SPICE, ECT*, Trento, Italy (May 13—May 17, 2024)

High Resolution Missing Mass Spectroscopy of Hypernuclei at JLab and J-PARC

Graduate School of Science, Kyoto University

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May 17, 2024

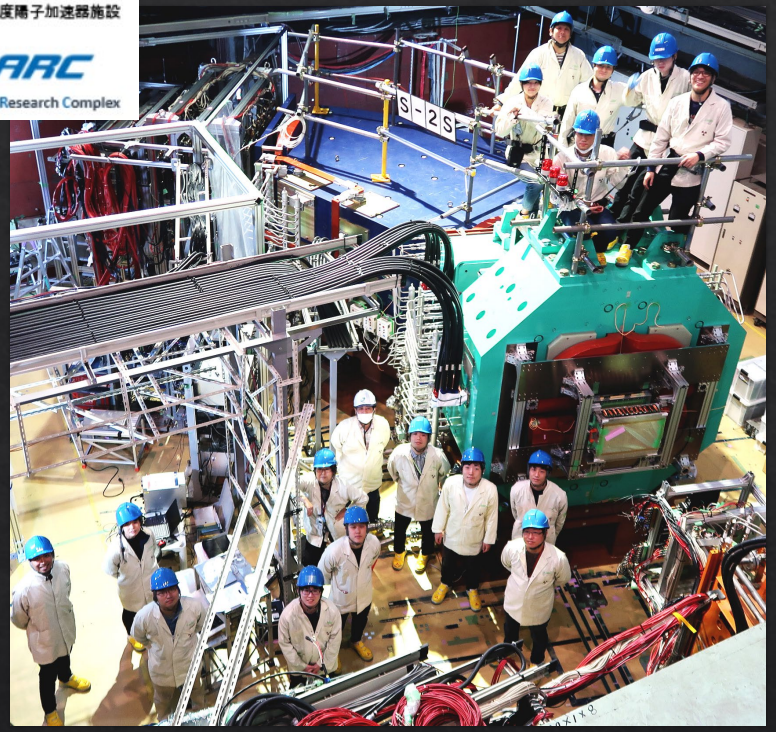
STRONG 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

GRADUATE SCHOOL OF FACULTY OF SCIENCE KYOTO UNIVERSITY

Λ hypernuclear studies in near future

大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex



S-2S (2025～)

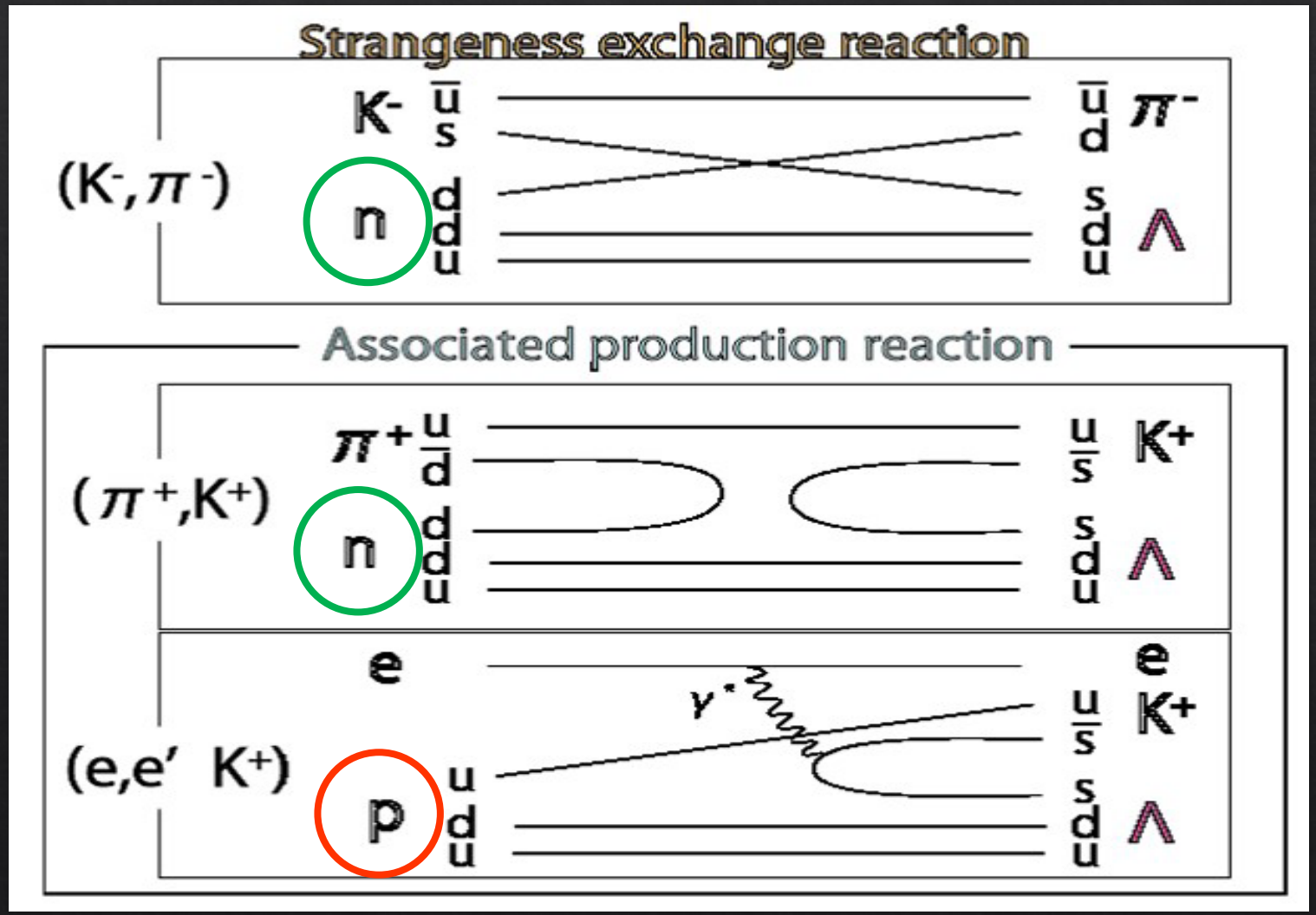
A = 7, 10, 12

Jefferson Lab
Thomas Jefferson National Accelerator Facility

HES-HKS (2027～)

A = 6, 9, 11, 12, 40, 48, 208

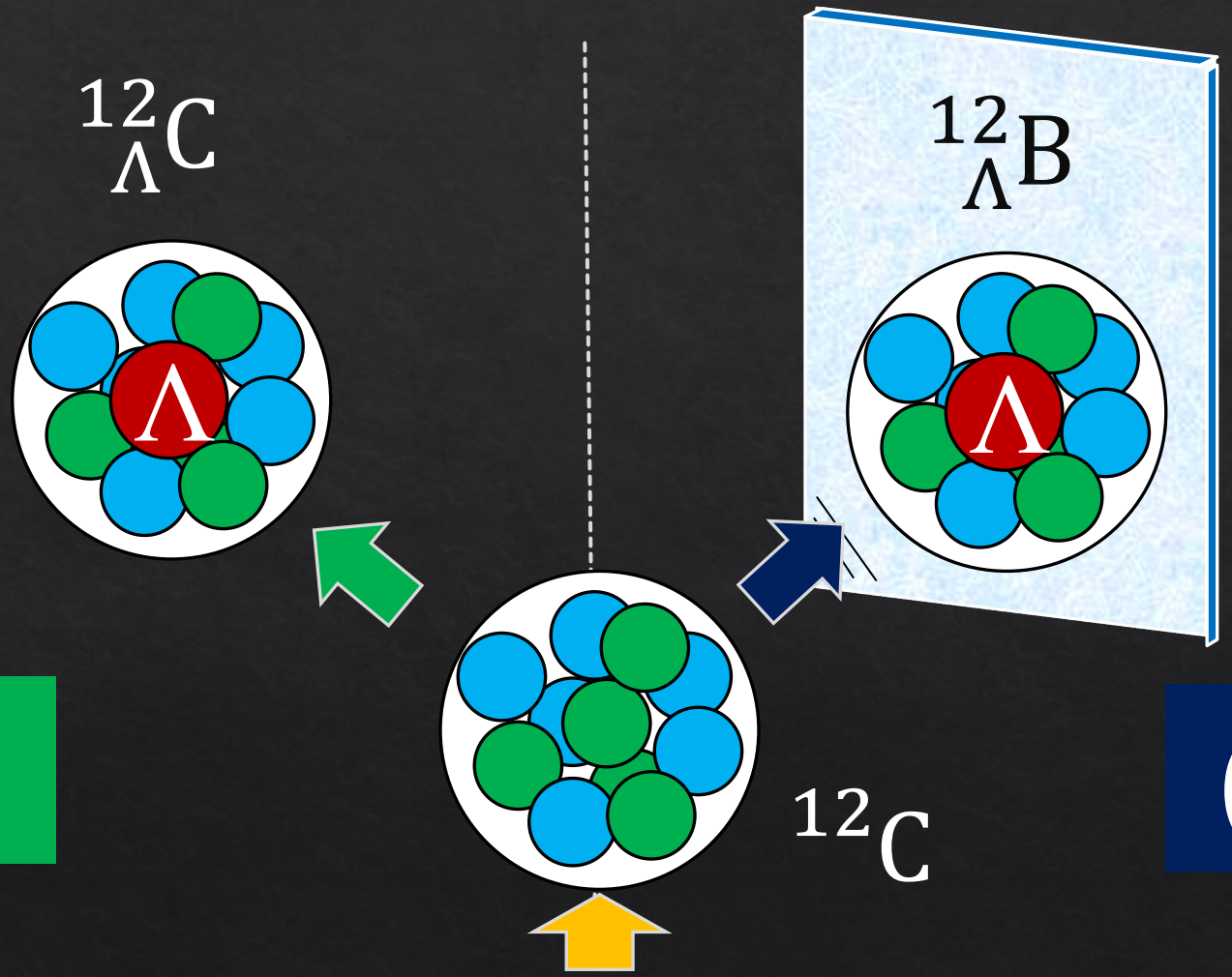
Reactions used at J-PARC and JLab



Hadron Beams @J-PARC

Electron Beams @JLab

Mirror Hypernuclear Study



大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex

(π^+, K^+)

Jefferson Lab
Thomas Jefferson National Accelerator Facility

$(e, e'K^+)$

Charge Symmetry Breaking (CSB), the mystery

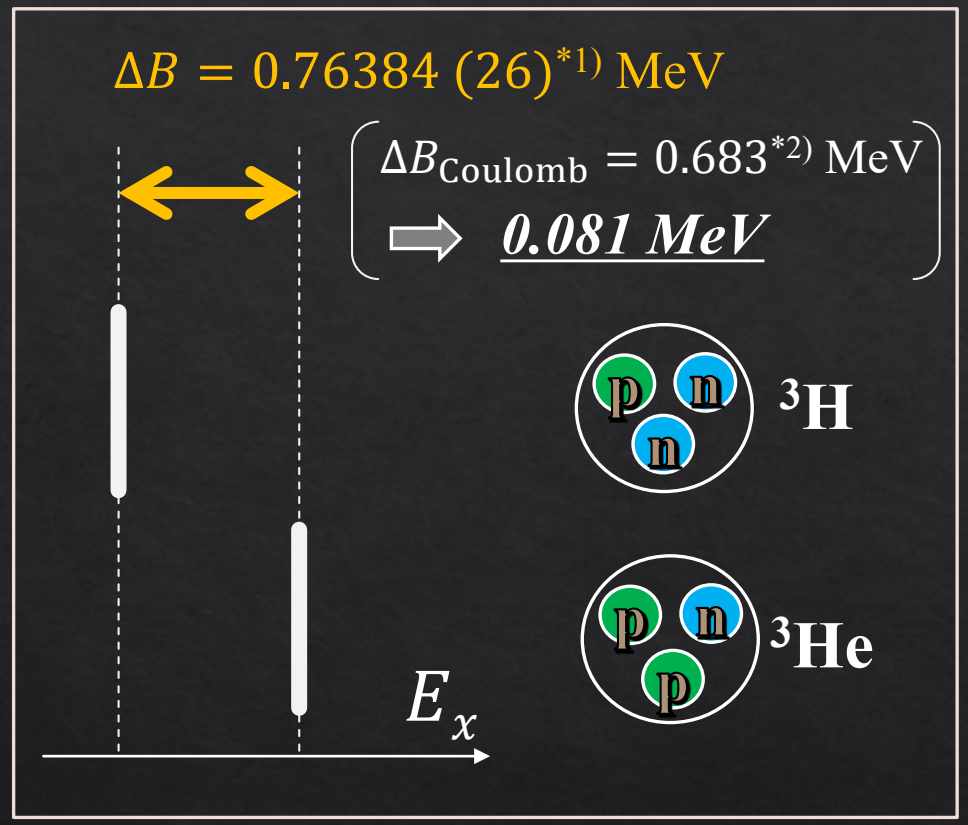
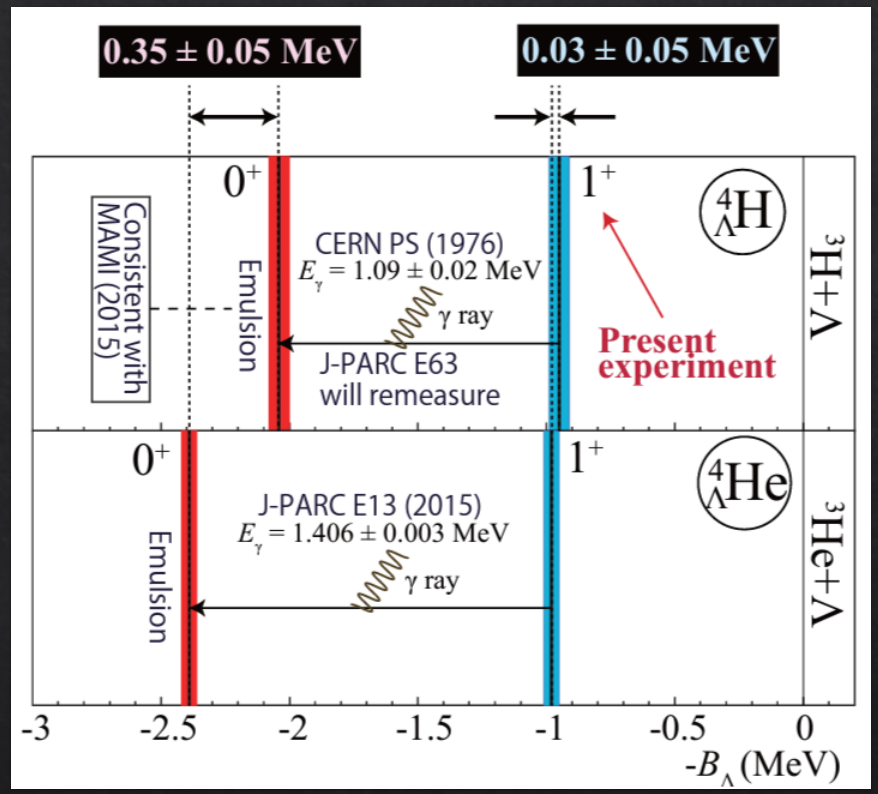


Figure from proposal of JLab E12-19-002



*1) J.H.E.Mattauch *et al., Nucl. Pys.* **67**, 1 (1965).

*2) R.A.Brandenburg, S.A.Coon *et al., NPA***294,** 305 (1978).

The CSB origin is not clear yet.

Mirror hypernuclear data for p-shell systems

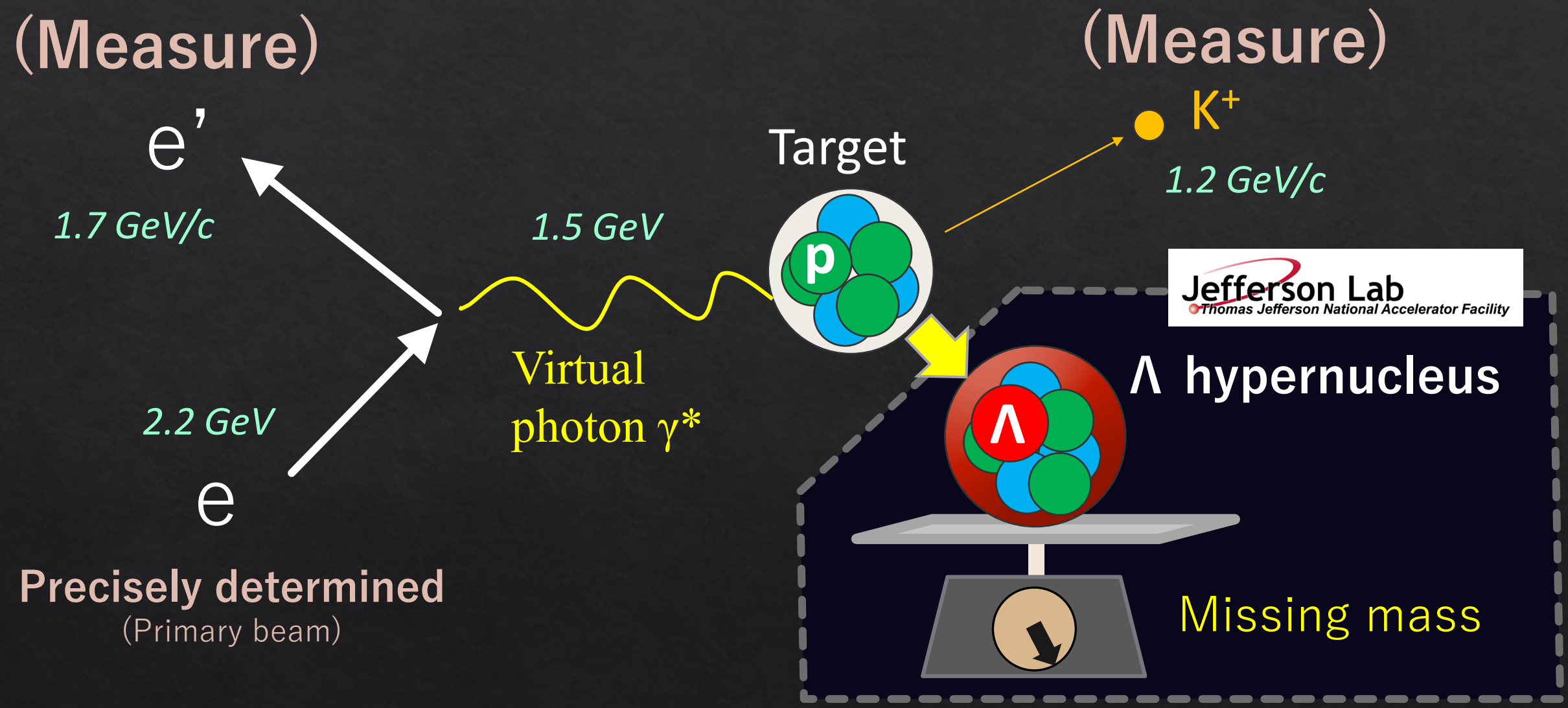
Isomultiplet	${}^{4}_{\Lambda}$He–${}^{4}_{\Lambda}$H	${}^{7}_{\Lambda}$Be–${}^{7}_{\Lambda}$Li*	${}^{7}_{\Lambda}$Li*–${}^{7}_{\Lambda}$He	${}^{8}_{\Lambda}$Be–${}^{8}_{\Lambda}$Li	${}^{9}_{\Lambda}$B–${}^{9}_{\Lambda}$Li	${}^{10}_{\Lambda}$B–${}^{10}_{\Lambda}$Be*
Shell model (Gal *et al.*) [41]	+226	−17	−28	+49	−54	−136
Cluster model (Hiyama *et al.*) [39, 40]		+150	+130			+20
No-core shell model (Le *et al.*) [43]	+238	−35	−16	+143		
Experiment	$+233 \pm 92$	-100 ± 90	-20 ± 230	$+40 \pm 60$	-210 ± 220	-220 ± 250

A. Gal, and D. Gazda, Jour. Phys.: Conf. Ser. 966, 012006 (2018)
E. Hiyama et al., Prog. Theor. Phys. 128, 105 (2012).
H. Le et al., Phys. Rev. C 107, 24002 (2023)

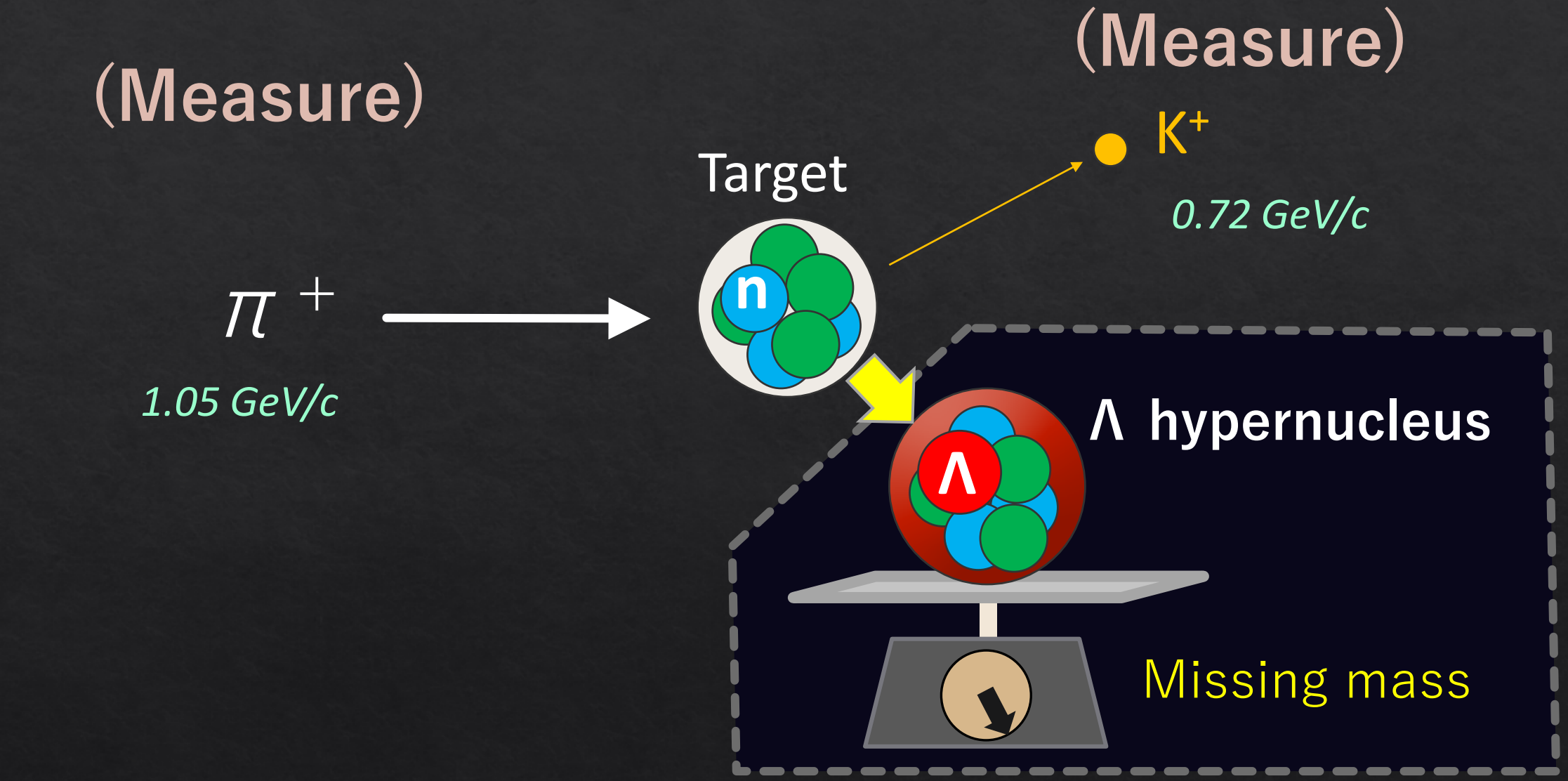
Existing data accuracy is not sufficient for CSB study (ΔB_{diff} > 200 keV)

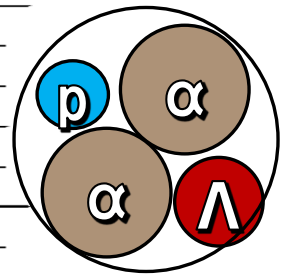
→ **ΔB_{diff}～100 keV for A = 6, 7, 9, 10, 11, 12**

Missing-mass spectroscopy



Missing-mass spectroscopy





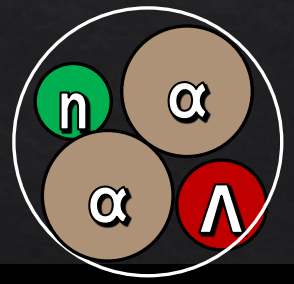
$^{10}_{\Lambda}\mathrm{B}$

FWHM = 2.2 MeV

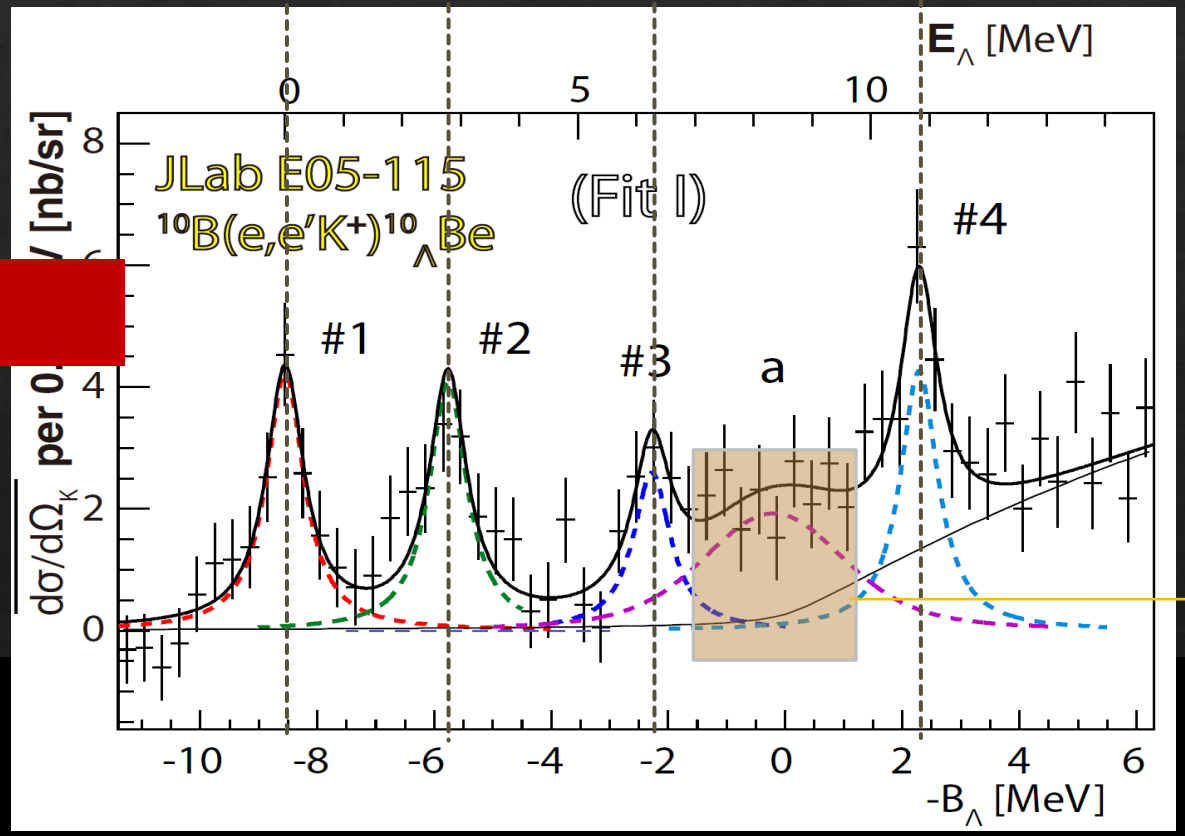
(π^+, K^+) @KEK, Japan

T. Hasegawa et al.,PRC 53, 3 (1996).

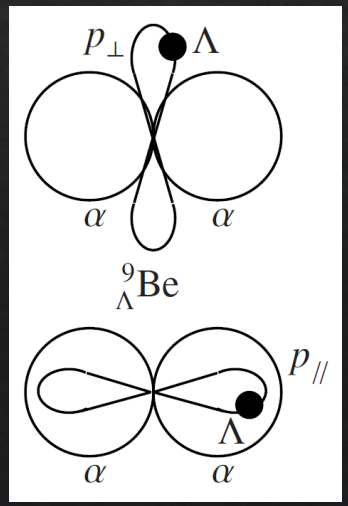
FWHM = 0.8 MeV



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



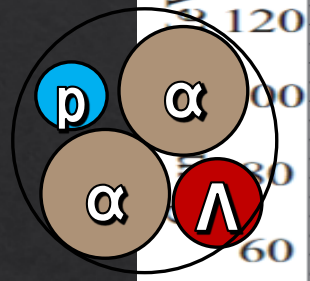
Cluster structure!!



TG et al.,
PRC 93, 034314 (2016).

A. Umeya *et al., J. Phys.: Conf. Ser.* **1643** 012110 (2020)

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

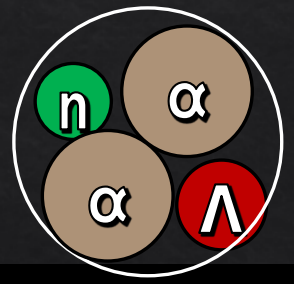


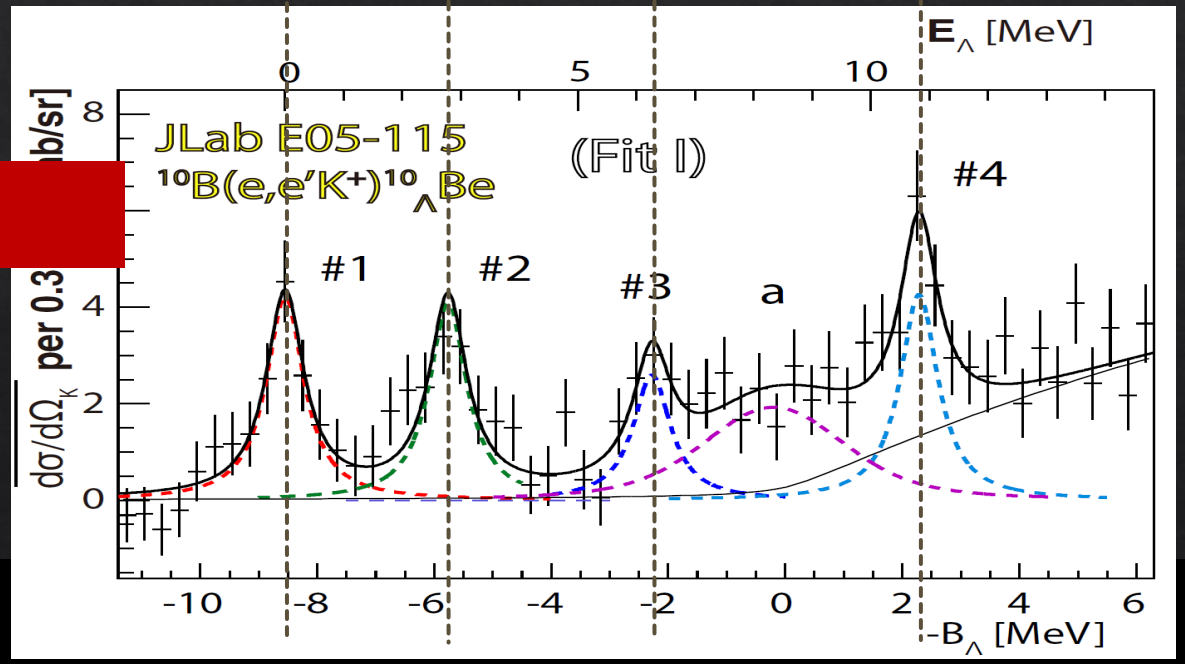
FWHM = 1 MeV

S-2S
@J-PARC
(J-PARC E94)

FWHM = 0.8 MeV

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

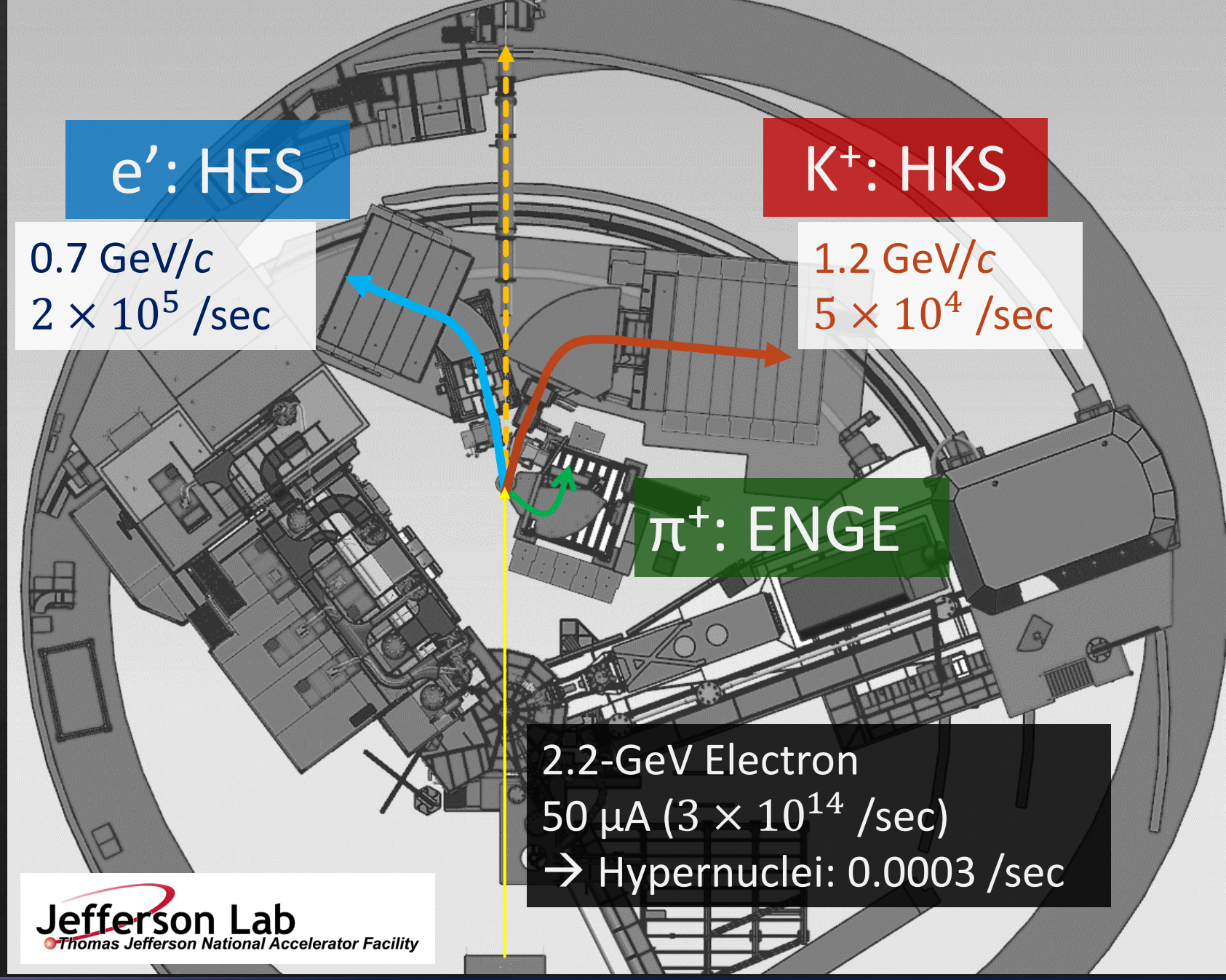


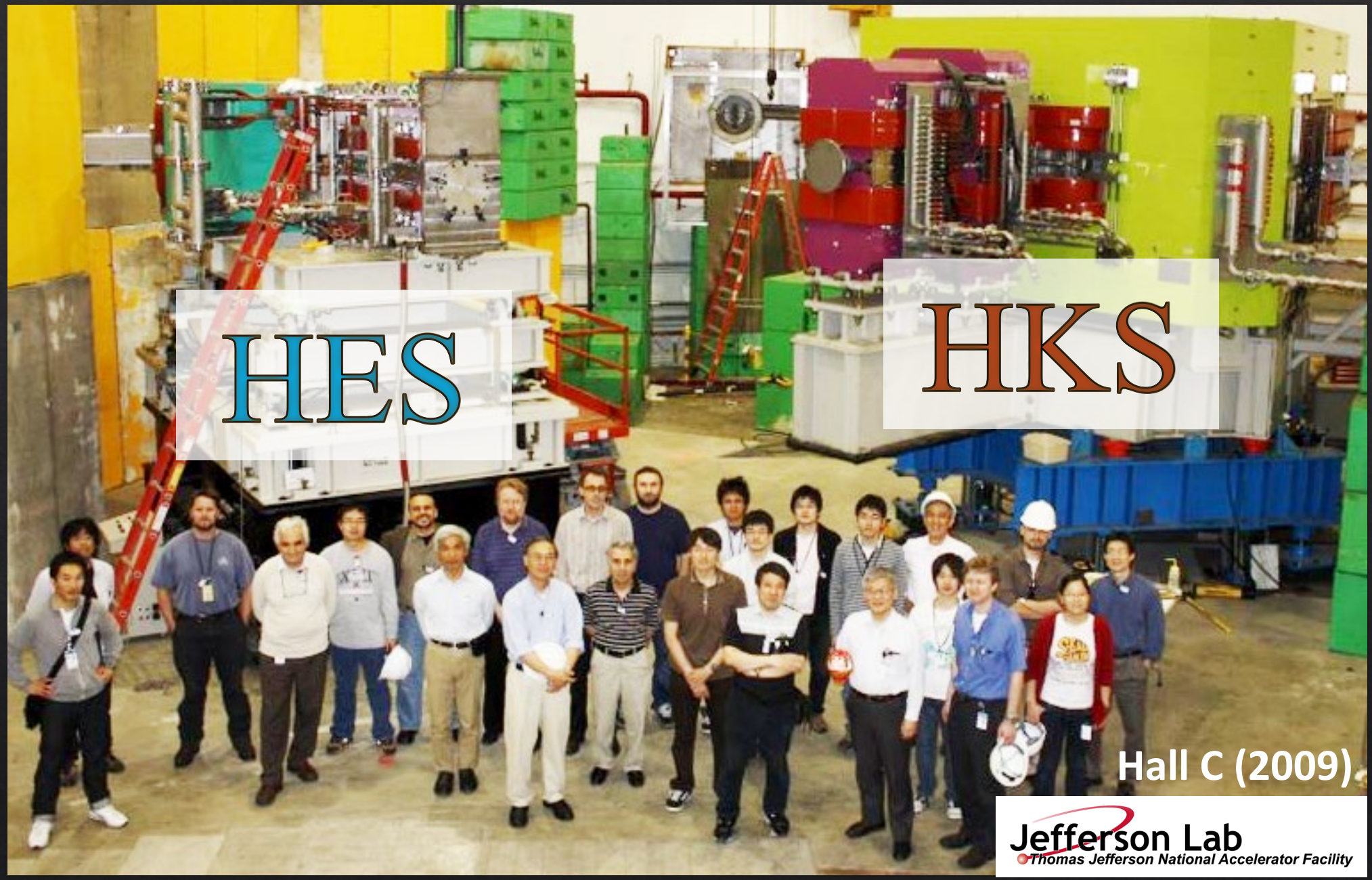


HKS
@JLab

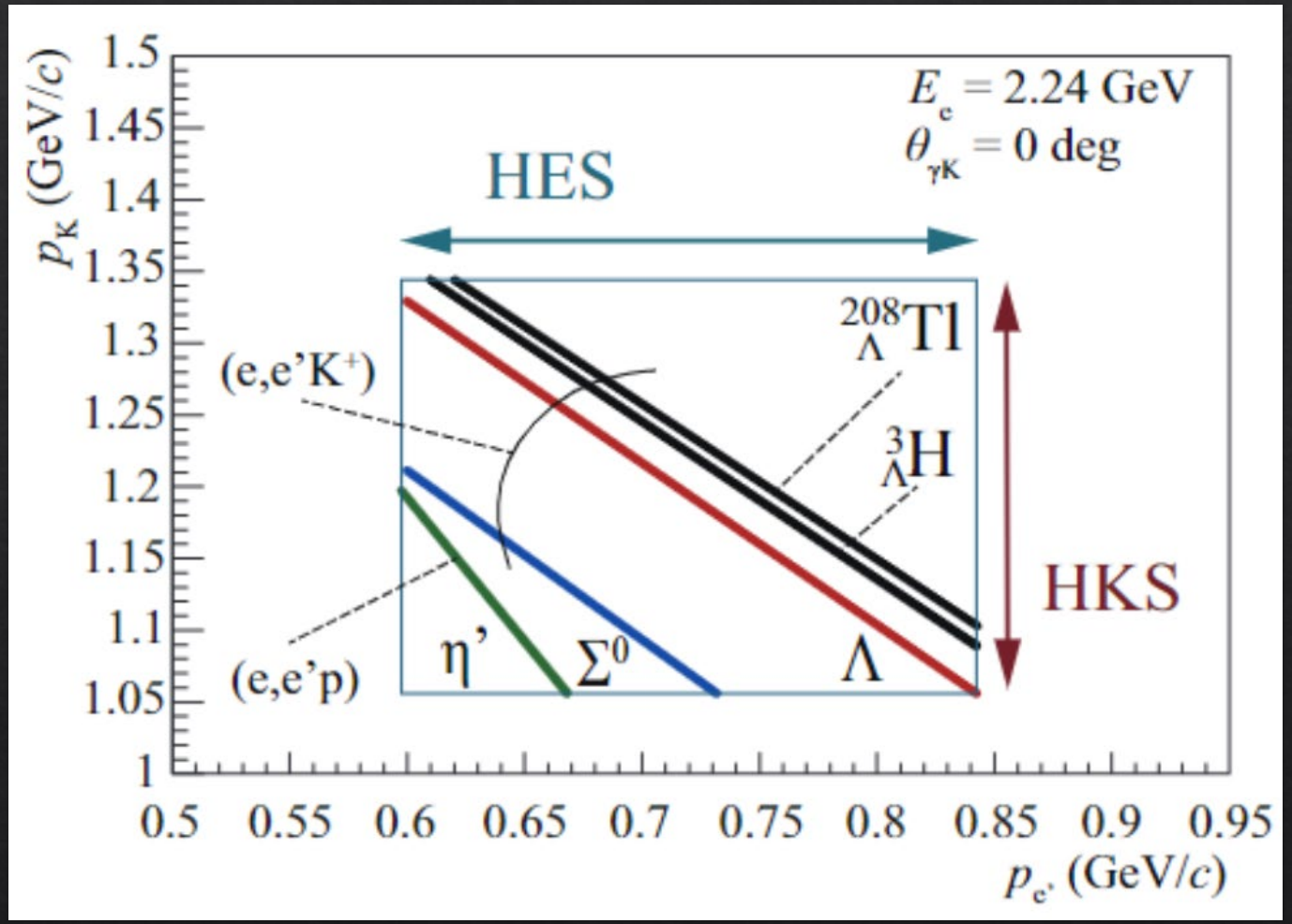
TG et al.,
PRC 93, 034314 (2016).

New experiment at JLab Hall-C (2027～)




HES
HKS
Hall C (2009)
Jefferson Lab
Thomas Jefferson National Accelerator Facility

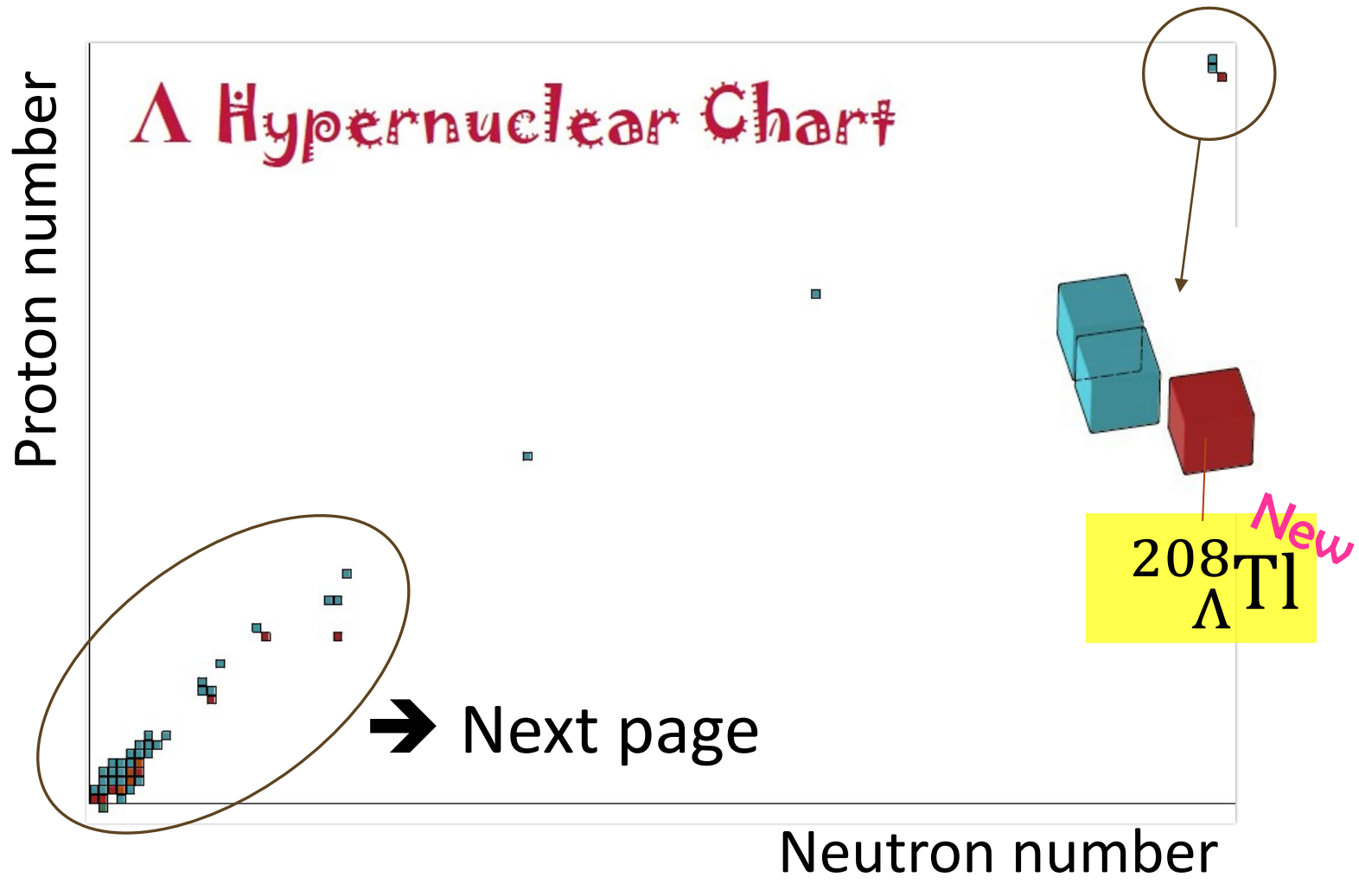
High accuracy calibration by known mass sources



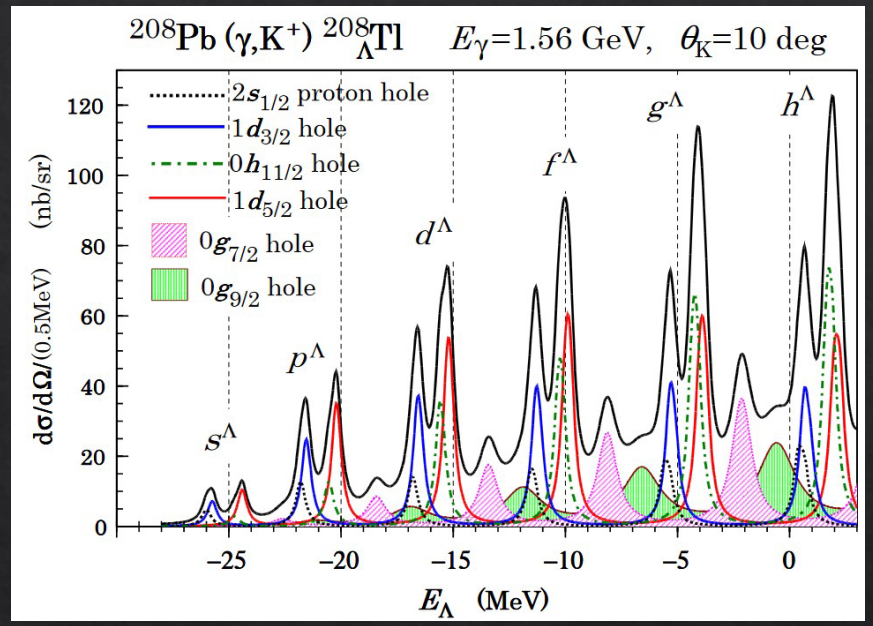
High Accuracy

$\left|\Delta B_{\Lambda}^{total}\right| \leq 70$ keV

Next JLab experiments; light to heavy hypernuclei



T. Motoba, JPS Conf. Proc. 17, 011003 (2017)



Approved

JLab E12-20-013

➔ ΛNN force

Next JLab experiments; light to heavy hypernuclei

New Proposals (2024)

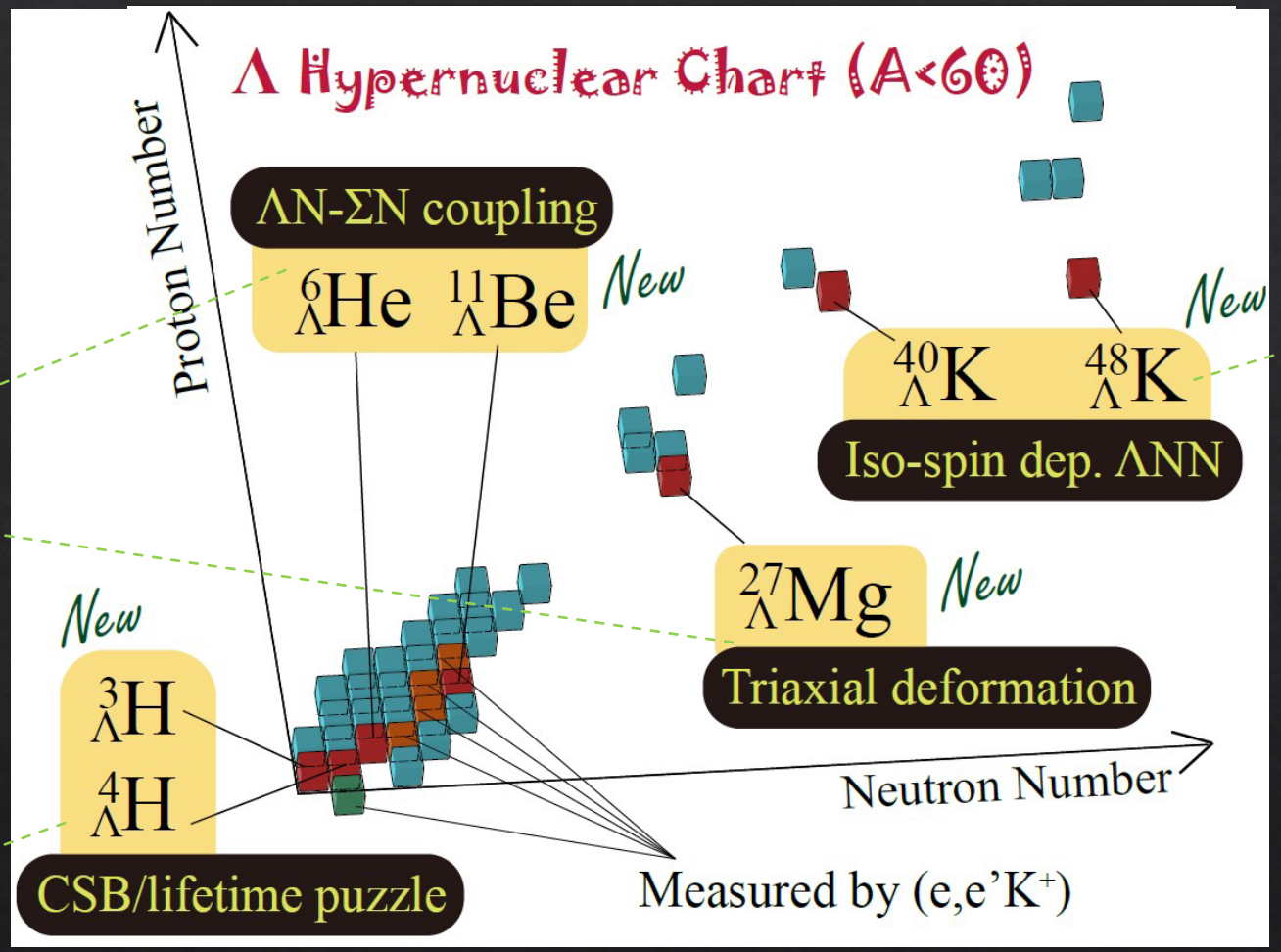
Missing mass

LOI12-23-013

LOI12-23-016

Decay pion

LOI12-23-011



Approved

E12-15-008

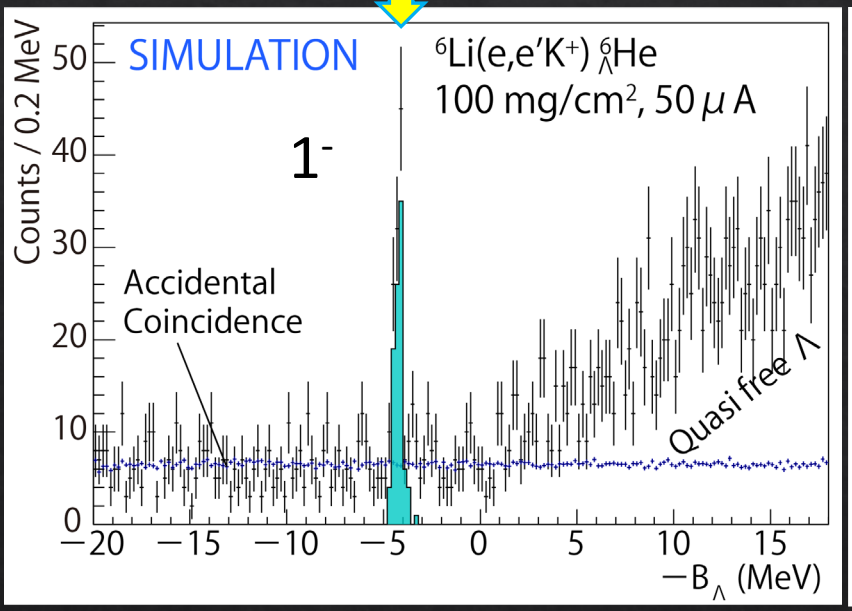
Approved

E12-19-002 *Excited states!*

JLab LOI12-23-013 → New proposal (2024)

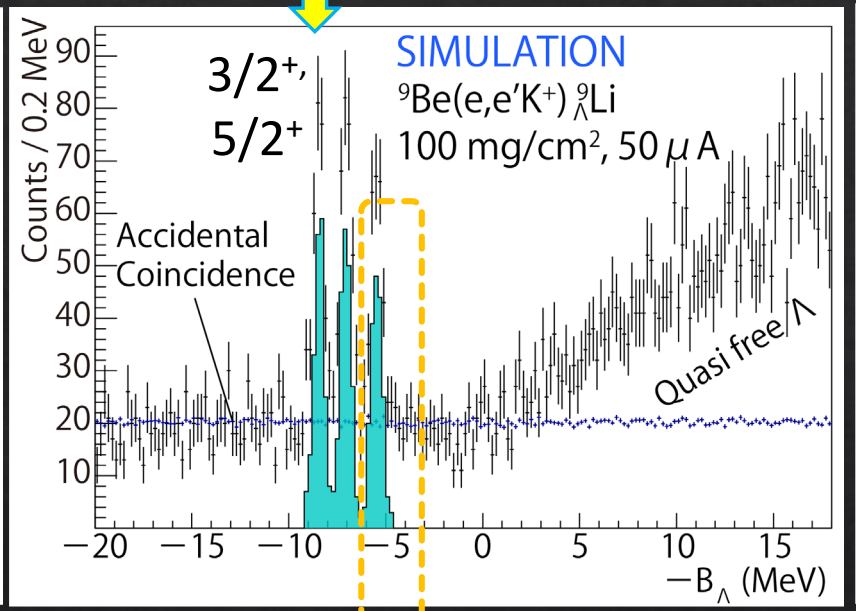
for CSB study

120 hours



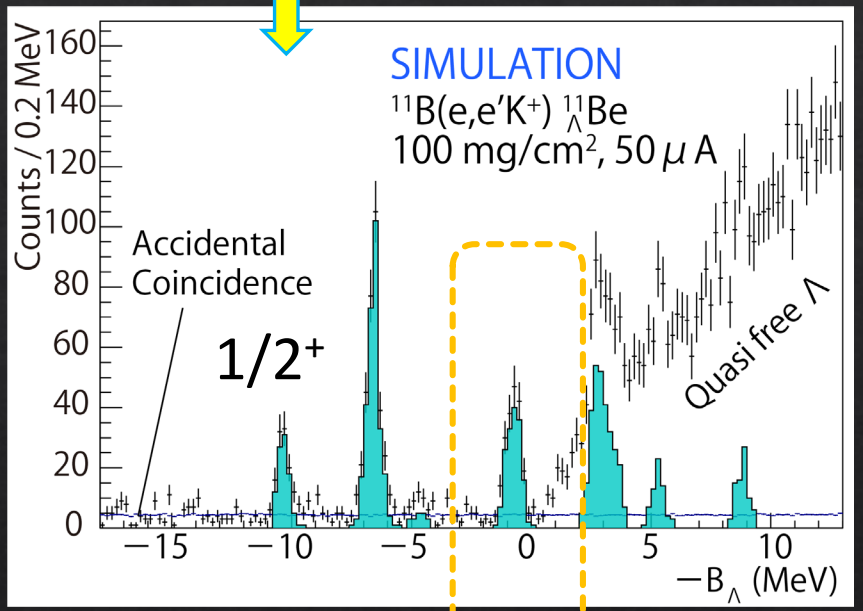
for CSB study

384 hours



for CSB study

72 hours



Accuracy:

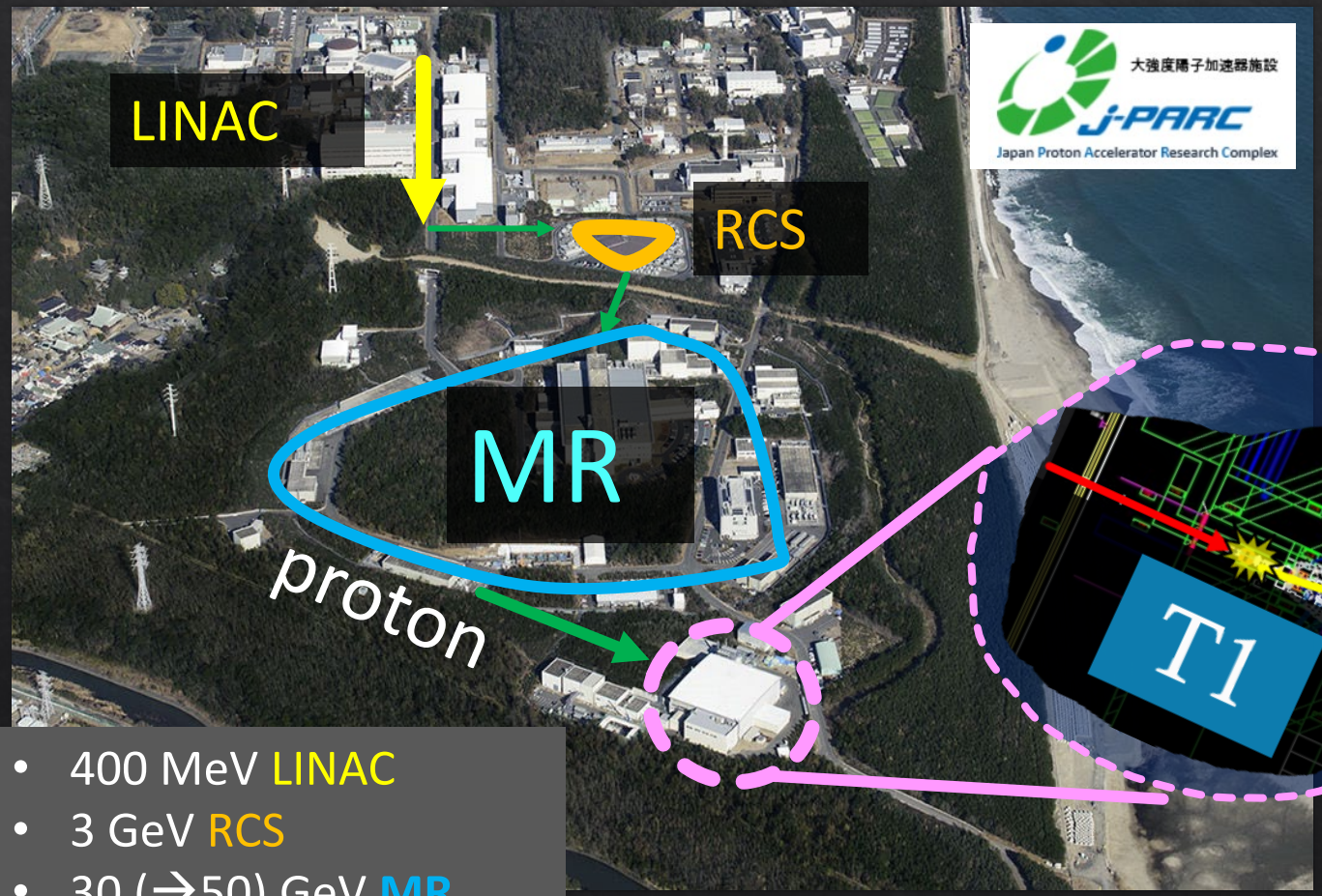
$\left|\Delta B_{\Lambda}^{\mathrm{total}}\right| \leq 70$ keV

c.f.) TG et al., PRC 103, L041301 (2021)

Cluster / deformation structures

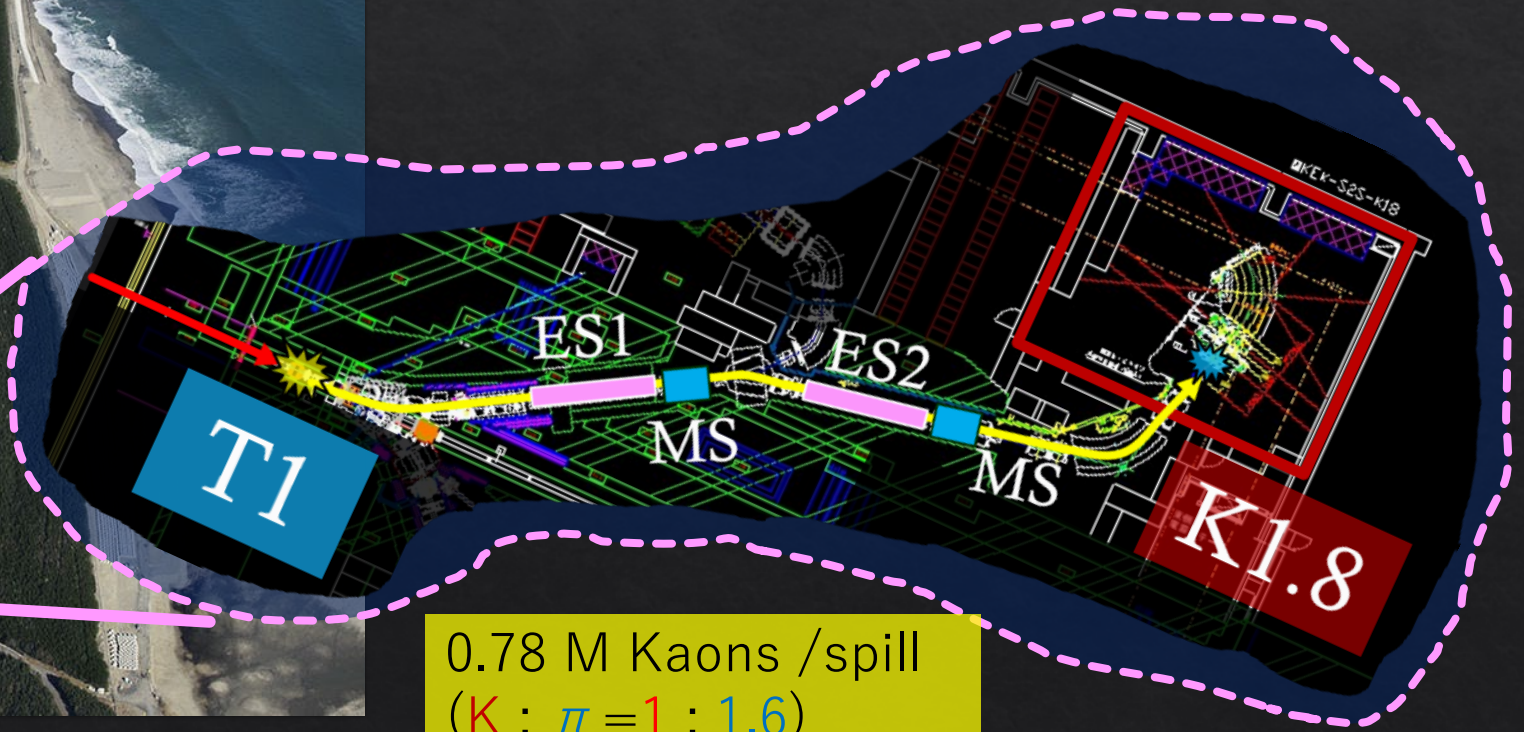
c.f.) Isaka-san's talk

Japan Proton Accelerator Research Complex (J-PARC), Ibaraki, Japan

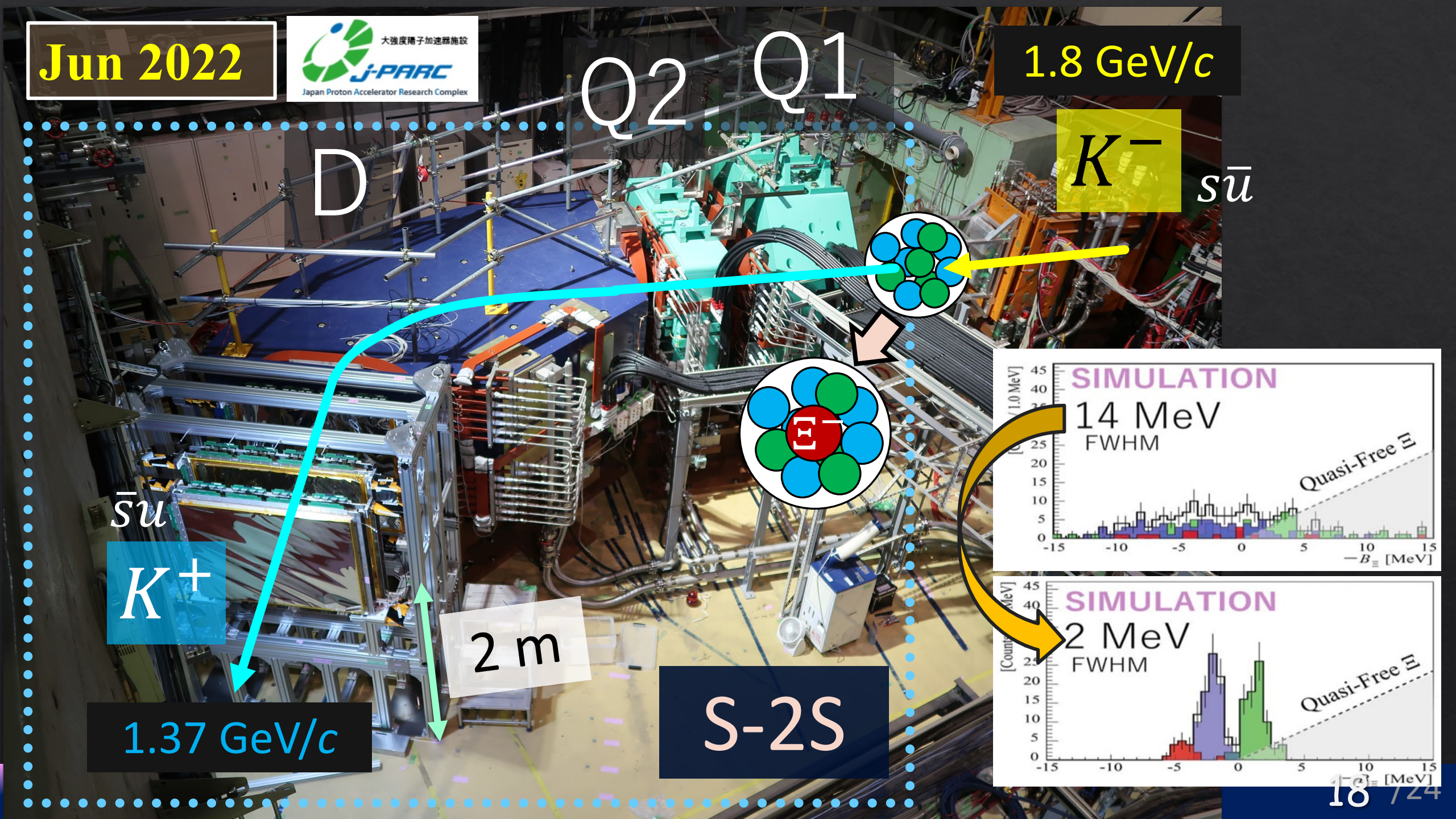


- 400 MeV LINAC
- 3 GeV RCS
- 30 (→50) GeV MR

$^{A}Z(\pi^+, K^+)^{A}_{\Lambda}Z$
@K1.8 Beam line



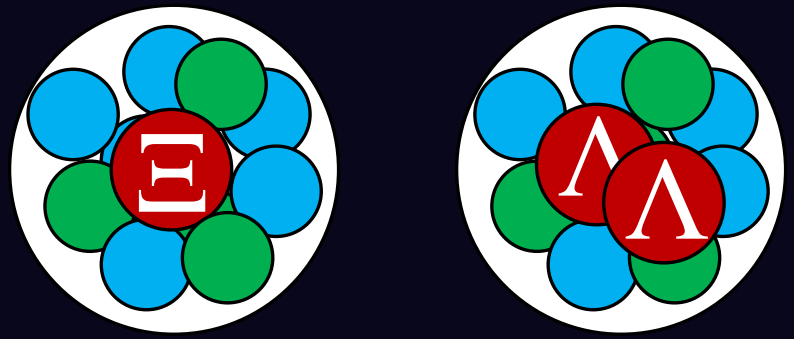
0.78 M Kaons /spill
(K : π =1 : 1.6)

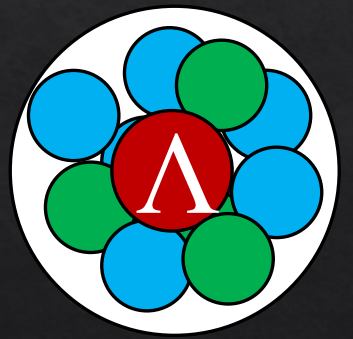

Jun 2022
大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex
Q2
Q1
1.8 GeV/c
D
K^-
$s\bar{u}$
$\bar{s}u$
K^+
2 m
1.37 GeV/c
S-2S
SIMULATION
14 MeV
FWHM
Quasi-Free Ξ
$-B_\Xi$ [MeV]
SIMULATION
2 MeV
FWHM
Quasi-Free Ξ
$-B_\Xi$ [MeV]

The first commissioning/calibration data were taken in 2023 and 2024

Nov 9, 2022 @K1.8 beam line, J-PARC, Japan

"S = −2" study will start!





"S = −1"

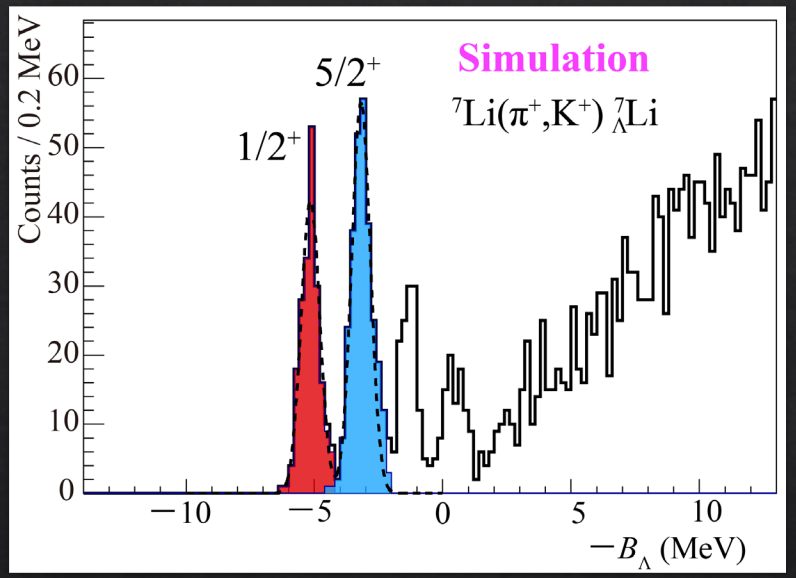
as well

T. Gogami et al., EPJ Web Conf. 271, 11002 (2022).

Expected spectra (J-PARC E94)

$^{7}_{\Lambda}$Li

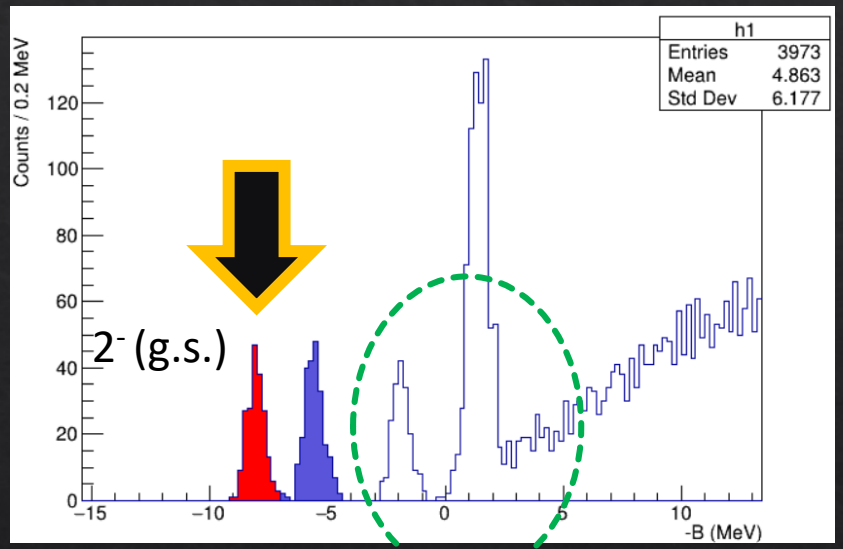
80 hours



Calibration source

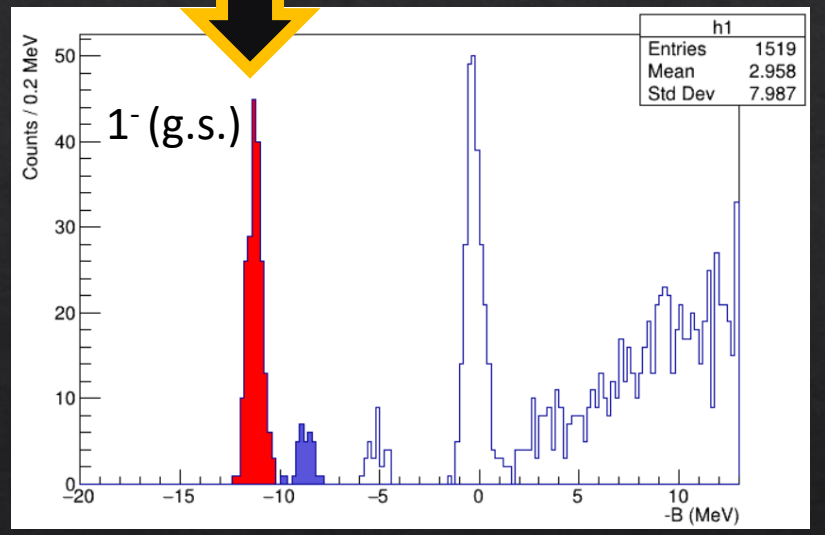
$^{10}_{\Lambda}$B

112 hours



$^{12}_{\Lambda}$C

36 hours



$$\left|\Delta B_{\Lambda}^{total\ (stat. \oplus sys.)}\right| < 0.1\ \text{MeV}$$

CSB $^{3}_{\Lambda}\mathrm{H}$ lifetime puzzle

$nn\Lambda$ bound puzzle

Strangeness	2B	Coupled channel	3B
-1		ΛN-ΣN	
-2		ΞN-ΛΛ	

Many Body effect
(Cluster, deformation)

Neutron star puzzle

CSB $^{3}_{\Lambda}\mathrm{H}$ **lifetime puzzle**

$nn\Lambda$ **bound puzzle**

Invariant mass spectroscopy by HI beam
@LHC, RHIC, GSI

- YN scat. exp.
- Femotoscopy

Strangeness	2B	Coupled channel	3B
-1		ΛN-ΣN	
-2		ΞN-ΛΛ	

Many Body effect
(Cluster, deformation)

- Space observation
- Graviton wave meas.

Neutron star puzzle

J-PARC E63

J-PARC E94

JLab LOI12-23-013

CSB $^{3}_{\Lambda}\mathrm{H}$ **lifetime puzzle**

JLab E12-19-002

JLab LOI12-23-011

$nn\Lambda$ **bound puzzle**

Invariant mass spectroscopy by HI beam @LHC, RHIC, GSI

JLab C12-20-013 (C2)

- YN scat. exp.
- Femotoscopy

Strangeness	2B	Coupled channel	3B
-1	YN	ΛN-ΣN	NYN
-2	YN	ΞN-ΛΛ	NYN

JLab LOI12-23-016

Many Body effect (Cluster, deformation)

- Space observation
- Graviton wave meas.

J-PARC E70

J-PARC E75

J-PARC E96

JLab E12-15-008

JLab E12-20-013

Neutron star puzzle

Summary

JLab (HES-HKS, 0.6 MeV FWHM, 0.07 MeV accuracy, 2027—)

- $(e, e'K^+)$ reaction at $\omega = 1.5$ GeV
- Approved: ${}^{3}_{\Lambda}\mathrm{H}$, ${}^{4}_{\Lambda}\mathrm{H}$, ${}^{6}_{\Lambda}\mathrm{He}$, ${}^{9}_{\Lambda}\mathrm{Li}$, ${}^{11}_{\Lambda}\mathrm{Be}$, ${}^{27}_{\Lambda}\mathrm{Mg}$, ${}^{40}_{\Lambda}\mathrm{K}$, ${}^{48}_{\Lambda}\mathrm{K}$, ${}^{208}_{\Lambda}\mathrm{Tl}$

➔ **ΛN CSB, ΛNN, tri-axial deformation**

J-PARC (S-2S, 1.0 MeV FWHM, 0.1 MeV accuracy, 2024—)

- (π^+, K^+) and (K^-, K^+) reactions at $p = 1.05$ and 1.8 GeV/c
- Approved: ${}^{6}_{\Lambda}\mathrm{Li}$, ${}^{10}_{\Lambda}\mathrm{B}$, ${}^{12}_{\Lambda}\mathrm{C}$, ${}^{7}_{\Xi}\mathrm{H}$, ${}^{12}_{\Xi}\mathrm{Be}$
- New additional plan: ${}^{6}_{\Lambda}\mathrm{Li}$, ${}^{11}_{\Lambda}\mathrm{B}$ *etc.*

➔ **ΛN CSB, ΞN interaction**

Backup

Hall A

- B. Pandey et al., PRC **105**, L051001 (2022)
- K.N. Suzuki et al., PTEP 2022, 1, 013D01 (2022)
- F. Garibaldi et al., PRC 99, 054309 (2019)
- G. M. Urciuoli et al., PRC 91, 034308 (2015)
- F. Cusanno et al., PRL 103, 202501 (2009)
- G. M. Urciuoli et al., NIMA612, 56—68 (2009)
- M. Iodice et al., PRL 99, 052501 (2007)

Hall C

- TG et al., PRC 103, L041301 (2021)
- TG et al., NIMA 900, 69—83 (2018)
- TG et al., PRC 94, 021302(R) (2016)
- TG et al., PRC 93, 034314 (2016)
- Y. Fujii et al., NIMA795, 351—363 (2015)
- L. Tang et al., PRC 90, 034320 (2014)
- S.N. Nakamura et al., PRL 110, 012502 (2013)
- TG et al., NIMA 729, 816—824 (2013)
- L. Yuan et al., PRC 73, 044607 (2006)
- T. Miyoshi et al., PRL 90, 232502 (2003)

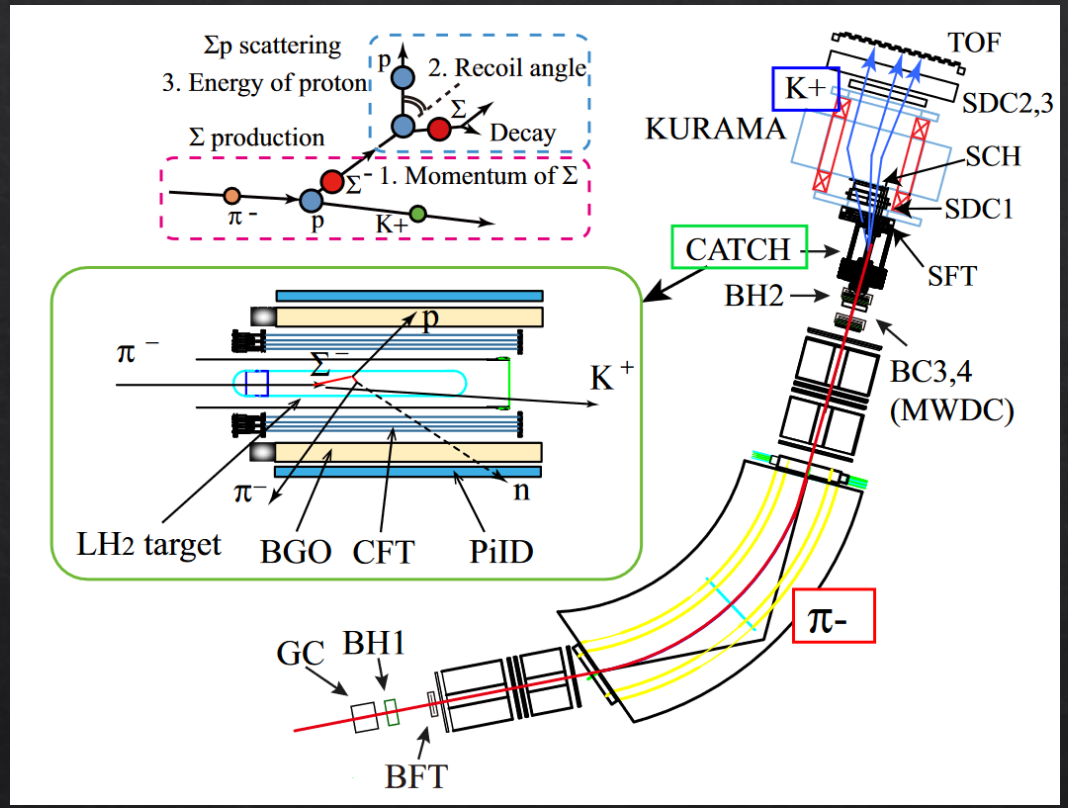
Experimental parameters for the next JLab Experiment

TABLE II. Summary of the kinematics parameters in the proposed experiment.

Item		Value
Beam (e)	Energy (/GeV)	2.24
	(Required) energy spread and drift	1×10^{-4} (FWHM)
PCS + HES (e')	Central momentum $p_{e'}^{\text{cent.}}$ [/(GeV/c)]	0.74
	Central angle $\theta_{ee'}^{\text{cent.}}$	8.5°
	Solid angle acceptance $\Omega_{e'}$ (/msr) (at $p_{e'}^{\text{cent.}}$)	3.4
	Momentum resolution $\Delta p_{e'}/p_{e'}$	4.4×10^{-4} (FWHM)
PCS + HKS (K^+)	Central momentum $p_{K^+}^{\text{cent.}}$ [/(GeV/c)]	1.20
	Central angle $\theta_{eK^+}^{\text{cent.}}$	11.5°
	Solid angle acceptance Ω_{K^+} (/msr) (at $p_{K^+}^{\text{cent.}}$)	7.0
	Momentum resolution $\Delta p_{K^+}/p_{K^+}$	2.9×10^{-4} (FWHM)
$p(e, e'K^+)\Lambda$	$\sqrt{s} = W$ (/GeV)	1.912
	Q^2 [/(GeV/c)^2]	0.036
	K^+ scattering angle wrt virtual photon, $\theta_{\gamma^* K^+}$	7.35°
	ϵ	0.59
	ϵ_L	0.0096

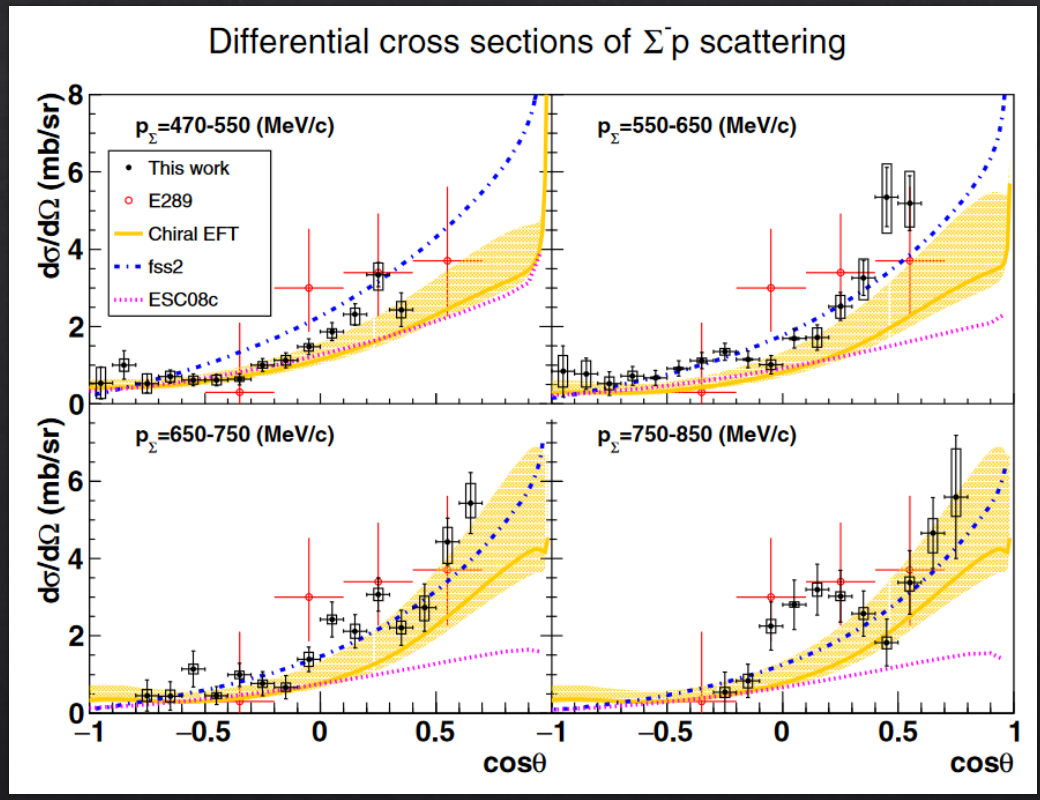
Recent progress in YN scattering experiment

K. Miwa et al., PRC 104, 045204 (2021)



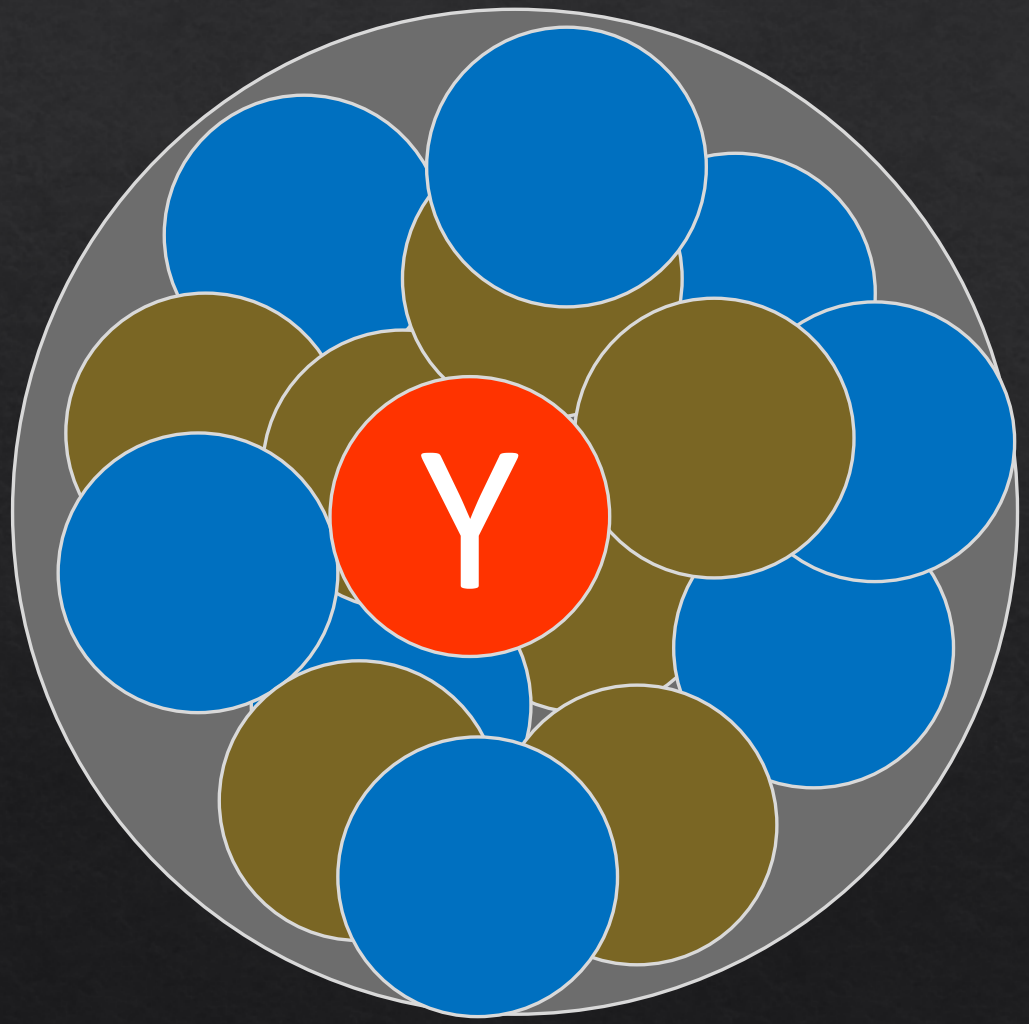
J-PARC E40 Experiment

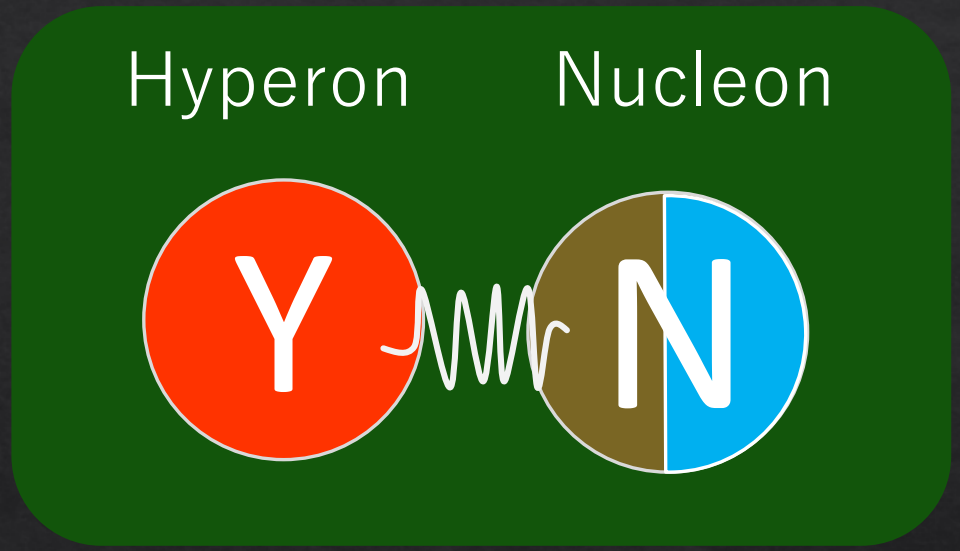
Σ⁻p elastic



Σ⁻p→ Λn ： K. Miwa et al., Phys. Rev. Lett. 128, 072501 (2022)
Σ⁺p: T. Nanamura et al., arXiv:2203.08393 [nucl-ex] (2022)
Λp : J. W. Price et al., AIP Conf. Proc. 2130, 020004 (2019)
Λp : K. Miwa et al., Proposal to J-PARC, P86 (2021)

Hypernuclei → YN/YY interactions





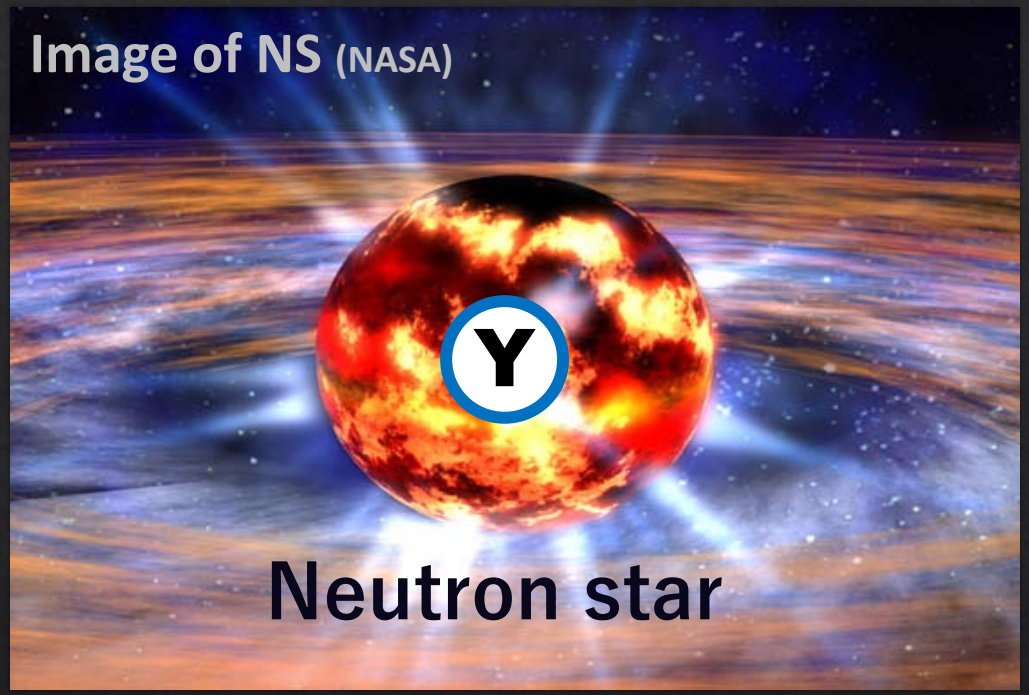
Hypernuclear spectroscopy has been playing the most important role for the YN/YY-interaction study

Hyperons in the nature

Hypernuclear research

- Internal structure

Microscopic



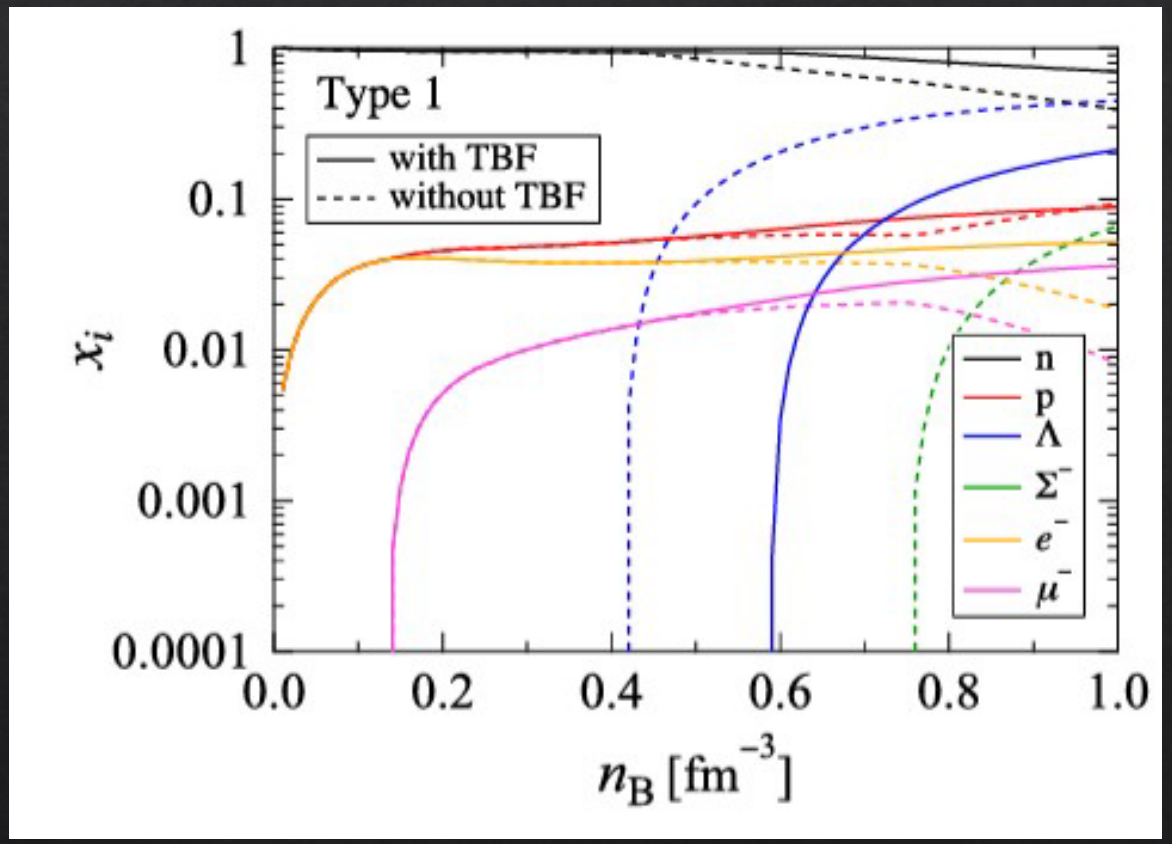
- Cosmological observation
- Gravitational wave measurement

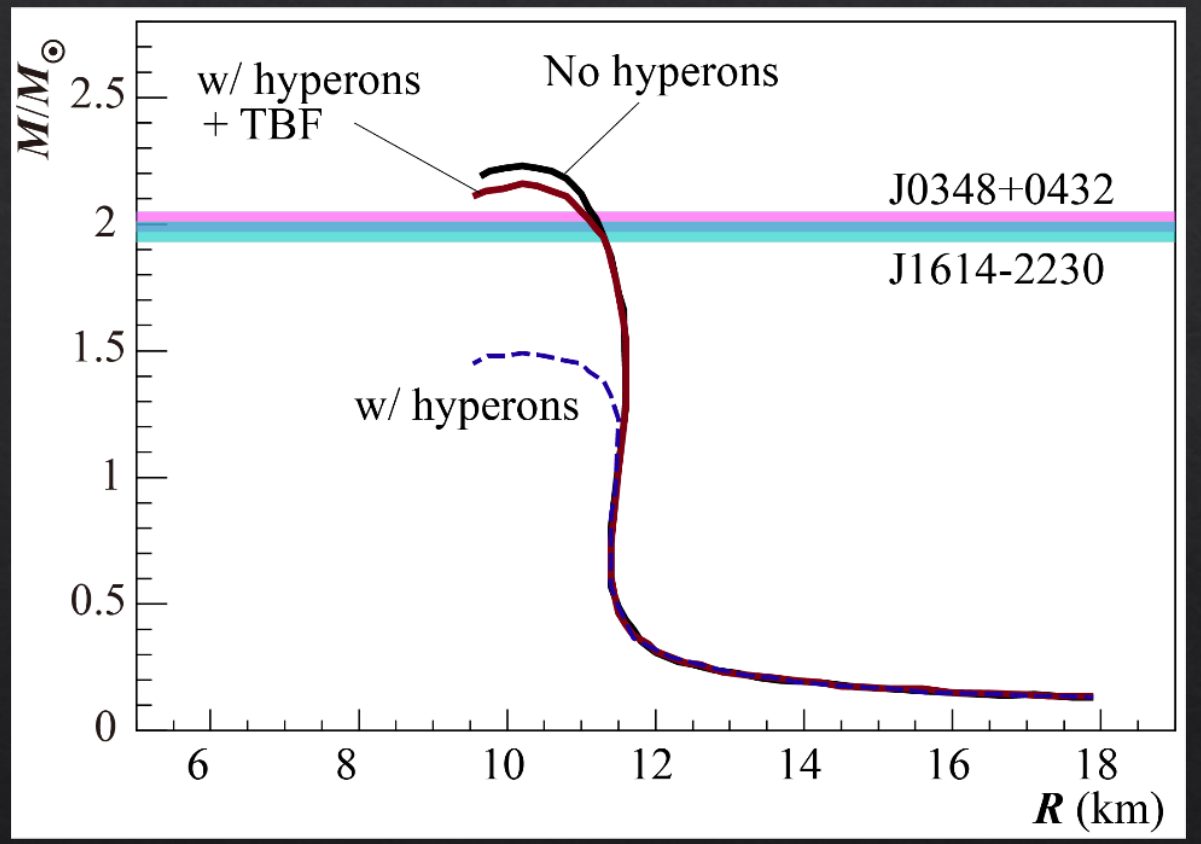
- Mass, radius etc.

Macroscopic

Hyperon puzzle for neutron stars

H. Togashi *et al.*, Phys. Rev. C 93, 035808 (2016)

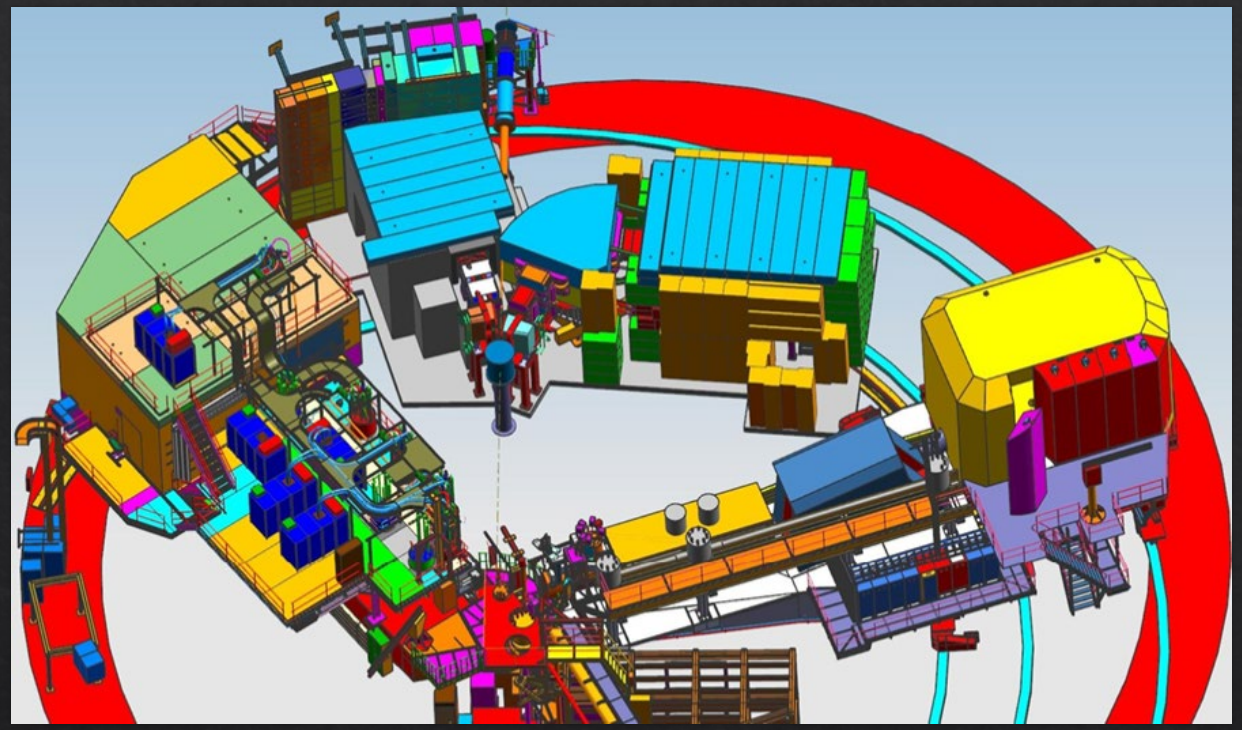




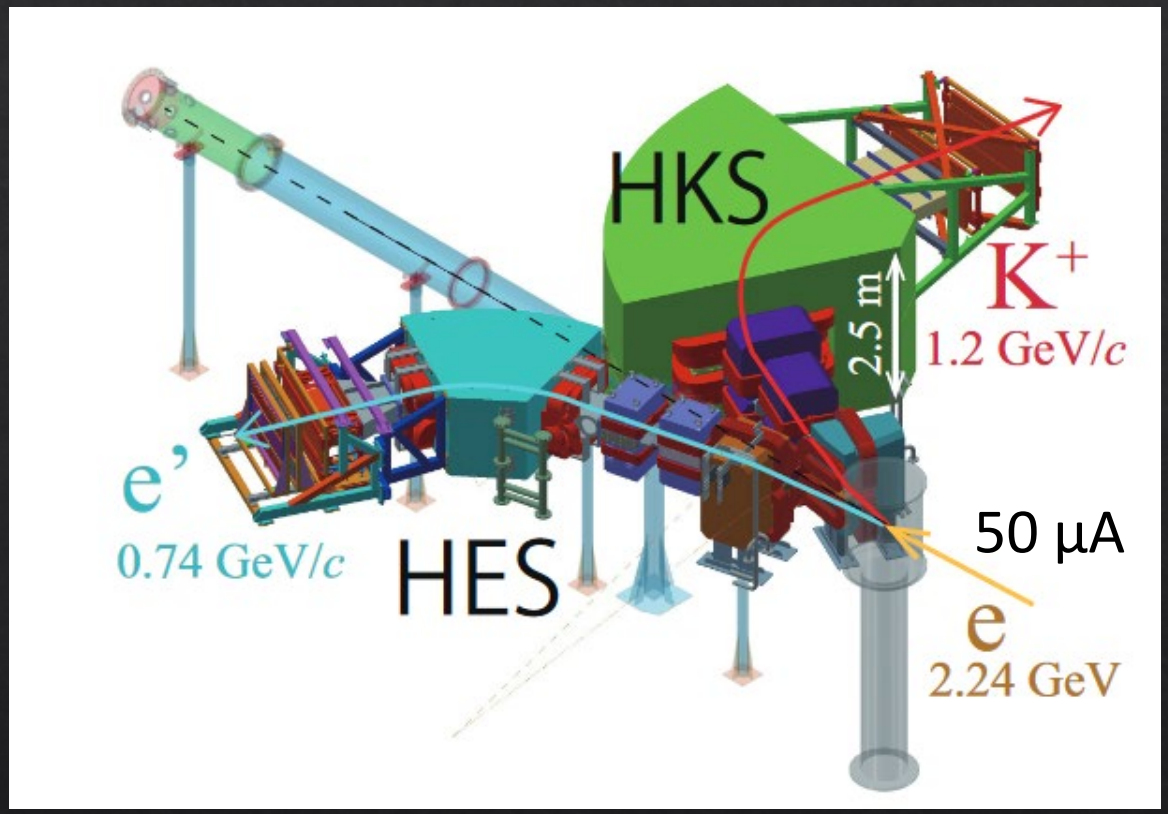
Multi-body force plays an important role

➔ JLab E12-15-008, E12-20-013

Next experiment at JLab Hall C (FY2026~)



Steven Lassiter & Bert Metzger, JLab Hypernuclear Collaboration Meeting 2022, online, Dec 2022, https://wiki.jlab.org/tegwiki/index.php/Hypernuclear_CollaborationMeeting_2022Dec

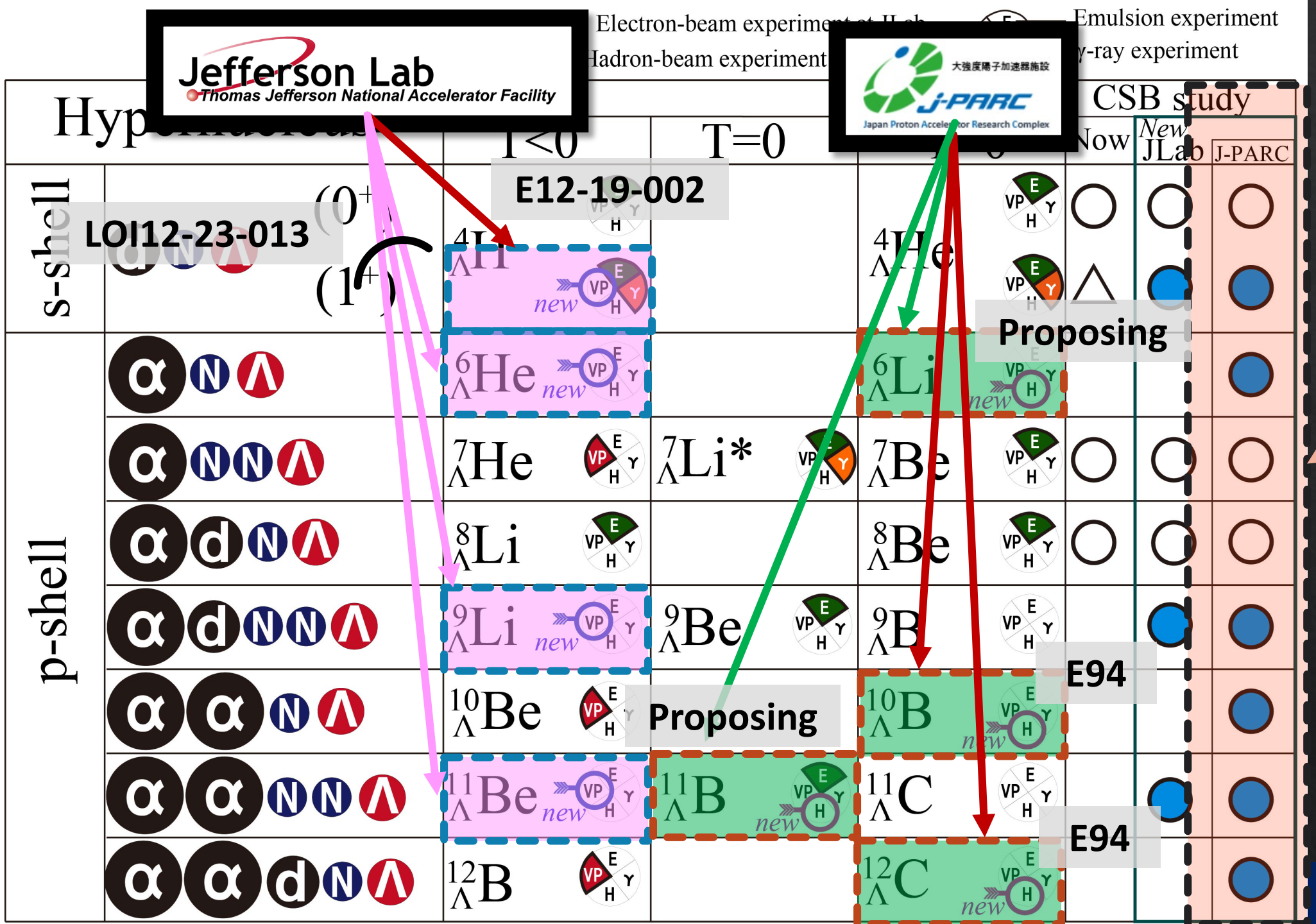


Schematic from LOI12-23-013 (TG et al., LoI to PAC51): https://researchmap.jp/gogami/published_papers/42361620/attachment_file.pdf

Electron-beam experiment at JLab
Hadron-beam experiment at J-PARC
Emulsion experiment
γ-ray experiment

Hypernucleus		T<0	T=0	T>0	CSB study: Now	CSB study: New JLab	CSB study: J-PARC
s-shell	d N Λ (0^+)	${}^{4}_{\Lambda}\mathrm{H}$		${}^{4}_{\Lambda}\mathrm{He}$	○	○	○
	d N Λ (1^+)	${}^{4}_{\Lambda}\mathrm{H}$ new		${}^{4}_{\Lambda}\mathrm{He}$	△	●	●
p-shell	α N Λ	${}^{6}_{\Lambda}\mathrm{He}$ new		${}^{6}_{\Lambda}\mathrm{Li}$ new			●
	α N N Λ	${}^{7}_{\Lambda}\mathrm{He}$	${}^{7}_{\Lambda}\mathrm{Li}^*$	${}^{7}_{\Lambda}\mathrm{Be}$	○	○	○
	α d N Λ	${}^{8}_{\Lambda}\mathrm{Li}$		${}^{8}_{\Lambda}\mathrm{Be}$	○	○	○
	α d N N Λ	${}^{9}_{\Lambda}\mathrm{Li}$ new	${}^{9}_{\Lambda}\mathrm{Be}$	${}^{9}_{\Lambda}\mathrm{B}$		●	●
	α α N Λ	${}^{10}_{\Lambda}\mathrm{Be}$		${}^{10}_{\Lambda}\mathrm{B}$ new			●
	α α N N Λ	${}^{11}_{\Lambda}\mathrm{Be}$ new	${}^{11}_{\Lambda}\mathrm{B}$ new	${}^{11}_{\Lambda}\mathrm{C}$		●	●
	α α d N Λ	${}^{12}_{\Lambda}\mathrm{B}$		${}^{12}_{\Lambda}\mathrm{C}$ new			●

Isospin multiplet for CSB study



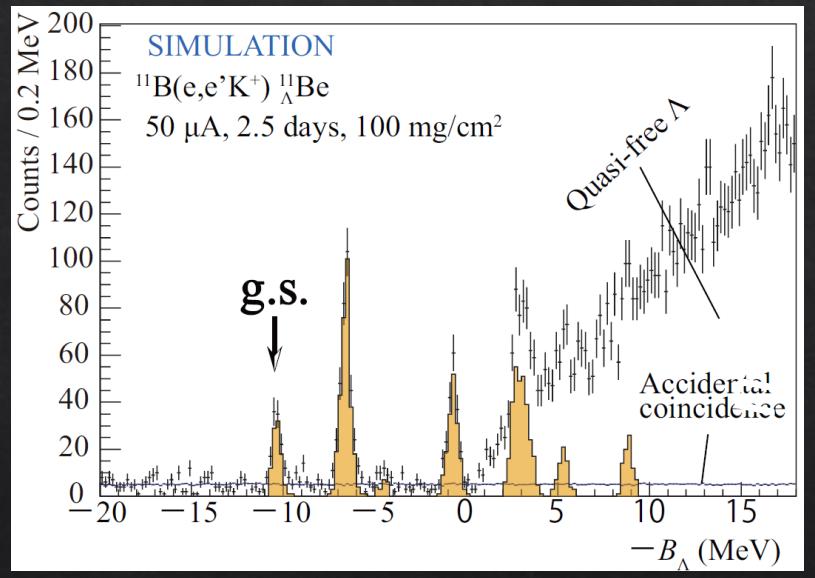
To "complete"
Isospin multiplet for CSB study

High resolution spectroscopy at J-PARC and JLab

$^{11}_{\Lambda}$Be

Jefferson Lab
Thomas Jefferson National Accelerator Facility

LOI12-23-013



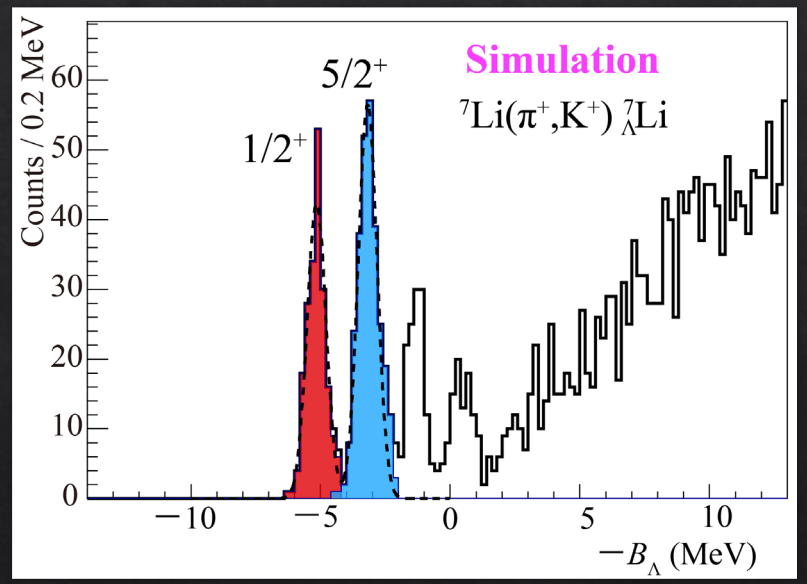
09

0.6 MeV (FWHM)

$^{7}_{\Lambda}$Li

大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex

E94



08

1 MeV (FWHM)

Hypernuclear Study at JLab

Λ hypernuclear spectroscopy

- Baryon interaction (YN, YNN)

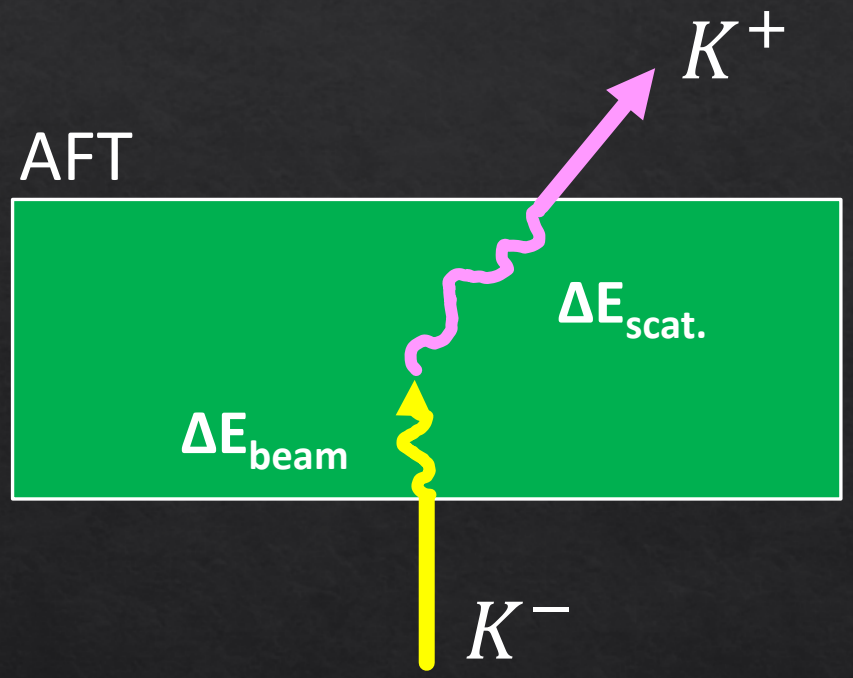
JLab Hypernuclear Collaboration

- (e,e'K^+) reaction → High resolution/accuracy spectroscopy
- The method was established at JLab
- Future experiment ($^{3}_{\Lambda}\mathrm{H}$, $^{4}_{\Lambda}\mathrm{H}$, $^{6}_{\Lambda}\mathrm{He}$, $^{11}_{\Lambda}\mathrm{Be}$, $^{27}_{\Lambda}\mathrm{Mg}$, $^{40}_{\Lambda}\mathrm{K}$, $^{48}_{\Lambda}\mathrm{K}$, $^{208}_{\Lambda}\mathrm{Tl}$)
  - hypertriton puzzle (biding energy vs. lifetime)
  - Charge symmetry breaking
  - Deformation
  - ΛN-ΣN coupling
  - iso-spin dependence of ΛNN force

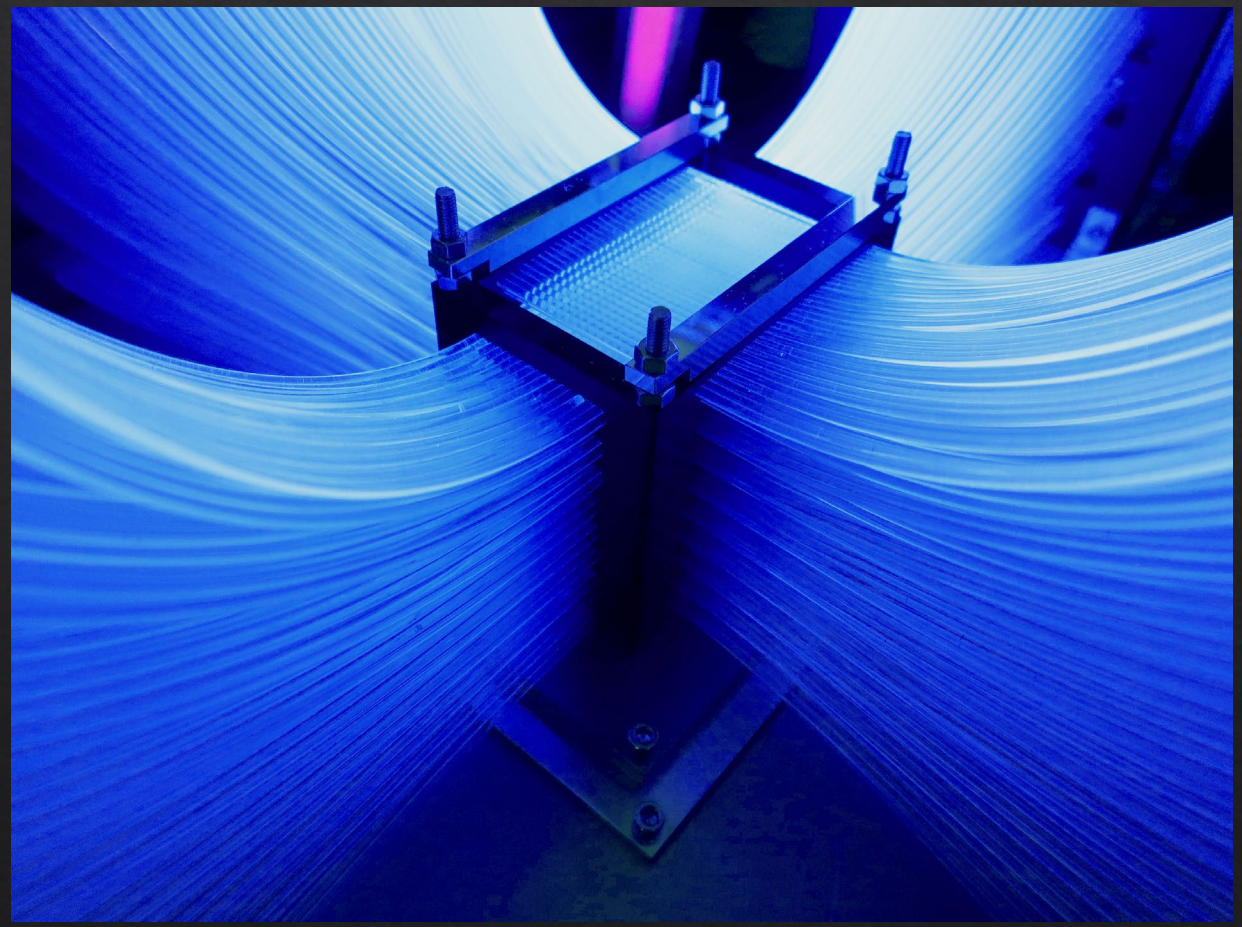
Mar 3, 2023

Hypernuclear Physics Workshop:
https://indico.jlab.org/event/685/

Direct measurement of energy loss in target



T. K. Harada, EPJ Web Conf. 271 (2022) 03006

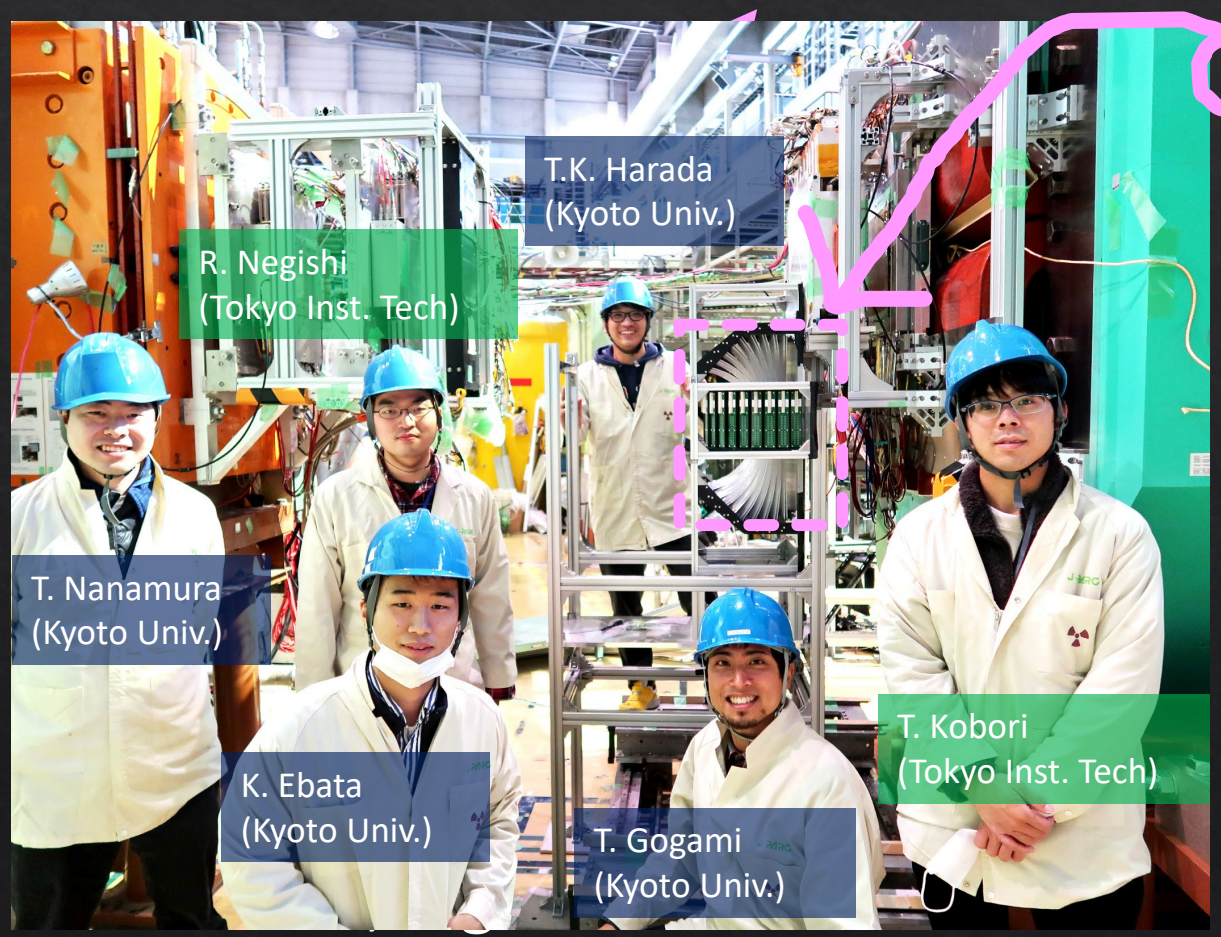


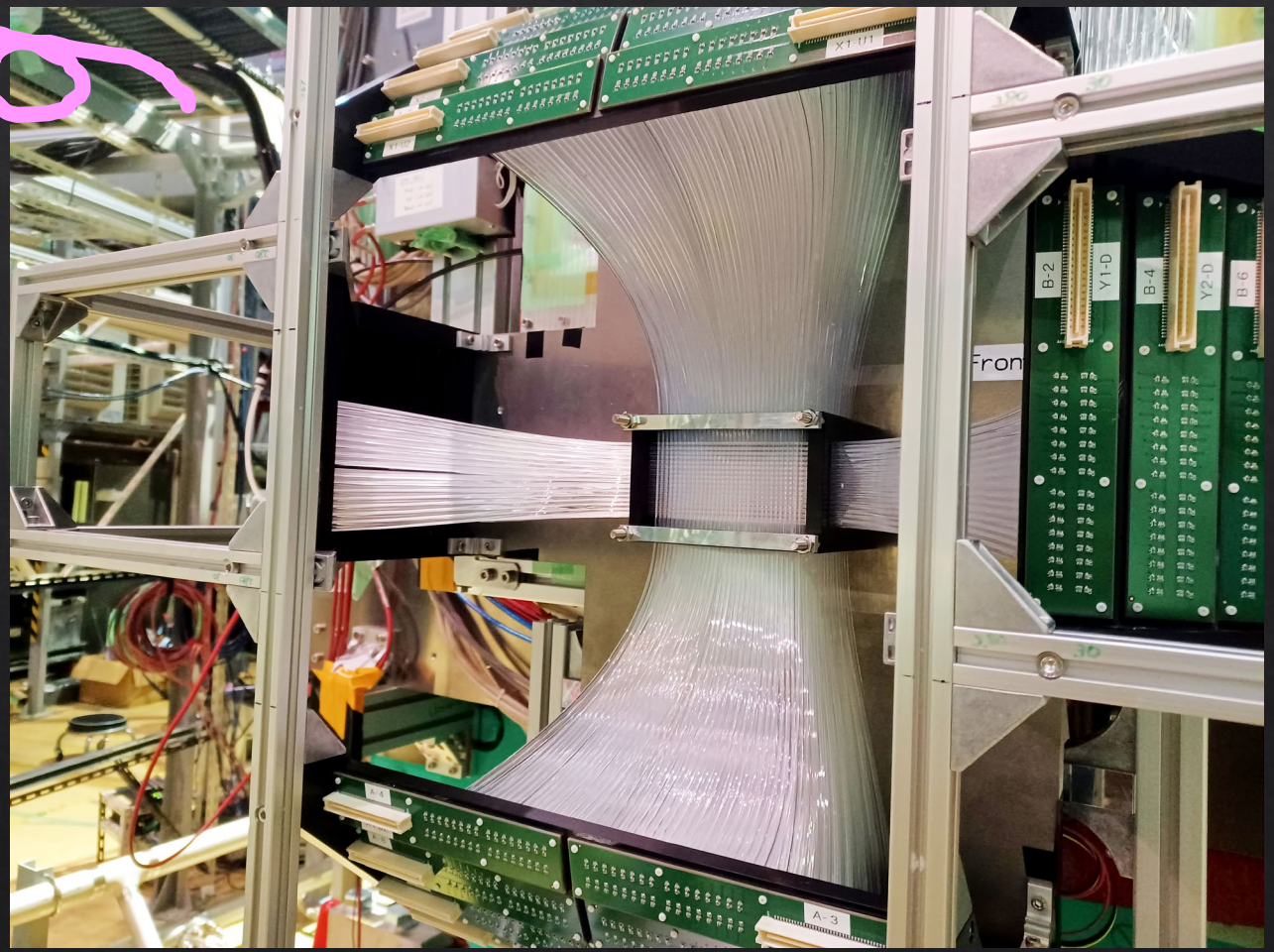
~900-ch of scintillation fibers (CH)

Thick target …
→ But, high resolution!!

Direct measurement of energy loss in target

T. K. Harada, EPJ Web Conf. 271 (2022) 03006

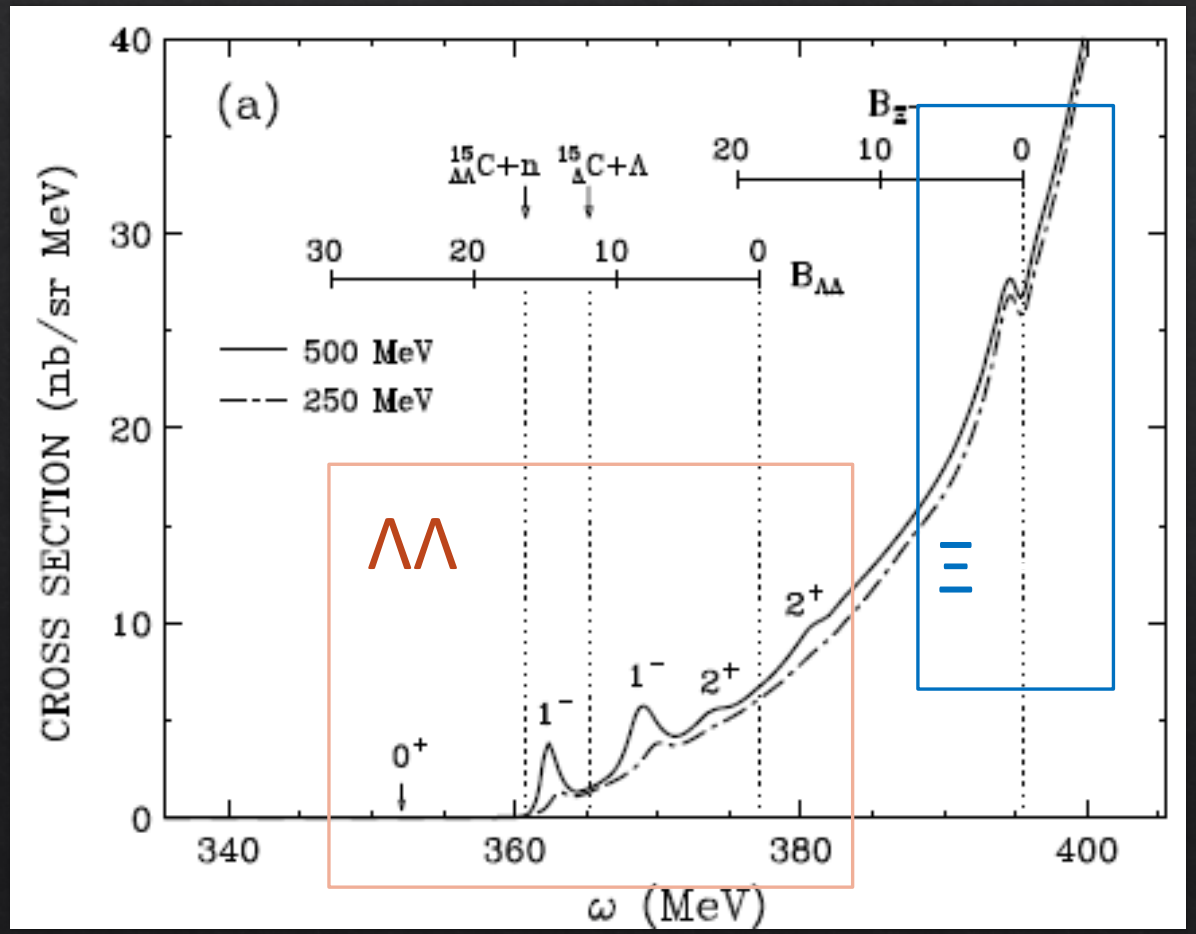


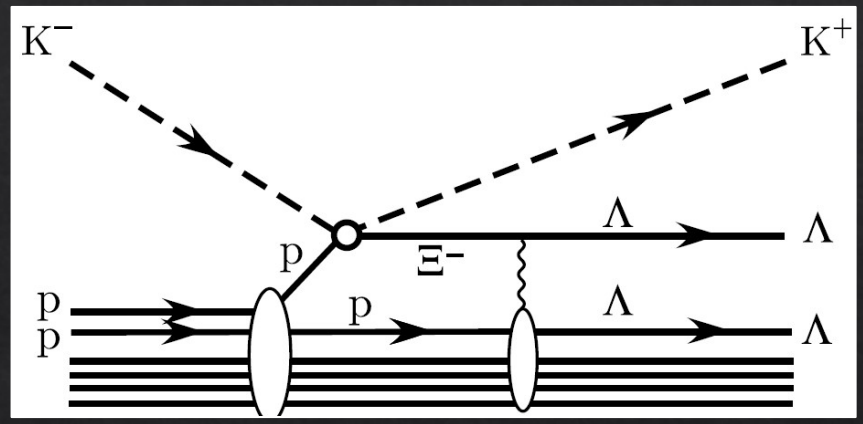


(Feb 16, 2023)

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

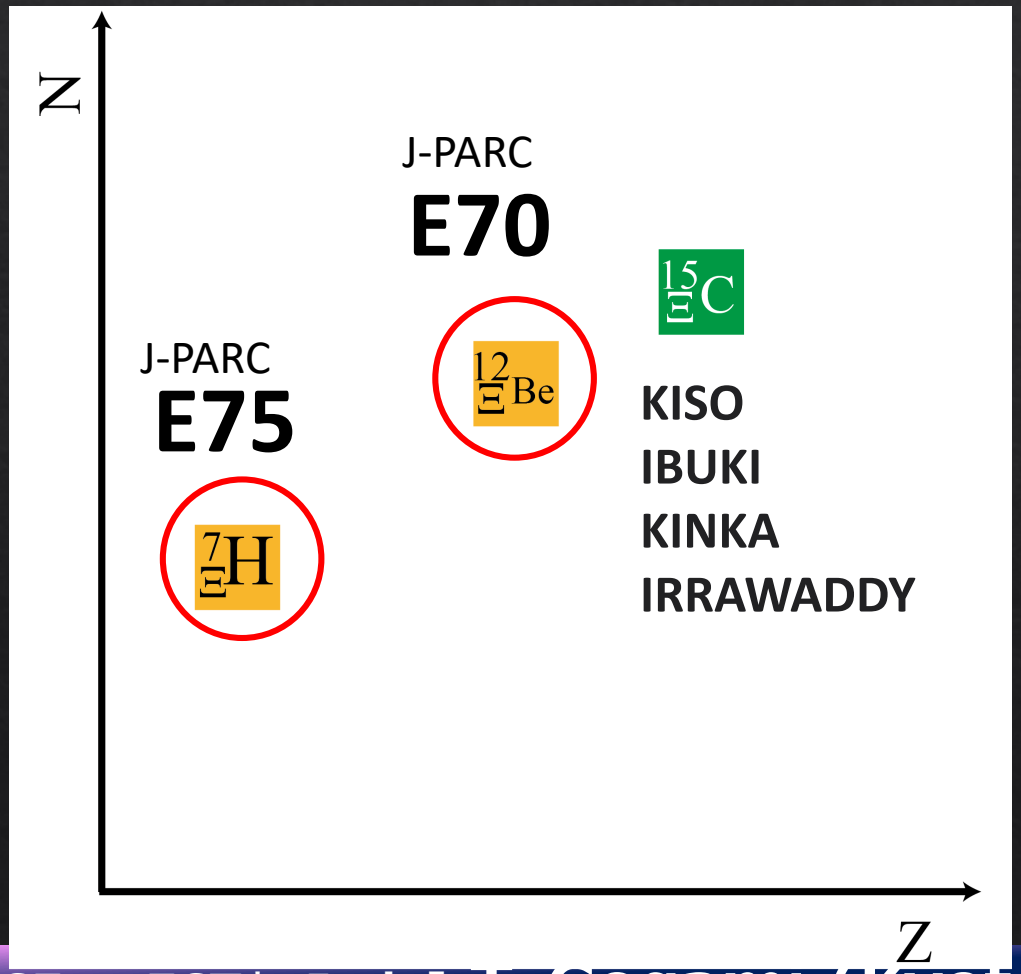
T. Harada, Y. Hirabayashi, A. Umeya, NPA 914, 85—90 (2013)

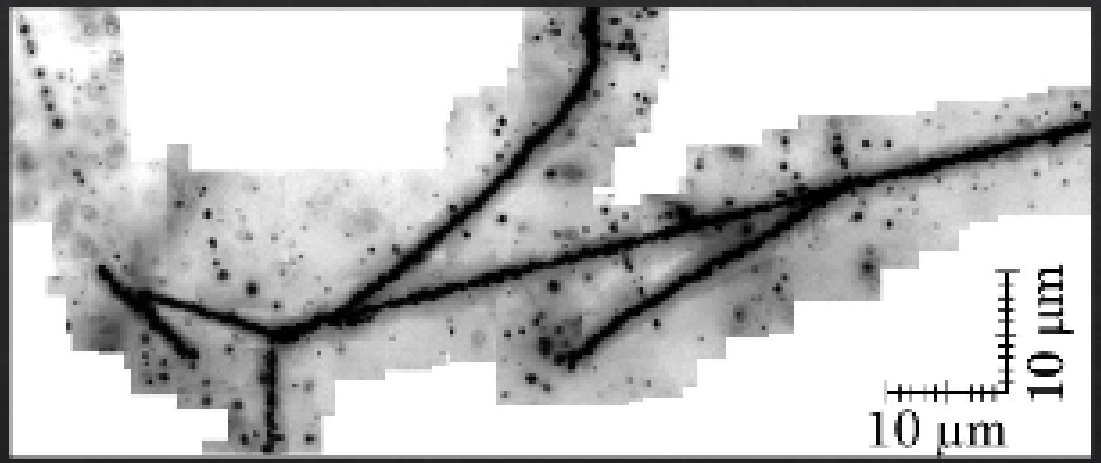




ΛΛ hypernuclei may be observed

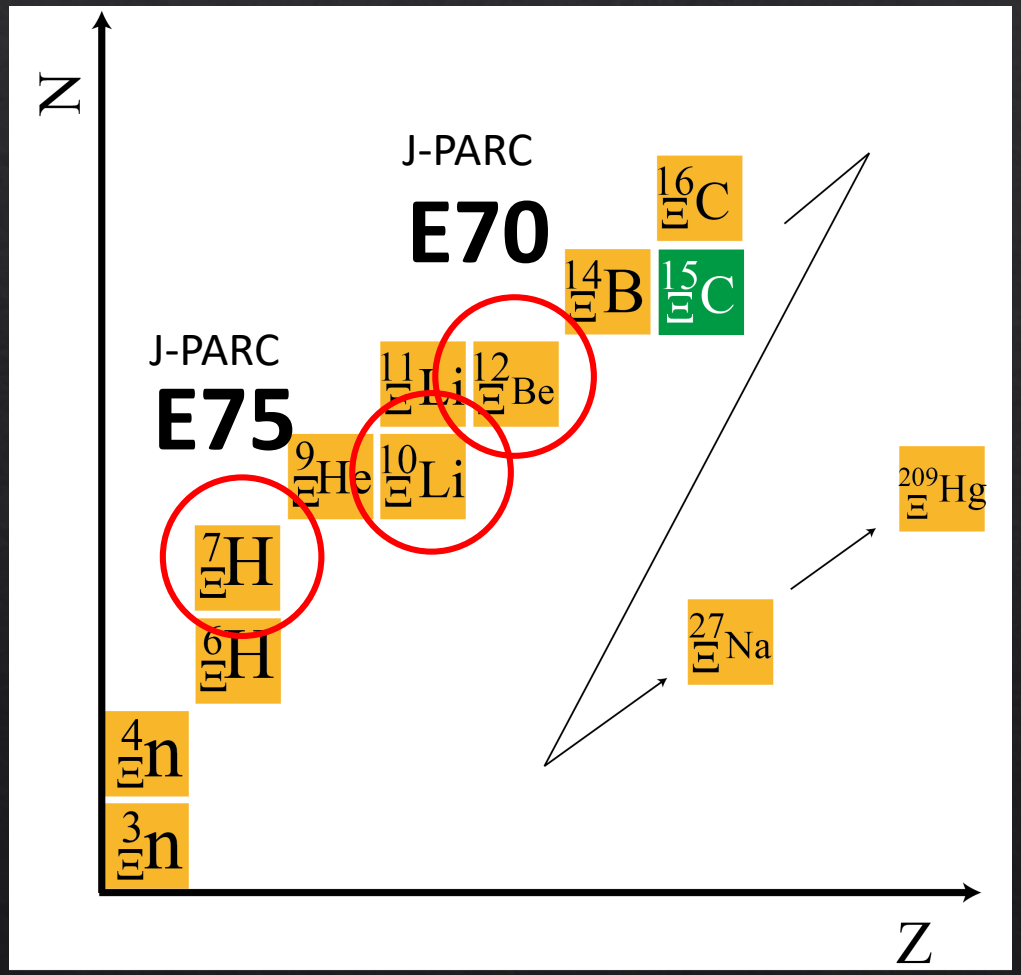
Hypernuclear chart ($S = -2$ floor)

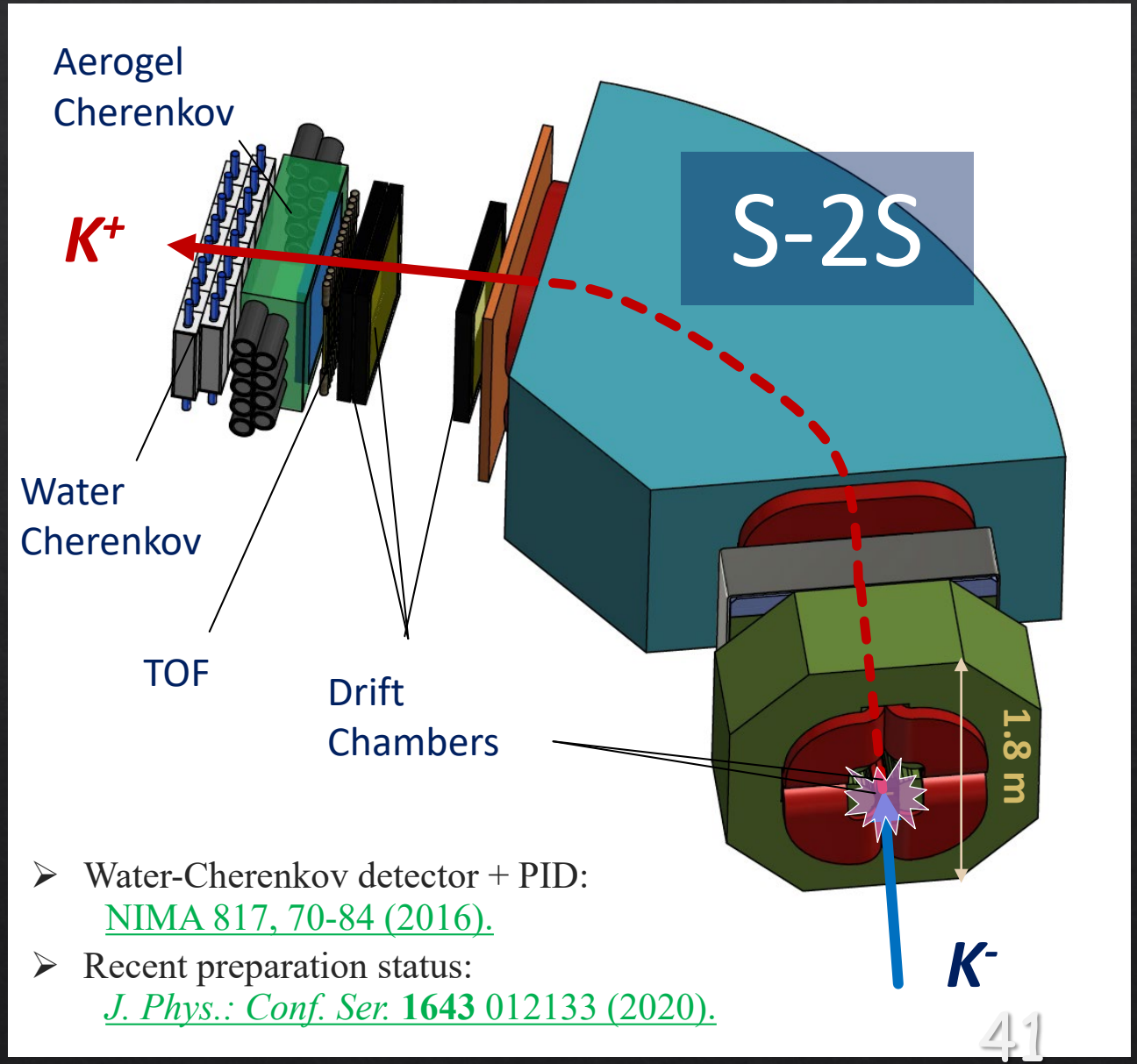




- K. Nakazawa et al., PTEP 2015, 033D02 (2015)
- M. Yoshimoto et al., PTEP 2021, 073D02 (2021)
- S. Hayakawa et al., PRL 126, 062501 (2021)

Hypernuclear chart ($S = -2$ floor)





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

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Some References

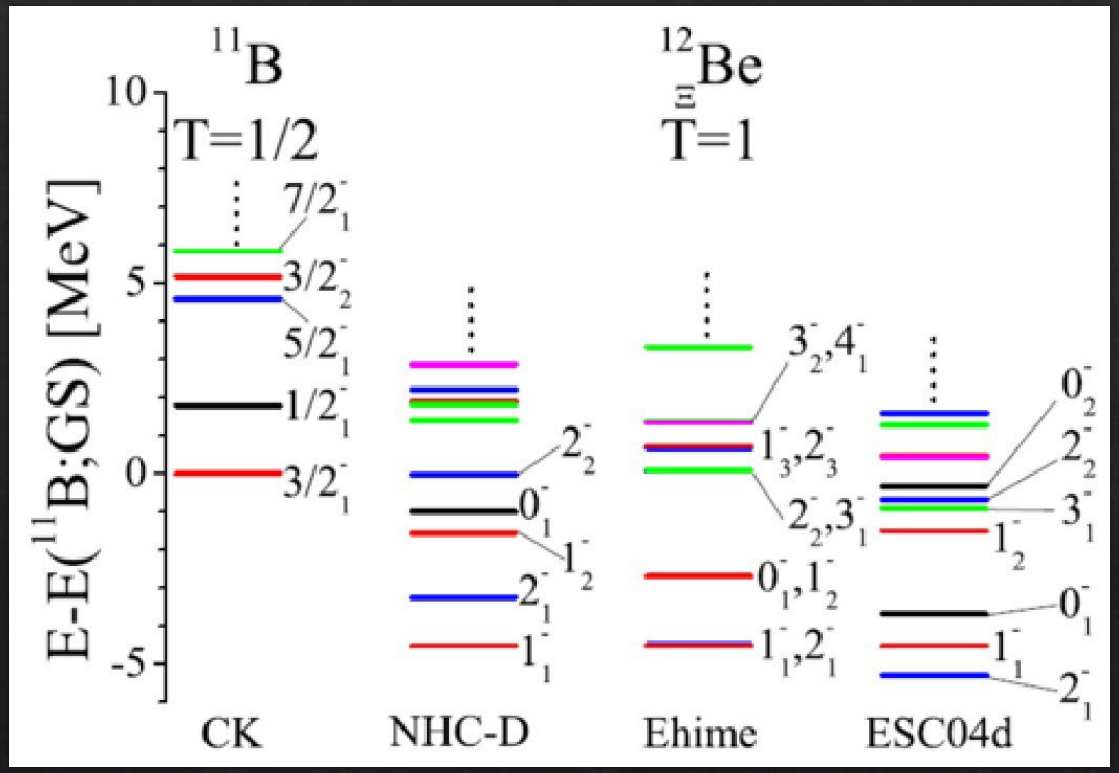
J-PARC

- Resent results：https://j-parc.jp/c/press-release/2022/09/05001005.html
- Future projects：https://doi.org/10.1051/epjconf/202227111002

JLab

- Resent results (nn Λ search experiment)：
  - https://doi.org/10.1051/epjconf/202227102002
  - https://www.kyoto-u.ac.jp/ja/research-news/2022-03-08
- Future projects：https://doi.org/10.1051/epjconf/202227101001

Complication of Ξ hypernuclear structures



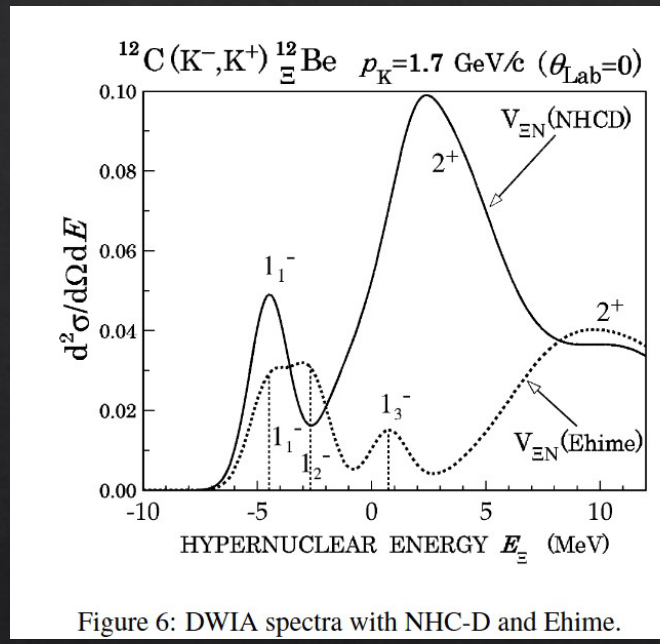


Figure 6: DWIA spectra with NHC-D and Ehime.

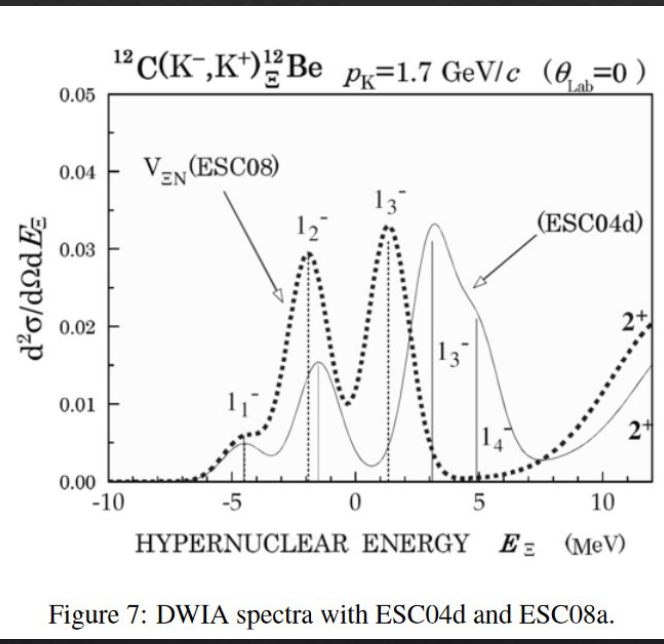
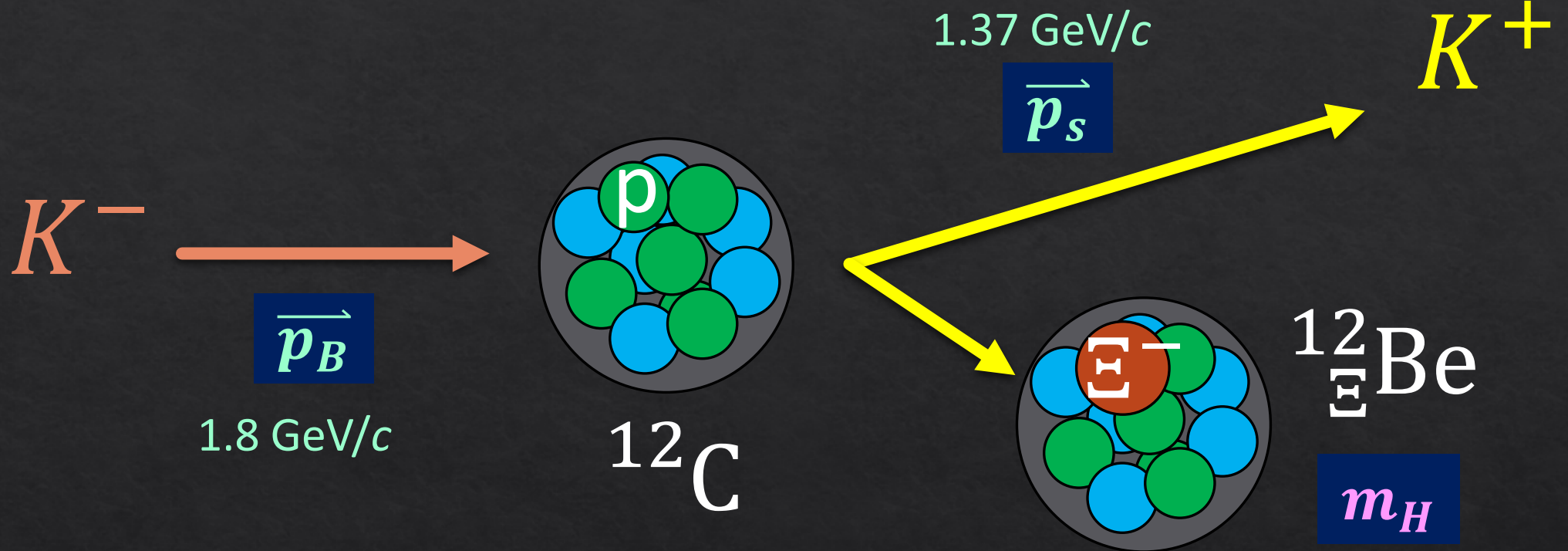


Figure 7: DWIA spectra with ESC04d and ESC08a.

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

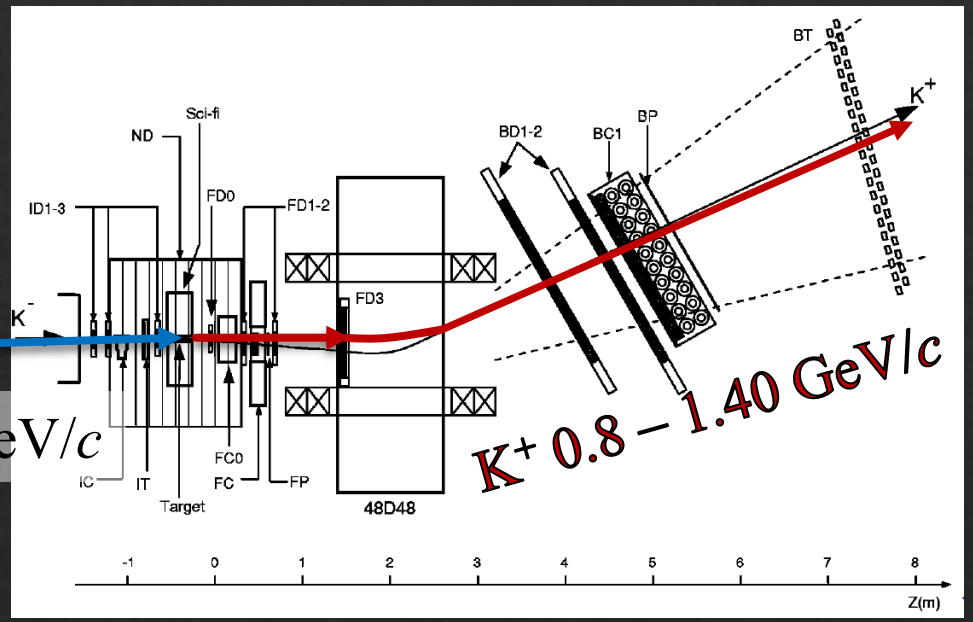
Missing mass spectroscopy with the (K^-,K^+) reaction



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

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

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



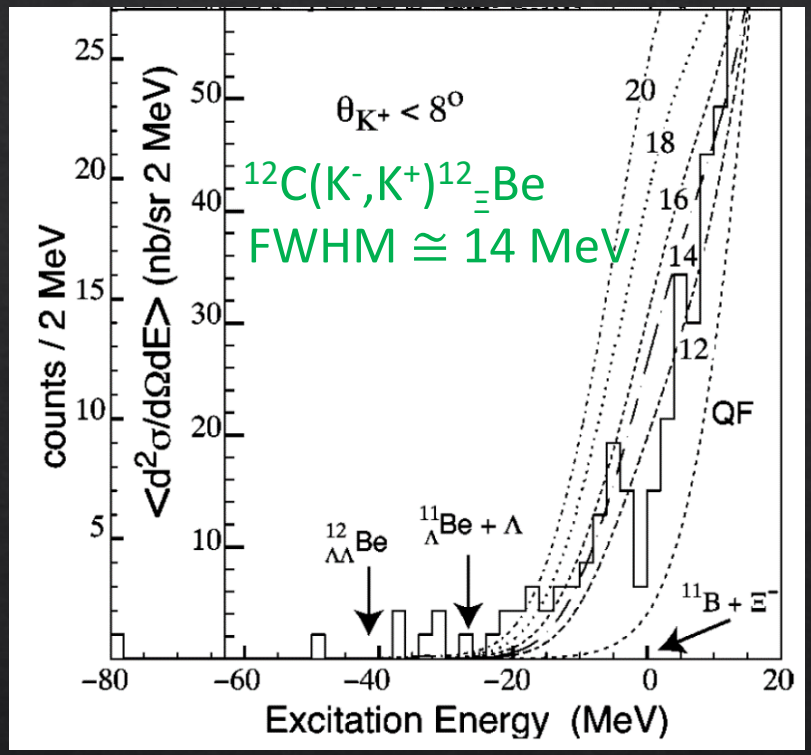
K- 1.8 GeV/c

K+ 0.8 – 1.40 GeV/c

Experiment	KEK E224	BNL E885	J-PARC E05
Resolution in FWHM (MeV)	22	14	8

➔ **2 MeV** in J-PARC E70

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



➔ $V_{0\Xi} \leq 14$ MeV

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

Assumption for ${}^{12}_{\Lambda}\mathrm{C}$ production

$^{12}\mathrm{C}(\pi^+, K^+)\,^{12}_{\Lambda}\mathrm{C}$ @ $p_\pi = 1.64$ GeV/c

- Total efficiency = 0.5
- K survival ratio = 0.46
- Cross section = 1 μb/sr
- Solid angle = 55 msr
- Target thickness = 2 g/cm^2
- Beam = 3 M pion per spill (spill cycle of 4.2 sec)
- 5 days
- S-2S momentum setting is the same as that for the Ξ production

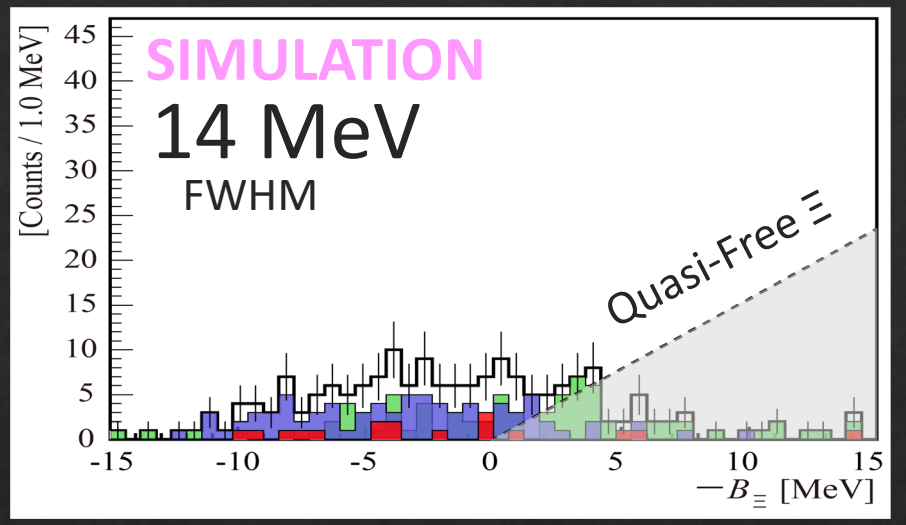
391 counts

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

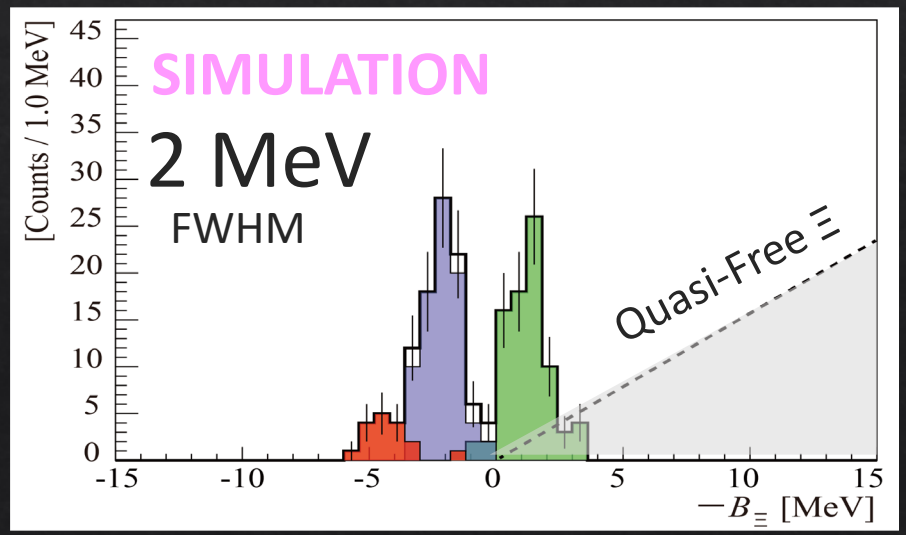
$^{12}\mathrm{C}(K^-, K^+)^{12}_{\Xi}\mathrm{Be}$ @ $p_\pi = 1.8$ GeV/c

- 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



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.	$^{12}\mathrm{C} + \Xi^-$	$^{14}\mathrm{N} + \Xi^-$	$^{27}\mathrm{Al} + \Xi^-$
	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

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	