

June 5-9 , 2023
Genova, Italy

Ξ -HYPERNUCLEI SPECTROSCOPY WITH THE S-2S SPECTROMETER

T. Nagae (Kyoto Univ.)
for J-PARC E70, E75, E94 exp.



OUTLINE

- Baryon-Baryon Interaction in SU(3)
 - UPDATE of YN scattering measurements
 - $\Sigma^\pm p$ scattering \leftarrow J-PARC E40; Λp scatt. (CLAS group)

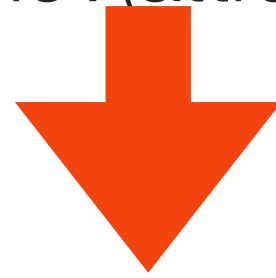
K. Miwa
K. Hicks
 - FEMTOSCOPY analysis for Ξp , $\Lambda\Lambda$
 - Emulsion data \leftarrow J-PARC E07 (Ξ^- , $\Lambda\Lambda$ -hyp)
- E70: Bound States of Ξ -HYP. $^{12}\text{C}(K^-, K^+)^{12}\Xi\text{Be}$
 - Status of S-2S spectrometer
- E94: $^{\text{nat}}\text{Li}(\pi^+, K^+)$; $\Delta E < 1\text{MeV}$



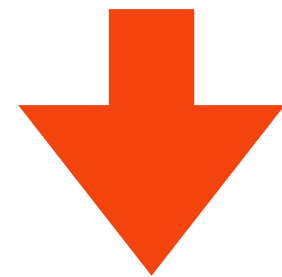
B-B INTERACTIONS IN SU(3)

Basic Questions to be Answered

- ΛN $V_{\Lambda} \sim 30$ MeV (attraction), $V_{\Lambda}^{SO} < \text{a few \% of } V_N^{SO}$ $\leftarrow \gamma$ ray Spectroscopy



- $\Sigma N > \sim 20$ MeV (repulsive)

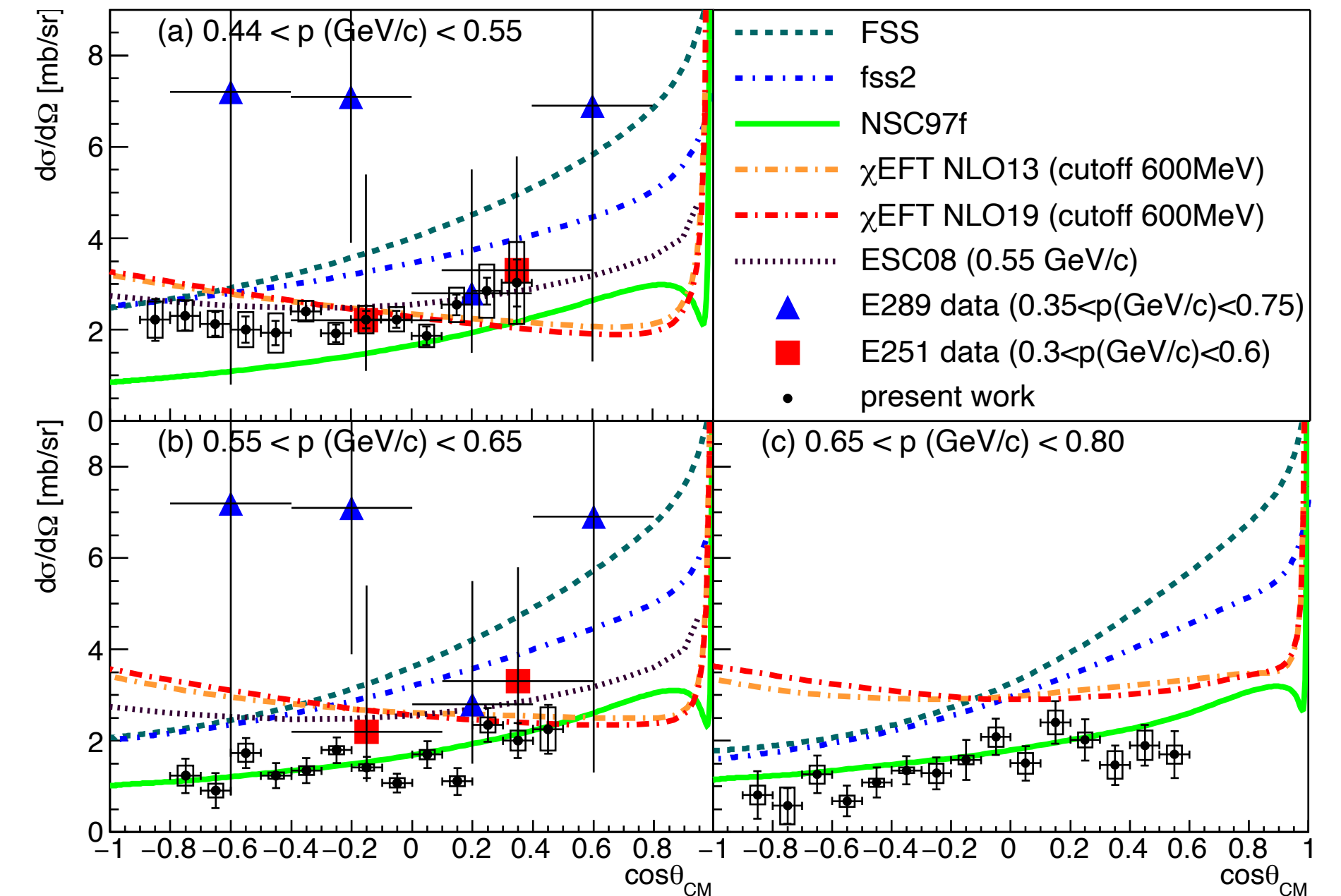


- ΣN scattering \leftarrow J-PARC E40

- ΞN : ~ 14 MeV (Attraction) \leftarrow BNL-E885 $^{12}\text{C}(K^-, K^+)^{12}_{\Xi}\text{Be}$

- How much deep ? \leftarrow Kiso Event, Ibuki Event,

- How about couplings $\leftarrow \Xi N \rightarrow \Lambda \Lambda$? Kinka Event, IRRAWADHI event



RECENT TOPICS ON S=-2

■ E07 (+E373) K. Nakazawa, K. Imai, H. Tamura et al.

■ Double Λ

■ Nagara event ${}^6_{\Lambda\Lambda}\text{He}$; s-orbital; $B_{\Lambda\Lambda}=0.67\pm0.17$ MeV

■ Mino event ${}_{\Lambda\Lambda}{}^{11}\text{Be}$; Not well-identified.

■ Ξ -hypernuclei

■ Kiso and Ibuki events Ξ - ${}^{14}\text{N}$:

Coulomb Assisted — Ξ state

■ Kinka & IRRRAWADHI events :

Deeply-bound Ξ state



E373 : HYBRID EMULSION EXPERIMENT

Fruitfull events observed !

- K. Nakazawa, K. Imai, H. Tamura et al.

KURAMA
Spectrometer

E373 $^{12}\text{C}(\text{K}^-, \text{K}^+)$

Diamond+SciFi+Emulsion

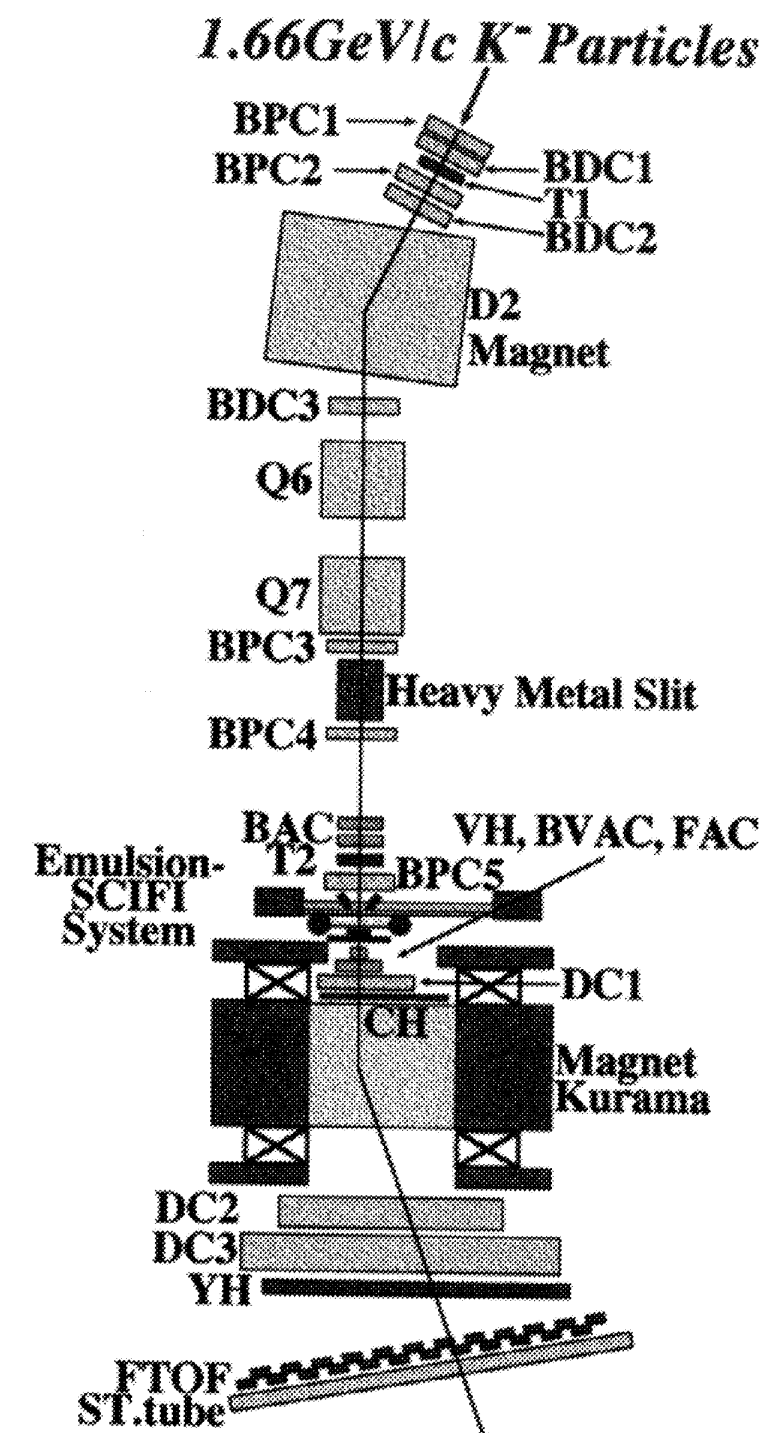


Fig.1 A schematic drawing of the experimental setup.

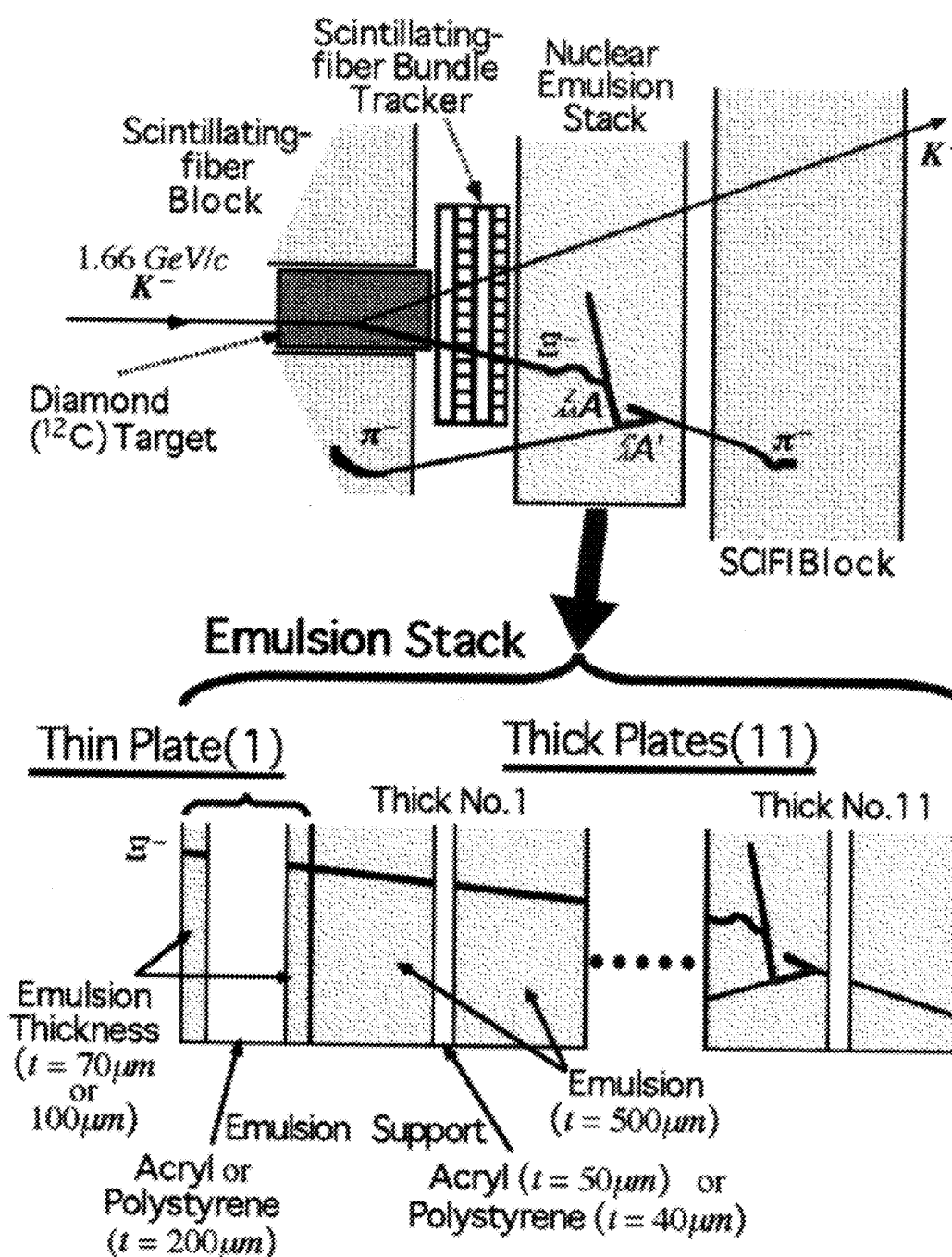


Fig.2 Around target area and the emulsion stack.

$p_{\text{K}^-} = 1.66\text{ GeV}/c$

Nagara event : $\Xi^- + ^{14}\text{N} \rightarrow {}^6_{\Lambda\Lambda}\text{He} + ^4\text{He} + t$,
 ${}^6_{\Lambda\Lambda}\text{He} \rightarrow {}^5_{\Lambda}\text{He} + \pi^- + p$,
 ${}^5_{\Lambda}\text{He} \rightarrow p + d + 2n$

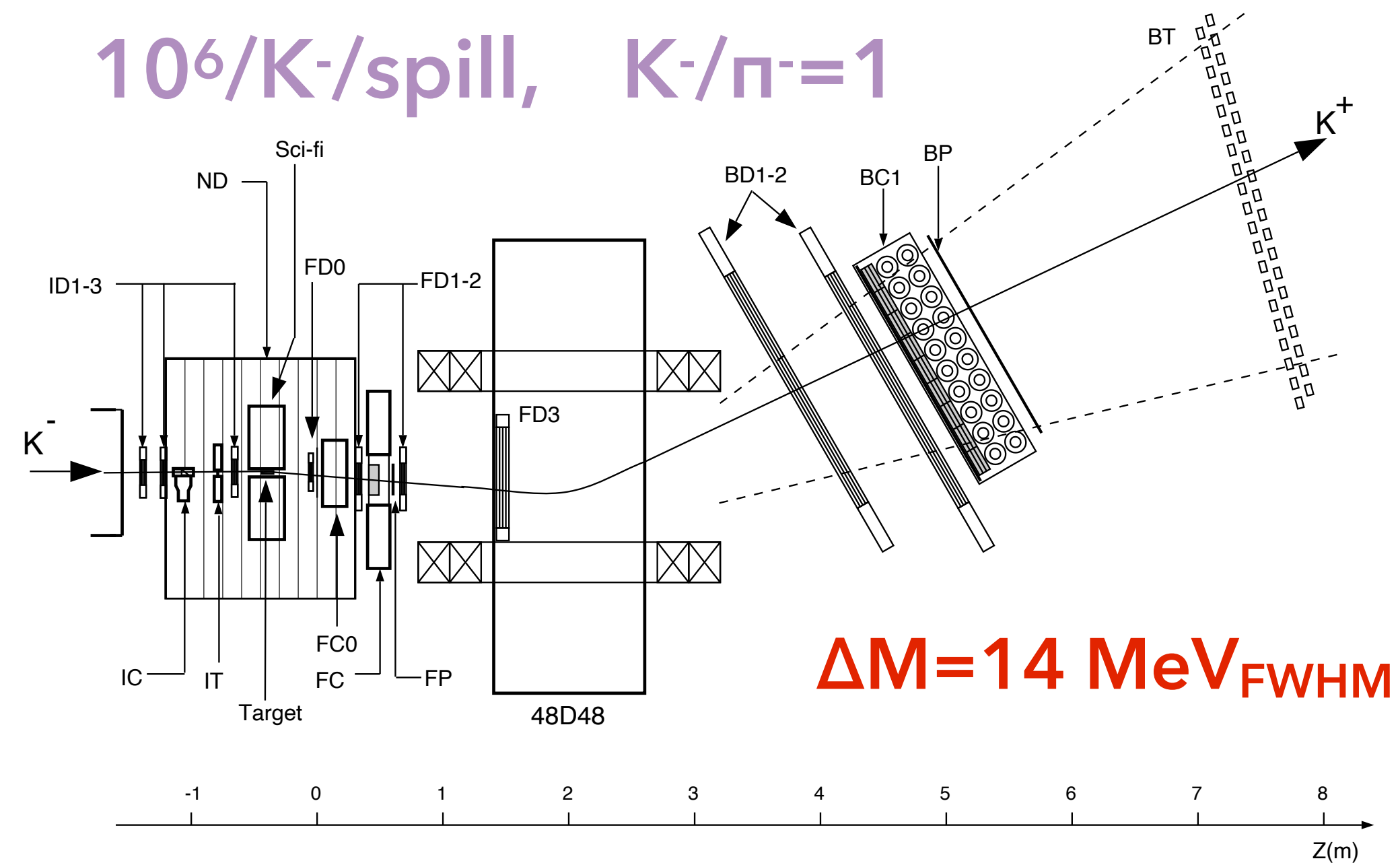


P. KHAUSTOV ET AL., PRC 61 (2000) 054603.

BNL AGS E885 D6

$^{12}\text{C}(\text{K}^-, \text{K}^+) @ 1.8 \text{ GeV}/c$

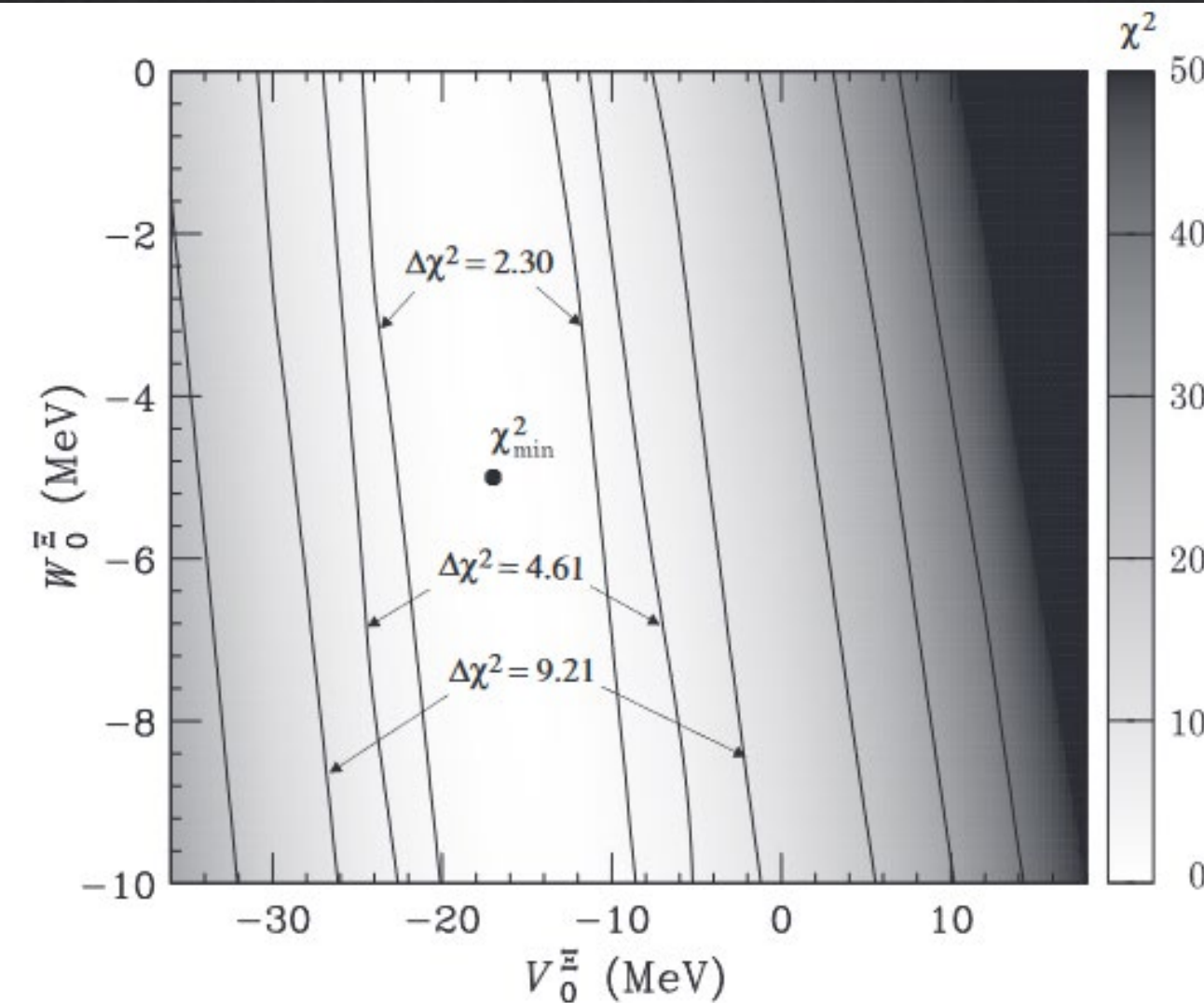
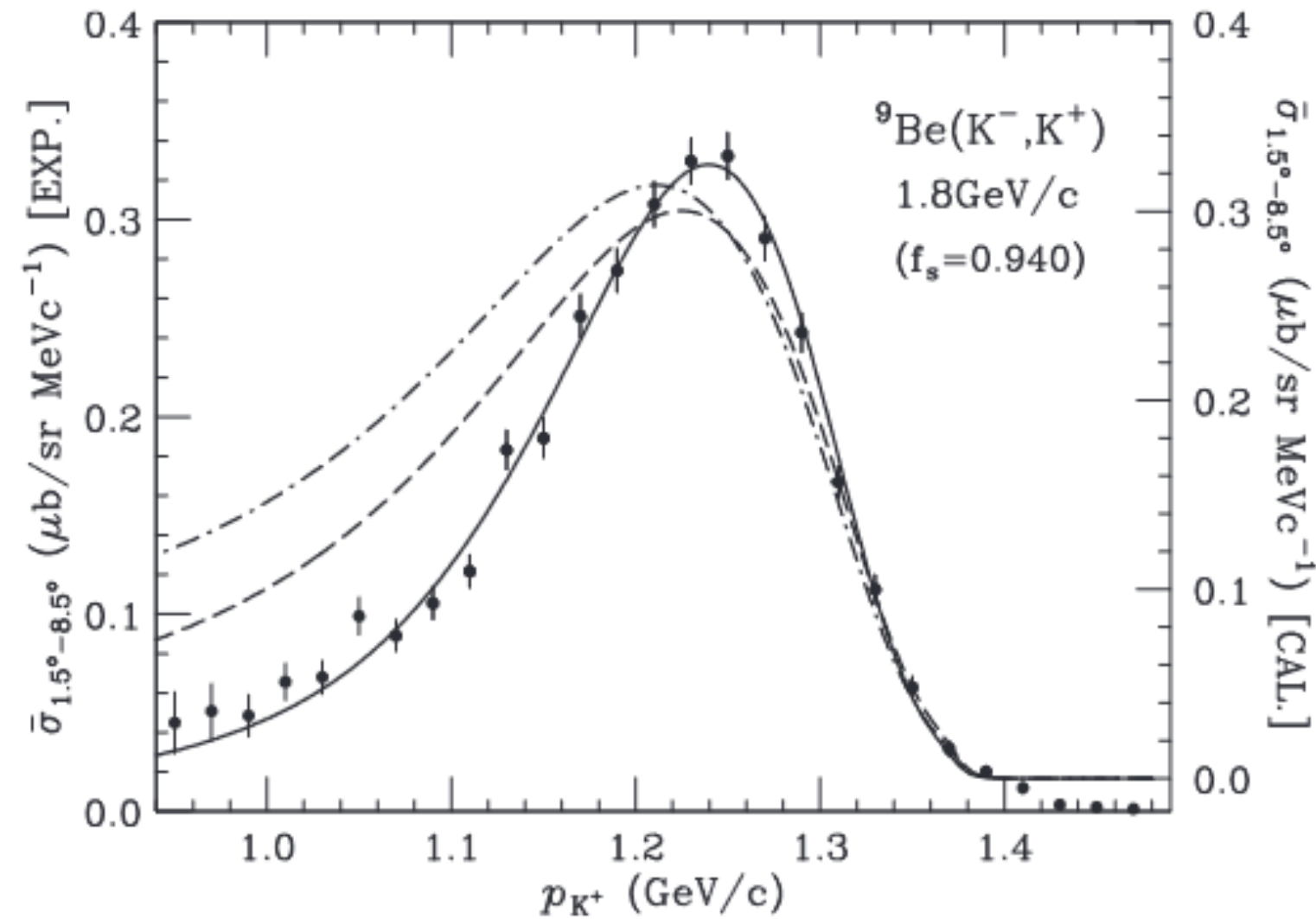
$10^6/\text{K}^-/\text{spill}, \text{K}^-/\pi^-=1$



ESTIMATES ON THE Ξ A POTENTIALS

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

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



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

${}^9\text{Be}(K^-, K^+)$
QF scatt.

FIRST EVIDENCE OF Ξ -NUCLEUS

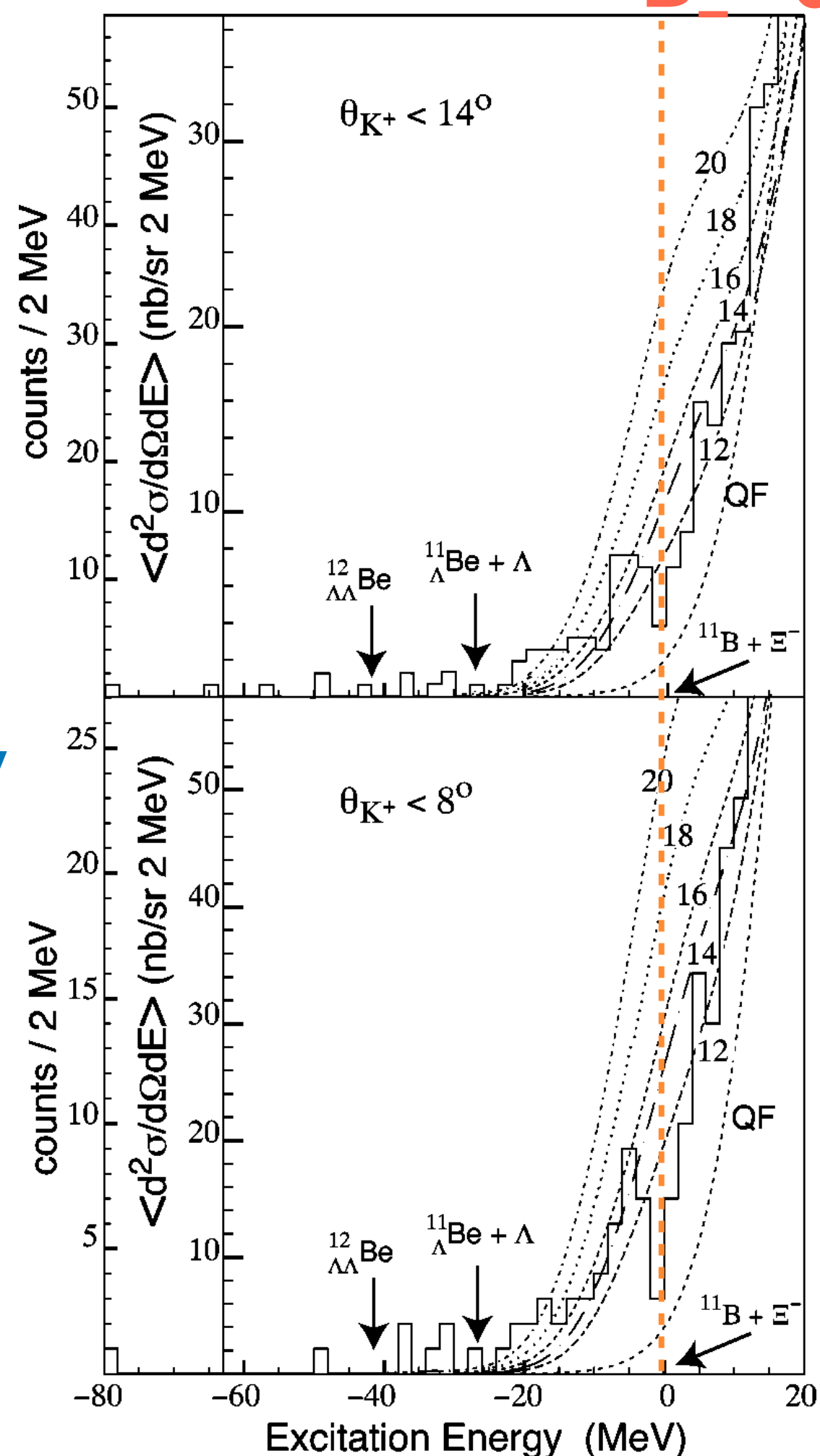
Weakly Attractive

PHYSICAL REVIEW C **61** 054603

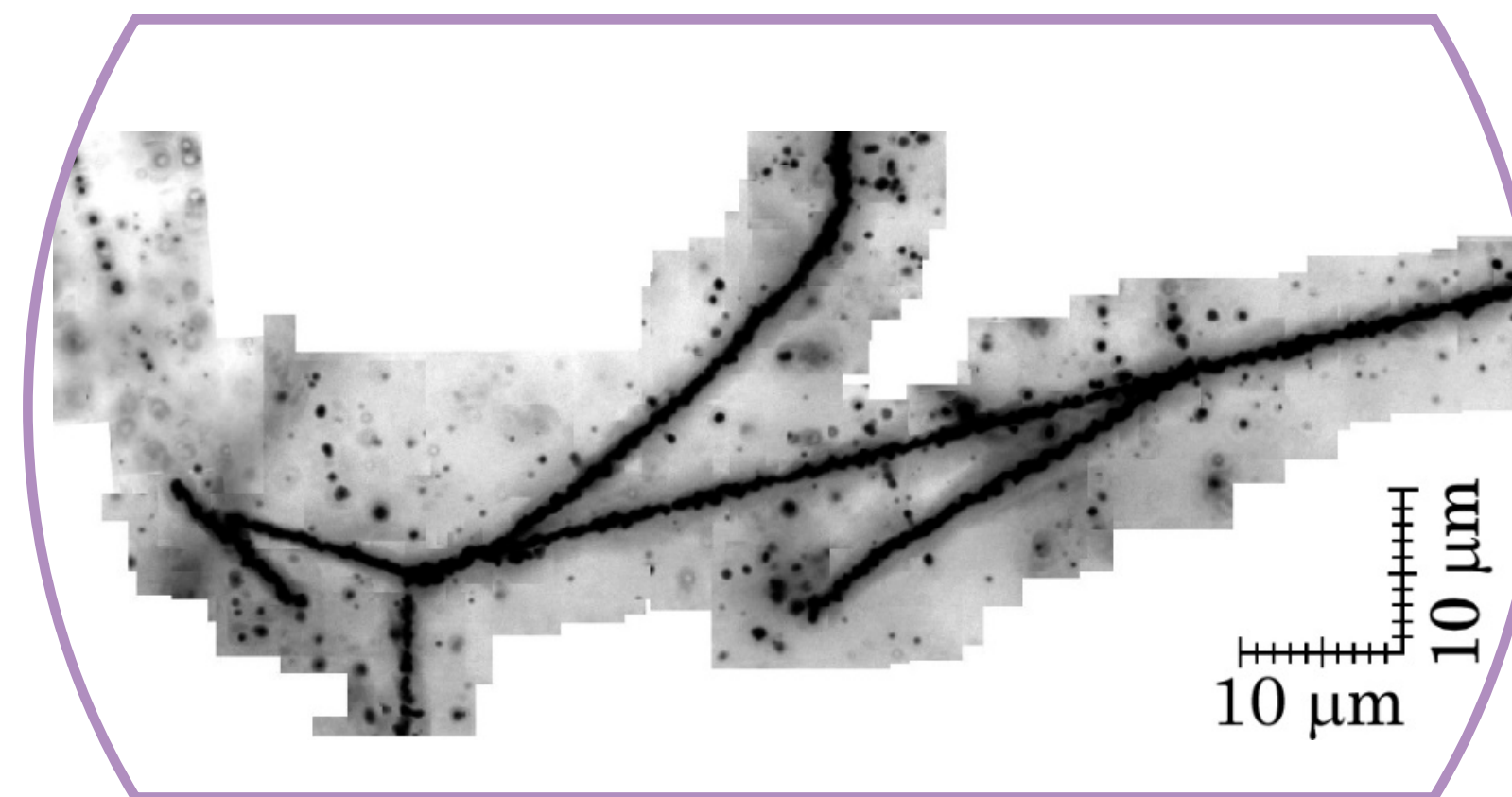
$B_{\Xi}=0$

$V_{\Xi}=14$ MeV

$B_{\Xi}=4.5$ MeV



■ KISO Event



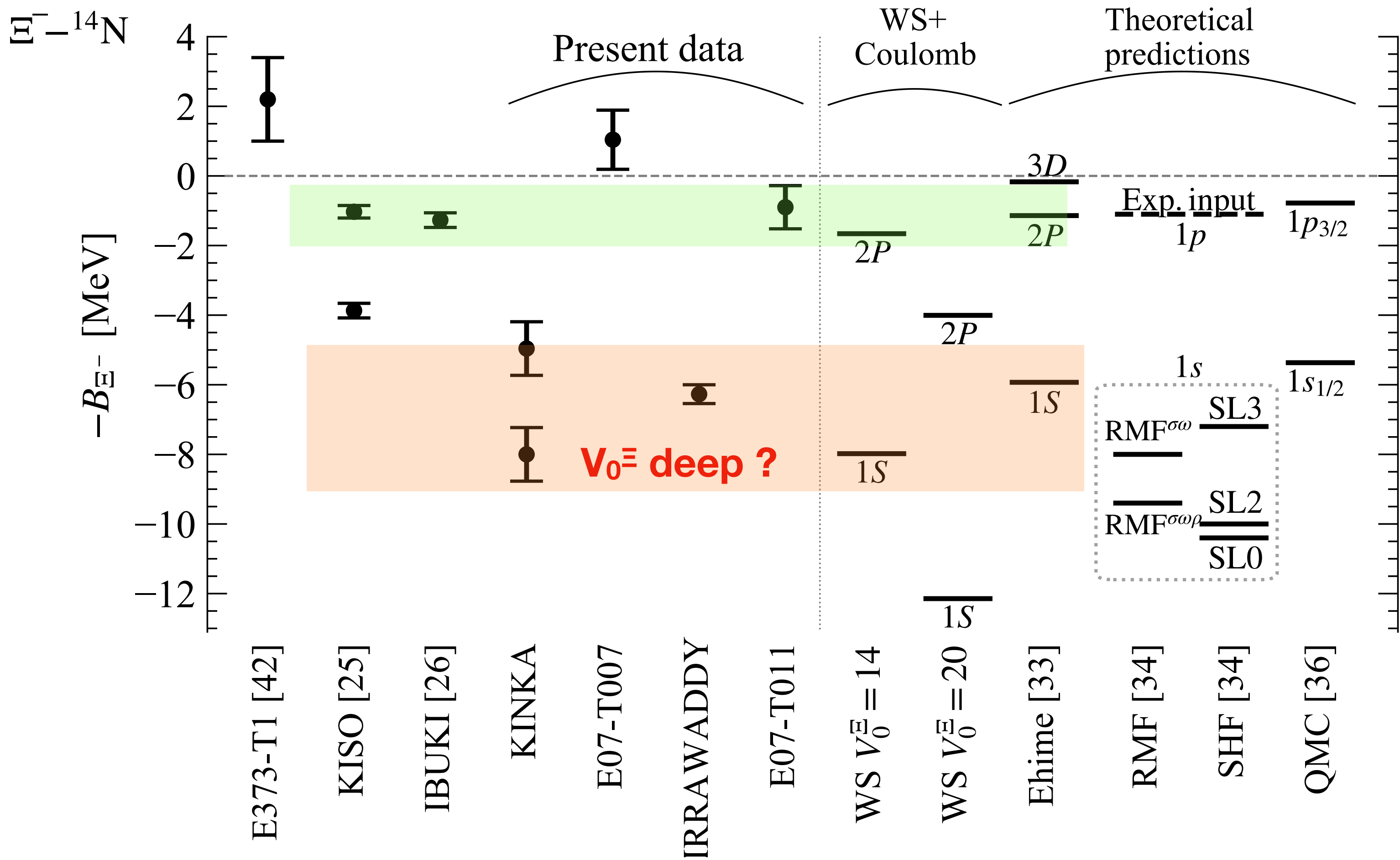
- ❖ $B_{\Xi}=1.03\pm0.18$ or 3.87 ± 0.21 MeV $\pm\Gamma/2$
- ❖ Well beyond the atomic binding of 0.17 MeV

Ξ -NUCLEUS POTENTIAL
ATTRACTIVE !



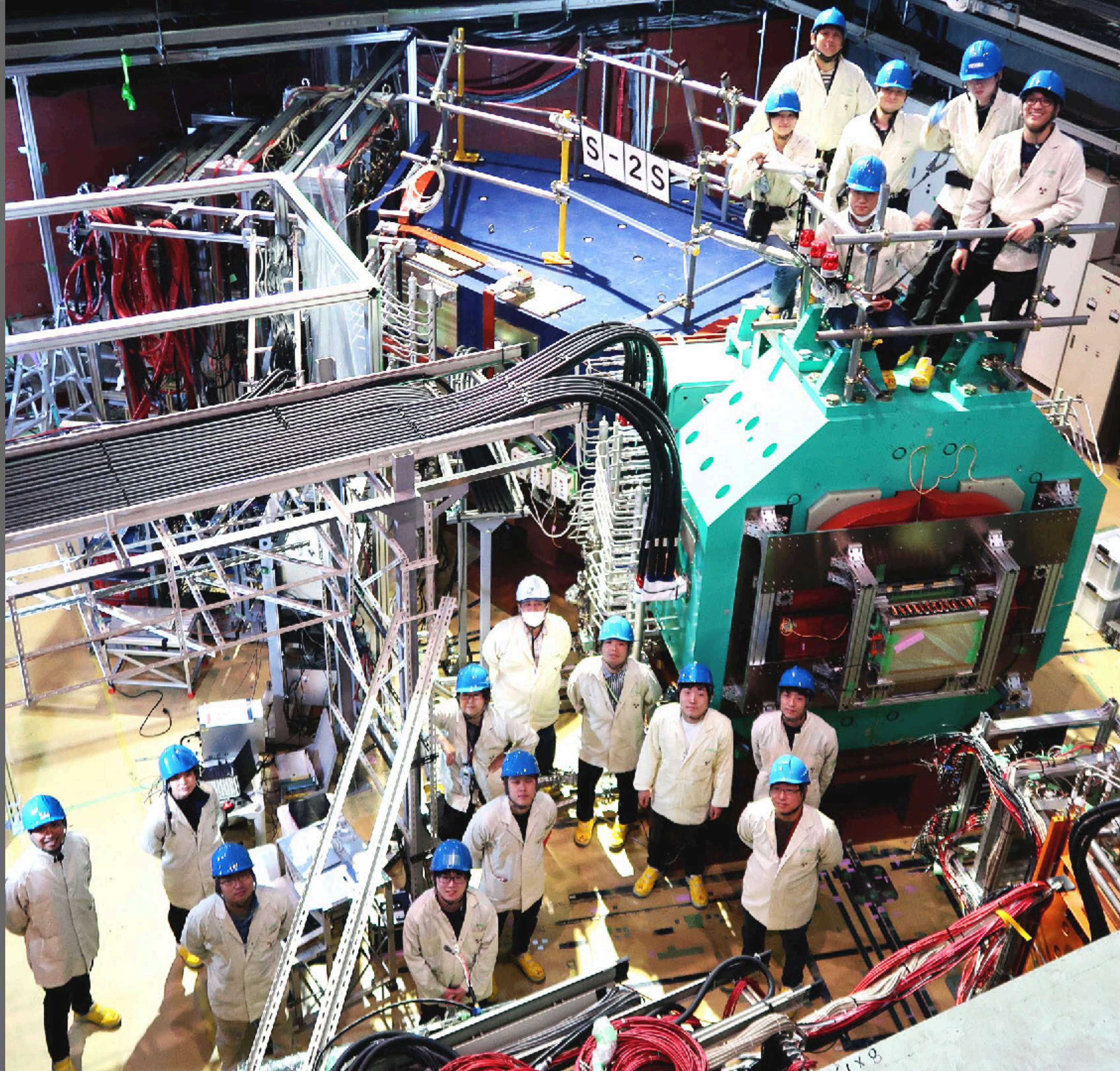
J-PARC E07

First Observation of a nuclear s-state of a Ξ hyper nucleus, $^{15}_{\Xi}\text{C}$



M. Yoshimoto et al., PTEP 2021 (2021) 7, 7
doi:10.1093/ptep/ptab073





S-2S

OUR STRATEGY TOWARDS S-2S

- **E05** : The Day One experiment for the J-PARC Hadron Hall

- Low K⁻ beam intensity at K1.8

SKS Spectrometer
($\Delta E=1.4$ MeV,
 $\Delta E=3.4$ MeV)

- π beam physics : **E19** $p(\pi^-, K^-)\Theta^+$, **E10** ${}^6\text{Li}(\pi^-, K^+){}^6\Lambda\text{H}$, **E27** $d(\pi^+, K^+)$

- K⁻ beam physics: **E07** hybrid emulsion, **E40** $\Sigma^\pm p$ scattering, **E42** H-dibaryon, ...

KURAMA Spectrometer

- S-2S Construction with a special Grant-In-aid

S-2S($\Delta E=1-2$ MeV)

- Q1, Q2 construction (2012)

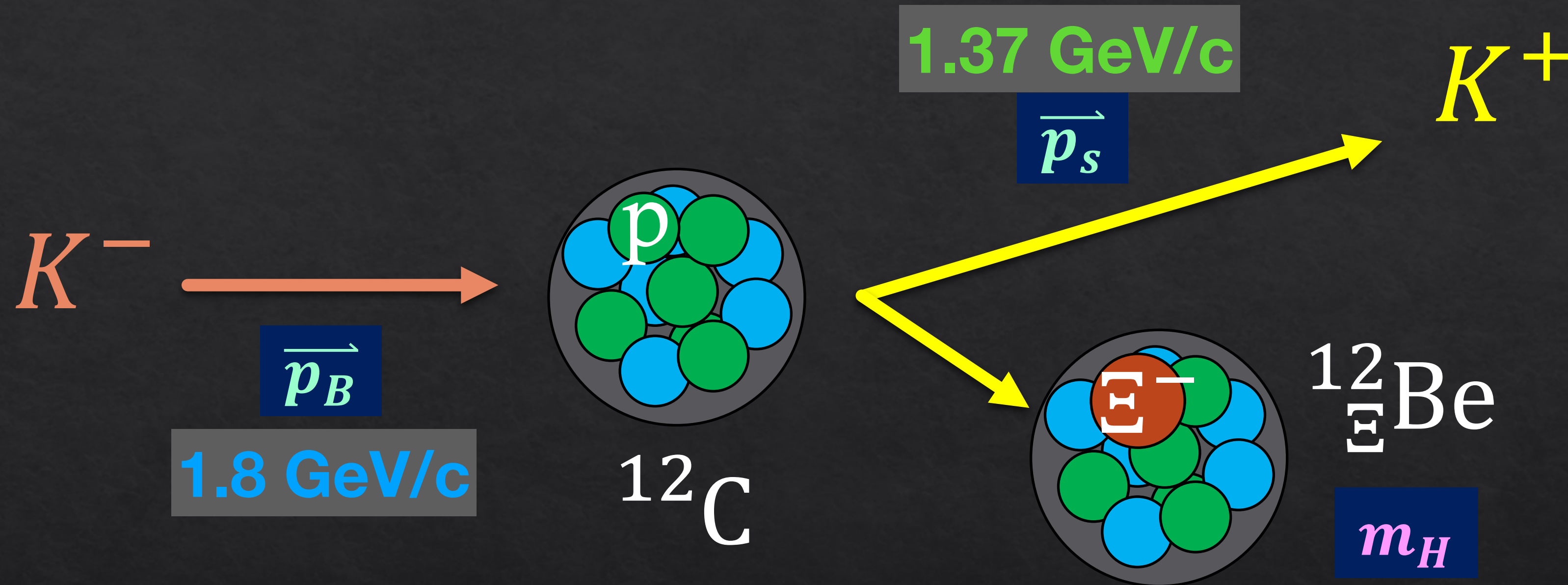
- D1 (2015) Field mapping (2016) at Tsukuba

- All the magnets moved to J-PARC (2022)



E70: (K⁻,K⁺) MISSING-MASS SPECTROSCOPY WITH S-2S

Missing mass spectroscopy (E70)



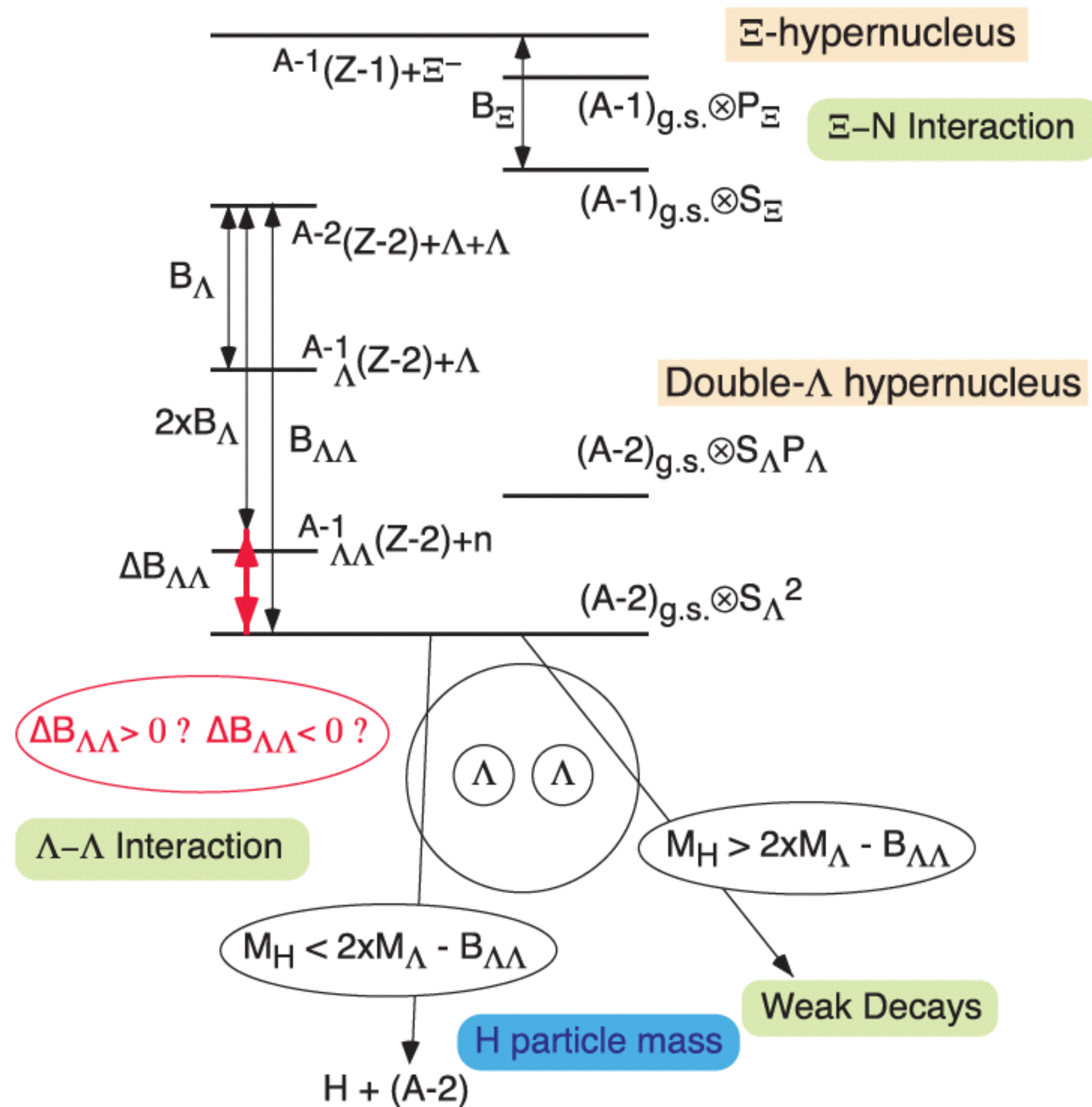
$$m_H = \sqrt{E_H^2 - \vec{p}_H^2} = \sqrt{(E_{\text{beam}} + M_t - E_s)^2 - (\vec{p}_B - \vec{p}_s)^2}$$

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

E70 : S-2S

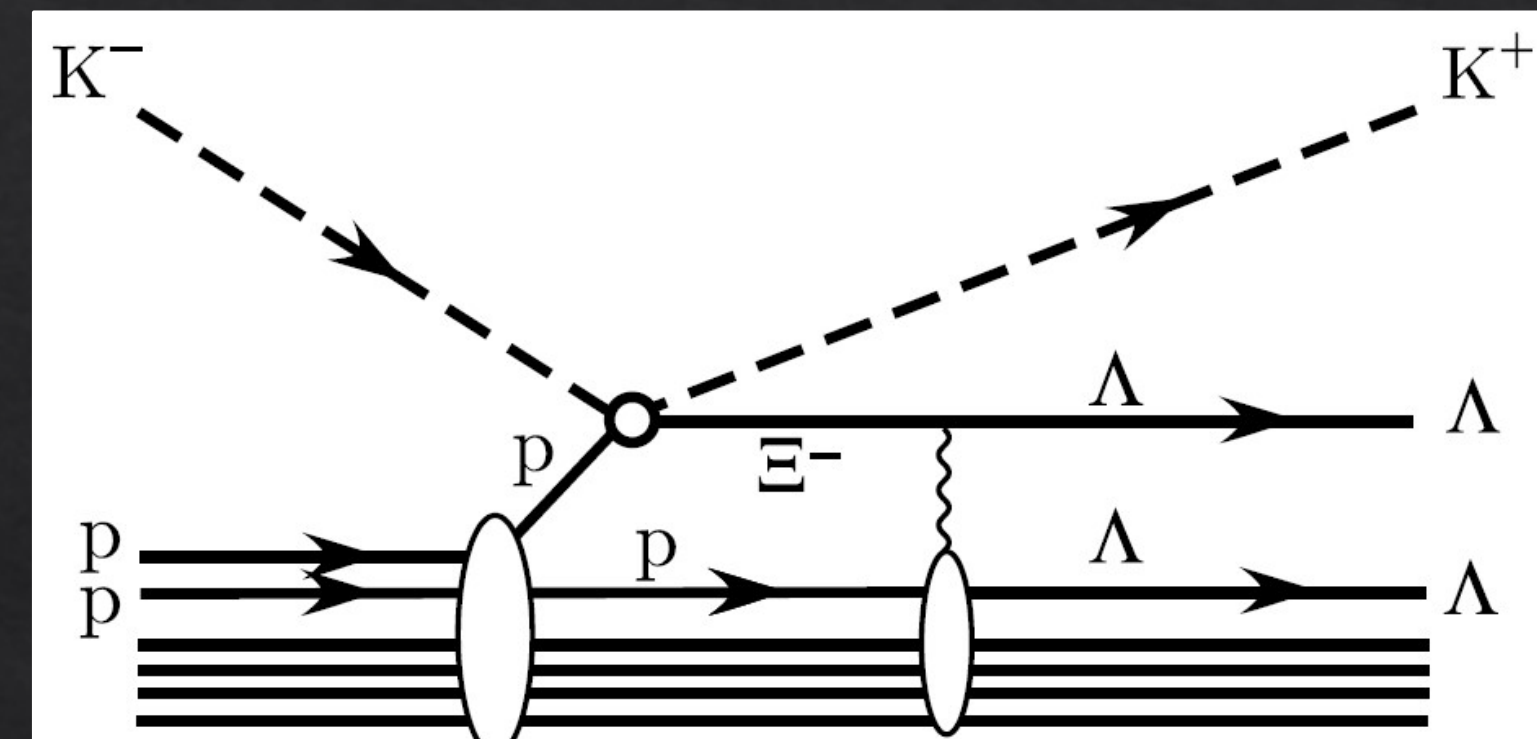
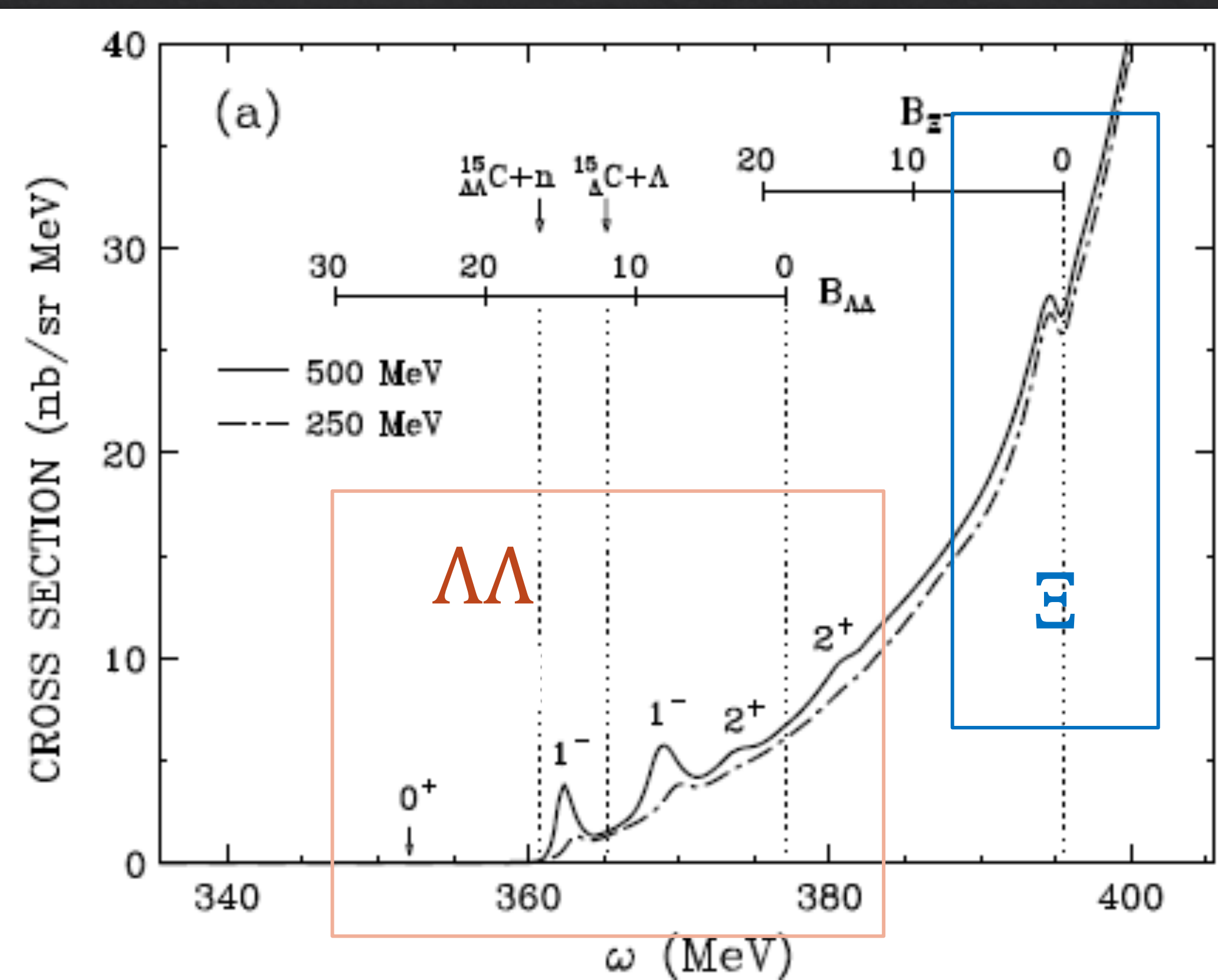
- $^{12}\text{C}(\text{K}^-, \text{K}^+)^{12}\Xi\text{Be}$ @ 1.8 GeV/c
- $\Xi\text{N}-\Lambda\Lambda$: 28 MeV apart

Energy Spectrum of S=-2 systems



COUPLING BETWEEN Ξ N AND $\Lambda\Lambda$

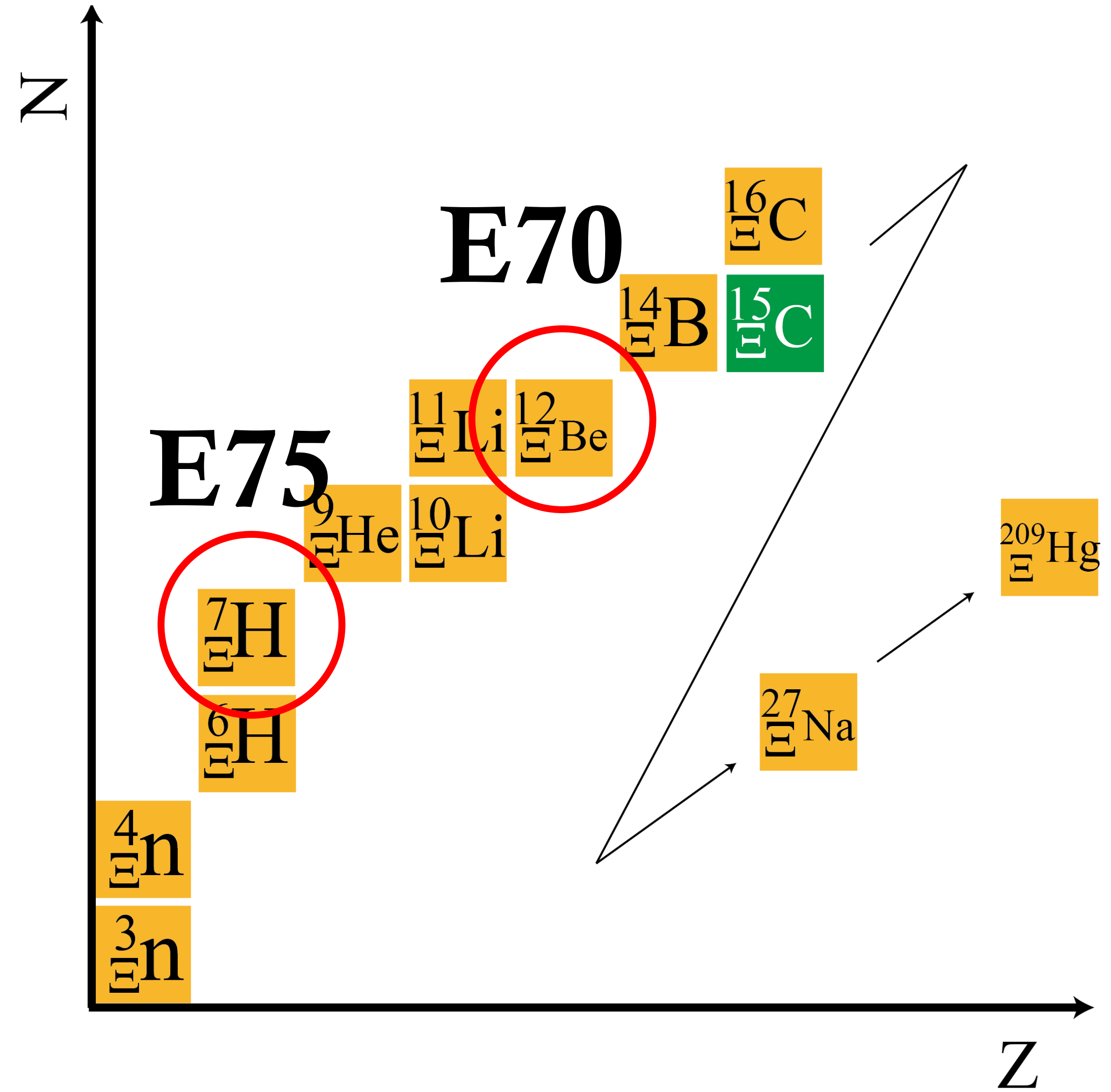
T. Harada, Y. Hirabayashi, A. Umeya, NPA 914, 85—90 (2013)



coupling with the same spin&parity



FULLY EXPLORE THE $S=-2$ WORLD WITH S-2S



A LOT OF QUESTIONS TO BE ANSWERED !

■ ΞN interaction $\sim \Sigma N$ interaction

■ $I=1/2$ $I=1$ **Coupling**

■ $\Xi N \rightarrow \Lambda\Lambda$ $\Sigma N \rightarrow \Lambda N$

■ How deep the Ξ ground state energy ?

■ How much absorptive the imaginary potential ?

■ What about the couplings ?

■ $pK=1.8$ GeV/c

■ Beam Intensity : 0.8 M/spill

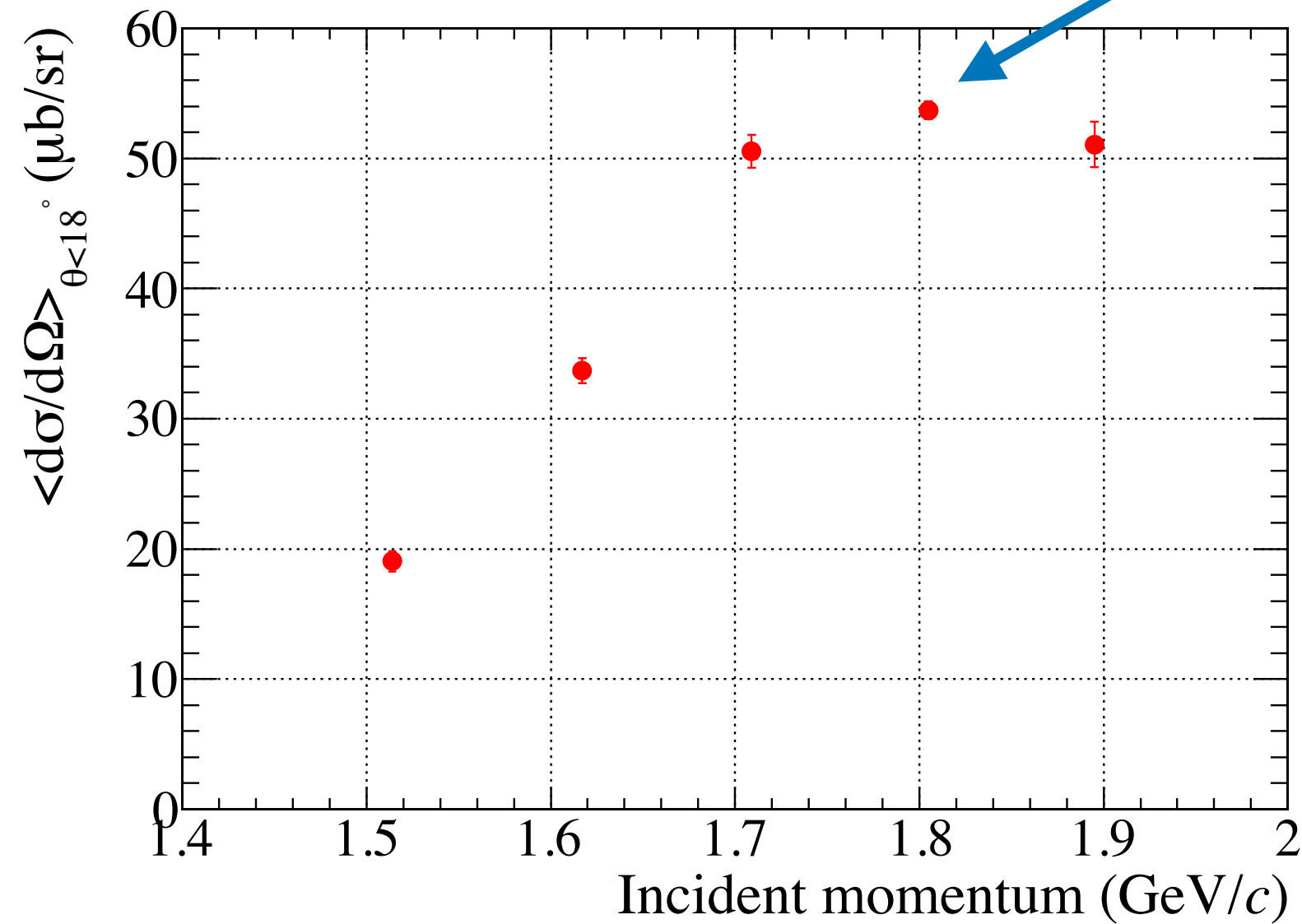
■ S-2S + Active Fiber + Ge Array

ΛN	ΣN	ΞN
$I=0$	$I=1$	$I=1/2$
$\Lambda N \rightarrow \Sigma N$	$\Sigma N \rightarrow \Lambda N$	$\Xi N \rightarrow \Lambda\Lambda$



PK- dependence

1.8 GeV/c



$d\sigma/d\Omega$

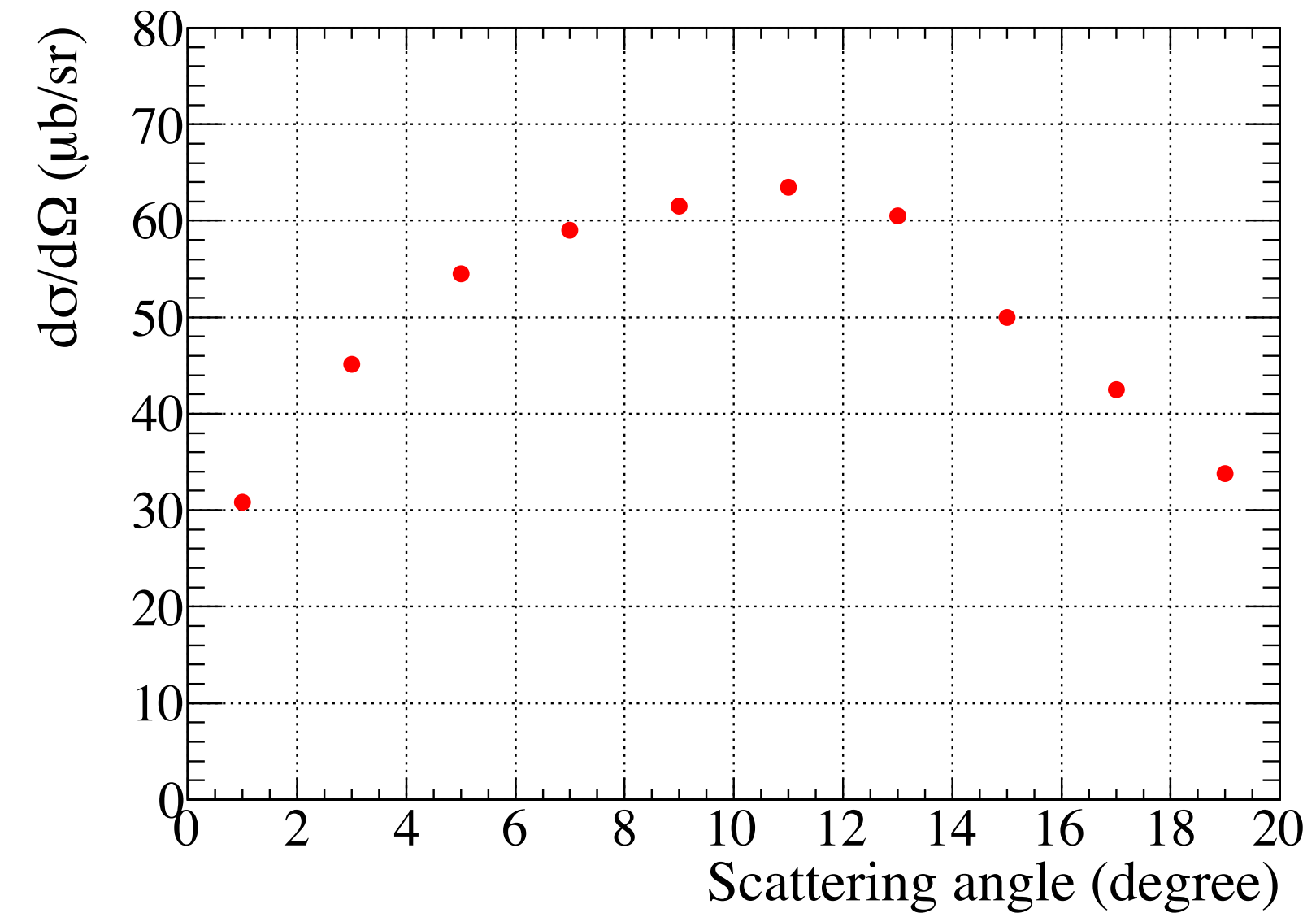


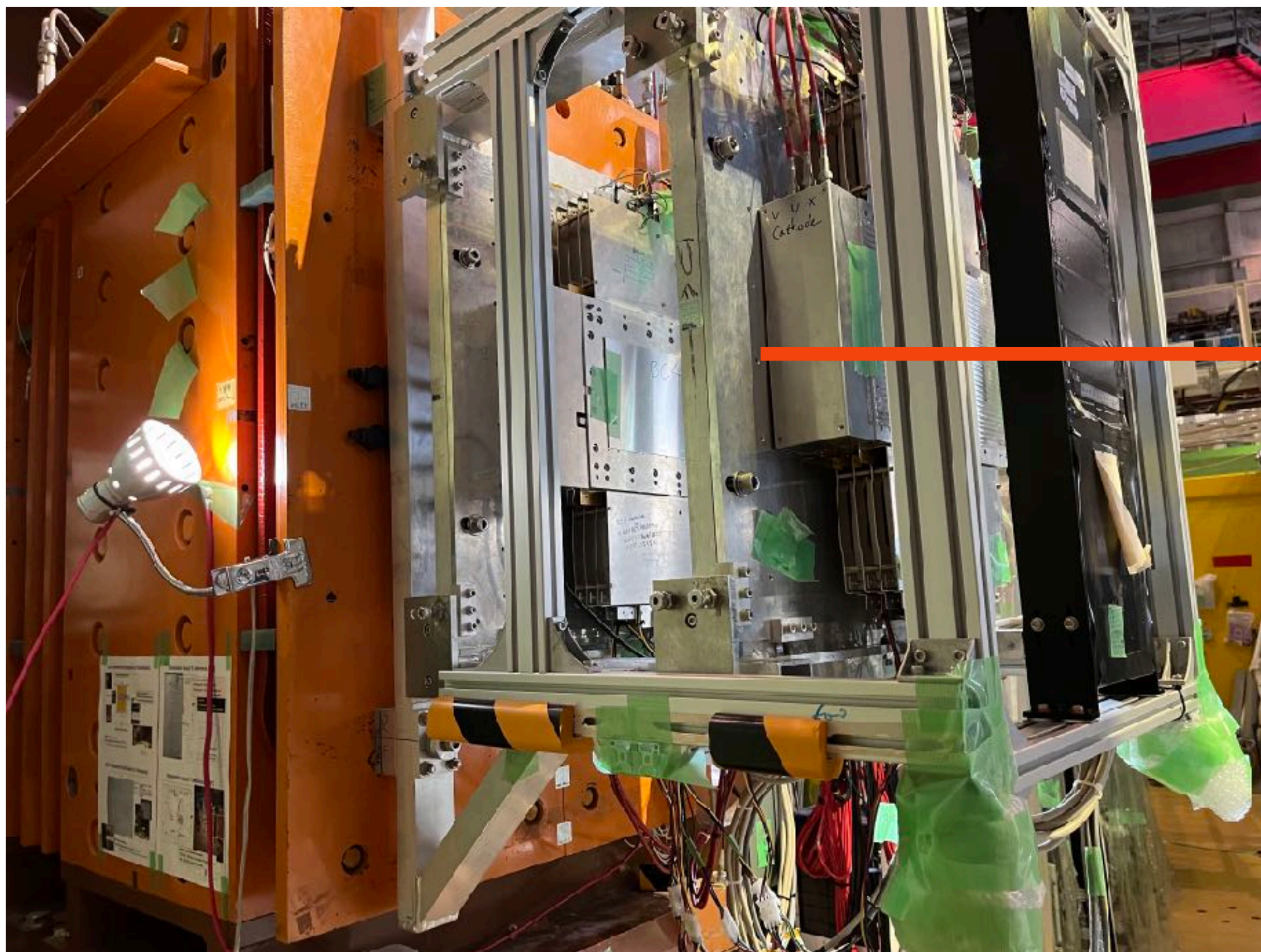
Fig. 5 (LEFT) Momentum dependence of the angle-averaged differential cross section for the $p(K^-, K^+)\Xi^-$ reaction. (RIGHT) Angular distribution for the $p(K^-, K^+)\Xi^-$ reaction at 1.8 GeV/c in the lab. system.



DETECTORS AT THE END OF THE BEAM LINE

BH2

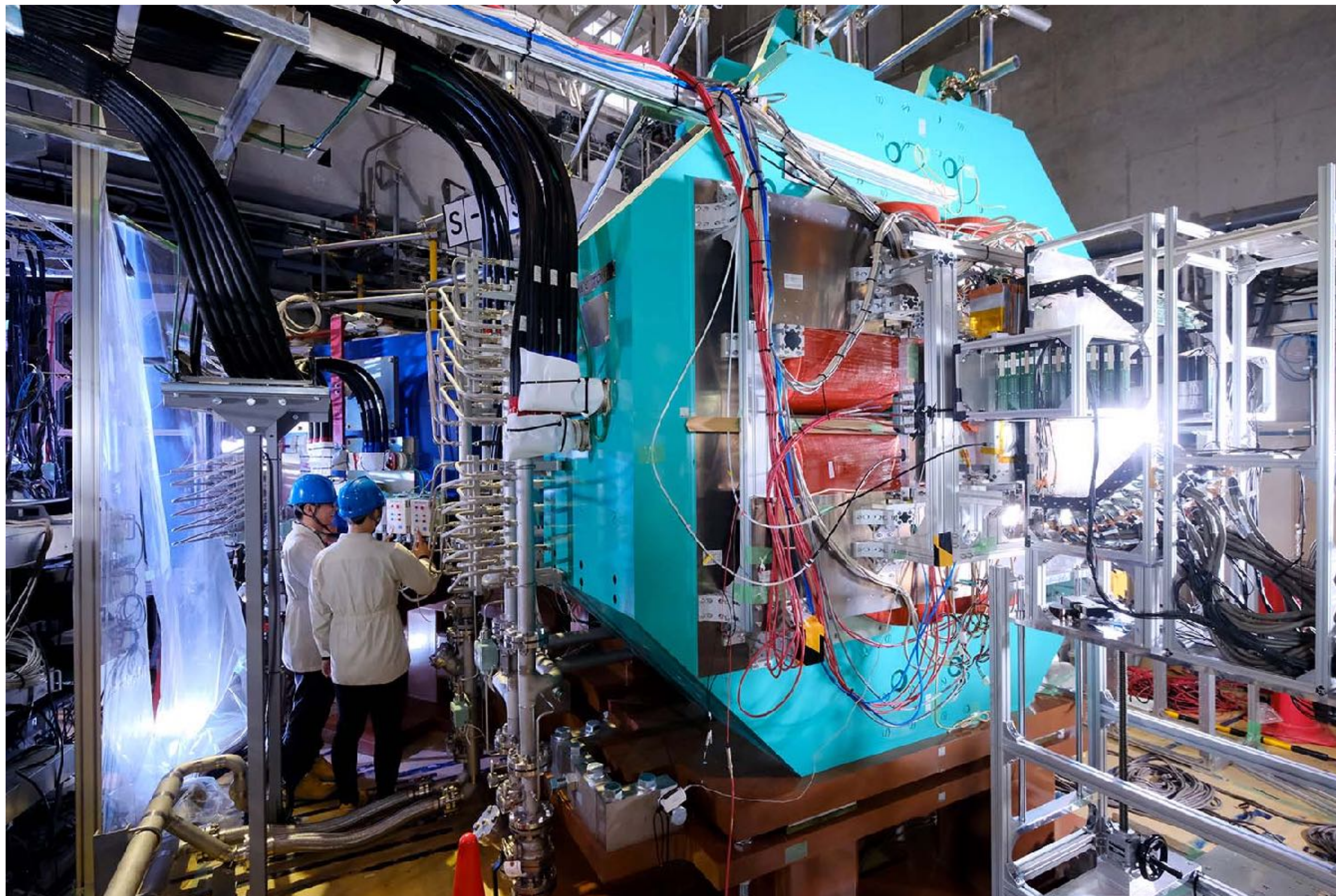
Electro-
Static
Separators



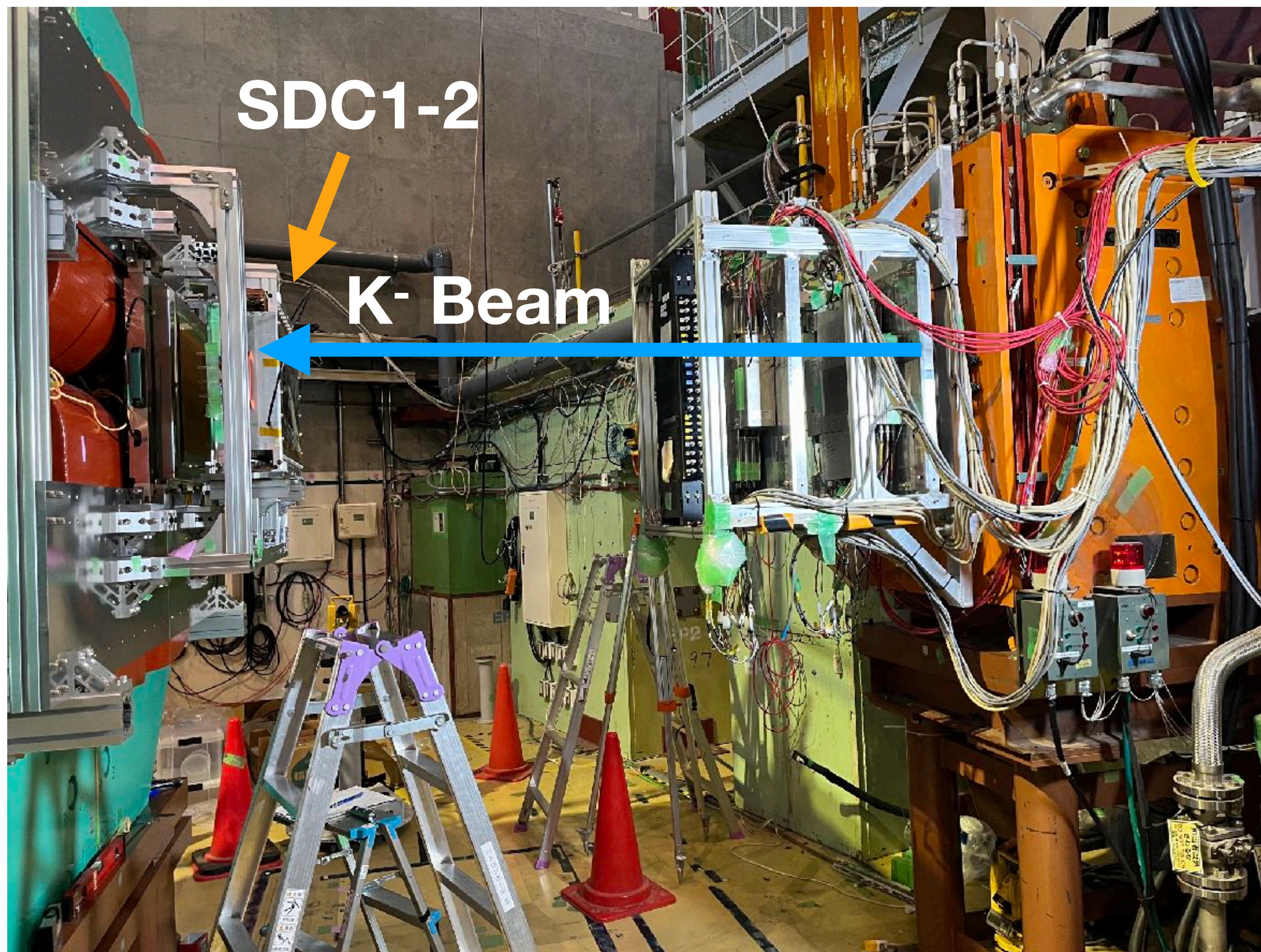
π/K - Beam



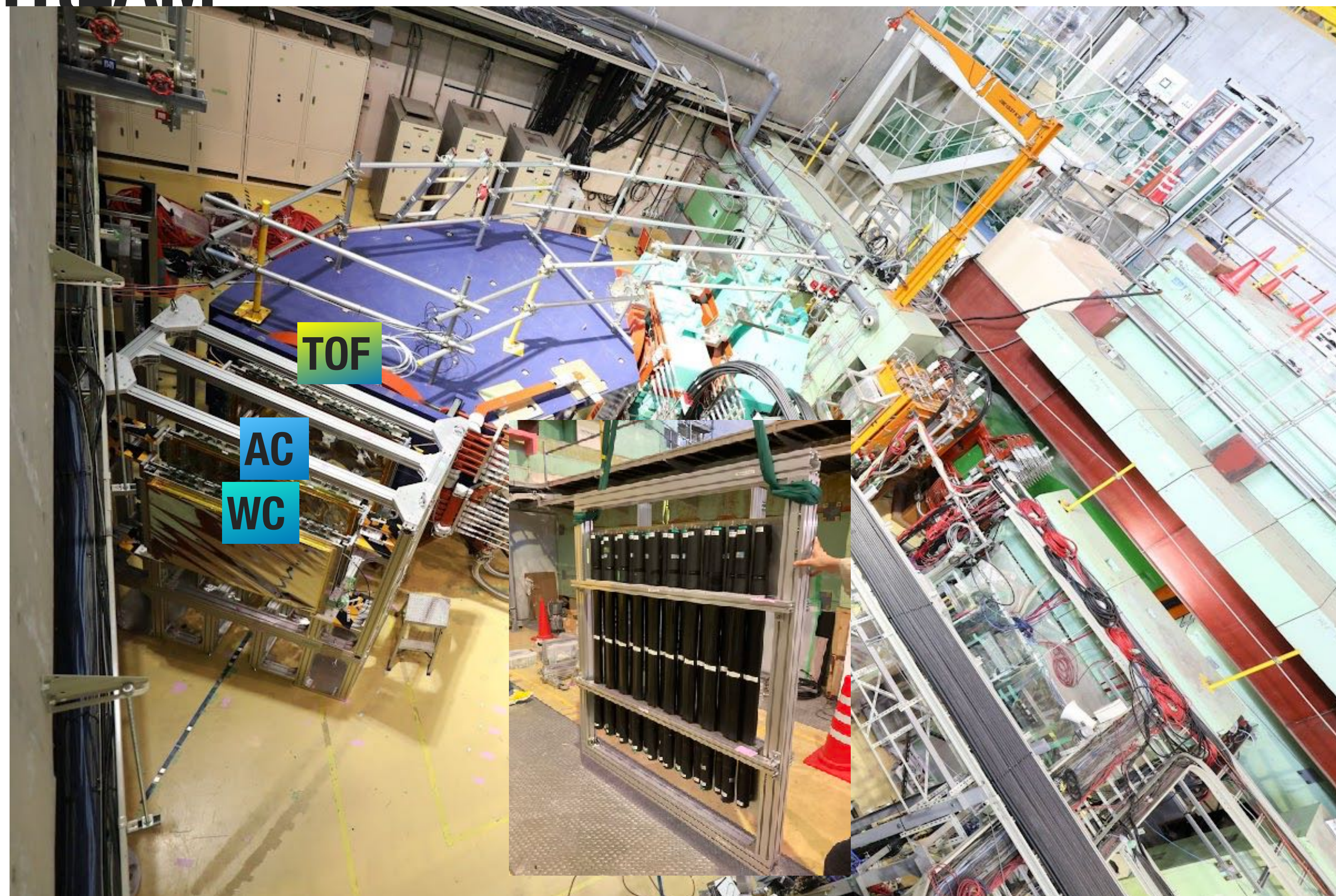
S-2S VIEWED FROM Q1 ENTRANCE



TARGET AREA



S-2S DOWNSTREAM



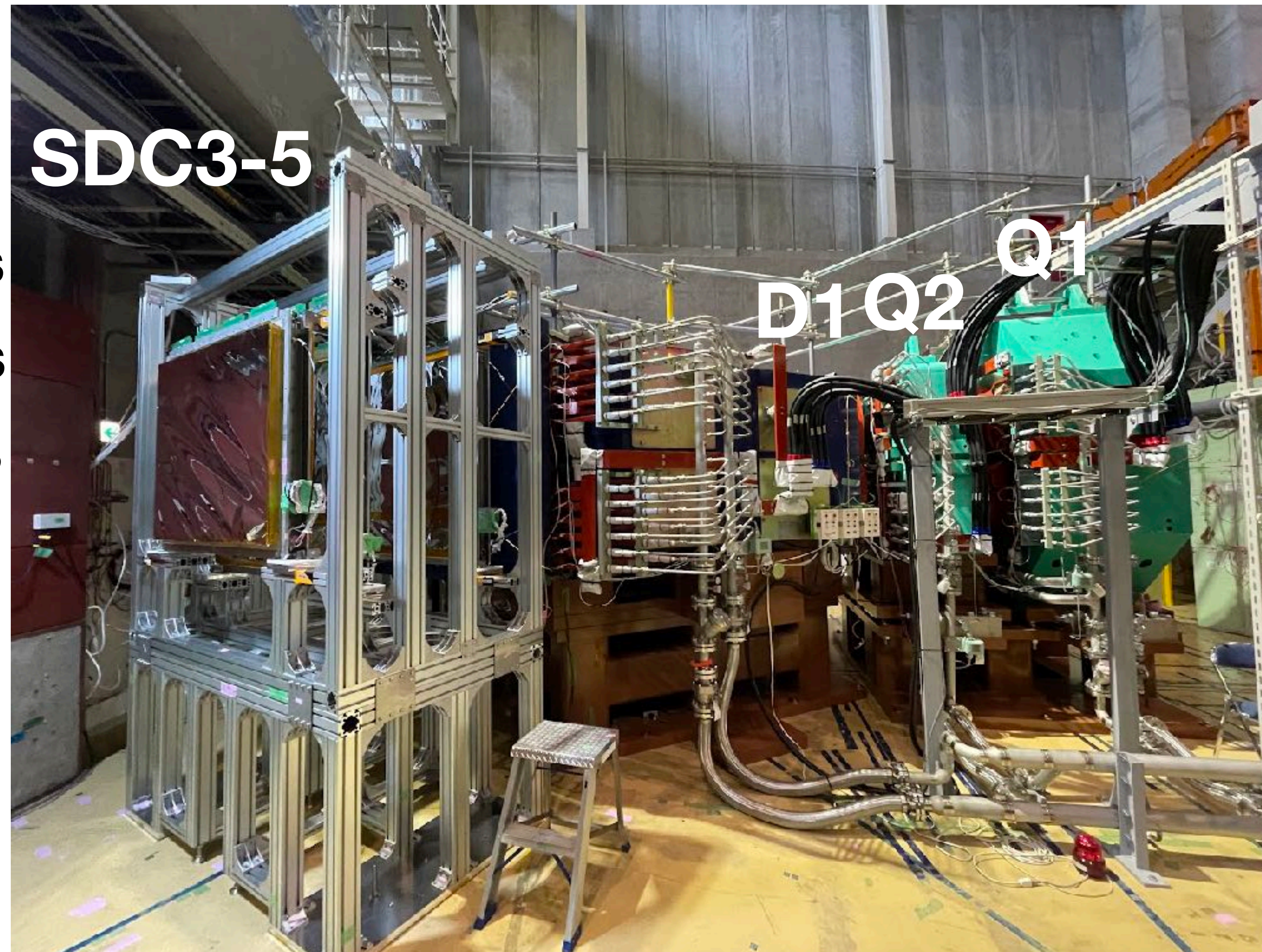
S-2S VIEWED FROM THE BACK

- S-2S Magnets

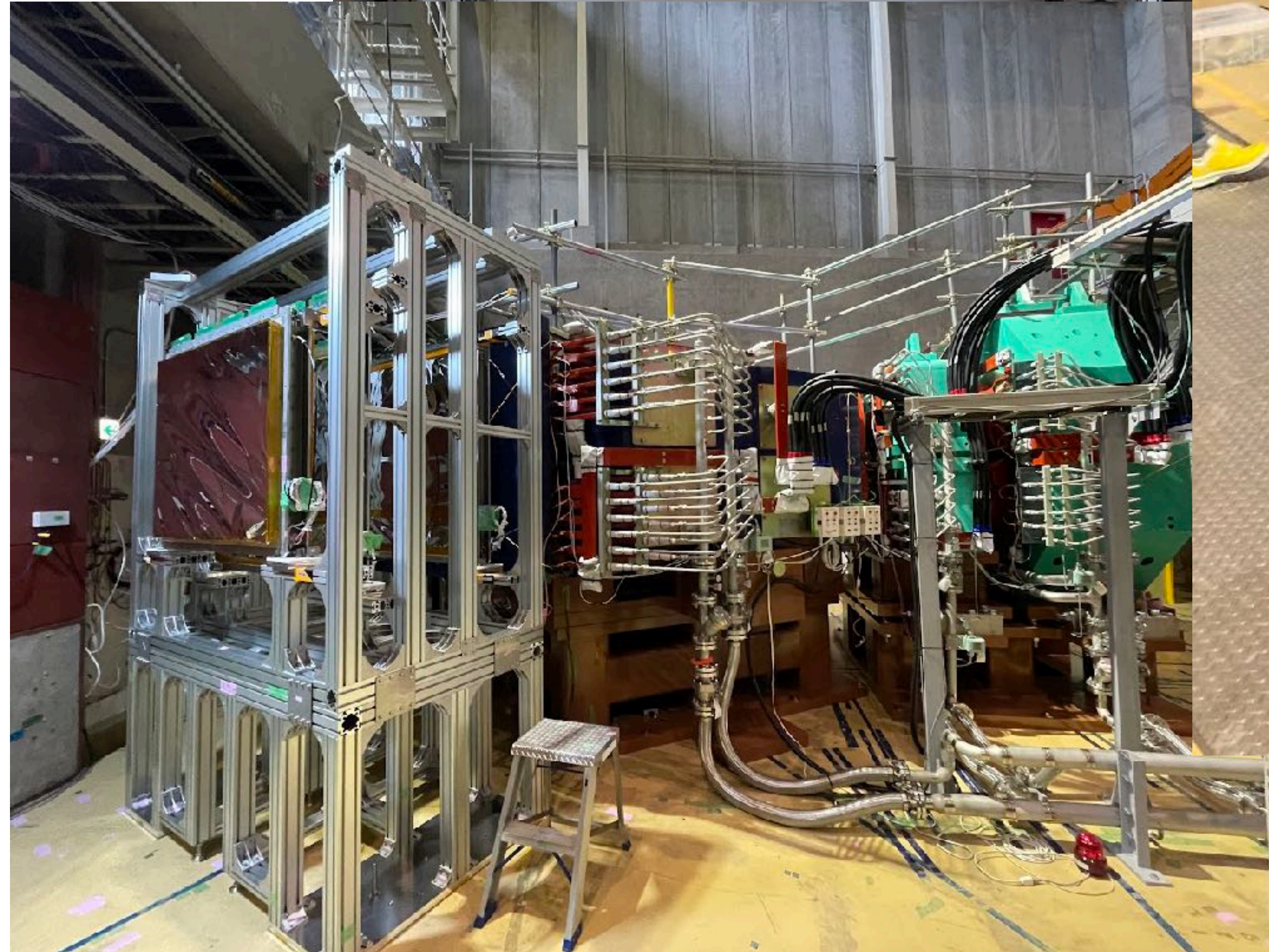
Q1:12 tons

Q2:37 tons

D1:86 tons



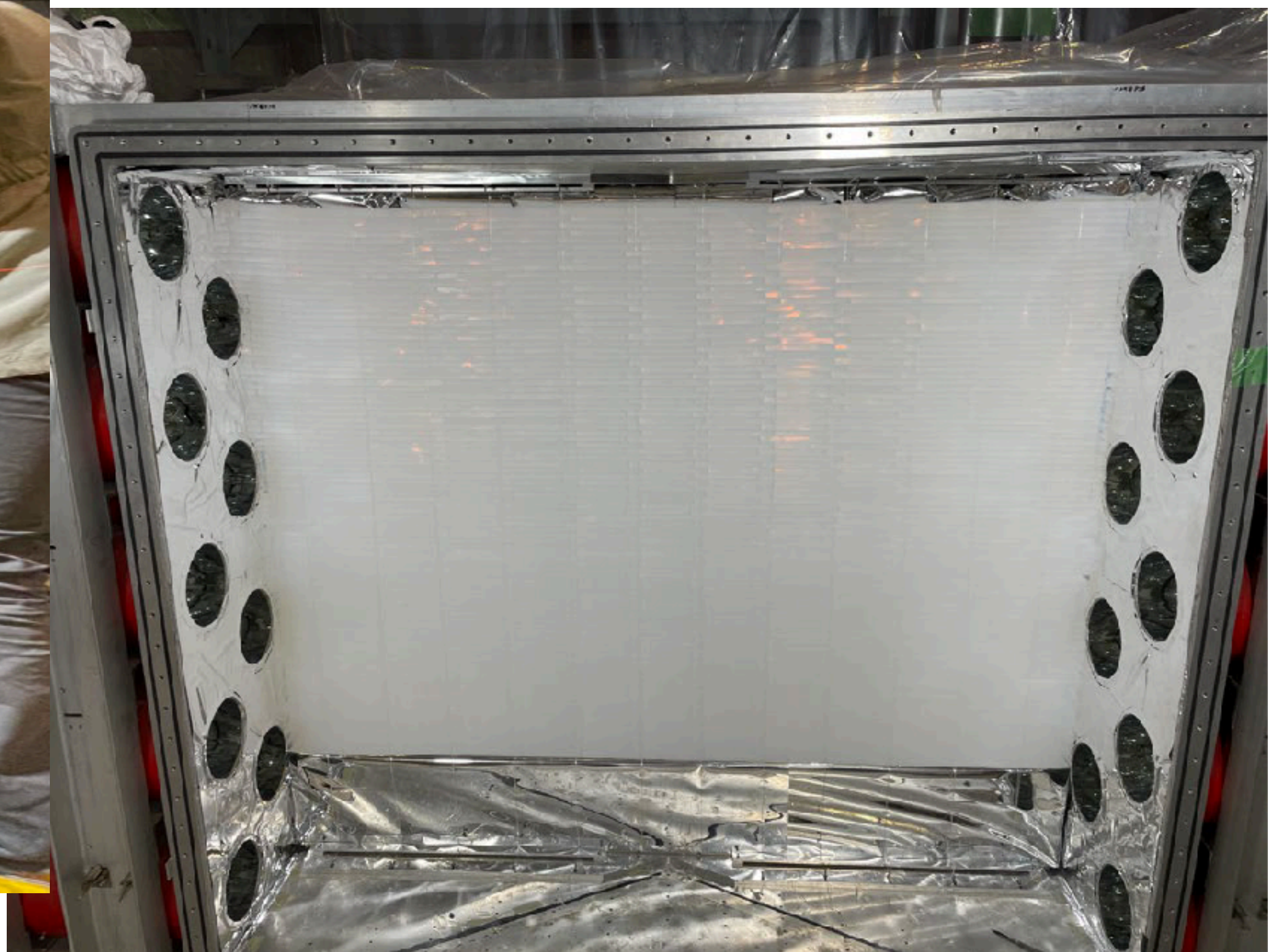
TOF, AC, SDC



DRIFT CHAMBERS INSTALLATION(JUNE, 2022)

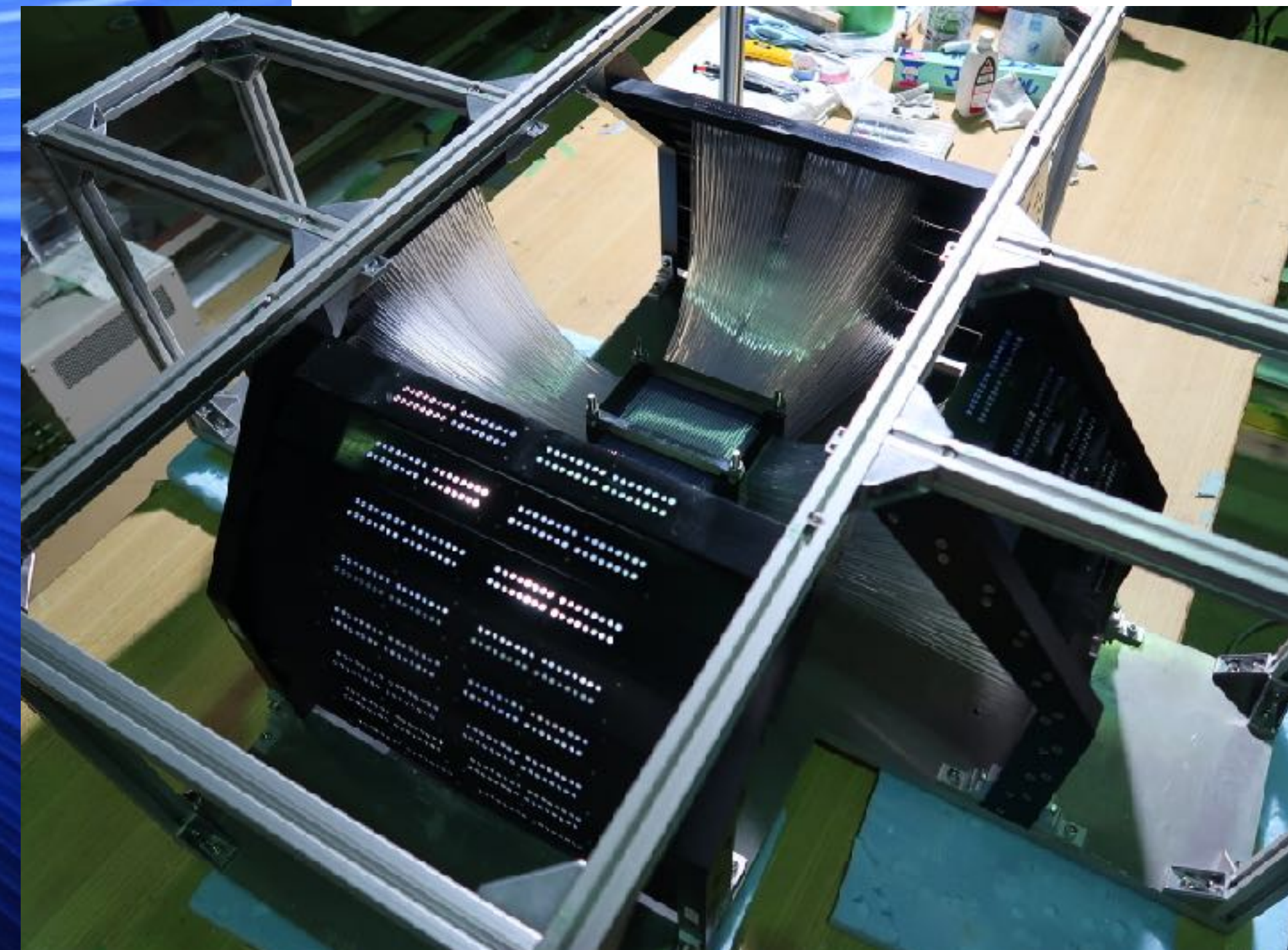
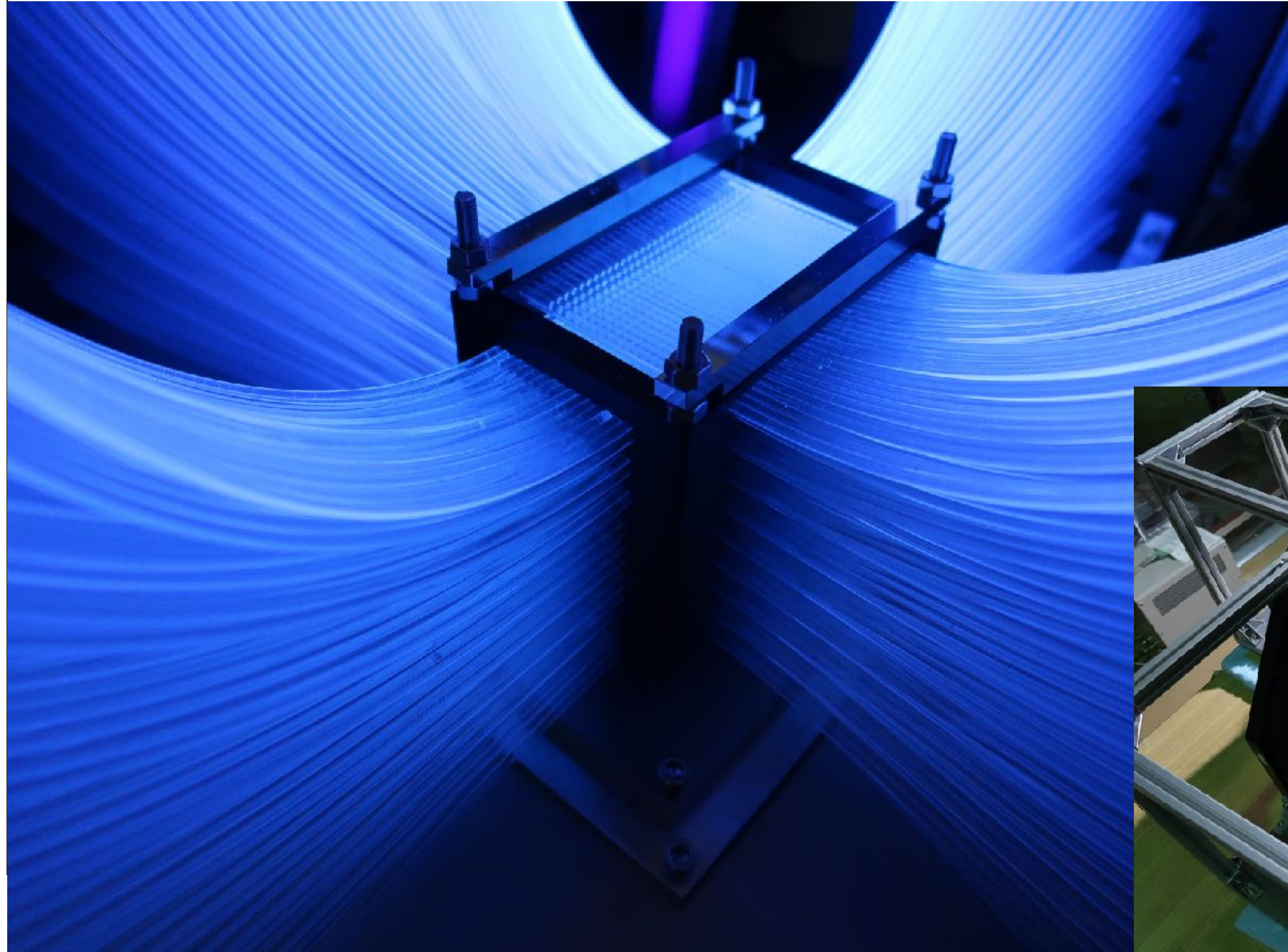


AeroGel Cherenkov



ACTIVE FIBERS TARGET $\Phi 3 \times 900$

**SIZE: 5 CM X
10 CM X 10CM
9G/CM² THICK**



E94 NEW GENERATION Λ HYPERNUCLEAR SPECTROSCOPY WITH THE (π^+, K^+) REACTION BY S-2S

T. Gogami (Kyoto Univ.) et al.

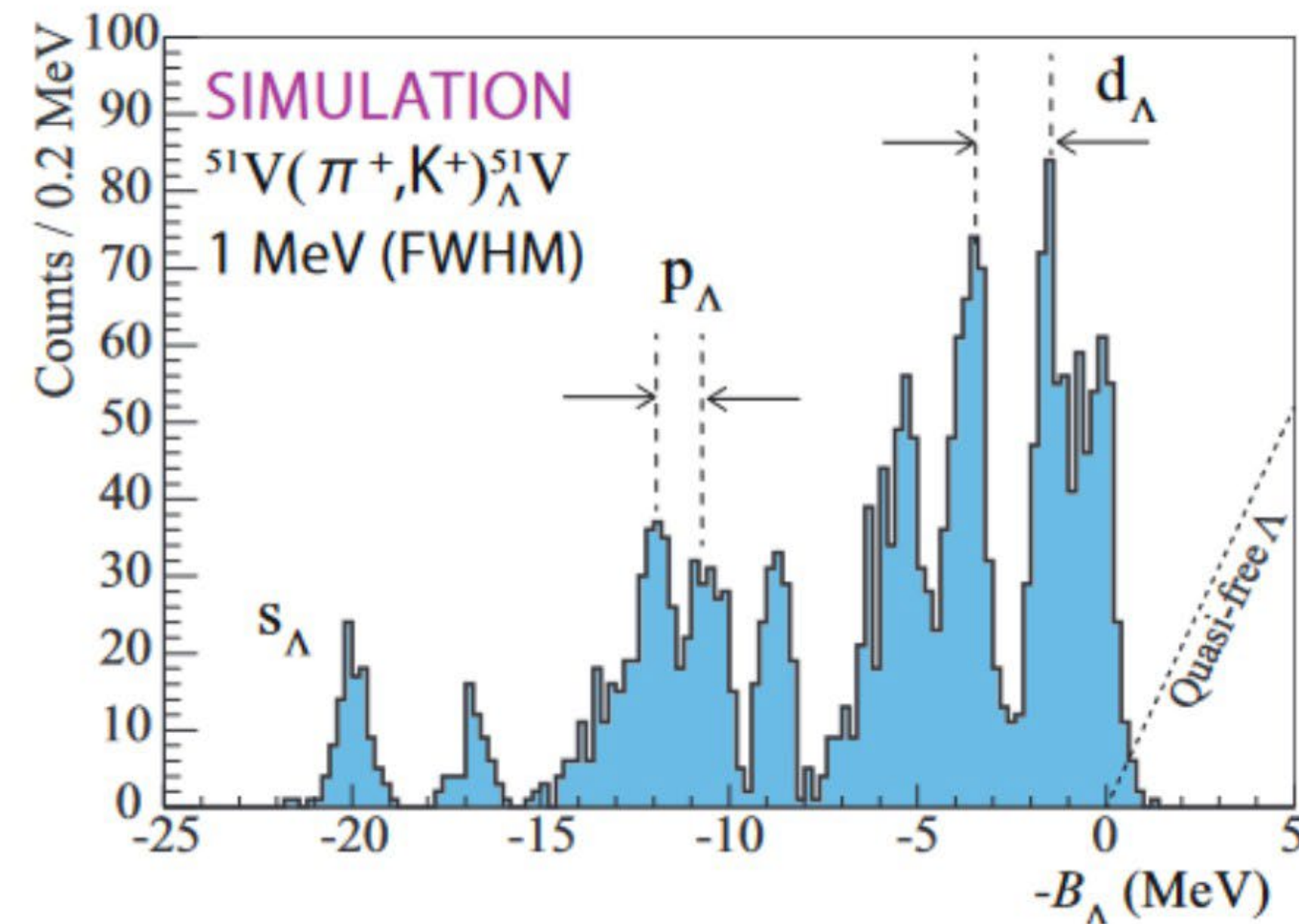
$\Delta M = 2$ MeV at 1.35 GeV/c (K^-, K^+)



$\Delta M = 1$ MeV at 0.72 GeV/c (π^+, K^+)

E94 : (π^+ , K^+) SPECTROSCOPY WITH S-2S ULTIMATE GOAL

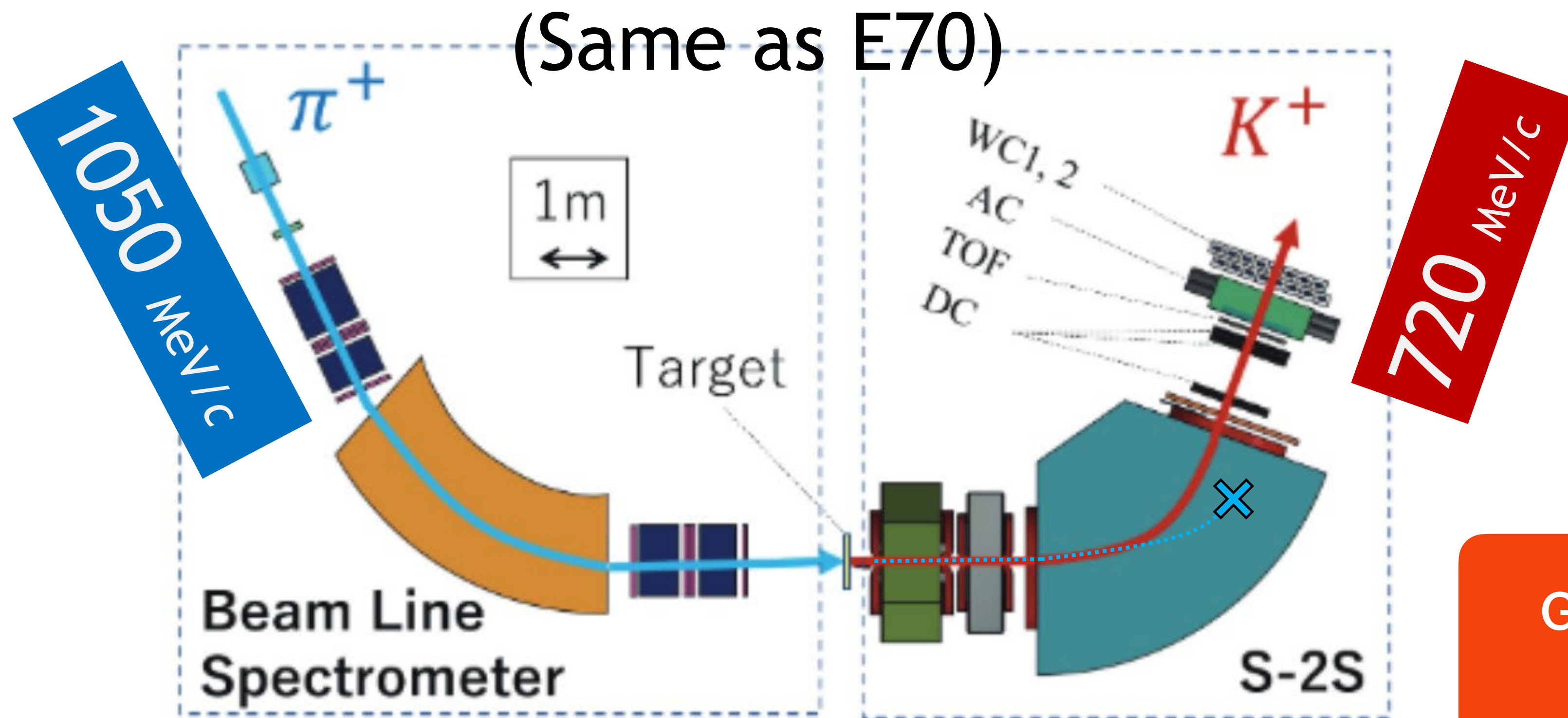
Expected spectrum for $^{51}_{\Lambda}\text{V}$



Expected B_{Λ} spectrum in 20 days of beam time on 1 g/cm² thick ^{51}V target.



E94 : (π^+ , K^+) SPECTROSCOPY WITH S-2S



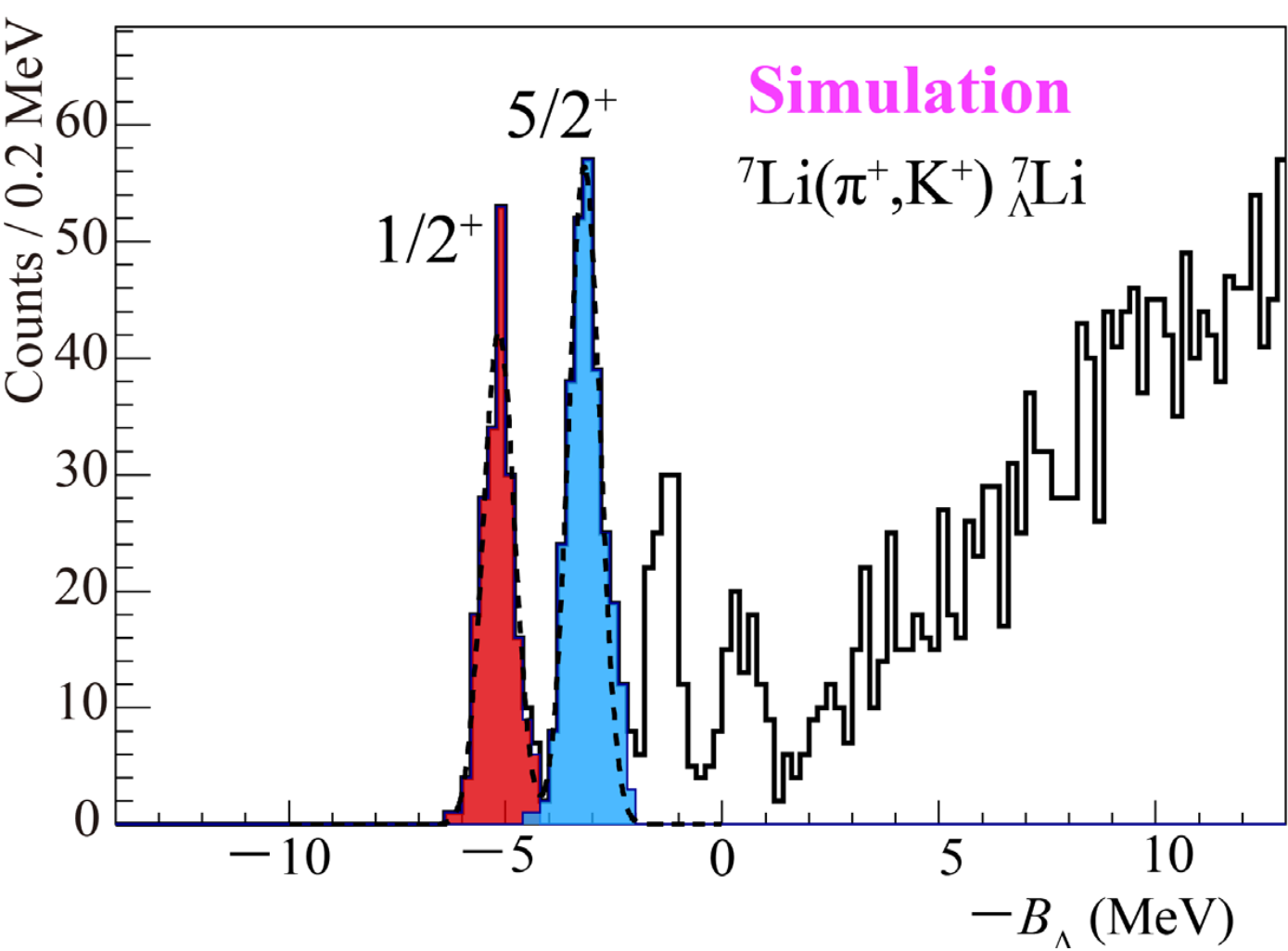
Great resolution of
 $\Delta M \sim 1$ MeV

Missing mass

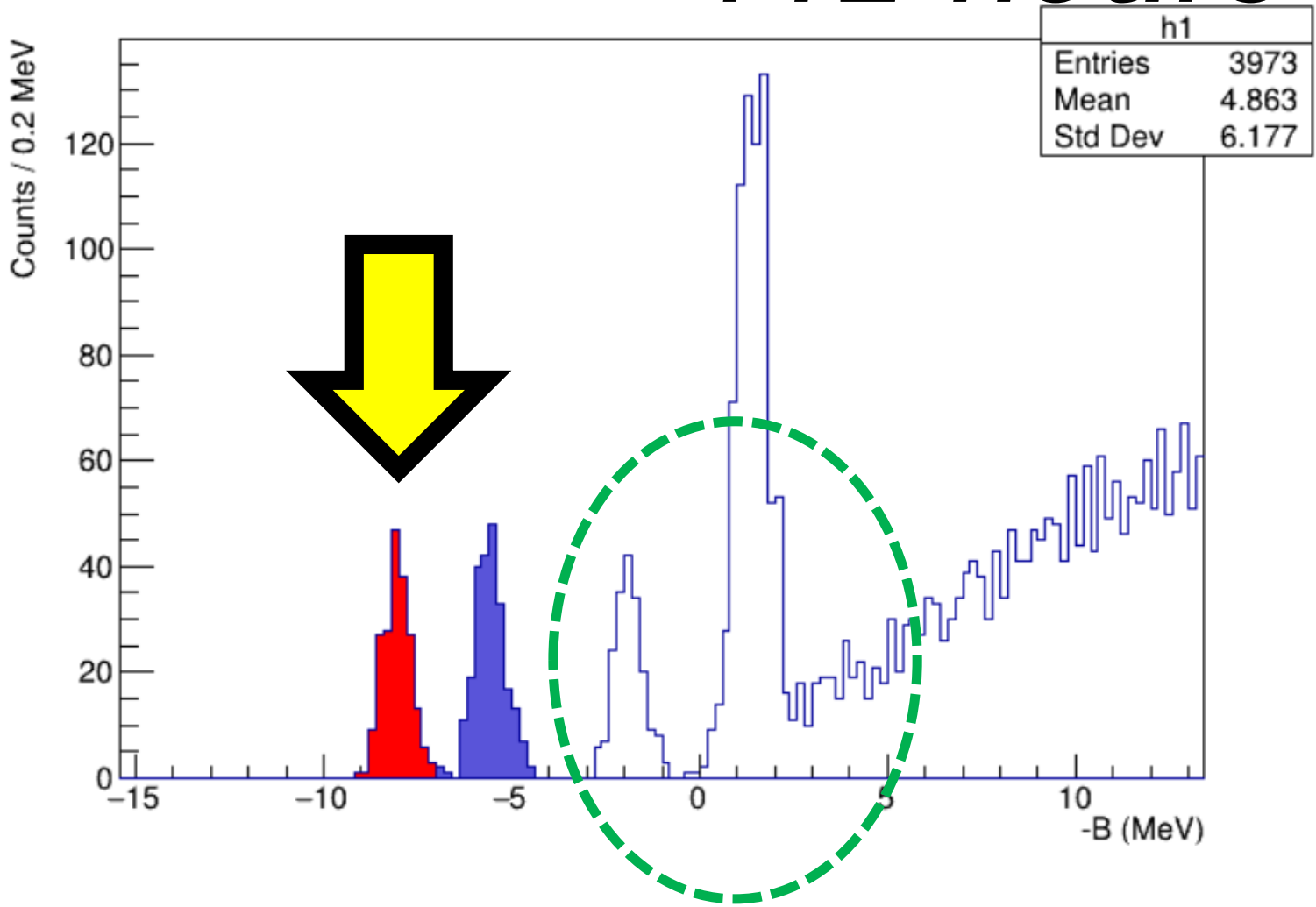


SIMULATED SPECTRA

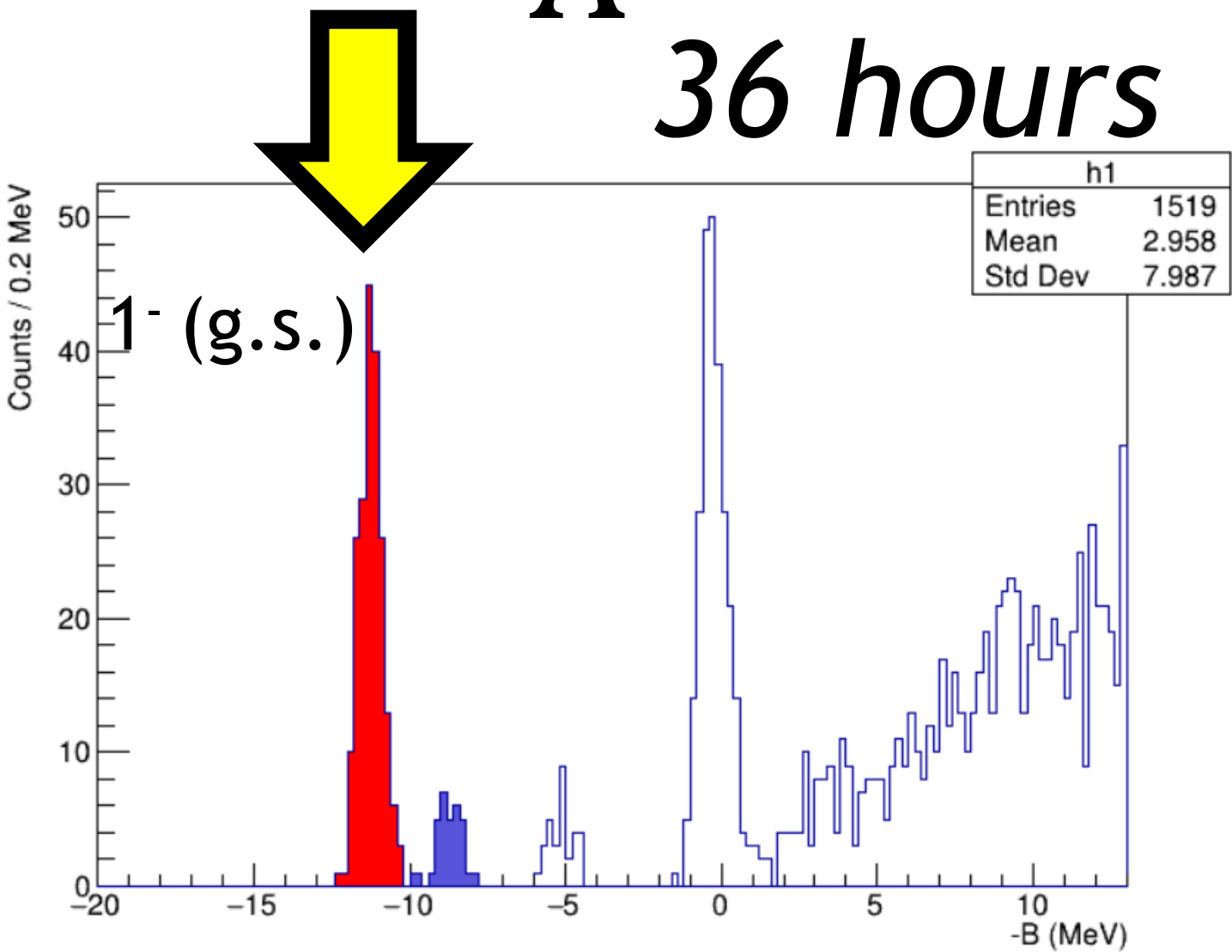
${}^7_{\Lambda}\text{Li}$
80 hours



${}^{10}_{\Lambda}\text{B}$
112 hours



${}^{12}_{\Lambda}\text{C}$
36 hours



Unprecedented Precision in (π^+ , K^+)



SUMMARY

- S-2S spectrometer is ready for data taking.
- Several emulsion data and L-QCD data, strongly suggest **attractive** ΞN potential
- A series of experiments are waiting for New data to confirm it.
 - **E70** : $^{12}\text{C}(\text{K}^-, \text{K}^+)$
 - **E96** : Ξ -atom x-rays. at the same time to E70
 - **E75** : $^6\text{Li}(\text{K}^-, \text{K}^+)$ just after the E70 commissioning runs
 - $^{10}\text{B}(\text{K}^-, \text{K}^+)$, ...
 - **E94** : Ultra-resolution Λ spectroscopy, $A(\pi^+, \text{K}^+)$; $\Delta E < 1-2 \text{ MeV}$
 - , $A=6, 10, 12, \dots$

