Report for Enge Detector Part

The University of Tokyo

Sho Nagao

on behalf of

JLab hypernuclear collaboration

Experimental Readiness Review 2026

Comments and Recommendation

Detectors

Estimation of SiPM sensors radiation damages (Resp. 6) **(slide 7-9)**
→ SiPMs will no longer be used. Conventional MA-PMTs will be employed instead.

Status of the equipment required (Resp. 1) **(slide 10-16, 21)**
→ Fiber: the expected performance has been confirmed. Chamber and TOF: performance has been evaluated using cosmic rays.

Completion/commissioning schedule and tasks (Resp. 1) **(slide 18)**
→ Fiber: the full set is expected to be delivered in November. Chamber and TOF: they will be ready this summer.

A minimum number of spare detector components. (Resp. 1) **(slide 21)**
→ Fiber: one spare unit will be built. Chamber: the repair procedure has been documented. TOF: sufficient spares are available.

Calibration

Detailed Enge calibration procedure (Resp. 1) **(slide 19-20)**

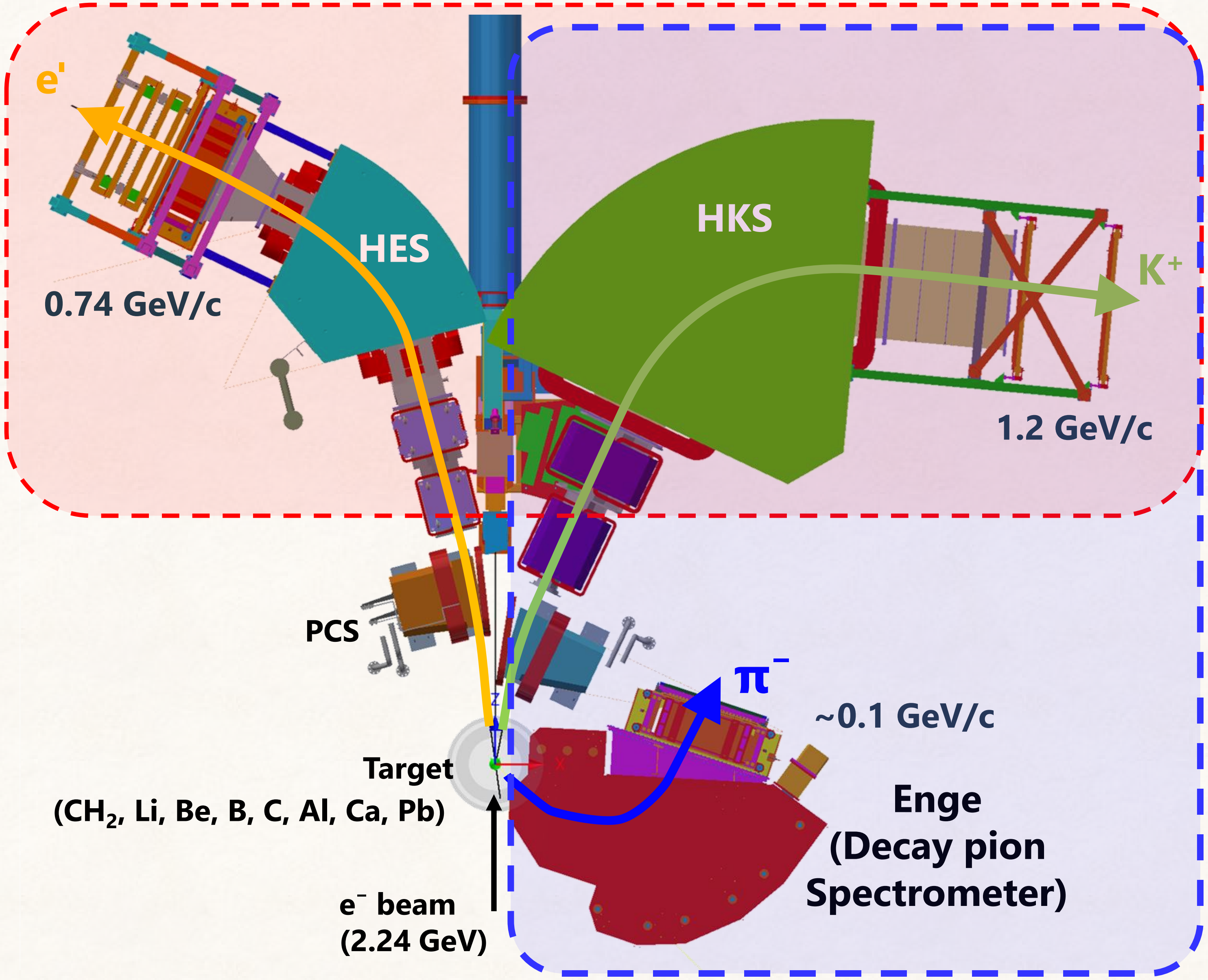
Polarity reversal and potential nonlinear calibration effects

An NMR probe should be installed to track magnetic field stability
→ The calibration procedure has been documented, and an NMR probe will be used.

Manpower, Resources

Identification of the manpower and other resources (Resp. 4) **(slide 18,21)**
→ Coordinator and workers have been assigned. Please see tables on slide 18, 21.

Enge Spectrometer for Decay Pion Spectroscopy



$(e,e'K^+)$ Experiments

"e', K^+" coincidence with HES & HKS

g.s & e.x B_Λ up to A=6 ~ **208**

with **<100 keV accuracy**

Simultaneous data taking

Decay Pion Experiment

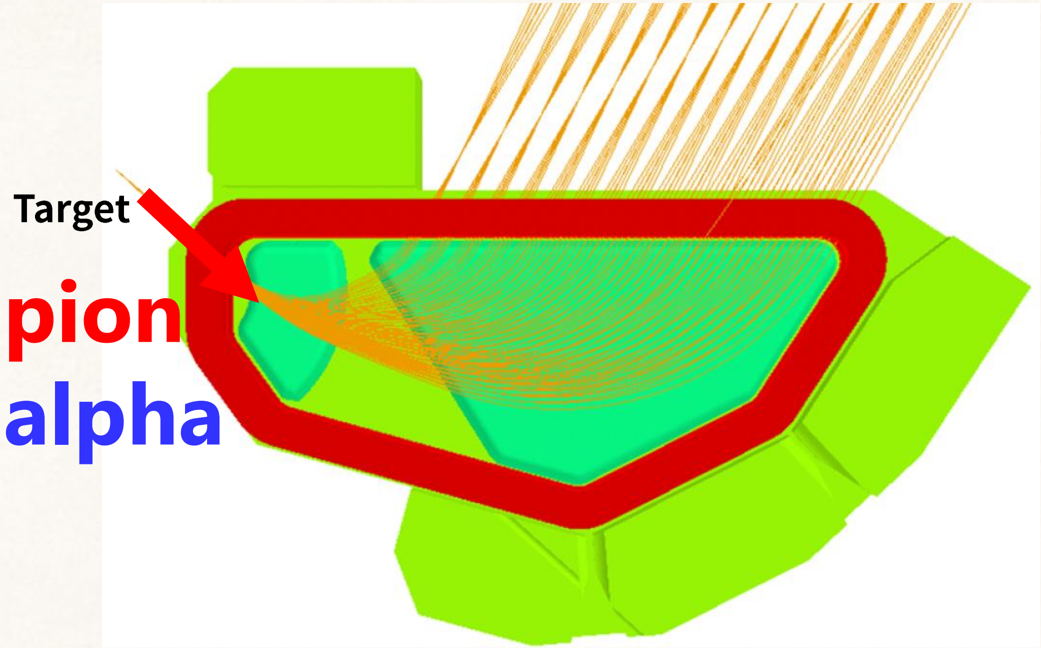
"π^-, K^+" coincidence with Enge & HKS

g.s B_Λ of **s-**, **p-**, (sd-) **shell**

with **a few 10 keV accuracy**

Enge As Pion Spectrometer

Central Momentum	110 MeV/c
Momentum acceptance	78 ~ 140 MeV/c
Dispersion	1.5 cm/(MeV/c)
Momentum Resolution	10^{-3} (FWHM)
Solid Angle	4 msr



Momentum resolution: $\Delta p/p \sim 10^{-3}$

Peak separation and better S/N

Momentum reconstruction from focal-plane position

Angular information for target reconstruction

Momentum calibration at the level of a few 10 keV/c

Using alpha sources (~100 MeV/c/q) at the target position

Detect alpha particles with well-known momenta at the focal plane in vacuum.

Target timing reconstruction: $\sigma \approx 100$ ps

Suppression of accidental coincidence background

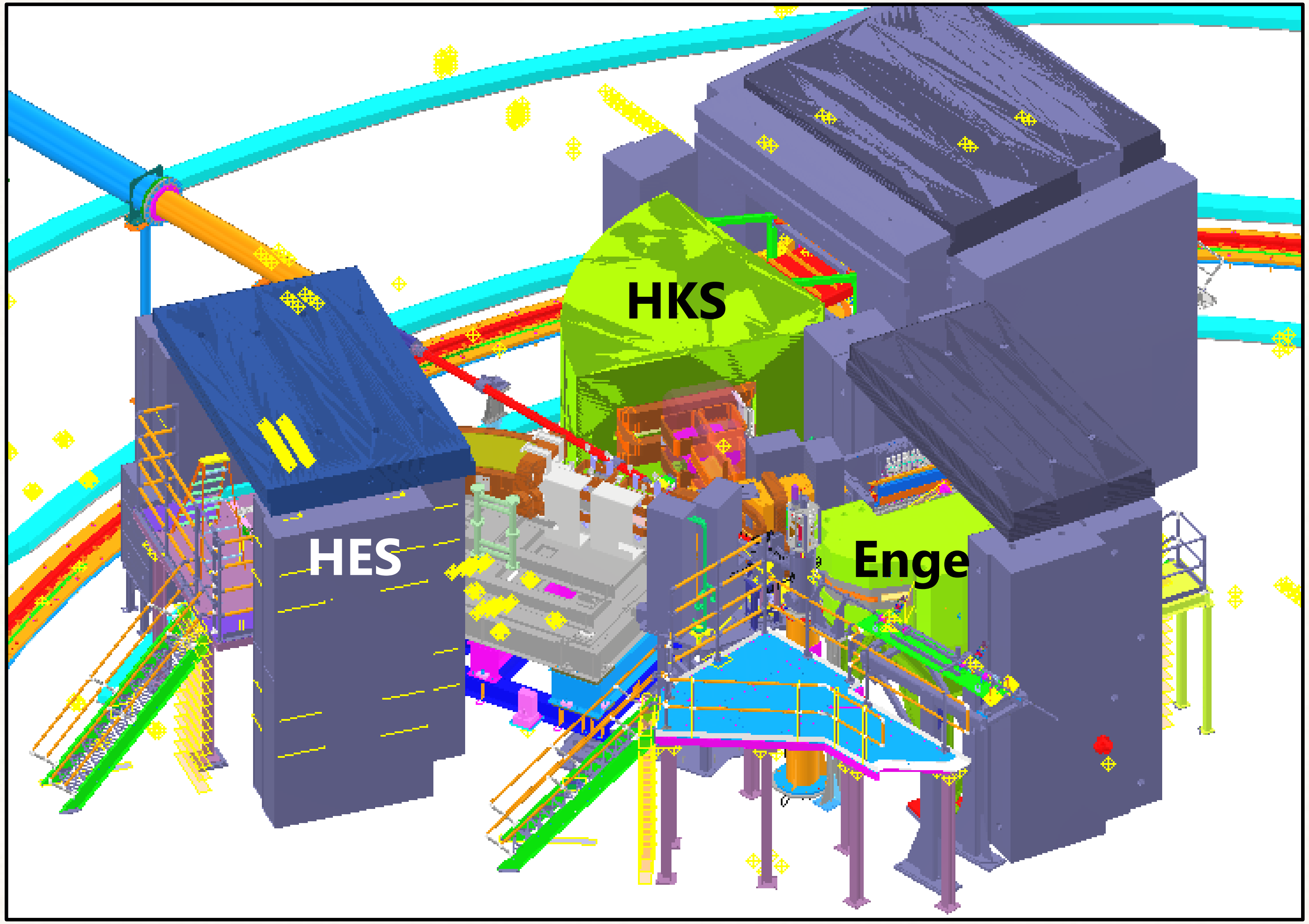
Particle identification (π / μ / e)

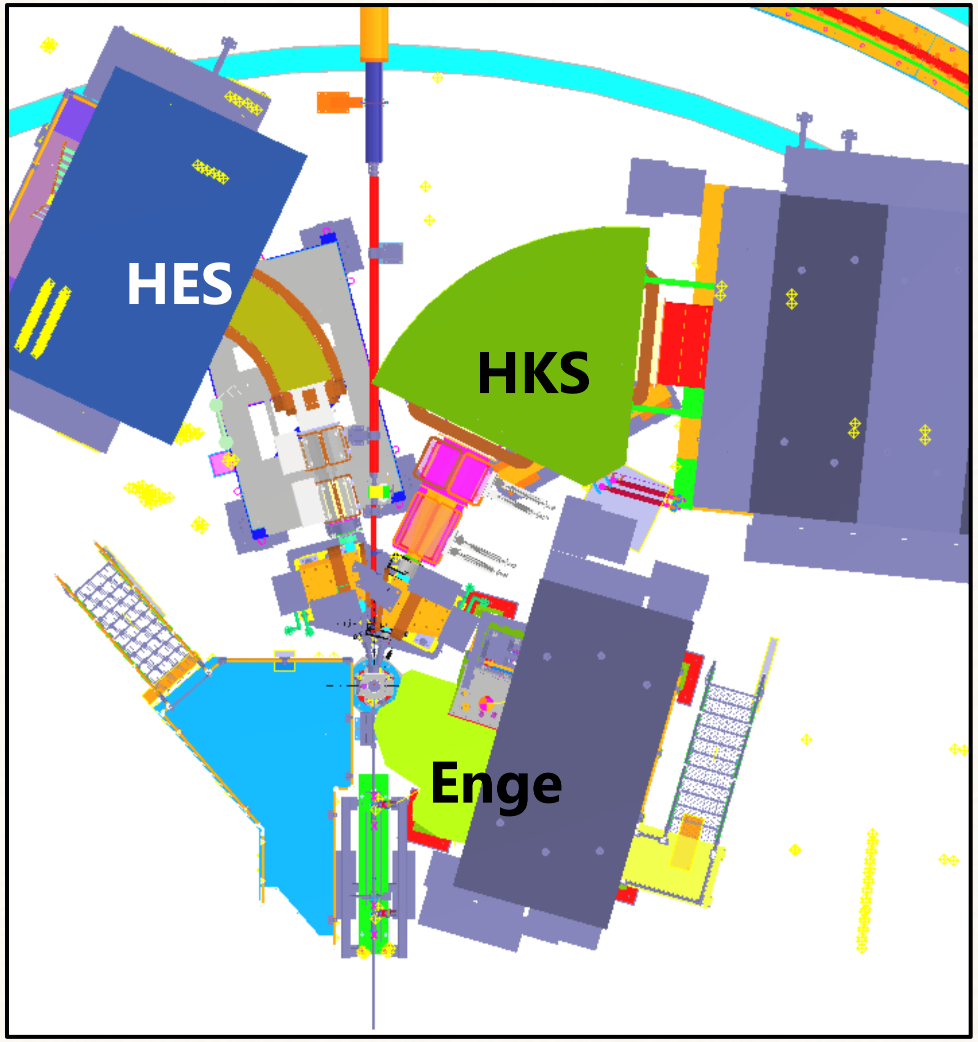
Lifetime measurement

→ Requires a good start-time counter ($\sigma \approx 100$ ps)

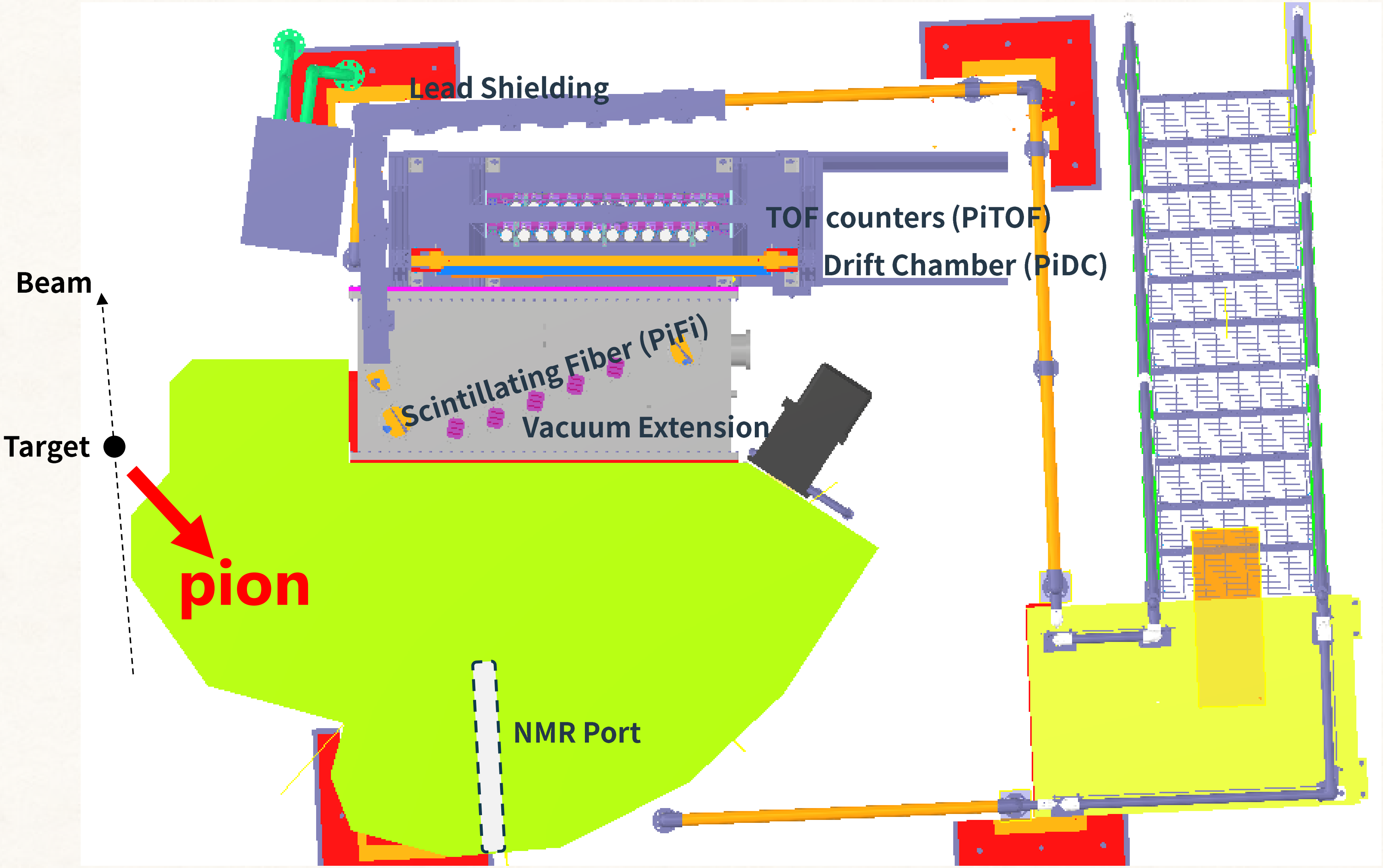
and position/angle measurements ($\sigma \approx 350$ μm, 6.7 mrad).

Latest Drawing (by Engineering Group)

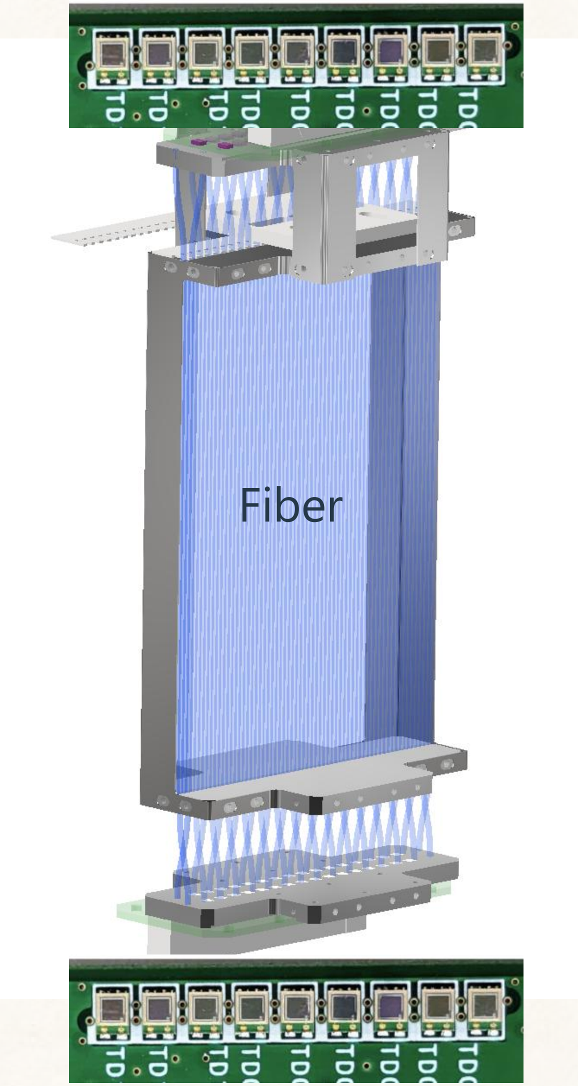


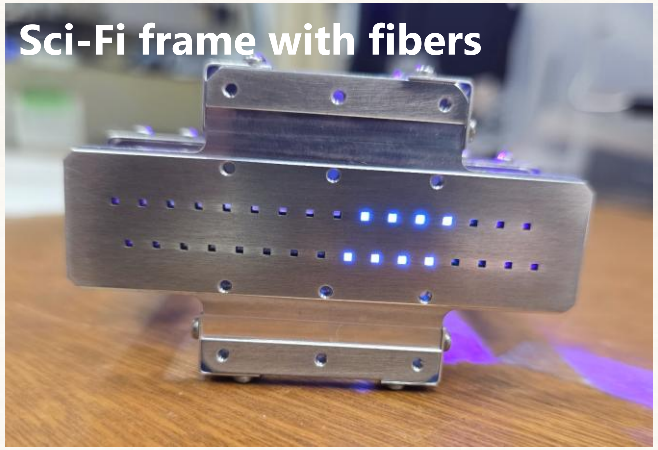


Enge Configuration

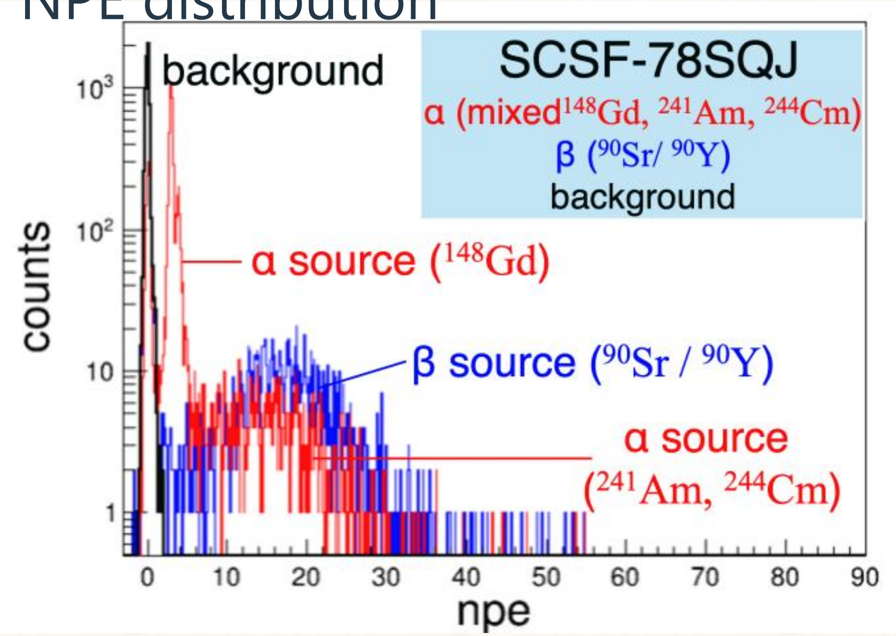


Enge Focal Plane Detector (PiFi) --Previous--





NPE distribution



PiFi Summary

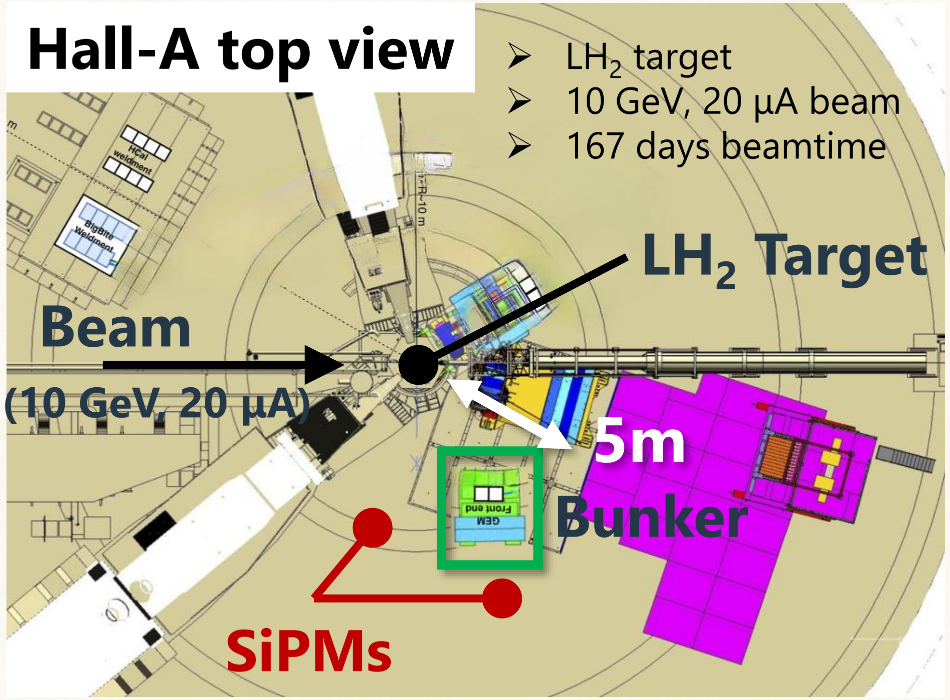
Regarding SiPM radiation damage, as pointed out in the previous ERR comments:

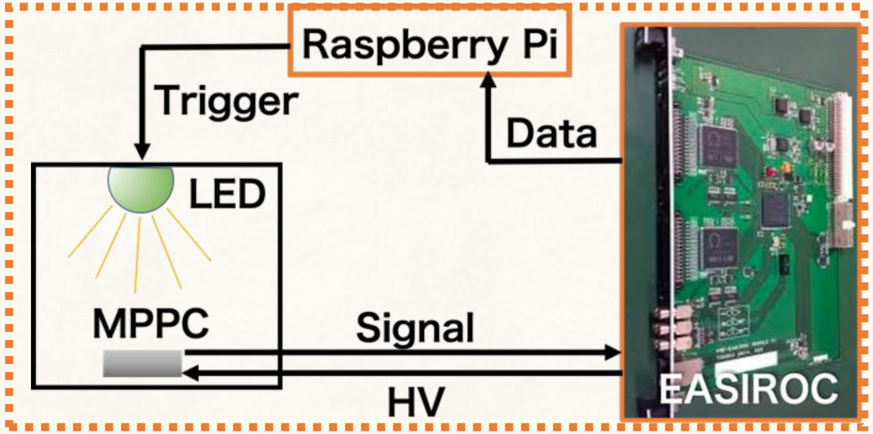
→ A SiPM radiation-tolerance test was performed at Hall A in 2025.

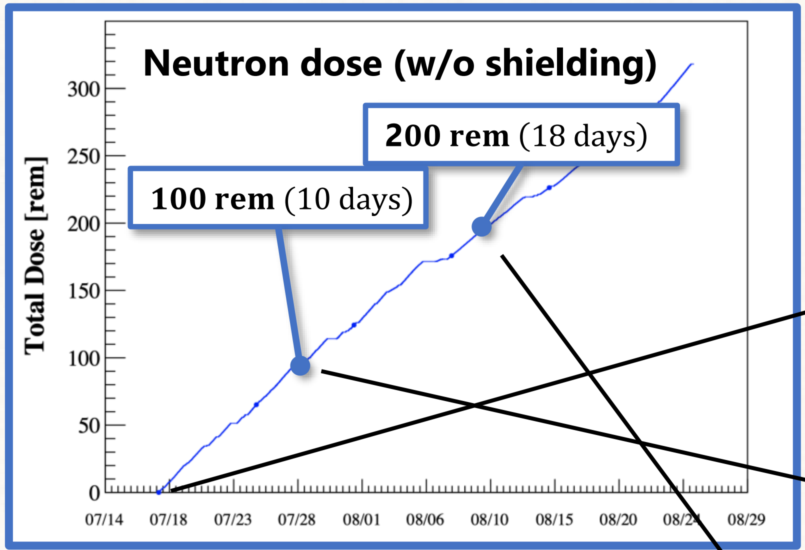
→ The lifetime was found to be too short.

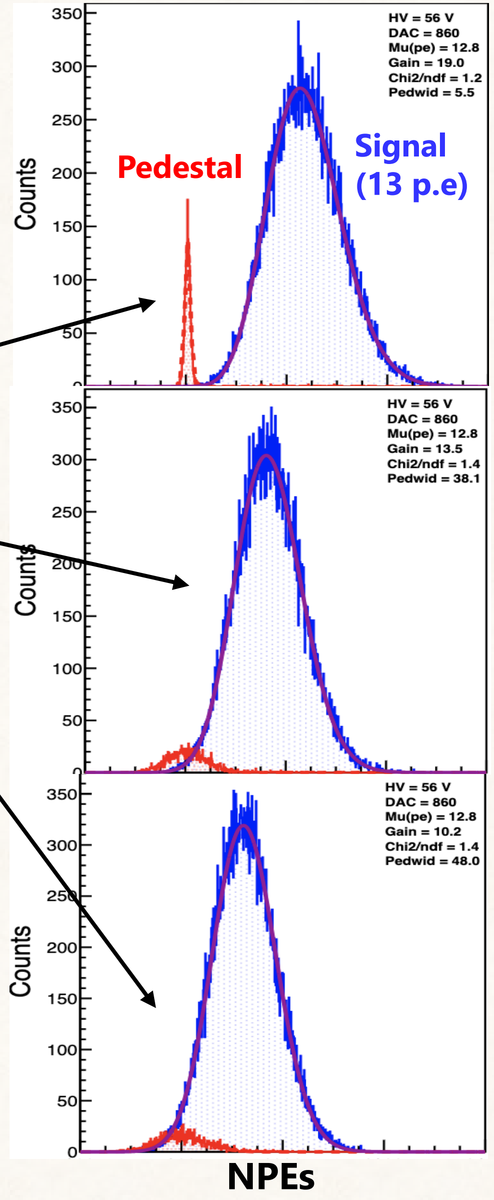
→ Conventional MA-PMTs will be employed instead of SiPMs.

Radiation Tolerance Test (2025)









Serious Damage to SiPMs

Degradation started above 2 rem.

NPE peaks were smeared out at 200 rem.

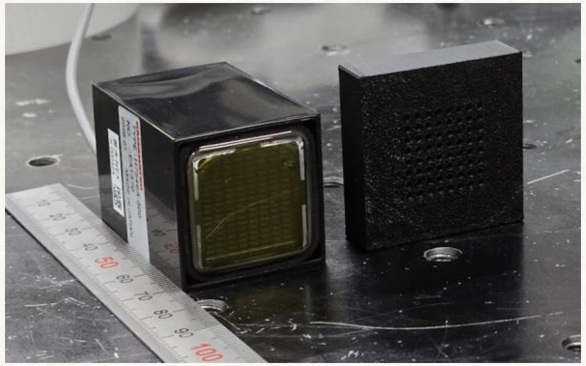
→ Approximately 2 days of operation

The SiPM lifetime was found to be too short for the expected radiation environment.

→ SiPM operation involves significant risk.

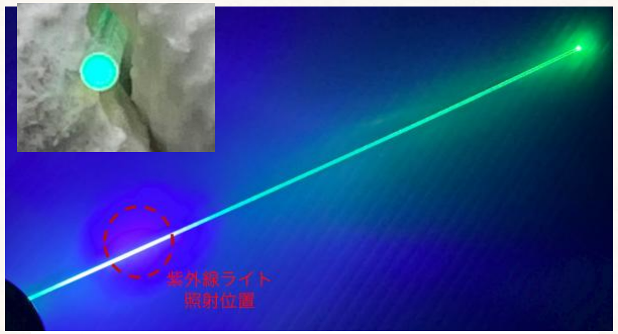
Enge Focal Plane Detector (PiFi) -- New Equipment --

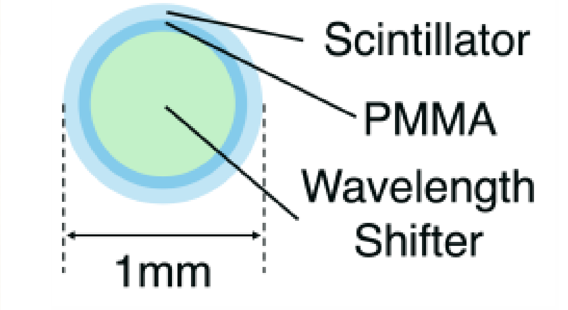
New PMT



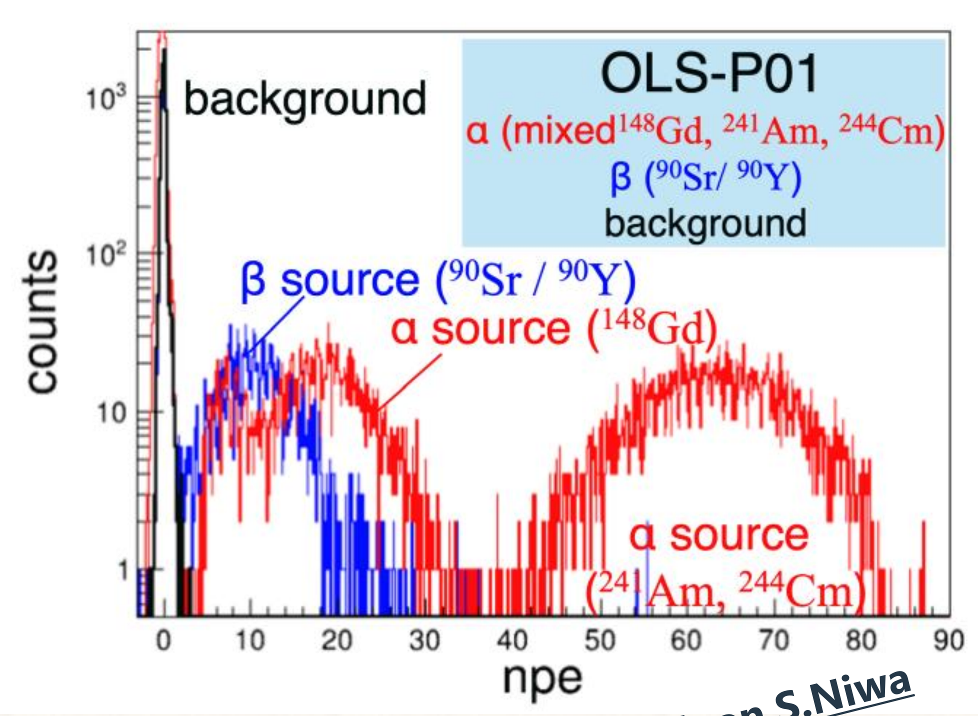
- Hamamatsu H7546A-300
- 64 ch (8×8) Multi-Anode PMT
- Anode Size: 2×2 mm
- Photocathode: EGBA
- Gain: 5×10^5
- Dark Counts: 20 k/sec

New Fiber





- Kuraray OLS-P01
- Outer-Layer Scintillating Fiber
- Diameter: Φ = 1 mm



Work on S.Niwa

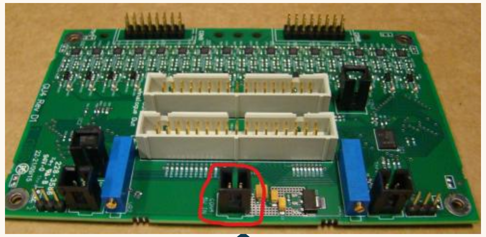
Clear peaks from alpha sources

Similar NPEs from beta rays

→ Good performance was confirmed on the test bench setup

Enge Focal Plane Detector (PiFi) -- New Configuration --

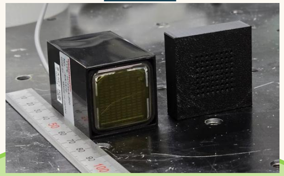
Enge Detector Hut



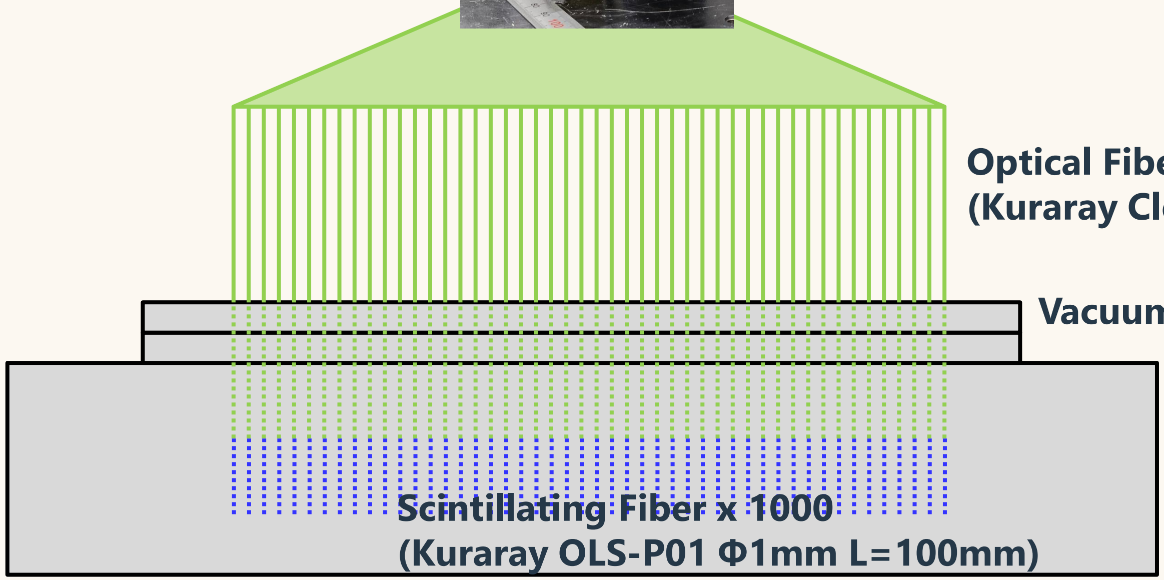
100-ft ribbon cables

LVDS

NINO Discriminator Card x 64



64 ch Multi-Anode PMT
(Hamamatsu H7546A-300 x 16)



Optical Fiber x 1000
(Kuraray Clear-Fiber)

Vacuum Port

Scintillating Fiber x 1000
(Kuraray OLS-P01 Φ1mm L=100mm)

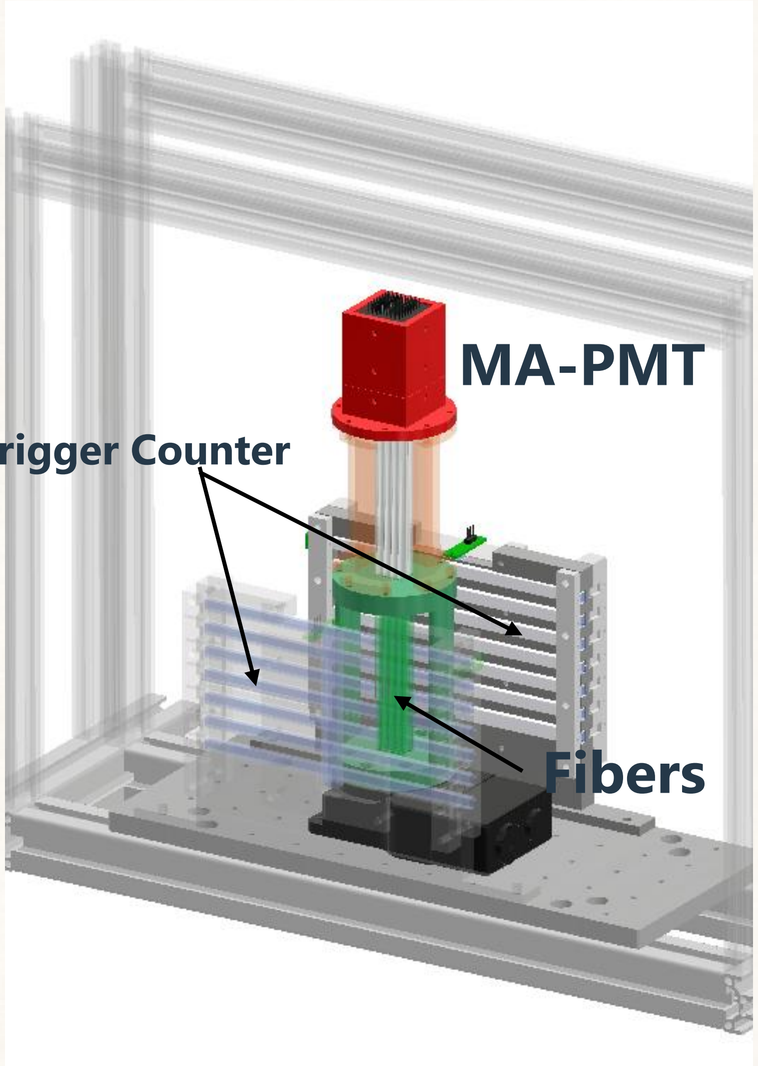
Vacuum Chamber Box

SHMS Platform

TDC @SHMS

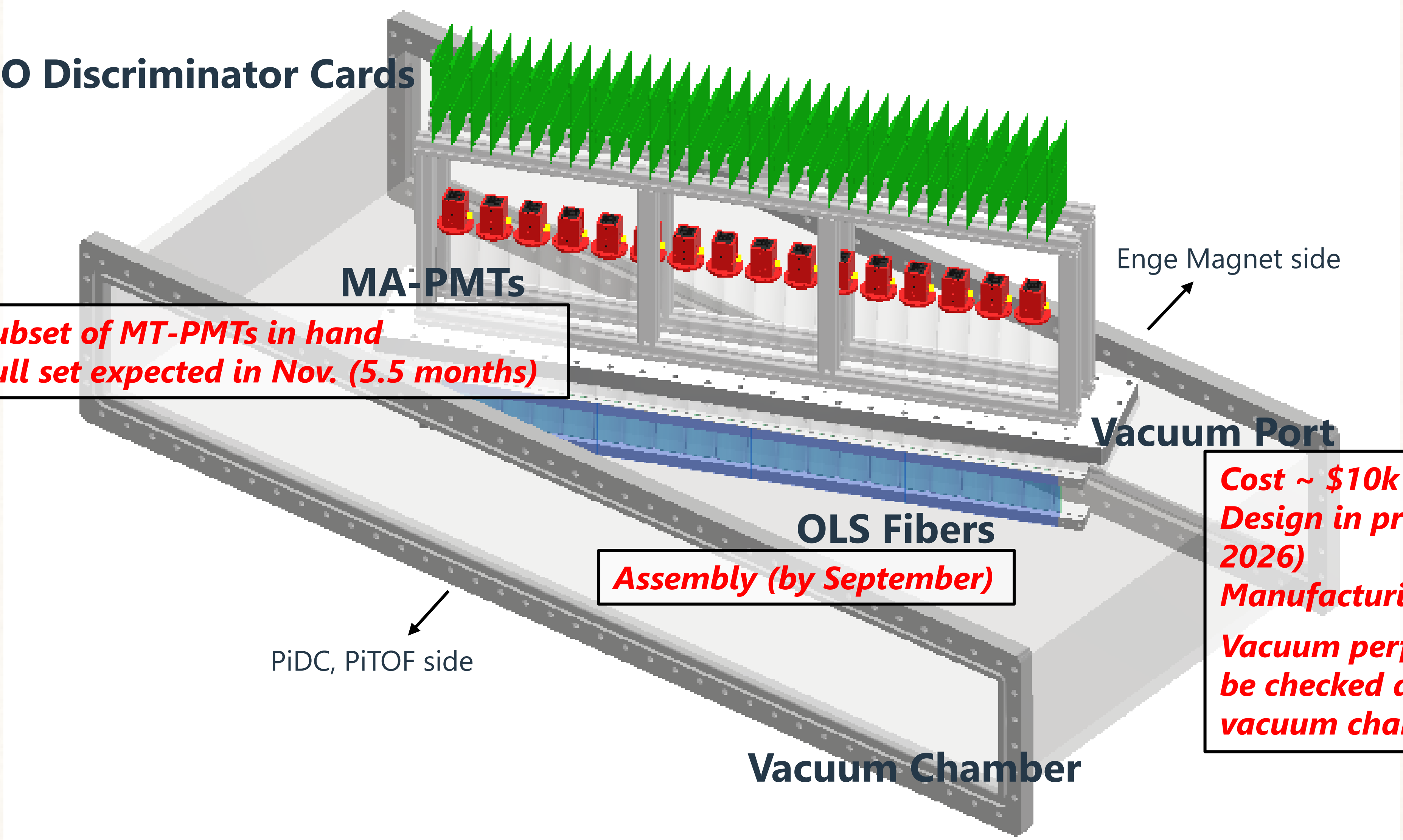
- Sufficient numbers of NINO cards, TDC modules, and cables are already available.
- The vacuum ports and fiber assemblies will be arranged to match the Enge vacuum extension box design.
- Cost and delivery estimates have been completed for all required components.
- The vacuum ports and fiber assemblies will be fabricated in Japan and shipped to JLab.
- The full system, including performance validation, is scheduled to be ready by March 2027.

Enge Focal Plane Detector (PiFi) -- 64 ch version --



- A 64-channel prototype has been constructed with a realistic configuration consisting of fibers, an MA-PMT, and NINO cards.
- Data are being taken with beta rays from ^{90}Sr.
- The setup will be tested with π/K beams (J-PARC) or electron beams (KEK, RARiS).

Enge Focal Plane Detector (PiFi) -- Drawing --



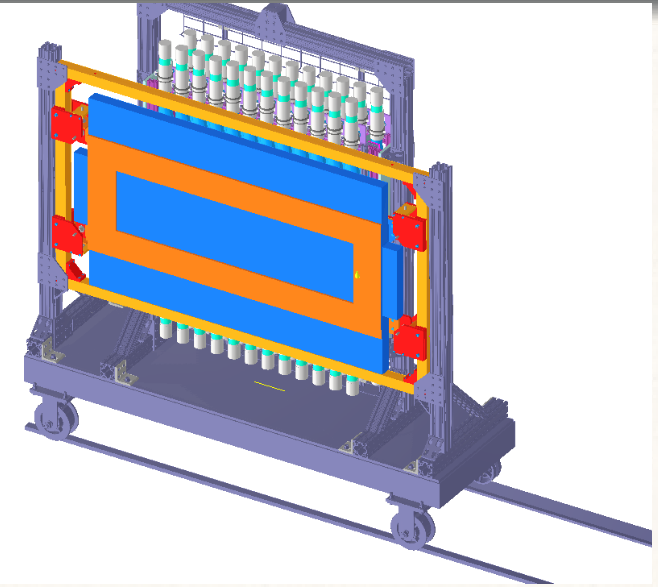
Subset of MT-PMTs in hand
Full set expected in Nov. (5.5 months)

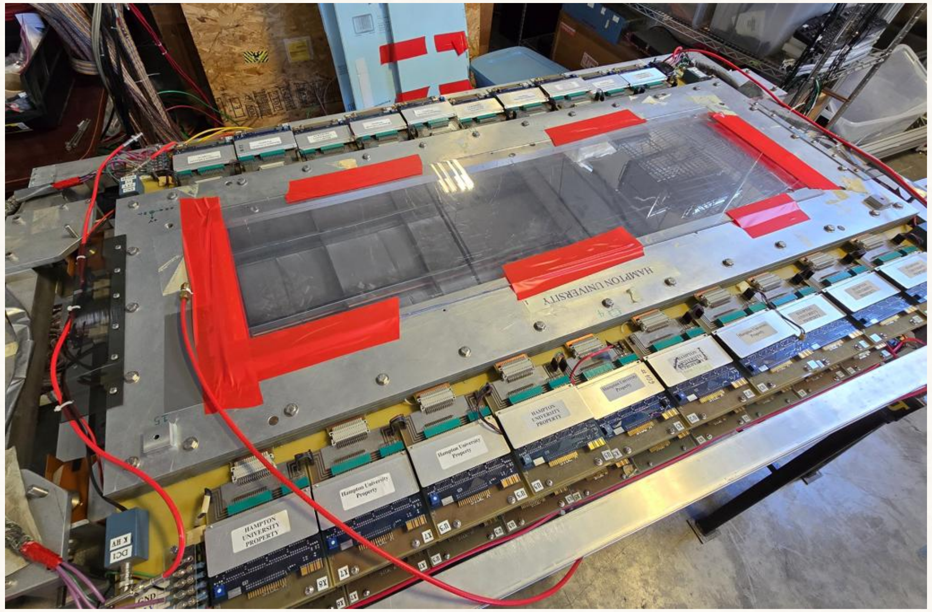
Assembly (by September)

Cost ~ $10k
Design in progress (June 2026)
Manufacturing (1 month)

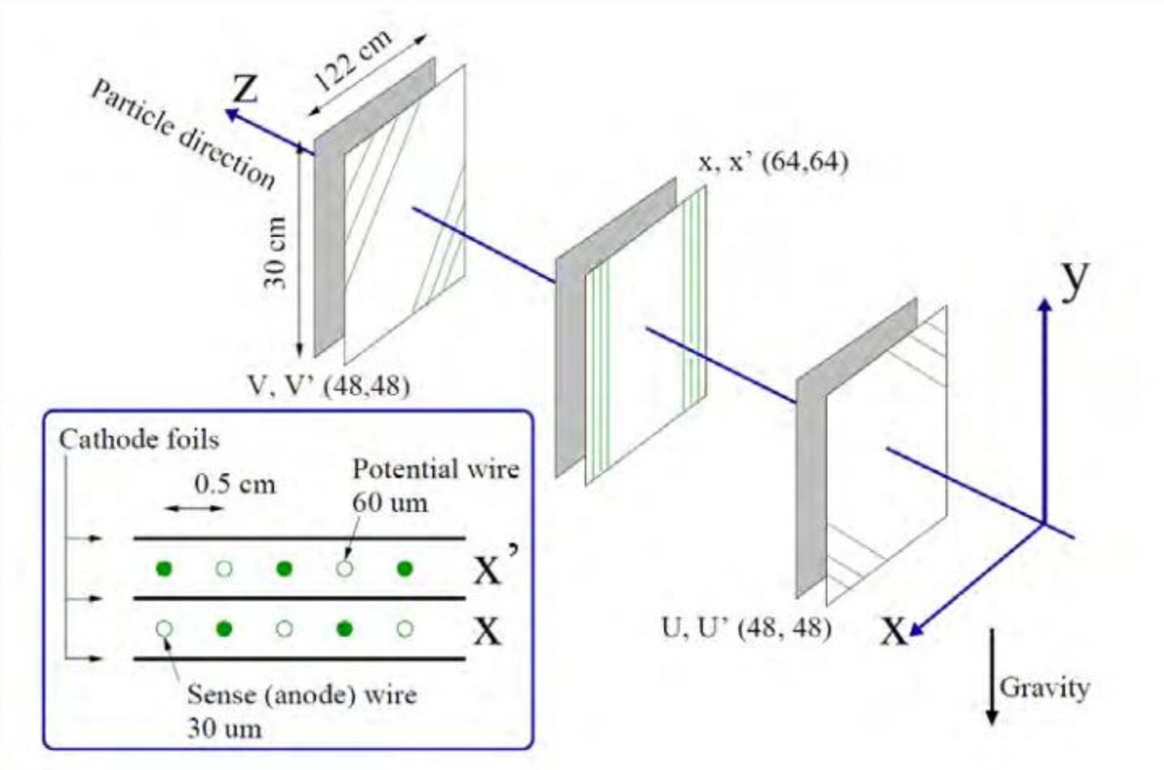
Vacuum performance will be checked at ESB after the vacuum chamber is ready.

Enge Tracking Detector (PiDC)

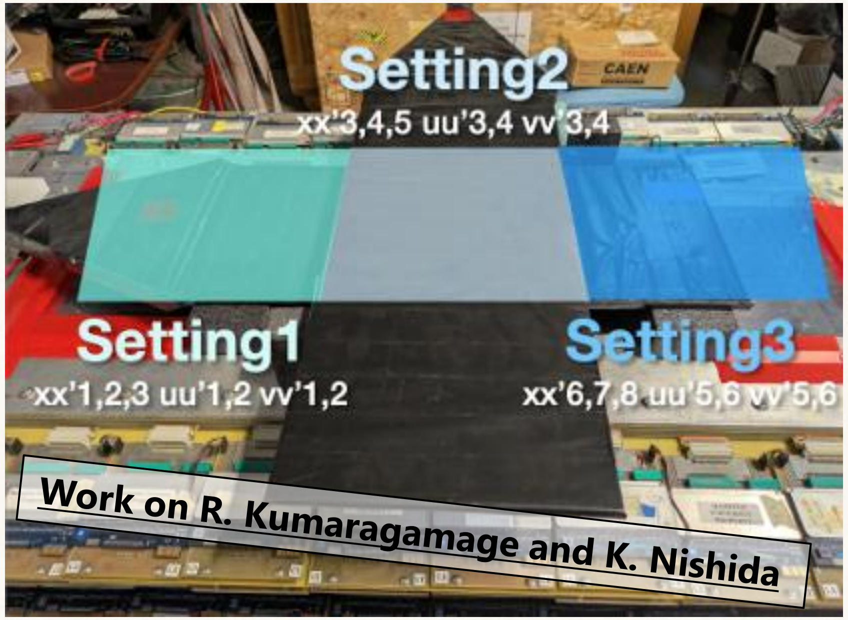


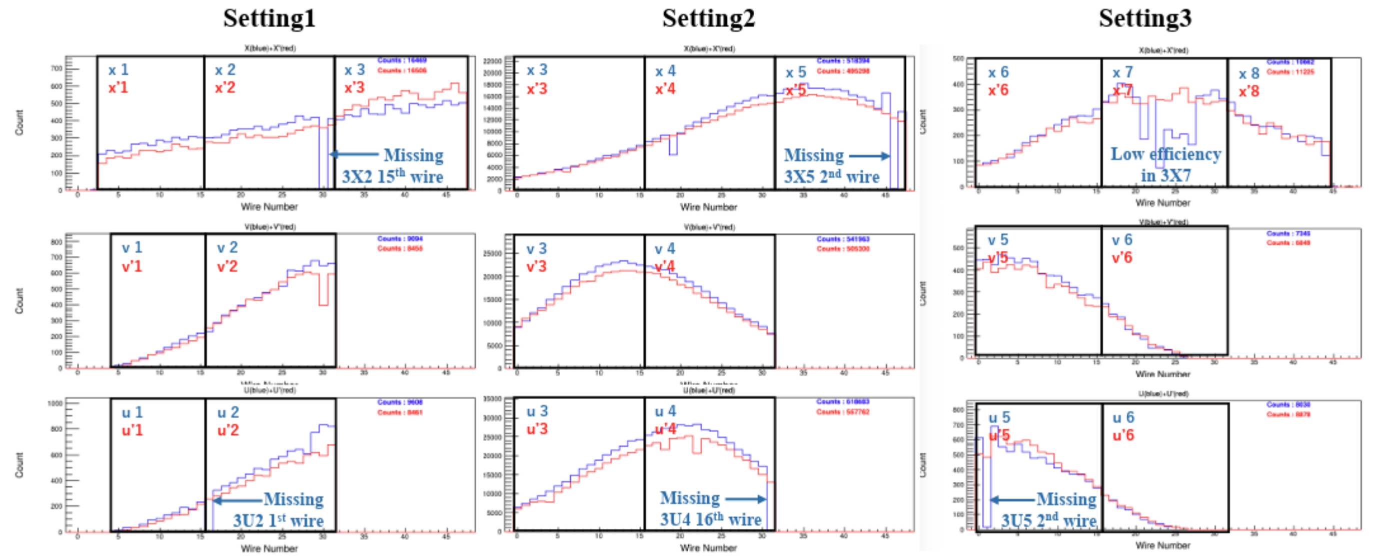


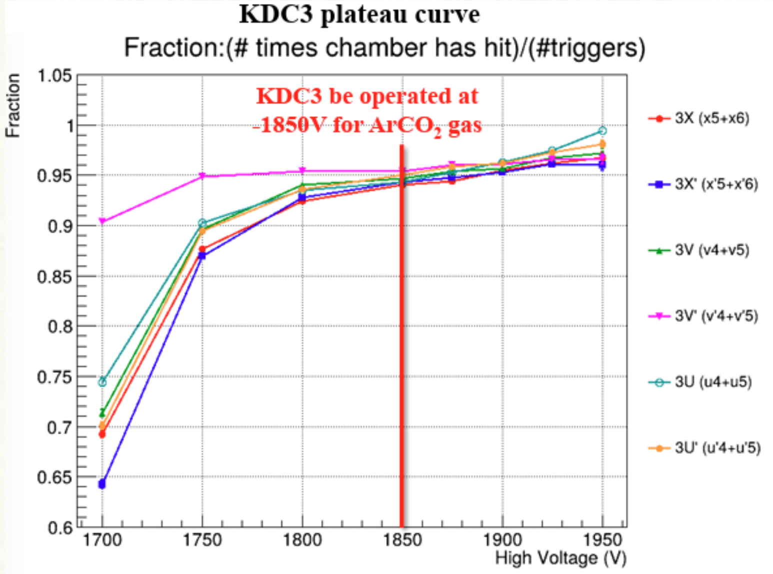
- Tracking chamber for π^- angle measurement
- Configuration: 6 planes (UU'XX'VV')
- Same type of chamber as the HKS Drift Chambers
- Position Resolution: $\sigma \simeq 100$ µm



Enge Tracking Detector (PiDC)







Performance check with cosmic rays by WG4 (Jan.--Feb. 2025)

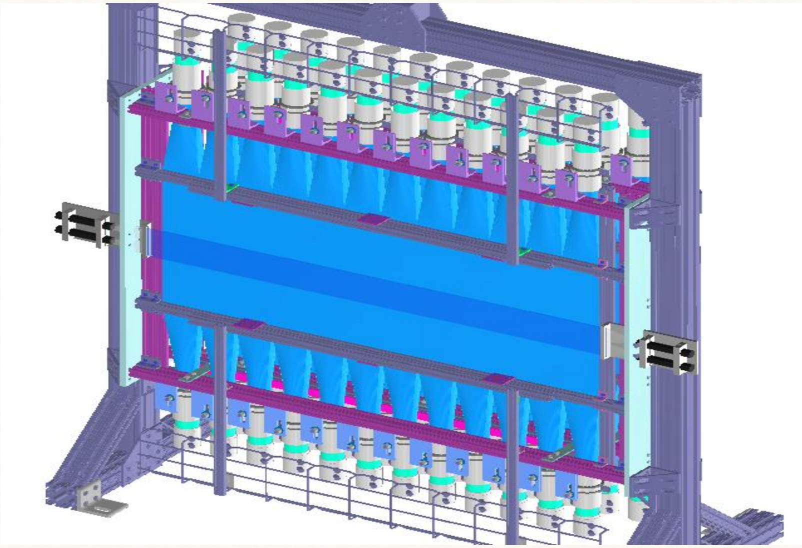
- Plateau Curves
- Wire Efficiencies

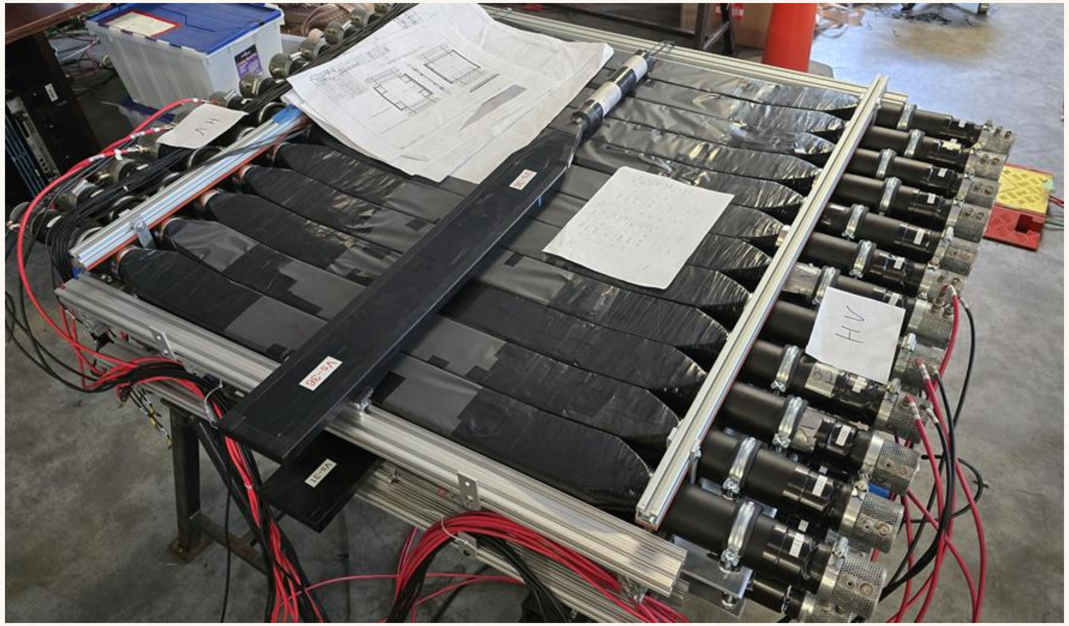
The expected performance was confirmed.

Chamber-related work is now shifting to the analysis phase.

The repair procedure during beam time has been documented.

Enge TOF Detector (PiTOF)





Counter for π^- trigger and timing measurement

Y - X1 - X2 Configuration

Y Layer

Scintillator: EJ-212 $1107^W \times 100^H \times 3^T$ mm^3

PMTs: Hamamatsu H6612

X1 Layer (12 segments)

Scintillator: BC400 $1067^W \times 500^H \times 3^T$ mm^3

PMTs: Phillips XP2262B

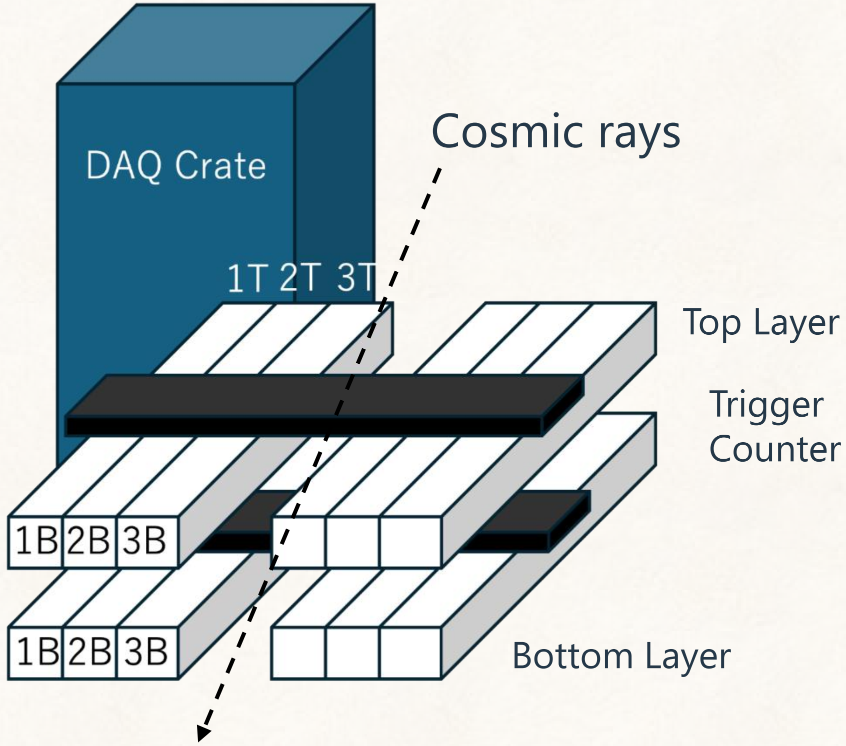
X2 Layer (12 segments)

Scintillator: BC400 $1067^W \times 500^H \times 28^T$ mm^3

PMTs: Phillips XP2262B

Enge TOF Detector (PiTOF)

Data taking with
VETROC TDC & FADC250
(2025 Summer & 2026 Feb.)



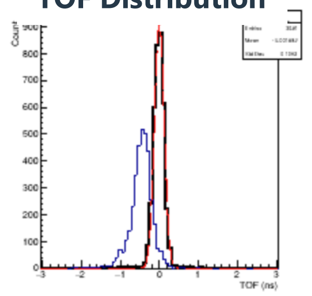
(Both layers have 28 mm thick scintillators)

Performance check with cosmic rays at ESB (WG3, WG5)

- PMT HV Adjustment by checking a MIP peaks
- Timing Resolution Evaluation

→ Good performance was confirmed (σ ≃ 70 ps after pulse-height correction)

TOF Distribution



Intrinsic Timing Resolution

Segment	PiTOF1 /ps	PiTOF2 /ps
0	77 ± 4	98 ± 3
2	73 ± 6	98 ± 5
4	68 ± 6	97 ± 4
6	76 ± 7	85 ± 6
8	70 ± 4	94 ± 3
10	61 ± 5	108 ± 5

Planned work

- One Layer will be replaced with a thinner scintillators (3 mm)
- The Y layer will be prepared and mounted

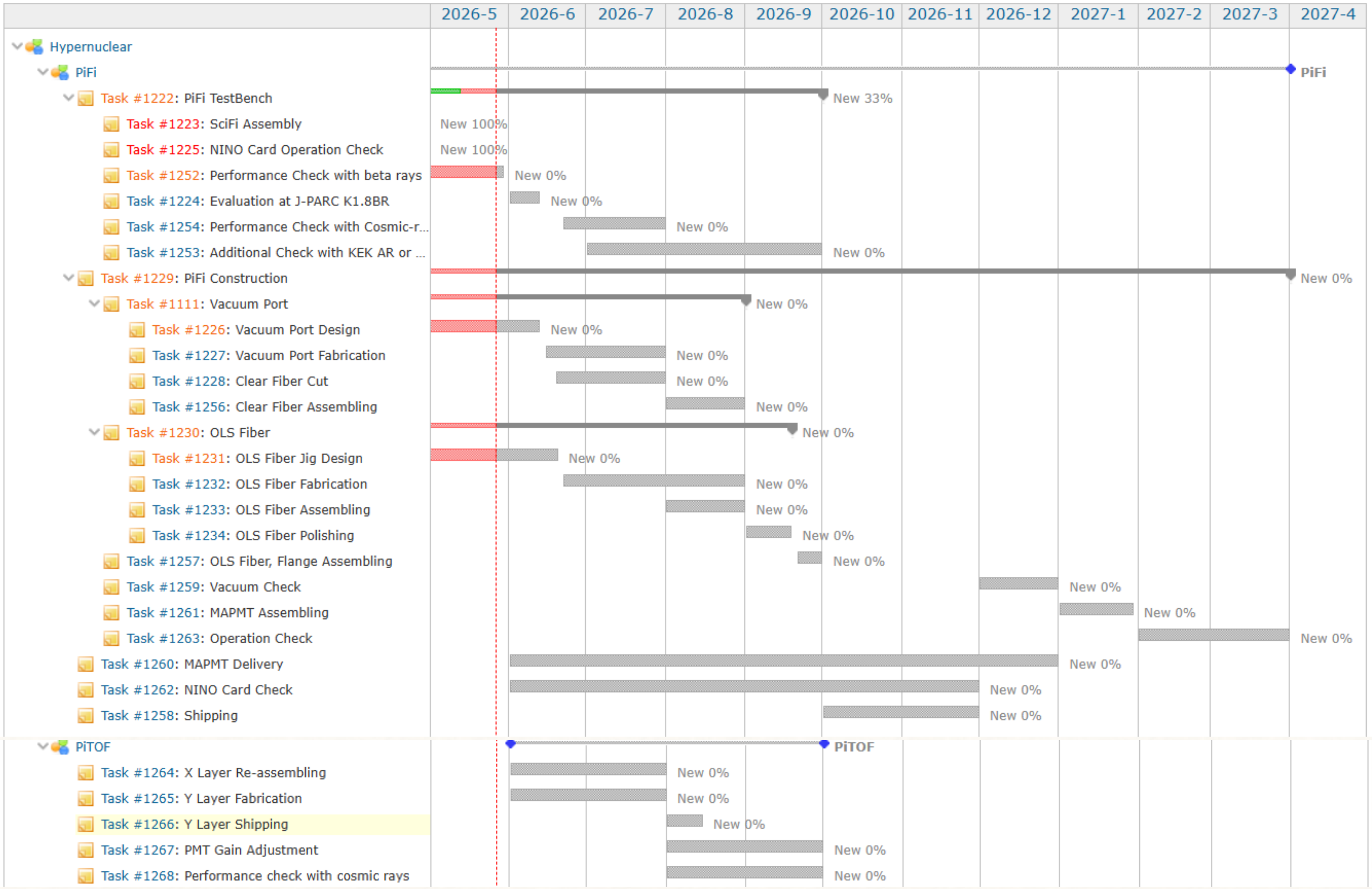
→ These tasks will be completed this summer

Spare counters: more than 10 segments for each layer

Status Summary

Detector	Completed	To Do
PiFi	• SiPM radiation test completed • SiPMs replaced by MA-PMTs • Fiber/MA-PMT performance confirmed • 64-ch prototype constructed	• Finalize vacuum-port / fiber-assembly design • Fabricate components in Japan • Deliver full MA-PMT set • Validate full system
PiDC	• Cosmic-ray test completed • Plateau curves evaluated • Wire efficiencies evaluated • Expected performance confirmed • Repair procedure documented	• Continue tracking-analysis preparation • Finalize beam-time readiness
PiTOF	• Cosmic-ray test completed • HV adjustment completed • Timing resolution evaluated • $\sigma \simeq 70$ ps achieved after PHC • Sufficient spares secured	• Replace one layer with thinner scintillators • Prepare and mount Y layer • Complete final assembly this summer

Schedule and FTEs



PiFi (WG3)

Staff:
- S. Nagao (0.2), M. Ichikawa (0.2)

Students:
- J. Takahashi (0.5)
- K. Higashimoto (0.1)

Available / Required: ~1.0 FTE / 0.8 FTE

+ external fabrication support

PiDC (WG4)

Staff:
- L. Tang, B. Pandey

Students:
- R. Kumaragamage (0.3)
- K. Nishida (0.3)

Available / Required: ~0.6 FTE / 0.5 FTE

PiTOF (WG3, WG5)

Staff:
- W. Henry, S. Nagao

Students:
- K. Nishi (0.1), K. Okabayashi (0.1)
- K. McCusker (0.1)

Available / Required: ~0.3 FTE / 0.2 FTE

Supported by Engineering Group

Momentum Calibration with alpha sources

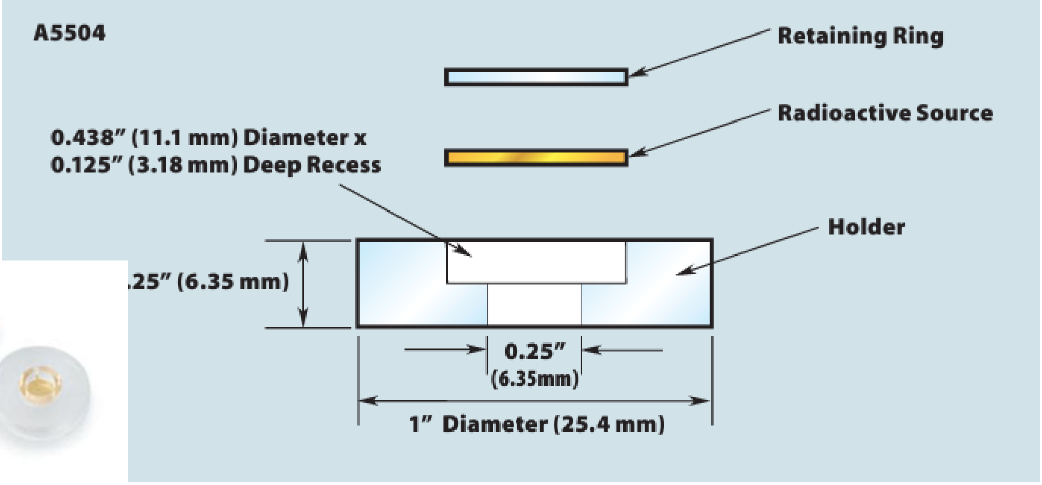
Commercial alpha sources are available from EZAG

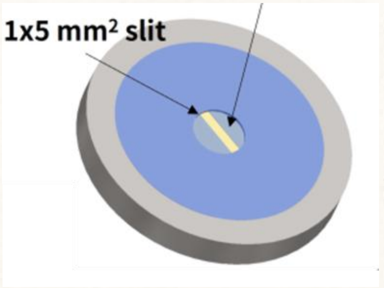
An AF-type mixed three-nuclide source will be procured via RadCon:

- **^{230}Th, ^{241}Am, ^{244}Cm (1~5 kBq each)**
- Active diameter: 5 mm, no window
- Resolution: <20 keV (FWHM)
- Removable package
- Cost: $3,610, Lead time: 5–6 weeks
- A special holder will be fabricated to mount the source on the target ladder
- A 1 × 5 mm² slit will be used to define a small source spot

Nuclide	Energy (MeV)	Momentum / Q (MeV/c)	Branching Ratio
^{241}Am	5485.56 (12)	**101.1479 (11)**	84.8
	5442.80 (13)	100.7526 (12)	13.1
^{244}Cm	5804.77 (5)	**104.0515 (4)**	76.9
	5762.64 (3)	103.6729 (3)	23.1
^{230}Th	4687.0 (15)	**93.491 (15)**	76.3
	4620.5 (15)	92.825 (15)	23.4

Figure 38-A: Type PM Disk



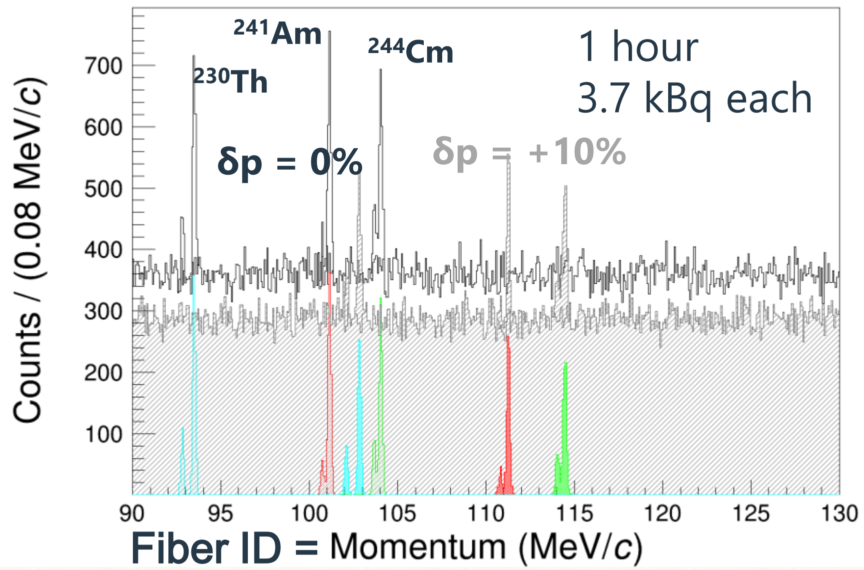


Momentum Calibration Procedure

See "Enge_Calibration_2026Apr.pdf"

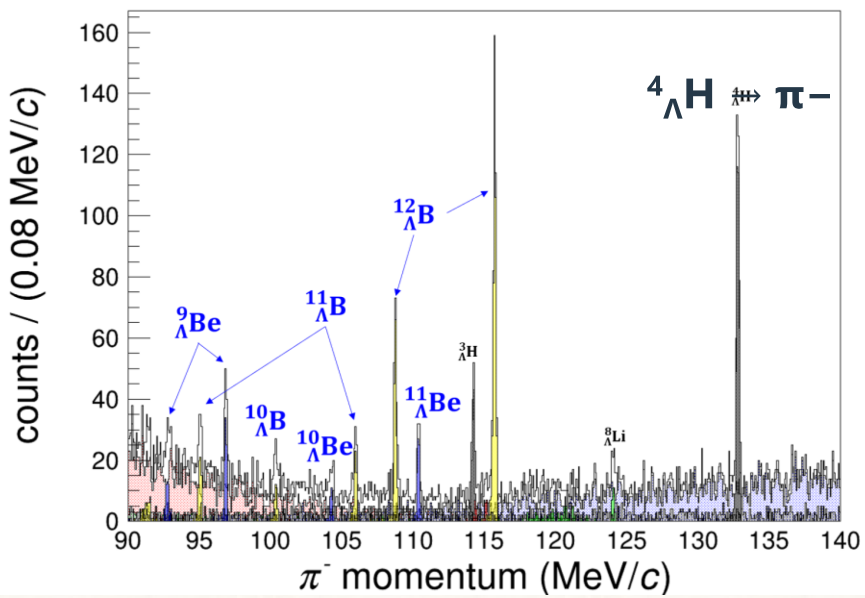
1. Momentum Calibration with alpha sources

- Use known alpha peaks from ^{230}Th, ^{241}Am, and ^{244}Cm
- Scan the Enge magnetic field from +30% to −30% in 5% steps
- Fit the peak positions to obtain the momentum calibration curve
- Fit the peak widths to evaluate the Enge momentum resolution



2. Final Check with Physics Data

- Use the well-known $^{4}_{\Lambda}$H → π⁻ peak from the ^{12}C target
- Acquire data at three magnetic-field settings



NOTE

- Evaluate the PCS fringe-field effect

  A 90 keV/c mom. shift is expected with/without the PCS stray field

  A PCS field monitor with 10% precision is sufficient to keep the ENGE systematic uncertainty below 10 keV/c.

  Monitor the field with the NMR probe to reduce systematic uncertainty from polarity reversal.

Equipment List

Detector	Item	Qty. (Spare)	Status	Cost Estimate
PiFi	Scintillating Fiber	1 (1)	In hand	--
	Vacuum Flange	1 (1)	Quotation obtained, delivery in 1 month	$10 k (U.Tokyo)
	Fiber Jigs	1 (1)	Same as above	$1 k (U.Tokyo)
	MA-PMT	16 (4)	Quotation obtained, delivery in 6 month	$35 k (U.Tokyo)
	HV (SHV) Cable	16 (0)	In hand	--
	NINO Discriminator Card	64 (0)	Hall-A has >200 cards	--
	Cable (MA-PMT to NINO)	16 (4)	To be produced, <1 month	--
	Ribbon Cable (NINO to TDC)	64 (0)	In hand	--
	NINO PSU	1 (1)	To be prepared	$1 k (U.Tokyo)
PiDC	Drift Chamber	1 (0)	In hand	--
	ASD Card	40 (25)	In hand	--
	Ribbon Cable (ASD to TDC)	40 (25)	In hand	--
	ASD Card PSU	1 (0)	In hand	--
PiTOF	X1, X2 Layer Paddle	12 (12)	In hand	--
	Y Layer Paddle	3 (3)	Fabricating, delivery in 1 month	$1 k (U.Tokyo)
	HV (SHV) Cable	54 (0)	In hand	--
	Coaxial Cable (PMT to Divider, BNC-LEMO)	54 (0)	In hand	--
	Ribbon Cable (Discri to TDC)	4 (0)	In hand	--
	Coaxial Cable (Divider to FADC)	4 (0)	In hand	--
	16 ch Divider	4 (0)	In hand	--
	16 ch Discriminator	4 (0)	In hand	--
Alpha	Alpha sources	1 (0)	To be prepared	$3.6 k
	Holder, Slit	1 (0)	To be prepared	--

Summary

The Enge detector system is technically feasible and the major detector risks have been addressed.

PiFi

SiPMs have been replaced by MA-PMTs.
The fiber/MA-PMT performance has been confirmed.
The remaining task is final fabrication and full-system validation.

PiDC

Cosmic-ray tests confirmed the expected performance.
The repair procedure has been documented.

PiTOF

A timing resolution of $\sigma \simeq 70$ ps has been achieved.
Final assembly will be completed this summer.

Calibration

A detailed alpha-source calibration procedure is prepared.
Field stability will be monitored using an NMR probe.

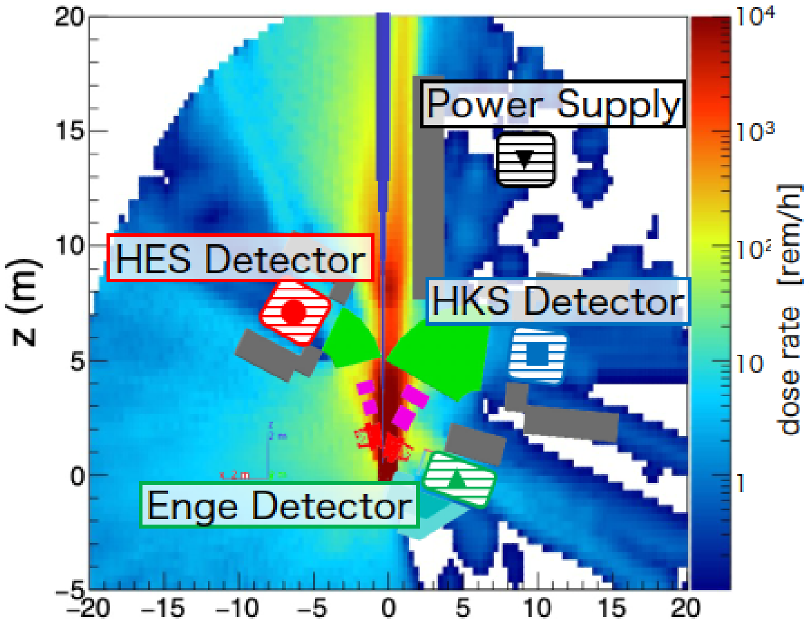
Resources

Manpower, spares, and key equipment have been identified.

Backup

Summary

1. Both Geant4 and FLUKA results are consistent.
2. Pb targets result in higher radiation dose, and shielding effectively reduces the dose.
3. Signal rates above MHz are expected.
   → More detail simulation & analysis
4. The radiation dose outside the hall is kept below 0.001 rem/h.



Beam current = 50 uA, Pb Target with Shielding

	HES [rem/h]	HKS [rem/h]	Enge [rem/h]	Power Supply [rem/h]
γ	0.080	0.033	0.60	0.048
$e^{\pm}$	0.49	0.43	5.6	0.37
n	0.020	0.000014	0.11	0.00020
Total	0.59	0.47	6.3	0.42

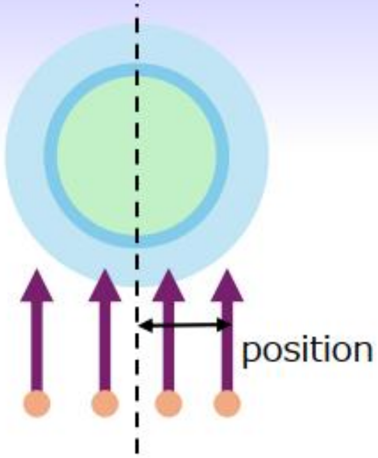
Single rate @ Beam current = 50 uA with Shielding

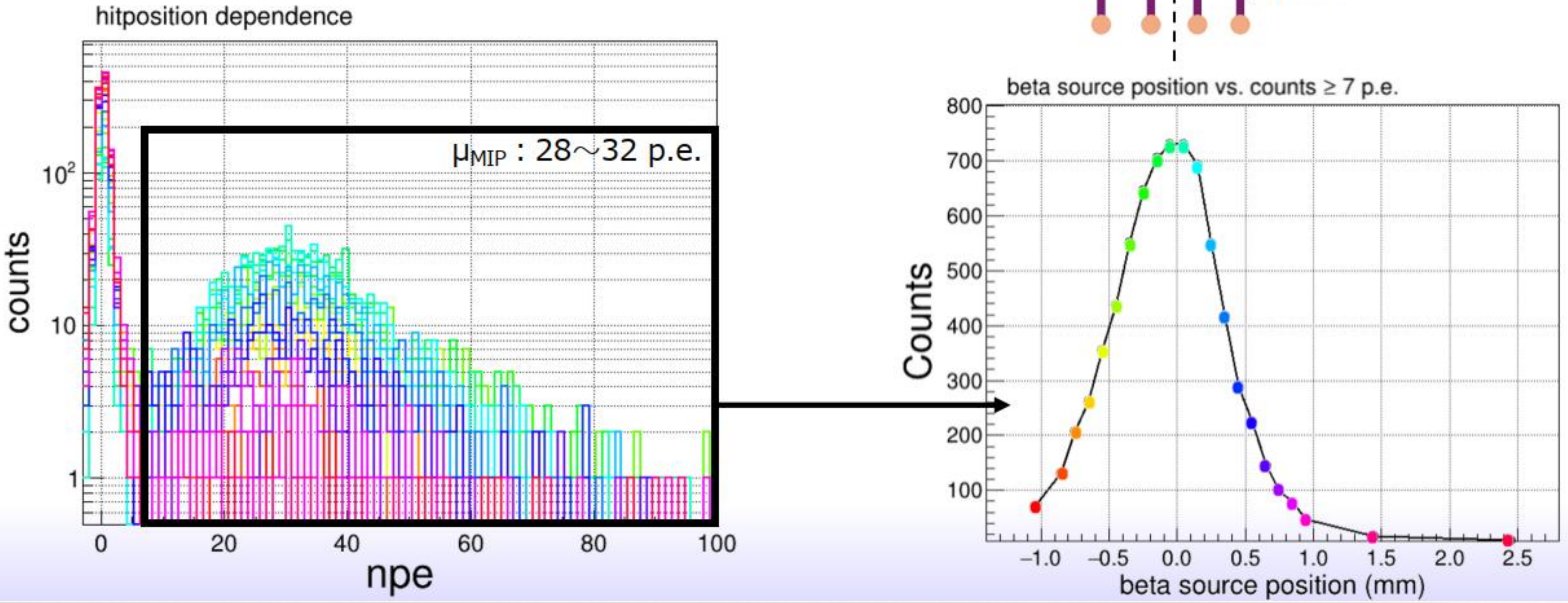
	HES	HKS	Enge	Power supply
Pb	2.8 MHz	4.6 MHz	2.3 MHz	0.34 MHz

SiPM and MA-PMTs (Hamamatsu)

Item	S13361-3050AE-08	H8711-200	H7546A-300	H12700A	H13700
Device type	MPPC array / SiPM	16-ch MAPMT	64-ch MAPMT	64-ch MAPMT	256-ch MAPMT
Photocathode	Si Geiger APD	Ultra Bialkali	Extended Green Bialkali	Bialkali	Bialkali
Number of channels	64 ch = 8 × 8	16 ch = 4 × 4	64 ch = 8 × 8	64 ch = 8 × 8	256 ch = 16 × 16
Channel size	3 × 3 mm^2	4.2 × 4.2 mm^2	2 × 2 mm^2	6 × 6 mm^2	3 × 3 mm^2
Spectral range	—	300–650 nm	300–650 nm	300–650 nm	300–650 nm
Peak wavelength	450 nm	400 nm	420 nm	~400 nm	400 nm
QE/PDE (λ = 480 nm)	PDE ~35–40%	QE ~30–35%	QE ~35–40%	QE ~25–30%	QE ~25–30%
Collection efficiency	Included in PDE	80% typ.?	80% typ.?	80% typ.?	80% typ.
Dark current /ch	Evaluated by DCR	~1.06 nA/ch typ.	~0.20 nA/ch typ.	0.10 nA/ch typ.	~0.020 nA/ch typ.
Total dark current	—	17 nA typ.	12.8 nA typ.	~6.4 nA typ.	5 nA typ.
Dark count rate	~500 kcps/ch typ.	~3.3 kHz/ch, estimated	~20 kHz/ch, measured	~10 kHz/ch, estimated	~8 kHz/ch, measured
Gain	1.7 × 10^6 typ.	2 × 10^6 typ.	5 × 10^5 typ.	1.5 × 10^6 typ.	1.5 × 10^6 typ.
Operation Voltage	56 V (~62 V max.?)	-800 V (-1000 V max.)	-800 V (-1000 V max.)	-1000 V (-1100 V max.)	-1000 V (-1100 V max.)
Channel uniformity	—	1:2 typ. (1:4 max.)	1:2 typ. (1:4 max.)	1:2 typ. (1:3 max.)	1:3 typ. (1:5 max.)
TTS	—	0.33 ns typ.	0.38 ns typ.	~0.35 ns typ.	0.38 ns typ.
Unit price	¥120,000	¥260,000	¥300,000	¥450,000	¥800,000

Appendix:
Hit Position Dependence

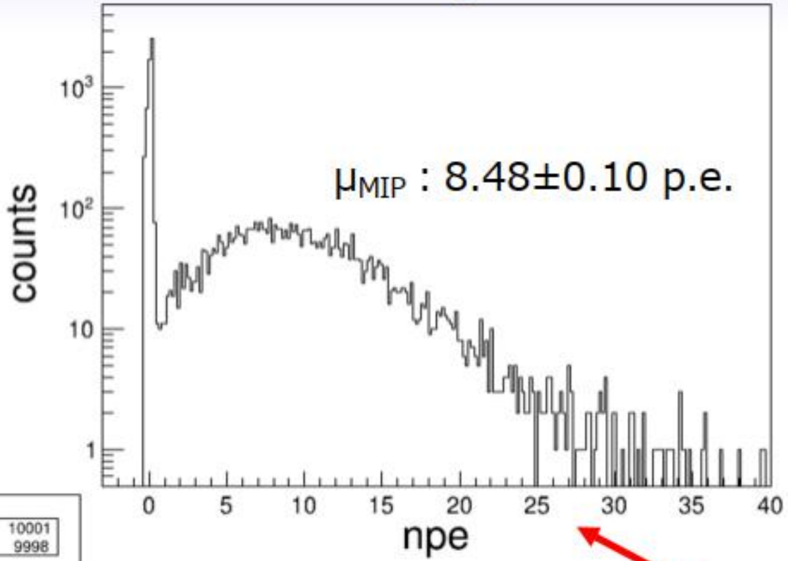


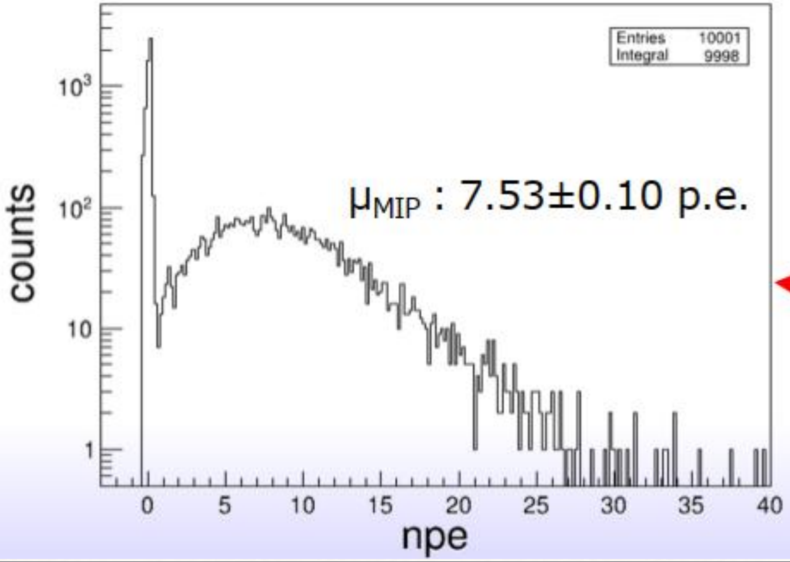


ADC histogram for H7546A-300 and OLS fiber

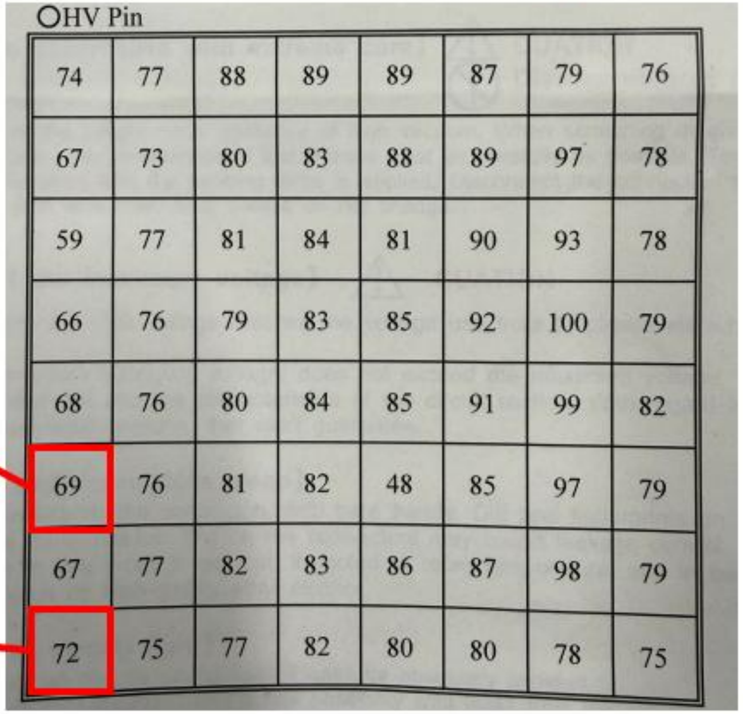
Appendix: MA-PMT (H7546A-300)

22





anode unifomity



○HV Pin

74	77	88	89	89	87	79	76
67	73	80	83	88	89	97	78
59	77	81	84	81	90	93	78
66	76	79	83	85	92	100	79
68	76	80	84	85	91	99	82
69	76	81	82	48	85	97	79
67	77	82	83	86	87	98	79
72	75	77	82	80	80	78	75

alpha source calibration with 5% steps

Current Scan Points	Equivalent Momentum (MeV/c) Under the Nominal Current Setting for 110 MeV/c Central P_0					
	^{244}Cm major	^{244}Cm minor	^{241}Am major	^{241}Am minor	^{230}Th major	^{230}Th minor
30%	80.040	79.748	77.806	77.502*	71.916 (out)	71.404 (out)
25%	83.241	82.938	80.918	80.602	74.793 (out)	74.260 (out)
20%	86.710	86.394	84.290	83.961	77.909	77.354*
15%	90.480	90.150	87.955	87.611	81.300	80.717
10%	94.592	94.248	91.953	91.593	84.992	84.386
5%	99.097	98.736	96.331	95.955	89.039	88.405
0%	104.052	103.673	101.148	100.753	93.491	92.825
-5%	109.528	109.129	106.471	106.055	98.412	97.711
-10%	115.613	115.192	112.387	111.947	103.879	103.139
-15%	122.414	121.968	118.998	118.532	109.989	109.206
-20%	130.064	129.591	126.435	125.941	116.864	116.031
-25%	138.735	138.231	134.864	134.337	124.655	123.767
-30%	148.645 (out)	148.104 (out)	144.497*	143.932	133.559	132.607

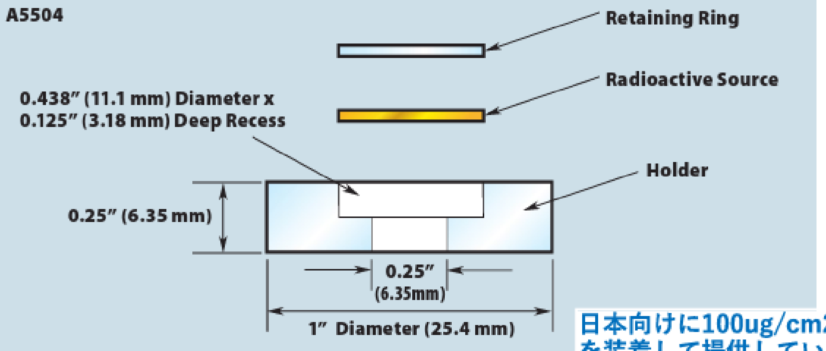
EZIP Catalog

Alpha Particle Standards—Type PM

The PM source is mounted in a plastic holder from which it can be separated for installation in a counting chamber or device. The holder is 1″ diameter x 0.125″ high (25.4 mm x 3.18 mm). The removable active foil is 0.438″ (11.1 mm) in diameter with the active diameter 0.197″ (5.0 mm). The foils are platinum or platinum clad nickel between 0.005″ and 0.010″ (0.127 mm and 0.254 mm) thick.

All alpha standards are offered as spectral grade sources up to the activity and active diameters listed unless otherwise noted. All electroplated alpha standards are manufactured to an accuracy of +/-30% of the nominal activity.

Figure 38-A: Type PM Disk



Overall Dimensions

Overall Diameter	Active Diameter	Height
1″	0.197″	0.25″
25.4 mm	5 mm	6.35 mm

Window & Exceptions

Window	Exceptions
None	Cf-252, Ra-226, and Th-228: 100 μg/cm^2 gold
	Po-210: 100 μg acrylic/cm^2 only

日本向けに100ug/cm2 金カバーを装着して提供しています。
Po-210のみ：100ug/cm2 アクリルカバー

Alpha Particle Standards—Type A-1

Catalog Number	Nudide	Half-Life	Significant Alpha Energies (keV)	Nature of Active Material	Available Activities
AF-241-PM	Americium-241	432.2 y	5388, 5443, 5486	Electroplated onto Platinum Surface	1 nCi-100 nCi (37 Bq-3.7 kBq)
AF-244-PM	Curium-244	18.11 y	5763, 5805	Electroplated onto Platinum Surface	1 nCi-100 nCi (37 Bq-3.7 kBq)
AF-148-PM	Gadolinium-148	75 y	3184	On Request	—
AF-237-PM	Neptunium-237[1]	2.140 x 10^6 y	4640-4873	Electroplated onto Platinum Surface	1 nCi-10 nCi (37 Bq-370 Bq)
AF-210-PM	Polonium-210	138.376 d	5304	Electroless Deposition onto Silver Substrate	1 nCi-100 nCi (37 Bq-3.7 kBq)

Composite Alpha Source—AF Comp

The composite alpha source is designed to be used as an energy marker for alpha spectroscopy systems. Pu-239, Am-241 and Cm-244,*1 0.01 μCi (370 Bq) each, are electroplated onto a polished platinum or platinum clad nickel foil. The active area is 0.197″ (5.0 mm). The source is supplied uncovered. These nuclides provide alpha particles from approximately 5100 to 5800 keV and exhibit line widths typically less than 20 keV FWHM.*2 This energy range is wide enough to provide a valid energy calibration for most alpha emitting nuclides.

The source, when purchased as a NIST traceable standard, can also be used to determine detector efficiencies for alpha particles. Total activity and individual activities are provided on the Certificate of Calibration.

The composite alpha source is available in the type A-2, A-1, and PM configurations as described on pages **2 - 4**

Figure 39-A: Composite Alpha Source Spectrum Using Silicon Barrier Detector