A New Cylindrical Detector System for Next Kaonic Nuclei exp. at J-PARC

Yuto Kimura, for the J-PARC E80 collaboration
RARiS, Tohoku University
RIKEN Nishina Center for Accelerator-Based Science, RIKEN

E-Mail: y_kimura@raris.tohoku.ac.jp

RARiS Tohoku University

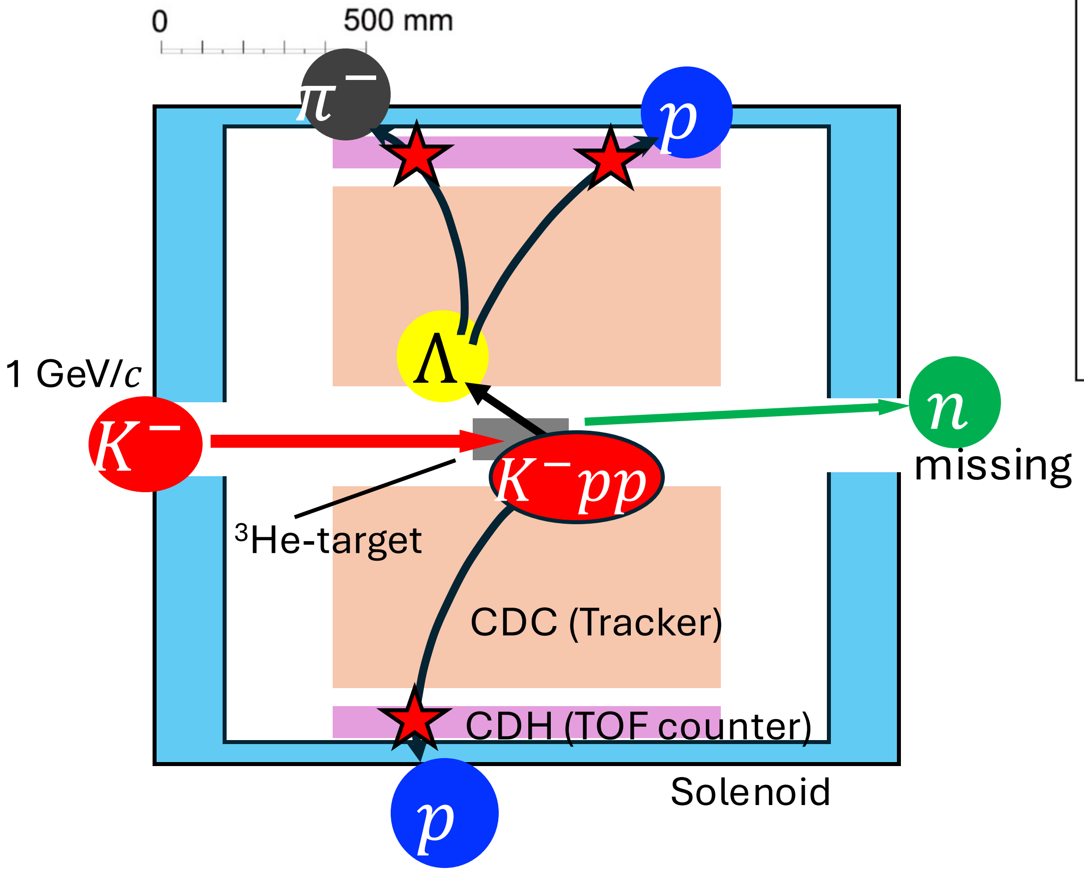
RIKEN NiSHiNA CENTER

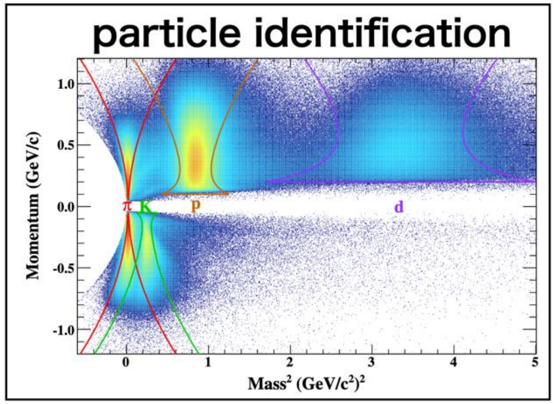
HYP2025 TOKYO

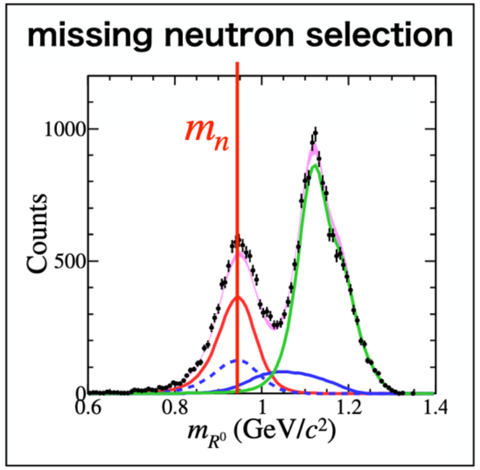
“K^-pp” observed : J-PARC E15

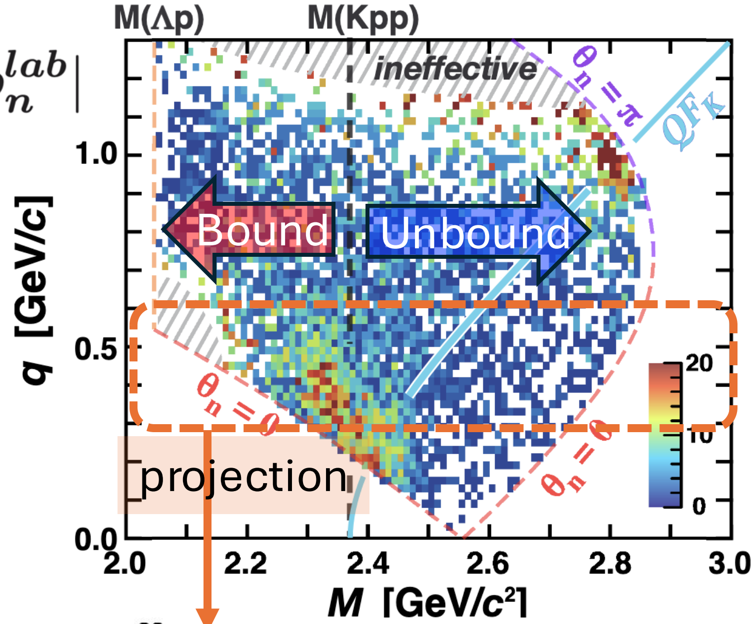
- ✓ **in-flight (K^-, n) reaction**
  - ✓ Effectively produce kaonic nuclei
  - ✓ Simplest target allows an **exclusive analysis**
- ✓ **Covering a wide kinematical region**

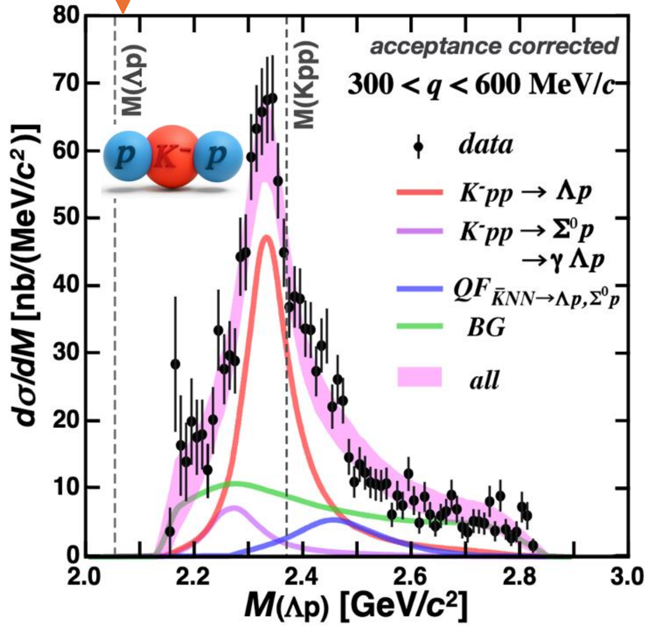
$$q = |p_{K^-}^{lab} - p_n^{lab}|$$





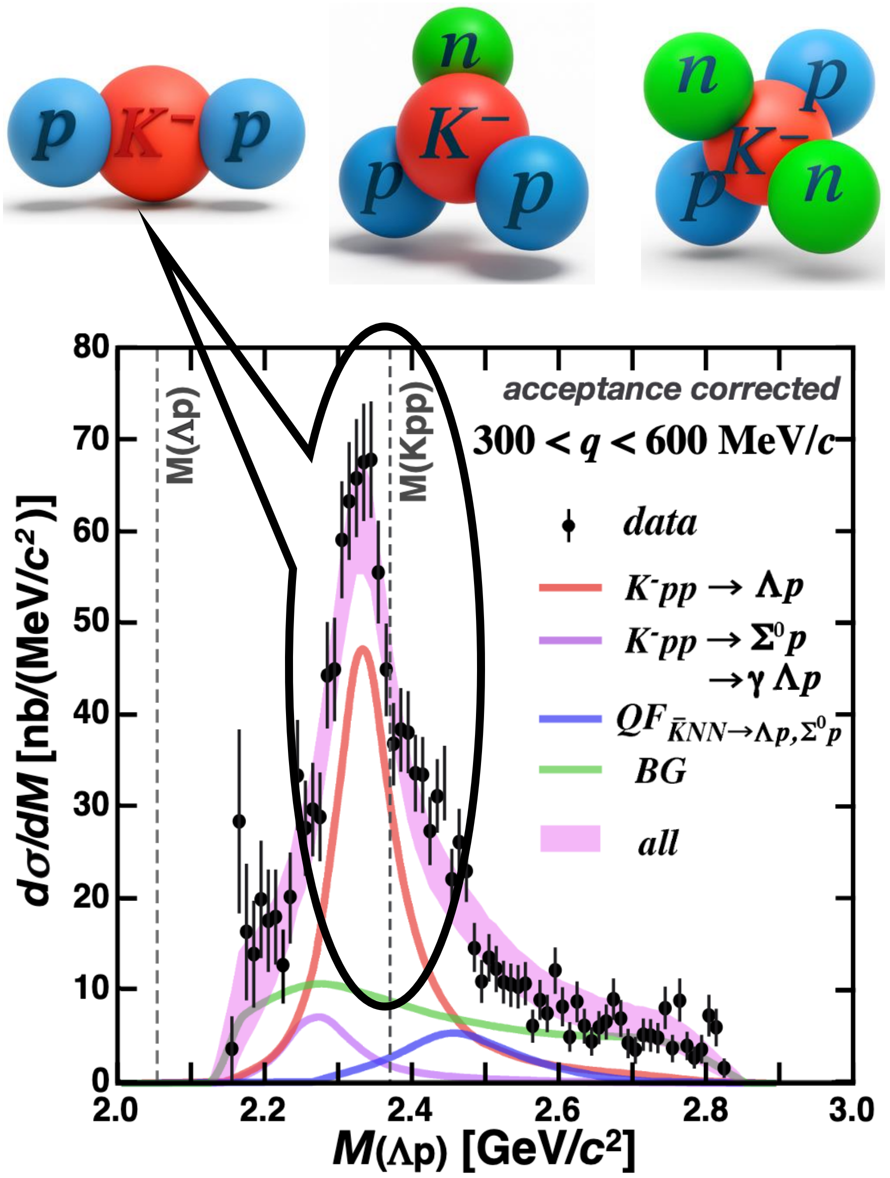






Next Kaonic Nuclei Experiments

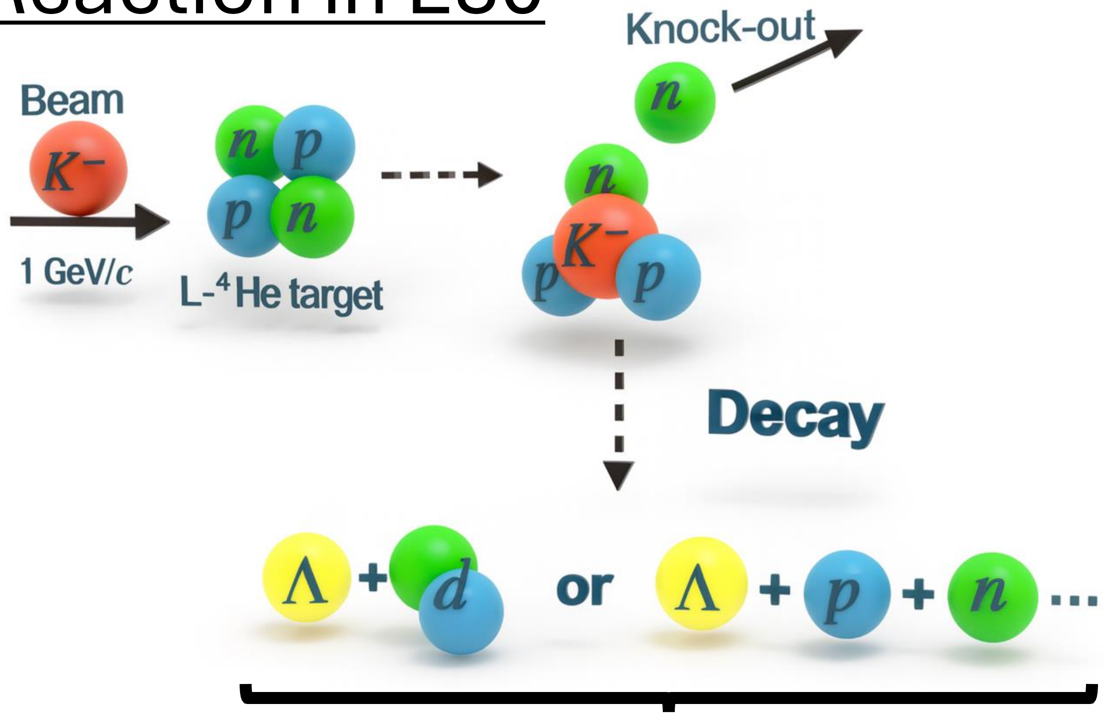
- ■J-PARC E15
  - ■ “K^-pp” was successfully observed.
- ■From Existence to their Properties
  - ■ Systematic investigation of Light Kaonic Nuclei
    - ■K^-ppn
    - ■K^-ppnn J-PARC E80 in 2027: First step toward these future exp.
  - ■“K^-pp” research in more detail
    - ■Its isospin partner “$\overline{K}^0nn$”
    - ■Spin-Parity of “$\overline{K}NN$”



"$K^- ppn$" Search: J-PARC E80

The experimental method follows that of J-PARC E15.

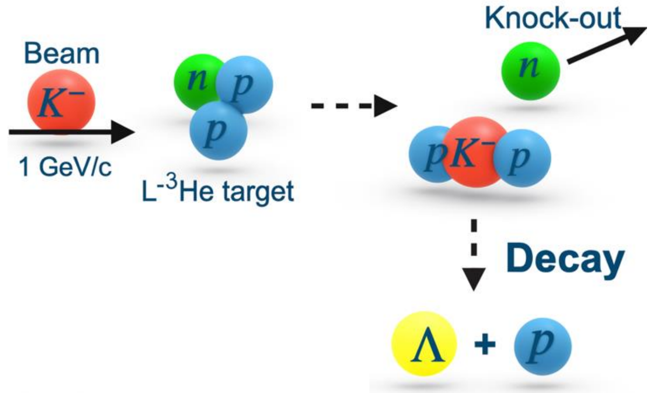
Reaction in E80



Detect all of the decay particles

→Reconstruct the $M_{K^- ppn}$

c.f.) Reaction in E15



Compared with E15 ("$K^- pp$"),

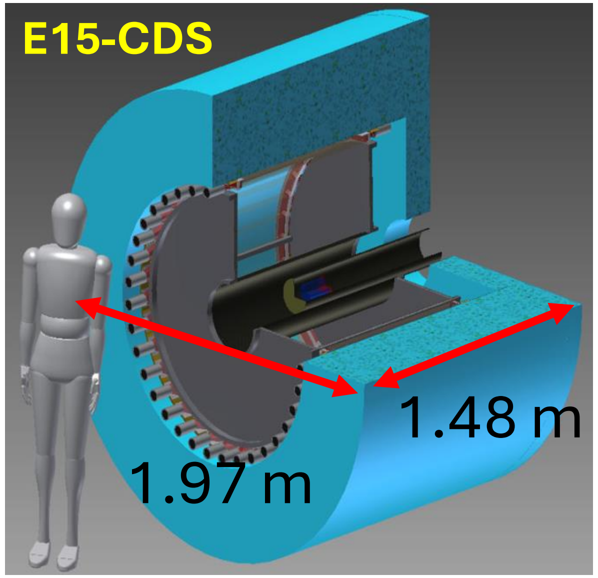
- ✓ **More decay particles**
- ✓ **Neutron must be detected**

⇩

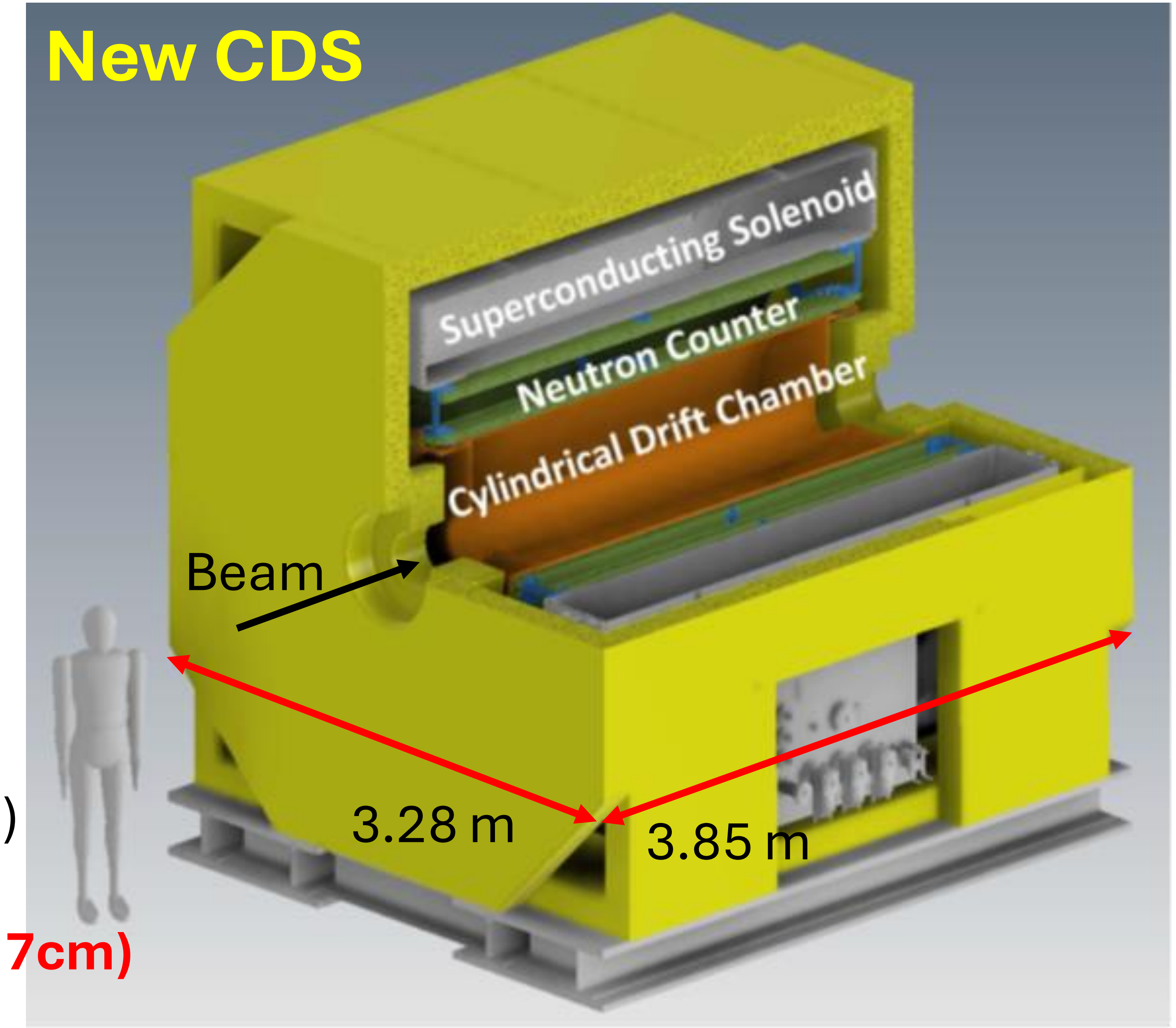
Our detector system must have

- ✓ **Larger solid angle**
- ✓ **Better neutron detection efficiency**

New Cylindrical Detector System, CDS



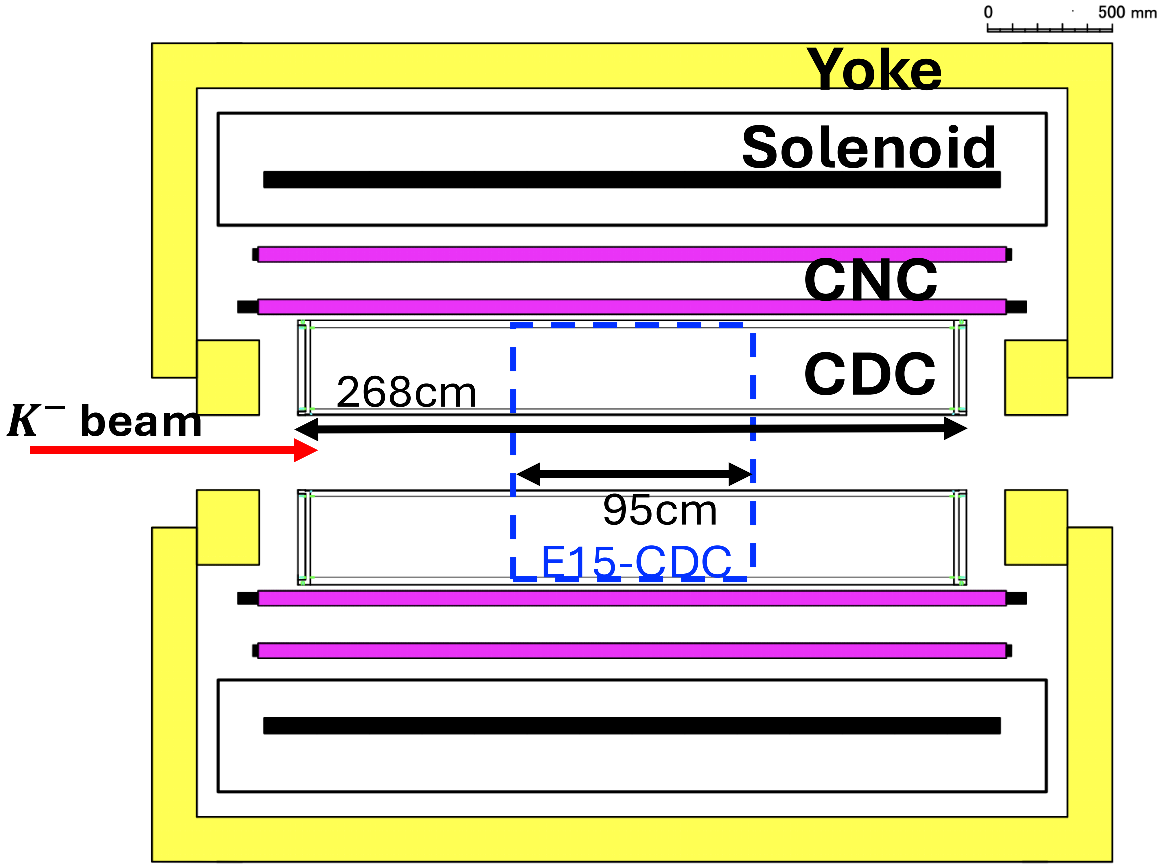
~8 times
the volume



To extend the detectors along beam ax.,
and to increase the total thickness
of the neutron counter,

- **<u>Superconducting Solenoid Magnet</u>**
  - (The same design as the COMET DS)
  - **Inner bore: 180cm (E15: 59cm)**
  - **Length (beam ax.): 320cm (E15: 117cm)**
  - Max. field of 1.0T @ center

How to upgrade



Compared to E15's detectors,

- ✓ CNC and CDC are extended about **x3 longer along the beam axis.**
- ✓ **CNC thickness is increased x4.**

■ Cylindrical Neutron Counter, CNC

- ■ Plastic Scintillator, 138 segments
  - ■ 300cm × 6cm × 6cm
  - ■ 2 Layers on a cylindrical geometry
    - ■ Total thickness 12cm (E15-CDH: 3cm)

■ Cylindrical Drift Chamber, CDC

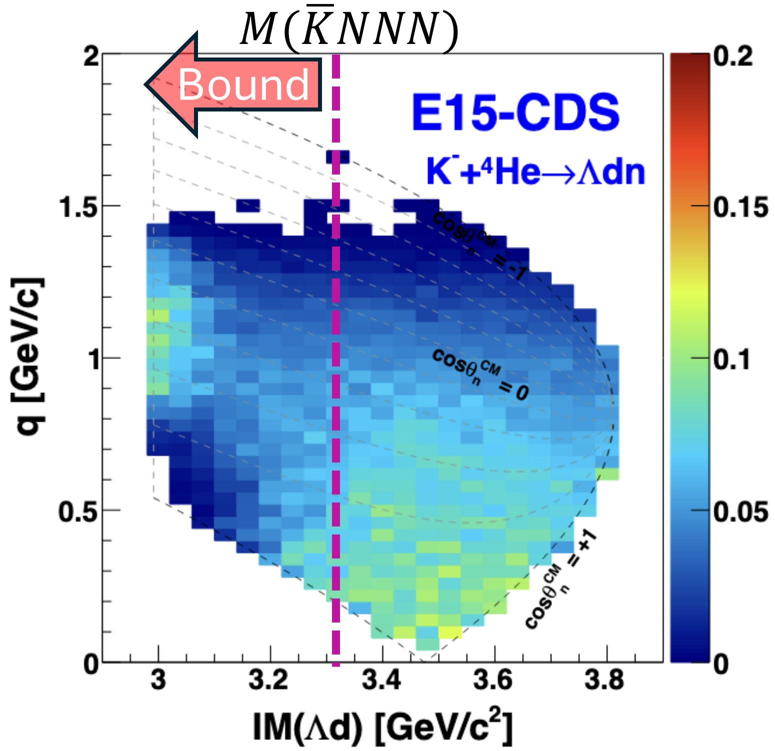
- ■ The same cell-structure design as the E15-CDC (8,244 wires)
- ■ Length 268 cm (E15-CDC: 95cm)

→ Solid Angle: x1.6 (59% → 93%)

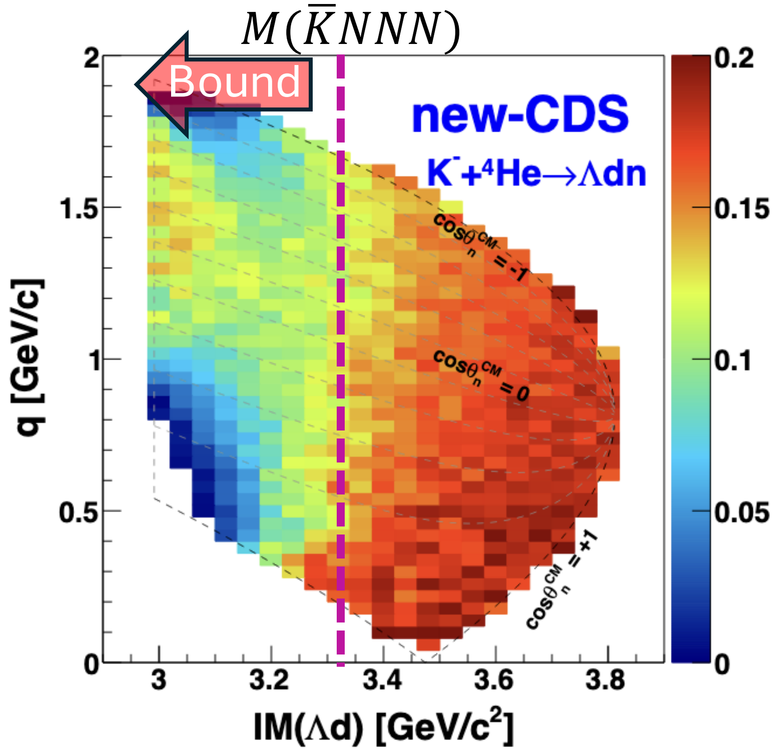
→ Neutron Eff.: x7 (3% → 12%x1.6=21%)

Acceptance improvement

e.g.) the case of "$K^- + {}^4\mathrm{He} \rightarrow \Lambda\, d + n$"



upgrade



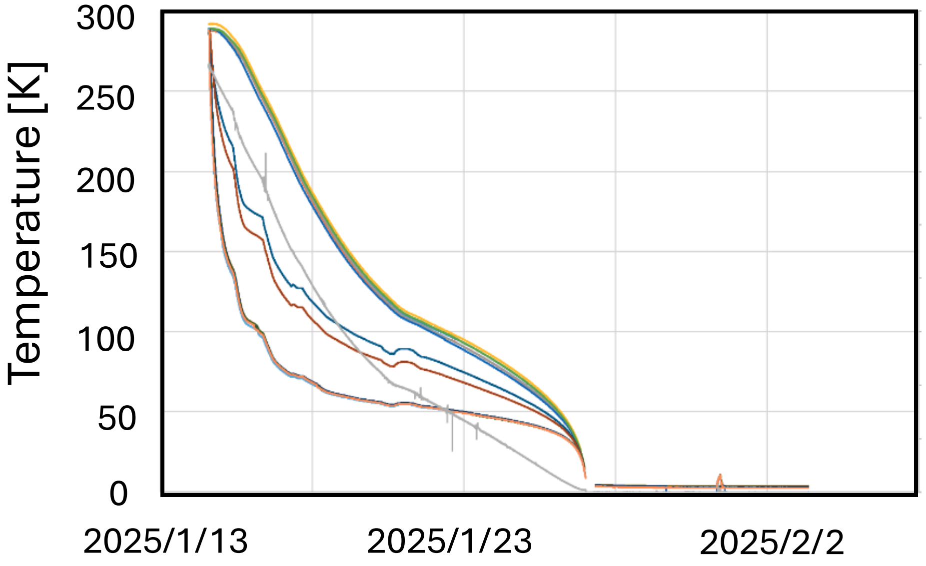
- ✓ **Enable analysis over a much wider kinematical region**
- ✓ **Data taking will become ~3 times more efficient.**

Status: SC Solenoid

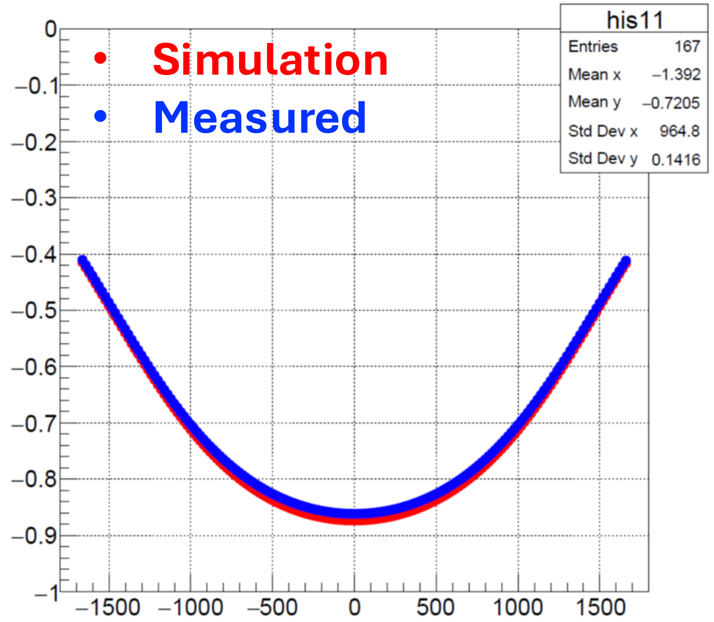
Return Yoke

SC Solenoid

Cooling Test



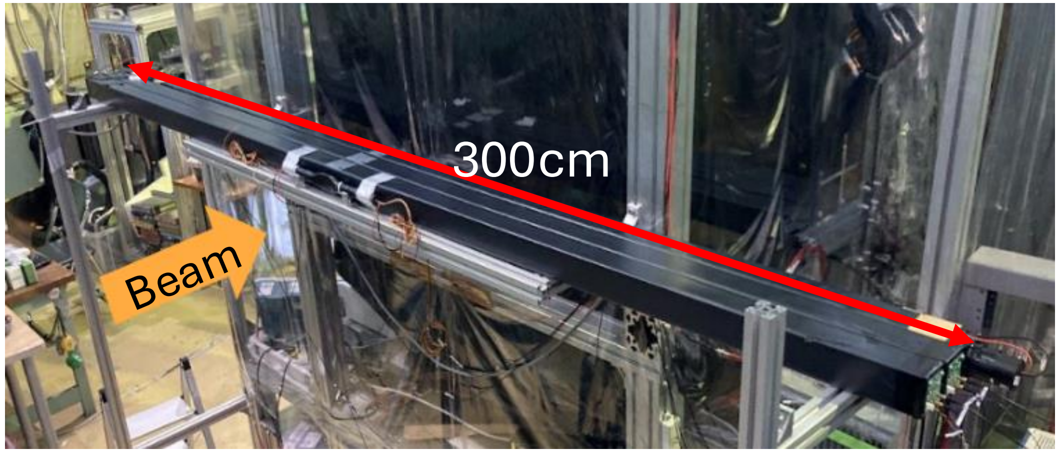
Magnetic field measurement w/o yoke @TOSHIBA (Beam axis scan, **I = 189A**)



- ✓ **With GM refrigerators, we achieved stable cooling down to the nominal temperature of 4K.**
- ✓ **Measured magnetic field w/o Yoke was consistent with TOSCA calculation.**

Status: CNC

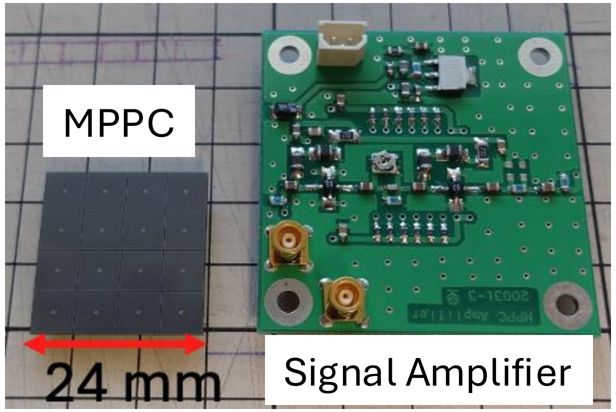
Proto-type test exp. in 2025



Result (Required time reso. ~80 ps)

Counter	Read out	Length	thickness	Time Reso.
E15-CDH	PMT	80 cm	3 cm	~ 80 ps
CNC	PMT	300 cm	6 cm	~ 120 ps
CNC	MPPC	300 cm	6 cm	~ 80 ps

- Readout of E15-CDH is not applicable for 3m long plastic scintillators.
- To improve light collection efficiency, we decided to use MPPCs w/o light guides.



MPPC (Hamamatsu)
- S13361-6050AE-04
- 6 mm square, 4 × 4 array

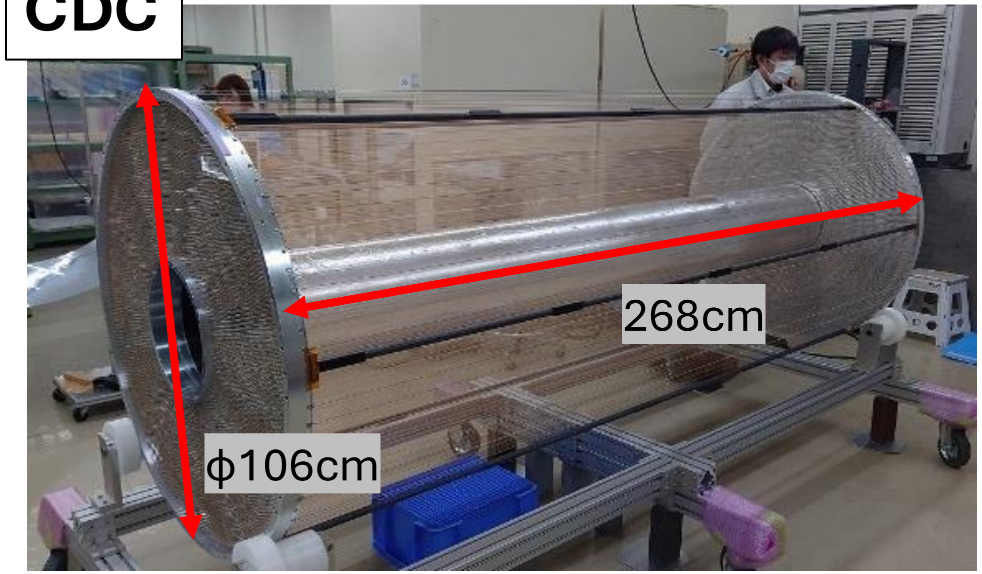
Signal Amplifier
- Two-stage RF amplifier
- PZC circuit

✓ **We achieved required value σ ~80 ps even with 3m length scintillators.**

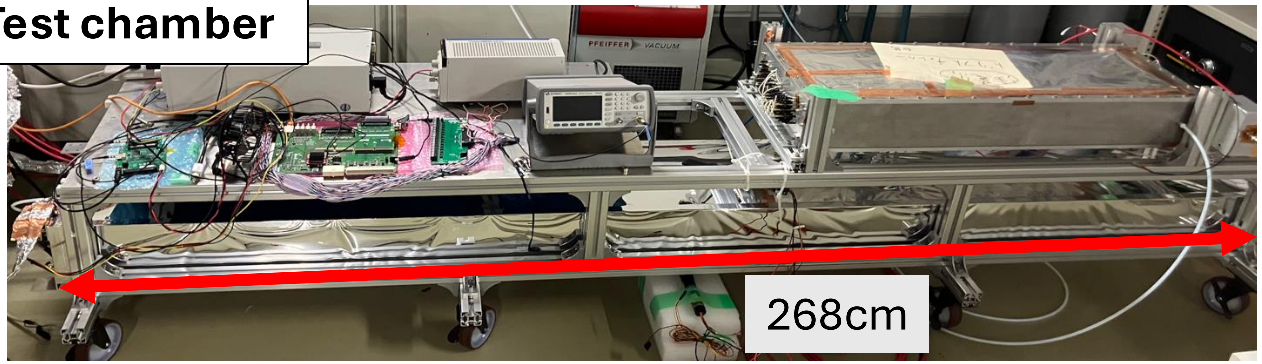
✓ **Now all 138 modules are in hand.**

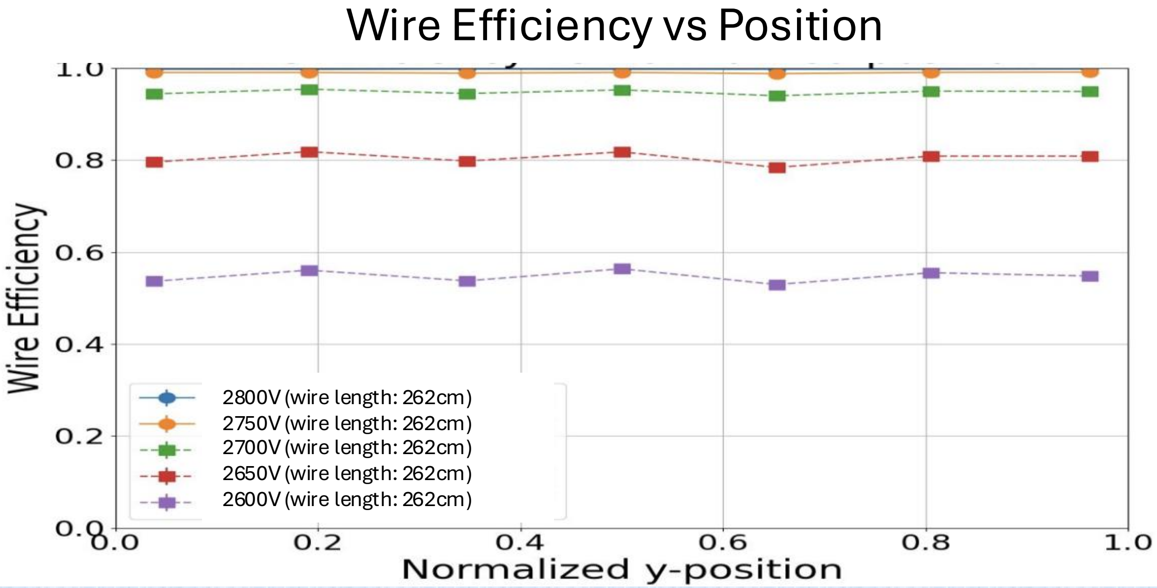
Status: CDC

CDC

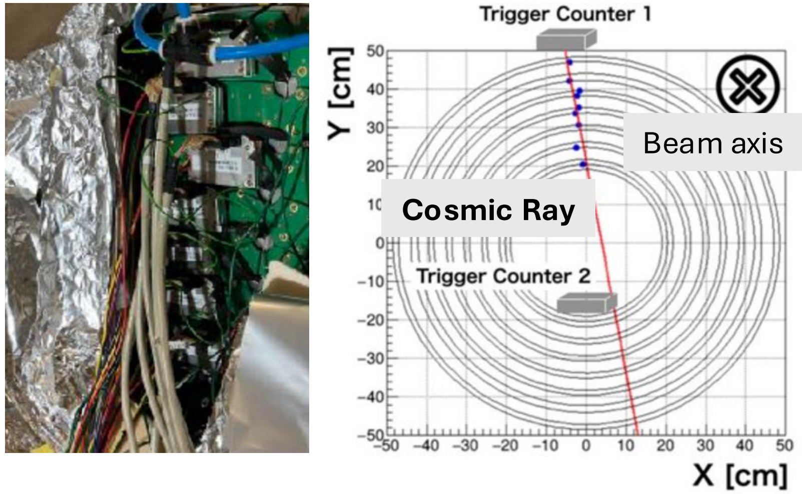


Test chamber





CDC w/ partial Pre-amp



- ✓ ~100% efficiency even w/ 268cm wire, no position dependence
- ✓ w/ partial preamps, cosmic-ray track was successfully reconstructed by CDC.
- ✓ We will start commissioning with full readout.

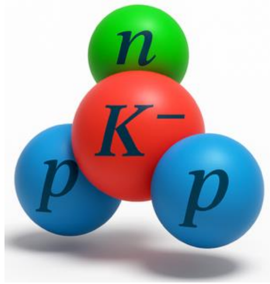
Summary

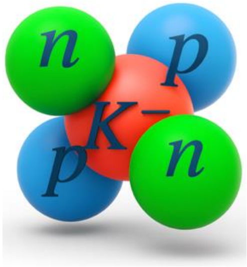
- **We developed and constructed a large-acceptance Cylindrical Detector System (CDS) for the future kaonic nuclei experiments.**

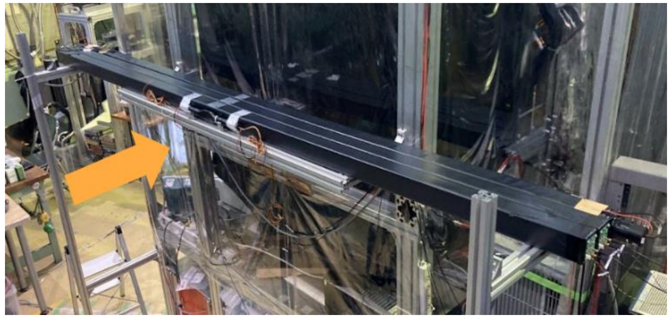
- **The three main components (SC Solenoid, CNC and CDC) have been established.**

- **Installation of the new CDS to K1.8BR is scheduled for 2026, and we plan to start the physics run (J-PARC E80) in 2027.**

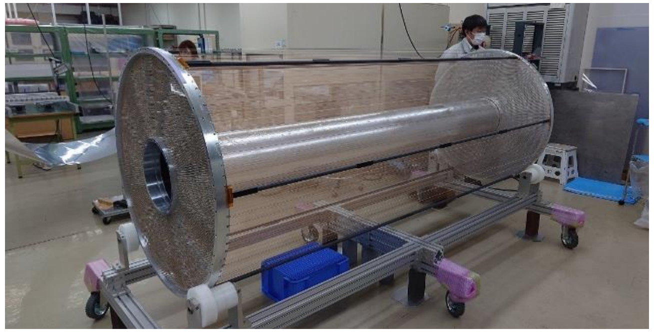
For **details on the physics of kaonic nuclei experiment**, please refer to **Dr. T. Hashimoto's talk on Thursday**, and for **related detectors**, to the **poster presentation by Yuto Tsutsumi (No. 68).**












Thank you for listening.

HYP2025
TOKYO

Back Up

New Cylindrical Detector System, CDS

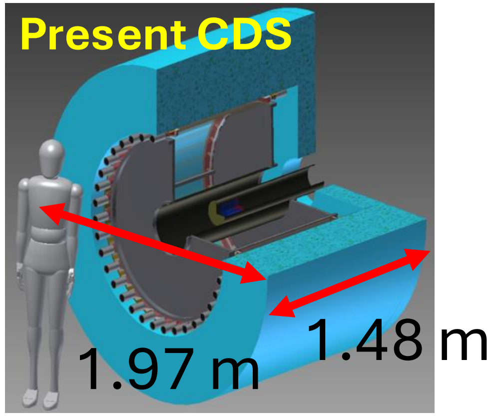
For our next kaonic nuclei experiments,

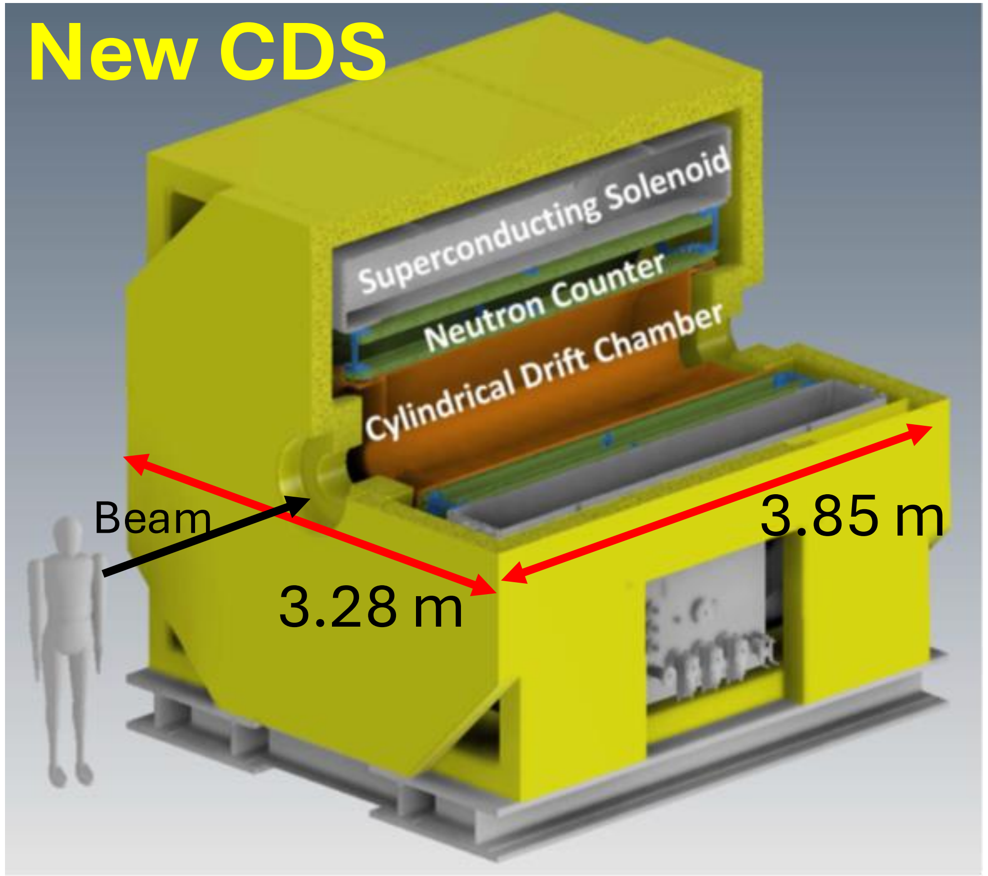
- ✓ **"High-precision"**
- ✓ **"Efficient Neutron Detection"**
- ✓ **"Large Acceptance"**

are important.

Keep the performance of the old CDS

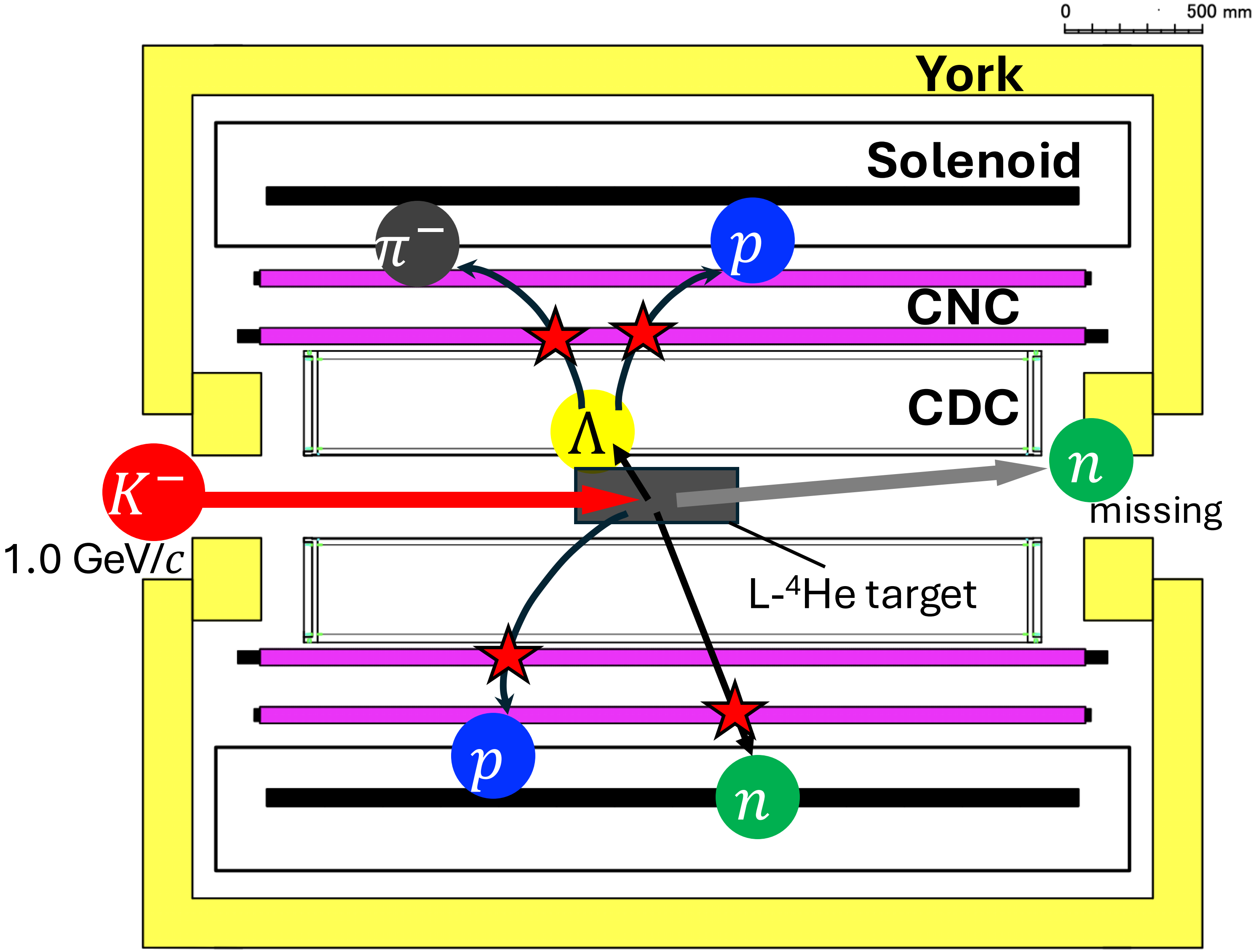
Upgrade with the new CDS





Event Reconstruction

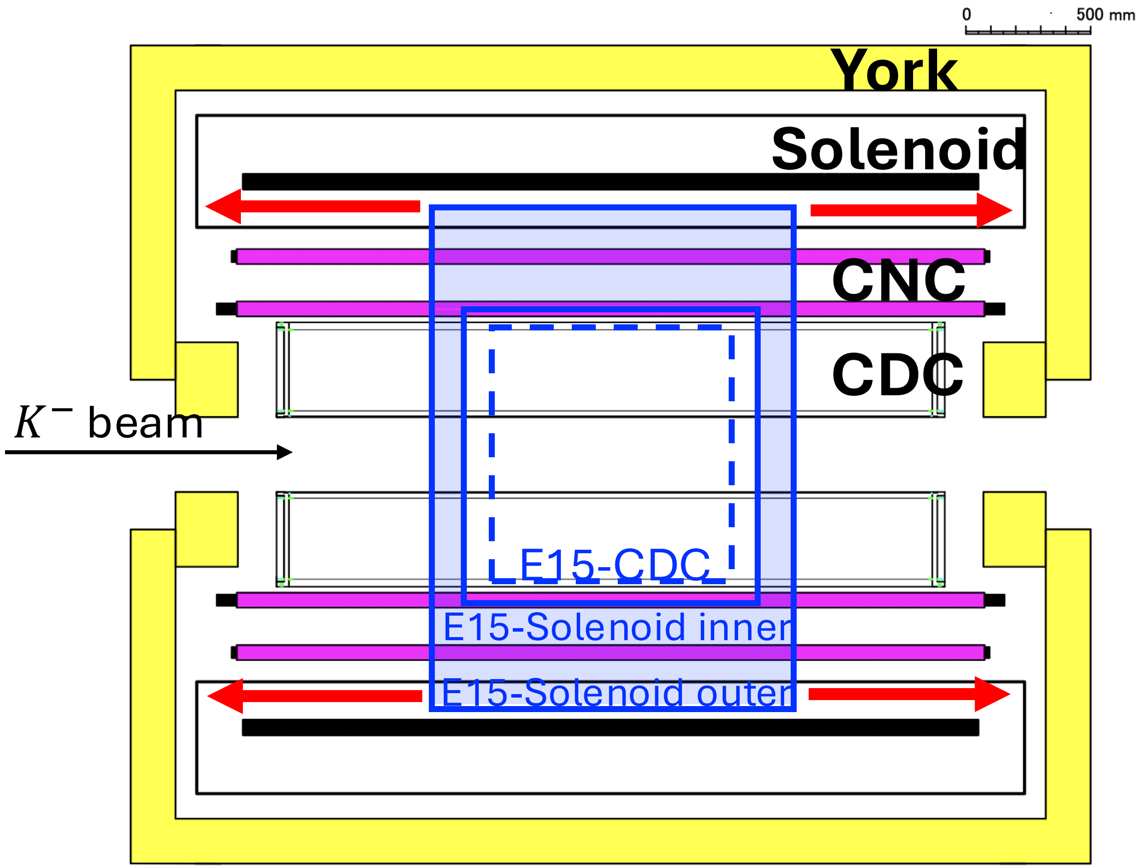
- **Charged Particle**
  - CDC x Solenoid
    - Momentum analysis
    - Reaction Vertex
  - CNC
    - PID by TOF
- **Neutron**
  - CNC
    - Momentum



How to upgrade

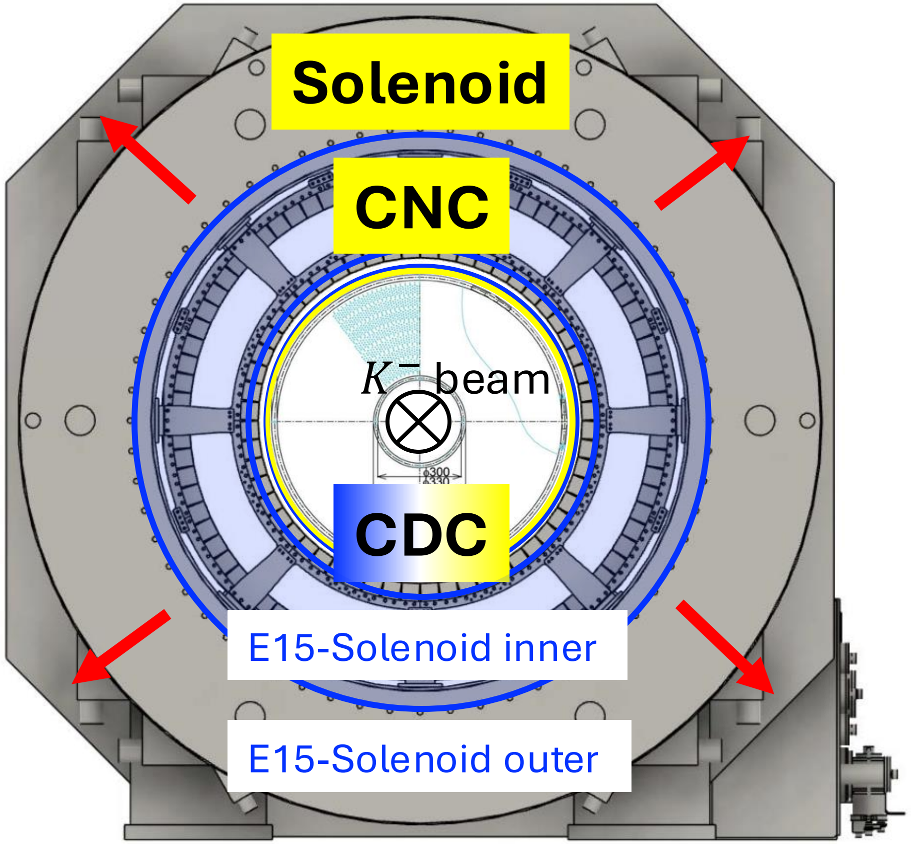
Solid Angle: x1.6 (59% → 93%)

Extend CNC and CDC about x3 longer along the beam axis



Neutron Eff.: x7 (3% → 12%x1.6)

Enlarged solenoid, then CNC thickness x4



* The radius of the new CDC is equal to E15-CDC.

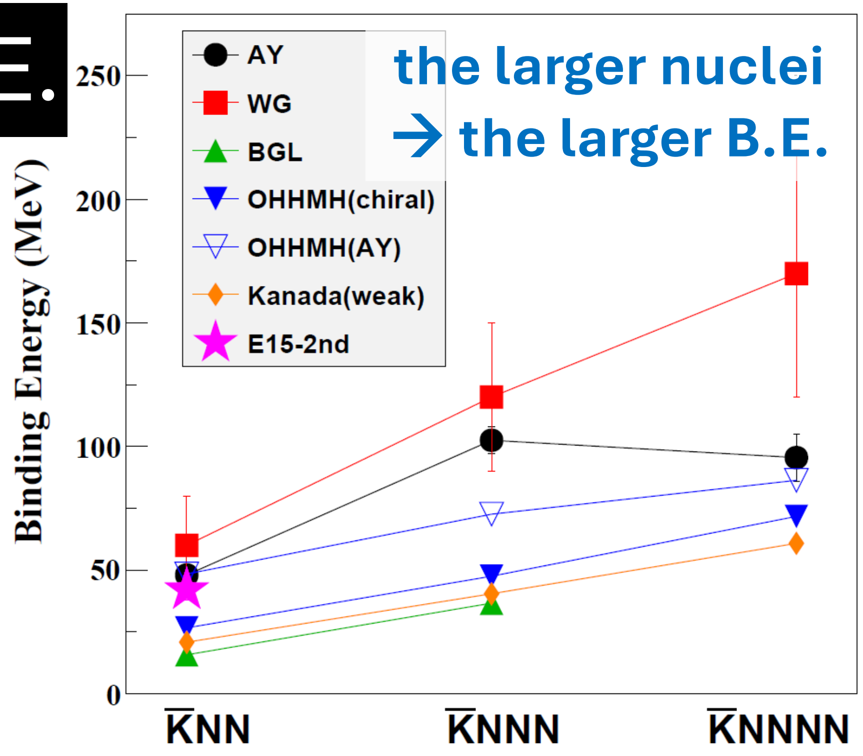
Mass Number Dependence

AY: PRC65(2002)044005, PLB535(2002)70.
WG: PRC79(2009)014001.
BGL: PLB712(2012)132.
OHHMH: PRC95(2017)065202.
Kanada: EPJA57(2021)185.

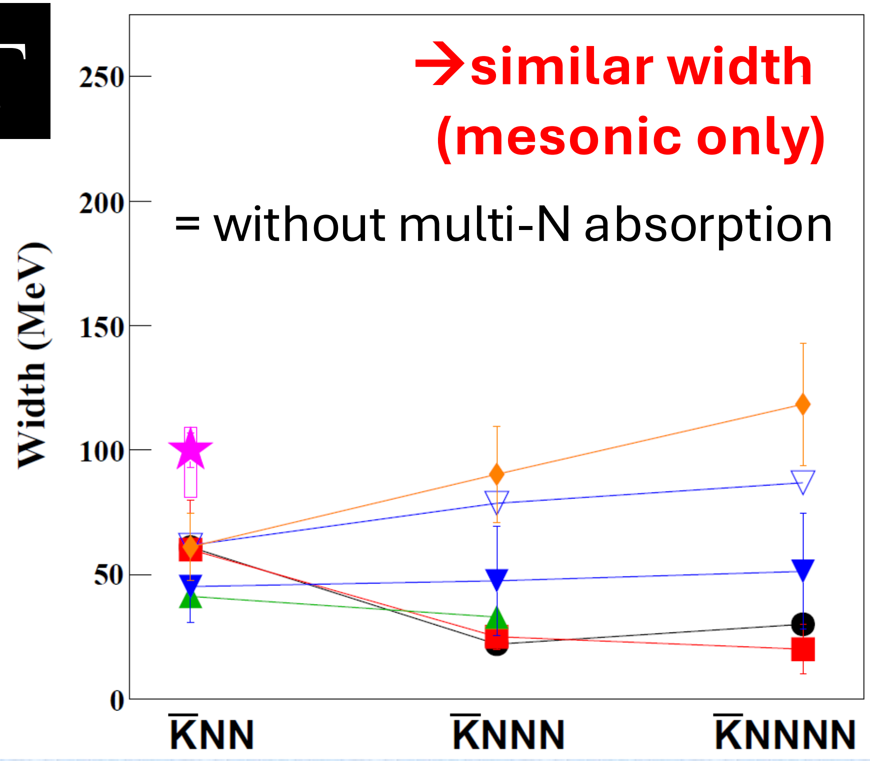
Theoretical calculation vs Measured B.E and Γ

There is uncertainty between the different theories.

B.E.



Γ



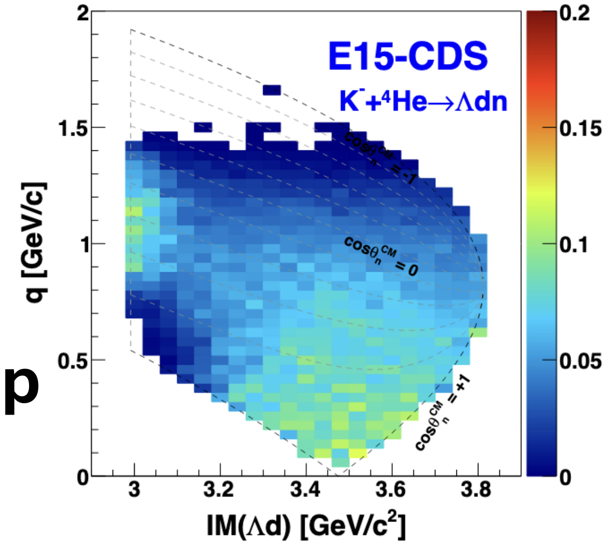
✓ **Systematic measurements will provide more conclusive evidence of the kaonic nuclei.**

✓ **As a first step, we plan to search for “$K^{-}ppn$” in J-PARC E80.**

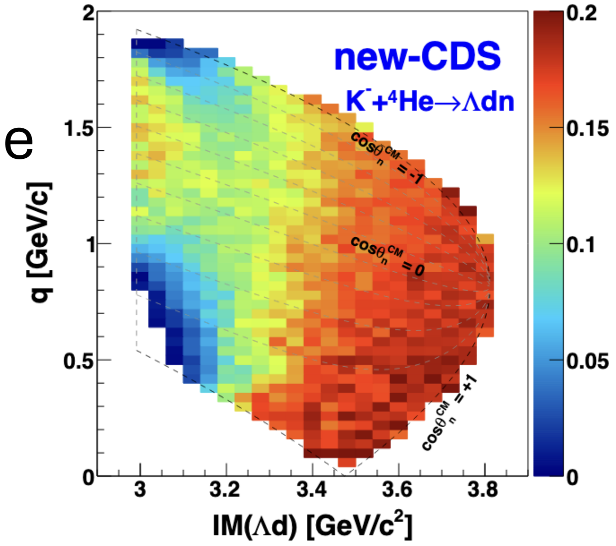
Acceptance and yield

- More efficient data taking
- Enable us analyze on larger kinematical region

- **Λd ~ 10 times statistic than K-pp**
- **Λpn ~ the same order as K-pp**



Upgrade



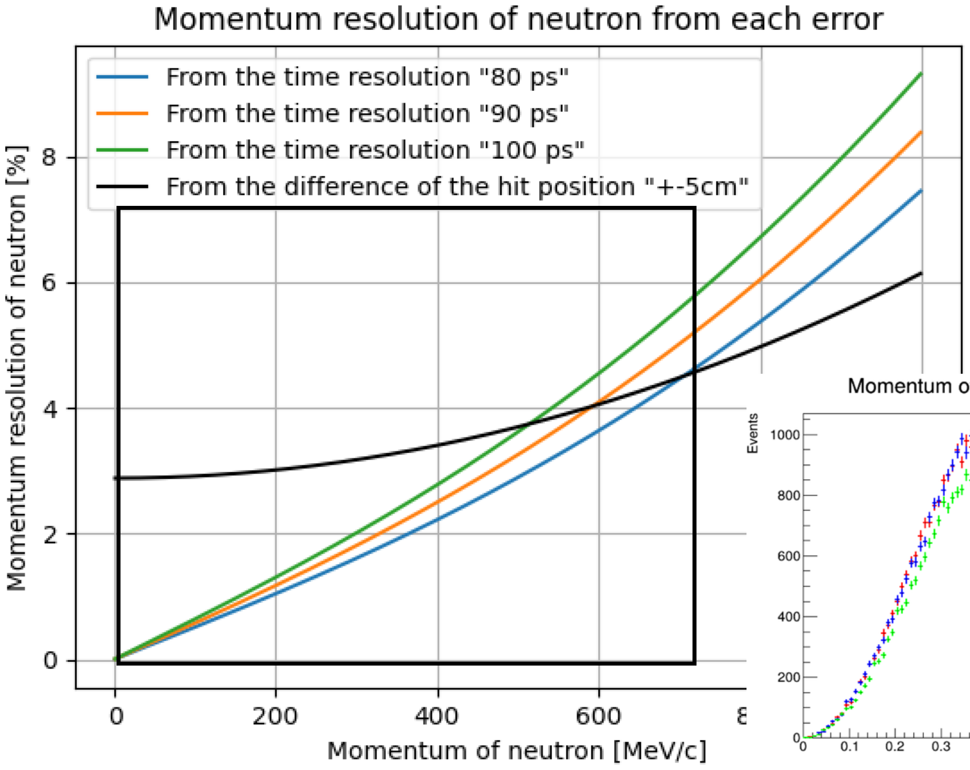
Decay mode	Lp (E15 w/ old CDS)	Ld (E80 w/ new CDS)	Lpn (E80 w/ new CDS)
$\sigma^{tot} \cdot BR$	10 μb	Assumed to be 5 μb	
MR beam power	42 kW	90 kW	
Beam-time duration	1 month	3 weeks	
Accelerator up-time	0.89	0.9	
# of K^- beam	62×10^9	155×10^9	
# of K^- on target	40×10^9	100×10^9	
# of expected yield	1.7×10^3	1.2×10^4	1.2×10^3

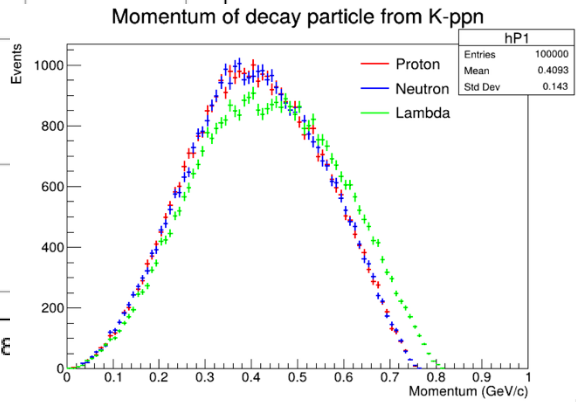
Cylindrical Neutron Counter, CNC

The required performance

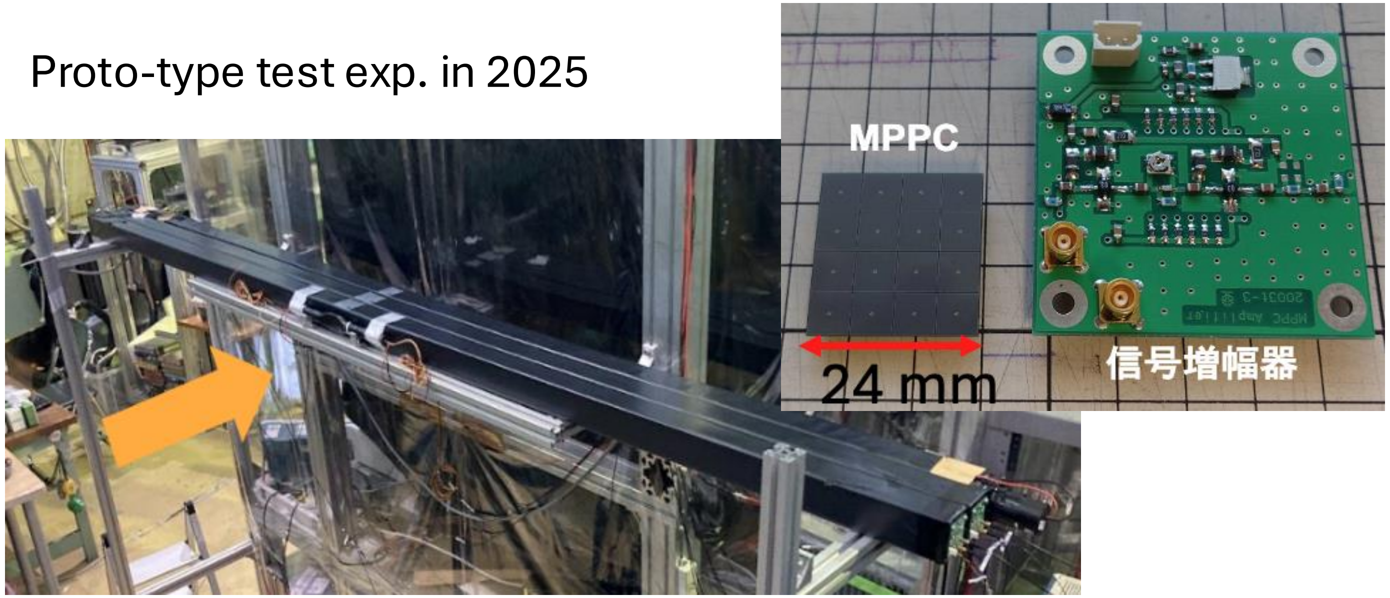
$$\sigma_{thick} > \sigma_{time}$$

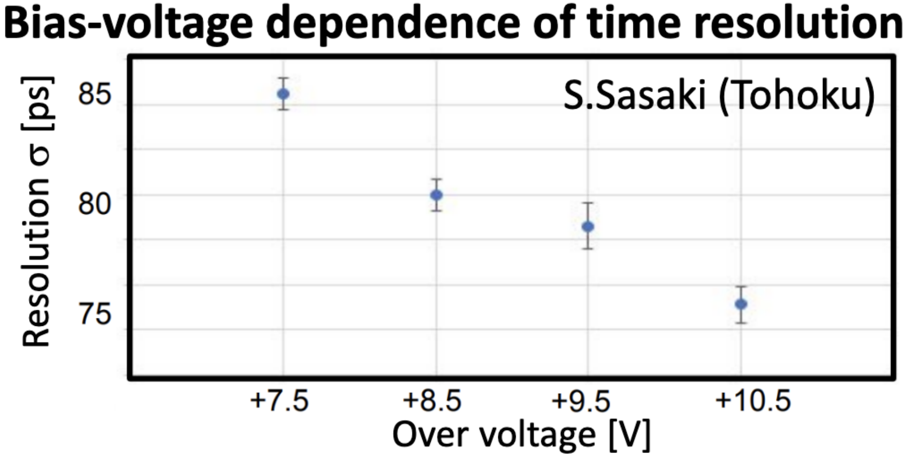
$$\Rightarrow \sigma_{time} \sim 80\text{ps}$$





Proto-type test exp. in 2025



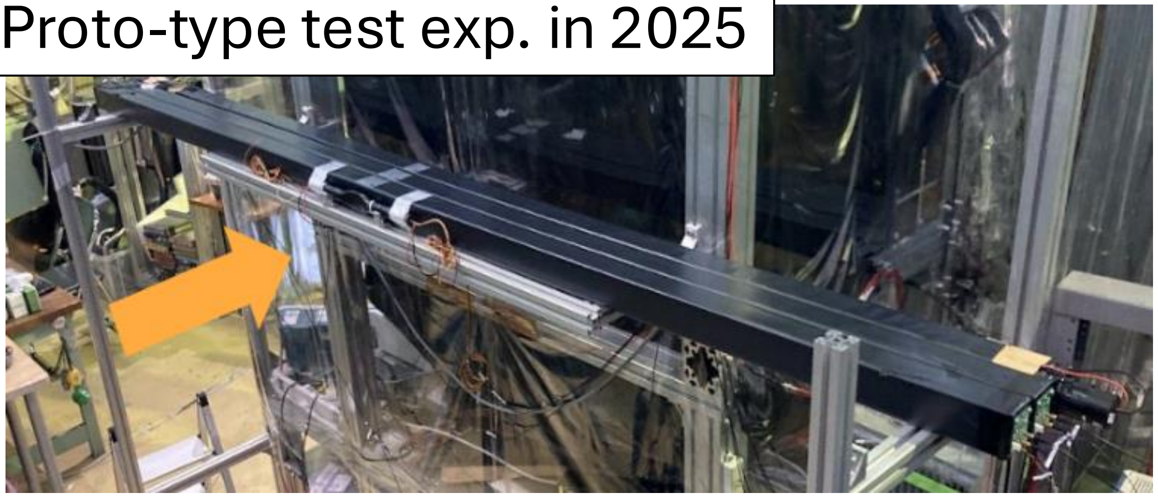


The required performance has been achieved:

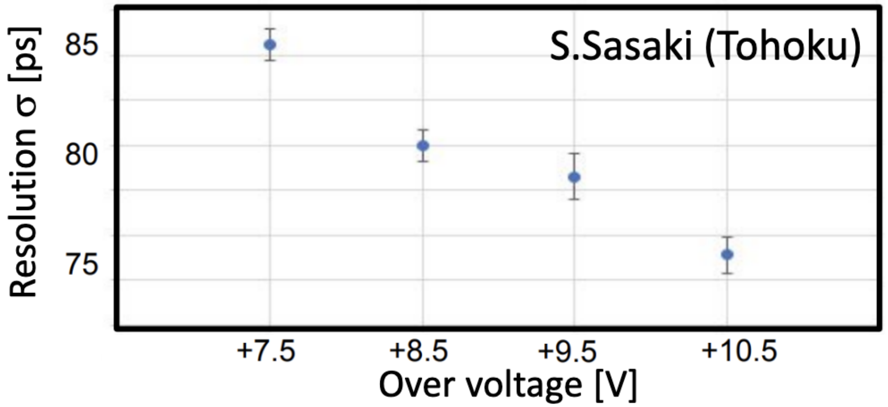
σ_{CNC} ~ 80ps @ V_{OV} ~ +9V

CNC

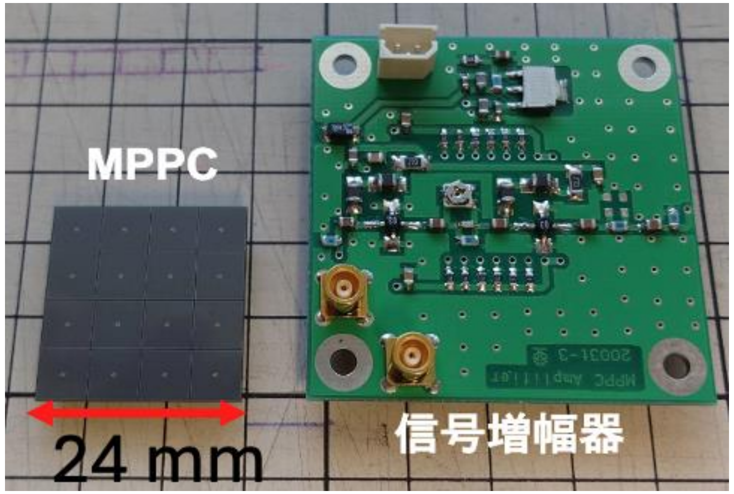
Proto-type test exp. in 2025



Bias-voltage dependence of time resolution



The required performance has been achieved:
σ_{CNC} ~ 80ps @ V_{OV} ~ +9V



- ✓ **Read-out study w/ prototype has done! (achieved required value σ ~80 ps even if 3m length counter)**
- ✓ **138 modules is in hand.**

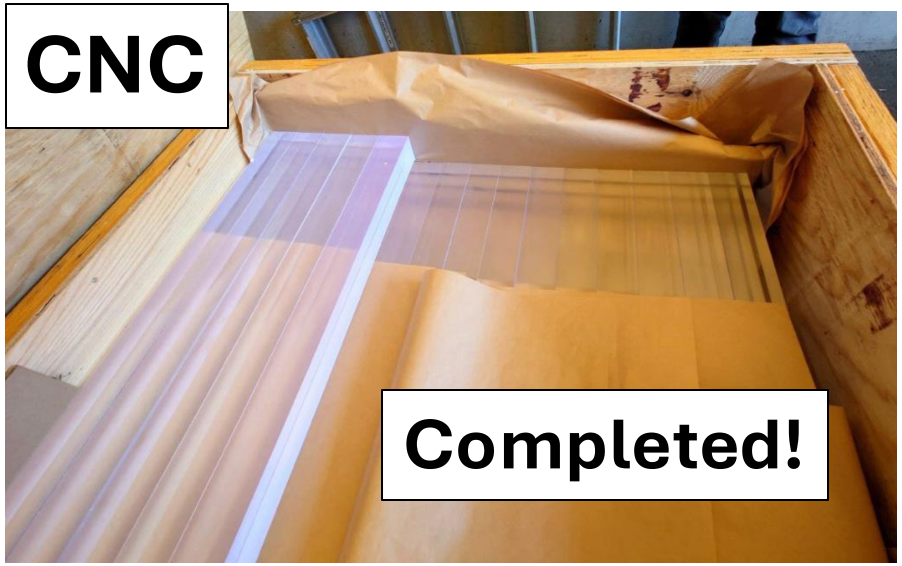
Construction status

Return York

SC Solenoid

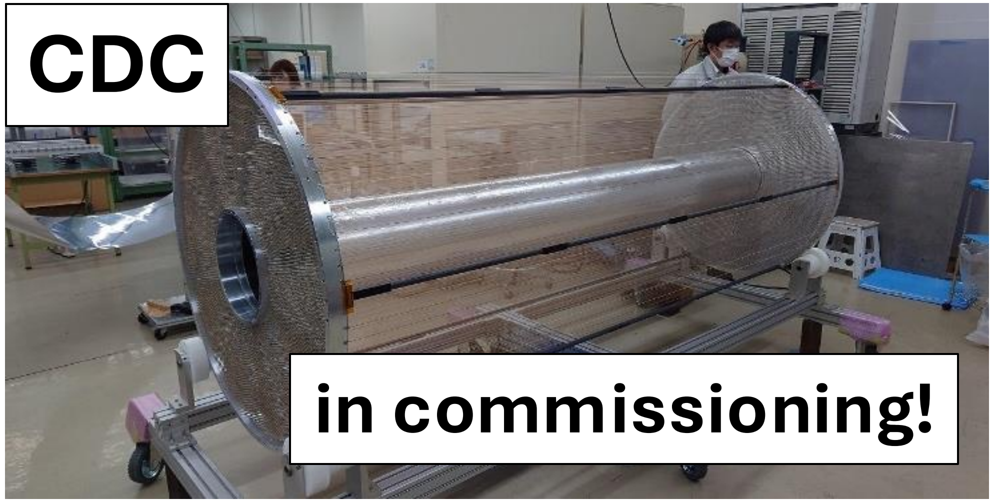
Install into K1.8BR beamline in 2026
Final measurement of the magnetic field w/ the york

CNC



Completed!

CDC

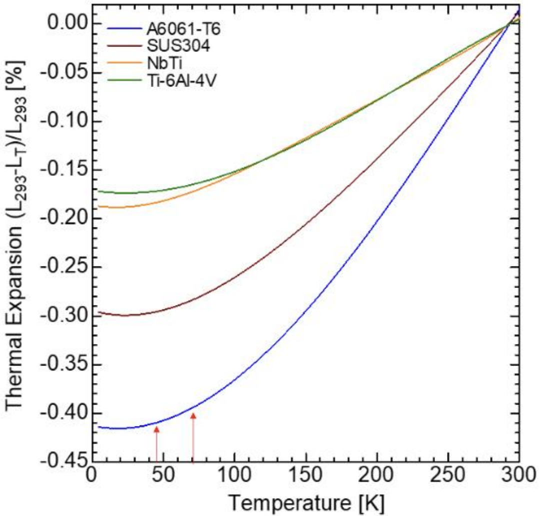


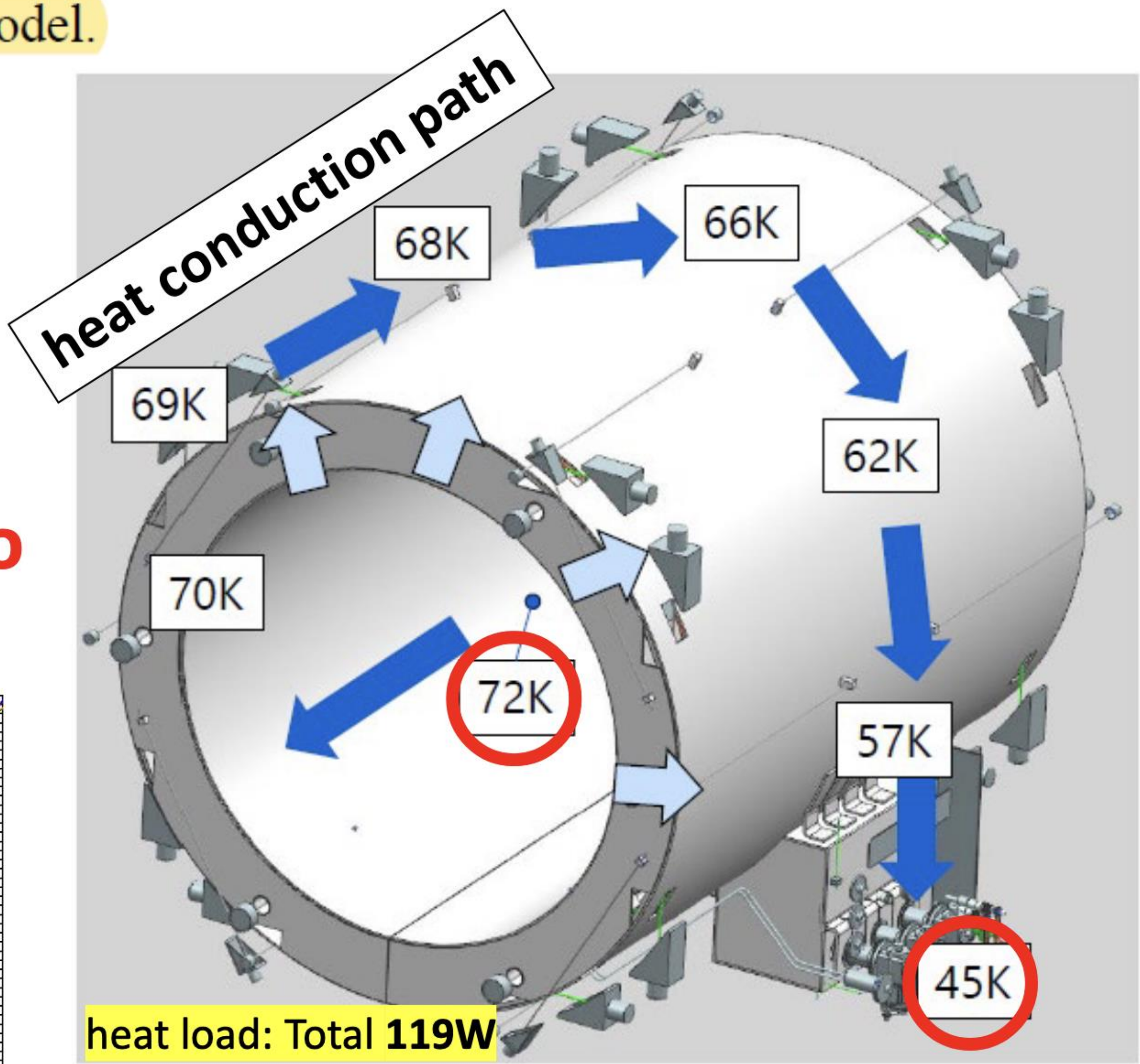
in commissioning!

- Since heavy cold mass is cooled down from one side in the present design, a large temperature gradient is expected in the cooling process. It is better to confirm whether it is mechanically acceptable using 3D model.

- Thermal shield temperature gradient is estimated based on the thermal resistance of the heat conduction path.
- **Temperature difference of 27K (= 72K - 45K) from the refrigerators to the farthest point of the center of the inner cylinder**

➤ **Acceptable range**
- Strain = 1.709E-04
- Stress = 12 MPa
  - Young's modulus = 70 Gpa
  - Tensile stress > ~60 MPa



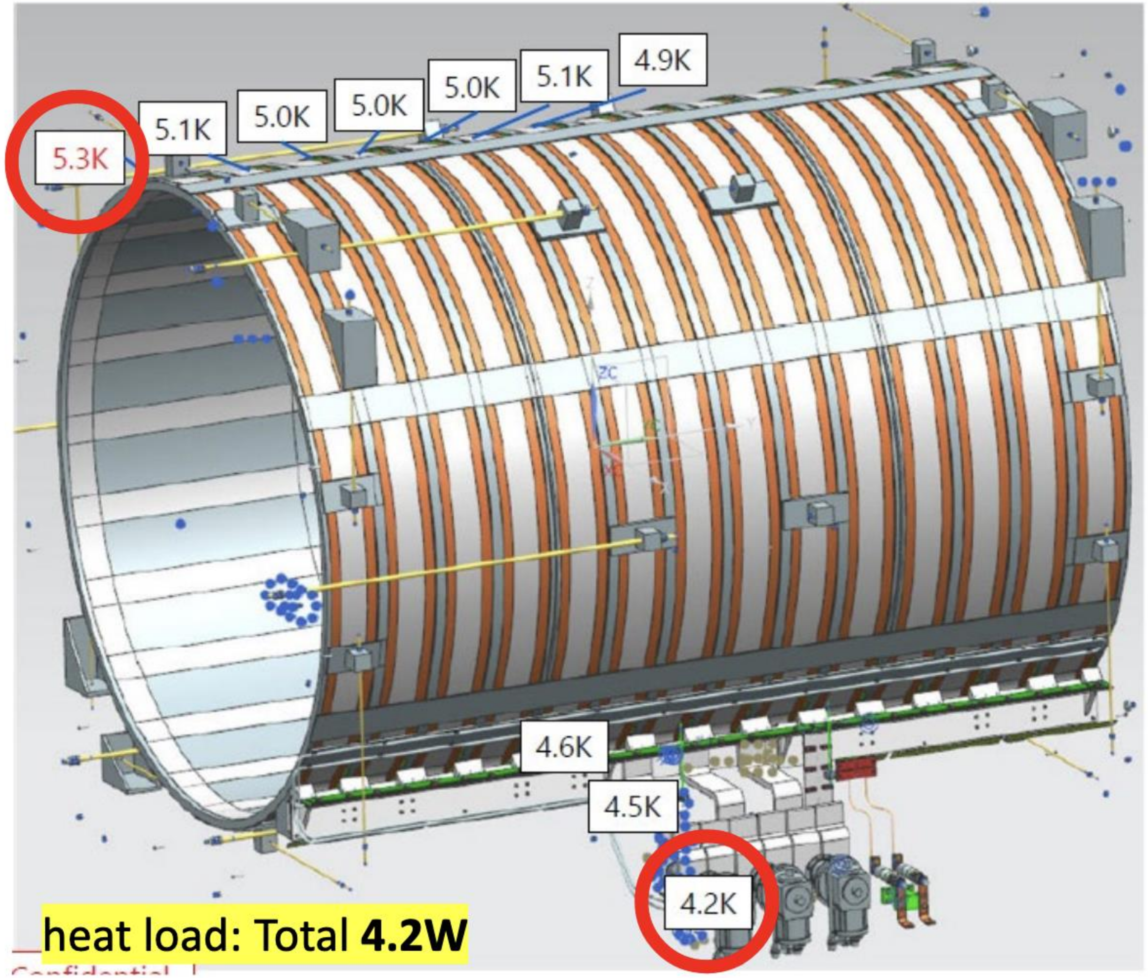


- Since heavy cold mass is cooled down from one side in the present design, a large temperature gradient is expected in the cooling process. It is better to confirm whether it is mechanically acceptable using 3D model.

- Temperature difference from the refrigerator to the farthest coil surface is calculated from the thermal resistance.
- **Temperature difference of 1.1K (= 5.3K - 4.2K) from the coil surface to the refrigerator.**

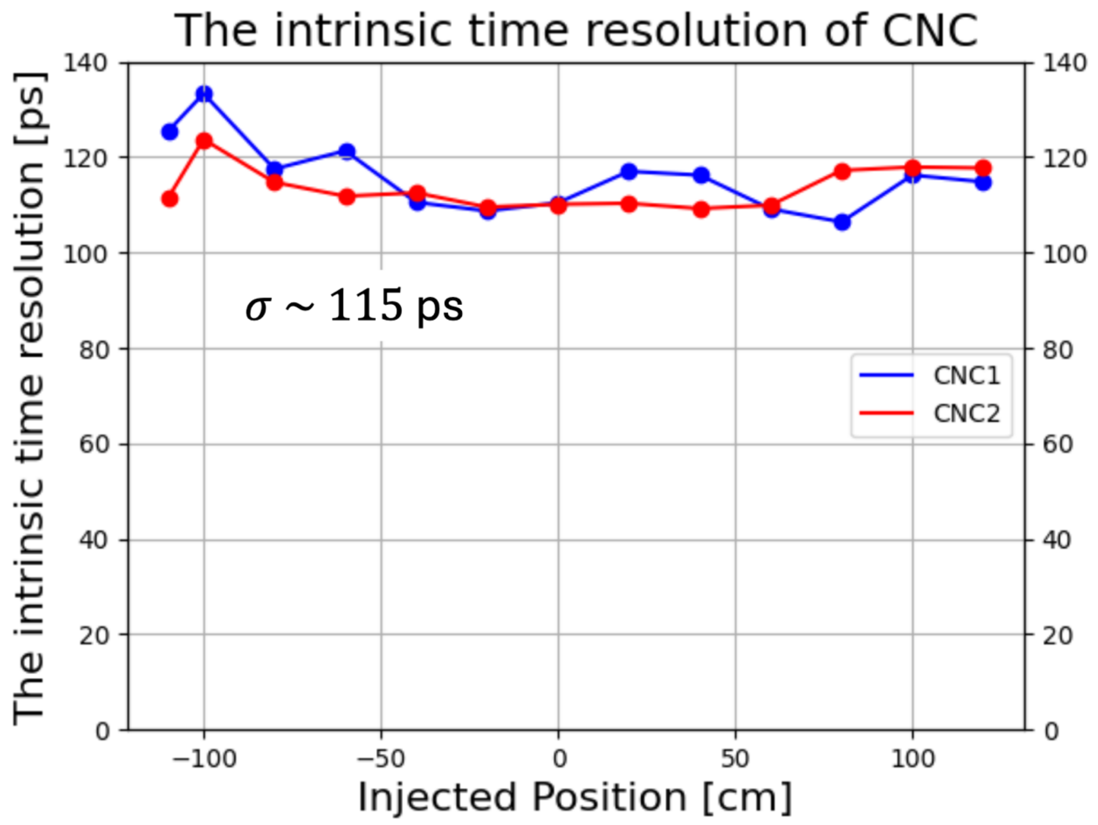
➢ **Sufficient temperature margin**
  - ✓ maximum temperature = 5.3 K
  - ✓ critical coil temperature = 8.0 K

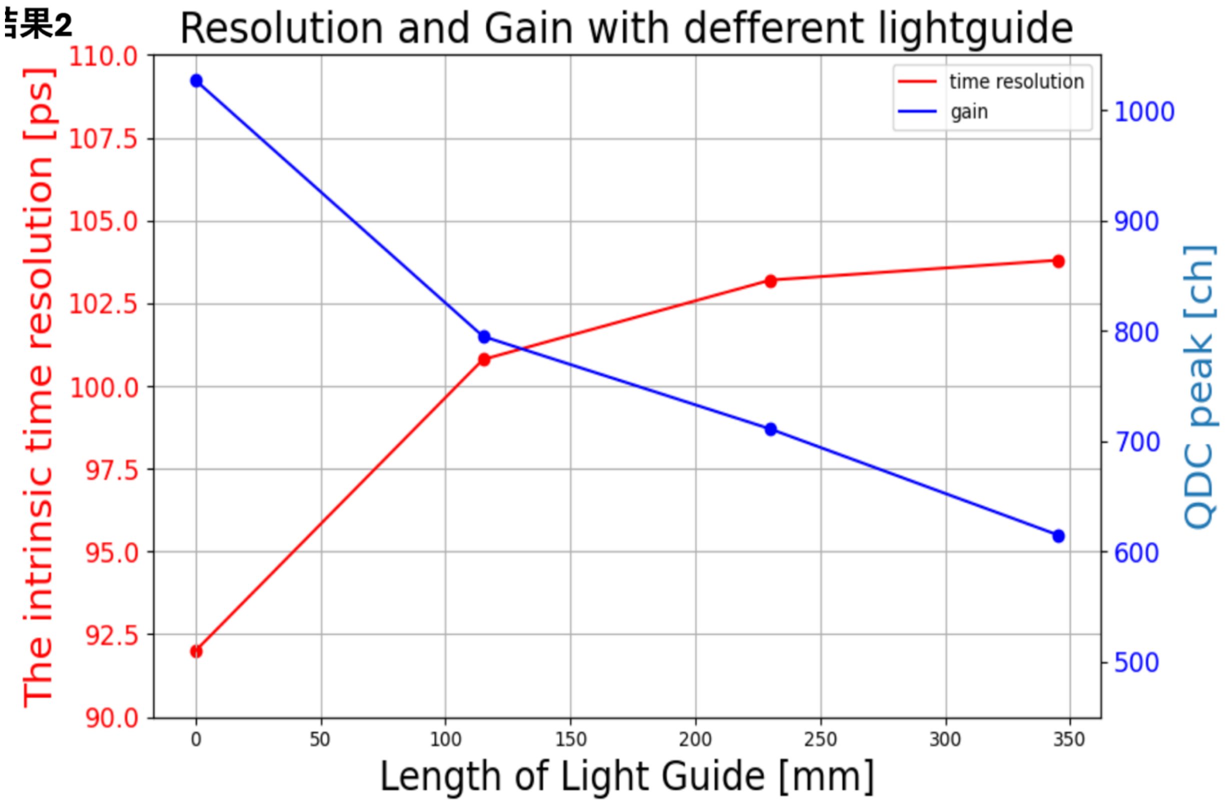
➢ **The cold mass is designed to come to the magnetic field design position after shrinkage at low temperatures.**
  - ✓ When cooled, the cold mass is lifted ~3mm to meet the design axis.



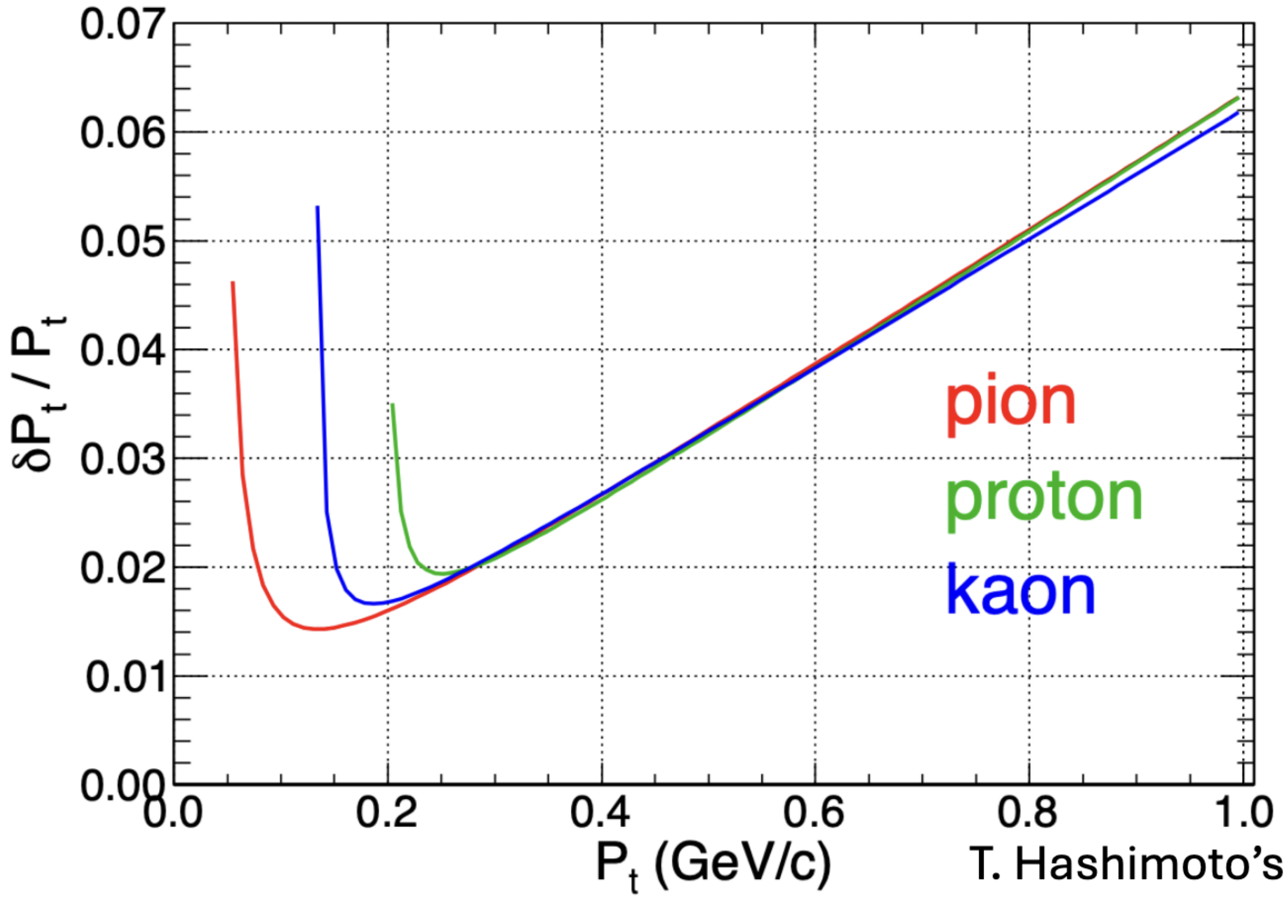
Each coil conduction cooling structure consists of cooling strips made of high purity aluminum with a thermal conductivity of approximately 4,000 W/m·K.

Time resolution of CNC





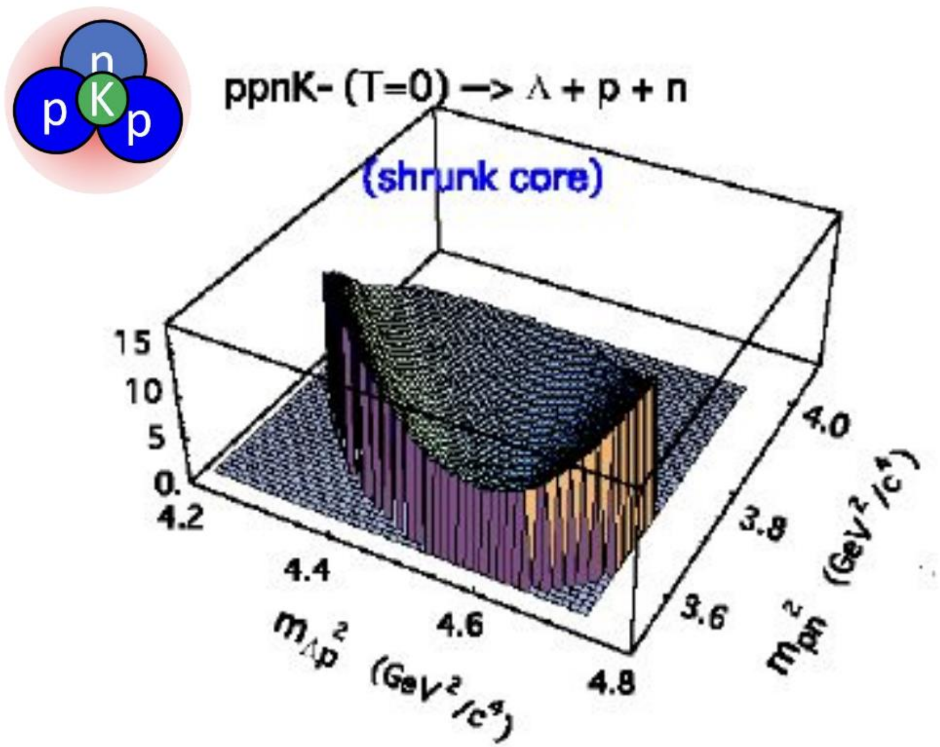
Momentum Resolution of CDC

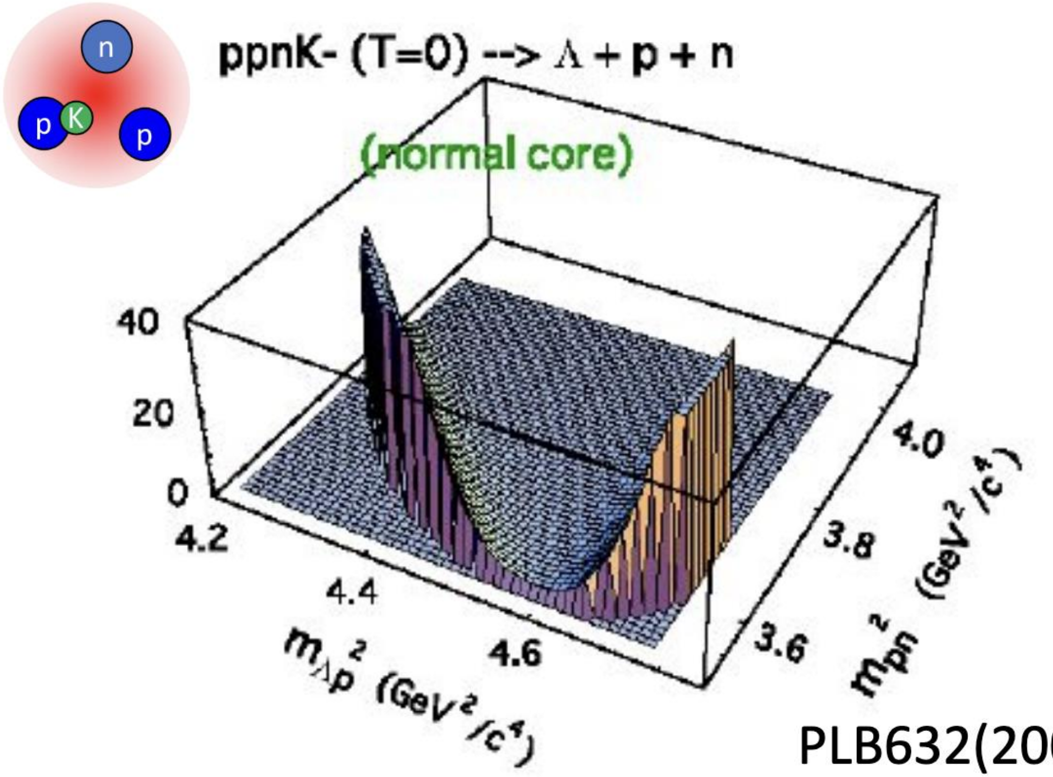


T. Hashimoto's D Thesisより

The simulated p_t resolution of the CDC single track for each particle species.

Why K-ppn → Λ p n ?

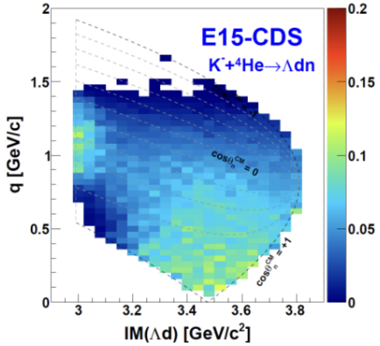


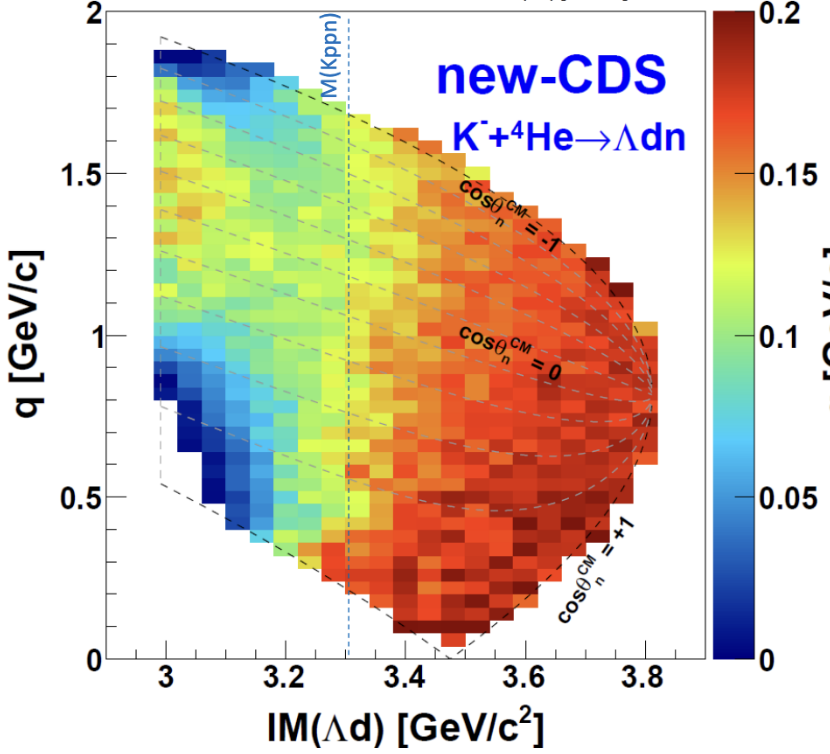


PLB632(2006)187

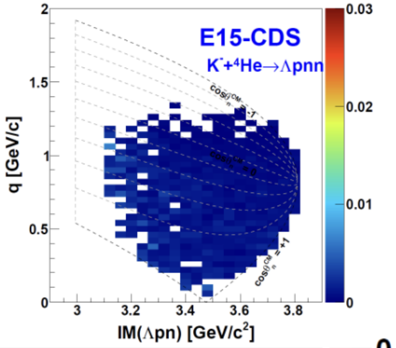
Acceptance improvement

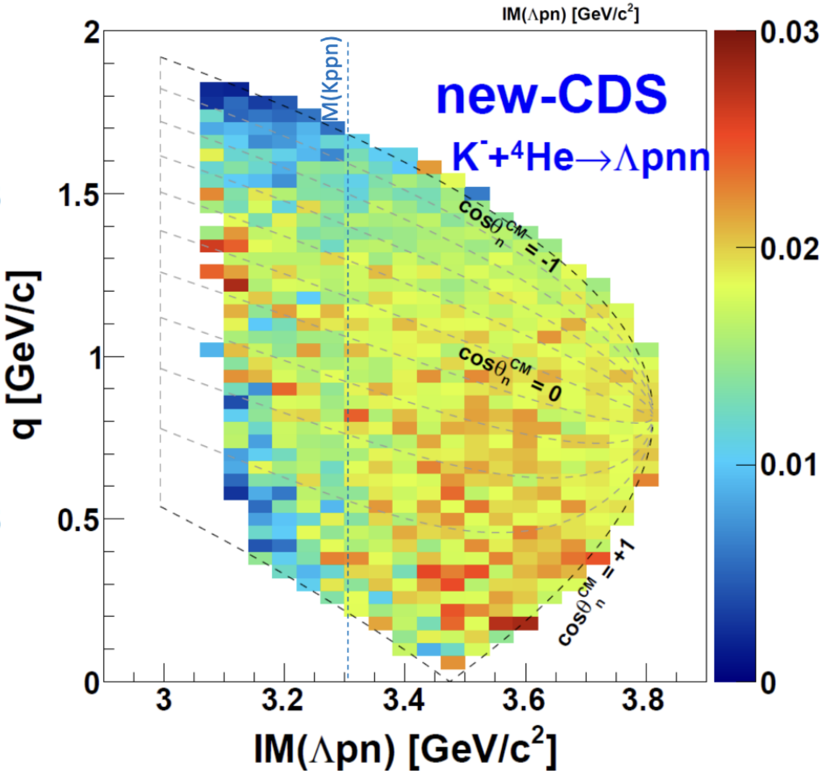
Λd in CDS





Λpn in CDS





Others

- The Λpn decay channel allows us to detect *all* final-state particles easily.
- By going from K^-pp to K^-ppn and K^-ppnn, we can study how the binding energy and decay width evolve with the number of nucleons.
- Such studies are directly connected to the physics of dense nuclear matter, which is relevant for neutron stars.
- Any new particle or exotic nucleus is first confirmed in dedicated experiments.
  - Only after accumulating sufficient evidence across multiple experiments does it get listed in the PDG.
- **“Aren’t there other possibilities besides K^-pp? For example,** Sigma**?”**
  - *We checked alternative scenarios, but the kinematics are best explained by* K^-pp.
  - ***That is a very important point, and actually, Dr. Hashimoto will give a dedicated talk on Thursday focusing on the physics aspects. I recommend attending his talk for a more detailed discussion.***
- **“How can you say the K^- is real?”**
  - *That is a very important point, and actually, Dr. Hashimoto will give a dedicated talk on Thursday focusing on the physics aspects. I recommend attending his talk for a more detailed discussion.*
- **“Can you extend this to heavy nuclei like iron or lead?”**
  - *In principle, yes, kaonic bound systems in heavier nuclei are of great interest.*
  - *However, our current focus is on light kaonic nuclei, where we can perform fully exclusive measurements.*
- *We have already confirmed that there is no position dependence. As for the angle dependence, to be honest, we have not yet tested it experimentally. It may require some adjustment of the readout side — namely, the MPPC preamps and the dynamic range of the QDC.*

Others

- To reconstruct the reaction mechanism comprehensively, we need data from as wide a phase space as possible.
- Wide acceptance is necessary to find such “sweet spots.”
- ***That is a very important point, and actually, Dr. Hashimoto will give a dedicated talk on Thursday focusing on the physics aspects. I recommend attending his talk for a more detailed discussion.***