Experimental Readiness Review for the JLab Hypernuclear Experiment

https://indico.jlab.org/event/1074/

HES/HKS Detector Readiness and Commissioning Plan

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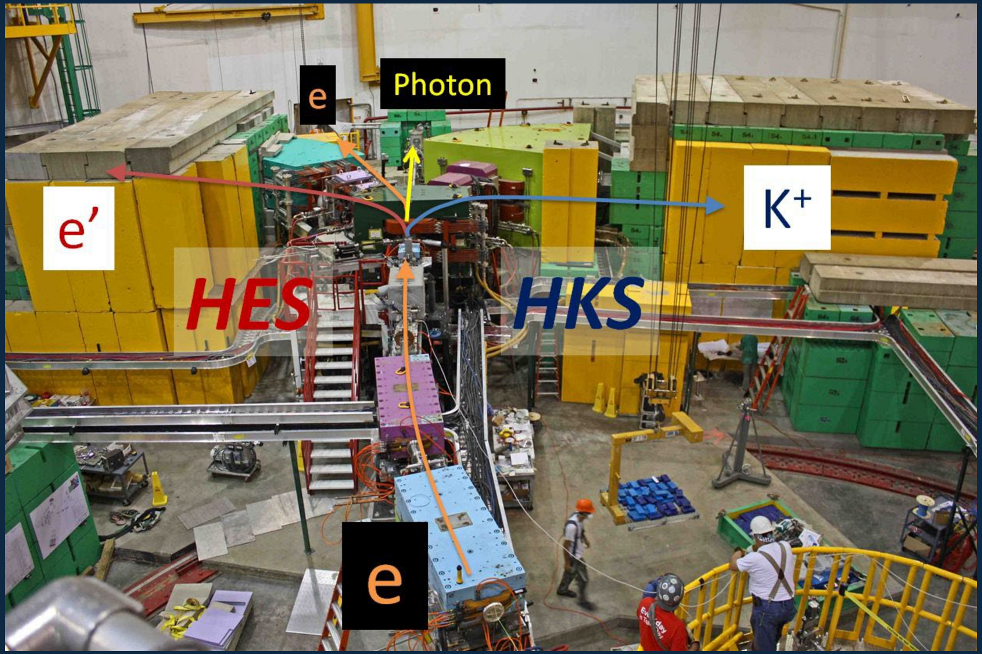
June 4, 2026

Status of the HES/HKS detectors



All detectors were used in the previous Hall C Experiment

TG et al., PRC 103, L041301 (2021)
TG et al., NIMA 900, 69—83 (2018)
TG et al., PRC 94, 021302(R) (2016)
TG et al., PRC 93, 034314 (2016)
Y. Fujii et al., NIMA795, 351—363 (2015)
L. Tang et al., PRC 90, 034320 (2014)
TG et al., NIMA 729, 816—824 (2013)

- ◆ No major detector show-stopper identified at this stage
- ◆ ESB preparation work should complete within calendar year 2026
- ◆ Detector preparation feeds directly into beam commissioning and optics calibration

HES and HKS detectors

TG et al., NIMA 900, 69—83 (2018)

HES

- ETOF (2 layers)
- EDC (10 layers)

HKS

- KTOF (3 layers)
- KDC (6 layers × 2)
- Aerogel C. (3 layers)
- Water C. (2 layers)

HES and HKS detectors

TG et al., NIMA 900, 69—83 (2018)

HES

- ETOF (2 layers)
- EDC (10 layers)

Trigger

Tracking

PID

HKS

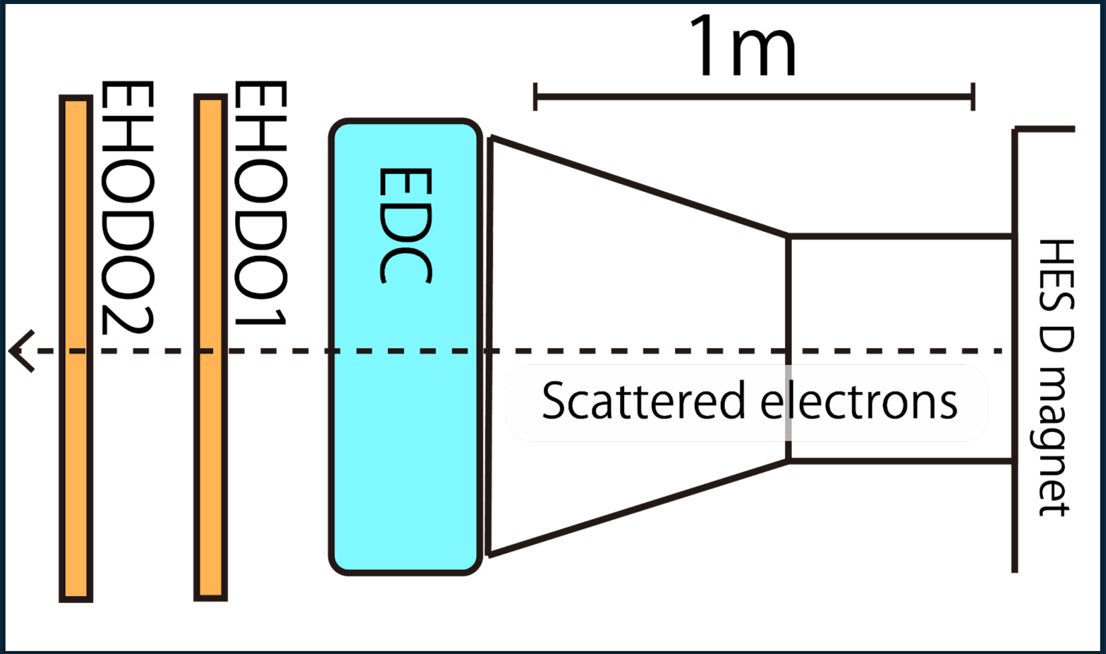
- KTOF (3 layers)
- KDC (6 layers × 2)
- Aerogel C. (3 layers)
- Water C. (2 layers)

Renewed

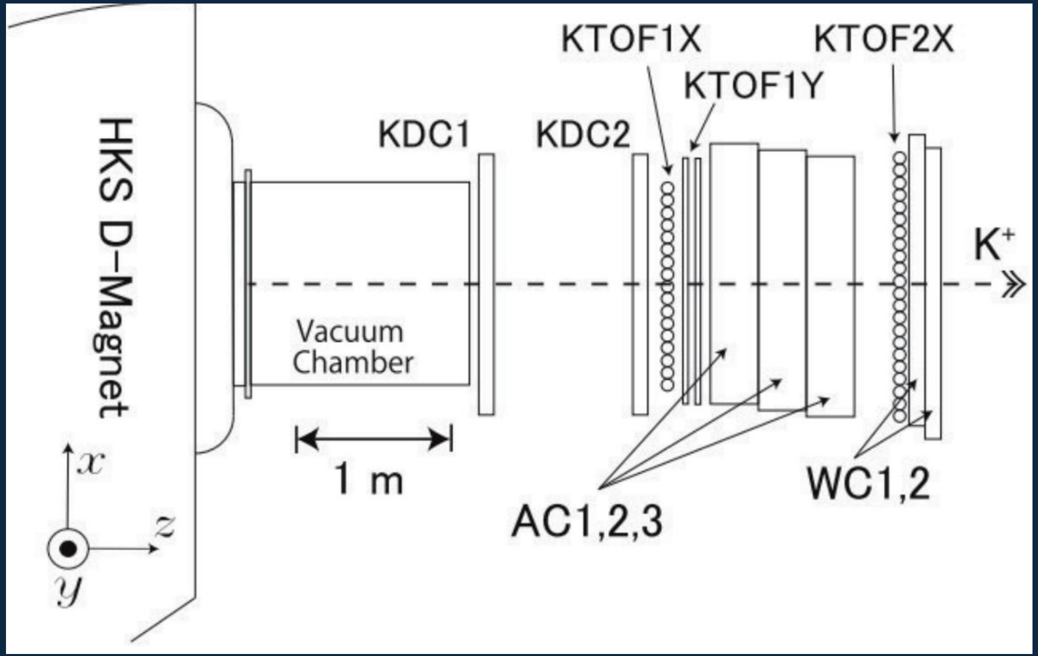
HES and HKS detectors

TG et al., NIMA 900, 69—83 (2018)

HES



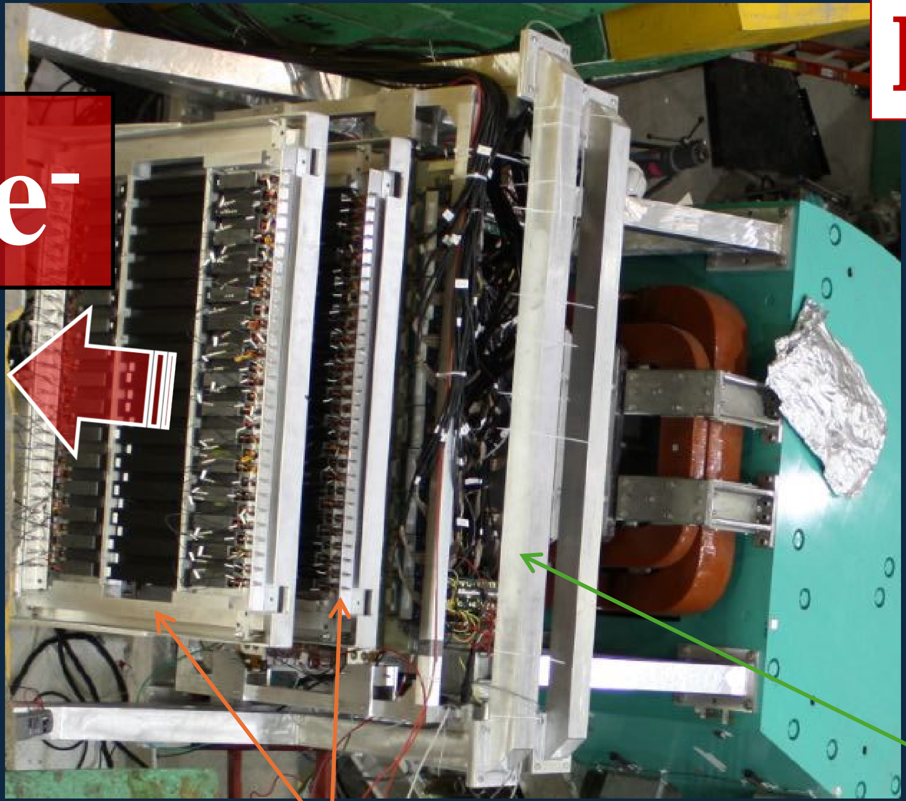
HKS

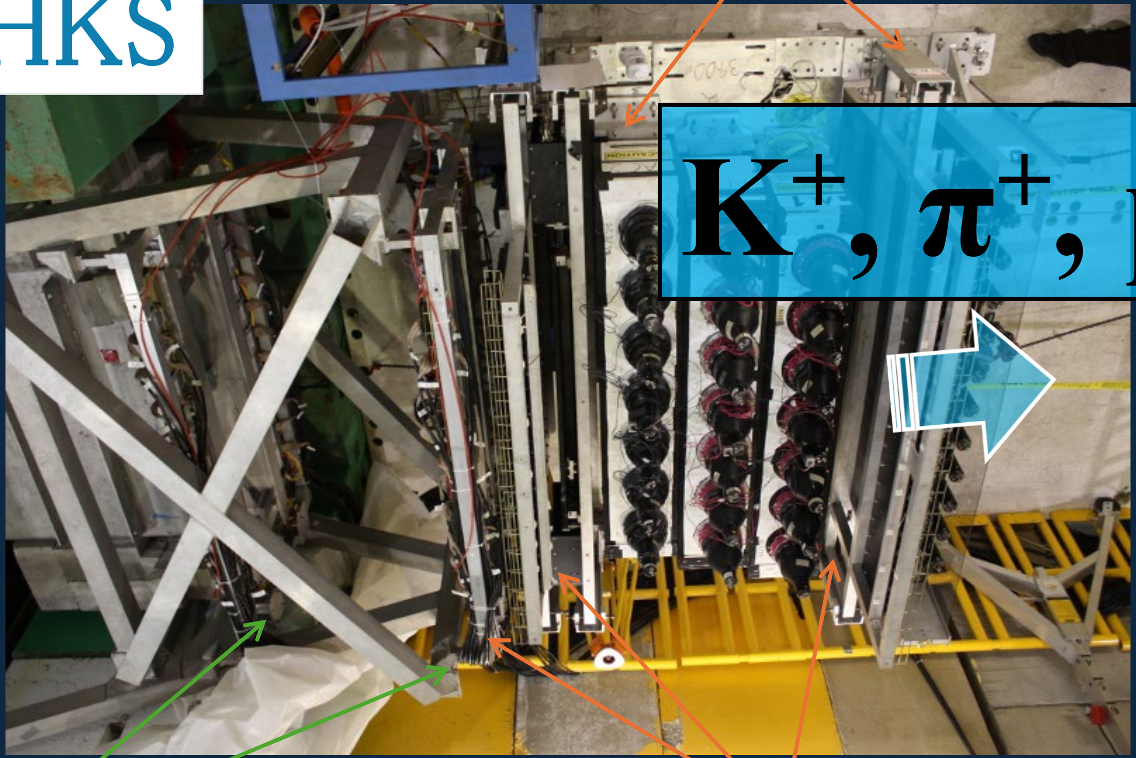


Photograph for the detectors

Cherenkov detectors
- Aerogel (n=1.05)
- Water (n=1.33)

HES | HKS





TOF walls
(Plastic scintillators)

Drift chambers

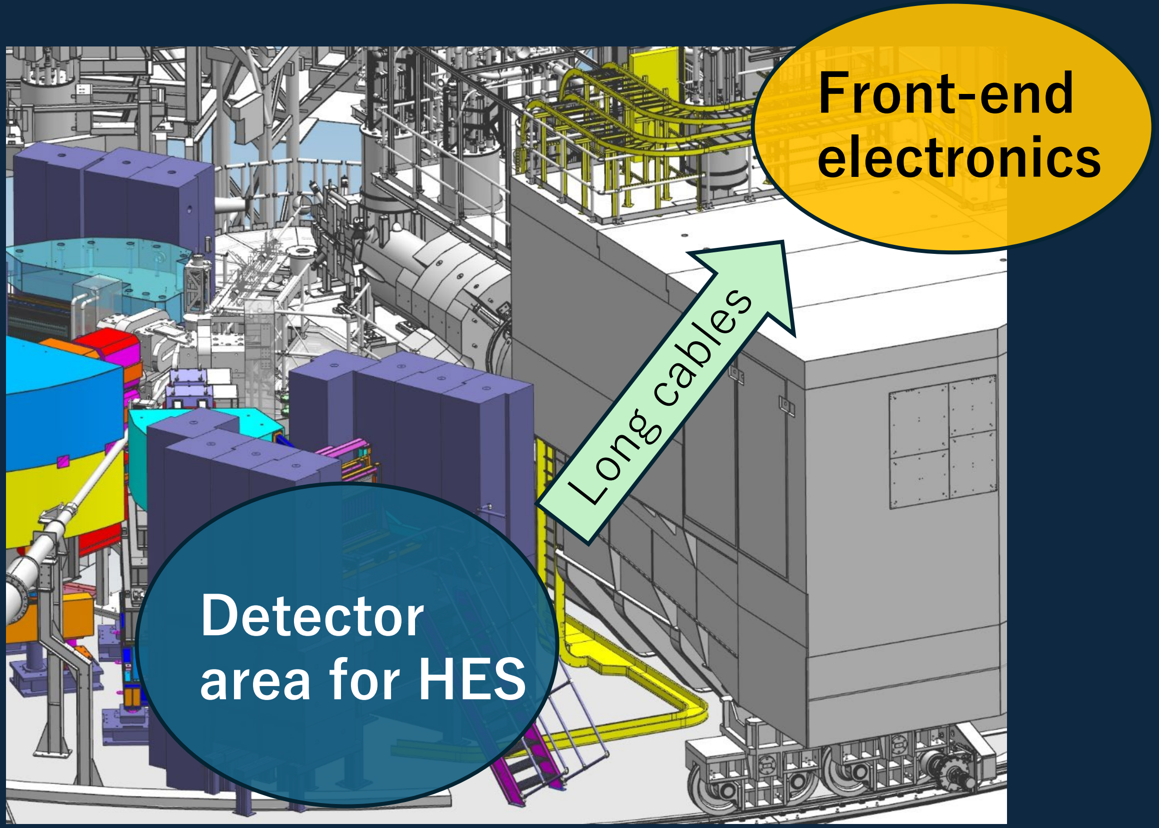
TOF walls
(Plastic scintillators)

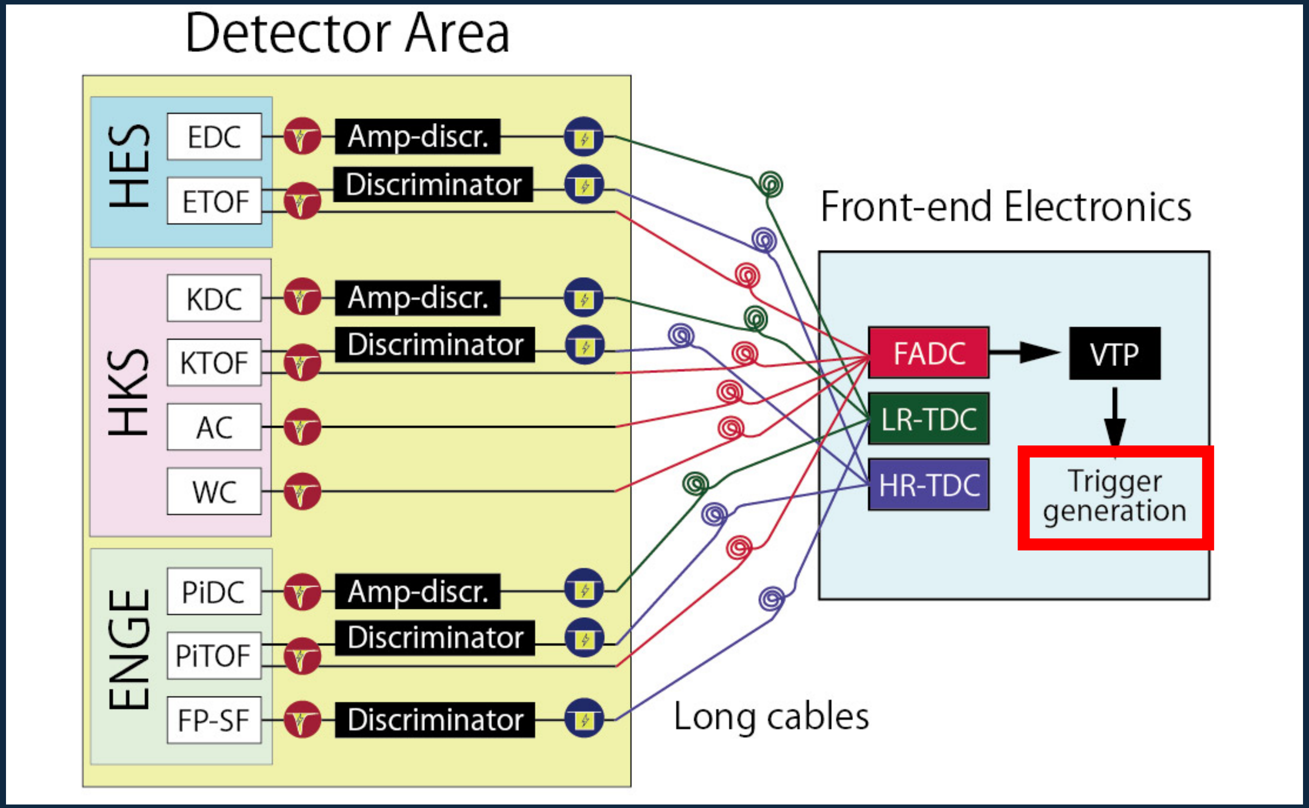
The number of channels for the detectors

Spectrometer	Detector	FADC (ADC/TDC)	Low resolution TDC	High resolution TDC
HKS	KDC	-	640 + 640	-
	TOF	88	-	88
	AC	42	-	-
	WC	48	-	-
HES	EDC	-	1120	-
	TOF	116	-	116
Number of total channels		**294**	**2400**	**204**

Spares and mitigation plan are described in wiki:
https://hallcweb.jlab.org/wiki/index.php?title=Hypernuclear_HKS

Front-end electronics on the SHMS hut





Front-end electronics will be placed on top of the SHMS hut to reduce radiation exposure, using a location with demonstrated electronics operation.

Trigger condition for HES-HKS

Trigger Request:

$$\mathbf{COIN_{MM}} + \mathbf{COIN_{DP}} + (A \times \mathrm{HKS}) + (B \times \mathrm{K}) + (C \times \mathrm{HES}) + (D \times \mathrm{ENGE})$$

where,

$\mathbf{COIN_{MM}} = \mathrm{HES} \otimes \mathrm{HKS}$ (or $\mathrm{HES} \otimes \mathrm{K}$)

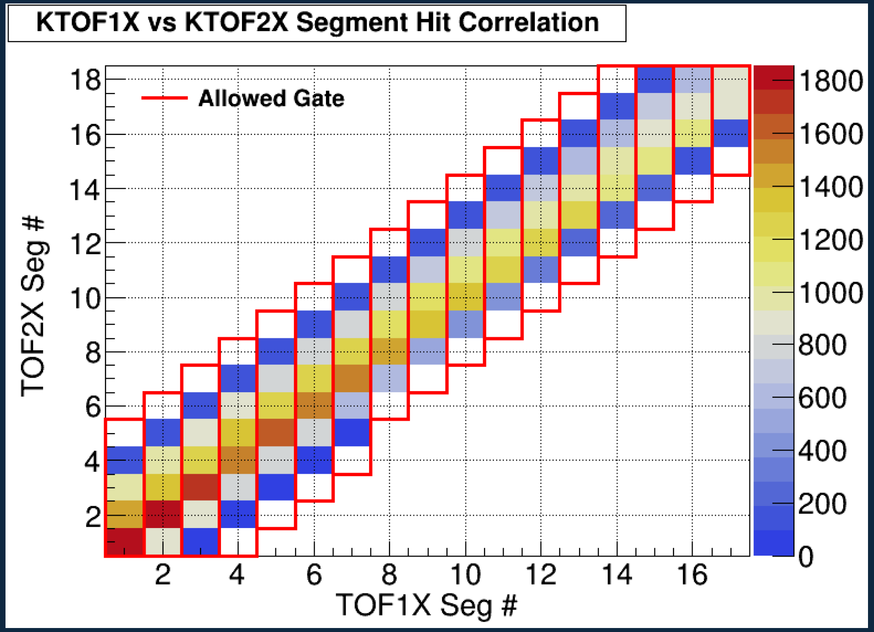
$\mathbf{COIN_{DP}} = \mathrm{ENGE} \otimes \mathrm{HKS}$ (or $\mathrm{ENGE} \otimes \mathrm{K}$)

$\mathrm{HES} = \mathrm{HES_{CP}} = \sum_{i=i}^{15} (\mathrm{ETOF1} \otimes \mathrm{ETOF2})_i$

$\mathrm{HKS} = \mathrm{HKS_{CP}} = \sum_{i=1}^{17} (\mathrm{KTOF1X} \otimes \mathrm{KTOF2X})_i \otimes \mathrm{KTOF1Y}$

$\mathrm{K} = \mathrm{HKS_K} = \sum_{i=1}^{17} (\mathrm{KTOF1X} \otimes \mathrm{KTOF2X} \otimes \mathrm{WC} \otimes \overline{\mathrm{AC}})_i$

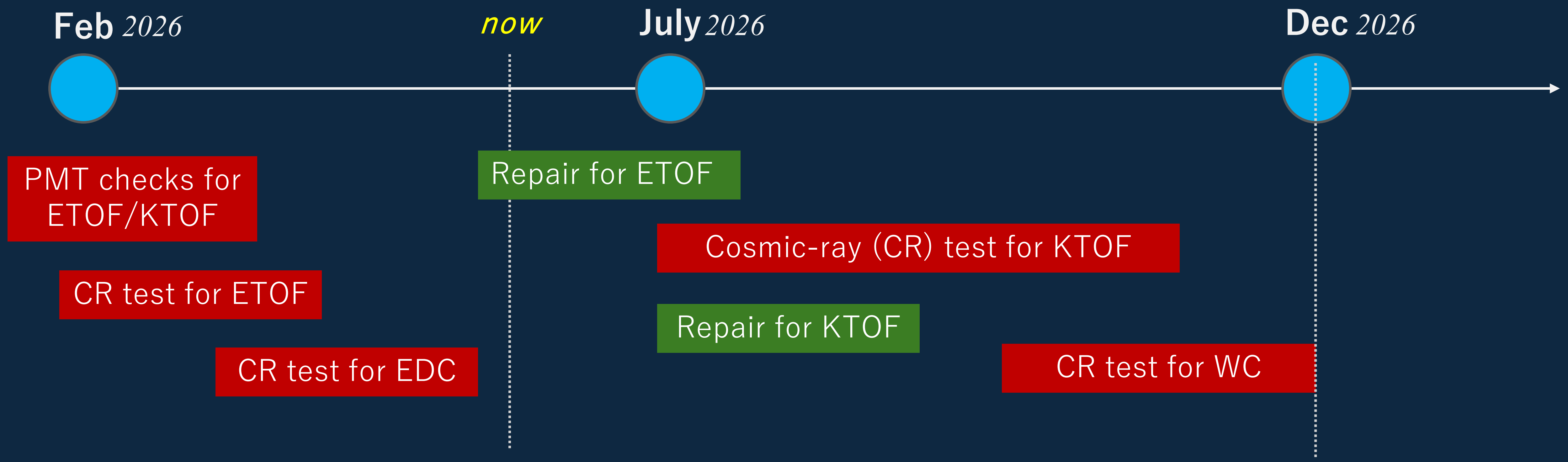
$\mathrm{ENGE} = \mathrm{ENGE_{CP}} = \mathrm{PiTOF1} \otimes \mathrm{PiTOF2}$



Status and to do before installation

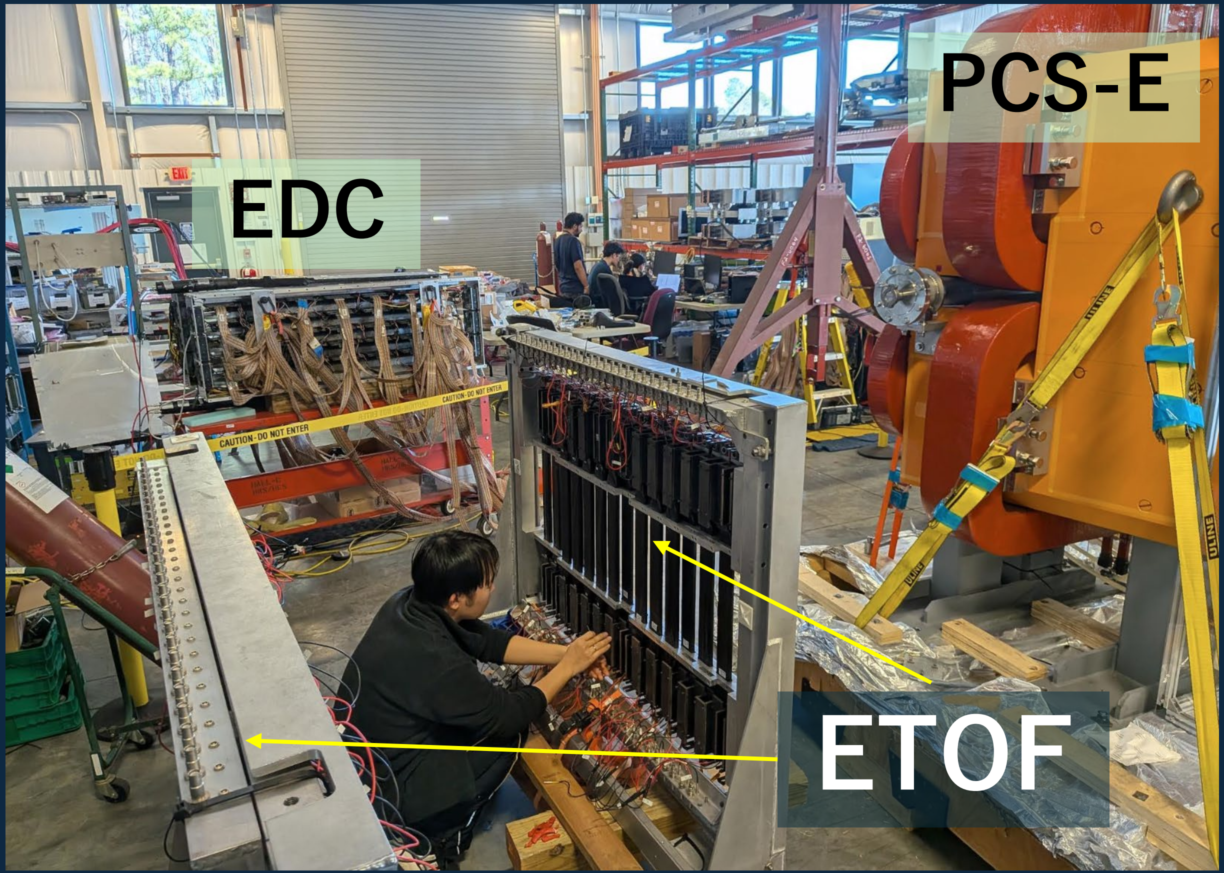
	Detector	Completed	To do
HKS	KDC	Cosmic ray (CR) test to confirm no missing channels	
	TOF	PMT checks	Repair for light leaks and detached optical joints, Cosmic ray test
	AC	CR test to confirm NPE performance	
	WC	New design, container fabrication in Japan	Transport to JLab, CR test for double checking NPE performance
HES	EDC	CR test to confirm no missing channels	
	TOF	CR test for timing resolution check	Repair for light leaks and detached optical joints

Detector work before installation



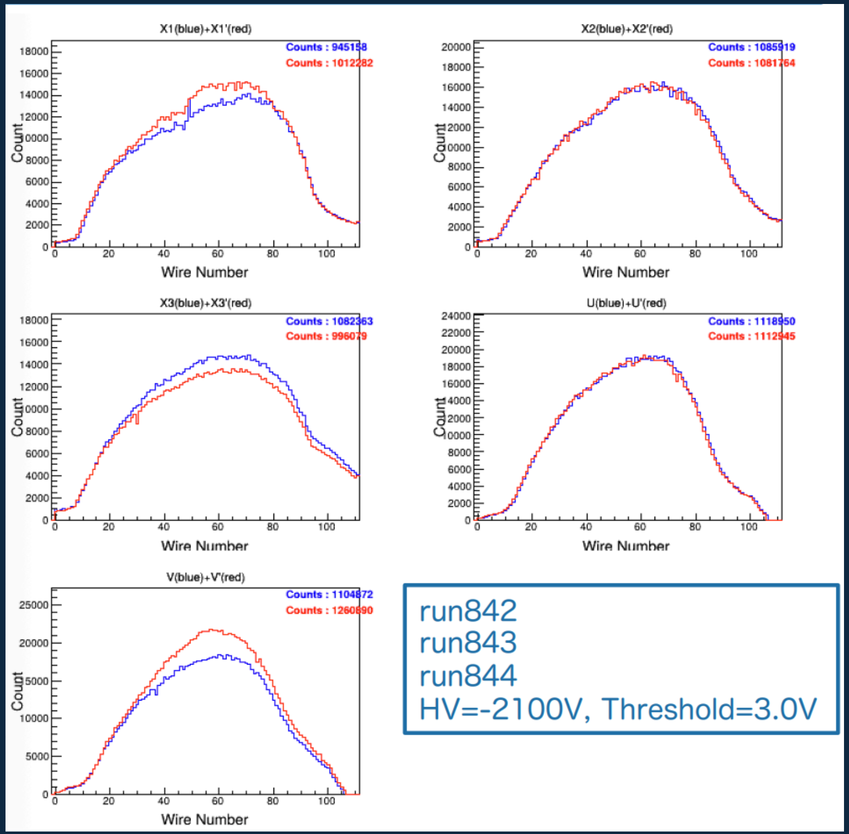
HES/HKS detectors will be ready for installation by December 2026

EDC test at ESB



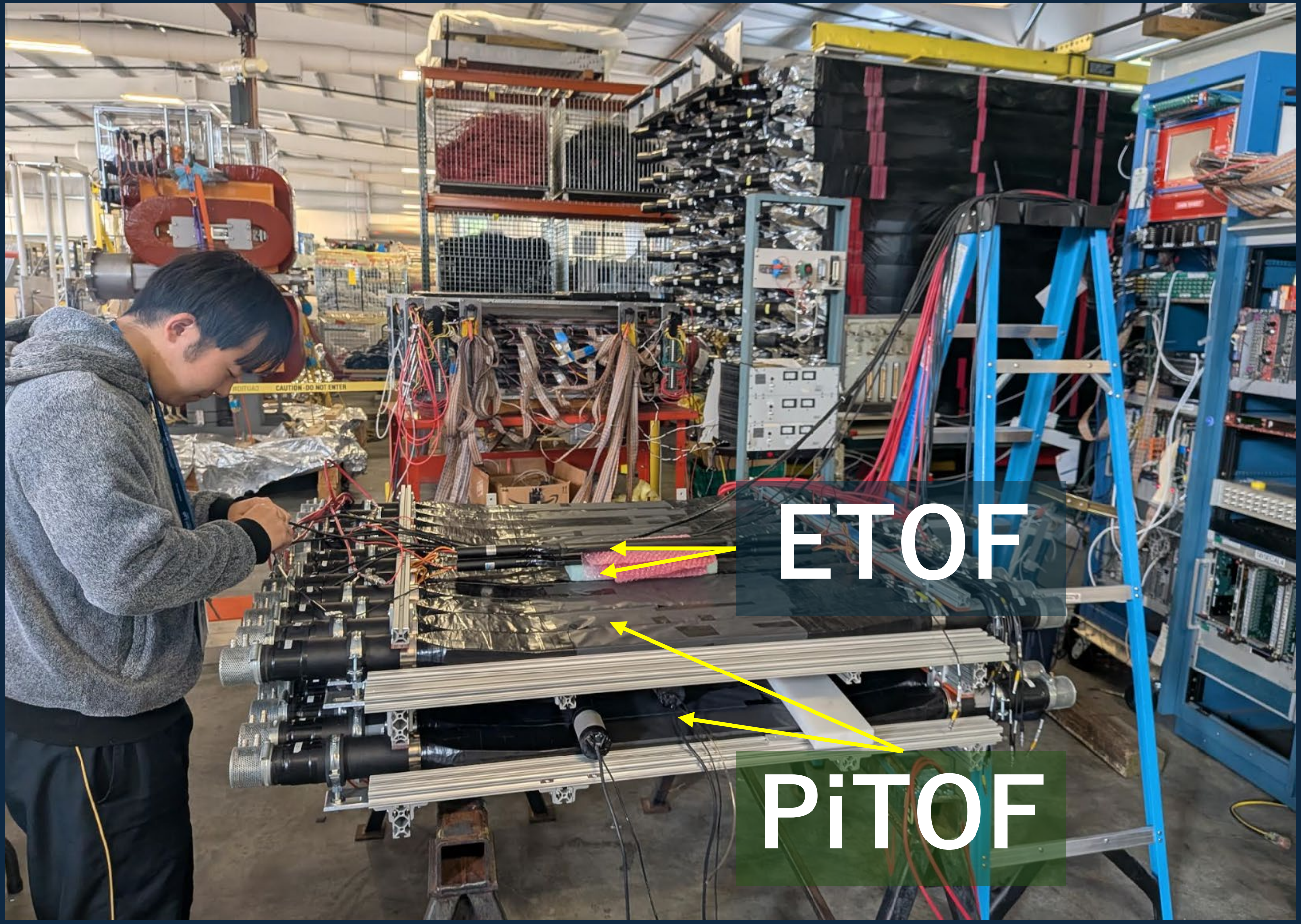
Mar 4, 2026

Figure by Ken Nishida (U. Tokyo)



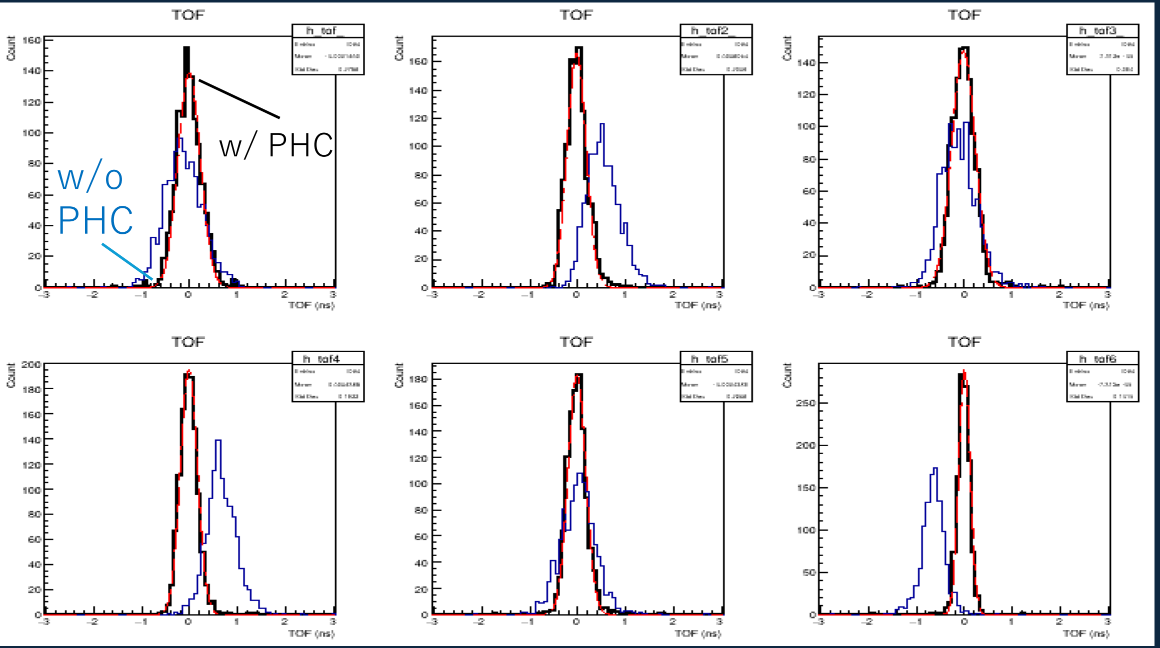
No missing wires

ETOF test at ESB



Mar 2026

ETOF1-PiTOF1	ETOF1-ETOF2	ETOF1-PiTOF2
198 ± 11 ps	212 ± 16 ps	247 ± 19 ps



ETOF2-PiTOF1	ETOF2-PiTOF2	PiTOF1-PiTOF2
178 ± 7 ps	185 ± 8 ps	119 ± 3 ps

Time resolution for ETOF:
σ = 130—170 ps ➔ Good enough

Calibration strategy (during the experiment)

Detector-level
- Gain matching
- Time offset
- xt curve
- etc.

Integration
- Alignment
- Readout sync.
- Monitoring constants
- etc.

Physics calib.
- Energy with Λ/Σ^0
- Angle with sieve slits
- Raster correction
- etc.

Analysis output
- Missing mass
- Resolution validation
- Production monitor
- etc.

Calibration strategy (offline analysis)

Detector calibrations
(TOF slewing corr., xt curve optimization etc.)

Particle / reaction identification
(coincidence time / Cherenkov etc.)

Missing mass reconstruction
➔ Binding energy

Energy / Angle calibrations
(Λ, Σ^0 and sieve slits)

Cross section calculations
(Efficiency, acceptance etc.)

Fitting analysis
➔ B_Λ and cross section

Physics outcome

Transfer matrix optimization

$$\begin{pmatrix} p \\ x' \\ y' \end{pmatrix}_{\mathrm{HKS}} = \begin{pmatrix} a_p^1 & b_{x'}^1 & c_{y'}^1 \\ a_p^2 & b_{x'}^2 & c_{y'}^2 \\ a_p^3 & b_{x'}^3 & c_{y'}^3 \\ a_p^4 & b_{x'}^4 & c_{y'}^4 \\ a_p^5 & b_{x'}^5 & c_{y'}^5 \\ \vdots & \vdots & \vdots \\ a_p^{210} & b_{x'}^{210} & c_{y'}^{210} \end{pmatrix} (x, x', y, y', x^2, xx', \ldots)^{\mathrm{FP}}$$

Optimization with

- (yellow box): Λ / Σ^0
- (magenta box): SS

630 parameters for each spectrometer when we take the 6th order
➔ 1260 parameters in total

Kinematic parameters

Item		Value
Beam (e)	Energy (/GeV)	2.24
	(Required) energy spread and drift	1×10^{-4} (FWHM)
PCS + HES (e')	Central momentum $p_{e'}^{\mathrm{cent.}}$ [/(GeV/c)]	0.74
	Central angle $\theta_{ee'}^{\mathrm{cent.}}$	8.5°
	Solid angle acceptance $\Omega_{e'}$ (/msr) (at $p_{e'}^{\mathrm{cent.}}$)	3.4
	Momentum resolution $\Delta p_{e'}/p_{e'}$	4.4×10^{-4} (FWHM)
PCS + HKS (K^+)	Central momentum $p_{K^+}^{\mathrm{cent.}}$ [/(GeV/c)]	1.20
	Central angle $\theta_{eK^+}^{\mathrm{cent.}}$	11.5°
	Solid angle acceptance Ω_{K^+} (/msr) (at $p_{K^+}^{\mathrm{cent.}}$)	7.0
	Momentum resolution $\Delta p_{K^+}/p_{K^+}$	2.9×10^{-4} (FWHM)
$p(e, e'K^+)\Lambda$	$\sqrt{s} = W$ (/GeV)	1.912
	Q^2 [/(GeV/c)^2]	0.036
	K^+ scattering angle wrt virtual photon, $\theta_{\gamma^* K^+}$	7.35°
	ϵ	0.59
	ϵ_L	0.0096

Optimal for Λ and Σ^0

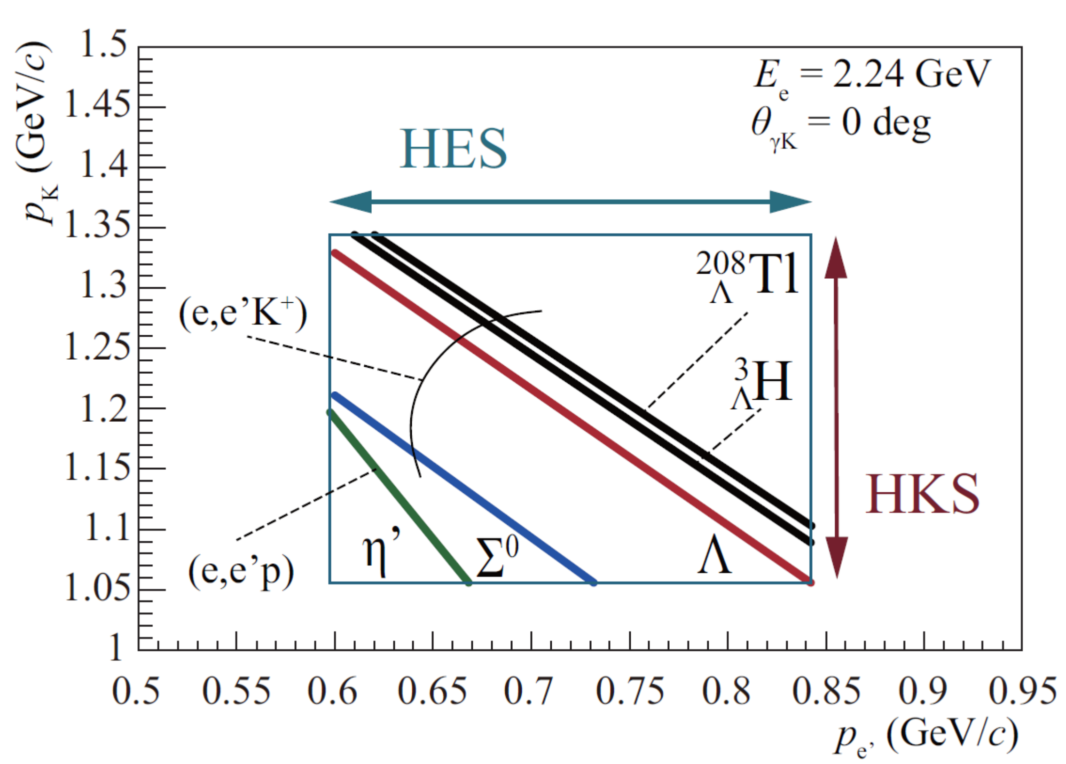
Small Q^2
➔ Almost real photon

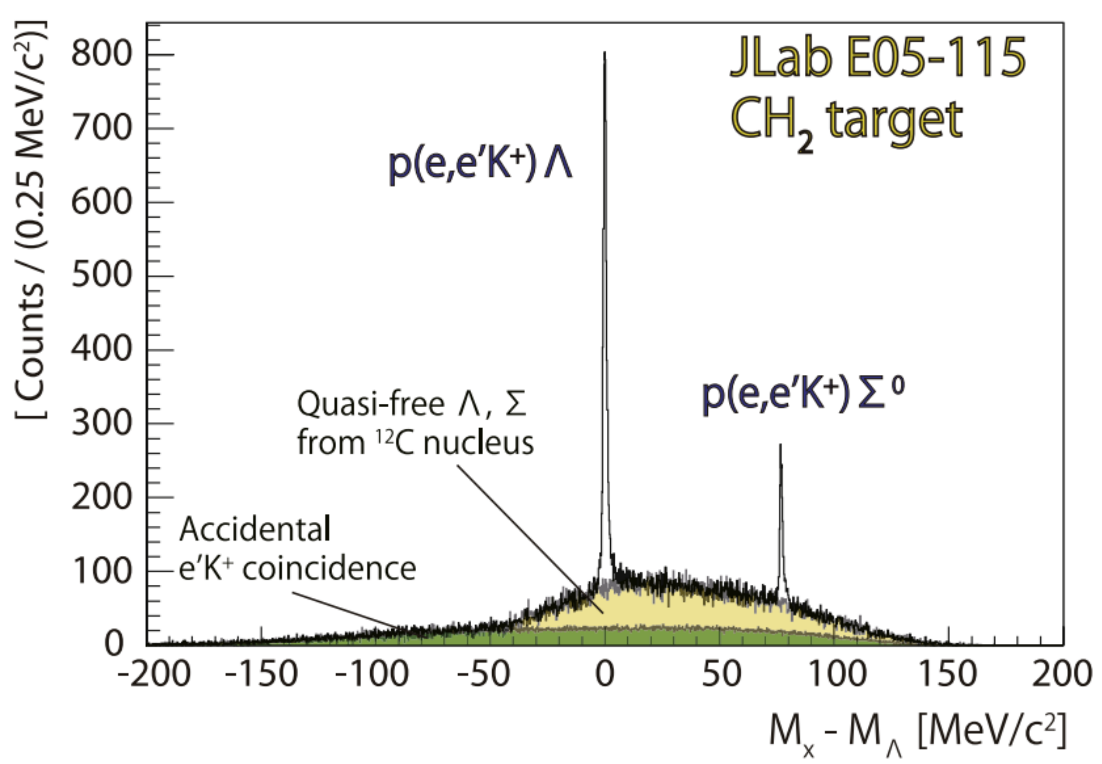
Forward angle
➔ Large cross section

TG et al., PoS (QCHSC24), 230 (2025)

Energy calibration

TG et al., NIMA 900, 69—83 (2018)





➔ Systematic error $\left|\Delta B_{\Lambda}^{\text{sys.}}\right| \simeq$ **60 keV**

Manpower for HES-HKS detectors

HES-HKS Detector

TOF	Cherenkov	Drift chambers
Coordinator **T. Gogami** (Shiga U.)	*Coordinator* **R. Marinaro** (CNU)	*Coordinator* **B. D. Pandey** (VMI)

Core workers

- K. Ishido (Kyoto U.)
- K. Nishi (U. Tokyo)

- K. Higashimoto (U. Tokyo)
- R. Yamakawa (U. Tokyo)

- K. Nishida (U. Tokyo)
- R. Kumaragamage (Hampton U.)
- Y. Ma (Hampton U.)

Technical Supervisors: L. Tang (Hampton U.), J. Reinhold (FIU), S. Nagao (U. Tokyo)

Roles and responsibilities

Coordinator role

- Track progress within each detector group
- Identify conflicts in work space, schedule, and manpower
- Arrange focused subgroup meetings when needed
- Coordinate with DAQ, analysis software, and other detector groups
- Report progress and open issues to the HES-HKS detector meeting and weekly meeting
- Communicate with the JLab liaison as needed for on-site coordination

Technical supervisor role

- Provide technical advice and support to core workers
- Help review detector-specific issues and troubleshooting
- Support preparation, commissioning, and installation

Summary

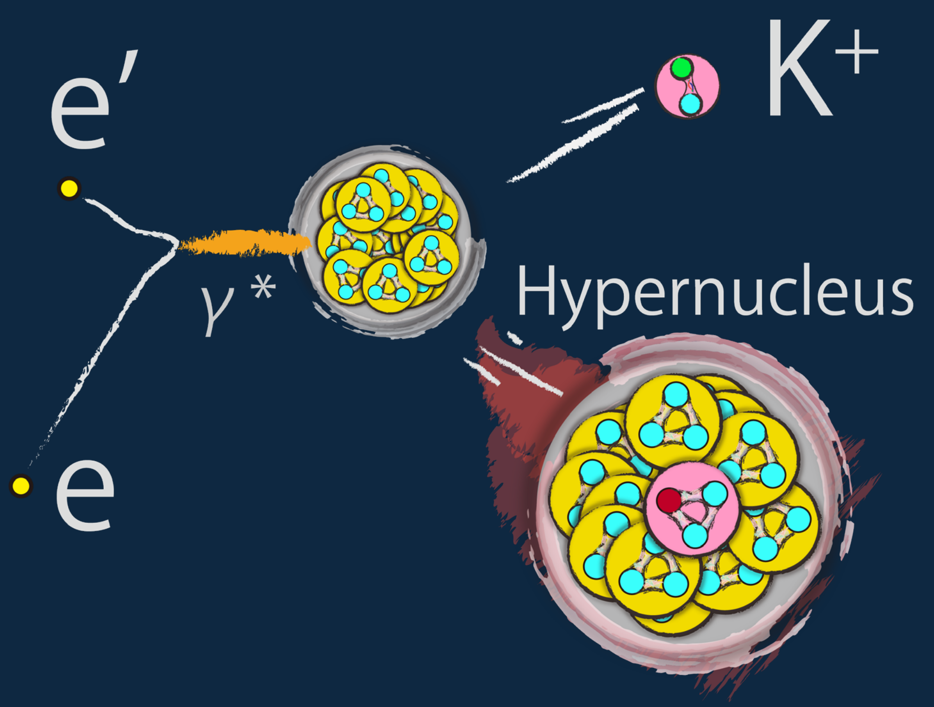
- HES/HKS detector systems (TOF, MWDC, AC, and WC) are known detector packages with previous operational experience

- Remaining work consists of standard repair, checkout, integration, and commissioning tasks

- All detectors are expected to be ready for installation by Dec 2026

Backup

Missing-mass spectroscopy



$$\boldsymbol{M_H} = \sqrt{(E_e + M_T - E_{e'} - E_K)^2 - (\vec{P_e} - \vec{P_{e'}} - \vec{P_K})^2}$$

$$B_\Lambda = \boldsymbol{M_H} - M_{core} - M_\Lambda$$

To be measured

Electro-production

- Better understanding of reaction GOOD
- Small cross section Bad
- Larger noise as Z gets larger Bad

Primary beam

- High precision / small emittance GOOD
- High intensity → thin target GOOD

(➔ High energy resolution)

Virtual photo production

➔ Large spin flip amplitude GOOD Bad

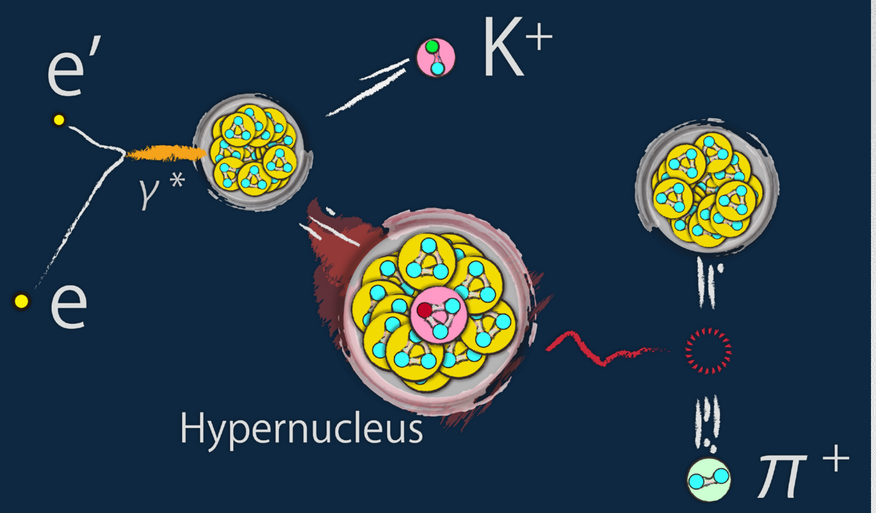
p → Λ

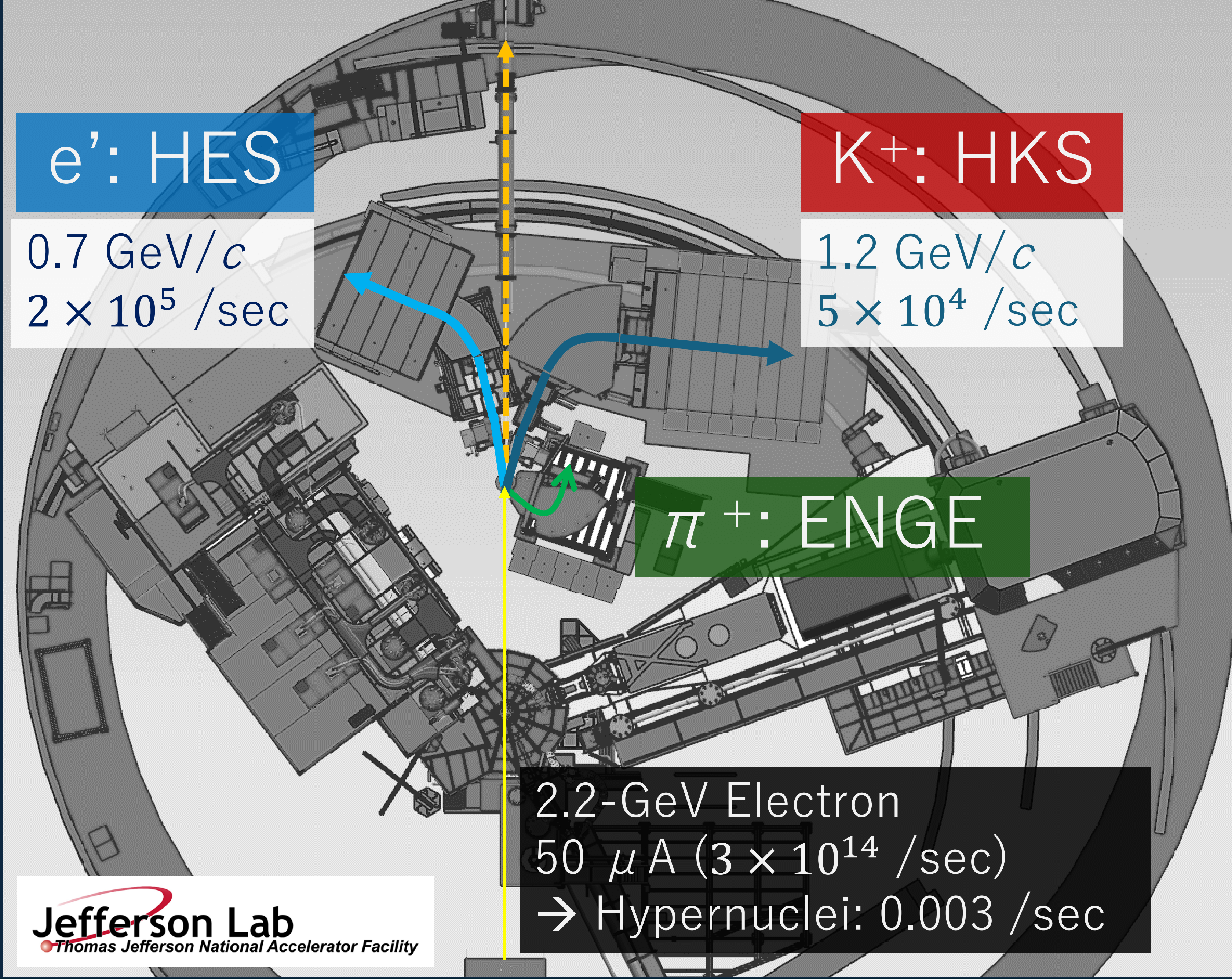
GOOD

➔ Good calibration with proton target

➔ Mirror Hypernuclear study GOOD

Experimental setup





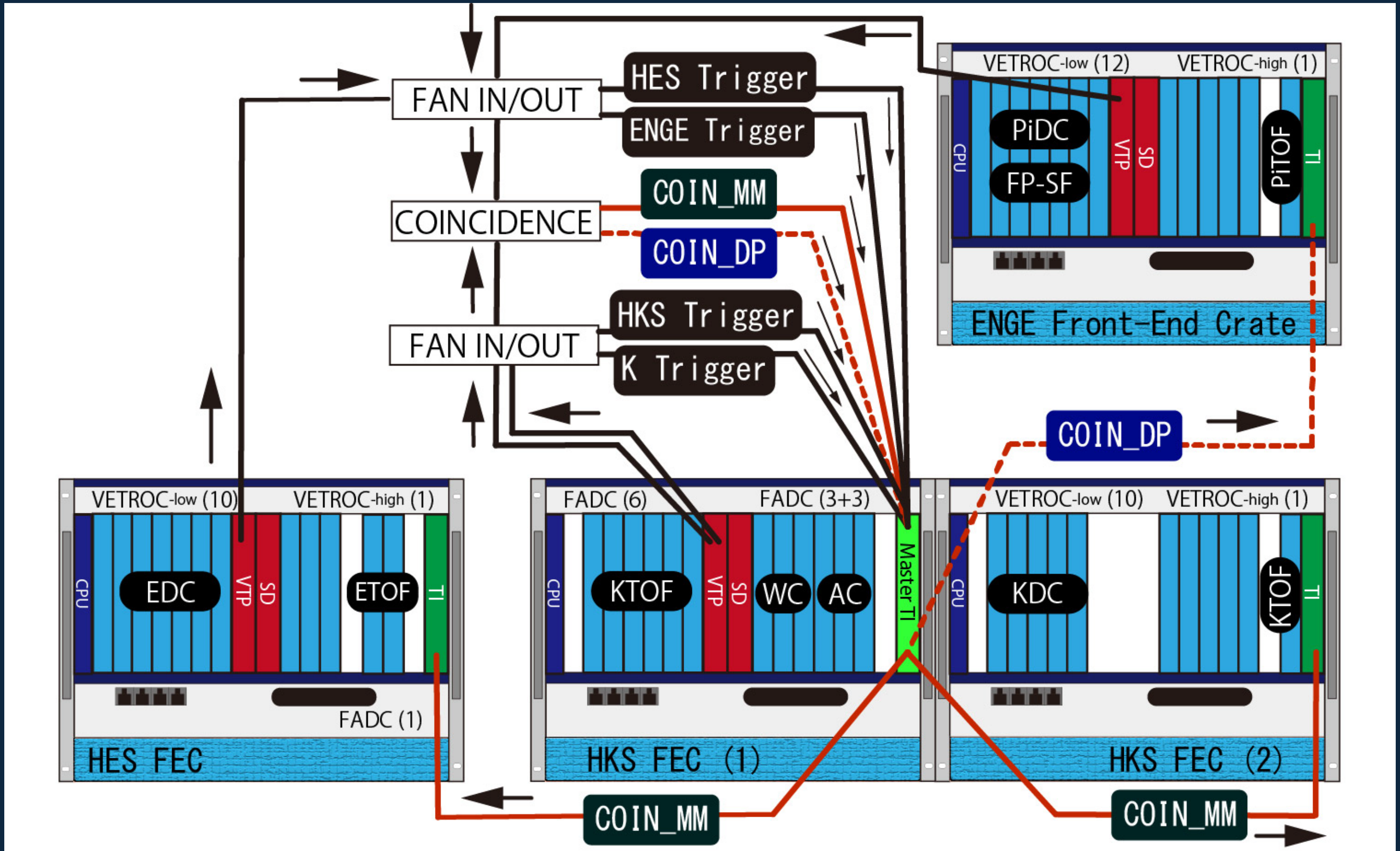
Comprehensive projects, unique research

Experiment	Hypernucleus	Title	PAC Days
E12-19-002	${}^{3}_{\Lambda}$H, ${}^{4}_{\Lambda}$H	High accuracy measurement of nuclear masses of hyperhydrogens	14.5
E12-24-004	${}^{6}_{\Lambda}$He, ${}^{9}_{\Lambda}$Li, ${}^{11}_{\Lambda}$Be	Study of charge symmetry breaking in p-shell hypernuclei	24
E12-24-013	${}^{40}_{\Lambda}$K, ${}^{48}_{\Lambda}$K	An isospin dependence of the ΛN interaction through the high precision spectroscopy of Lambda hypernuclei	55
E12-24-011	${}^{27}_{\Lambda}$Mg	Study of a triaxially deformed nucleus using a Lambda particle as a probe	28
E12-24-003	${}^{208}_{\Lambda}$Tl	Studying Lambda interactions in nuclear matter with the ${}^{208}\mathrm{Pb}(e, e'K^{+}){}^{208}_{\Lambda}\mathrm{Tl}$ reaction	42
Run group (E12-15-008A)		High-resolution spectroscopy of light hypernuclei with the decay-pion spectroscopy	N/A

Next campaign

TG et al., PoS (QCHSC24), 230 (2025)

Front-ends for DAQ



- Signals in FADCs are used for each trigger logic
- FPGA logics are implemented in VTP for each trigger
- Master TI distributes the triggers to labor TIs