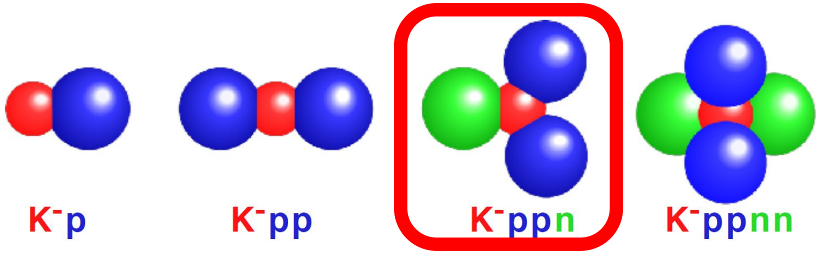
E80 Status Report

Systematic Investigation of the Light Kaonic Nuclei

– from the $\bar{K}N$ to $\bar{K}NNNN$ systems, and more –



F. Sakuma, RIKEN

on behalf of

the J-PARC E80 collaboration

40th J-PARC PAC meeting, Jul 16 – 18, 2025

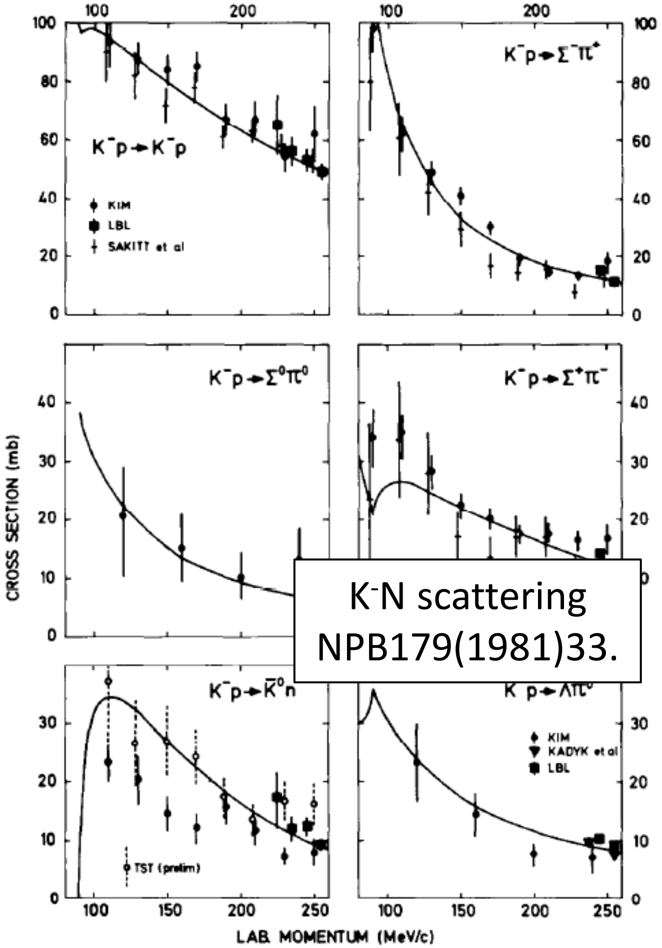
Physics Motivation

Reveal the meson properties inside nuclei via **<u>the $\bar{K}N$ interaction</u>**

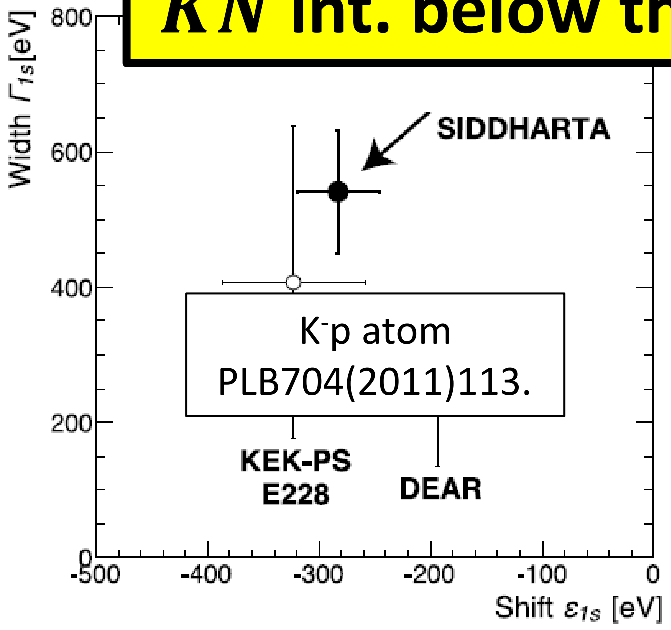
A powerful probe to understand low energy QCD

Strongly attractive in I=0 from extensive measurements

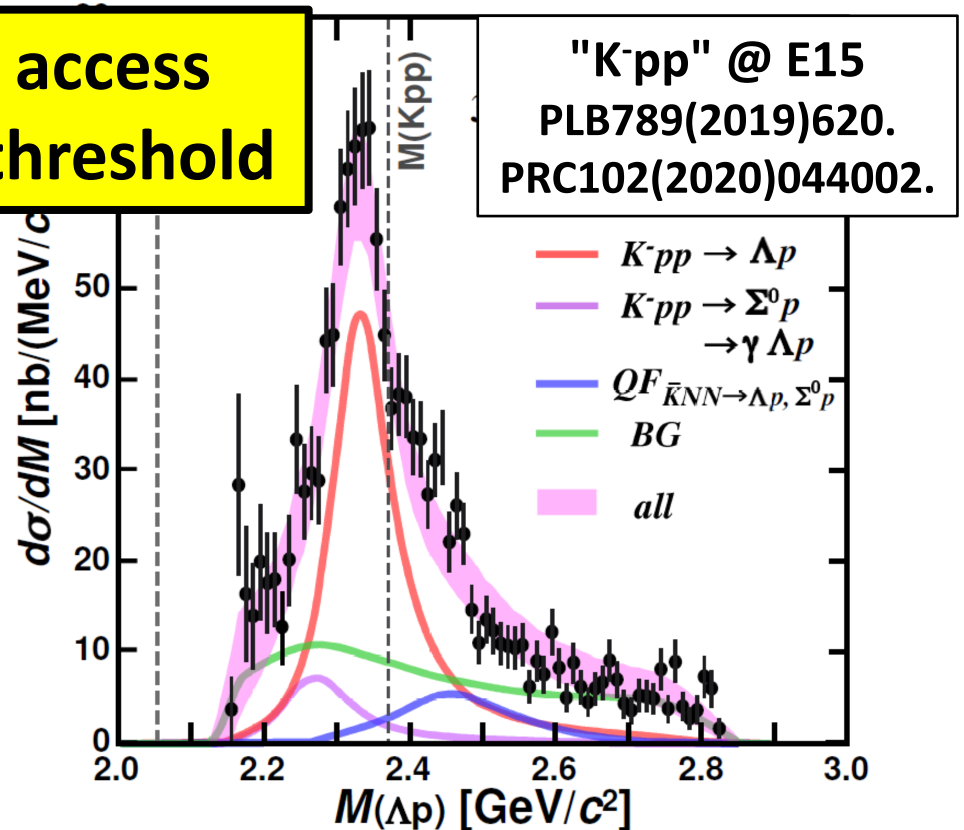
Kaonic nuclei can access $\bar{K}N$ int. below the threshold



K⁻N scattering
NPB179(1981)33.



K⁻p atom
PLB704(2011)113.

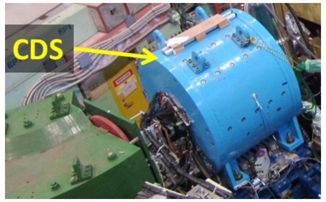


"K⁻pp" @ E15
PLB789(2019)620.
PRC102(2020)044002.

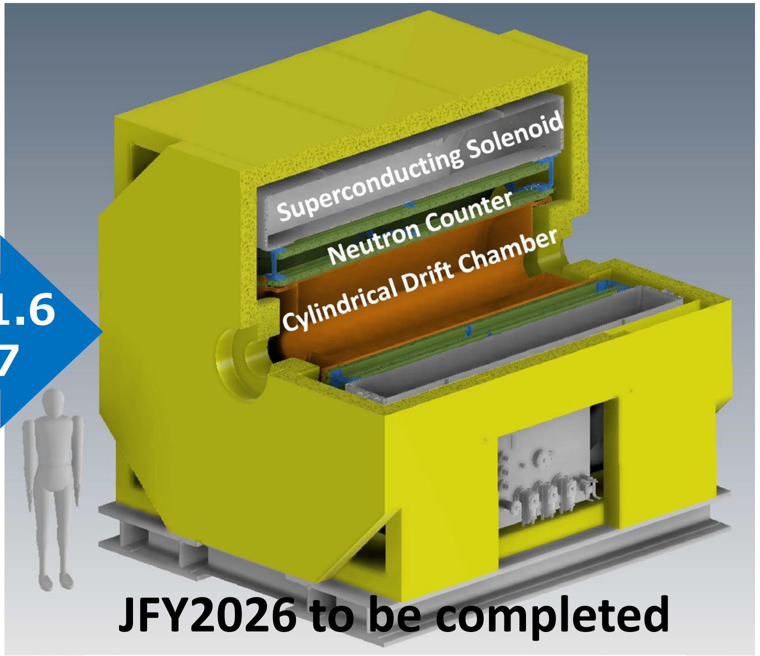
Systematic investigation of the light kaonic nuclei

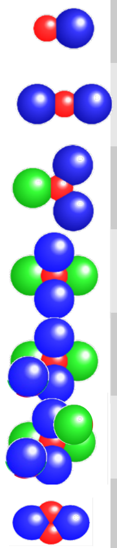
- ●Systematic measurement will be promoted
  - Mass number dependence
    - Binding energy, Branching ratio, *q* dependence, ..
  - Spin/parity determination

➢Extract internal structure, by combining experimental data with theoretical studies

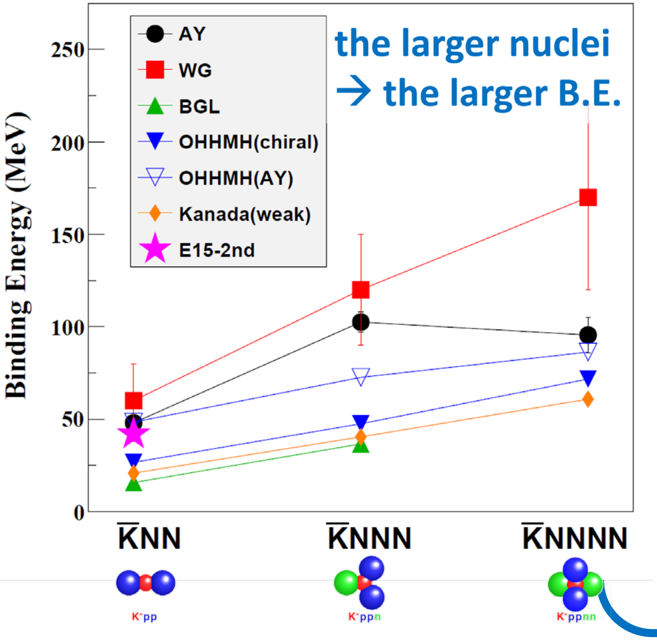


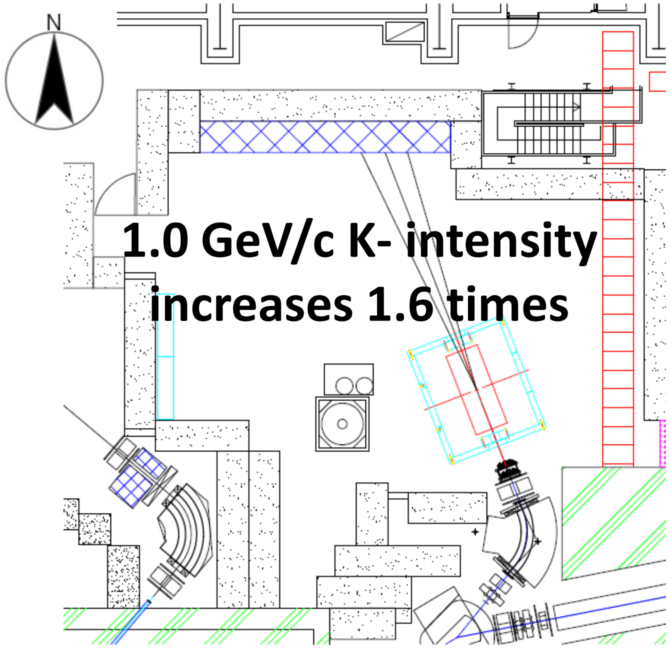
✓Solid angle: x1.6
✓Neutron eff.: x7

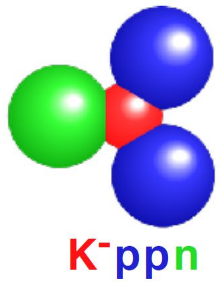




	Reaction	Decays
$\bar{K}N$	d(K⁻,n)	$\pi^{\pm 0}\Sigma^{\mp 0}$
$\bar{K}NN$	^{3}He(K⁻,N)	Λp/Λn
$\bar{K}NNN$	^{4}He(K⁻,N)	Λd/Λpn **E80** ← first step
$\bar{K}NNNN$	^{6}Li(K⁻,d)	Λt/Λdn
$\bar{K}NNNNN$	^{6}Li(K⁻,N)	Λα/Λdd/Λdpn
$\bar{K}NNNNNN$	^{7}Li(K⁻,N)	Λαn/Λddn
$\bar{K}\bar{K}NN$	*$\bar{p} + {}^3He$*	*ΛΛ*







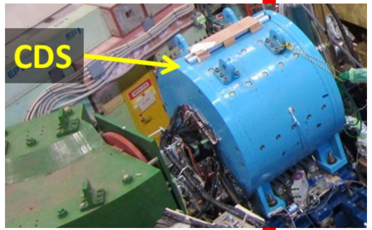
a first step of the systematic investigation

$\bar{K}NNN$ @ E80

via ^{4}He(1 GeV/c K^-, n) reaction

① Establish the existence of $\bar{K}NNN$

- "K-ppn"→Λd 2-body decay

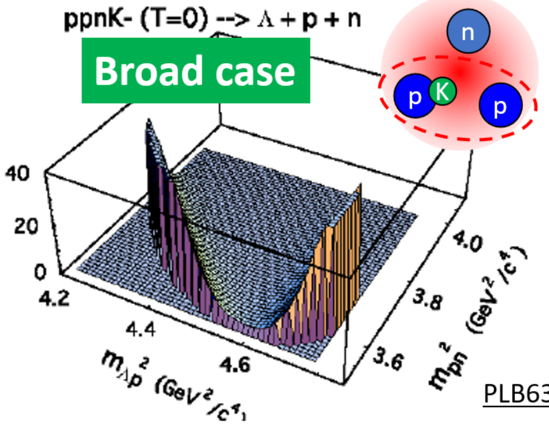


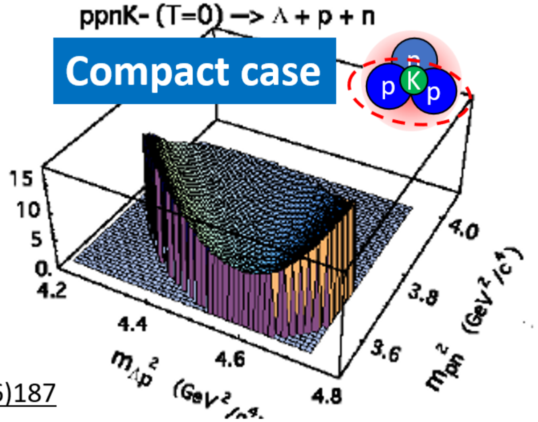
② Study the multi-particle decay mode of $\bar{K}NNN$ toward understanding its internal structure

- "K-ppn"→Λpn 3-body decay

Paul Kienle[a,b], Yoshinori Akaishi[c,d], Toshimitsu Yamazaki[d,e,*]

Utilize Dalitz plots → Differences in distribution

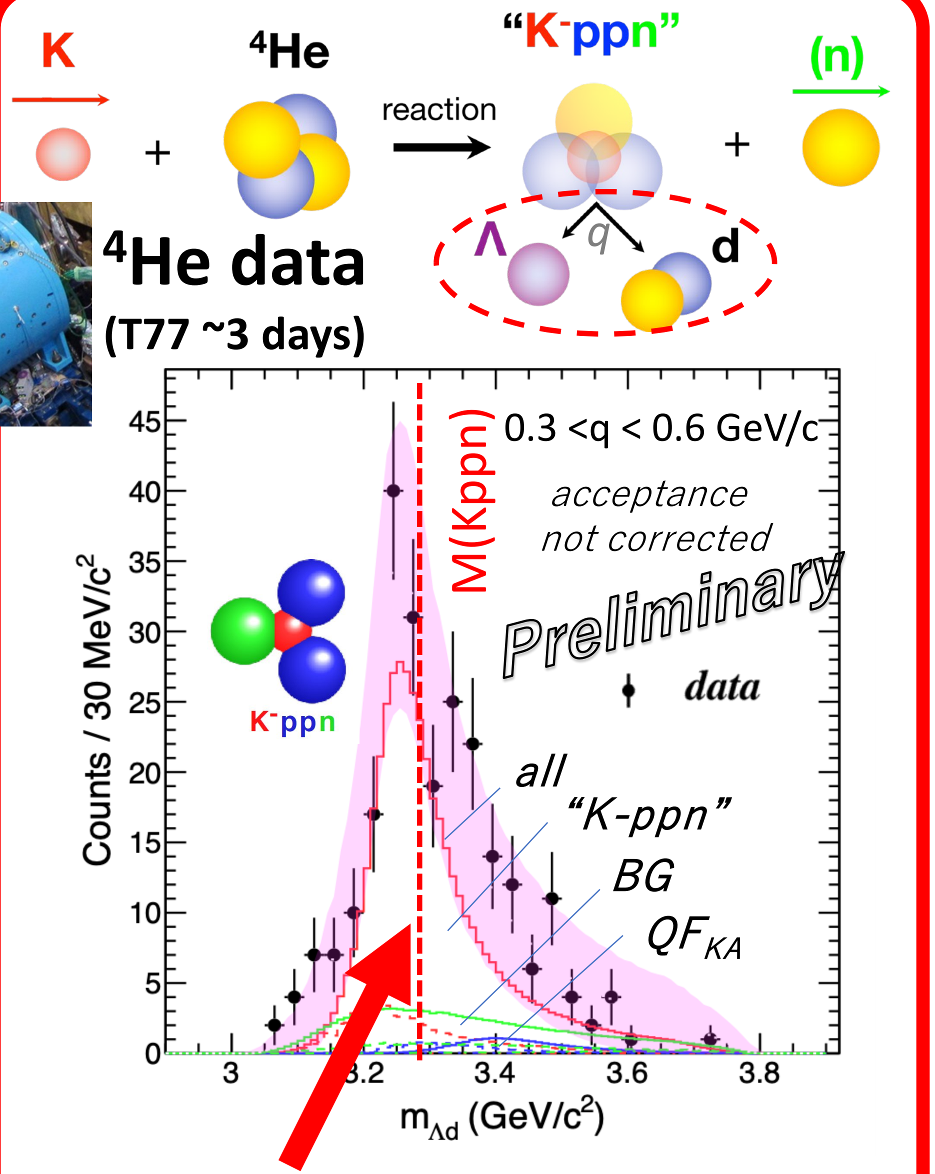




PLB632(2006)187

Distributed in parts of the plane
- 1 nucleon has the Fermi momentum

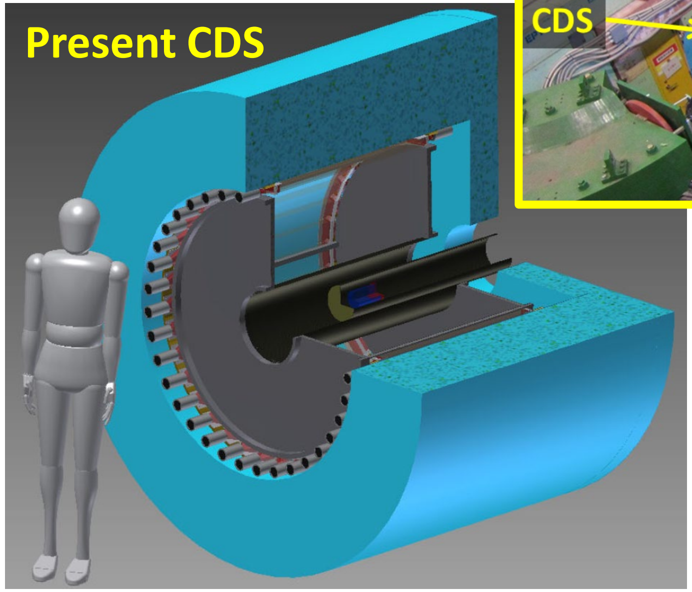
Widely distributed in the plane
- All particles have a momentum larger than the Fermi momentum

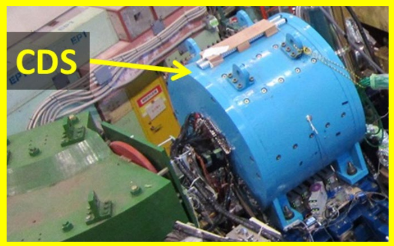


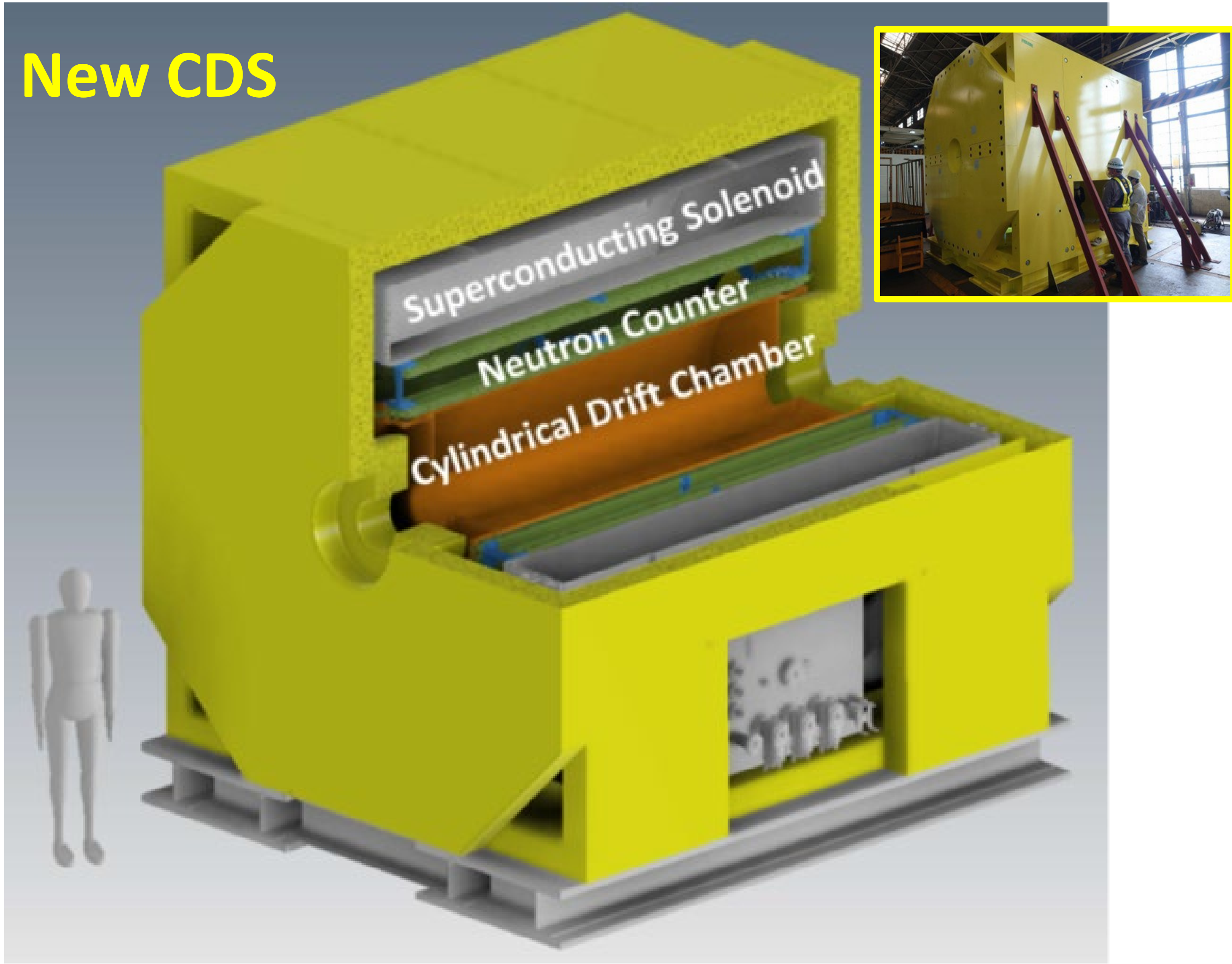
the sign of the "K⁻ppn"

Preparation Status

New Cylindrical Detector System (CDS)







✓**Solid angle: x1.6** (59% → 93%)

✓**Neutron eff.: x7** (3% → 12%x1.6)

Superconducting Solenoid Magnet

- Completed and stored at KEK Tsukuba Campus

- A three-year construction project

Mar. 14, 2025 @ KEK-Tsukuba

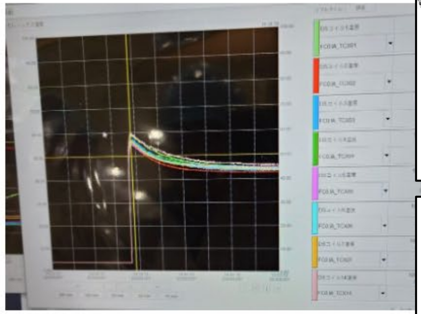
Superconducting Solenoid Magnet

- "Qualification test" and "magnetic field measurement" at TOSHIBA w/o the return yoke (2025 Feb.)

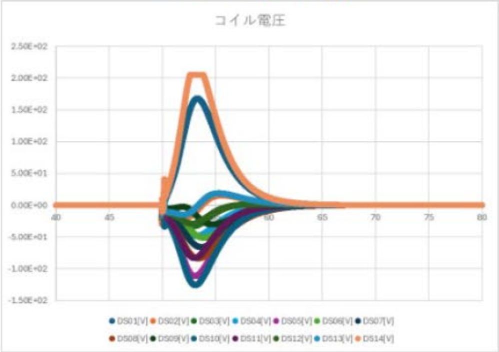
Power Shutdown (Quench) Test on Feb.3-7

- at rated 189A
  - Coil temperature: max. 60 K
  - Total coil voltage (between both ends): max. 262 V
  - Time constant: 3.6s (magnetic field * 1/e)

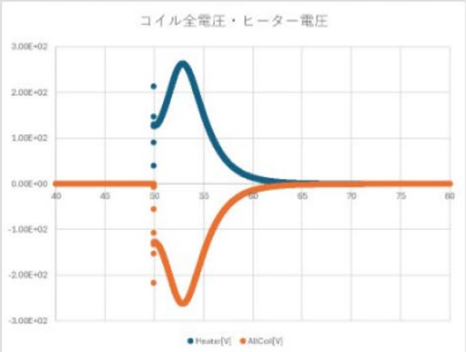
worked as designed



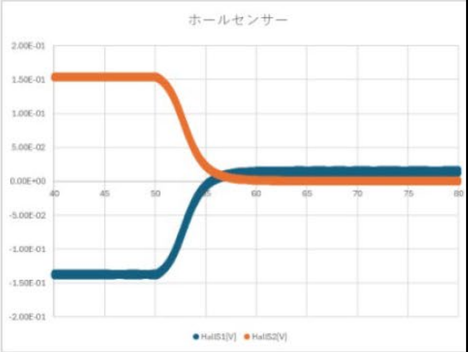
each coil voltage



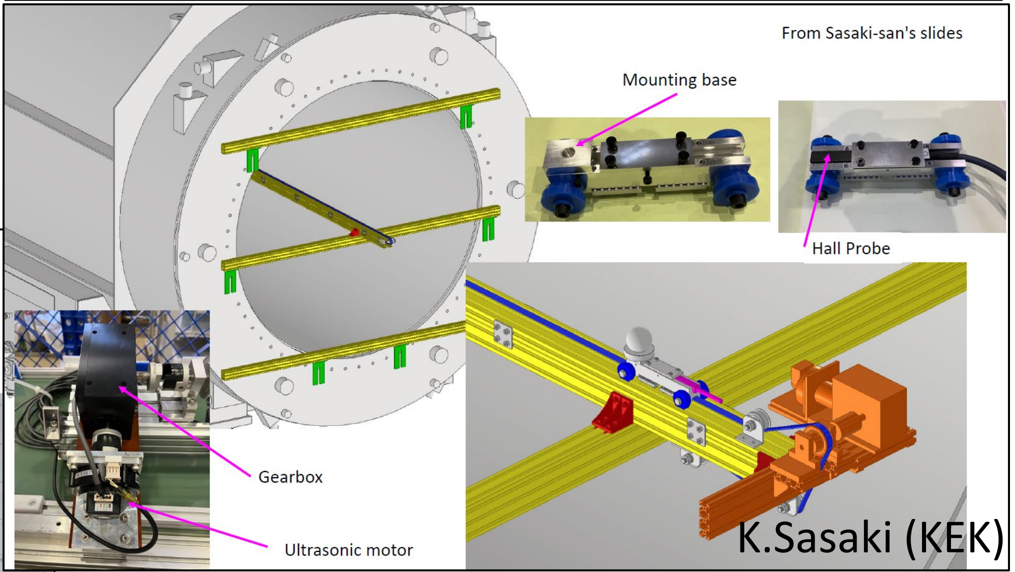
total coil voltage, heater voltage

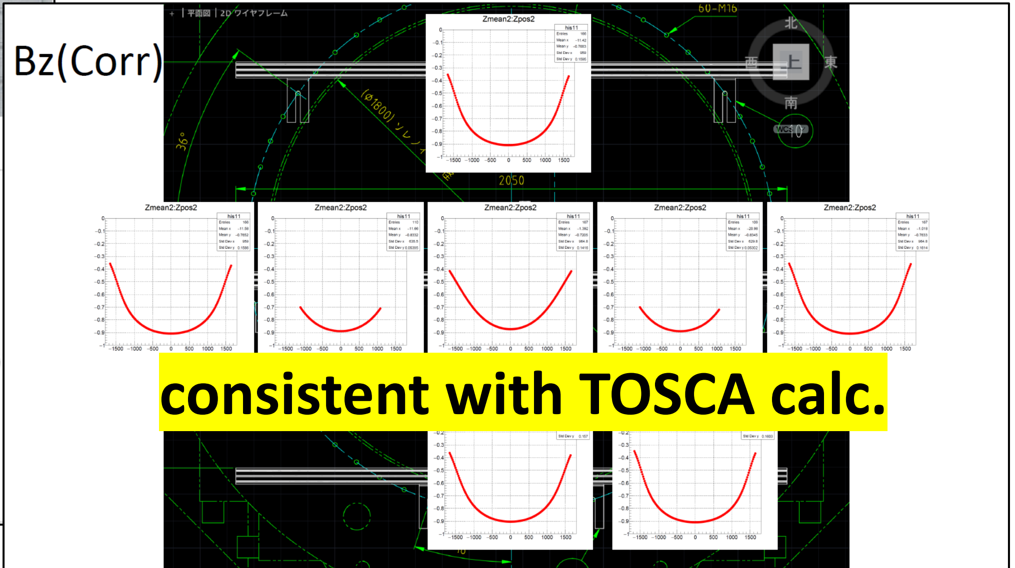


hall sensor



Magnetic Filed Measurement on Feb.12-14

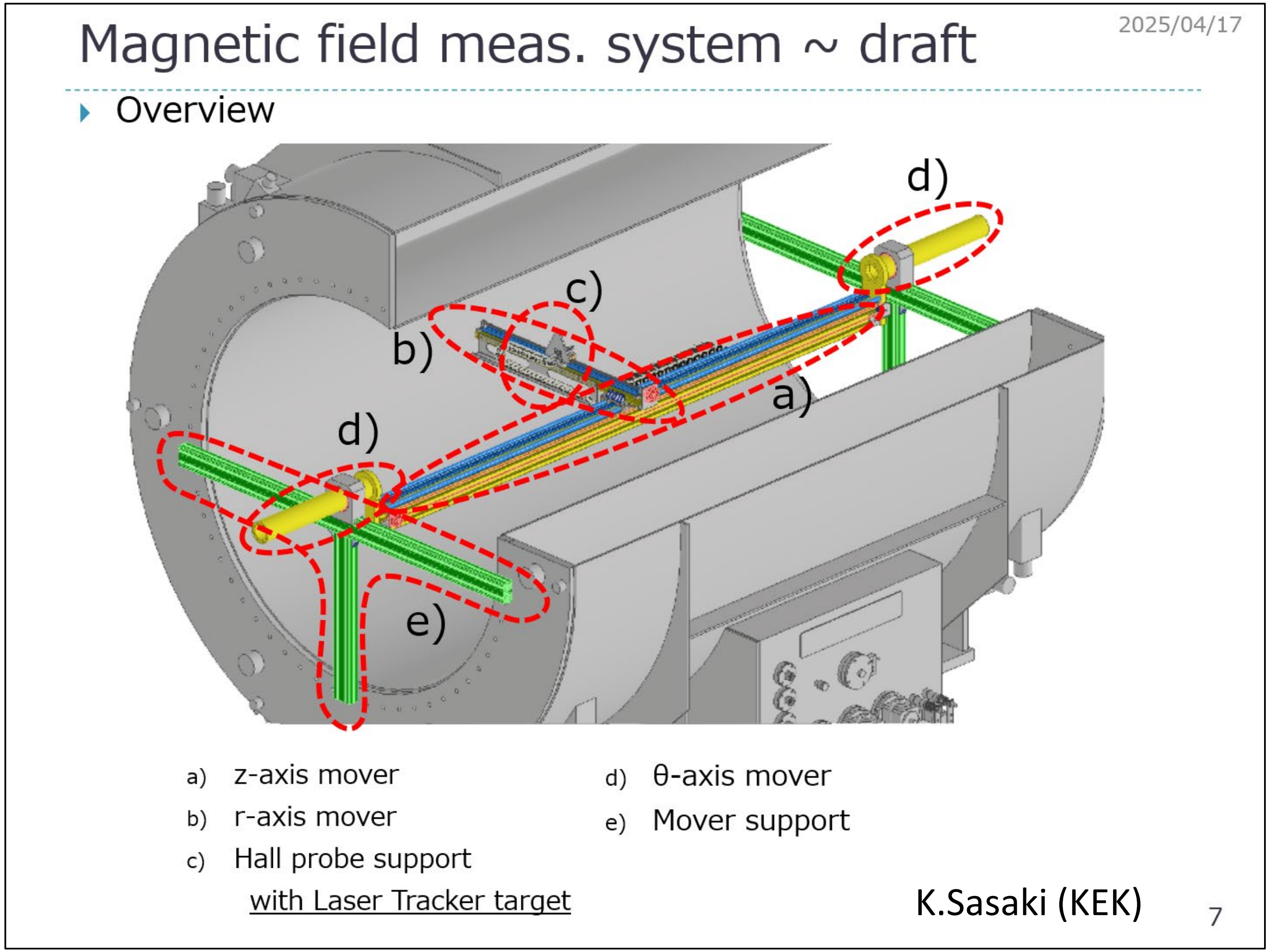




consistent with TOSCA calc.

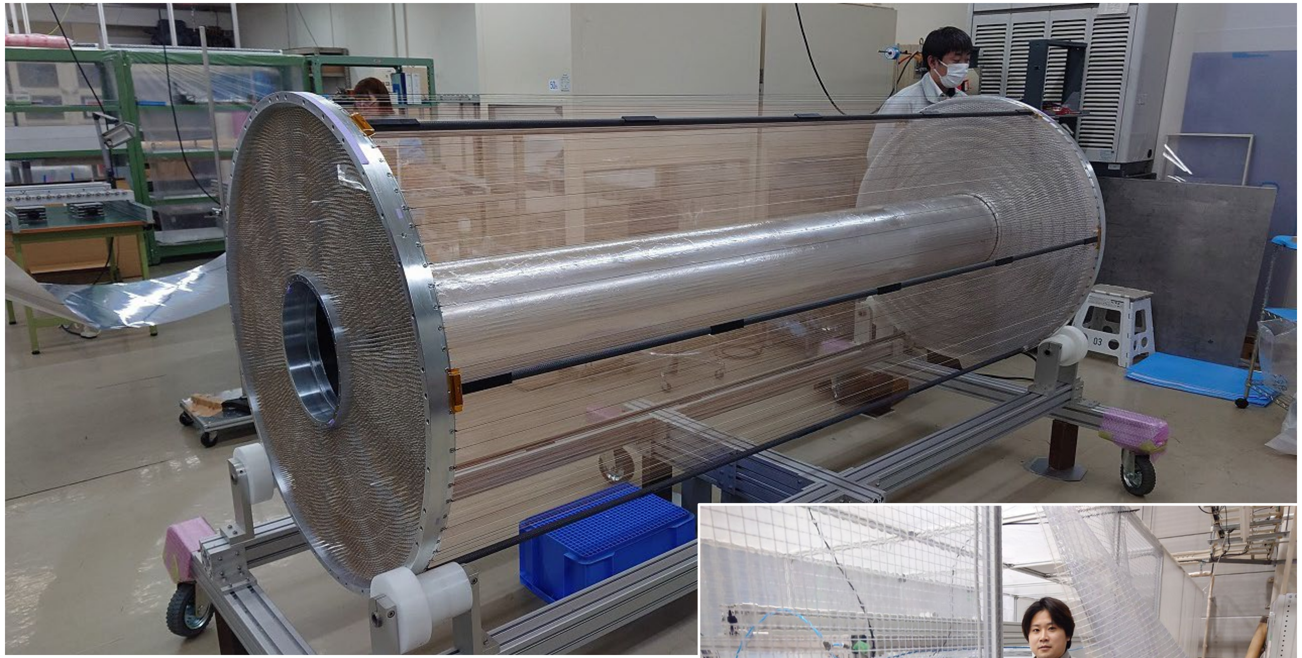
Superconducting Solenoid Magnet

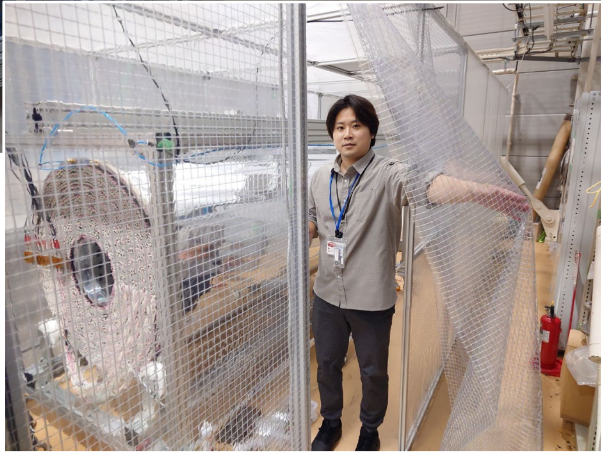
- **Preparing magnetic field measurement**
  - 3D measurement using 3-axis movable mechanism
- The basic design is the same as that of the COMET
  - Design work is ongoing in collaboration with the COMET Group
- Schedule:
  - Test the moving components this summer
  - Magnetic field measurement with return yoke at K1.8BR in autumn 2026



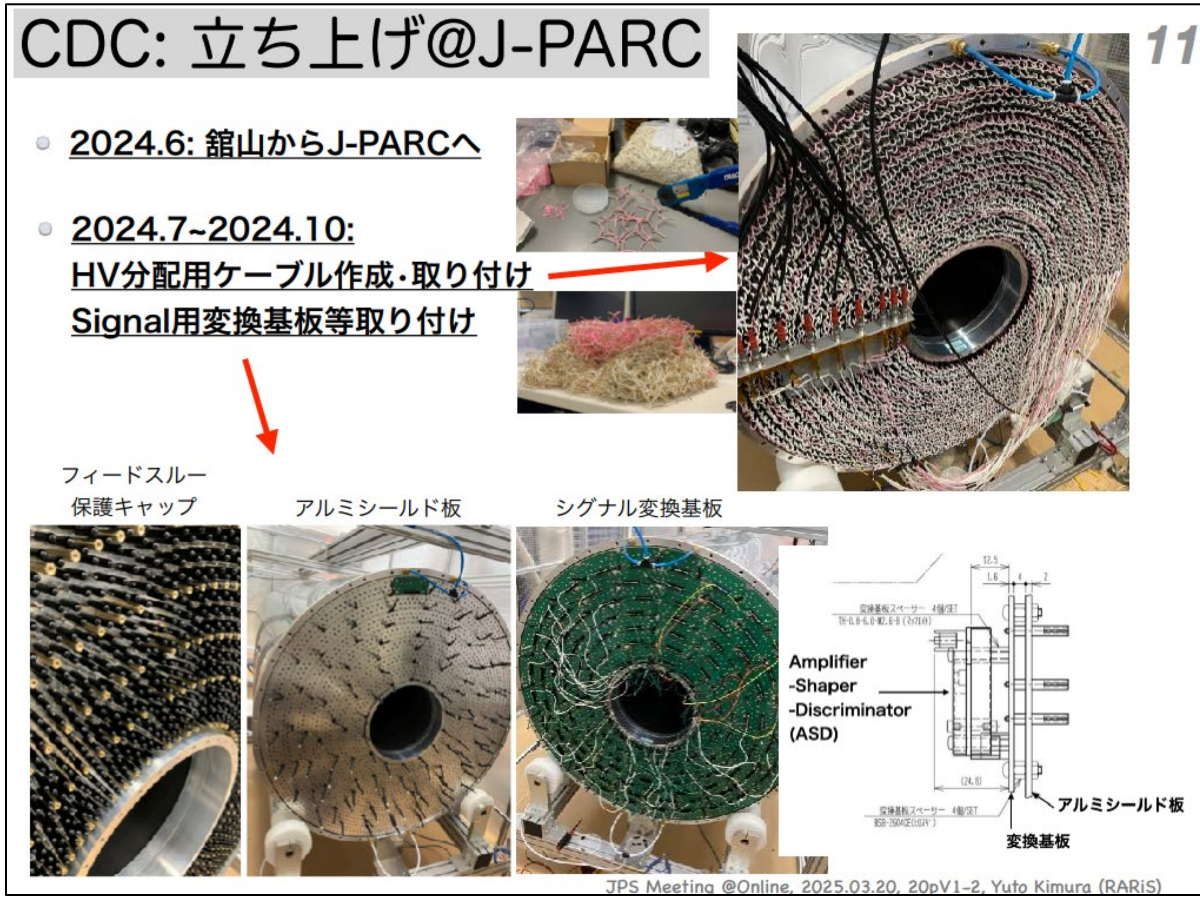
Cylindrical Drift Chamber (CDC)

- Completed and proceeded with commissioning at J-PARC





→ Y.Kimura, Master thesis
(2025 Mar, Tohoku-U)



Y.Kimura (Tohoku)

Cylindrical Drift Chamber (CDC)

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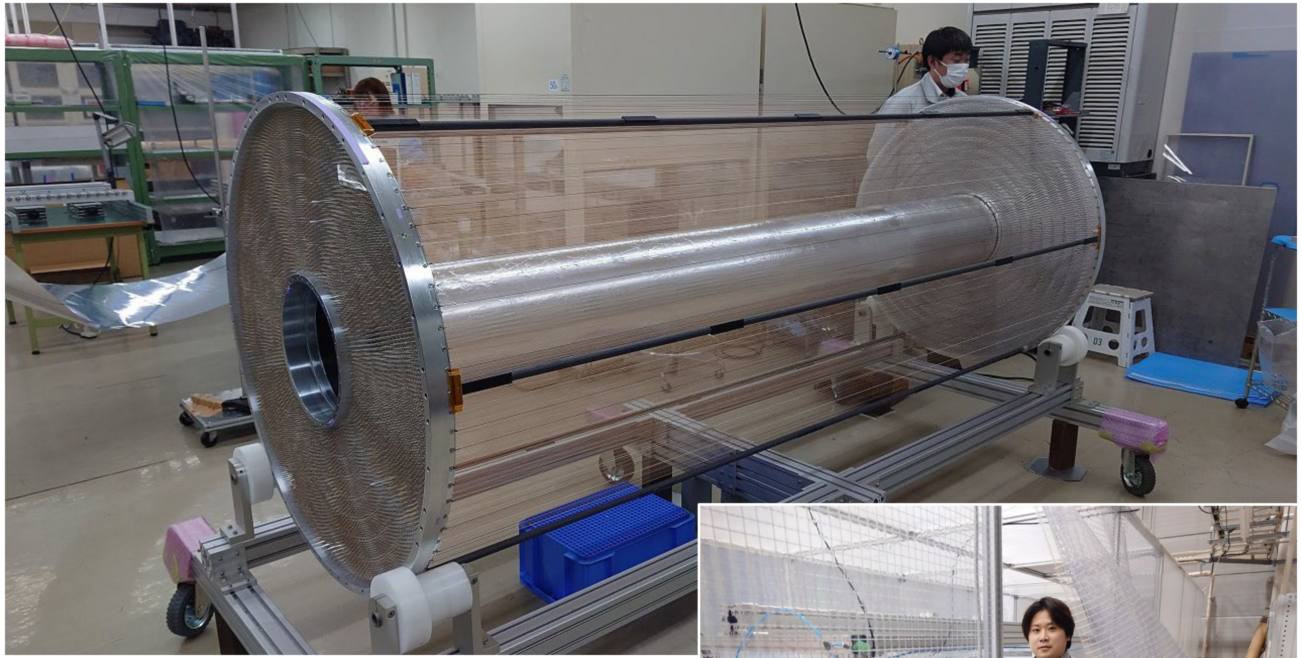
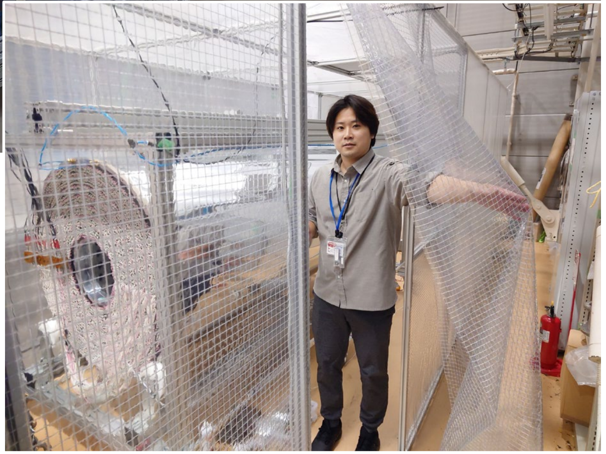
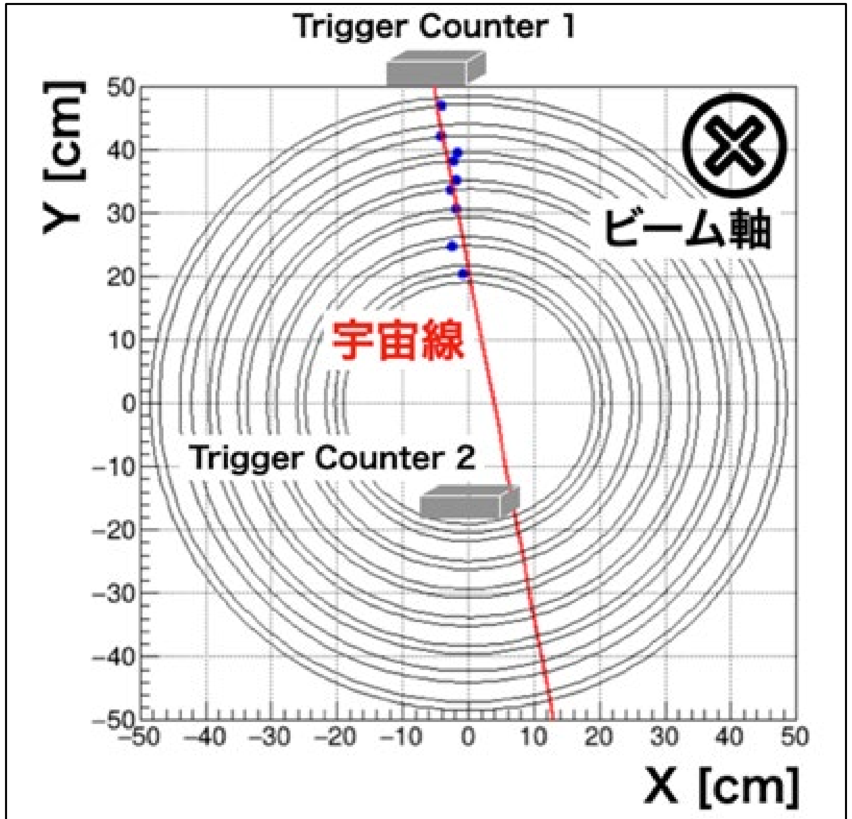




→ Y.Kimura, Master thesis (2025 Mar, Tohoku-U)

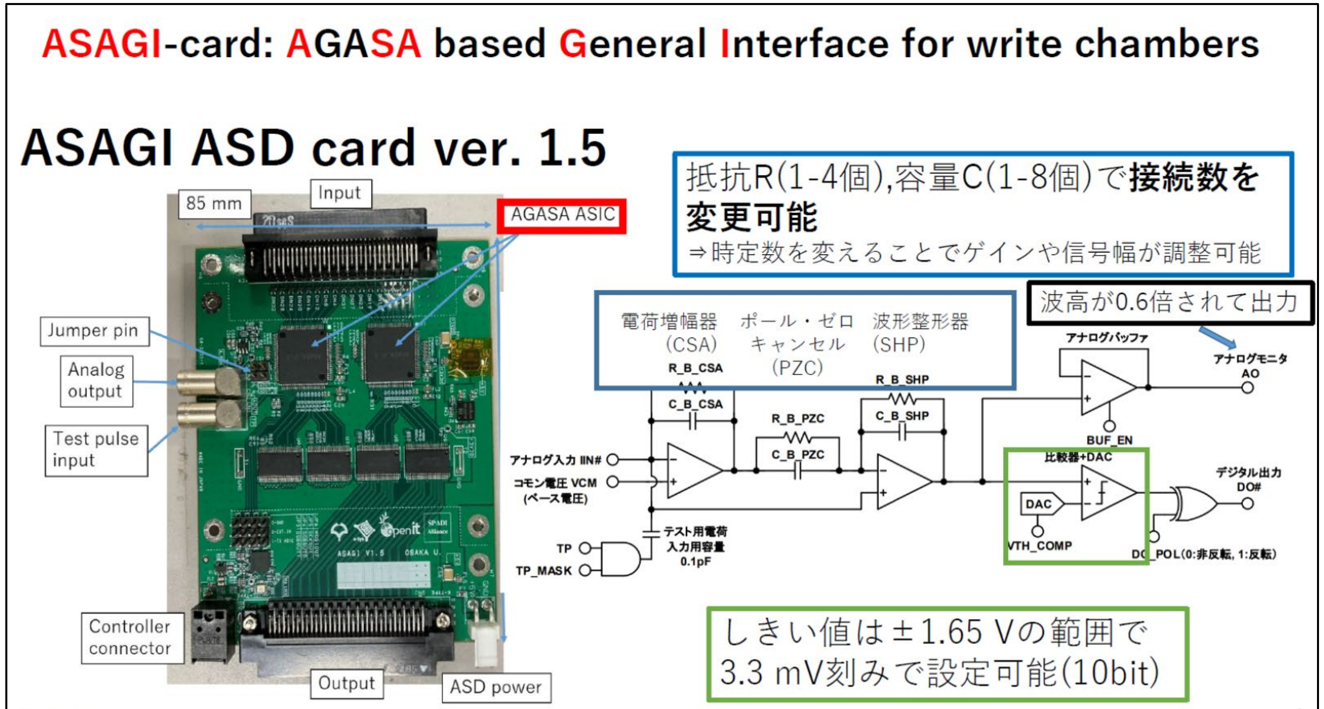
- **Commissioning is proceeding using the existing readout system**



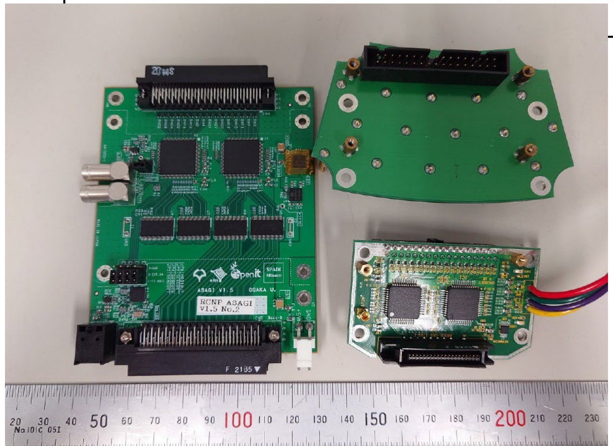
Cylindrical Drift Chamber (CDC)

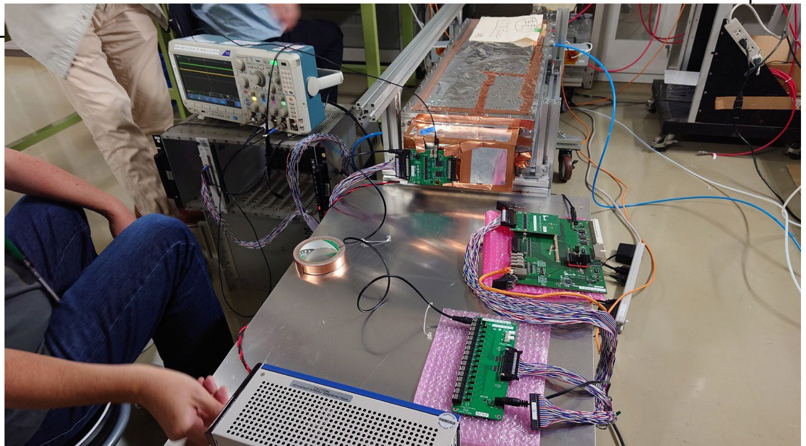
K.Shirotori (RCNP)

- **Developing a new preamp card - ASAGI - in cooperation with SPADI/E50/NEOLITH**
  - Variable time constant and gain
  - New version of ASIC, AGASA v3.0, is currently under design
  - A new preamp card with the same dimensions as the current one is also being designed



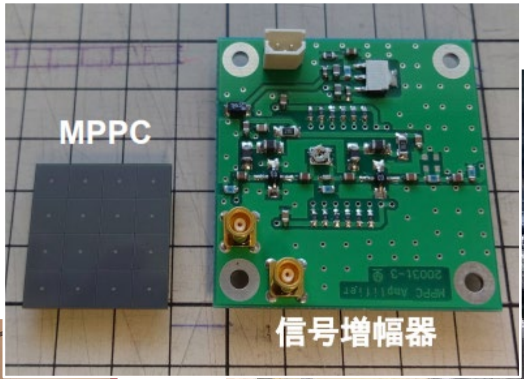
- ASAGI schedule:
  - Completed in JFY2025
  - Mass production in early JFY2026

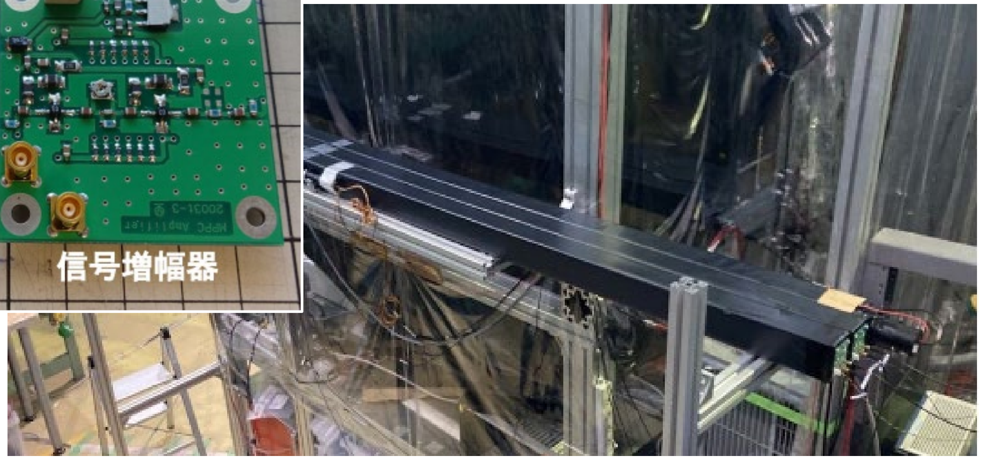


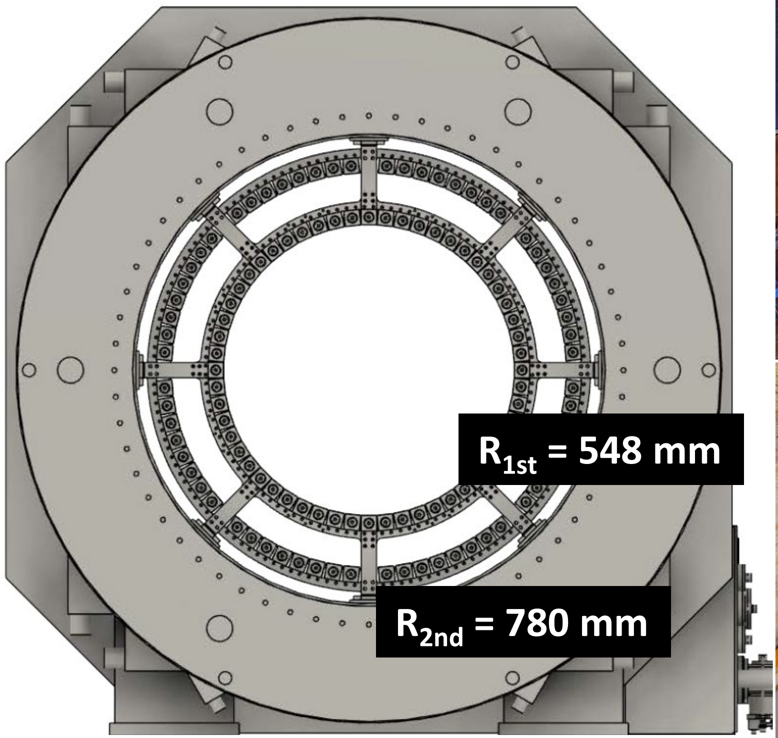


Cylindrical Neutron Counter (CNC)

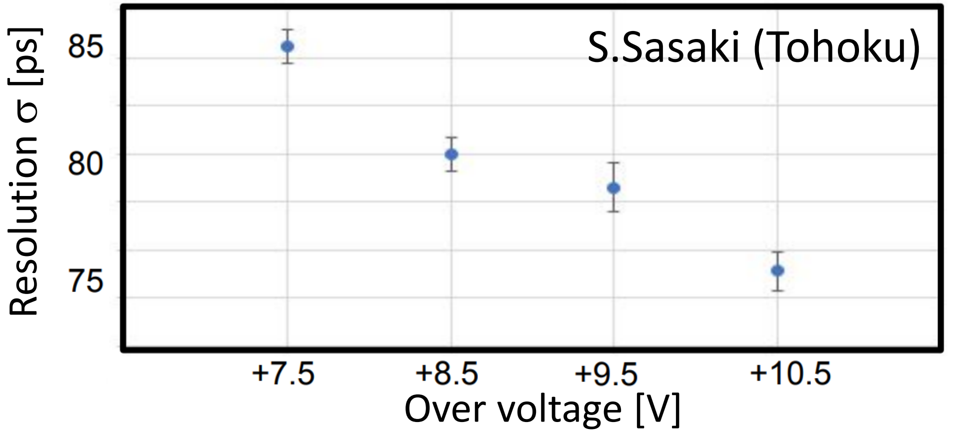
- Scintillators and MPPCs have been purchased
- R&D work for the readout is ongoing
- Ready in early JFY2026







Bias-voltage dependence of time resolution



The required performance has been achieved:

σ_{CNC} ~ 80ps @ V_{OV} ~ +9V

K1.8BR Upgrade

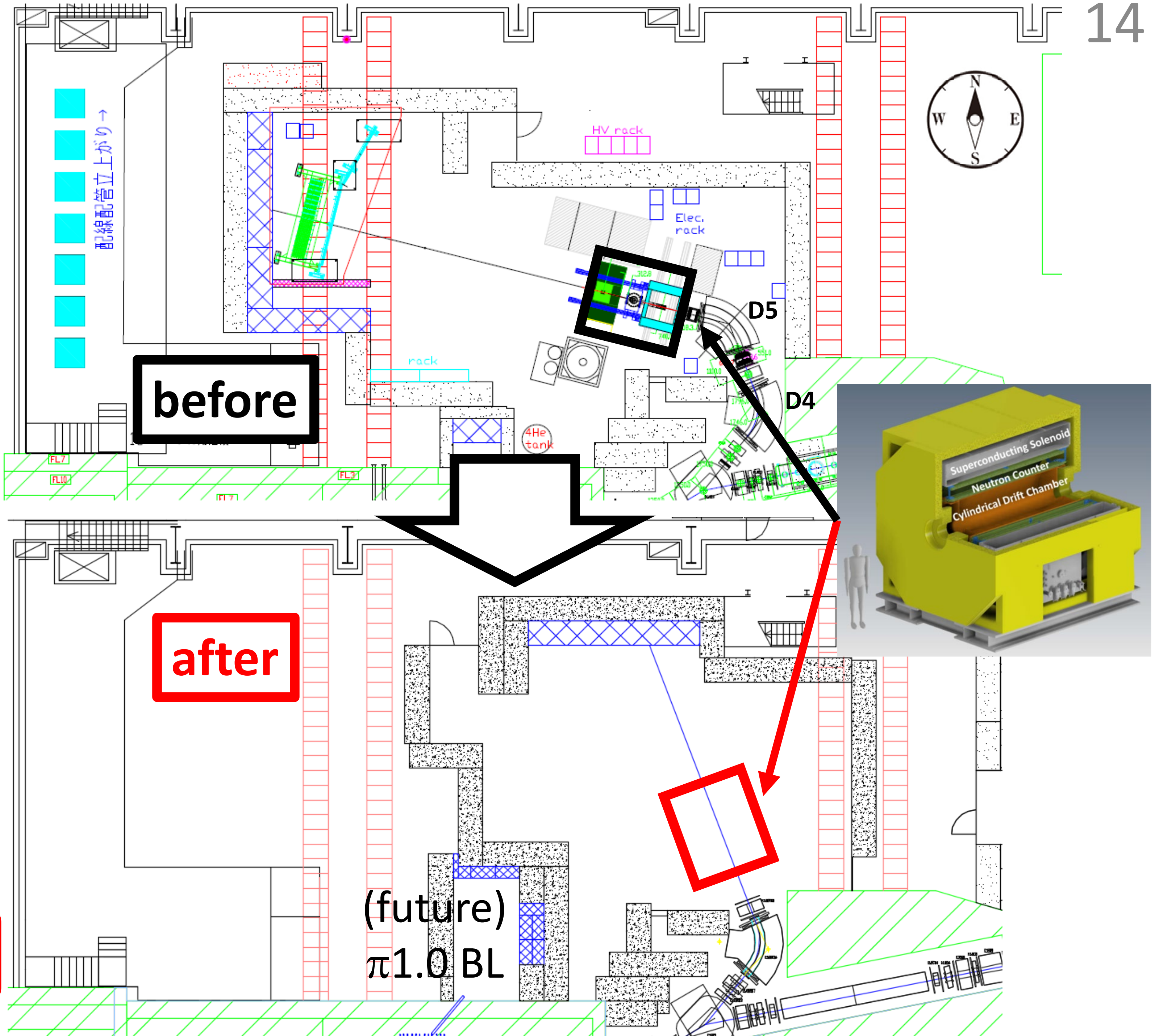
- We have proposed a new configuration of the beam line

Shorten the beamline (~3.7m)
by removing the final D5 magnet

➢**1.0 GeV/c K^- intensity increases 1.6 times**

with $\pi/K \sim 2$

Relative beam-line length (beam yield)	D4+D5	D4
Present CDS	0 (x1)	-3.7m (x1.6)
New CDS	+1.2m (x0.9)	**-2.5m (x1.4)**



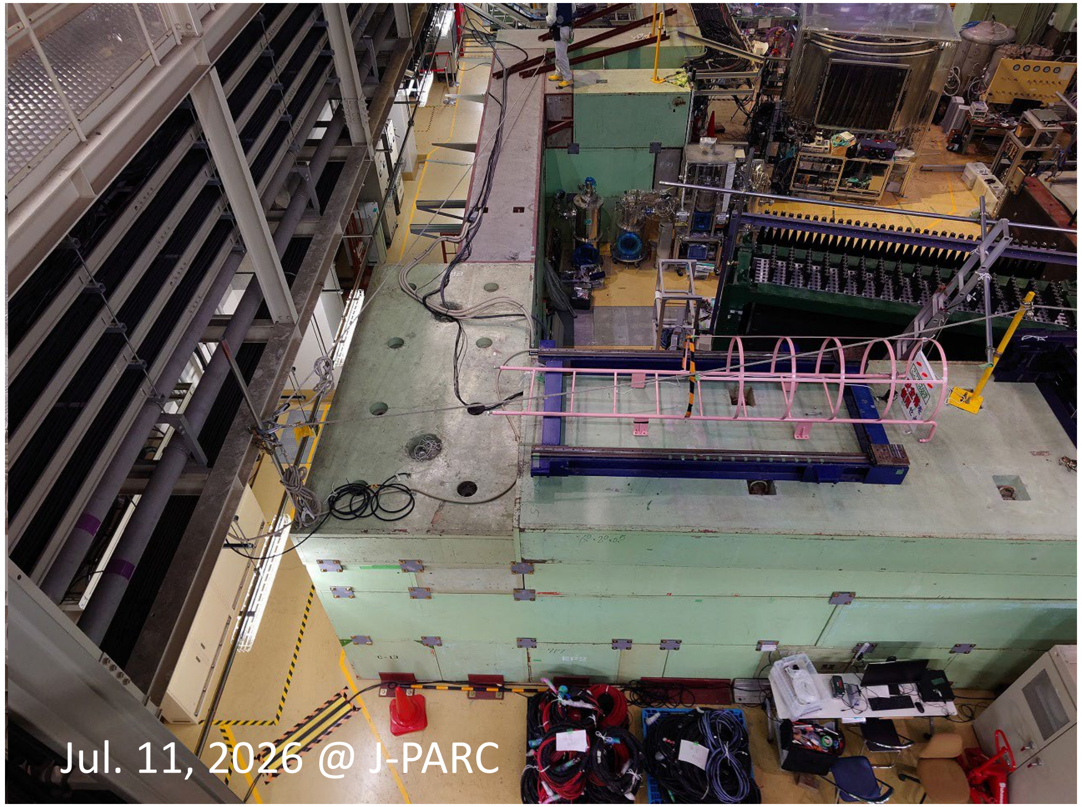
K1.8BR Upgrade

- **The design has been finalized in collaboration with the Hadron Group**
- Cable removal work for the upgrade will be completed this month
- Application for the area modification will be submitted to the Nuclear Regulation Authority (原子力規制委員会) this autumn

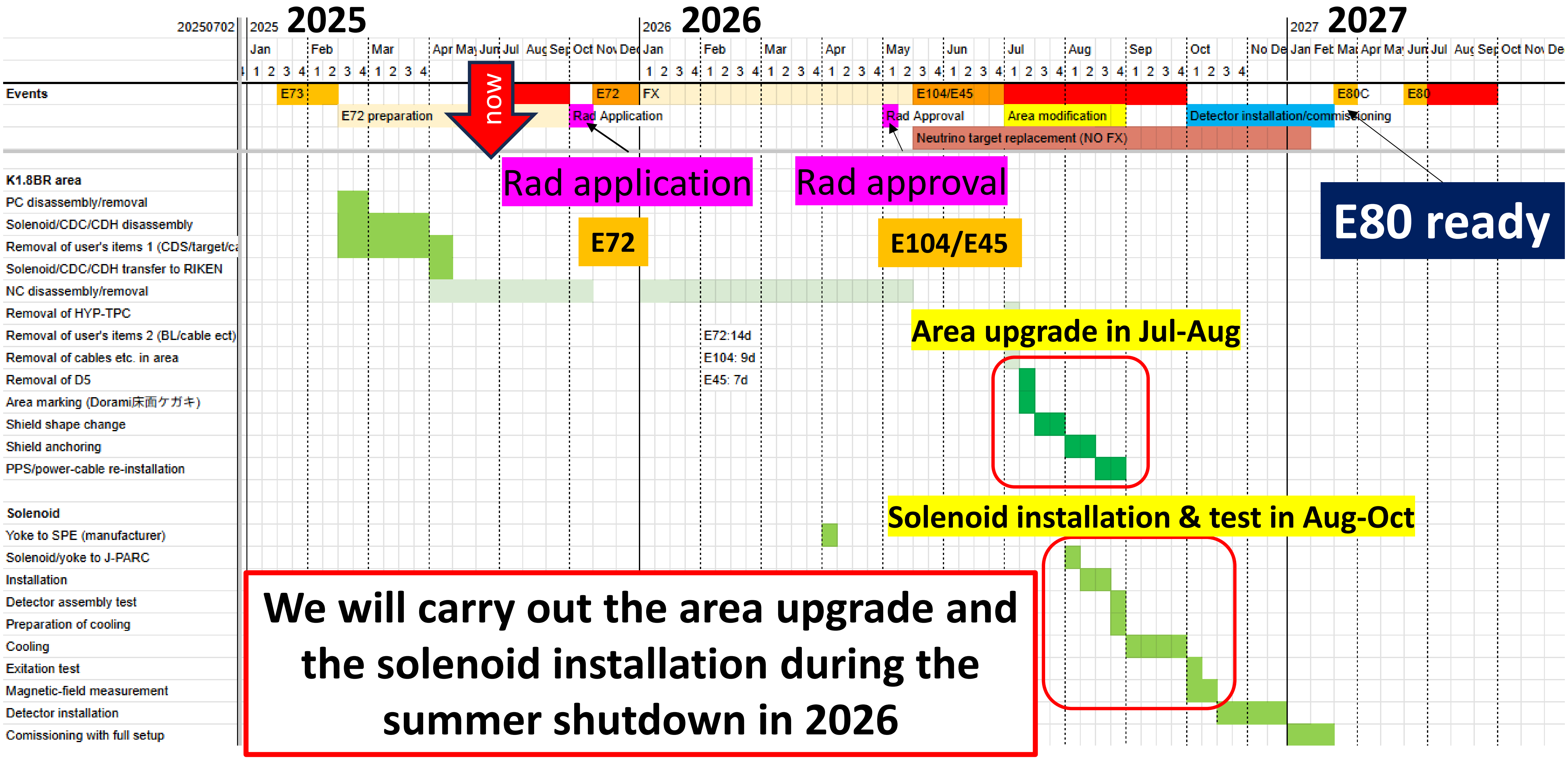
Estimated Cost of the K1.8BR Modification

We are currently working to reduce the cost further, but we hope it will be covered by the facility budget.

Item	Cost (k JPY)
Cable removal	~~3,000~~ →0
Shield reconfiguration	7,000
D5 removal	1,000
PPS and other interlocks rearrangement	5,000
total	**~~16,000~~** →13,000



Expected Timeline

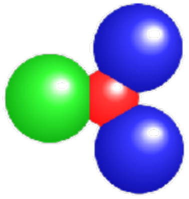


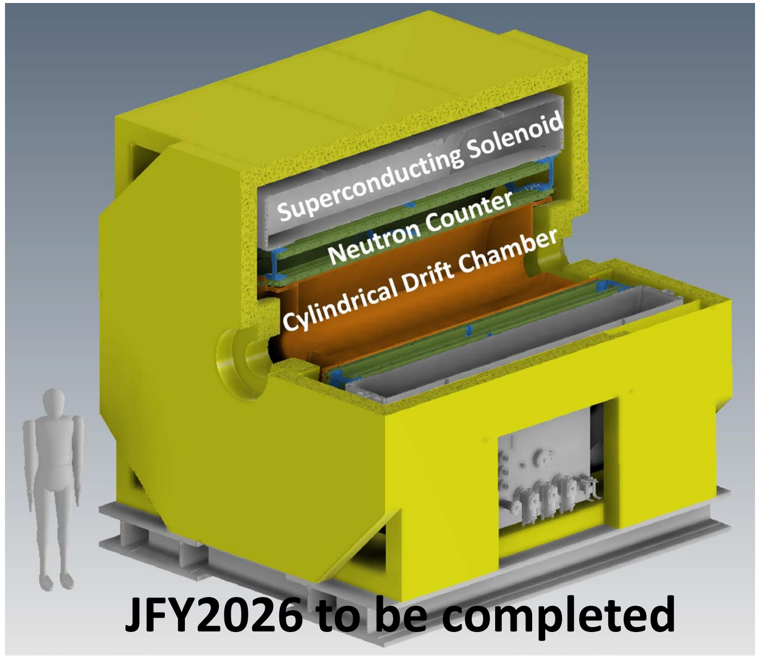
Summary

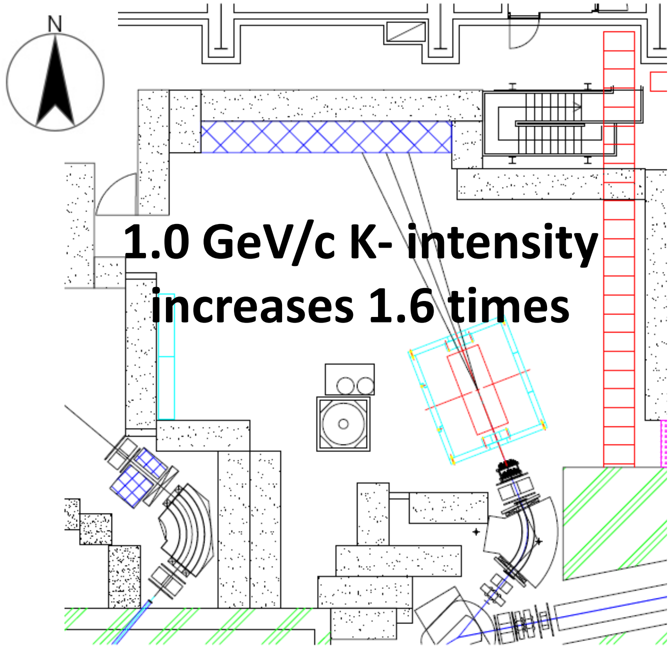
E80 investigates the **"K⁻ppn"** bound state as a first step toward the systematic study of kaonic nuclei

- The large solenoid spectrometer is under construction
  - the SC magnet, the CDC, and the CNC will be ready in JFY2026
- Preparation for the K1.8BR upgrade is in progress
  - the upgrade is expected to take place during the summer shutdown in 2026

Beam intensity	90kW
Beam time	1+1+3 weeks







The experiment will be ready in JFY2026

J-PARC E80 Collaboration

M. Iwasaki, T. Hashimoto, Y. Ma, R. Murayama, F. Sakuma[1]
RIKEN, Saitama, 351-0198, Japan

T. Akaishi, K. Inoue, S. Kawasaki, T. Kishimoto, T. Nagae, H. Noumi, K. Shirotori, K. Suzuki
Research Center for Nuclear Physics (RCNP), Osaka University, Osaka, 567-0047, Japan

Y. Kimura, G. Kojima, H. Ohnishi, S. Sasaki, K. Toho, M. Tsuruta
Research Center for Accelerator and Radioisotope Science (RARiS), Tohoku University, Sendai, 982-0826, Japan

M. Iio, S. Ishimoto, Y. Makida, H. Ohhata, M. Oonaka, K. Ozawa, K. Sasaki, N. Sumi, S. Suzuki, T. Yamaga, M. Yoshida
High Energy Accelerator Research Organization (KEK), Ibaraki, 305-0801, Japan

K. Tanida
Japan Atomic Energy Agency (JAEA), Ibaraki 319-1195, Japan

H. Fujioka
Institute of Science Tokyo, Tokyo, 152-8551, Japan

S. Okada
Chubu University, Aichi, 487-0027, Japan

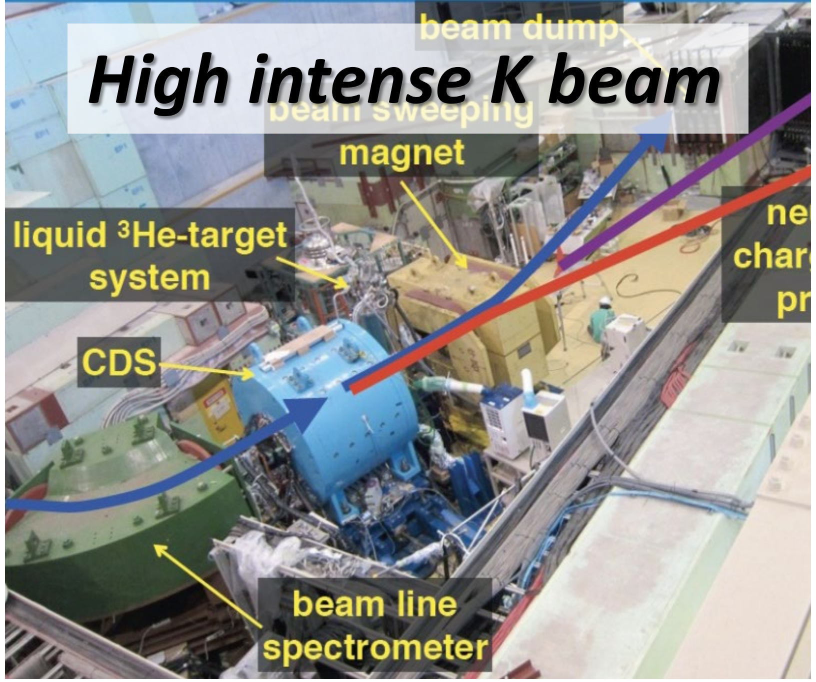
T. Nanamura
Tohoku University, Miyagi, 980-8578, Japan

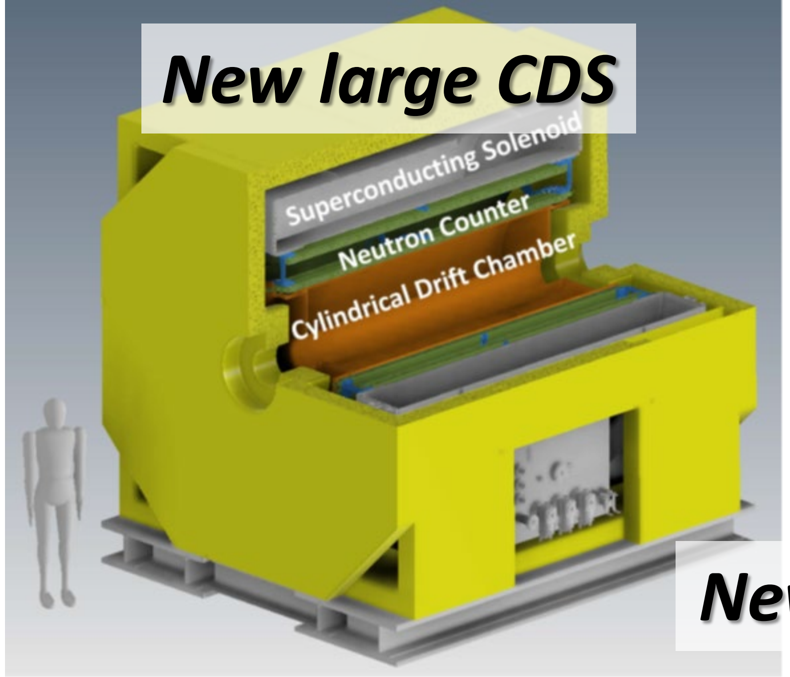
M. Fujita, S. Nagao, S.N. Nakamura, Y. Tsutsumi
The University of Tokyo, Tokyo, 113-8654, Japan

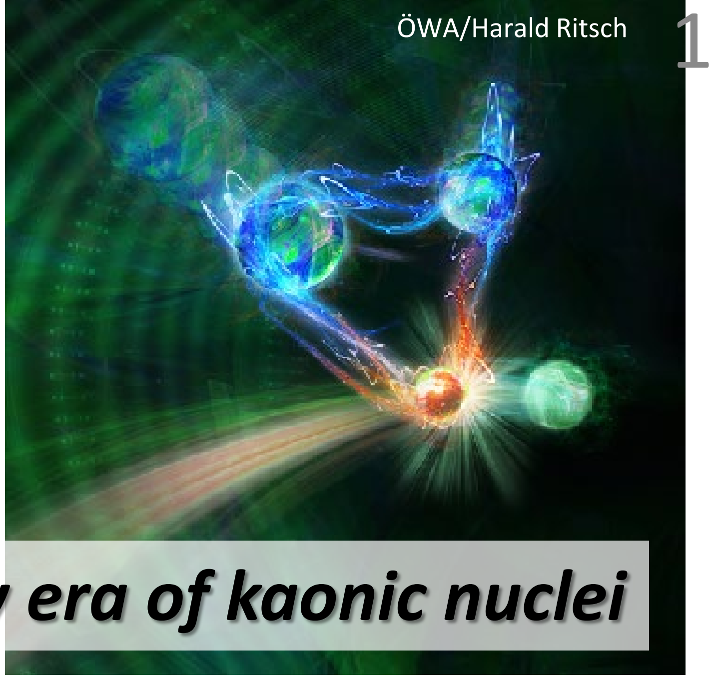
K. Itahashi
Osaka University, Osaka, 565-0871, Japan

M. Bazzi, A. Clozza, C. Curceanu, M. Iliescu, S. Manti, A. Scordo, F. Sgaramella, D. Sirghi, F. Sirghi
Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy

P. Buehler, E. Widmann
Stefan-Meyer-Institut für subatomare Physik, A-1090 Vienna, Austria

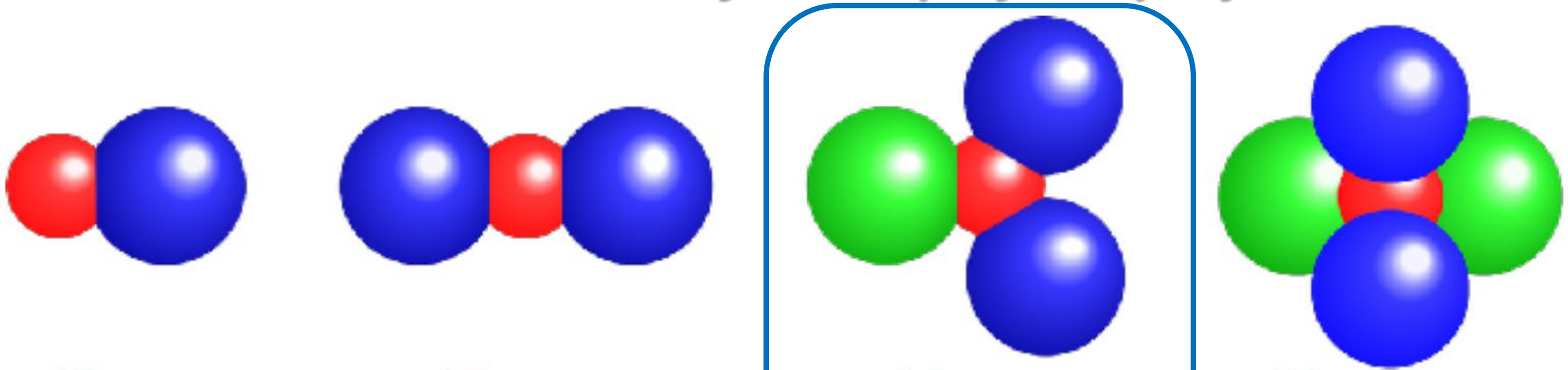






Thank you for your attention!

A first step of the project



K^-p K^-pp K^-ppn K^-ppnn

via in-flight $^{4}He(K^{-},N)$

Experiments @ K1.8BR

- **Dora CDS**
  - ✓E73 ($^{3}_{\Lambda}$H lifetime) Completed in Feb. 2025

now

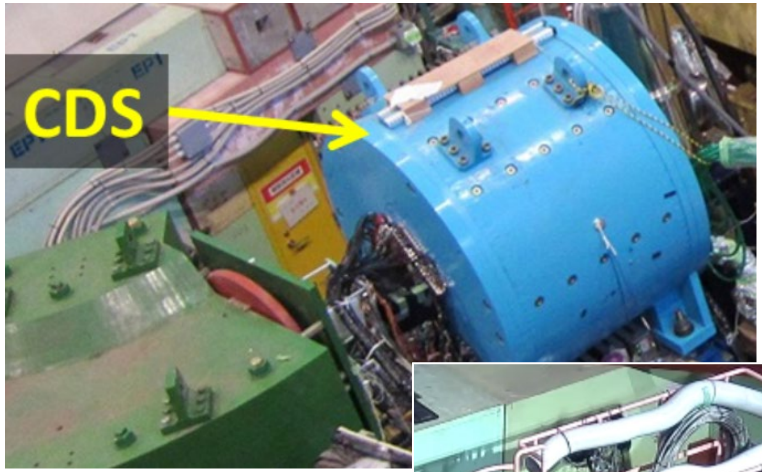
need 9 months

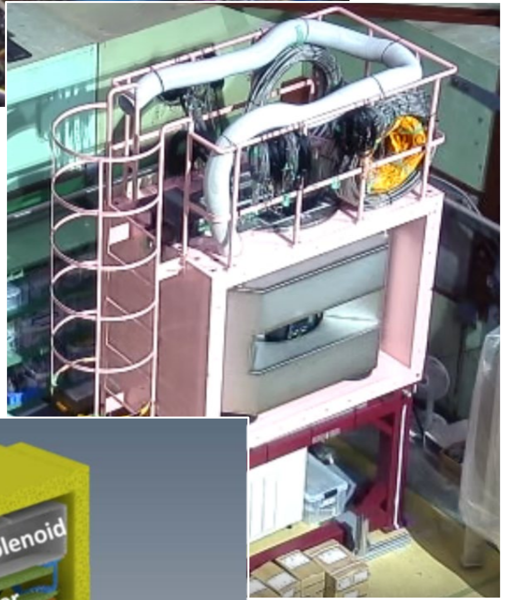
- **Hyp-TPC**
  - ✓E72 (Λ*) 7(+6)d@90kW
  - ✓ P109 (Θ+) 3h
  - ✓E104 ($p^{bar}p \rightarrow \phi\phi$) 10(+3)d@90W
  - ✓E45 (Baryons) 2.5+2+2.5(+4)d

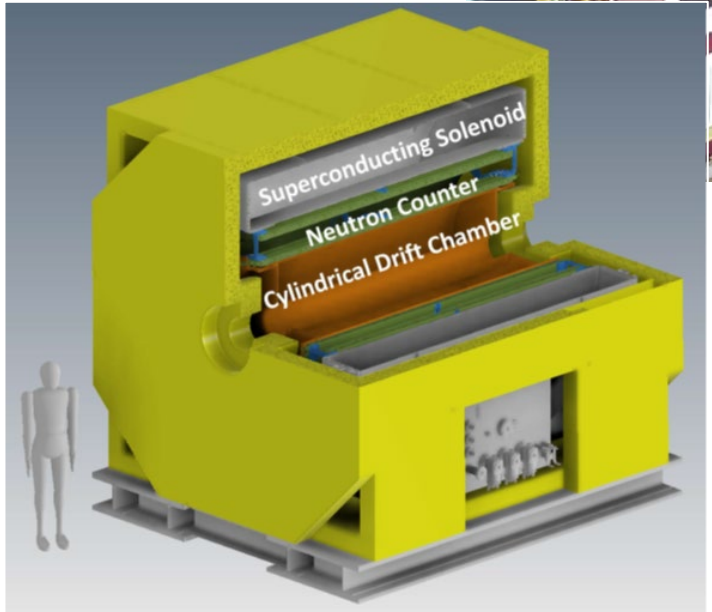
K1.8BR upgrade

need ~9 months

- **Dolami CDS**
  - ✓E80 ($K^{-}ppn \rightarrow \Lambda d/\Lambda pn$) ~14+21d@90kW
  - ✓E89 ($J^{P}(K^{-}pp)$) 56d@90kW
  - ✓E57 ($K^{-}d$ atm) 7d@80kW → ~30d@80kW







Urgency of E80

- Detectors are being completed on schedule

- New K^-d atom results from DAFNE
  - Strong motivation to proceed with $K^{bar}N$ interaction studies at J-PARC as soon as possible

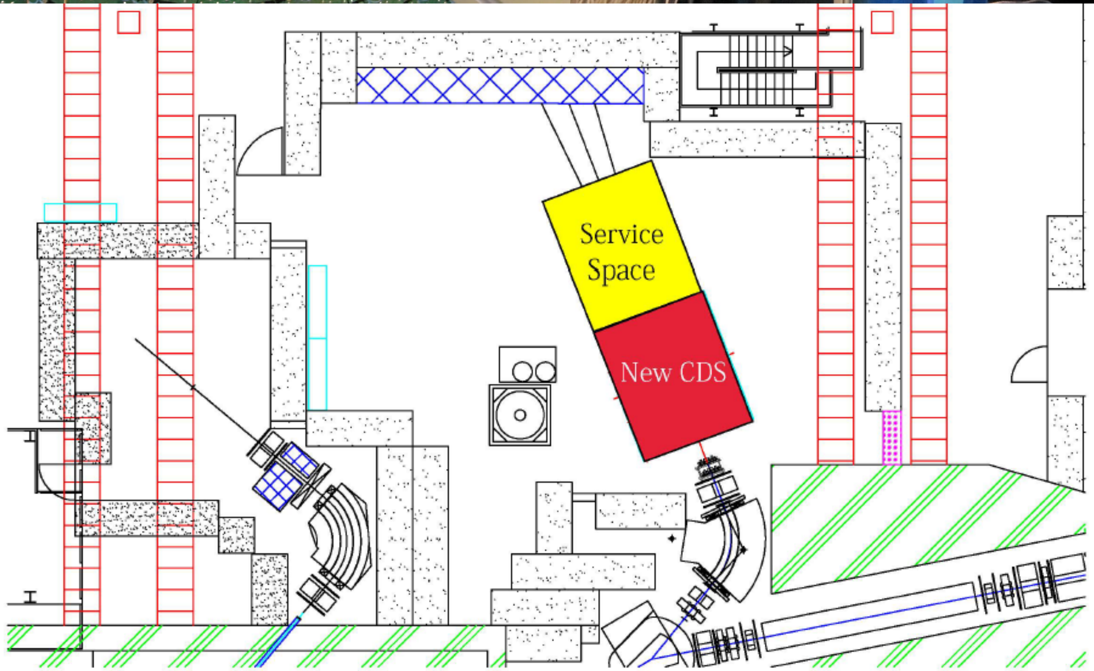
- E80 must begin within the period of the large research grant
  - Grant-In-Aid for Specially Promoted Research by JSPS (JFY2022-26)
  - Magnet assembly at K1.8BR must be completed using this grant
  - Part of the shield reconfiguration cost may be covered in FY2026 using this grant

CDC Installation

- CDC is installed by inserting a long frame bar into the center of the CDC and magnet
  - We plan to use a splittable bar twice the length of the solenoid.

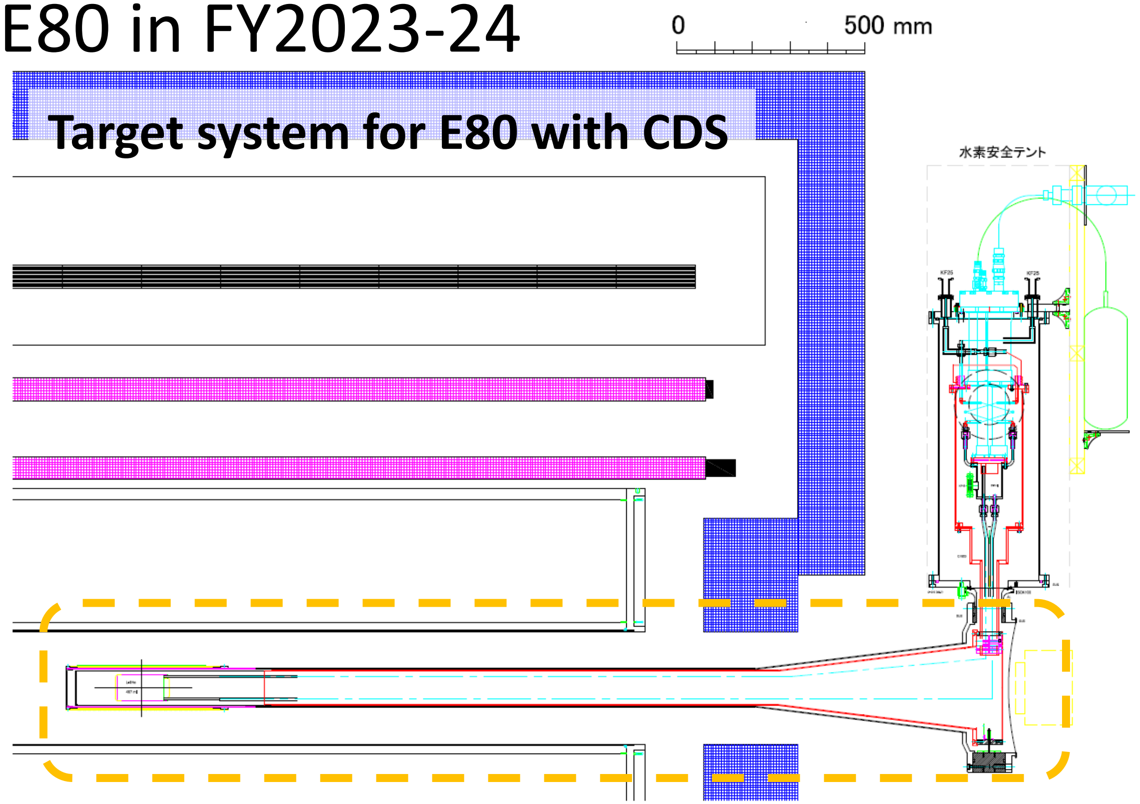
Will be prepared in FY2026

- Service space equivalent to the installation area of the magnet is required downstream of the magnet
  - to prepare and install the CDC by rolling it in and out of the magnet



Target System

- Cool down below 3K with pulse tube (Cryomech PT410), no cryogen required
- Capable to liquefy H_2/D_2/^3He/^4He gasses [Target replacement takes a few days]
- **The system has already worked well (T77/E73)**
- The horizontal part will be extended for E80 in FY2023-24



Expected Spectrum of $K^{-}+^{4}He$

@ 3 weeks, 90kW

$K^{-}+^{4}He \rightarrow \Lambda d+n$

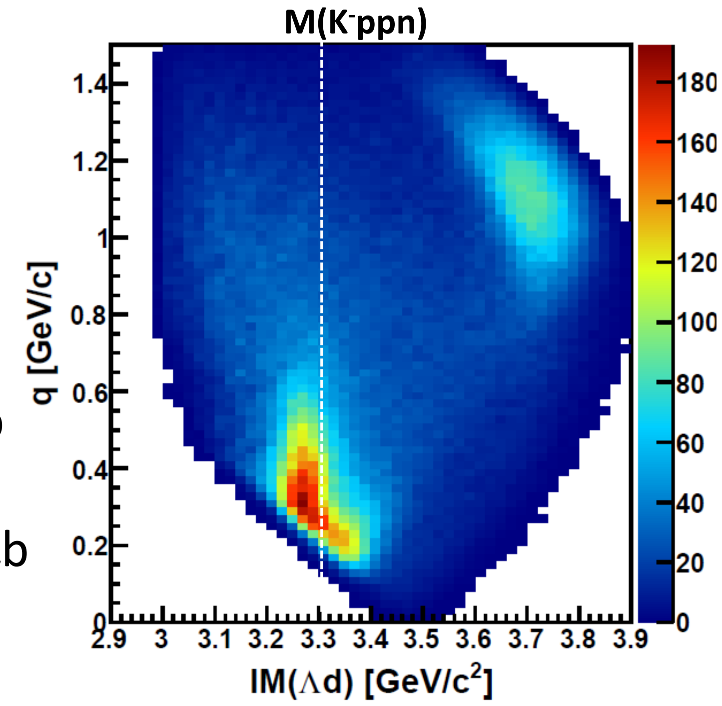
$K^{-}+^{4}He \rightarrow \Lambda pn+n$

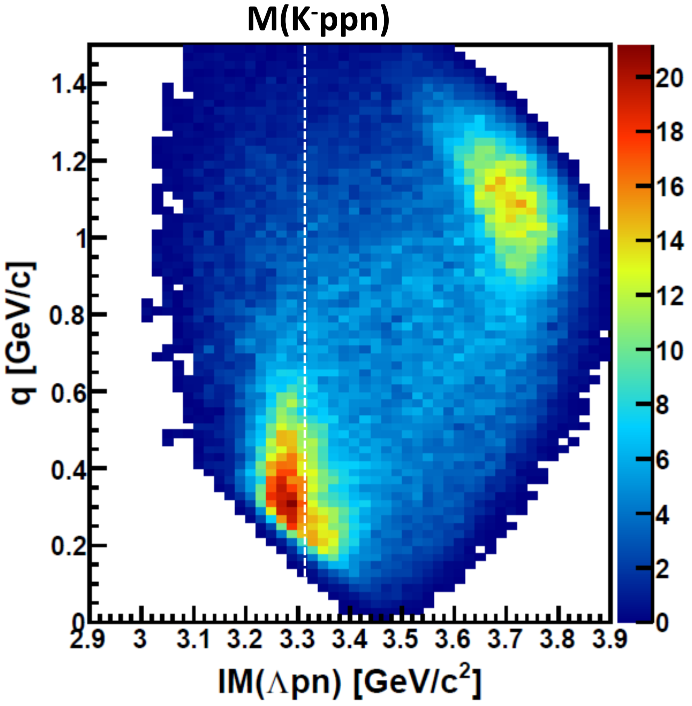
B_{Kppn} ~ 40 MeV

Γ_{Kppn} ~ 100 MeV

Q_{kppn} ~ 400 MeV/c

$\sigma(K^{-}ppn)$*Br ~ 5 μb
σ(QF) ~ 5 μb
σ(BG) ~ 10 μb





- Similar parameters obtained with the $K^{-3}He \rightarrow \Lambda pn$ (PRC102(2020)044002.) are adopted to K-ppn/QF/BG shapes
- K-ppn signal [q-independent] can be seen clearly

Expected Spectrum of K^{-}+^{4}He

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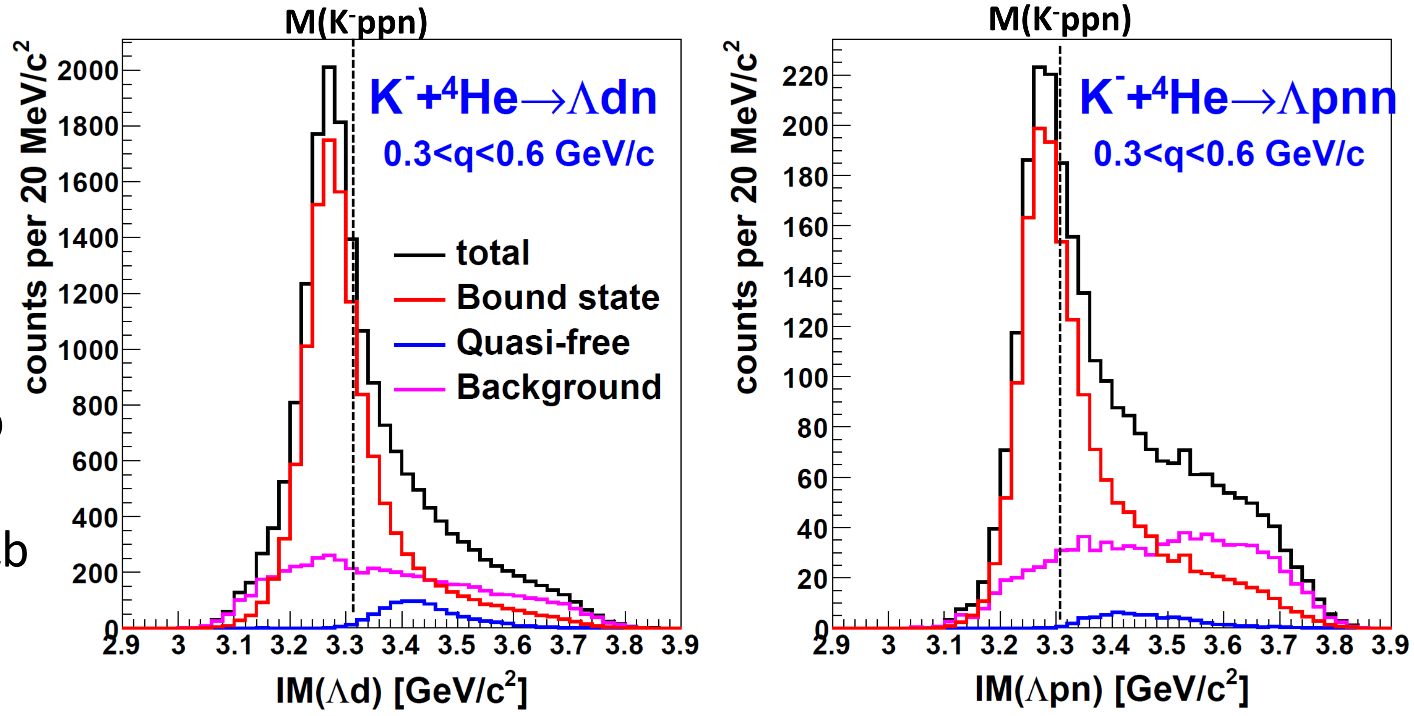
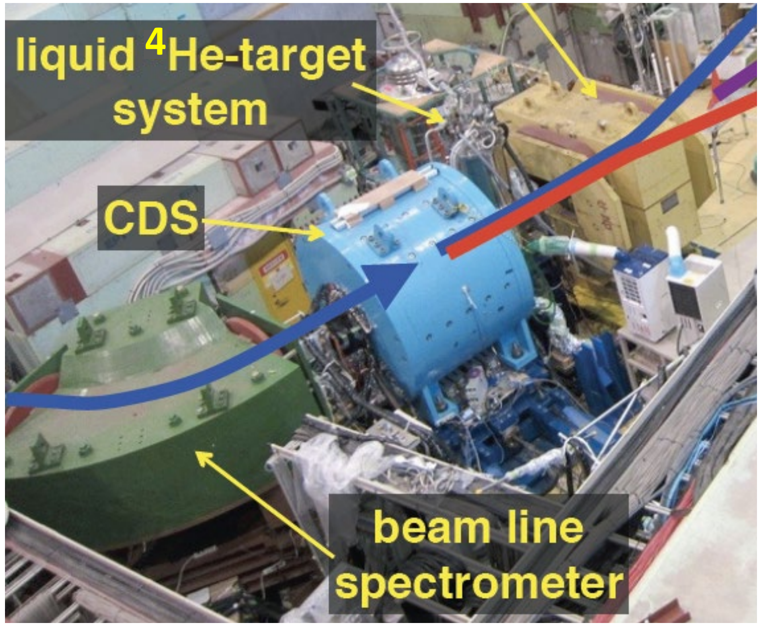
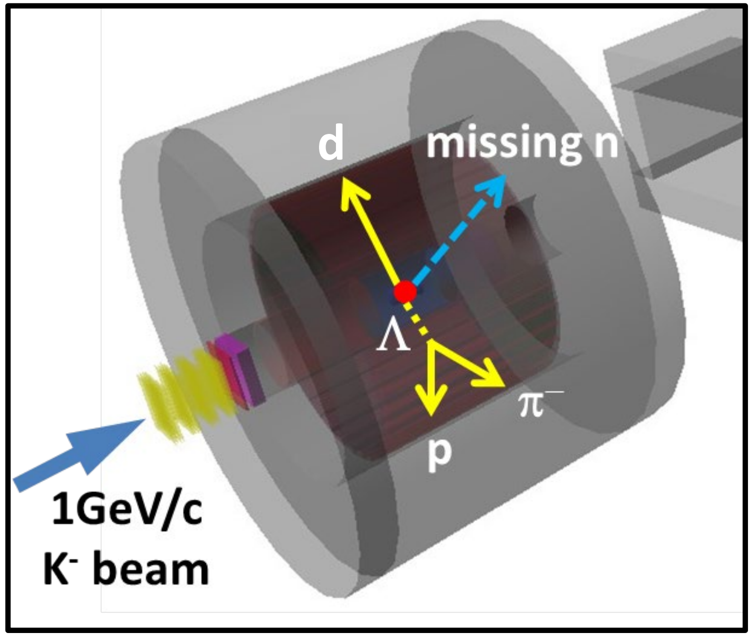


- The signals can be enhanced by selecting 0.3 < q < 0.6 GeV/c
- K-ppn signal can be seen clearly

$K^{-4}He \to \Lambda dn$ Analysis with the T77 Data

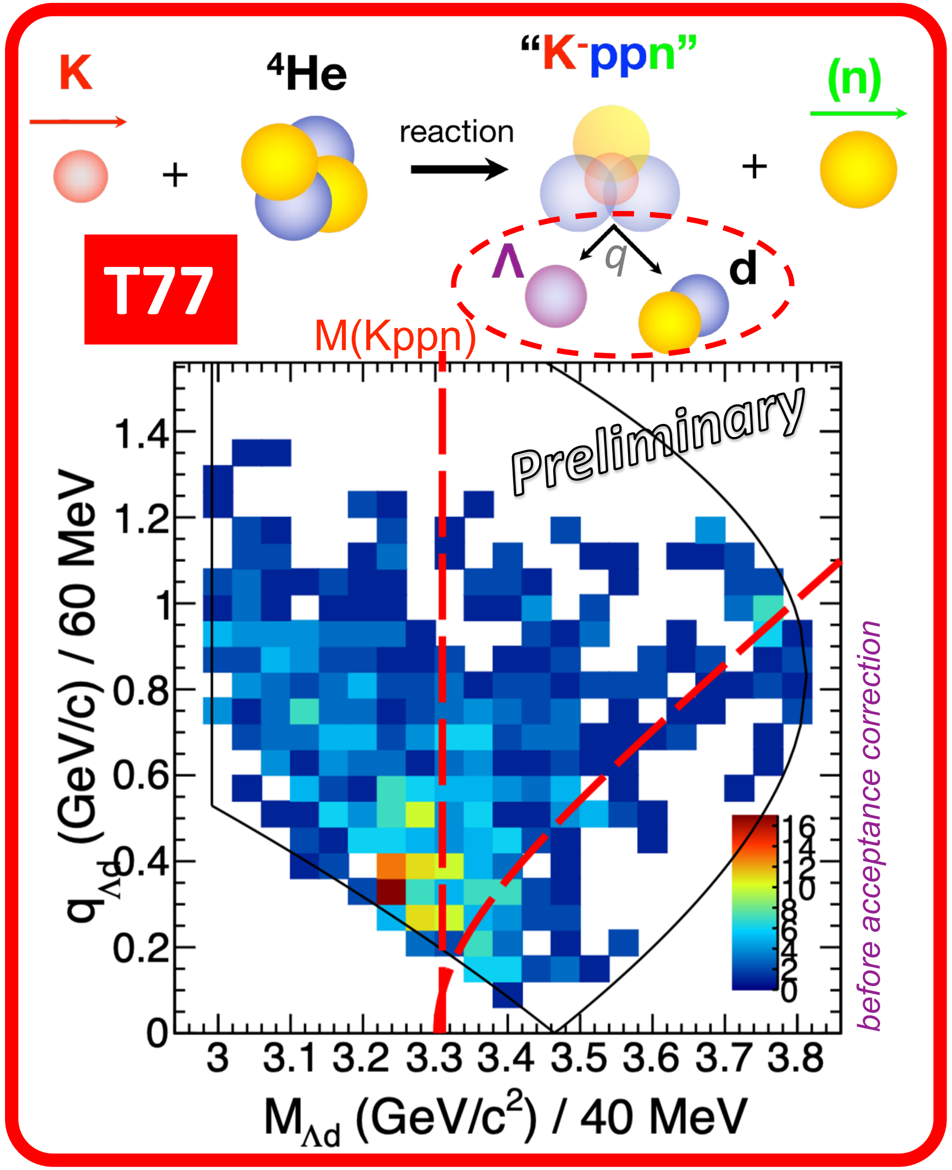
- An analysis of the **Λdn** final state with **$K^{-4}He$** reaction at **1 GeV/c** has been conducted
  - T77: lifetime measurement of $^{4}_{\Lambda}H$ in 2020
- The results will be updated with a part of the E73 controlled data
  - E73: lifetime measurement of $^{3}_{\Lambda}H$ in 2024

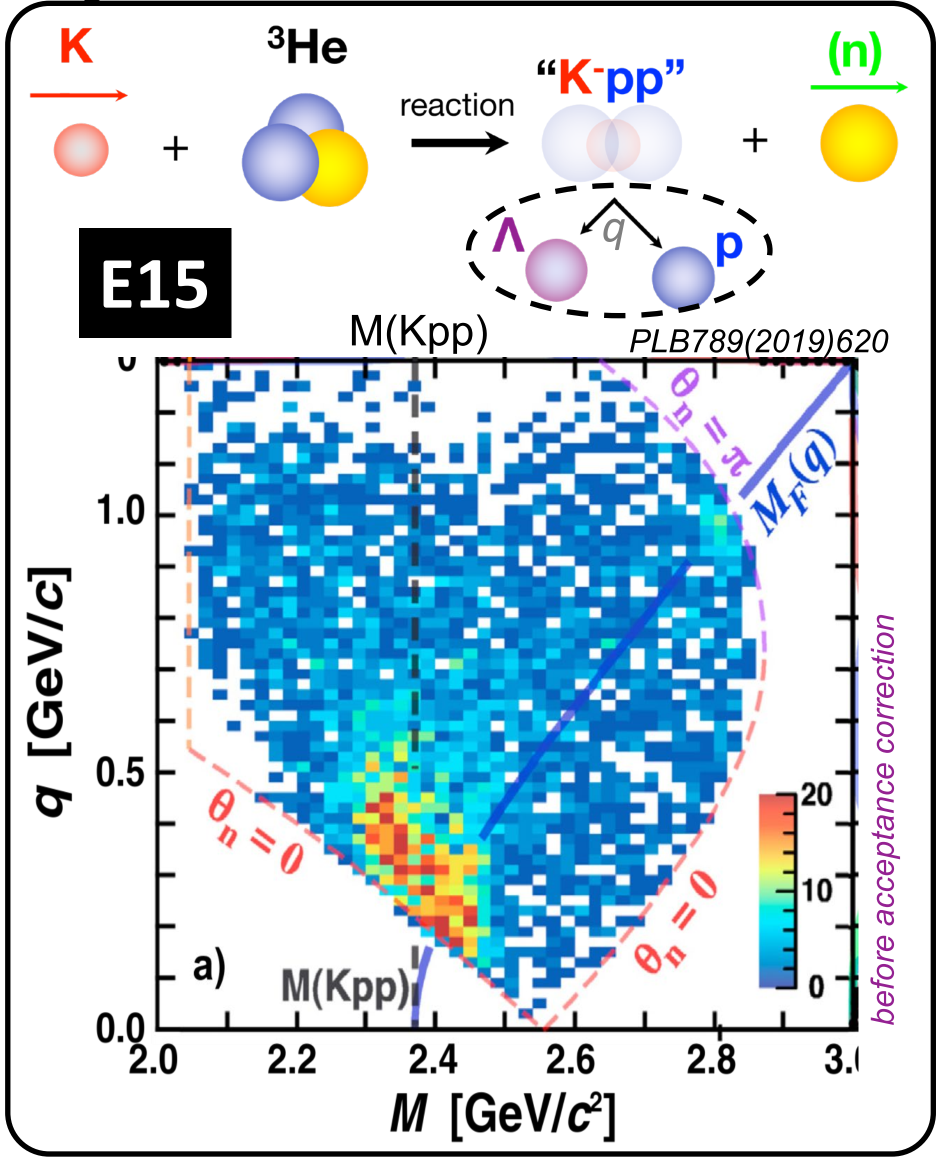




Experiment	K^- on target
E15 (^{3}He)	~42 x 10^9
T77 (^{4}He)	~6 x 10^9
E73 (^{4}He)	~6 x 10^9

Preliminary result





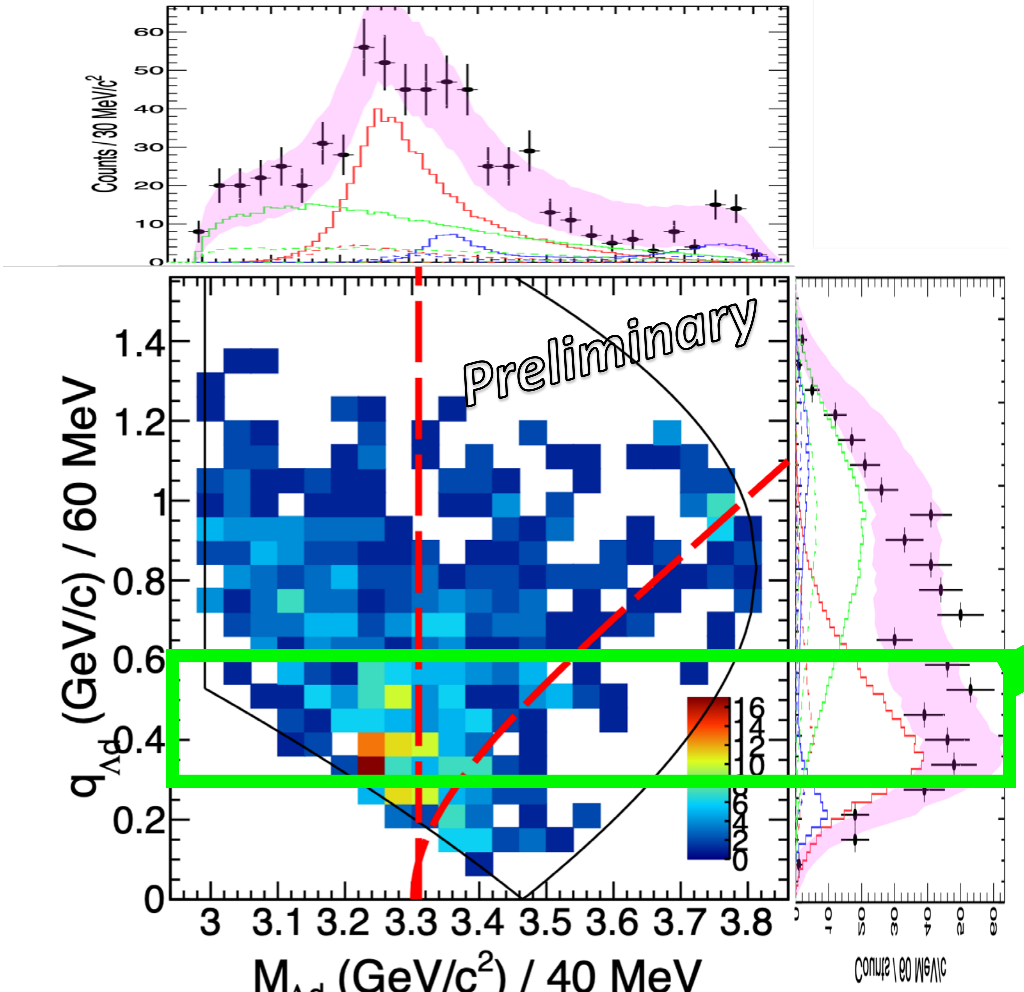
- **Two distributions are quite similar**
- structure below the threshold (**seems *q*-independent**), QF-K, BG

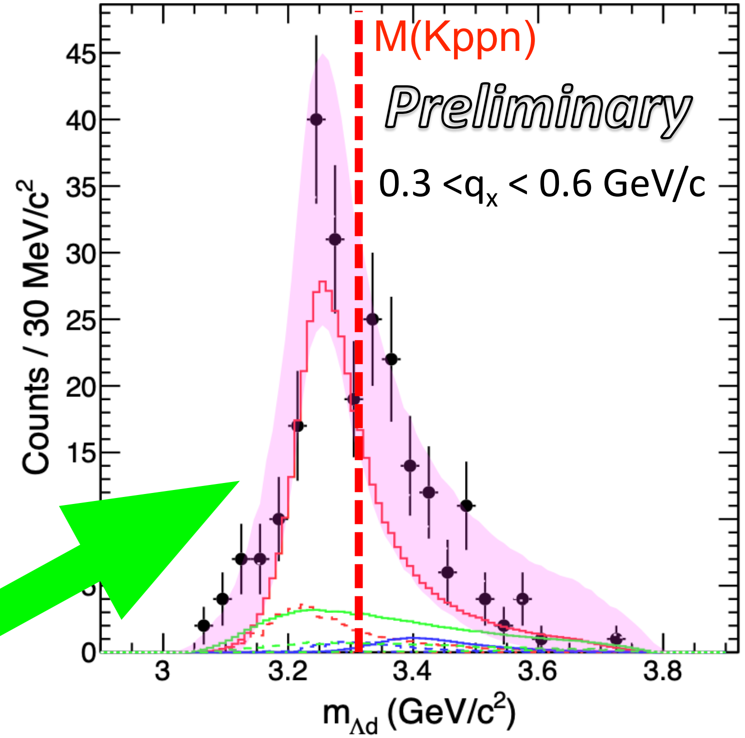
$K^{-4}He \rightarrow \Lambda dn$ Analysis with the T77 Data

2D fit on the (M,q) space with similar shapes to E15:

Breit-Wigner wtih Gaus. form factor (PWIA), QF-K^-, and Broad BG

$$\sigma(M,q) \propto \rho(M,q) \times \frac{(\Gamma_X/2)^2}{(M-M_X)^2+(\Gamma_X/2)^2} \times exp\left(-\frac{q^2}{{Q_X}^2}\right)$$





$B_X = 64 \pm 11(stat)\ MeV$

$\Gamma_X = \sim 100\ MeV$

$\sigma_{X\rightarrow\Lambda d} \sim 4\ \mu b$

$K^{-4}He \rightarrow \Lambda dn$ Analysis with the T77 Data

What is the observed structure? [Discussion]

1. **<u>"X"→Λd decay mode is unique evidence of $I_{"X"} = 0$</u>**
   - $I(J^P)$: $\Lambda = 0(1/2^+)$, $d = 0(1^+)$, $K^- = 1/2(0^-)$, $^3He = 1/2(1/2^+)$, $^4He = 0(0^+)$

2. **<u>"X"="K^-ppn" with $J_{"X"} = 1/2$</u>** <u>would be likely, considering the isospin and spin combination in S-wave interaction</u>
   - **$J_{"X"} = 1/2$:** ^4He initial state is I(J) = 0(0) and low-momentum intermediate $\bar{K}$ would react with remaining NNN [I(J) = 1/2(1/2)] in S-wave
   - **Exclusion of Y*(I=1)NN**: probability of "X"→Λd decay would be suppressed because spin/isospin flip is needed to reconfigure NN [I(J) = 1(0)] into deuteron [I(J) = 0(1)]
     - ➢ Λpn decay would be dominant