

15th International Conference on Hypernuclear and Strange Particle Physics (HYP2025),
U. Tokyo, Japan, Sep29—Oct 3, 2025

<https://sites.google.com/nex.phys.s.u-tokyo.ac.jp/hyp2025>

High Precision Spectroscopy of Light Lambda hypernuclei at Jefferson Lab

Graduate School of Science, Kyoto University

Toshiyuki Gogami

for JLab Hypernuclear Collaboration

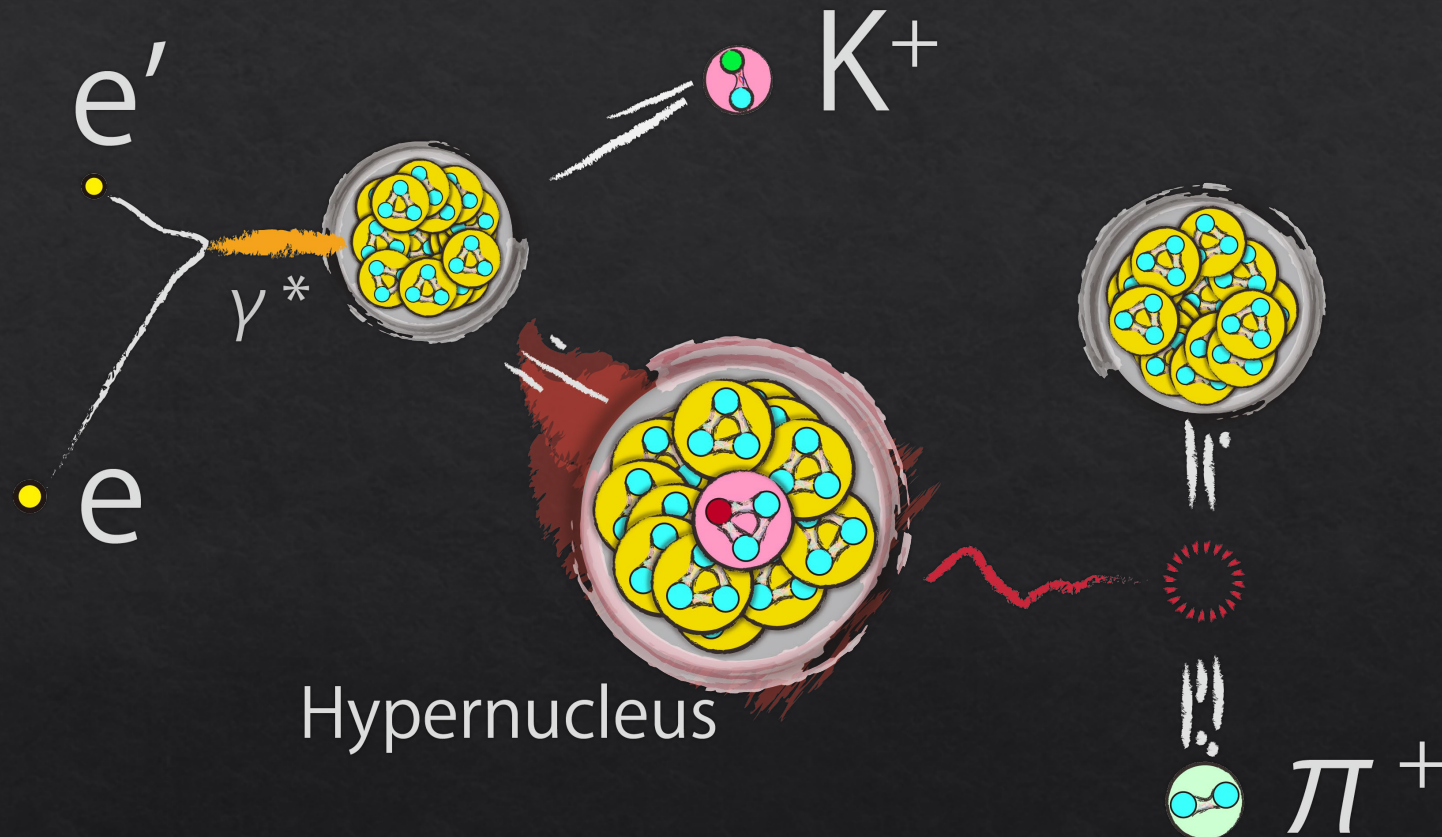
Oct 3, 2025



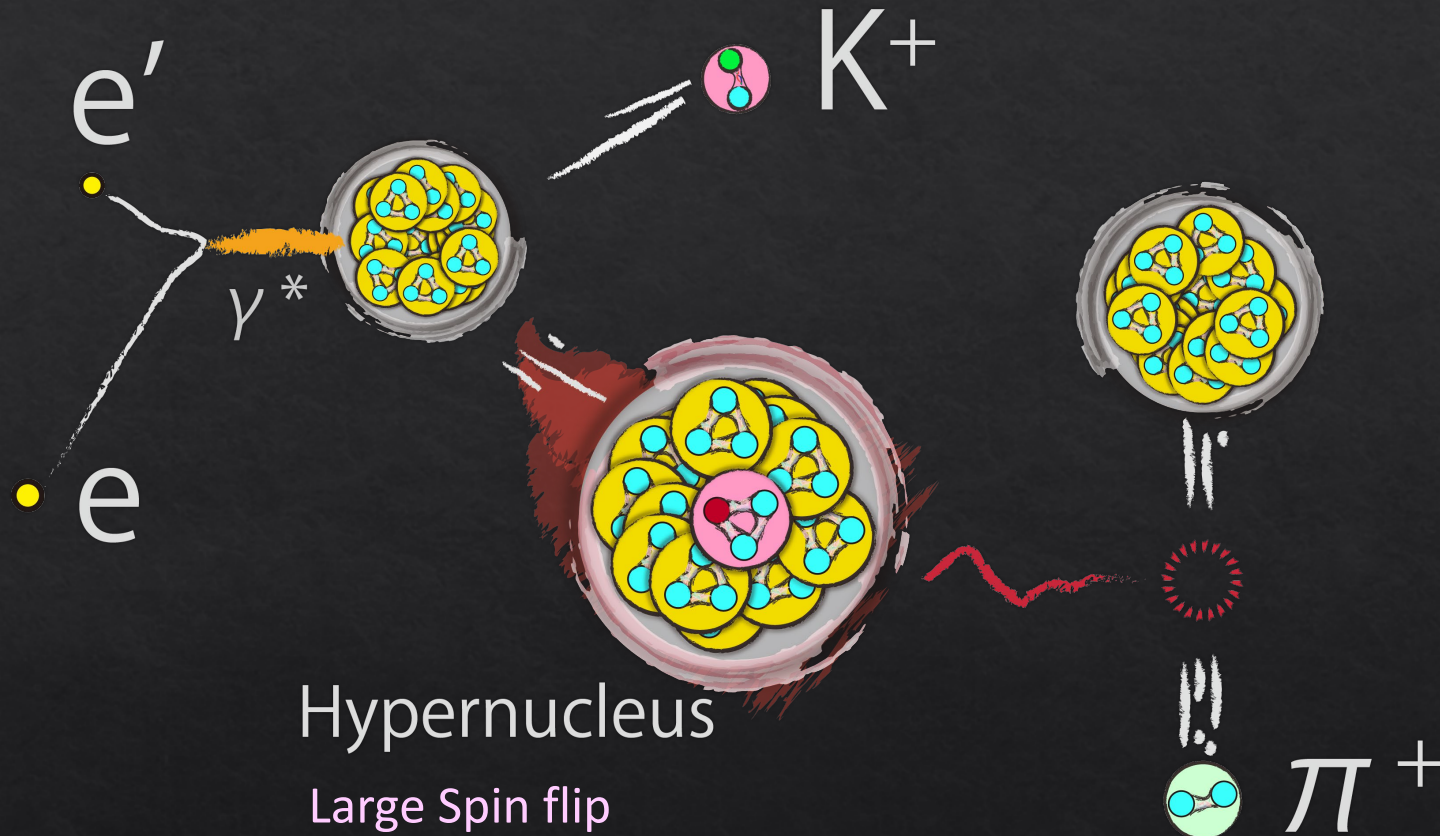
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$(e,e'K^+)$ spectroscopy / decay π spectroscopy



$(e,e'K^+)$ spectroscopy / decay π spectroscopy



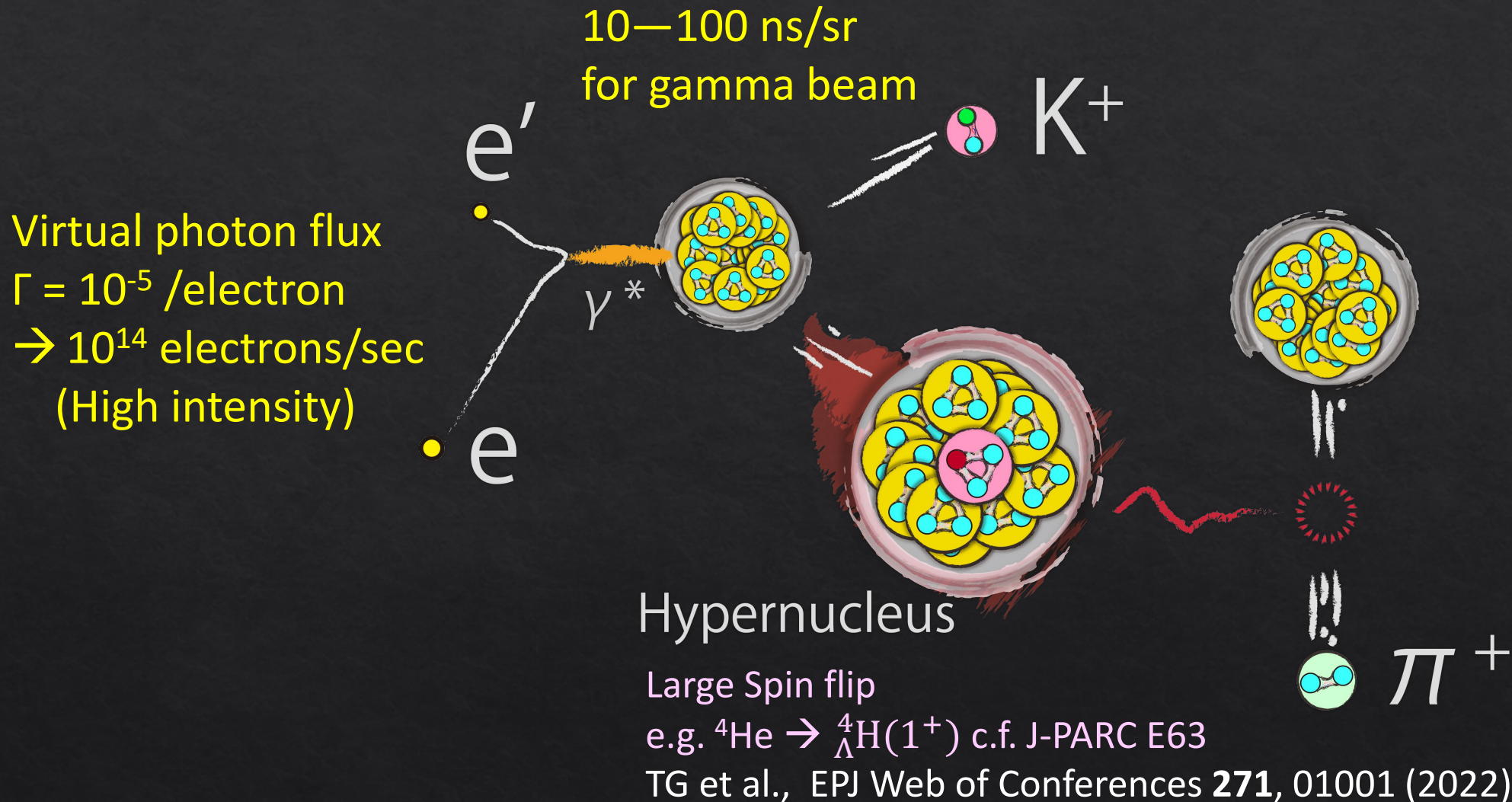
Hypernucleus

Large Spin flip

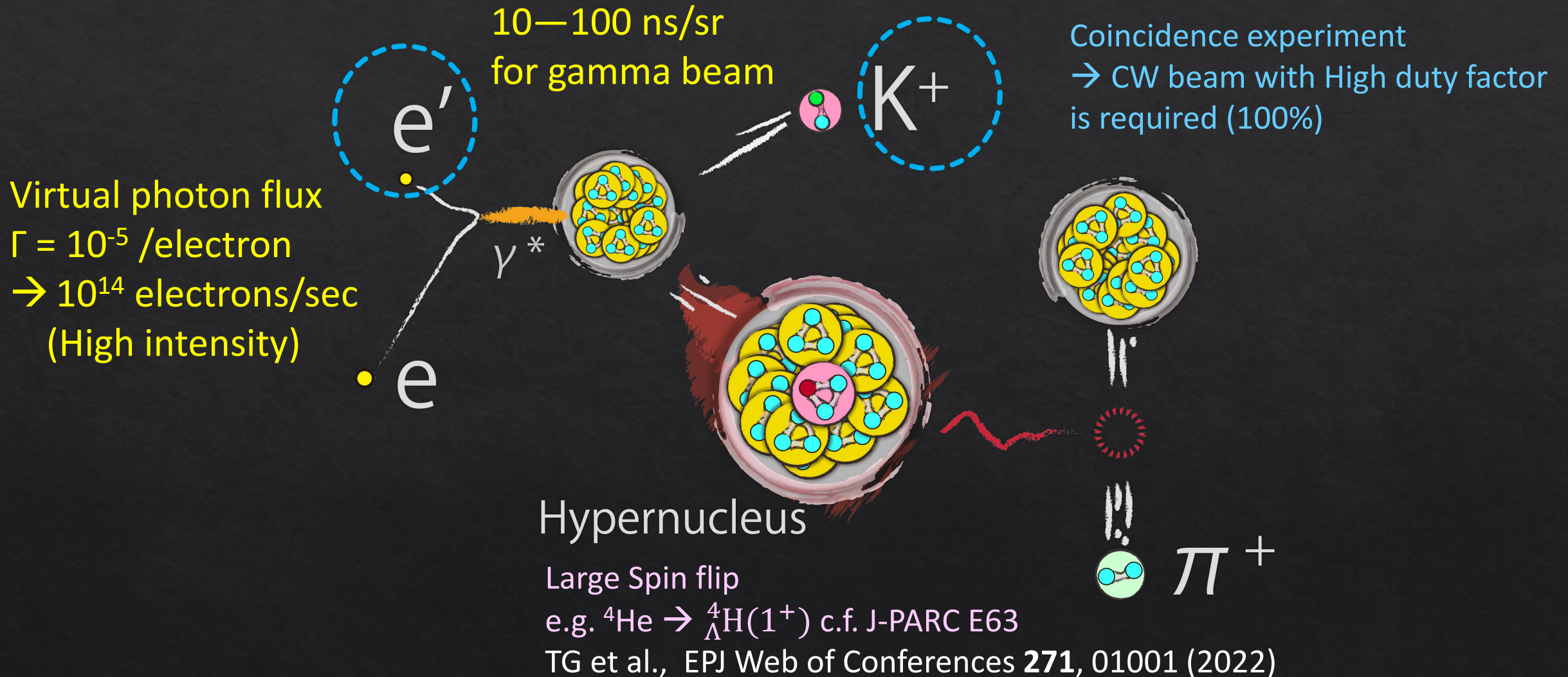
e.g. ${}^4\text{He} \rightarrow {}^4_{\Lambda}\text{H}(1^+)$ c.f. J-PARC E63

TG et al., EPJ Web of Conferences **271**, 01001 (2022)

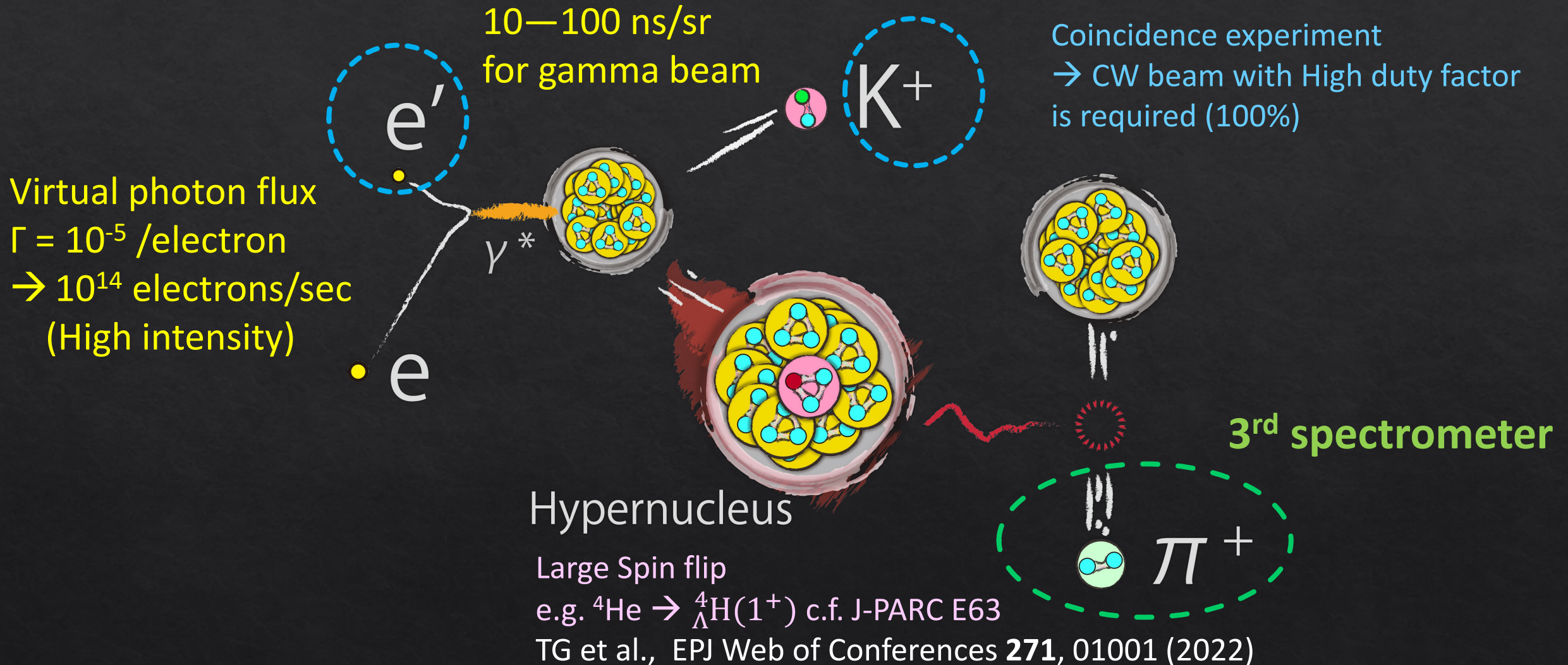
$(e,e'K^+)$ spectroscopy / decay π spectroscopy



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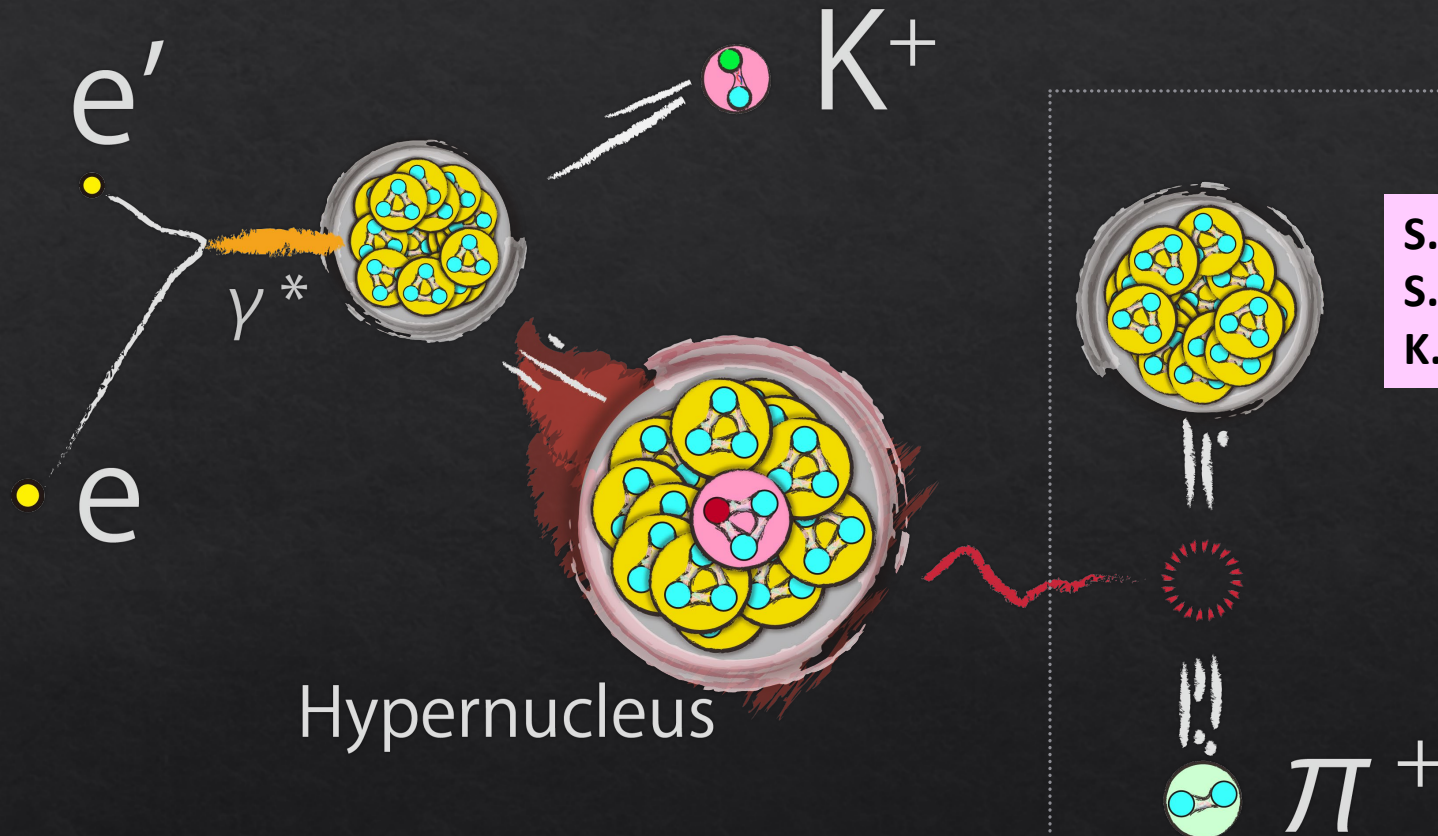


$(e, e' K^+)$ spectroscopy / decay π spectroscopy



$(e,e'K^+)$ spectroscopy / decay π spectroscopy

J. Takatashi, Poster
K. Higashimoto, Poster



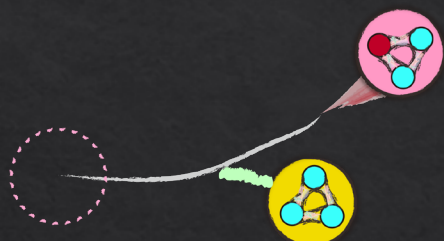
S. Nagao, 1PLE1
S. Niwa, Poster
K. Nishida, 3A2B

Roles of hypernuclear study

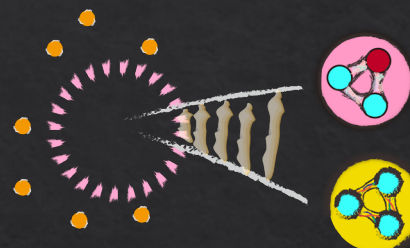
3BF

F. Hildenband, 29P1A
A. Nogga, 1PLE2
D. Gadza, 1P1A
etc.

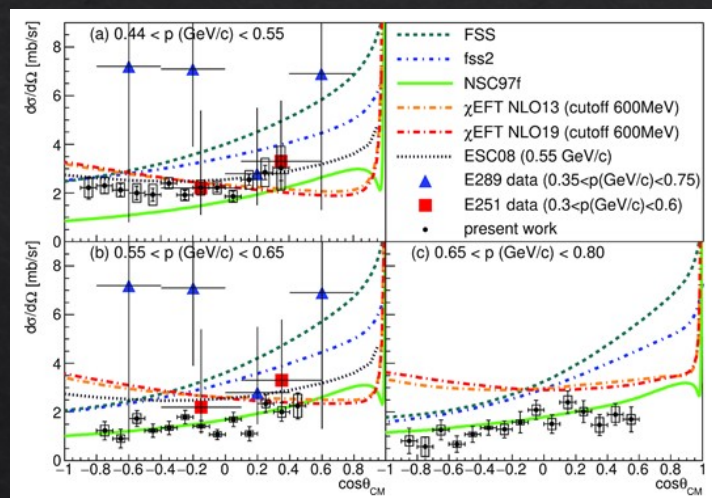
Scattering experiments



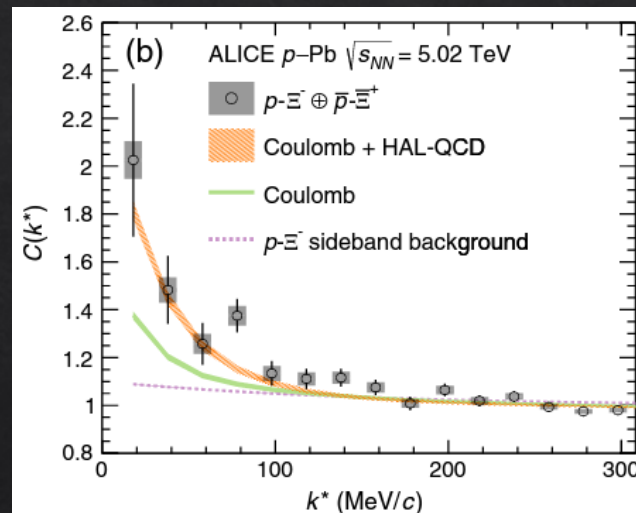
Femtoscscopy



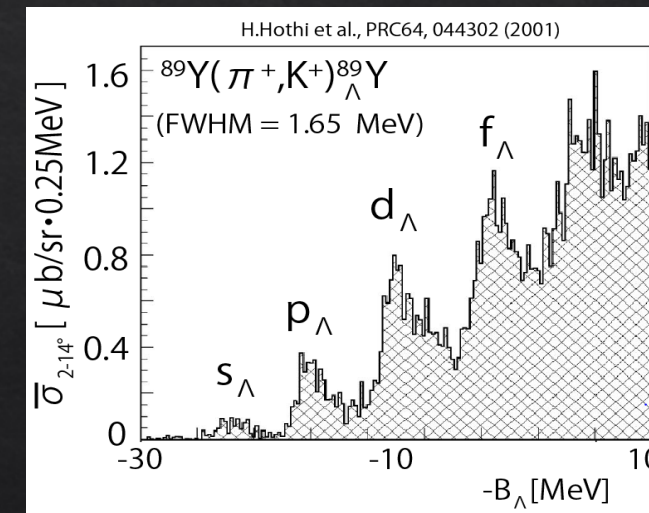
Hypernuclear spectroscopy



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



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



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

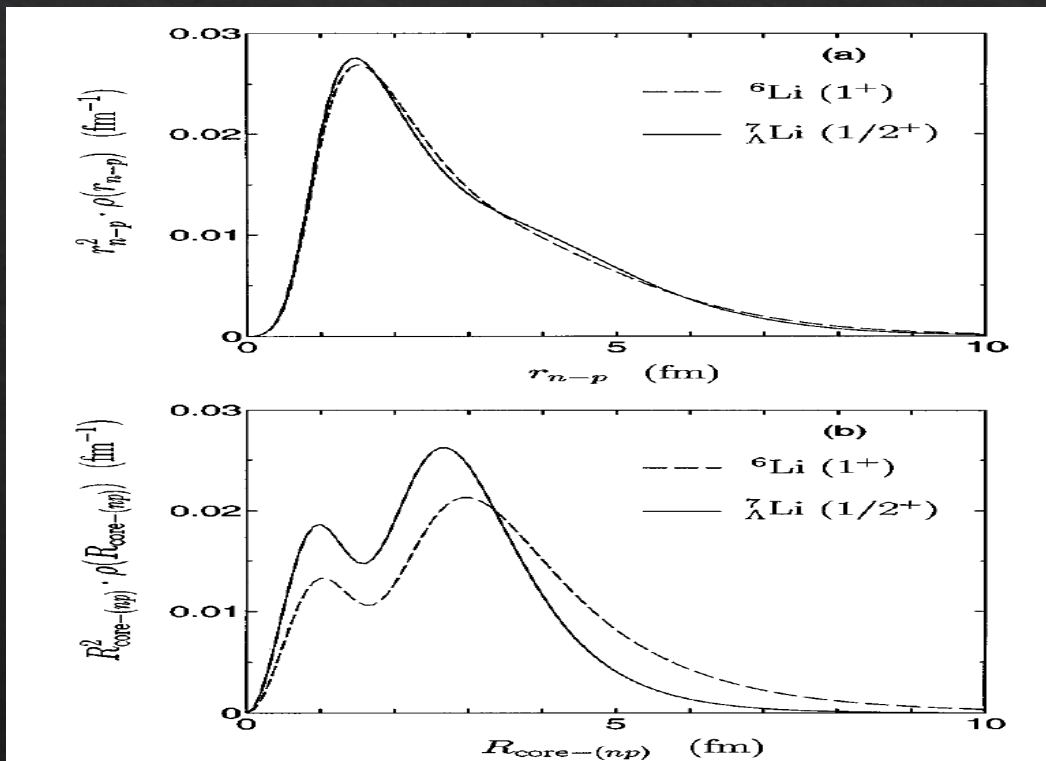
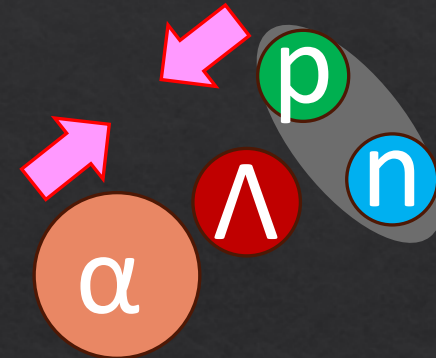
High Precision Spectroscopy of Light Lambda hypernuclei at Jefferson Lab

T. Gogami (Kyoto Univ.), HYP2025, U. Tokyo, Tokyo, Japan, Oct 2, 2025

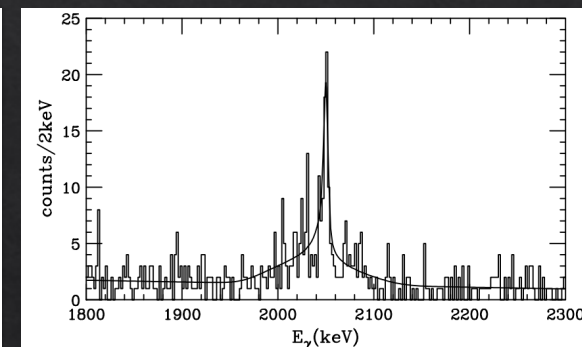
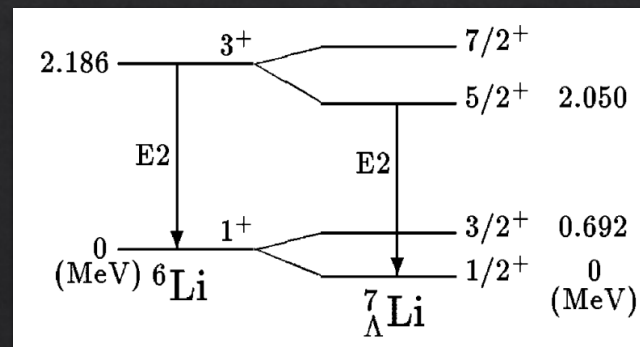


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Core contraction due to Λ (${}^7_{\Lambda}\text{Li}$)



K. Tanida, H. Tamura et al., PRL 86, 1892 (2001).

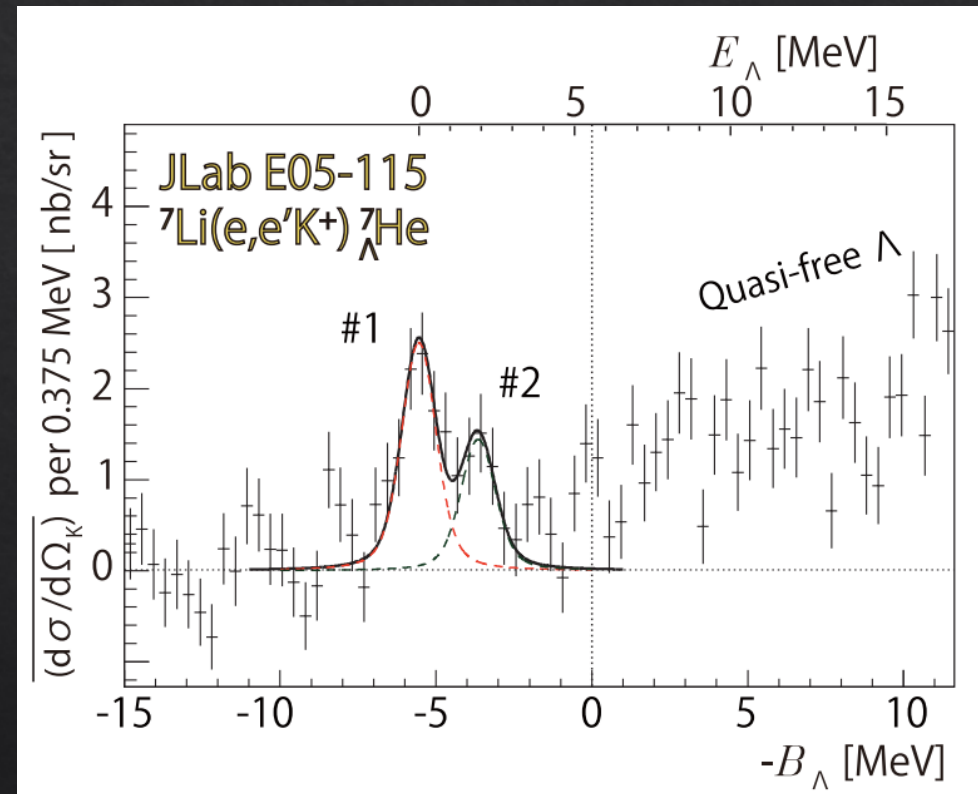
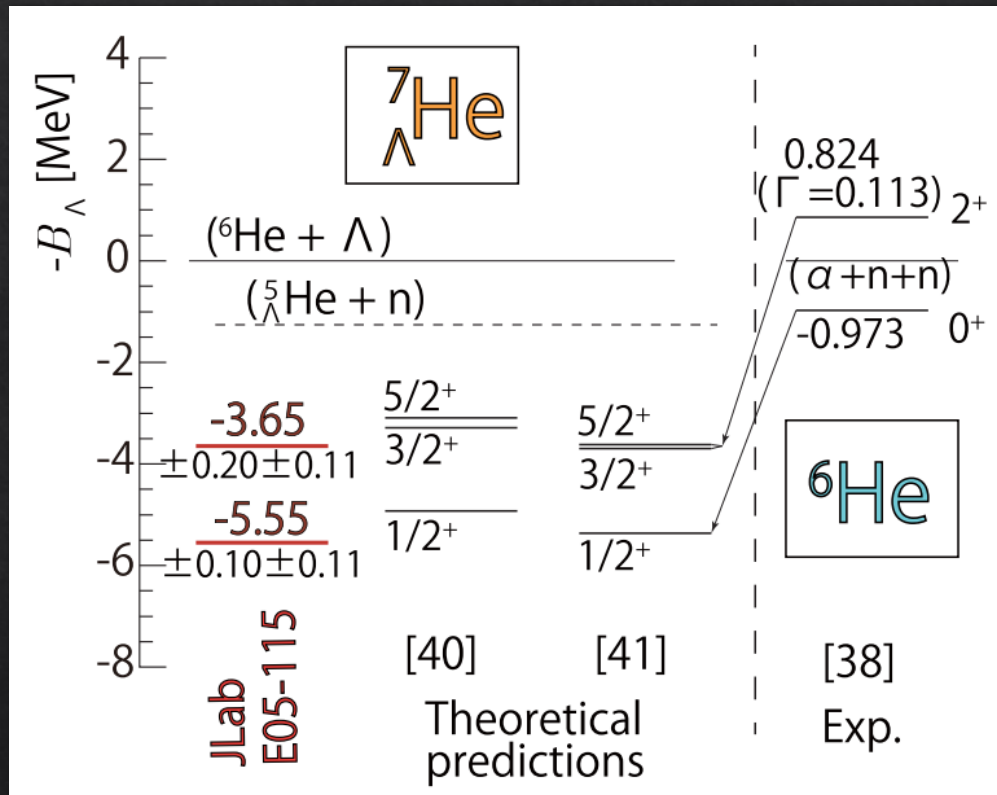


$$B(E2) = 3.6 \pm 0.5^{+0.5}_{-0.4} \text{ e}^2 \text{ fm}^4$$

→ 19% reduction of α -d distance

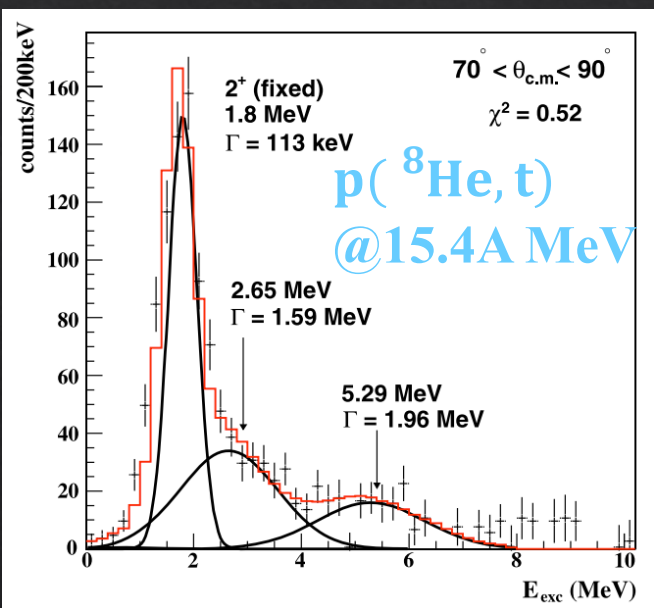
E. Hiyama, M. Kamimura, K. Miyazaki, T. Motoba, PRC 59, 5 (1999)

Unstable to stable (${}^7_{\Lambda}\text{He}$)

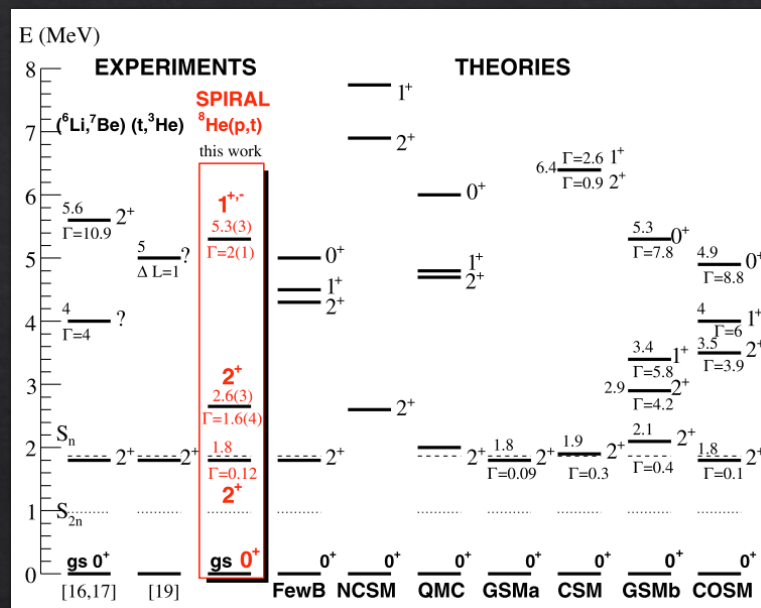


T. Gogami et al., Phys. Rev. C **94**, 021302(R) (2016).

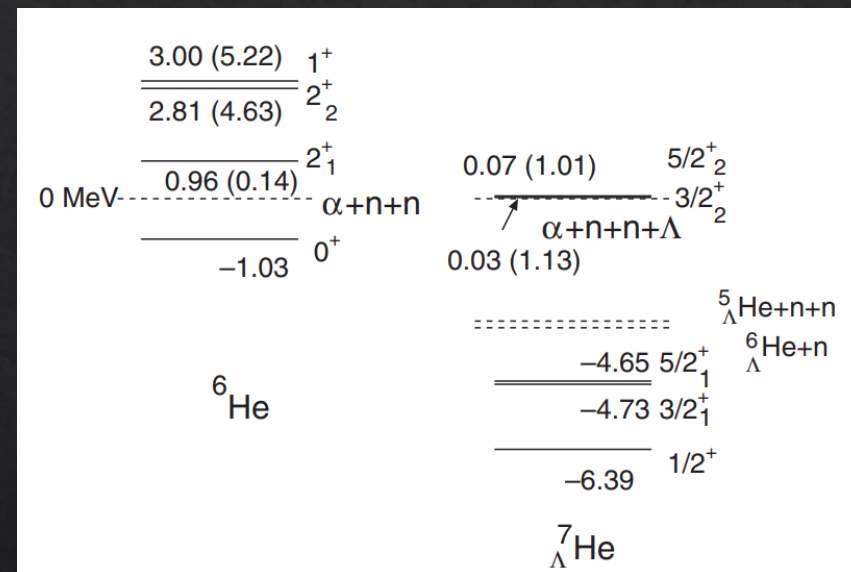
Λ probe for unstable states



X. Mougeot et al., PLB 718, 2, 441— 446 (2012)



Cluster model calculation using CSM:
E. Hiyama et al., PRC 91, 054316 (2015)



Accurate 2_2^+ measurement would be possible thanks to Λ 's glue-like role

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

DATA

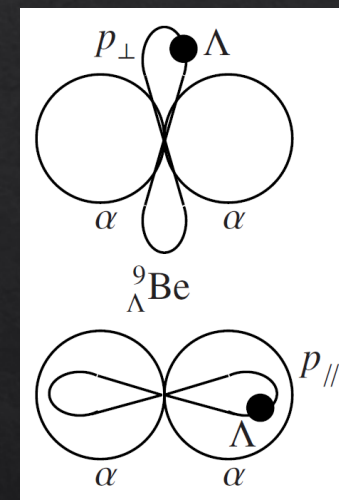
(TG et al., PRC93,
034314 (2016))

New finding from improved precision

A. Umeya, 20P1A

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

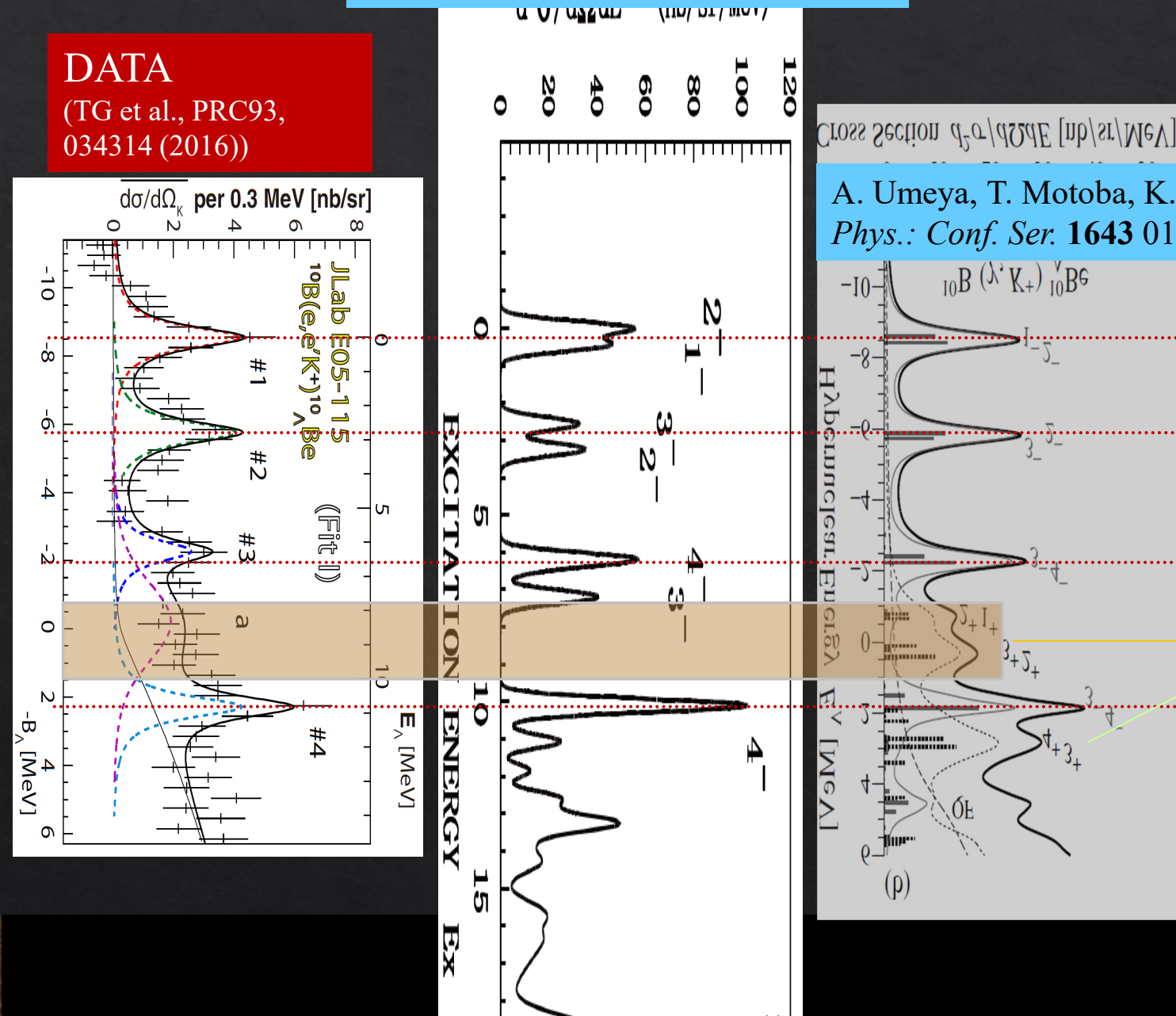
α - α structure splits p_{Λ} state



$J_C^- \otimes p_{\Lambda}$

c.f.)

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

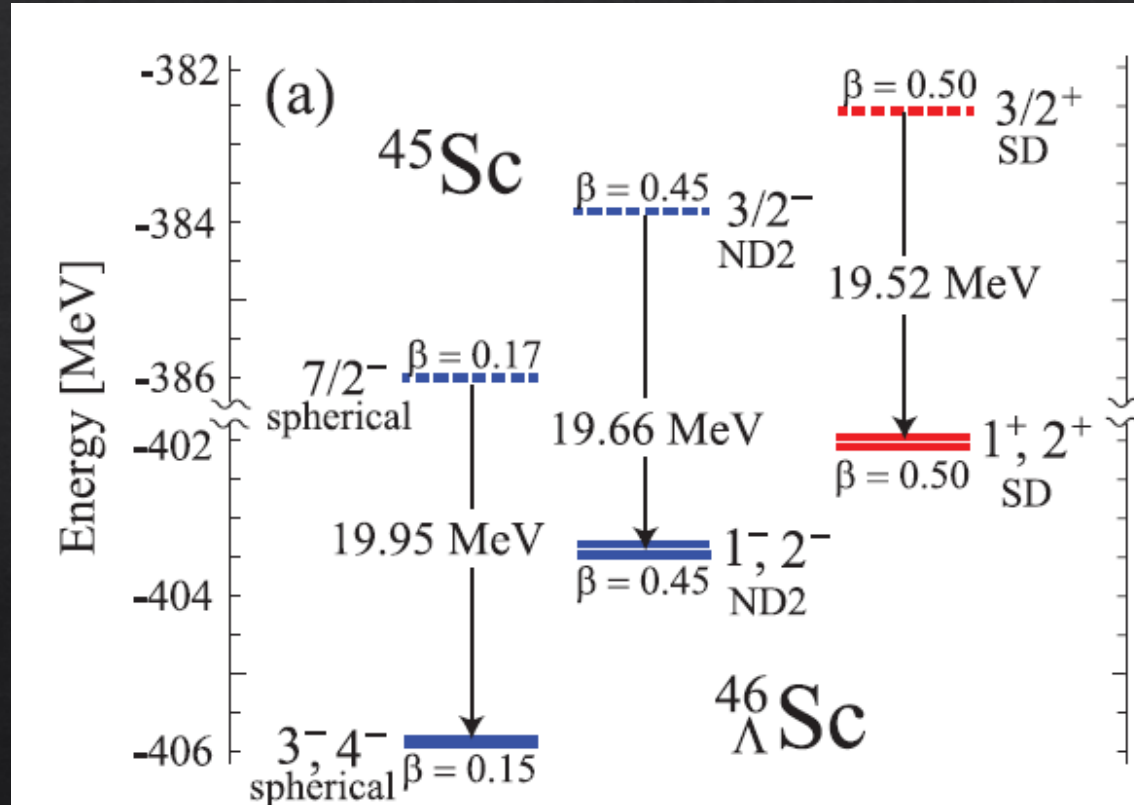
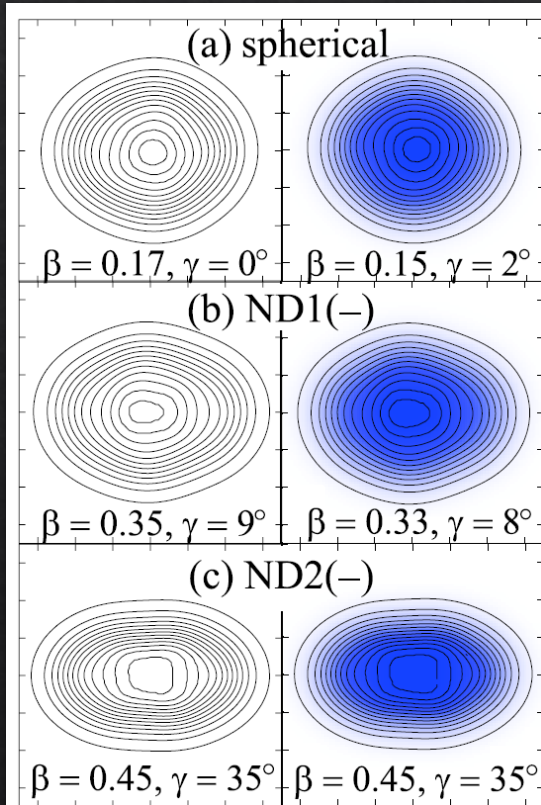


$^{46}\text{Ti}(e, e' K^+) ^{46}_{\Lambda}\text{Sc}$

c.f.)

X.R. Zhou, 1P1A

M. Isaka et al., PRC 89, 024310 (2014)

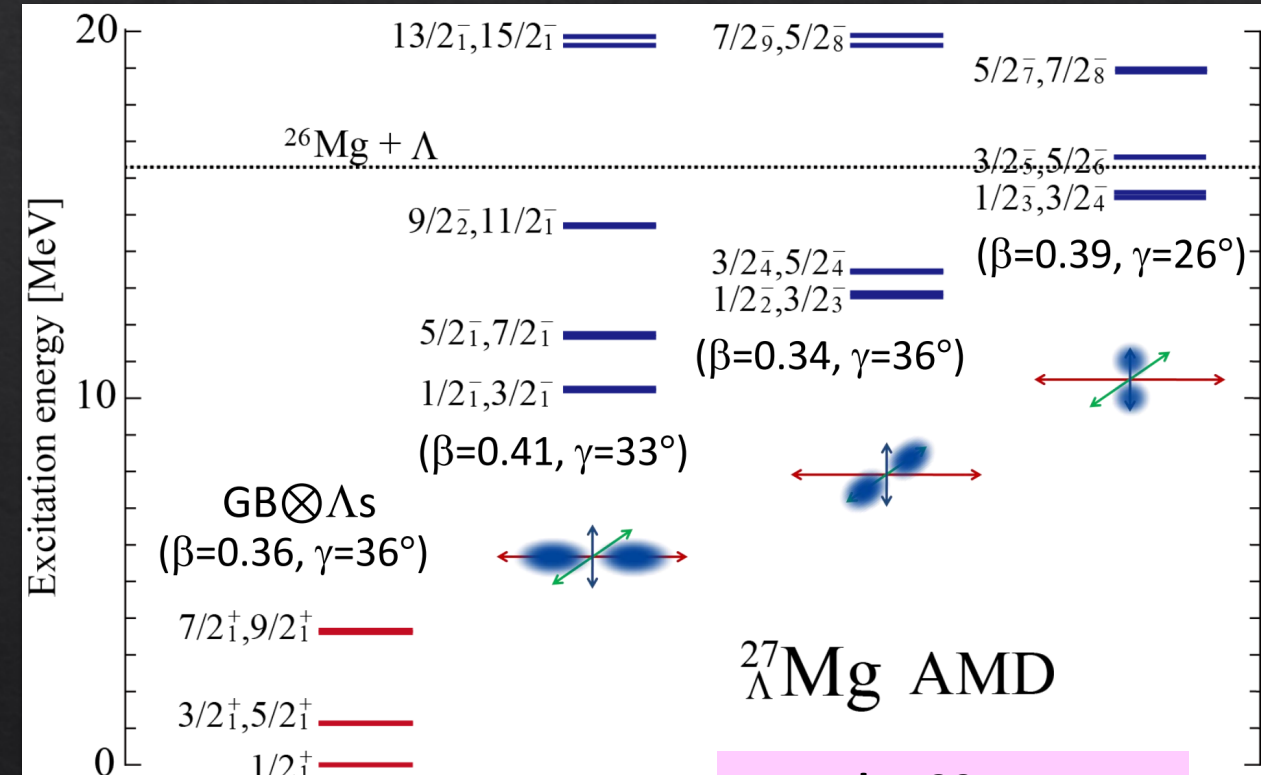
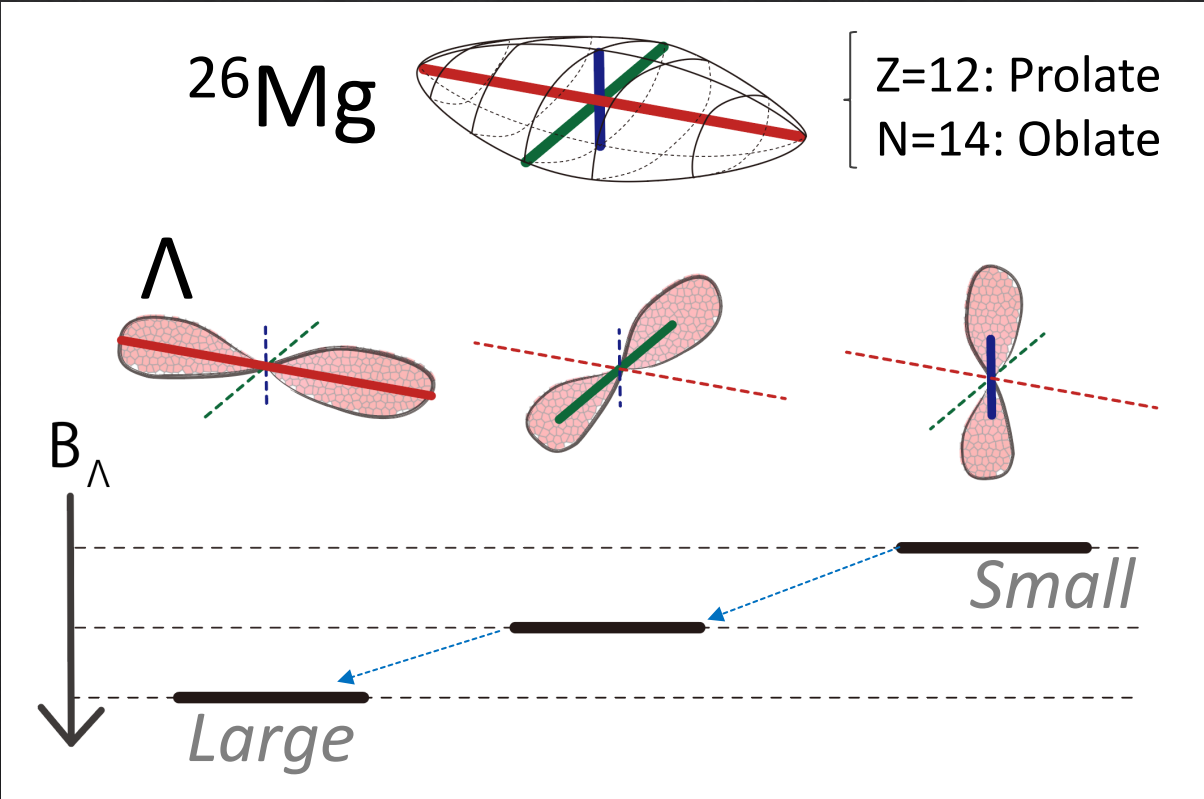


Less bound as the core is more deformed due to smaller overlap between core and Λ

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

Anti-molecular dynamics (AMD) calculation

Presentation by M. Isaka (2023); <https://indico.jlab.org/event/705/>

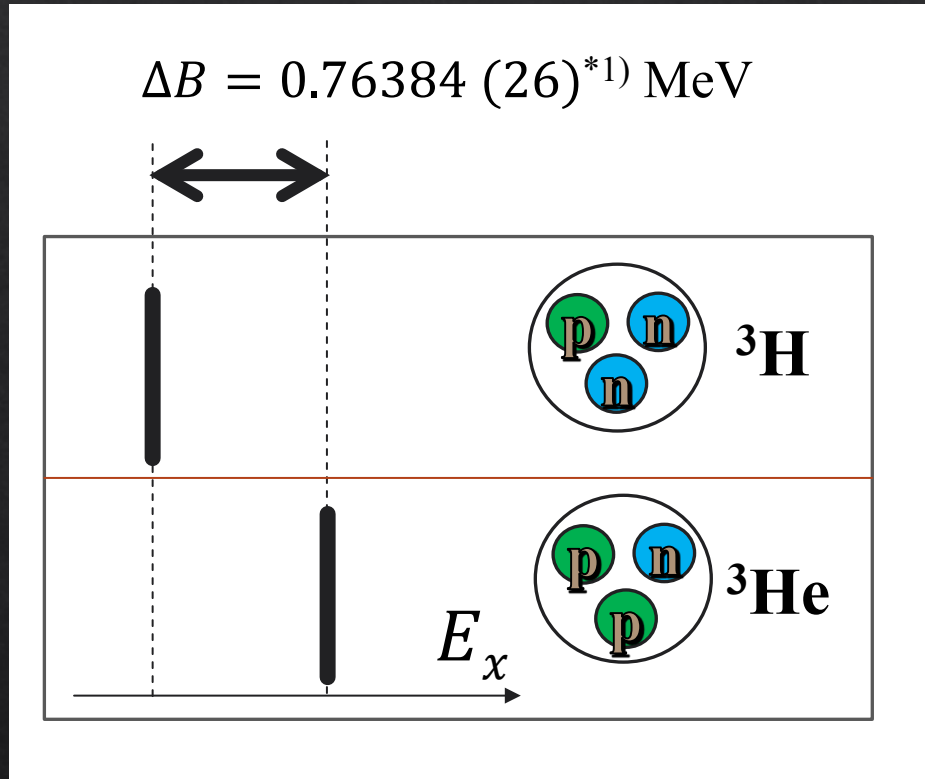


M. Isaka, 29P1A

$^{26}\text{Mg} \times p_{\Lambda} \rightarrow$ Probing triaxially deformation

Charge Symmetry Breaking (CSB), the mystery

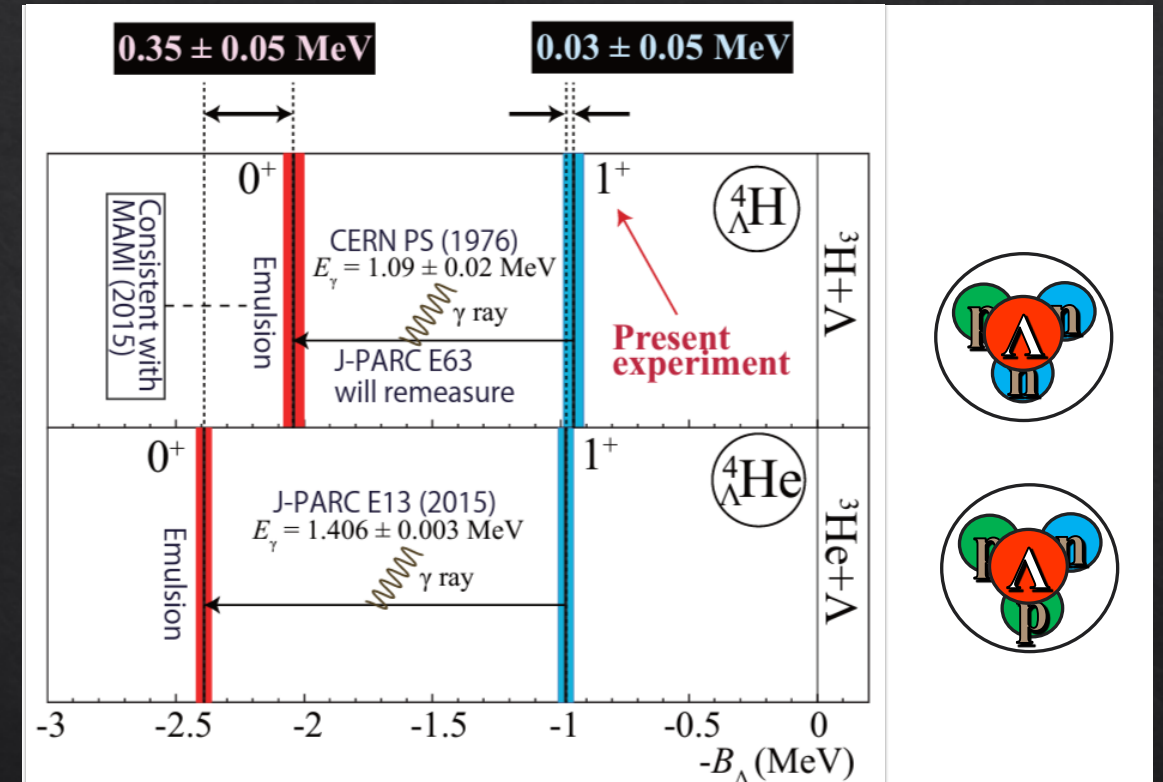
*1) J.H.E.Mattauch *et al.*, *Nucl. Pys.* **67**, 1 (1965).



81 keV after Coulomb correction

[R.A.Brandenburg, S.A.Coon *et al.*, *NP***A294**, 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

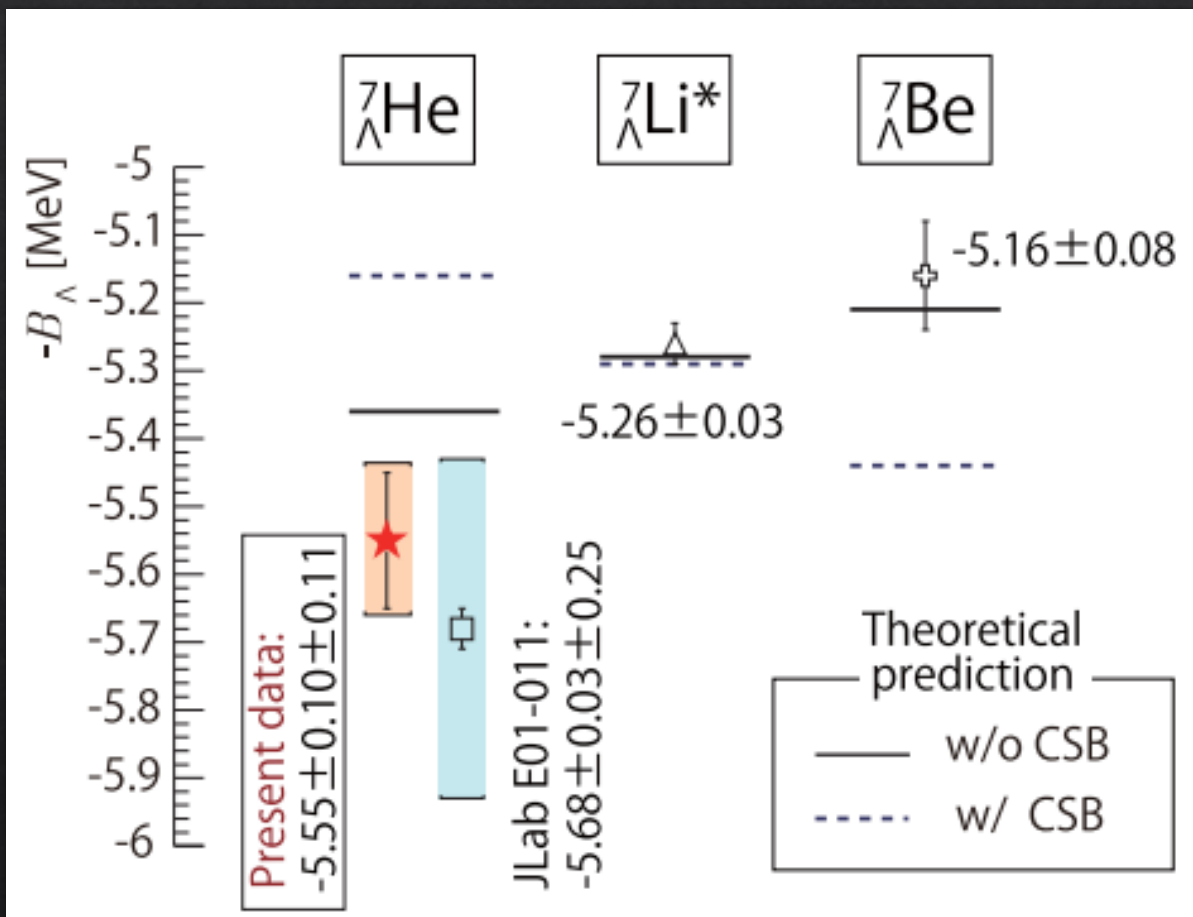
E. Hiyama et al., PRC80, 054321 (2009)

Phenomenological CSB potential

$$V_{\Lambda N}^{\text{CSB}}(r)$$

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

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



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



The calc. w/o the CSB potential is more consistent with the data.
The origin of CSB is more complex?

Mirror hypernuclear data for p-shell systems

Energies in keV

Isomultiplet	${}^4_{\Lambda}\text{He}-{}^4_{\Lambda}\text{H}$	${}^7_{\Lambda}\text{Be}-{}^7_{\Lambda}\text{Li}^*$	${}^7_{\Lambda}\text{Li}^*-{}^7_{\Lambda}\text{He}$	${}^8_{\Lambda}\text{Be}-{}^8_{\Lambda}\text{Li}$	${}^9_{\Lambda}\text{B}-{}^9_{\Lambda}\text{Li}$	${}^{10}_{\Lambda}\text{B}-{}^{10}_{\Lambda}\text{Be}^*$
Shell model (Gal <i>et al.</i>)	+226	-17	-28	+49	-54	-136
Cluster model (Hiyama <i>et al.</i>)		+150	+130			+20
No-core shell model (Le <i>et al.</i>)	+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)

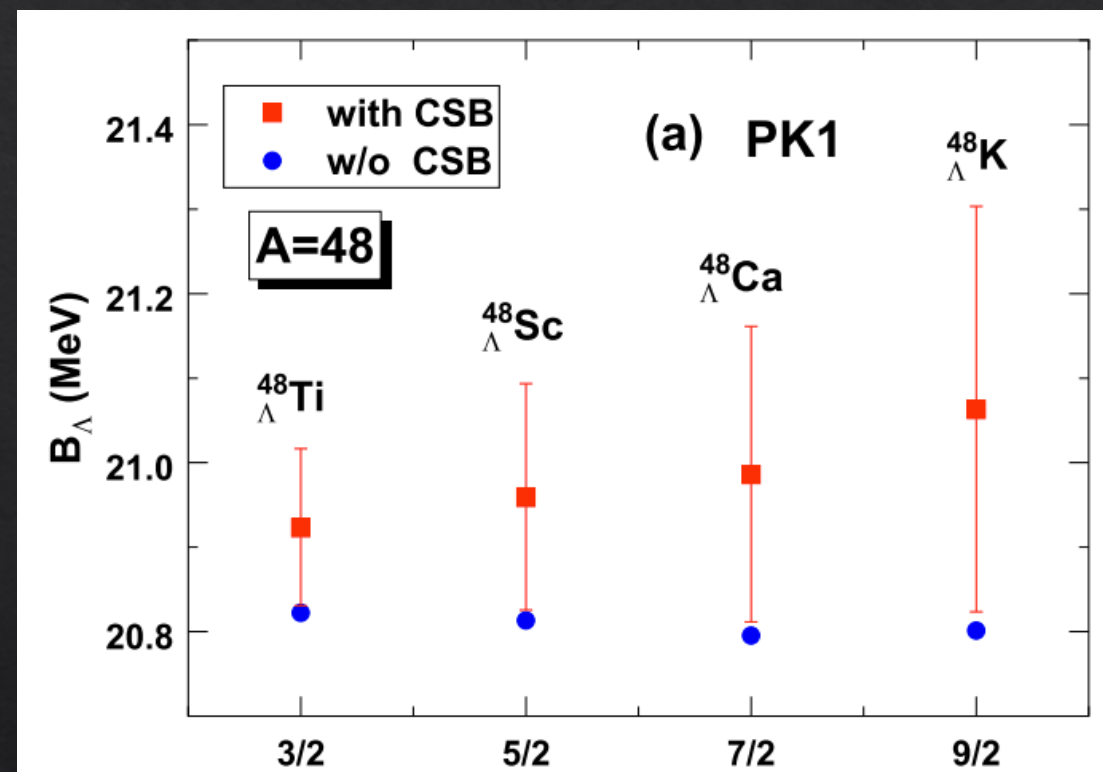
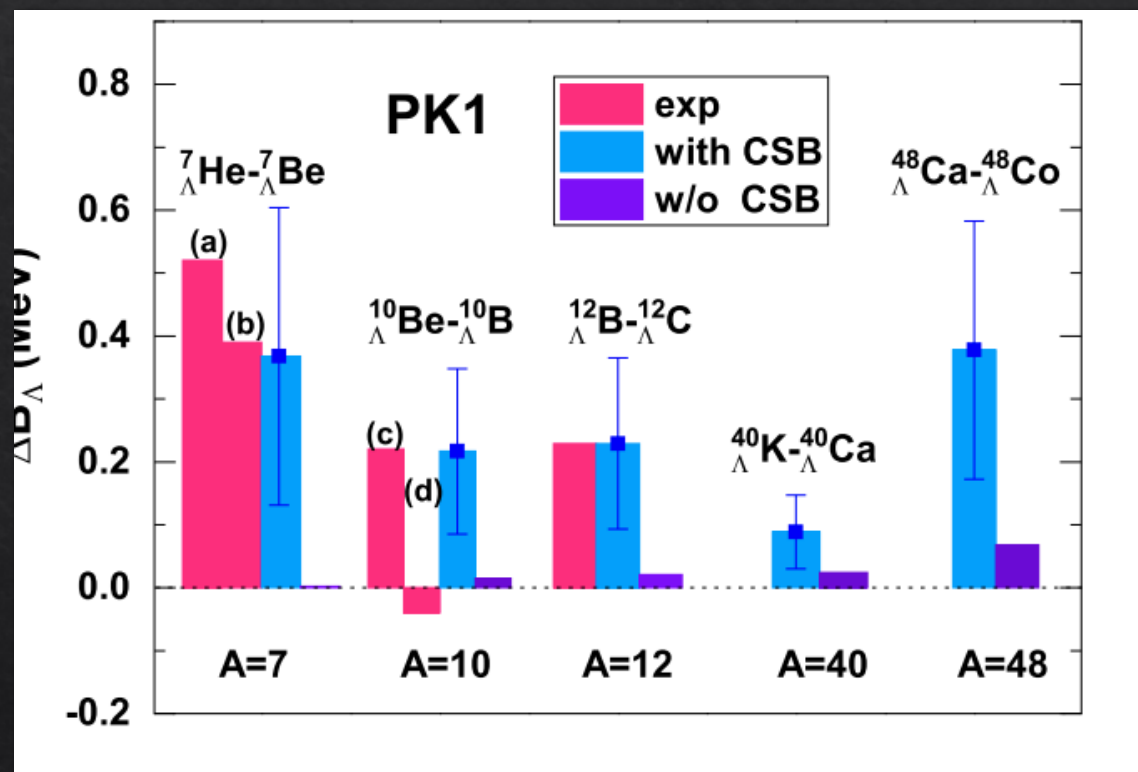


Existing data accuracy is not sufficient for CSB study ($\Delta B_{\text{diff}} > 200 \text{ keV}$)

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

CSB in heavier system

T. Sun, Y. Tanimura, H. Sagawa, E. Hiyama, PLB 865, 139460 (2025)



Y. Tanimura, 29P1A

Mirror Hypernuclear Study

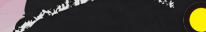
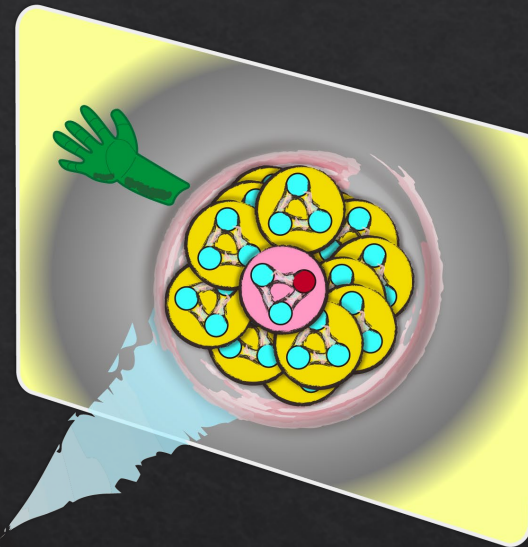
$^{12}_{\Lambda}\text{C}$



^{12}C



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



(π^+, K^+)

$n \rightarrow \Lambda$



$(e, e' K^+)$

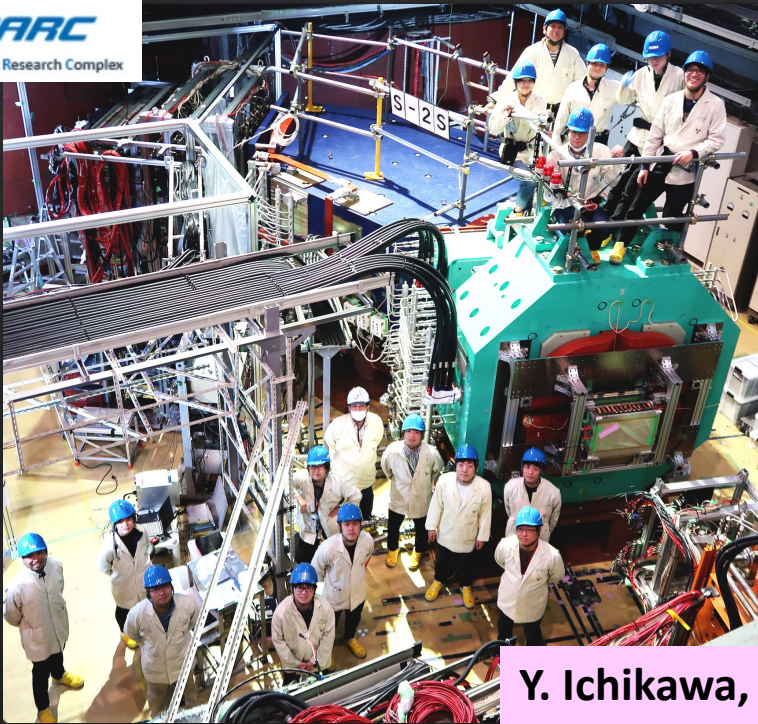
$p \rightarrow \Lambda$



Missing mass spectroscopy for Λ hypernuclei



TG et al., [EPJ Web Conf. 271, 11002 \(2022\)](#)



Y. Ichikawa, 1PLE1
K. Ebata, 1P2B

S-2S (2025~)

Λ : $A = 7, 10, 12$

Ξ : $A = 12, 7$



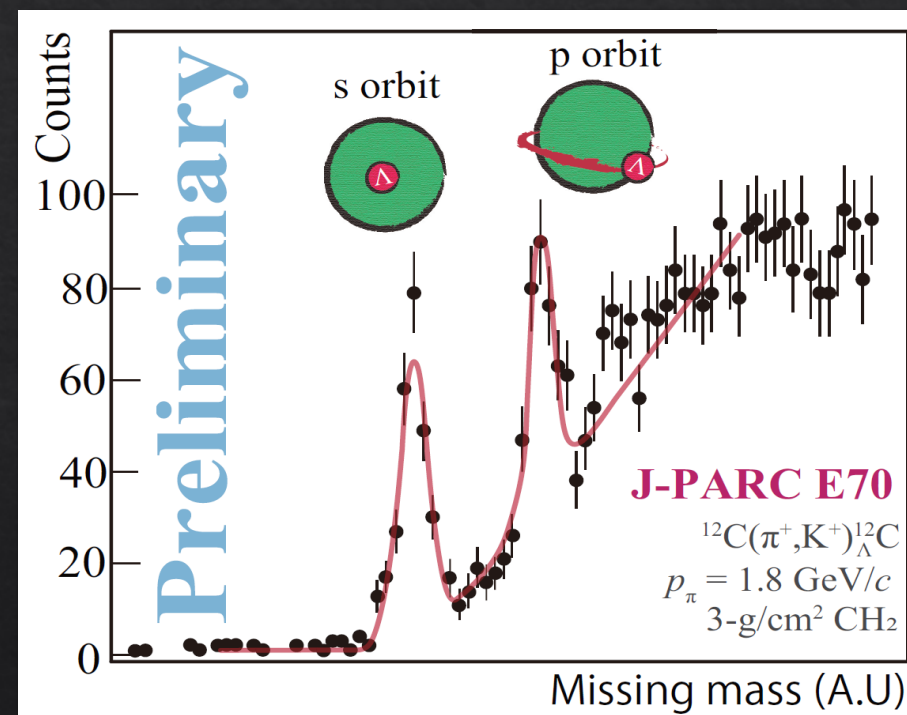
HES-HKS (2027~)

Λ : $A = 6, 9, 11, 12, 27, 40, 48, 208$

New Spectrometer at J-PARC for high precision



2023.6 commissioning
2025.4—5 Physics data ($^{12}_{\Lambda}\text{Be}$)



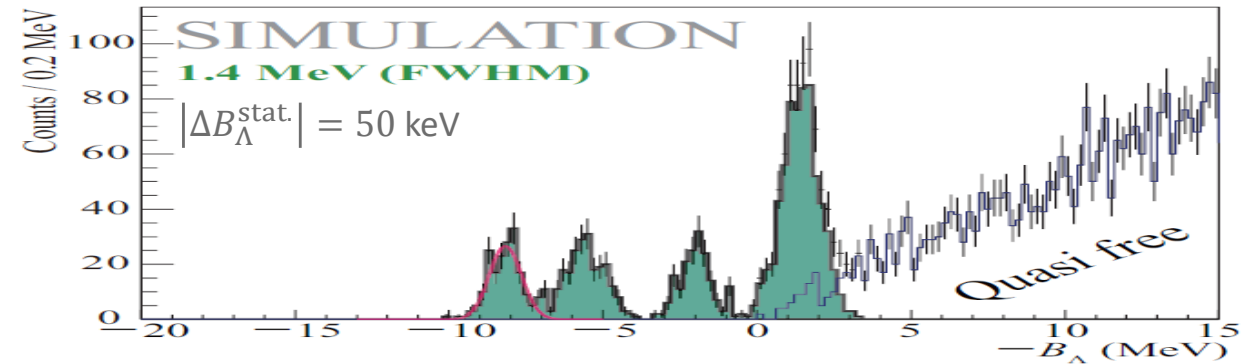
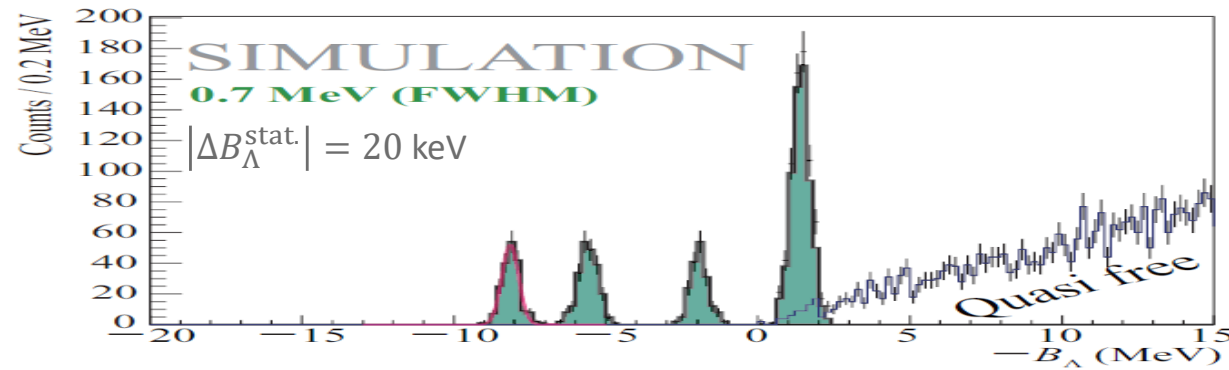
T. Gogami et al., TDR for J-PARC FIFC, J-PARC E94 (2025)

Expected spectra (J-PARC E94)

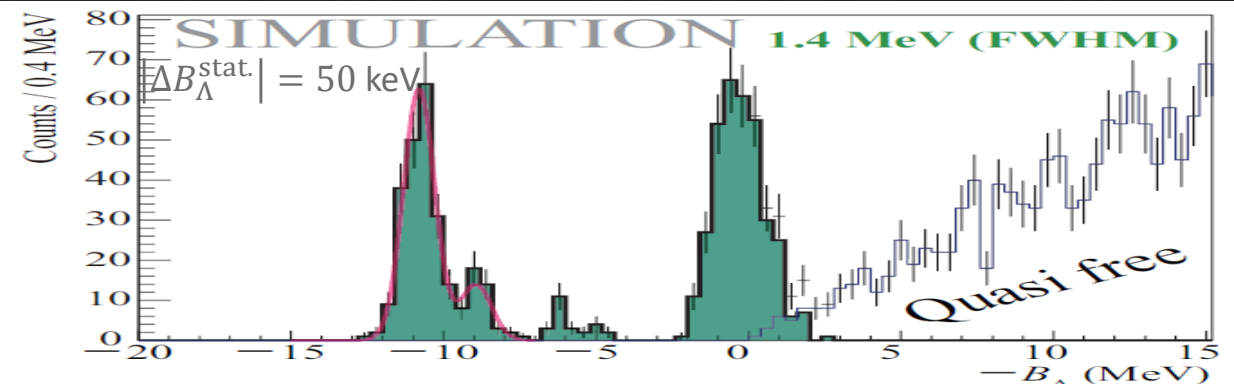
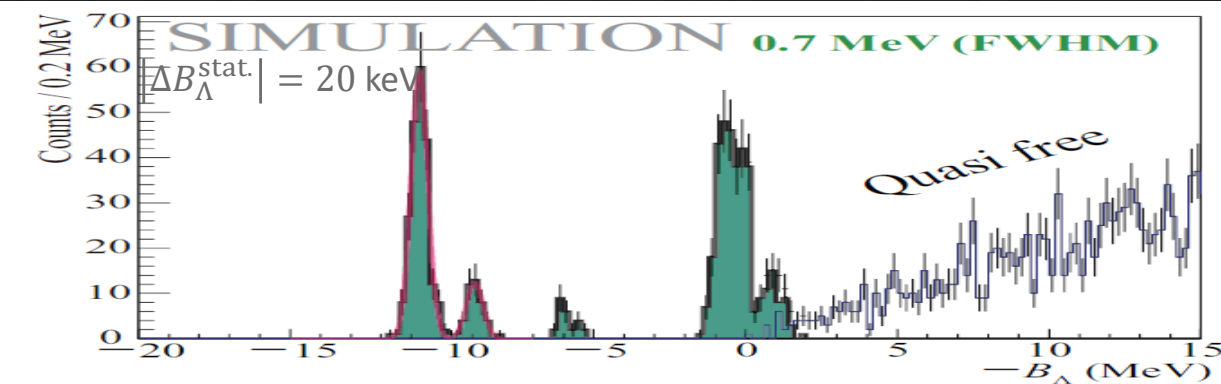
D. Watanabe, 1P2B
T. Taniguchi, Poster



Great precision!



Great precision!



Approved Hypernuclear Experiments (proposed by JLab Hypernuclear Collaboration)

- ① E12-15-008 $\rightarrow$ $^{40}_{\Lambda}\text{K}$, $^{48}_{\Lambda}\text{K}$
“Isospin dependence of ΛN interaction”
- ② E12-19-002 $\rightarrow$ $^3_{\Lambda}\text{H}$, $^4_{\Lambda}\text{H}$
“Hypertriton puzzle, s-shell CSB”
- ③ E12-20-013 $\rightarrow$ $^{208}_{\Lambda}\text{Tl}$
“ ΛNN three body force”
- ④ E12-24-004 $\rightarrow$ $^6_{\Lambda}\text{He}$, $^9_{\Lambda}\text{Li}$, $^{11}_{\Lambda}\text{Be}$
“p-shell CSB”
- ⑤ E12-24-011 $\rightarrow$ $^{27}_{\Lambda}\text{Mg}$
” Search for triaxially deformation states in ^{26}Mg ”
- ⑥ Run group experiment (E12-15-008A):
Decay-pion spectroscopy

Approved Hypernuclear Experiments (proposed by JLab Hypernuclear Collaboration)

① E12-15-008 $\rightarrow$ ${}^4_{\Lambda}K$, ${}^8_{\Lambda}K$
“Isospin dependence of ΛN interaction”

⑥ Run group experiment (E12-15-008A):
Decay-pion spectroscopy

② E12-19-002 $\rightarrow$ ${}^3_{\Lambda}H$, ${}^4_{\Lambda}H$
“Hypertriton puzzle, s-shell CSB”

③ E12-20-013 $\rightarrow$ ${}^{208}_{\Lambda}Tl$
“ ΛNN three body force”

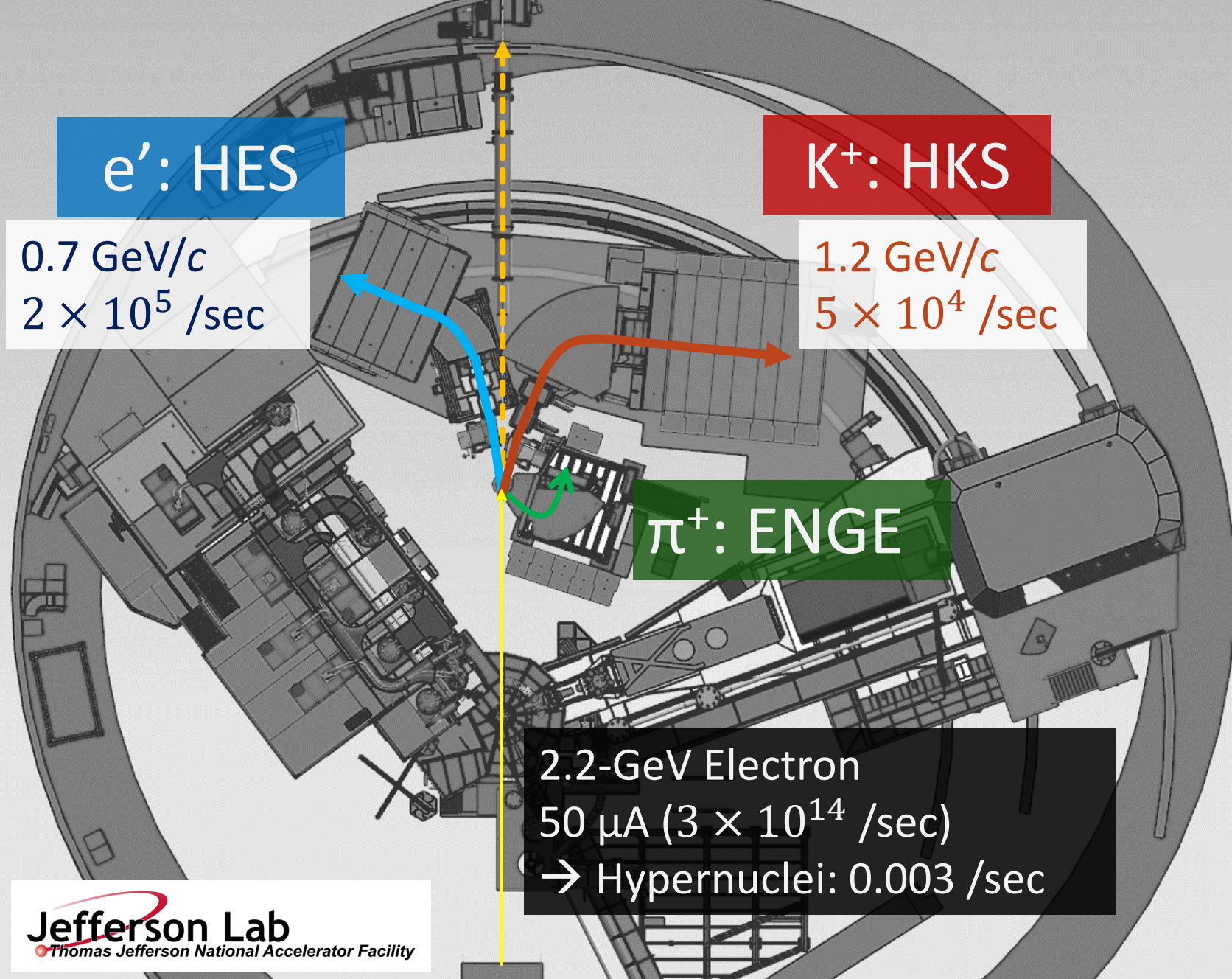
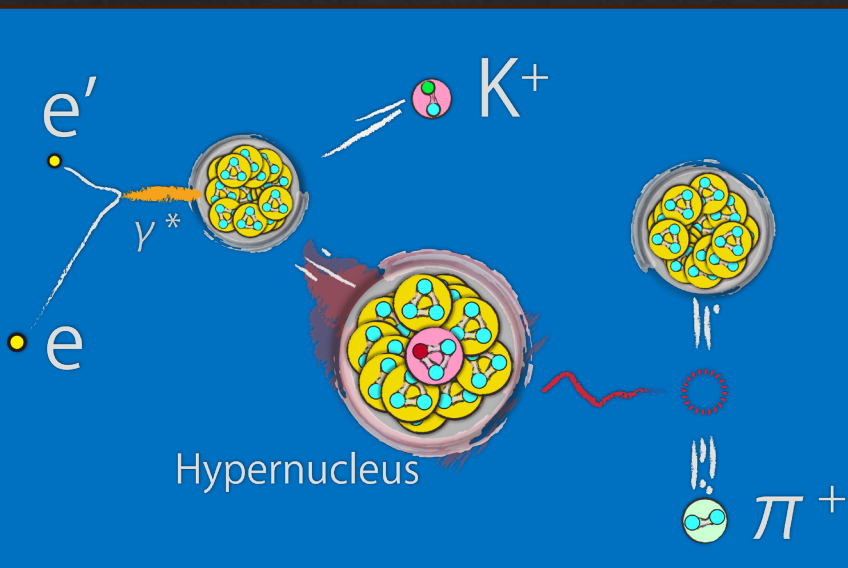
④ E12-24-004 $\rightarrow$ ${}^6_{\Lambda}He$, ${}^9_{\Lambda}Li$, ${}^{11}_{\Lambda}Be$
“p-shell CSB”

⑤ E12-24-011 $\rightarrow$ ${}^{27}_{\Lambda}Mg$
” Search for triaxially deformation states in ${}^{26}Mg$ ”

Will be performed
from 2027~

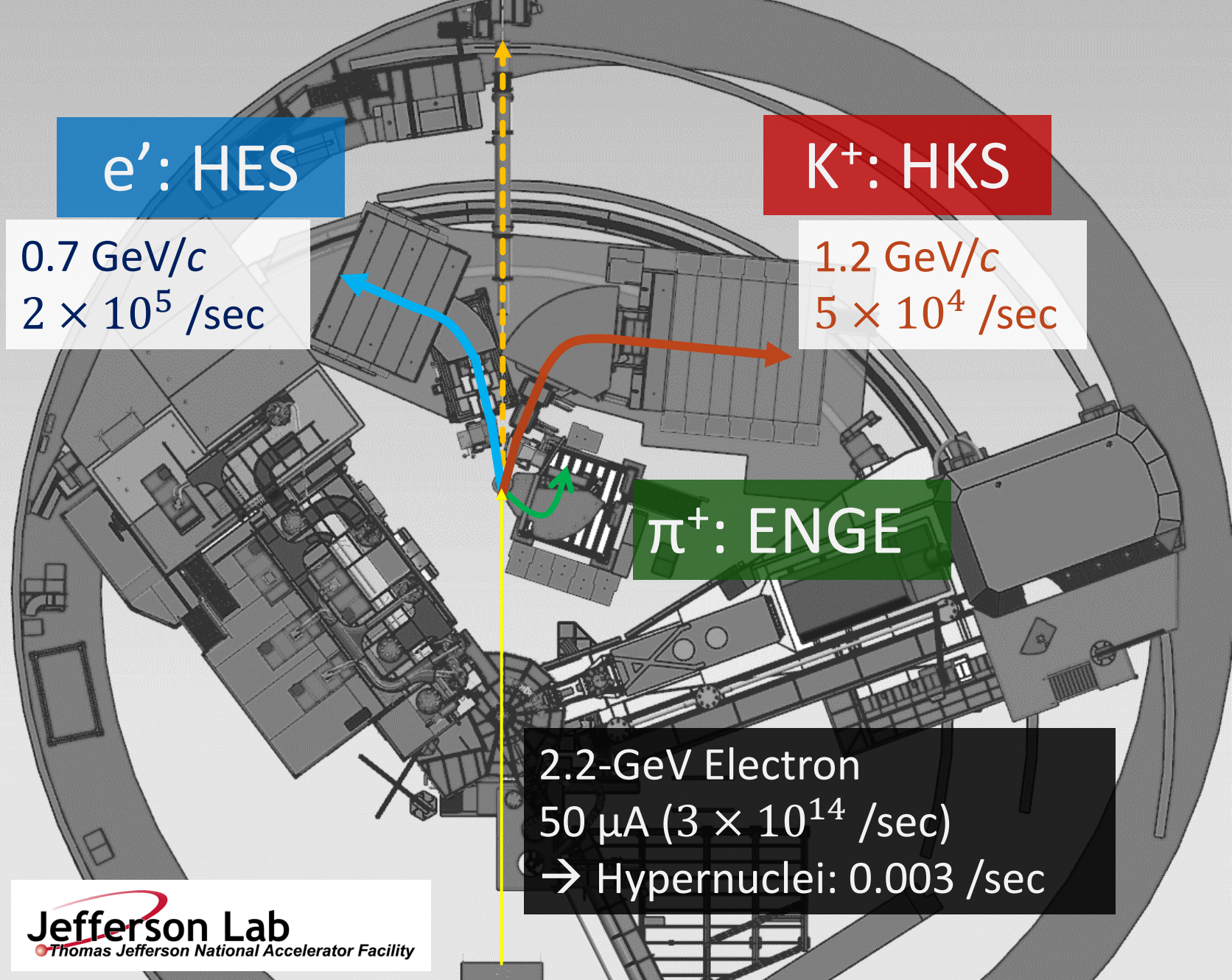
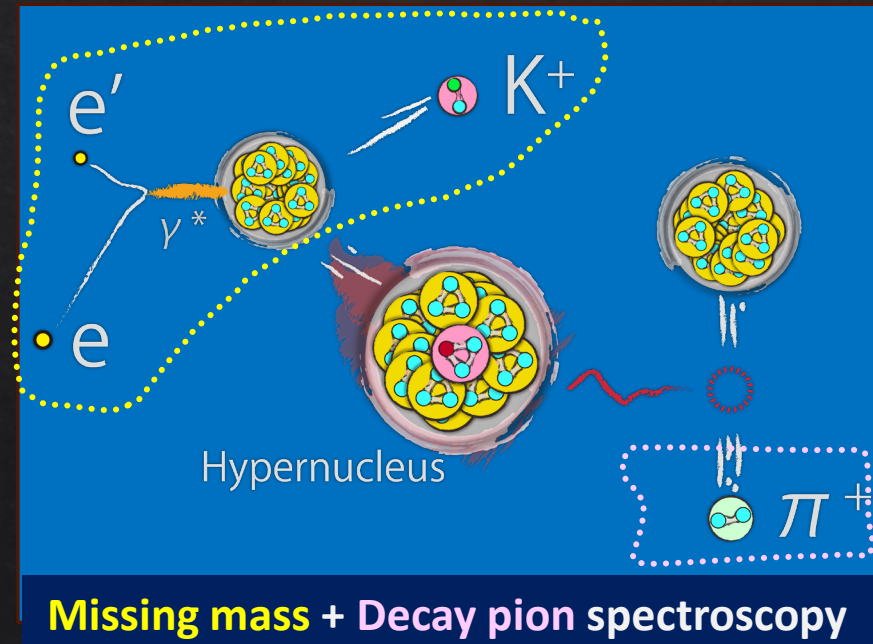
New experiment at JLab Hall-C (2027~)

- High resolution: 0.6 MeV FWHM
- High accuracy: 0.07 MeV
- Wide mass number: $A = 6\text{--}208$



New experiment at JLab Hall-C (2027~)

- High resolution: 0.6 MeV FWHM
- High accuracy: 0.07 MeV
- Wide mass number: $A = 6\text{--}208$

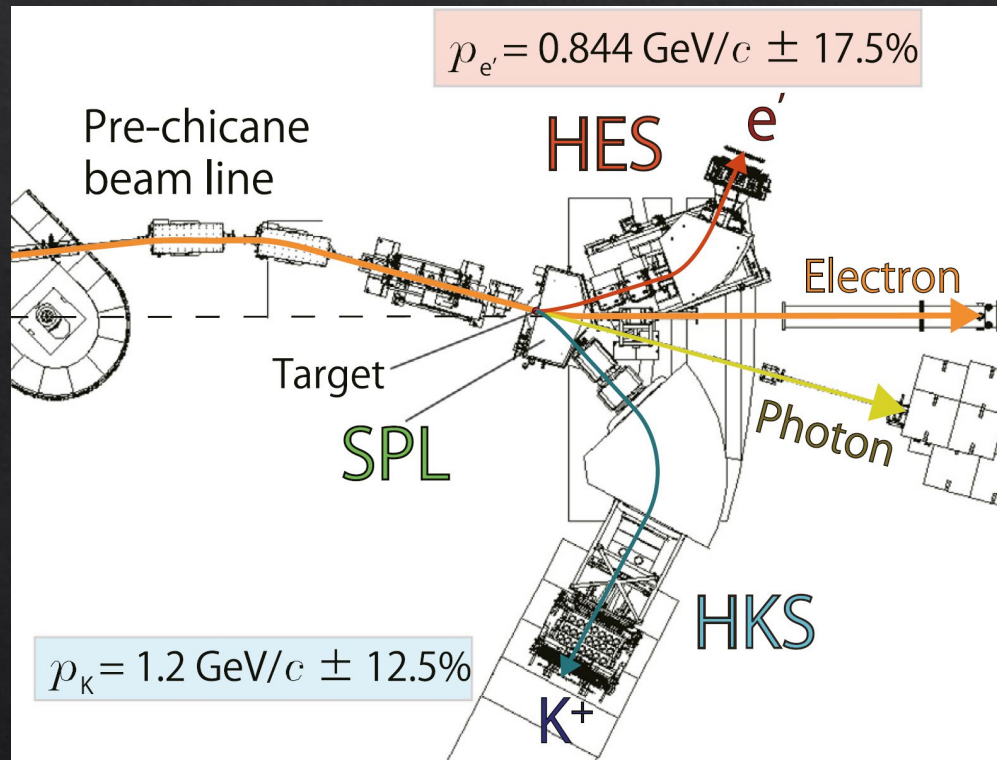


Jefferson Lab
Thomas Jefferson National Accelerator Facility

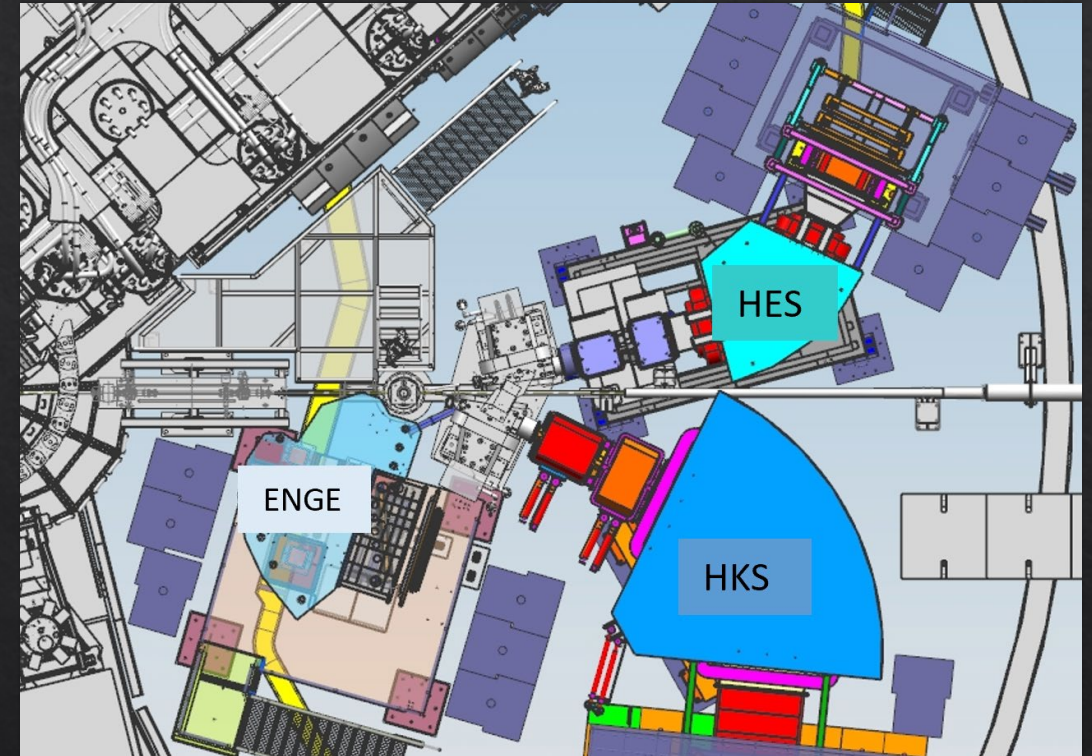
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T. Gogami (Kyoto Univ.), HYP2025, U. Tokyo, Tokyo, Japan, Oct 2, 2025

To realize heavier hypernuclear measurements



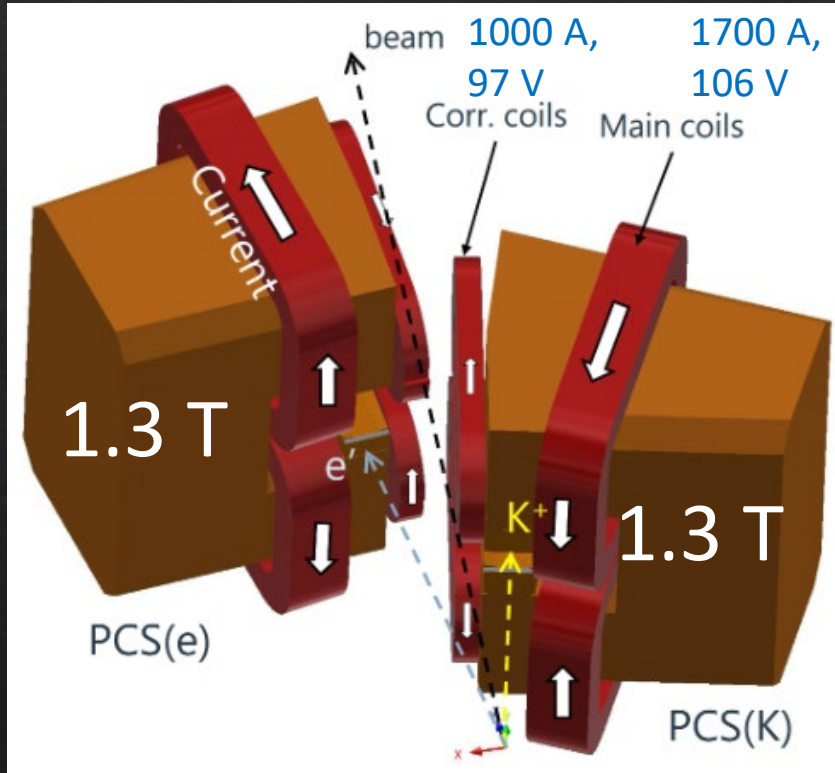
T. Gogami et al., NIMA 900, 69—83 (2018)



**e^+ contamination is eliminated →
Better S/N**

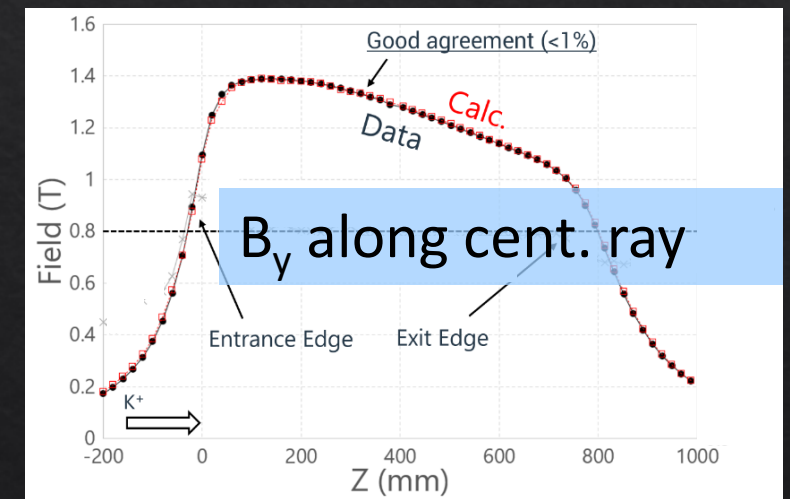
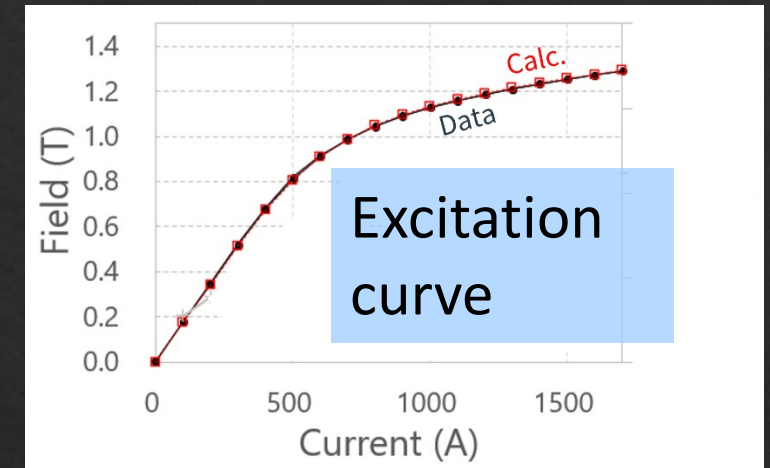
New magnet PCS

(Pair of charge separation dipole magnets)



Shipping

Measurement vs. TOSCA calc.

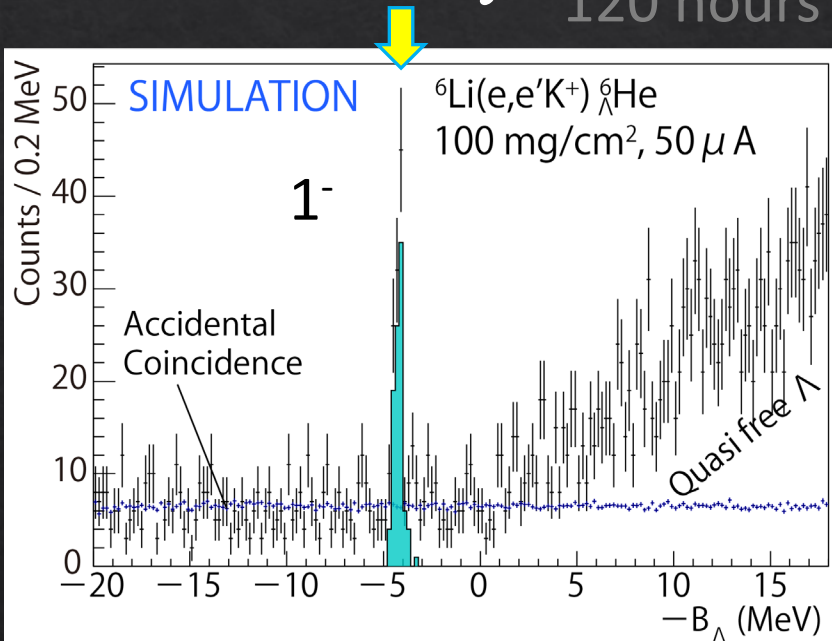


It worked as expected !!

Expected Spectra (JLab E12-24-004)

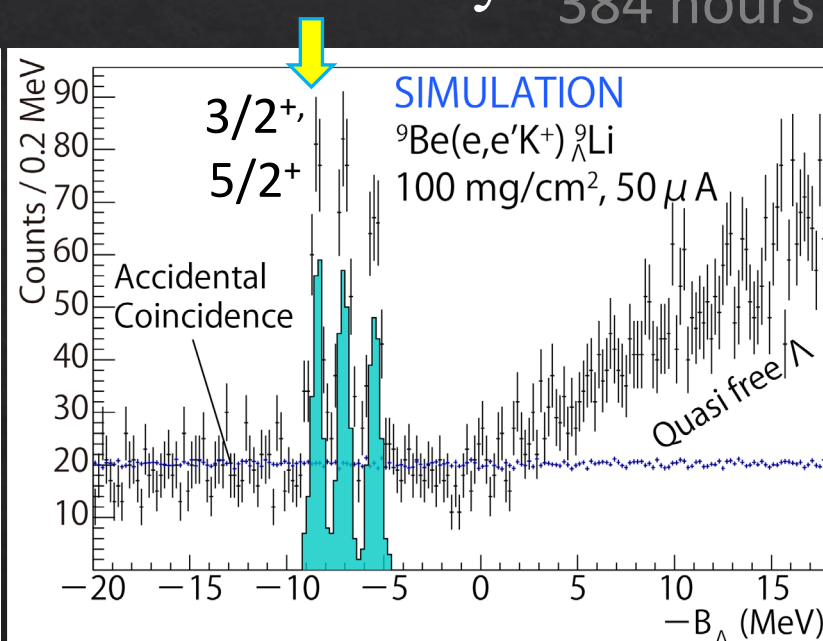
for CSB study

120 hours



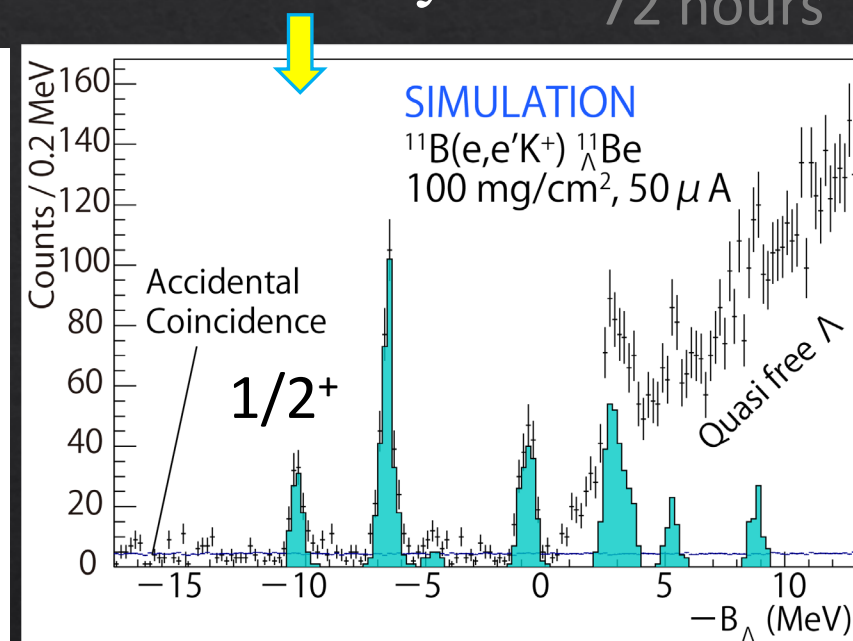
for CSB study

384 hours



for CSB study

72 hours



Total accuracy:

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

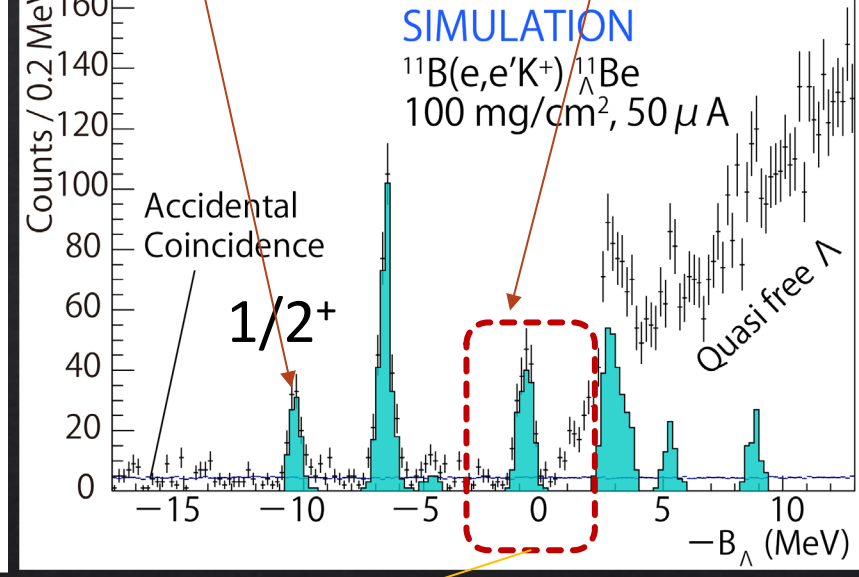
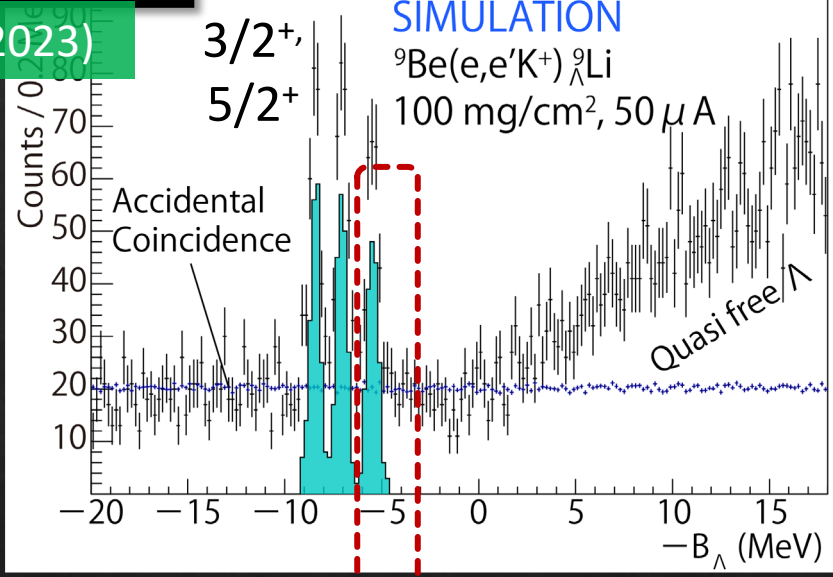
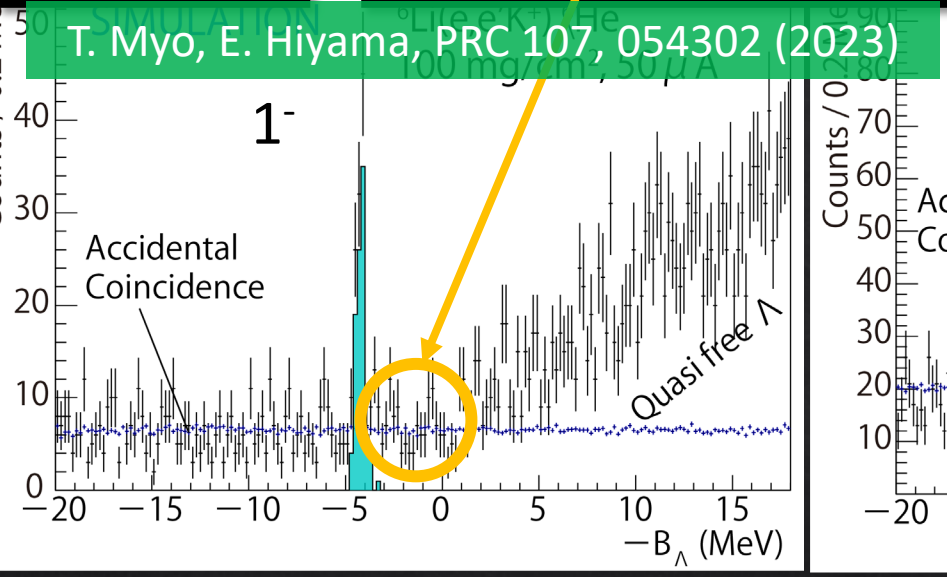
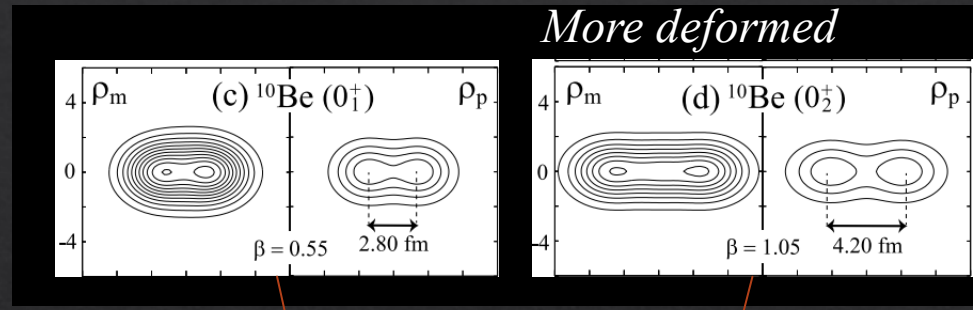
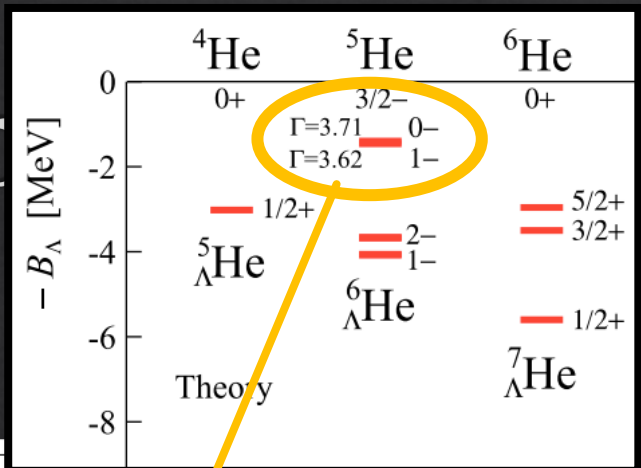
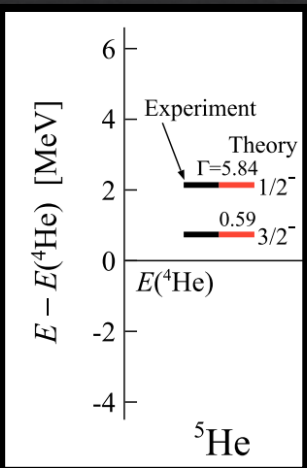
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Total accuracy:
 $|\Delta B_\Lambda^{\text{total}}| \leq 70 \text{ keV}$

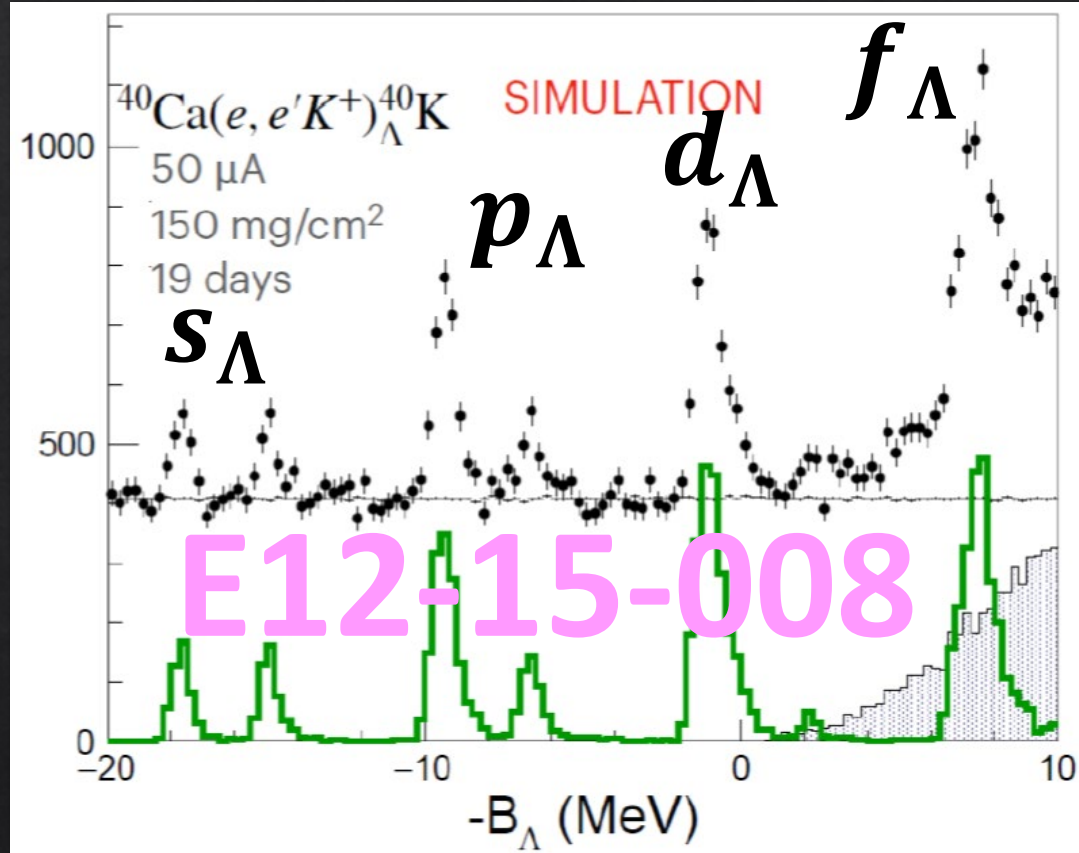
c.f.) [TG et al., PRC 103, L041301 \(2021\)](#)

[M. Isaka et al., PRC 92, 044326 \(2015\)](#)

Cluster / deformation structures

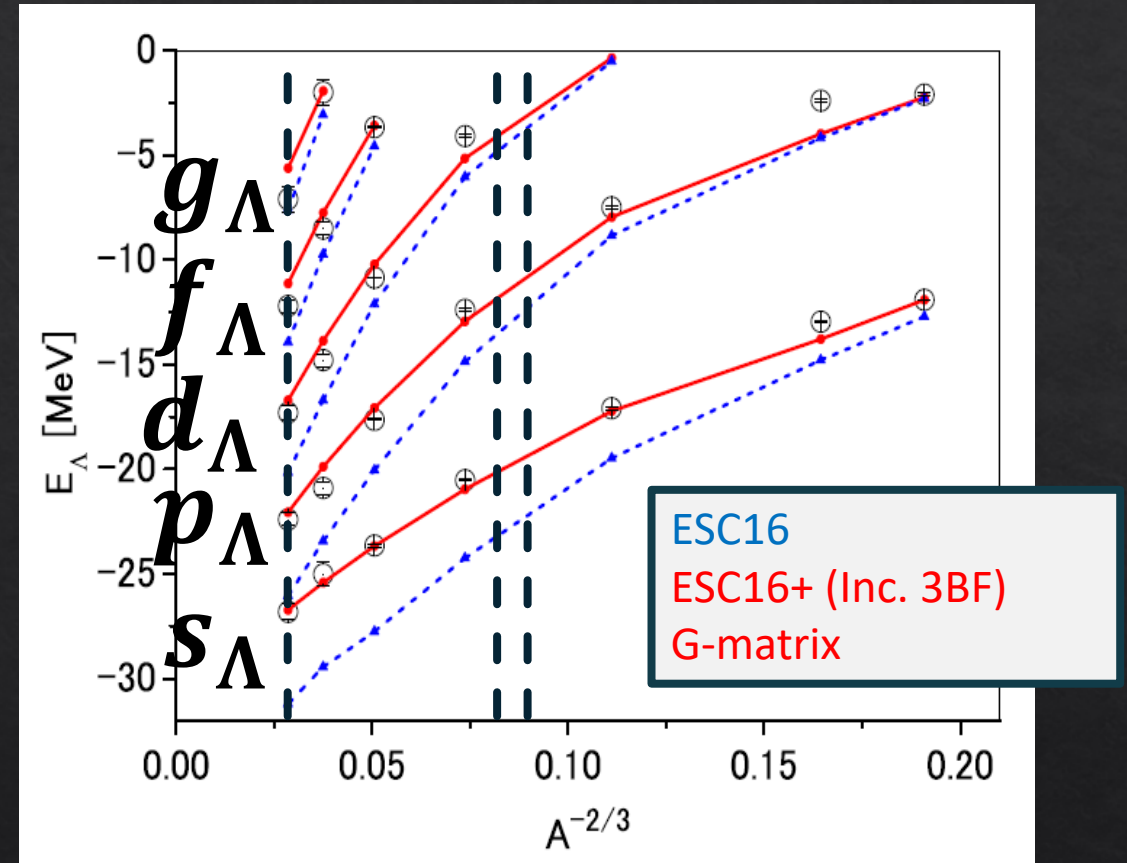
High accuracy experiment → 3-body force study

Expected spectrum based on Geant4 simulation



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

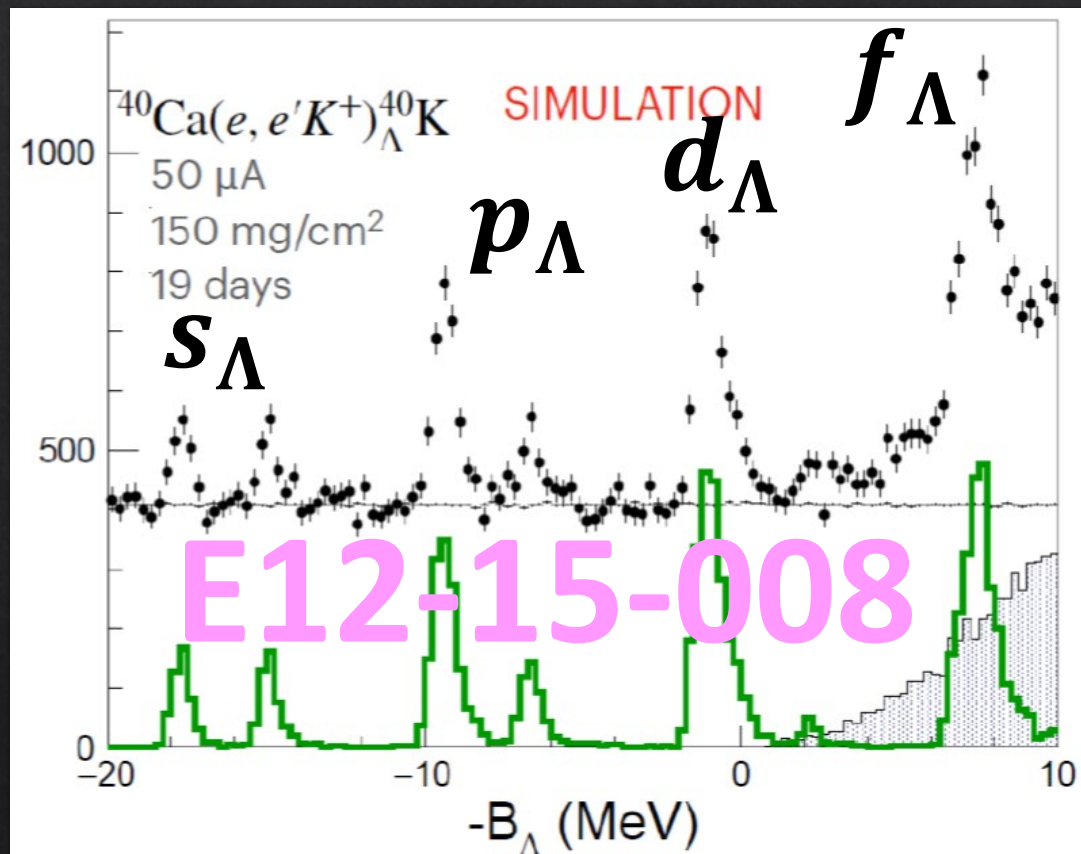
M.M. Nagels et al., PRC 99 (2019) 044003.



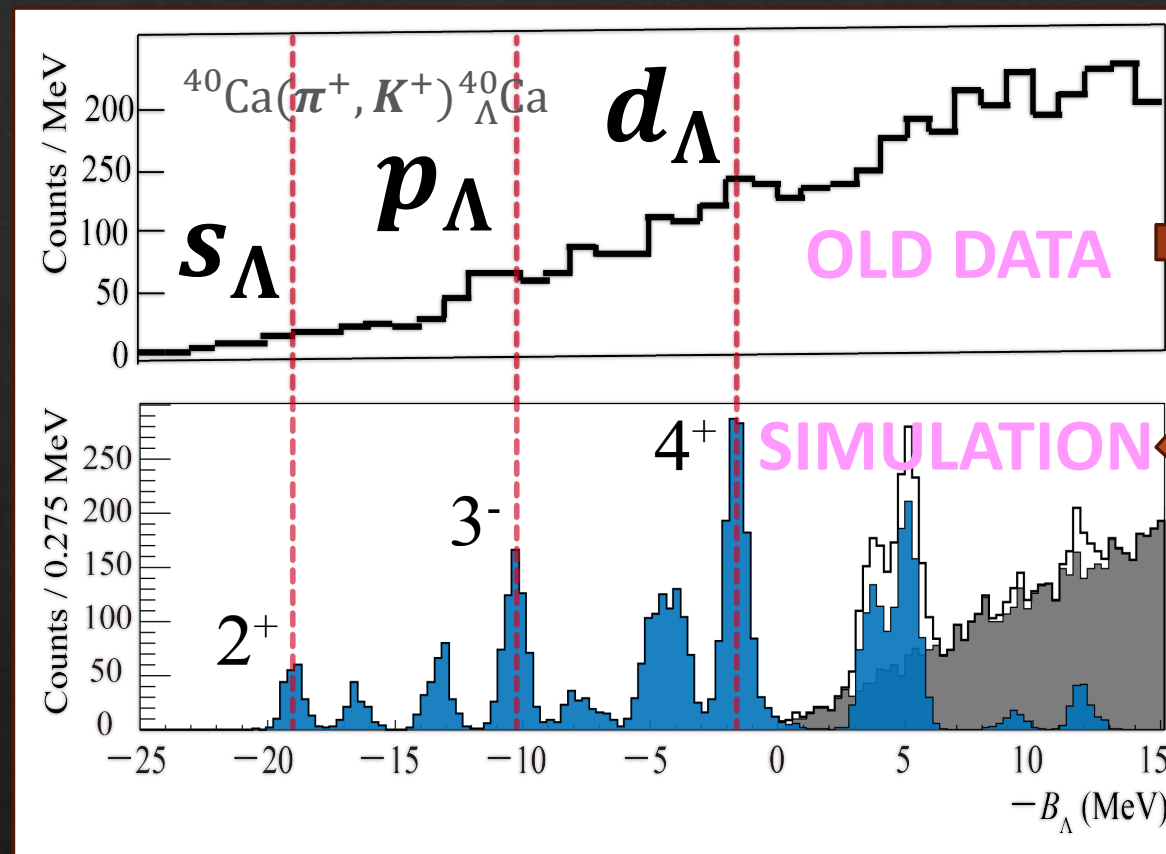
New information for 3-body force

$^{40}_{\Lambda}\text{K}$ (JLab) and $^{40}_{\Lambda}\text{Ca}$ (J-PARC) $\rightarrow$ CSB in medium heavy mass

HES-HKS at JLab ($^{40}_{\Lambda}\text{K}$)



S-2S at J-PARC ($^{40}_{\Lambda}\text{Ca}$)



Simulation based on T. Motoba et al., PRC 38, 3 (1988)

Summary

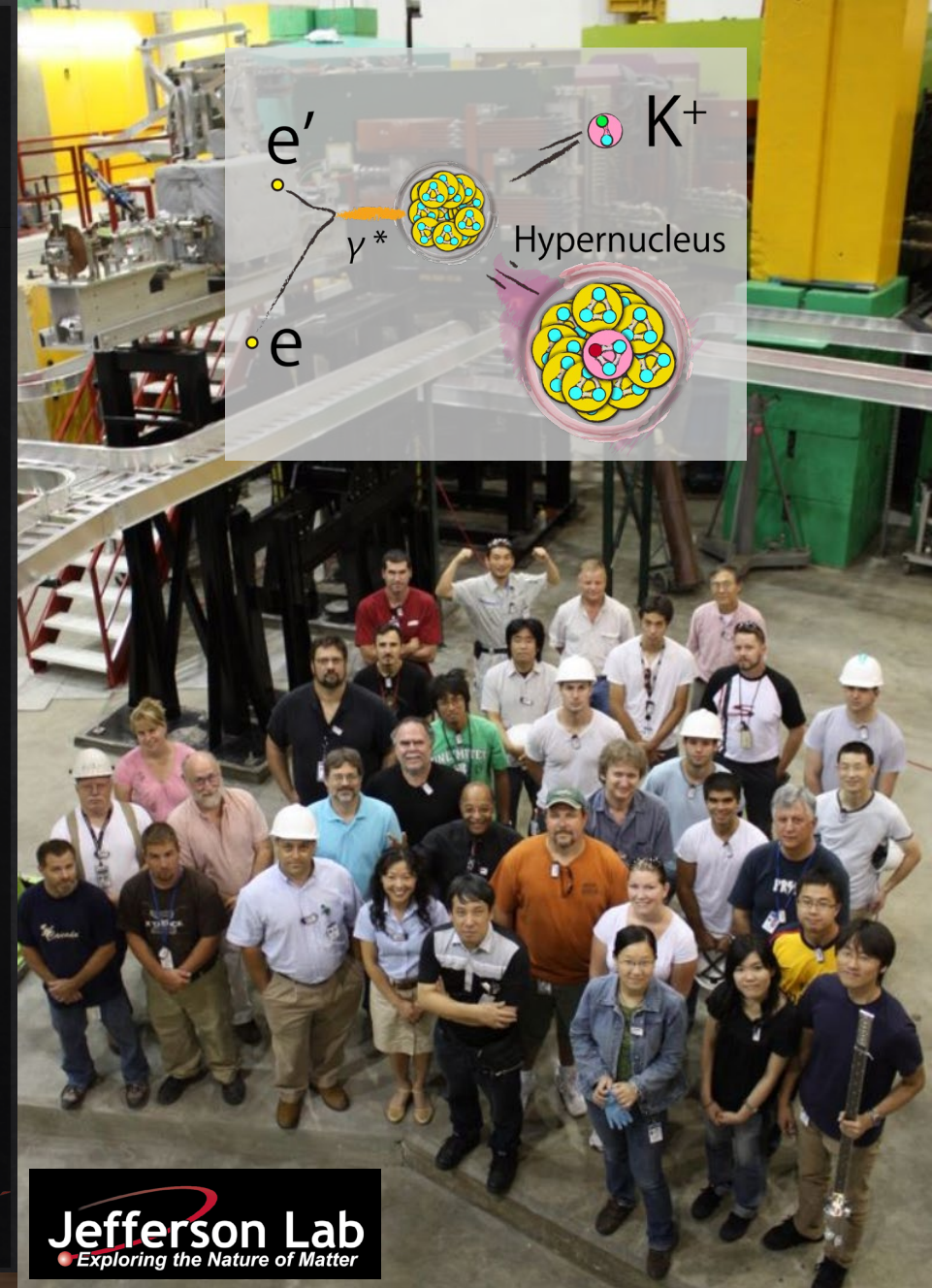
Λ hypernuclear spectroscopy

- ◇ Baryon interaction (YN, YNN)

JLab Hypernuclear Collaboration

- ◇ $(e, e' K^+)$ reaction $\rightarrow$ High resolution/accuracy spectroscopy
- ◇ The method was established at JLab
- ◇ Future experiment (${}^3_{\Lambda}\text{H}$, ${}^4_{\Lambda}\text{H}$, ${}^6_{\Lambda}\text{He}$, ${}^{11}_{\Lambda}\text{Be}$, ${}^{27}_{\Lambda}\text{Mg}$, ${}^{40}_{\Lambda}\text{K}$, ${}^{48}_{\Lambda}\text{K}$, ${}^{208}_{\Lambda}\text{Tl}$)
 - ◇ hypertriton puzzle (binding energy vs. lifetime)
 - ◇ Charge symmetry breaking
 - ◇ (Triaxially) deformation
 - ◇ Λ N- Σ N coupling
 - ◇ iso-spin dependence of Λ NN force

2027~



Jefferson Lab
Exploring the Nature of Matter



GRADUATE SCHOOL OF
FACULTY OF SCIENCE
KYOTO UNIVERSITY

Thank you for your attention

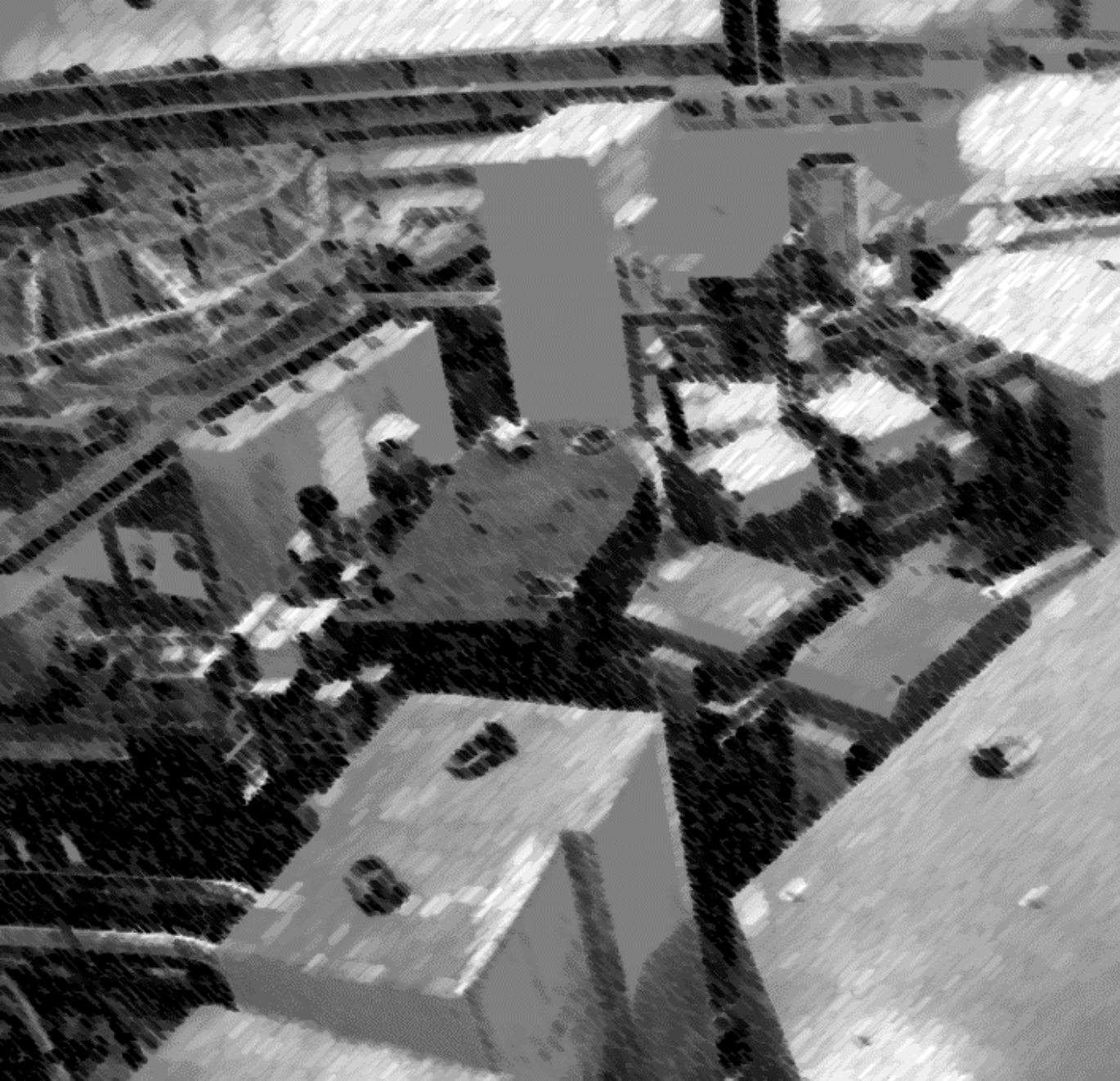


JLab Hypernuclear Collaboration Meeting 2025 (May 2025, JLab)
<https://indico.jlab.org/event/931/>



Backup





Hall A

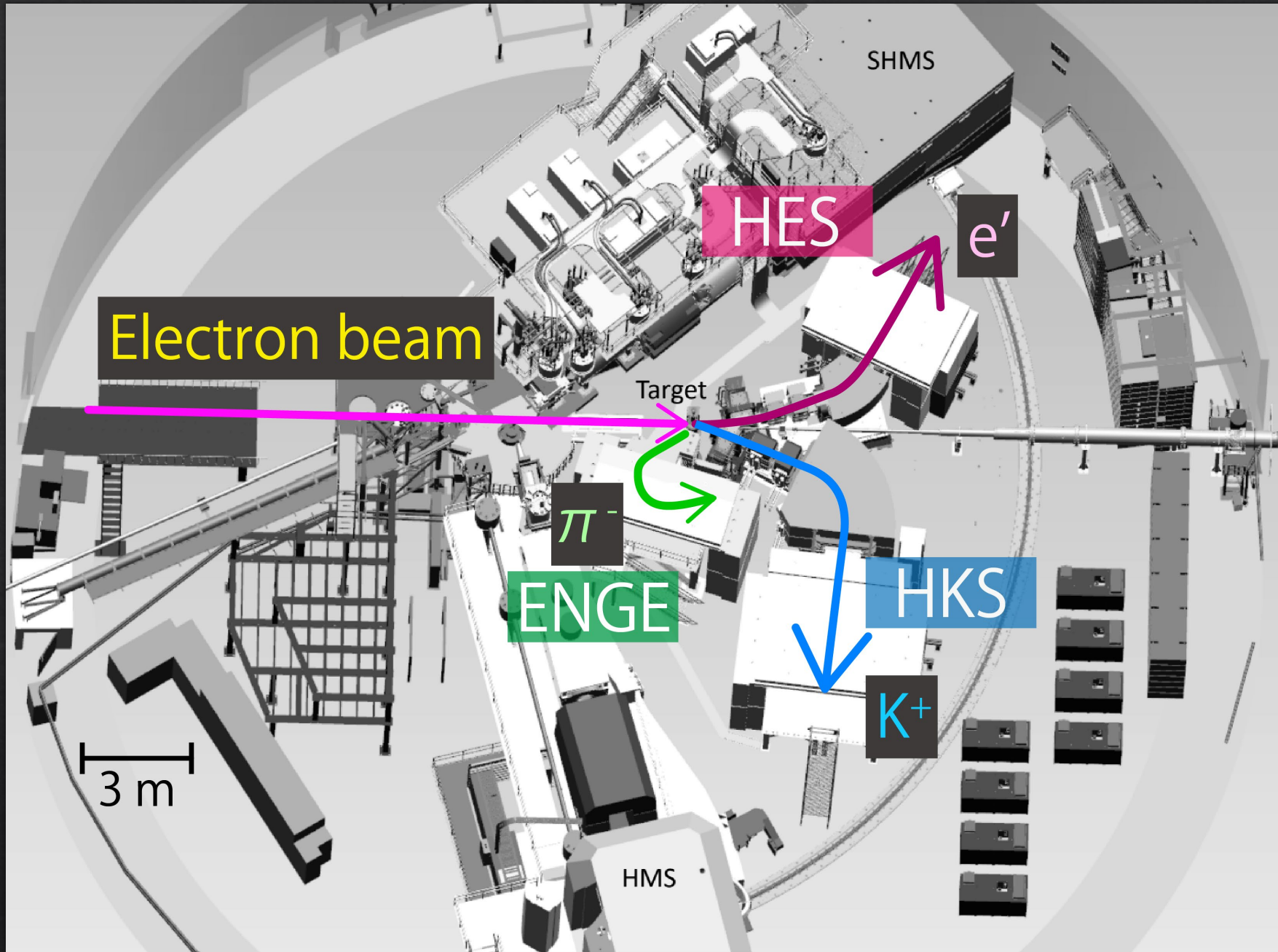
- K. Okuyama et al., PRC 110, 025203 (2024)
- B. Pandey et al., PRC 105, L051001 (2022)
- K.N. Suzuki et al., PTEP 2022, 1, 013D01 (2022)
- F. Garibaldi et al., PRC 99, 054309 (2019)
- G. M. Urciuoli et al., PRC 91, 034308 (2015)
- F. Cusanno et al., PRL 103, 202501 (2009)
- G. M. Urciuoli et al., NIMA612, 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 setup



Experimental setup

- High resolution: 0.6 MeV FWHM
- High accuracy: 0.07 MeV
- Wide mass number: $A = 6\text{--}208$

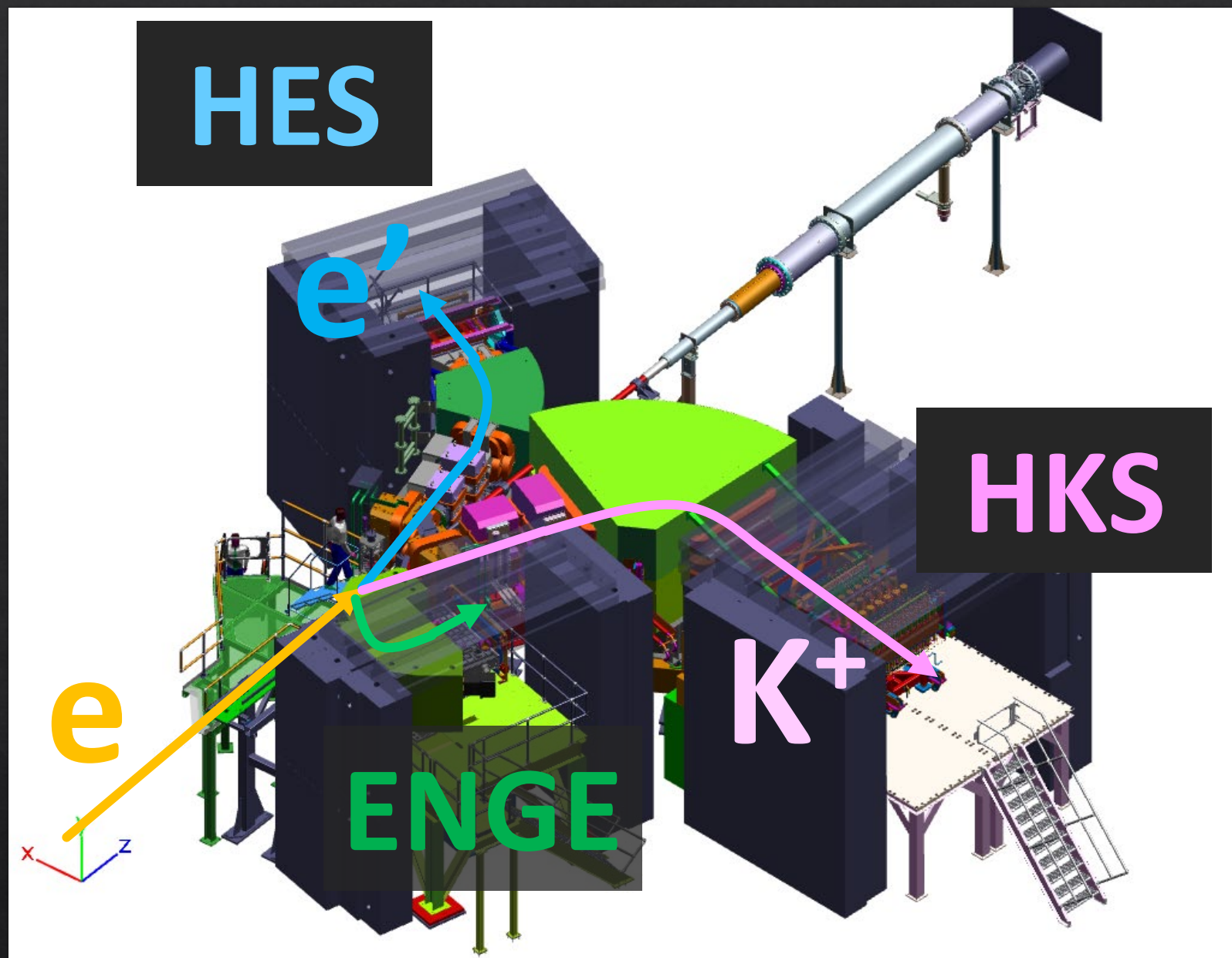
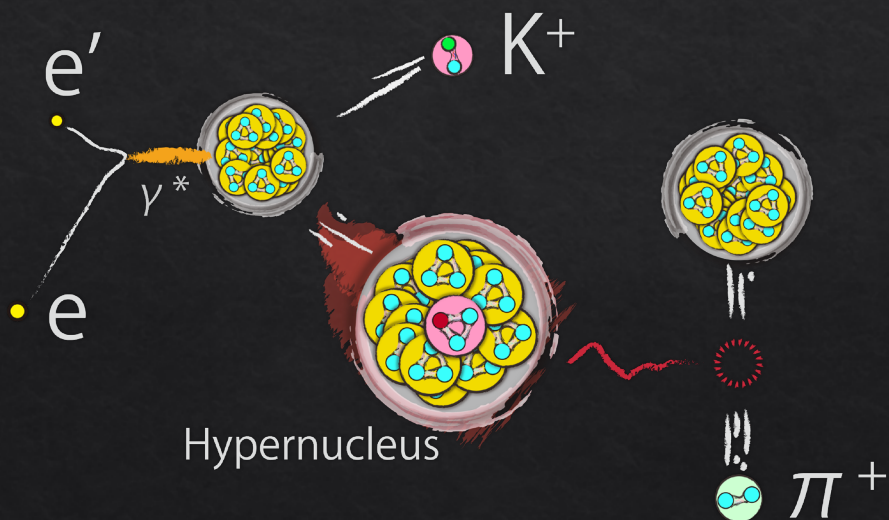


Figure from J. Shiflett's talk, <https://indico.jlab.org/event/931/>



High Precision Spectroscopy of Light Lambda hypernuclei at Jefferson Lab
T. Gogami (Kyoto Univ.), HYP2025, U. Tokyo, Tokyo, Japan, Oct 2, 2025



Kinematic parameters

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

Optimal for Λ and Σ^0

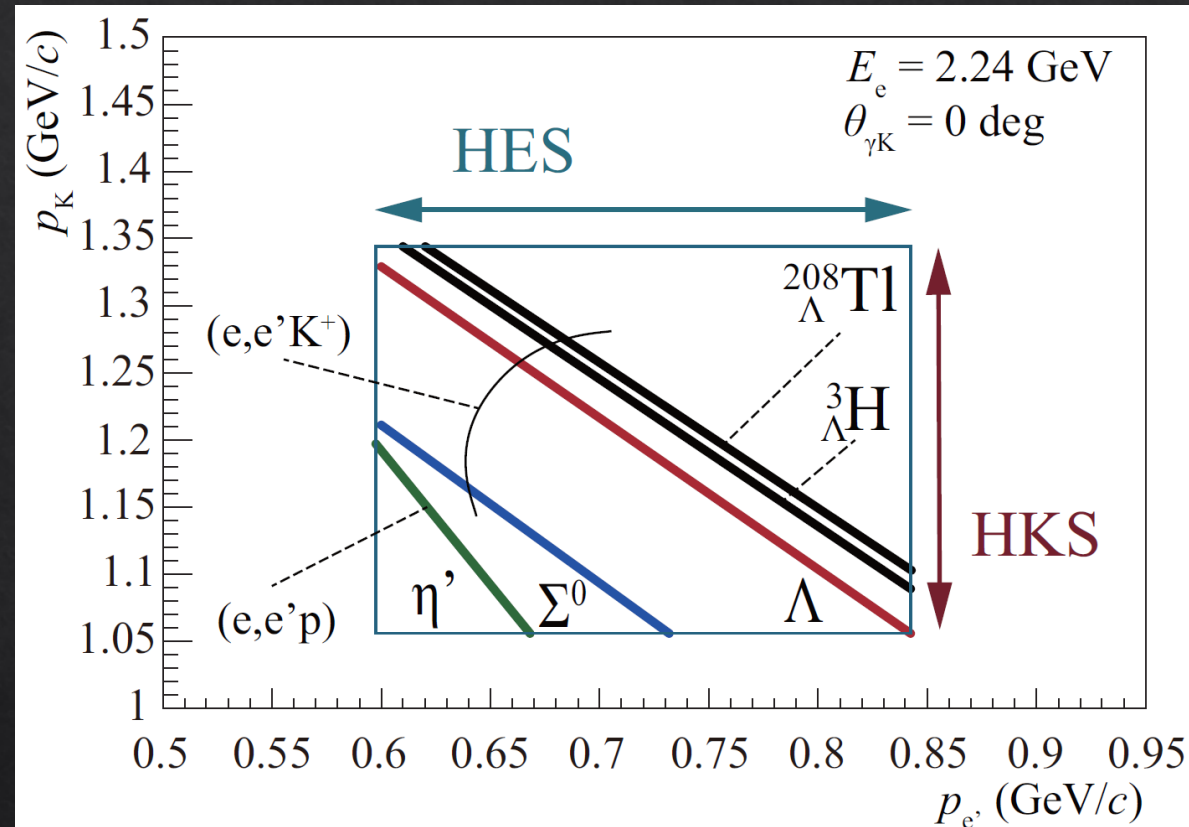
Small Q^2

→ Almost real photon

Forward angle

→ Large cross section

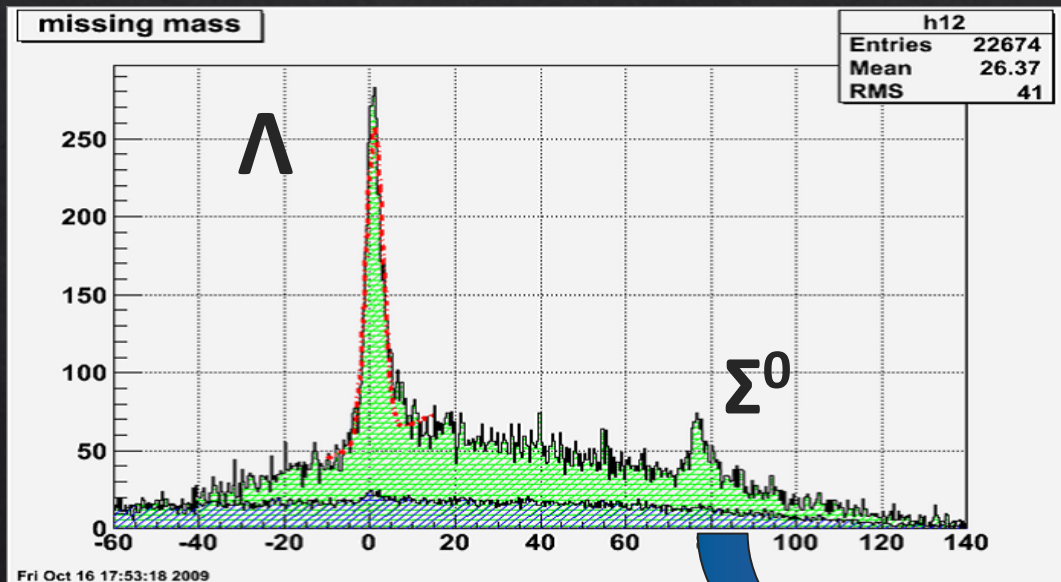
High accuracy measurement by good calibration



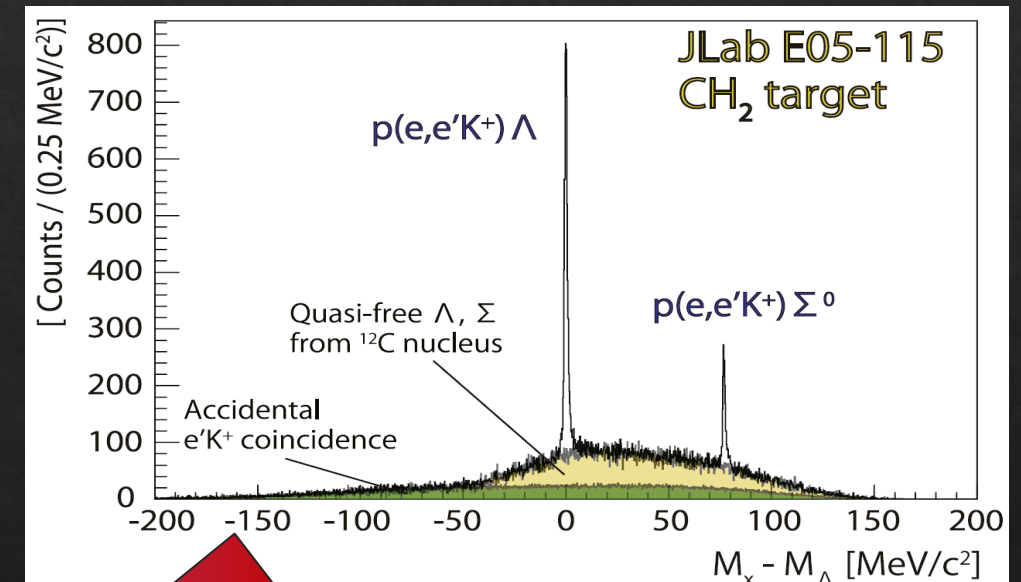
→ Good calibration ♡

Backward transfer matrix optimization

4 MeV (FWHM)



1.5 MeV (FWHM)



TG et al., NIMA 900 (2018) 69–83

Experimental target → D. Meekins

Material	Thickness / (mg/cm ²)	Length in radiation Length	Beam time /hours	Beam current /μA	Remark
CH ₂	450	10.1×10^{-3}	144	2	Energy calibration, Raster 2×2 mm ²
⁶ Li	100	1.40×10^{-3}	120	50	E12-24-004, Raster 2×2 mm ²
⁹ Be	100	1.53×10^{-3}	384	50	E12-24-004
¹¹ B	100	1.87×10^{-3}	72	50	E12-24-004, B ₄ C
¹² C	150	2.34×10^{-3}	168	50	Energy calibration
¹² C hole	150	2.34×10^{-3}	-	10	Beam position check Raster 2×2 mm ²
²⁷ Al	150	6.24×10^{-3}	672	50	E12-24-011
⁴⁰ Ca	150	9.31×10^{-3}	456	50	E12-15-008/E12-24-013
⁴⁸ Ca	150	7.76×10^{-3}	552	50	E12-15-008/E12-24-013
²⁰⁸ Pb	150	23.5×10^{-3}	1000	25	E12-20-013/E12-24-003, Raster 2×2 mm ²

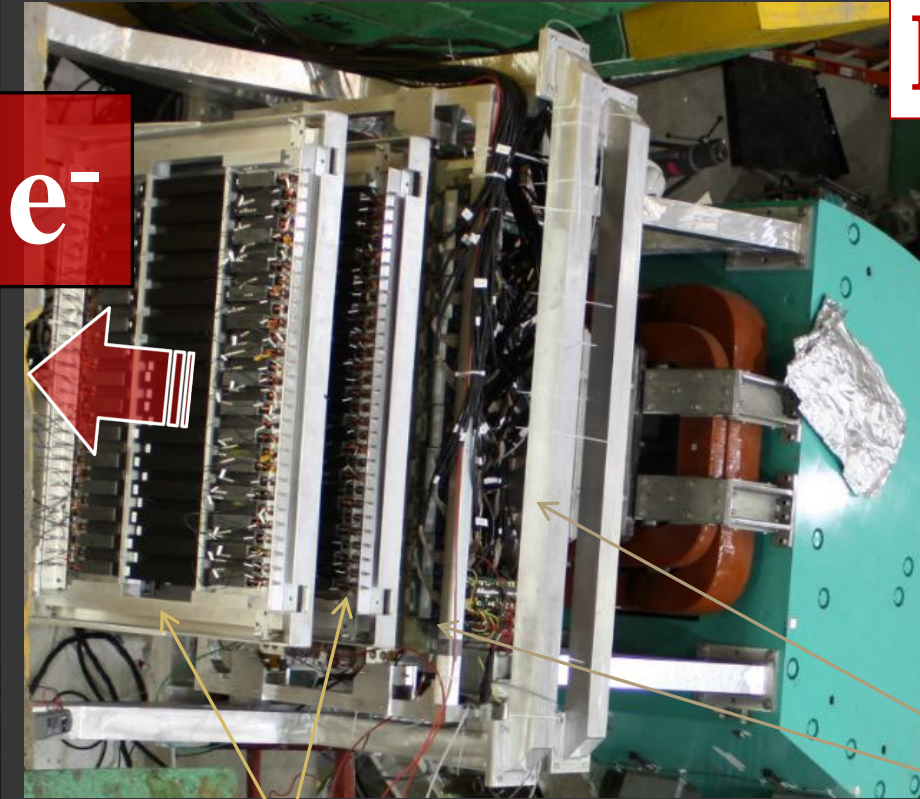
Particle Detectors

TG et al., NIMA 900, 69—83 (2018)

TG et al., NIMA 729, 816—824 (2013)

Cherenkov detectors

- Aerogel ($n=1.05$)
- Water ($n=1.33$) → K. Higashimoto

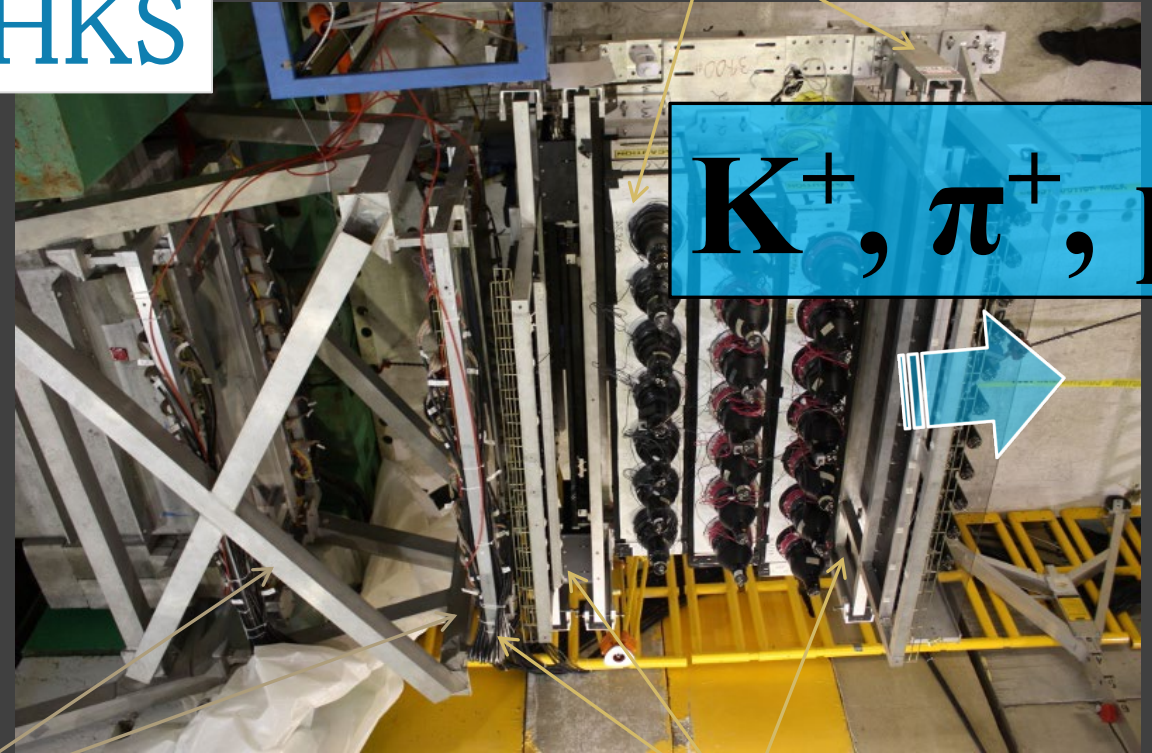


HES

HKS

TOF walls
(Plastic scintillators)

Drift chambers
→ L.Tang

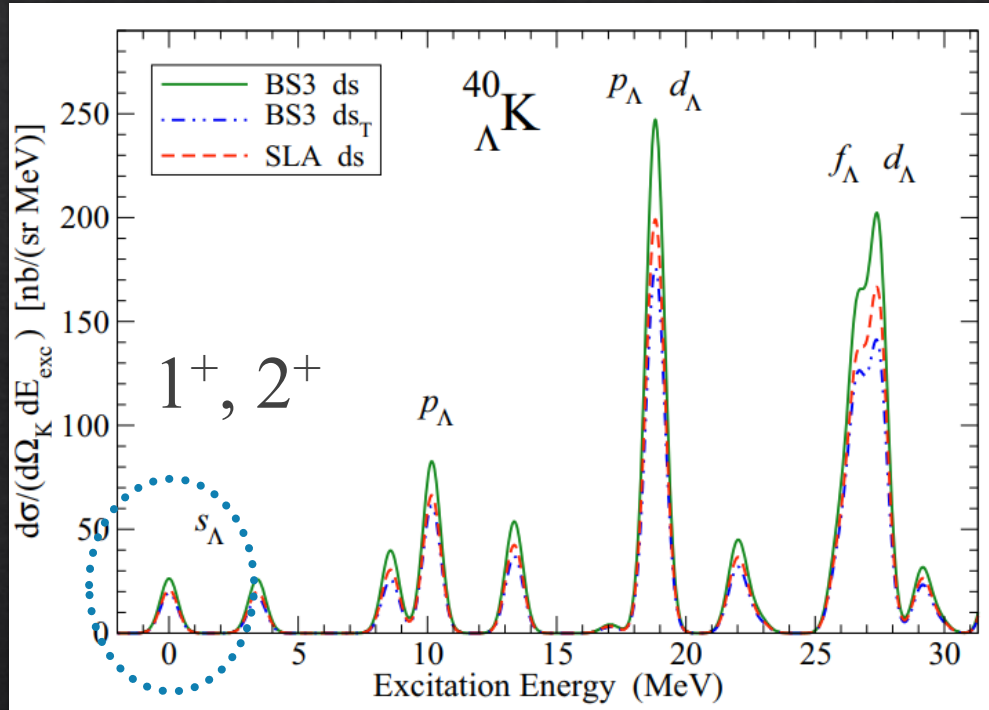


K^+ , π^+ , p

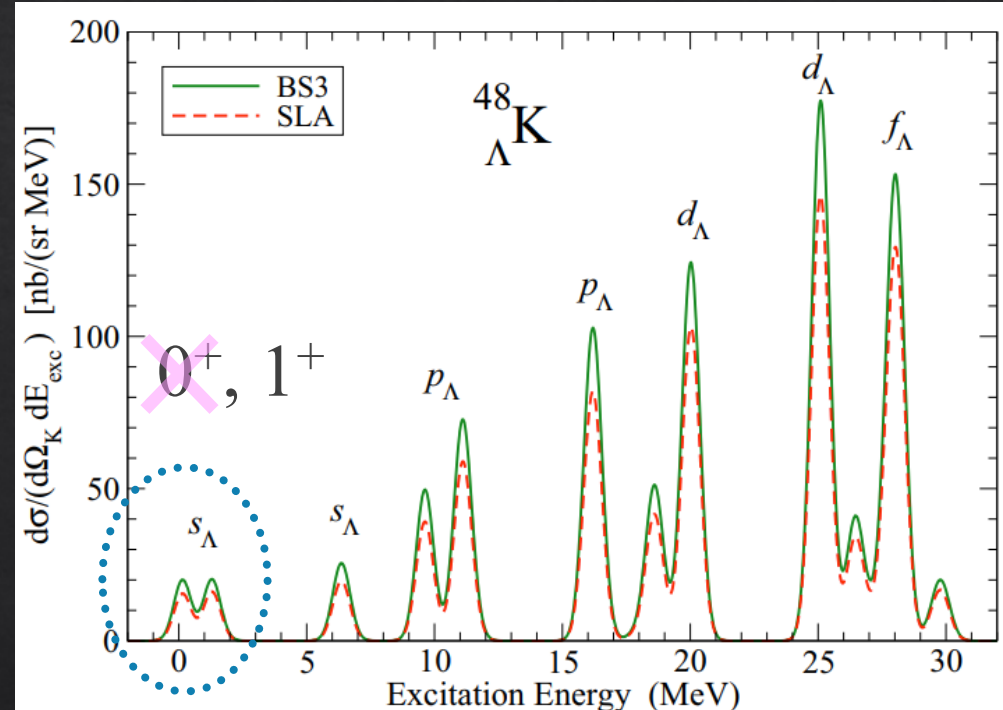
TOF walls
(Plastic scintillators)

Comparison between $^{40}_{\Lambda}\text{K}$ and $^{48}_{\Lambda}\text{K}$

P. Bydžovský et al., PRC **108**, 024615 (2023)



E_x (MeV)	J^P	s.p. states		Cross sections	
		p	Λ	SLA	BS3
0.000	1^+	$0d_{3/2}$	$0s_{1/2}$	4.47	7.55
0.004	2^+	$0d_{3/2}$	$0s_{1/2}$	13.43	14.84
3.417	1^+	$1s_{1/2}$	$0s_{1/2}$	17.02	21.77
8.570	3^+	$0d_{5/2}$	$0s_{1/2}$	17.34	24.53



E_x (MeV)	J^P	s.p. states		Cross sections	
		p	Λ	SLA	BS3
0.148	1^+	$1s_{1/2}$	$0s_{1/2}$	13.14	16.80
1.294	1^+	$0d_{3/2}$	$0s_{1/2}$	3.41	5.67
1.297	2^+	$0d_{3/2}$	$0s_{1/2}$	10.30	11.52
6.359	3^+	$0d_{5/2}$	$0s_{1/2}$	11.14	15.61
6.364	2^+	$0d_{3/2}$	$0s_{1/2}$	5.56	6.10

0^+ :
negligible