Strangeness Physics Programs by S-2S at J-PARC

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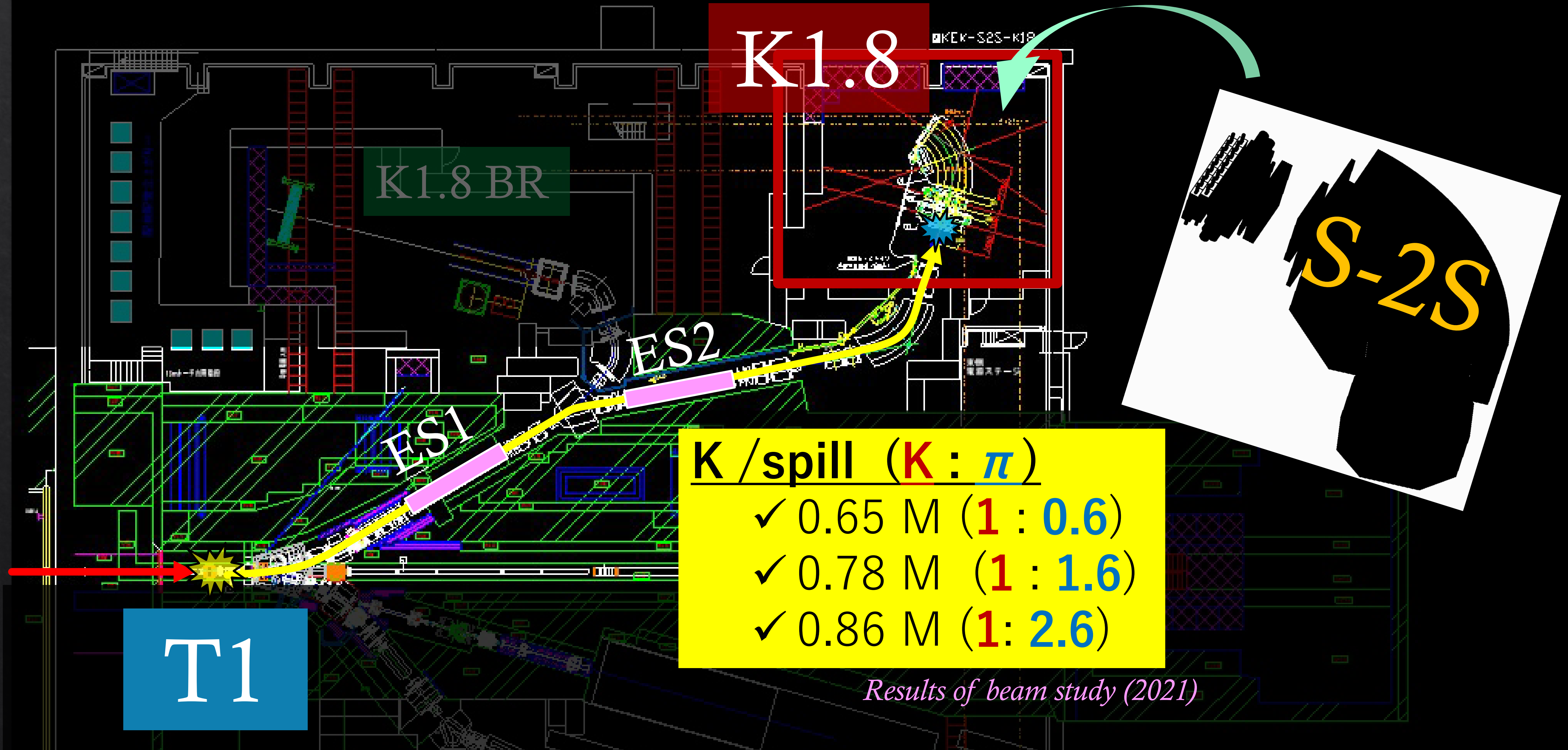
for the S-2S Collaboration

GRADUATE SCHOOL OF SCIENCE
FACULTY OF SCIENCE
KYOTO UNIVERSITY

July 1, 2022

Strangeness −2 Spectrometer (S-2S) at K1.8



K /spill (K : π)

- ✓ 0.65 M (1 : 0.6)
- ✓ 0.78 M (1 : 1.6)
- ✓ 0.86 M (1: 2.6)

Results of beam study (2021)

Physics on a dish of S-2S

Strangeness $S = -2$ nuclear physics

Hypernuclei
Λ, Ξ, ΛΛ
(E70, E75, +)

- Missing mass
- Decay pion
- Gamma / X rays
- …

✓ **T.O. Yamamoto (1; Mon-III)**
✓ **H. Fujioka (4; Thu-IIb)**
✓ **A. Tokiyasu (4; Thu-IIb)**
✓ **T. Harada (4; Thu-IIIa)**
✓ **K. Ebata (Poster)**

Mesic nuclei
η'

Ξ* spectroscopy

ΣN cusp (E90)

→ **Y. Ichikawa (4; Thu-IIb)**

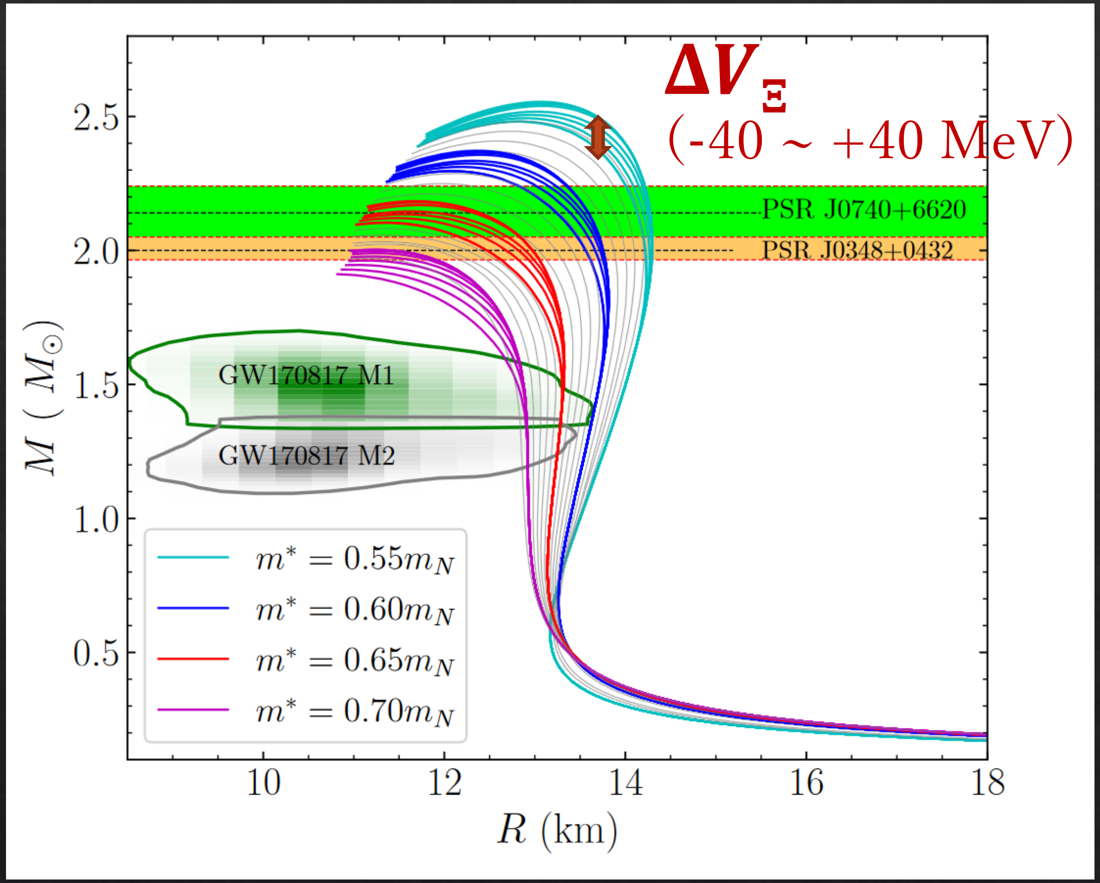
etc.

S-2S workshop (Oct 14, 2021)
https://kds.kek.jp/event/39644/

Ξ ($S = -2$ baryon) in neutron stars

Nice reviews in Strangeness4:
https://kds.kek.jp/event/40010/sessions/19804/#20220217

RMF model



B. K. Pradhan and D. Chatterjee, PRC 103, 035810 (2021)

Tolman-Oppenheimer-Volkoff eqs.

$p = p(\epsilon)$ ← EOS

$$\frac{dm}{dr} = 4\pi r^2 \epsilon(r)$$

$$\frac{dp}{dr} = -[p(r) + \epsilon(r)] \times \frac{m(r) + 4\pi r^3 p(r)}{r[r - 2m(r)]}$$

V_Ξ is one of ingredients to tackle the hyperon puzzle of NS

Theory (Interaction) LQCD etc.

M.M. Nagels, Th. A. Rijken, Y. Yamamoto, PRC 102, 054003 (2020)

	ESC16	A1	A2	B1	B2	HAL-QCD
X_2	0.0	2.85	2.55	1.65	1.07	
X_3	0.0	0.0	1.6	0.0	3.0	
X_s	0.0	0.0	0.0	10.	10.	
$^{11}S_0$	2.1	1.4	1.4	−4.0	−4.0	−4.9
$^{13}S_1$	−0.4	−2.2	−2.2	−2.8	−2.8	−2.2
$^{11}P_1$	−0.2	−0.3	−0.3	−0.3	−0.3	
$^{13}P_0$	−5.3	−3.5	−3.5	−2.0	−2.0	
$^{13}P_1$	1.5	1.3	1.3	1.7	1.7	
$^{13}P_2$	−1.2	−1.2	−1.2	−2.3	−2.3	
$^{31}S_0$	9.2	9.9	9.9	6.8	6.8	1.8
$^{33}S_1$	7.6	−13.5	−13.9	−4.7	−4.9	−5.4
$^{31}P_1$	1.0	1.3	1.3	1.0	1.0	
$^{33}P_0$	0.8	1.0	1.0	0.8	0.7	
$^{33}P_1$	−2.0	−2.8	−2.8	−3.0	−3.0	
$^{33}P_2$	0.5	0.1	0.1	−1.0	−1.0	
U_Ξ	+13.7	−8.5	−9.0	−10.1	−10.4	−10.6
Γ^c_Ξ	5.1	5.7	5.7	0.5	0.5	0.2

K. Sasaki et al., NPA 998, 121737 (2020)

Calc.	$^{12}C + \Xi^-$	$^{14}N + \Xi^-$	$^{27}Al + \Xi^-$
	B_Ξ (Γ) [/MeV]		
ESC16 (A1)	4.8 (2.8)	5.1 (3.3)	9.0 (2.9)
ESC16 (B1)	4.9 (0.2)	5.2 (0.24)	9.2 (0.22)
HAL-QCD	4.4 (0.13)	5.5 (0.16)	9.6 (0.12)

→ The **width** is important to be measured as well as the **energy**

The lightest Ξ hypernuclei

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

Hypernuclei	chEFT (NLO)	HAL QCD	ESC08c
	B_Ξ (Γ) [/MeV]		
${}^{4}_{\Xi}\mathrm{H}$ (1^+)	0.48 (0.74)	0.36 (0.03—0.06)	10.2 (0.89)
${}^{4}_{\Xi}n$ (1^+)	0.64 (0.11)	Not bound 😥	10.1 (0.03)

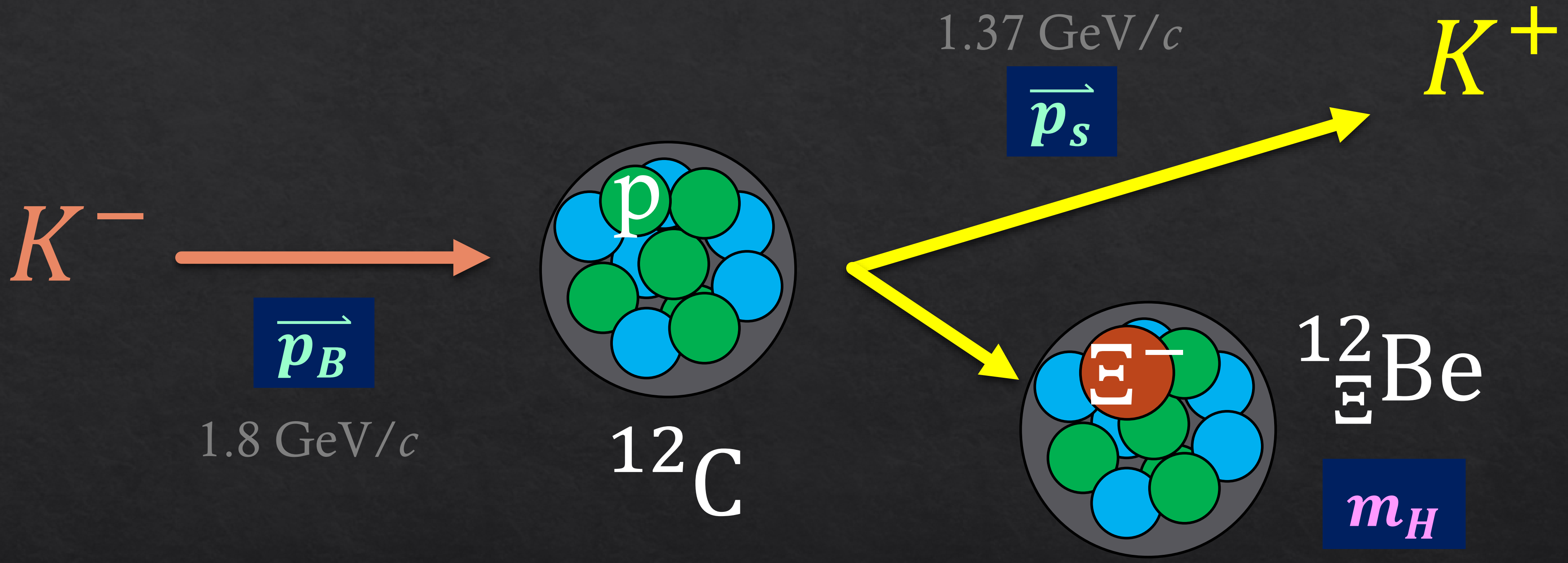
S-2S

H. Le, J. Haidenbauer, Ulf-G. Meiβner,
A. Nogga, Eur. Phys. J. A (2021) 57:339

→ Talk by E. Hiyama (1; Man-III)

→ Talk by H. Le (3; Wed-I)

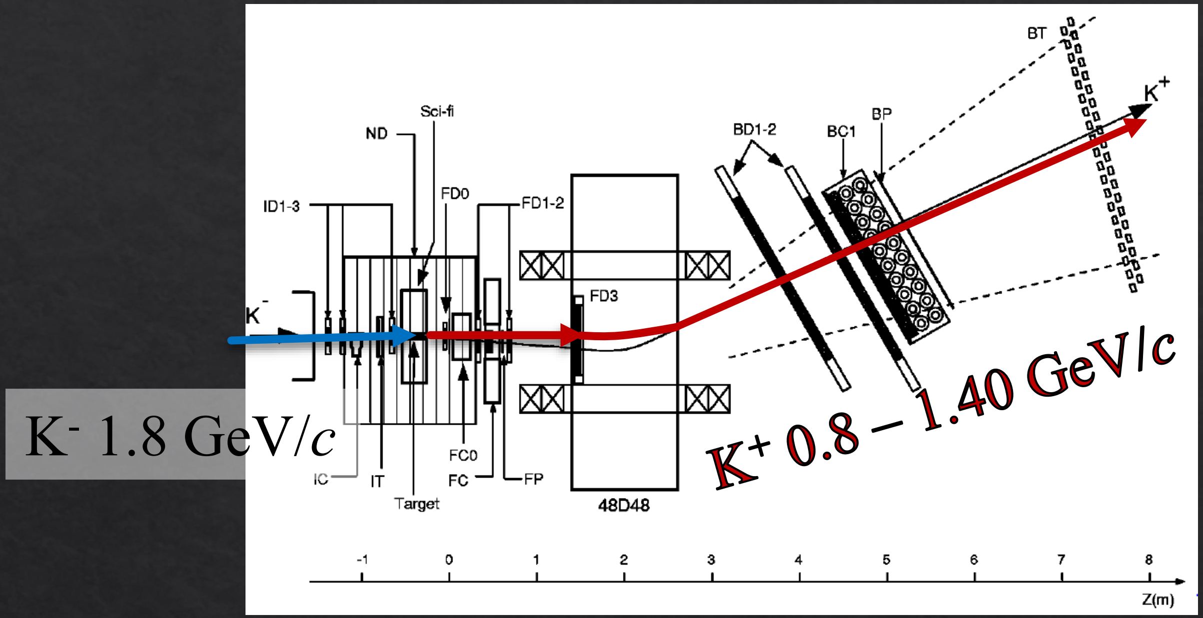
Missing mass spectroscopy (E70)



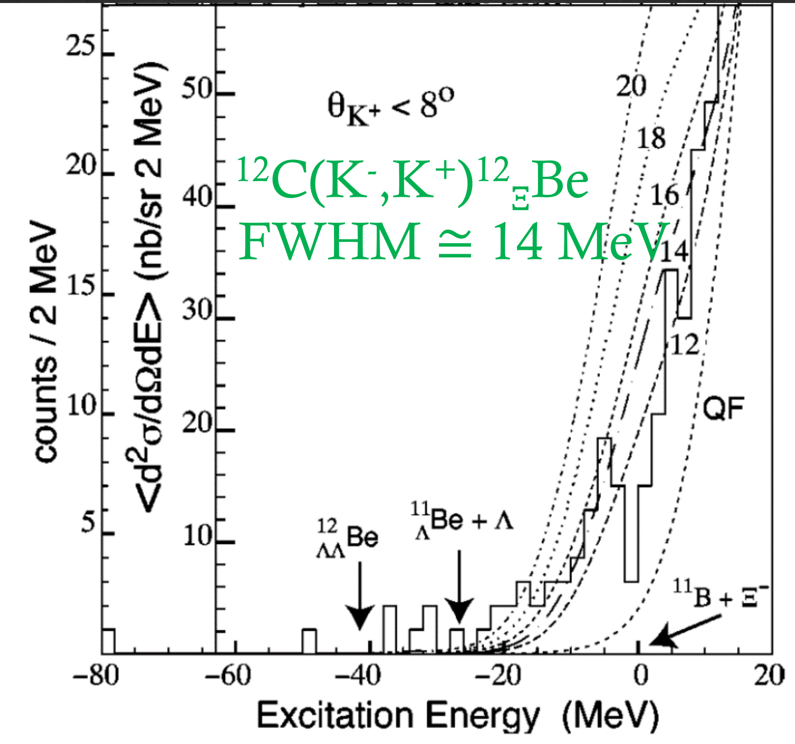
$$m_H = \sqrt{E_H^2 - \overrightarrow{p_H}^2} = \sqrt{(E_{beam} + M_t - E_s)^2 - (\overrightarrow{p_B} - \overrightarrow{p_s})^2}$$

$$\rightarrow B_\Xi = (m_{core} + m_\Xi) - m_H$$

$^{12}C(K^-,K^+)^{12}_{\Xi}Be$ ← Missing-mass measurement



P. Khaustov et al., PRC **61** (2000) 054603



Experiment	KEK E224	BNL E885	J-PARC E05
Resolution in FWHM (MeV)	22	14	6

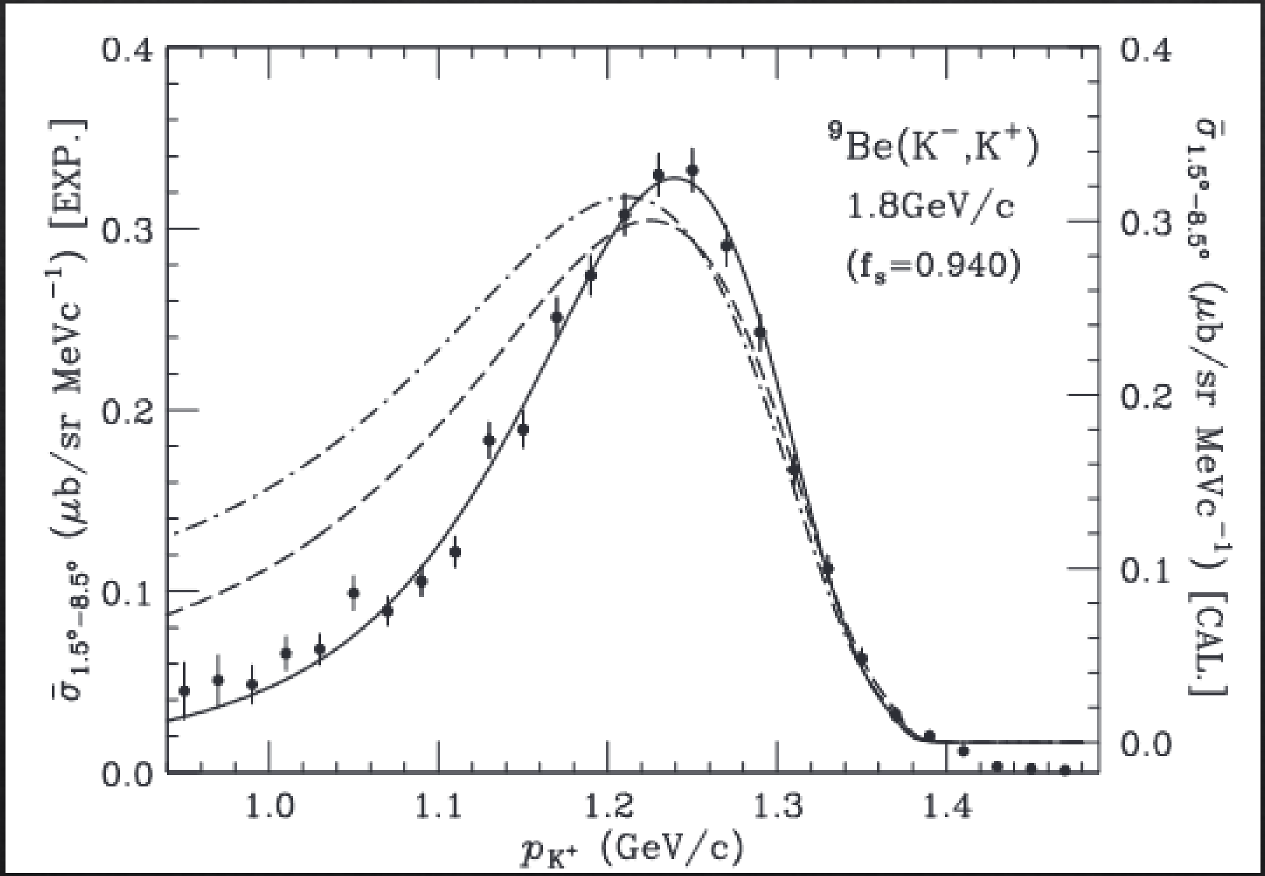
$\Rightarrow$ $V_{0\Xi} \lesssim 14$ MeV

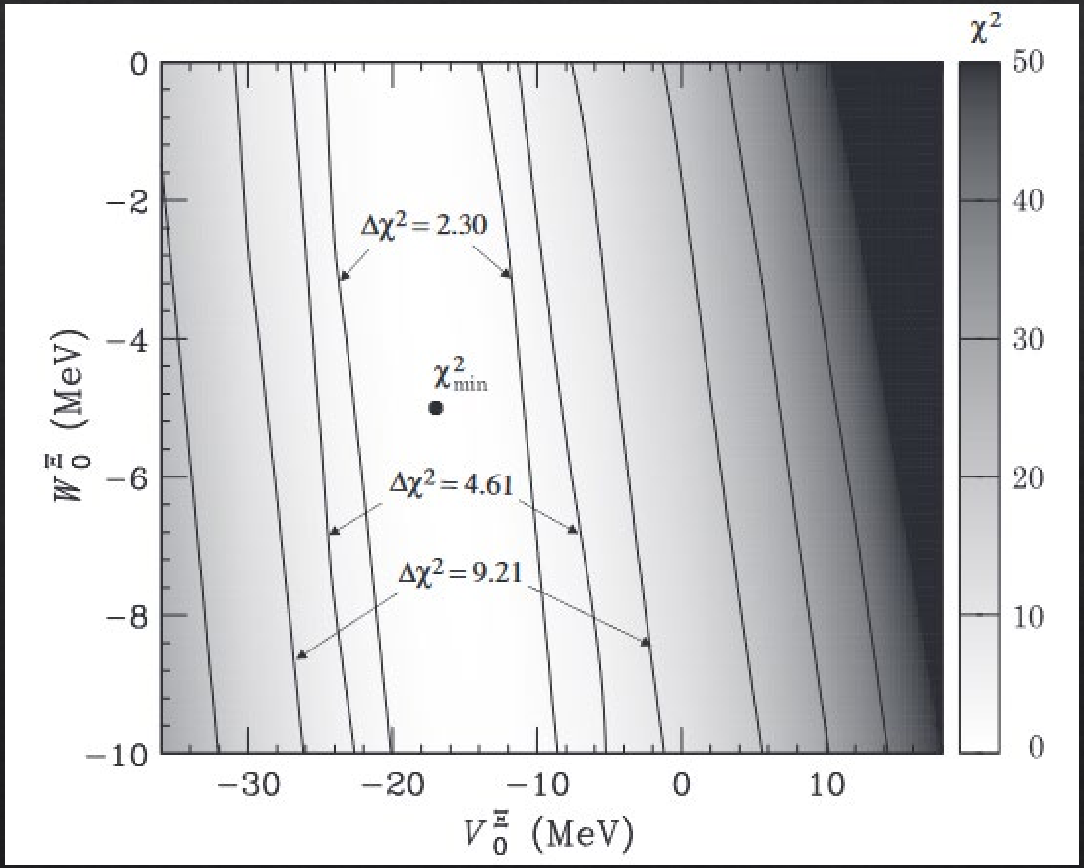
→ **2 MeV** in J-PARC E70

c.f.)
M. Kohno et al., PTP123, 1 (2010)
M. Kohno, PRC 100, 024313 (2019)

$^{9}\mathrm{Be}(K^-,K^+)^{9}_{\Xi}\mathrm{He}$ spectrum analysis (BNL-E906)

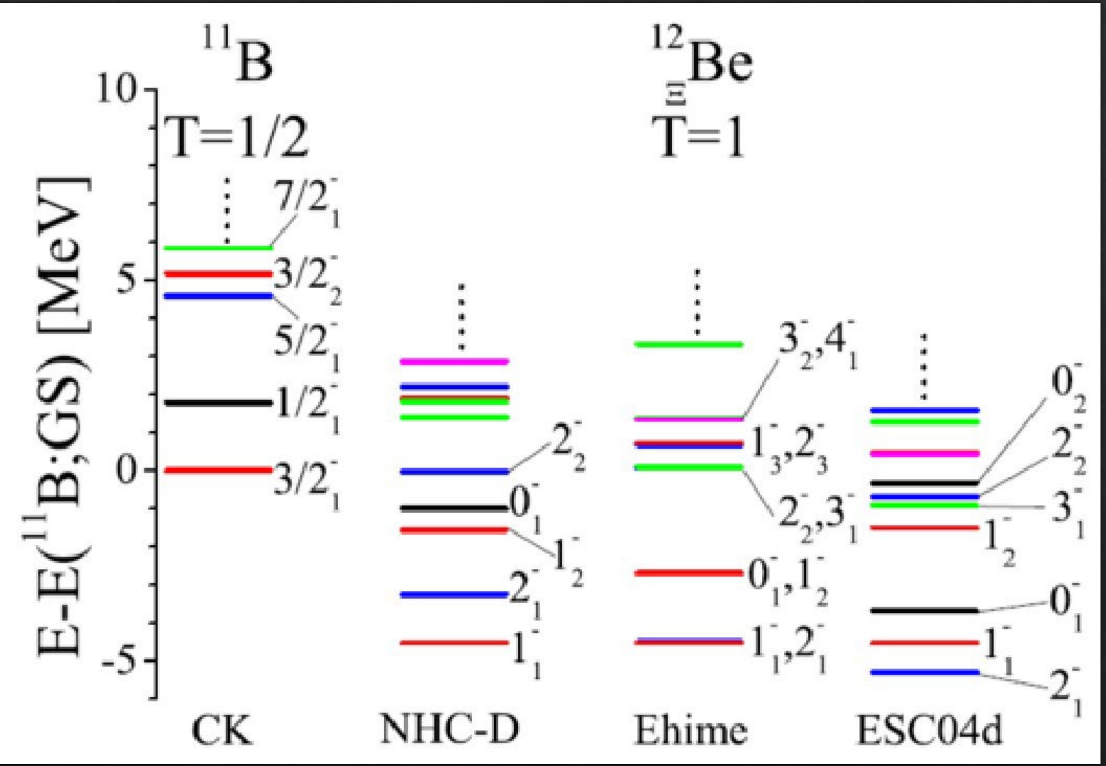
T. Harada, Y. Hirabayashi, PRC 103, 024605 (2021)





$$V_0^{\Xi} = -17 \pm 6\ \mathrm{MeV}$$

Expected spectrum



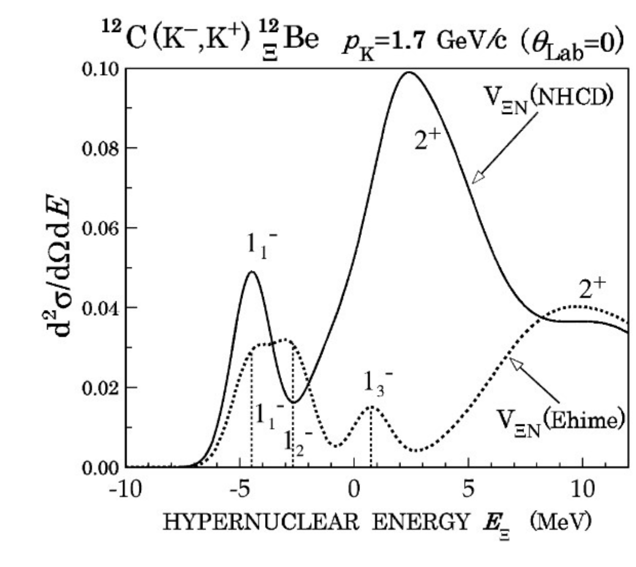


Figure 6: DWIA spectra with NHC-D and Ehime.

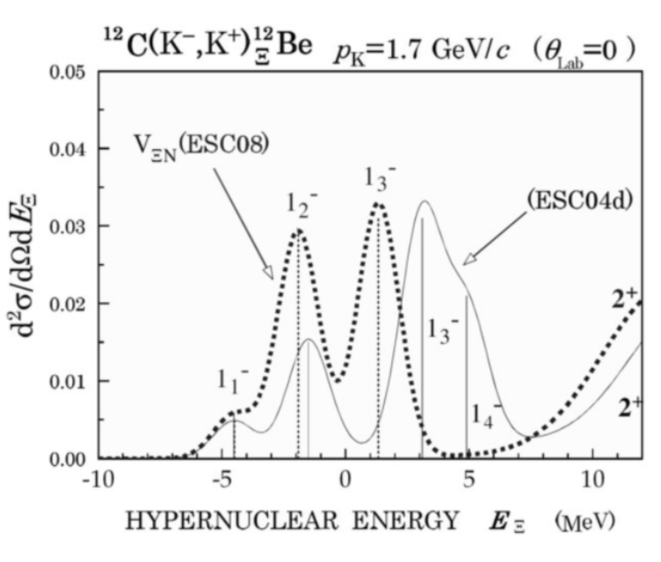
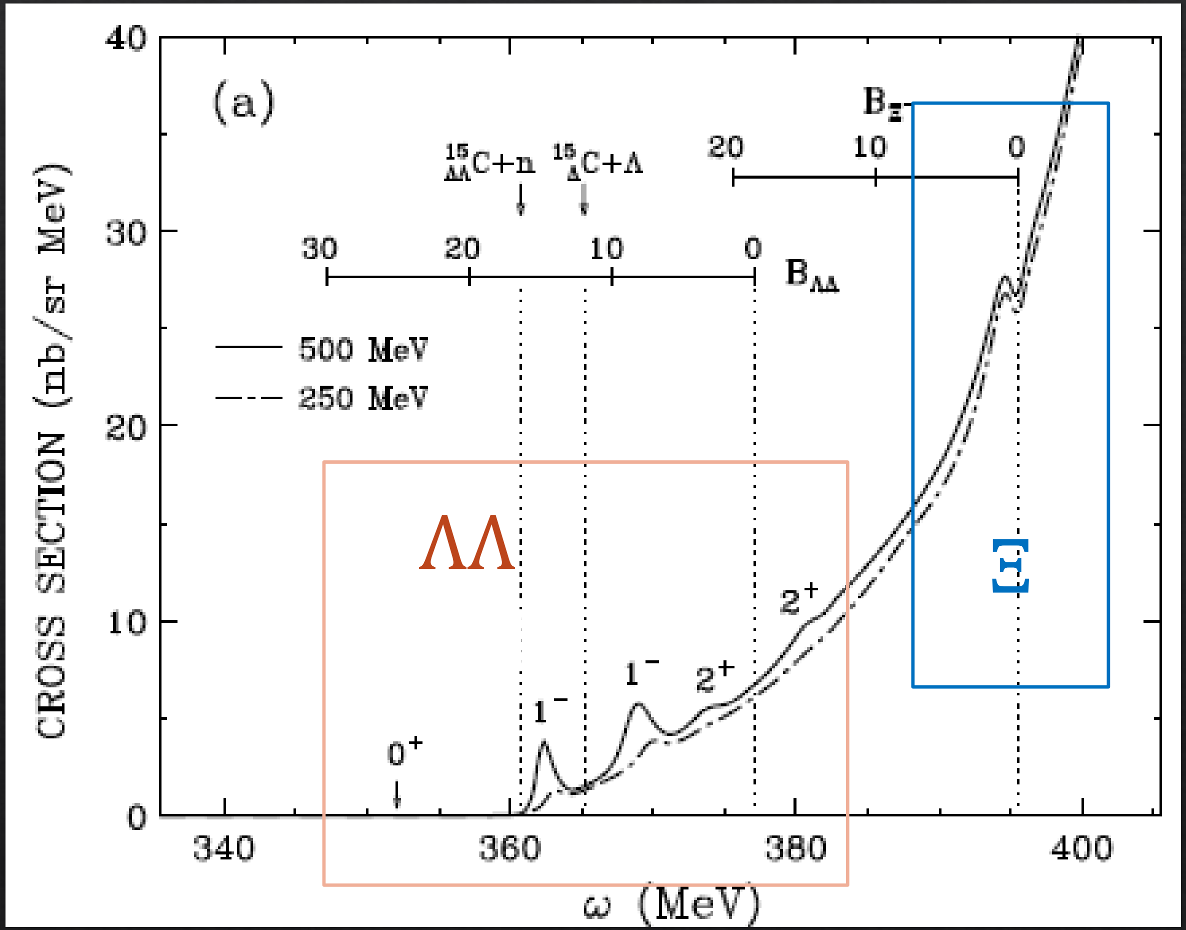


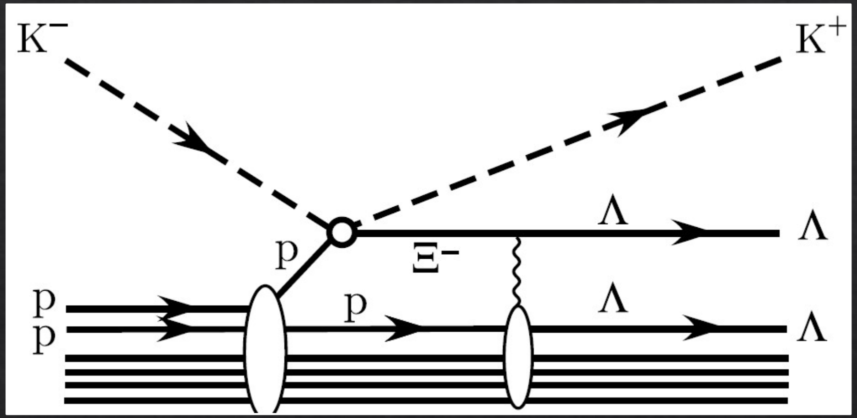
Figure 7: DWIA spectra with ESC04d and ESC08a.

T. Motoba and S. Sugimoto, *NPA* **835** (2010) 223-230

Energy spectrum with the (K^-, K^+) reaction

T. Harada, Y. Hirabayashi, A. Umeya, NPA 914, 85—90 (2013)



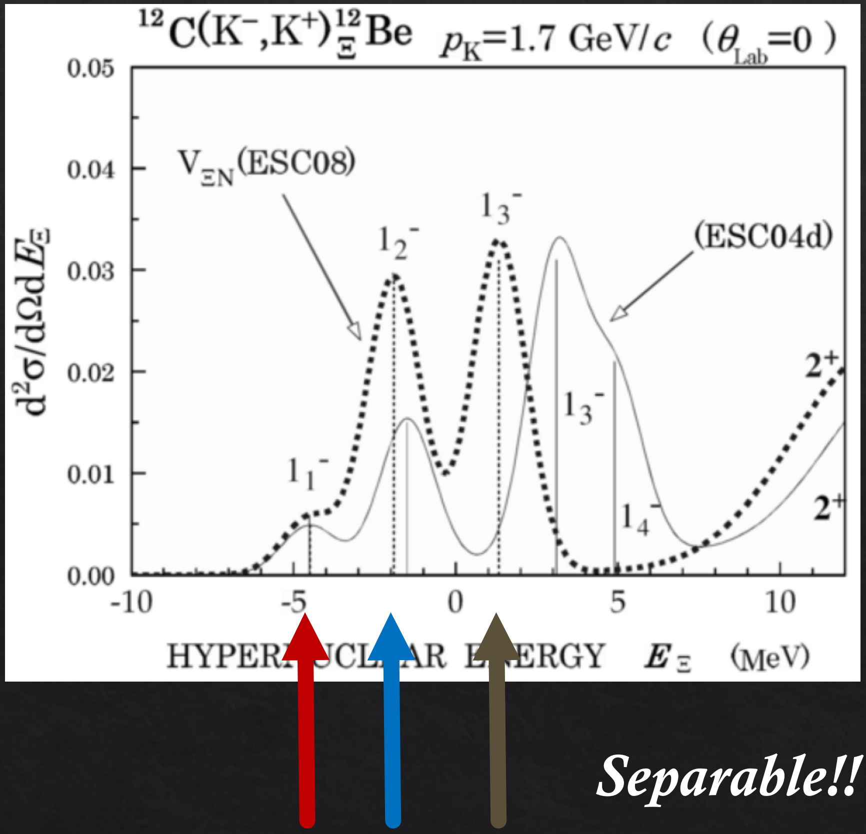


ΛΛ hypernuclei may be observed

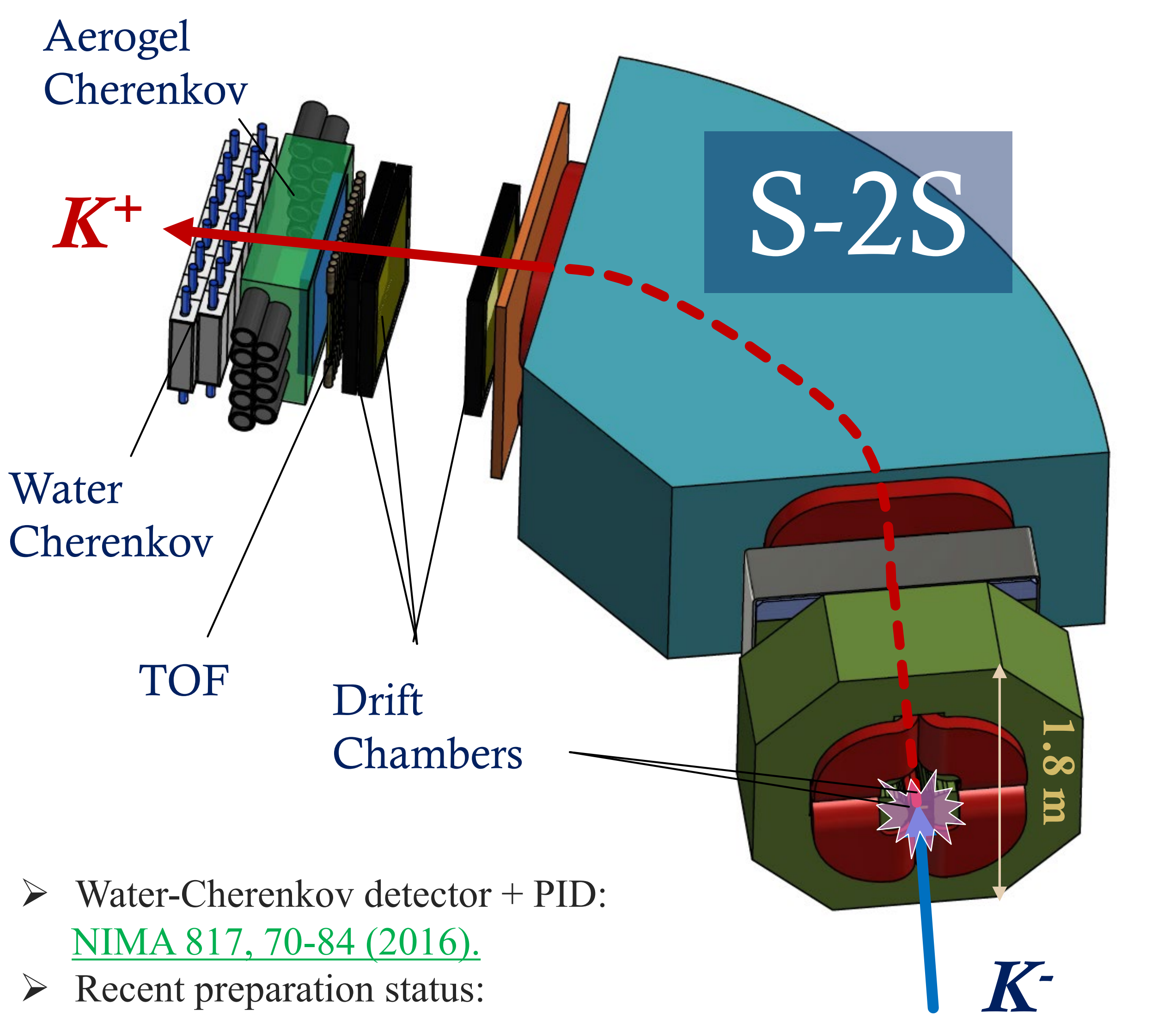
E70 with Strangeness −2 Spectrometer (S-2S)

$\Delta p/p = 6 \times 10^{-4}$ (FWHM)
➔ $\Delta E \sim 2$ MeV (FWHM)

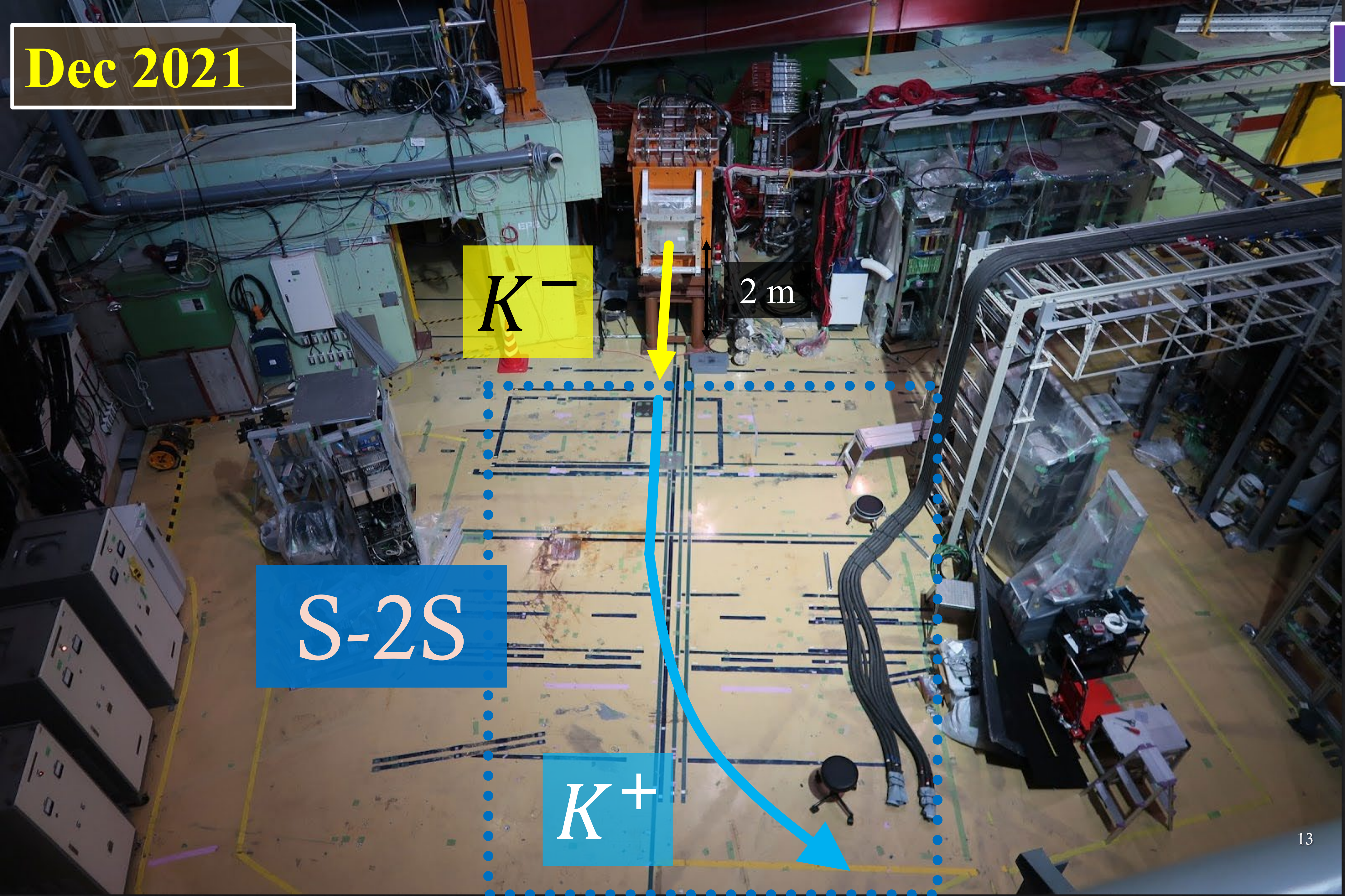
T. Motoba and S. Sugimoto, *NPA* **835** (2010) 223-230

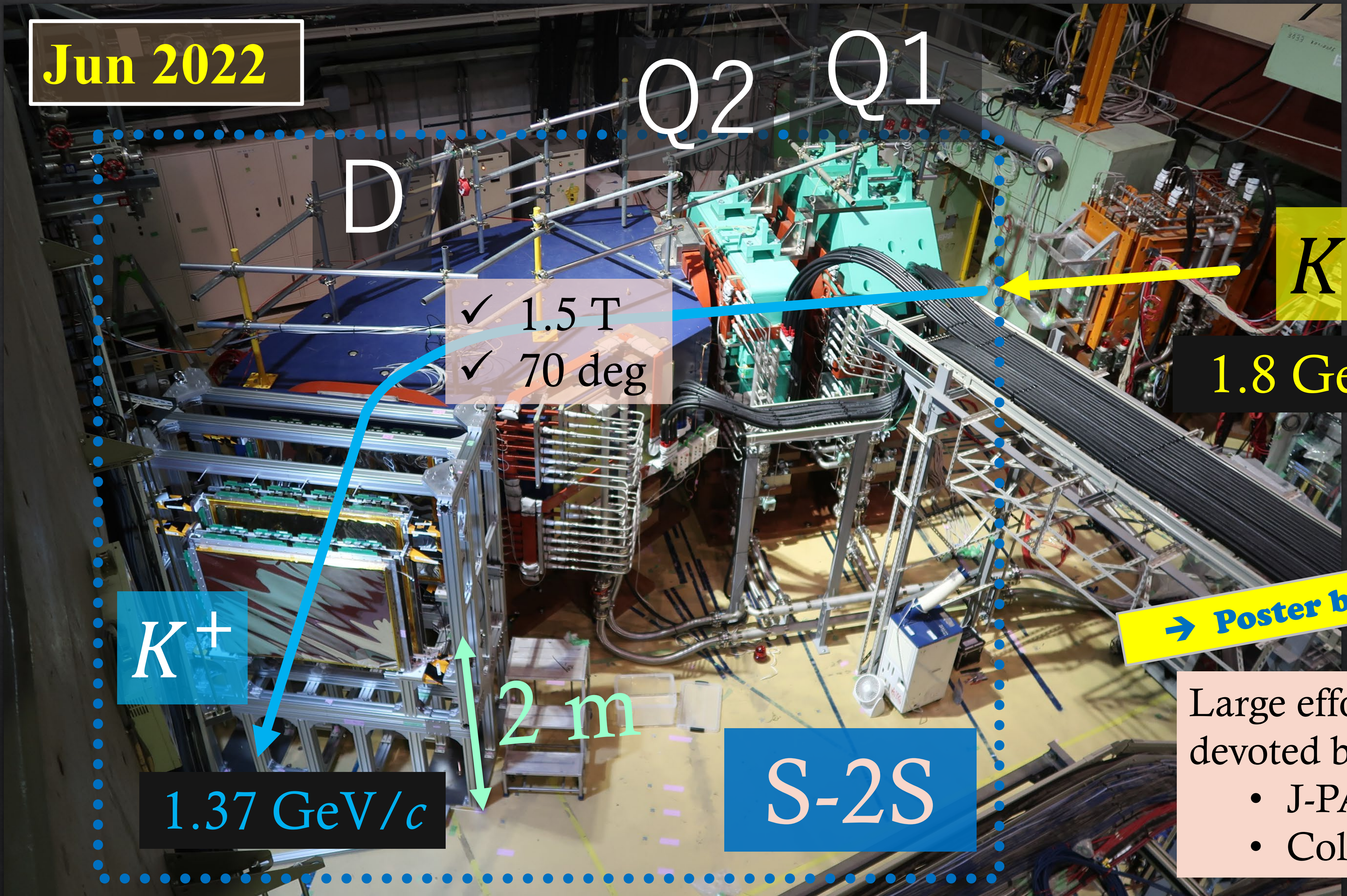


Separable!!



- ➢ Water-Cherenkov detector + PID: NIMA 817, 70-84 (2016).
- ➢ Recent preparation status: *J. Phys.: Conf. Ser.* **1643** 012133 (2020).


Dec 2021
K^-
2 m
S-2S
K^+



→ Poster by K. Ebata

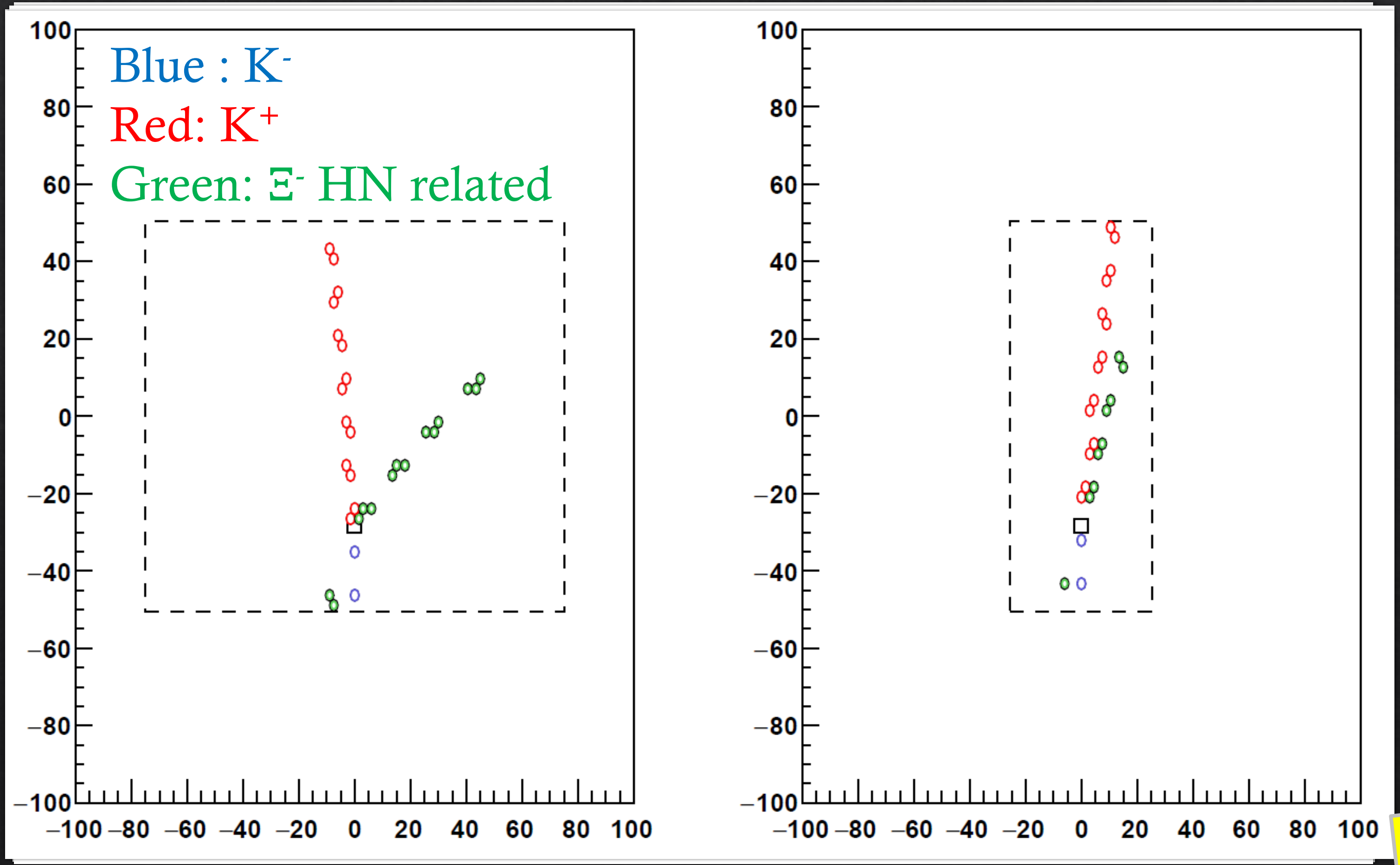
Large efforts are being devoted by

- J-PARC staff
- Collaborators

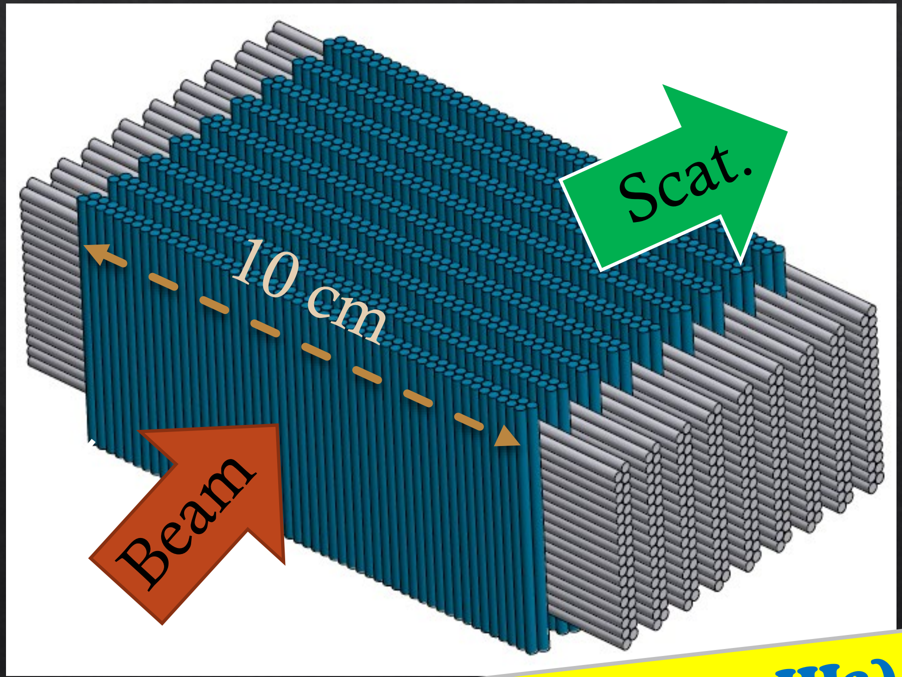
Active fiber target for dE straggling correction

Direct measurement of the energy loss (including straggling)
→ Better energy resolution in resulting missing mass

→ ~ 2 MeV FWHM



Scintillating fiber (φ3 mm)



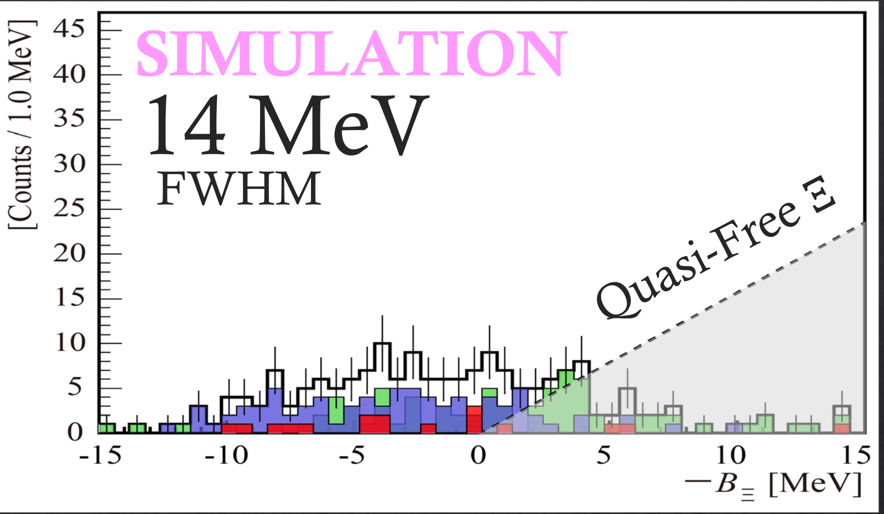
→ **Talk by T. Harada (4; Thu-IIIa)**

Expected spectrum for the ${}^{12}_{\Xi}$Be production

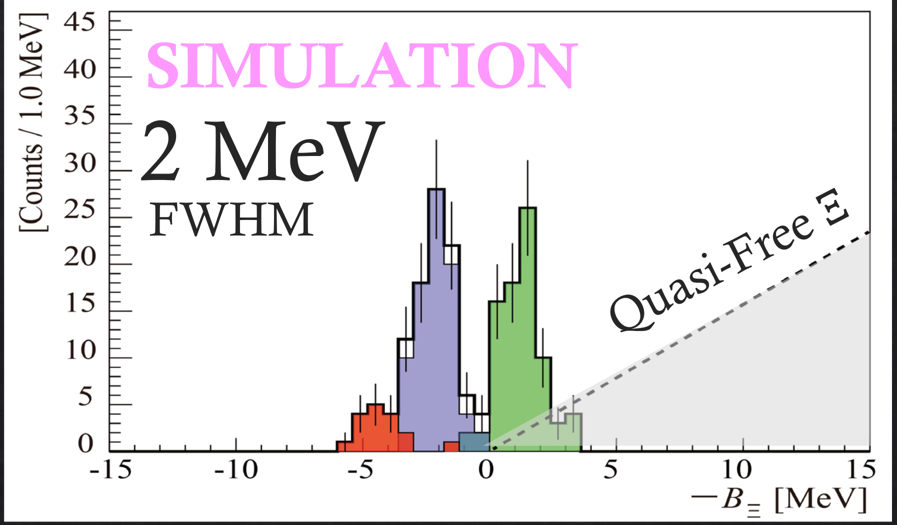
$^{12}\mathrm{C}(K^-, K^+)\,^{12}_{\Xi}\mathrm{Be}$ @ $p_\pi = 1.8$ GeV/c

- Total efficiency = 0.5
- K survival ratio = 0.46 (8 m optical length)
- Solid angle = 60 msr
- Cross section = 60 nb/sr (0—10 deg)
- Target thickness = 9 g/cm^2 (AFT made of CH)
- Beam = 0.8 M kaon per spill (spill cycle of 4.2 sec)
- 20 days

→ **~100 counts**

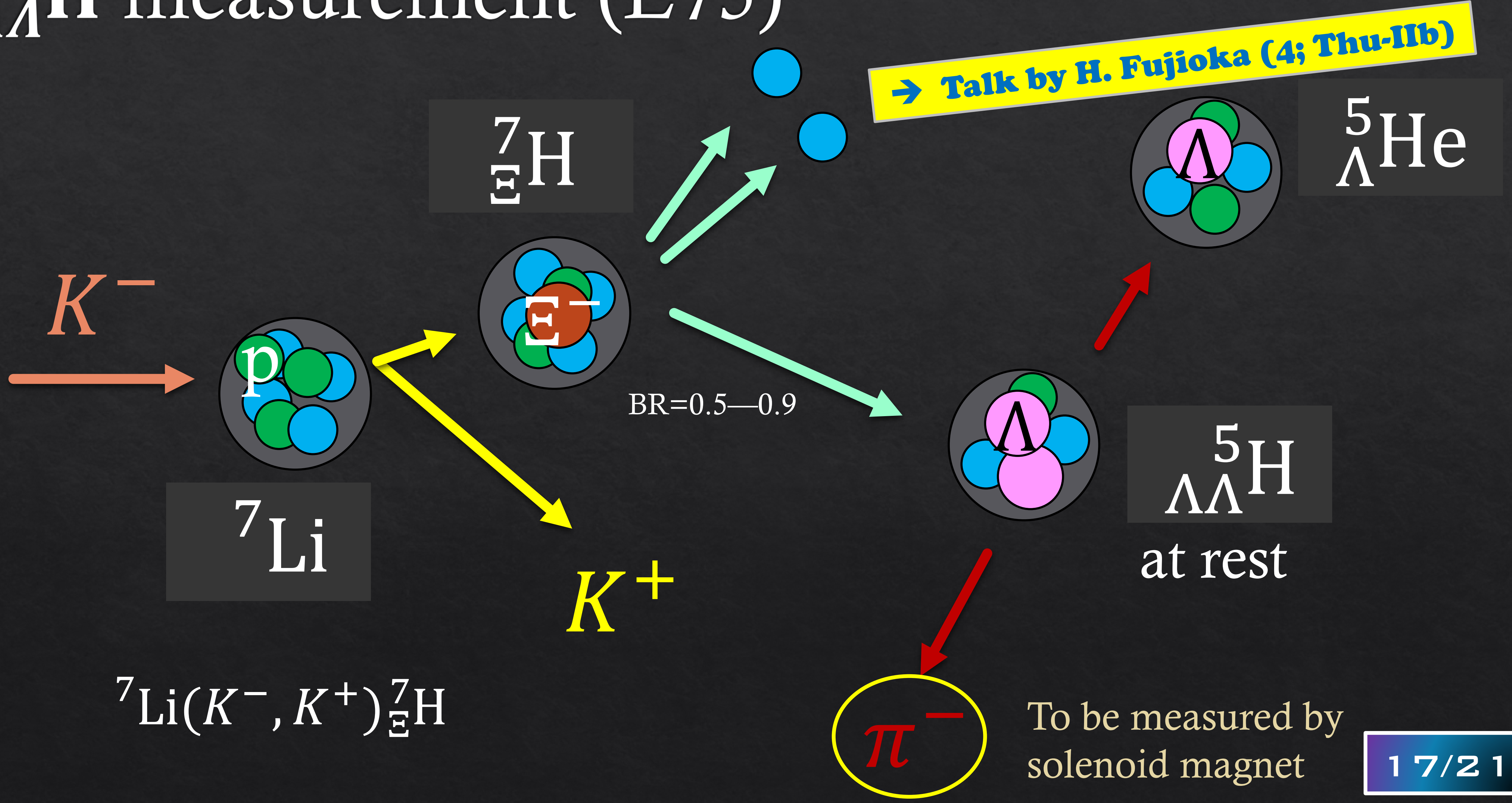


S-2S



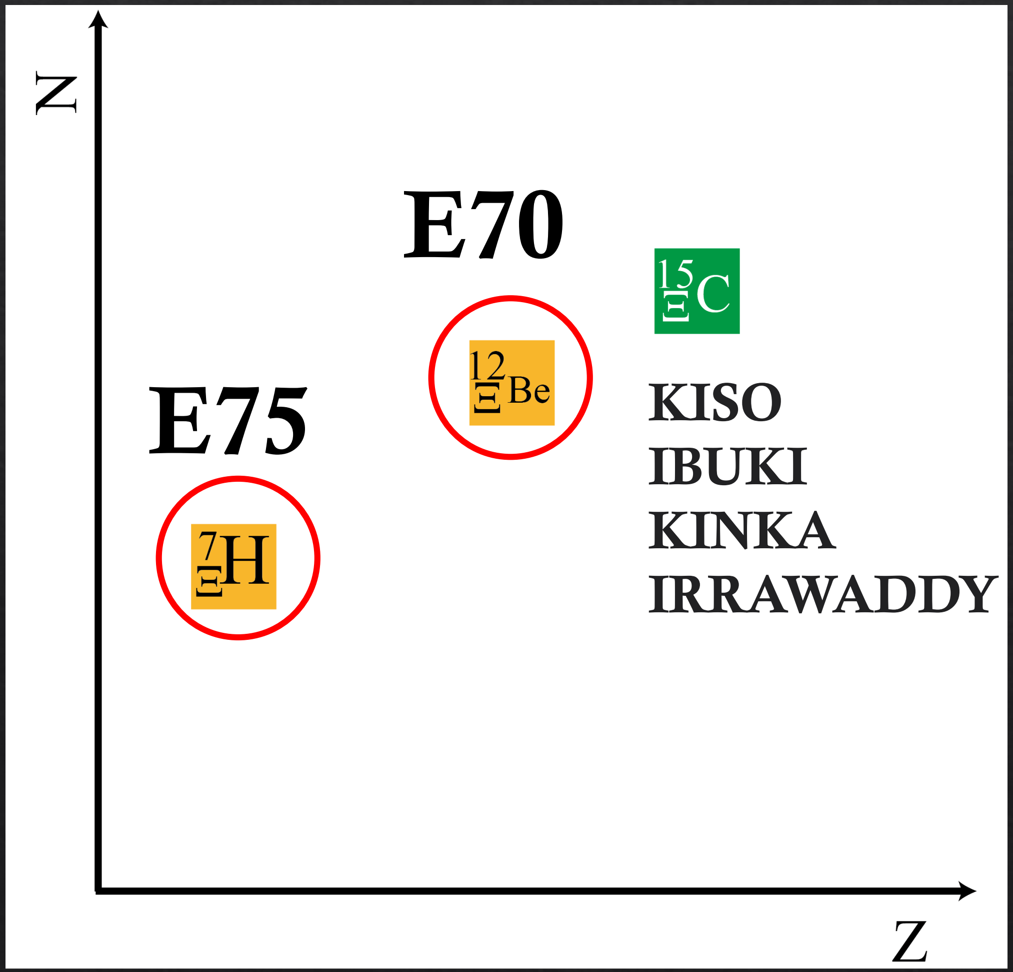
${}^{5}_{\Lambda\Lambda}$H measurement (E75)

*I. K. Fuse et al., PRC **54**, R24–R27 (1996)*
*A. Ohnishi, et al., PTEP **2020**, 063D01 (2020)*

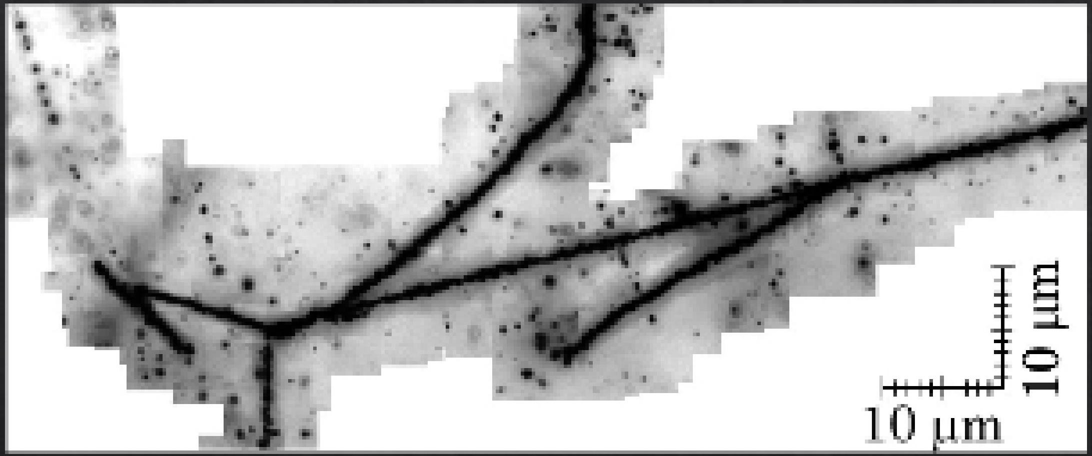


${}^{7}\mathrm{Li}(K^-, K^+){}^{7}_{\Xi}\mathrm{H}$

Further beyond



→ Talk by K. Nakazawa (1; Mon-III)



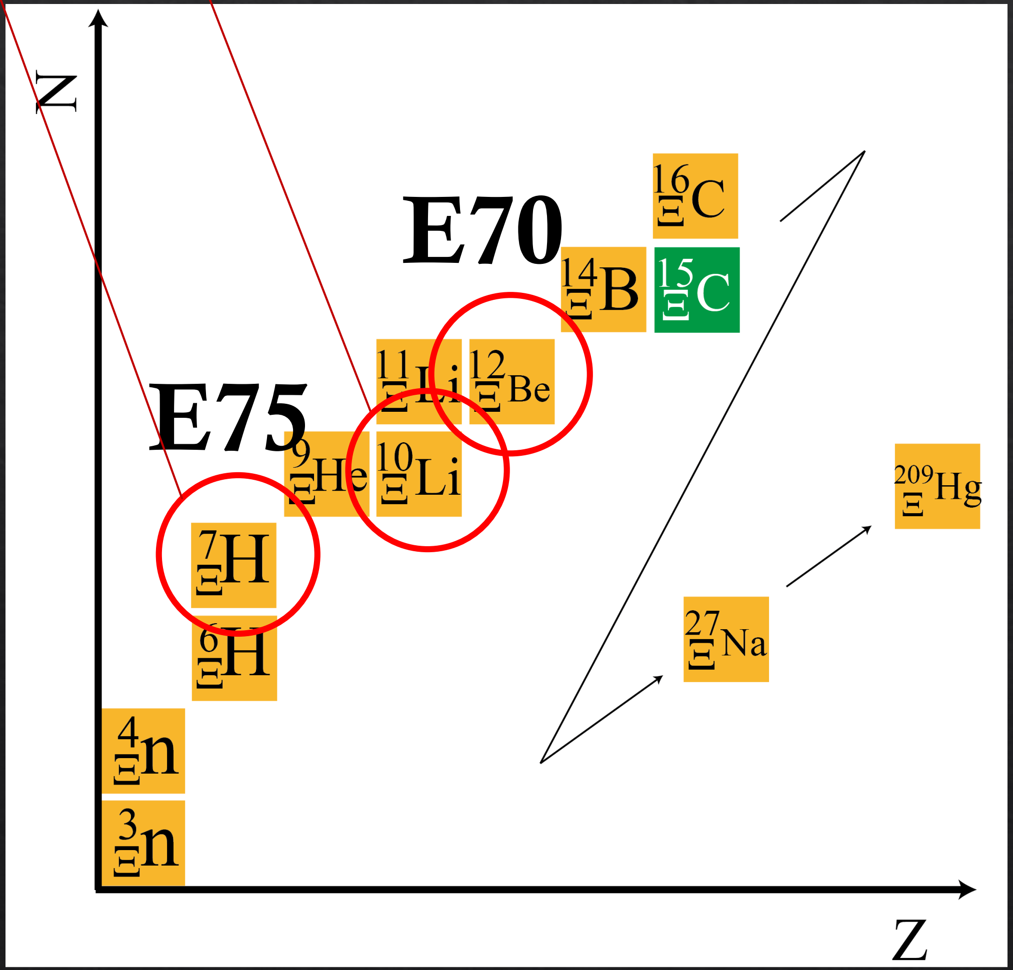
- K. Nakazawa et al., PTEP 2015, 033D02 (2015)
- M. Yoshimoto et al., PTEP 2021, 073D02 (2021)
- S. Hayakawa et al., PRL 126, 062501 (2021)

Presented by K. Nakazawa in the previous talk

Further beyond

→ Talk by H. Fujioka (4; Thu-IIb)

→ Talk by A. Tokiyasu (4; Thu-IIb)



S-2S will open new era

- Missing mass spectroscopy
- X / gamma ray spectroscopy
- decay pion spectroscopy

for variety of Ξ / ΛΛ hypernuclei

Theoretical supports are indispensable !

- ✓ Structure
- ✓ **Production**
- ✓ Decay

Beam time plan (2023/Jan～)

(ex. 3-day beamtime = 12 hours × 6 days)

Beamtime (/ day)	1—3	4	5	6	7	8	9	10	11	12	13	14	15		16—
Detectors	1													Analysis (~1 month)	
BT		2													
AFT			3												
$^{12}_{\Lambda}C$															
CH_2															
Ξ w/ AFT												7			7

High power is not necessary

We aim to start in 2023 Jan ~

1. Detector commissioning
2. Beam-through (BT) runs (w/ and w/o target)
3. AFT calibration run (changing position and angle)
4. (π^+, K^+) with ^{12}C target (2 g/cm^2)
   [$^{12}_{\Lambda}C$ production (1 μb/sr); ~ 400 counts, FWHM = 1.5—2 MeV]
5. CH_2 target (3 g/cm^2) run (Ξ production; >5000 counts)
6. CH_2 thin target (1 g/cm^2) run (energy straggling)
7. Ξ hy

(Phys

Slide for E70 (J-PARC PAC33 (2022)):
https://kds.kek.jp/event/40624/

Summary

- Strangeness -2 Spectrometer (S-2S) at K1.8
- High resolution data for Ξ / ΛΛ hypernuclei
  - Missing mass
  - X / gamma rays
  - decay pions
- S-2S project will start in the beginning of 2023