HYP2025

Sep. 29 – Oct. 1, 2025

Prospects of missing-mass spectroscopy of Λ hypernuclei via the (π^+, K^+) reaction using a high resolution spectrometer S-2S

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for the S-2S Collaboration

Oct. 1, 2025

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- CSB problem in Λ hypernuclei
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J-PARC E94

Physics motivation

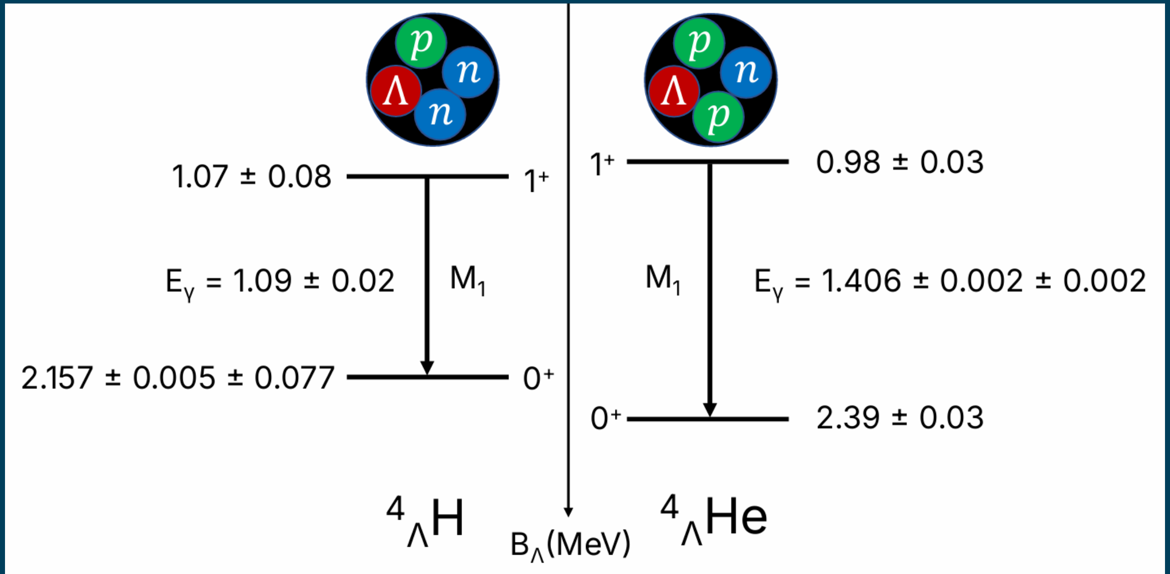
- Charge Symmetry Breaking (CSB) study ΛN interaction
  ➔Provide high precision data for **p-shell systems($^{10}_{\Lambda}$B, $^{12}_{\Lambda}$C)**

Method & feature

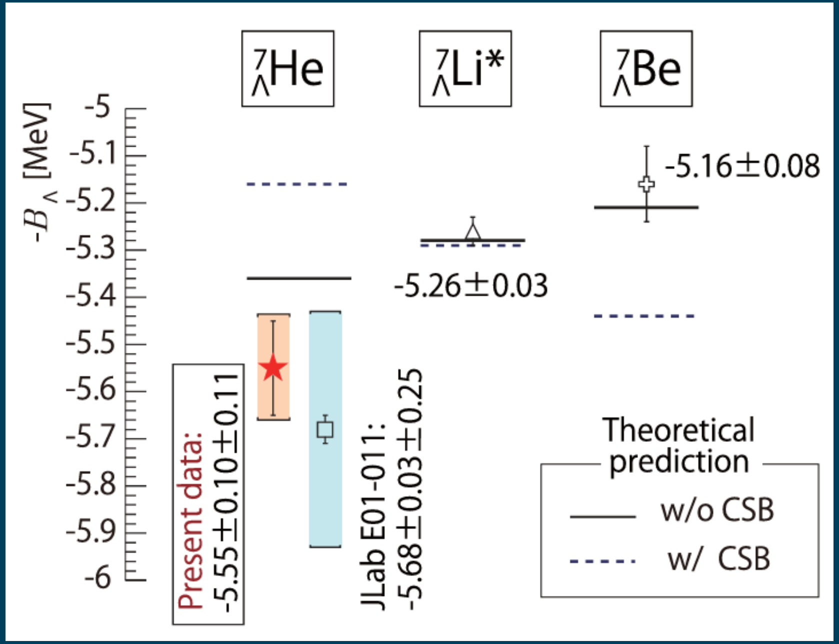
- Missing mass spectroscopy via (π^+, K^+)
- Measure Λ binding energy of $^{7}_{\Lambda}$Li , $^{10}_{\Lambda}$B, $^{12}_{\Lambda}$C
- Energy resolution : **0.7 – 1.4 MeV (FWHM)**
- Energy calibration : $^{7}_{\Lambda}$Li (alternative calibration data for $^{12}_{\Lambda}$C)
- Total accuracy of B_Λ : **$|\Delta B_\Lambda^{total}|$ = 100 keV**

Charge Symmetry Breaking (CSB)

A=4 system



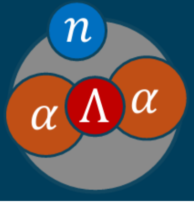
A=7 system



- Charge symmetry is broken in ΛN interaction(CSB)
  - Large CSB in A=4 system
  - Understanding the origin of CSB using phenomenological models, ab initio calculations, lattice QCD, etc.
  - It is necessary to carry out a systematic investigation of heavier hypernuclei, such as p-shell systems, in the experimental field.

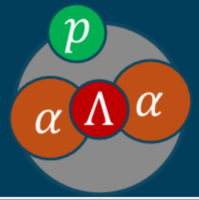
High precision measurement of $^{10}_{\Lambda}\mathrm{B}$

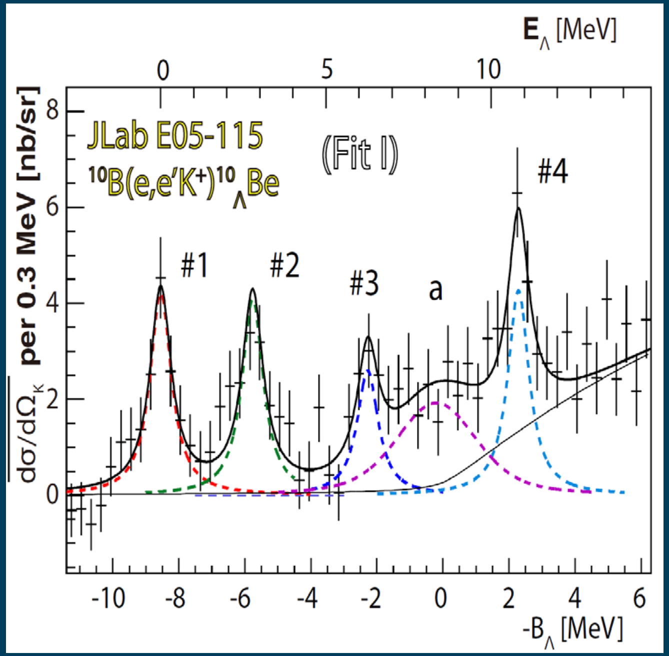
$^{10}_{\Lambda}\mathrm{Be}$



mirror
hypernucleus

$^{10}_{\Lambda}\mathrm{B}$

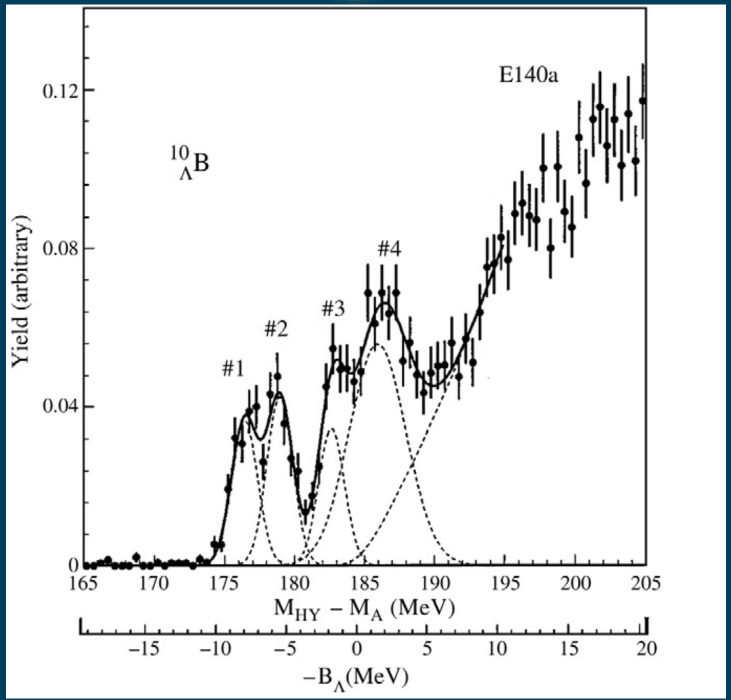




T. Gogami et al., PRC93, 034314 (2016).

$-B_{\Lambda}^{g.s.} = -8.6 \pm 0.07 \pm 0.16$ MeV

MM resolution ~ 0.78 MeV(FWHM)



O. Hashimoto and H. Tamura, Prog. Part. Nucl. Phys. 57, 564–653 (2006).

$-B_{\Lambda}^{g.s.} = -8.1 \pm 0.1 \pm 0.5$ MeV

MM resolution ~ 2 MeV(FWHM)

→ Measure in the J-PARC E94

The $^{12}{}_{\Lambda}$C Calibration Problem

Calibration source of (π^+, K^+) reaction:

$$B_{\Lambda}^{\text{emul.}}({}^{12}_{\Lambda}\text{C}) = 10.76 \pm 0.19^{\text{stat.}} \pm 0.04^{\text{sys.}}\,\text{MeV}$$

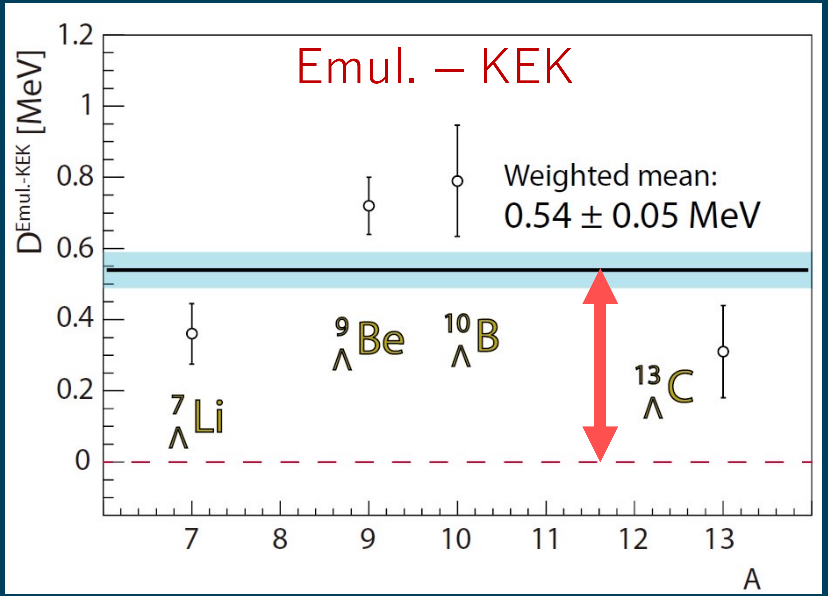
(Average of 6 events)

$0.5 - 0.6$ MeV shift in weaker binding direction

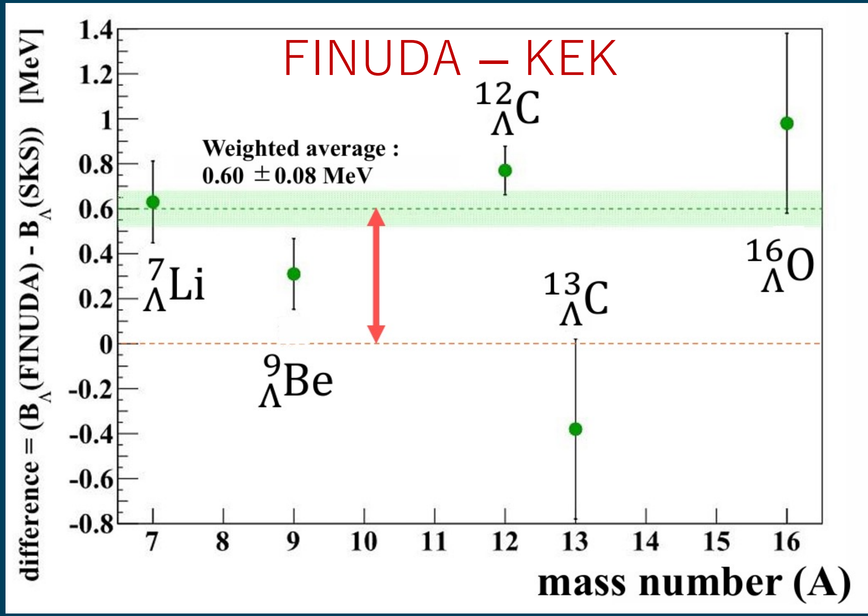
Directly measure $B_{\Lambda}({}^{12}_{\Lambda}\text{C})$ in J-PARC E94

(calibration source : ${}^{7}_{\Lambda}\text{Li}$)

Indirect measure

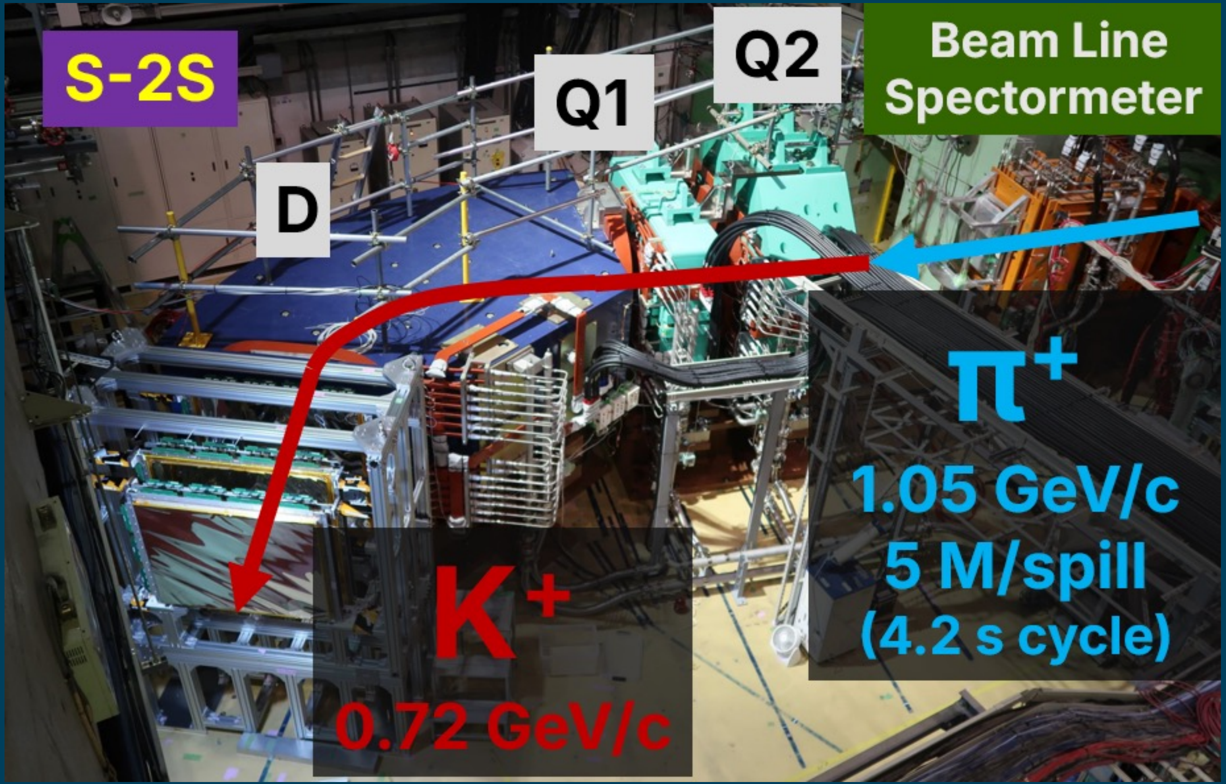


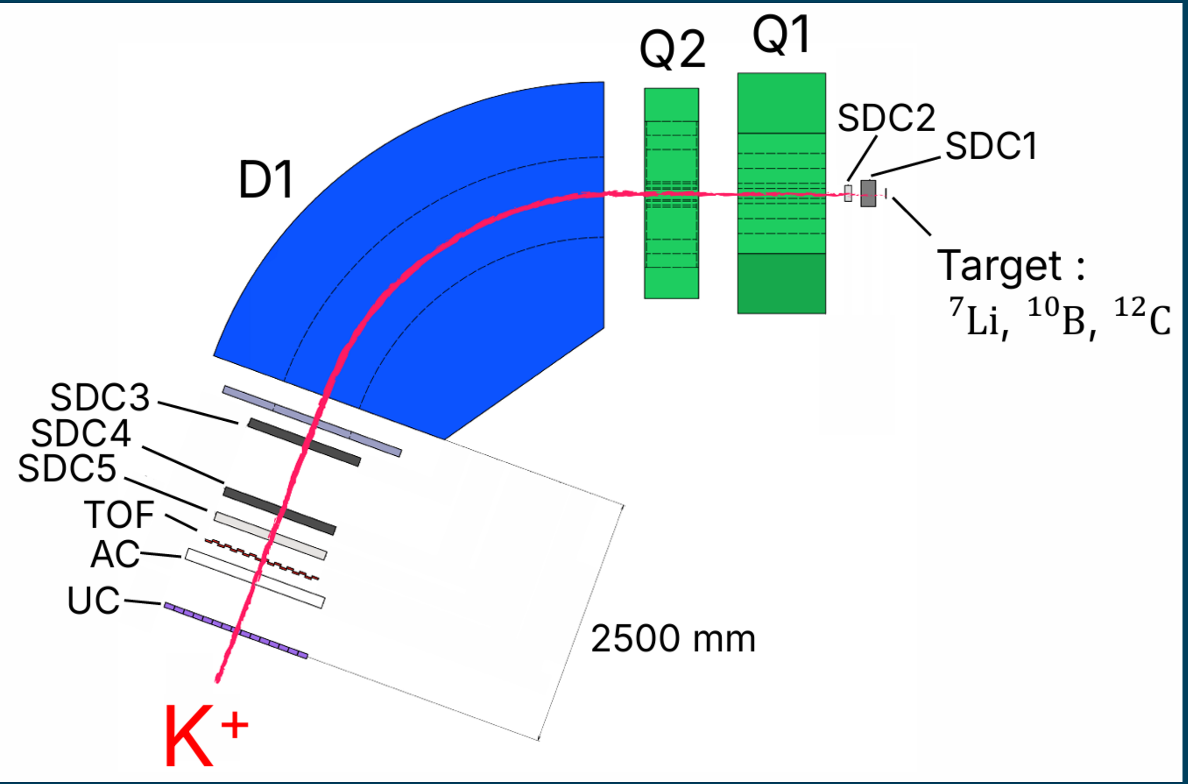
T. Gogami et al., PRC93, 034314 (2016).



E. Botta et al., NPA 960, 165-179 (2017).

Experimental setup





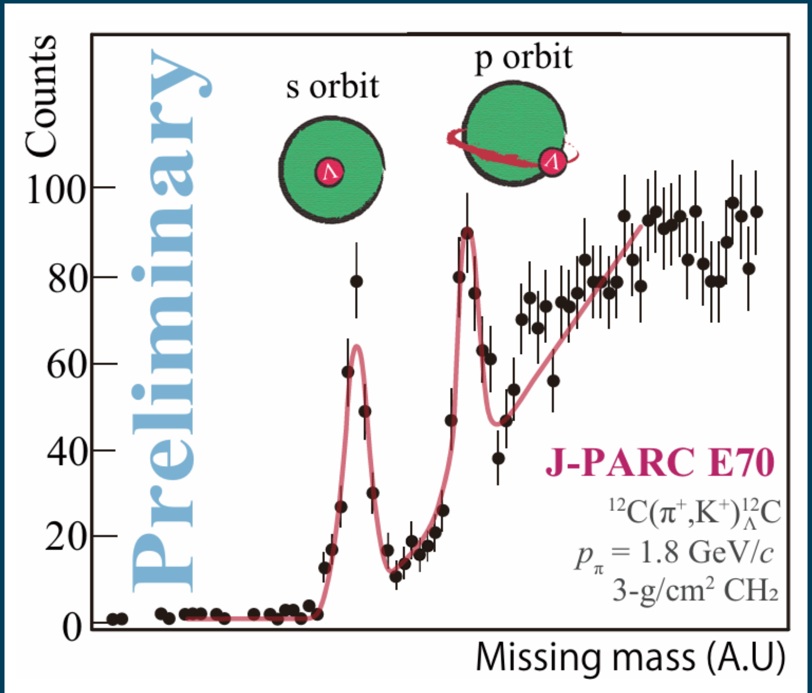
$$M_{\mathrm{H}} = \sqrt{{E_{\mathrm{H}}}^2 - (\vec{p}_{\mathrm{H}})^2} = \sqrt{(E_\pi + M_{\mathrm{T}} - E_{\mathrm{K}})^2 - (\vec{p}_\pi - \vec{p}_{\mathrm{K}})^2}$$

$$B_\Lambda = M_{\mathrm{core}} + M_\Lambda - M_{\mathrm{H}}$$

(π^+, K^+) trigger : $\pi^+\mathrm{Beam} \otimes \mathrm{TOF} \otimes \overline{\mathrm{AC}} \otimes \mathrm{UC}$

Expected Performance

MM resolution ~3.2 MeV (FWHM)

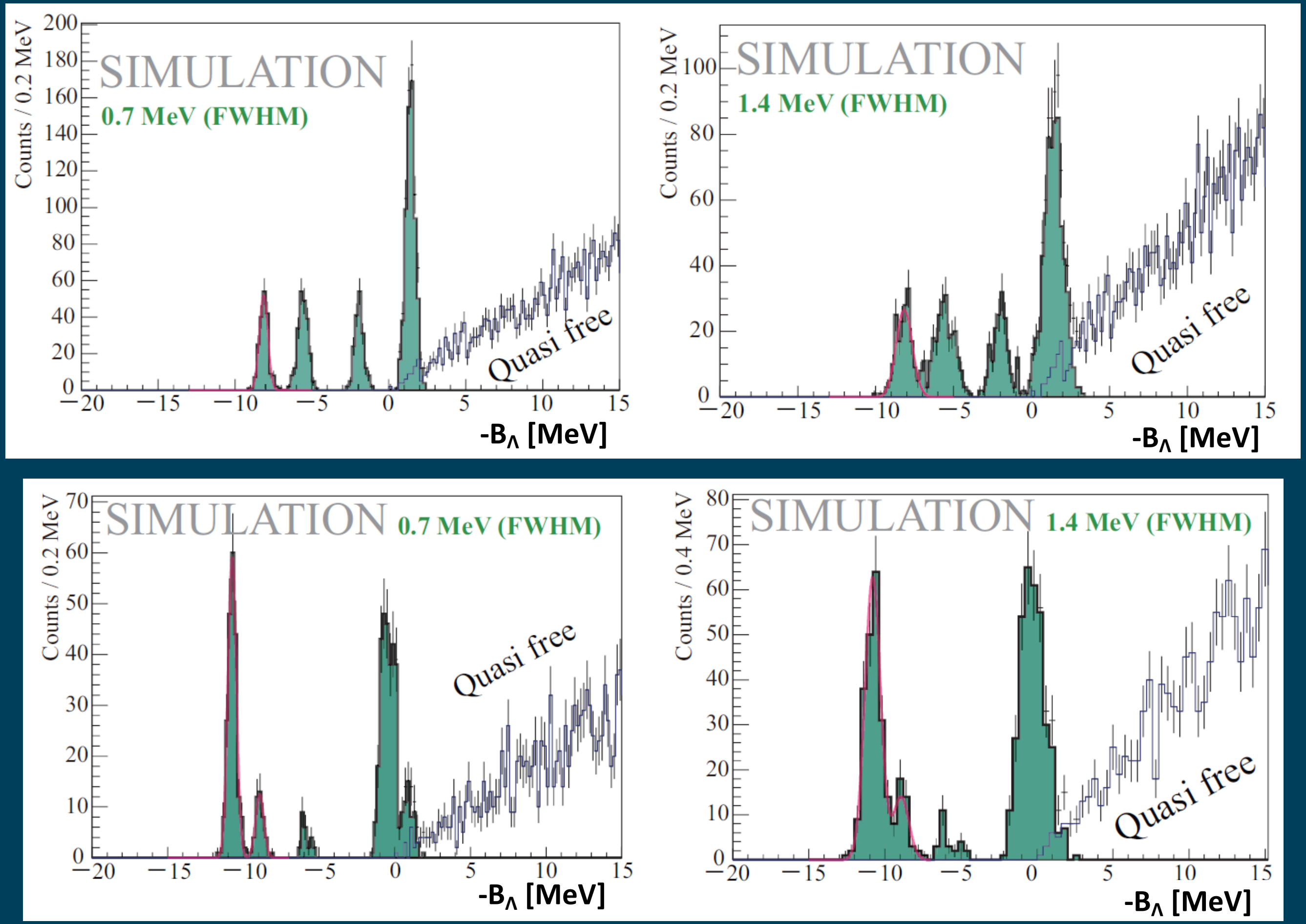


Design
MM resolution ~ 0.7 MeV(FWHM)

Current analysis based on J-PARC E70
MM resolution ~ 1.4 MeV(FWHM)

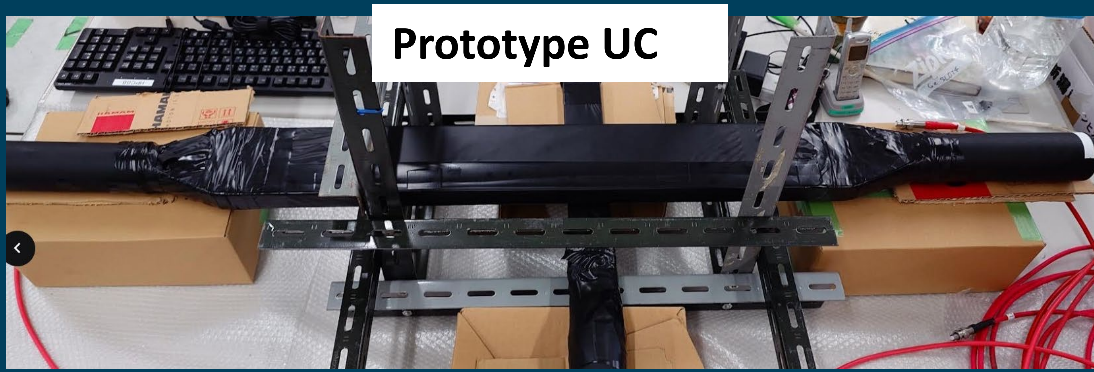
$^{10}{}_{\Lambda}B$

$^{12}{}_{\Lambda}C$

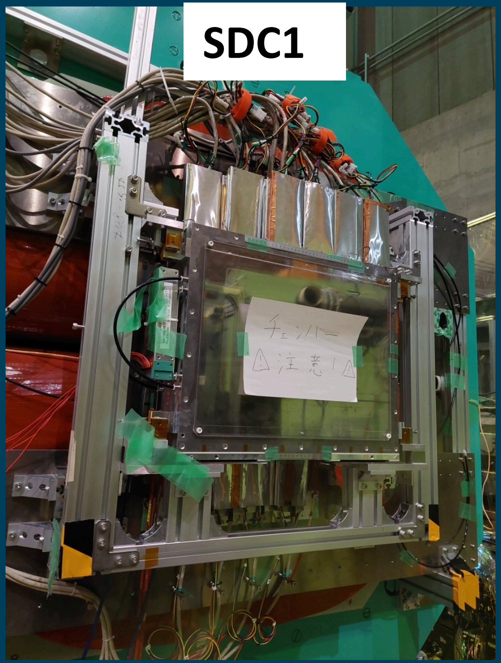


Preparation status of J-PARC E94

- Detectors for J-PARC E94
  - PID detector
    - Designing of UVT Acrylic Cherenkov detector(UC)
    - Cosmic ray test of prototype is ongoing



  - Tracking device : SDC1
    - Already installed on the beamline
    - Rate tolerance test (5 M/spill beam) is planned



- Aim to complete preparations by 2026 summer

Summary

J-PARC E94 experiment

- Provide high precision data on the CSB in the ΛN interaction
  ➔Aim for 100 keV accuracy measurement in p-shell systems ($^{10}_{\Lambda}$B, $^{12}_{\Lambda}$C)

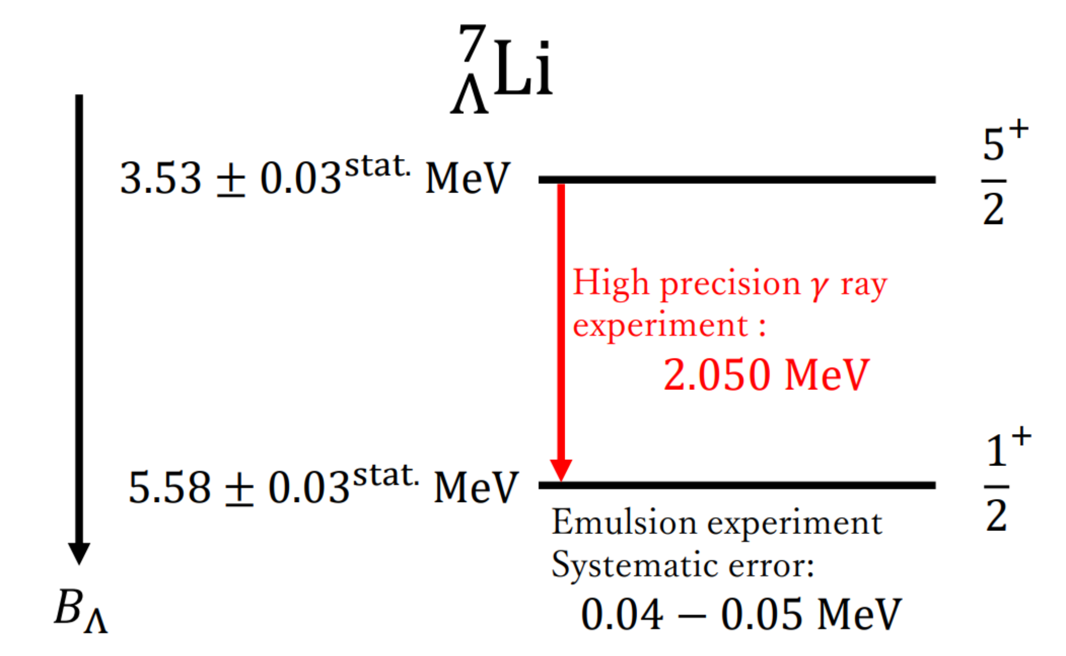
Outlook and setup of J-PARC E94

- High precision Λ hypernuclear experiment via (π^+, K^+) reaction
- Detectors
  - Designing of PID detector (WC→UC)
  - High rate test for tracking device (SDC1) is planned

- Aim to complete preparations by 2026 summer

Backup

Calibration source $^{7}_{\Lambda}$Li



- $^{7}{}_{\Lambda}$Li $\frac{1}{2}^{+}$ and $\frac{5}{2}^{+}$ states are used for calibration source
- B_{Λ} of $^{7}{}_{\Lambda}$Li $\frac{1}{2}^{+}$ state :$5.58 \pm 0.03^{\mathrm{stat.}}$ MeV
  - Emulsion experiment ~160 events
- B_{Λ} of $^{7}{}_{\Lambda}$Li $\frac{5}{2}^{+}$ state : $3.53 \pm 0.03^{\mathrm{stat.}}$ MeV

(Systematic error : $0.04 - 0.05$ MeV)

Accuracy of B_{Λ} : **$|\Delta B_{\Lambda}^{\mathrm{total}}|$ = 100 keV**

D. H. Davis, NPA 754 3c–13c (2005).
K. Tanida et al., PRL 86, 10 (2001).
M. Ukai et al., PRC 73, 012501(R) (2006).

Estimation of B_Λ accuracy

Systematic error

- Errors due to correction of energy losses in the target: ~50 keV
- Errors due to linearity of B_Λ : ~50 keV
- Errors due to energy calibration : ~50 keV

These estimates are based on the results of Λ hypernuclear spectroscopy experiments using the $(e, e'K^+)$ reaction at JLab

Total systematic error is

$$\Delta B_\Lambda^{\text{sys.}} = \sqrt{50^2 + 50^2 + 50^2} \sim 96\ \text{keV}$$

Including the statistical error $\Delta B_\Lambda^{\text{stat.}} = 30\ \text{keV}$,

$$\Delta B_\Lambda = \sqrt{{\Delta B_\Lambda^{\text{stat.}}}^2 + {\Delta B_\Lambda^{\text{sys.}}}^2} = \sqrt{30^2 + 96^2} \sim 100\ \text{keV}$$

Yield estimation

Hypernucleus	$^{7}_{\Lambda}$Li (g.s.)	$^{10}_{\Lambda}$B (g.s.)	$^{12}_{\Lambda}$C (g.s.)
Differential Cross Section $\frac{d\sigma}{d\Omega}$ [/(μb/sr)]	1.2	1.2	5
Target (thickness)	^{7}Li (1 g/cm^2)	^{10}B (1 g/cm^2)	^{12}C (1 g/cm^2)
The Number of Target Nuclei N_{target} (/cm^{-2})	8.60×10^{22}	6.02×10^{22}	5.02×10^{22}
Solid Angle Acceptance $\Delta\Omega$ (/msr)	55		
Total Efficiency ϵ	0.1 [K^+ survival ratio (= 0.2) and others (= 0.5)]		
Beam Intensity	5M pions / spill (4.2 sec)		
Beam time (/hours)	80	112	36
Yield	194	190	212