QCHSC2024, Cairns, Australia (Aug 19—Aug 24, 2024)

# Lambda Hypernuclear Spectroscopy by Electron Scattering at JLab


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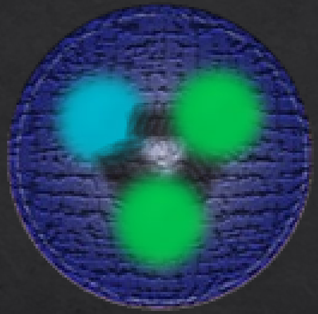
Aug 22, 2024



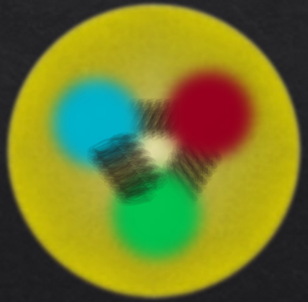
GRADUATE SCHOOL OF SCIENCE FACULTY OF SCIENCE
KYOTO UNIVERSITY

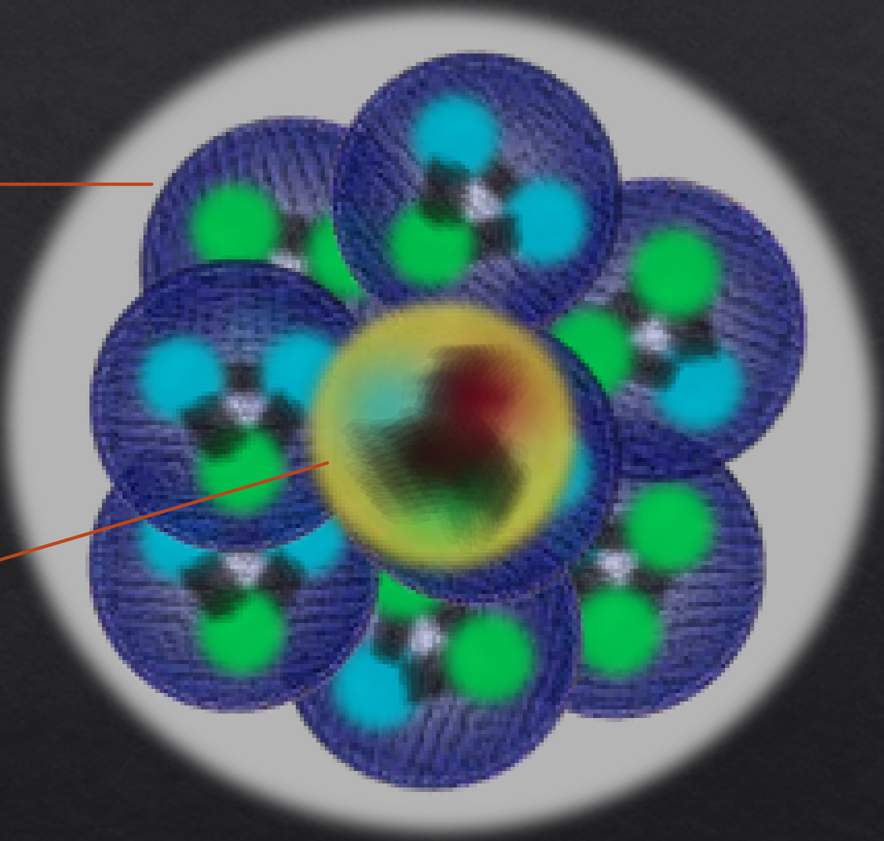
# Hypernuclei

## Nucleon
only up, down quarks



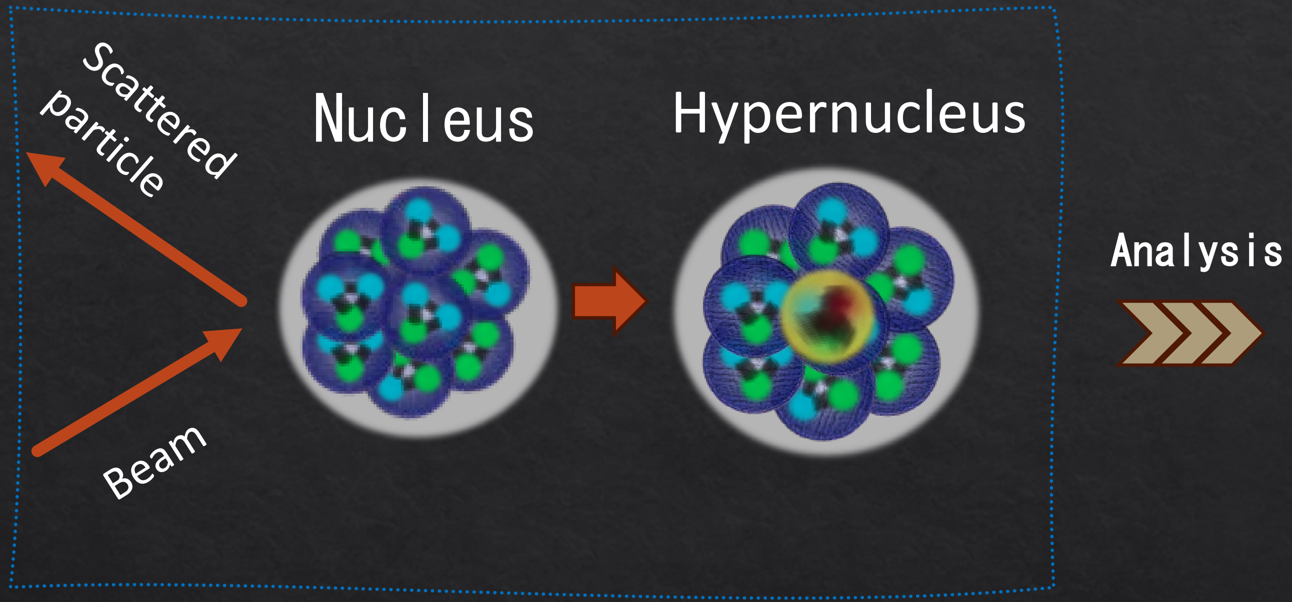
## Hyperon
(u, d +) strange (s) quark

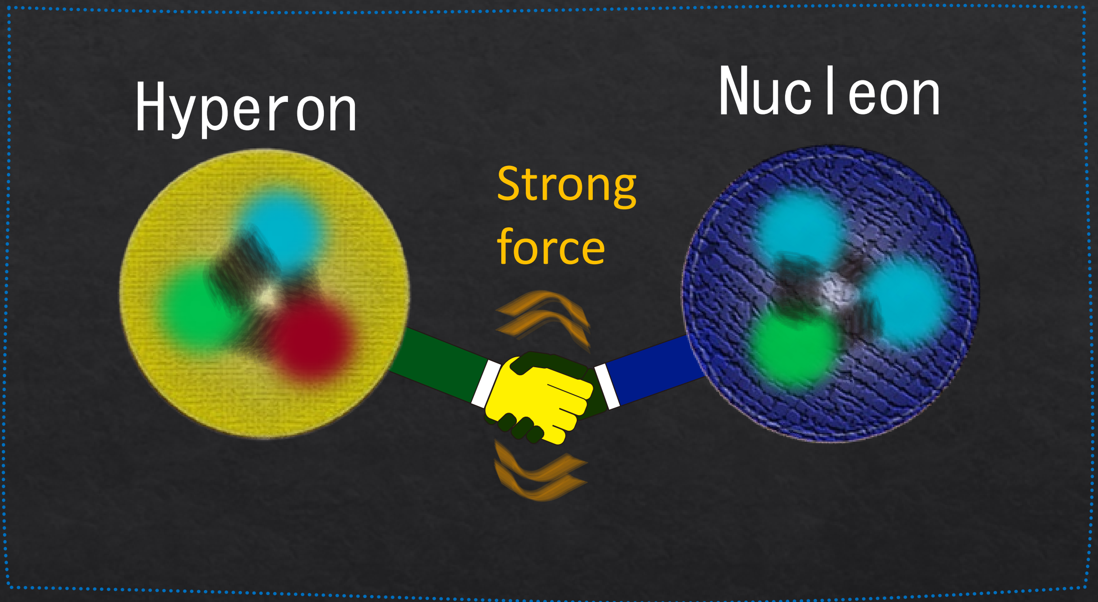




## Hypernucleus

# Baryon interaction study through hypernuclei



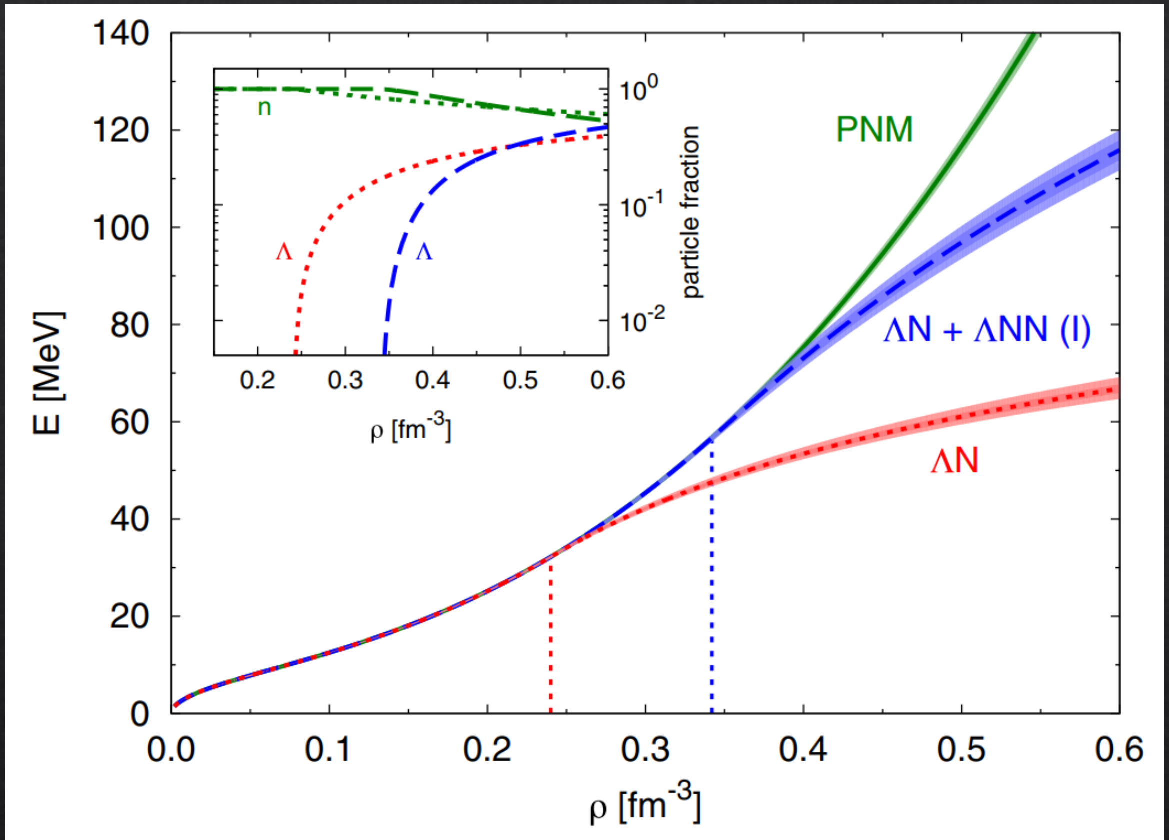



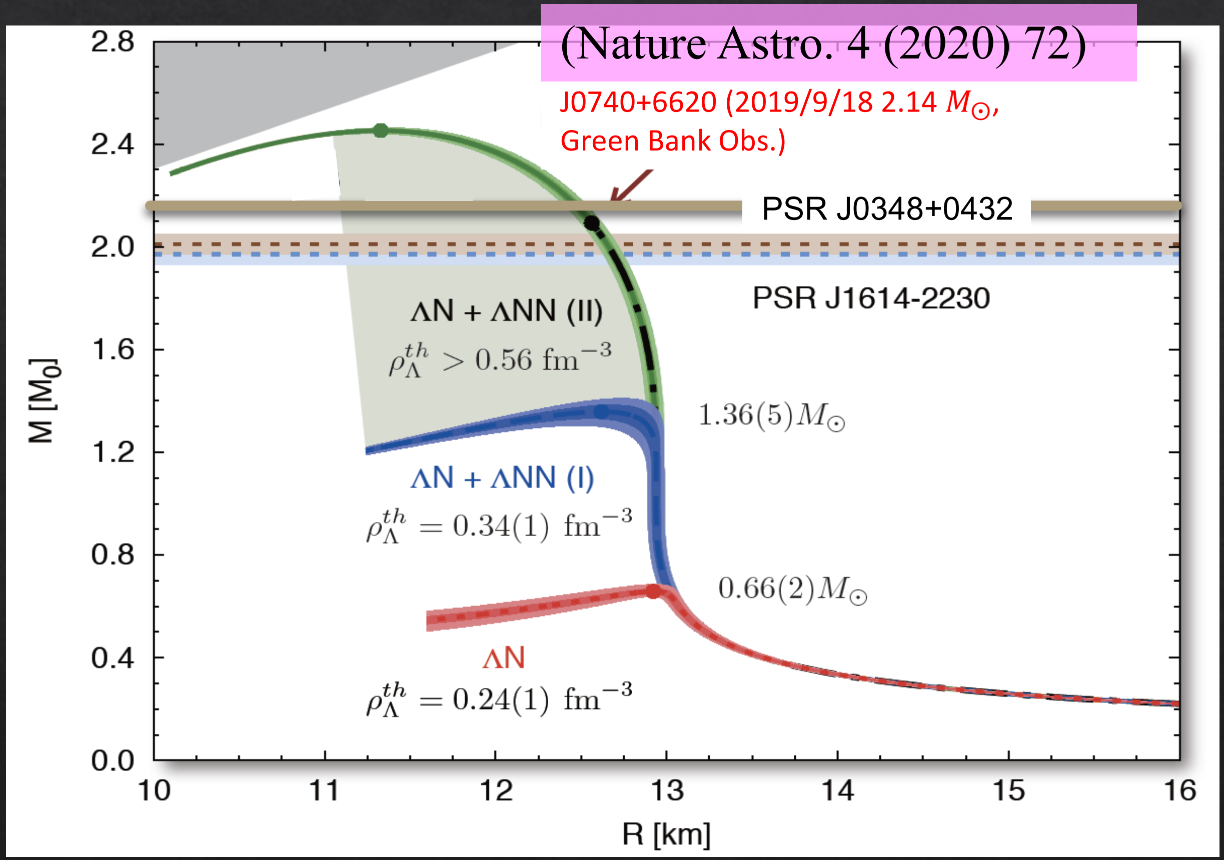

➔ Hyperon(Y)-nucleon(N) interaction

➔ More general baryon-baryon interaction

# Hyperons in neutron stars

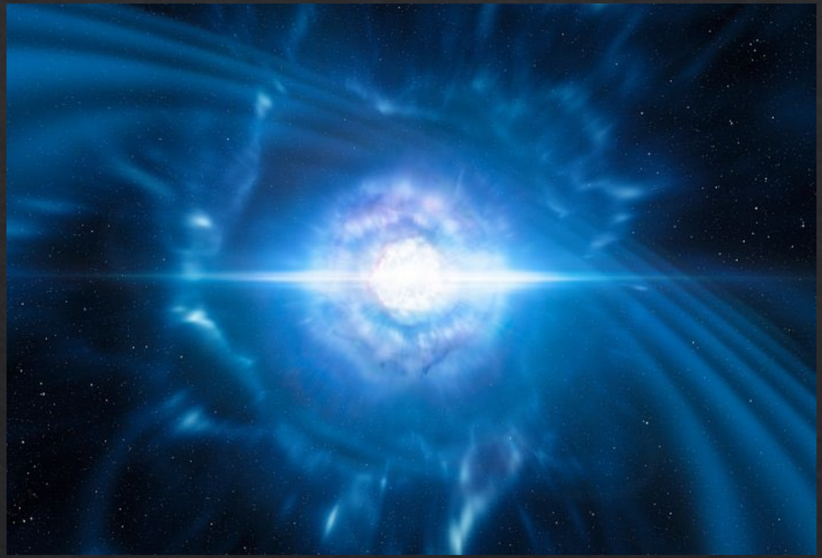
D. Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015)




➔ Multi-body force may play an important role

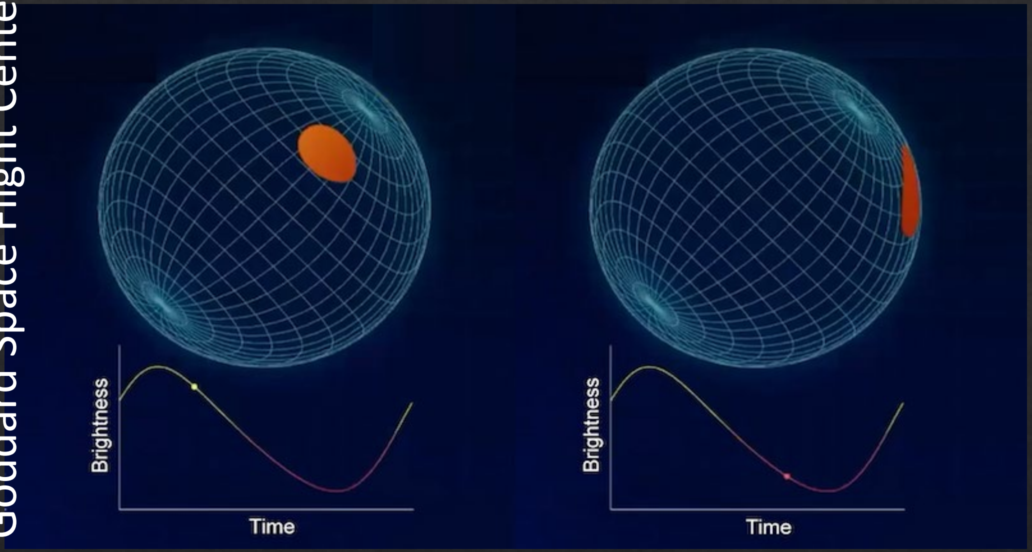
# New astronomical observations



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)

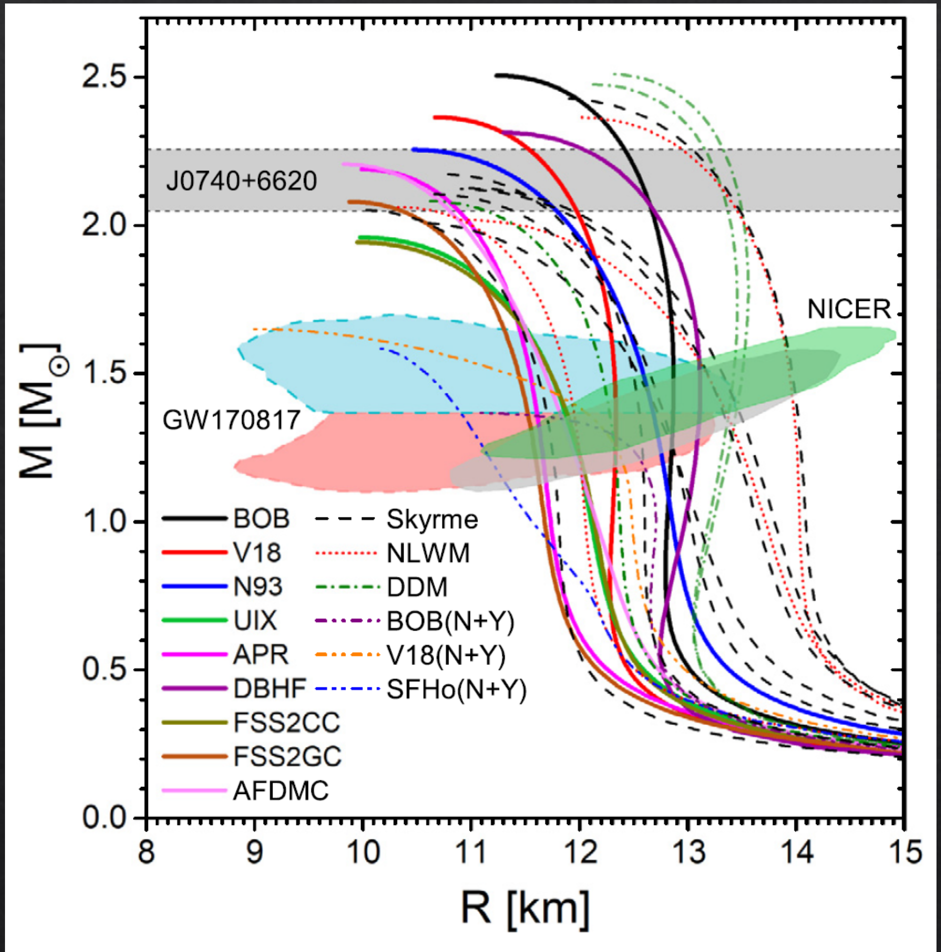
**Macroscopic features of NS : Tidal deformability, masses and radii**

***vs.***

**Microscopic investigation of NS: Inner composition** → HYPERNUCLEAR SPECTROSCOPY

# New constrains from astronomical observations

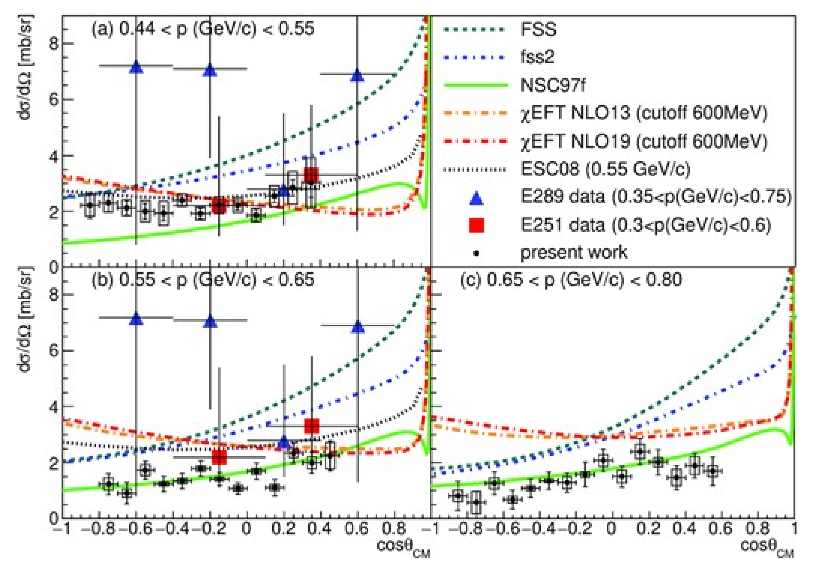
C.F. Burgio et al. Prog. Part. Nucl. Phys 120 (2021) 103879.




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

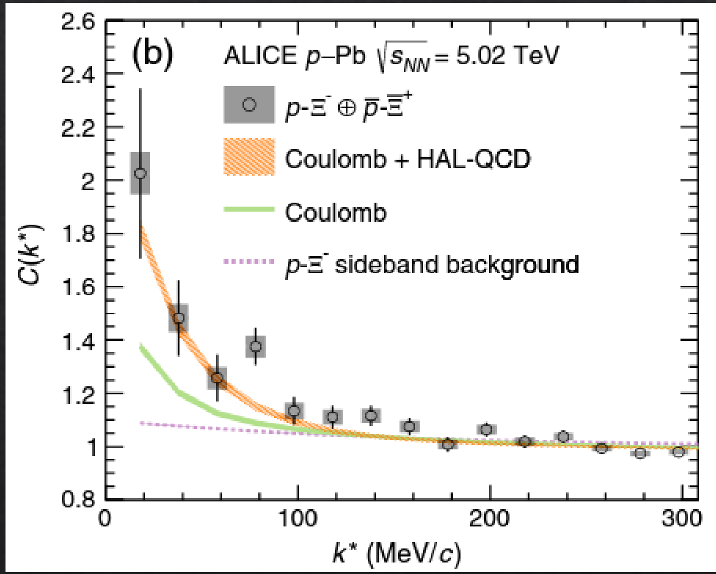
# YN/YY interaction study

## Scattering experiments



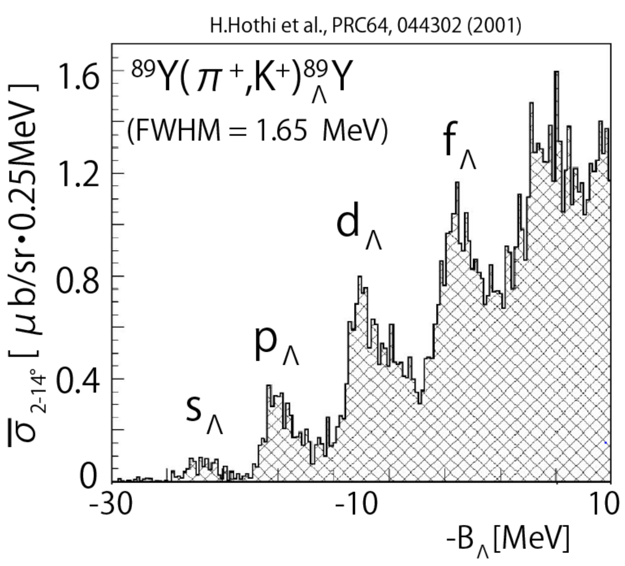
T. Nanamura et al., PTEP 2022, 9, 093D01 (2022)

## Femtoscopy



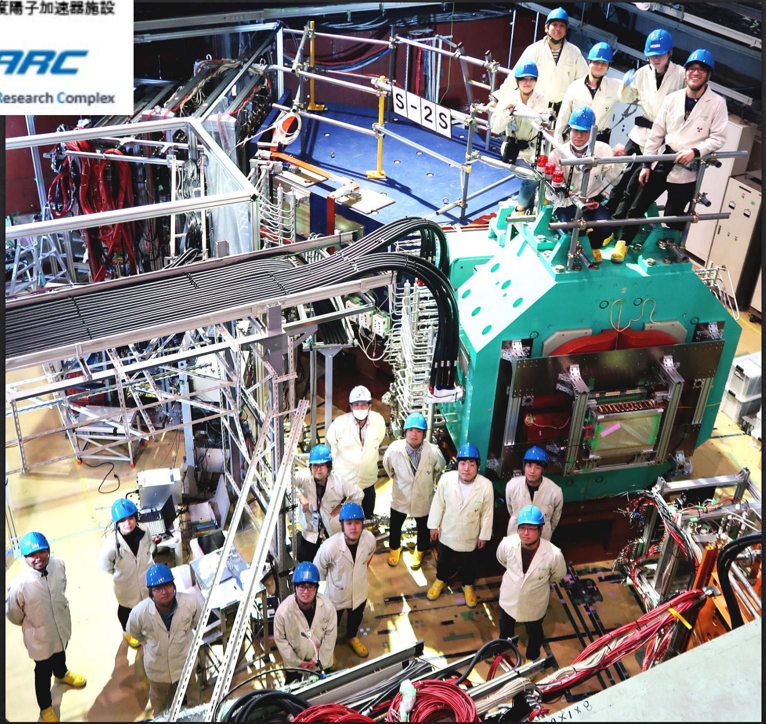
S. Acharya et al., Phys. Rev. Lett. 123, 112002 (2019)

## Hypernuclear spectroscopy



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

# Missing mass spectroscopy for Λ hypernuclei




S-2S (2025～)

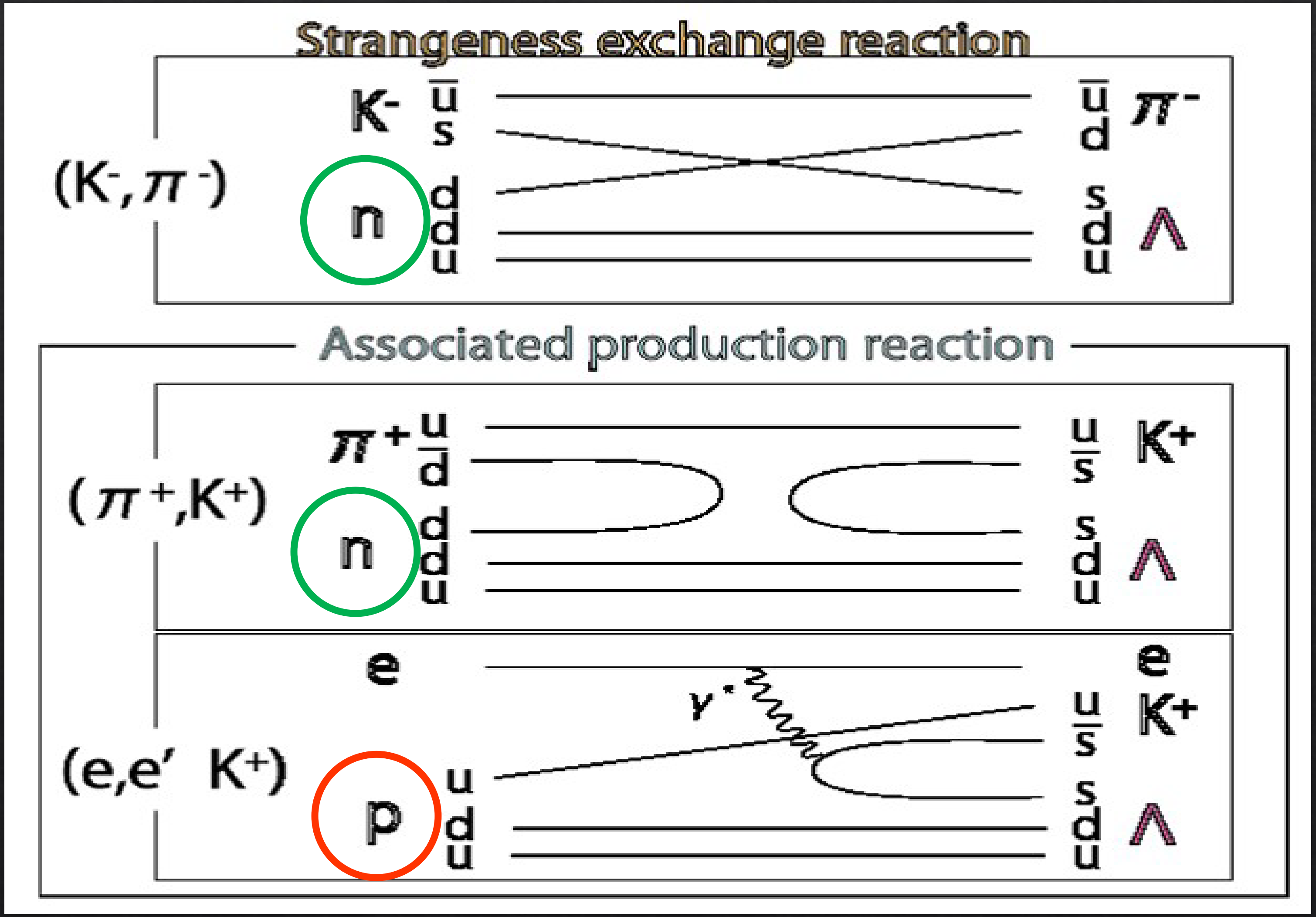
A = 7, 10, 12

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

HES-HKS (2027～)

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

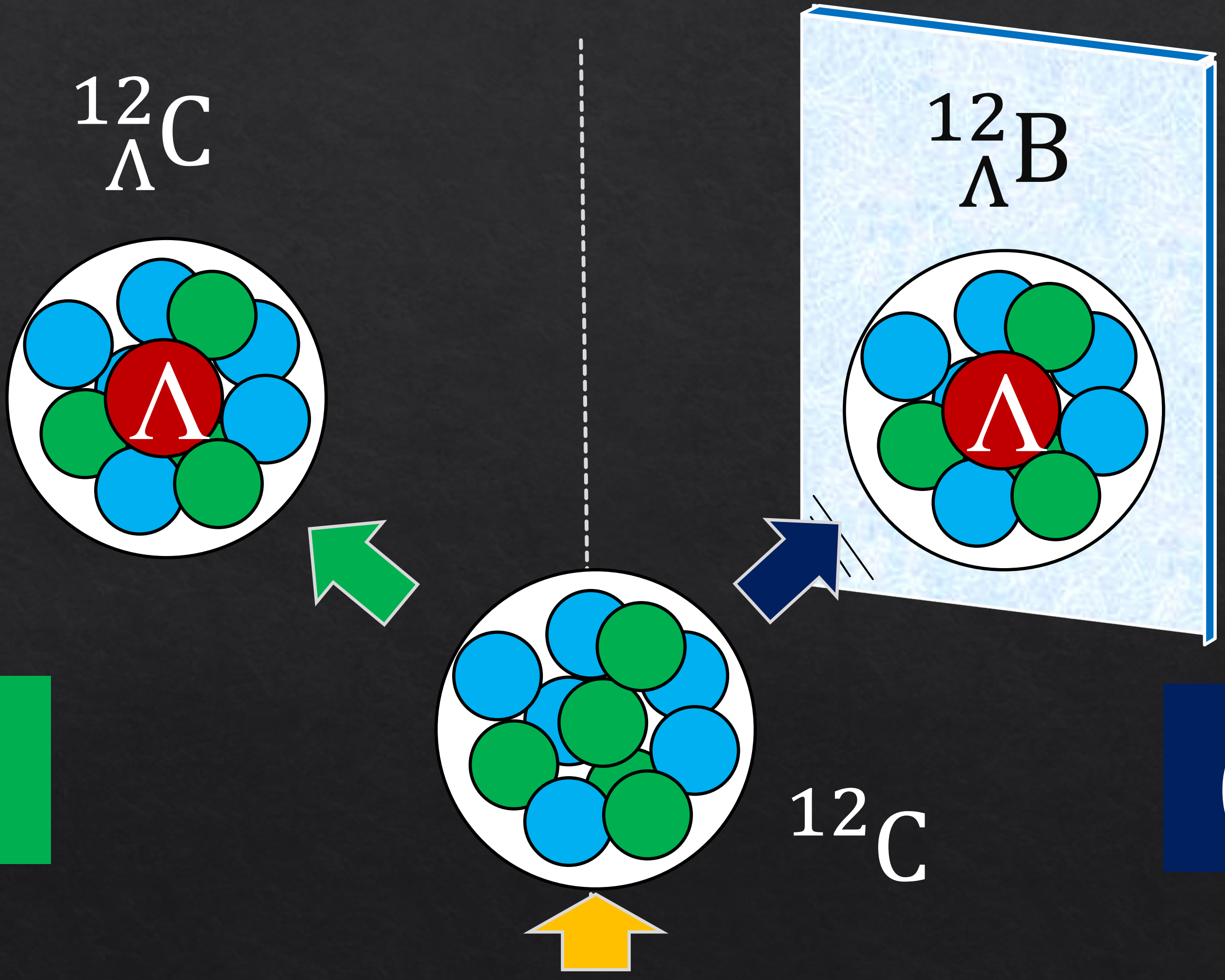
# Reactions used at J-PARC and JLab




Hadron Beams
@J-PARC, Japan

Electron Beams
@JLab, US

# Mirror Hypernuclear Study




J-PARC (Japan Proton Accelerator Research Complex)

$(\pi^+, K^+)$

n→Λ

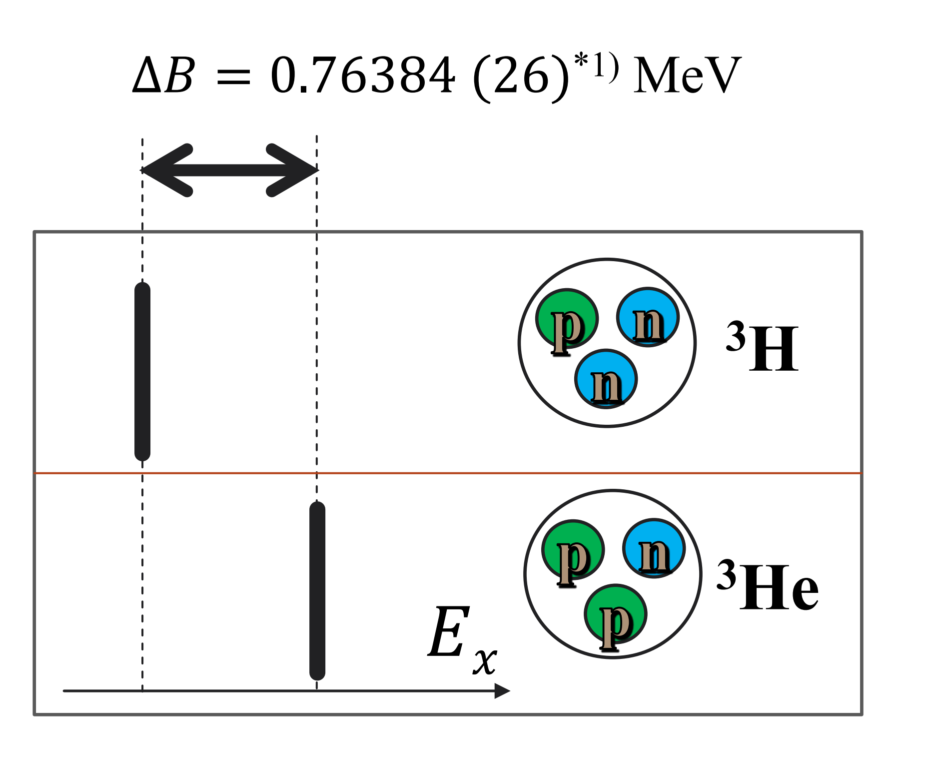
Jefferson Lab (Thomas Jefferson National Accelerator Facility)

$(e, e'K^+)$

p→Λ

# Charge Symmetry Breaking (CSB), the mystery

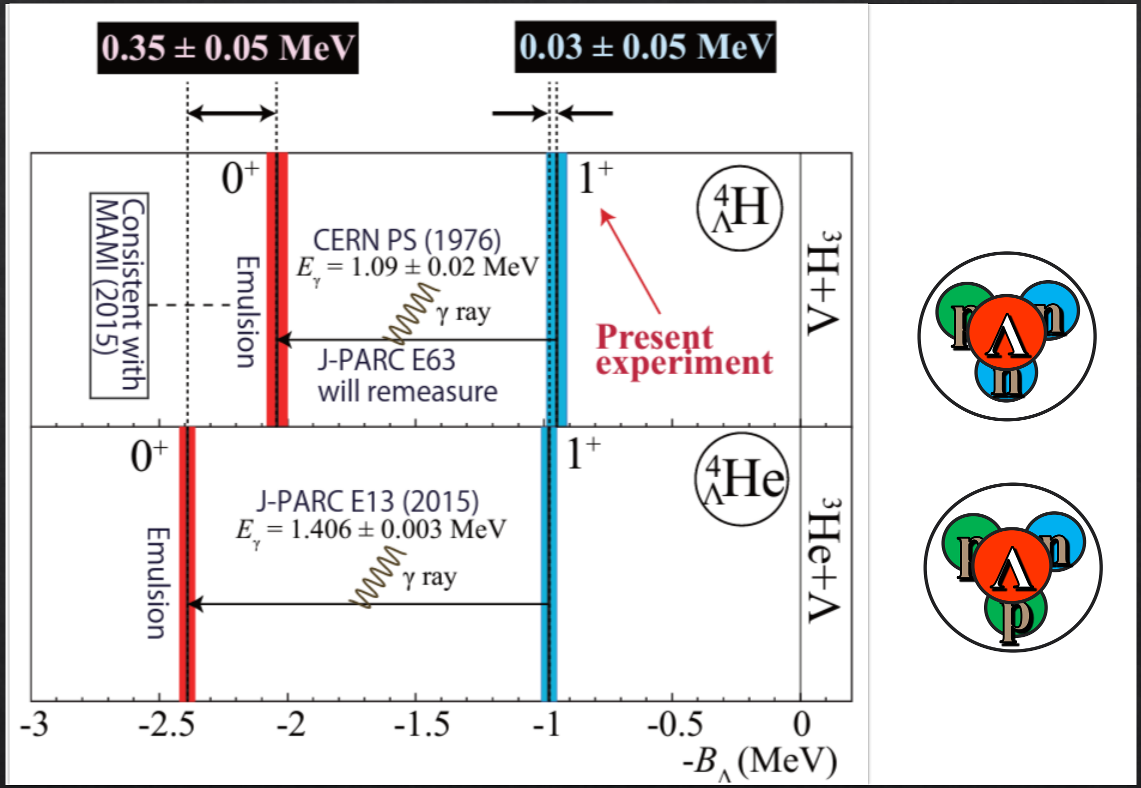
*1) J.H.E.Mattauch *et al.*, *Nucl. Pys.* **67**, 1 (1965).




**81 keV** after Coulomb correction

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

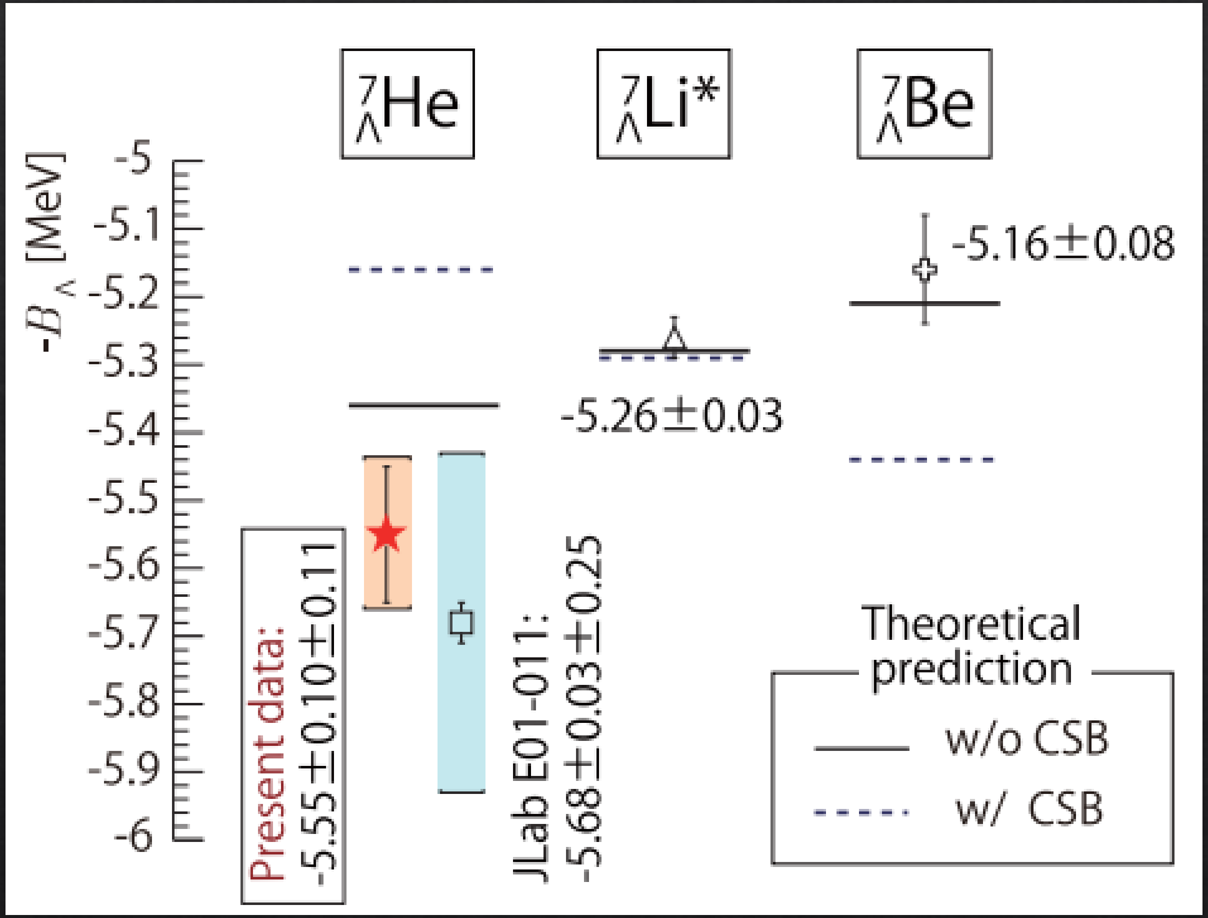
Figure from proposal of JLab E12-19-002




**~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

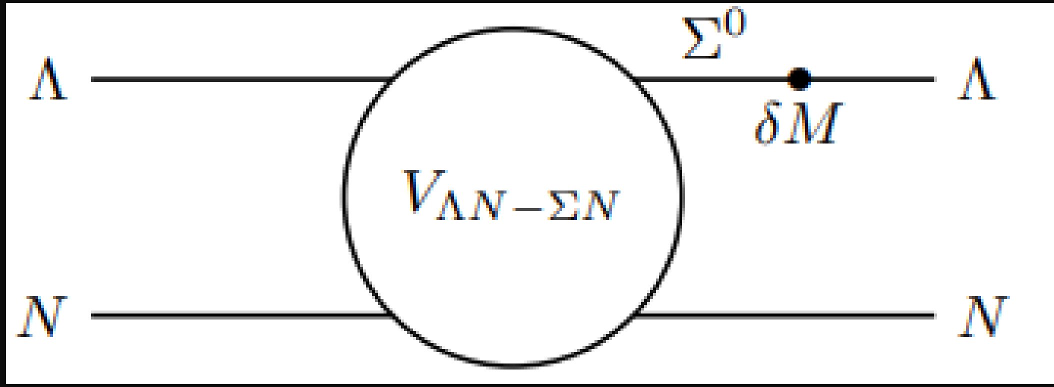
$$V^{\mathrm{CSB}}_{\Lambda N}(r) = -\frac{\tau_z}{2}\left[\frac{1+P_r}{2}\left(v_0^{\mathrm{even,CSB}} + \boldsymbol{\sigma}_\Lambda \cdot \boldsymbol{\sigma}_N v^{\mathrm{even,CSB}}_{\sigma_\Lambda \cdot \sigma_N}\right) e^{-\beta_{\mathrm{even}} r^2} + \frac{1-P_r}{2}\left(v_0^{\mathrm{odd,CSB}} +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

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

→ **The above CSB potential seems to be too naïve**

# ΛN-ΣN coupling effect

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




Charge symmetric ΛN-ΣN

±1

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

ΛΣ mixing matrix element

| A = 4 CS average | LO | LO [22] | NLO [22] | Exp. (Fig. 1) |
|---|---|---|---|---|
| $B_\Lambda^{J=0}$ | $2.37^{+0.20}_{-0.13}$ | $2.5\pm0.1$ | $1.53^{+0.08}_{-0.06}$ | $2.27\pm0.09$ |
| $B_\Lambda^{J=1}$ | $1.08^{+0.58}_{-0.47}$ | $1.4^{+0.5}_{-0.4}$ | $0.83^{+0.07}_{-0.10}$ | $1.03\pm0.09$ |
| $E_{\rm x}(0^+_{\rm g.s.}\to1^+_{\rm exc})$ | $1.29\pm0.38$ | $1.05\pm0.25$ | $0.71\pm0.04$ | $1.25\pm0.02$ |

w/o CSB

# 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 | $+233 \pm 92$ | $-100 \pm 90$ | $-20 \pm 230$ | $+40 \pm 60$ | $-210 \pm 220$ | $-220 \pm 250$ |

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)

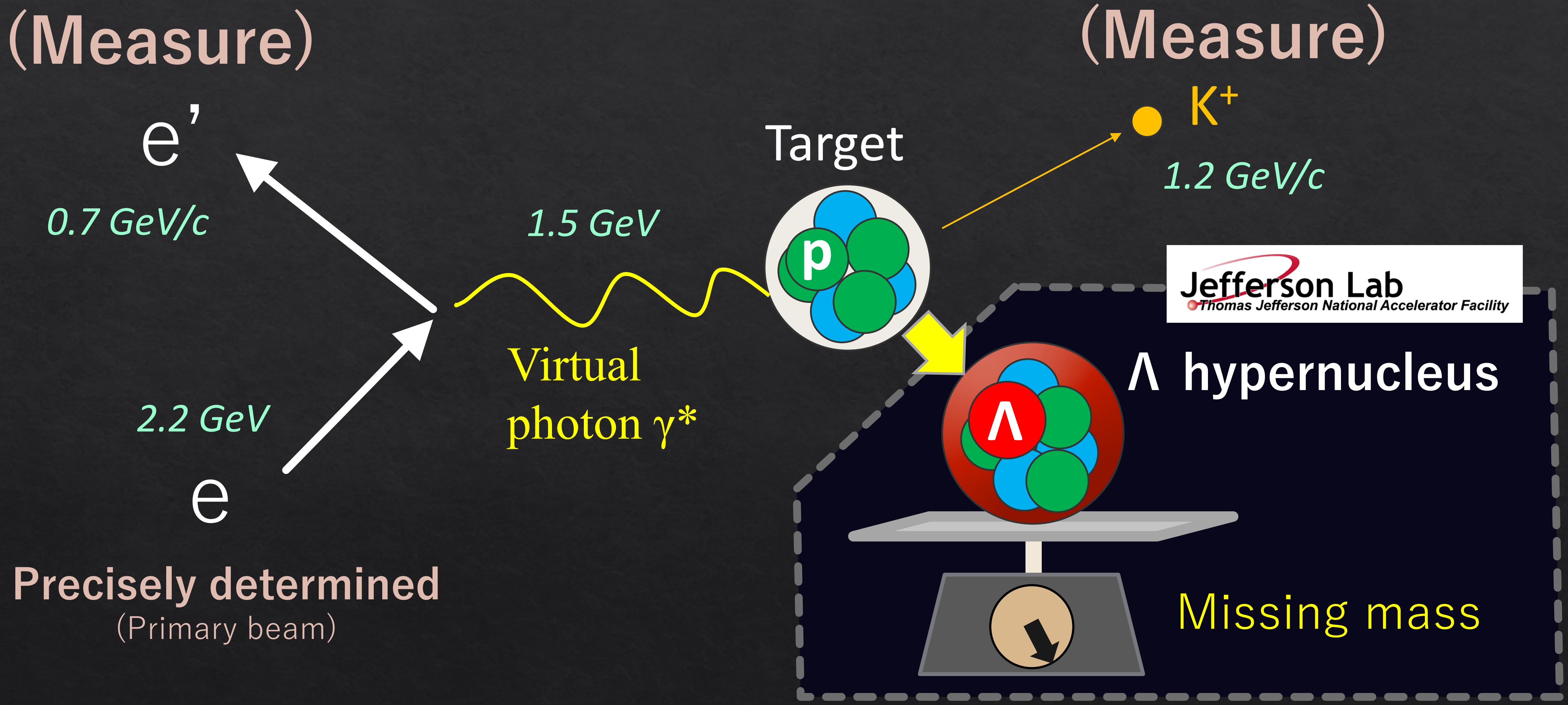
大強度陽子加速器施設 J-PARC Japan Proton Accelerator Research Complex

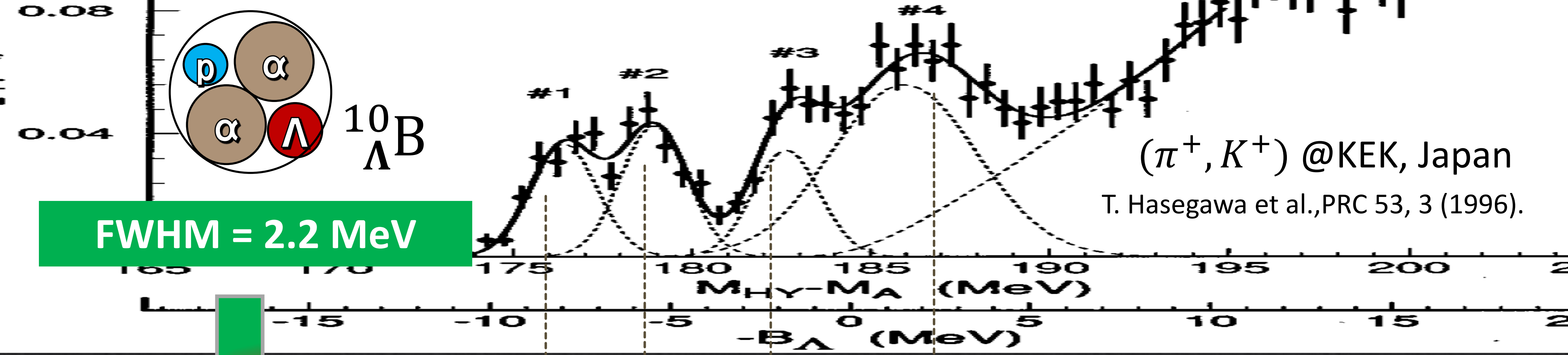
Jefferson Lab Thomas Jefferson National Accelerator Facility

Existing data accuracy is not sufficient for CSB study ($\Delta B_{diff}$ > 200 keV)

**→ $\Delta B_{diff}$～100 keV for A = 6, 7, 9, 10, 11, 12**

# Missing-mass spectroscopy



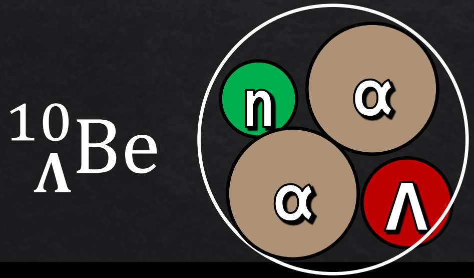


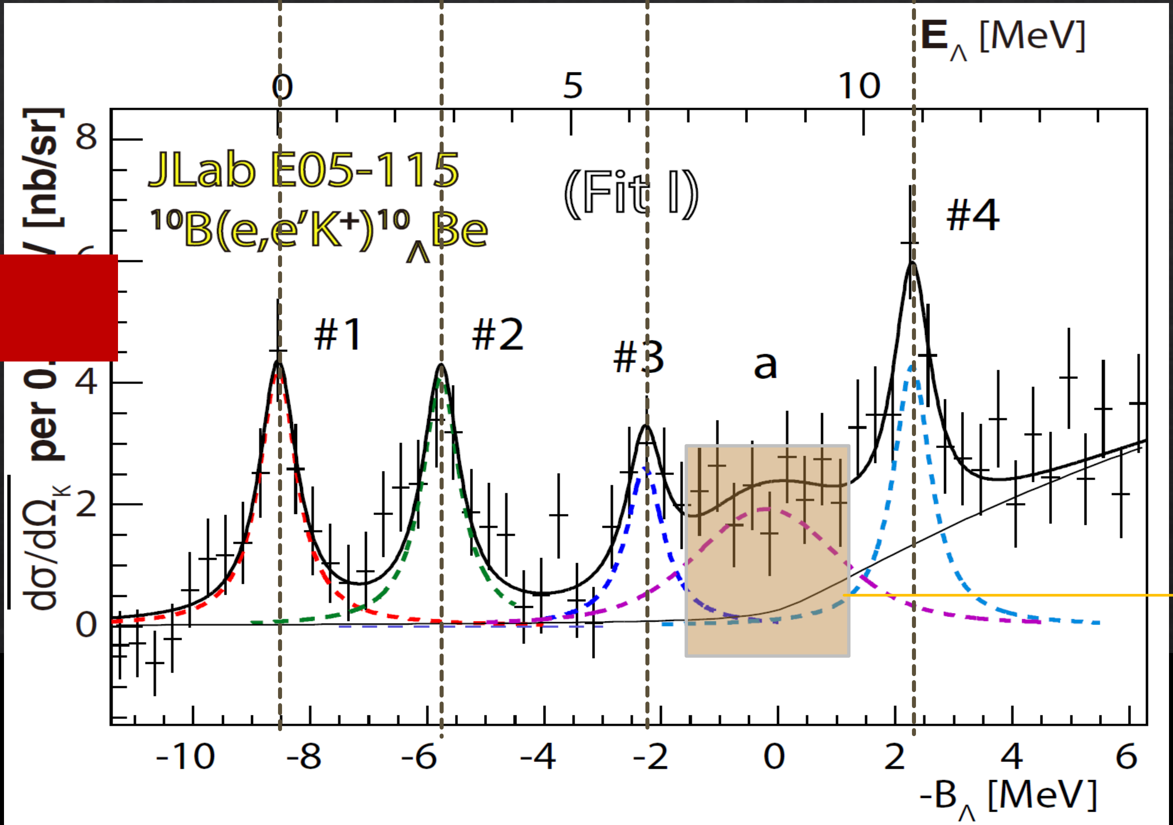

$(\pi^+, K^+)$ @KEK, Japan

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

**FWHM = 2.2 MeV**

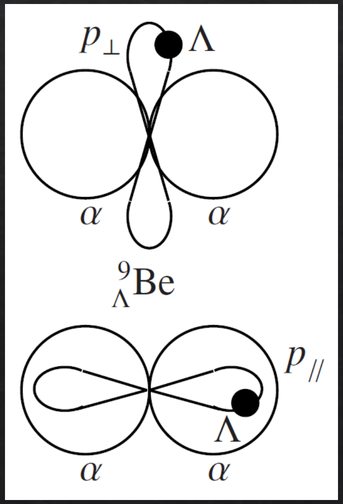
**FWHM = 0.8 MeV**




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

Cluster structure!!




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

# Approved Hypernuclear Experiments (proposed by JLab Hypernuclear Collaboration)

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

② E12-19-002 (CP: TG) → $^{3}_{\Lambda}$H、$^{4}_{\Lambda}$H
"Hypertriton puzzle, s-shell CSB"

③ E12-20-013 (CP: F. Garibaldi (INFN)) → $^{208}_{\Lambda}$Tl
"ΛNN three body force"

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

⑤ E12-24-011 (CP: S.N. Nakamura) → $^{27}_{\Lambda}$Mg
" Search for triaxially deformation states in $^{26}$Mg"

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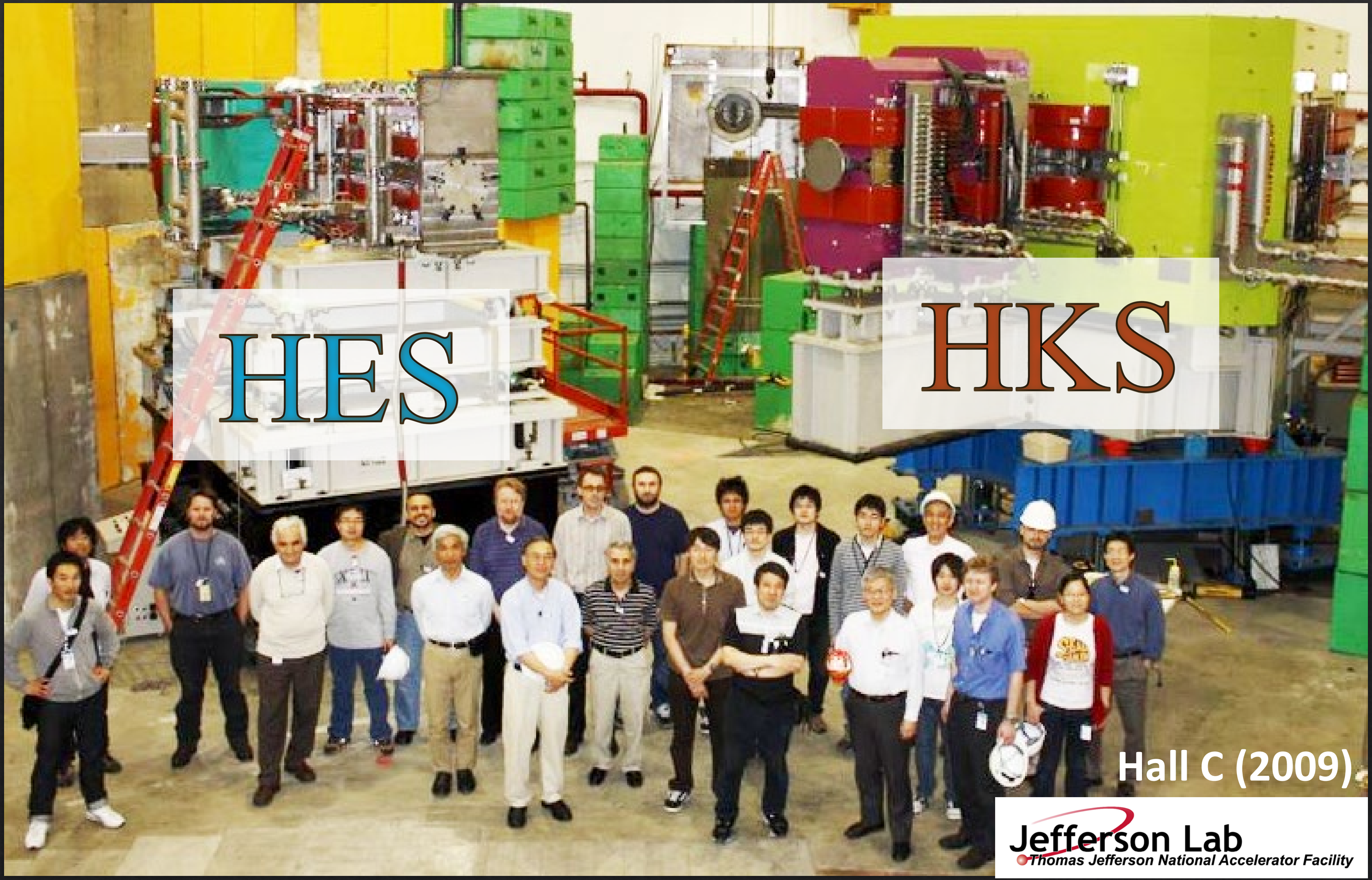
"p-shell CSB"

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

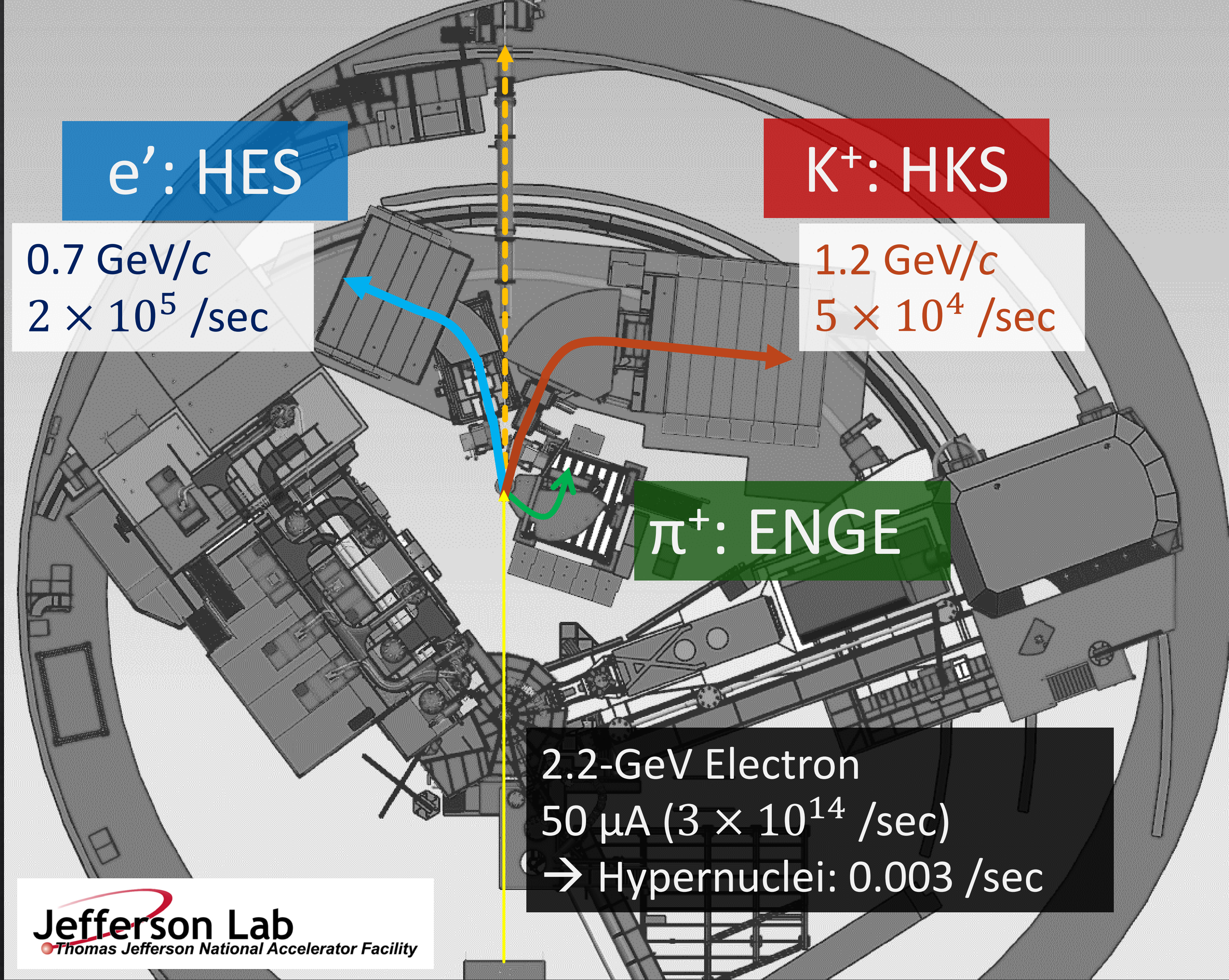
" Search for triaxially deformation states in $^{26}Mg$"

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



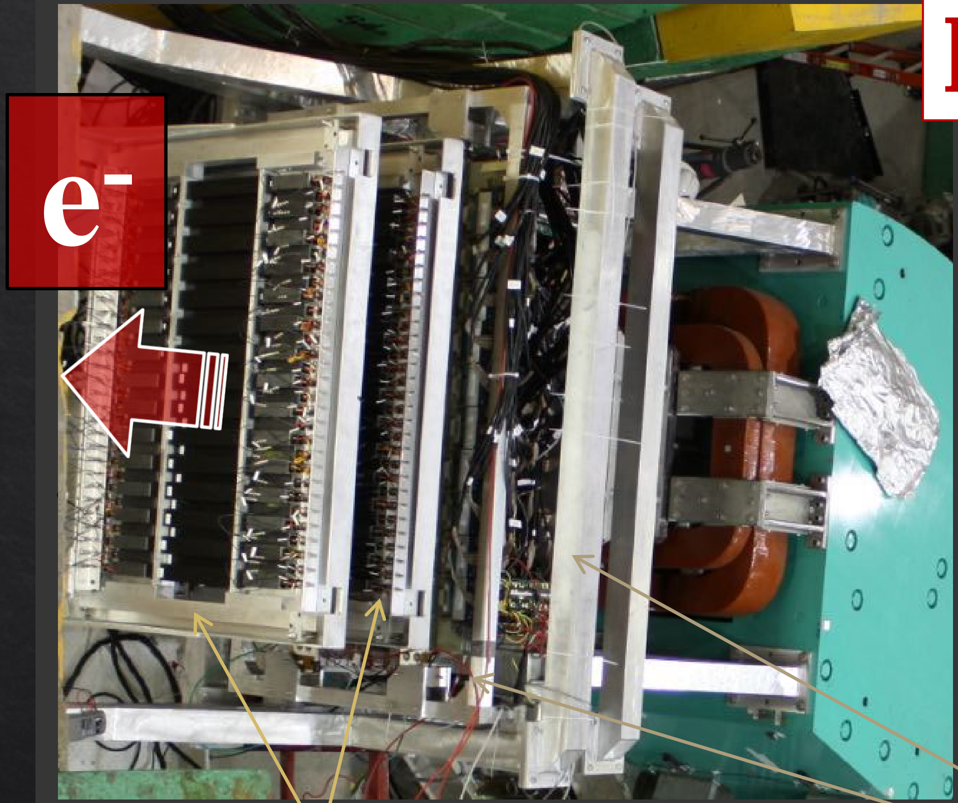
# Particle Detectors

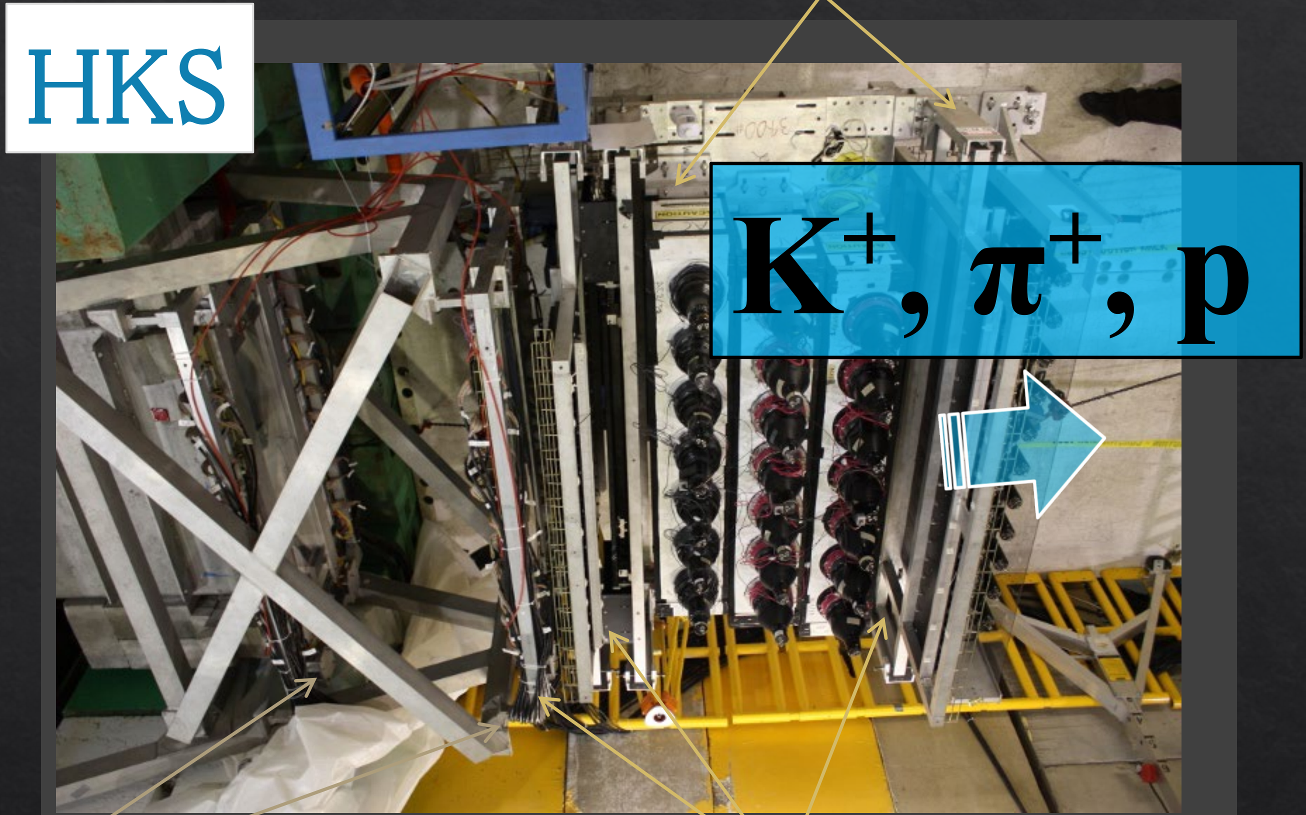
TG et al., NIMA 900, 69—83 (2018)

TG et al., NIMA 729, 816—824 (2013)

**Cherenkov detectors**

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




**TOF walls**
**(Plastic scintillators)**

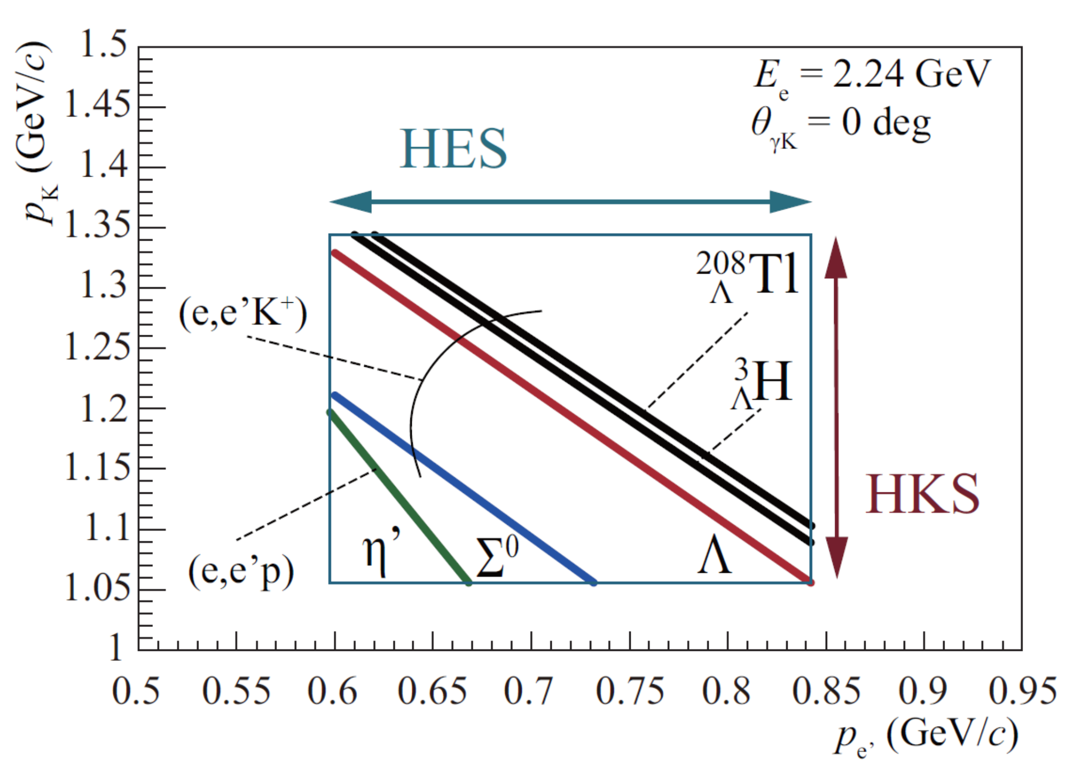
**Drift chambers**

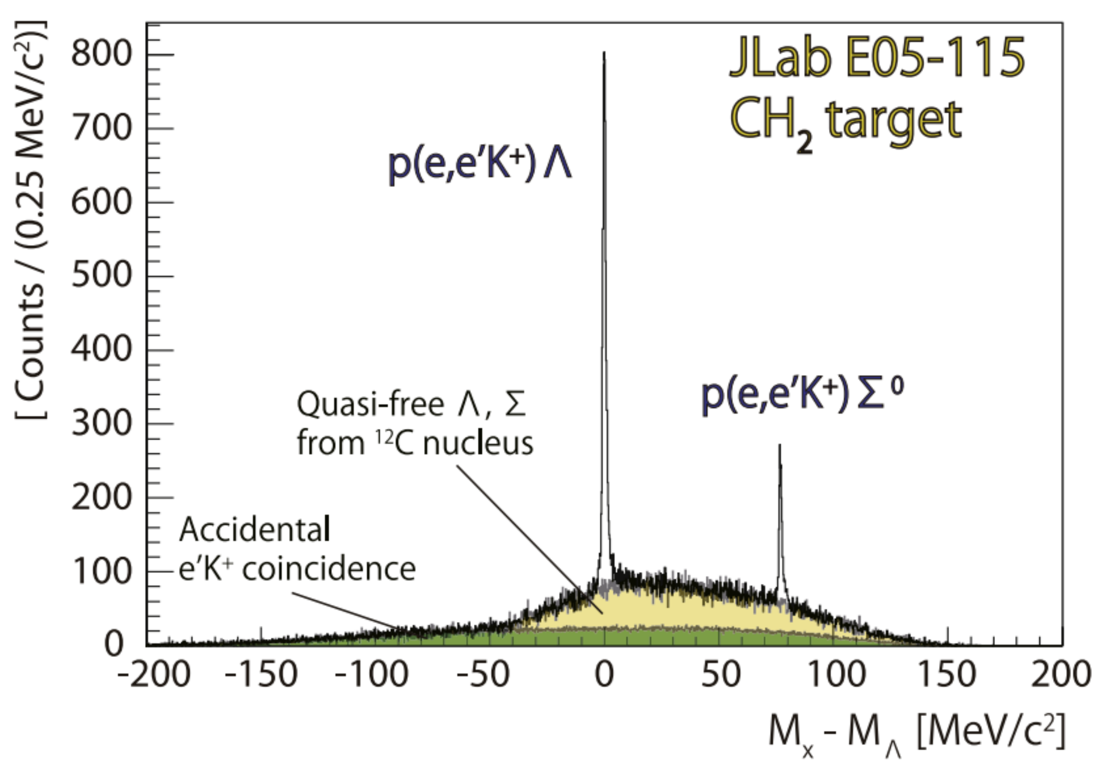
**TOF walls**
**(Plastic scintillators)**

# Energy Calibration

*Calibration is common with approved experiments*

TG et al., NIMA 900, 69—83 (2018)



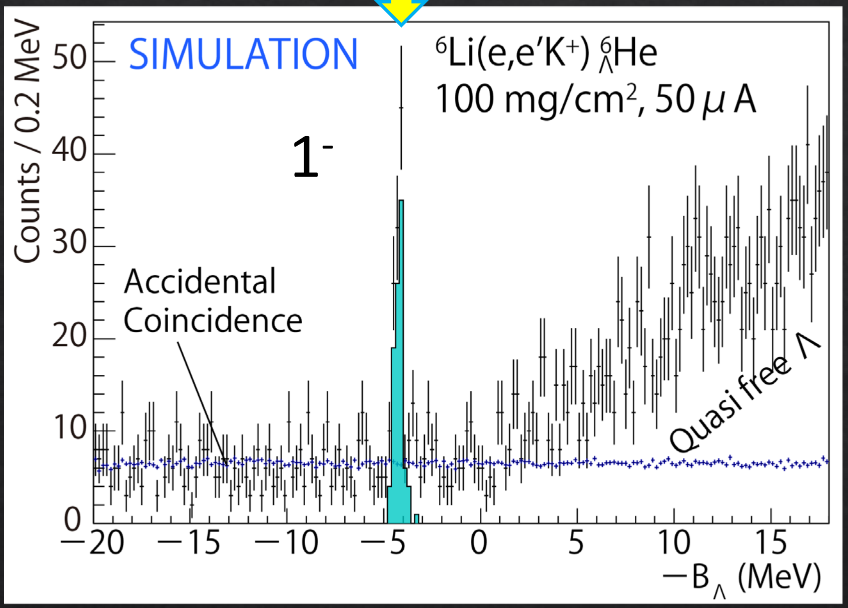




➔ Systematic error $|\Delta B_{\Lambda}^{sys.}| \simeq$ **60 keV**

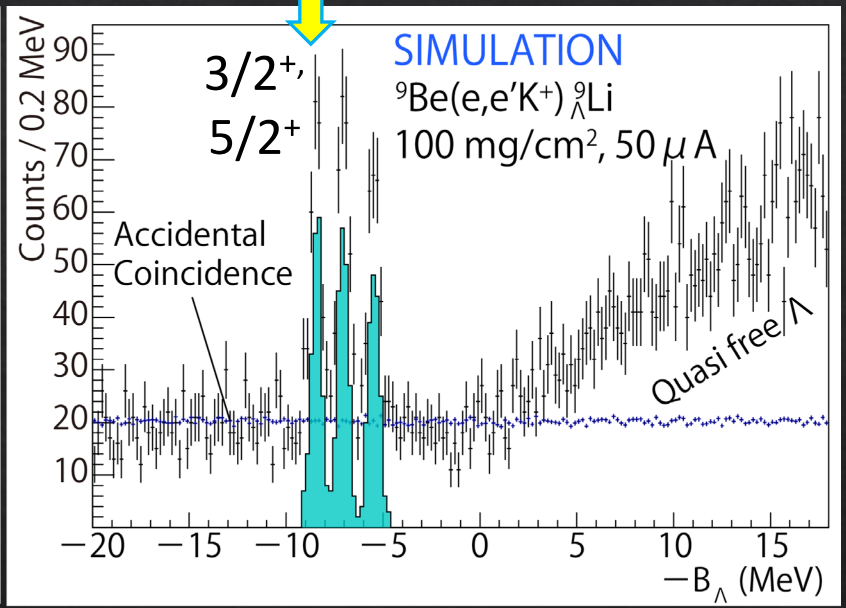
c.f.) T. Toyoda, Master's Thesis, *Kyoto* University, Kyoto, Japan, 2021 (in Japanese)

# Expected Spectra

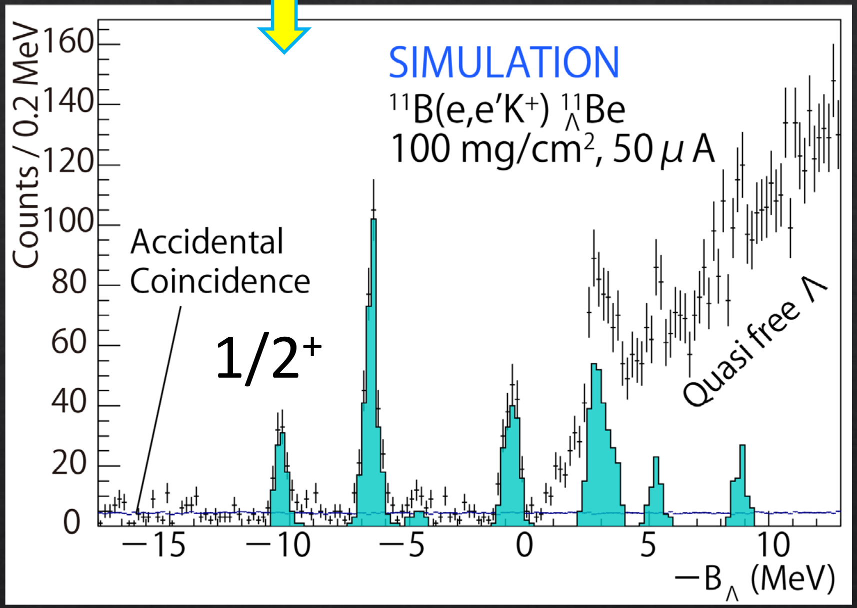
for CSB study 120 hours




for CSB study 384 hours



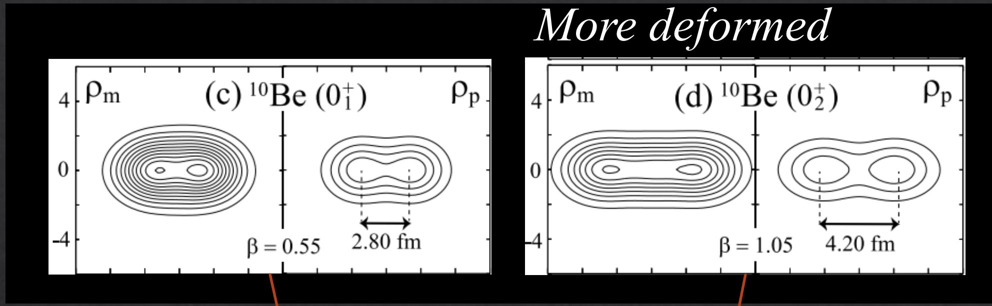

for CSB study 72 hours



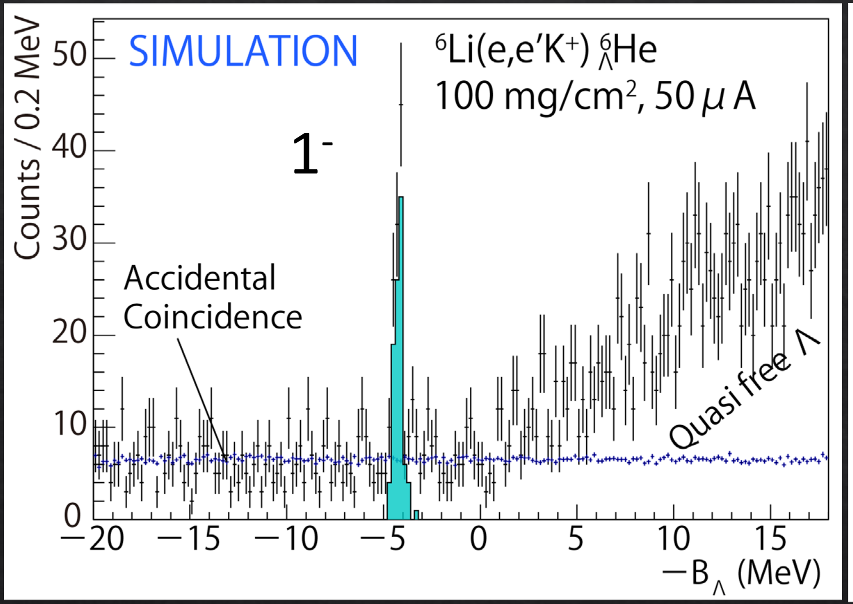

Total accuracy:

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

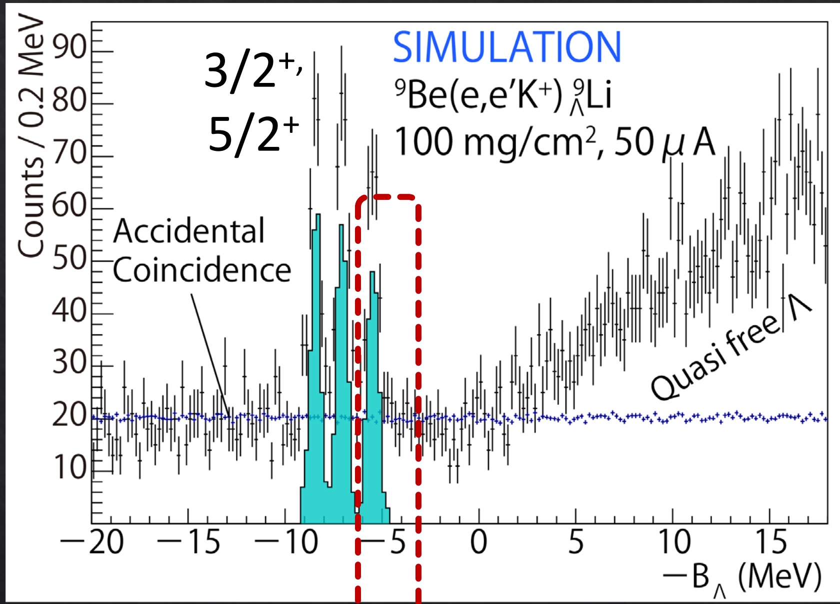
# Expected Spectra



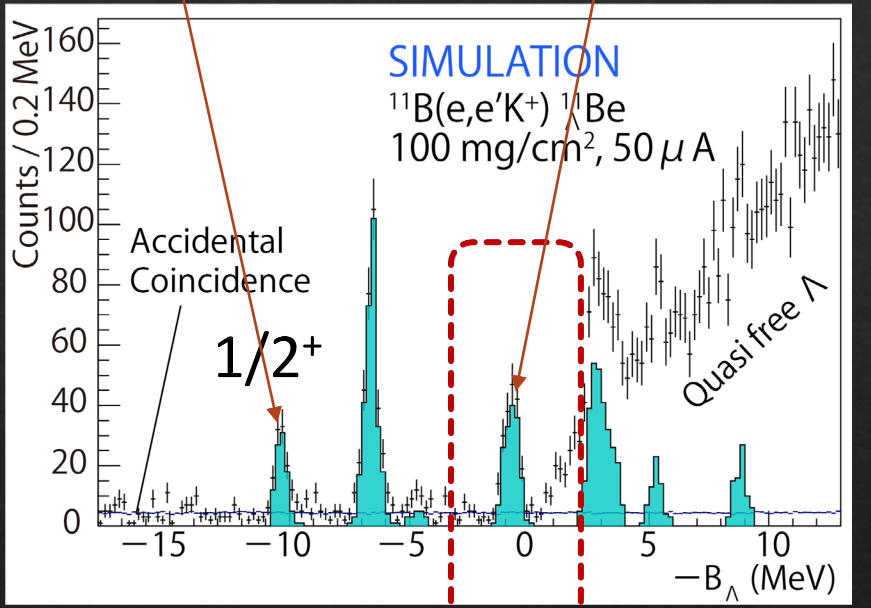

120 hours




384 hours




72 hours



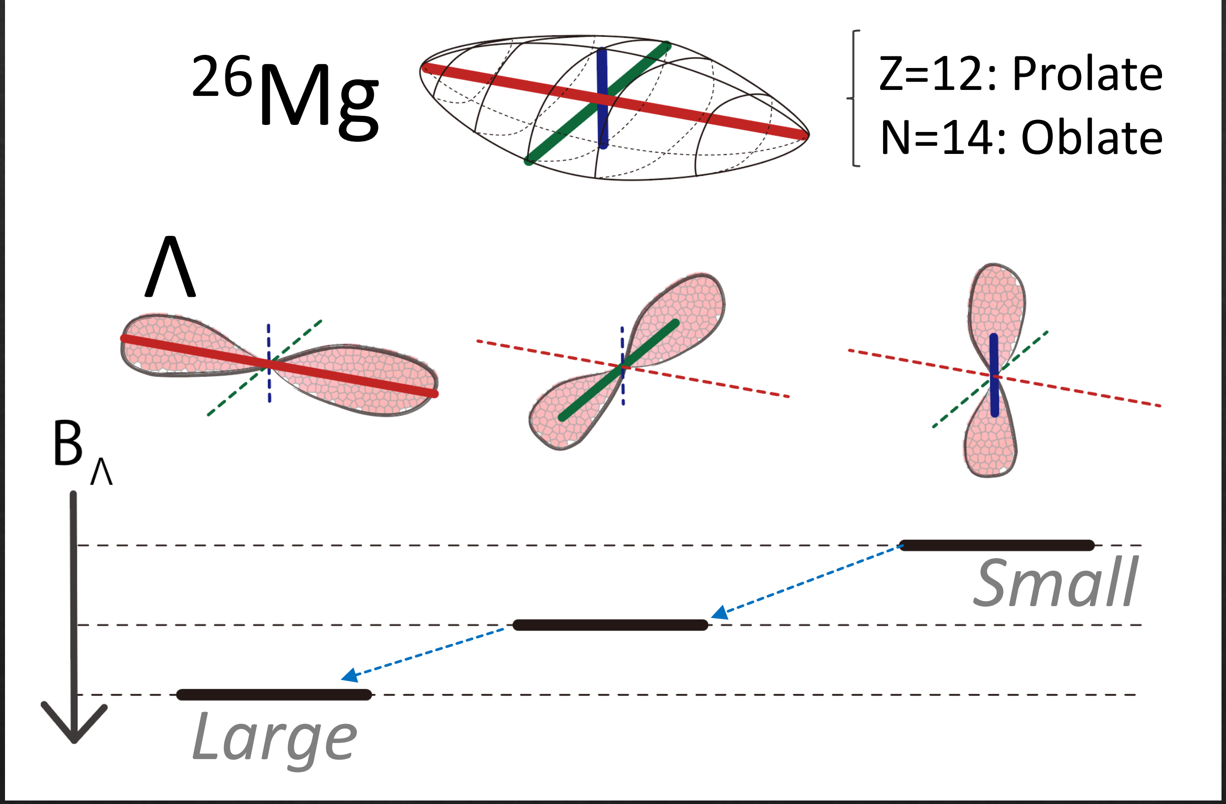

Total accuracy:
$\left|\Delta B_\Lambda^{\text{total}}\right| \leq$ **70 keV**

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

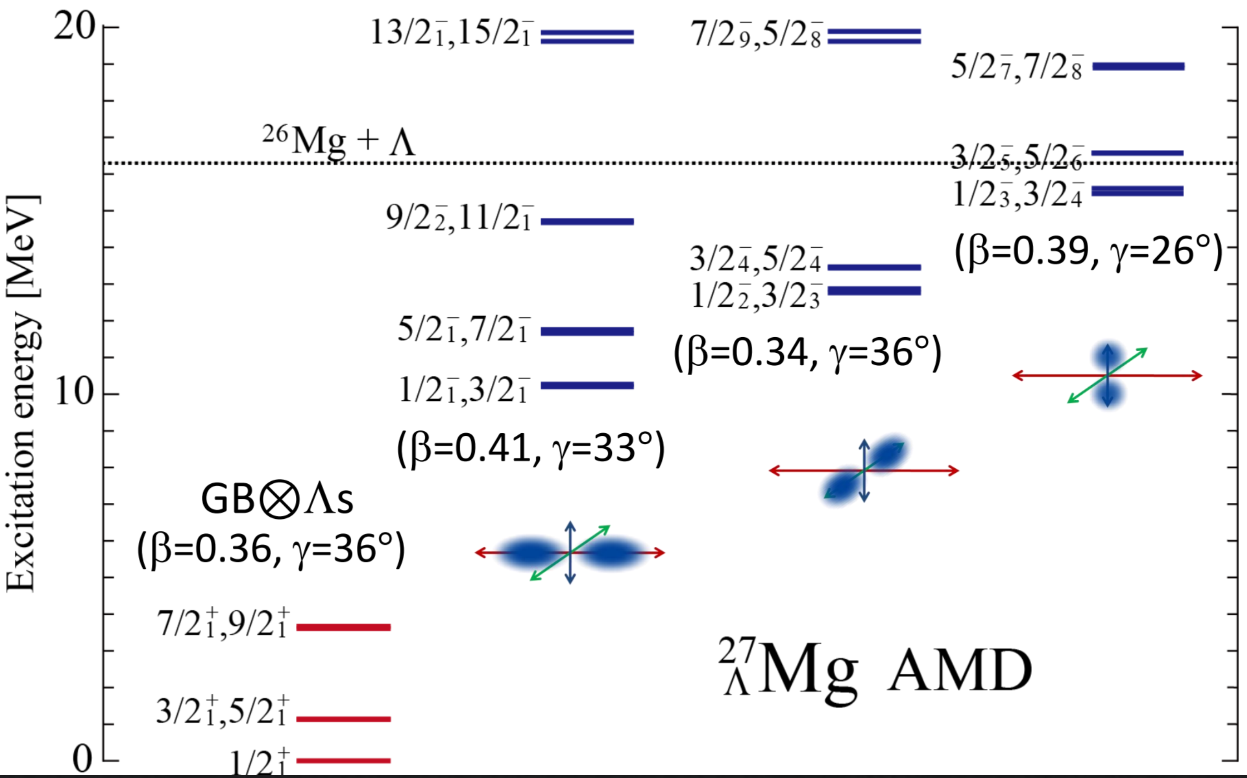
Cluster / deformation structures

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

# $^{27}\mathrm{Al}(e,e'K^+)^{27}_{\Lambda}\mathrm{Mg}$



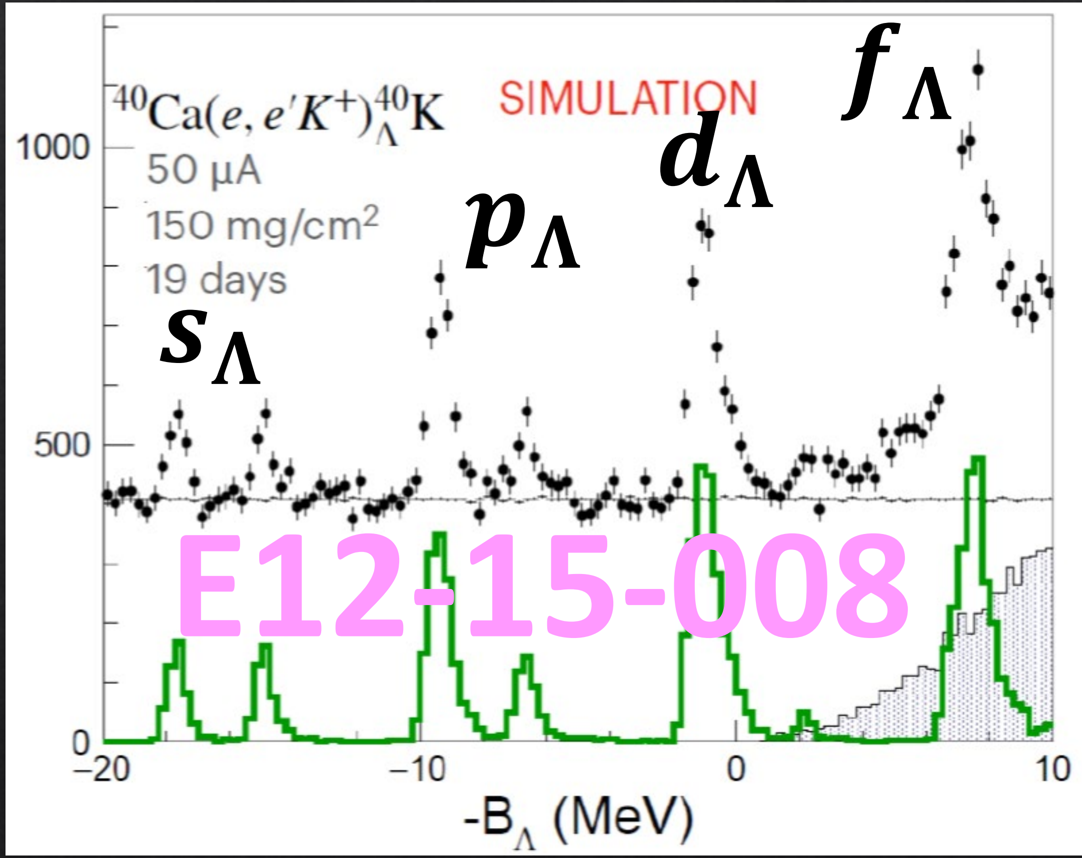

Anti-molecular dynamics (AMD) calculation
Presentation by M. Isaka (2023); https://indico.jlab.org/event/705/



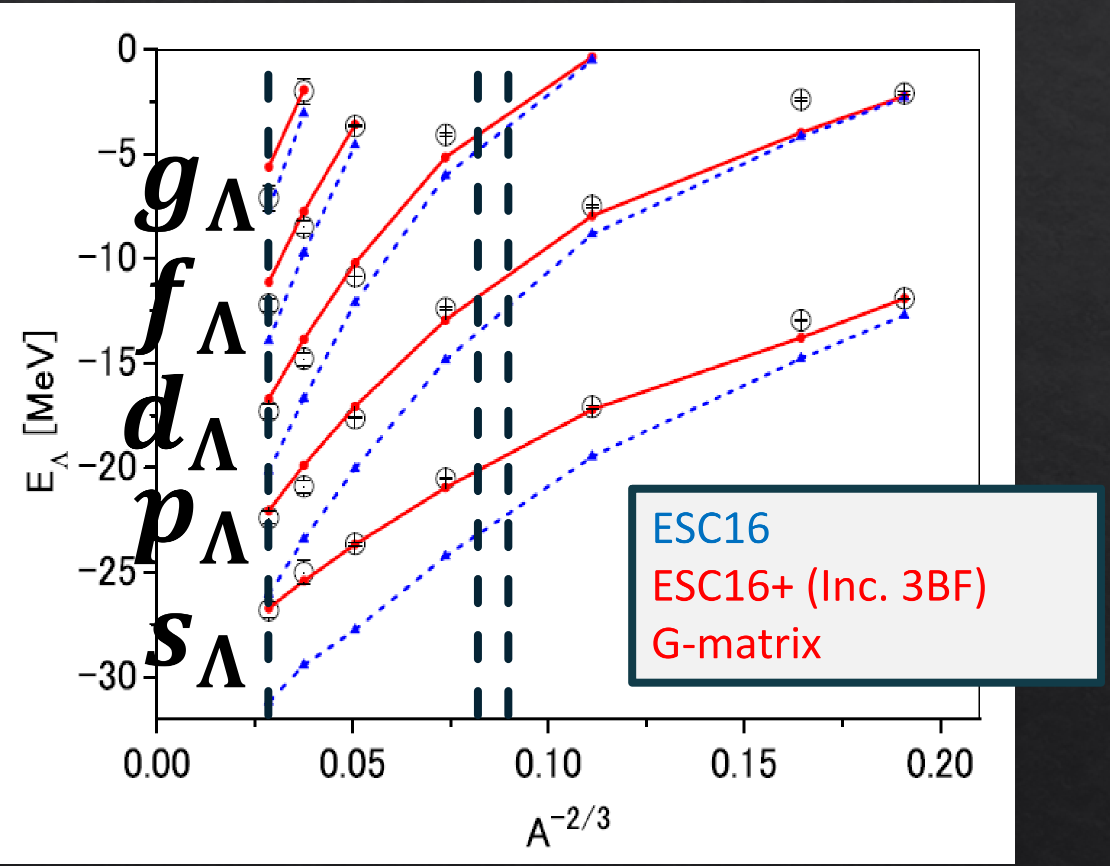

$^{26}\mathrm{Mg} \times p_\Lambda$ ➔ Probing triaxially deformation

# High accuracy experiment → 3-body force study

Expected spectrum based on Geant4 simulation



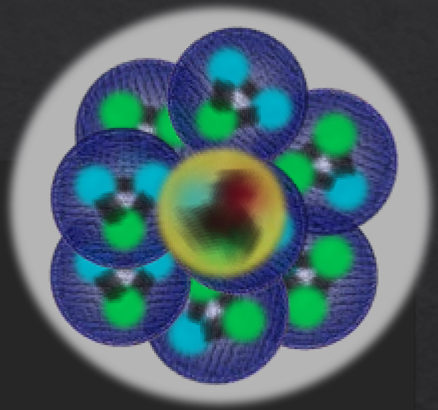

M.M. Nagels et al., PRC 99 (2019) 044003.




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

→ New information for 3-body force

# Summary

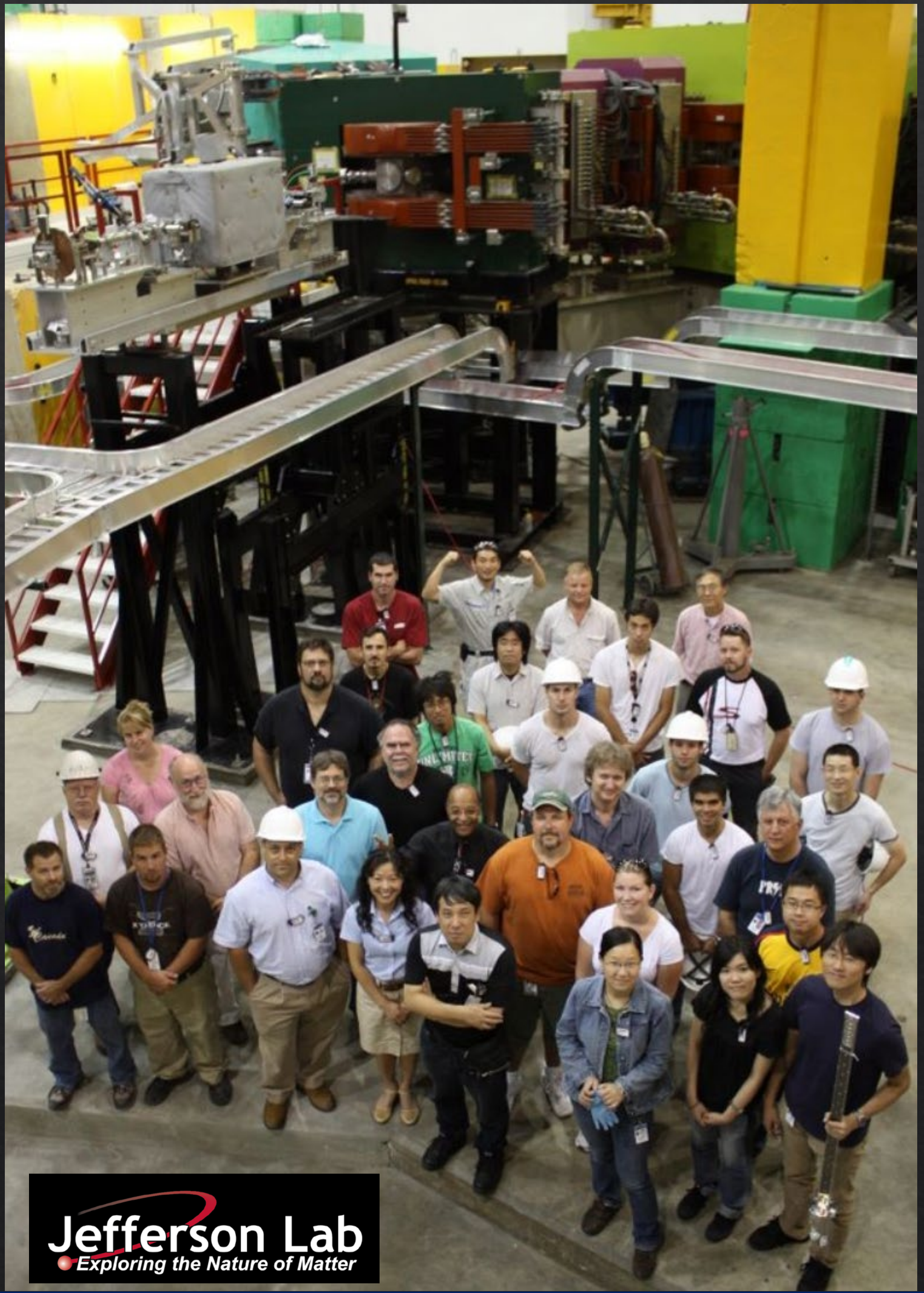


## Λ hypernuclear spectroscopy

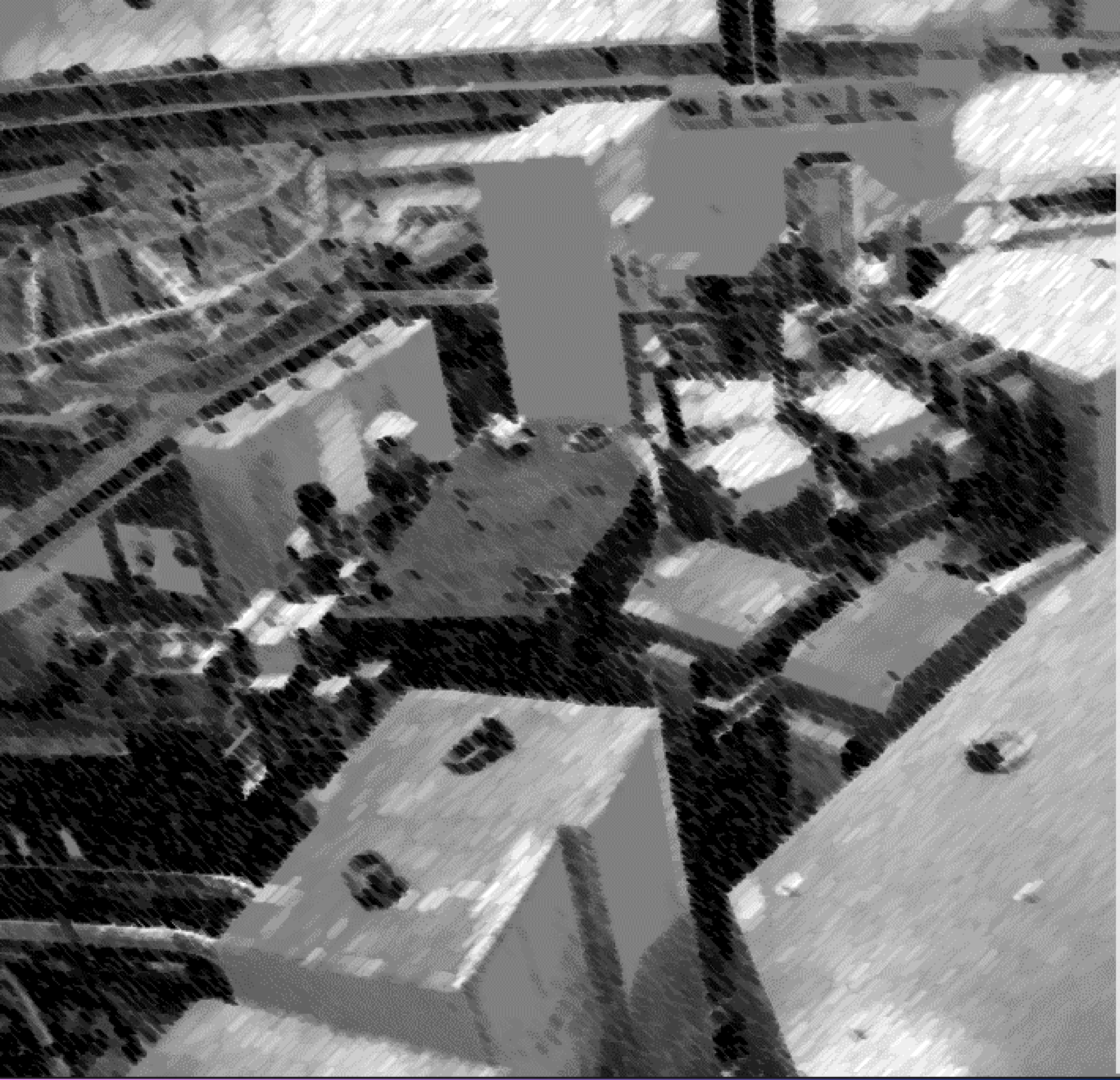
- Baryon interaction (YN, YNN)

## 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
  - (Triaxially) deformation
  - ΛN-ΣN coupling
  - iso-spin dependence of ΛNN force



# 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)
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- M. Iodice et al., PRL 99, 052501 (2007)

## Hall C

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- 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 | $1 \times 10^{-4}$ (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 $\Delta p_{e'}/p_{e'}$ | $4.4 \times 10^{-4}$ (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 $\Omega_{K^+}$ (/msr) (at $p_{K^+}^{\mathrm{cent.}}$) | 7.0 |
| | Momentum resolution $\Delta p_{K^+}/p_{K^+}$ | $2.9 \times 10^{-4}$ (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, $\theta_{\gamma^* K^+}$ | $7.35°$ |
| | $\epsilon$ | 0.59 |
| | $\epsilon_L$ | 0.0096 |

# Limited data for the CSB study

○: Data w/ ≤100 keV accur. exists

| Shell | A | Component | Isospin T<0 | Isospin T=0 | Isospin T>0 | CSB study w/ 100 keV accur. |
|---|---|---|---|---|---|---|
| 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 T<0 | Isospin T=0 | Isospin T>0 | CSB study w/ 100 keV accur. |
|---|---|---|---|---|---|---|
| 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 |

# Limited data for the CSB study

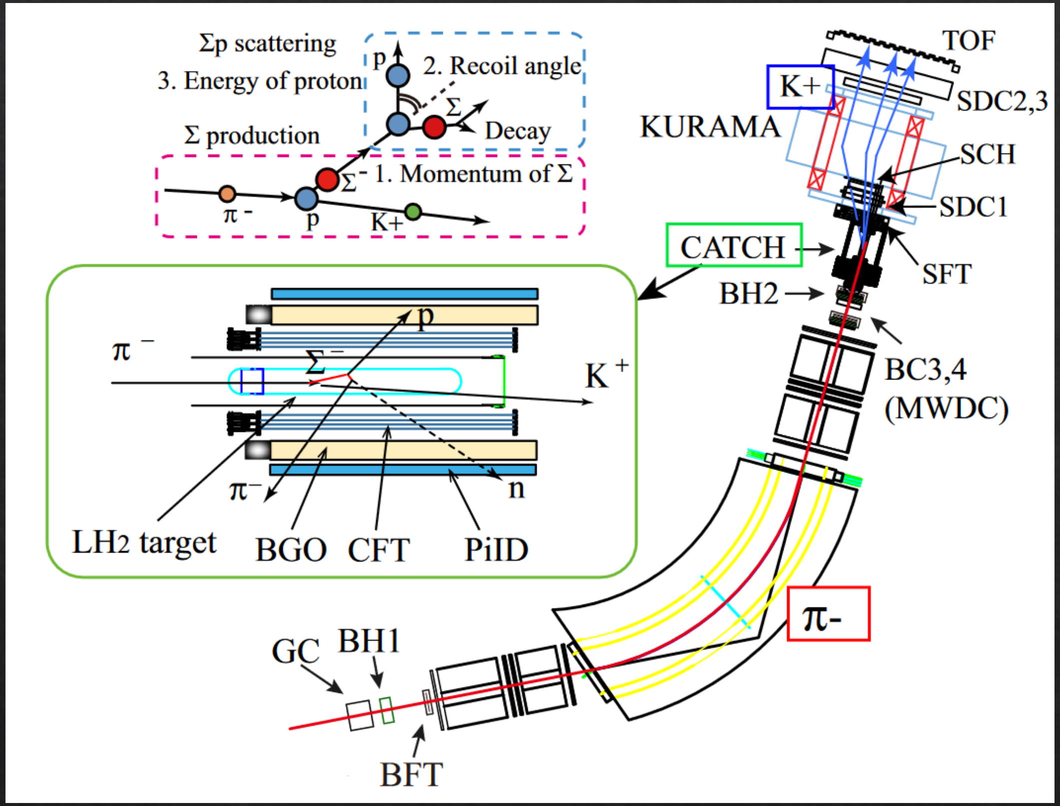
○: Data w/ ≲100 keV accur. exists

| Shell | A | Component | Isospin T<0 | Isospin T=0 | Isospin T>0 | CSB study w/ 100 keV accur. |
|---|---|---|---|---|---|---|
| | | | | | | Yes / Yes |
| | | | | | | Yes |
| | | | | | | Yes |
| | | | | | | Yes |
| | | | | | | 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 |

**Data from JLab ($^{6}_{\Lambda}\mathrm{He}$, $^{9}_{\Lambda}\mathrm{Li}$, $^{11}_{\Lambda}\mathrm{Be}$) are unique and necessary to pin down the CSB origin**

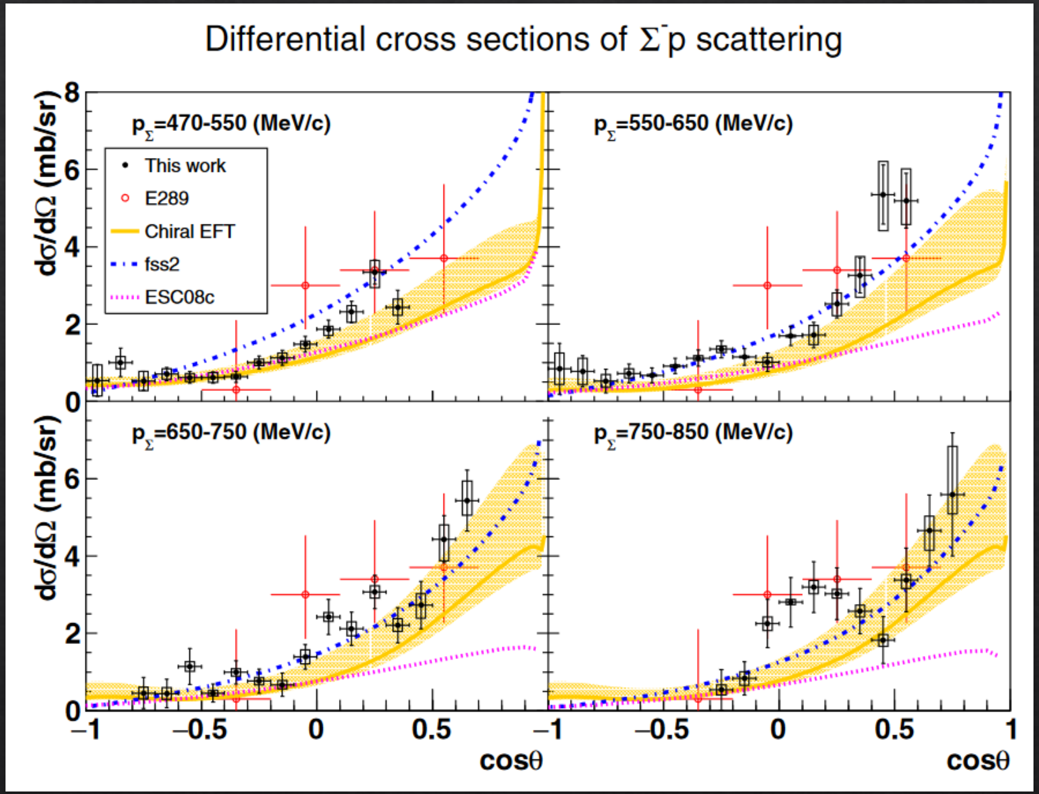
# Recent progress in YN scattering experiment

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



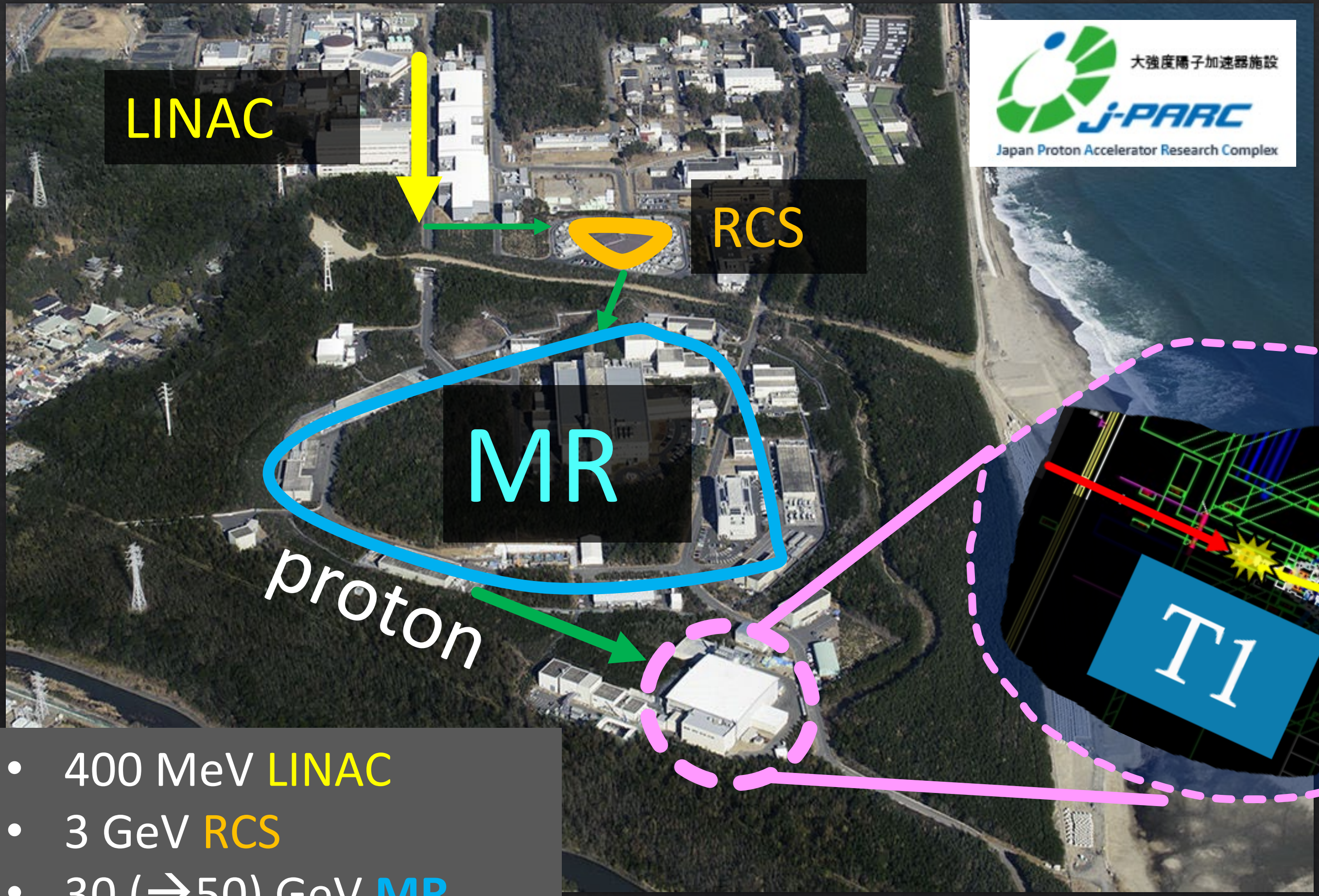

J-PARC E40 Experiment

## $\Sigma^{-}p$ elastic



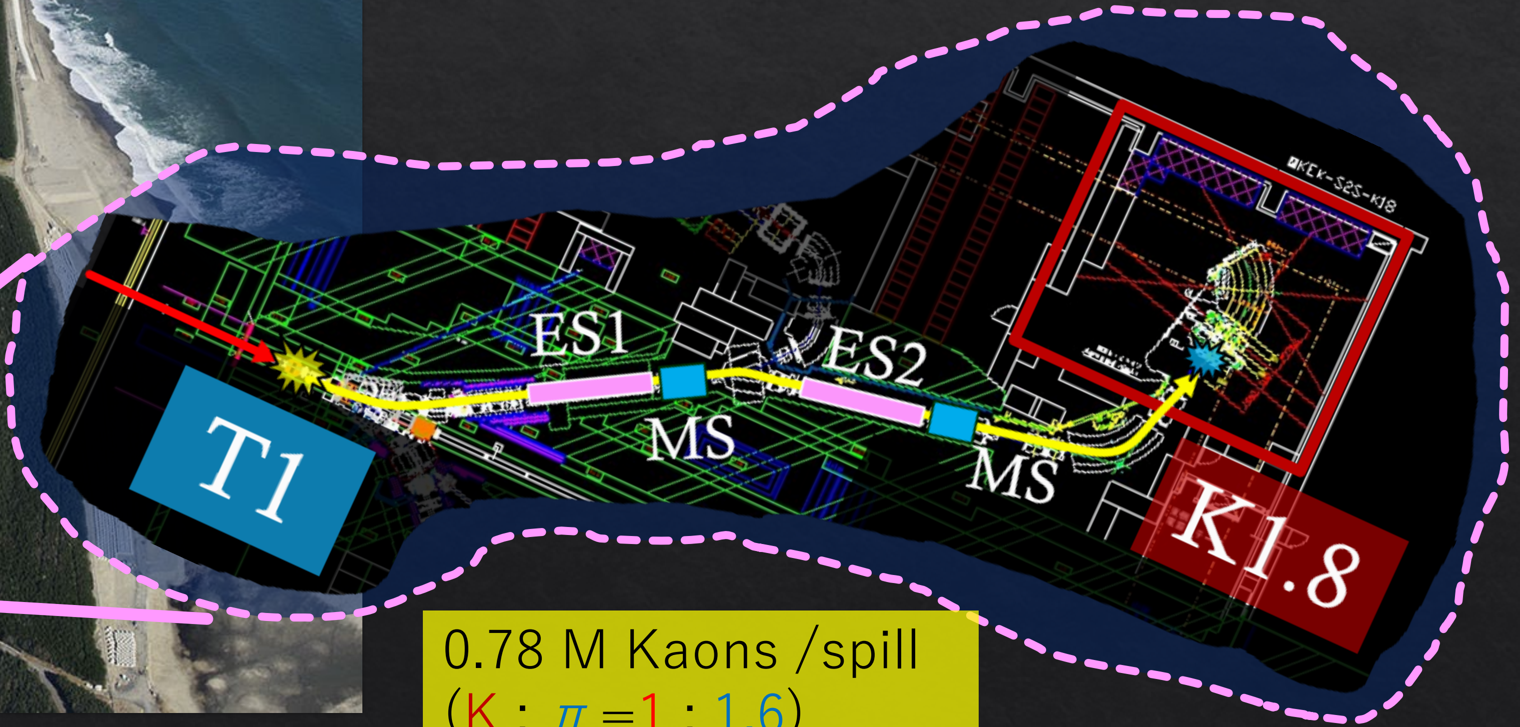

$\Sigma^{-}p \rightarrow \Lambda n$ ： K. Miwa et al., Phys. Rev. Lett. 128, 072501 (2022)
$\Sigma^{+}p$: T. Nanamura et al., arXiv:2203.08393 [nucl-ex] (2022)
$\Lambda p$ : J. W. Price et al., AIP Conf. Proc. 2130, 020004 (2019)
$\Lambda p$ : K. Miwa et al., Proposal to J-PARC, P86 (2021)

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

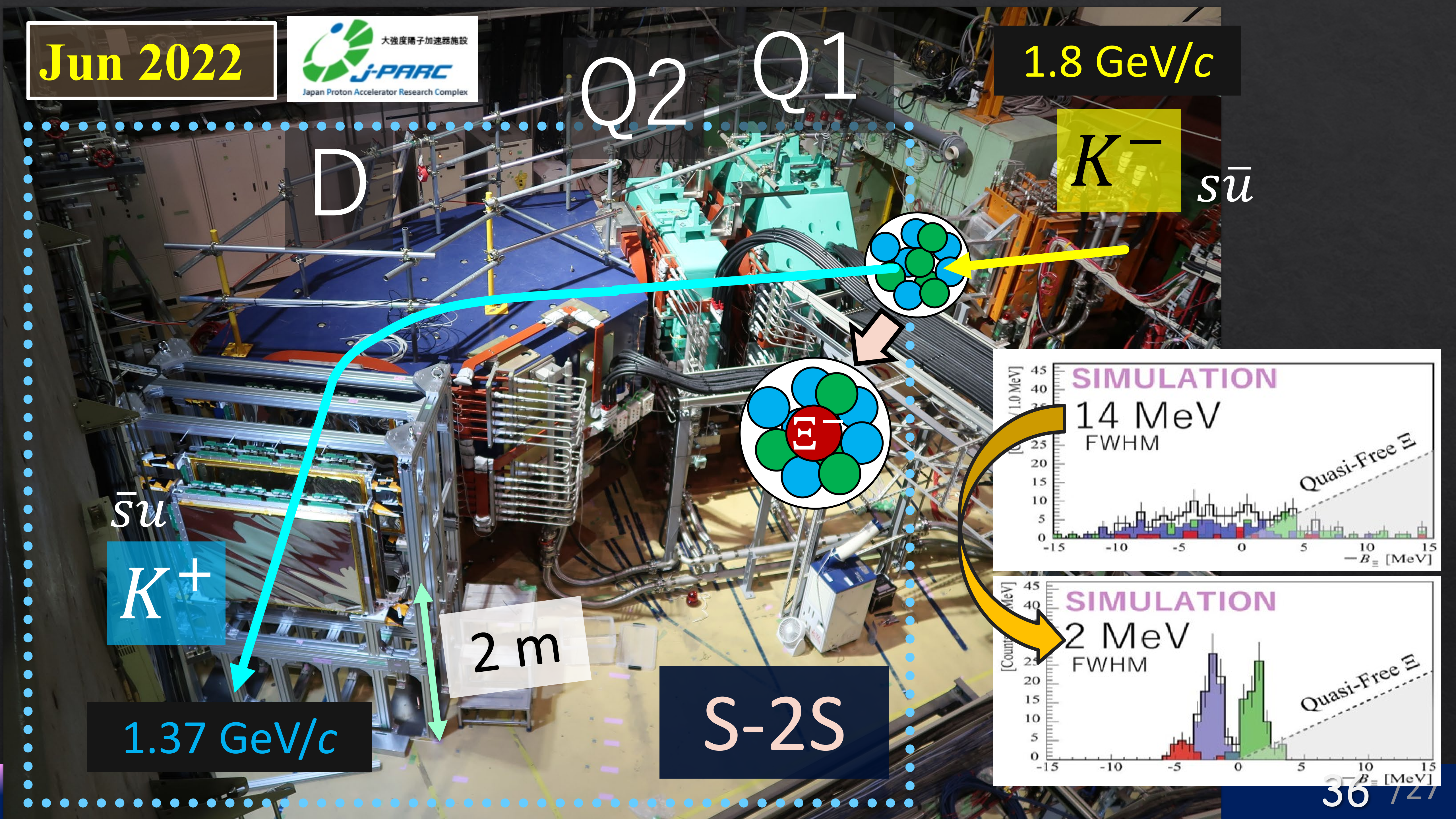



- 400 MeV LINAC
- 3 GeV RCS
- 30 (→50) GeV MR

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



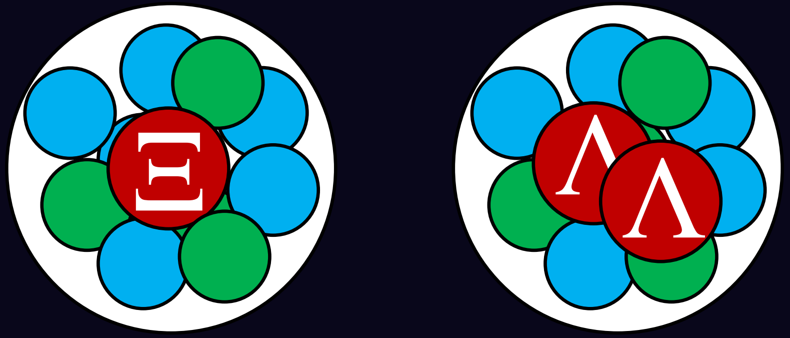

0.78 M Kaons /spill
(K : $\pi$ =1 : 1.6)

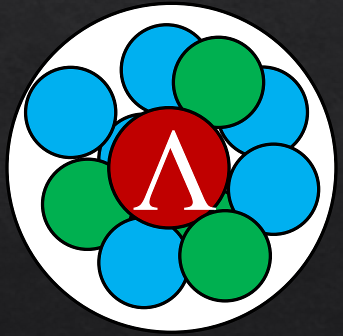


Jun 2022
大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex
Q2
Q1
D
1.8 GeV/c
$K^-$
$s\bar{u}$
$\Xi^-$
$\bar{s}u$
$K^+$
1.37 GeV/c
2 m
S-2S
SIMULATION
14 MeV
FWHM
Quasi-Free Ξ
$-B_\Xi$ [MeV]
SIMULATION
2 MeV
FWHM
Quasi-Free Ξ


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

## "S = −2" study will start!



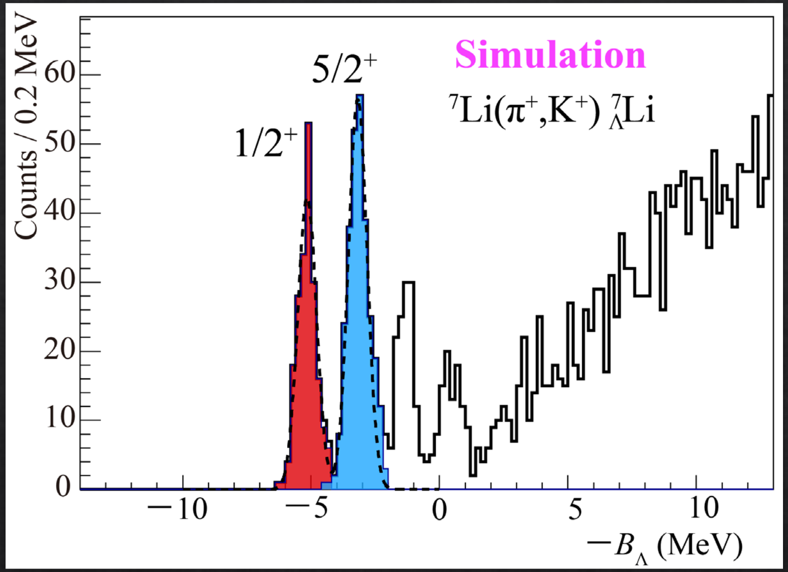

"S = −1" as well

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

# Expected spectra (J-PARC E94)

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

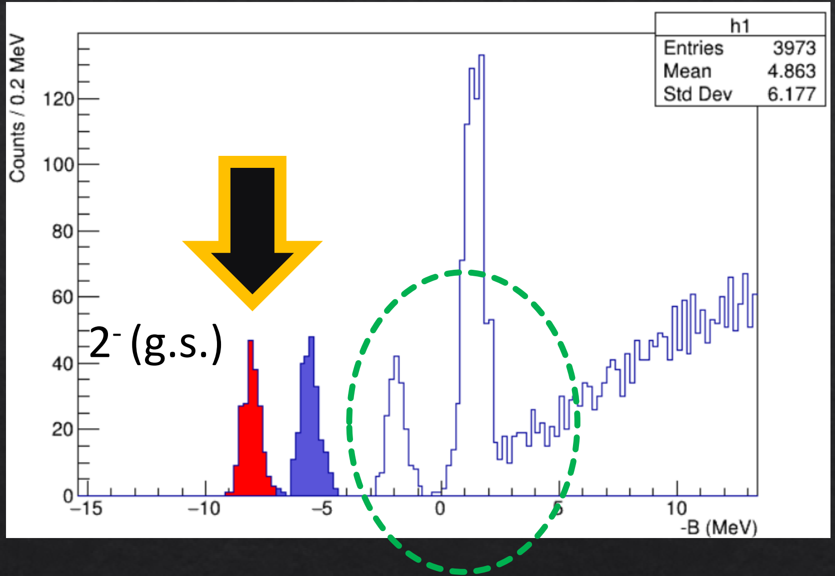
*80 hours*




Calibration source

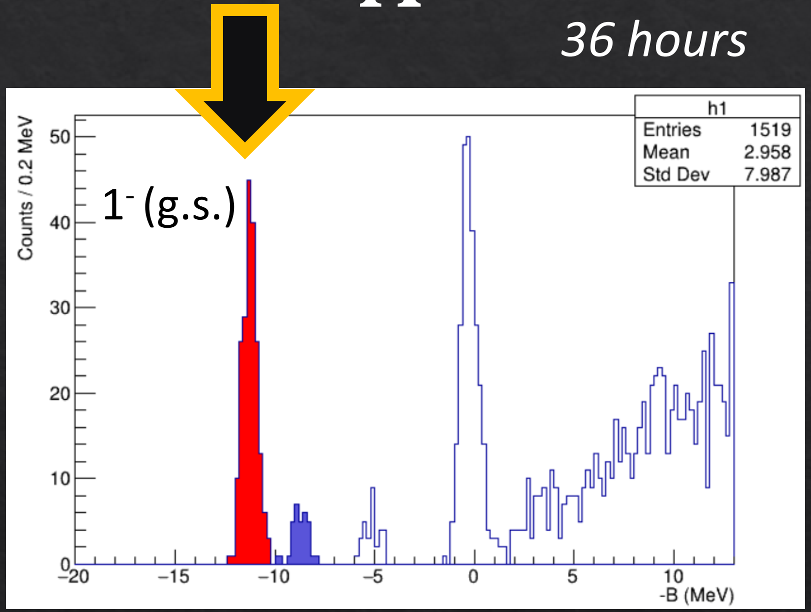
$^{10}_{\Lambda}$B

*112 hours*




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

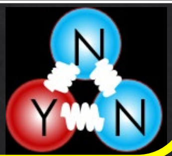
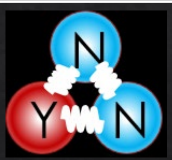
*36 hours*




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

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 $^{3}_{\Lambda}H$ 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 | Y N | ΛN-ΣN | N Y N |
| -2 | Y N | ΞN-ΛΛ | N Y N |

**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

$^{3}_{\Lambda}$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 | Y N | ΛN-ΣN | N N Y N |
| -2 | Y N | ΞN-ΛΛ | N N Y N |

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**

# Missing mass spectroscopy of hypernuclei at JLab and J-PARC

**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—)**

- $(\pi^+, K^+)$ 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**