A spectroscopic study of $^{10}_{\Xi}$Li hypernucleus via the ^{10}B(K^-,K^+)X reaction

A. O. Tokiyasu
ELPH

HYP2022
2022/06/30

Introduction

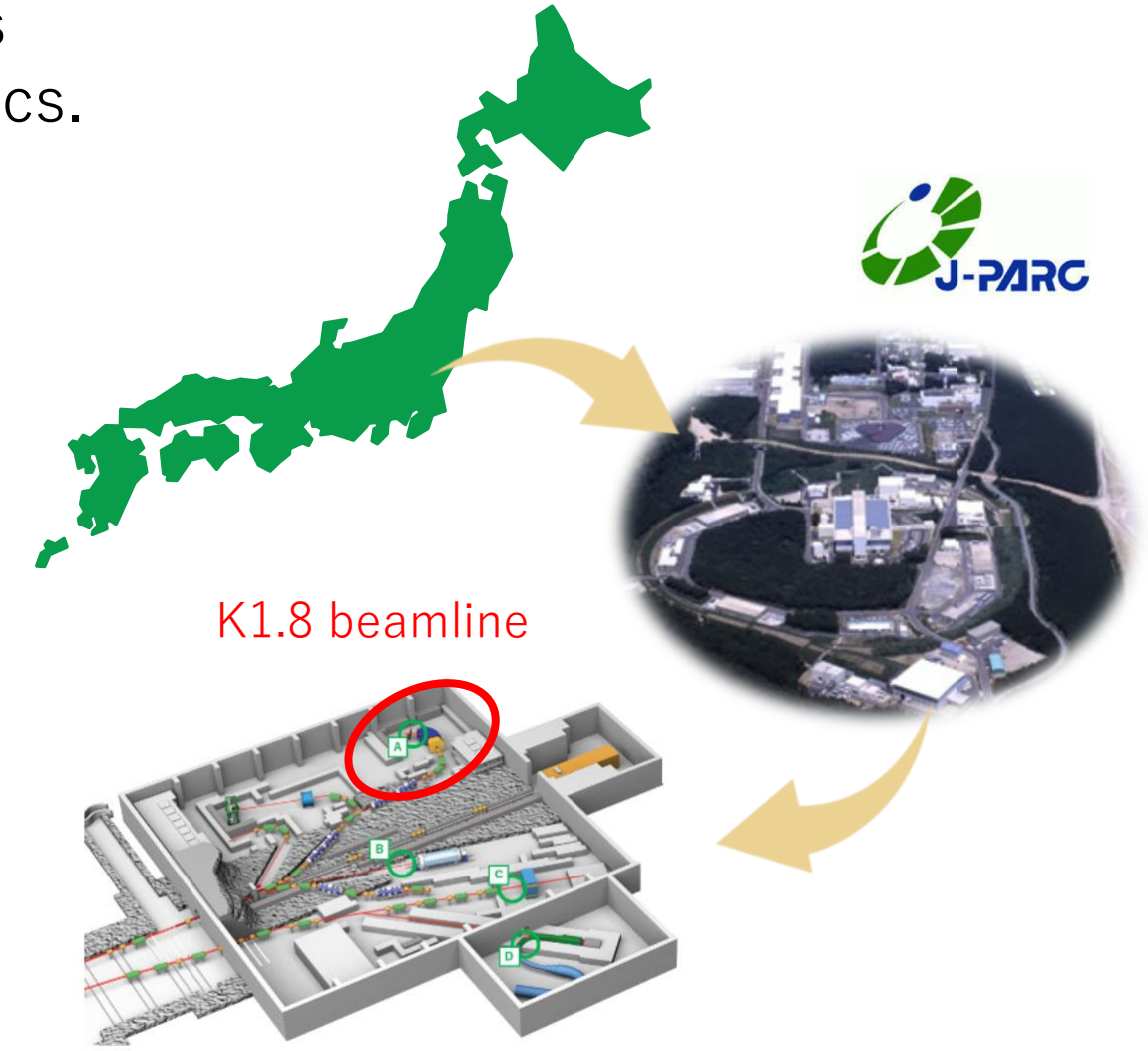
☆Understanding of the B-B interaction is one of the main topics of nuclear physics.

S = 0 : N-N scattering experiment

S =-1 : hypernuclei (A=3 — 208)
Y-N scattering experiment

S =-2: double Λ hypernuclei,
Ξ hypernuclei
experimental data is limited.

☆J-PARC/K1.8 beamline
High intensity, high purity K^- beam.
→ Open the S=-2 frontier.



Ξ hypernuclei study at J-PARC

Done
- E07 experiment(emulsion) : ${}^{15}_{\Xi}$C (KISO, IBUKI, KINKA, IRRAWADDY) .
- E05 experiment (SKS) : indication of ${}^{12}_{\Xi}$Be.

Approved
- E70 experiment (S-2S) : ${}^{12}_{\Xi}$Be spectroscopy with active ^{12}C target.

Cf) T.Harada's talk in Thu-IIIa

- E75 experiment(phase-1) : ${}^{7}_{\Xi}$H spectroscopy with ^{7}Li target.

Cf) H.Fujioka's talk in Thu-IIb

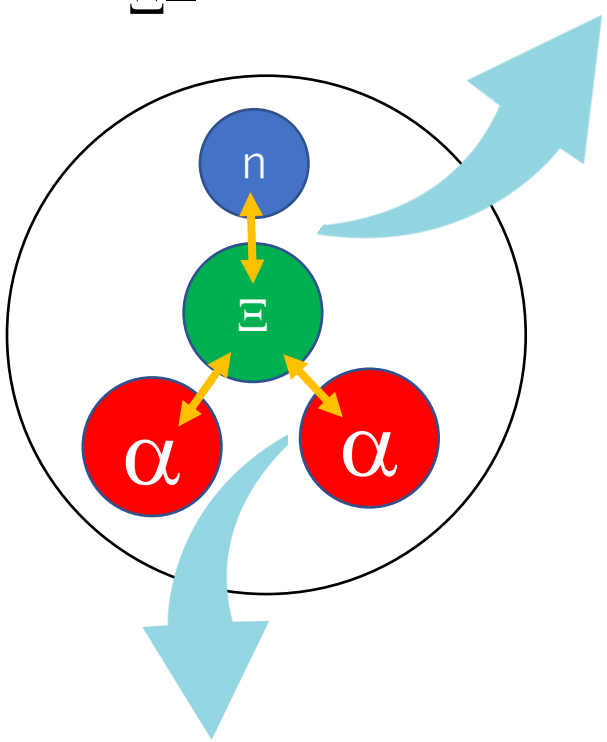
Future
- A systematic study of Ξ hypernuclei by using various targets.

→ ${}^{10}_{\Xi}$Li spectroscopy via the ^{10}B (K^-,K^+)X reaction with S-2S.

Why $_{\Xi^-}{}^{10}$Li ?

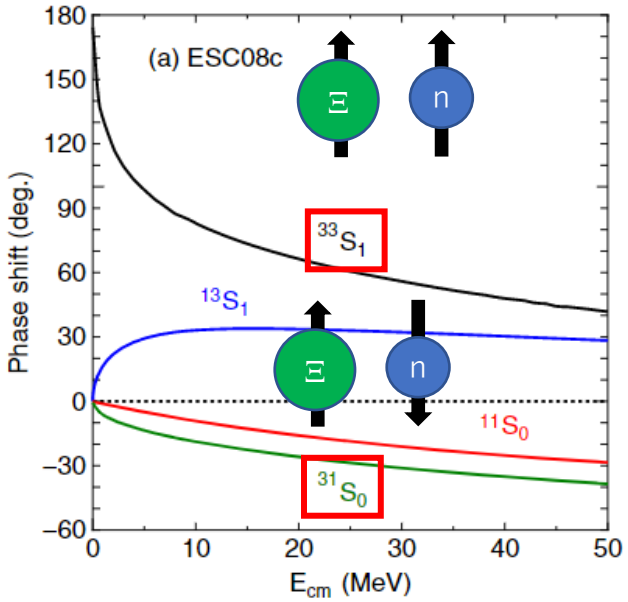
Cf) E.Hiyama's talk in Mon-III

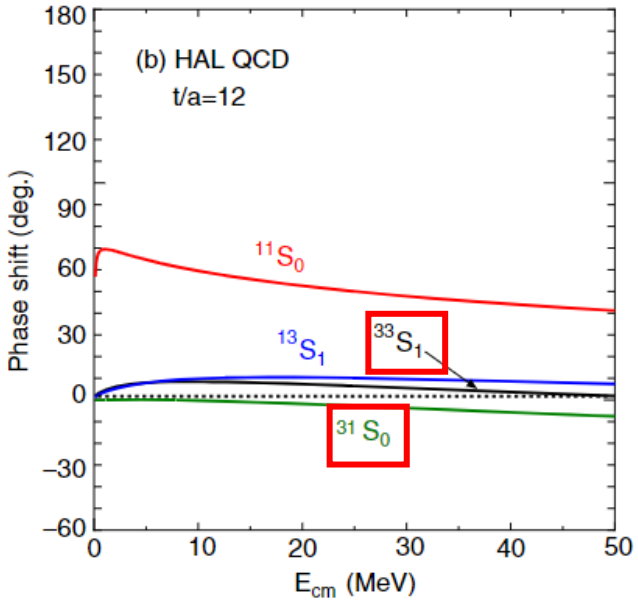
$_{\Xi^-}{}^{10}$Li



Ξ–α interaction:
Determined from the investigation of $^{7}_{\Xi}$H. (α+n+n+Ξ)

☆Information of spin-dependent Ξ-n interaction.

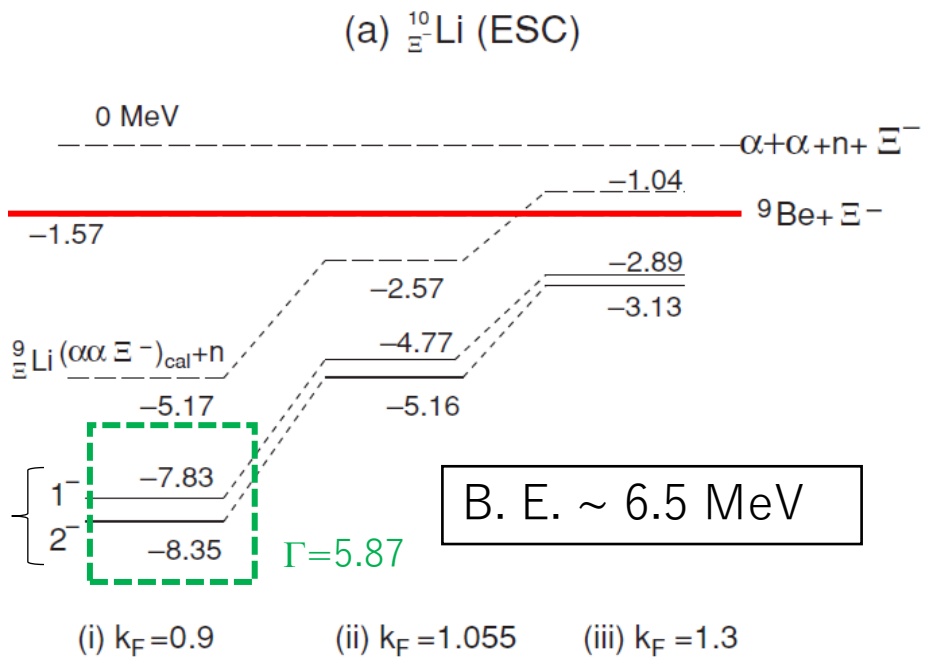


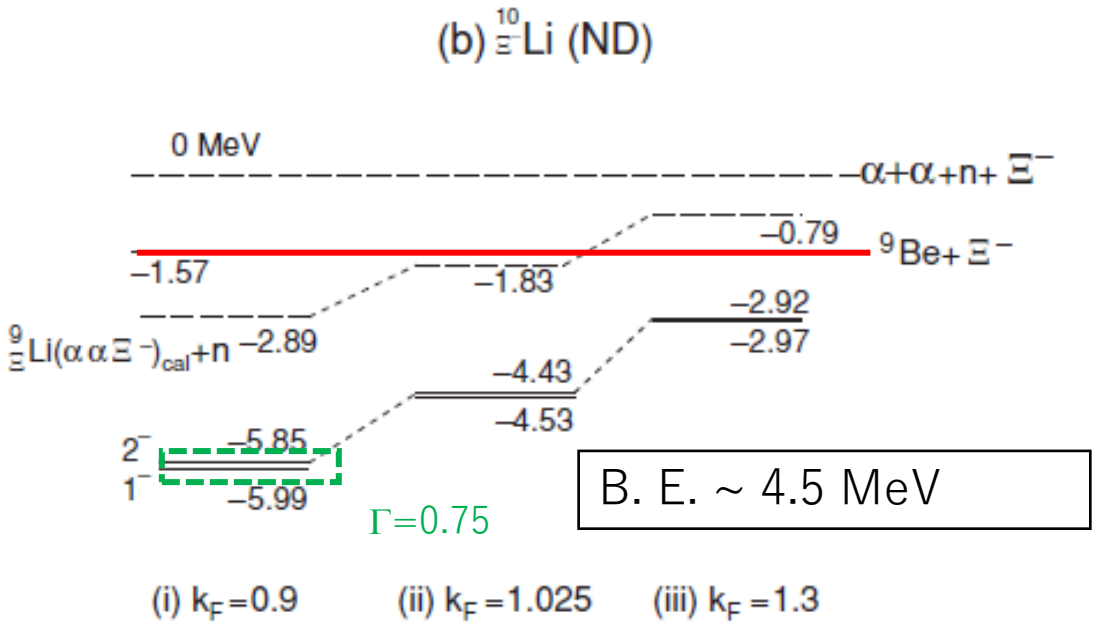


The phase shift of S-wave Ξ-n interaction. Notation: $^{2T+1,2S+1}S_J$

(Ref. E.Hiyama *et al.*, PRL(2020)124,092501)

Prediction of B.E. by few-body calculation





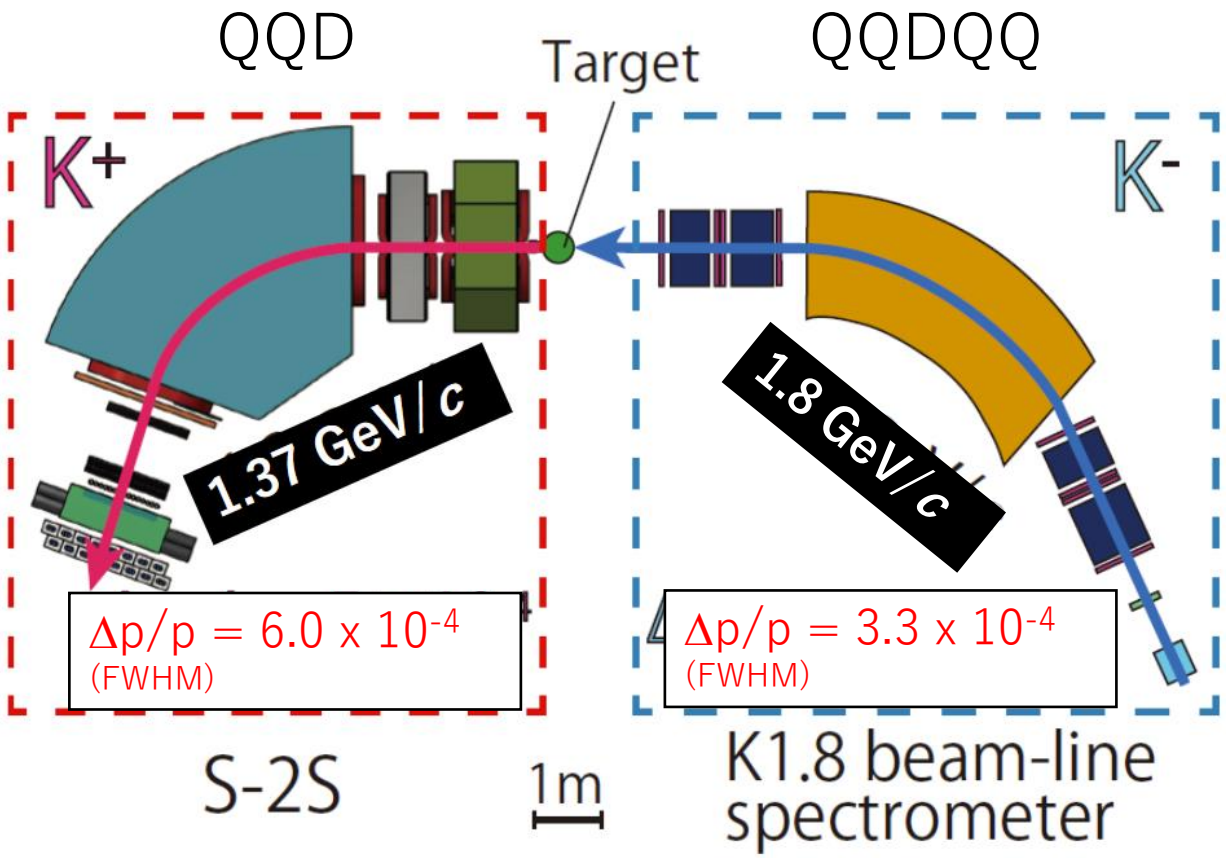
Ref): Hiyama et al., PRC78, 054316(2008)

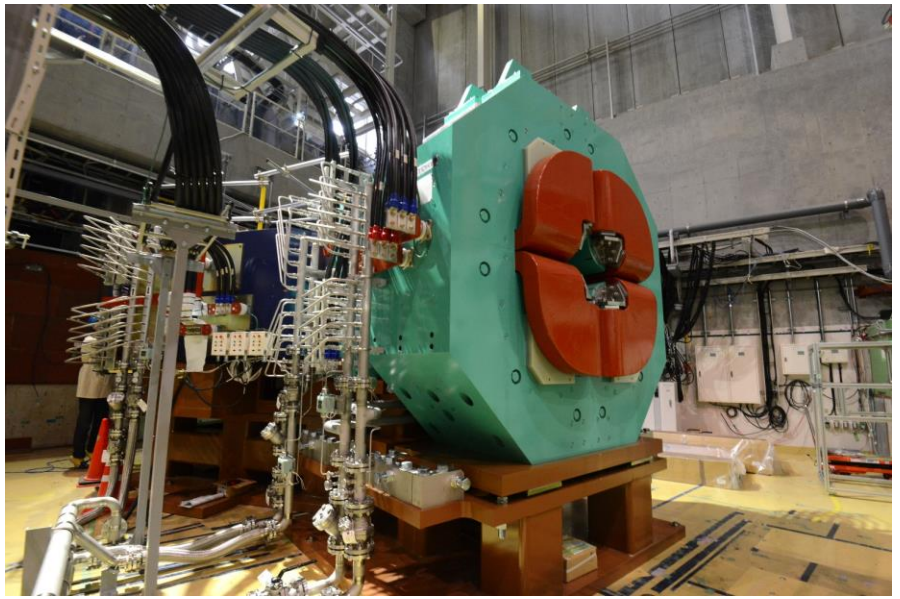
+ preliminary result (HAL-QCD) reported by E.Hiyama in MonII.

1^- : -7.72 (0.06)
2^- : -8.28 (0.06)

Measurement of B.E, Γ and level ordering is useful to check the validity of theory.
→ Spectroscopy with the resolution < 3 MeV. → S-2S

(K^-,K^+) missing mass spectroscopy @ J-PARC/K1.8 beam line





ΔMM(K-,K+) < 3 MeV (FWHM)

Cf) T.Gogami's talk in Fri-II

Yield estimation

$$Yield = N_{beam} \times N_{target} \times \frac{d\sigma}{d\Omega} \times \Delta\Omega \times f_{eff}$$

S-2S

O(10) nb　55 msr

100 events (10 gcm^{-2} target, 20 days beam time @ J-PARC)

To increase the statistics:

1. HL K$^-$beam
2. Long beam time

} Strongly coupling to the facility situation or budget…

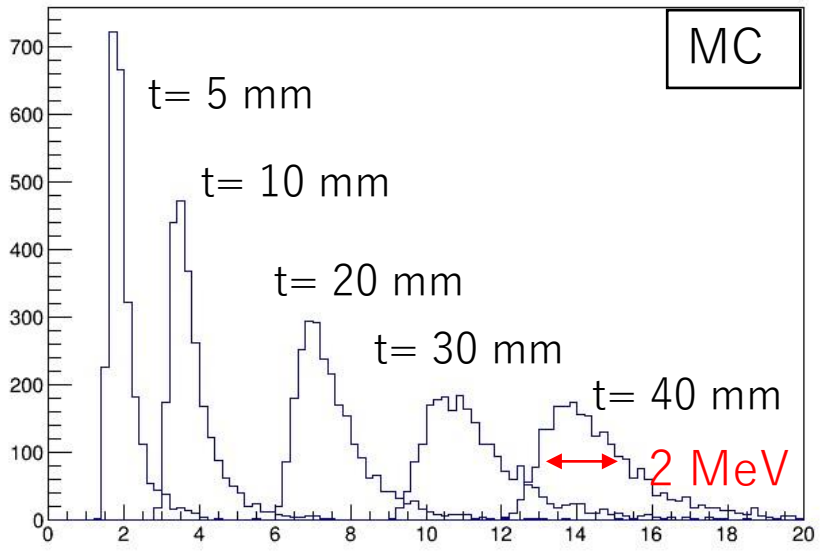
3. Thick target ⇔ Worse missing mass resolution
   ← active target　(E70)
   ← exclusive measurement (E75)
   ← semi-exclusive method (This talk)

Missing Mass resolution

$$3\text{MeV} > \Delta M = \sqrt{\left(\frac{\partial M}{\partial p_{K^-}}\right)^2 \Delta p_{K^-}^2 + \left(\frac{\partial M}{\partial p_{K^+}}\right)^2 \Delta p_{K^+}^2 + \left(\frac{\partial M}{\partial \theta}\right)^2 \Delta\theta^2} + \Delta E_{target}^{\ 2}$$

< 2.5 MeV (FWHM)

~1.8 MeV (FWHM)
S-2S and kinematics

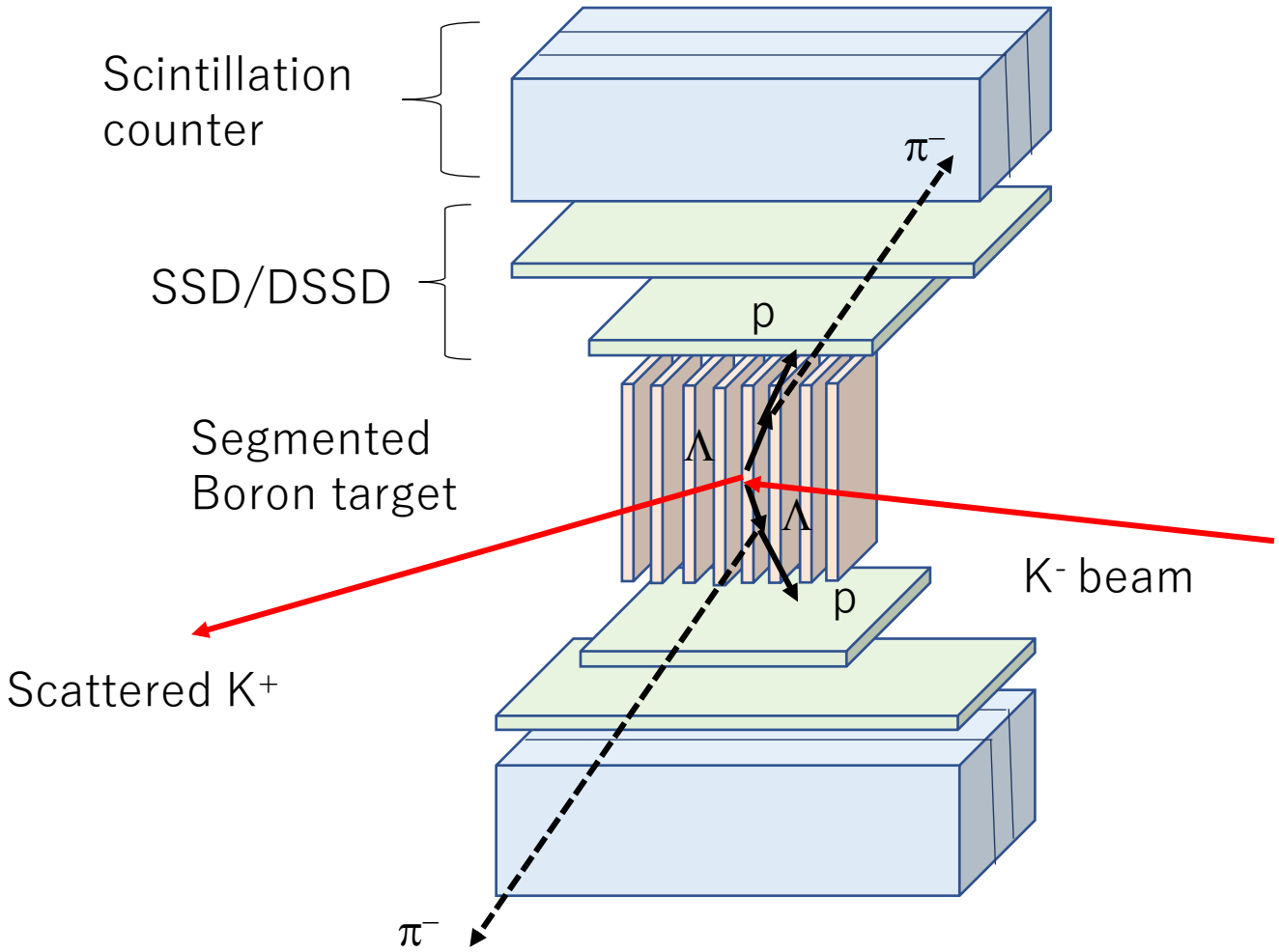


Energy deposit of K^+ in ^{10}B[MeV]

E_{strag} cannot be corrected.
→ Limit the target thickness. (In case of B: 40 mm)

But,
Mean Energy loss should be corrected by Bethe-Bloch formula
→ Vertex reconstruction within the resolution of 1 mm.

Conceptual setup (segmented target + tracking system)



* Detection of charged decay particle in the sideway region.
  - Tracking : SSD/DSSD
  - PID : Scintillator

Reconstruction of the vertex point.

↓

Identification of the target segment.

↓

Correction of energy deposit of K^-, K^+

* Vertex resolution of (K^-, K^+) > 5.0 mm
  Vertex resolution of ($K^{-/+}$,π^-) < 1.0 mm
  (from MC)

Decay modes of $^{10}_{\Xi}$Li

NOTE: π^- comes from any decay mode → semi-exclusive.

* Double Λ hypernucleus

  ex) $_{\Xi^-}{}^{10}\mathrm{Li} \rightarrow {}_{\Lambda\Lambda}{}^{9}\mathrm{Li} + n \rightarrow \Lambda + \Lambda{}^{7}\mathrm{Li} + n + n \rightarrow \cdots$

* twin Λ hypernuclei

  ex) $_{\Xi^-}{}^{10}\mathrm{Li} \rightarrow {}_{\Lambda}{}^{3}\mathrm{H} + {}_{\Lambda}{}^{7}\mathrm{He} \rightarrow {}^{3}\mathrm{He} + \pi^- + {}^{7}\mathrm{Li} + \pi^- \rightarrow \cdots$

* Λ hypernucleus + free Λ

  ex) $_{\Xi^-}{}^{10}\mathrm{Li} \rightarrow {}_{\Lambda}{}^{9}\mathrm{Li} + \Lambda \rightarrow n + n + 7\mathrm{Li} + n + \pi^0 \rightarrow \cdots$

* NMWD, H decay…

> 35 decay modes…

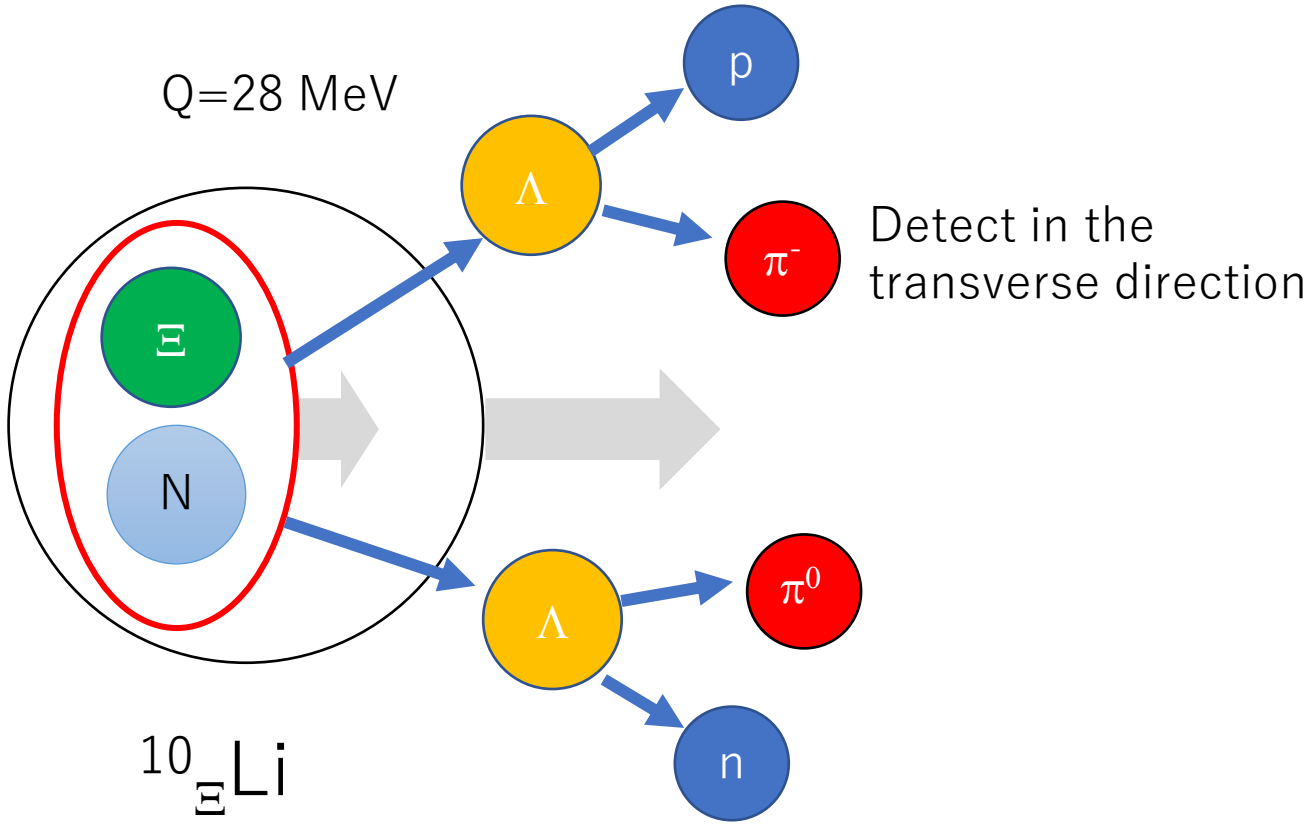
Feasibility check with a simple assumption

Assumption

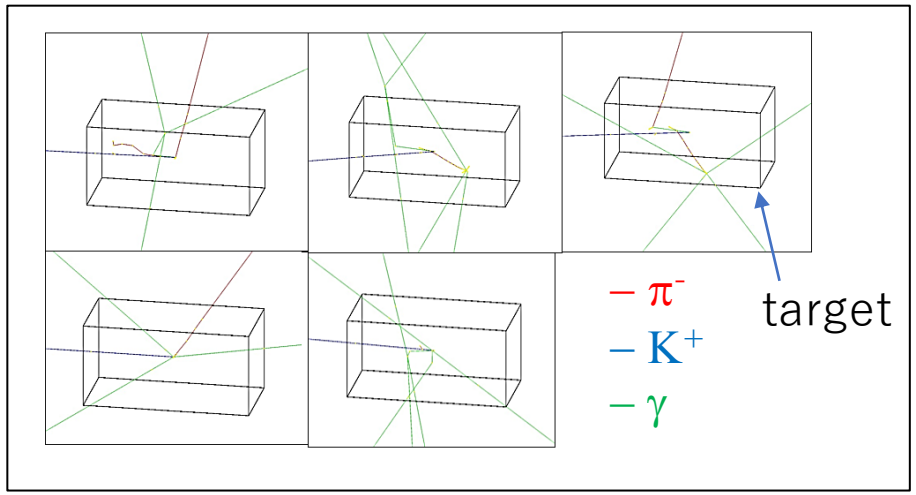
* $^{10}_{\Xi}$Li is generated via ^{10}B(K^-,K^+)X @ P(K-)=1.8 GeV/c.

* ΞN pair inside Ξ-hypernuclei converted to ΛΛ.

* Mass(ΞN)/Mass($^{10}_{\Xi}$Li) = P(ΞN) /P($^{10}_{\Xi}$Li)



Detect in the transverse direction



Events are generated with Geant4 MC

Efficiency to select the correct vertex ~30%.

Reasons why reconstruction fails:
- neutral decay mode : Λ → nπ^0
- multiple scattering of π$^-$ inside target.
- π$^-$ from other source (p-N reaction)

Summary

- Ξ hypernuclei spectroscopy is planned at J-PARC/K1.8 beamline.
  - E70 ${}^{12}_{\Xi}$Be spectroscopy from ^{12}C target
  - E75 ${}^{7}_{\Xi}$H spectroscopy from ^{7}Li target

- ${}^{10}_{\Xi}$Li spectroscopy from ^{10}B target is also interesting because we can obtain the information on the interaction btw Ξ^- and n.

- To increase the statistics, thick (40 mm) target is necessary.

- Semi-exclusive method. Vertex reconstruction by decay particle tracking.

- The study of FOM is on-going now.

- If the feasibility is confirmed, this method can be applied to the other target.