Development of ZDC ECal Status Report

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Outline

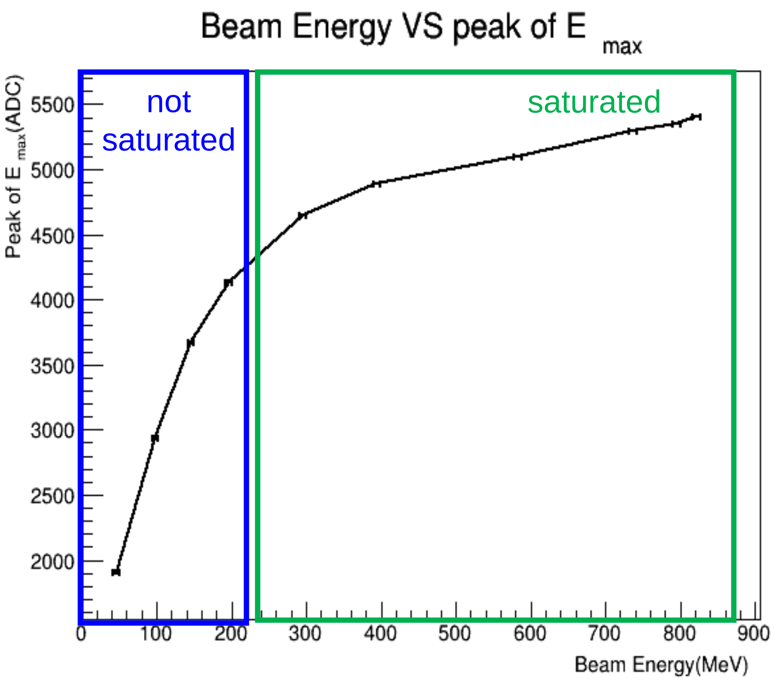
- Beam test analysis

① Implementation of beam features

② Compare MC and RD

- Temperature test @ Lab
- Design of 2^{nd} ZDC ECal prototype

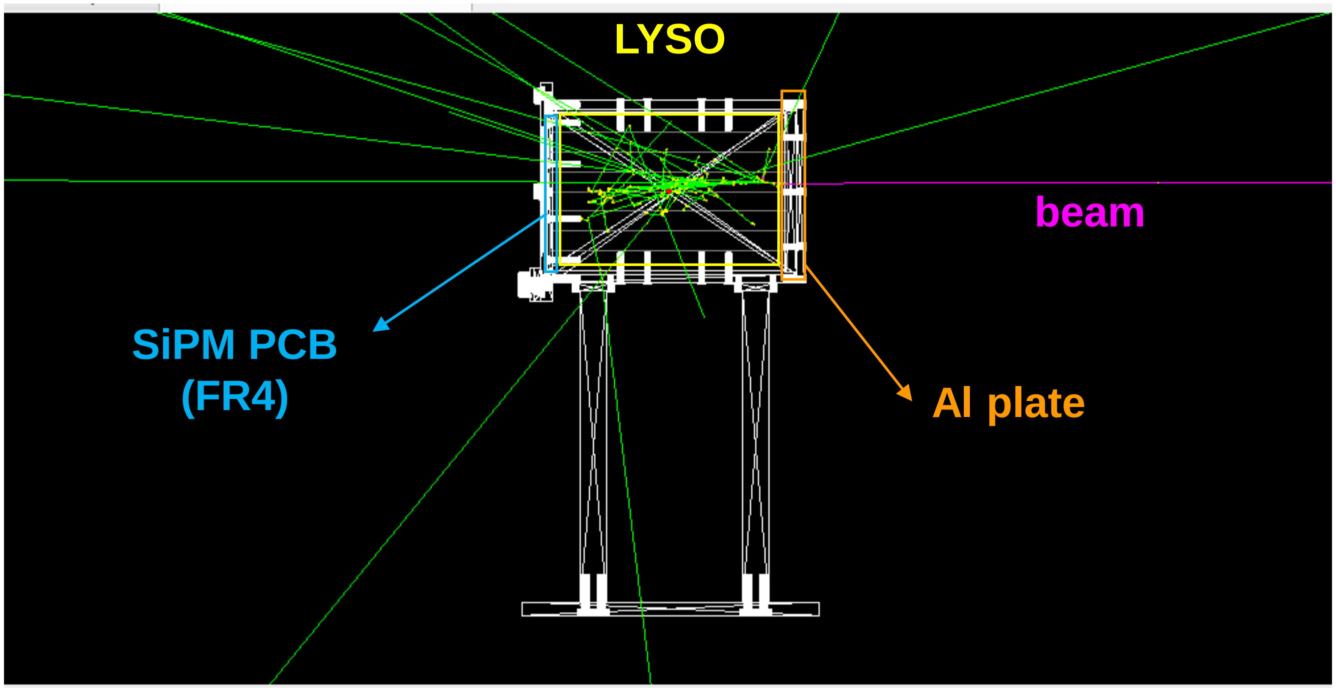
Beam Test of 1st Prototype ZDC ECal



- We performed beam test w/ 1st prototype at ELPH this Feb.
- The saturated beam energy ~ 200MeV.
- We will compare data and MC w/ beam energy ~ 47, 98, 198 MeV in this presentation.

Beam Test of 1st Prototype MC Simulation

- Detector geometry/material



- Beam Mom. w/ Res.

I (A)	x_{PS} 制限なし		
	μ_P (MeV/c)	σ_P (MeV/c)	σ_P/μ_P (%)
025	47.18(2)	5.48(1)	11.63(3)
050	98.19(4)	4.92(3)	5.01(3)
075	148.22(4)	4.77(2)	3.22(2)
100	197.94(3)	4.91(2)	2.48(1)
125	247.79(3)	5.00(2)	2.02(0)
150	297.30(2)	5.29(2)	1.78(0)
175	346.81(2)	5.31(1)	1.53(0)
200	395.90(2)	5.55(1)	1.40(0)
225	444.56(2)	5.73(1)	1.29(0)
230	454.25(2)	5.74(1)	1.26(0)
250	492.50(2)	5.83(1)	1.18(0)
275	539.29(2)	6.00(1)	1.11(0)
300	584.59(2)	6.17(1)	1.06(0)
325	628.06(2)	6.32(1)	1.01(0)
350	669.20(2)	6.45(1)	0.96(0)
375	706.61(2)	6.58(1)	0.93(0)
400	739.16(2)	6.71(1)	0.91(0)
425	768.86(2)	6.87(1)	0.89(0)
450	796.60(2)	6.89(1)	0.87(0)
475	823.26(2)	7.01(1)	0.85(0)
500	849.10(2)	7.08(1)	0.83(0)

- MC implementation

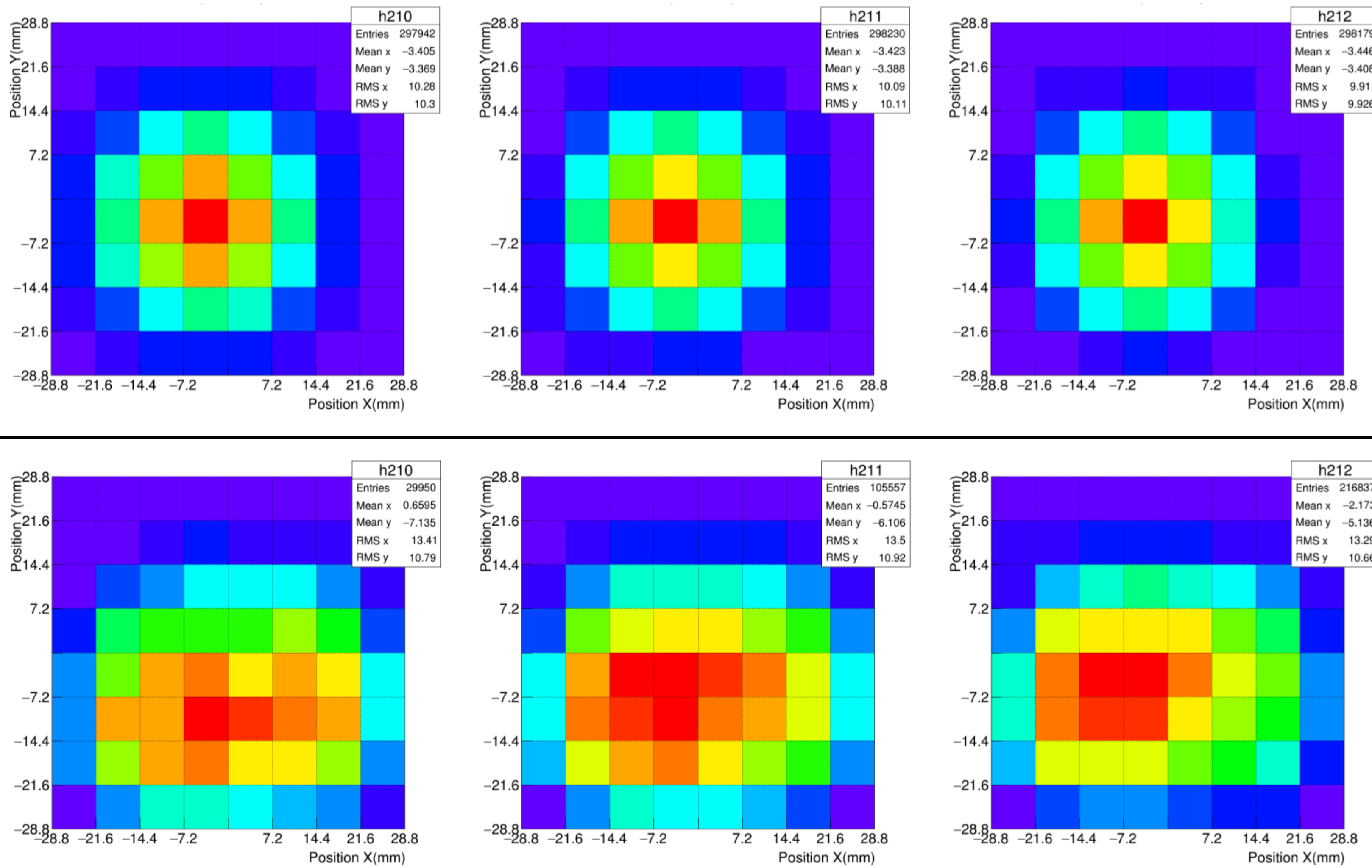
① Detector geometry/material
② Beam momentum w/ resolution
③ Beam shape : center (-3.6mm, -3.6mm), sigma (10mm, 10mm)
④ Beam inject perpendicular to the detector.

Beam Test of 1st Prototype
Compare Data VS MC : Beam Profile in 2D

47MeV **98MeV** **198MeV**

MC

Data

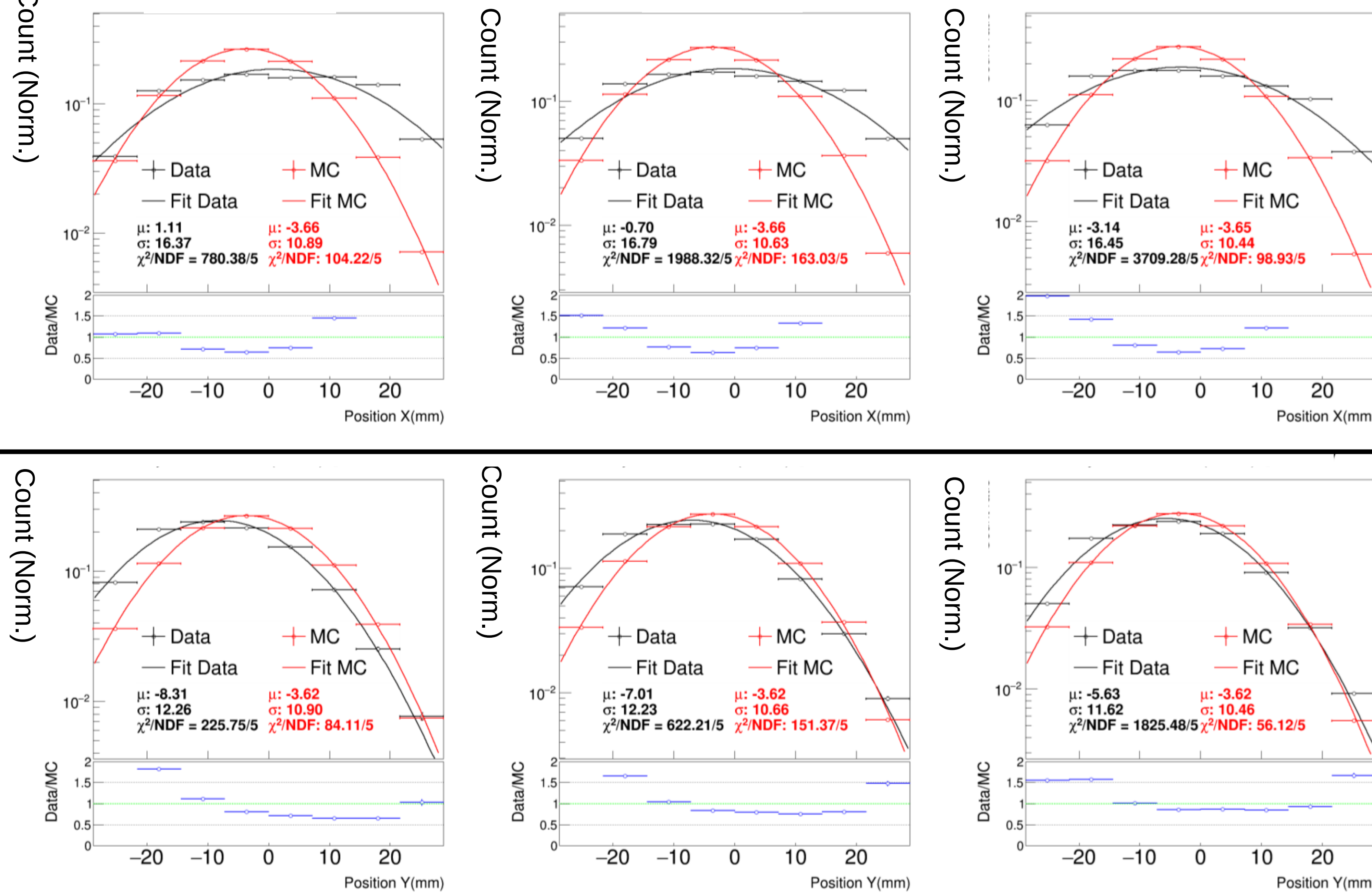


Beam Test of 1st Prototype
Compare Data VS MC : Beam Profile in 1D

47MeV | 98MeV | 198MeV

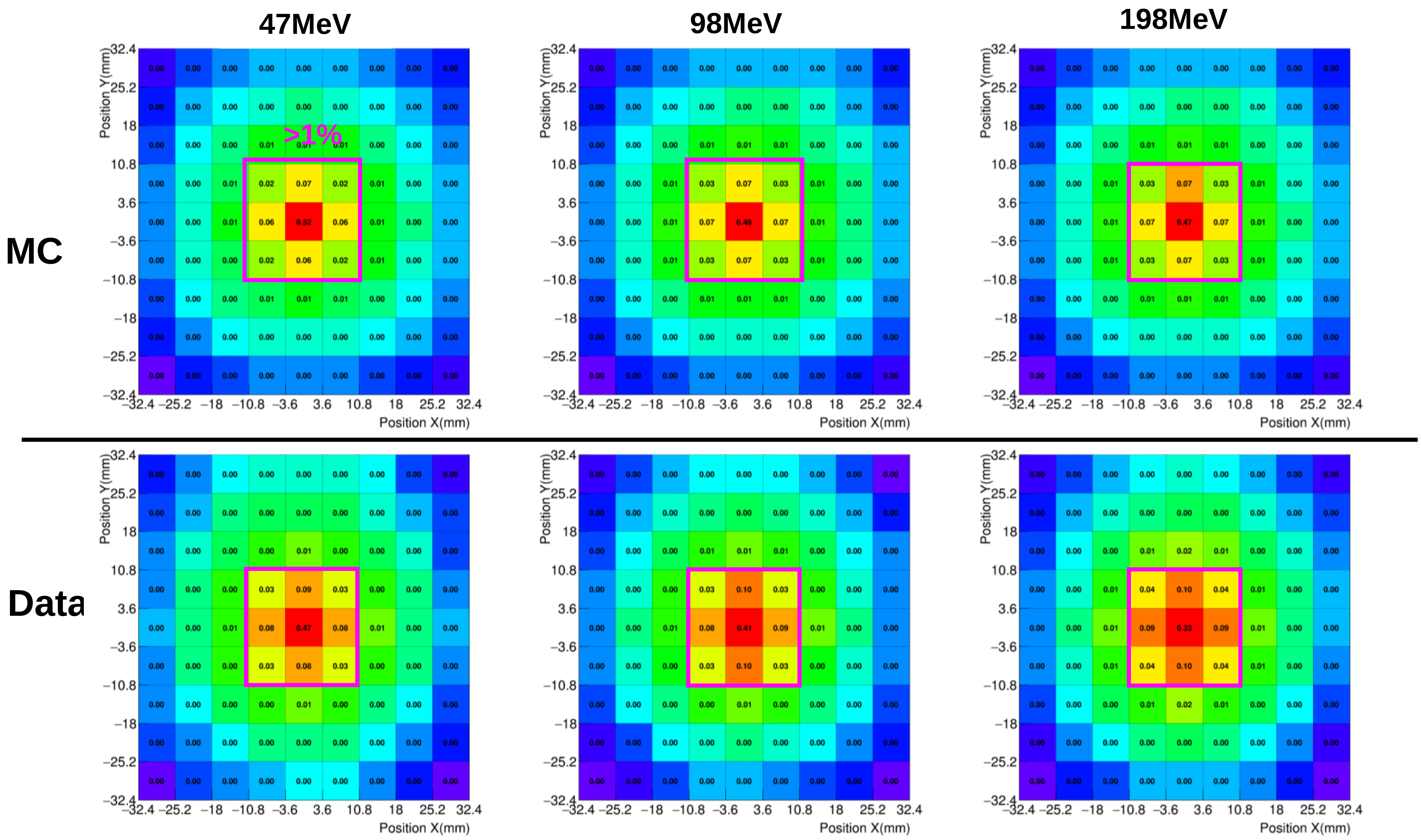
MC

Data



Data have wider beam profile than MC. MC will be further fine tuned.

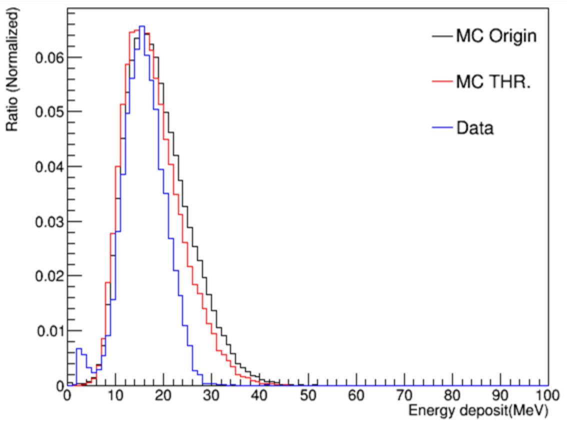
Beam Test of 1st Prototype
Compare Data VS MC : Shower Shape



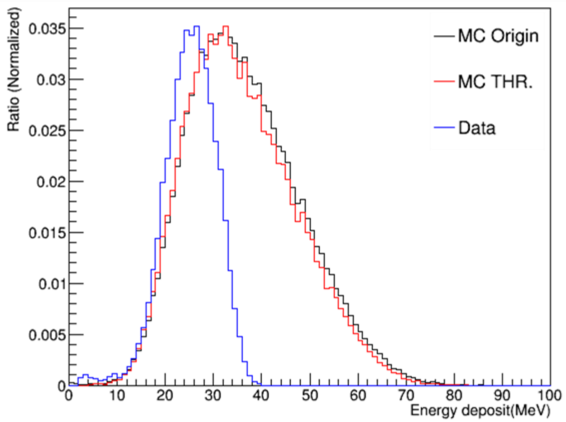
Data has wider shower shape.

Compare Data VS MC : Emax

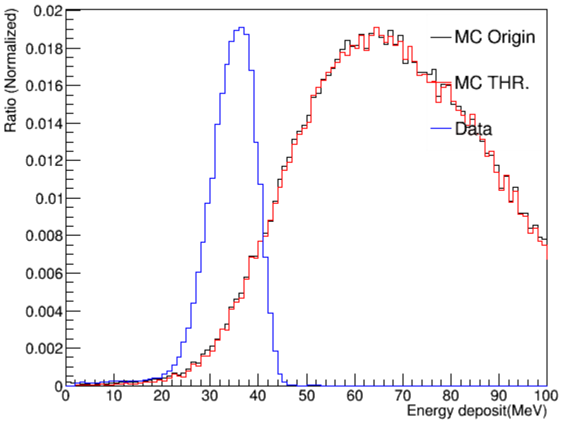
47MeV



98MeV



198MeV



- **Observation**

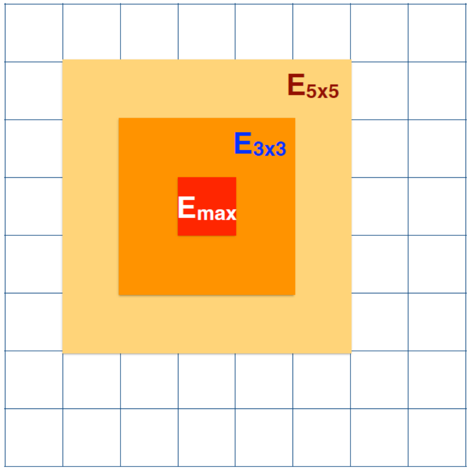
① There is more energy deposit in MC simulation.
② Disagreement gets larger towards to higher beam energy.

- **Suspicion**

① We need less MC deposit in MC.
② Detector already starts saturate below 200MeV.

- **Ideas**

① More realistic beam profile in MC
② No Birk's law in MC
③ Detector has saturated below 200MeV : Check data w/ absorber.



Birk’s Law

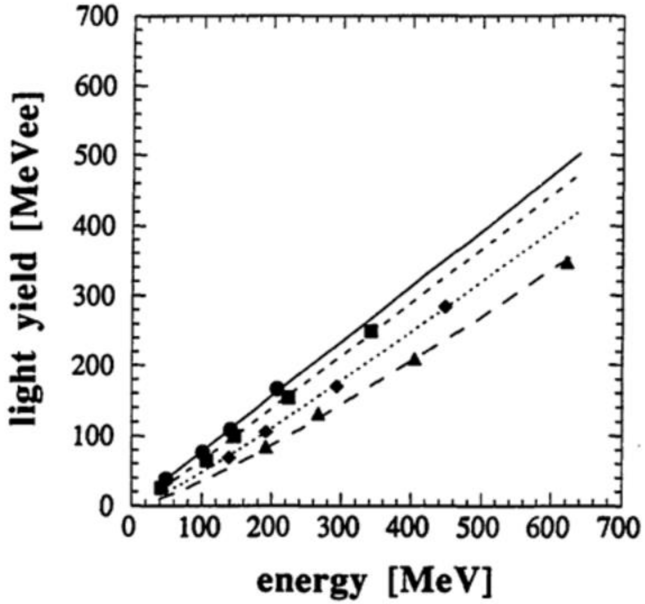


Figure 1: Light output (in electron-equivalent energy) of BaF_2 scintillator for protons (circles), α-particles (squares), ^{7}Li (diamonds) and ^{9}Be (triangles). The data are of Ref.[7] while the lines result from the integration of Birks law (Eq.1).

The description of the effect of quenching of the light yield for highly-ionizating particles can be based on Birks theory [6], which relates the light yield dL to the energy loss dE by the following equation:

$$dL = S \cdot \frac{dE}{1 + k_B \frac{dE}{dx}} \qquad (1)$$

where k_B is Birks constant and S is the scintillation efficiency. The total light yield produced by a particle is given by the integration of equation (1) from the initial energy down to zero energy. Recently, new data on the light yield of BaF_2 have been obtained by Lanzanó et al. [7] in the energy range of several tens A MeV.

https://inis.iaea.org/collection/NCLCollectionStore/_Public/24/054/24054764.pdf

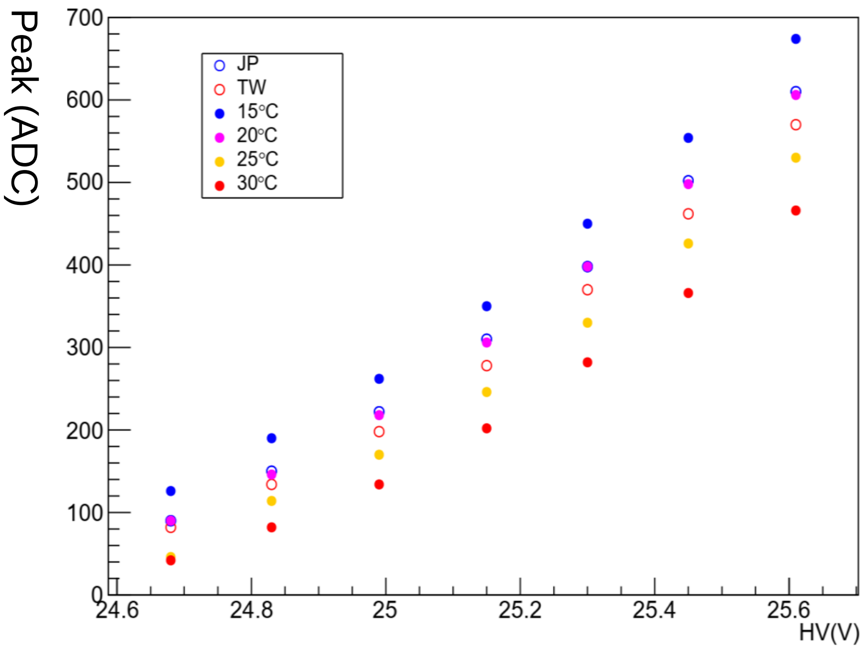
- Birk’s law :

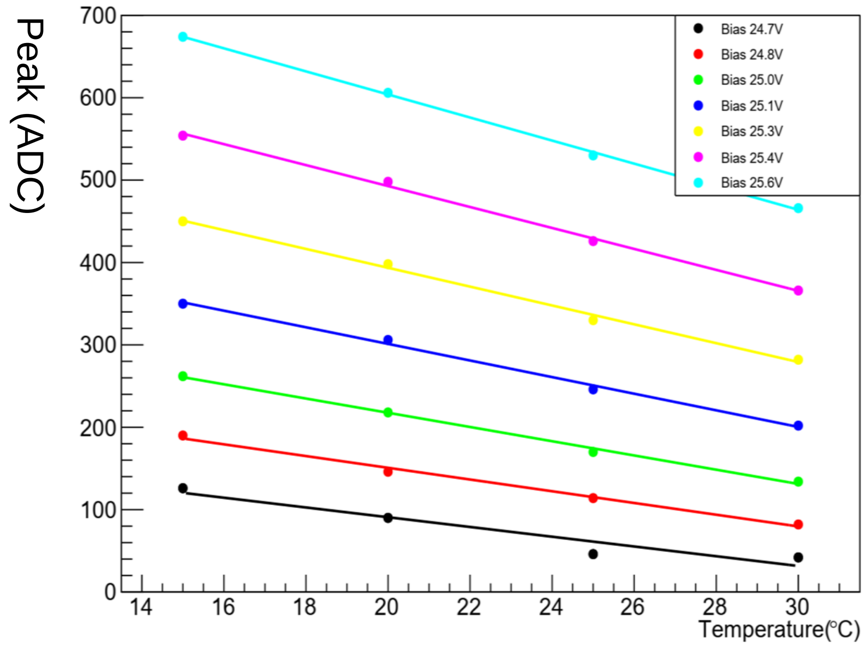
① Light yield as a function of the energy loss for a particle passing scintillator.
② It is an empirical formula.

Temperature Test w/ Na22 @ Lab

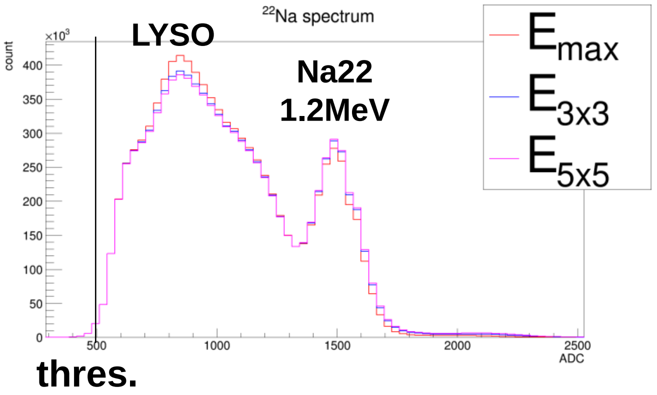
We test the temperature from 15 to 30 degree w/ Na22 source.

Temperature Test w/ Na22 @ Lab





- The Peak values shows the ΔT between beam test in Japan and lab test in Taiwan is about 2~3ºC.
- For SiPM, The change of 5 degree gives around 25 percent change on gain.



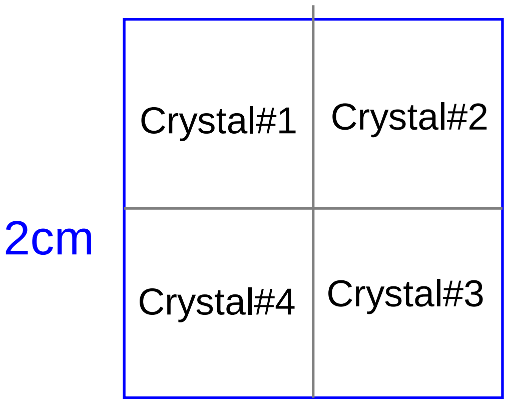
Plan for 2nd ZDC ECal Prototype Change from SiPM to APD

	PIN [55] (SFH2704)	**APD** [56] (S12053-05)	**SiPM** [50] (C10010)
Gain	1	1 – 50	2×10^5
Output Type	Analogue	Analogue	Analogue or Digital
Operational Bias (V)	6	150 – 200	24.2 – 24.7
Overvoltage (V)	–	–	1 – 5
Spectral Range (nm)	400 to 1100	200 to 1000	300 to 950
Peak Sensitivity (nm)	900	620	420 *
PDE/QE (%)	–	80	18 **
Capacitance (pF)	13.4	5	50
Max Photocurrent (μA)	1.22	84	16×10^3
Dark Current (nA)	0.1 – 25	0.2 – 5	1 – 10
Area (mm^2)	3.6	21.24	2.4
Active Area (mm^2)	1.51	7.07	1
Responsivity (A/W)	0.34	21	4×10^3
Rise Time (ns)	47	0.875	0.3

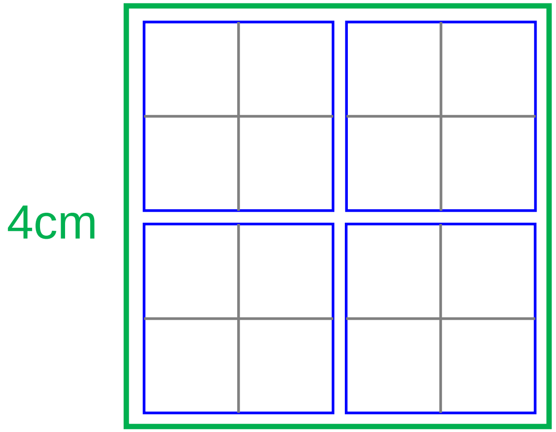
APD is chosen due to its gain is lower than SiPM. We expect to push the measured energy up to hundreds GeV. We should not have saturation issue w/ ELPH beam energy (800MeV) in the next beam test.

Plan for 2nd ZDC ECal Prototype
Design of Crystal Geometry (LYSO)

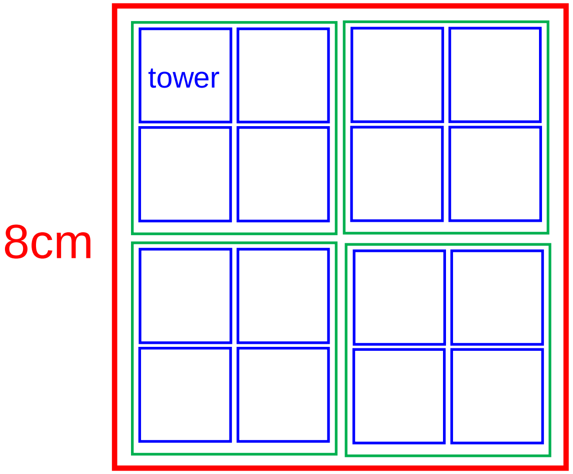
One tower



One unit



2nd ZDC ECal



- One tower = 4 crystals
- No inner wrap between crystals.
- Outer wrap w/ ESR reflection.
- One crystal size = 1cm * 1cm
- One tower size = 2cm * 2cm

- One unit = 4 towers
- Wrap w/ Al tape.
- One unit = 4cm * 4cm

- 2nd prototype = 4 units
- 4 tower * 4 towers
- 8cm * 8cm
- 16 channels
- 10 X0

OR

- 2nd prototype = 2 units
- 4 tower * 2 towers
- 8cm * 4cm
- 8 channels

Depends on budget.

- We will still use LYSO crystal.
- We aim for the beam test of 2nd porotype on Oct. in ELPH.

Summary and To do

- Beam test analysis

We have implemented MC in beam test conditions. The comparison between data and MC shows there are more energy deposit in MC than data if we consider the most energetic tower. We will implement more realistic beam profile and Birk's law in MC. Also, we will check if data stars saturated already below 200MeV.

- Temperature test of SiPM

For SiPM, there is around 25% change of gain with 5 degree temperature changes. We might need to consider cooling if SiPM is used in the future.

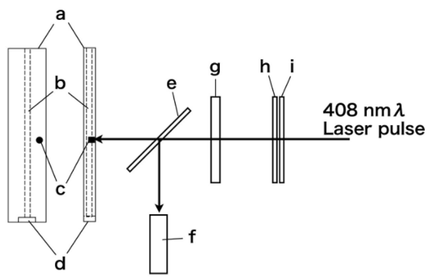
- Design of 2nd ZDC ECal prototype

We will change from SiPM to APD to measure wider energy range. Concerning crystal, LYSO will be used. Work is undergoing. We aim for the beam test of 2nd porotype on Oct. in ELPH.

Back up

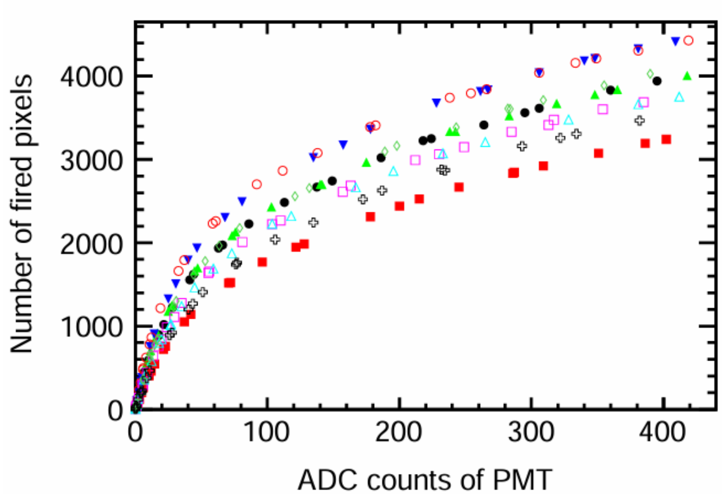
Study of SiPM Saturation

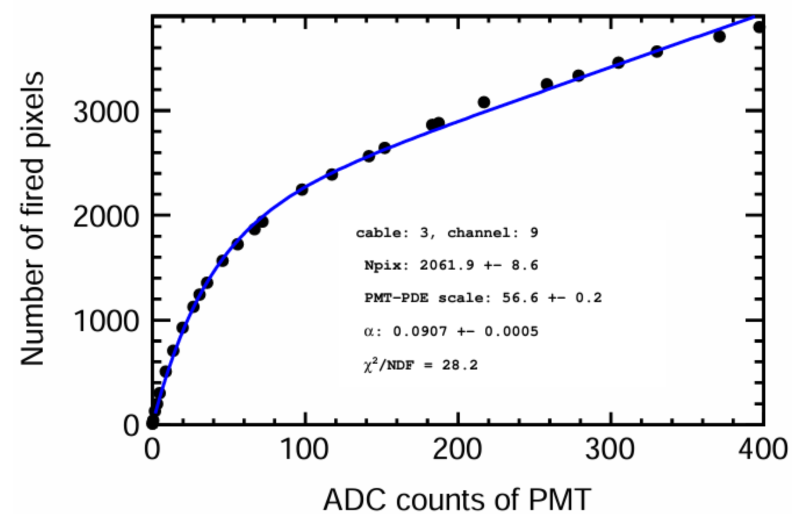
A 408 nm laser[3] pulse with a FWHM duration of 31 ps was used to illuminate the scintillator strip via a 2.5 mm diameter hole in the reflector film. Crossed polaroid films were used to control the laser intensity, and a half mirror was used to independently monitor the light intensity.



ADC count of PMT = laser intensity
Number of fired pixels = SiPM gain

Figure 1: Setup of the N_{pix}^{eff} measurement: a) target scintillator enveloped in reflector (left, top view; right, side view); b) WLS fiber; c) irradiation position with a small hole in reflector; d) MPPC; e) half mirror: f) photomultiplier tube; g) lens; h) polaroid (fixed); and i) polaroid (rotatable).





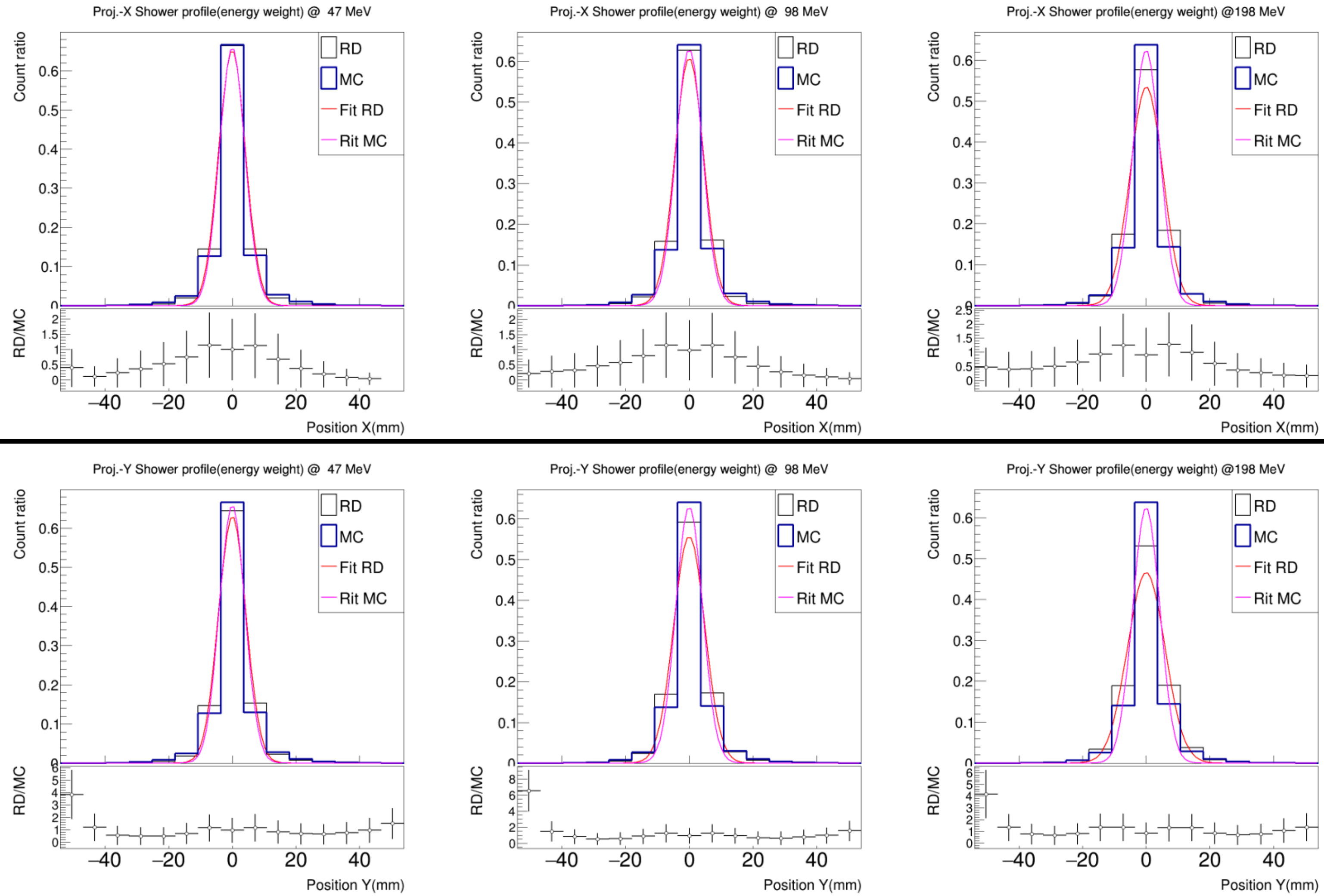
https://arxiv.org/abs/1510.01102

Data VS MC : Shower shape in 1D

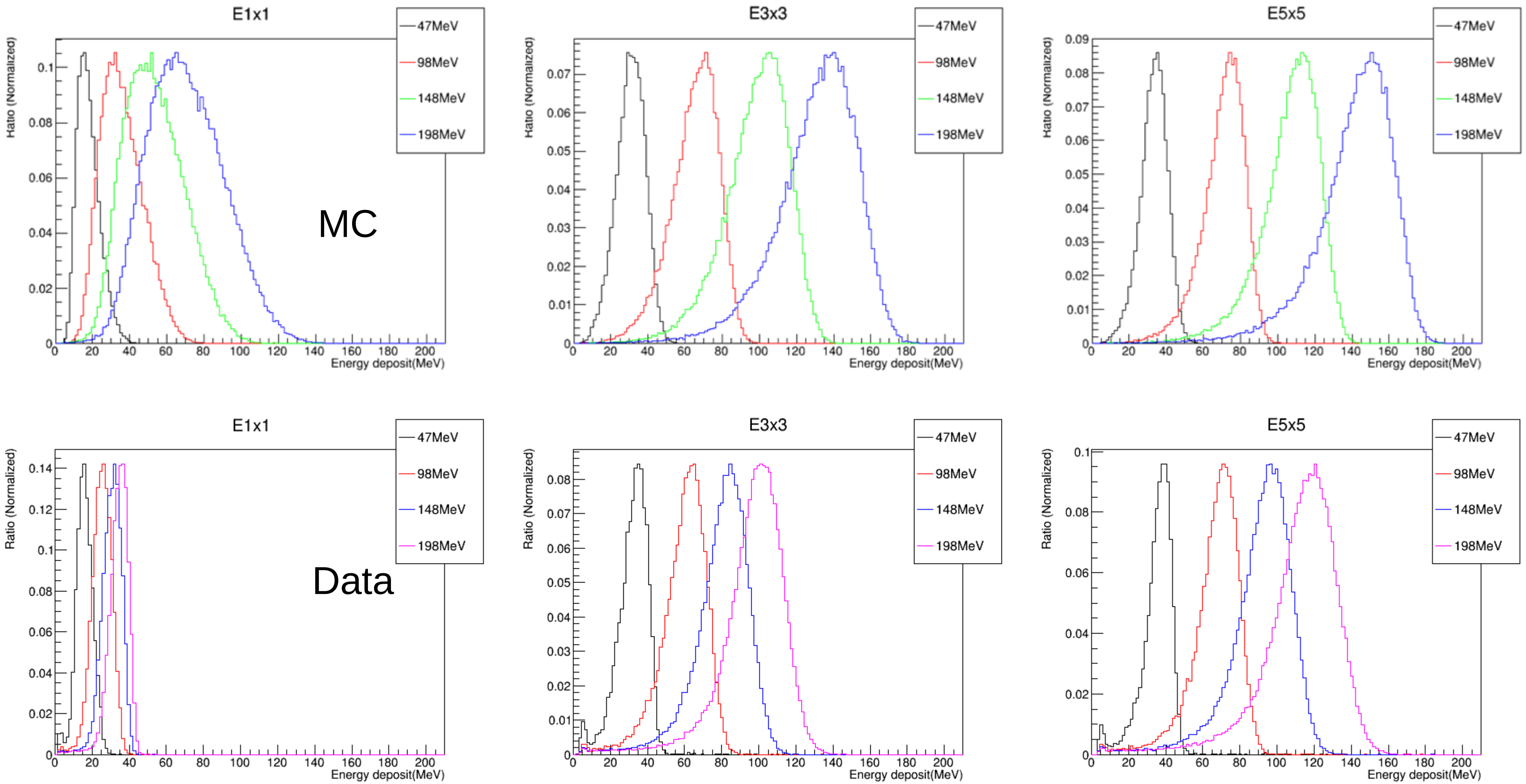
47MeV **98MeV** **198MeV**

X proj.

Y proj.

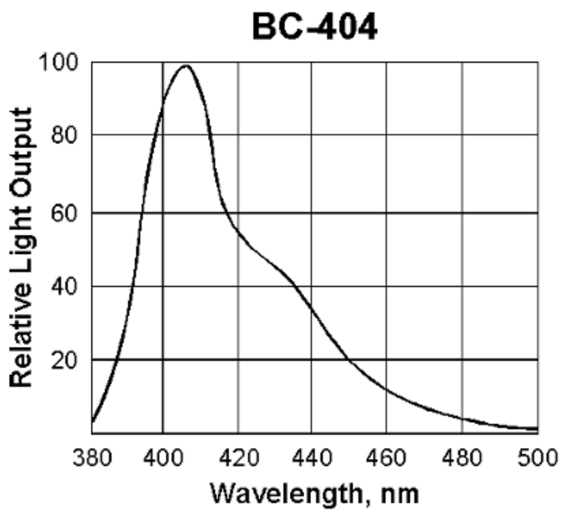


Data VS MC : Energy Deposit



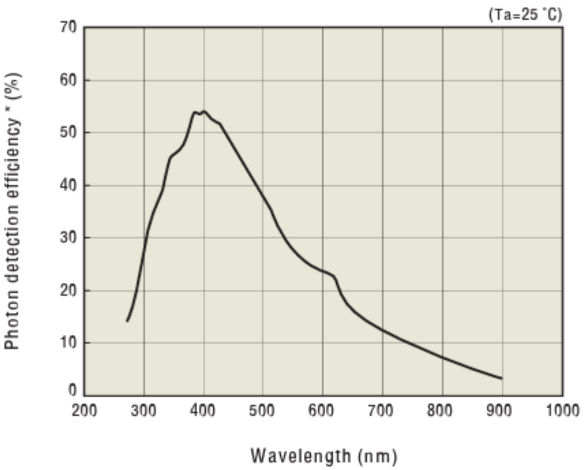
LYSO Light Output and SiPM Photon Detection Efficiency

LYSO Light Output



(a) Emission spectrum of the BC-404 scintillator. The peak of the emitted wavelength is at 408 nm.

SiPM Photon Detection Efficiency



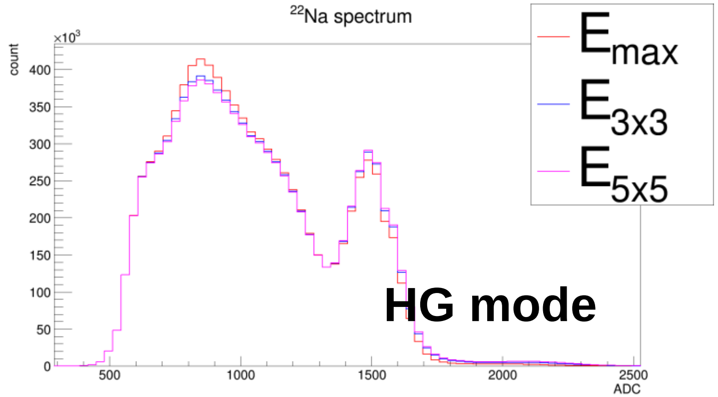
(b) Absorption spectrum of the SiPM. Peak sensitivity wavelength is at 400 nm.

- Reference : http://cds.cern.ch/record/2284023/files/kuensken_bachelor.pdf
- We need to double check LYSO light output in MC

and implement SiPM photon detection efficiency in MC.

Uncertainty of Energy Conversion Factor

Na22



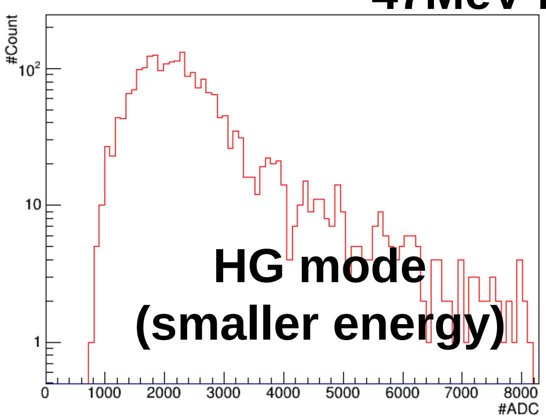
Na22 calibration data

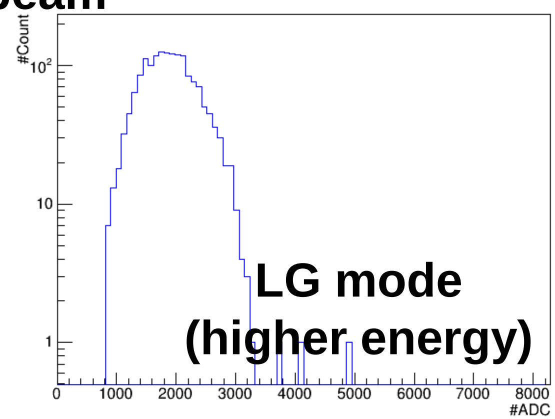
(1) Only HG output is used since the energy of radiation source is low.

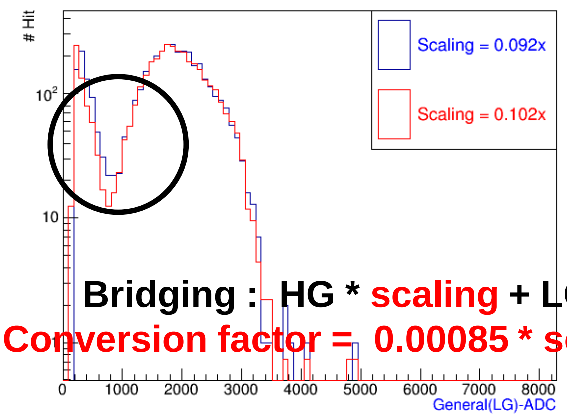
(2) We evaluate energy conversion vector in HG

1.2MeV / 1500 ADC-HG
= 0.00085 MeV/ADC-HG

47MeV beam





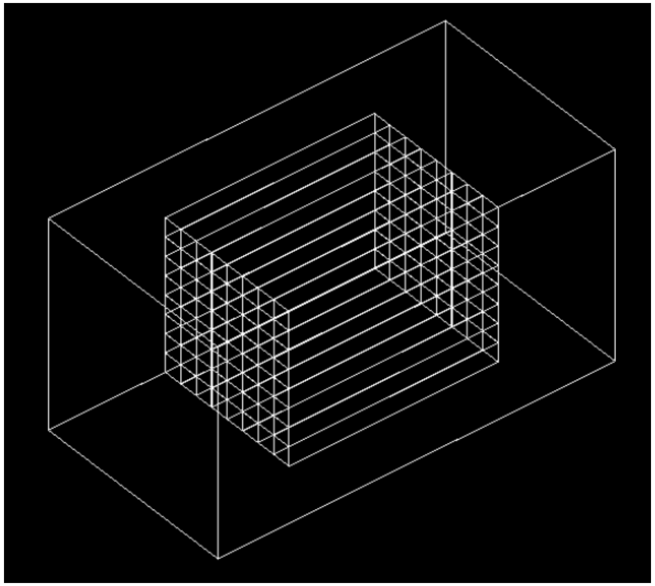


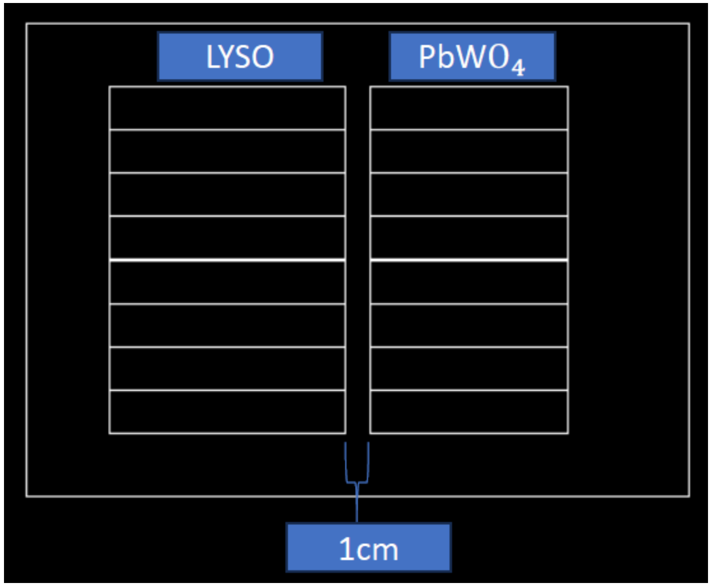
Bridging : HG * scaling + LG

Conversion factor = 0.00085 * scaling

- There are two gain mode in FEE, high gain (HG) and low gain (LG).
- ADC to energy conversion factor in HG was evaluated by Na22 source test.
- **ADC to energy conversion factor in LG can only decided after the bridging of energy spectrum of beam (scaling factor is decided after bridging).**
- We have not yet finalized the bridging. It gives the uncertainty of conversion factor around 30%.

MC Simulation for Final ZDC Ecal Part





- **Size of Crystal**

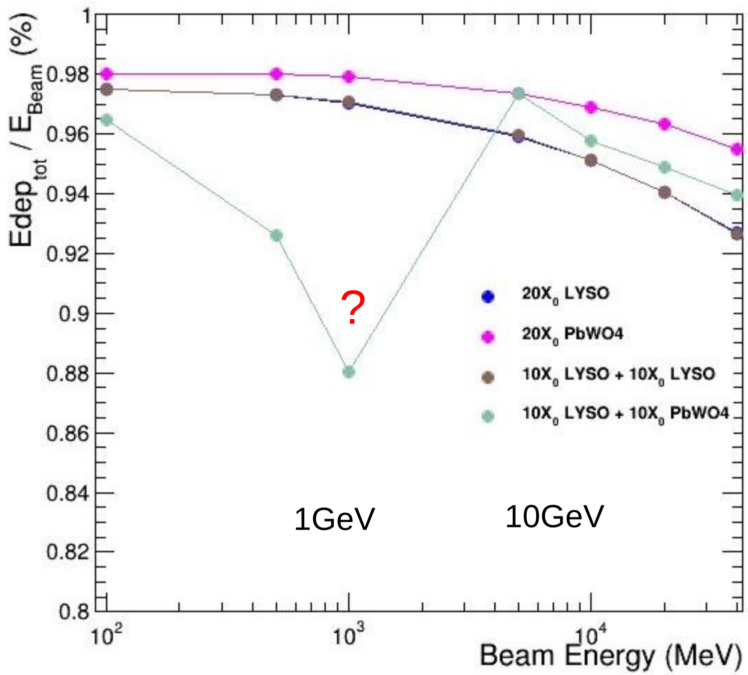
1. 2cm*2cm for one pixel
2. 8*8 array (16cm*16cm)

- **Choice of Crystal (20X0)**

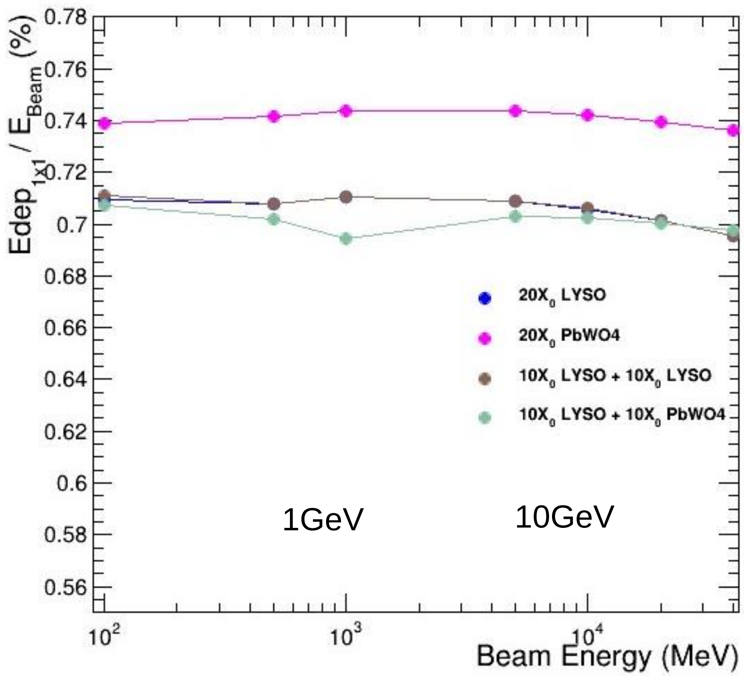
1. 20X0 LYSO.
2. 20X0 PbWO4
3. 10X0 LYSO + 10X0 LYSO (1cm gap)
4. 10X0 LYSO + 10X0 PbWO4 (1cm gap)

MC Simulation for Final ZDC Ecal Part

E8x8/Ebeam



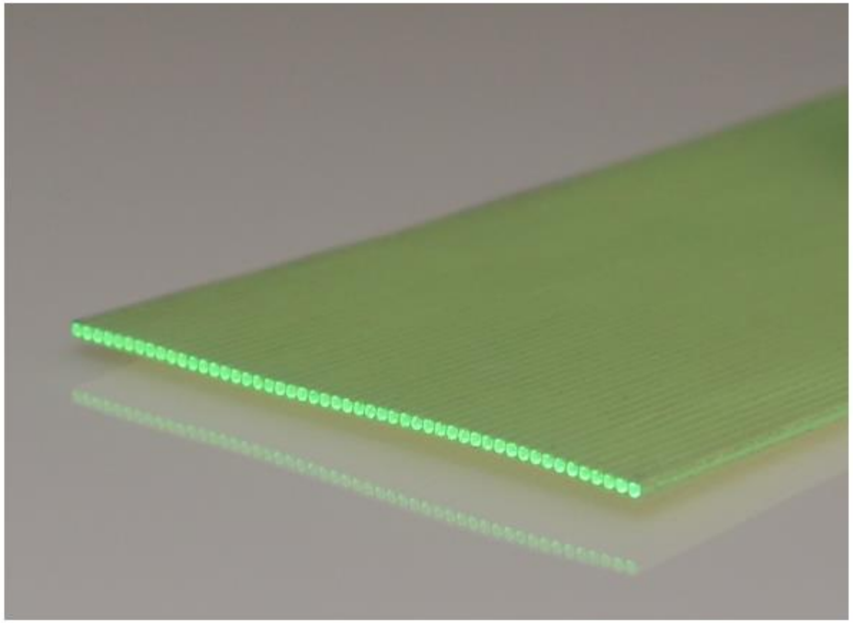
E1x1/Ebeam



- Tested beam energy : 100MeV, 500MeV, 1GeV, 5GeV, 10GeV, 20GeV, 40GeV.
- When beam energy below 1GeV, >96% beam energy dumped in the crystals (all 4 combinations).
- dE/dx of PbO4 is slighter larger than LYSO.
- "10X0 LYSO + 10X0 PbO4" should sit in between "20X0 LYSO" and "20X0 PbO4". Results need to be check again.

External Trigger System : Fiber Tracker

Fibers : Diameter of fiber = 0.5mm



https://www.luxiumsolutions.com/radiation-detection-scintillators/fibers

SiPM : used also for 1^{st} ZDC prototype

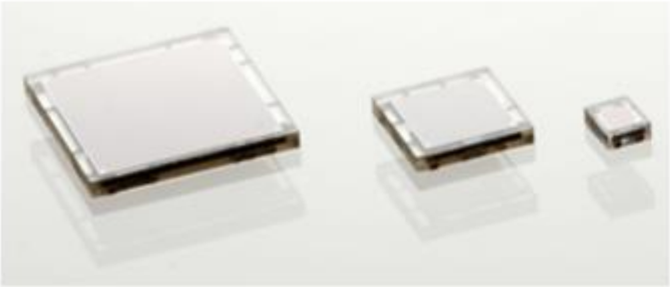


Figure 1. C–Series Sensors

https://www.onsemi.com/pdf/datasheet/microc-series-d.pdf

- To better determine the beam position, we plan to build up a new fiber tracker to use as trigger for the next beam test.
- The existing SiPM system will be used.
- We will purchase small sample of fibers to practice the assymbling.