CANDY's resolution and positioning study using geant4

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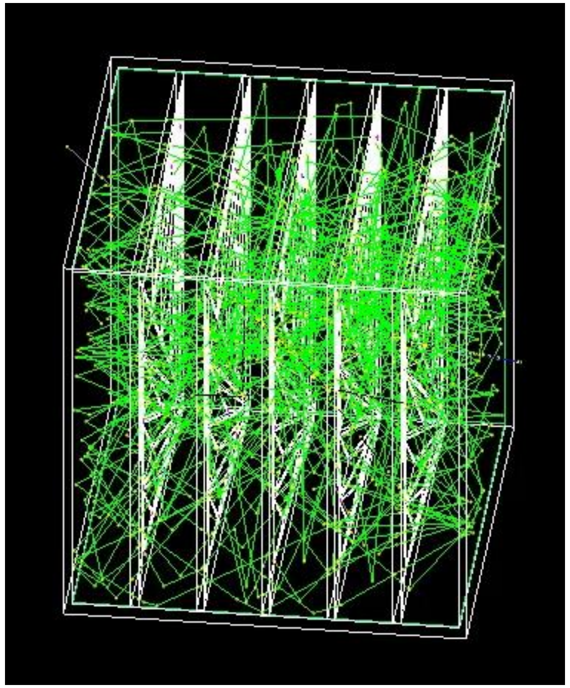
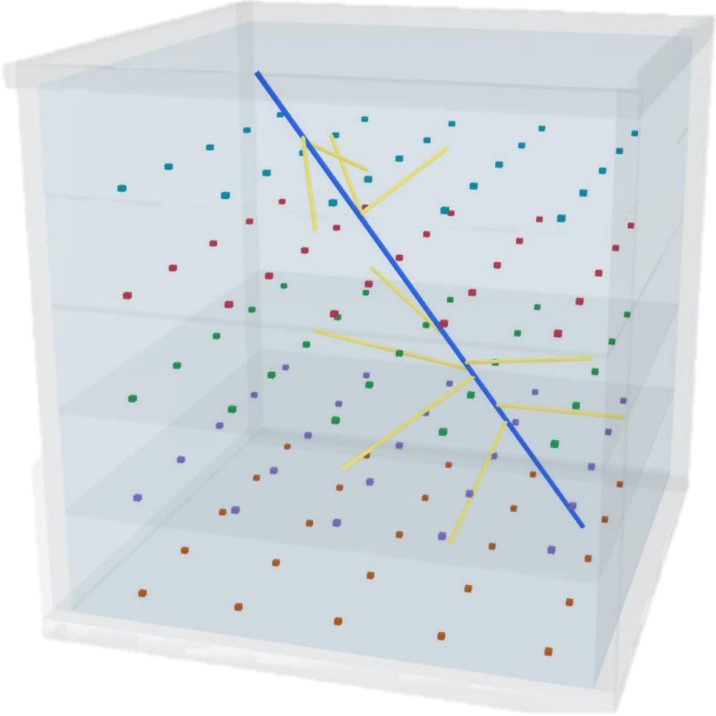
2025 CPNR

What is CANDY

- CANDY stands for CAU Neutrino Detection Yolk.
- The purpose of CANDY is to develop a detector with good positioning capability.

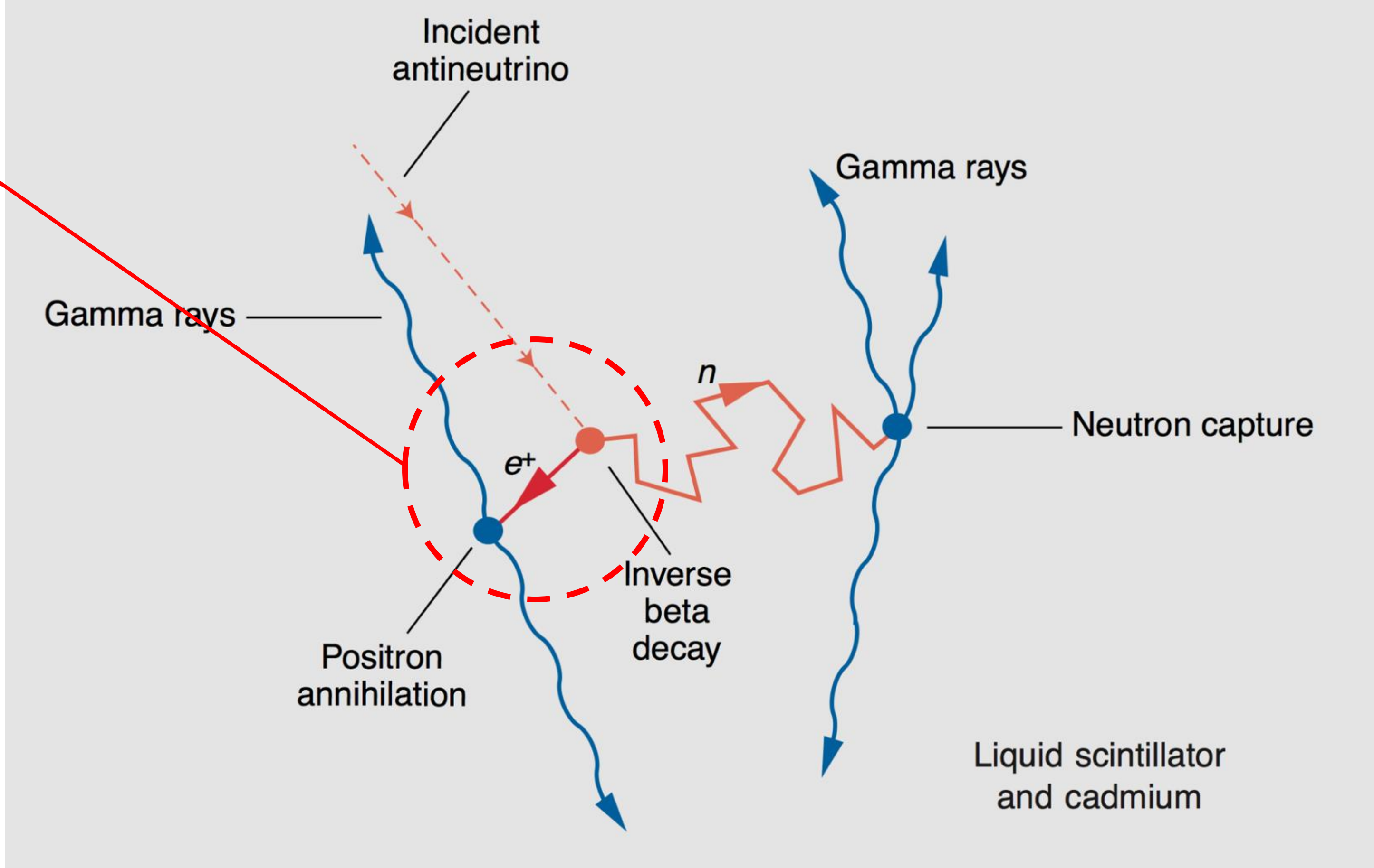




Why good positioning is necessary?

Positron scintillation has not yet been separated from other signals.

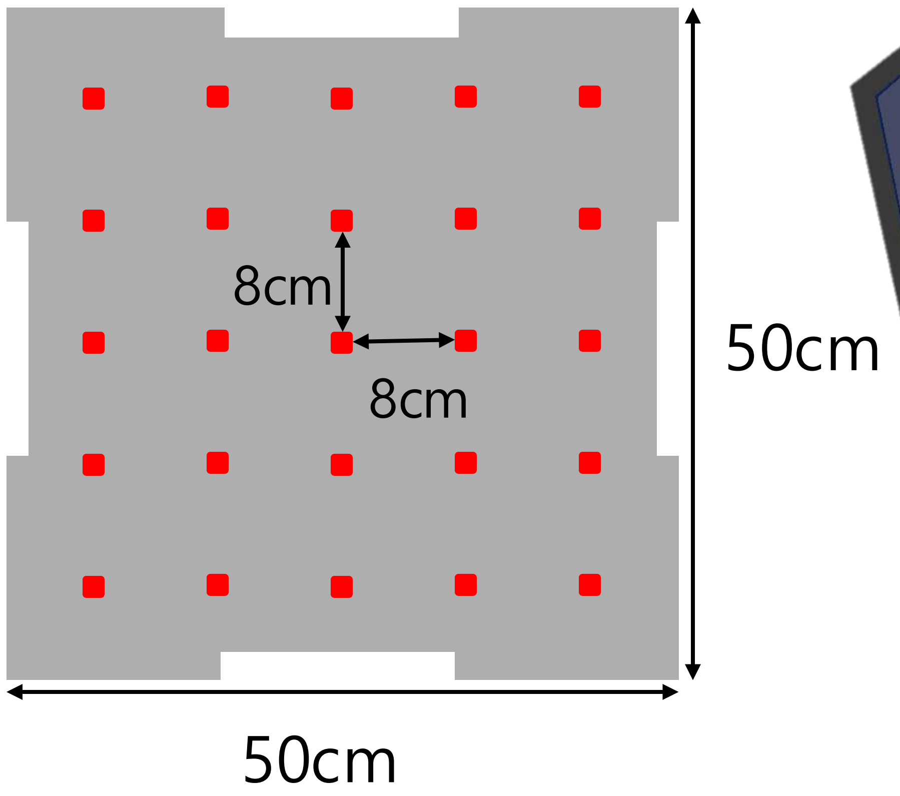
- Therefore, we designed the CANDY detector for good positioning and study it through Geant4 simulations.

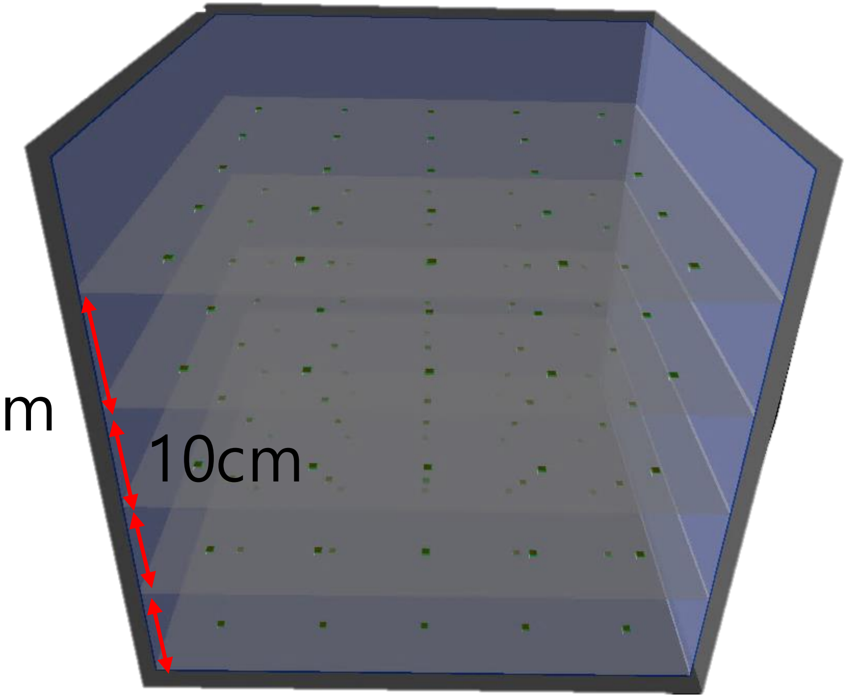


Los Alamos Science, Number 25 -- 1997: Celebrating the neutrino

The structure of CANDY in Simulation

Each acrylic plate contains 25 SiPMs.

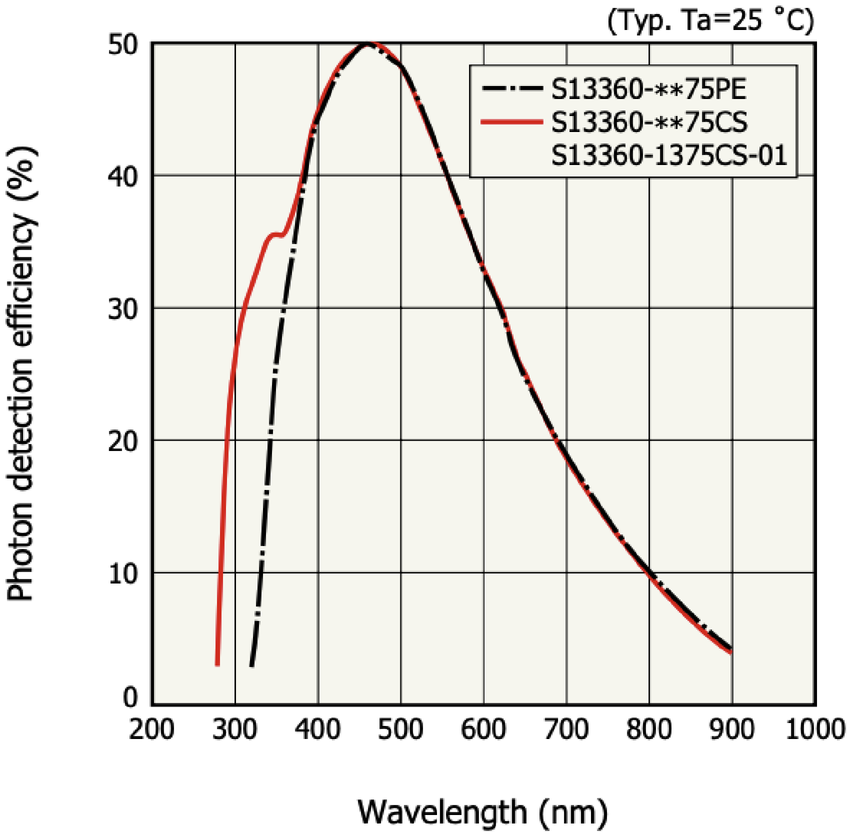




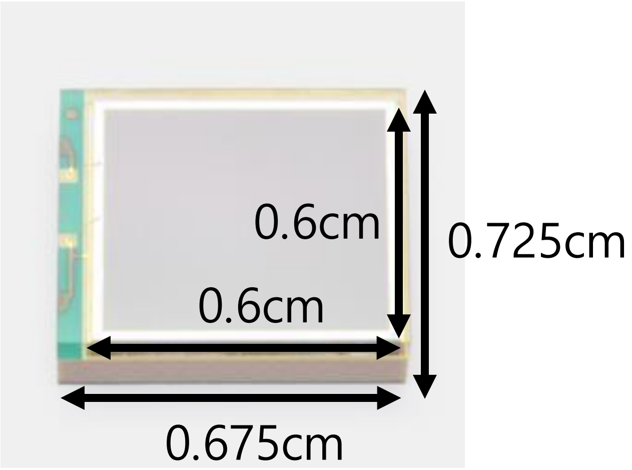
- The overall size is 50 cm × 50 cm × 50 cm
- The spacing between SiPMs is 8 cm × 8 cm × 10 cm.
- A total of 125 SiPMs are used.

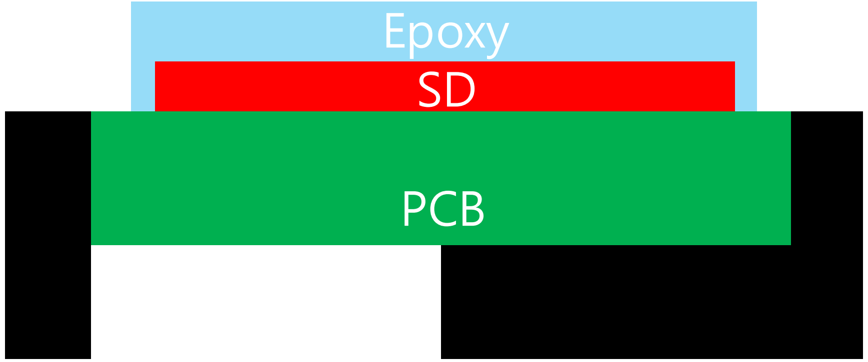
The structure of CANDY in Simulation

SiPM quantum efficiency was applied.



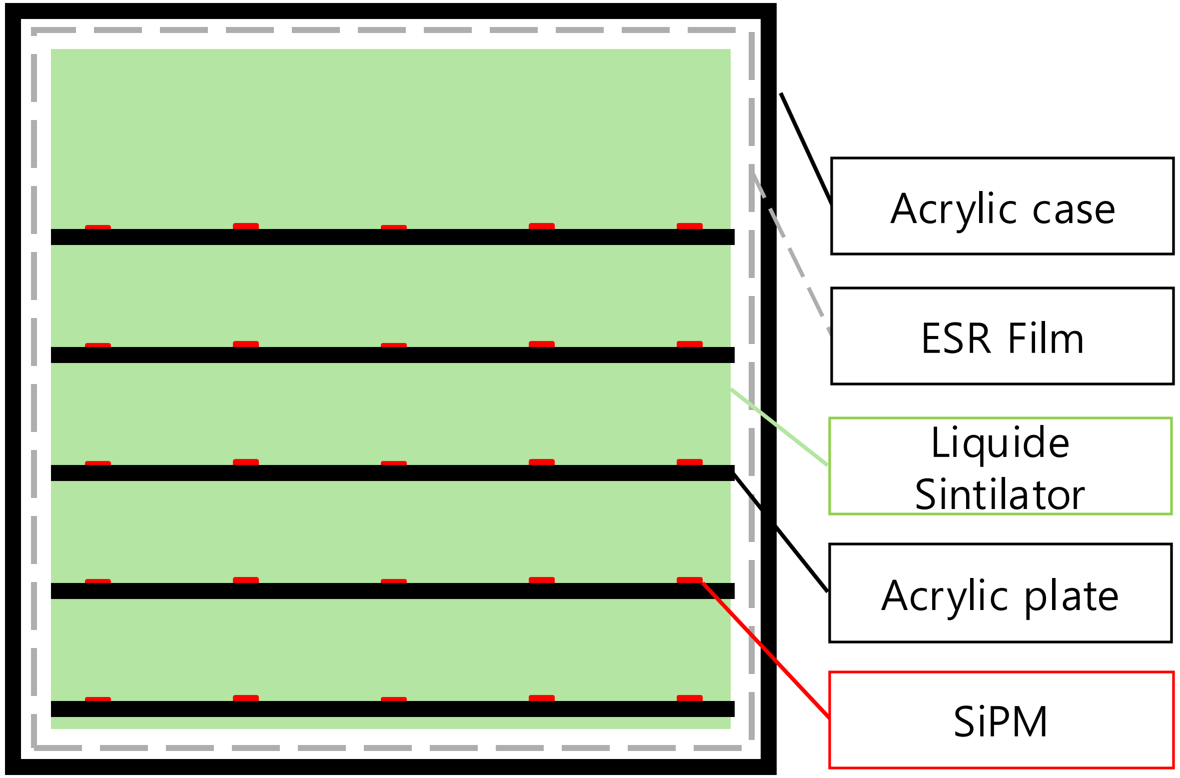
Hamamatsu MPPCs for precision measurement





Hamamatsu SiPM
S13360-6075PE

The structure of CANDY in Simulation

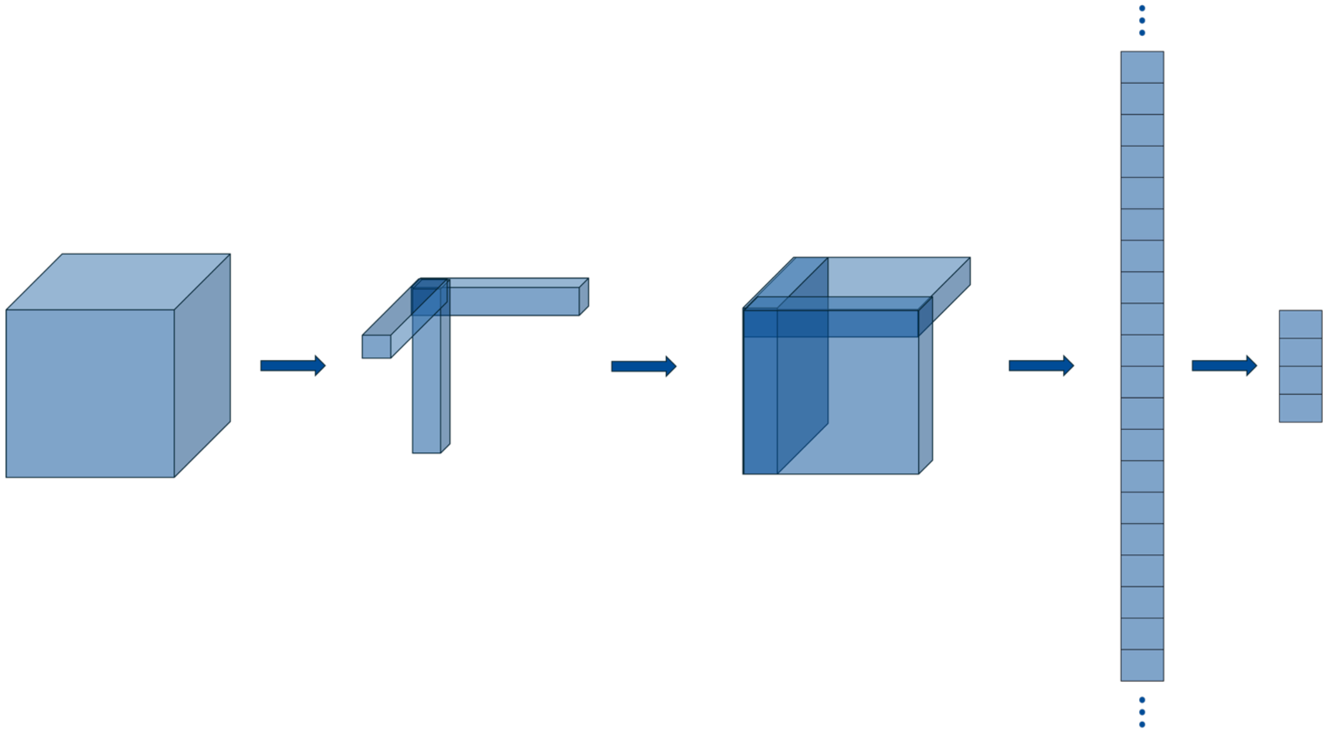


- LS : LAB-based liquid scintillator.
- Attenuation length : 10 m
- scintillation efficiency : 3,000 ~10,000 photons/MeV

Because we don't know actual performance of LS. So we simulated various options

We used CNN to reconstruction

- The model was designed to effectively learn the geometric characteristics of the CANDY detector during training.



3D structure

↓

axis information

↓

plane information

↓

predicted parameters

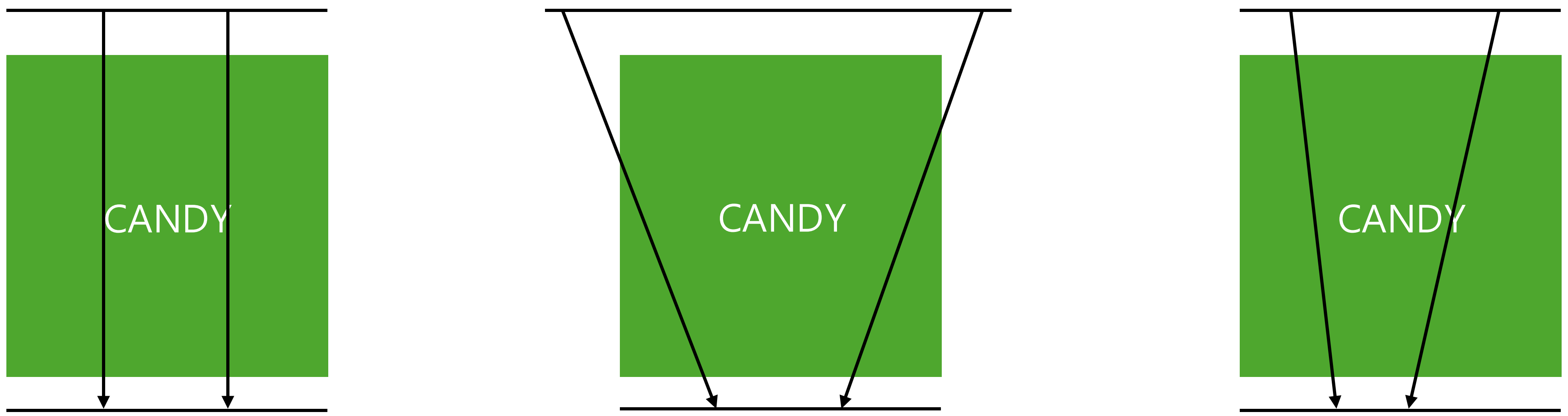
CNN (Convolutional Neural Network)

- CNN is a type of deep learning model that recognizes spatial patterns input data such as images or 3D structures.

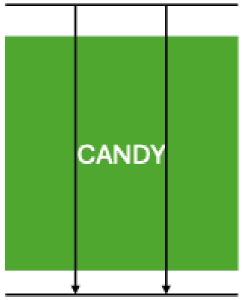
- It automatically extracts local and global spatial features.
- It works well with grid data (such as detector arrays).
- It can learn the relationship between photon distributions and particle positions effectively.

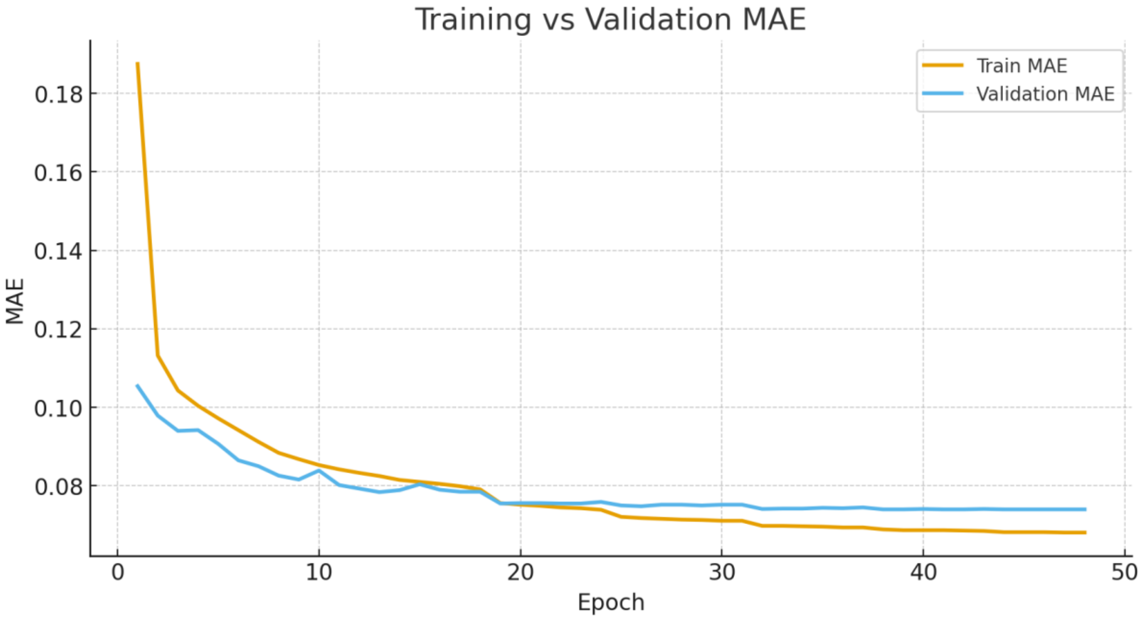
We simulated several cases

1. Muons entering vertically
2. Muons entering from various directions
3. Muons entering from the top surface to the bottom



Entering vertically result

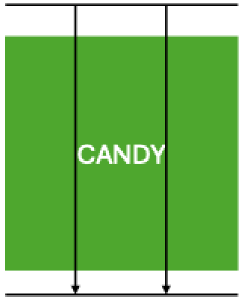


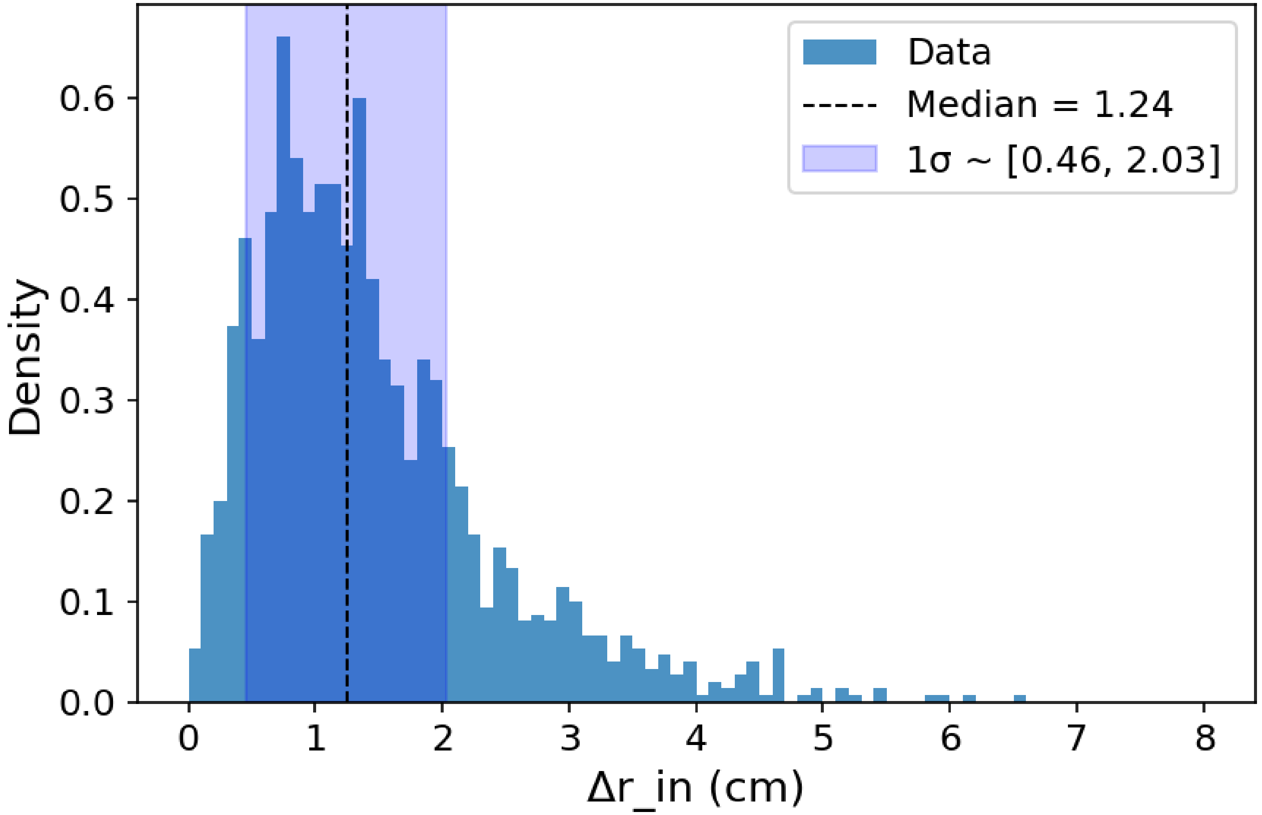


Not Over-Fitting

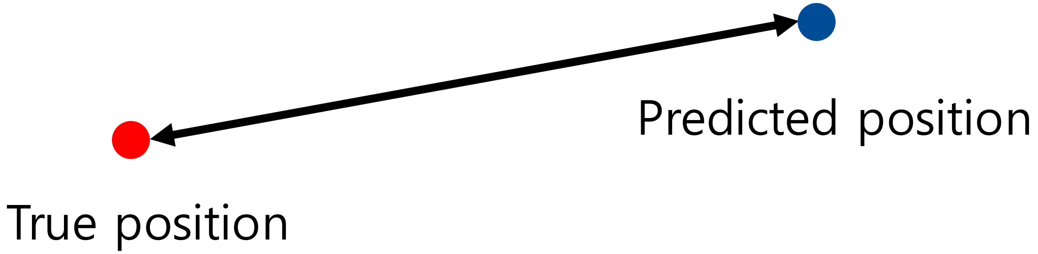
- 20,000 events
- The train/validation/test split was 0.7 / 0.15 / 0.15.
- scintillation efficiency : 3000 photons/MeV

Entering vertically result

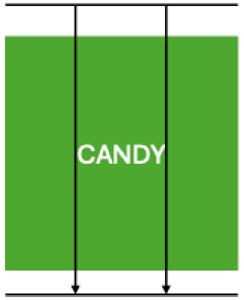


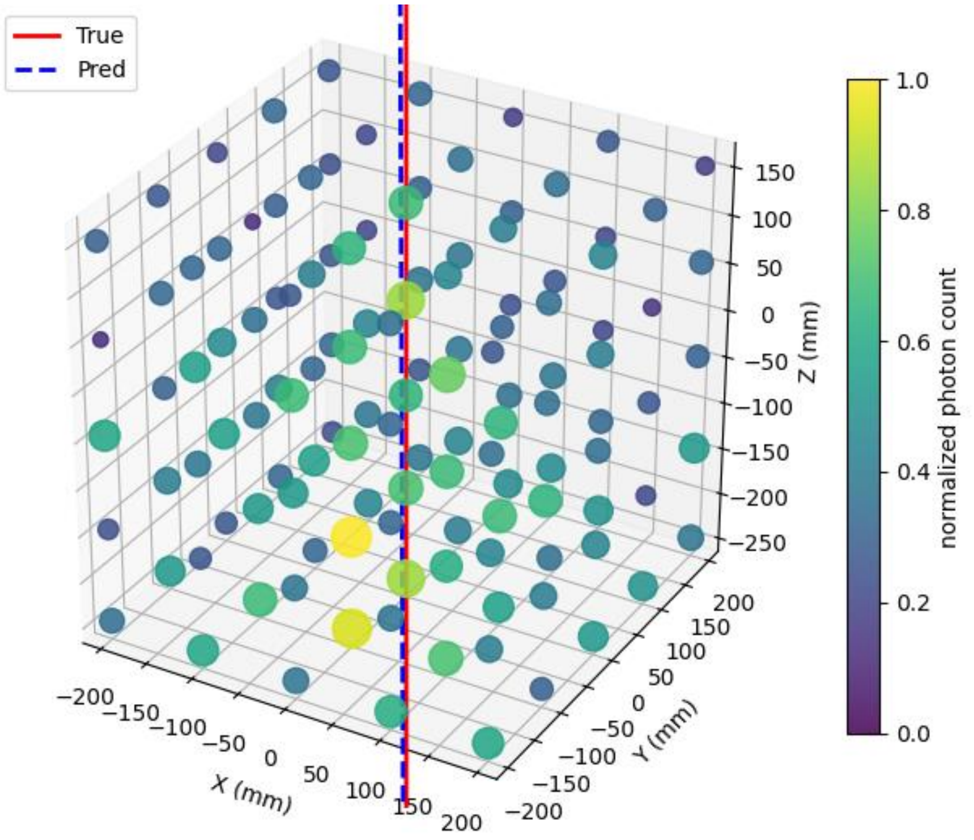


Δr Resolution: 1.24±0.79cm



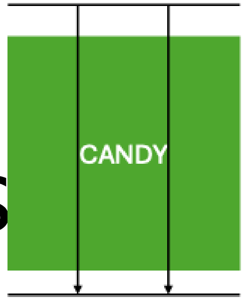
Entering vertically : well-predicted event

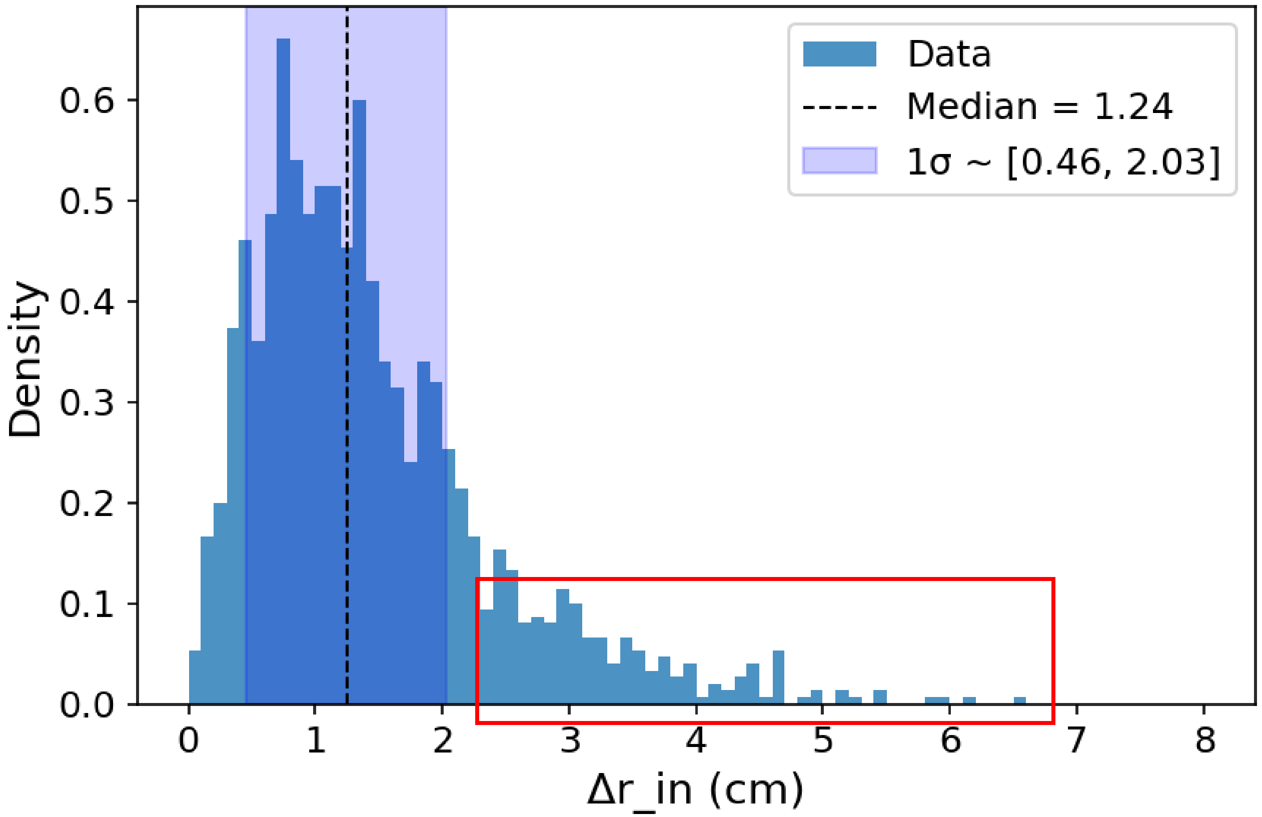




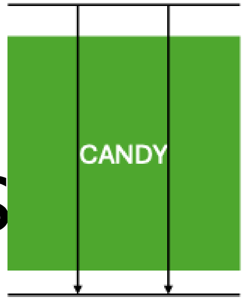
- Red line: actual muon path
- Blue dashed line: CNN predicted path
- Color and sphere size: photon count

Entering vertically : poorly predicted events

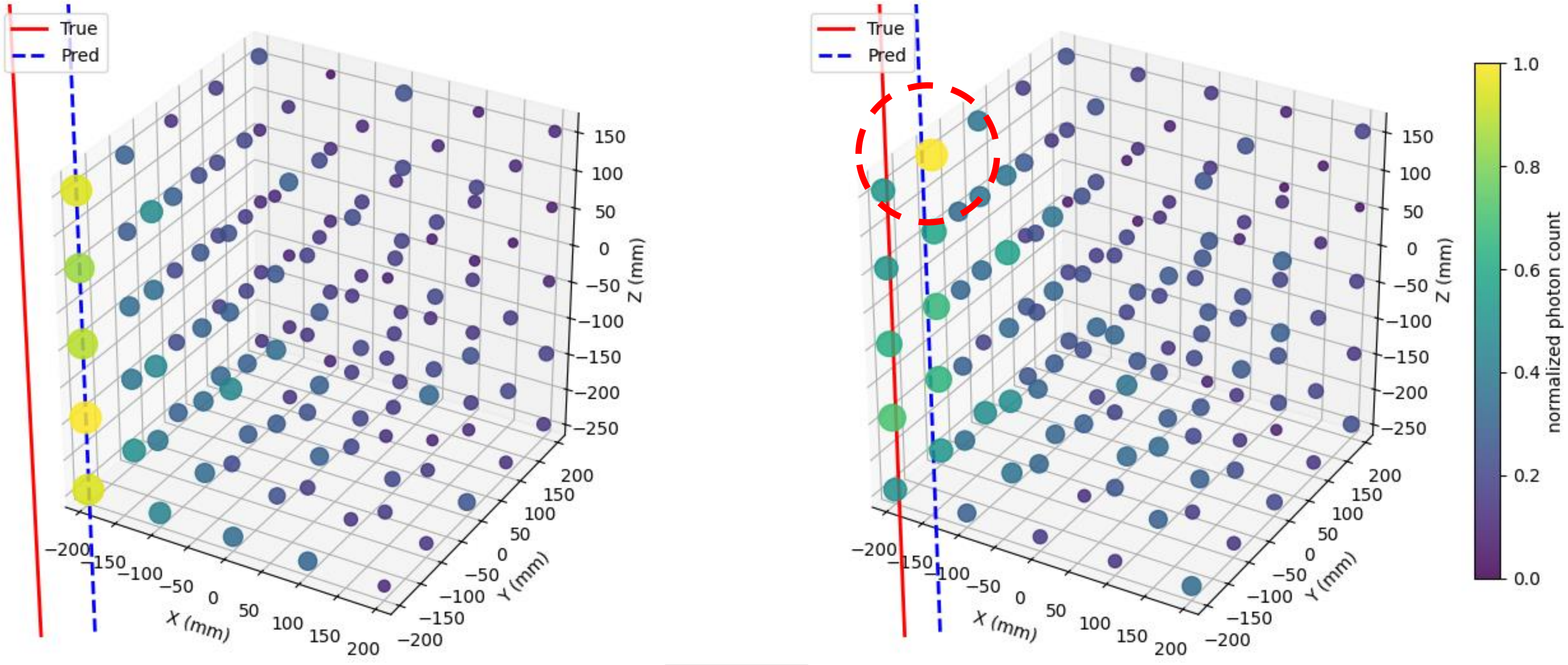




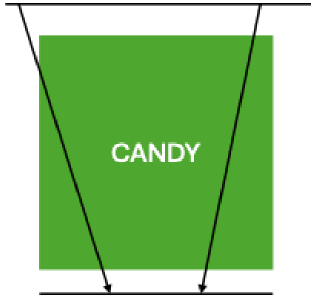
Entering vertically : poorly predicted events

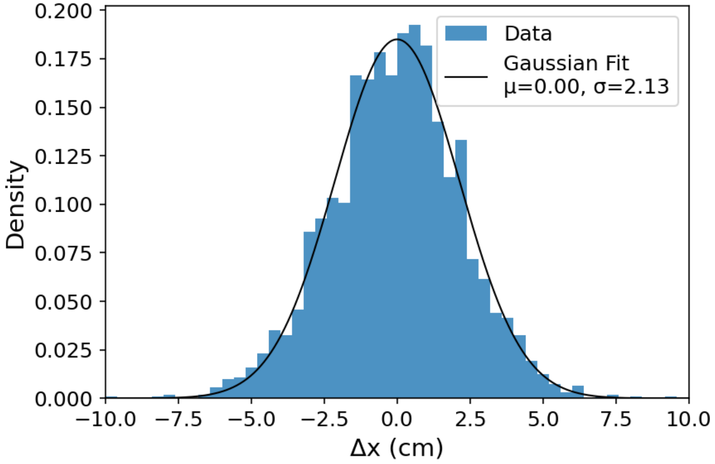


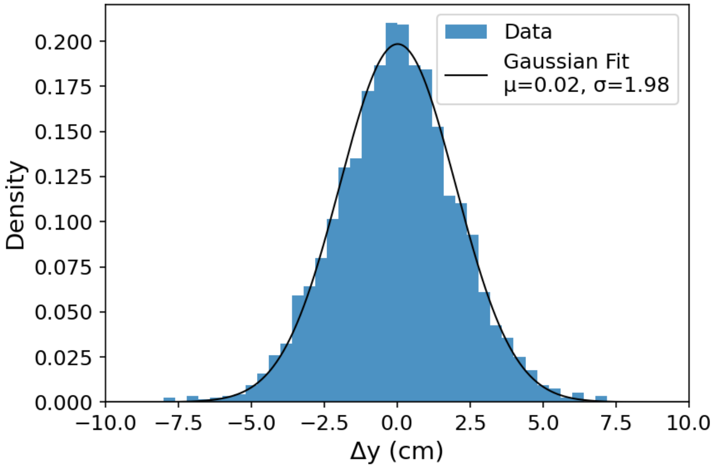
- muon enters near the edge of the detector.
- higher photon counts were not recorded at the actual path

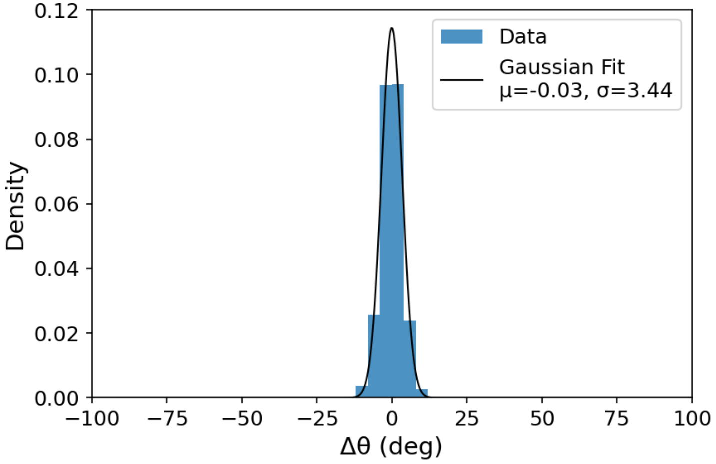


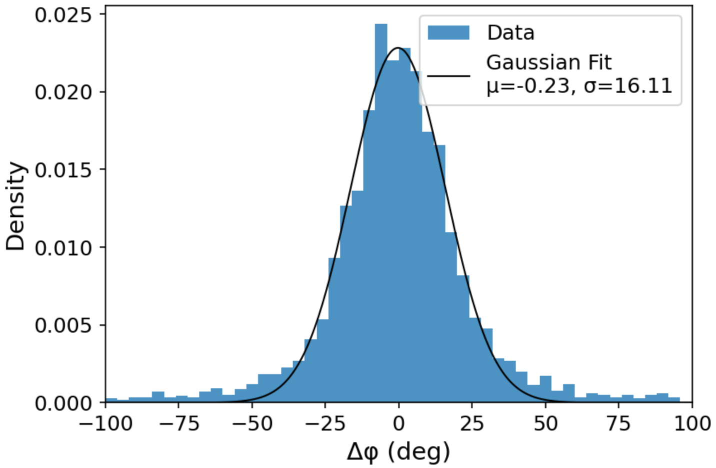
Entering from various directions result









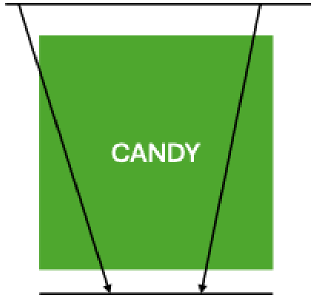


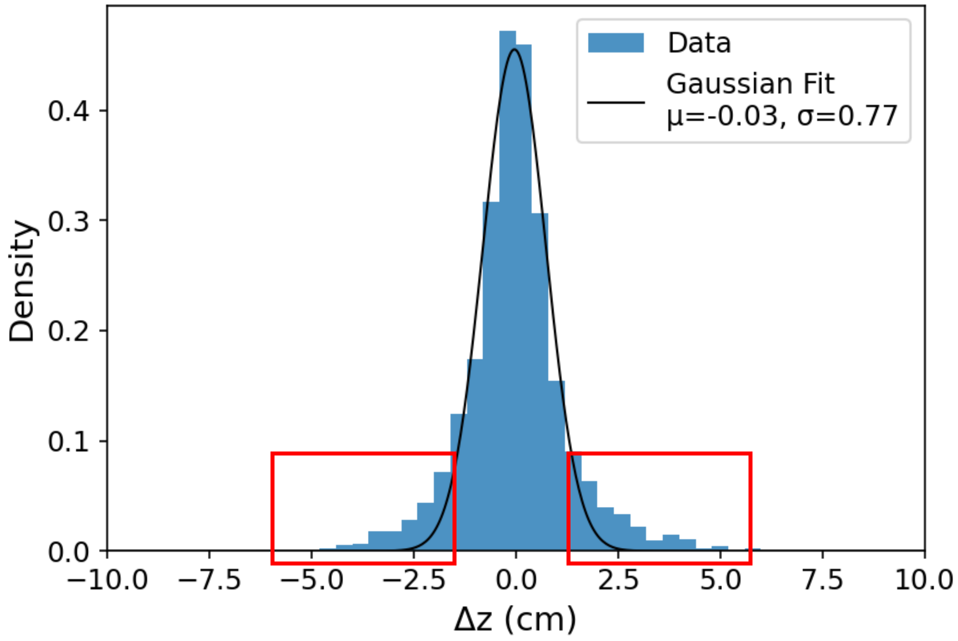
- Δx σ: 2.13cm, Δy σ : 1.98cm
- $\Delta\theta$ σ: 3.44°, $\Delta\phi$ σ : 16.11°

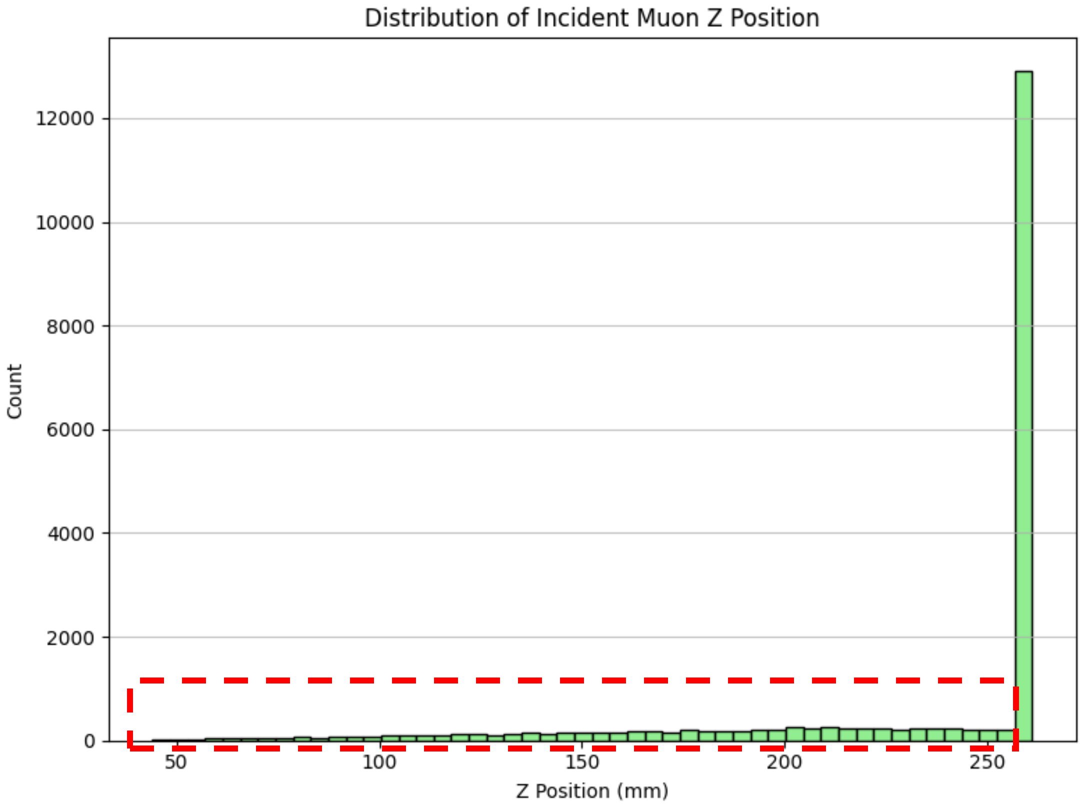
- The range of θ is small because the muon must pass through the CANDY detector.

- Since φ can take any angle, its error is relatively large.

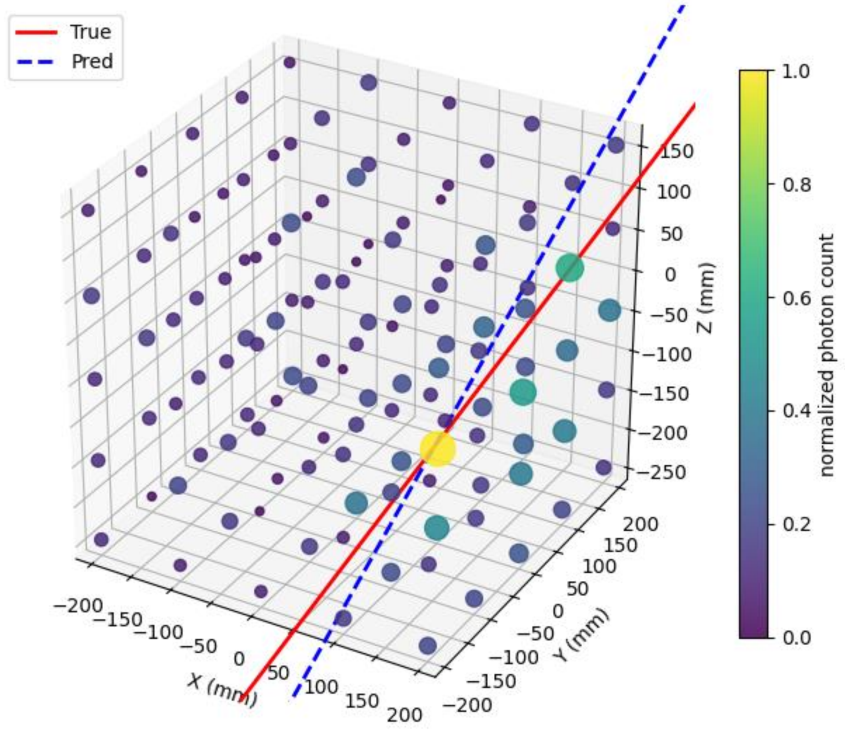
Entering from various directions result

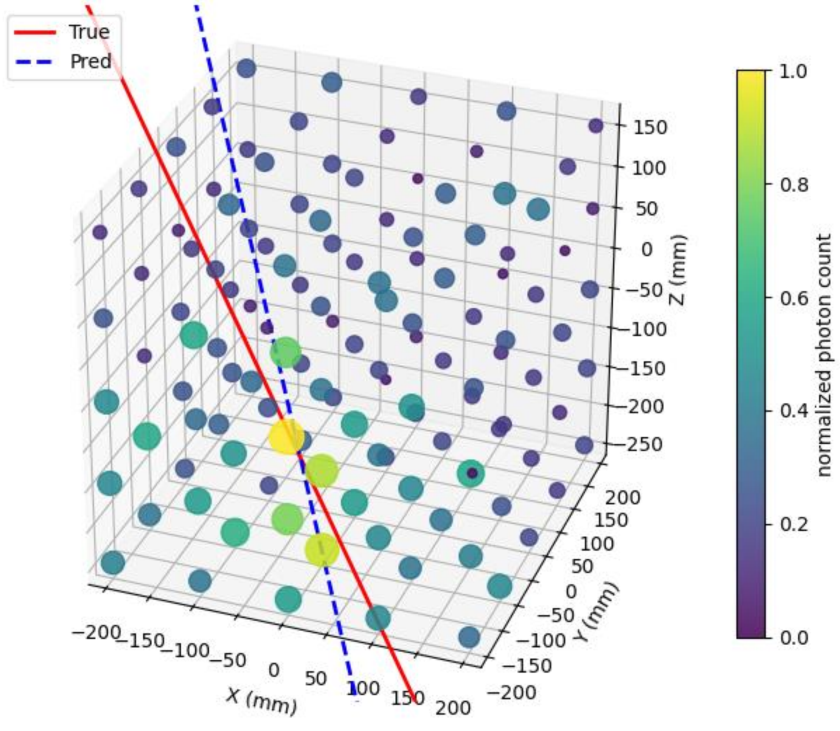


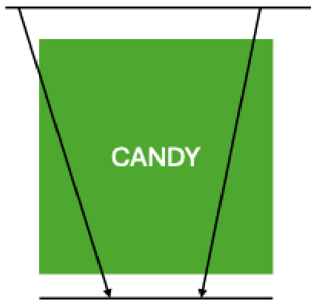




They account for about 35% of all events in this case.

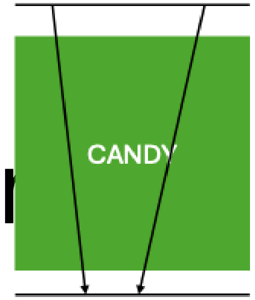


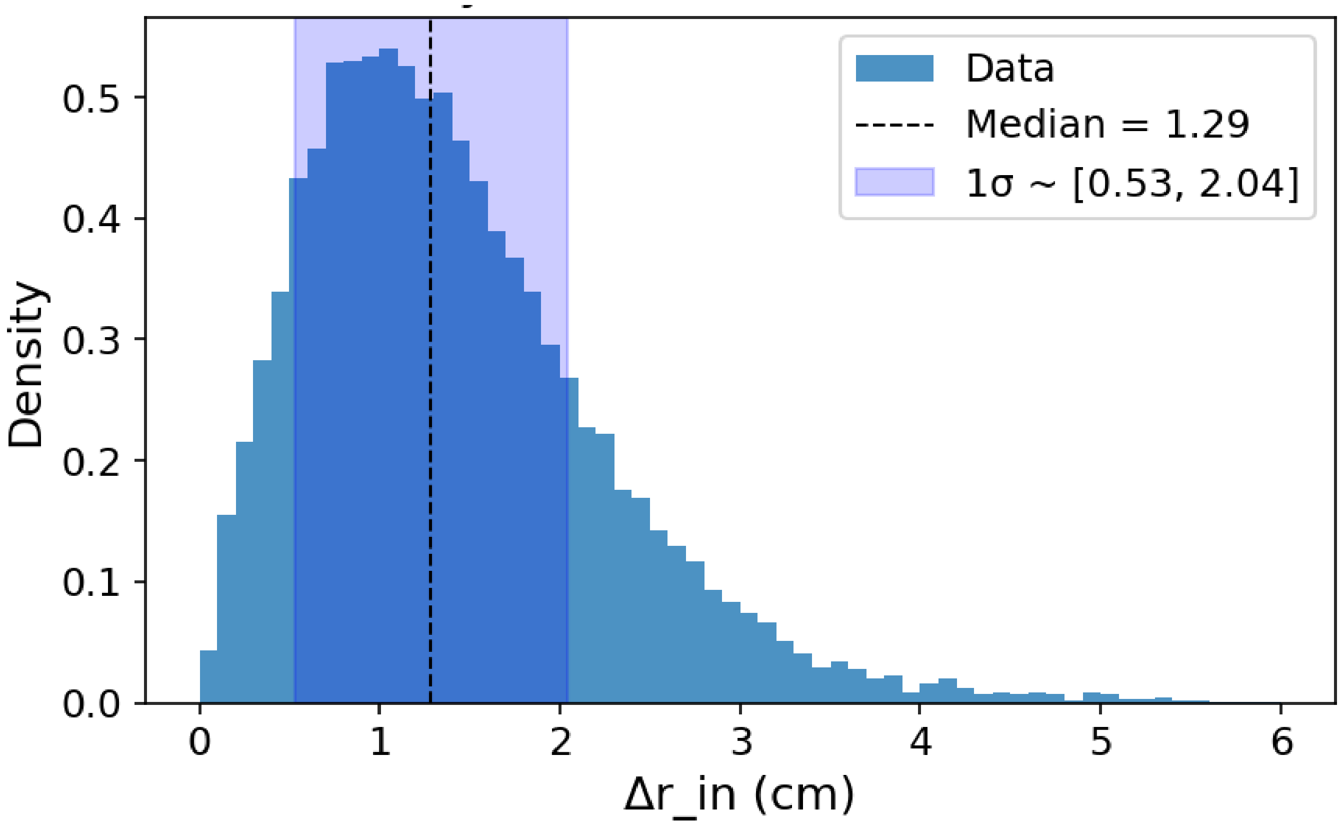




- the model predict that the muons entered from a slightly higher or lower position than their actual entry paths

Entering from the top surface to the bottom

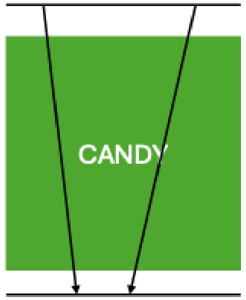


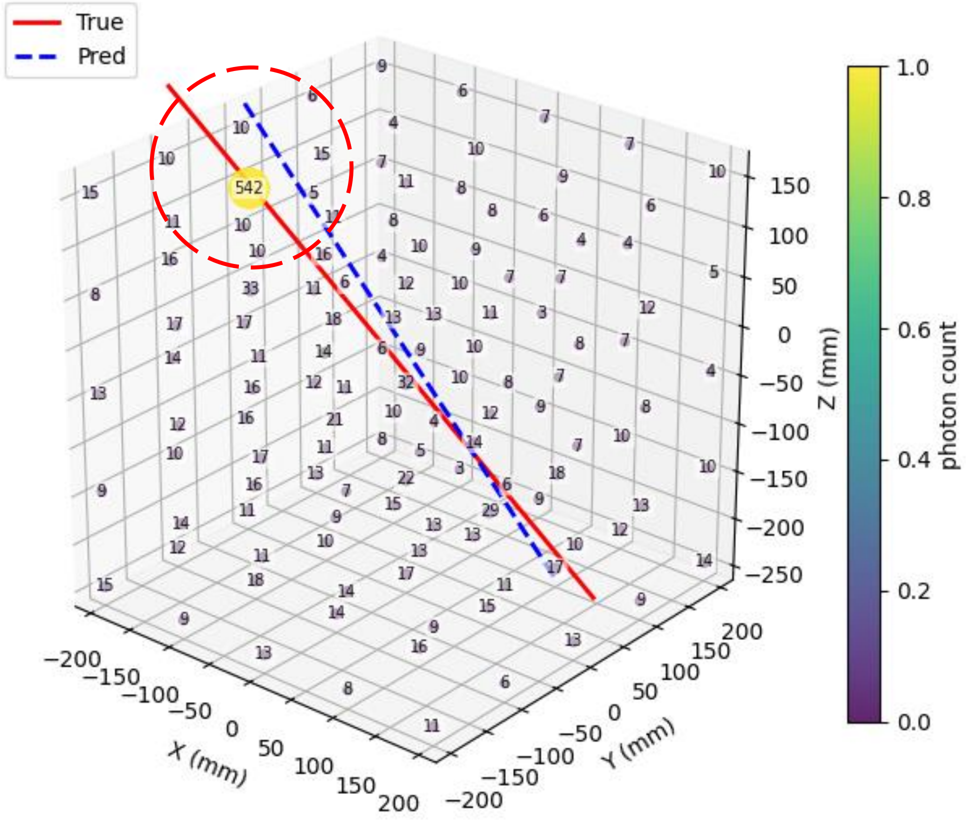


*Δ*r Resolution: 1.29±0.75cm

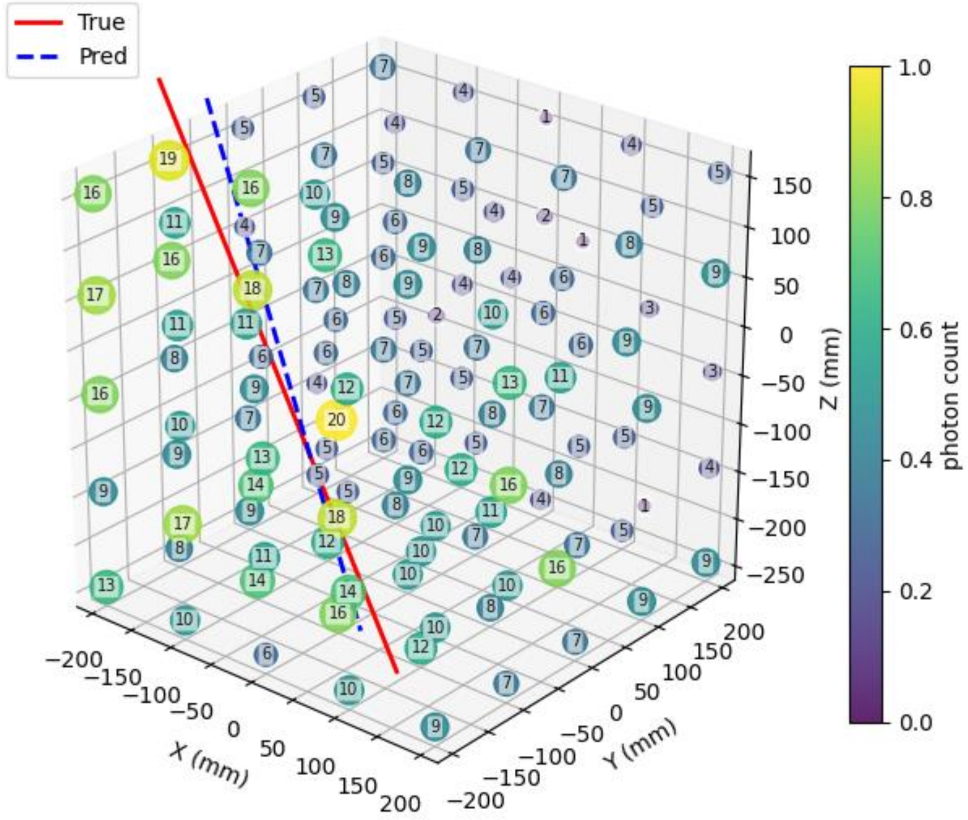
- 100,000 events
- The train/validation/test split was 0.7 / 0.15 / 0.15.
- scintillation efficiency : 6000 photons/MeV

Greedy Photon Count



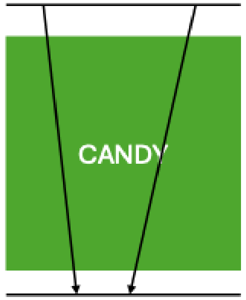


Special Case

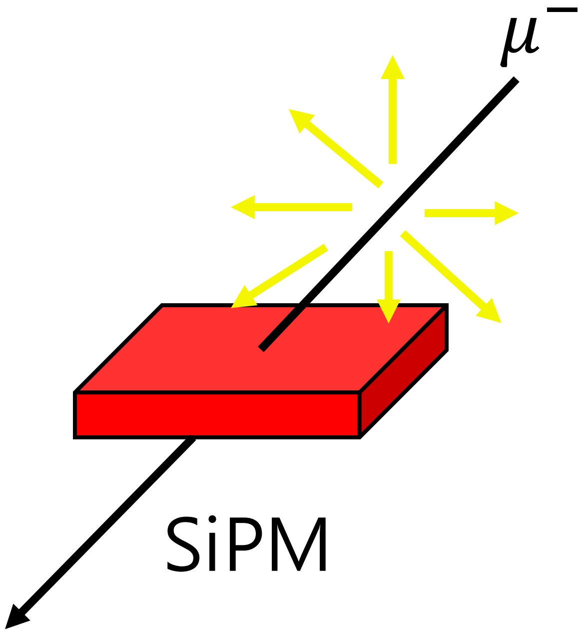


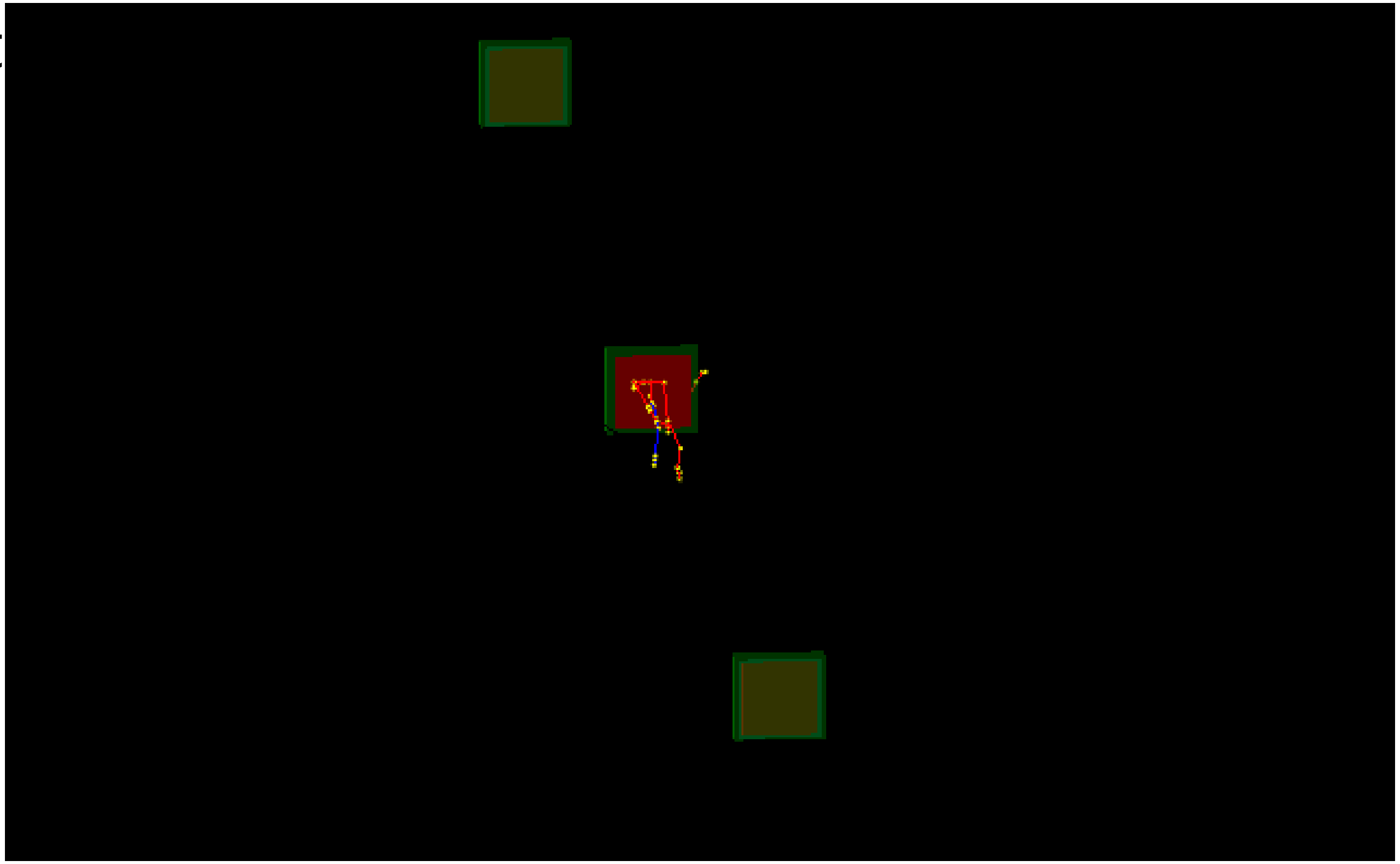
Normal Case

Muon passed directly through an SiPM



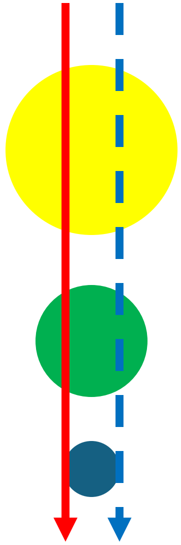
Made a Greedy Photon Count



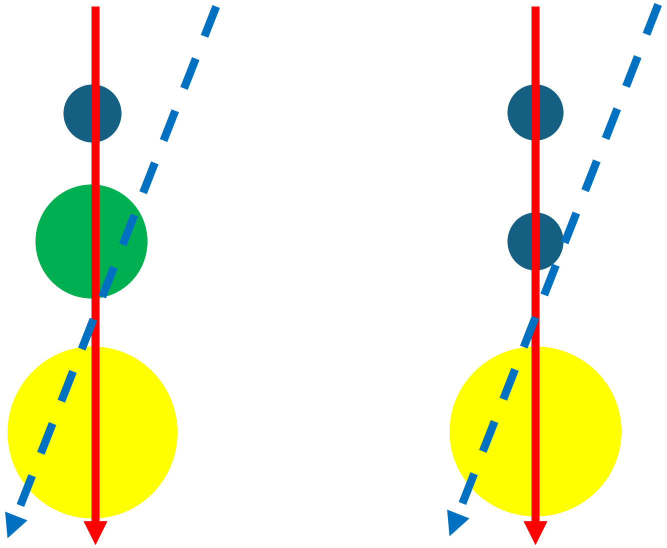


Study summary

- SiPM's quantum efficiency, sometimes the model cannot predict the muon's path correctly. >> Main factor
- Greedy Photon Counts occur with low probability. >> About 0.5% of all events

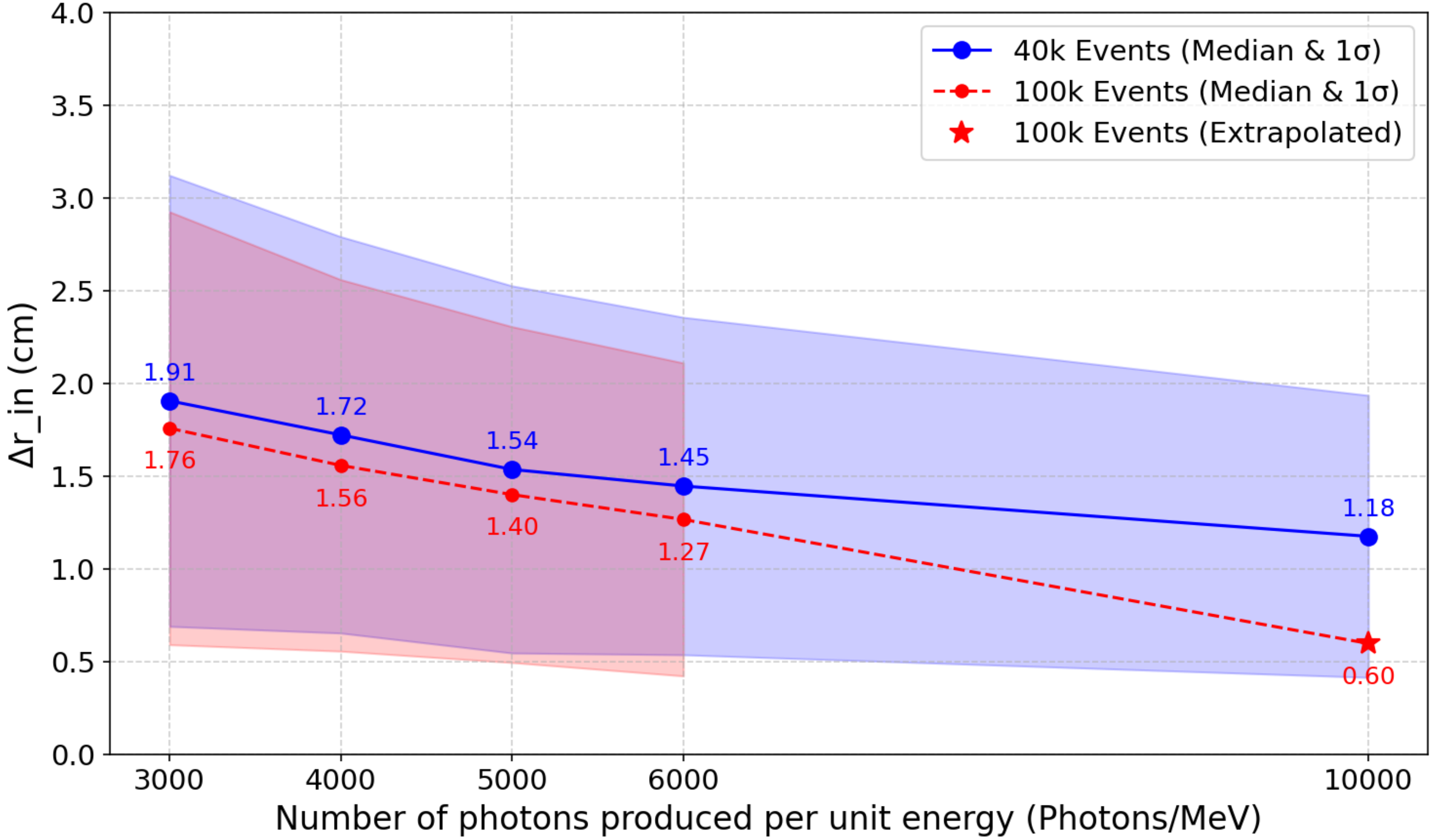


Ideal case

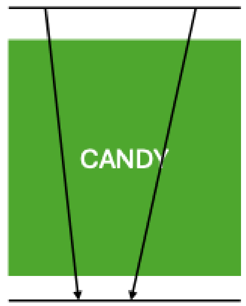


Non-ideal case

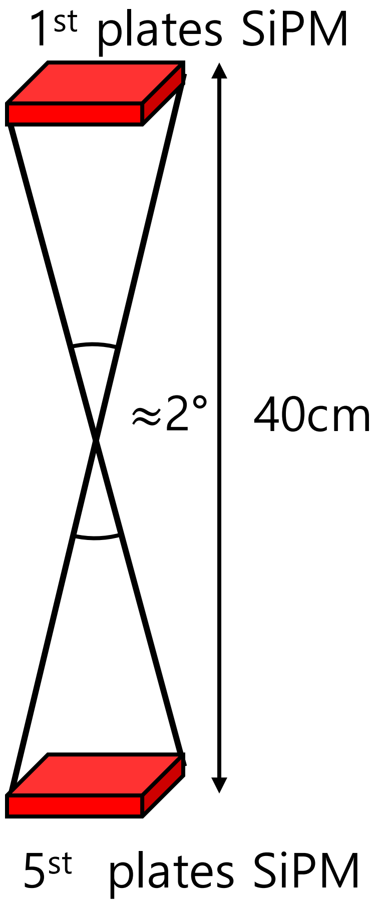
Increases the scintillation efficiency.



- Reduce random errors caused by quantum efficiency.



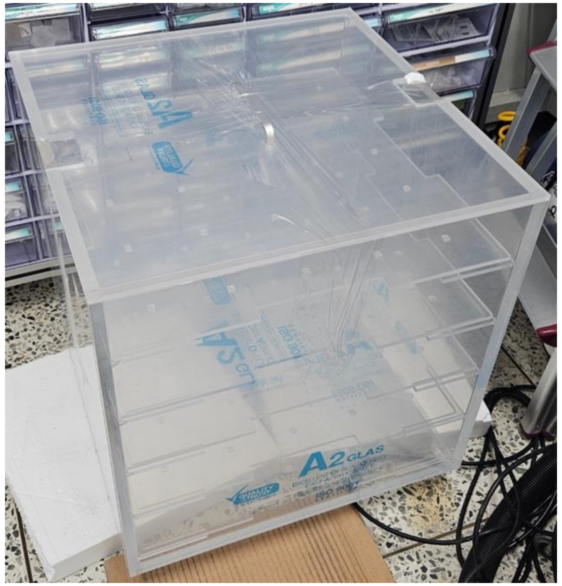
Using Greedy Photon Counts for Position Reconstruction



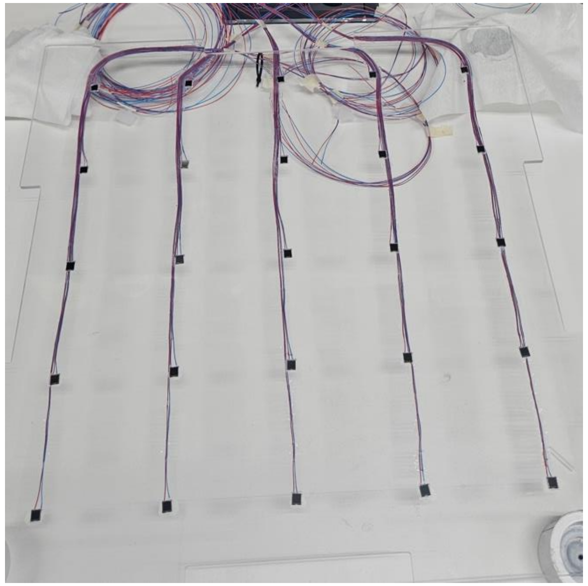
- Since the SiPM area is small, it might be possible to use Greedy Photon Counts for position reconstruction.

- However, it is uncertain whether such events actually occur in real data.

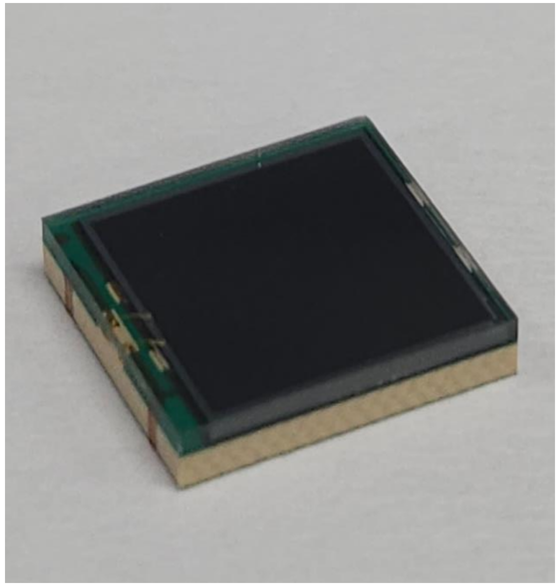
Current progress of the CANDY



Acrylic Box
50x50x50 (cm)



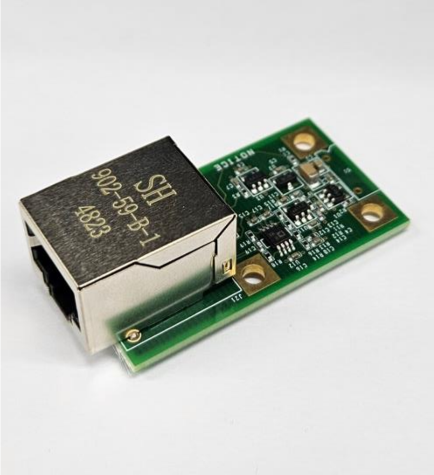
Acrylic Plate x 1
50x50x0.5 (cm)

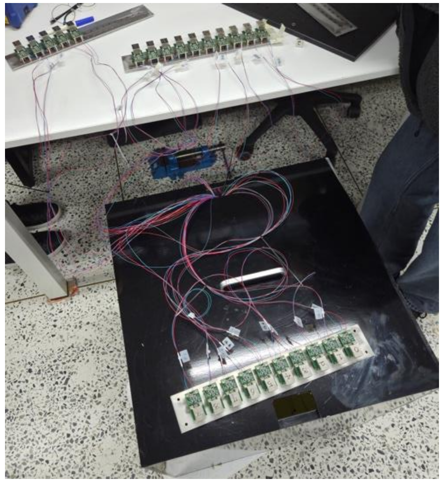


SiPM x 25
6.75x7.25x1.5 (mm)
(HAMAMATSU S13360-6075PE)

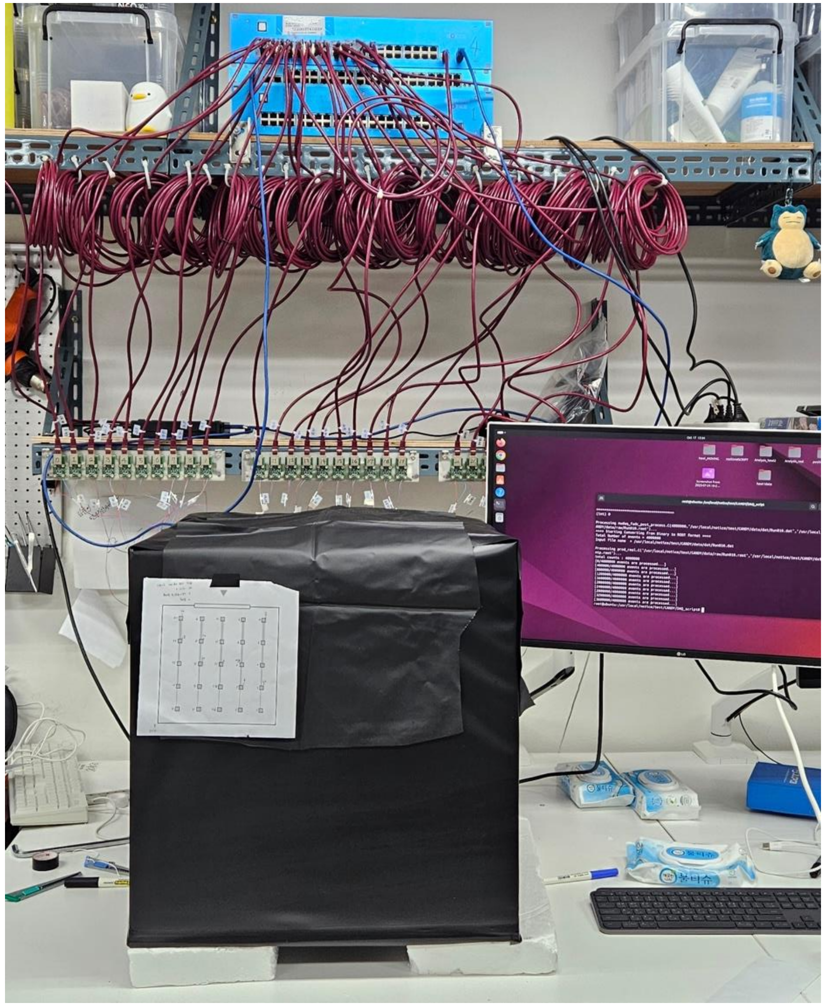
Liquid Scintillator
17L
(LAB-based, used in COSINE100)

Current progress of the CANDY

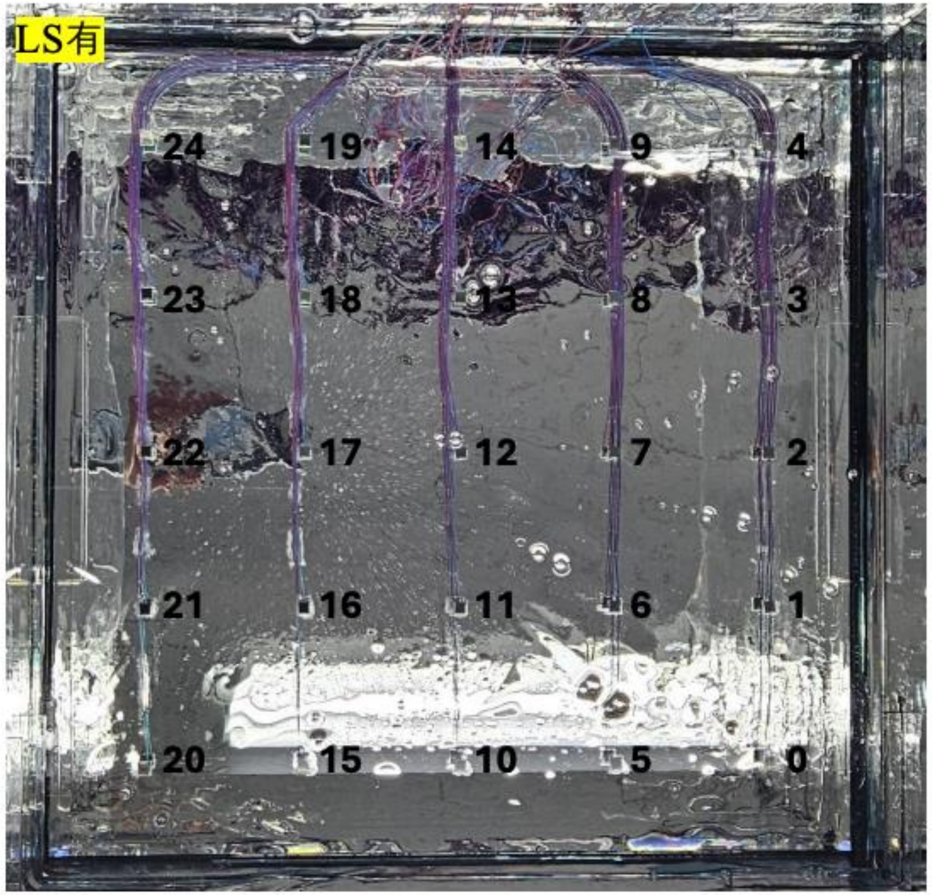


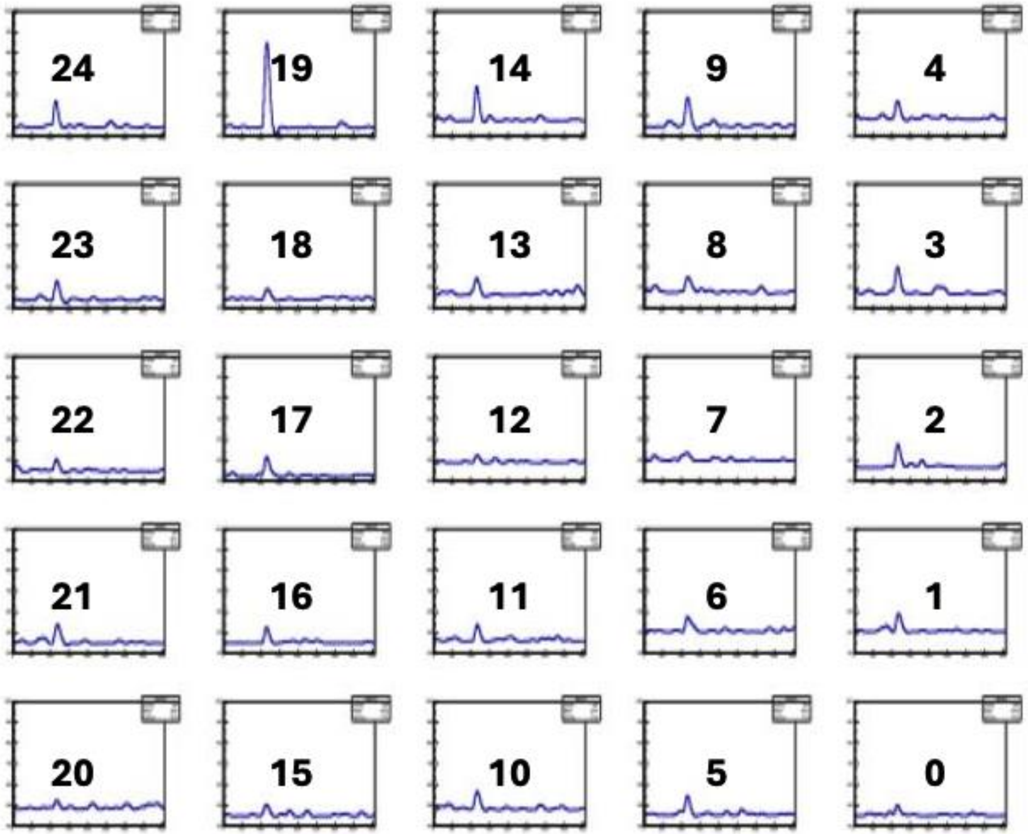


↑ SiPM Board (NOTICE KOREA) TCB & MUON DAQ ↓

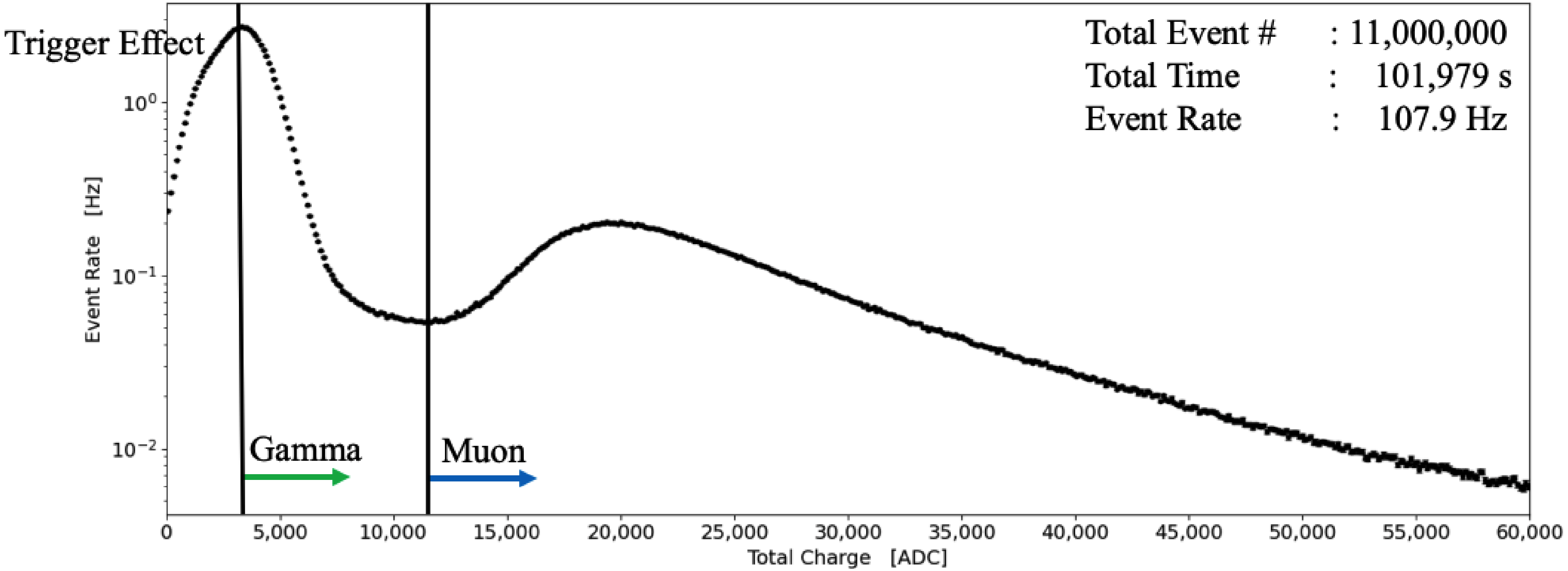


Current progress of the CANDY





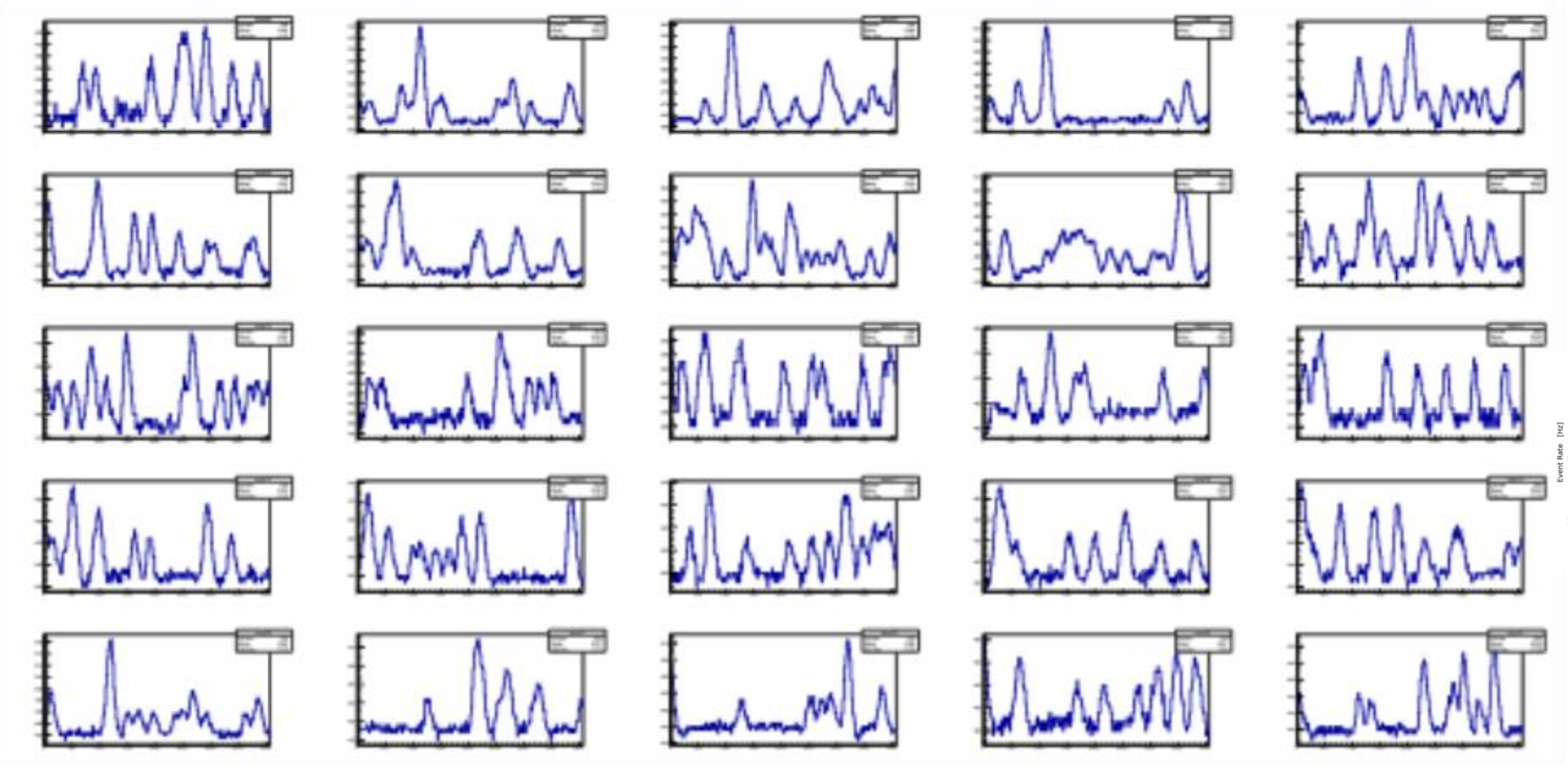
Event Spectrum



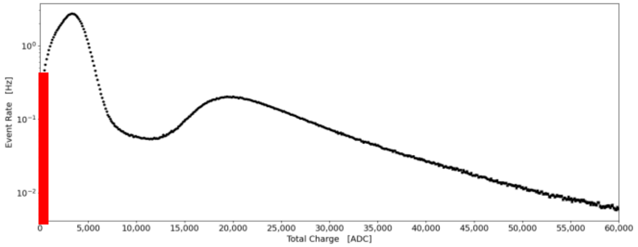
Trigger: $4 \leq$ Multiplicity $\approx$ 2MeV

Due to noise, a Landau function does not adequately fit the data.

Noise Event

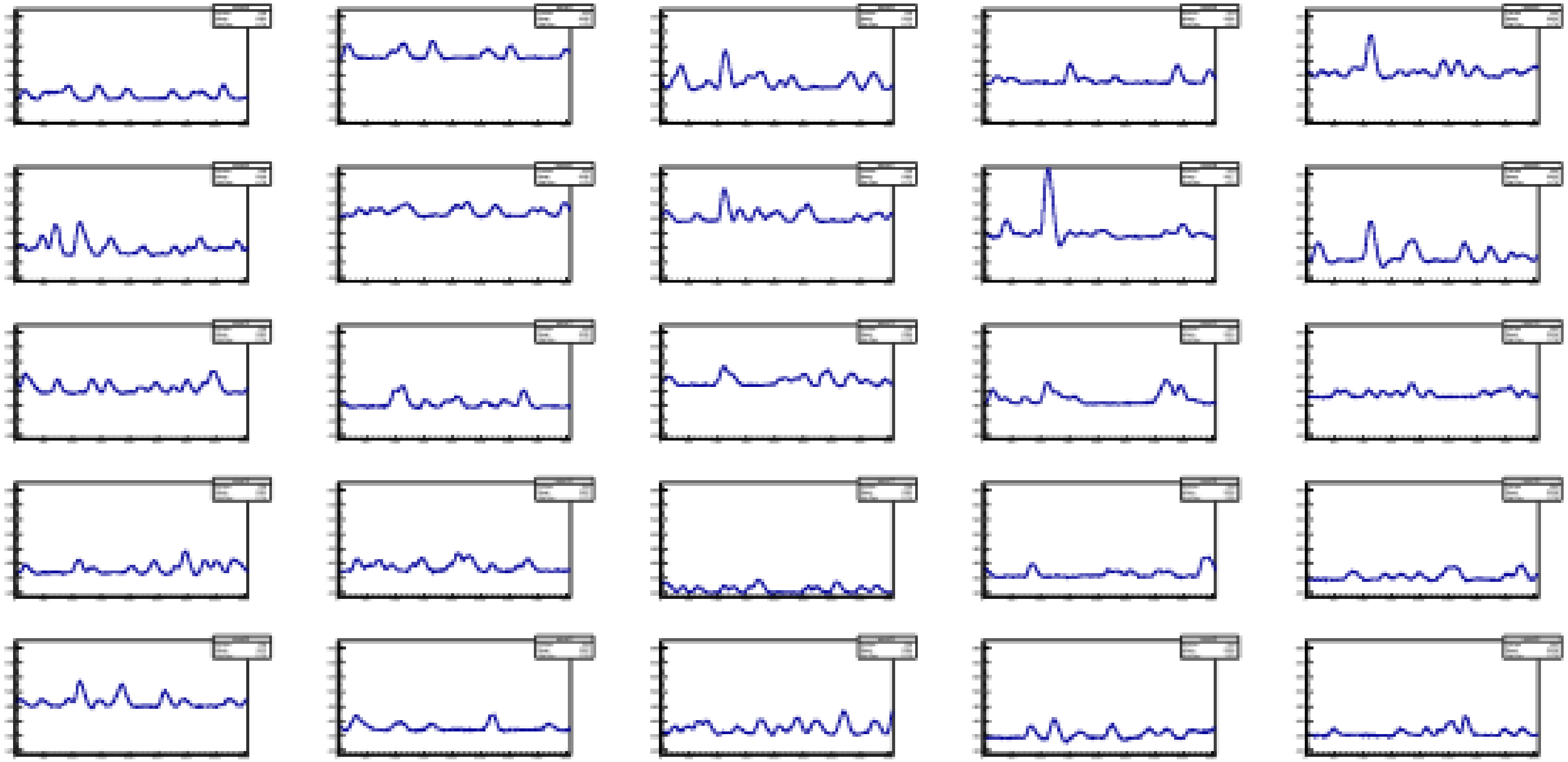


2025/10/17 16h
Run number : 11
Event ID : 103365

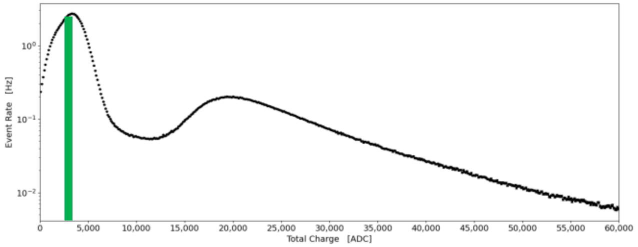


Reason
- Thermal noise (20~25°C)
- Opened Top

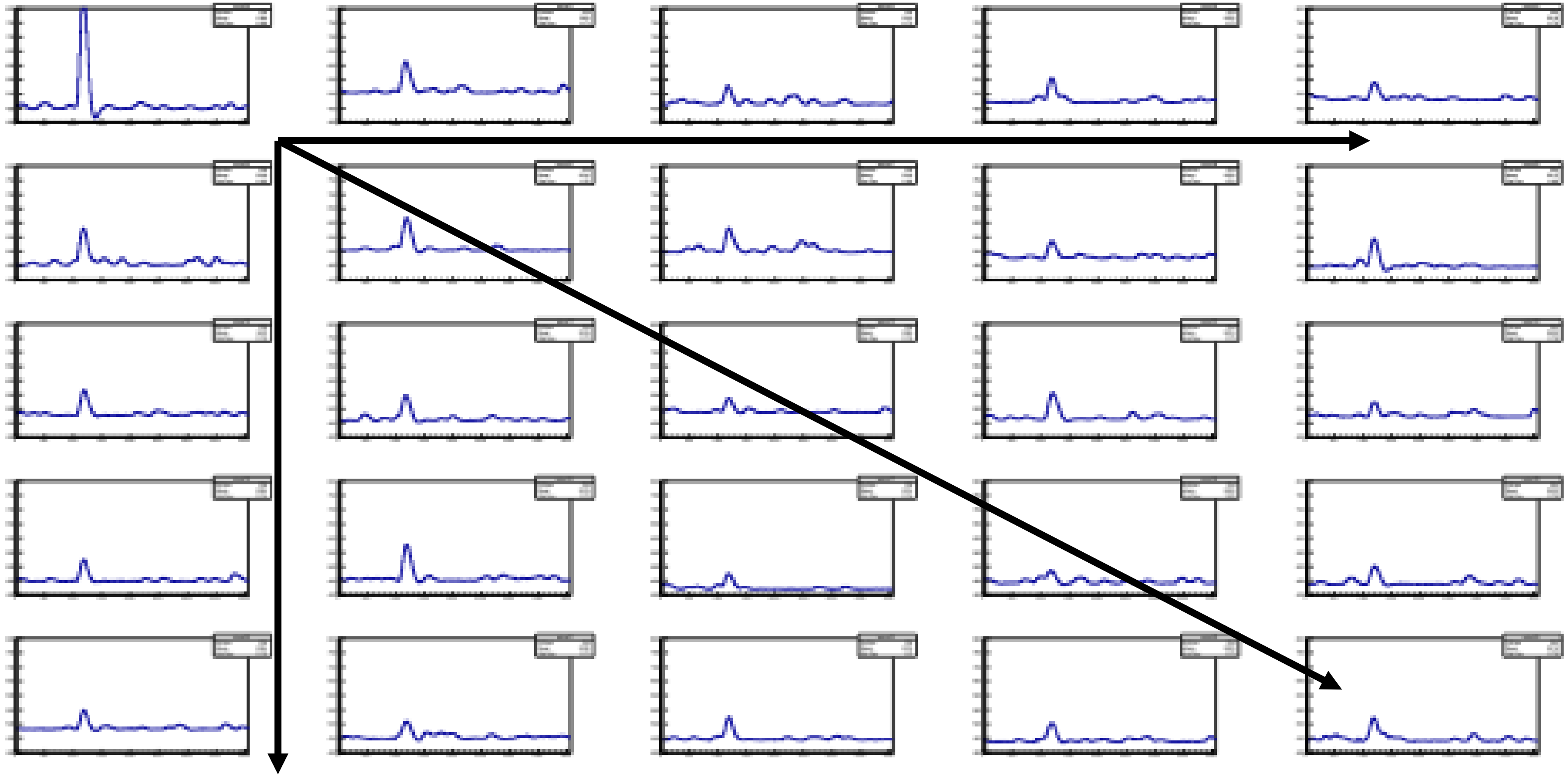
Gamma Event



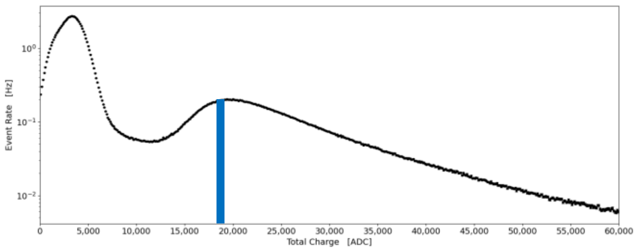
2025/10/14 23h
Run number : 3
Event ID : 36



Muon Event

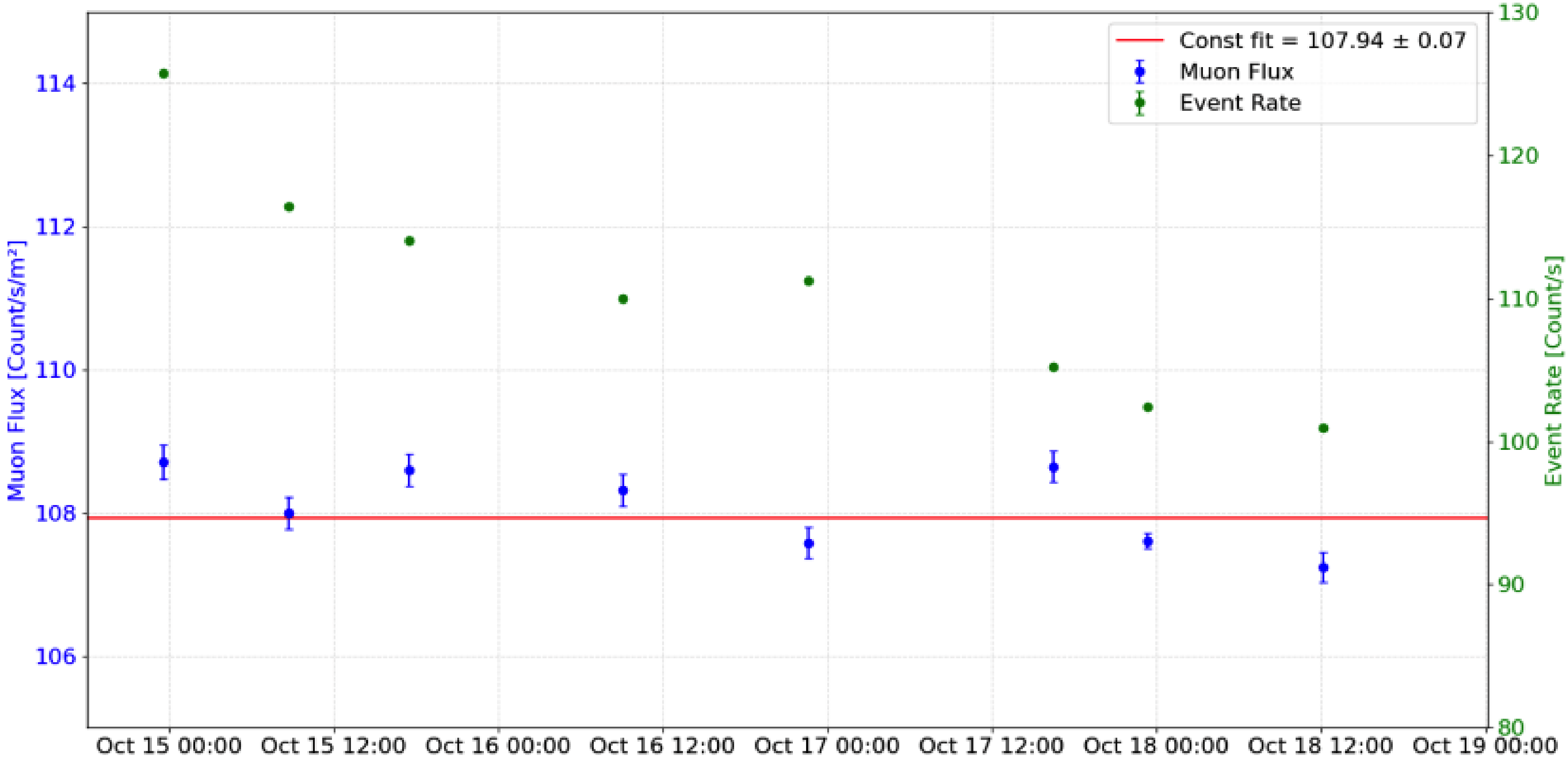


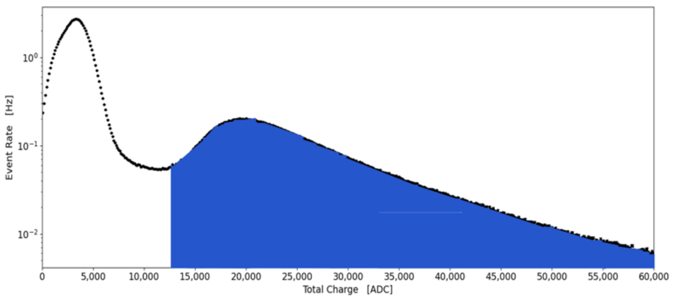
2025/10/14 23h
Run number : 3
Event ID : 167



RARE EVENT SEARCH LABORATORY

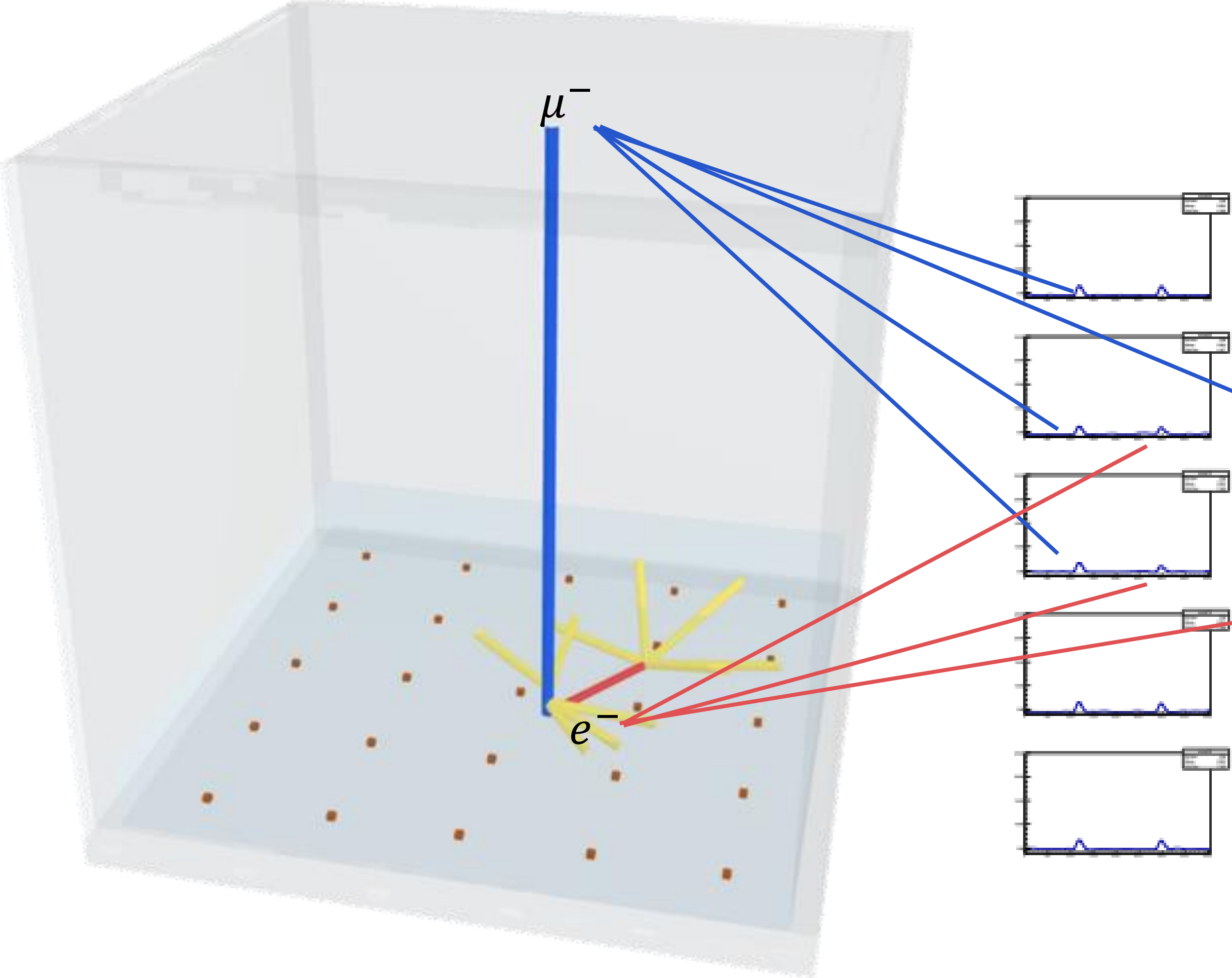
Muon Flux



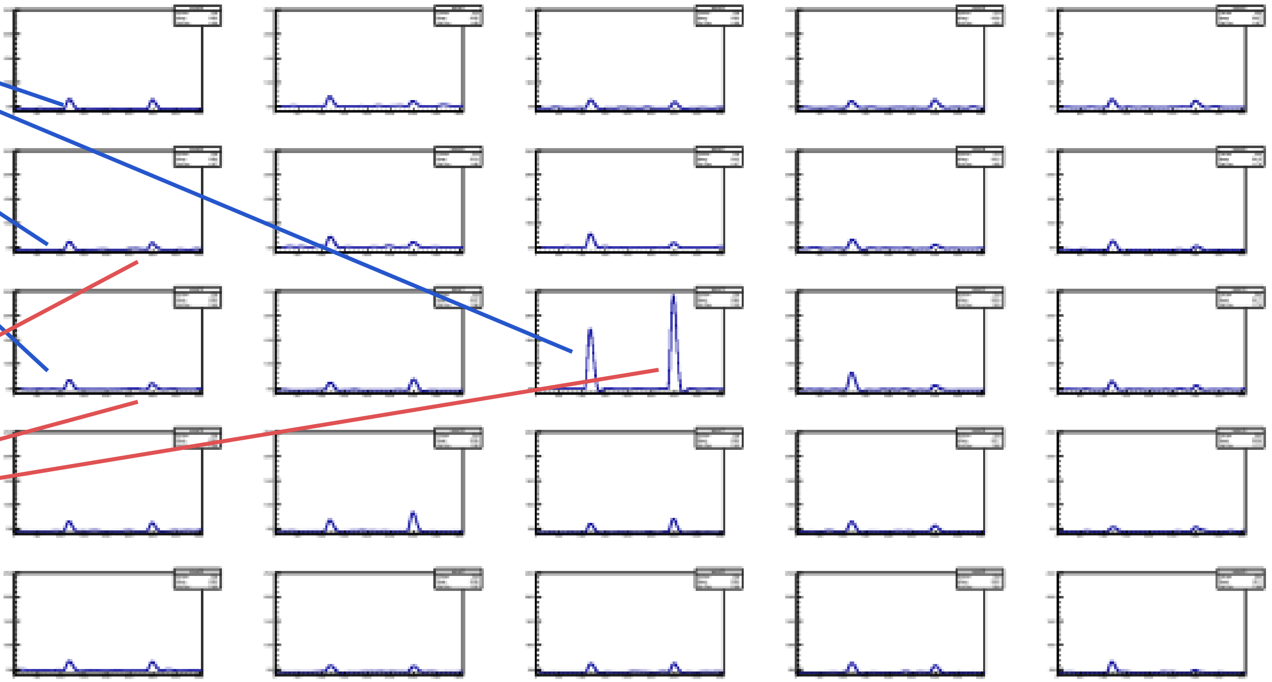


Muon cut : Total ADC > 13,000

Muon Decay Candidate Event

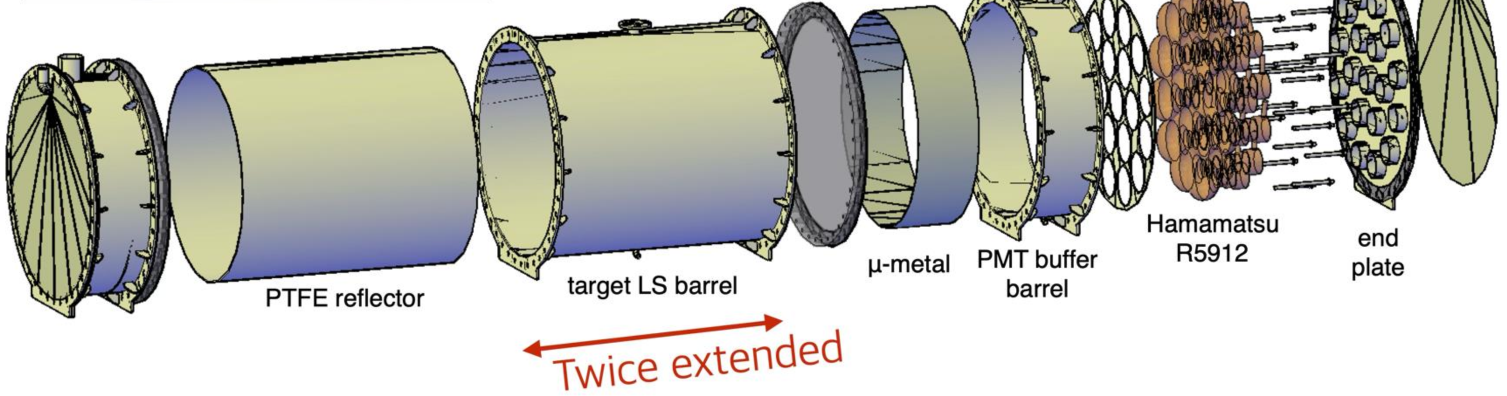


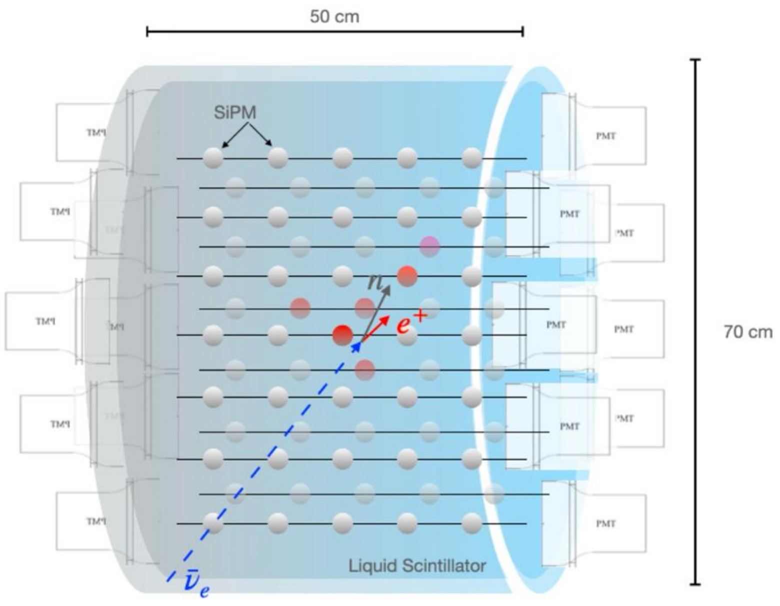
2025/10/17 23h
Run number : 12
Event ID : 1045171



We plan the Big-CANDY

Using NEOS skeleton, order additional extension
(One more Target LS barrel)





Thank you!