Study of the response of the CALICE Si-W ECAL physics-prototype to positrons

LCWS13 - Tokyo @The University of Tokyo
11-15 November 2013

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Contents

Motivation

- The CALICE Si-W ECAL physics prototype was constructed and tested.
  - the first beam test was conducted at CERN in 2006 using electron beams (6-45 GeV).
  - the second beam test was conducted at FNAL in 2008 using positron beams (4-20 GeV).
- We analyzed the prototype test beam data taken at FNAL in 2008.
- We want to evaluate linearity and energy resolution for positrons and to compare the prototype response to positrons and electorons.

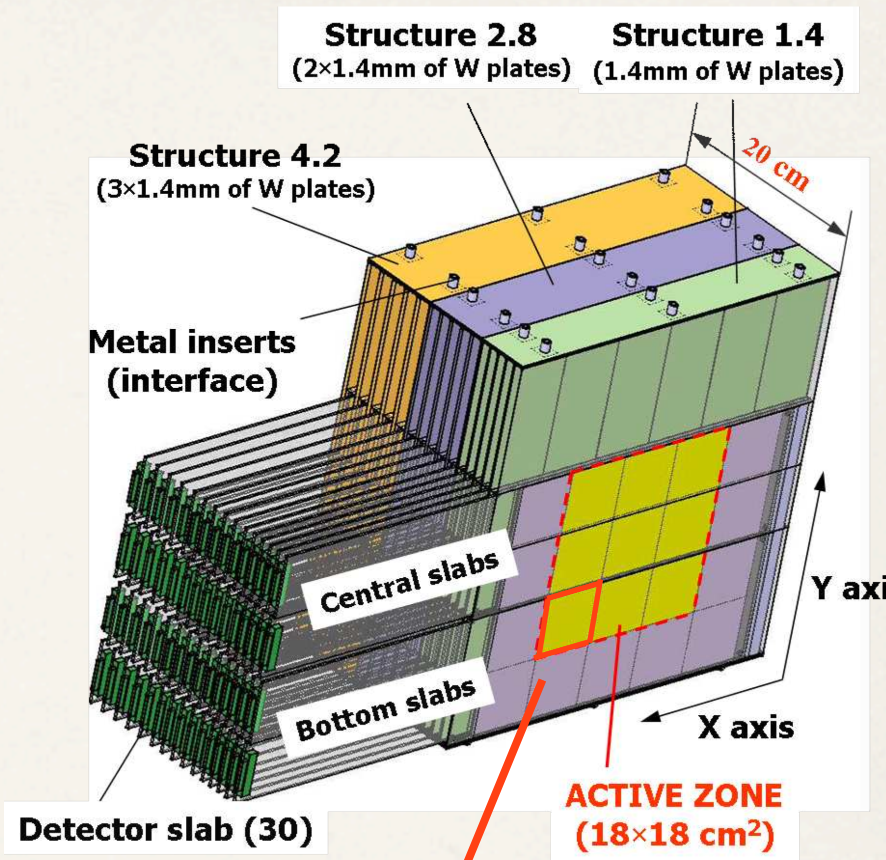
Physics Prototype Design

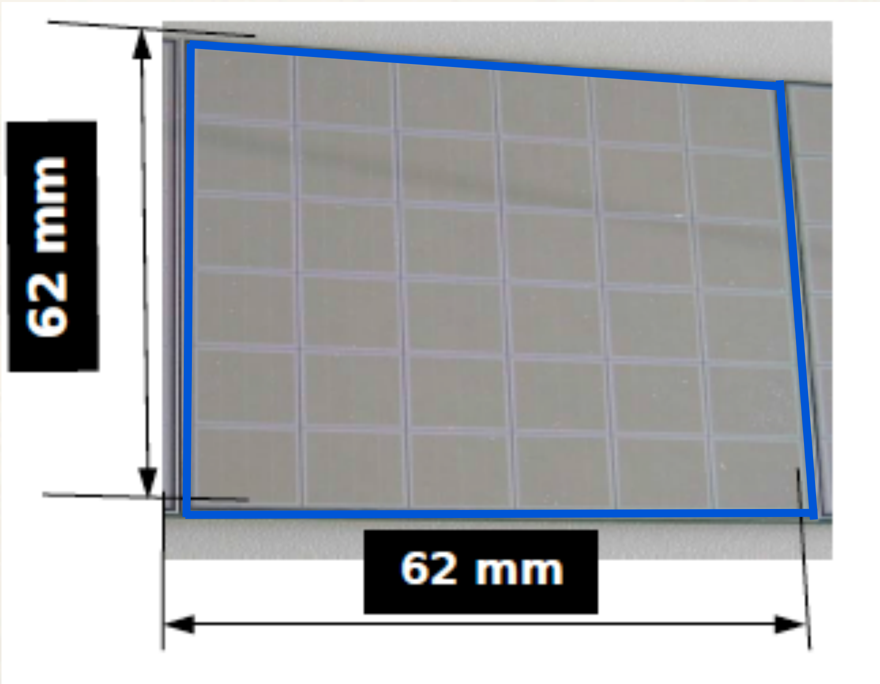
- The physics prototype consists of thirty sensitive layers and absorber layers.

  - sensitive layer : silicon
    - 6×6 pixels for one module
    - 3×3 modules in a layer (18×18 cm^2)
    - ➡ Total 9720 channels

  - absorber layer : tungsten
    - Structure1.4 : 1-10 layer 1.4 mm (0.4X_0)
    - Structure2.8 : 11-20 layer 2.8 mm (0.8X_0)
    - Structure4.2 : 21-30 layer 4.2 mm (1.2X_0)
    - ➡ Total 24X_0

Prototype Design





Silicon sensor

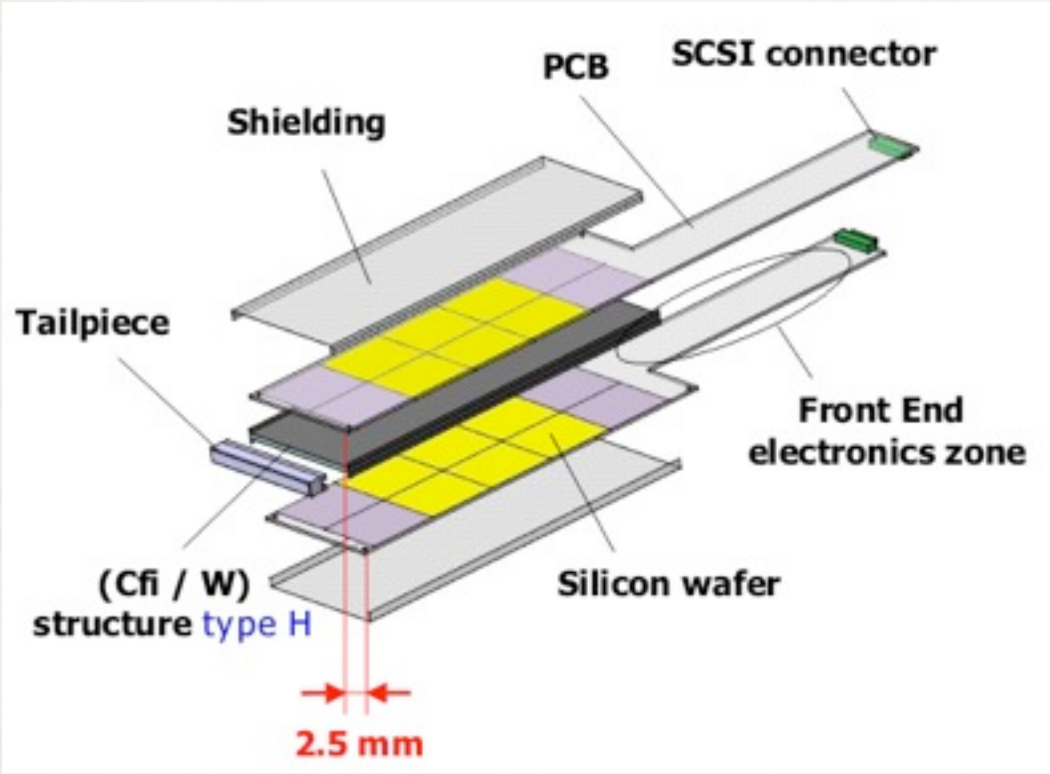
Thickness: 525 μm

pixel size: 10 mm

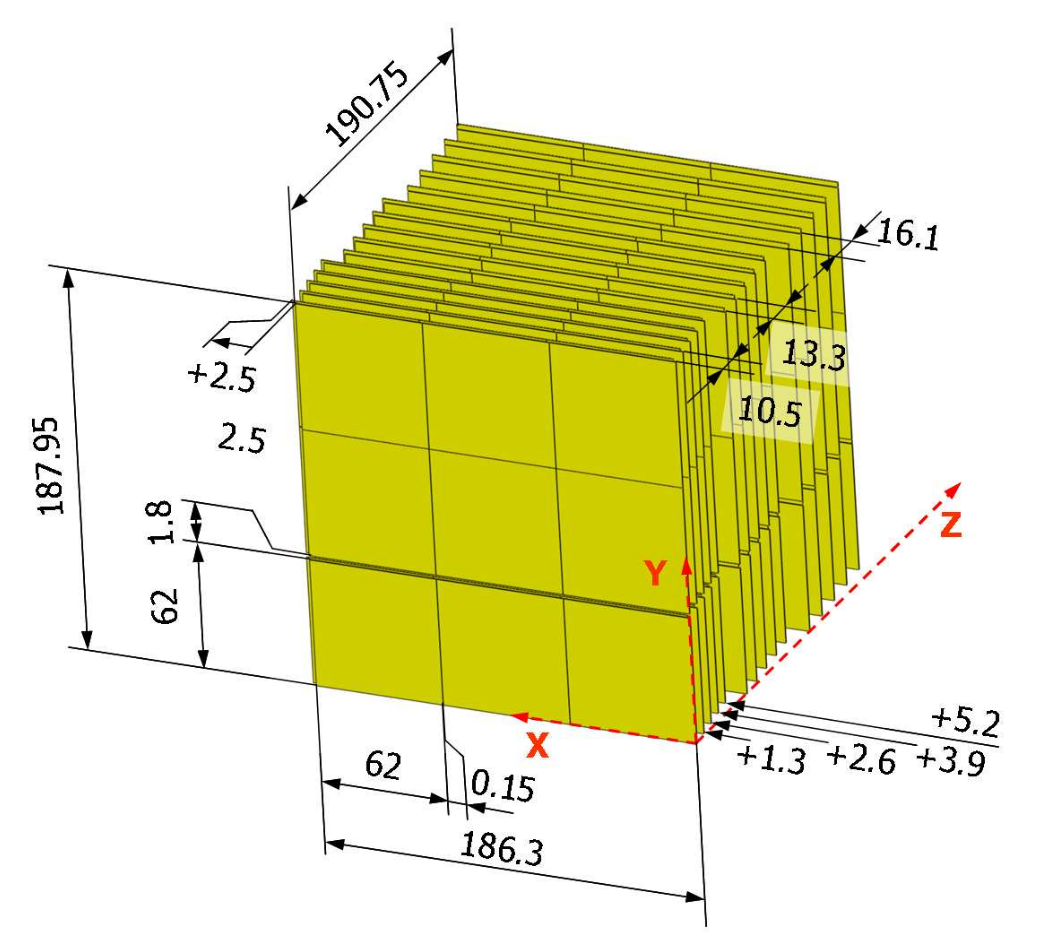
guard ring 1 mm

Details of the passive area and offsets

- There is an inactive area in an active layer due to 1 mm guard ring around the modules.
- In order to reduce their overlapping, the two layers are offset by 2.5 mm in the x direction (no offset in the y direction)



Detector slab



Test Beam @FNAL in 2008

- The CALICE ECAL prototype was tested at FNAL MTest area in 2008.
  - 4, 6, 8, 12 and 20 GeV positron beams

The analog HCAL was located behind the ECAL

➡ hit number information is available

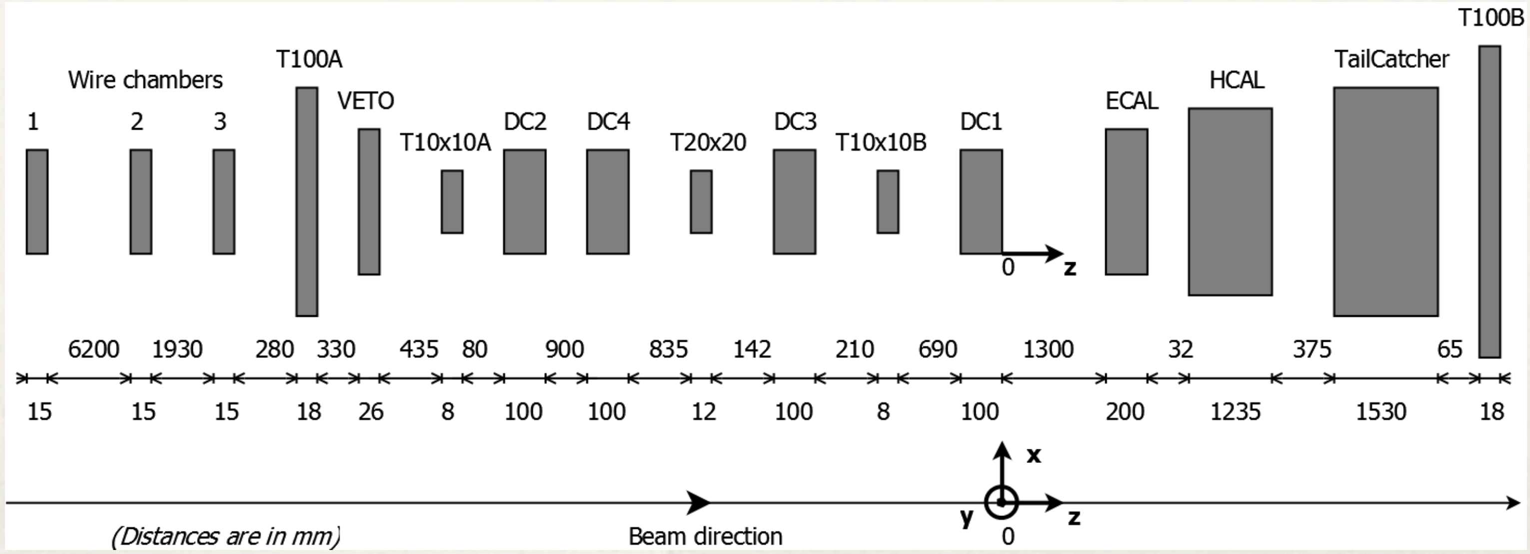
<u>Beam momentum spread:</u>

2.7±0.3% for 2-4 GeV

2.3±0.3% for 8-32 GeV

Hit energy is measured in MIP units.

The MIP calibration for each channel is performed using 32 GeV muons.

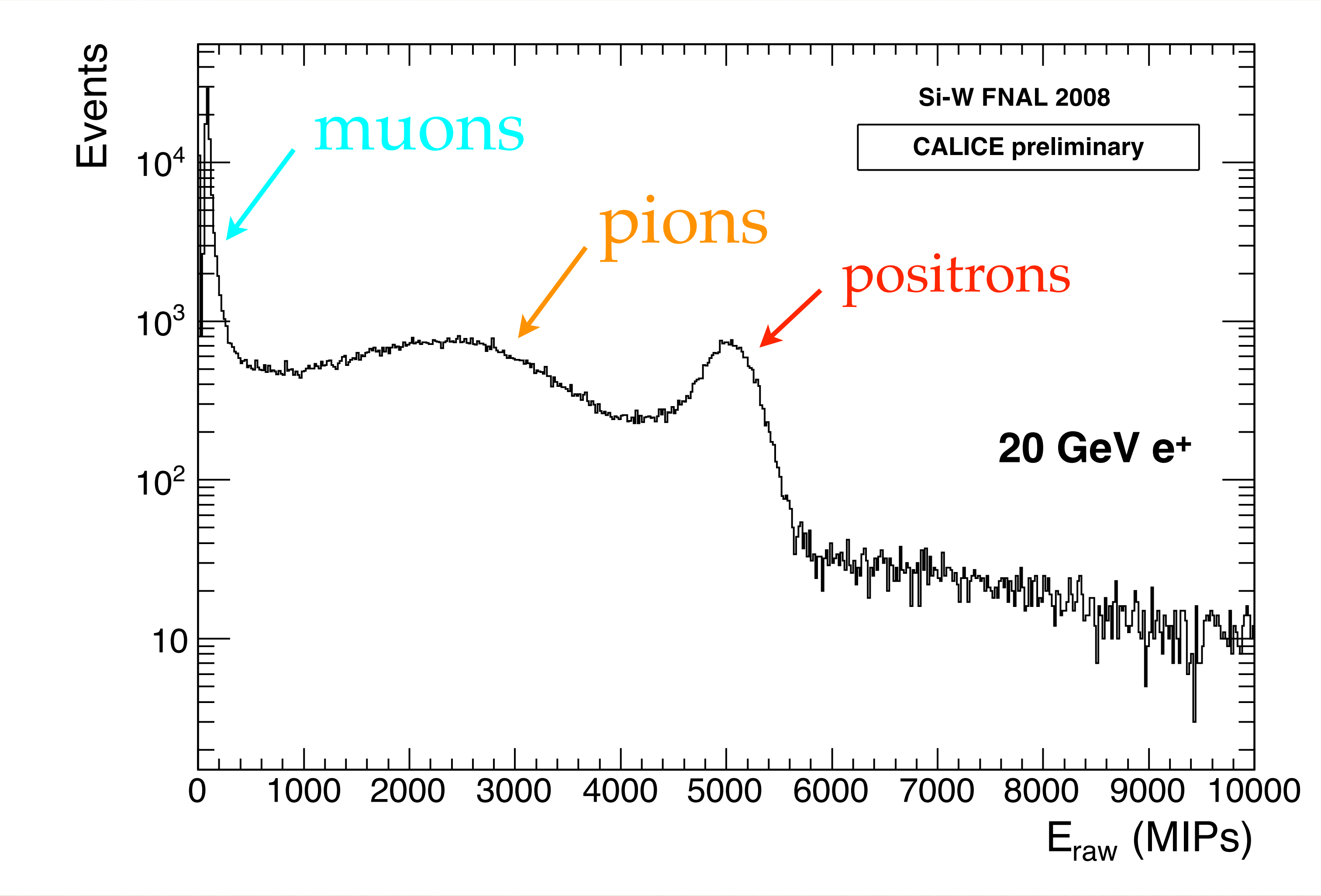


Event Selection

The total energy deposited on ECAL

$$E_{\text{raw}} = \sum_{i=0}^{9} E_i + 2\sum_{i=10}^{19} E_i + 3\sum_{i=20}^{29} E_i$$

Ei : total energy in *i*th layer



Event Selection

Event selection

1. set the energy window.

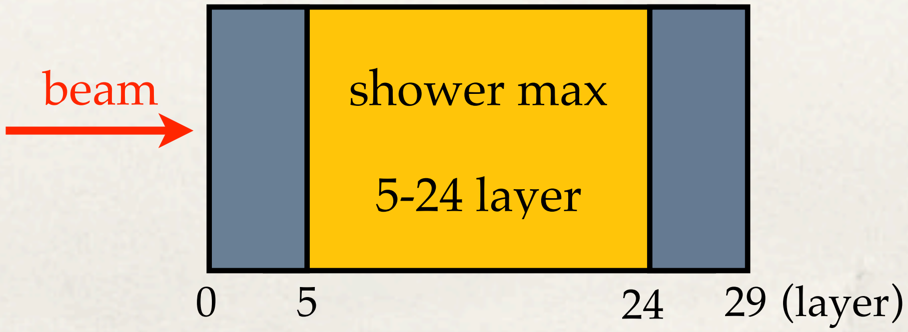
$$125 < \frac{E_{\mathrm{raw}}\,(\mathrm{MIPs})}{E_{\mathrm{beam}}\,(\mathrm{GeV})} < 375$$

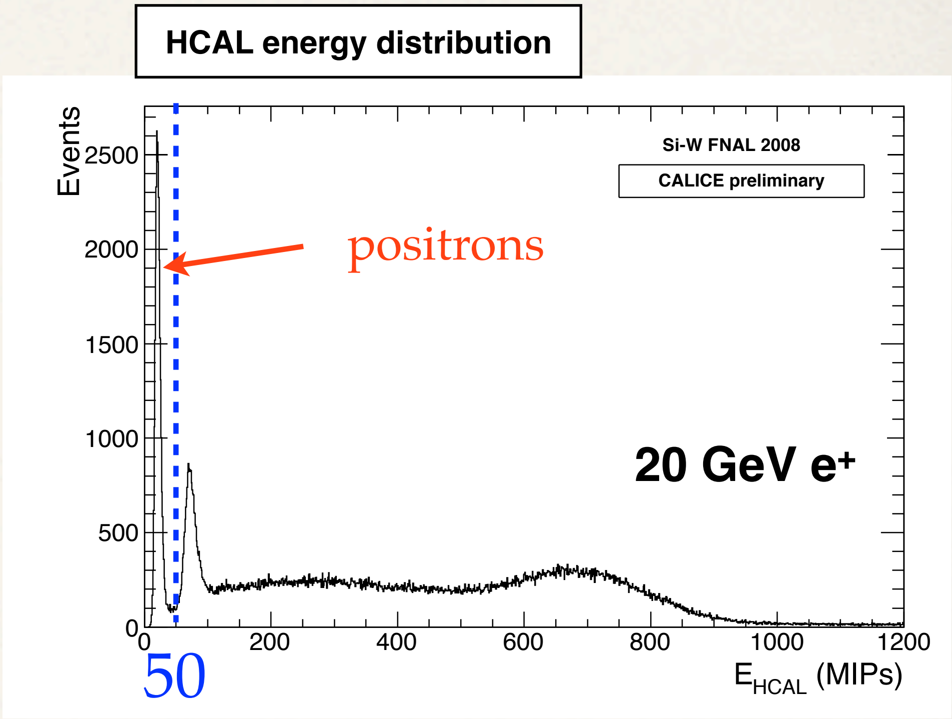
2. reject pion contamination by using HCAL information.

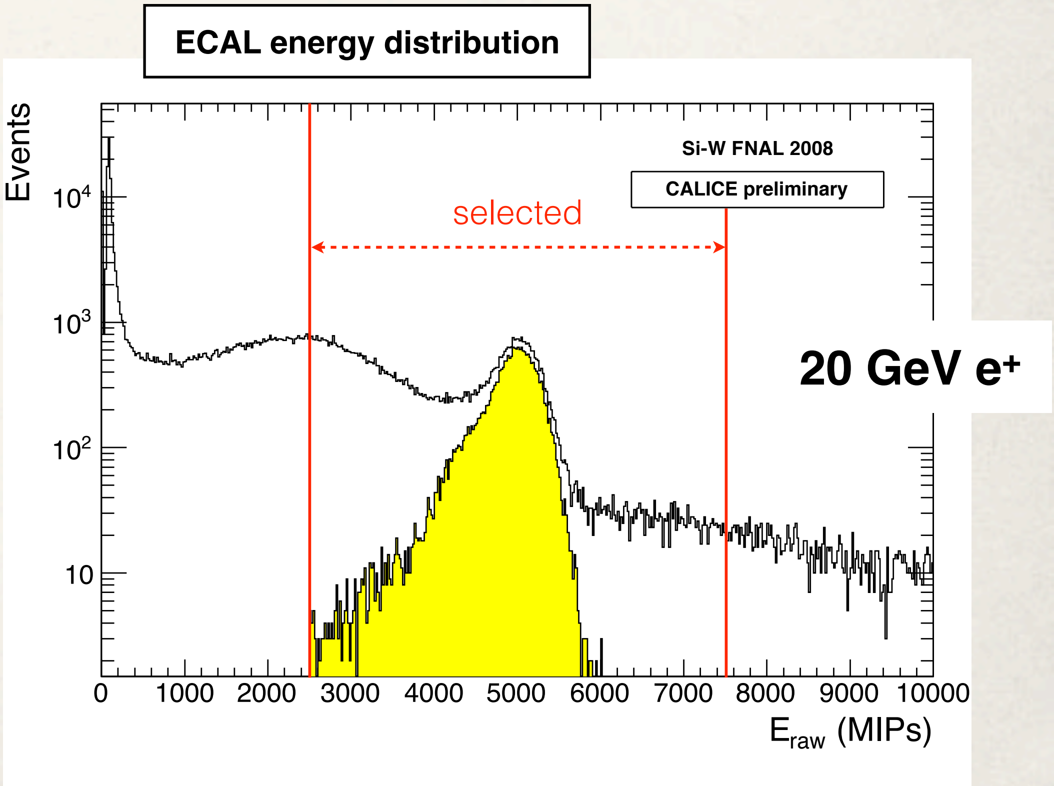
$$E_{\mathrm{HCAL}} < 50\ \mathrm{MIPs}$$

3. reject the event that the shower maximum layer is in the first five layers and the last five layers.

$$5 \leq L_{\mathrm{max}} \leq 24$$

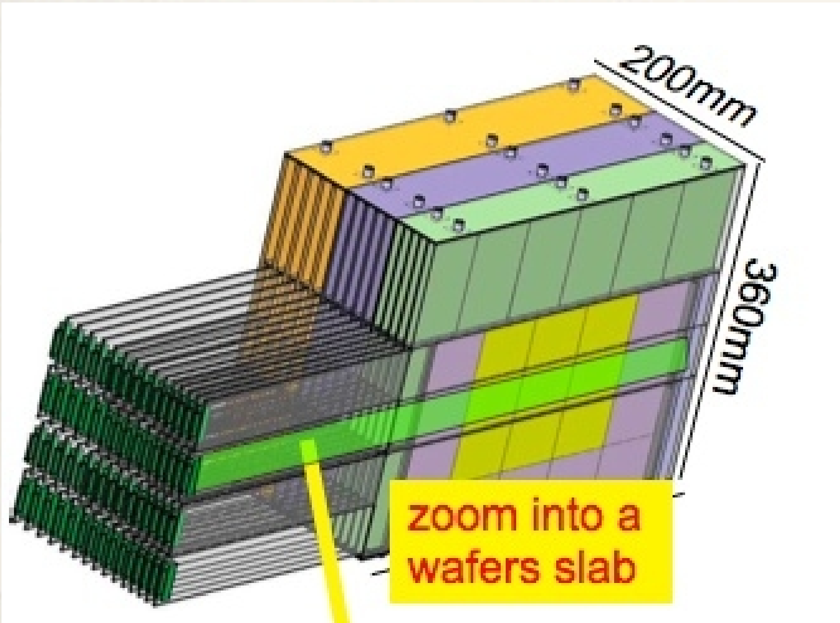


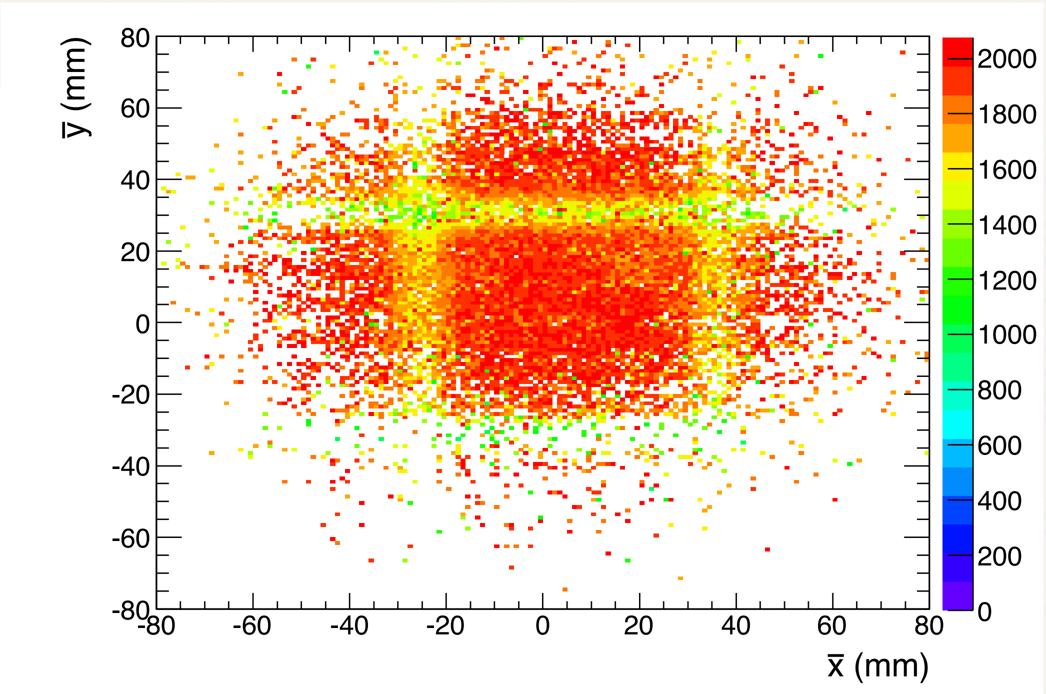


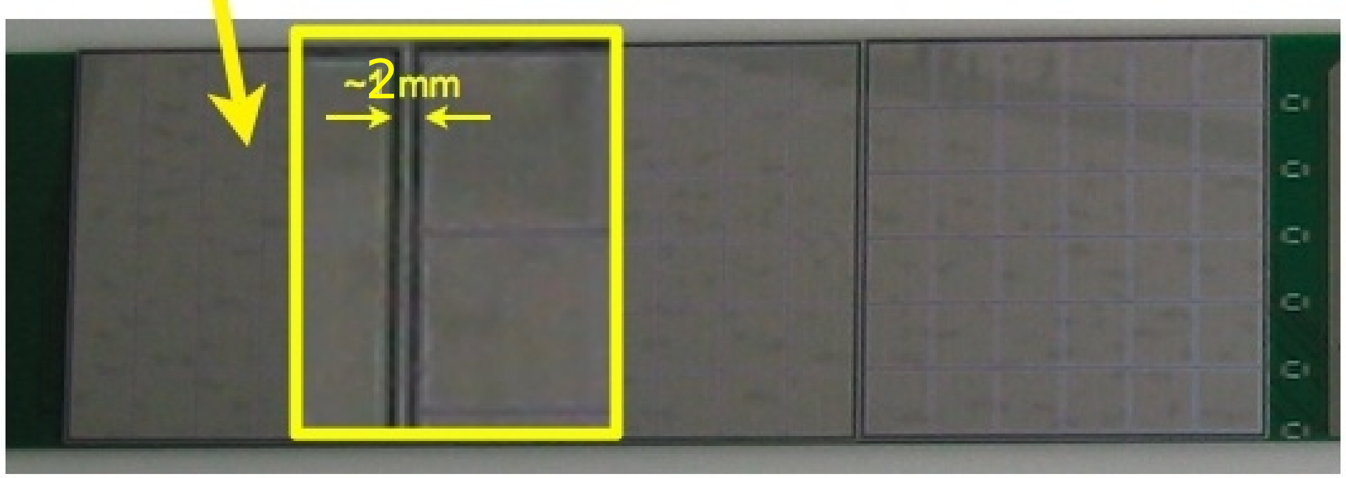


Gap Effect

- Each silicon wafer has 1 mm guard ring which induces an inactive area.
  - There are 2 mm inter wafer gaps.
  - They represents the dominant source of the non-uniformity.







E_{mean} (MIPs)

shower barycenter

$$(\bar{x}, \bar{y}) = \left(\sum_i wE_i x_i, \sum_i wE_i y_i \right) / \sum_i wE_i$$

E_i : hit energy
x_i, y_i : hit position
w : weight (1., 2., 3.)

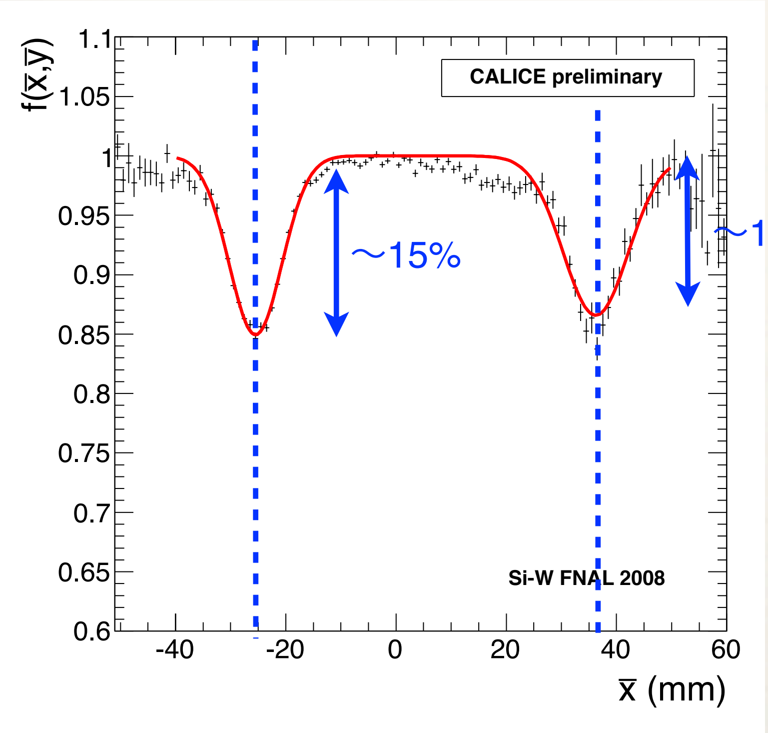
Need to take the gap effect into account in analysis

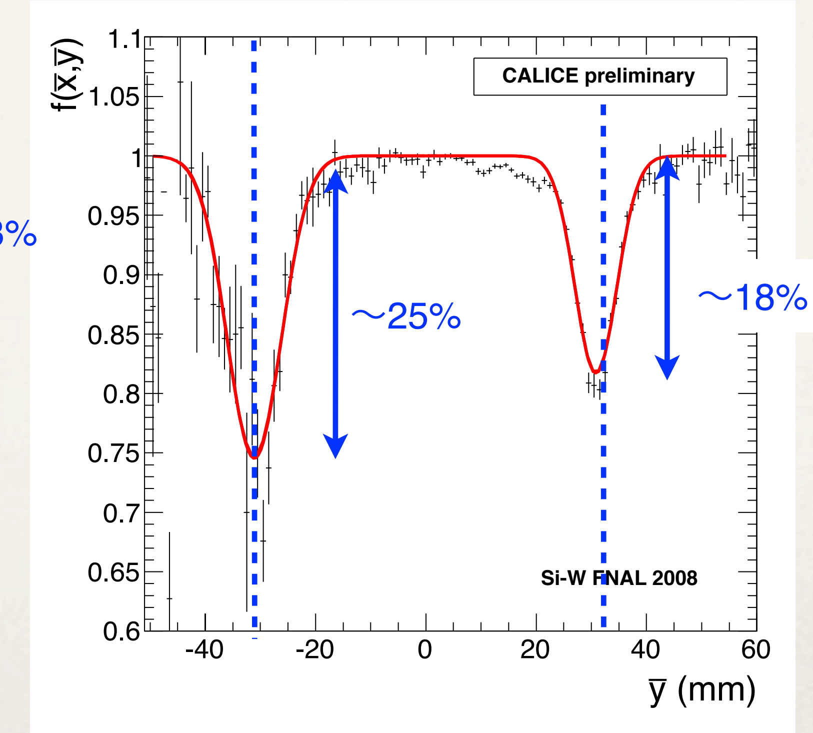
Gap Correction

- The response around the inter wafer gaps was fitted with the Gaussian.

$$f(\bar{x},\bar{y}) = \left[1 - a_{x,-}\exp\{-\frac{(\bar{x}-x_{-,gap})^2}{2\sigma_{x,-}}\}\right]\left[1 - a_{x,+}\exp\{-\frac{(\bar{x}-x_{+,gap})^2}{2\sigma_{x,+}}\}\right]$$
$$\times\left[1 - a_{y,-}\exp\{-\frac{(\bar{y}-y_{-,gap})^2}{2\sigma_{y,-}}\}\right]\left[1 - a_{y,+}\exp\{-\frac{(\bar{y}-y_{+,gap})^2}{2\sigma_{y,+}}\}\right]$$

- The value of the parameters $a_{x,\pm}$, $x_{gap,\pm}$, $\sigma_{x,\pm}$, $a_{y,\pm}$, $y_{gap,\pm}$ and $\sigma_{y,\pm}$ was extracted from the results of the fits.

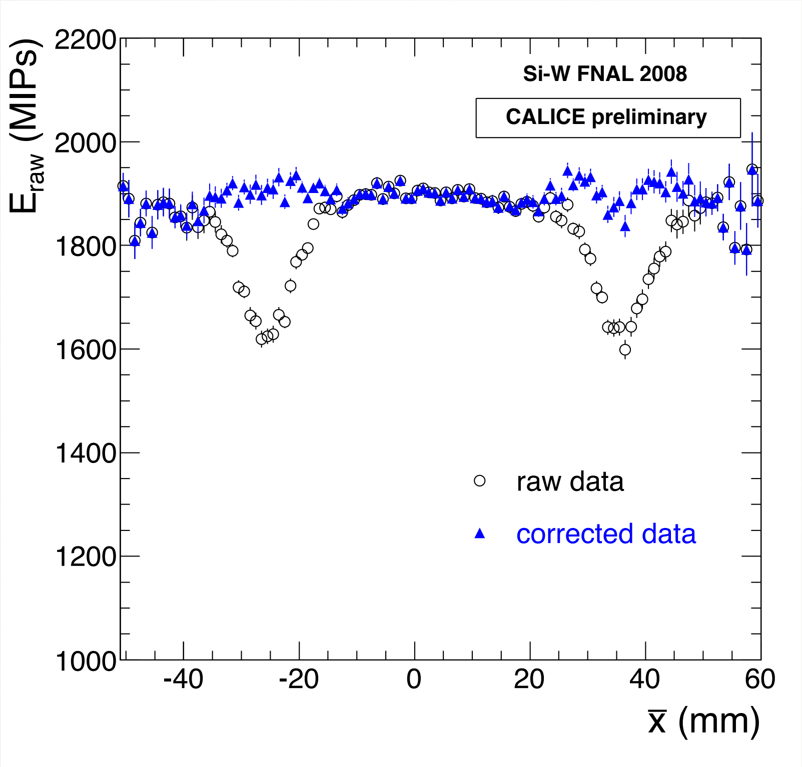


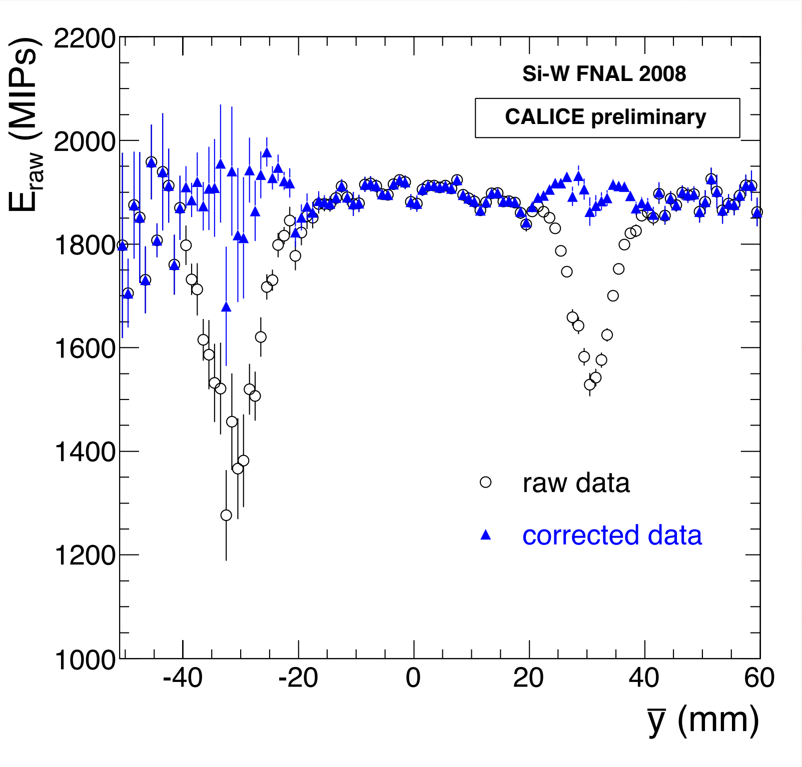


The results of the gaussian fit

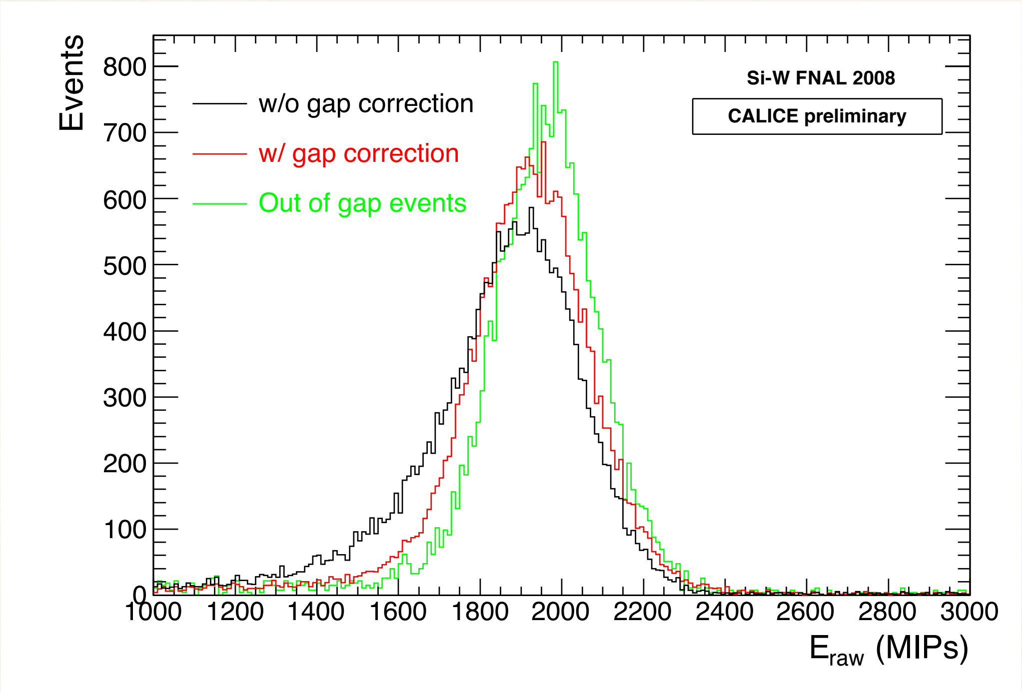
	position (mm)	σ (mm)	a
$x_{-,gap}$	-25.5	4.77	0.15
$x_{+,gap}$	36.2	5.92	0.13
$y_{-,gap}$	-31.1	4.94	0.25
$y_{+,gap}$	30.8	3.80	0.18

Gap Correction





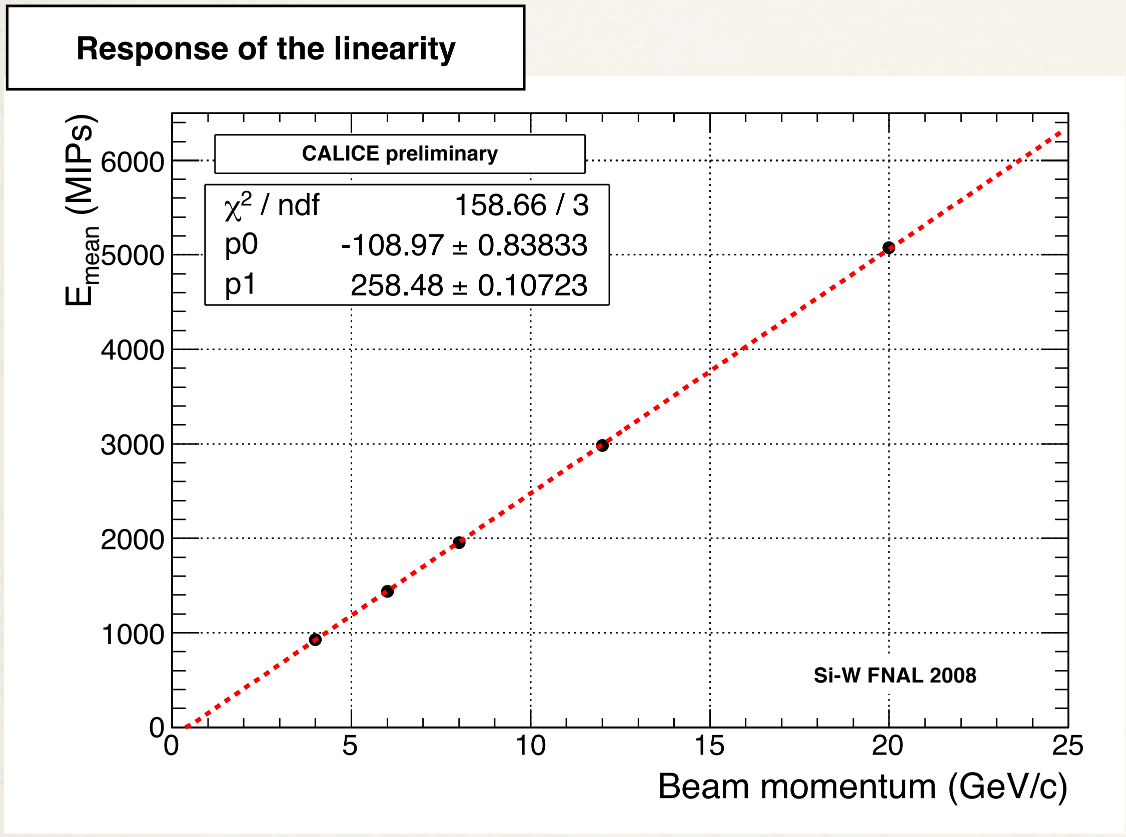
The energy loss in the inter wafer gaps can be corrected by applying $1/f(\bar{x},\bar{y})$ correction factor.

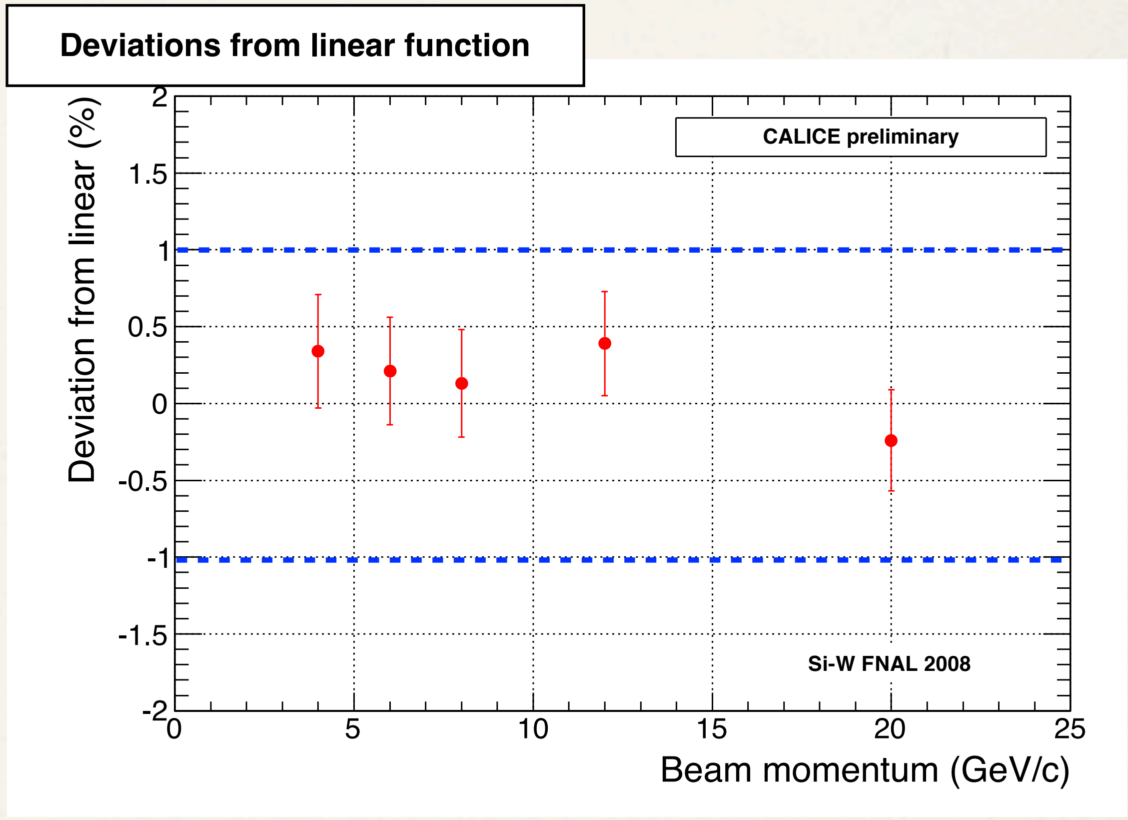


The shape of the energy distribution becomes more symmetric after gap correction.

Performance (Linearity)

- We evaluated the perfomance of linearity and energy resolution after gap correction.

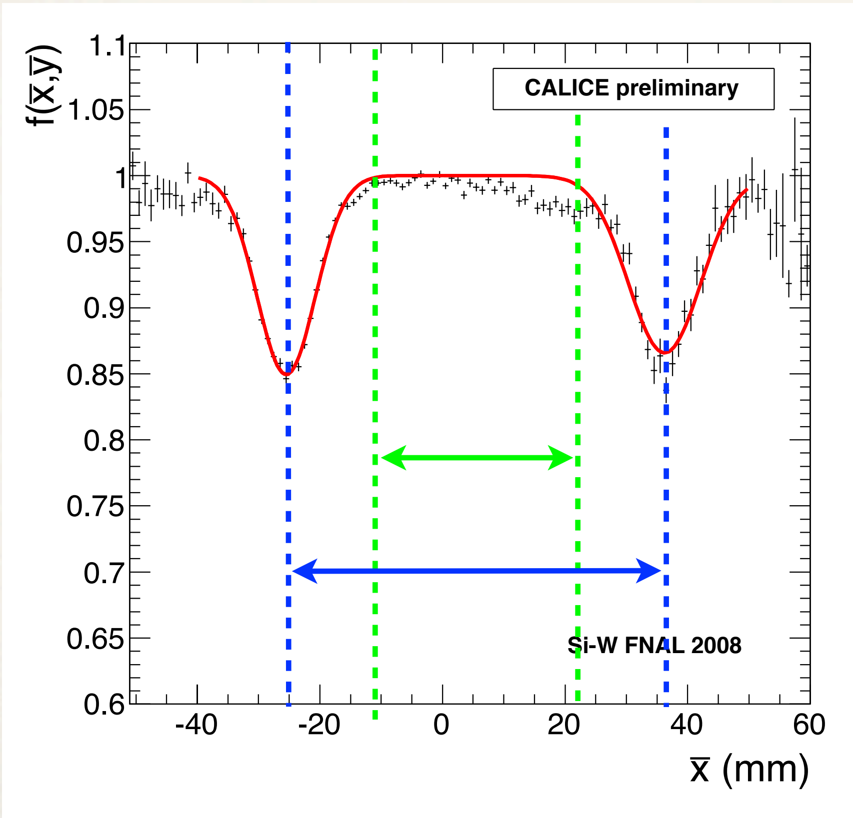


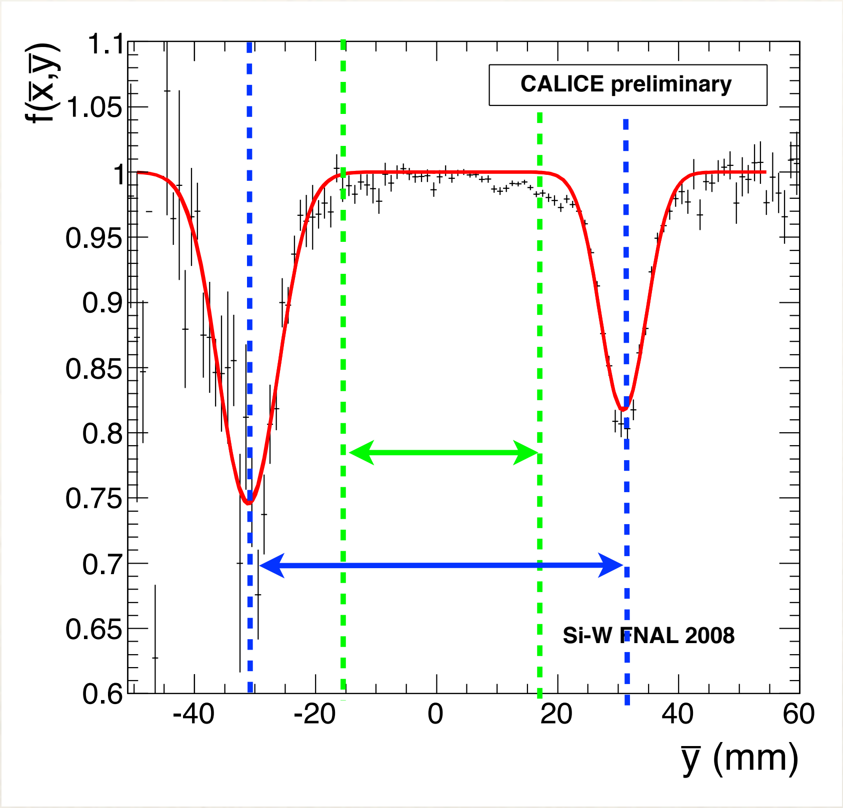


The deviations from linear function are less than 1 %

Performance (Energy resolution)

- We classified the energy resolution into four situations
  1. "no correction" : the gap correction was not applied for all positron candidates
  2. "gap correction" : the gap correction was applied for all positron candidates
  3. "center region w/ gap" : only positron candidates with the shower barycenter in the central region which includes gaps around the central Si pad are selected.
  4. "center region w/o gap" : it selects the events in the center region without gap. There is no (little) influence on gap effect



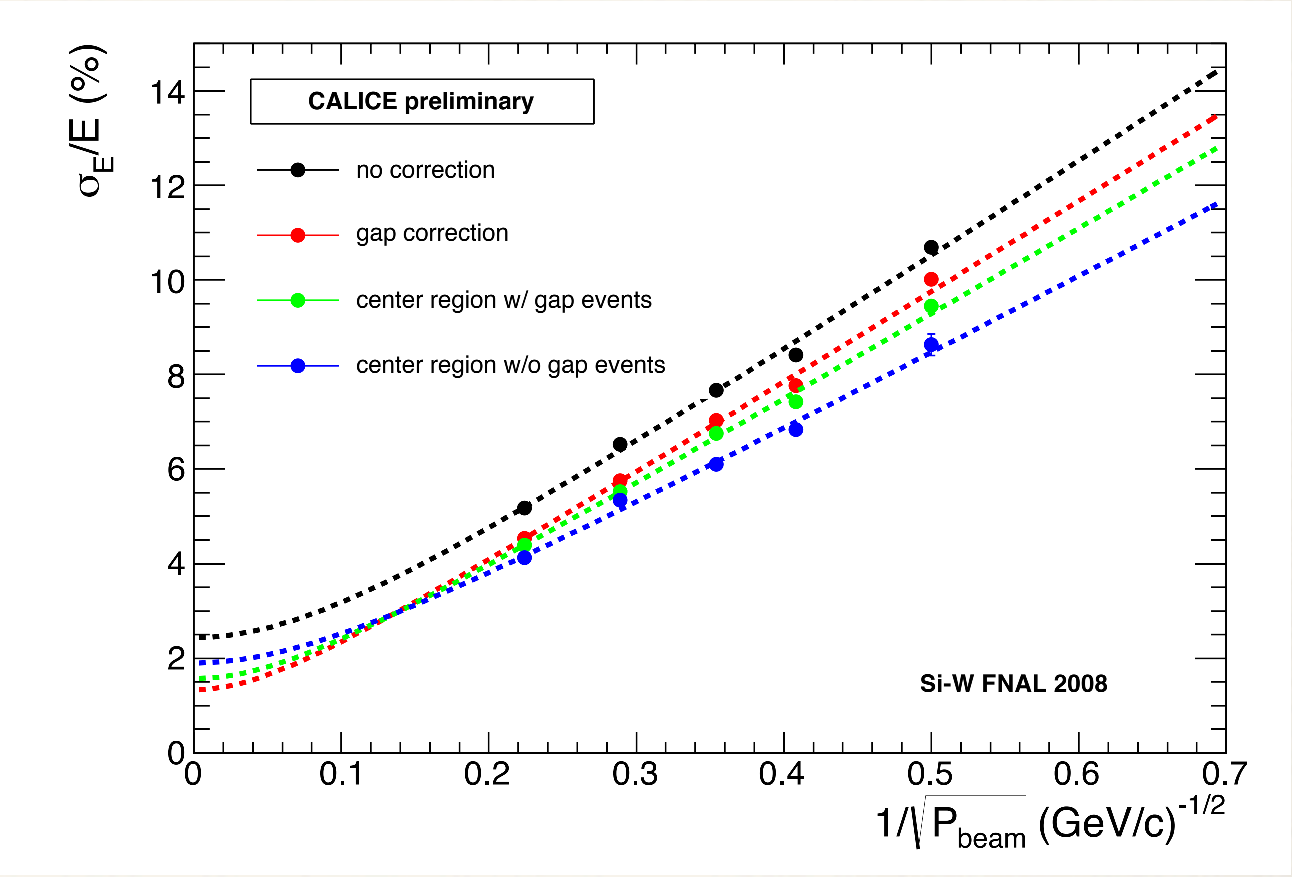


Performance (Energy resolution)

- We checked the energy resolution in four situations.

  Resolution curve:

$$\frac{\sigma_E}{E} = \frac{\sigma_{\mathrm{stoc}}(\%)}{\sqrt{E}} \oplus \sigma_{\mathrm{const}}(\%)$$



The energy resolution of the CERN data was evaluated using center region w/o gap.

Compared with CERN data, the stochastic term is consistent.

	stochastic	constant
no correction	20.47±0.21%	2.44±0.17%
gap correction	19.33±0.12%	1.33±0.16%
center region w/ gap	18.30±0.16%	1.57±0.15%
center region w/o gap	16.51±0.35%	1.90±0.15%
2006 CERN data	16.53±0.14±0.4%	1.07±0.07±0.1%

The beam momentum spread is not subtracted in the FNAL data

Summary

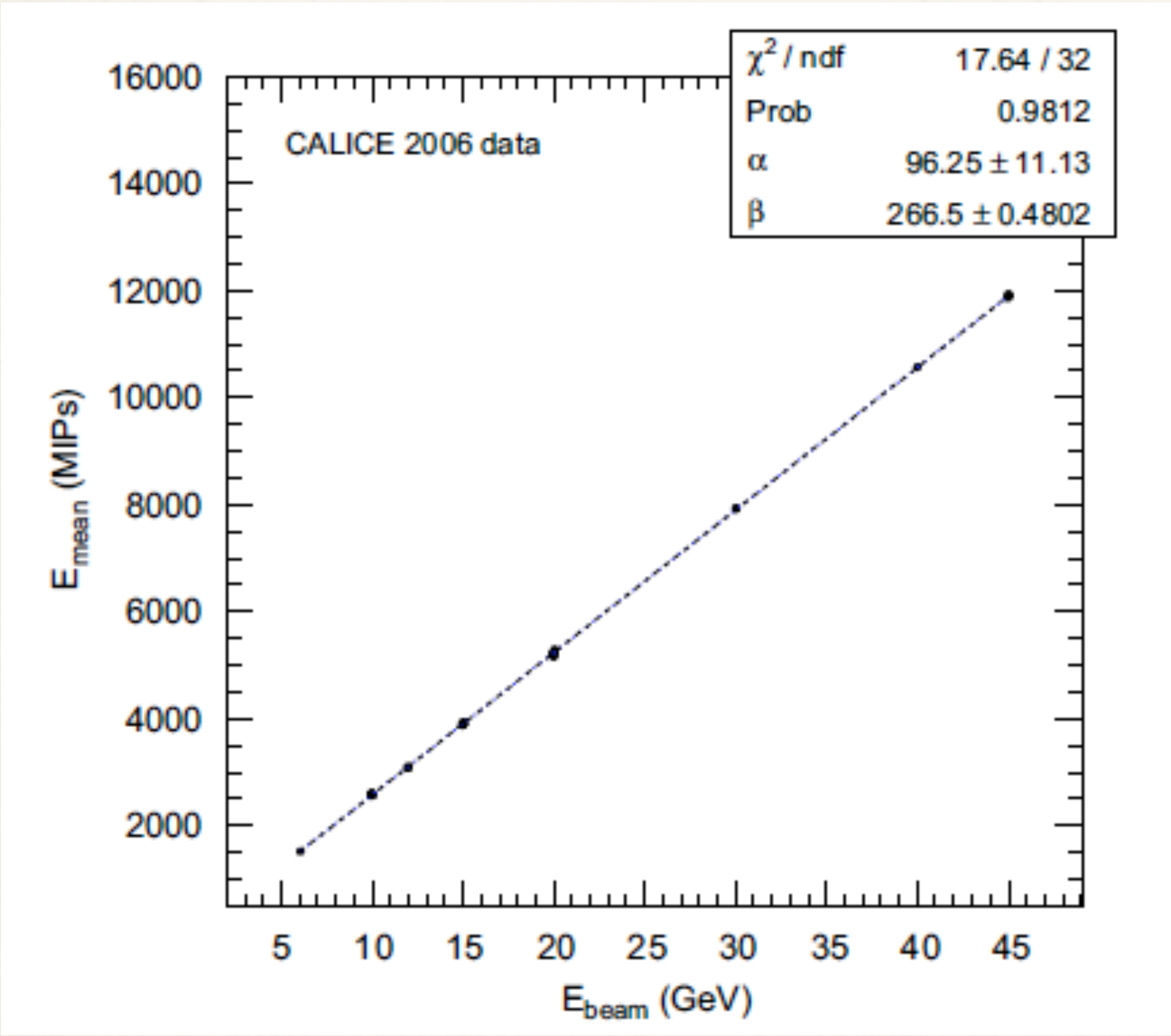
- The CALICE Si-W ECAL physics prototype was tested at FNAL in 2008 using 4 to 20 GeV positron beams and we evaluated the response of the prototype in terms of linearity and energy resolution.

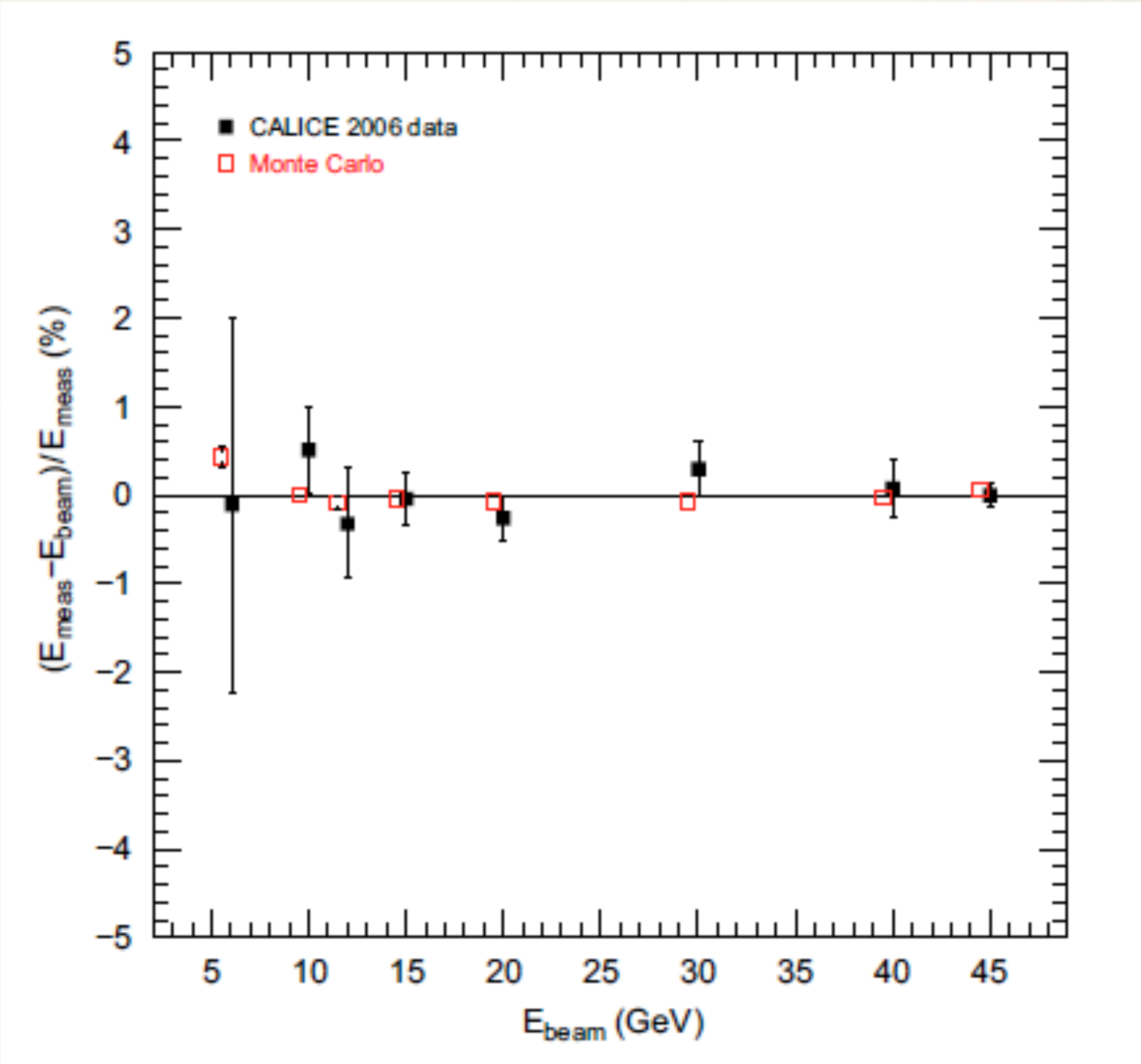
- Linearity:
  - The response has good linearity
  - Deviations from linear function are less than 1%

- Energy resolution:
  - The energy resolution has a stochastic term of 16.51±0.35% and constant term of 1.90±0.23%.
  - In comparison with TB 2006 analysis at CERN, stochastic term is consistent with CERN data. The constant term will be improved taking the beam momentum spread into account.

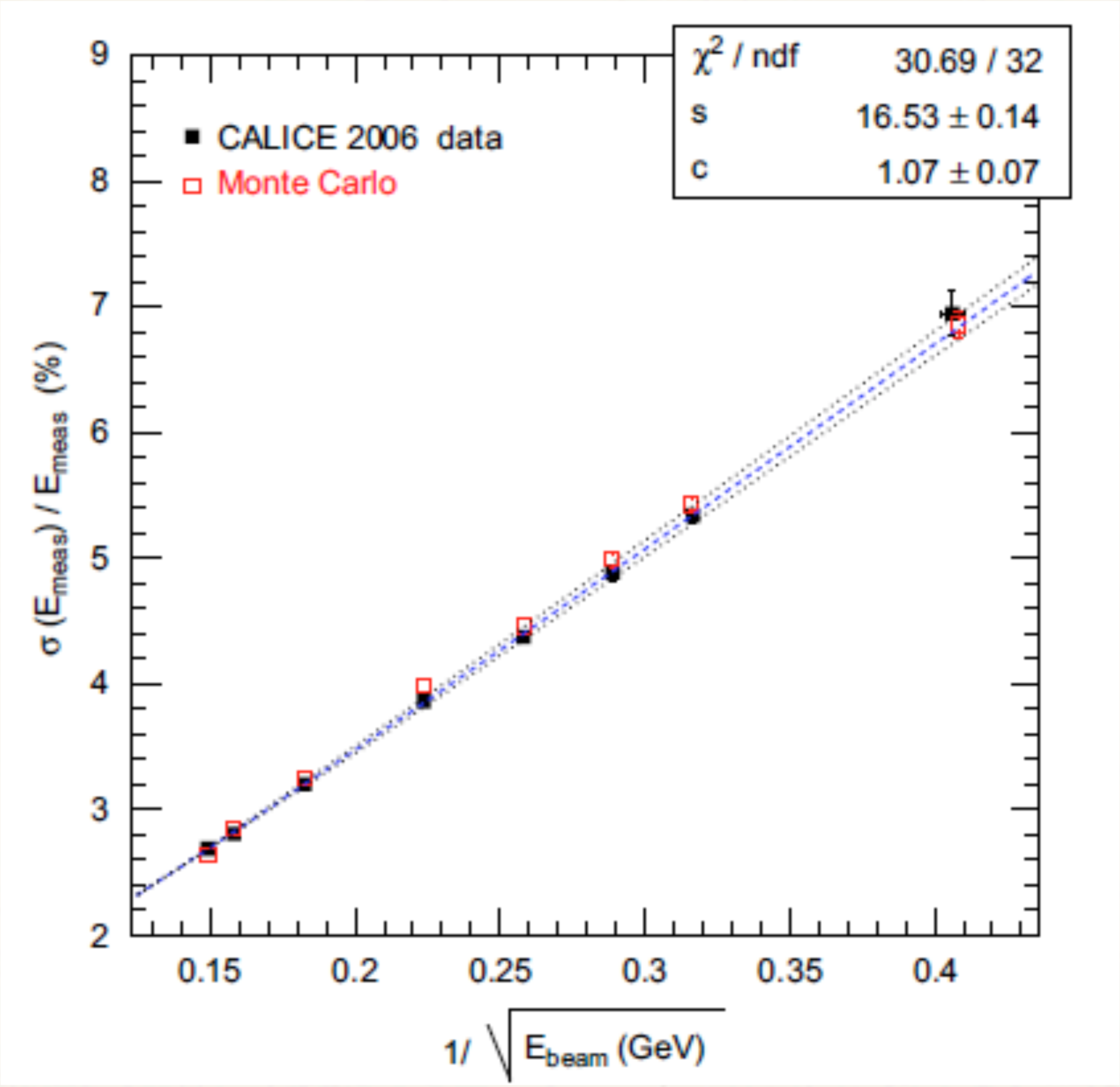
back up

Linearity (CERN 2006)





Energy resolution (CERN 2006)



$$\frac{\sigma(E_{meas})}{E_{meas}} = \left(\frac{16.53 \pm 0.14(stat) \pm 0.4(syst)}{\sqrt{E(GeV)}} \oplus (1.07 \pm 0.07(stat) \pm 0.1(syst))\right)\%$$