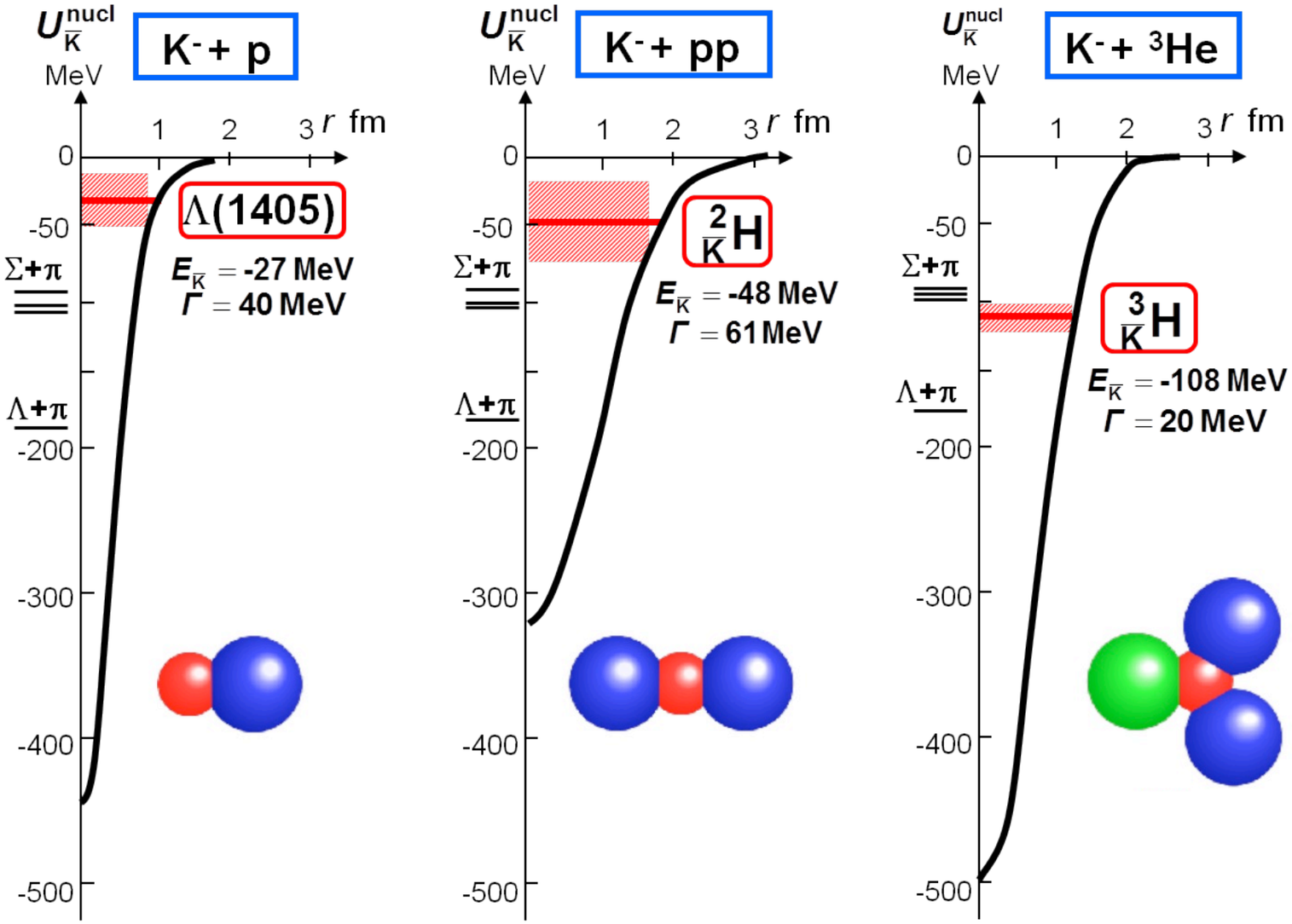
Search for the $\bar{K}NNN$ bound state in the Λdn final states of the in-flight K^- reaction on ^{4}He

Tadashi Hashimoto (JAEA ASRC)
for the J-PARC E73/T77 collaboration

from June 27 to July 1, 2022 @ Prague, Czech

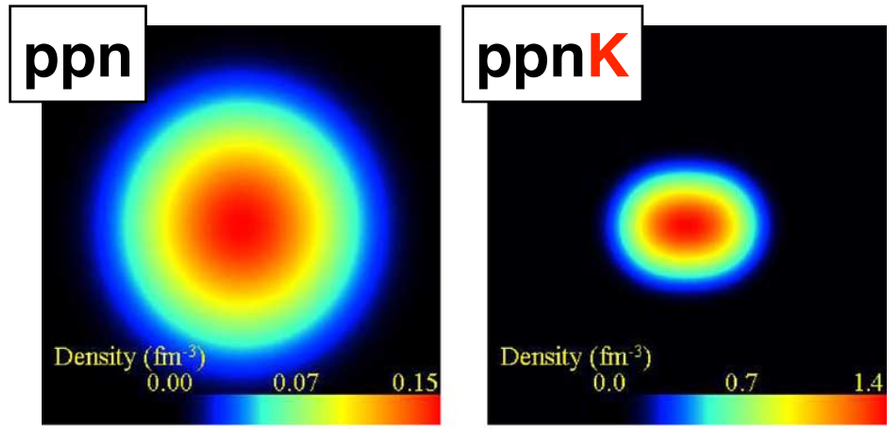
Kaonic nuclei

predicted from
attractive K^{bar}N interaction in I=0



1.Y. Akaishi and T. Yamazaki. *Phys. Rev. C* **65,** 044005 (2002).
2.T. Yamazaki and Y. Akaishi. *Physics Letters B* **535,** 70–76 (2002).

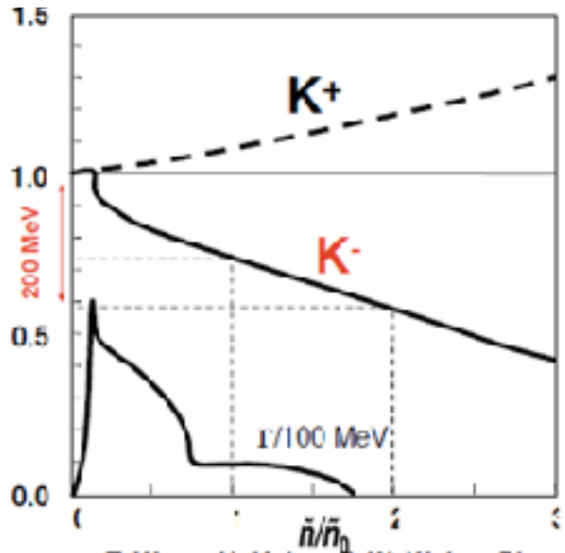
dense nuclei are predicted



(a) ^{3}He (b) ^{3}HeK^{-}

Phys. Lett. B 590 (2004) 51

Kaon mass changes in nuclear medium?



T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.

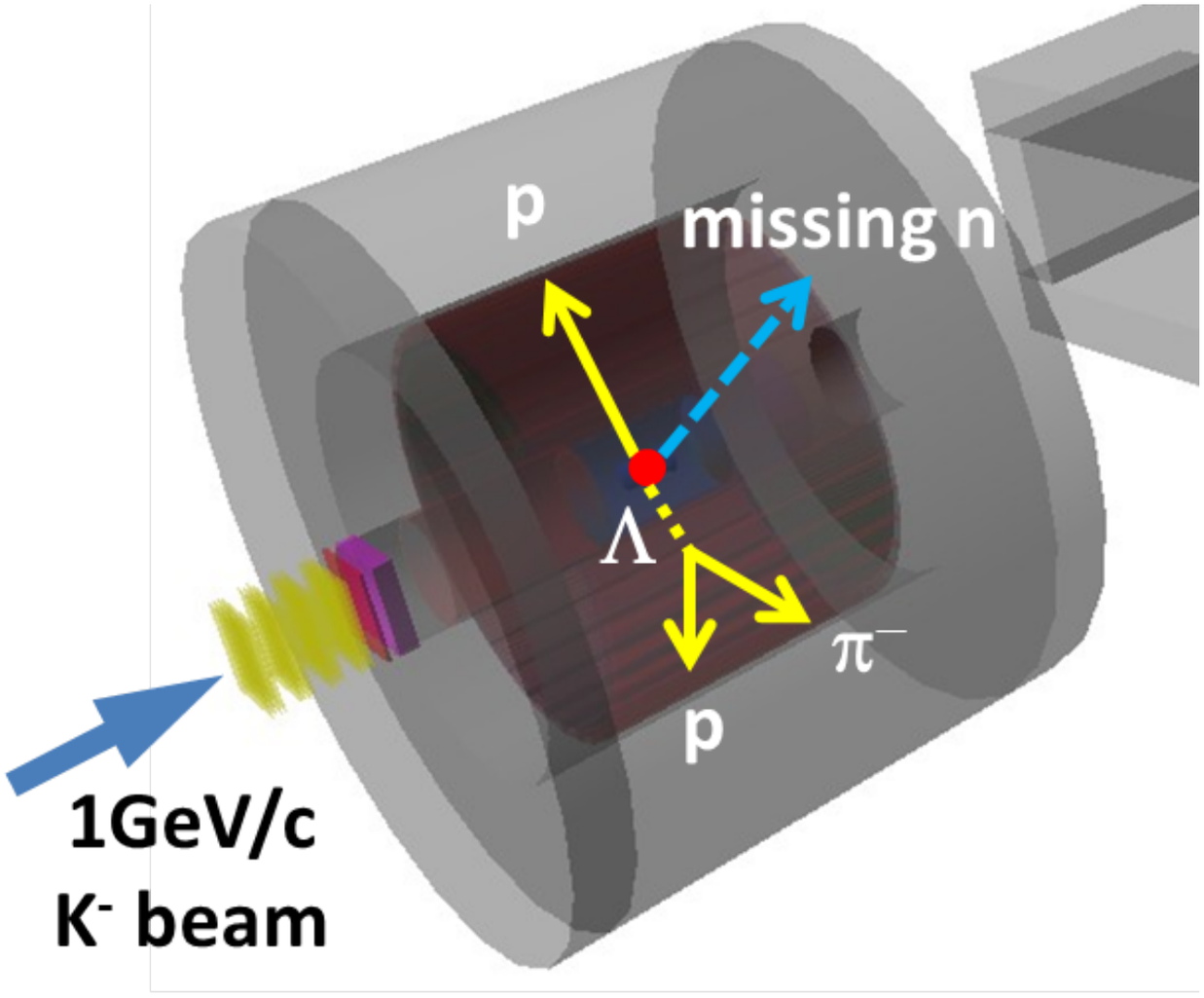
Anti-Kaon could be a unique probe for hadron/nuclear physics

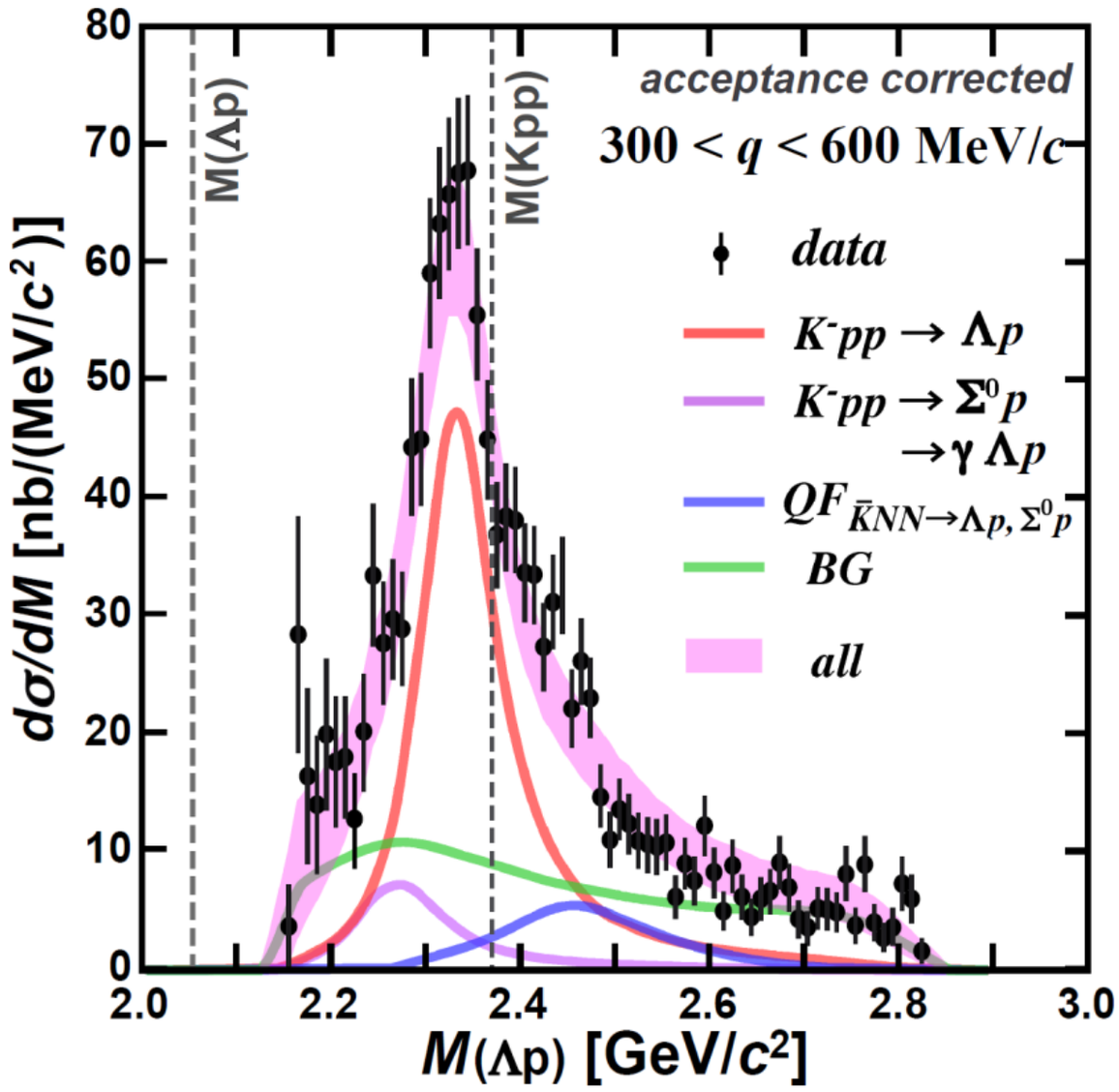
"$\bar{K}NN$" in J-PARC E15

Details in T. Yamaga's talk on Thursday morning

$$I(J^p) = \frac{1}{2}(0^-),\ I_z = +\frac{1}{2}$$

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



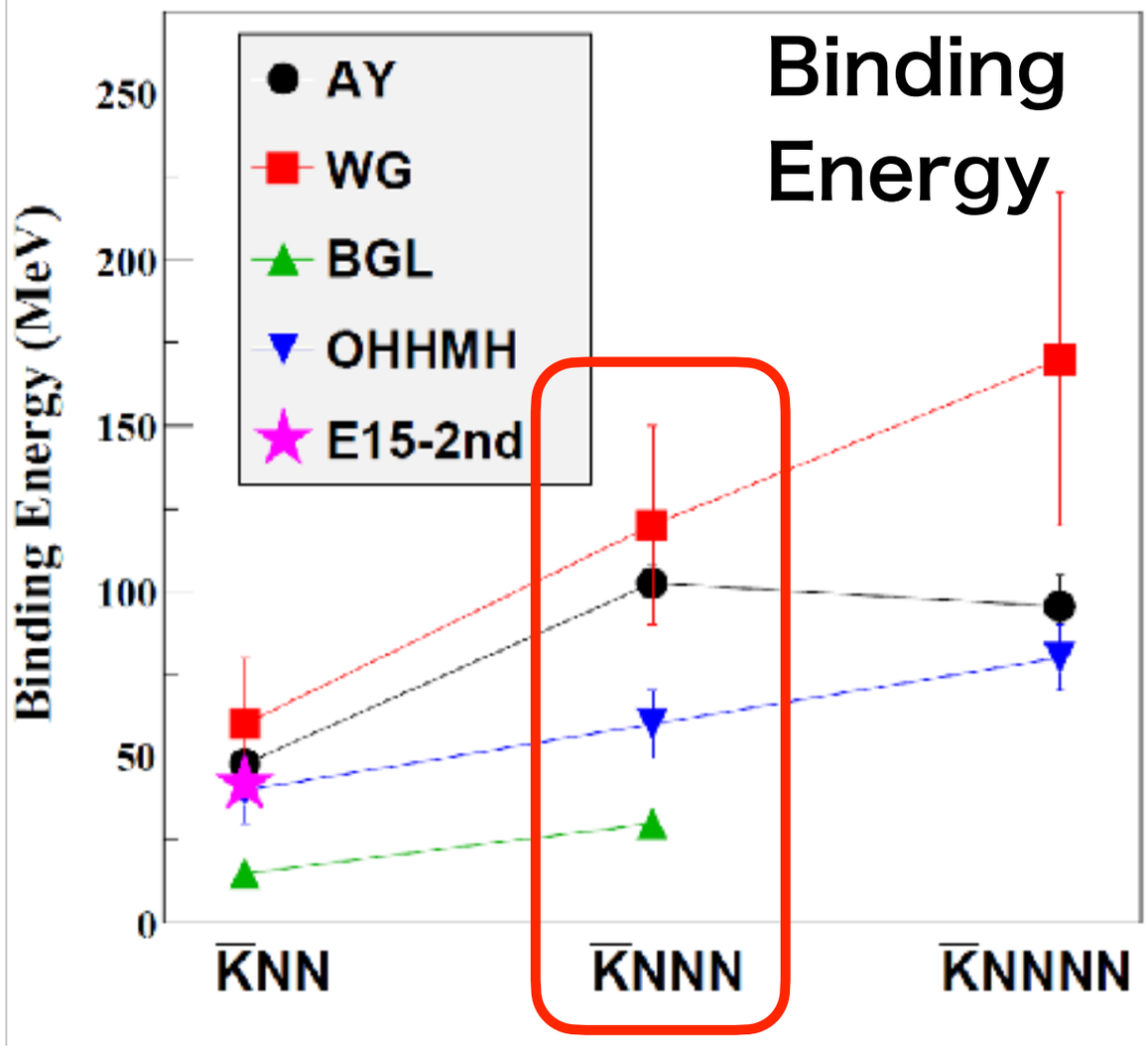


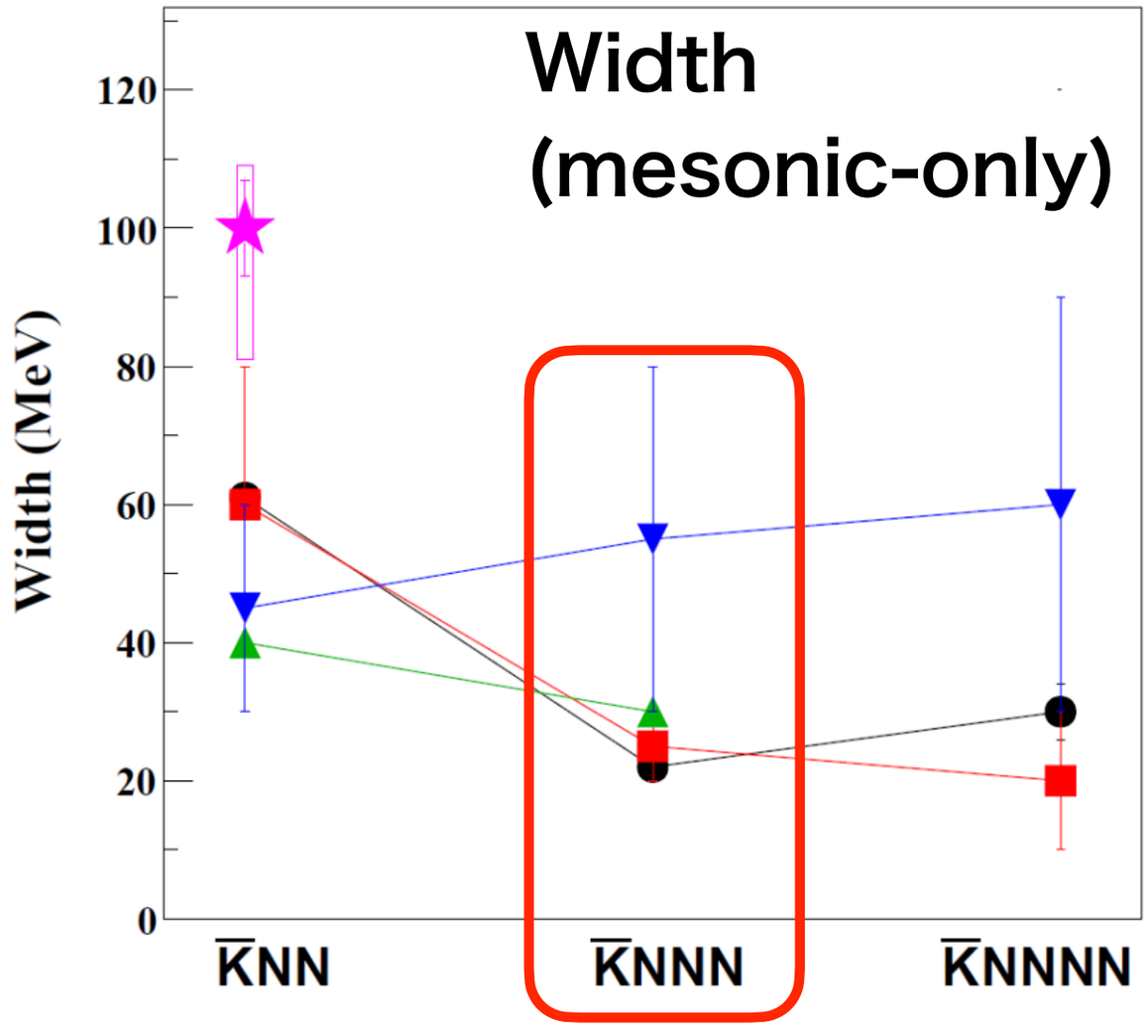
- Exclusive measurement of all the final state particles in a wide q region
- Most convincing data after a history of 20-year search
- Next step → $\bar{K}NNN$ search to investigate the A-dependence of kaonic nuclei

$\bar{K}NNN$: Theoretical situaion

$$I(J^p) = 0(\frac{1}{2}^-)$$

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



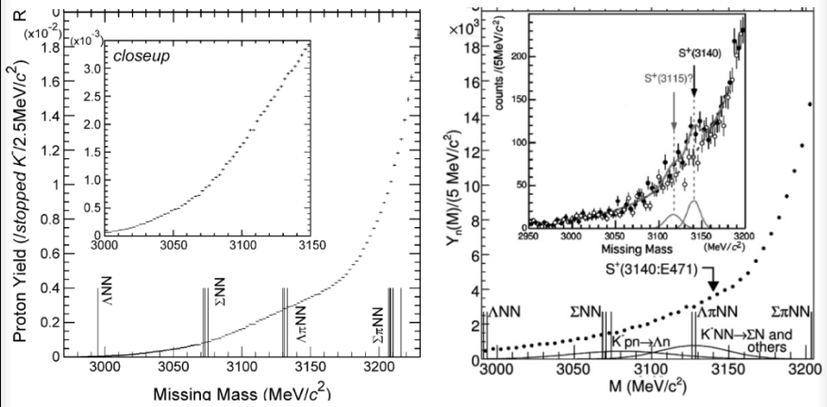


Larger binding than $\bar{K}NN$ and similar width are predicted.

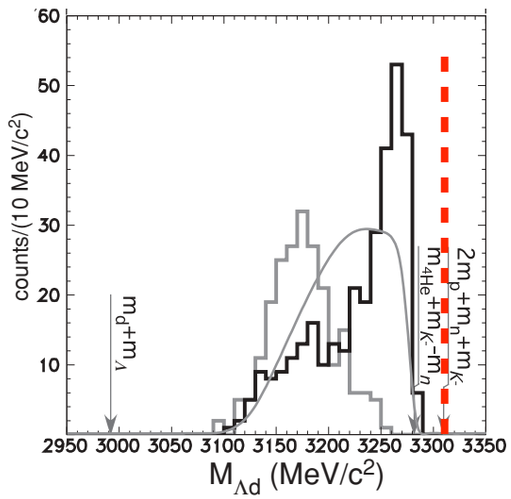
$\bar{K}NNN$: Experimental situaion

Stopped K^- on ^{4}He

E471/E549@KEK



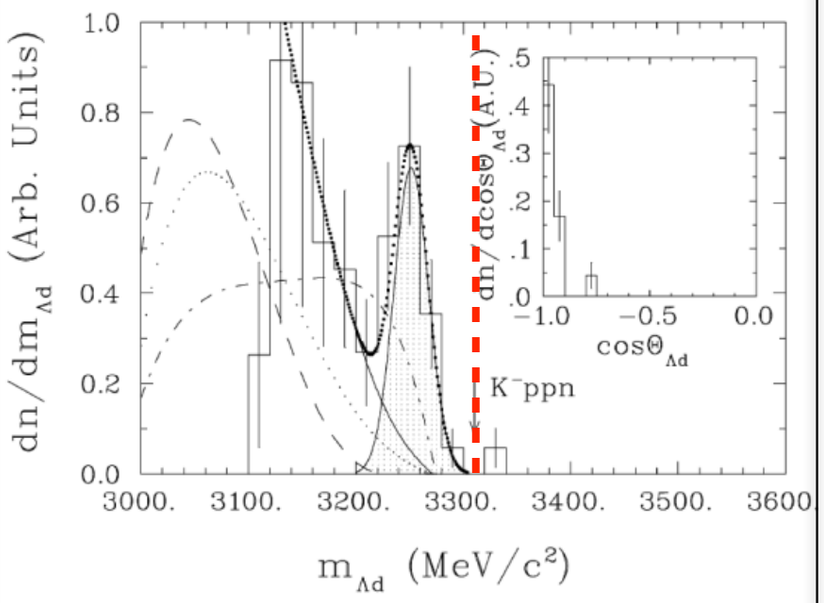
PLB659(2008)107, PLB688(2010)43



PRC76(2007)068202

Stopped K^- on Li/C back-to-back Λd

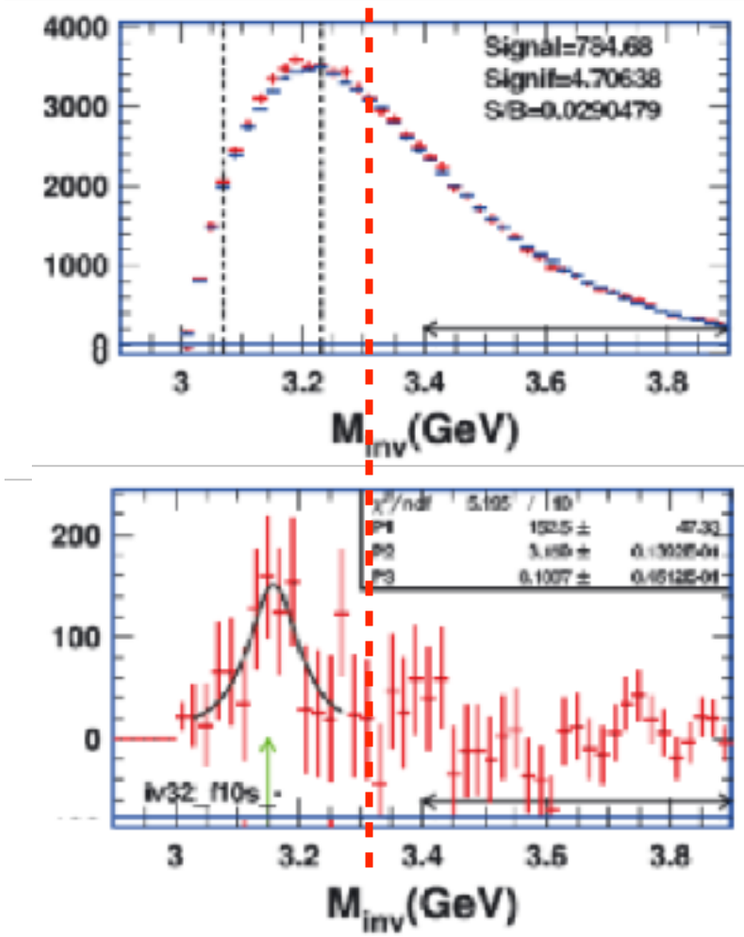
FUNUDA@DAΦNE



PLB654(2007)80

Λd in Ni+Ni

FOPI@GSI

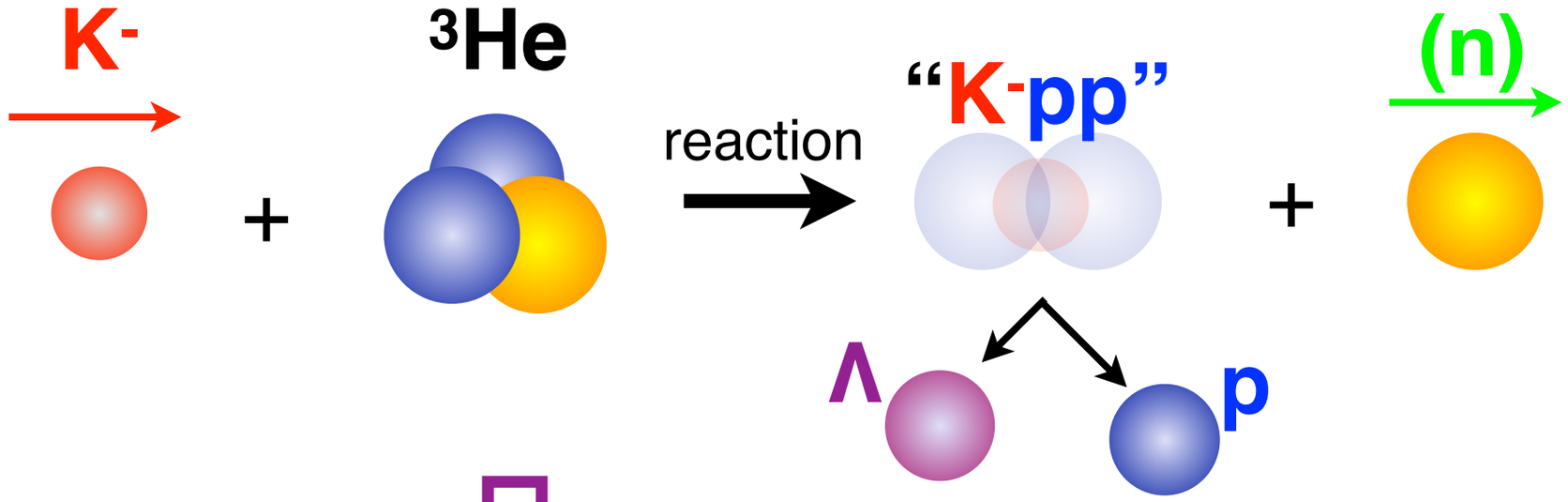


EXA05 Proceedings (2005)

- Some experimental searches in 2000s. No conclusive result.
- multi-N absorptions hide bound-state signals in Stop-K

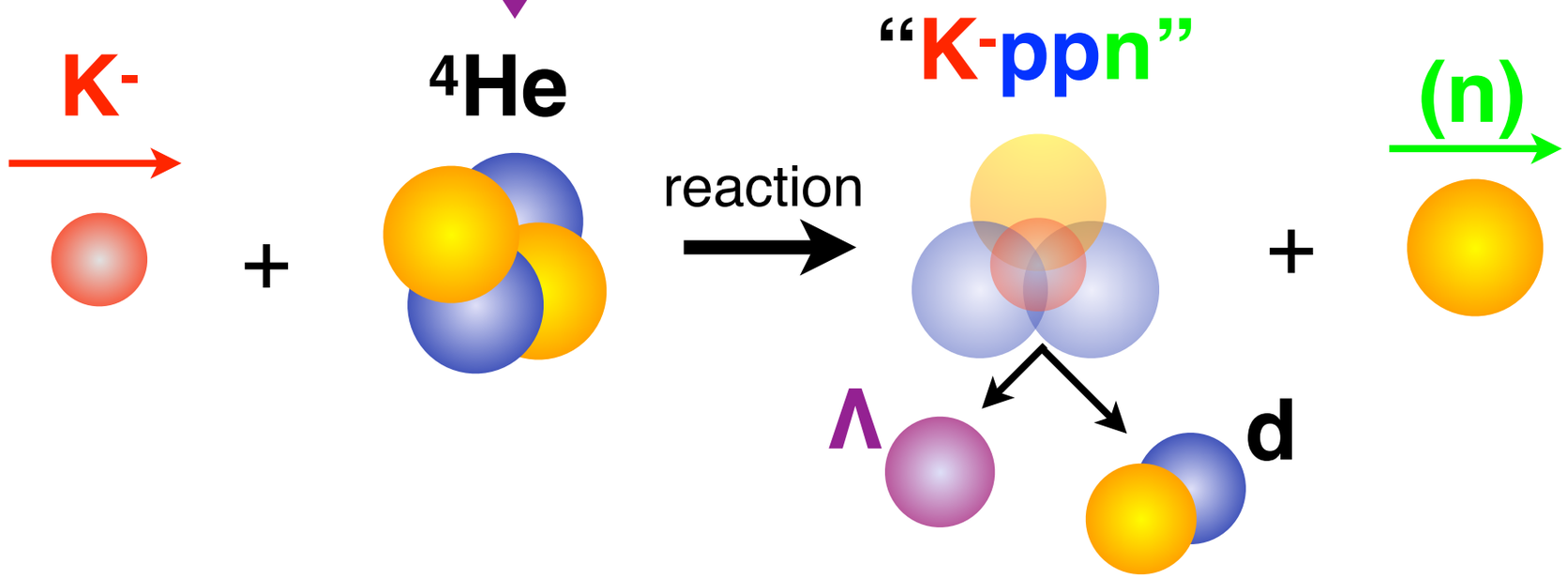
Our approach

J-PARC E15



add one neutron

This talk



Use in-flight (K^-,n) reaction, just as J-PARC E15

J-PARC E15 vs T77 @ K1.8BR

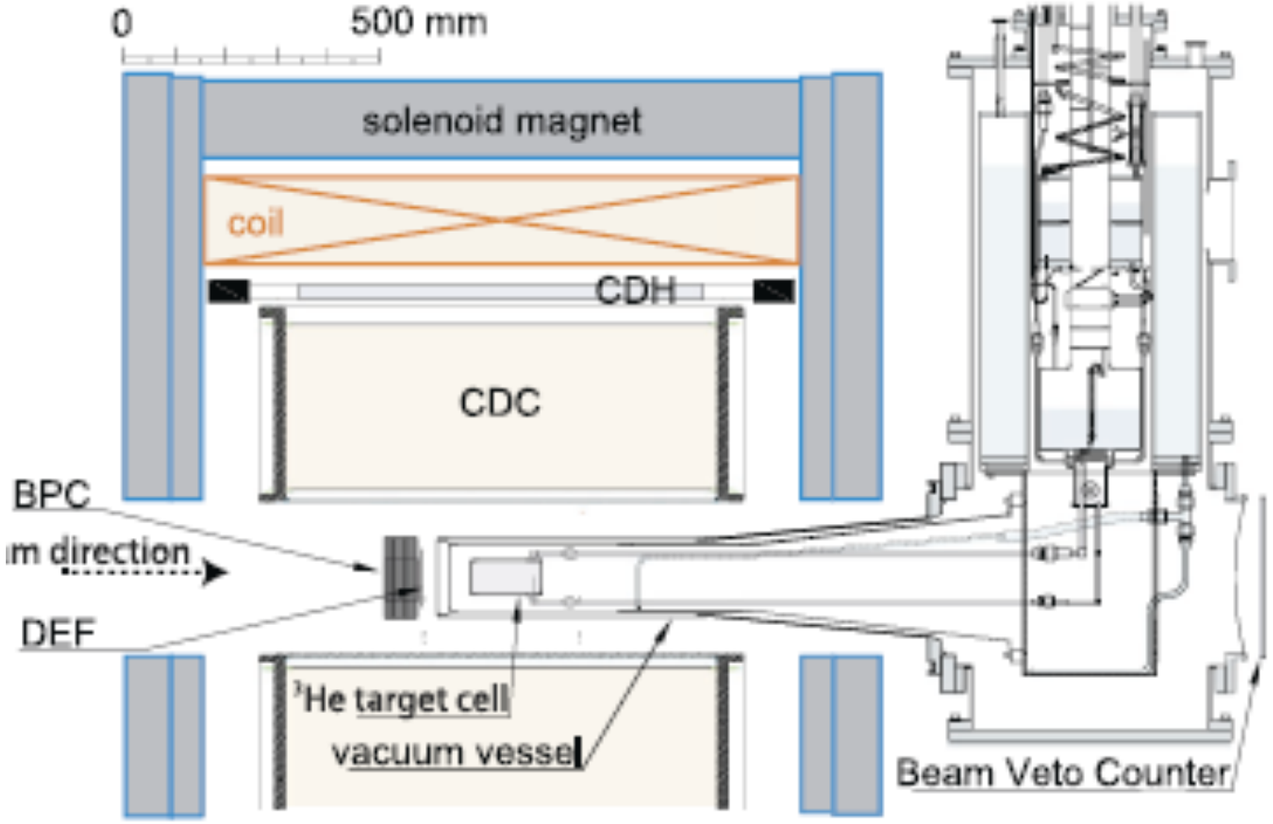
We already have small dataset with ^{4}He target

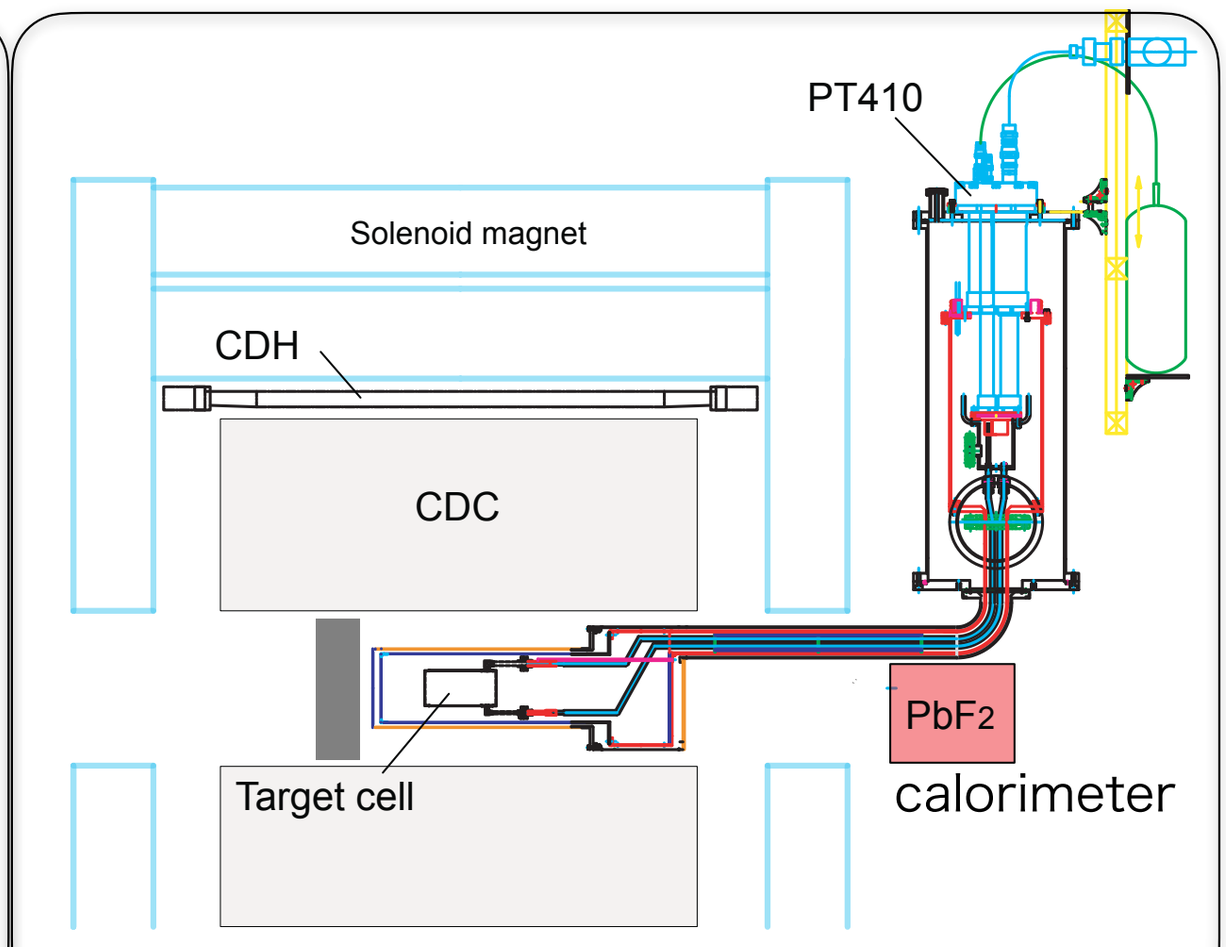
J-PARC E15@2015

42G K^- on **^{3}He**

J-PARC T77@2020

6G K^- on **^{4}He** only 3 days!





- The same cylindrical detector system
  + forward calorimeter in T77 for lifetime measurements of hypernuclei

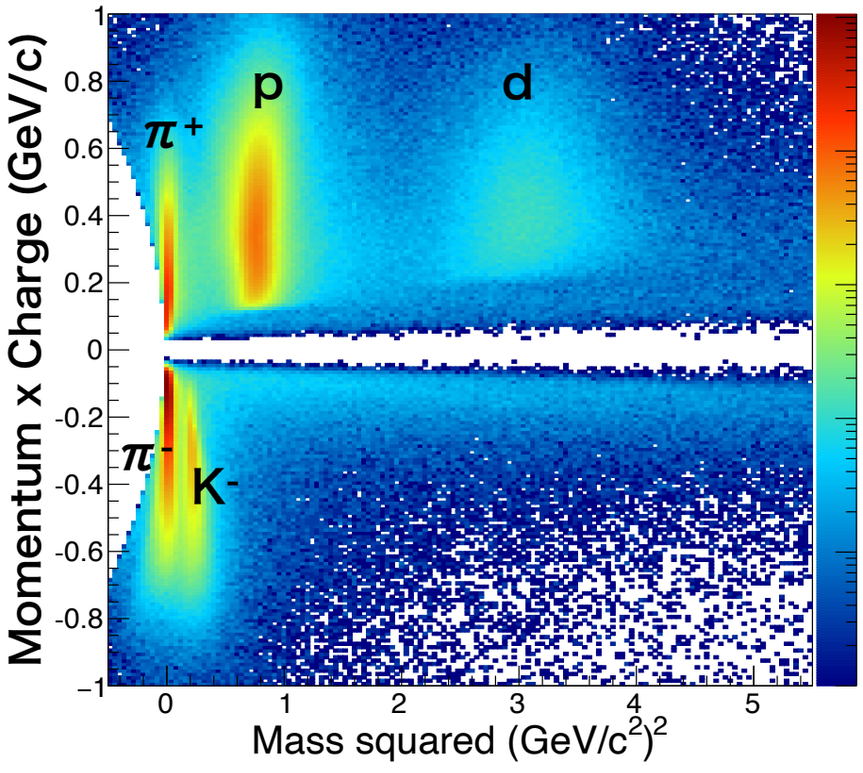
$K^-(^4\mathrm{He}, \pi^0)^4_\Lambda\mathrm{H}$

Y. Ma's talk (Mon), T. Akaishi's poster

Λdn event selection

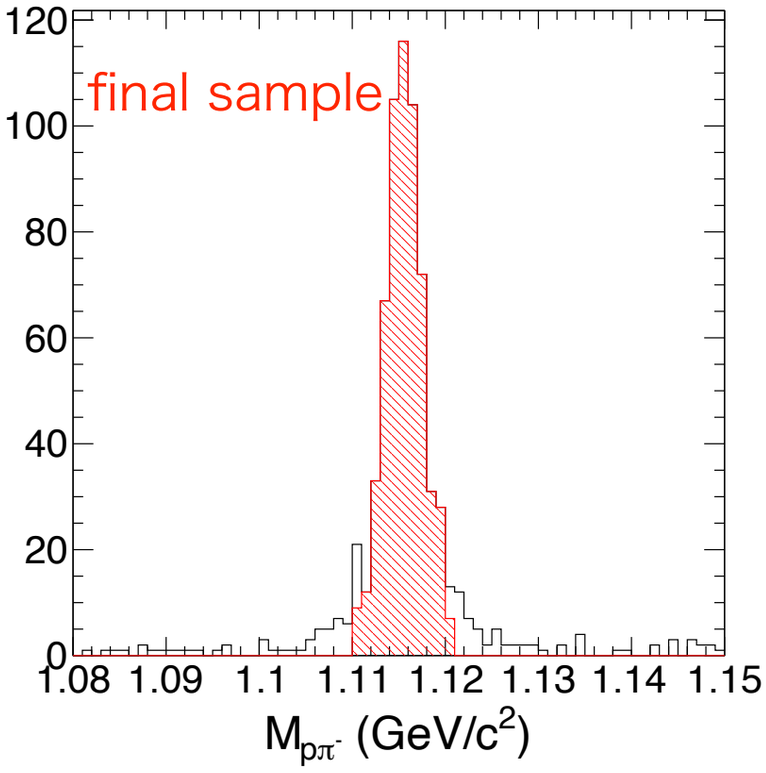
deuteron ID

CDC track curvature &
CDH time of flight



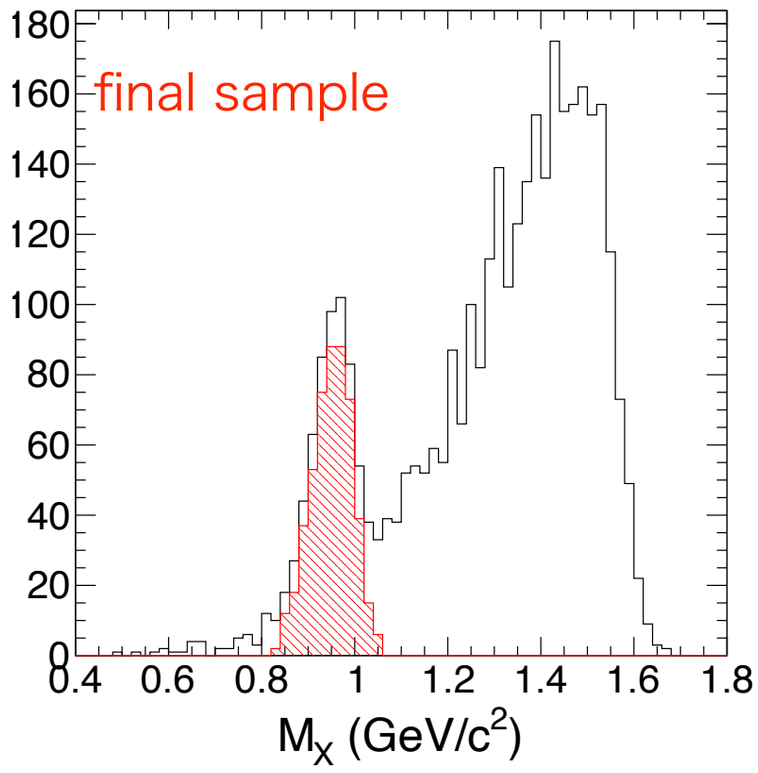
Λ reconstruction

w/ vertex consistency cut
w/ pipd missing mass cut



Missing neutron ID

w/ vertex consistency cut
w/ lambda mass cut



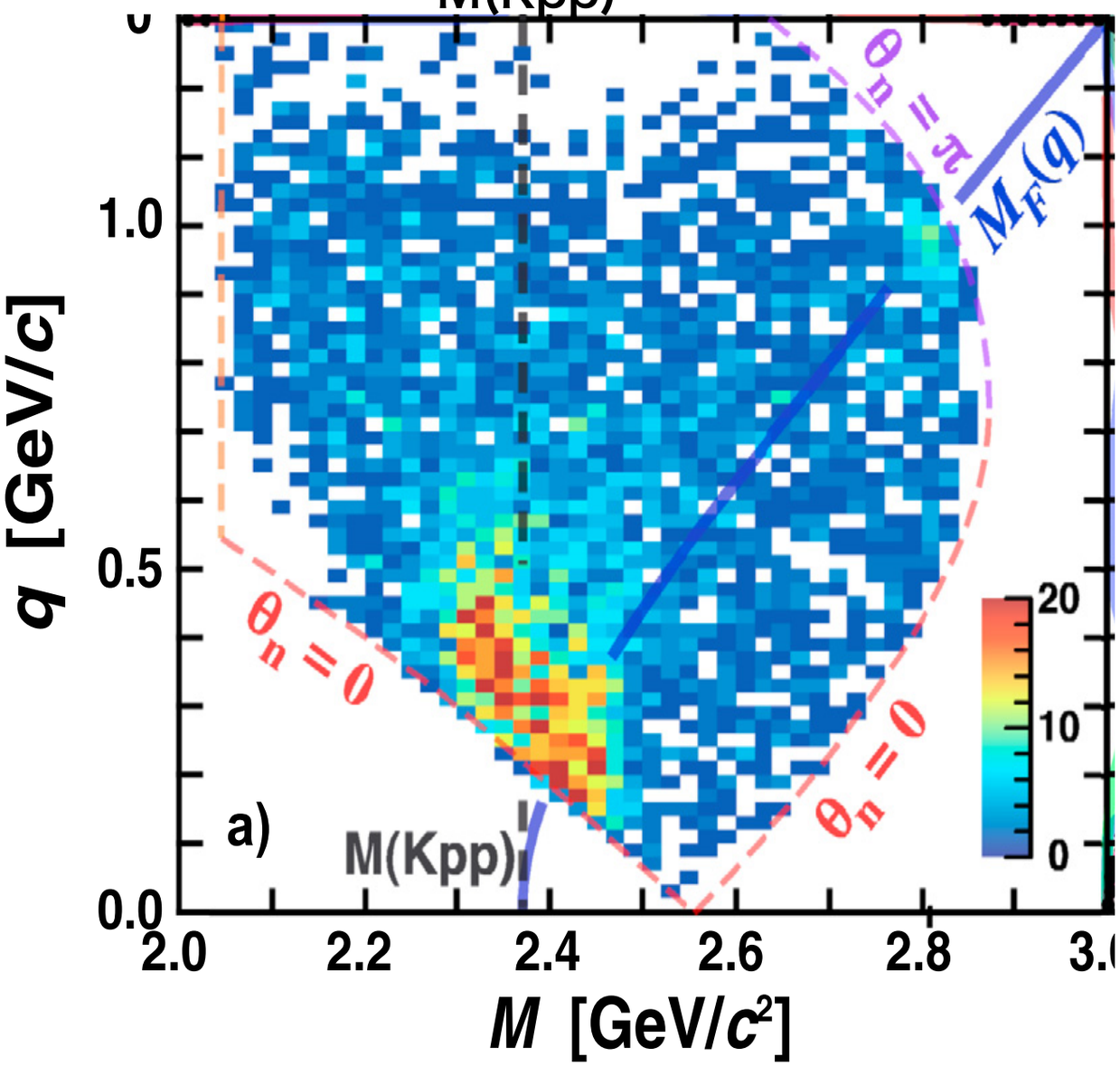
- Λdn final states are identified with a good purity
  by considering kinematical & topological consistensies
- ~20% contamination from Σ^0dn/Σ^-dp

Preliminary result

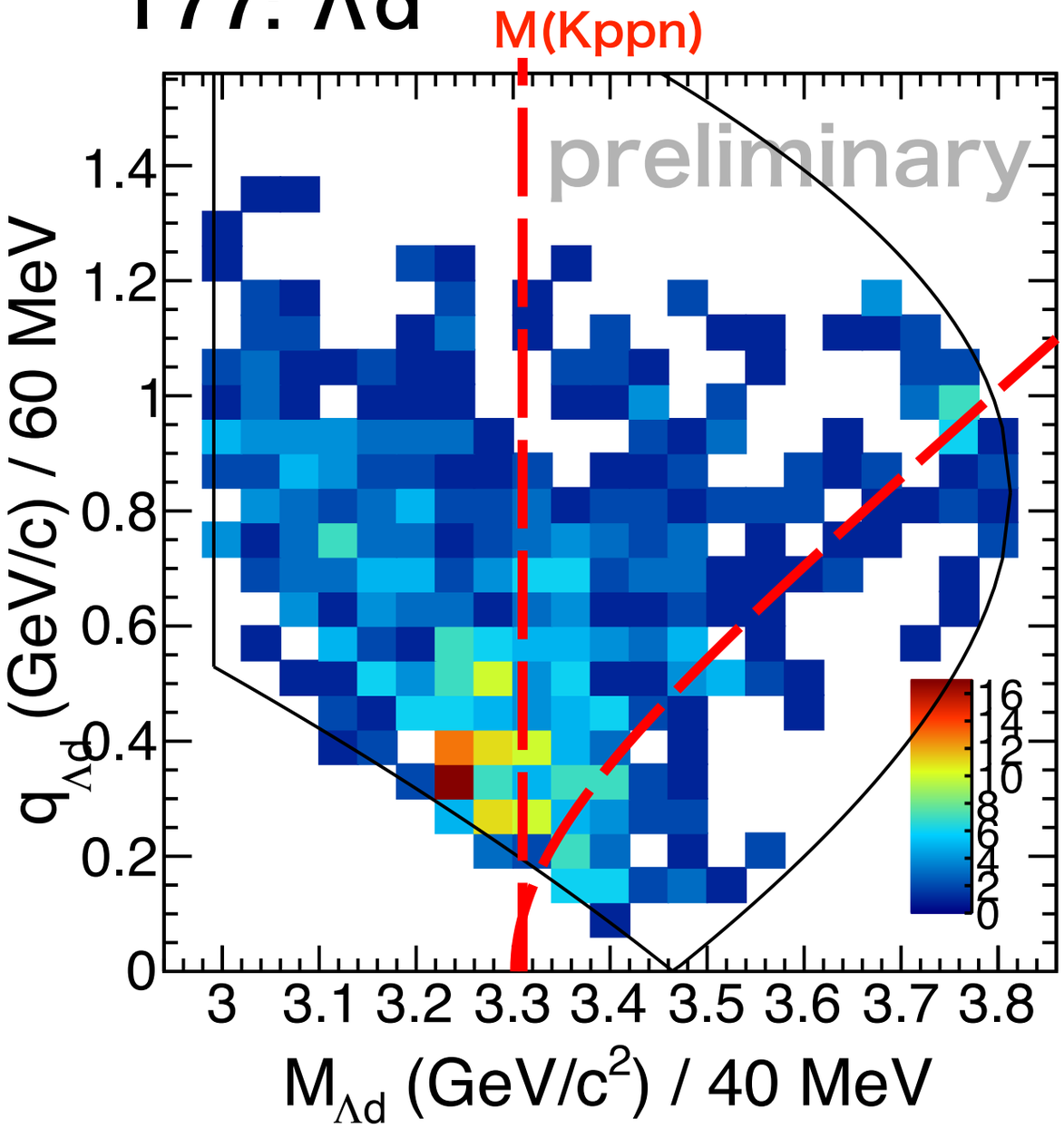
before acceptance correction

E15: Λp

PLB789(2019)620



T77: Λd

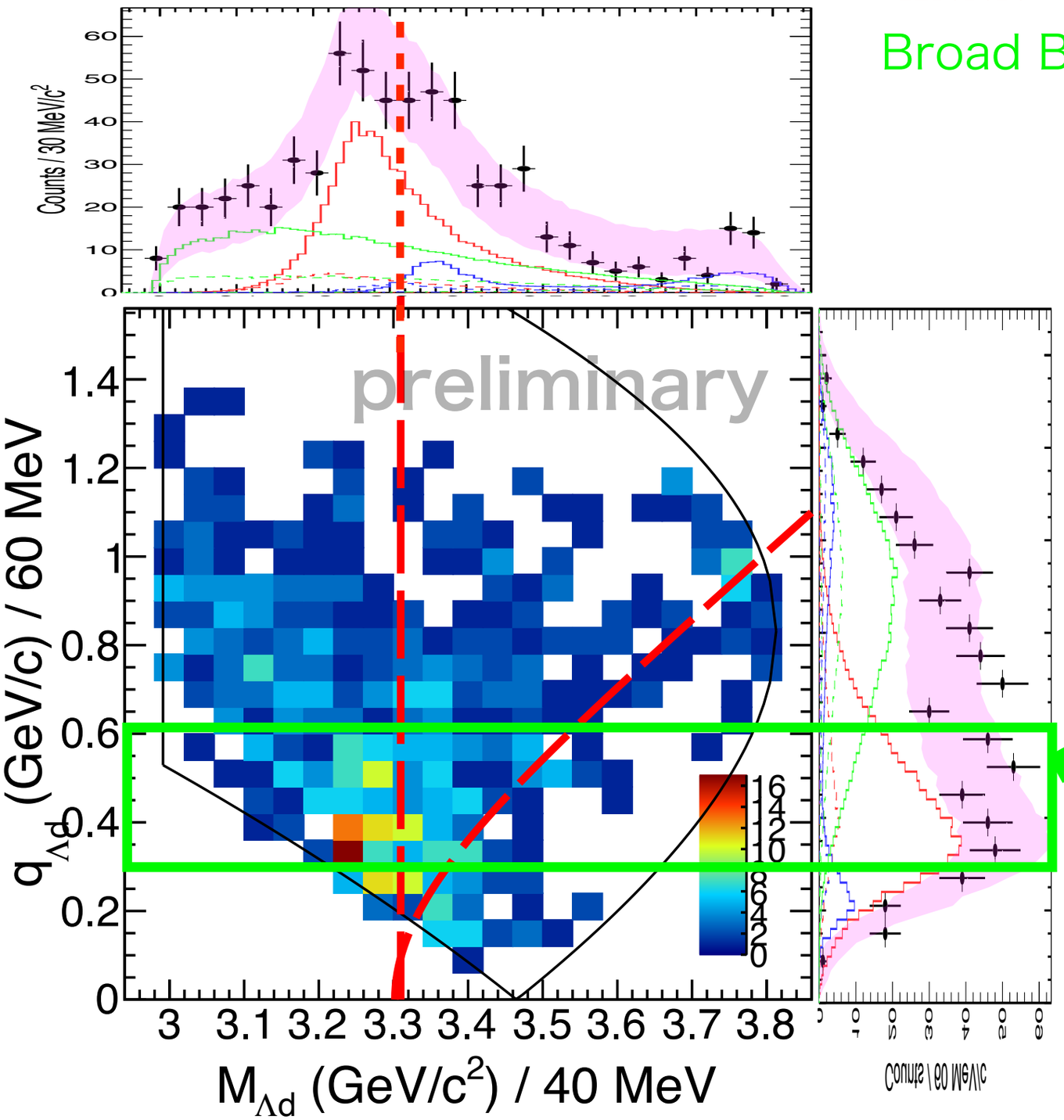


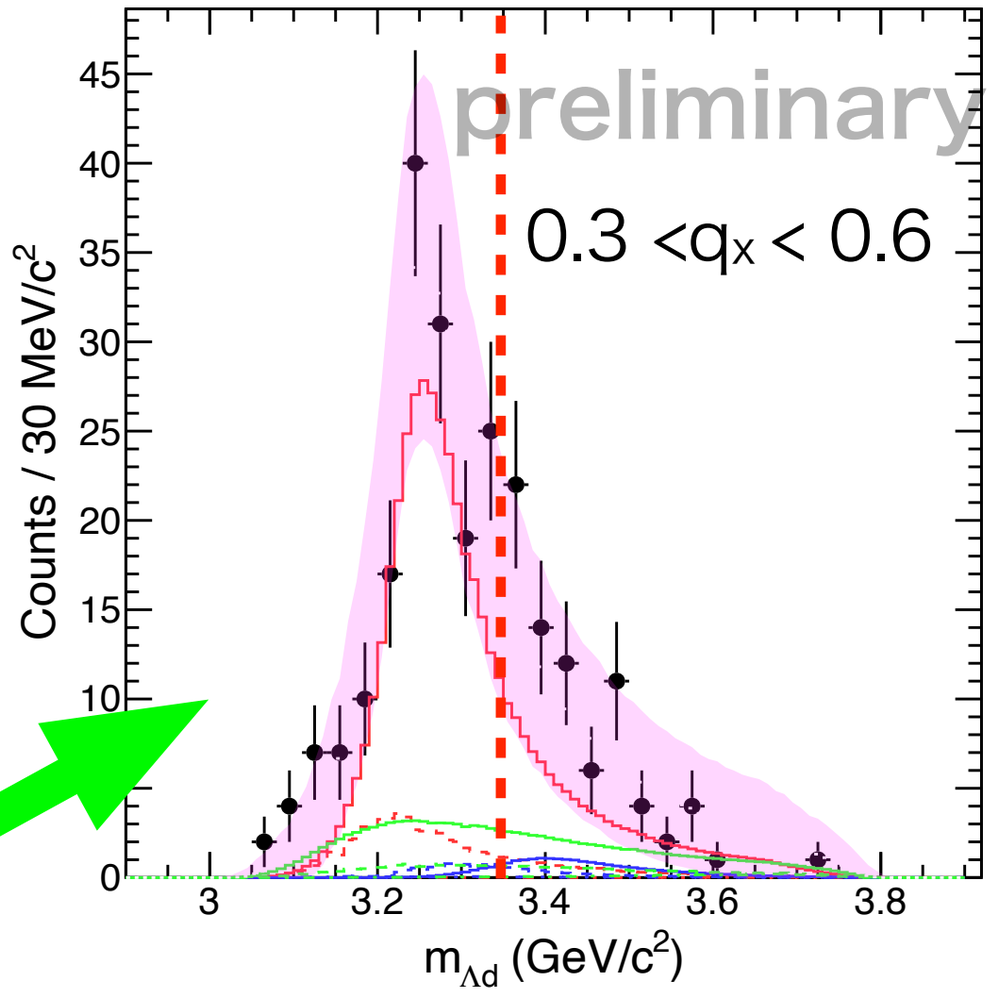
- Two disributions are quite similar
- structure below the threshold, QF-K^-, and broad background

Preliminary result

"$\bar{K}NNN$" Breit-Wigner wtih Gaus. form factor

Broad BG and QF-K$^-$ shape from E15





$B_{\bar{K}NNN} = xx \pm 11(\text{stat})$ MeV

$\Gamma_{\bar{K}NNN} \sim 100$ MeV

$\sigma_{\bar{K}NNN \to \Lambda d} \sim 4\ \mu$b

$cf.\ B_{\bar{K}NN} = 42 \pm 3\ (\text{stat})\ ^{+3}_{-4}\ (\text{syst})$ MeV@E15 PRC

- The binding energy of the "$\bar{K}NNN$" system seems to be larger than "$\bar{K}NN$", although we expect a large systematic error 10~20 MeV.

$$B_{\bar{K}NNN} = xx \pm 11(\text{stat})\ \text{MeV} \quad cf.\, B_{\bar{K}NN} = 42 \pm 3\ (\text{stat})\ ^{+3}_{-4}\ (\text{syst})\ \text{MeV}$$

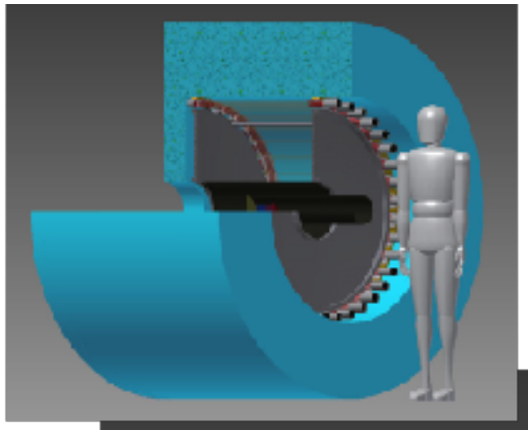
- The isospin of the observed state is uniquely assinged as $I = 0$ from the its decay to $\Lambda(I = 0)\ d(I = 0)$,
  J^P=1/2$^-$ assuming all the consistuents are in S-wave

$$\bar{K}NNN\ (I = 0,\ J^p = 1/2^-)$$

- $\Sigma^*NN\ (I = 0,\ J^p = 3/2^+)$ possibility still remains
  - Λ spin asymmetry against production-plane would be observed, because Σ^* would produced polirized and conserve its spin in decay.
  - Present data is not enough to judge the decay assymetry

We would like to obtain more data with ^{4}He target

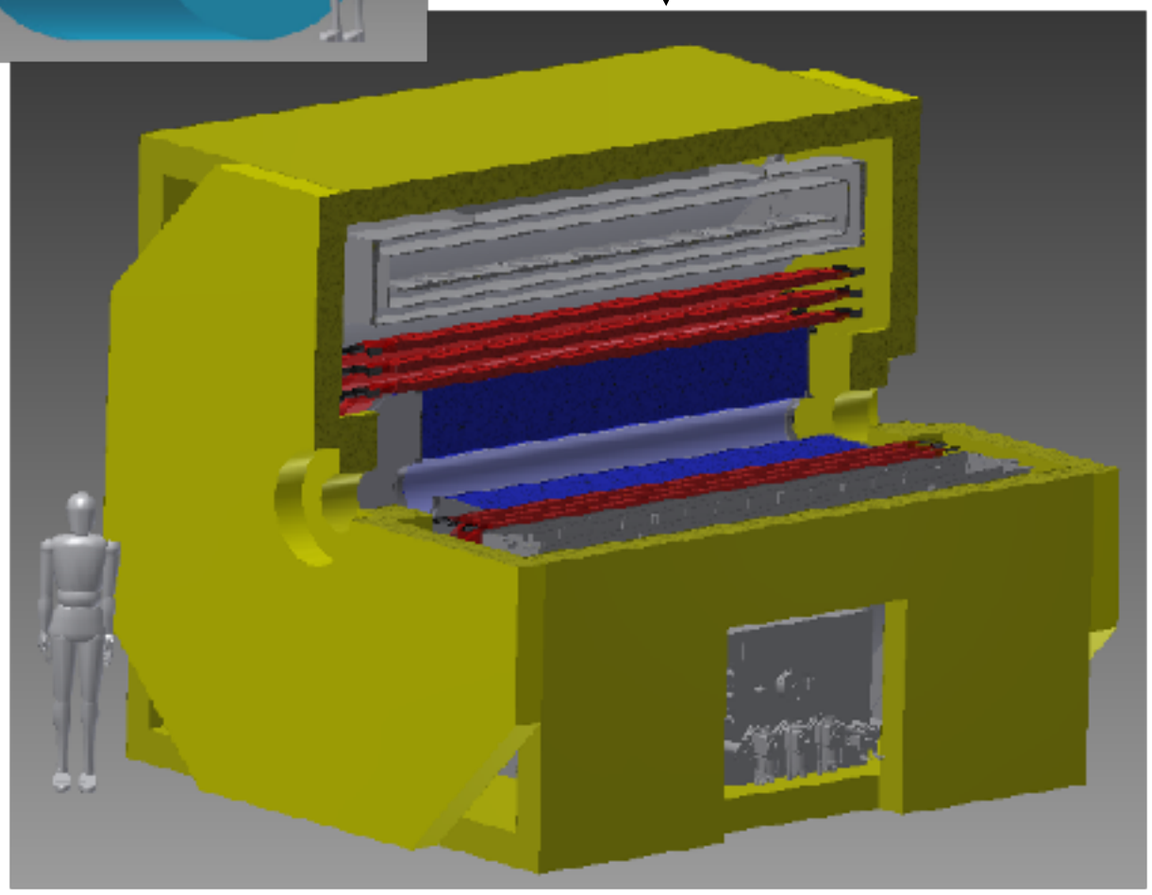
Future prospects

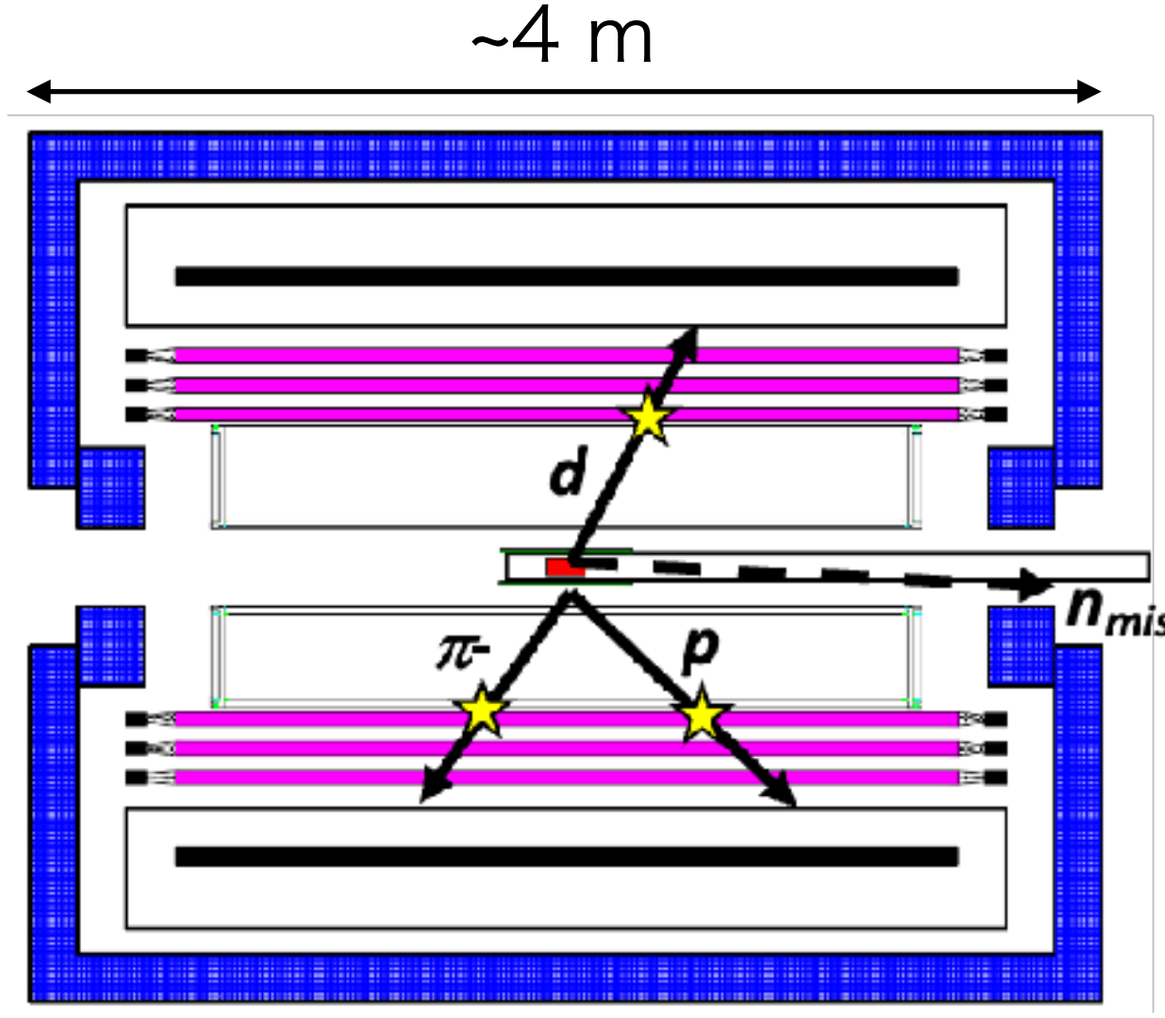


E15 CDS

- Super-conducting solenoid
- x3 longer CDC: **solid angle 59%→93%**
- 3-layer barrel NC: **neutron efficiency 3%→15%**

new CDS





- We have just started a construction to complete by the end of JFY2025
- We wish to perform first physics experiment in JFY2026 with ^{4}He target
  → Establish $\bar{K}NNN$ with a larger & higher quality data including $\bar{K}NNN \to \Lambda pn$ decay

Summary & Outlook

- We observed **^{4}He(K$^-$,ΛN)nn** events as a by-product of J-PARC T77:
  (Lifetime measurement of hypernuclei. →Y. Ma's talk, T. Akaishi's poster)

- The observed distribution is similar to that of ΛN in E15,
  and would include signals of $\bar{K}NNN$.
  → **First A-dependence data of Kaonic nuclei.**

- We are constructing new large solenoid spectrometer for further study of $\bar{K}NNN$ (J-PARC E80) and other kaonic nuclei → T. Yamaga's talk
  - ~4π acceptance & enhanced neutron detection capability
  - Start experiments ~JFY2026

- We are also seeking the way to take more data with the present CDS in near future (J-PARC P92)

J-PARC E73/T77 collaboration

T. Akaishi[1], H. Asano[2], X. Chen[5], A. Clozza[7], C. Curceanu[7], R. Del Grande[7], C. Guaraldo[7], C. Han[5], T. Hashimoto[4], M. Iliescu[7], K. Inoue[1], S. Ishimoto[3], K. Itahashi[2], M. Iwasaki[2], Y. Ma[2], M. Miliucci[7], R. Murayama[2], H. Noumi[1], H. Ohnishi[10] S. Okada[2], H. Outa[2], K. Piscicchia[7,9], A. Sakaguchi[1], F. Sakuma[2], M. Sato[3], A. Scordo[7], K. Shirotori[1], D. Sirghi[7,8], F. Sirghi[7,8], S. Suzuki[3] K. Tanida[4], T. Toda[1], M. Tokuda[1], T. Yamaga[2], X. Yuan[5], P. Zhang[5], Y. Zhang[5], H. Zhang[6]

[1]Osaka University, Toyonaka, 560-0043, Japan
[2]RIKEN, Wako, 351-0198, Japan
[3]High Energy Accelerator Research Organization (KEK), Tsukuba, 305-0801, Japan
[4]Japan Atomic Energy Agency, Ibaraki 319-1195, Japan
[5]Institute of Modern Physics, Gansu 730000, China
[6]School of Nuclear Science and Technology, Lanzhou University, Gansu 730000, China
[7]Laboratori Nazionali di Frascati dell' INFN, I-00044 Frascati, Italy
[8]Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Magurele, Romania
[9]CENTRO FERMI - Museo Storico della Fisica e Centro Studi e Ricerche Enrico Fermi, 00184 Rome, Italy
[10]Tohoku University, 982-0826, Sendai, Japan

Thank you for your attention!