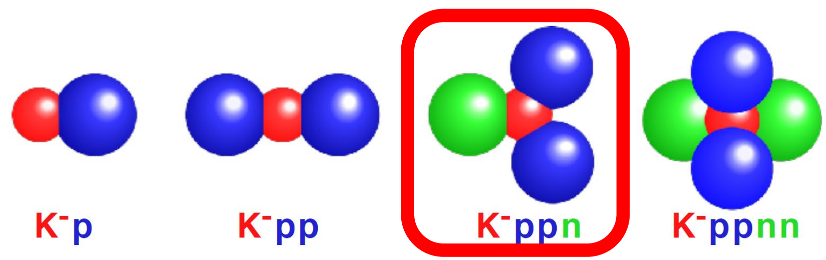
Status report on E80/P92

Systematic Investigation of the Light Kaonic Nuclei

– from the $\overline{K}N$ to $\overline{K}NNNN$ systems –



F. Sakuma, RIKEN

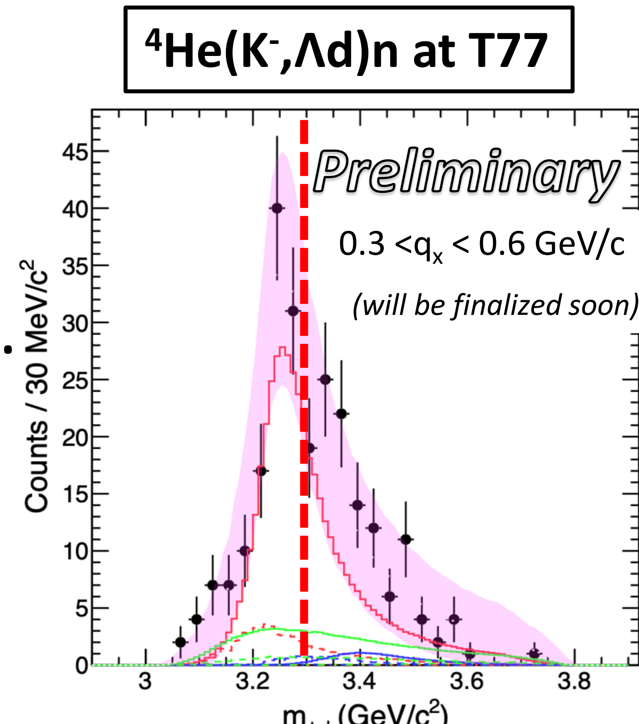
on behalf of

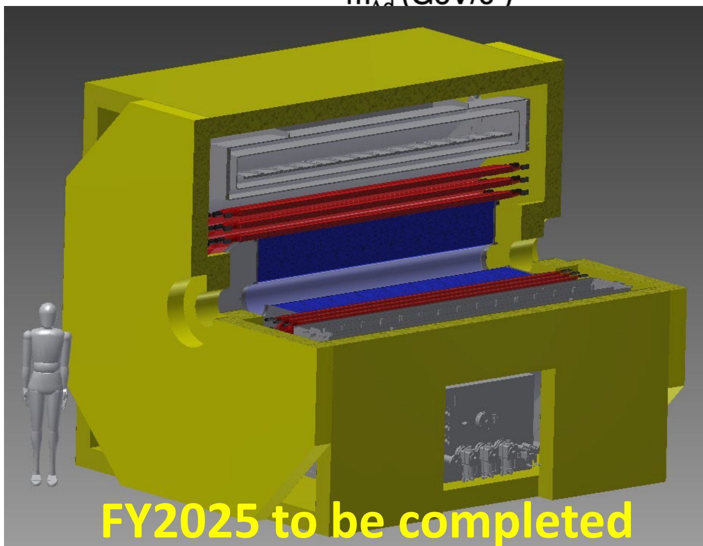
the J-PARC E80/P92 collaboration

34th J-PARC PAC meeting, Aug 3-5, 2022

Summary

- E80/P92 aim to establish the $\bar{K}NNN$ bound state as a first step.
- We observed a peak structure below M(K^-ppn) via **^{4}He(K^-,Λd)n** using T77 data.
  - ➢ suggests **the $\bar{K}NNN$ bound state**
  - ➢ we need further investigation at E80/P92
- We successfully obtained **a large research grant (FY2022-26)** this April.
  - ◆ E80 experiment will be ready to start in late FY2025
- **We'd like to concentrate on E80 with the new CDS.**
  - ✓ We'd like to maintain the possible realization of P92 with the existing CDS in case unforeseen circumstances arise





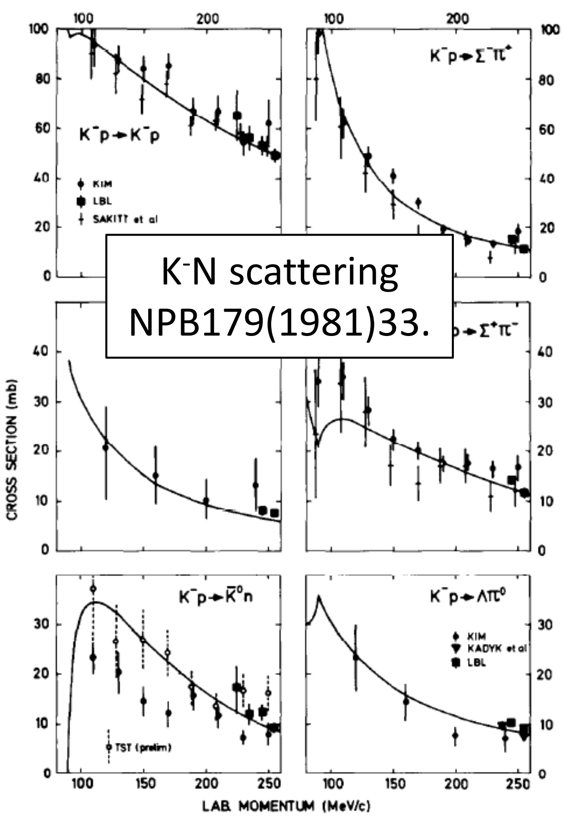
Introduction

Physics Goal

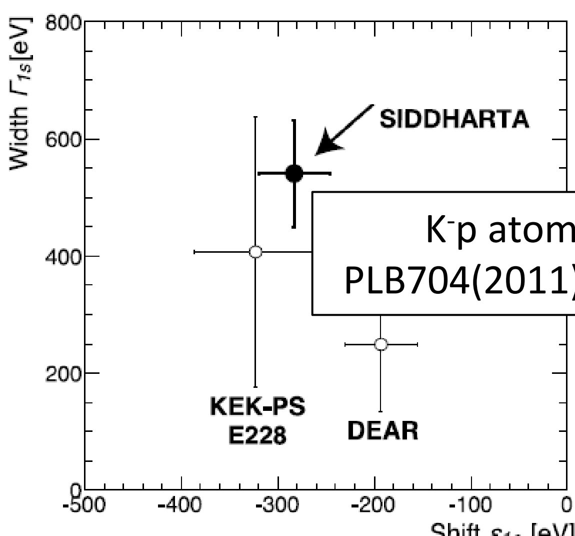
Reveal the meson properties inside nuclei
via **the $\bar{K}N$ interaction**

A powerful probe to understand low energy QCD

Strongly attractive in I=0 from extensive measurem… **→ Kaonic Nuclei**

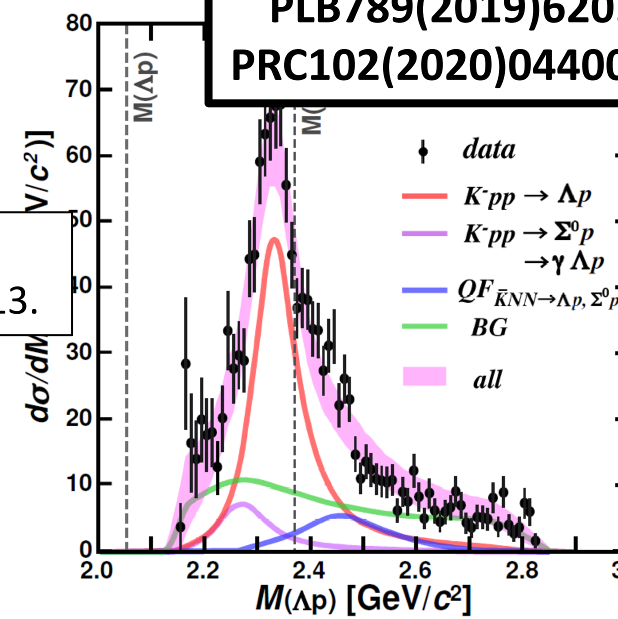


K⁻N scattering
NPB179(1981)33.



K⁻p atom
PLB704(2011)113.

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

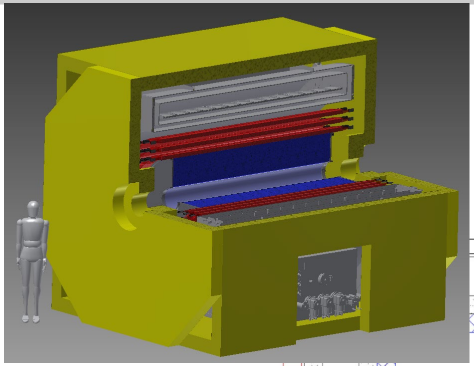


Strategy of the New Project

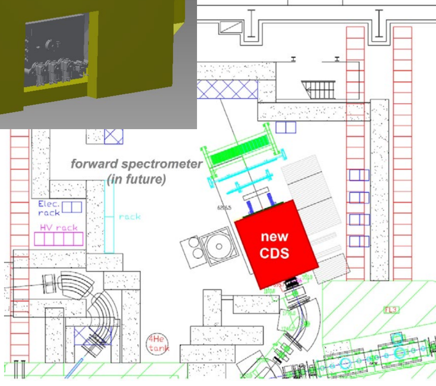
- for systematic study from the $\bar{K}N$ to $\bar{K}NNNN$ systems -

	Reaction	Decays	Key	
$\bar{K}N$	d(K$^-$,n)	$\pi^{\pm0}\Sigma^{\mp0}$	n/γ identification	
$\bar{K}NN$	^{3}He(K$^-$,N)	Λp/Λn	polarimeter	← P89
$\bar{K}NNN$	^{4}He(K$^-$,N)	Λd/Λpn	large acceptance	← E80/P92
$\bar{K}NNNN$	*^{6}Li(K$^-$,d)*	*Λt/Λdn/Λpnn*	*many body decay*	
$\bar{K}\bar{K}NN$	*$\bar{p}$ + ^{3}He*	*ΛΛ*	*$\bar{p}$ beam yield*	

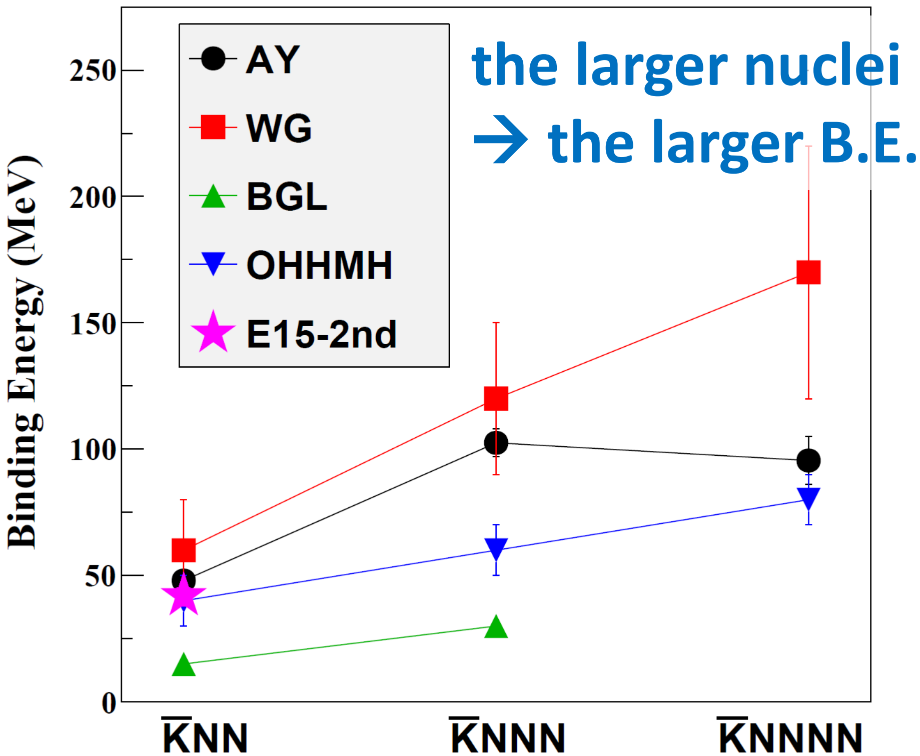
*We take a **step-by-step** approach*

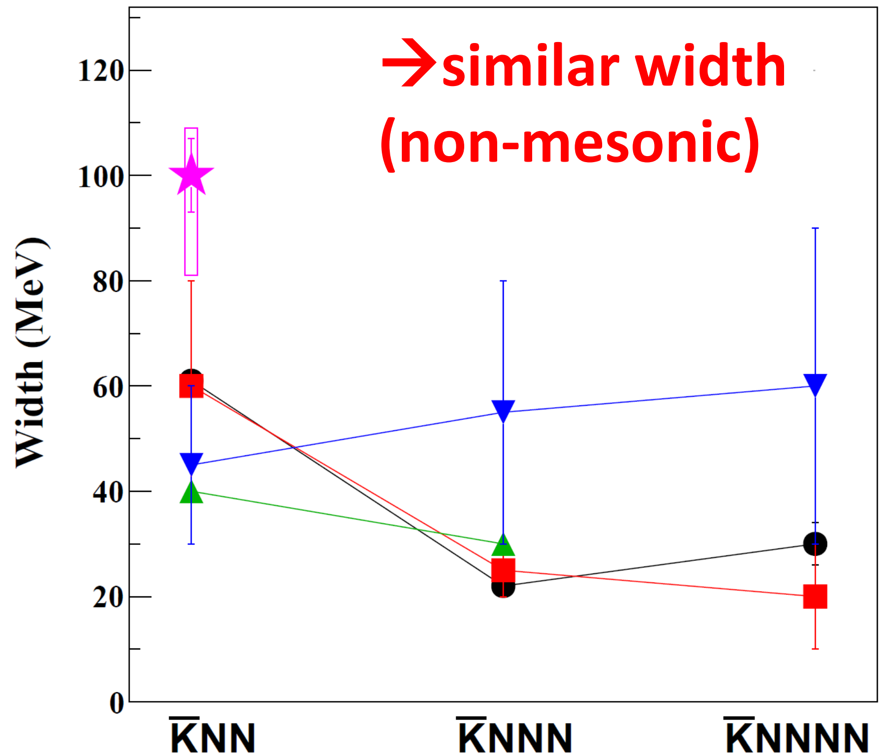


- For the realization, we utilize
  - ☐ **a large acceptance spectrometer**
    - detect/identify all particles
  - ☐ **high-intensity kaon beam**
    - more K$^-$ yield than the existing beam line

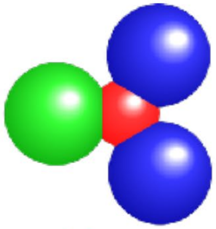


Systematic Study will Deepen our Knowledge of the Kaonic Nuclei





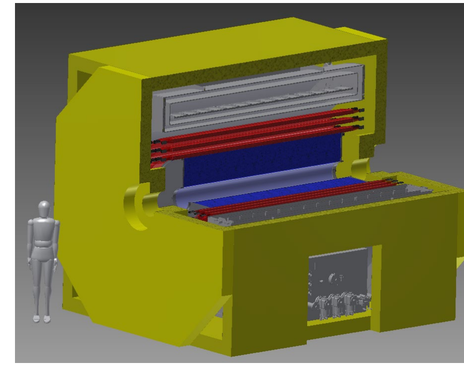
- Systematic measurements will provide more conclusive evidence of the kaonic nuclei



$K^{-}ppn$

A First Step: Search for $\bar{K}NNN$

via ^{4}He(1 GeV/c K^{-}, n) reaction



Goals of the E80 experiment:

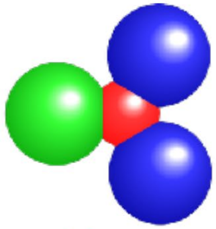
① **Establish the $\bar{K}NNN$ state conclusively**

- Observation of the "$K^{-}ppn$" state via 2-body Λd decay

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

- Reconstruction of the "$K^{-}ppn$" state via 3-body Λpn decay

- **Feasibility study of spin-spin correlation measurement for P89**
  - *e.g.*, by installing a prototype module of a polarimeter



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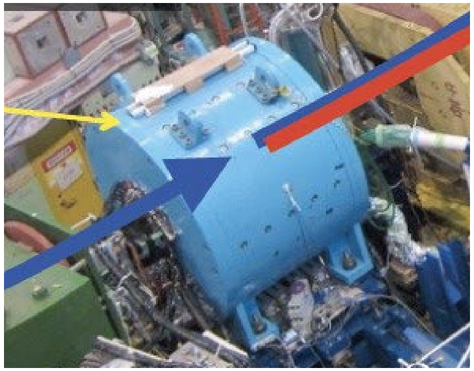


Goals of the P92 experiment:

① **Establish the $\bar{K}NNN$ state conclusively**

➢ Observation of the "K⁻ppn" state via 2-body Λd decay

→ we have already demonstrated the Λdn reconstruction with the present setup

- P92 aims at an immediate investigation into $\bar{K}NNN$ using **the present setup**
  - focusing on the K^{-4}He → Λdn measurement
  - **as Phase-I experiment of E80**
- **The goal of P92 is the same as a part of the E80 goal**

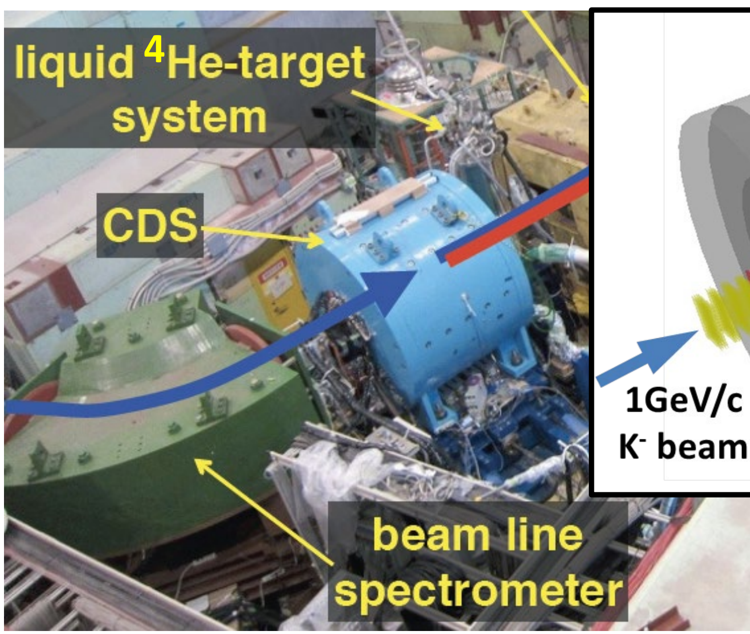
$K^{-4}\mathrm{He} \to \Lambda d n$

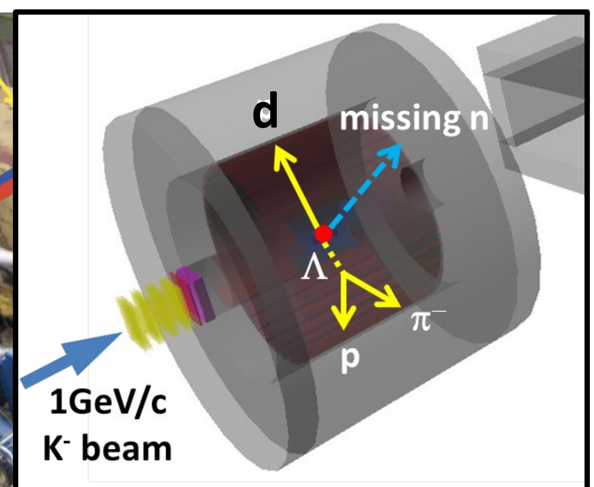
using the T77 data

T77: lifetime measurement of ${}^{4}_{\Lambda}\mathrm{H}$ conducted in 2020

Analysis of K^{-} ^{4}He → *Λdn* at T77

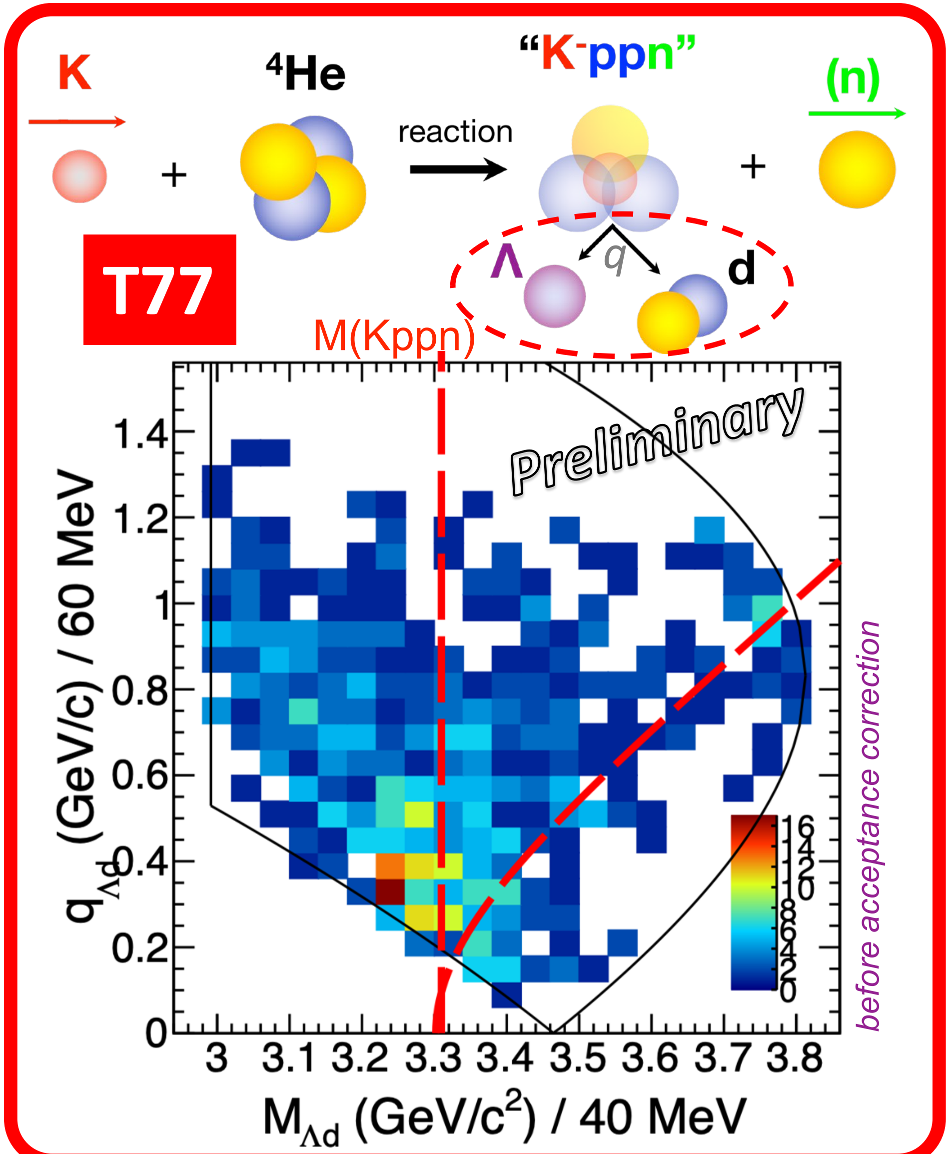
- We have conducted an analysis on ***Λdn*** final state of ***K***$^{-4}$**He** reaction at **1 GeV/*c***
  - 66 hours under 51 kW corresponding to **140 kW*days**
- T77 experiment used the **present CDS** (Cylindrical Detector System)

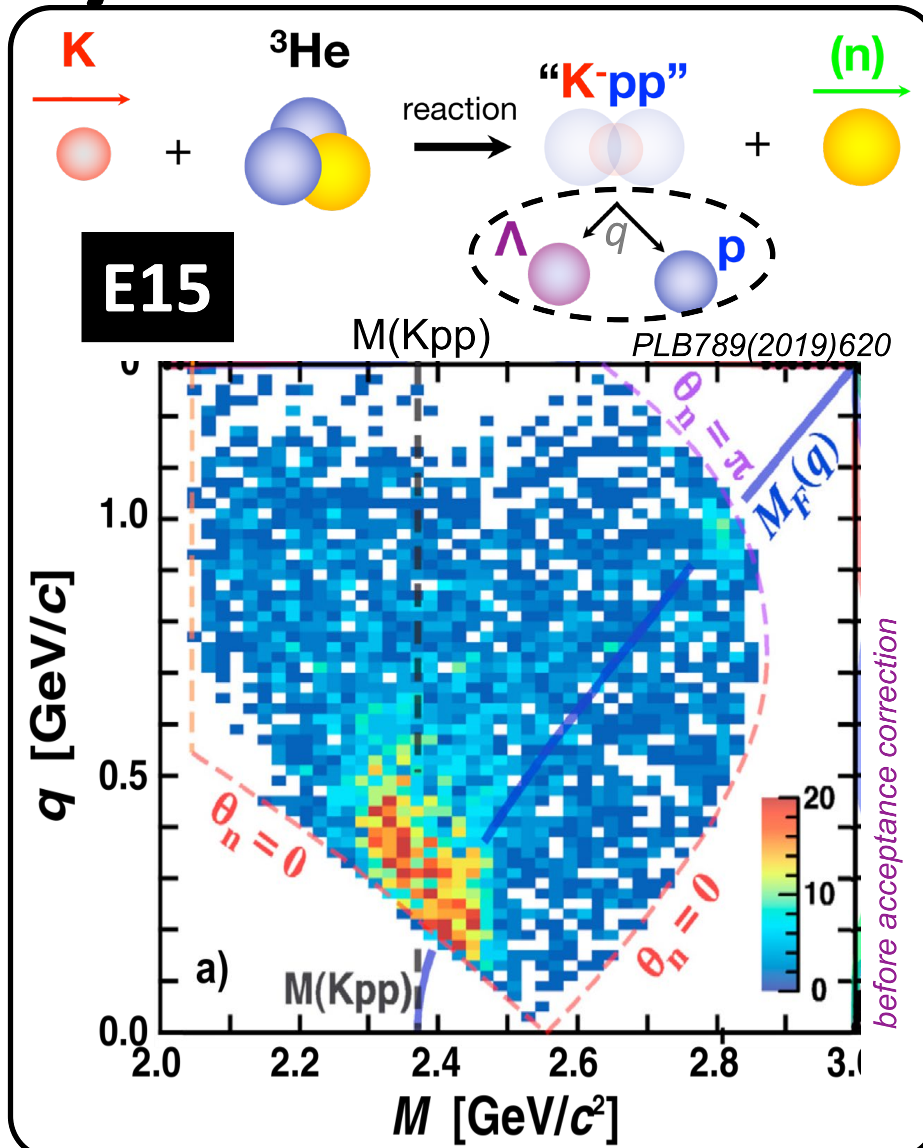




K.Agari et al.,
PTEP, 2012, 02B011

Preliminary result





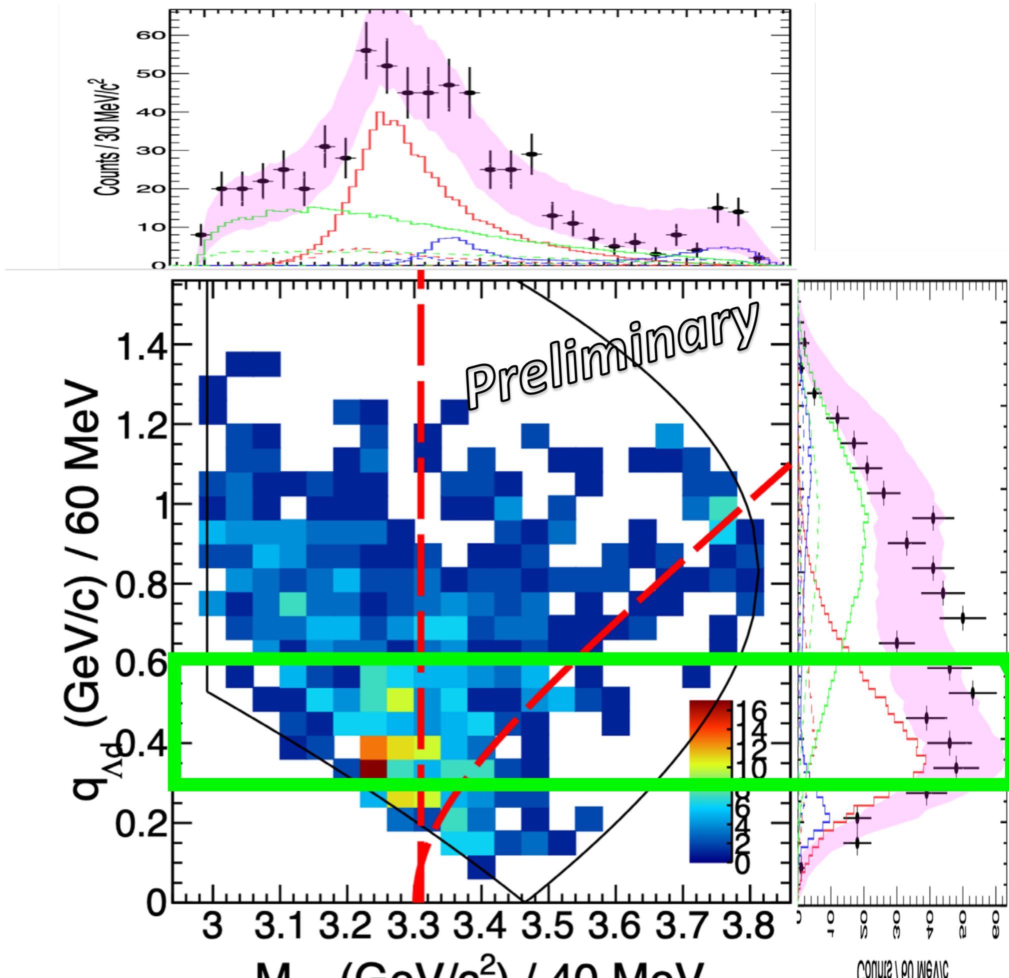
- **Two distributions are quite similar**
- structure below the threshold (**seems *q*-independent**), QF-K, BG

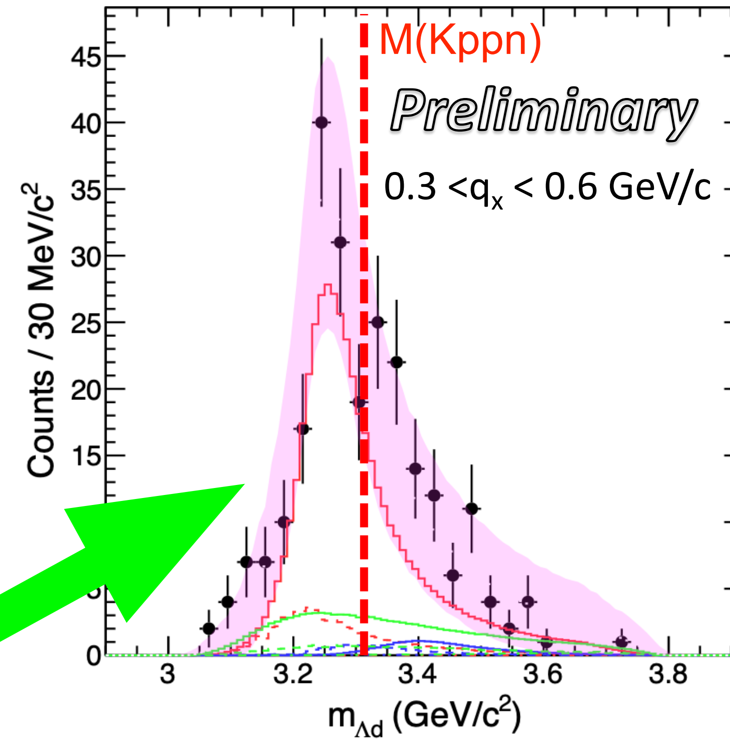
Preliminary result

2D fit on the (M,q) space with similar shapes to E15:

Breit-Wigner wtih Gaus. form factor (PWIA), QF-K$^-$, and Broad BG

$$\sigma(M,q) \propto \rho(M,q) \times \frac{(\Gamma_X/2)^2}{(M-M_X)^2+(\Gamma_X/2)^2} \times exp\left(-\frac{q^2}{{Q_X}^2}\right)$$





$B_X = 64 \pm 11(stat)\ MeV$

$\Gamma_X = 128 \pm 19(stat)\ MeV$

$Q_X = 435 \pm 30(stat)\ MeV$

$\sigma_X \sim 4\ \mu b$ (N_X ~ 230 counts)

Preliminary result

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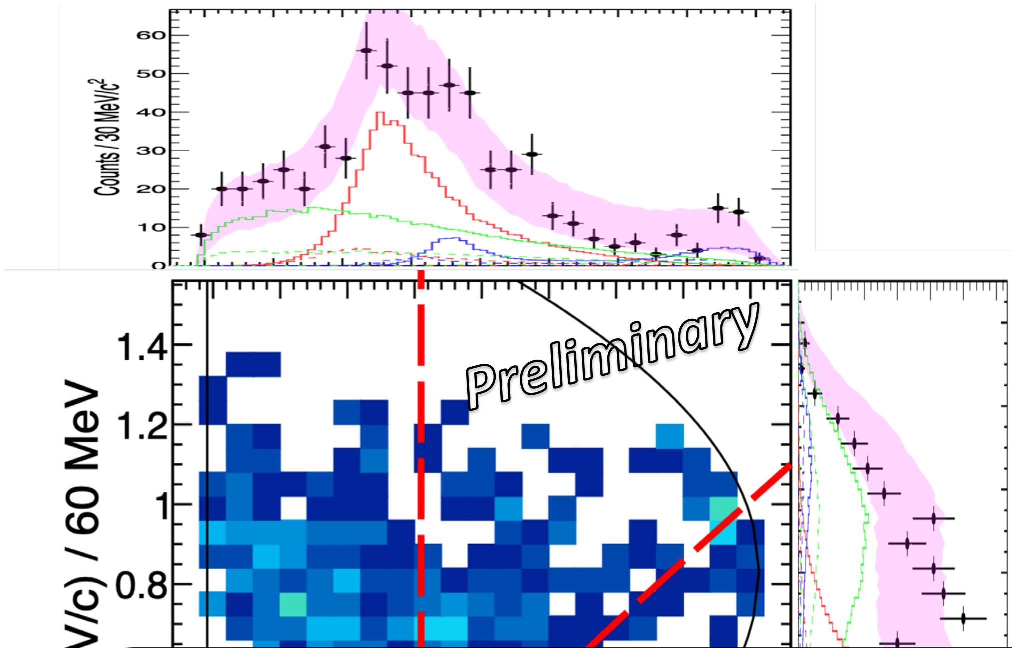
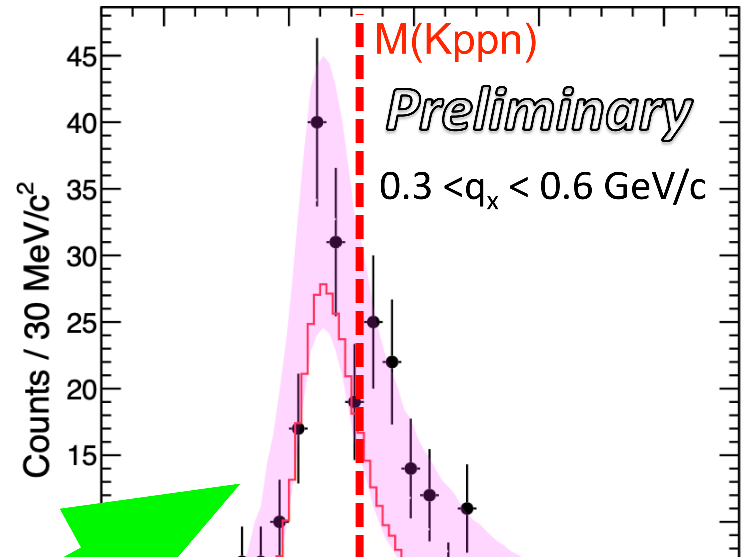




c.f. Λpn result at E15

$B_K = 42 \pm 3(\text{stat.})^{+3}_{-4}(\text{syst.})$ MeV
$\Gamma_K = 100 \pm 7(\text{stat.})^{+19}_{-9}(\text{syst.})$ MeV
$Q_K = 383 \pm 11(\text{stat.})^{+4}_{-1}(\text{syst.})$ MeV/c
$\sigma_K^{\text{tot}} BR_{\Lambda p} = 9.3 \pm 0.8(\text{stat.})^{+1.4}_{-1.0}(\text{syst.})$ μb

large systematic errors of >10 MeV will be added

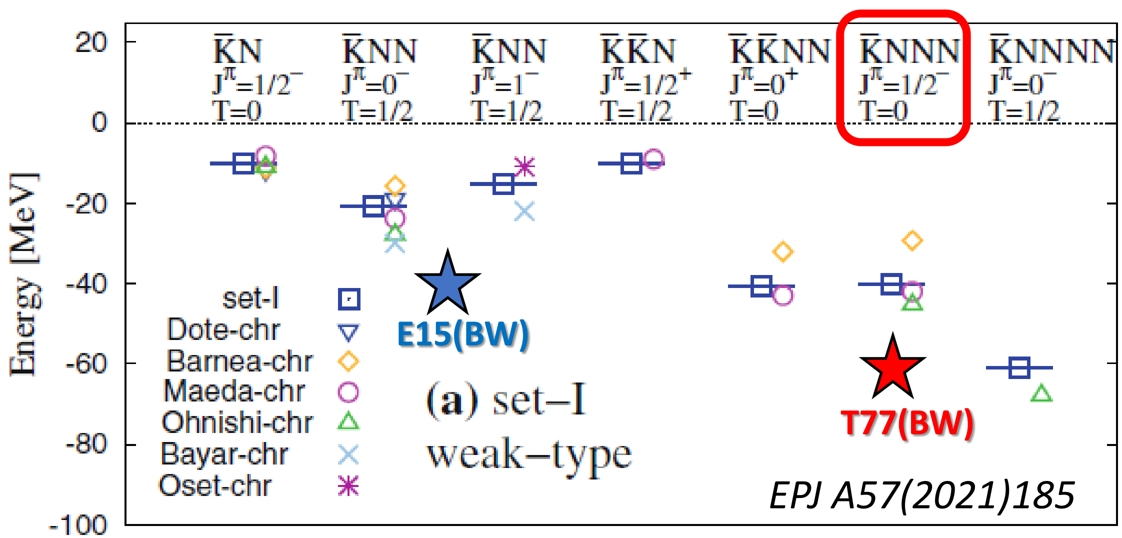
$B_X = 64 \pm 11(stat)\ MeV$
$\Gamma_X = 128 \pm 19(stat)\ MeV$
$Q_X = 435 \pm 30(stat)\ MeV$
$\sigma_X \sim 4\ \mu b$ (N_X ~ 230 counts)

What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound state interpretation.

comment asked in the Minutes of the 33rd PAC

1. **The "X"→*Λd* decay mode is unique evidence that <u>the isospin of the "X" system is 0</u>**
   - $I(J^P)$: $\Lambda = 0(1/2^+)$, $d = 0(1^+)$, $K^- = 1/2(0^-)$, $^3He = 1/2(1/2^+)$
   - If the "X" is the "$\bar{K}NNN$" state with $I(J^P)=0(1/2^-)$, "$\bar{K}NNN$" seems to have larger binding energy than "$\bar{K}NN$"



What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound state interpretation.

comment asked in the Minutes of the 33rd PAC

2. **An interpretation for the "$\bar{K}NNN$,0(1/2⁻)" seems to be a more natural candidate than "$\Sigma^* NN$,0(3/2⁺)" in terms of <u>the formation cross-section</u>.**

"X"	I(J^P)	σ(J^P)/σ(1/2-)
"K-ppn"	0(1/2-)	1$^{(*)}$
"Σ*-pp"	0(3/2+)	1/3 x $r_{stk}(\Sigma^* NN/\bar{K}NNN)$

$^{(*)}$: normalization channel
$r_{stk(\Sigma^* NN/\bar{K}NNN)}$: the ratio of sticking probabilities between "$\Sigma^* NN$" and "$\bar{K}NNN$", including $\bar{K}N \rightarrow \Sigma(1385)$ conversion probability in ($\bar{K}NNN$)-system

- evaluated from Clebsch-Gordan coefficients and known elementary processes
- there is uncertainty of the parameter, r_{stk}
- see more details in *M. Iwasaki, "Nuclear Physics Handbook, Section 9: Kaonic Nuclei from the Experimental Viewpoint"*

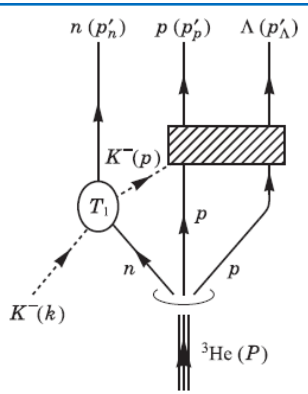
What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound state interpretation.

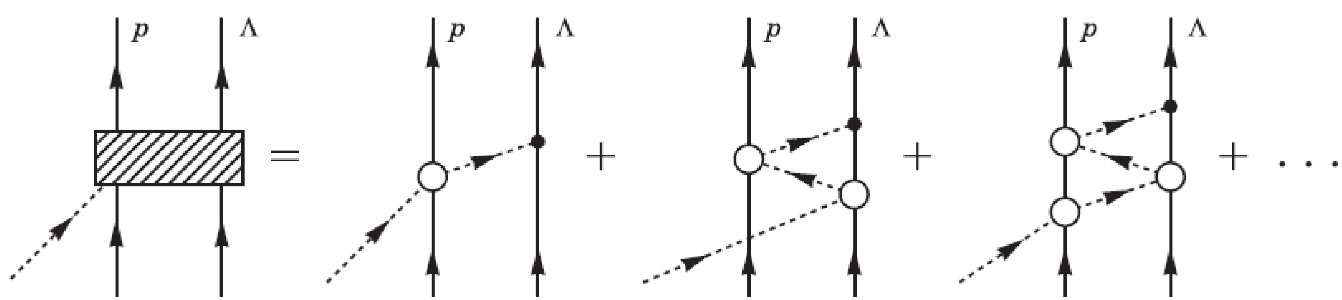
comment asked in the Minutes of the 33rd PAC

3. An interpretation for the "$\bar{K}NNN$,0(1/2⁻)" would be a more natural candidate than "$\Sigma^* NN$,0(3/2⁺)" in terms of <u>decay branch</u>.

- At "$\Sigma^* NN$" decay, natural decay process will be the $\Sigma^* N \rightarrow \Lambda N'$ conversion with high energy N' (~250MeV), thus "$\Sigma^* NN$"→Λpn could be dominant in non-mesonic decay
- "$\bar{K}NNN$"→Λd will be naturally introduced from the $\bar{K}N \rightarrow \Lambda$ conversion (w/ off-shell $\bar{K}$) similar to a theoretical calc. of $\bar{K}NN \rightarrow \Lambda p$:



K^{-3}He→$\bar{K}NN$+n→Λp+n calculation [PTEP(2016)123D03]



What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound ate interpretation.

comment asked in the Mi C

With the present data set of T77, however, it's hard to justify these interpretations conclusively.

3. An interpretation for the "$\bar{K}$
be a more natural ca
in terms of d

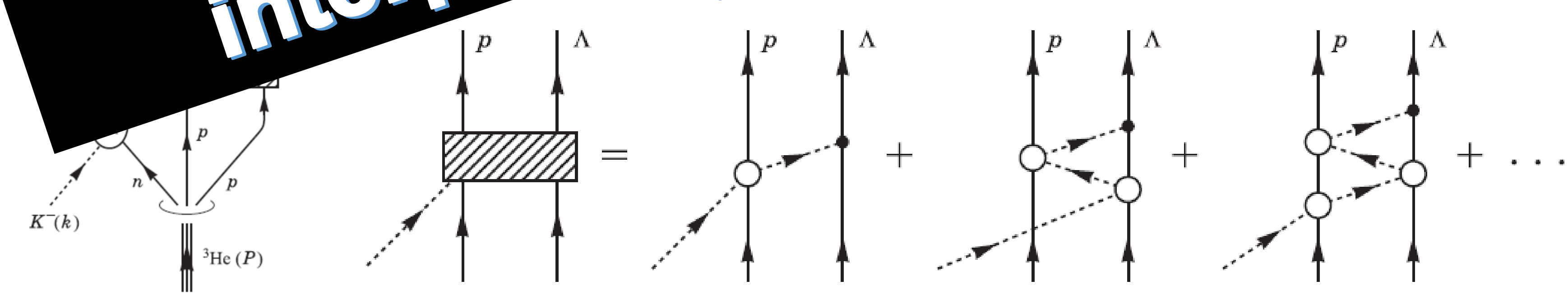
- At "$\Sigma^* N$

$N \rightarrow \Lambda pn$ could be

duced from the $\bar{K}N \rightarrow \Lambda$ conversion

theoretical calc. of $\bar{K}NN \rightarrow \Lambda p$:

N+n→Λp+n calculation [PTEP(2016)123D03]

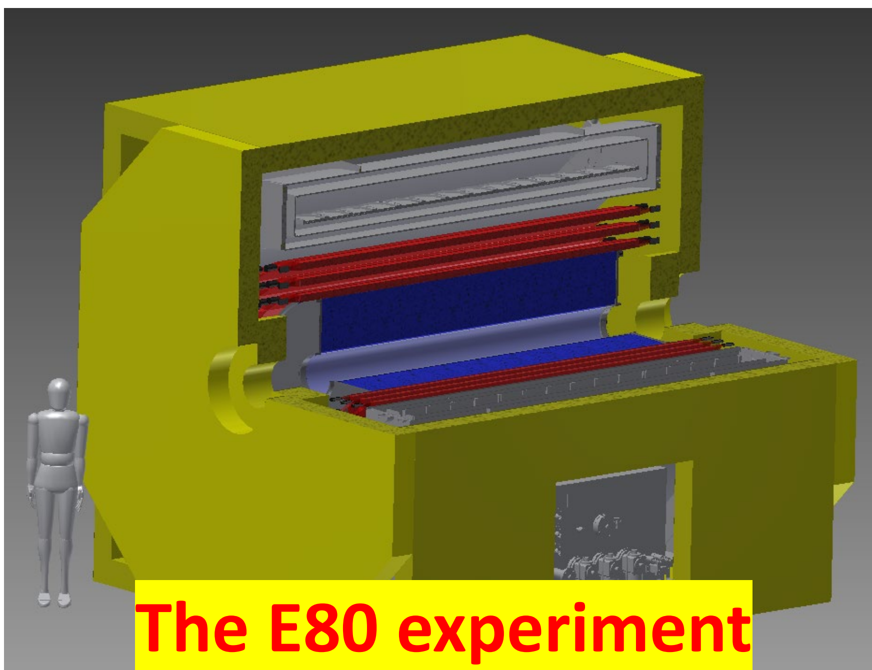


What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound state interpretation.

comment asked in the Minutes of the 33rd PAC

- **We need to seek further justification using high-quarity data-set for $\Lambda d/\Lambda pn$ branches with further theoretical studies.**



Theory

TITECH	Structure	D.Jido, Students
Kyoto Pref. U	Reaction	T.Sekihara, Students
Osaka Elec. U	Reaction	T.Harada, Students
KEK	Structure	A.Dote, O.Morimatsu, Students
RIKEN	Lattice-QCD	T.Hatsuda, Students

Postdoctoral position opens for this purpose:
Oct.2022
– (max) Mar.2027

See details in [ml-np:12663]
Application Deadline: 19 Aug.

What is the observed structure?

The PAC recommends that the proponents should carefully analyze the T77 data and seek further justification for the K-NNN bound state interpretation.

comment asked in the Minutes of the 33rd PAC

- **We will continue discussions and deepen the K-nucl physics through workshops, etc.**

International workshop on "Hadron physics with kaon beam and related topics"

3-4 October 2022
Online
Asia/Tokyo timezone

3-4 Oct. 2022, Online https://kds.kek.jp/event/43204/

will be announced soon.

Overview
Participant List

Welcome to the international workshop on "Hadron physics with kaon beam and related topics". The workshop will focus on recent experimental and theoretical development of kaon interactions with nucleons and nuclei, particularly, those activities using the unique kaon beams available at J-PARC and DAFNE. The topics covered by the workshop will be

- kaonic nuclei
- L(1405)
- kaonic atoms
- kaon-nucleon scattering

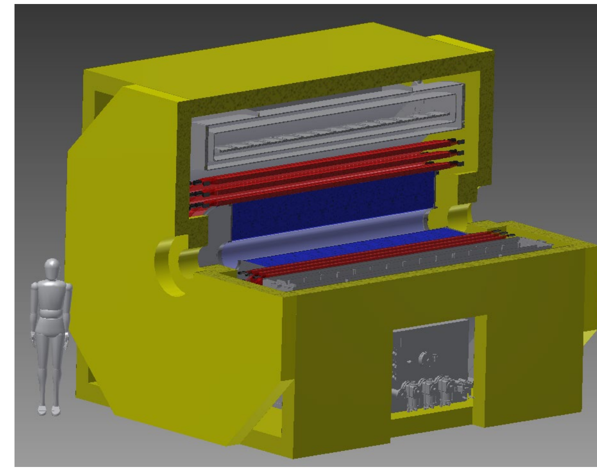
RIKEN NiSHiNA CENTER · THEORY CENTER · TOHOKU · HUA · RCNP · JAEA

The workshop will be held online on October 3 -4, 2022. It is organized by RIKEN Nishina Center and Grant-In-Aid for Specially Promoted Research "Toward revolutionary Nuclear Study via revealing Internal Structure of Kaonic Nuclei" (MEXT Kakenhi 22H04917), and supported by Hadron Hall User Association (HUA), KEK Theory Center, RCNP, ELPH, and JAEA.

Status *and* ***Strategy***

Status of E80

- This April, we successfully obtained a large research grant, “Grant-In-Aid for Specially Promoted Research by MEXT (FY2022-26).”
  - The main detector components of the CDS for E80 will be constructed with the grant



- **E80 will be ready to start in late FY2025**

	FY2022				FY2023				FY2024				FY2025				2026~	
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4		
SC Solenoid	Design		Purchase (SC Wire)		Construction							Installation & Test			Integration	Commissioning	Physics Run	Analysis & Pblication
NC	Design		Purchase (Scinti.)		Assembly				Test & Commissioning									
CDC	Design				Construction				Test & Commissioning									
K1.8BR Beam Line	E73(CDC) -> E72(HypTPC) Experiments										Upgrade					E80 Experiment		

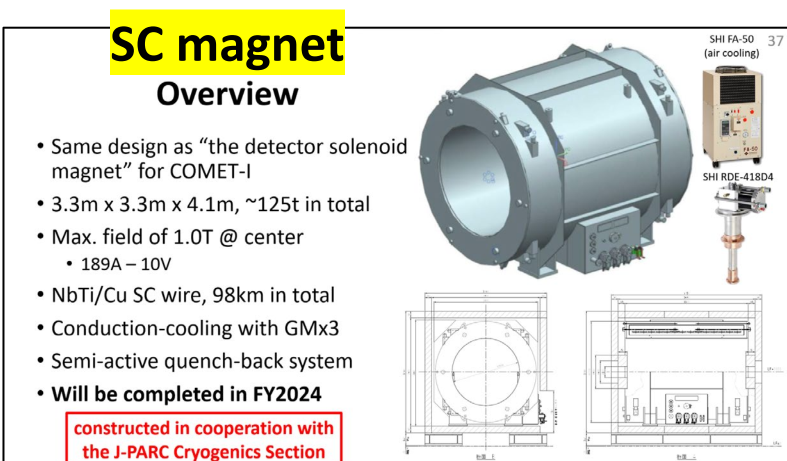
Status of E80

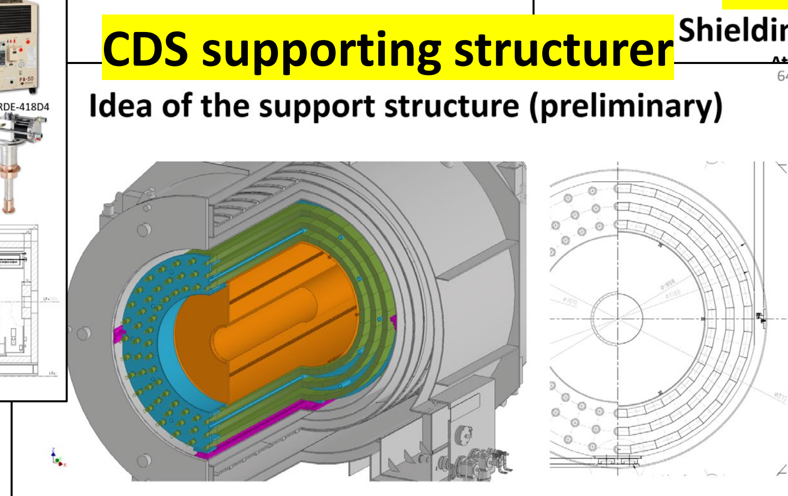
- We submitted the TDR and discussed details at the FIFC in June 2022
  - We have received many comments from the FIFC

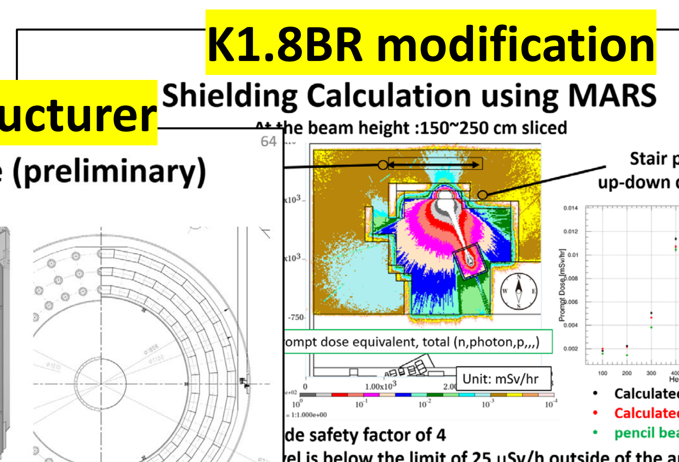
> In conclusion, FIFC requests to submit an updated TDR which should include concrete design of the CDS based on the discussion at the FIFC meeting and this report. FIFC

- We will submit the revised TDR in May 2023

← Detector design and construction schedule will be solidified in early FY2023







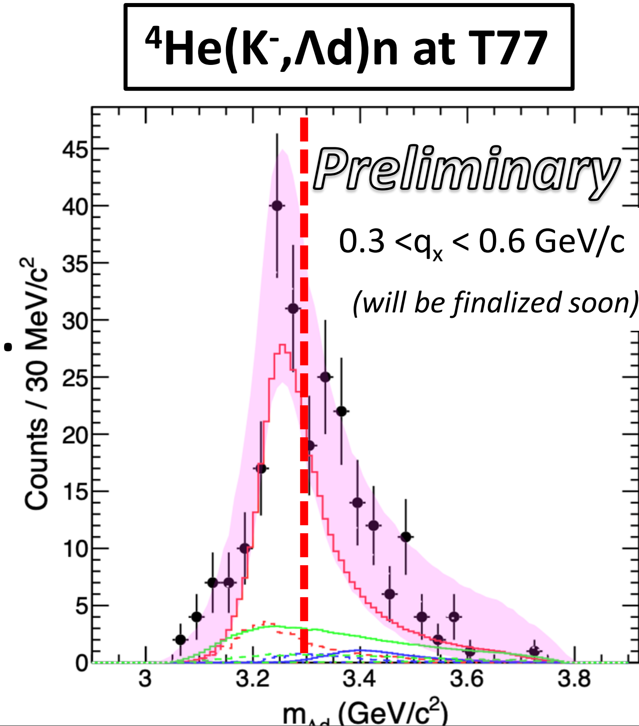
Strategy of E80/P92

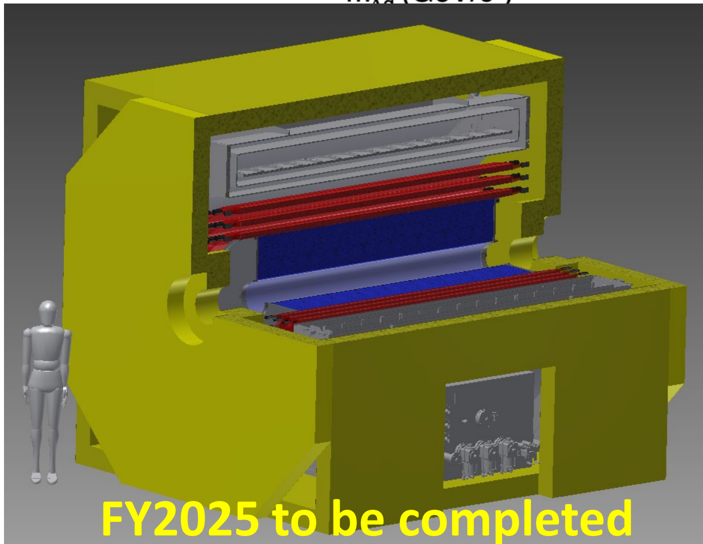
The PAC also requests the proponents to clarify their strategy in combination with related experiments in which they propose to search for deeply bound kaonic states. *comment asked in the Minutes of the 33rd PAC*

- **We'd like to concentrate all our efforts on the early realization of E80 with the new CDS.**
- However, to maximize the physics outcome from our project, we would like to maintain the possible realization of the P92 proposal in case unforeseen circumstances arise
  - such as significant delays in the new CDS construction due to the COVID-19 pandemic and/or the Ukraine war
- For further confirmation of the kaonic nuclei, determining the J^P of the kaonic nuclei (P89) is the next direction.

Summary

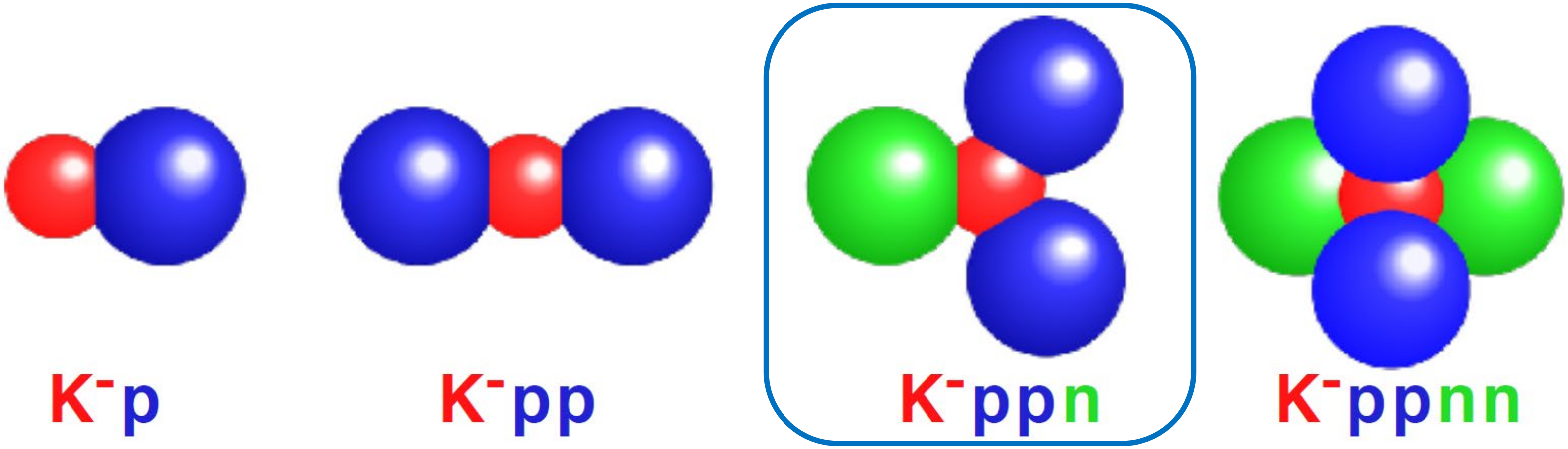
- E80/P92 aim to establish the $\bar{K}NNN$ bound state as a first step.
- We observed a peak structure below M($K^{-}ppn$) via ^{4}**He(*K*$^{-}$,*Λd*)*n*** using T77 data.
  - ➢ suggests **the $\bar{K}NNN$ bound state**
  - ➢ <u>we need further investigation at E80/P92</u>
- **E80 experiment will be ready to start in late FY2025.**
  - ◆ We successfully obtained a large research grant (FY2022-26) this April
- **We'd like to concentrate on E80 with the new CDS.**
  - ✓ We'd like to maintain the possible realization of P92 with the existing CDS in case unforeseen circumstances arise





We will submit the revised TDR in May 2023 for requesting stage-2 approval

A first step of the project



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

Thank you for your attention!

Collaboration of E80/P92

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