Status of ePIC ZDC

Cheng Kai-Yu

Tatsuya Chujo, Yuji Goto, Motoi Inaba, Subaru Ito, Kentaro Kawade, Yongsun Kim, Wen-Chen Chang, Chia-Ming Kuo, Po-Ju Lin, Chih-Hsun Lin, Chia-Yu Hsieh, Rong-Shyang Lu, Jen-Chieh Peng, Yu-Siang Xiao, Shao-Yang Lu

Electron Ion Collider (EIC)

EIC

- High luminosity ep, eA collider
- Polarized target collider
- Wide center of mass energy range

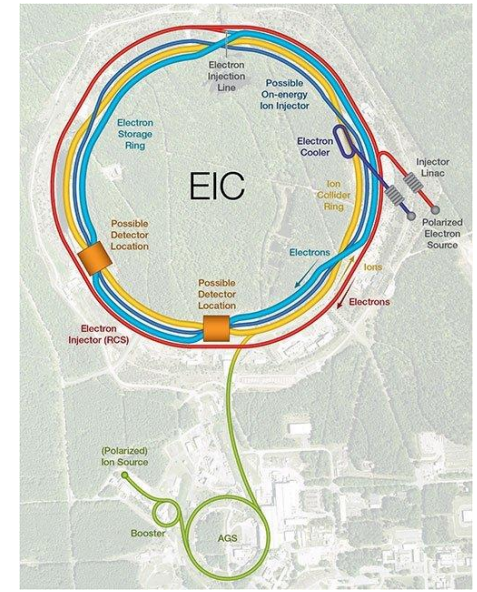
ePIC

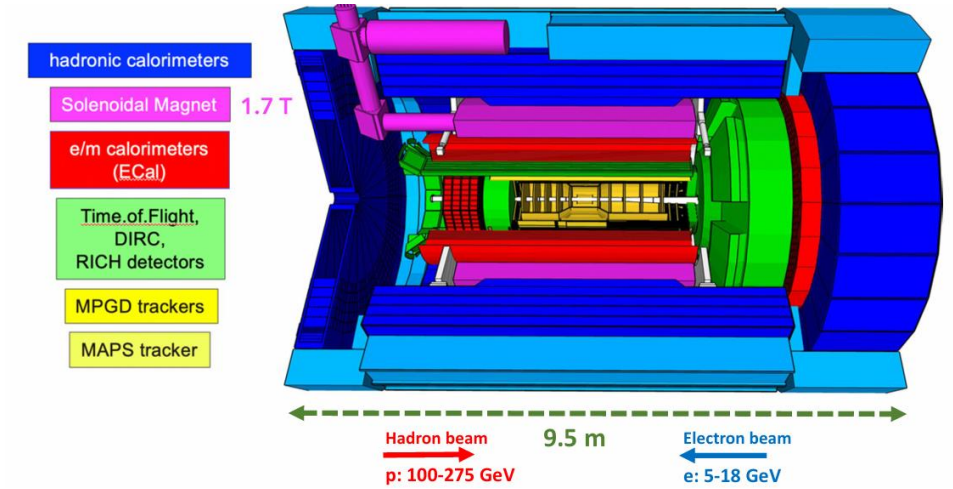
- The first experiment in EIC
- 27 sub-detectors

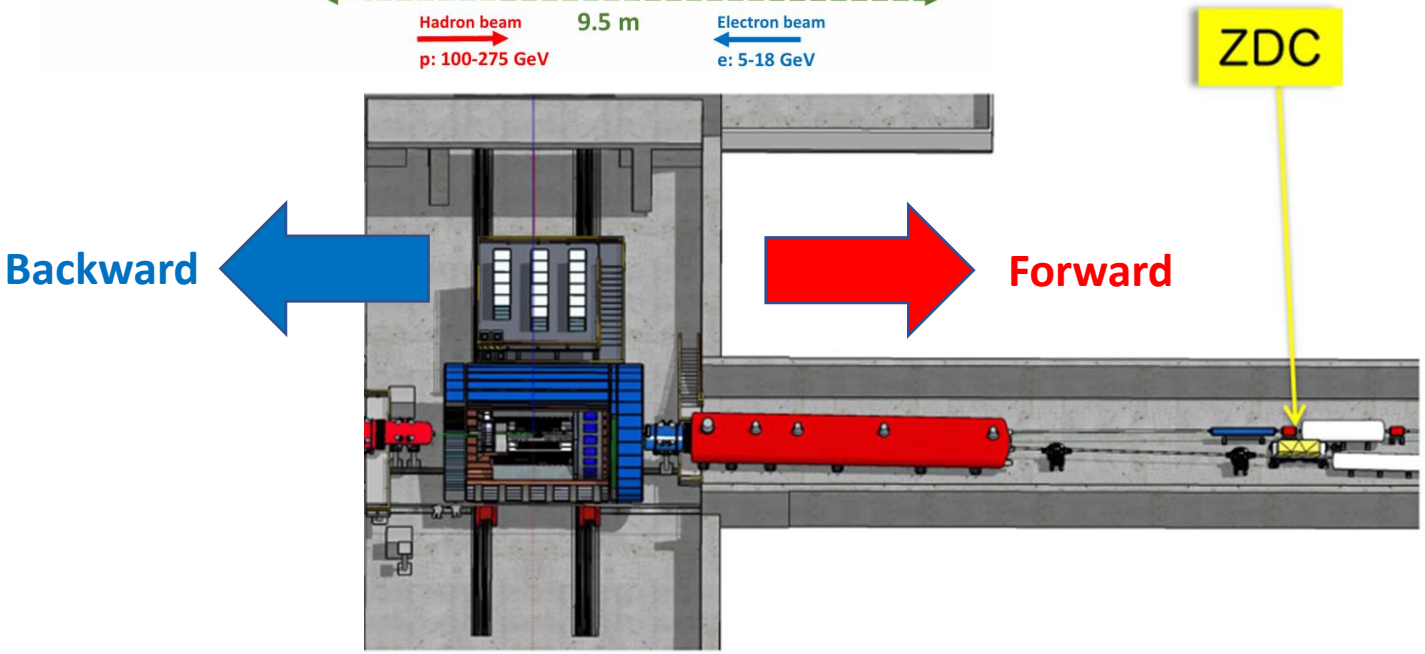
Topic

e+p DVCS, Sullivan process,

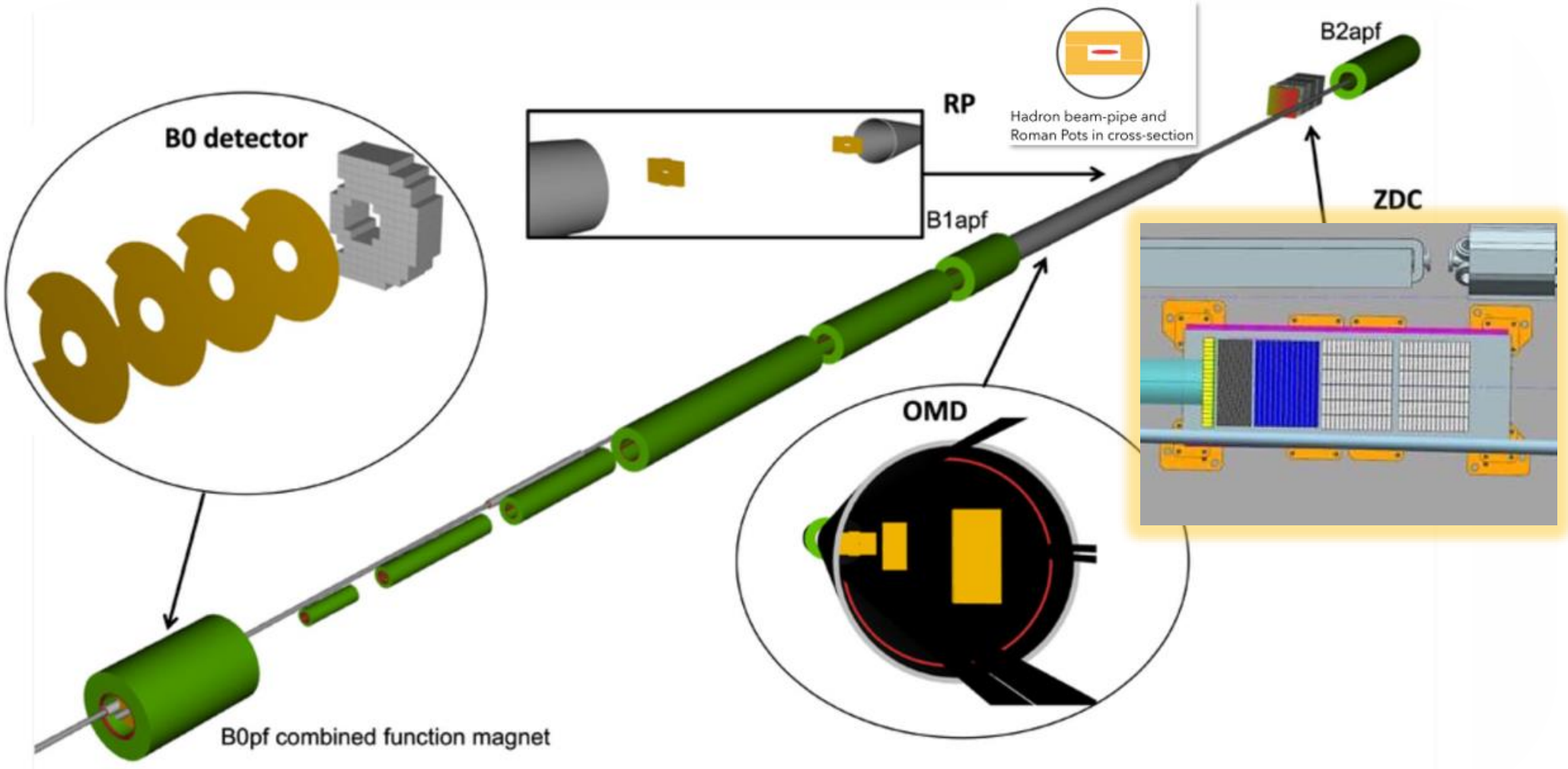
e+d exclusive J/Ψ with p/n tagging, etc.







Forward Detectors of ePIC



Zero Degree Calorimeter (ZDC)

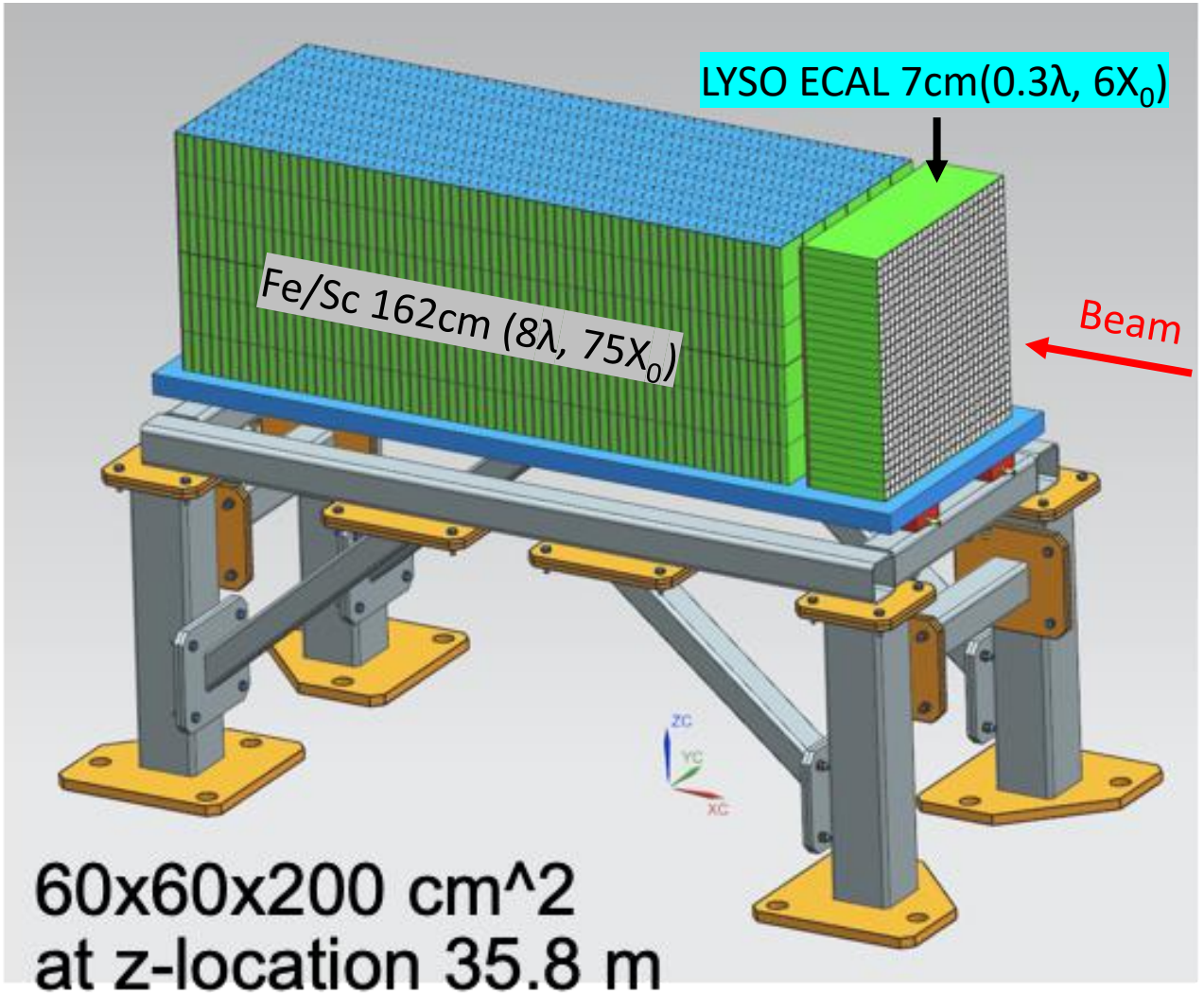
Structure

- 6X0 LYSO ECAL
- 75X0 Fe/Sc System

Target

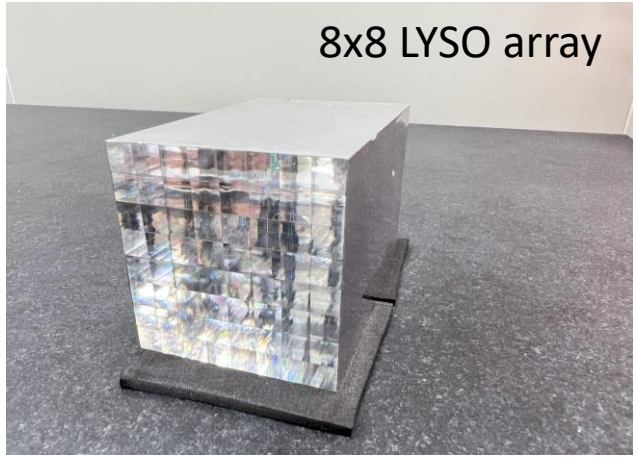
- Measuring forward neutrons and photons

	Energy Range	Energy Resolution	Position Resolution
Neutron	~275GeV	$50\%/\sqrt{E}$	$3mrad/\sqrt{E}$
Photon	100MeV~1GeV	20~30%	
	20~40GeV	$35\%/\sqrt{E}$	0.5~1mm



Lutetium Yttrium Orthosilicate (LYSO)

- Higher light yield
  - Increase the energy resolution of low energy
- Lower temperature dependence
- Made by Taiwan Applied Crystal

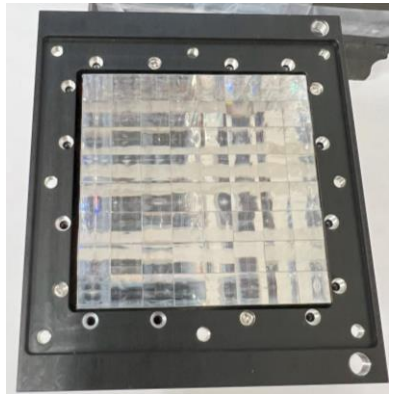


One crystal : 7.12mm*7.12mm*88.3mm
Array size : 56.96mm*59.96mm*88.3mm

Crystal	X_0(cm)	LY(#/MeV)	T dep.	Decay time(ns)	λ_{em}
$PbWO_4$	0.89	200	-1.98% / °C	5(73%) 14(23%) 110(4%)	420nm
LYSO	1.14	30,000	-0.28% / °C	39	420nm
GAGG	1.59	40,000~ 60,000		50~150	520nm

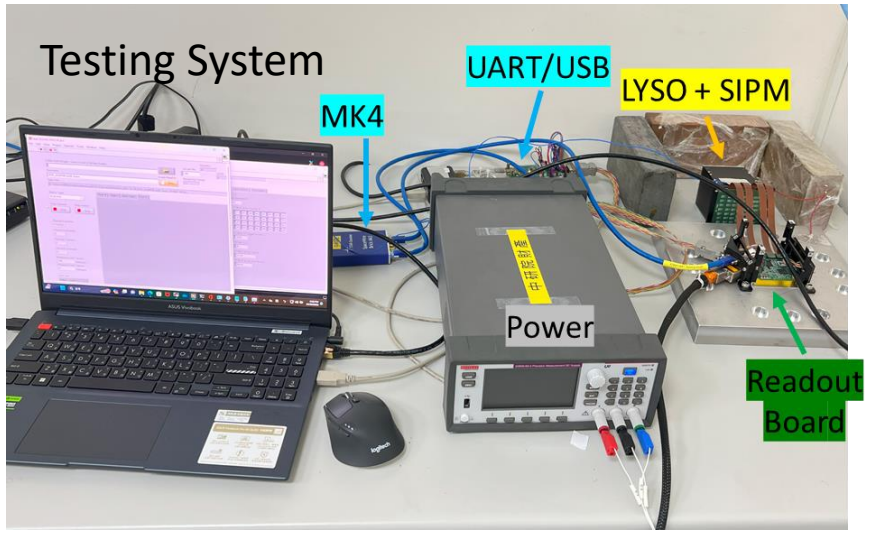
Prototype LYSO ECAL

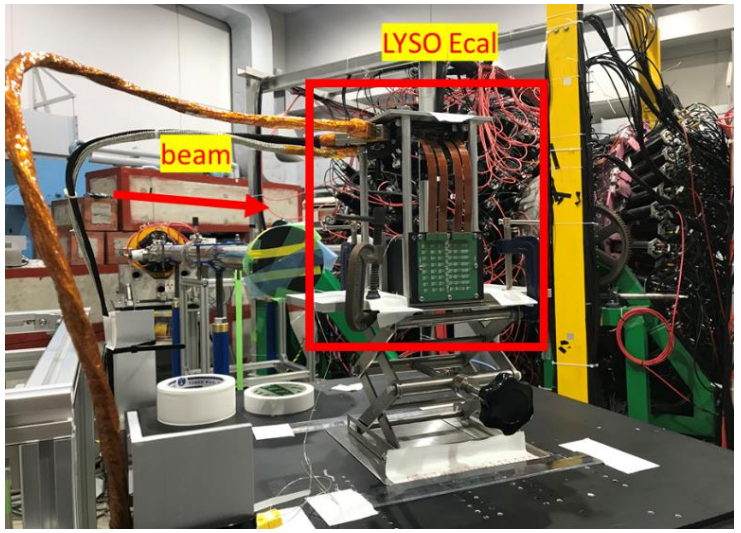
- **LYSO**
  - 8x8 array
  - Each crystal : 7.1mm*7.1mm*88.3mm ($8X_0$)
  - ESR reflection layer
- **SiPM**
  - Radiation tolerance
    - SiPM : $2x10^{14}/cm^2$ (CMS ECAL)
    - APD : $4x10^{13}/cm^2$ (CMS MTD BTL)
  - MICROFC-60035
- **GTM Readout board**
  - 2 Citiroc1A (2 x 32 channels)
  - Separate voltage adjustment
  - Self-triggered



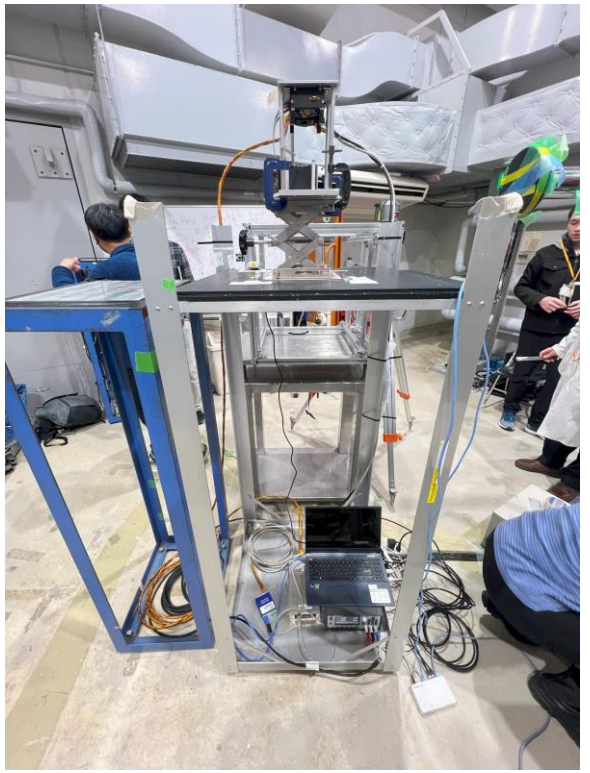
8x8 SiPM array

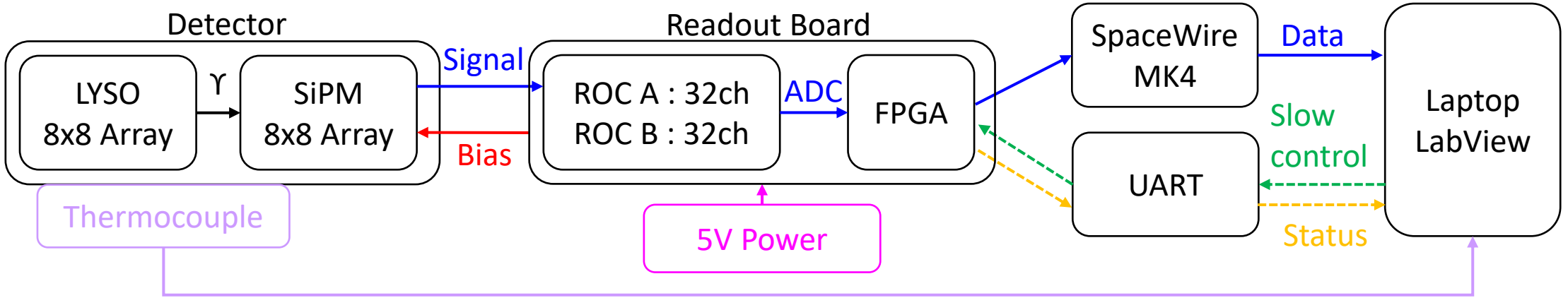
Setup





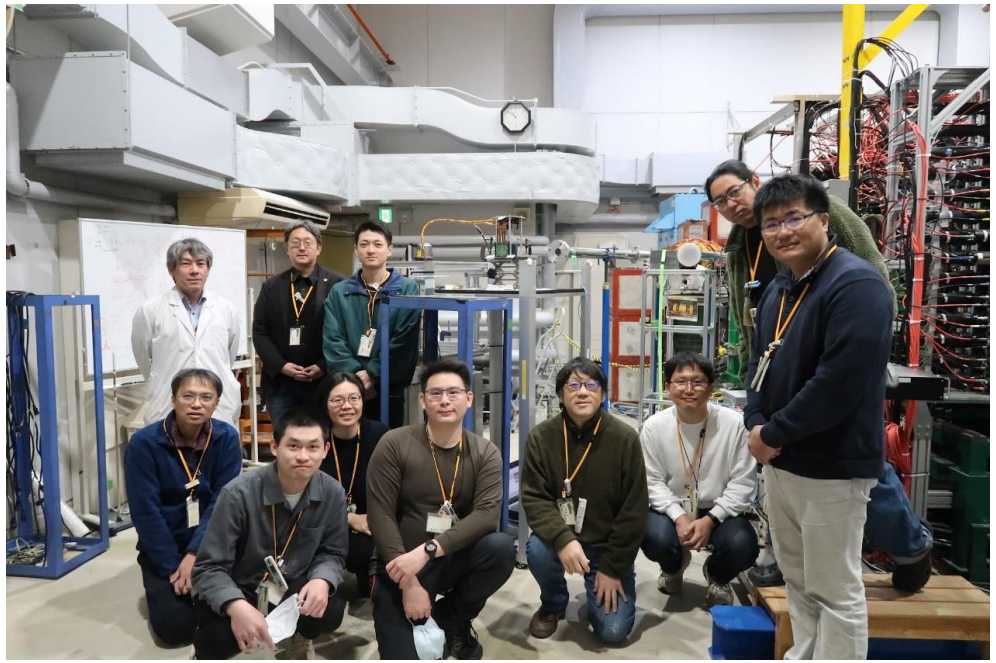
Setup @ ELPH





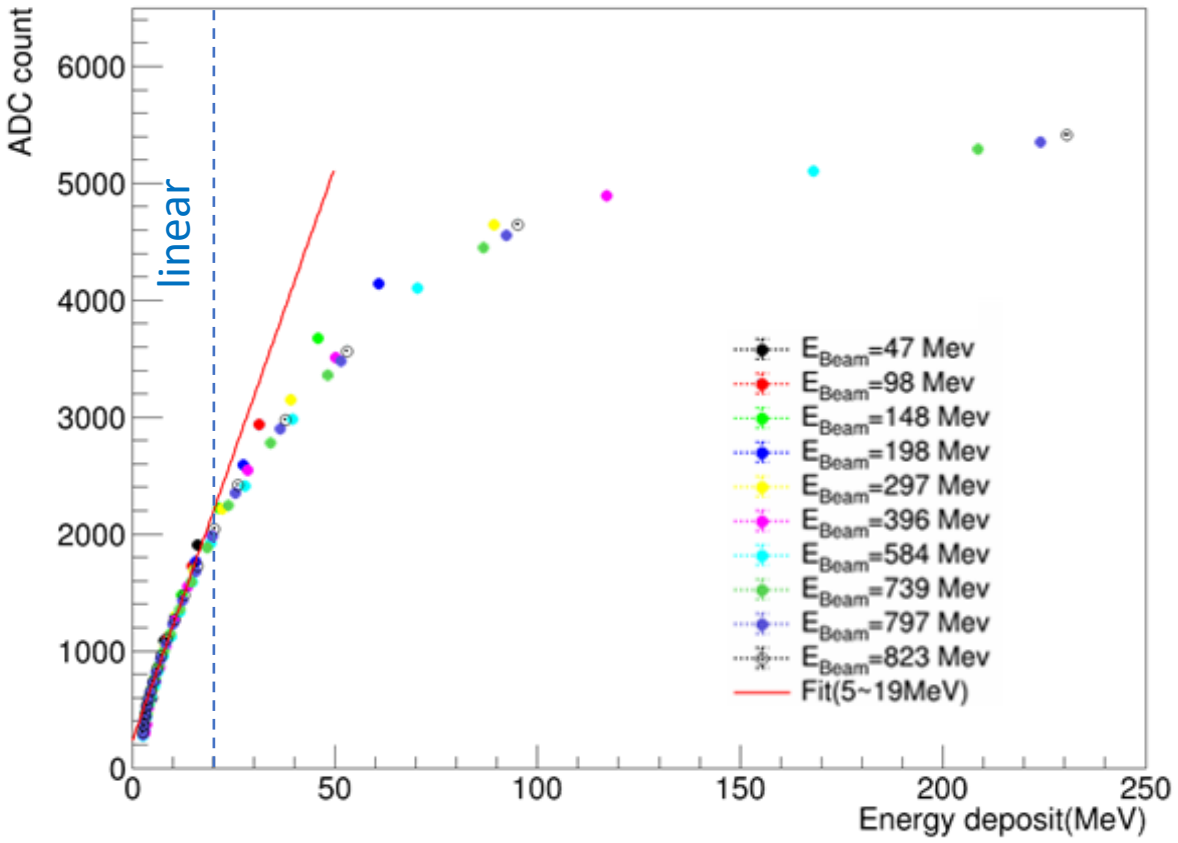
First Beam Test

- **Time**
  - 2024 Feb. 15th to Feb. 21th
- **Location**
  - ELPH@Tohoku, Japan
- **Participants**
  - RIKEN, Tsukuba University, Tsukuba University of Technology, Sejong University, EIC-Taiwan
- **Beam**
  - 47.18 MeV to 823.36 MeV positron beam
- **Scan list**
- SiPM HV Scan, Beam energy scan, detector rotation, etc.



ADC function with E_{dep}

- The plot shows the saturation behavior of SiPM.
- Each data point represents the peak value of channels from the highest to lowest signals at different beam energies.
- Conversion of deposited energy references the results of MC simulations.
- Most of the data fall within the saturated range, except for the 47 MeV data.
- ~60% of the data from the 47 MeV beam remain in the linear range



Selection Criteria

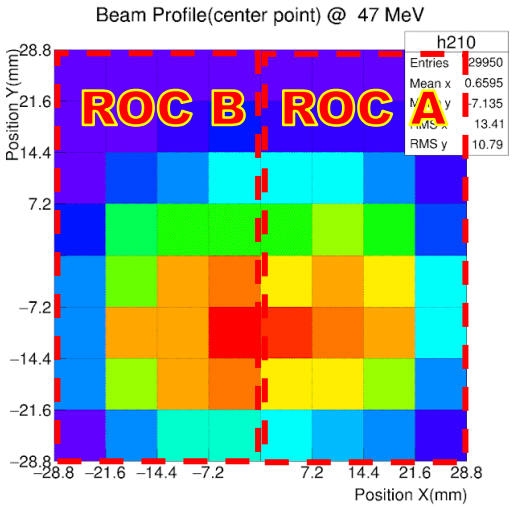
Using linear fitting function to convert ADC values into deposited energy.

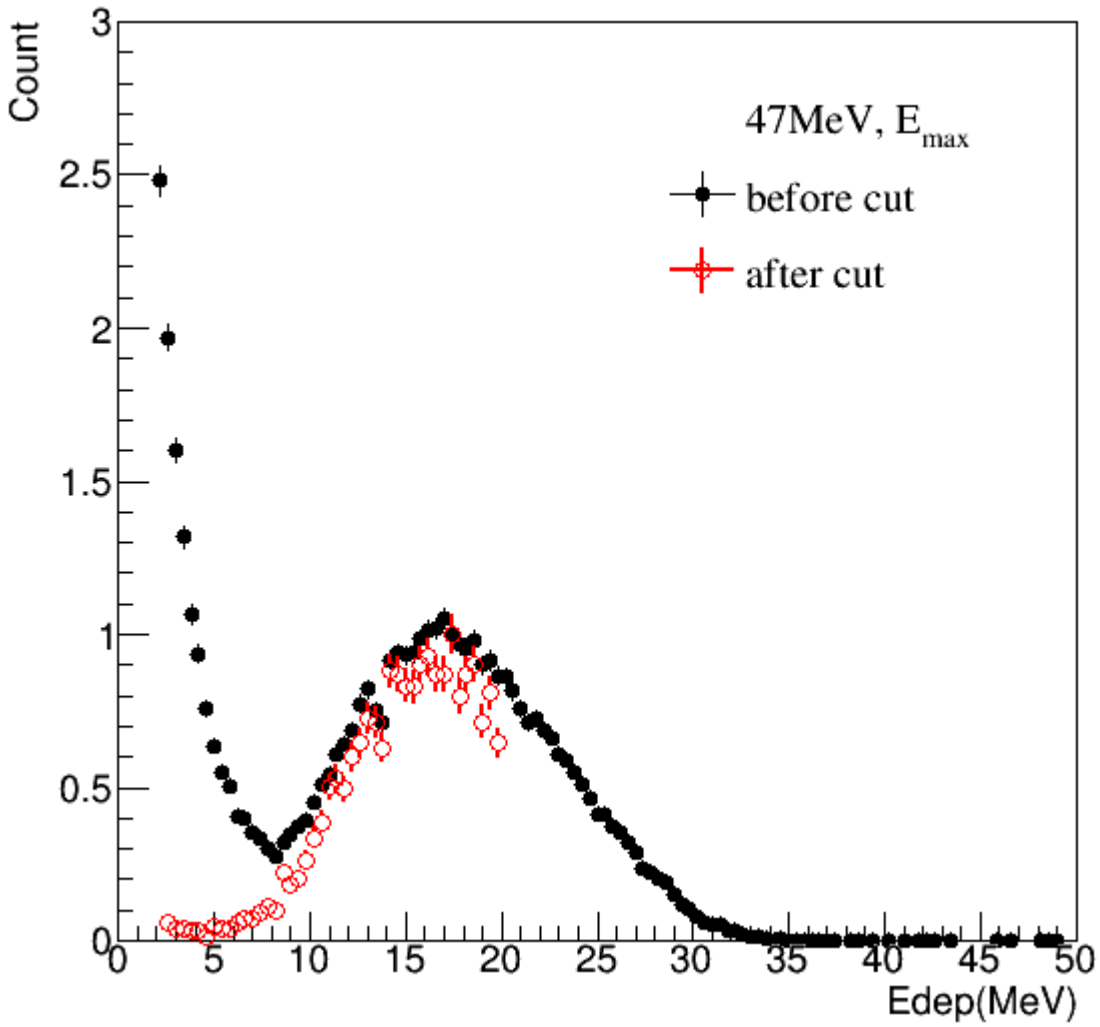
1) Fire two Citiroc

- Remove the events that only contains noise

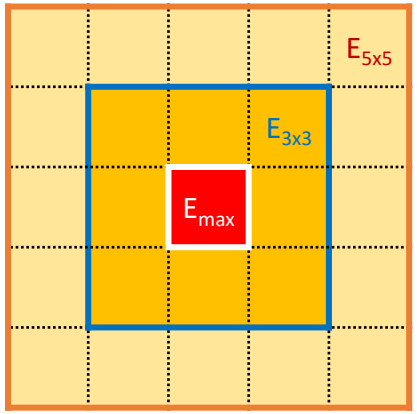
2) 2.5MeV < E_{dep} < 20MeV

- Remove the low momentum photons
- Focus on the linear region

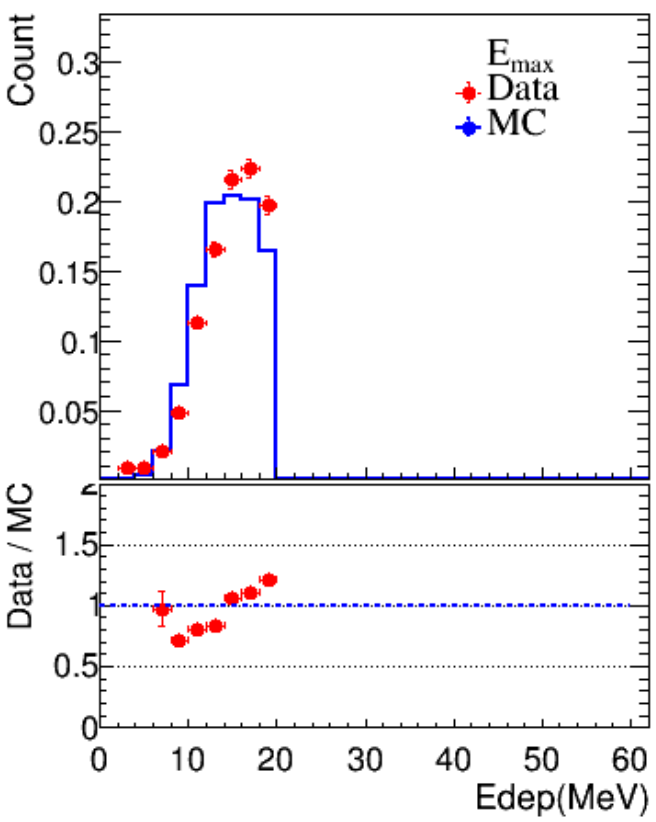


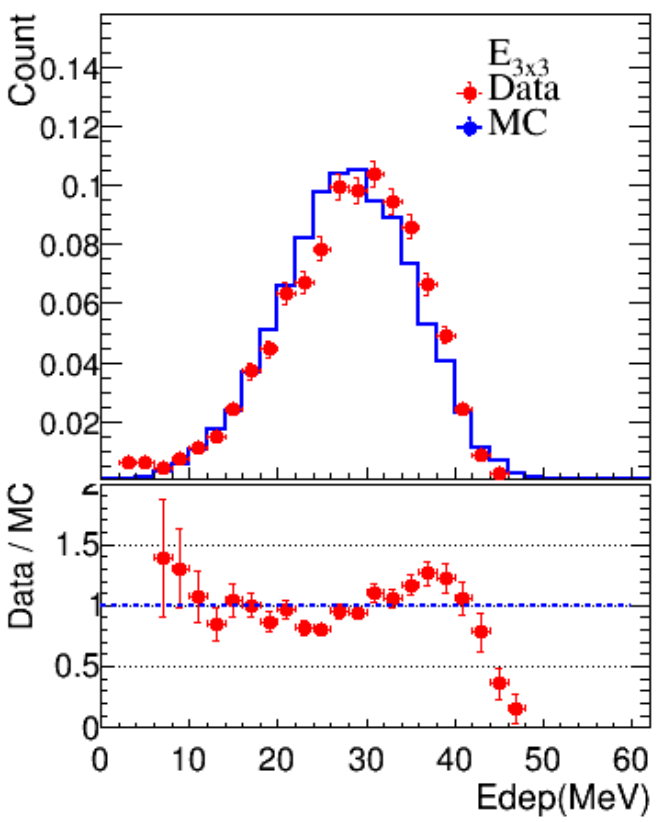


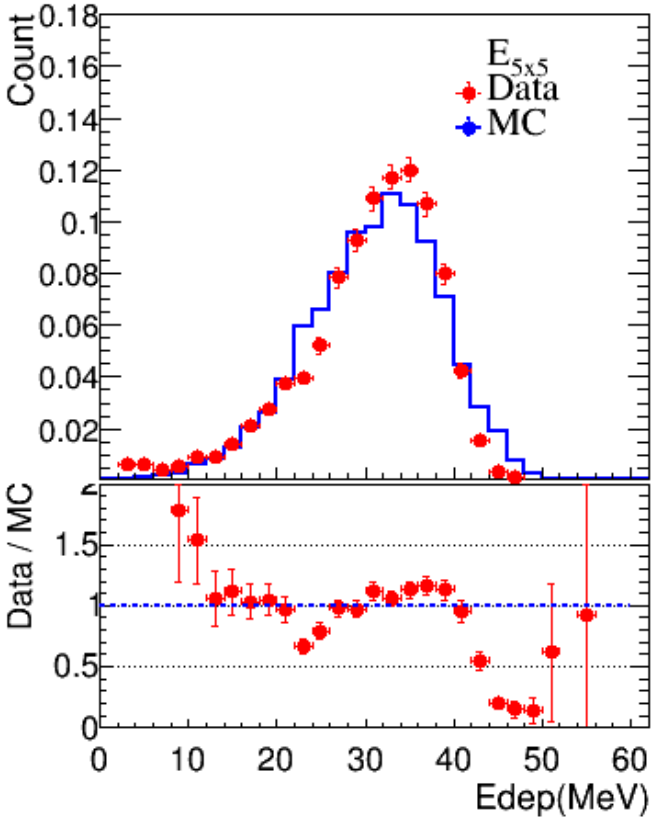
Data and MC Comparison



- Clustering comparison at 47MeV Beam Energy
- Energy selection : [2.5MeV, 20MeV]
- E_{3x3}, E_{5x5} : energy sum for each channels in 3x3 or 5x5 region

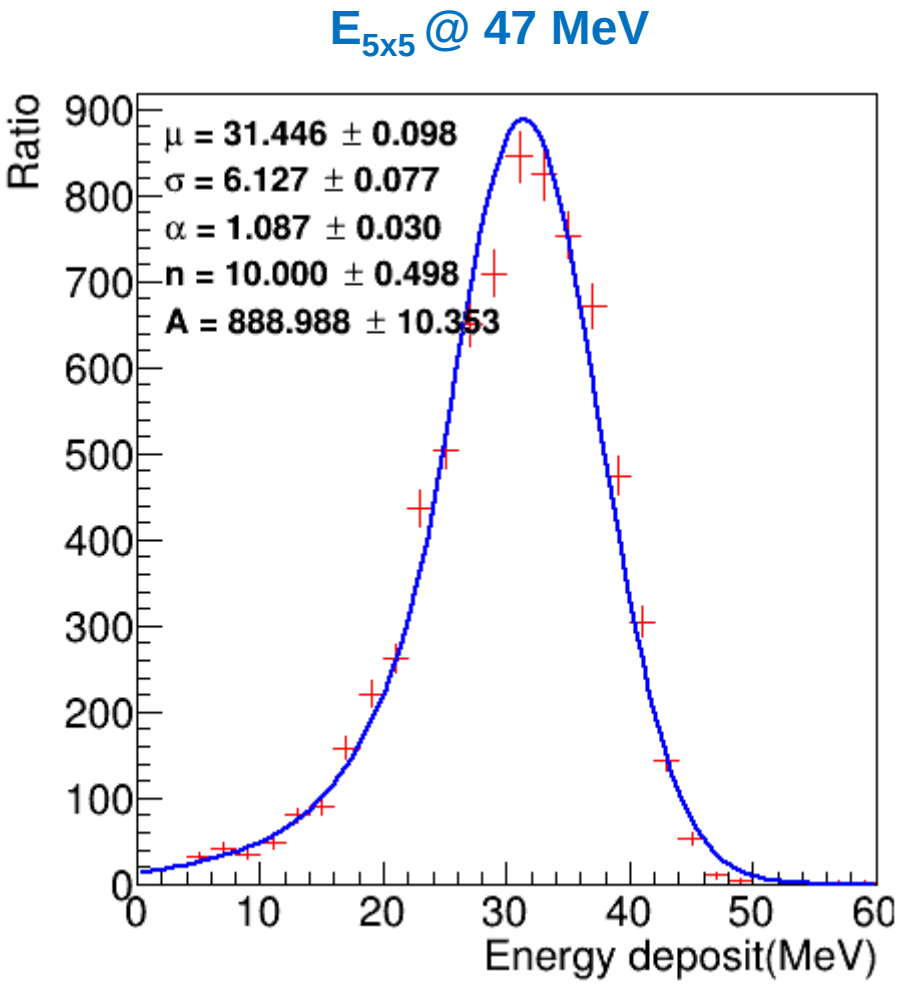






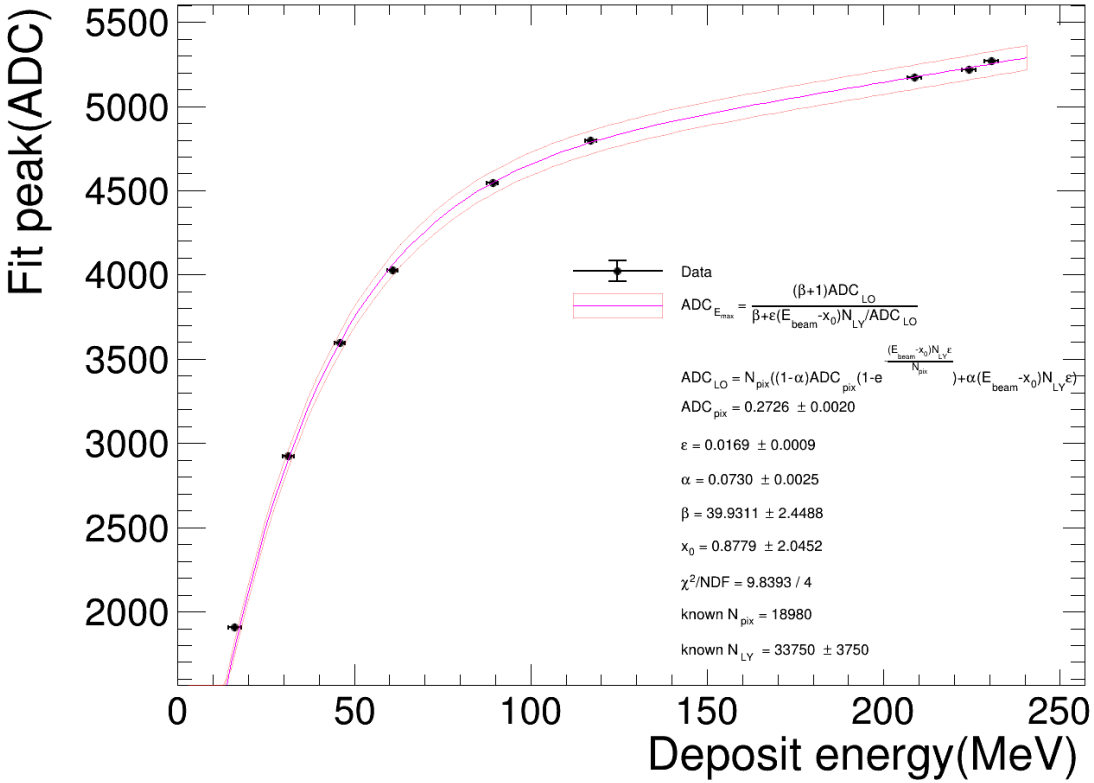
Energy Resolution for 47MeV

- E5x5 distribution converted using a linear fitting function, without applying energy regression or calibration.
- Crystal ball fitting:
  - Mean = $31.446 \pm 0.098\mathrm{MeV}$
  - Sigma = $6.127 \pm 0.077\mathrm{MeV}$
- 19.5% energy resolution for 47MeV positron beam
- Including 11.6% beam momentum resolution.
- Removing beam uncertainty the resolution is ~15.6%



Nonlinear Reconstruct

- Using SiPM saturated function to obtain the non-linear relationship between ADC values and deposited energies.
- SiPM saturated function[1]:
- $ADC = \frac{(\beta+1)ADC_{LO}}{\beta+\epsilon LE_{dep}/ADC_{LO}}$
- $ADC_{LO} = N_{Pix}\left[(1-\alpha)ADC_{pix}\left(1-e^{-\frac{\epsilon LE_{dep}}{N_{pix}}}\right)+\alpha\epsilon LE_{dep}\right]$
- α represent contribute factor of remaining photons
- β represent decay factor of hit channels
- ϵ represent factor photon collection



[1]*Katsushige Kotera, https://arxiv.org/abs/1510.01102v4*

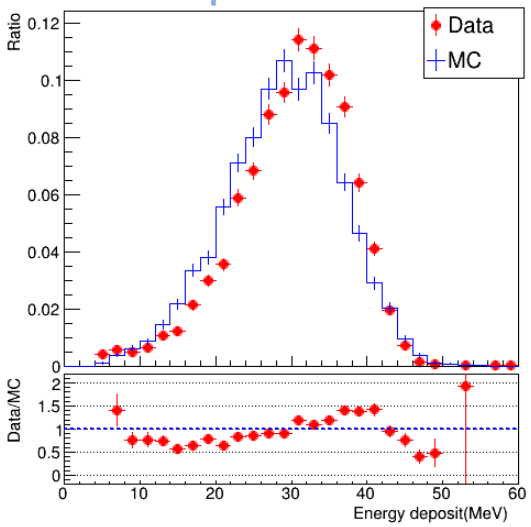
Data and MC Comparison

- Comparison of E_{5x5} distributions obtained from SiPM nonlinearity fitting, without applying energy regression.
- The offline energy cut are adjusted with different beam energies
- The distribution widths are similar in lower beam energy (<200MeV)

x_{PS} 制限なし		
μ_P (MeV/c)	σ_P (MeV/c)	σ_P/μ_P (%)
47.18(2)	5.48(1)	11.63(3)
98.19(4)	4.92(3)	5.01(3)
148.22(4)	4.77(2)	3.22(2)
197.94(3)	4.91(2)	2.48(1)

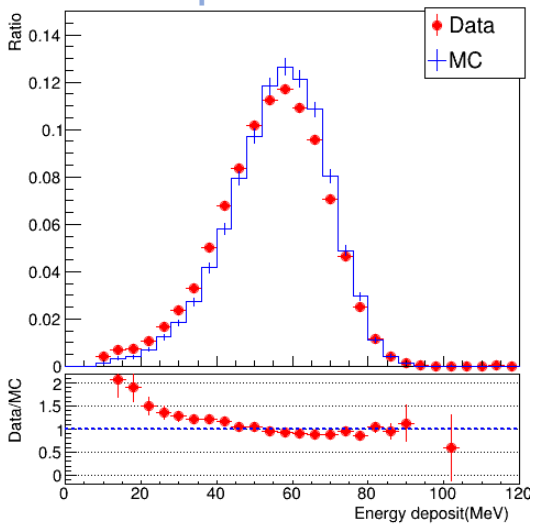
E_{5x5} @ 47 MeV

E_{dep}>5MeV



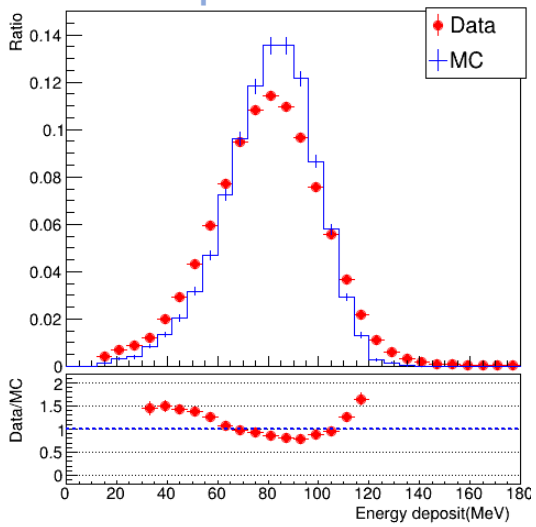
E_{5x5} @ 98 MeV

E_{dep}>10MeV



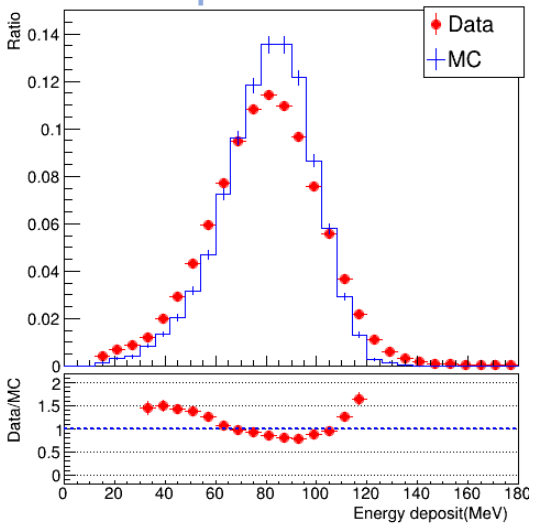
E_{5x5} @ 147 MeV

E_{dep}>15MeV



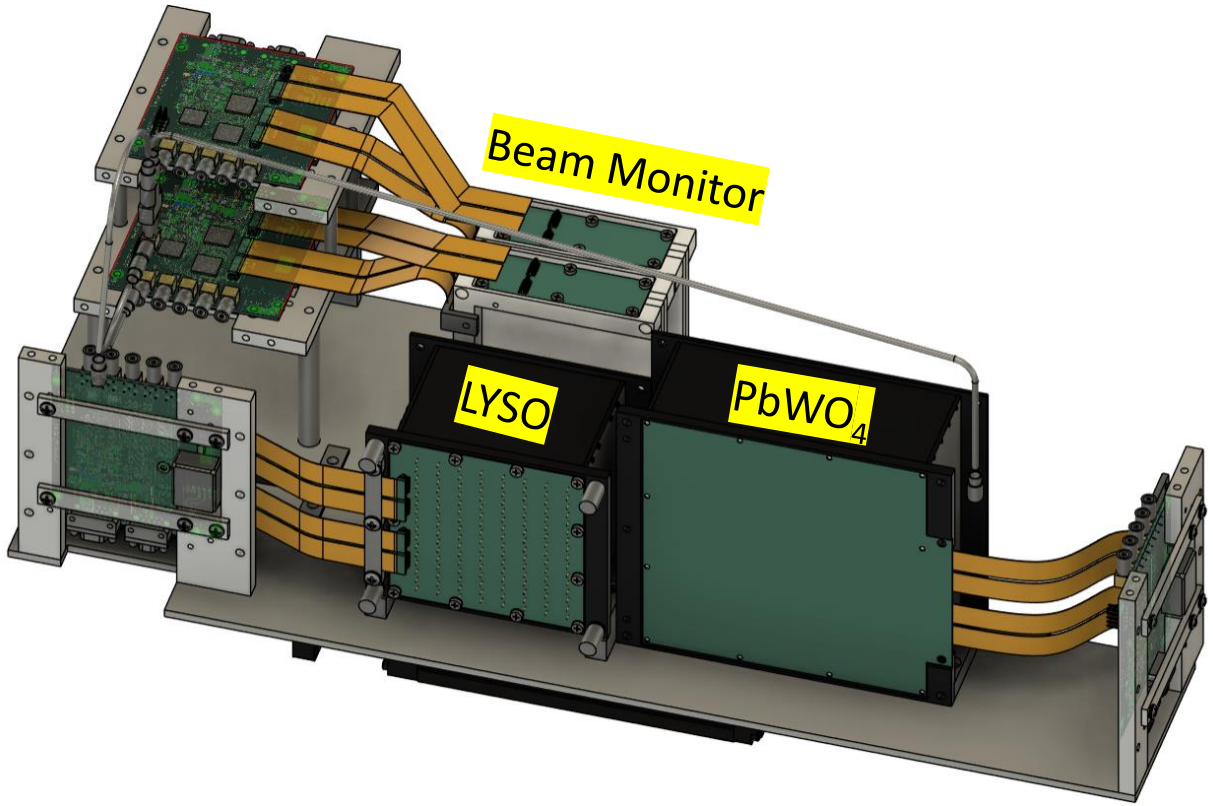
E_{5x5} @ 197 MeV

E_{dep}>20MeV



2nd Beam Test

- 2025 Feb. 17th to Feb. 20th at ELPH
- 2nd Prototype:
  - Radiation length $8X_0 \rightarrow 6X_0$
  - 64ch LYSO + APD
  - 36ch $PbWO_4$ + SiPM / APD
  - 2*Beam monitor (2mm scintillator bar arrays)
- Target
  - Test the performance of LYSO with APD
  - Compare with $PbWO_4$
  - Study the position resolution
  - Improve the event selection



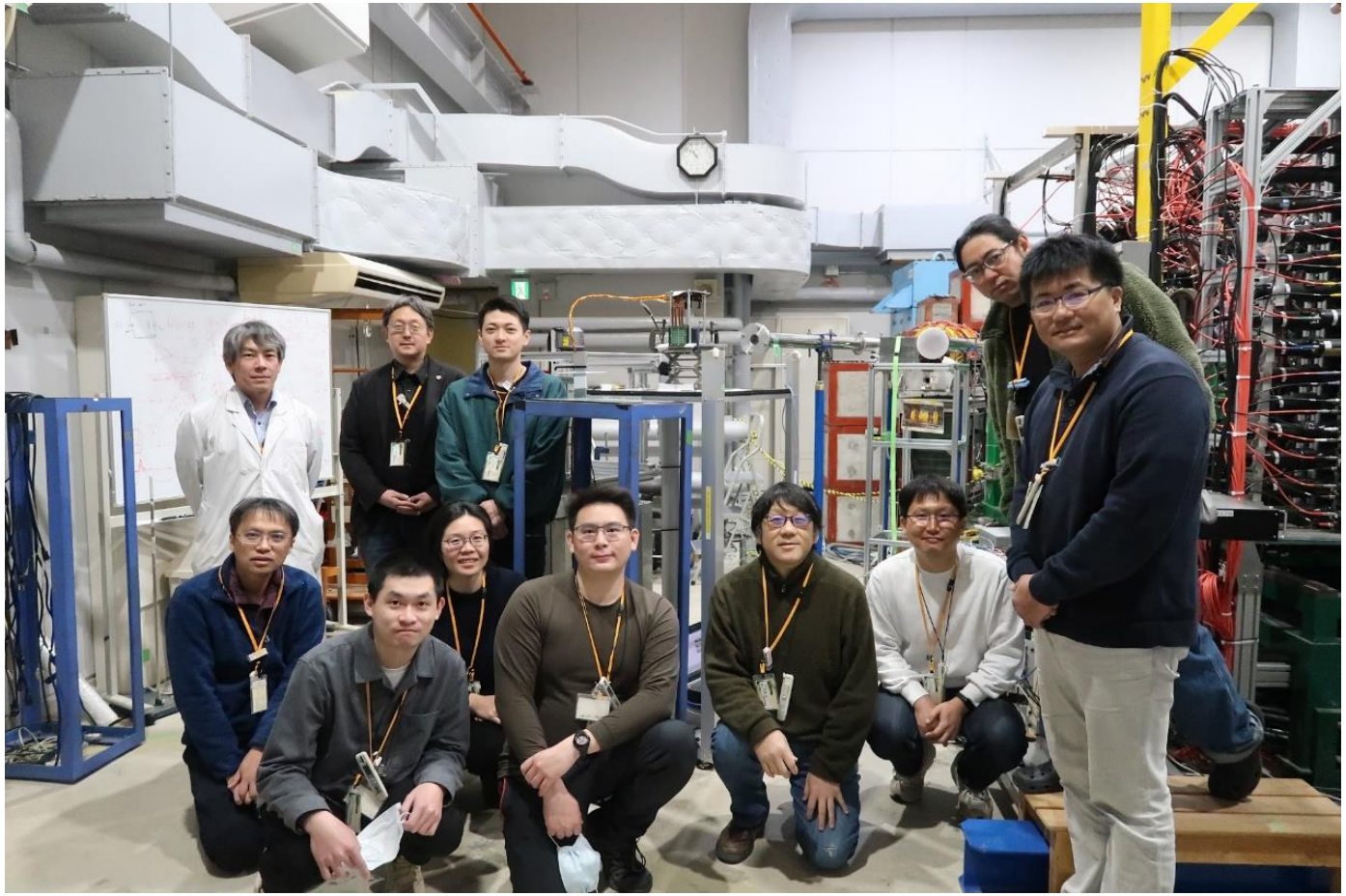
Summary

- **Status of first ZDC prototype**
  - >90% data from higher energy beam falls within the saturated region.
  - 60% data from 47MeV positron beam falls within the linear region.
  - For the 47 MeV positron beam, our prototype achieves an energy resolution of 15.6% in linear region (E_{dep}< 20MeV)
  - Using SiPM saturated function and removing the lower energy channels, the energy distribution between data and simulation are similar from 47 to 197MeV positron beam.

  To do
  - Applying energy regression to improve the result.
  - Modify the higher energy beam simulation to improve analysis beam data.

- **Secondary Beam Test in 2025**
  - Using APD to avoid nonlinear behavior caused by pixels of SiPM, and reducing the gain to increase dynamic range.
  - Add beam monitor for studying position resolution and improve event selection.

Thank you for your attention!

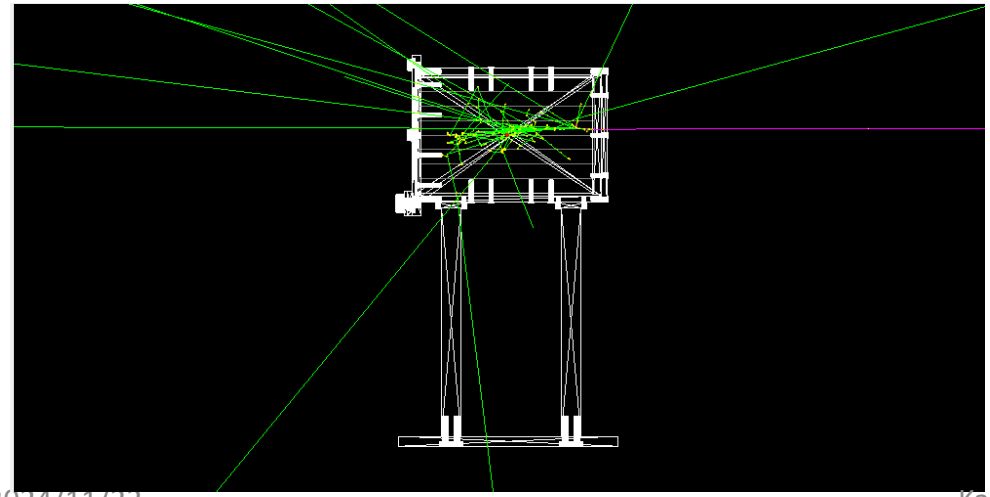


Backup

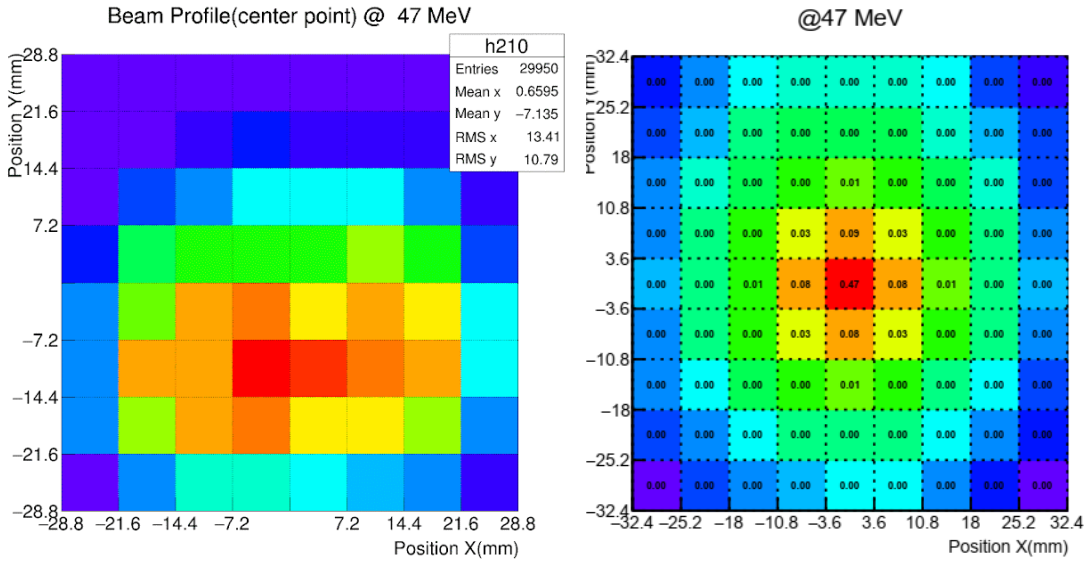
Data and MC Comparison

MC Simulation:

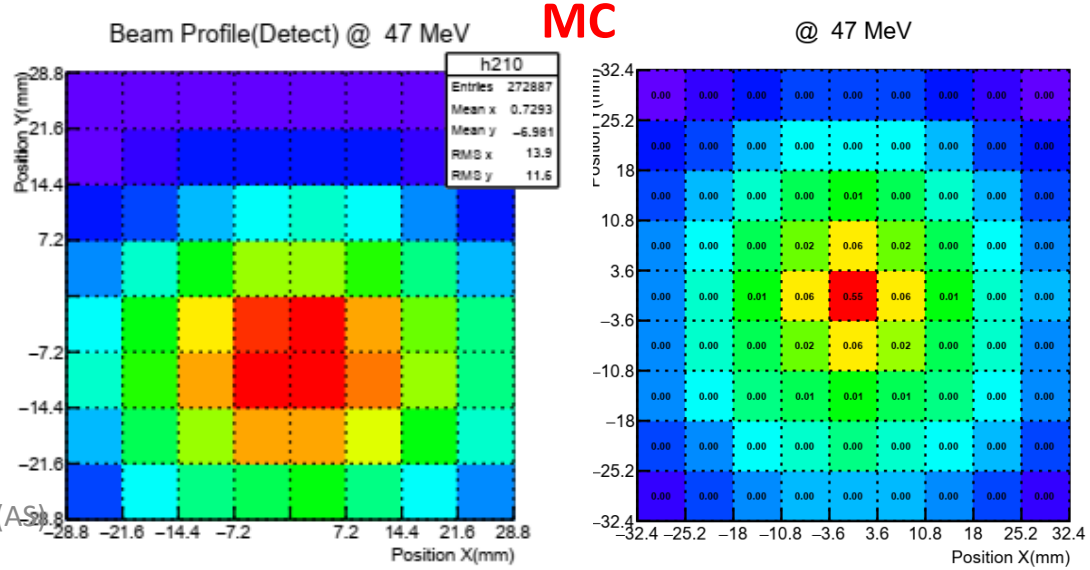
- Including all detector geometry and material
- Beam condition follow the manual of ELPH
- Beam Energy : 47.18MeV ± 11.63% (gaussian)
- Gaussian beam profile
- Beam angle : 90^{o}



Beam Profile **Data** **Clustering**



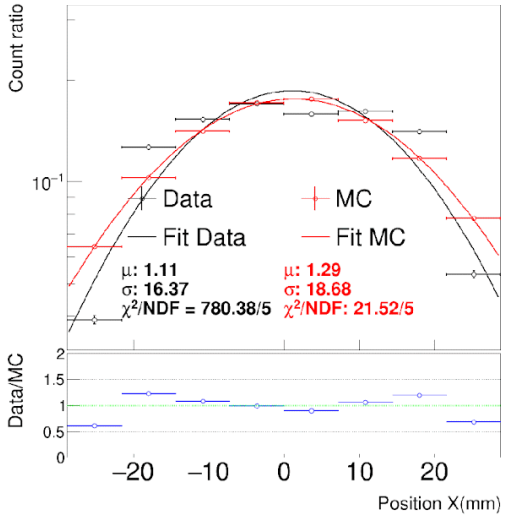
MC

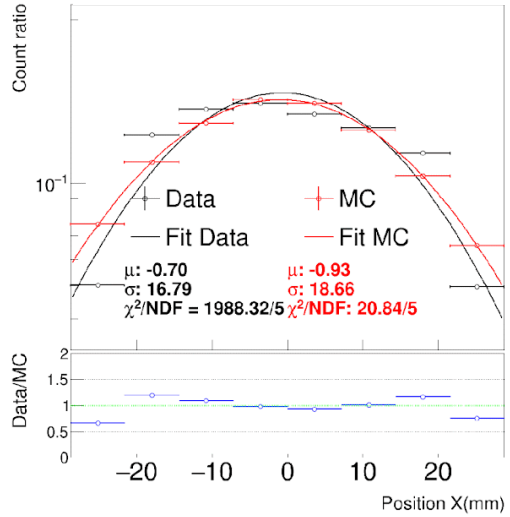


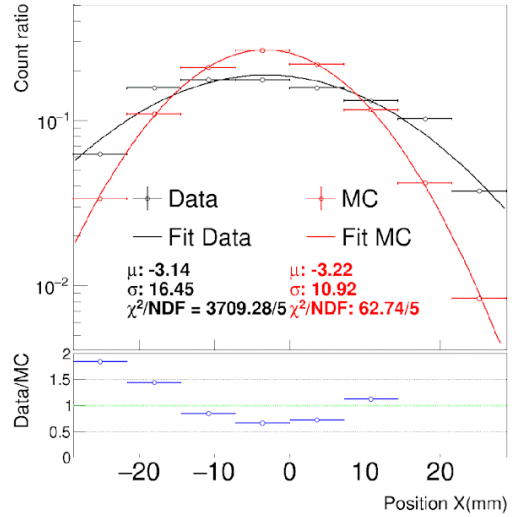
Beam Profile

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

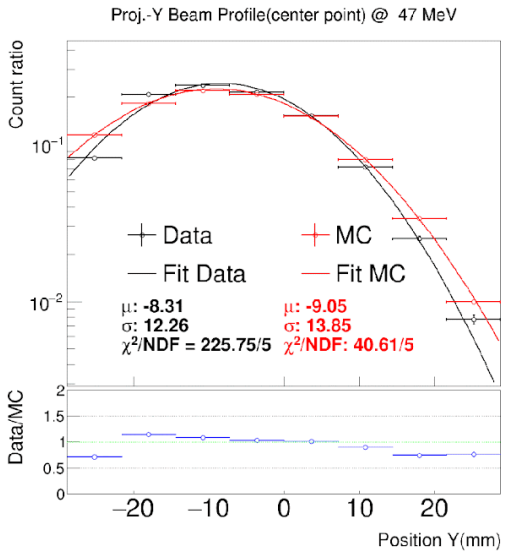
X

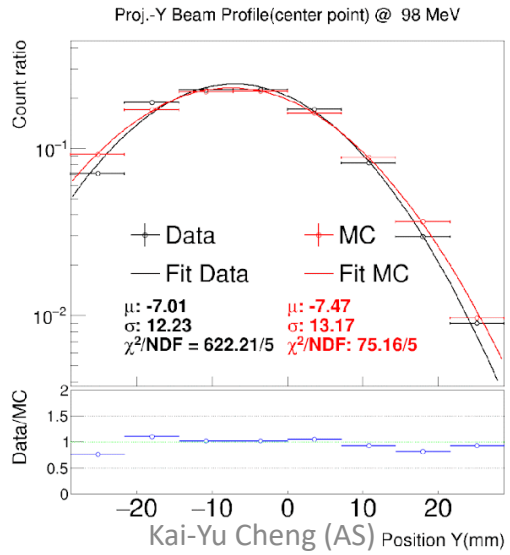


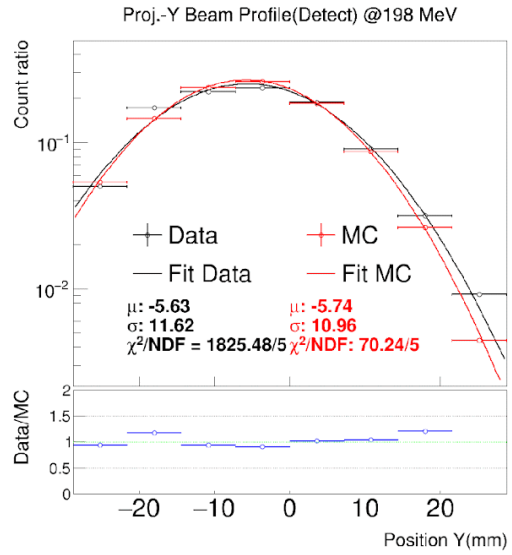




Y



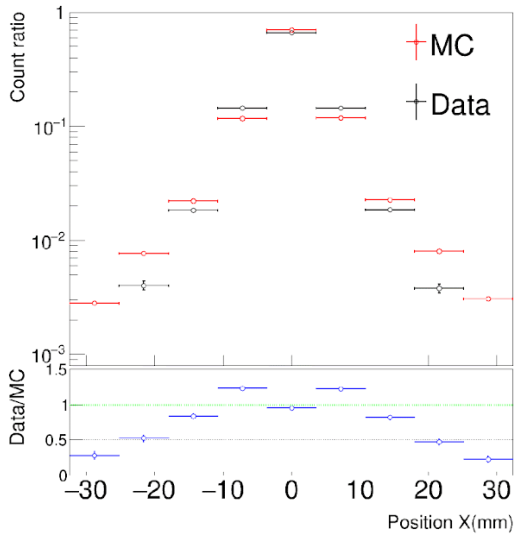


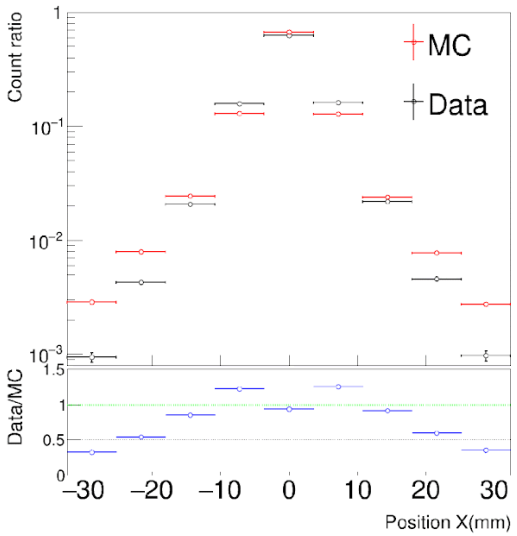


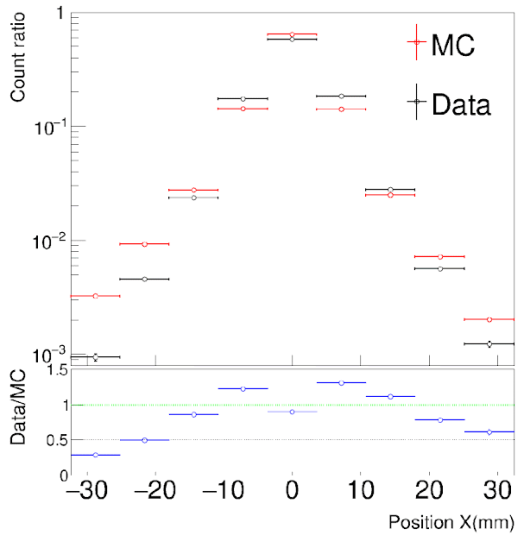
Shower Profile

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

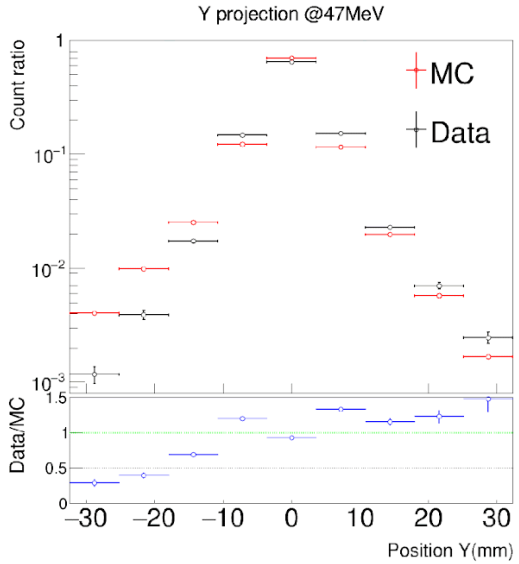
X

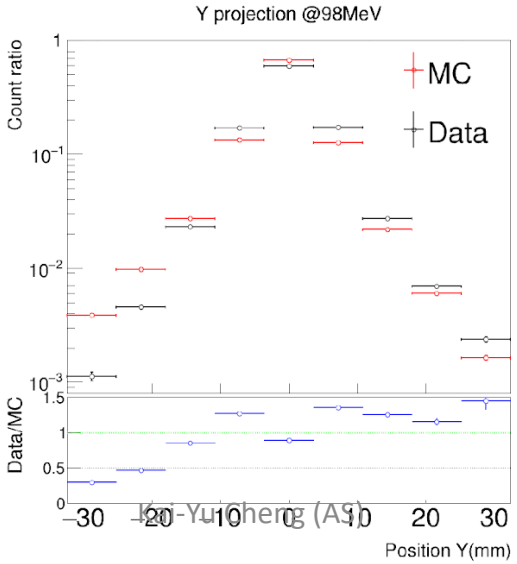


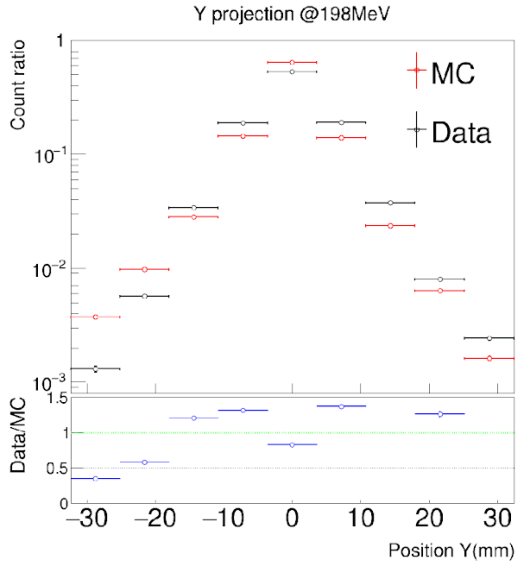




Y

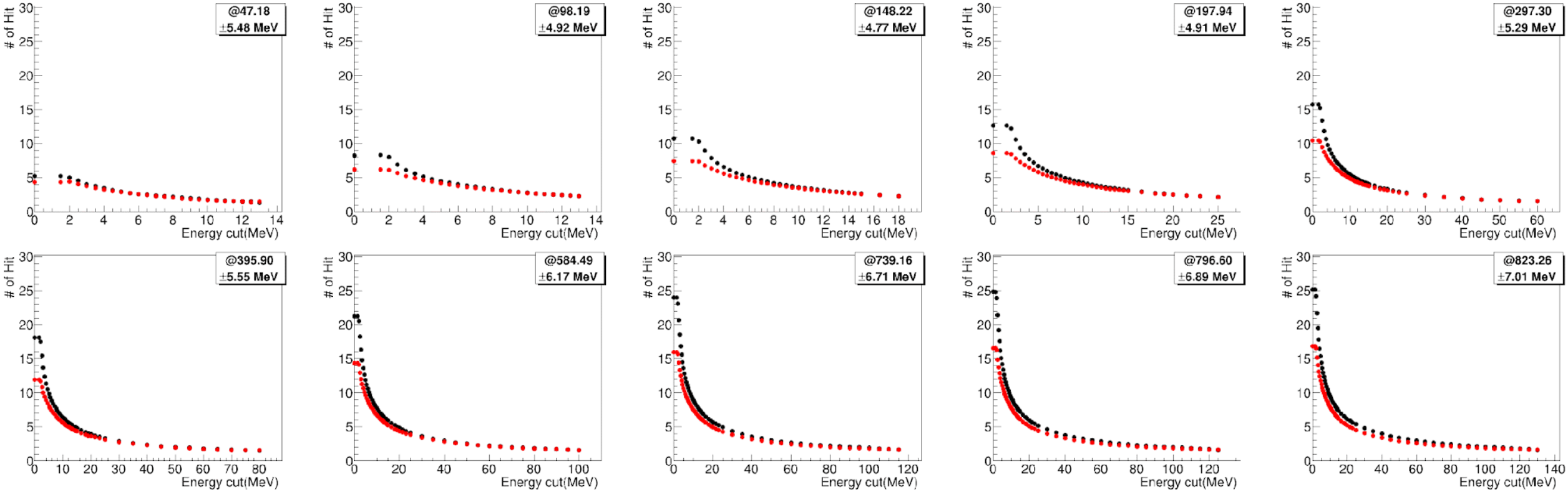




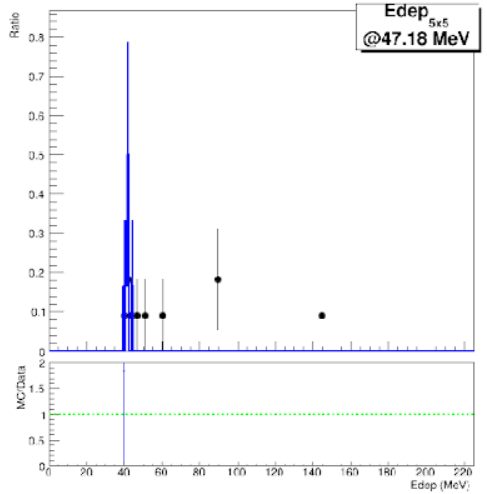


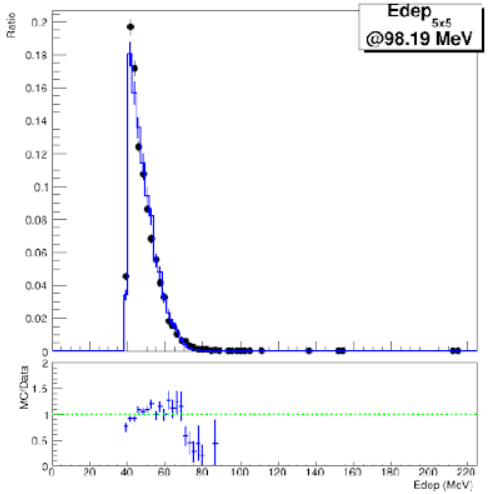
Energy Cut

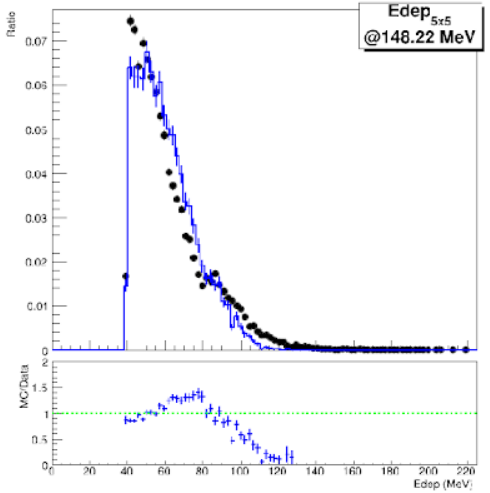
- Comparison number of hit channels in data and simulation with different energy cut.
- We select the cut to ensure the number of hit channels is similar between the data and simulation.

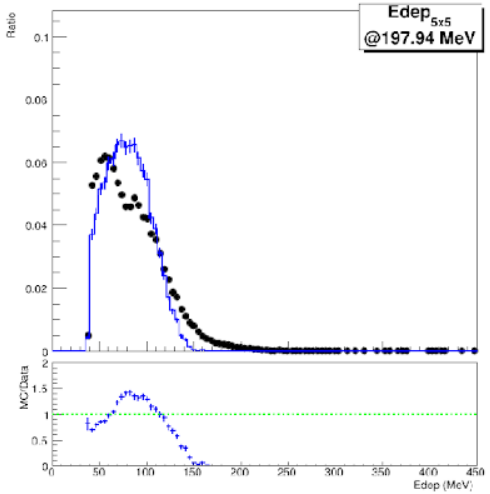


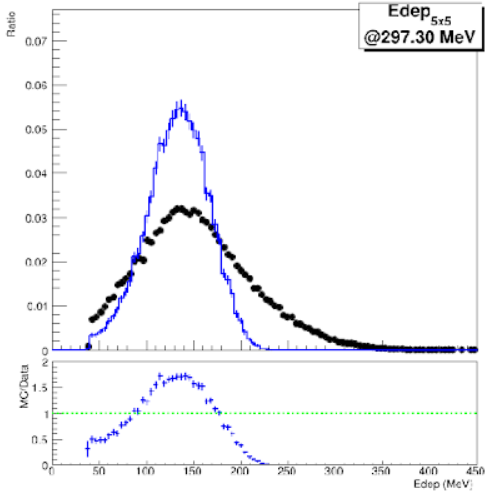
Data and MC Comparison

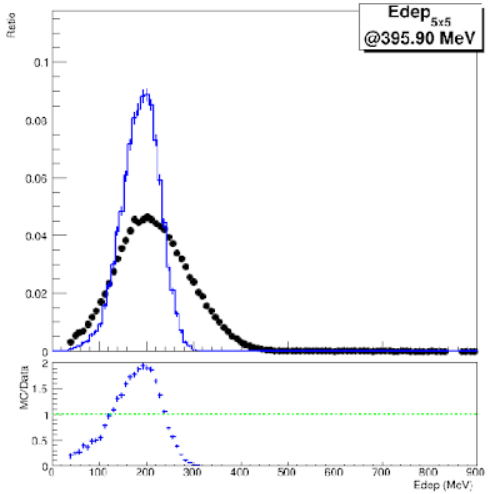


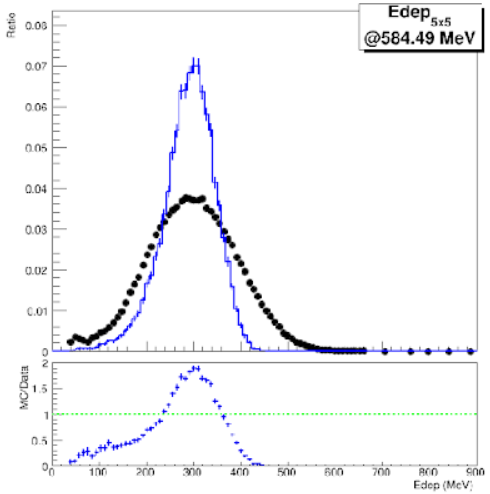


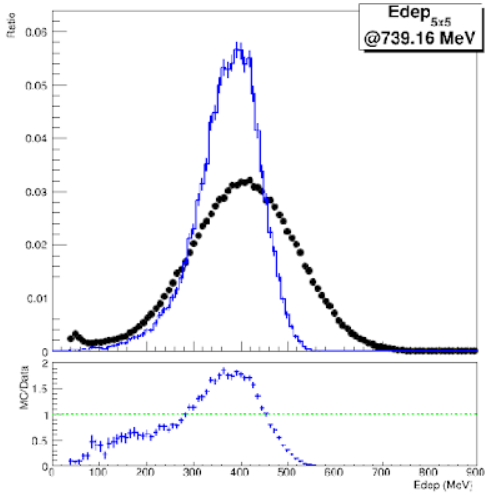


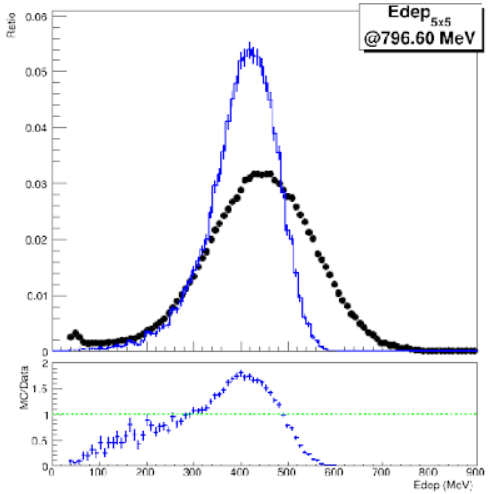


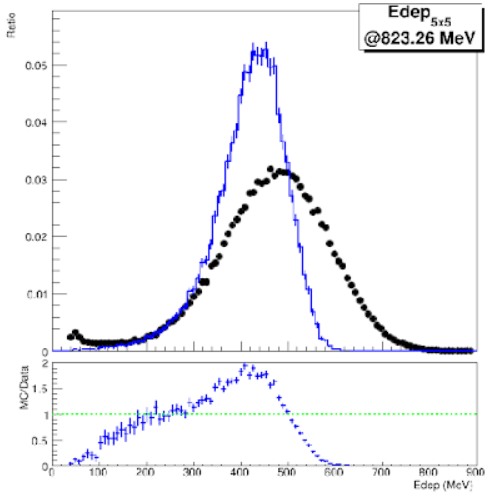


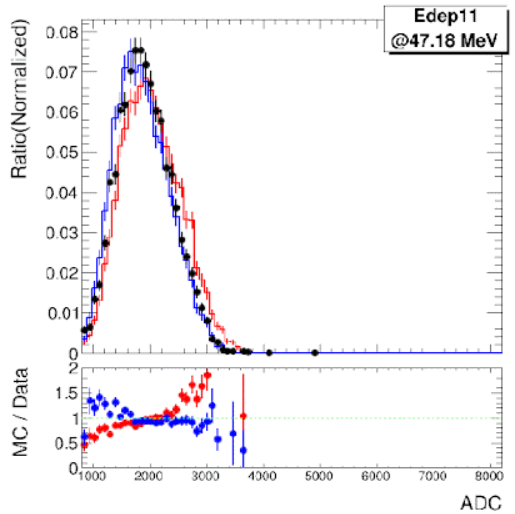


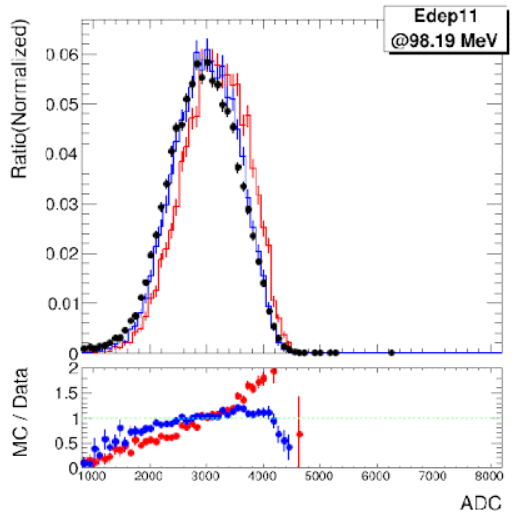


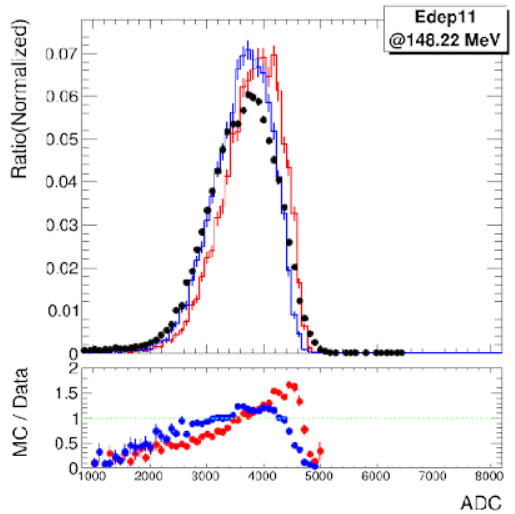


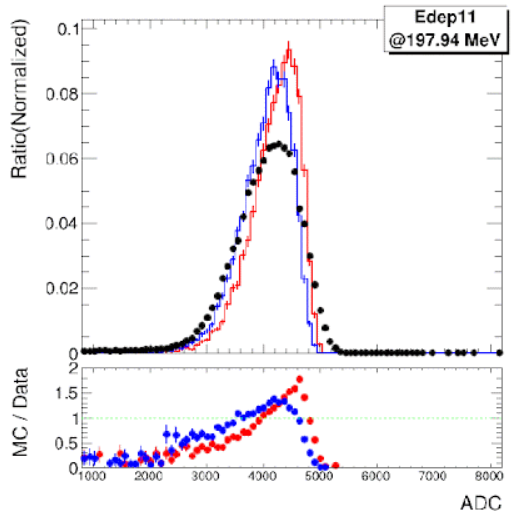


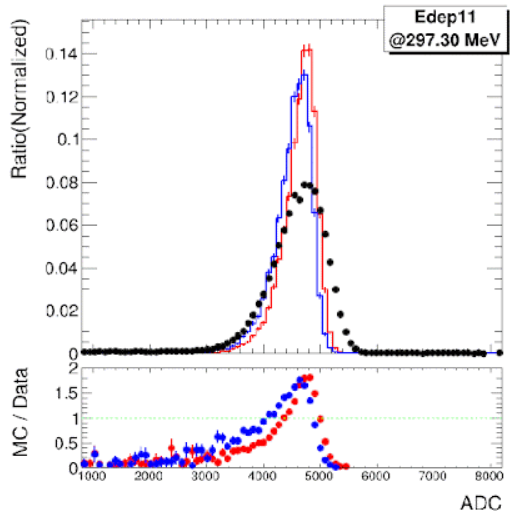


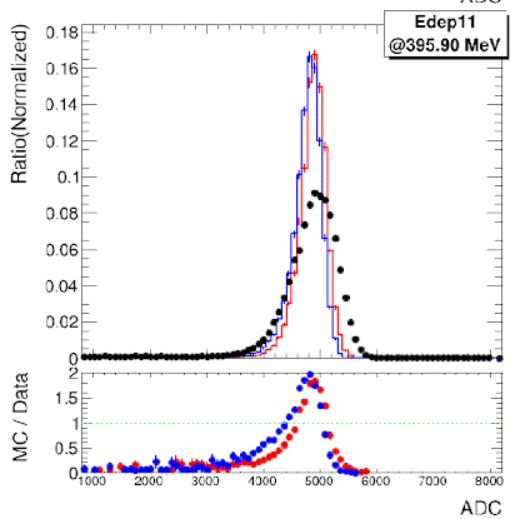

Edep11
@47.18 MeV
Ratio(Normalized)
MC / Data
ADC

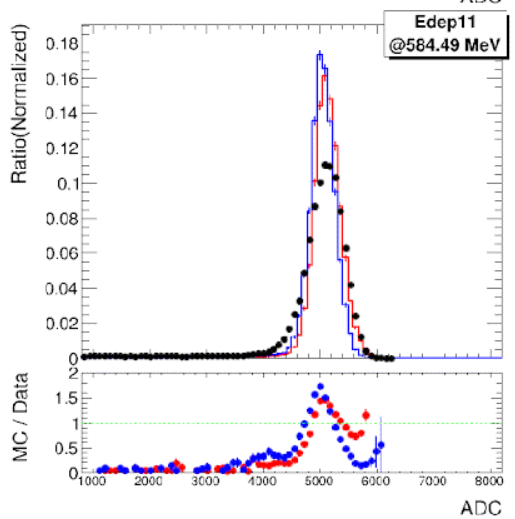

Edep11
@98.19 MeV
Ratio(Normalized)
MC / Data
ADC

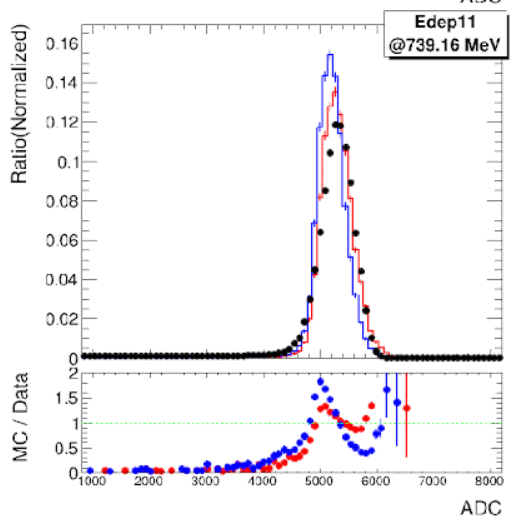

Edep11
@148.22 MeV
Ratio(Normalized)
MC / Data
ADC

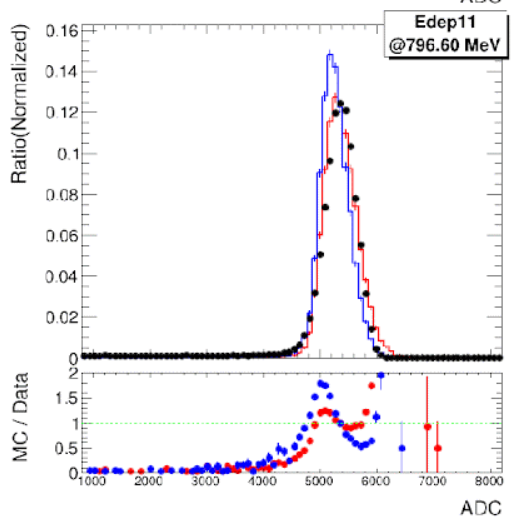

Edep11
@197.94 MeV
Ratio(Normalized)
MC / Data
ADC

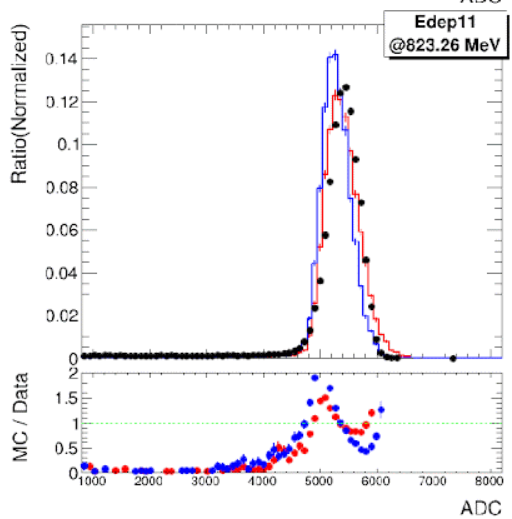

Edep11
@297.30 MeV
Ratio(Normalized)
MC / Data
ADC


Edep11
@395.90 MeV
Ratio(Normalized)
MC / Data
ADC


Edep11
@584.49 MeV
Ratio(Normalized)
MC / Data
ADC

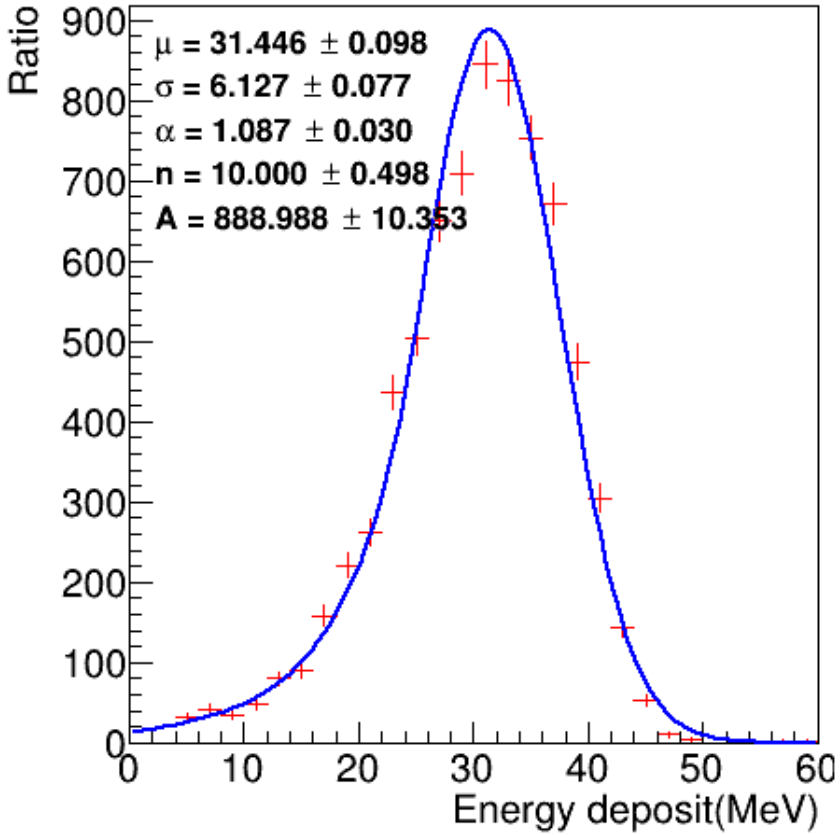

Edep11
@739.16 MeV
Ratio(Normalized)
MC / Data
ADC


Edep11
@796.60 MeV
Ratio(Normalized)
MC / Data
ADC


Edep11
@823.26 MeV
Ratio(Normalized)
MC / Data
ADC

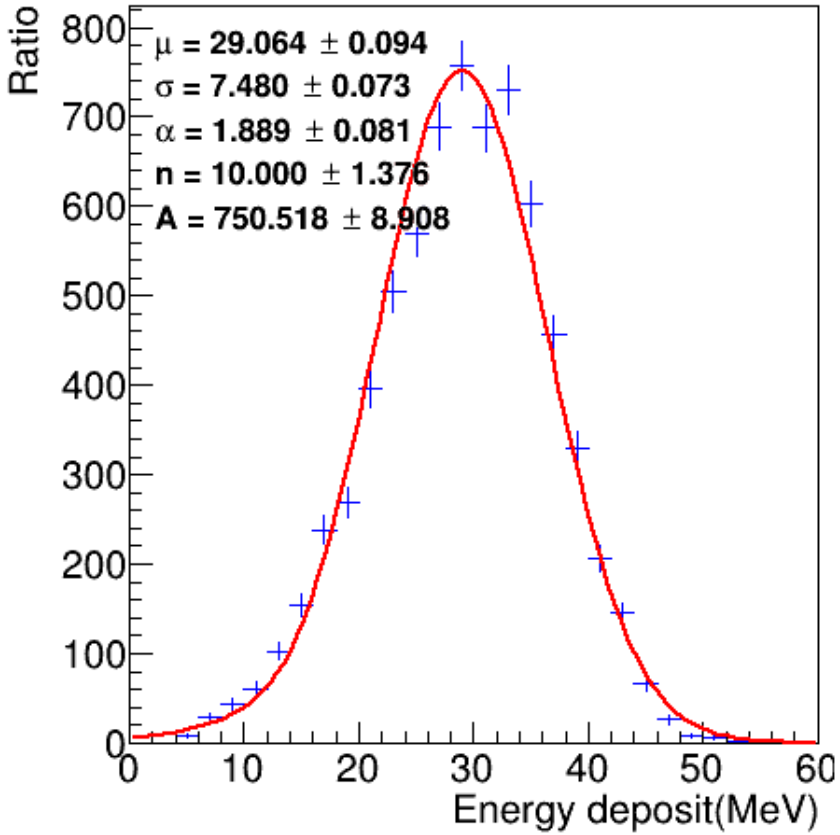
Energy Resolution for 47MeV

Data E_{5x5} @ 47 MeV



$$\frac{\Delta E}{E} = 19.5\%$$

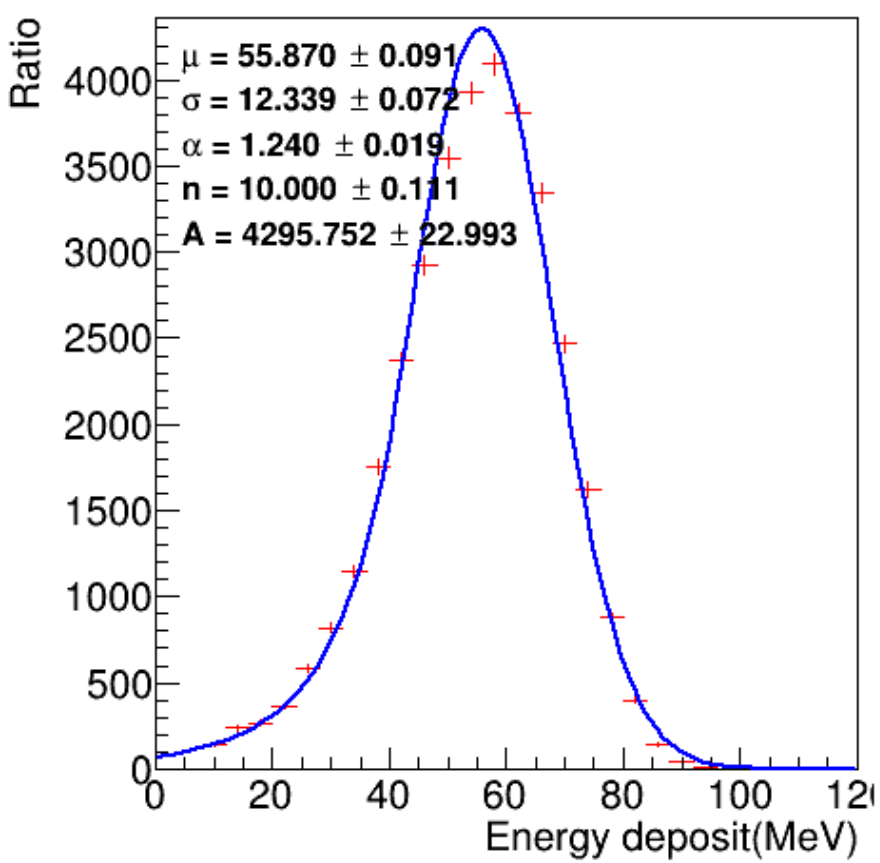
MC E_{5x5} @ 47 MeV



$$\frac{\Delta E}{E} = 25.7\%$$

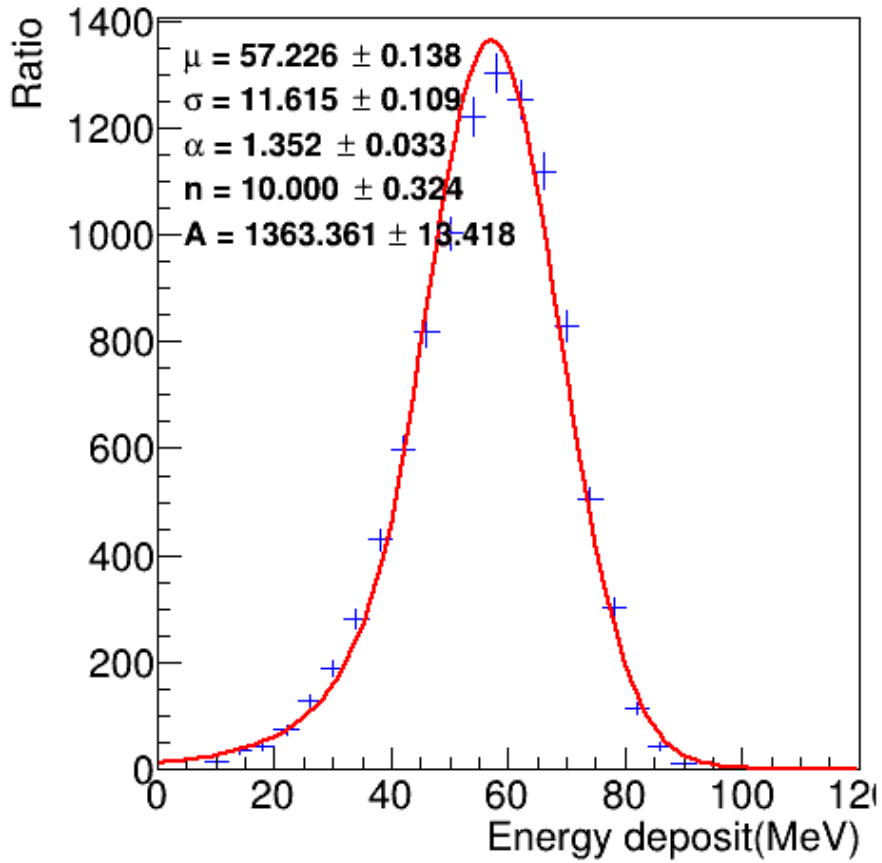
Energy Resolution for 98MeV

Data E_{5x5} @ 98 MeV



$$\frac{\Delta E}{E} = 22.1\%$$

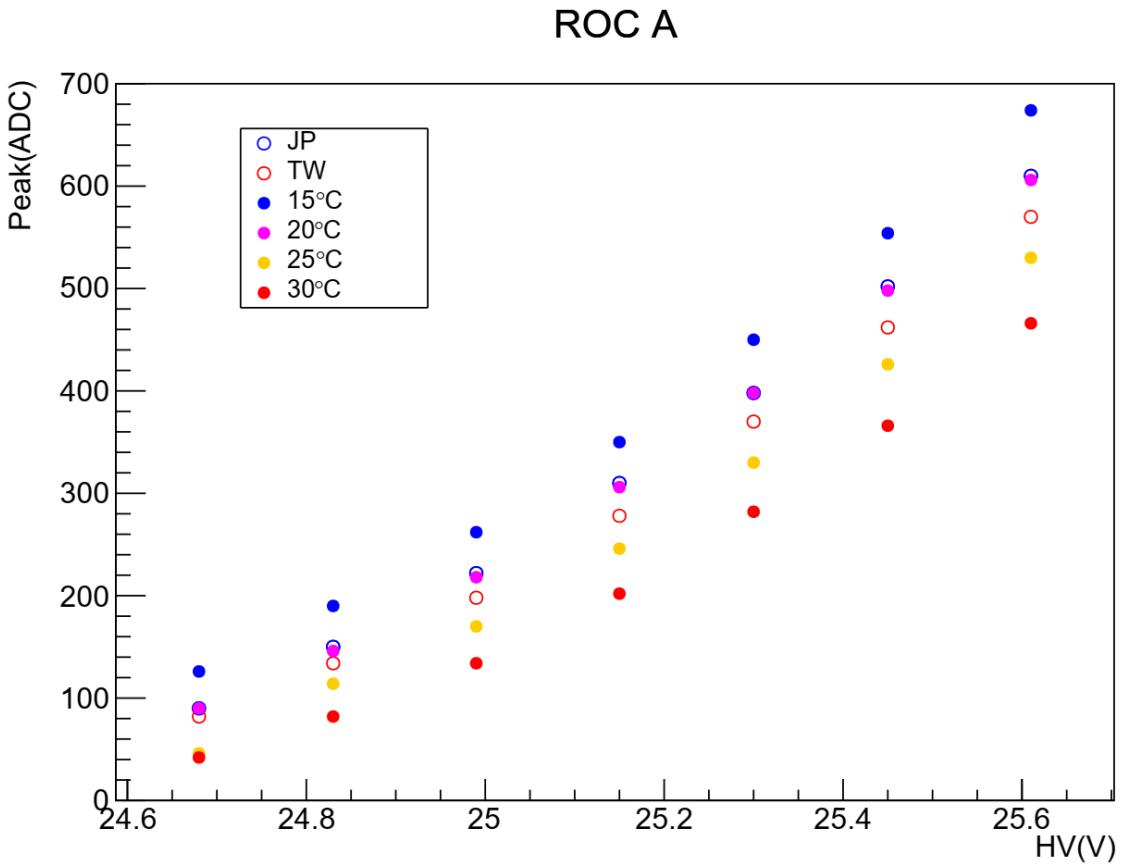
MC E_{5x5} @ 98 MeV

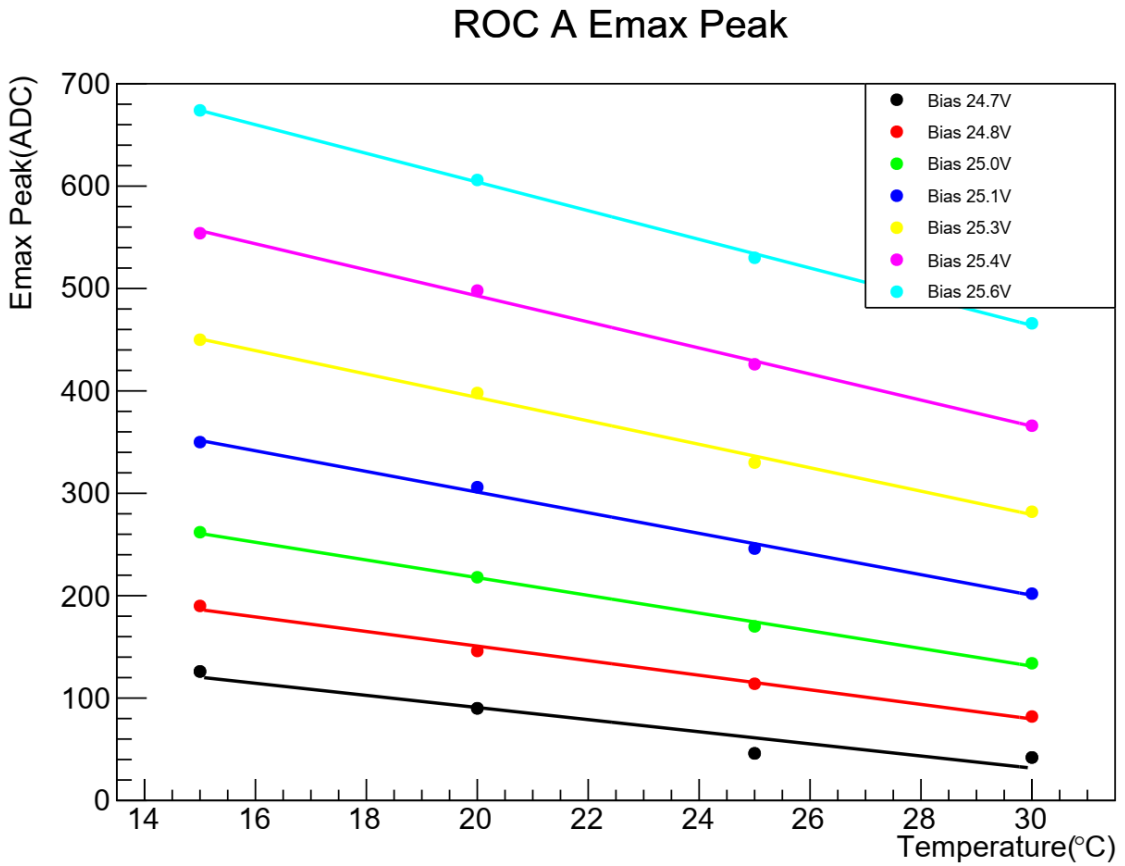


$$\frac{\Delta E}{E} = 20.3\%$$

Temperature Test with Na^{22}

- The Peak values shows the ΔT between the Lab in Japan and Taiwan is about 2~3ºC.
- The change of 5 degree gives around 25% change on gain.

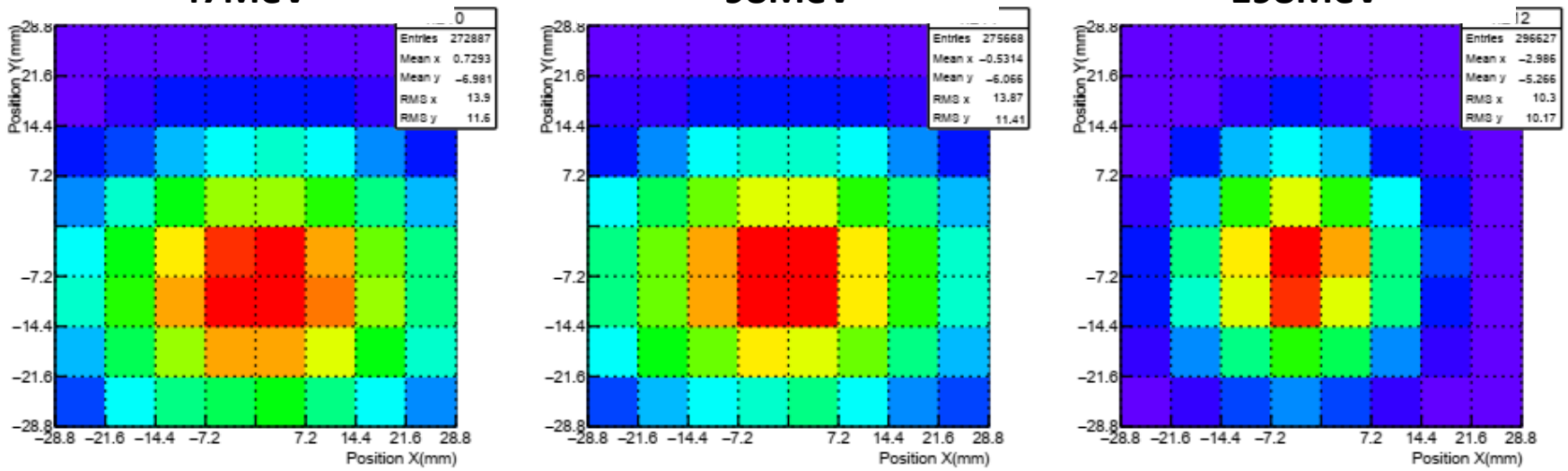




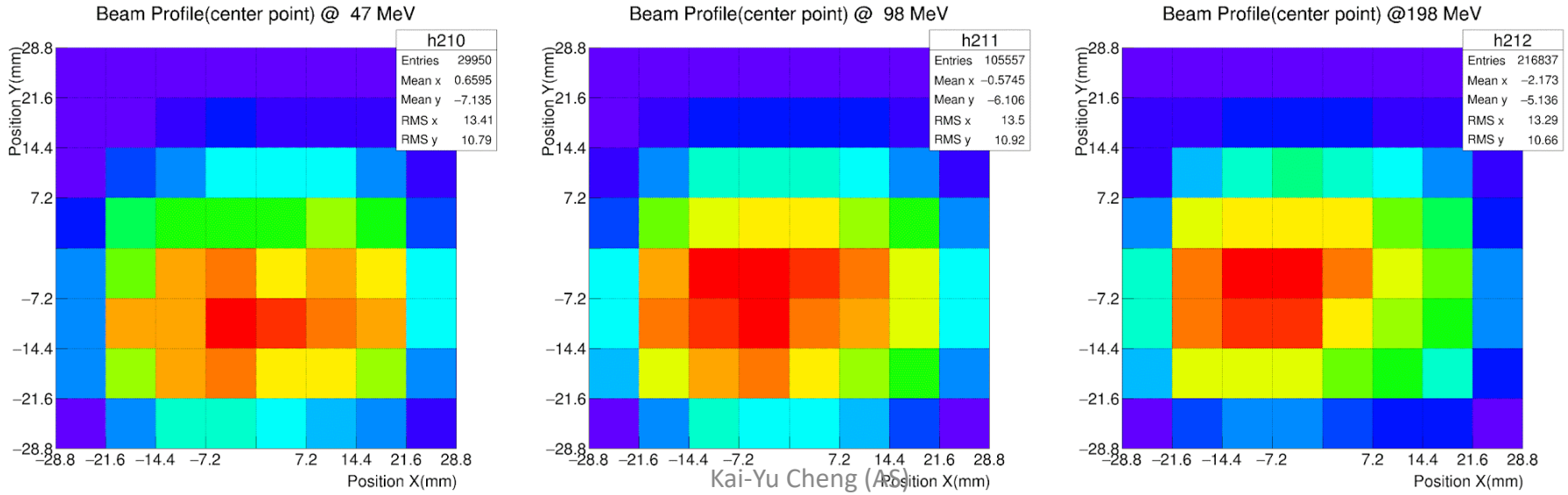
Beam Profile in 2D

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

MC



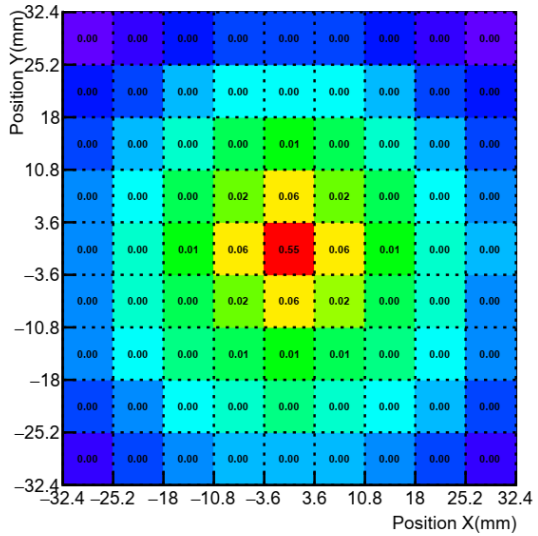
Data

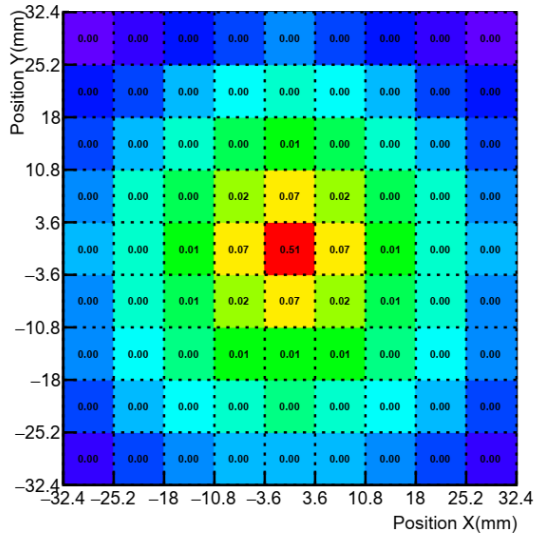


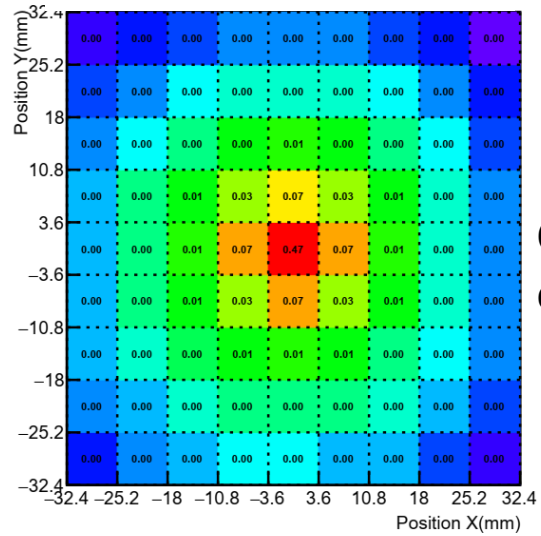
Shower Profile in 2D

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

MC

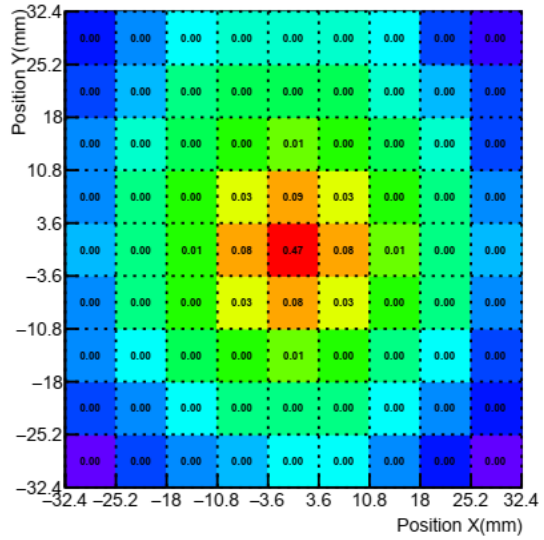


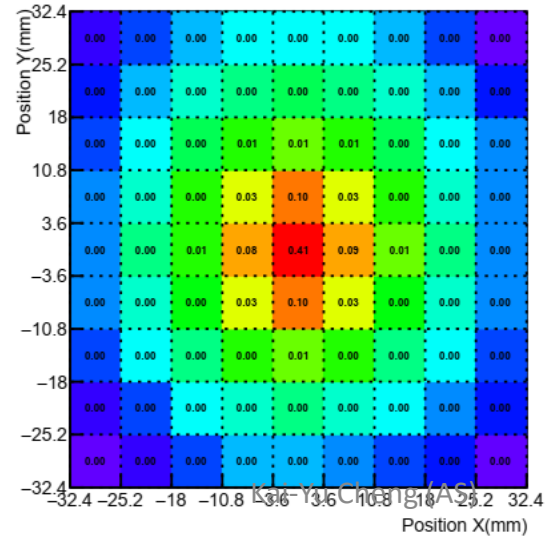


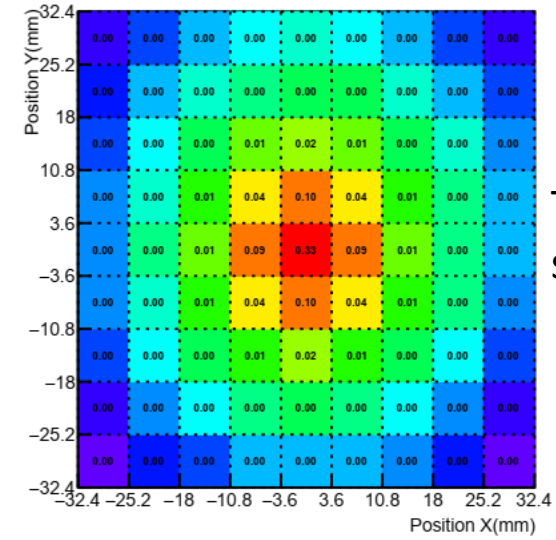


Center crystal has higher energy deposit

Data







The data have wider shower profile