Workshop of Electro- and Photoproduction of Hypernuclei and Related Topics 2024
Oct. 15 – 18, 2024

Λ hypernuclear Spectroscopy to Study P-shell Charge Symmetry Breaking at J-PARC (E94 Experiment)

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Oct. 17, 2024

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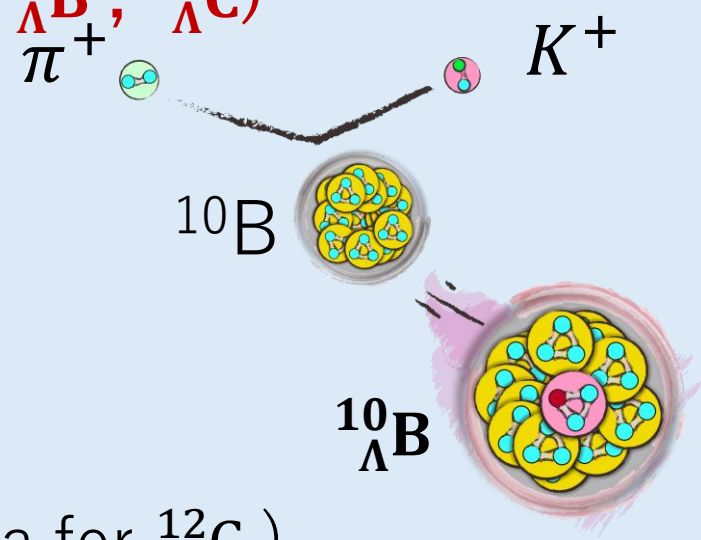
Λ hypernuclear experiments using S-2S spectrometer (J-PARC E94)

Physics motivation

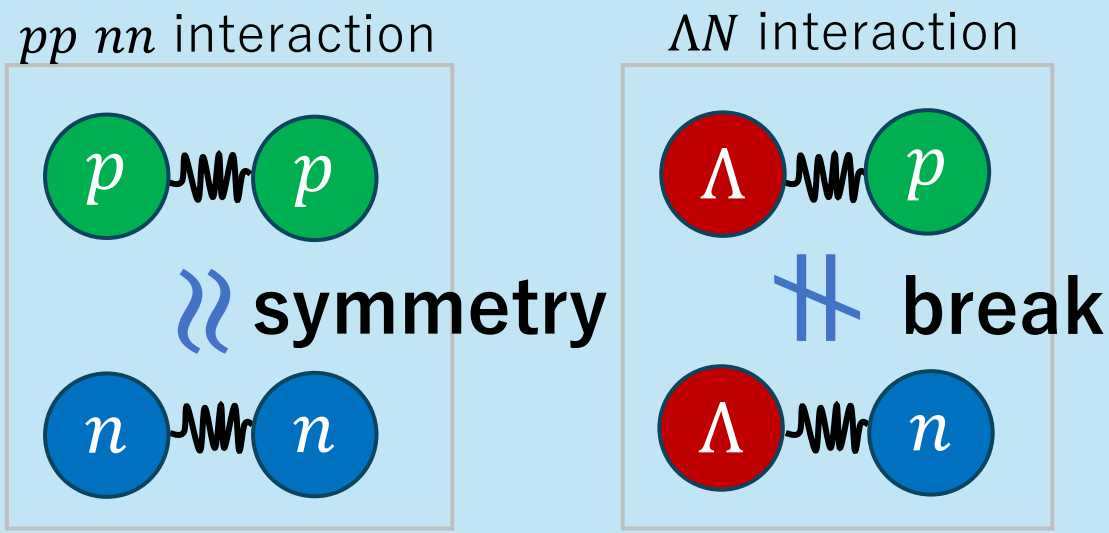
- Charge Symmetry Breaking (CSB) study ΛN interaction
  ➔Provide high precision data for **p-shell systems($^{10}_{\Lambda}$B , $^{12}_{\Lambda}$C)**

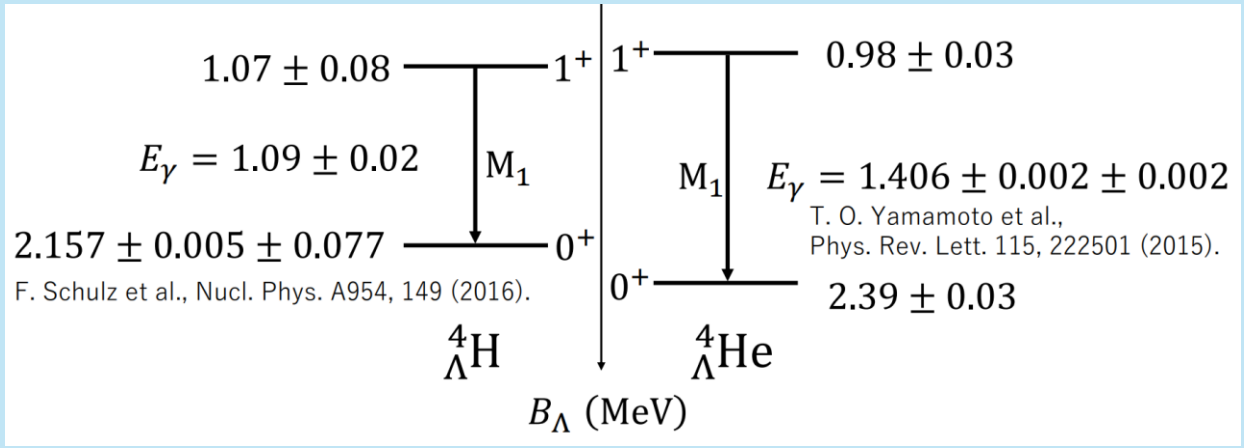


Method & feature

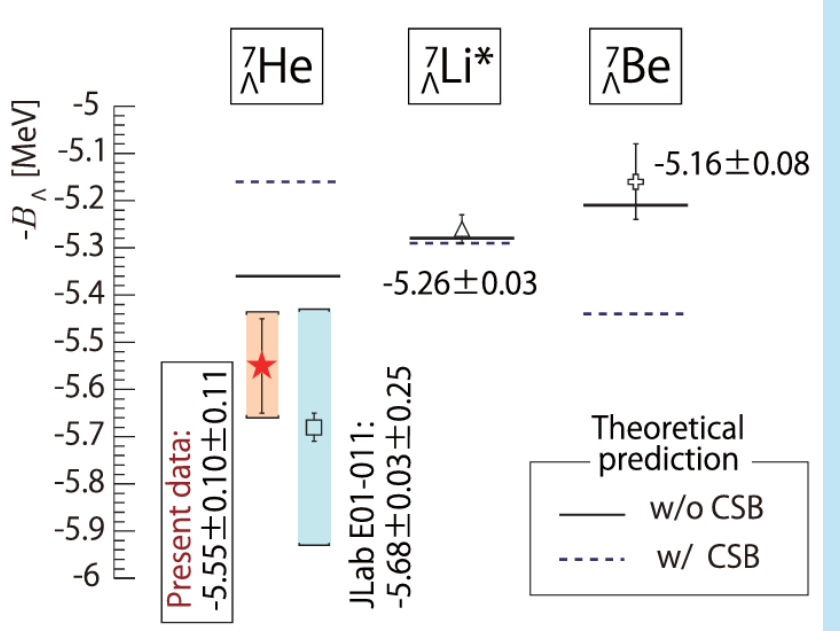
- Missing mass spectroscopy via (π^+, K^+)
- Measure Λ binding energy of $^{7}_{\Lambda}$Li , $^{10}_{\Lambda}$B , $^{12}_{\Lambda}$C
- Energy resolution : **1 MeV (FWHM)**
- Energy calibration : $^{7}_{\Lambda}$Li (alternative calibration data for $^{12}_{\Lambda}$C)
- Total accuracy of B_Λ : $\left|\Delta B_{\Lambda}^{\mathrm{total}}\right|$ **=100 keV**

Charge symmetry breaking in ΛN interaction





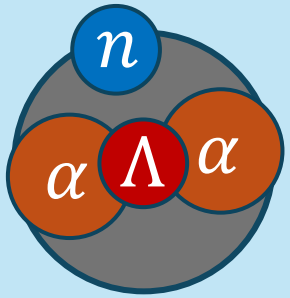
- p-p, n-n interactions have charge symmetry
- Charge symmetry is broken in ΛN interaction(CSB)
  - Large CSB in A=4 system
  - Further investigation is needed for A ≧ 7 hypernuclei



T. Gogami et al., PRC94, 021302(R) (2016)

Physics motivation : high precision measurement of ${}^{10}_{\Lambda}\mathrm{B}$

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



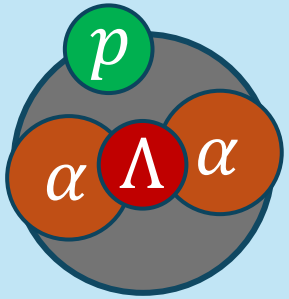
JLab E05-115

$-B_\Lambda = -8.6 \pm 0.07 \pm 0.16$ MeV

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

mirror hypernucleus

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



KEK E140a

$-B_\Lambda = -8.1 \pm 0.1 \pm 0.5$ MeV

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

Considering energy shift :

$-B_\Lambda = -8.6 \sim 8.7$ MeV

Measure in the J-PARC E94

New calibration data : ${}^{7}_{\Lambda}\mathrm{Li}$

→$|\Delta B_\Lambda^{\mathrm{total}}| = 100$ keV

Provide new information about CSB at A=10

Physics motivation : $B_\Lambda(^{12}_\Lambda\mathrm{C})$ shift problem

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

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

(Average of 6 events)

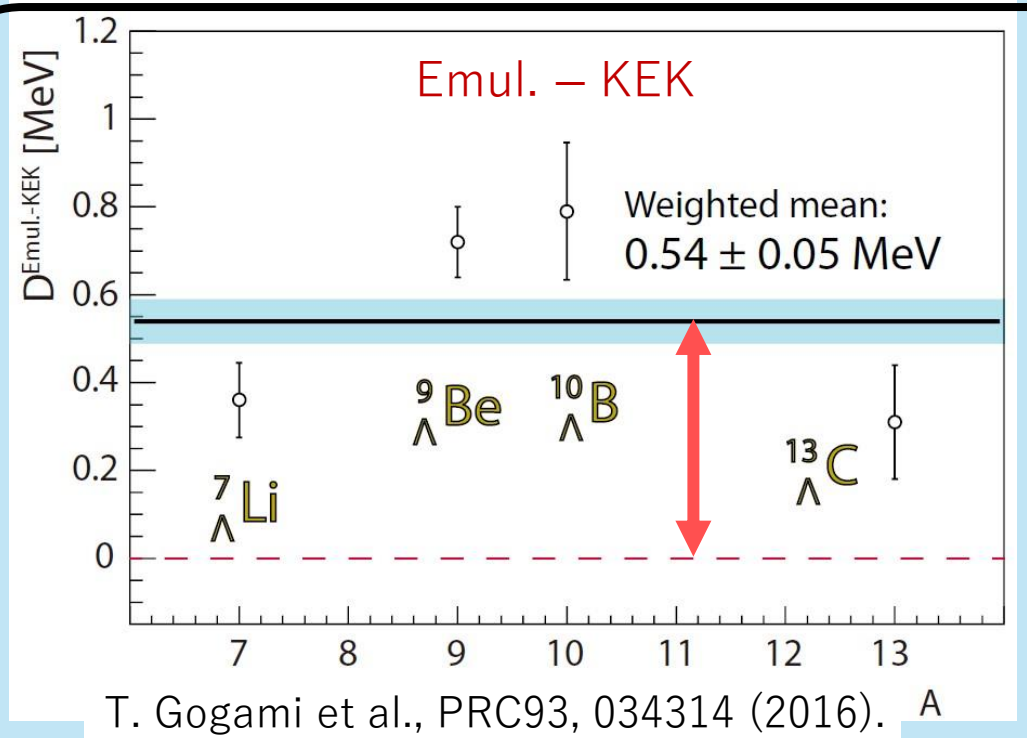
$0.5 - 0.6$ MeV shift in weaker binding direction

All B_Λ measured by (π^+, K^+) reaction are affected

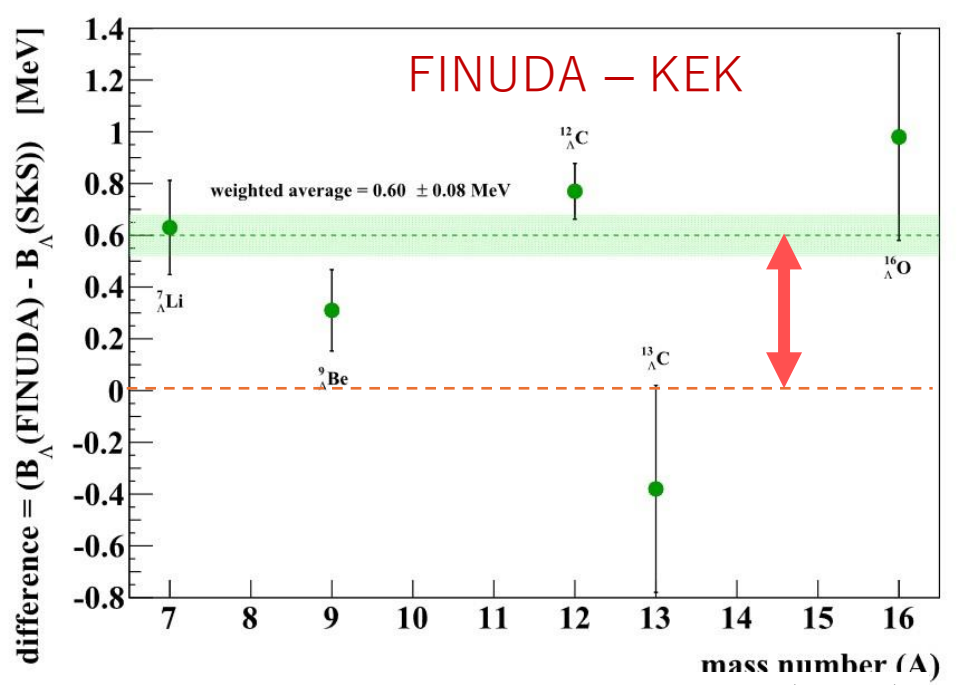
Directly measure in J-PARC E94 $B_\Lambda(^{12}_\Lambda\mathrm{C})$

KEK data : Calibrated by $B_\Lambda^{\mathrm{emul.}}(^{12}_\Lambda\mathrm{C})$

Indirect measure

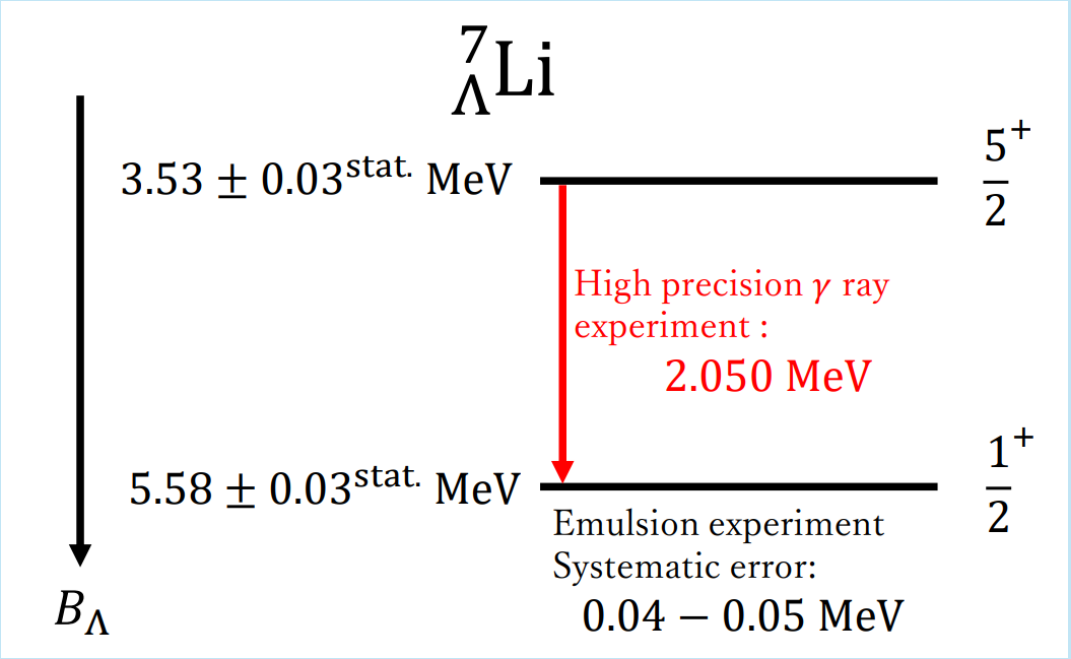


T. Gogami et al., PRC93, 034314 (2016).



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

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



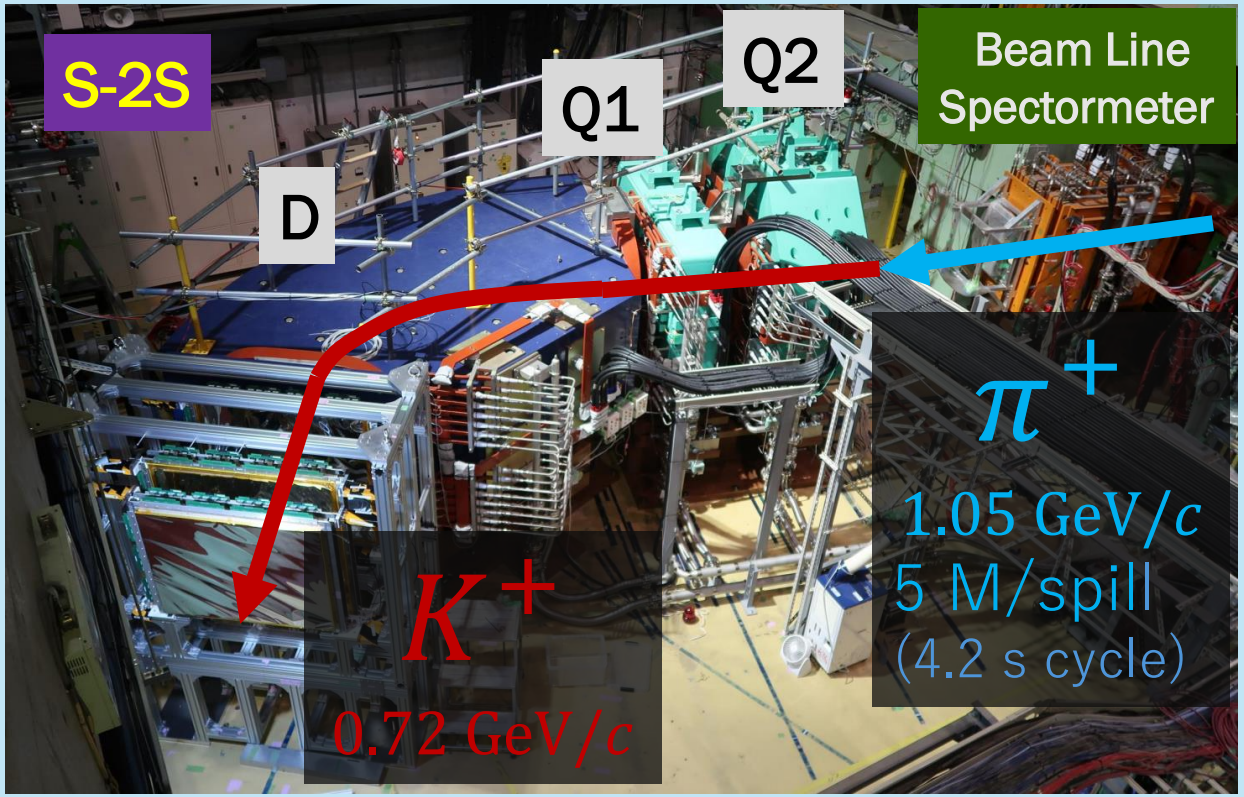
- ${}^{7}_{\Lambda}\mathrm{Li}\ \frac{1^+}{2}$ and $\frac{5^+}{2}$ states are used for calibration source
- B_Λ of ${}^{7}_{\Lambda}\mathrm{Li}\ \frac{1^+}{2}$ state :$5.58 \pm 0.03^{\mathrm{stat.}}$ MeV
  - Emulsion experiment ~160 events
- B_Λ of ${}^{7}_{\Lambda}\mathrm{Li}\ \frac{5^+}{2}$ state :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

(Systematic error : $0.04 - 0.05$ MeV)

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).

Accuracy of B_Λ : $\left|\Delta \mathrm{B}_{\Lambda}^{\mathrm{total}}\right| = 100$ keV

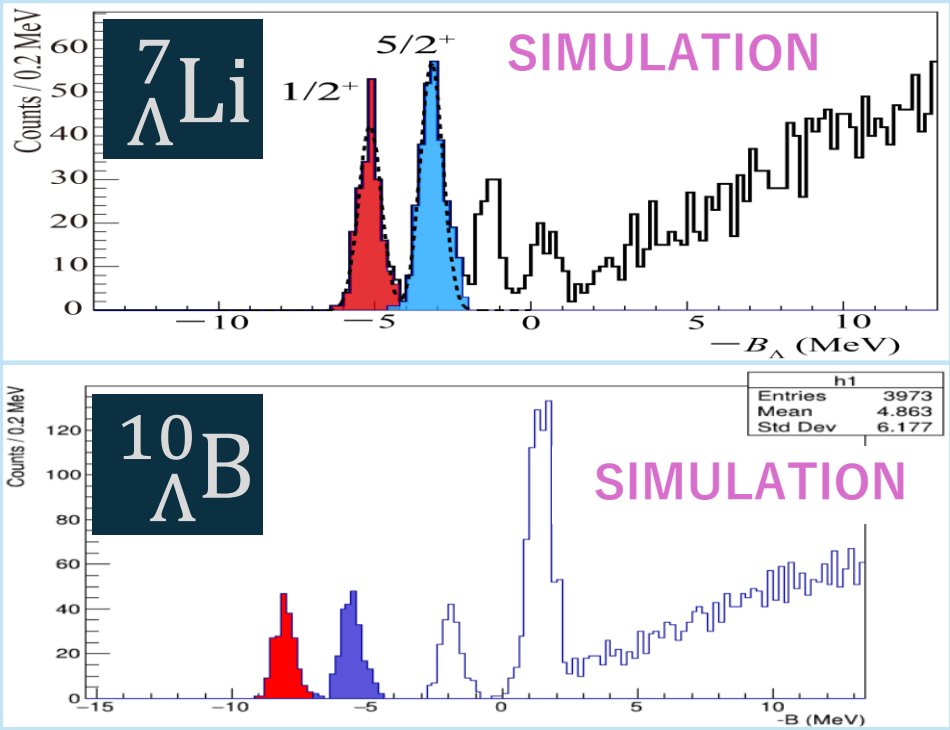
Missing mass spectroscopy of Λ hypernucleus (J-PARC E94)



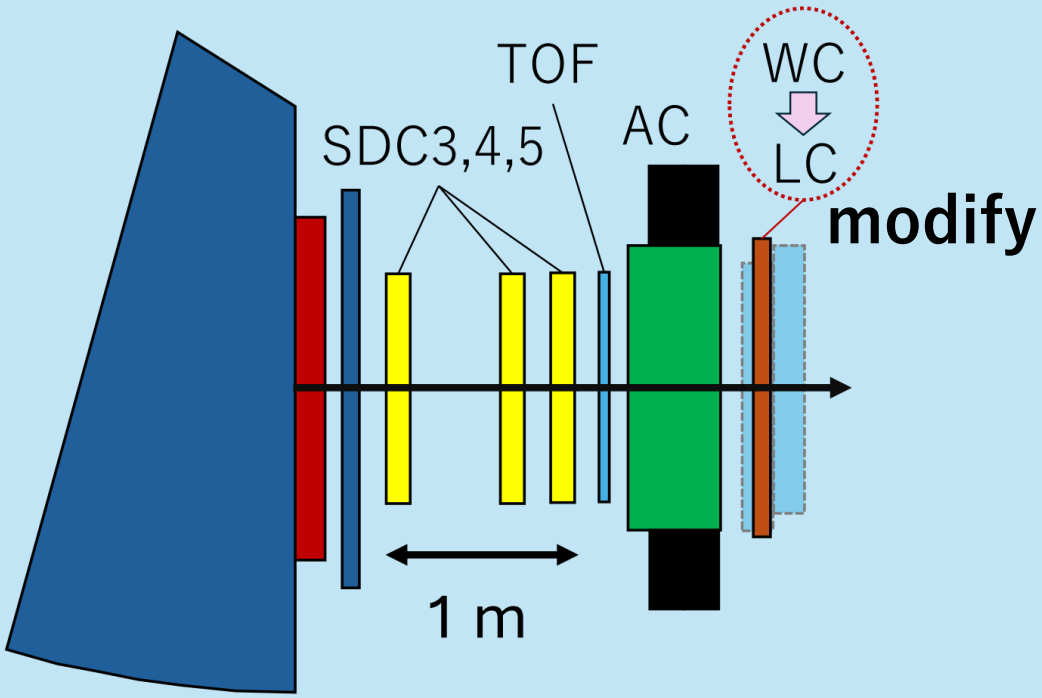
$$M_{\mathrm{H}} = \sqrt{{E_{\mathrm{H}}}^2 - (\vec{p}_{\mathrm{H}})^2} = \sqrt{(E_\pi + M_{\mathrm{T}} - E_{\mathrm{K}})^2 - (\vec{p}_\pi - \vec{p}_{\mathrm{K}})^2}$$

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

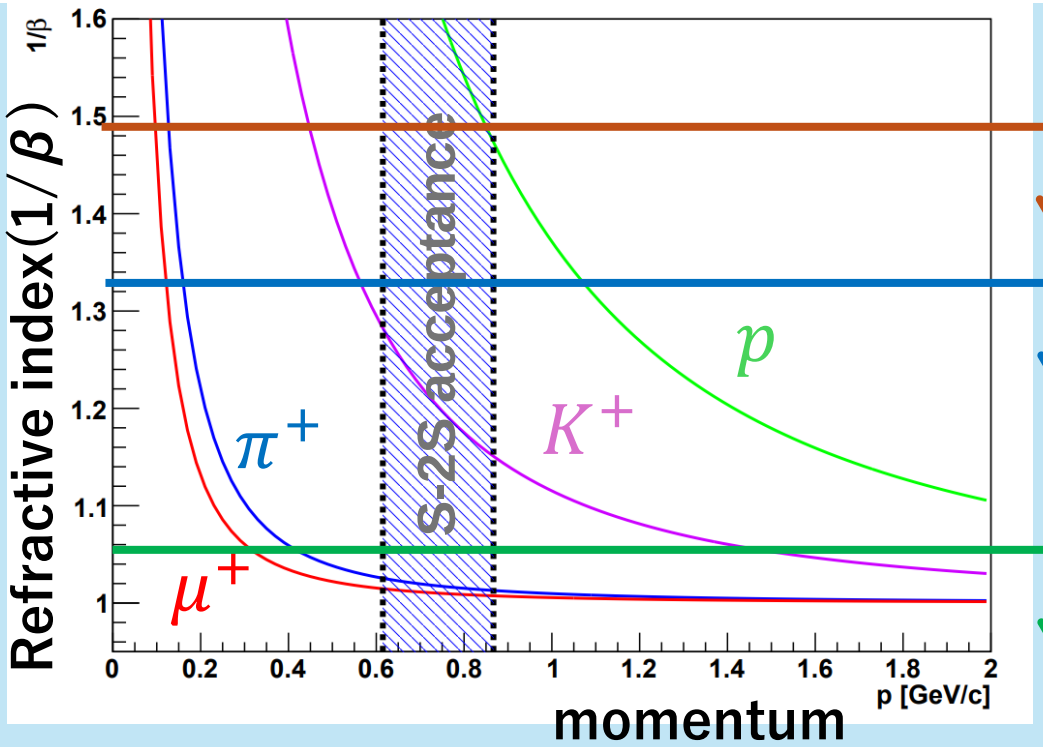
Obtain B_Λ from the measurement of $\overrightarrow{p_\pi}$ and $\overrightarrow{p_K}$



K^+ identification



Cherenkov light emission condition: $1/\beta < n$



Lucite
light emission

water
light emission

Aerogel
light emission

(π^+, K^+) trigger : π^+Beam $\otimes$TOF$\otimes\overline{\text{AC}}\otimes$(WC/LC)

AC, (WC/LC) : Identify K^+ from background events (p、 π^+)

radiation medium	p	K^+	π^+, μ^+
Aerogel(n=1.055)	×	×	◎
Water(n=1.33)	×	○	◎
Lucite(n=1.49)	△	○	◎

Water Cherenkov detector (WC)
➔WC does not sensitive to K^+ (signal) for lower momentum side
➔Decreased K^+ detection efficiency
➔ Introduce new detector (LC) that Lucite as radiation medium

Measurement of trigger rate(@K1.8 + S-2S)

Data summary (2024)

- 1.05 GeV/c π^+ (0.85 ~ 0.88 M /spill)
- S-2S central momentum : 0.72 GeV/c
- Without target

Trigger rate(estimated from real data)

condition	Trigger rate /(k/spill) @ 5 M /spill
TOF	332
TOF⊗WC	242
TOF⊗WC⊗ $\overline{\mathrm{AC}}$	16.3

- **16.3 k /spill**(TOF⊗WC⊗ $\overline{\mathrm{AC}}$) > **10 k / spill (DAQ requirement)**
- To do / On going
  - Matrix trigger of TOF and WC(LC)
  - Particle identification and investigate their origin

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 $({}^{10}_{\Lambda}\mathrm{B}\ ,\ {}^{12}_{\Lambda}\mathrm{C})$

Outlook and setup of J-PARC E94

- High precision Λ hypernuclear experiment via (π^+, K^+) reaction
- Modification of Cherenkov detector (water➔lucite)
- Aim to complete preparations by 2025

Analysis of background data

- Obtain 1.05 GeV/c π^+ data (in the J-PARC E70 beamtime)
- Trigger rate :
  16.3 k/spill @ 5 M π^+/spill(TOF$\otimes$WC$\otimes\ \overline{\mathrm{AC}}$) $>$ 10 k/spill (DAQ requirement)
- To do / On going
  - Particle identification and investigate their origin