JLab Hall A meeting (Jan 21—22, 2021)

Future hypernuclear experiments with HKS

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Toshiyuki Gogami
for the ***JLab Hypernuclear Collaboration***

Jan 22, 2021

京都大学
KYOTO UNIVERSITY

@KUANS, Kyoto Univ. (2020)

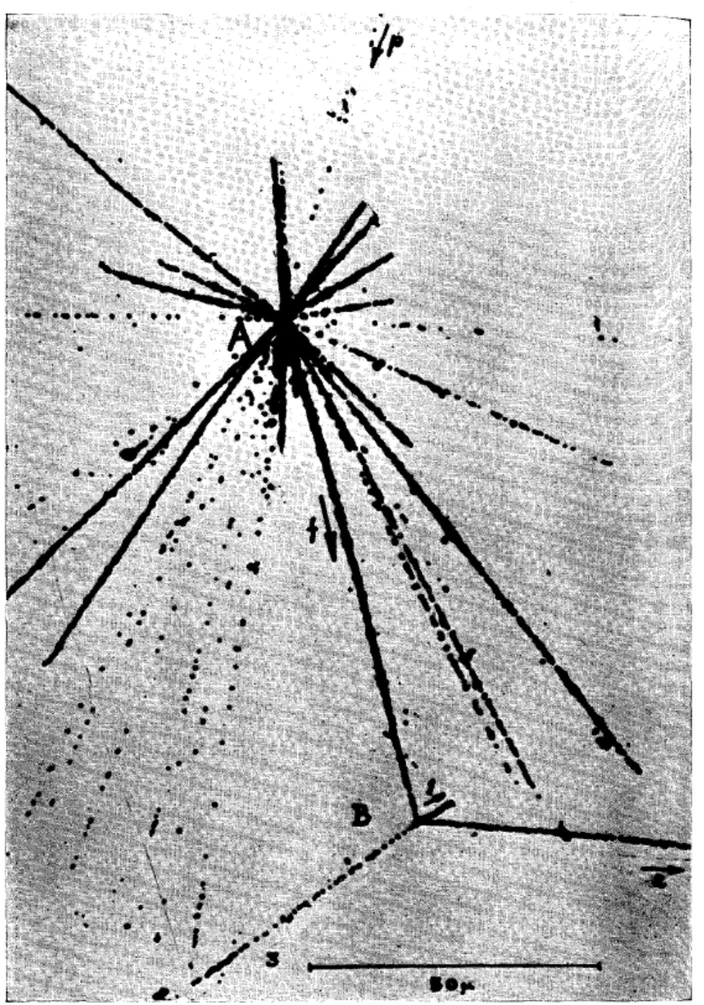
科研費
KAKENHI
SPIRITS
SUPPORTING PROGRAM FOR INTERACTION-BASED INITIATIVE TEAM STUDIES

CONTENTS

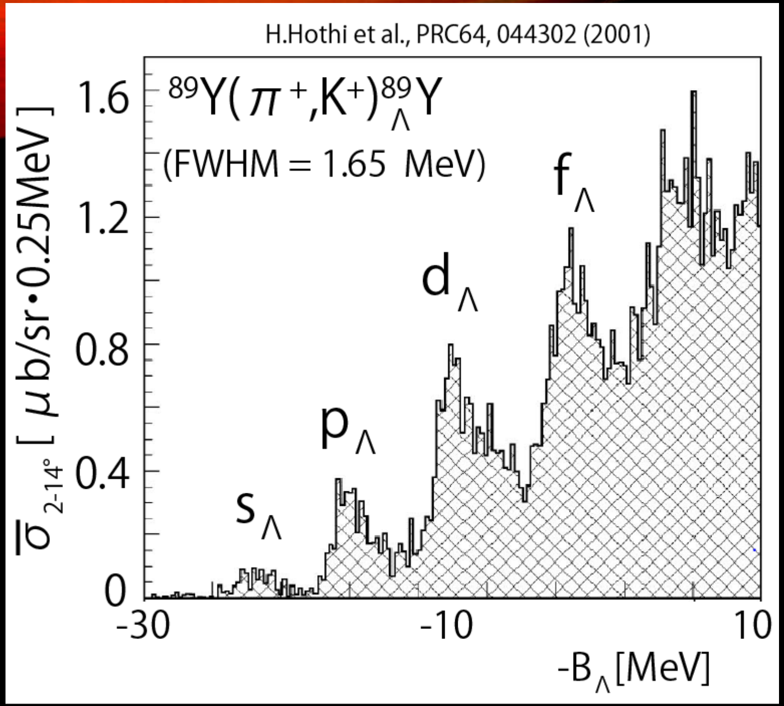
THE FIRST HYPERNUCLUS

A.K. Wroblewski,
Acta Physica Polonica B 35, 3 (2004).

The fist Λ hypernucleus in history



M. Danysz & J. Pniewski, Phil. Mag.
Ser. 7, 44, 14 (1953).


H.Hothi et al., PRC64, 044302 (2001)

WHAT WE CAN STUDY?

- YN / YY Interaction：Strong forces with different flavor from u and d
- Prove to investigate deep in nucleus：No Pauli Blocking from N
- Impurity effect：Deformation, Shrinkage

ROLE OF STRANGENESS IN HIGH-DENSITY HADRONIC MATTERS

- Hyperon appearance → Softening of EOS
- The EOS cannot hold $2M_\odot$ (Hyperon puzzle)
- YNN three-body force would be a key

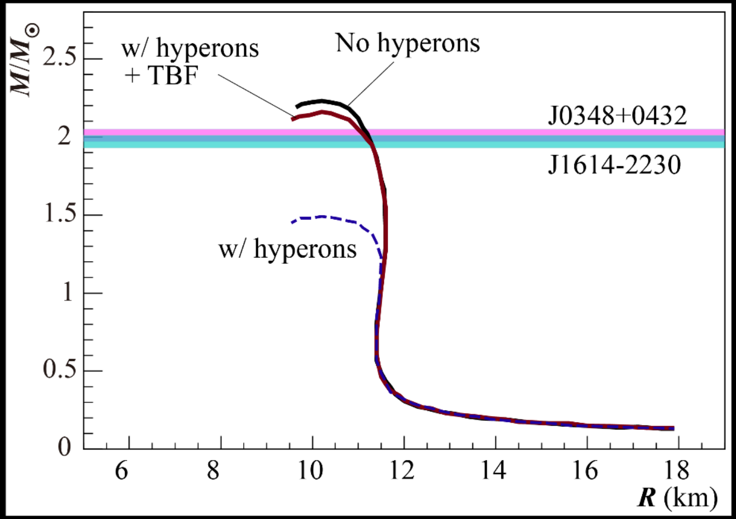
Terrestrial experiments

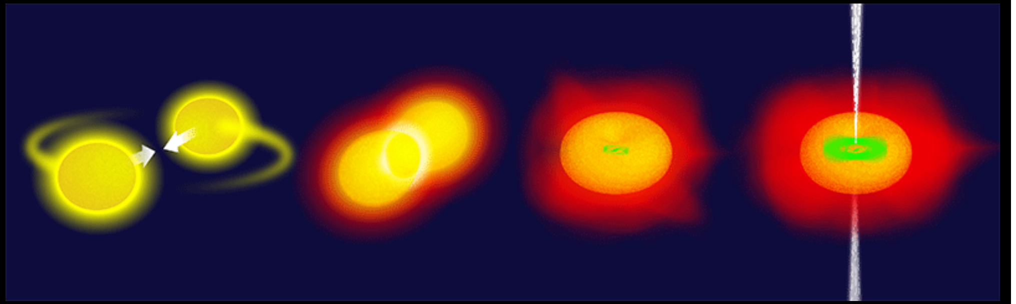
✓ BB interaction with strangeness degree of freedom

Astronomical observation

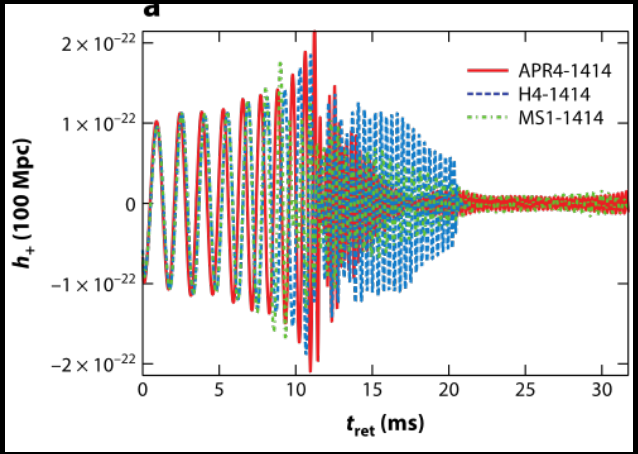
✓ Binary NS Mergers observed

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





B. P. Abbott et al., Phys. Rev. Lett. 119, 161101 (2017).

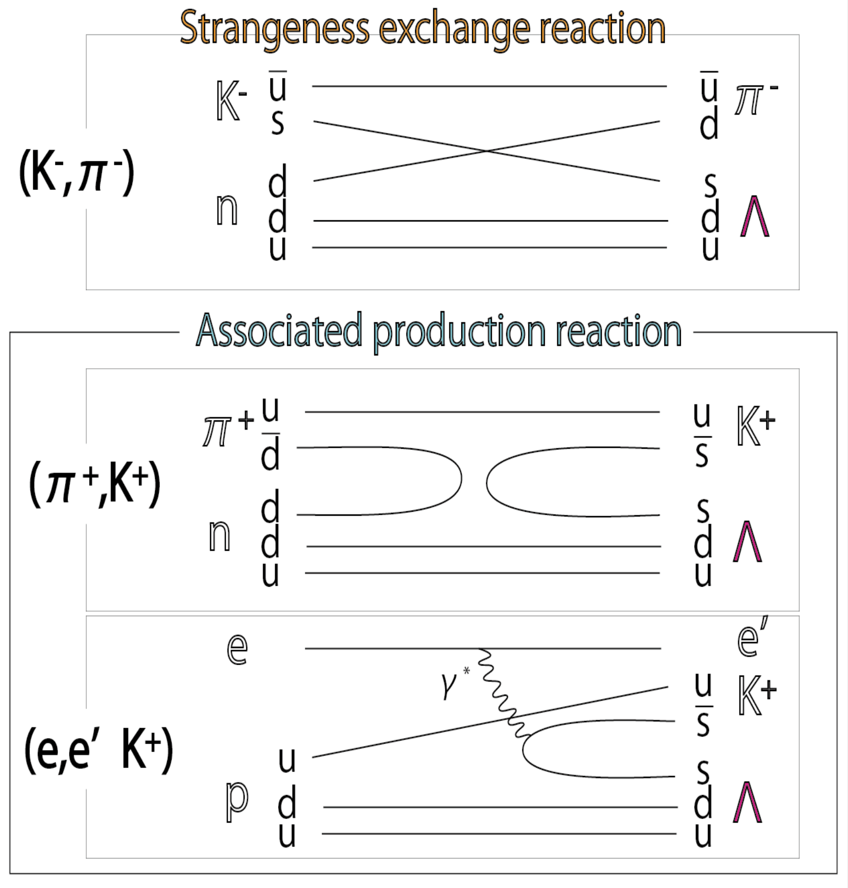


MAMI GSI
CERN FAIR

KEK
J-PARC

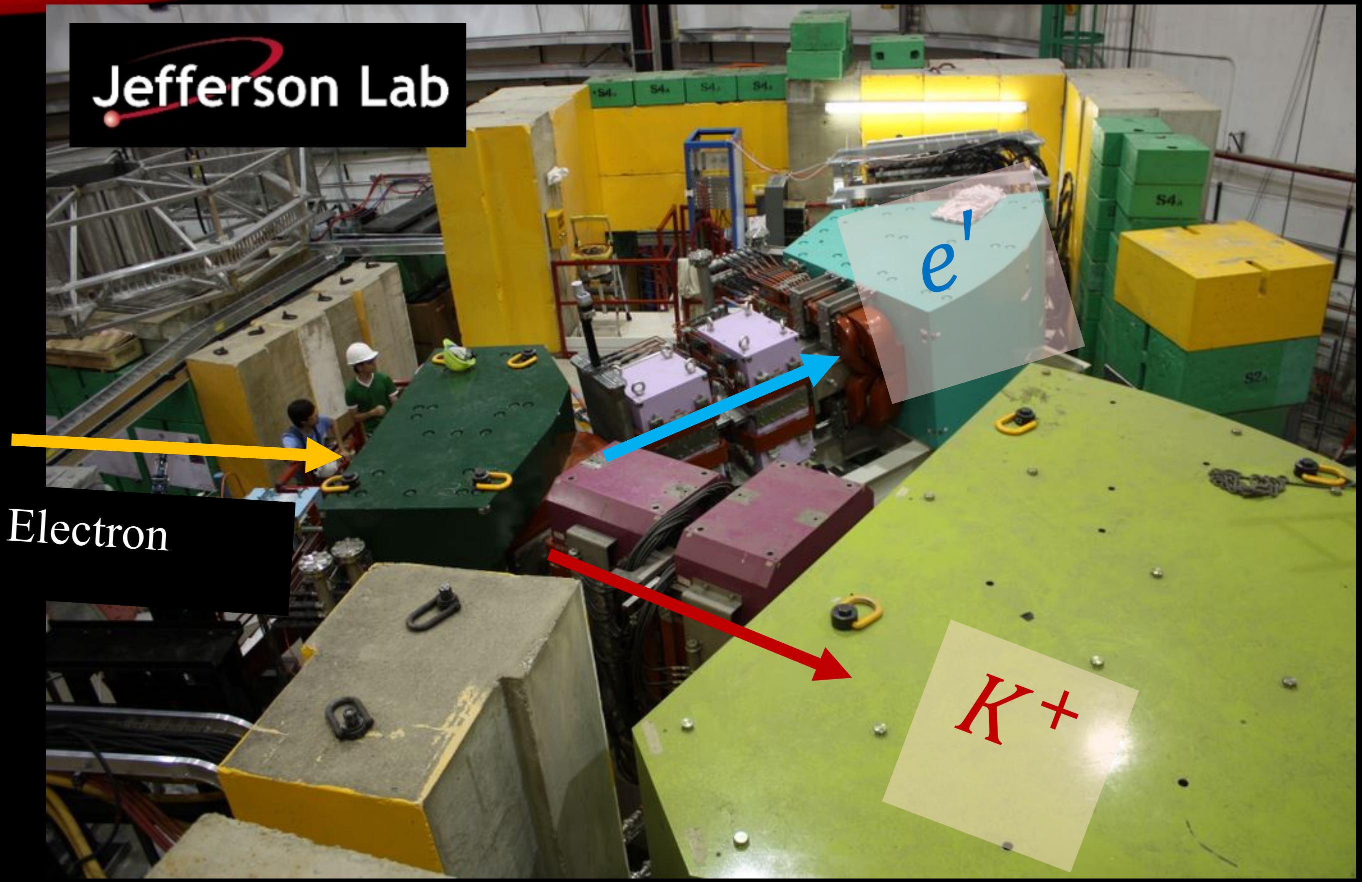
BNL
JLab

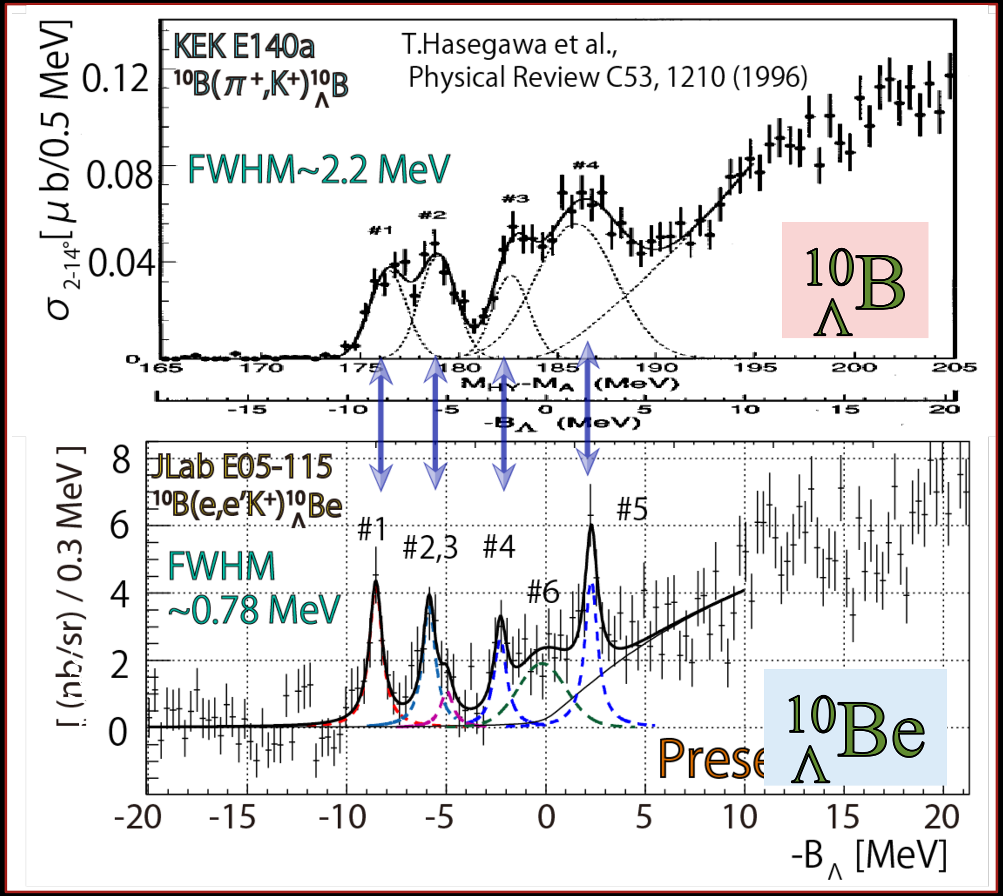
REACTIONS



<u>electron vs. hadron beams</u>

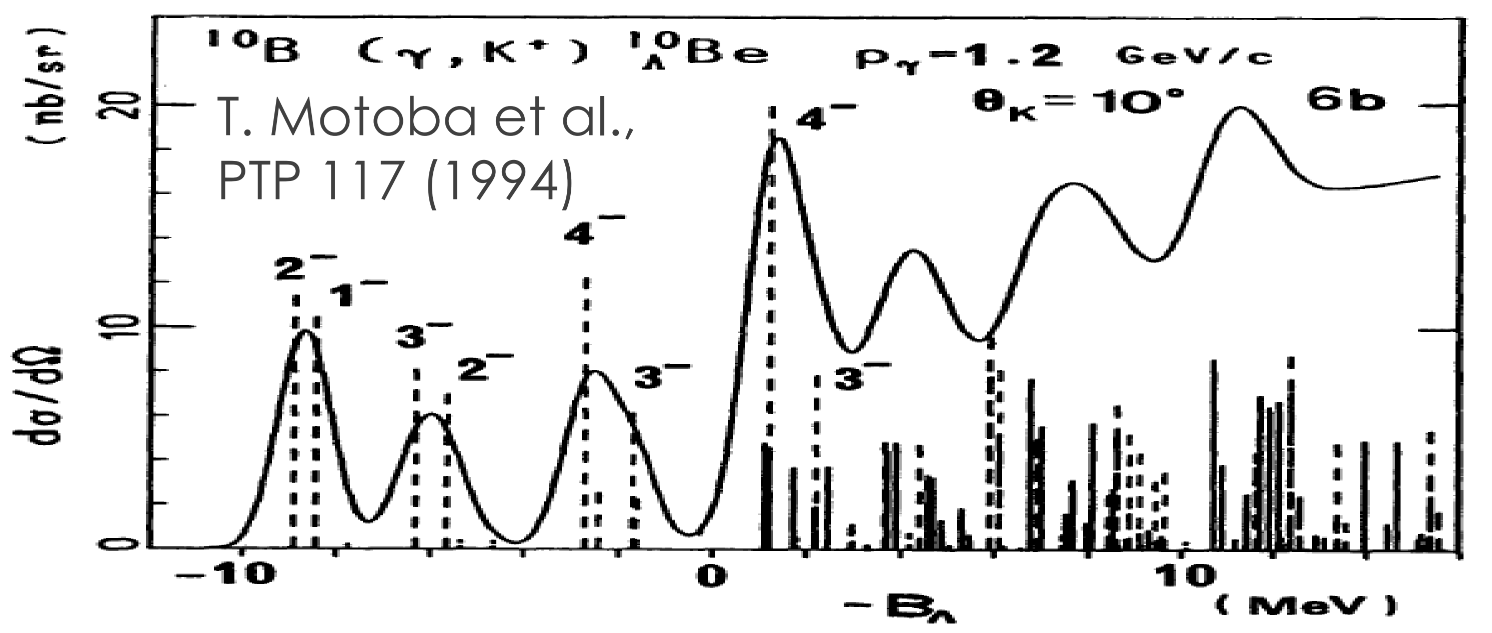
High precision measurement $^{10}_{\Lambda}$B and $^{10}_{\Lambda}$Be



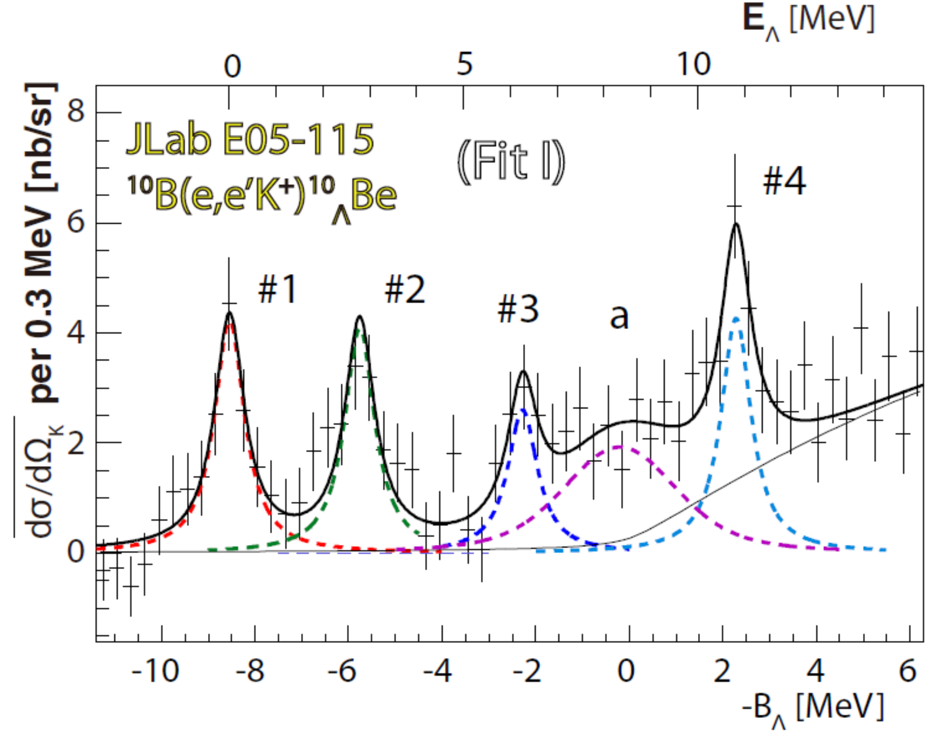


- ✓ High resolution
- ✓ High accuracy

RPC 93 (2016) 034314.



T. Motoba et al., PTP 117 (1994)



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

What's surplus, a ？

→ Conventional shell model did not predict the state

→ It was found that model space needs to be extended (A. Umeya et al., JPS Conf. Proc. 26, 023016 (2019)).

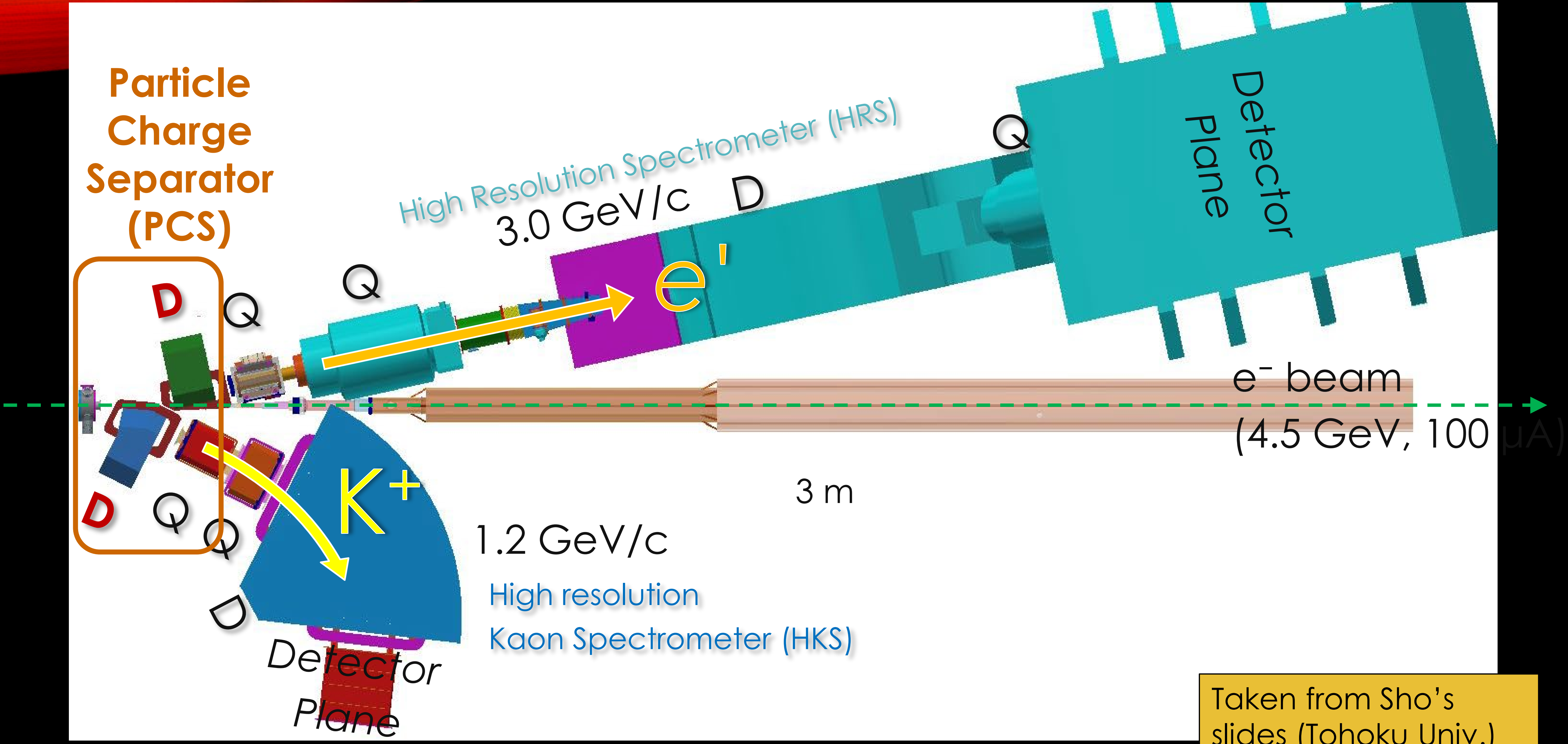
Future hypernuclear measurements that I am going to talk

① C12-19-002 ($^{3,4}_{\Lambda}\mathrm{H}$): hypertriton puzzle, CSB issue

② E12-15-008 ($^{40,48}_{\Lambda}\mathrm{K}$): ΛNN isospin interaction

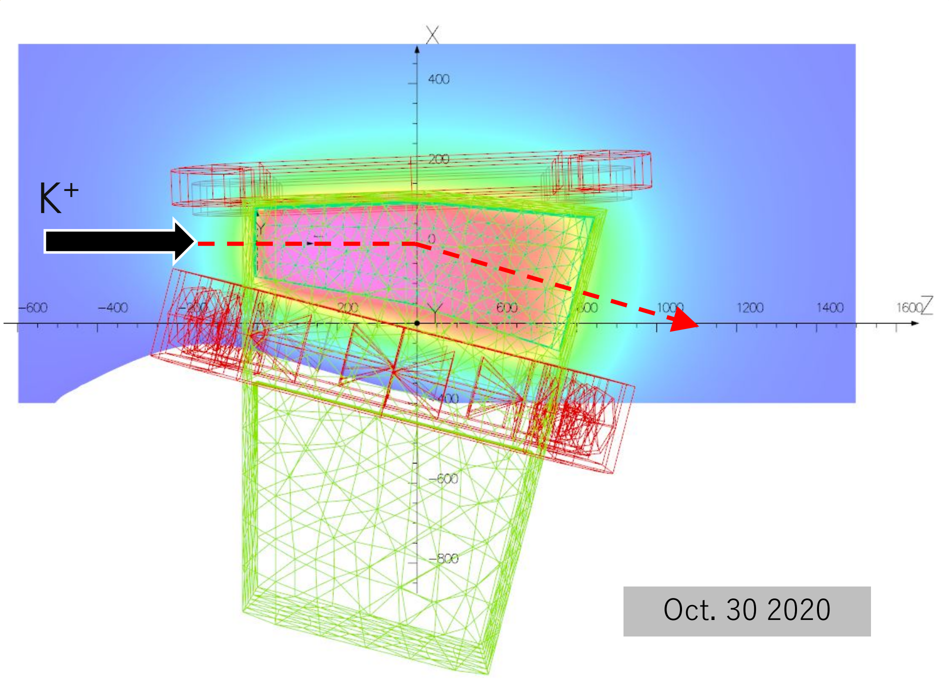
③ E12-20-013 ($^{208}_{\Lambda}\mathrm{Tl}$): ΛNN 3BF in uniform nuclear medium

Experimental Setup

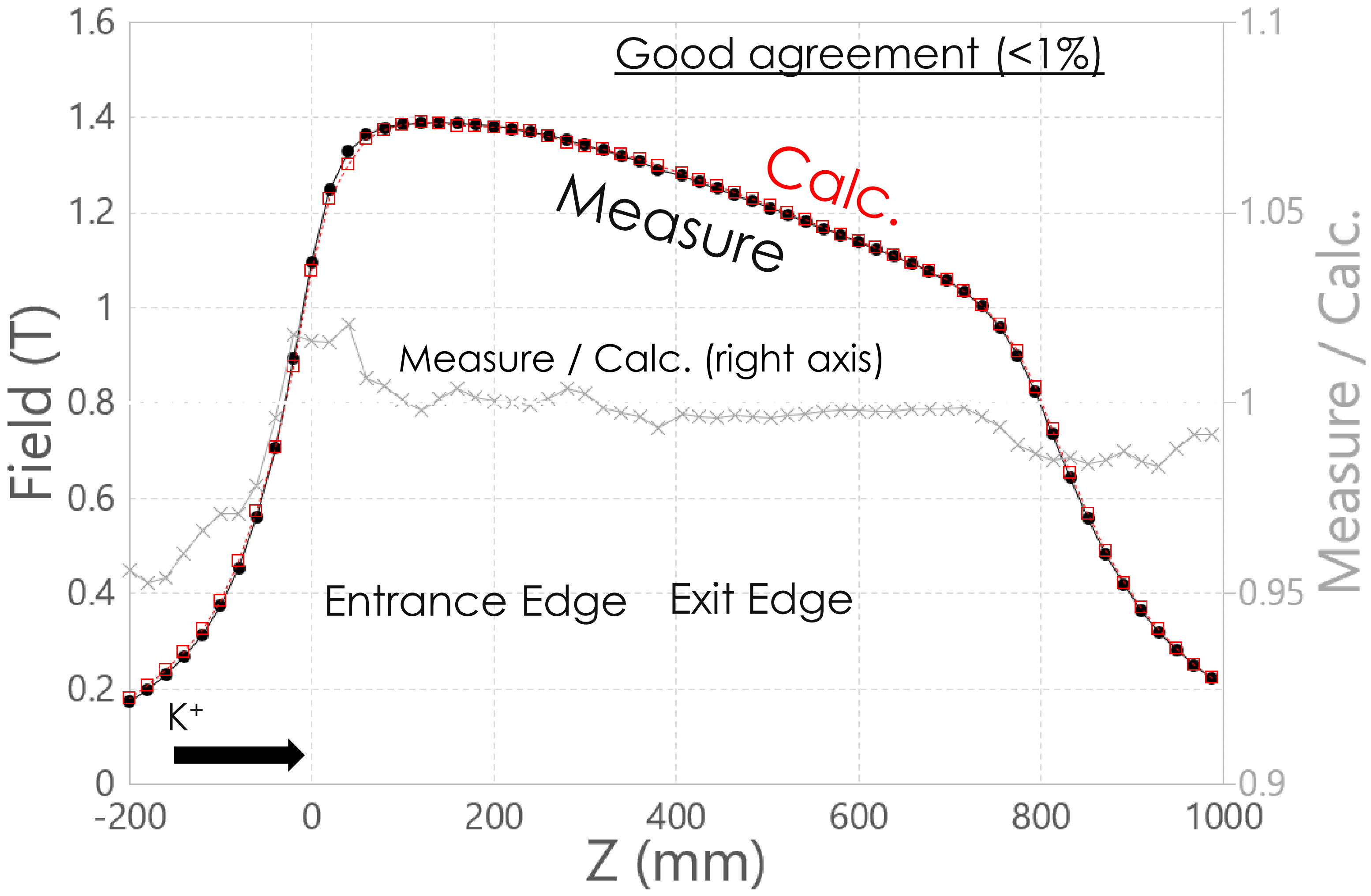


Taken from Sho's slides (Tohoku Univ.)

MAGNETIC FIELD MEASUREMENT



Oct. 30 2020



Good agreement (<1%)

Measure / Calc. (right axis)

Entrance Edge

Exit Edge

Taken from Sho’s slides (Tohoku Univ.)

C12-19-002 (${}^{3,4}_{\Lambda}\mathrm{H}$)

HYPERTRITON ($^{3}_{\Lambda}\mathrm{H}$) PUZZLE

Small B_Λ vs. **Short Lifetime**

$B_\Lambda = 0.13 \pm 0.05$ MeV (emulsion[1])
$B_\Lambda = 0.41 \pm 0.12 \pm 0.11$ MeV (STAR[2])

➡ RMS radius, $\sqrt{< r^2 >} \cong \frac{\hbar}{\sqrt{4\mu B_\Lambda}}$

$\tau = (0.5 \sim 0.92)\, \tau_\Lambda$
(HypHI, STAR, ALICE)

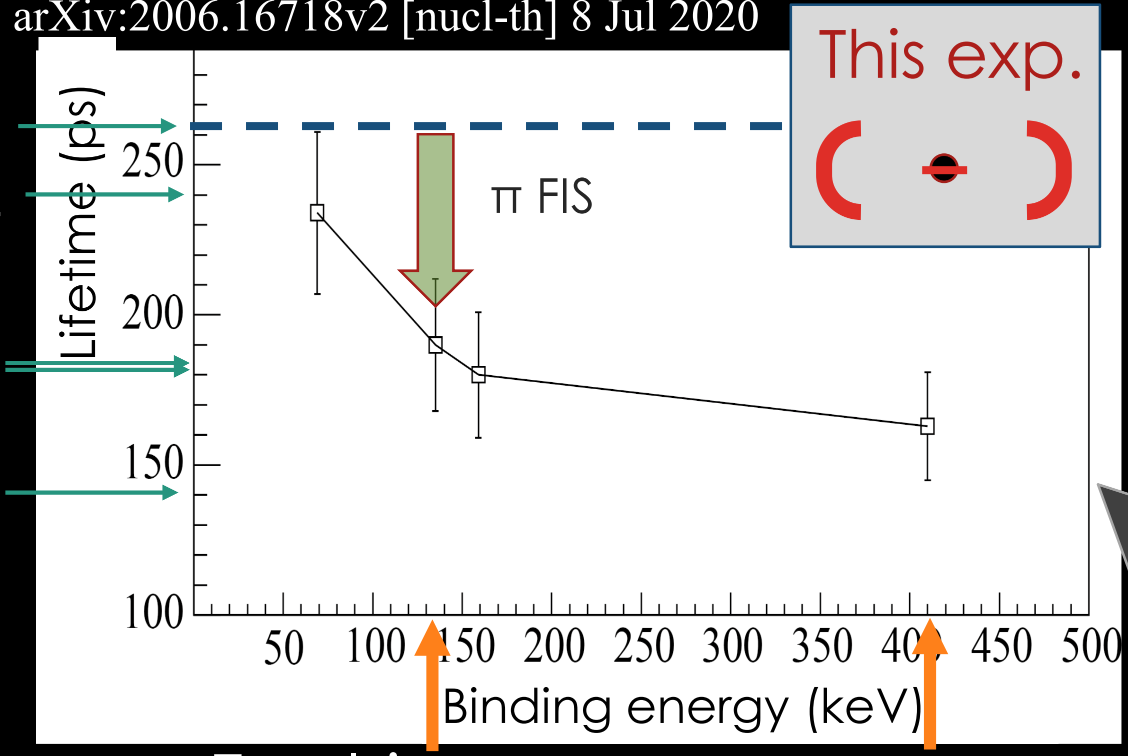
Fadeev calcuation with realistic NN/YN interactions
→ $\boldsymbol{\tau = 0.97\, \tau_\Lambda}$
(H. Kamada *et al.*, *Phys. Rev. C* **57**, 4 (1998))

[1] M. Juric *et al.*, *Nucl. Phys. B* **52**, 1-30 (1973).

[2] The STAR Collaboration, *Nature Physics* (2020); https://doi.org/10.1038/s41567-020-0799-7

LIFETIME VS. BINDING ENERGY OF ${}^{3}_{\Lambda}\mathrm{H}$

arXiv:2006.16718v2 [nucl-th] 8 Jul 2020



Emulsion

NPB52 (1973)1—30
2BD: 60±110 keV
3BD: 230±110 keV

STAR

PRA982 (2019)811—814
2BD: 176±150 keV
3BD: 586±160 keV

ex.) Decay width of 2BD channel:

$$\frac{\Gamma_{{}^{3}_{\Lambda}\mathrm{H}\to{}^{3}\mathrm{He}+\pi^-}}{(G_F m_\pi^2)^2} \approx \frac{q}{\pi}\frac{M_{{}^3\mathrm{He}}}{M_{{}^3\mathrm{He}}+\omega_{\pi^-}(q)} \times \left[\underbrace{\mathcal{A}_\Lambda^2}_{\text{Spin indep. amp.}} + \frac{1}{9}\underbrace{\mathcal{B}_\Lambda^2}_{\text{Spin dep. amp.}}\left(\frac{k_{\pi^-}}{2\bar{M}}\right)^2\right] \boxed{3|F^{\mathrm{PV}}(q)|^2}$$

Spin indep. amp.

Form factor
(π FSI is included)

Spin dep. amp.

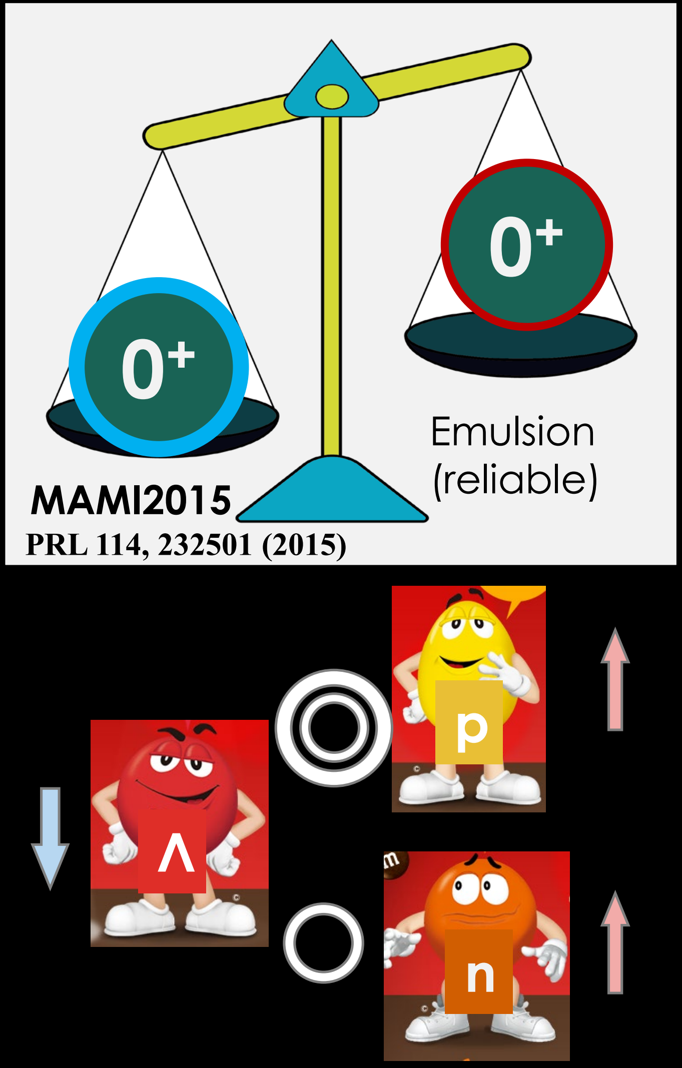
$\propto \sqrt{B_\Lambda}$

Proposed experiment (C12-19-002)
$|\Delta B^{\mathrm{stat.}}| = 30$ keV, $|\Delta B^{\mathrm{sys.}}| = 70$ keV

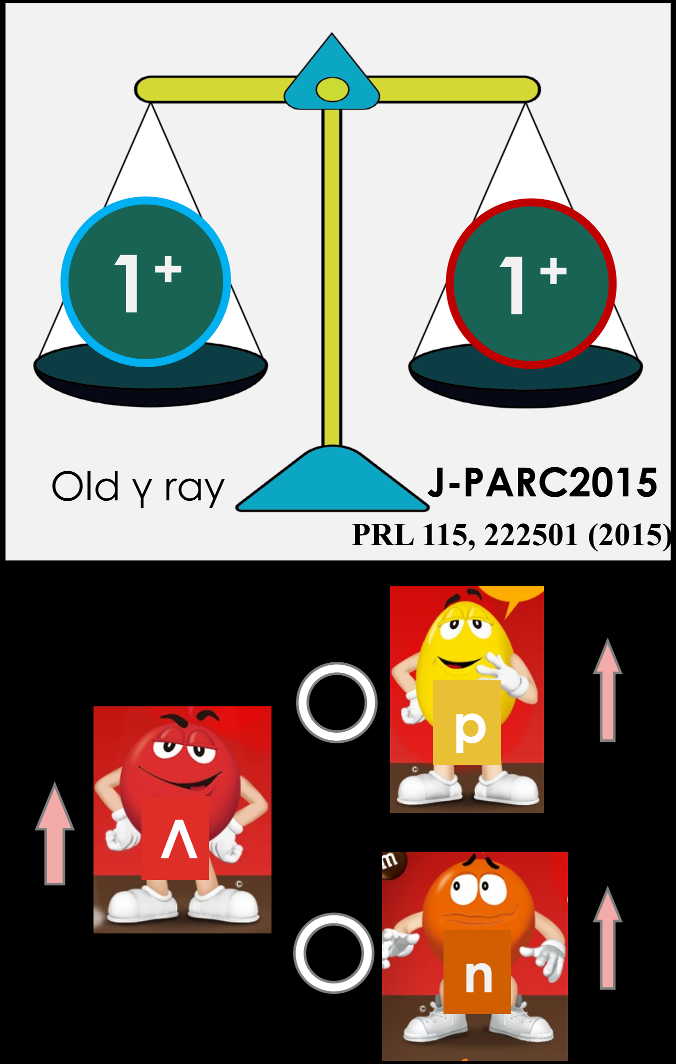
Best Accuracy on $B_\Lambda({}^{3}_{\Lambda}\mathrm{H})$
➔ Pin down the hyperon puzzle

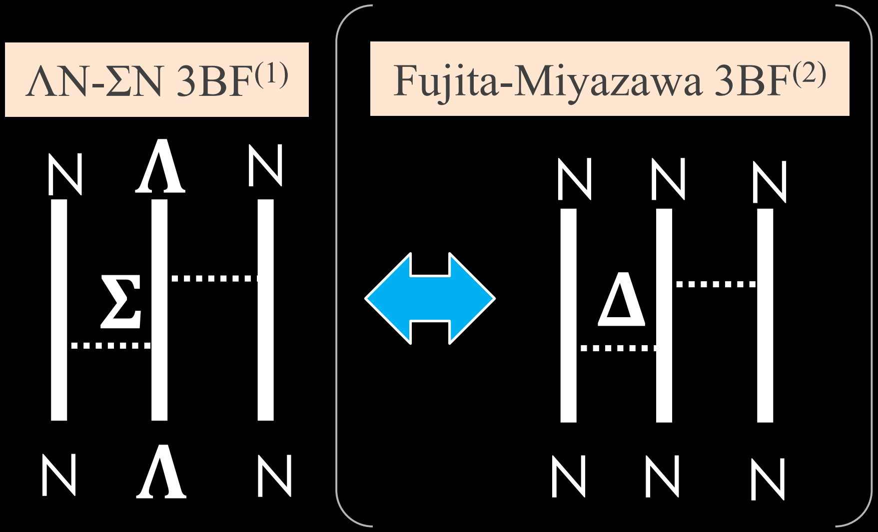
CHARGE SYMMETRY BREAKING IN THE ΛN INTERACTION

Unbalanced



Balanced





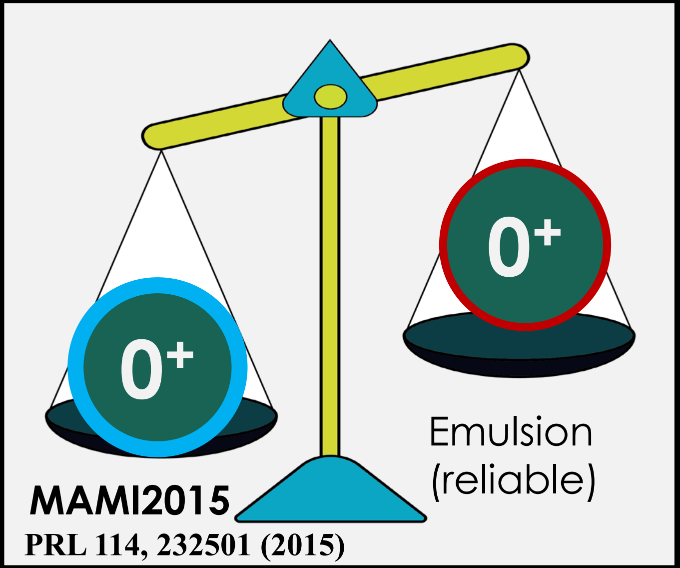
Σ may admix in the ΛN/ΛNN interaction

(1) Y. Akaishi et al., PRL 84, 3539 (2000)

(2) J. Fujita and H. Miyazawa, Prog. Theor. Phys.,17, 3, 360–365 (1957)

CHARGE SYMMETRY BREAKING IN THE ΛN INTERACTION

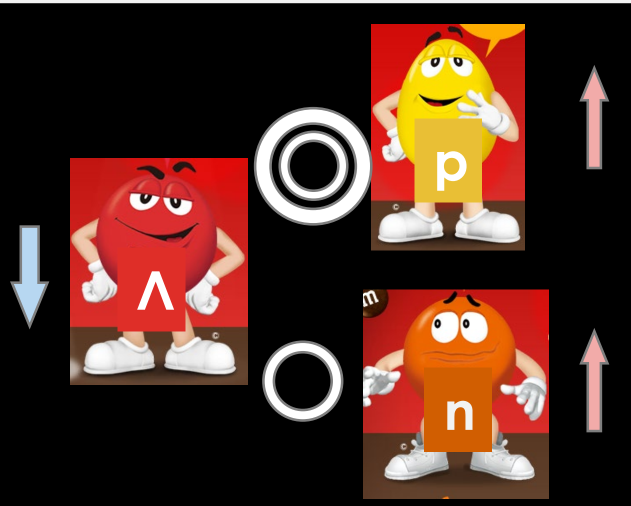
Unbalanced



Emulsion (reliable)

MAMI2015

PRL 114, 232501 (2015)

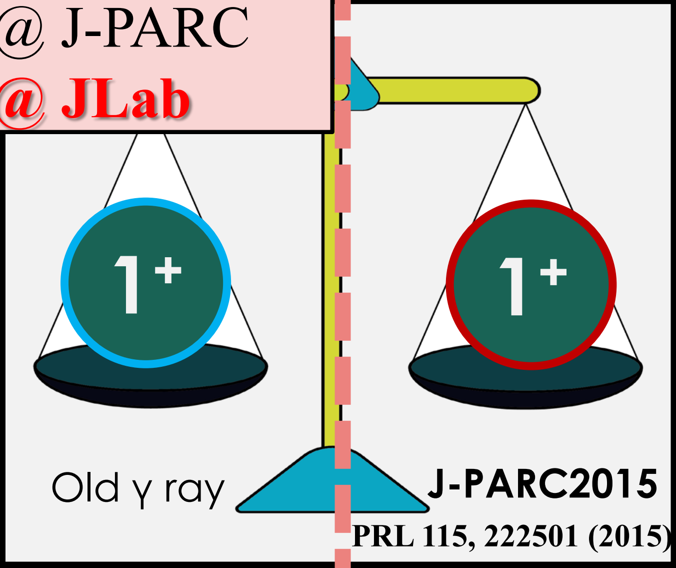


ced

New exps.

@ J-PARC

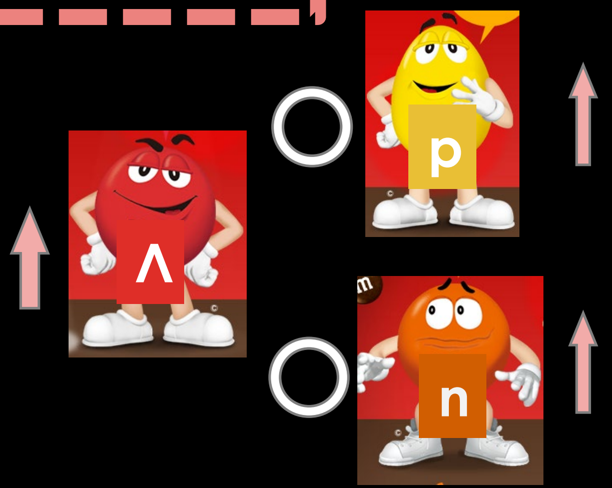
@ JLab

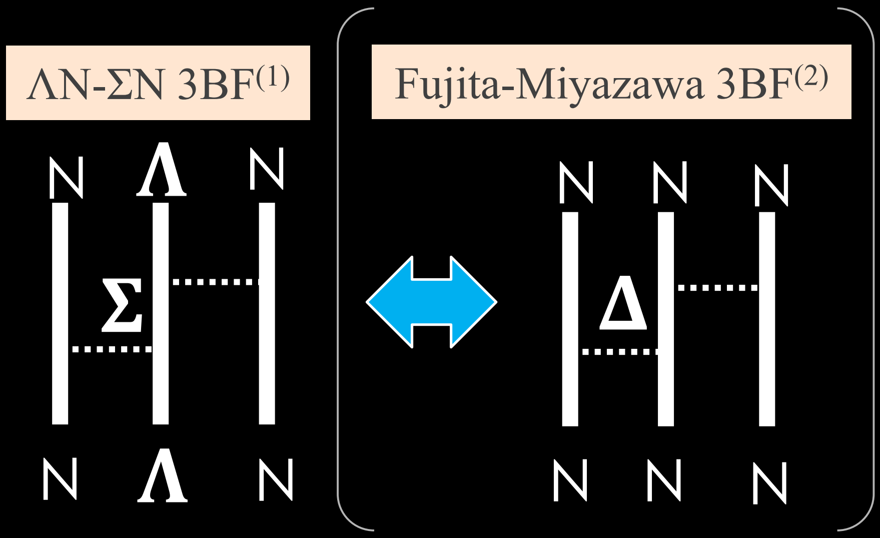


Old γ ray

J-PARC2015

PRL 115, 222501 (2015)





Σ may admix in the ΛN/ΛNN interaction

(1) Y. Akaishi et al., PRL 84, 3539 (2000)

(2) *J. Fujita and H. Miyazawa, Prog. Theor. Phys.,17, 3, 360–365 (1957)*

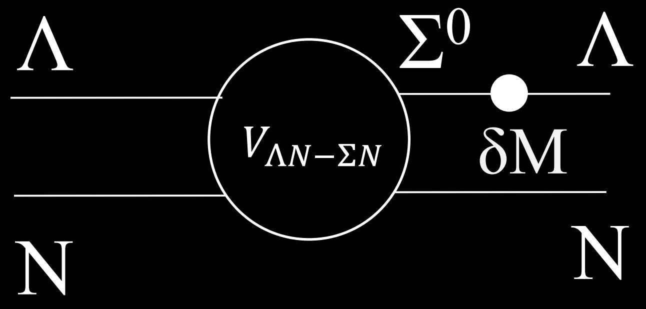
BASIC INFORMATION FOR THE ΛN CSB STUDY: $^{4}_{\Lambda}\mathrm{He} - ^{4}_{\Lambda}\mathrm{H}$

Explicit inclusion of Σ

A. Gal, Phys. Lett. B 744, 352 (2015)

D. Gazda and A. Gal, Phys. Rev. Lett. 116, 122501 (2016)

A. Gal et al., IOP Conf. Series: Jour. Phys.: Conf. Ser. **966** (2018) 012006



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

Phenomenological potential

E. Hiyama *et al.*, *Phys. Rev. C* **80**, 054321 (2009).

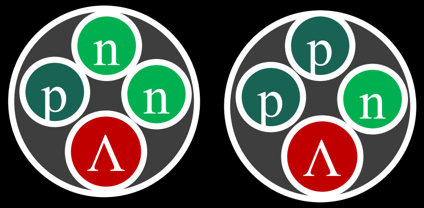
M. Isaka et al., Phys. Rev. C 101, 024301 (2020).

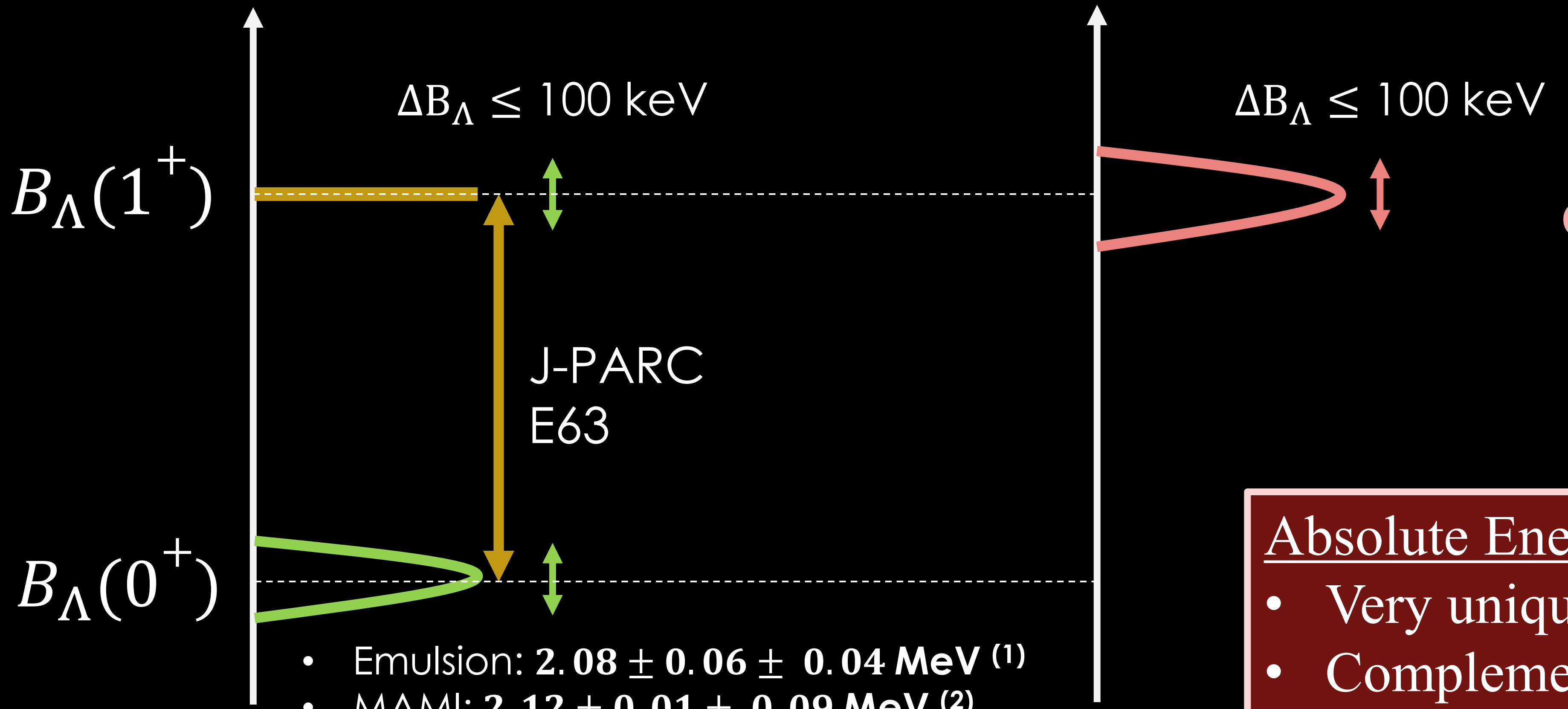
$$V_{\Lambda N}^{\rm CSB}(r) = -\frac{\tau_z}{2}\left[\frac{1+P_r}{2}\left(v_0^{\rm even,CSB} + \sigma_{\Lambda}\cdot\sigma_{\rm N} v_{\sigma_\Lambda\cdot\sigma_N}^{\rm even,CSB}\right)e^{-\beta_{\rm even}r^2} + \frac{1-P_r}{2}\left(v_0^{\rm odd,CSB} + \sigma_{\Lambda}\cdot\sigma_{\rm N} v_{\sigma_\Lambda\cdot\sigma_N}^{\rm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

Fundamental benchmark

HKS, PRL 110, 012502 (2013)
HKS, PRC 94, 021302(R) (2016)
Hall A, PRC 91,034308 (2015)
HKS, PRC 93, 034314 (2016)
HKS, PRC 90, 034320 (2014) …

HOW WE CONFIRM THE $B_{\Lambda}({}^{4}_{\Lambda}\mathrm{H};\ 1^{+})$





Conventional way

Proposed exp.

$\Delta B_{\Lambda} \lesssim 100$ keV

$\Delta B_{\Lambda} \lesssim 100$ keV

$B_{\Lambda}(1^{+})$

J-PARC
E63

$B_{\Lambda}(0^{+})$

- Emulsion: $\mathbf{2.08 \pm 0.06 \pm\ 0.04}$ **MeV** (1)
- MAMI: $\mathbf{2.12 \pm 0.01 \pm\ 0.09}$ **MeV** (2)

C12-19-002
(2 days)

Absolute Energy Measurement:
- Very unique (direct meas.)
- Complementary with other data

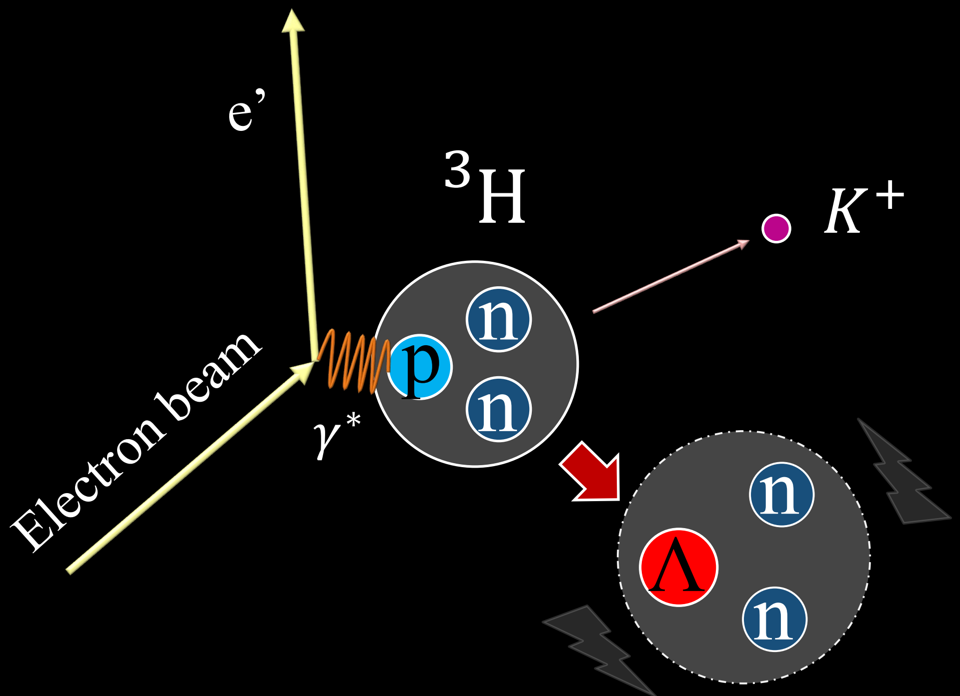
(1) NPB 52, 1-30 (1973)
(2) PRL 114, 232501 (2015)

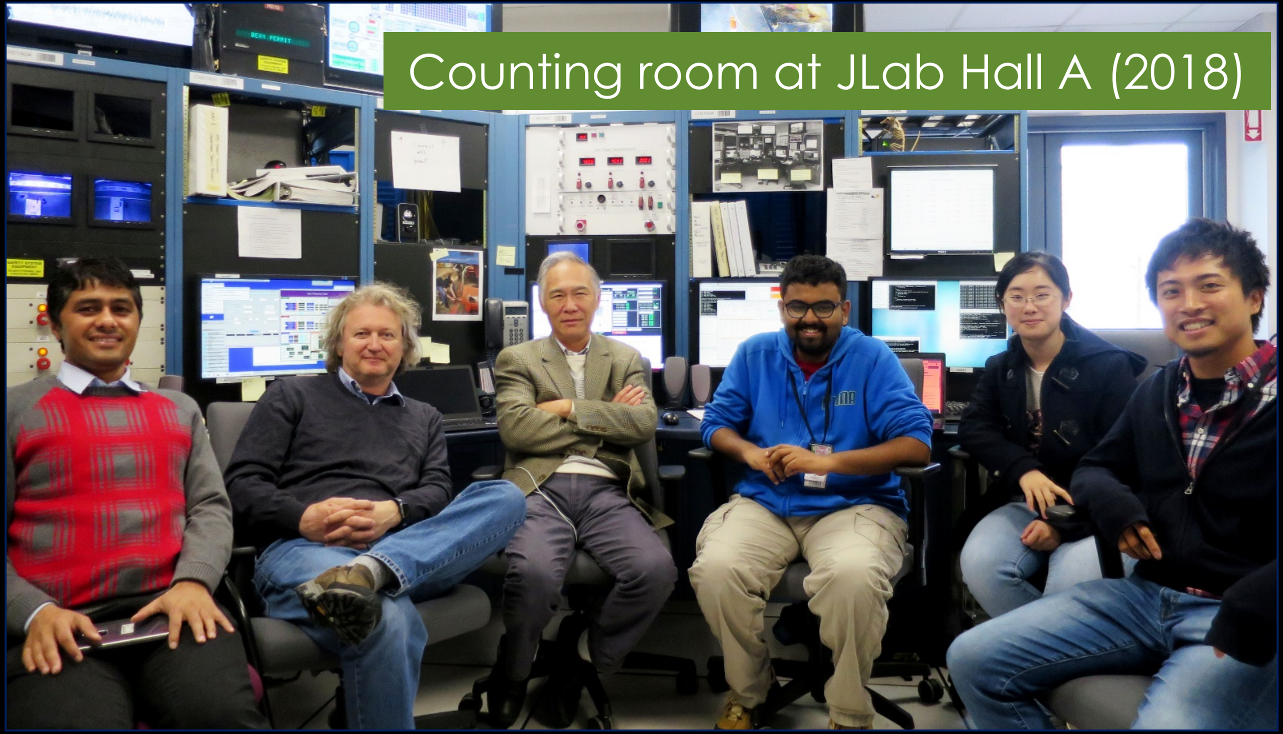
E12-17-003 (nnΛ)

nnΛ search experiment at JLab

$^{3}\mathrm{H}(e, e'K^{+})nn\Lambda$ with HRSs

E12-17-003 (Oct 30—Nov 25, 2018)

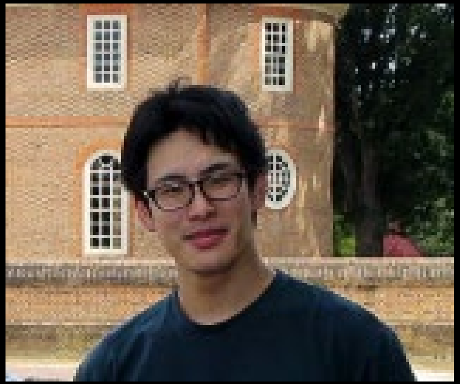



Counting room at JLab Hall A (2018)

We have sensitivity to both bound and resonant states

STUDENTS WHO ANALYZE DATA

Independent analyses are in progress by students to doublecheck (triplecheck) results

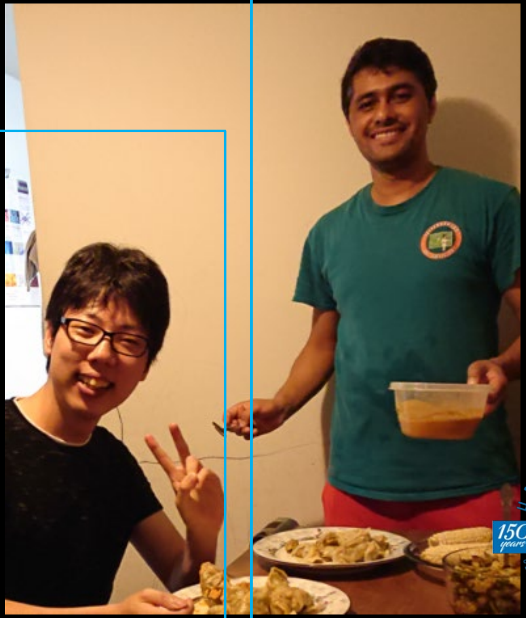


K. Itabashi

K. Okuyama

Tohoku Univ., Japan

E. Umezaki



K.N. Suzuki

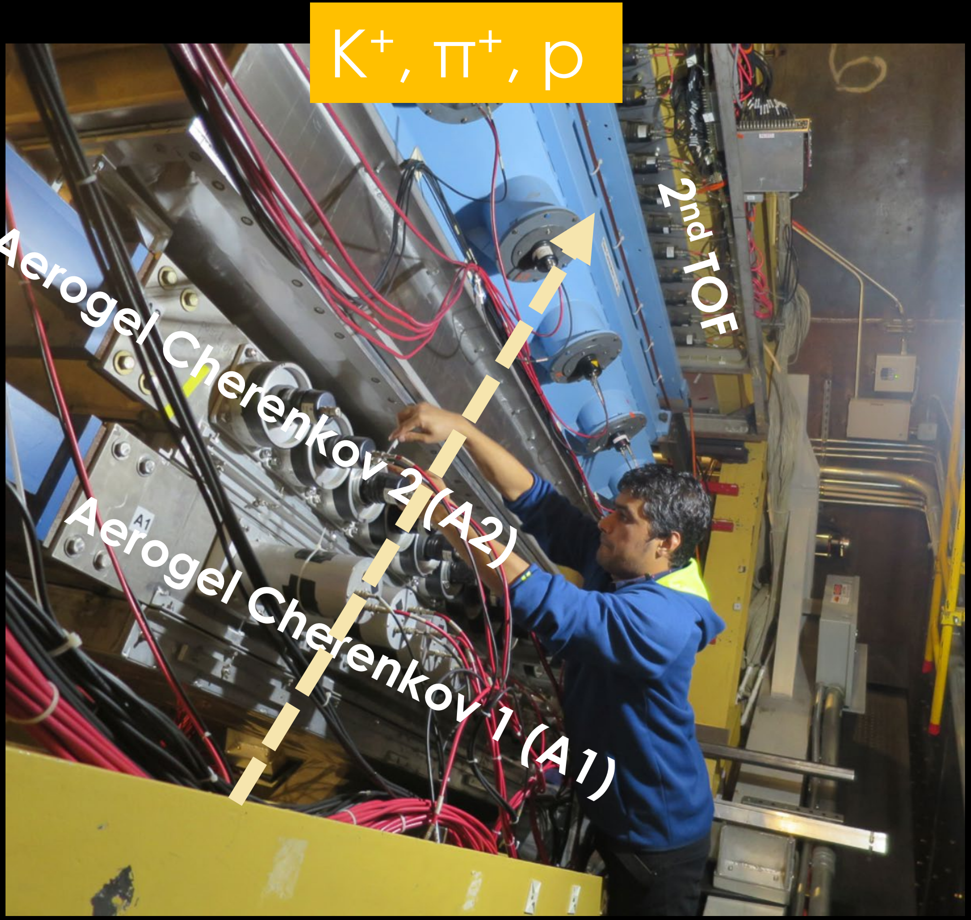
Kyoto Univ., Japan

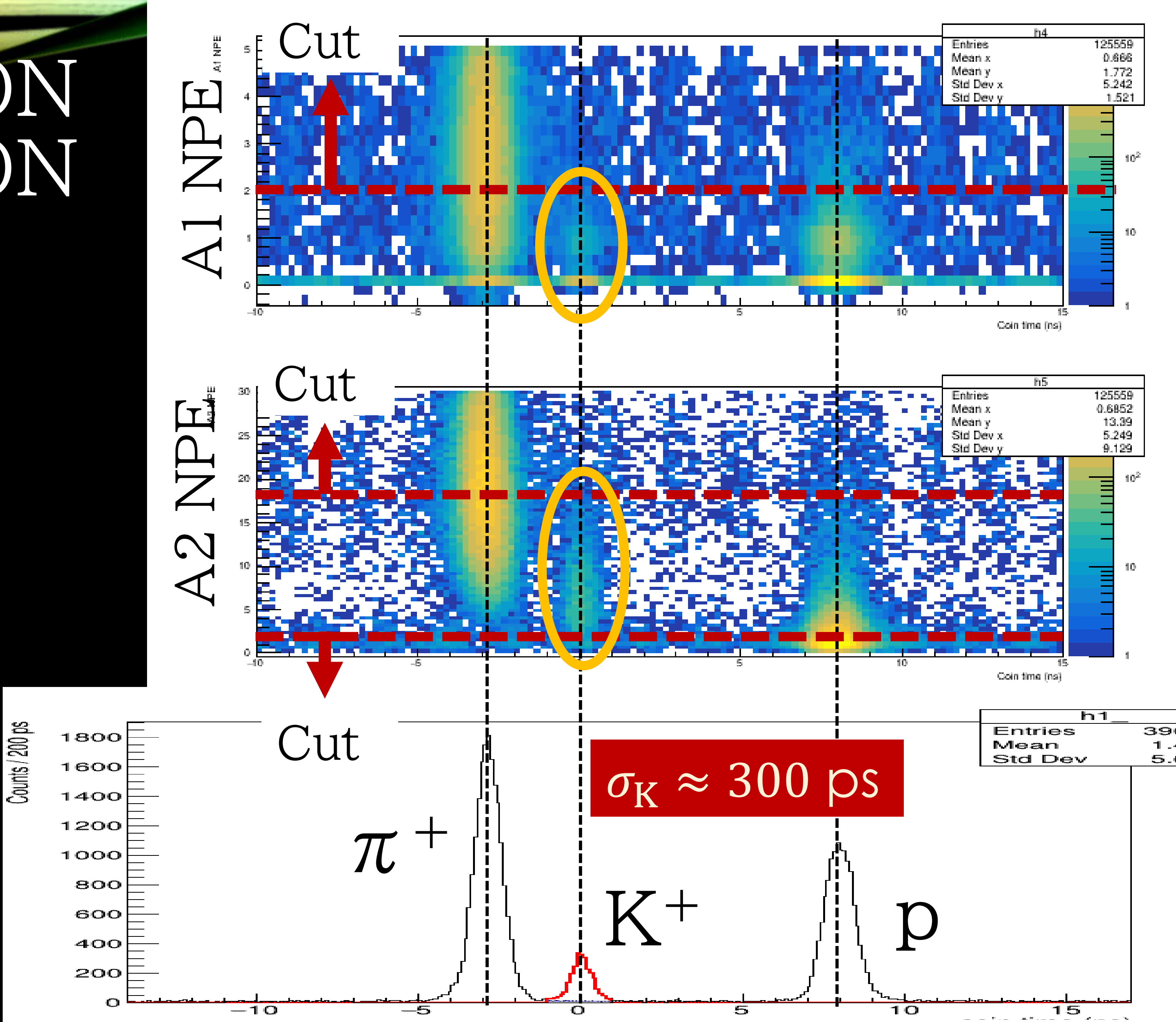
B. Pandey

Hampton Univ., US

Λn FSI, elementary production, nnΛ search/CS, etc.

KAON IDENTIFICATION

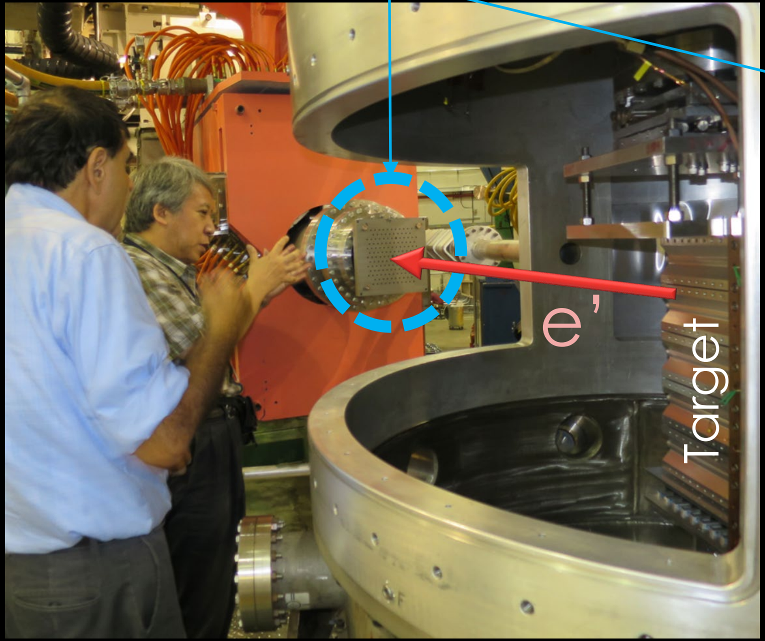




Timing consistency between L and R assuming m_K → Coin time (ns)

CALIBRATION

Sieve Slit



5th order matrix (z_t<2)

Angle calibration

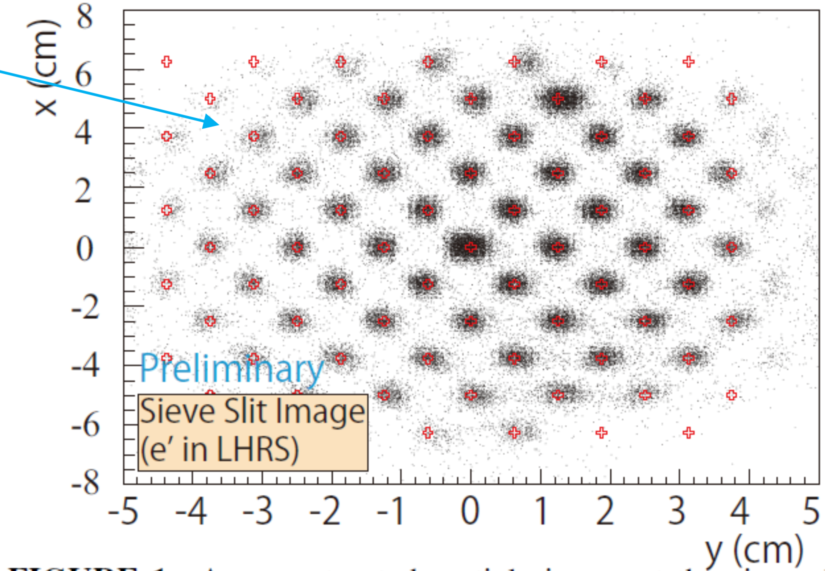


FIGURE 1. A reconstructed particle image at the sieve slit for the sieve slit data in LHRS (e'). Matrix parameters for reconstruction of angle at target were calibrated by using the sieve slit image. π^-s were eliminated by an event selection of light yield of a gas Cherenkov detector (CO_2) [41] installed in LHRS.

5th order matrix (z_t<2)

Momentum calibration

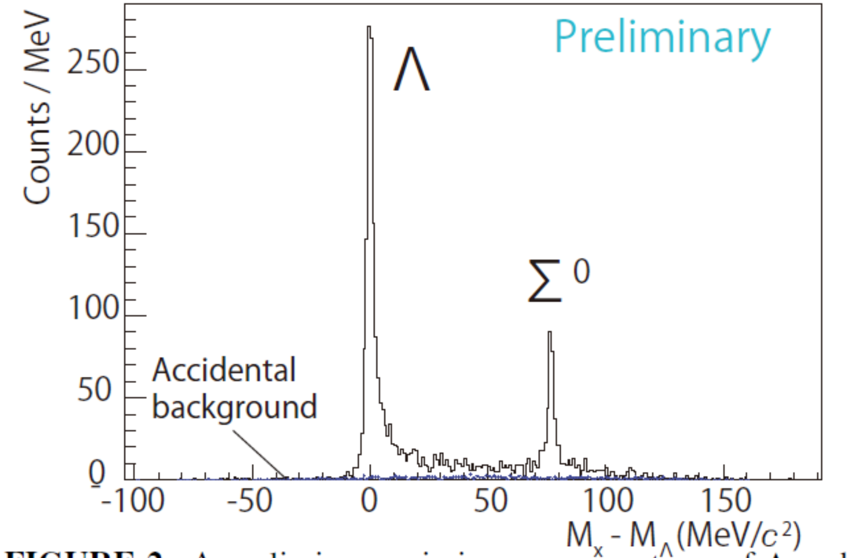


FIGURE 2. A preliminary missing mass spectrum of Λ and Σ^0 from a 71-mg/cm^2 H_2 gas target for a kinematics condition of M-kine in JLab E12-17-003. The beam charge on the H_2 target with M-Kine was about 2.5 C. The mass resolution is about 3.5 MeV/c^2 (FWHM).

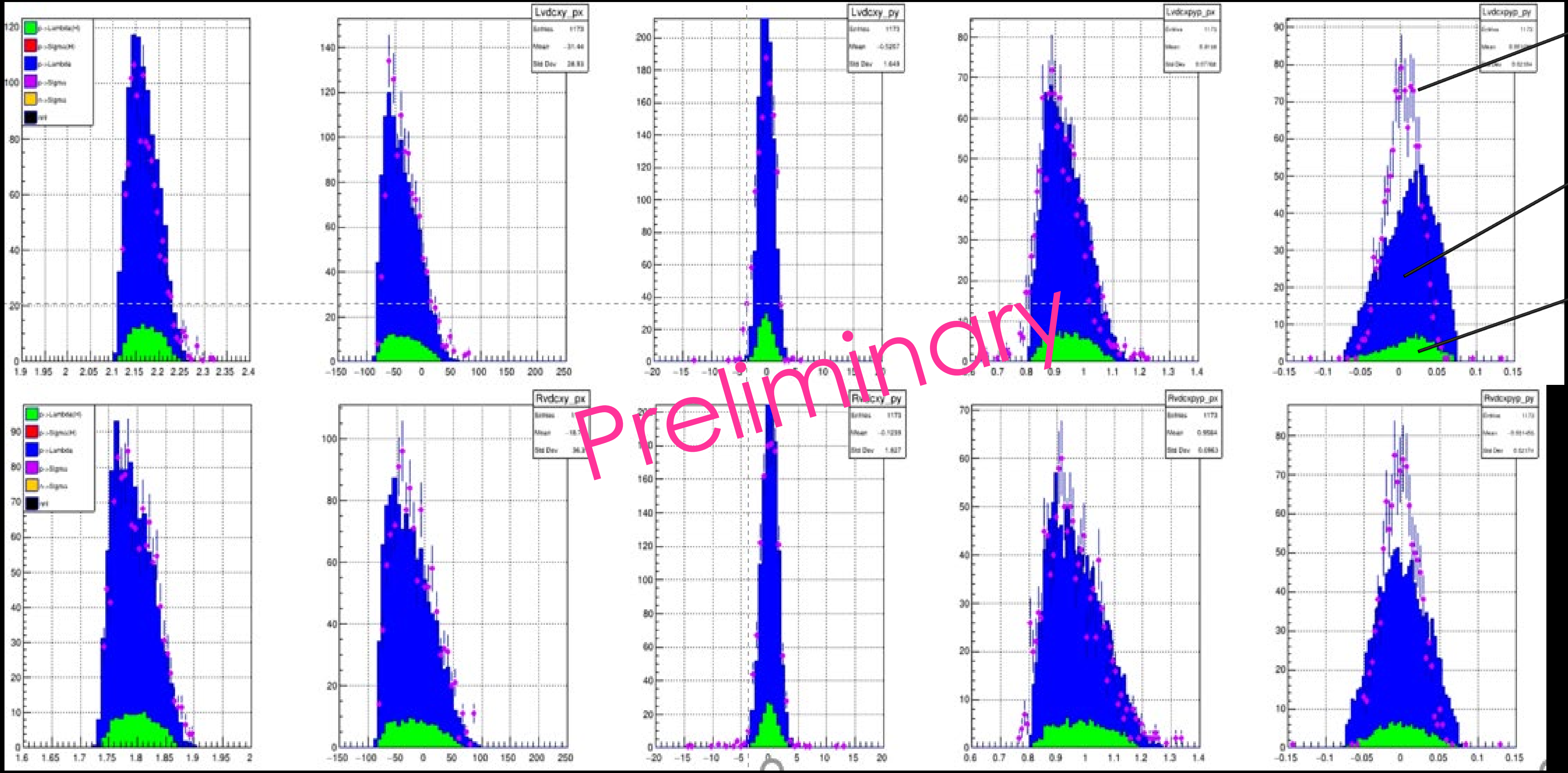
TG et al., APPC14, Proceedings (in Press)

Data vs. Geant4 (sim) for T_2 target

Momentum | x_{FP} (cm) | y_{FP} (cm) | x'_{FP} | y'_{FP}

L-HRS (e')

R-HRS (K^+)



DATA (Λ, Σ)

G4 SIM. (T2)

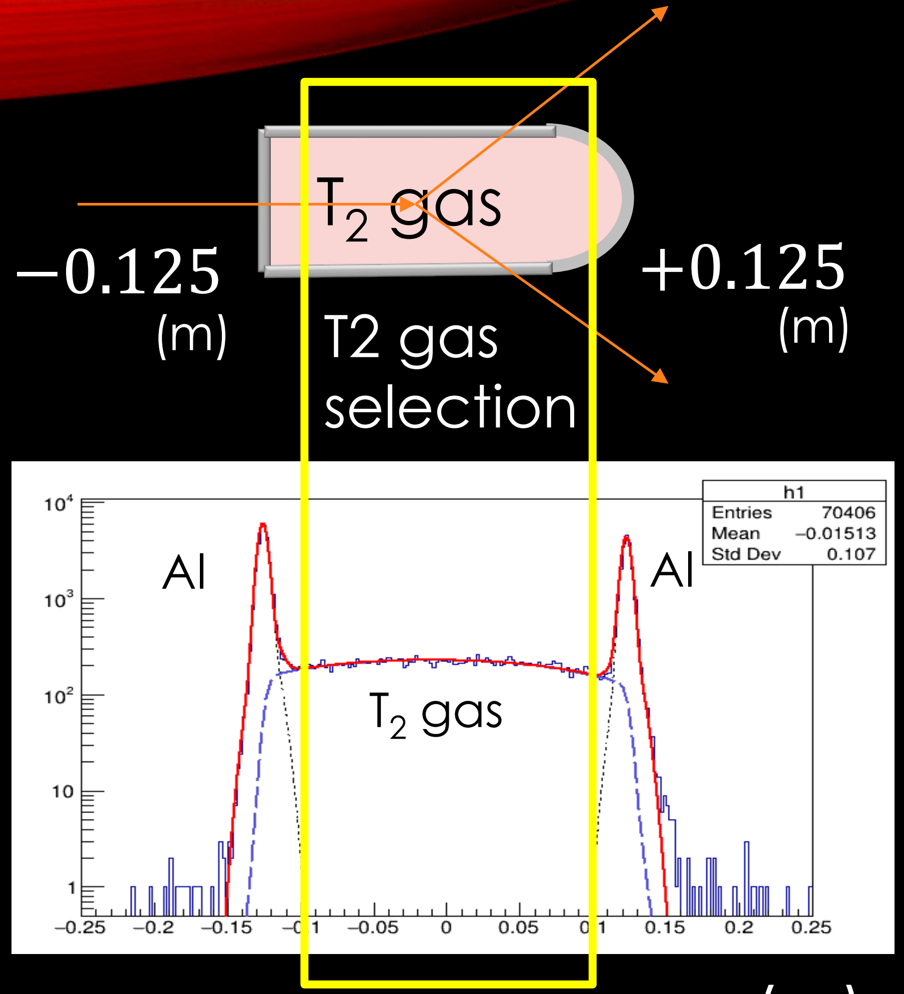
G4 SIM. (H)
H contamination

→ Acceptance evaluation

→ Cross section

Simulation by K.N. Suzuki (Kyoto Univ., 2020)

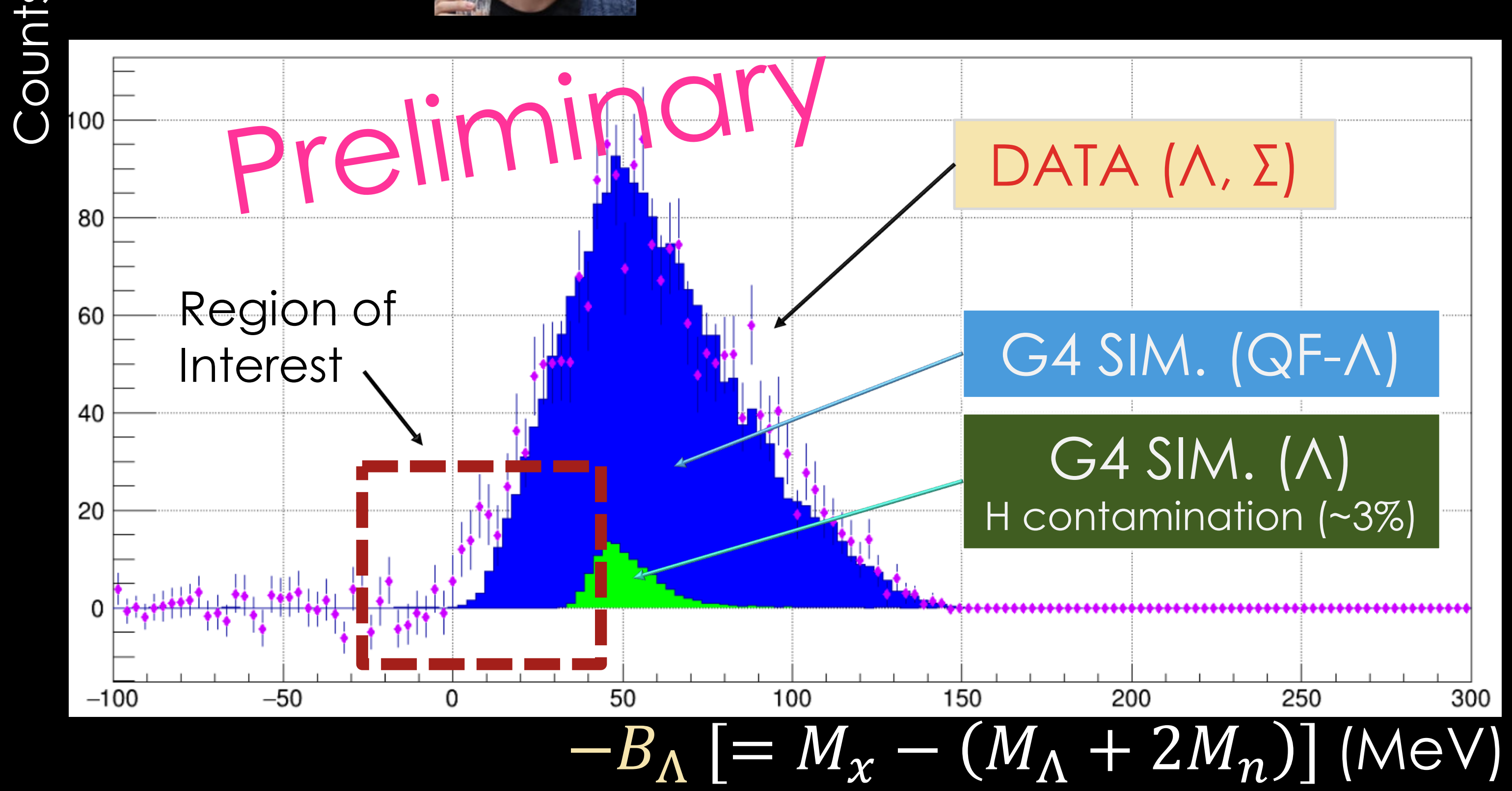
PRELIMINARY $^{3}\mathrm{H}(e,e'K^{+})nn\Lambda$



z_t (m)

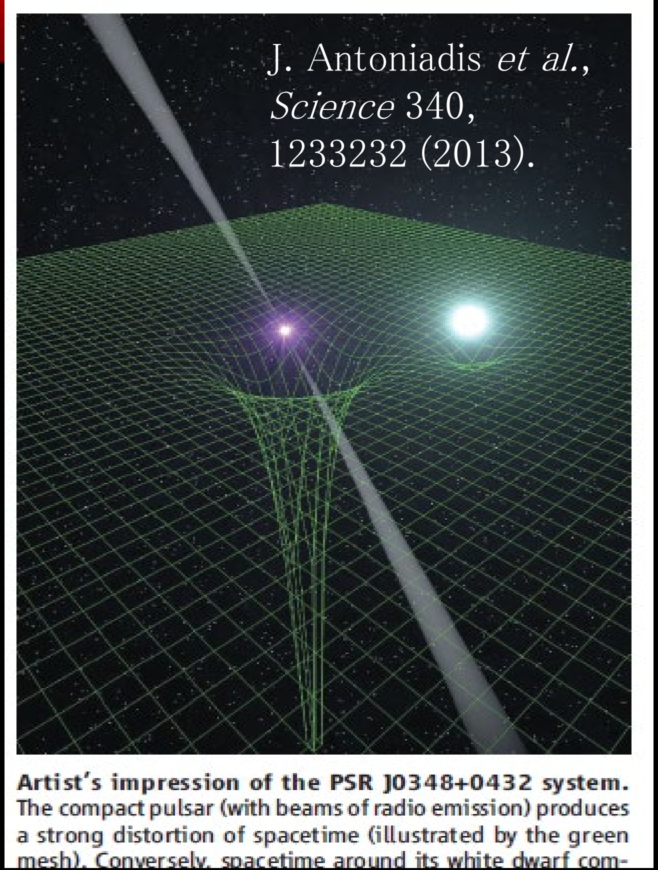
FWHM = 8.5 mm
(by two arms)

Figure made by K.N. Suzuki 2021 (Kyoto)

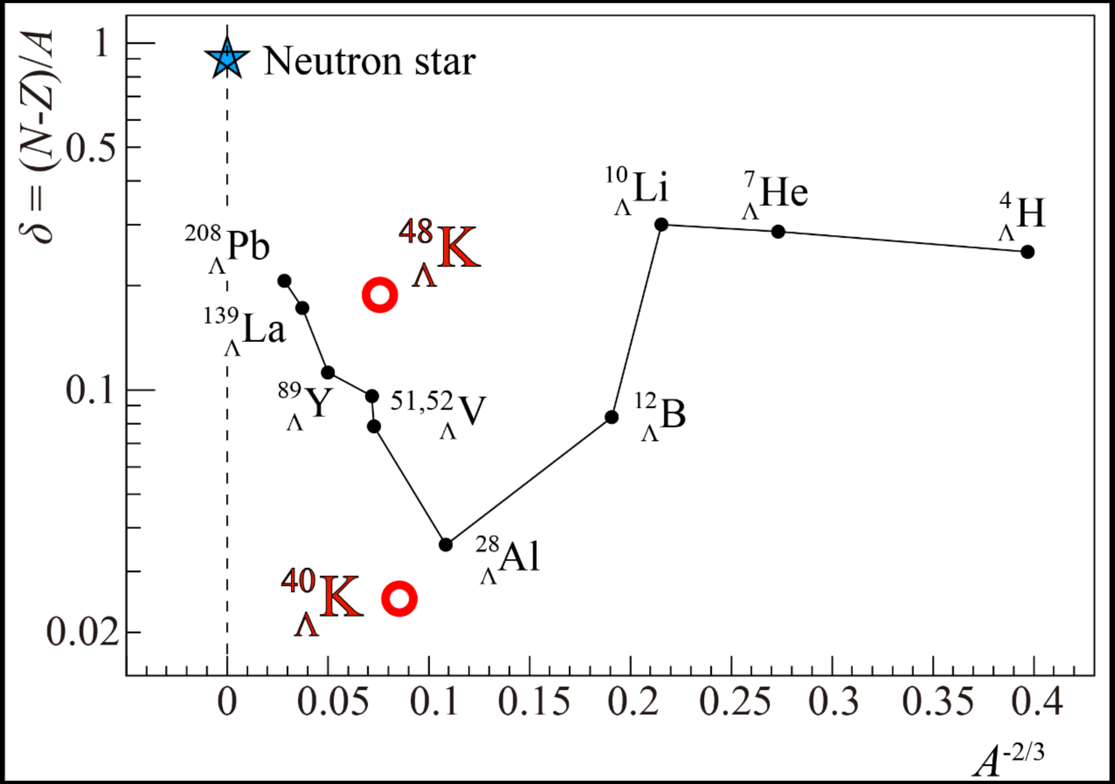


E12-15-008 ($^{40,48}_{\Lambda}$K)

Study of isospin dependence through precise measurement of $^{40,48}\mathrm{Ca}(e,e'K^+)^{40,48}_{\Lambda}\mathrm{K}$


J. Antoniadis *et al.*, *Science* 340, 1233232 (2013).

Artist's impression of the PSR J0348+0432 system. The compact pulsar (with beams of radio emission) produces a strong distortion of spacetime (illustrated by the green mesh). Conversely, spacetime around its white dwarf com-



Neutron star:

- ✓ Very dense nuclear matter ($\delta = \frac{N-Z}{A} \sim 0.9$)
- ✓ $\leq 2M_{\odot} \not\Leftrightarrow \Lambda$ inclusion (hyperon puzzle)

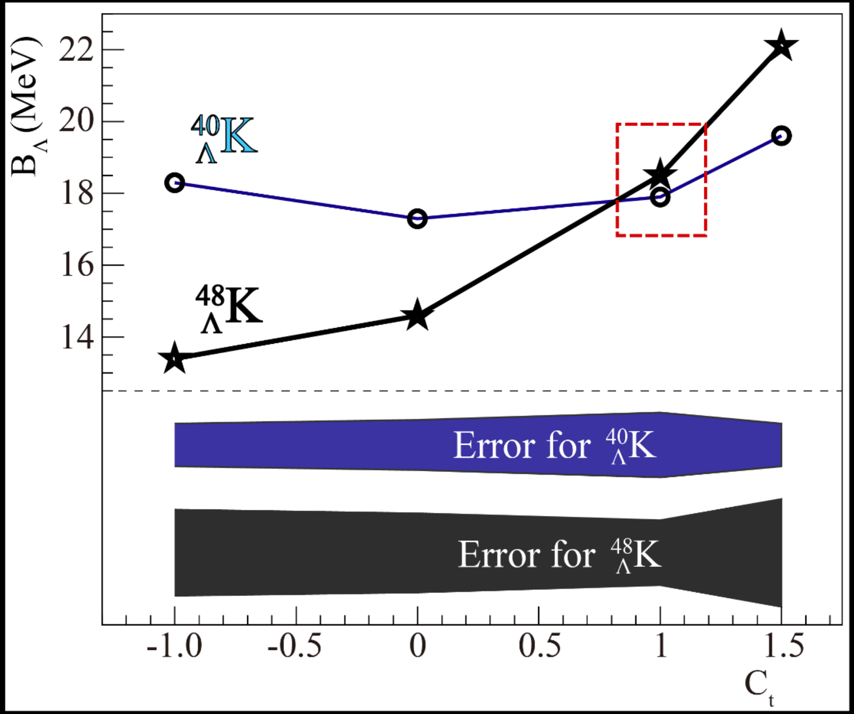
$B_{\Lambda}(^{40,48}_{\Lambda}\mathrm{K})$ with high precision

➡ **Isospin dependence of the *NNΛ* interaction**

ΛNN isospin dependence

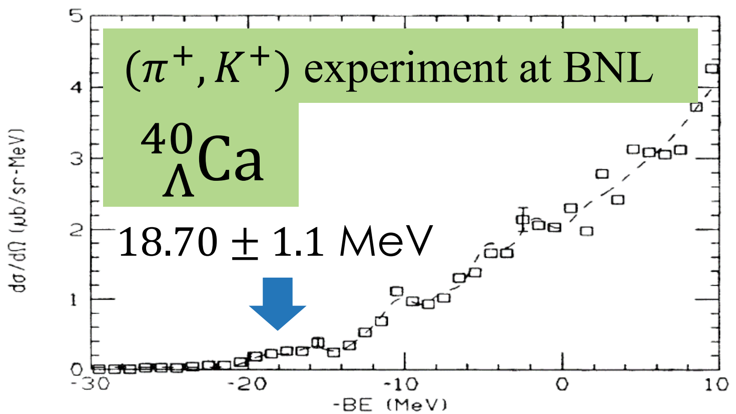
AFDMC calculation

(F. Paderiva et al., arXiv:1506.04042v1 (2015))



C_t: Strength factor for the isospin triplet term

P. H. Pile et al., Phys. Rev. Lett. 66, 20 (1991).

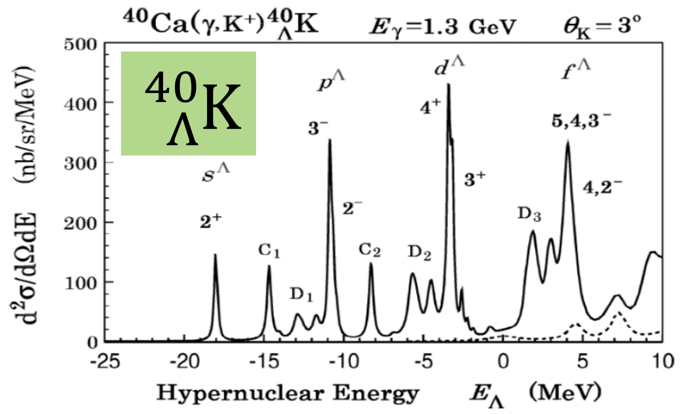


(π^+, K^+) experiment at BNL

${}^{40}_{\Lambda}$Ca

18.70 ± 1.1 MeV

T. Motoba et al., Prog. Theor. Phys. Suppl., 185, 224 (2010).



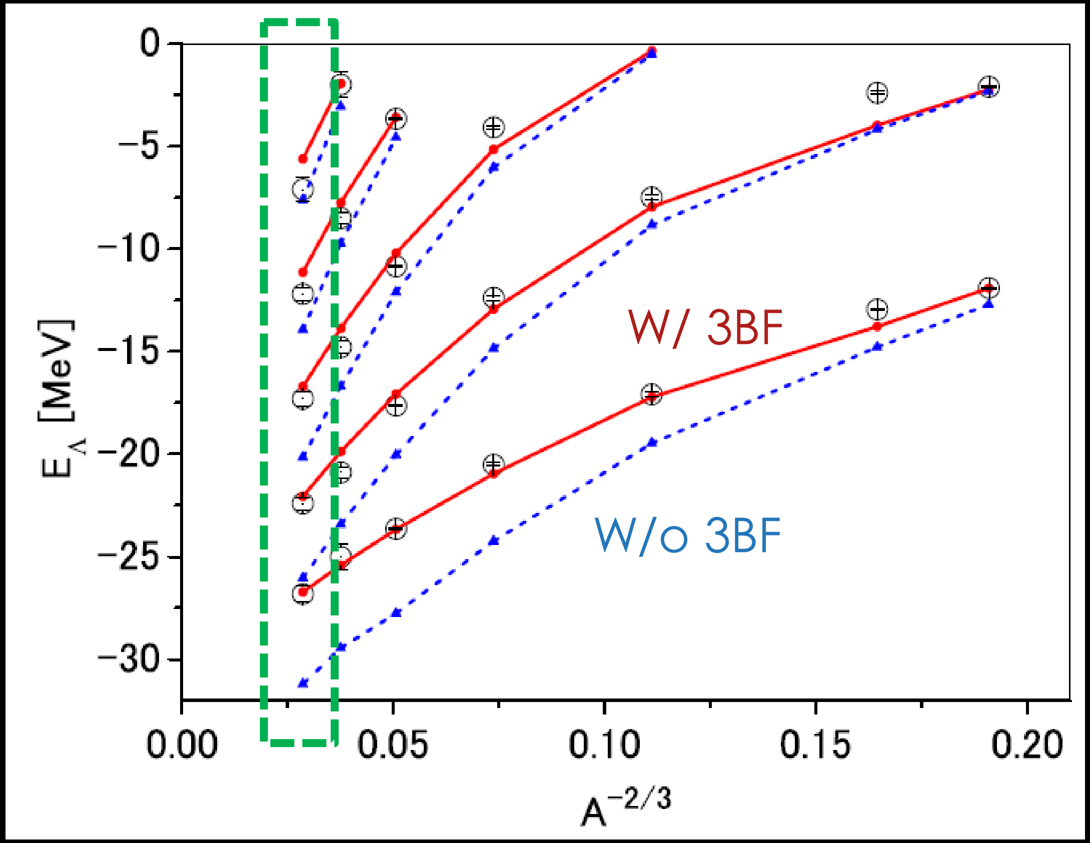
${}^{40}_{\Lambda}$K

$B_\Lambda({}^{40}_{\Lambda}\mathrm{K}) - B_\Lambda({}^{48}_{\Lambda}\mathrm{K})$
with < **100 keV accuracy**
→ Insights for the isospin dependence of ΛNN force

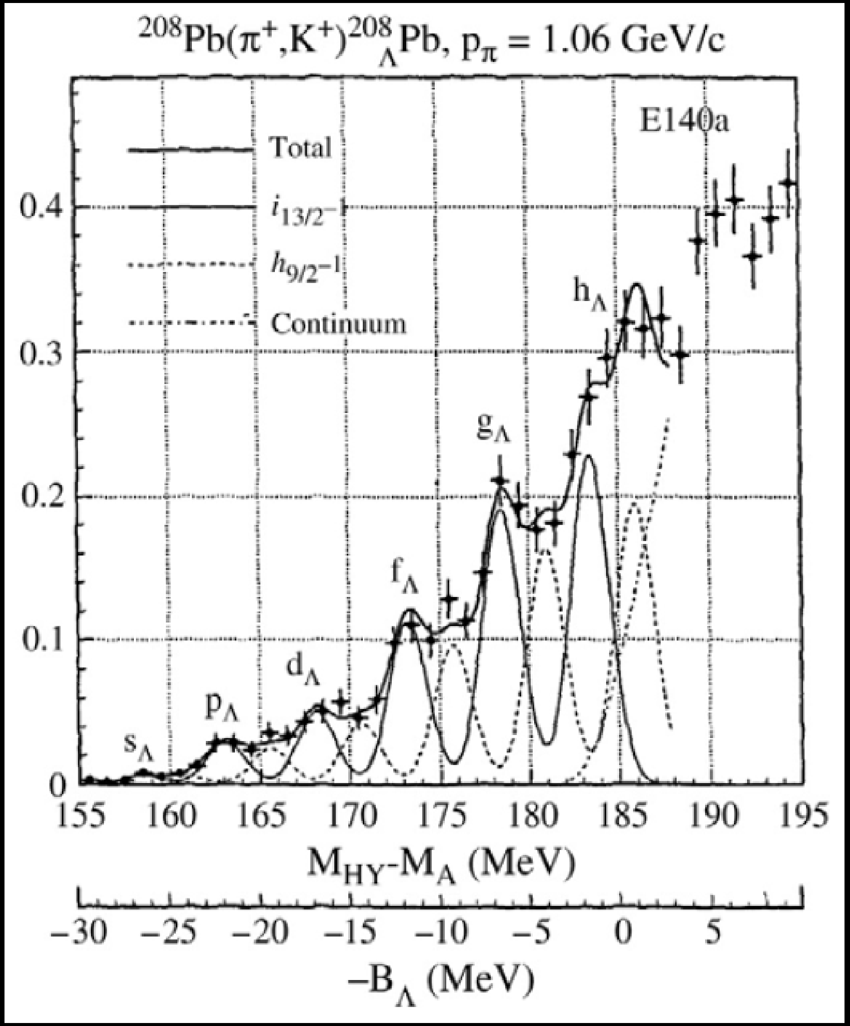
E12-20-013 ($^{208}_{\Lambda}\mathrm{Tl}$)

THREE BODY FORCE

ESC16+ / ESC16



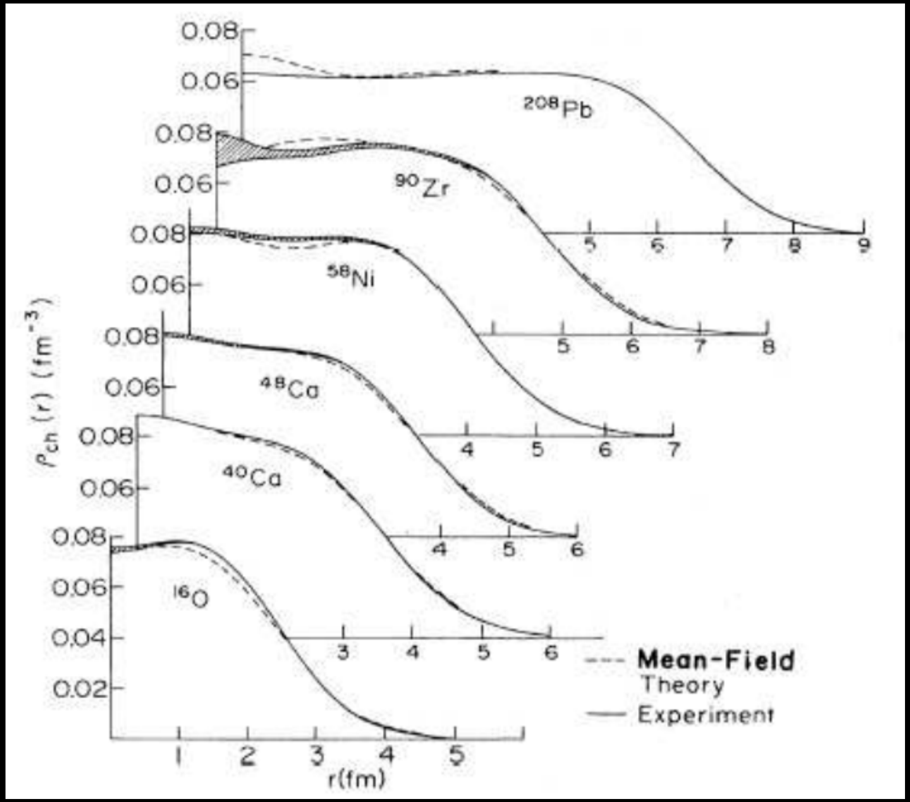
M. M. Nagels et al., Phys. Rev. C **99**, 044003 (2019)



T. Hasegawa et al., Phys. Rev. C 53 (1996) 1210.

Λ in (almost) nuclear matter

B. Frois and C.N. Papanicolas, Ann. Rev. Nucl. Part. Sci. 37, 133 (1987)

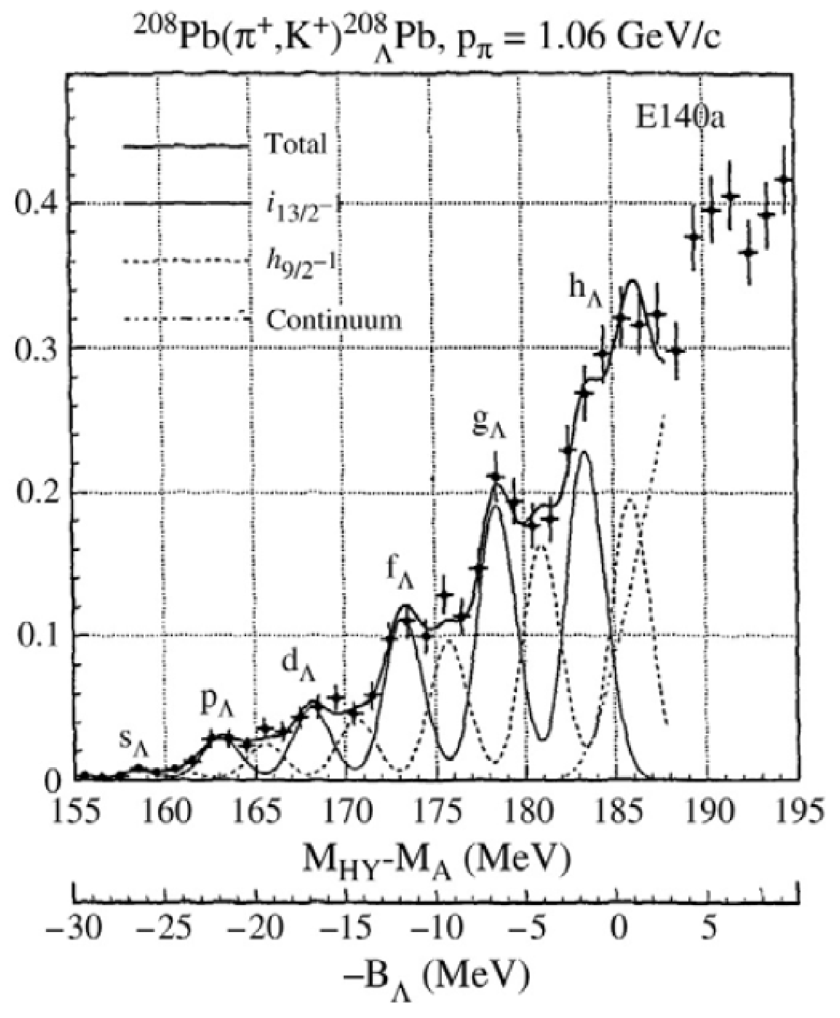


Deeply bound protons in the ^{208}Pb ground state largely unaffected by finite size and shell effect

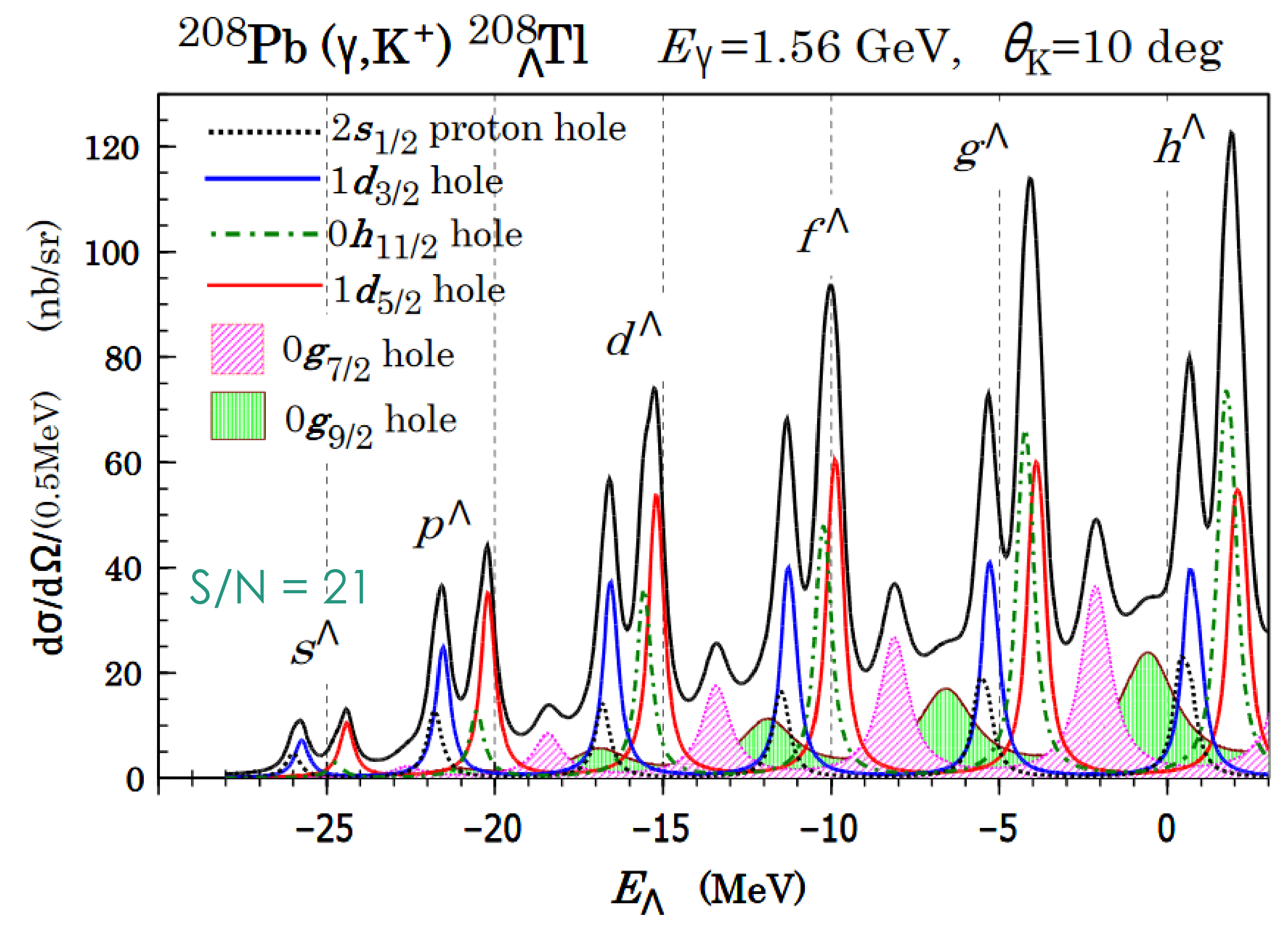
→ It behave as if they were in **nuclear matter**

→The use of a ^{208}Pb target appears to be uniquely suited to study Λ interactions in a uniform nuclear medium with **large neutron excess**

TOWARD PRECISE SPECTROSCOPY

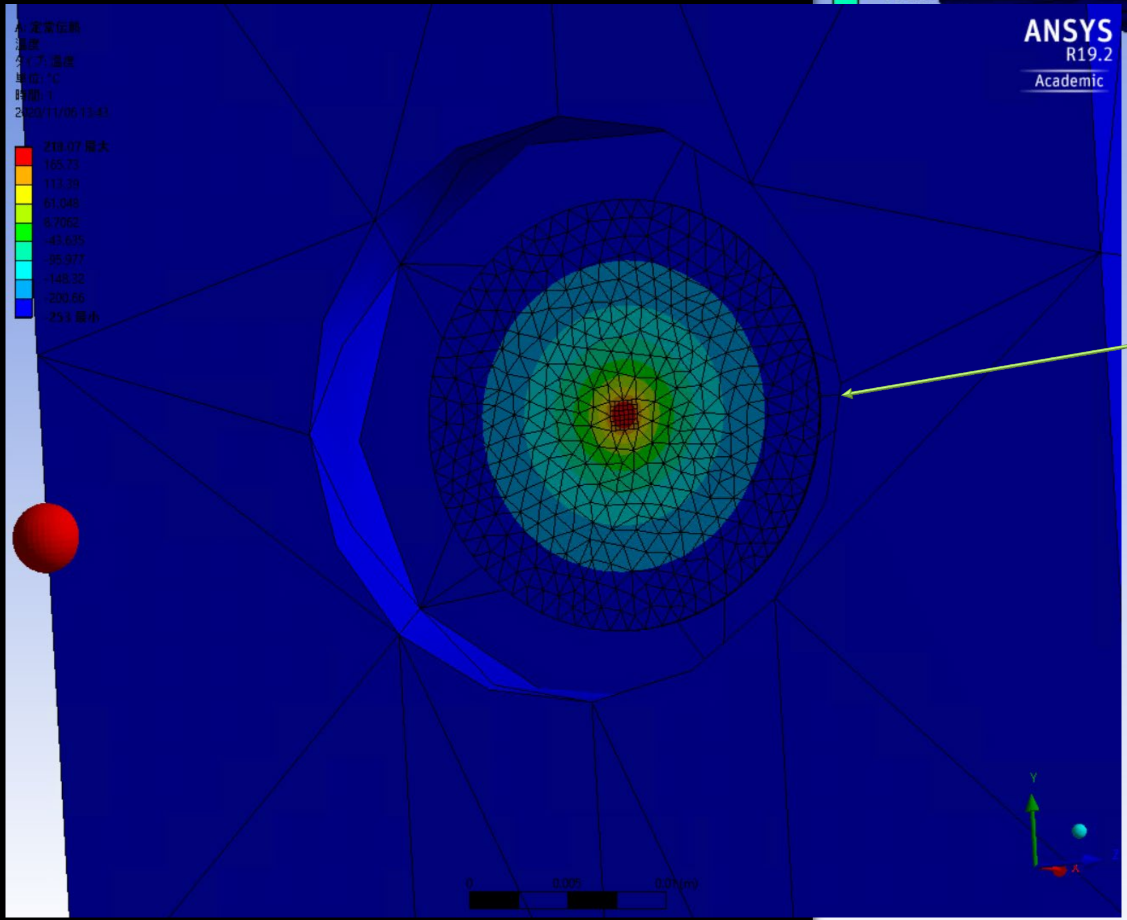


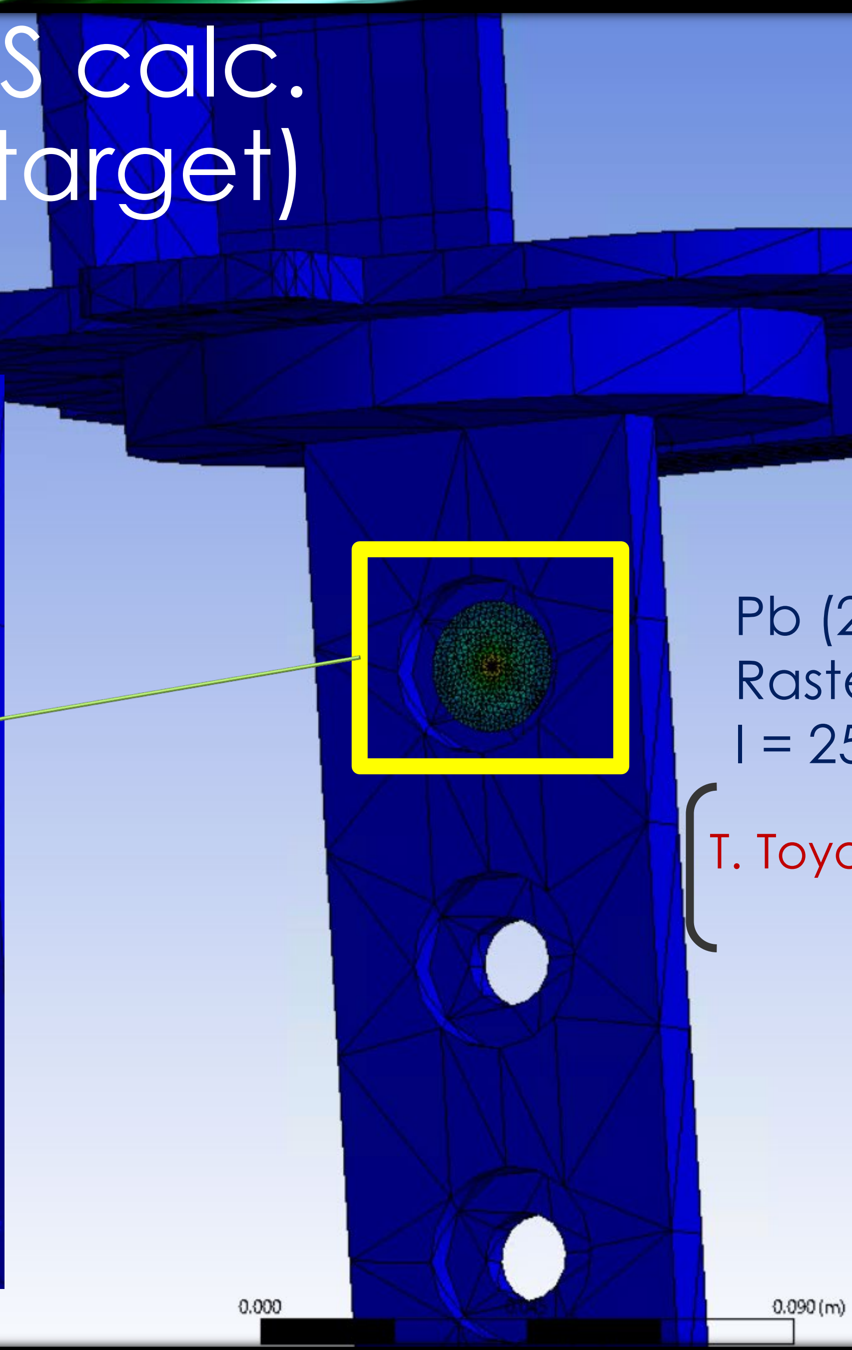
T. Hasegawa et al., Phys. Rev. C 53 (1996) 1210.



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

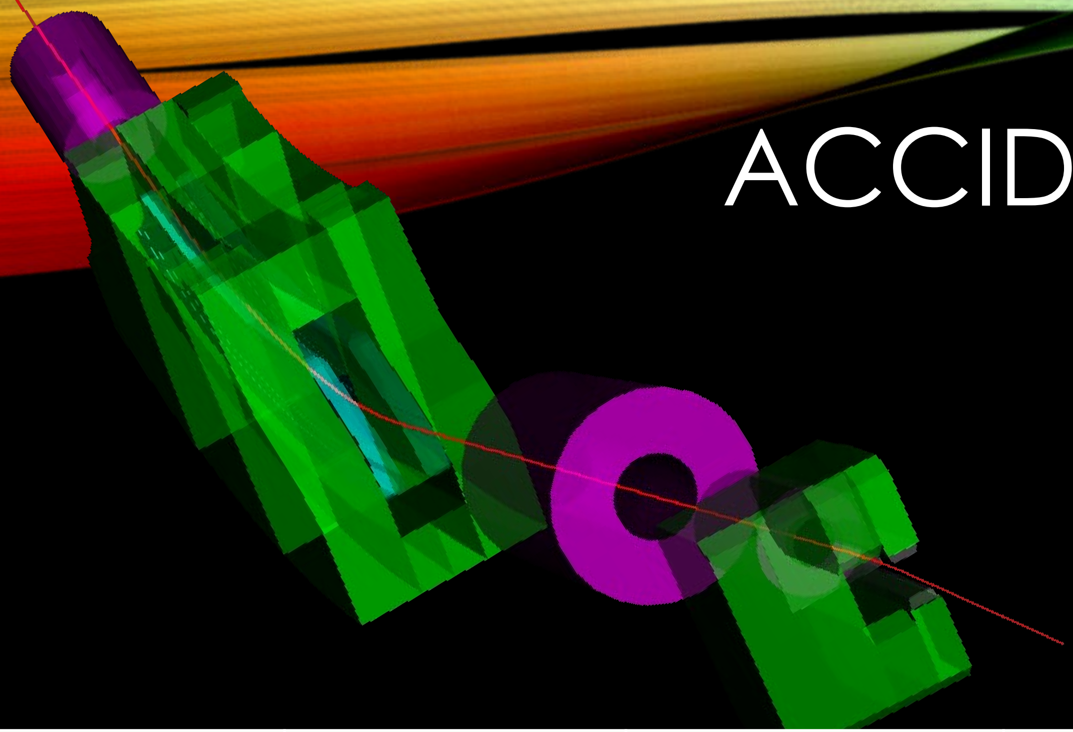
ANSYS calc.
w/ simple model (Pb target)





Pb (200 mg/cm^2)
Raster: 1.5 x 1.5 mm^2
I = 25 μA

(T. Toyoda, Master's thesis, Kyoto Univ. JFY2020)



ACCIDENTAL RATE ESTIMATIONS

Geant4 (PCS+HRS+HKS) + Physics Event Generators
(K. Katayama, Master's Thesis, Kyoto Univ. 2020)

Target	Thickness (mg/cm^2)	Beam Current (μA)	e' (kHz)	p (kHz)	π (kHz)	Acc. rate (kHz)	Acc. rate w/ Chernkovs (kHz)
^{12}C	100	100	21.5	56	71	**0.4**	**0.023**
^{40}Ca	100	50	64.5	48	71	**1.2**	**0.060**
^{208}Pb	100	25	97.0	22	33	**0.8**	**0.041**
^{3}He+^{27}Al	37+160	50	71.8	95	170	**2.8**	**0.13**
^{4}He+^{27}Al	74+160	50	74.0	112	197	**3.4**	**0.16**

SUMMARY

① E12-17-003 (${}^{3}_{\Lambda}\mathrm{n}$): nnΛ puzzle, ΛN interaction

② C12-19-002 (${}^{3,4}_{\Lambda}\mathrm{H}$): hypertriton puzzle, CSB issue = **25 days (requesting)**

③ E12-15-008 (${}^{40,48}_{\Lambda}\mathrm{K}$): ΛNN isospin interaction = **28 days (approved)**

④ E12-20-013 (${}^{208}_{\Lambda}\mathrm{Tl}$): ΛNN 3BF in uniform nuclear medium = **20 days (approved)**

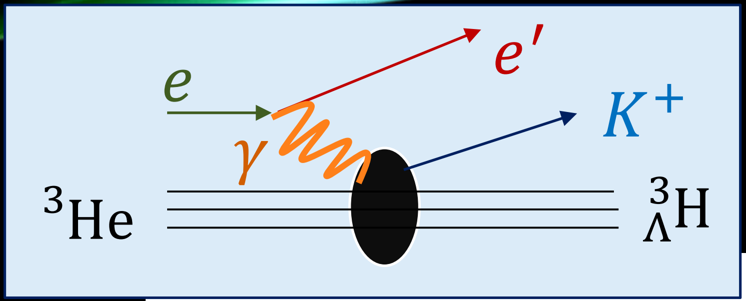
- Spectrometer system
  - PCS was constructed → needs to be transported to JLab
  - HKS base design/construction
- Detectors
  - New WC → Design was done (Master's thesis, Tohoku Univ. JFY2020)
  - Need detectors' commissioning
- Target
  - Basic concept to integrate solids and He targets was agreed

    → Detailed design with JLab target group will be done
- Software
  - Geant4 → Trigger rate / yield / resolutions were estimated
  - FPGA → Being developed (Master's thesis, Kyoto Univ. JFY2020)
  - Analyzer needs to be developed

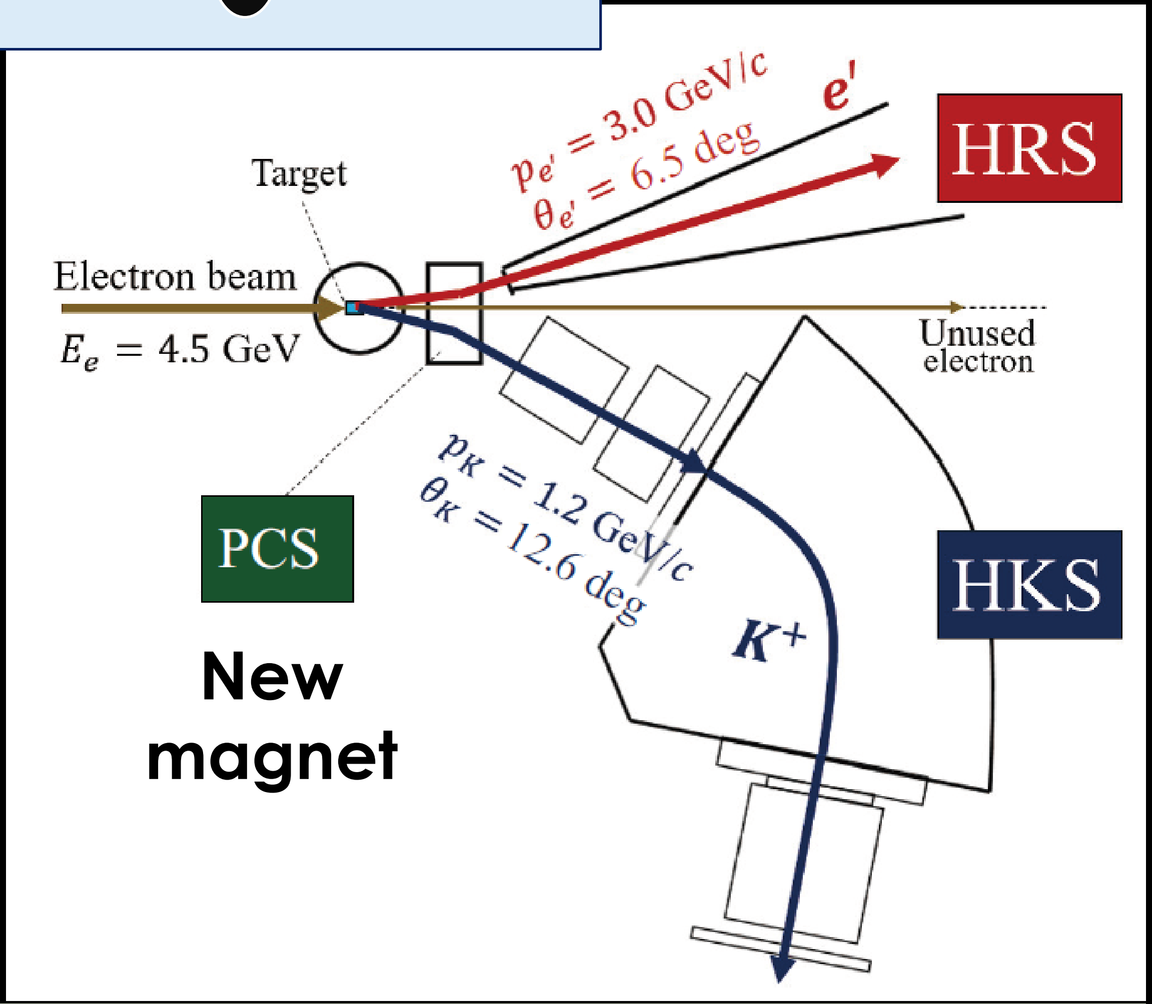
→ Ready by 2022

BACKUP

EXPERIMENTAL SETUP



- Same as E12-15-008 (${}^{40,48}_{\Lambda}\mathrm{K}$)
- PCS → constructed in Japan
- Proposed targets
  - Physics: ^{3}He, ^{4}He gases
  - Calibration: ^{1}H gas, Multi-C, Empty
- Target ladder may be separated from others

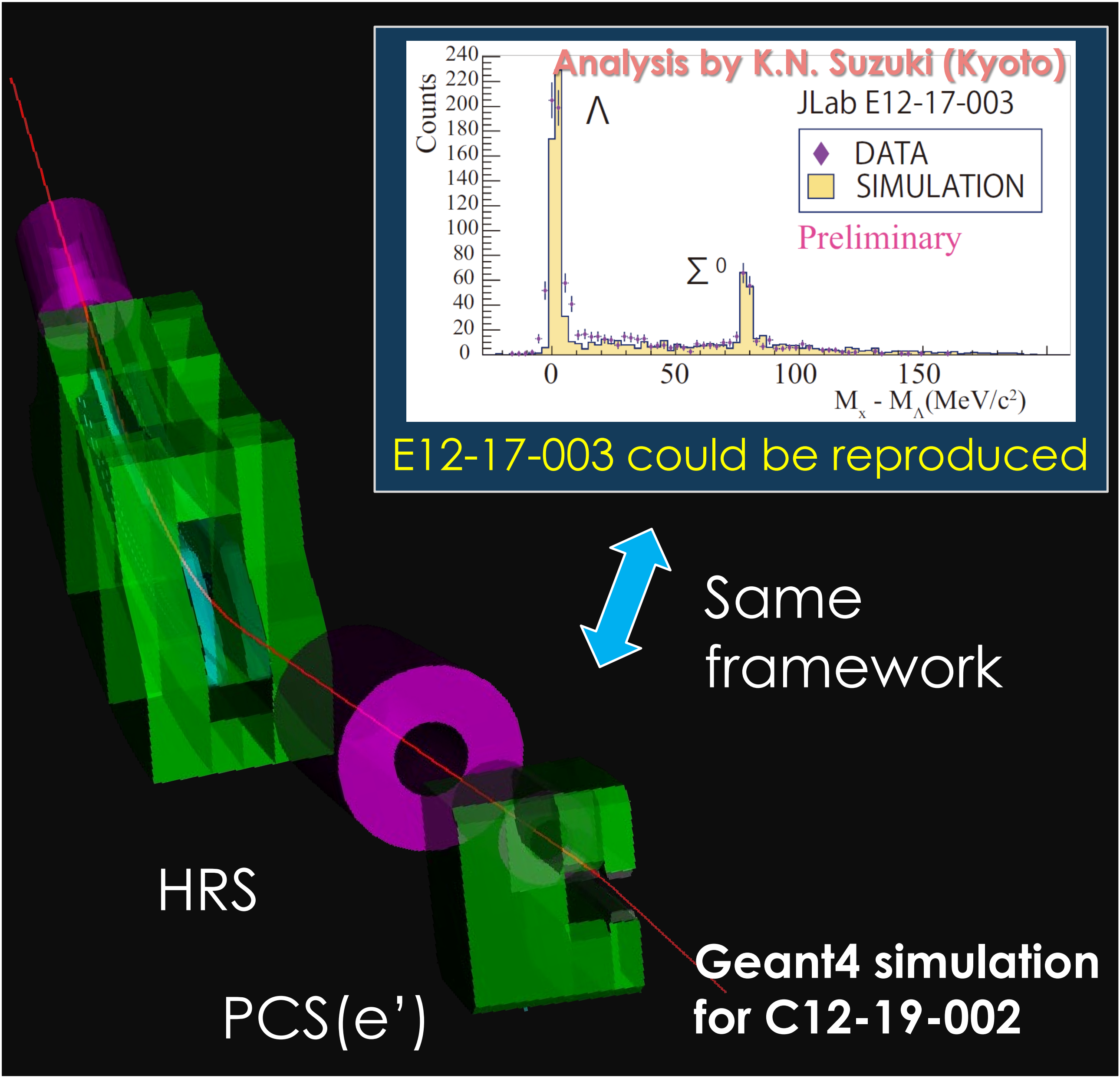


New magnet

PCS @ TOKIN, Sendai, Japan (March 2020)

HKS magnet: Y. Fujii et al., NIMA 795 (2015) 351—363
Kaon ID: TG et al., NIMA 729 (2013) 816—824

EXPECTED MISSING MASS RESOLUTION



E12-17-003 could be reproduced

Same framework

Geant4 simulation for C12-19-002

$$z_{T,\mathrm{HRS}} = \sum_{i+j+k+l=0}^{n_1} a_{ijklm}\, x^i_{\mathrm{FP}}\, x'^j_{\mathrm{FP}}\, y^k_{\mathrm{FP}}\, y'^l_{\mathrm{FP}}$$

$$\overrightarrow{p^{\mathrm{HRS,HKS}}} = \sum_{i+j+k+l+m=0}^{n_2} a_{ijklm}\, x^i_{\mathrm{FP}}\, x'^j_{\mathrm{FP}}\, y^k_{\mathrm{FP}}\, y'^l_{\mathrm{FP}}\, z^m_{T,\mathrm{HRS}}$$

	$\Delta p/p$	$\boldsymbol{\Delta\theta}$ (mrad)
HRS	2.6×10^{-4}	0.6
HKS	4.2×10^{-4}	1.5

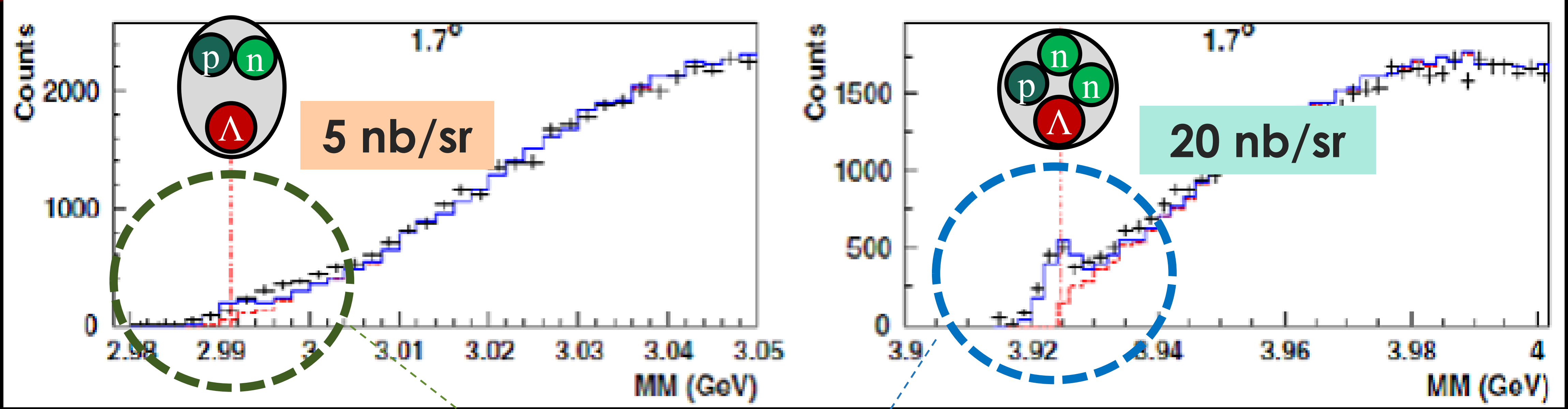
w/ materials (e.g. target):

$$\frac{\Delta p}{p} \Rightarrow \boldsymbol{\frac{\Delta p}{p} \times 1.1},\ \ \Delta\theta \Rightarrow \boldsymbol{\Delta\theta \times 1.4}$$

$$\boldsymbol{\Delta M_{\mathrm{HYP}} = 1\ \mathrm{MeV}\ (\mathrm{FWHM})}$$

YIELD ESTIMATION

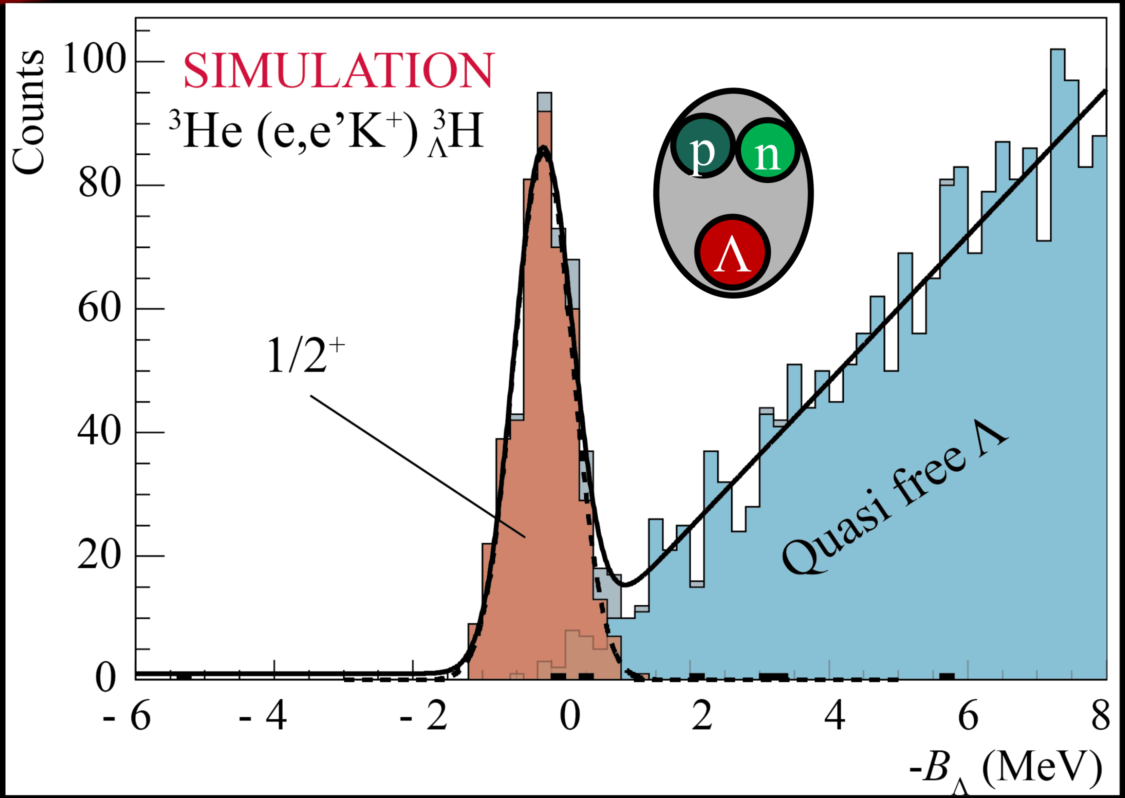
F. Dohrmann et al., *Phys. Rev. Lett.* **93**, 242501 (2004).

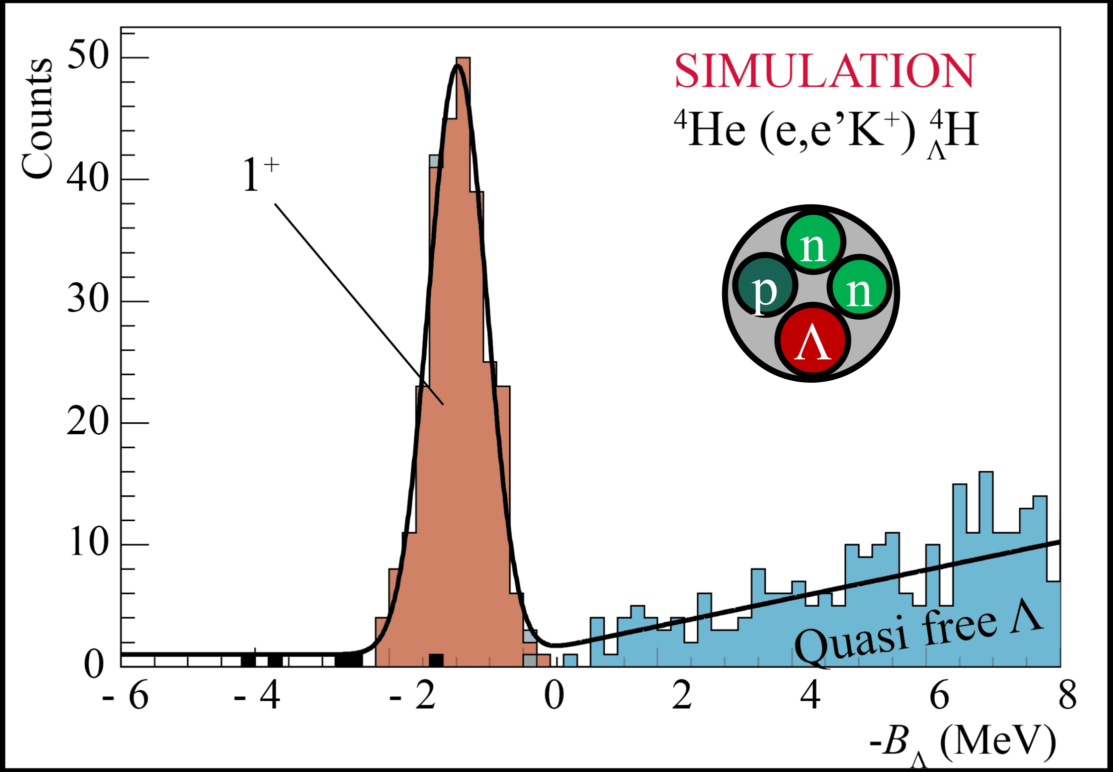


Product	Target (mg/cm^2)	I_{beam} (μA)	CS (nb/sr)	Yield / day	Beamtime (day)	**Total yield**
$^{3}_{\Lambda}\mathrm{H}$	^{3}He (37)	50	5	23	20	**464**
$^{4}_{\Lambda}\mathrm{H}$	^{4}He (74)		20	139	2	**278**

VP flux = 2×10^{-5} (/e), $\epsilon_{\mathrm{det}} = 0.75, f_{\mathrm{density}} = 0.85, f_{Kdecay} = 0.26, \Omega_K = 7$ msr

EXPECTED SPECTRA AND STATISTICAL ERRORS





$$\left|\Delta B_{\Lambda}^{\text{stat.}}\right| = 20\ \text{keV}$$

$$\left|\Delta B_{\Lambda}^{\text{stat.}}\right| = 30\ \text{keV}$$

➡ Hypertriton Puzzle + ΛN int.
(g.s. or excited states)

➡ ΛN CSB in A = 4

CALIBRATIONS AND A SYSTEMATIC ERROR ON B_Λ

Calibration	Target + Sieve Slit	Reaction	z_t range (mm)	Beamtime (day)	Remarks
Mom. + z_t	H	$p(e,e'K^+)\Lambda,\Sigma^0$	$-115 < z_t < 115$	1	$\Lambda: 6100,\ \Sigma^0: 2030$
Mom. + z_t	^{12}C (multi foils)	$^{12}\mathrm{C}(e,e'K^+)^{12}_{\Lambda}\mathrm{B}$		1	$^{12}_{\Lambda}\mathrm{B}^{\mathrm{g.s.}}: 300 \times 5$
Angle + z_t	^{12}C (multi foils) + SS	-		0.2	
z_t	Empty	-	$-100 < z_t < 100$	0.1	+ Background study
	Empty (or gas) + SS	-		0.2	+ Angle resolution check
Physics	^{3,4}He	$^{3,4}_{\Lambda}$H	$-100 < z_t < 100$	22	

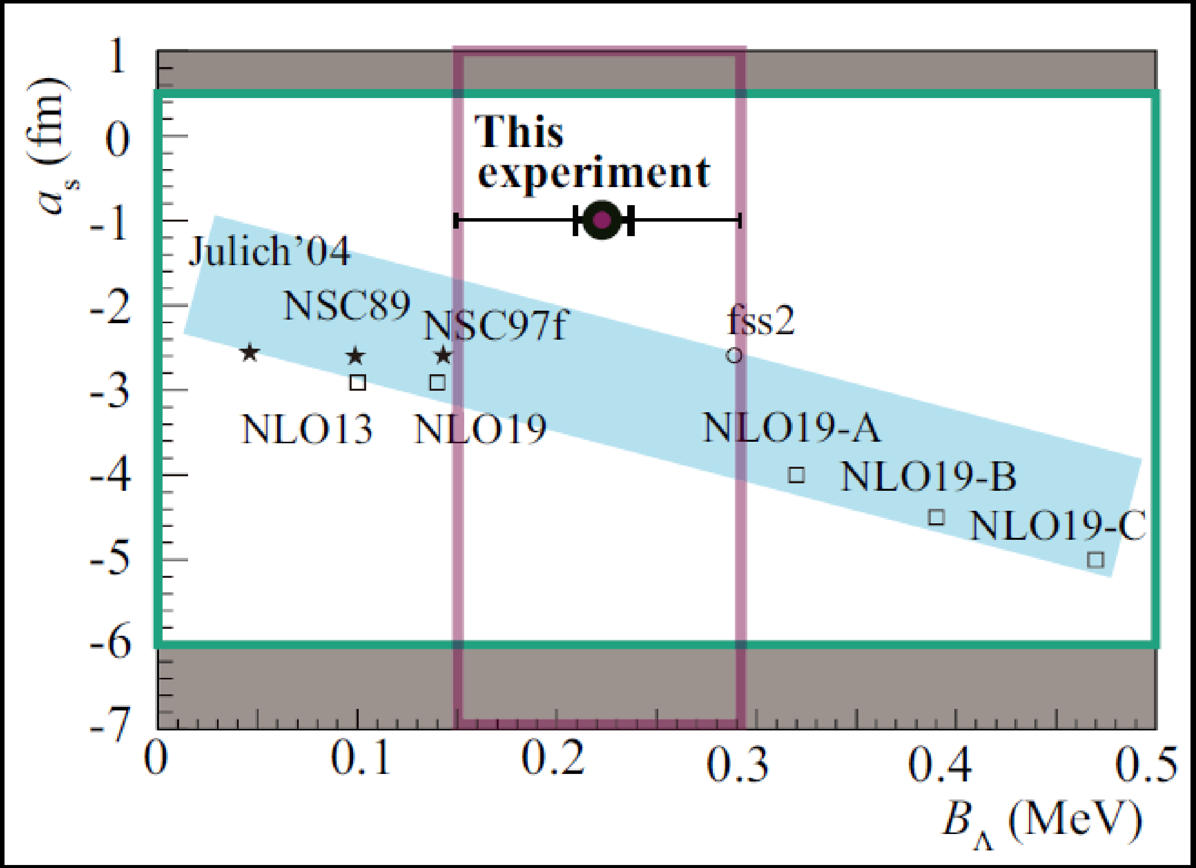
Major contributions to a systematic error on B_Λ

- Energy scale calibration$^{(*)}$: ±50 keV
- Energy loss correction: ±40 keV
  - target density $|\Delta d| = 3\%$
  - cell thickness uniformity $|\Delta t| = 10\%$

$$|\Delta B_{\Lambda}^{\mathrm{sys.}}| = 70\ \mathrm{keV}$$

(*) TG et al., NIMA 900 (2018) 69—83

GROUND STATE OF ${}^{3}_{\Lambda}\mathrm{H}\ (T = 0, J^{\pi} = 1/2^{+})$



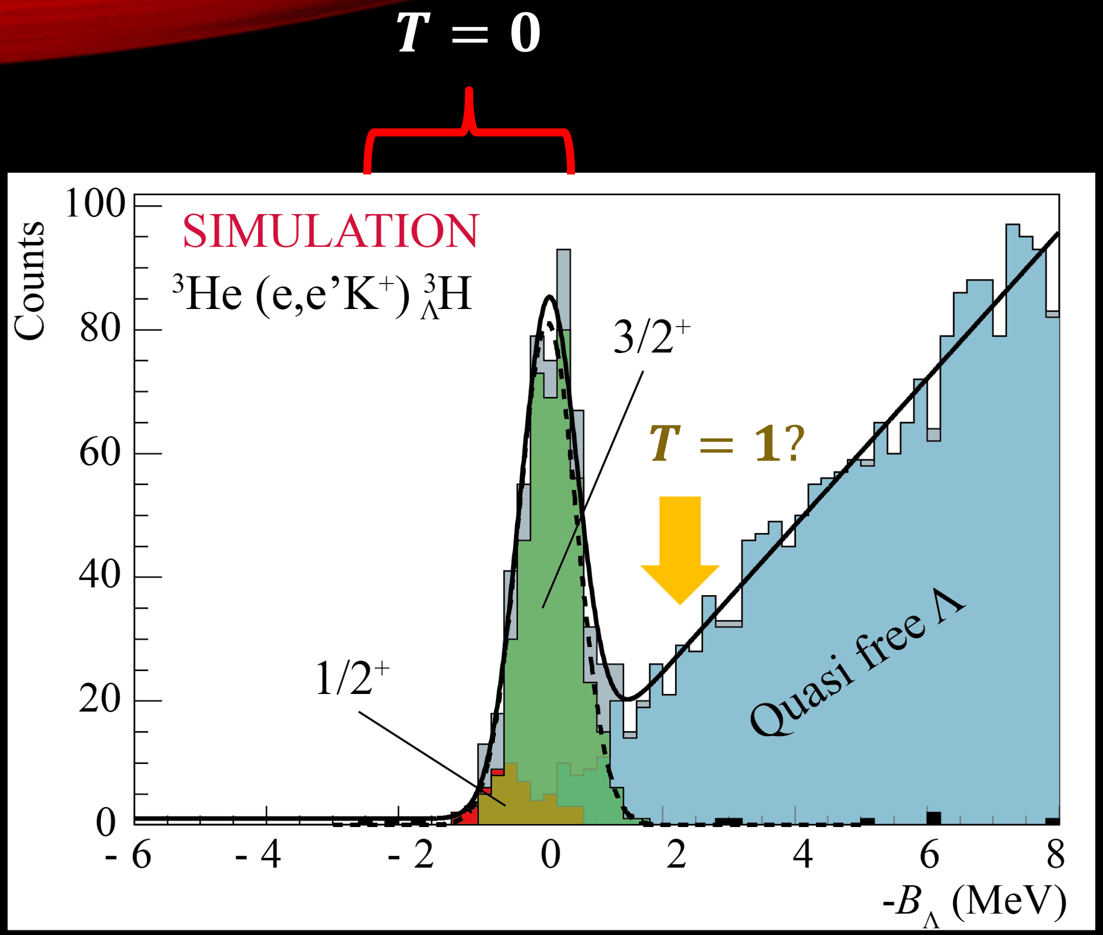
Hypertriton Puzzle

- Λd rm radius (**$|\Delta r| \lesssim 1$ fm**)
  ➔ Better estimation for the lifetime

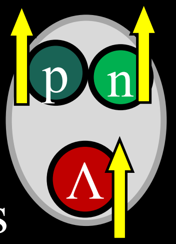
ΛN interaction

- Constraint for
  - Interaction models
  - The ΛN spin singlet scattering length (**$|\Delta a_s| \sim 1$ fm**; cf. $a_s = 1.8^{+2.3}_{-4.2}$ fm)

EXCITED STATES OF $^{3}_{\Lambda}\mathrm{H}$

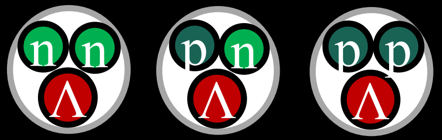


$^{3}_{\Lambda}\mathrm{H}\ (T = 0,\ J^{\pi} = 3/2^{+})$



- Has NOT been measured
- Hard to measure by emulsion / HI experiments
- Does it exist?
  - If yes, the CS is larger than ½ by a factor of 8 (1)
  - If no, only the 1/2^{+} state will be observed
    🡐 $\pi\!\!\!/$EFT predicts 3/2^{+} as a virtual state (2)
- Strong constraint for **the ΛN spin triplet interaction**

$^{3}_{\Lambda}\mathrm{H}\ (T = 1,\ J^{\pi} = 1/2^{+})$



- Isospin partner of *nn*Λ (and *pp*Λ)
  ➔ significant information on the existence of *nn*Λ
- CSB study in the A = 3 hypernuclear system
- If the CS is 0.5 nb/sr → $|\Delta B_{\Lambda}^{\mathrm{stat.}}| \sim 70$ keV

(1) T. Mart *et al*, *Nucl. Phys. A* **640**, 235-258 (1998)
(2) M. Schäfer et al., Phys. Lett. B 808, 135614 (2020)

SUMMARY

HRS-HRS @ Hall A (JLab E12-17-003, 2018)

- $^{3}\mathrm{H}(e,e'K^{+})nn\Lambda$
- Analysis in progress (by 3 independent teams)
  ➔ Peak search, n(n)-Λ FSI, reaction cross section

HRS-HKS @ Hall A (JLab C12-19-002, 2022/2023)

- $B_\Lambda({}^{3,4}_{\Lambda}\mathrm{H})$ with an accuracy of

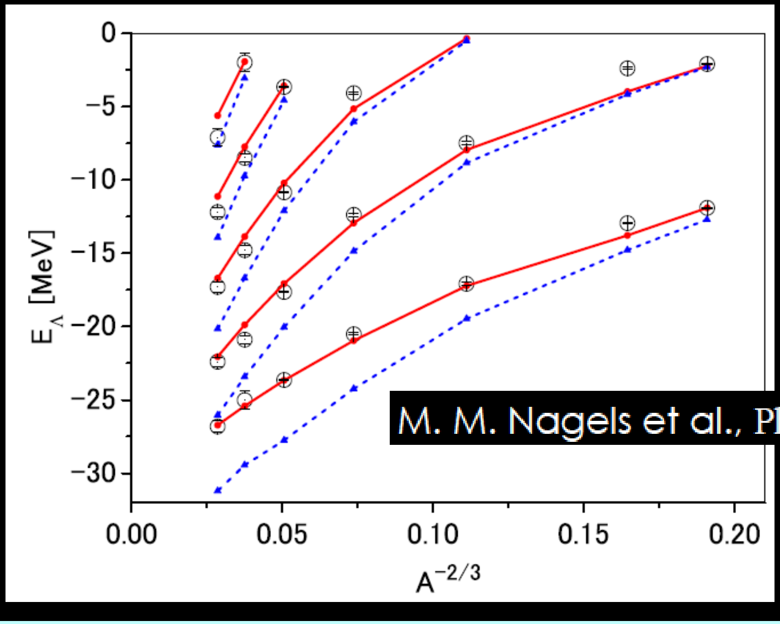
$$\Delta B_\Lambda^{\text{tot.}} = \sqrt{\left|\Delta B_\Lambda^{\text{sys.}}\right|^2 + \left|\Delta B_\Lambda^{\text{stat.}}\right|^2} < 80\ \text{keV}$$

➔ Hypertriton Puzzle / Charge Symmetry Breaking

Studying Λ interactions in nuclear matter with the $^{208}Pb(e,e'K^+)^{208}_{\Lambda}Tl$

Hyperon Puzzle

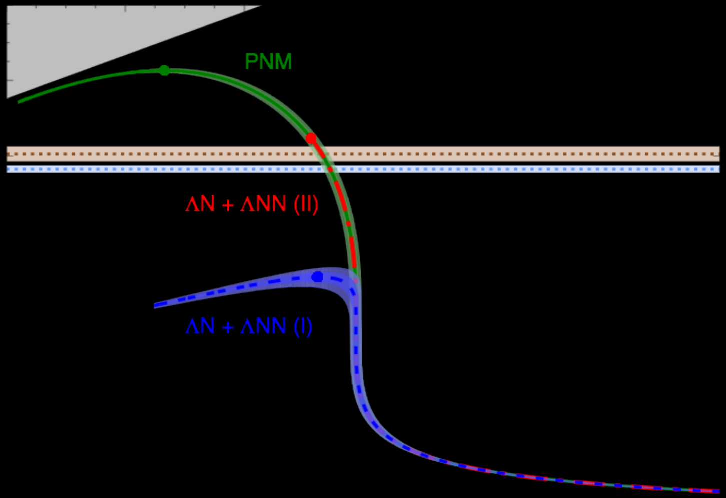
Strong softening of the EoS of dense matter due to the appearance of hyperons which leads to maximum masses of compact stars that are not compatible with the observations.



M. M. Nagels et al., Phys. Rev. C 99, 044003 (2019)

It clearly appears that the inclusion of YNN forces (PNM) leads to the right mass (~2 solar masses

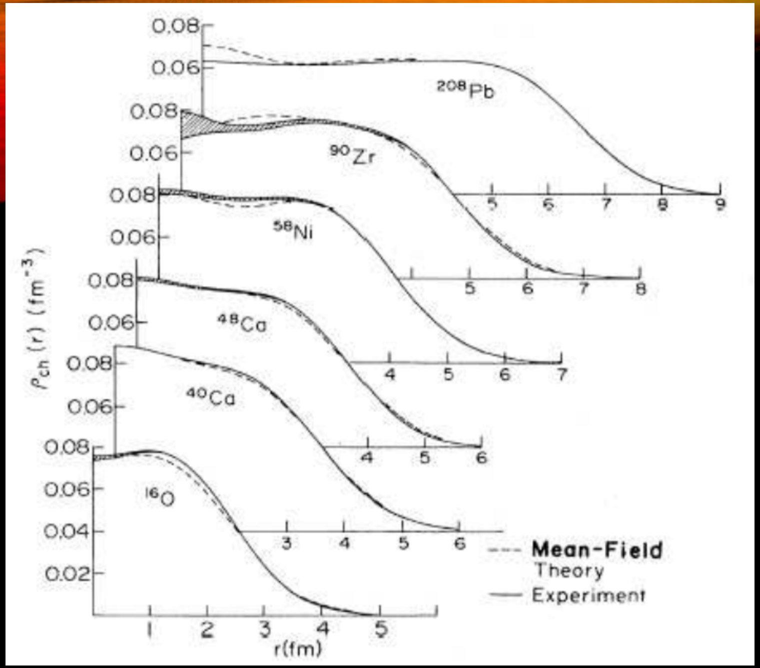
D.Lonardoni *et al.*, Phys. Rev. Lett. 114, 092301 (2015)



Three-body ΛNN forces are known to be strongly A-dependent, making the ^{208}Pb target uniquely suited to study Λ interaction in a uniform nuclear medium with large neutron excess

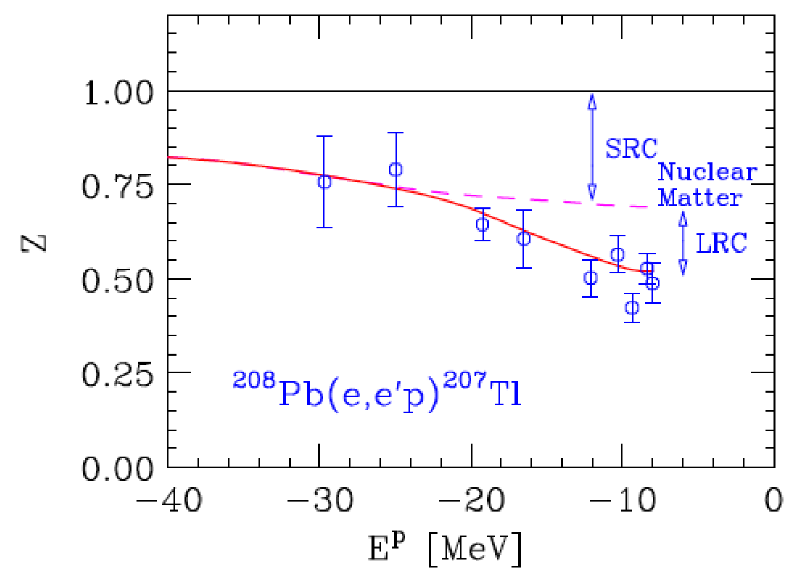
From Franco

B. Frois and C.N. Papanicolas, Ann. Rev. Nucl. Part. Sci. 37, 133 (1987)



The measured charge density distribution of ^{208}Pb clearly shows that the region of nearly constant density accounts for a very large fraction (~70 %) of the nuclear volume, thus suggesting that its properties largely reflect those of uniform nuclear matter in the neutron star

The validity of this conjecture has been long established by a comparison between the results of theoretical calculations and the data extracted from the ^{208}Pb(e,e´p)^{207}Tl cross sections measured at NIKHEF in the 1990s



Deeply bound protons in the ^{208}Pb ground state largely unaffected by finize size and shell effect

→ behave as if they were in nuclear matter

→ The use of a ^{208}Pb target appears to be uniquely suited to study Λ interactions in a uniform nuclear medium with large neutron excess

From Franco