16th September 2016

Summary of EM response of ScECAL at FNAL-TB

CALICE meeting at Arlington Texas

K. Kotera, Shinshu University/DESY

In last meeting at Santander

in our draft

Explained major 5 updates according to the CALICE editorial board: F. Simon, N. Watson, L. Xia,

1) brief explanation for the calibration,
2) Cut value of Inter calibration,
3) explanation for systematic uncertainties from cuts,
4) wave structure of deviation from liner,
5) realistic simulation.

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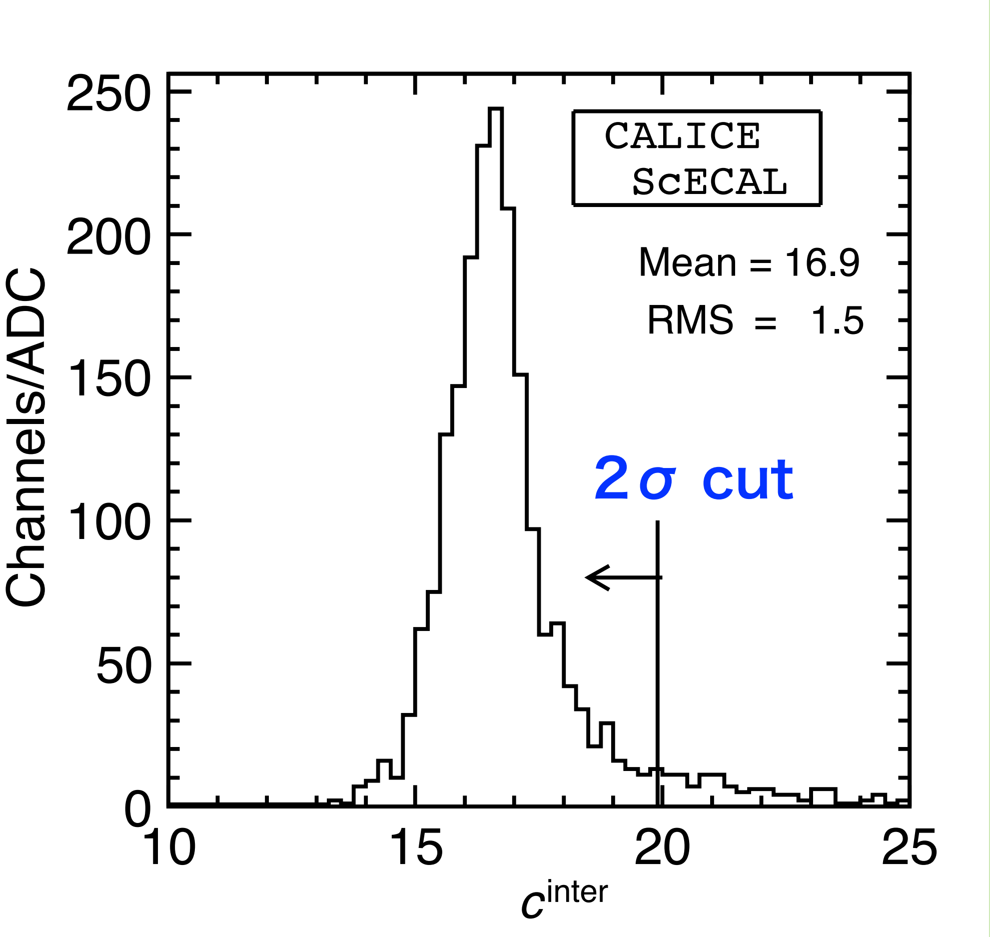
cut	effect on σE(%)
1σ	< 0.01
2σ	reference
3σ	< 0.01
no cut	< 0.1

Distribution of Inter-calibration constant $C^{inter} = \langle ADCs\rangle^{high}/\langle ADCs\rangle^{low}$

1, 2, 3σ cut:
no change
results<0.01

no cut:
resolution
<0.1% (rel)
systematic



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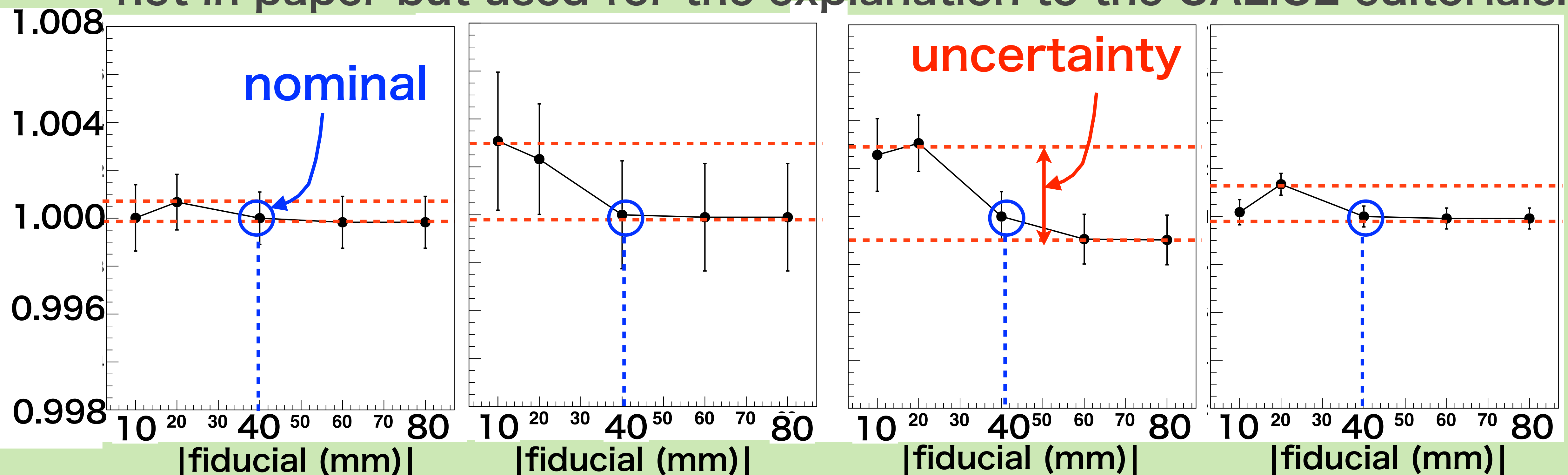
5

not in paper but used for the explanation to the CALICE editorials.



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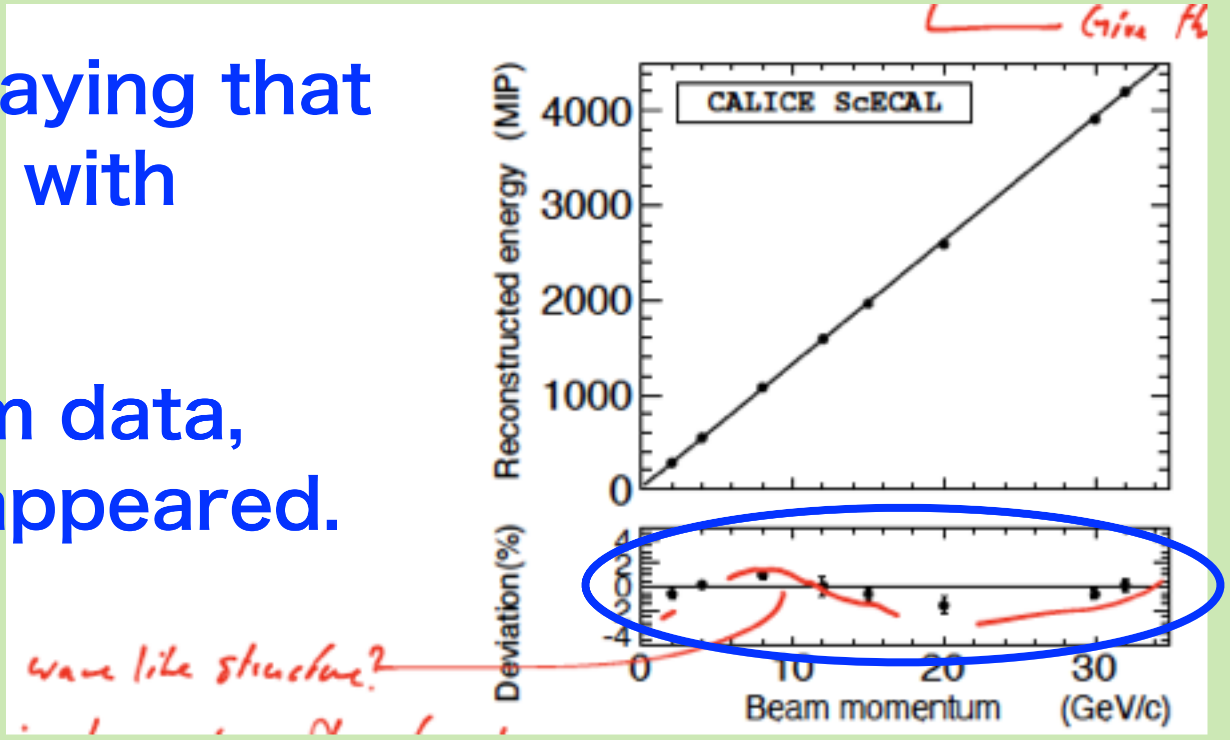
We found a mail from MT6 saying that three 20GeV runs were taken with different beam condition.

We removed those runs from data, then the wave structure disappeared.



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Lateral profile is added

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There is no essential change from Santander

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Lateral profile is added

There is no essential change from Santander.

Instead:
I will summarize our paper... we will circulate.

Title and contents

Construction and Electromagnetic Response of a Highly Granular Scintillator-based Electromagnetic Calorimeter

1. **Introduction**
2. **The ScECAL prototype**

   Explanation of;

   1) dimensions, structure, material, devices, and DAQ,

   2) Calibration procedure,

   3) MPPC properties and saturation correction

3. **Test beam at FNAL**

   Setup, temperature variations, and information of runs

4. **Analysis: Reconstruction**

   Determinations of calibration factor(constant)s

   Reconstruction of electron events ➡ mean, resolution

Title and contents, cond.

5. Results: Performance of the prototype

Results as performance on the energy measurement

1) Linearity

2) Resolution

6. Comparison with Monte Carlo simulation

Naive simulation ➡ realistic (Thanks O. Hartbrich) :

photon statistics, SiPM saturation, position variation from data, BG,

Output has the same structure as data ➡ the same analysis package.

Comparisons

Shower profile; longitudinal, transverse

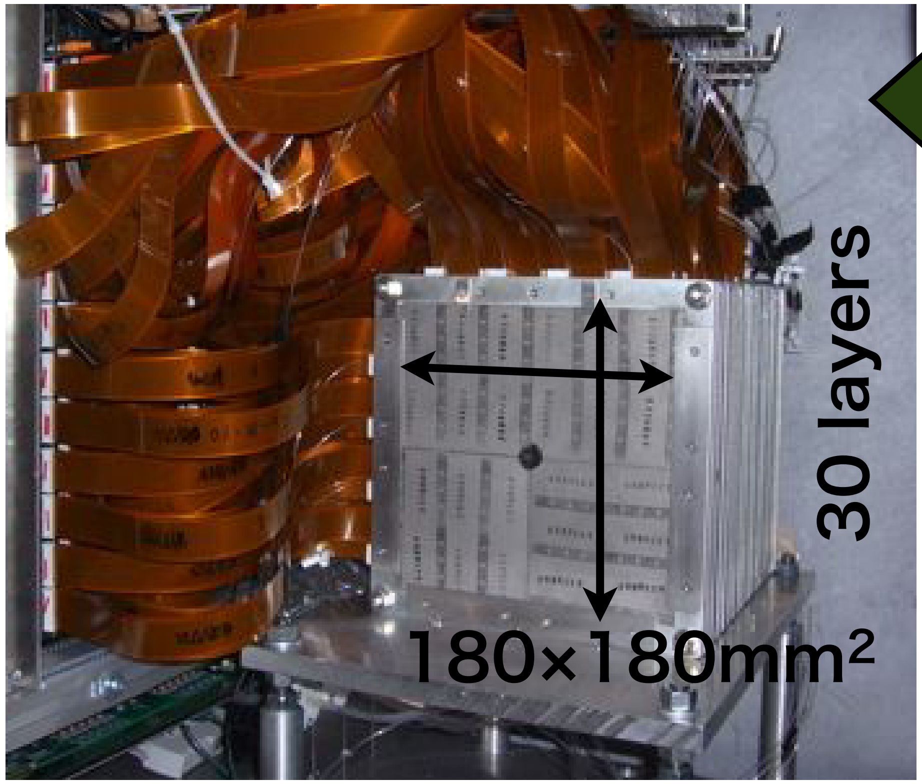
Linearity, resolution

7. Discussion, 8 Summary

Number of Figures = 29, Number of tables = 7.

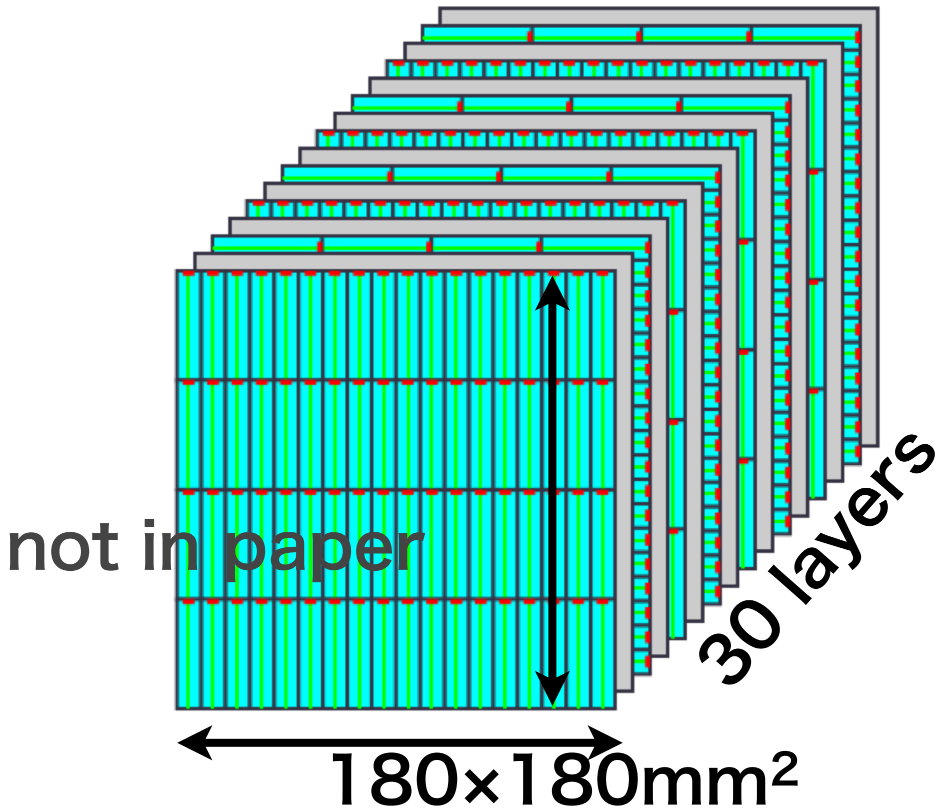
ScECAL Physics Prototype

ScECAL Physics Prototype



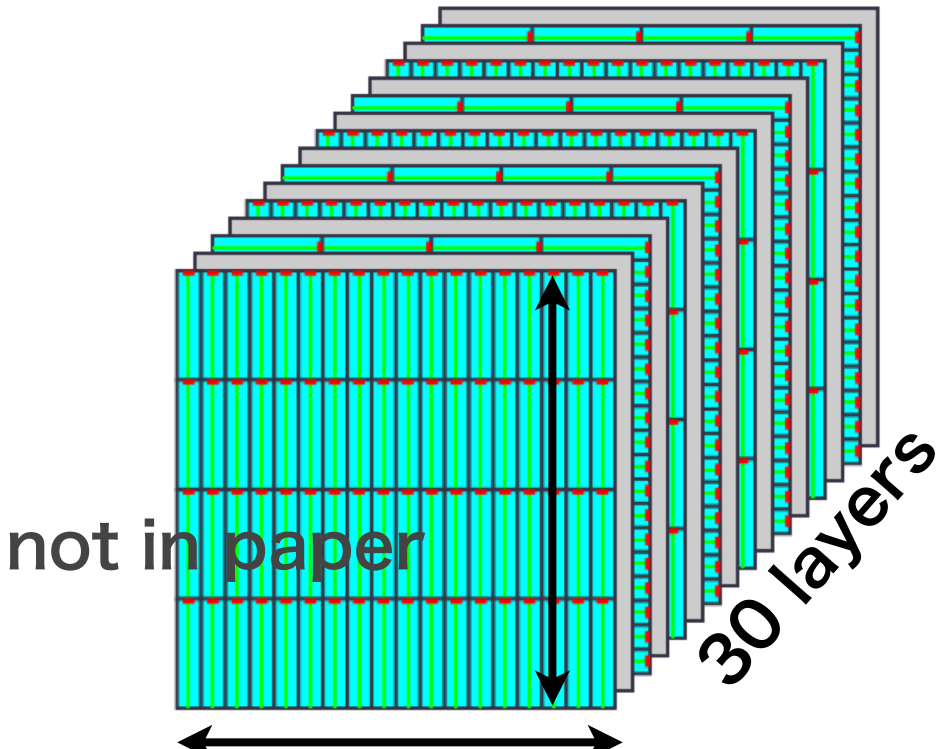
AHCAL front face

Dimensions



- 3.5mm tungsten-C* abs.

Dimensions



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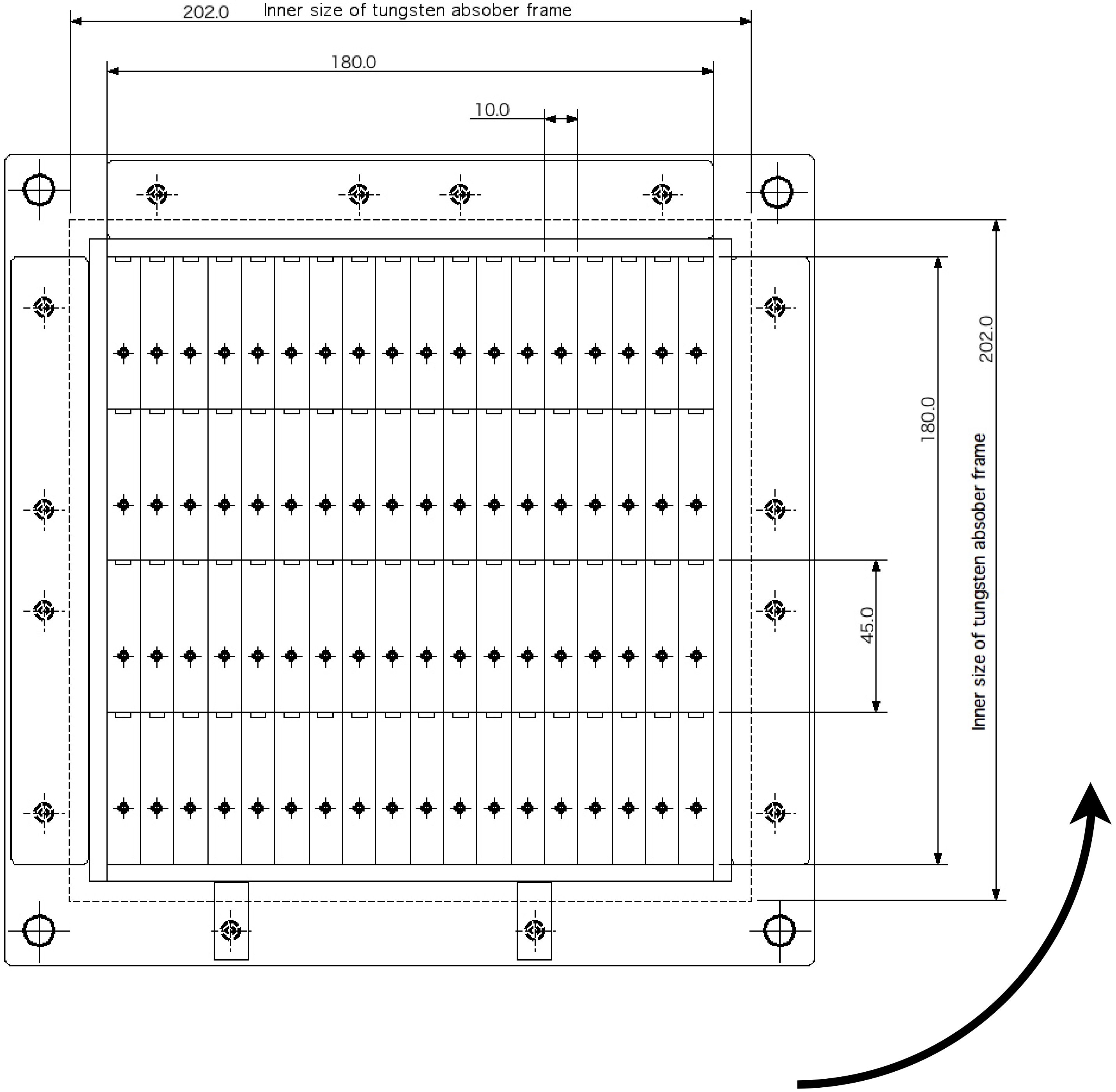
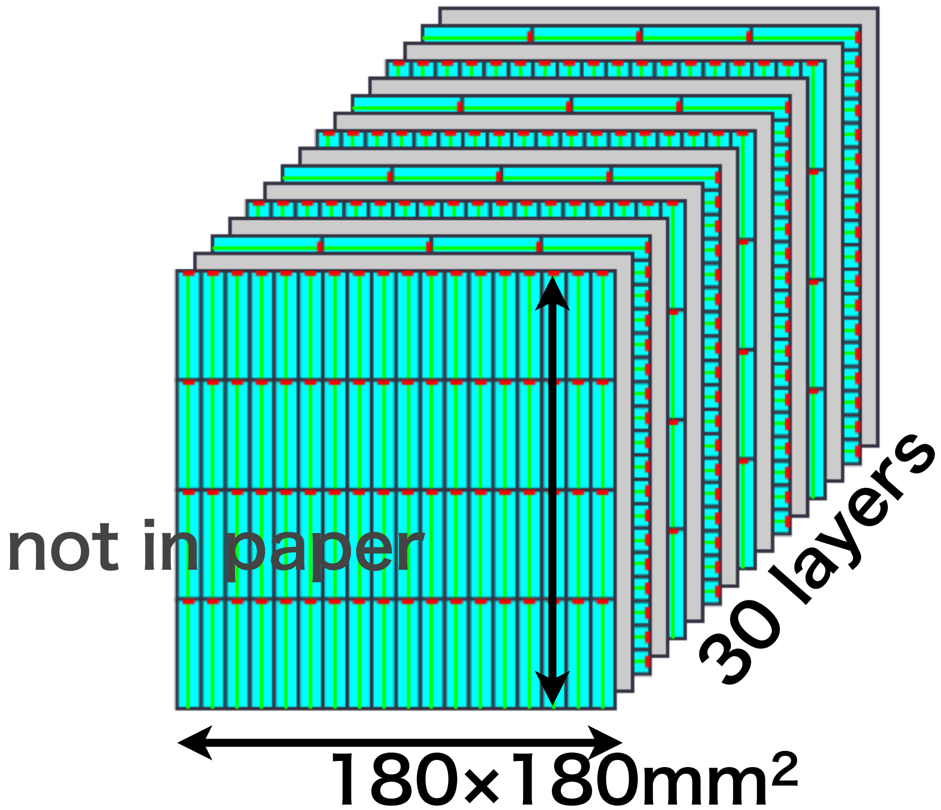


rotate 90° w.r.t. previous layer

Dimensions



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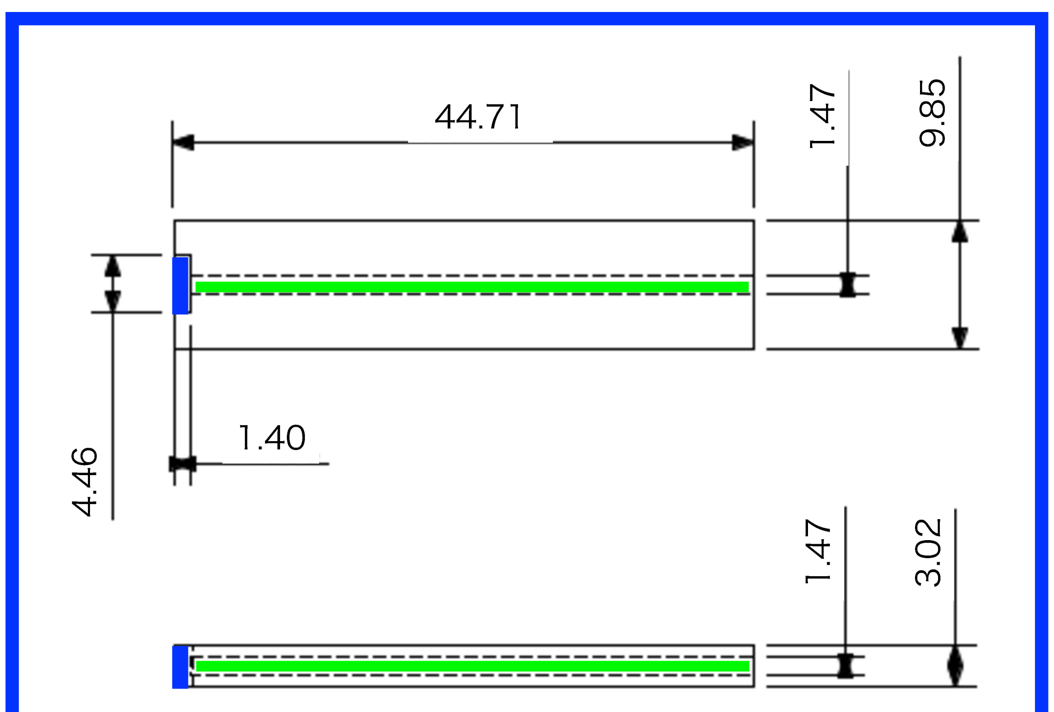
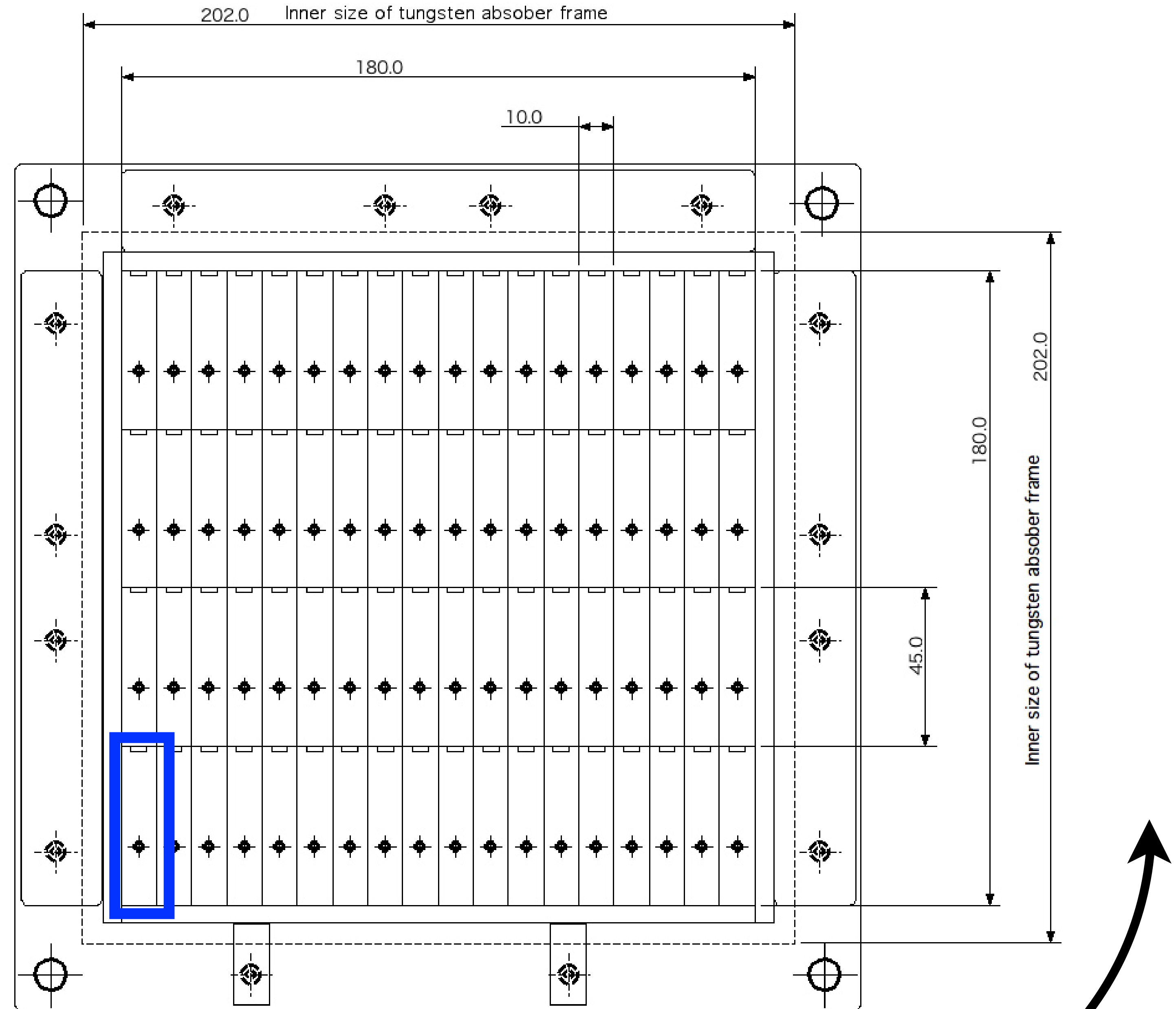
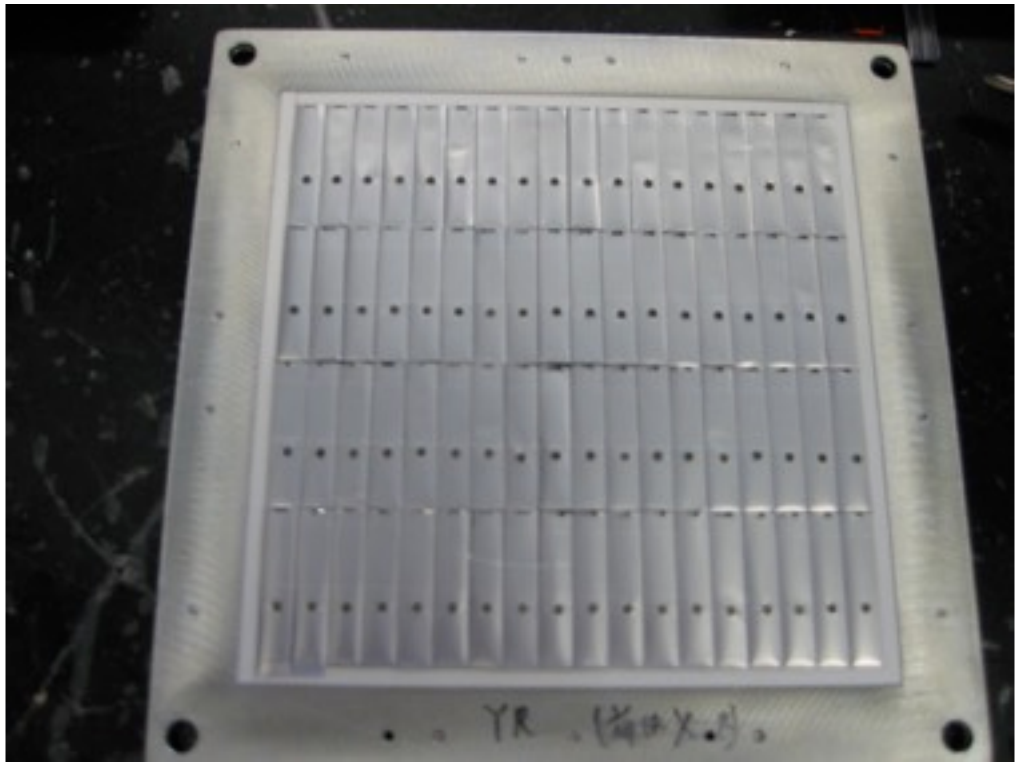


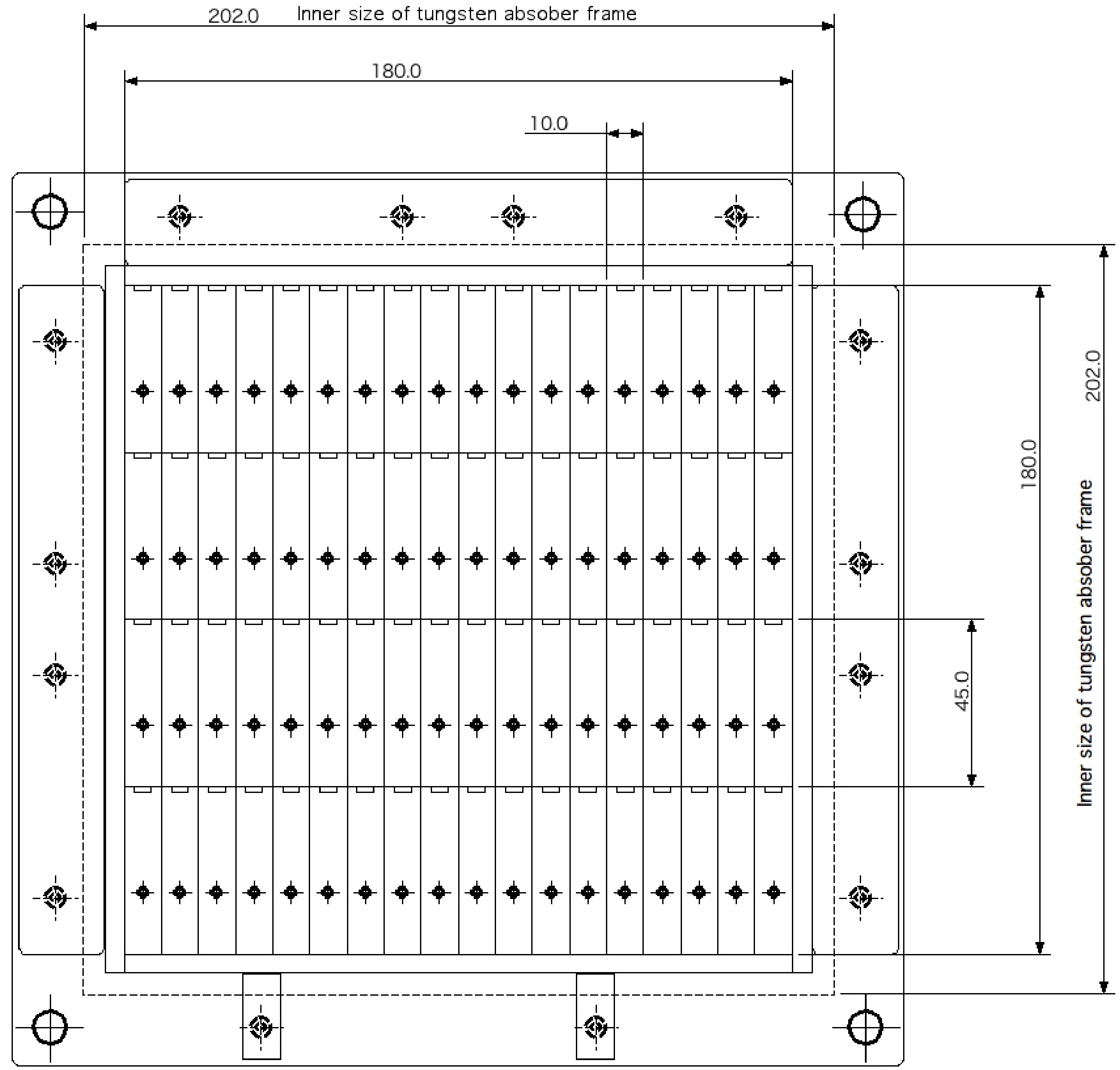


rotate 90° w.r.t. previous layer

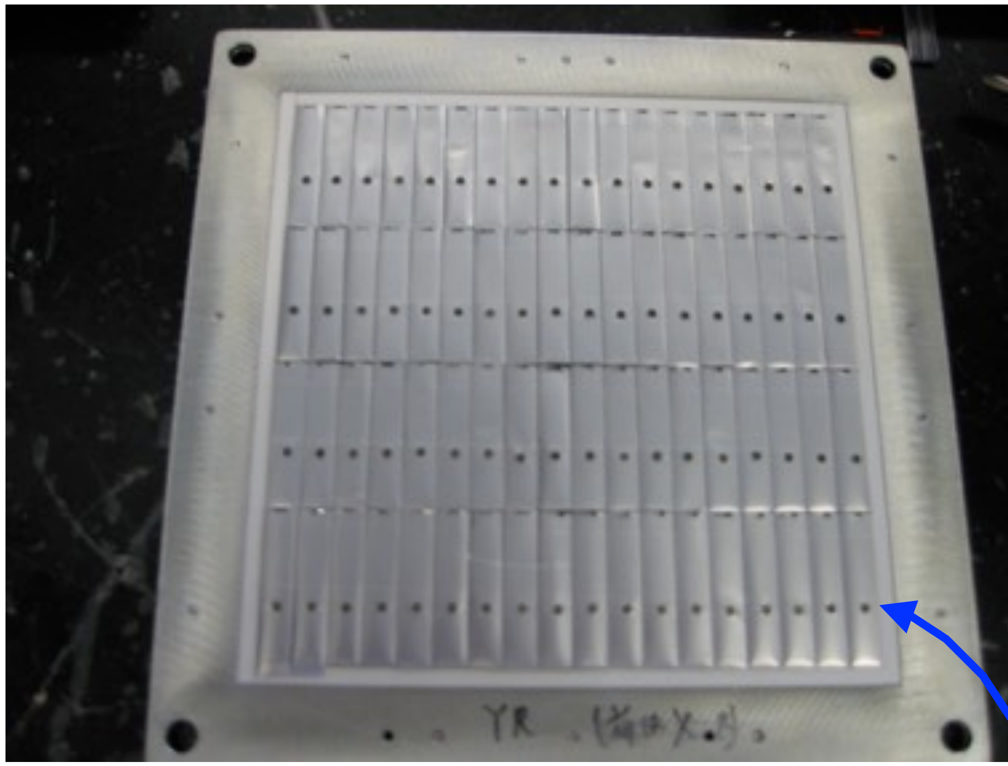
Reflector



2500 strips were wrapped in reflector film.



Holes for LED monitor



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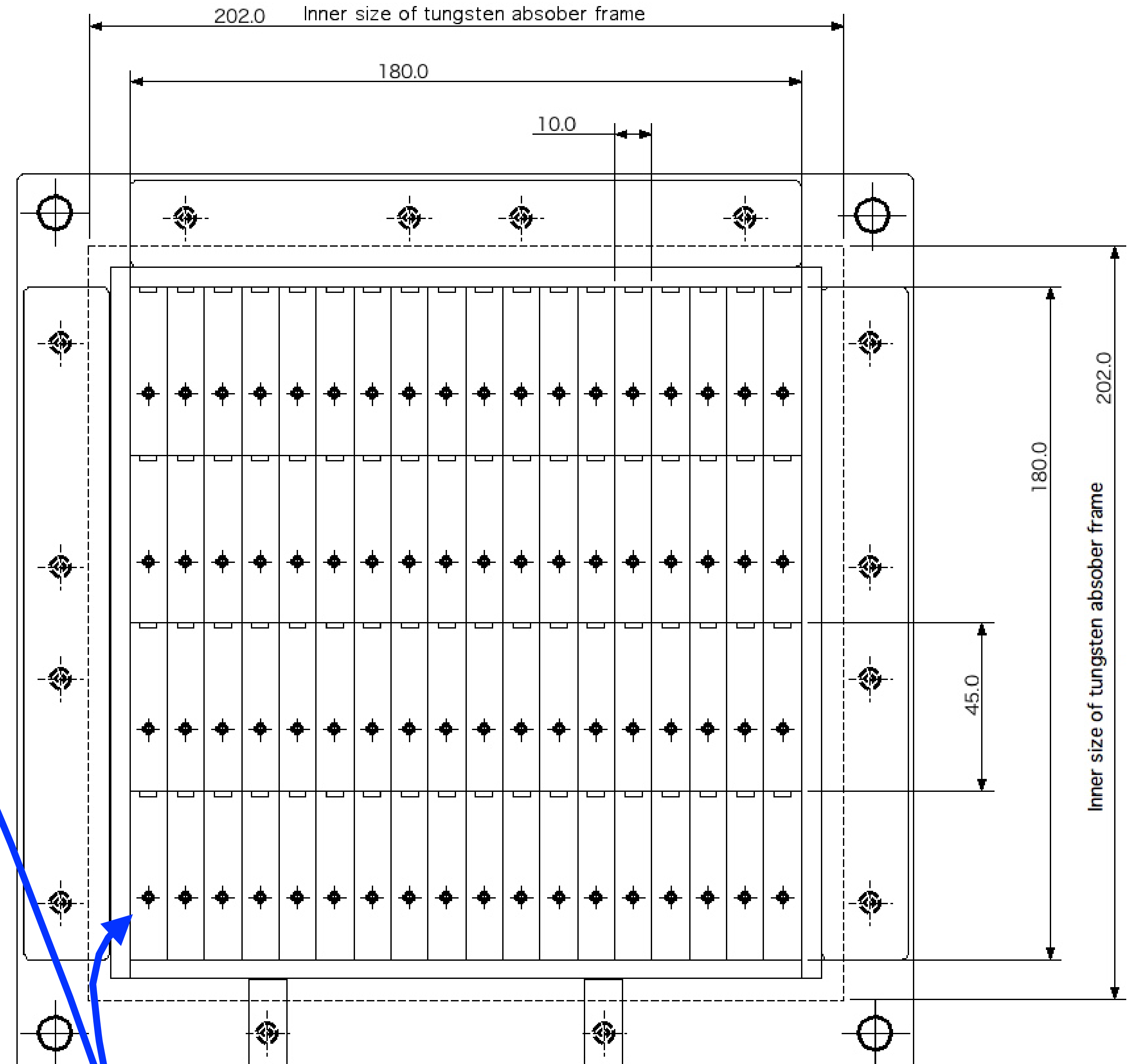
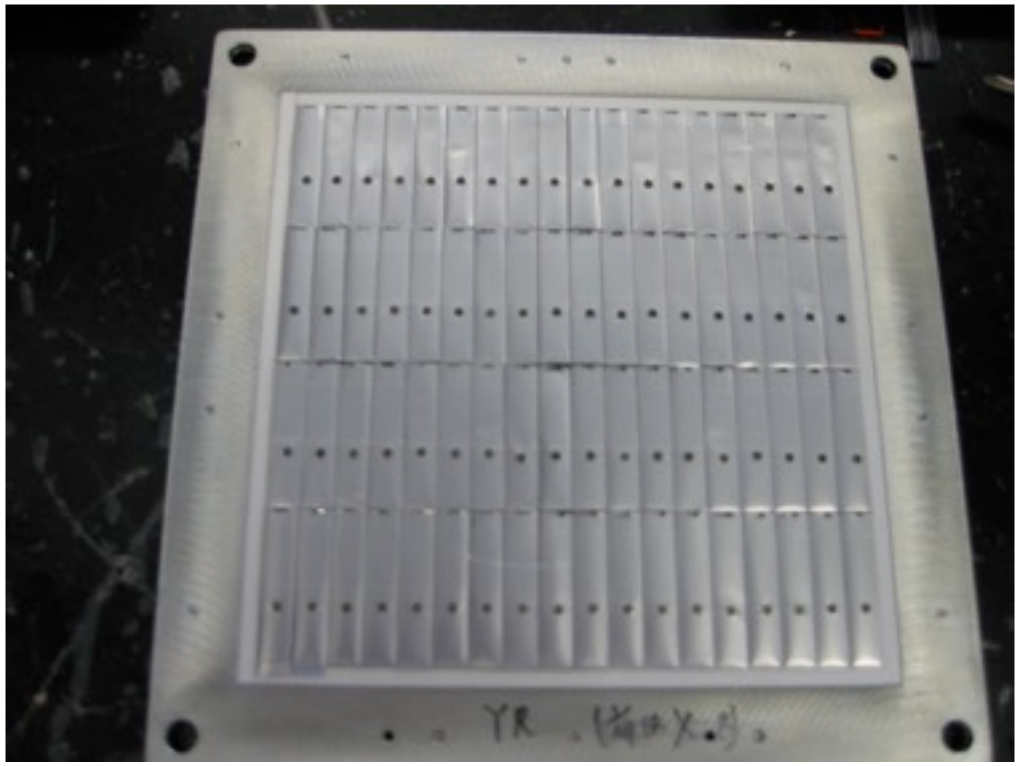
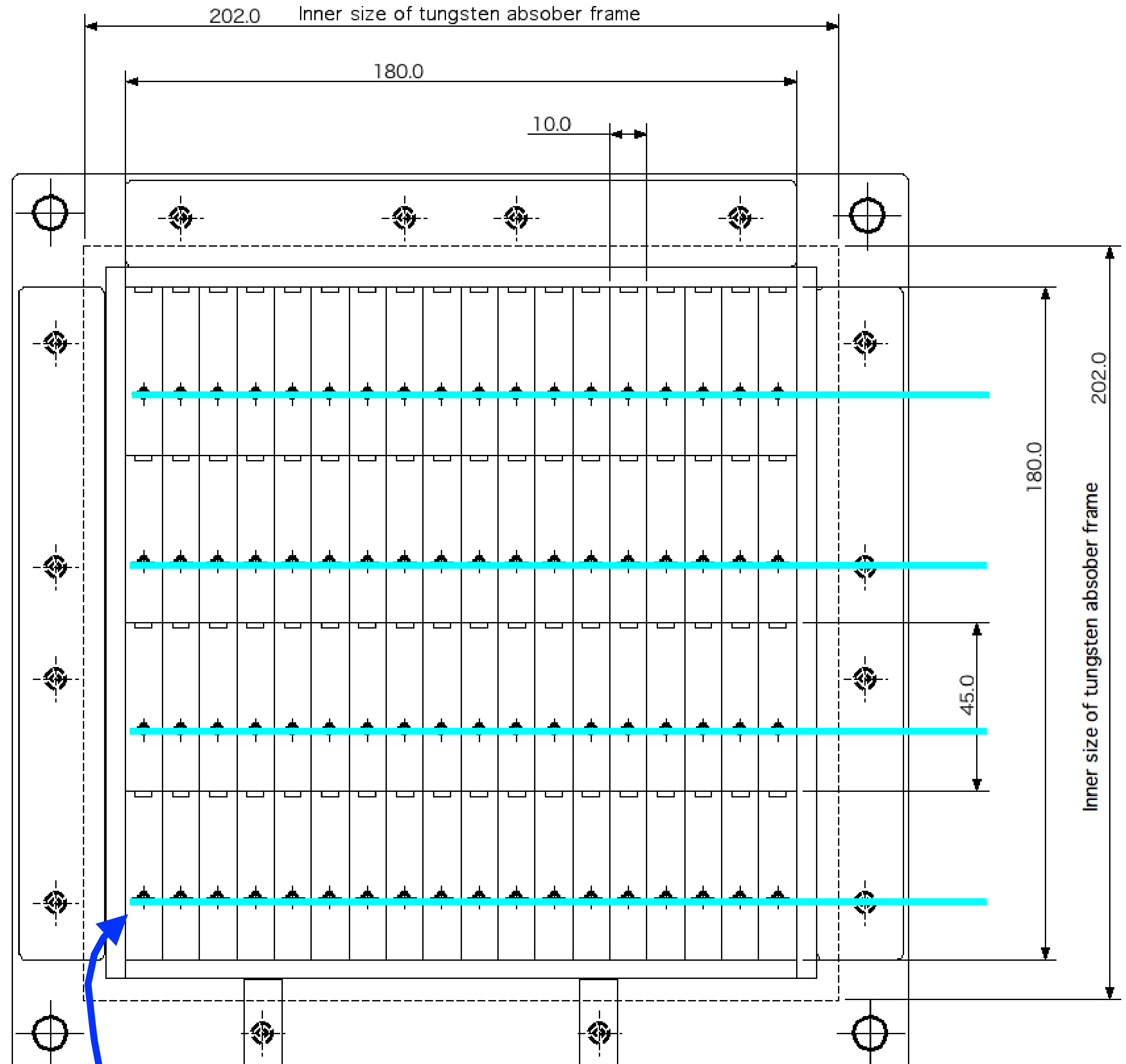


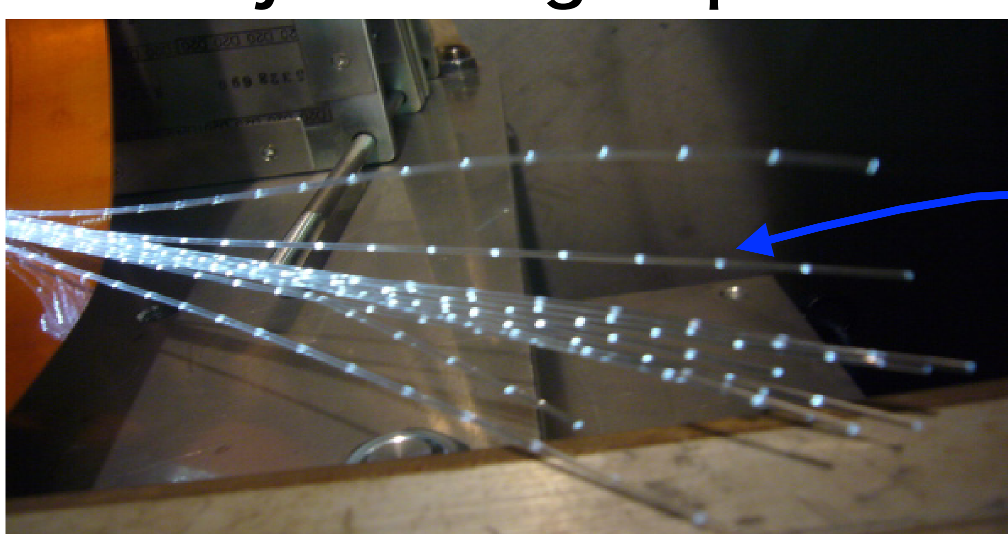
LED light went into strips for monitoring.

LED light





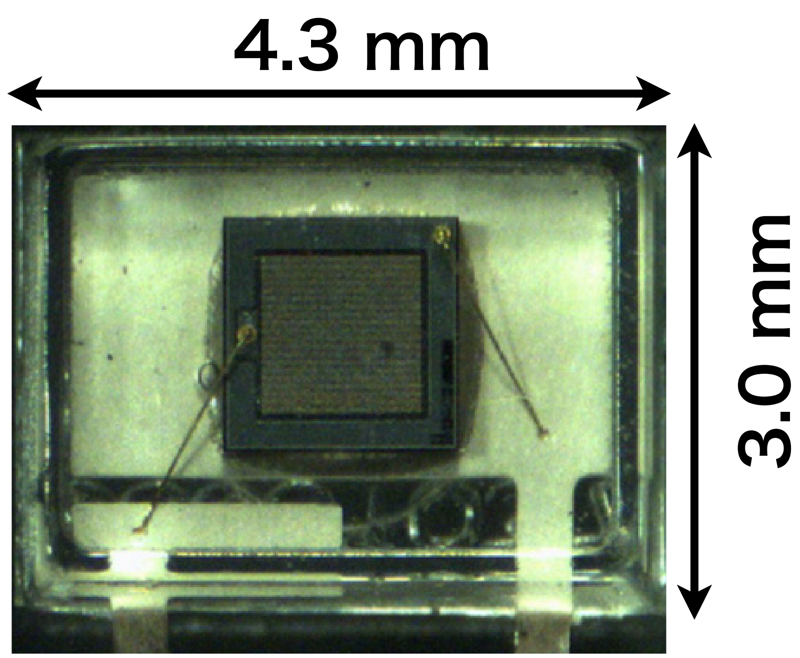
driver by Czech group

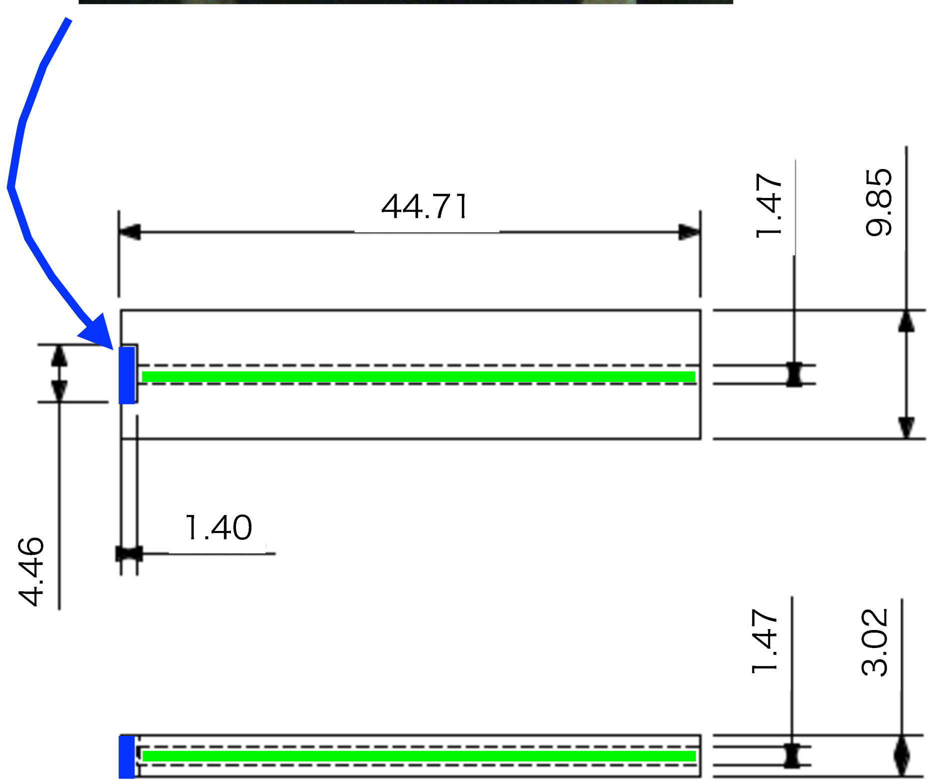


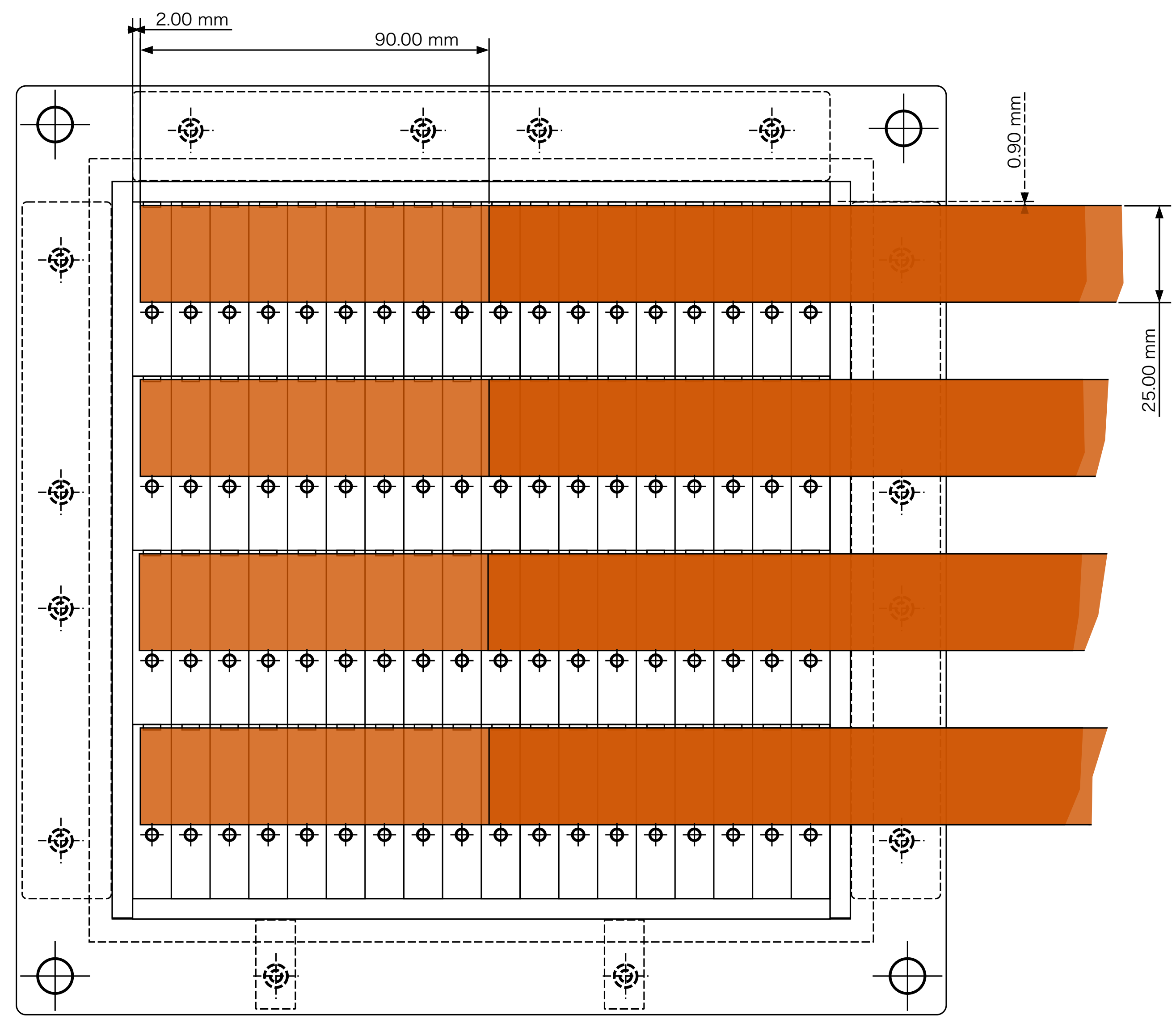
LED light was distributed via clear fibers

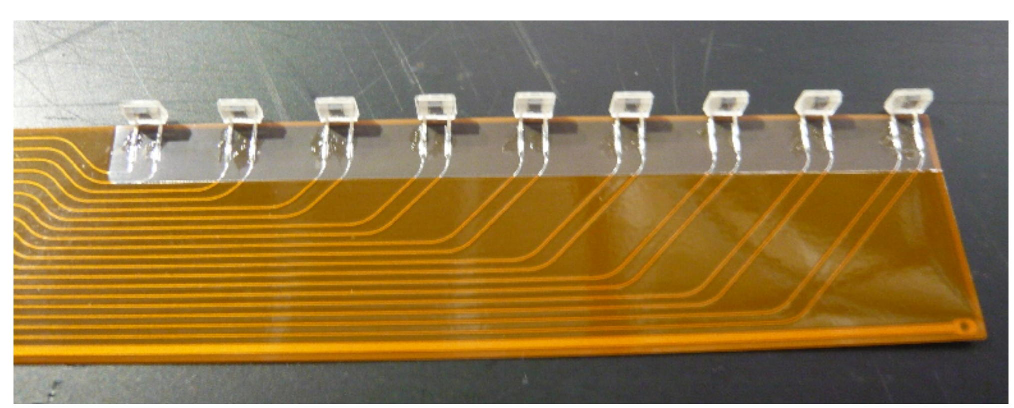
MPPC and WLS fiber

25μm pitch 1600 pix in 1×1mm² MPPC









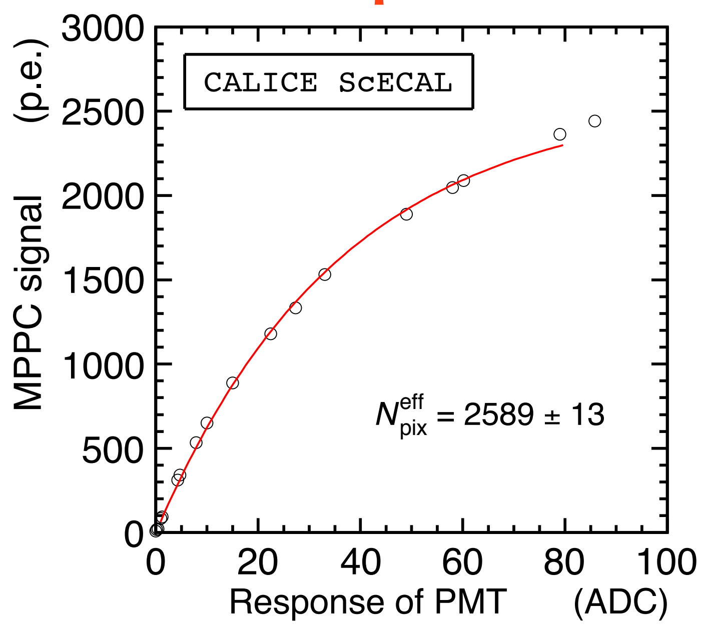
9 MPPCs on a cable

Calibration Procedure

1. MIP calibration; #ADCs corresponds to one MIP,
   for the channel by channel equalization,

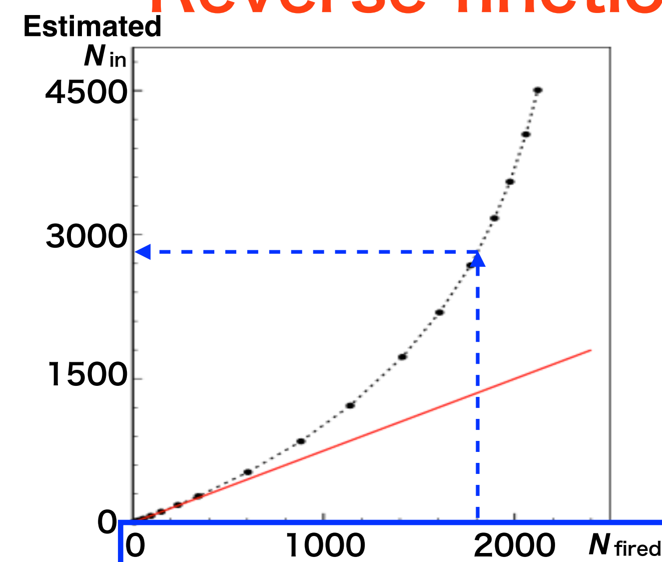
2. MPPC gain calibration; #ADCs corresponds to one p.e.,
   for i. gain monitoring,
   ii. MPPC saturation correction,

MPPC response curve: F



Use reverse of
MPPC response F

Reverse finction: F^{-1}



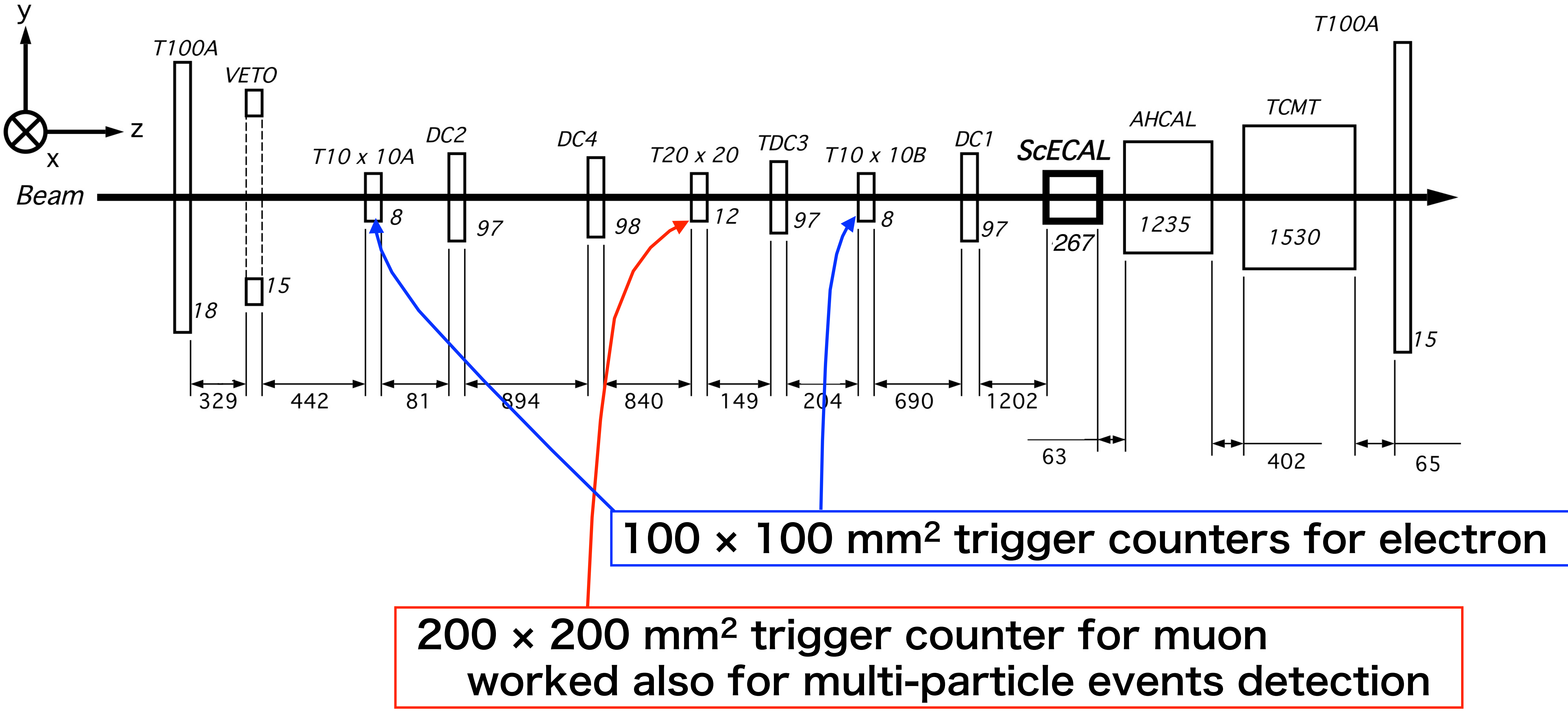
Input is # p.e.

3. Inter calibration; ratio-response of high_gain/low_gain,
   for that
   ADC/p.e was measured with high gain
   Physics data was measured with low gain.

Test beam May 2009 at FNAL

MT6 in Fnal Test Beam Facility

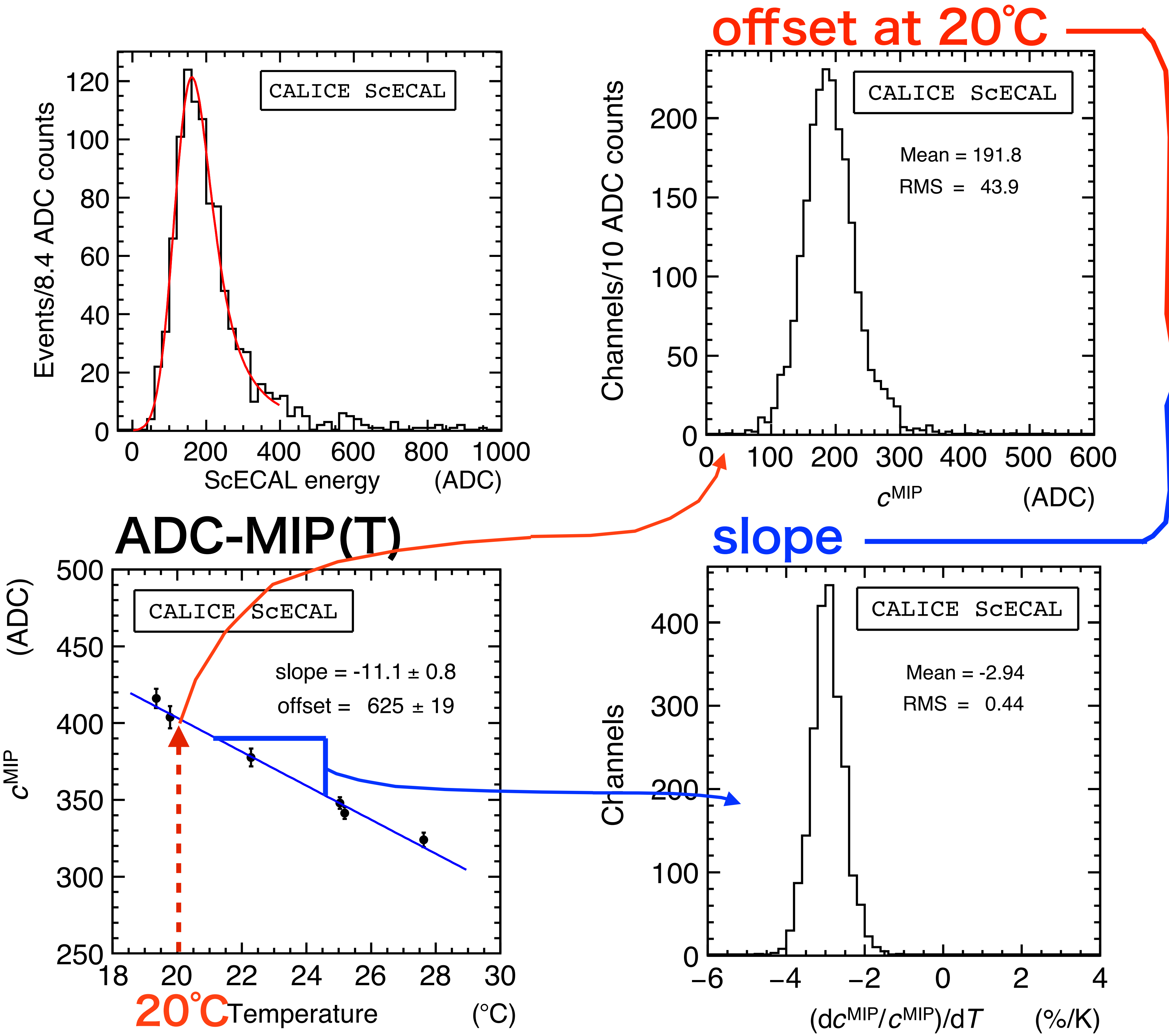
Sep 2008, May 2009



A differential Čerenkov counter was upstream : select particles

- DAQ system was the same as AHCAL phys. prototype.

Temperature depending calib. factor



Database for each channel

use ADC-MIP(T@daq)

cancel temp. effect

Same way for ADC-p.e.(gain)

Selection criteria

0. Čerenkov counter

1. highest energy layer < 20th (to reduce π)

2. highest energy layer has energy >

15 MIPs for		2 GeV/c
27 MIPs for		4 GeV/c
54 MIPs for		8 GeV/c
80 MIPs for		12 GeV/c
95 MIPs for		15 GeV/c
125 MIPs for		20 GeV/c
200 MIPs for	>	30 GeV/c

3. highest energy layer in AHCAL < 20 MIPs (to reduce π)

4. most downstream layer of AHCAL < 0.4 MIP

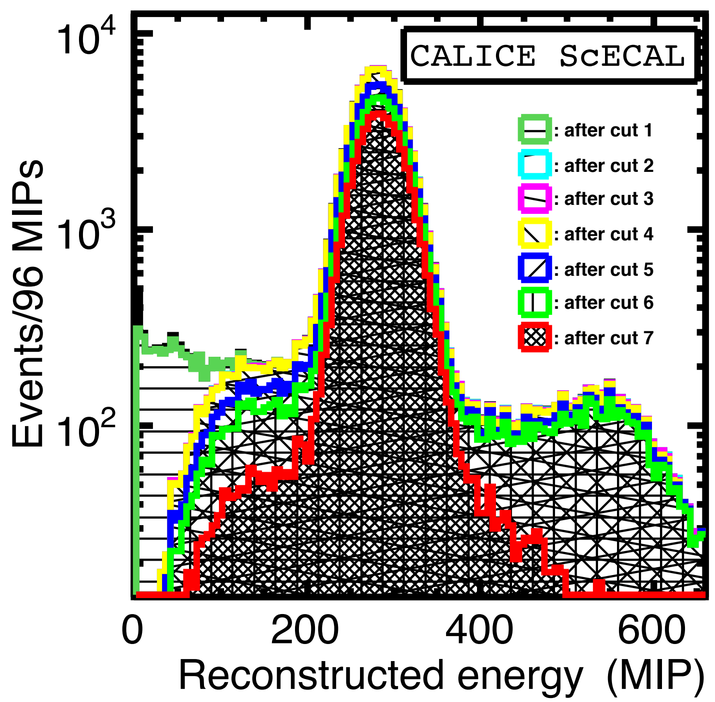
5. (6). -40 mm < gravitational center energy < 40 mm in x (y)

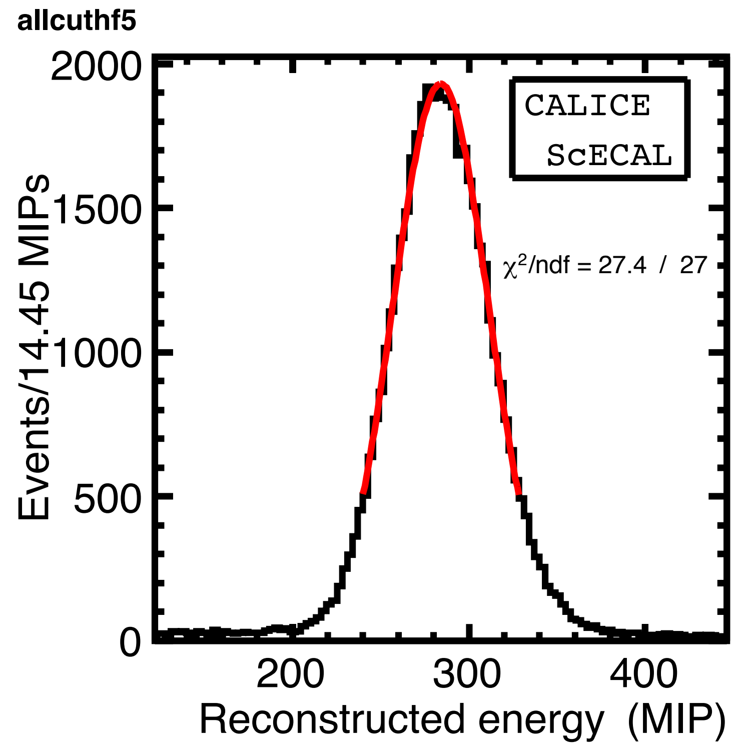
7. energy in multi-particle counter < 1.4 MIPs corresponds

thanks for Oskar

Energy spectra after selection

a run of 2 GeV

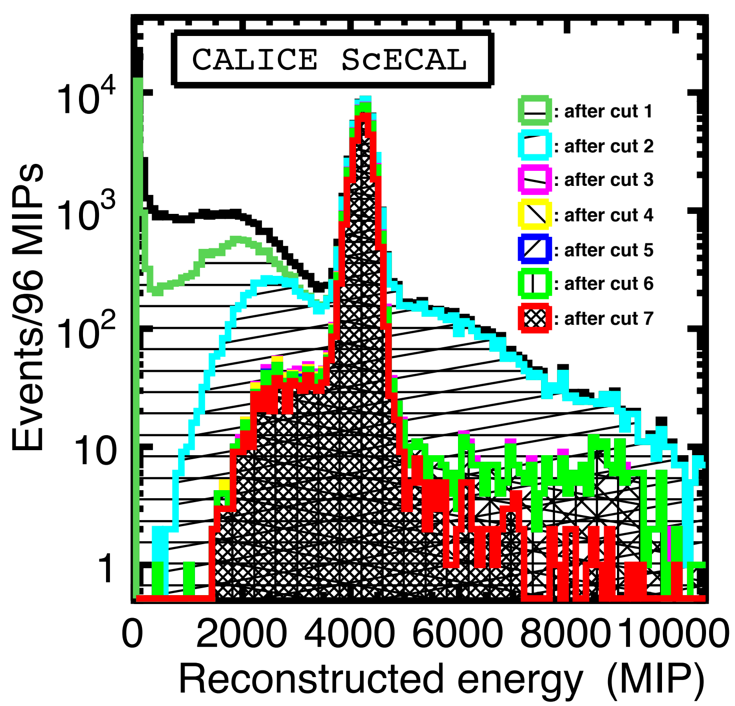


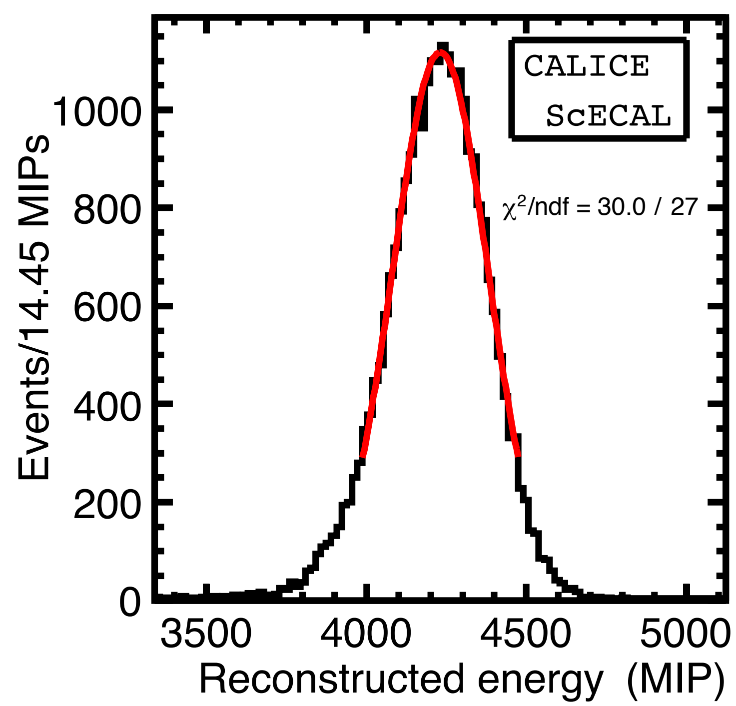


Gauss fitting area:
$\pm 1.6\sigma$ = 90% of area.

$0.9 < \chi^2/\text{ndf} < 1.2$
for all runs

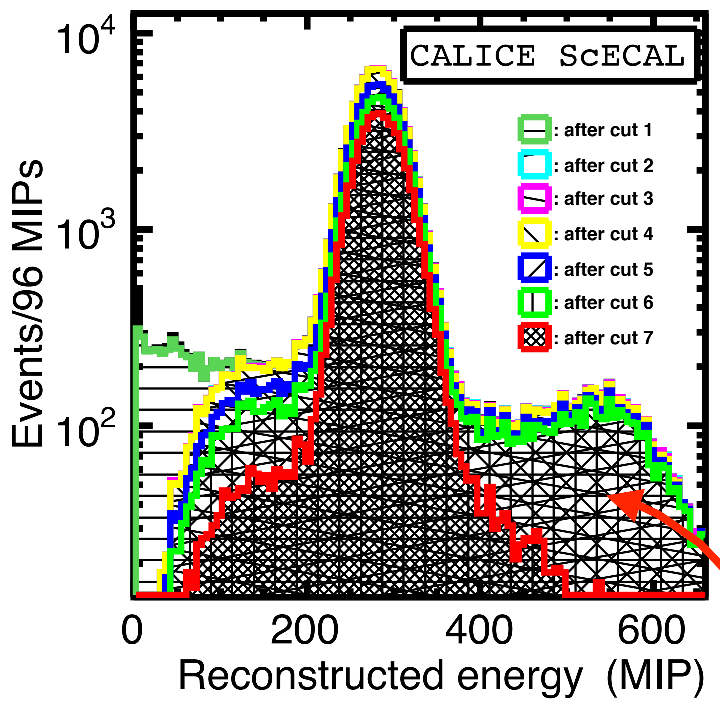
a run of 32 GeV

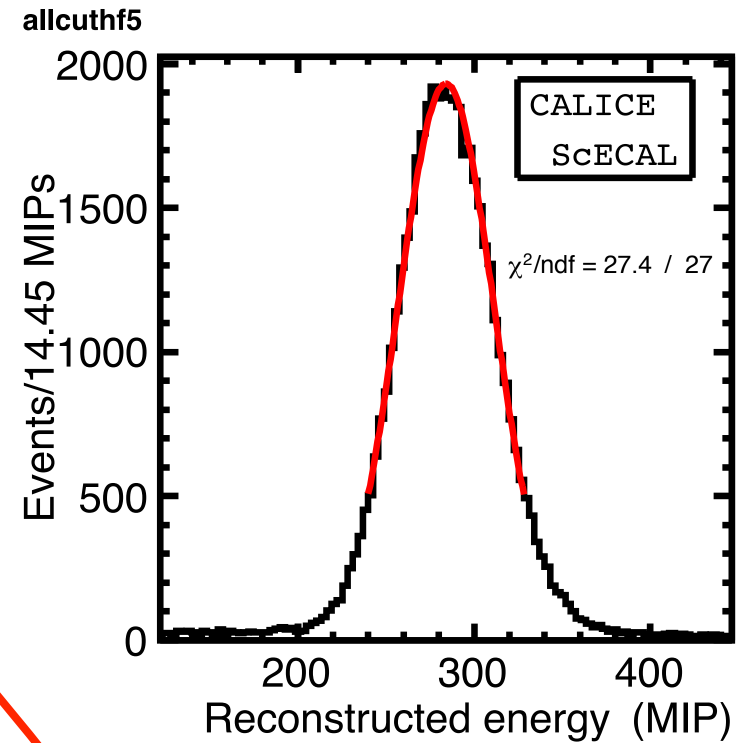




Energy spectra after selection

a run of 2 GeV



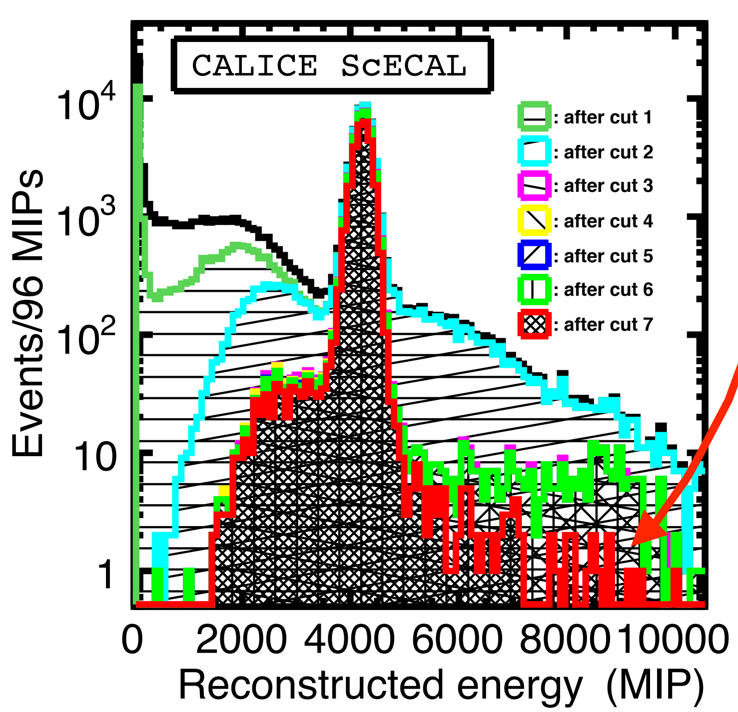


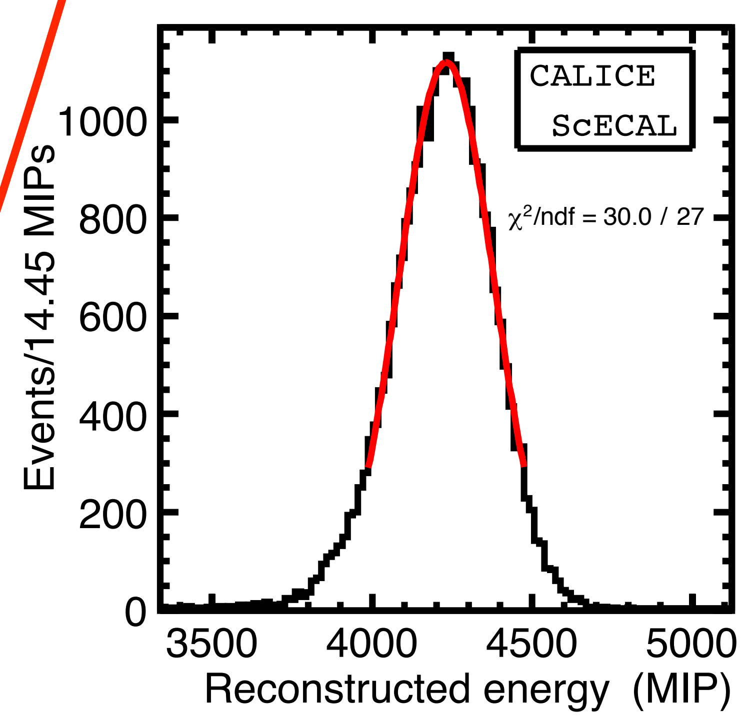
Gauss fitting area:
± 1.6σ = 90% of area.

0.9 < χ^2/ndf < 1.2
for all runs

Multi-particle event cut reduced double e⁻ event

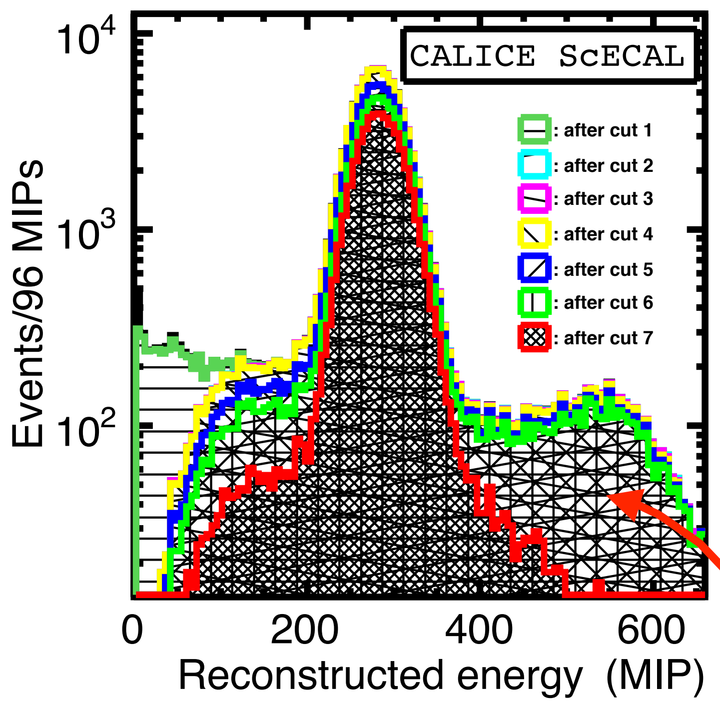
a run of 32 GeV

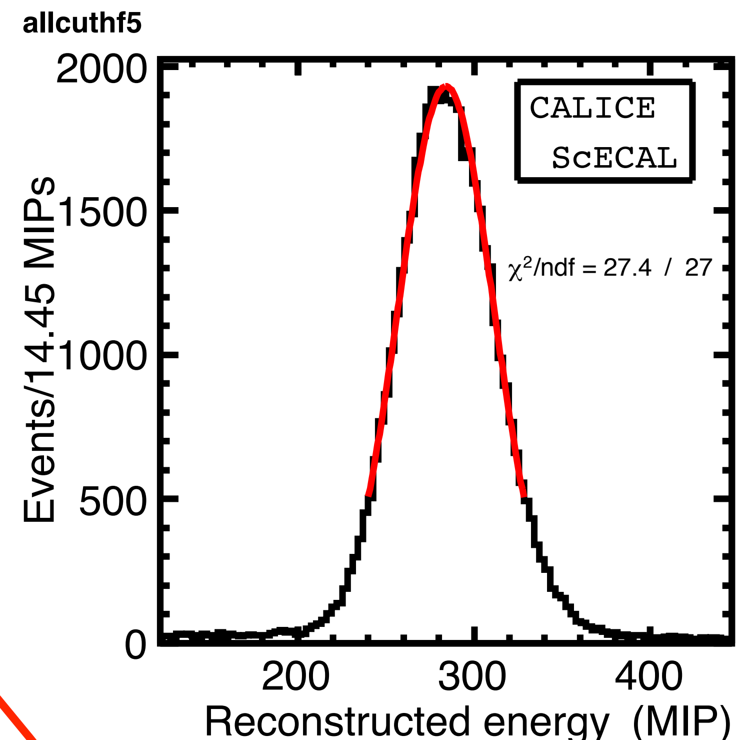




Energy spectra after selection

a run of 2 GeV





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0.9 < χ^2/ndf < 1.2 for all runs

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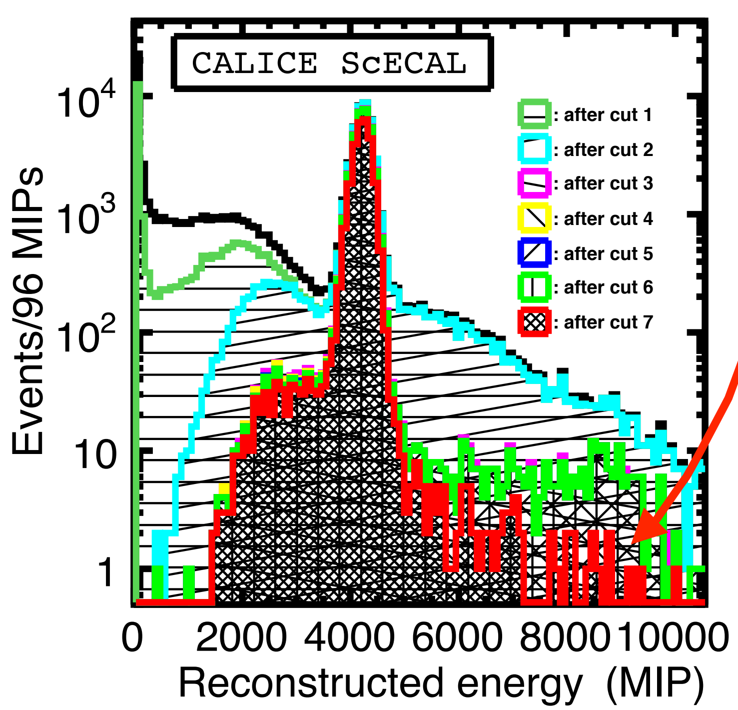
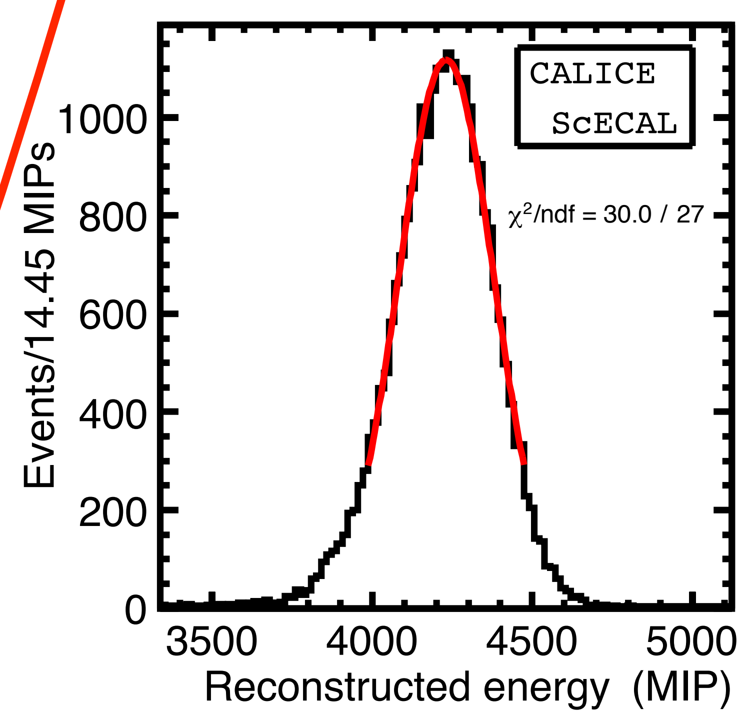
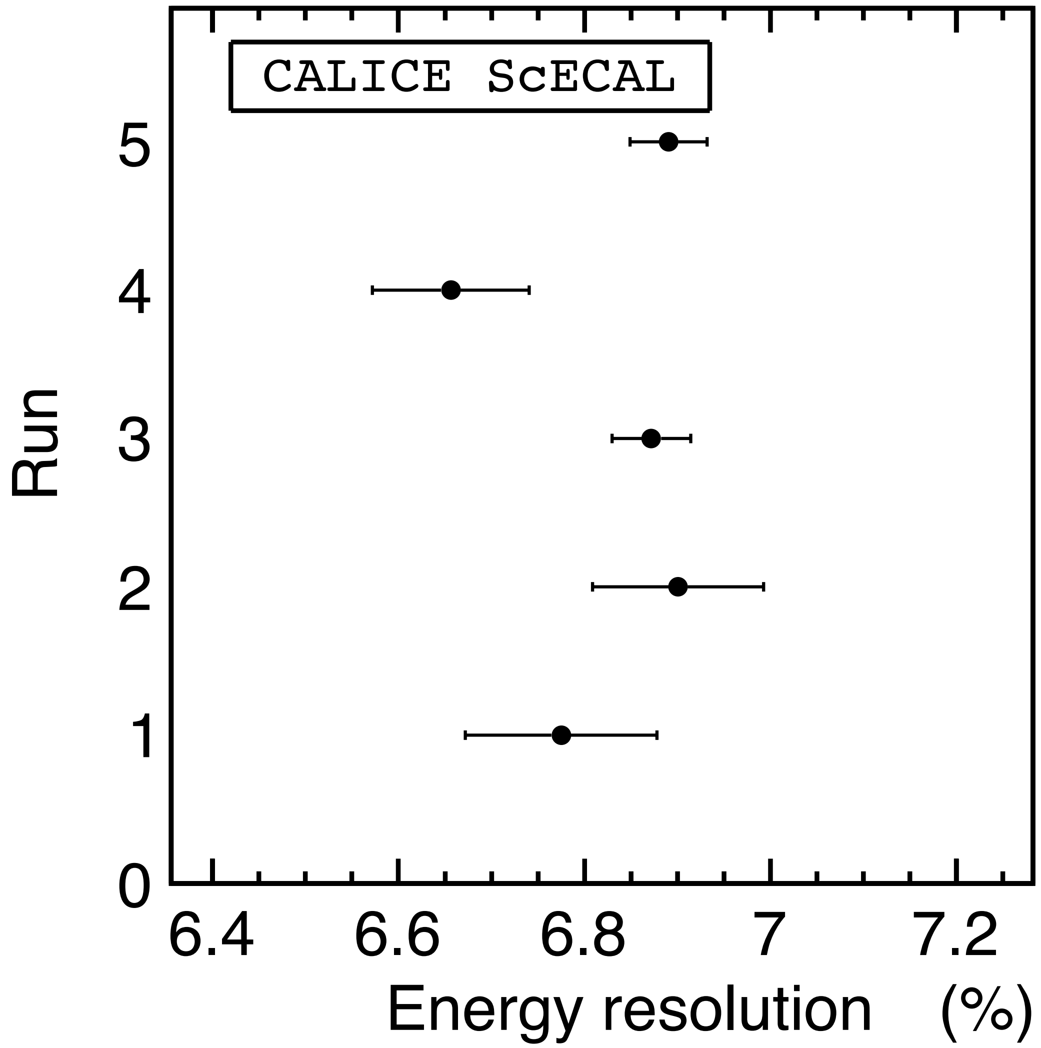




The mean and σ of the gaussian were taken as the energy mean and its resolution.

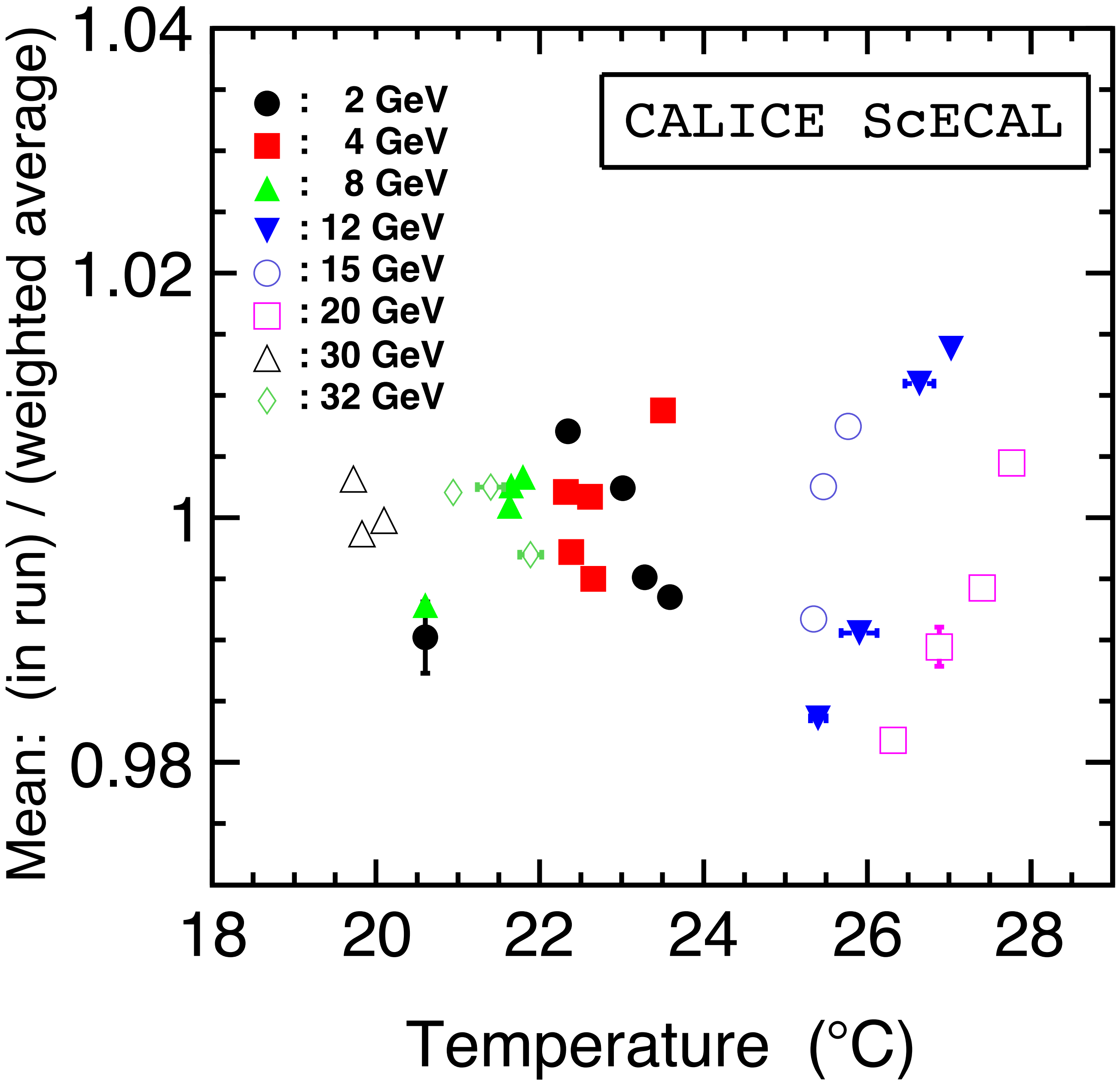
Run variations-σ_E

run by run fluctuation--almost agrees with statistical uncertainties.



Run variations - <E>

ratio of Energy mean
(run by run / average) vs temperature



Unclear dependence on temperature,
except 8, 20, and 12 GeV

Systematic uncertainties

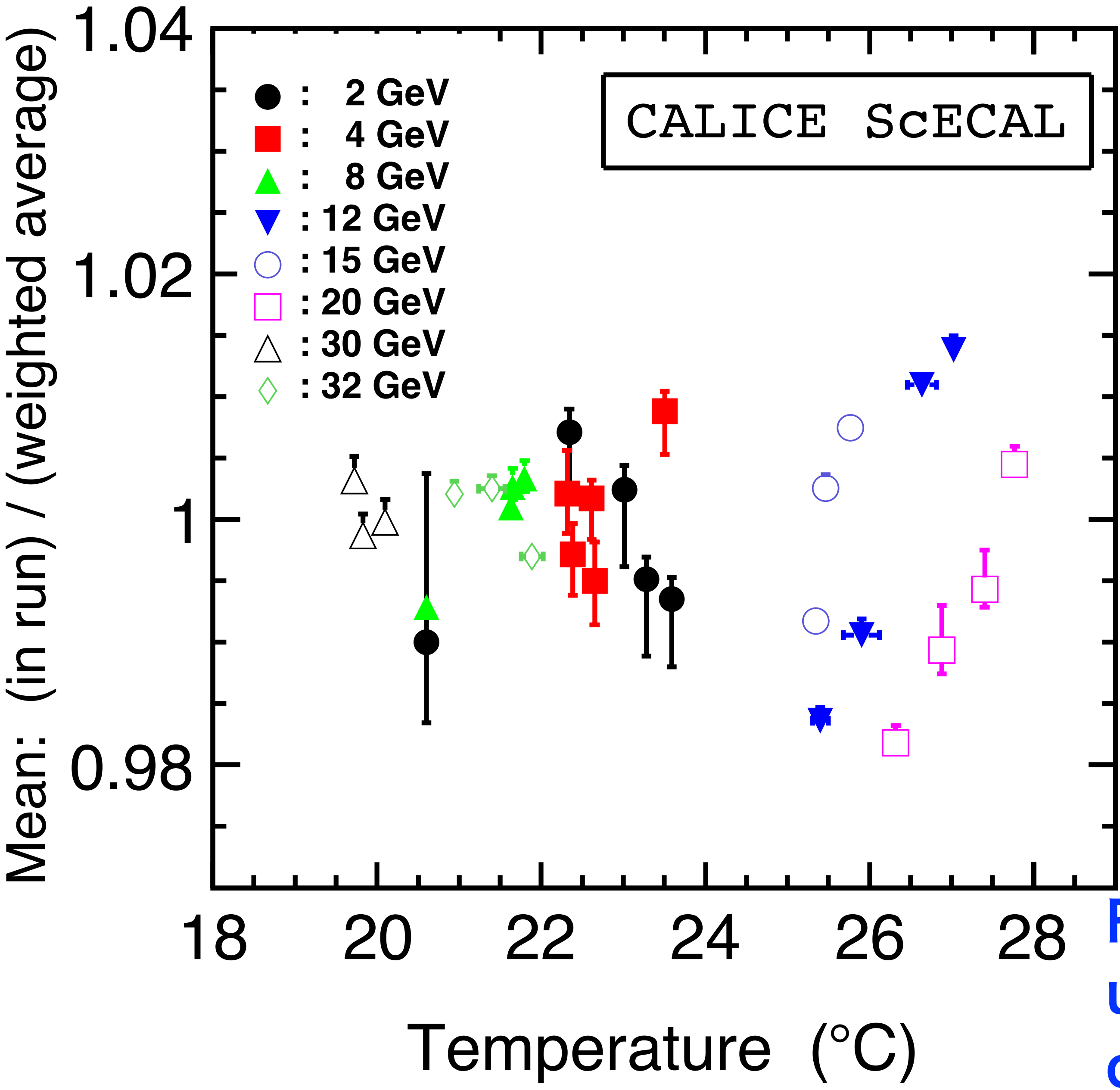
Table 3: The uncertainties of mean value of measured energy deposit (%).

$p^*_{\rm beam}$	range-x	other cuts	$c^{\rm MIP}(20°{\rm C})$	$dc^{\rm MIP}/dT$	Npix	stat	total
2	$^{+0.22}_{-0.45}$	$^{+0.09}_{-0.37}$	±0.23	±0.03	±0.11	±0.03	$^{+0.36}_{-0.64}$
4	$^{+0.21}_{-0.25}$	$^{+0.07}_{-0.22}$	±0.09	±0.02	±0.01	±0.02	$^{+0.24}_{-0.35}$
8	$^{+0.12}_{-0.08}$	$^{+0.06}_{-0.03}$	±0.21	±0.03	±0.05	±0.01	$^{+0.27}_{-0.25}$
12	$^{+0.10}_{-0.02}$	$^{+0.04}_{-0.04}$	±0.16	±0.03	±0.05	±0.01	$^{+0.21}_{-0.19}$
15	$^{+0.07}_{-0.06}$	$^{+0.04}_{-0.03}$	±0.13	±0.04	±0.04	±0.01	$^{+0.18}_{-0.17}$
20	$^{+0.18}_{-0.04}$	$^{+0.06}_{-0.04}$	±0.13	±0.04	±0.04	±0.01	$^{+0.24}_{-0.16}$
30	$^{+0.13}_{-0.01}$	$^{+0.12}_{-0.02}$	±0.12	±0.06	±0.16	±0.01	$^{+0.28}_{-0.22}$
32	$^{+0.02}_{-0.00}$	$^{+0.09}_{-0.03}$	±0.23	±0.04	±0.13	±0.02	$^{+0.30}_{-0.28}$

$*$ Beam momentum (GeV/c).

Run variations - <E>

with systematic uncertainties



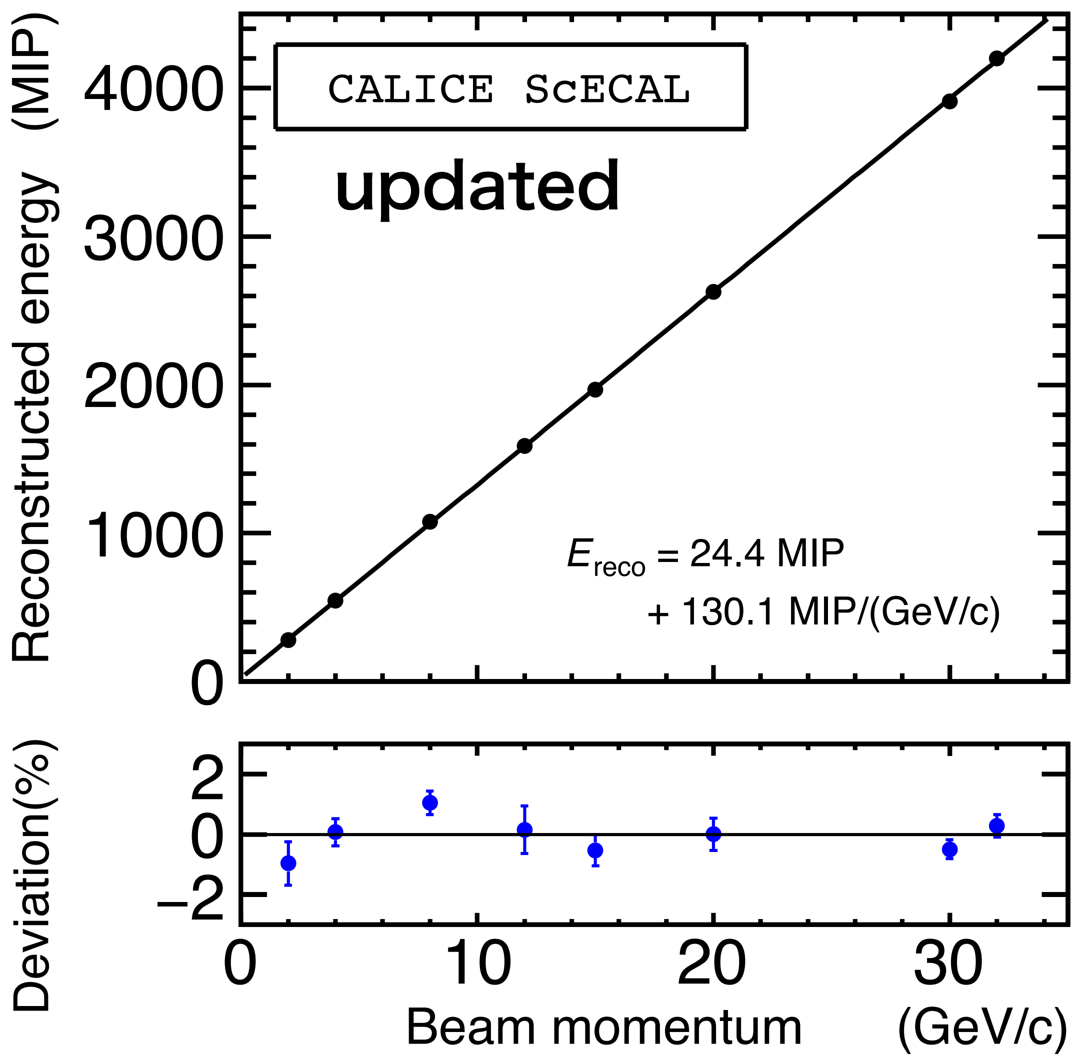
p^*_{beam}	run difference (%)	estimated uncertainties (%)	
2	±0.58	−0.64	+0.36
4	±0.34	−0.35	+0.24
8	±0.44	−0.25	+0.27
12	±1.23	−0.19	+0.21
15	±0.66	−0.17	+0.18
20	±0.79	−0.16	+0.24
30	±0.17	−0.22	+0.28
32	±0.27	−0.28	+0.30

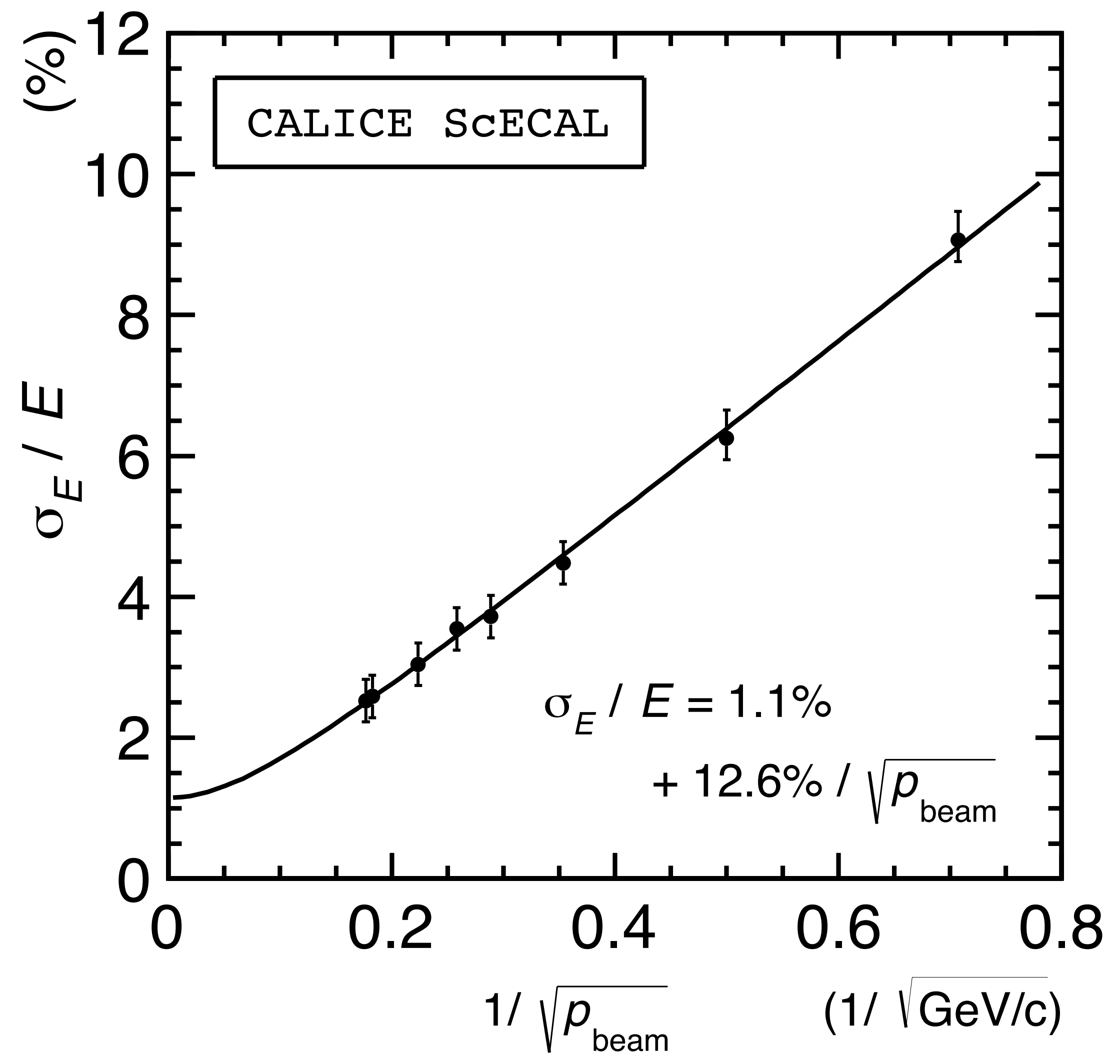
∗ Beam momentum (GeV/c).

For evaluation of linearity, larger uncertainties were taken between run difference and estimated uncertainties.

Performance of prototype

Linearity and resolution





	response			resolution	
	offset (MIP)	slope (dMIP/dGeV)	dev.	constant(%)	stochastic(%)
CAN16c	22.5±1.4	130.44±0.30	<1.6	$1.0^{+0.5}_{-1.0}$	12.8±0.4
current	24.4±1.7	130.12±0.25	<1.1	$1.1^{+0.5}_{-0.7}$	12.6±0.4

Uncertainty: statistic ⊕ systematic

Comparisons with MC

Data vs. MC

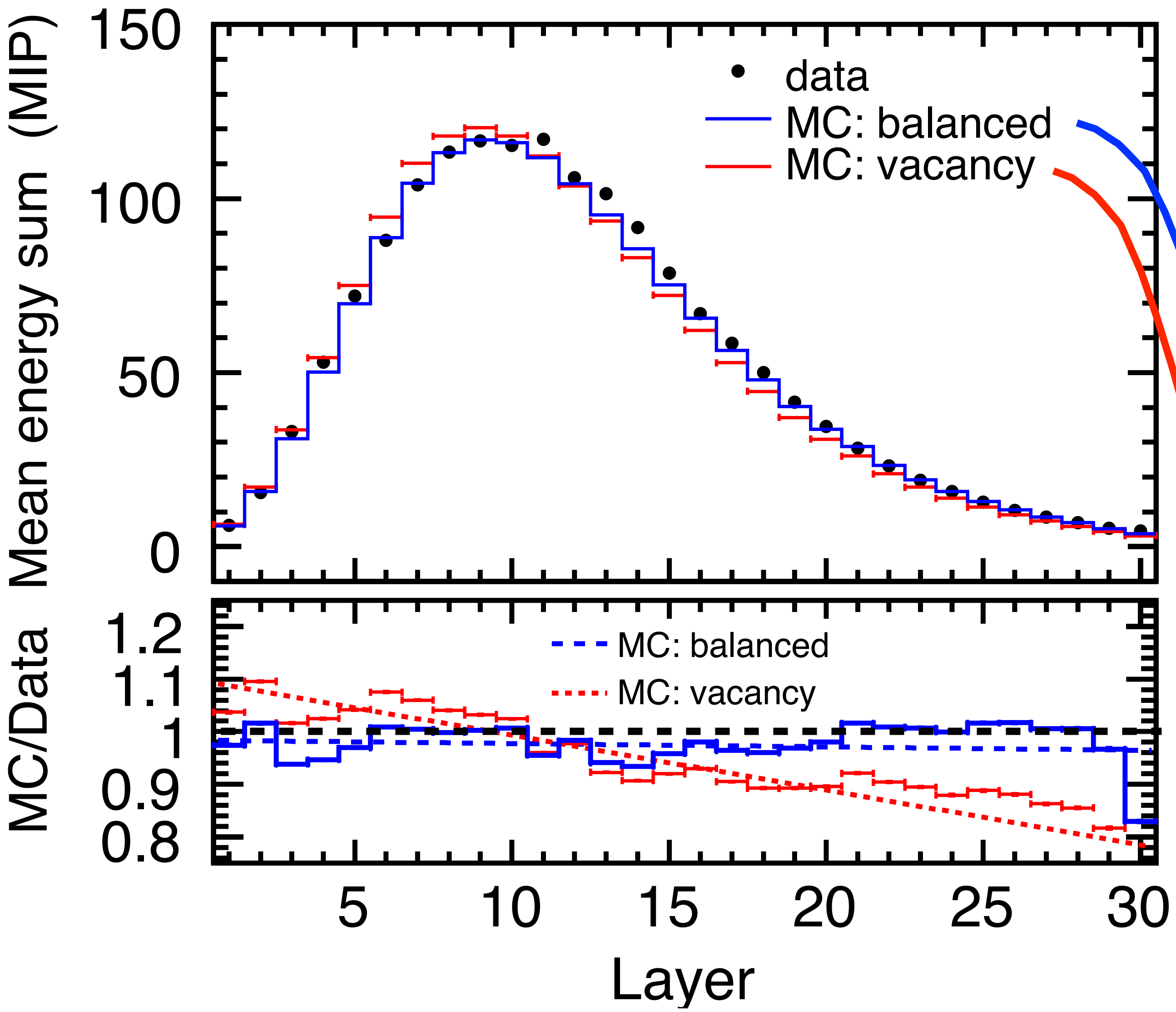
Thanks for Oskar!

Longitudinal profile (20 GeV/c)

Absorber, WC + Co + Cr (measured with XRD)

We measure the density for GEANT4 in two method.

believable
see CIN-025



- weight/size meas. 14.25g/cm³
- calc. from materials 14.76g/cm³

Density conflict each other.

Two ways to adjust;

1. WC : Co ➡ decrease : increase.
2. assume vacancies in the abs.

Case 1 has good agreement.

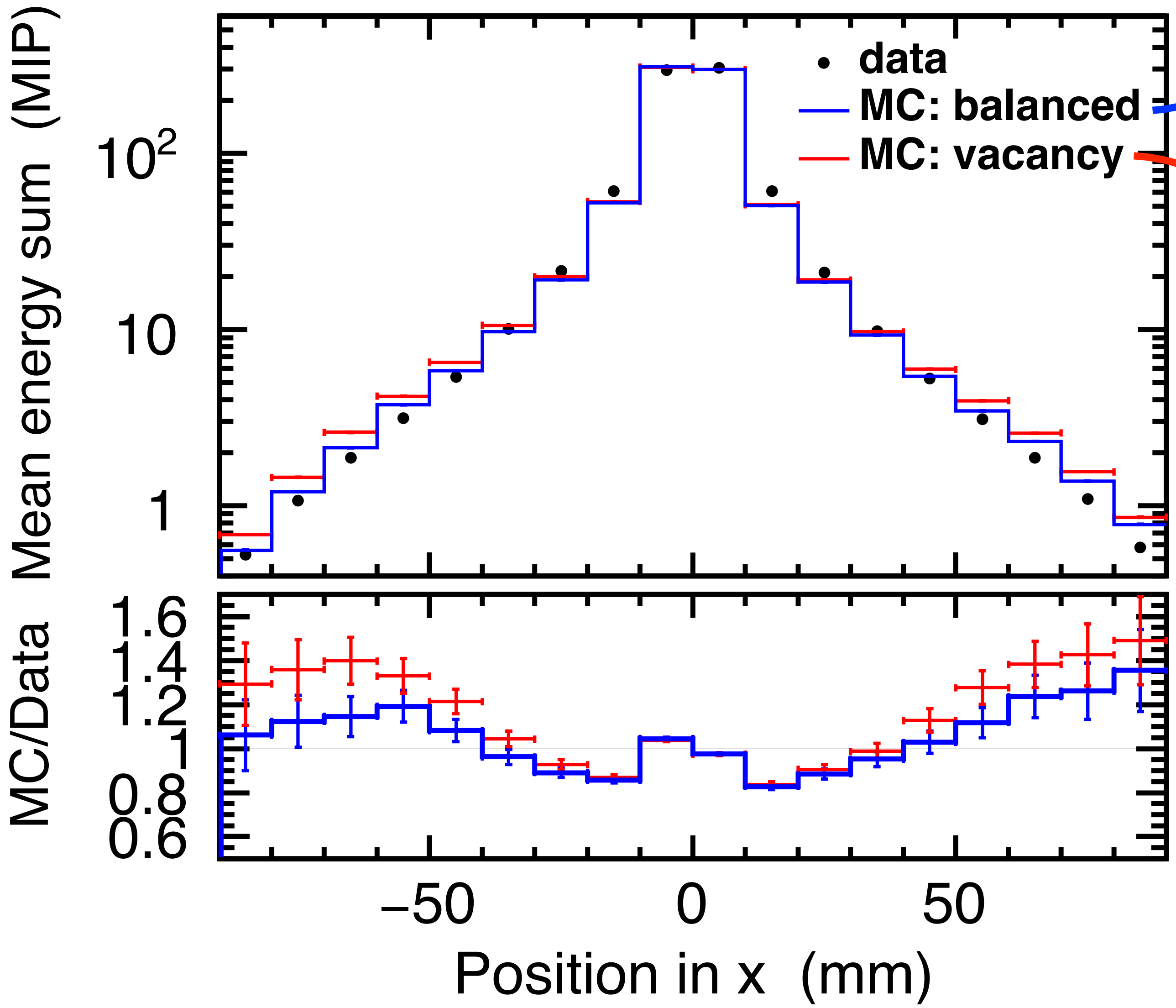
We take case 1 as default.

not change quantitative values
ex. dp/dMIP resolution etc.

Data vs. MC

Thanks for Oskar!

Lateral profile (20 GeV/c)



1. WC : Co ➡ decrease : increase.

2. assume vacancies in the abs.

again

Case 1 has better agreement.

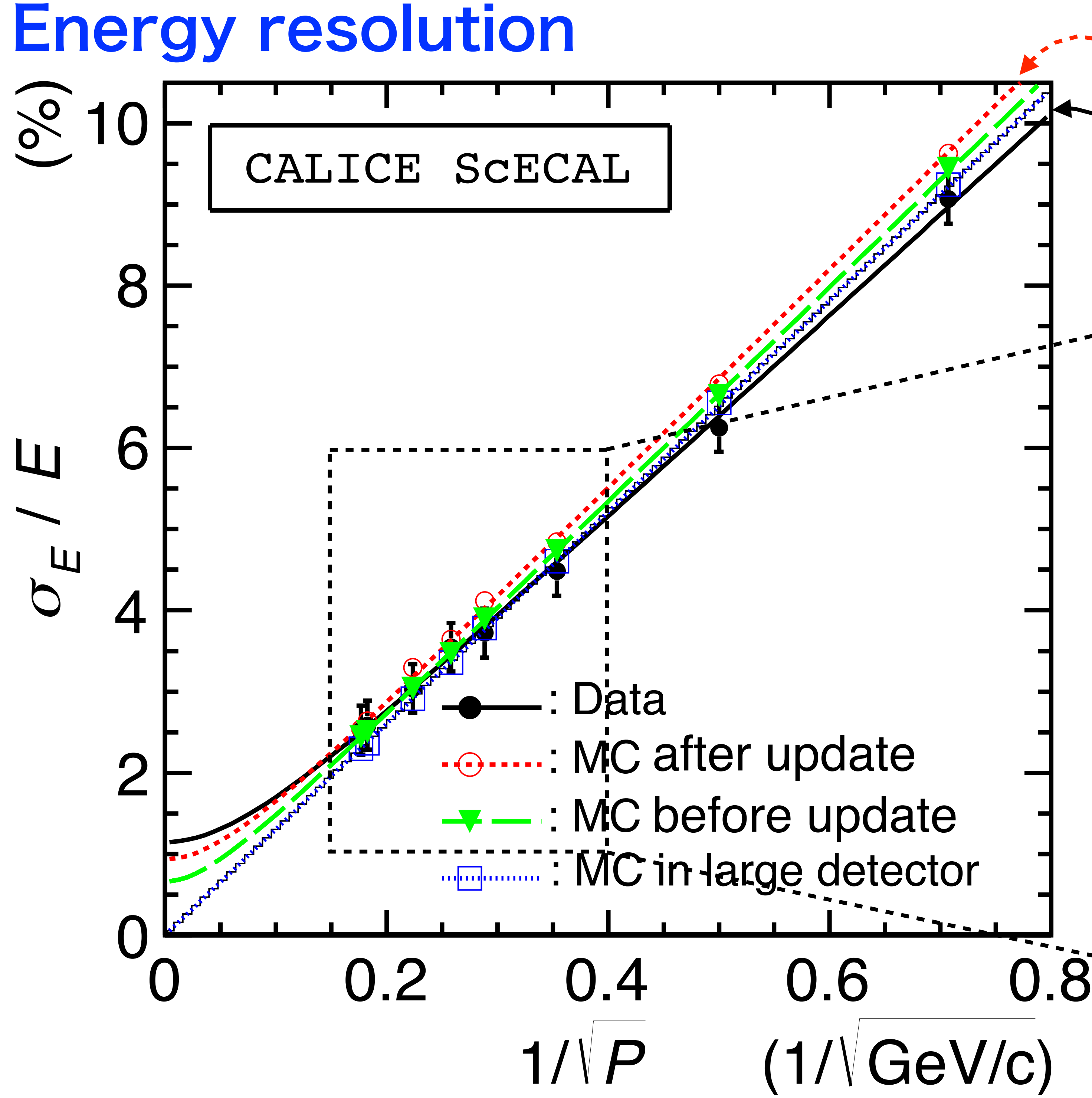
MC has sharper peak than DATA.

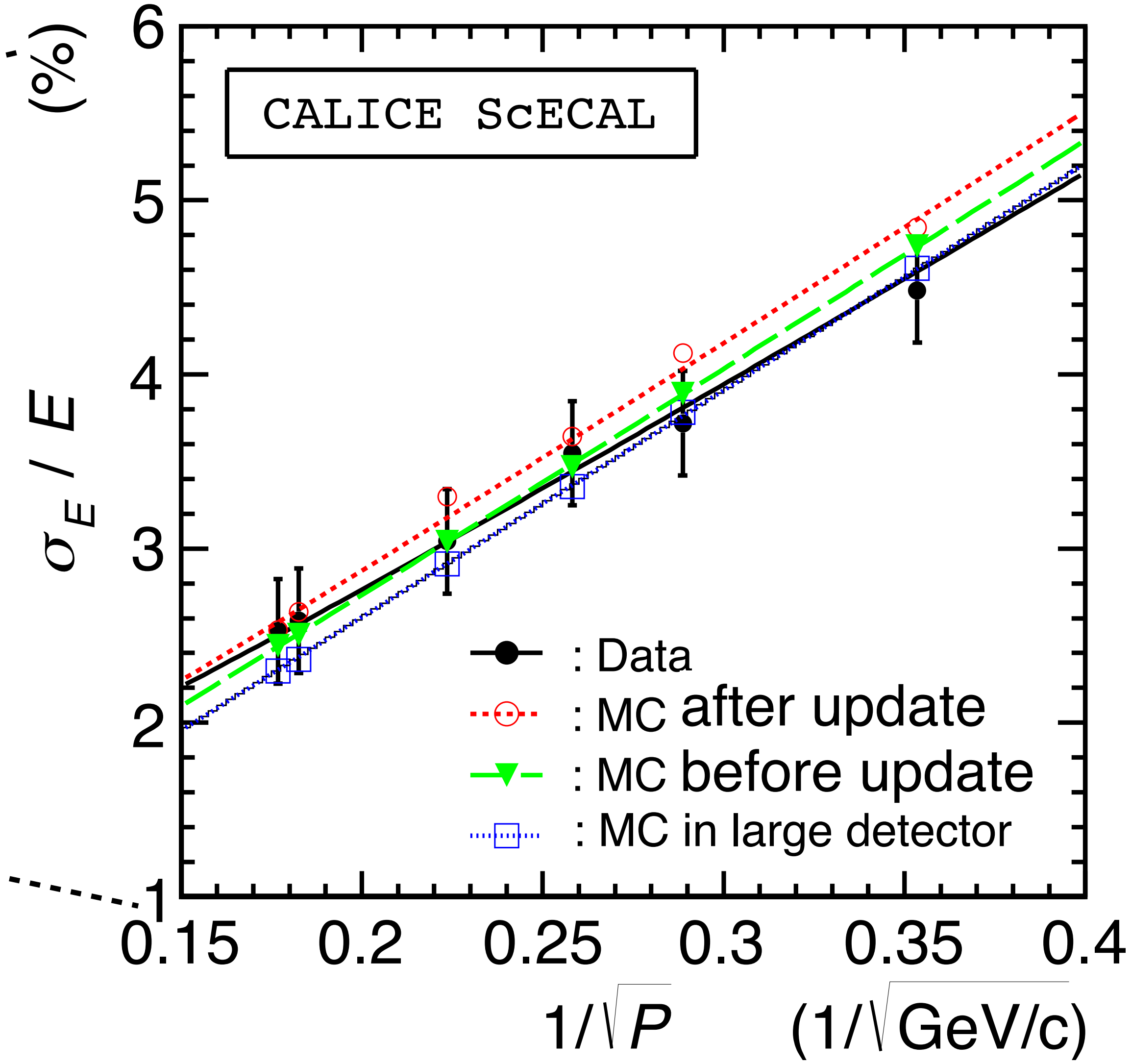
- Tilt angle,
- Implementing reflector film btw. strips,
- rescaling of saturation correction,

those do not succeed to explain the discrepancy.

Data vs. MC

Energy resolution





Realistic simulation agrees data within 1 uncertainty, except 2 GeV (1.6 uncertainties).

Discussion, Summary

Discussion

1. Linear deviation <1.1% ➡ Calibration factors(T) work well in severe temperature condition 19℃ - 27.5℃,
2. stochastic term,12.6±0.4% (require 15%) ➡ we can reduce thickness to 1.5-2mm for ILD(not mention directly ILD),
3. wide distribution of ADC-MIP, 23% comes from MPPC/WLS mismatch ➡ current design for ILD: direct coupling,
4. Shade to prevent direct photon succeeded to reduce the constant (1.1%) term of σ_E, uniformity 88.3±4.3%,
5. Four/2016 channels were not operational, short circuits by conductive reflector ➡ 3M radiant (nonconductive),
6. intrinsic beam momentum spread ➡ maximum possible information from FTBF is implemented ➡ σ_E agree Data/MC,
7. Response has offset, coherent among every energy ➡ indicates; imperfect correction of MPPC saturation does not the reason.

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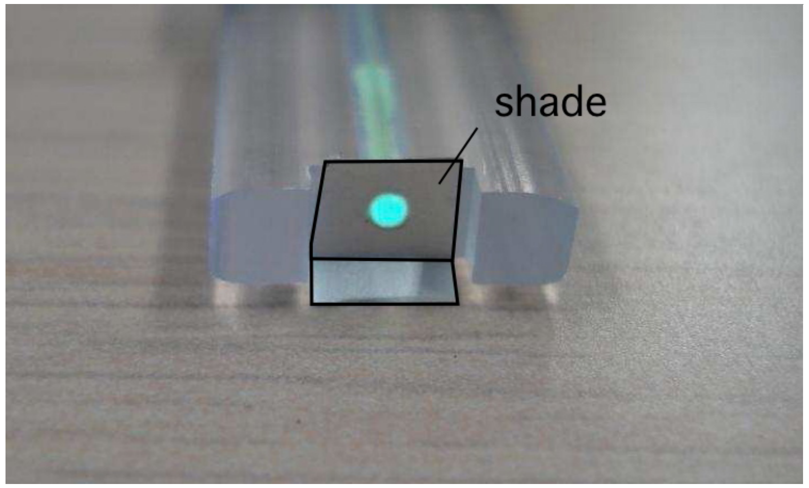
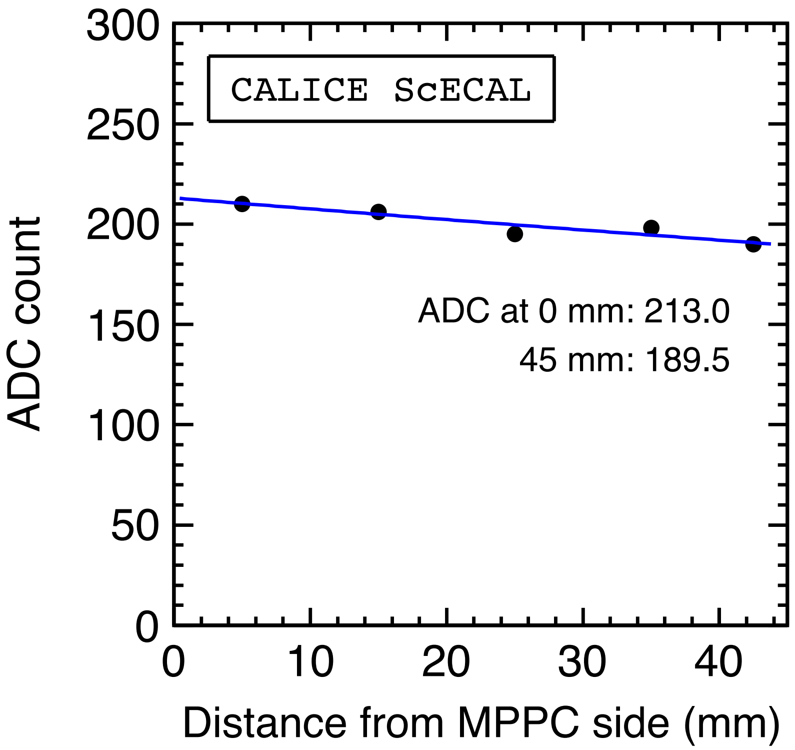
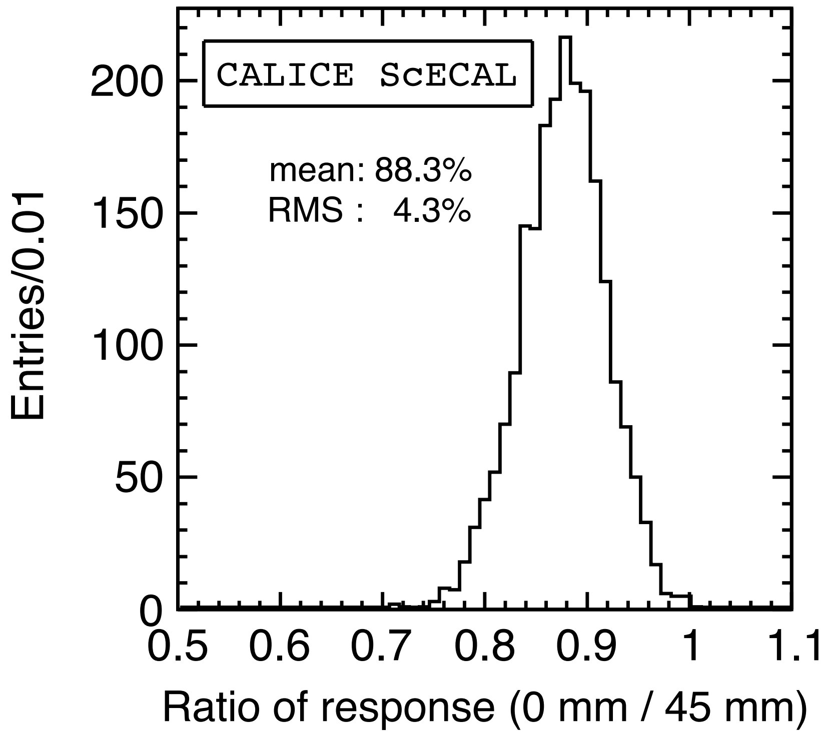


7. Response has of indicates; imperf not the reason.





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Back up

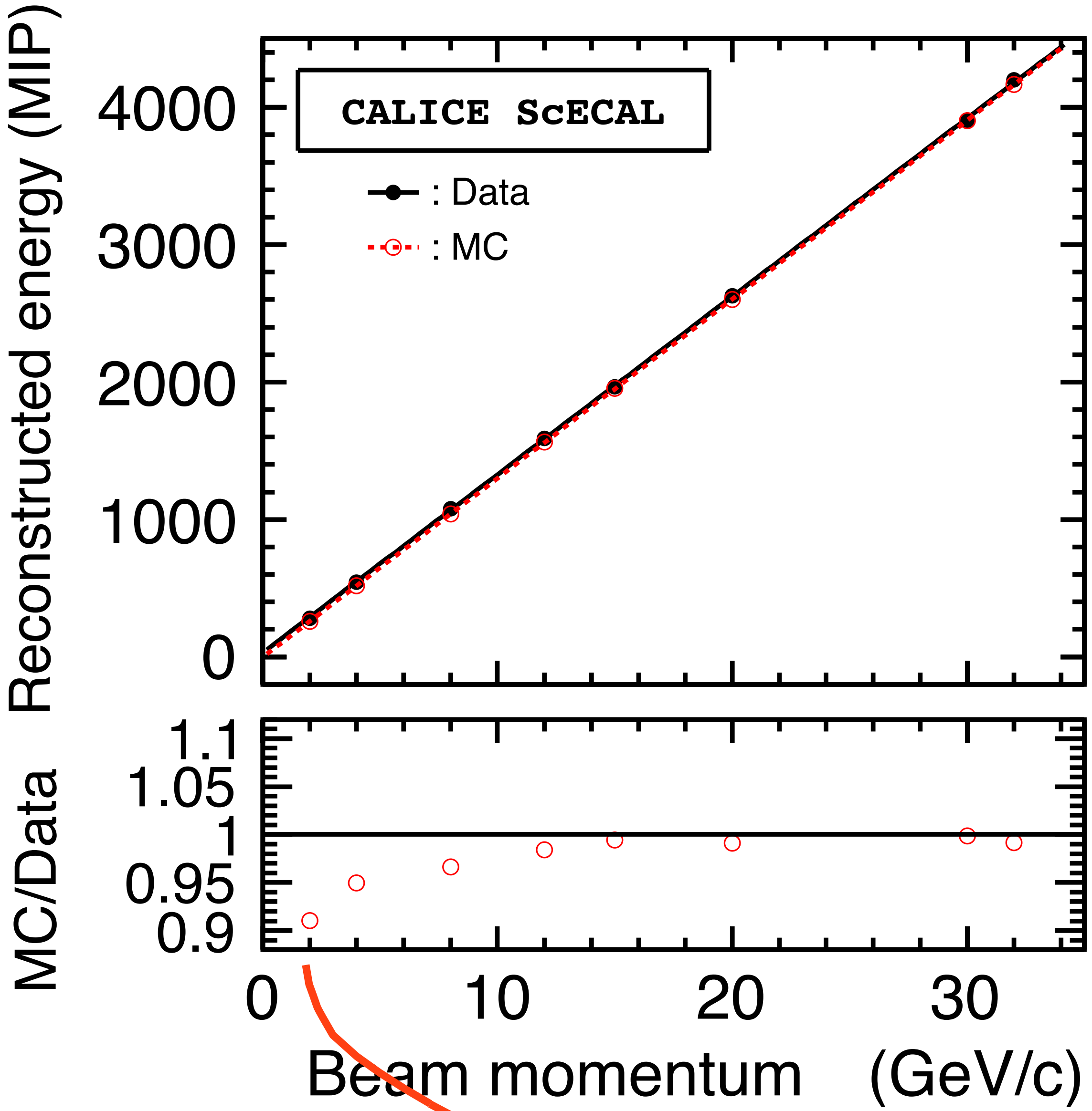
More realistic simulation

implement realistic simulation: thanks Oskar Hartbrich

- binomial photon statistics was implemented,
    - MPPC saturation→ photon statistics → unfolding,
- photon yield variation for strip by strip, -- from data,
- gain for channel by channel -- from data,
- beam position spread -- from data (center-of-gravity),
- background overlay--from data (recycling),
- intrinsic momentum fluctuation,
- use the same analysis code as data analysis.

Data vs. MC

Response



	offset (MIP)	slope (dMIP/dGeV)
data	24.4±1.7	130.1±0.3
MC	-3.0±0.1	130.3±0.1

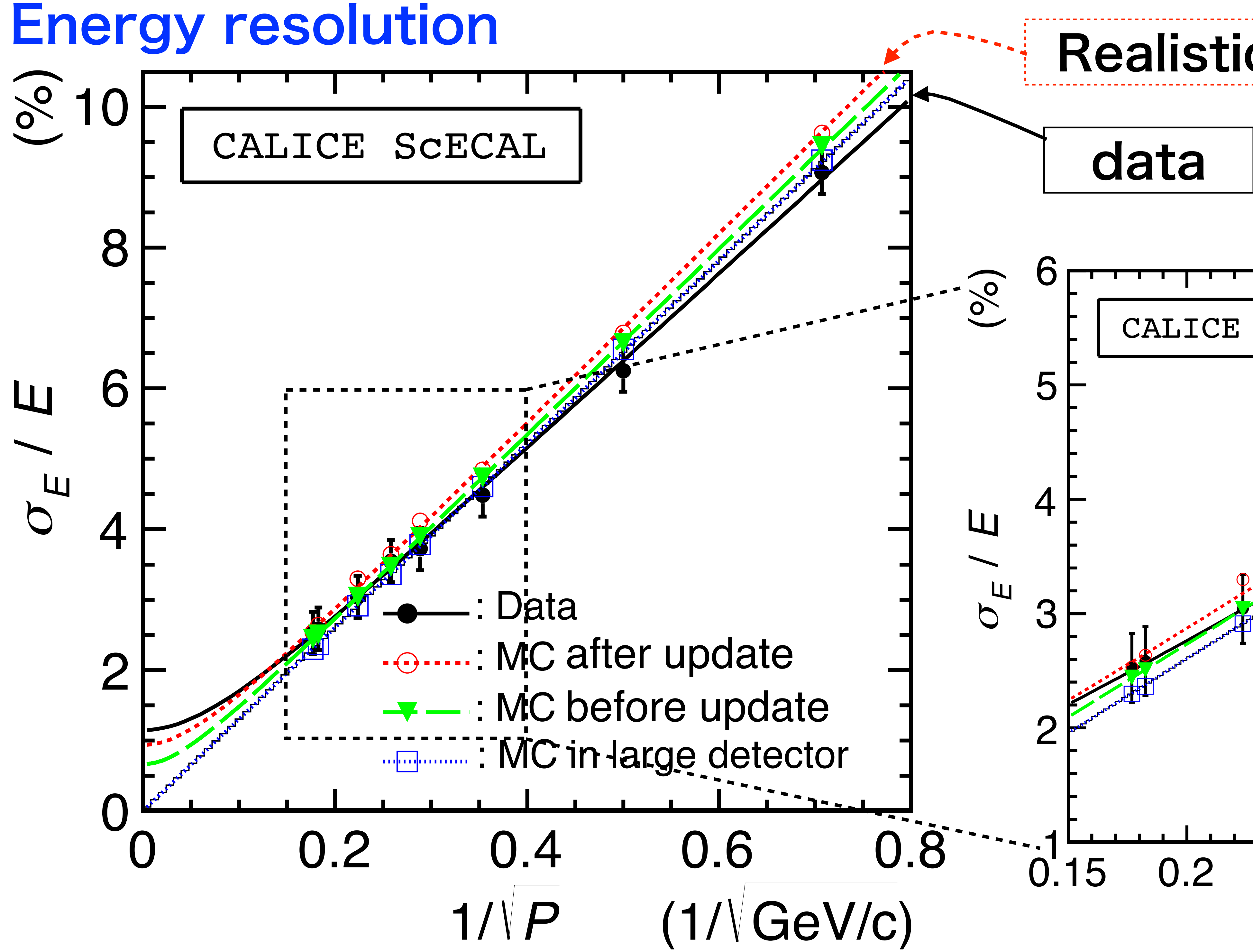
MC agrees on the slope of response.

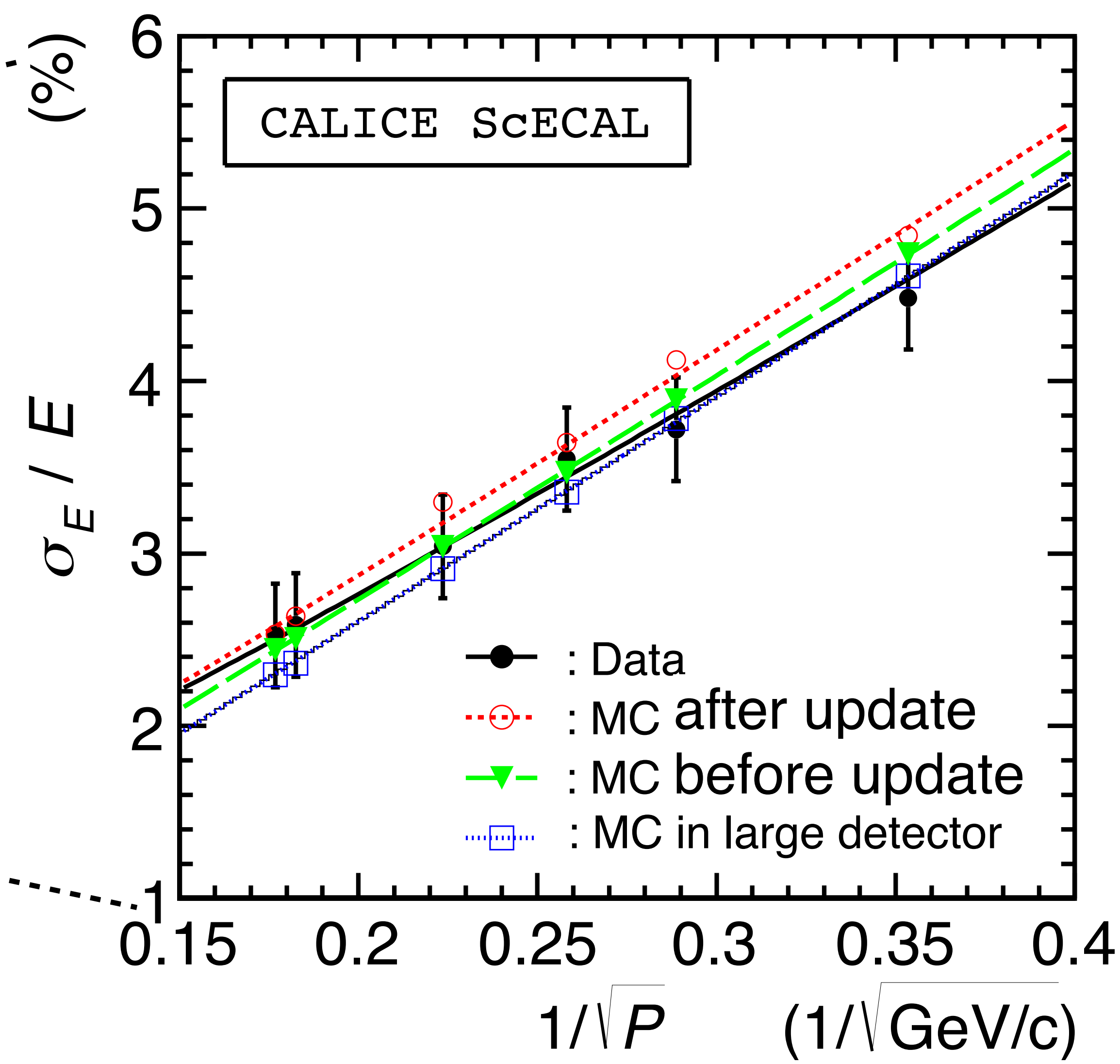
MC failed to represent an offset. (note that BG was overlaid)

Although the ratio becomes clearly smaller as beam momentum becomes smaller, absolute difference corresponds to 0.18 ± 0.20(RMS) GeV/c, not so large.

Data vs. MC

Energy resolution





Realistic simulation agrees data within 1 uncertainty, except 2 GeV (1.6 uncertainties).

Summary

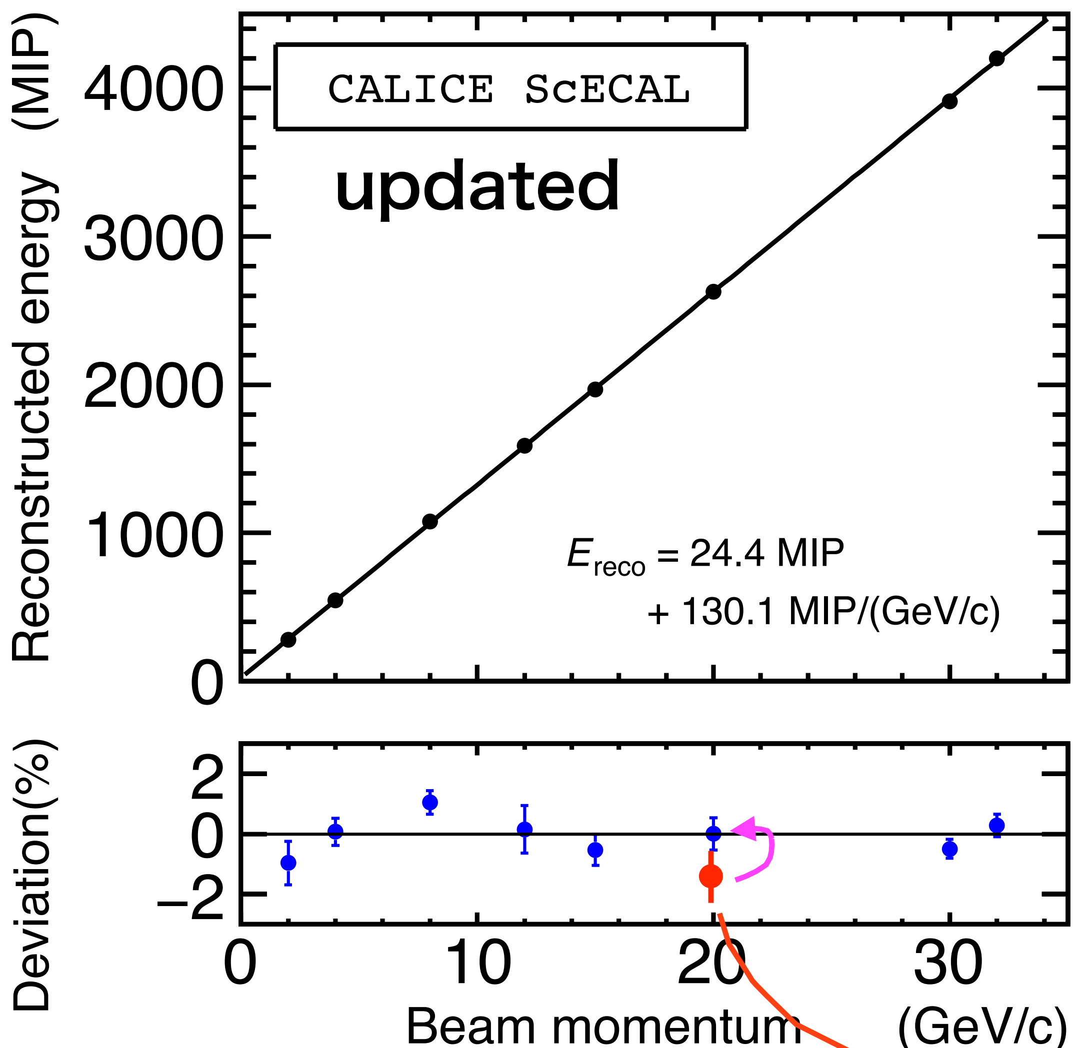
We've shown five modifications according to the requests from CALICE editorial board,

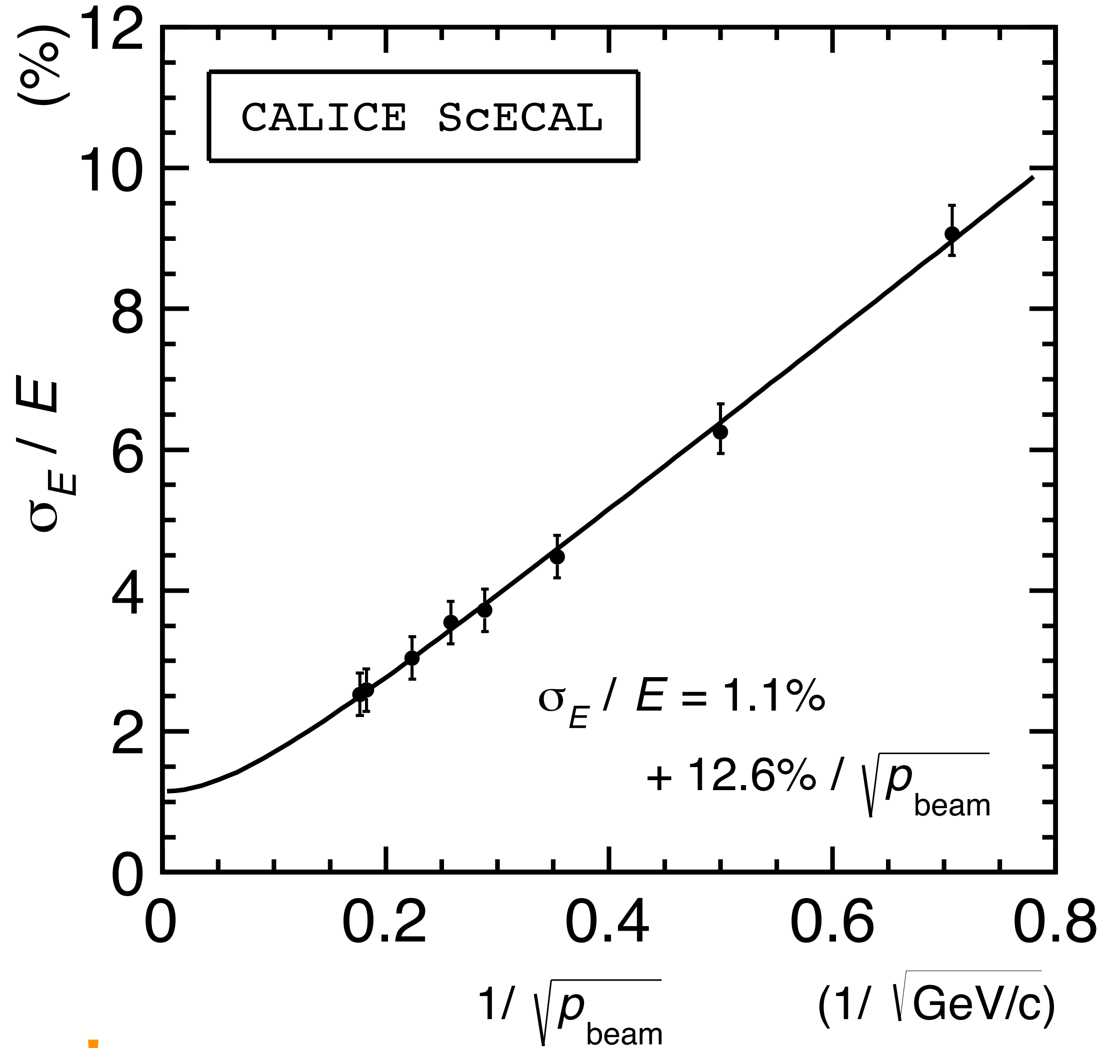
1. Calibration procedure should be entirely explain in a dedicating section.
   ➡ done.
2. Reason of cut on the inter calibration.
   ➡ done.
3. explain how to determine the systematic uncertainties come from selection cuts.
   ➡ done.
4. explain wave like structure of deviation plot from linear
   ➡ Wave like structure was disappeared.
5. more realistic simulation.
   ➡ done.

Next step:

Discuss with editorial board ➡ PUBLISH!!

Linearity and resolution





updated

	response			resolution	
	offset (MIP)	slope (dMIP/dGeV)	dev.	constant(%)	stochastic(%)
CAN16c	22.5±1.4	130.44±0.30	<1.6	$1.0^{+0.5}_{-1.0}$	12.8±0.4
current	24.4±1.7	130.12±0.25	<1.0	$1.1^{+0.5}_{-0.7}$	12.6±0.4

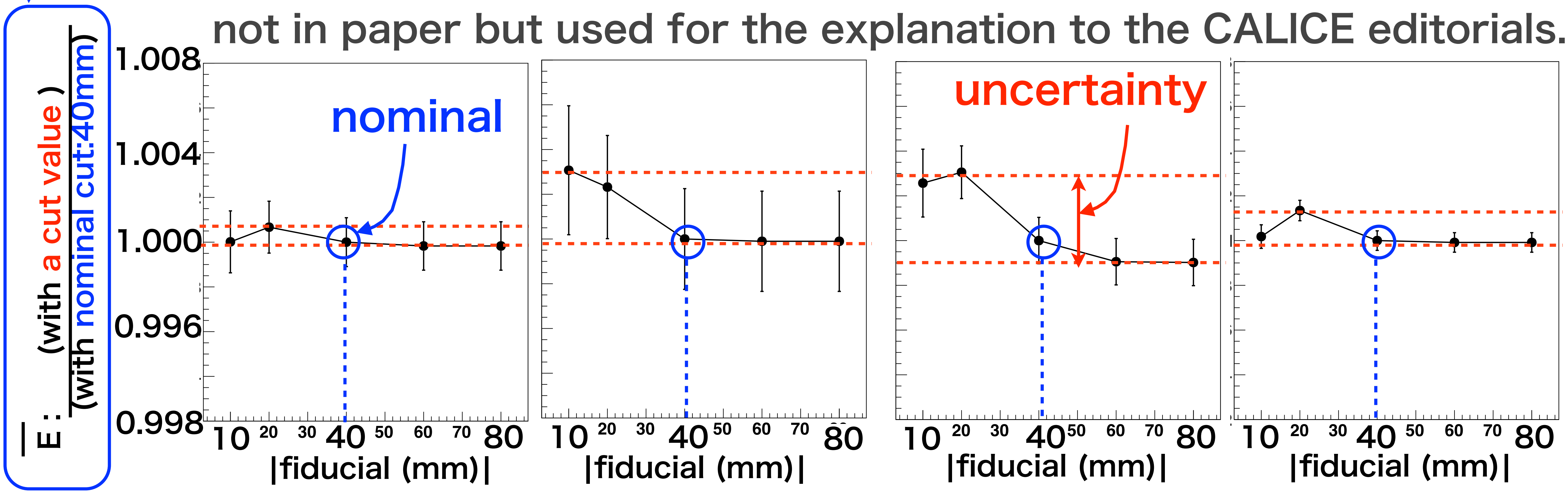
Uncertainty: statistic ⊕ systematic

Cut variations on Shower center

Ratio Ē : (with a cut value) / (with nominal cut)

example: |center-of-gravity | < 40 mm in x; 20 GeV, 4 runs
fiducial volume

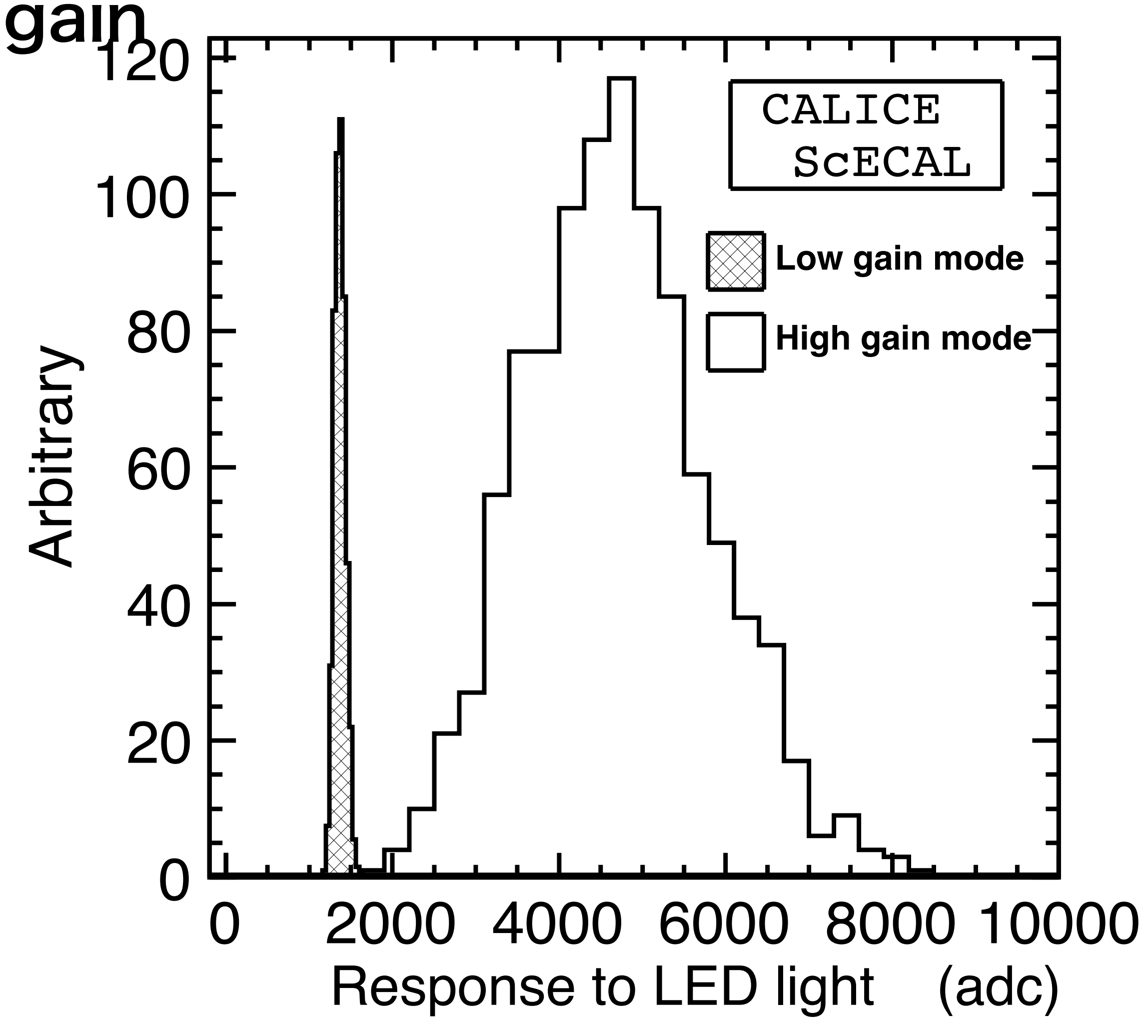
not in paper but used for the explanation to the CALICE editorials.



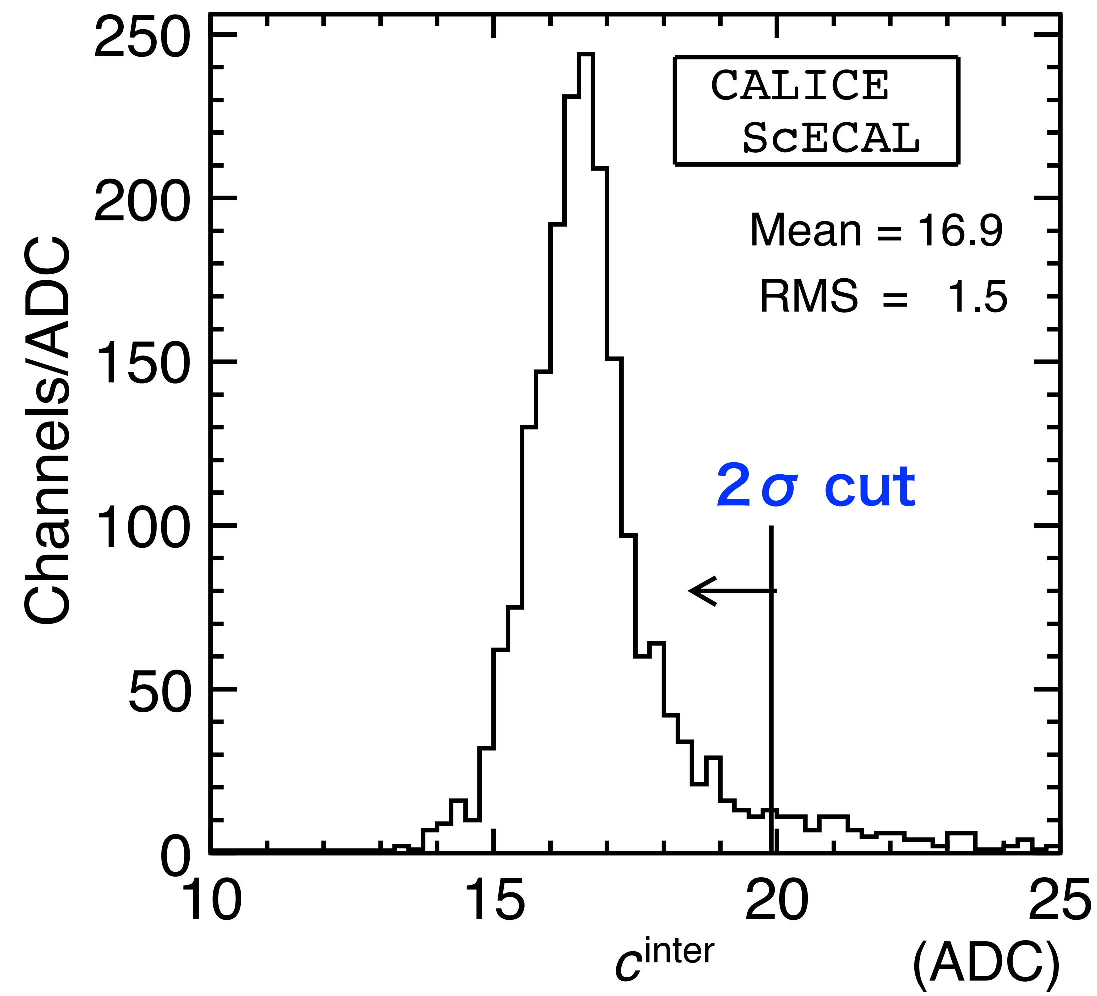
average of highest and lowest variations in runs is taken as a systematic uncertainty; variations were weighted with their uncertainty

Inter calibration

Response to a certain strength of LED light w/ Low and High gain



Distribution of Inter calibration constant c^{inter} = <ADCs>^{high}/<ADCs>^{low}



10% channels were suffered by noise from LED system (not occurs in physics runs)+ large tail

updated ➡

cut	effect on σE(%)
1σ	< 0.01
2σ	reference
3σ	< 0.01
no cut	< 0.1

Electron energy spectra

MPPC Saturation correction

add a section to entirely explain it.

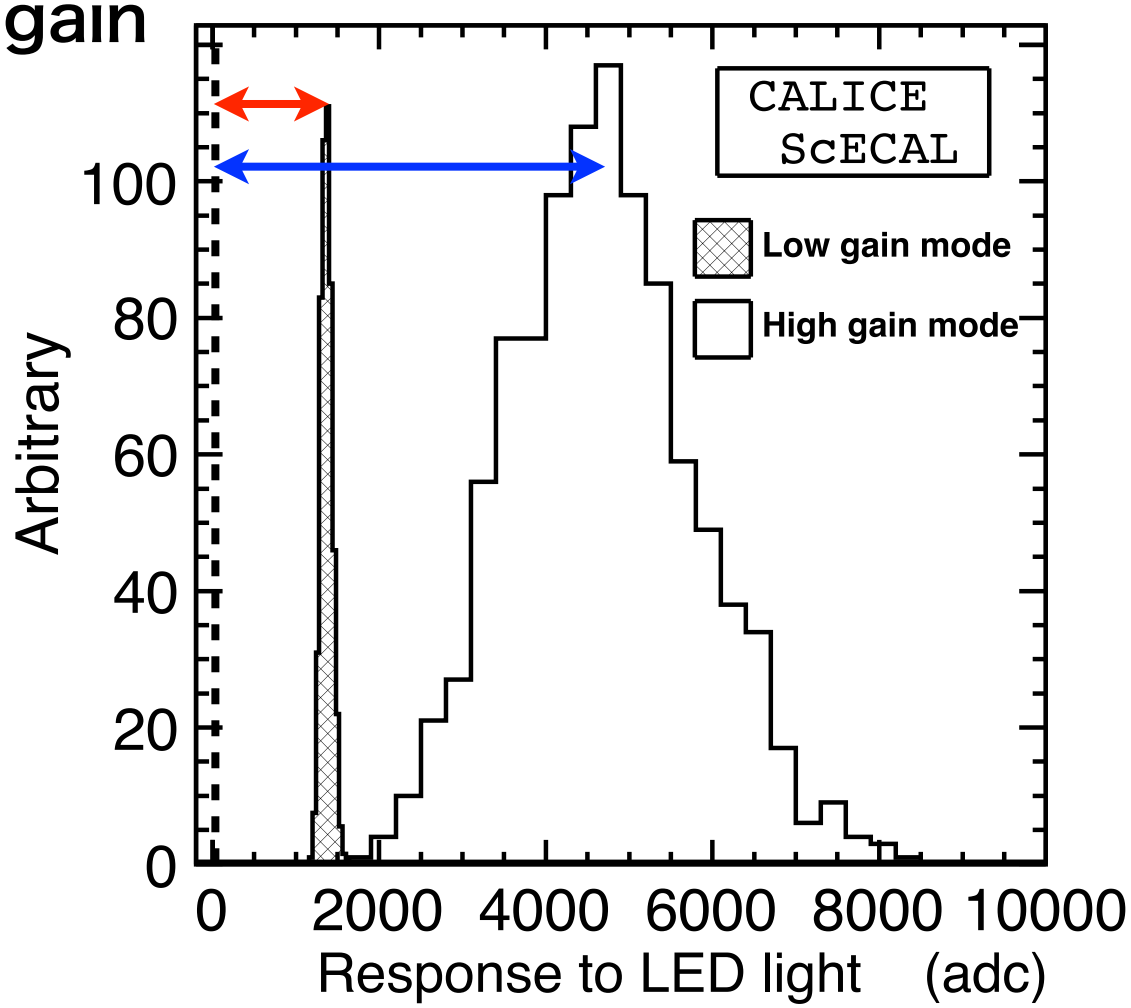
↑

We added a dedicating subsection,

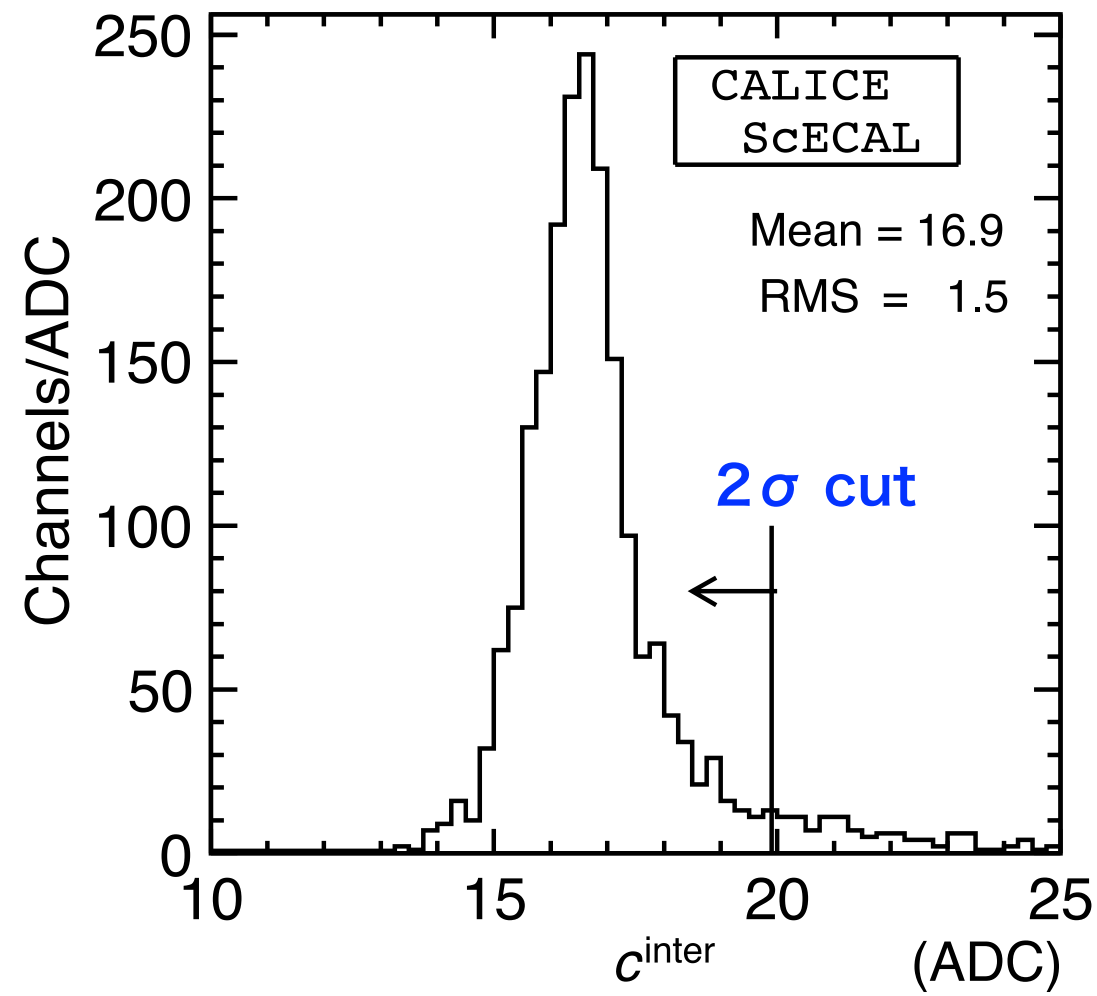
This is not update on the results, but better to give you a brief explanation of our calibration procedure.

Inter-calibration

Response to a certain strength of LED light w/ Low and w/ High gain



Distribution of Inter-calibration constant C^{inter} = $\langle ADCs \rangle^{high} / \langle ADCs \rangle^{low}$



10% channels were suffered by noise from LED system (not occurs in physics runs)+ large tail

average of C^{inter} was applied for the failed channels.

Beam momentum fluctuation

Design of MT6 beam $\Delta p/p$ (1-60 GeV/c): 2%

Pb/glass calorimeter measurement (1-4 GeV/c): 2.7±0.3%

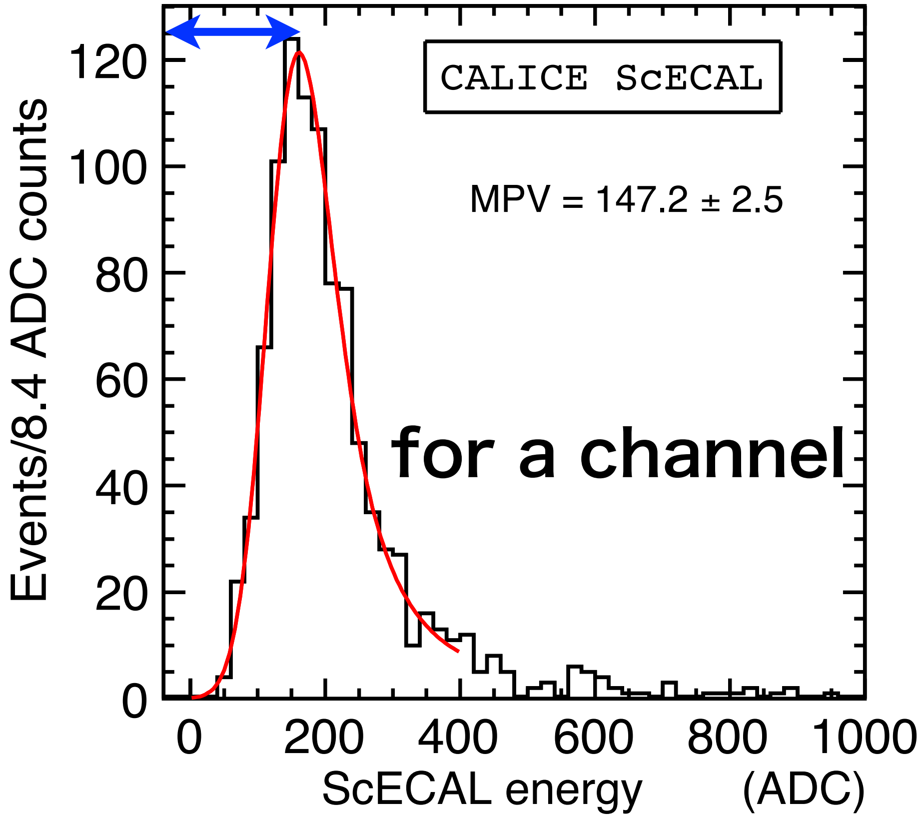
Pb/glass calorimeter measurement (8 GeV/c): 2.3±0.3%

Our limited / best knowledge:

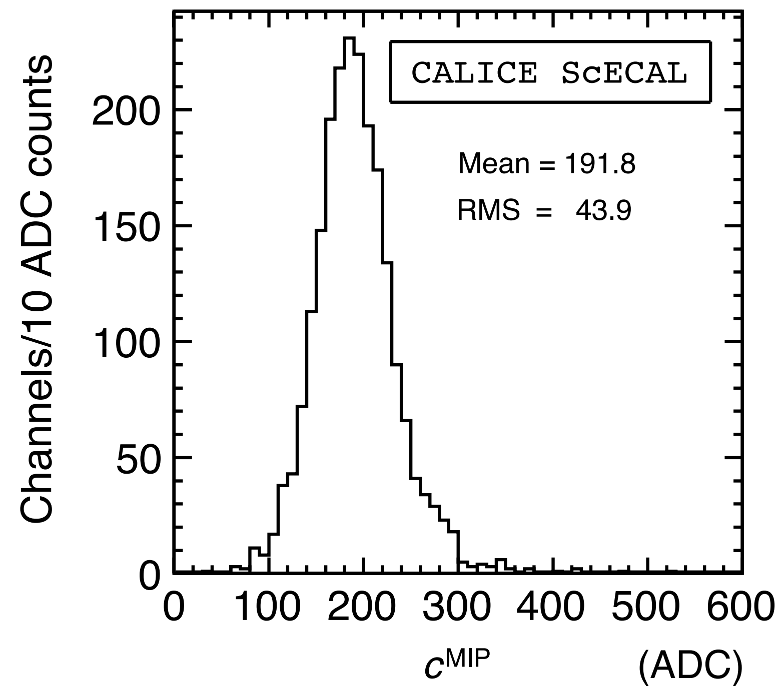
- 2 - 4 GeV/c : 2.7%, 4 GeV/c > 2.3% of intrinsic fluctuation
- systematic uncertainty : 0.3%

MIP calibration

MIP calibration factor(c^{MIP})

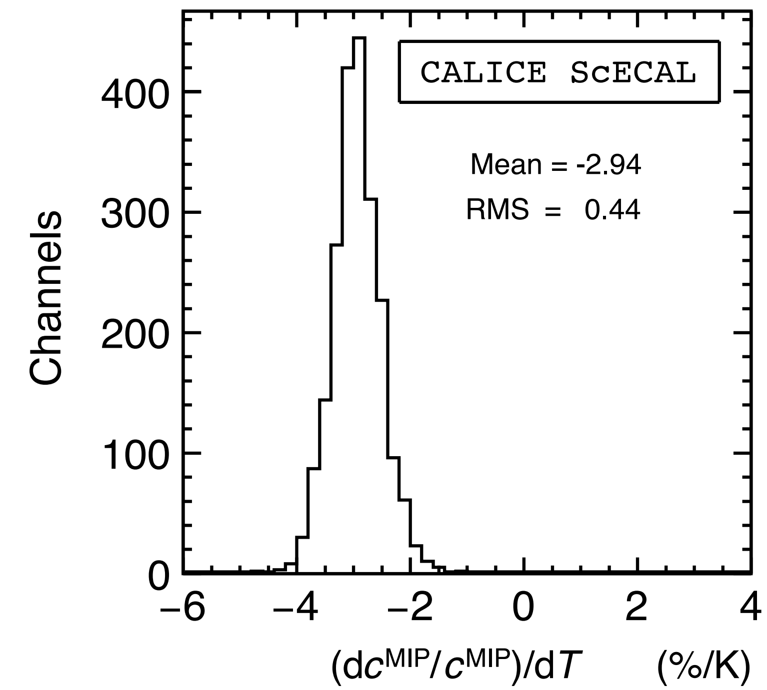


dist. c^{MIP} at 20℃

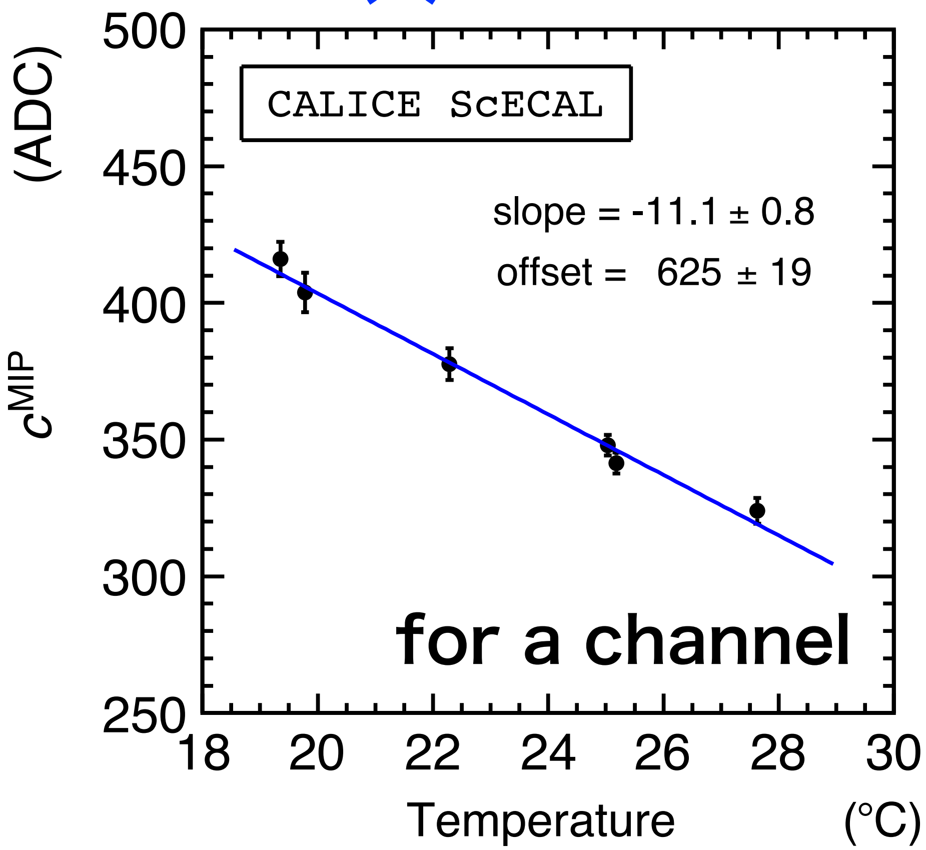


dist. slope

$(dc^{MIP}/c^{MIP})/dT$



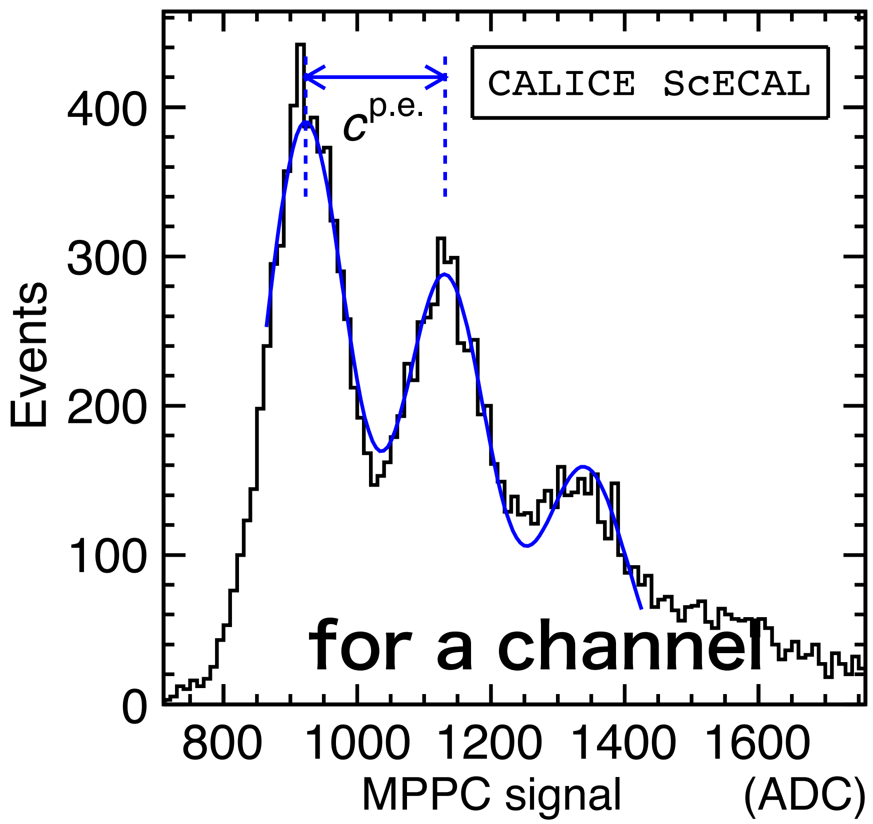
$c^{MIP}(T)$



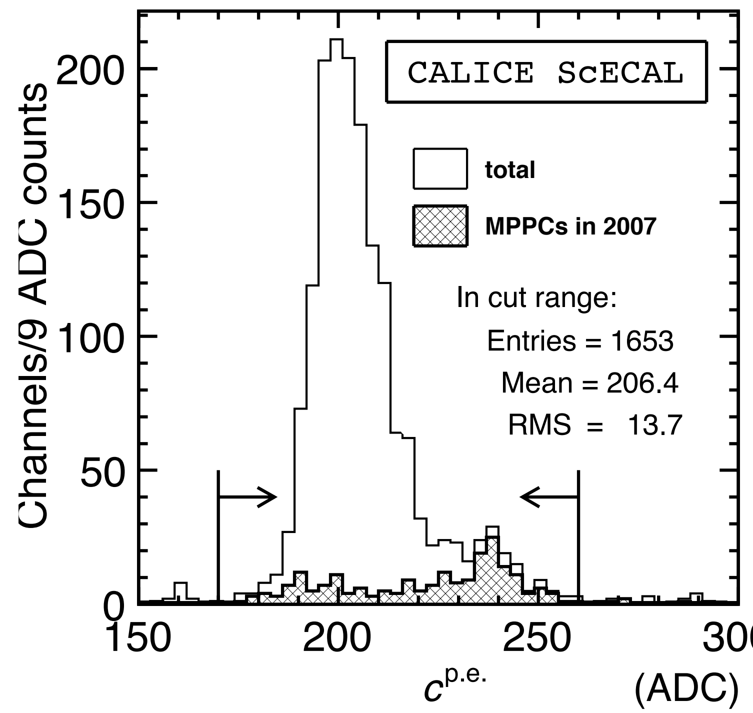
- MPV (c^{MIP})s of 7 temperature conditions were measured
- Each signal was converted in the # of MIPs using c^{MIP} at 20°C and slope $(dc^{MIP}/c^{MIP})/dT$
- $c^{MIP}(T)$ for every channel was determined except 2 dead channels.

MPPC Gain calibration

Gain calibration factor($c^{p.e.}$)

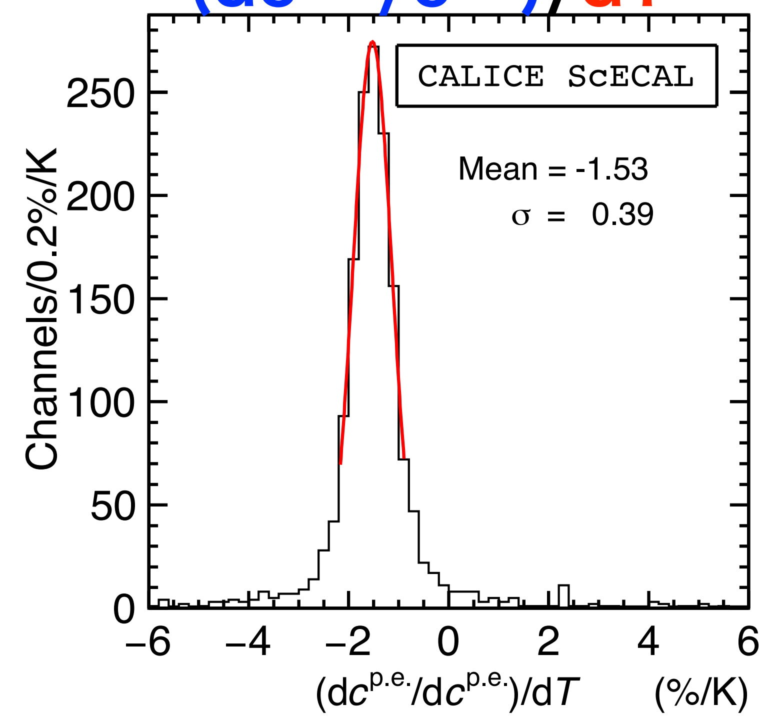


dist. $c^{p.e.}$ at 20℃

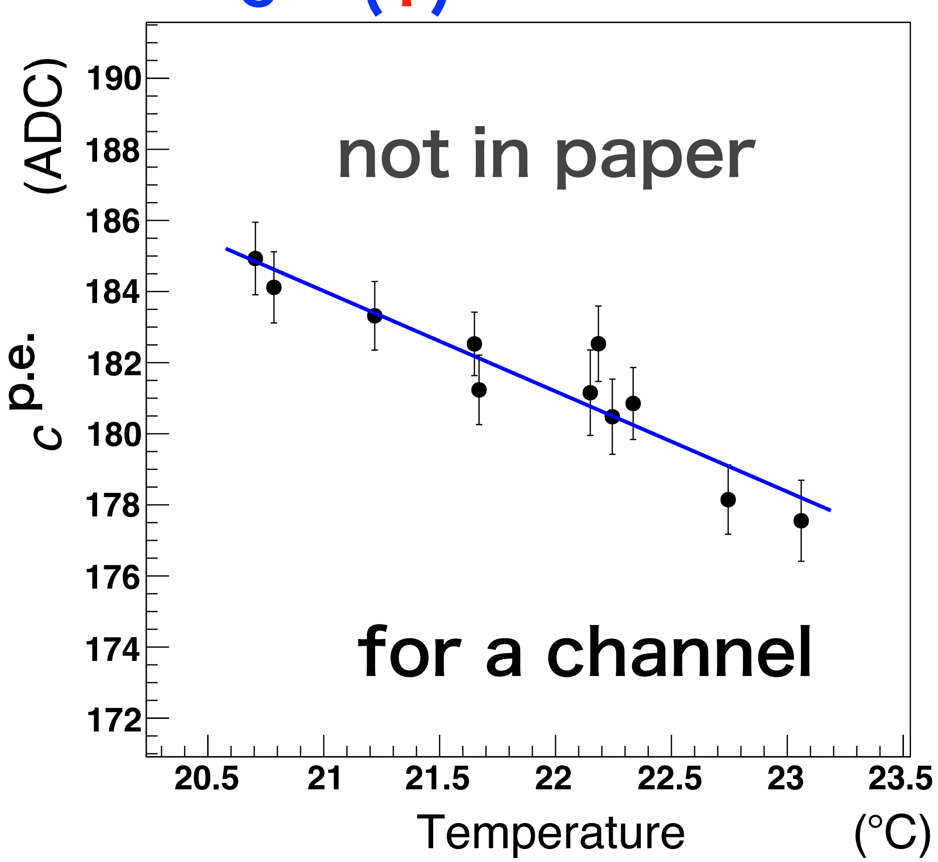


dist. slope

$(dc^{p.e.}/c^{p.e})/dT$



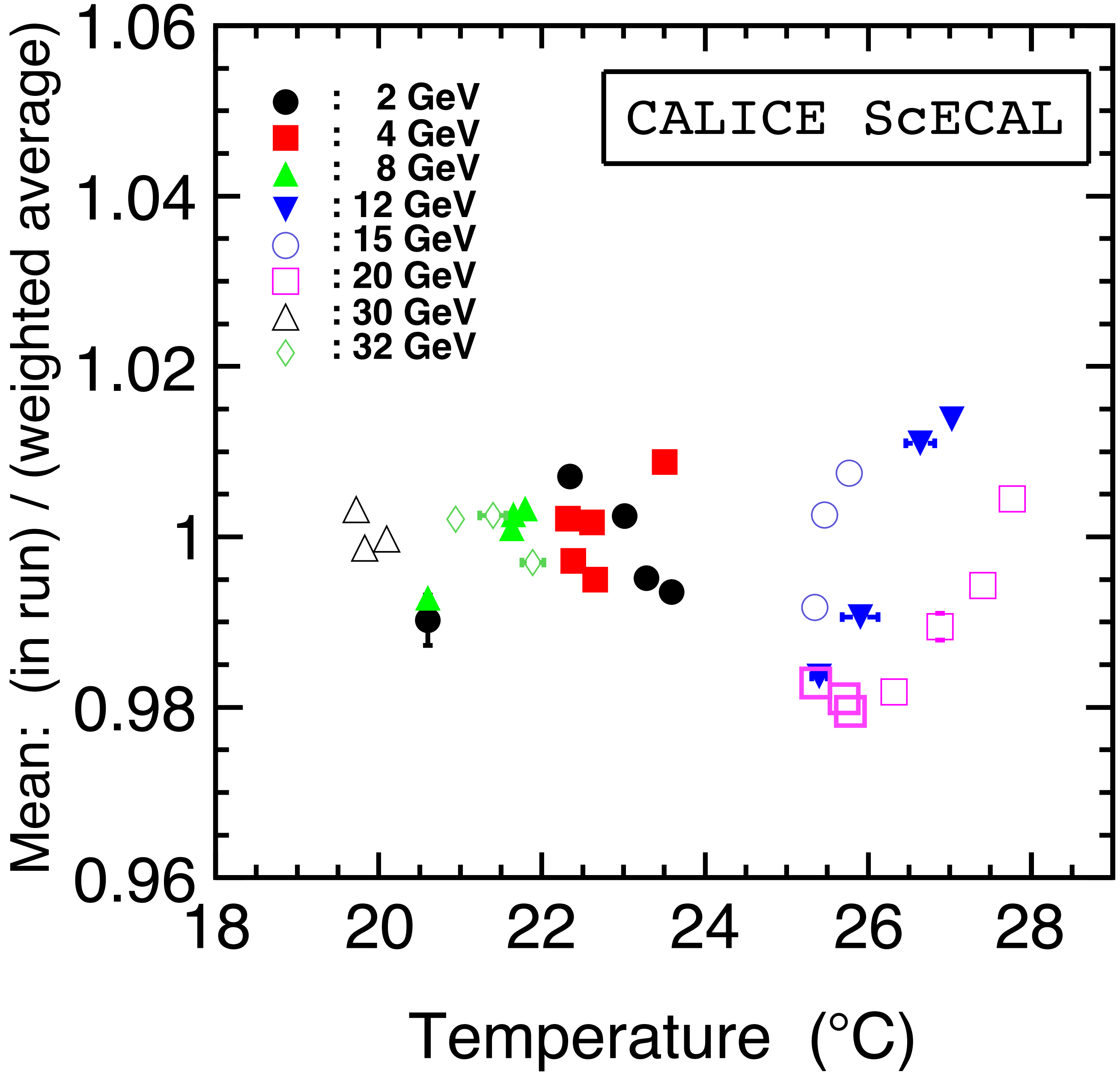
$c^{p.e.}(T)$



- Gain ($c^{p.e.}$)s of 11 temperature conditions were measured
- Each signal was converted in the # of p.e. using $c^{p.e.}$ at 20°C and slope $(dc^{p.e.}/c^{p.e.})/dT$
- $c^{p.e.}(T)$ for 76.5% of 2160 channels ware determined,
  20%: double-peak pedestal or no separation,
  3%: range cut--above plot.
- use average value of $c^{p.e.}$(20℃) and $(dc^{p.e.}/c^{p.e})/dT$ for failed channels.

Run variations

We had known that the run variations of E_{mean} is larger than their uncertainty



Plot shows
ratio of Energy mean
[run by run / average].

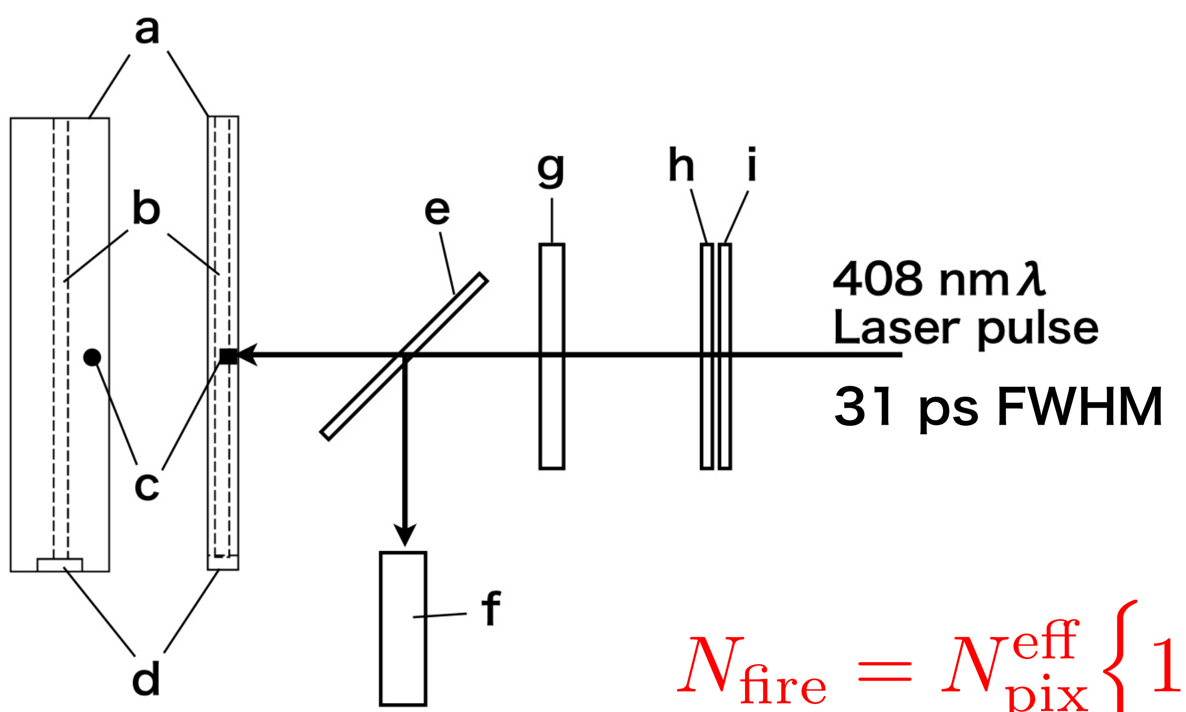
Unclear dependence on temperature.

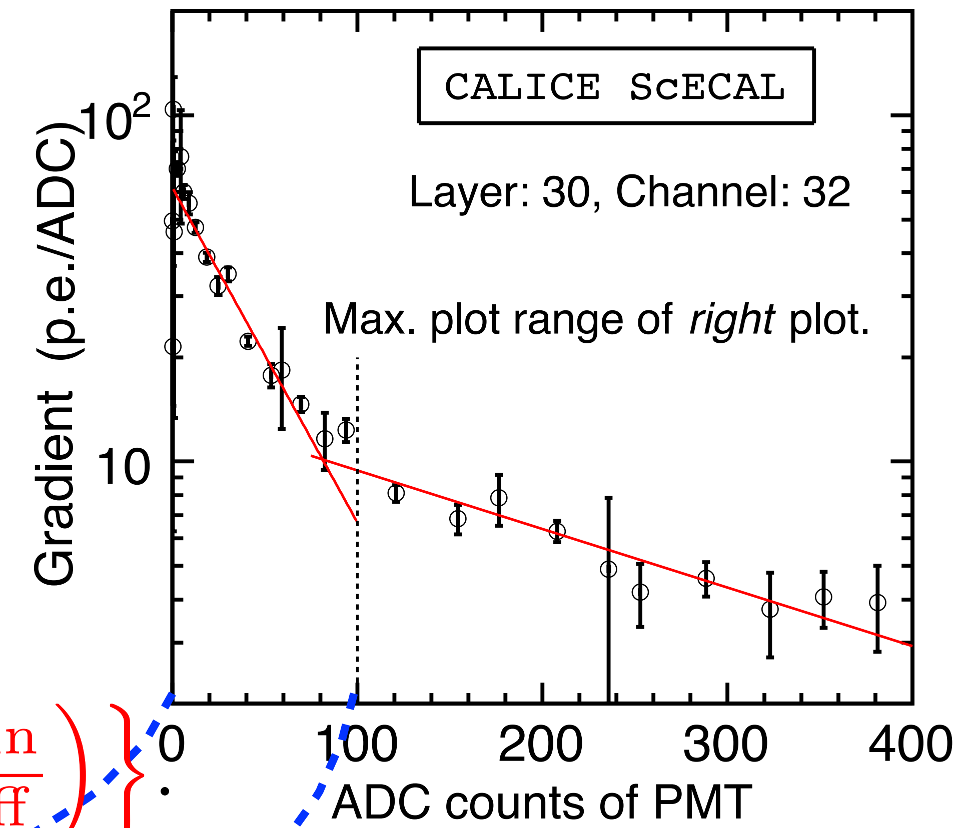
$$\bar{x} \pm \delta\bar{x} = \frac{\sum_i \omega_i x_i}{\sum_i \omega_i} \pm \left(\sum_i \omega_i\right)^{-1/2}$$

$$\omega_i = 1/(\delta x_i)^2$$

MPPC response function

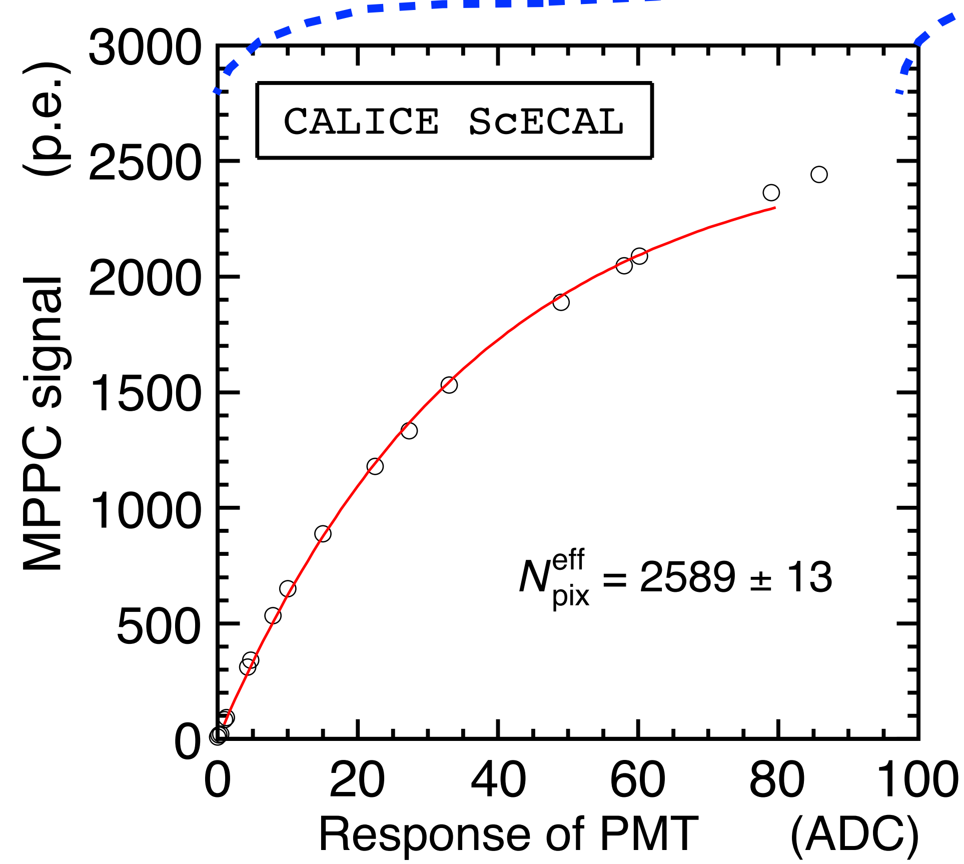
Samples are 72 channels in 30th layer.



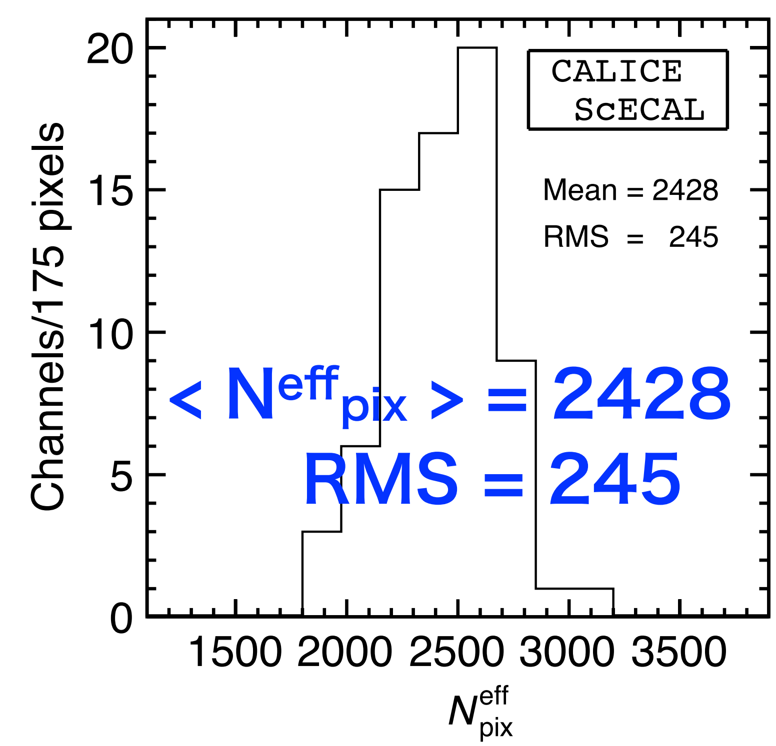


$$N_{\rm fire} = N_{\rm pix}^{\rm eff}\left\{1-\exp\left(-\frac{\epsilon N_{\rm in}}{N_{\rm pix}^{\rm eff}}\right)\right\}.$$

a. scintillator
b. WLS fiber
c. hole on reflector
d. MPPC
e. half miller
f. PMT
g. lens
h,i. polaroid

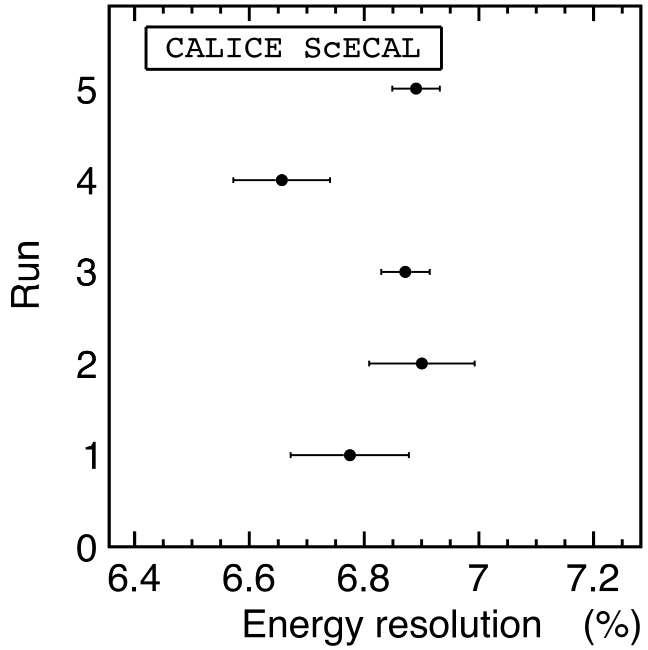


Distribution of N^{eff}_{pix}



Run variations

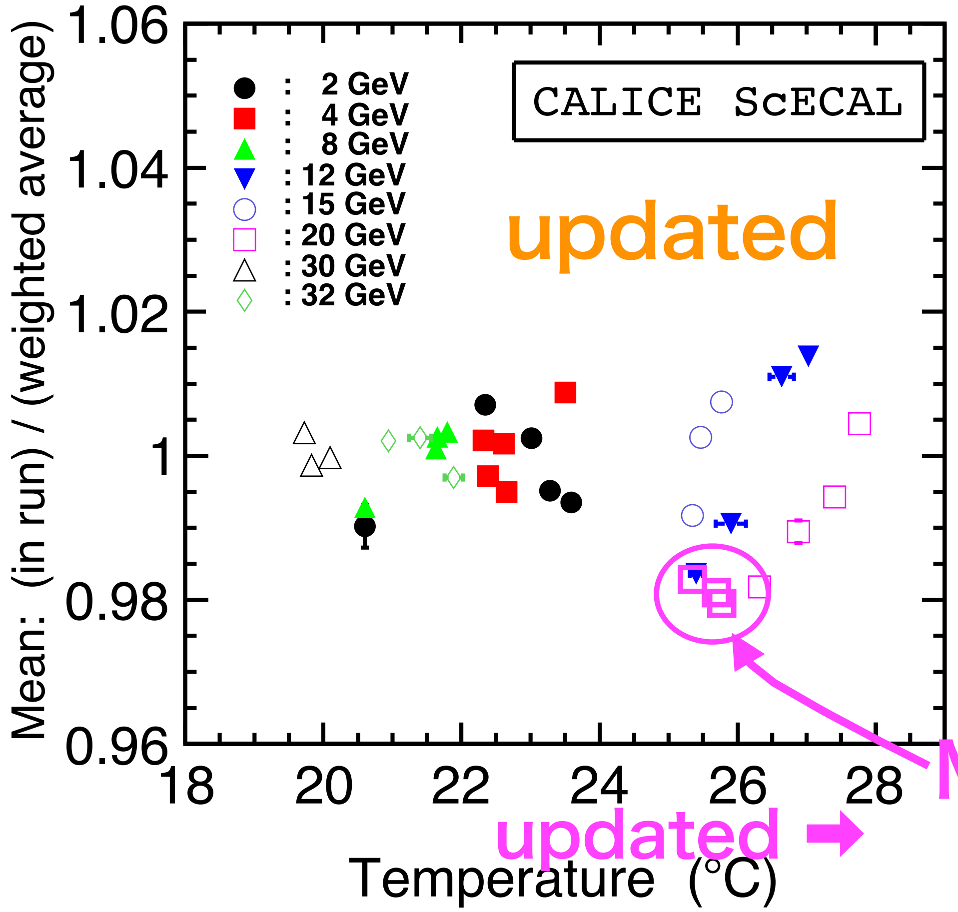
Energy resolution



Run variations in the energy resolution are reasonable w.r.t their uncertainties.

4 GeV/c as an example

Energy mean [mean(run)/ average]



Run variations are larger than that uncertainties.

Unclear dependence on temperature.

use Error weighted mean:

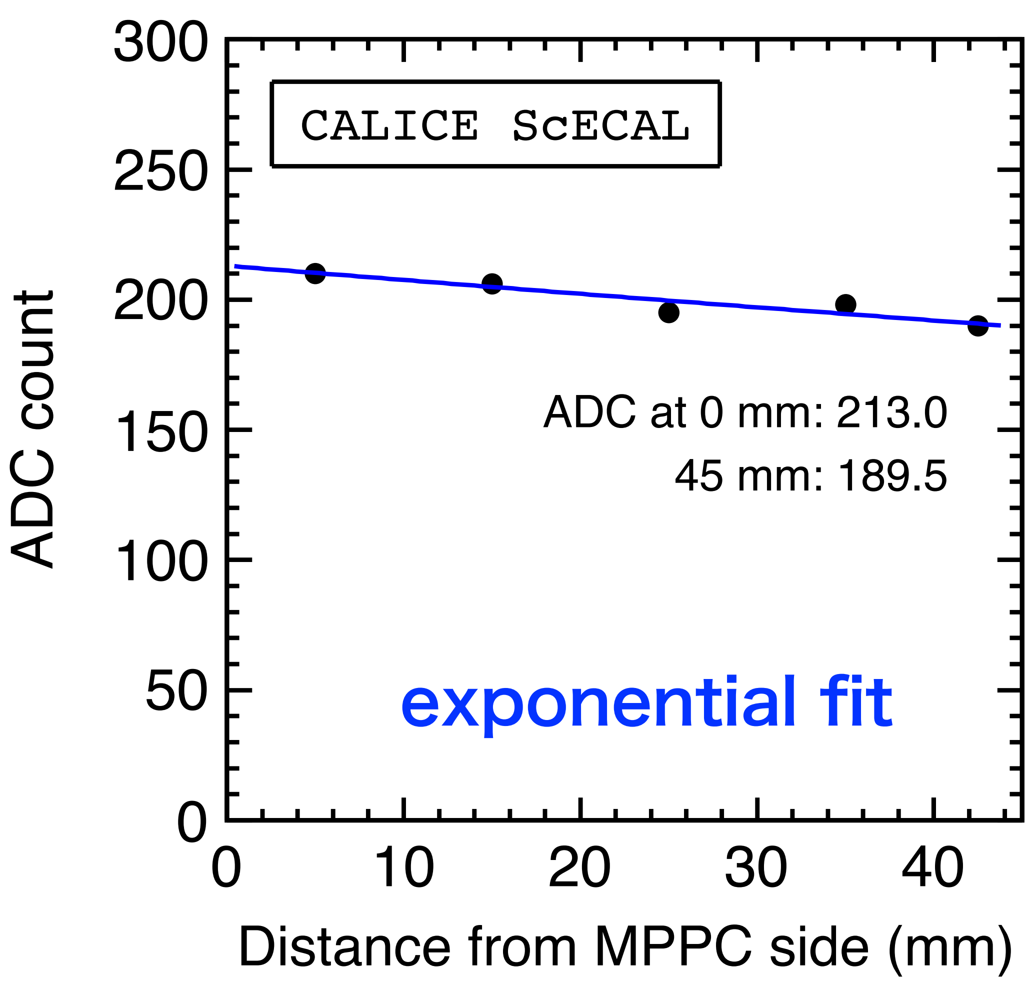
$$\bar{x} \pm \delta\bar{x} = \frac{\sum_i \omega_i x_i}{\sum_i \omega_i} \pm \left(\sum_i \omega_i\right)^{-1/2}$$

$$\omega_i = 1/(\delta x_i)^2$$

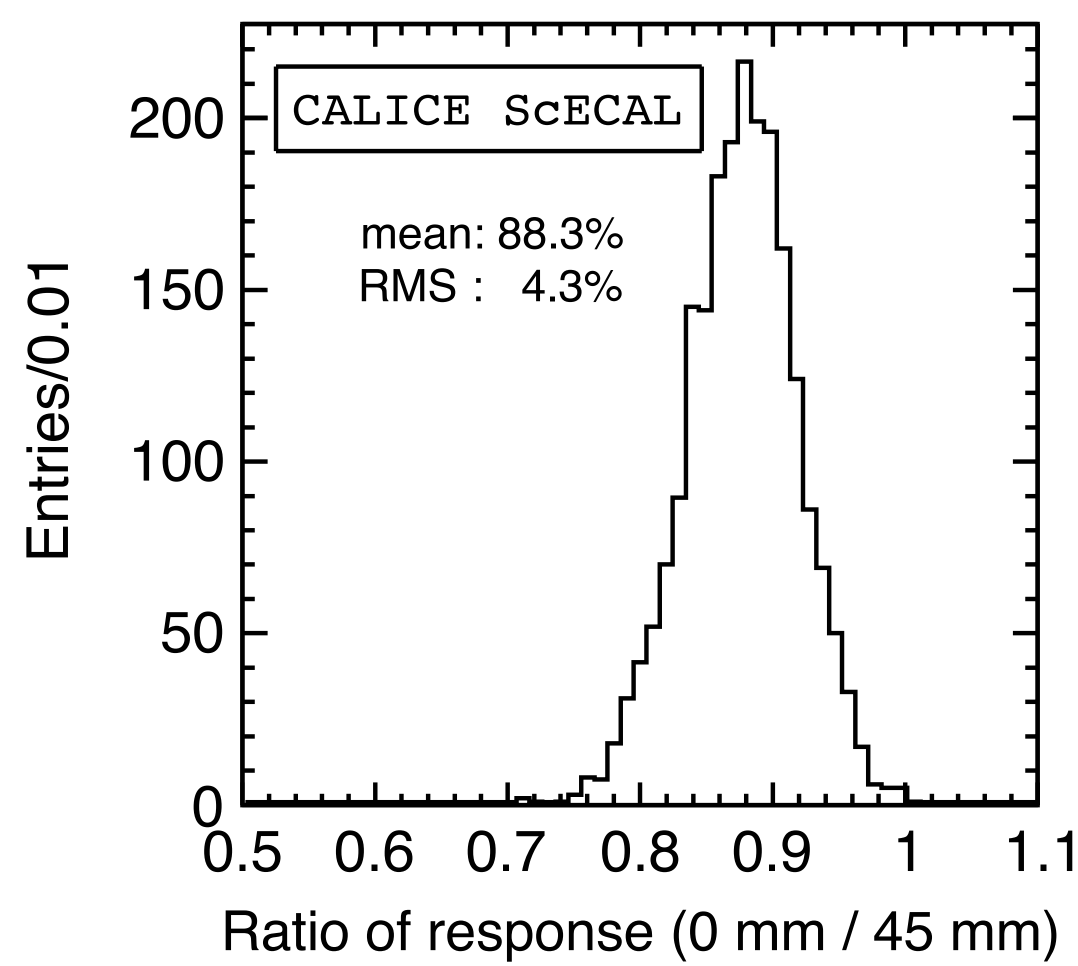
Response uniformities

updated

Position dependence of response--the distance from MPPC--was determined by position information from hits on the orthogonal layers.



Distribution of ratio $\frac{\text{response at 45mm}}{\text{response at 0mm}}$



MC ignores the effect of this non uniformity

➡ 88.3% uniformity is enough.

Other properties

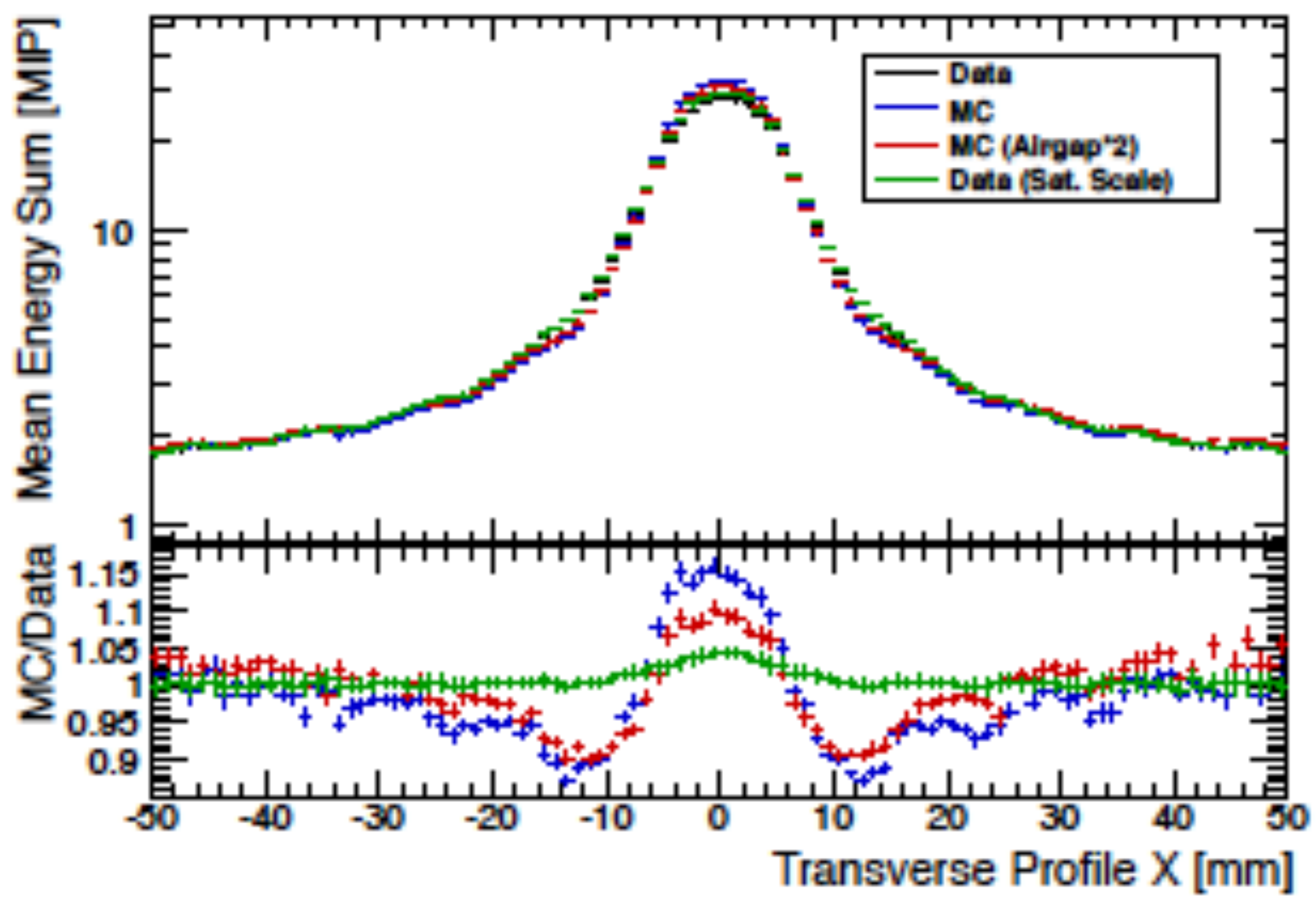
- DAQ system was the same as AHCAL phys. prototype,

- Scintillator strips were made with an extrusion method at KNU,

- Response uniformity of strip was improved than 1st prototype,

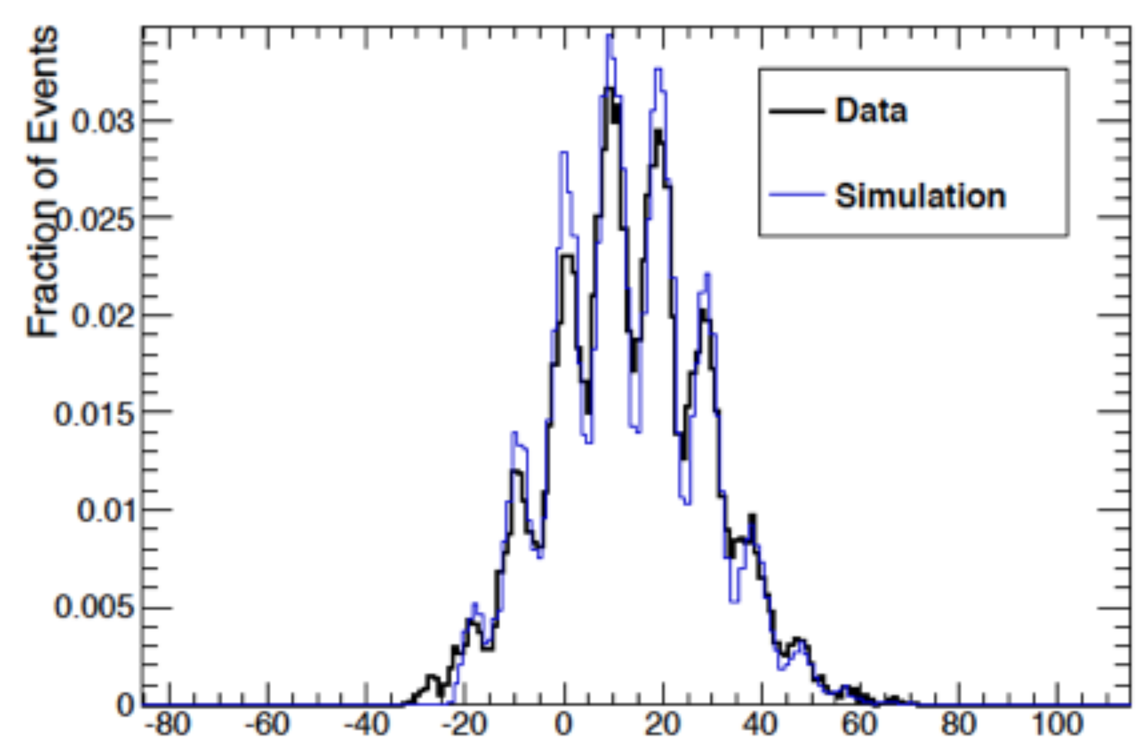
Data vs. MC

lateral projection (20 GeV/c)



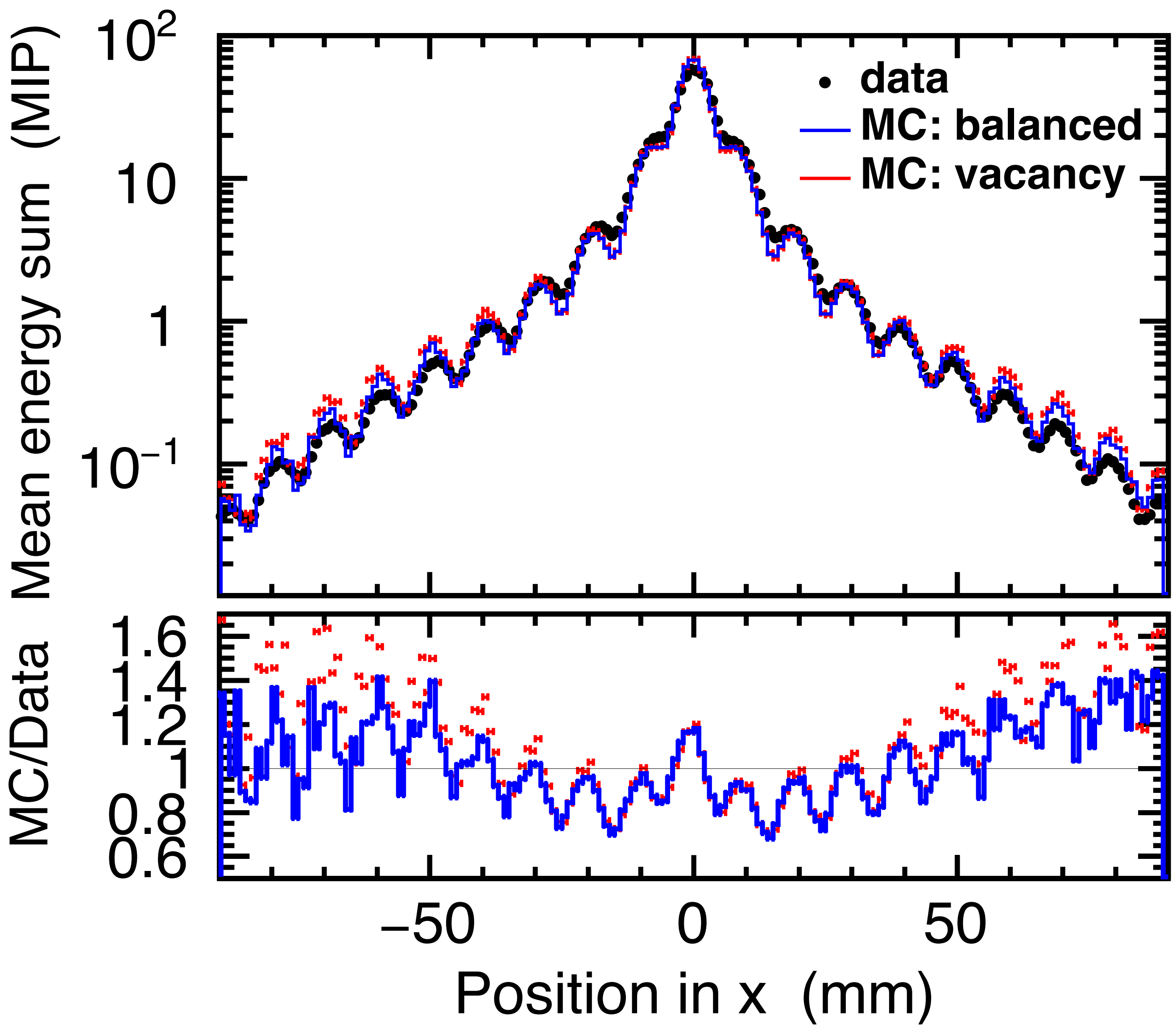
MC distribution is sharper than data.

Any assumptions failed to explain the phenomenon to date.



Data vs. MC

lateral projection (12 GeV/c)



Hit position - shower center
c-o-g

10 mm structure was smeared by subtraction of C-o-G.

Totally good agreement.
Again balanced method has good agreement

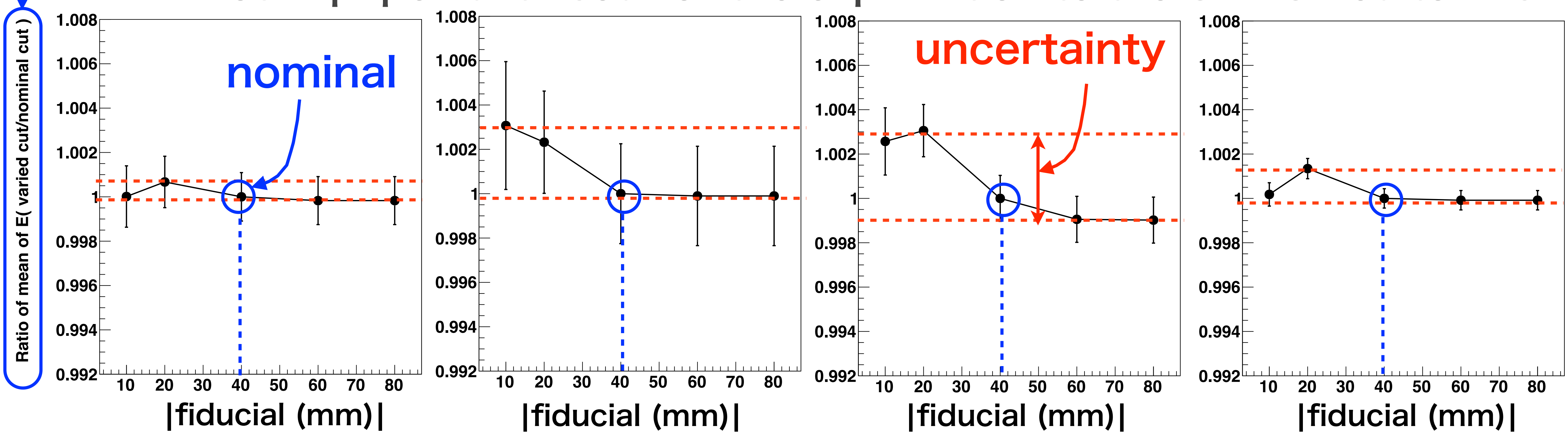
Effect of difference of the distribution of C-o-G between MC and Data reflects the disagree here.

Cut variations on Shower center

Ratio Ē : (with a cut value) / (with nominal cut)

example: |center-of-gravity | < 40 mm in x; 20 GeV, 4 runs
fiducial volume

not in paper but used for the explanation to the CALICE editorials.



average of highest and lowest variations in runs is taken as a systematic uncertainty; variations were weighted with their uncertainty.