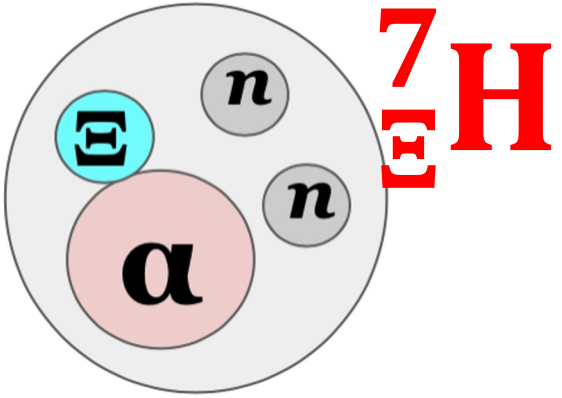
The missing-mass spectroscopy for $^{7}_{\Xi}$H via the ^{7}Li (K^-, K^+) reaction in J-PARC

Kyoto Univ[A], JAEA[B],

Kengo EBATA [A,B] et al.,

for J-PARC E75 -1 Collaboration



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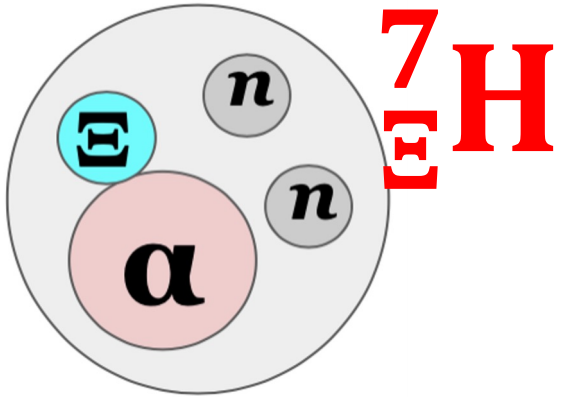
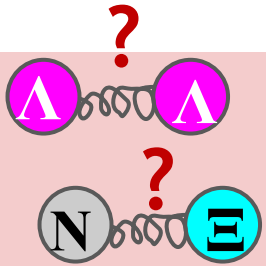
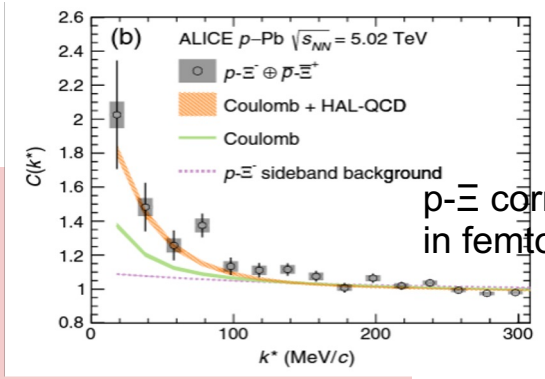


Recent S=−2 Physics

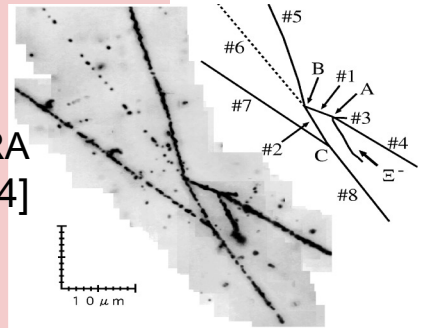
- Femtoscopy
  - **p-Ξ is attractive**[1],
  - **ΛΛ is weakly attractive**[2].
- Nuclear emulsion
  - **Ξ bound. (Ξ-^{14}N, IRRAWADDY,…[3])**
  - **$^{6}_{\Lambda\Lambda}$He (NAGARA[4], $\Delta B_{\Lambda\Lambda}$ = 0.67± 0.17 MeV)**
- Counter experiments (hypernuclei) via (K^-, K^+)
  - J-PARC E05[5] → **peak structure in bound region $^{12}_{\Xi}$Be**
  - J-PARC E42[6] → **ΞN − ΛΛ coupling is very weak、Γ_{Ξ} <~ 0.6 MeV**



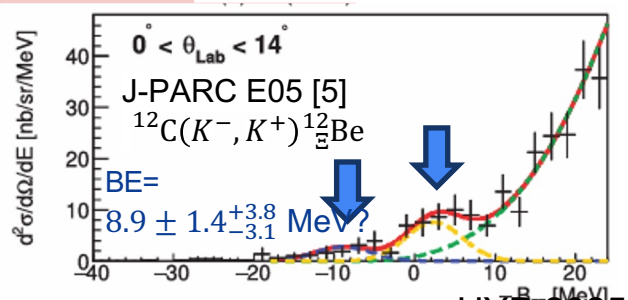


p-Ξ correlation in femtoscopy [1]

NAGARA $^{6}_{\Lambda\Lambda}$He [4]



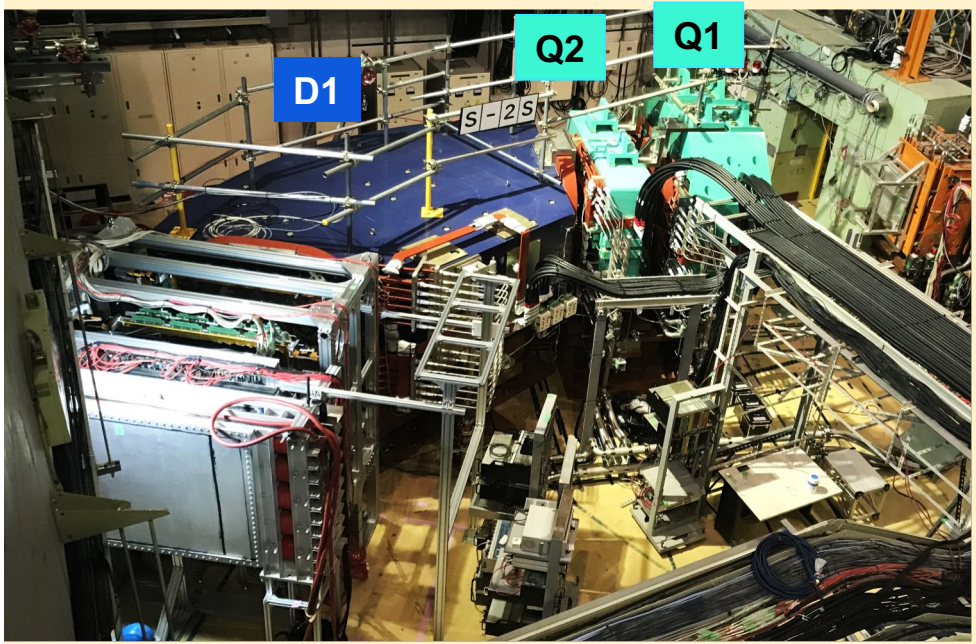
Details of ΞN、ΛΛ interaction（spin, isospin）
→ high resolution spectroscopy for Ξ / ΛΛ hypernuclei



[1] ALICE, PRL.123, 112002 (2019)., [2] ALICE PLB 797 (2019) 134822, [3] M. Yoshimoto et al., PTEP. **2021**, 073D02, [4] H. Takahashi et al., PRL. 87, 212502 (2001) [5] Y. Ichikawa et al, PTEP 2024 091D01 (2024). [6] W. S. Jung et al., PTEP 2025 in press.

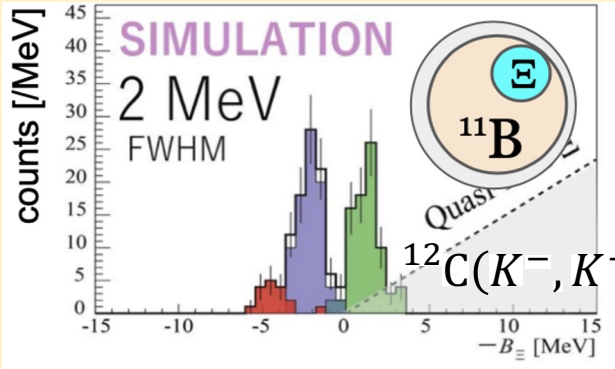
The Dawn of Ξ Hypernuclear Spectroscopy

S-2S magnetic spectrometer @K1.8 beamline in J-PARC



First Ξ hypernuclear spectroscopy experiment w/ S-2S (J-PARC E70) was **complete.**

Now analyzing…



Simulation based on T. Motoba et al., NPA 835, 223 – 230 (2010)

ΛΛ Hypernuclear spectroscopy（J-PARC E75）

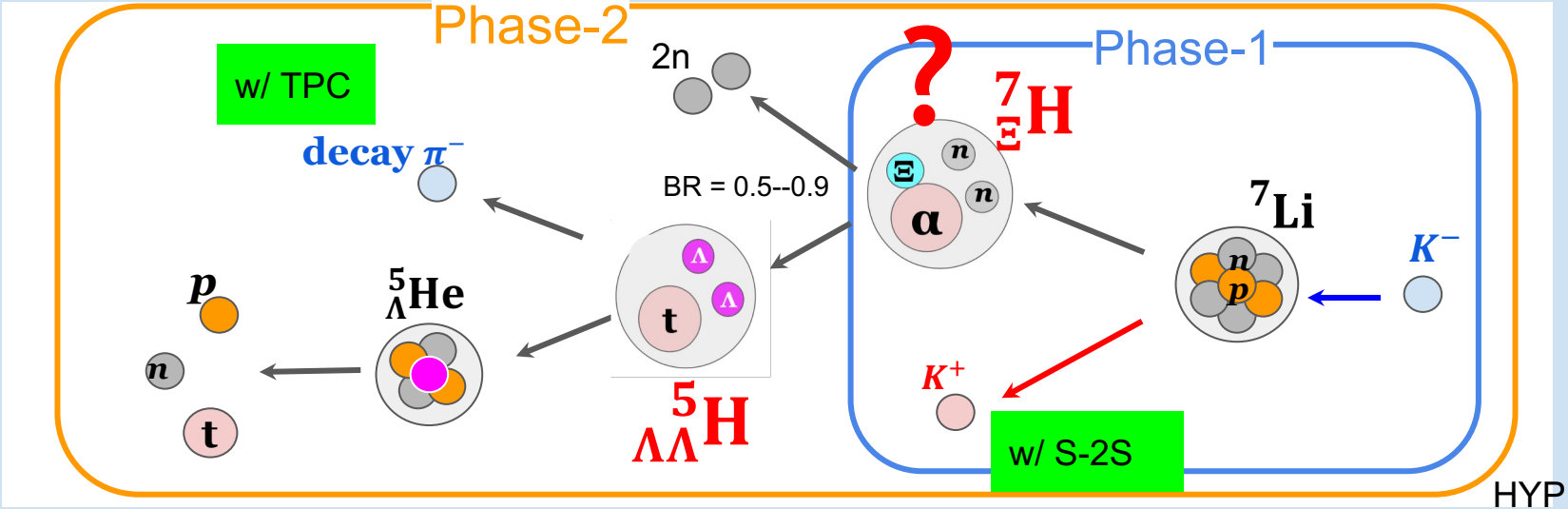
Next step after E70 experiment ($^{12}\mathrm{C}(K^-,K^+)^{12}_{\Xi}\mathrm{Be}$),

Decay-π spectroscopy of ΛΛ hypernuclei (J-PARC E75 experiment)

- **$^{5}_{\Lambda\Lambda}\mathrm{H}$ by decay-π** w/ TPC ⇒ **binding energy** ⇒ **ΞN − ΛΛ coupling** （compared to **$^{6}_{\Lambda\Lambda}\mathrm{He}$** ）

$^{5}_{\Lambda\Lambda}\mathrm{H}$ produced from $^{7}_{\Xi}\mathrm{H}$ **but, $^{7}_{\Xi}\mathrm{H}$ production cross section is unknown.**

I will talk about **$^{7}_{\Xi}\mathrm{H}$ (phase-1)** in this session.

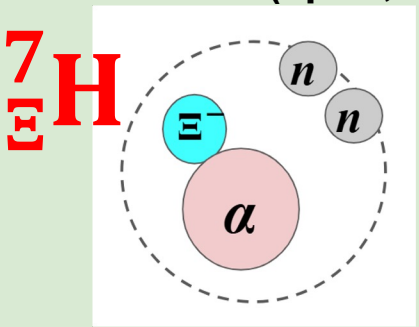


Motivation of E75 Phase-1 experiment

Main motivation = ${}^{7}_{\Xi}\mathrm{H}$ **production cross section via** ${}^{7}\mathrm{Li}(K^-, K^+)$

Moreover, ${}^{7}_{\Xi}\mathrm{H}$ is interesting.

- **V_o of ΞN interaction (spin-, isospin- independent term)** [1,2]



$2n$ = halo
→ $\Xi\alpha$ interaction is dominant

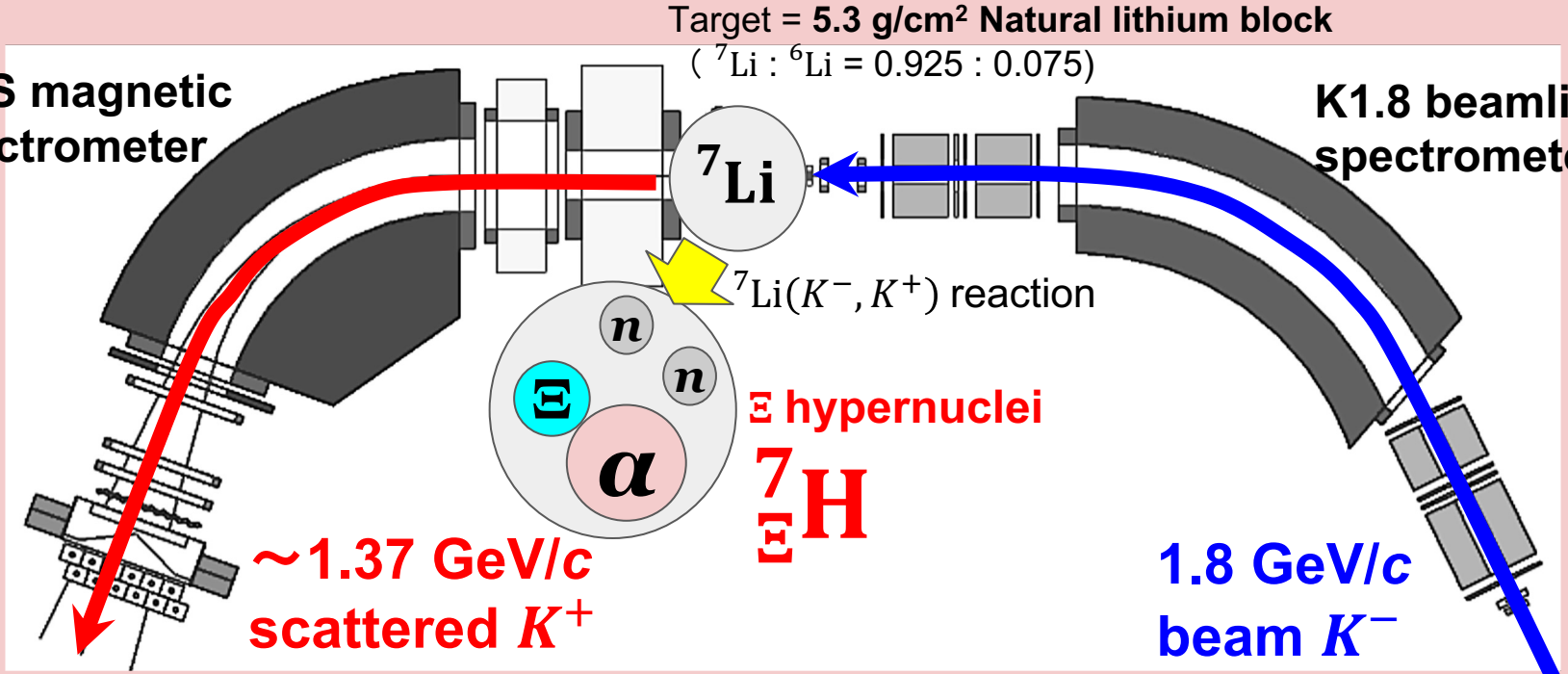
$$V_\Xi = \boxed{V_0} + (\sigma\cdot\sigma)V_{\sigma\sigma} + (\tau\cdot\tau)V_{\tau\tau} + (\sigma\cdot\sigma)(\tau\cdot\tau)V_{\sigma\sigma\tau\tau}$$

And, we will measure ${}^{6}\mathrm{Li}(K^-, K^+)$ for BG estimation.

- ${}^{6}_{\Xi}\mathrm{H}$ is bound ? or not bound?
- Compare ${}^{6,7}_{\Xi}\mathrm{H}$ & ${}^{12}_{\Xi}\mathrm{Be}$ (E70) spectrum (QF) → A-dependency of V_Ξ

[1] T. Koike and E. Hiyama, Few Body Syst. **54**, 1275–1278 (2013). [2] E. Hiyama et al., PRC, **106**, 064318 (2022)

Experiment Set-up (J-PARC E75-1)

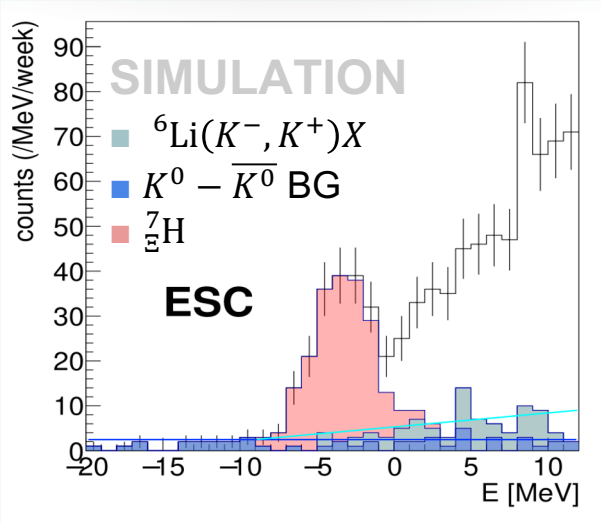


K^-, K^+ **momentum** → Spectrum of Ξ hypernuclei by **Missing-mass** method
In Phase-2, TPC installed in target position.

Yield & Spectrum Estimation

$^{nat}\mathrm{Li}(K^-, K^+)X$ spectrum

simulated based on theoretical calculation of E. Hiyama et al



- **Yield : 100-150 counts/ 6 days** (ESC08c, HALQCD)
- **Missing Mass resolution : ~ 4 MeV (FWHM)**

Main Background (BG)

1. $K^0 - \overline{K^0}$ **mixing BG**
   - i. $^7\mathrm{Li} + K^- \rightarrow K^0 + \mathrm{X}$
   - ii. $K^0 \rightarrow \overline{K^0}$
   - iii. $^7\mathrm{Li} + \overline{K^0} \rightarrow K^+ + \mathrm{X}$

   These reaction chain → a few nb/sr/MeV static BG

2. $^6\mathrm{Li}(K^-, K^+)X$ **BG**

   $^{nat}\mathrm{Li}$ includes 7.5 % $^6\mathrm{Li}$.

   → ~10 counts in $^7_{\Xi}\mathrm{H}$ bound region

And, $^6\mathrm{Li}(K^-, K^+)$ run will be conducted also

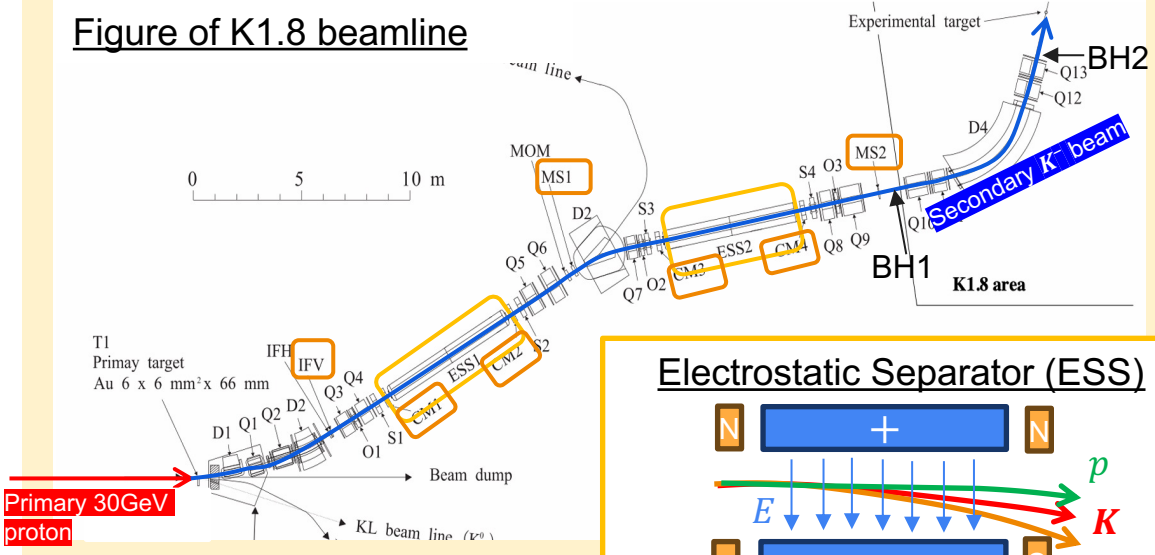
→ Not serious

K^- Beam Tuning Test (Preparation Status)

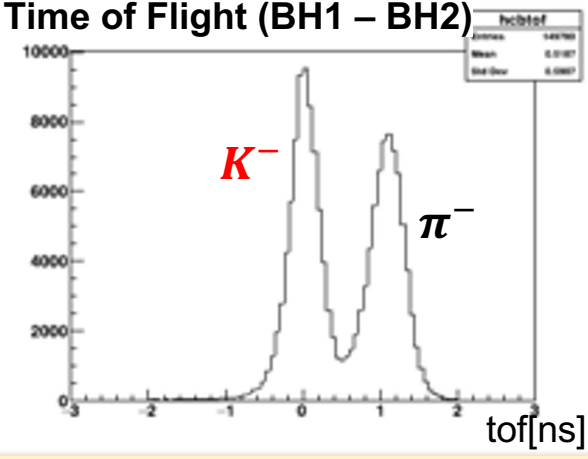
- K^- beam Tuning test at K1.8 beamline
  - we tuned **beamline magnets** and **slits**,
  - improved **ESS** voltage (250kV → 300kV)

⇒ **high intensity & purity K^- beam achieved ! ☺**

Figure of K1.8 beamline



Time of Flight (BH1 – BH2)



- **1.6 M K^- /spill(4.2 s)**
- **K^-/π^- ratio = 1 : 0.88**

Electrostatic Separator (ESS)

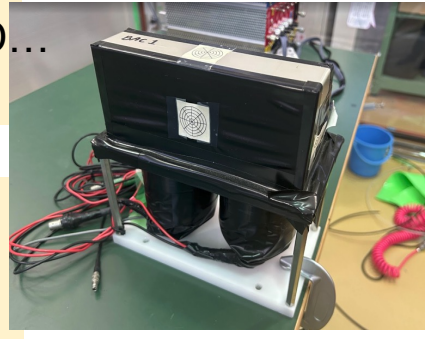
ESS supply high electronic field E
& can separate beam particles.

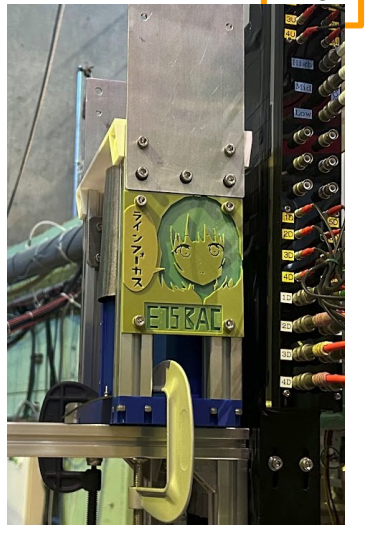
$$\frac{d^2y}{dz^2} = \frac{eE}{\gamma m v^2}$$

Preparation Status of Detectors

☺ **high intensity & purity K^- beam rate achieved !**
☹ But, rate tolerance of some existing detectors are BAD…

Figures of BAC candidates.
Left one is new design detector.

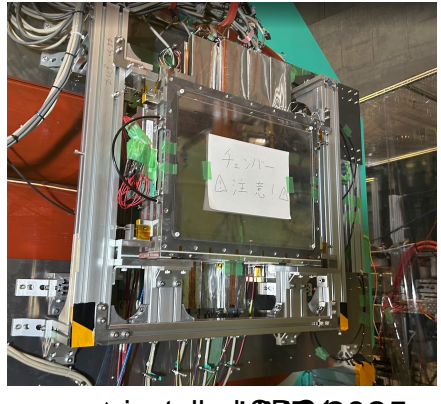




Now we're preparating some detectors for E75-1

- **Beam Aerogel Cherenkov detector (BAC)** for π^- suppression
  → 4 candidates will be studied in next beam test
- **One of tracking detectors (SDC1)** for scattered K^+

↑ wire repairment work of SDC1



↑ installed SDC1

In 2026 Autumn,
E75 phase-1 is planned to commence

Summary

S=-2 spectroscopy w/ S-2S(J-PARC E70) has began.
E70 ($^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$) was complete in this spring.
Next step of Ξ hypernuclear spectroscopy → **^{7}Li target,** $^{7}\mathbf{Li}(\boldsymbol{K^-}, \boldsymbol{K^+})^{7}_{\Xi}\mathbf{H}$ (J-PARC E75)

J-PARC E75

- Main motivation = **Decay-π spectroscopy for ΛΛ hypernuclei** $^{5}_{\Lambda\Lambda}\mathbf{H}$

J-PARC E75 phase-1

- Main = measurement of $^{7}_{\Xi}\mathbf{H}$ **production cross section w/ S-2S**
- $^{7}_{\Xi}\mathbf{H}$ **binding energy** → V_0 term of ΞN interaction.

- Yield estimation：100-150 counts / 6 day,
- Background： $K^0 - \overline{K^0}$ mixing BG & ^{6}Li BG → enough suppressible.

- $\boldsymbol{K^-}$ **beam rate 1.6 M/spill ($\boldsymbol{K^-/\pi^-}$ = 1 : 0.88)** achieved. Very high intensity & high purity.
- And **detector preparation is ongoing**.
- **JFY 2026、E75-1 is planned to commence.**

Thank you for attention

BACK UP

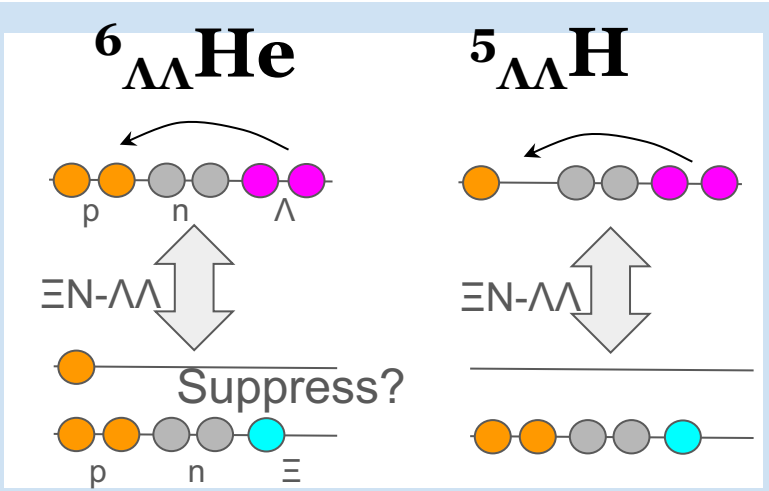
Motivation (J-PARC E75)

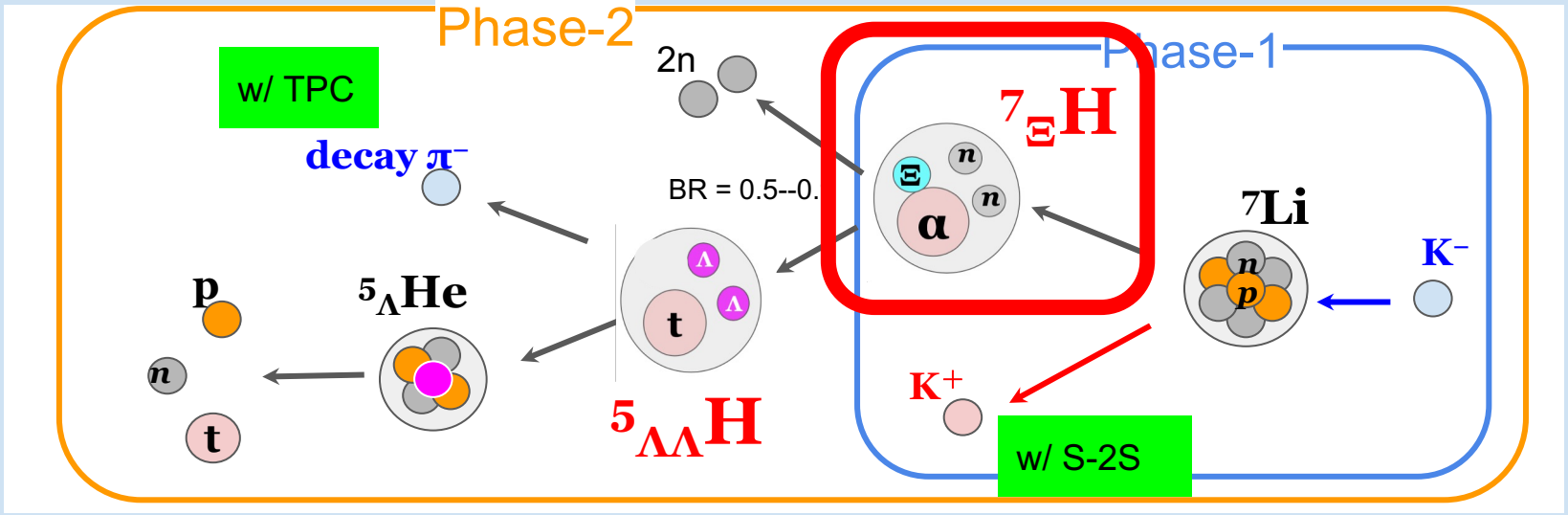
After E70 experiment (^{12}C(K$^-$,K$^+$)$^{12}_{\Xi}$Be)

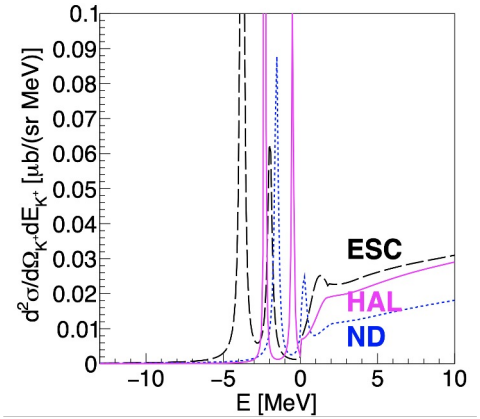
decay-π spectroscopy of ΛΛ hypernuclei

- **$^{5}_{\Lambda\Lambda}$H by decay-π** w/ TPC → **binding energy**
- **ΞN-ΛΛ coupling** （compared to $^{6}_{\Lambda\Lambda}$He ）

→ **But, $^{7}_{\Xi}$H cross section is unknown.**
I will talk about **$^{7}_{\Xi}$H** in this session.





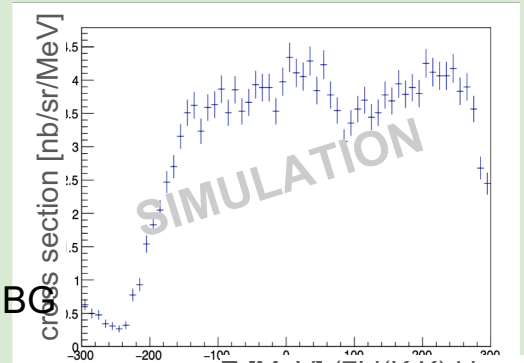

0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−10
−5
0
5
10
E [MeV]
d²σ/dΩK'dEK' [μb/(sr MeV)]
ESC
HAL
ND

Background (BG) Estimation by simulation

・K0 mixing BG

1. $^{7}Li + K^{-} \rightarrow \overline{K^{0}} + X$
2. $\overline{K^{0}} \rightarrow K^{0}$
3. $^{7}Li + K^{0} \rightarrow K^{+} + X$

→～4 nb/sr/MeV static BG in bound region.

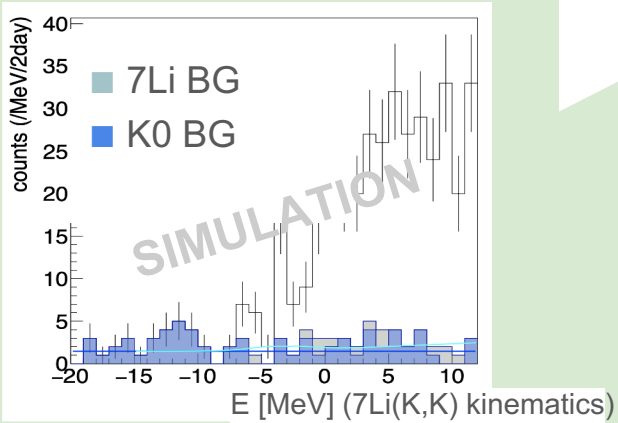


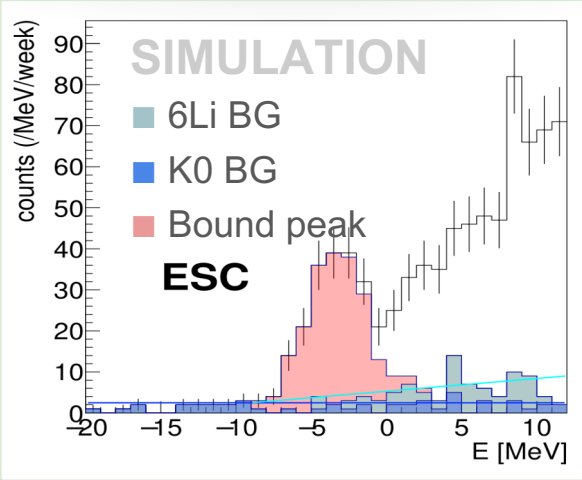
N(^{6}Li) ～10 counts in bound region
S(^{7}Li)/N(^{6}Li) > 10
And, to estimate ^{6}Li BG,
^{6}Li run（2days）will be conducted.

→ Feasible

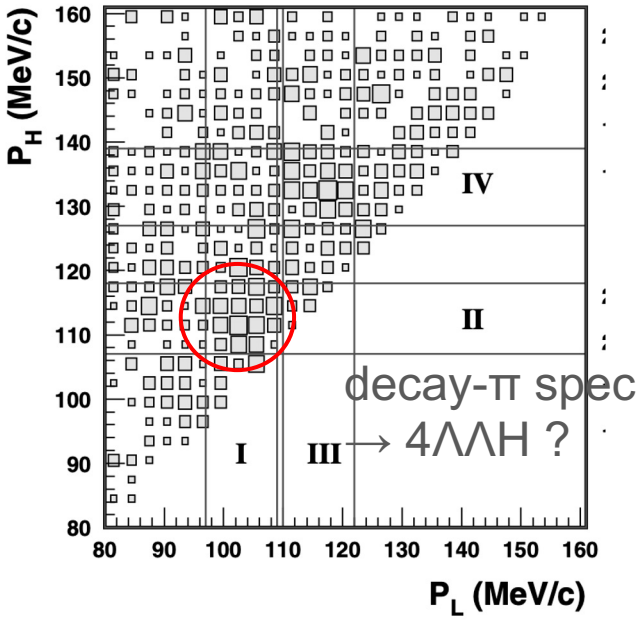
・$^{6}Li(K^{-},K^{+})X$

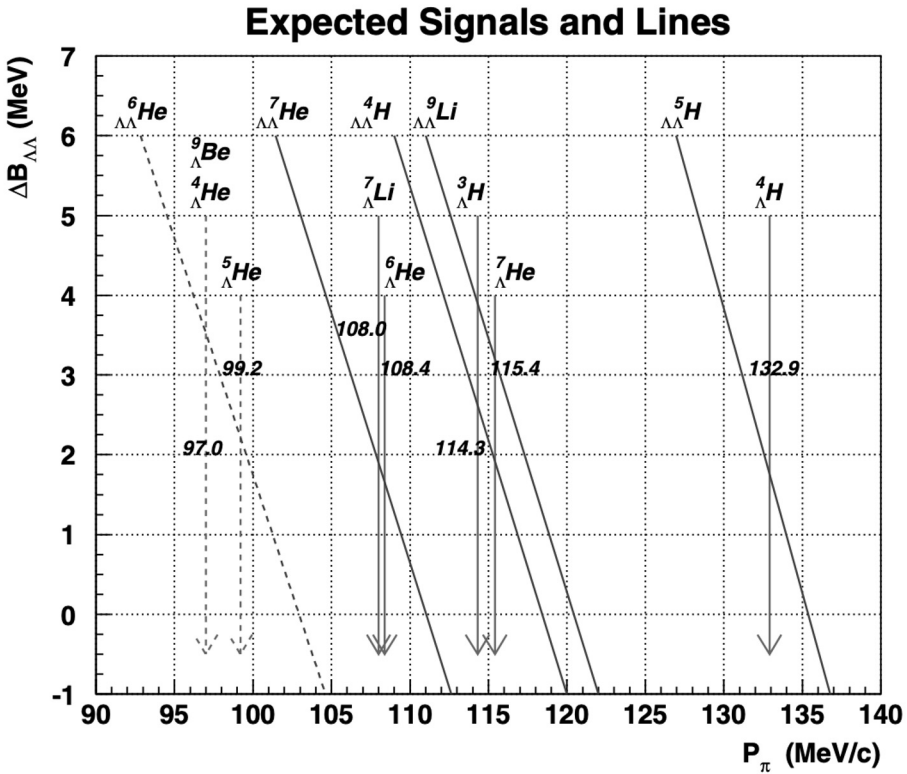
Target= natural Li
^{7}Li = 92.5%,
^{6}Li = 7.5 %



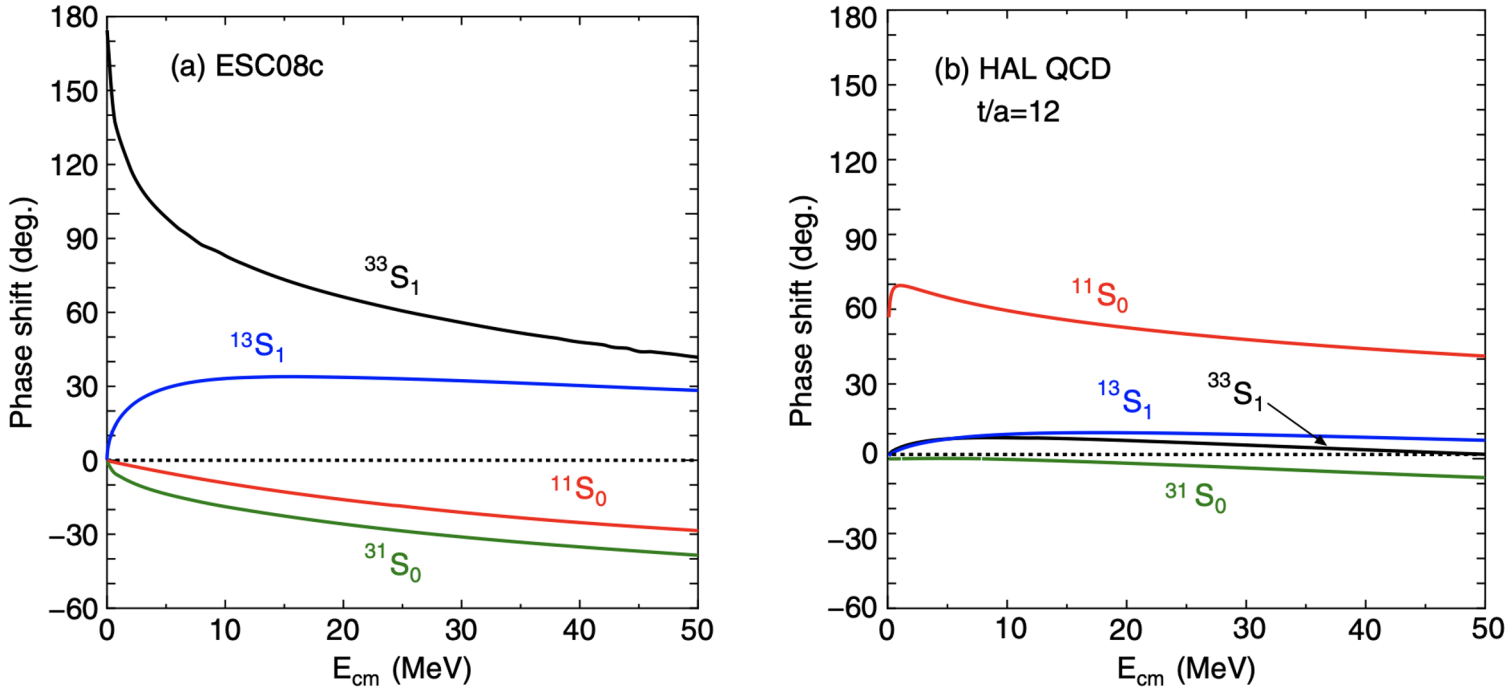


decay-pi spectroscopy

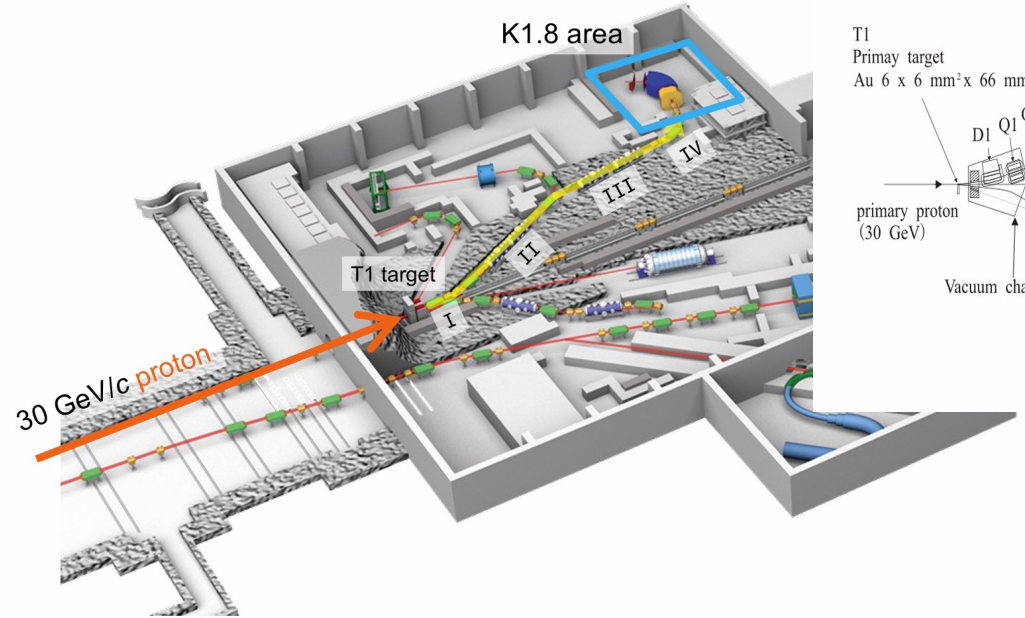




J. K. Ahn et al., PhysRevLett.87.132504 (2001)


(a) ESC08c
$^{33}S_1$
$^{13}S_1$
$^{11}S_0$
$^{31}S_0$
Phase shift (deg.)
E_{cm} (MeV)
(b) HAL QCD
t/a=12
$^{11}S_0$
$^{13}S_1$
$^{33}S_1$
$^{31}S_0$
Phase shift (deg.)
E_{cm} (MeV)

K1.8 beamline



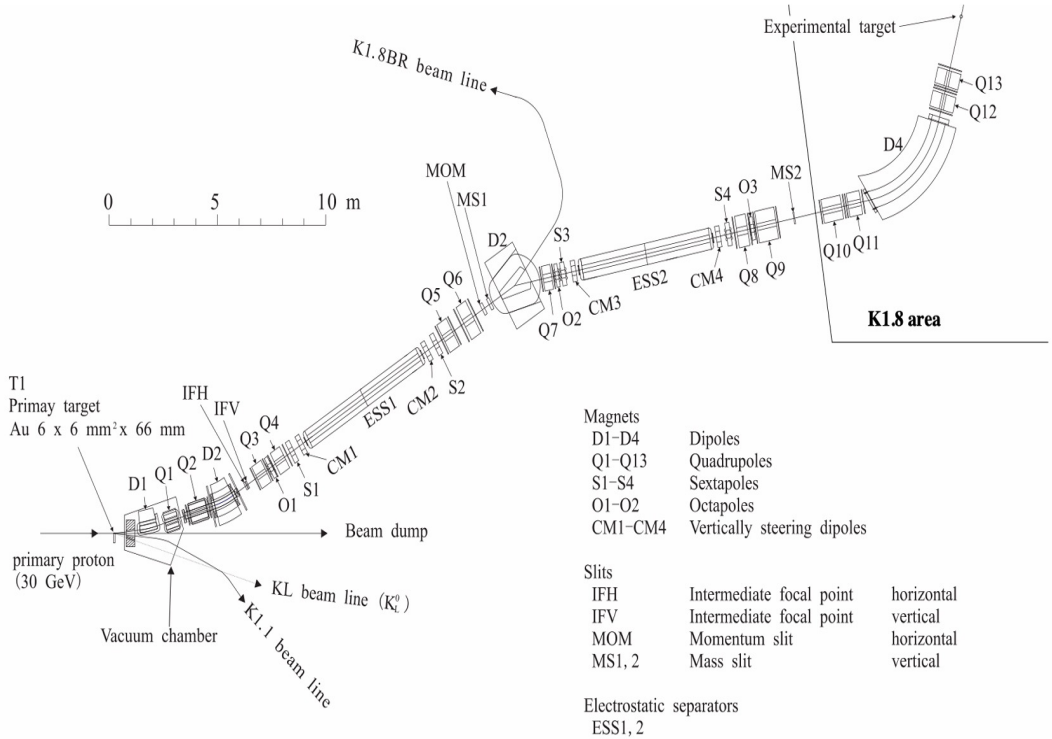
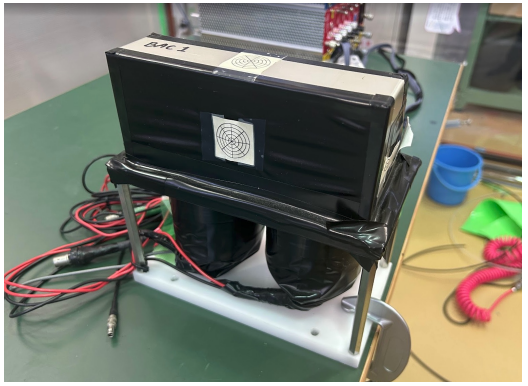


図 2.3: ハドロン実験施設の全体図。

BAC

Preparation of E75 BAC



Existing BAC (E70 BAC) was weak at high rate beam…
Possible causes include:
- The beam hitting the photocathode,
- or the PMT is bad.

→ We are preparing 3 type BAC for test experiment.

- **y-resized BAC w/ Finemesh PMT (Belle PMT)**
  → y-resized E70 BAC1 (Right Fig.)
- **BAC w/ Finemesh PMT (Belle PMT)**
  → Reuse E70 BAC2
- **New BAC with Line-Focus PMT (Right Fig.)**
  - Design → DONE, Now making.
  - made by 3D printer
  - **excitation test by S-2S Q1** excitation → OK