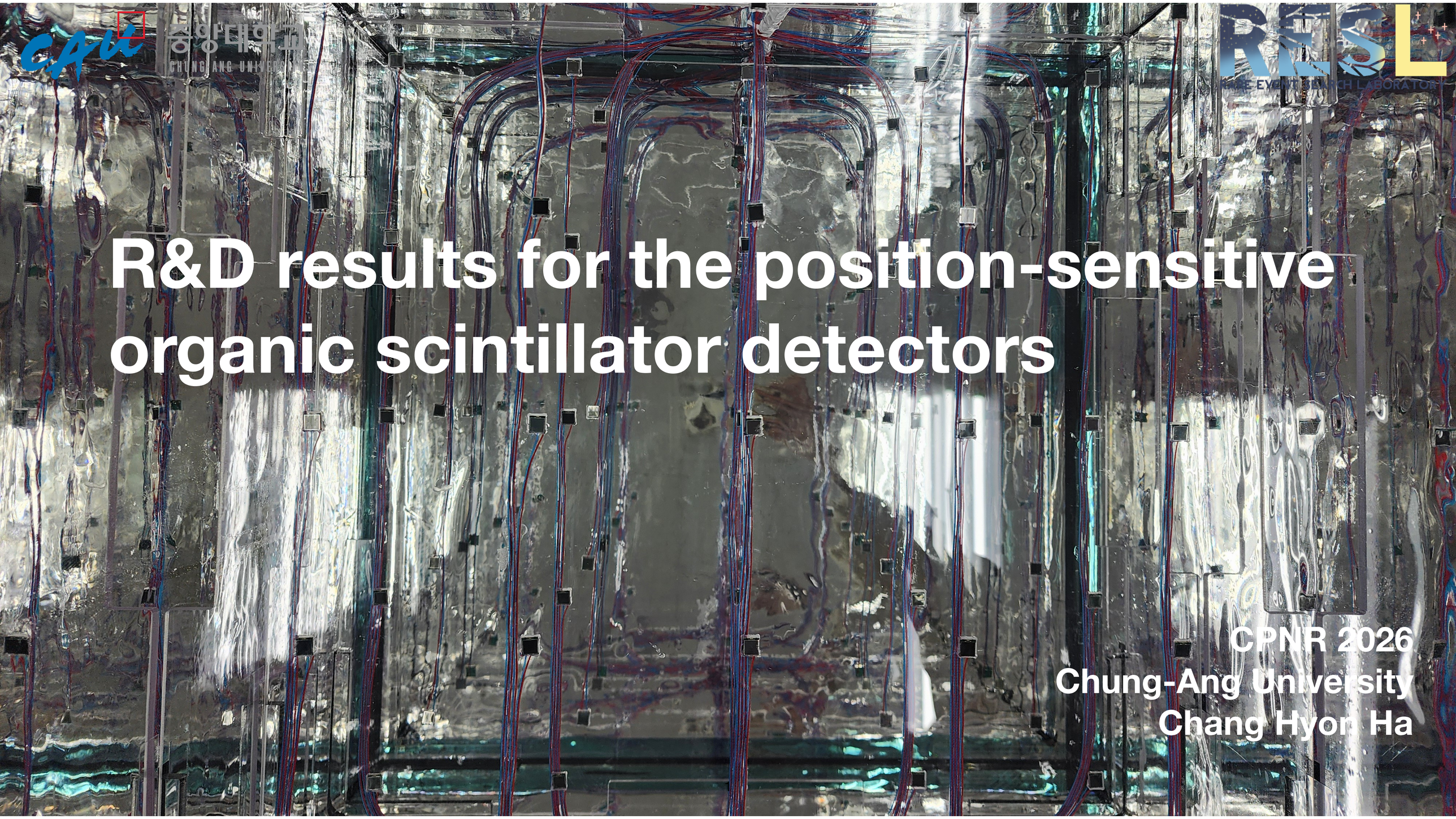


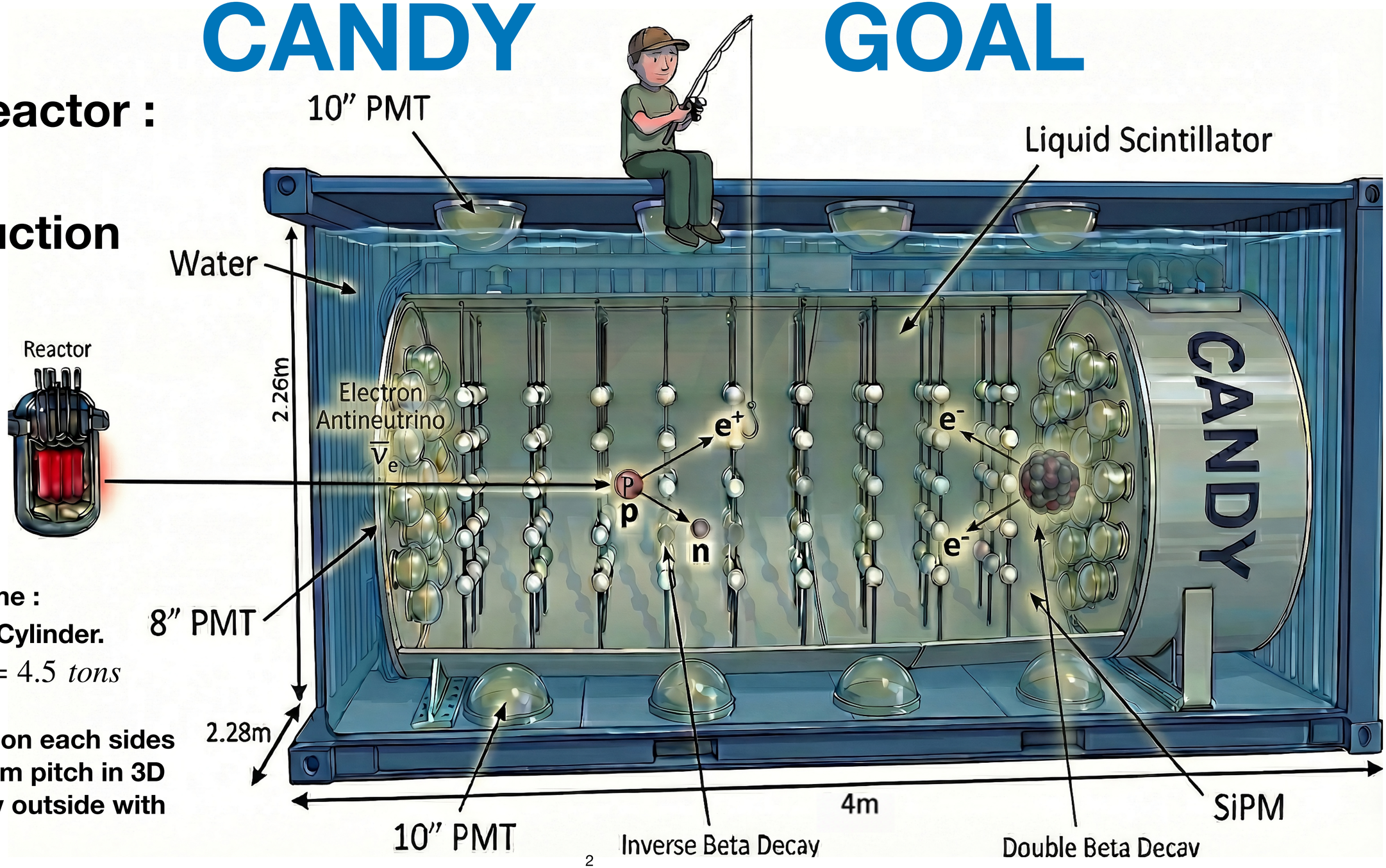
R&D results for the position-sensitive organic scintillator detectors

CPNR 2026

Chung-Ang University
Chang Hyon Ha

CANDY GOAL

$\bar{\nu}_e$ from reactor : position reconstruction



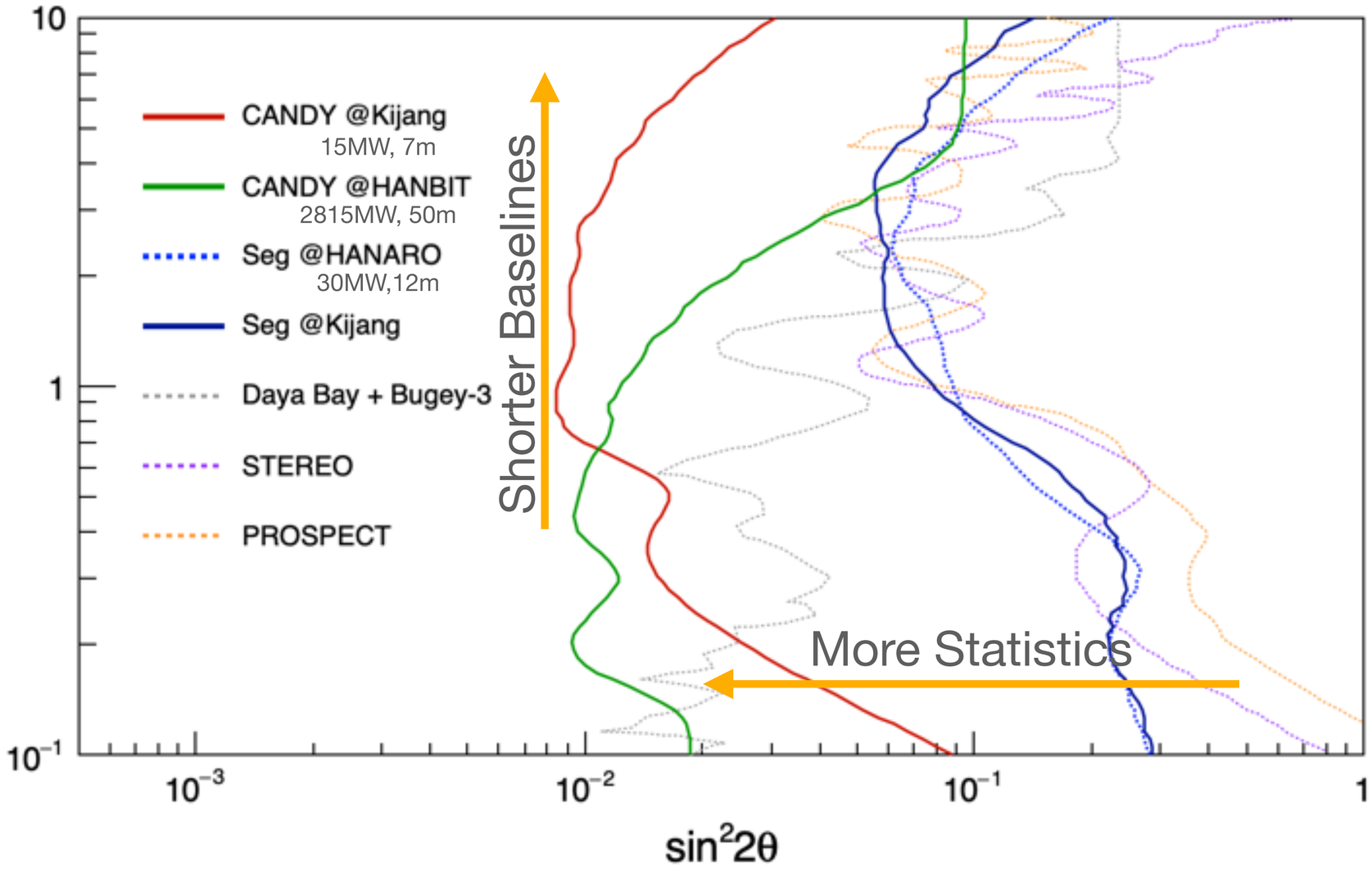
Target LAB Volume :
$D1.5m \times L3.0m$ **Cylinder.**
$V = 5.3m^3, \;\; M = 4.5 \; tons$

40 PMTs : 8-inch on each sides
2000 SiPMs : 10cm pitch in 3D
Water Cherenkov outside with 10-inch PMTs.

CANDY Sensitivity for ν_s

Good Position Resolution~a few cm —> Background Rejection & —> Various Baseline sampling

Sizable volume for statistics.
Underground will be better for muon & neutron background.



R&D efforts
HAWL & CANDY

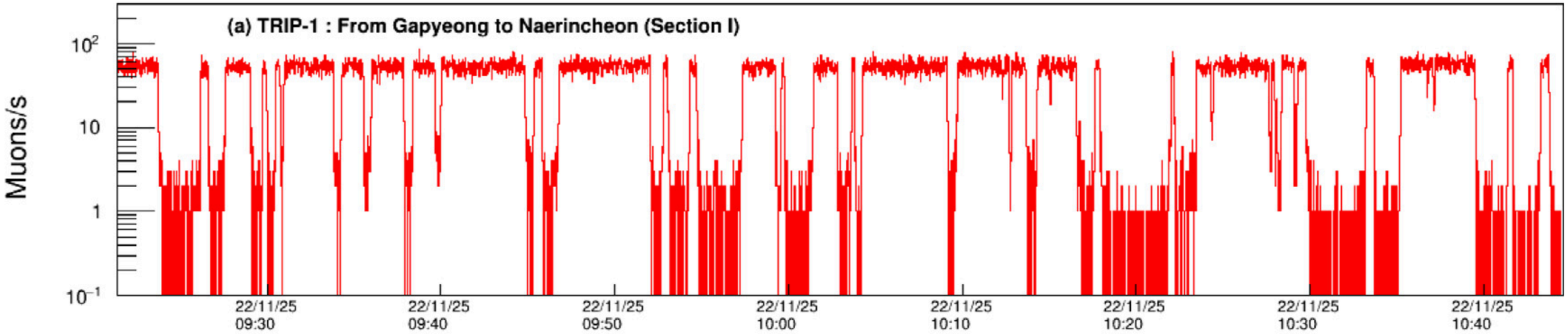
Hankuk Atmospheric-muon Wide Landscaping (HAWL)

Chung-Ang university Neutrino Detection Yolk (*CANDY*)

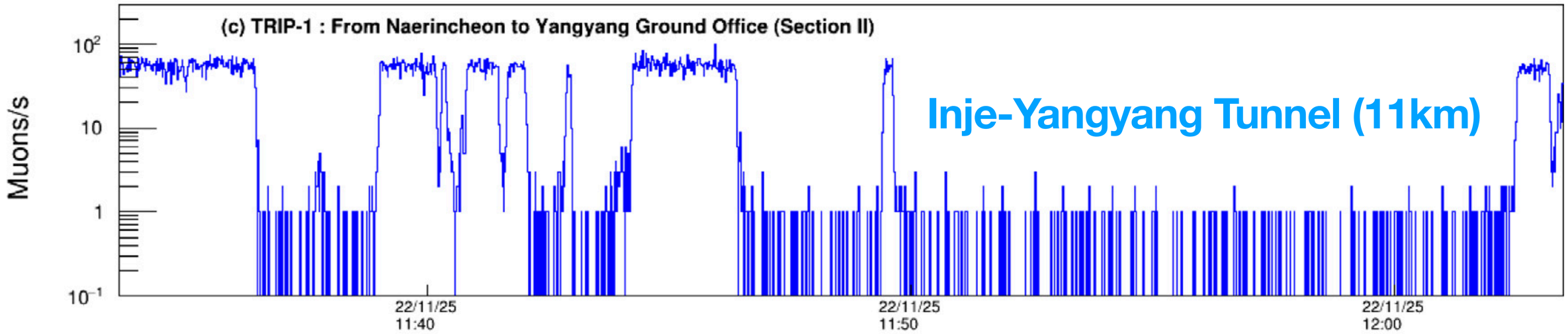
Hankuk Atmospheric-muon Wide Landscaping (HAWL)



Moving Muon Detector (Highway Tunnel Scan)

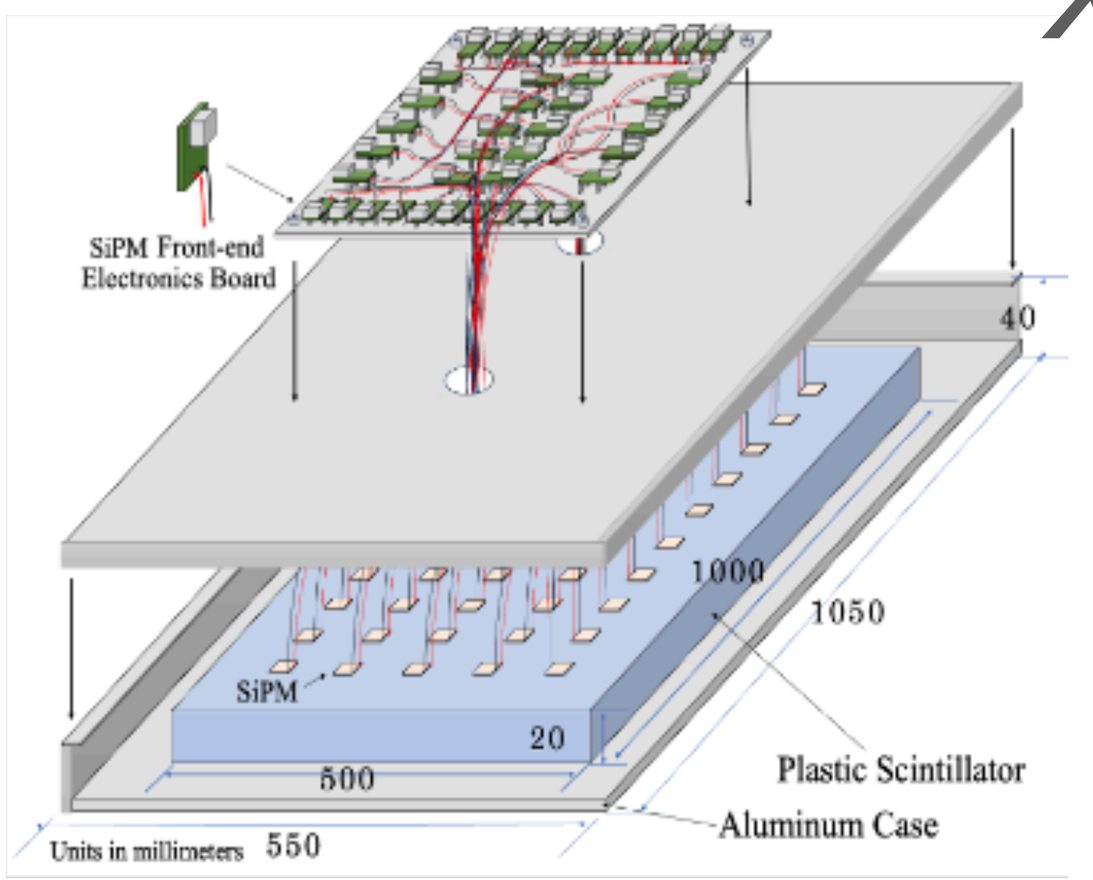


Radiat.Phys.Chem. 225 (2024) 112117



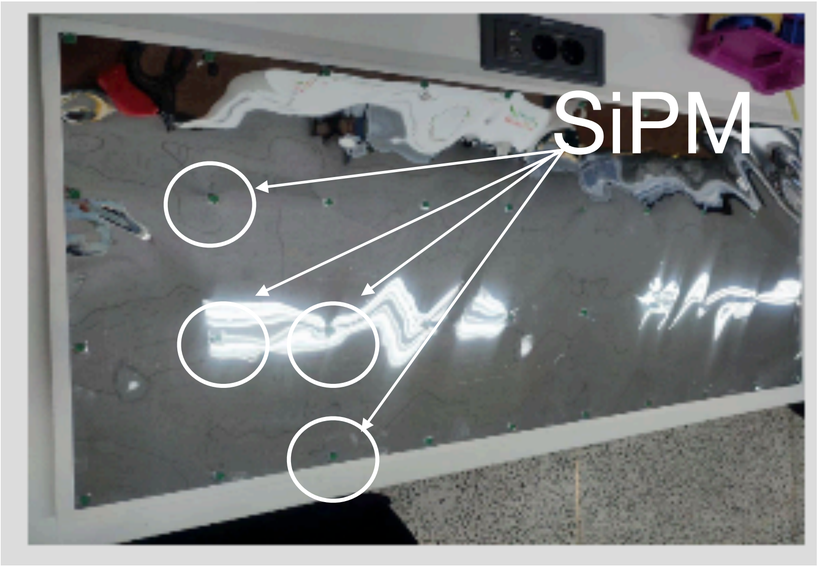
HAWL Upgrade (2 panels with 80 channel SiPM array)

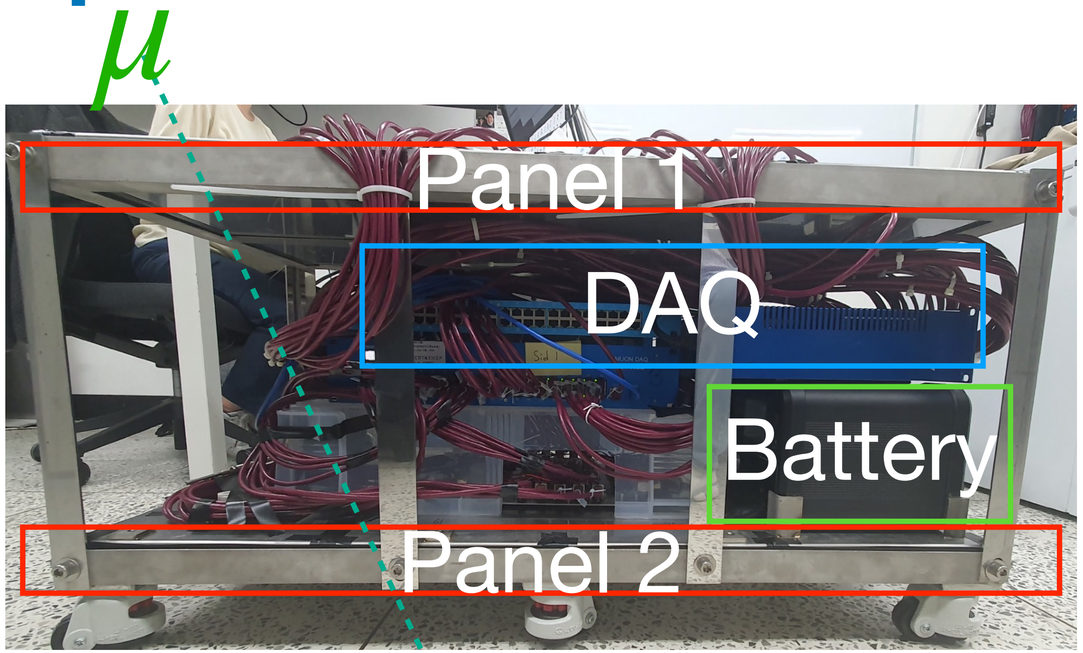
x 2



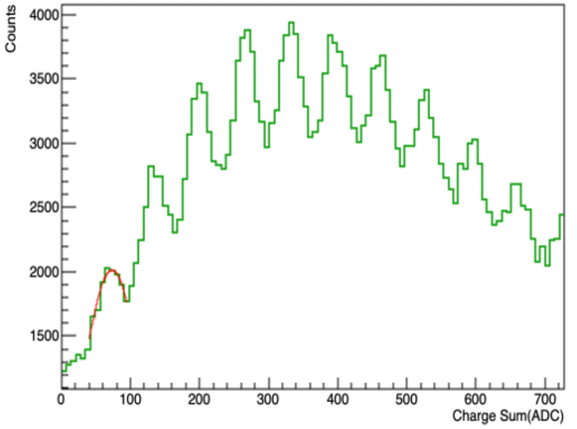
- Two Panel Coincidence
- New Panel (Larger area $0.3m^2 \rightarrow 0.5m^2$)
- Large SiPM coverage ($1.7mm^2 \rightarrow 36.0mm^2$)
- Direct attachment to the scintillator (No fibers)
- Position Sensitivity using Light Pattern

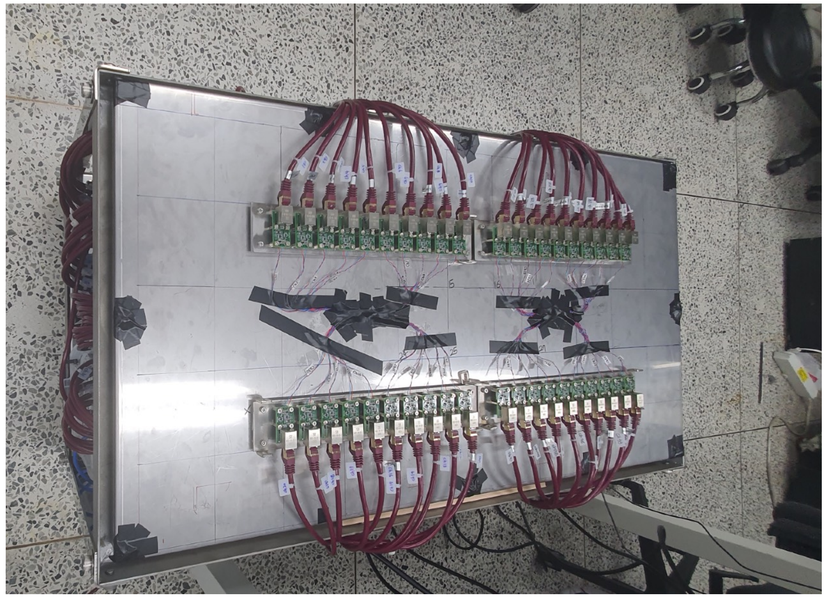
HAWL Upgrade (2 panels with 80 channel SiPM array)

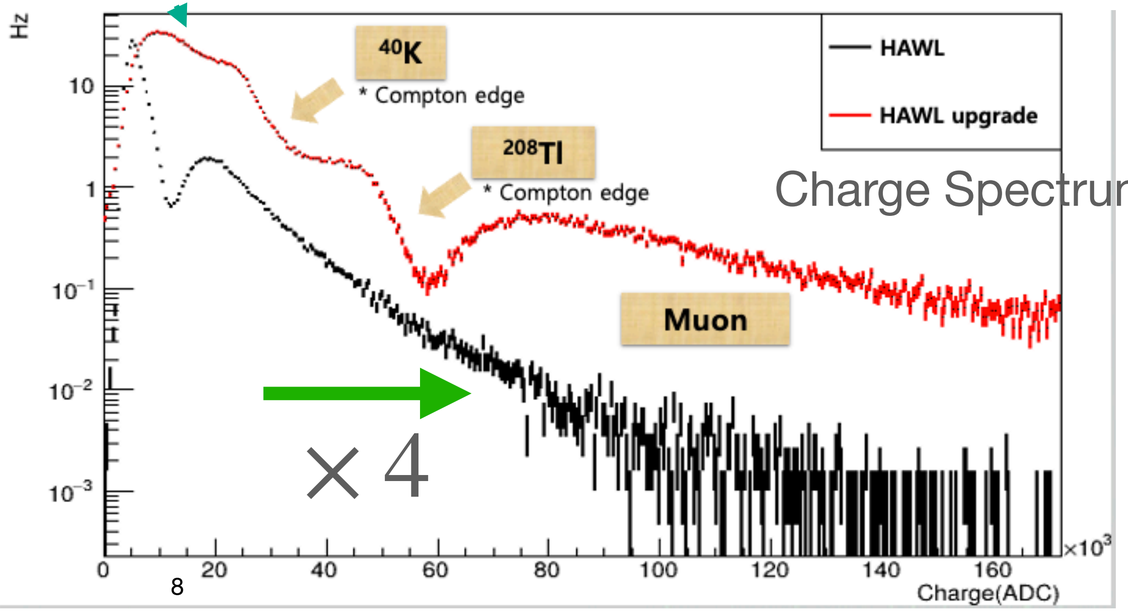




SPE Spectrum for 1 SiPM



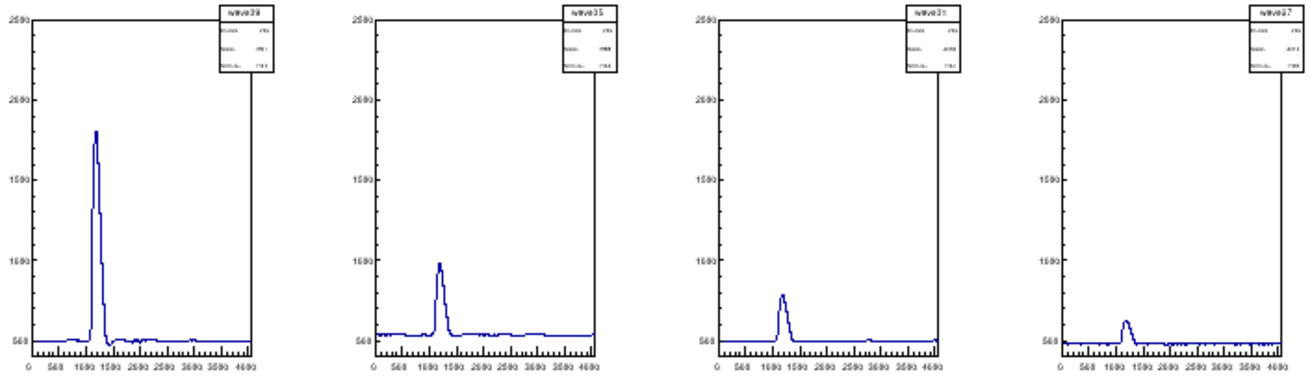


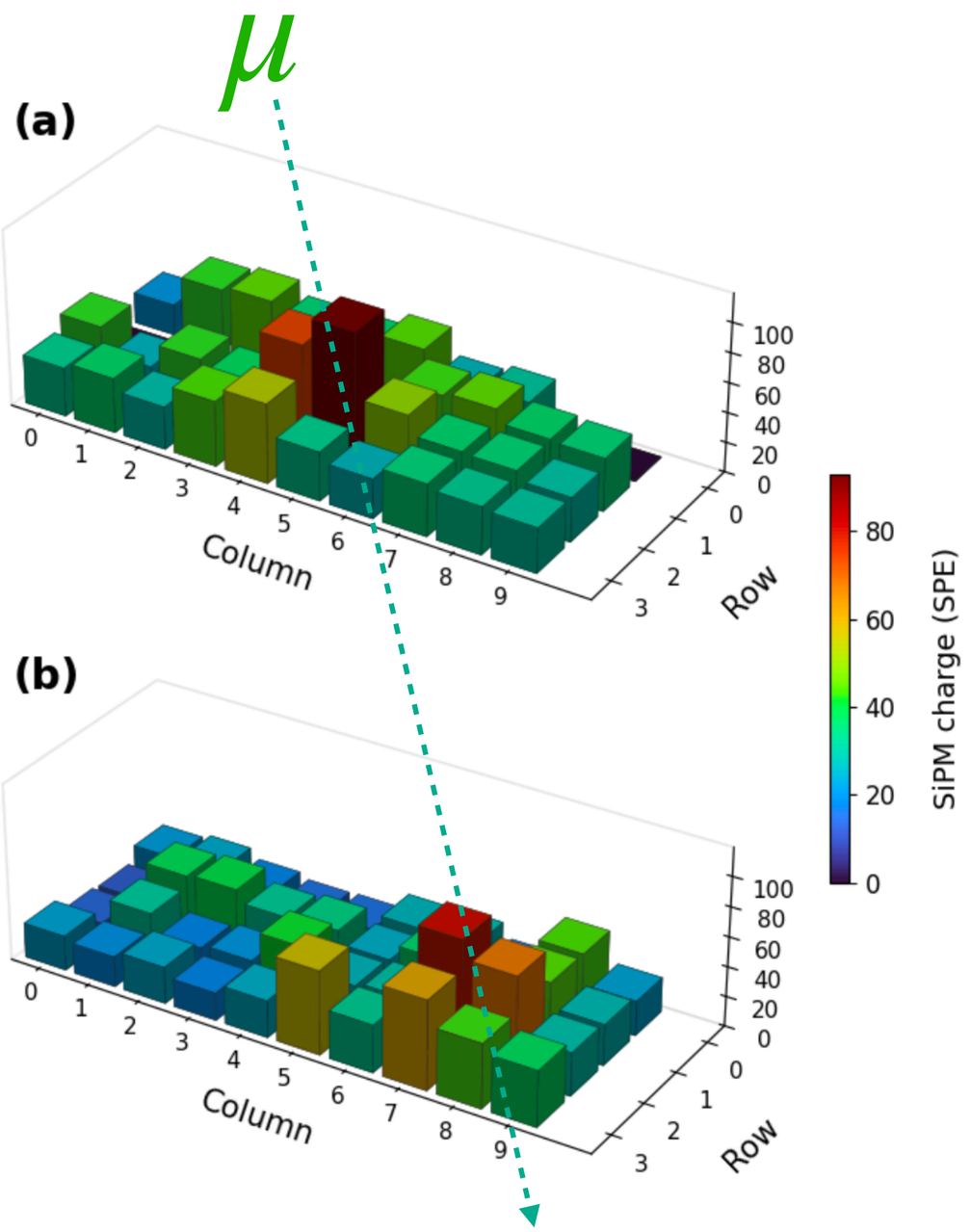


Charge Spectrum (x4 increase)

HAWL Upgrade (2 panels with 80 channel SiPM array)

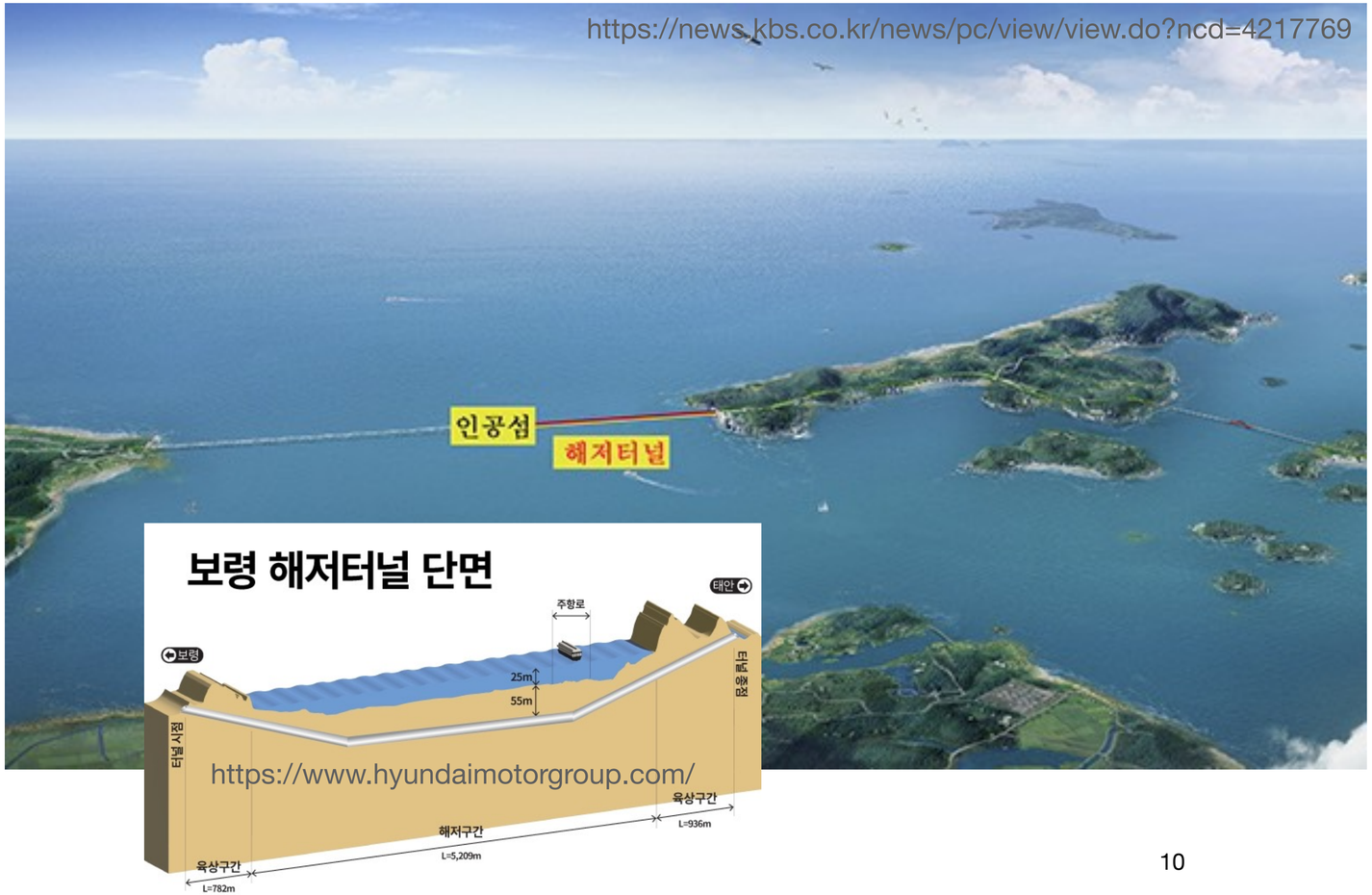
- Gain Corrections with SPE spectrum
- Full Waveform Mode & Peak Mode possible
- Coincident measurements.
- Energy threshold of about 1 MeV
- Muon-Gamma separation of 99%





HAWL Upgrade Trip : Boryoung Tunnel

- World 5th longest undersea tunnel ~ 7 km
- West Sea Tide : One of the largest in the world (~10m max)
- Tsunami Early Warning system using HAWL





HAWL Upgrade Measurement in the Boryoung Tunnel

Tunnel Scan
(June 30, 2025)





Long-term Measurement installations
(August 11, 2025)

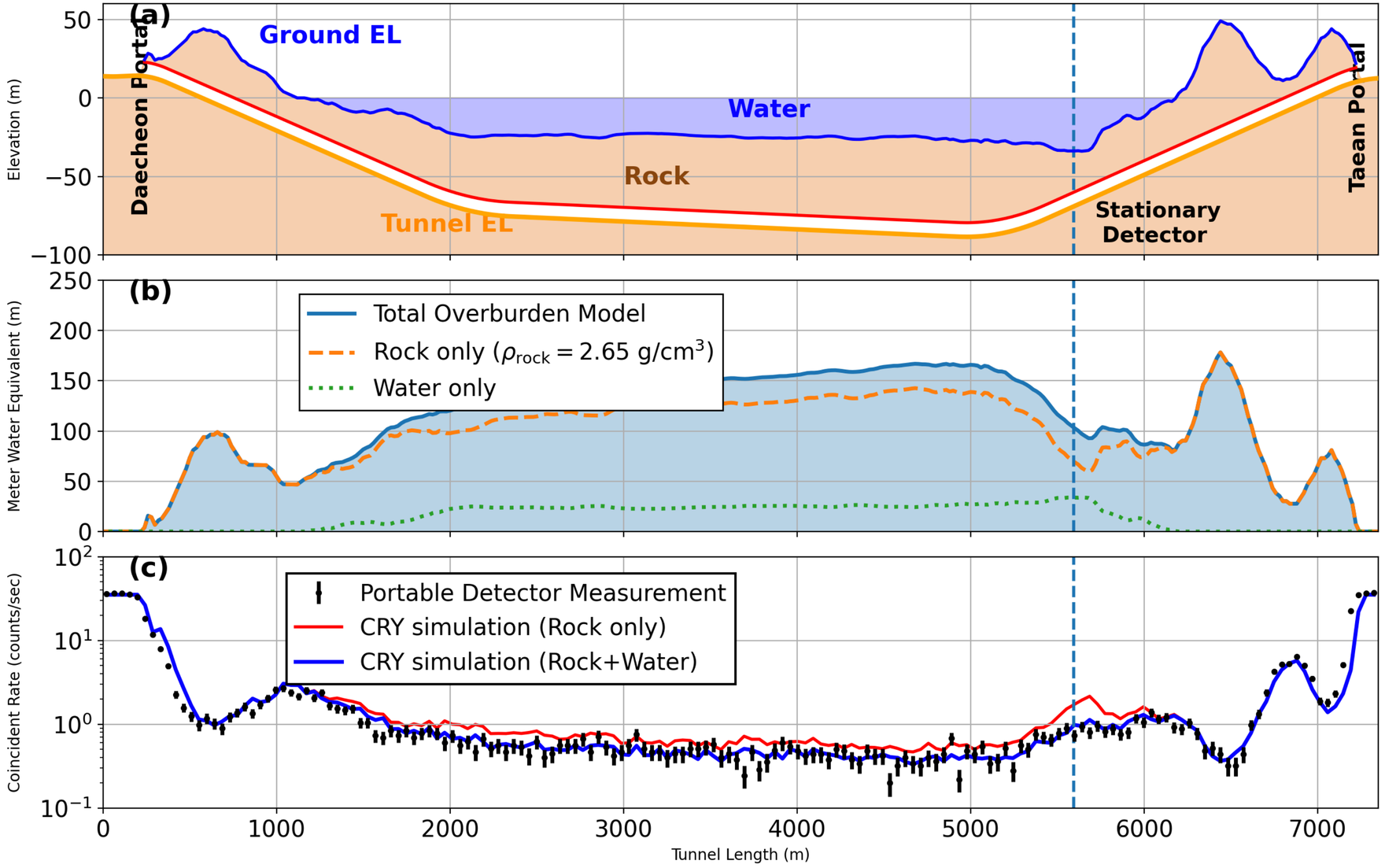




Boryoung Tunnel Scan Results

https://arxiv.org/abs/2610.05294

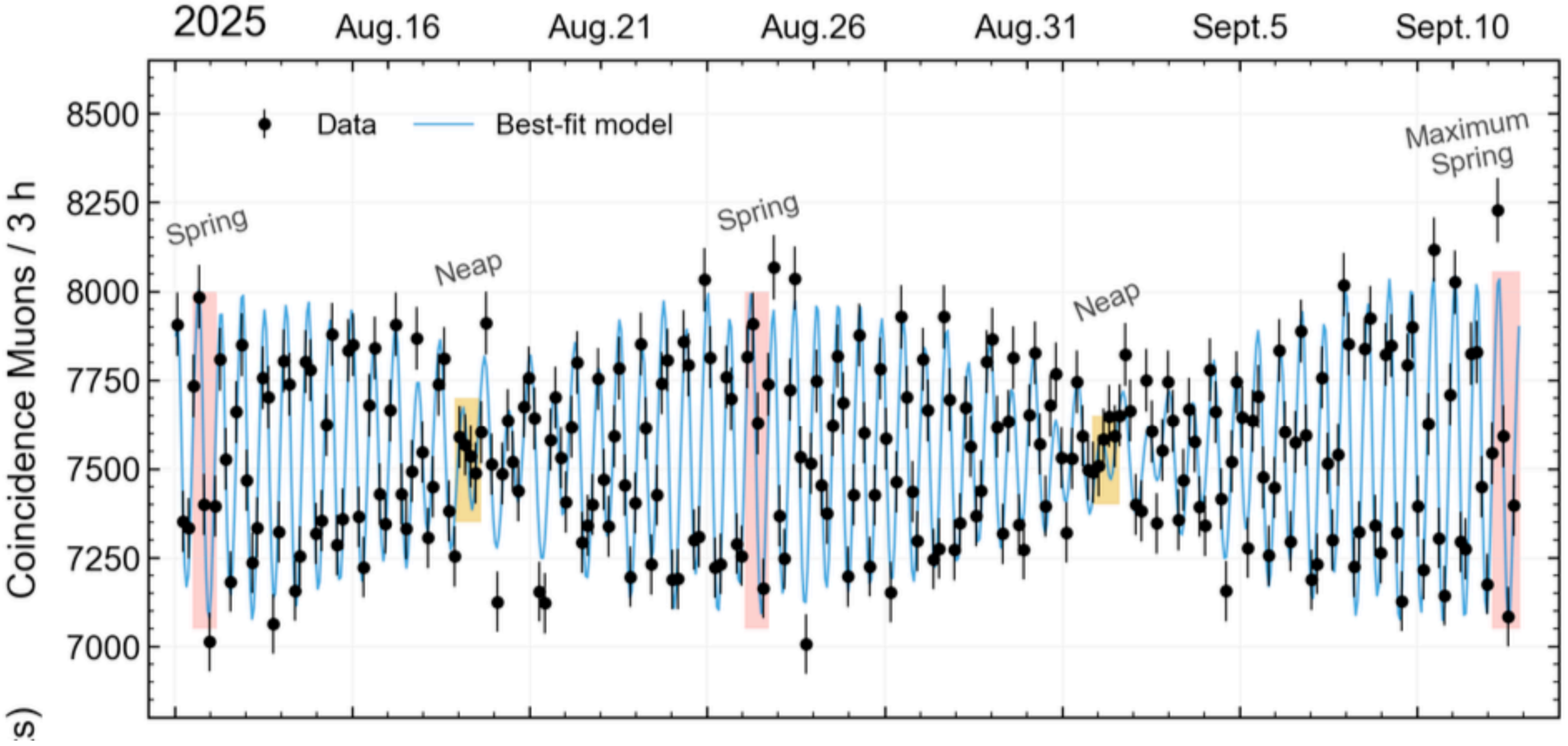
- Detector is moved speed of about 31 km/h.
- CRY-based simulations along the tunnel direction
- No-water model rejected (>10σ)
- Overburden matches well with measurements (systematic due to rock density <5%)
- Calibration for the Long-term measurements



Boryoung Tunnel Long-term Tidal Results

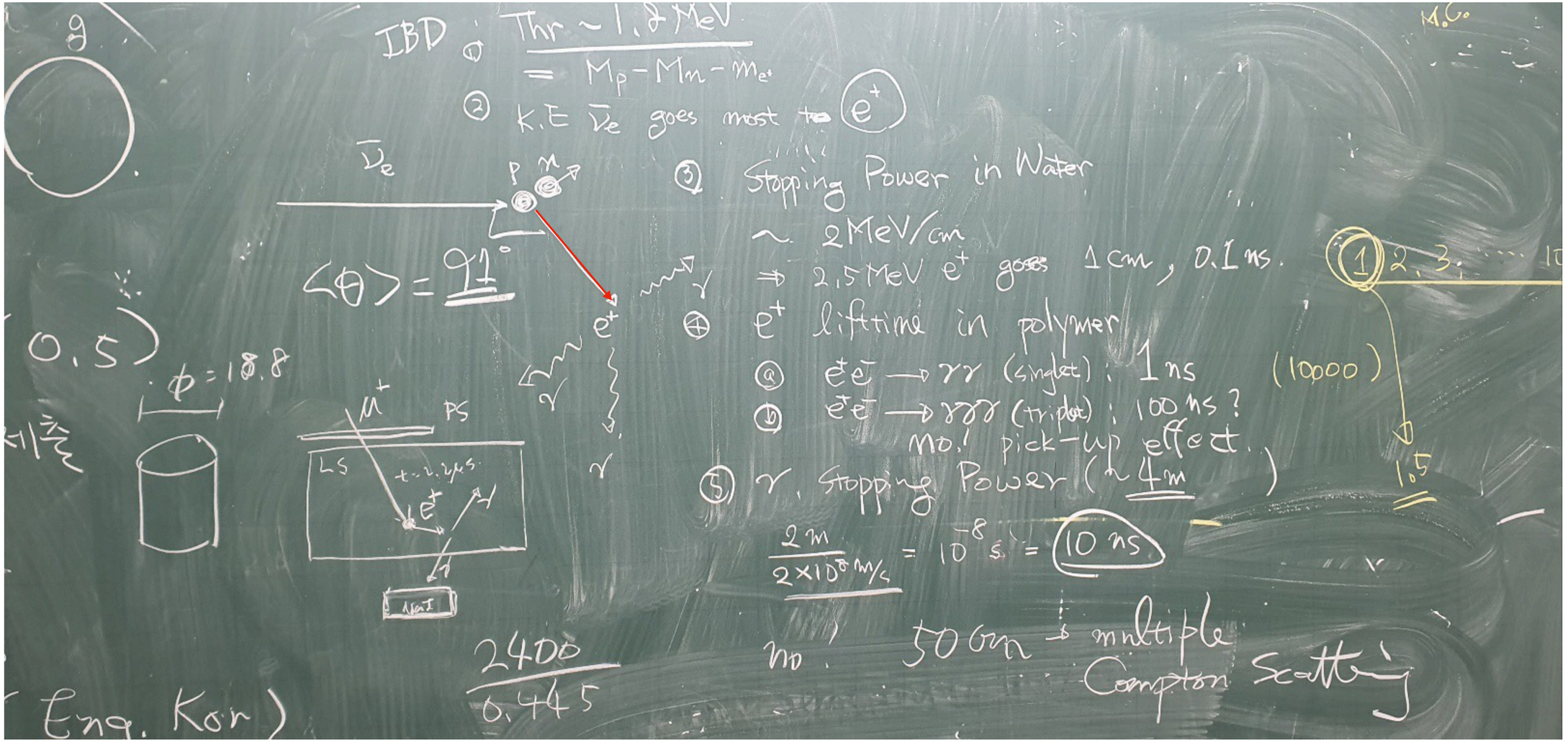
- Model is derived from nearby tidal gauge measurements.
- Model fit attenuation of muon rate as a function of water thickness (k)
- Model fit shows good agreement ($\chi^2/ndf = 768.1/755$)
- CRY simulation shows consistent results
- Fit to other gauge data show consistent results.

$$k = 43.2 \pm 1.0\ counts/h/m$$

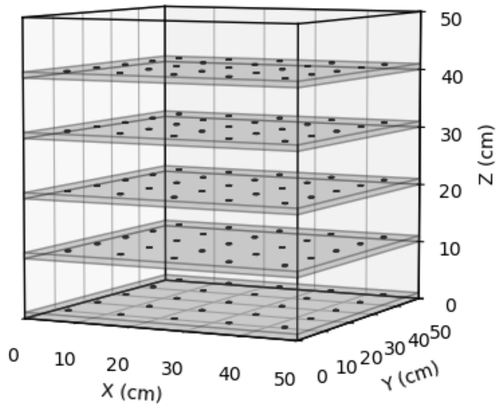


https://arxiv.org/abs/2610.05294

CANDY Goal : Identification of direct positron scintillation
CANDY-prototype Goal : Reconstruction of muon decay position



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



CANDY (Liquid Scintillator)

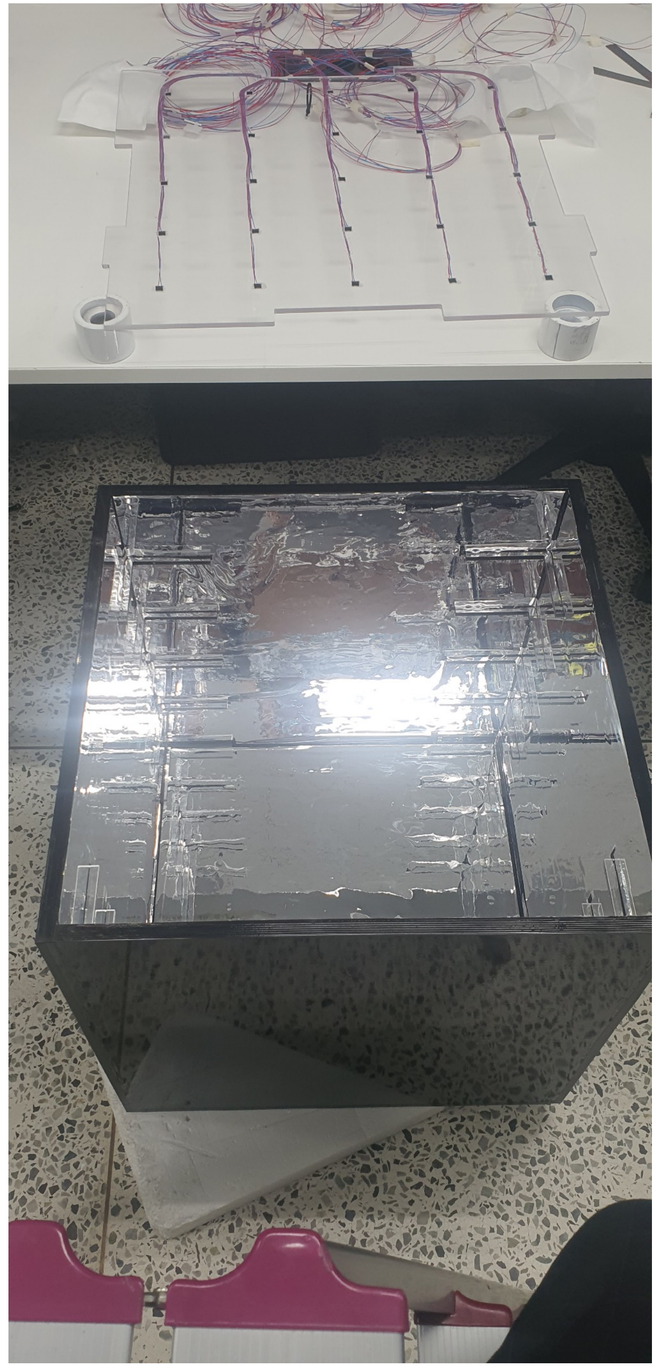
Target LAB Volume : $0.5m \times 0.5m \times 0.5m$

Cylinder. $V = 0.125m^3, \quad M = 0.1\ tons$**, 45 times smaller than CANDY**

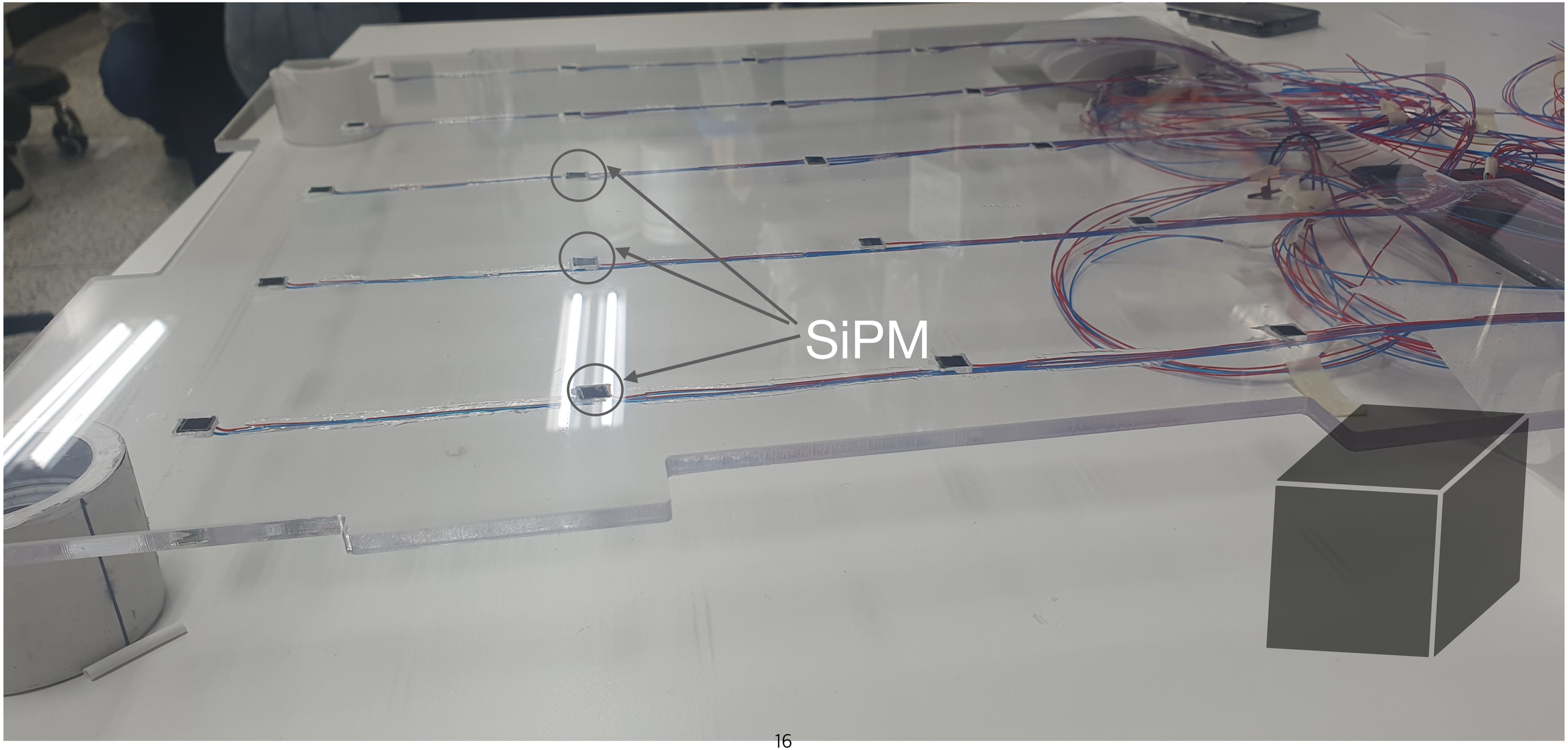
125 SiPMs : 10cm pitch in 3D



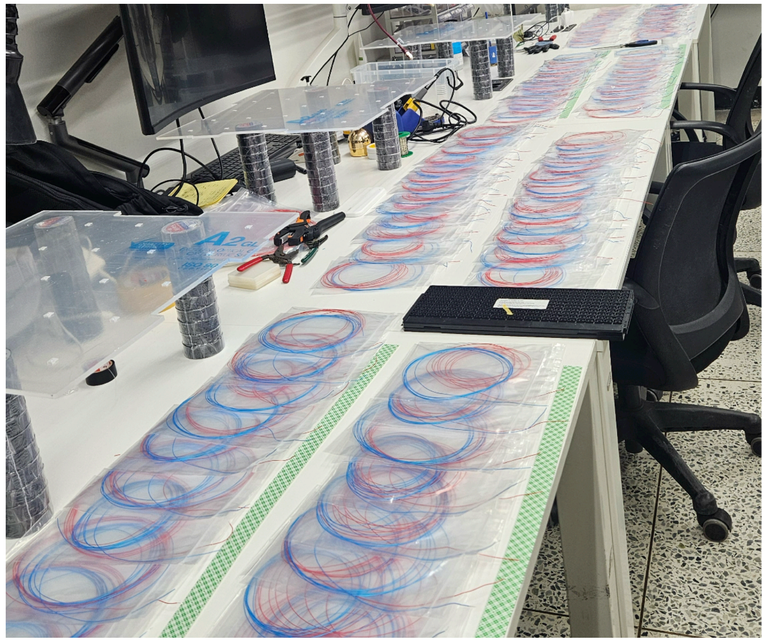


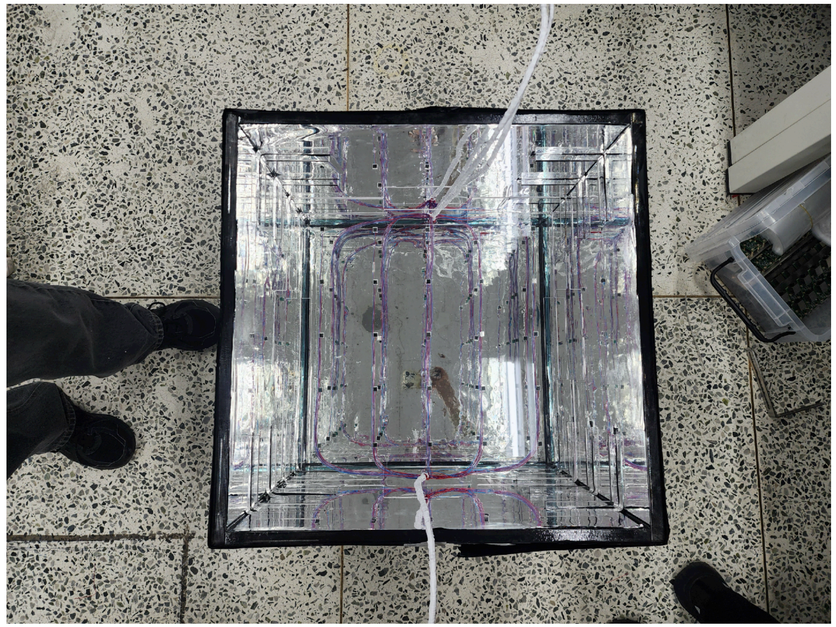


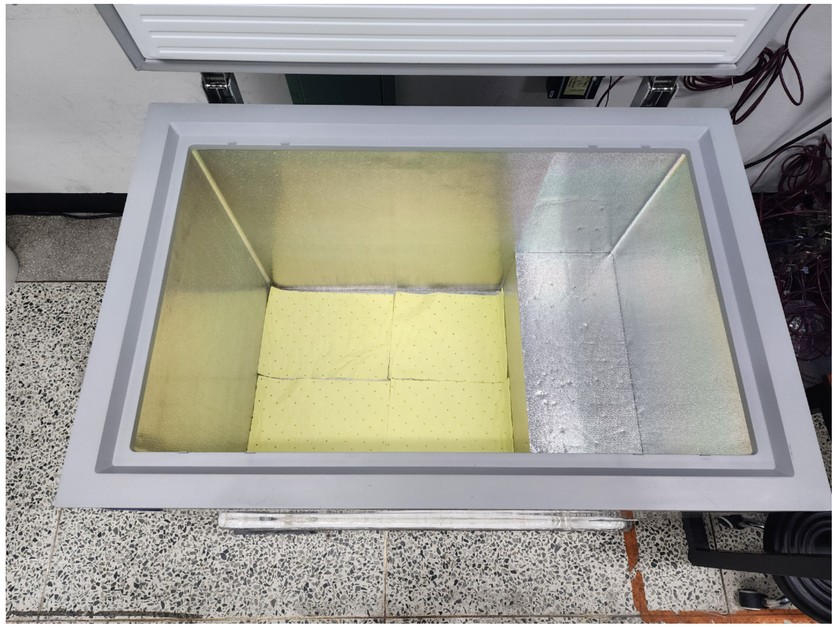
CANDY 1 layer (25 SiPM array in 10 cm pitch)

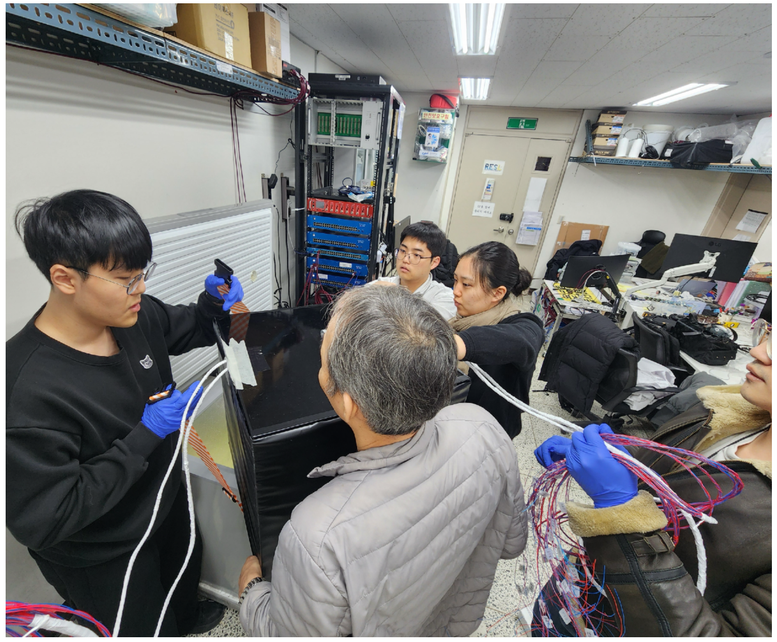


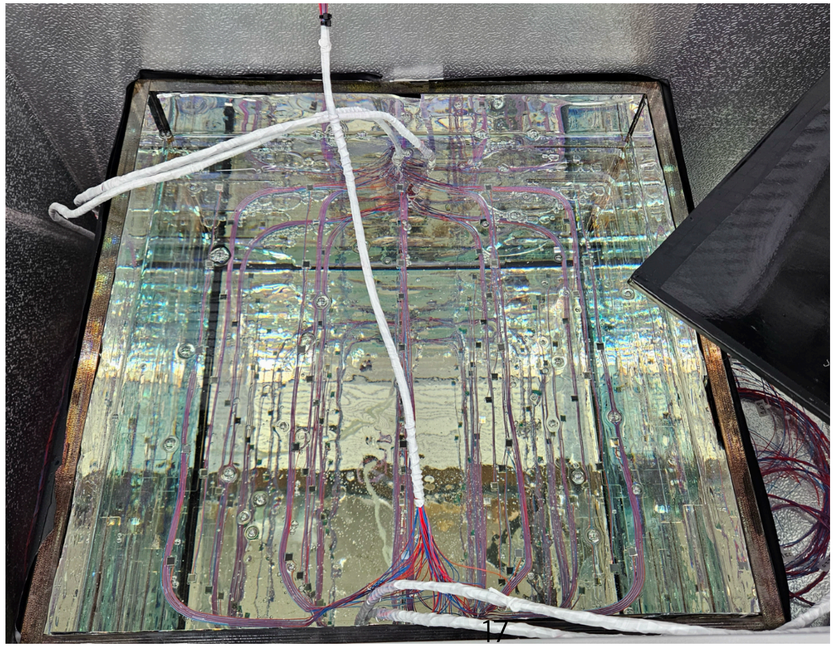
CANDY (5 layers, 125 channels)

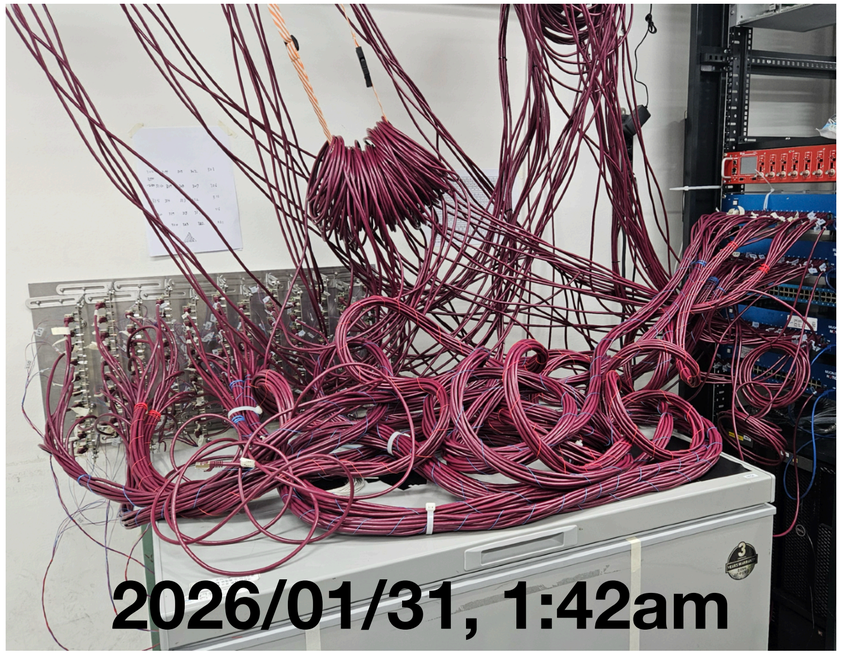




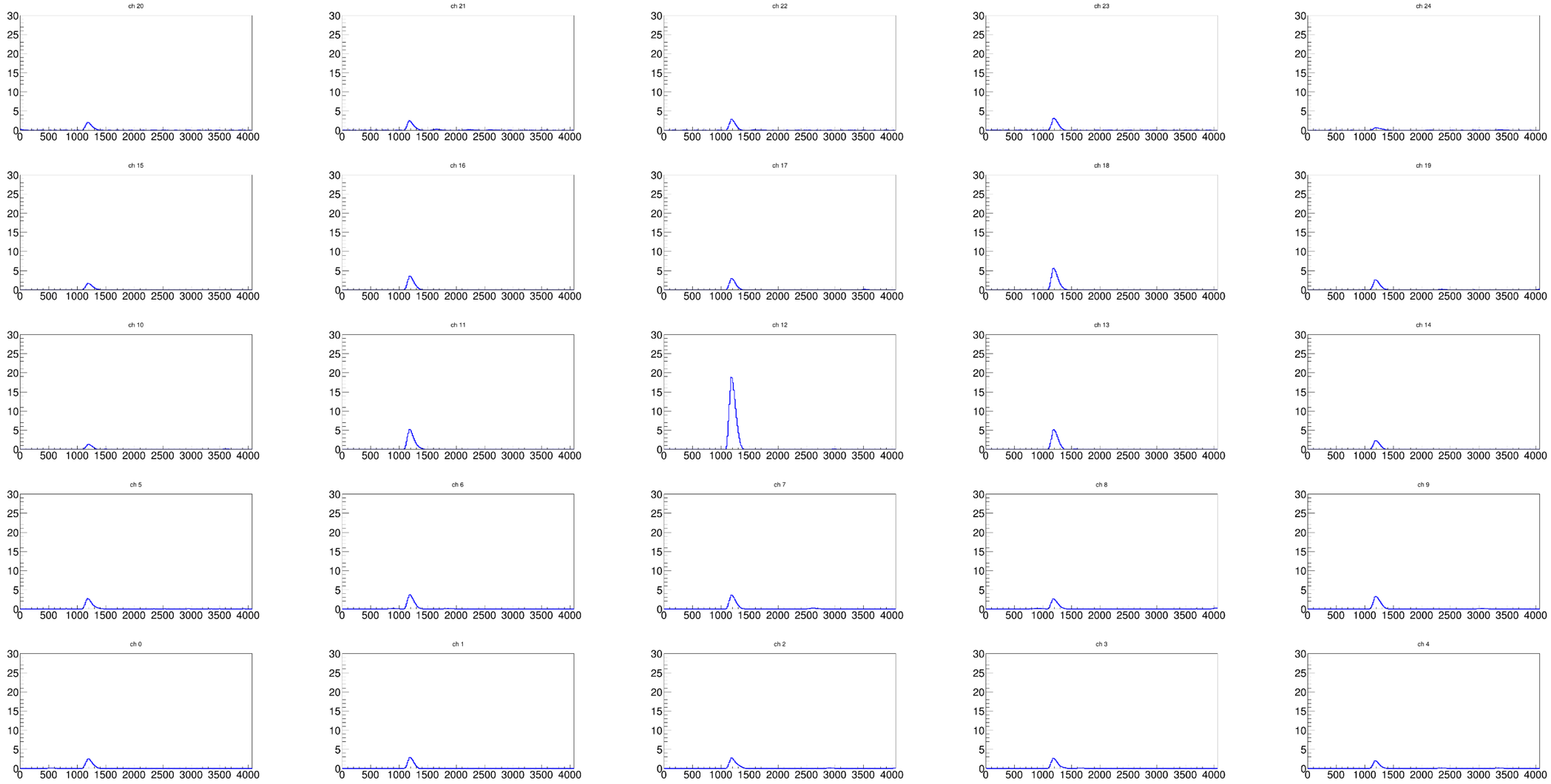






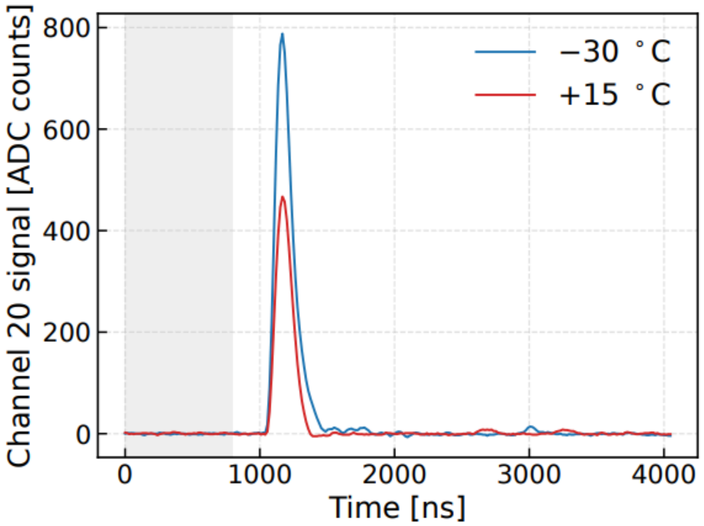


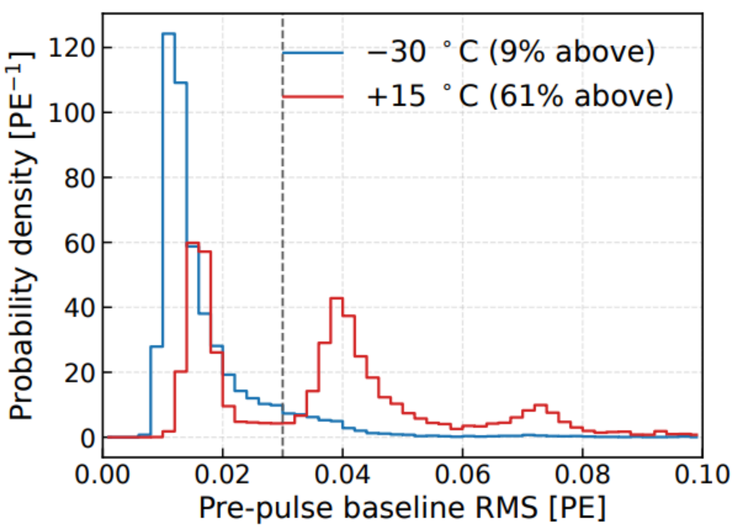
CANDY (125 channel SiPM array)



Layer-1

CANDY Characteristics

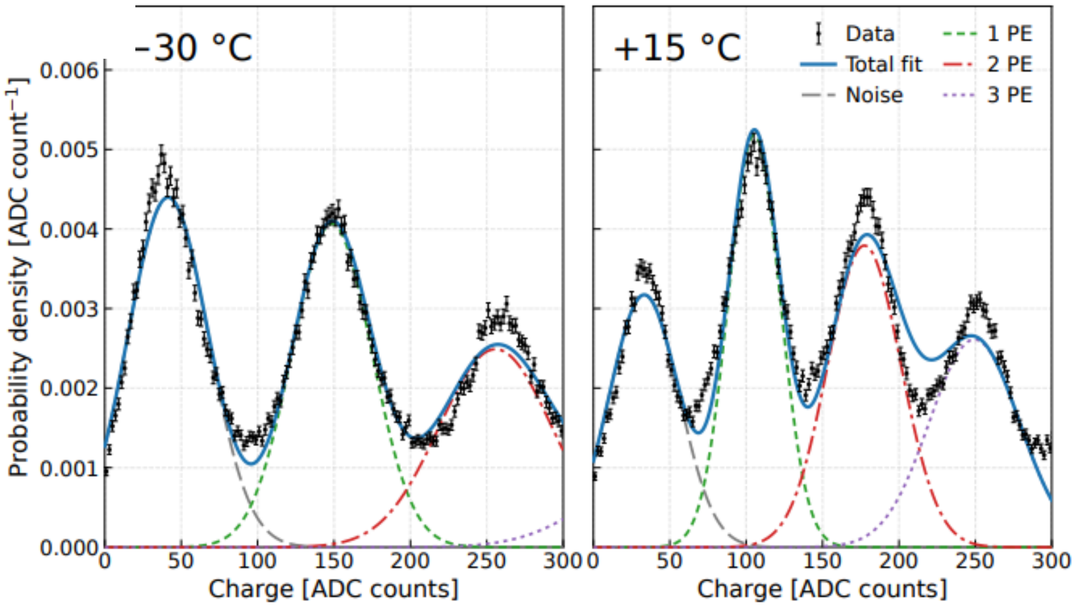




https://arxiv.org/pdf/2609.25534

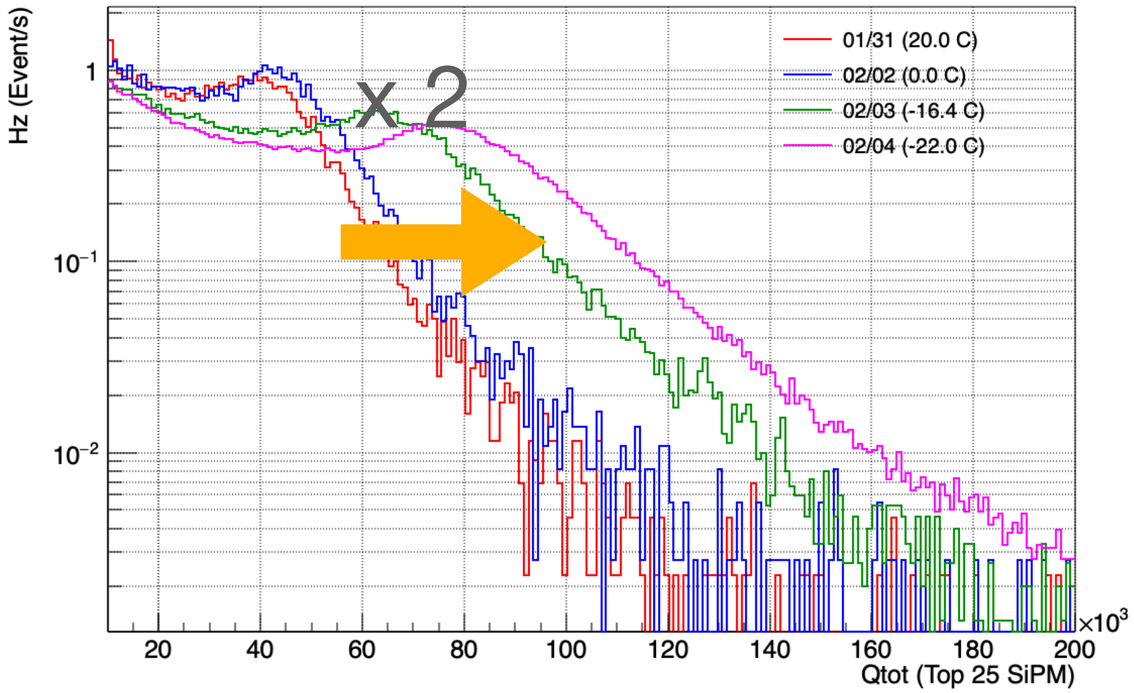
Dark and Crosstalk noise reduced at lower temperature by a factor of 13.5

SPE is well separated

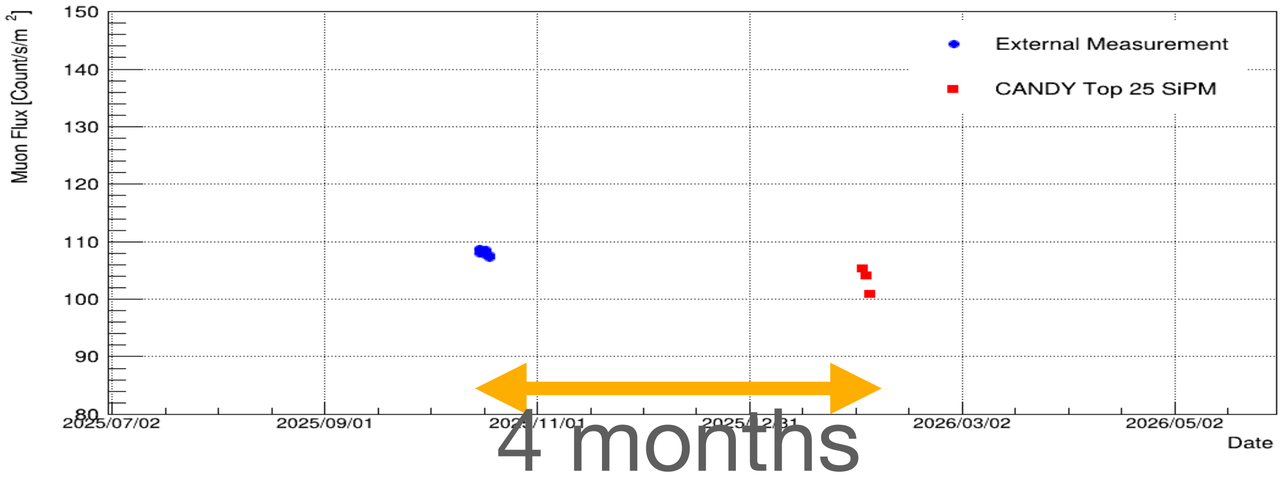


CANDY Characteristics

Gain increase with lower temperature



Muon Flux Stable

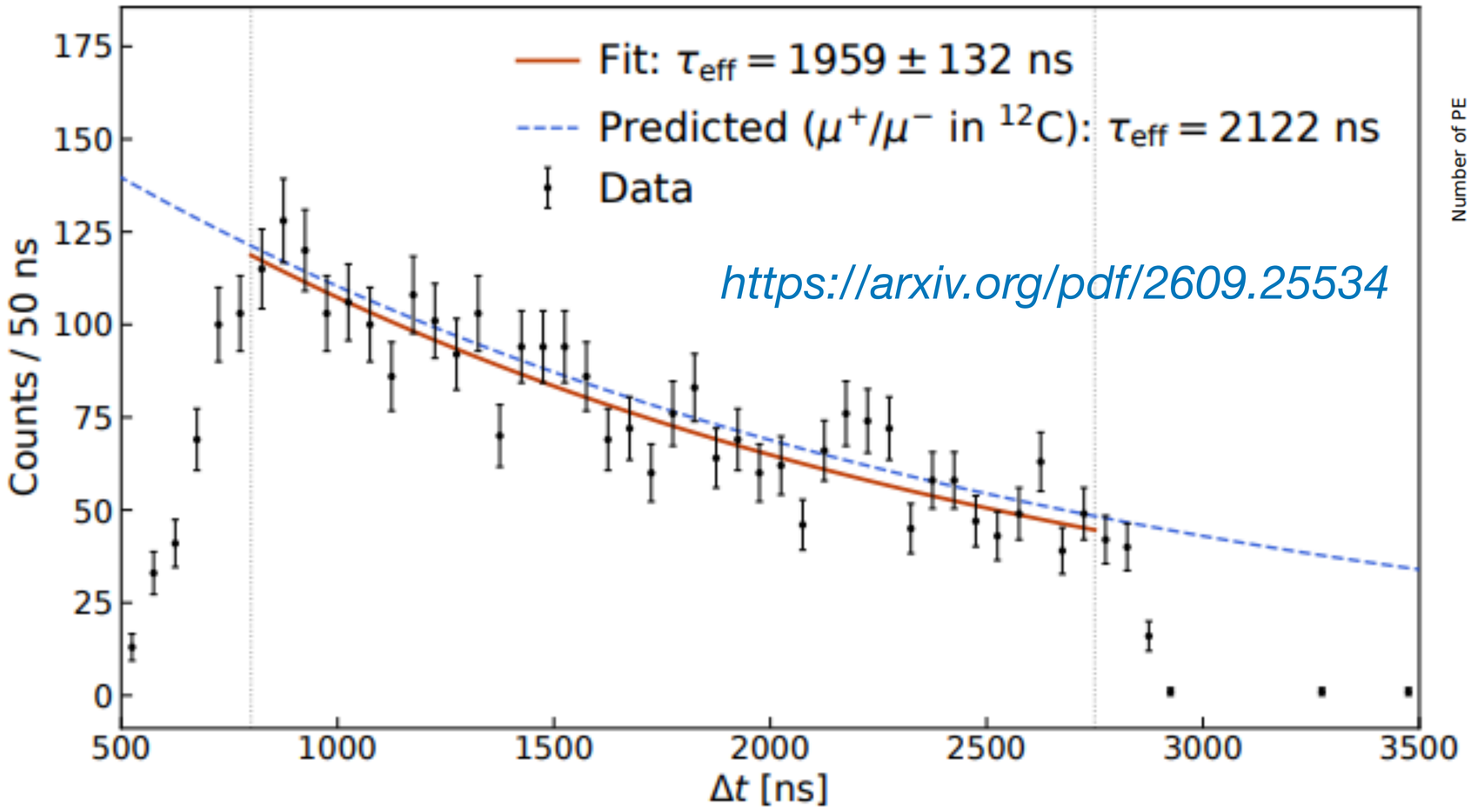


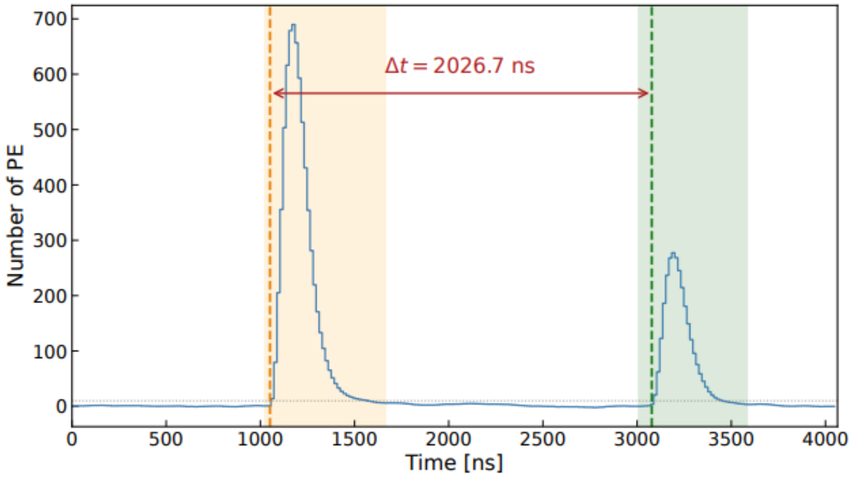
Gain increase with lower temperature
LS (muon) light yield increase by 17%
and SPE gain increase by 50%

LS is stable (check by SPEs
and Muon trigger rates)
Additional Boil-off N2 gas in the LS

CANDY Muon Decay events

Muon decay events measurements



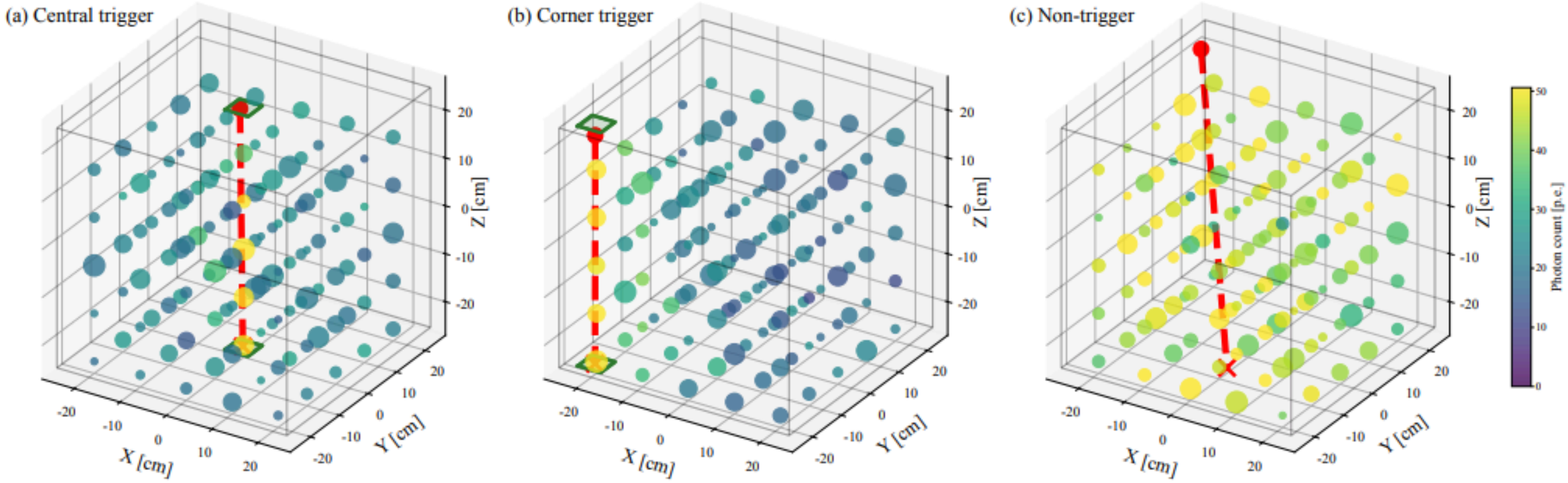


After selecting muon events, additional pulse is required.
Time difference of two pluses for stopping events

CANDY Reconstruction

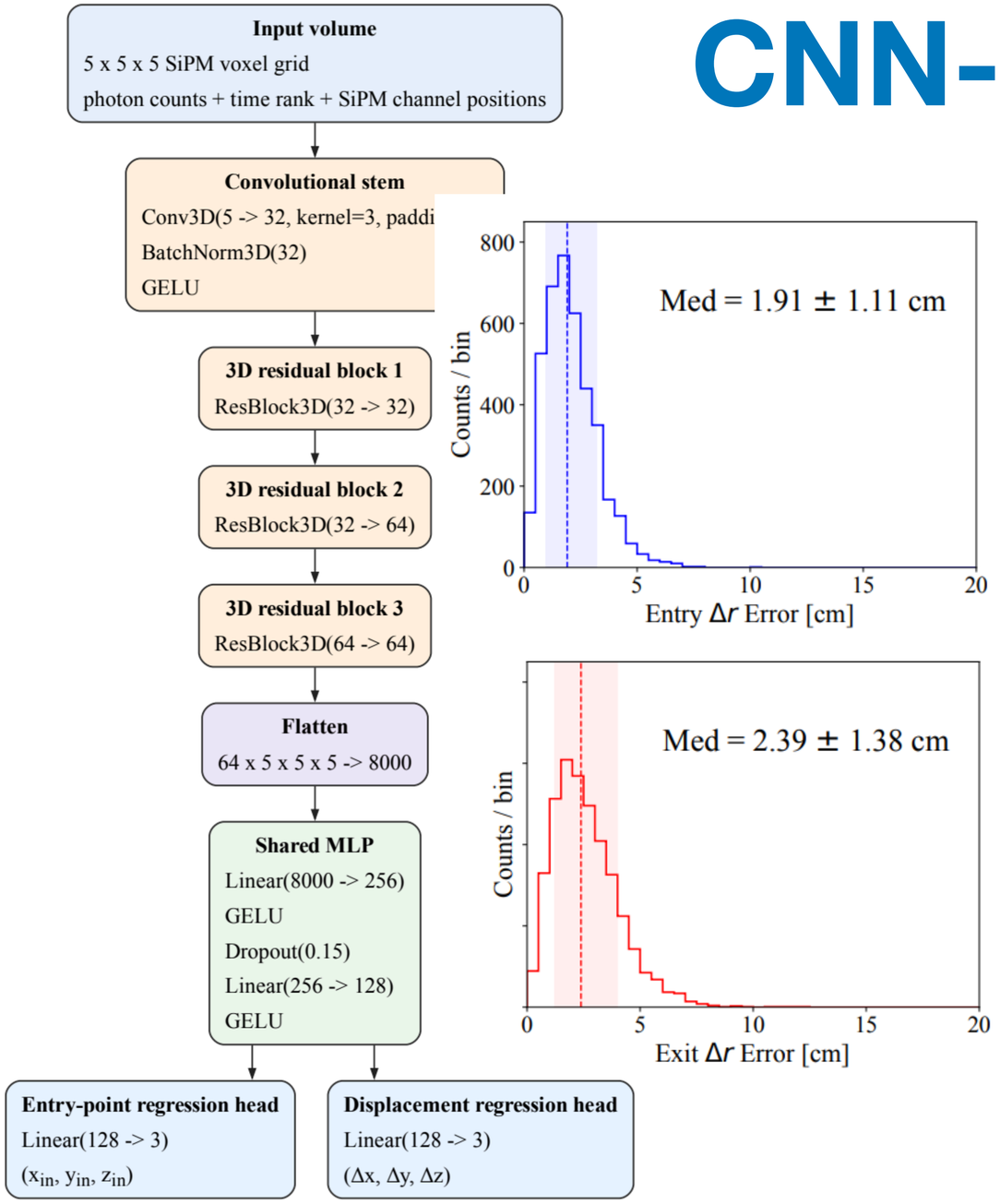
Selection of Real-data Events

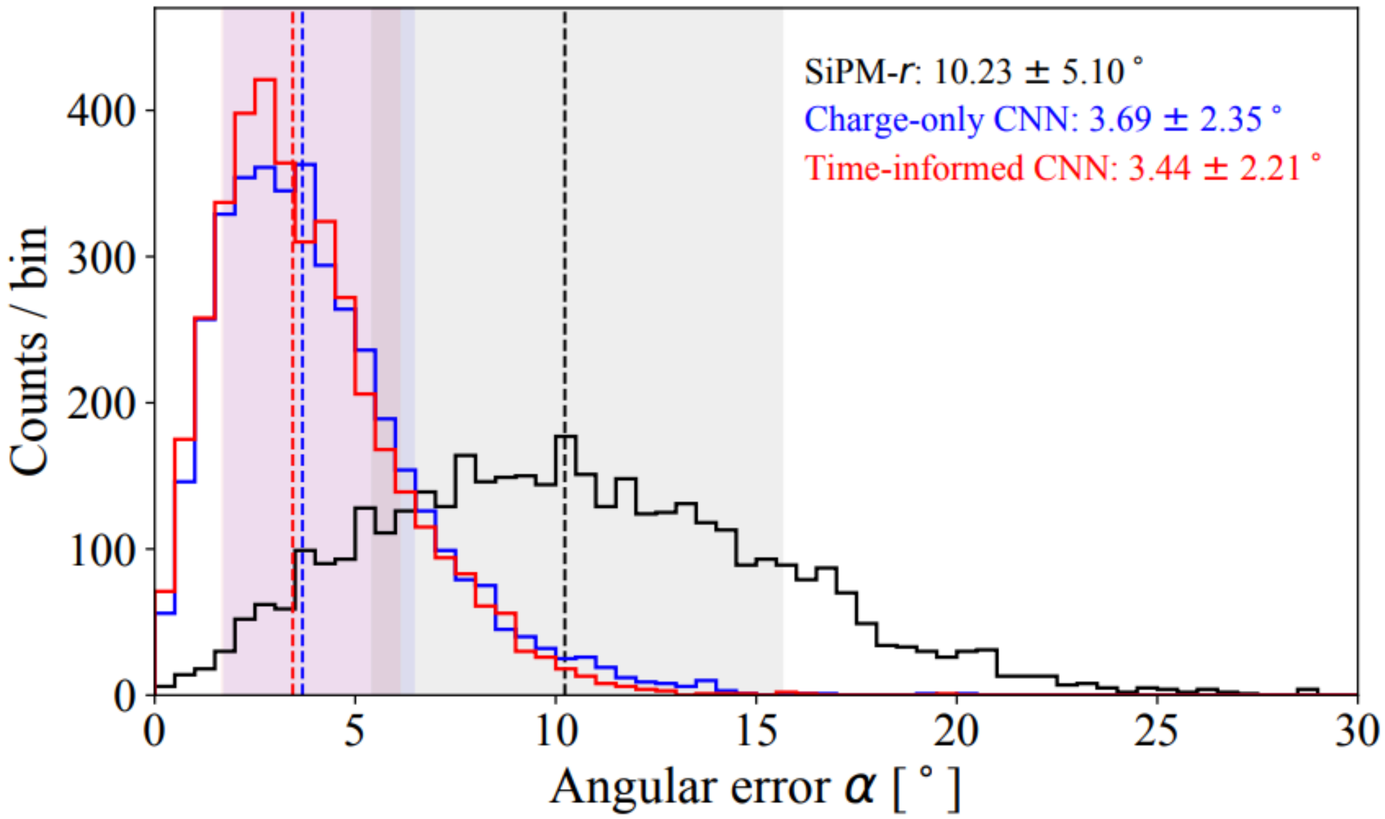
https://arxiv.org/pdf/2609.25532



CNN-based Reconstruction

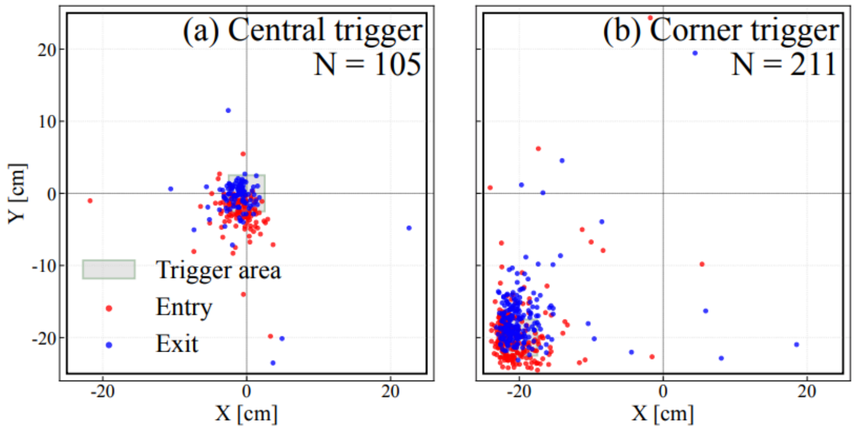
https://arxiv.org/pdf/2609.25532

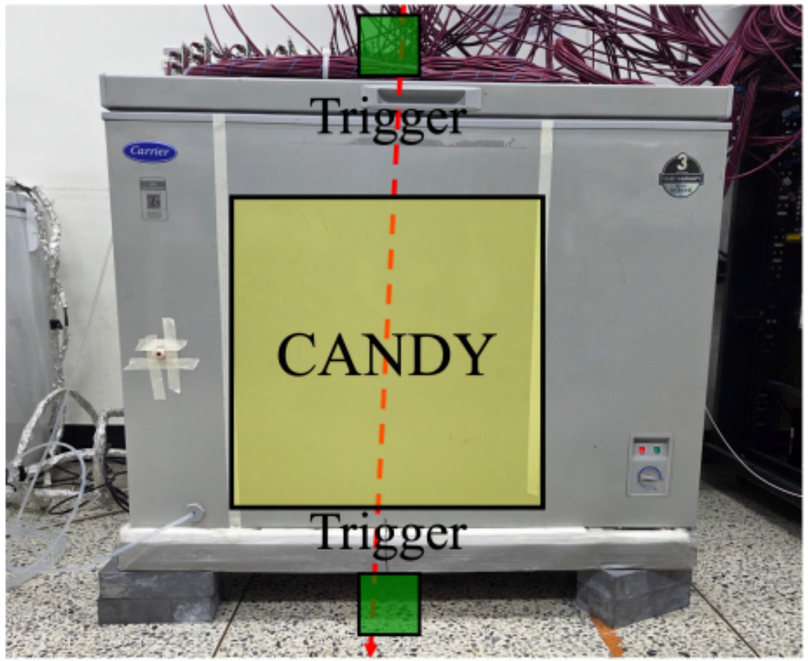


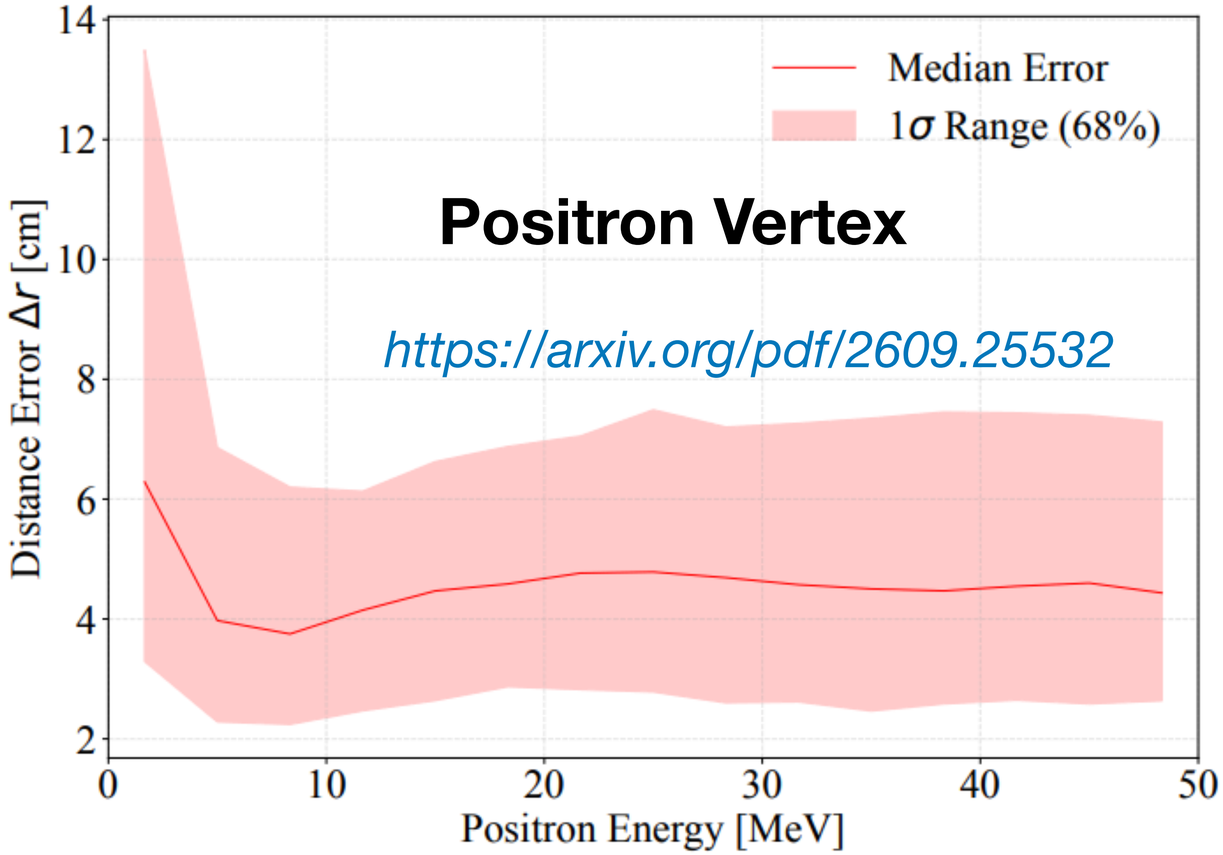


Neural-network reconstruction outperformed
Including channel time information helps

Positron Vertex Reconstruction







Detector entry/exit position reconstruction are verified by separate trigger data.
Muon-decay positron vertex position is reconstructed.

Summary and Outlook

position sensitive organic scintillation detectors

- We focus on R&Ds for position-sensitive scintillation detectors.
- The 4-ton CANDY detector has been proposed for IBD positron direct detection.
- West sea tides using upgraded 80ch-HAWL detector are studied.
- Long-term measurements including gauge data with a portable scan show consistent results.
- Our goal for CANDY is to achieve sub-centimeter resolution scintillation detector.
- Initial data from 125-channel CANDY (50cmX50cmX50cm, 125 SiPMs) at -30 deg. C is delivered and looks promising.
- Reconstruction of Michel electron starting position has been presented.

Rare Event Search Laboratory (RESL)



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

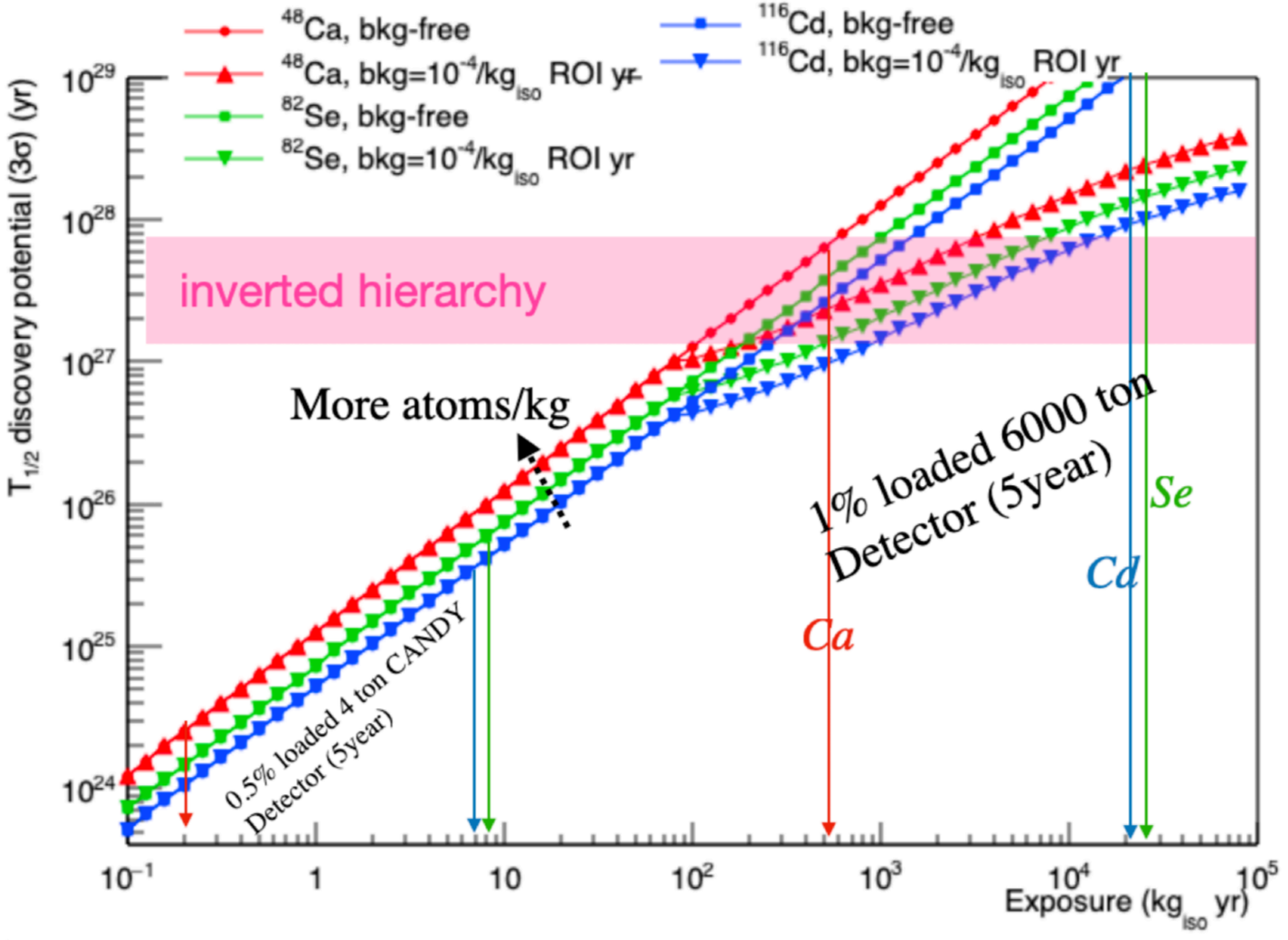


Back

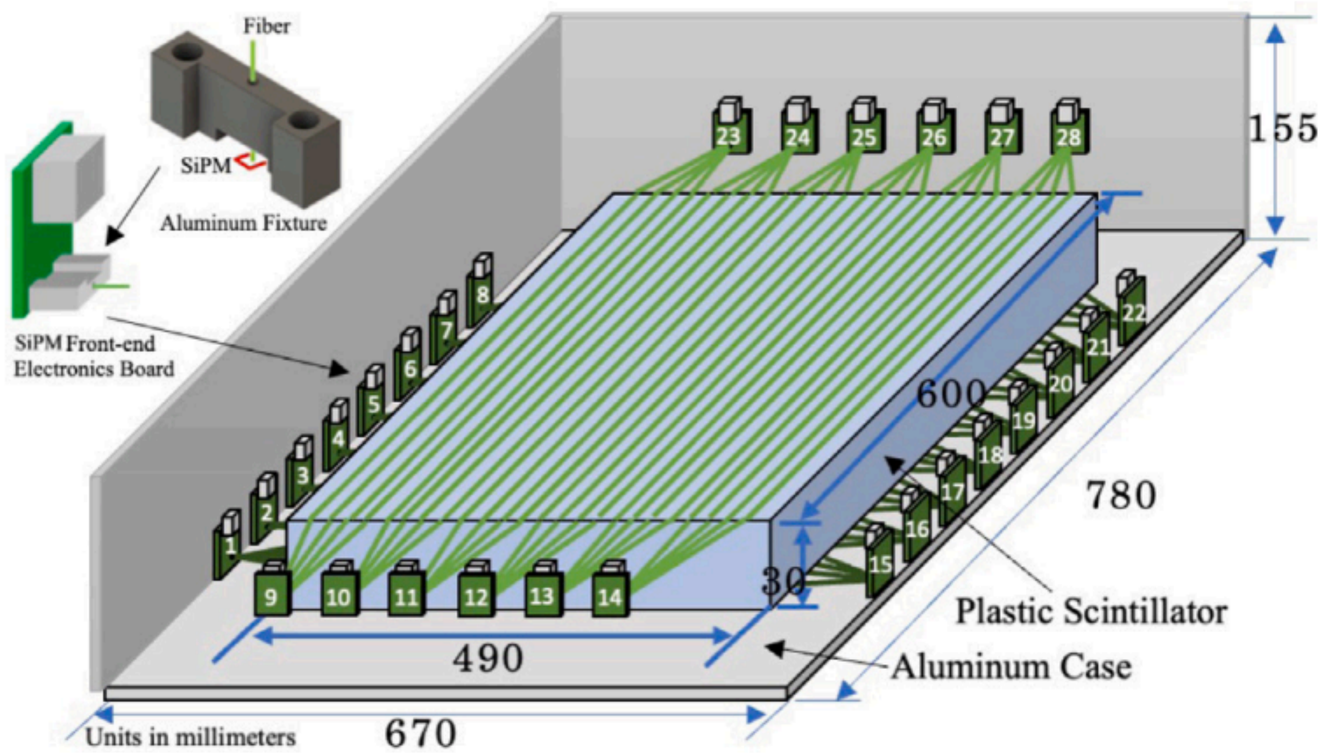
CANDY Sensitivity for $0\nu\beta\beta$

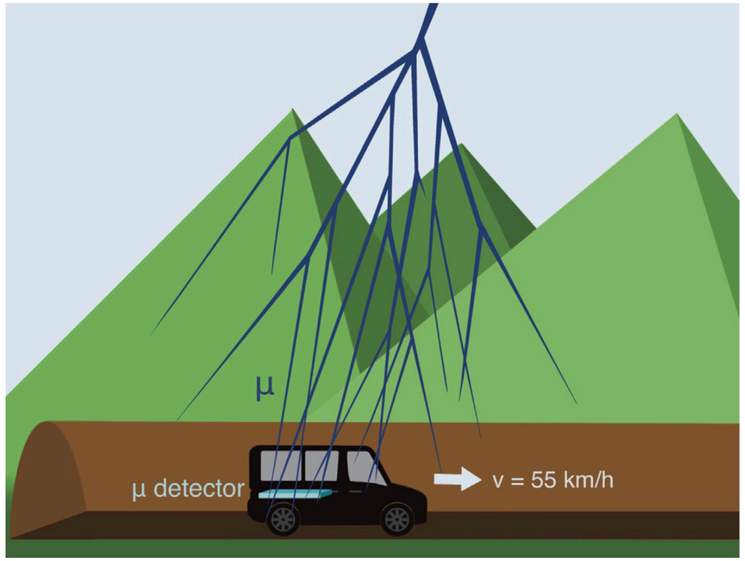
A prototype for the LSC $0\nu\beta\beta$ experiment with double beta isotope loading and extracting at Yemilab.

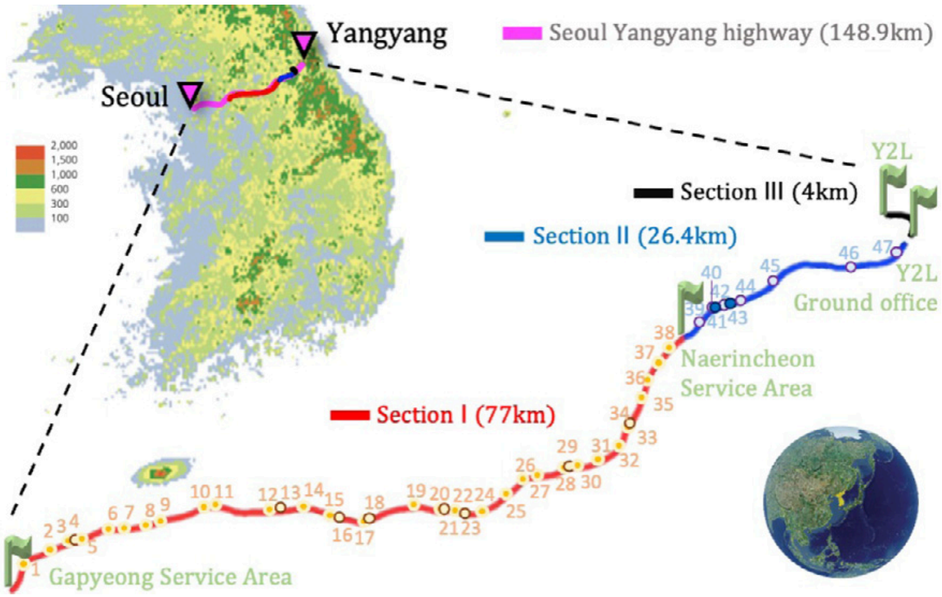
1% level Metal Loading and Extraction with stable LS, background control at the level of 10^{-4}ckky are challenges.



Hankuk Atmospheric-muon Wide Landscaping (HAWL)

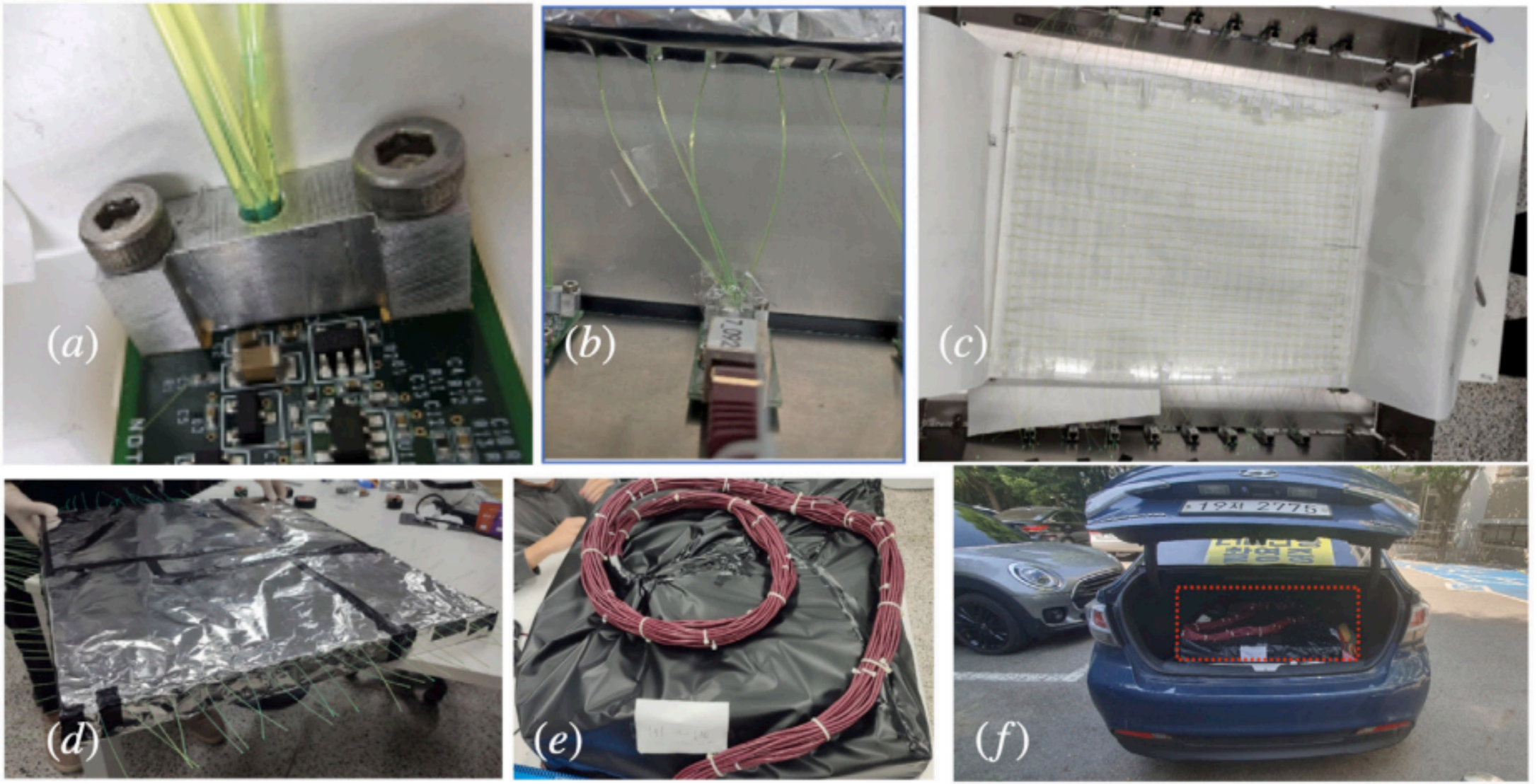




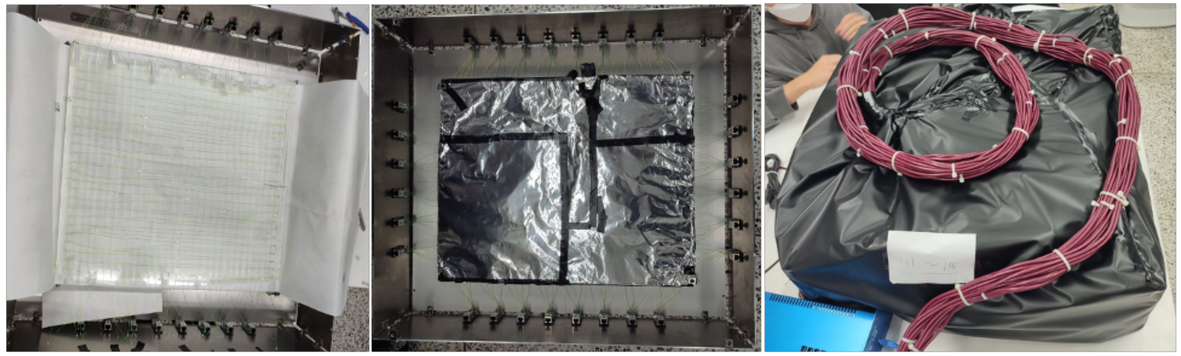


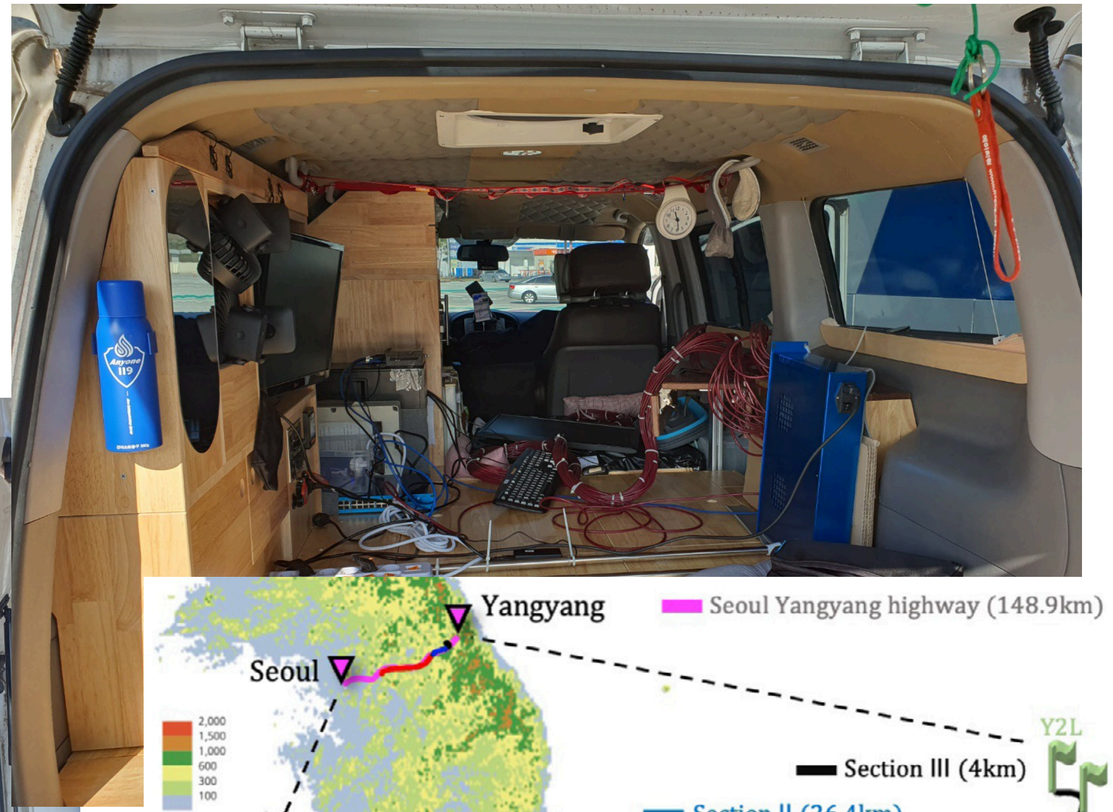
- Simple and compact Cosmic Ray muon detector using SiPMs
- Easily Portable Detector with custom DAQ under 68 Watt. power consumption
- Rugged detector with a good PID
- Wide Area Mapping in short measurement duration.
- Position-sensitive detector.
- Educational Demonstration (Real-time data displays)

Hankuk Atmospheric-muon Wide Landscaping (HAWL)



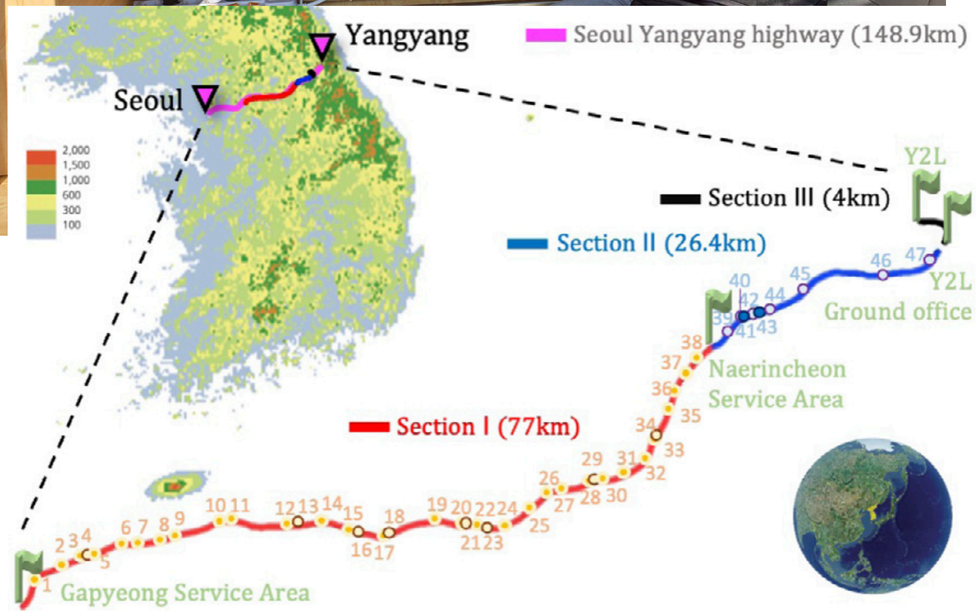
Hankuk Atmospheric-muon Wide Landscaping (HAWL)







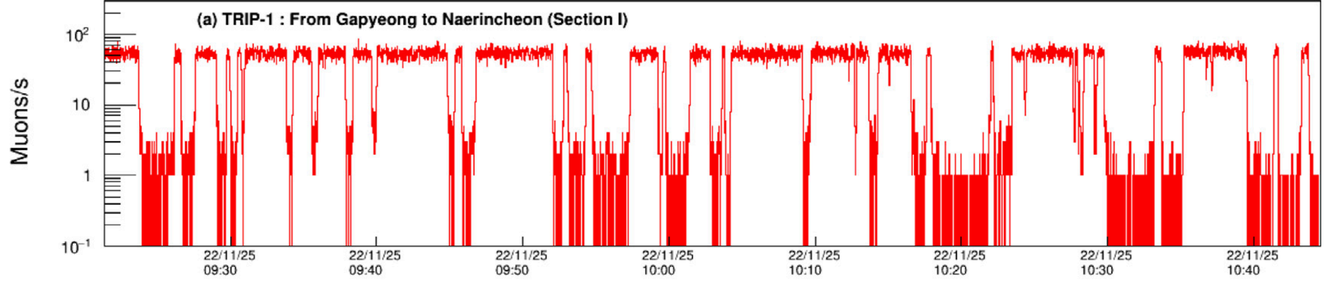


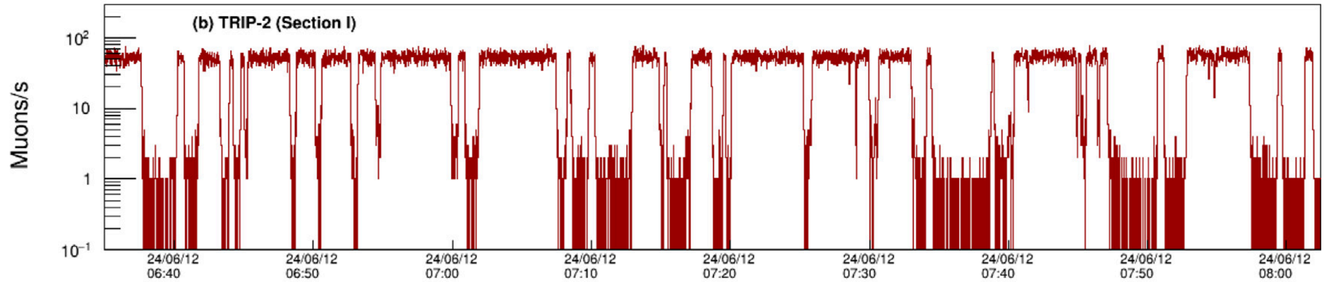


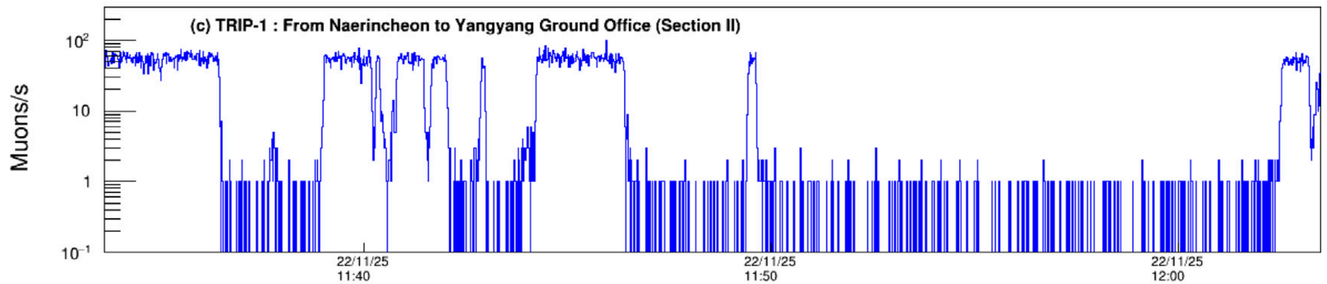
Muon Rates (Second Trip)

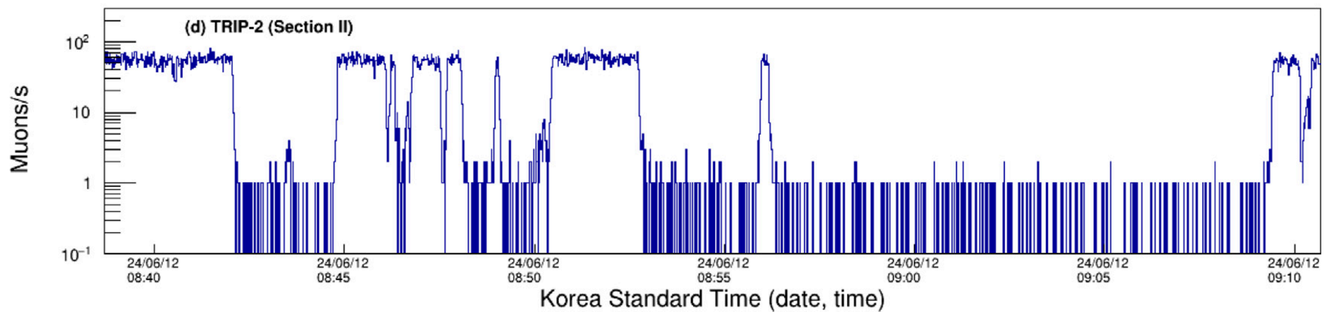
- GPS installation
- New Battery and new car
- Event Time recording at nanosecond precision.
- Velocity recording of the vehicle
- High altitude measurements



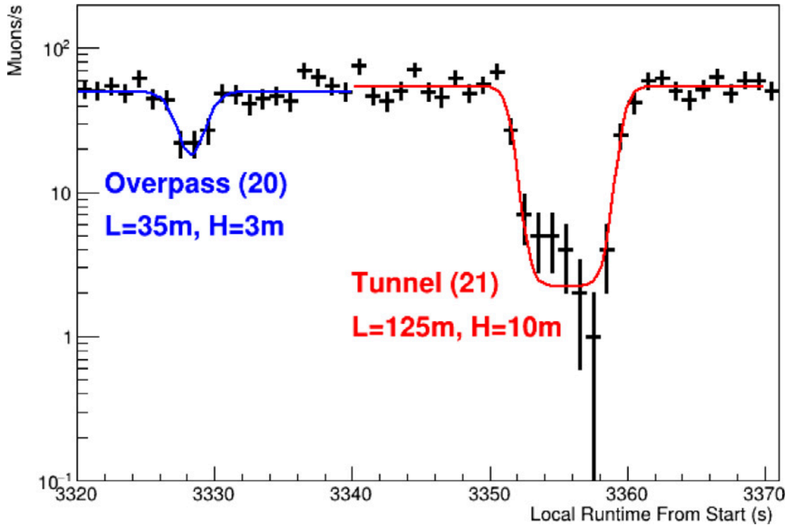




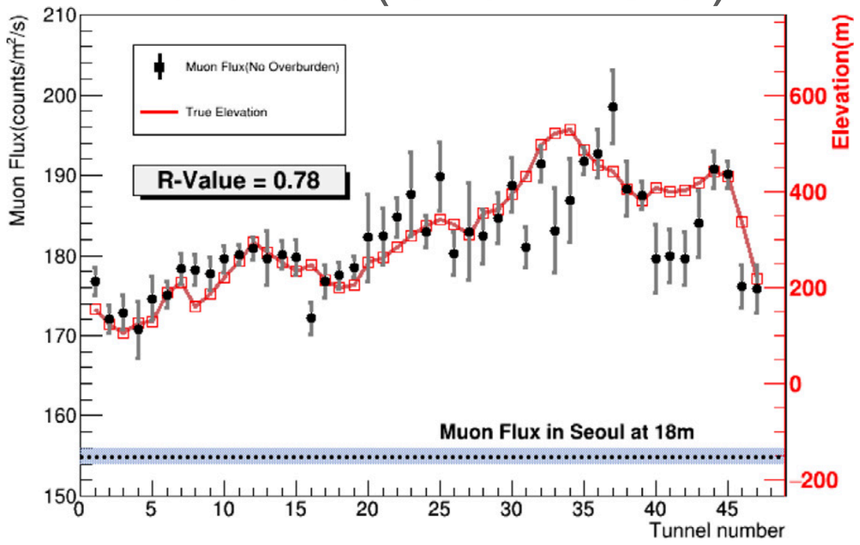




Animal Pass



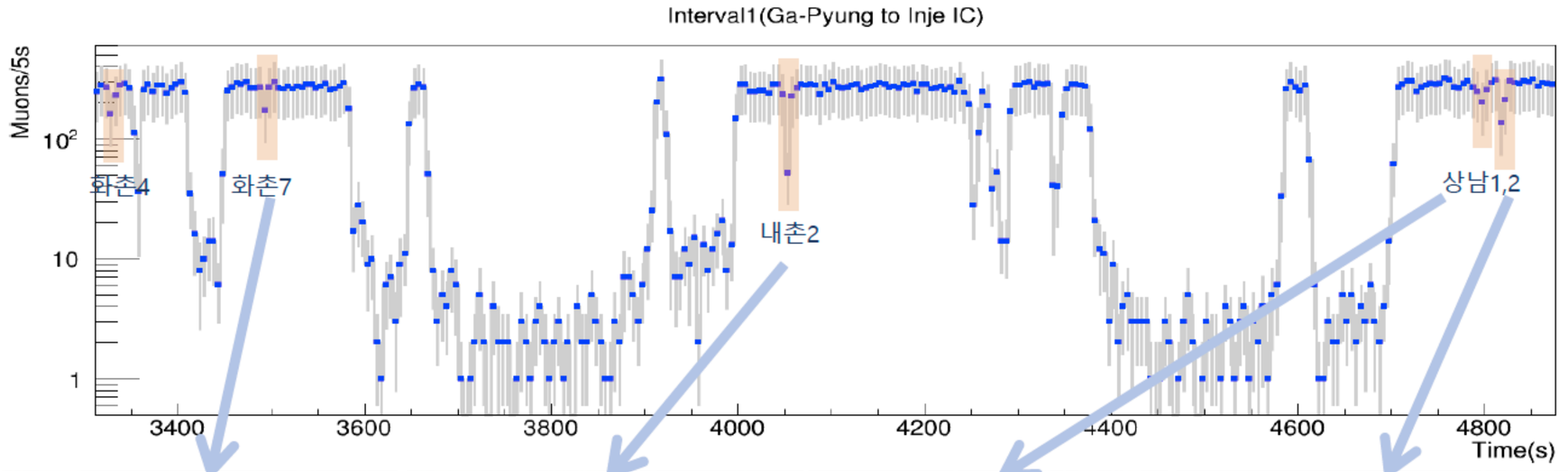
태백산맥 (영서->영동)



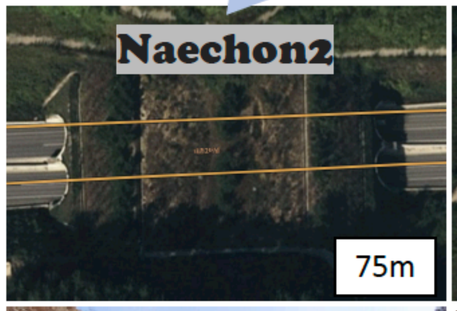
47 tunnels and animal passes

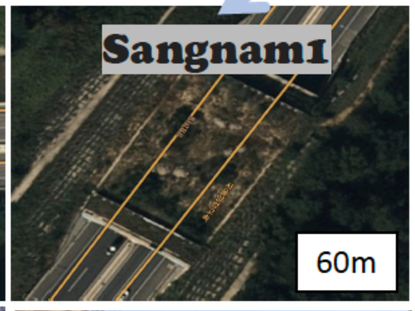
No.	Name	L (m)	Max. H (m)	Elev. (m)	Meas. L (m)	Depth H (/s)	μ Flux (/m^2/s)
1	Misa	2171	284	155	2213.7	1.33	176.7
2	Magok	919	85	124	903.0	1.52	172.0
3	Balsan 1	633	84	106	619.0	1.67	172.9
4	Balsan 2	480	97.5	126	455.4	1.76	170.7
5	Balsan 3	254	30.5	129	213.2	2.89	174.6
6	Balsan 4	433	60.5	189	421.4	1.91	175.0
7	Chugok	433	32	211	426.7	2.87	178.3
8	Haengchon	463	63.5	160	475.7	1.79	178.2
9	Gwangpan	358	18	186	353.9	4.05	177.6
10	Gunja 1	474	51	220	467.0	2.34	179.5
11	Gunja 2	885	120	255	879.8	1.88	180.1
12	Dongsan 1	680	86	295	684.8	1.73	180.8
13	Dongsan 2	1113	120.5	273	1146.7	1.42	179.6
14	Bukbang 1	2307	152	252	2339.7	1.38	180.0
15	Bukbang 2	326	65	235	321.5	1.64	179.7
16	Bukbang 3	1518	159	246	1533.7	1.34	172.1
17	Hwachon 1	721	85	216	716.7	1.51	176.7
18	Hwachon 2	378	80	200	378.5	1.26	177.4
19	Hwachon 3	527	61	204	517.9	2.10	178.5
20	Hwachon 4	35	3	252	36.8	21.10	182.2
21	Hwachon 5	125	10	264	118.4	2.34	182.3
22	Hwachon 6	629	41	283	594.4	2.25	184.7
23	Hwachon 7	40	3	308	37.2	18.50	187.6
24	Hwachon 8	978	124	328	964.1	1.82	182.9
25	Hwachon 9	3705	304	342	3725.1	1.18	189.8
26	Naechon 1	1261	52.5	332	1193.6	1.82	180.2
27	Naechon 2	88	4	309	84.8	10.30	182.9
28	Naechon 3	135	8.5	354	146.9	4.04	182.3
29	Naechon 4	355	39	362	356.6	3.10	184.6
30	Naechon 5	205	19.5	393	179.3	3.90	188.8
31	Seoseok	3061	221.5	430	3122.0	1.24	181.0
32	Haengchiryeong	1422	104	497	1424.3	1.23	191.3
33	Sangnam 1	60	3	520	59.9	28.70	183.1
34	Sangnam 2	115	5	527	102.3	21.10	186.8
35	Sangnam 3	1719	126.5	485	1710.6	1.25	191.7
36	Sangnam 4	1434	195	454	1444.6	1.20	192.7
37	Sangnam 5	1773	149	442	1762.8	1.25	198.4
38	Sangnam 6	1816	100	405	1786.4	1.59	188.3
39	Sangnam 7	2278	264	381	2338.8	1.22	187.4
40	Girin 1	114	7	408	97.3	2.60	179.5
41	Girin 2	397	41	398	375.8	2.27	179.9
42	Girin 3	162	11.5	402	157.9	2.00	179.6
43	Girin 4	750	128.5	418	762.3	1.25	183.9
44	Girin 5	1148	109.5	441	1169.2	1.48	190.7
45	Girin 6	2665	288.5	432	2757.8	1.15	190.0
46	Inje-Yangyang	10962	440	335	11543.3	1.06	176.1
47	Seomyeon 2	248	13.5	217	236.0	4.67	175.8

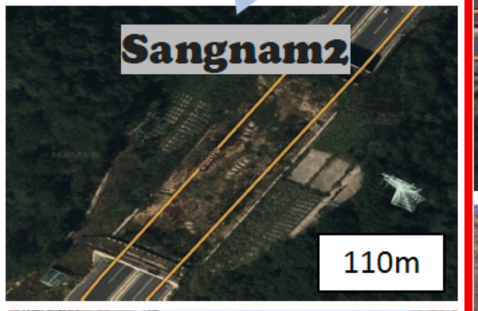
Length relation (small tunnels)





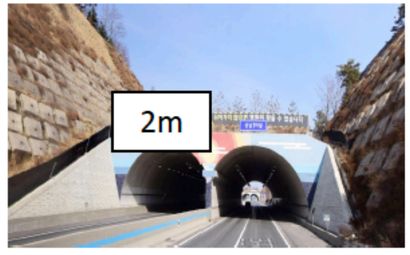














The Shortest tunnel

