Beam Test of the ZDC EMCal Prototype with LYSO+SiPM

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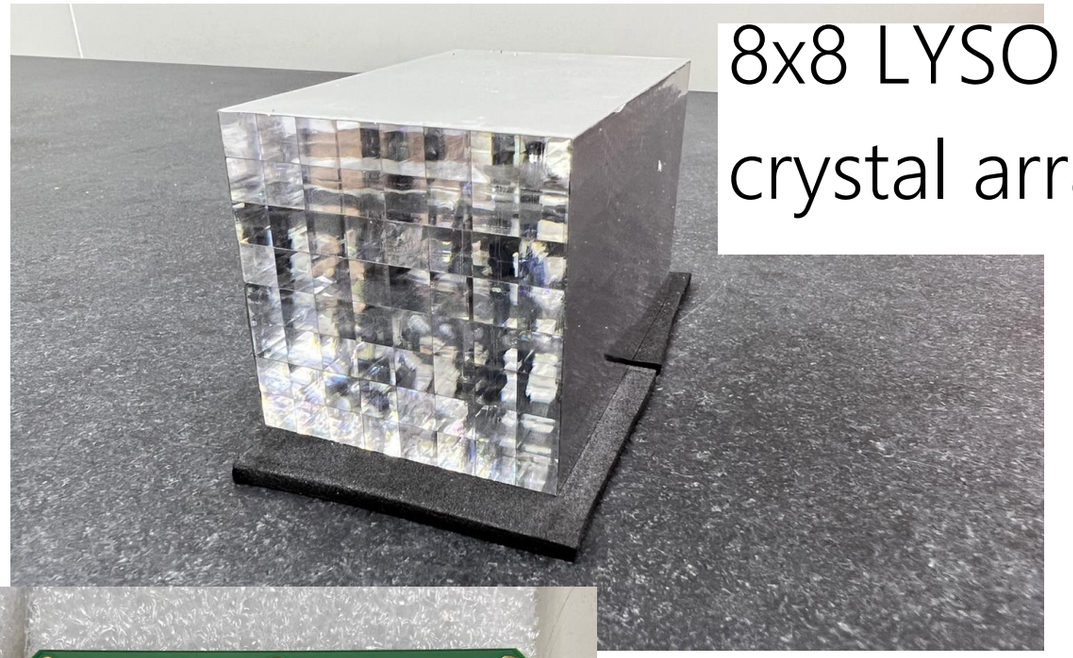
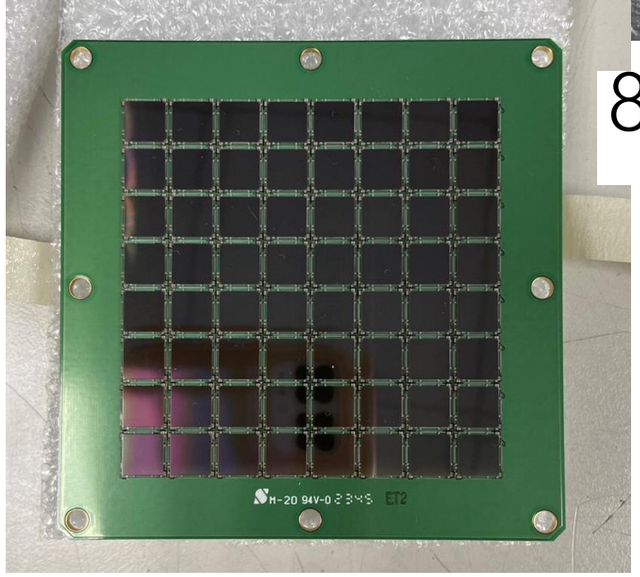
Comparison of various crystals

	X_0	LY (ph/MeV)	T dep. of LY (%/K)	Decay time (ns)	λ_{em} nm
$PbWO_4$ (CMS)	0.89 cm	200	-1.98	5 (73%) 14 (23%) 110 (4%)	420
LYSO	1.14 cm	30,000 (market standard)	-0.28	36	420
GAGG	1.59 cm	40,000 - 60,000		50 - 150	520
SciGlass	2.4-2.8 cm	>100		22 - 400	440-460

ZDC ECAL Prototype with LYSO Crystals

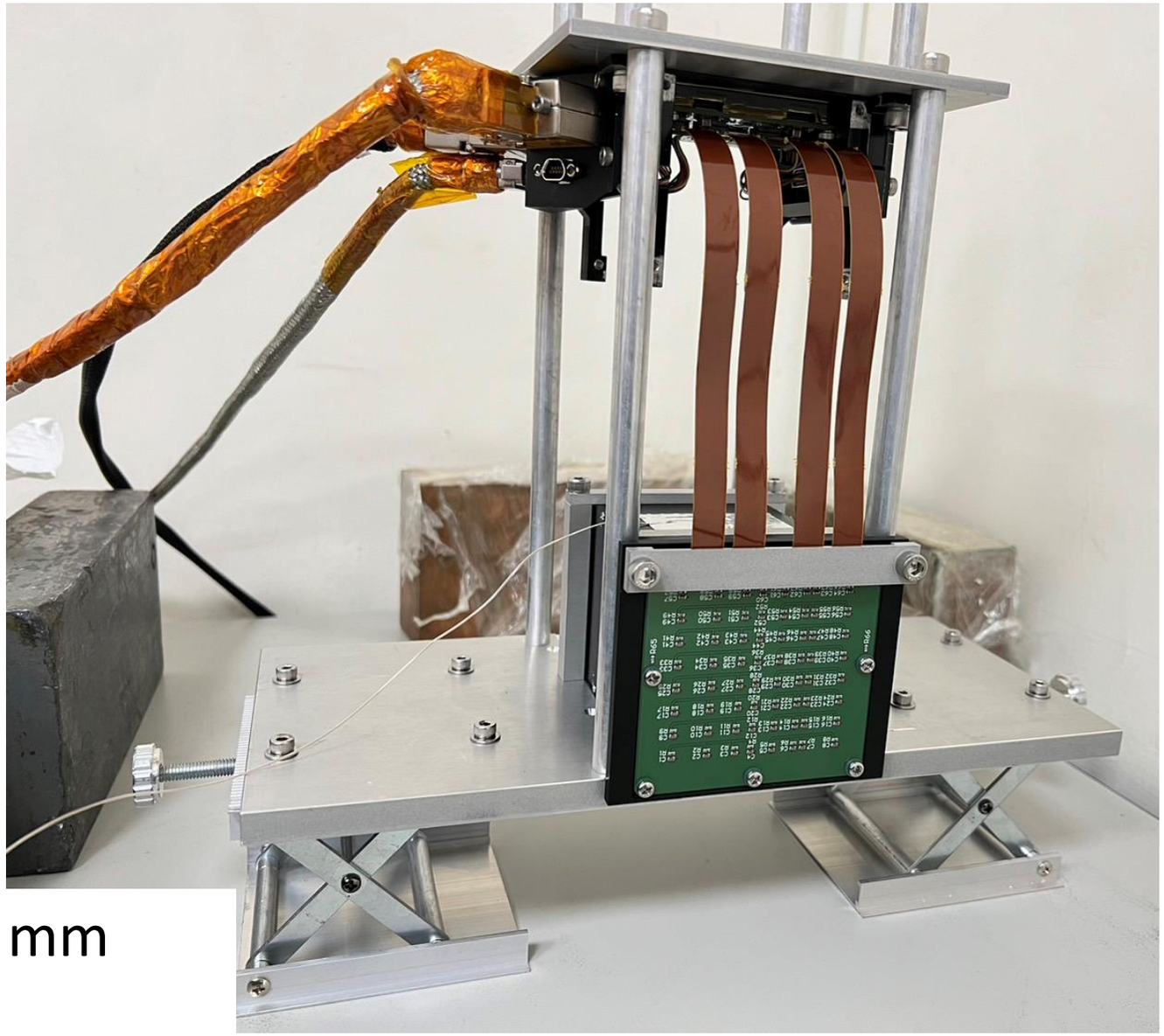


8x8 LYSO crystal array



8x8 SiPM array

LYSO calorimeter prototype

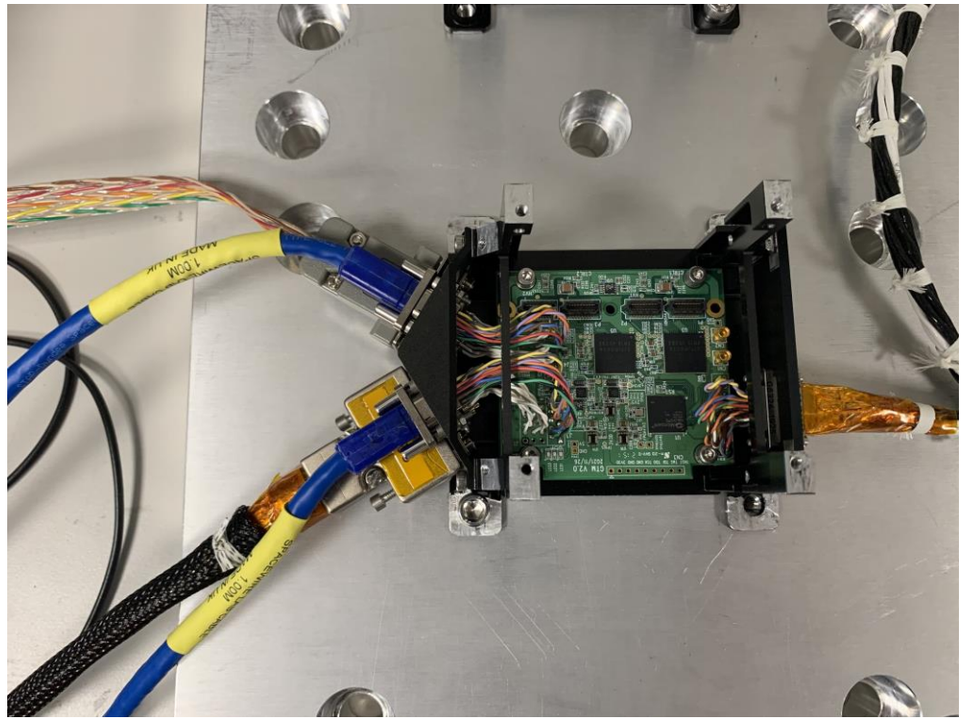


One crystal: 7.12 mm x 7.12 mm x 88.3 mm

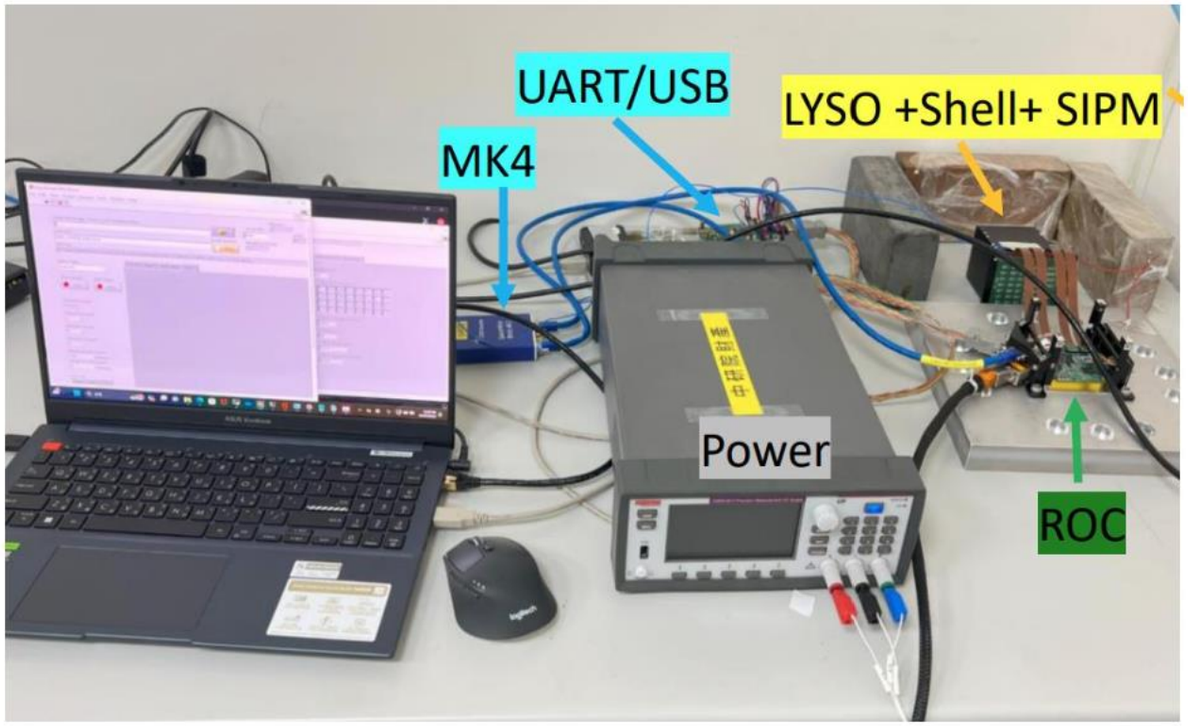
8x8 array: 56.96 mm x 56.96 mm

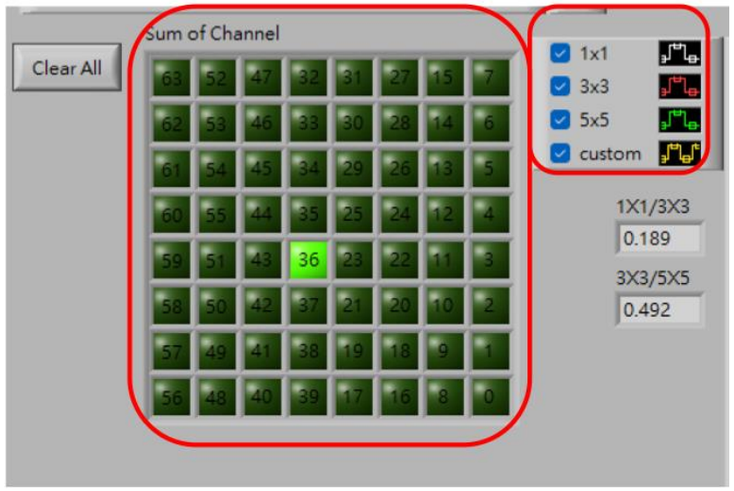
Readout for the ZDC ECAL Prototype with LYSO Crystals

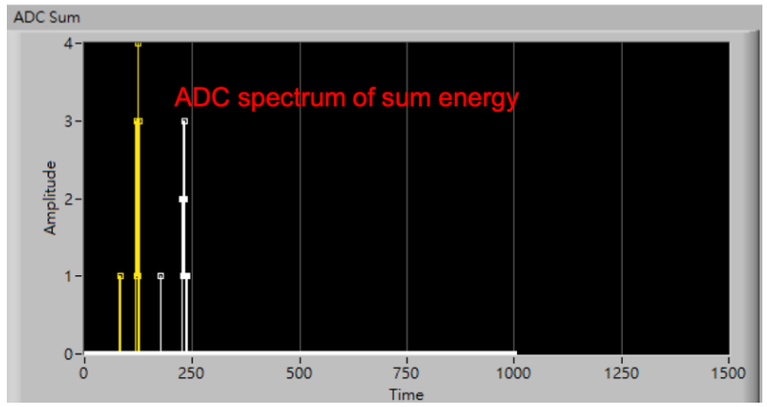
- Designed by Chih-Hsun Lin of Academia Sinica
- 64 channels
- Trigger:
  - Self-triggered
  - Can accept external timing signal → needs to be studied
  - May accept external trigger → needs to be studied

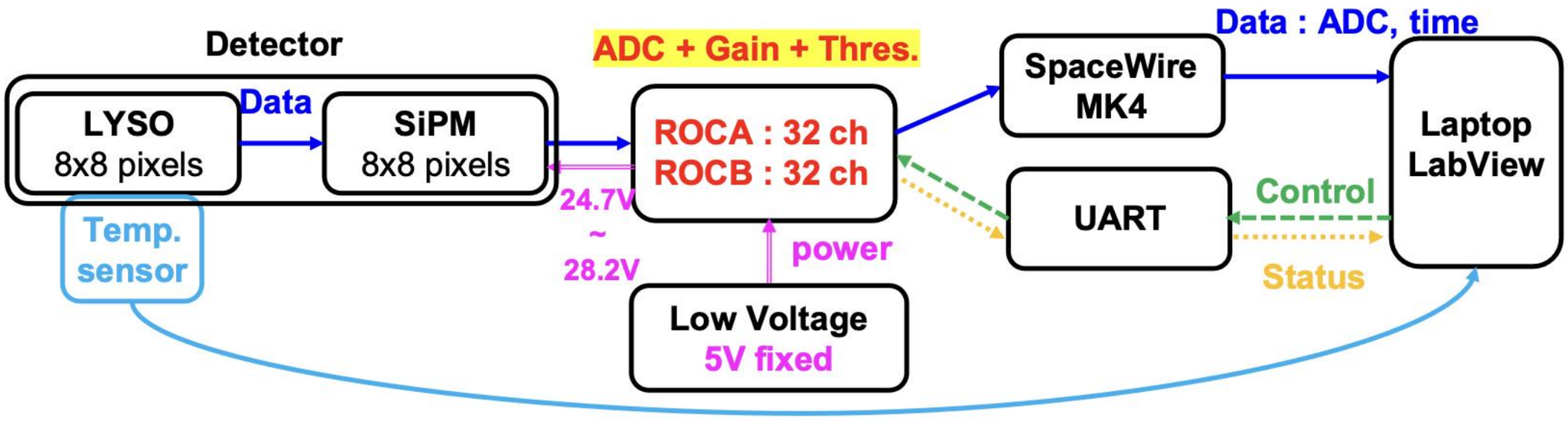


Test Setup

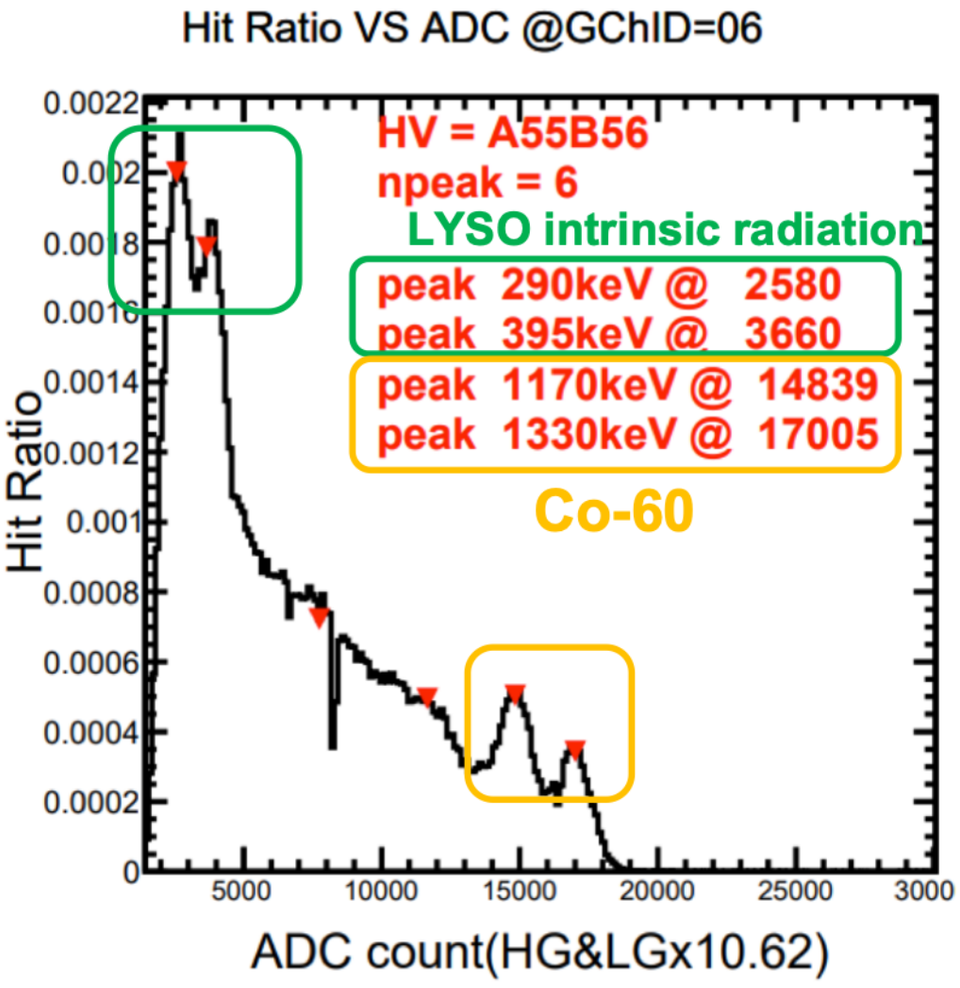

UART/USB
MK4
LYSO +Shell+ SIPM
Power
ROC


Clear All
Sum of Channel
63 52 47 32 31 27 15 7
62 53 46 33 30 28 14 6
61 54 45 34 29 26 13 5
60 55 44 35 25 24 12 4
59 51 43 36 23 22 11 3
58 50 42 37 21 20 10 2
57 49 41 38 19 18 9 1
56 48 40 39 17 16 8 0
1x1
3x3
5x5
custom
1X1/3X3
0.189
3X3/5X5
0.492


ADC Sum
ADC spectrum of sum energy
Amplitude
Time
0
1
2
3
4
0
250
500
750
1000
1250
1500


Detector
LYSO
8x8 pixels
Data
SiPM
8x8 pixels
Temp.
sensor
24.7V
~
28.2V
ADC + Gain + Thres.
ROCA : 32 ch
ROCB : 32 ch
power
Low Voltage
5V fixed
SpaceWire
MK4
UART
Data : ADC, time
Laptop
LabView
Control
Status

Tests with Co-60



We use Co-60 and LYSO intrinsic radiation to calibrate the detector.

- **@HV = 27.00V**

➔ 1.330 MeV @ 17005 digit
➔ 1.330 MeV / 17005 digit ~ 7.8e-5 MeV / digit
Saturated digit = 11, 0000 digit

➔ **Saturated at 8.6MeV**
This HV/gain is too high for our beam test condition.

- HV setting range = 24.7V to 28.2V

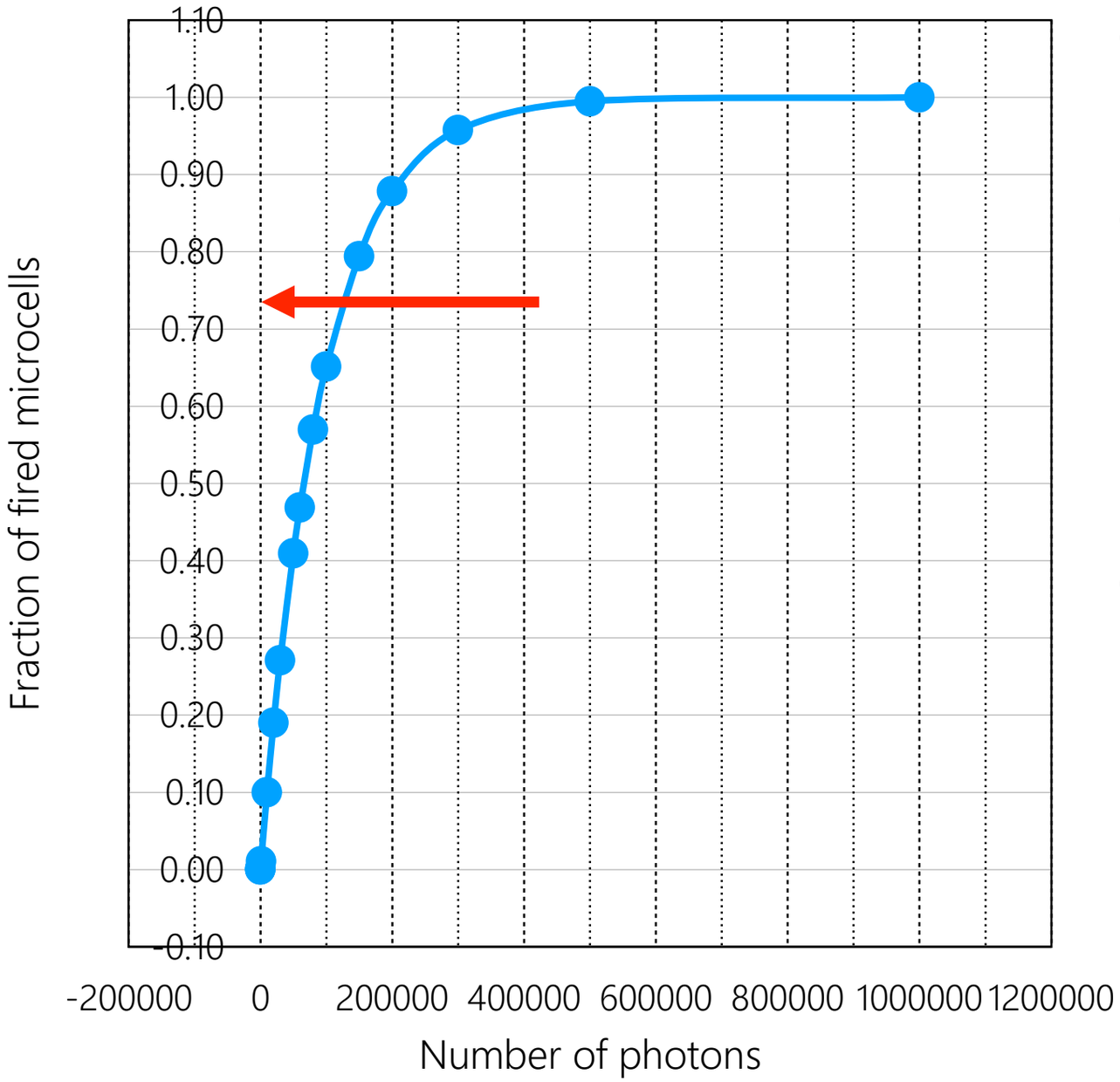
Why SiPM?

- Available readout board with CITIROC1A from wee roc for multichannel SiPM (Chih-Hsun Li, Academia Sinica) → can be used for first prototype study

- Need a suitable photodetector for critical fluence value $(10^{14}/cm^2)$
  - CMS ECAL
    - barrel: APD, up to $4 \times 10^{13}/cm^2$, gain: 1 - 100
    - endcap: VPT (vacuum phototriodes), up to $7 \times 10^{15}/cm^2$

- CMS MTD BTL (LYSO tiles with SiPM readout)
  - radiation (4/ab): $2 \times 10^{14}/cm^2$, gain: 2×10^5

SiPM Performance vs Number of Photons

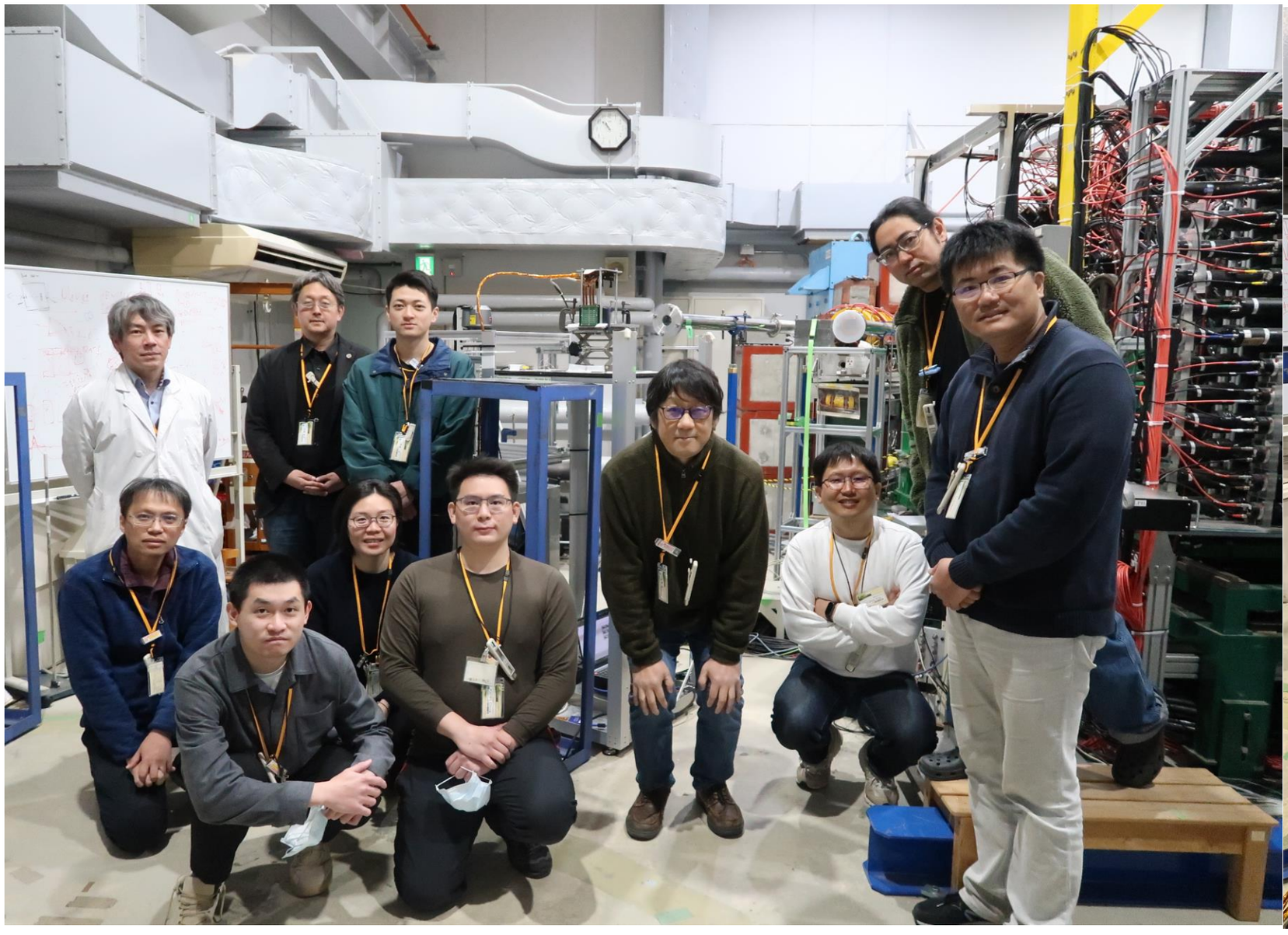


- Need the fraction of fired microcells of a SiPM below 70% for a linear response
- Number of microcells in currently used SiPM: 18,980
  - the one from HPK used by CMS BTL has 40,000 microcells
- LYSO light yield for 500MeV energy deposit: 500MeV × 40,000 photons/MeV × 0.2 (photon detection efficiency) × 0.25 (light collection efficiency) = 1,000,000 photons

Beam Test @ ELPH

- A beam test with positrons was conducted at the ELPH, Tohoku University, between **15 to 21 February 2024**
- Beam time: ~36 hours (**19 to 21 February 2024**)
- Beam energy: 47.18 MeV up to 823.26 MeV
- Rate: 1,000 - 3,000 Hz
- Participants: RIKEN, Tsukuba University, Tsukuba University of Technology, Sejong University, EIC-Taiwan

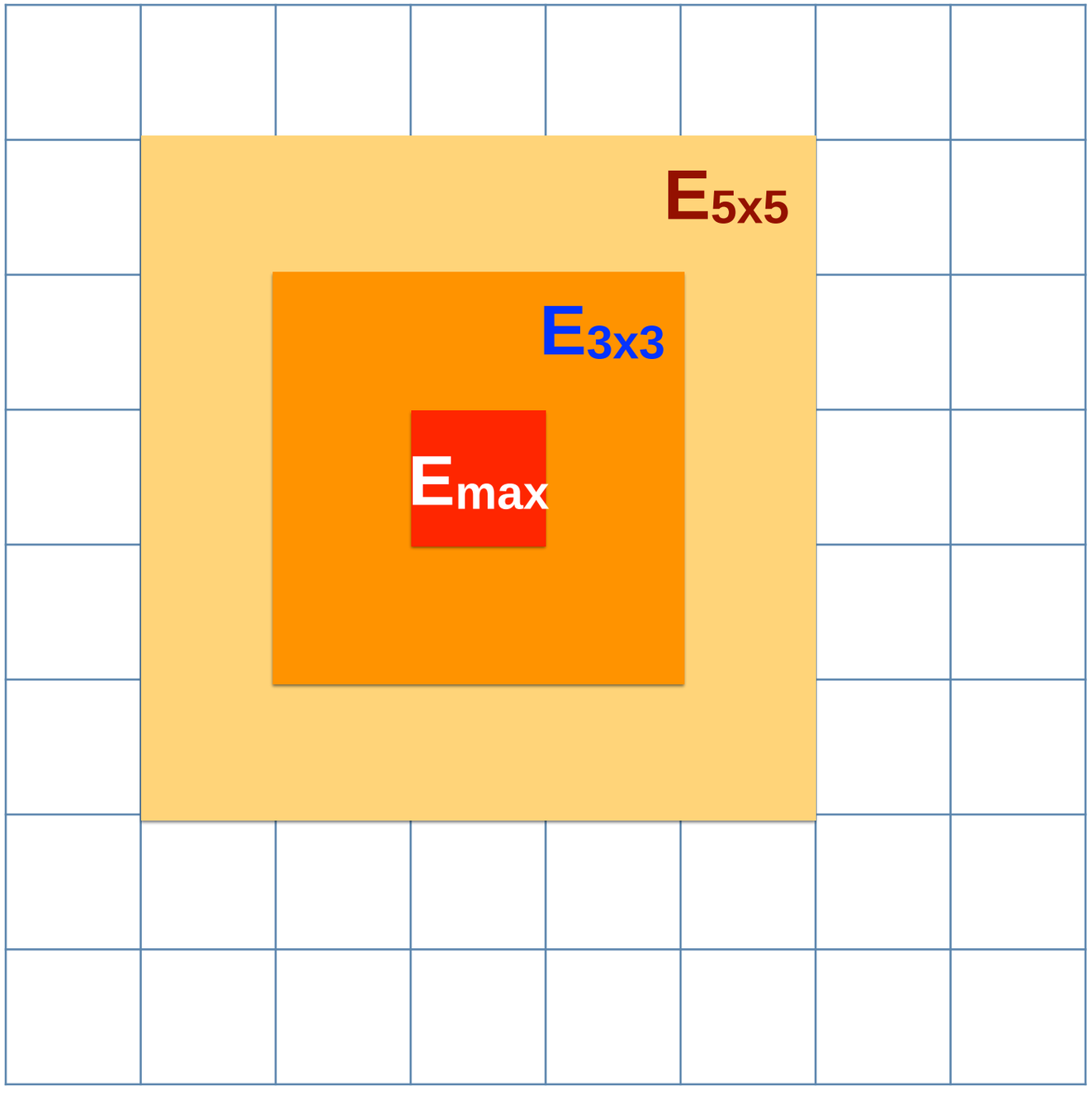
Beam Test @ ELPH



Run list

	Run range	Source/Beam	Purpose
HV Scan	1 - 20	Co60 (1 - 6, 20) Na22 (7 - 19)	Verify gains
“Background”	21 - 33	Intrinsic radiation	Understand instrinsic radiation rate with threshold cuts
Gain Calibration	33 - 36	Na22 (34 - 37)	Calibrate each channel
HV and Beam Energy Scan	41 - 99	Beam (47 - 823 MeV)	Understand detector performance and study energy resolution and shower shapes
Position Scan	101 - 129	Beam (197 MeV)	
HV and Beam Energy Scan at Low Energy	129 - 157	Beam (< 297 MeV)	
With Absorbers	160 - 225	Beam (197 - 823 MeV)	
Rotation	227 - 238	Beam (98, 197, 297 MeV)	Understand detector performance

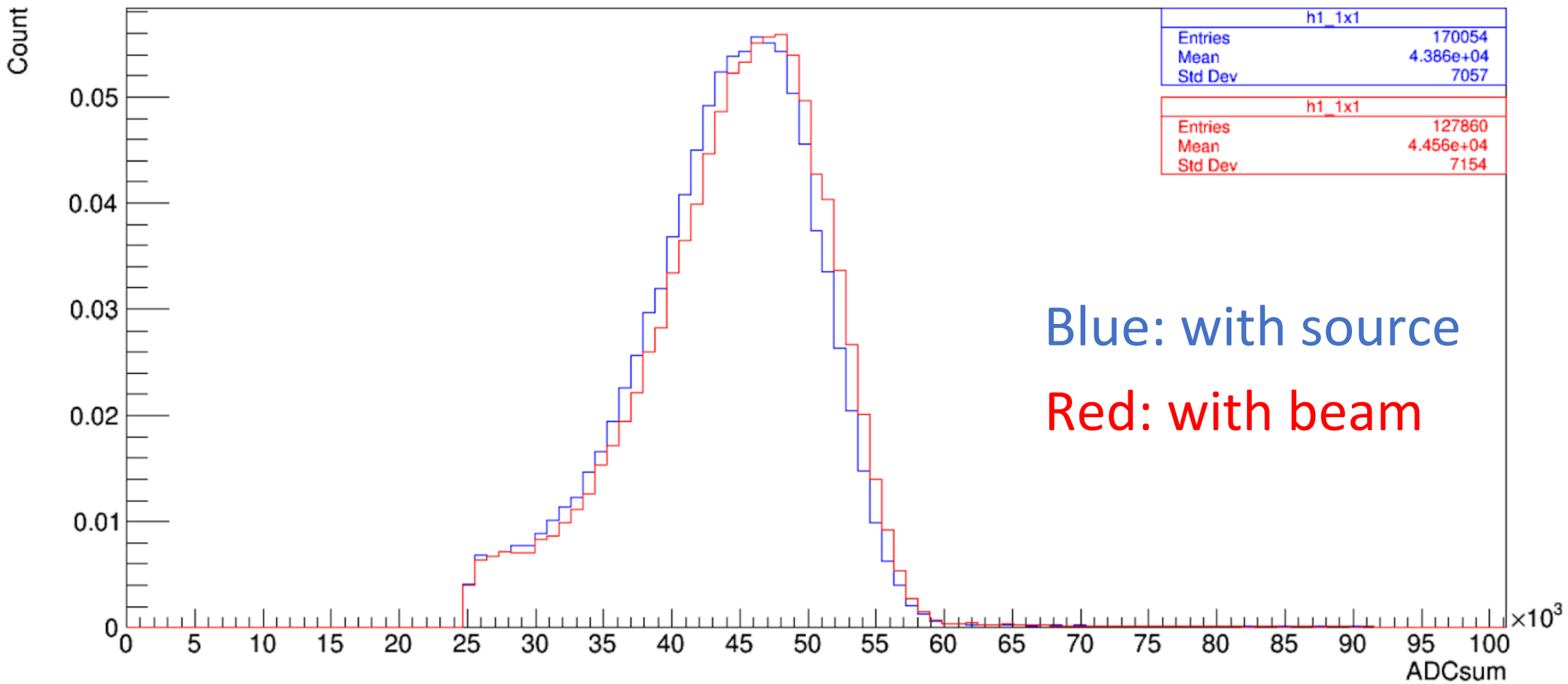
Clustering



Items to be studied

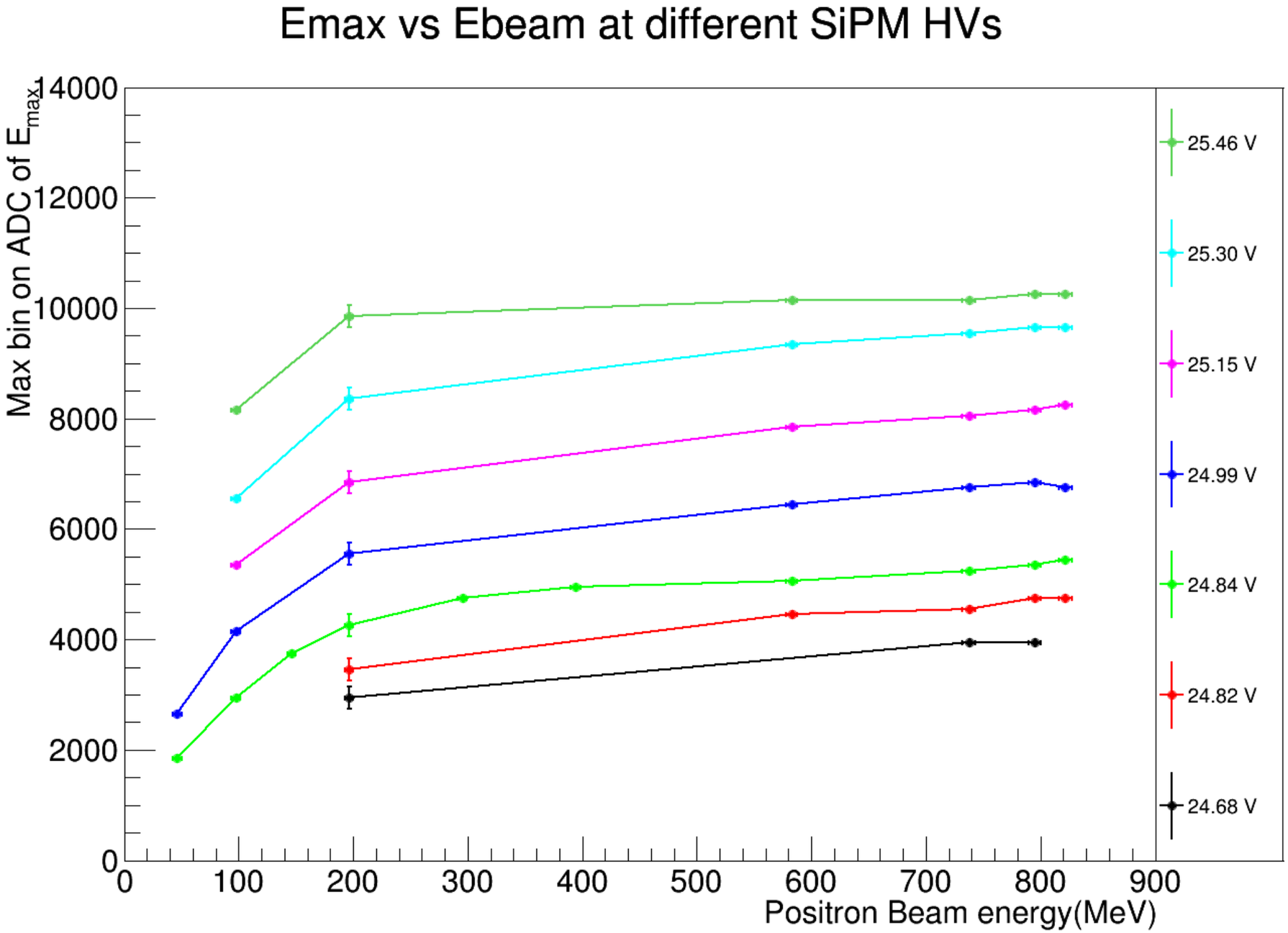
- Detector performance
- Comparison between data and simulation
- E_{max} vs E_{beam} at different SiPM HVs
- Hit multiplicity
- Energy spectra (E_{max}, E_{3x3}, E_{5x5})
- Shower shapes (E_{max}/E_{5x5}, E_{3x3}/E_{5x5}, E_{max}/E_{3x3}, E_{2x5}/E_{5x5}, σ_X, σ_Y, ...)
- Beam profile
- Energy resolution as a function of beam energy

Channel-by-Channel Gain Calibration



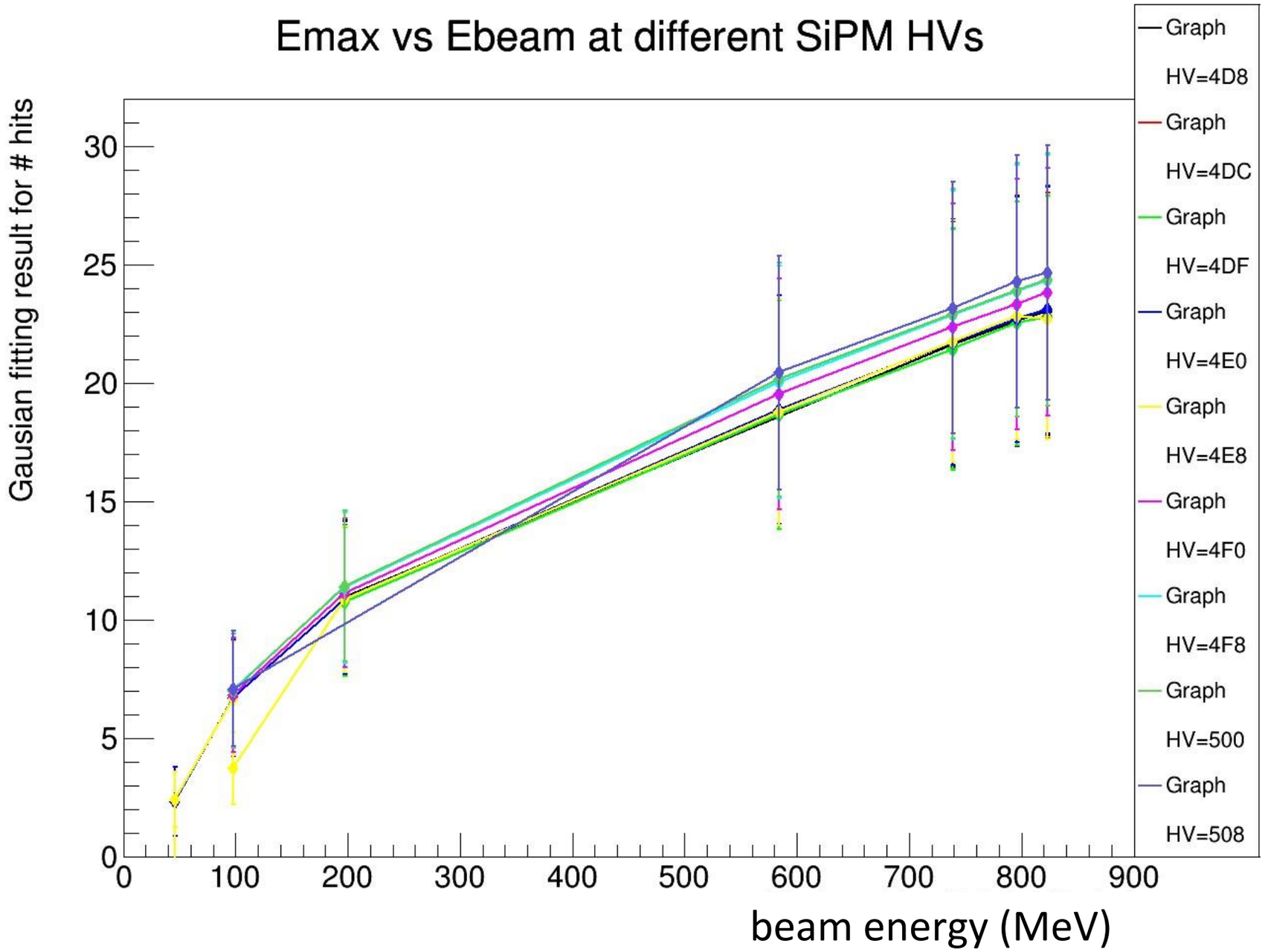
- Channel-by-channel gain calibration was performed using radiation source and beam, respectively
- The calibration obtained with the radiation source is not significantly different from the one obtained with high energy beam

E_{max} vs Beam Energy



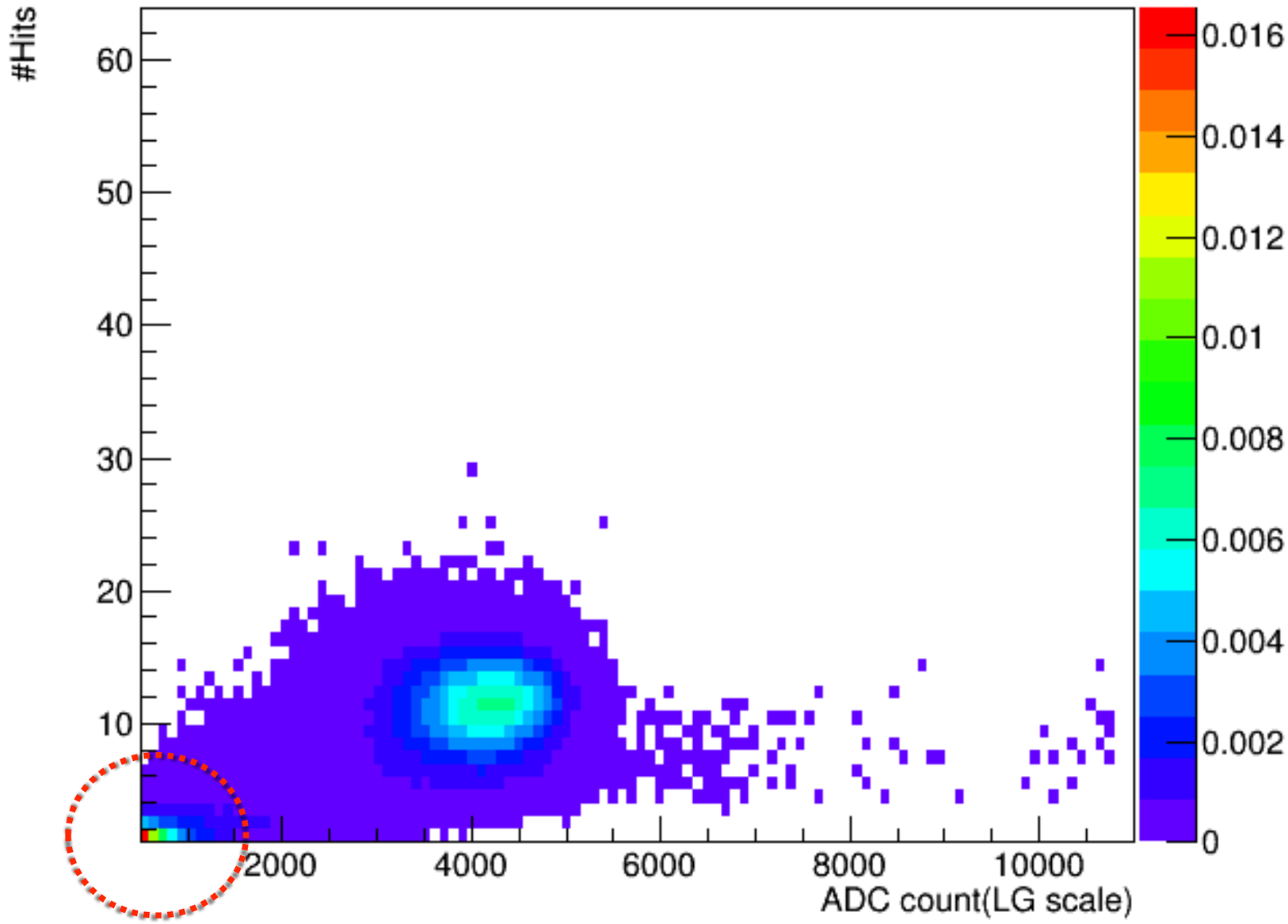
- Detailed analysis with more runs is being carried out

Number of Hits vs Beam Energy



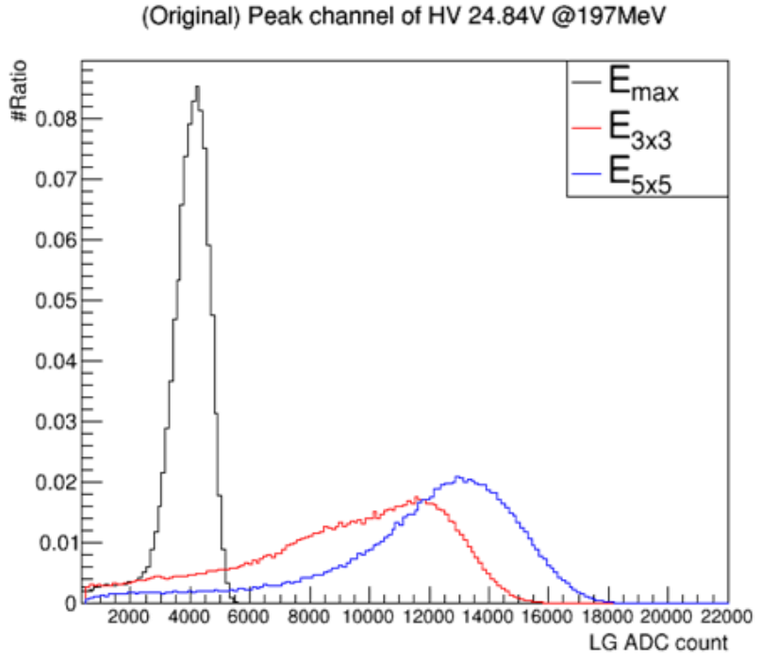
- To be compared with simulation

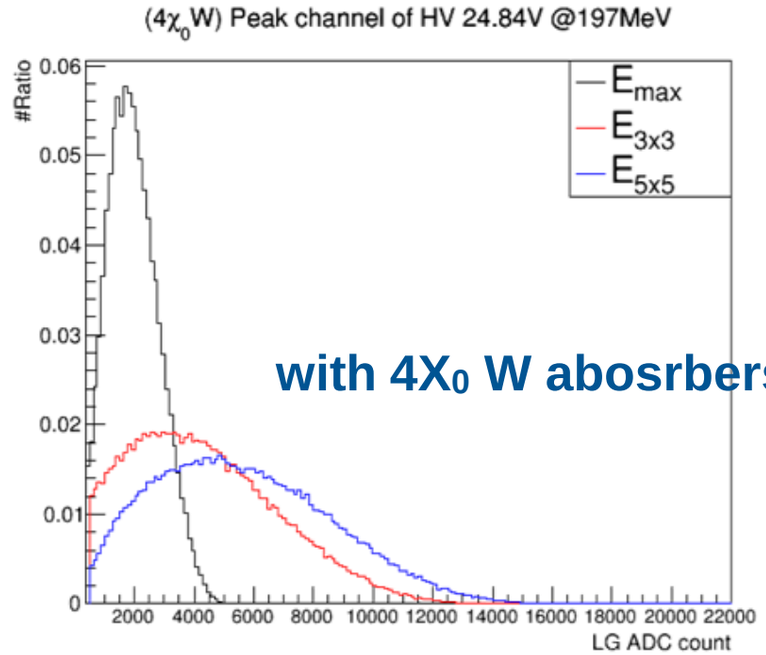
Number of Hits vs E_{max}



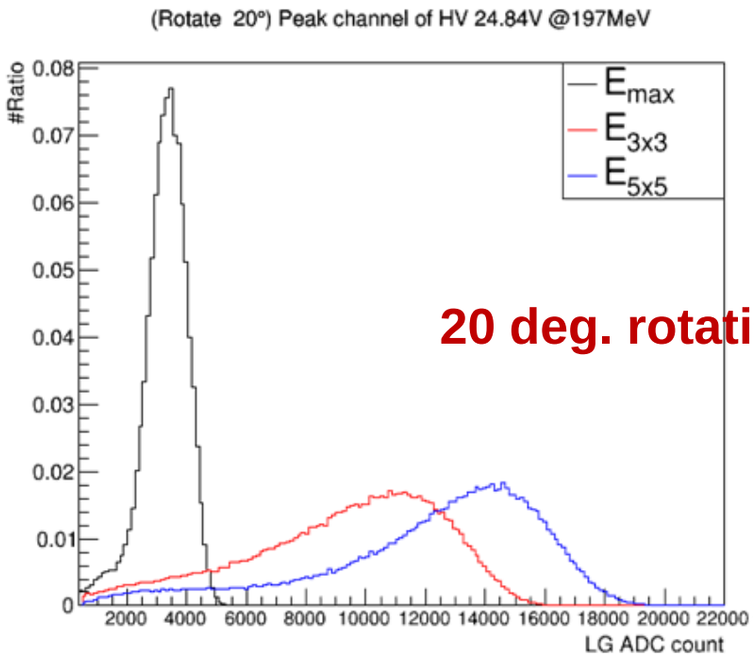
- Temporarily require to have at least 3 hits

Cluster Energy

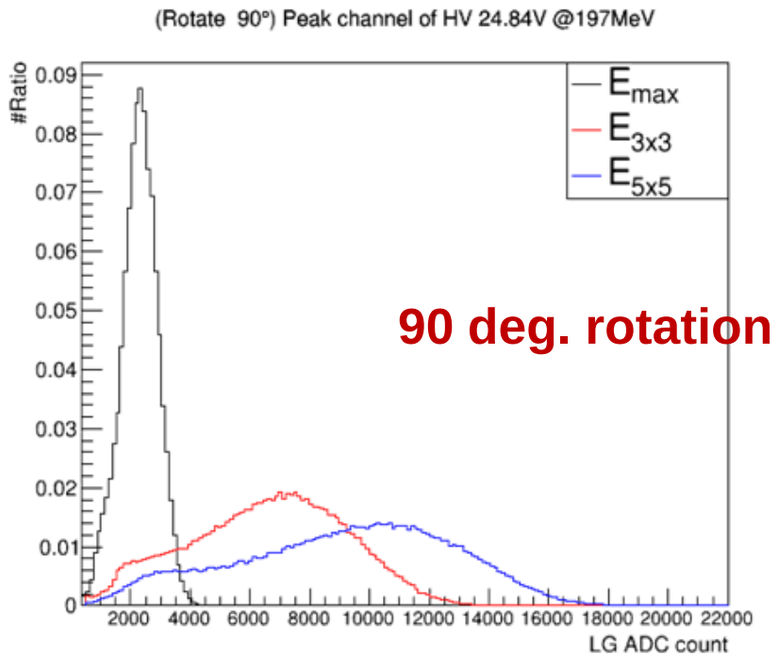




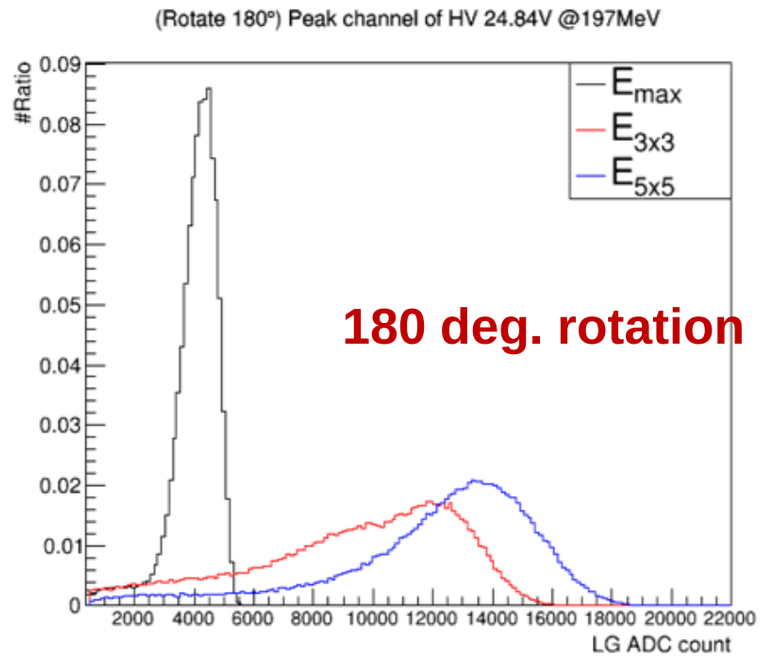
with $4X_0$ W abosrbers



20 deg. rotation



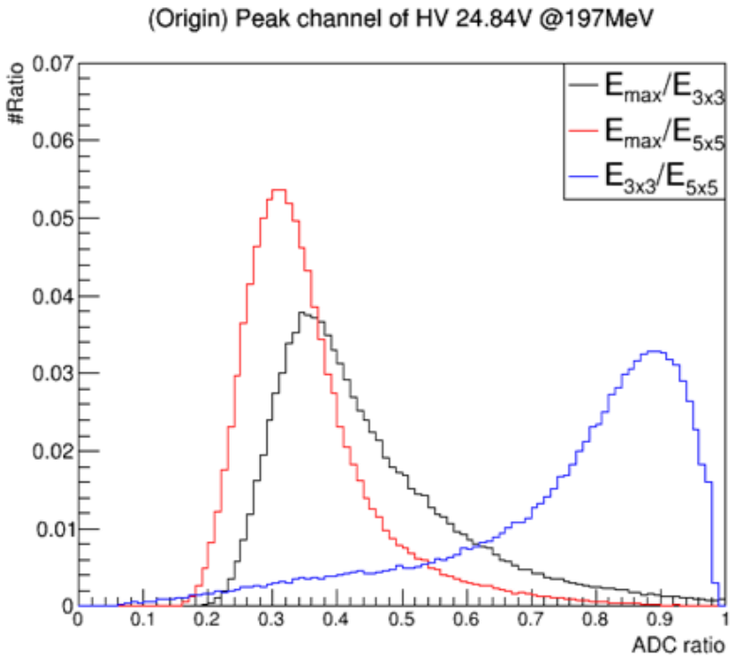
90 deg. rotation

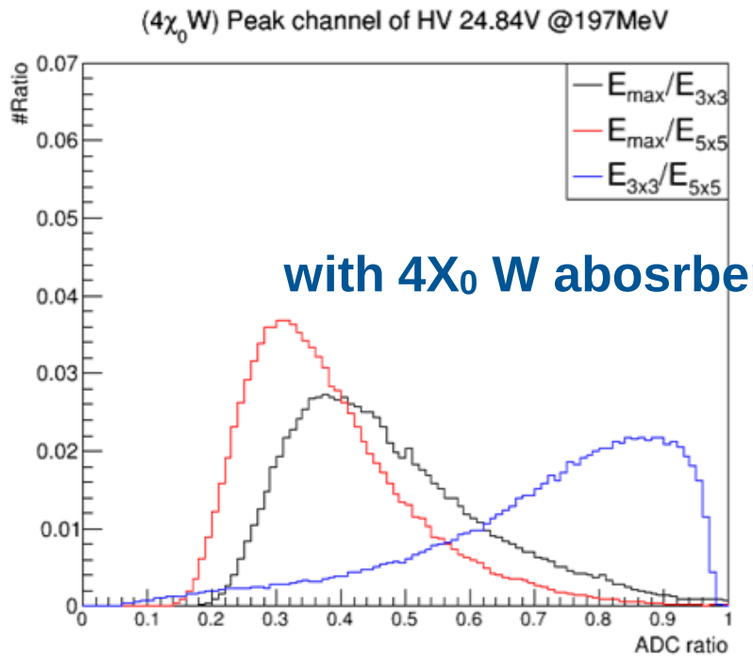


180 deg. rotation

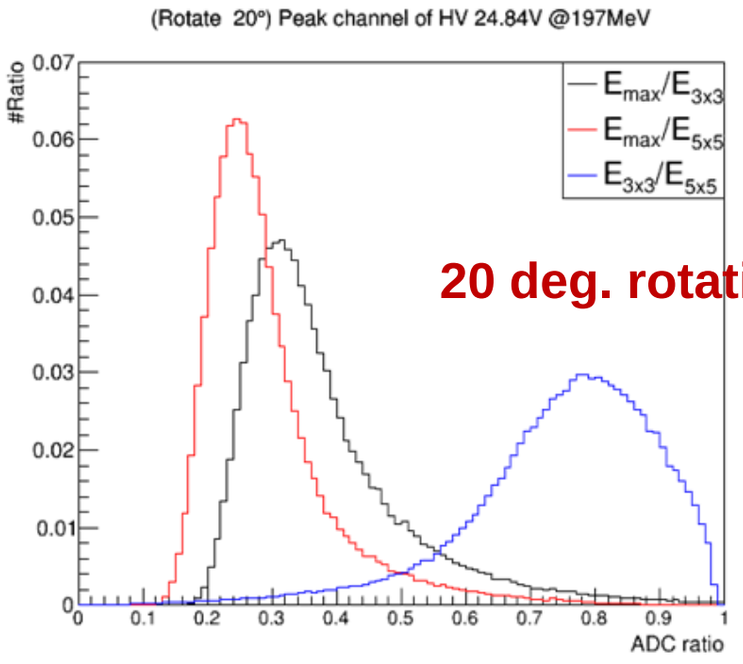
- To be compared with simulation

Shower Shapes

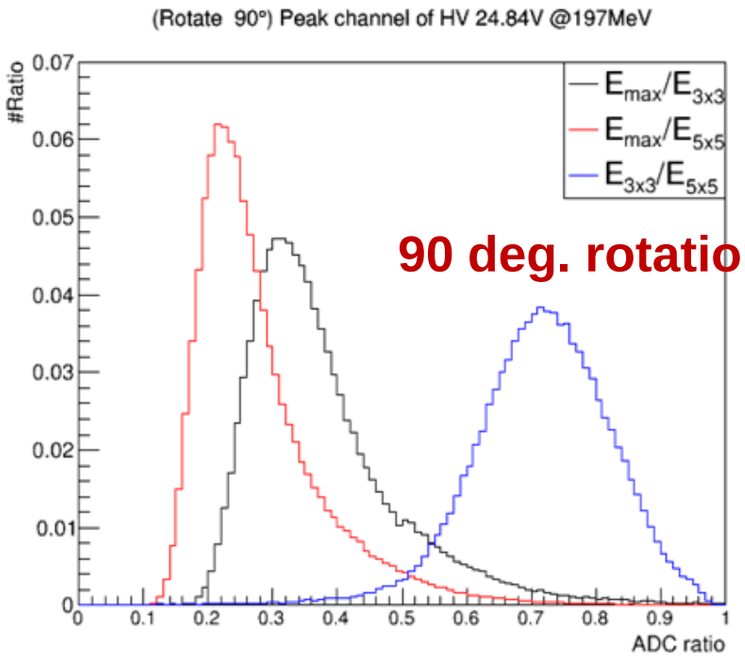




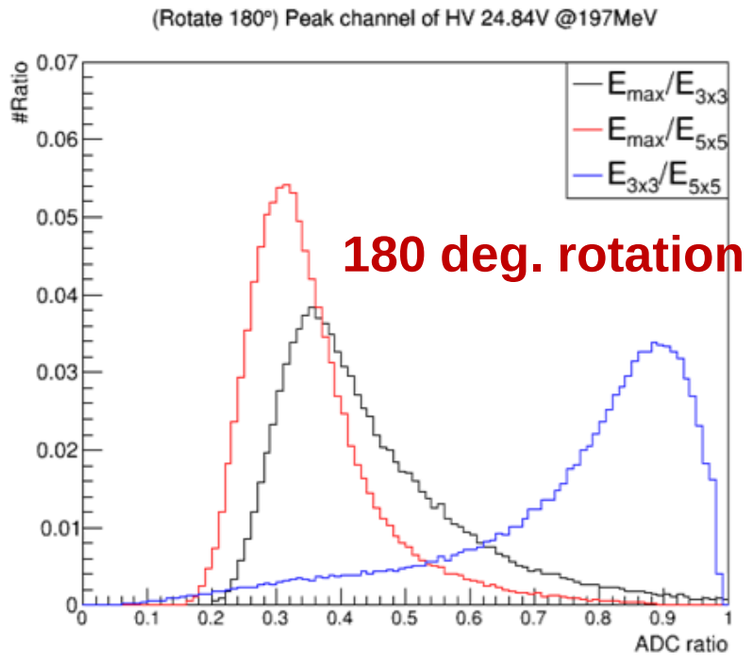
with $4X_0$ W abosrbers



20 deg. rotation



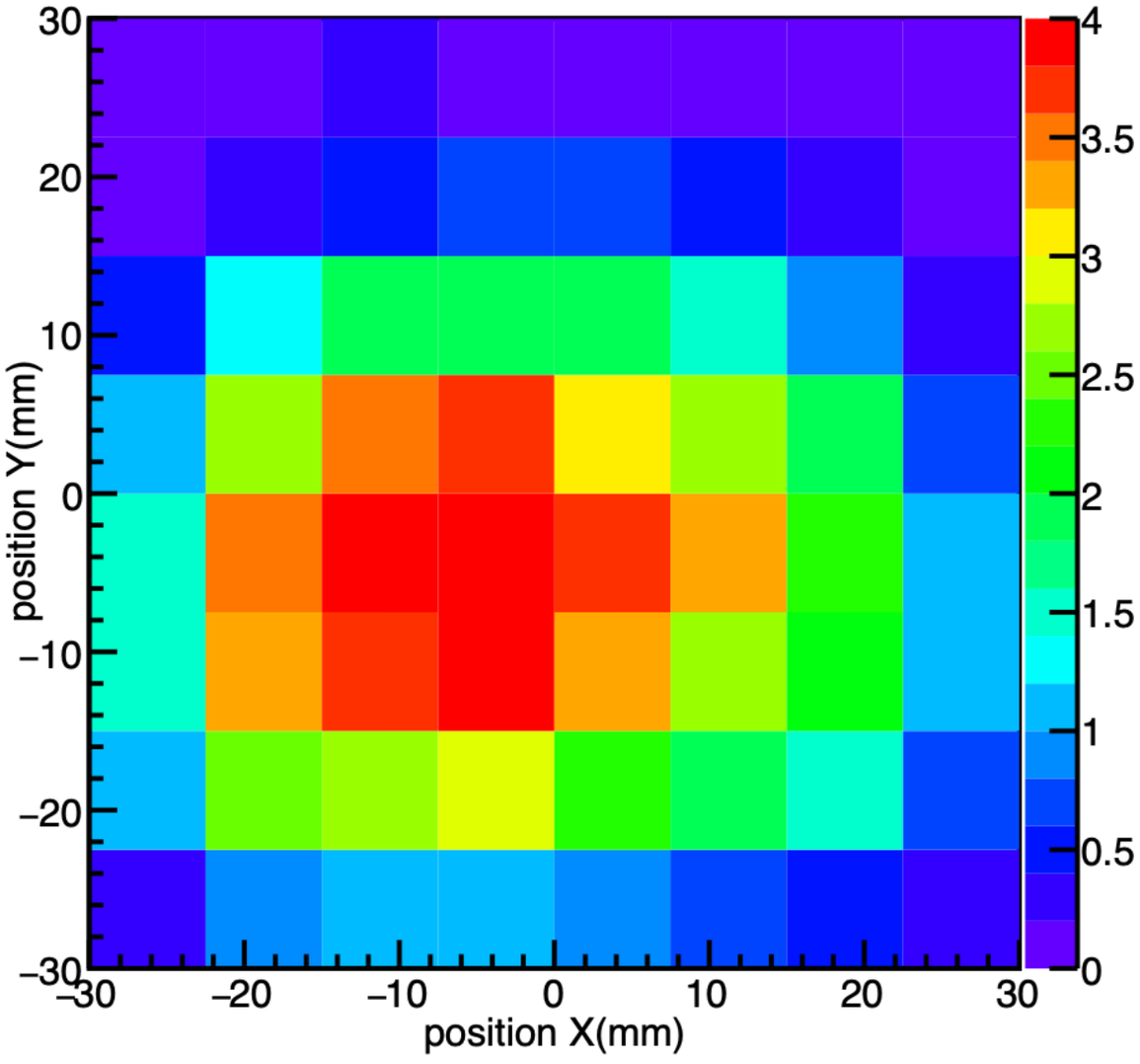
90 deg. rotation

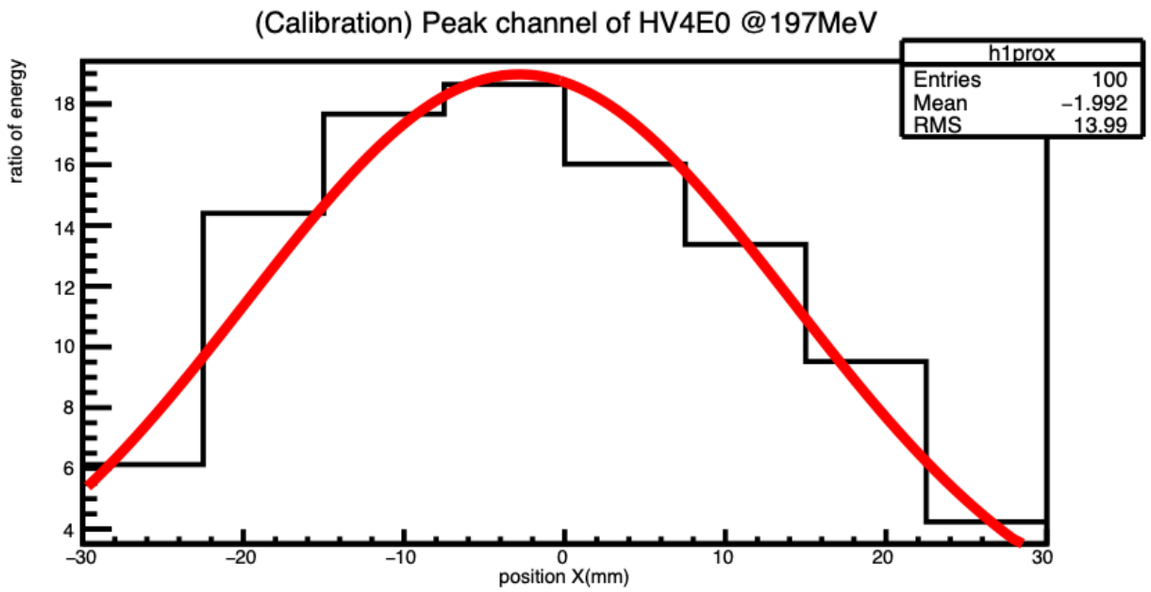


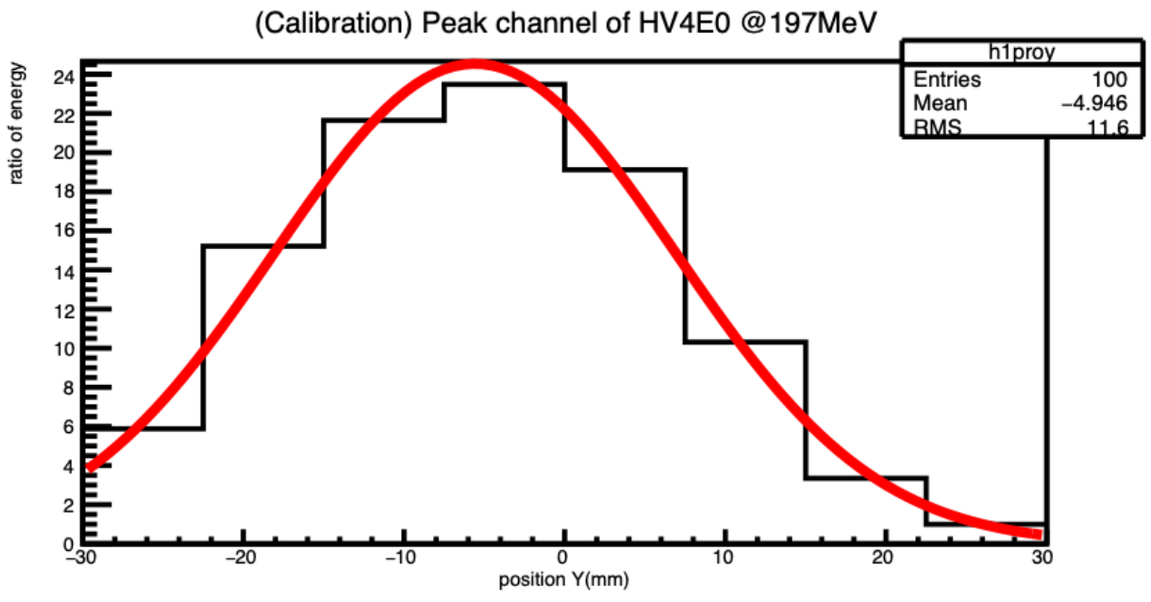
180 deg. rotation

- To be compared with simulation

Beam Profile

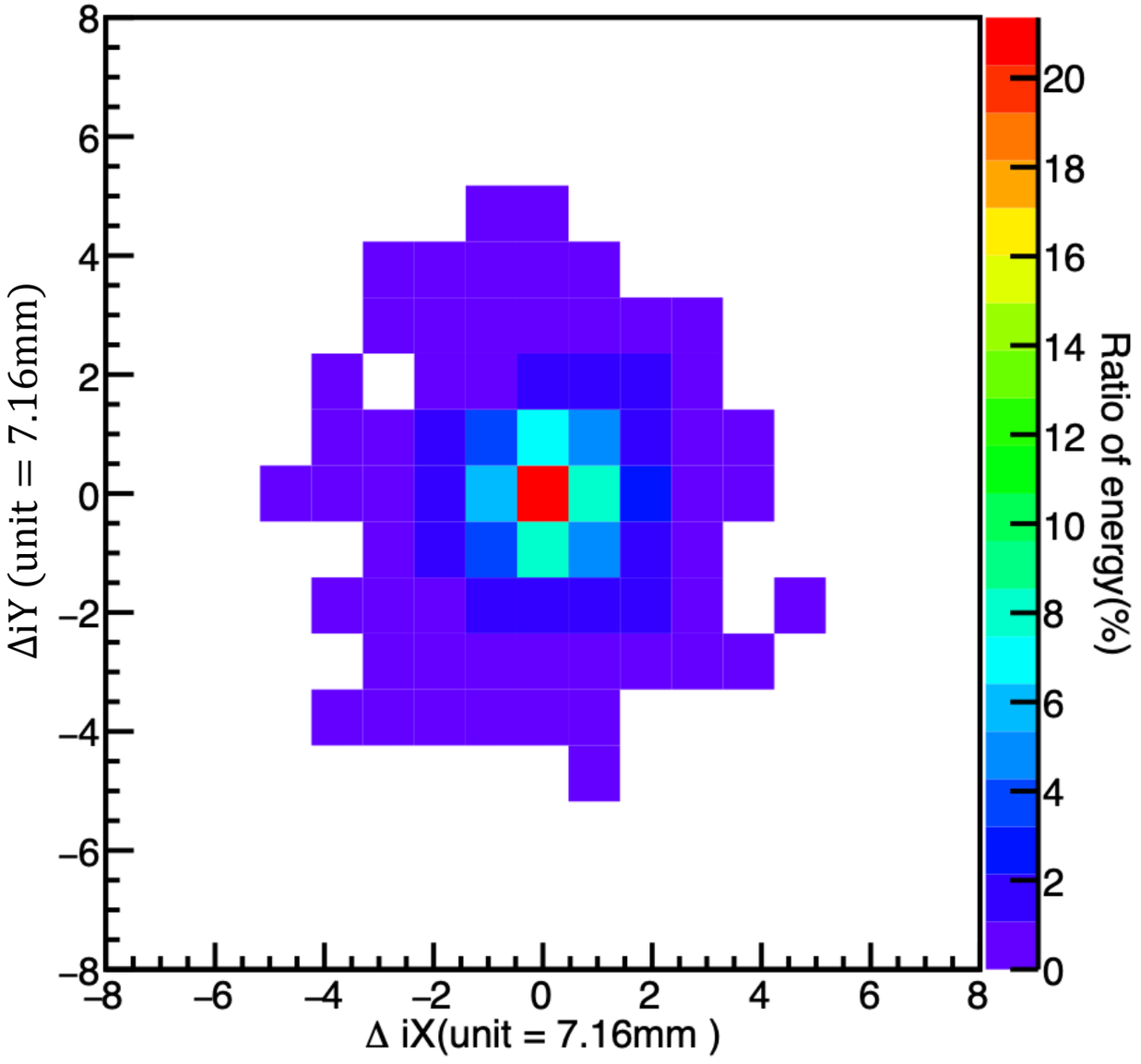


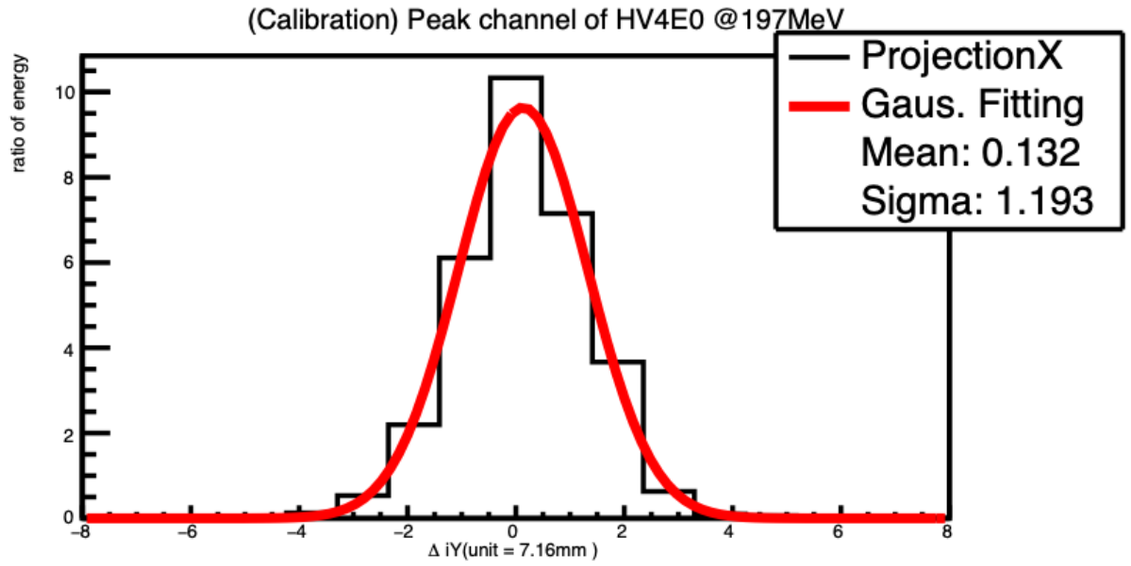


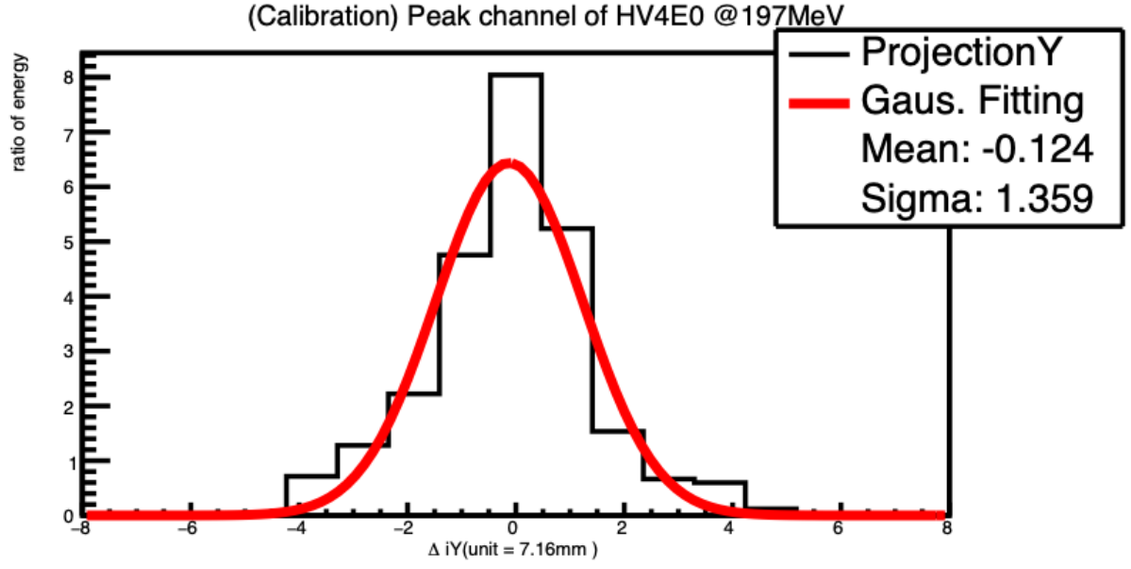


- Beam position is calculated with energy weighted method

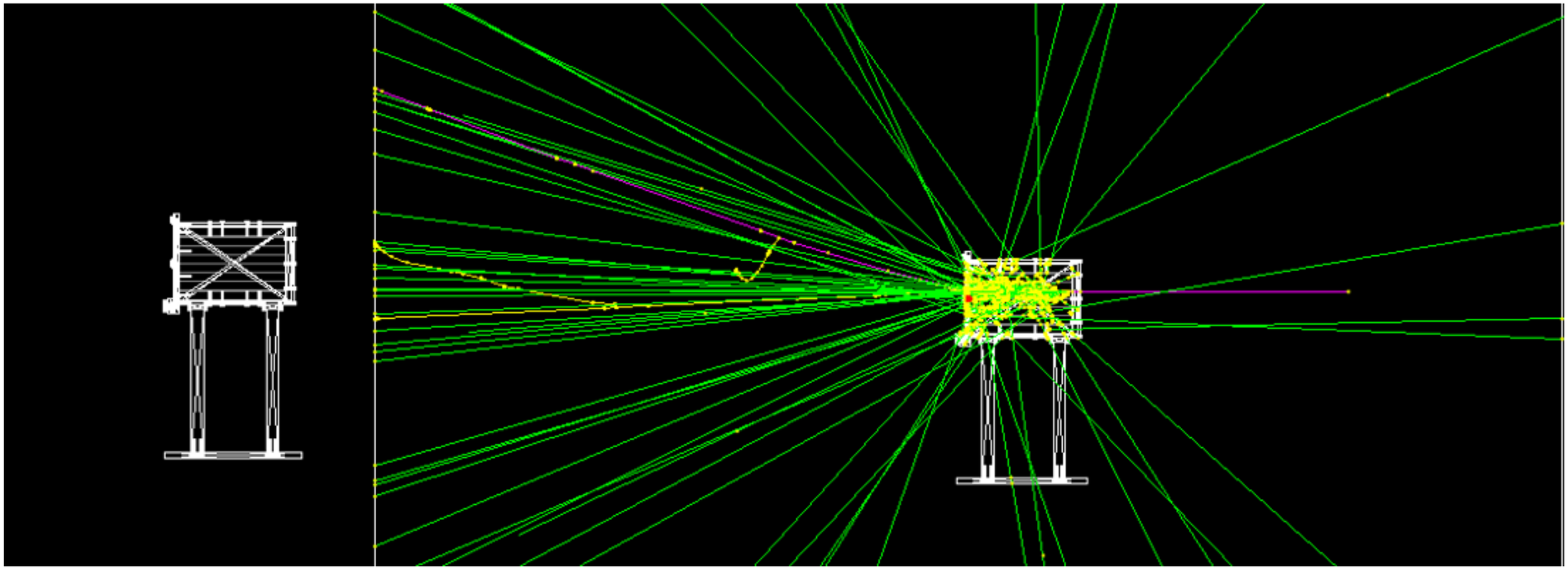
Shower Spread







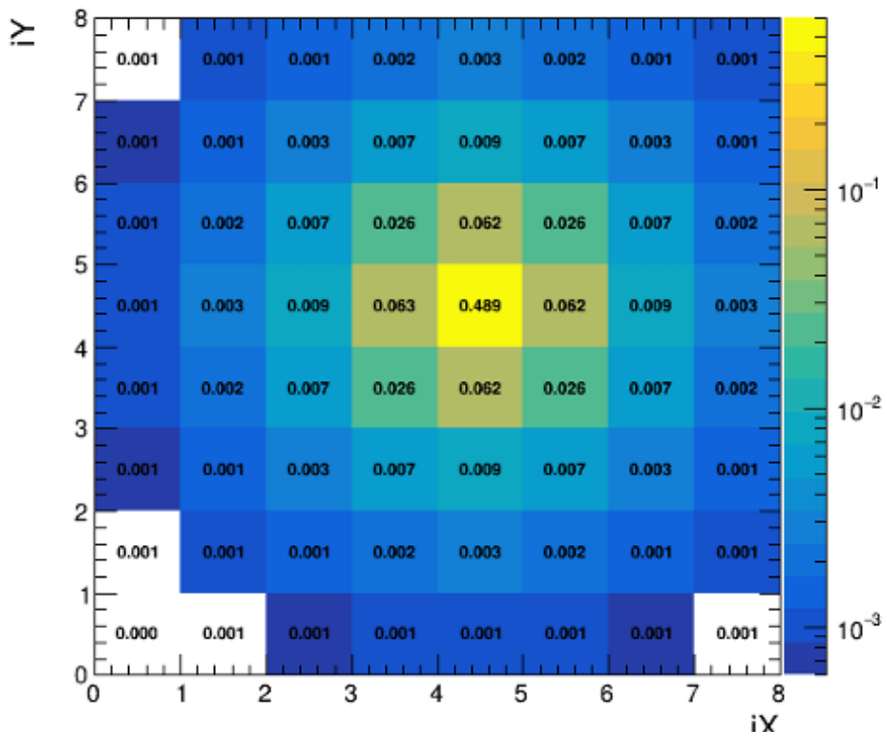
“Standalone” Simulation

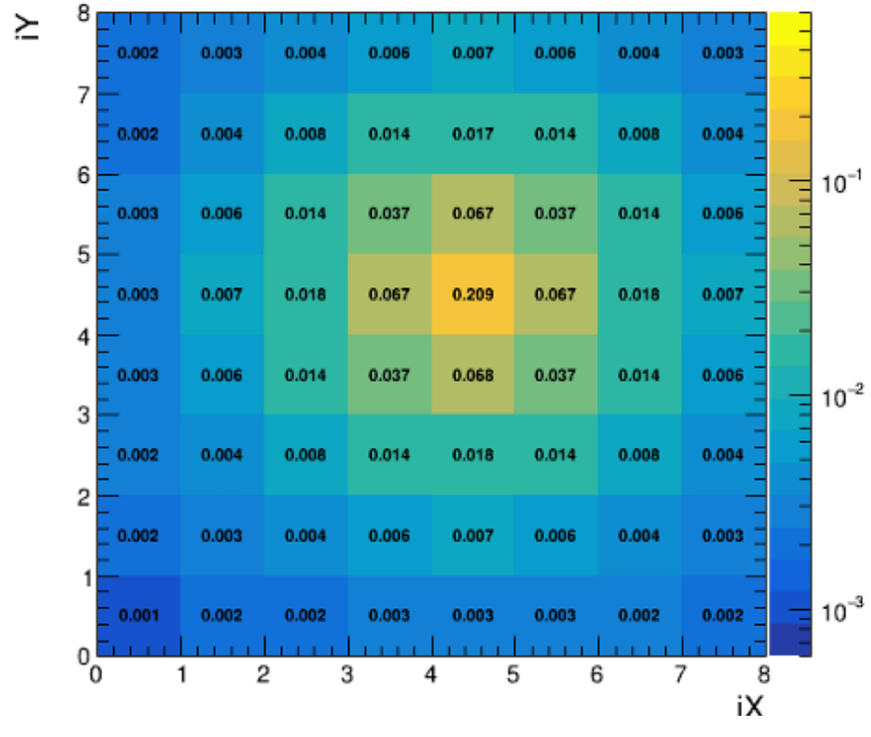


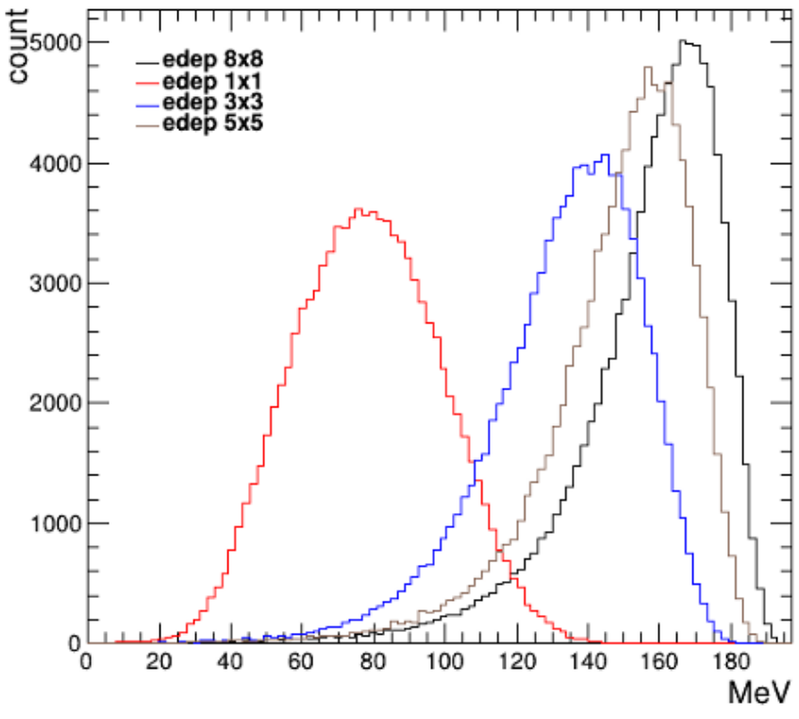
- The first round of simulation with different beam energies, $4X_0$ W absorber, and different rotation angles was done

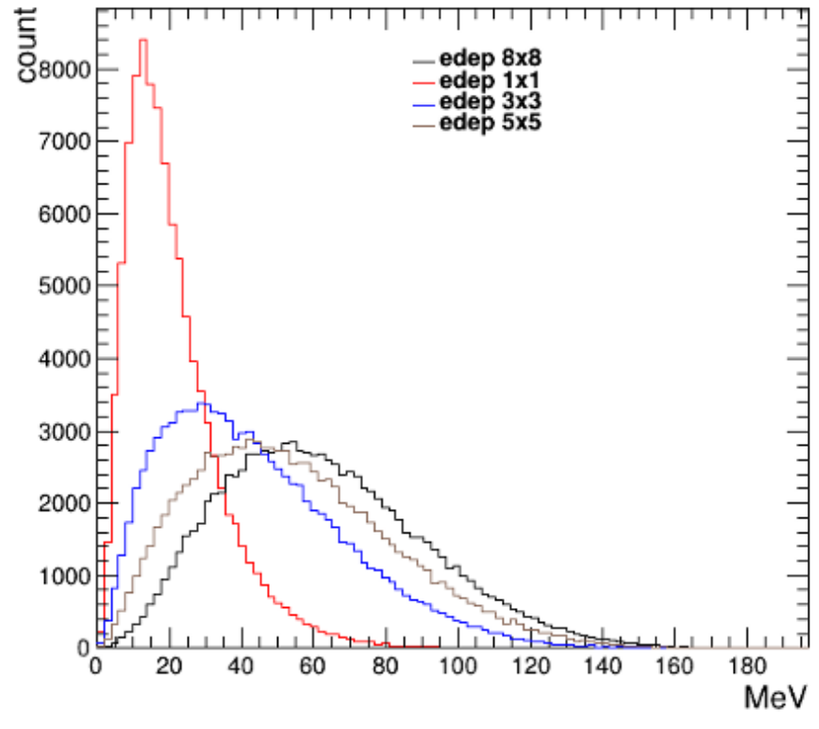
Preliminary Simulation Results

197.9 MeV positron beam with $4X_0$ W abosrbers

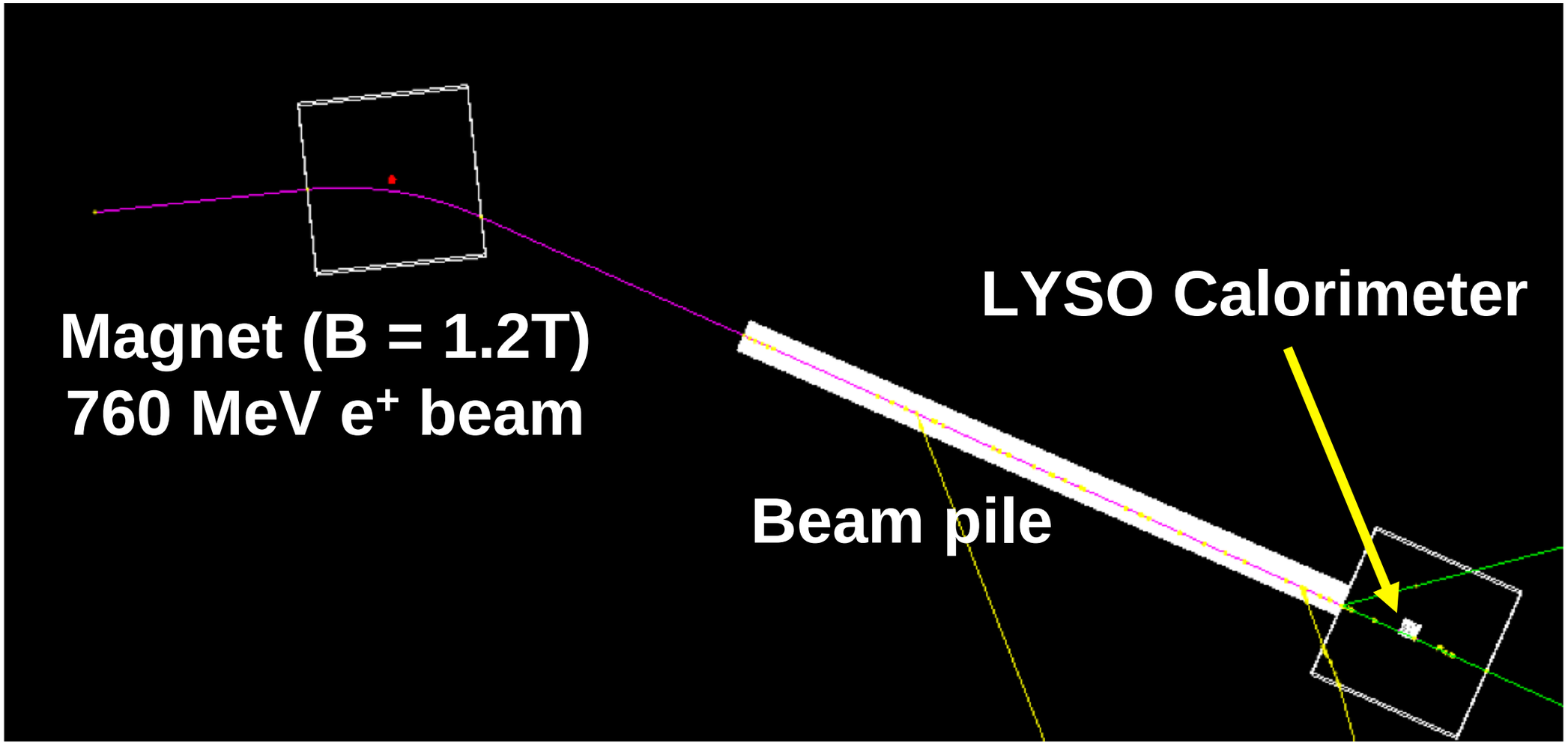






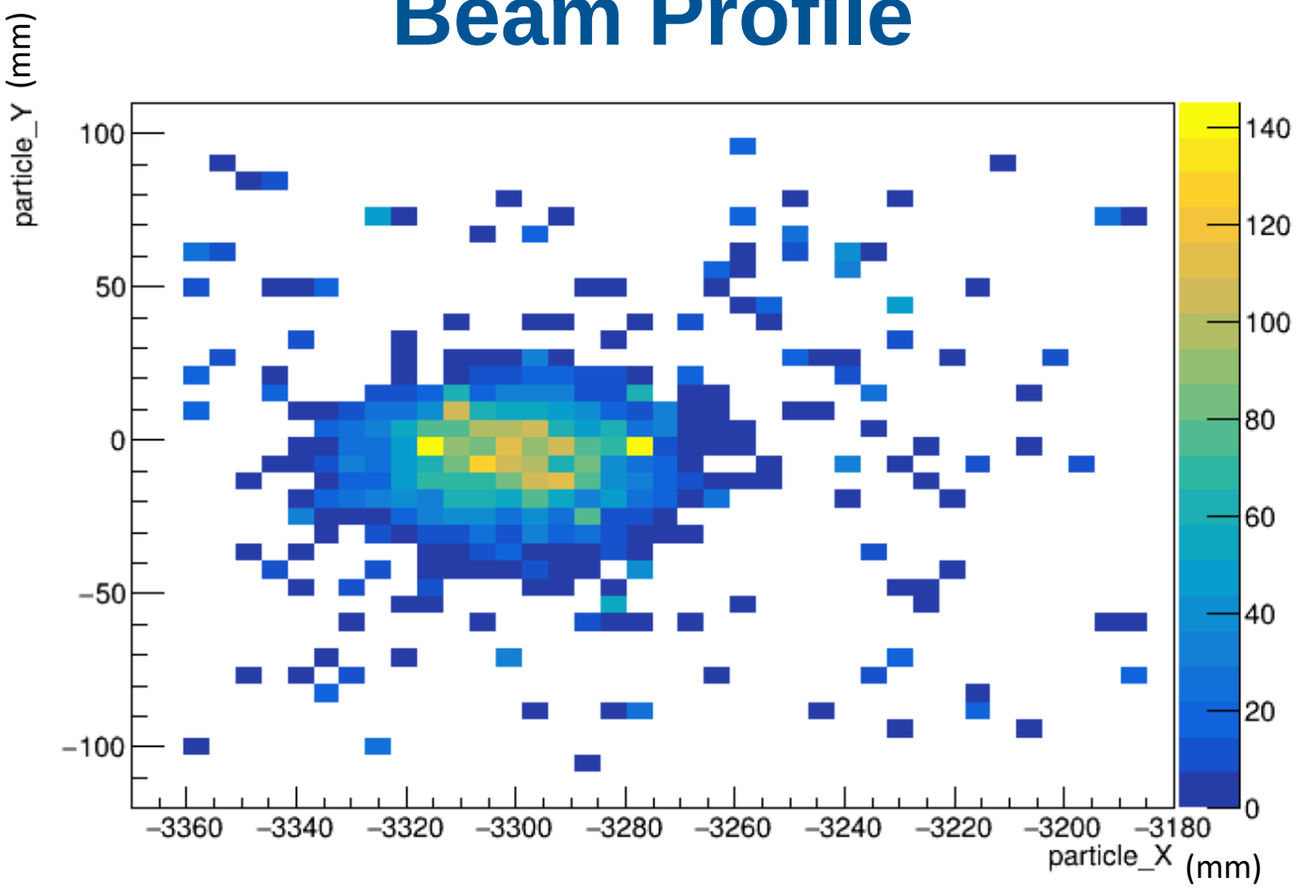


Simulation with “Realistic Beam”



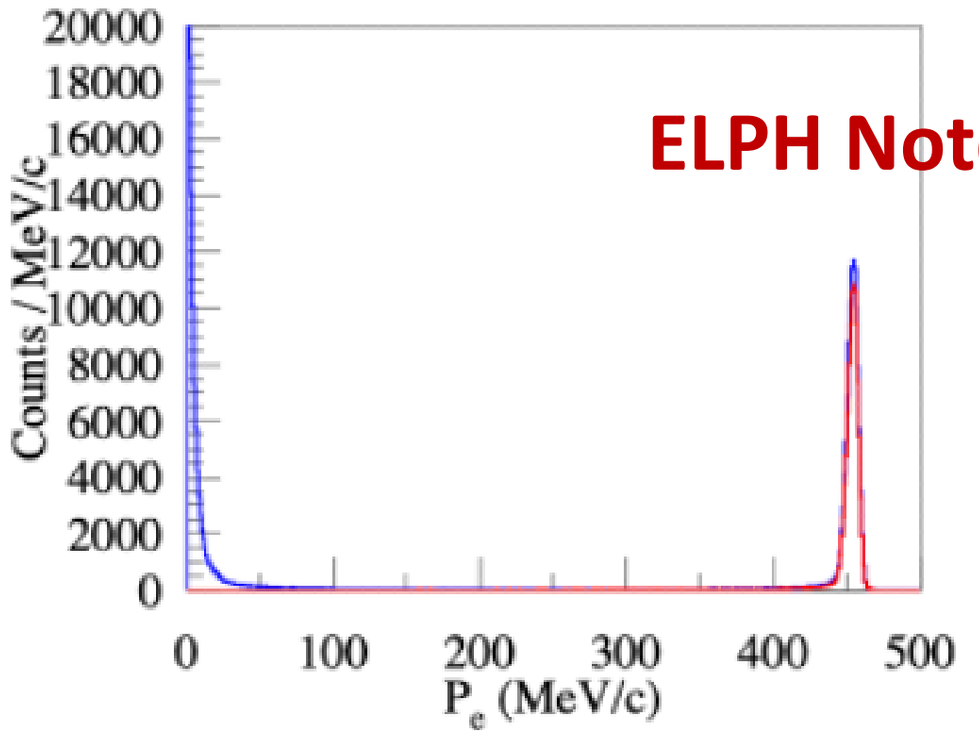
Very Preliminary Simulation Results

Beam Profile

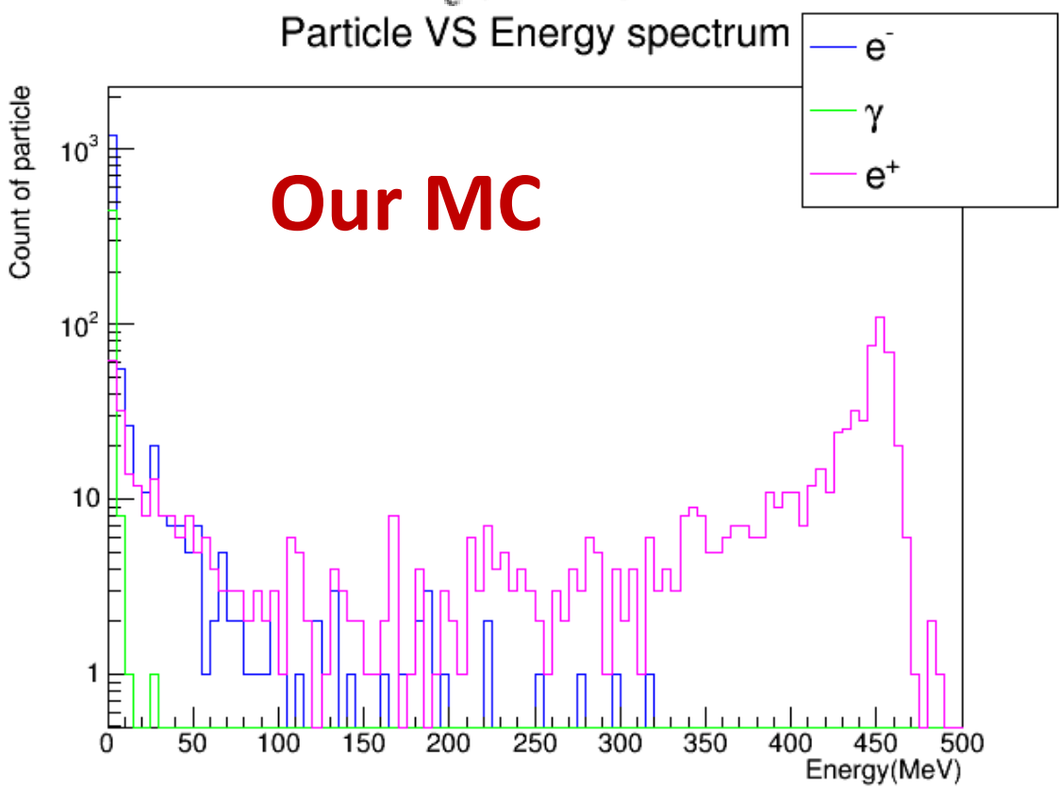


Particle Momentum

ELPH Note



Our MC



Future Plan:

- Finalize the analysis of beam test data as soon as we can
- Target at another beam test at ELPH in October
  - LYSO + APD
  - $PbWO_4$ + SiPM
  - GAGG + APD
  - Combine with other detectors
- Perform simulation studies for the final ZDC EMCal design

Summary

- We had the first beam test for the prototype of ePIC ZDC EMCal with LYSO+SiPM at ELPH
- Both data analysis and simulation are on-going
- We hope to be able to test different combinations of crystals and photodetectors in October