A New Cylindrical Detector System for Studying Light Kaonic Nuclei at J-PARC

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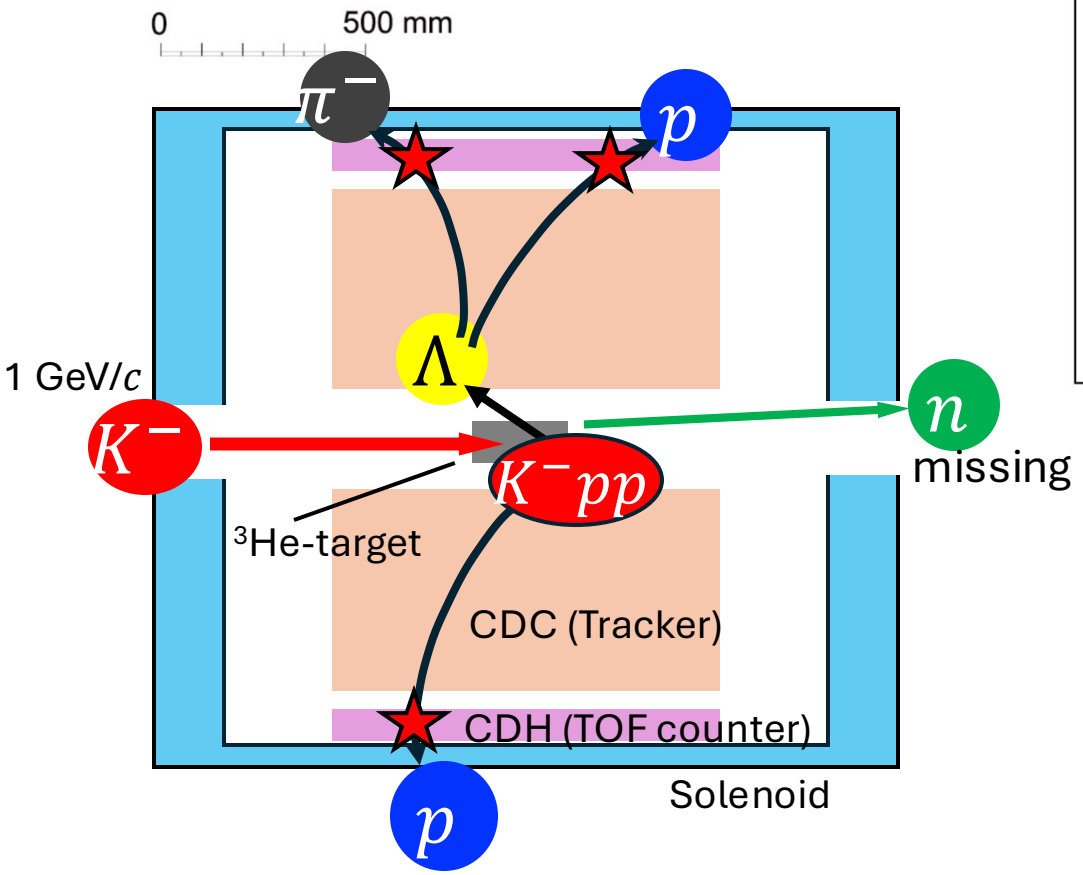
RARiS Tohoku University

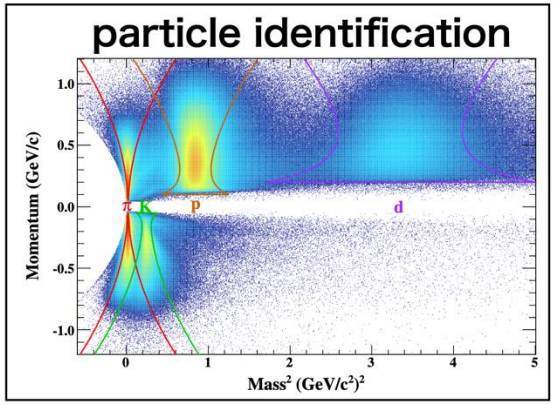
RIKEN NiSHiNA CENTER

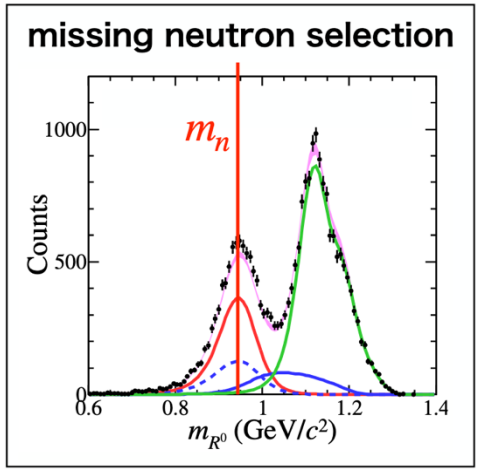
HYP2025 TOKYO

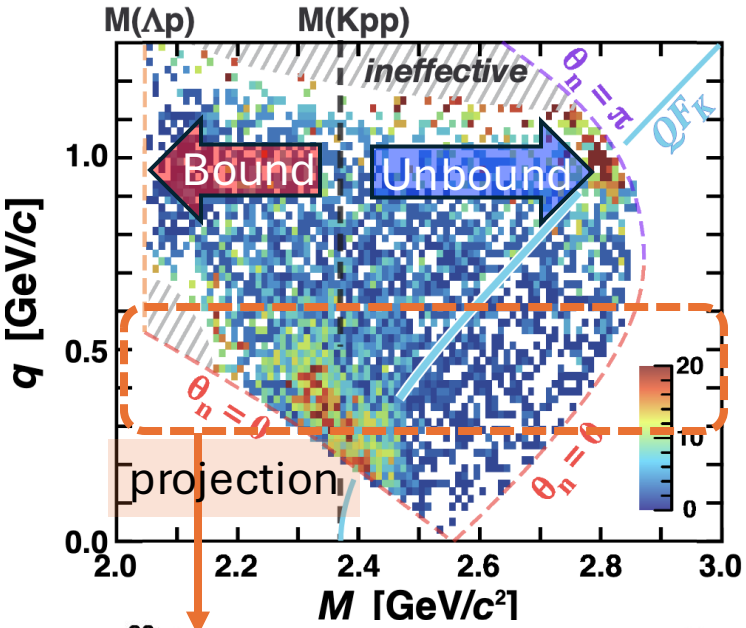
"K^-pp" confirmed : J-PARC E15

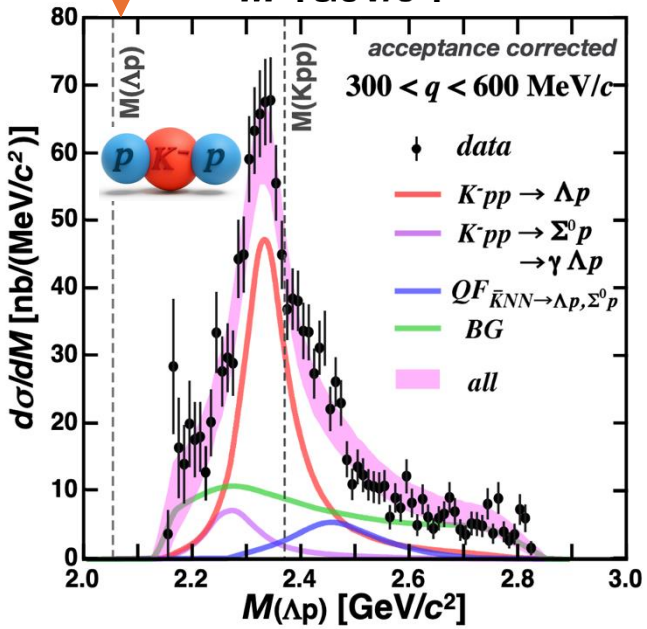
- ✓ **in-flight (K^-, n) reaction**
  - ✓ Effectively produce kaonic nuclei
  - ✓ Simplest target allows an **exclusive analysis**
- ✓ **Covering a wide kinematical region**









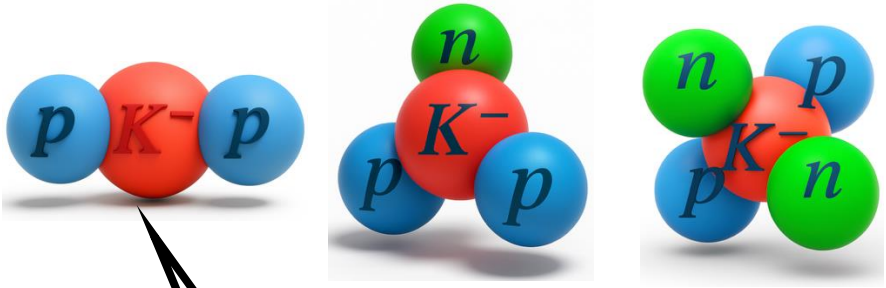


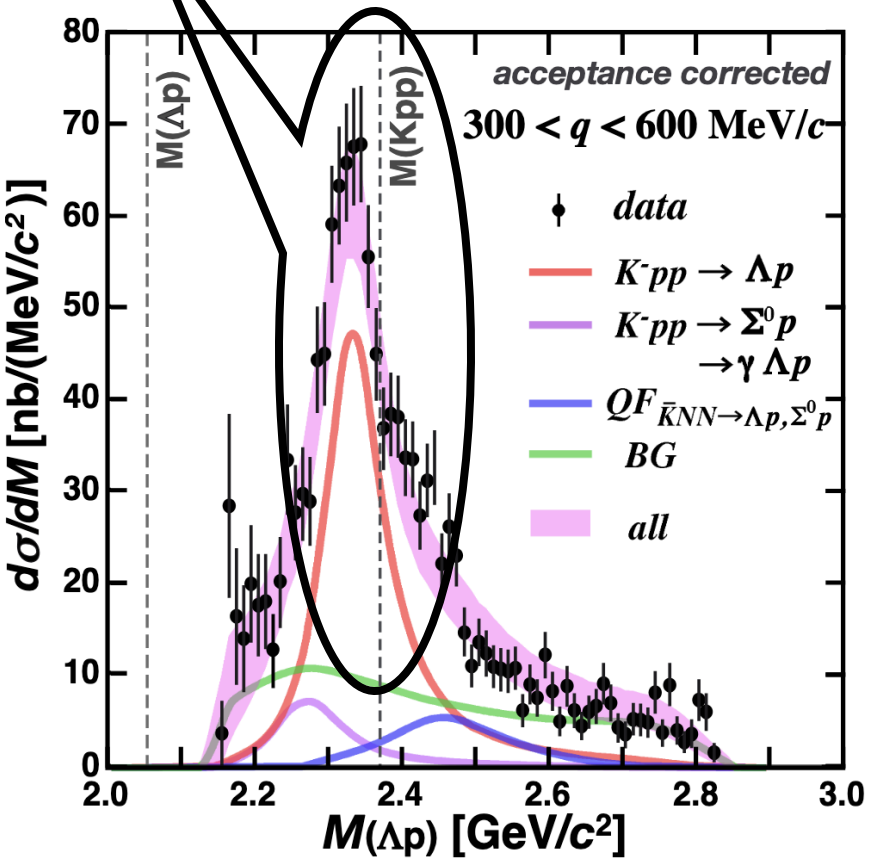
Next Kaonic Nuclei Experiments

- J-PARC E15
  - "K^-pp" was successfully observed.

- From Existence to its Natures
  - Systematic investigation for Light Kaonic Nuclei
    - K^-ppn
    - K^-ppnn

    Plan to start J-PARC E80 in 2027
  - "K^-pp" research in more detail
    - Its isospin partner "$\overline{K^0}nn$"
    - Spin-Parity of "$\bar{K}NN$"

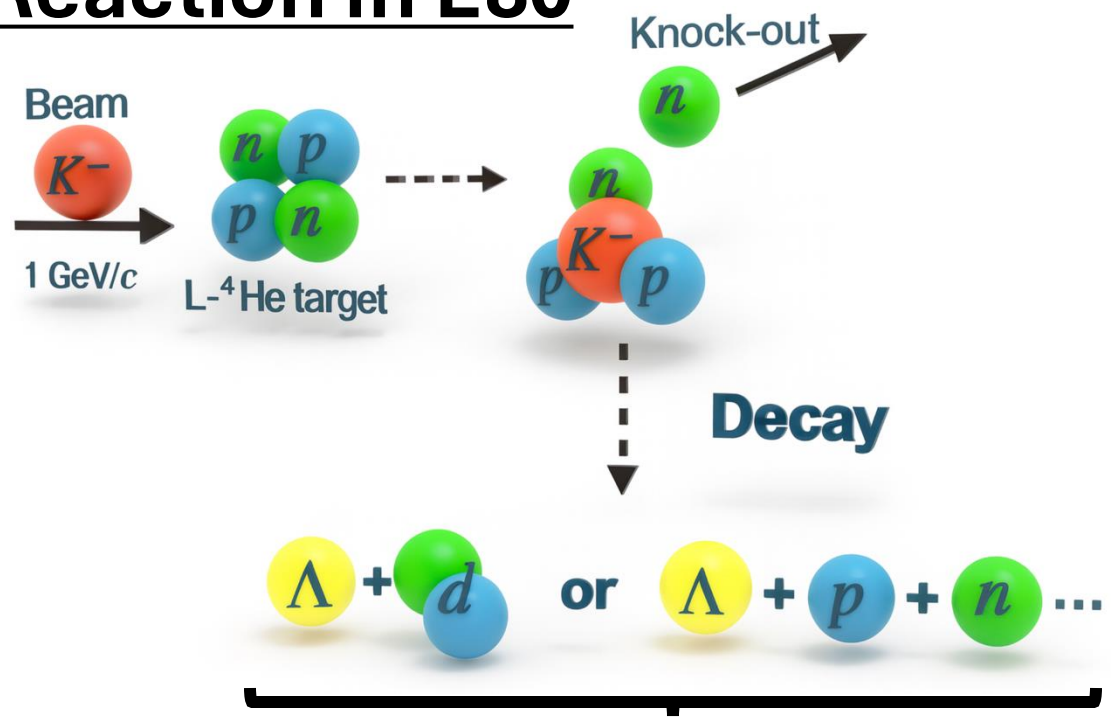




"K^-ppn" Search: J-PARC E80

The experimental method follows that of J-PARC E15.

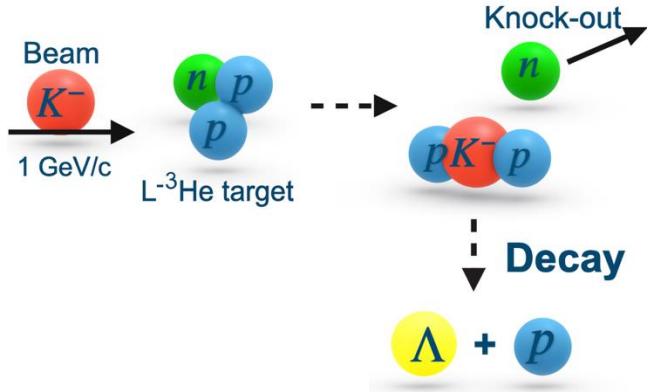
Reaction in E80



Detect

→Reconstruct the M_{K^-ppn}

c.f.) Reaction in E15



Comparing to E15 ("K^-pp"),

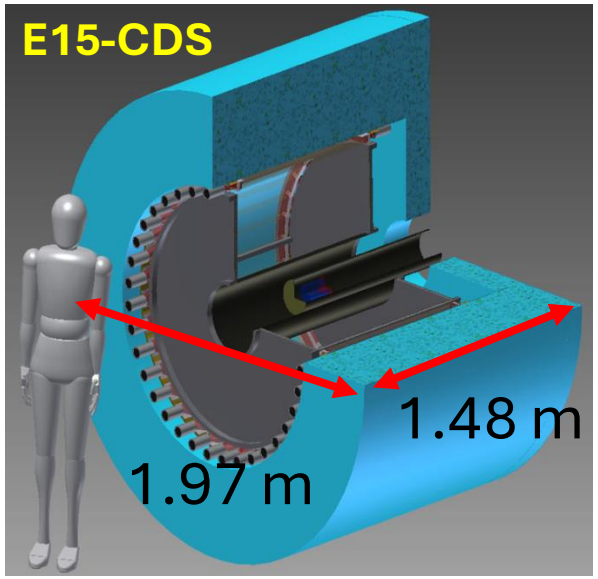
- ✓ **More decay particles**
- ✓ **Neutron to be detected**

⇩

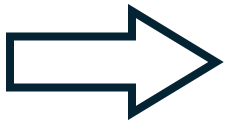
Our detector system must have

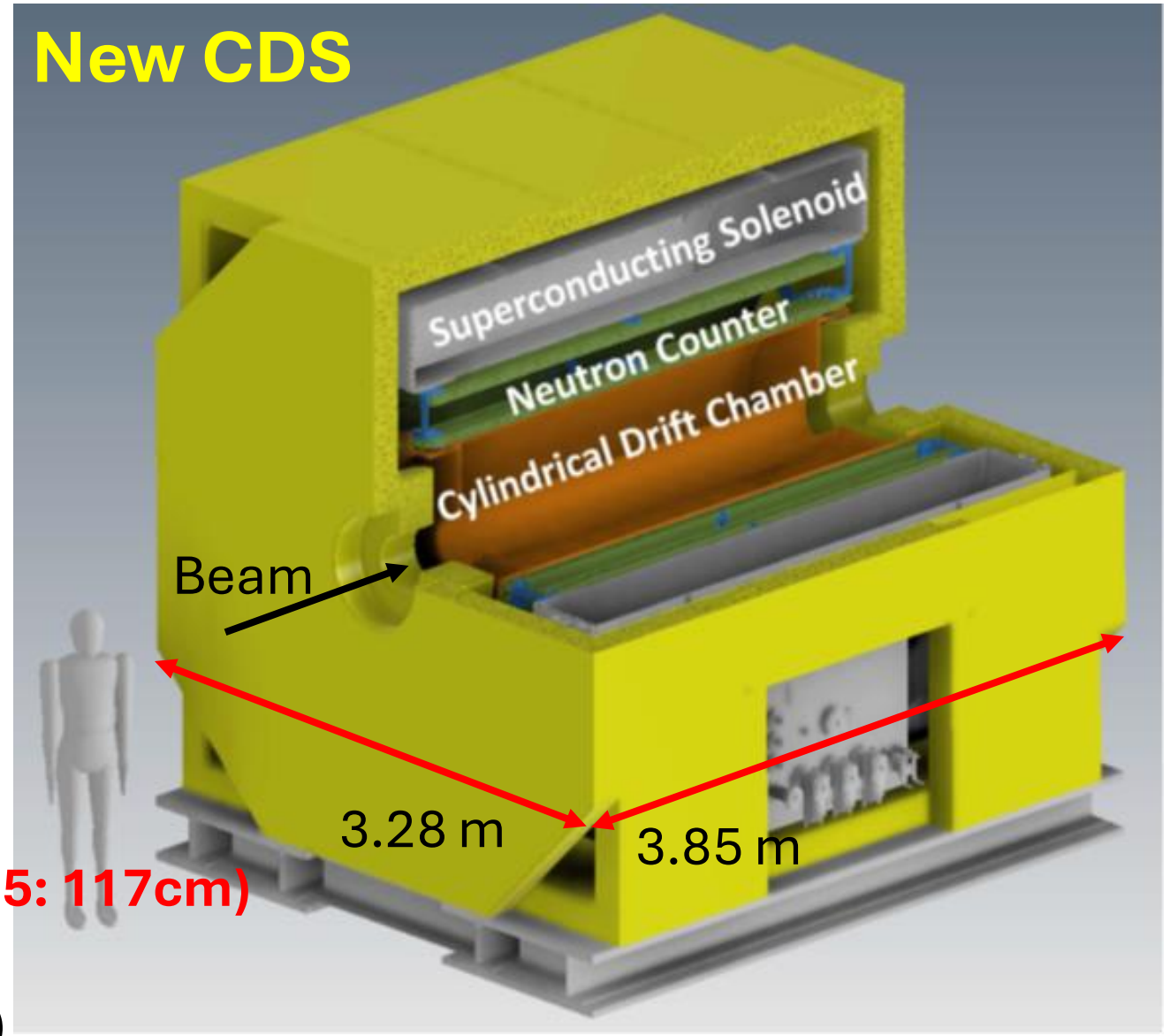
- ✓ **Larger solid angle**
- ✓ **Better neutron detection efficiency**

New Cylindrical Detector System, CDS



~8 times the volume

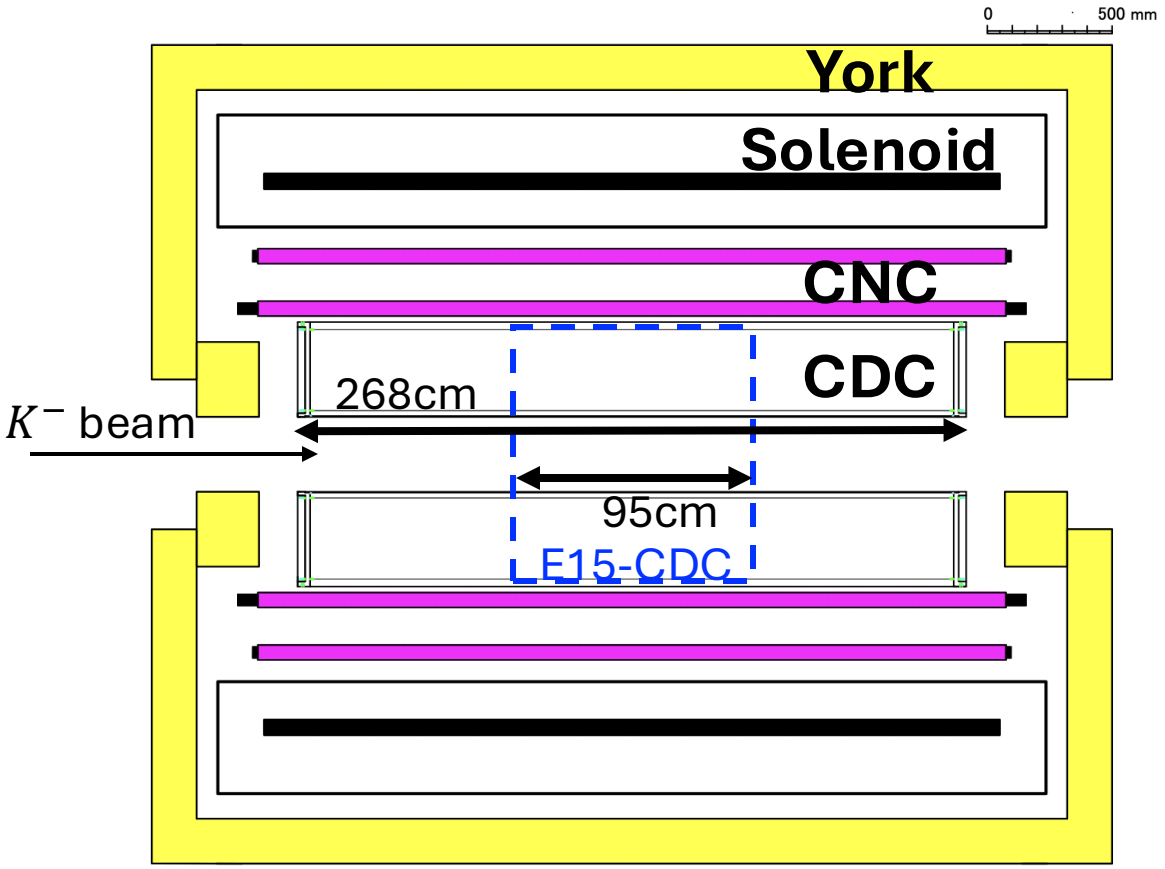




To extend the detectors,
and to increase the total thickness
of the neutron counter,

- **Superconducting Solenoid Magnet**
  - **Inner Radius 180cm (E15: 59cm)**
  - **Length along beam axis 320cm (E15: 117cm)**
  - Max. field of 1.0T @ center
  - (The same design as the COMET DS)

How to upgrade



- ✓ Extend CNC and CDC about **x3 longer along the beam axis**
- ✓ **CNC thickness x4**

Cylindrical Neutron Counter, CNC

- Plastic Scintillator
  - 300cm × 6cm × 6cm x 138 segments
  - 2 Layers
    - Total thickness 12cm (E15-CDH : 3cm)

Cylindrical Drift Chamber, CDC

- Length 268 cm × 8,244 wires
- The same cell-structure design as the E15- CDC

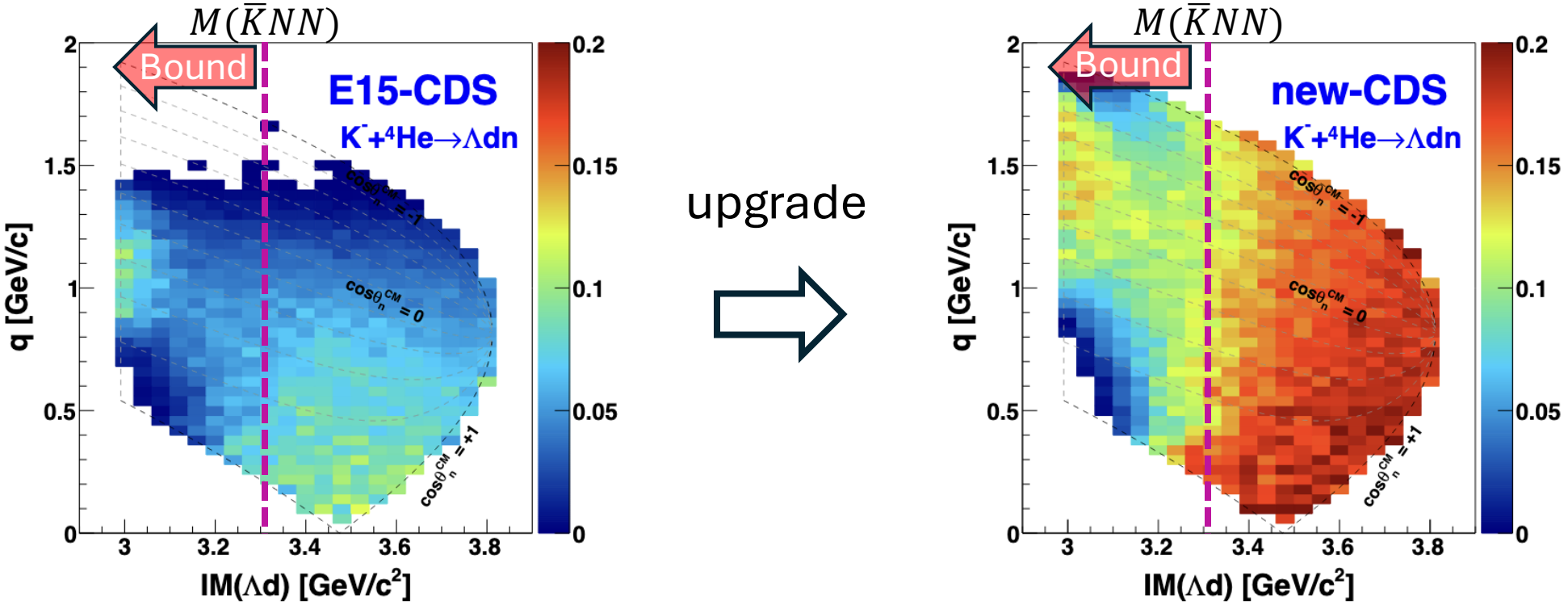
→ Solid Angle: x1.6 (59% → 93%)

→ Neutron Eff.: x7 (3% → 12%x1.6)

Acceptance improvement

- ✓ **Enable us analyze on larger kinematical region**
- ✓ **Data taking became 2~4 times more efficient**

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

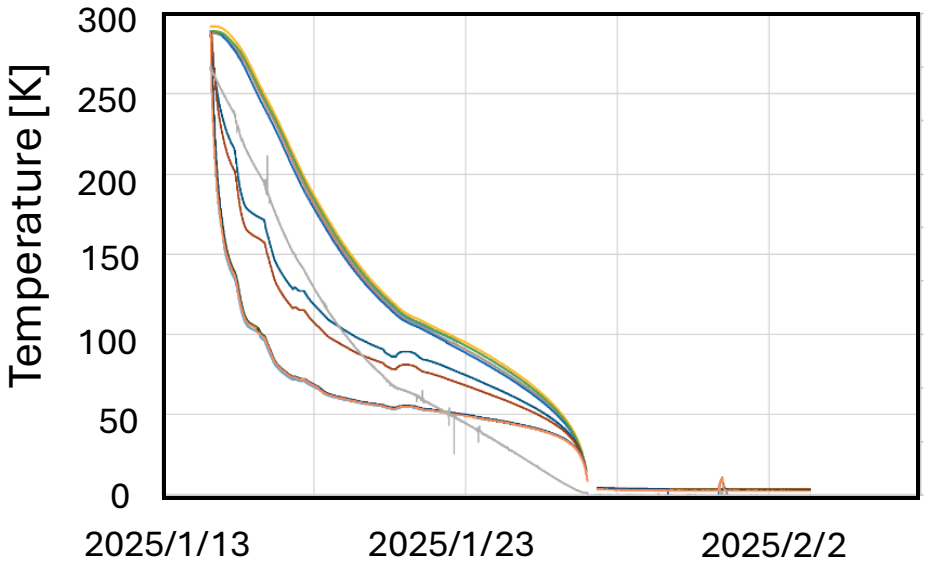


Status: SC Solenoid

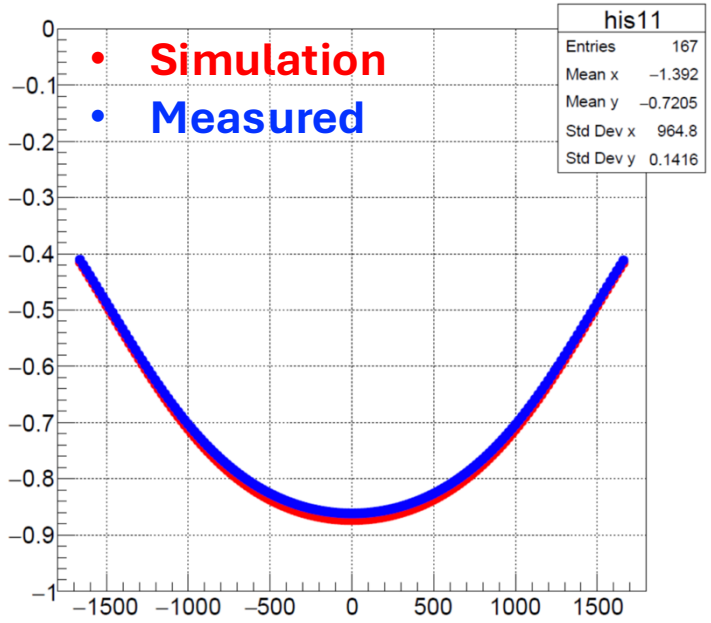
Return York

Solenoid

Cooling Test



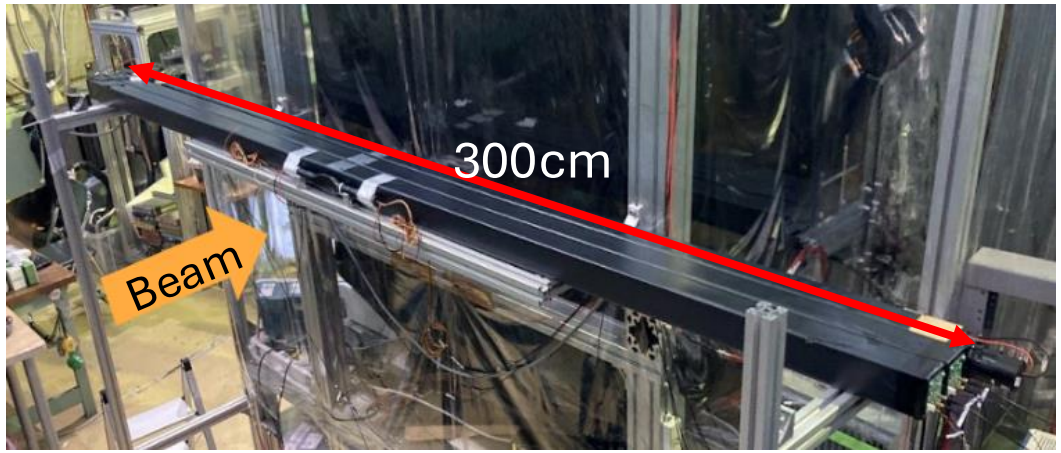
Magnetic field measurement
w/o yoke @TOSHIBA
(Beam axis scan, **I = 189A**)

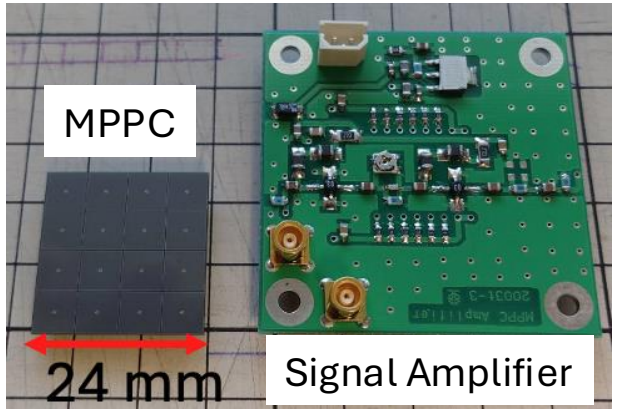


- ✓ **Cooled by GM and successfully excited**
- ✓ **Measured magnetic field w/o York consistent with TOSCA calculations!**

Status: CNC

Proto-type test exp. in 2025





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

Signal Amplifier
- Two-stage RF amplifier
- PZC circuit

Result

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

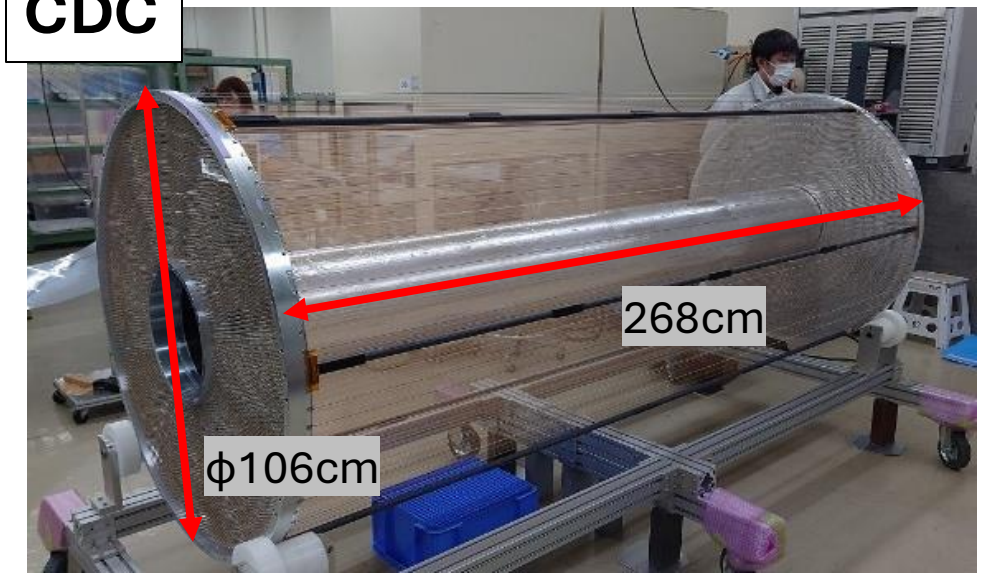
- Readout method of E15-CDH is not applicable for 300cm length.
- To improve light collection efficiency, we dicided to use MPPCs w/o light guides.

✓ **Readout study w/ prototype done (achieved required value σ ~80 ps even if 3m length counter)**

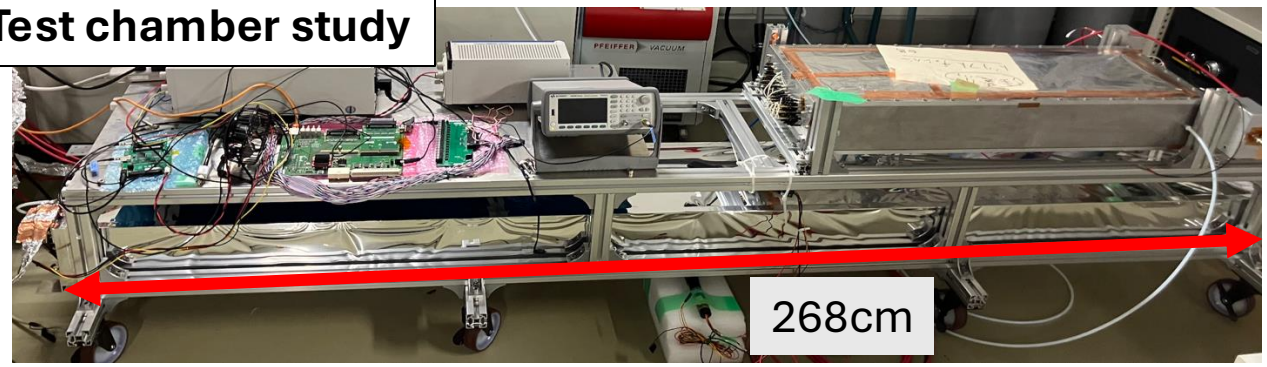
✓ **138 modules is in hand.**

Status: CDC

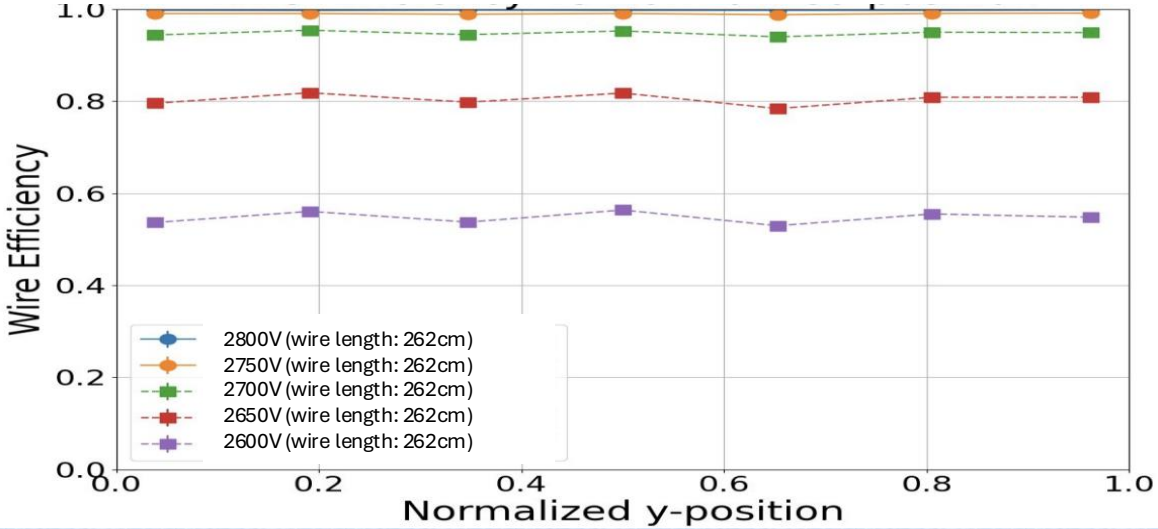
CDC



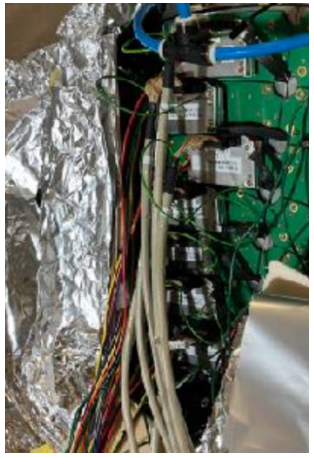
Test chamber study

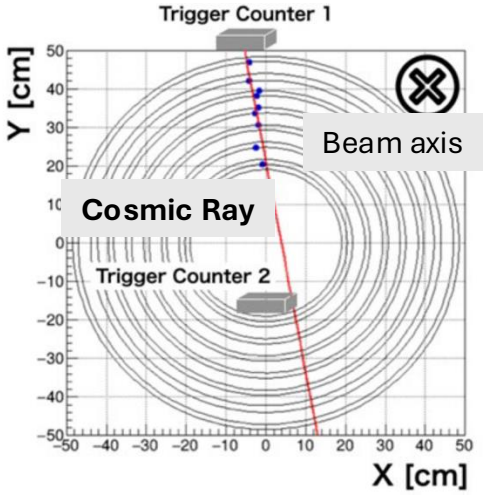


Wire Efficiency vs Position



CDC w/ partial Pre-amp





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

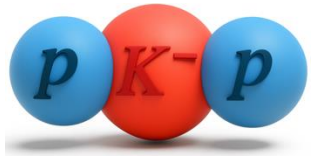
Summary

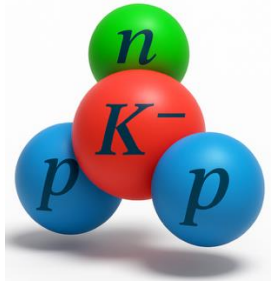
- We developed and constructed a large-acceptance Cylindrical Detector System (CDS) for the next kaonic nuclei experiments.

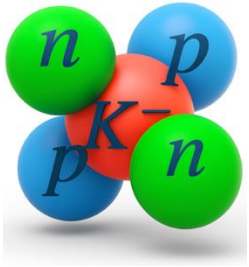
- The three main components (SC Solenoid, CNC and CDC) have been successfully established.

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

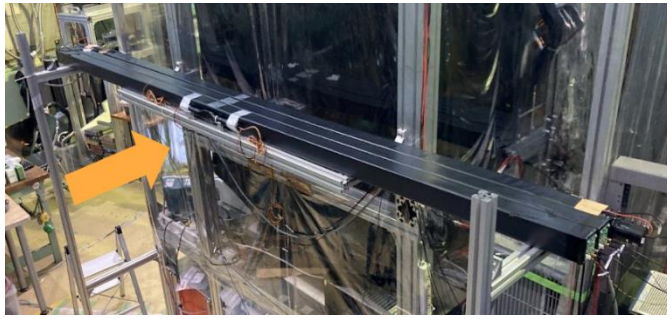
Talk about physics of Kaonic nuclei @talk by T. Hashimoto (on Thursday)
Related Detectors Study @poster by Y. Tsutsumi, No.68

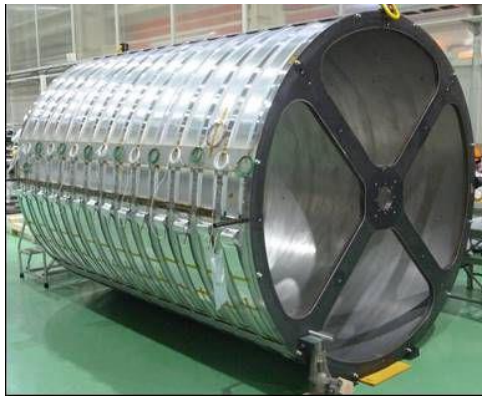


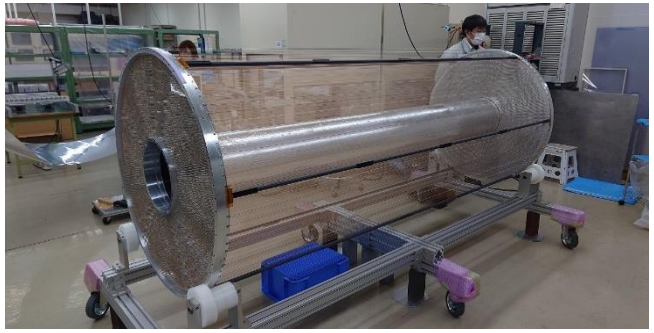




Thank you for listening.







Back Up

New Cylindrical Detector System, CDS

For our next kaonic nuclei experiments,

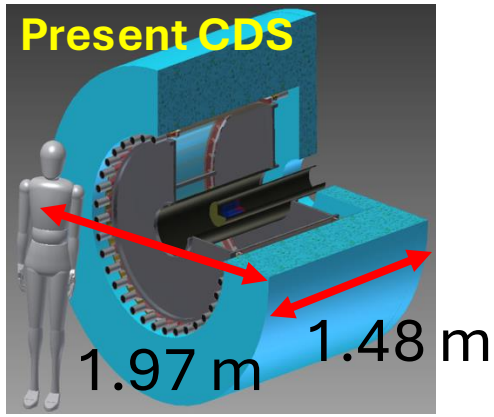
- ✓ **“High-precision”**
- ✓ **“Efficient Neutron Detection”**
- ✓ **“Large Acceptance”**

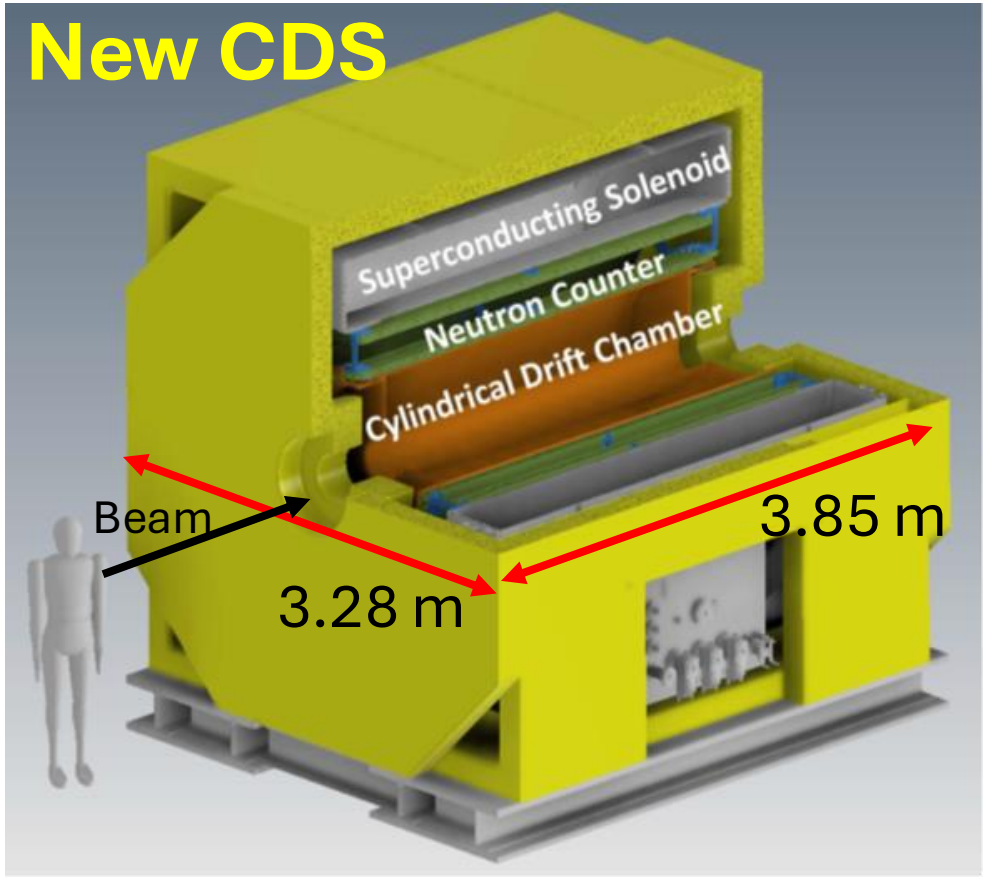
are important.

このページ要注意

Keep the performance of the old CDS

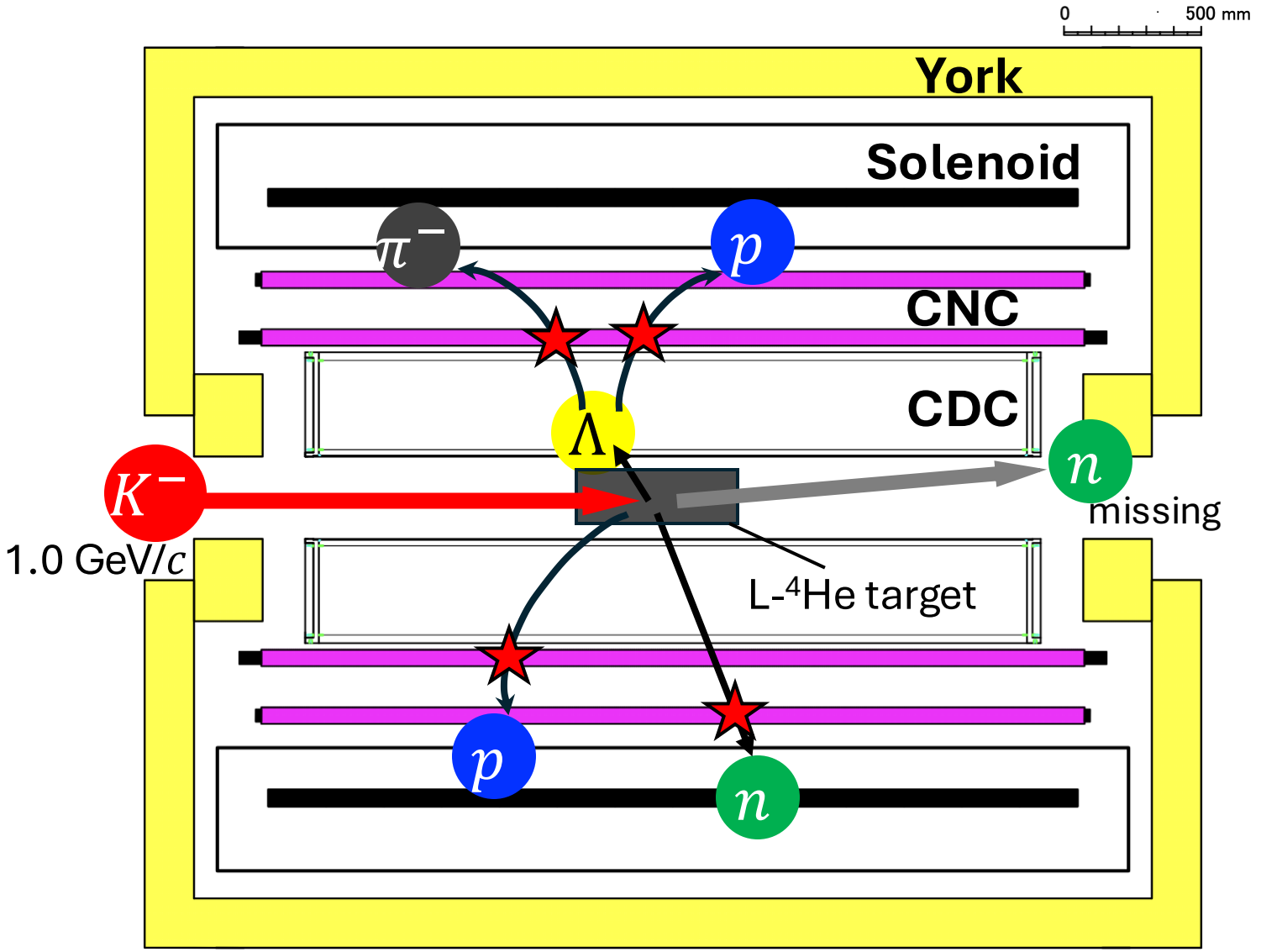
Upgrade with the new CDS





Event Reconstruction

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



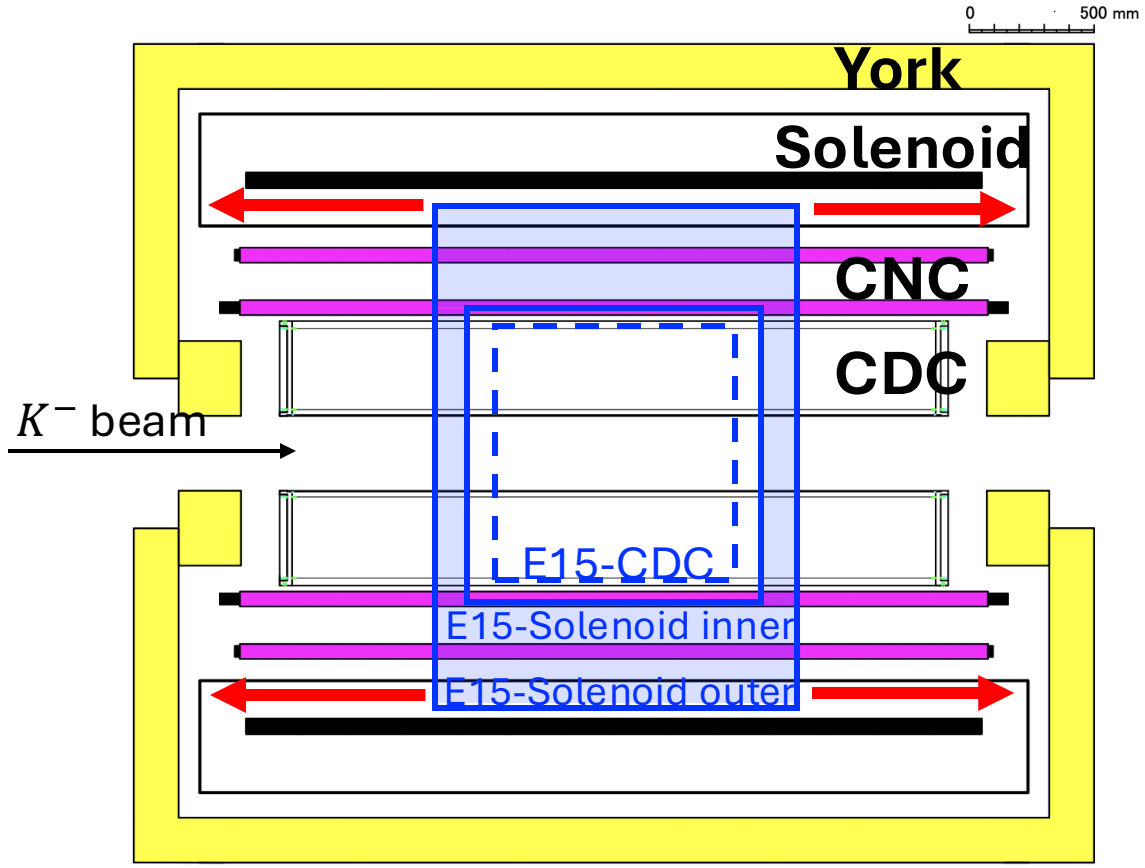
How to upgrade

Solid Angle: x1.6 (59% → 93%)

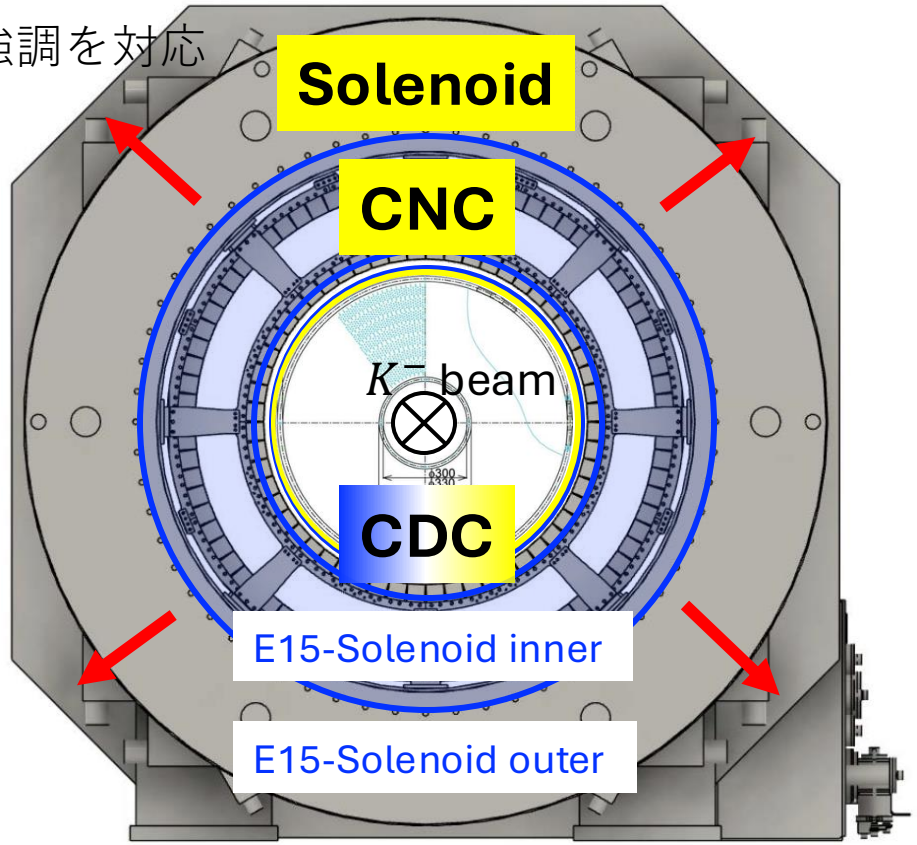
Extend CNC and CDC about x3 longer along the beam axis

Neutron Eff.: x7 (3% → 12%x1.6)

Enlarged solenoid, then CNC thickness x4



タイトルと強調を対応



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

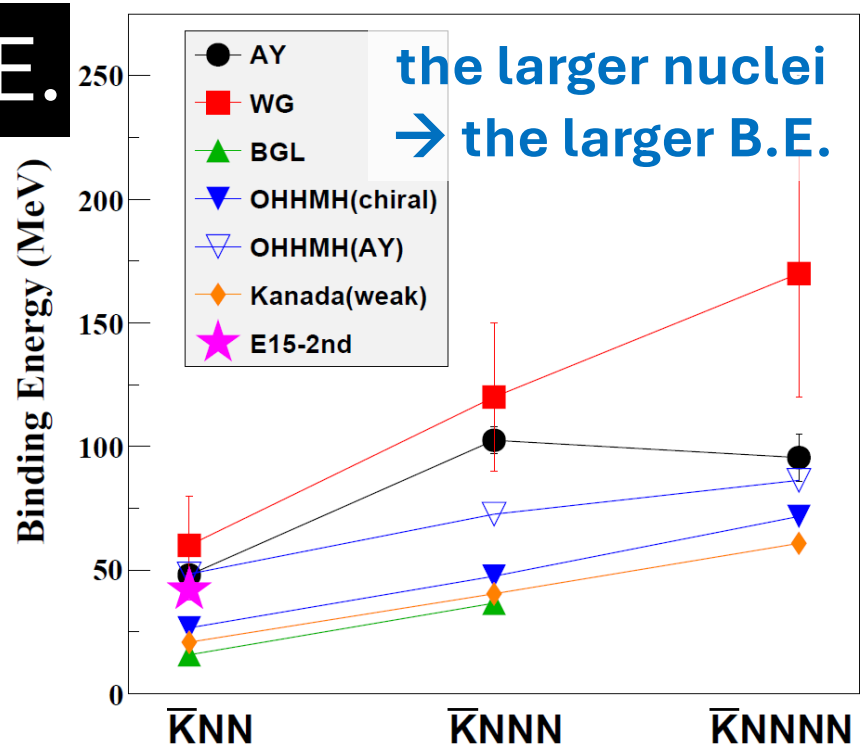
Mass Number Dependence

Theoretical calculation vs Measured B.E and Γ

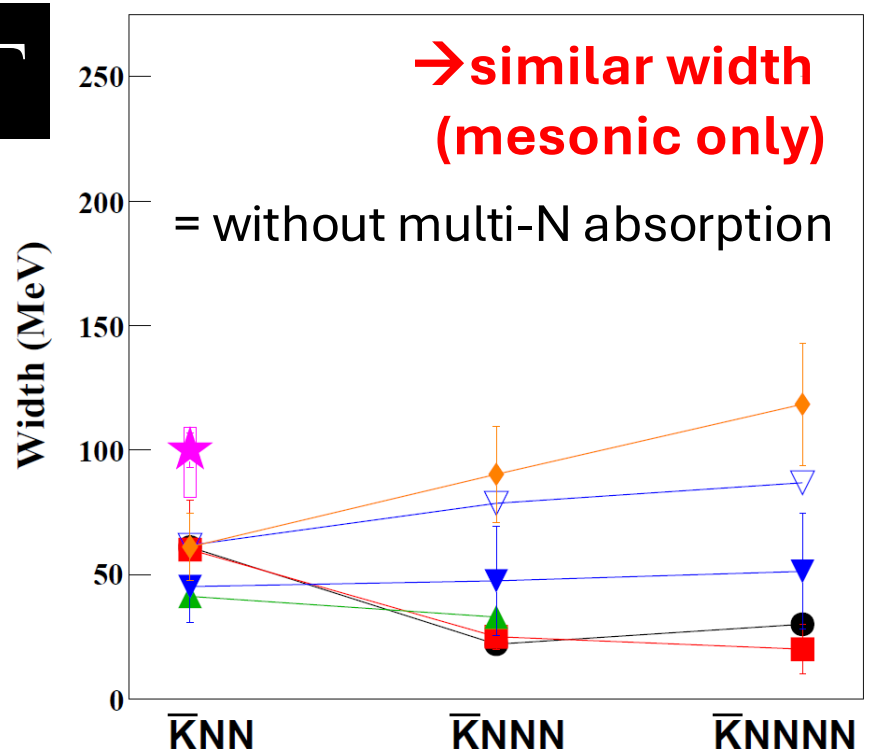
There is uncertainty between the different theories.

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

B.E.



Γ

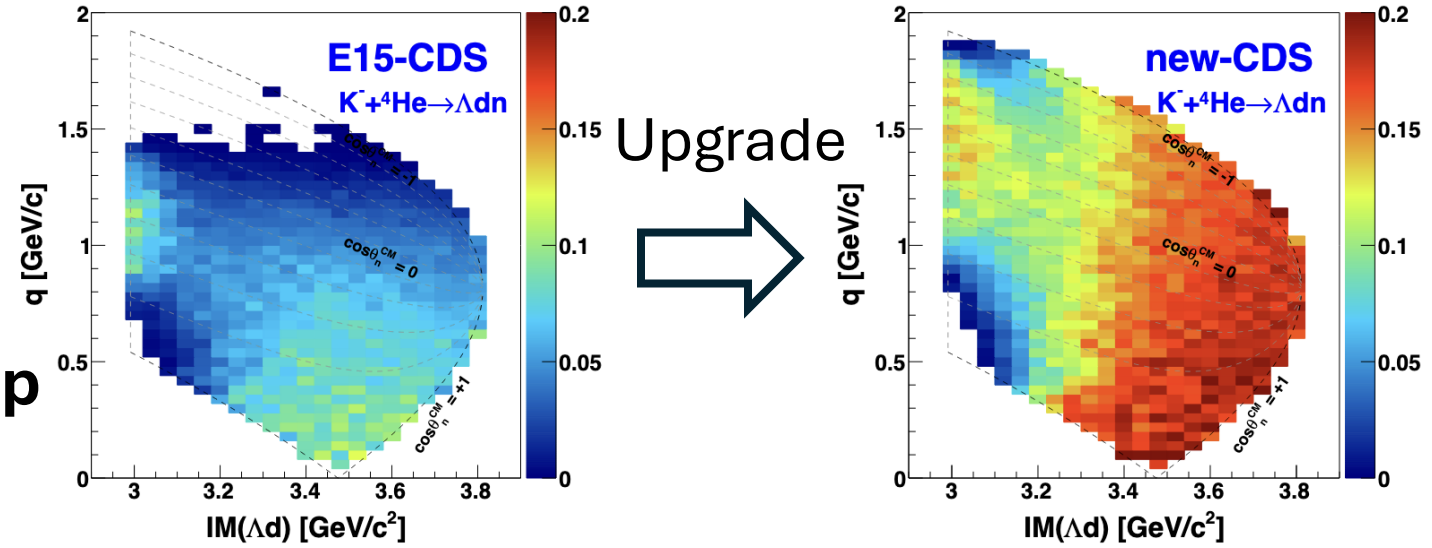


- ✓ **Systematic measurements will provide more conclusive evidence of the kaonic nuclei.**
- ✓ **As a first step, we plan to search for "K^-ppn" in J-PARC E80.**

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**



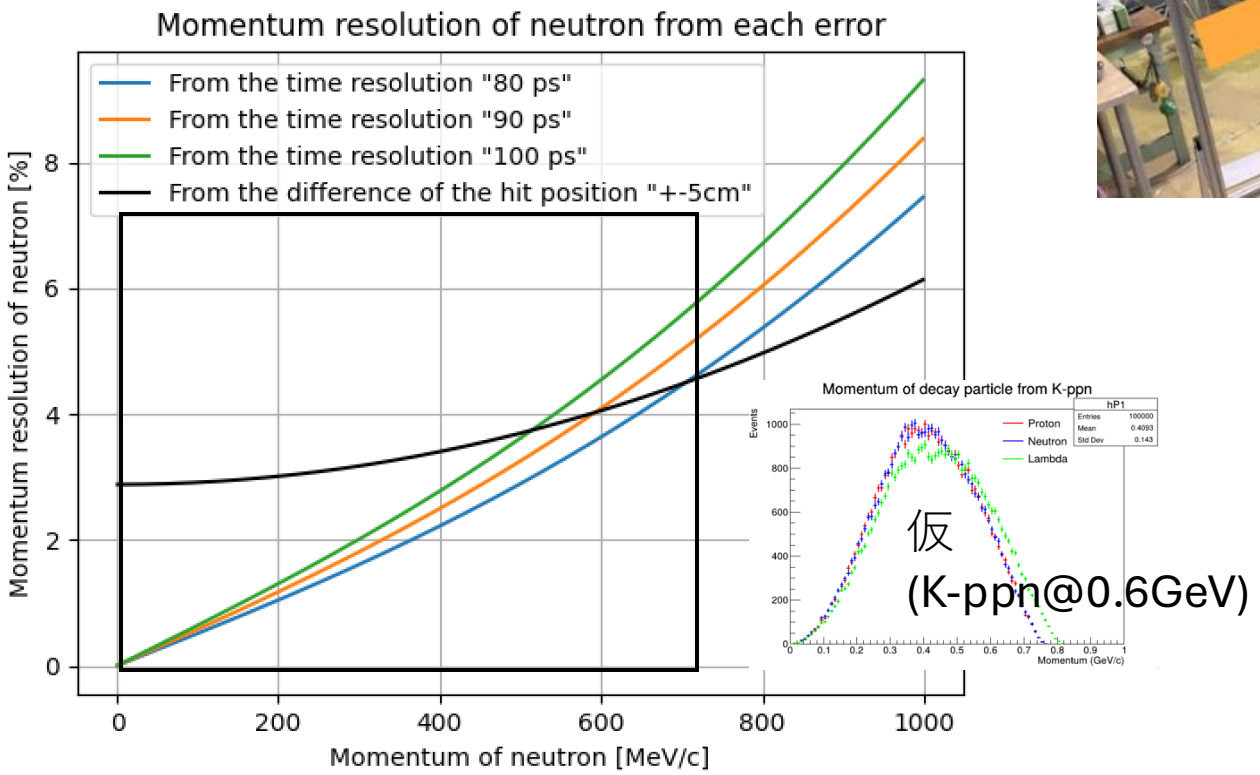
Decay mode	Lp (E15 w/ old CDS)	Ld (E80 w/ new CDS)	Lpn (E80 w/ new CDS)
$\sigma^{tot} \cdot BR$	10 μb	Assumed to be 5 μb	
MR beam power	42 kW	90 kW	
Beam-time duration	1 month	3 weeks	
Accelerator up-time	0.89	0.9	
# of K^- beam	62×10^9	155×10^9	
# of K^- on target	40×10^9	100×10^9	
# of expected yield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

Cylindrical Neutron Counter, CNC

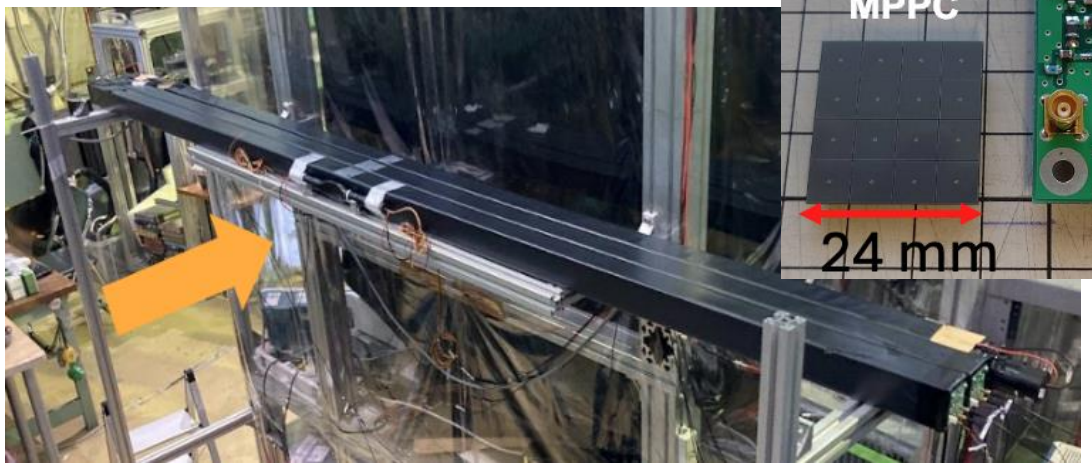
The required performance

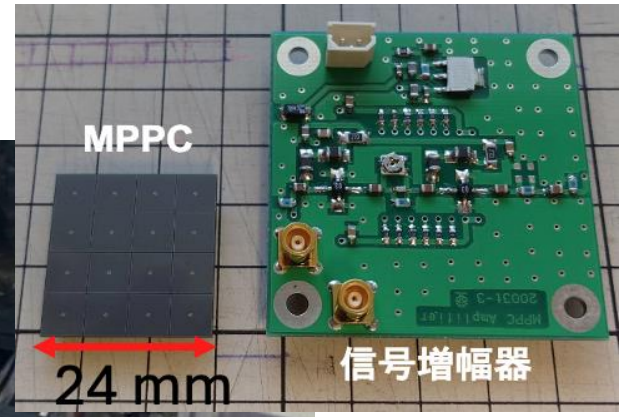
$$\sigma_{thick} > \sigma_{time}$$

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

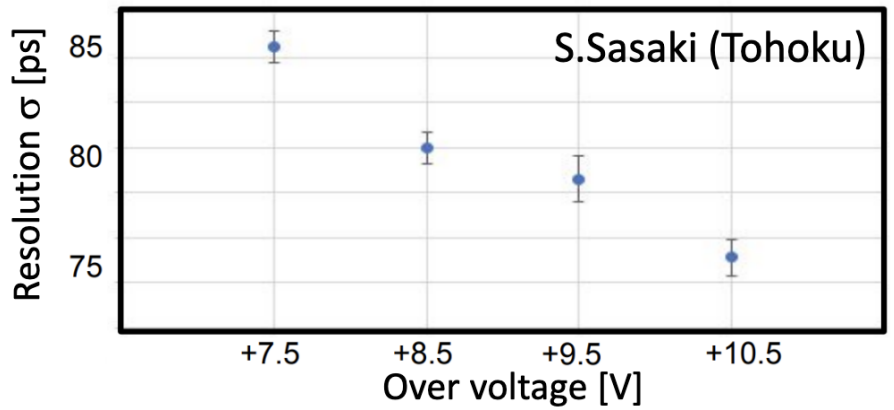


Proto-type test exp. in 2025





Bias-voltage dependence of time resolution

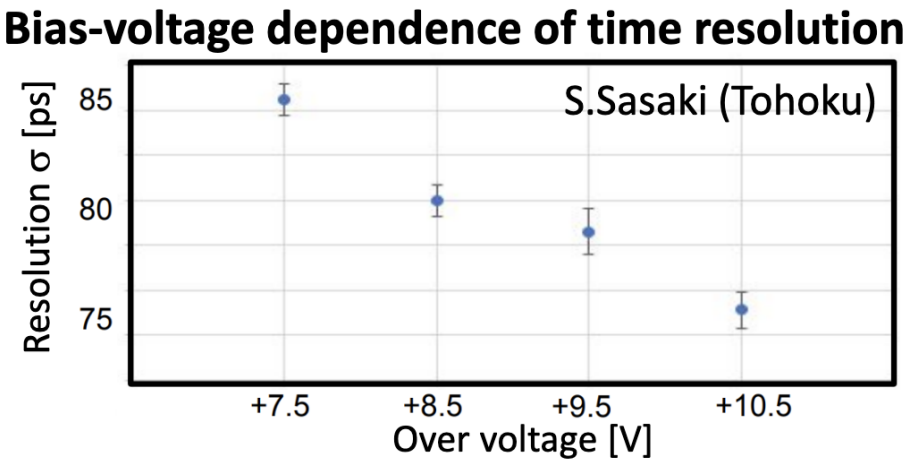


The required performance has been achieved:

$\sigma_{CNC} \sim 80\text{ps}$ @ $V_{OV} \sim +9\text{V}$

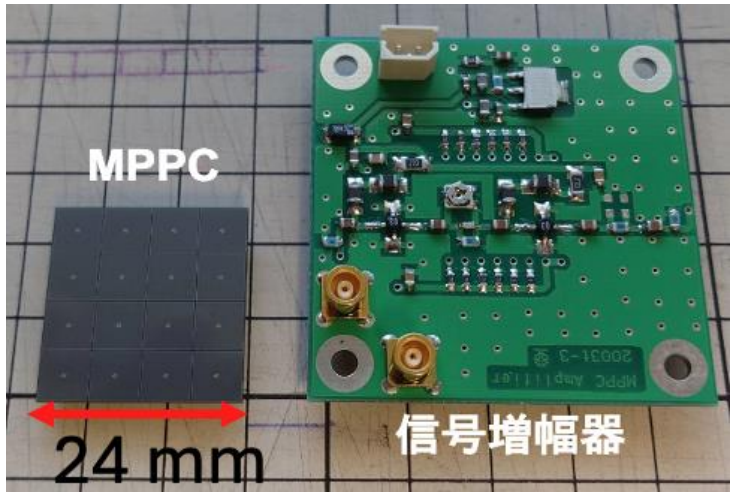
CNC

Proto-type test exp. in 2025



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

単にE15-CDHのままだとダメ。
就航効率を考えてライトガイドなしでMPPCに。それでようやく８０ps
表も作ってみてください(CDHとの比較。)



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

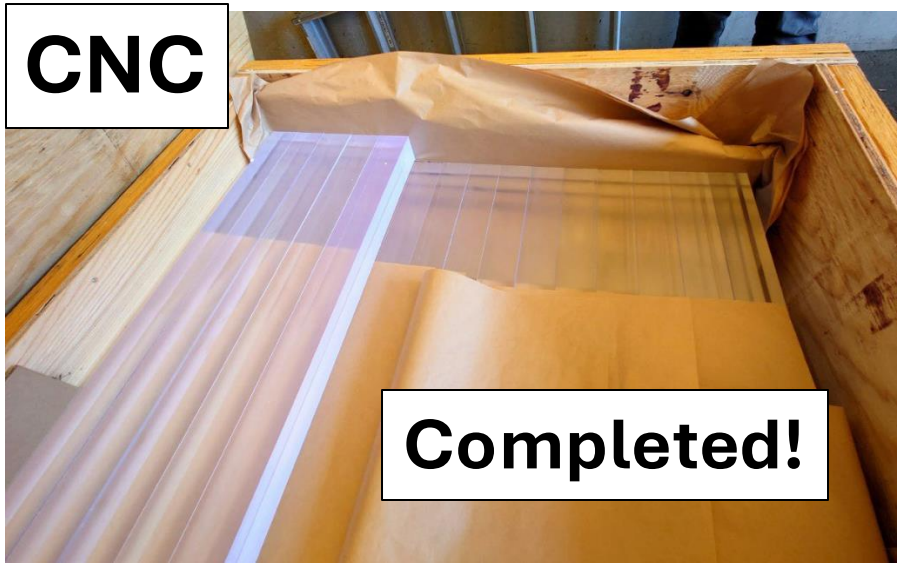
Construction status

Return York

SC Solenoid

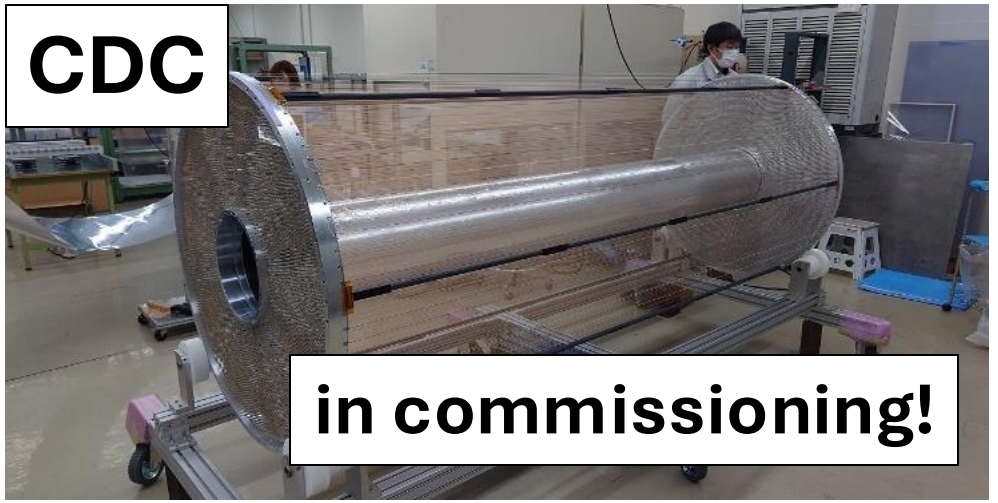
Install into K1.8BR beamline in 2026
Final measurement of the magnetic field w/ the york

CNC



Completed!

CDC



in commissioning!