Performance evaluation of Cylindrical Neutron Counter (CNC) for J-PARC E80 at K1.8BR

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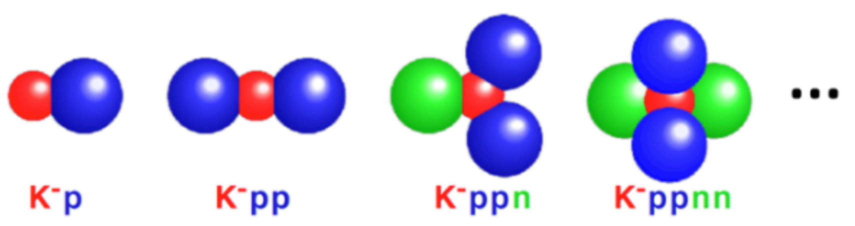
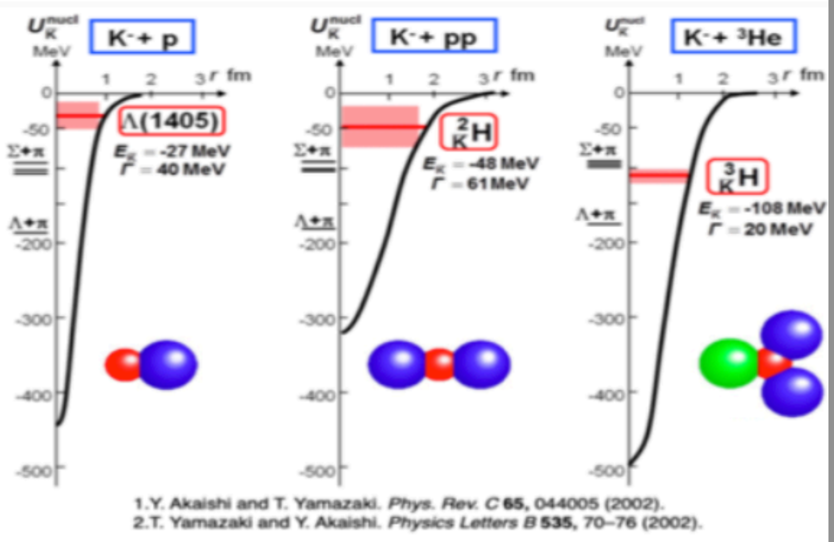
1. Introduction

Kaonic nuclei

・What is "Kaonic nuclei" ?



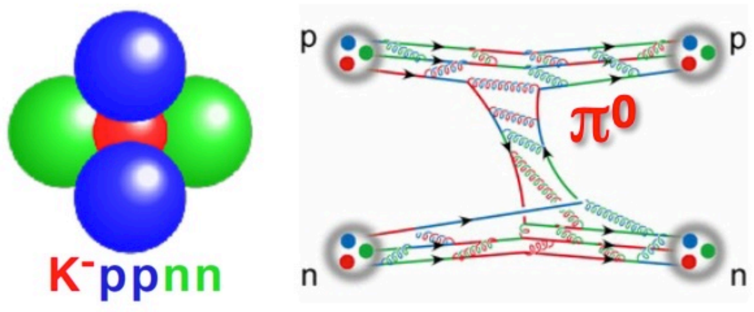


Kaonic nuclei = $\bar{K}$ - NN… bound states

Predicted from strong attractive $\bar{K}N$ interaction in $I = 0$ channel

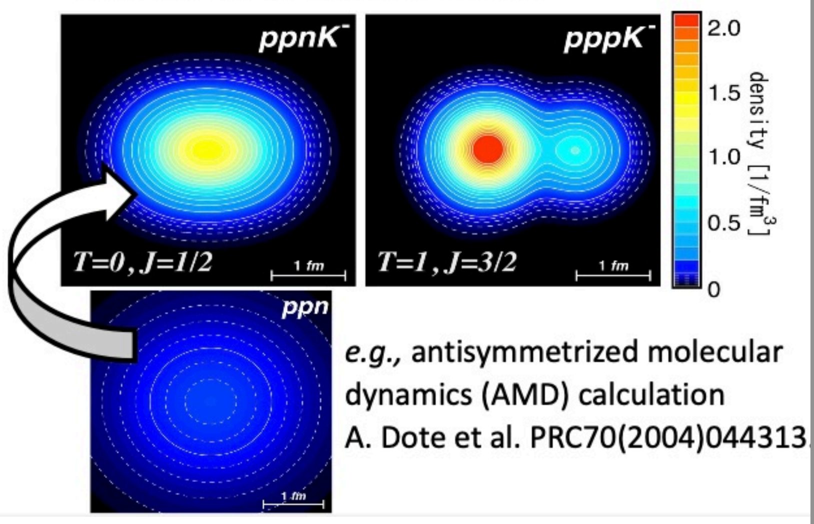
・What is interesting about 'Kaonic nuclei' ?

- **Meson can be the building block of nuclei → New forms of nuclei**
  - *cf.*, "virtual" light mesons play an important role in a nucleus as "glue"



$\bar{K}$ = "real" particle　　π = "virtual" particle (Force Mediating Particle)

- **Possibility of high-density matter formation ← strongly attractive $\bar{K}N$**
  - large binding energies are expected compared to normal nuclei

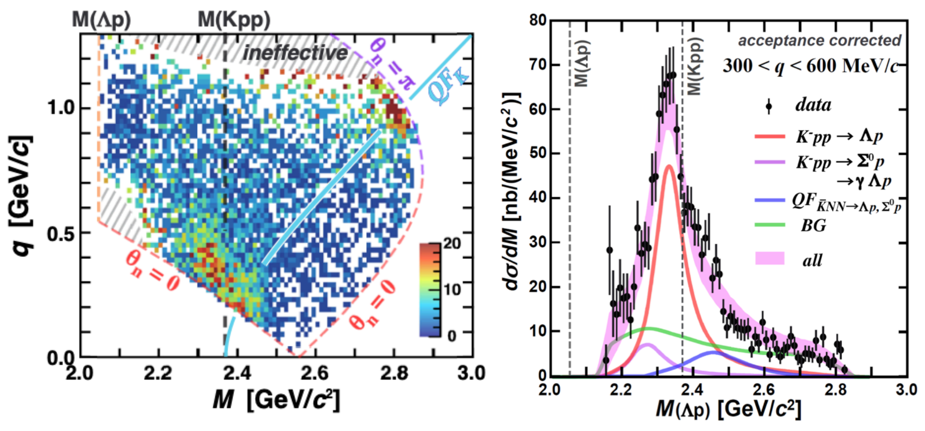


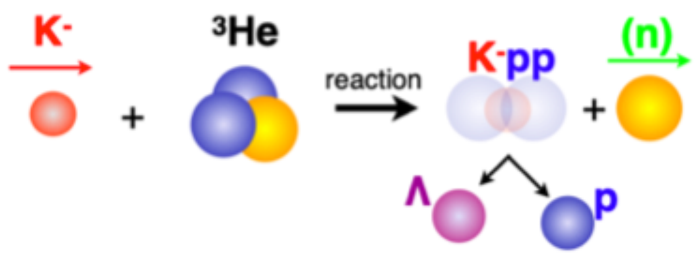
e.g., antisymmetrized molecular dynamics (AMD) calculation
A. Dote et al. PRC70(2004)044313

J-PARC E15 experiment

K^-pp bound state was observed at K1.8BR in J-PARC !

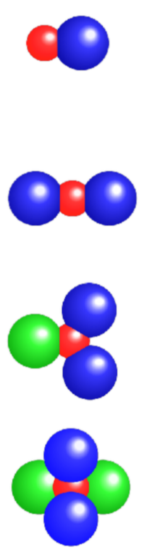
We confirmed the existence of the K^-pp bound state by using the simplest reaction of in-flight $^3He(K^-,N)$ at the J-PARC E15 experiment. A distinct peak structure was observed well below the mass threshold of K^-+p+p in the Λp invariant-mass (IM) spectrum, obtained from the $^3He(K^-,\Lambda p)n$ measurement.





However,

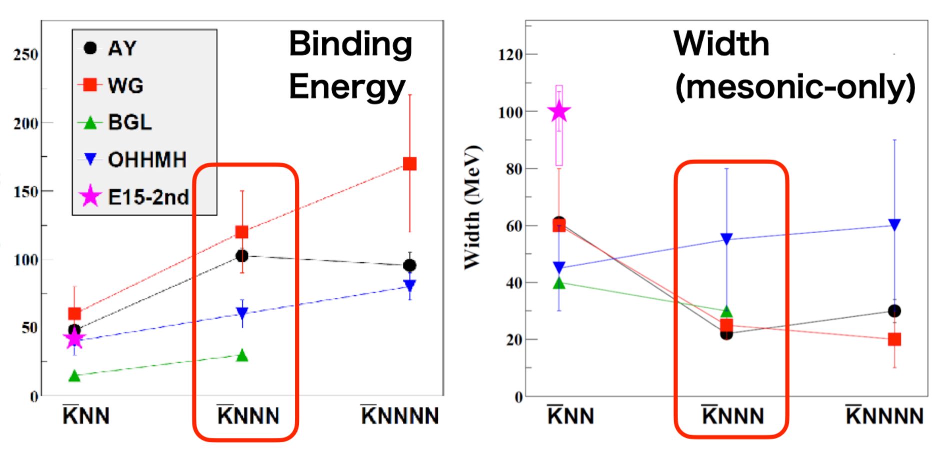
the detailed properties need to be clarified by further experimental studies. For this purpose, we have planed a series of experimental programs using the $(K^-,N/d)$ reactions on light nuclear targets at the K1.8BR beam line. The programs comprise :



- [$\bar{\mathrm{K}}$N(Λ(1405))] Precise measurement of the $\Lambda(1405)$ state in large momentum transfer region via the $d(K^-,n)$ reaction, to experimentally clarify the picture whether it is a baryonic state or a $\bar{K}N$ molecular state,
- [$\bar{\mathrm{K}}$NN] Investigation of the spin and parity of the $\bar{K}NN$ state via the ^{3}He(K^-,N) reactions,
- [$\bar{\mathrm{K}}$NNN] Precise measurement of the $\bar{K}NNN$ states via the ^{4}He(K^-,N) reactions, as for the bridge to access heavier system, and,
- [$\bar{\mathrm{K}}$NNNN] Advanced search for the $\bar{K}NNNN$ states via the ^{6}Li(K^-,d) reaction.

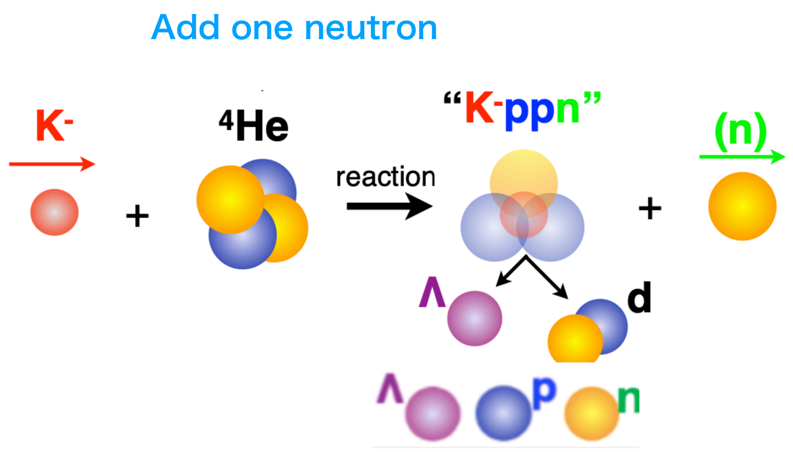
・Larger binding than and similar width are predicted.

・Some experimental searches in 2000s. No conclusive result.



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

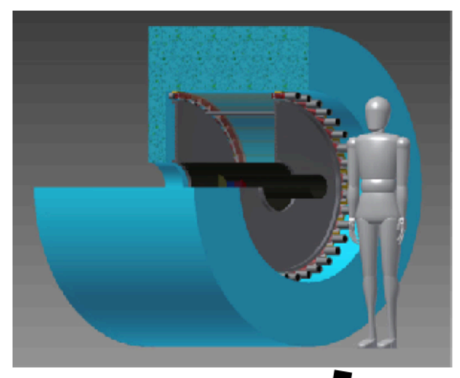
Our approach to next step



・Decay to more particle than E15
・Particles to be detected include neutrons

—> Necessity of detector Improvements

New spectrometer

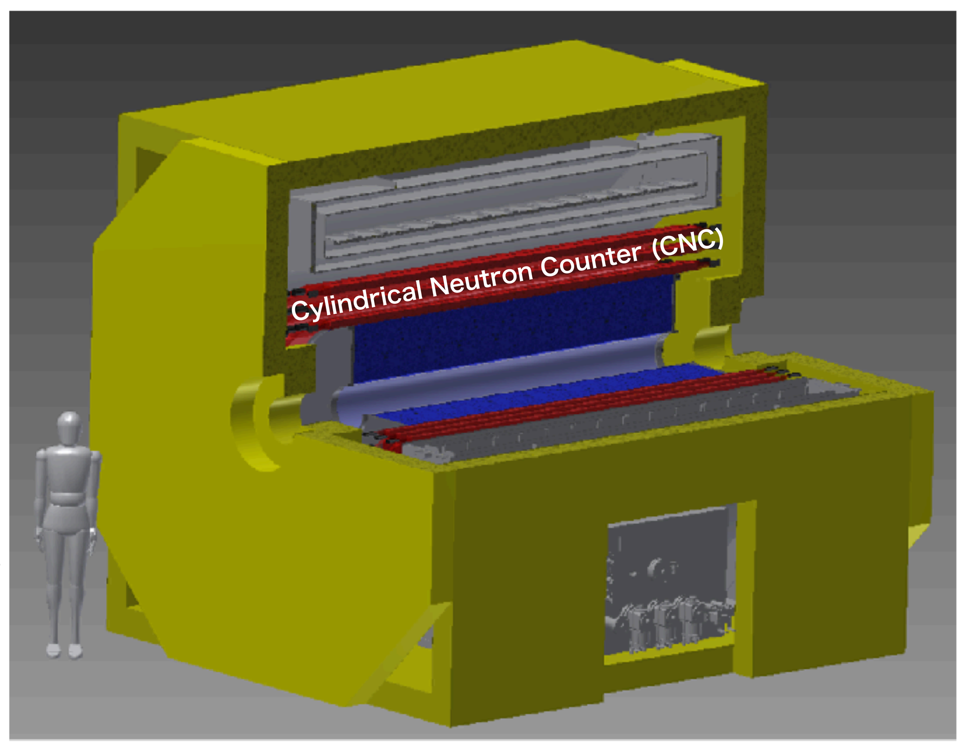


・Larger acceptance
59% —> 93%
・higher capability of detecting neutron
~3% —> ~15%

Solenoid:
Copy of COMET DS

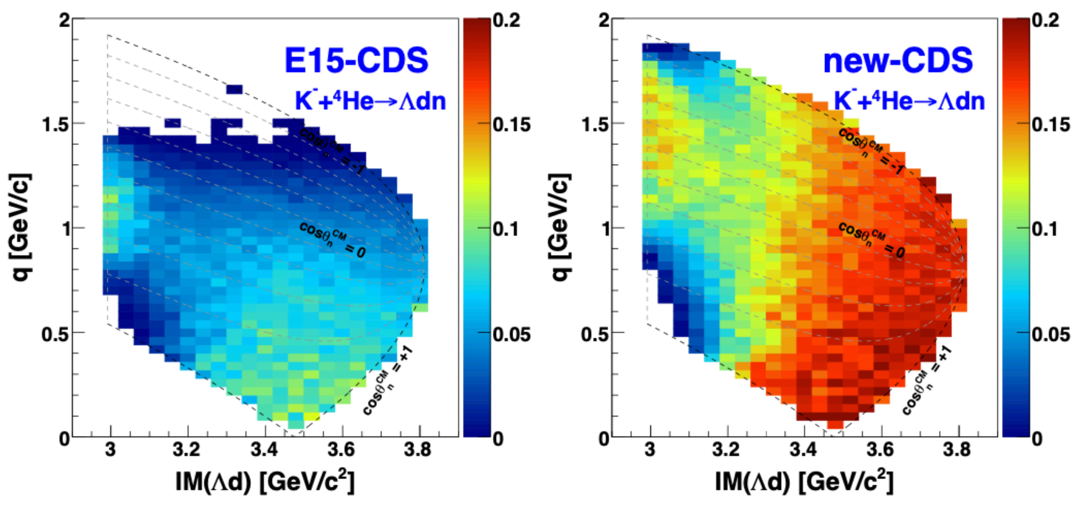
CDC:
15-layer DC

CNC:
3-layer 5-cm thick plastic scintillator



Full Monte-Carlo

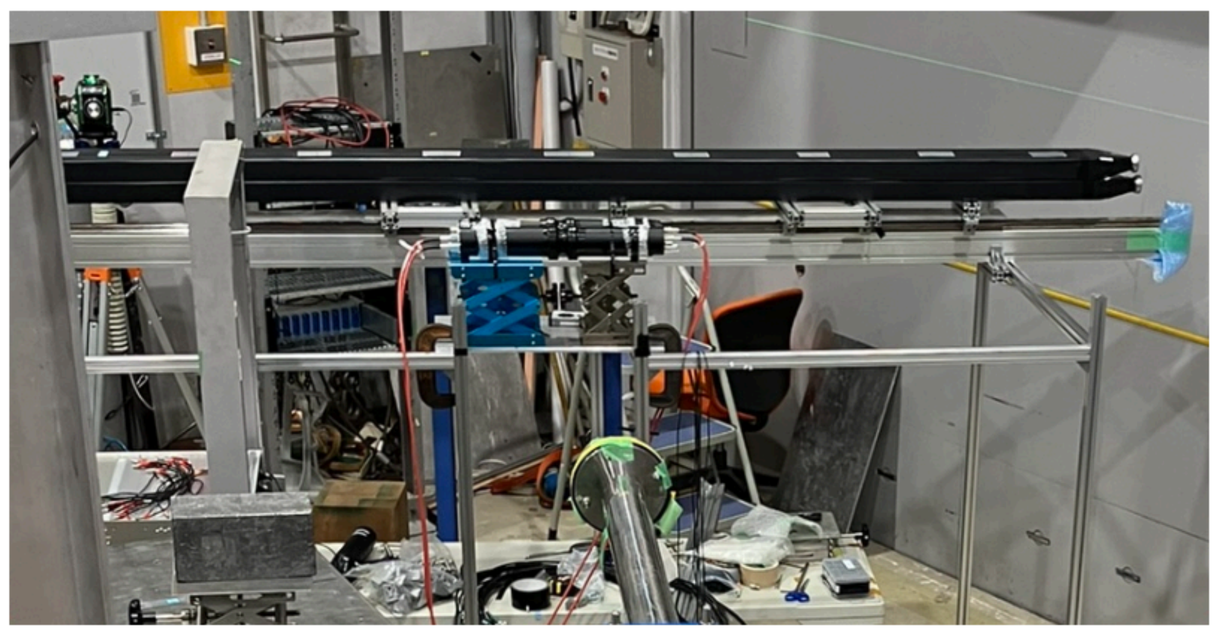
Detector acceptance for the Λd detection with the CDS in the K⁻ + ⁴He → Λdn reaction. The left figure shows the acceptance with the existing CDS (E15 CDS), and the right shows that with the newly constructed CDS (new-CDS). The relation between q and cos(θ CM) is also represented, where cos(θ CM) denotes the polar angle of the missing neutron in the center-of-mass frame of the K⁻+ ⁴He reactions.



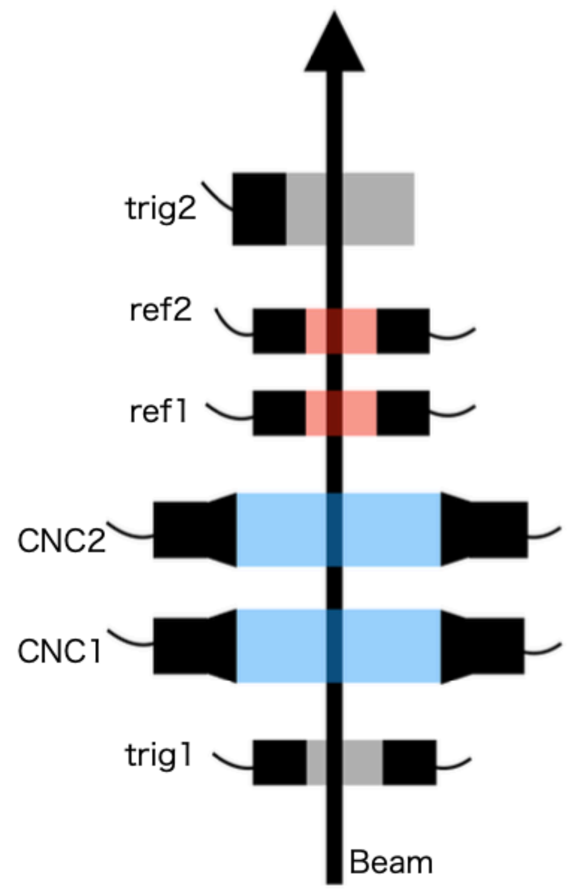
•Larger region of momentum transfer

2. Beam test at ELPH

Beam (e^+) momentum : 584 MeV/c



@ GeV-γ irradiation room in ELPH



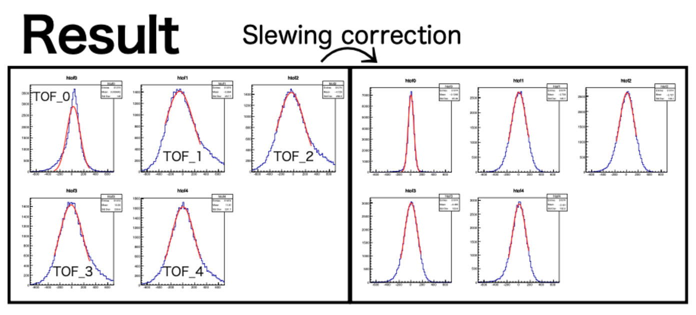
Purpose of this experiment

・Measurement of the time resolution of CNC
・Position dependence of it ?

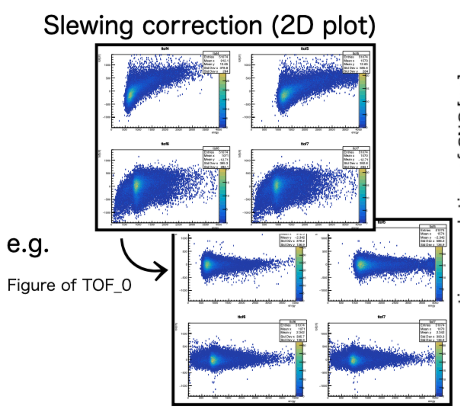
Define of TOF
TOF_0 = Ref1 - Ref2
TOF_1 = CNC1 - Ref1
TOF_2 = CNC1 - Ref2
TOF_3 = CNC2 - Ref1
TOF_4 = CNC2 - Ref2

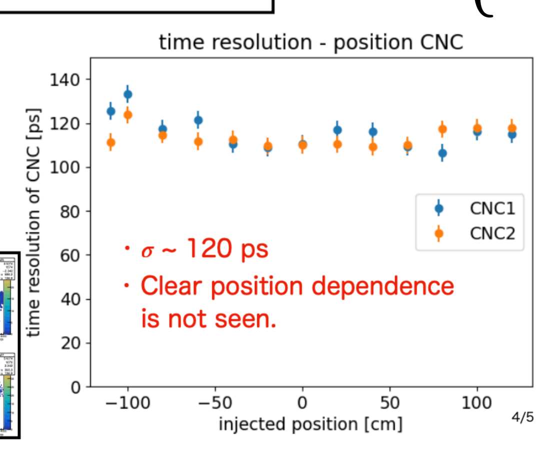
We performed beam tests at ELPH to investigate the time resolution of CNC and its position dependence. Five TOFs were defined as shown on the left. Slewing corrections were made for each TOF to produce the time resolution. Then, the intrinsic time resolution of CNC1,2 and Ref1,2 can be derived from the following two simultaneous equations.

Result



$$\begin{cases} \sigma^2_{TOF0} = \sigma^2_{Ref1} + \sigma^2_{Ref2} \\ \sigma^2_{TOF1} = \sigma^2_{Ref1} + \sigma^2_{CNC1} \\ \sigma^2_{TOF2} = \sigma^2_{Ref2} + \sigma^2_{CNC1} \end{cases} \qquad \begin{cases} \sigma^2_{TOF0} = \sigma^2_{Ref1} + \sigma^2_{Ref2} \\ \sigma^2_{TOF3} = \sigma^2_{Ref1} + \sigma^2_{CNC2} \\ \sigma^2_{TOF4} = \sigma^2_{Ref2} + \sigma^2_{CNC2} \end{cases}$$

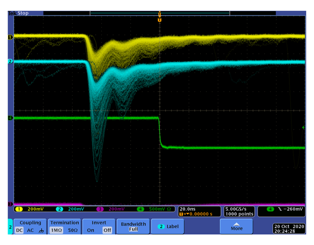




$\sigma_{Ref1} = 25 \pm 3$ [ps]　$\sigma_{Ref2} = 45 \pm 3$ [ps]

$\sigma_{CNC1,2} \sim 120$ [ps]

We have tried to obtain a correlation between gain and time resolution, but have not yet been able to do so. This is because the true gain could not be obtained due to reflected waves from the light guide, and we could not establish an analysis method for this.



3. Summery

The J-PARC E80 experiment, the next step in K meson bound nucleus research, must detect more decay particles than the E15 experiment, and the neutron detection efficiency must also be higher. For this purpose, we plan to use a neutron counter, which we call CNC, with a scintillator more than three times as long and about twice as thick as that of the E15 experiment. In this study, I conducted an experiment to investigate the time resolution of this CNC and its position dependence The results are shown above, σ ~ 120 ps, almost flat.

How does changing the length of the light guide change the time resolution, and what happens when MPPC is used instead of PMT?We are currently analyzing.