

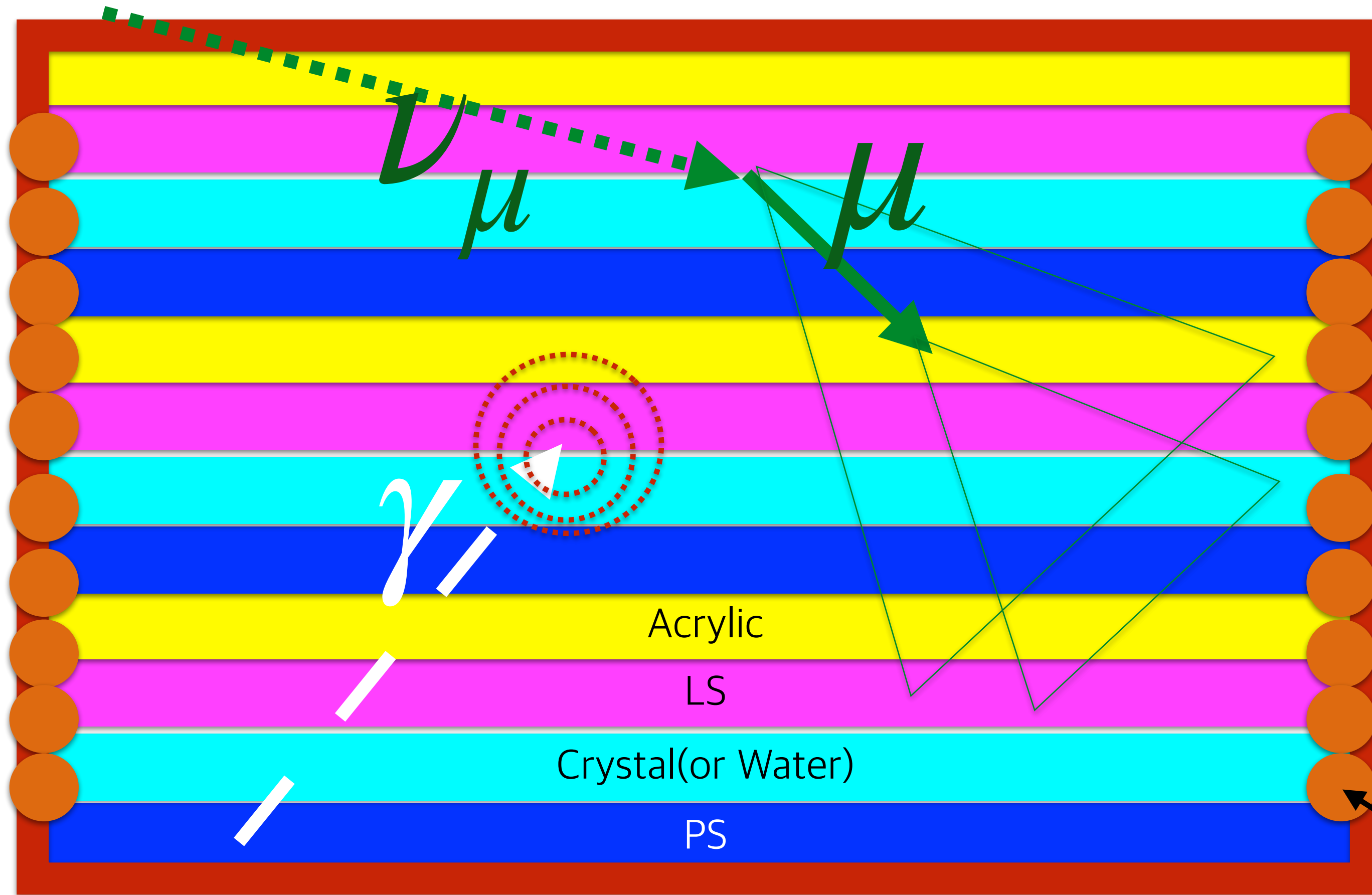
Dynamic Particle Detector R&D at Chung-Ang University

Position-sensitive scintillation detectors

CPNR Workshop 2025
Chung-Ang University
Chang Hyon Ha

Optically Dynamic : Layered Detector Concept

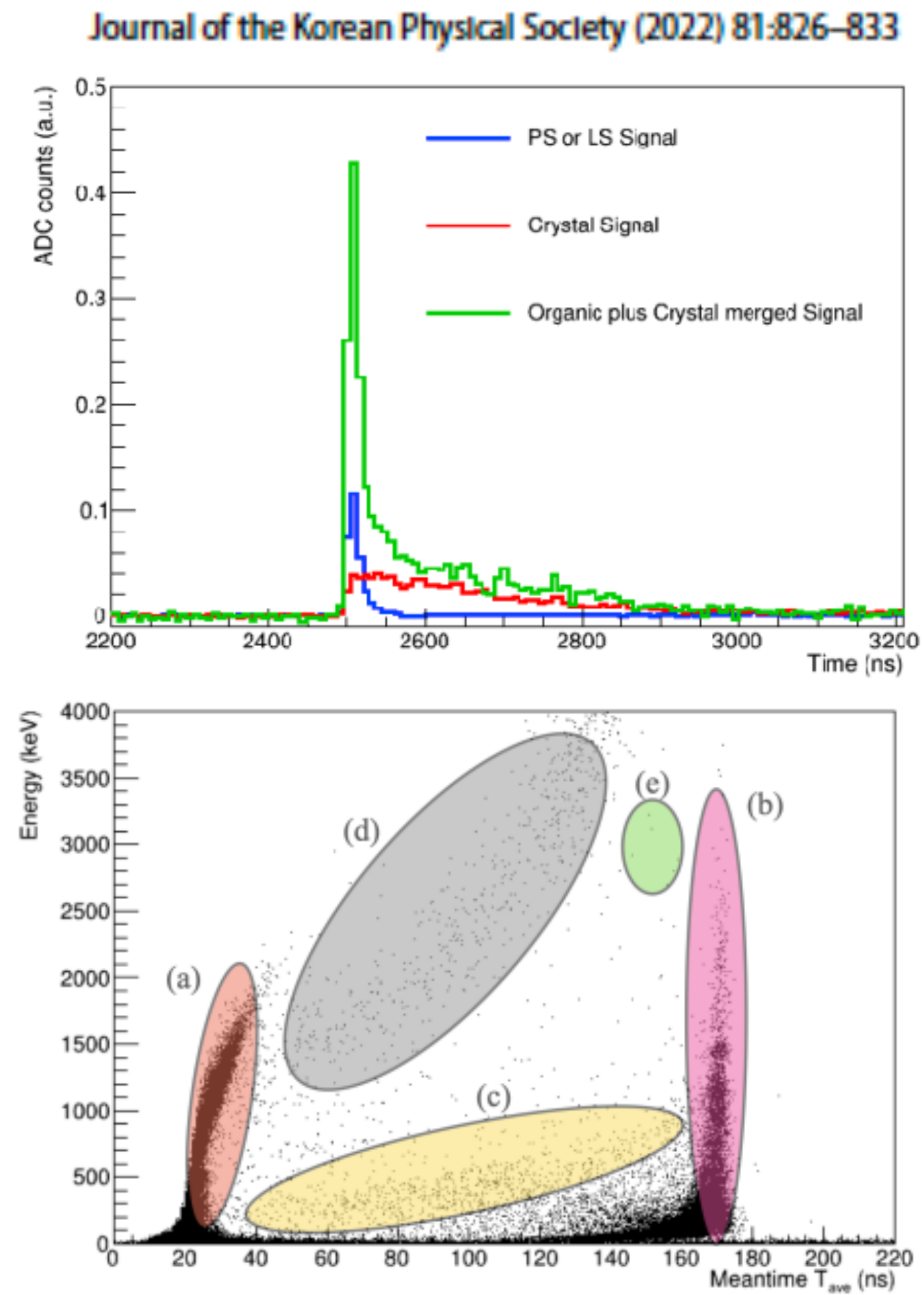
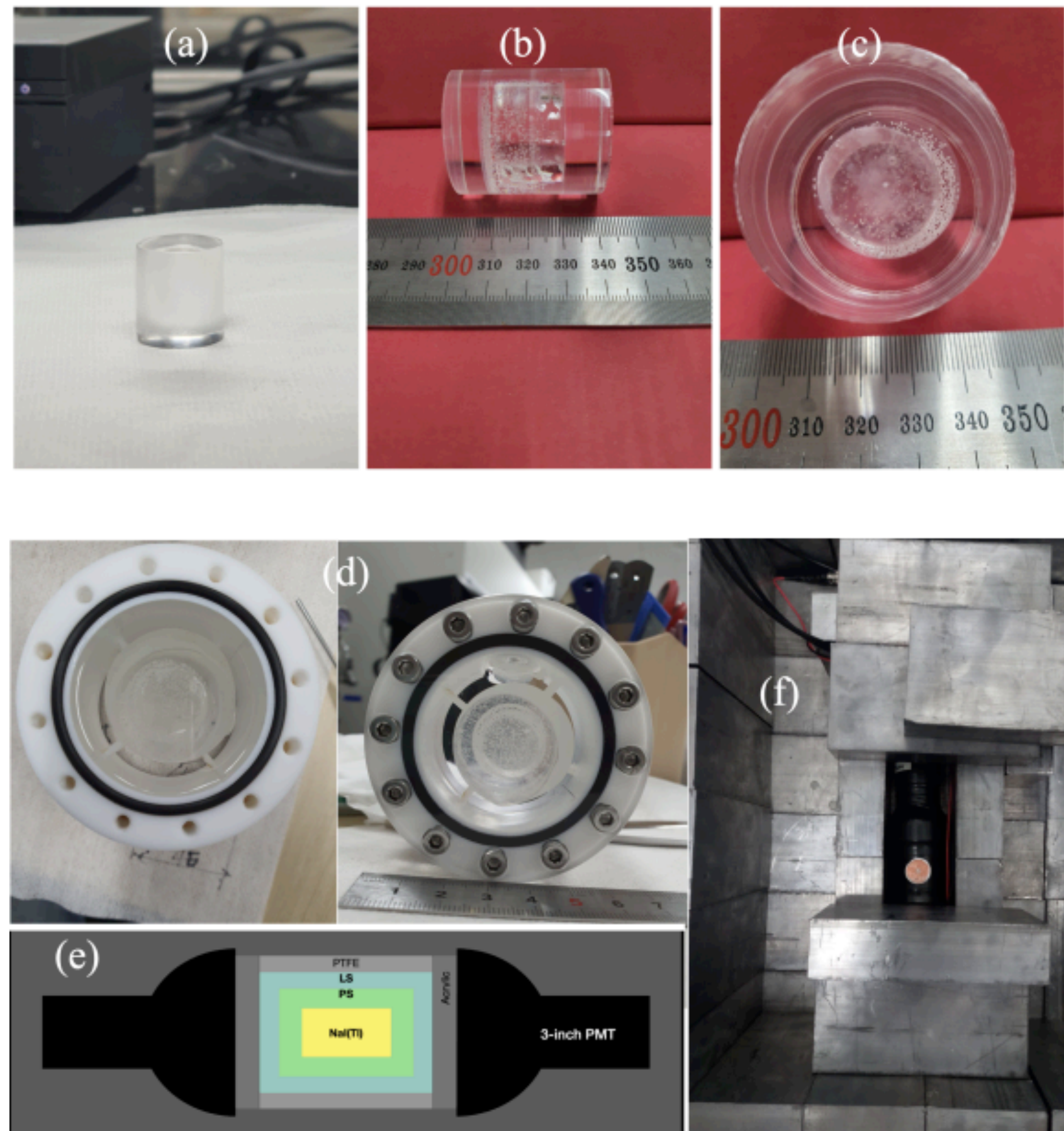
Plastic Scintillator-Crystal (Water)-Liquid Scintillator-Acrylic



- **Cherenkov Radiation :** Direction, Threshold (PID), and Low attenuation.
- **Scintillation :** High Light, Low threshold, and Neutron capture
- **Segmentation : Position**

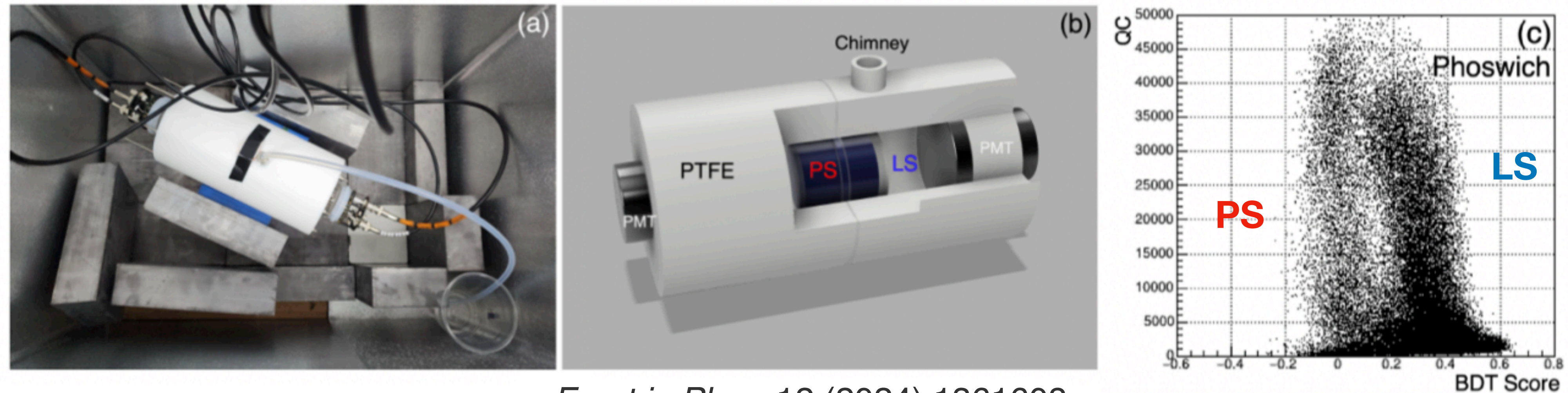
Assume LSC and inner tank is covered with PMTs

Triple phosphor sandwich (Phoswich) detector

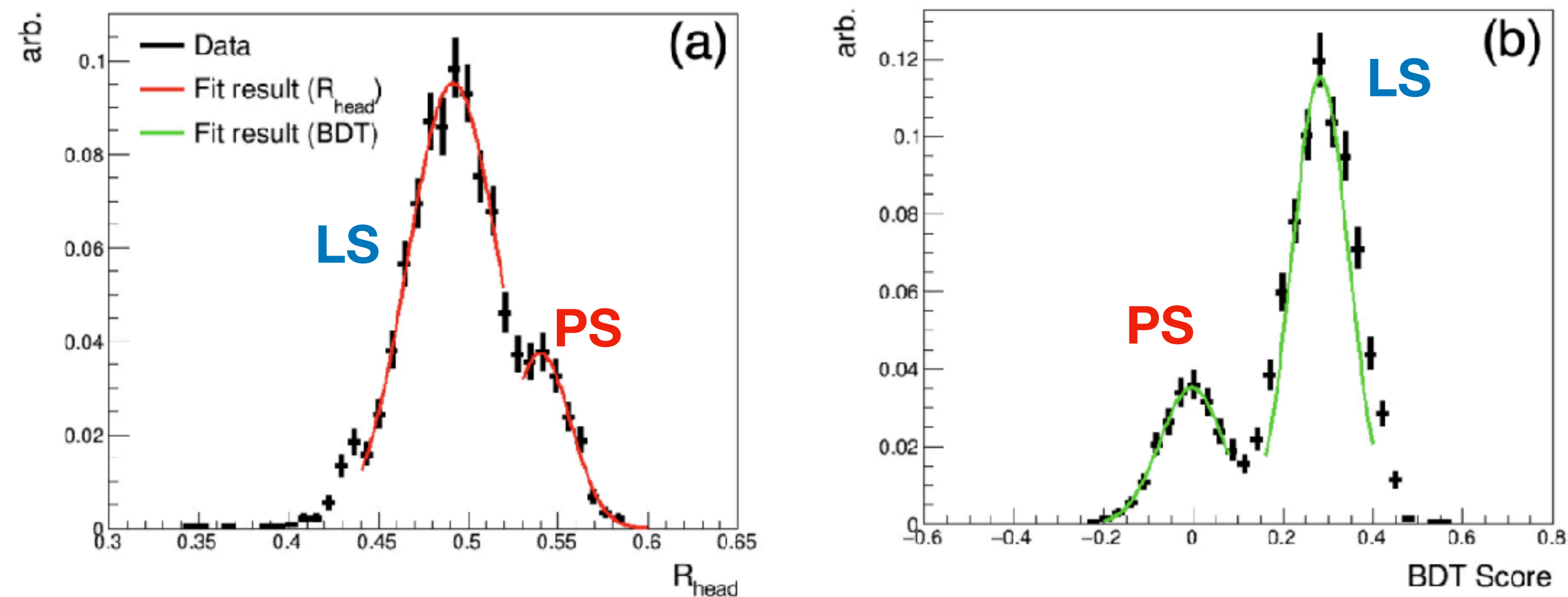


Crystal signal and Organic scintillator signal are separated by a single readout

Plastic vs Liquid Scintillator (Phoswich)

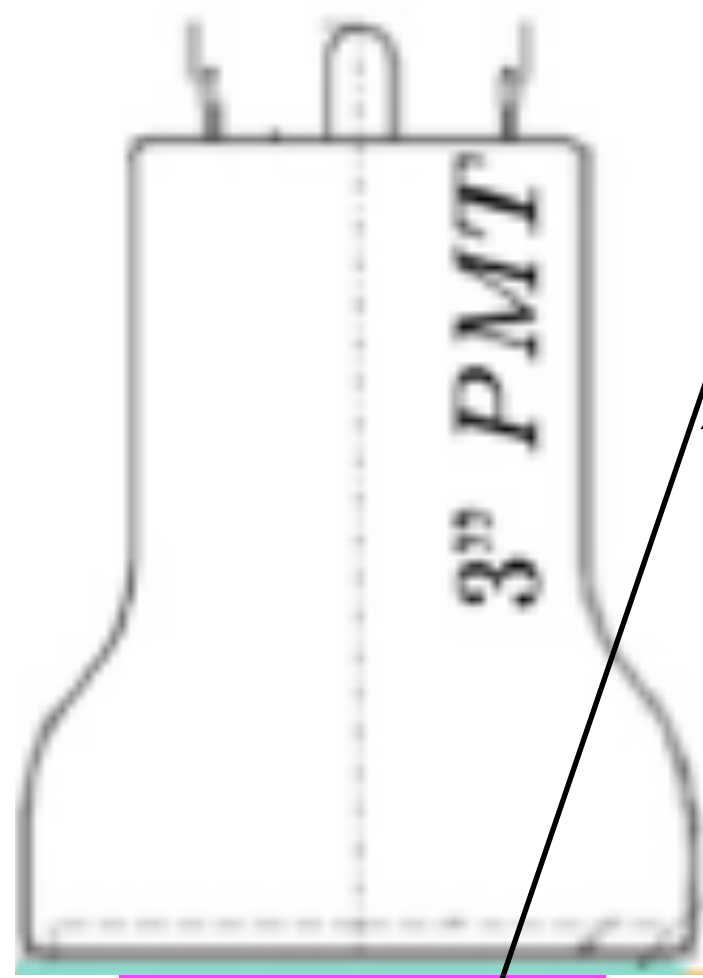


• *Front.in Phys.* 12 (2024) 1361608



Plastic and Liquid scintillator signals are separated by using machine learning

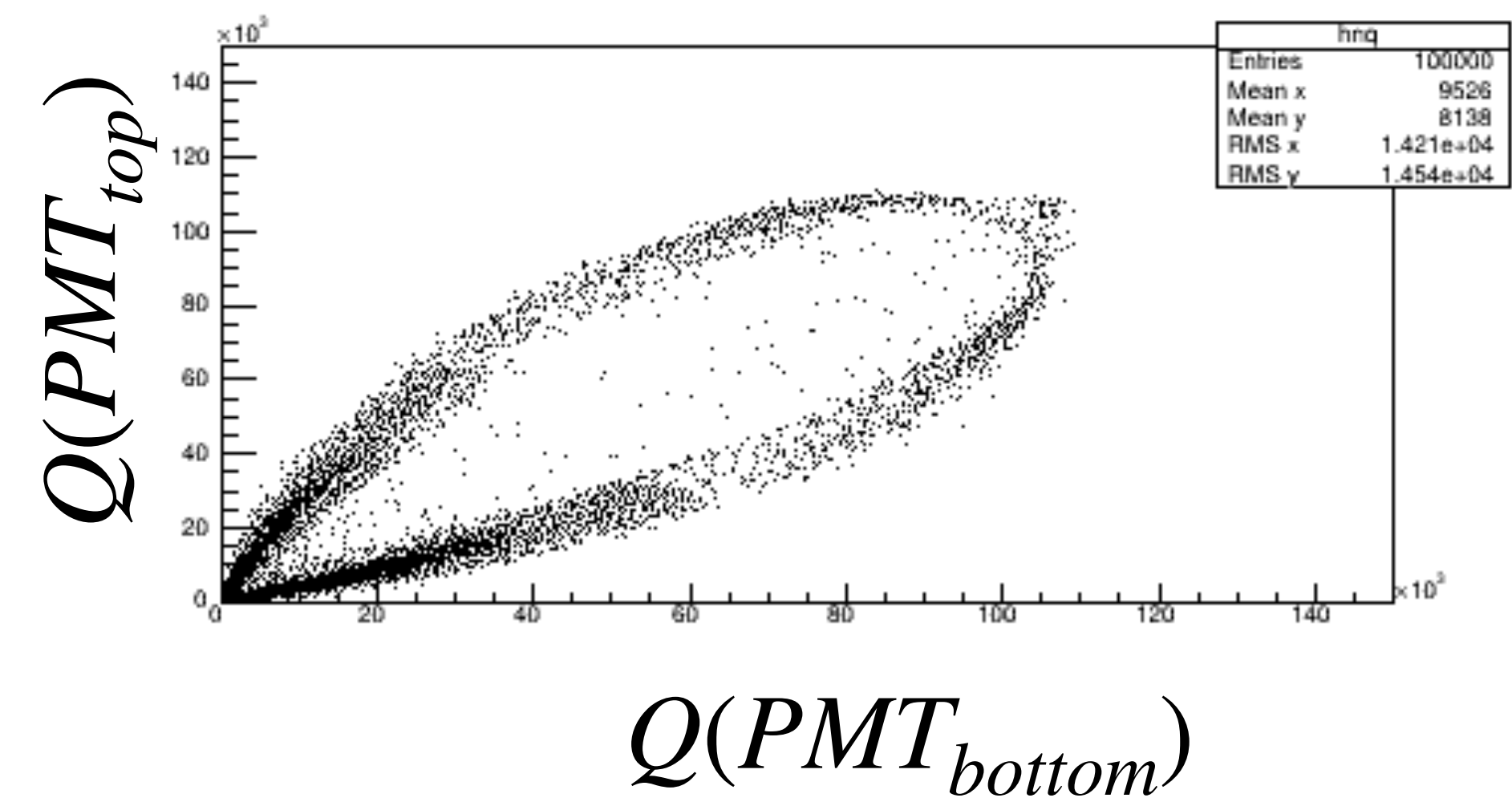
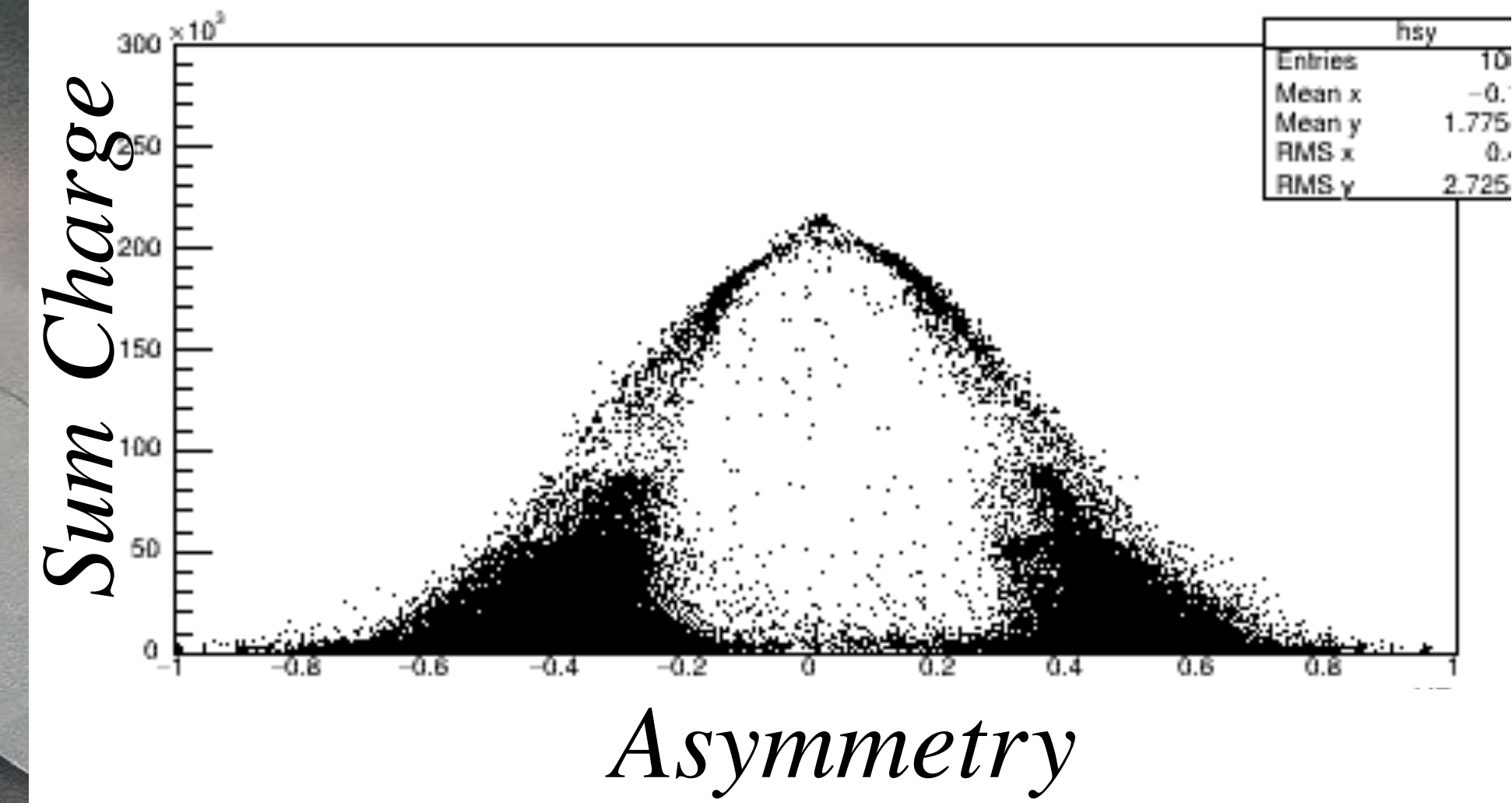
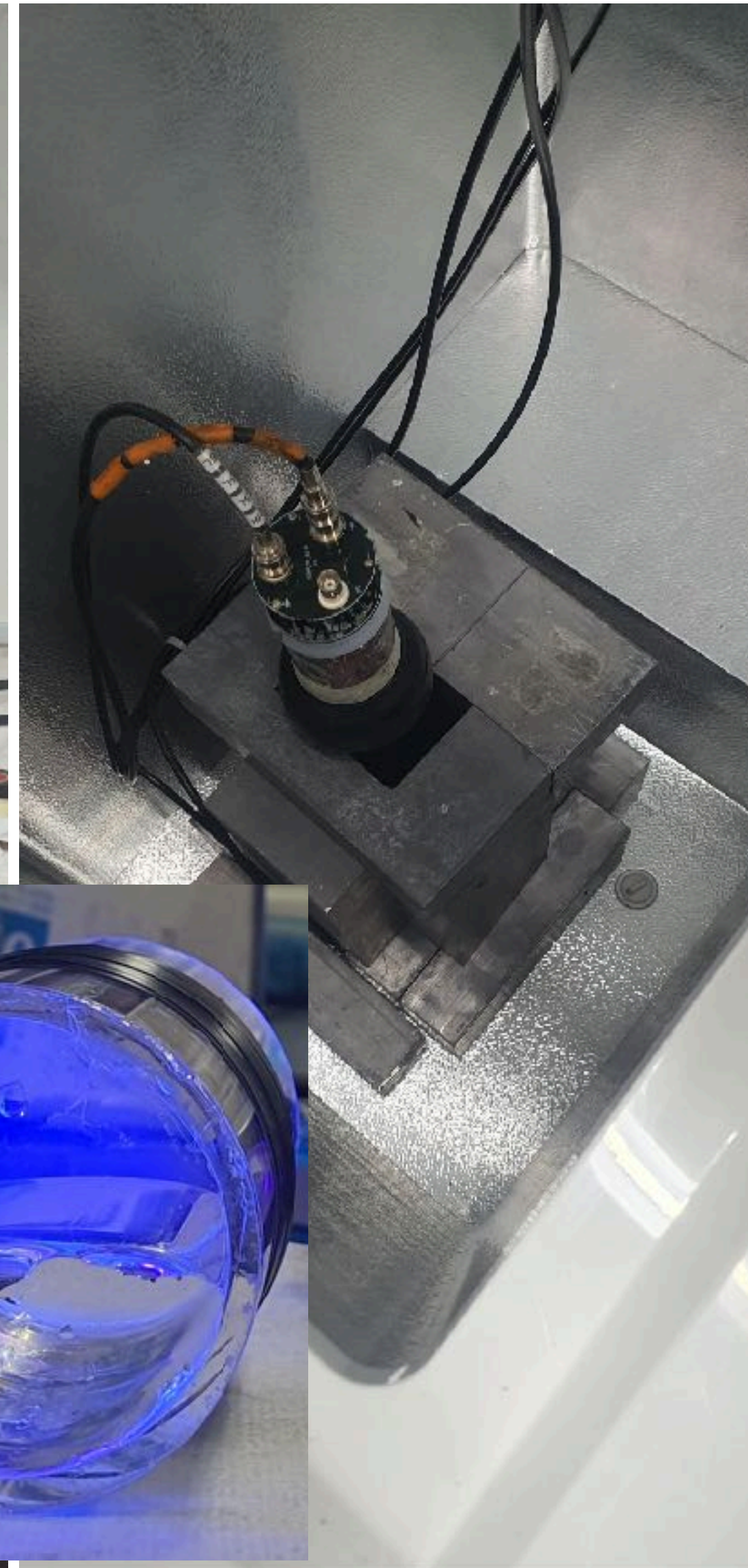
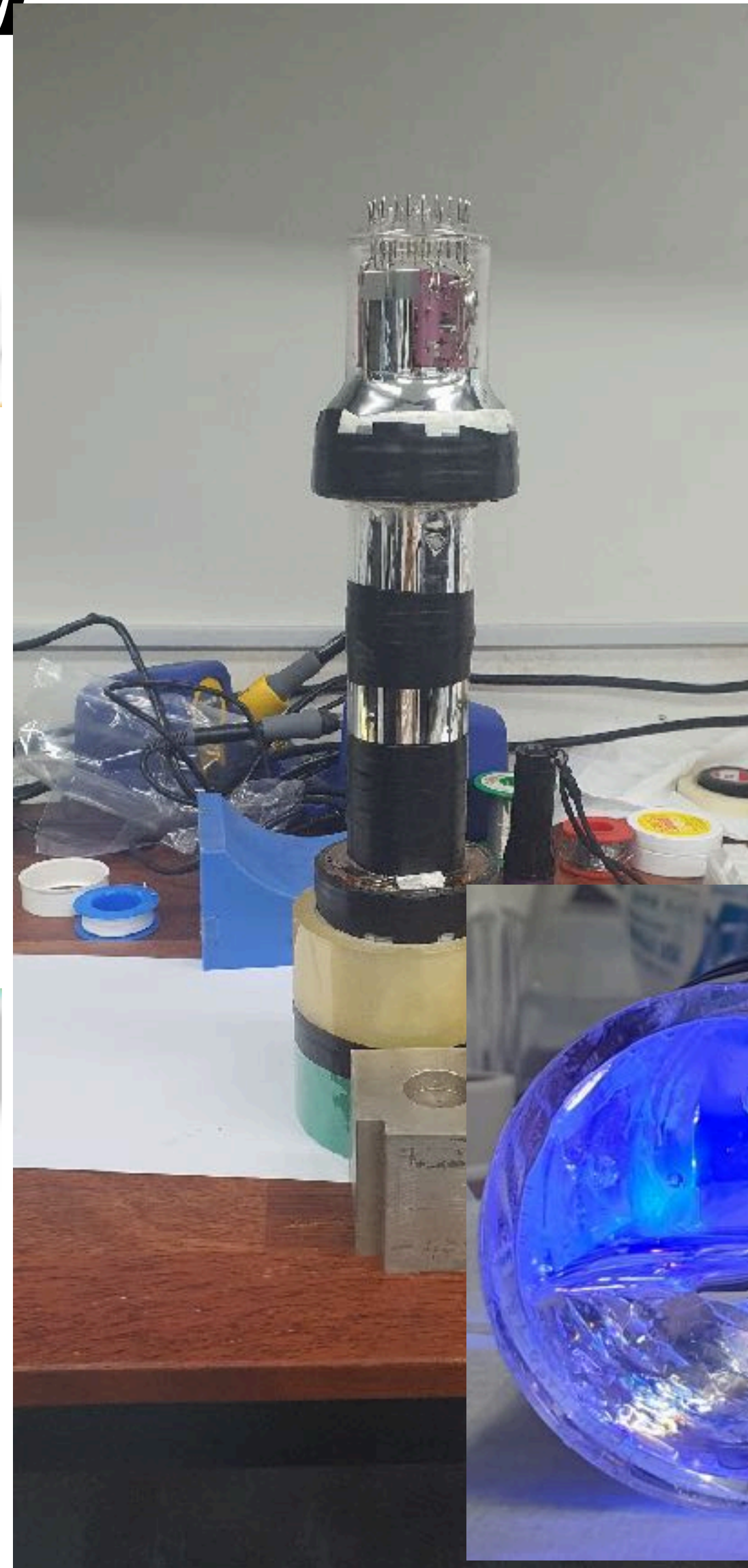
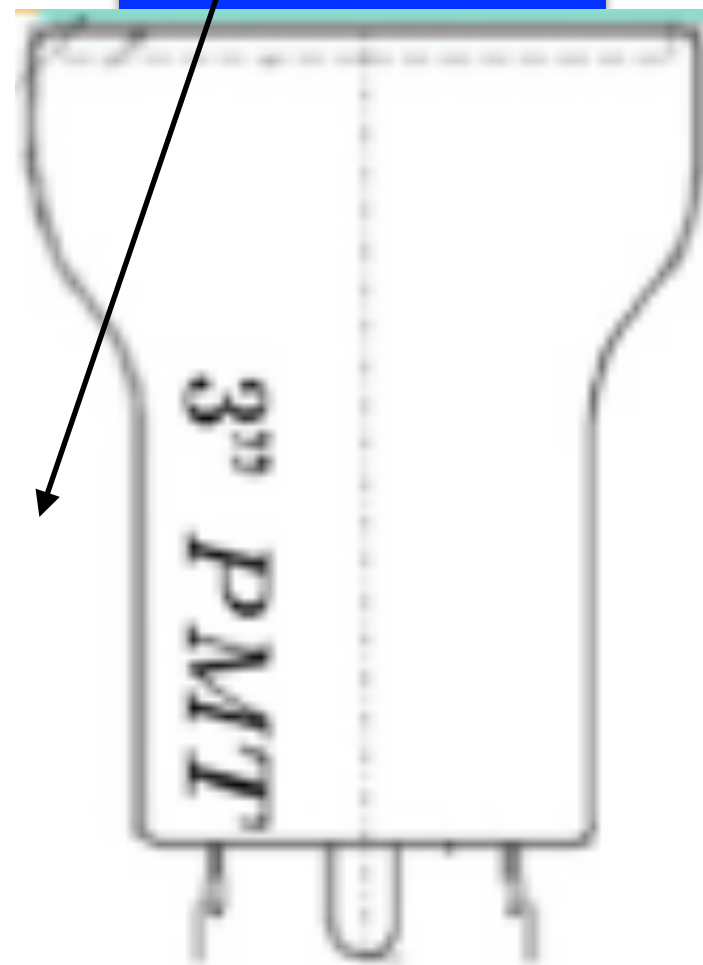
Small scale R&D (On-going)



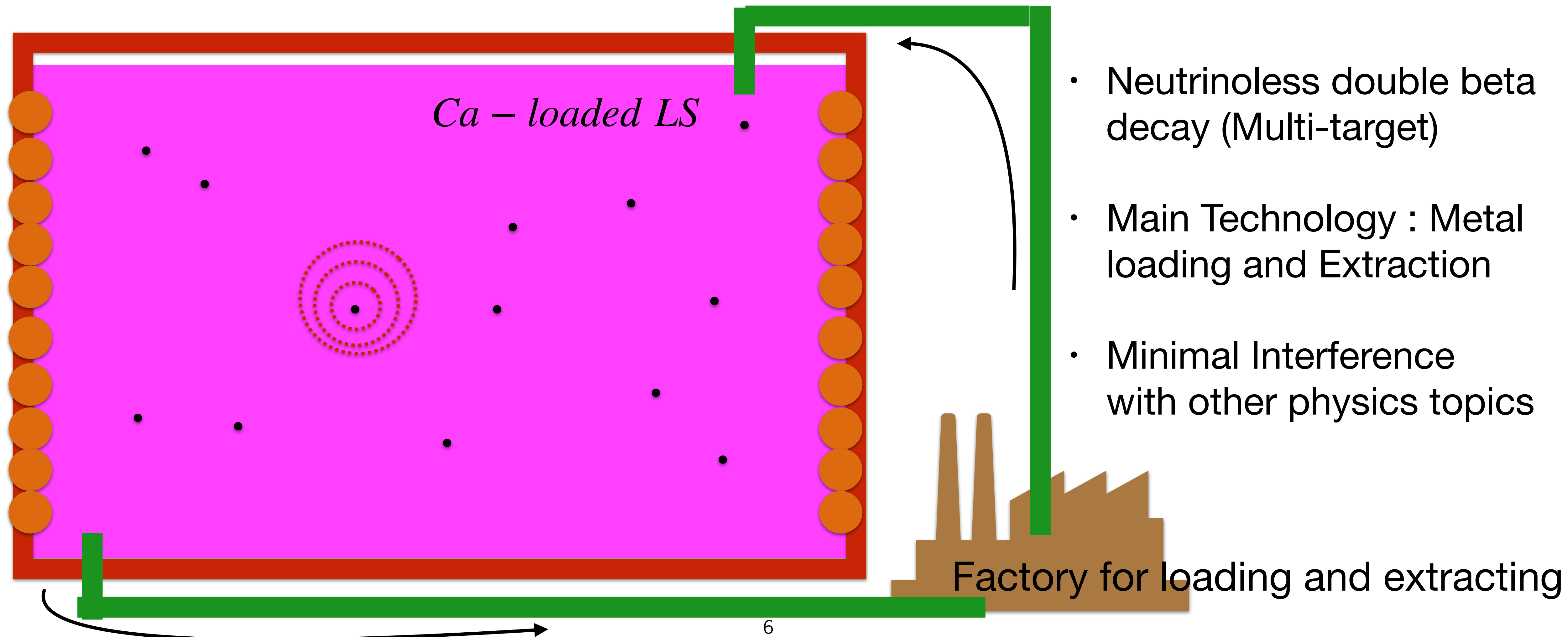
LS

Water

PS



Chemically Dynamic : Isotope loading and extracting concept to LS

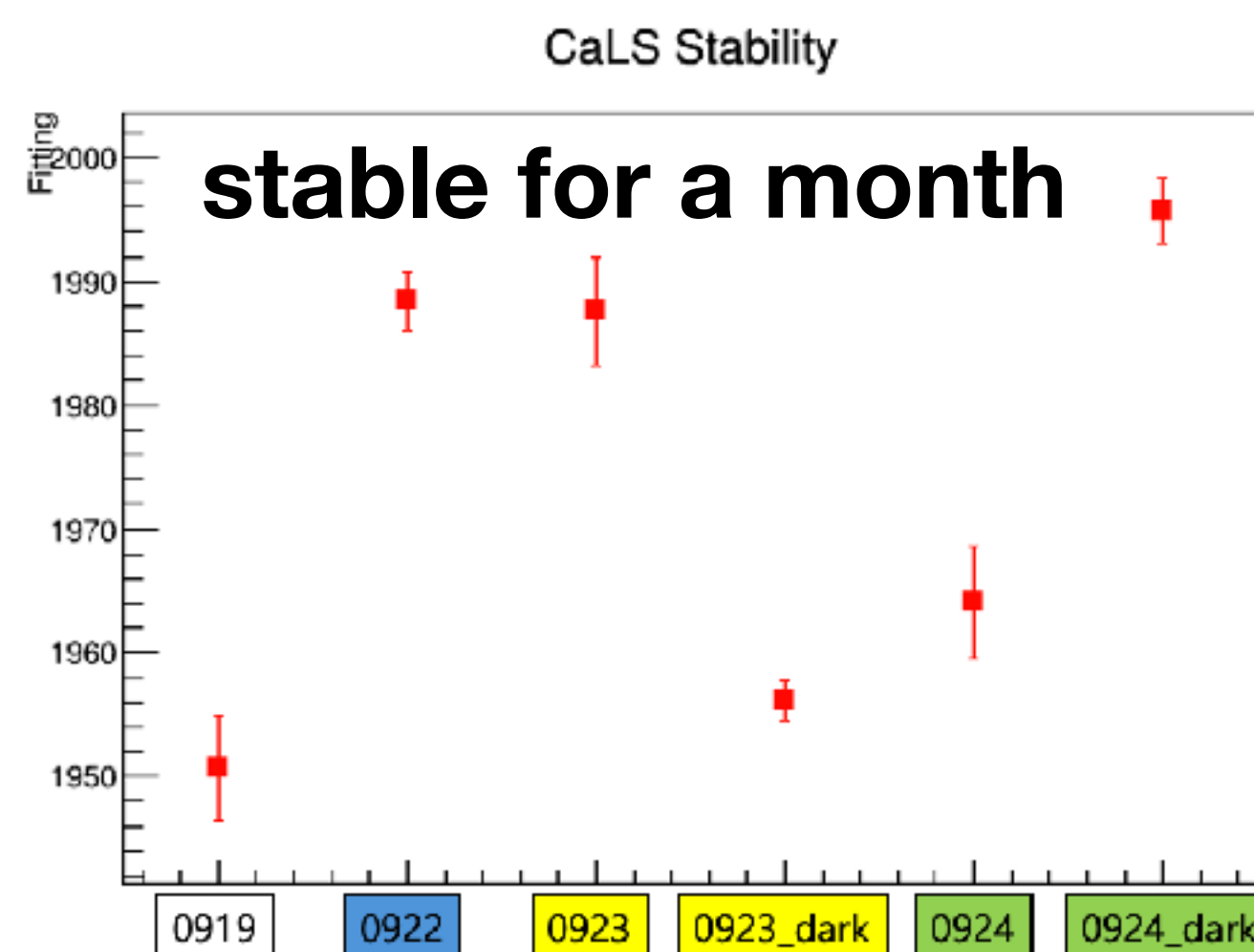
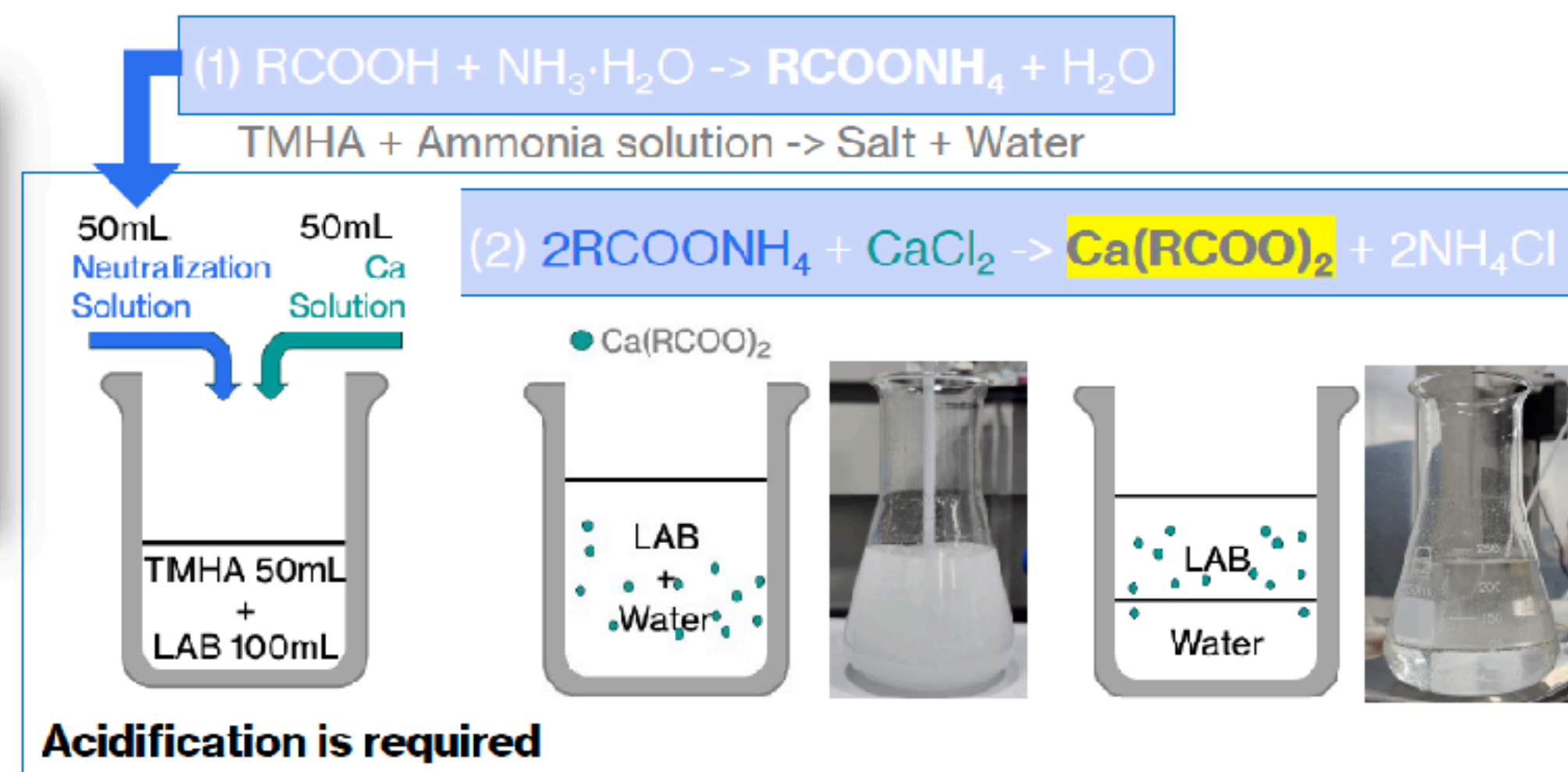


Motivation

How do we go about the kTon-scale next generation $0\nu\beta\beta$ detector?

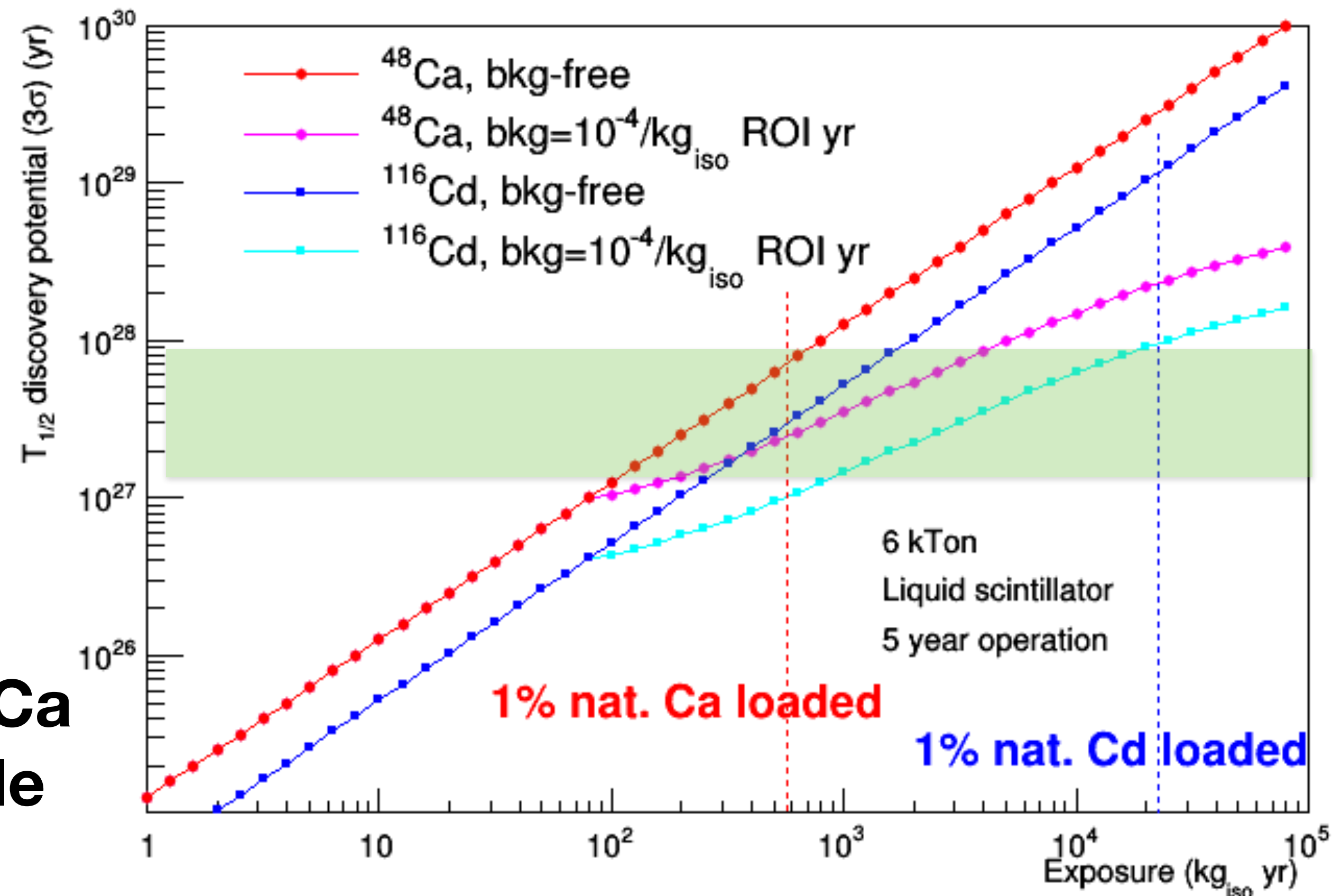
- LSC space ($\phi = 20m, H = 20m, \sim 6\text{kTon}$ liquid, Yemilab) is ready $\rightarrow$ It will eventually come true. The liquid would either be water or LS
- Metal loading technology ($\sim\%$ level) is widely studied nowadays.
- Roughly 1% metal loading gives 60 tons of which N.A. is on average 10% (6 ton targets).
 - C.f. : 320 kg of (enriched) ^{136}Xe target on LS(decane+PC) by KamLAND-Zen
 - C.f. : $\sim$ hundreds of ^{130}Te target on LAB by SNO+
- Korea has LS expertise and underground space.
- Isotopes above 2614 keV, quality LS, and high concentration target mass would be competitive.

Current R&Ds and Sensitivity



R&D with KNU shows 2.8 g/L Ca loading possible

1% nat. Ca loading would give us 114kg * 5yr Exposure (bkg. better, mass lower)
 For Cd, 22,500 kg yr exposure (higher mass, a bit of bkg will not be competitive),
 For Se and Mo, somewhere in between.



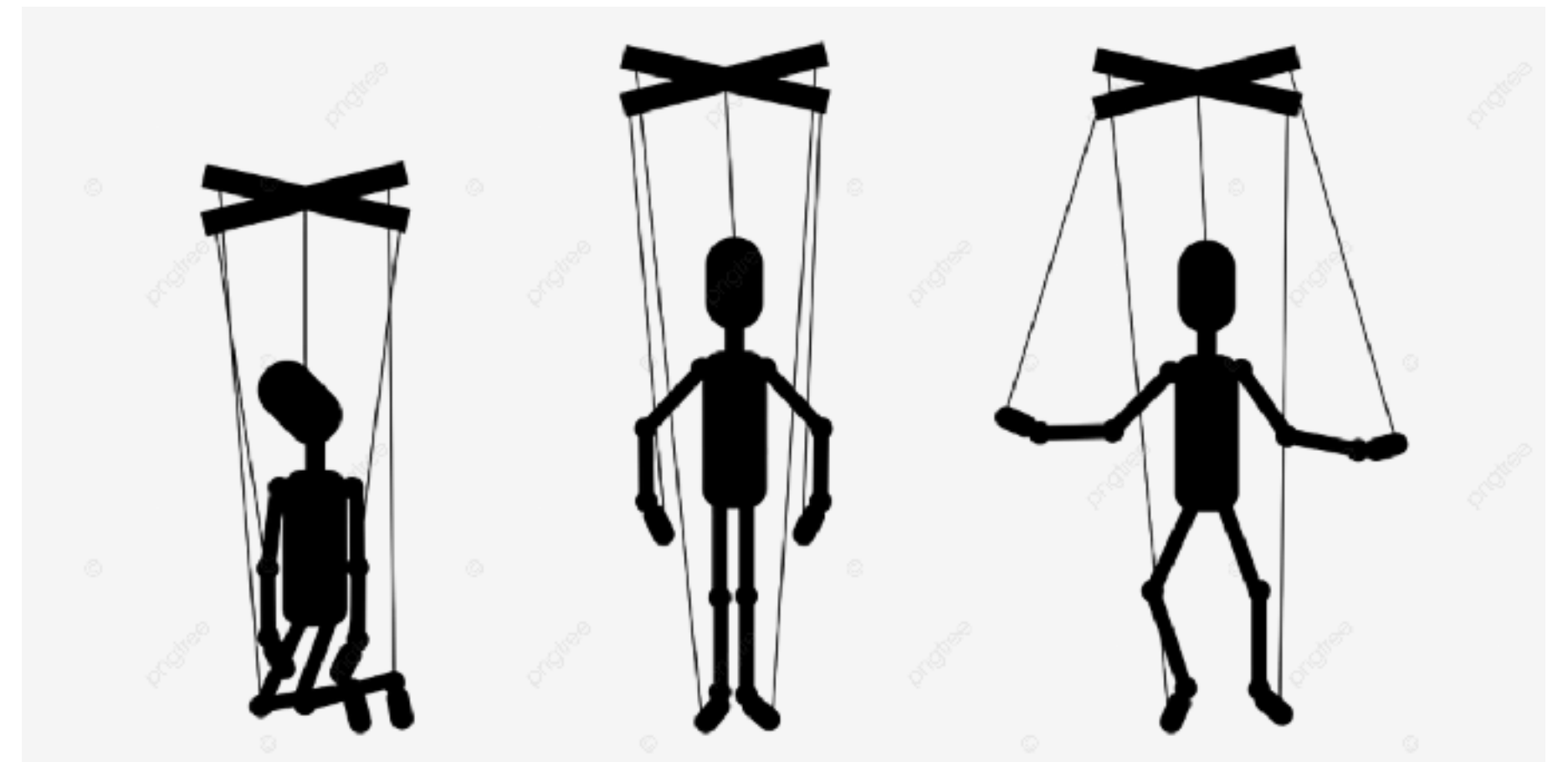
Geometrically Dynamic : Change in dynamic range.

Fishing-line style sensor array

Baseline Mode



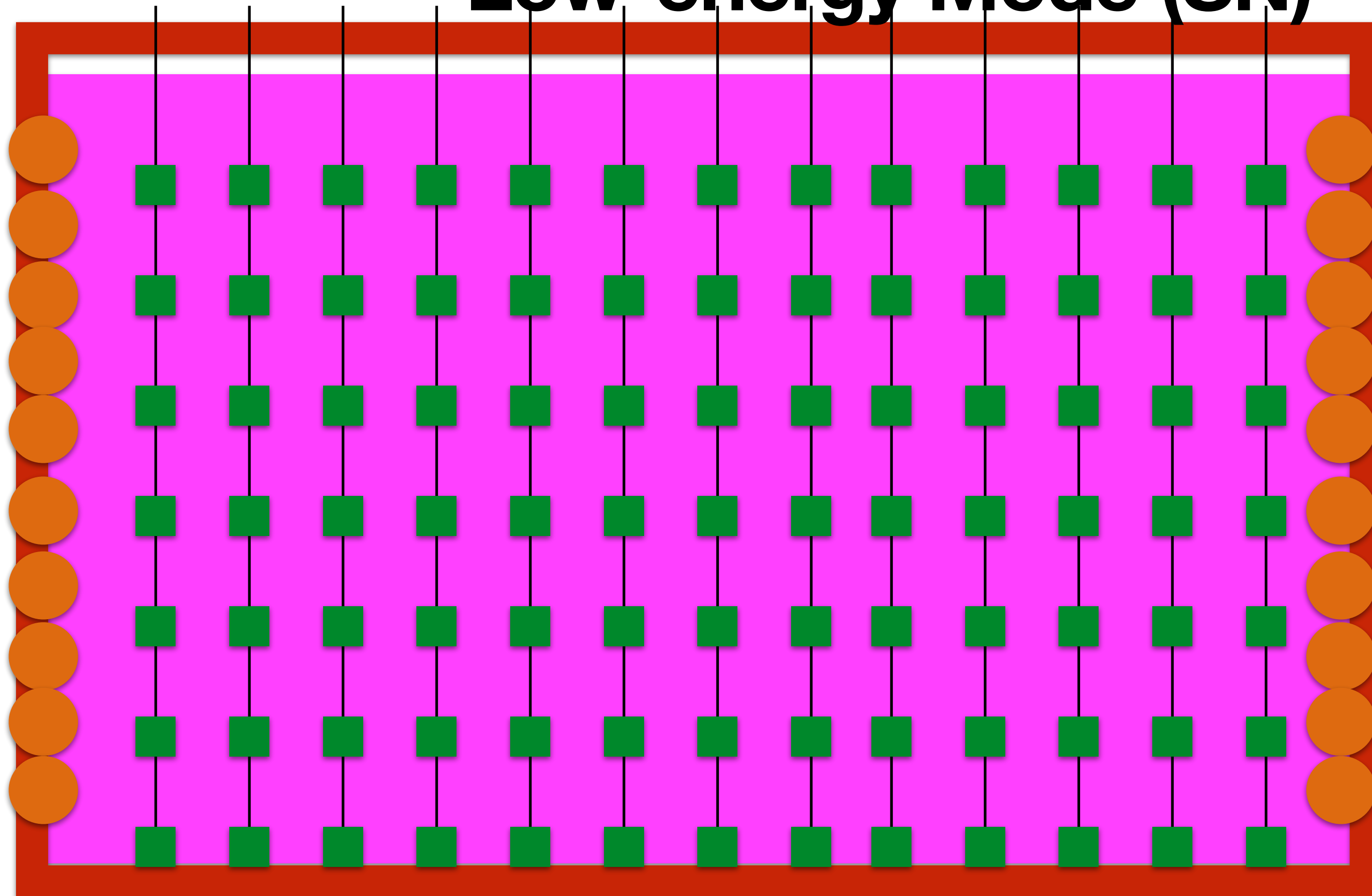
- Total Energy mainly measured by PMTs on the detector surface
- LS-embedded sensors (SiPMs or small PMTs) intercept fraction of light
- Lines can be moveable and reconfigured easily.



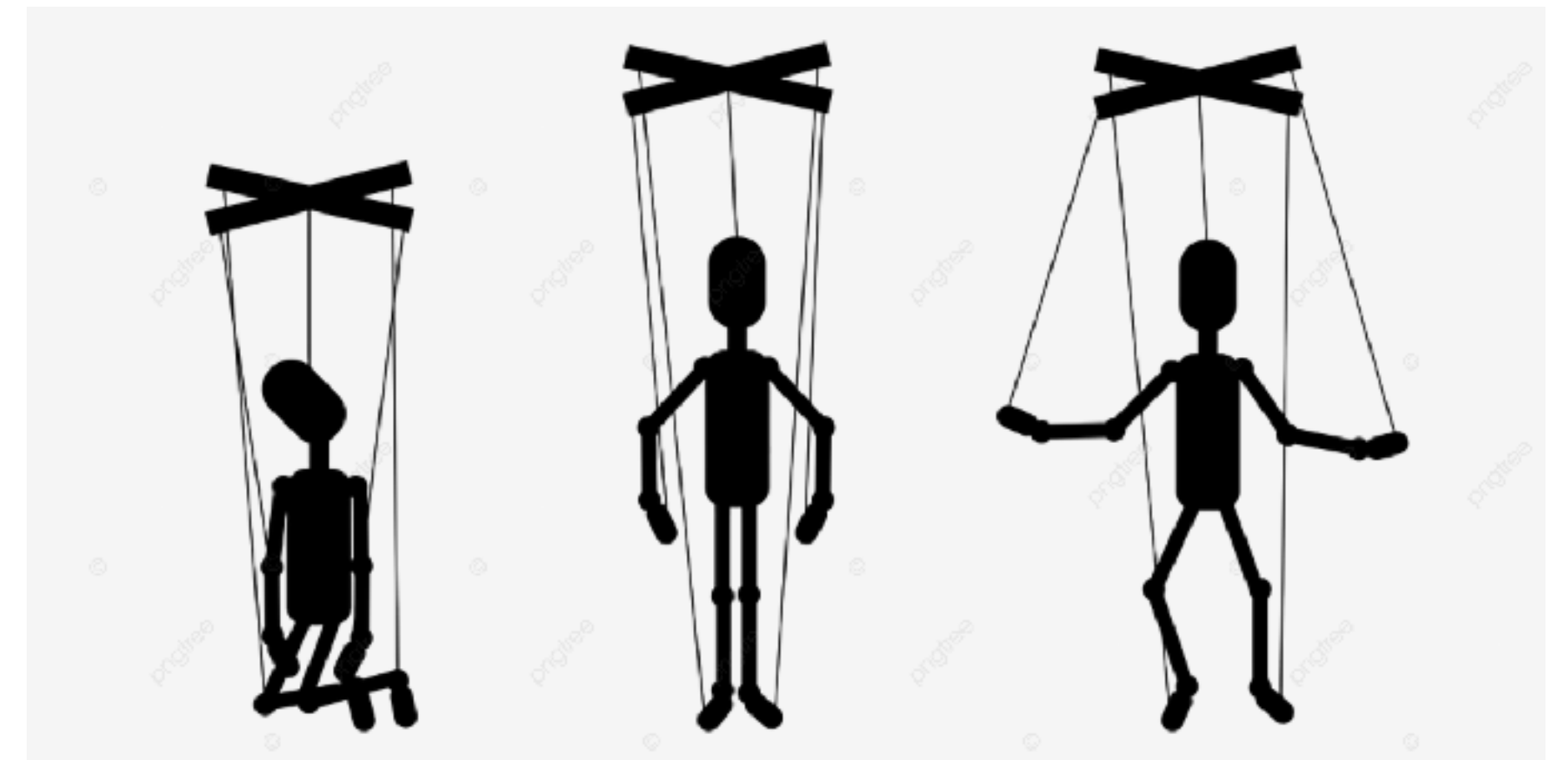
Geometrically Dynamic : Change in dynamic range.

Fishing-line style sensor array

Low-energy Mode (SN)



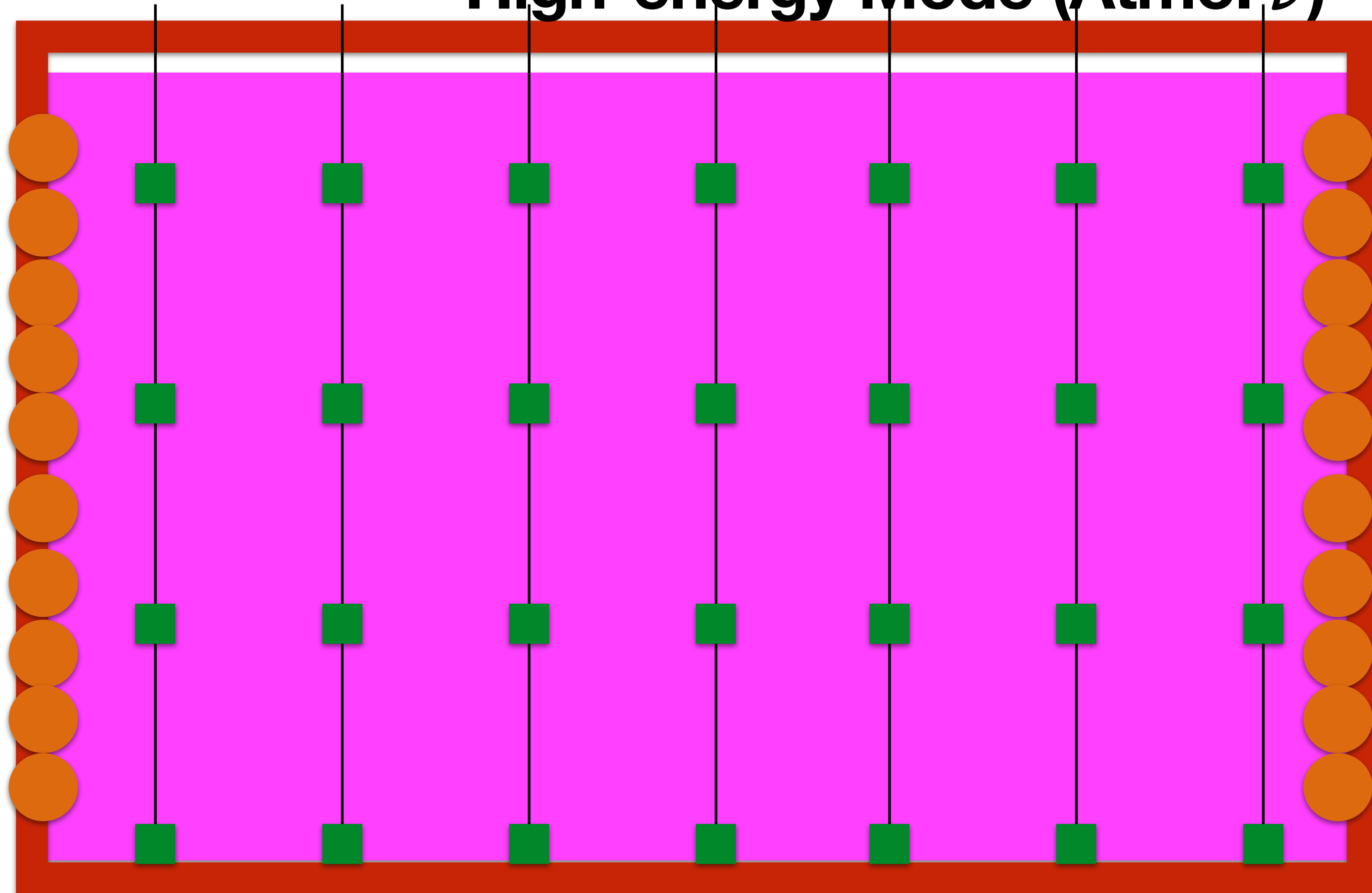
- Total Energy mainly measured by PMTs on the detector surface
- LS-embedded sensors (SiPMs or small PMTs) intercept fraction of light
- Lines can be moveable and reconfigured easily.



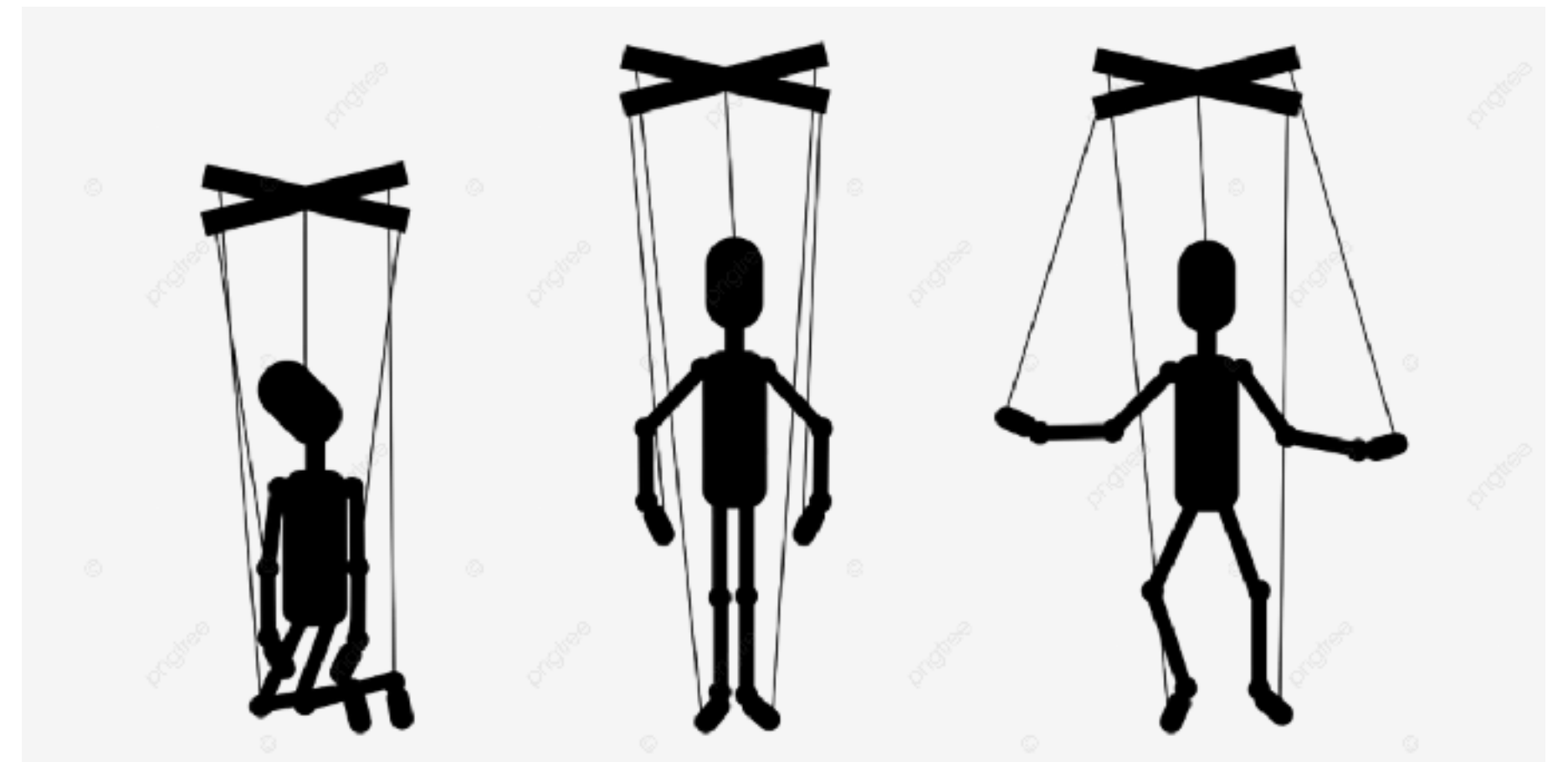
Geometrically Dynamic : Change in dynamic range.

Fishing-line style sensor array

High-energy Mode (Atmo. ν)



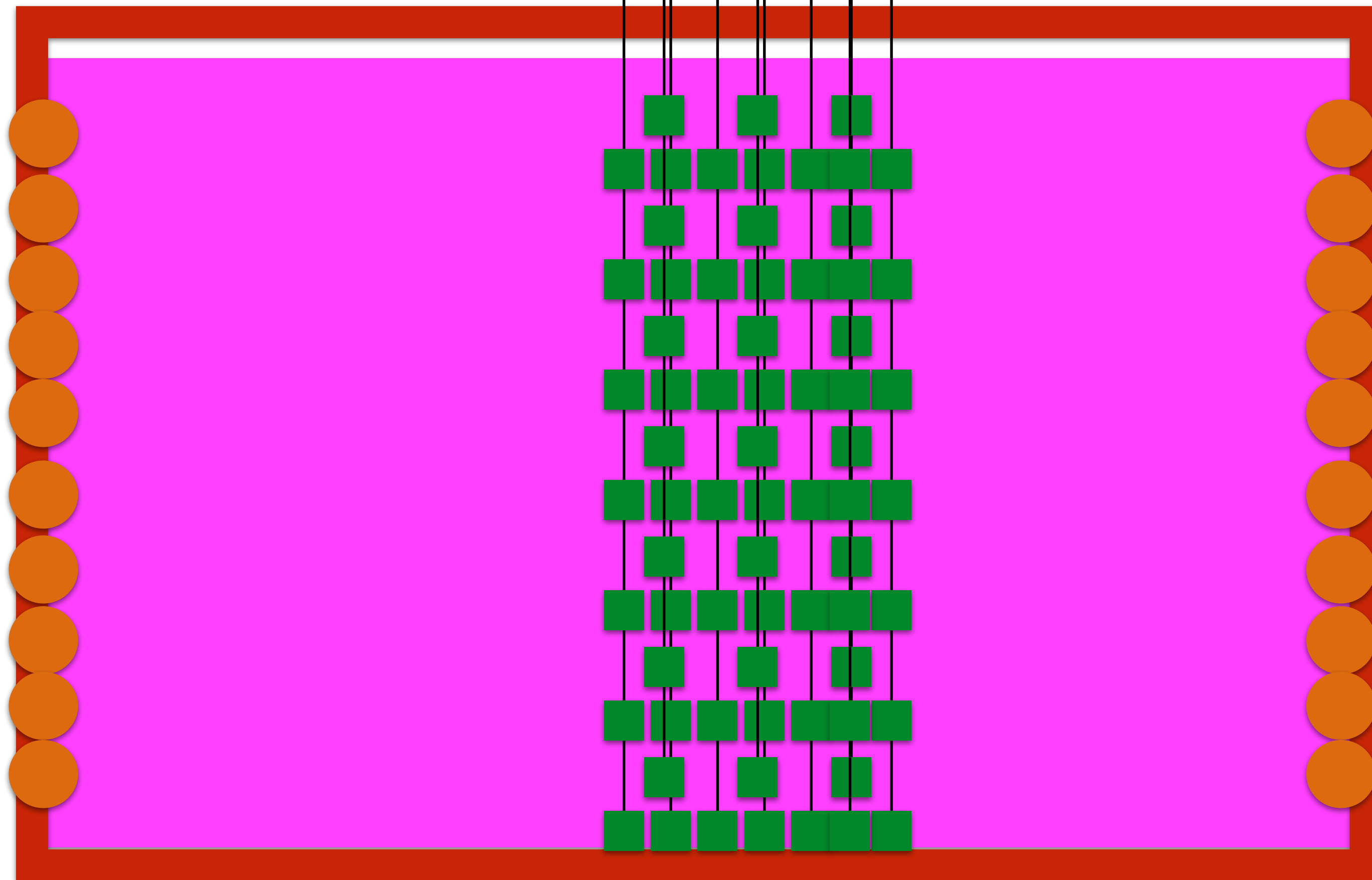
- Total Energy mainly measured by PMTs on the detector surface
- LS-embedded sensors (SiPMs or small PMTs) intercept fraction of light
- Lines can be moveable and reconfigured easily.



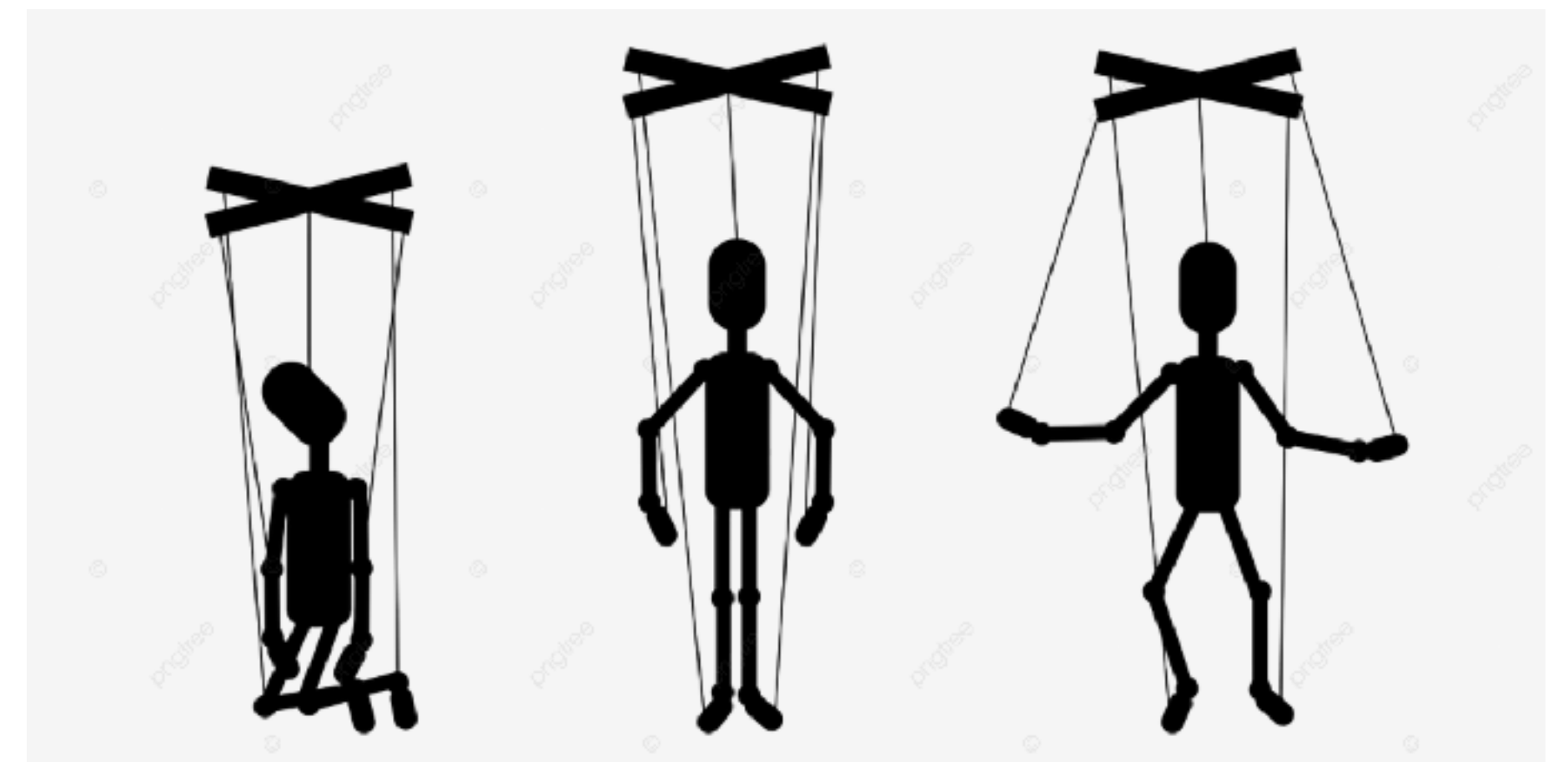
Geometrically Dynamic : Change in dynamic range.

Fishing-line style sensor array

Super Low-energy Mode (Solar ν)

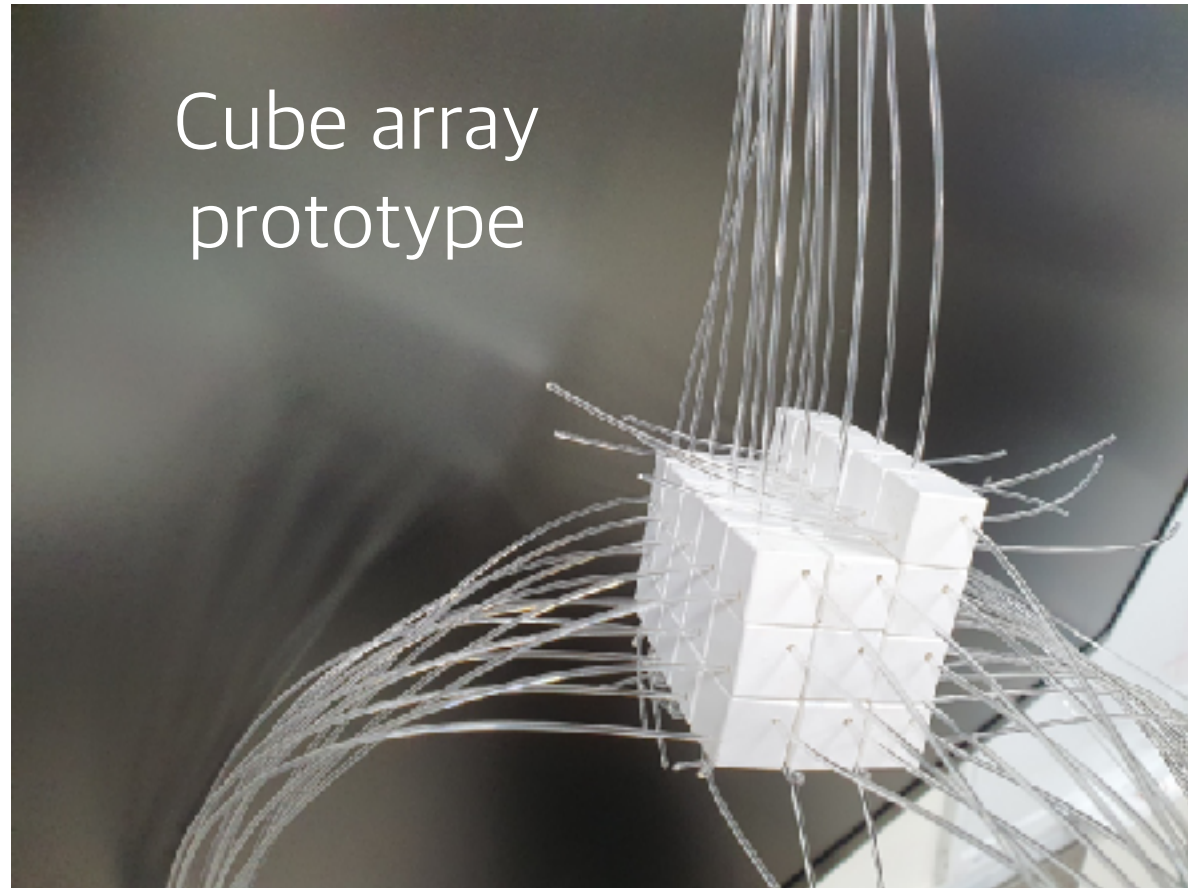
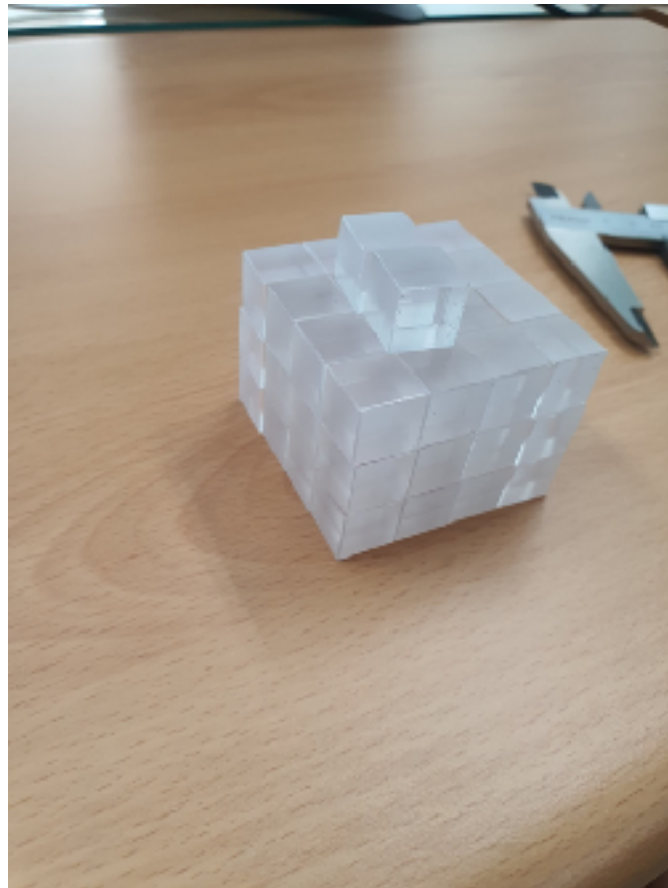
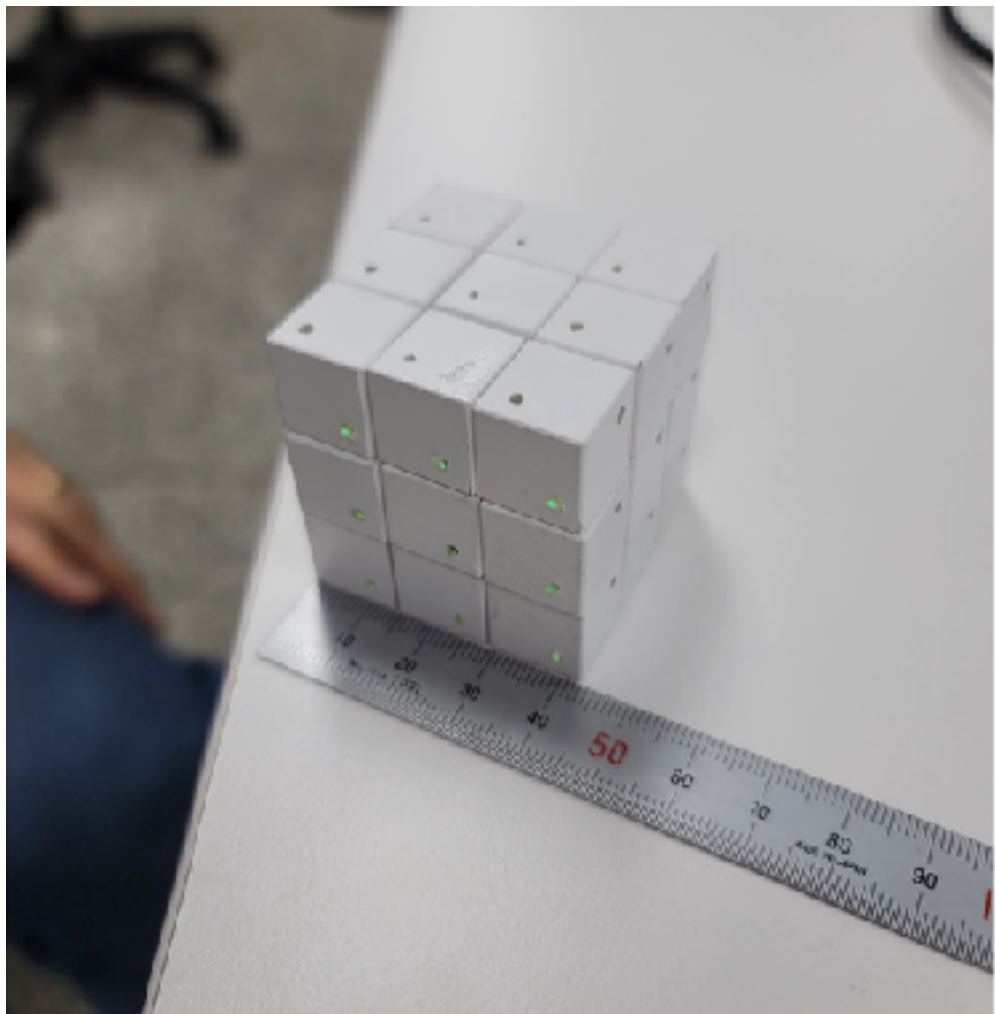
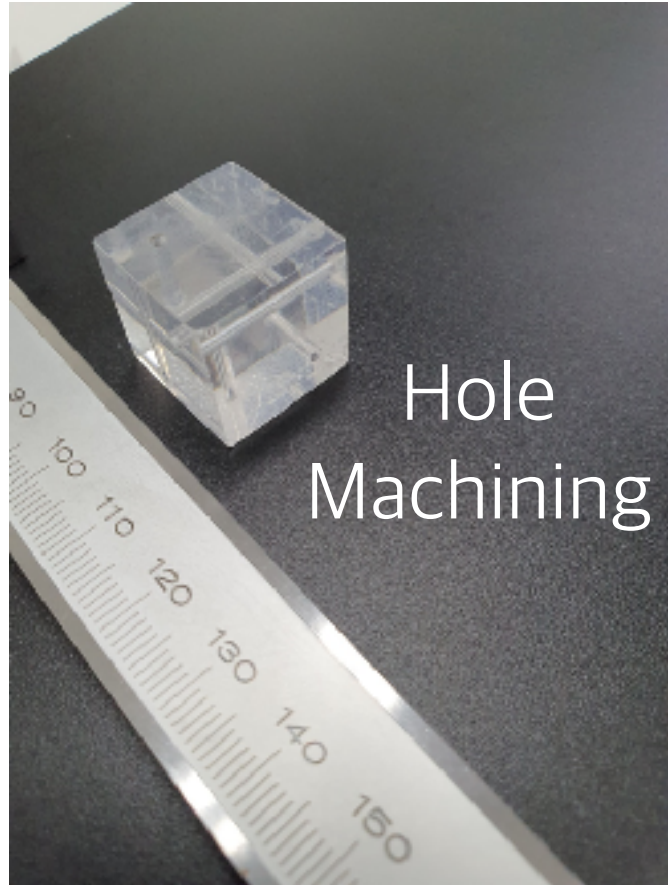


- Total Energy mainly measured by PMTs on the detector surface
- LS-embedded sensors (SiPMs or small PMTs) intercept fraction of light
- Lines can be moveable and reconfigured easily.

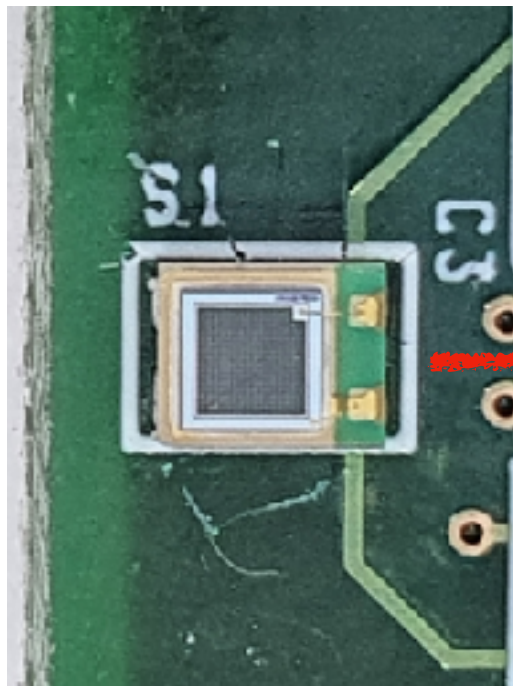


Journey to Position-sensitive detector R&Ds

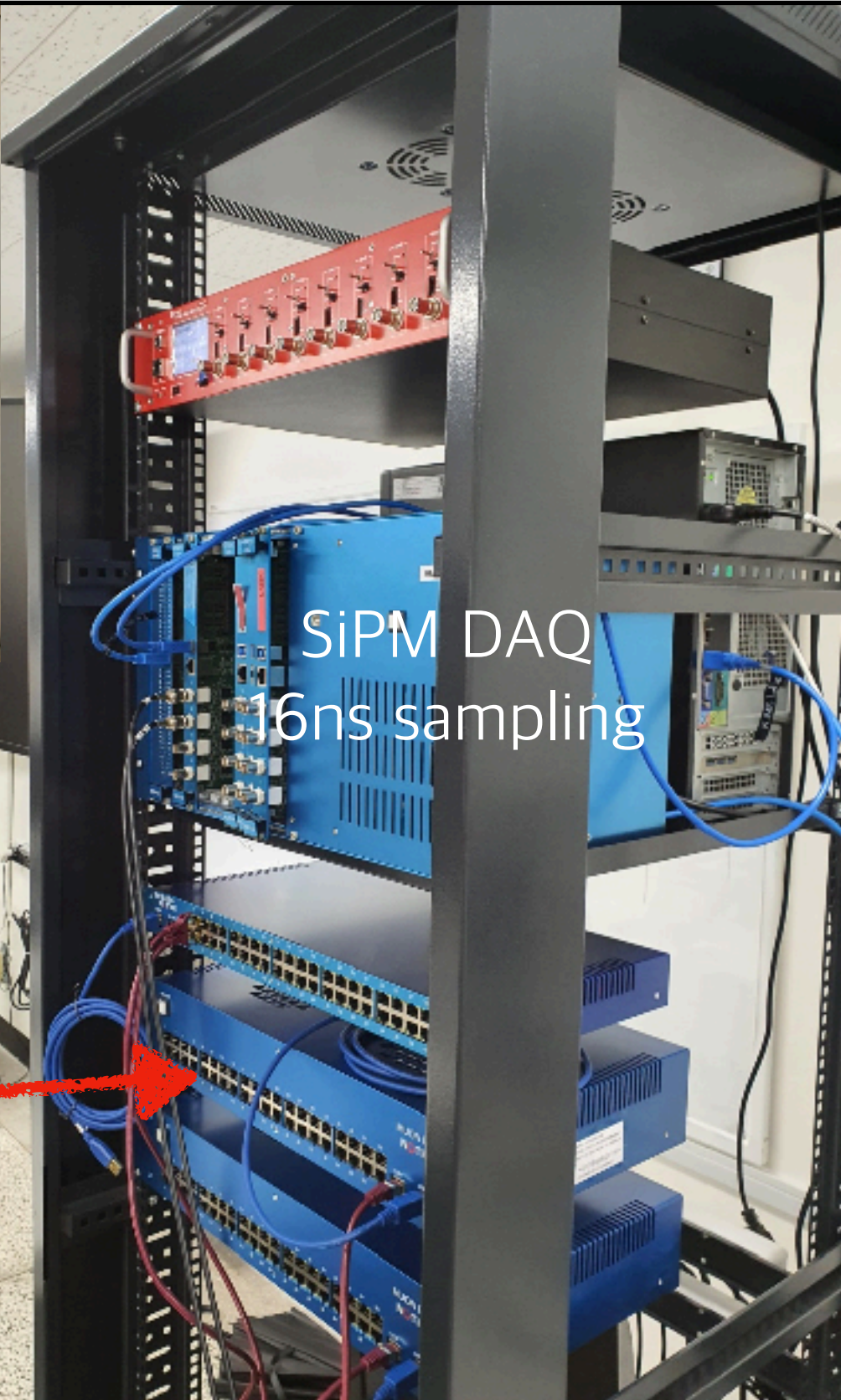
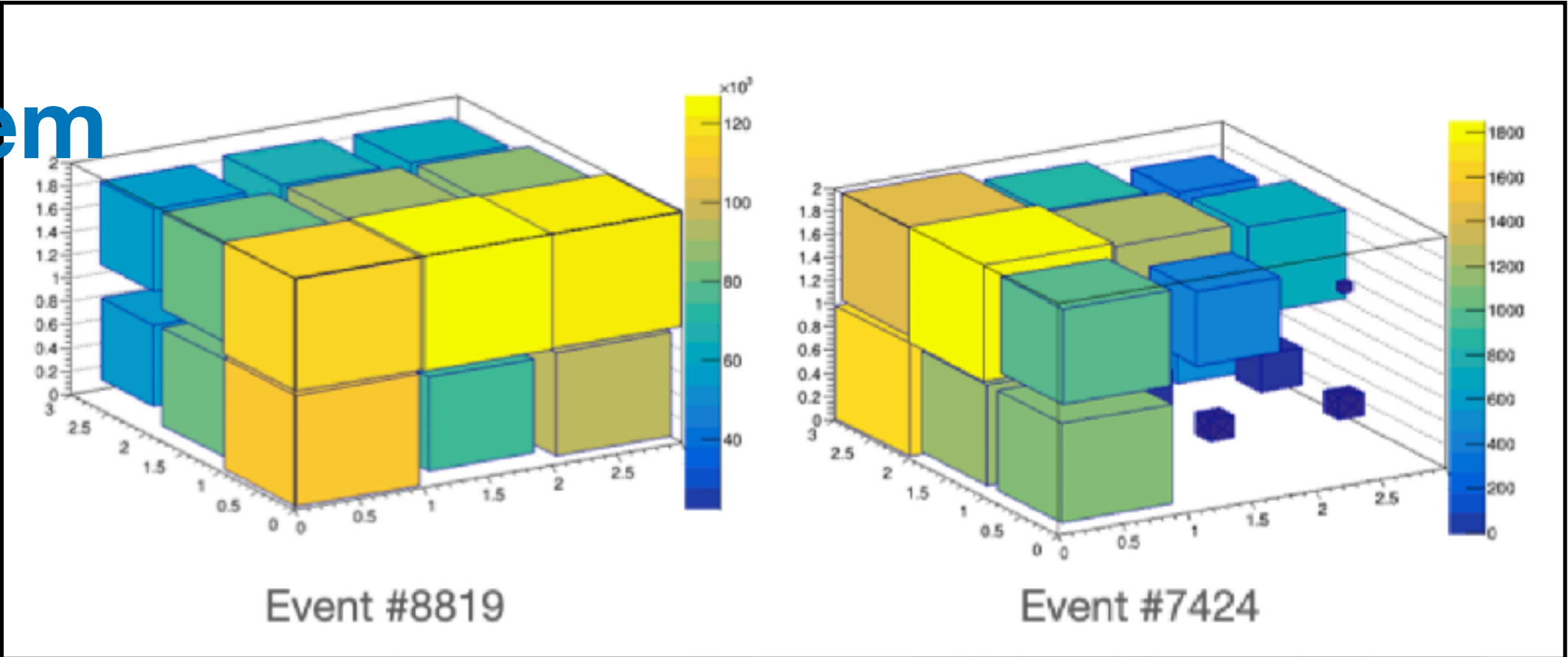
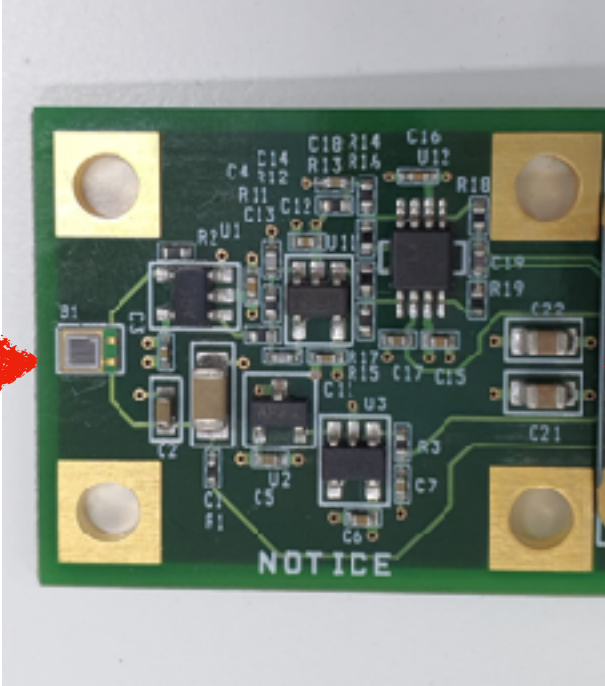
Plastic scintillator array + SiPM readout system



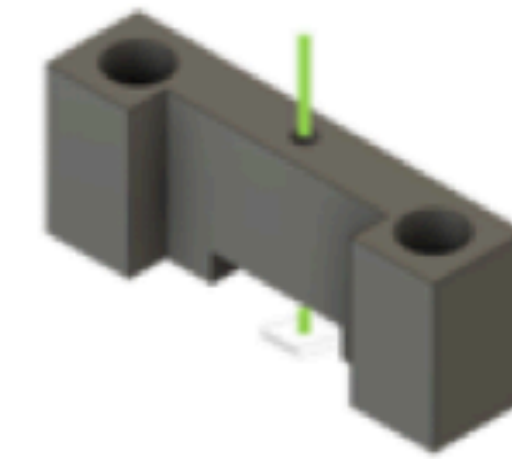
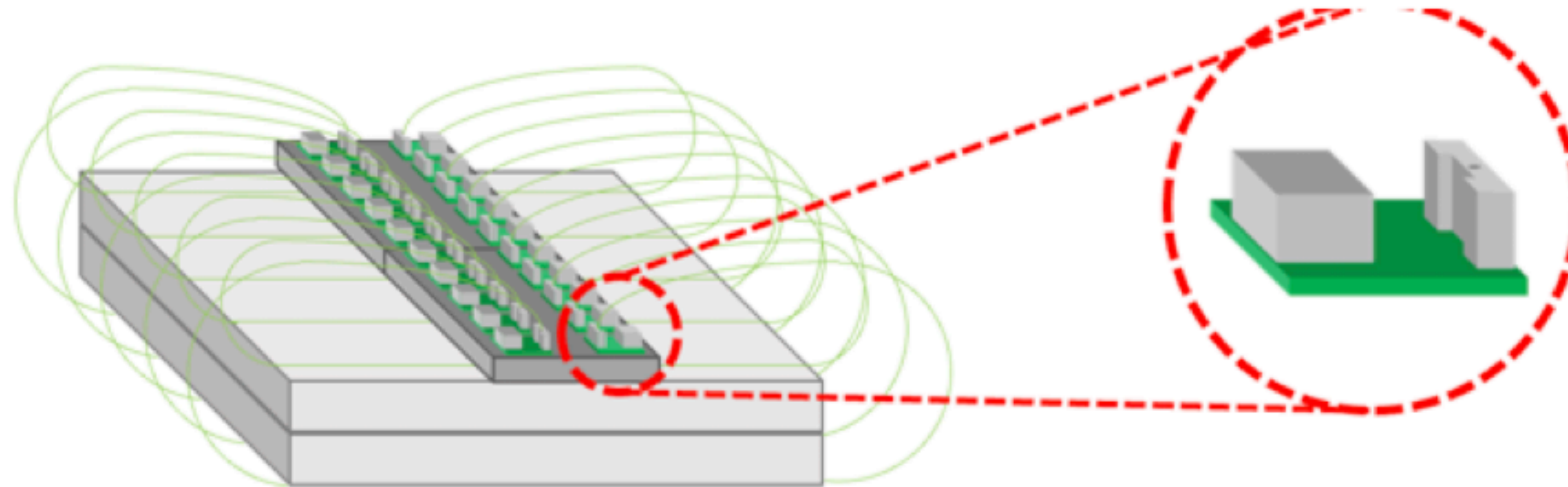
1mmX1mm SiPM



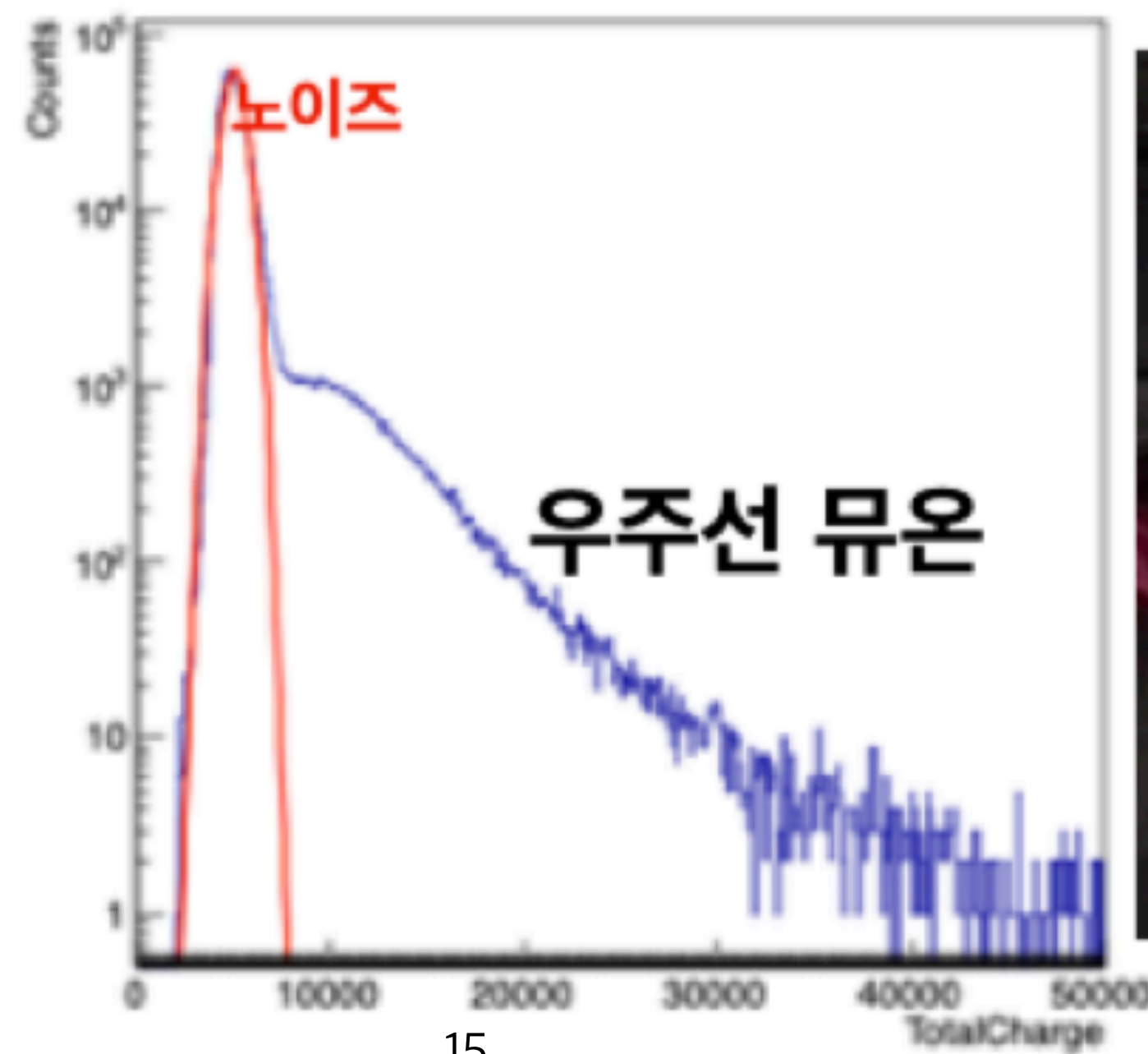
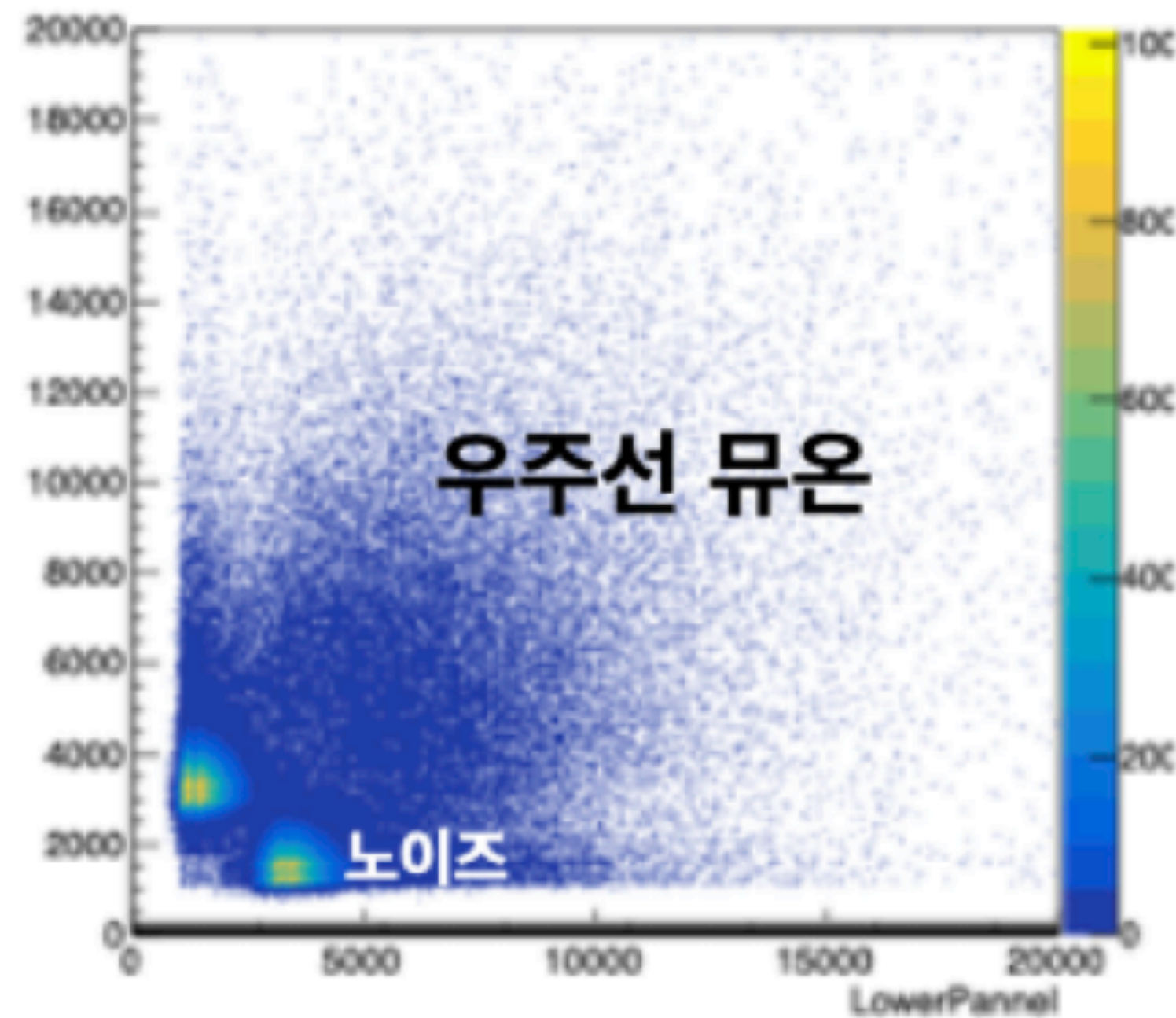
Front-end Board



Plastic Scintillator Panels with Optical Fibers

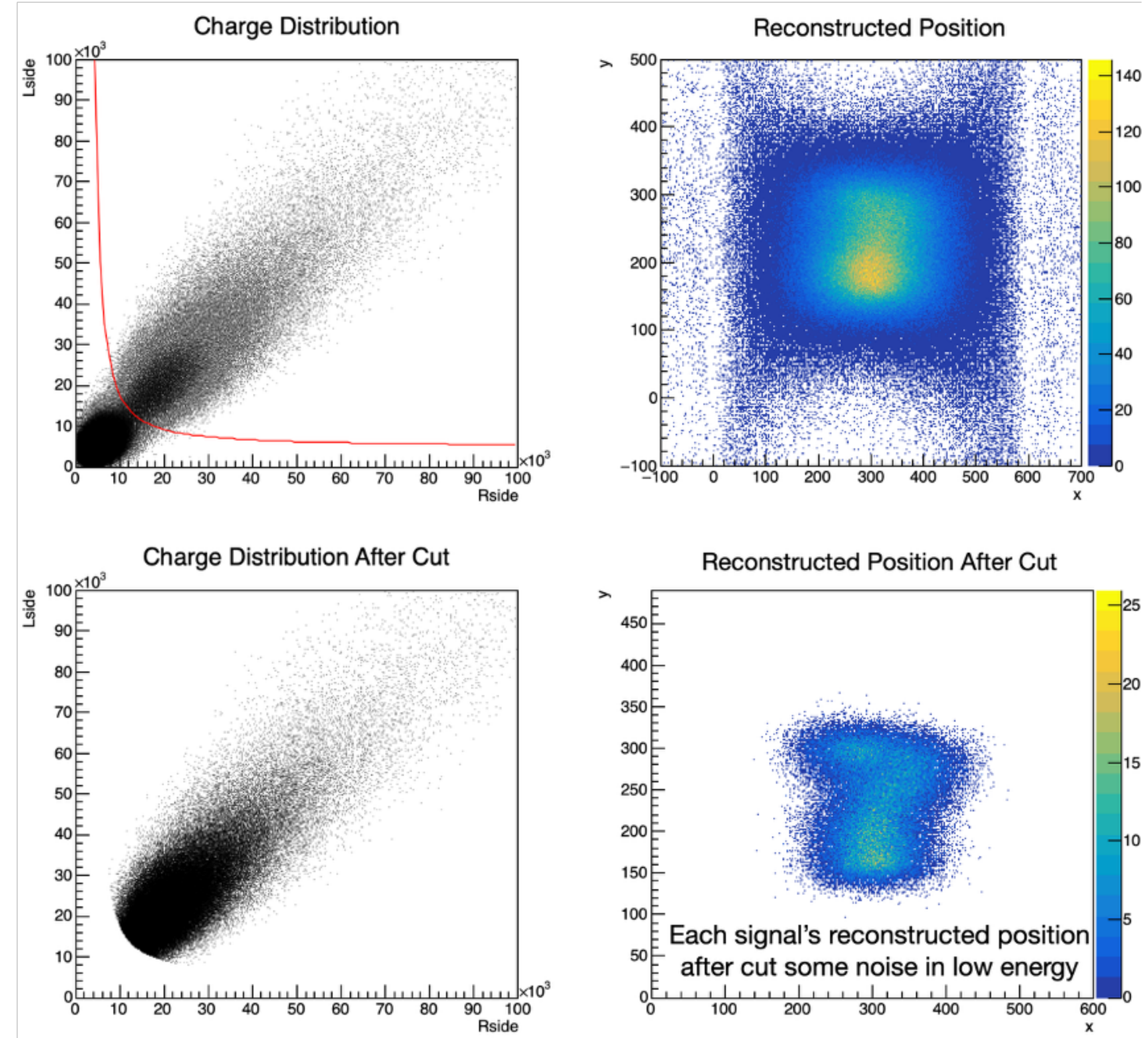
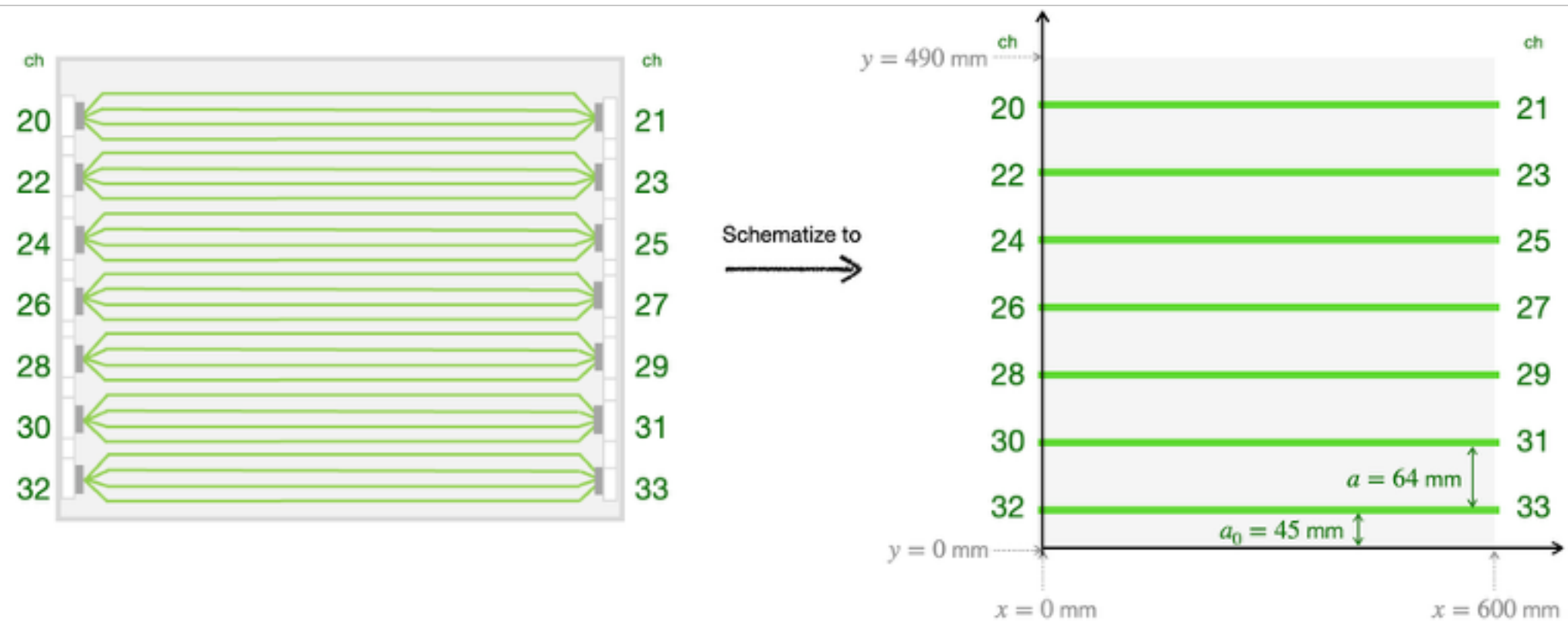
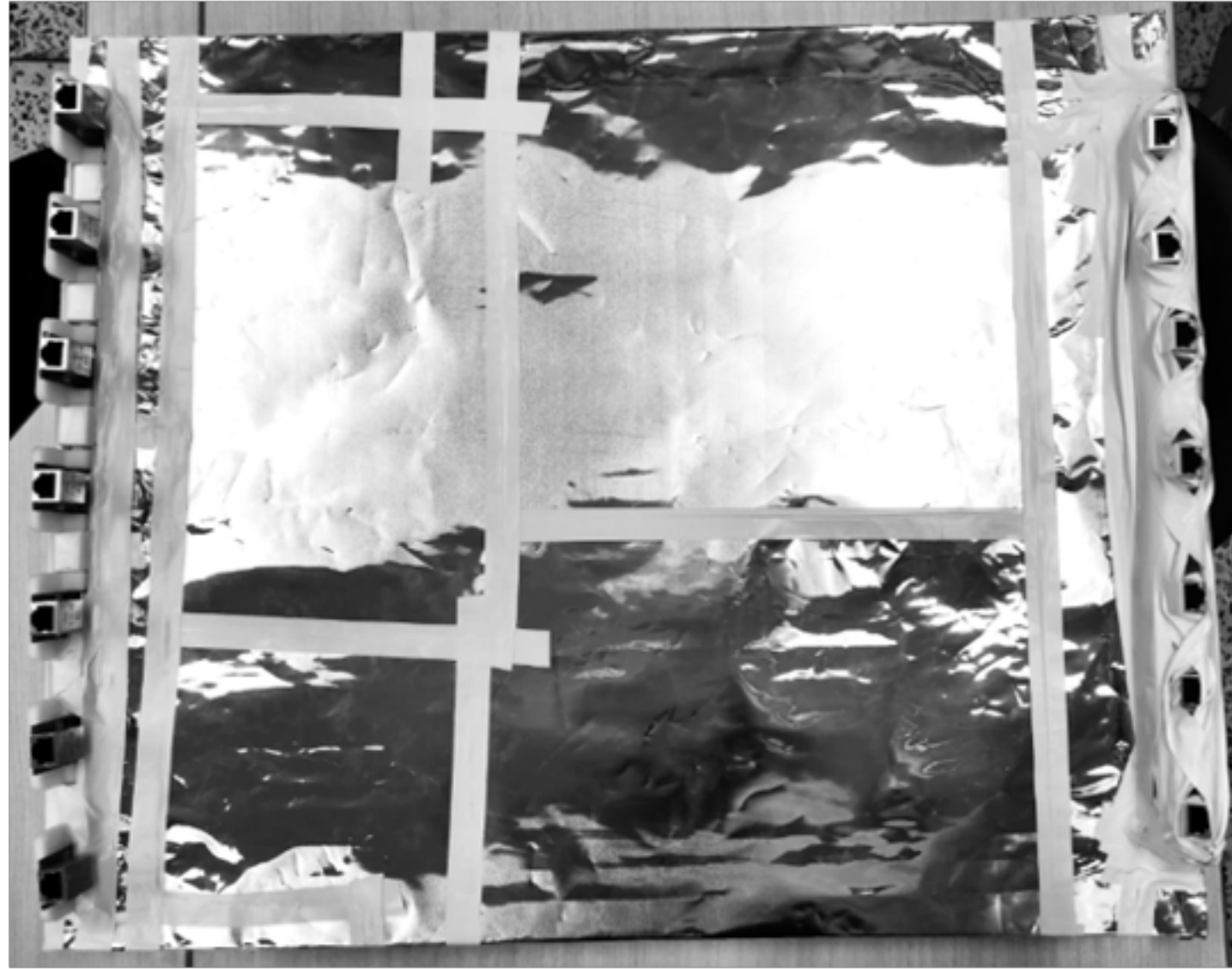


검출기 모식도



Plastic Scintillator Muon Detector v4

Study of cosmic-ray muon trajectories



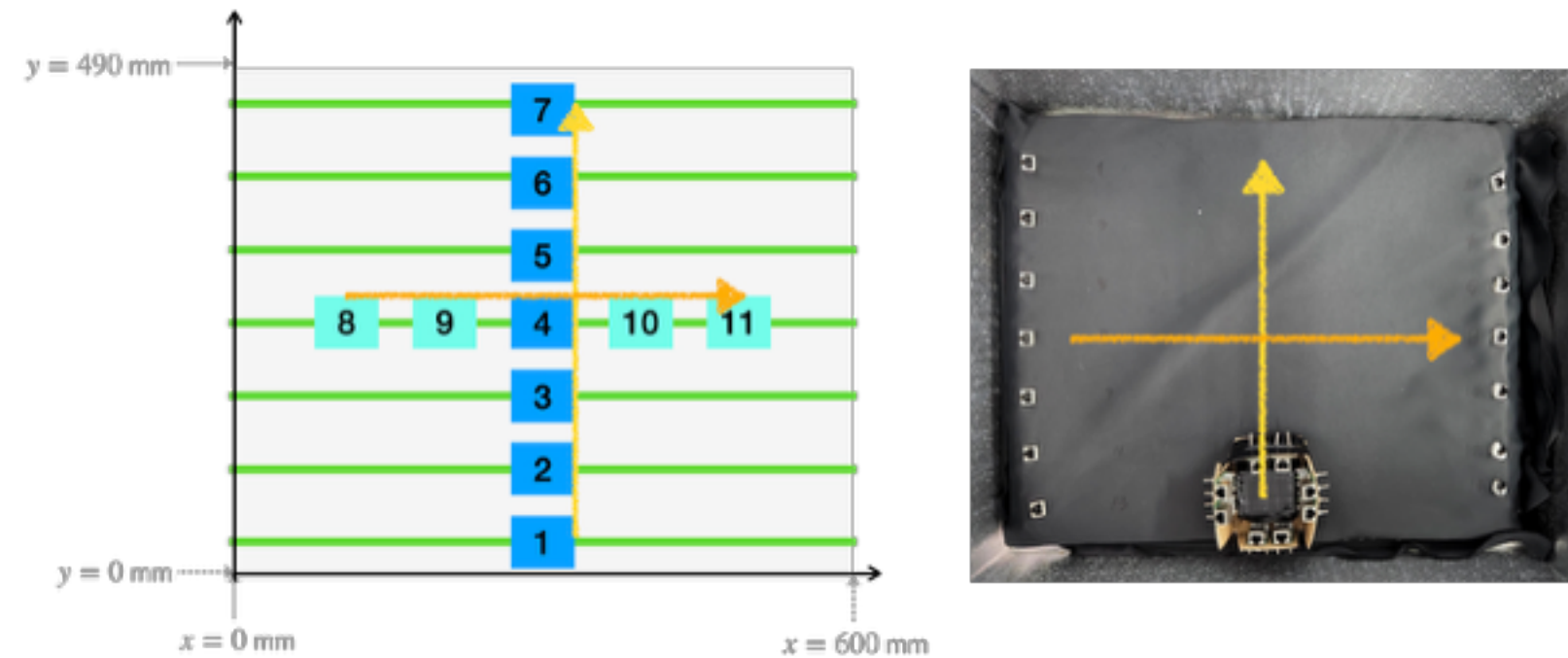
- PS panel (490mm x 600mm) + 28 WLS fibers + 14 SiPMs
- Calculate the center of gravity of charge from each SiPM to reconstruct the muon incident position

Position-resolution estimates

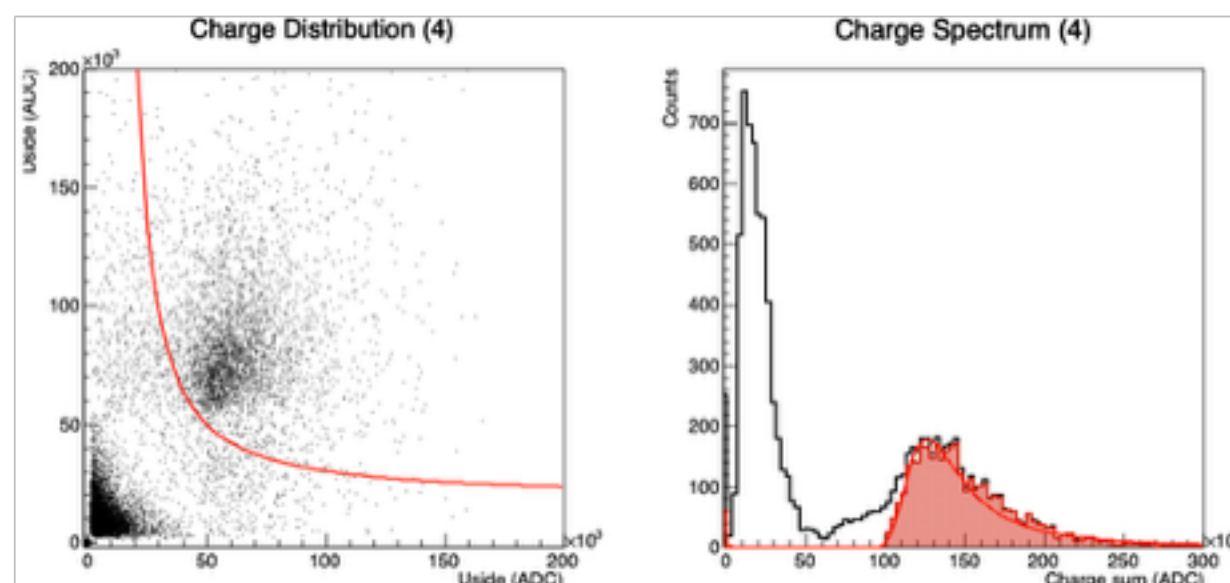
- Two PS pieces (PS : Fermilab sample)
- The dimension of trigger detector : 62.5mm x 51.2 mm



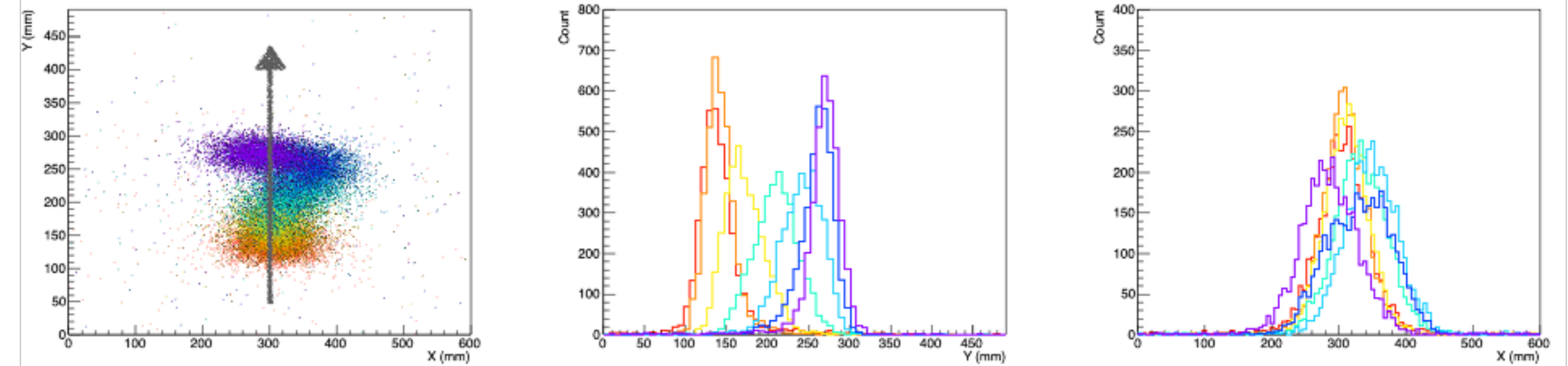
- Moving the trigger detector along X or Y axis
- Only the trigger detector participate in trigger



- Muon Event Selection

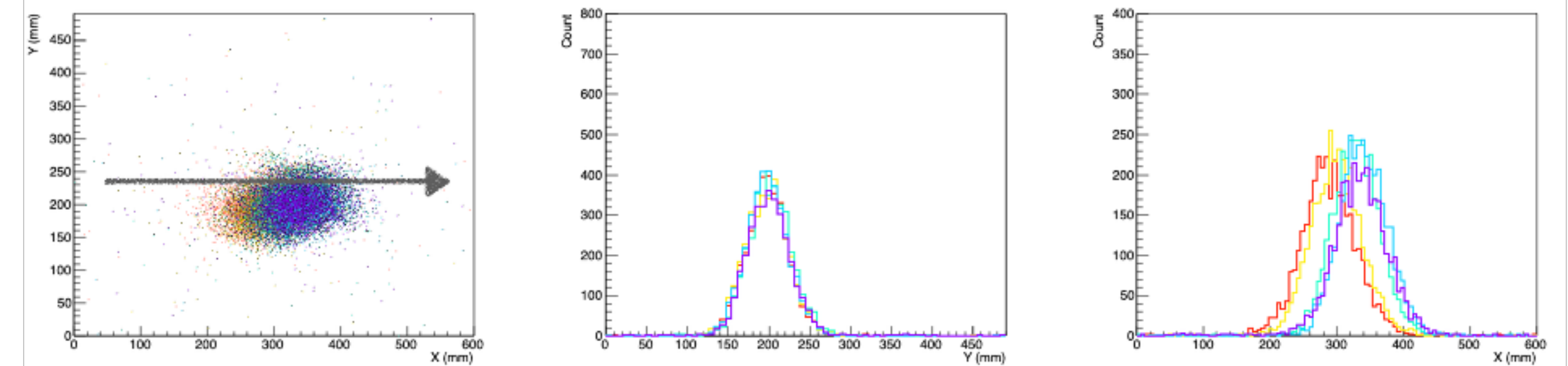


Move along the Y-axis



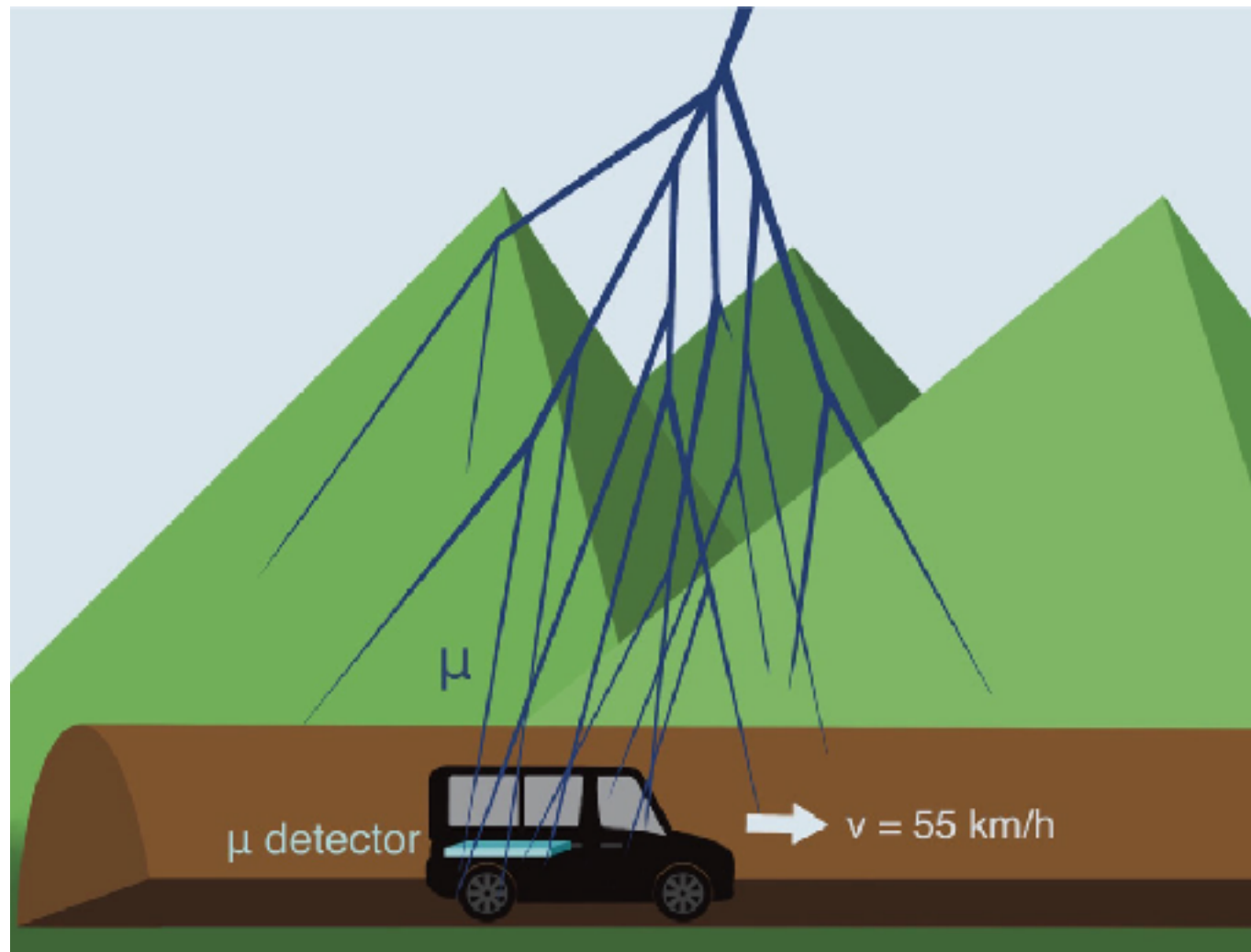
- Different color with different real position of the trigger detector
- Resolution of Y-axis = 24.20 ± 0.17 mm (calculated with only three point)
- Resolution of X-axis = 38.07 ± 0.19 mm

Move along the X-axis



- Different color with different real position of the trigger detector
- Resolution of Y-axis = 24.20 ± 0.17 mm
- Resolution of X-axis = 38.07 ± 0.19 mm

Muon Tomography



- Simple and compact Cosmic Ray muon detector using SiPMs
- Easily Portable Detector with custom DAQ under 68 Watt. power consumption
- Rugged detector with a good PID
- Wide Area Mapping in short measurement duration.
- Position-sensitive detector.
- Educational Demonstration (Real-time data displays)



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journal homepage: www.elsevier.com/locate/radphyschem

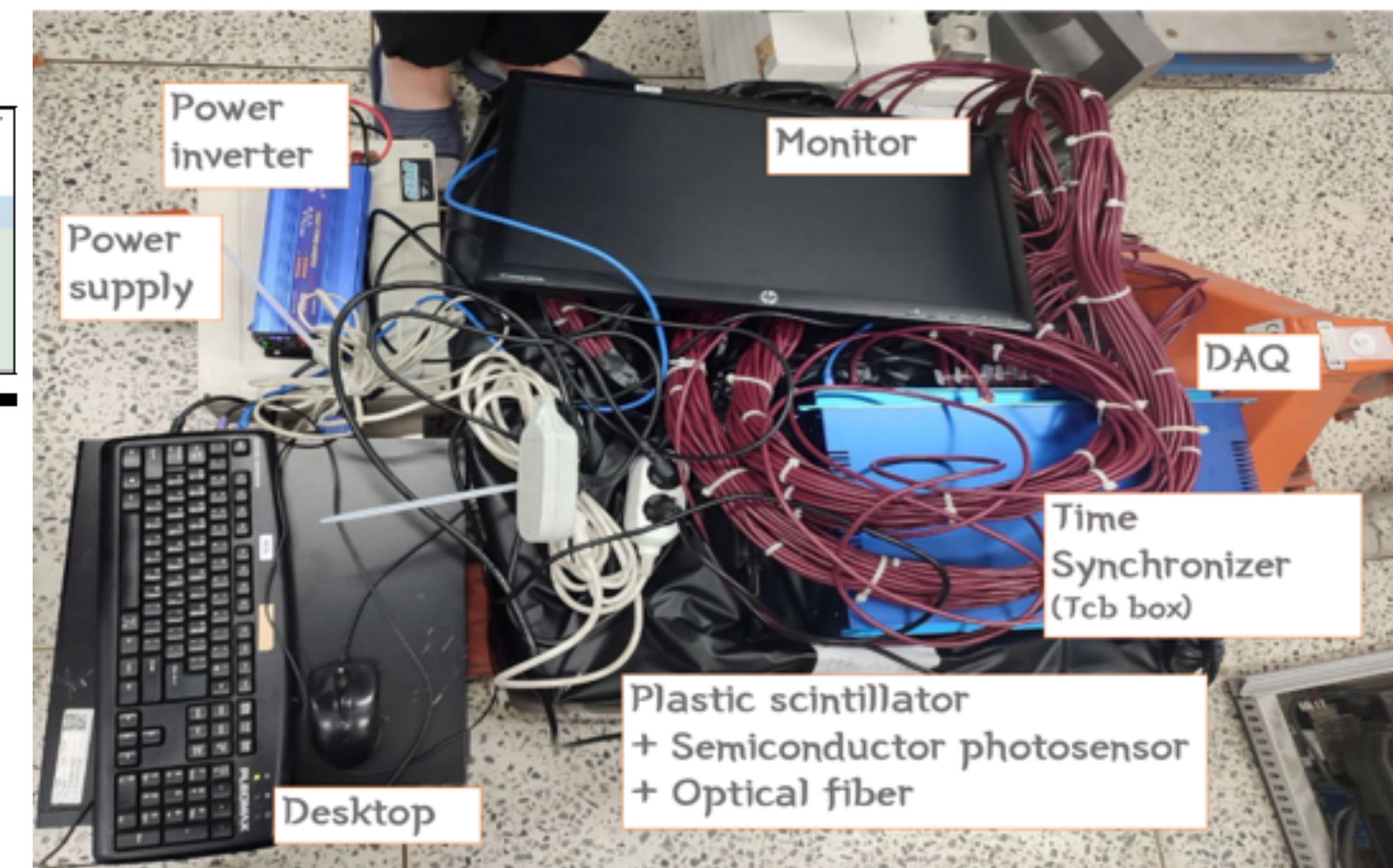


Real-time portable muography with Hankuk Atmospheric-muon Wide Landscaping : HAWL

J. Seo^a, N. Carlin^b, D.F.F.S. Cavalcante^b, J.S. Chung^a, L.E. França^b, C. Ha^{a,*}, J. Kim^a, J.Y. Kim^a, H. Kimku^a, B.C. Koh^a, Y.J. Lee^a, B.B. Manzato^b, S.W. Oh^a, R.L.C. Pitta^b, S.J. Won^a

^a Department of Physics, Chung-Ang University, Seoul, 06974, Republic of Korea

^b Physics Institute, University of São Paulo, São Paulo, 05508-090, Brazil



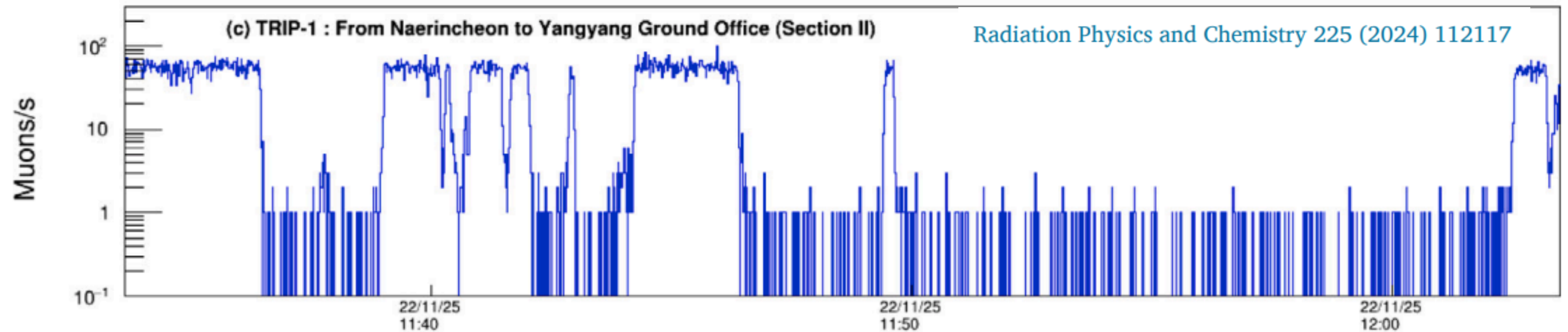
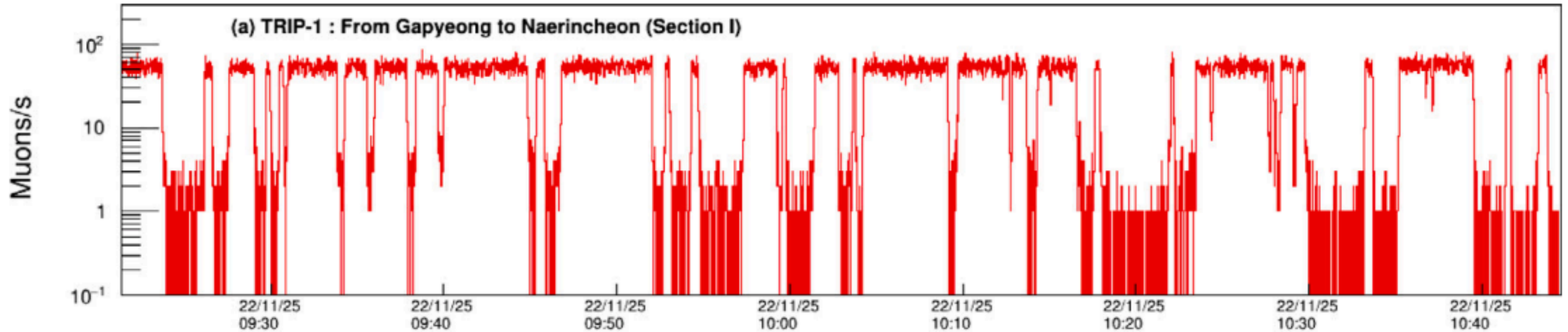
Hankuk Atmospheric-muon Wide Landscaping (HAWL)



Hankuk Atmospheric-muon Wide Landscaping (HAWL)

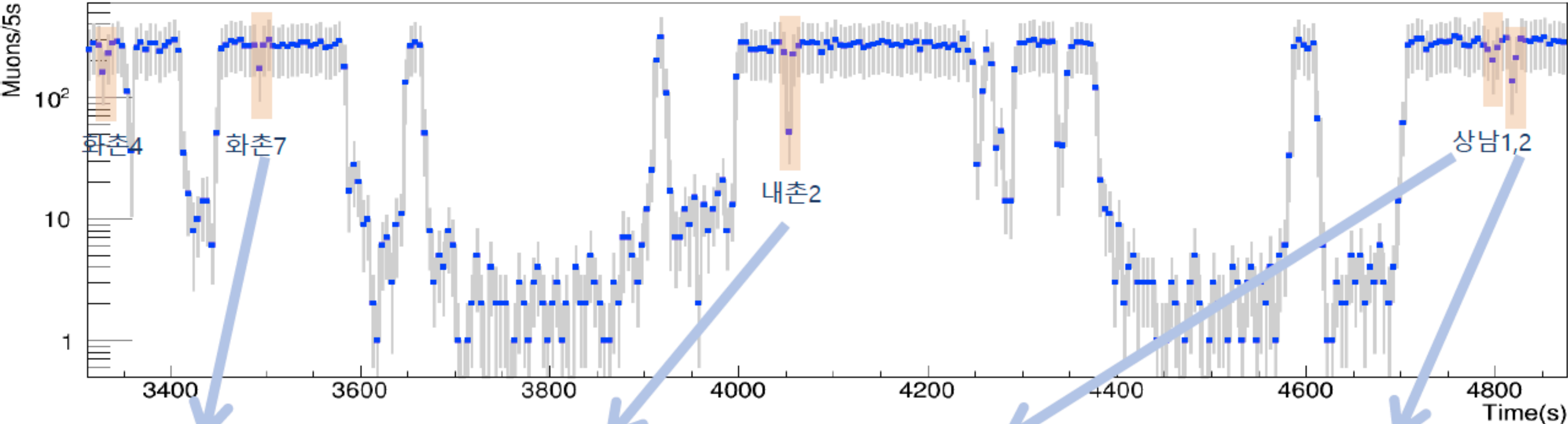


All highway tunnels (47 structures) are mapped within two hours

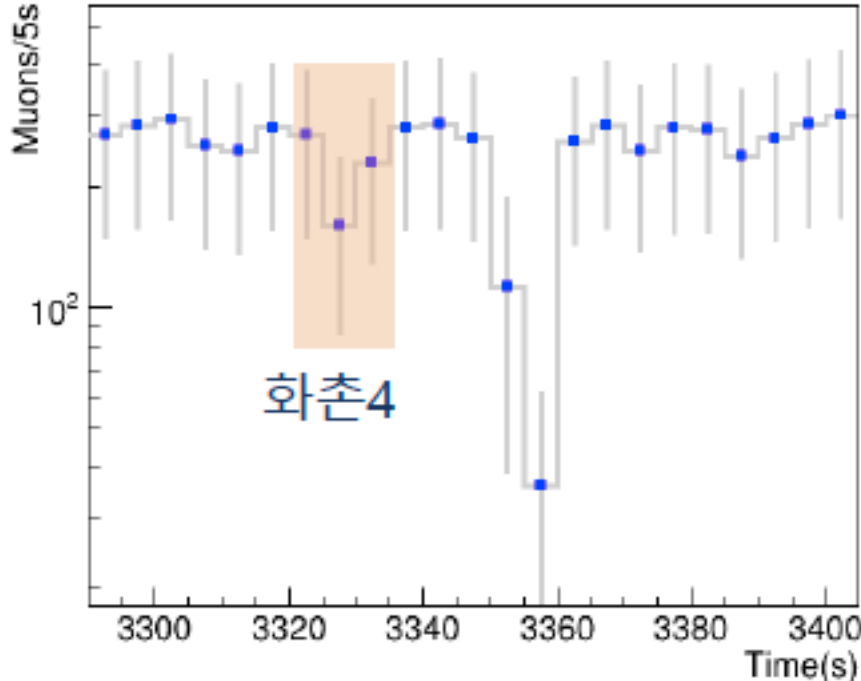


Length relation (small tunnels)

Interval1(Ga-Pyung to Inje IC)



The Shortest tunnel



Hwachon4

34m

Hwachon7

38m

Naechon2

75m

Sangnam1

60m

Sangnam2

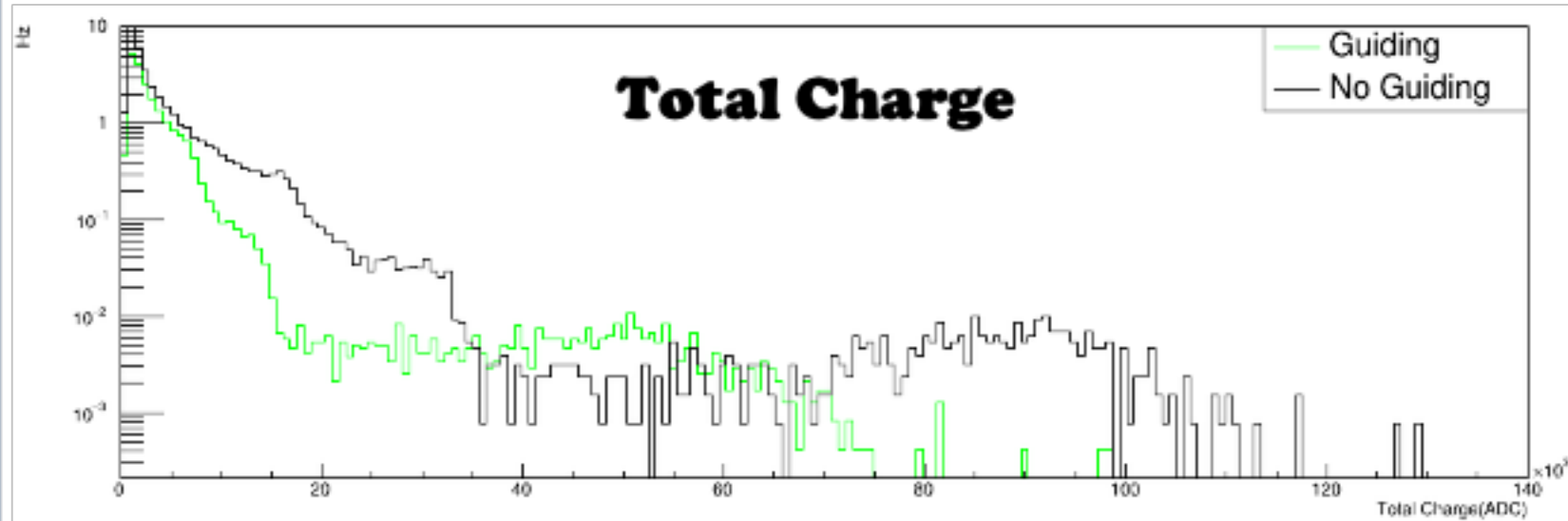
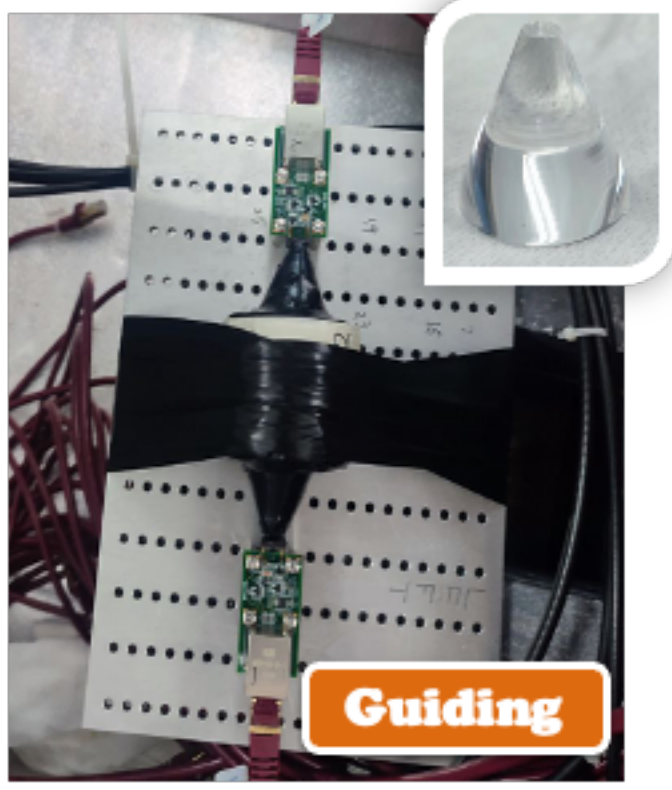
110m

2m

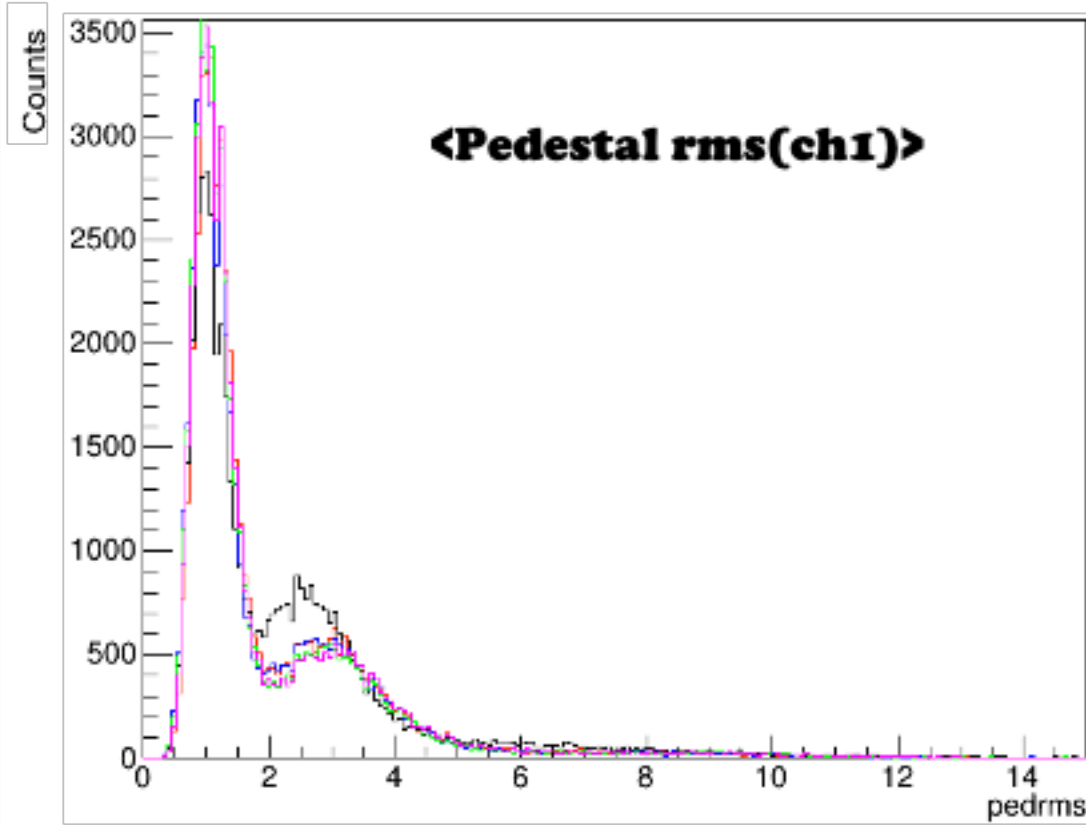
2m

Transition towards no fibers and SiPM array

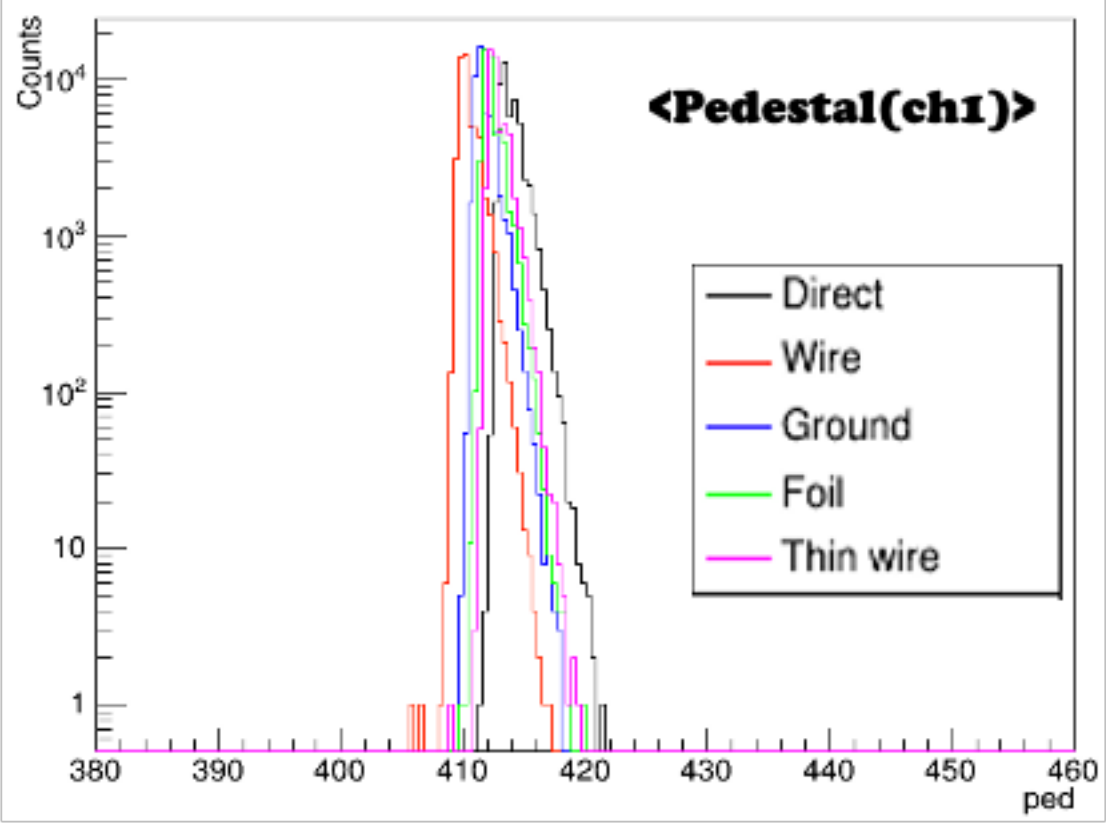
1. Guiding



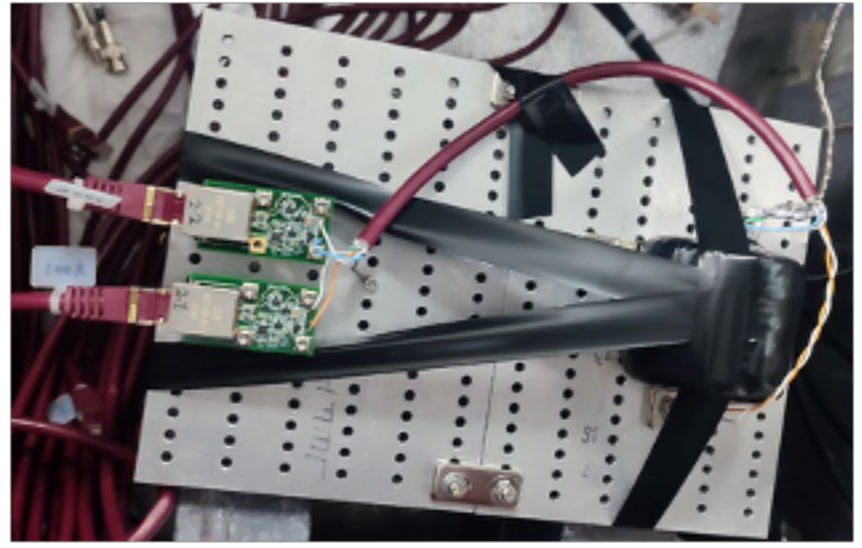
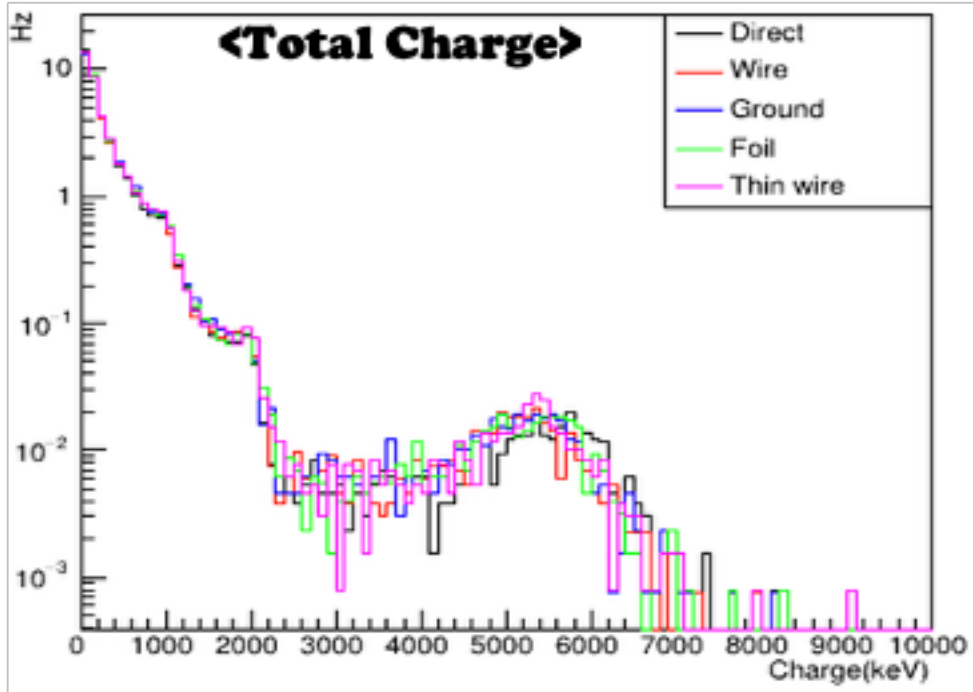
2. Wire



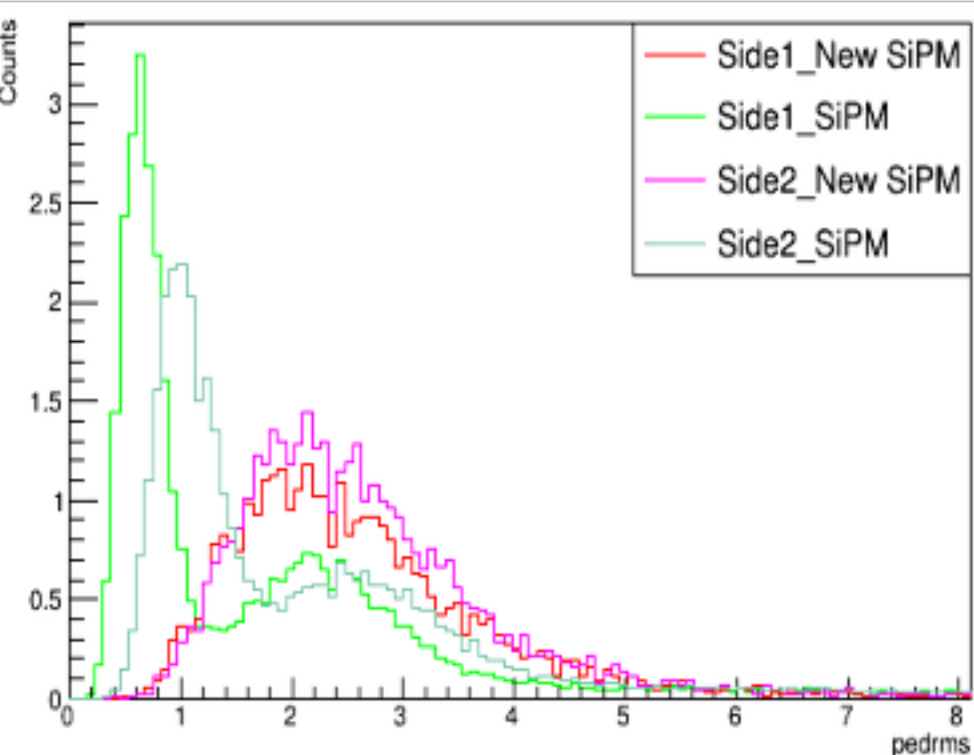
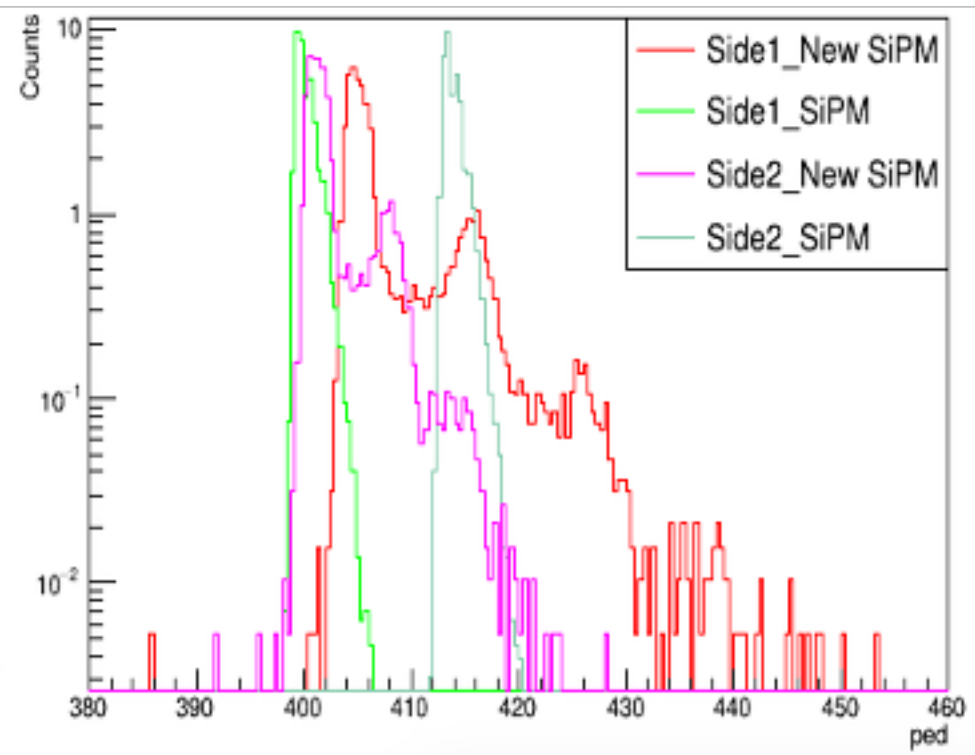
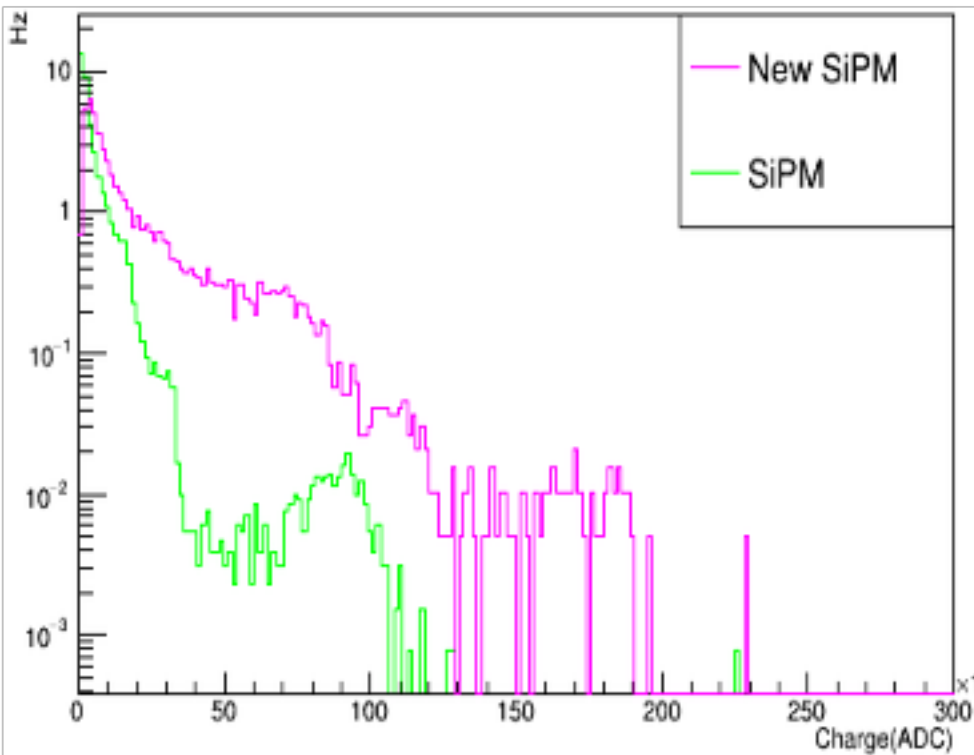
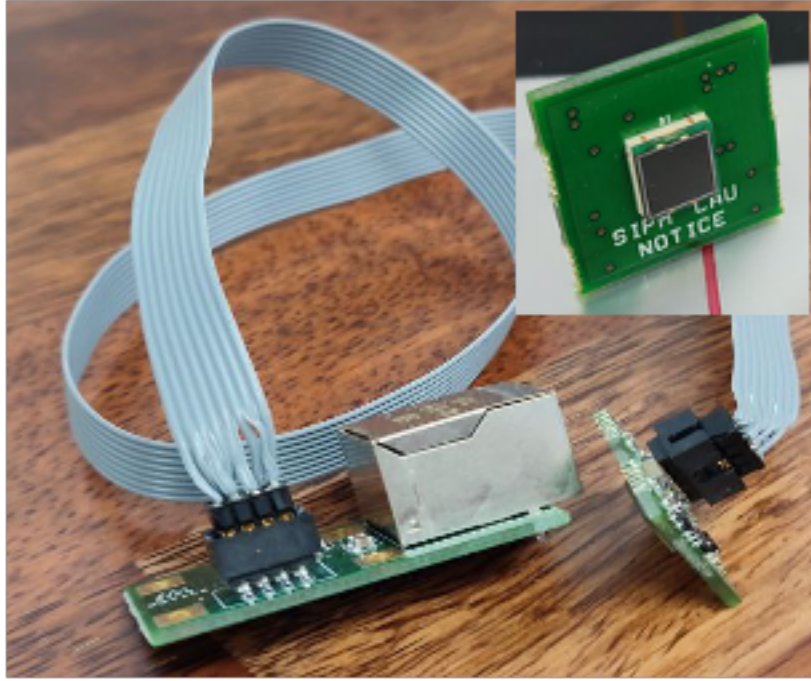
	Direct	Wire	Ground	Foil	Thin
mean	2.26	2.047	2.013	1.973	2.034
rms	1.903	1.698	1.73	1.734	1.775



	Direct	Wire	Ground	Foil	Thin wire
mean	413.9	410.4	411.8	412.4	412.9
rms	0.9512	0.8199	0.8228	0.7950	0.7998



3. New SiPM board



HAWL Upgrade

HAWL upgrade detector

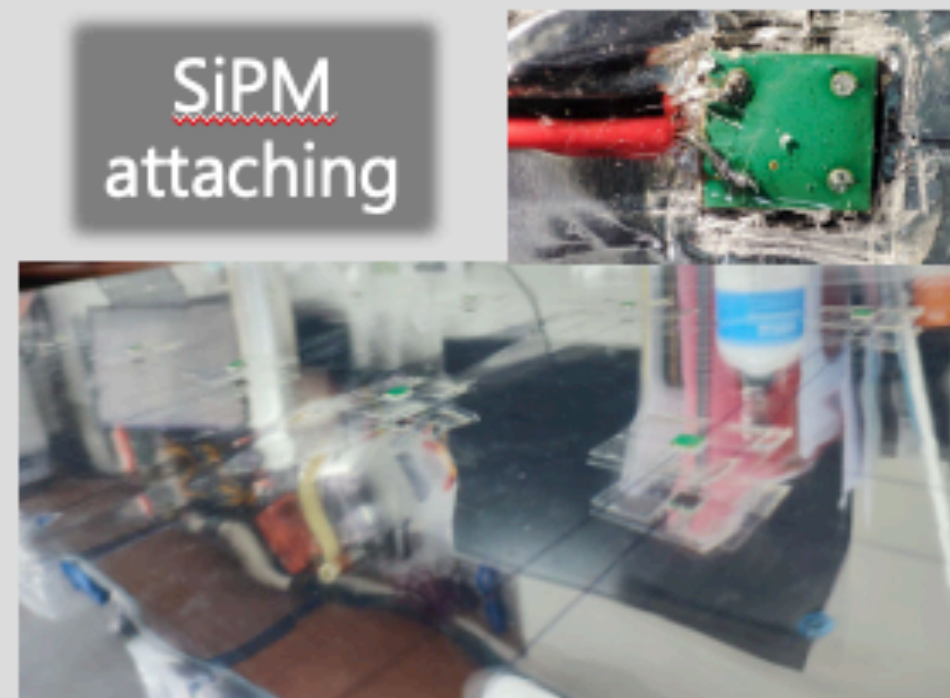
Shielding



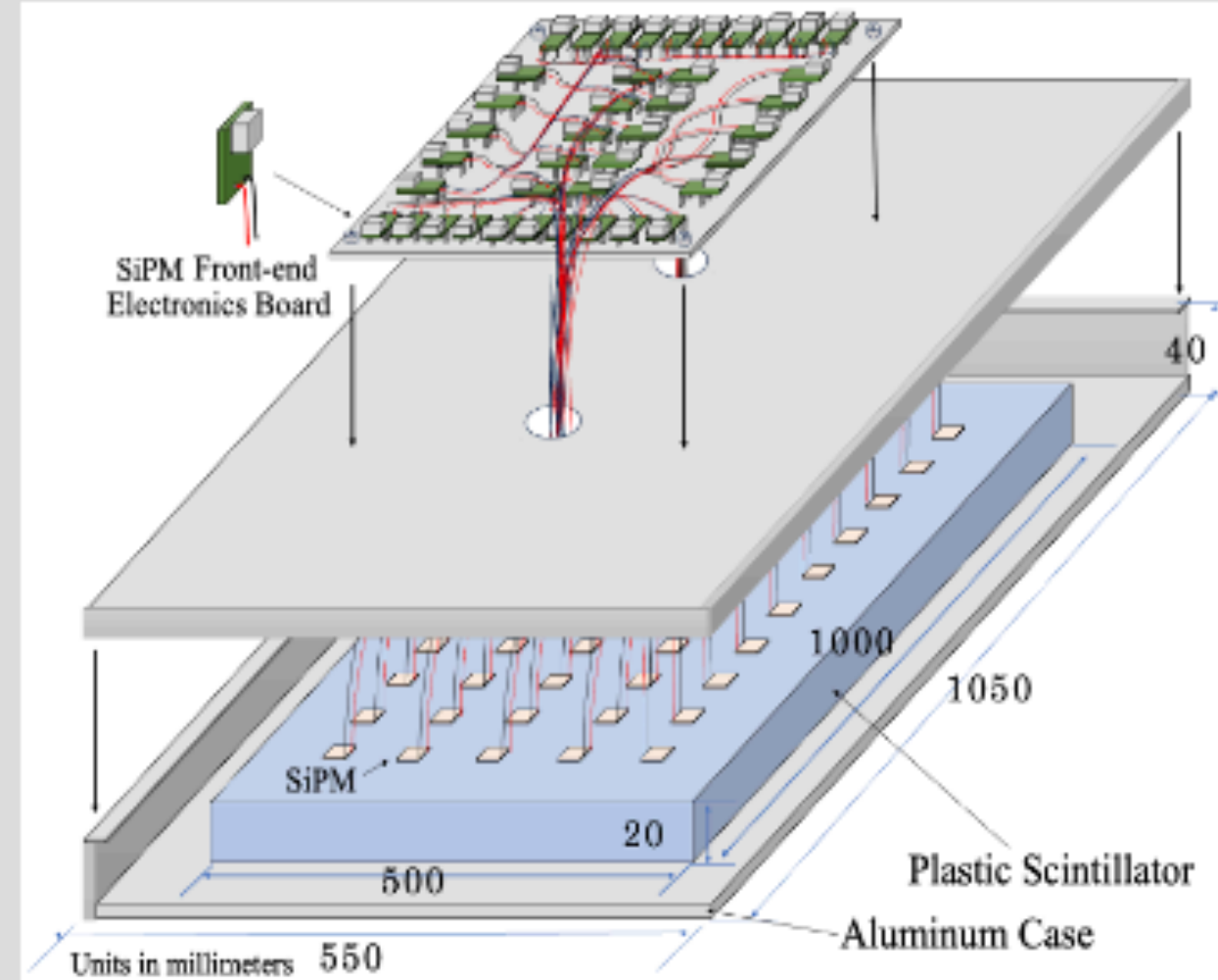
Front-end board



SiPM attaching

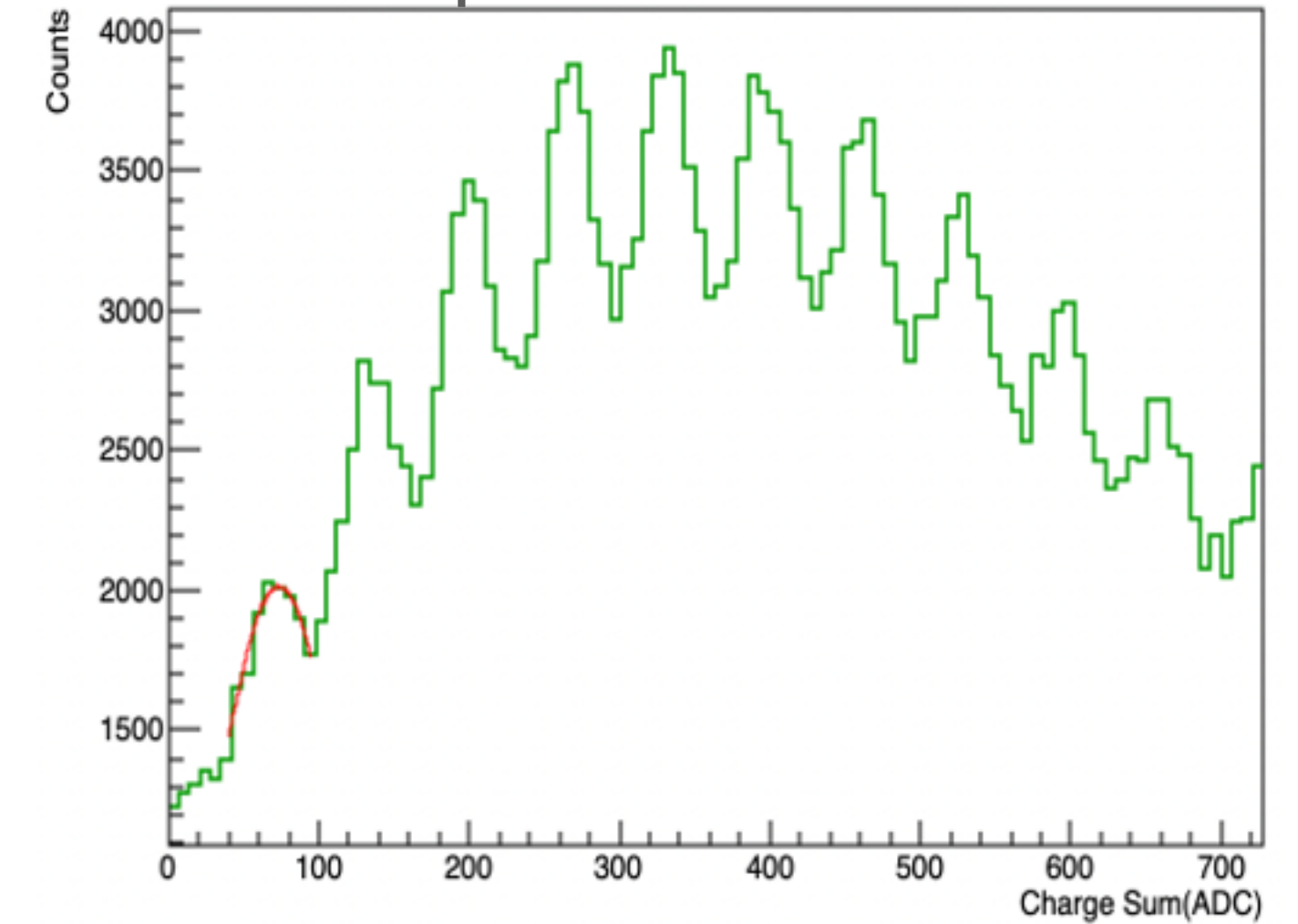


Blueprint

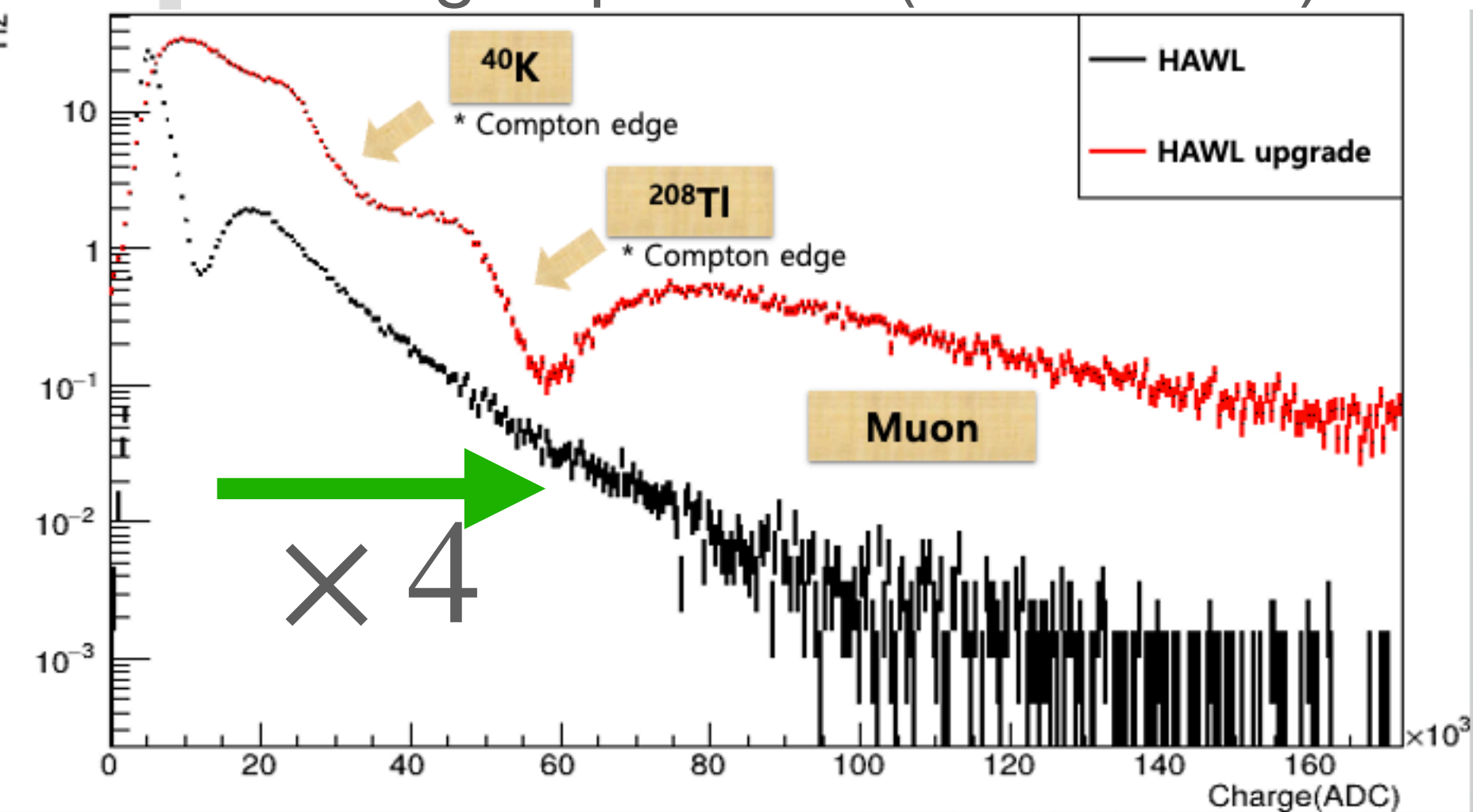


→ HAWL upgrade will use **two panels** to **positioning**.
Upper panel is being manufactured.

SPE Spectrum for 1 SiPM

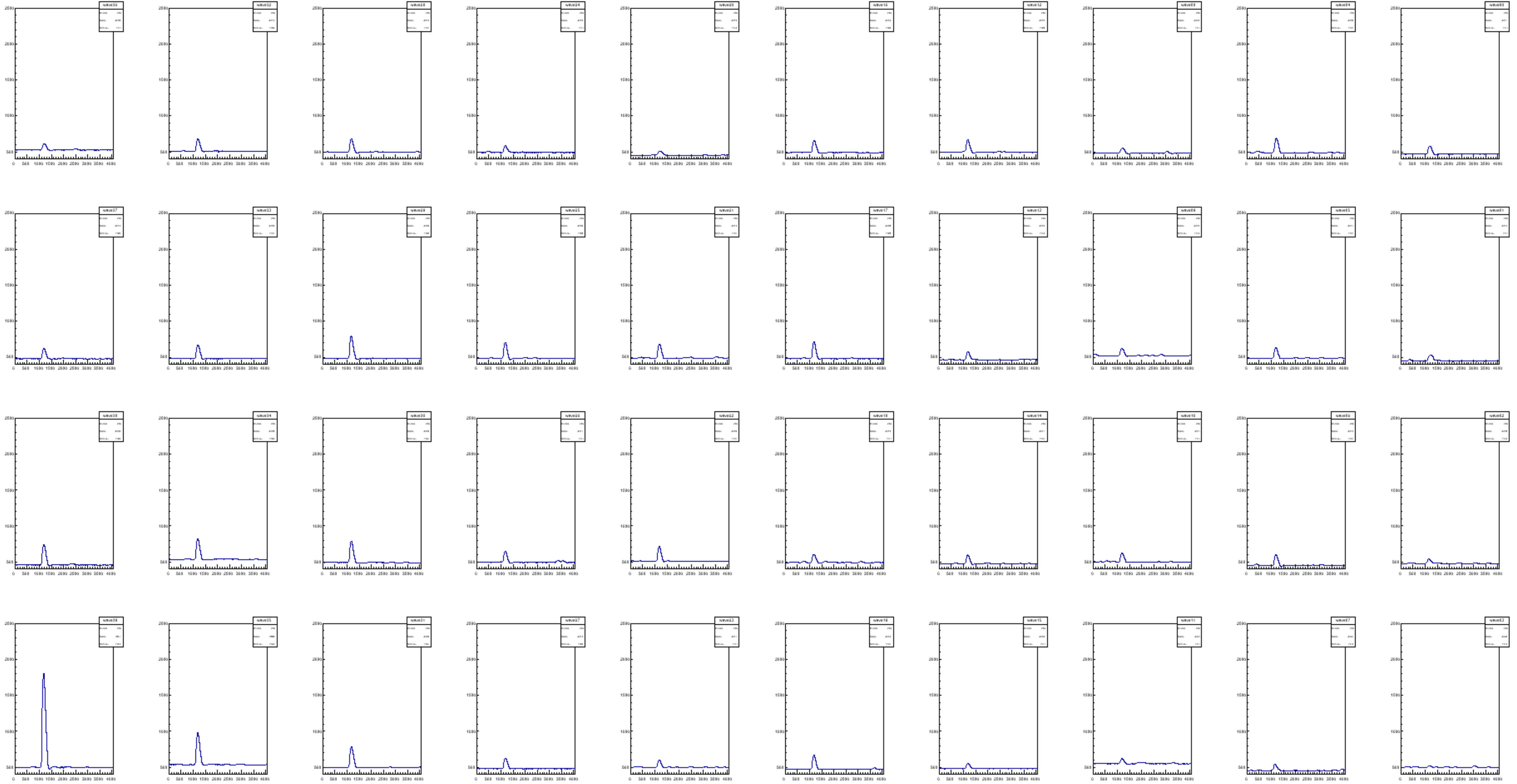


Charge Spectrum (x4 increase)



- New Panel (Larger area $0.3m^2 \rightarrow 0.5m^2$)
- Large SiPM coverage ($1mm^2 \rightarrow 36mm^2$)
- Direct attachment to the scintillator (No fibers)
- Position Sensitivity

- Boryeung Undersea Tunnel (Earthquake warning)
- Subway (Sink hole)
- Ulleungdo Lava bed (Volcano)



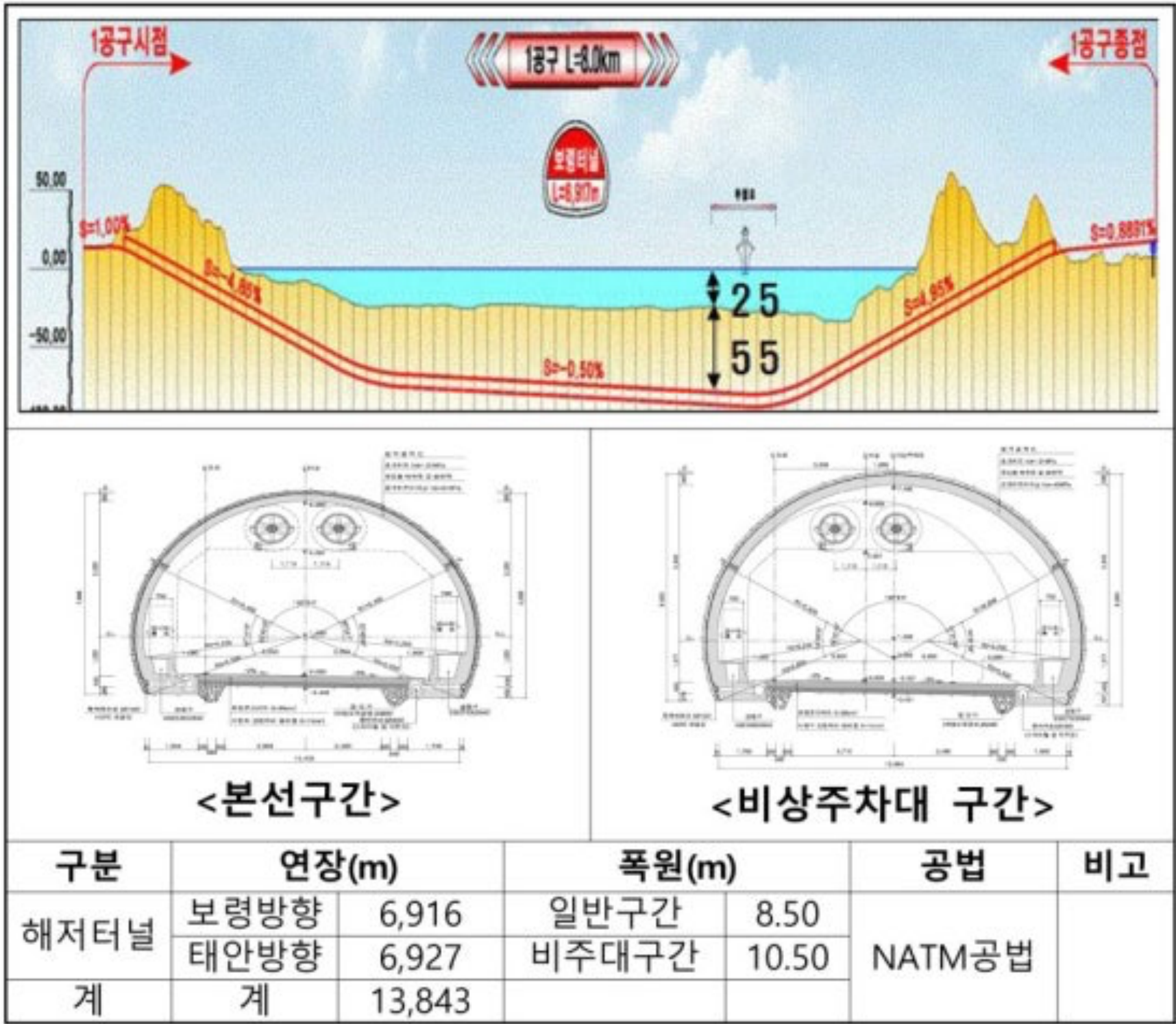
HAWL Upgrade Trip : Boryoung Tunnel

- Next Destination- Currently Detector testing and communications with Ministry of Land, Infrastructure and Transport
- World 5th longest undersea tunnel
- West Sea Tide : One of the largest in the world (~10m max)
- Tsunami Early Warning system using HAWL



□ 보령 해저터널 제원

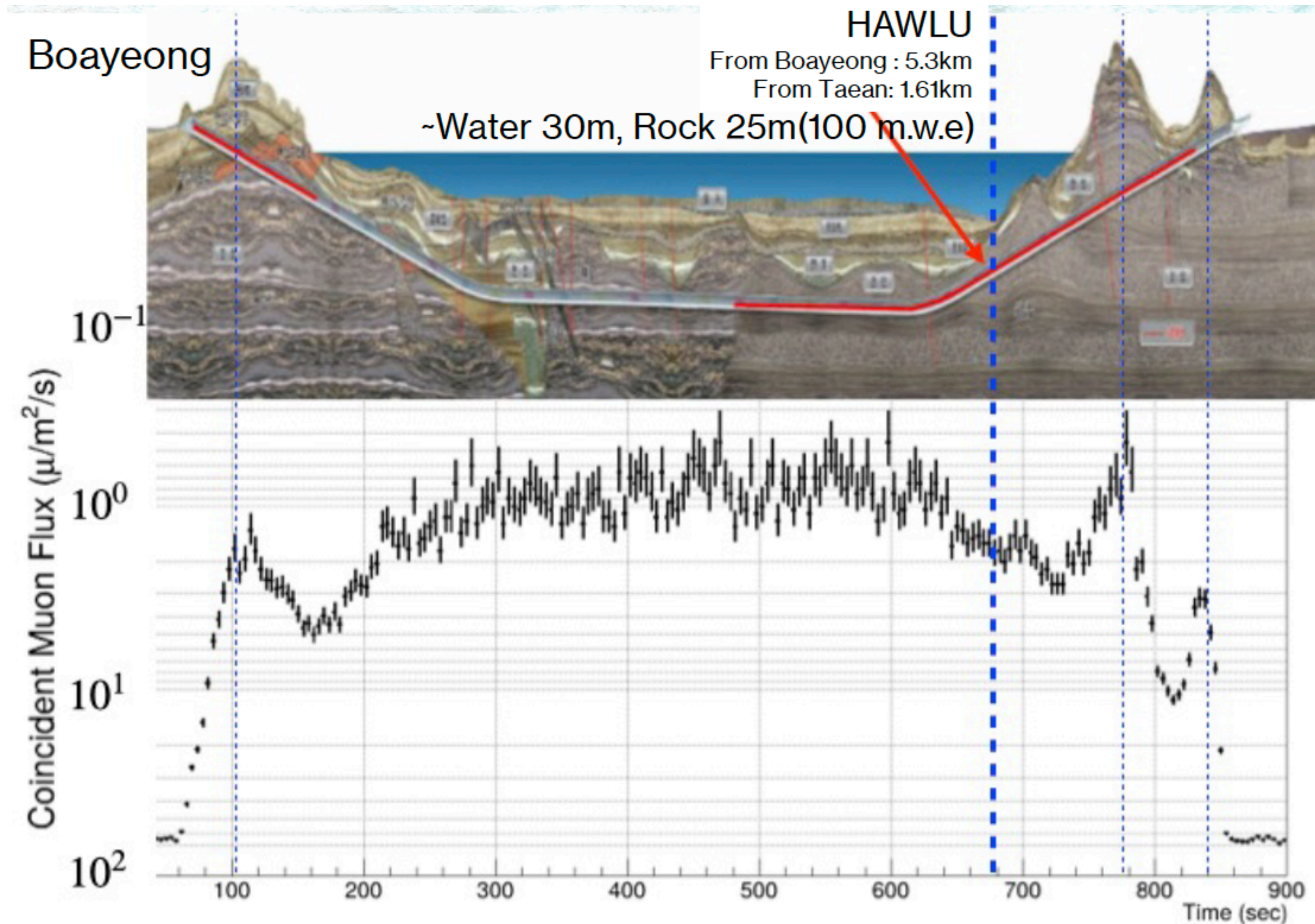
- 연 장 : L=6,927m(해저구간 5,209m), B=8.5m(2차로 병렬)
- 수 심 : 평균 해수면에서 터널상단까지 최대 80m



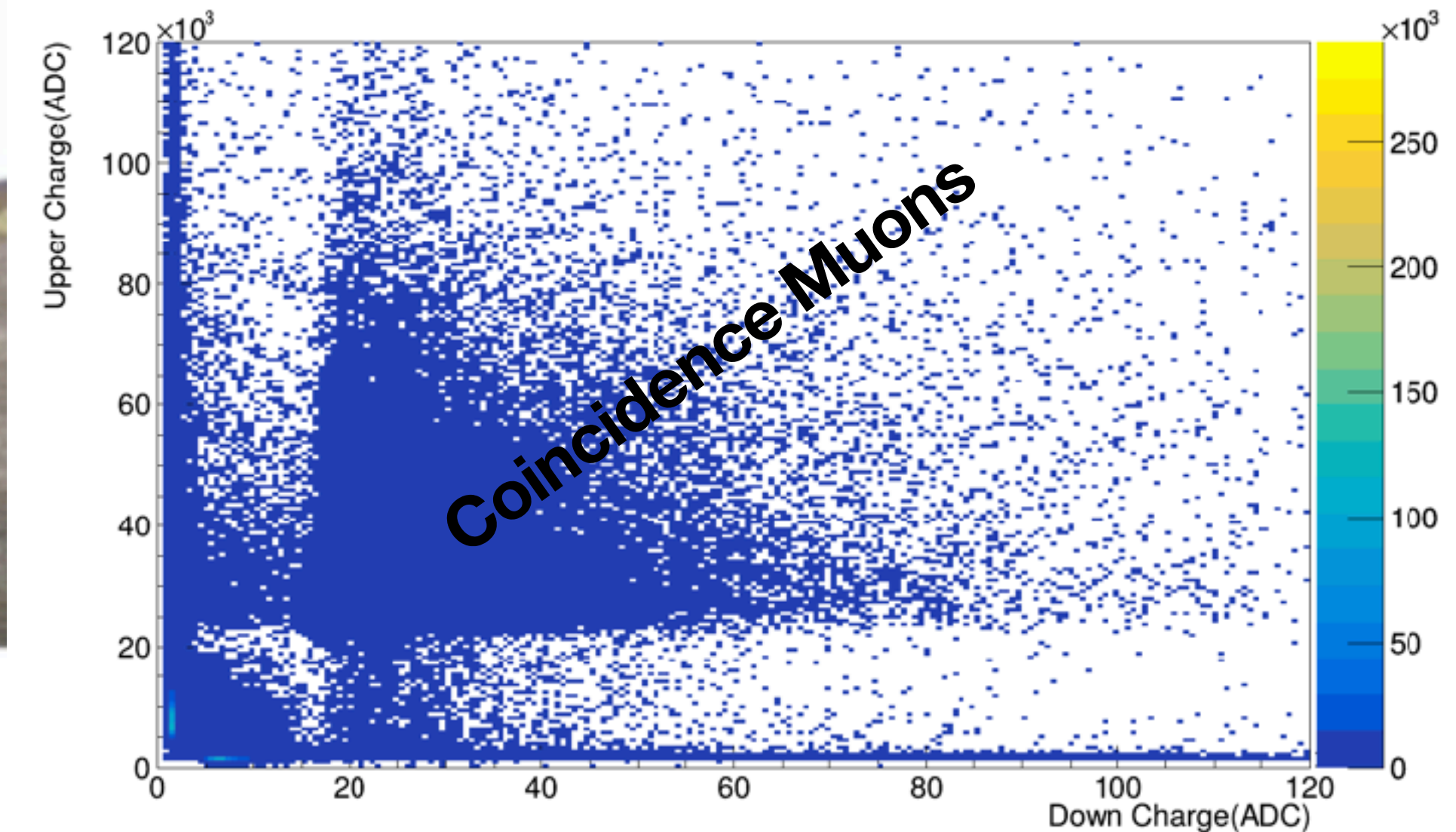
□ 완공 조감도



Similarly, we mapped undersea tunnel with moving muon detector



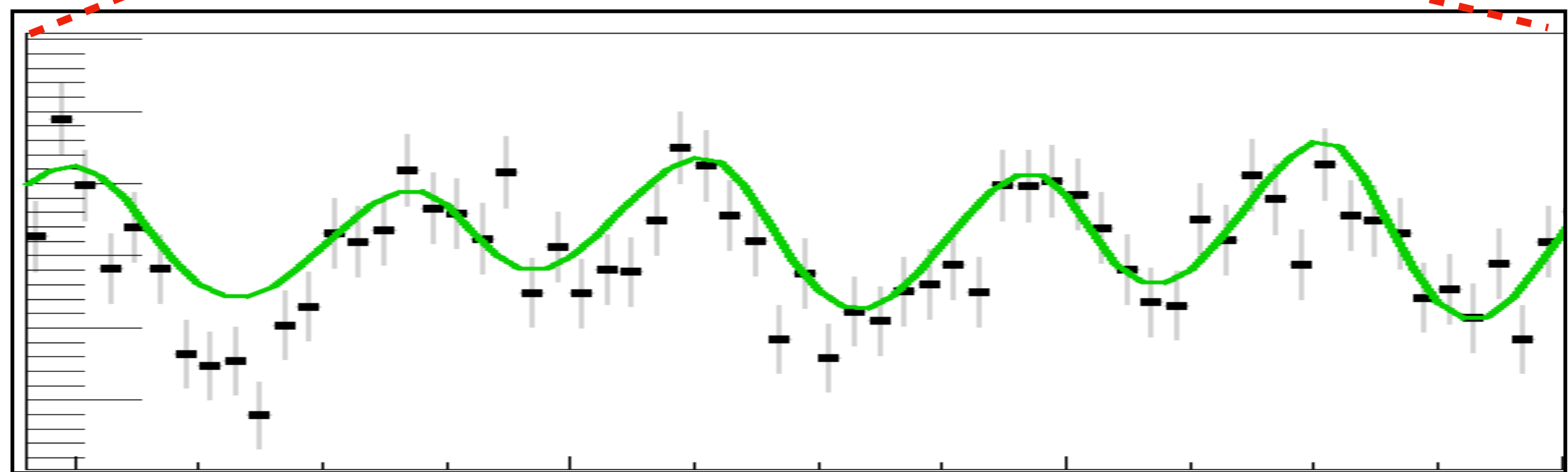
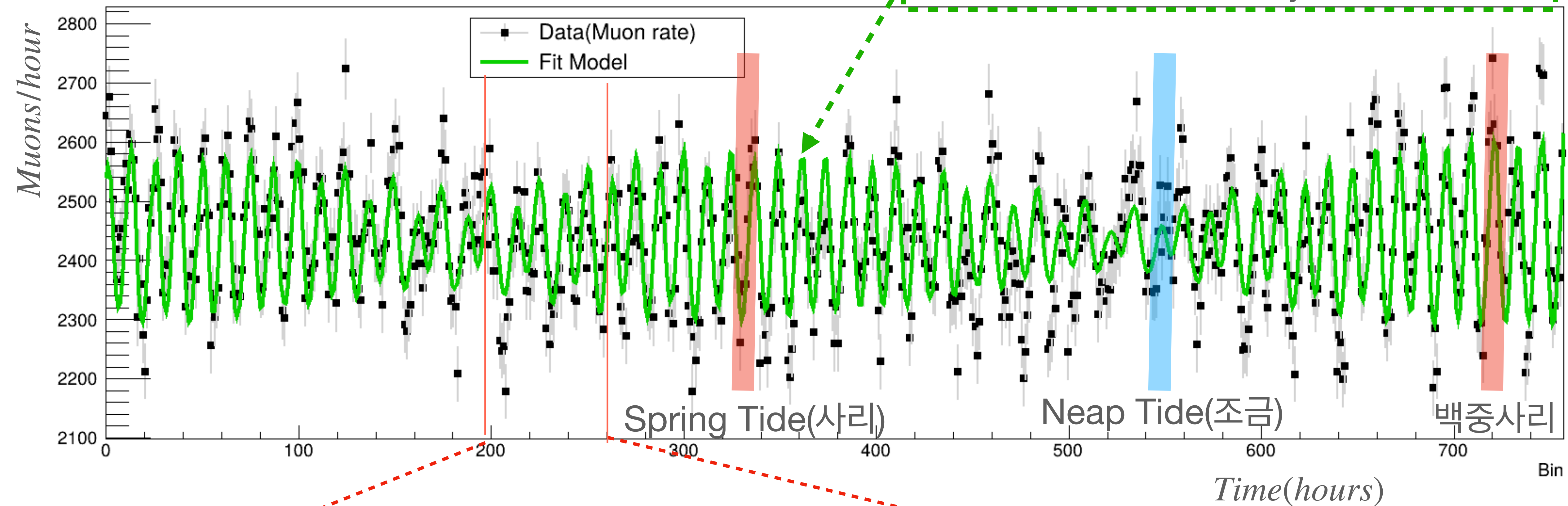
Charge spectrum of two panels



Long-term measurements at the location where it shows low overburden (high flux) but variable water height.

Tidal Level Measurement

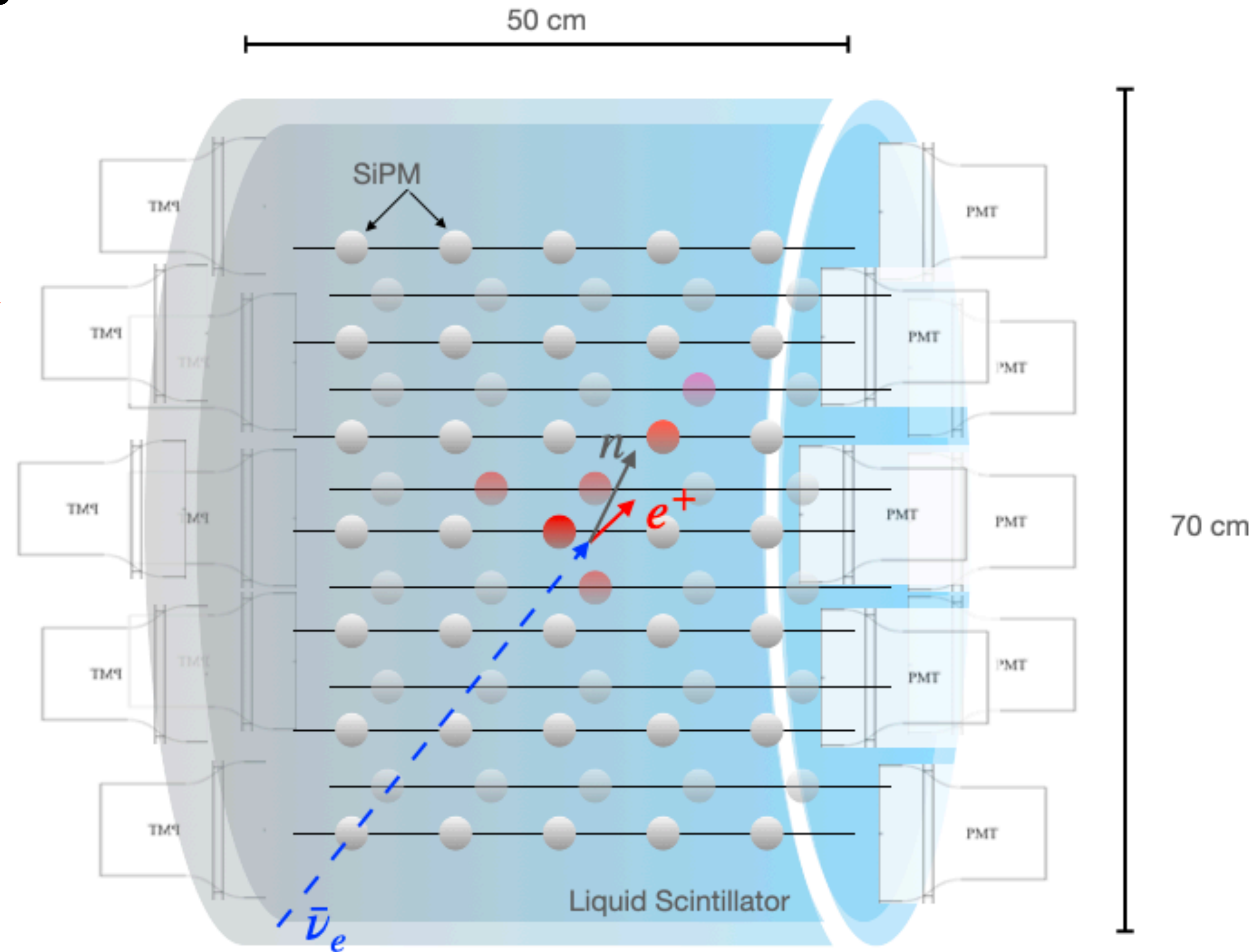
Model based on water level data
measured at the nearby KHOA station



- Data : Aug.11 ~Sept.12, 2025 (31 days)
- Average muon flux : $1.35/m^2/sec$

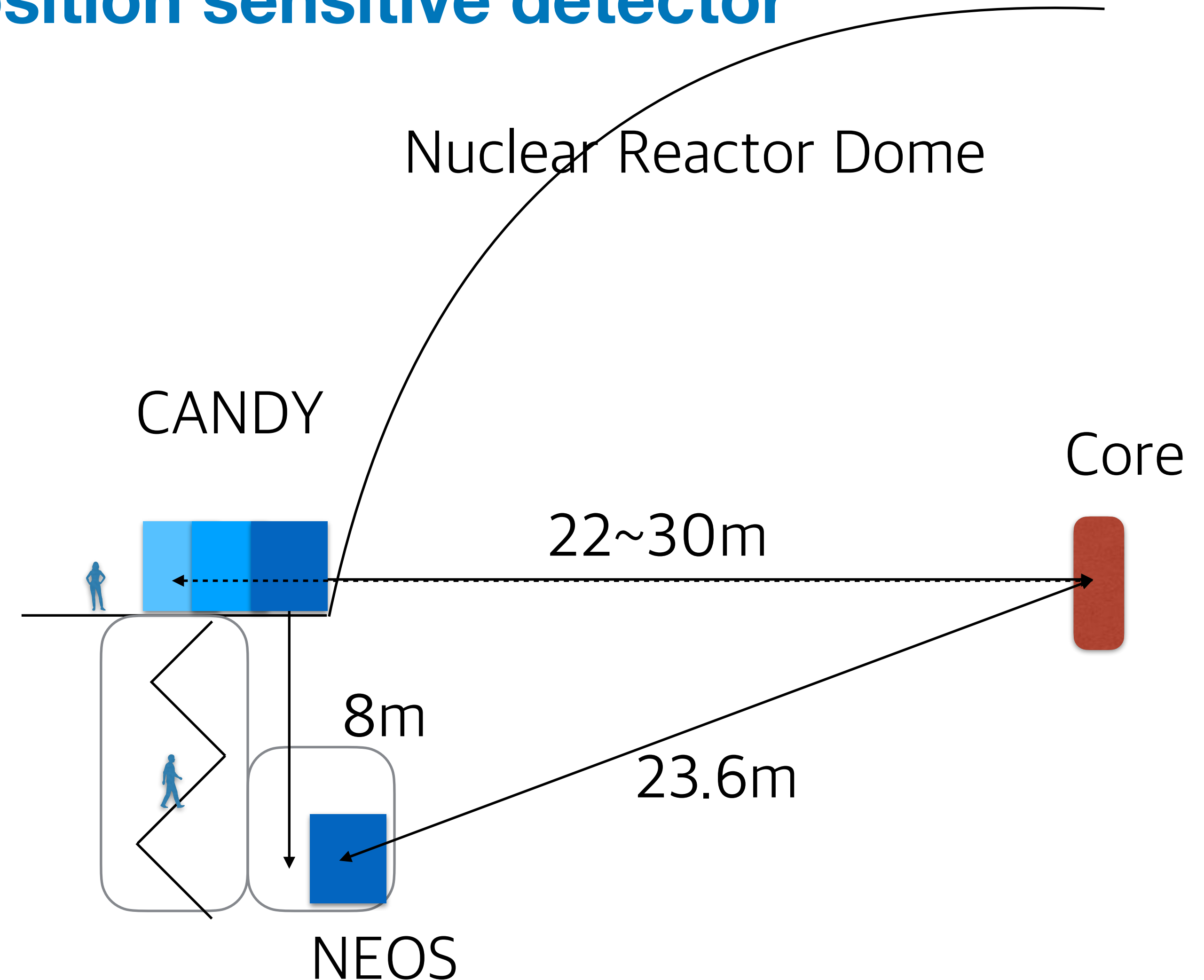
CANDY

Chung-Ang University Neutrino Detection Yolk



One motivation for position sensitive detector

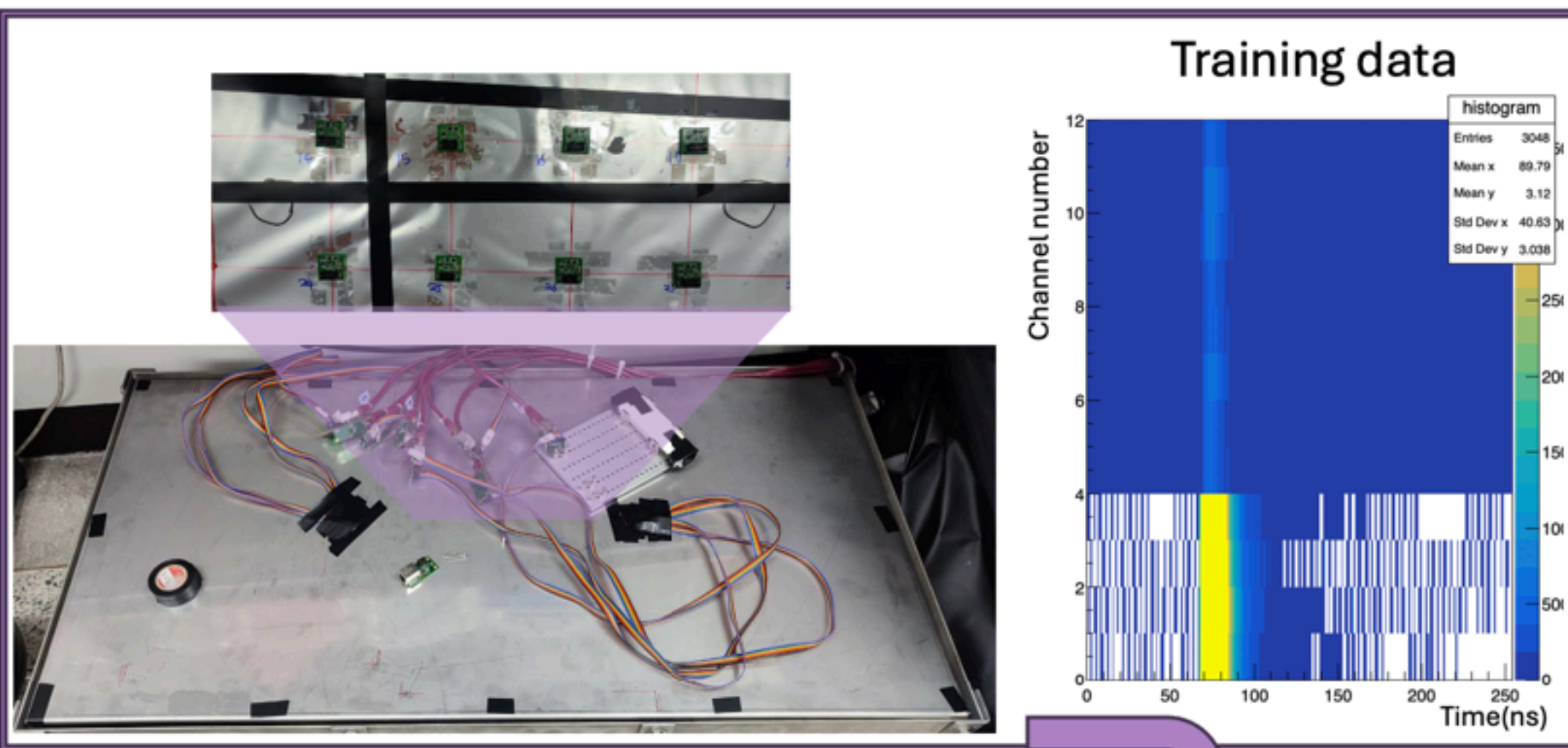
- A closer position at the ground level.
- If we can put **CANDY** to the dome, we can have a similar baseline as **NEOS**.
- Now, radial direction has no constraints
- **CANDY** can be placed in radial direction on a container box.
- Muon rate needs measurements but can be dealt with additional shielding



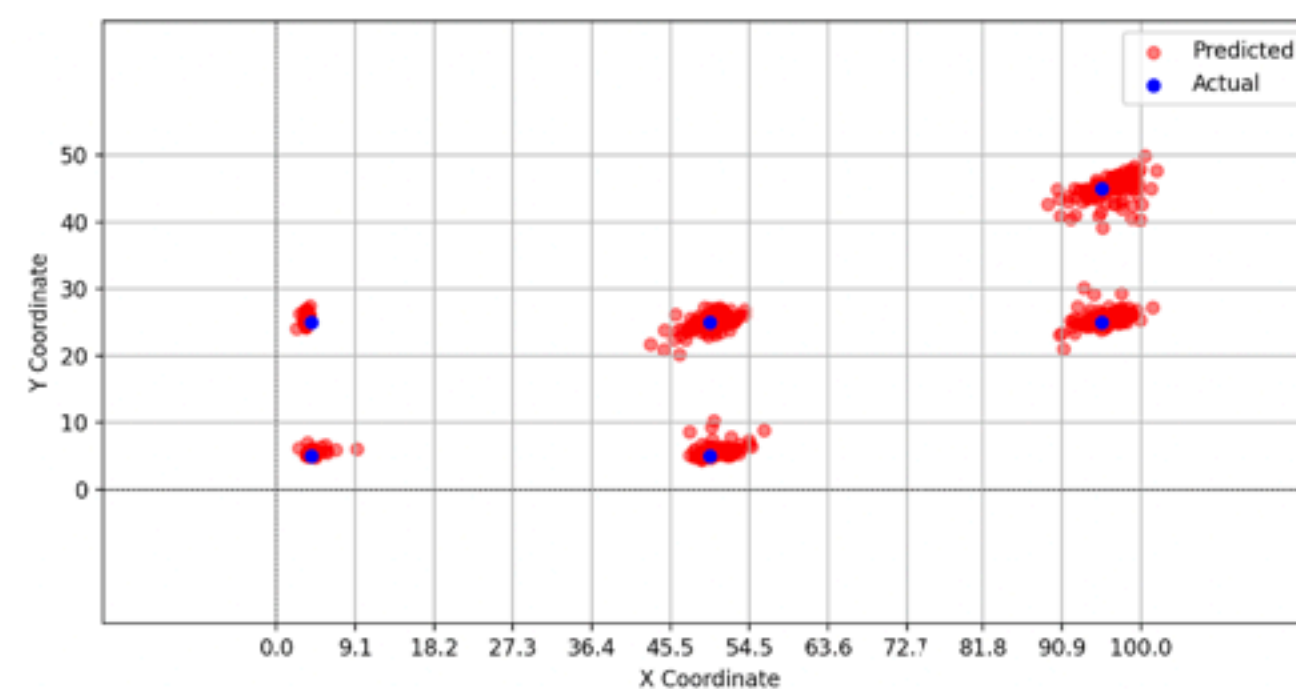
Position-sensitive SiPM array : Simulations and Reconstruction

Small Test Data

Simulations



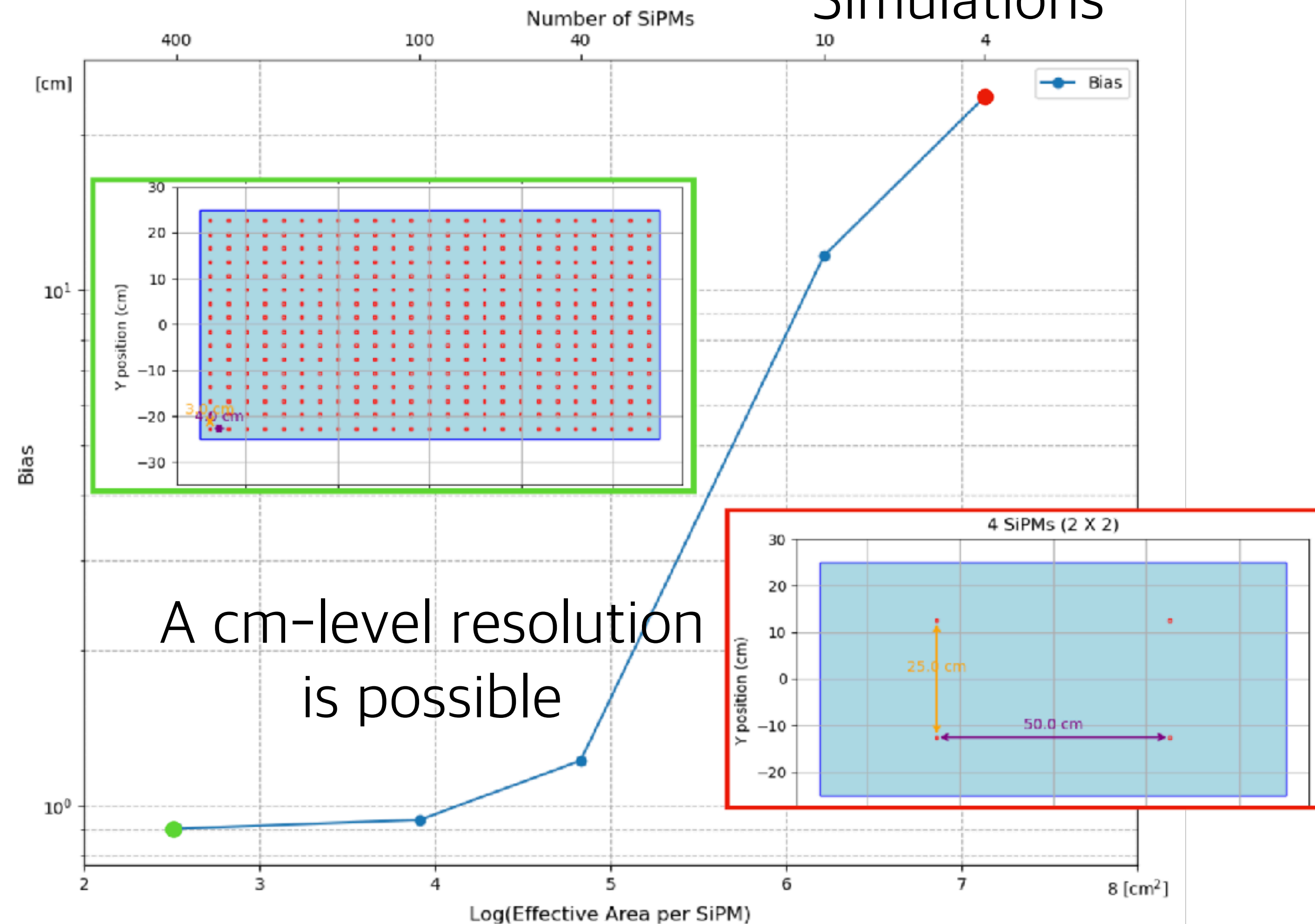
CNN training



Mean result

MAE	3.38
Loss	24.60
Sigma_x	1.93
Sigma_y	2.87

* unit :cm



Identification of positron scintillation

IBD ① Thr $\sim 1.8 \text{ MeV}$
 $= M_p - M_n - m_e$
 ② K.E $\bar{\nu}_e$ goes most to e^+

$\bar{\nu}_e$ $\rightarrow$ e^+ $\rightarrow$ γ

③ Stopping Power in Water
 $\sim 2 \text{ MeV/cm}$
 $\Rightarrow 2.5 \text{ MeV } e^+$ goes 1 cm , 0.1 ns .

④ e^+ lifetime in polymer
 (a) $e^+e^- \rightarrow \gamma\gamma$ (singlet): 1 ns
 (b) $e^+e^- \rightarrow \gamma\gamma\gamma$ (triplet): 100 ns ?
 no! pick-up effect.

⑤ γ Stopping Power ($\sim 4 \text{ MeV/cm}$)
 $\frac{2 \text{ m}}{2 \times 10^8 \text{ m/s}} = 10^{-8} \text{ s} = 10 \text{ ns}$

no! $50 \text{ cm} \rightarrow$ multiple Compton Scattering

$\langle \theta \rangle = 91^\circ$

$\phi = 18.8$

LS $\rightarrow$ e^+ $\rightarrow$ γ

1 ns

2400
 0.445

Eng. Kon)

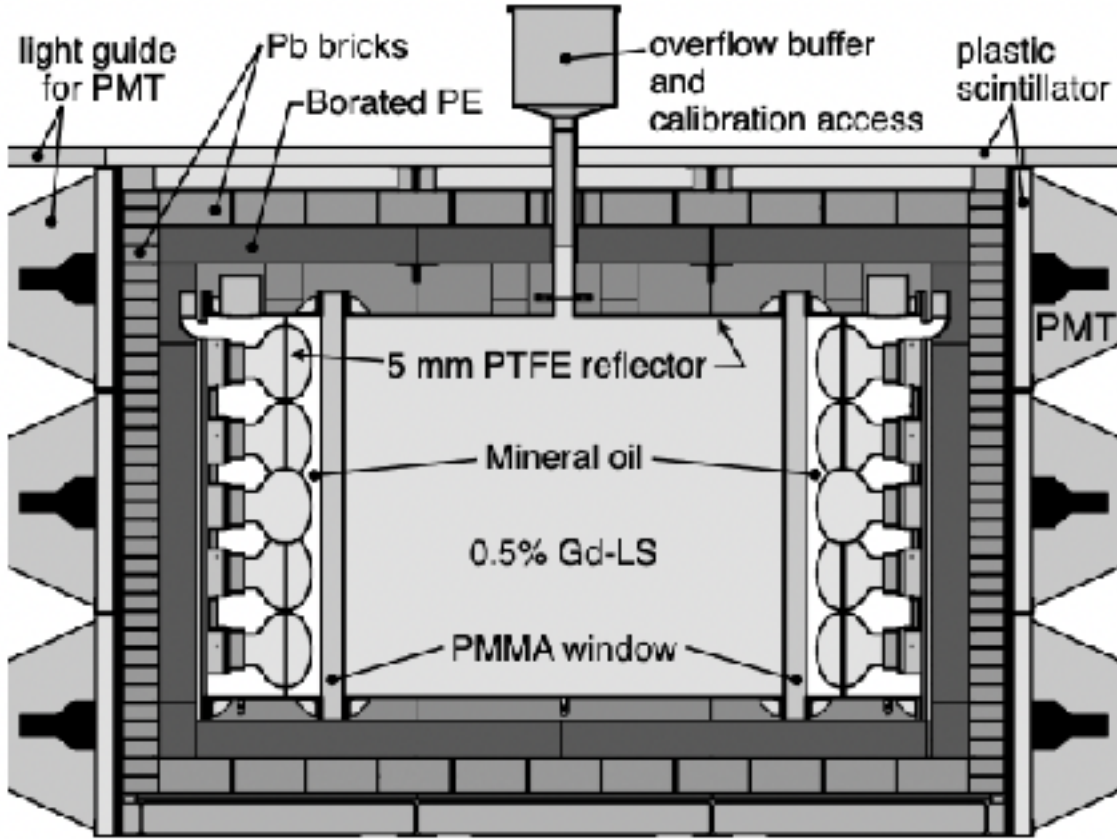
0.5)

10000

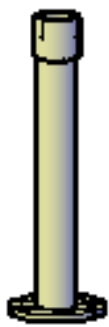
10.5

1 2 3 10

Using NEOS skeleton, extend to the radial direction (One more Target LS barrel)

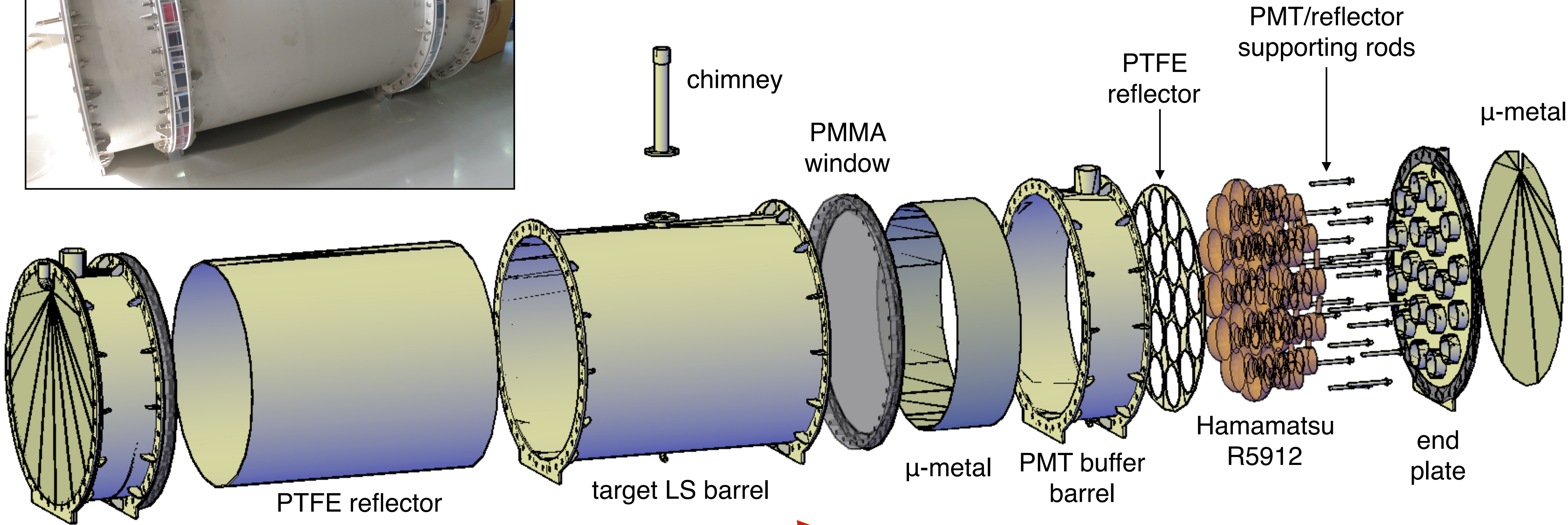


overflow buffer



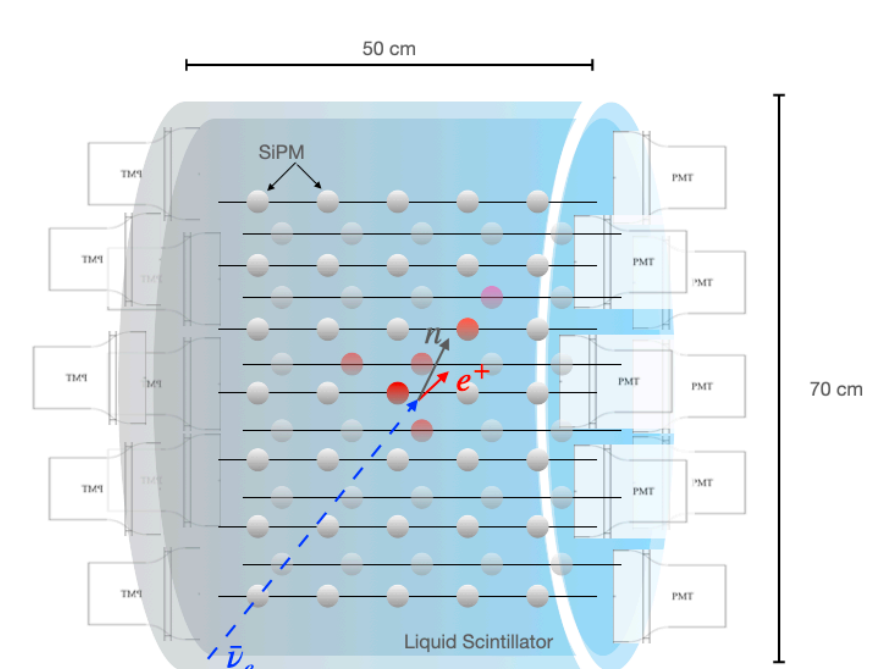
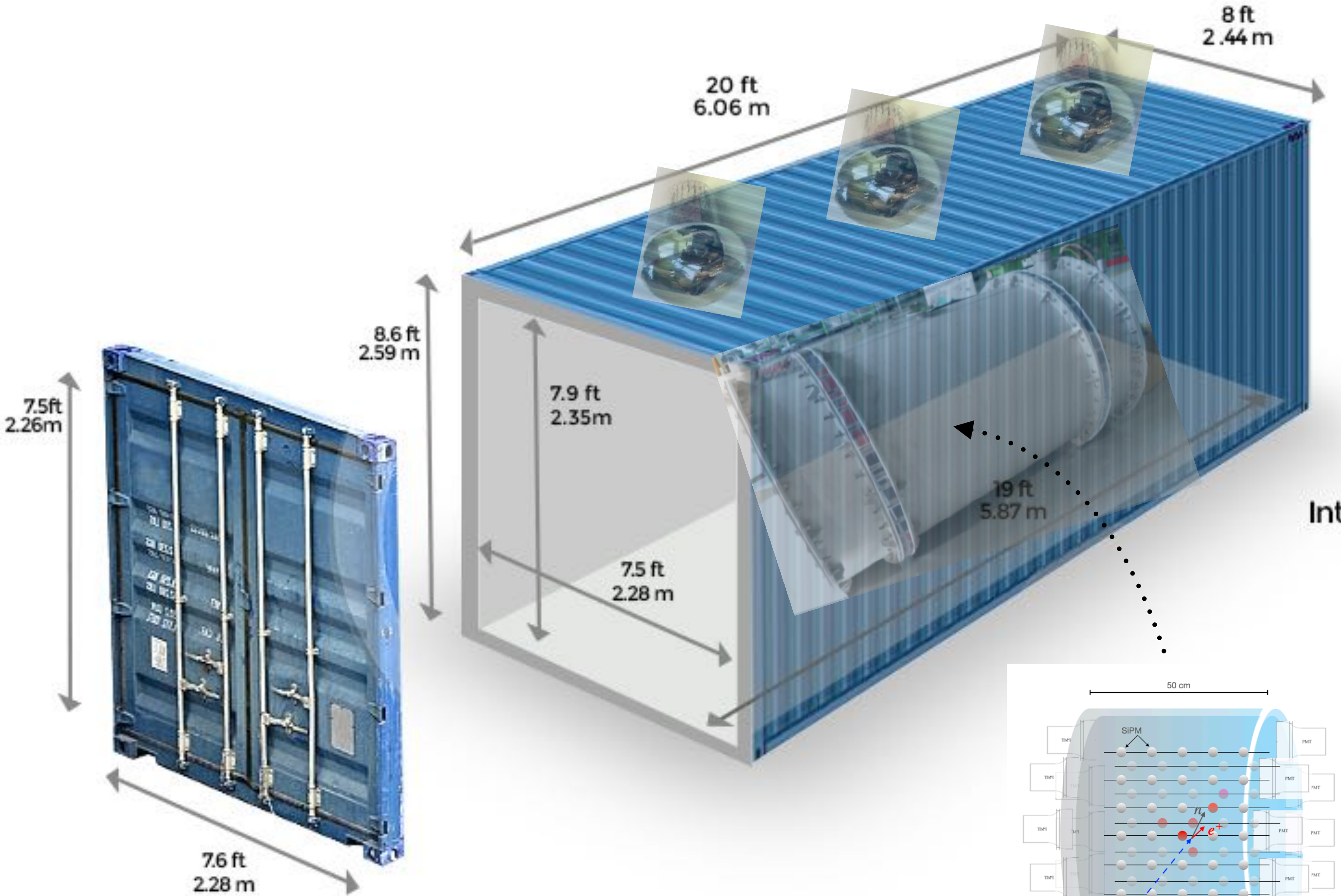
chimney

PMMA window

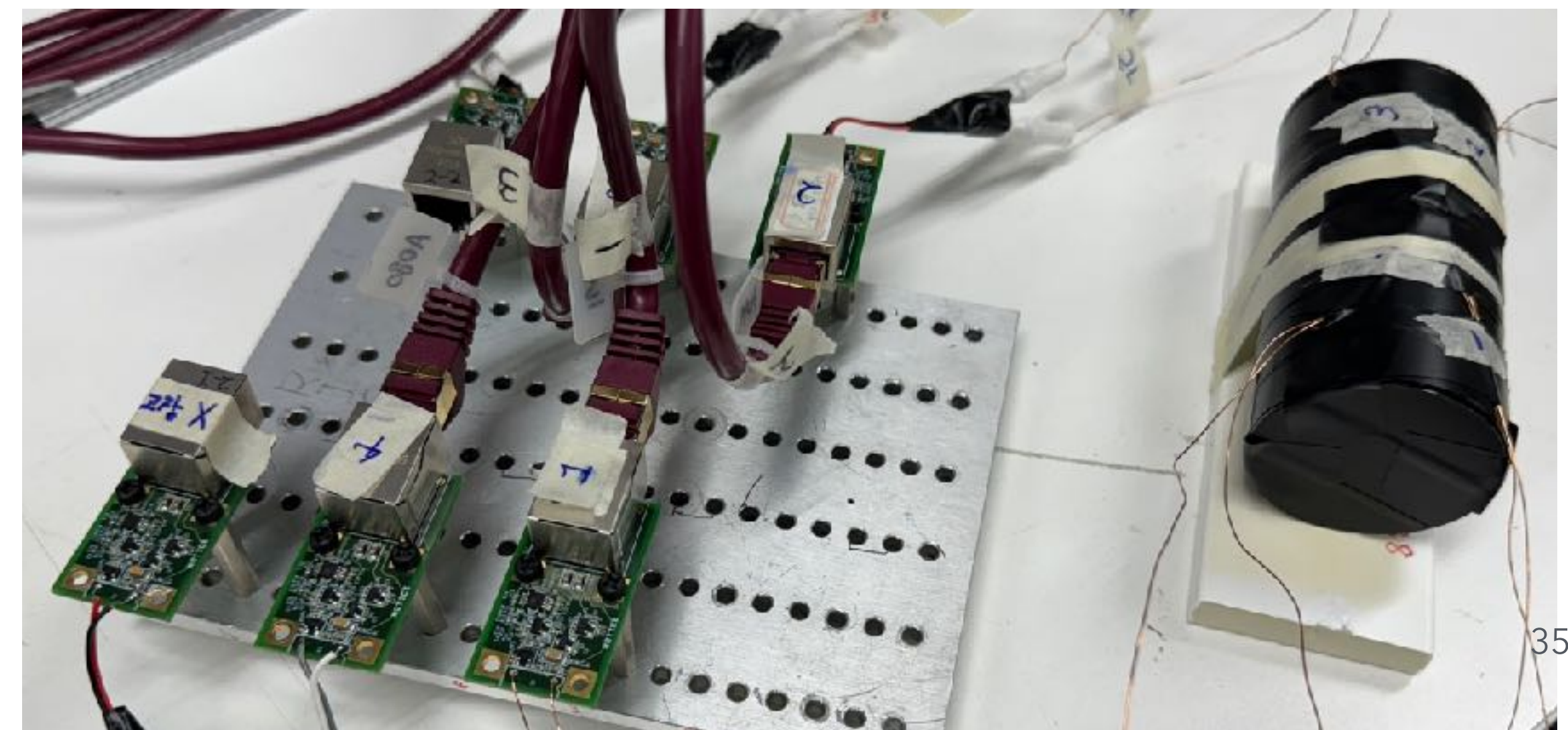
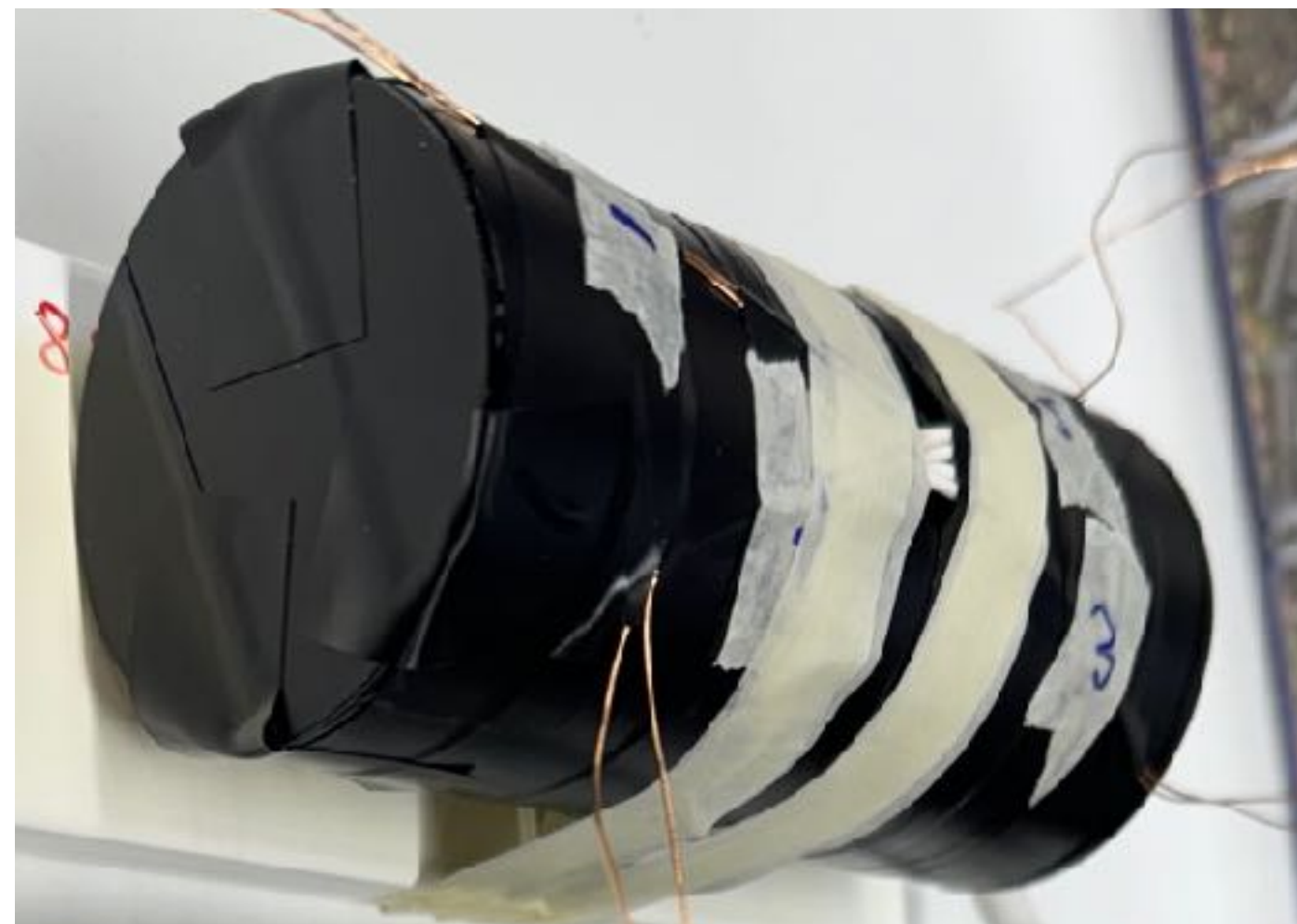
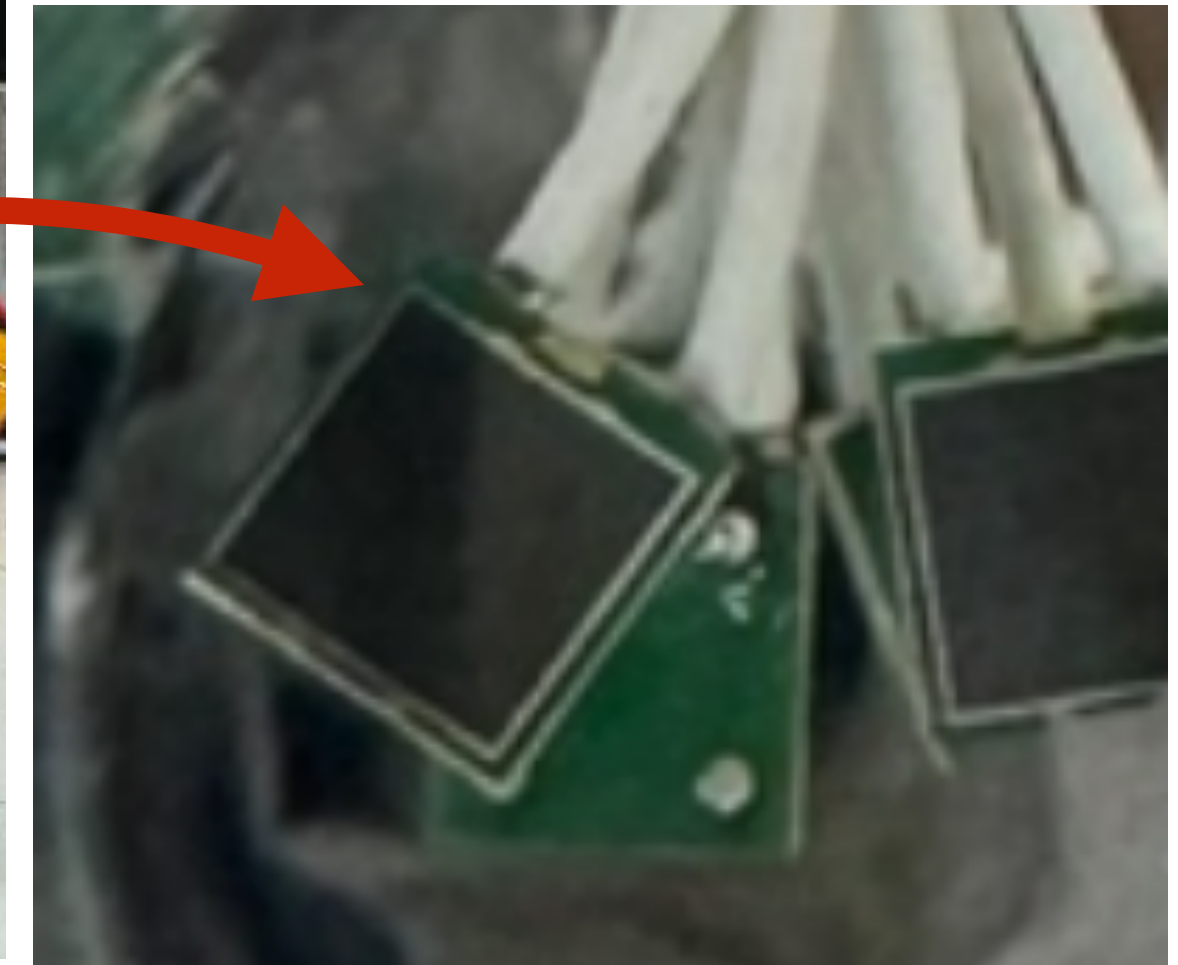
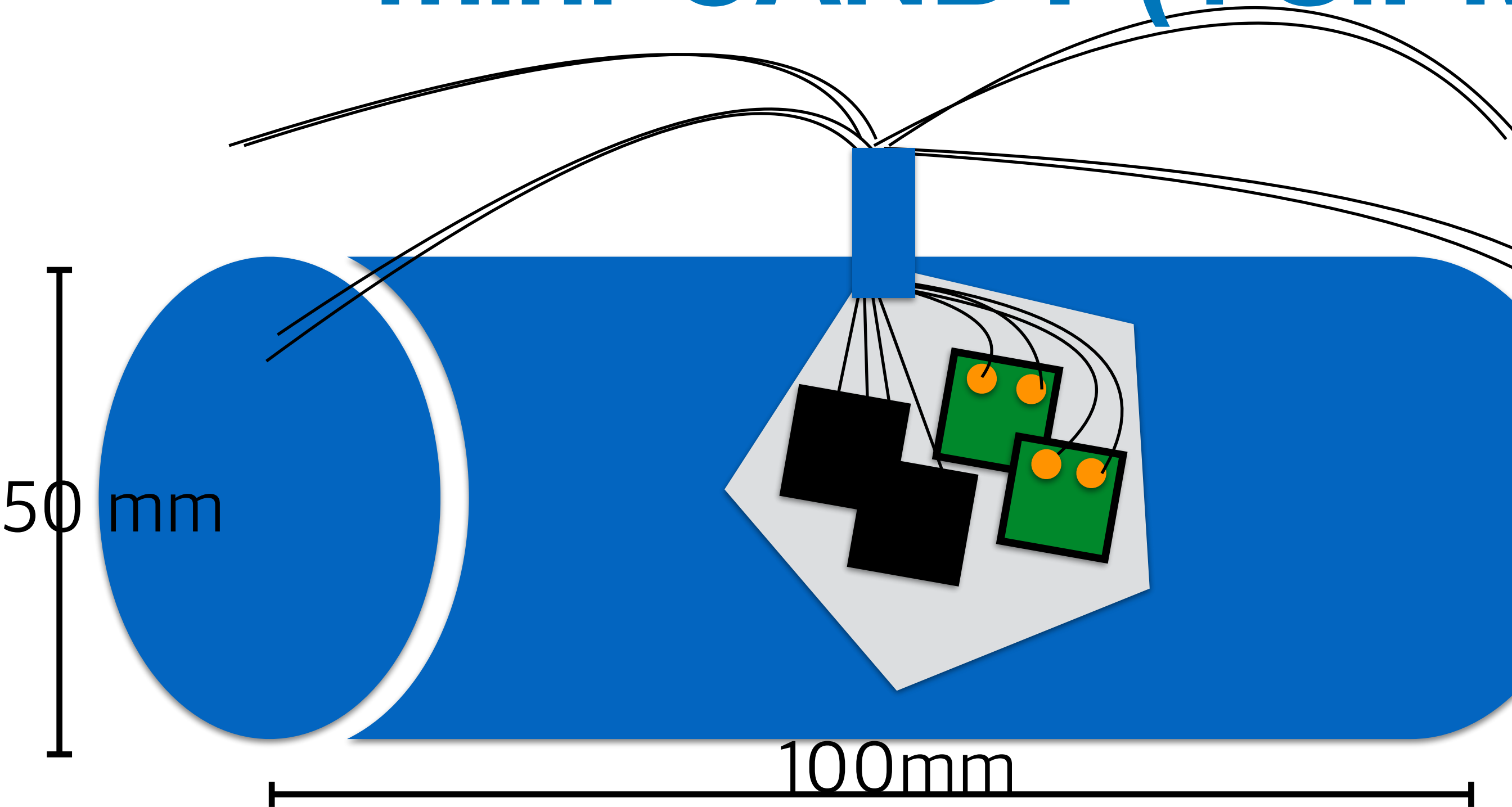


Twice extended

CANDY in a Borated Water Shield for muon and neutron tagging

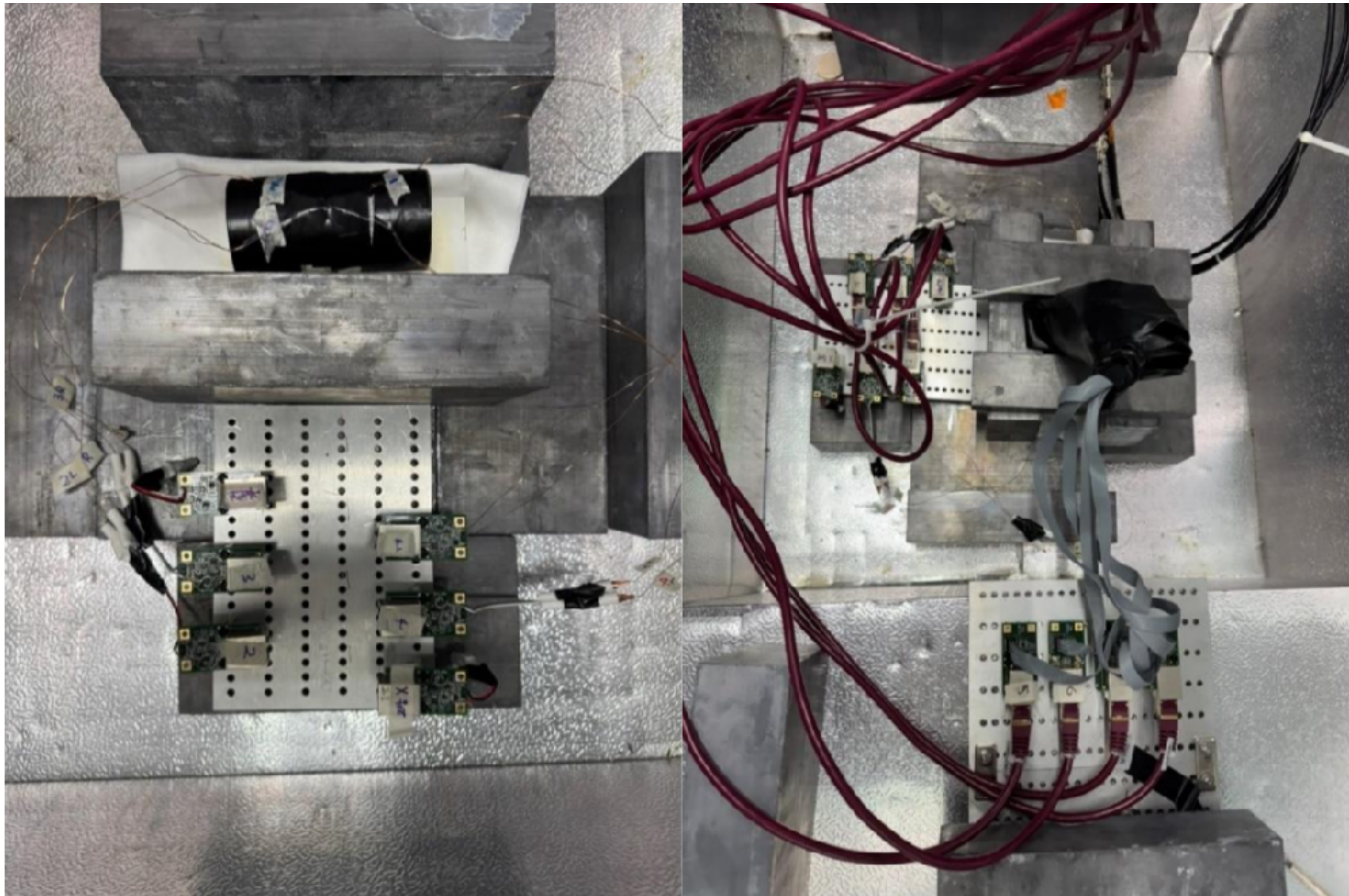


mini-CANDY (4 SiPMs, two each side)

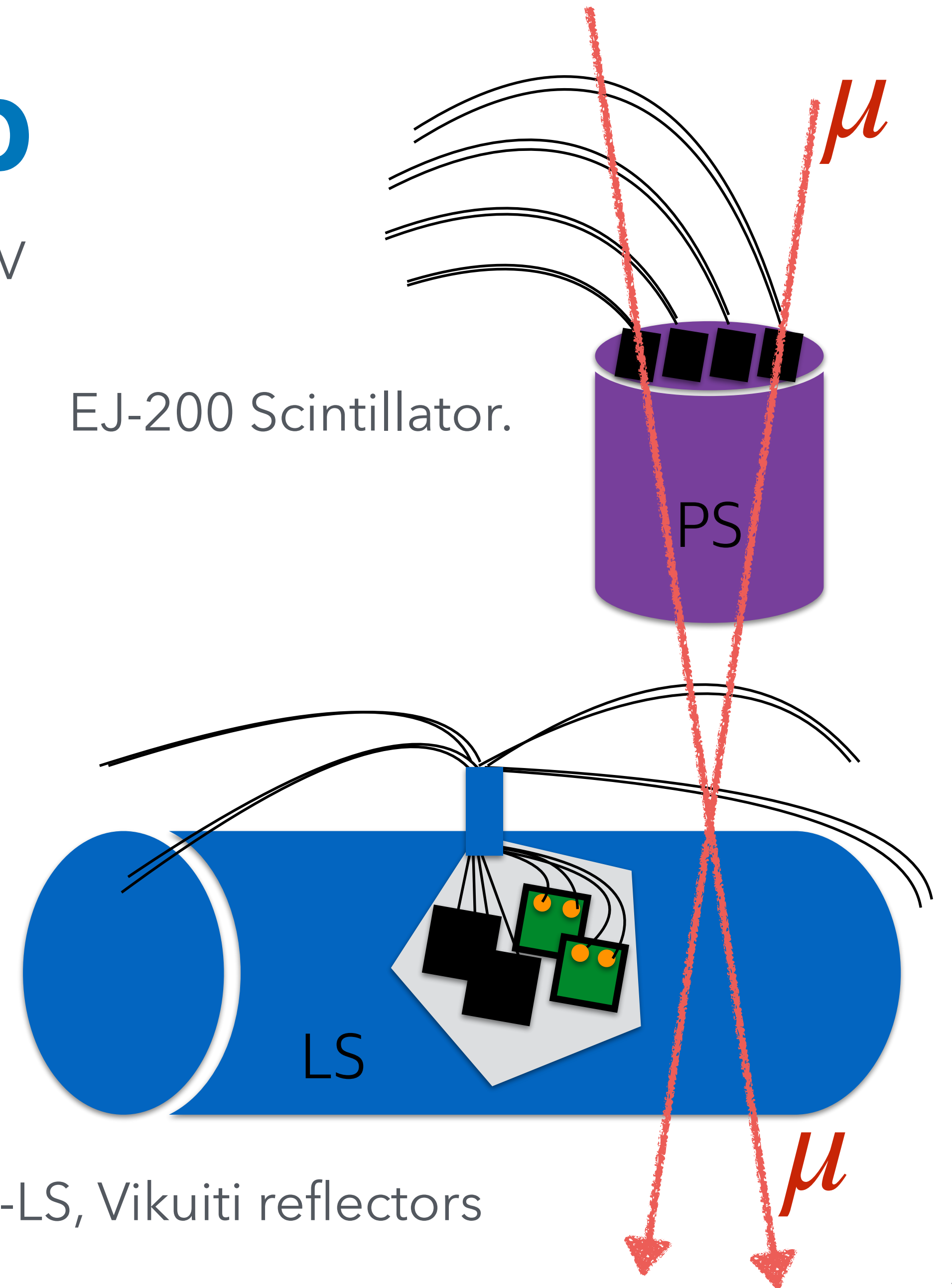


Data Acquisition Setup

8ch. Coincident PS + LS data. 62.5 MSPS FADC DAQ, 56.5 V



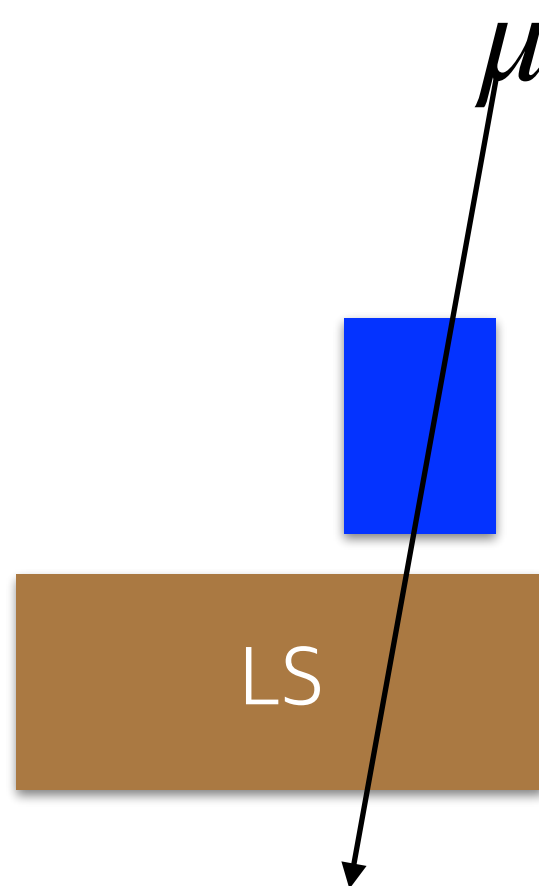
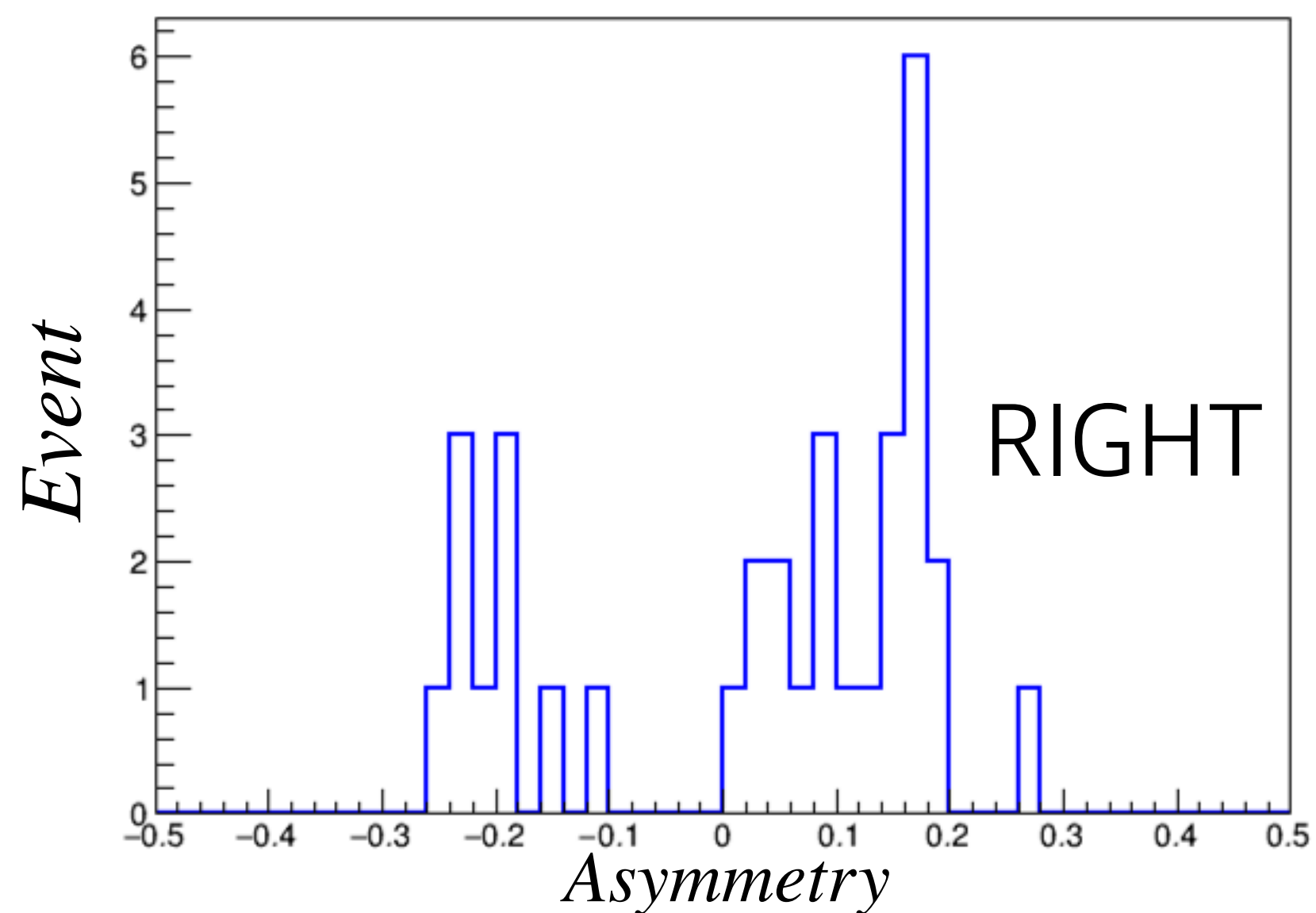
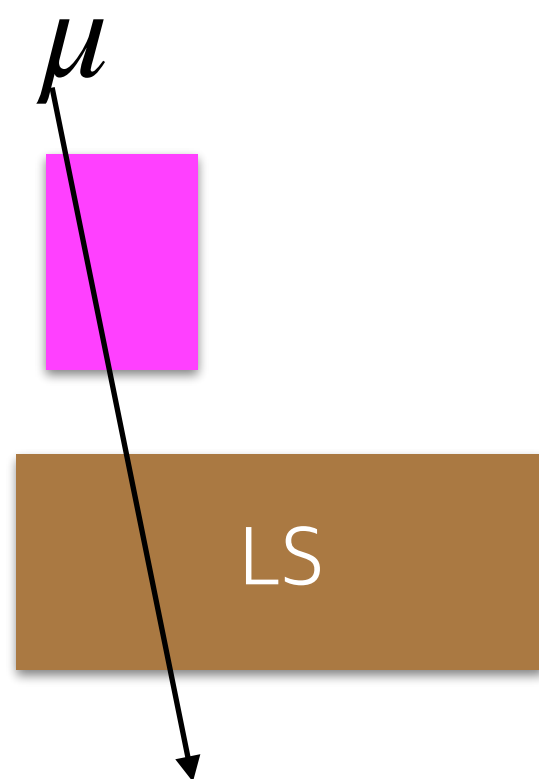
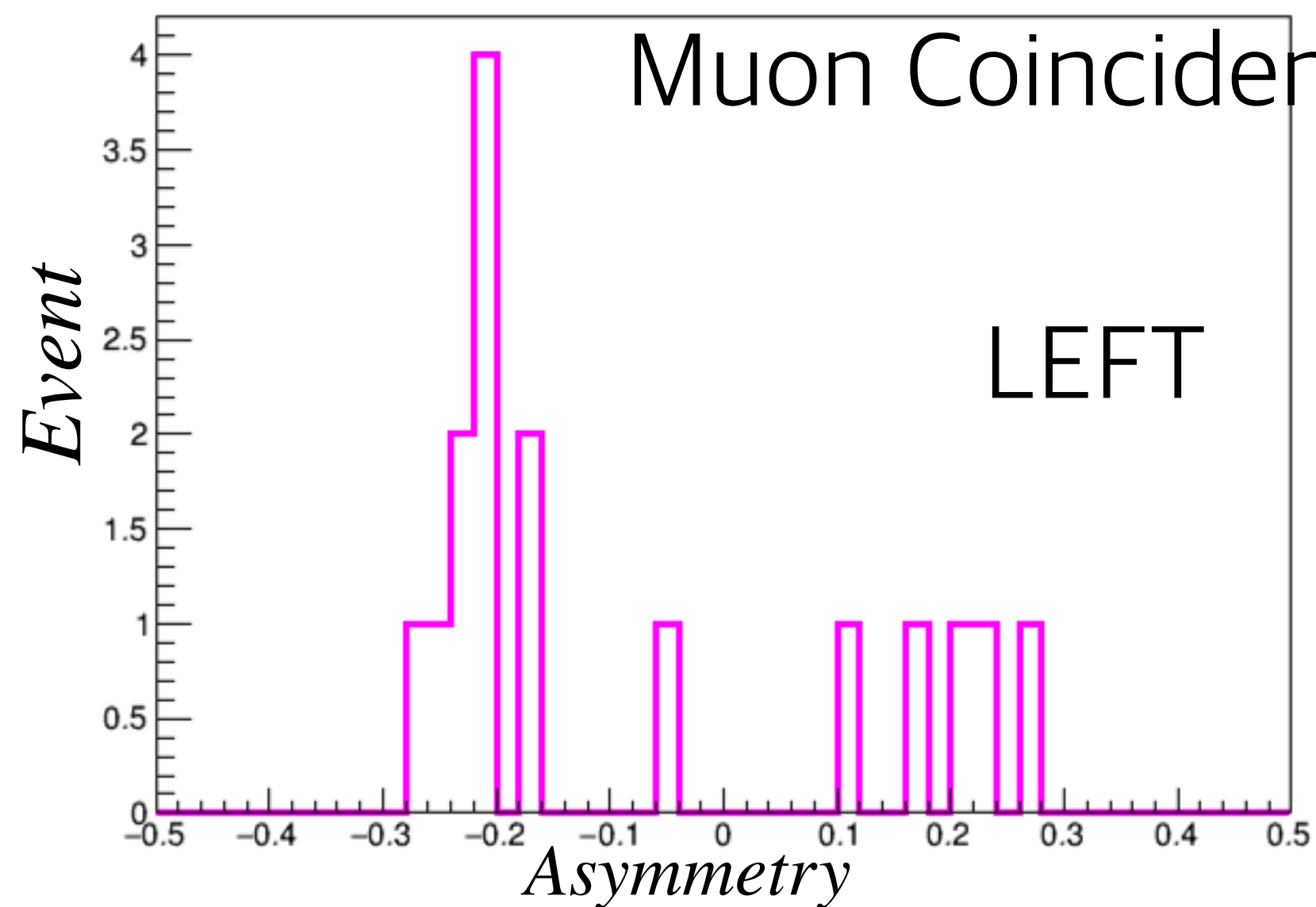
EJ-200 Scintillator.



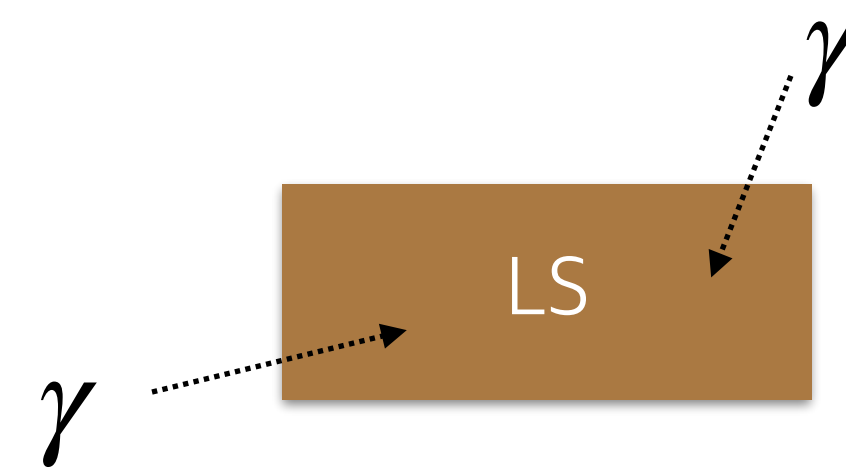
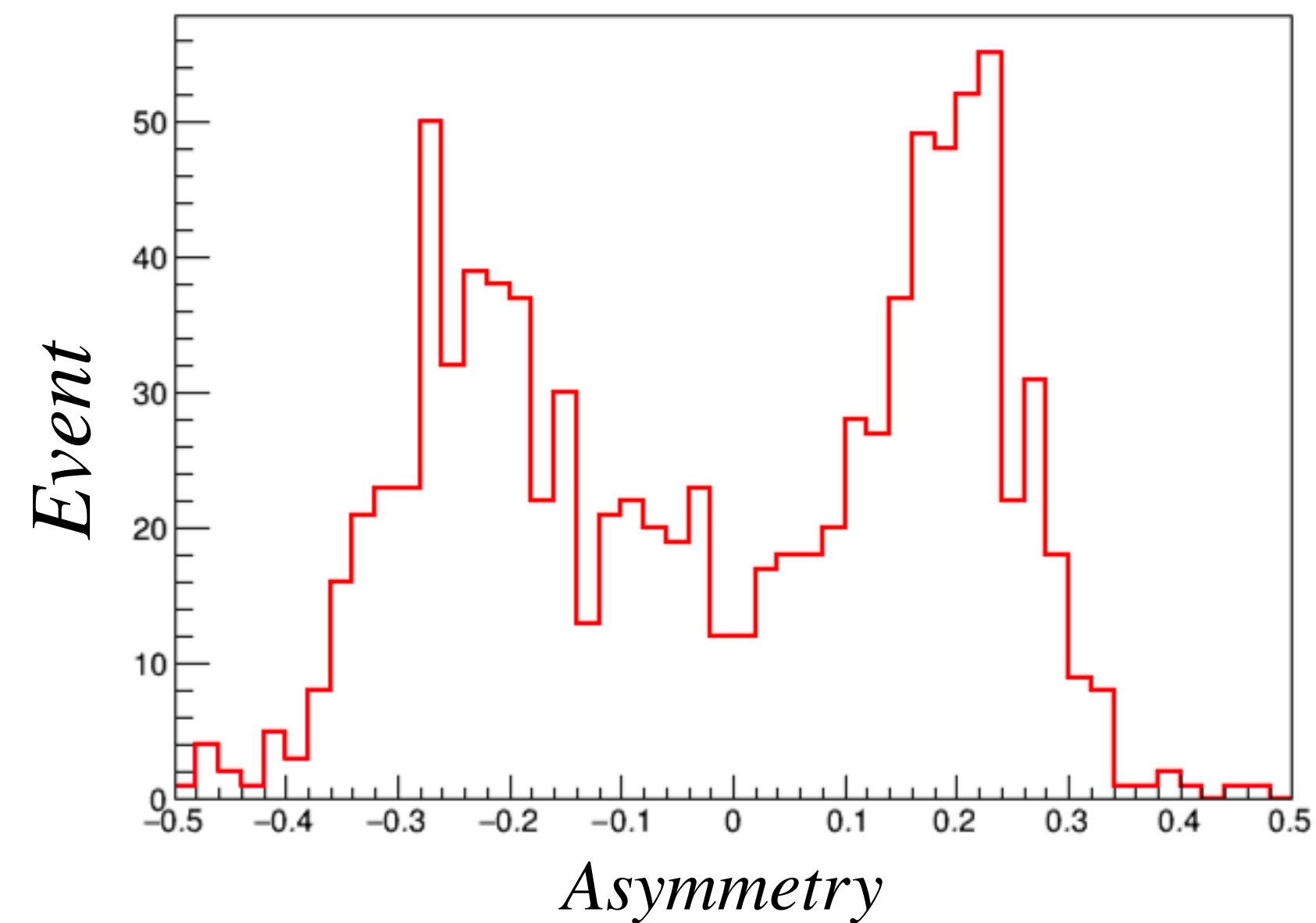
LAB-LS, Vikuiti reflectors

Position-sensitive SiPM array : Data

Muon Coincidence Measurements



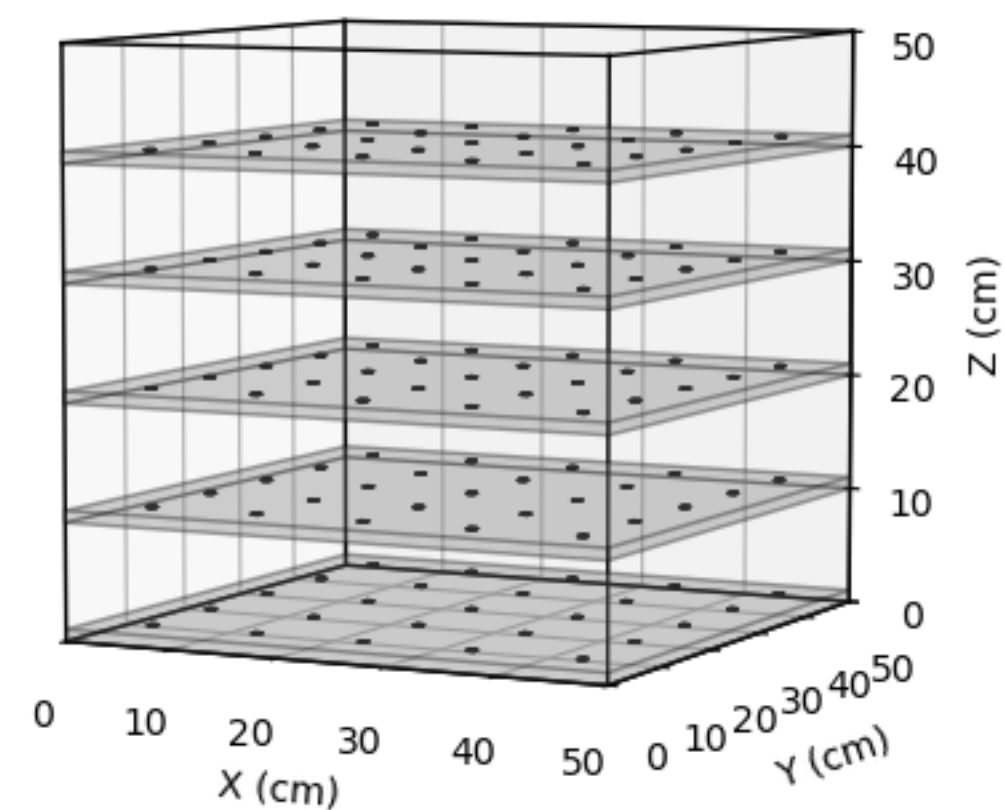
Gamma Background Measurements



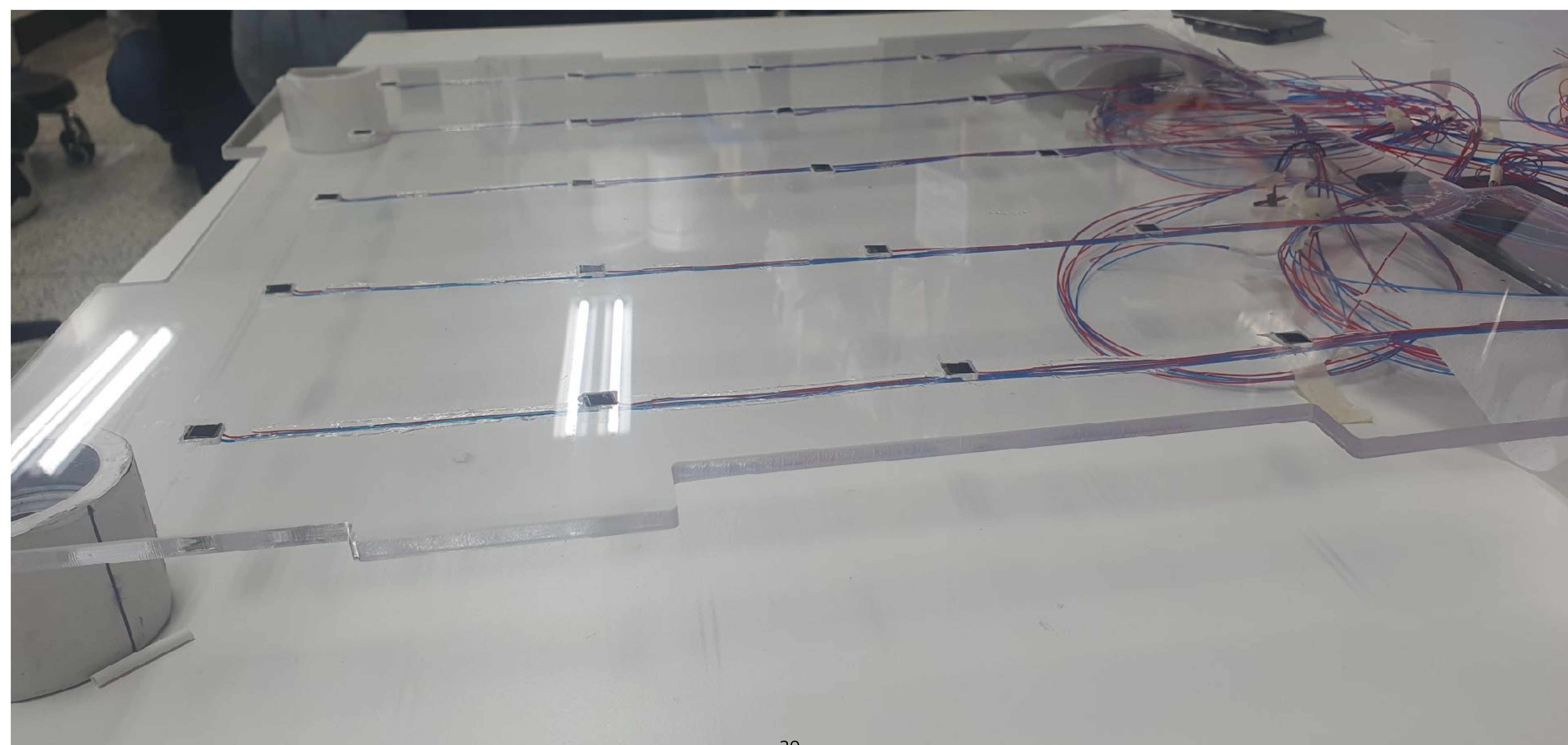
Position-sensitive detector can be made with a larger array

50 x 50 x 50 cm Acrylic Cube with Plates and SiPMs

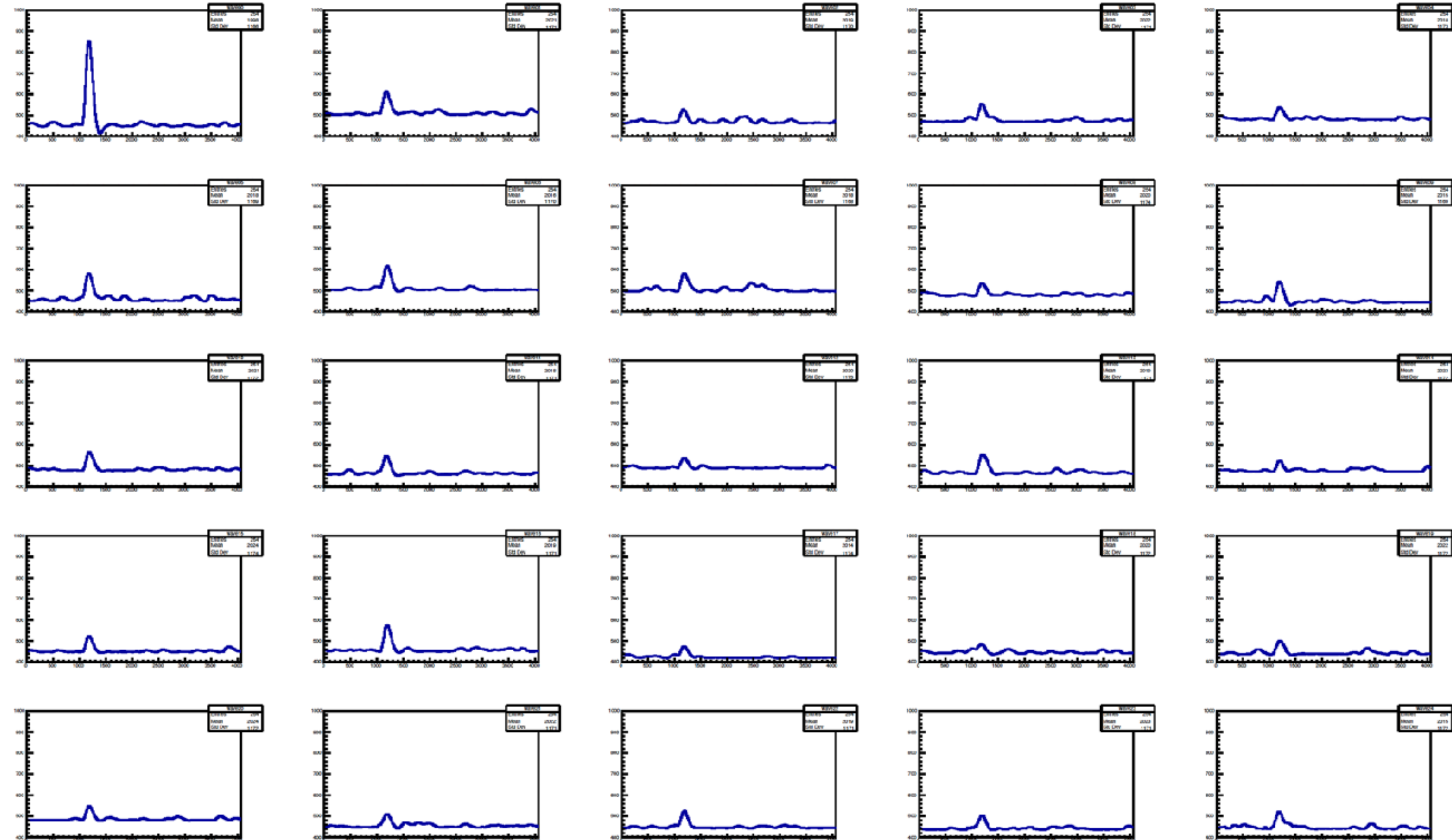
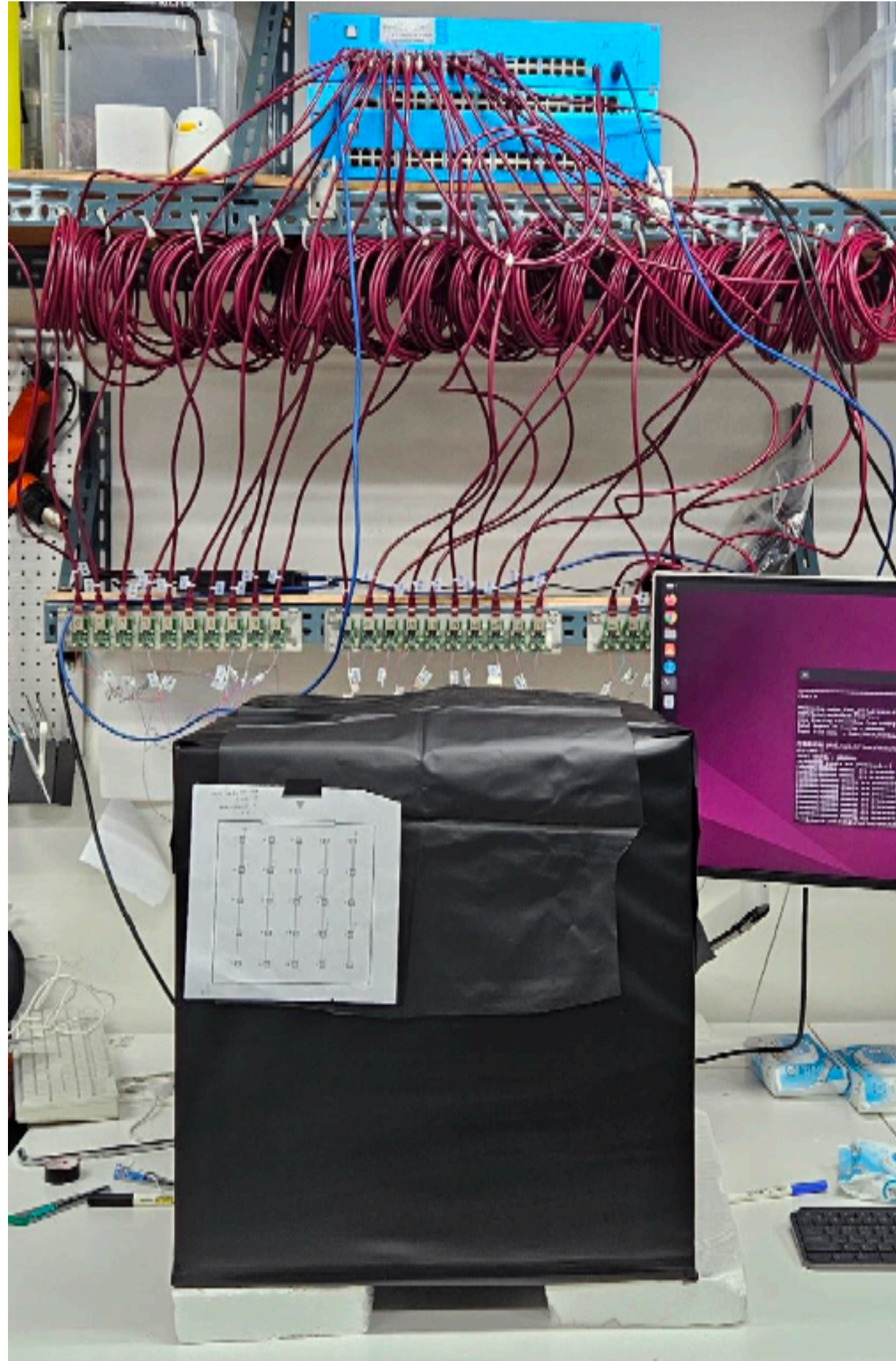
Medium-CANDY ongoing



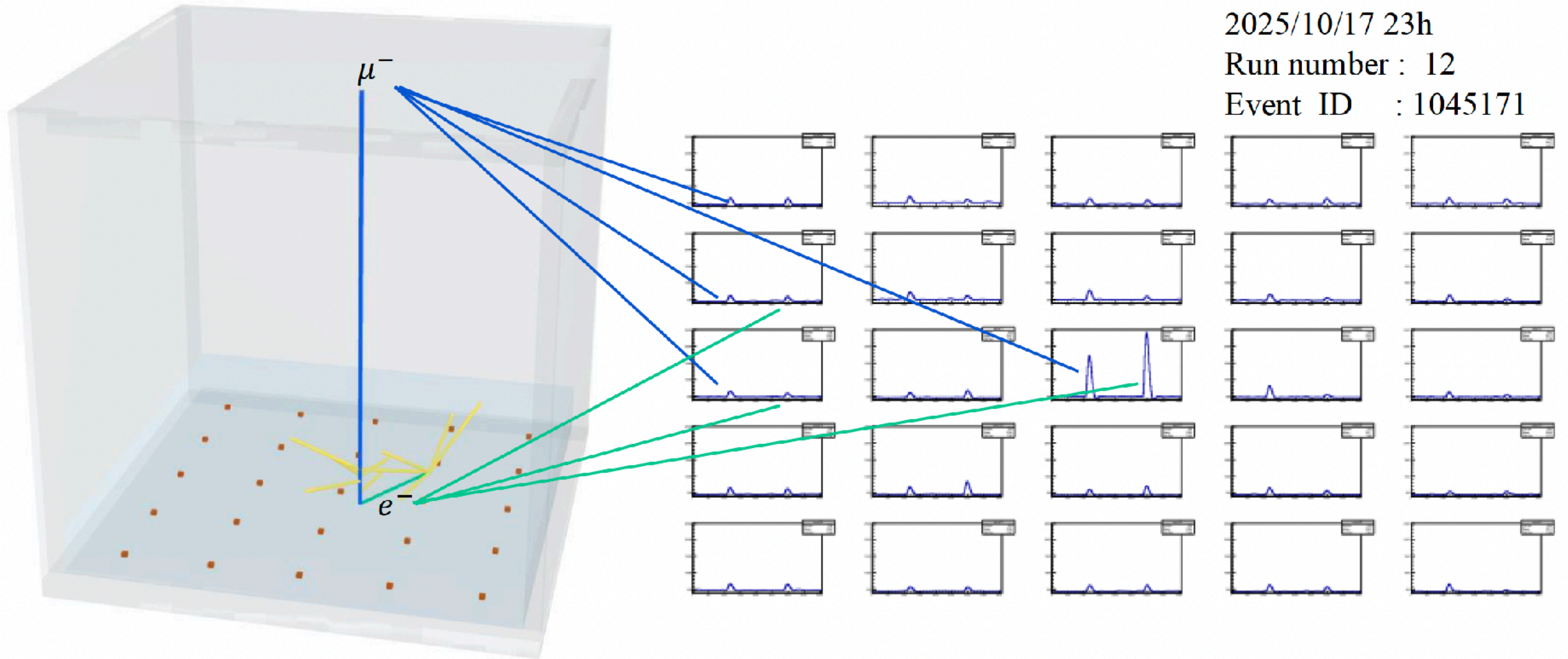
SiPM Array (One layer detector with 25 SiPMs, LAB-LS ~10 cm thick)



Medium-CANDY v1 data (Muon Candidate)



Medium-CANDY v1 data (Muon-decay Candidate)



Summary and Outlook

We focus on position sensitive scintillation detectors

- We focus on R&Ds for position-sensitive scintillation detectors
- HAWL project turns out to be very useful and we'd like to improve as much as we can.
- Our goal is to achieve sub-centimeter resolution scintillation detector (See Minsu's talk later)
- Currently building Medium CANDY (50cmX50cmX50cm, 125 SiPM) with hardware costs roughly at 20k usd.

Rare Event Search Laboratory (RESL)

Webpage : <https://sites.google.com/view/dmnu>

