Status of ZDC ECAL

EIC-ASIA @ 20251016

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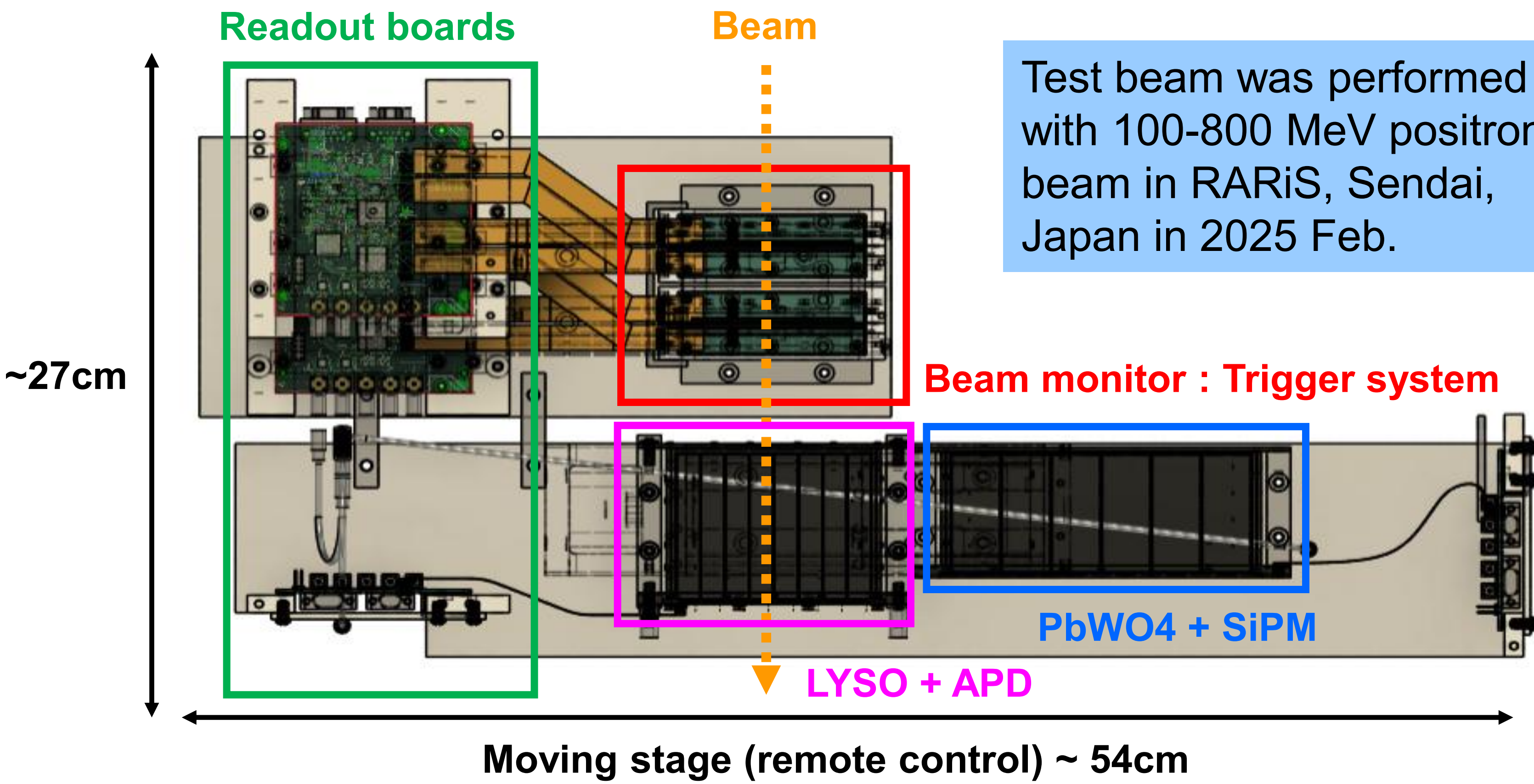
(Review) 2nd ZDC ECAL Prototype

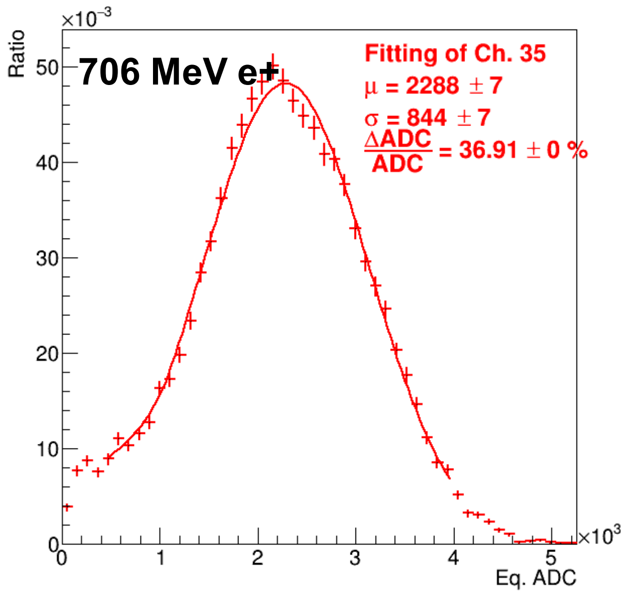


Test beam was performed with 100-800 MeV positron beam in RARiS, Sendai, Japan in 2025 Feb.

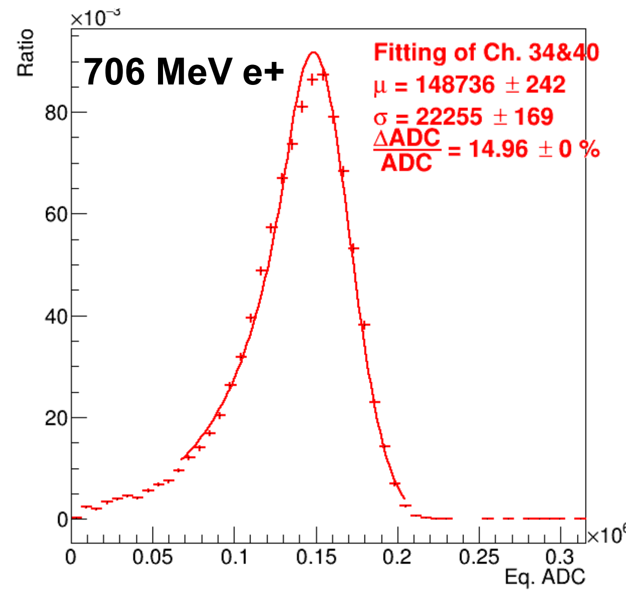
	Detector	Crystal				Sensor		DAQ
		name	Size of one cell	Length	Array	Type	sensor/crystal	
2nd prototype 2024-2025	LYSO + APD	LYSO	1cm*1cm	6.6cm (6X0)	8x8	APD C30739ECERH	1	CITIROC
	PbWO4 + SiPM	PbWO4	2cm*2cm	5.3cm (6X0)	6x6	SiPM Onsemi MICROFC-60035	2	CITIROC

(Review) 2nd ZDC ECAL Prototype

LYSO + APD ~ 35%



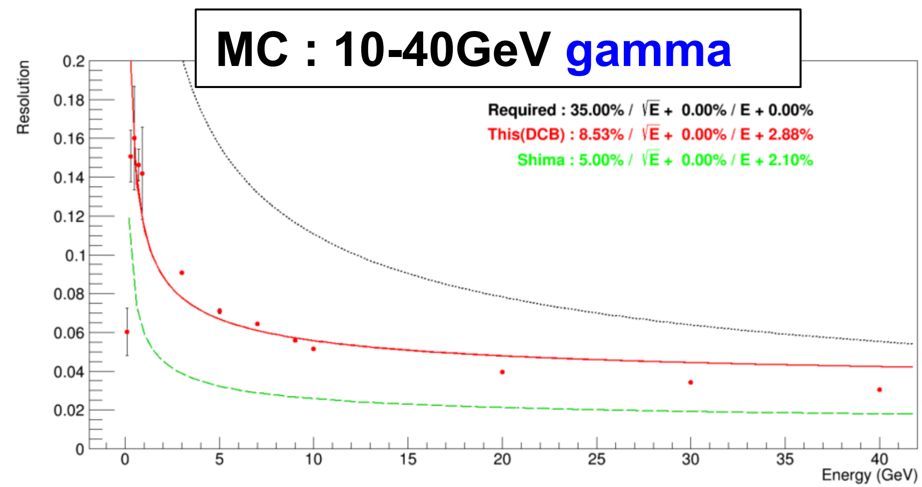
PbWO4 + SiPM ~ 15%



Preliminary results gave energy resolution **<u>without energy regression and any specific even selection.</u>**

- **LYSO + APD = 36.91%**
  (> 15% requirement)
- **PbWO4 + SiPM = 14.95%**
  (> 15% requirement)

Performance of "PbWO4 +SiPM" system satisfied the requirement but "LYOS + APD" is not.

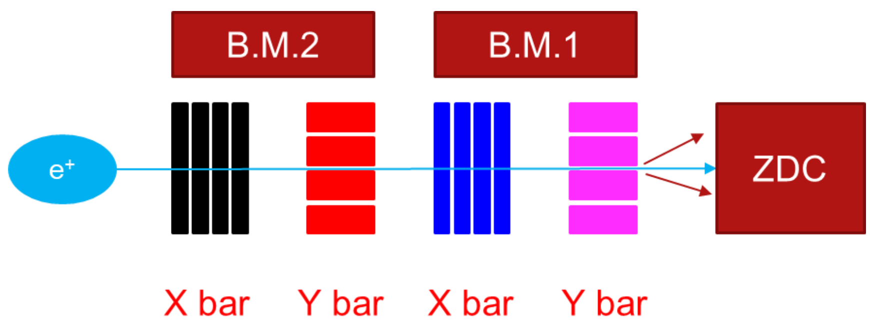


Today's Topic

- Study **energy deposit**
- Energy regression
  - Study **threshold (Find DAC to ADC Mapping)**
  - Compare data and MC (Find ADC to energy mapping)
  - Energy regression (Traditional method, linear)

- We study the event selection and the implement energy regression to improve the energy resolution.
- Today's results are for **PbWO4 system only.**

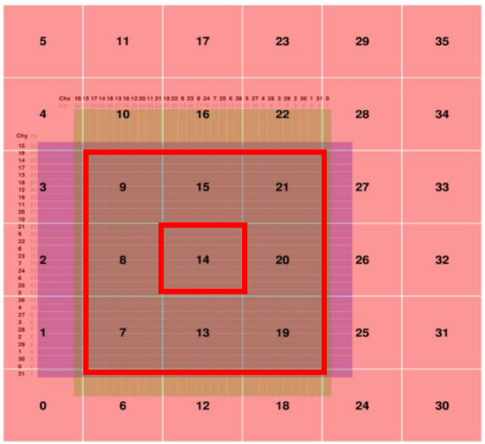
MC Setting



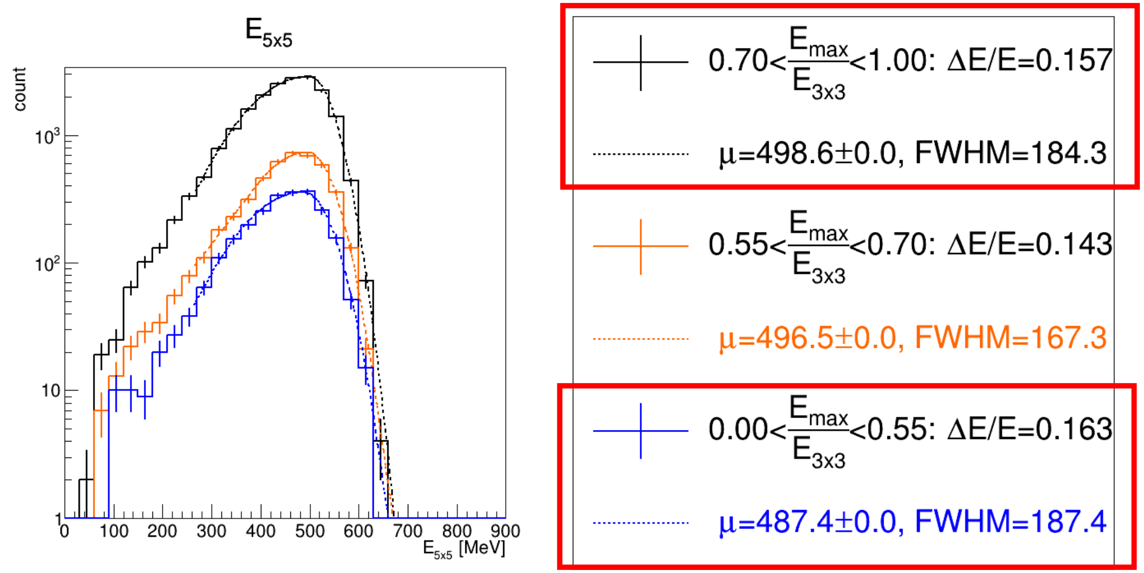
- **Particle:** Positron
- **Beam energy : table on left**
- **Beam position:** ZDC center
- **Beam direction:** perpendicular to ZDC surface (pencil beam)
- **Experimental Setup :** same as test beam
- **No optical photon turned on**
- **No APD/SiPM simulation**

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)

Study Energy Deposit : MC



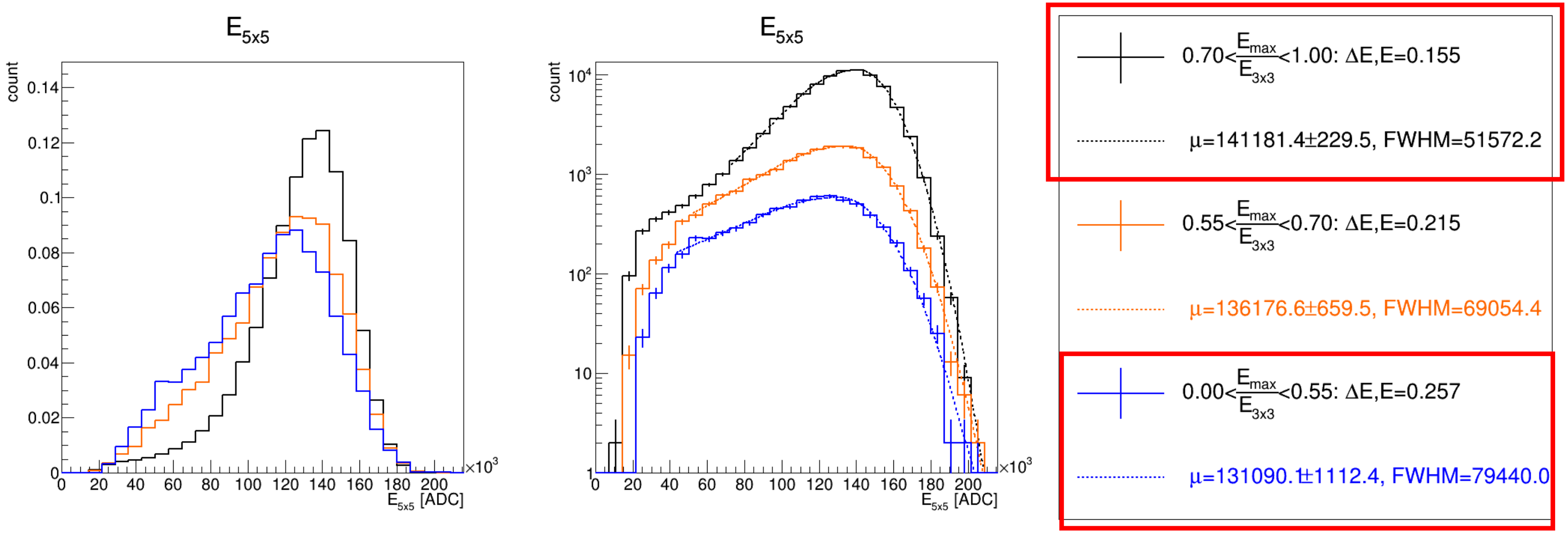
Narrower spread
➔ larger Emax/E3x3



- We analyzed the ratio between Emax and E3 × 3 in the data to characterize the shower size. A larger Emax/E3 × 3 ratio indicates a more concentrated, narrower shower spread.

- **No significant difference is observed between the narrower and wider energy deposit,** which is reasonable since the **MC simulation collects all deposited energy without applying a threshold cut.**

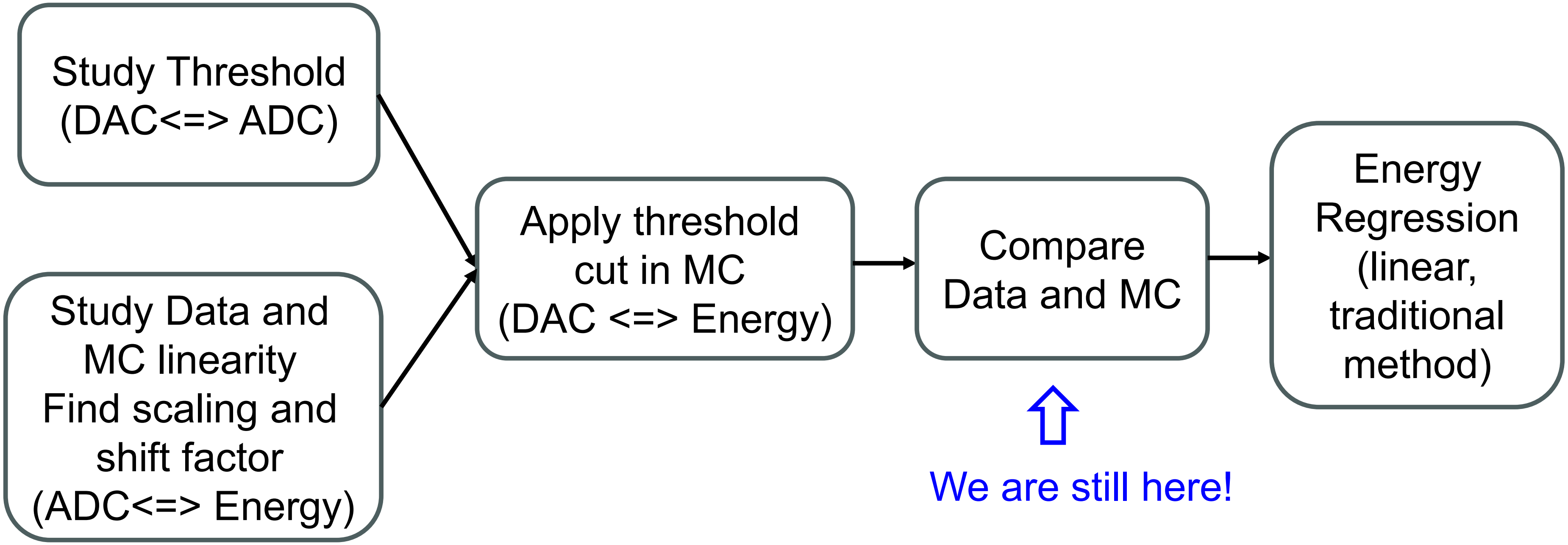
Study Energy Deposit : Data



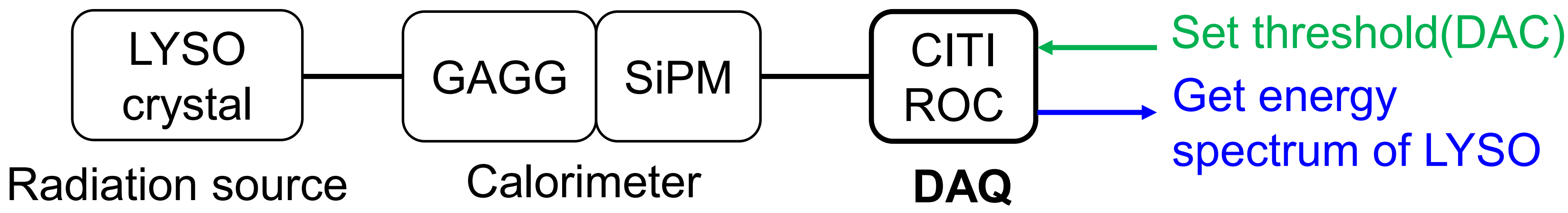
- **Events with narrow energy deposit has better energy resolution**, which is reasonable since fewer crystals have low-energy deposits and are therefore less affected by the hardware threshold cut.

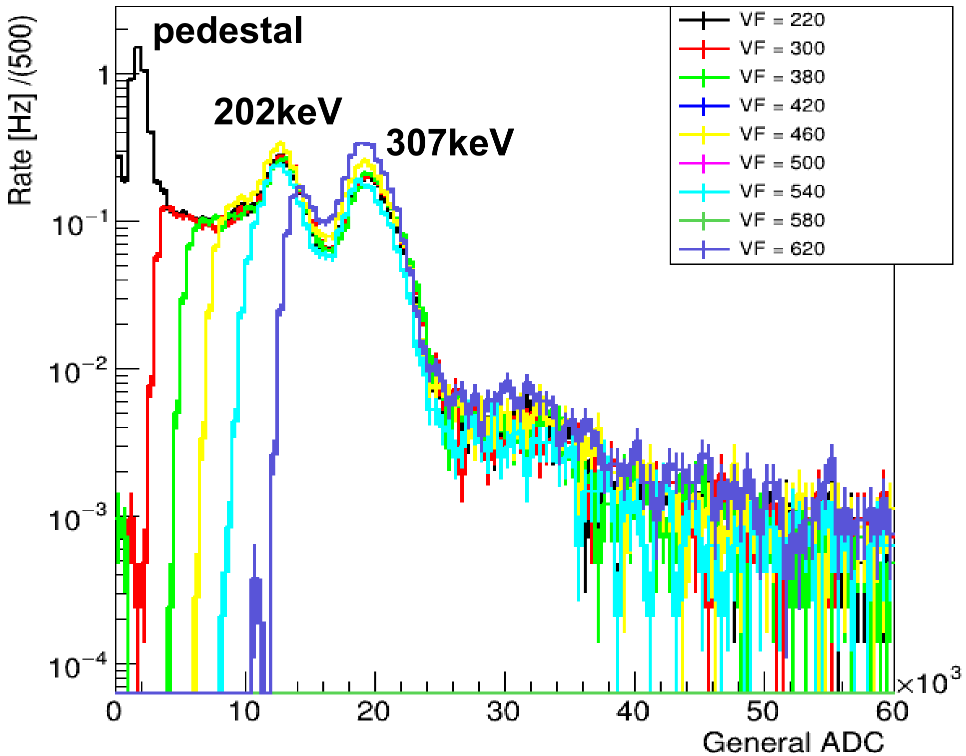
- **The results suggest that the threshold setting during data taking was likely too high.** Later studies indicate that the threshold was set at approximately 50 MeV.

Energy Regression



Study Threshold (Find DAC to ADC Mapping)





- How to find the DAC to energy mapping of CITIROC?

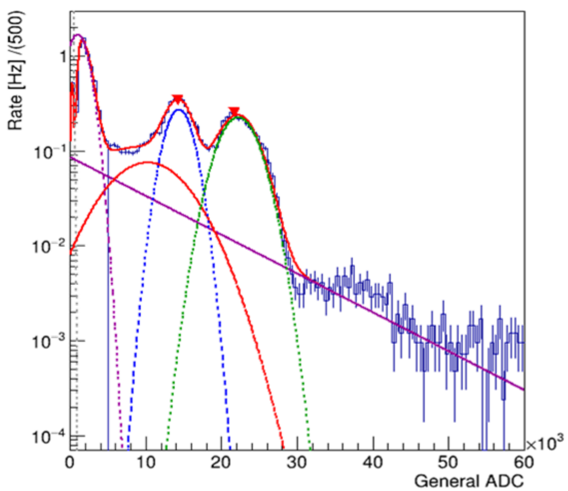
① **Set different threshold on CTIROC 220 ~ 620 (digit)**
During test beam :
LYSO threshold = 268 ~ 300 (digit)
PbWO4 threshold = 400 ~ 650 (digit)

② **Get energy spectrum with different threshold setting**

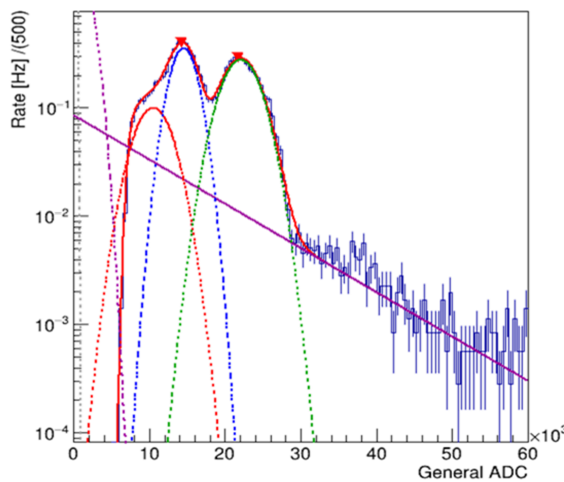
③ **Fit energy spectrum** to the find the corresponding threshold in DAC(digit) to ADC(MeV) mapping

Study Threshold (Find DAC to ADC Mapping)

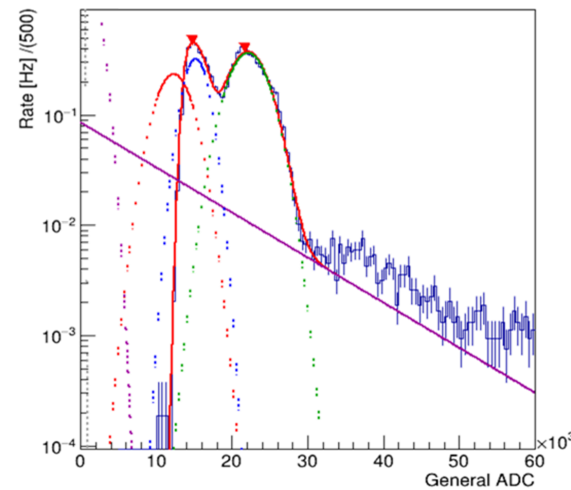
DAC = 220 (digit)

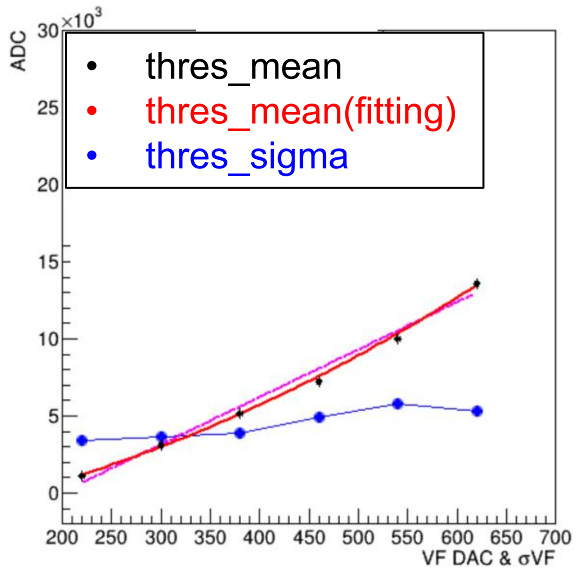


DAC = 300 (digit)



DAC = 580 (digit)

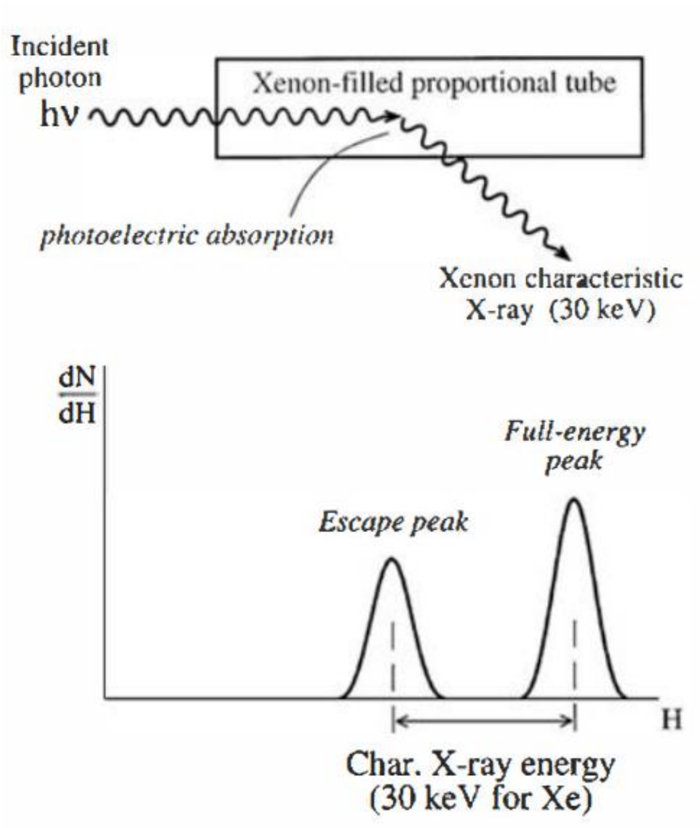




- Total fitting function
  - ① pedestal
  - ② 202keV gaussian peak
  - ③ 307keV gaussian peak
  - ④ Gamma escape energy gaussian peak
  - ⑤ Exponential background

Get the ADC value of left edge of total fitting function (Gaussian CDF).

Escape Energy



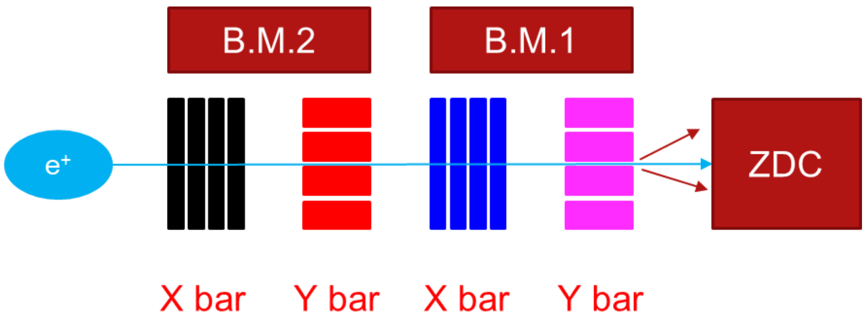
G. F. Knoll, ***Radiation Detection and Measurement*, 4th ed. (Wiley, 2010)**

- An incident photon is absorbed by scintillator, it excited atoms/molecules in material via the photoelectric effect, The ionized atom emits a photon with the same energy of incident photon.

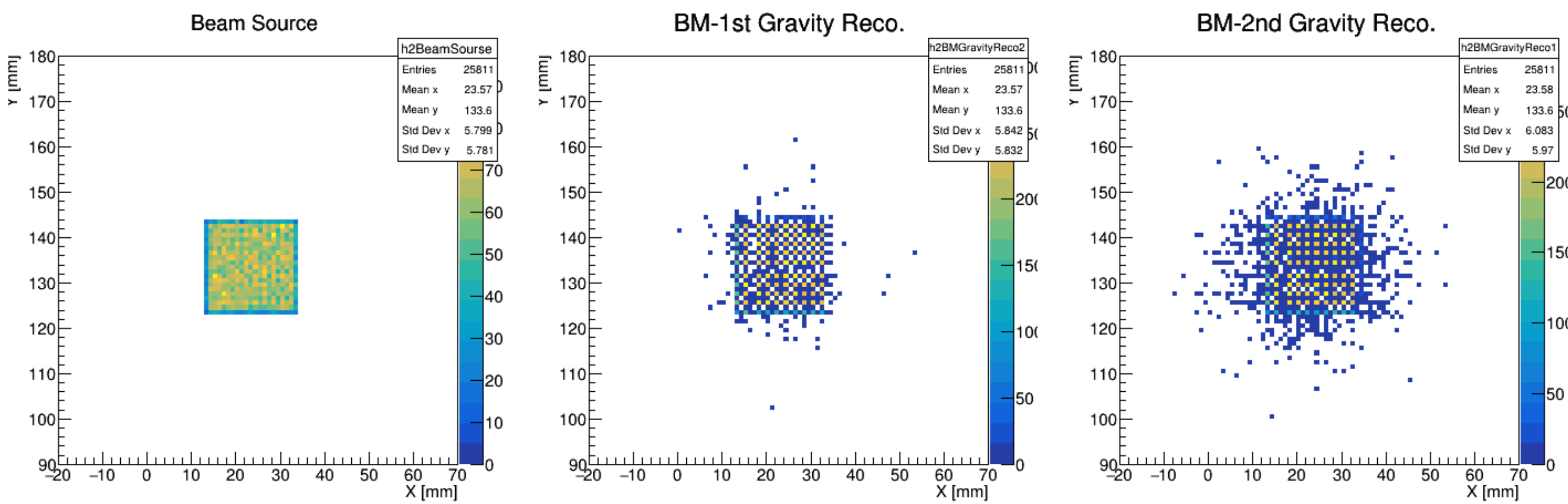
(1) Full-energy peak :
full energy of emitted photon is observed by PMT.

(2) Escape Peak :
the emitted photon interacted with the other atoms/molecules through Compton scattering or pair production, not full energy is received by PMT.

Find ADC to Energy mapping : MC Setting

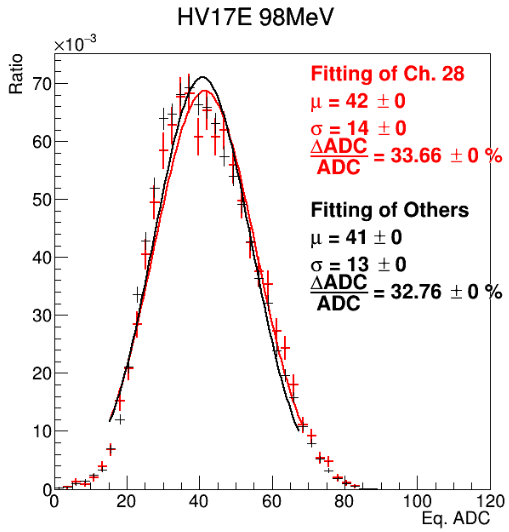


- **Particle:** Positron
- **Beam position:** spread beam
- **Beam direction:** perpendicular to ZDC surface
- **Experimental Setup :** same as test beam
- **With optical photon turned on**
- **No APD/SiPM simulation**

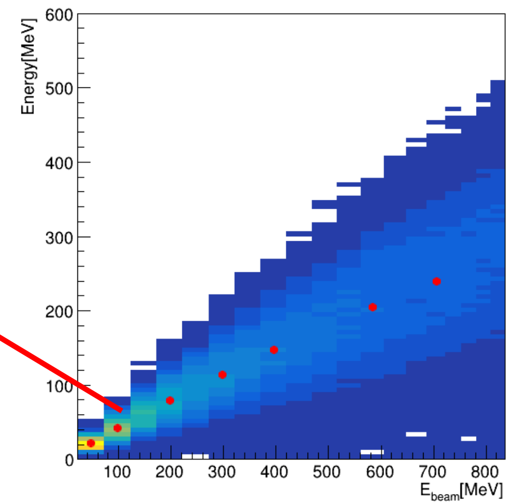


We update the beam setting and turn on optical photons.

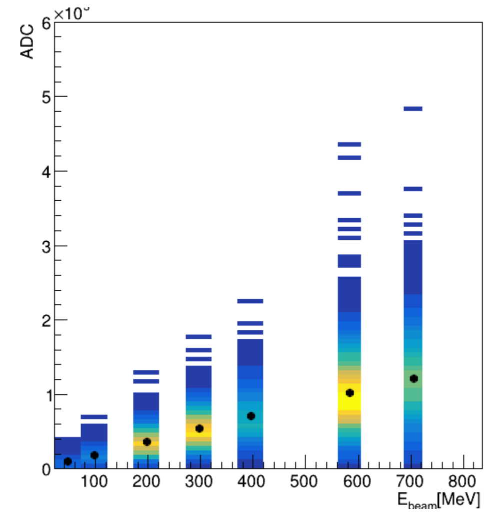
Check Linearity of Data and MC (Find ADC to Energy Correlation)



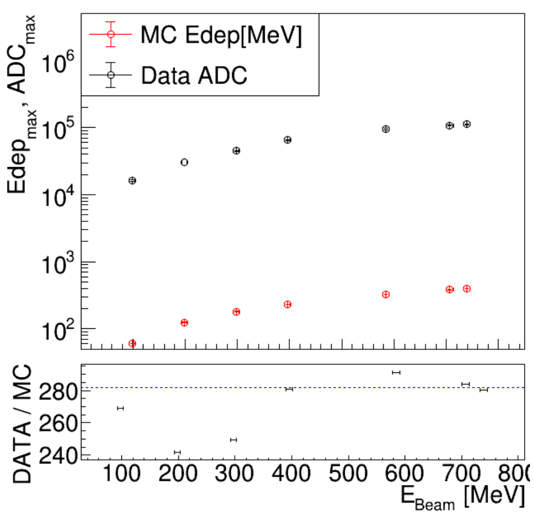
MC : Ebeam VS Emax



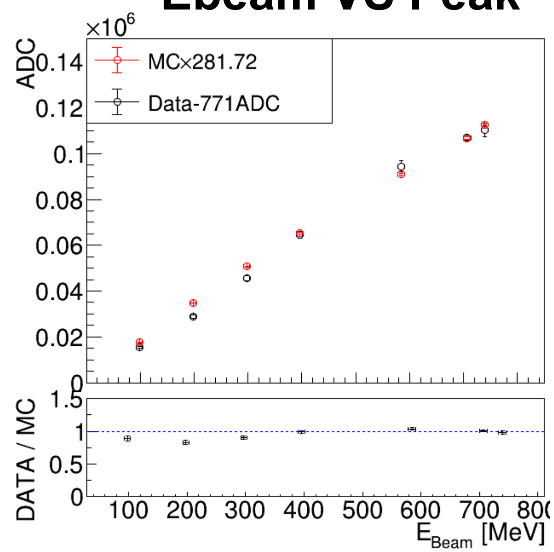
Data : Ebeam VS ADC



Ebeam VS Peak



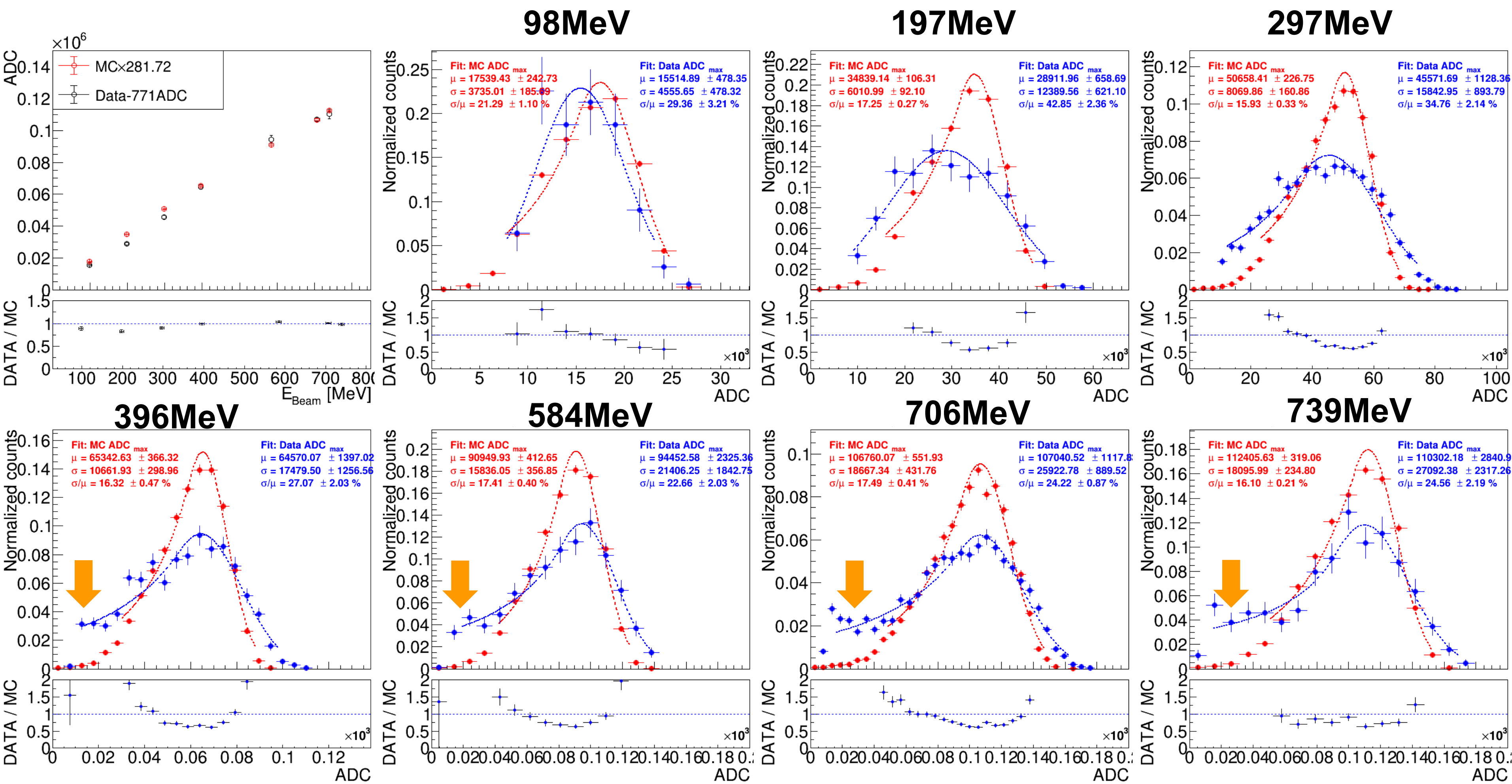
Ebeam VS Peak



- Both data and MC show good energy linearity.
- **ADC <=> Energy**
  Data = (MC × 281.72) + 771

Compare Data and MC : **Emax**

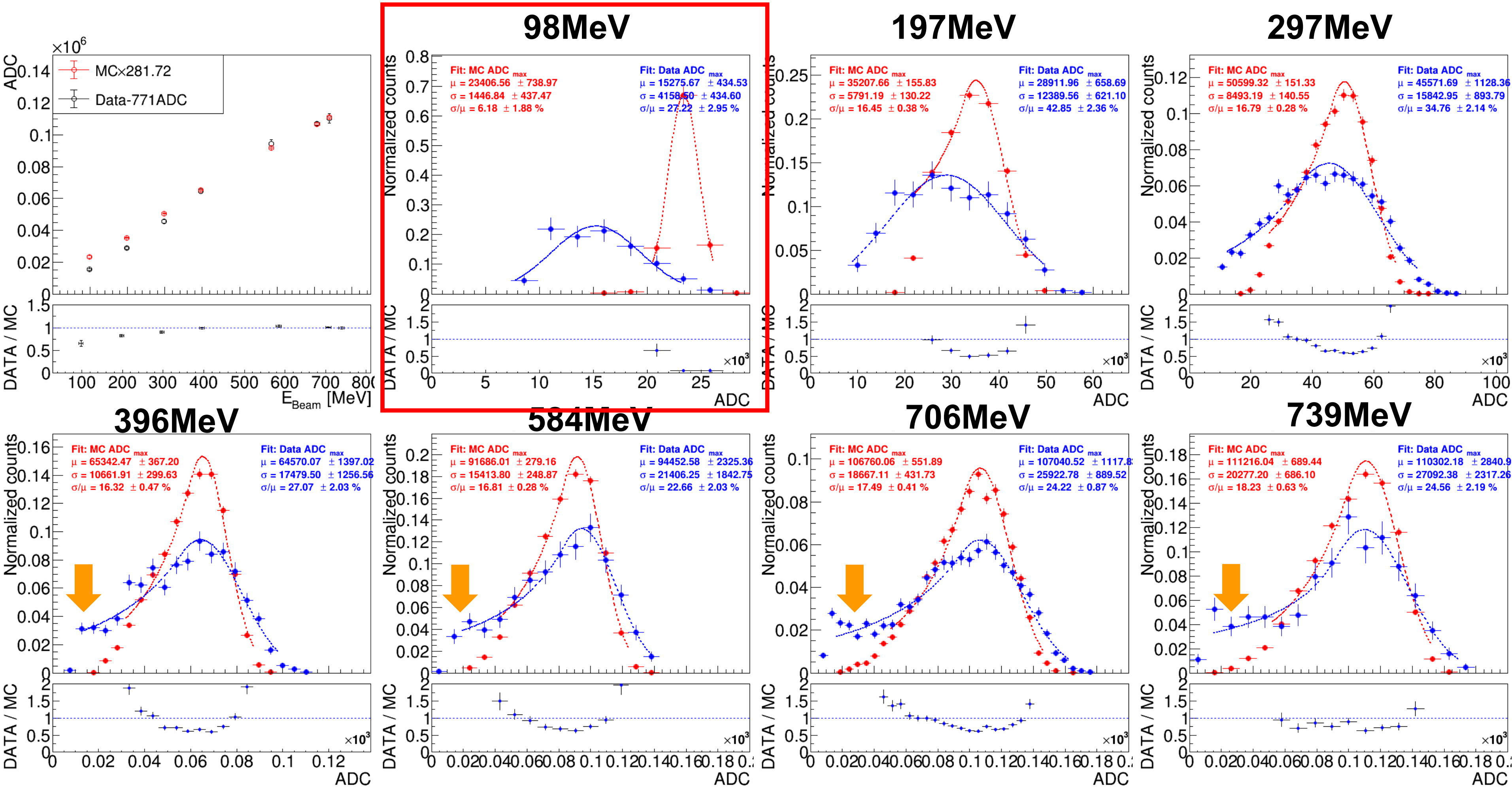
- Data (threshold ~ 50MeV)
- MC (no threshold cut)



- The energy resolution of the data is worse than that of the MC.
- A large number of low-energy hits observed in the data (possibly from noise).

Compare Data and MC : **Emax**

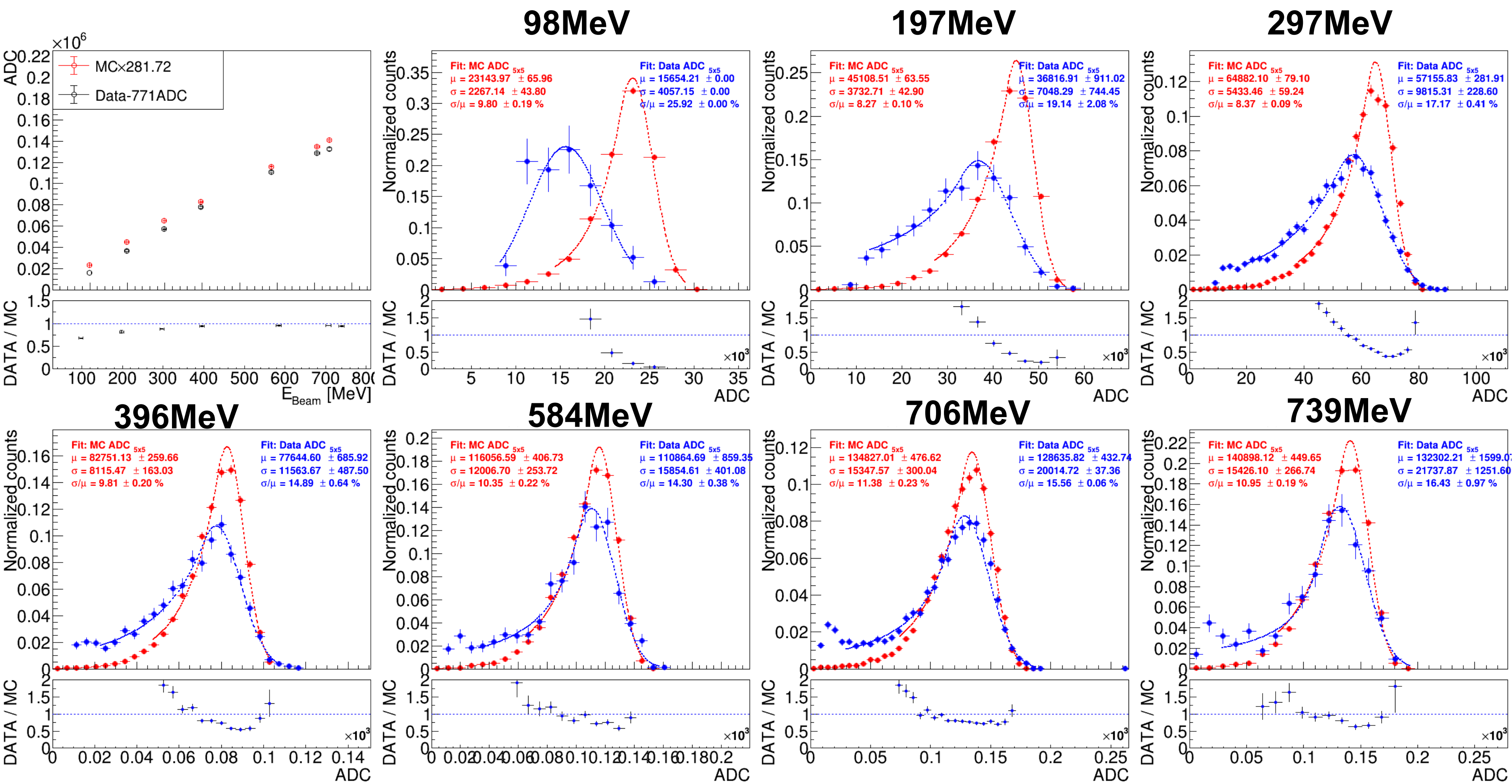
- Data (threshold ~ 50MeV)
- MC (threshold ~ 50MeV)



- The threshold cut removes too many hits at 98 MeV
- The consistency in the MC does not improve after applying the cut.

Compare data and MC : **E5x5**

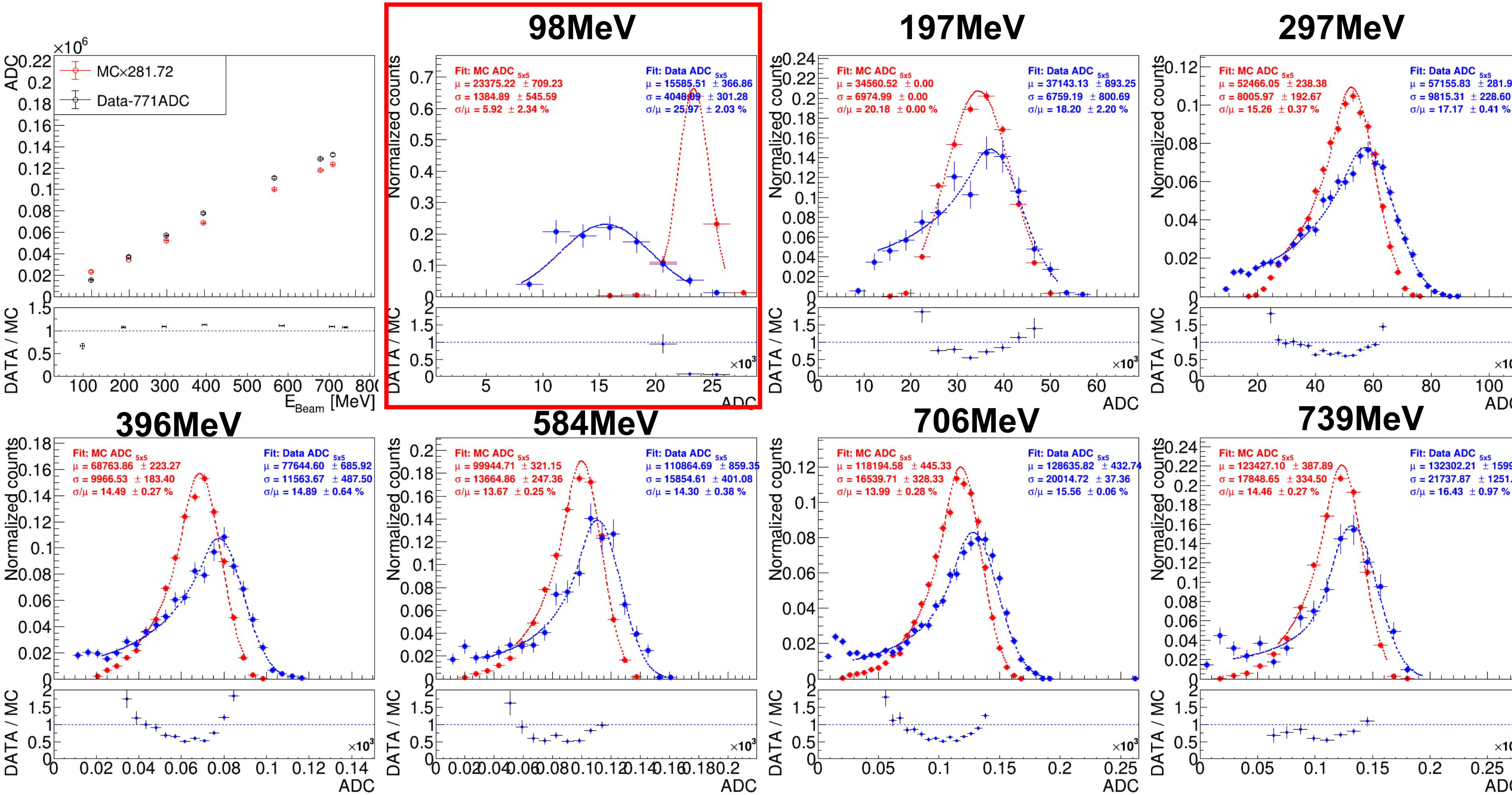
- Data (threshold ~ 50MeV)
- MC (no threshold cut)



- Bad consistency for Ebeam<300MeV.
- Better consistency for Ebeam>300MeV.

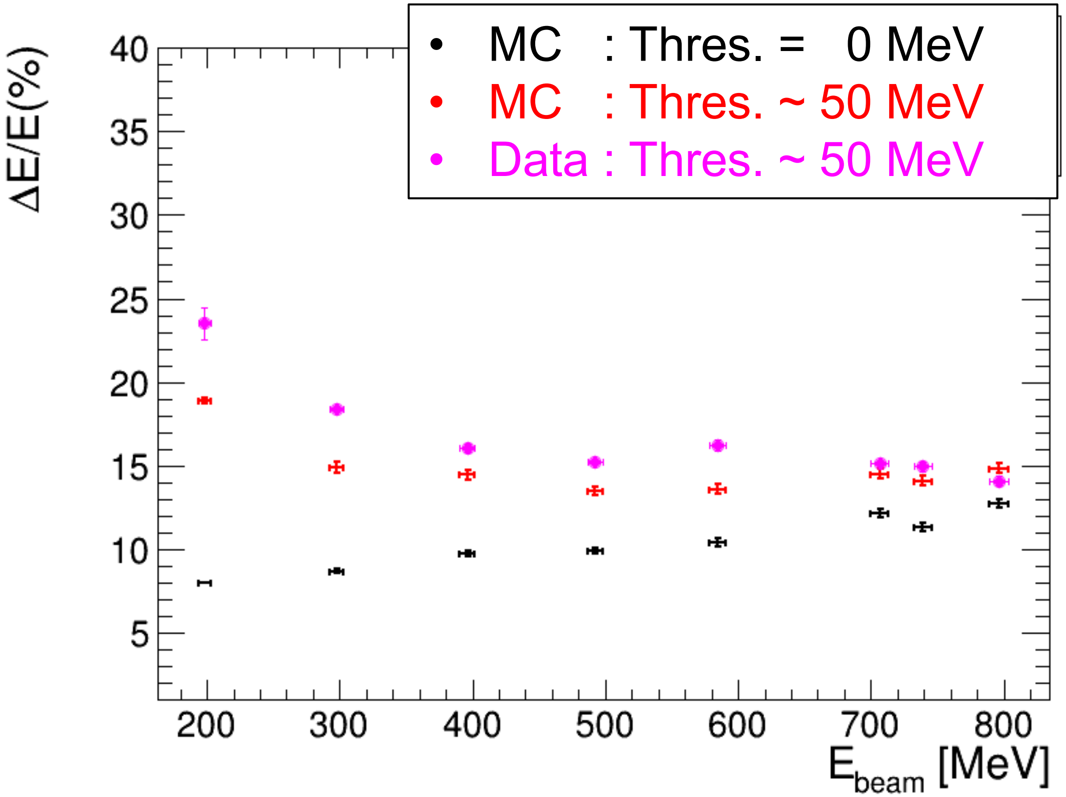
Compare data and MC : **E5x5**

- Data (threshold ~ 50MeV)
- MC (threshold ~ 50MeV)



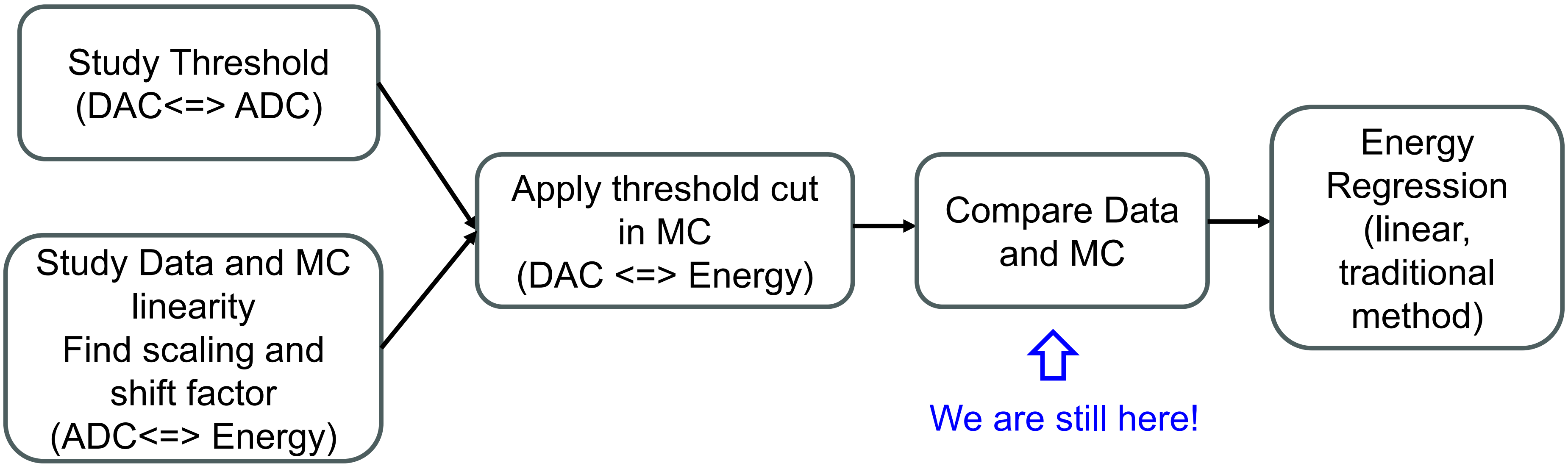
After applying threshold cut, the situation is reversed. We have worse consistency with Ebeam<300MeV but a better one with the rest.

Energy Resolution (w/o Energy Regression)



- Comparing data and MC with this 50MeV threshold applied, the MC shows a 1–4% better energy resolution than the data.
- The energy resolution improves as the threshold is lowered based on MC study.

Short Summary for Energy Regression



- We performed threshold study and the linearity of MC/Data in order to access the conversion between DAC and energy.
- We compare data and MC with 50MeV threshold cut. **The agreement between data and MC is not yet perfect** — the **data show more low-energy hits also gives wider spread**. We plan to **further investigate the hit energy and hit multiplicity distributions** to improve this consistency.
- According to the MC, lowering the threshold could enhance the energy resolution. **During the test beam, the threshold was set around 50 MeV, which appears to be too high. We plan to reduce the system noise and aim for another test beam next year with a lower threshold setting.**

Plan for the Test Beam next March

- **To do for PbWO4 + SIPM system**
  - Improve data and MC consistency
  - Energy regression
- **To do for LYSO + APD system**

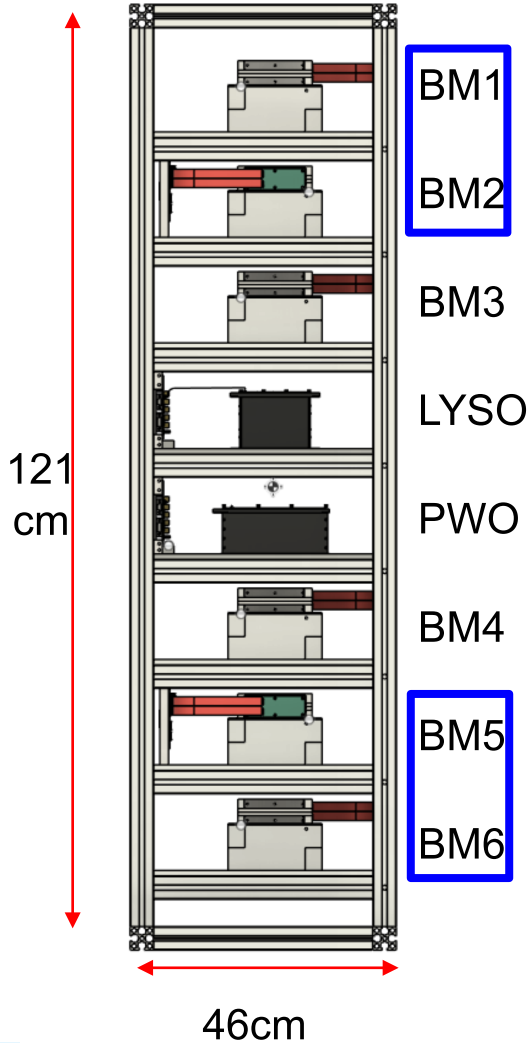
  \- Repeat all the studies have been done for PbWO4
- **Next test beam in 2026**
  - **“$PbWO_4$ + SiPM” system with a lower threshold setting**
  - **new DAQ system with H2GCROC chip.**

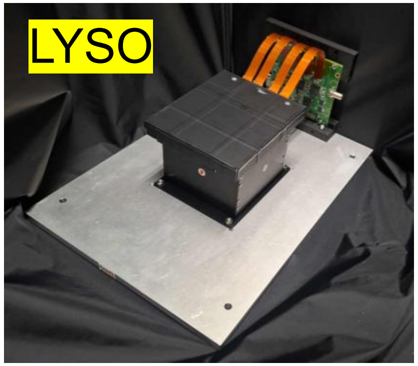
1. PbWO4 + oldSiPM + CITIROC (lower threshold)
2. PbWO4 + oldSiPM + H2GCROC (new DAQ)
3. LYSO + APD + CITIROC (If we can find the problem in Taiwan…)

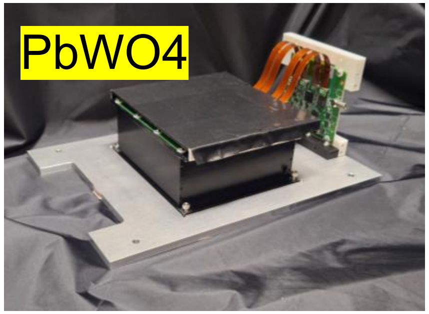
A **cosmic ray test** setup is currently being prepared in Taiwan to enhance system shielding to reduce noise for both PbWO4 and LYSO system.

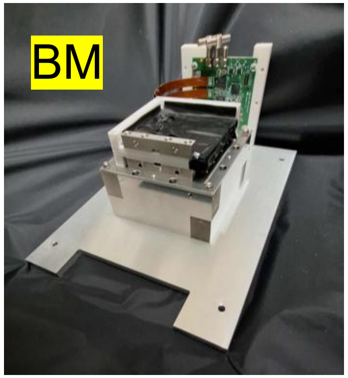
Cosmic Ray Test in Taiwan

Future Plan







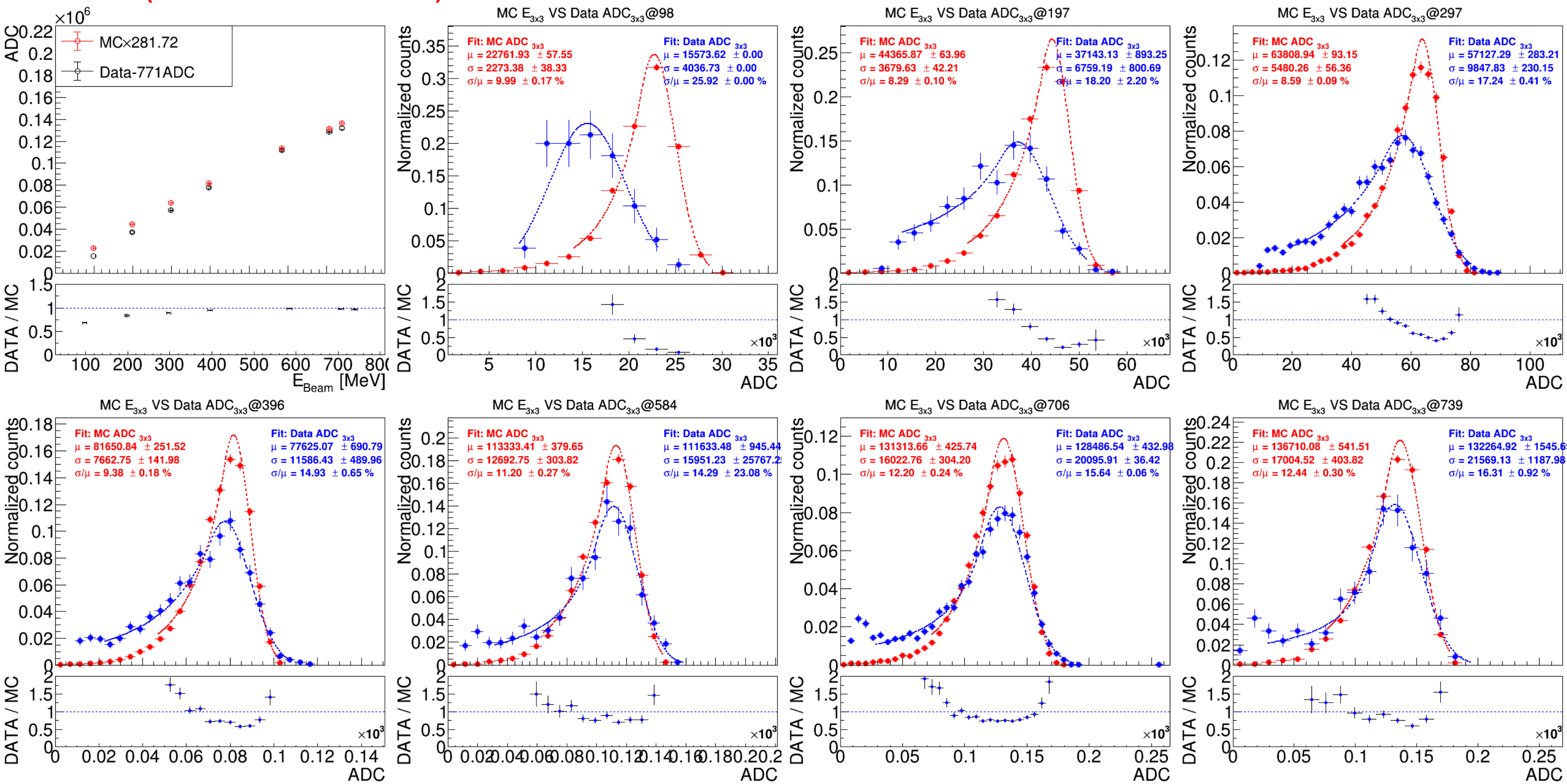


Cosmic ray data collection is currently in progress. A high noise level has been observed in the Taiwan setup, and we plan to investigate improvements to the shielding system.

Back up

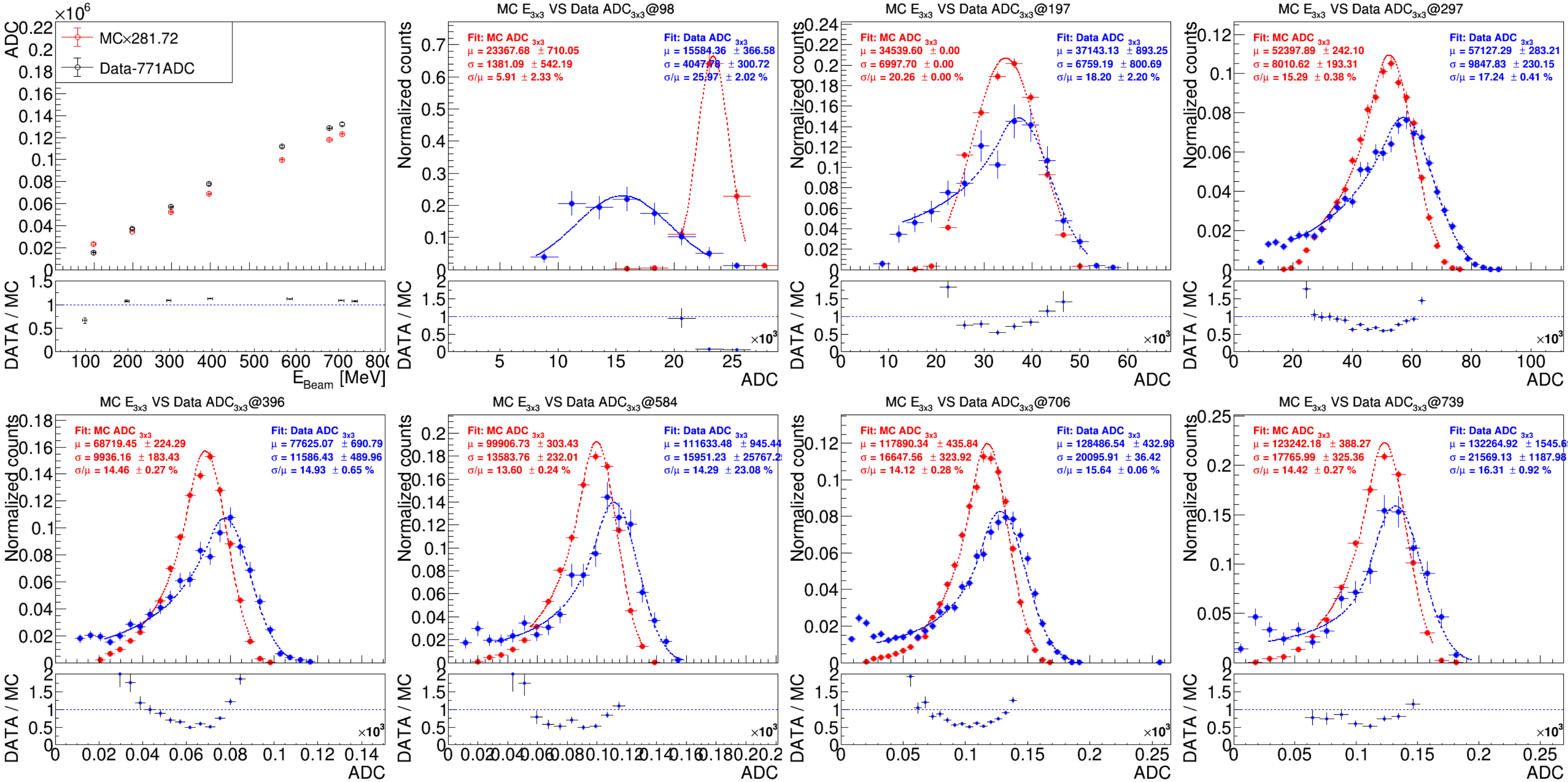
Compare data and MC : PbWO4, E3x3

- Data (with threshold = 30MeV)
- MC (no threshold cut)

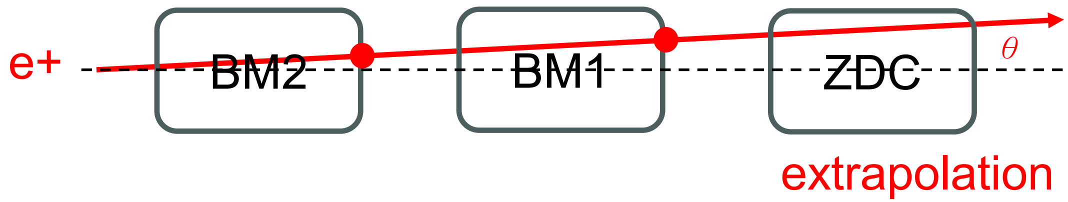


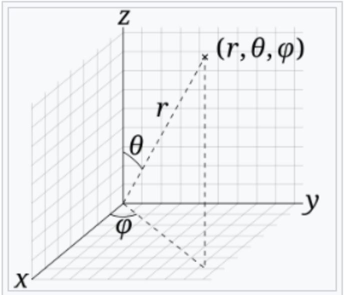
Compare data and MC : PbWO4, E3x3

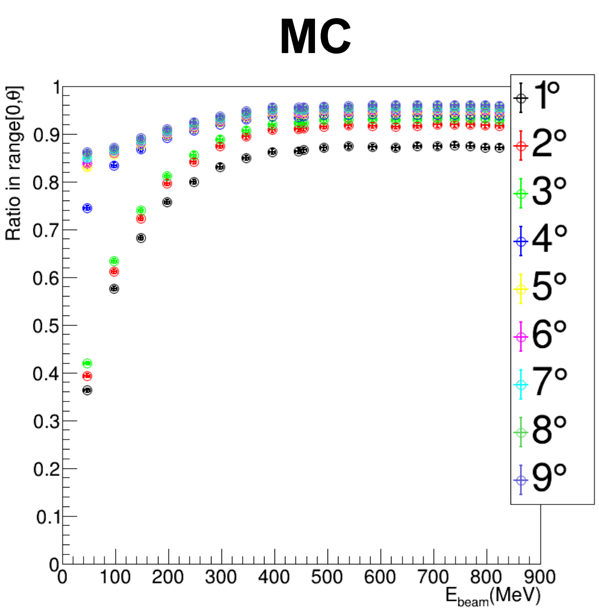
- Data (with threshold = 30MeV)
- MC (with threshold = 30MeV)

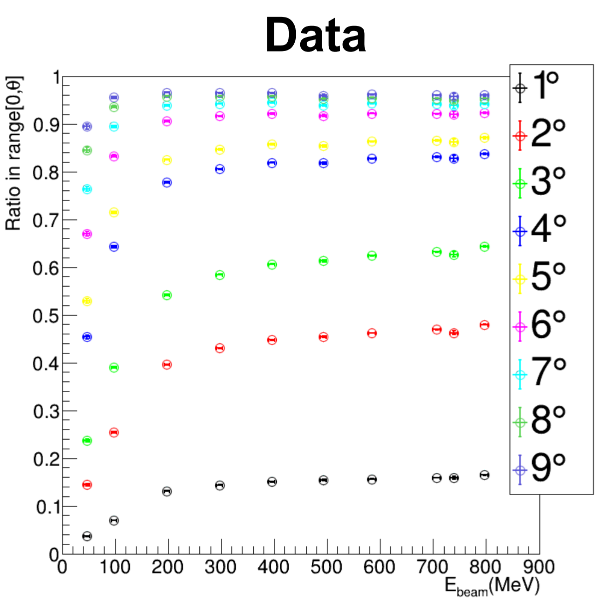


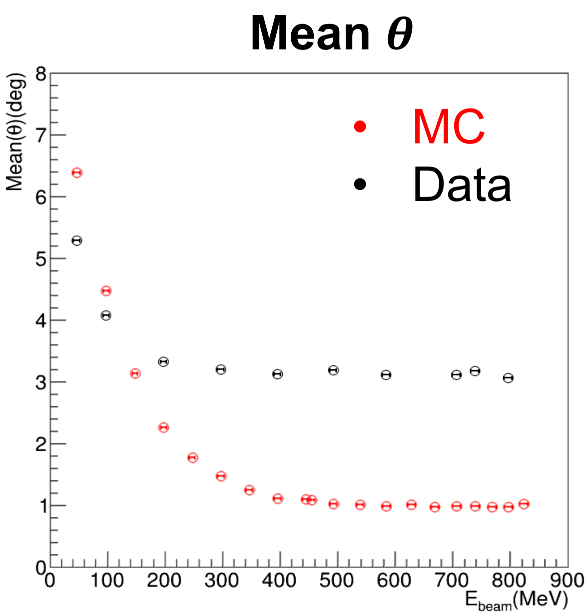
Study Beam Angle





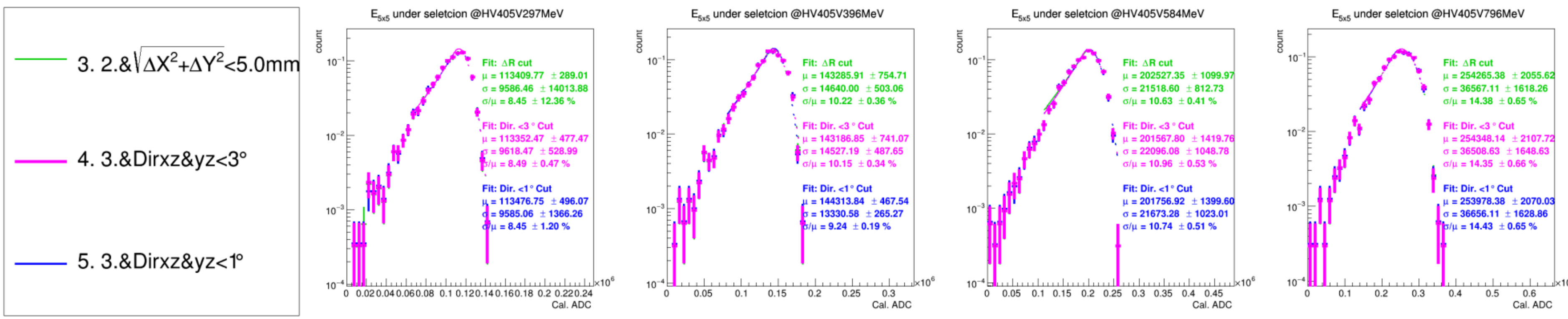


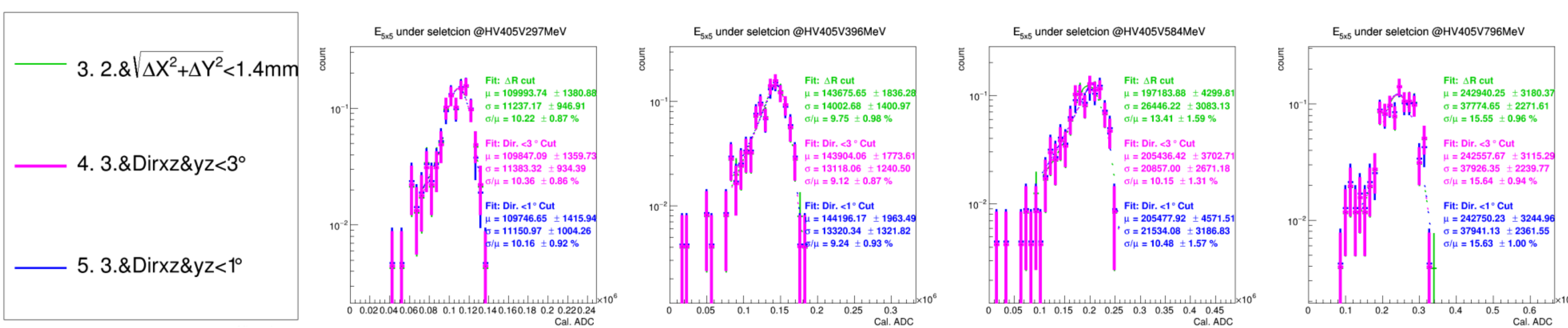




Data has larger angle compared to MC. The reason is still unknow. We suspect the beam setting in MC is not realistic enough (pencil beam setting).

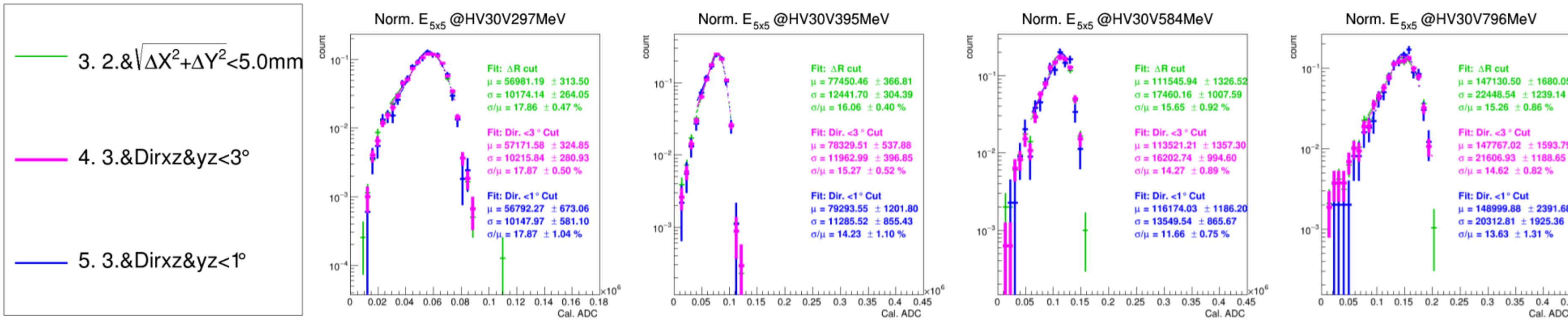
Study Beam Angle : MC

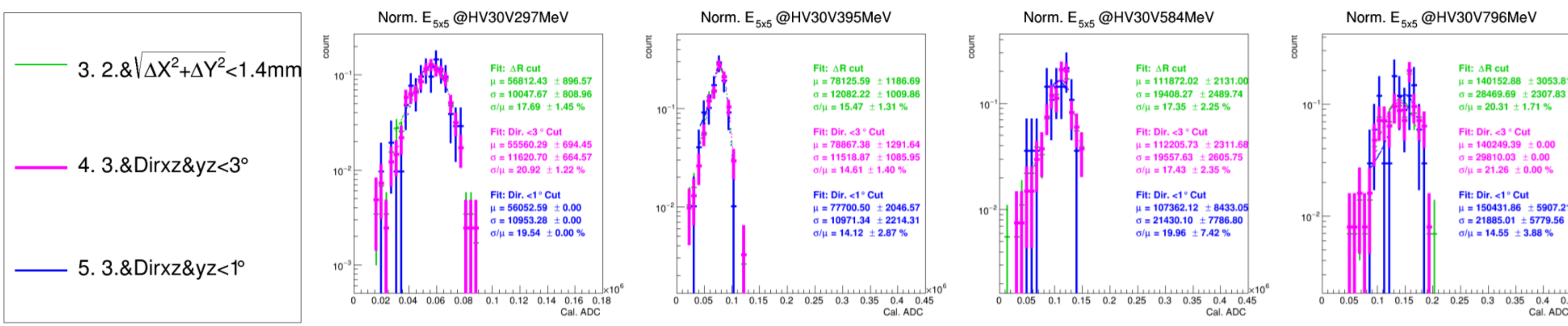




No obvious improvement after smaller beam angle cut.

Study Beam Angle : Data

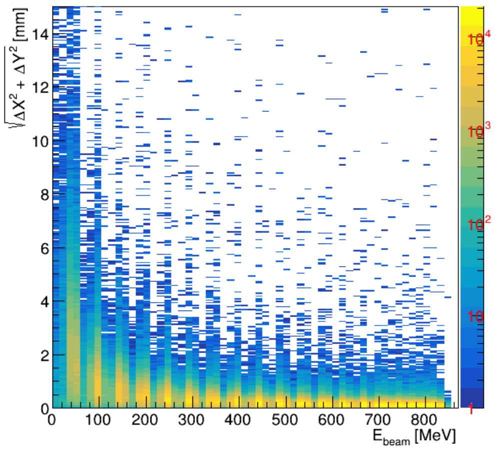




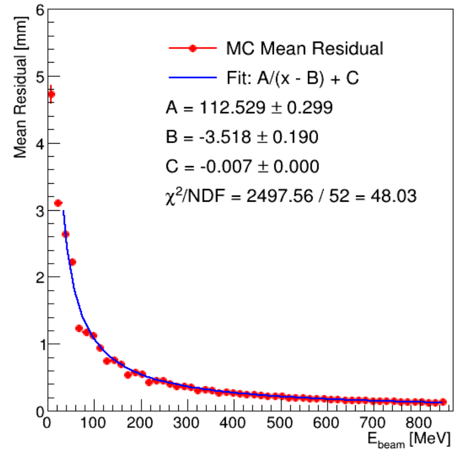
No obvious improvement after smaller beam angle cut.

Study Residual : MC Sample

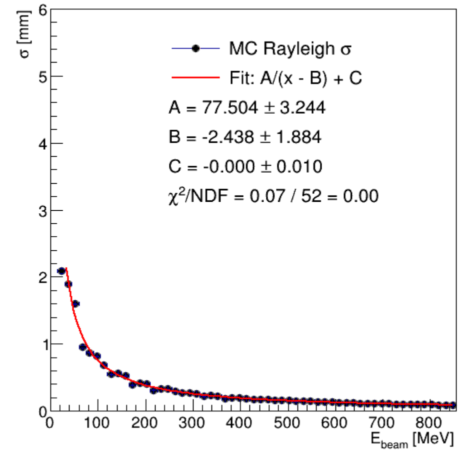
Δ : Residual in R



Energy VS mean Δ



Energy VS sigma Δ



Ebeam (MeV)	Mean Δ [mm]
50	**1.68**
100	0.84
250	0.36
500	0.21
800	0.15

The beam is set as a pencil beam, so the residual here indicates how much the beam is affected by the material of the beam monitor. Beams with lower energy exhibit a wider spread after passing through the beam monitors.