Construction of the new Cylindrical Drift Chamber and Performance Comparison of Filling Gases for the Systematic Studies of Kaonic Nuclei at J-PARC

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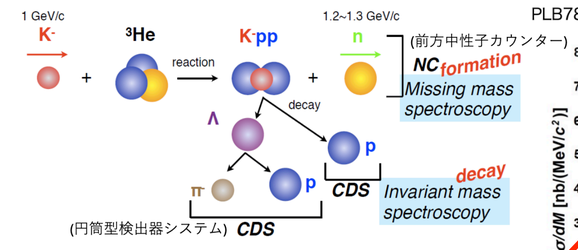
- Abstract -

The simplest kaonic nuclear-bound state, known as Kbar NN , was observed in the J-PARC E15 experiment. However, some issues remain to be addressed. First of all, is KbarNN the only bound state in kaonic nuclei, or do other states exist, such as \KNNN, \KNNNN, and so forth? Second, what are the quantum numbers, namely, the spin and parity, of the observed state? Lastly, what is the internal structure of the observed state? Has the extremely high density, exceeding that of normal nuclear matter, been realized inside the state as predicted by theoretical calculations? To answer these questions, we plan to conduct a new experiment at J-PARC, the J-PARC E80 experiment, which is expected to begin data-taking in FY 2027. For this experiment, a spectrometer has been designed to detect all decay particles from kaonic nuclei, including not only charged particles but also neutrons. The central detector for the E80 experiment is a large cylindrical drift chamber (CDC). The construction of the CDC has been completed, and it is now placed in the J-PARC assembly area. However, one issue regarding the detector gas filled in the CDC needs to be clarified. We have two candidates: one is Ar-C_2H_6 (at a 50:50 ratio), and the other is Ar-CO_2 (at a 90:10 ratio). A series of test experiments has been conducted using a radioactive source and cosmic rays. The S/N ratio of Ar-C_2H_6 (50:50) was better than that of Ar-CO_2 (90:10). Moreover, Ar-CO_2 (90:10) met our expected performance requirements in terms of detector efficiency and position resolution. Therefore, we began commissioning the new CDC filled with Ar-CO_2 (90:10) on October 20.

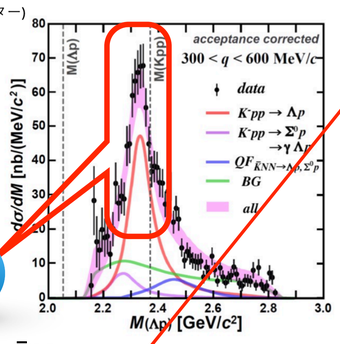
- To J-PAEC E80 From J-PARC E15 and the new Cylindrical Detector System -

The J-PARC E15 experiment confirmed the existence of the simplest kaonic nuclei K^-pp.

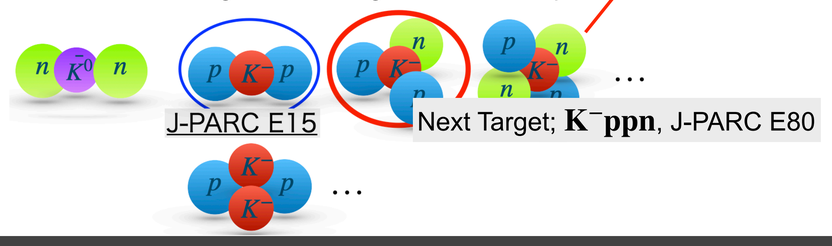


束縛エネルギー ~50 MeV
崩壊幅 ~100 MeV

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



- Kaonic nuclei are formed by the strongly attractive $\bar{K}N$ interaction
  —> The best probe to understand $\bar{K}N$ interaction in the subthreshold region.
- Deeper binding energy than normal nuclei
  —> Could this suggest high dense matter?
- The system includes a real boson.
  —> Potential to gain new insight into the composition of matter



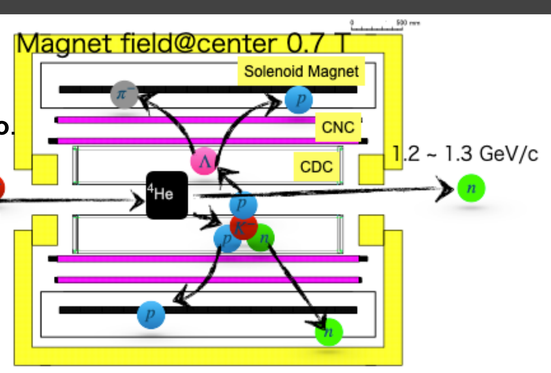
J-PARC E80 : We will measure all the decay particles from "K^-ppn".

Then, **the invariant mass of "K^-ppn"** will be reconstructed.
If it exists, we can obtain its **binding energy, decay width and branching ratio.**

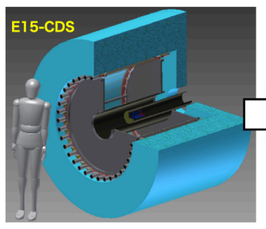
In E80:

- The neutrons to be detected are produced.
- The number of final-state particles increases compared to E15

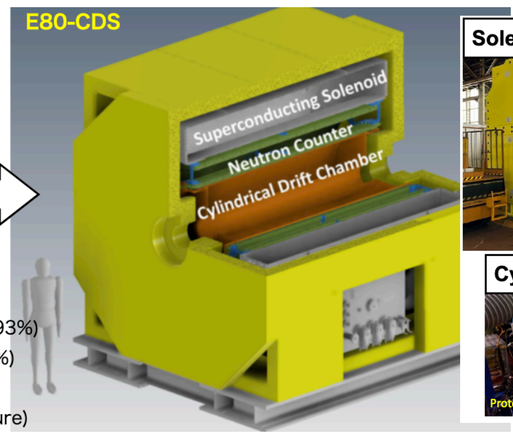
→ **Up-grade of the detector system is needd.**

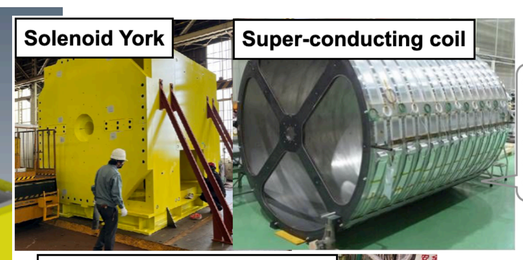


New CDS

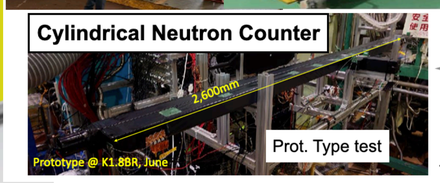


✓ **Solid angle: x1.6** (59%→93%)
✓ **Neutron eff. x4** (3%→12%)
✓ **forward TOF counters**
✓ (proton polarimeter in future)





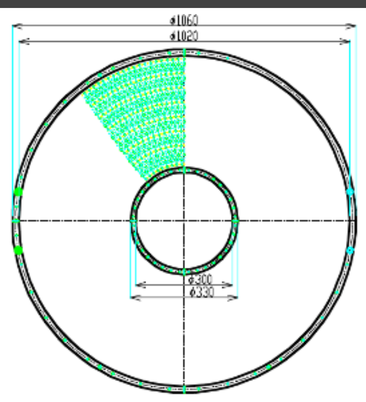
- 3.3m x 3.3m x 3.9m, ~108t in total
- Max. Field of 1.0T @ center
  - 189A - 10V
- NbTi/Cu SC wire, 98km in total
- Have been built in Feb. 2025
- Magnet field measurement -> no probrem

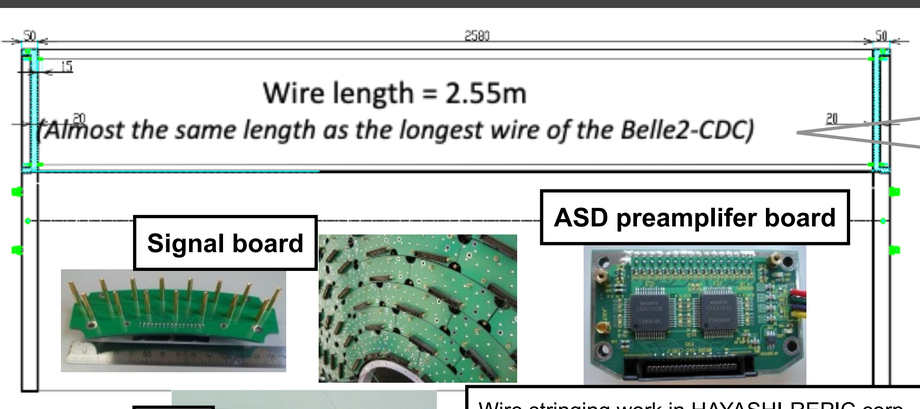


- Scintillator array: 2 layers, 12 cm thickness
- MPPC array
- Neutron detection efficiency of 12~36%
- Intrinsic time resolution of ~80ps

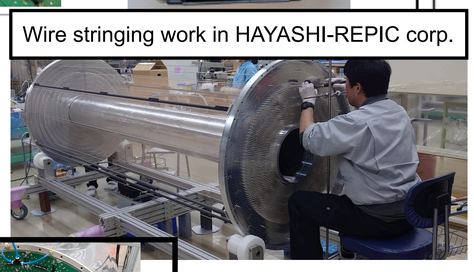
The detail of the CNC is written in S. Sasaki's poster.

- The new Cylindrical Drift Chamber (E80-CDC) -





Wire stringing work in HAYASHI-REPIC corp.

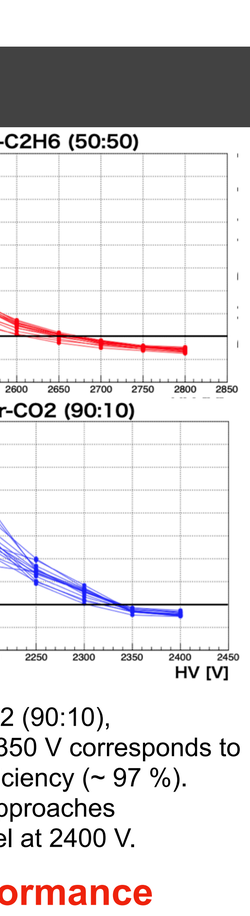


- The CDC consists of two aluminum end plates and a CFRP cylinder as the inner wall.
- 8,244 wires
  (The wire tension was applied so that the wire sag was less than 200 um.);

Wire type	Wire diameter	Wire material	Number of wires	Wire tension
Sense	$\phi 30$ μm	Au-W	1,816	70 g
Filed	$\phi 80$ μm	Be-Cu	5,376	240 g
Guard	$\phi 80$ μm	Be-Cu	1,052	240 g
In total			8,244	1.67 tons

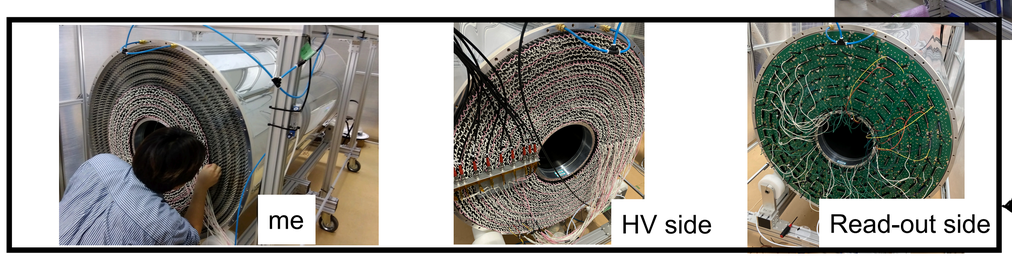
- 15 layers of hexagonal cells with a typical drift length of 9 mm

Super-layer	layer	Wire direction	Radius (mm)	Cell width (degree)	Cell width (mm)	Stereo angle (degree)	Signal channels per layer
A1	1	X	190.5	5.00	16.7	0	72
	2	X'	204.0		17.8	0	
	3	X	217.5		19.0	0	
U1	4	U	248.5	4.00	17.3	-2.27	90
	5	U'	262.0		18.3	-2.39	
V1	6	V	293.0	3.60	18.4	2.42	100
	7	V'	306.5		19.3	2.53	
A2	8	X	337.5	3.00	17.7	0	120
	9	X'	351.0		18.4	0	
U2	10	U	382.0	2.40	16.0	-2.82	150
	11	U'	395.5		16.6	-2.92	
V2	12	V	426.5	2.25	16.7	2.96	160
	13	V'	440.0		17.3	3.05	
A3	14	X	471.0	2.00	16.4	0	180
	15	X'	484.5		16.9	0	



Readout system

- Preamplifiers with ASDs
  (SONY CXA3653Q or 16ch-ASAGI)
- HUL (multi-hit TDCs) or AMANEQ (Streaming DAQ)



Transfered to J-PARC

- A total of 6,428 field wires have been connected using daisy chains.
- Signal readout side has been assembled in Dec. 2024.

What gases will we use?

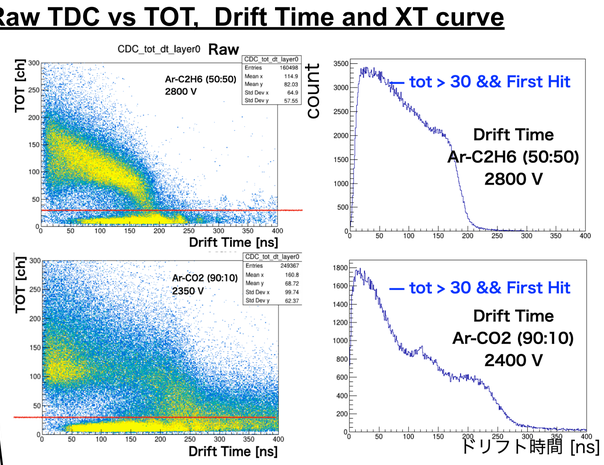
We used Ar-C_2H_6 (50-50) mixture for the E15-CDC. However, we want to use non flammable and low-cost gases because the CDC has 3 times the volume of the E15-CDC.

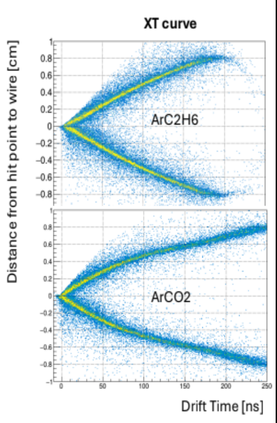
- Gas study; Comparison between Ar-C2H6 and Ar-CO2 -

Cosmic ray with E15-CDC

- The study used the E15-CDC
- No magnetic field
- Ar-C_2H_6 (50-50) : -2500 ~ -2800 V
- Ar-CO_2 (90-10) : -2250 ~ -2400 V
- Preamplifiers with ASDs
  (SONY CXA3653Q, τ =16ns)
- HUL (multi-hit TDCs)

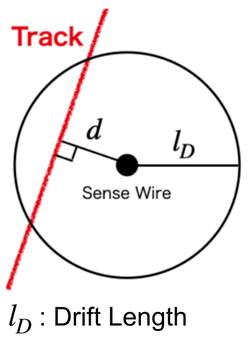
Raw TDC vs TOT, Drift Time and XT curve





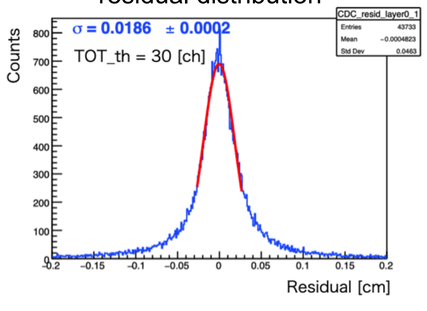
Position Resolution Requirement < 200 um

Def : Residual = $l_D - d$

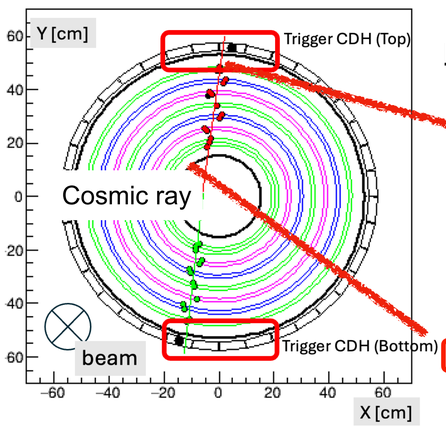


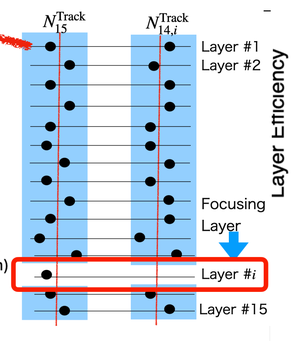
l_D : Drift Length

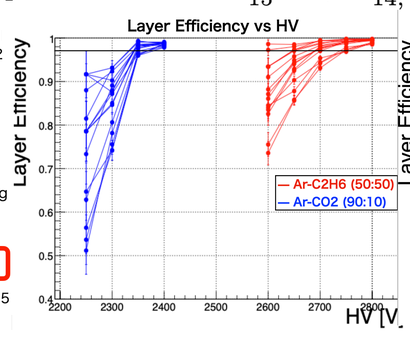
Example of residual distribution

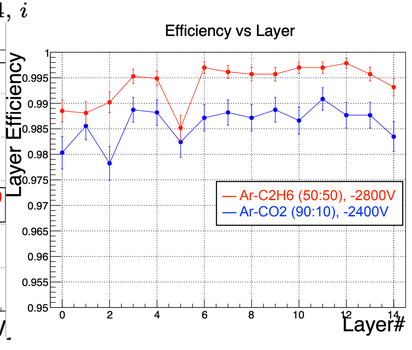


Layer Efficiency Requirement $E_i = \dfrac{N_{15}^{\text{track}}}{N_{15}^{\text{track}} + N_{14,i}^{\text{track}}} > 97\%$

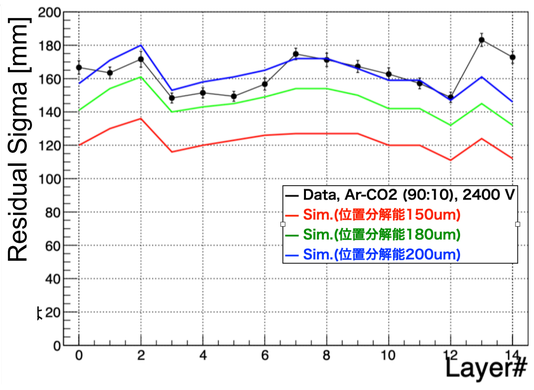








Residual Sigma of Exp. and Simuration



In case of Ar-CO2 (90:10), Approximately 2350 V corresponds to the expected Efficiency (~ 97 %). The resolution approaches an adequate level at 2400 V.

The performance with Ar-CO_2 (90:10) is satisfactory.

- Summary -

Ar-CO_2 (90:10) also met our required performance. However, at the HV value that satisfies the required performance, the S/N ratio of Ar-C_2H_6(50:50) was better than that of Ar-CO_2 (90:10). Hereafter, Ar-CO_2 test will be conducted with all ASDs installed with E80-CDC. And We will proceed with the preparations for the J-PARC E80 experiment scheduled for the 2026 fiscal year.