자기 소개 및 연구 계획

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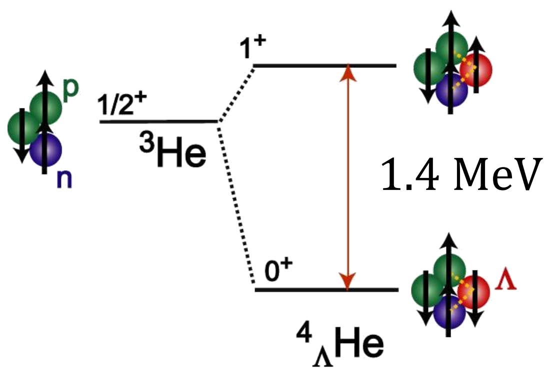
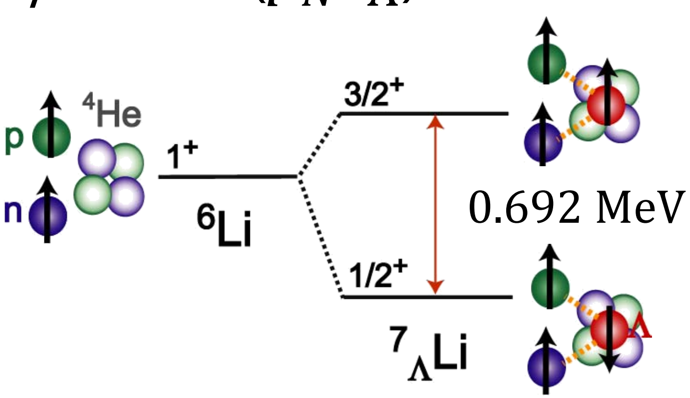
Gamma-ray Spectroscopy of ${}^{19}_{\Lambda}\mathrm{F}$

- Precise level data for *s*- and *p*-shell hypernuclei have revealed strengths of the spin-dependent ΛN interaction and the ΛNN interaction ($\Lambda\Sigma$ coupling effect).
- It is the first measurement of fine structure of an *sd*-shell hypernuclei, beyond *s*- and *p*-shell hypernuclei.

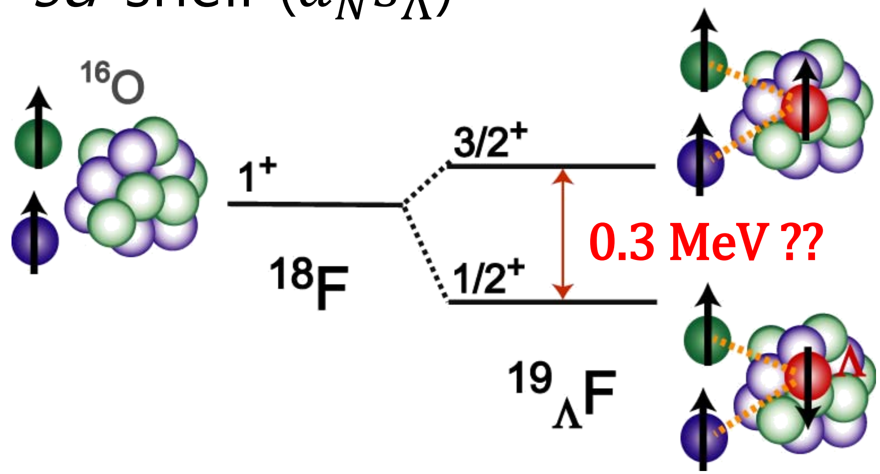
s-shell ($s_N s_\Lambda$)



p-shell ($p_N s_\Lambda$)



sd-shell ($d_N s_\Lambda$)

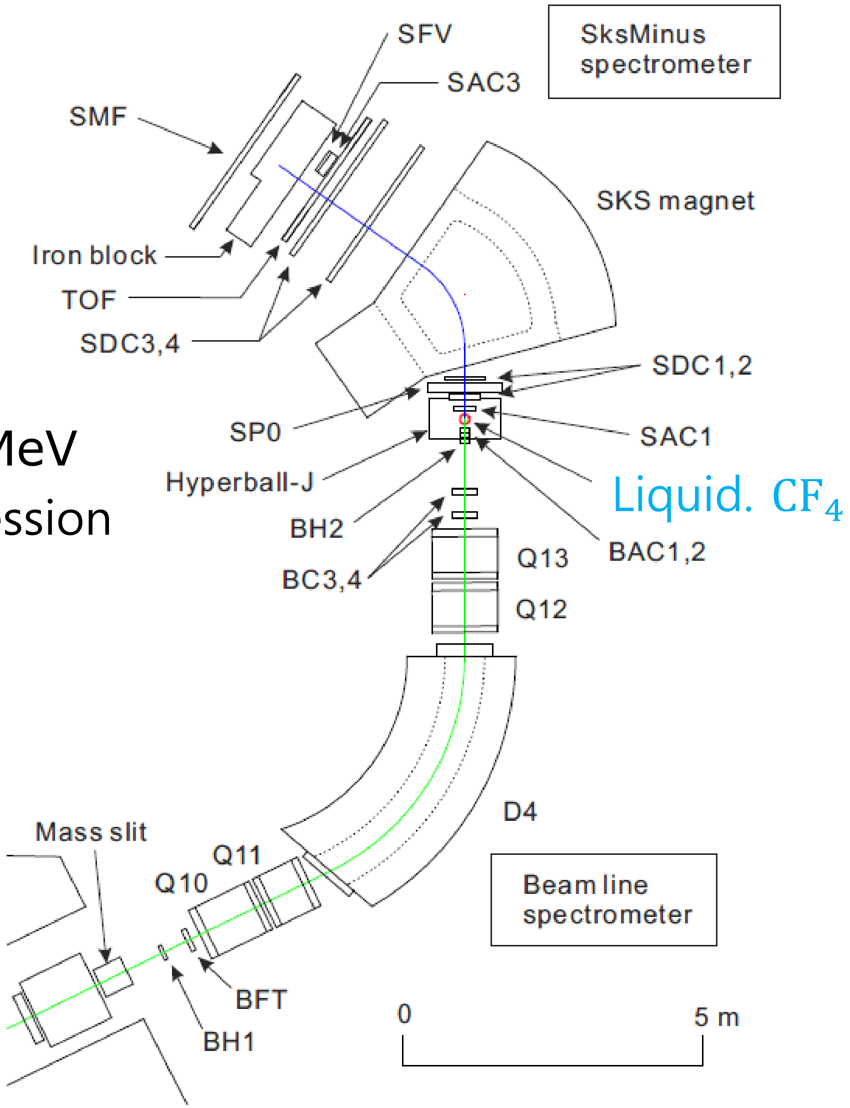


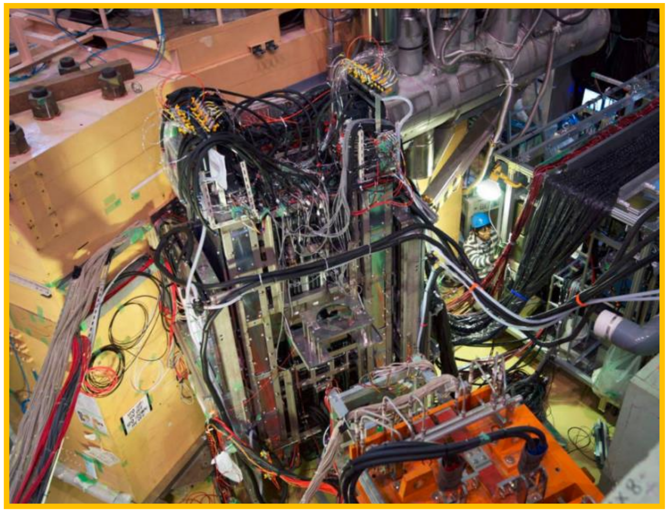
They have $\bar{r}(d_N - s_\Lambda) > \bar{r}(d_N - s_\Lambda) > \bar{r}(d_N - s_\Lambda)$ and different wave functions. Can we apply the ΛN interactions to heavier hypernuclei?

Gamma-ray Spectroscopy of ${}^{19}_{\Lambda}\mathrm{F}$

■ SKS & K1.8 Beamline Spectrometers
→ High resolution of missing mass
→ Large acceptance for (K^-, π^-)
→ good beam decay suppressor (SP0, SMF)

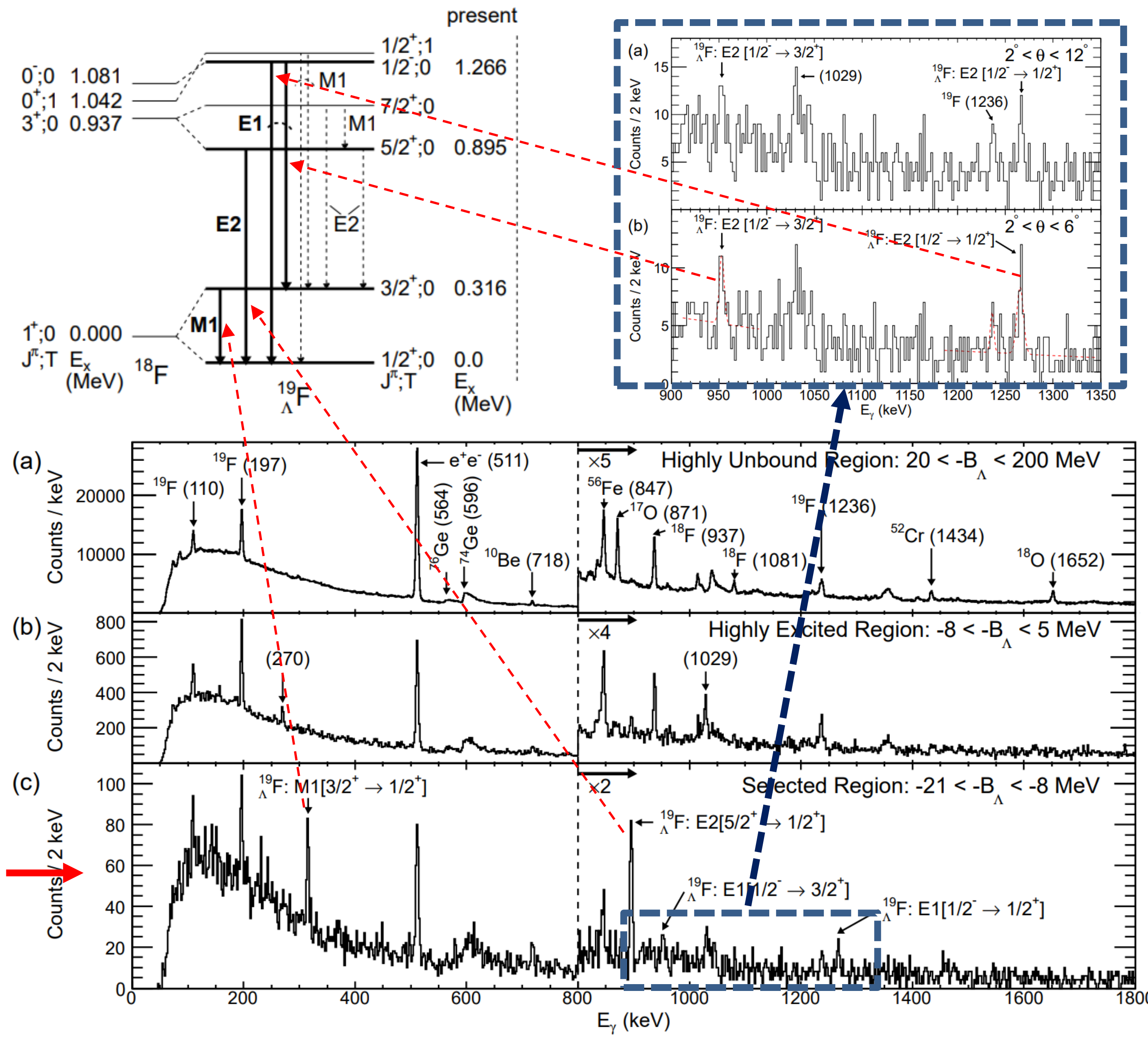
■ Hyperball-J
→ 25 HPGe detectors - ΔE ~4.5 keV @ 1MeV
→ PWO counters - Fast background suppression





■ Four γ-ray peaks from ${}^{19}_{\Lambda}\mathrm{F}$ were successfully observed. The $(1/2^+, 3/2^+)$ energy spacing is determined to be $315.5 \pm 0.4^{+0.3}_{-0.2}$ keV.

Coincident events with ${}^{19}_{\Lambda}\mathrm{F}$ production

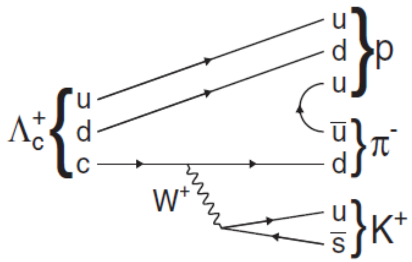


Doubly Cabibbo-Suppressed Decay, $\Lambda_c^+ \to pK^+\pi^-$

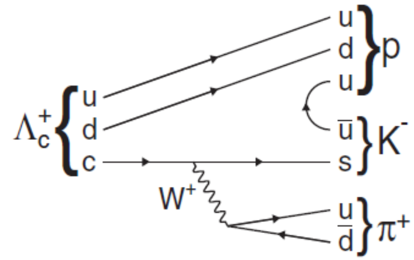
■ Several doubly Cabibbo-suppressed decay of charmed mesons were observed, but there was no evidence in charmed baryons.

■ Doubly Cabibbo-suppressed decay of Λ_c^+, $\Lambda_c^+ \to pK^+\pi^-$

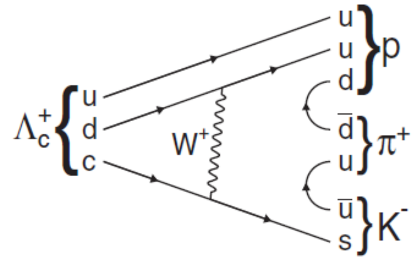
Doubly Cabibbo-Suppressed (DCS) Decay, $\Lambda_c^+ \to pK^+\pi^-$



Cabibbo-Favored (CF) Decay, $\Lambda_c^+ \to pK^-\pi^+$



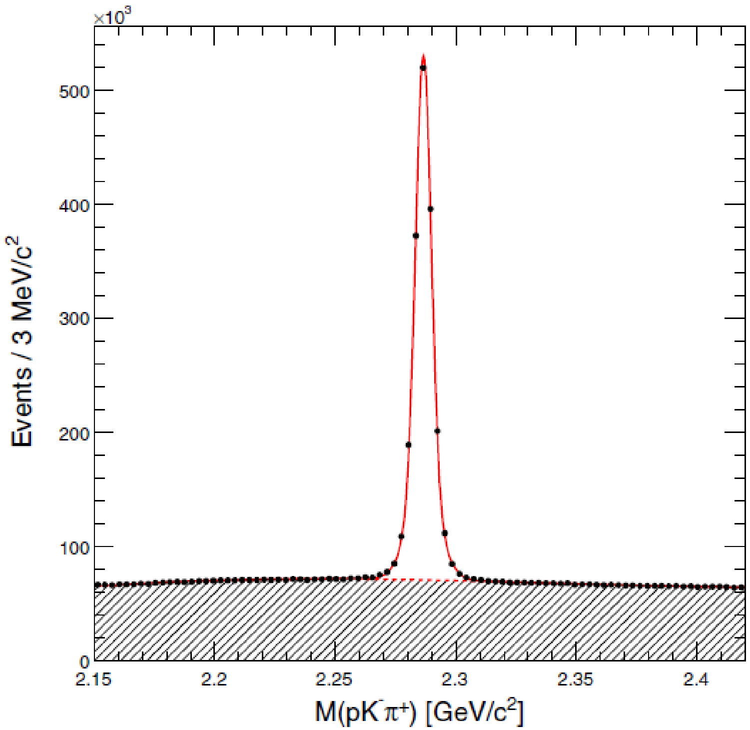
The W-exchange decay channel is forbidden in $\Lambda_c^+ \to pK^+\pi^-$.



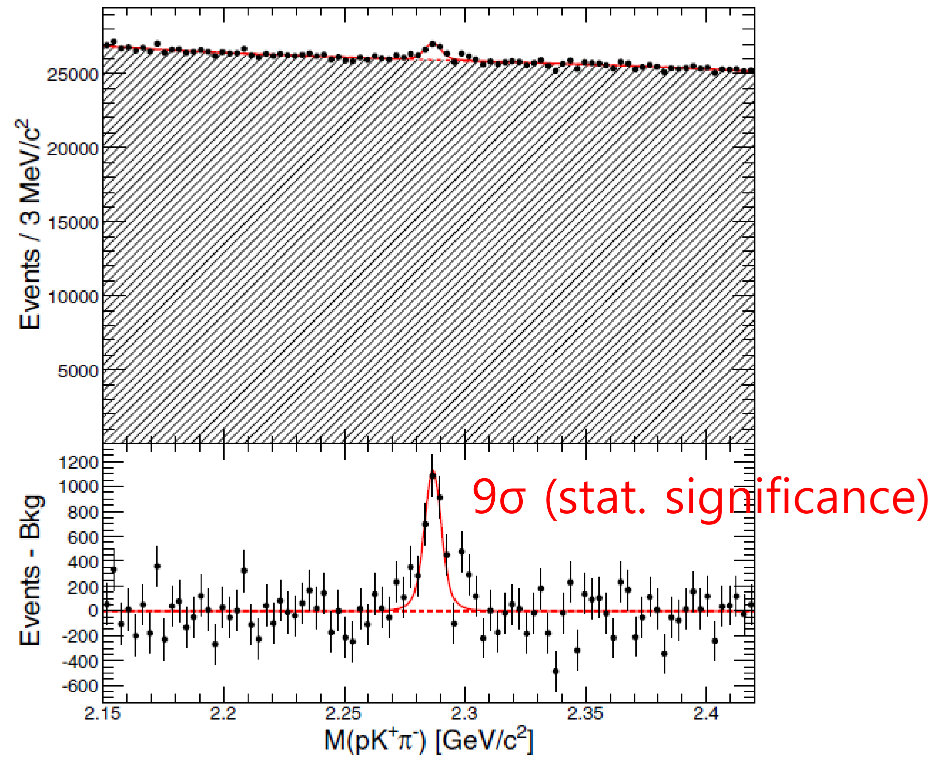
→ Branching ratio, $\frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)}$, is expected to be lower than $\tan^4\theta_C (= 0.00285)$.

- Using the full data sample of Belle, 980 fb^{-1}, we observed the DCS decay.

CF Decay, $\Lambda_c^+ \to pK^-\pi^+$



DCS Decay, $\Lambda_c^+ \to pK^+\pi^-$

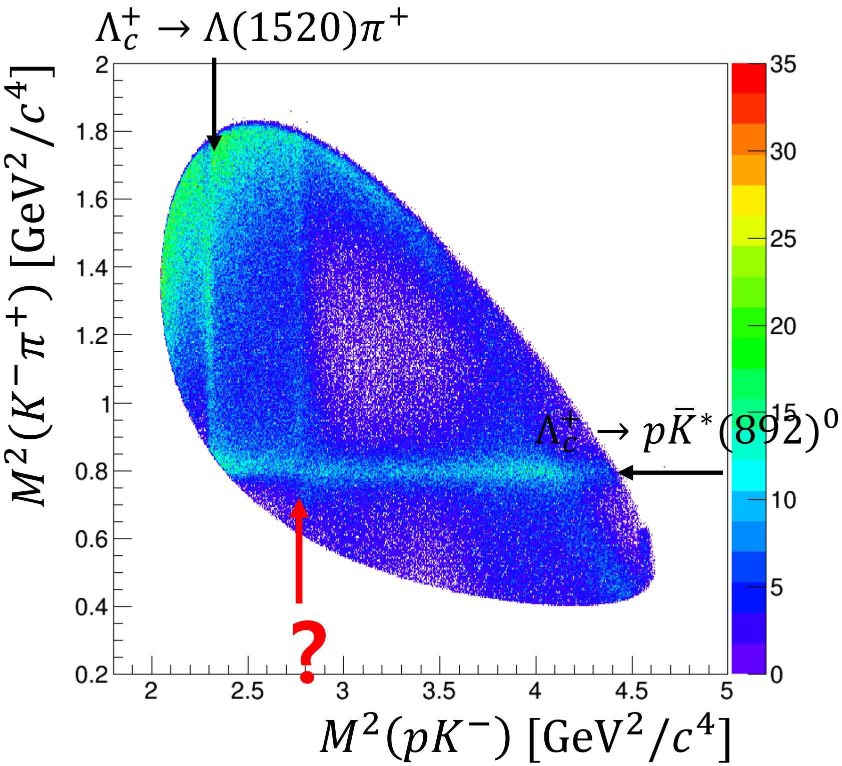


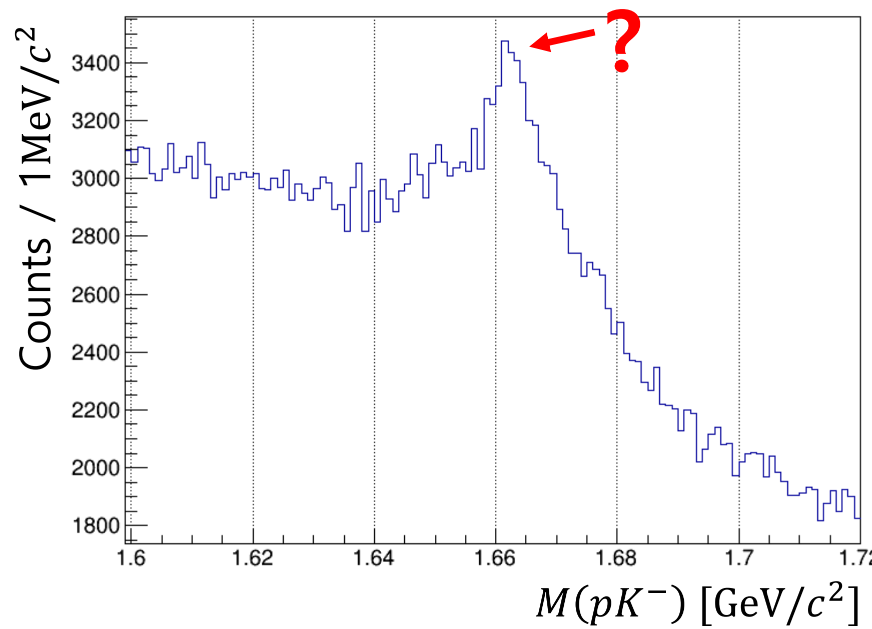
$$\rightarrow \frac{B(\Lambda_c^+ \to pK^+\pi^-)}{B(\Lambda_c^+ \to pK^-\pi^+)} = (2.35 \pm 0.27(Stat.) \pm 0.21(Syst.)) \times 10^{-3}$$

A New Λ Resonance Search

- In my formal Belle analysis of $\Lambda_c^+ \to pK^-\pi^+$,

→ Dalits plot for $\Lambda_c^+ \to pK^-\pi^+$,

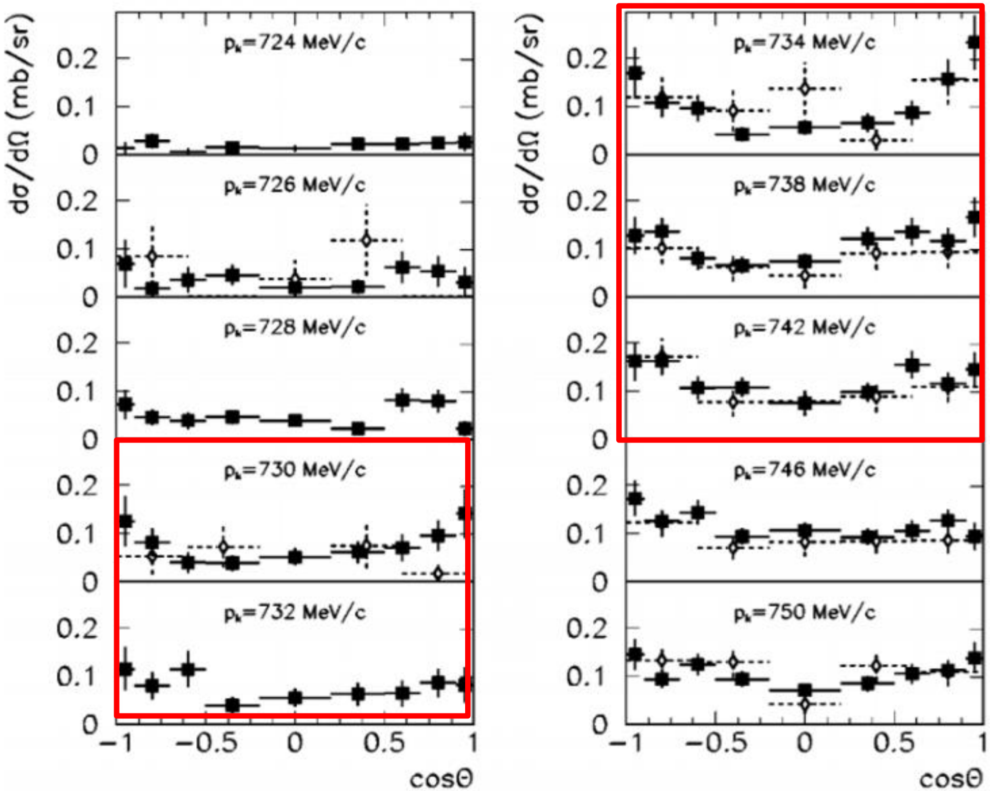




→ Mass, 1.663 GeV/c^2 (very close to $M(\eta) + M(\Lambda)$)
→ Narrow width, ~8 GeV/c^2
→ Not in PDG, new particle? Not expected at all in constituent quark models.

- A hint of the new resonance

→ Crystal ball experiment, $Kp \to \eta\Lambda$.



Concave shapes → Evidence for a narrow resonance (~1.670 GeV/c^2) with $J = 3/2$

*PRC 64, 055205

→ Two theoretical models suggested a new Λ resonance (~1.670 GeV/c^2) with $J = 3/2$. *PRC 92, 025205 and PRC 85, 038201

→ The data size is not enough to make a clear conclusion, especially a parity.

A new Λ resonance with $\mathrm{M} = \sim 1.665\ \mathrm{GeV}/c^2$ and $J = 3/2$?

■ Experimental Setup

→ We would like to perform $Kp \rightarrow \eta\Lambda$ experiment with HypTPC at J-PARC. It is almost similar with J-PARC E42 and E45 except beam momentum.

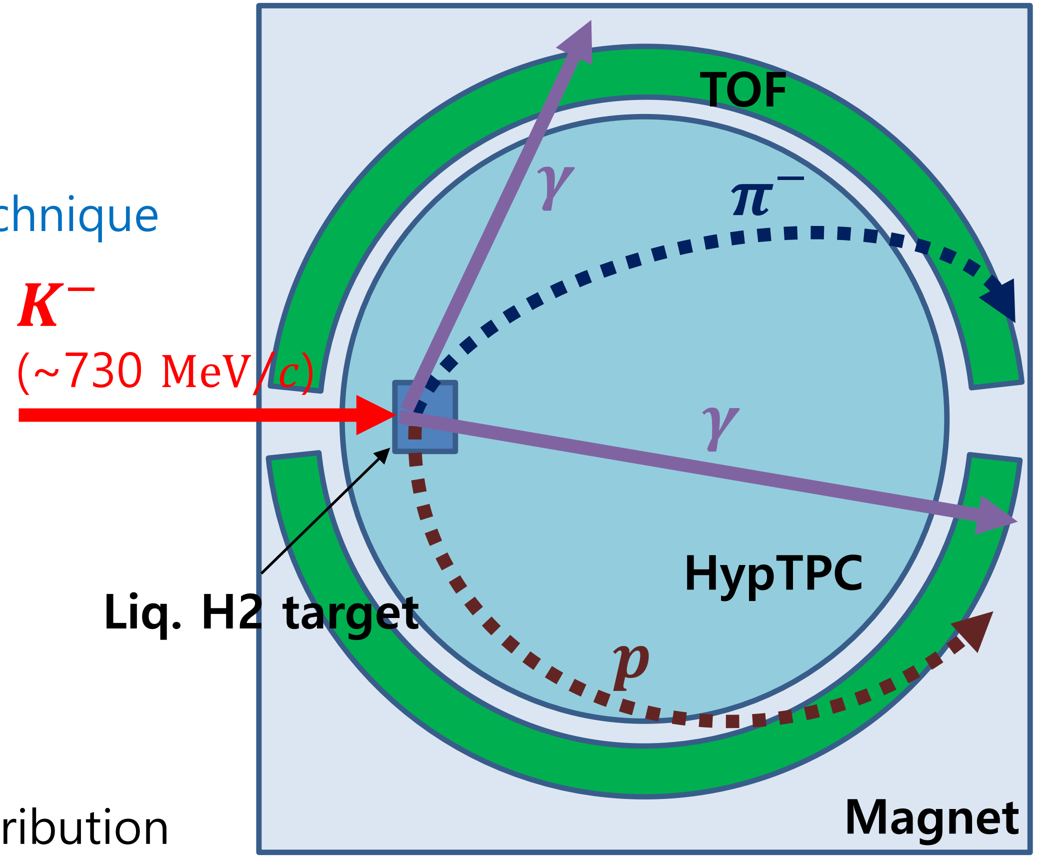
*Reaction:

$K^- p \rightarrow \Lambda^*$

$\Lambda^* \rightarrow \Lambda\,\eta$ *Missing mass technique

$\Lambda \rightarrow p\pi^-$

*Detected by HypTPC



→ Resonance peak: cross-section distribution according to beam momentum

→ Spin of Λ^*: $\cos\theta$ distribution

→ Parity of Λ^*: Λ polarization distribution

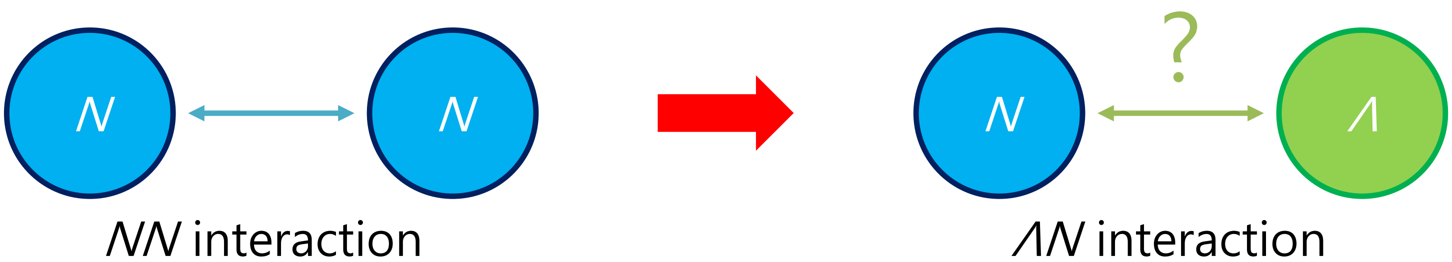
→ We can get enough data to determine the spin and parity by using the HypTPC having a large acceptance in high rate beam condition.

*Backup Slides

ΛN Interaction and Λ Hypernucleus

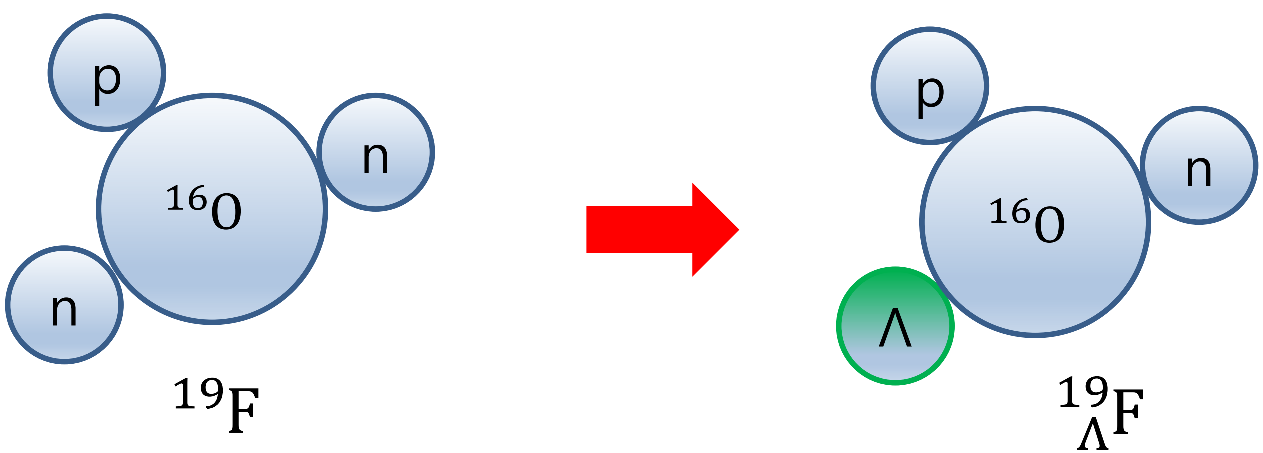
■ ΛN interaction

It is the first step to understand the general baryon-baryon interaction.



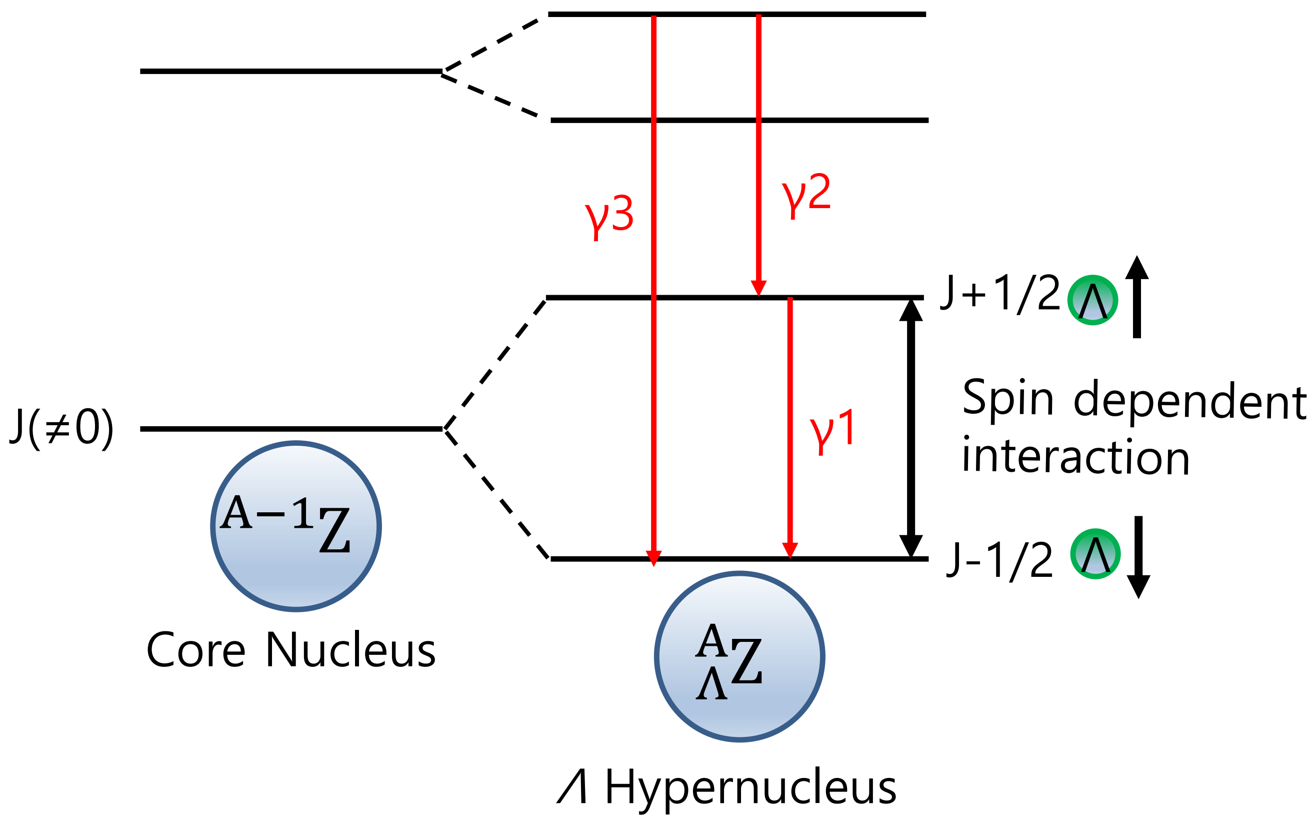
■ Λ hypernucleus

Due to the short life time of Λ, a scattering experiment is impossible for the ΛN interaction. In this case, a spectroscopy of Λ hypernucleus is the most powerful tool.



Gamma-Ray Spectroscopy of *Λ* Hypernucleus

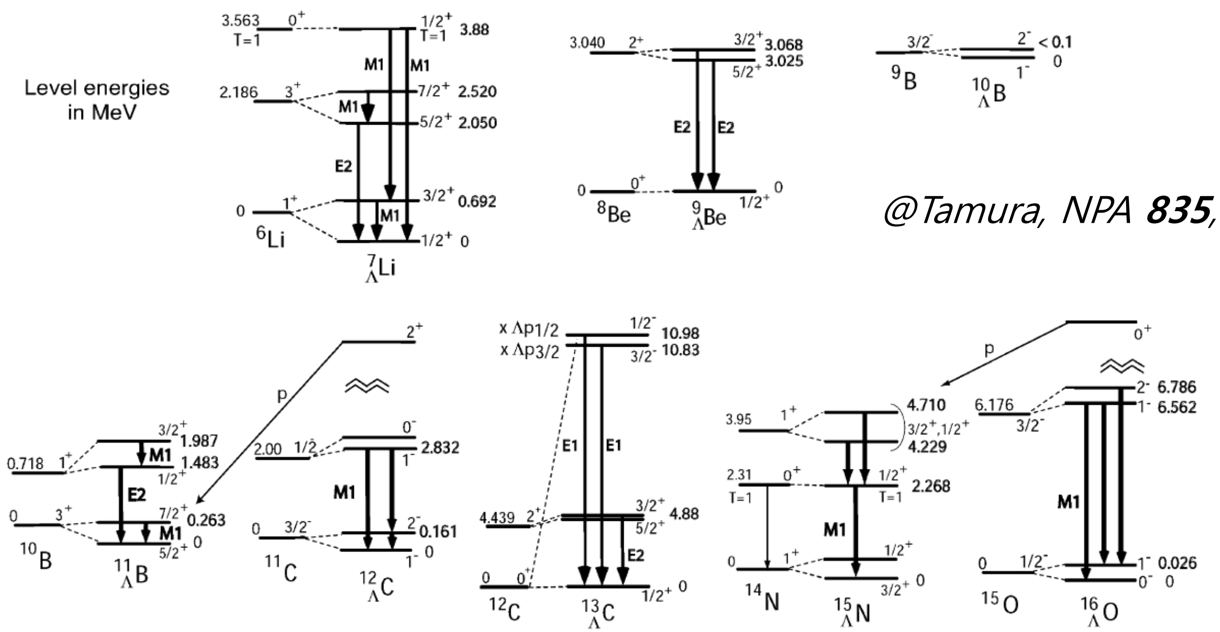
- Gamma-ray spectroscopy of *Λ* hypernucleus



→ By measuring energies of the γ rays, the split energy spacing is precisely estimated and we can know a fine structure of the hypernucleus.

■ Previous gamma-ray spectroscopies of hypernuclei

From 1998, several *s*- and *p*-shell hypernuclei were well studied through the method.



@Tamura, NPA ***835***, *3 (2010)*

→ From the experiment results, we understood the spin-dependent interaction in *s*- and *p*-shell hypernuclei.

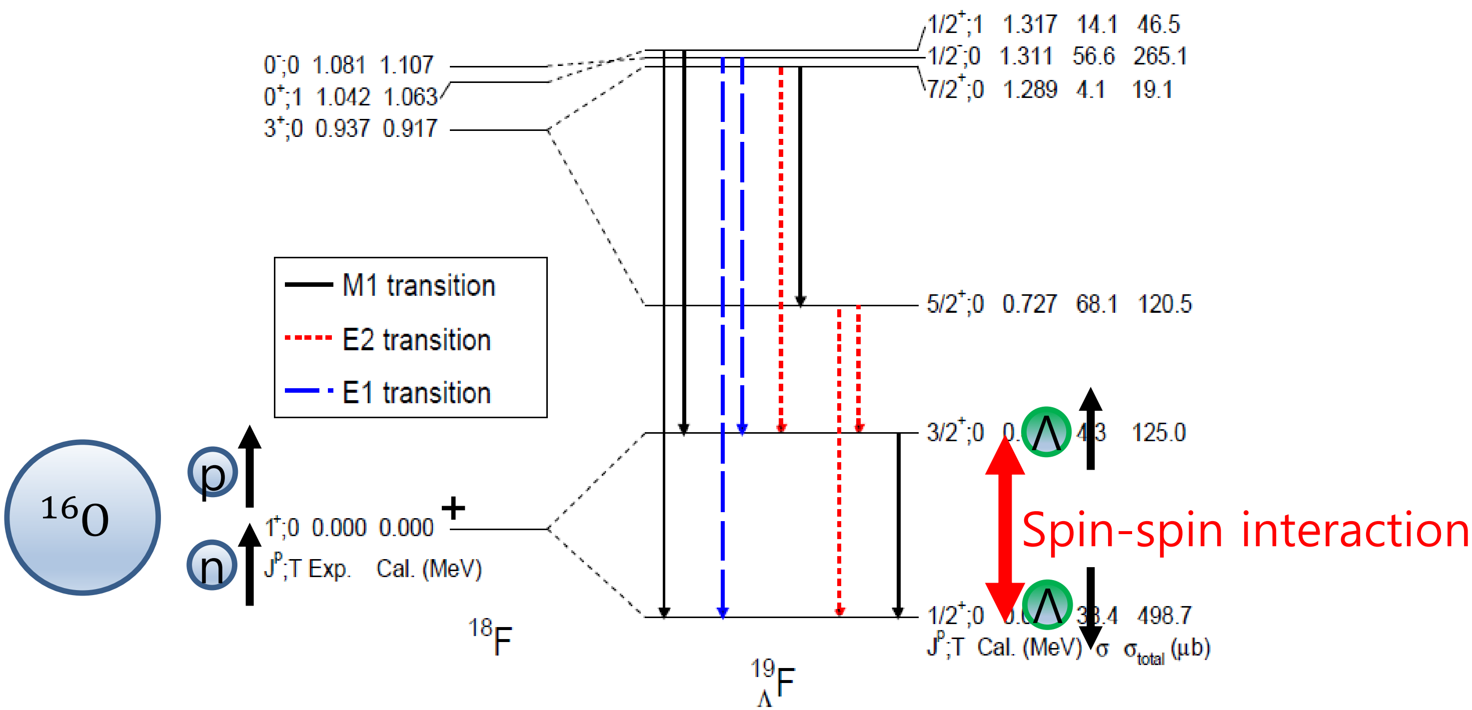
The next step is for *sd*-shell and heavier hypernuclei.

Gamma-ray Spectroscopy of $^{19}_{\Lambda}$F (J-PARC E13 1st Phase)

- It is the first γ-ray spectroscopy for *sd*-shell hypernuclei.
- Energy spacing between ground state doublet (1/2+, 3/2+)

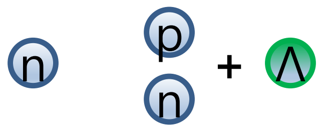
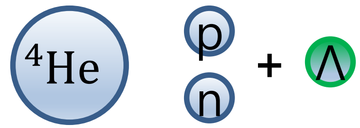
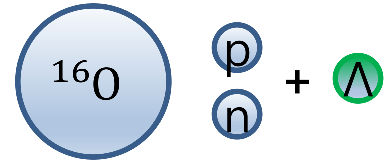
→ Radial dependency of the *ΛN* spin-spin interaction?

→ *ΛN* spin-dependent interaction with different wave-function?



low-lying energy levels of $^{19}_{\Lambda}$F

**A. Umeya and T. Motoba, NPA 116, 122501 (2016)*

	$^{4}_{\Lambda}\mathrm{H}$	$^{7}_{\Lambda}\mathrm{Li}$	$^{19}_{\Lambda}\mathrm{F}$
Four-body Cluster model			
Wave-function	$s_N s_\Lambda$	$p_N s_\Lambda$	$(sd)_N s_\Lambda$
N, RMS radius [fm] @by Millener, private communication	2.5 $(0s)$	3.0 $(0p_{1/2})$ 2.9 $(0p_{3/2})$	3.4 $(1s_{1/2})$ 3.5 $(0p_{1/2})$ 3.3 $(0d_{5/2})$
Λ, RMS radius [fm] @by Millener, private communication	3.5 $(0s)$	2.6 $(0s)$	2.3 $(0s)$
ΔE_x (ground state doublet)	1.1 MeV	0.695 MeV ($\Delta_{p_N s_\Lambda}$=0.43 MeV)	?

γ-ray Detector (Hyperball-J)

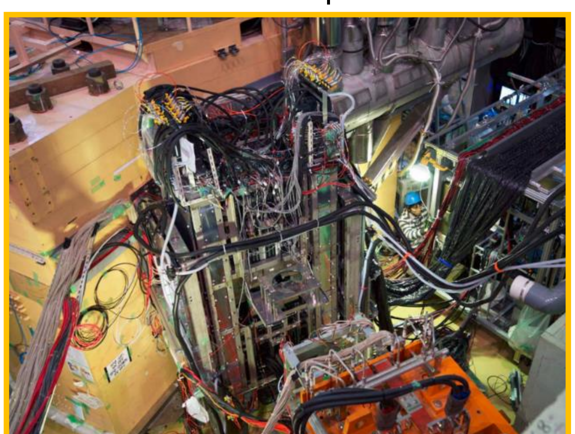
- $^{19}\mathrm{F}(K^-,\ \pi^-)\,^{19}_{\Lambda}\mathrm{F}^*,\ ^{19}_{\Lambda}\mathrm{F}^* \rightarrow \gamma + {}^{19}_{\Lambda}\mathrm{F}$
- Hyperball-J

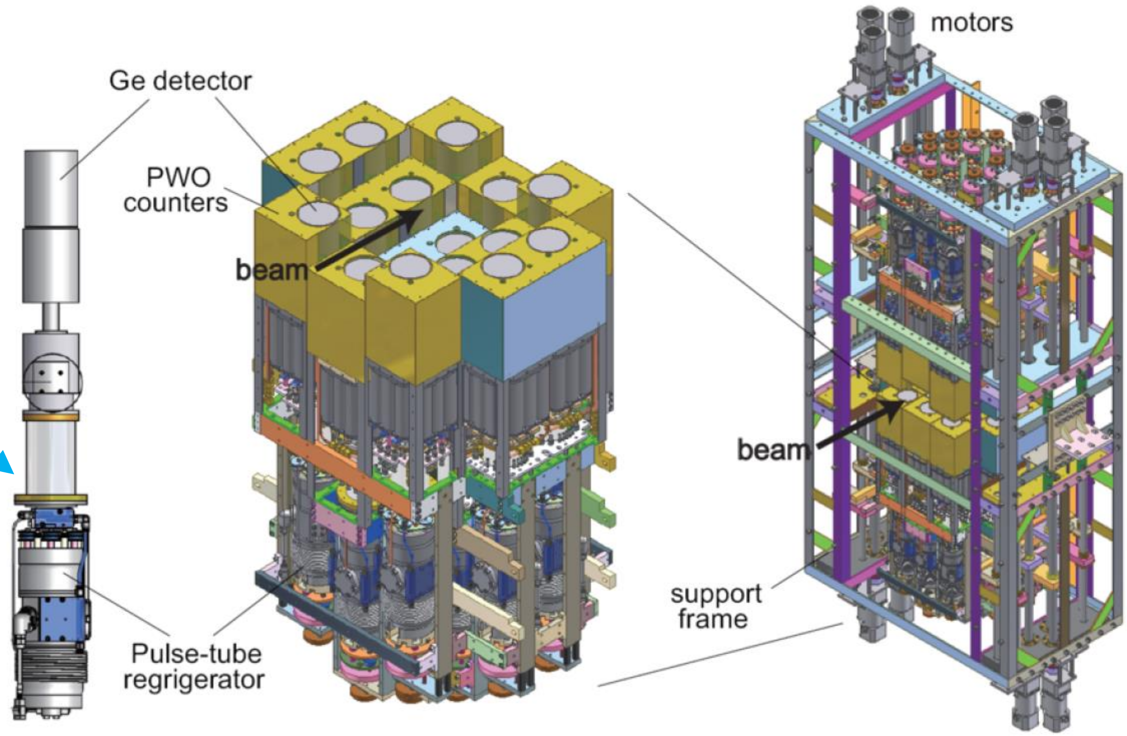
→ 25 HPGe detectors - ΔE ~4.5 keV @ 1MeV

→ PWO counters - Fast background suppression

Mechanical cooling system
Crystal temp. ~70 K

*a view of K1.8 experimental hall

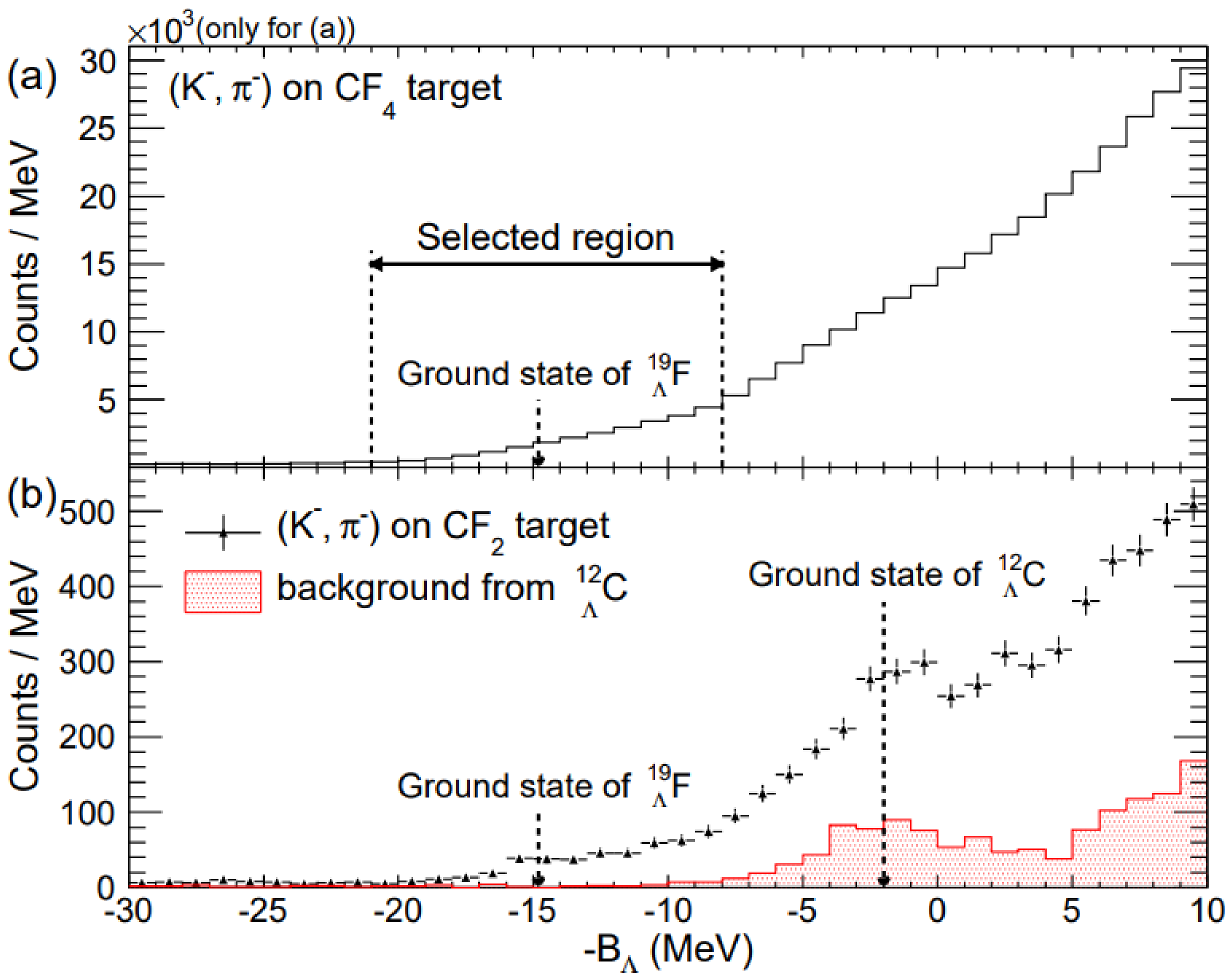




@NPA, 835, 3 (2012)

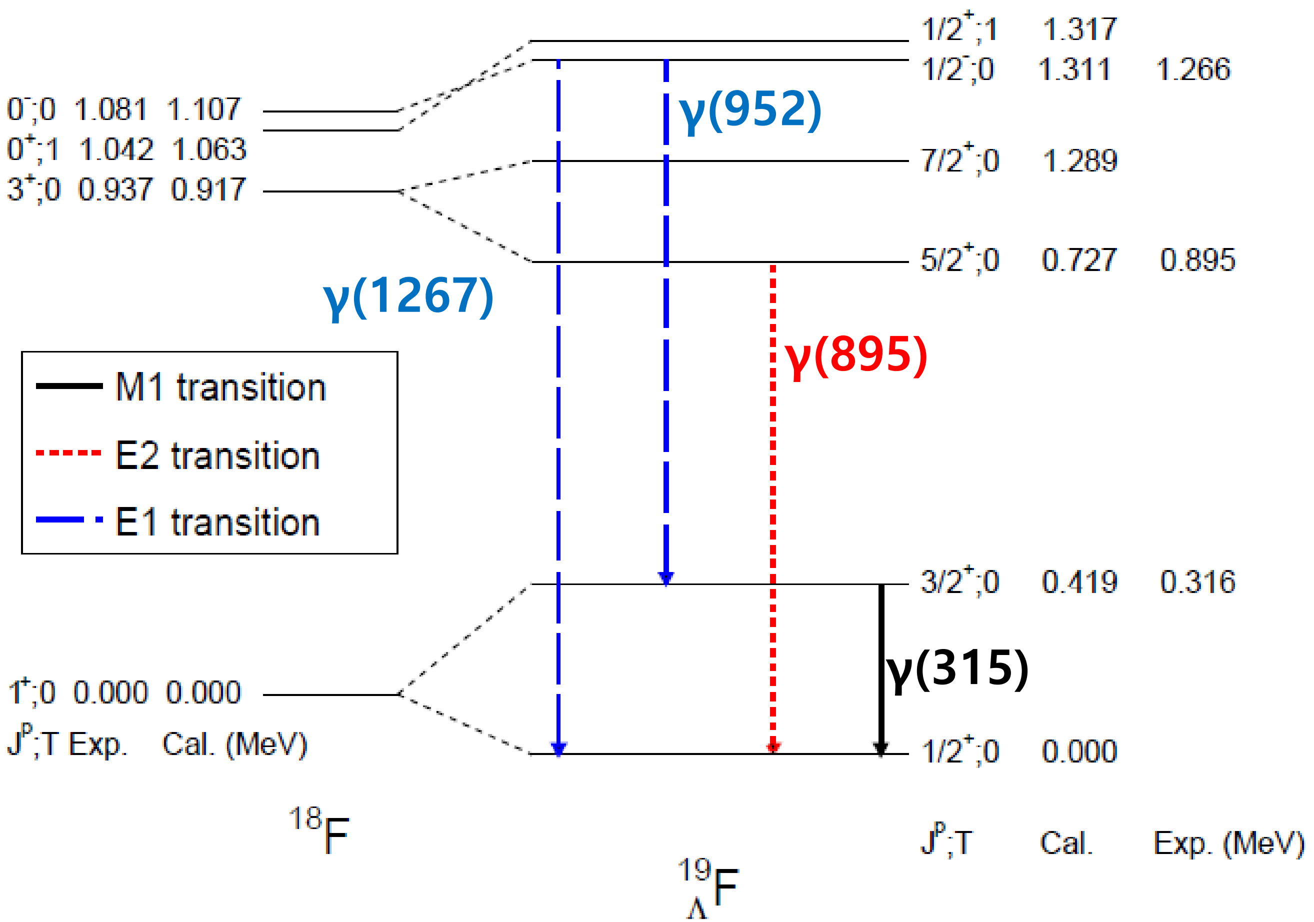
$-B_\Lambda$ Distribution of ${}^{19}_{\Lambda}F$

- Λ binding energy spectra of ${}^{19}_{\Lambda}F$.



Transition Assignments

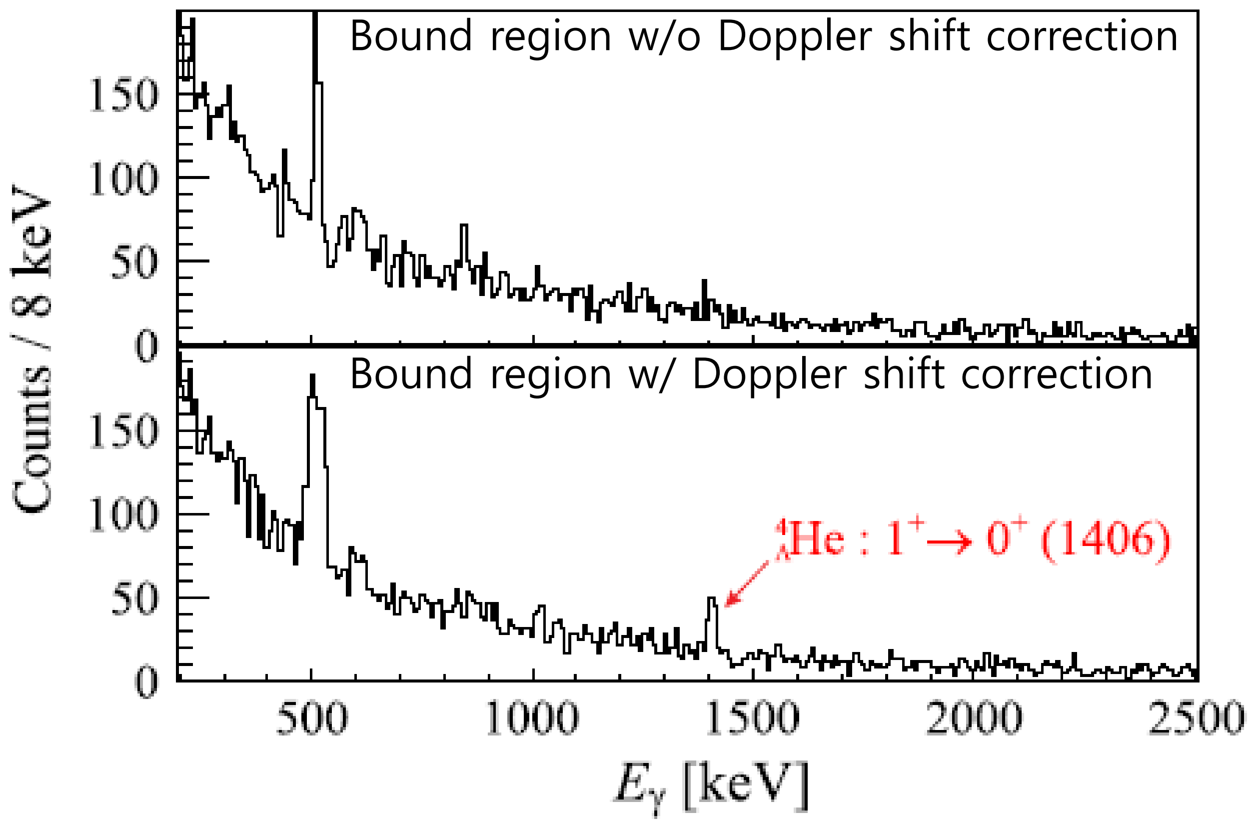
■ Based on theoretical calculations, the gamma rays are assigned to their gamma transitions.



Gamma-ray Spectroscopy of ${}^{4}_{\Lambda}$He

- Another target (${}^{4}_{\Lambda}$He) of J-PARC E13 1st phase
- We observed a γ ray at 1.406 MeV which emitted from ($1^+ \rightarrow 0^+$) transition of ${}^{4}_{\Lambda}$He.

→ Compared with ${}^{4}_{\Lambda}$H result (1.09 MeV), we found a large charge symmetric breaking effect in *ΛN* interaction.



*@T.O. Yamamoto et. al., PRL **115**, 222501 (2015)*

Other Experiments at J-PARC

1. Search for Θ^+ pentaquark (J-PARC E19)
→ The upper limit of $p(\pi^-, K^-)\Theta^+$ cross section was reported.
K. Shirotori et. al., PRL **109, 132002 (2012) and M. Moritsu et. al., PRC **90**, 035205 (2014)*

2. Search for ${}^{6}_{\Lambda}\mathrm{H}$ hypernucleus (J-PARC E10)
→ The upper limit of ${}^{6}\mathrm{Li}(\pi^-, K^-){}^{6}_{\Lambda}\mathrm{H}$ cross section was reported.
H. Sugimura et. al., PLB **729, 39-44 (2014)*

3. Search for bound state of K^-pp (J-PARC E27)
→ We found "K^-pp"-like structure.
Y. Ichikawa et. al., PTEP **2014, 101D03 (2014) and Y. Ichikawa et. al., **2015**, 021D01 (2015)*

Doubly Cabibbo-Suppressed Decay, $\Lambda_c^+ \to pK^+\pi^-$

■ Data sample

→ Full data sample of Belle, 980 fb^{-1}, at and near $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S), \Upsilon(4S)$, and $\Upsilon(5S)$ is used.

■ Analysis

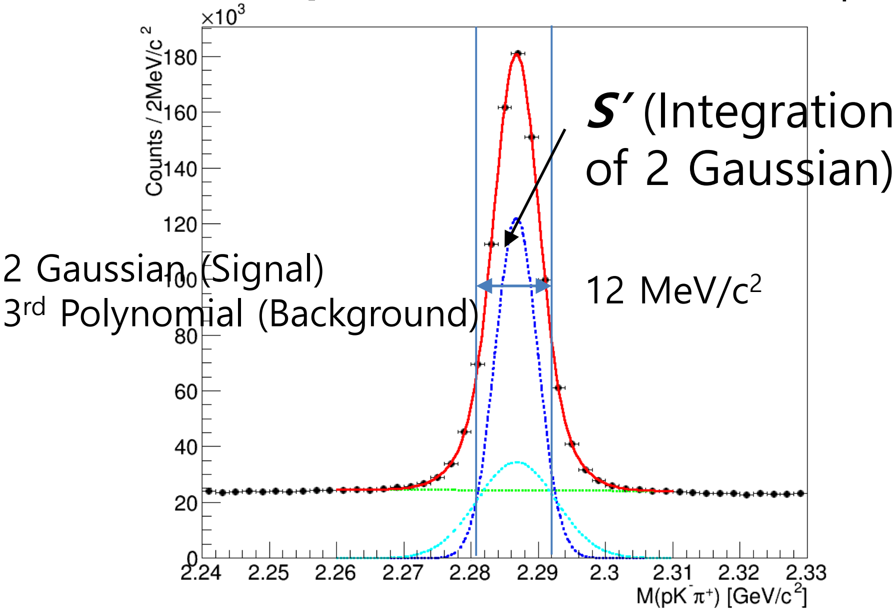
→ Optimization by using a control sample, $\Lambda_c^+ \to pK^-\pi^+$, to keep a blinded condition.

→ Reconstruction efficiency and backgrounds are estimated by MC samples.

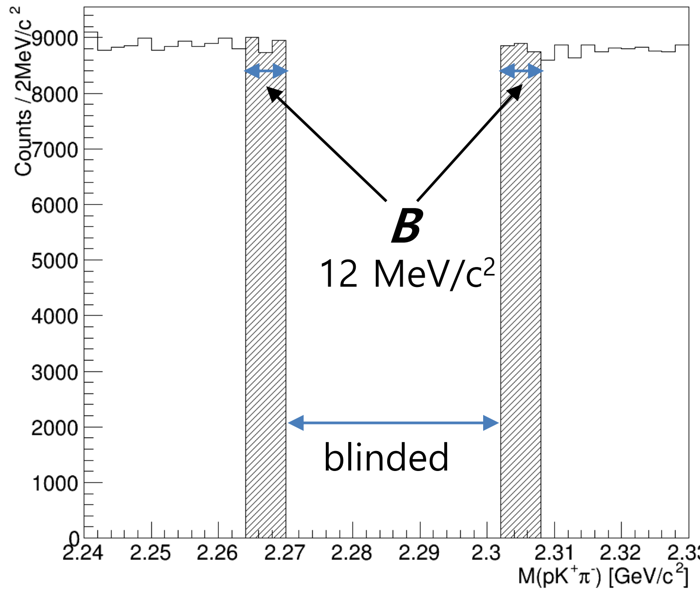
→ Most systematic sources (efficiency, phase space, etc.) for the branching fraction cancel out.

- Figure-of-merit study for optimization

*$M(K^-\pi^+p)$ distribution, control sample



*$M(K^+\pi^-p)$ distribution, side band

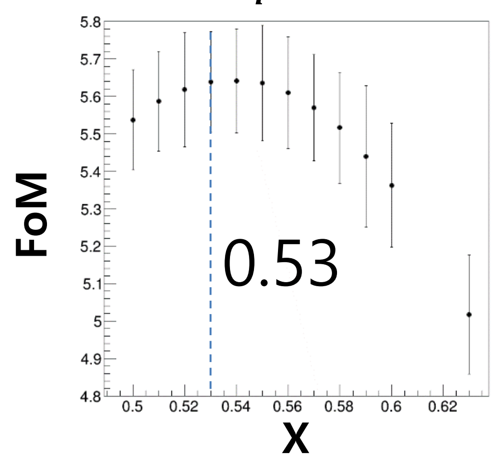


$$FoM = S/\sqrt{S+B}, \text{ where } S = 0.0025 \times S'$$

*example: scaled momentum, x_p

→ A condition with maximum FoM is selected.

* $x_p > \mathrm{X}$



HypTPC

■ Time projection chamber

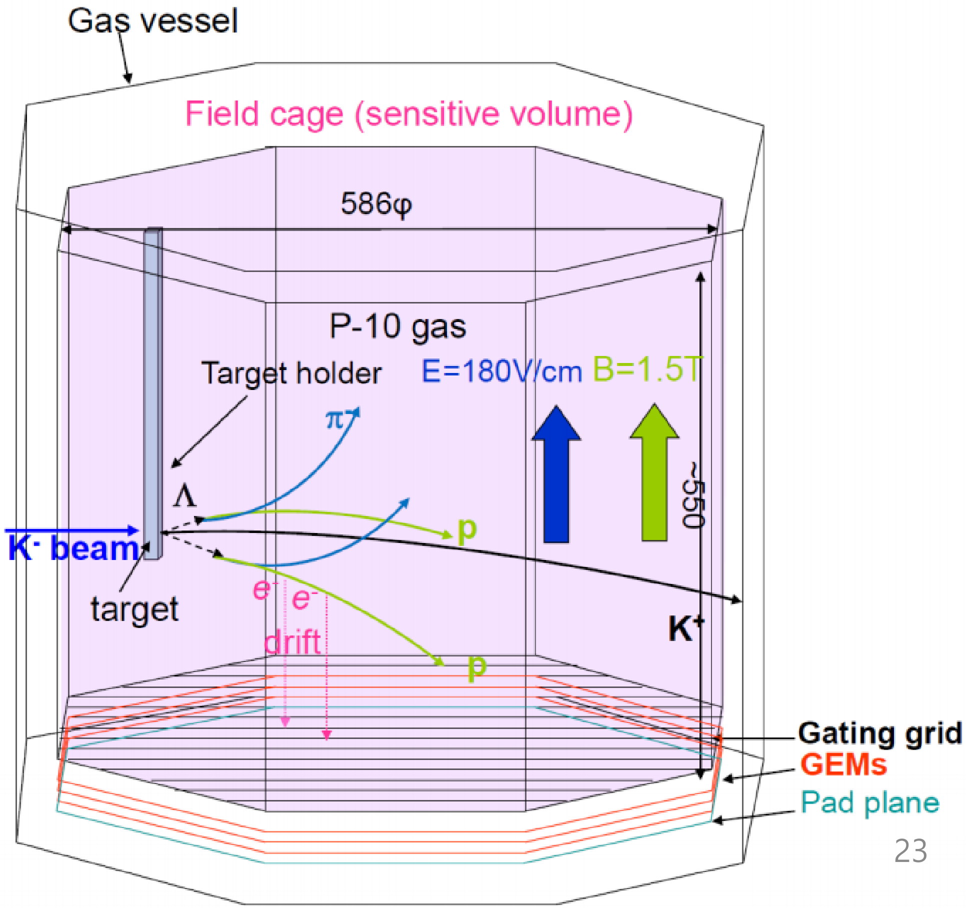
→ Developed for hadron experiments, H-dibaryon search (E42) and baryon spectroscopy (E45) at J-PARC

→ The JAEA hadron group is one of main collaborators of these experiments.

→ Construction already completed.

→ Large acceptance ~4π

→ Position resolution < 300 μm



How to Determine Spin and Parity

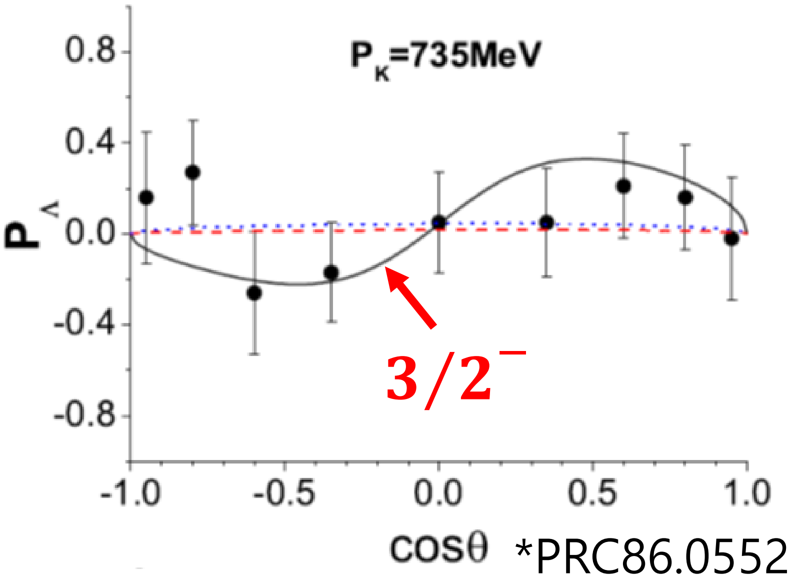
■ Angular distribution

→ When $J = 3/2$ or high, $\cos^2\theta$ term is appeared. Other cases, constant or $\cos\theta$ distribution.

→ However, we cannot distinguish $3/2^+$ and $3/2^-$.

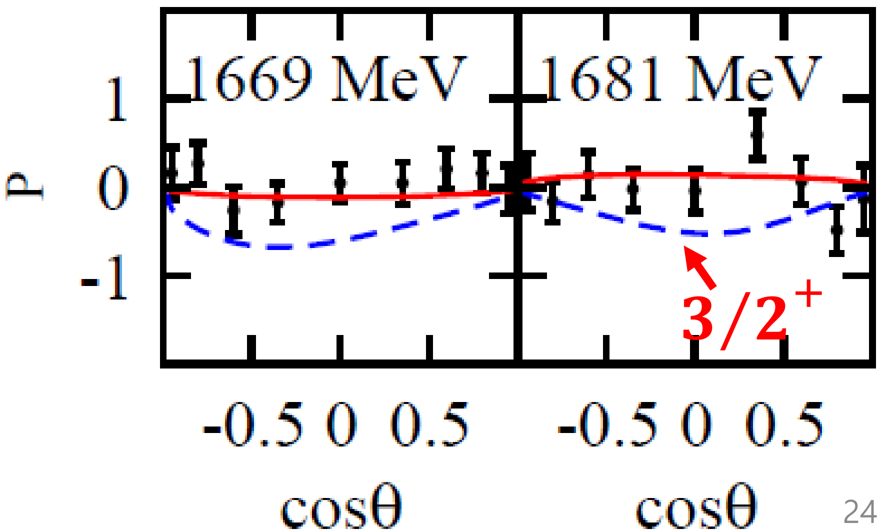
■ We can determine the parity from Λ polarization distribution.

→ P wave ($3/2^+$) and D wave ($3/2^-$) can be distinguished by the Λ polarization distribution.



*PRC86.055202

*PRC92.025205

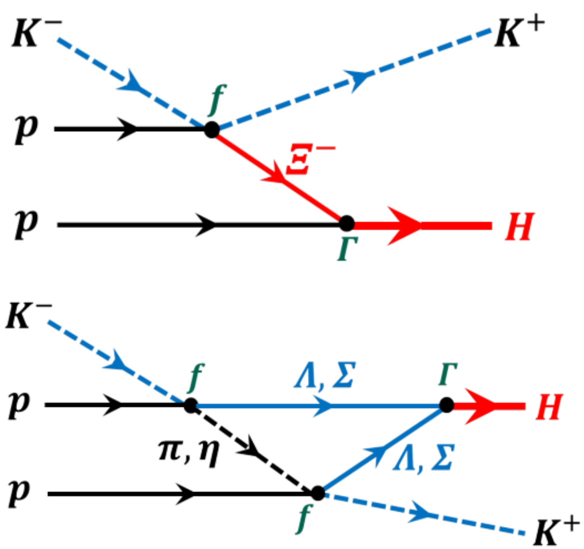


H-dibaryon Search (E42) and Baryon Spectroscopy (E45)

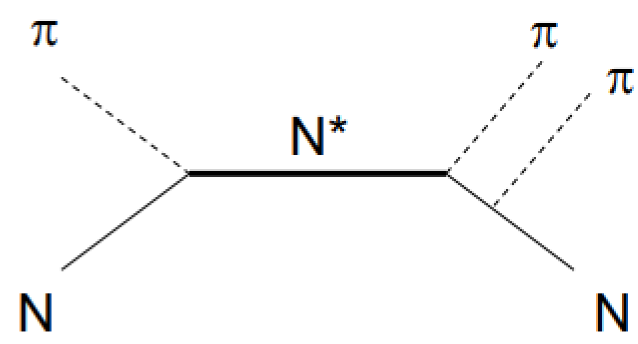
■ These two experiments are being prepared by the JAEA hadron group as a series of experiments using the HypTPC. Both experiments will extend our knowledge of hadron structure and provide a key information for non-perturbative QCD calculation.

■ The E42 is a search for H-dibaryon consisting of $uuddss$ quarks. It will provide a crucial information to determine whether the H-dibaryon exists or not.

■ The E45 is a baryon spectroscopy with $(\pi, 2\pi)$ reaction (J-PARC E45). Precise experimental data of high mass baryons will be taken and we also expect to observe new nucleon resonances.



H-dibaryon production process, 1.8 GeV/c K beam

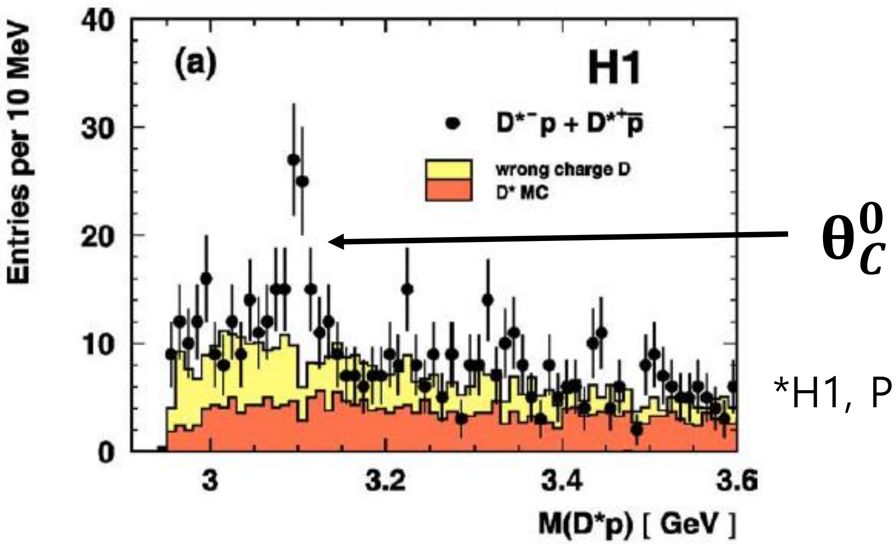


N^* production process, 1.8 GeV/c
π beam

Θ_C^0 Search at J-PARC

■ Previous searches for Θ_C^0

→ Only one positive result at ~ 3.1 GeV/c^2 from H1 group.



*H1, PLB 588 (2004) 17

→ After the positive result, only negative results have been reported from BELLE, BABAR, CLEO, H2 and FOCUS.

→ But there have been searches through $\Theta_C^0 \to D^{(*)-}p$ strong decay only.

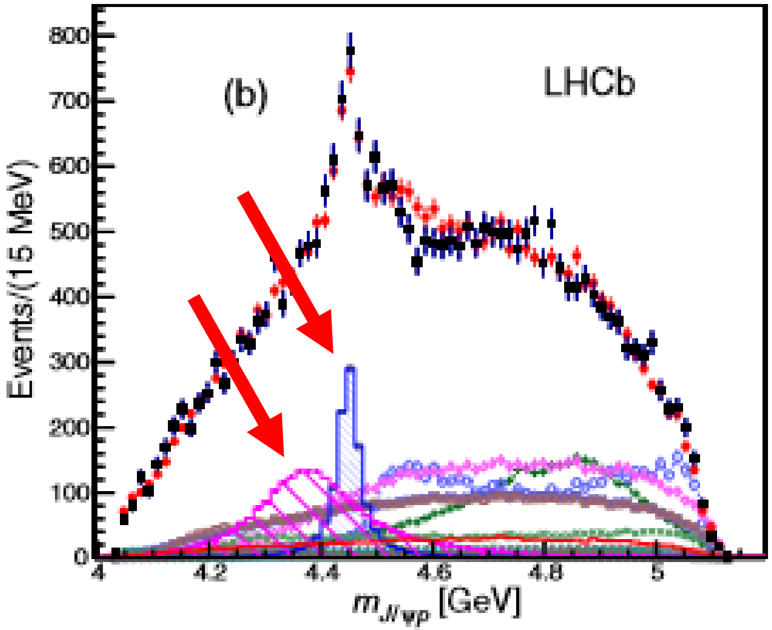
■ Θ_C^0 mass in several models

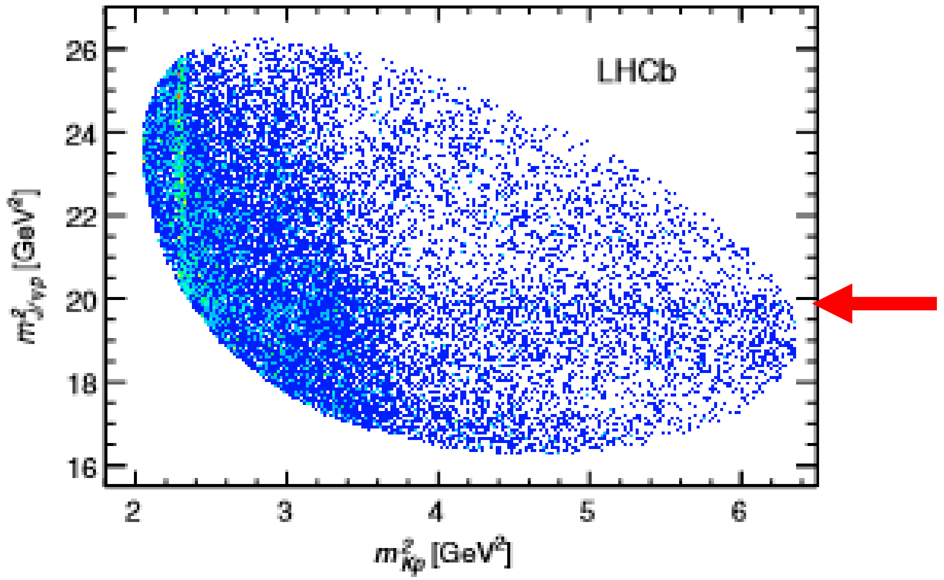
Model	Mass of Θ_C^0	Ref.
Jaffe and Wilczek's model	2.710 GeV/c^2	PRL, 91, 23(2003)
Karliner and Lipkin's model	2.985 GeV/c^2	Hep-ph/0307343
Karliner and Lipkin's model with the color-spin SU(6) hyperfine interaction	2.757 GeV/c^2	PRD, 77, 074016 (2008)
D^-p molecular state	2.806 GeV/c^2	PRD, 80, 034008 (2009)

→ Several models suggest that the Θ_C^0 mass is less than a threshold of D^-p strong decay (2.807 GeV/c^2).

→ In this case, we can search Θ_C^0 through only weak decay channel.

■ $J/\psi p$ resonances at $\Lambda_b^0 \rightarrow J/\psi K^- p$
→ Two new resonances at 4.45 GeV/c^2 and 4.38 GeV/c^2
→ They are supposed to be pentaquarks, $uudc\bar{c}$.





*LHCb, PRL 115, 072001 (2015)

→ The results motivate exotic particle search in charmed area.

■ The following reaction can be possible.

$$\pi^{\pm} p \rightarrow \pi^{\pm} D^{(*)+} \Theta_c^0$$

→ Experimental setup for Charmed Baryon Spectroscopy at J-PARC (E50) is suitable for the search.

■ Analysis methods

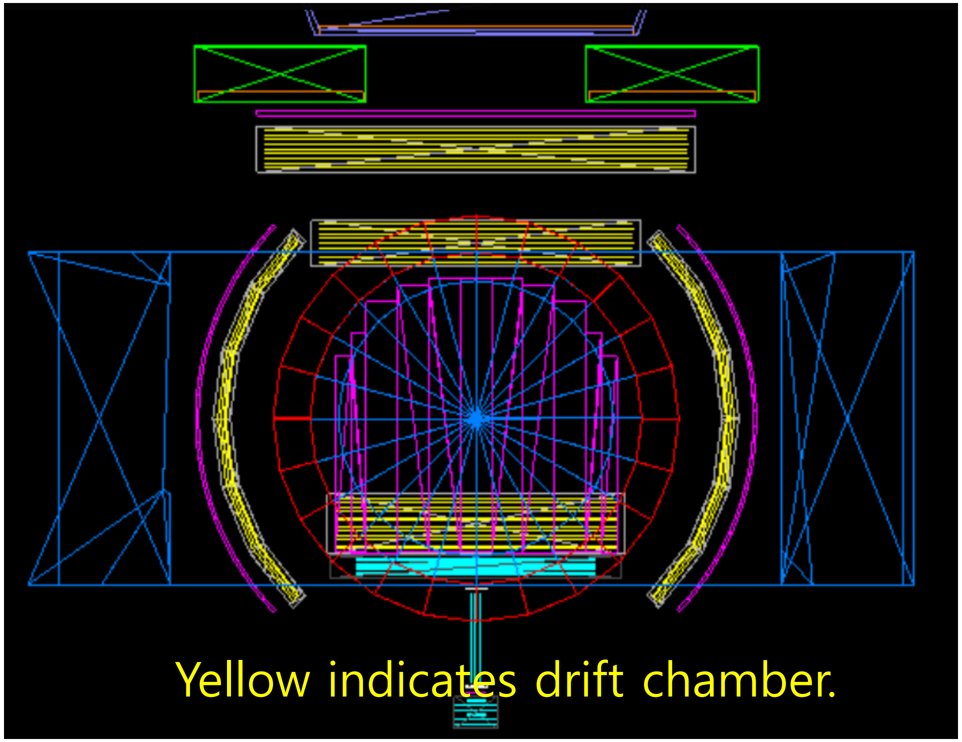
→ Missing Mass of $p(\pi^{\pm}, \pi^{\pm} D^{(*)-})$

→ Inclusive analysis of $\Theta_c^0 \rightarrow p D^{(*)-}$ and $\Theta_c^0 \rightarrow p K^+ \pi^- \pi^-$ both.

Drift Chamber Development for J-PARC E50

■ Simulation work

→ To optimize layer structure of drift chambers.



■ Drift chamber test

→ I am preparing a test of drift chambera with high rate beam condition.