Strangeness $S = -1$ and -2 hypernuclear research at JLab and J-PARC

Graduate School of Science, Kyoto University

Toshiyuki Gogami

Oct 18, 2024

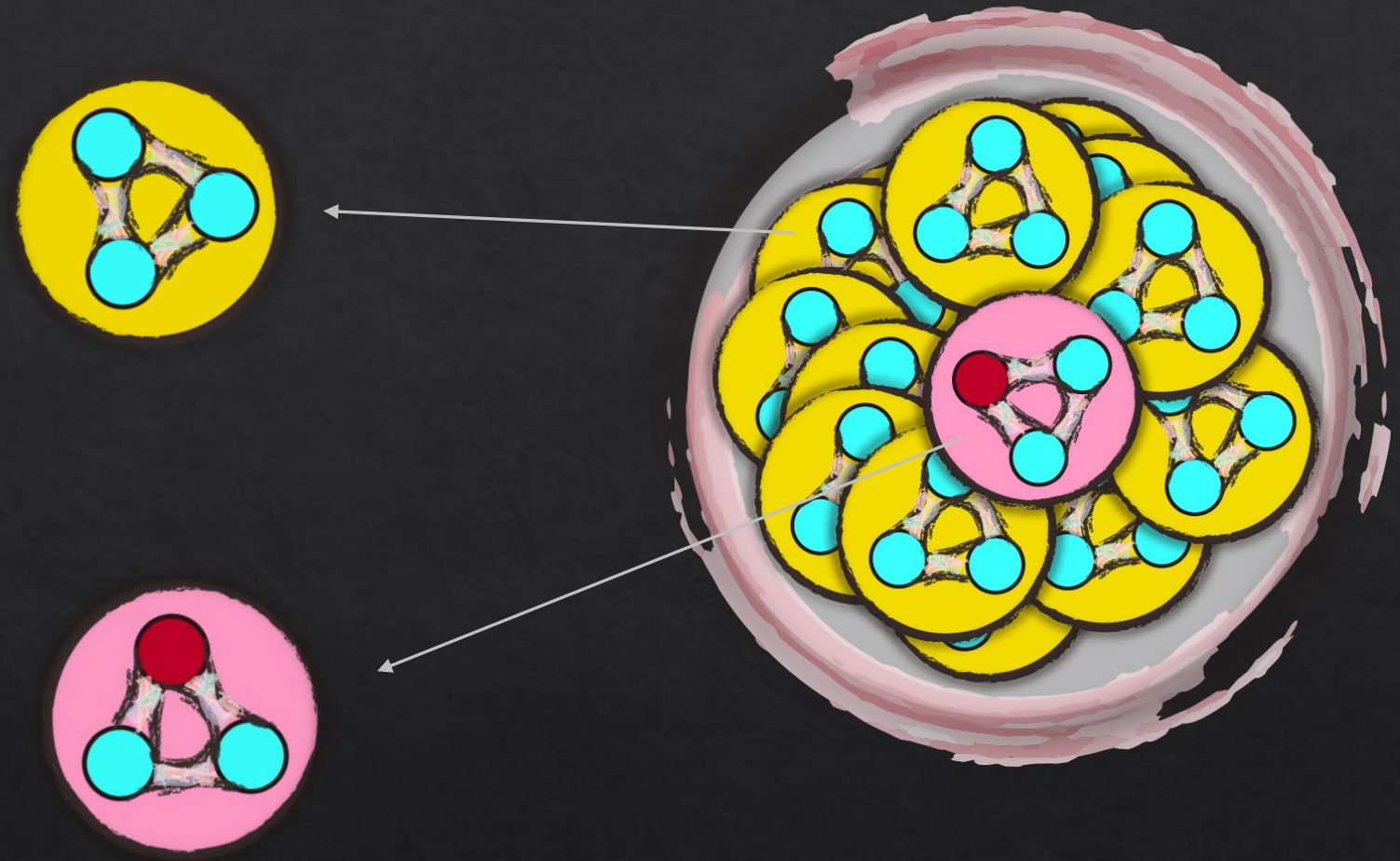
Hypernucleus

Nucleon

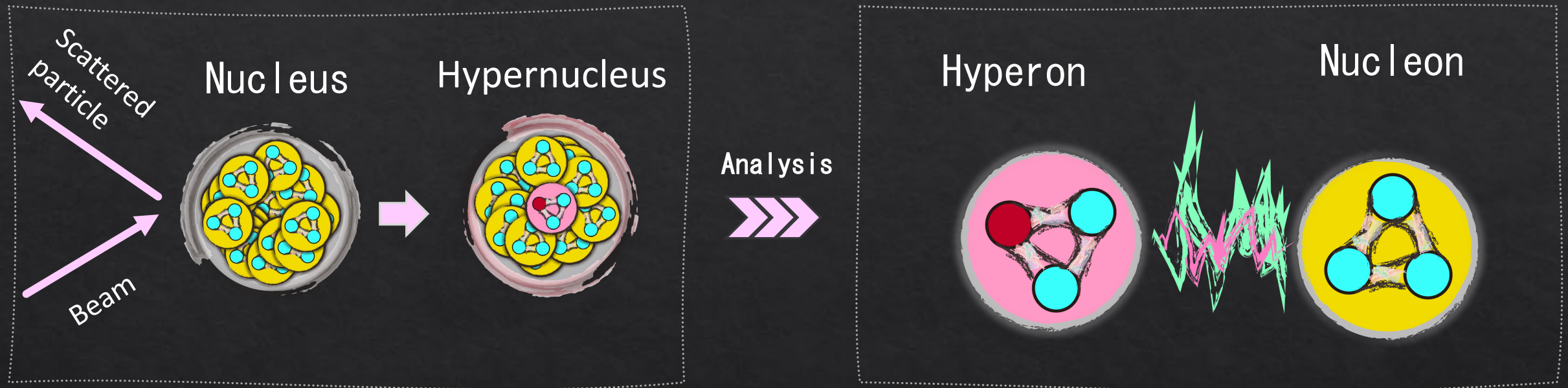
up (u), down (d) quarks

Hyperon

(u, d +) strange (s)



Baryon interaction study through hypernuclei

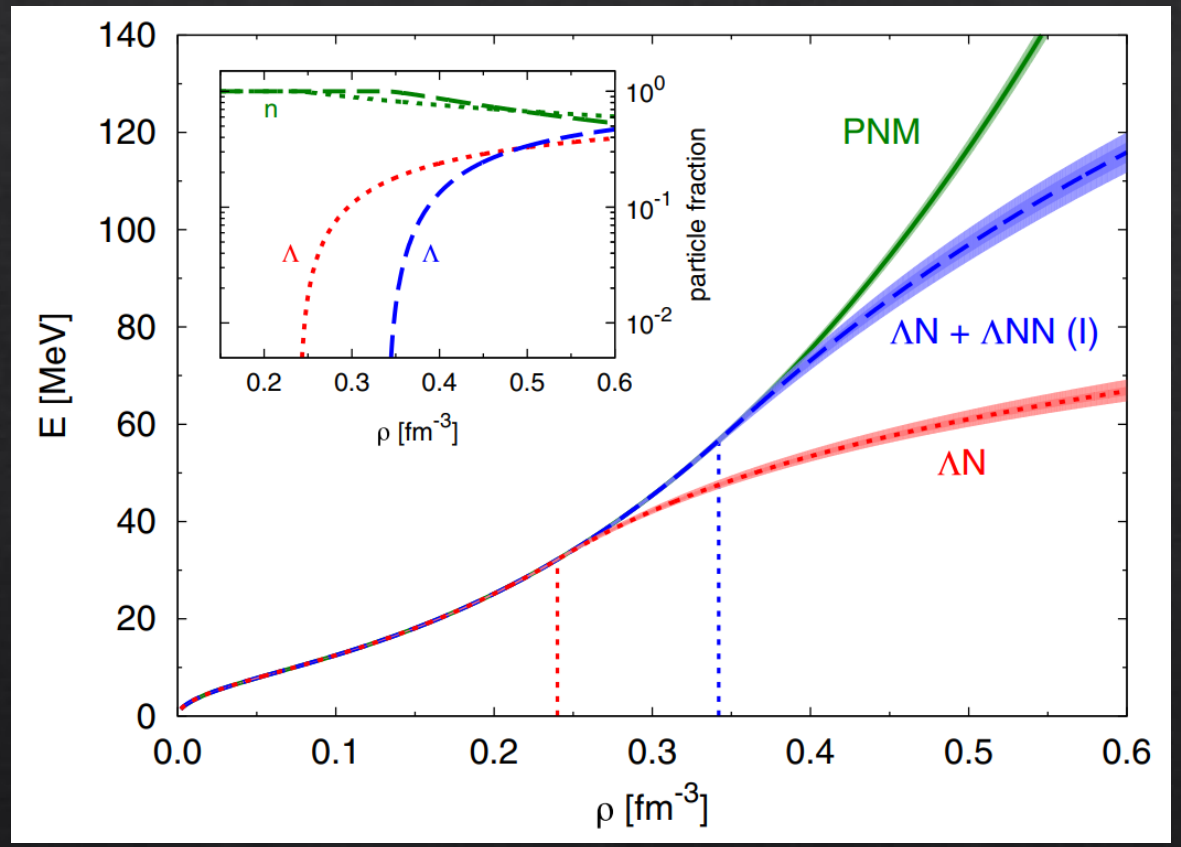


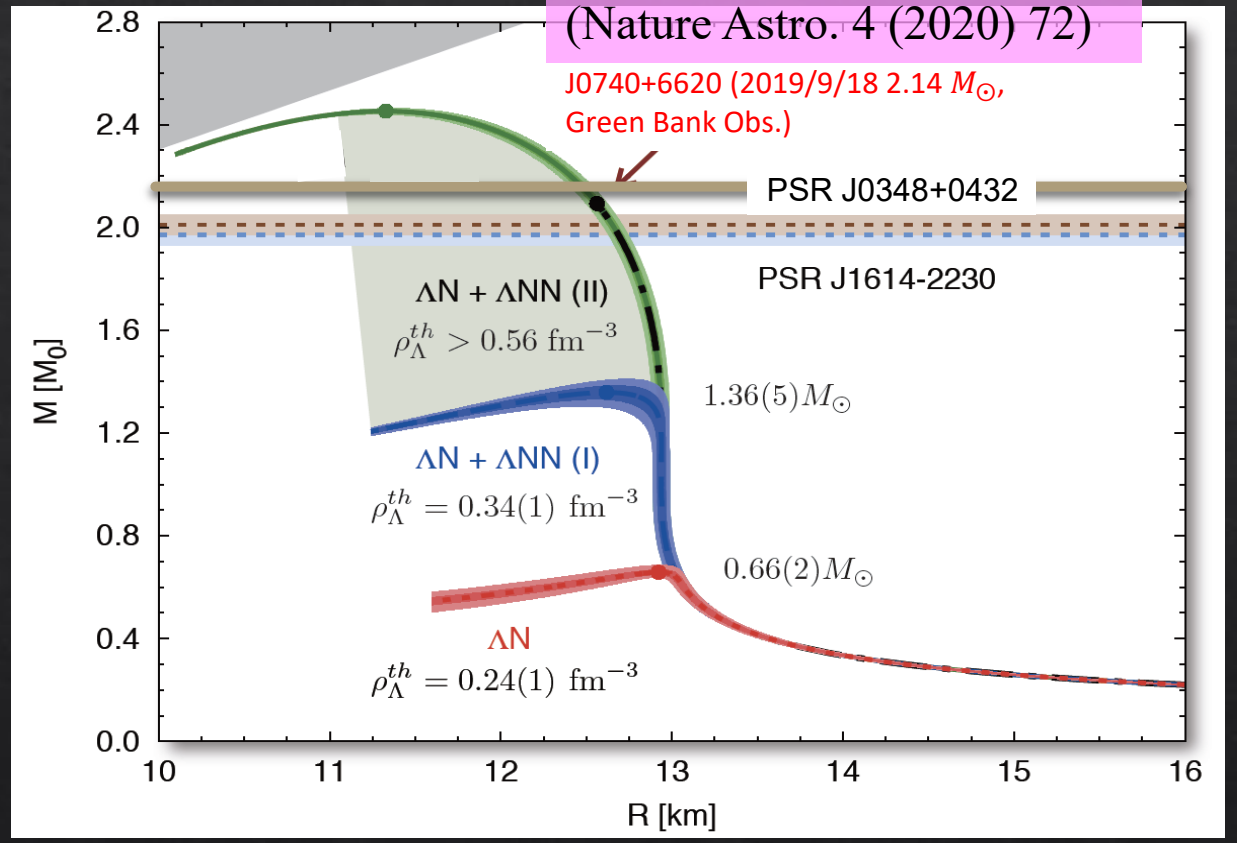
➔ Hyperon(Y)–nucleon(N) interaction

➔ More general baryon–baryon interaction

Hyperons in neutron stars

D. Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015)



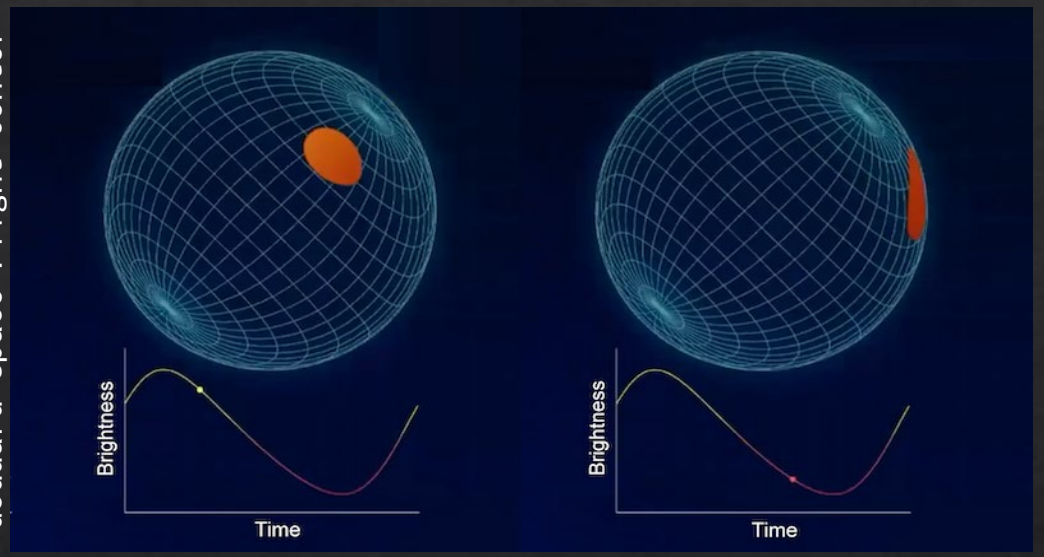


➔ Multi-body force may play an important role

New astronomical observations

CC4.0 ESO/L. Calçada/M. Kornmesser

Gravitation Wave from neutron star mergers
LIGO/Virgo PRL 119, 161101 (2017)



Goddard Space Flight Center

NICER : NS x-ray hot spot measurement
Physics 14, 64 (Apr. 29, 2021)

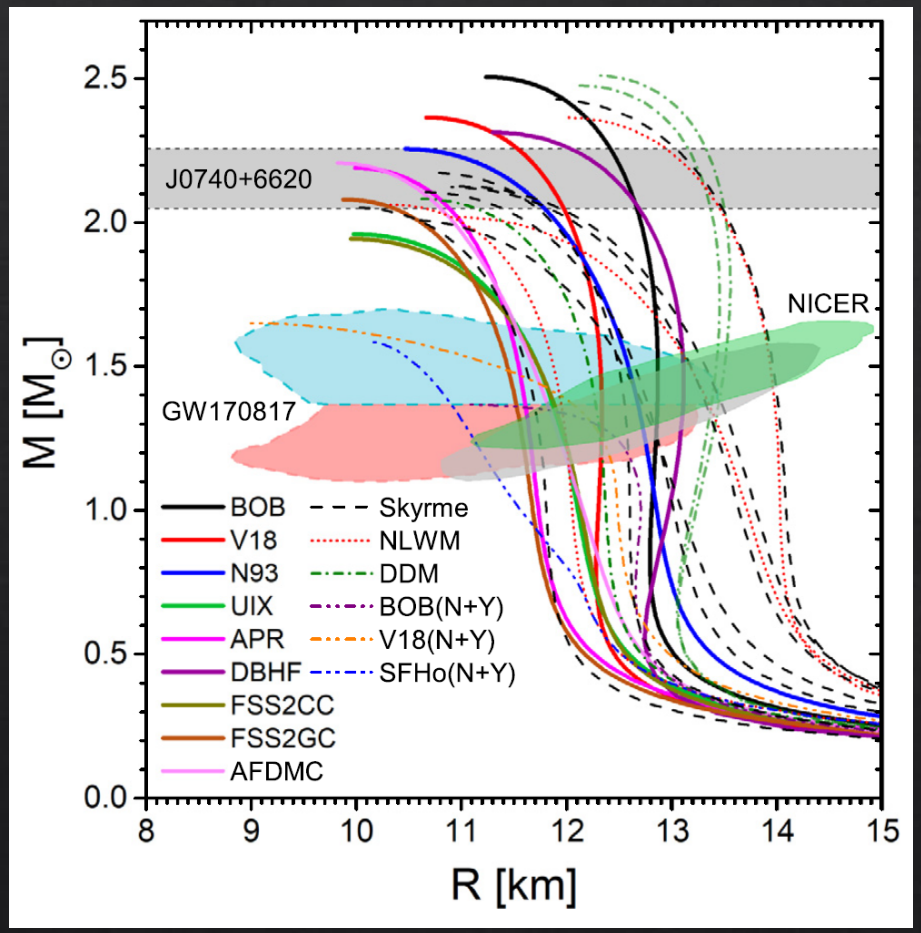
Macroscopic features of NS : Tidal deformability, masses and radii

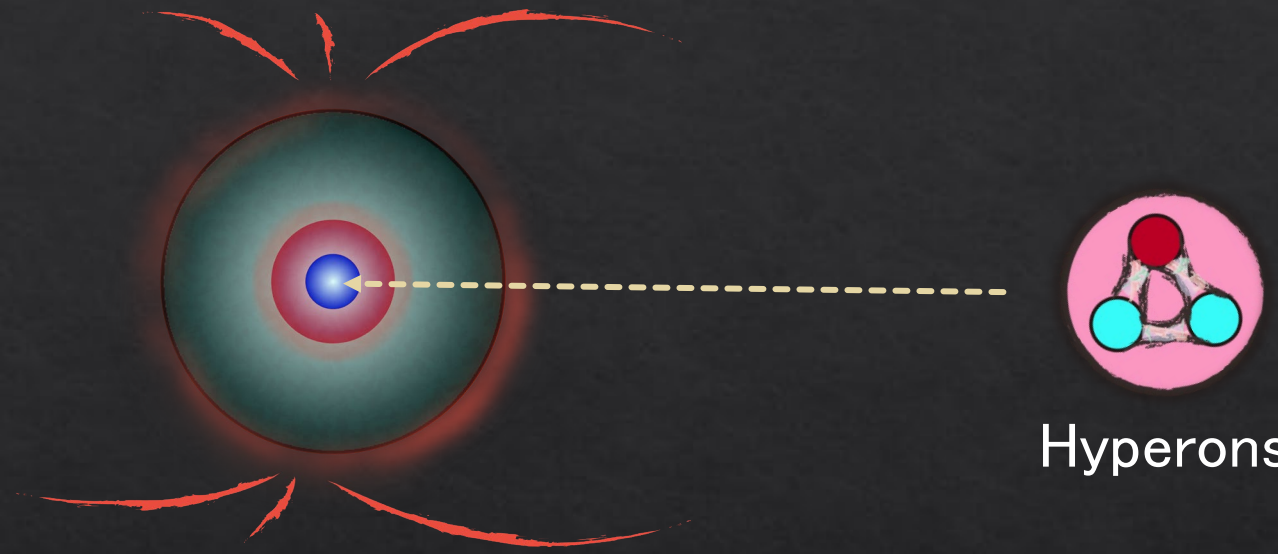
vs.

Microscopic investigation of NS: Inner composition ➡ HYPERNUCLEAR SPECTROSCOPY

New constrains from astronomical observations

C.F. Burgio et al. Prog. Part. Nucl. Phys 120 (2021) 103879.

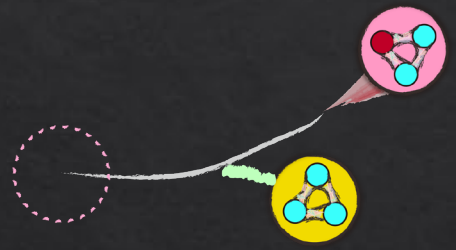


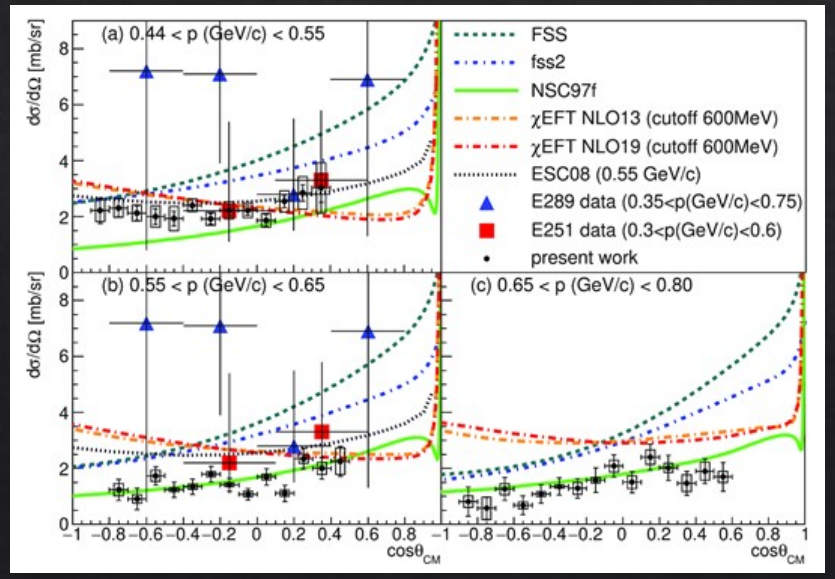


Microscopic study
(← nuclear/hypernuclear research) has become more important as the macroscopic study is in great progress

YN/YY interaction study

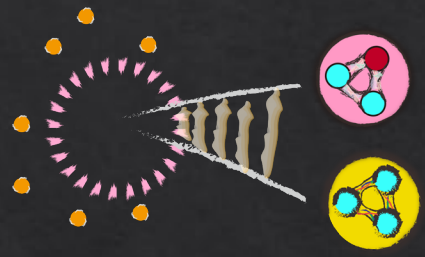
Scattering experiments

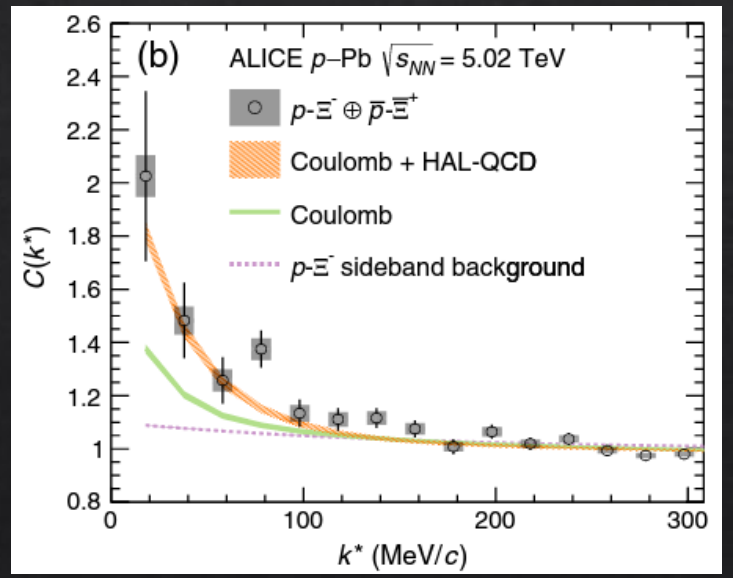




T. Nanamura et al., PTEP 2022, 9, 093D01 (2022)

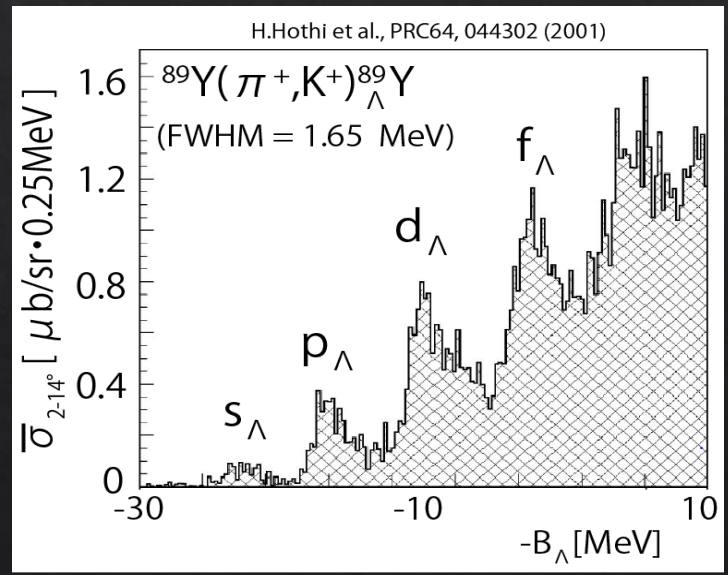
Femtoscopy





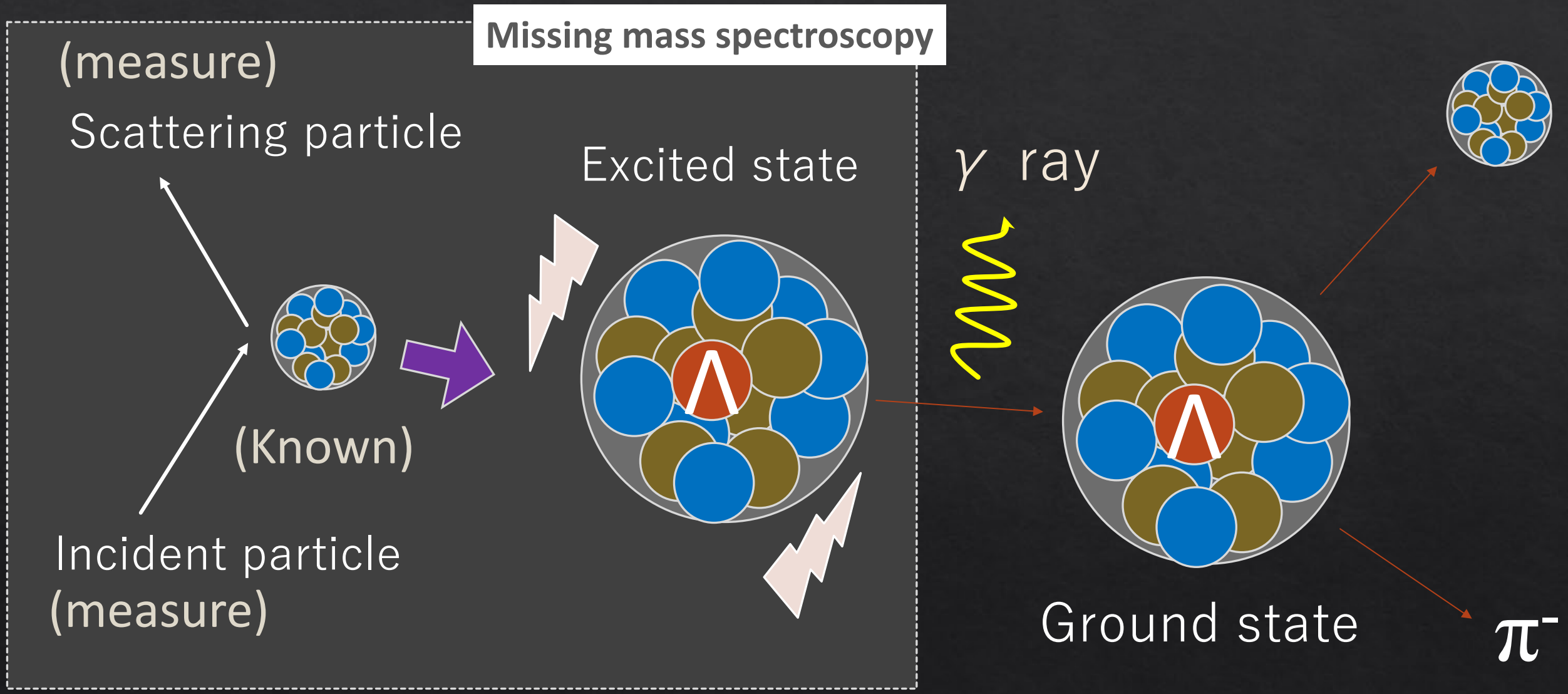
S. Acharya et al., Phys. Rev. Lett. 123, 112002 (2019)

Hypernuclear spectroscopy

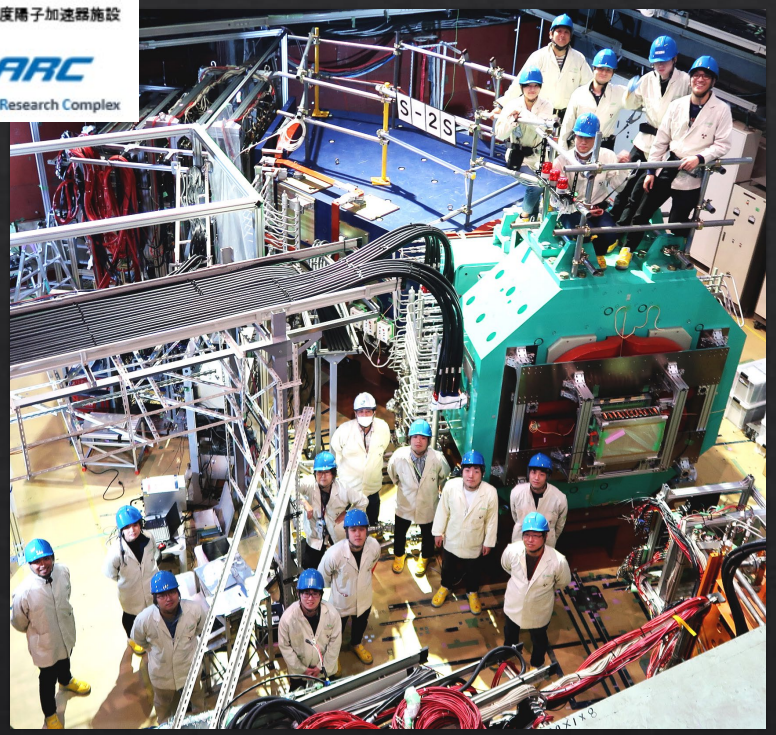


H. Hotchi et al., Phys. Rev. C 64, 044302 (2001)

The mass at the moment of production



Missing mass spectroscopy for Λ hypernuclei



S-2S (2025～)

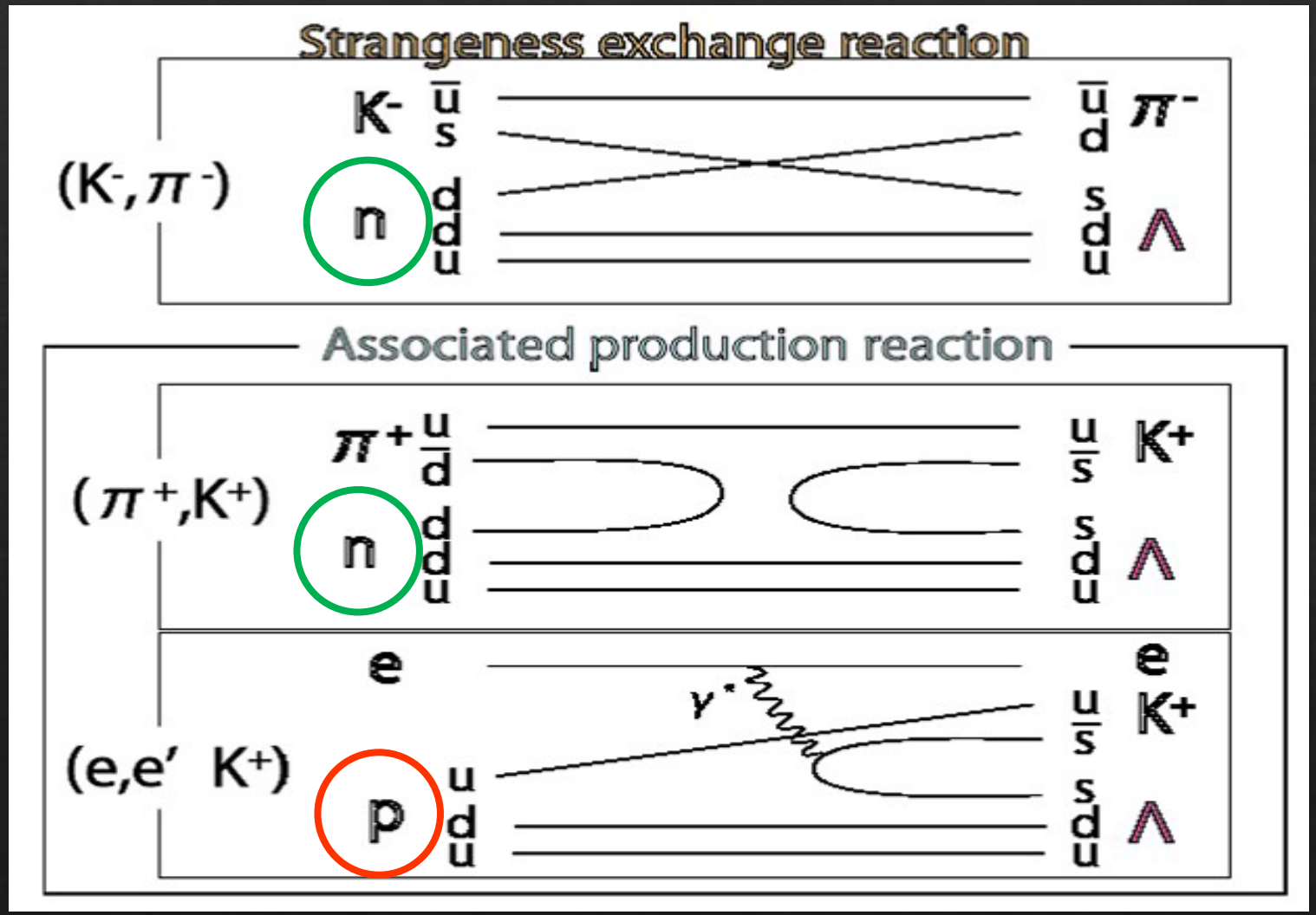
A = 7, 10, 12

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

HES-HKS (2027～)

A = 6, 9, 11, 12, 27, 40, 48, 208

Reactions used at J-PARC and JLab



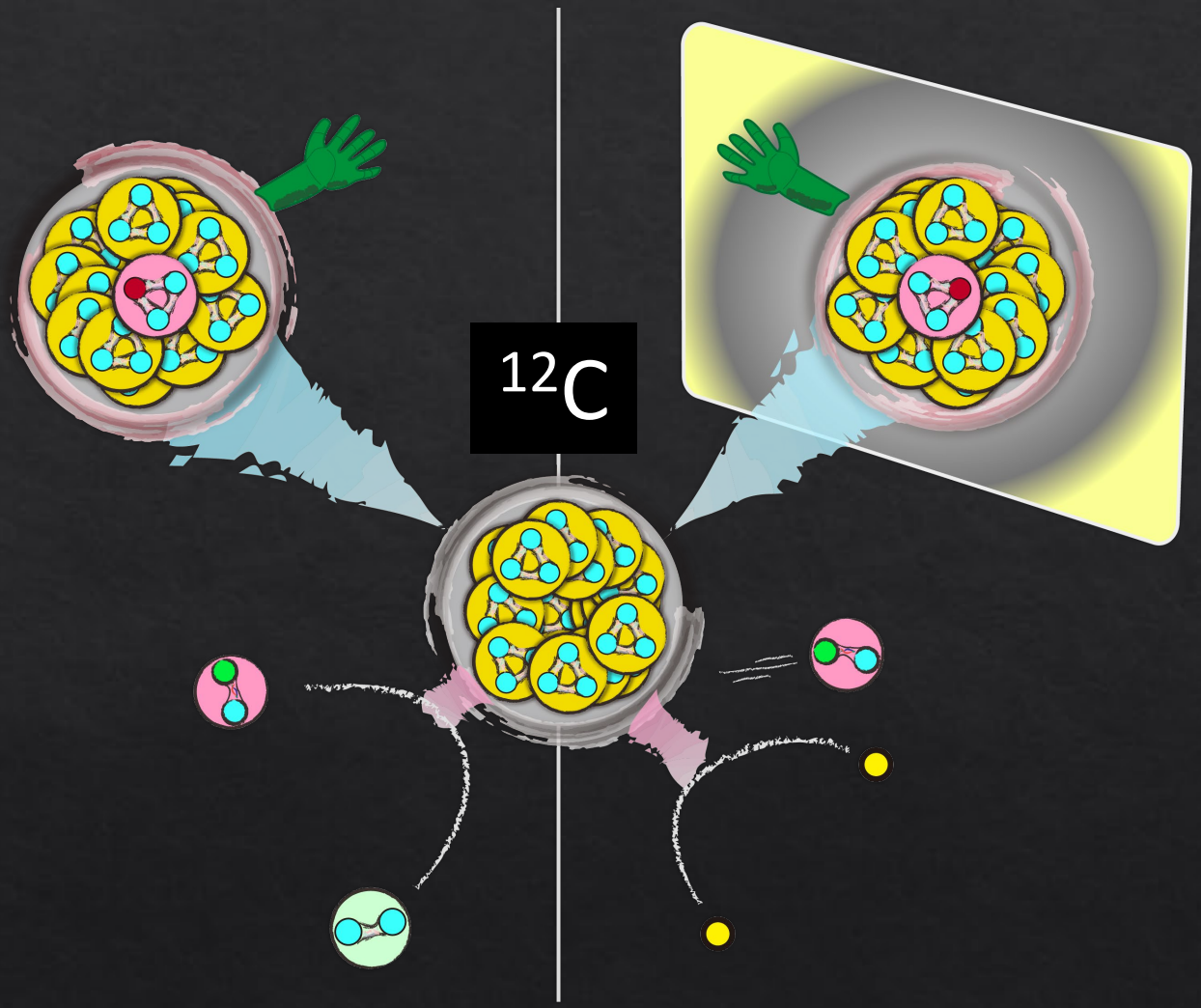
Hadron Beams
@J-PARC, Japan

Electron Beams
@JLab, US

Mirror Hypernuclear Study

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

$^{12}_{\Lambda}\mathrm{B}$



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

(π^+, K^+)

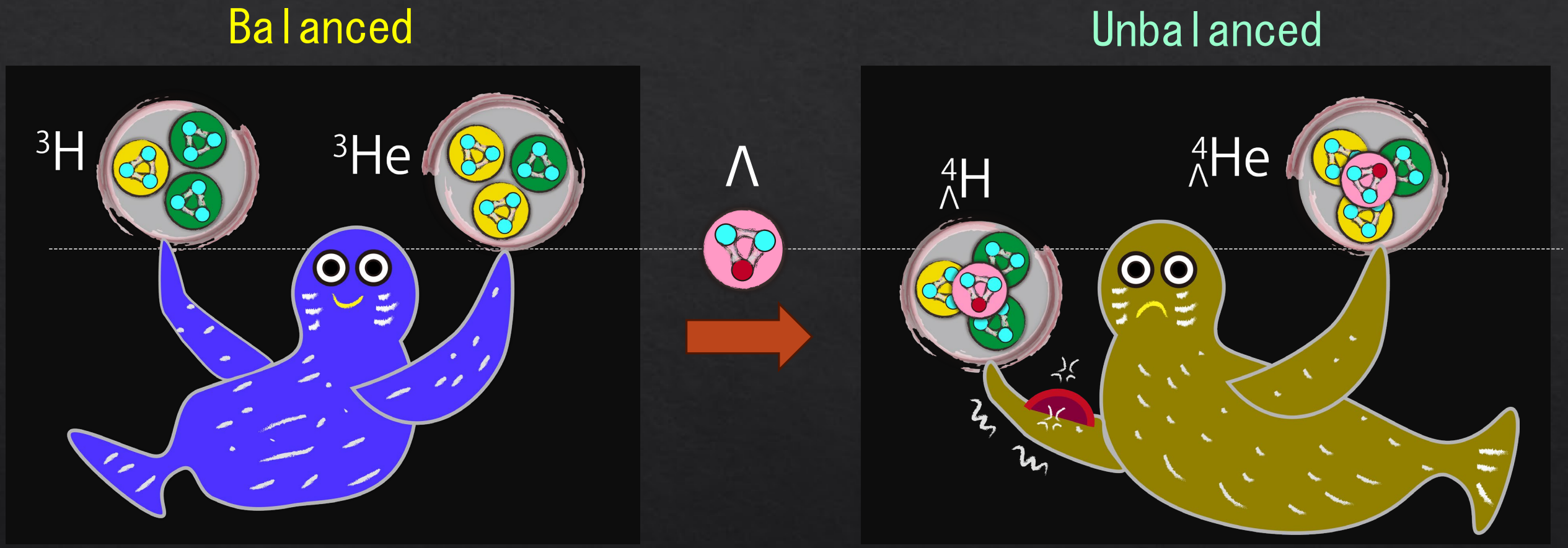
n→Λ

Jefferson Lab Thomas Jefferson National Accelerator Facility

$(e, e'K^+)$

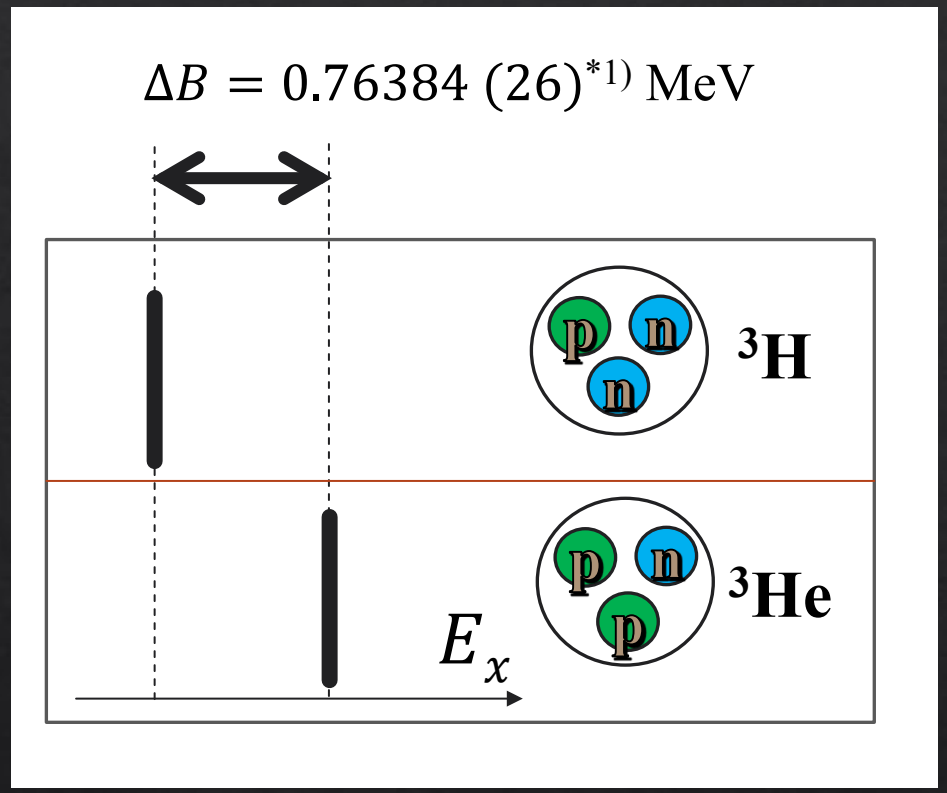
p→Λ

Charge Symmetry Breaking (CSB)



Charge Symmetry Breaking (CSB), the mystery

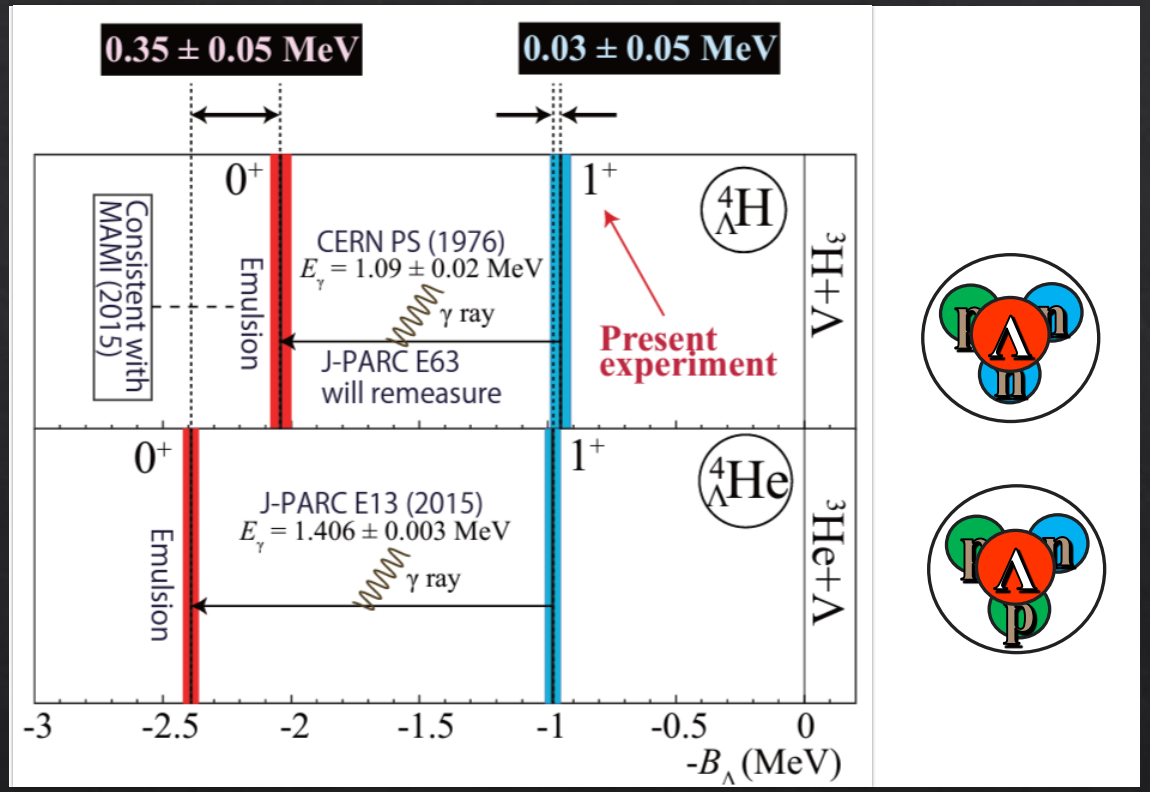
*1) J.H.E.Mattauch *et al., Nucl. Pys.* **67**, 1 (1965).



81 keV after Coulomb correction

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

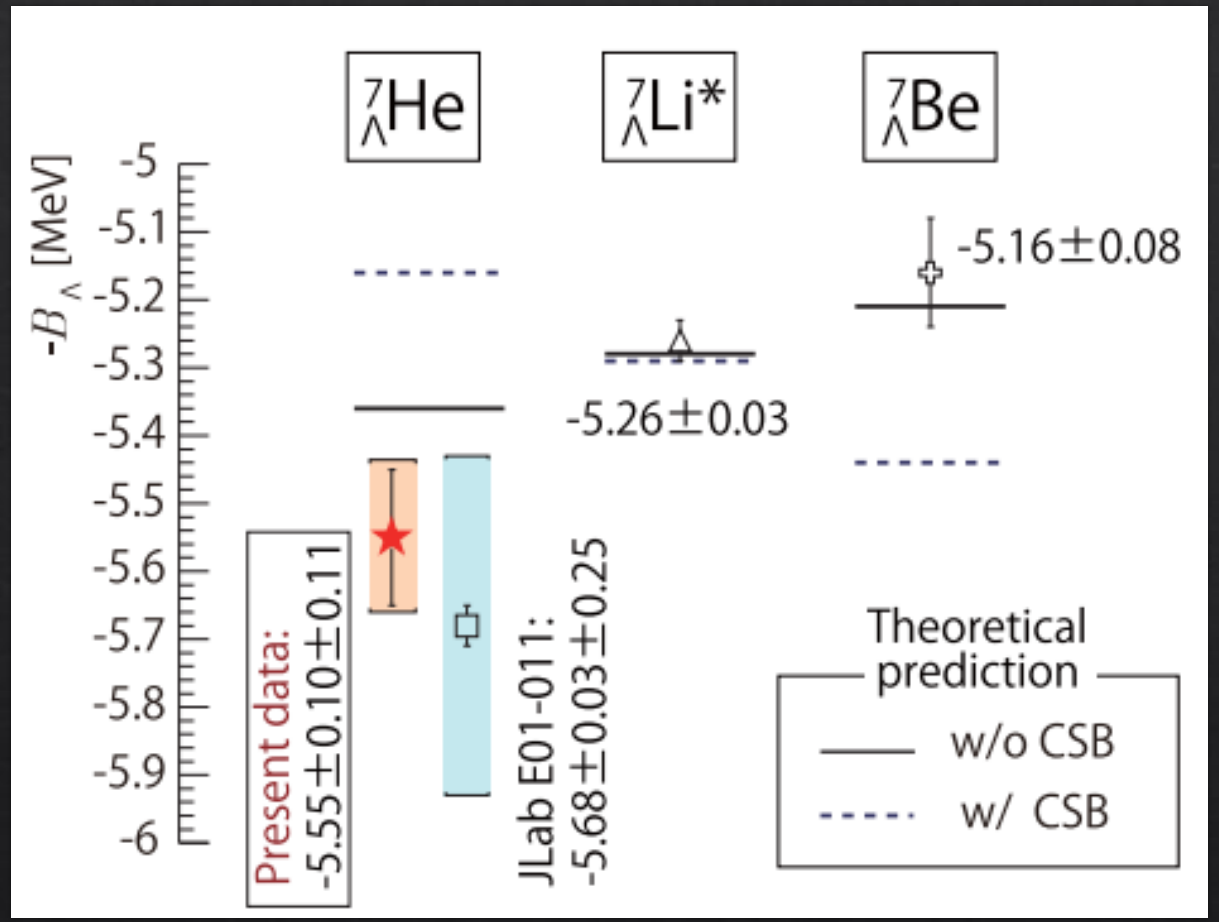
Figure from proposal of JLab E12-19-002



~400 KeV after Coulomb correction

➡ **5 times larger CSB than NN interaction!**

Previous study of CSB effect for A = 7 at JLab



TG et al., PRC 94, 021302(R) (2016)

E. Hiyama et al., PRC80, 054321 (2009)

Phenomenological CSB potential

$$V_{\Lambda N}^{\mathrm{CSB}}(r) = -\frac{\tau_z}{2}\left[\frac{1+P_r}{2}\left(v_0^{\mathrm{even,CSB}} + \boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_N v_{\sigma_\Lambda \cdot \sigma_N}^{\mathrm{even,CSB}}\right) e^{-\beta_{\mathrm{even}} r^2} + \frac{1-P_r}{2}\left(v_0^{\mathrm{odd,CSB}} + \boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_N v_{\sigma_\Lambda \cdot \sigma_N}^{\mathrm{odd,CSB}}\right) e^{-\beta_{\mathrm{odd}} r^2}\right],$$

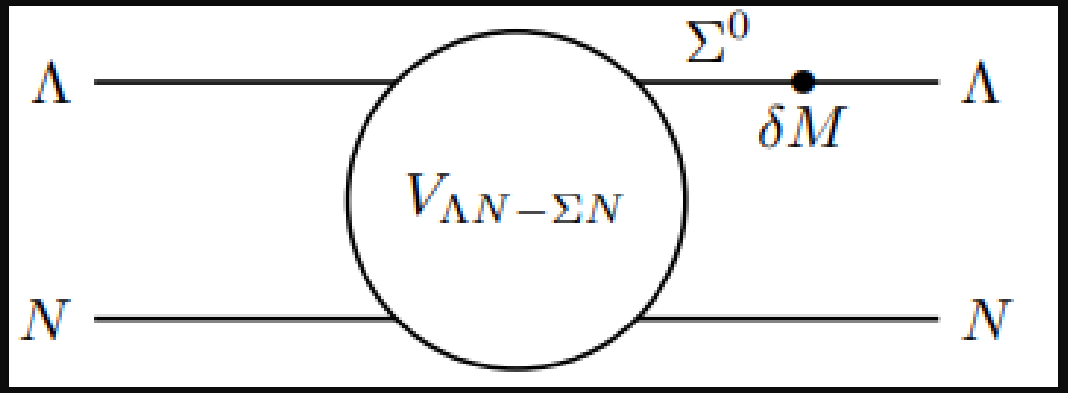
Parameters were adjusted to reproduce the binding energies of $^{4}_{\Lambda}$He, $^{4}_{\Lambda}$H, $^{8}_{\Lambda}$Li, $^{8}_{\Lambda}$Be hypernuclei

The calc. w/o the CSB potential is more consistent with the data.

The origin of CSB is more complex?

ΛN-ΣN coupling effect

A. Gal and D. Gazda, J. Phys.: Conf. Ser. 966 012006 (2018)



Charge symmetric ΛN-ΣN

$$\langle N\Lambda|V_{\rm CSB}|N\Lambda\rangle = -0.0297\,\tau_{Nz}\,\frac{1}{\sqrt{3}}\,\langle N\Sigma|V_{\rm CS}|N\Lambda\rangle$$

±1

ΛΣ mixing matrix element

A = 4 CS average	LO	LO [22]	NLO [22]	Exp. (Fig. 1)
$B_\Lambda^{J=0}$	$2.37^{+0.20}_{-0.13}$	2.5 ± 0.1	$1.53^{+0.08}_{-0.06}$	2.27 ± 0.09
$B_\Lambda^{J=1}$	$1.08^{+0.58}_{-0.47}$	$1.4^{+0.5}_{-0.4}$	$0.83^{+0.07}_{-0.10}$	1.03 ± 0.09
$E_{\rm x}(0^+_{\rm g.s.}\to1^+_{\rm exc})$	1.29 ± 0.38	1.05 ± 0.25	0.71 ± 0.04	1.25 ± 0.02

w/o CSB

Mirror hypernuclear data for p-shell systems

Isomultiplet	${}^{4}_{\Lambda}\mathrm{He}$–${}^{4}_{\Lambda}\mathrm{H}$	${}^{7}_{\Lambda}\mathrm{Be}$–${}^{7}_{\Lambda}\mathrm{Li}^{*}$	${}^{7}_{\Lambda}\mathrm{Li}^{*}$–${}^{7}_{\Lambda}\mathrm{He}$	${}^{8}_{\Lambda}\mathrm{Be}$–${}^{8}_{\Lambda}\mathrm{Li}$	${}^{9}_{\Lambda}\mathrm{B}$–${}^{9}_{\Lambda}\mathrm{Li}$	${}^{10}_{\Lambda}\mathrm{B}$–${}^{10}_{\Lambda}\mathrm{Be}^{*}$
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

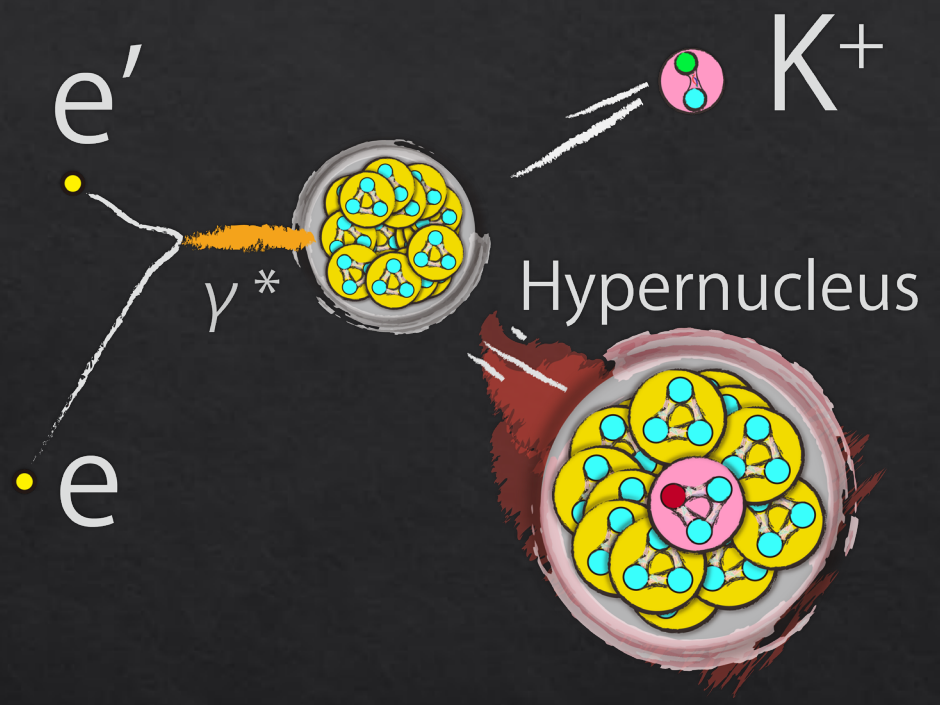
A. Gal, and D. Gazda, Jour. Phys.: Conf. Ser. 966, 012006 (2018)
E. Hiyama et al., Prog. Theor. Phys. 128, 105 (2012).
H. Le et al., Phys. Rev. C 107, 24002 (2023)

Nice review by Martin (Oct 15, 2024) → here

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 at JLab



$$M_H = \sqrt{(E_e + M_T - E_{e'} - E_K)^2 - \left(\overrightarrow{P_e} - \overrightarrow{P_{e'}} - \overrightarrow{P_K}\right)^2}$$

To be measured

$$B_\Lambda = M_H - M_{core} - M_\Lambda$$

Electro-production

- Better understanding of reaction — GOOD
- Small cross section — Bad
- Larger noise as Z gets larger — Bad

Primary beam

- High precision / small emittance — GOOD
- High intensity → thin target — GOOD
  (→ High energy resolution)

Virtual photo production

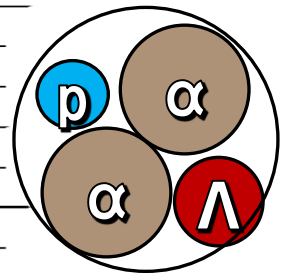
→ Large spin flip amplitude — GOOD / Bad

p → Λ

GOOD

→ Good calibration with proton target

→ Mirror Hypernuclear study — GOOD



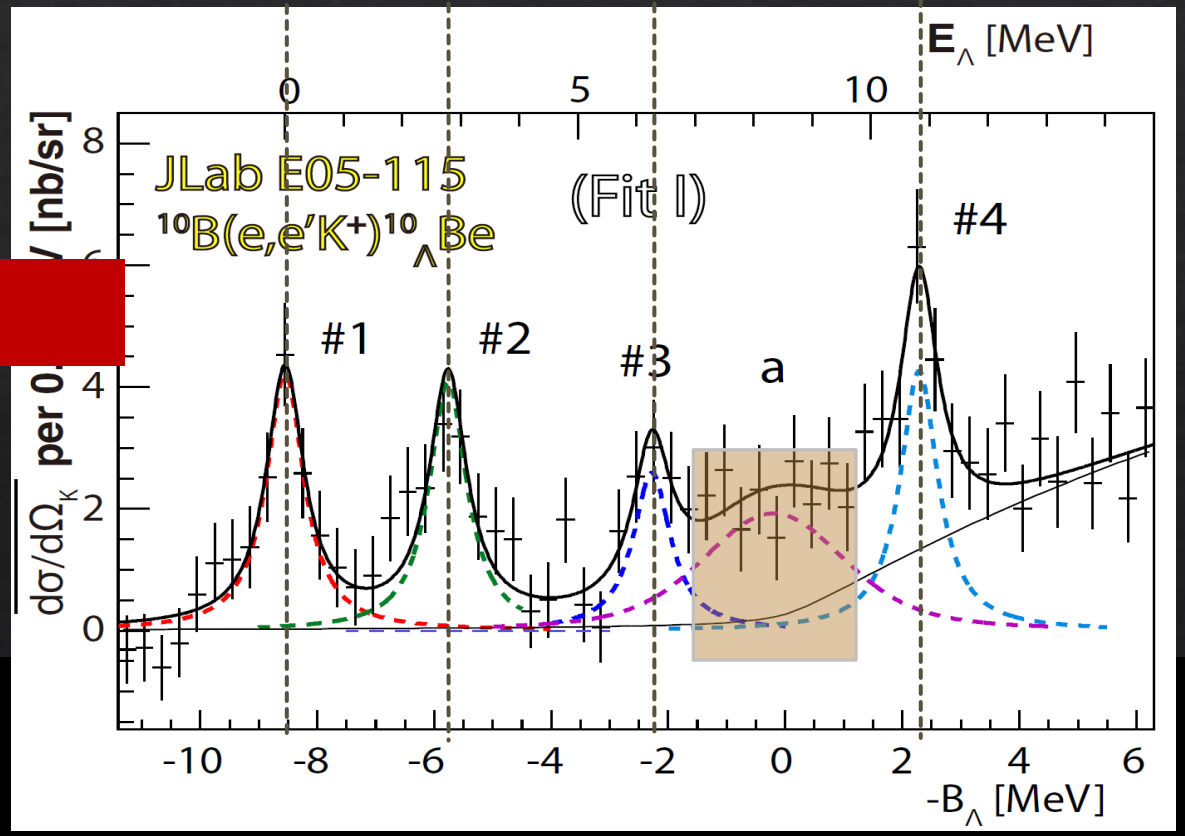
$^{10}_{\Lambda}\mathrm{B}$

FWHM = 2.2 MeV

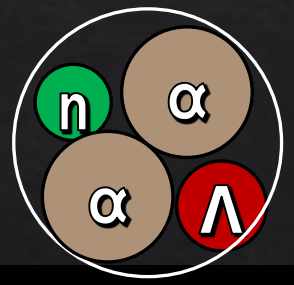
(π^+, K^+) @KEK, Japan

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

FWHM = 0.8 MeV



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

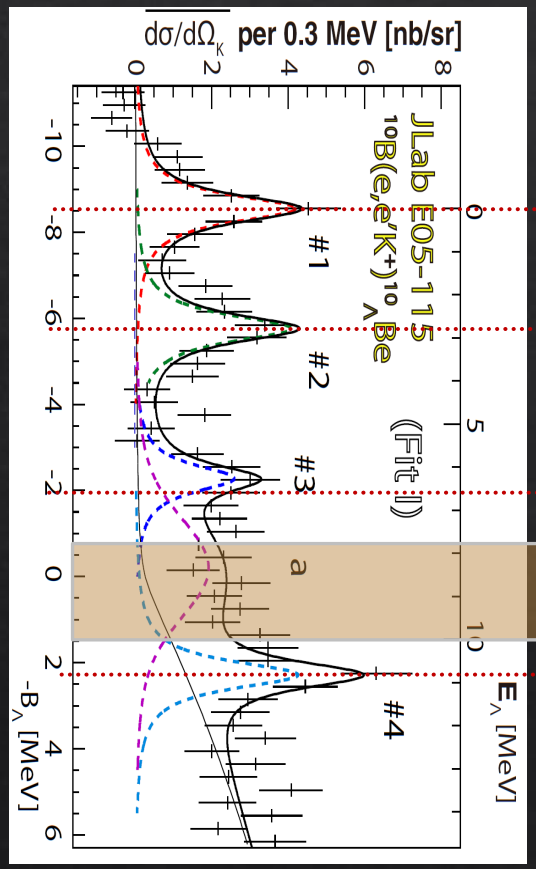


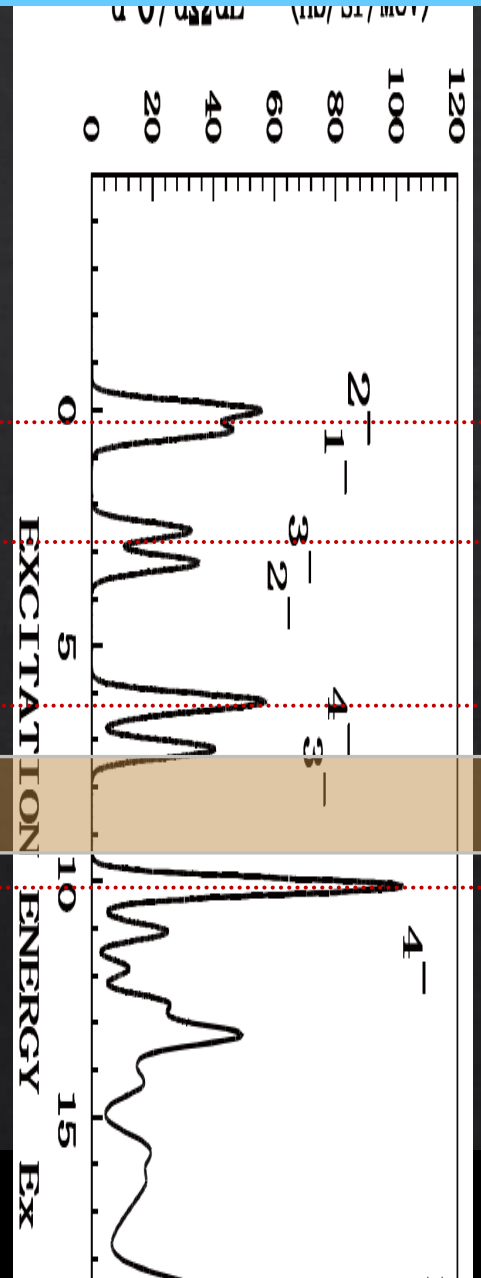
TG et al.,
PRC 93, 034314 (2016).

New finding from improved precision

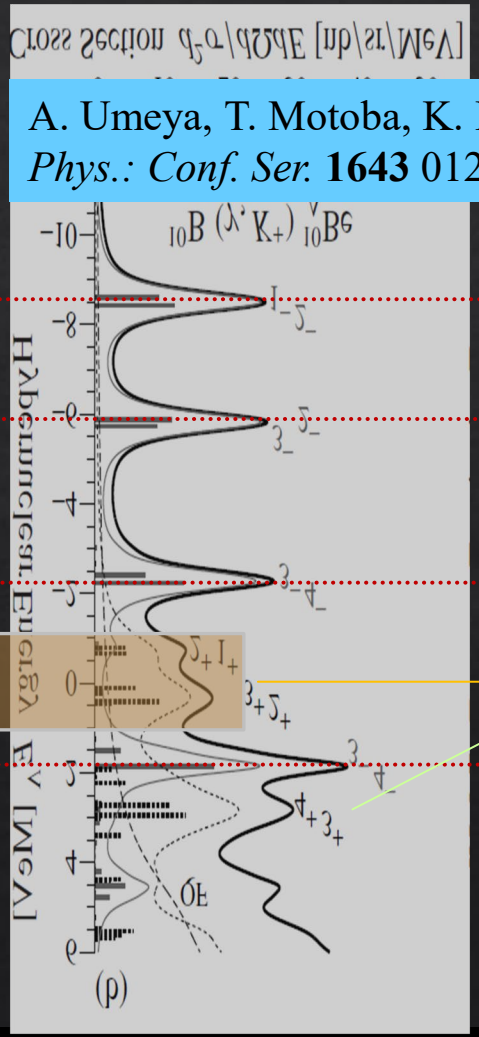
T. Motoba, P. Bydzovsky, M. Sotona, K. Itonaga, PTP Suppl. 185 (2010)

DATA
(TG et al., PRC93, 034314 (2016))





A. Umeya, T. Motoba, K. Itonaga, *J. Phys.: Conf. Ser.* **1643** 012110 (2020)



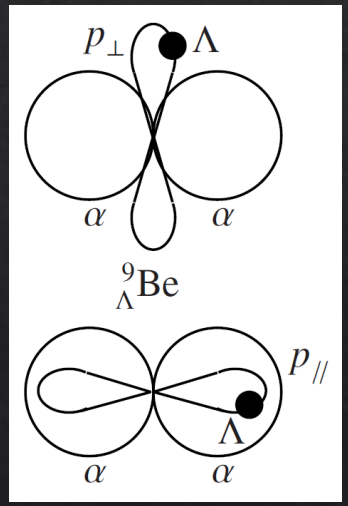
$J^-_C \otimes s_\Lambda$

$J^-_C \otimes s_\Lambda$

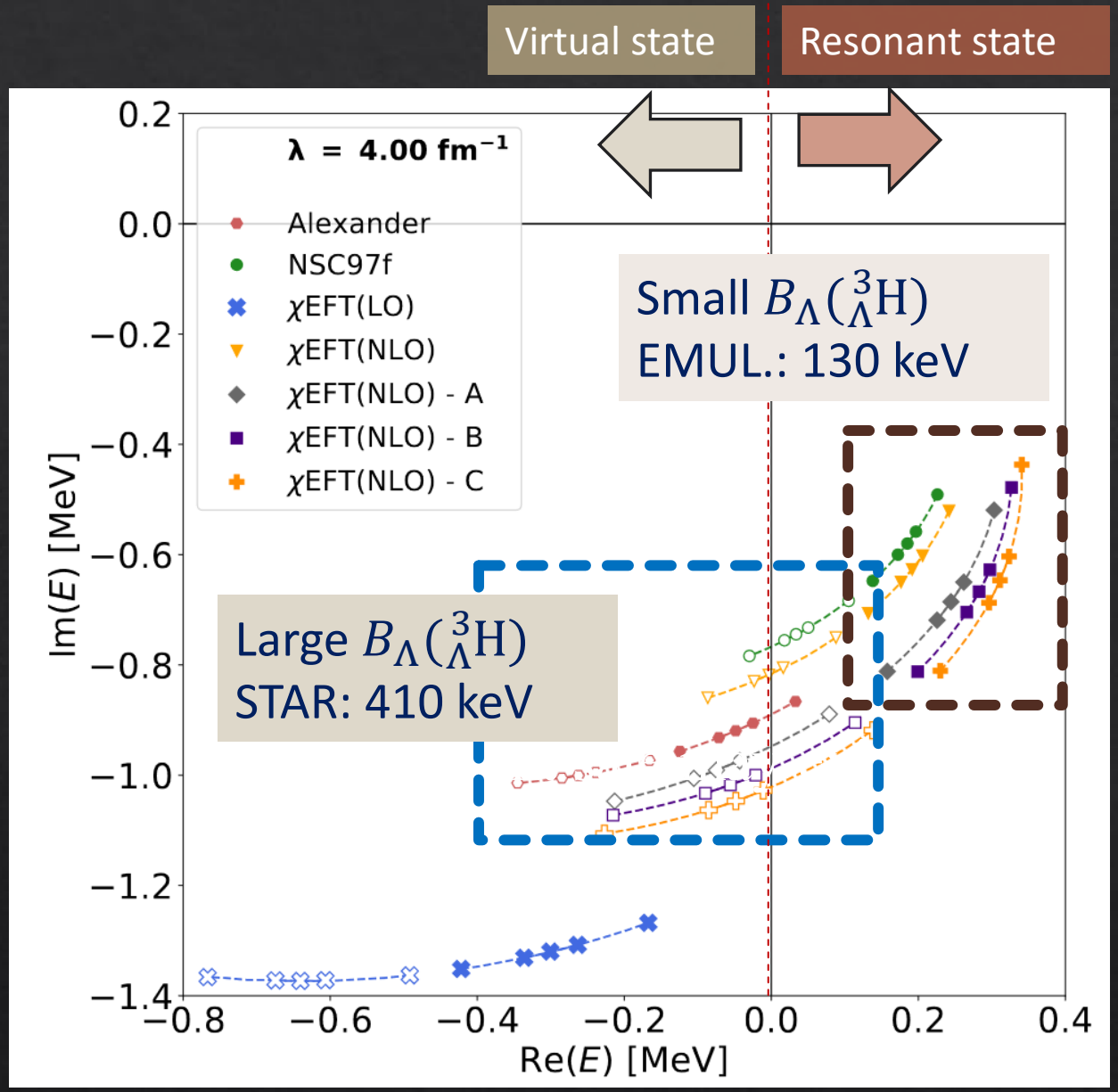
$J^-_C \otimes s_\Lambda$

$J^-_C \otimes s_\Lambda$

α - α structure splits p_Λ state



c.f.)
A. Umeya, T. Motoba, K. Itonaga, EPJ Web Conf. 271, 01010 (2022)



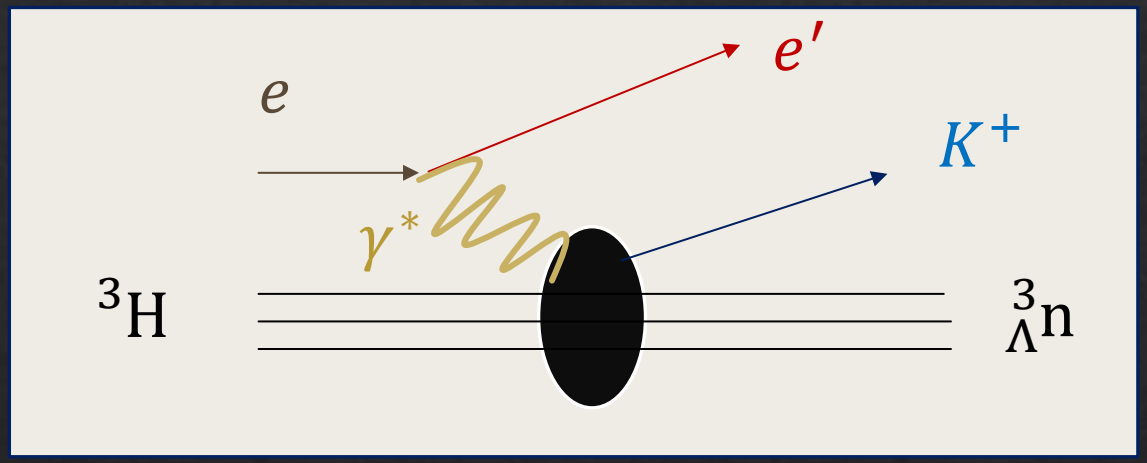
M. Schäfer et al., PRC 105, 015202 (2022)

Resonant nnΛ state

nnΛ

- ✓ Resonant state may exist
- ✓ Energy + width → nΛ Interaction
- ✓ Strongly related to $B_\Lambda(^3_\Lambda\mathrm{H})$
  → E12-19-002 (HKS)

(e,e'K$^+$) reaction spectroscopy in 2018

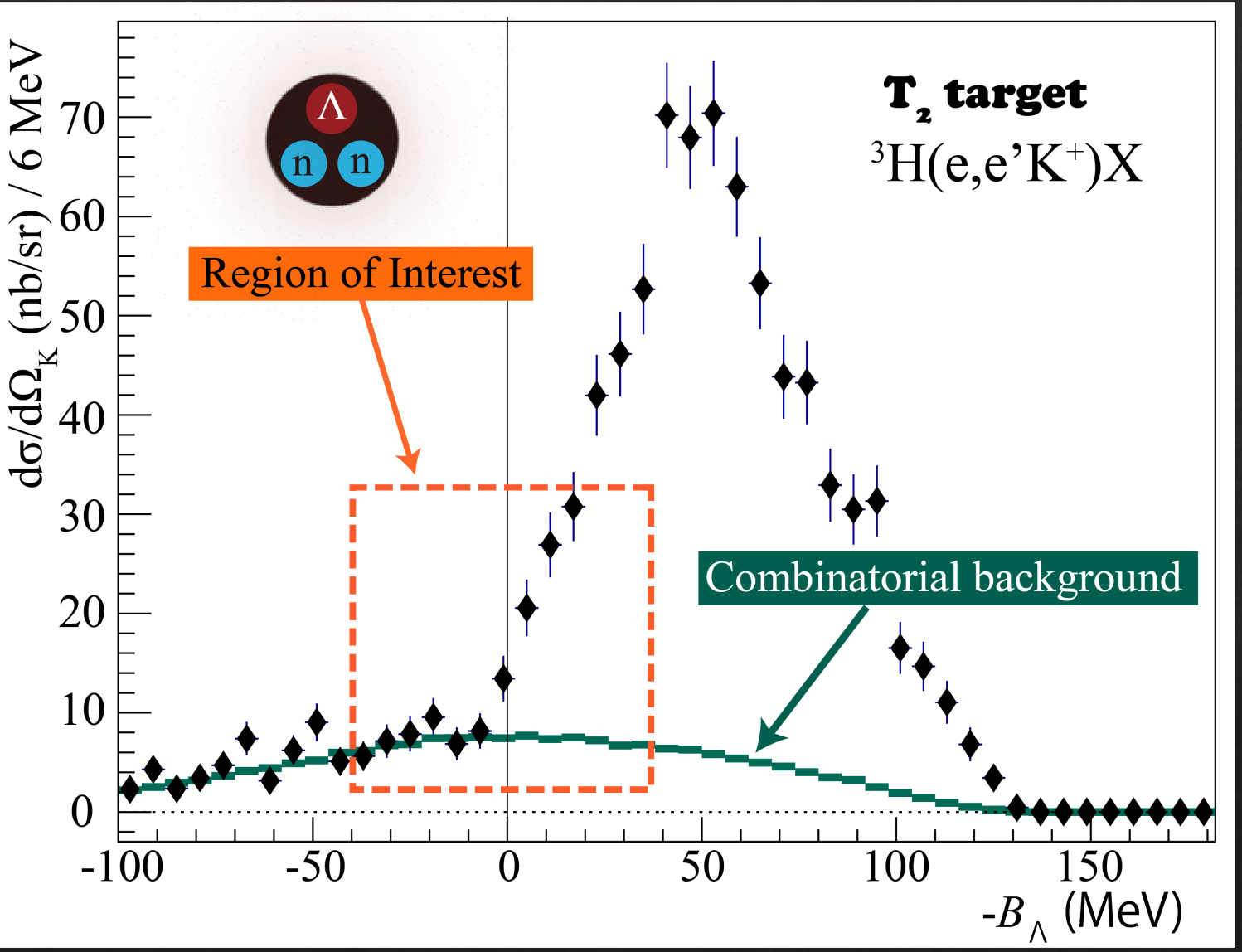


Missing-mass measurement at JLab

➔ **Sensitive to both bound and resonant states !!**

c.f.) Invariant mass spectroscopy is sensitive to only bound state

Cross section spectrum for Λnn



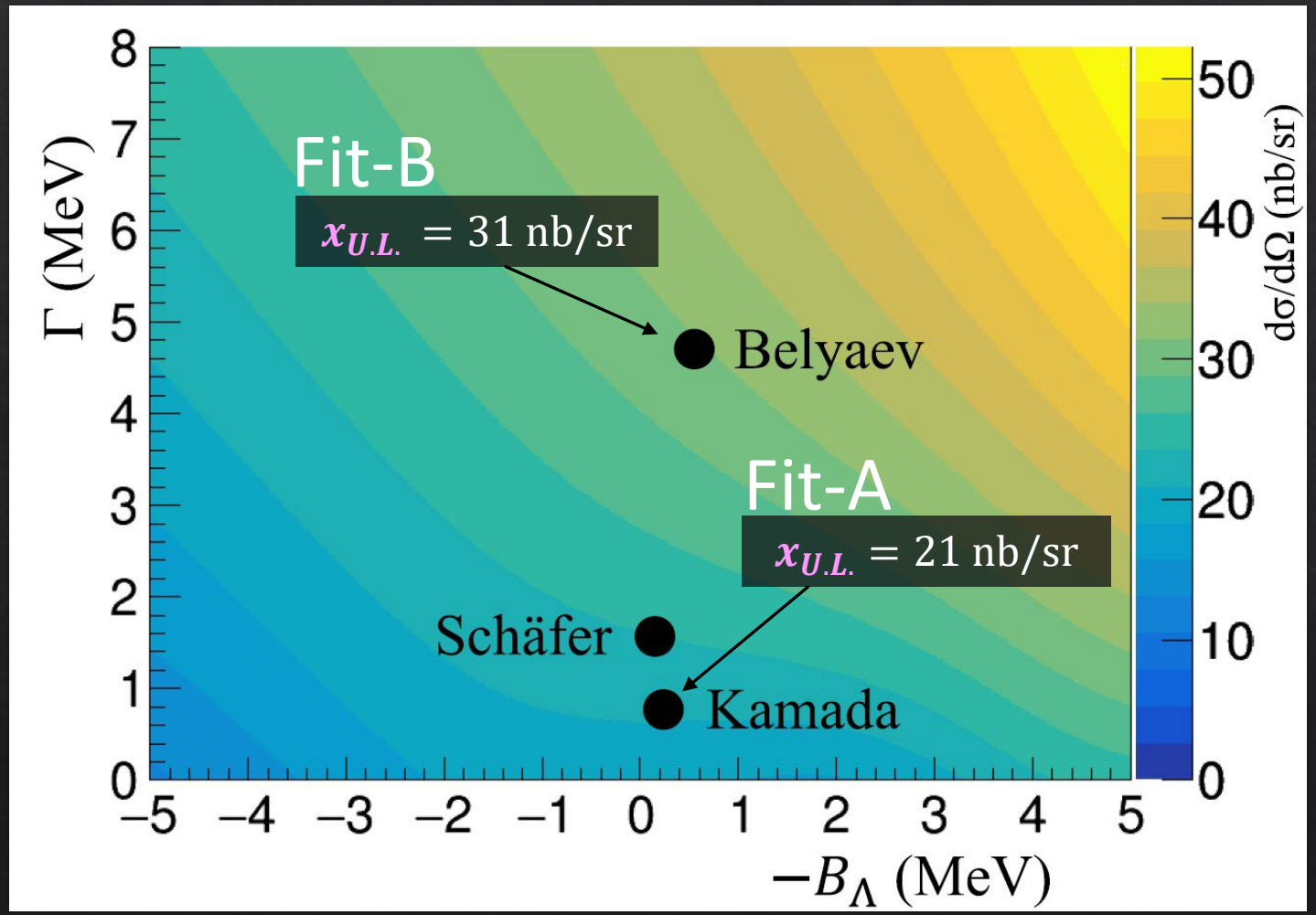
Unbinned maximum likelihood fit

($-20 < B_\Lambda < 20$ MeV)

Probability density function (PDF):

1. Response function (RF)
   - Geant4 simulation
2. Decay width
   - Breit Wigner
3. QF shape ($-B_\Lambda > 0$)
   - Unknown
     → Linear function ⊗ RF
4. Combinatorial background
   - Data → the 4th order polynomial

Upper limit at 90% C.L. (2-D scan)



Upper limit $x_{U.L.}$:

$$\frac{\int_0^{x_{U.L.}^{stat.}} g(x)dx}{\int_0^{\infty} g(x)dx} = 90\%$$

where, $g(x)$ is a Gaus.

$$x_{U.L.} = x_{U.L.}^{stat.} + sys.err.$$

Theoretical calculations to be compared with the results are awaited !!

- ✓ HRS-HRS @ Hall A
- ✓ Tritium target
- ✓ (e,e'K^+)
- ✓ Oct—Nov 2018

PTEP Progress of Theoretical and Experimental Physics — JPS The Physical Society of Japan

The cross-section measurement for the ^{3}H(e, $e'K^+$)$nn\Lambda$ reaction

K N Suzuki ✉, T Gogami, B Pandey, K Itabashi, S Nagao, K Okuyama, S N Nakamura, L Tang, D Abrams, T Akiyama, D Androic, K Aniol, C Ayerbe Gayoso, J Bane, S Barcus, J Barrow, V Bellini, H Bhatt, D Bhetuwal, D Biswas, A Camsonne, J Castellanos, J-P Chen, J Chen, S Covrig, D Chrisman, R Cruz-Torres, R Das, E Fuchey, K Gnanvo, F Garibaldi, T Gautam, J Gomez, P Gueye, T J Hague, O Hansen, W Henry, F Hauenstein, D W Higinbotham, C E Hyde, M Kaneta, C Keppel, T Kutz, N Lashley-Colthirst, S Li, H Liu, J Mammei, P Markowitz, R E McClellan, F Meddi, D Meekins, R Michaels, M Mihovilovič, A Moyer, D Nguyen, M Nycz, V Owen, C Palatchi, S Park, T Petkovic, S Premathilake, P E Reimer, J Reinhold, S Riordan, V Rodriguez, C Samanta, S N Santiesteban, B Sawatzky, S Širca, K Slifer, T Su, Y Tian, Y Toyama, K Uehara, G M Urciuoli, D Votaw, J Williamson, B Wojtsekhowski, S A Wood, B Yale, Z Ye, J Zhang, X Zheng

Progress of Theoretical and Experimental Physics, Volume 2022, Issue 1, January 2022, 013D01, https://doi.org/10.1093/ptep/ptab158

Published: 06 December 2021 **Article history** ▾

https://doi.org/10.1093/ptep/ptab158 *(see also here)*

PHYSICAL REVIEW C
covering nuclear physics

Letter

Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the $(e, e'K^+)$ reaction with a tritium target

B. Pandey[1], L. Tang[1,2,*], T. Gogami[3,4], K. N. Suzuki[4], K. Itabashi[3], S. Nagao[3], K. Okuyama[3], S. N. Nakamura[3], D. Abrams[5], I. R. Afnan[6], T. Akiyama[3], D. Androic[7], K. Aniol[8], T. Averett[9], C. Ayerbe Gayoso[9], J. Bane[10], S. Barcus[9], J. Barrow[10], V. Bellini[11], H. Bhatt[12], D. Bhetuwal[12], D. Biswas[1], A. Camsonne[2], J. Castellanos[13], J-P. Chen[2], J. Chen[9], S. Covrig[2], D. Chrisman[14,15], R. Cruz-Torres[16], R. Das[17], E. Fuchey[18], C. Gal[5], B. F. Gibson[19], K. Gnanvo[5], F. Garibaldi[11,20], T. Gautam[1], J. Gomez[2], P. Gueye[1], T. J. Hague[21], O. Hansen[2], W. Henry[2], F. Hauenstein[22], D. W. Higinbotham[2], C. Hyde[22], M. Kaneta[3], C. Keppel[2], T. Kutz[17], N. Lashley-Colthirst[1], S. Li[23,24], H. Liu[25], J. Mammei[26], P. Markowitz[13], R. E. McClellan[2], F. Meddi[11], D. Meekins[2], R. Michaels[2], M. Mihovilovič[27,28,29], A. Moyer[30], D. Nguyen[16,31], M. Nycz[21], V. Owen[9], C. Palatchi[5], S. Park[17], T. Petkovic[7], S. Premathilake[5], P. E. Reimer[32], J. Reinhold[13], S. Riordan[32], V. Rodriguez[33], C. Samanta[34], S. N. Santiesteban[23], B. Sawatzky[2], S. Širca[27,28], K. Slifer[23], T. Su[21], Y. Tian[35], Y. Toyama[3], K. Uehara[3], G. M. Urciuoli[11], D. Votaw[14,15], J. Williamson[36], B. Wojtsekhowski[2], S. Wood[2], B. Yale[23], Z. Ye[32], J. Zhang[5], and X. Zheng[5] (Hall A Collaboration)

https://doi.org/10.1103/PhysRevC.105.L051001

Approved Hypernuclear Experiments (proposed by JLab Hypernuclear Collaboration)

① E12-15-008 (Contact Person: S.N. Nakamura (Univ. Tokyo)) → $^{40}_{\Lambda}\mathrm{K}$、$^{48}_{\Lambda}\mathrm{K}$

"Isospin dependence of ΛN interaction"

② E12-19-002 (CP: TG) → $^{3}_{\Lambda}\mathrm{H}$、$^{4}_{\Lambda}\mathrm{H}$

"Hypertriton puzzle, s-shell CSB"

③ E12-20-013 (CP: F. Garibaldi (INFN)) → $^{208}_{\Lambda}\mathrm{Tl}$

"ΛNN three body force"

④ E12-24-004 (CP: TG) → $^{6}_{\Lambda}\mathrm{He}$、$^{9}_{\Lambda}\mathrm{Li}$、$^{11}_{\Lambda}\mathrm{Be}$

"p-shell CSB"

⑤ E12-24-011 (CP: S.N. Nakamura) → $^{27}_{\Lambda}\mathrm{Mg}$

"Search for triaxially deformation states in ^{26}Mg"

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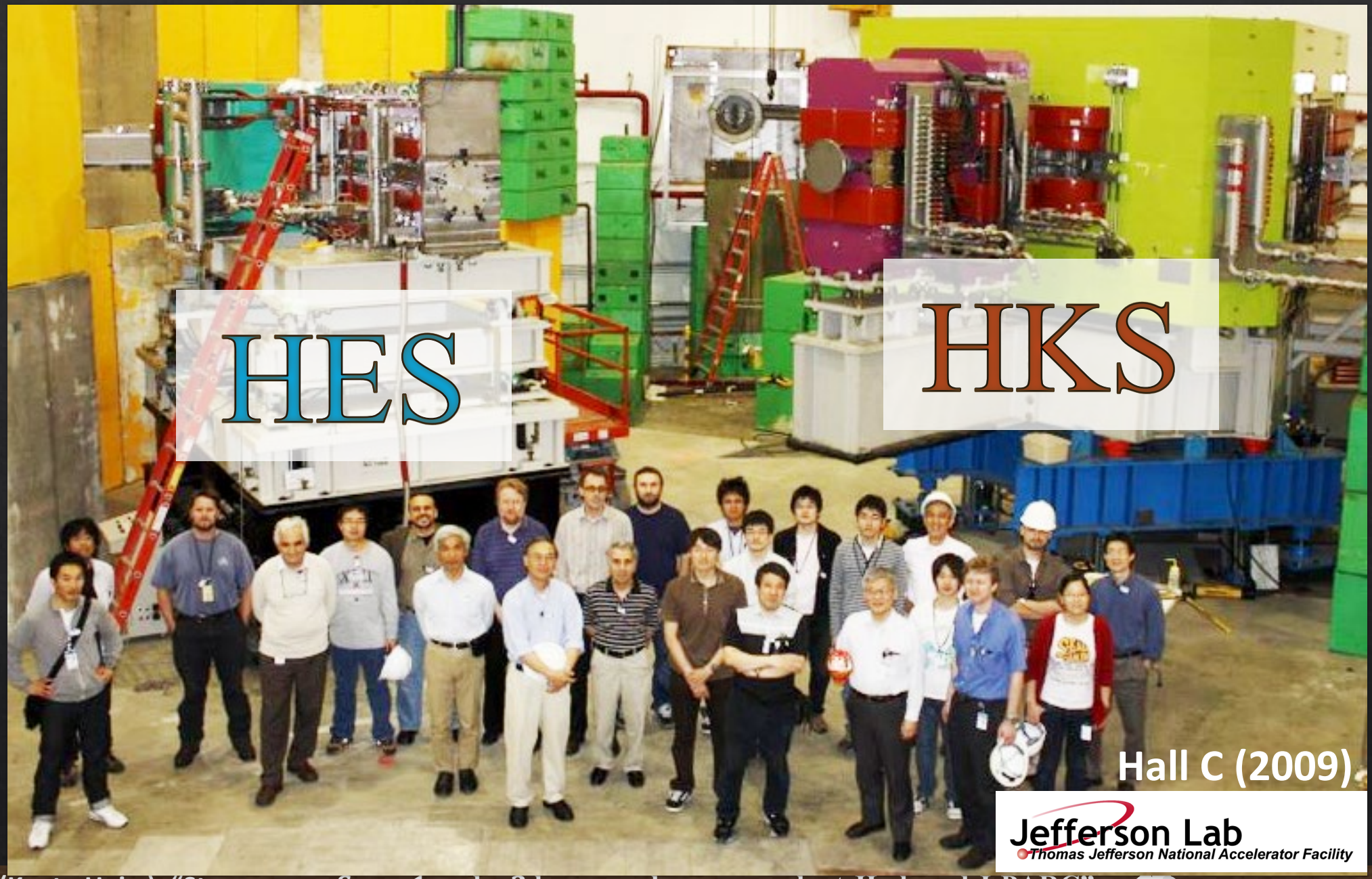
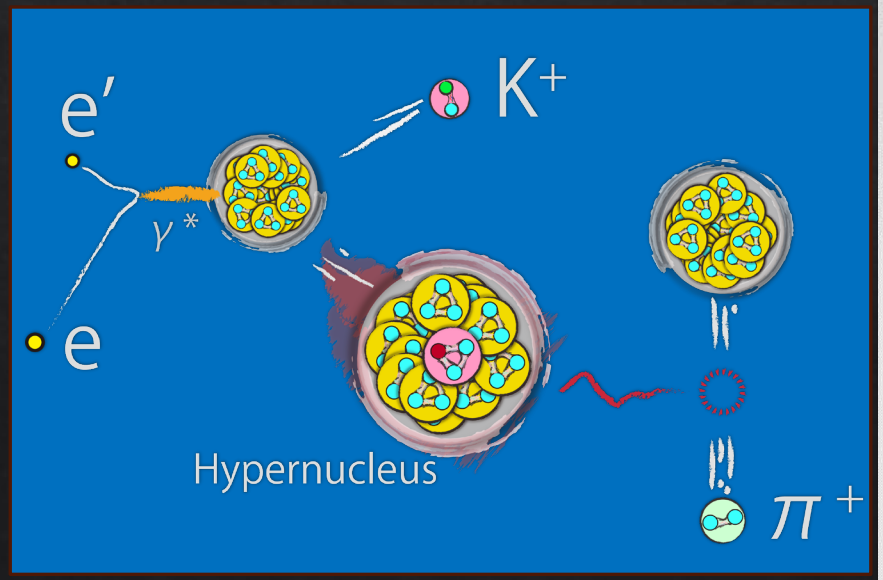
"Search for triaxially deformation states in ${}^{26}\mathrm{Mg}$"

Will be performed in 2027~


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

New experiment at JLab Hall-C (2027～)

- High resolution: 0.6 MeV FWHM
- High accuracy: 0.07 MeV
- Wide mass number: A = 6—208



e′: HES

0.7 GeV/c
2×10^5 /sec

K+: HKS

1.2 GeV/c
5×10^4 /sec

π+: ENGE

2.2-GeV Electron
50 μA (3×10^{14} /sec)
→ Hypernuclei: 0.003 /sec

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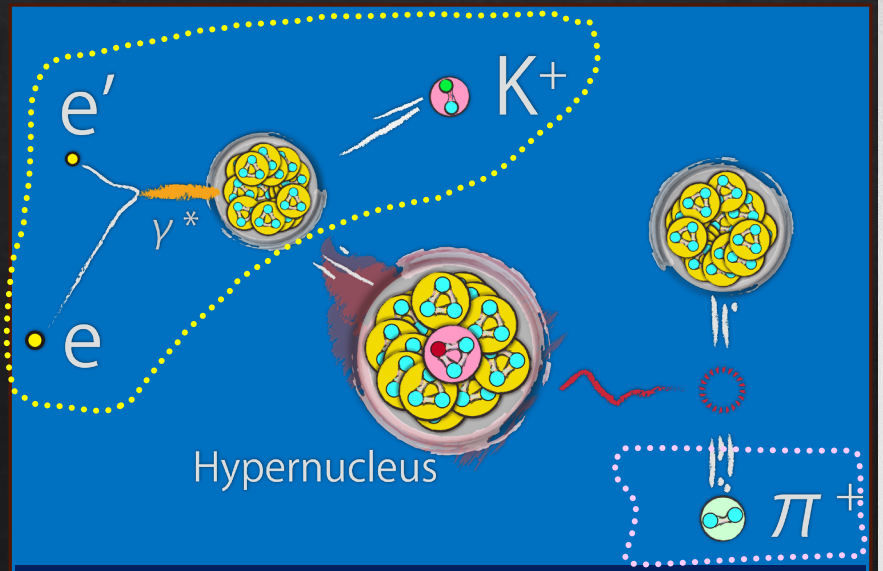

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Jefferson Lab
Thomas Jefferson National Accelerator Facility

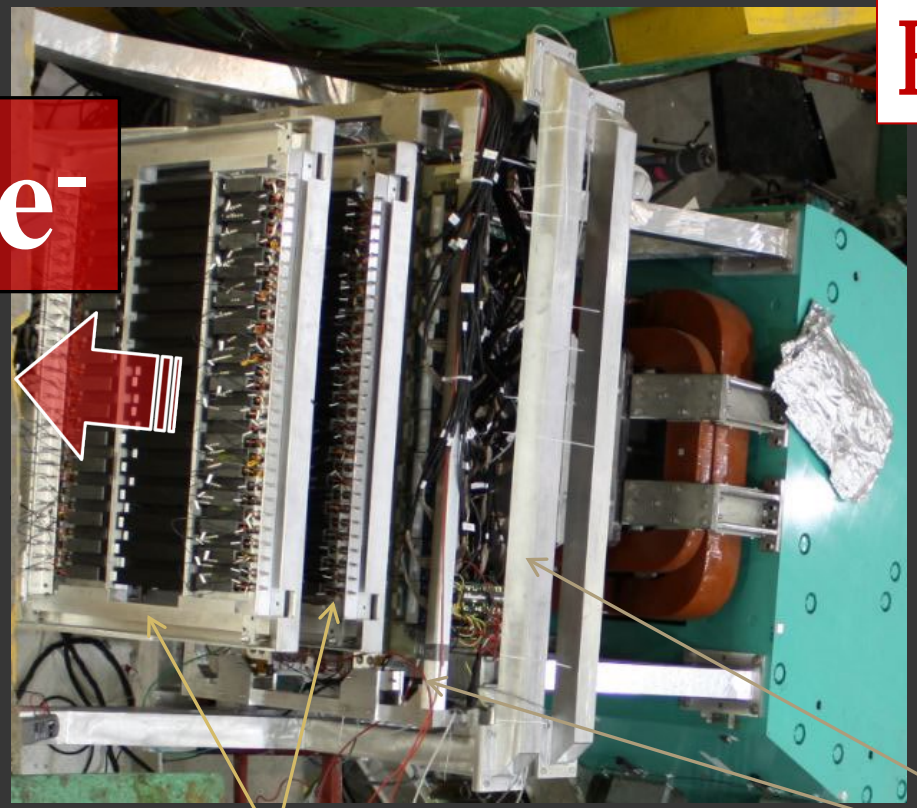
Particle Detectors

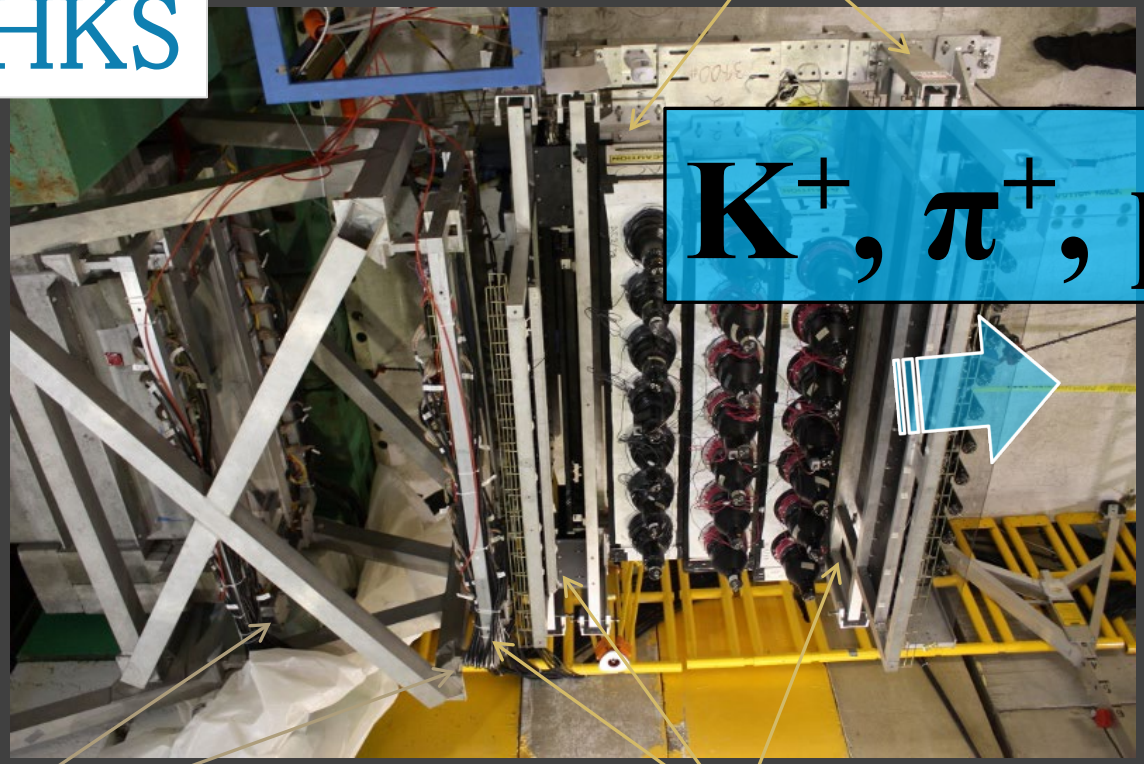
TG et al., NIMA 900, 69—83 (2018)
TG et al., NIMA 729, 816—824 (2013)

Cherenkov detectors
- **Aerogel (n=1.05)**
- **Water (n=1.33)**

HES

HKS





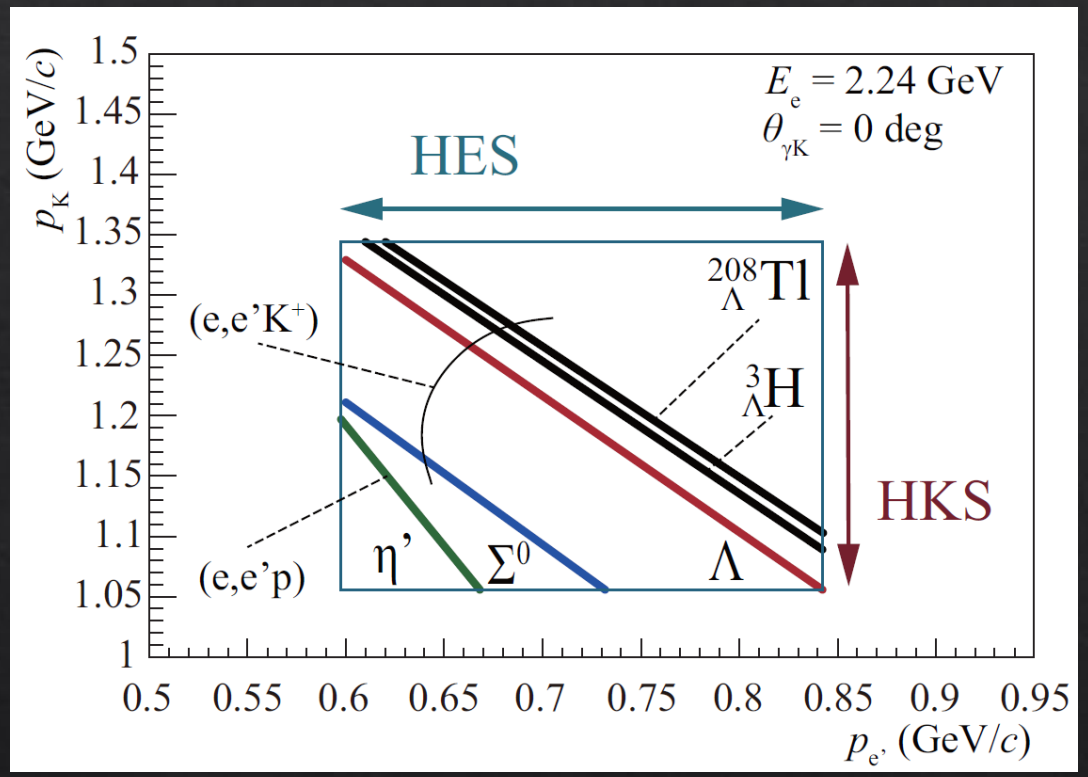
TOF walls (Plastic scintillators)

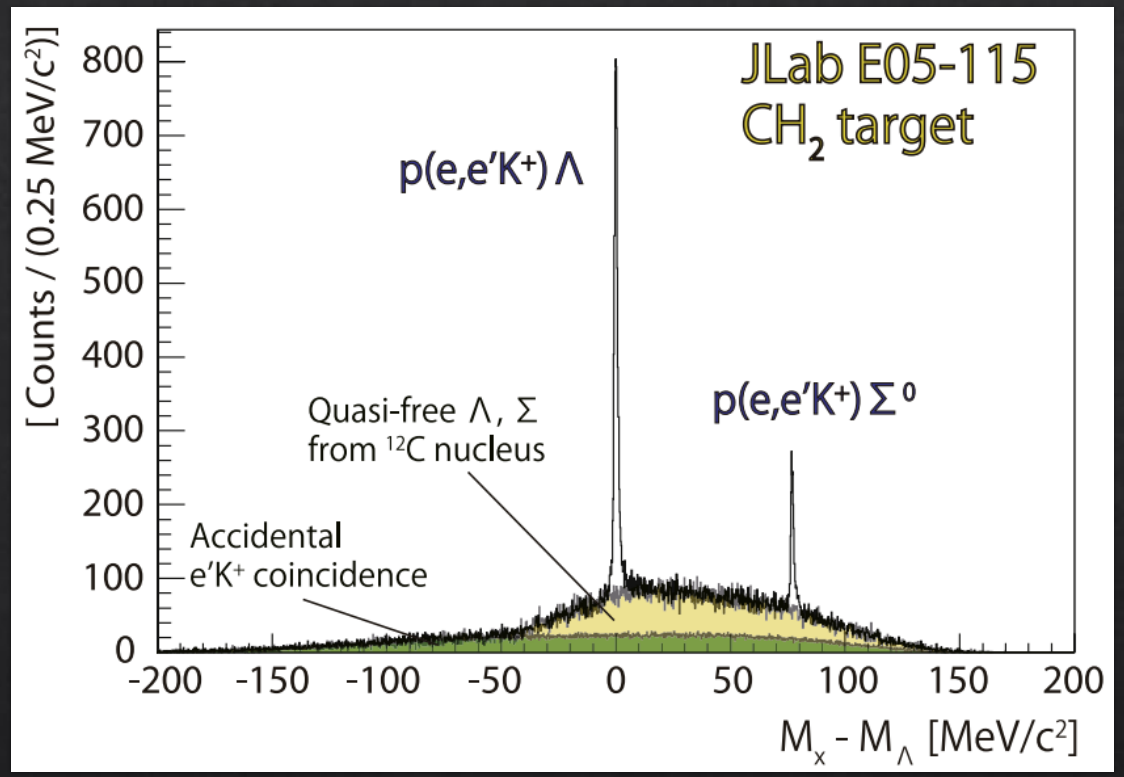
Drift chambers

TOF walls (Plastic scintillators)

Energy Calibration

TG et al., NIMA 900, 69—83 (2018)



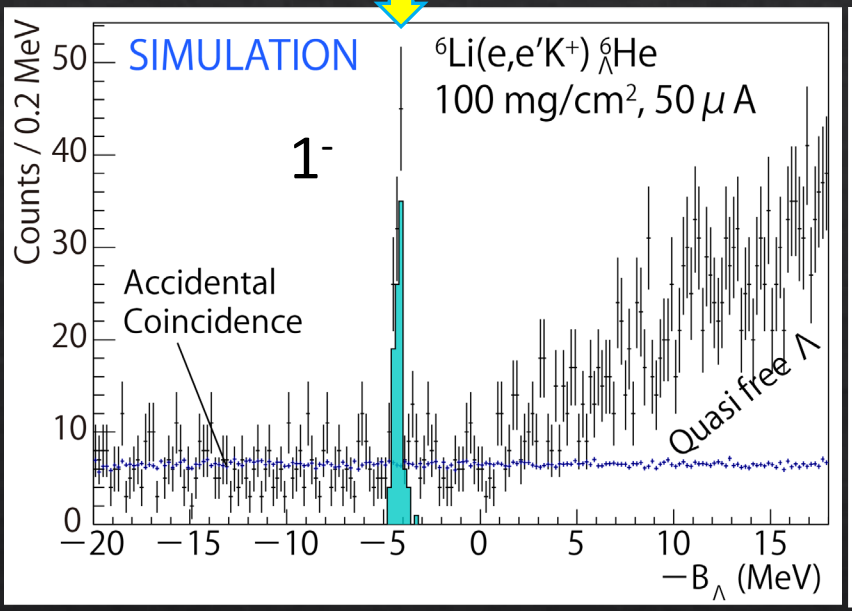


➔ Systematic error $|\Delta B_\Lambda^{\text{sys.}}| \simeq$ **60 keV**

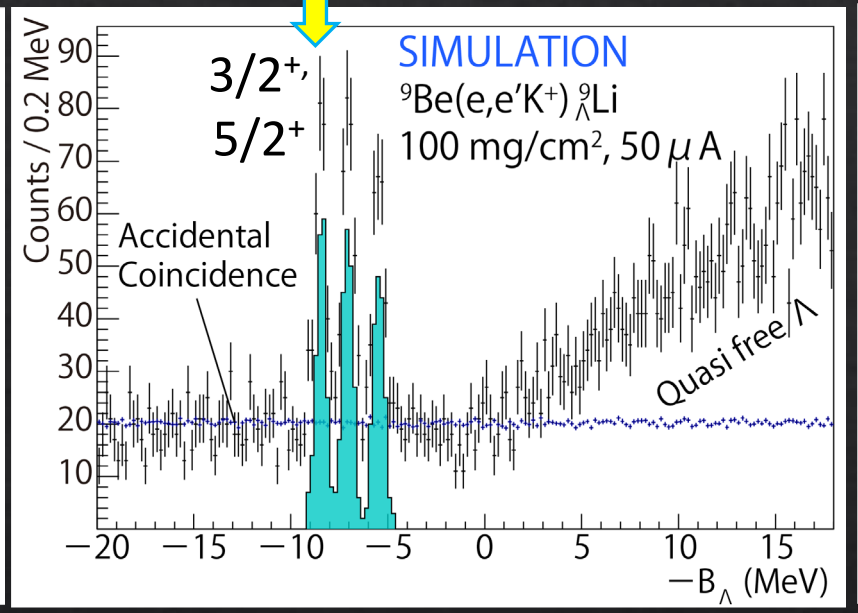
c.f.) T. Toyoda, Master's Thesis, *Kyoto University*, Kyoto, Japan, 2021 (in Japanese)

Expected Spectra (JLab E12-24-004)

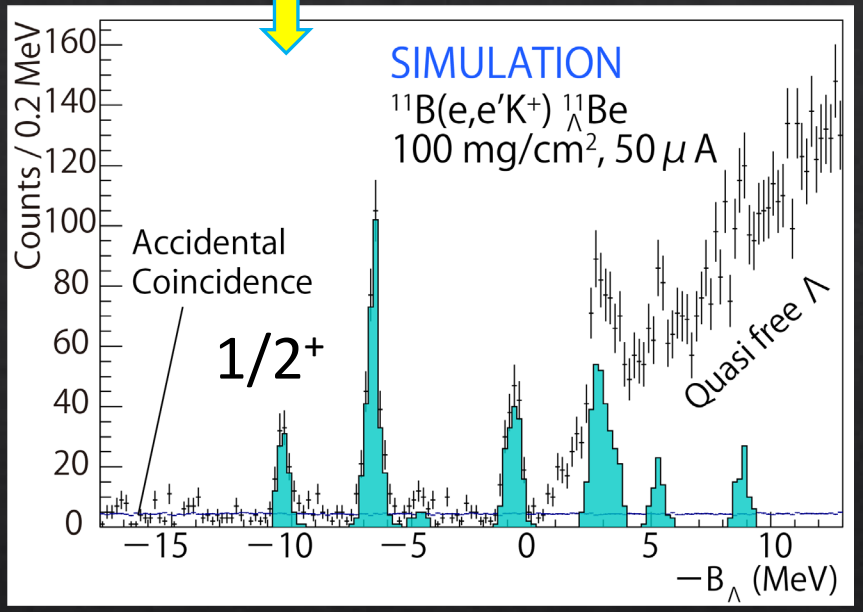
for CSB study 120 hours



for CSB study 384 hours



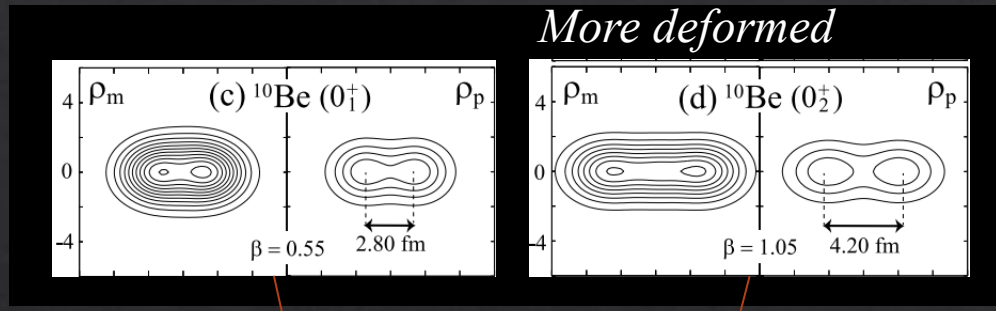
for CSB study 72 hours



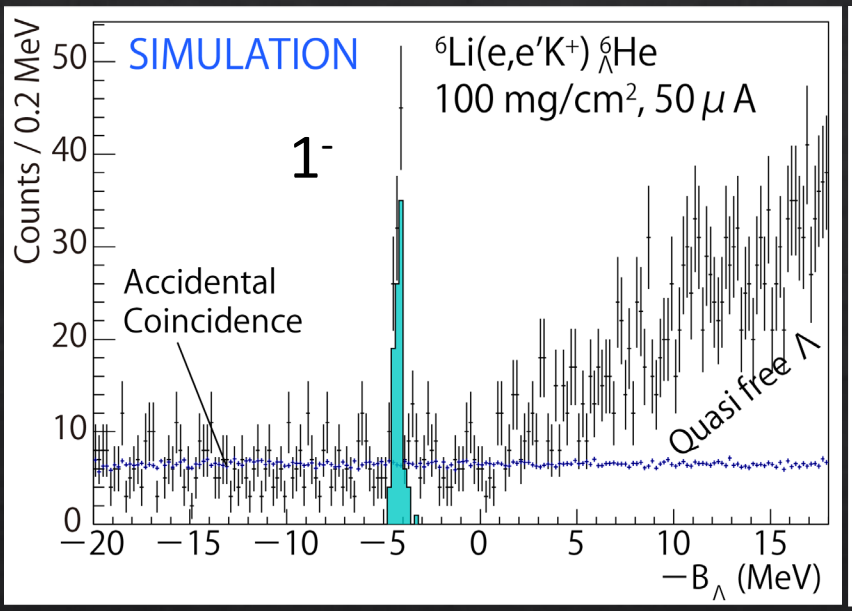
Total accuracy:

$$\left|\Delta B_{\Lambda}^{\text{total}}\right| = \sqrt{\left(\Delta B_{\Lambda}^{\text{stat.}}\right)^2 + \left(\Delta B_{\Lambda}^{\text{sys.}}\right)^2} \leq \textbf{70 keV}$$

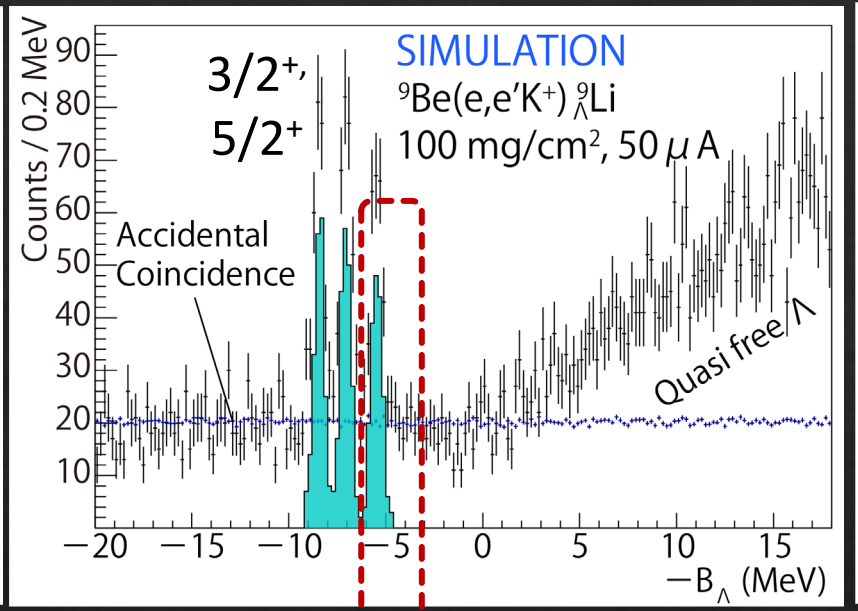
Expected Spectra



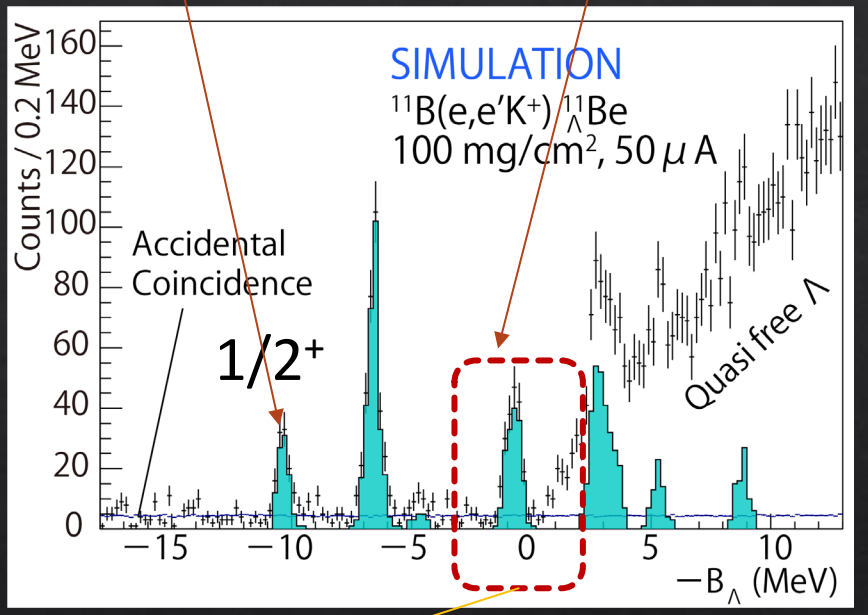
120 hours



384 hours



72 hours



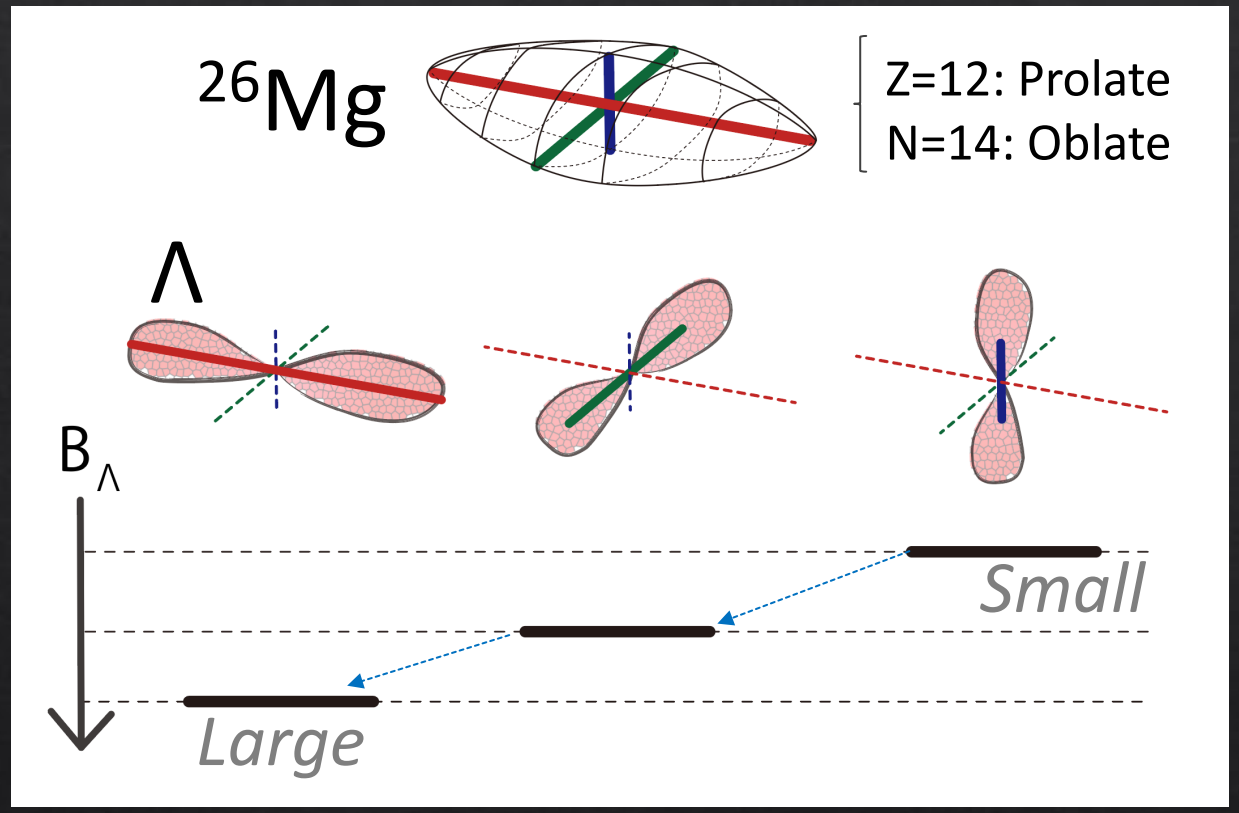
Total accuracy:
$\left|\Delta B_\Lambda^{\text{total}}\right| \leq$ **70 keV**

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

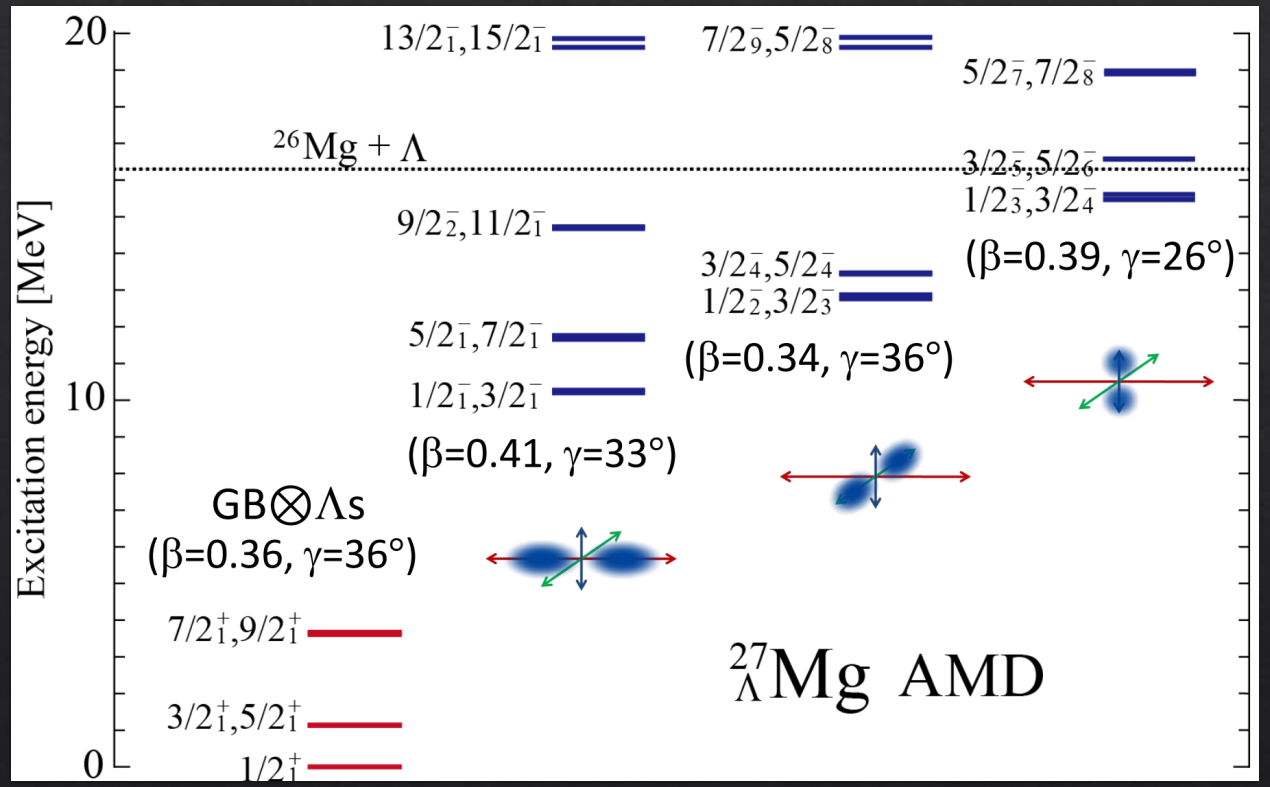
Cluster / deformation structures

M. Isaka et al., PRC 92, 044326 (2015)

$^{27}\mathrm{Al}(e,e'K^+)^{27}_{\Lambda}\mathrm{Mg}$ (JLab E12-24-011)



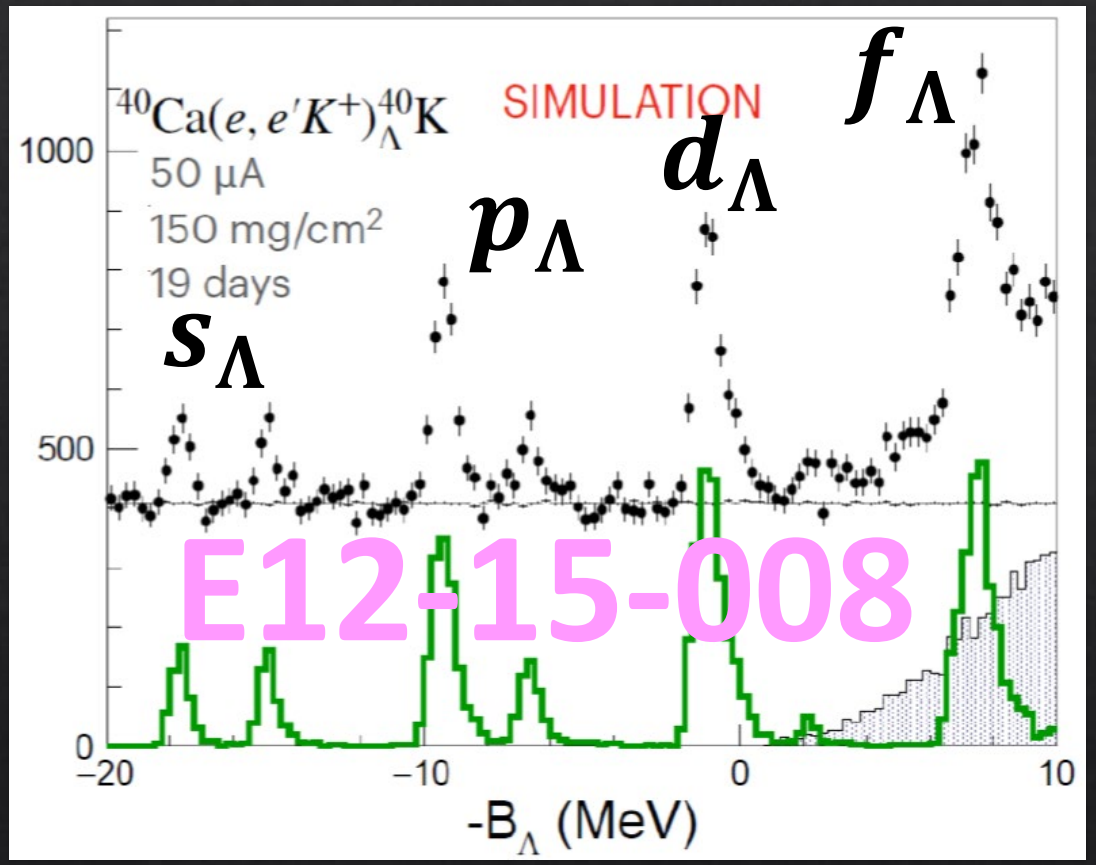
Anti-molecular dynamics (AMD) calculation
Presentation by M. Isaka (2023); https://indico.jlab.org/event/705/



^{26}Mg × p$_\Lambda$ ➔ Probing triaxially deformation

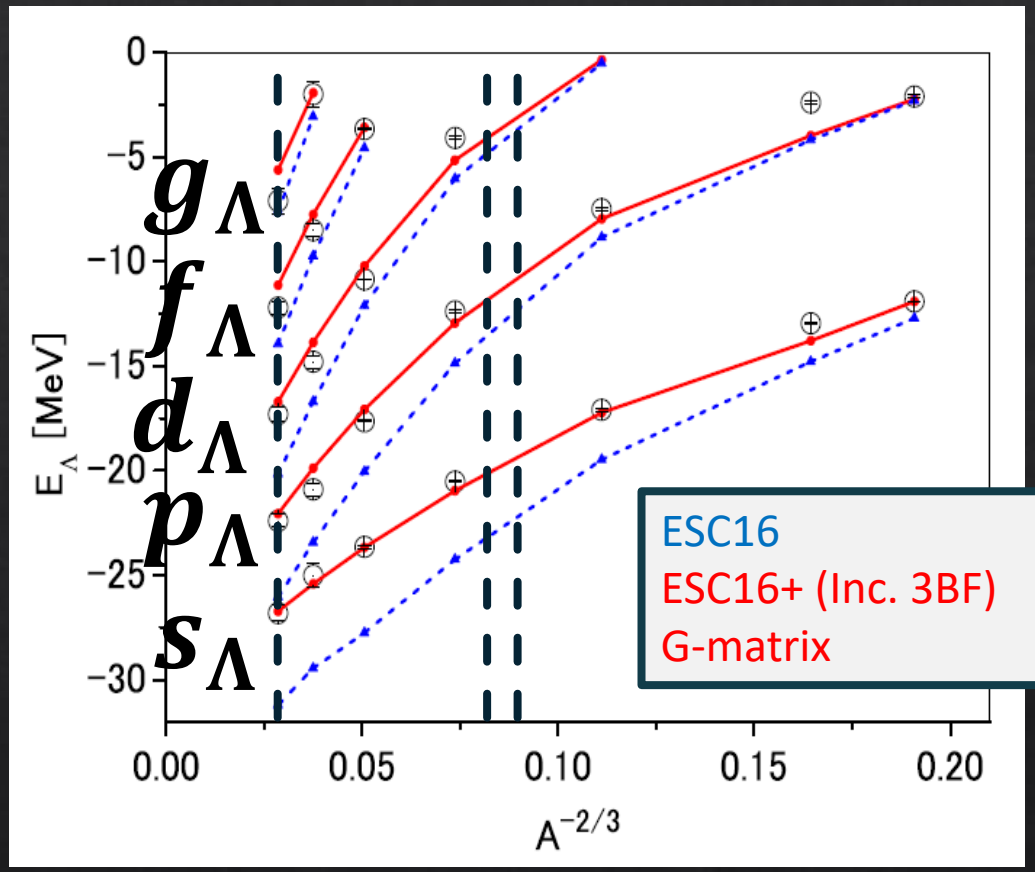
High accuracy experiment → 3-body force study

Expected spectrum based on Geant4 simulation



Missing mass spectroscopy with the world best accuracy $|\Delta B_\Lambda| \leq 100$ keV

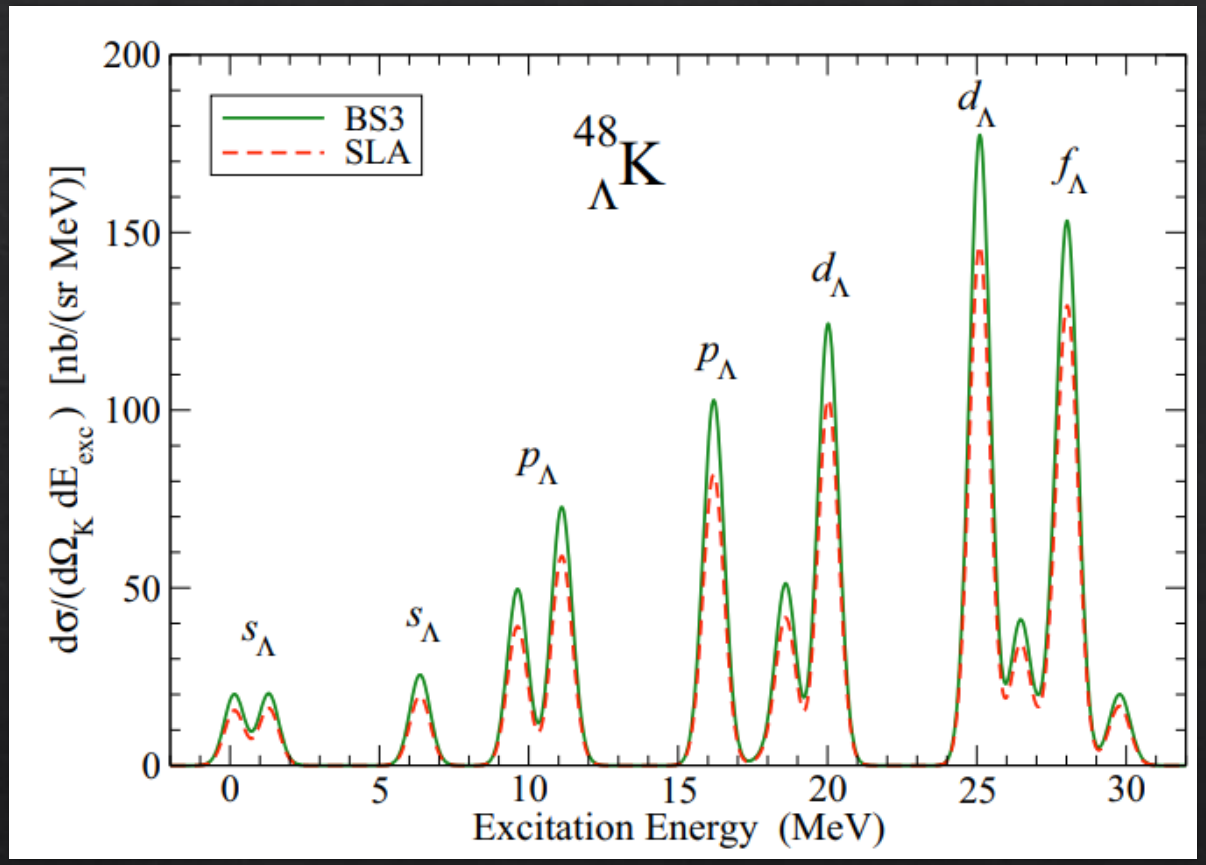
M.M. Nagels et al., PRC 99 (2019) 044003.



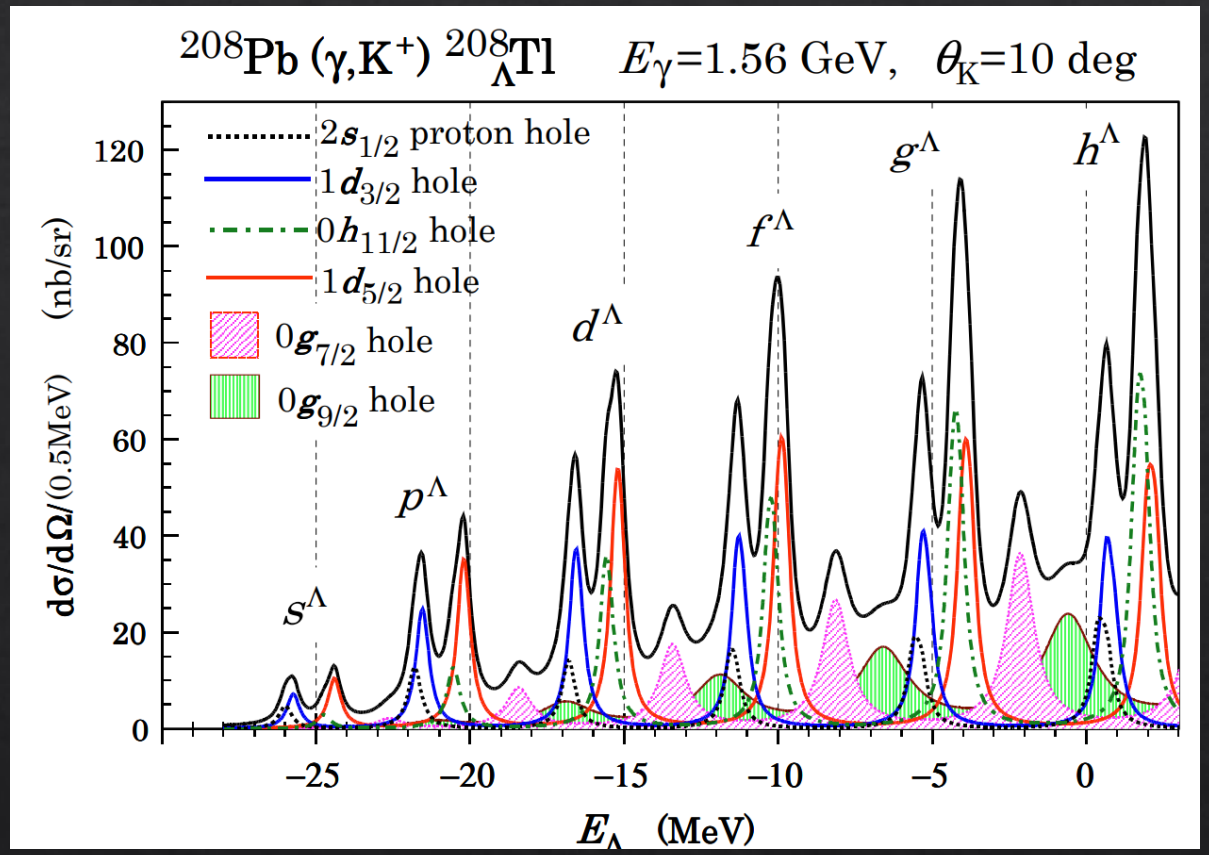
New information for 3-body force

Great progress in theoretical predictions

Ref.) Talks by Bydzovsky (Oct 15, 2024) and Skoupil (Oct 17, 2024)



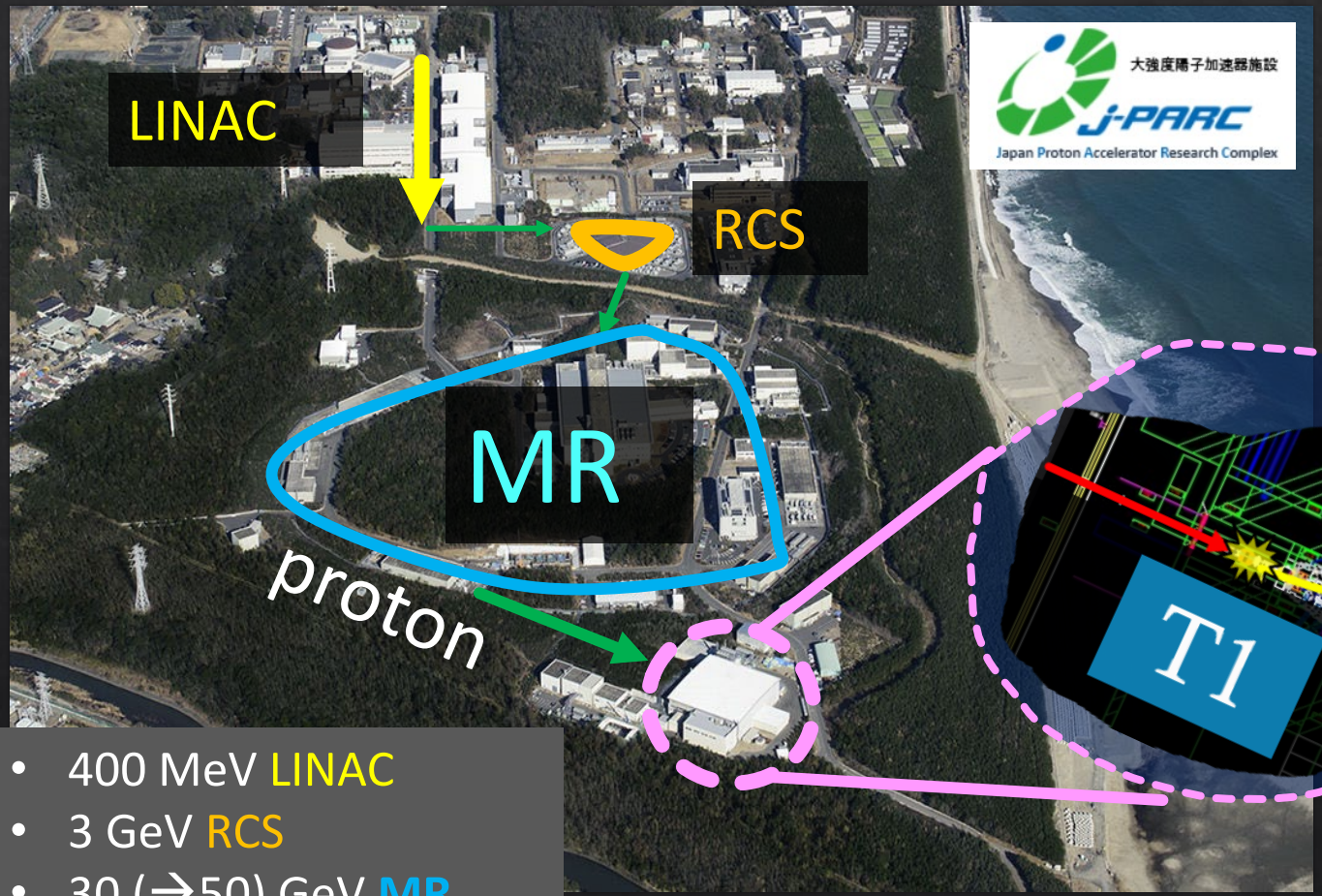
P. Bydžovský , D. Denisova, D. Petrellis , D. Skoupil, P. Veselý , G. De Gregorio, F. Knapp, and N. Lo Iudice, PRC 108, 024615 (2023)

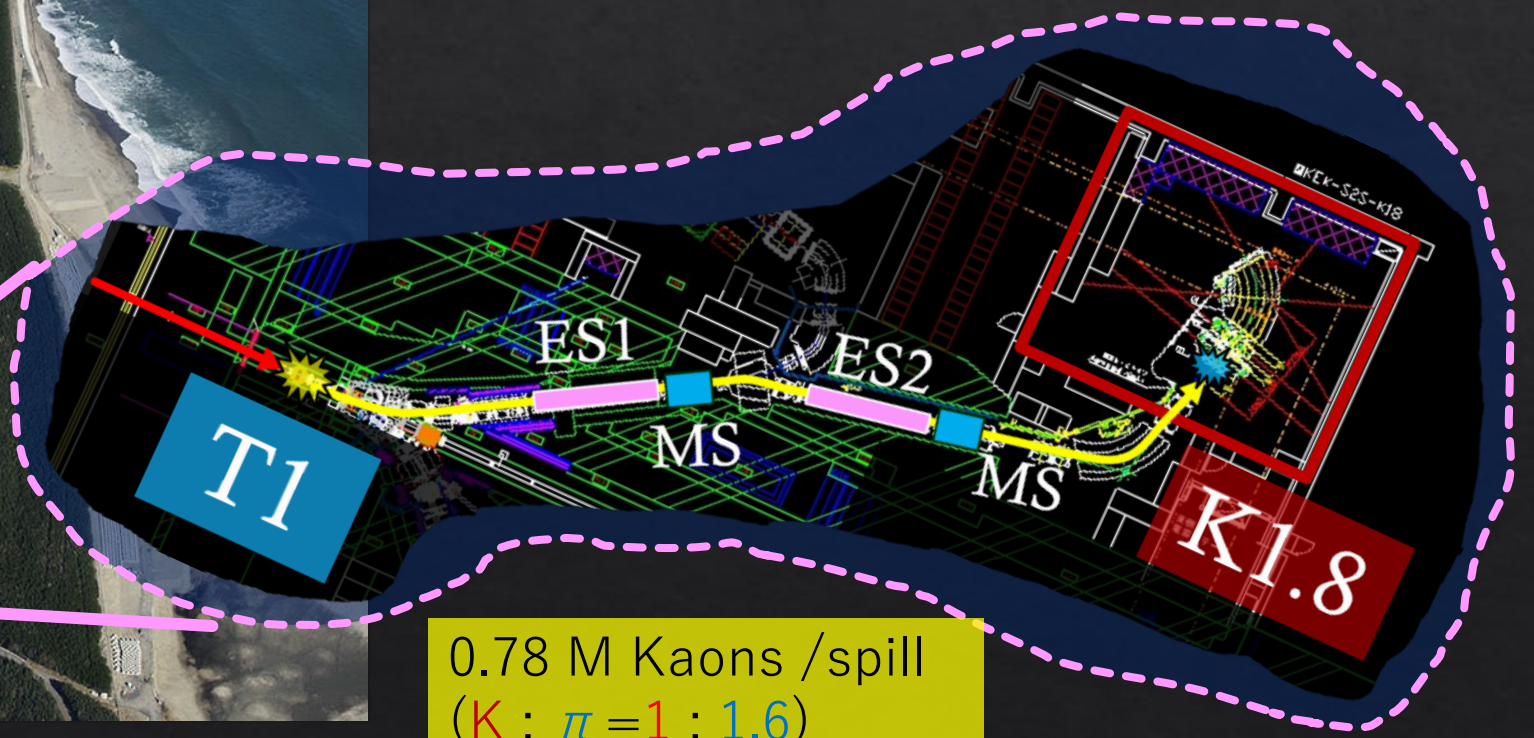


T. Motoba, JPS Conf. Proc. , 011003 (2017)

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

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

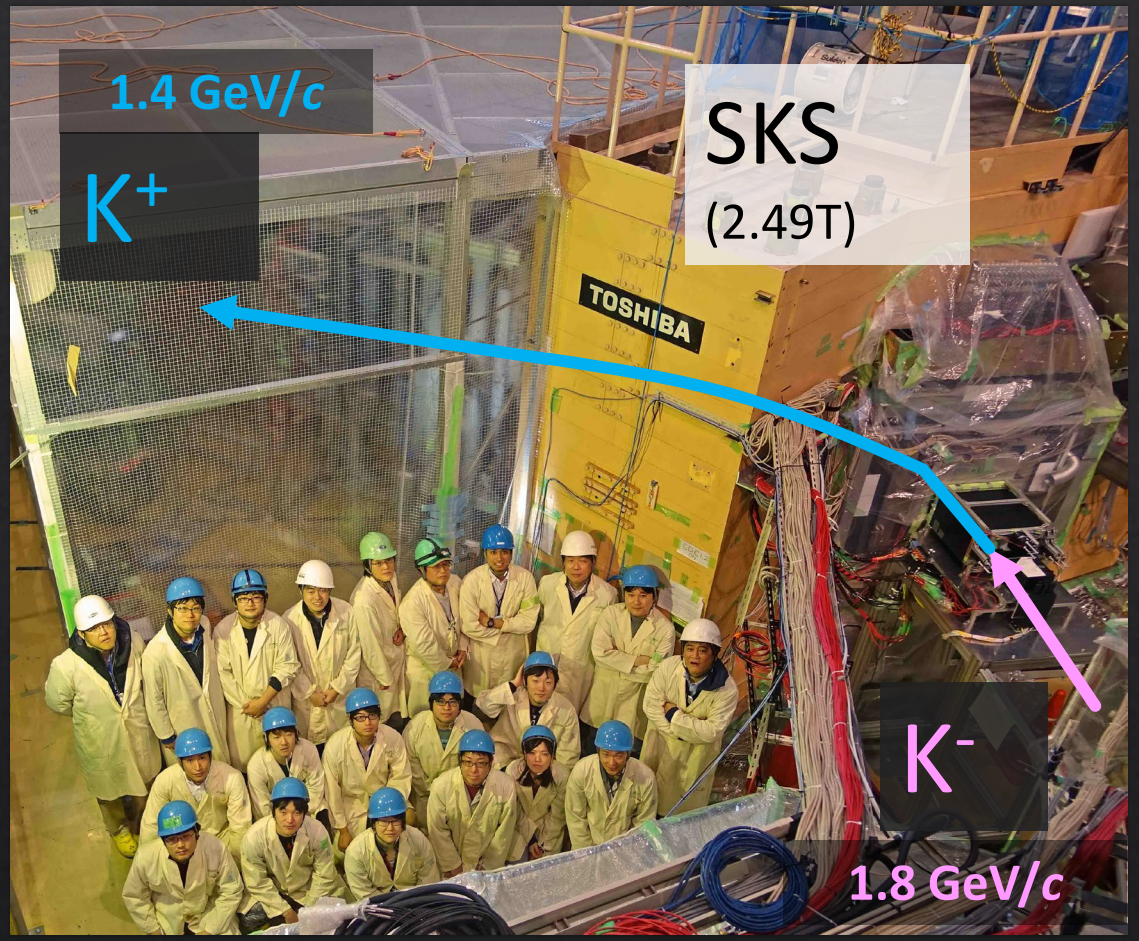




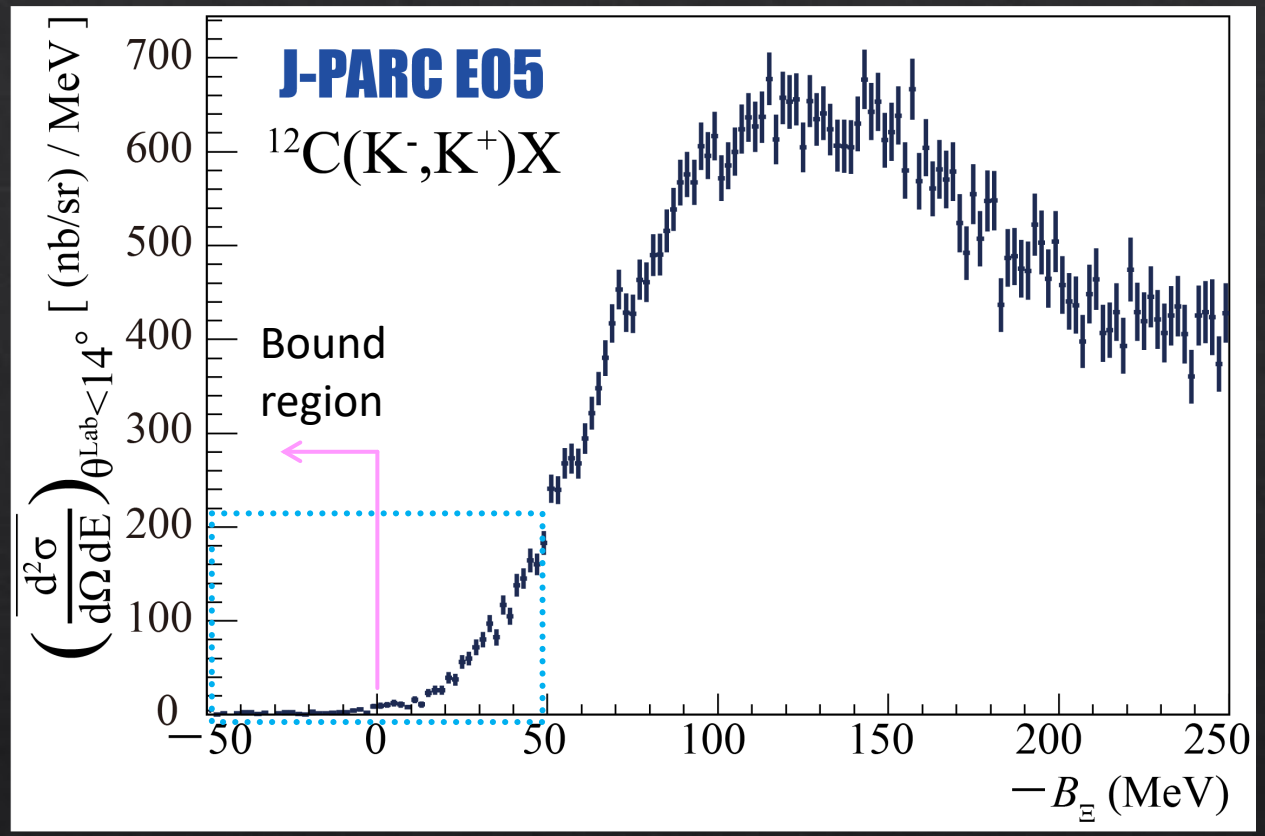
- 400 MeV LINAC
- 3 GeV RCS
- 30 (→50) GeV MR

0.78 M Kaons /spill
(K : π =1 : 1.6)

J-PARC E05 at K1.8 beam line



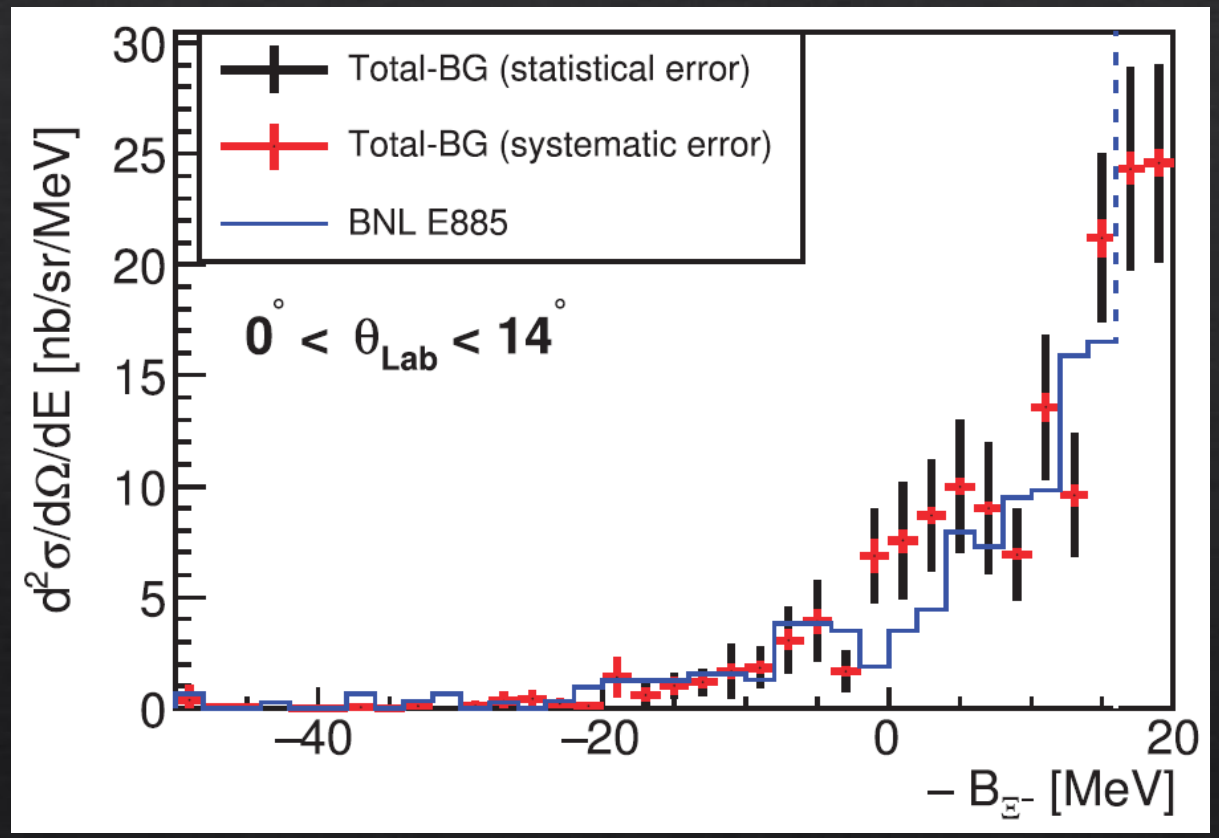
Analysis by Dr. Y. Ichikawa

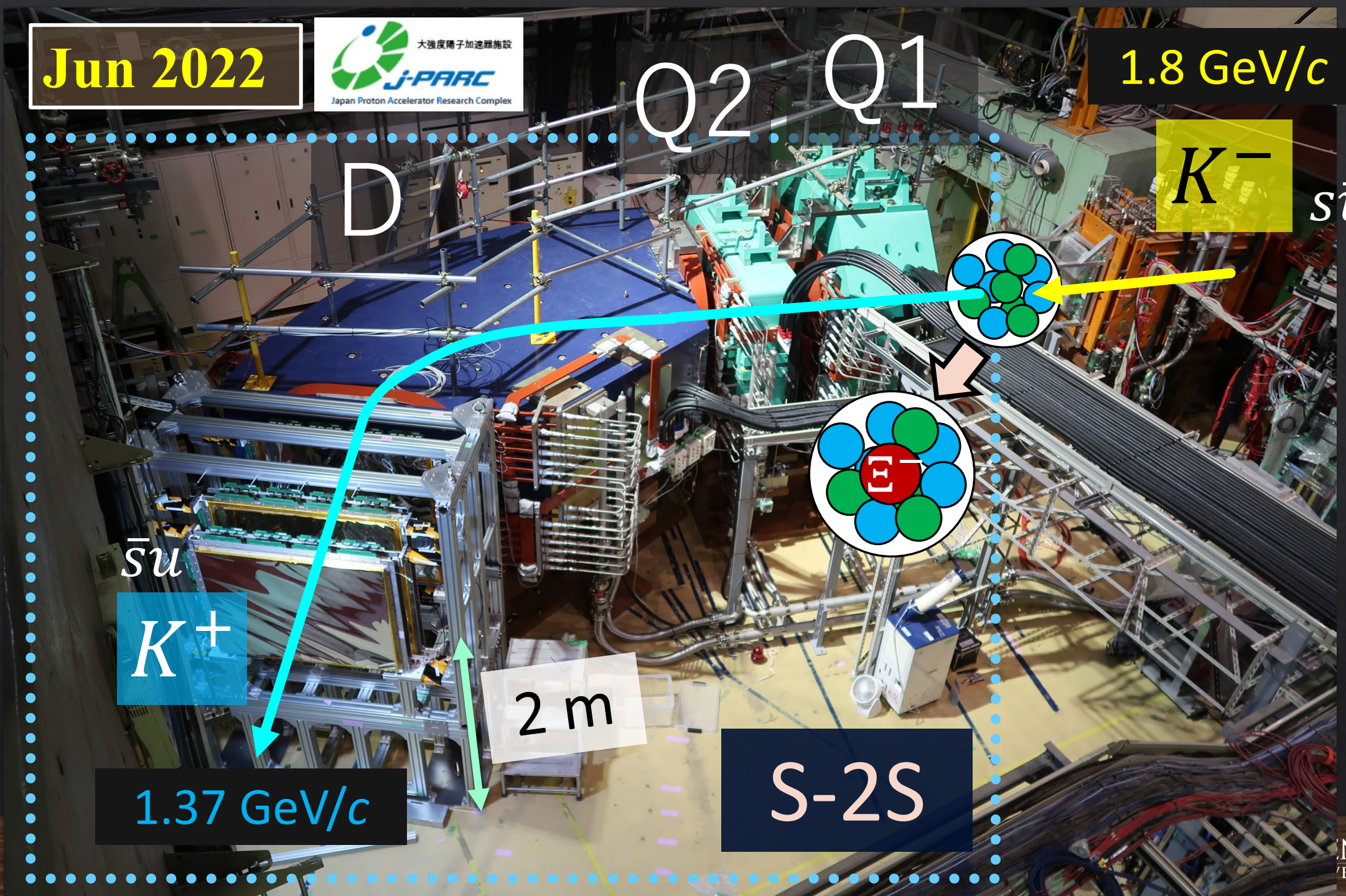


c.f.) Result for the **^{12}C(K$^-$,p)** reaction:
Y. Ichikawa et al., PTEP 2020, 123D01 (2020)

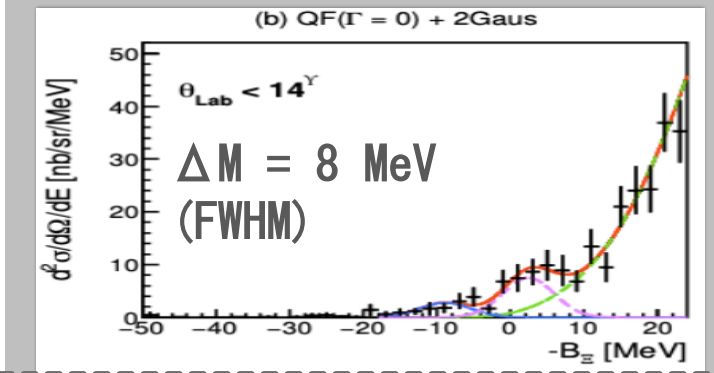
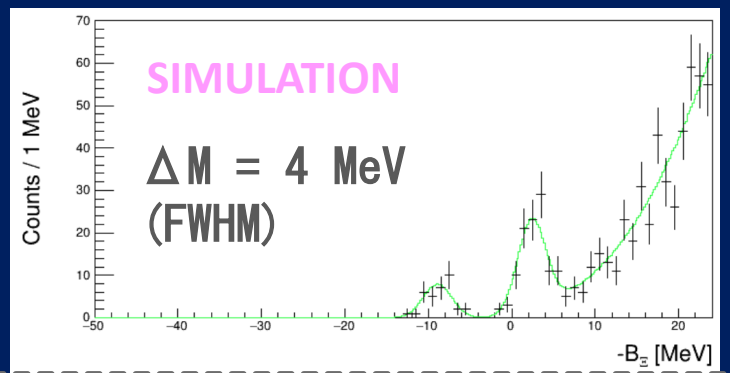
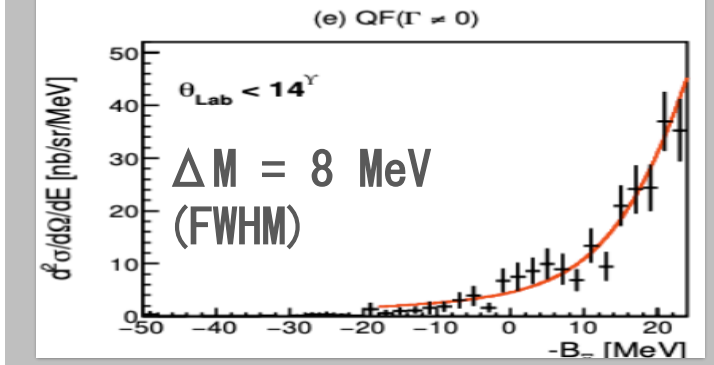
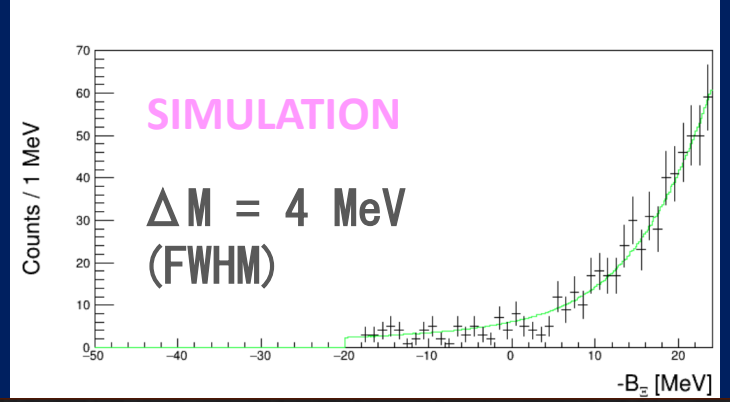
Result (J-PARC E05), 8 MeV (FWHM)

Y. Ichikawa et al., PTEP 2024, 9, 091D01 (2024), https://doi.org/10.1093/ptep/ptae133




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

Expected spectra (based on E05 result)

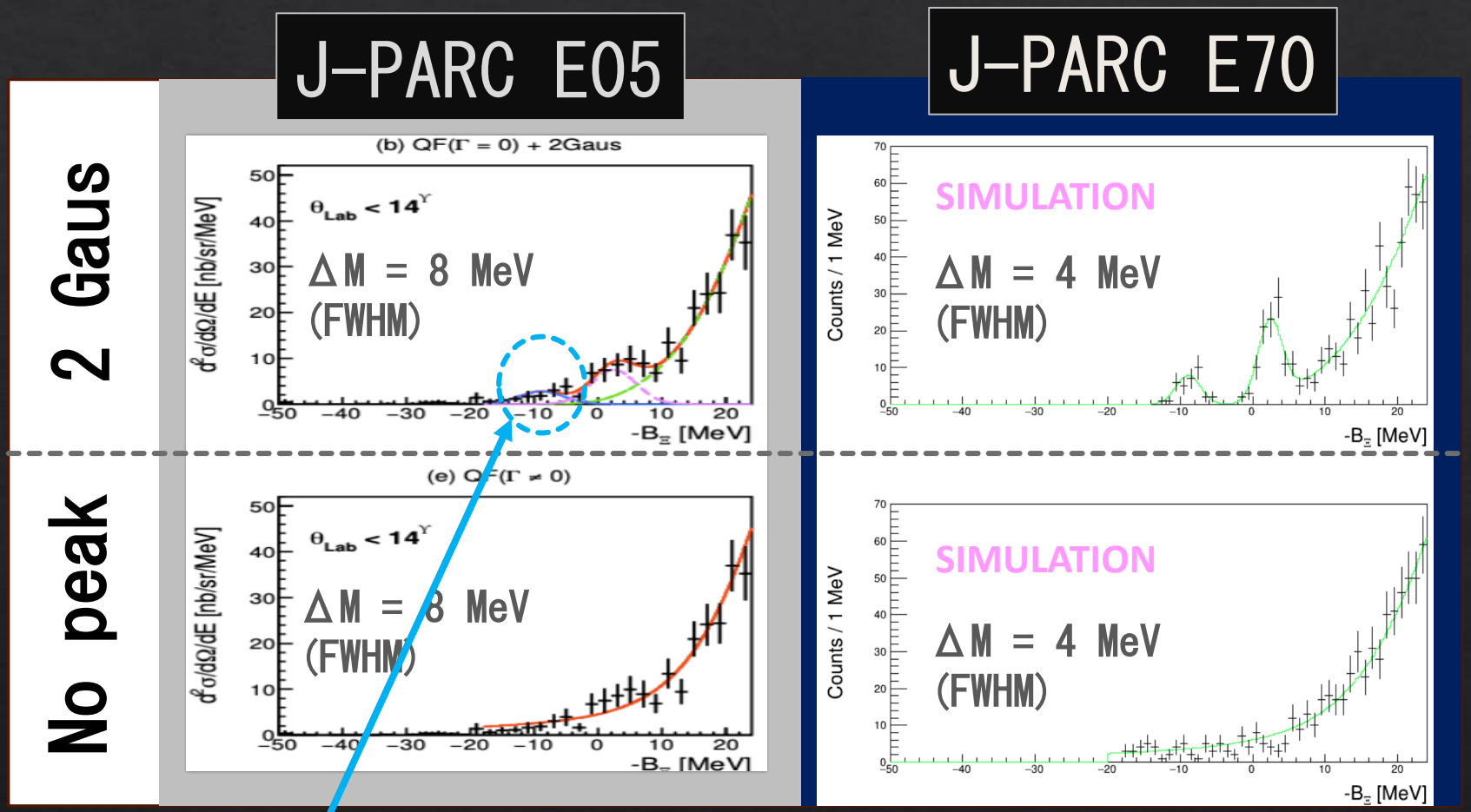
	J-PARC E05	J-PARC E70
2 Gaus		
No peak		

Two scenarios which E05 could not clarify would be clear in E70

4 MeV (achieved resolution now)
→ analysis in progress to reach 2 MeV (design value)

c.f.) $B_{\Xi}^{\mathrm{theor.}} = 8.4$ MeV (Γ = 0.89 MeV)
E. Friedman, A. Gal, Phys. Lett. B 820, 136555 (2021)

Expected spectra (based on E05 result)



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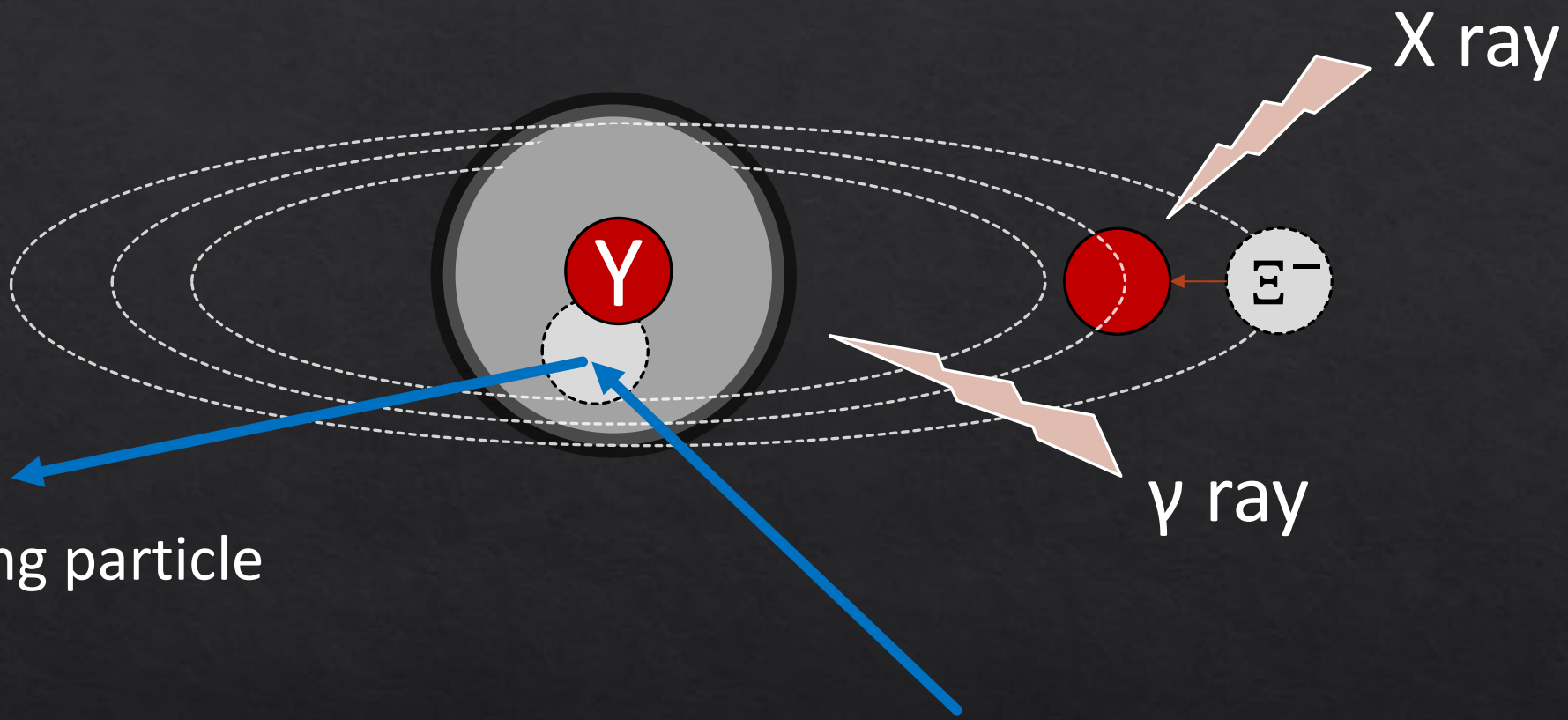
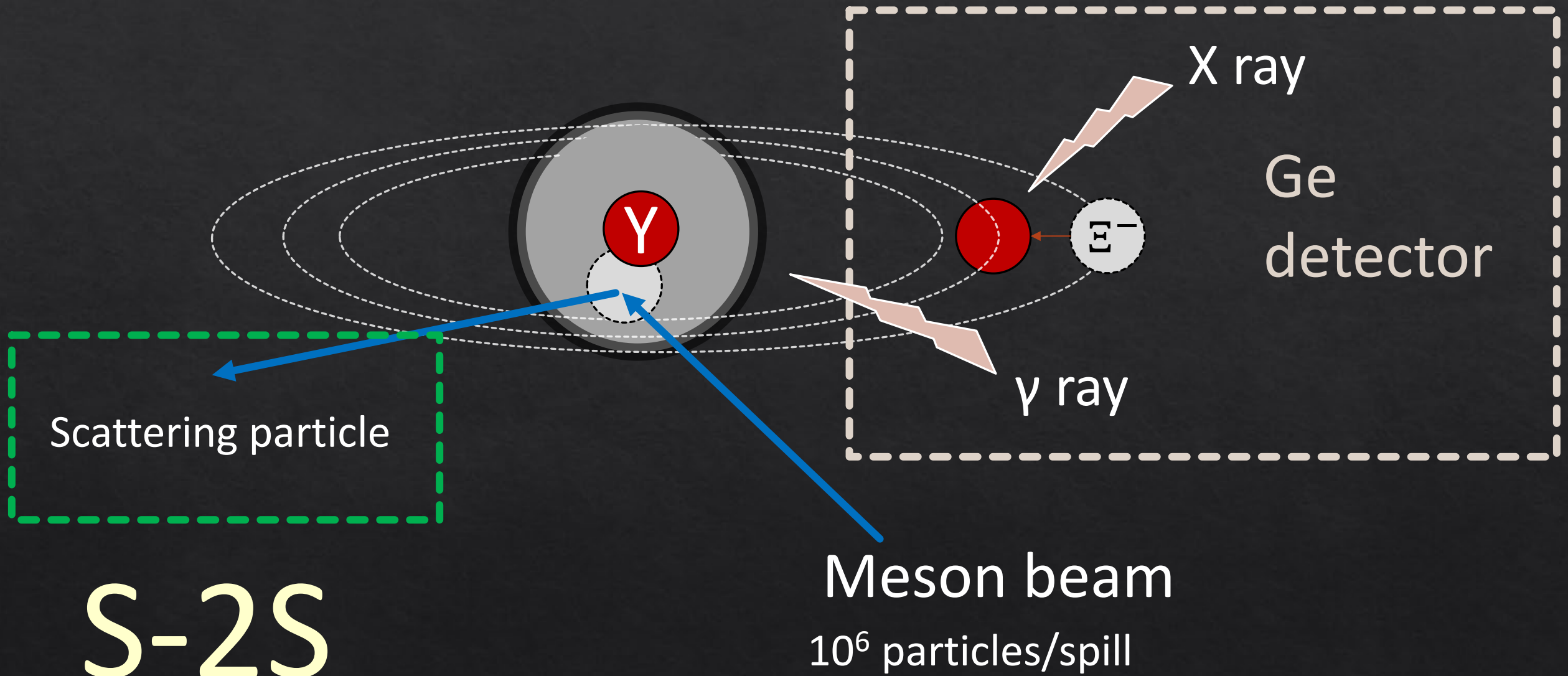
Strangeness nuclear physics by S-2S



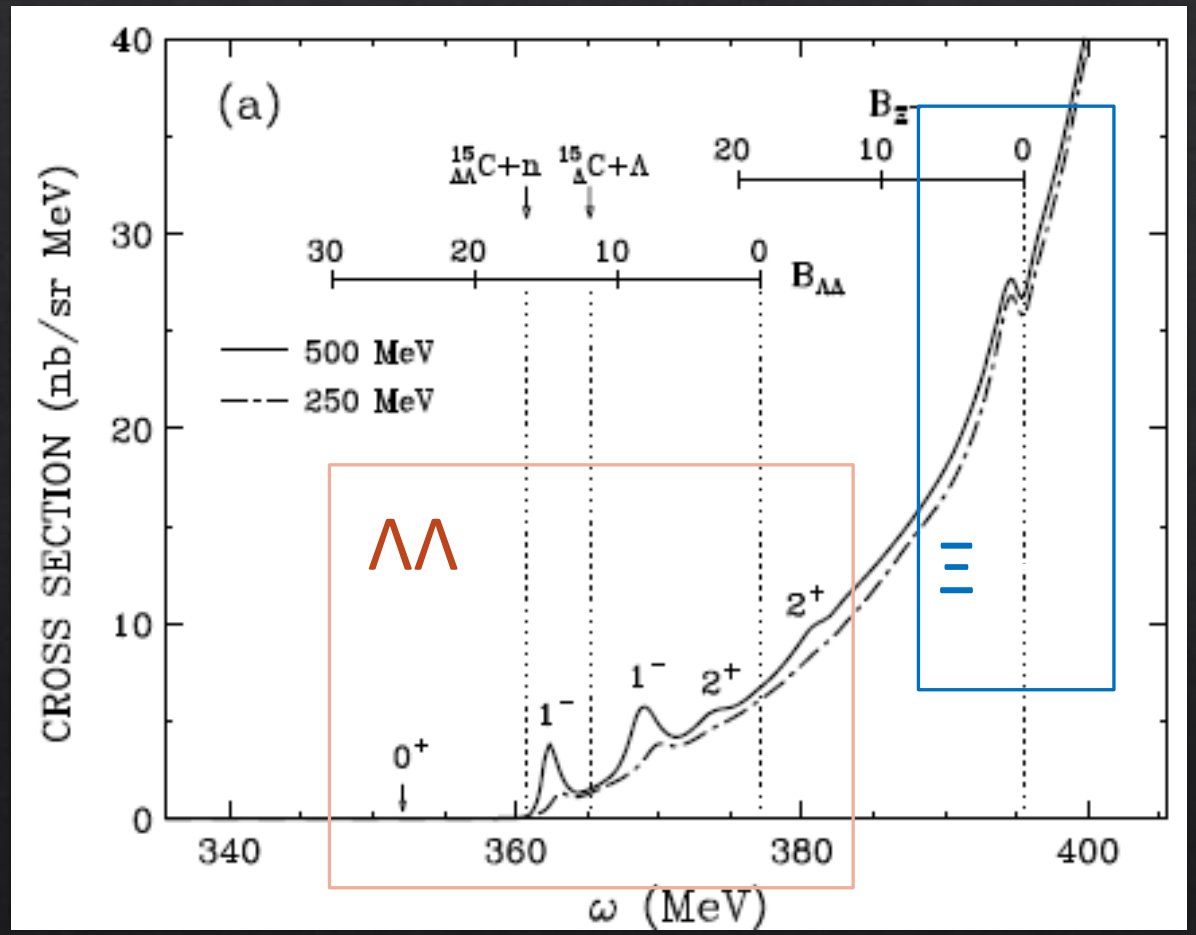
Strangeness nuclear physics by S-2S

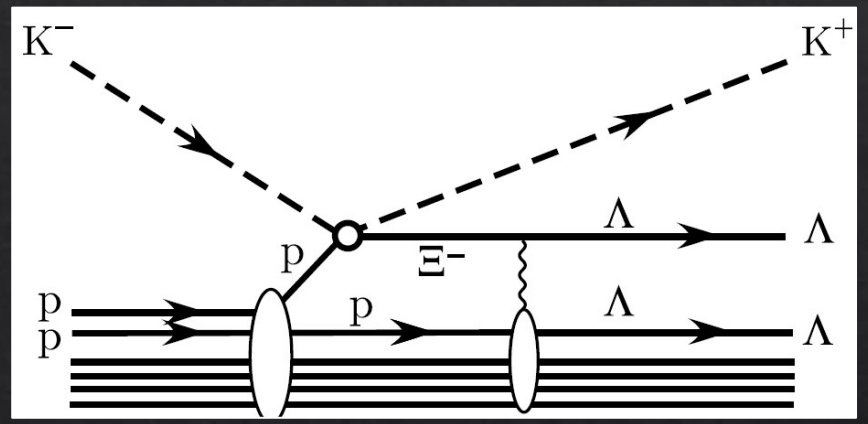


S-2S

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

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

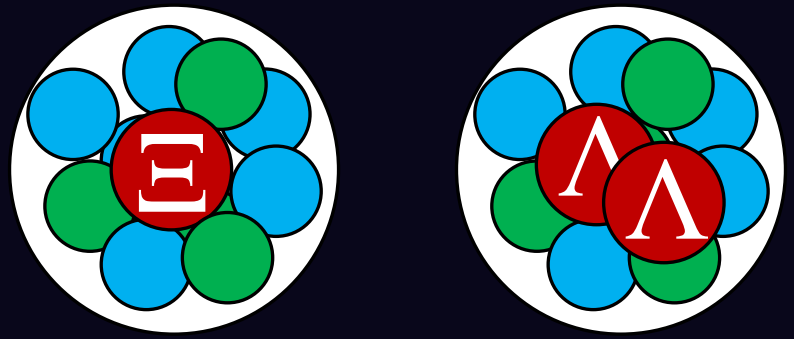


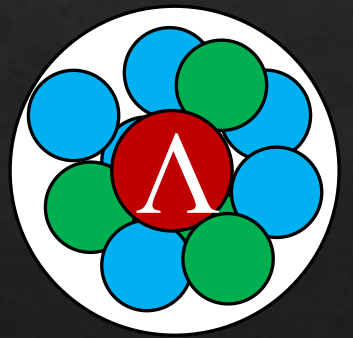


ΛΛ hypernuclei may be observed

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).

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

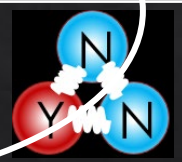
CSB $^{3}_{\Lambda}\mathrm{H}$ **lifetime puzzle**

$nn\Lambda$ **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 E12-24-004

- YN scat. exp.
- Femotoscopy

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

$nn\Lambda$ **bound puzzle**

JLab E12-19-002

JLab LOI12-23-011

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

JLab C12-20-013 (C2)

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

JLab E12-24-011

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, 2025—)

- (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**

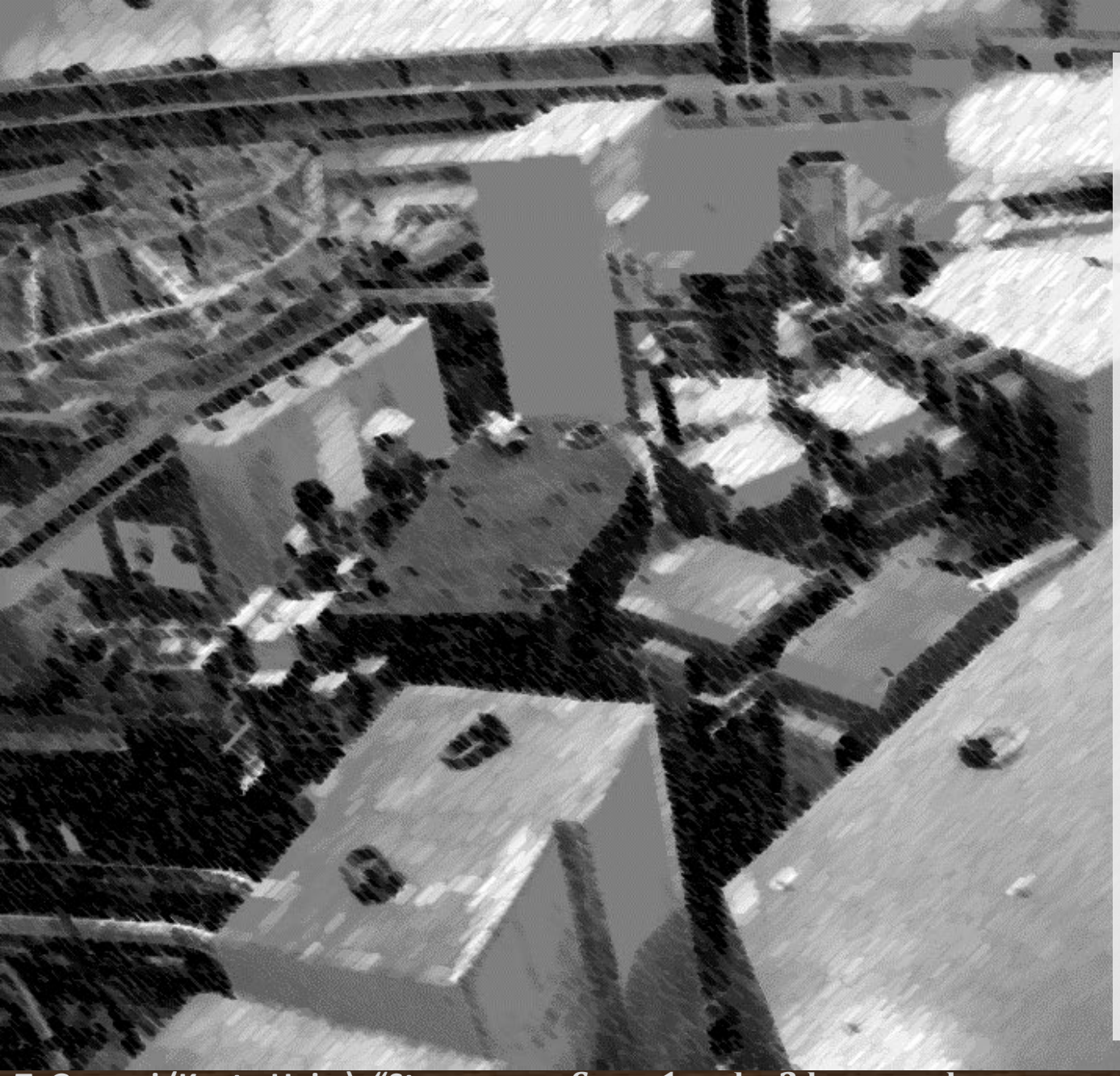
New data with high accuracy and precision data will be provided in a few—5 years

Theoretical calculations are necessary

Czech Academy of Sciences has been playing important roles and will be!

Thank you for your attention

Backup



Hall A

- K. Okuyama et al., PRC 110, 025203 (2024)
- 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

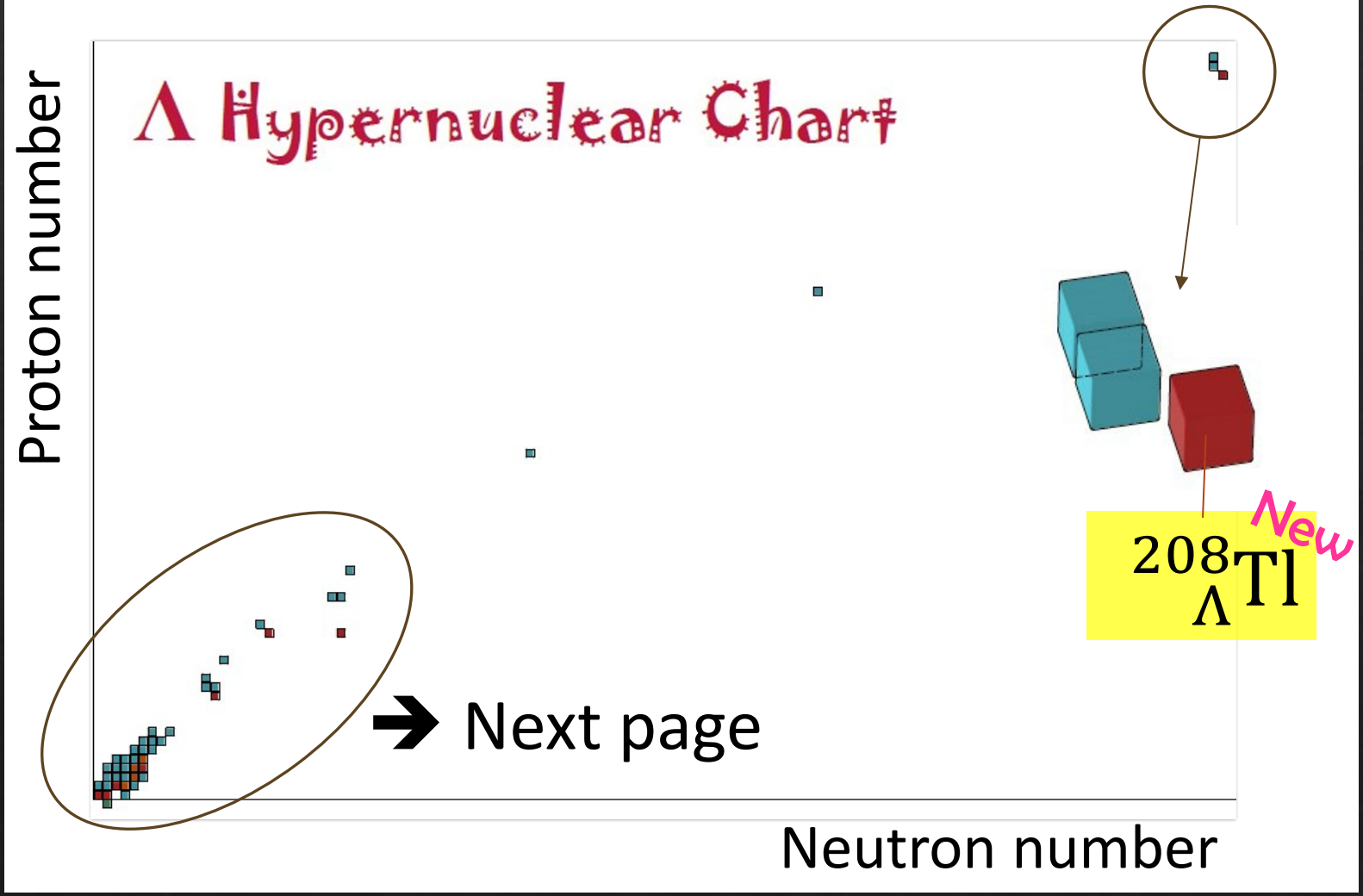
- TG et al., PRC 103, L041301 (2021)
- TG et al., NIMA 900, 69—83 (2018)
- TG et al., PRC 94, 021302(R) (2016)
- TG et al., PRC 93, 034314 (2016)
- Y. Fujii et al., NIMA795, 351—363 (2015)
- L. Tang et al., PRC 90, 034320 (2014)
- S.N. Nakamura et al., PRL 110, 012502 (2013)
- TG et al., NIMA 729, 816—824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

Experimental parameters for the next JLab Experiment (2027-)

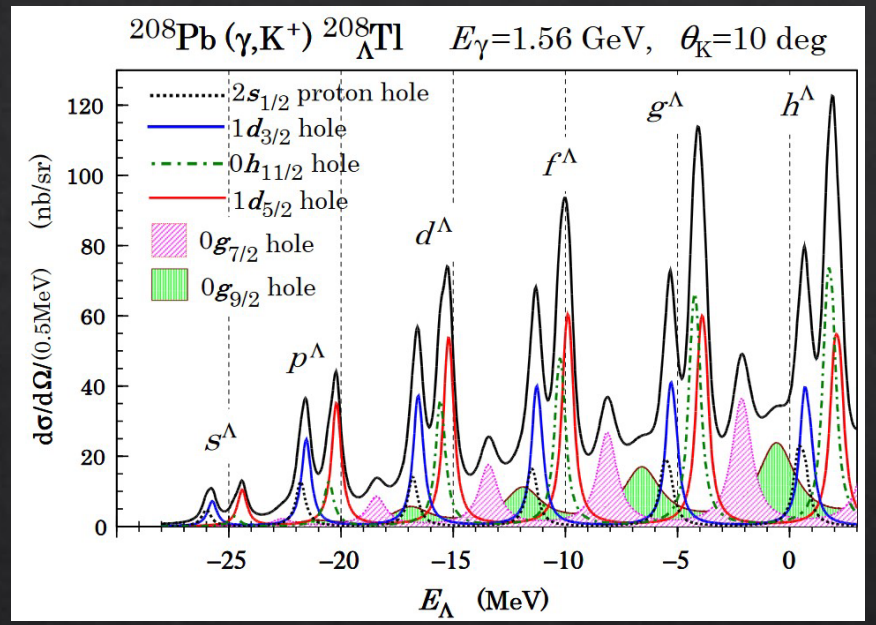
TABLE II. Summary of the kinematics parameters in the proposed experiment.

Item		Value
Beam (e)	Energy (/GeV)	2.24
	(Required) energy spread and drift	1×10^{-4} (FWHM)
PCS + HES (e')	Central momentum $p_{e'}^{\mathrm{cent.}}$ [/(GeV/c)]	0.74
	Central angle $\theta_{ee'}^{\mathrm{cent.}}$	8.5°
	Solid angle acceptance $\Omega_{e'}$ (/msr) (at $p_{e'}^{\mathrm{cent.}}$)	3.4
	Momentum resolution $\Delta p_{e'}/p_{e'}$	4.4×10^{-4} (FWHM)
PCS + HKS (K^+)	Central momentum $p_{K^+}^{\mathrm{cent.}}$ [/(GeV/c)]	1.20
	Central angle $\theta_{eK^+}^{\mathrm{cent.}}$	11.5°
	Solid angle acceptance Ω_{K^+} (/msr) (at $p_{K^+}^{\mathrm{cent.}}$)	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

Next JLab experiments; light to heavy hypernuclei



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

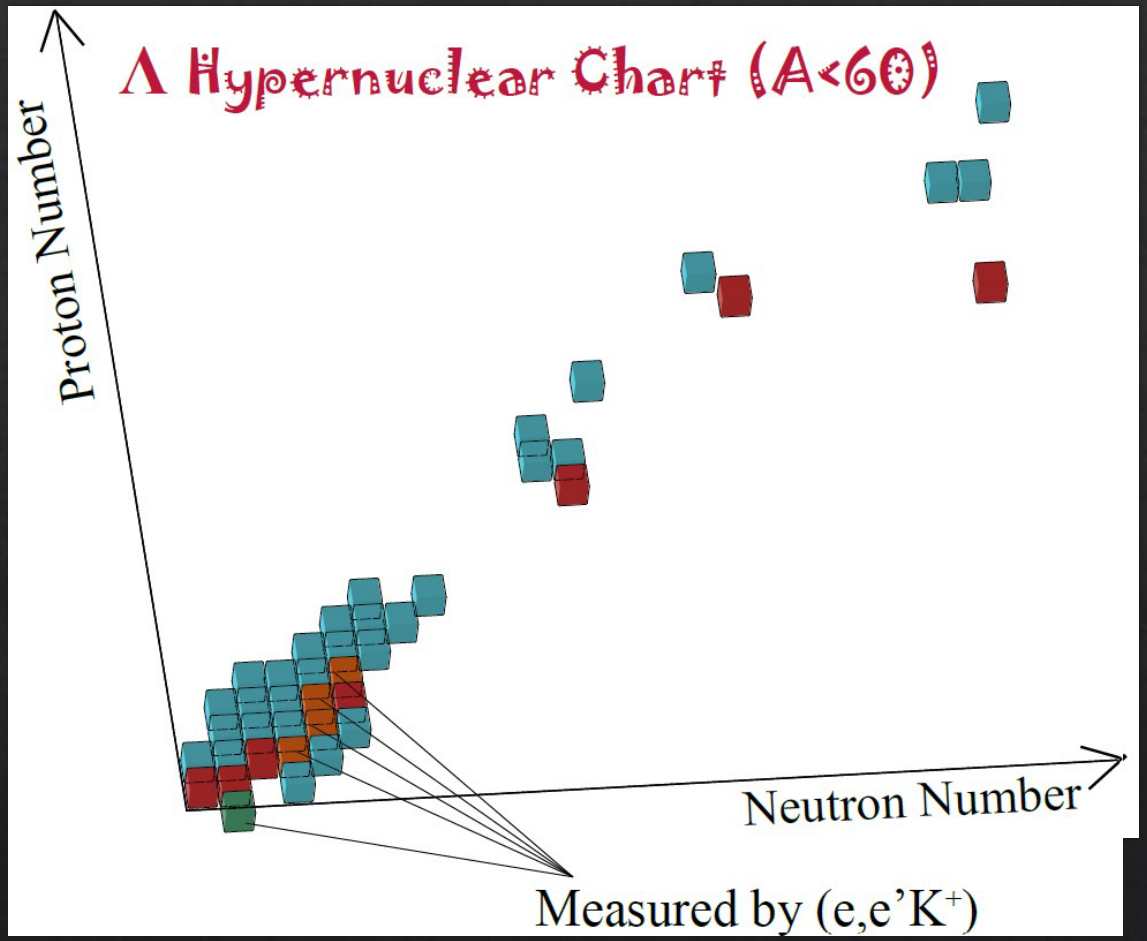


JLab E12-20-013

➔ ΛNN force

F. Garibaldi et al.,
EPJ Web Conf. 271, 01007 (2022).

Next JLab experiments; light to heavy hypernuclei



Next JLab experiments; light to heavy hypernuclei

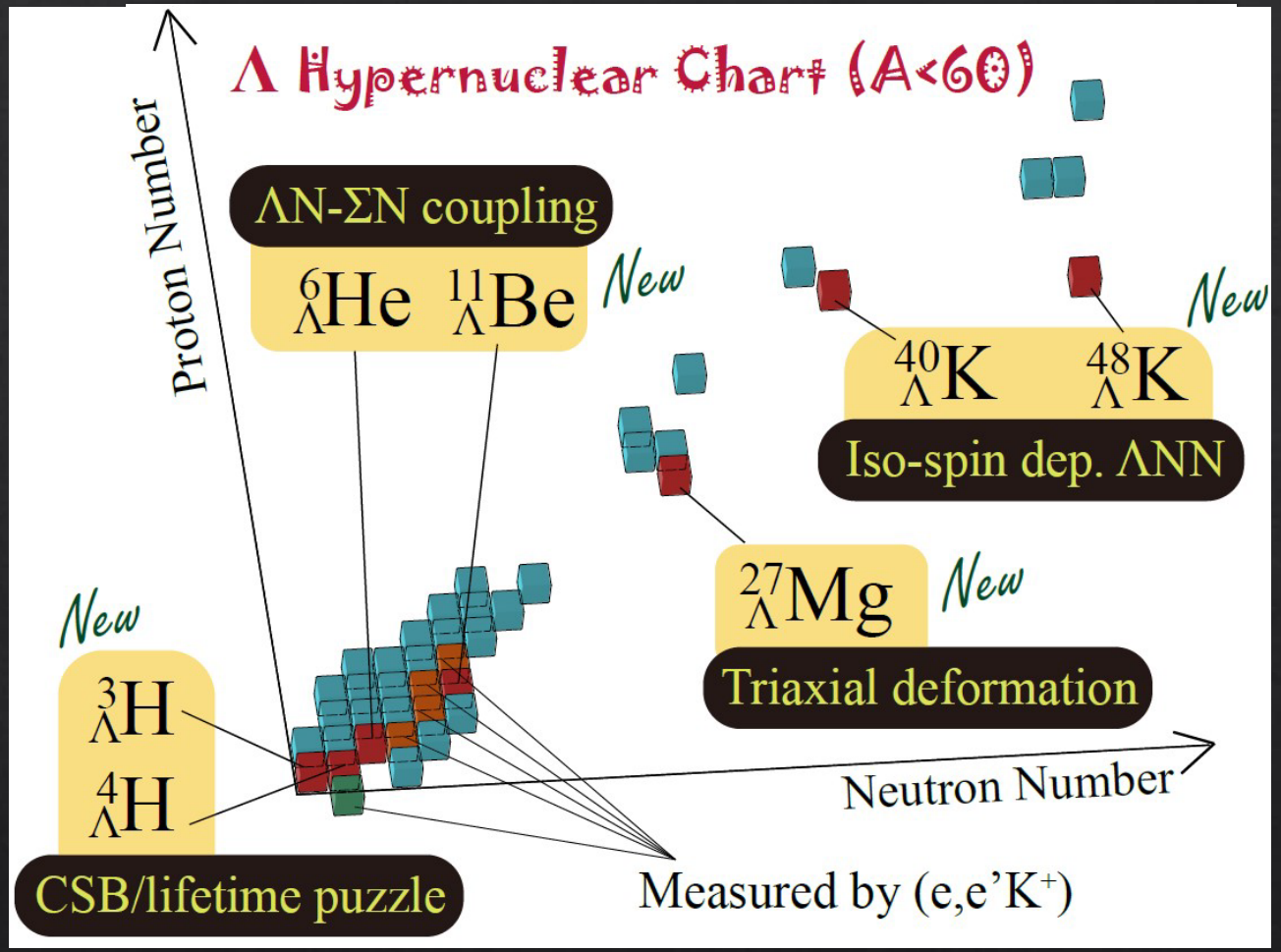
E12-24-004

→ Link

Contact person
Prof. T. Gogami
(Kyoto Univ.)

E12-19-002

- Proposal → Link
- TG et al., EPJ Web Conf. 271, 01001 (2022).



E12-15-008

Contact person
Prof. S. N. Nakamura
(U. Tokyo)

E12-24-011

LOI12-23-011

Contact person
Prof. S. Nagao (U. Tokyo)

Limited data for the CSB study

○: Data w/ ≤100 keV accur. exists

Shell	A	Component	Isospin			CSB study w/ 100 keV accur.
			T<0	T=0	T>0	
s	4	d N Λ (0^+ / 1^+)	○	-	○ ○	Yes
p	6	α N Λ		-		
	7	α N N Λ	○ (JLab)	○	○	Yes
	8	α d N Λ	○	-	○	Yes
	9	α d N N Λ		○		
	10	α α N Λ	○ (JLab)	-		
	11	α α N N Λ				
	12	α α d N Λ	○ (JLab)	-		

Limited data for the CSB study

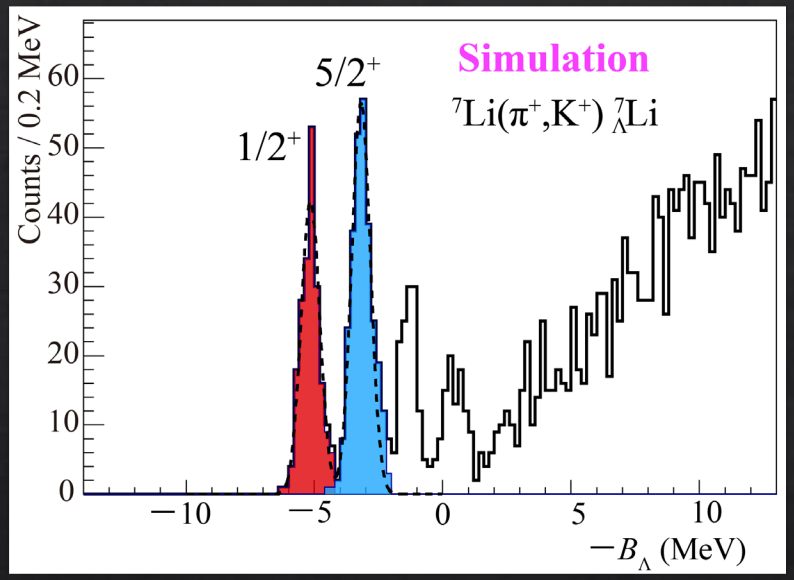
○: Data w/ ≤100 keV accur. exists

Shell	A	Component	Isospin			CSB study w/ 100 keV accur.	
			T<0	T=0	T>0		
s	4	d N Λ (0⁺ / 1⁺)	○ E12-19-002	-	○ ○	Yes	**Yes**
p	6	α N Λ	This prop.	-	J-PARC	**Yes**	
	7	α N N Λ	○ (JLab)	○	○	Yes	
	8	α d N Λ	○	-	○	Yes	
	9	α d N N Λ	This prop.	○		**Yes**	
	10	α α N Λ	○ (JLab)	-	J-PARC E94	**Yes**	
	11	α α N N Λ	This pro.	J-PARC		**Yes**	
	12	α α d N Λ	○ (JLab)	-	J-PARC E94	**Yes**	

Expected spectra (J-PARC E94)

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

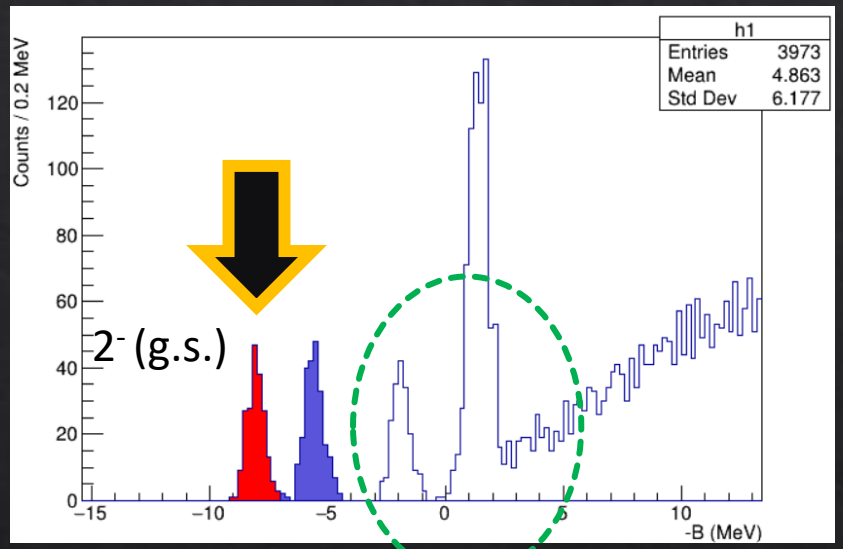
80 hours



Calibration source

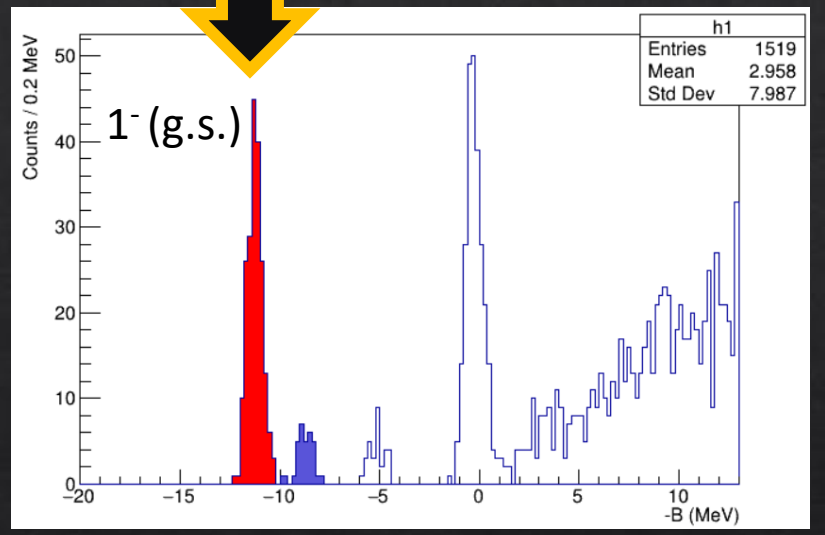
$^{10}_{\Lambda}$B

112 hours



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

36 hours



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