Results of ScECAL FNAL-TB
-Linearity and Energy Resolution-

CALICE ScECAL group
Toshinori Ikuno
(University of Tsukuba)

Outline

1. ScECAL FNAL-TB
2. ScECAL proto-type
3. MIP calibration constants
4. The selection of beam position
5. Correction for MPPC saturation
6. Results
7. Summary

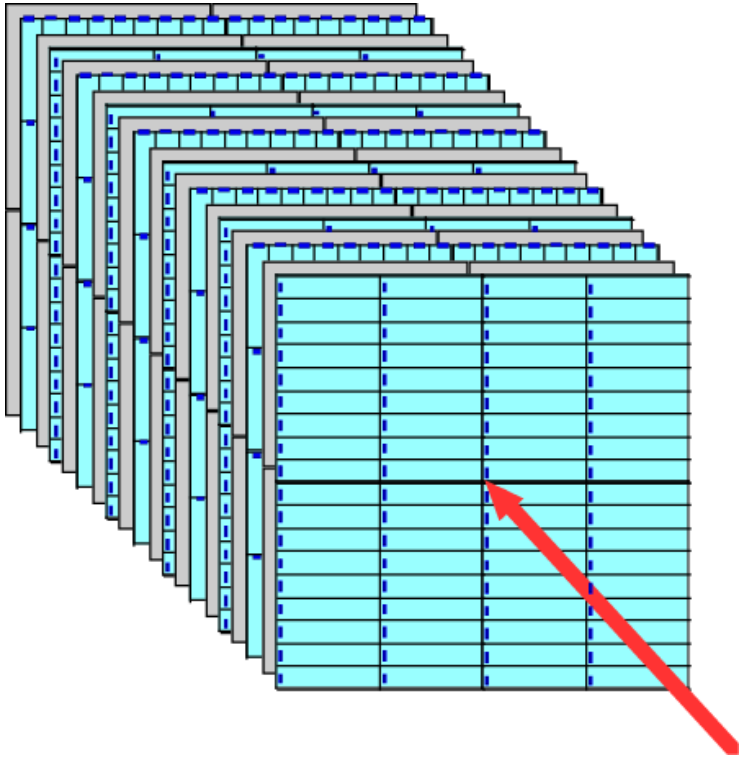
ScECAL FNAL-TB

ScECAL

Scintillator stirp structure to achieve fine granularity for PFA.

- Strip production
- Photon sensor (MPPC)
- Huge number of channels
- Gain monitoring system

• First need to establish the feasibility. → **Beam Test**



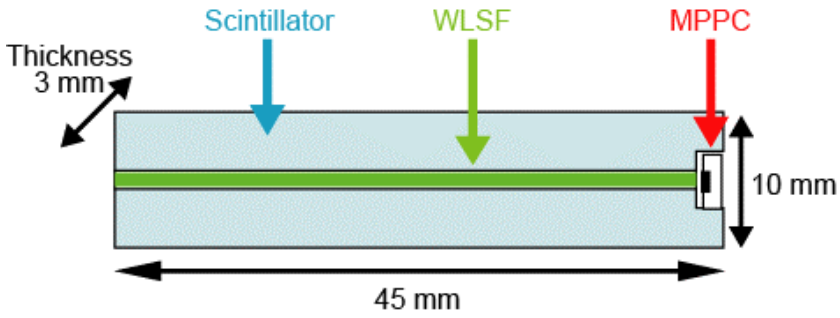
CALICE FNAL-TB

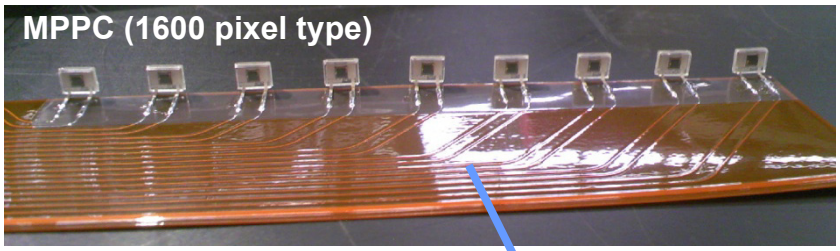
The ScECAL was tested with AHCAL in September.

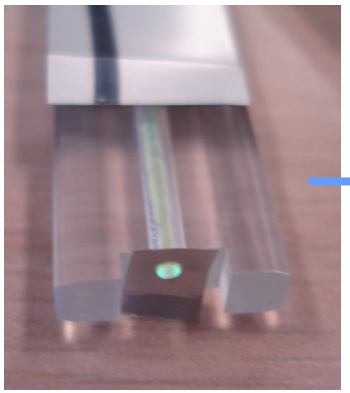
Calorimeter for ILC

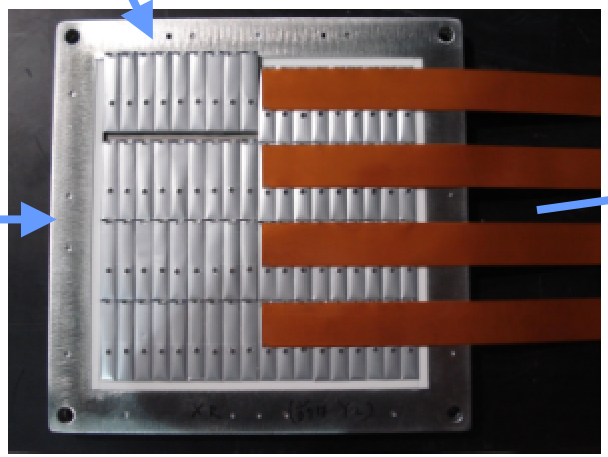
ScECAL proto-type

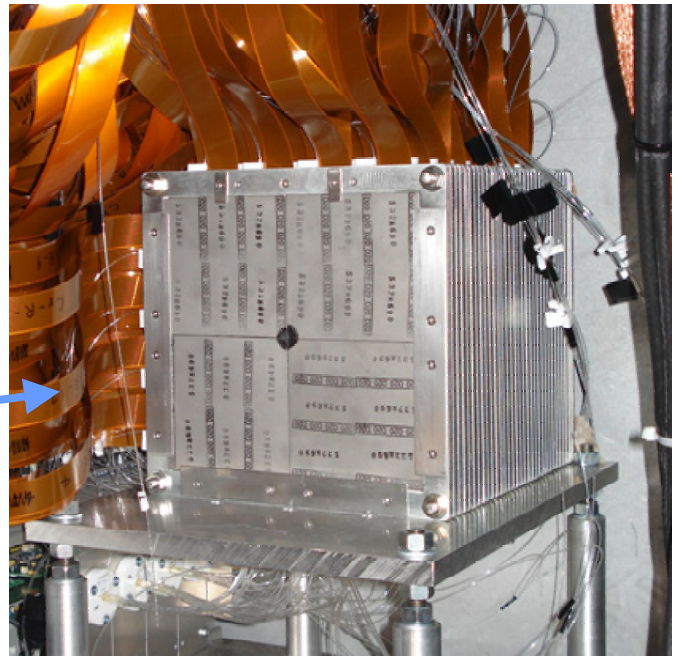
18 cm x 18 cm x 26 cm (without frames)
Radiation Length : 21.45 X_0
Absorber : mainly Tungsten (85%)
18 x 4 channels / layer
Total : 30 layers (2160 channels)









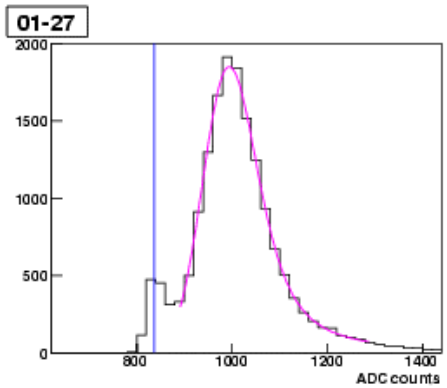


Odd : X layer
Even : Y layer

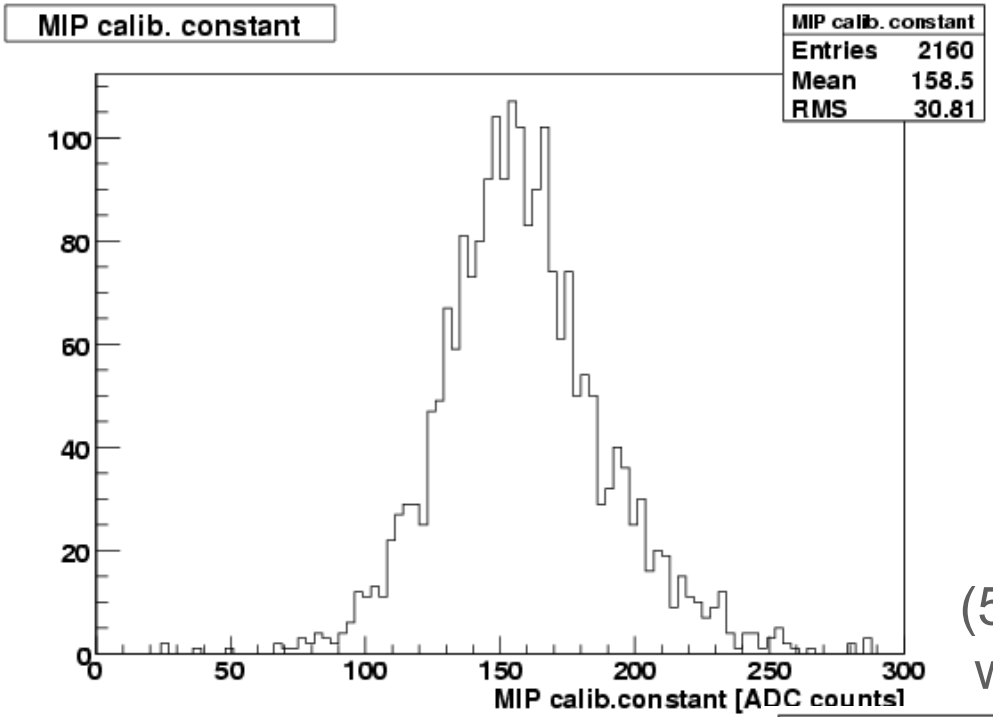
MIP calibration constants

with 32 GeV μ beam.

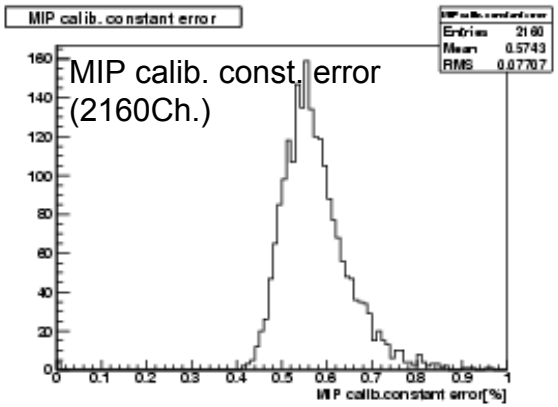
A typical
MIP distribution



The fitting function:
Gaussian convoluted
landau distribution



(5 channels were dead.)

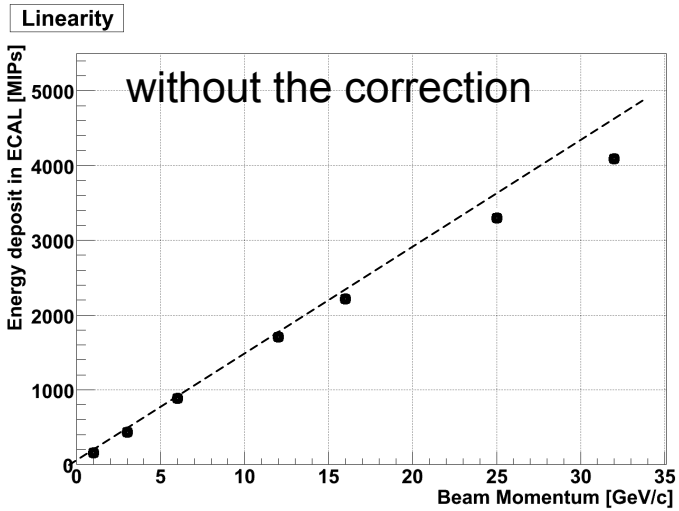


The average is about 160 ADC counts / MIP, and the average of the errors is about 0.5%. For the 2160 channels, the deviation is about 20 % (30 ADC counts).

Correction for MPPC saturation

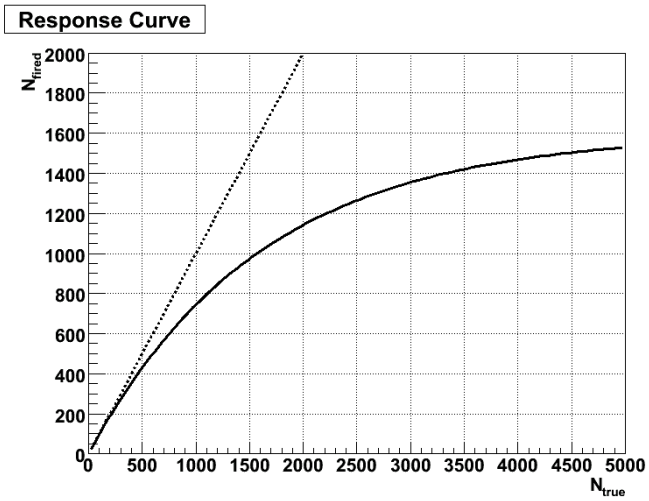
A one of important points on the energy estimation with ScECAL. (common with AHCAL as long as with a similar structure)

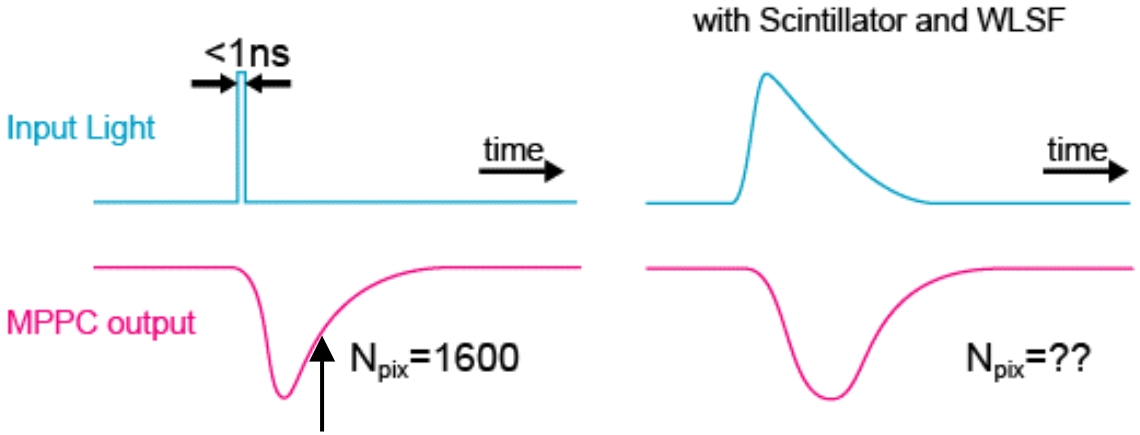
->The response curve is required.



The response curve function

$$N_{fired} = N_{pix}\left(1-\exp\left(\frac{N_{true}}{N_{pix}}\right)\right)$$

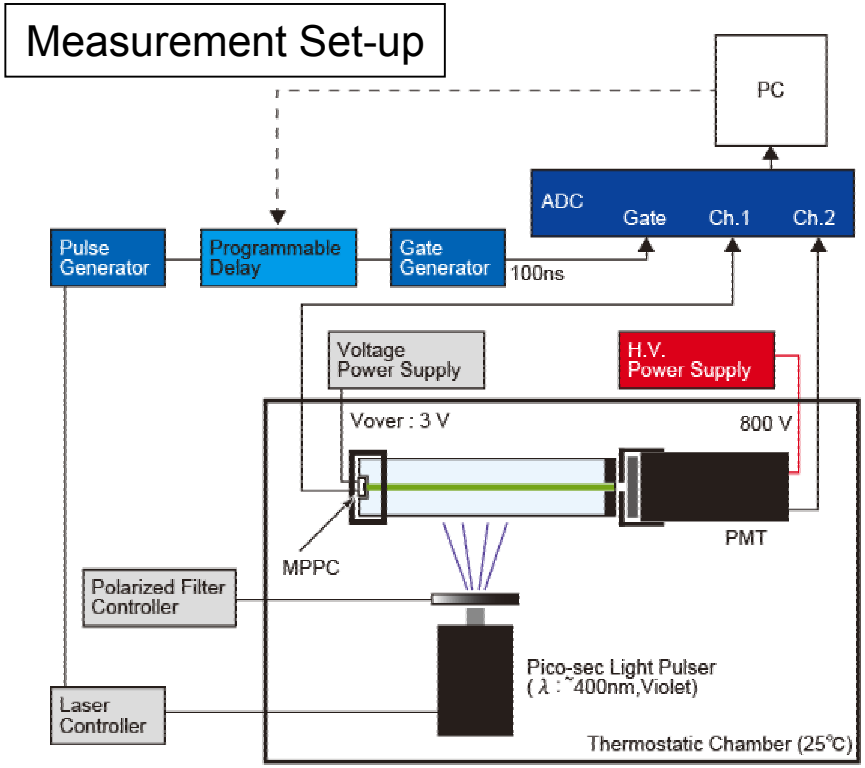




Hamamatsu MPPC(APD pixel)
Recovery Time : τ = ~ 4 ns

-> Measurement of the response curve with Scintillator and WLSF

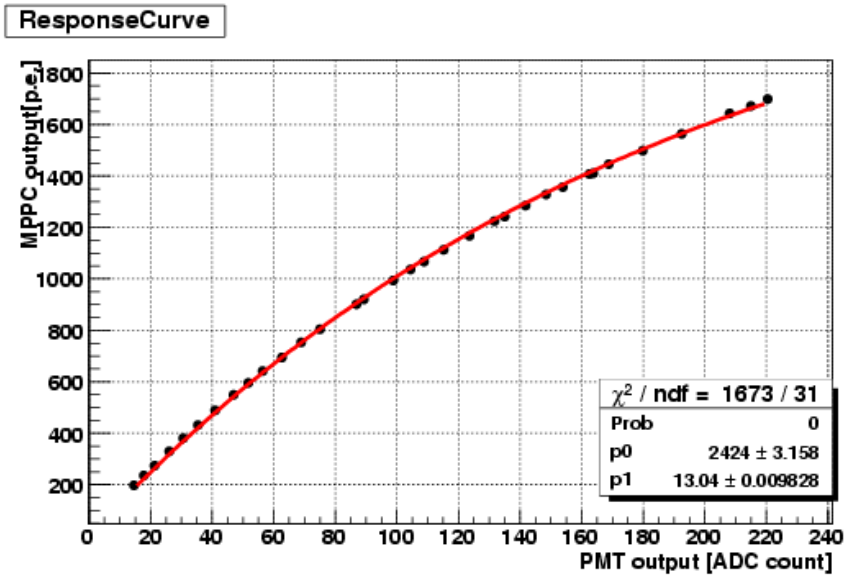
The response curve measurement



$$N_{fired} = N_{pix}\left(1-\exp\left(\frac{N_{true}}{N_{pix}}\right)\right)$$

Fit function

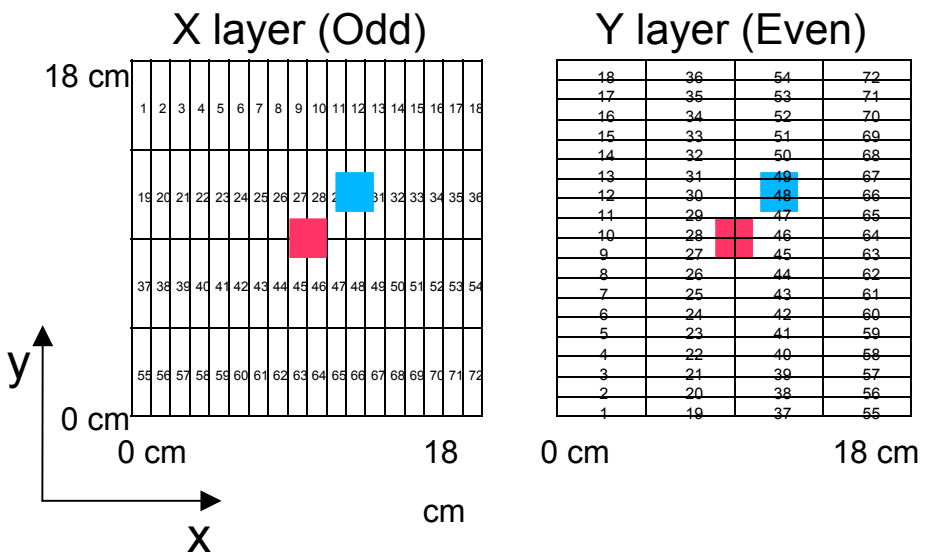
$$Output_{MPPC} = \mathrm{p0}\left(1-\exp\left(\frac{\mathrm{p1}\times Output_{PMT}}{\mathrm{p0}}\right)\right)$$



Result : N_{pix}=2424 ± 3

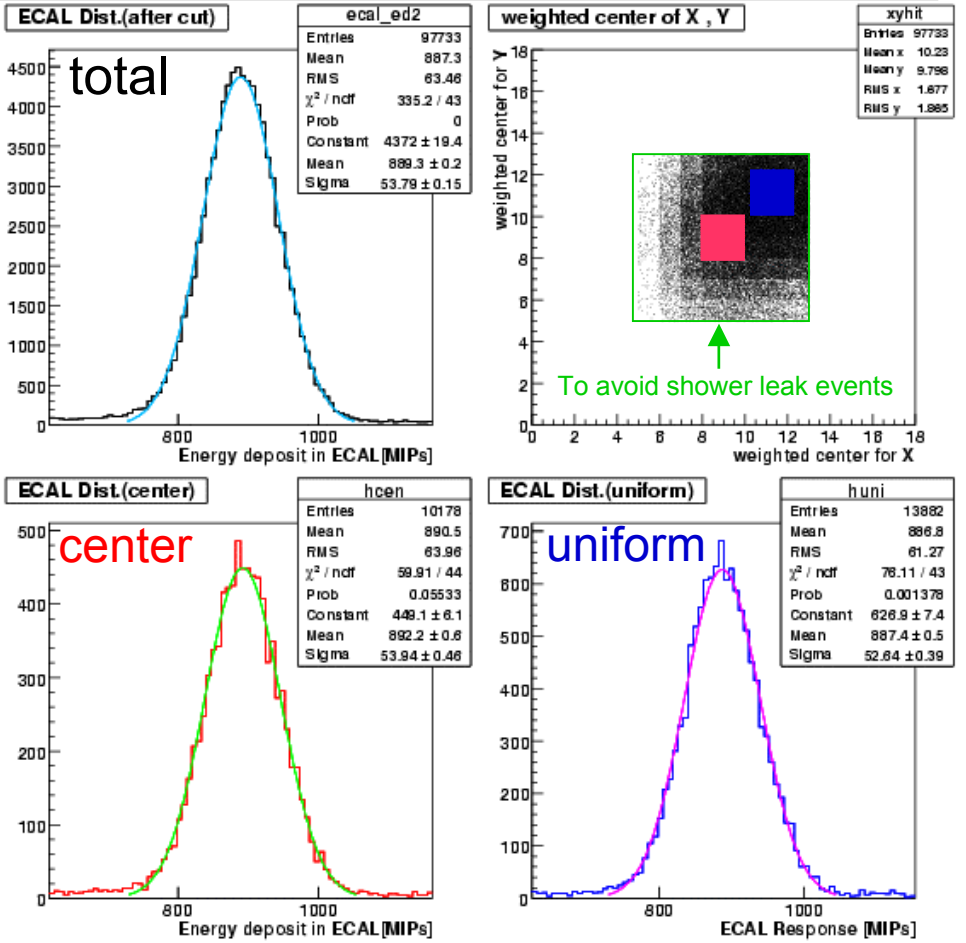
The selection of beam position

Because of the non-uniformity of scintillator,
The difference of the energy resolution
is expected by beam position.



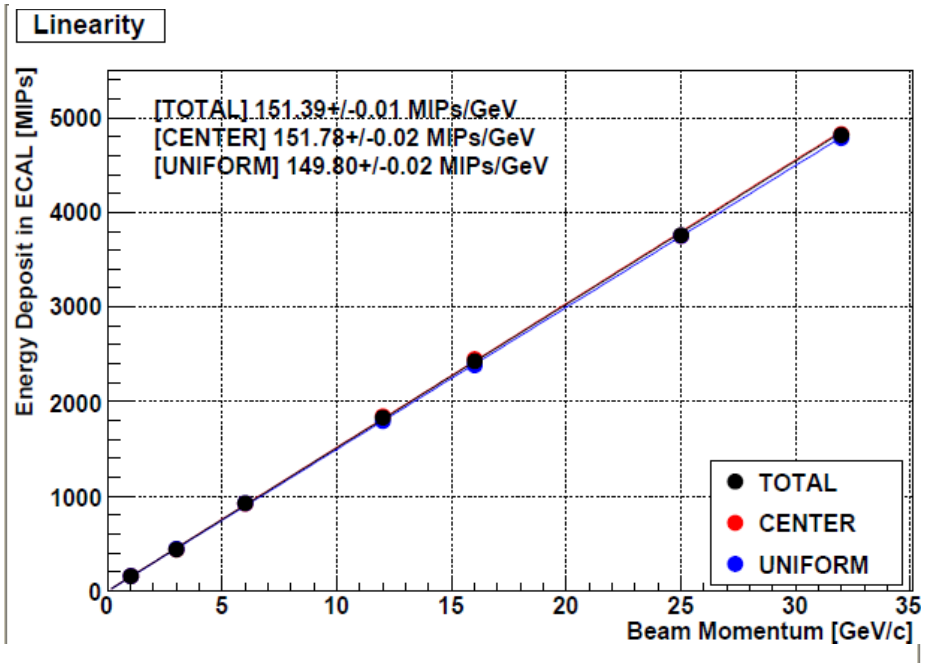
The center region (non-uniform)
(x,y)=(9.0 ± 1.0, 9.0 ± 1.0) cm
The uniform region
(x,y)=(11.5 ± 1.0, 11.5 ± 1.0) cm

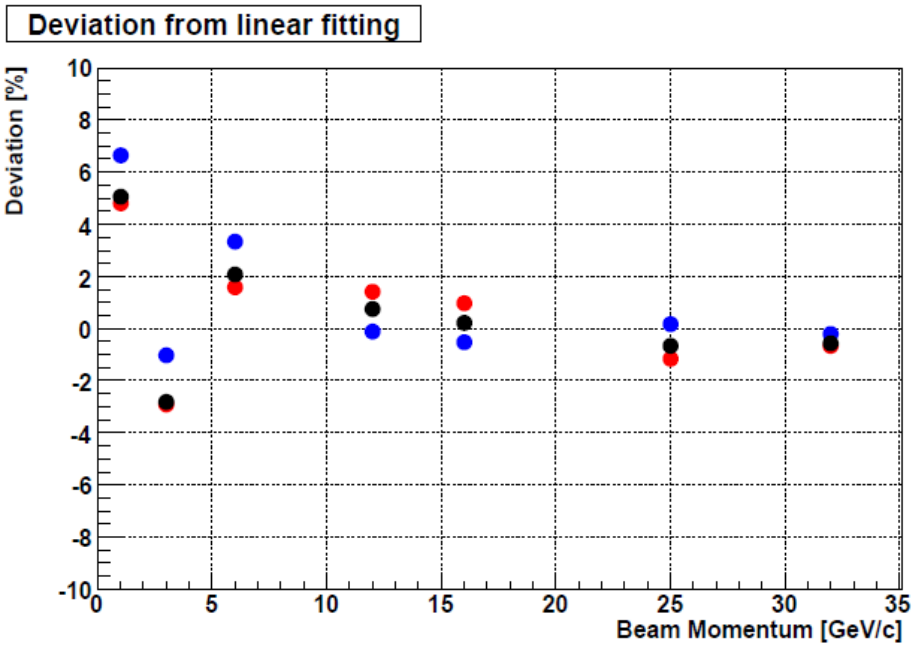
The selection of beam position (6GeV)



Results : Linearity

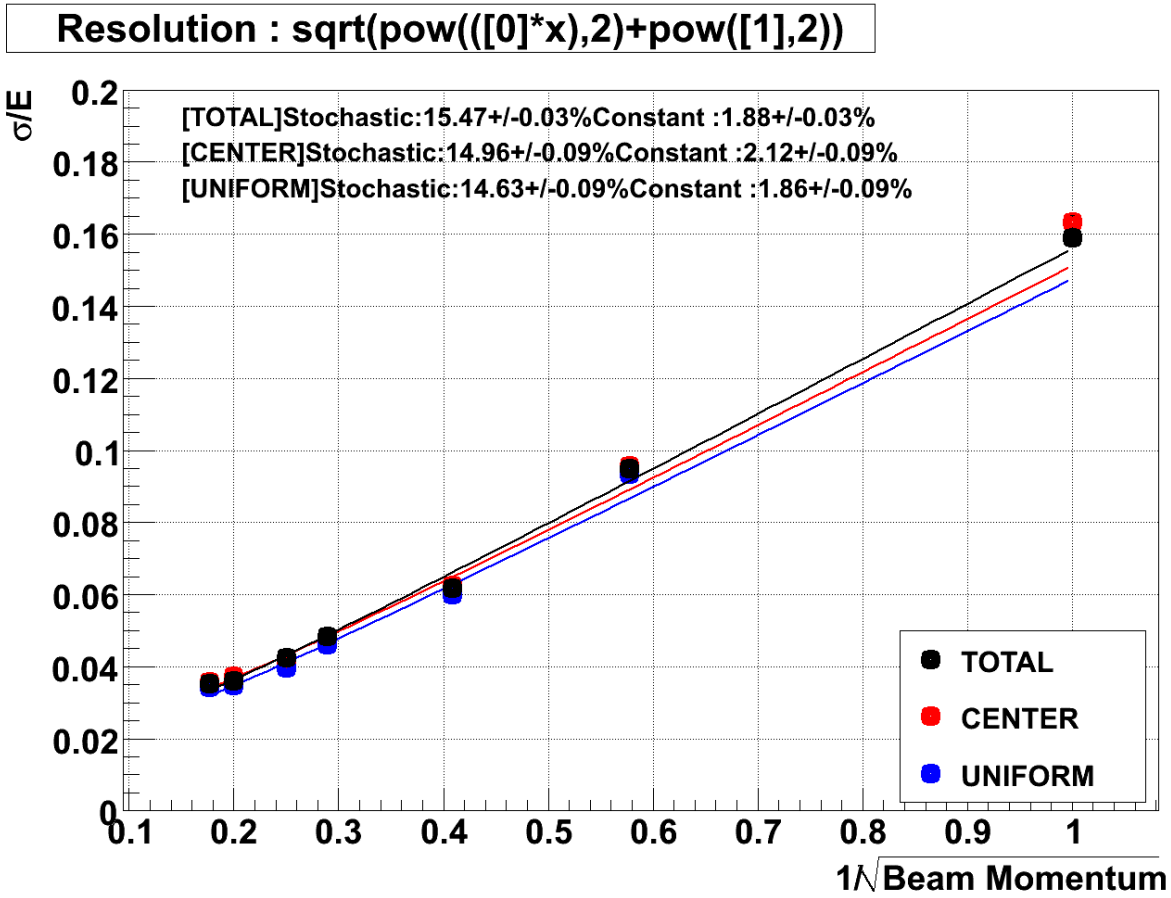
Energy scan with electron(1,3,6,12,16,25,32 GeV).





The fluctuation of the deviation from linear fitting is less than 5%, in 12 GeV or more, it is less than 2%.
The values of lower beam momentum should be discussed.

Results : Energy Resolution



the Total

$\sigma_{stochastic}$=15.47±0.03%

$\sigma_{constant=}$=1.88±0.03%

the center-region

$\sigma_{stochastic}$=14.96±0.09%

$\sigma_{constant=}$=2.12±0.09%

the uniform-region

$\sigma_{stochastic}$=14.63±0.09%

$\sigma_{constant=}$=1.86±0.09%

The difference between the center-region and the uniform-region is not so big . To get better constant term, the improvements of MPPC dynamic-range and scintillator uniformity are necessary.

Summary

Results of ScECAL FNAL-BT in Sep. ’09

- **MIP calibration constants**
  The average is about 160 ADC counts / MIP.
- **Linearity**
  The fluctuation of the deviation is less than 5%,
  in 12 GeV or more, it is less than 2%.
- **Energy Resolution**

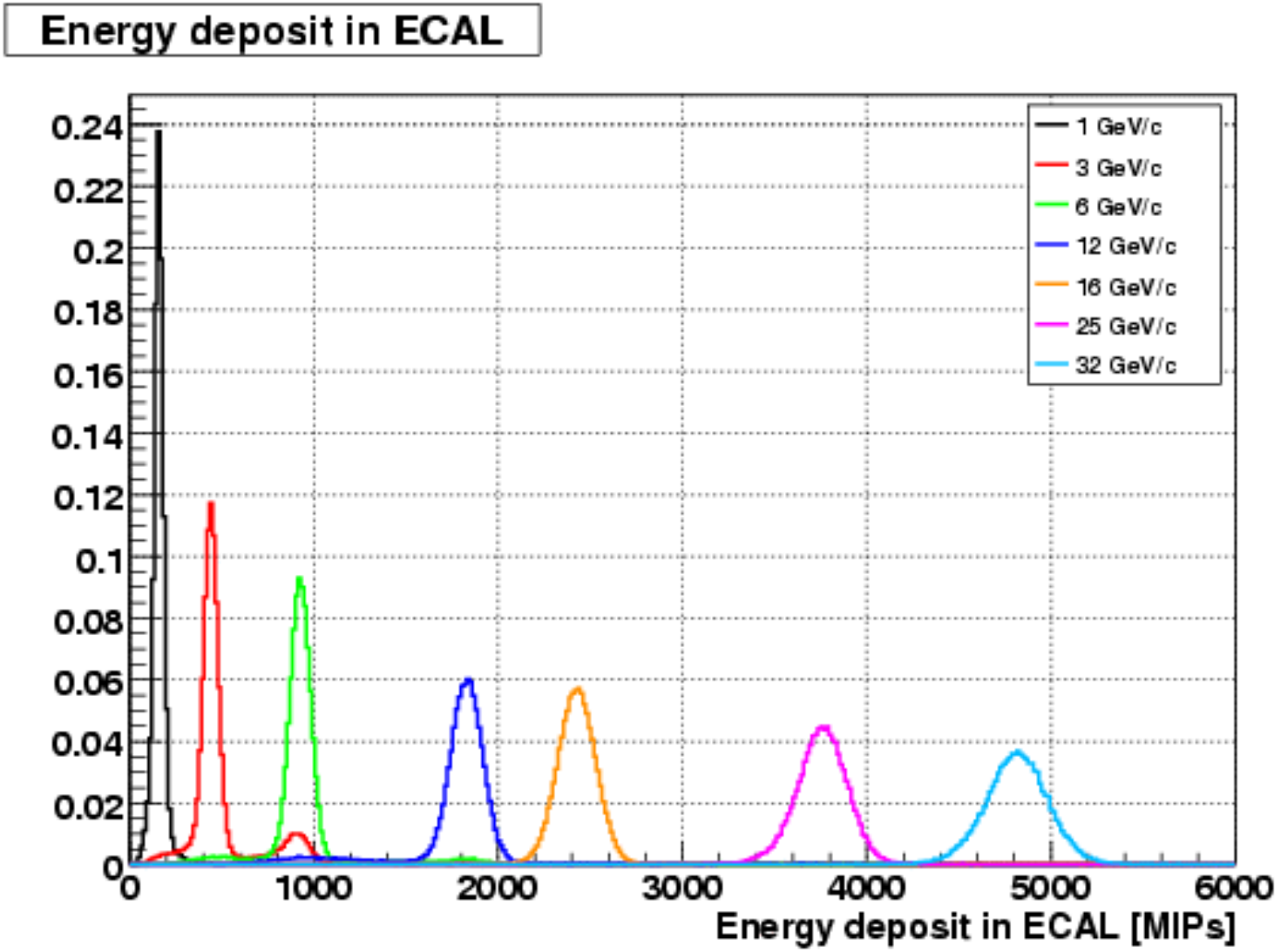
$$\frac{\sigma}{E} = \frac{15.47\%}{\sqrt{E}} \oplus 1.88\%$$

To get better constant term, the improvements of MPPC dynamic-range and scintillator uniformity are necessary.

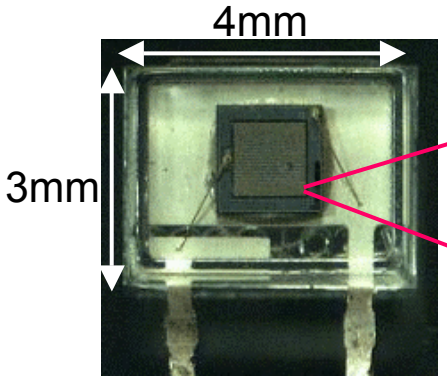
BACK UP

Energy Spectrum (electron)

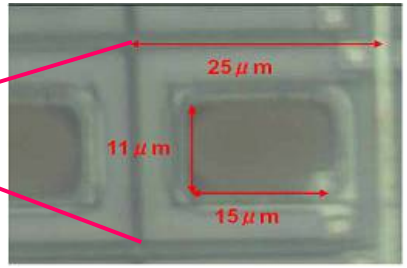
Energy scan with electron(1,3,6,12,16,25,32 GeV).



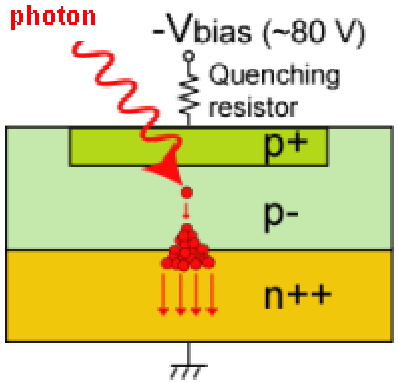
MPPC(Multi-Pixel Photon Counter)

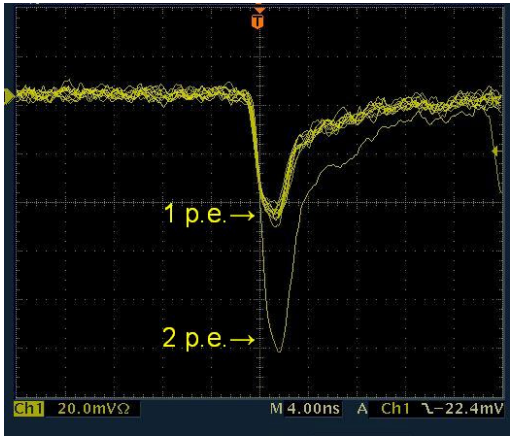


MPPC(1600 pixel type)



APD pixel





Pulse shape

An APD pixel outputs the same pulse-height for any light intensity.
->The MPPC maximum-output is restricted by the number of pixels.
->The response is not linear

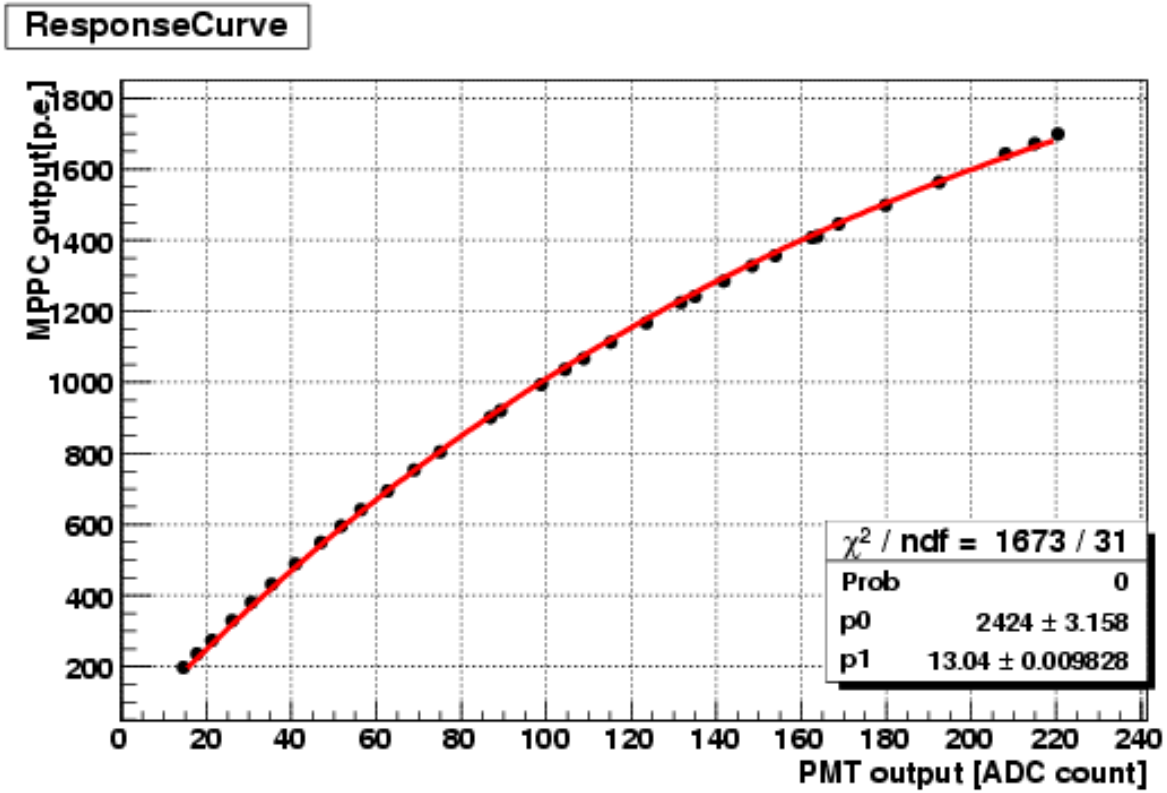
$$N_{fired} = N_{pix}\left(1-\exp\left(\frac{N_{true}}{N_{pix}}\right)\right)$$

N_{fired} : The MPPC detected photons
N_{true} : The true photons
N_{pix} :The number of pixels

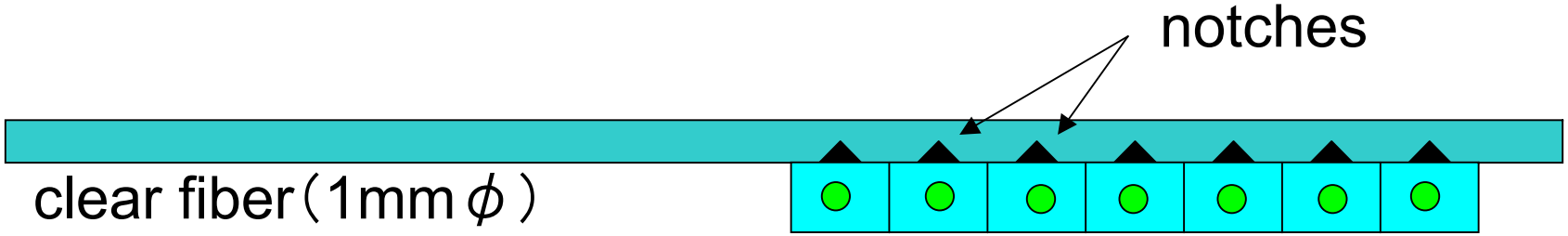
Response Curve

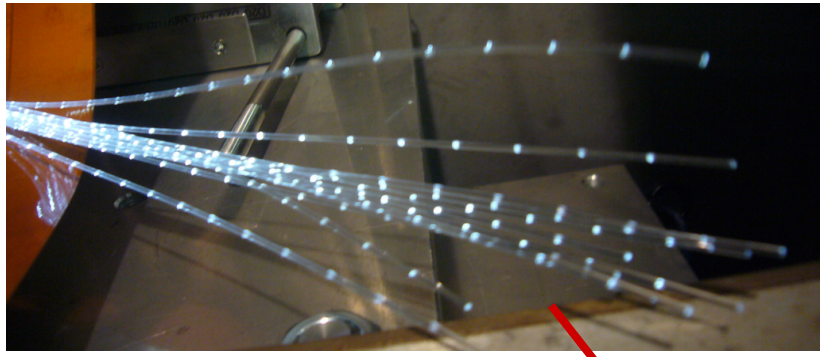
Max Energy deposit in a channel

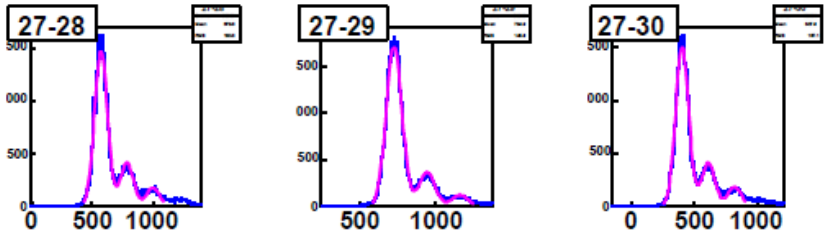
32 GeV : ~1800 p.e.
25 GeV : ~1500 p.e.
16 GeV : ~1200 p.e.
12 GeV : ~1000 p.e.
6 GeV : ~600 p.e.
3 GeV : ~300 p.e.
1 GeV : ~120 p.e.



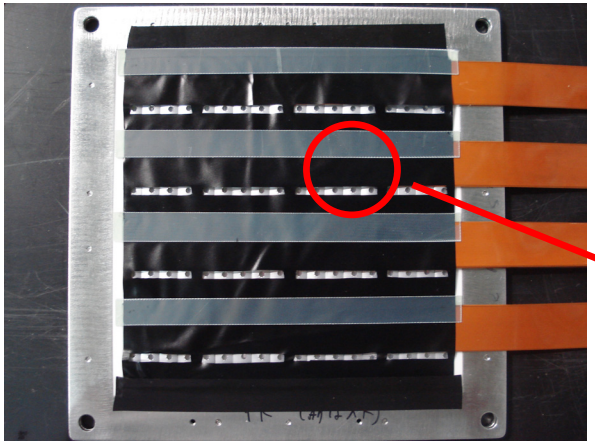
MPPC Gain Monitoring

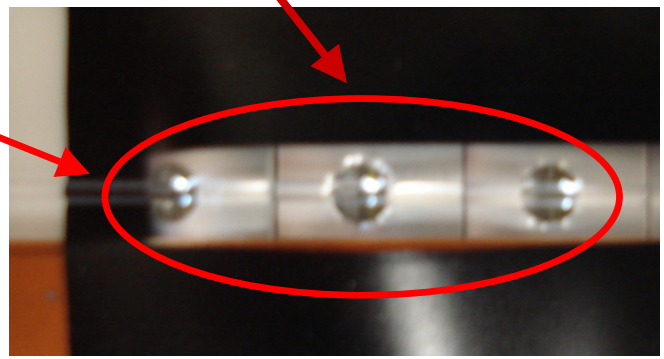






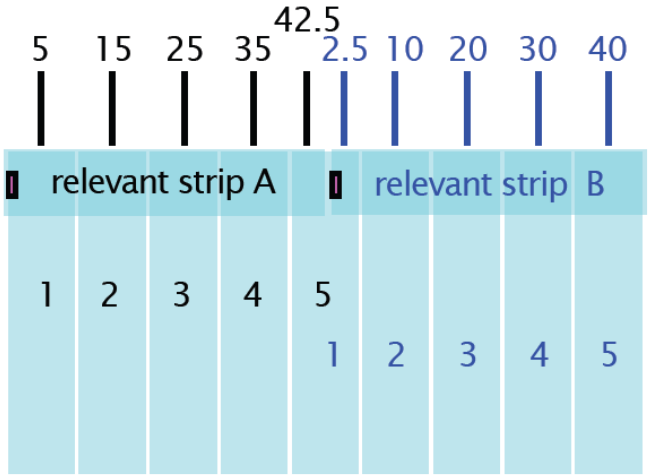
ADCdist



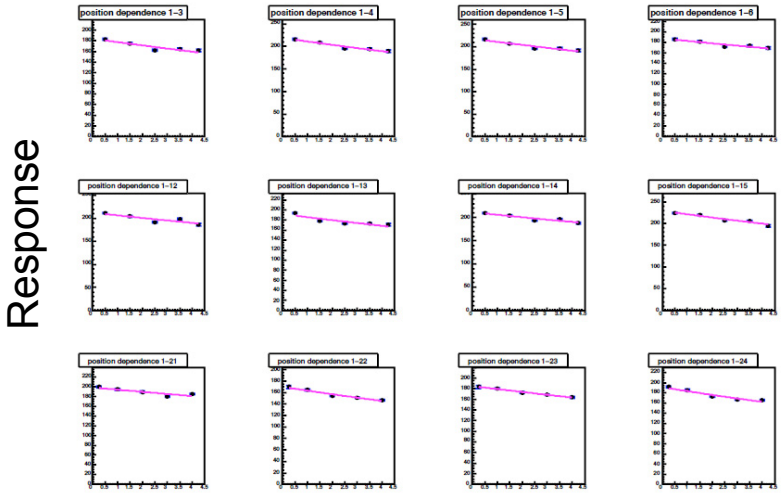


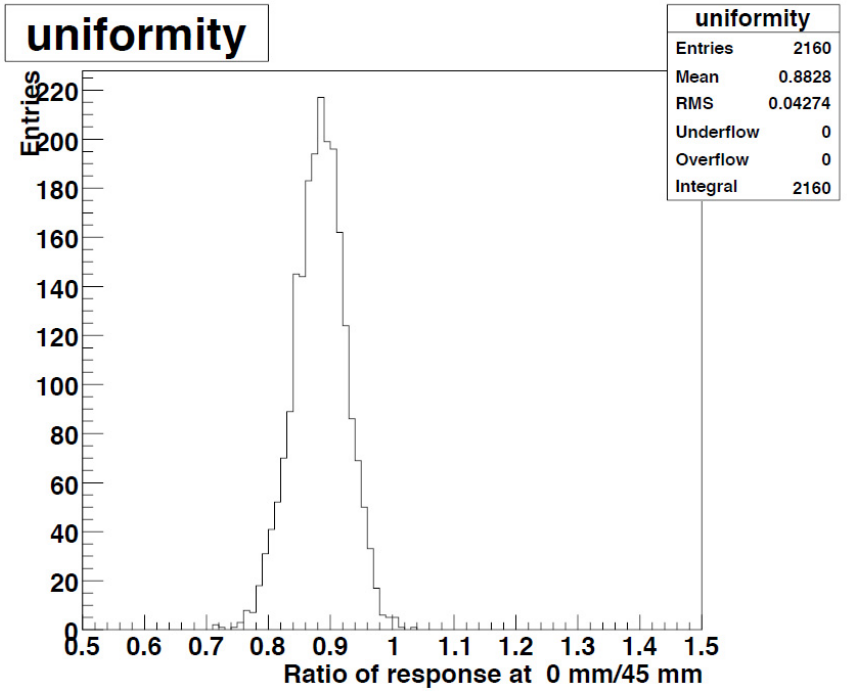
（Results from Shinshu Univ.）

Scintillator non-uniformity



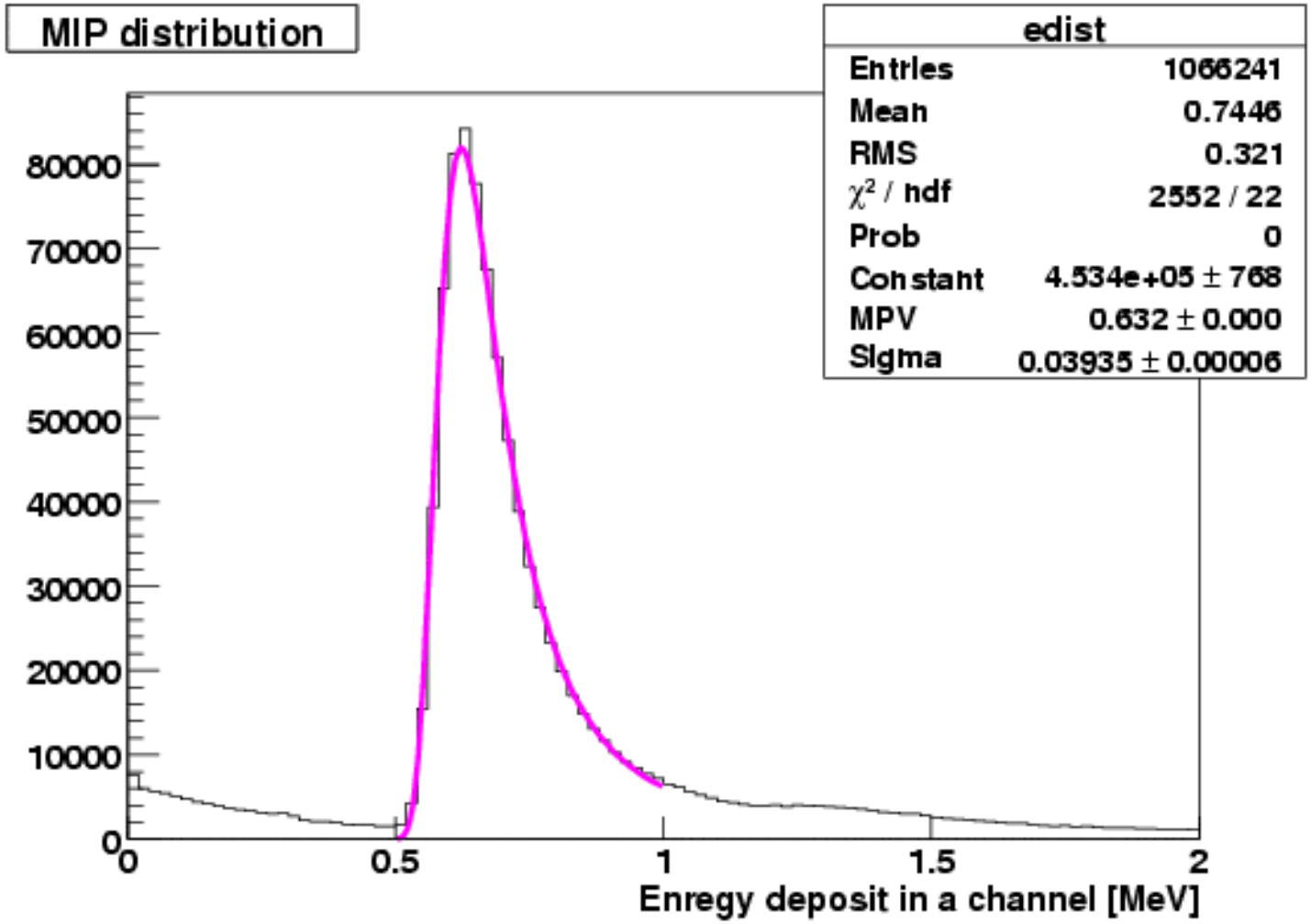
Response@45mm from MPPC / Response@0mm from MPPC



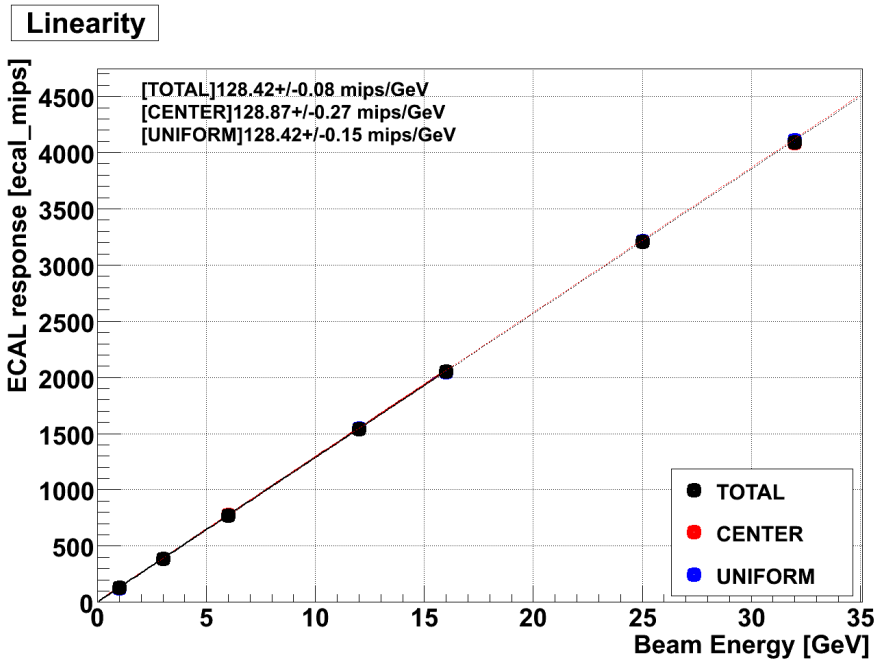


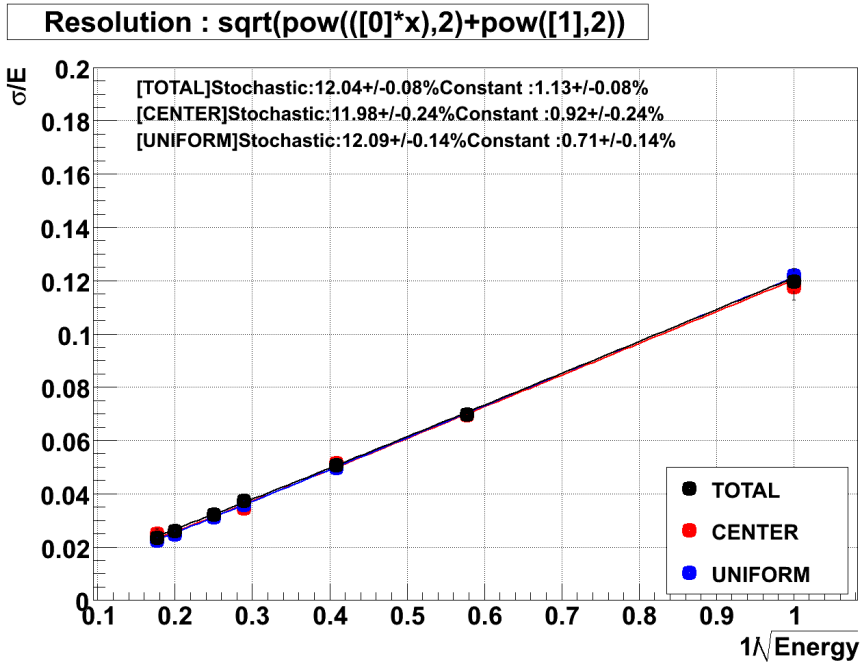
（Results from Shinshu Univ.）

MC (MIP)


MIP distribution
edist
Entries 1066241
Mean 0.7446
RMS 0.321
χ² / hdf 2552 / 22
Prob 0
Constant 4.534e+05 ± 768
MPV 0.632 ± 0.000
Sigma 0.03935 ± 0.00006
80000
70000
60000
50000
40000
30000
20000
10000
0
0
0.5
1
1.5
2
Enregy deposit in a channel [MeV]

MC (Electron)

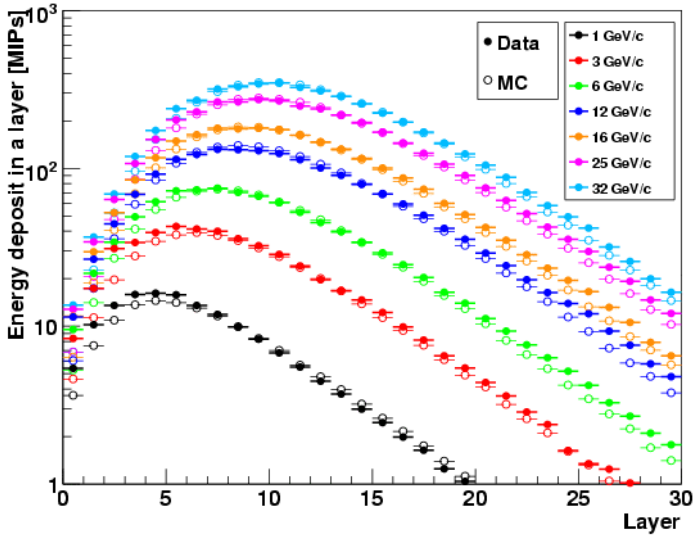




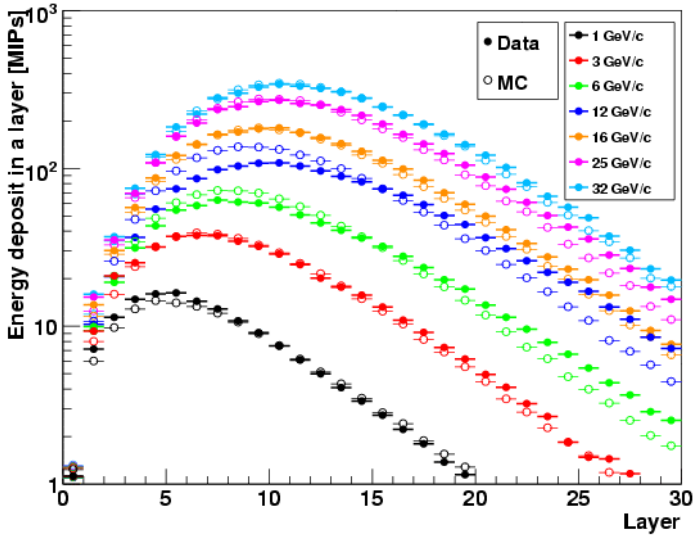
MIPs/GeV is different between MC and data.
->Maybe the parameters for material in MC
is different from true.

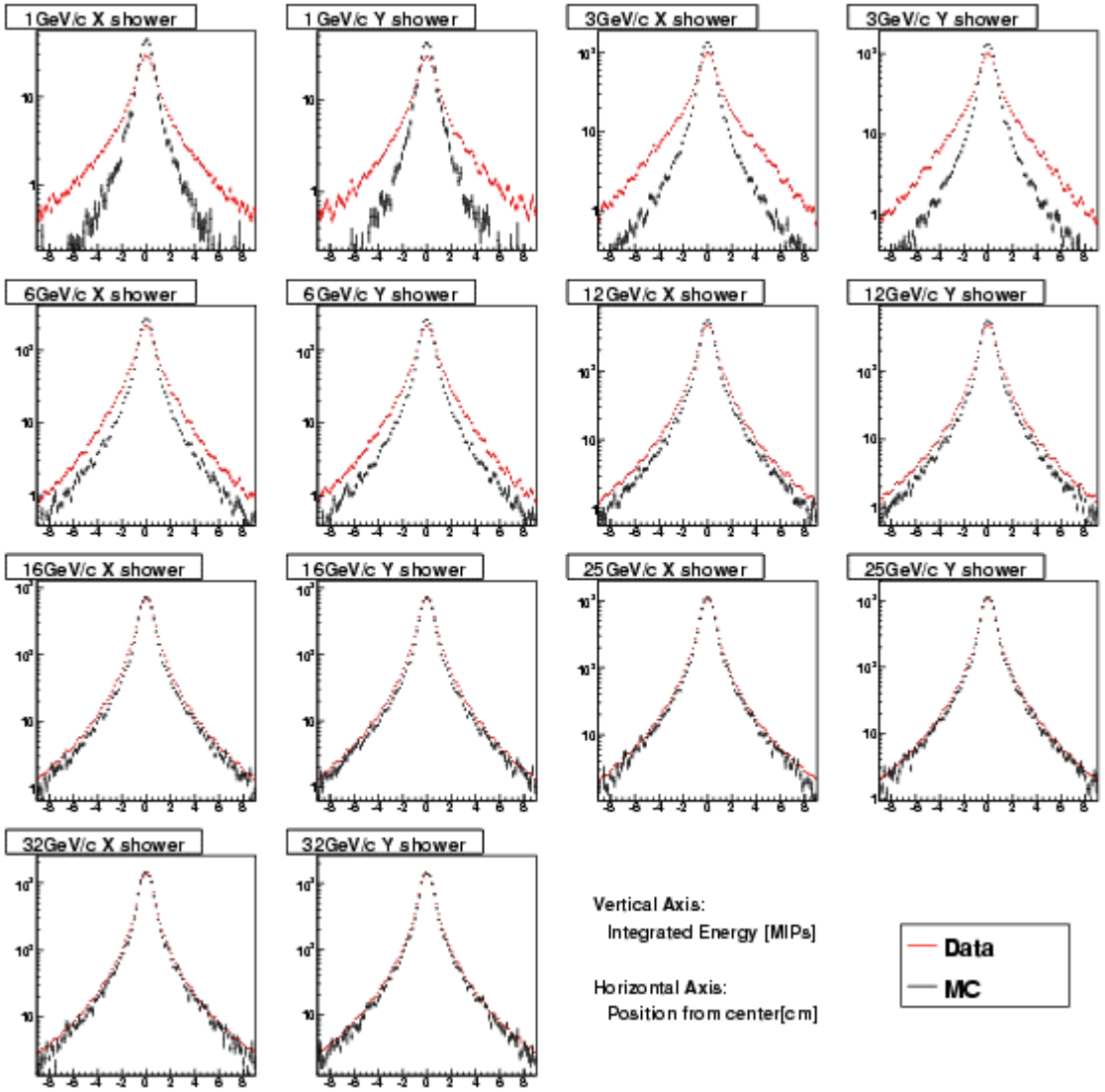
Shower shap

Shower Shape

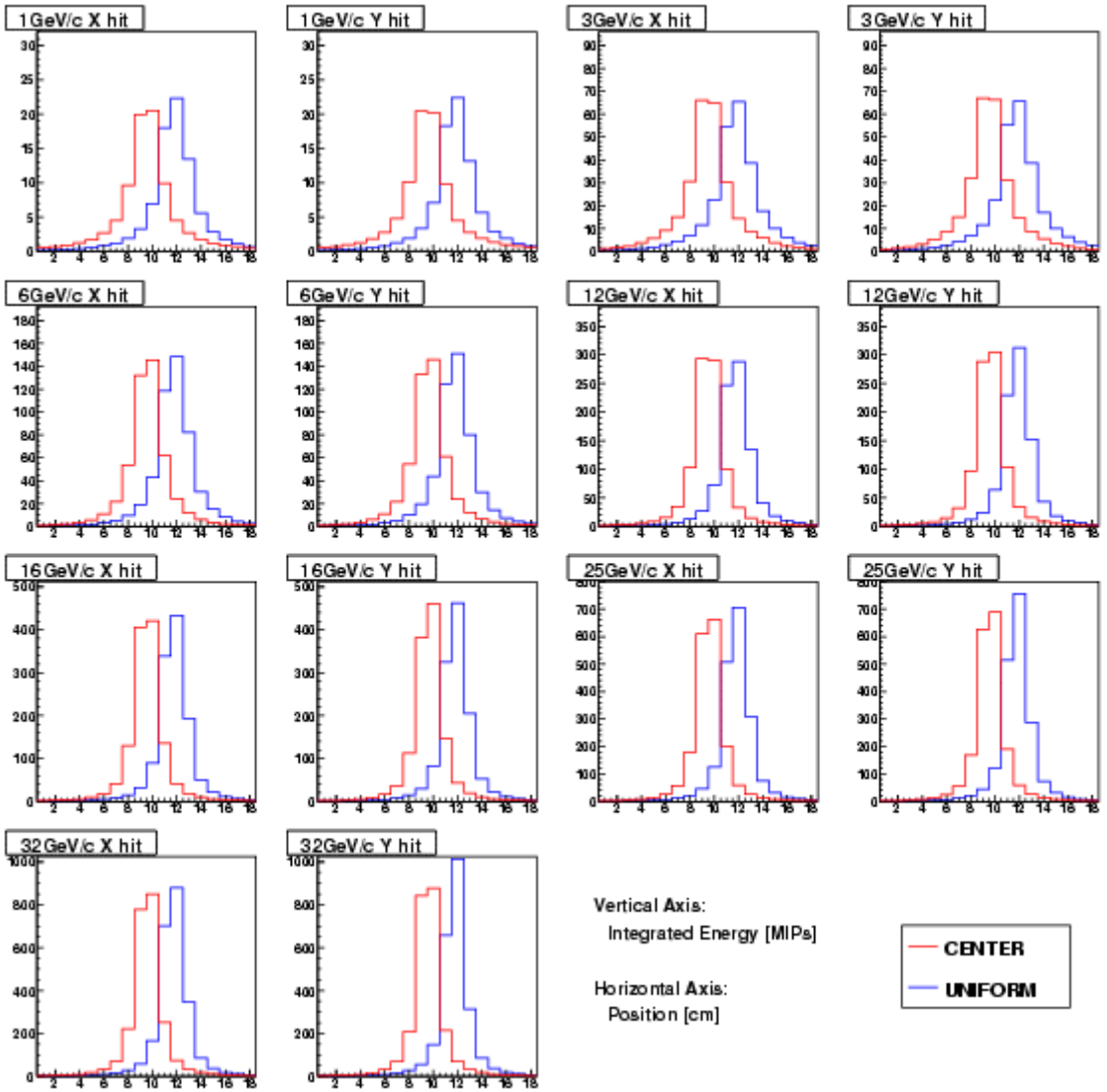


Shower Shape





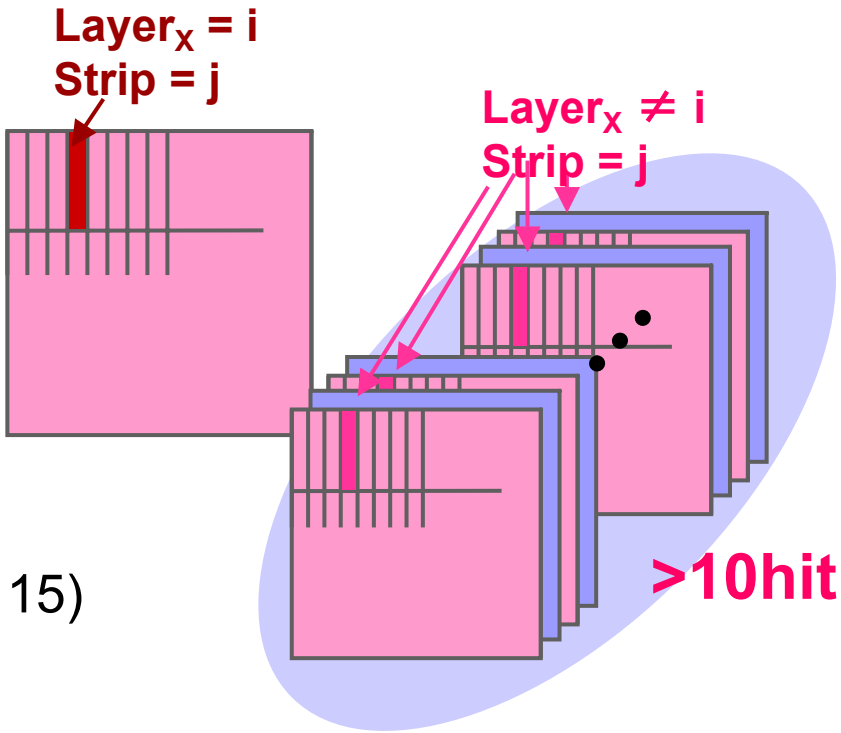
Shower leak



No shower leak

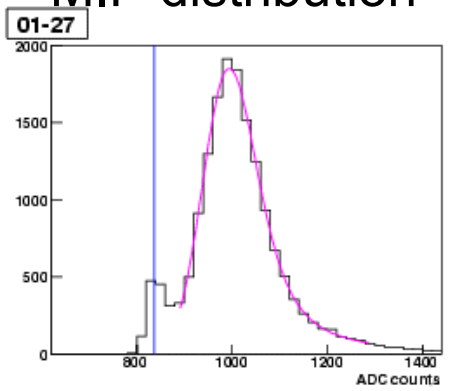
MIP selection

●Event selection
Example: For X-Layer i, Strip j
→Check a hit of the strip j on other X-layers excepting i.(total 14 layers)
If there are more than 10 hits,
it is presumed that a muon passed through the channel i-j.(MIP event)
Hit def. : $ADC>ADC_{ped}+3\sigma_{ped}$ ($\sigma_{ped} \fallingdotseq 15$)



●Fitting MIP distribution
The fitting function:
Gaussian convoluted landau distribution
(4 parameters : mean , norm , landau-width , gaussian-width)

MIP distribution

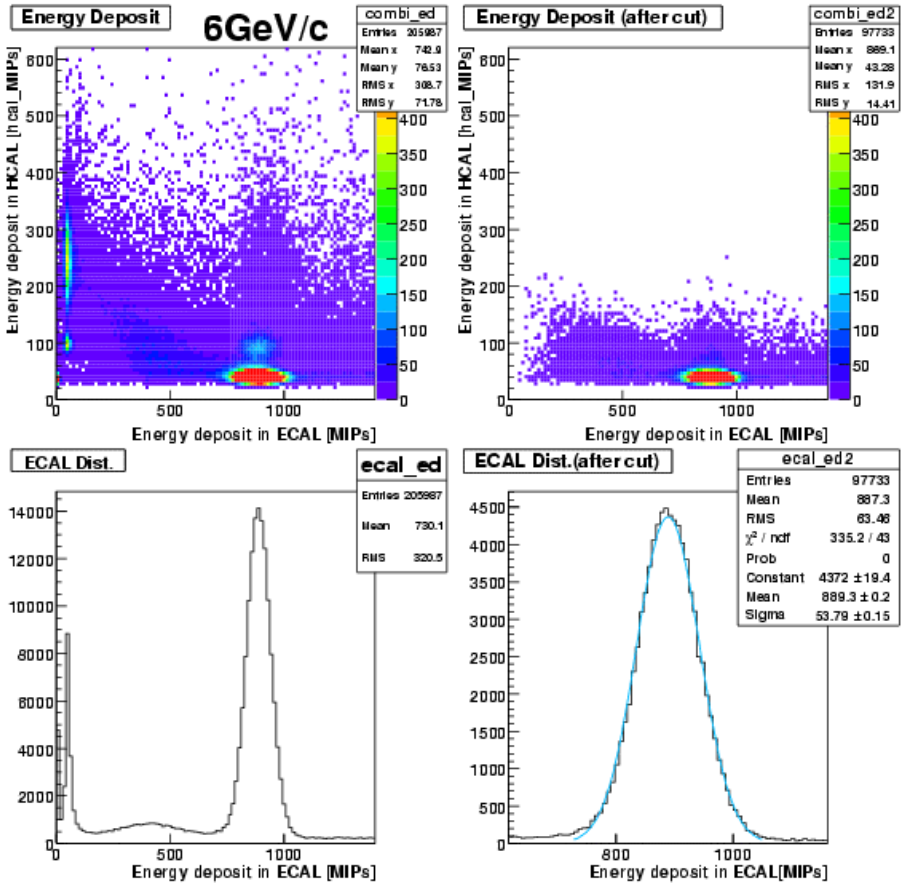


Electron selection

- Event selection (rough)

Using shower max layer

- Muon Cut:
  - ECAL hit >20 ecal_MIPs
  - Last layer of HCAL <1 hcal_MIP
- Pion Cut:
  - ECAL layer <20 layers
  - HCAL hit <20 hcal_MIPs



Dead channels

The dead channels of scECAL:
layer-strip
11-58(too noisy)
12-64(no signal)
19-11(too noisy)
26-65(no signal)
29-48(too noisy)

The channels that have problems:
11-22(low gain)
25-06(low gain)
26-67(low gain)
30-66(sometimes no signal)

5 dead channels
(+ 4 NG channels)

The response curve

$$N_{fired} = N_{pix}\left(1-\exp\left(\frac{N_{true}}{N_{pix}}\right)\right)$$

N_{fired} : The MPPC detected photons

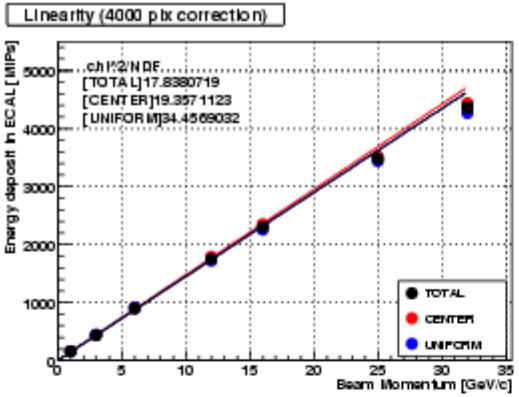
N_{true} : The true photons

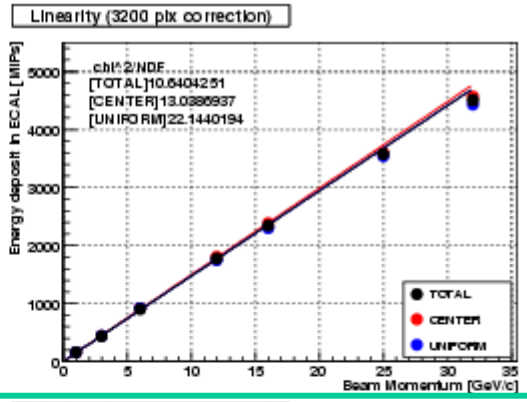
N_{pix} :The number of pixels

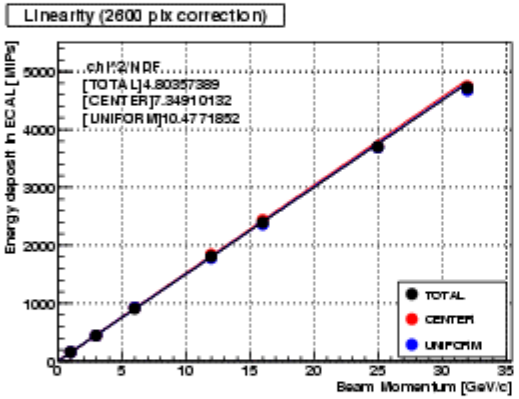
The response curve (N_{pix}) is depending on:

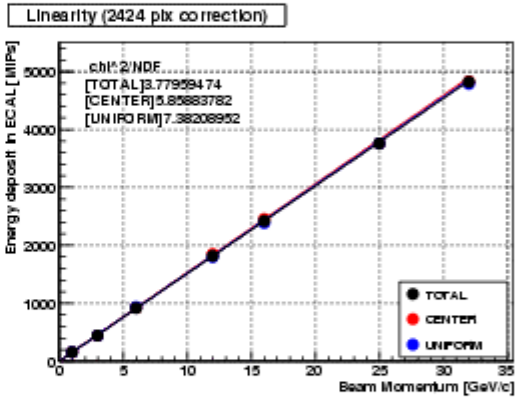
- MPPC characteristics(crosstalk, after-pulse, recovery)
- Time width of Light Input(Sci,WLSF decay time)
- Temperature
- MPPC and WLSF matching
- Non-uniformity of each strip.

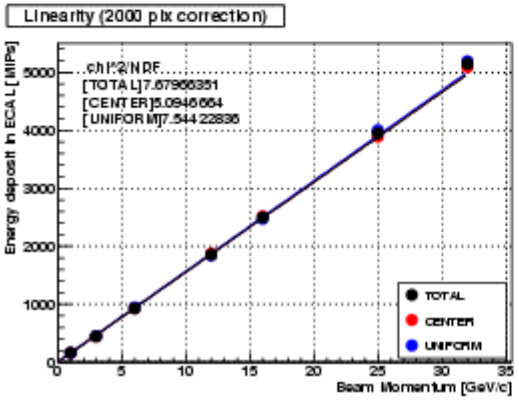
Npix=2424

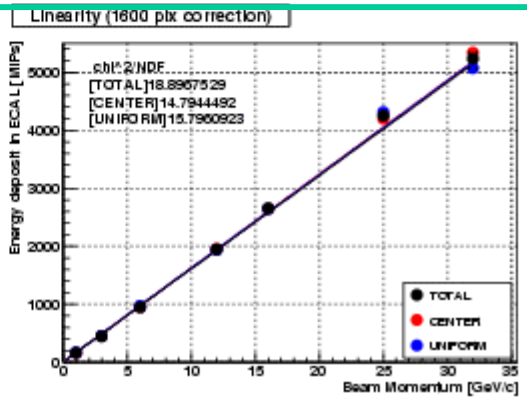

Linearity (4000 pix correction)
chi^2/NDF
[TOTAL]17.8380719
[CENTER]19.3571123
[UNIFORM]34.4569032
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]


Linearity (3200 pix correction)
chi^2/NDF
[TOTAL]10.6404251
[CENTER]13.0386937
[UNIFORM]22.1440194
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]


Linearity (2600 pix correction)
chi^2/NDF
[TOTAL]4.80357389
[CENTER]7.34910132
[UNIFORM]10.4771852
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]


Linearity (2424 pix correction)
chi^2/NDF
[TOTAL]3.77959474
[CENTER]5.85883782
[UNIFORM]7.38208952
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]


Linearity (2000 pix correction)
chi^2/NDF
[TOTAL]7.67966351
[CENTER]5.0946664
[UNIFORM]7.54422836
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]


Linearity (1600 pix correction)
chi^2/NDF
[TOTAL]18.8967529
[CENTER]14.7944492
[UNIFORM]15.7960923
TOTAL
CENTER
UNIFORM
Energy deposit in ECAL [MIPs]
Beam Momentum [GeV/c]

Npix=2424

N_{pix}	total		center		uniform	
	MIPs/GeV	χ^2/NDF	MIPs/GeV	χ^2/NDF	MIPs/GeV	χ^2/NDF
4000	144.76 ± 0.55	17.84	147.25 ± 0.56	19.36	144.65 pm 0.55	34.46
3200	146.86 ± 0.56	10.64	149.12 ± 0.57	13.04	146.97 pm 0.56	22.14
2600	149.71 ± 0.57	4.80	151.60 ± 0.58	7.35	150.17 pm 0.57	10.48
2424	150.99 ± 0.57	3.78	152.68 ± 0.58	5.86	151.61 pm 0.58	7.38
2000	154.95 ± 0.59	7.68	155.41 ± 0.61	5.09	156.23 pm 0.61	7.54
1600	160.63 ± 0.61	18.90	161.78 ± 0.61	14.79	161.61 pm 0.61	15.80