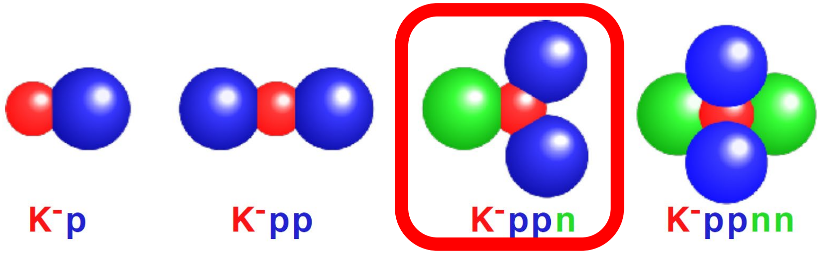
# E80 Stage-2 Request

# 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


38th J-PARC PAC meeting, Jul 29 – Aug 1, 2024

# E80 Experiment to date

- 2020 Jul (30th PAC): proposal submitted
- 2021 Jan (31st PAC): Stage-1 approved
- 2022 Aug (34th PAC): TDR submitted
  - 2024 Jan (37th PAC): status reported
- **2024 Jul (38th PAC): revised TDR submitted**

**FIFC REVIEW REPORT**

July 4th, 2024

*approval of the detector design and construction plan*

…e superconducting solenoid magnet and Cylindrical Drift Chamber (CDC) and mainly discussed those matters. In conclusion, there is no major concern on the design and construction of detectors including safety issues. The experiment is feasible in the current detector design and construction plan.

**We would like to request Stage-2 approval**

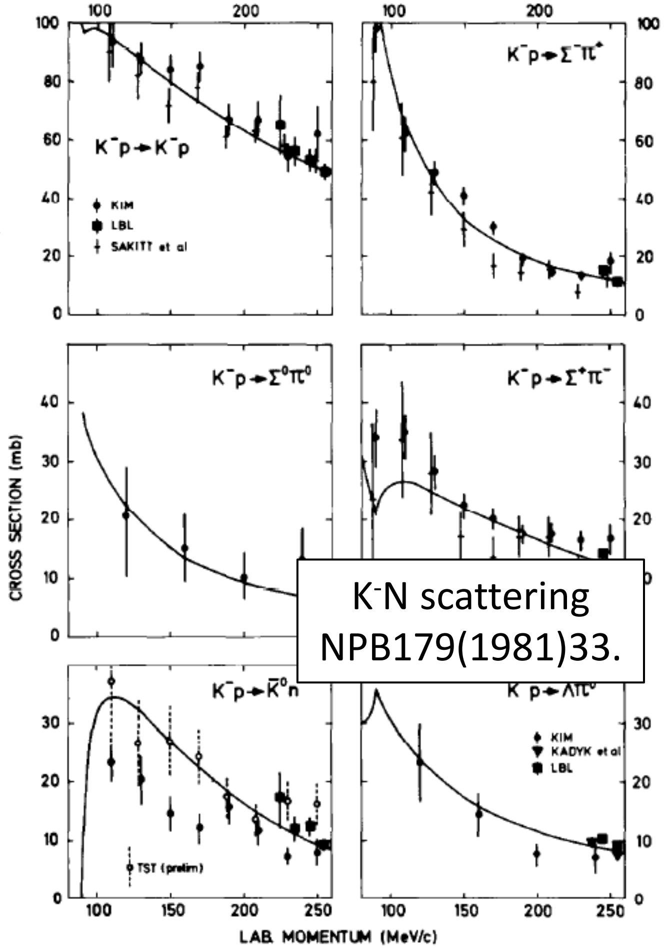
# Physics Goal

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

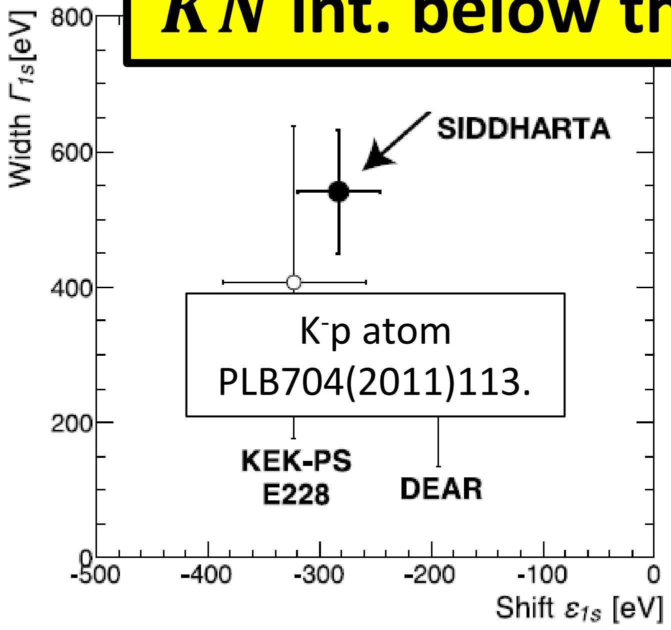
A powerful probe to understand low energy QCD

Strongly attractive in I=0 from extensive measurements

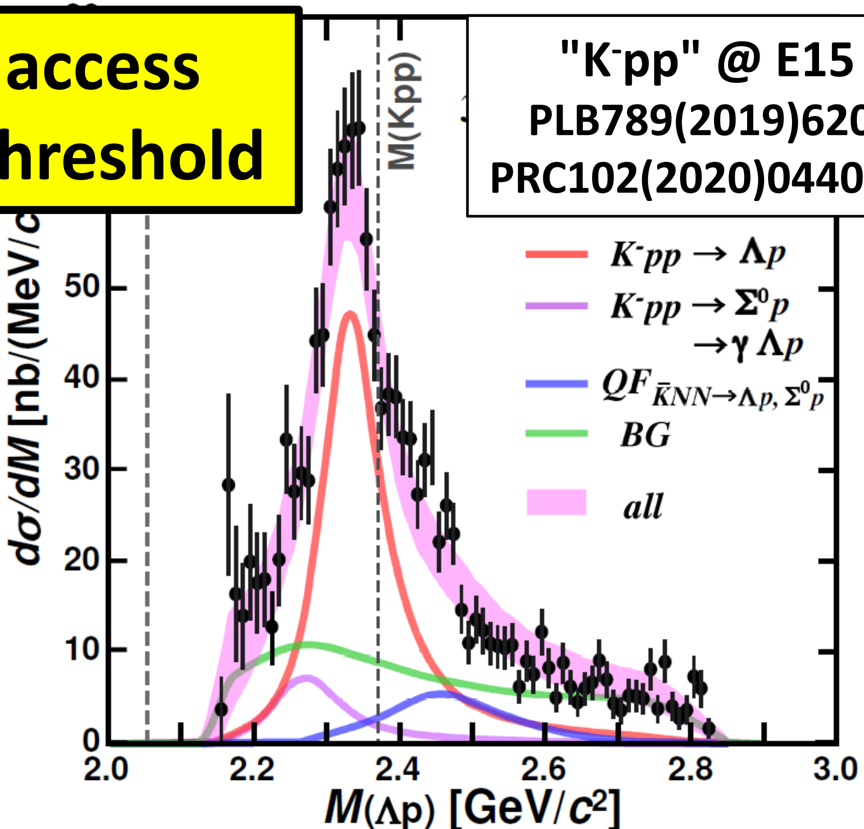
**Kaonic nuclei can access $\bar{K}N$ int. below the threshold**



K⁻N scattering
NPB179(1981)33.



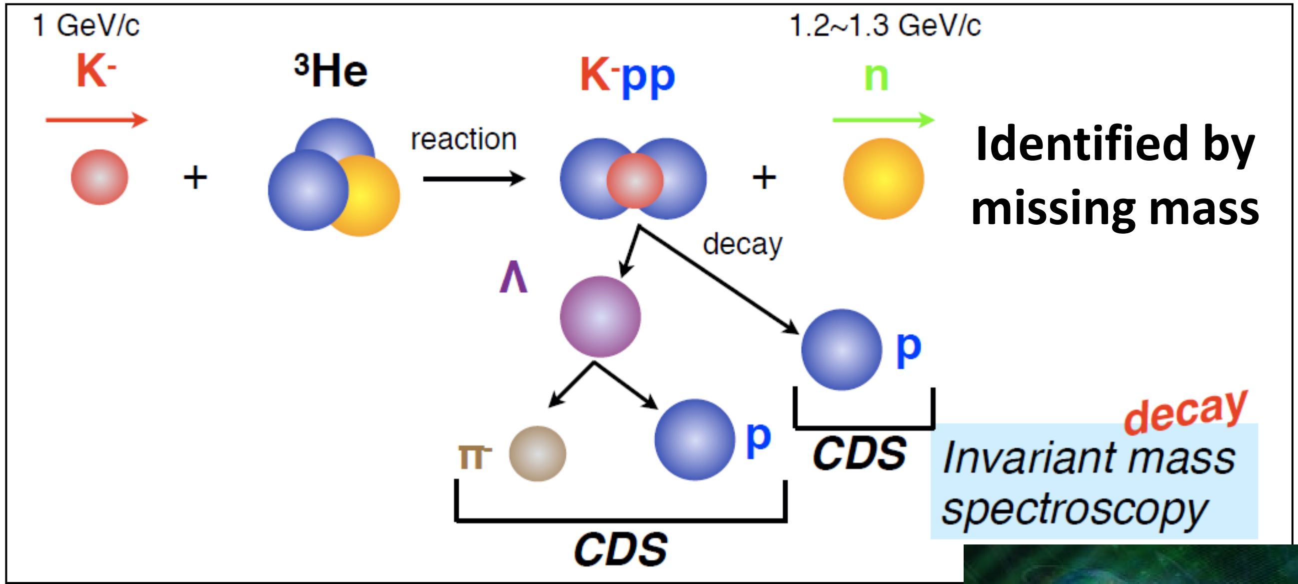
K⁻p atom
PLB704(2011)113.



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

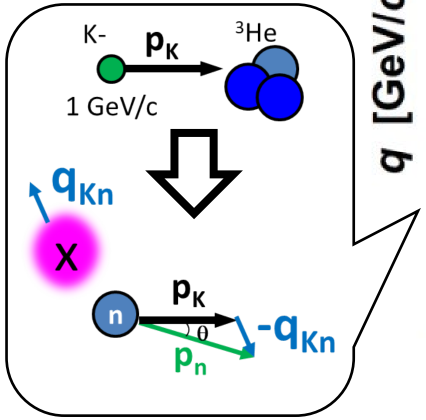
# Predecessor Experiment (E15)

- "K⁻pp" bound state was observed in $^3$He(K⁻, Λp)n

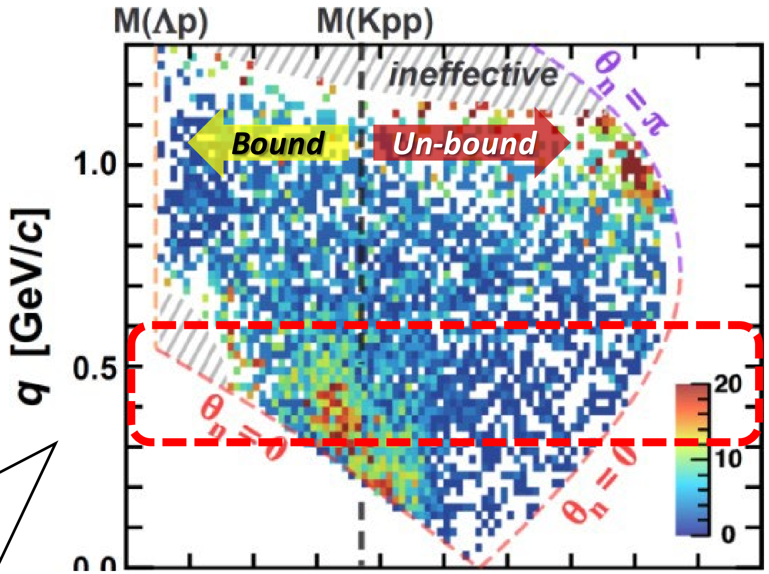


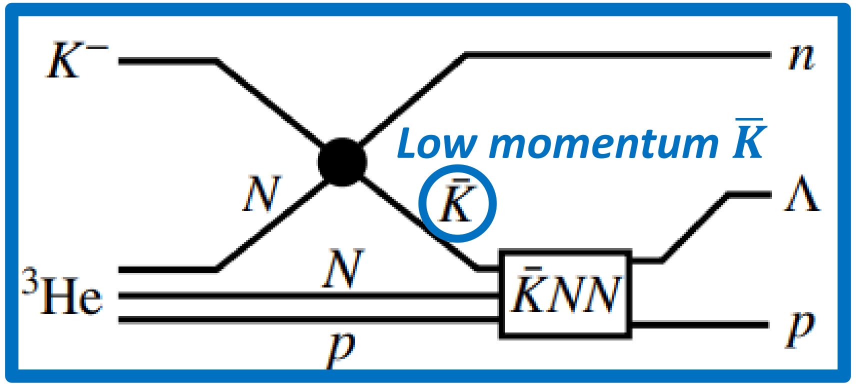

**Identified by missing mass**

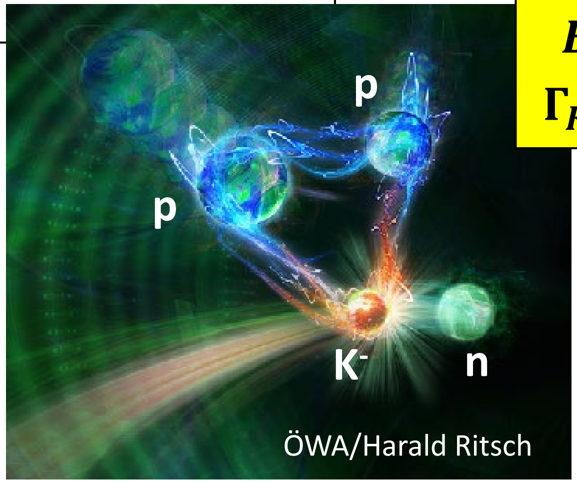
*Invariant mass spectroscopy*



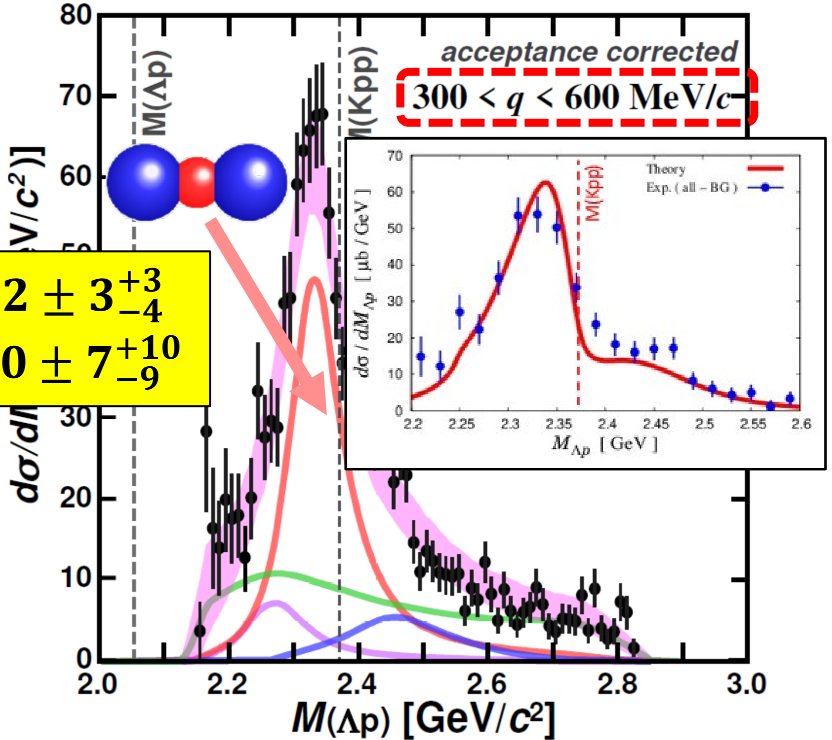

*PLB789(2019)620., PRC102(2020)044002.*



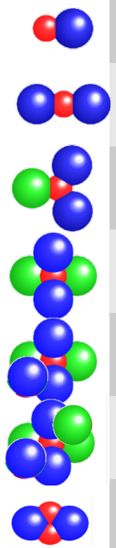

$$B_{Kpp} = 42 \pm 3^{+3}_{-4}$$
$$\Gamma_{Kpp} = 100 \pm 7^{+10}_{-9}$$



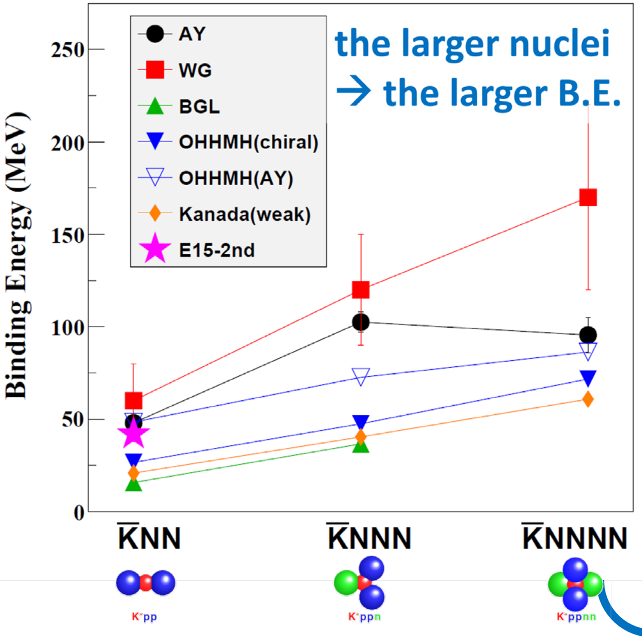
# Systematic investigation of the light kaonic nuclei

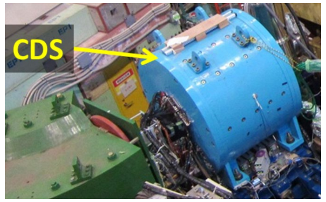
- Systematic measurement will be promoted
  - Mass number dependence
    - Binding energy, Branching ratio, *q* dependence, ..
  - Spin/parity determination

➢ Extract internal structure with theoretical investigations

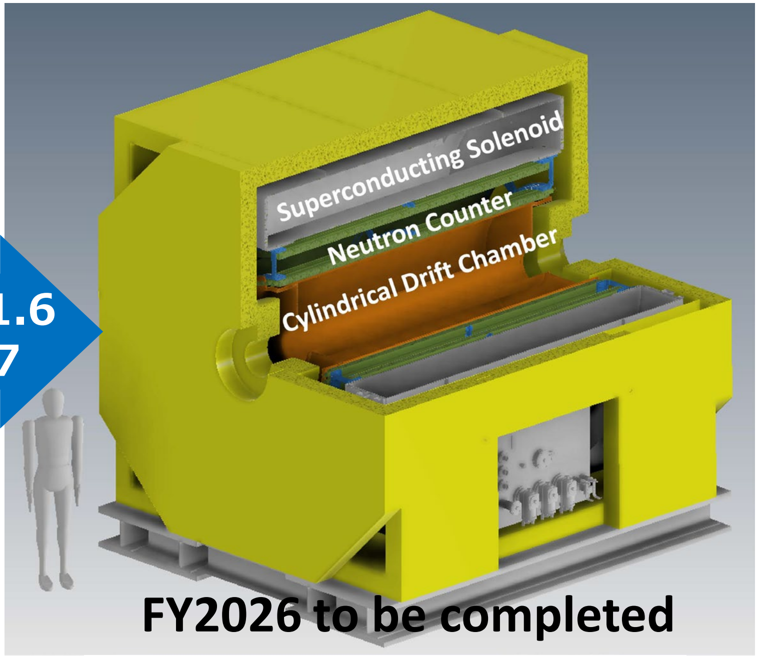


| | Reaction | Decays |
|---|---|---|
| $\bar{K}N$ | d(K$^-$,n) | $\pi^{\pm 0}\Sigma^{\mp 0}$ |
| $\bar{K}NN$ | $^3$He(K$^-$,N) | Λp/Λn |
| $\bar{K}NNN$ | $^4$He(K$^-$,N) | Λd/Λpn ← first step **E80** |
| $\bar{K}NNNN$ | $^6$Li(K$^-$,d) | Λt/Λdn |
| $\bar{K}NNNNN$ | $^6$Li(K$^-$,N) | Λα/Λdd/Λdpn |
|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

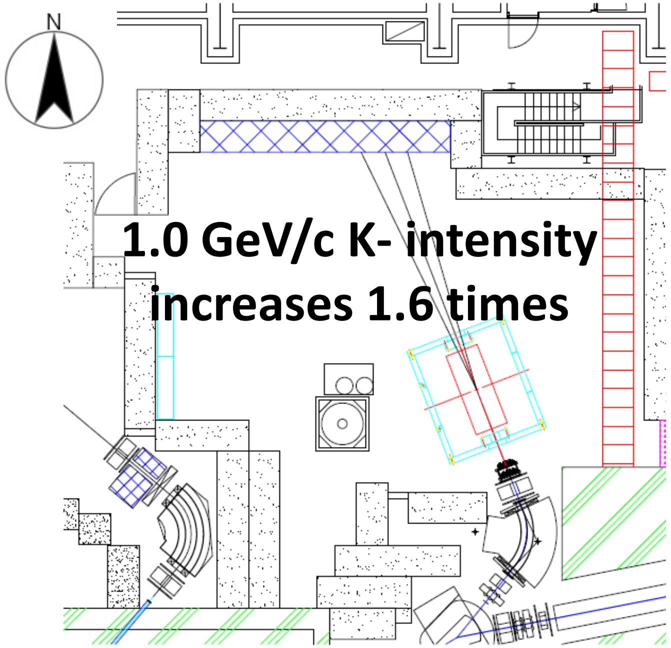


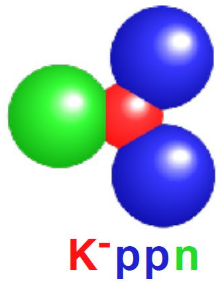

✓Solid angle: x1.6
✓Neutron eff.: x7




FY2026 to be completed



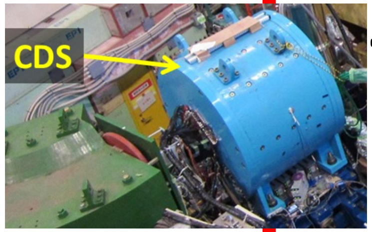

1.0 GeV/c K- intensity increases 1.6 times




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 $\bar{K}NNN$

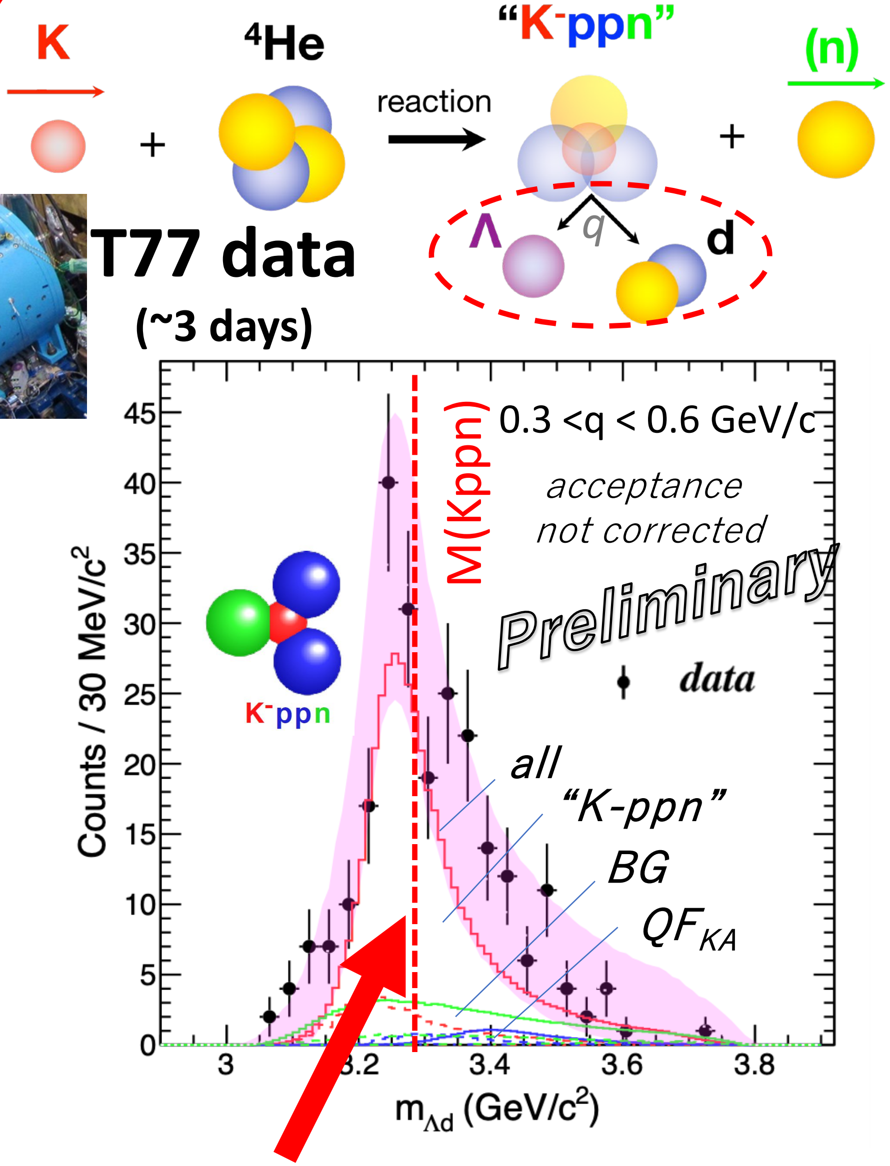
- "K-ppn"→Λd 2-body decay

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

- "K-ppn"→Λpn 3-body decay

- **Feasibility study of spin-spin correlation measurement for P89 ($J^P$ determination of $\bar{K}NN$)**
  - *e.g.*, installing a prototype module of a polarimeter tracker

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




**the sign of the "K⁻ppn"**

# Expected Yield of $\bar{K}NNN$

$$N = \sigma \times N_{beam} \times N_{target} \times \epsilon,$$
$$\epsilon = \epsilon_{DAQ} \times \epsilon_{trigger} \times \epsilon_{beam} \times \epsilon_{fiducial} \times \Omega_{CDS} \times \epsilon_{CDS},$$

- $N_{beam}$ = **100 G** K- on target
  - MR beam power of **90 kW**
  - **3 weeks** data taking (90% up-time)

$$\sigma(K^{-}ppn) \cdot Br(\Lambda d) \sim 5\ \mu b$$
$$\sigma(K^{-}ppn) \cdot Br(\Lambda pn) \sim 5\ \mu b$$

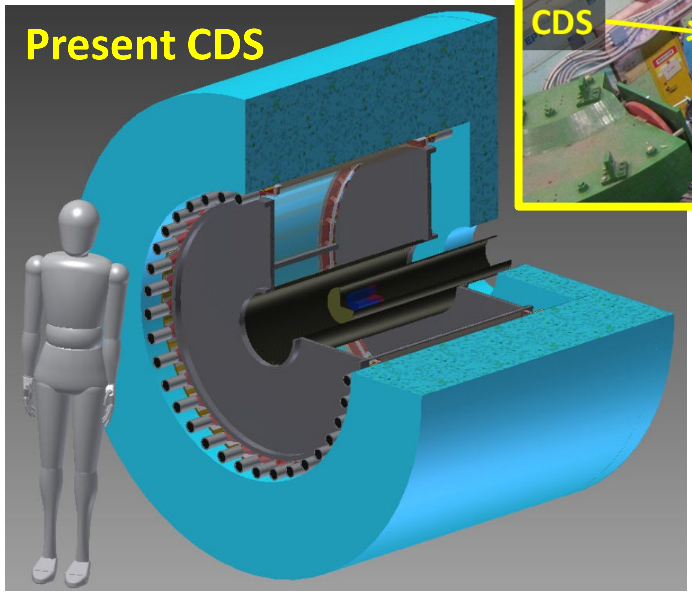
*from the T77 preliminary result and an assumption*

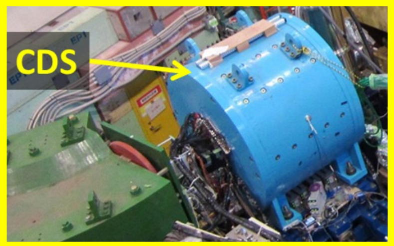
- **$N(K^{-}ppn \rightarrow \Lambda d)$ ~ 1.2 x $10^4$**
- **$N(K^{-}ppn \rightarrow \Lambda pn)$ ~ 1.2 x $10^3$**
  - c.f. 1.7 x $10^3$ "$K^{-}pp$"$\rightarrow \Lambda p$ accumulated in E15-2nd (40 G $K^{-}$)

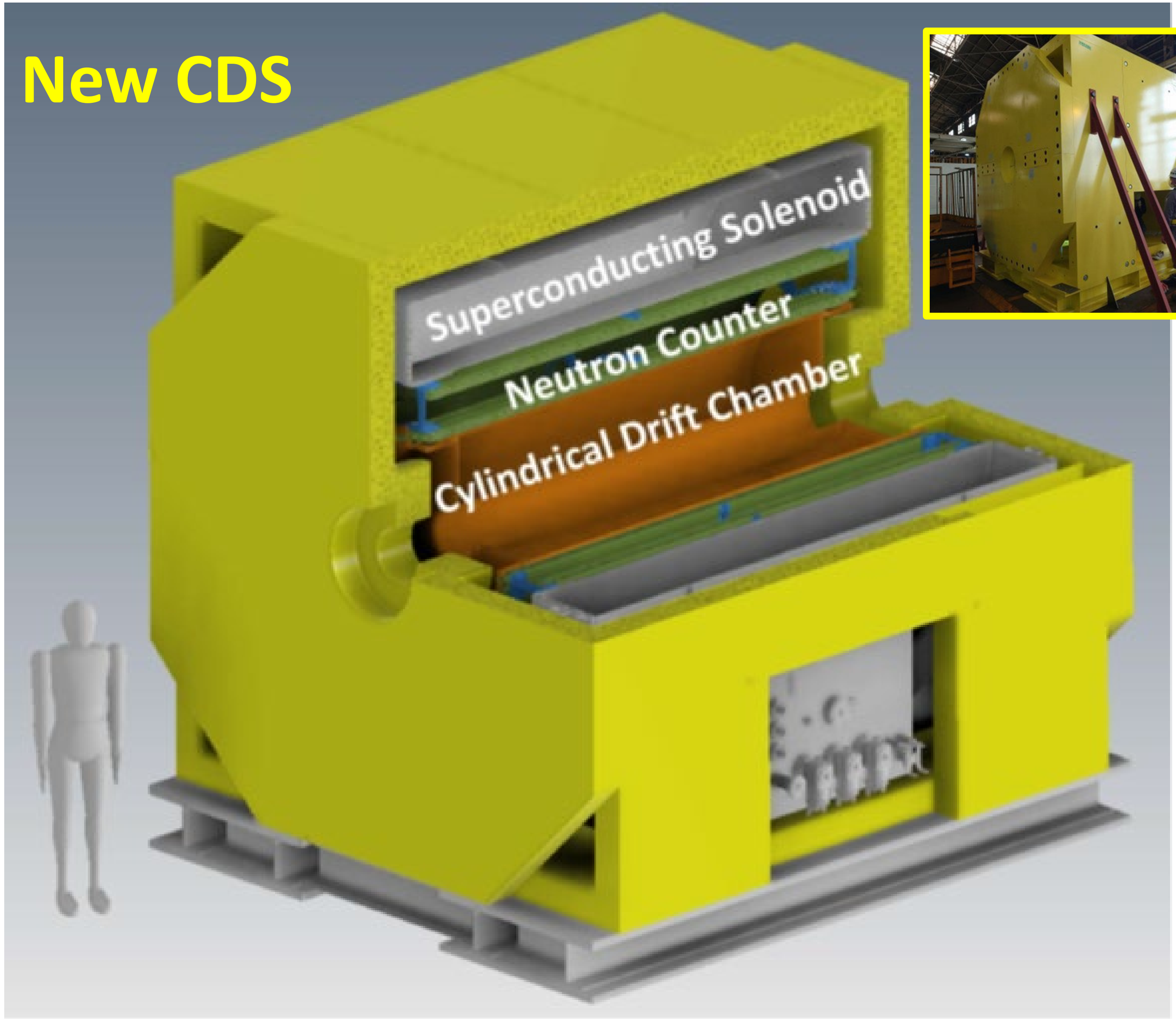
| | Λd / Λpn |
|---|---|
| $\sigma(K^{-}ppn)$*Br | 5 μb |
| $N(K^{-}$ on target) | 100 G |
| N(target) | 2.56 x $10^{23}$ |
| ε(DAQ) | 0.92 |
| ε(trigger) | 0.98 |
| ε(beam) | 0.72 |
| Ω(CDC) | 0.23 / 0.047 |
| ε(CDC) | 0.6 / 0.3 |
| $N(K^{-}ppn)$ | 12 k / 1.2 k |

# Preparation Status

# New Cylindrical Detector System (CDS)




✓**Solid angle: x1.6** (59% → 93%)

✓**Neutron eff.: x7** (3% → 12%x1.6)

# Superconducting Solenoid Magnet

- Same design as "the detector solenoid magnet" for COMET-I

**being constructed in cooperation with the J-PARC Cryogenics Section**

- 3.3m x 3.3m x 3.9m, ~108t in total
- Max. field of 1.0T @ center
  - 189A – 10V
- NbTi/Cu SC wire, 98km in total
- **Conduction-cooling with GM*3**
- Semi-active quench-back system
- **Will be completed in FY2024**

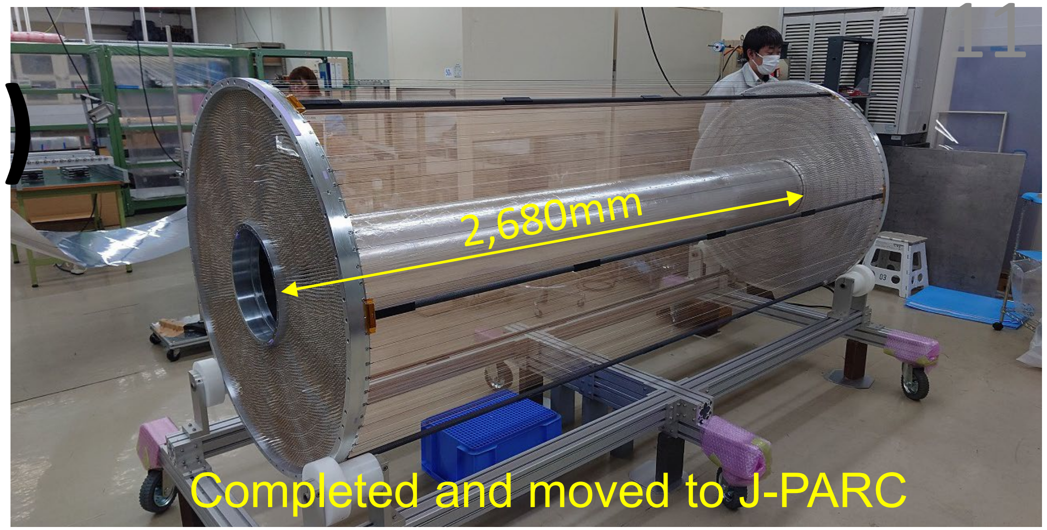

SHI FA-50
(air cooling)

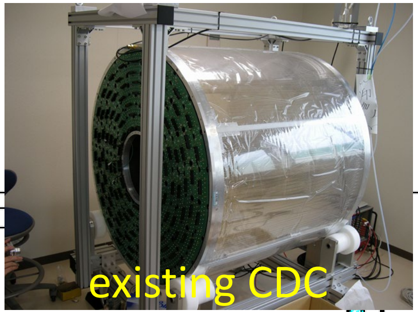

RDE-418D4



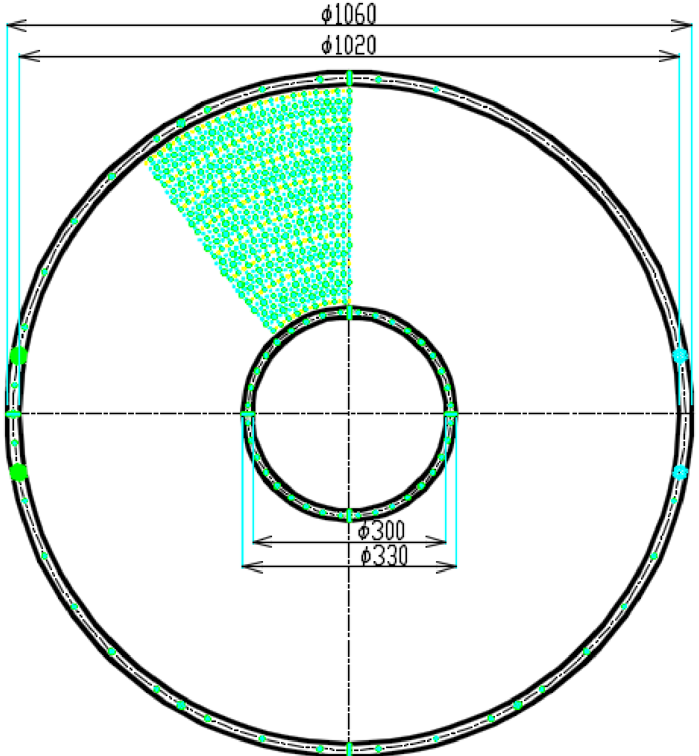
# Cylindrical Drift Chamber (CDC)

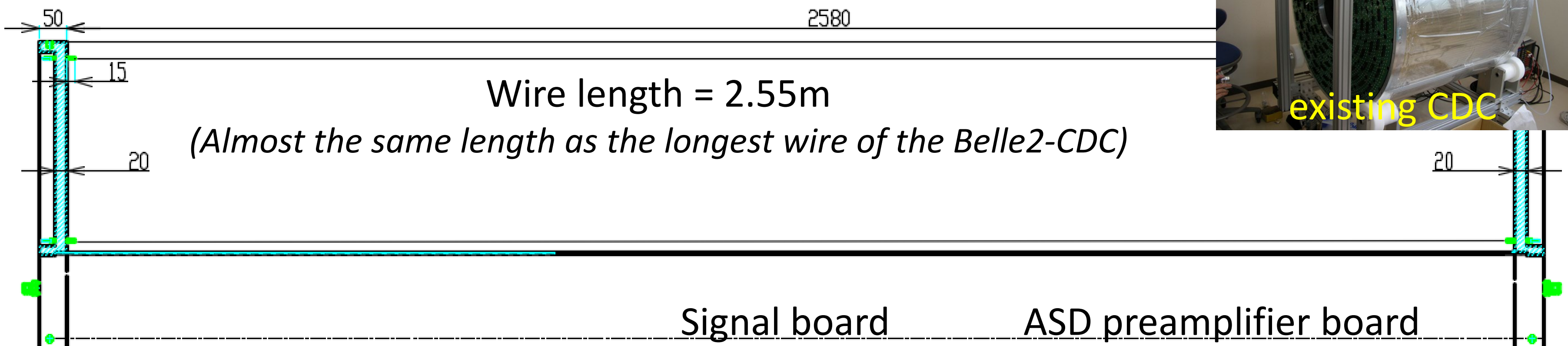
- 3 times the length of the existing CDC
  - Gas: $Ar/CO_2$=90/10
- The same design of the present end-cap
- Readout systems are reused



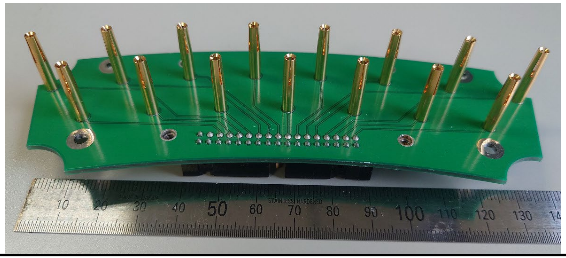

**Completed this month, and commissioning will soon start @ J-PARC**



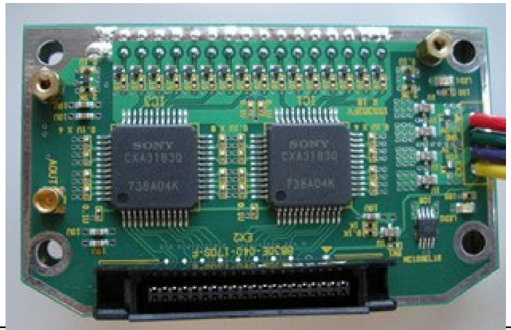

Wire length = 2.55m

*(Almost the same length as the longest wire of the Belle2-CDC)*

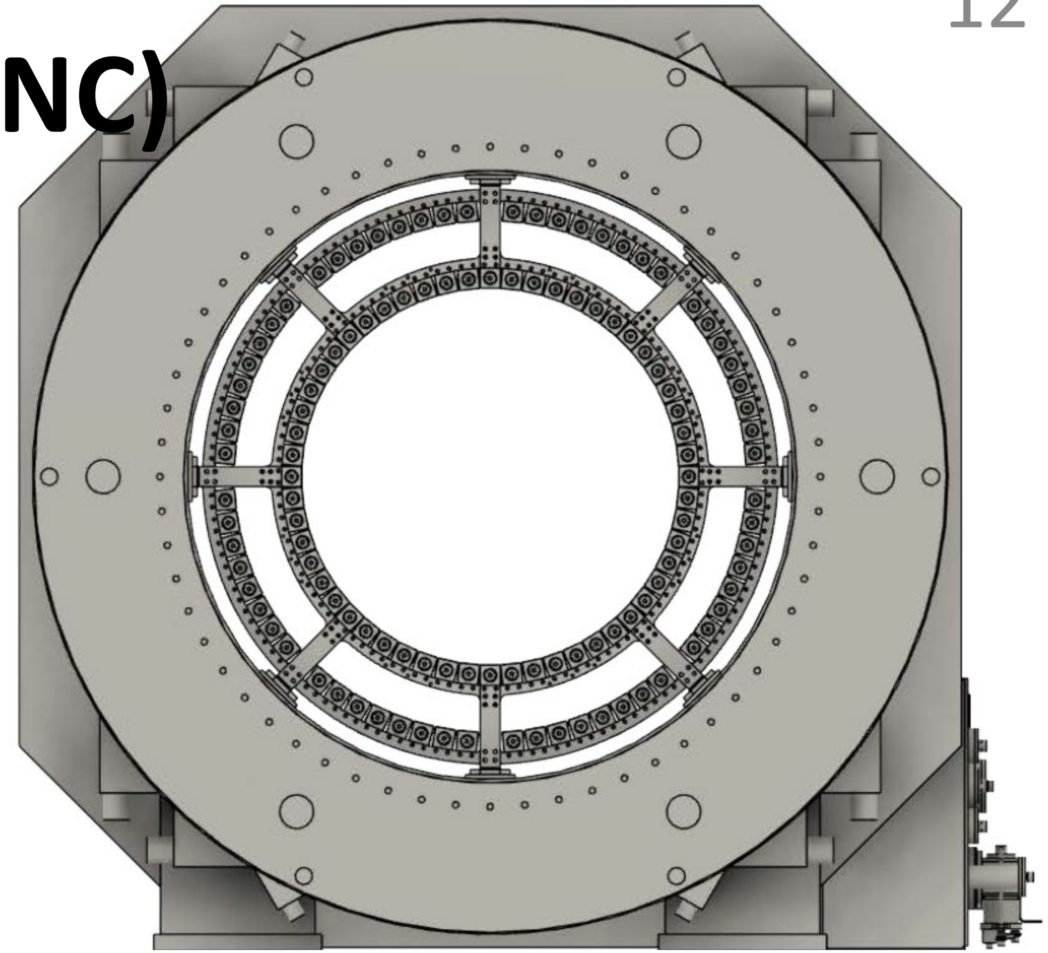


Signal board

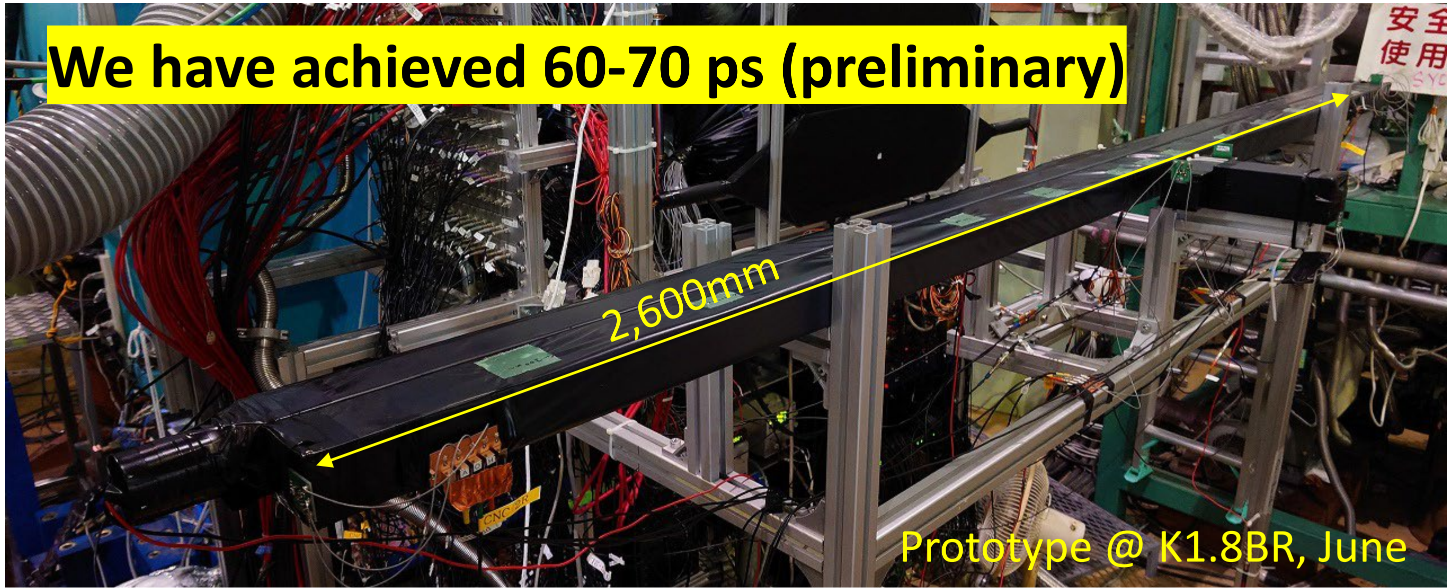
ASD preamplifier board



# Cylindrical Neutron Counter (CNC)



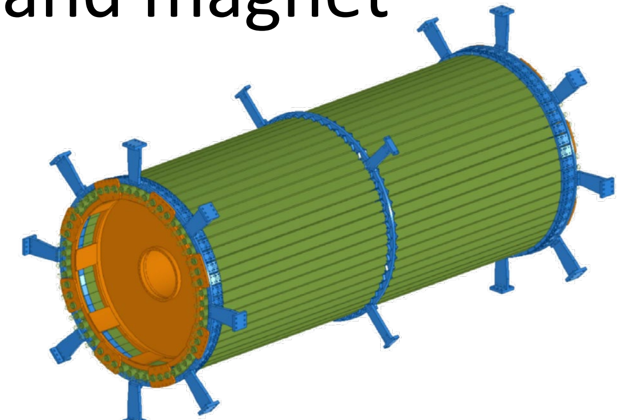
- scintillator array: 2 layers, 12cm thickness
- Neutron detection efficiency of 12~36%
- 56+80=136 modules
  - ELJEN EJ-200: (T)60mm, (W)60mm, (L)3,000mm
- 1.5-inch FM-PMT [H8409(R7761)] & MPPC array [S13361-6050AE-04]
- **Will be completed in FY2025**

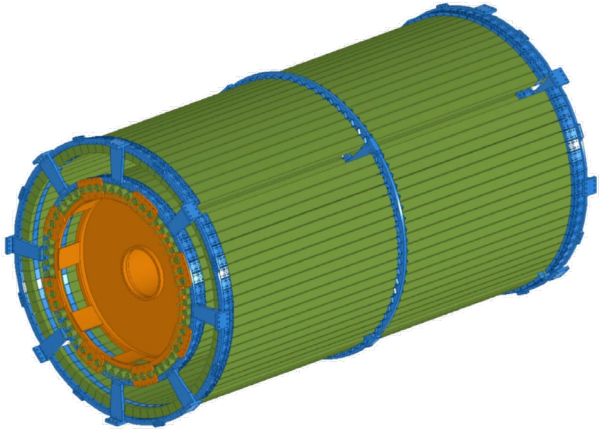


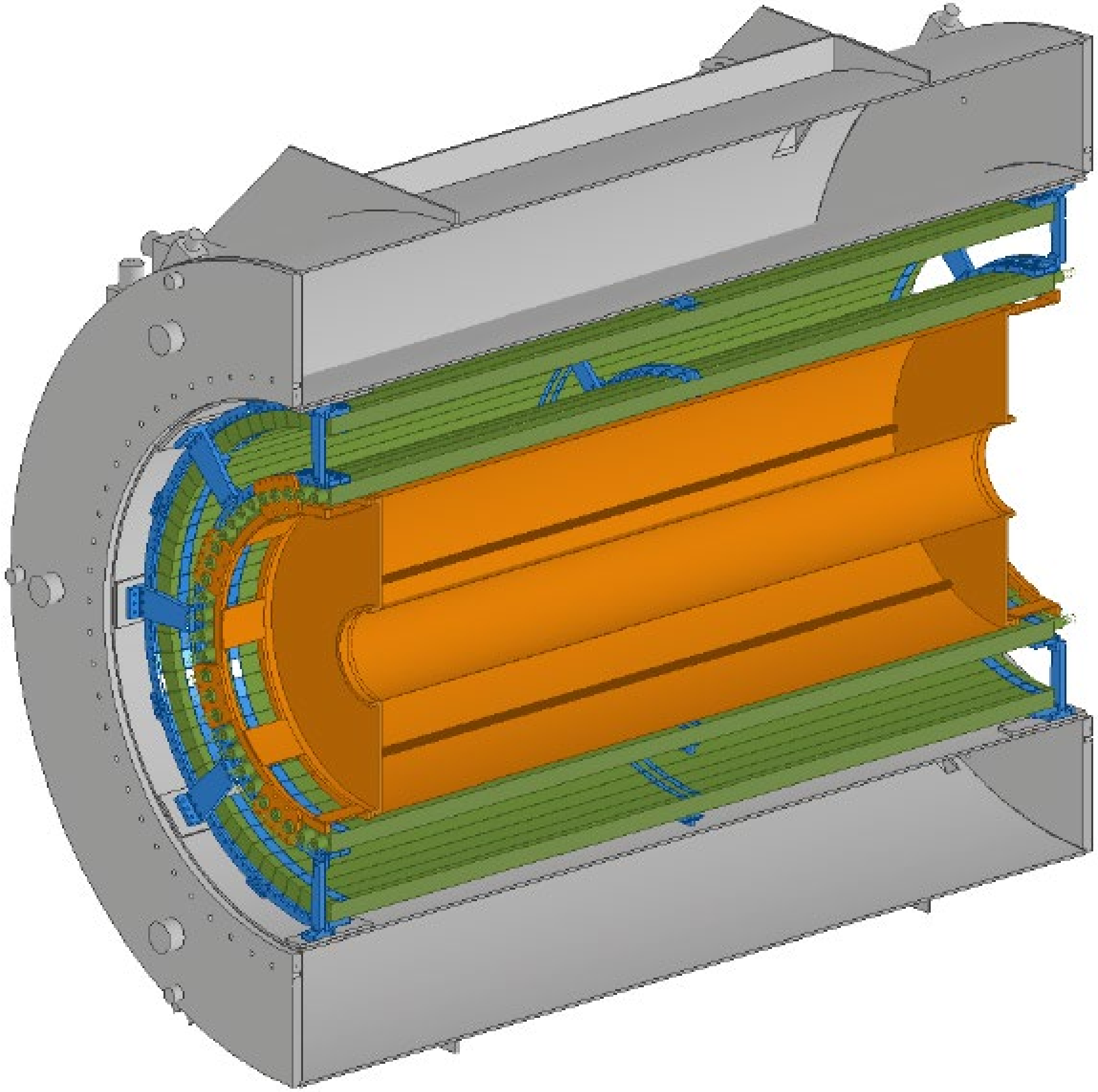

136 scintillators in total
- 56 segments @ r548~608mm
  - ➢ 112 FM-PMTs
- 80 segments @ r780~840mm
  - ➢ 160 MPPC-arrays

# Support Structure

- CNC is supported at upstream, downstream and middle position
    1. pillars are mounted on the inner cylinder of the magnet
    2. ring structures are installed on the pillars
    3. each module is mounted on the ring structures
- CDC is installed by inserting a long frame bar into the center of the CDC and magnet







**Will be prepared in FY2025-26**

# K1.8BR Upgrade

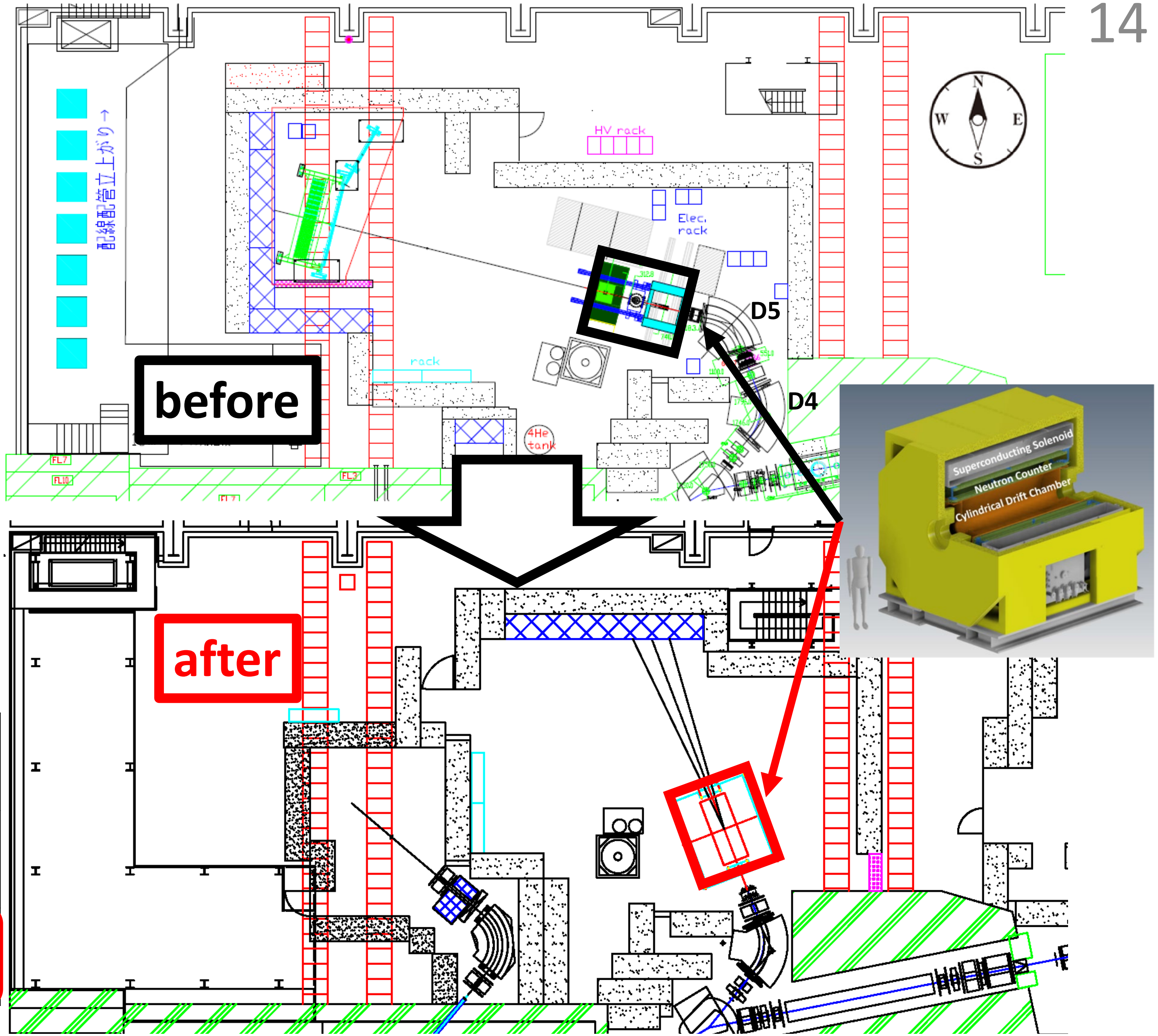
- We have proposed a new configuration of the beam line

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

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

with $\pi/K$ ~ 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)** |



# Benefit of K1.8BR Upgrade

- **Save 1.6 times the electricity @ 1.0 GeV/c**
  - It takes 1.6 times the beam time without the BL upgrade

| Requested beam-time | New CDS @ upgraded K1.8BR (D4) | New CDS @ current K1.8BR (D4+D5) |
|---|---|---|
| E80 ($K^-ppn$) | 3 weeks | 5 weeks |
| P89 ($J^P$ of $K^-pp$) | 8 weeks | 13 weeks |

- We will continue proposing new experiments using the new large CDS

# K1.8BR Upgrade

- <u>We have consulted with the HD-G and the Radiation Control Section</u>
  - ➢radiation application is required
- Process
  1. Removal of D5/detectors/cables/etc.
  2. Installation of new solenoid
  3. Re-arrangement of shield
  4. Re-installation of cables/PPS/etc.

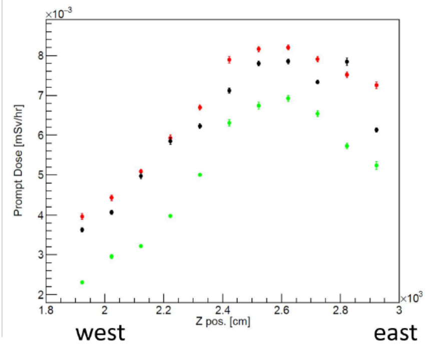
  It will take ~6 months

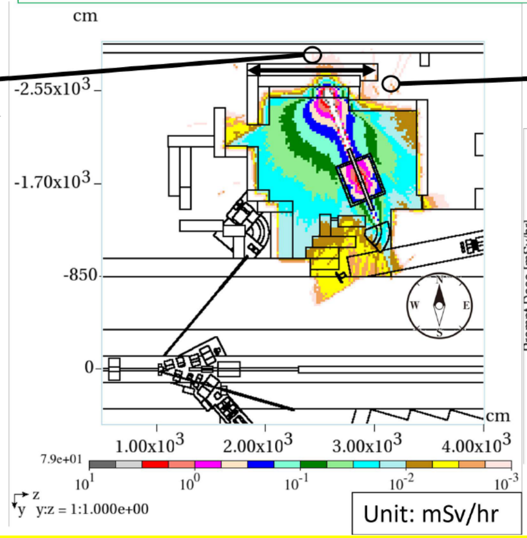
- **We would like to upgrade K1.8BR in late FY2025 – early FY2026**
  - ➢the application should be submitted in early FY2025

At the beam height (150~250 cm sliced)

Prompt dose equivalent, total (n,photon,p,,,)

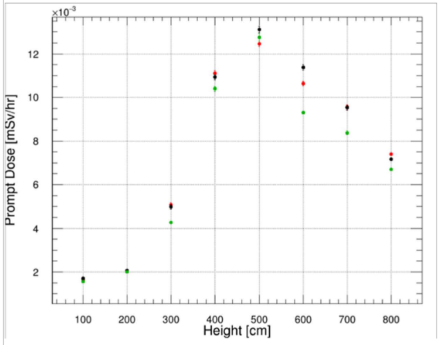
Catwalk position, east-west dependence



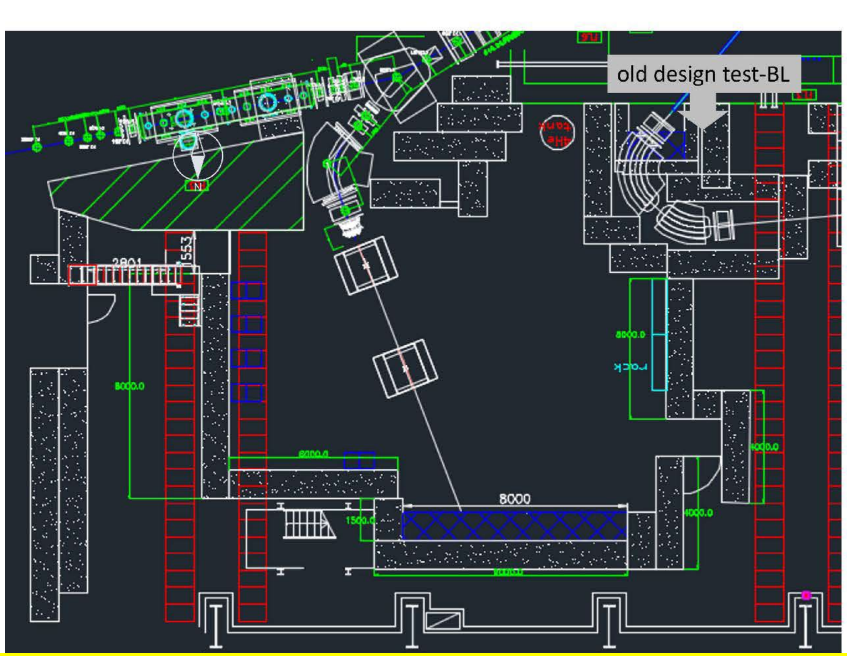

Unit: mSv/hr

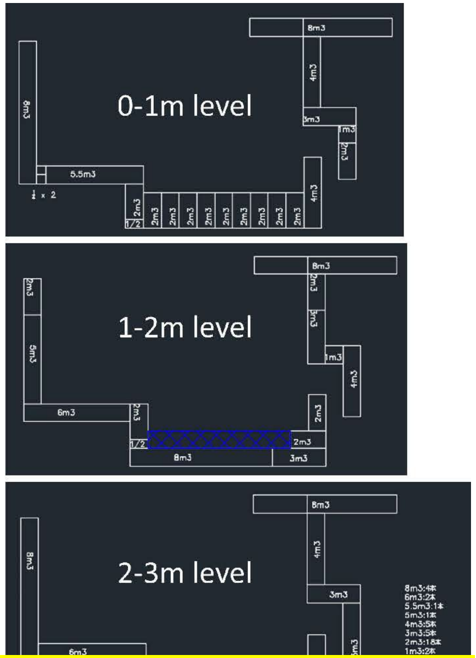
Stair position, up-down dependence




- Calculated optics
- Calculated optics (δy' x 3)

**the radiation level is well below the 25 μSv/h limit**




**possible to rearrange the shields without purchasing new ones**

# Schedule

now

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<tr><th rowspan="2"></th><th colspan="4">FY2022</th><th colspan="4">FY2023</th><th colspan="4">FY2024</th><th colspan="4">FY2025</th><th colspan="4">FY2026</th><th colspan="4">FY2027</th></tr>
<tr><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th><th>Q1</th><th>Q2</th><th>Q3</th><th>Q4</th></tr>
<tr><td>SC Solenoid Magnet</td><td colspan="2">Design</td><td colspan="2">Purchase (SC Wire)</td><td colspan="8">Construction</td><td colspan="4">Stored at KEK</td><td>Installation</td><td colspan="2" rowspan="3">Integration, Test & Commissioning</td><td rowspan="3">Commissioning w/ Beam</td><td rowspan="3">Physics Run</td><td colspan="3" rowspan="3">Analysis & Pblication</td></tr>
<tr><td>CDC</td><td colspan="4">Design</td><td colspan="5">Construction</td><td colspan="8">Test & Commissioning</td></tr>
<tr><td>NC</td><td colspan="10">Design & R&D</td><td colspan="2">Purchase (Scinti.)</td><td>Assembly</td><td colspan="4">Test & Commissioning</td></tr>
<tr><td>K1.8BR Beam Line</td><td colspan="15">E73(CDS) -> E72(HypTPC) Experiments</td><td colspan="2">Upgrade</td><td colspan="7">E80 Experiment</td></tr>
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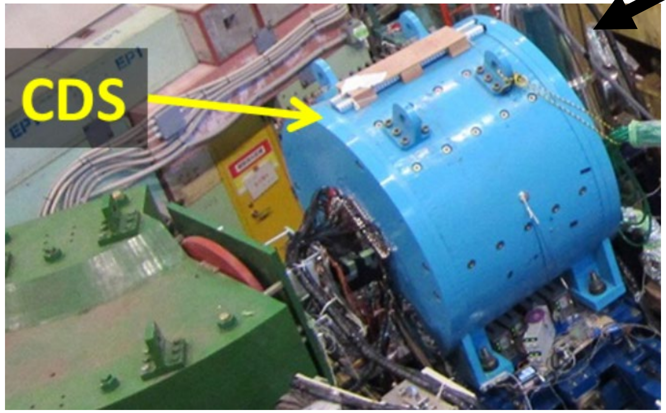
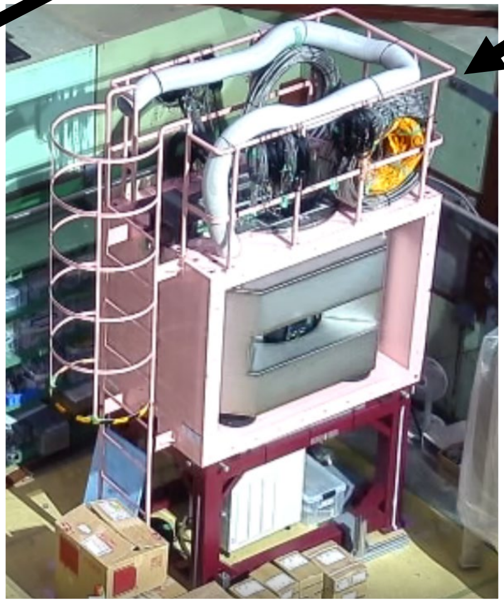
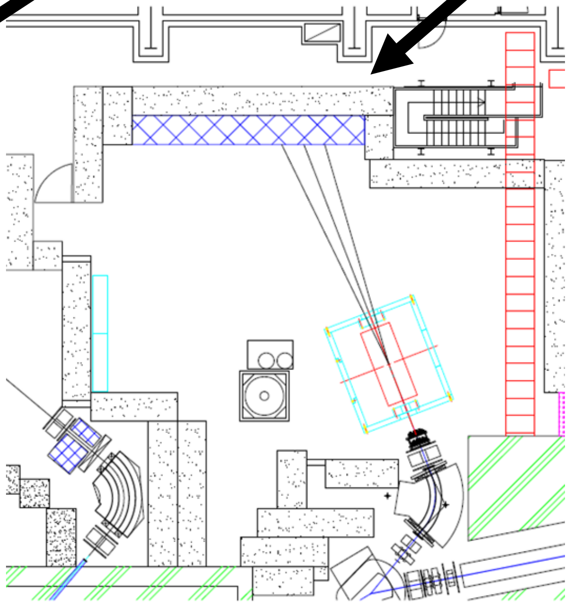
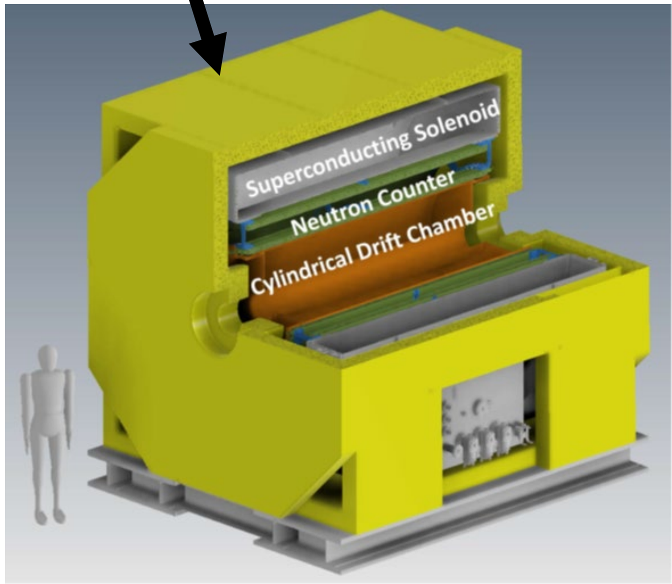






# Budget Situation

**We have already secured the budget to construct the CDS.**

- The magnet and CDC cost have been covered by **"Grant-In-Aid for Specially Promoted Research by JSPS (FY2022-26)"**.

| | |
|---|---|
| **Superconducting solenoid magnet** | ~370M JPY |
| **CDC (cylindrical drift chamber)** | ~54M JPY |

- The CNC will be built with a new budget, **"Grant-in-Aid for Scientific Research (S) by JSPS (FY2024-28)"**.

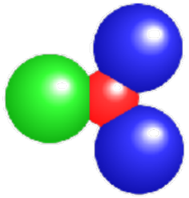
| | |
|---|---|
| **CNC (cylindrical neutron counter)** | ~80M JPY |

# Summary

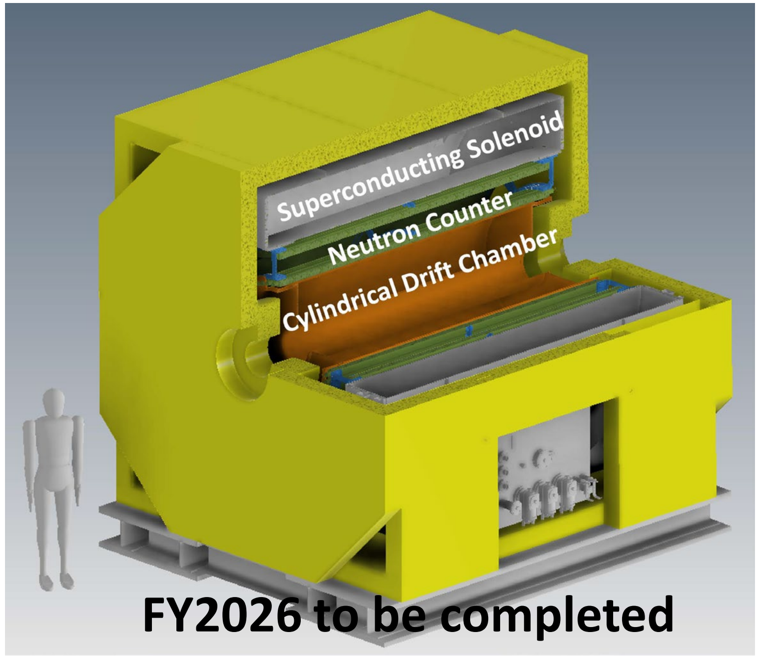
**E80** investigates the **“K$^-$ppn”** bound state, toward a systematic study of the kaonic nuclei

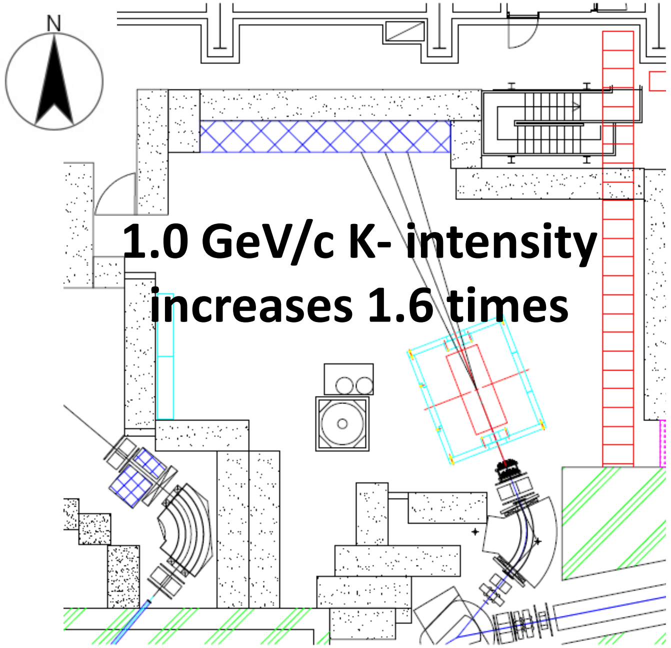
- a large solenoid spectrometer is being constructed
- K1.8BR upgrade is needed to improve the K$^-$ yield
- **the experiment will be ready in FY2026**

| Beam intensity | 90kW |
|---|---|
| **Beam time** | **1+1+3 weeks** |


K$^-$ppn

- <u>We have received FIFC approval of the detector design and construction plan</u>
- We would like to request **“Stage-2 approval”**
  - We would also like a **“PAC recommendation for the K1.8BR upgrade”**



# J-PARC E80 Collaboration

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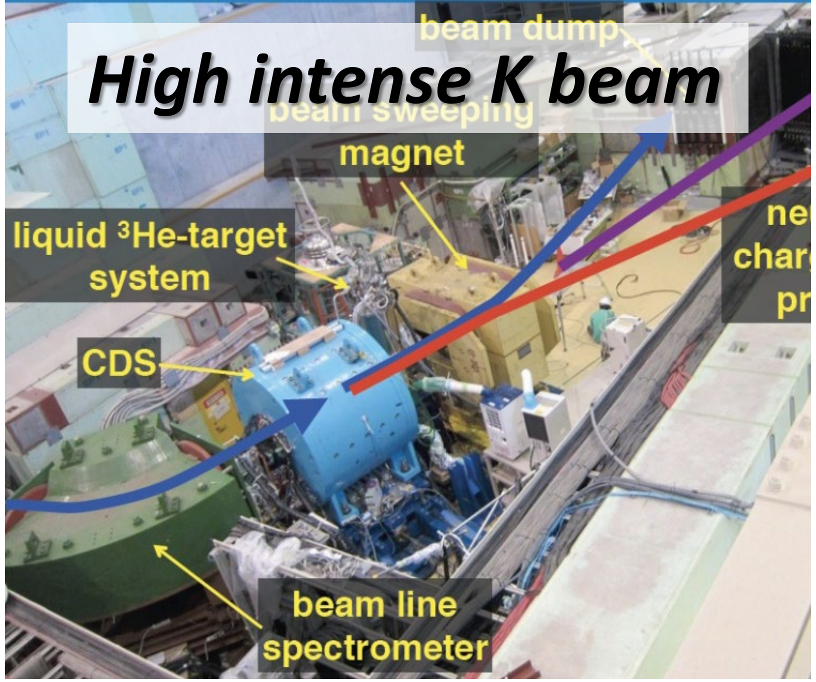
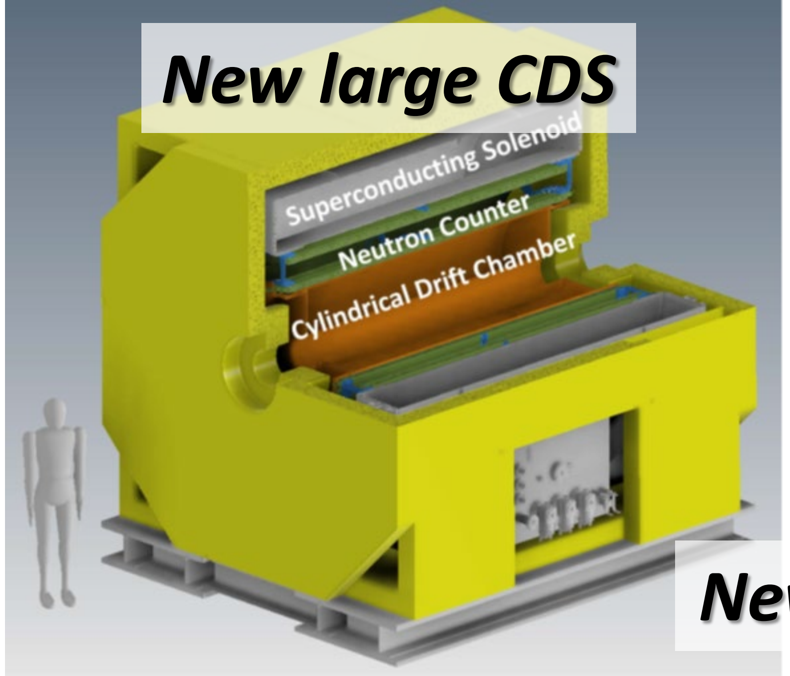
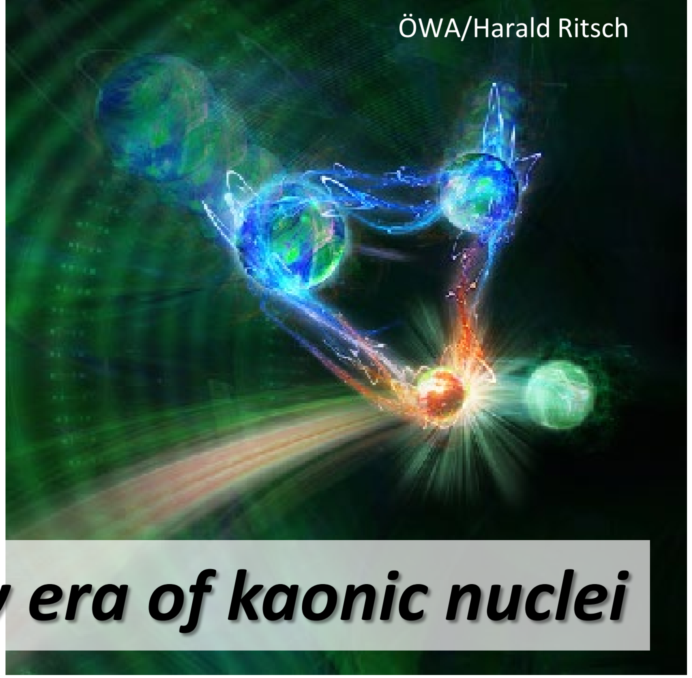
**We're looking for new collaborators!**

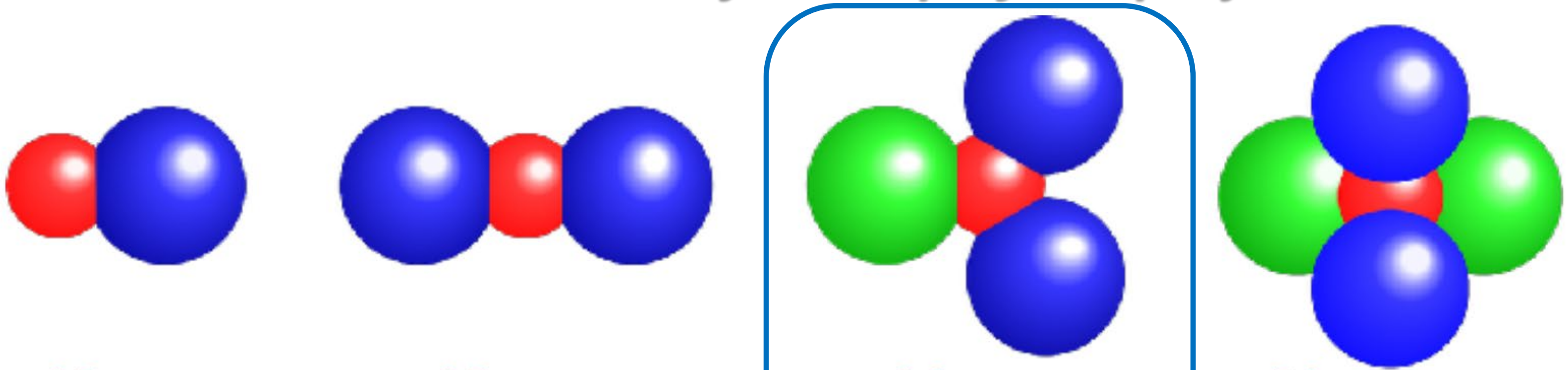



# Thank you for your attention!

*A first step of the project*



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

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

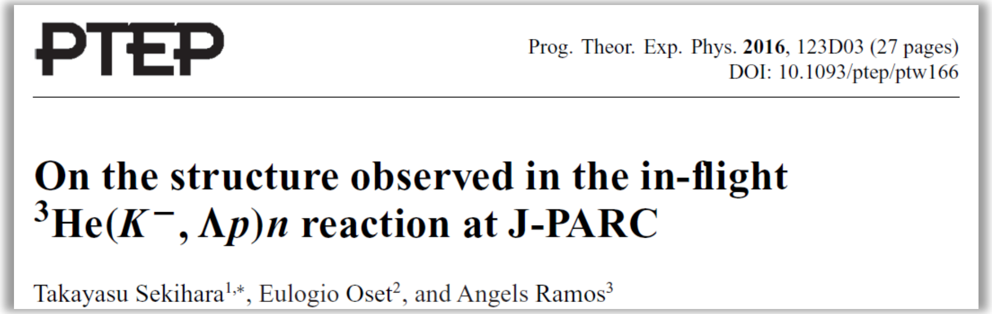
# Estimated Cost of the K1.8BR Modification

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

**We are now trying to reduce costs further.**

# A Theoretical Interpretation

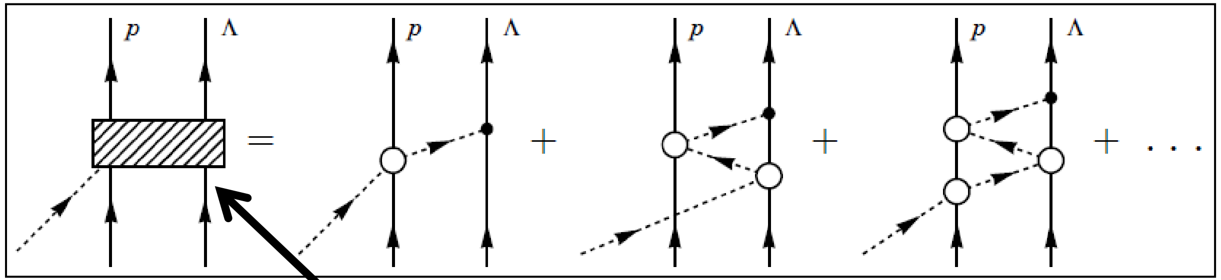
A calculation based on chiral unitary approach
**reproduces the data well using the $\bar{\mathrm{K}}$NN bound state**

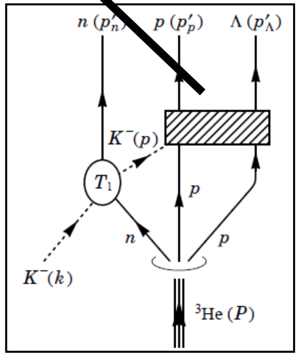

PTEP

Prog. Theor. Exp. Phys. **2016**, 123D03 (27 pages)
DOI: 10.1093/ptep/ptw166

**On the structure observed in the in-flight $^3$He($K^-$, $\Lambda p$)$n$ reaction at J-PARC**

Takayasu Sekihara[1,*], Eulogio Oset[2], and Angels Ramos[3]

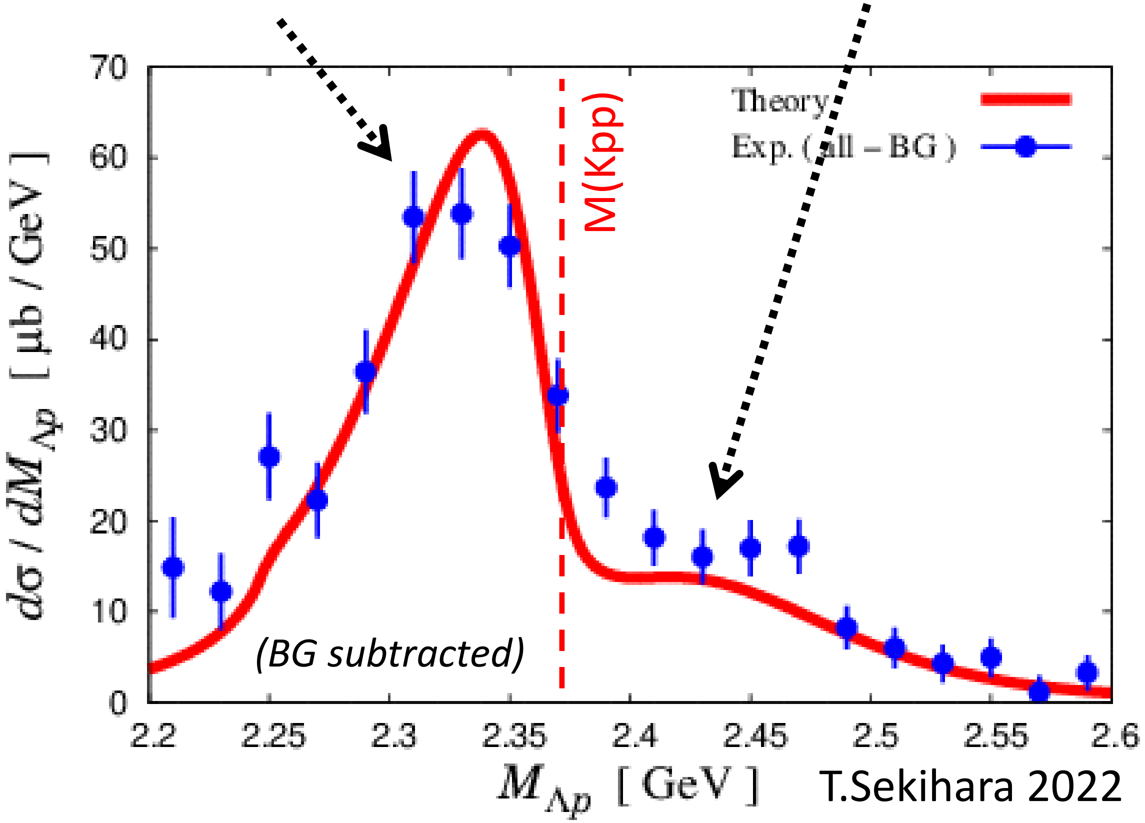



**Theoretical investigations are indispensable!**

**K^bar NN bound state**

**Quasi-free K⁻ scattering**




T.Sekihara 2022