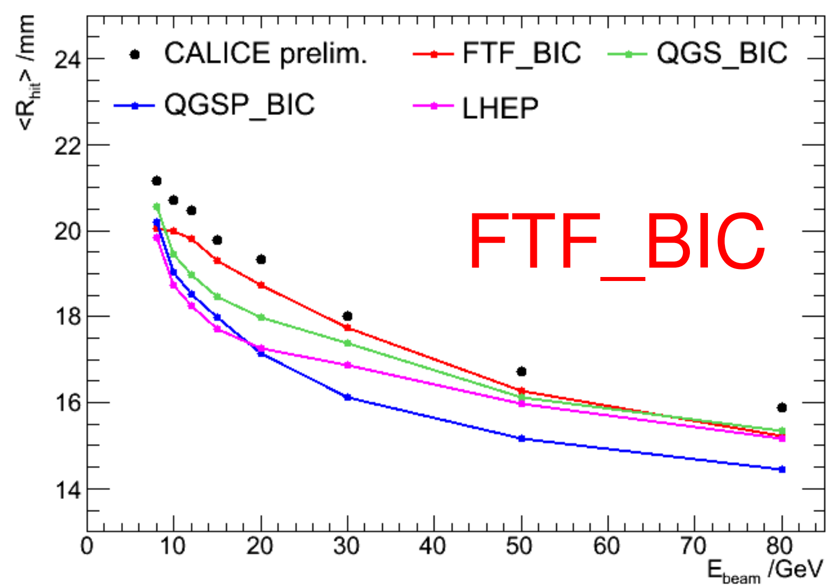
Ratio of mean of MC/DATA for total energy in ECAL



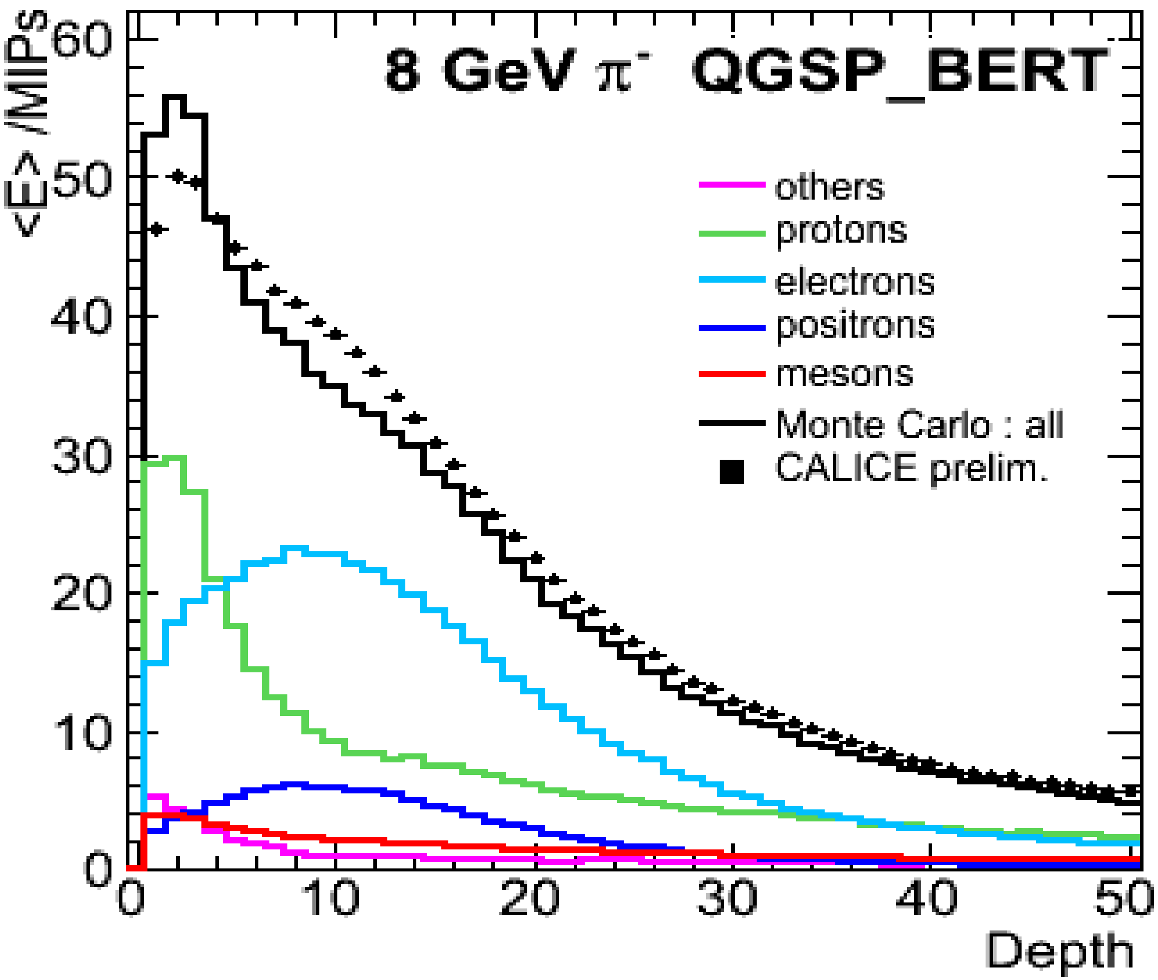


MC/DATA comparison of the shower radius





Shower composition



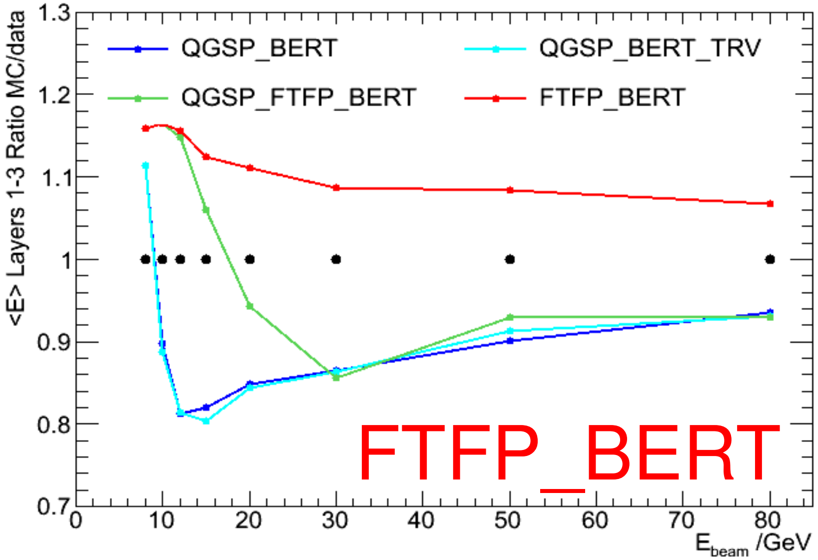
Three region defined from the interaction point:
layer 1-3: protons
layer 5-20: electrons
layer 30-50: penetrating hadrons

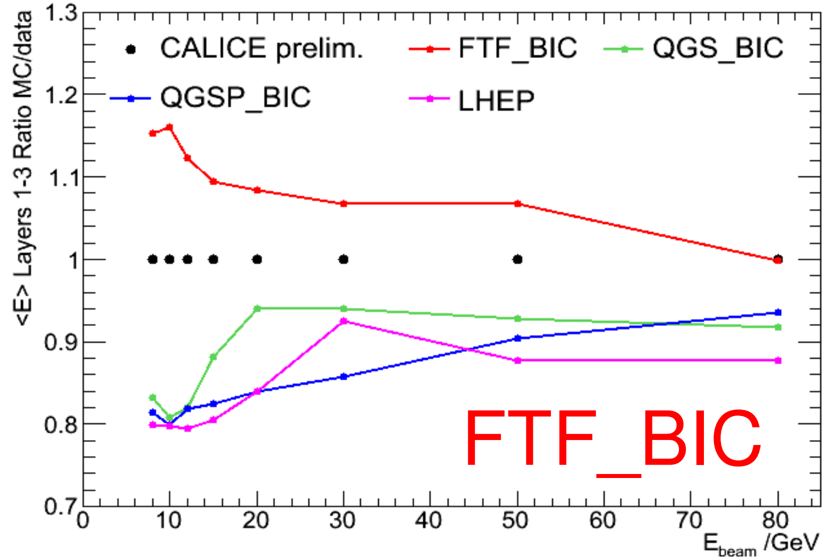
Repeated for all physics lists and all energies

Possible thanks to the high granularity and small X_0/λ_{int}

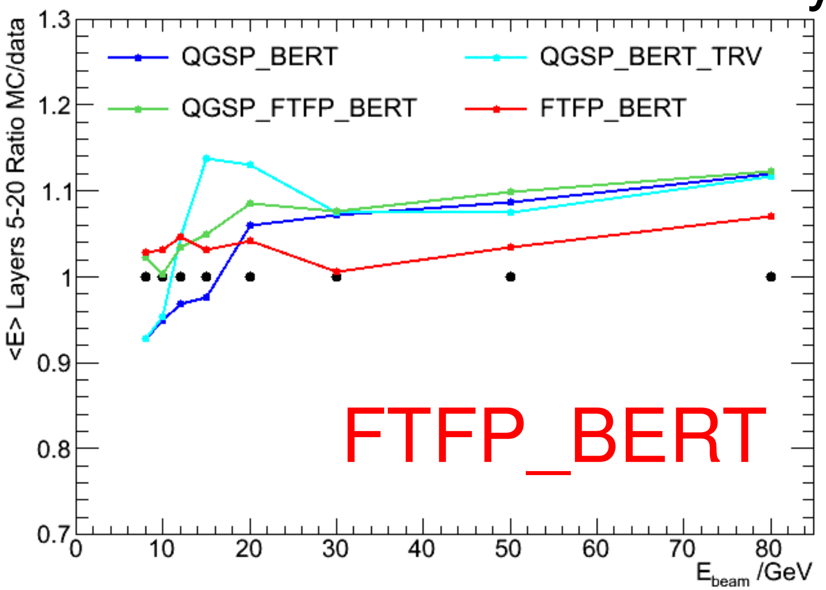
Shower composition

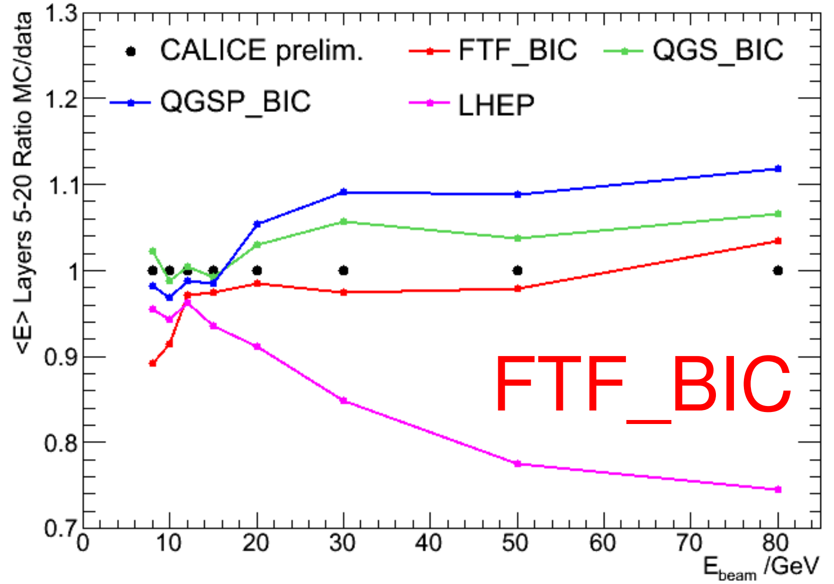
Layers 1-3





Layers 5-20

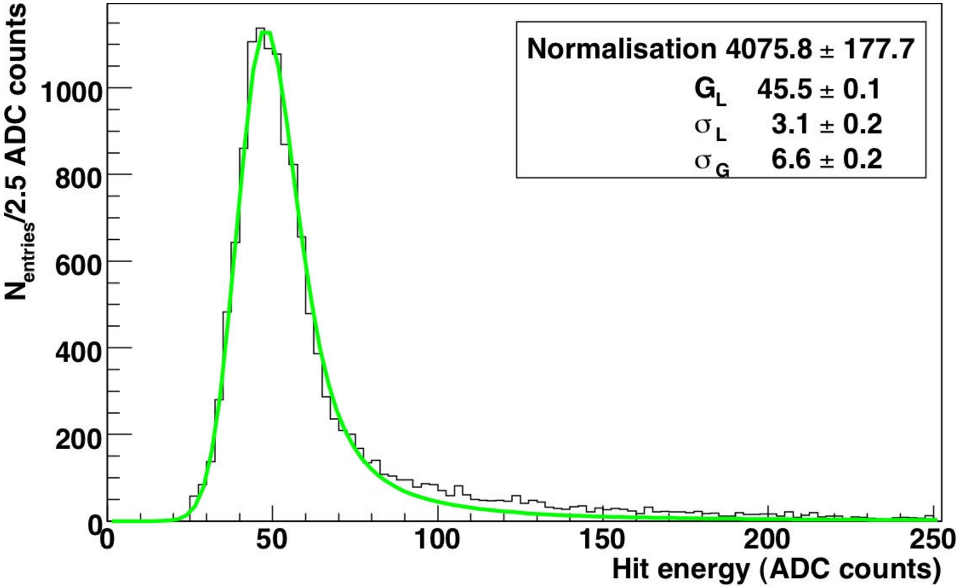




Conclusion

- The SiW ECAL operated since 2006 in several beam tests with no major problems
- Response is stable with only 0.14% dead cells
- Linear response within 1%
- Energy resolution of $\left(\frac{16.6 \pm 0.1}{\sqrt{E(GeV)}} \oplus (1.1 \pm 0.1)\right)\%$
- Position resolution better than 1mm
- Angular resolution of $\left(\frac{100 \pm 2}{\sqrt{E(GeV)}} \oplus (14 \pm 1)\right) mrad$
- Pion shower study to compare physics lists
  - FTFP_BERT and FTF_BIC well describe the lateral profile
  - FTFP_BERT is the best to describe the longitudinal profile

Calibration



Calibration with muon beam

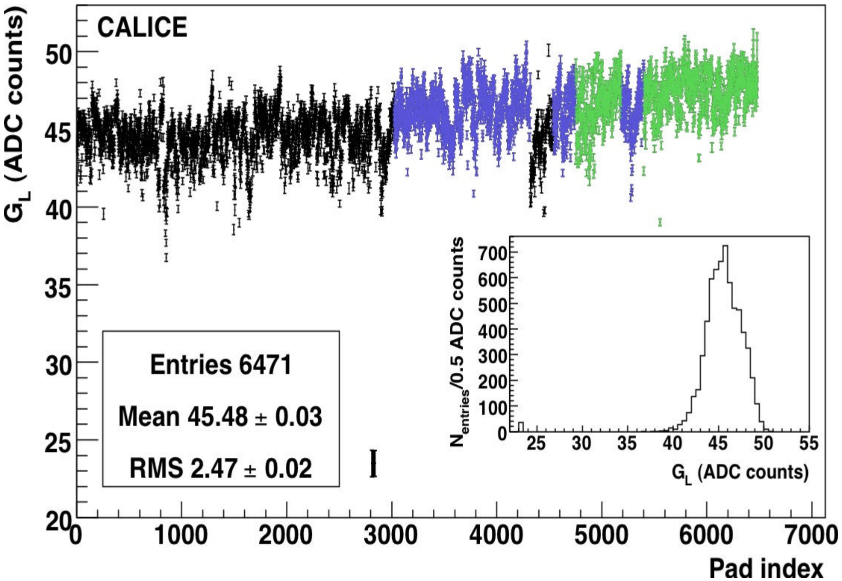
18 Mi. events

Only 0.14% of dead cells

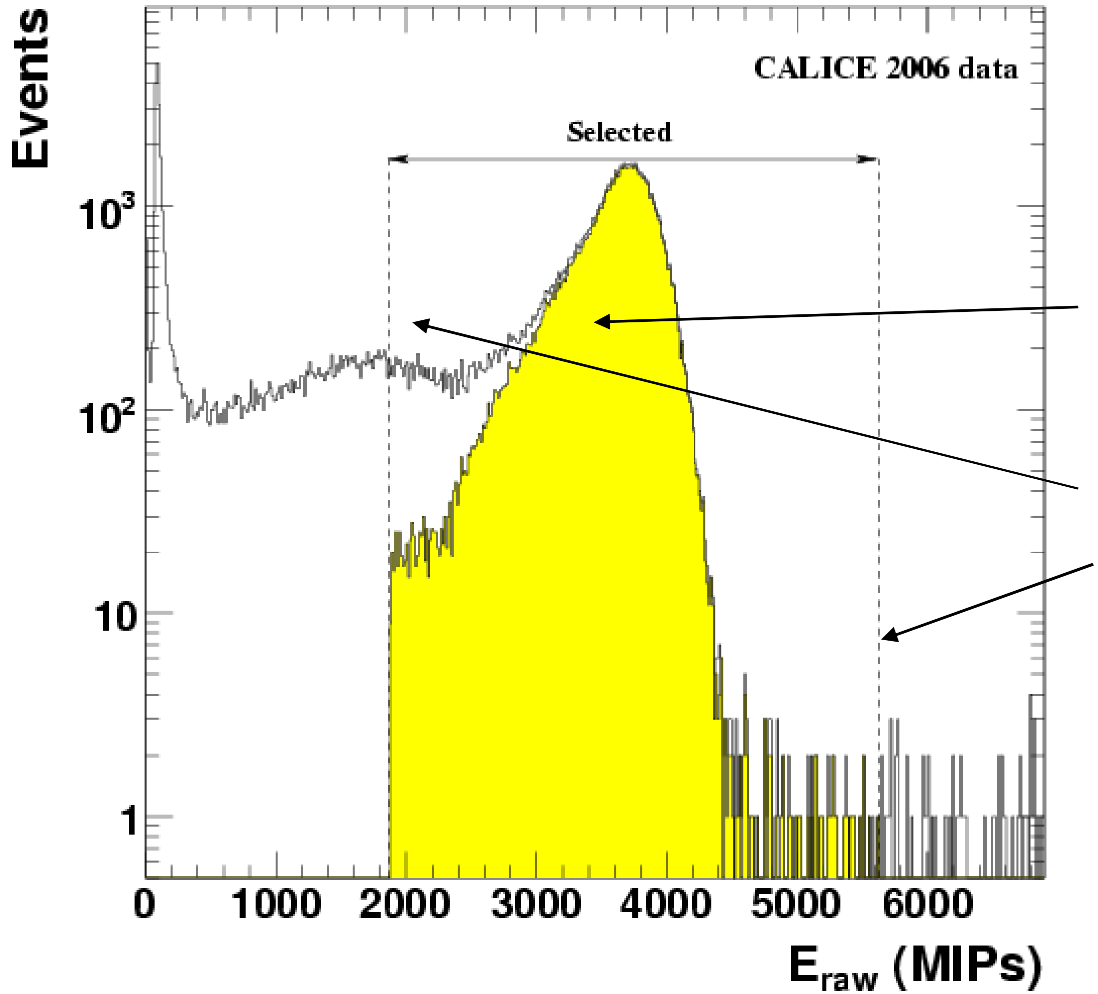
Uniform response

The differences can be associated with:
- Different manufacturers
- Different production

For final detector:
Experience to deal with different manufacturers to produce the needed ~3000 m^2



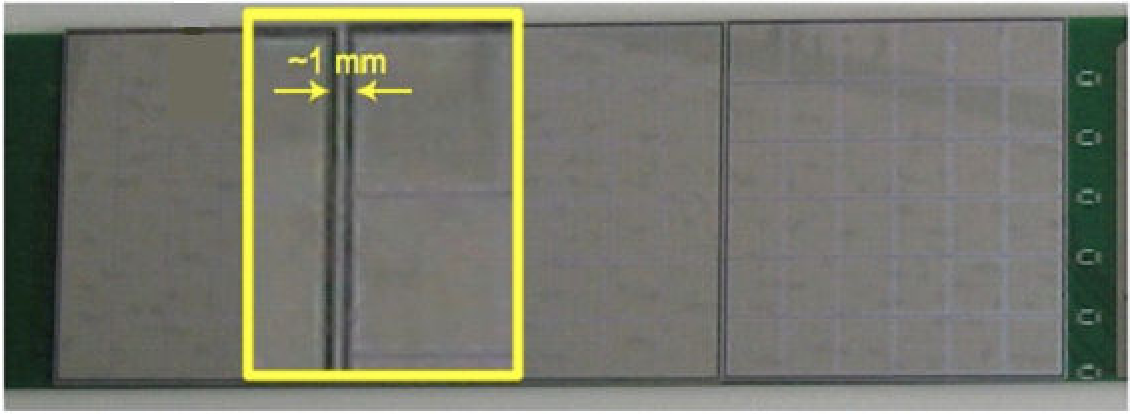
Electron selection



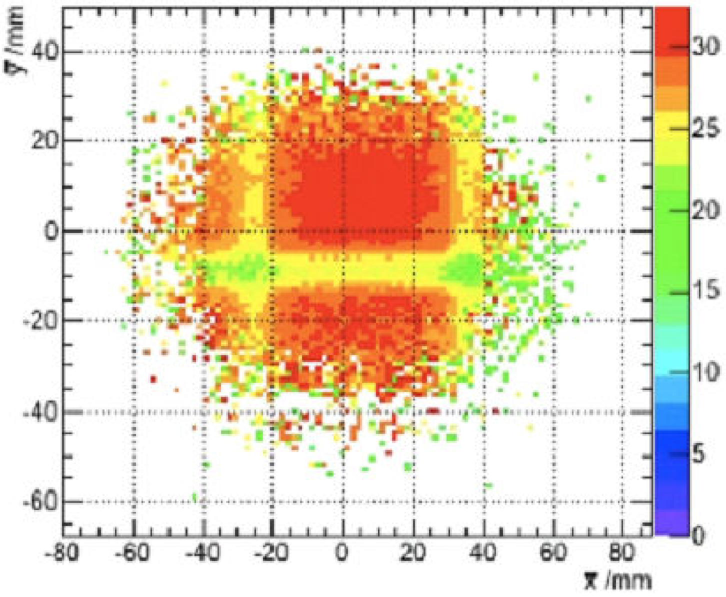
Cerenkov used to reject pions

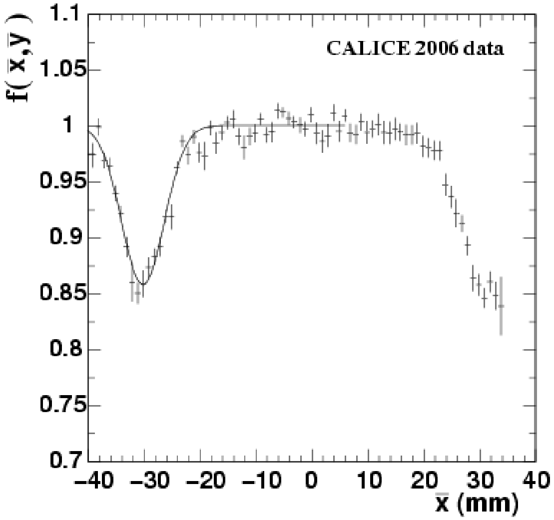
Energy cut to remove:
- pions
- double particle events

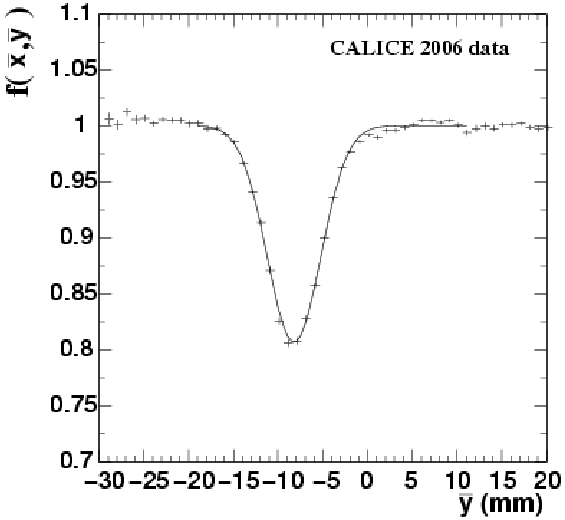
Detailed ECAL structure 1



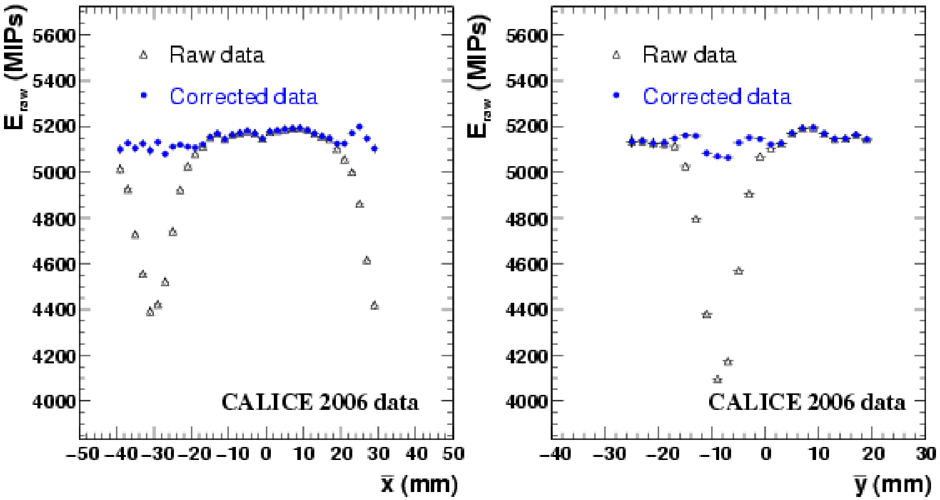
Wafers are separated by ~1 mm on both directions







Wafer correction

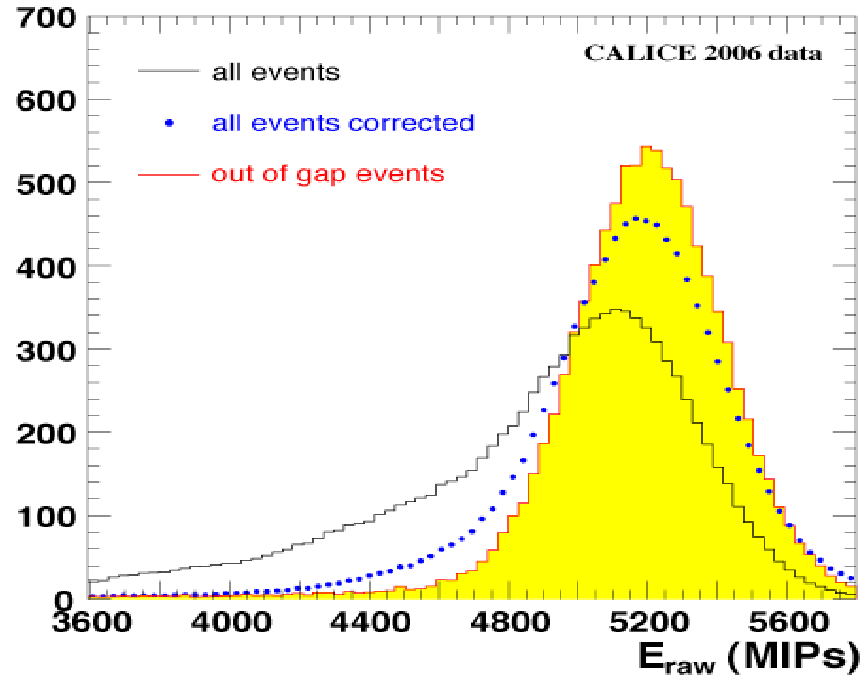


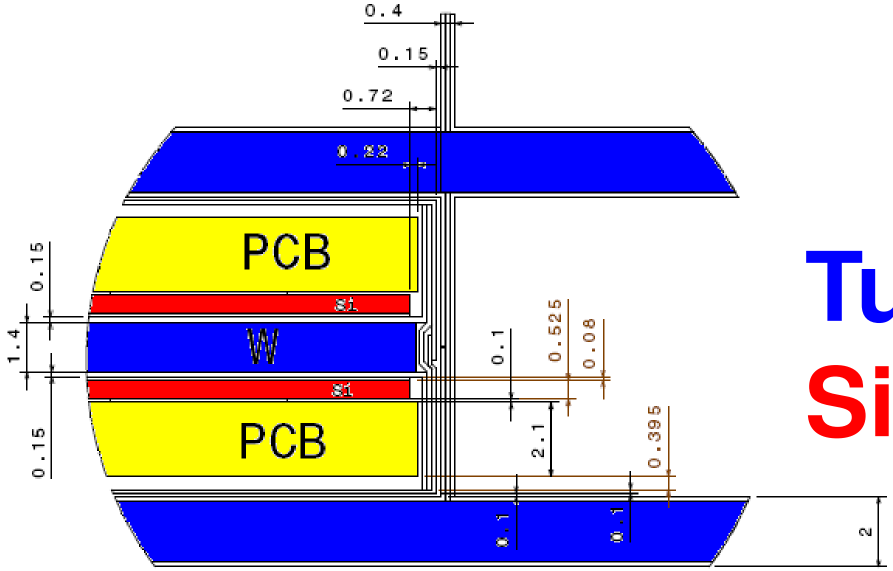
Gap region corrected using:

$$f\left(\bar{x},\bar{y}\right)=\left(1-a_x\exp\left(-\frac{\left(\bar{x}-x_{gap}\right)^2}{2\sigma_x^2}\right)\right)\left(1-a_y\exp\left(-\frac{\left(\bar{y}-y_{gap}\right)^2}{2\sigma_y^2}\right)\right)$$

Energy loss not fully recovered

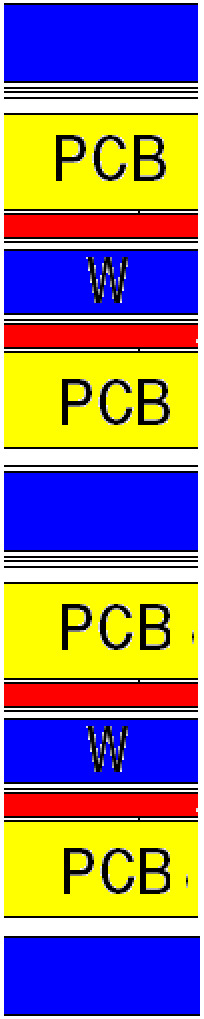
This result will drive the next generation of detector that will have smaller gaps





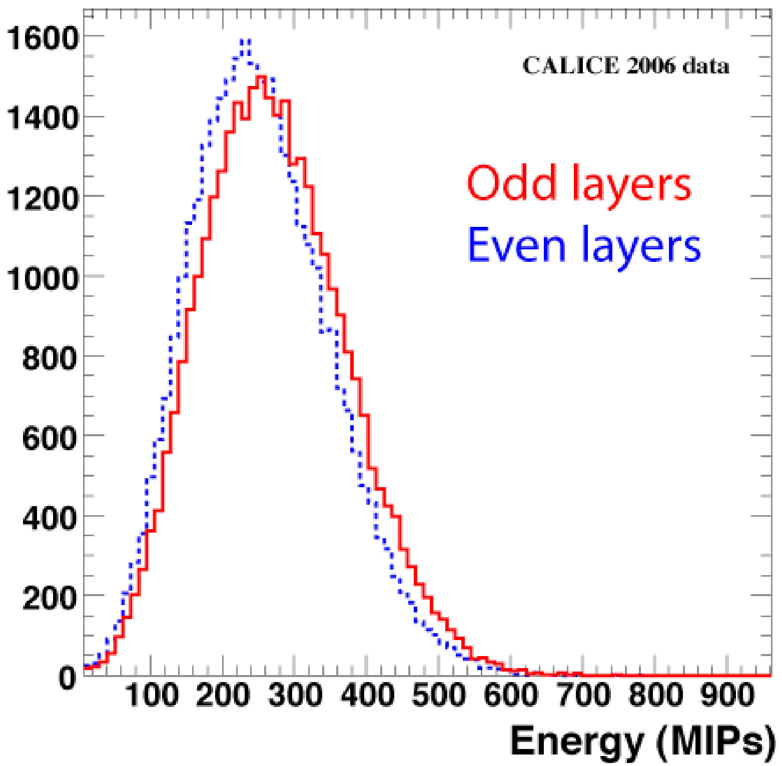
Tungsten

Silicon



Odd and even layers have different material due to the PCBs

Material correction



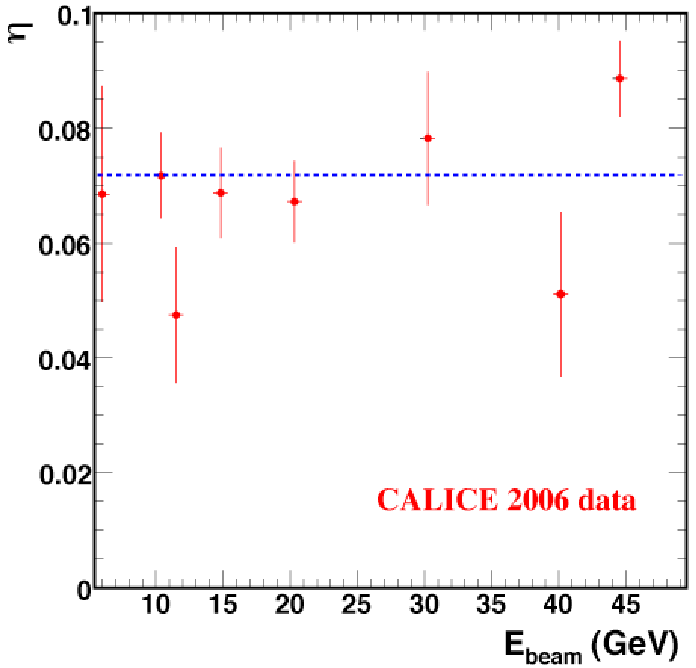
Sampling Fraction increases with calorimeter depth

$$E_{rec} = \sum_i w_i E_i \quad \text{with} \quad \begin{array}{l} w_i = 1 \text{ for } i = 0,9 \\ w_i = 2 \text{ for } i = 10,19 \\ w_i = 3 \text{ for } i = 20,29 \end{array}$$

Different weights for odd and even layers:

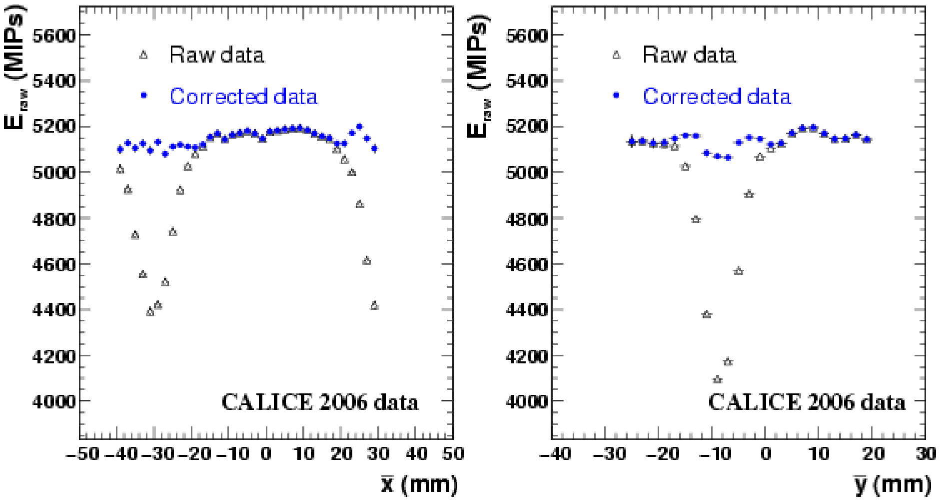
Odd layers: $w = k + \eta$

Even layers: $w = k$



$\eta = (7.2 \pm 0.2 \pm 1.2)\%$

Energy corrections



Gap region corrected using:

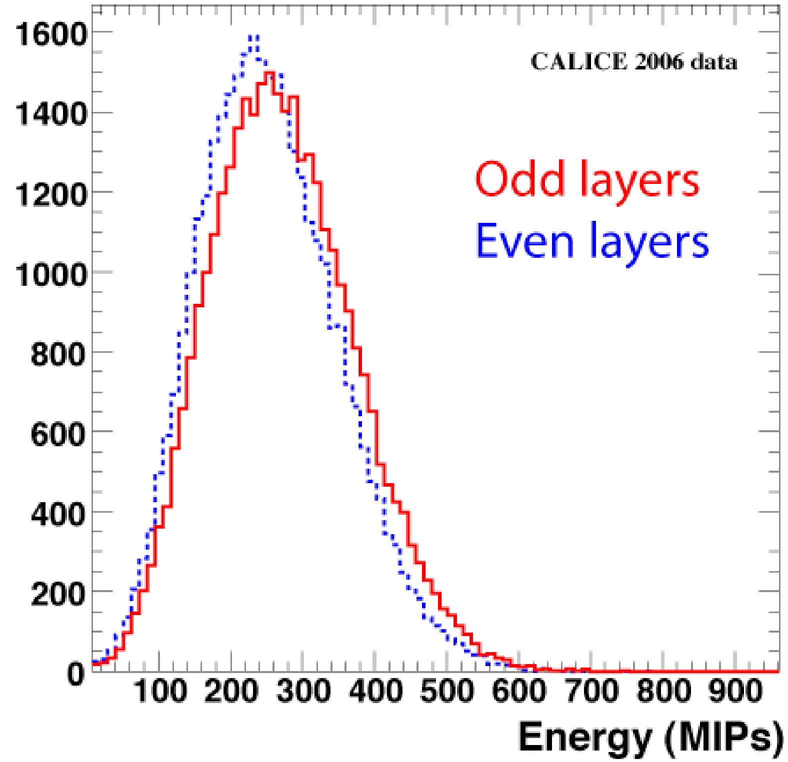
$$f(\bar{x},\bar{y}) = \left(1 - a_x \exp\left(-\frac{(\bar{x} - x_{gap})^2}{2\sigma_x^2}\right)\right)\left(1 - a_y \exp\left(-\frac{(\bar{y} - y_{gap})^2}{2\sigma_y^2}\right)\right)$$

Different weights for odd and even layers:

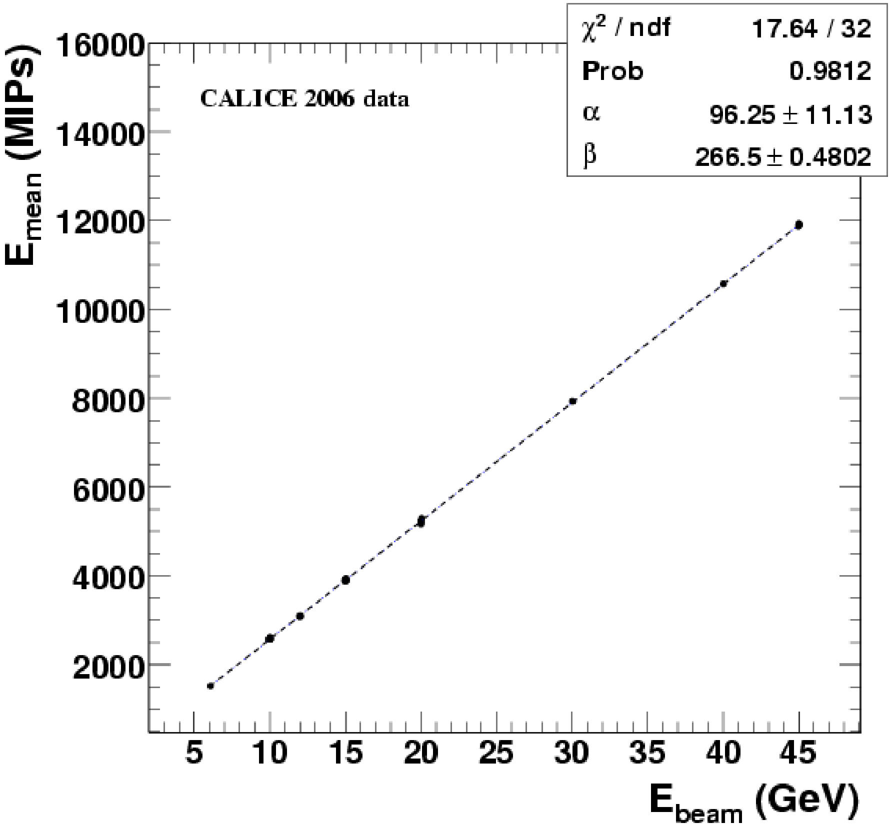
Odd layers: w = k + η

Even layers: w = k

η=(7.2 ± 0.2 ± 1.2)%

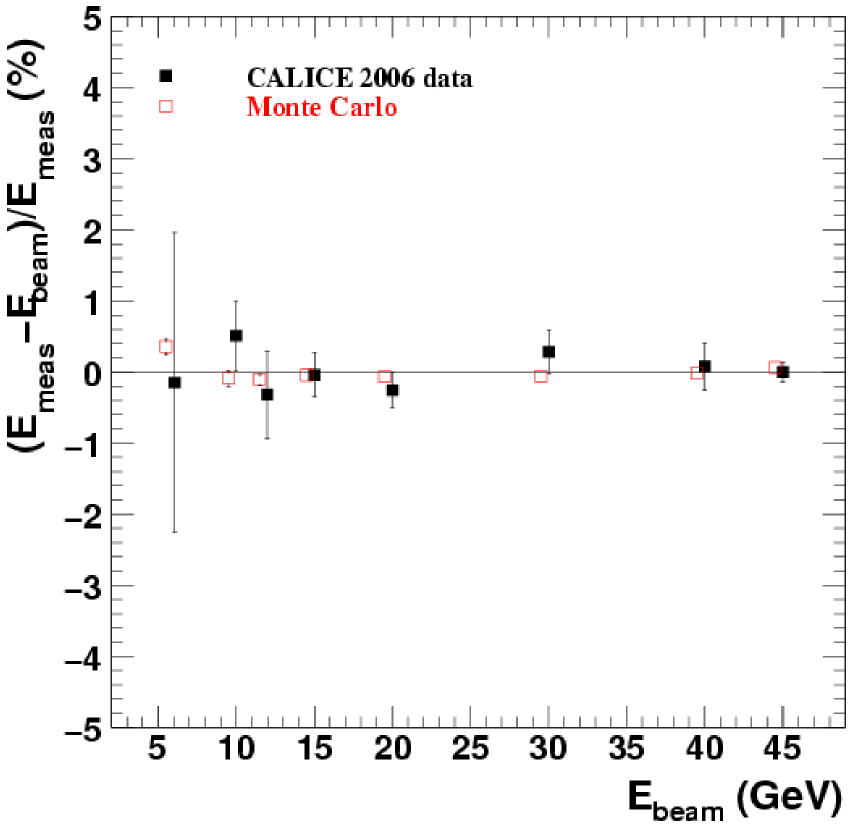


Linearity



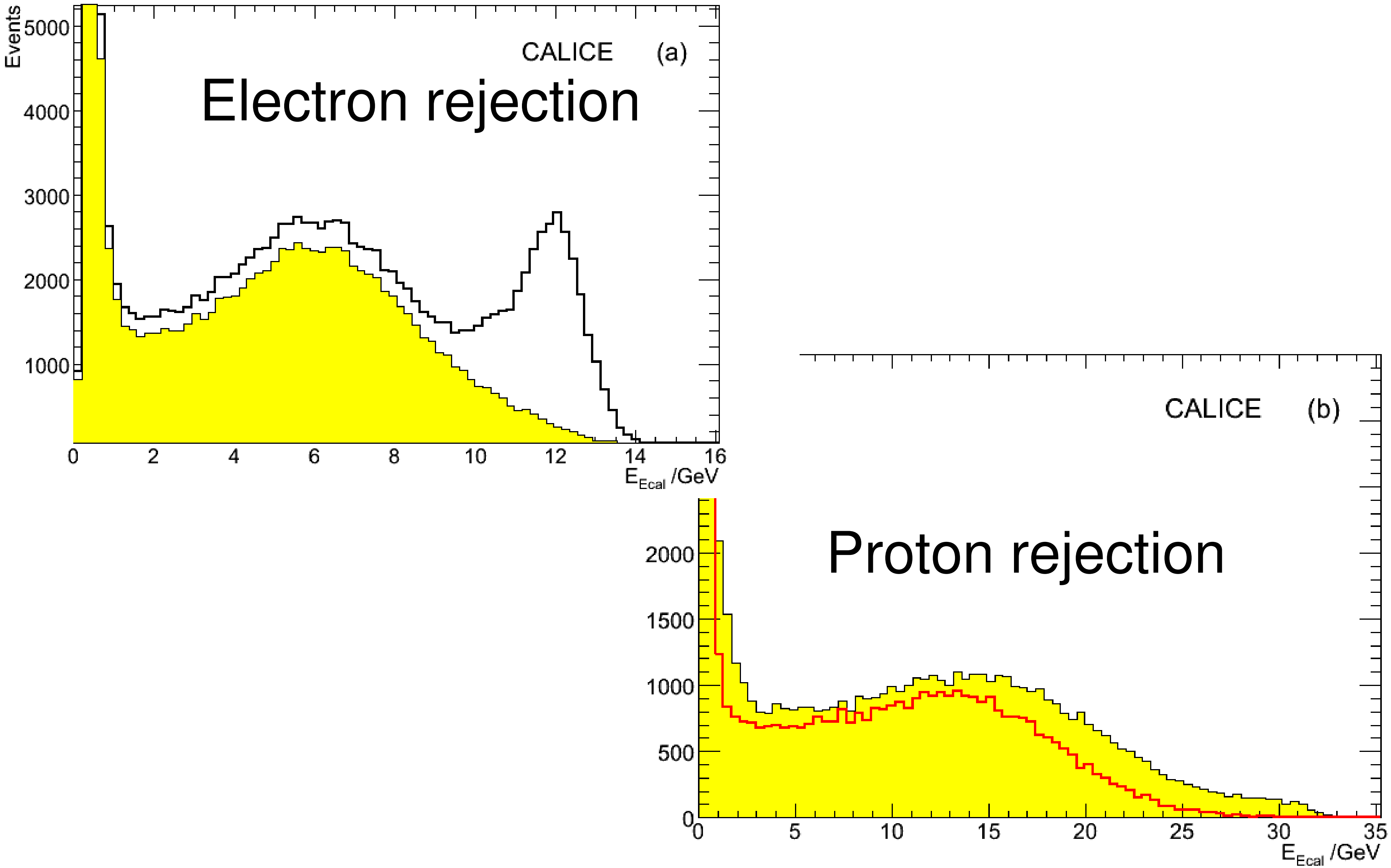
Good linearity over a large energy range

Good agreement between data and MC



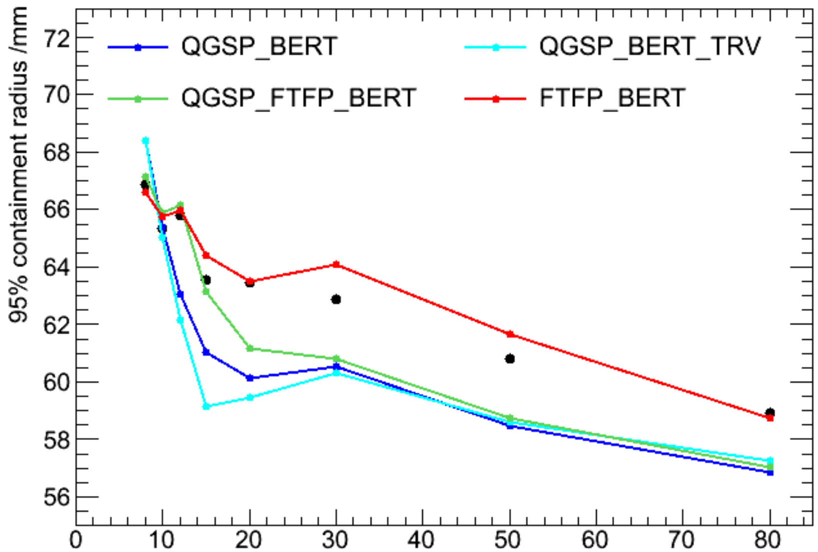
Linear response within 1%

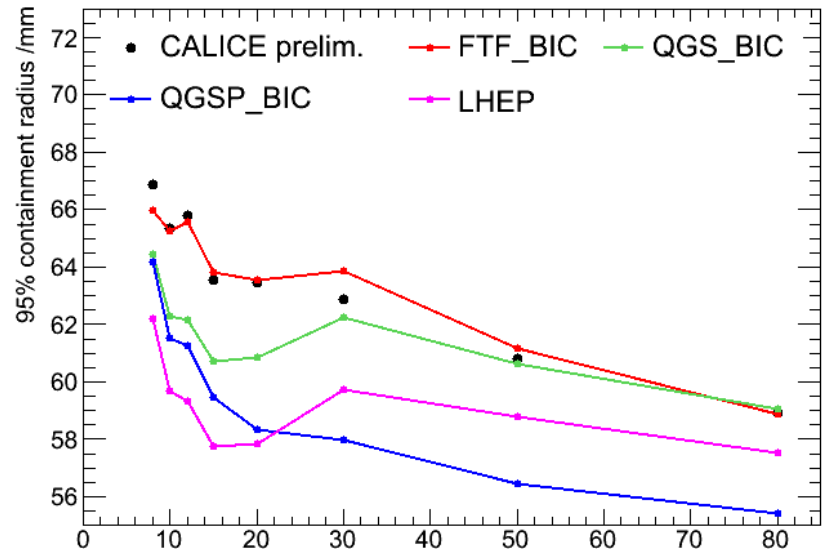
Pion Cherenkov



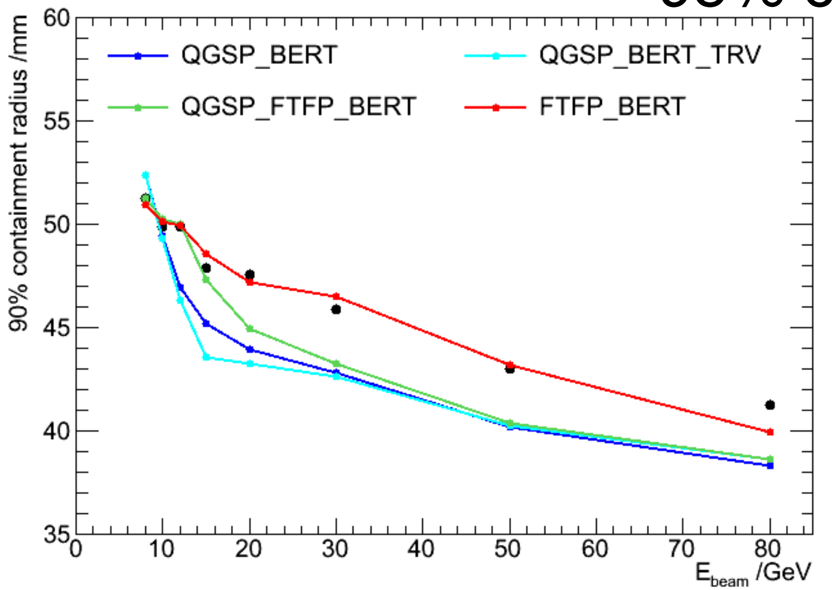
Shower lateral profile

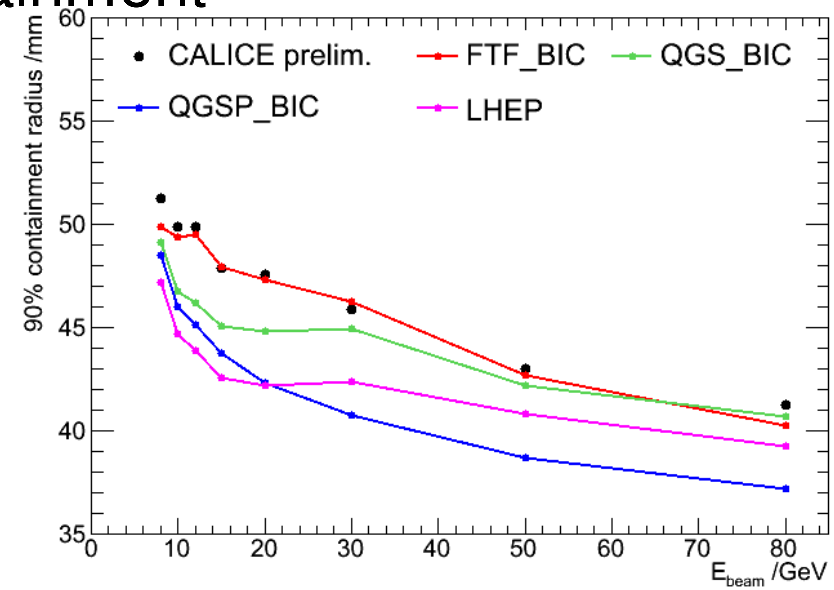
90% containment



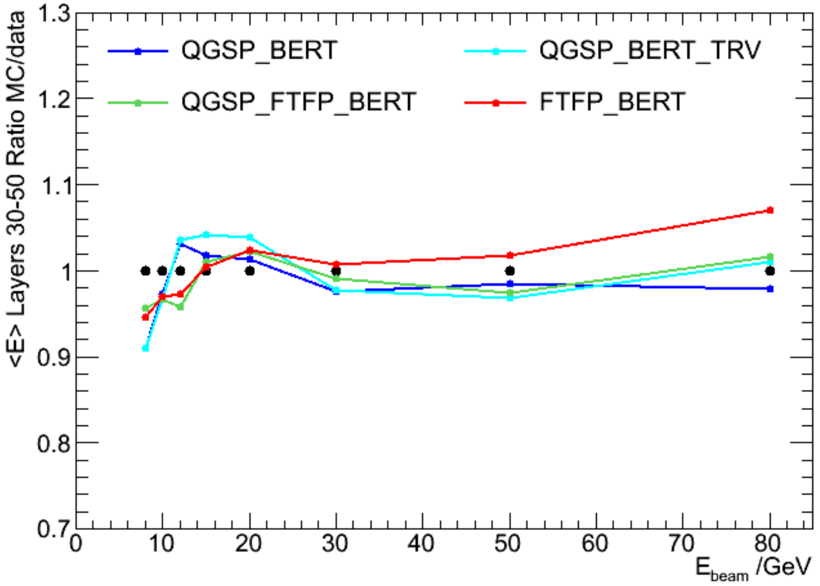


95% containment

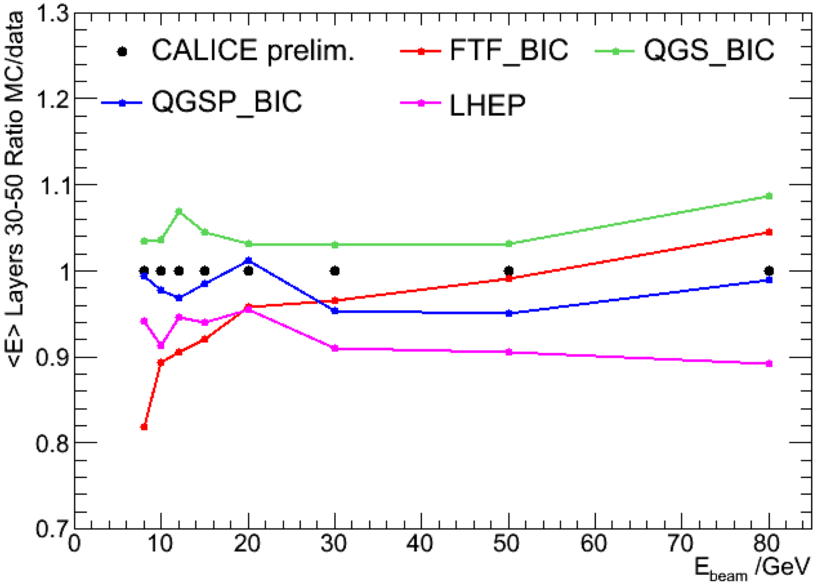




Layer 30-50



<E> Layers 30-50 Ratio MC/data
QGSP_BERT
QGSP_BERT_TRV
QGSP_FTFP_BERT
FTFP_BERT
1.3
1.2
1.1
1
0.9
0.8
0.7
0
10
20
30
40
50
60
70
80
E_{beam} /GeV



<E> Layers 30-50 Ratio MC/data
CALICE prelim.
FTF_BIC
QGS_BIC
QGSP_BIC
LHEP
1.3
1.2
1.1
1
0.9
0.8
0.7
0
10
20
30
40
50
60
70
80
E_{beam} /GeV

Overview

- The CALICE collaboration
- The Si-W prototype
- Testbeam results
  - energy resolution and linearity
  - angular and position resolution
- Conclusion