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

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Kyushu University
Yohei Miyazaki

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).

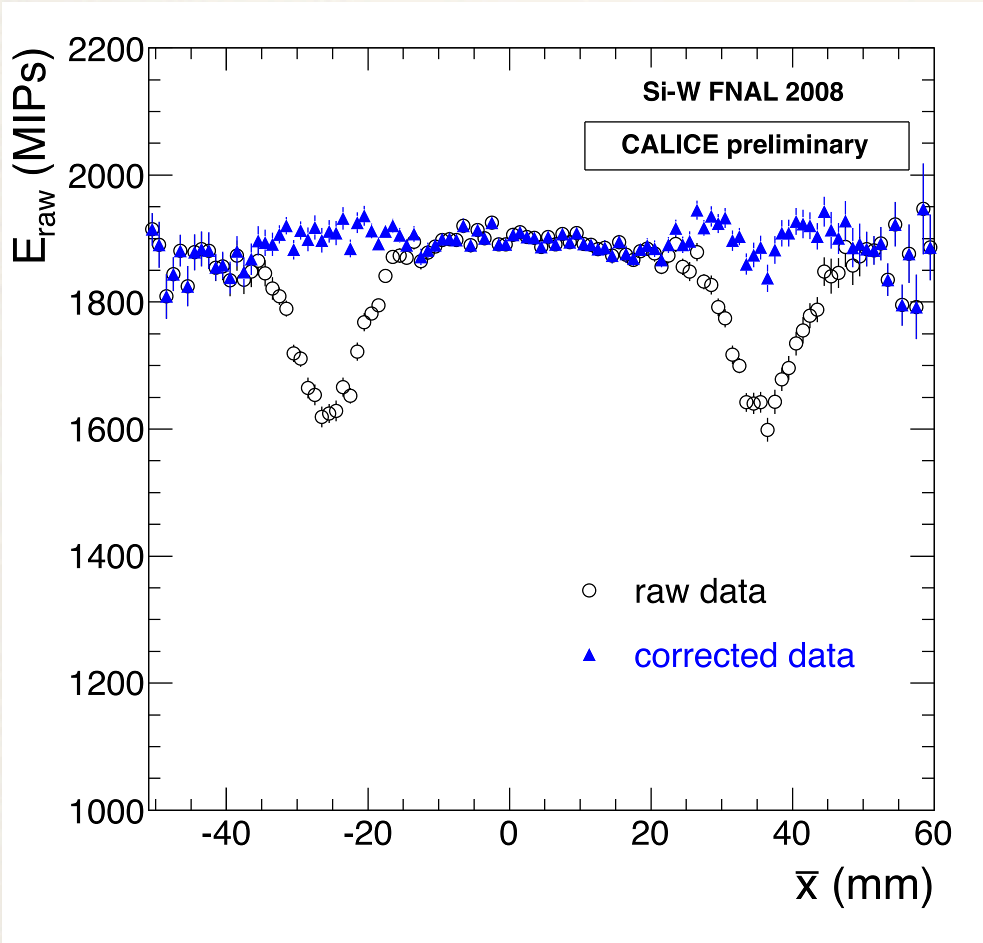
- We analyzed the prototype test beam data taken at FNAL in 2008.

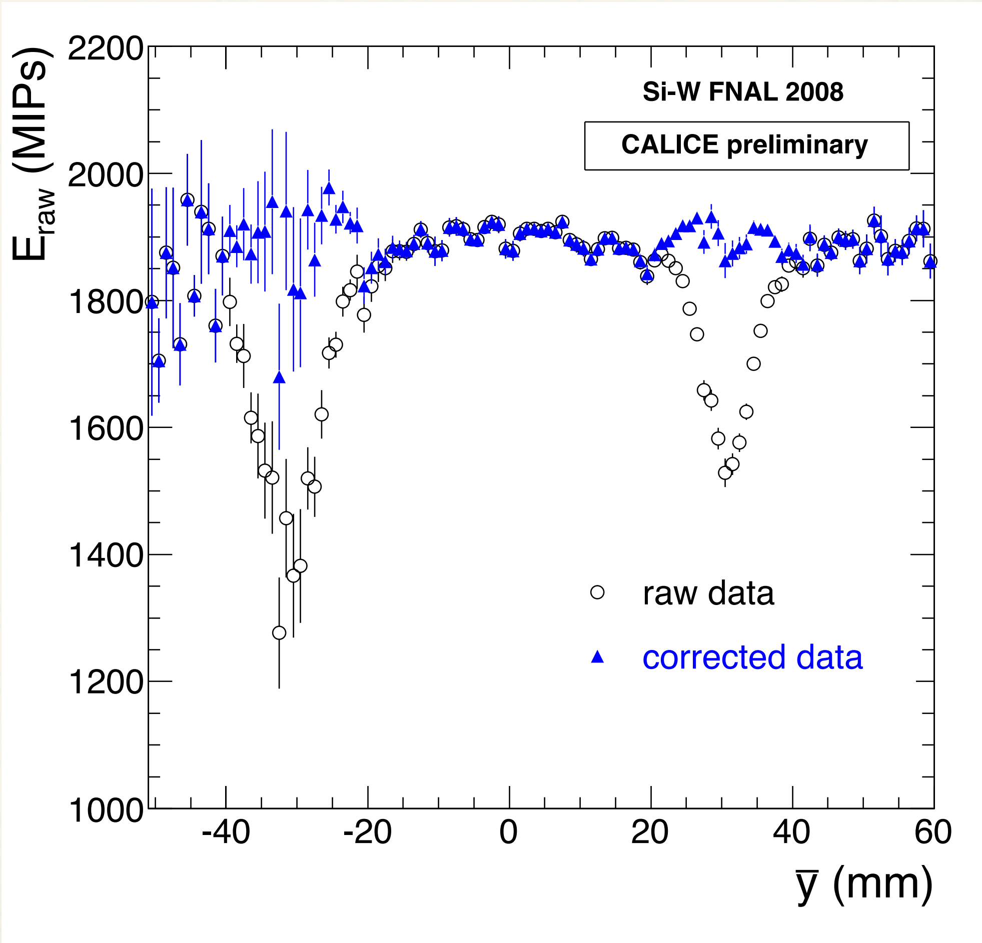
- We want to evaluate linearity and energy resolution for positrons and to compare the prototype response to positrons and electrons.

Update of Calibration Constant

- There was mis-calibration in the bottom slab's modules.

  →We re-reconstructed the data with new calibration constants and rechecked the energy linearity and resolution.





Performance Study

- We rechecked the energy linearity and resolution.
  - energy resolution

    stochastic term :

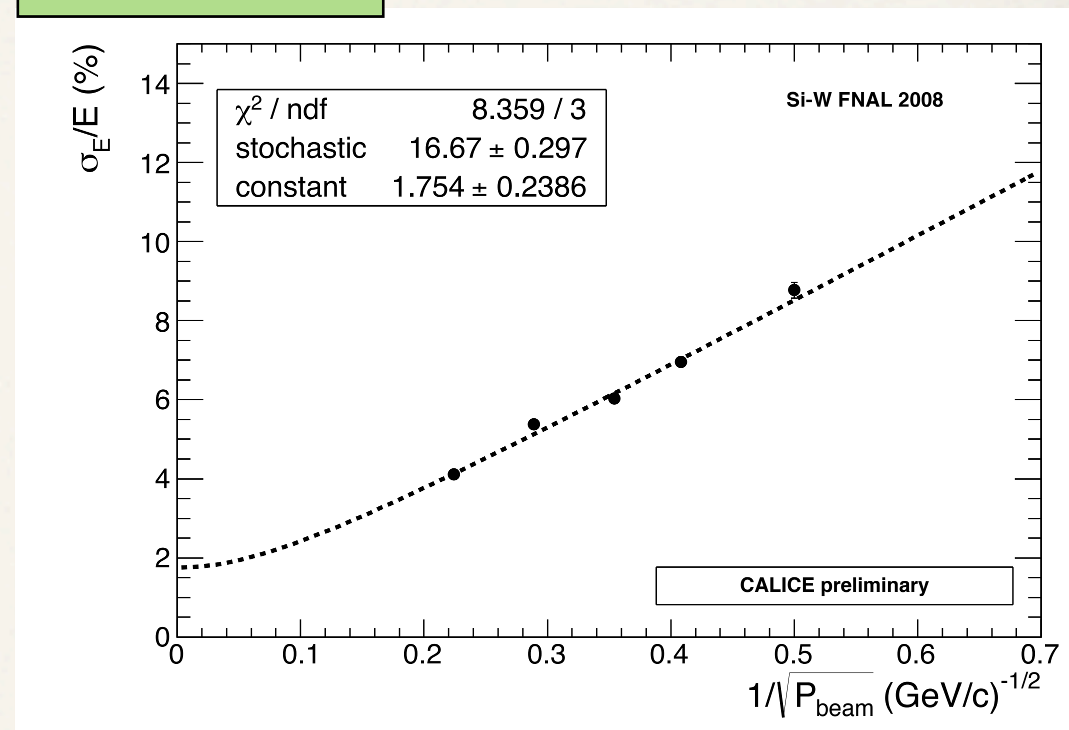
    16.51±0.35(stat.)% → 16.67±0.30(stat.)%

    constant term:

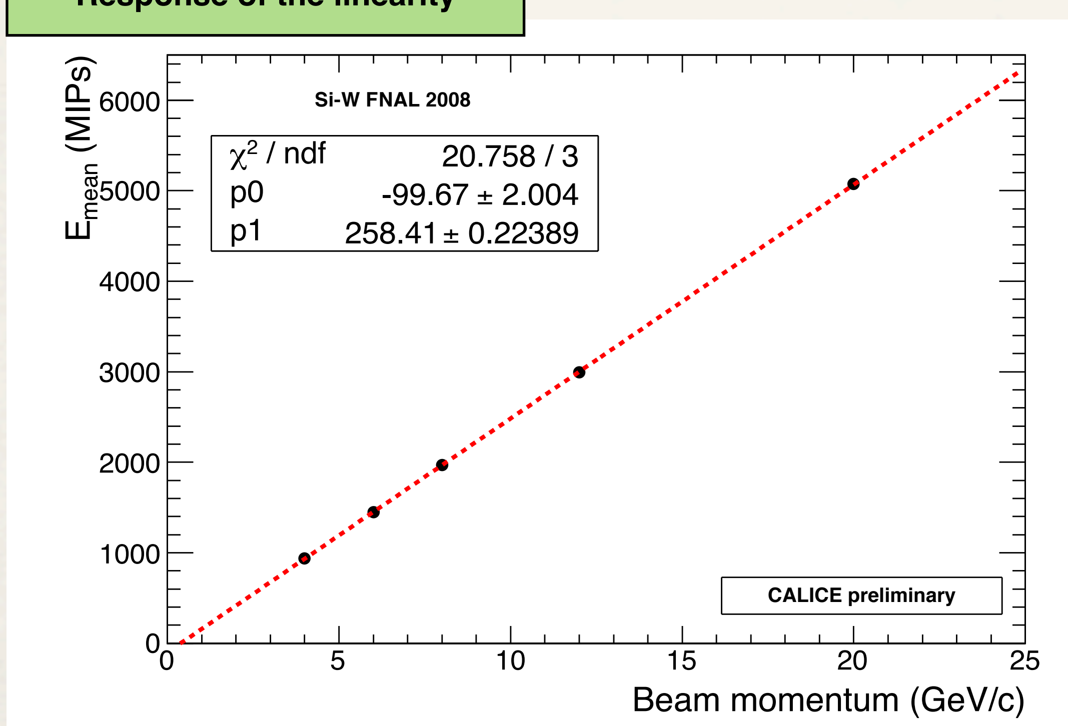
    1.90±0.15(stat.)% → 1.75±0.24(stat.)%
  - energy linearity

    the deviations from linear function is less than 0.5 %

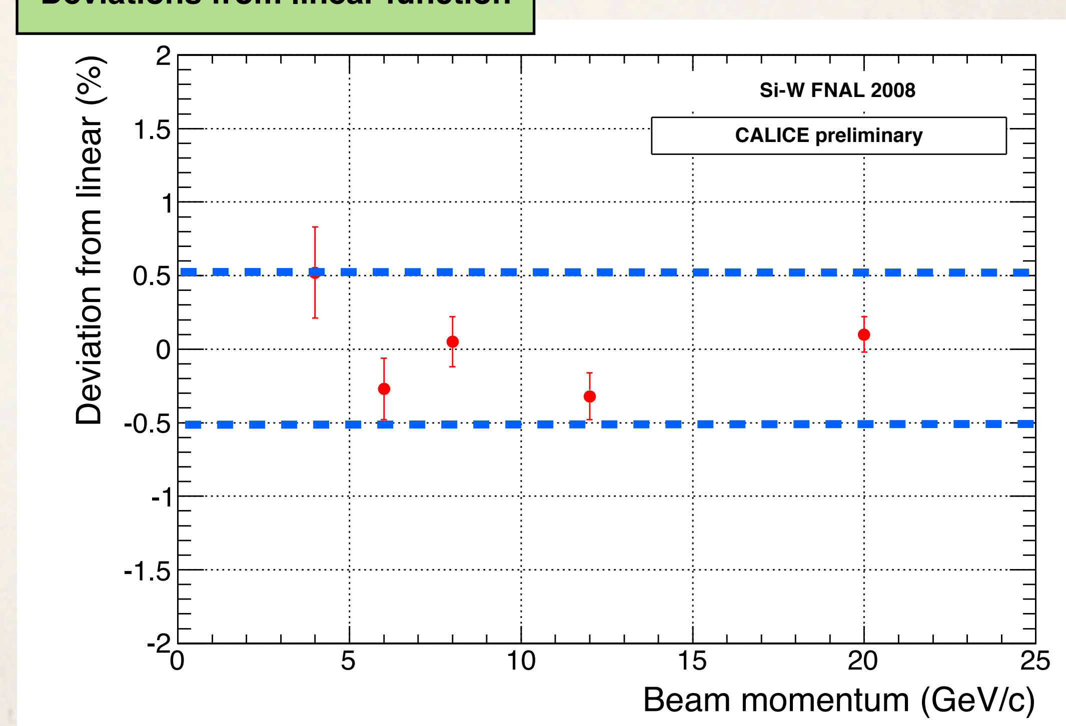
Energy resolution



Response of the linearity



Deviations from linear function

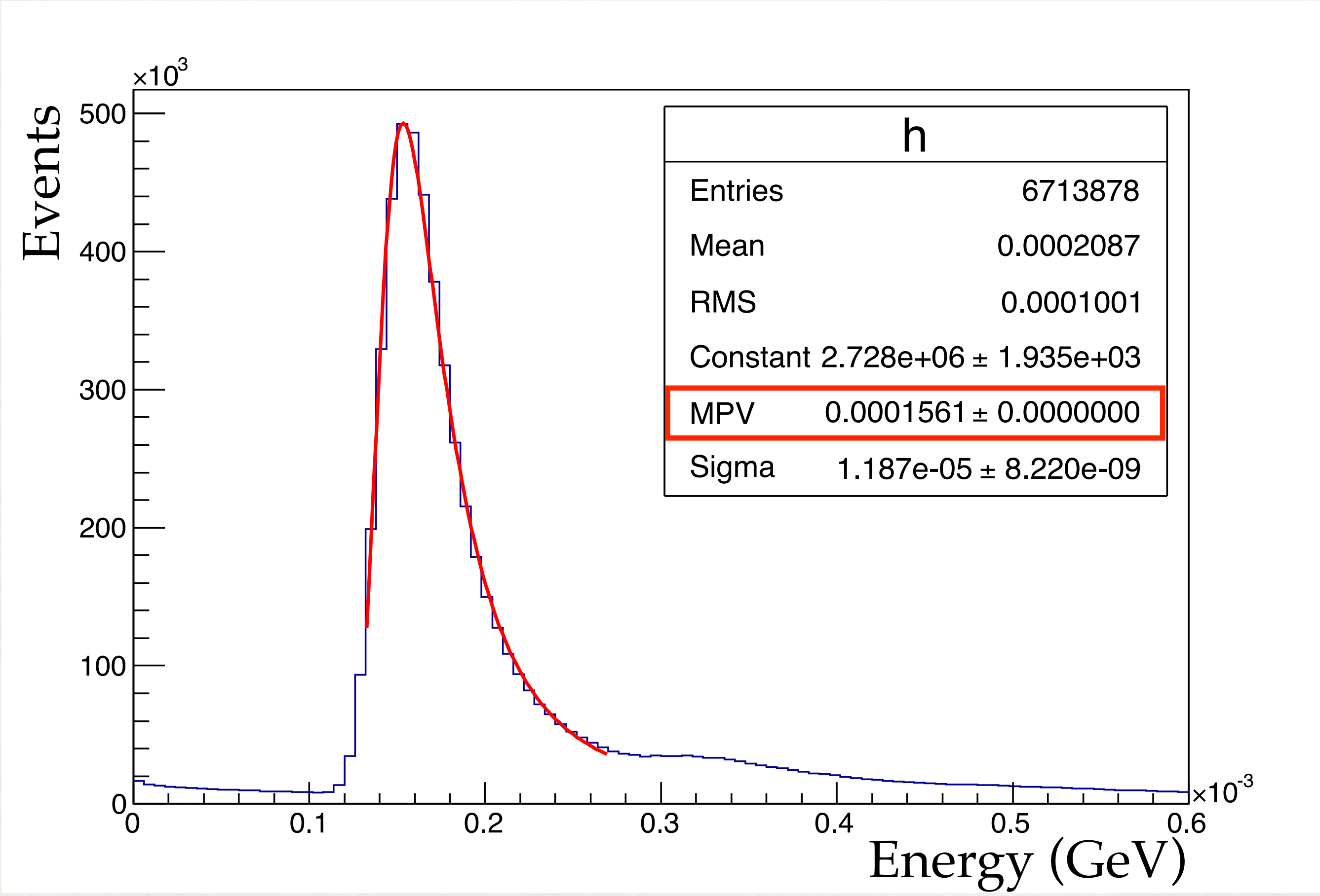


MC Simulation

- Analysis setup
  - calice soft : v04-07
  - ilcsoft : v01-17-03
  - Mokka Detector Model : TBFnal0508_p0709

- MIP Calibration : 32 GeV muon

  fitted with the landau function and extracted the MPV value.



GeV to MIP conversion factor

1 MIP = 0.000156 GeV

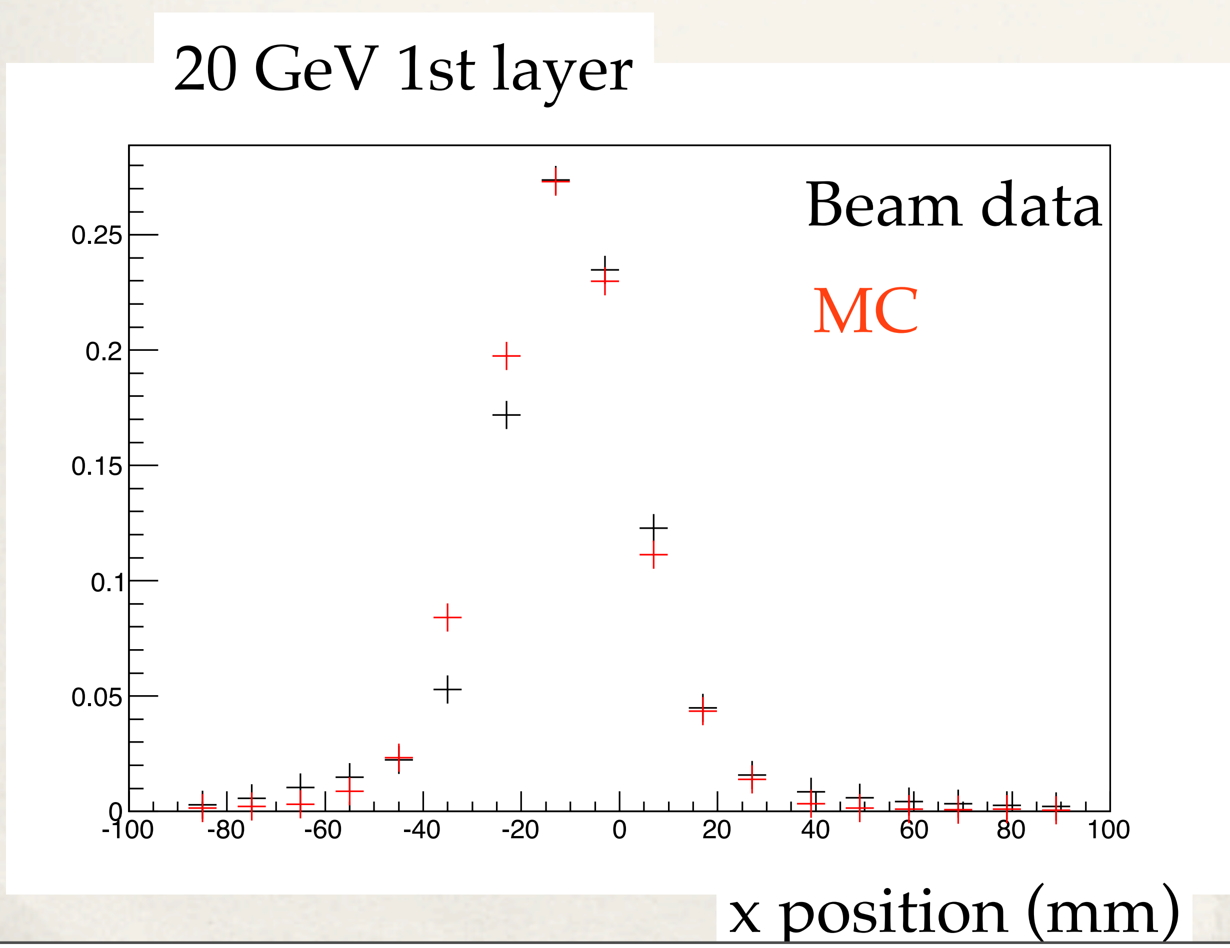
Beam Position

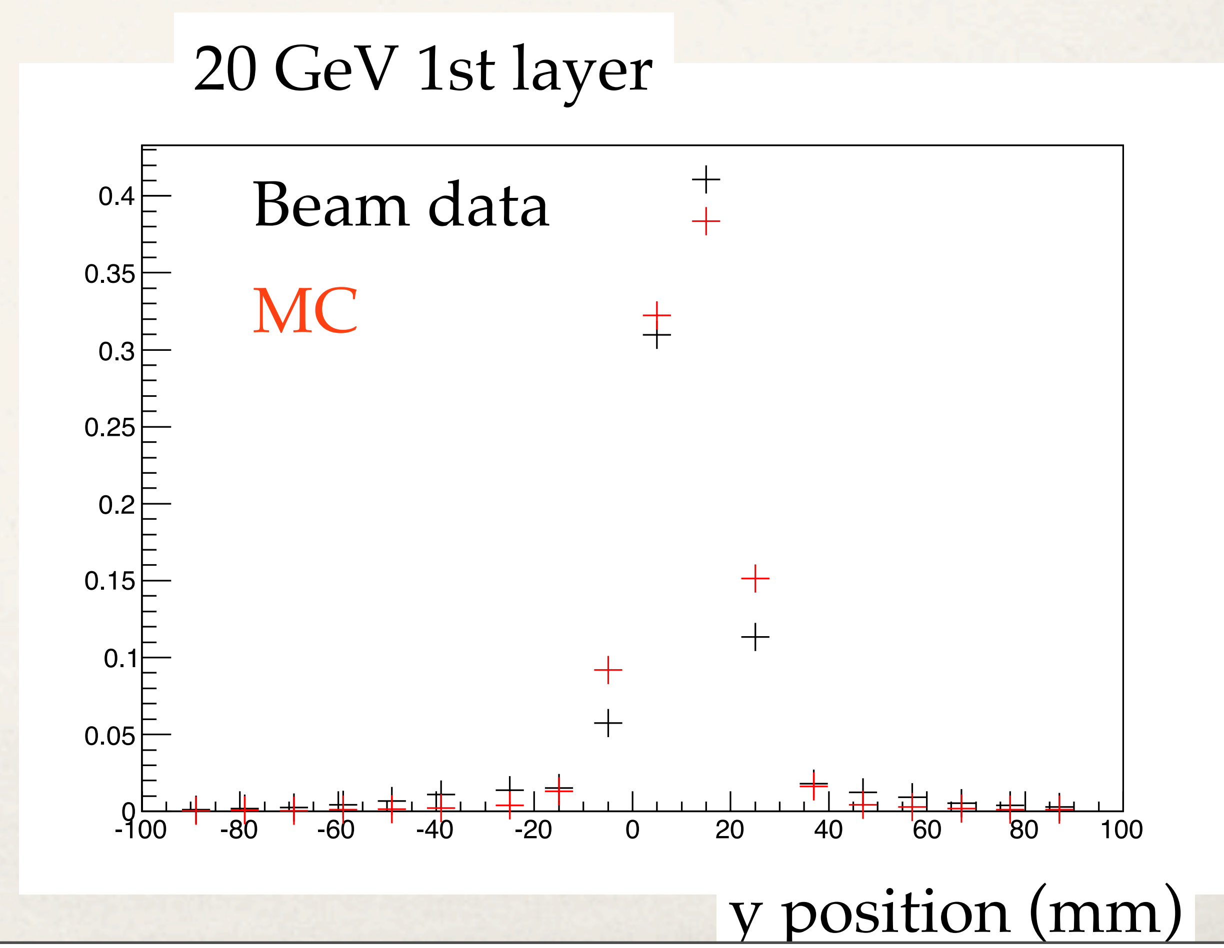
- We adjusted beam position of MC to that of the beam data by using single hit in a first layer.

- <u>Beam momentum spread</u>

  2.7% for 4, 6 GeV

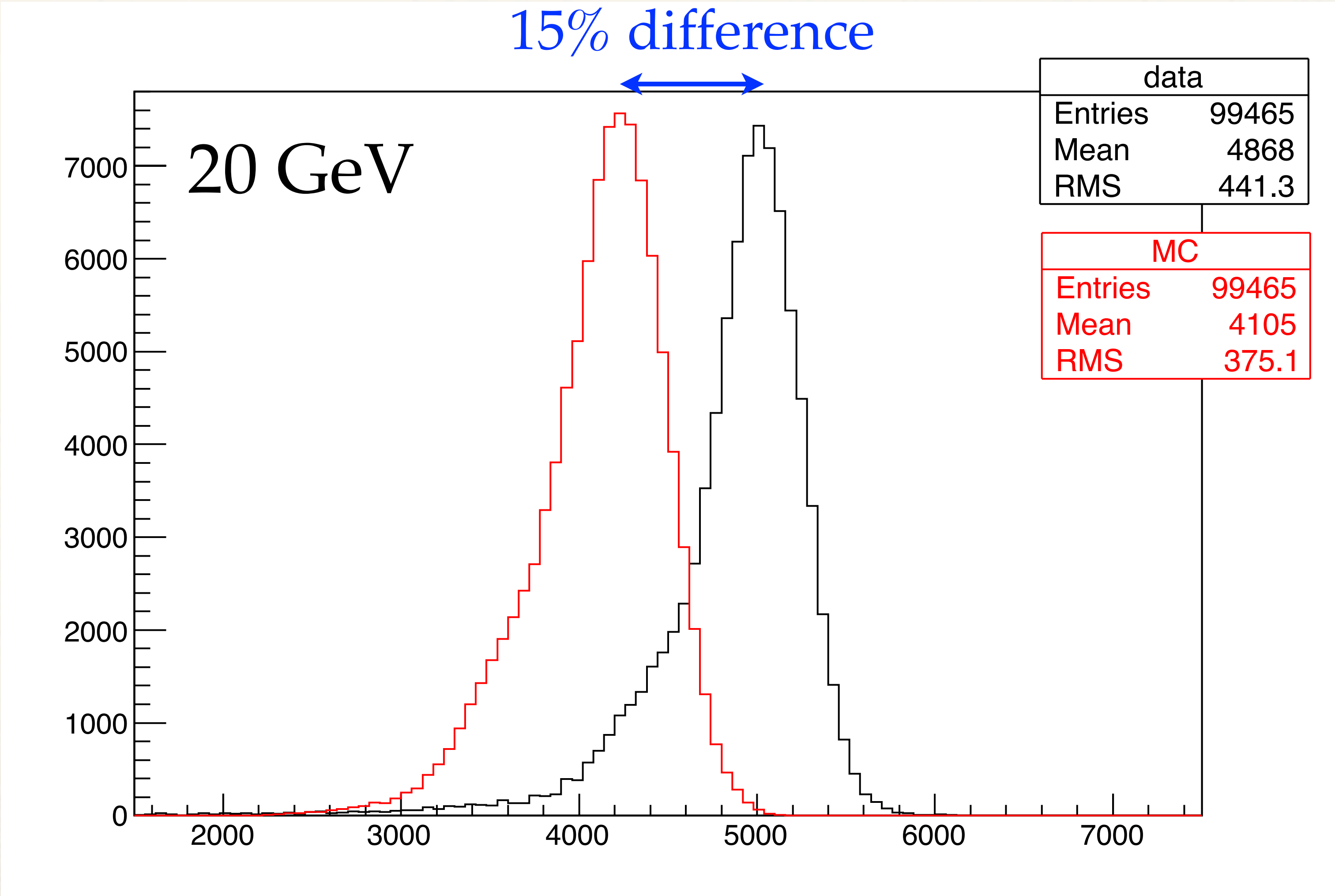
  2.3% for 8, 12 , 20 GeV





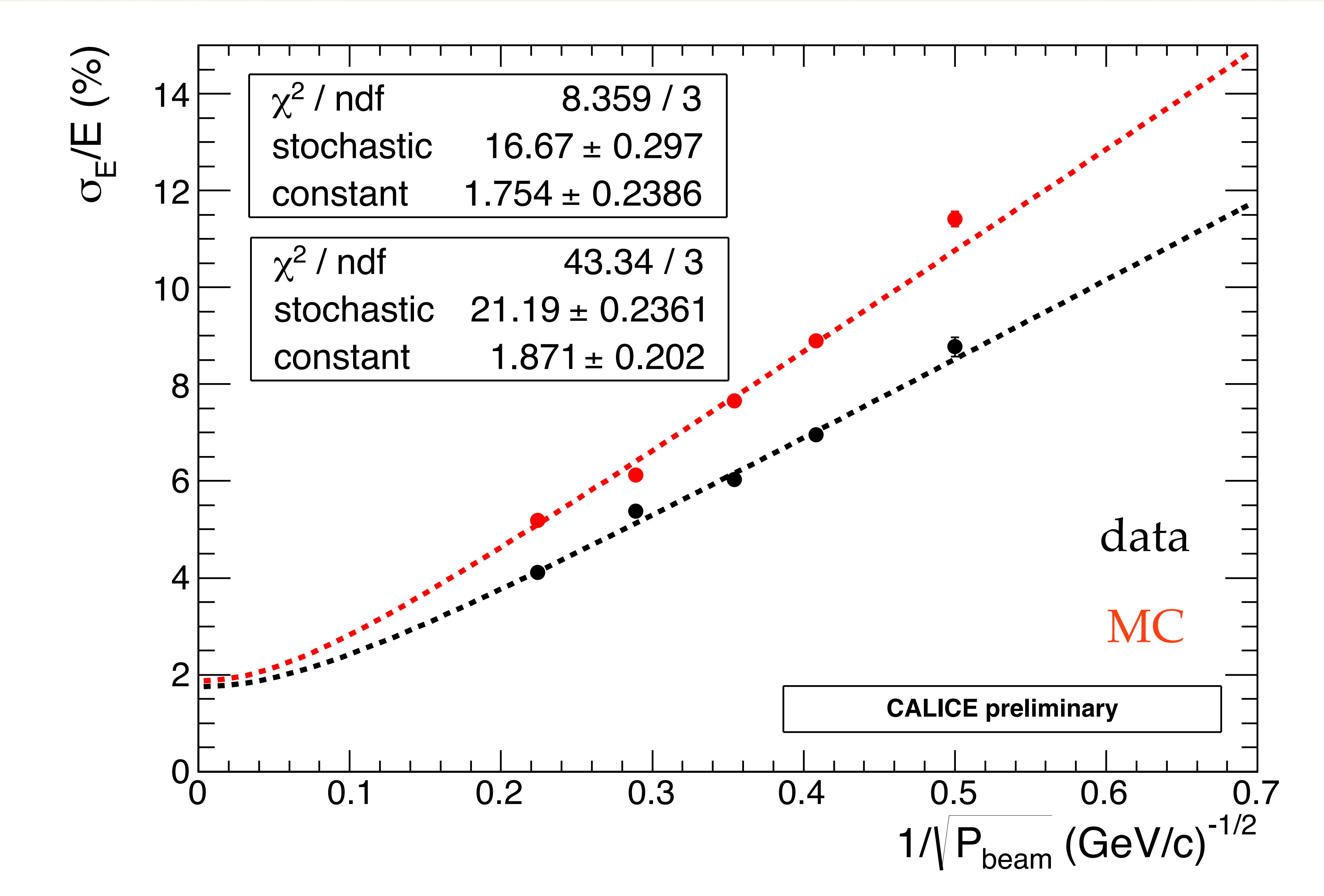
MC result

- We compared a energy distribution of MC with that of the test beam data.
- A mean of the MC is about 15% lower than that of test beam data and distribution is wider.
  →We scaled up the MC and adjust the mean value.



MC results

- We compared a energy resolution of the MC with that of the data.
  - There is 5% difference on stochastic term between data and MC
- The reason is now under investigation.



Systematic Error

- Example of the systematic error of the energy resolution.
  - shower distance to the gaps
    - distance between the barycenter and the nearest inter-wafer gaps.
    - We checked the effect of varying this distance : 4σ→3σ, 3.5σ, 4.5σ
  - MIP threshold
  - binning

shower distance to the gaps (in standard deviations)				
	3σ	3.5σ	4σ	4.5σ
χ^2/ndf	5.51/3	6.31/3	8.40/3	8.67/3
stochastic term (%)	16.74±0.24	16.44±0.25	16.67±0.30	16.48±0.36
constant term (%)	2.04±0.17	2.09±0.17	1.75±0.24	1.79±0.30

Systematic Error

- Example of the systematic error of the energy resolution.
  - shower distance to the gaps
  - MIP threshold
    - In this study, the energy threshold for considering the hits is 0.5 MIPs
    - We checked the effect of varying this threshold : 0.5 MIPs → 0.7 MIPs, 0.9 MIPs
  - binning

MIP threshold			
	0.5 MIPs	0.7 MIPs	0.9 MIPs
χ^2/ndf	8.40/3	9.16/3	5.42/3
stochastic term (%)	16.67±0.30	16.52±0.32	16.53±0.29
constant term (%)	1.75±0.24	1.77±0.27	1.90±0.21

Systematic Error

- Example of the systematic error of the energy resolution.
  - shower distance to the gaps
  - MIP threshold
  - binning
    - In order to investigate the effect of the width of the bin, we changed it.

binning		
	double	half
χ^2/ndf	8.46/3	5.61/3
stochastic term (%)	16.33±0.30	16.66±0.28
constant term (%)	1.88±0.22	1.81±0.23

Systematic Error

- We estimated the systematic error of the energy resolution by quadratic sum.

stochastic term $16.67 \pm 0.30(\mathrm{stat.})^{+0.07}_{-0.44}(\mathrm{syst.})\%$

constant term $1.75 \pm 0.24(\mathrm{stat.})^{+0.39}_{-0.00}(\mathrm{syst.})\%$

- We didn't take a momentum spread into account in this estimation.
  - We need to add the effect of a beam momentum spread.

Summary

- We re-reconstructed the data with a new calibration constants
  - energy linearity

    the deviations from linear function is less than 0.5 %
  - energy resolution

    energy resolution changes little bit

- We performed a MC simulation
  - There was large difference between data and MC
  - The reason is now under investigation

- We estimated the systematic error of the energy resolution.

  stochastic term $16.67 \pm 0.30(\text{stat.})^{+0.07}_{-0.44}(\text{syst.})\%$

  constant term $1.75 \pm 0.24(\text{stat.})^{+0.39}_{-0.00}(\text{syst.})\%$

back up

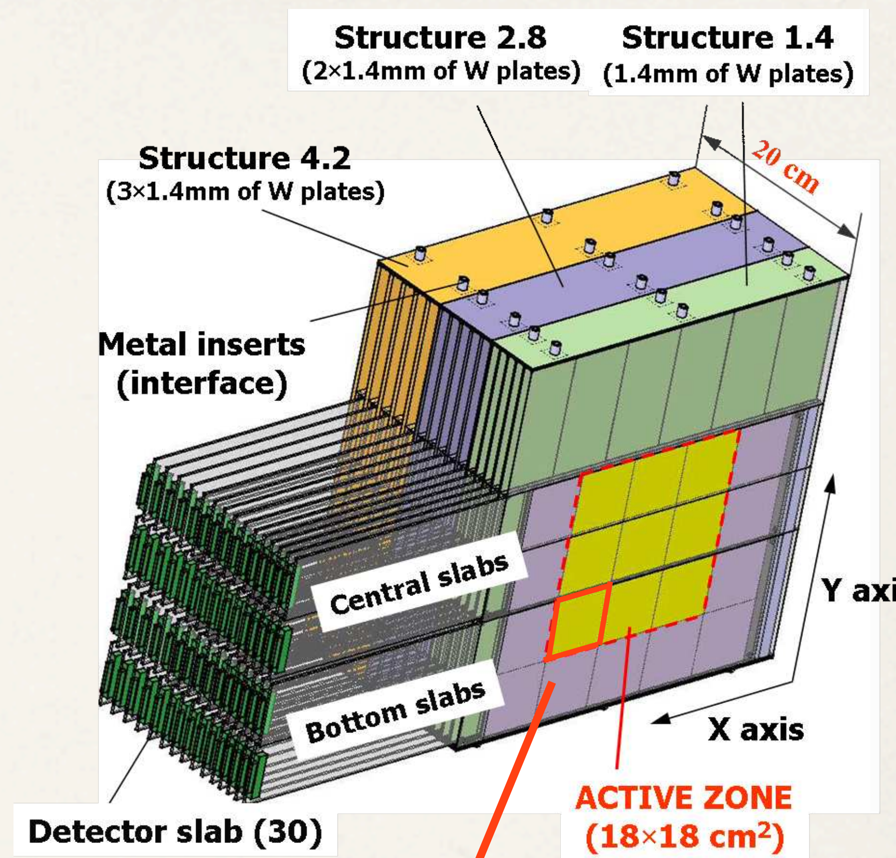
Physics Prototype Design

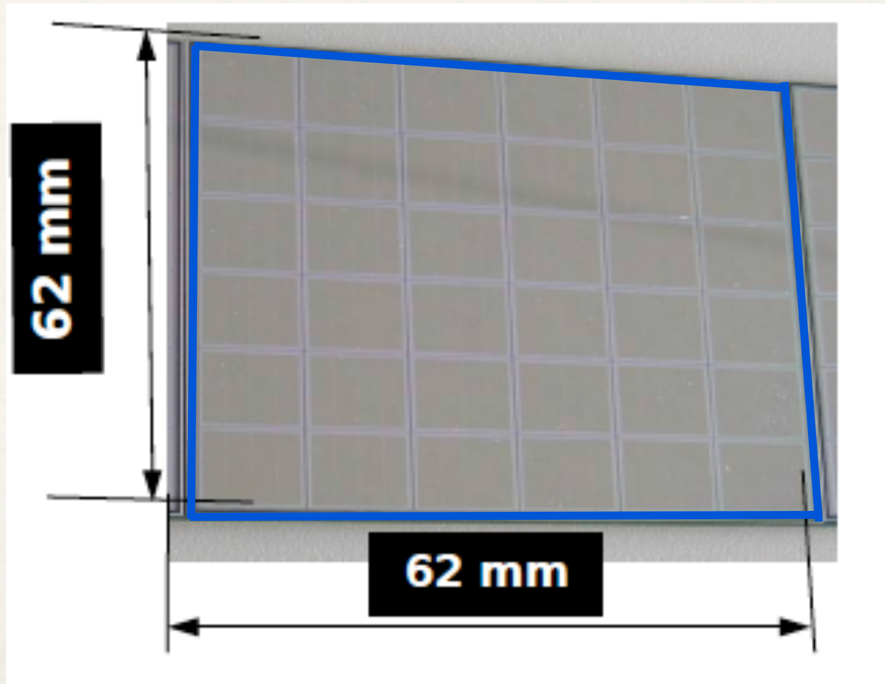
Prototype Design

- 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





Thickness: 525 μm

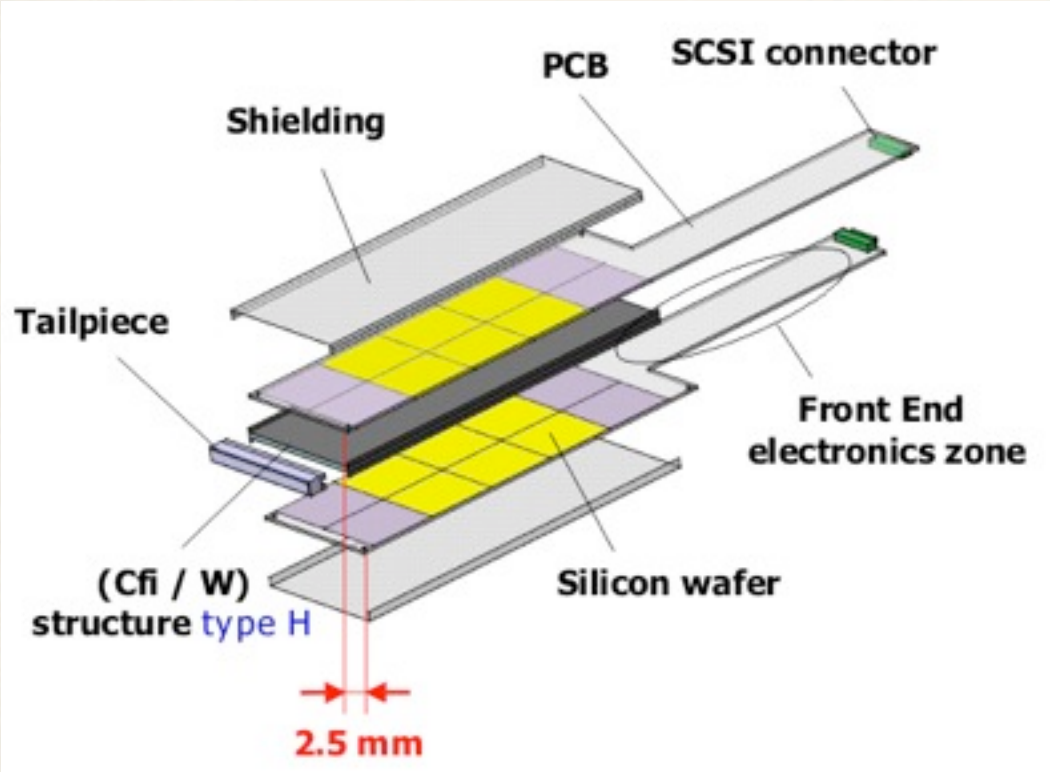
pixel size: 10 mm

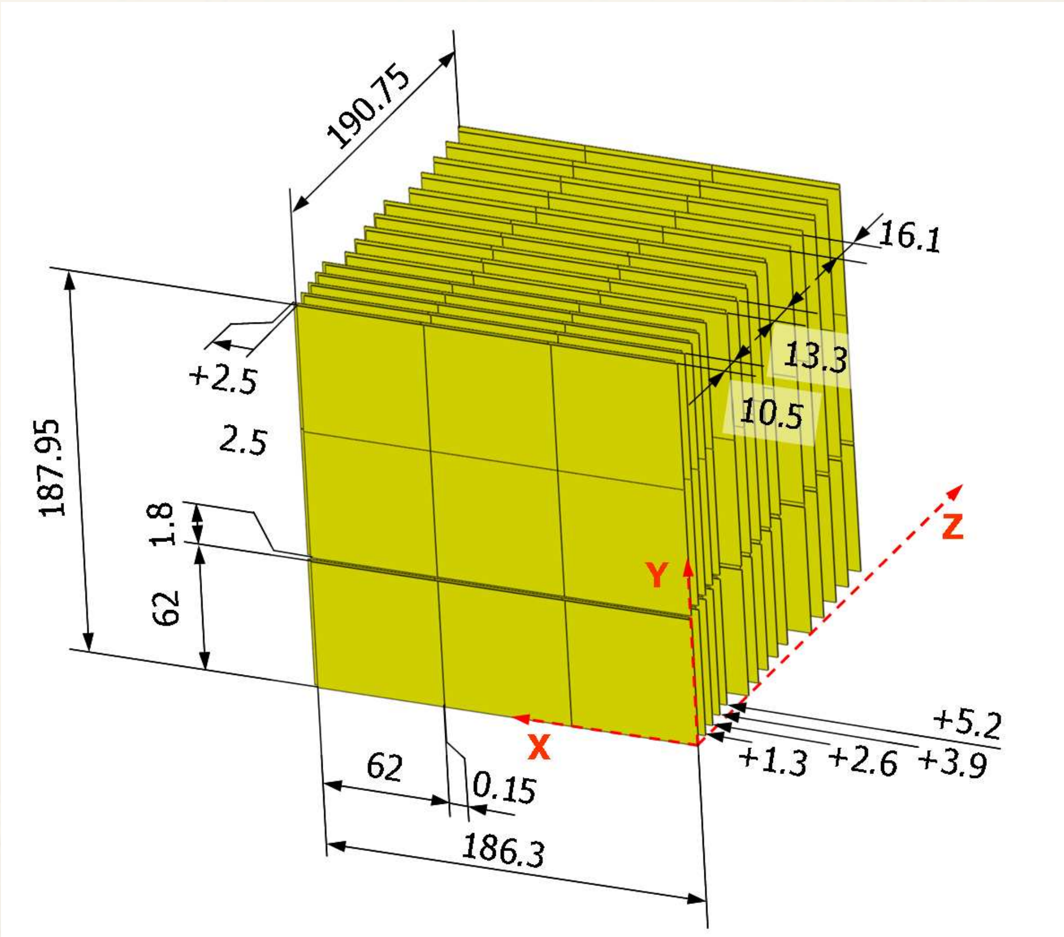
guard ring 1 mm

Silicon sensor

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

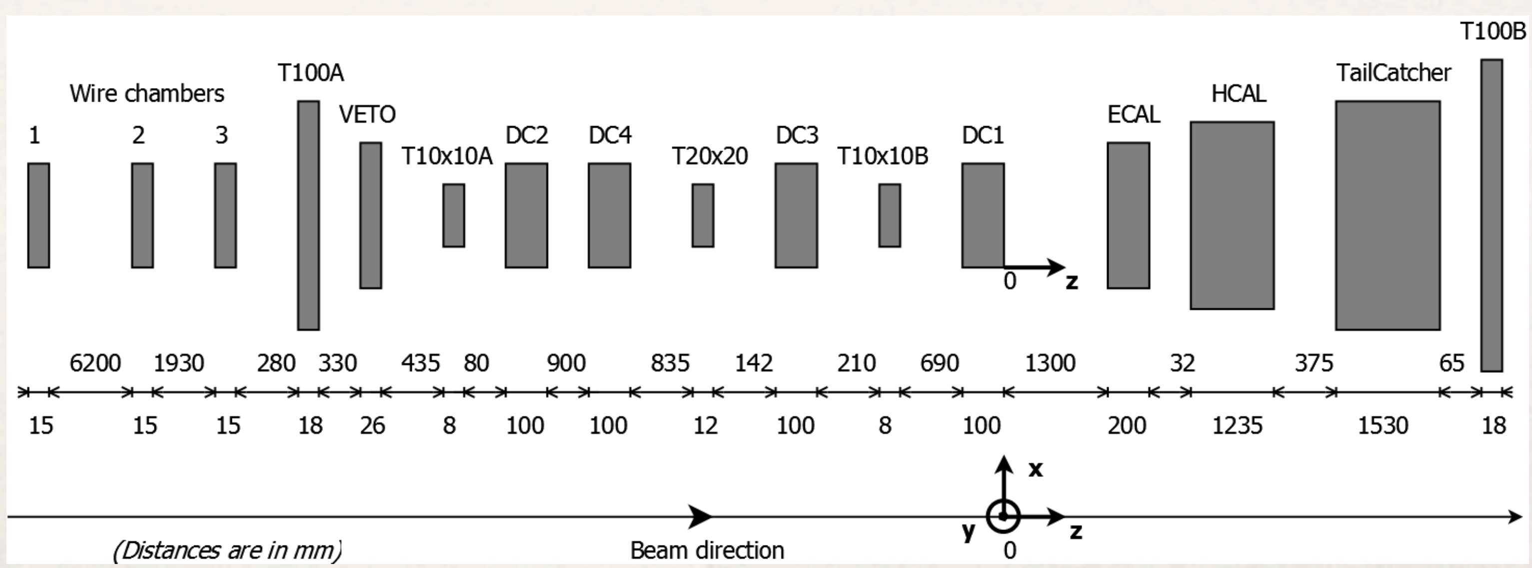
<u>Beam momentum spread:</u>

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.

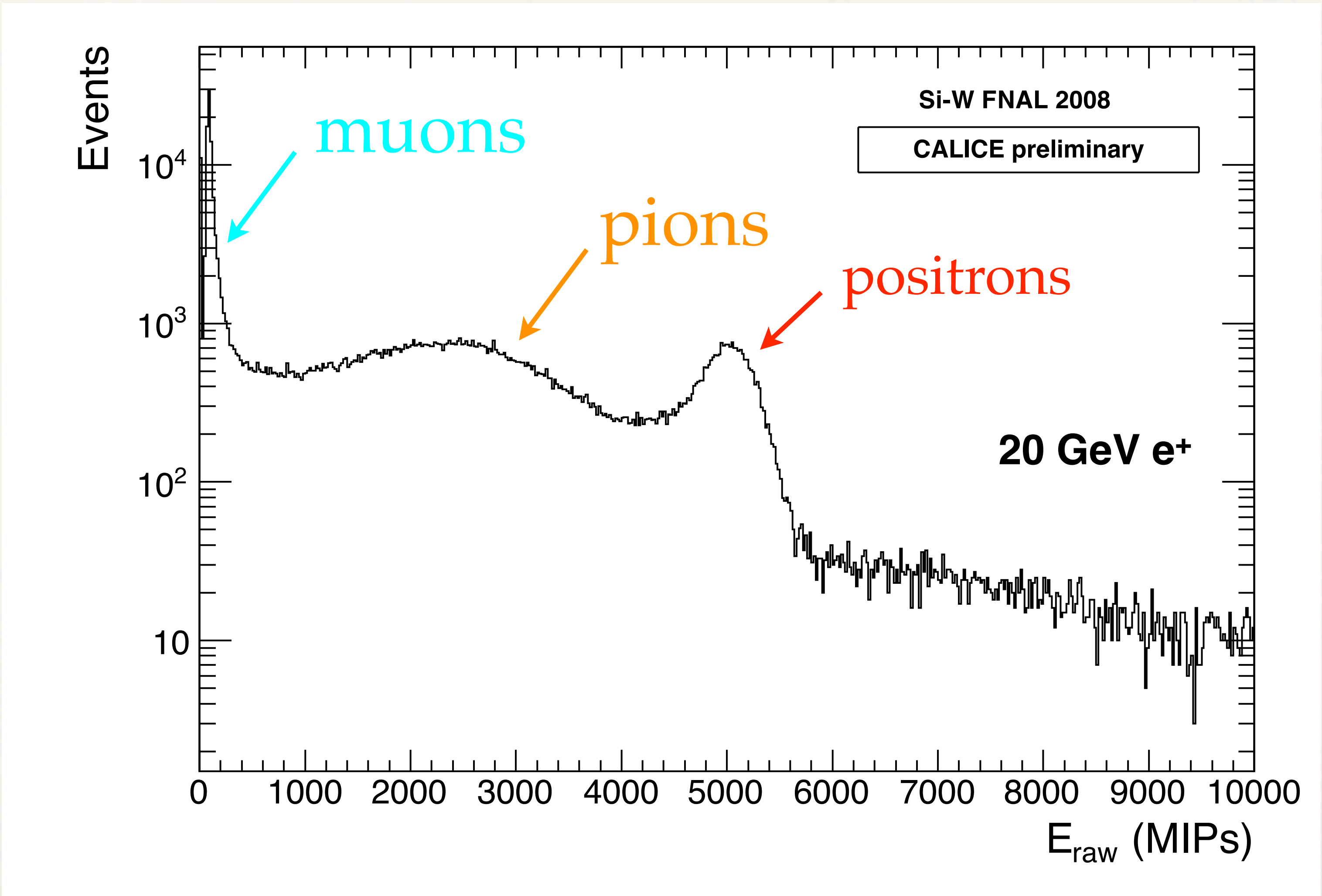


Event Selection

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.

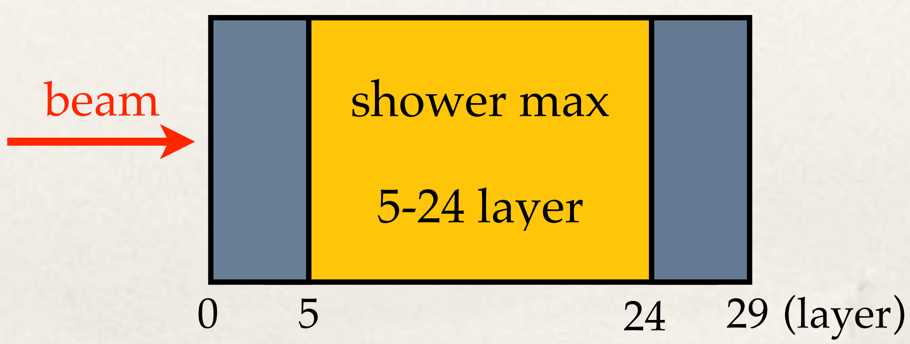
$$125 < \frac{E_{\rm raw}\,({\rm MIPs})}{E_{\rm beam}\,({\rm GeV})} < 375$$

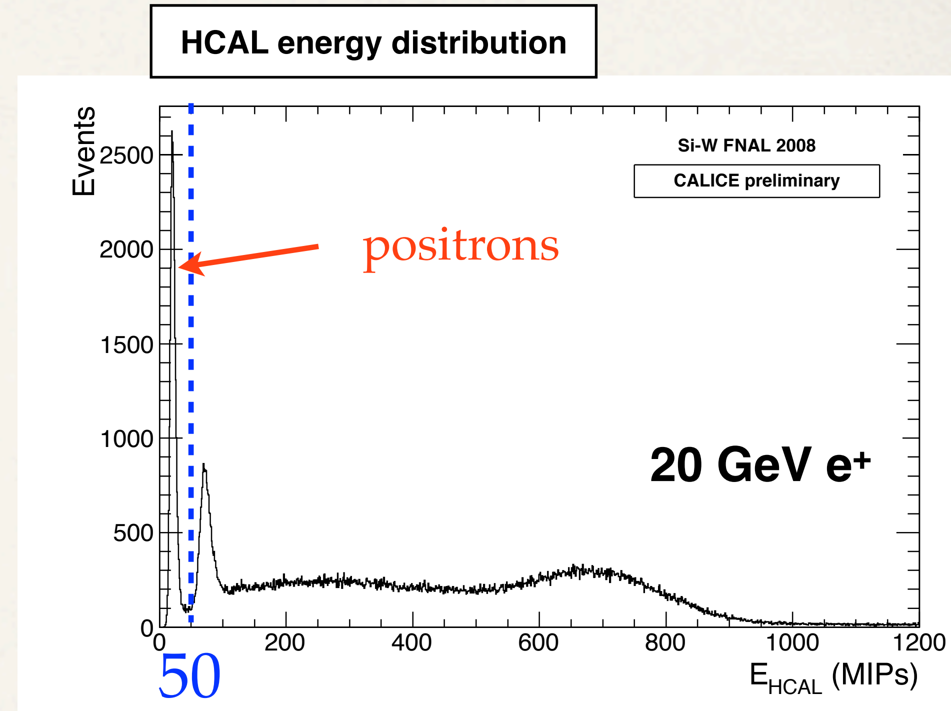
2. reject pion contamination by using HCAL information.

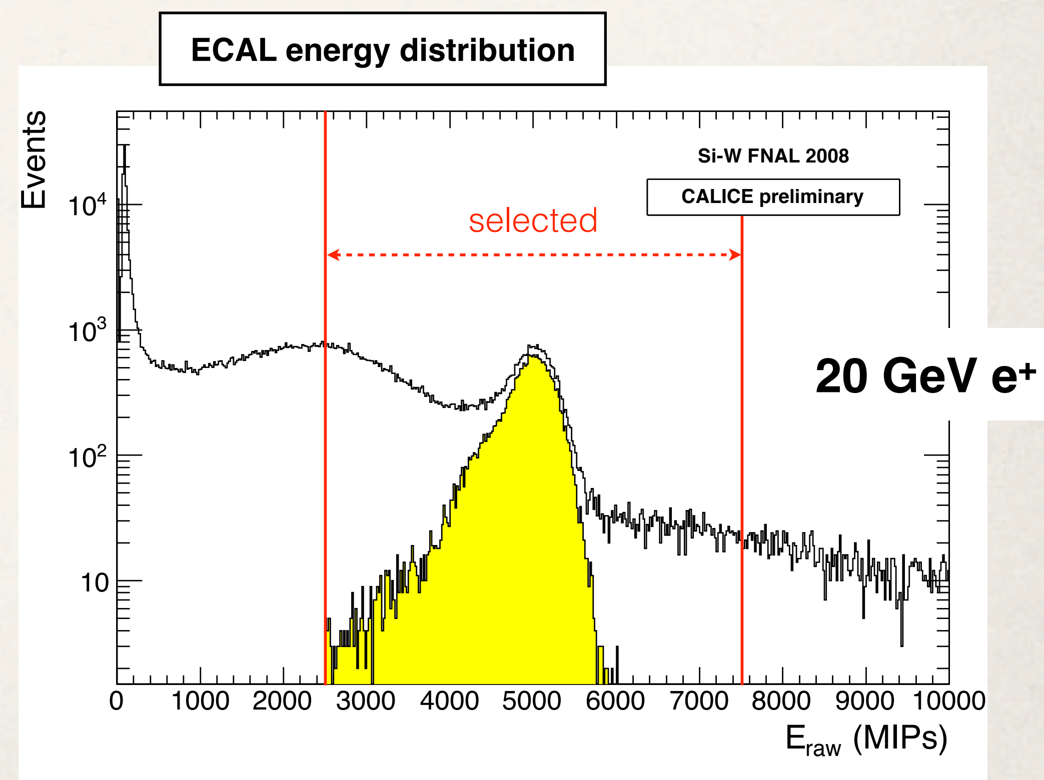
$$E_{\rm HCAL} < 50\ {\rm MIPs}$$

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

$$5 \le L_{\rm max} \le 24$$

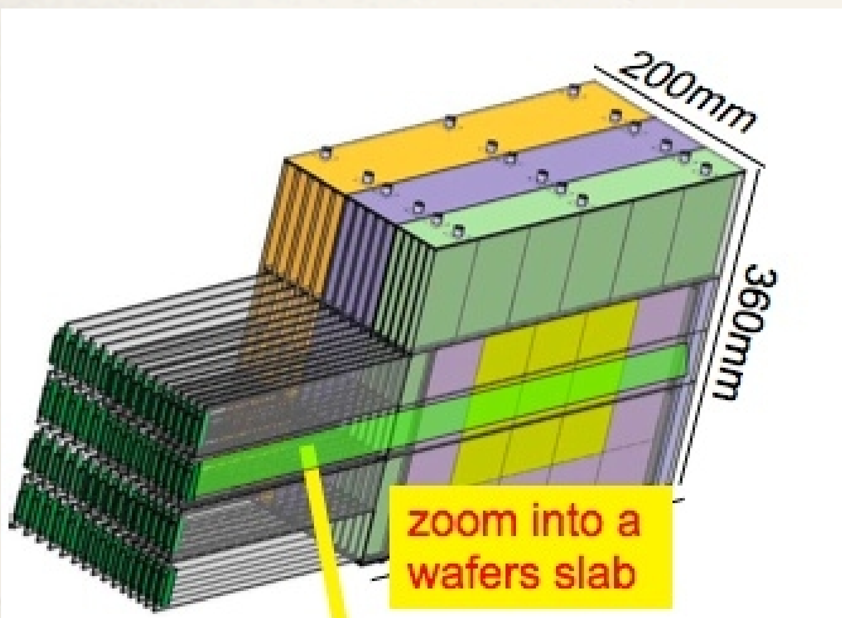


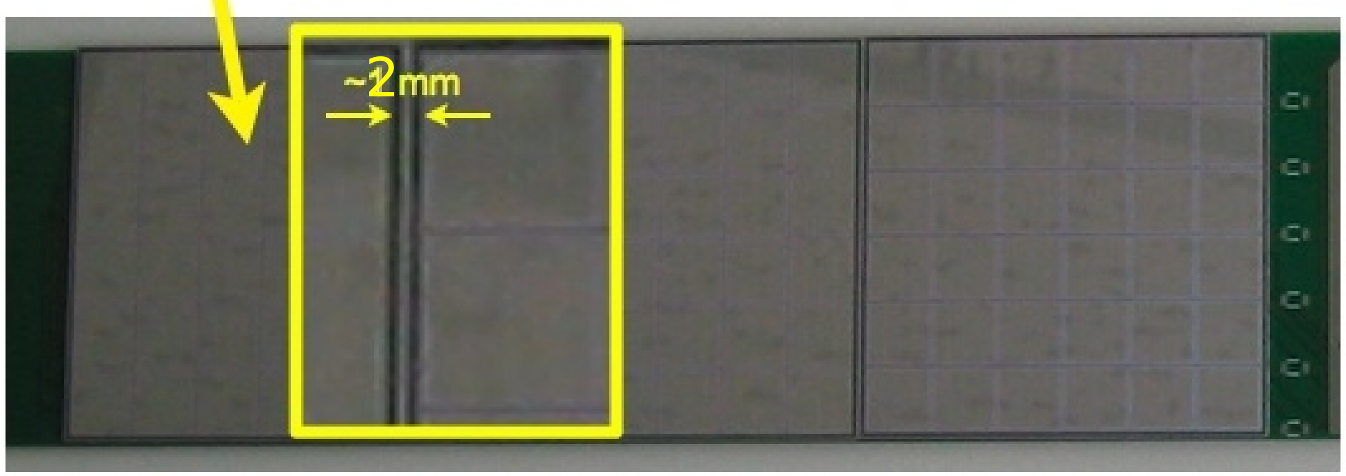


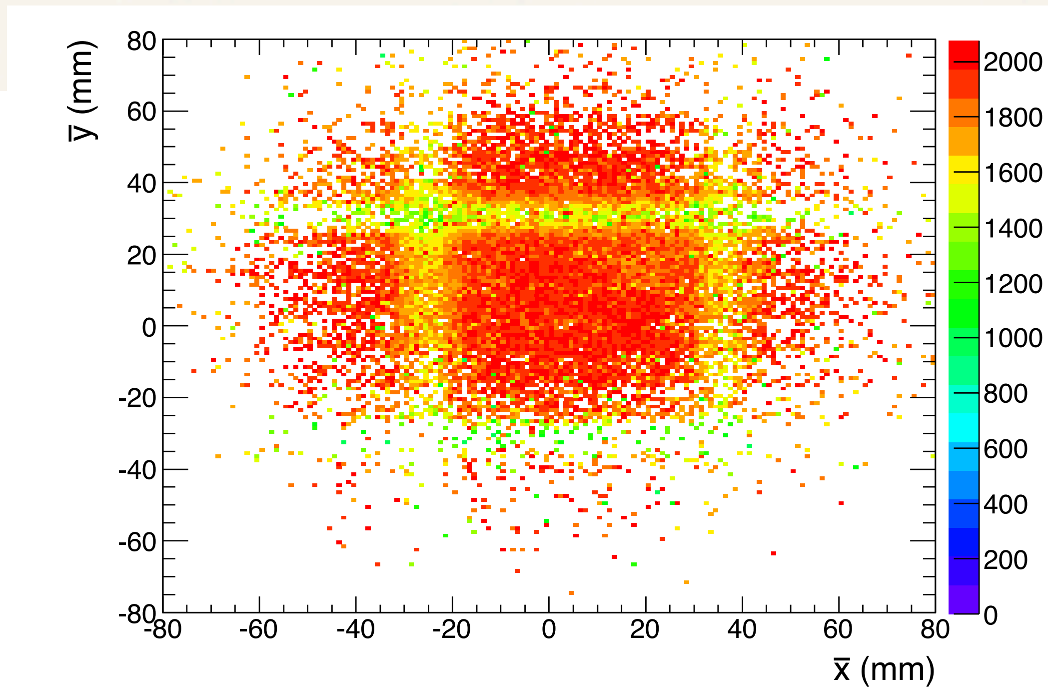


Gap Effect

- 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.)

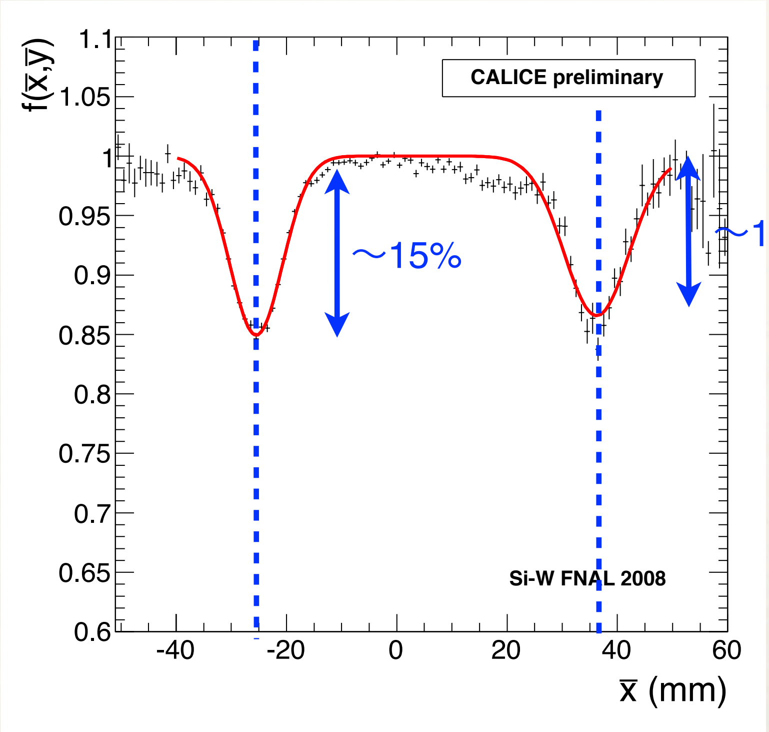
Need to take the gap effect into account in analysis

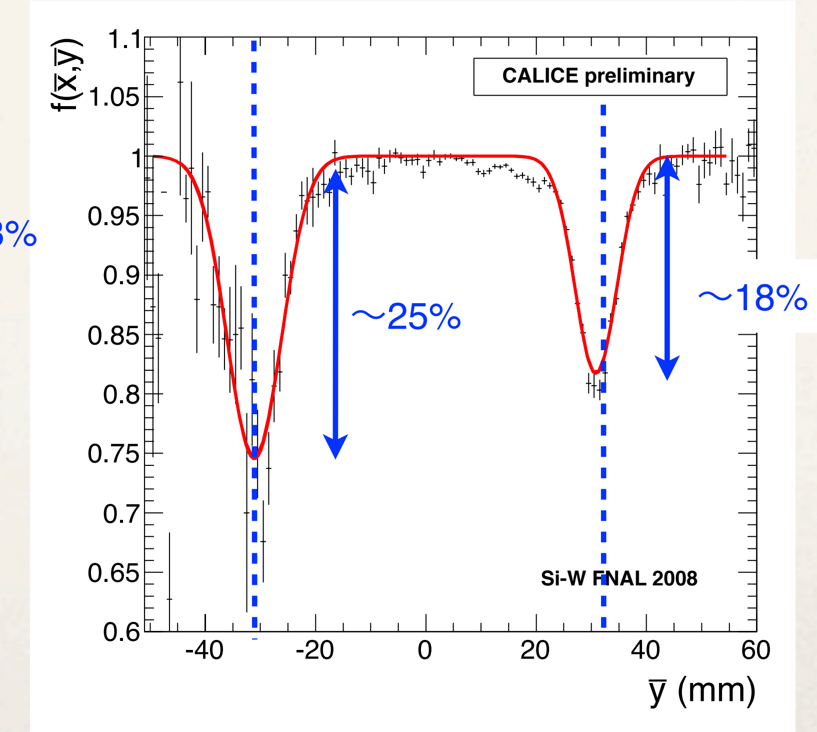
Gap Correction

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

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

- 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.

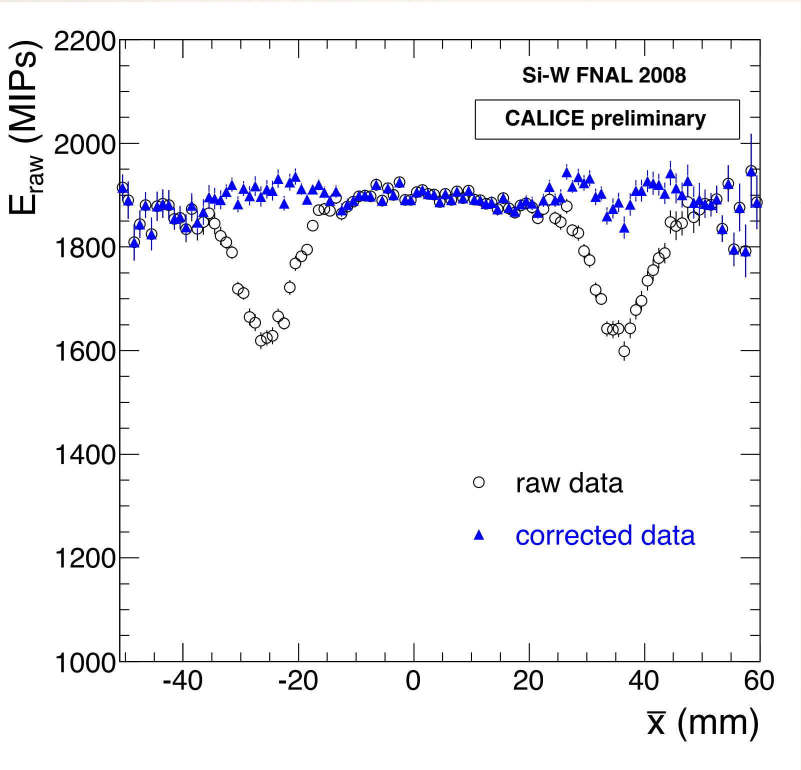


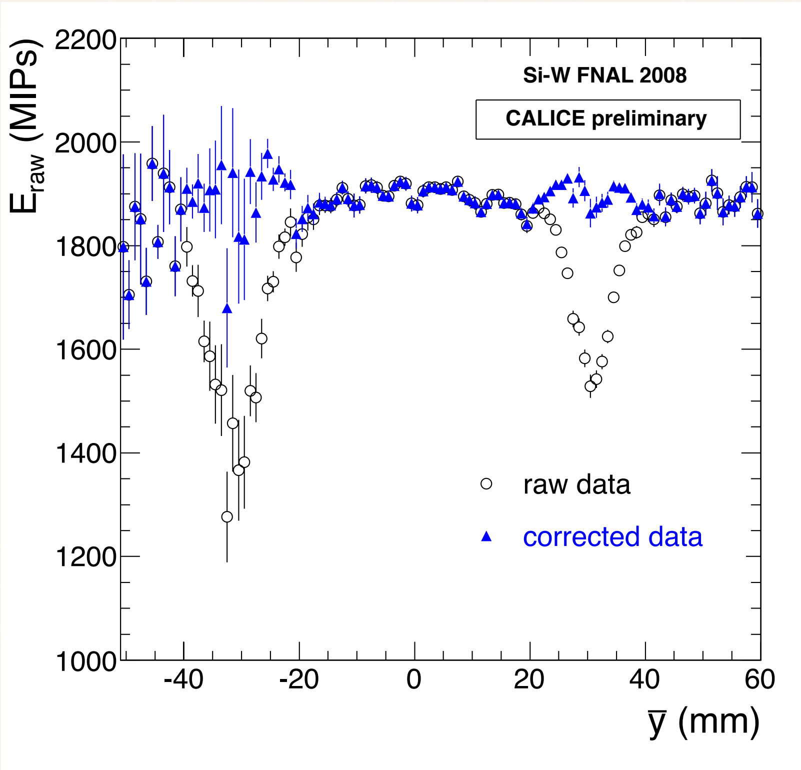


The results of the gaussian fit

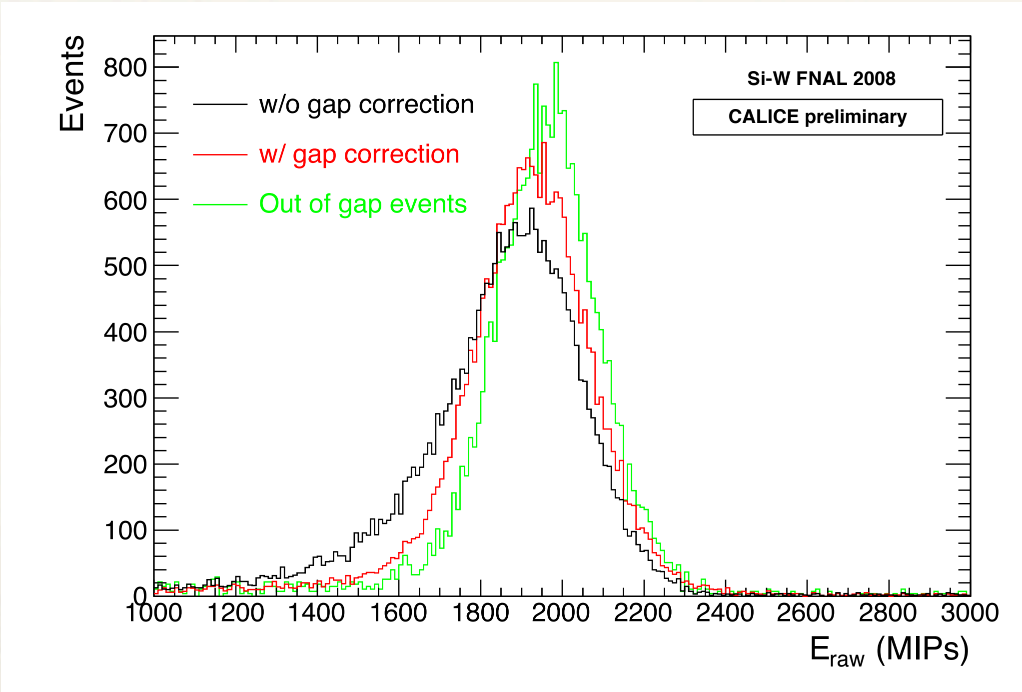
	position (mm)	σ (mm)	a
$x_{-,gap}$	-25.5	4.77	0.15
$x_{+,gap}$	36.2	5.92	0.13
$y_{-,gap}$	-31.1	4.94	0.25
$y_{+,gap}$	30.8	3.80	0.18

Gap Correction





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



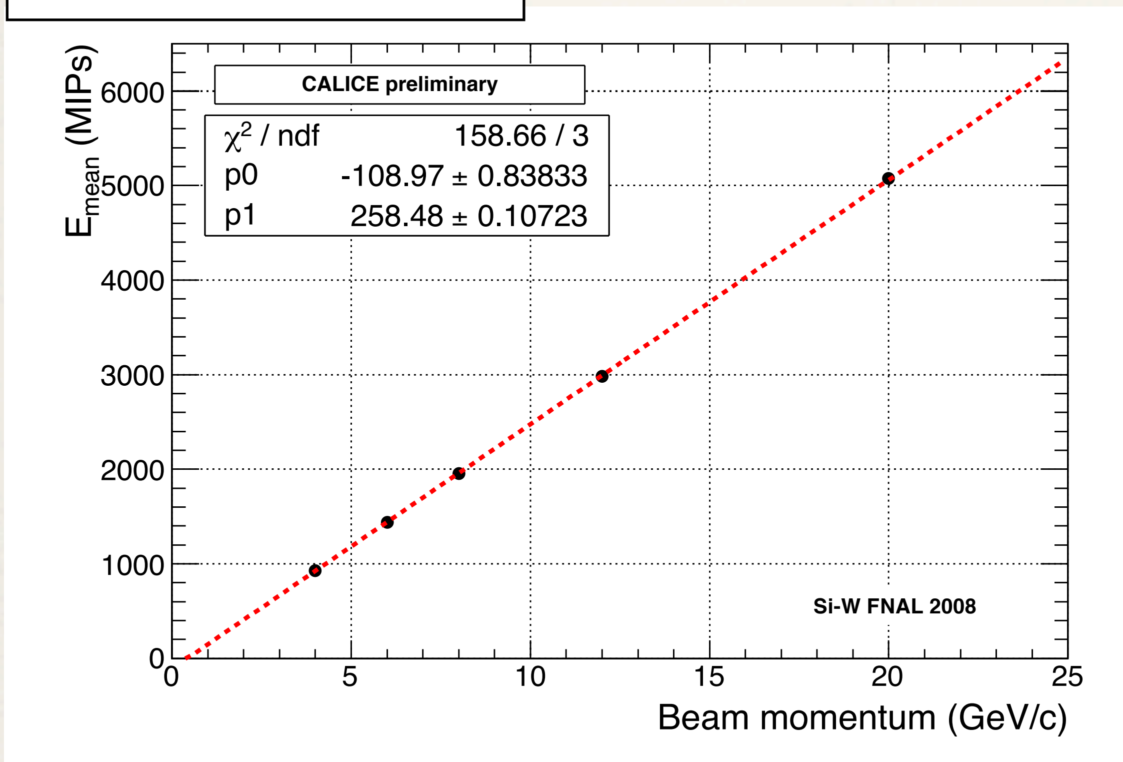
The shape of the energy distribution becomes more symmetric after gap correction.

14年3月20日木曜日

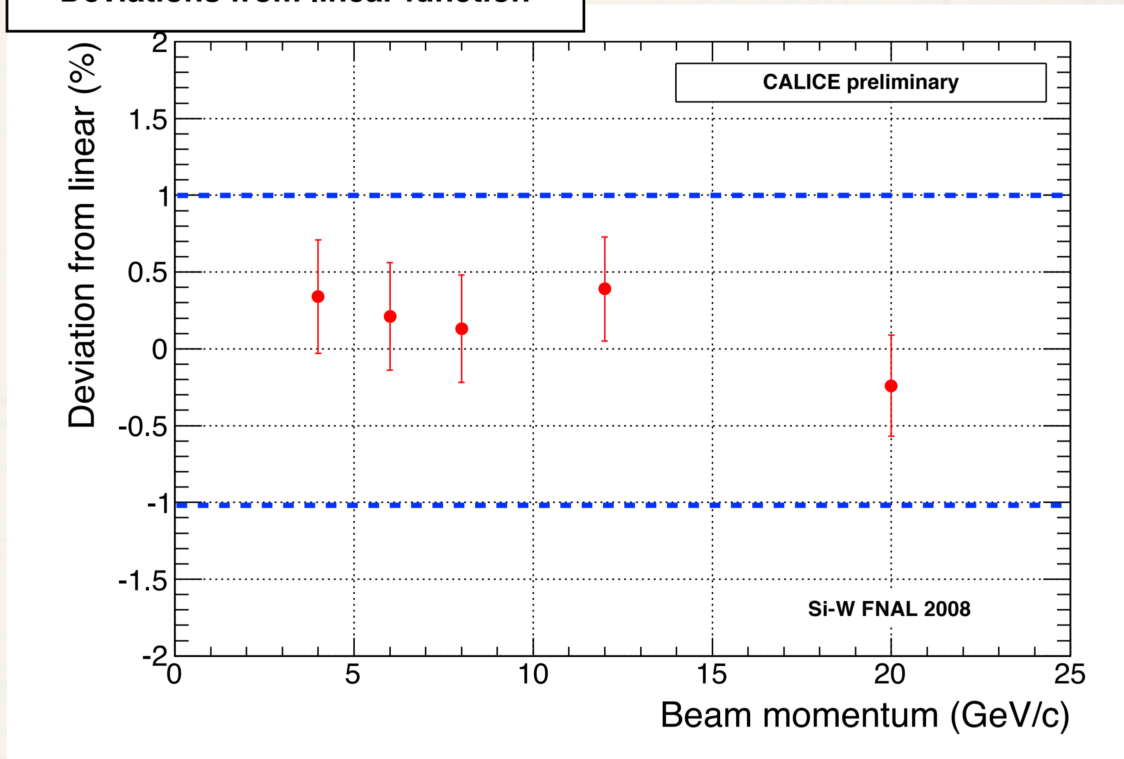
Performance (Linearity)

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

Response of the linearity



Deviations from linear function



The deviations from linear function are less than 1 %

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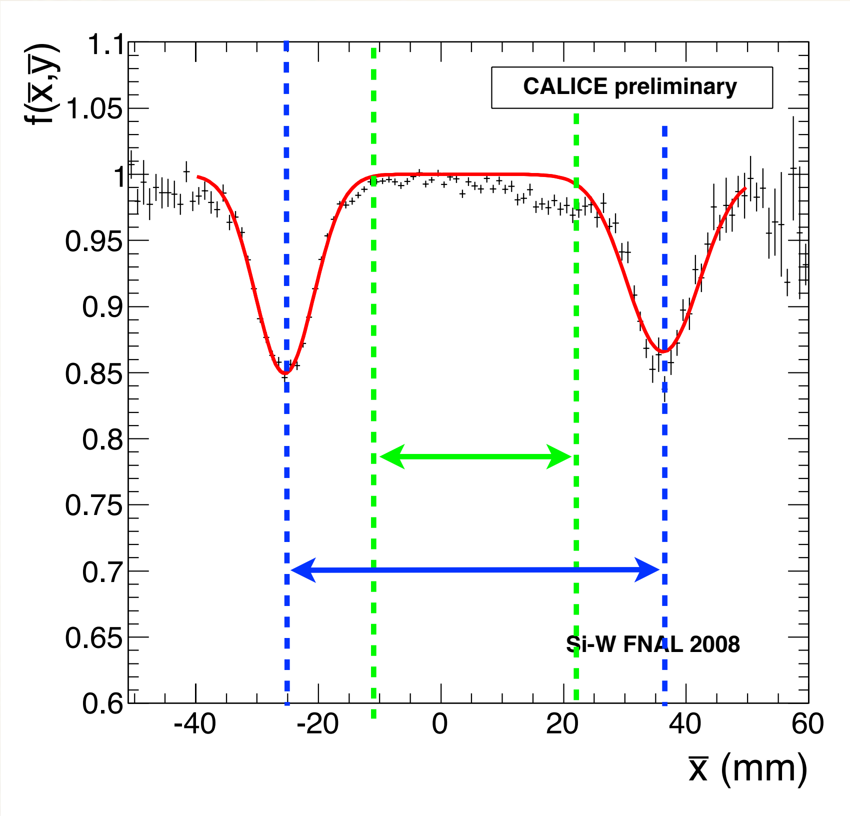
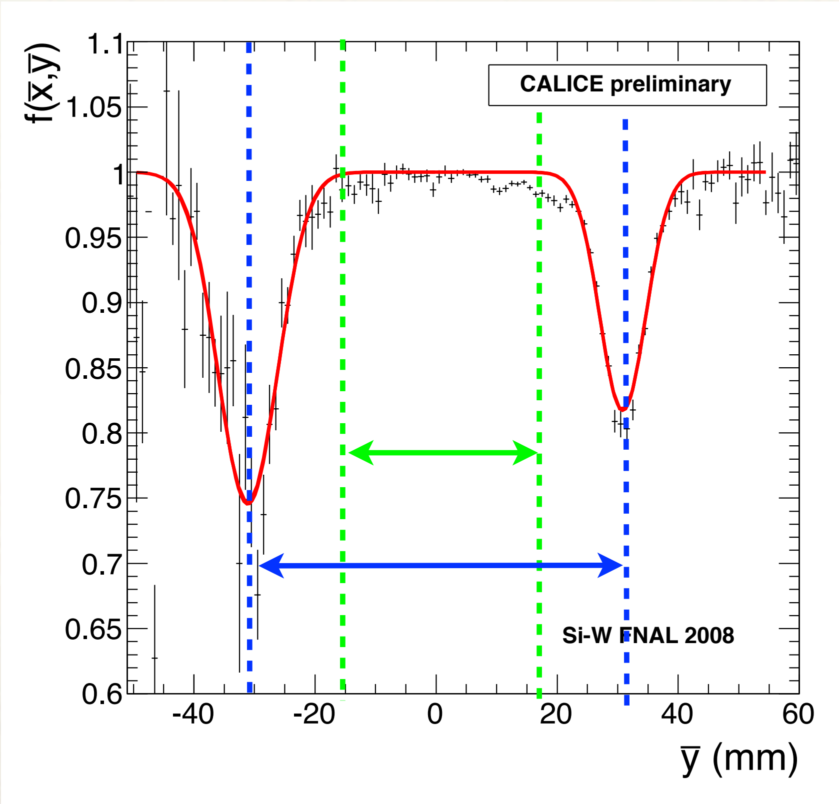
Performance (Energy resolution)

- 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



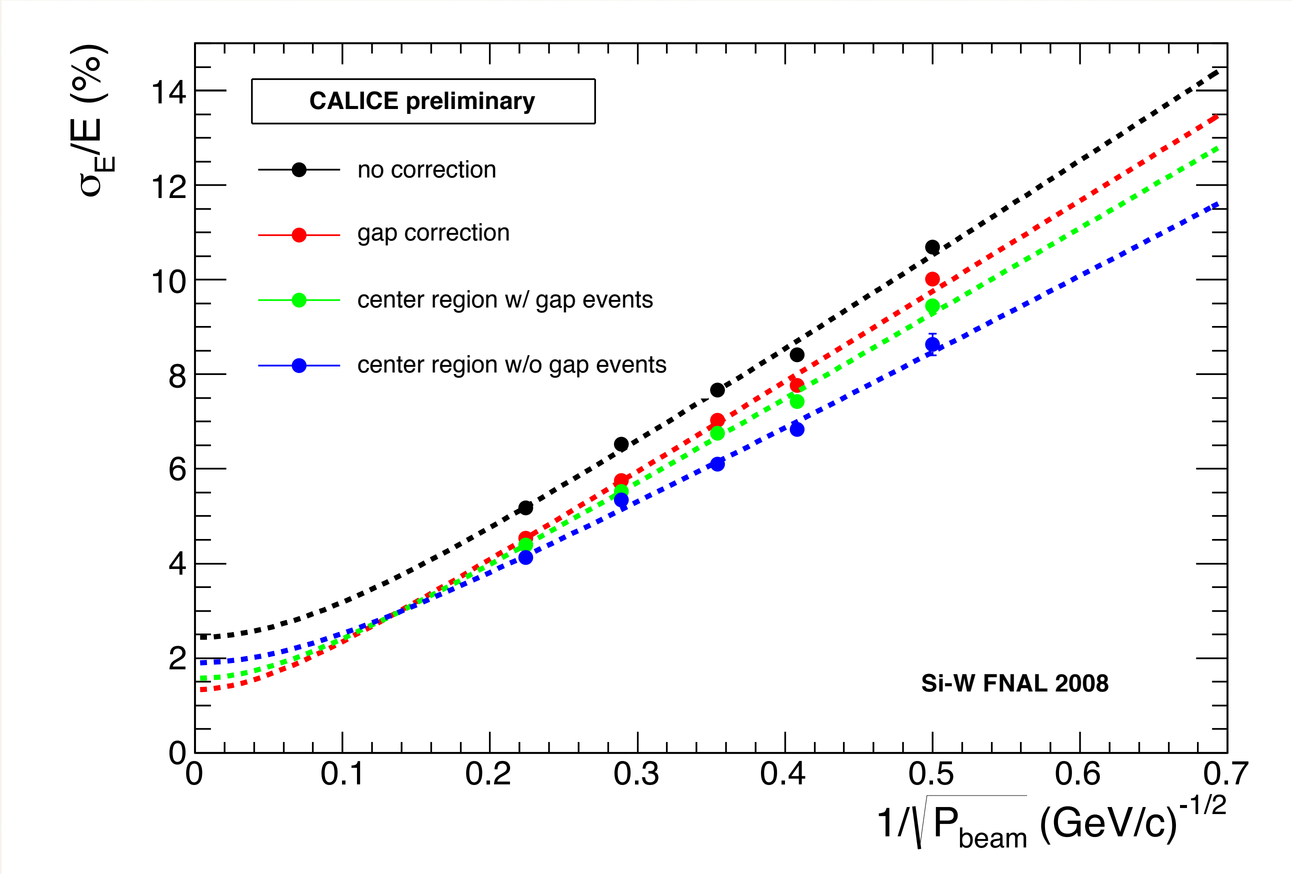


Performance (Energy resolution)

- We checked the energy resolution in four situations.

Resolution curve:

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



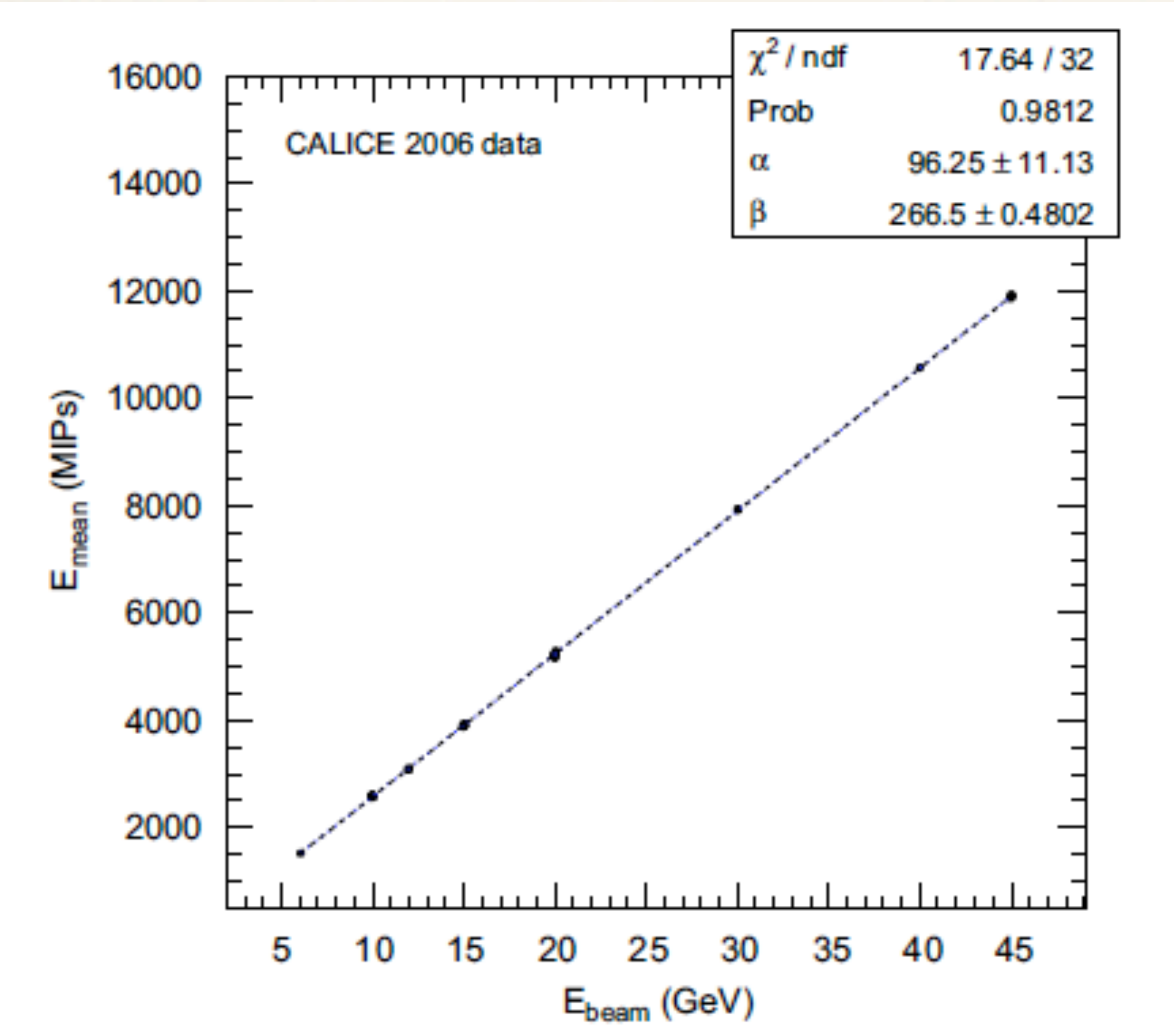
The energy resolution of the CERN data was evaluated using center region w/o gap.

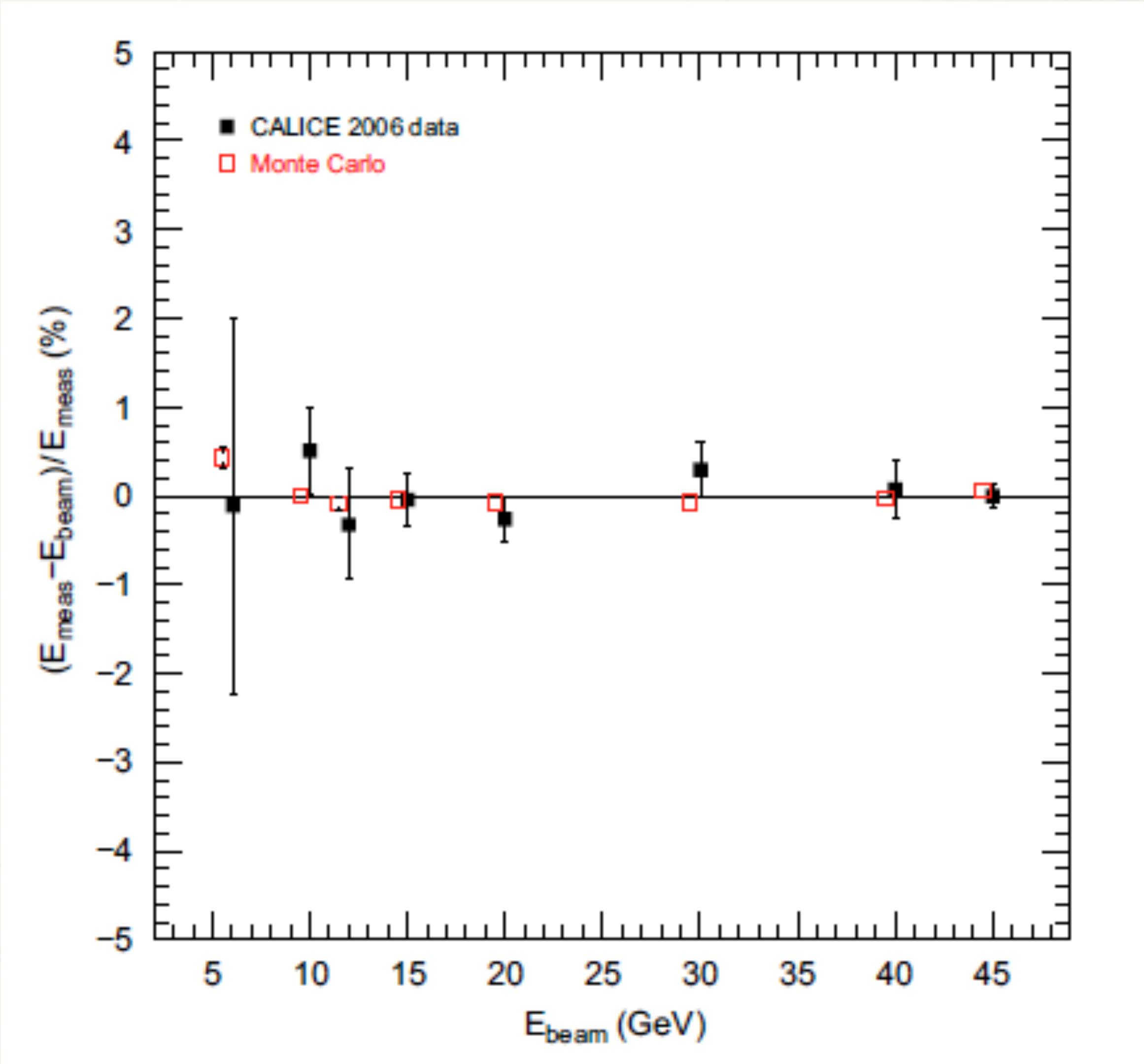
Compared with CERN data, the stochastic term is consistent.

	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%

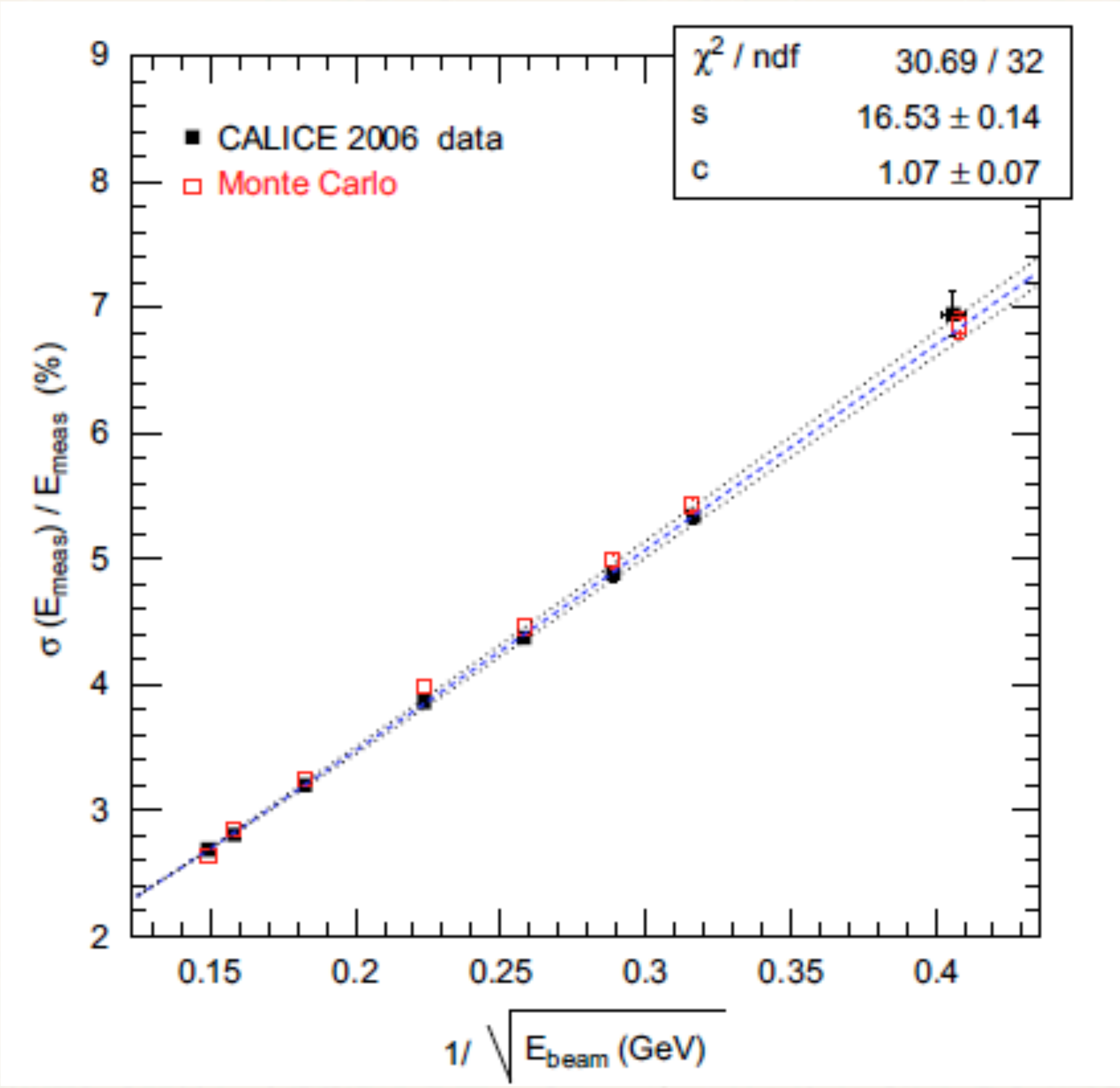
The beam momentum spread is not subtracted in the FNAL data

Linearity (CERN 2006)





Energy resolution (CERN 2006)



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