Recent results and future prospects of the JLab hypernuclear program

Contents

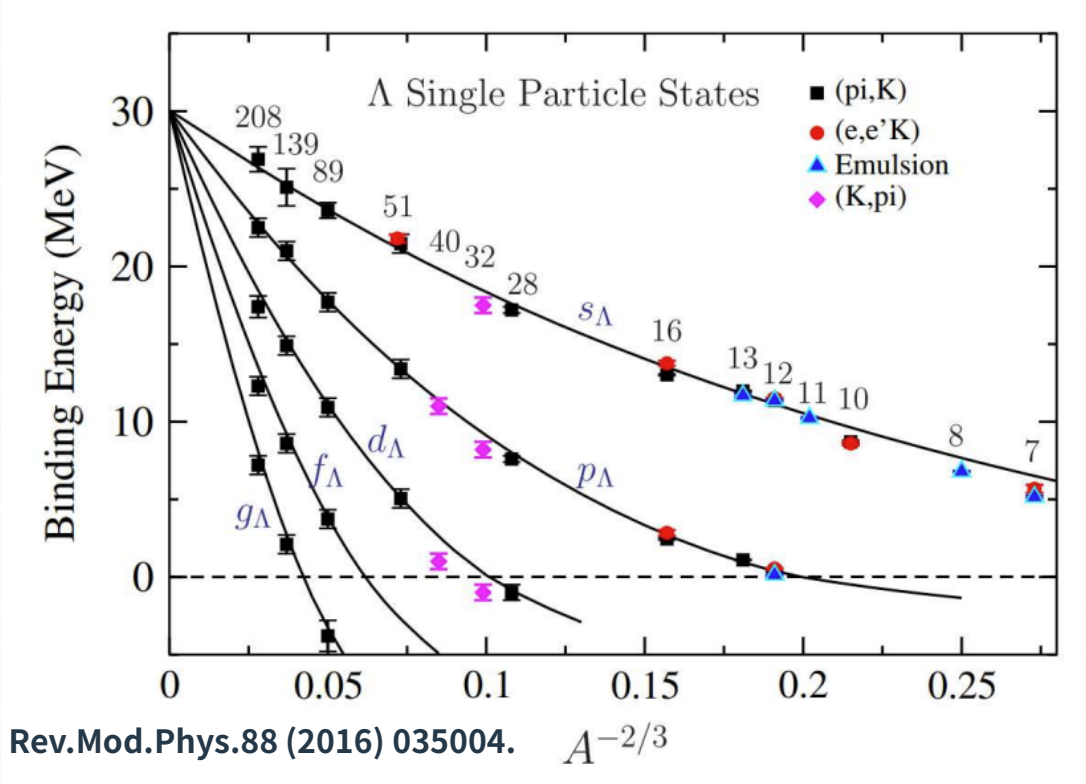
- (e,e'K^+) reaction spectroscopy
- past and recent results
- Search for nnΛ
- Future three experiments

The University of Tokyo

Sho Nagao

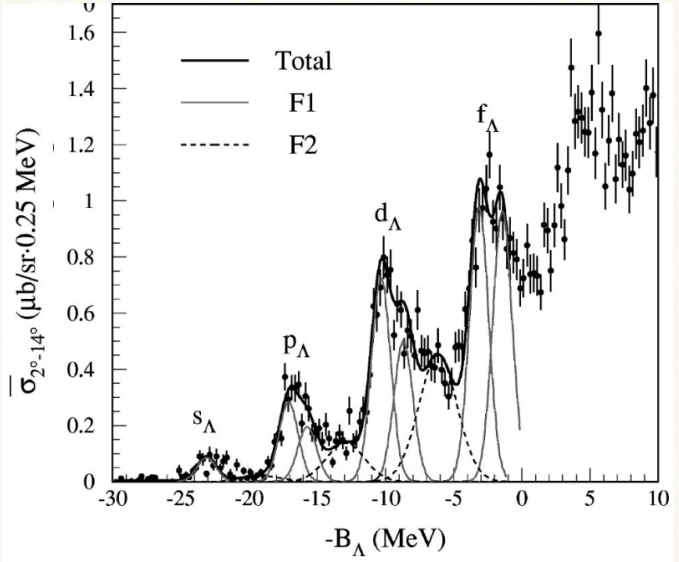
2023/02/14

Hypernuclear Spectroscopy



Rev.Mod.Phys.88 (2016) 035004.

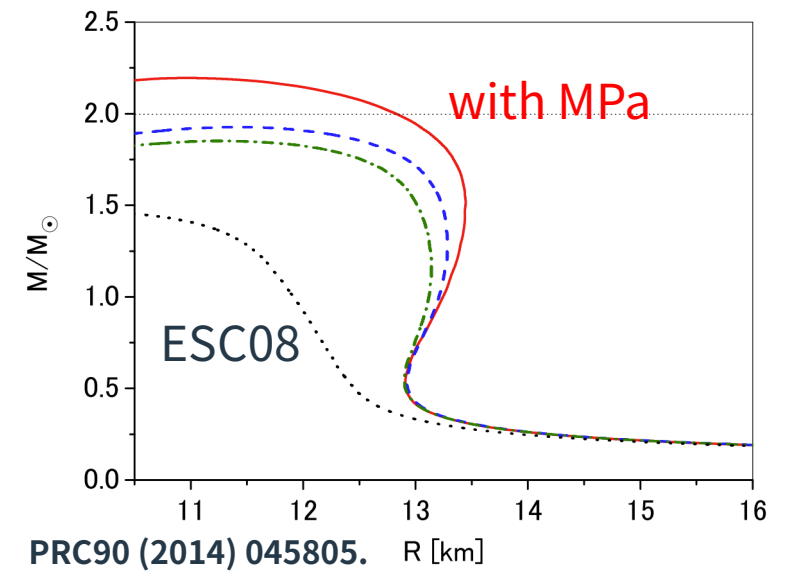
B_Λ of $^{89}_{\Lambda}$Y from (π^+,K^+) reaction



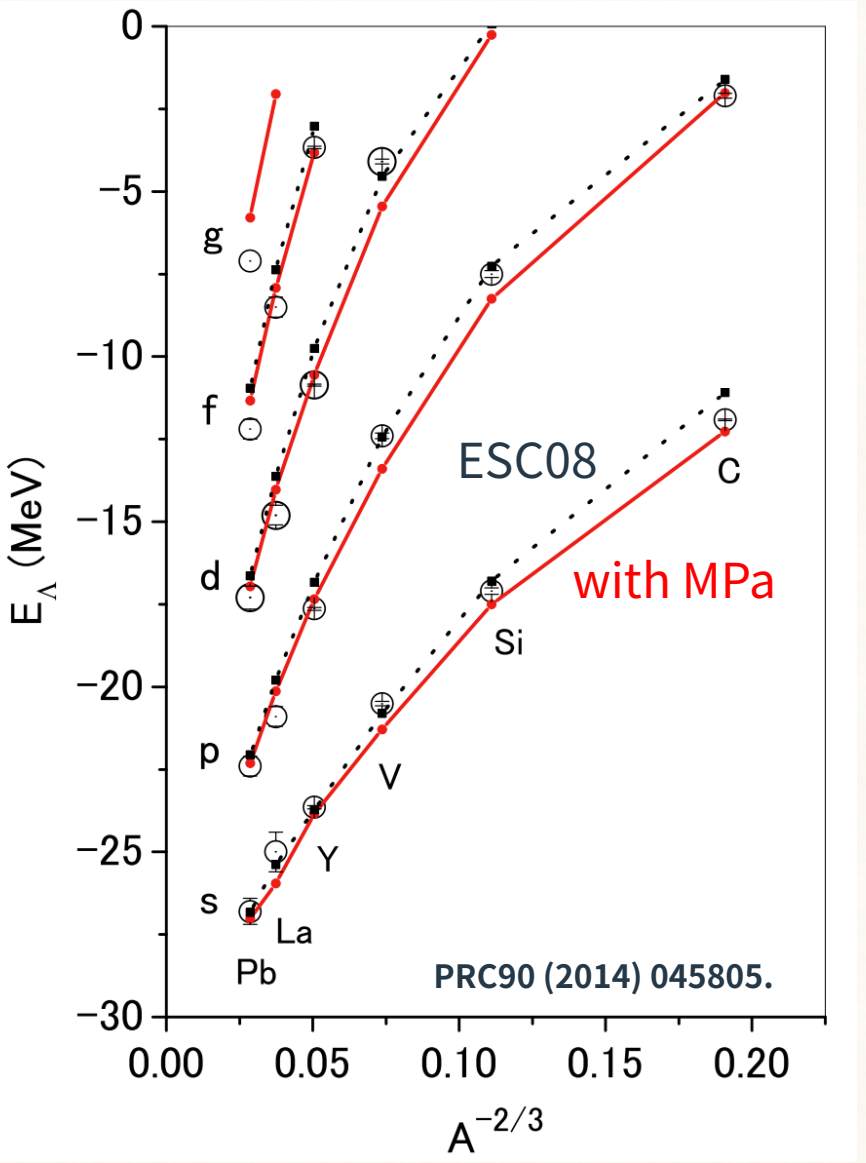
PRC64 (2001) 044302.

- Deduced Λ potential in nuclear matter from A-dependence of Λ binding energies in hypernuclei
- Hypernuclear spectroscopies played an important rule to measure B_Λ
- NS is good bench mark to confirm our framework
- Resolving Hyperon-Puzzle is one of the important motivation

ΛNN 3-body force may make hard-core of NS



- ΛNN 3-body repulsive force plays important rule to reproduce 2⊙ NS.
- ΛNN 3-body force would appear on E_Λ shifts of hypernuclei



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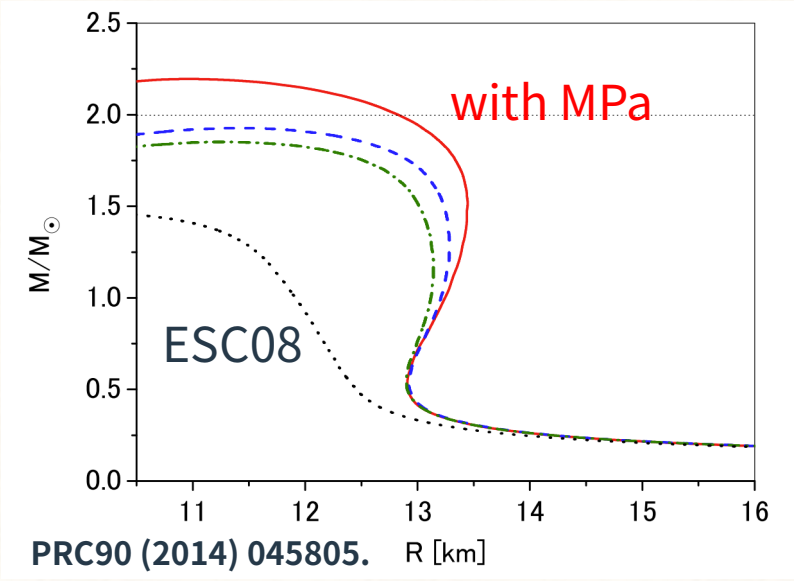

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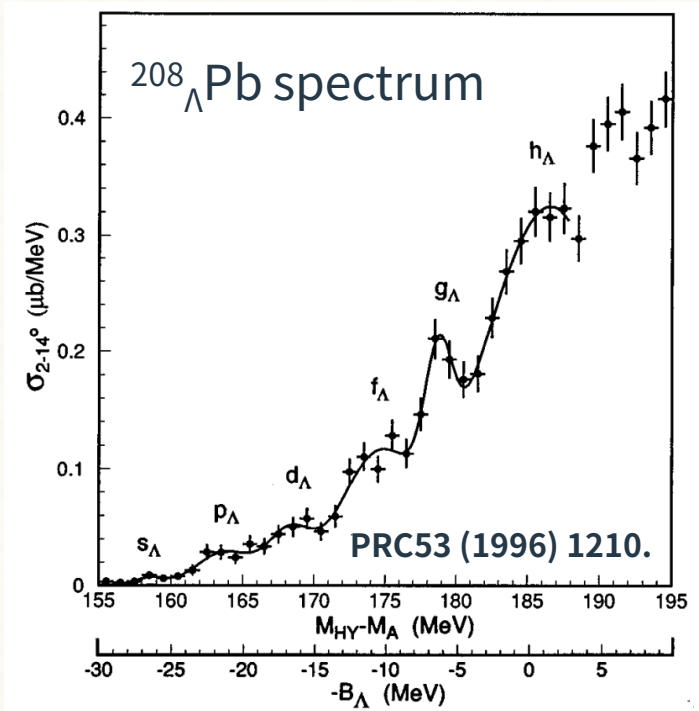
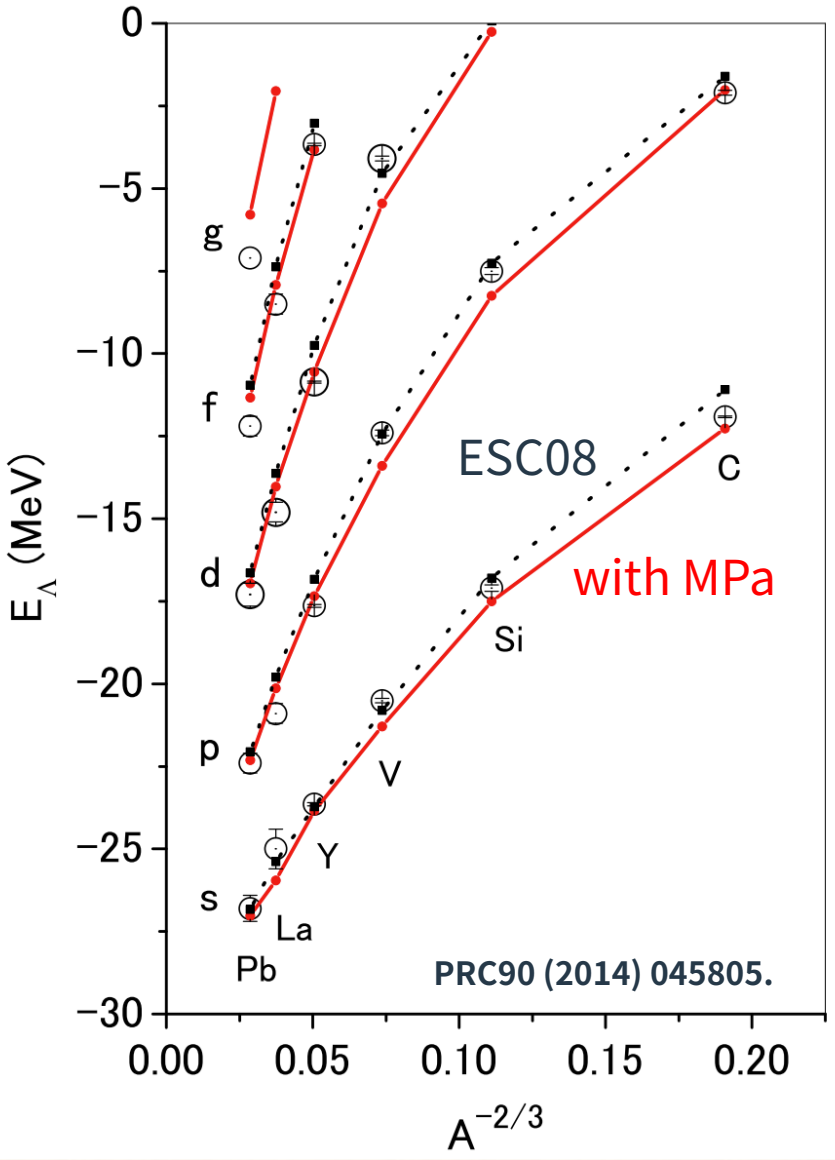
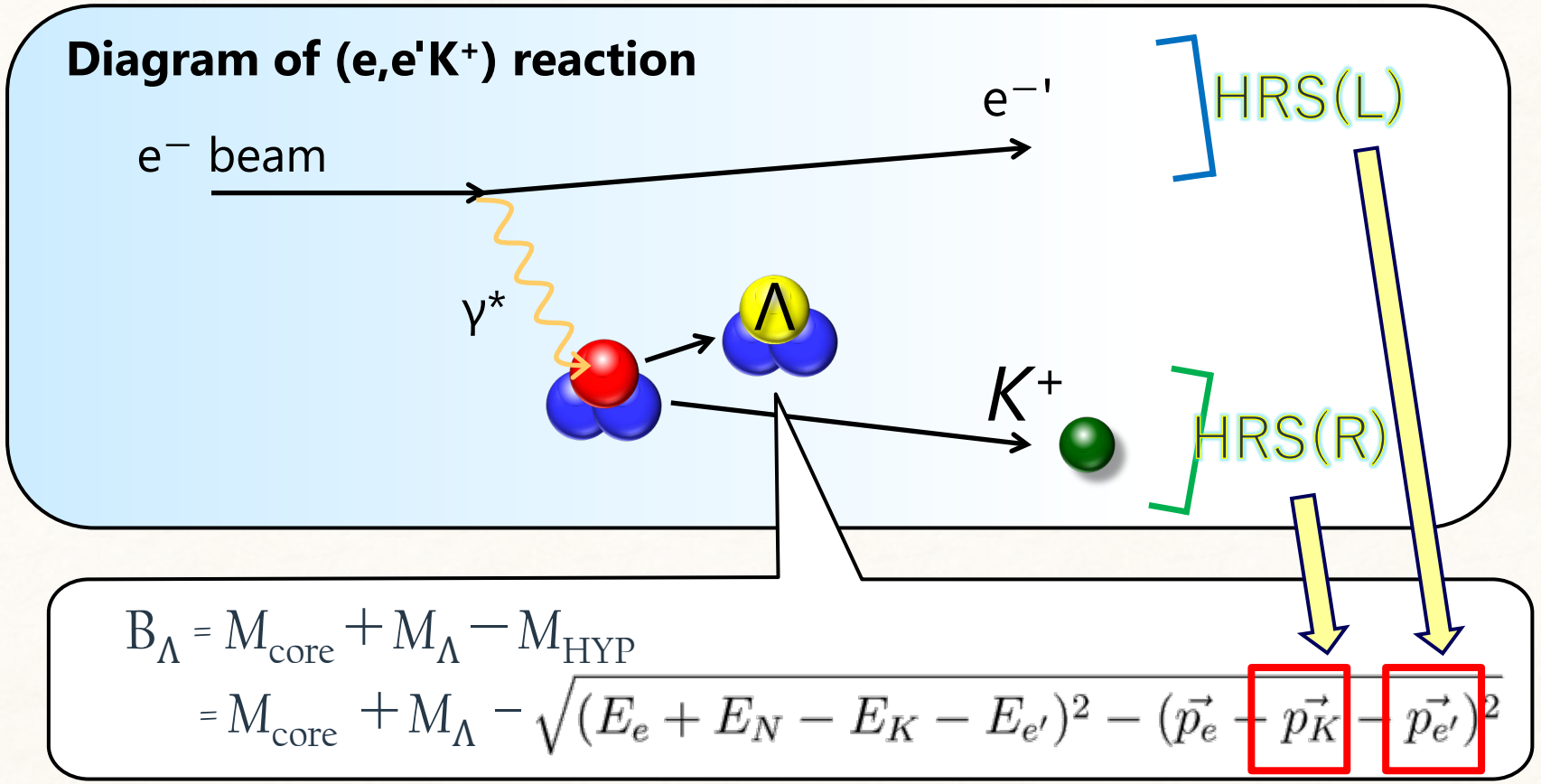




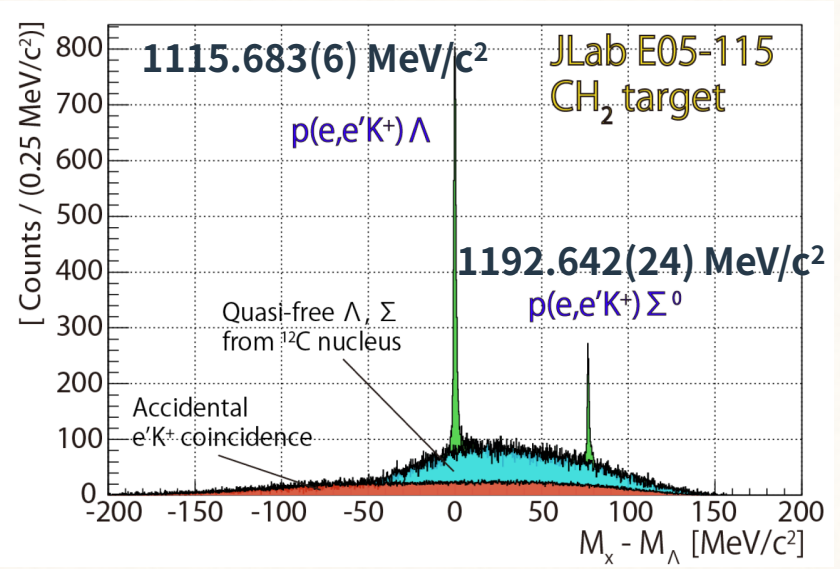
- Hypernuclear measurement with the (π^+,K^+) reaction has not enough accuracy
- High-resolution & High-accuracy measurements are necessary.

(e,e'K⁺) reaction spectroscopy



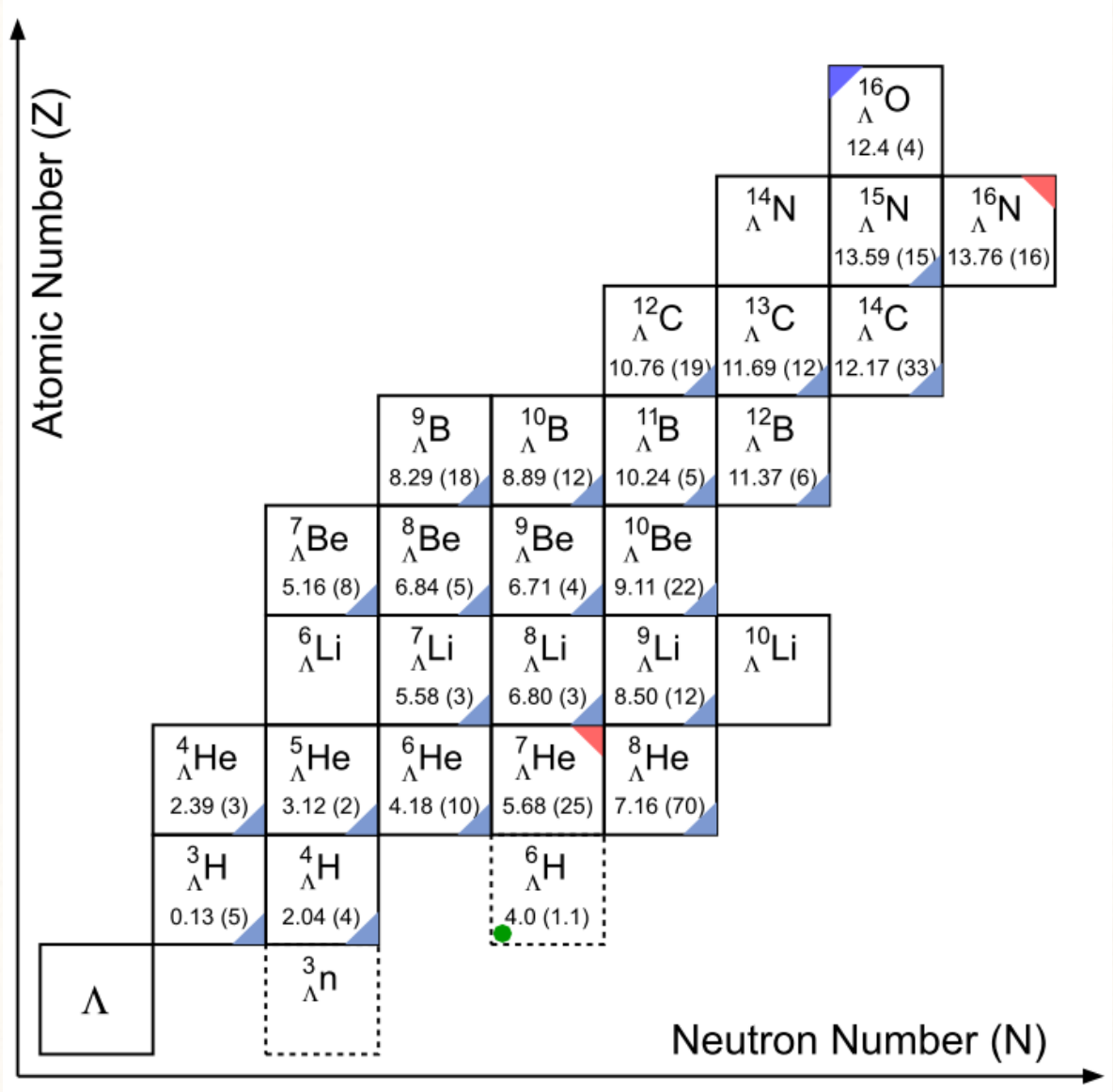
$$B_\Lambda = M_{core} + M_\Lambda - M_{HYP}$$
$$= M_{core} + M_\Lambda - \sqrt{(E_e + E_N - E_K - E_{e'})^2 - (\vec{p_e} - \vec{p_K} - \vec{p_{e'}})^2}$$

p(e,e'K⁺)Λ/Σ⁰ spectrum

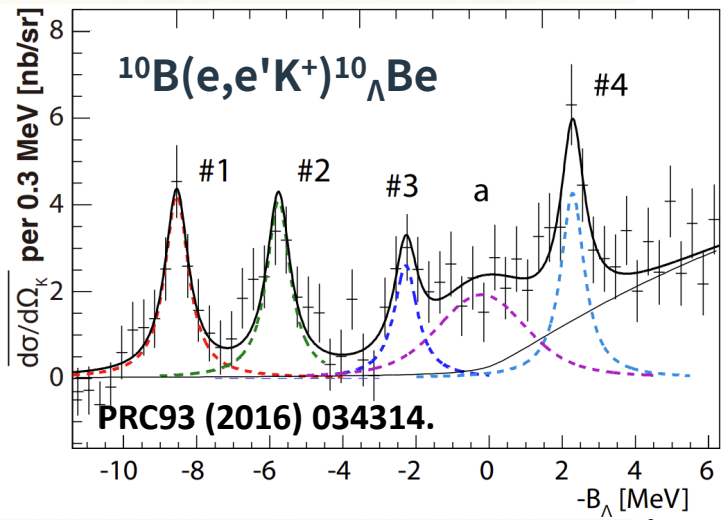


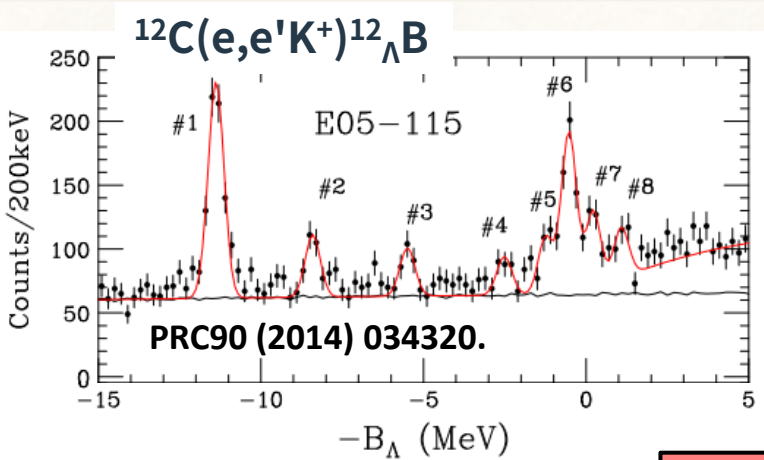
- Hypernuclear production with primary electron beam via virtual photon
- High-intensity electron beam provides enough yield even for thin fixed target
- Good energy resolution thanks to low-emittance beam and high-resolution spectrometers
- Well known energy calibration sources could be used

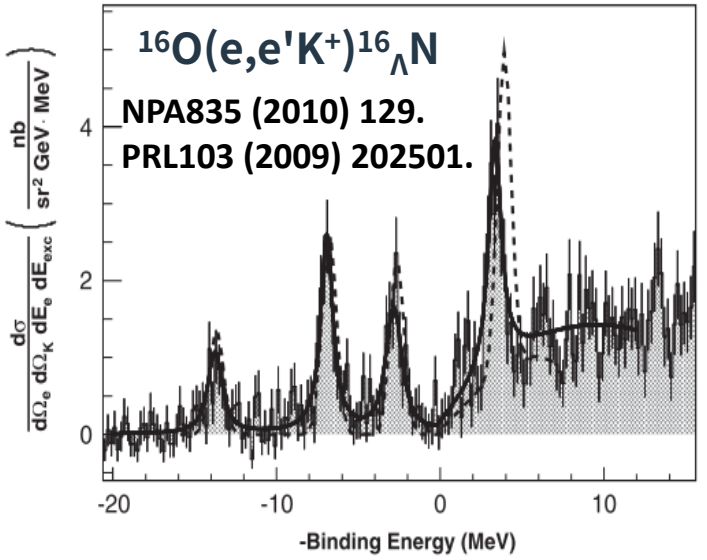
(e,e'K$^+$) reaction spectroscopy past and present

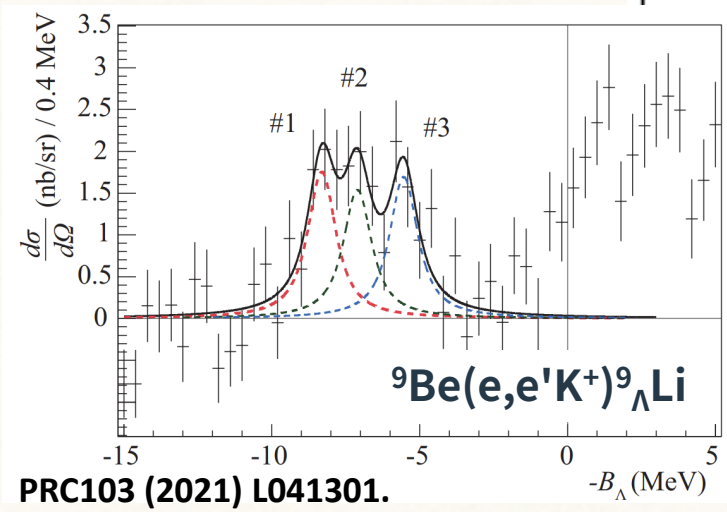


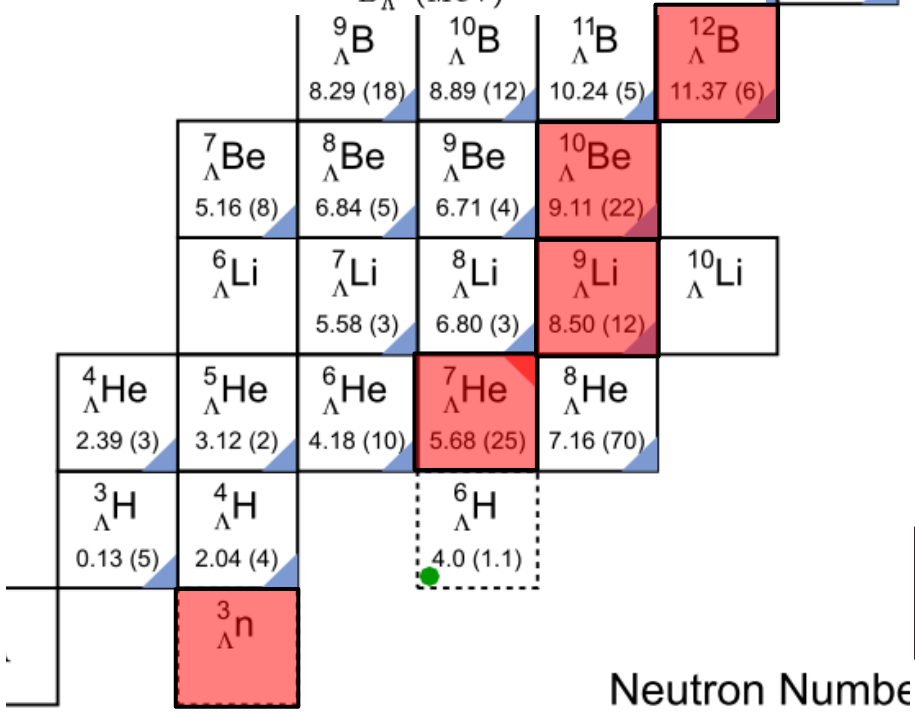
(e,e'K⁺) reaction spectroscopy past and present

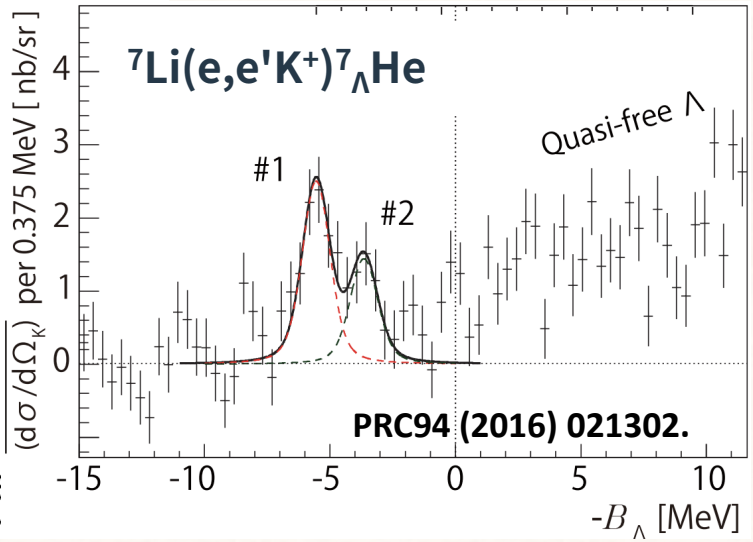












Search for nnΛ

PTEP

Prog. Theor. Exp. Phys. **2022** 013D01(19 pages)
DOI: 10.1093/ptep/ptab158

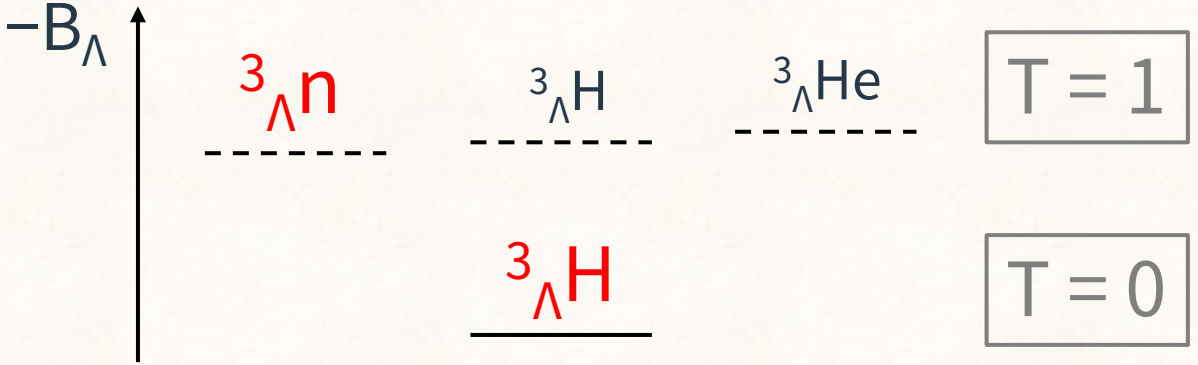
The cross-section measurement for the ^{3}H(e, $e'K^{+}$)$nn\Lambda$ reaction

PHYSICAL REVIEW C **105**, L051001 (2022)

Letter

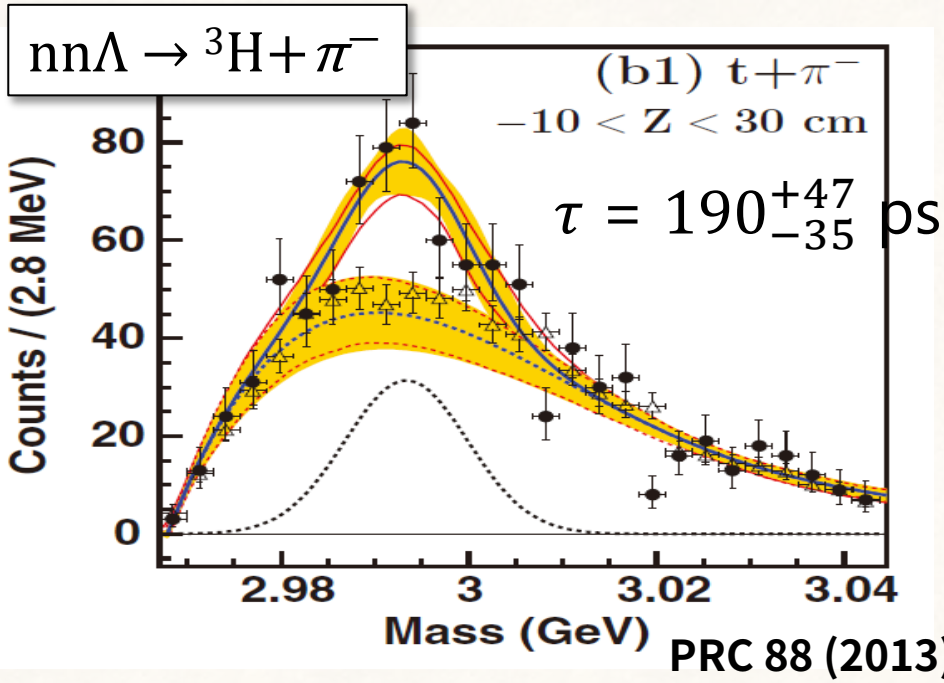
Spectroscopic study of a possible Λnn resonance and a pair of ΣNN states using the (e, $e'K^{+}$) reaction with a tritium target

A=3 hypernuclei

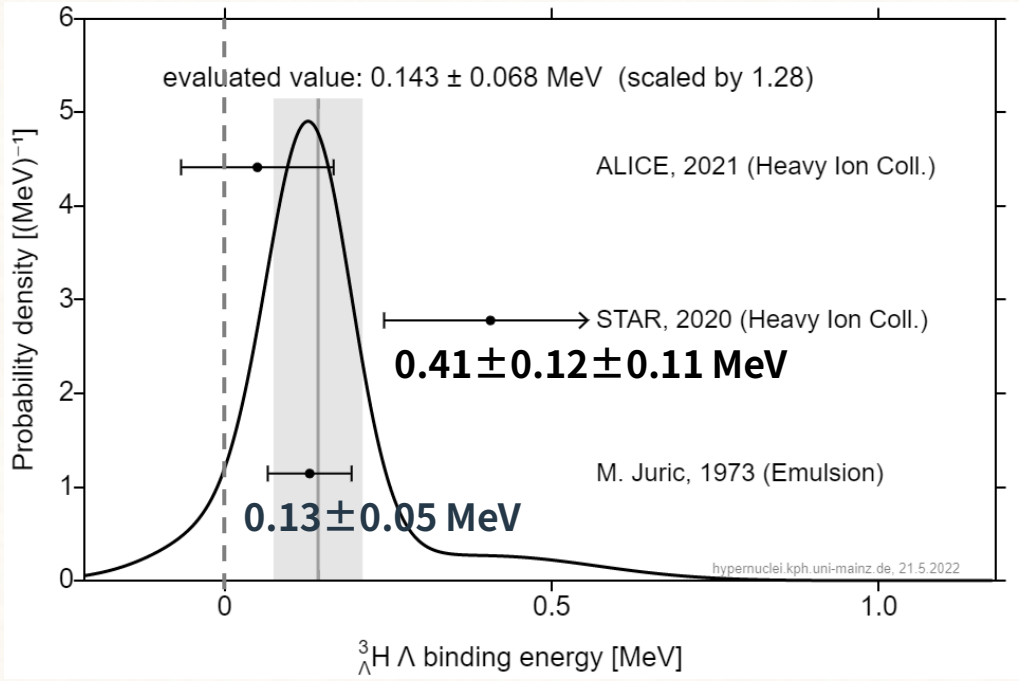


0.13±0.05 MeV [NPB52(1973)1.]

- nnΛ is a T=1, A=3 hypernucleus
- Existence of nnΛ is not robust yet
- Possibility of bound/resonance nnΛ if $^3_\Lambda$H would bound deeply.

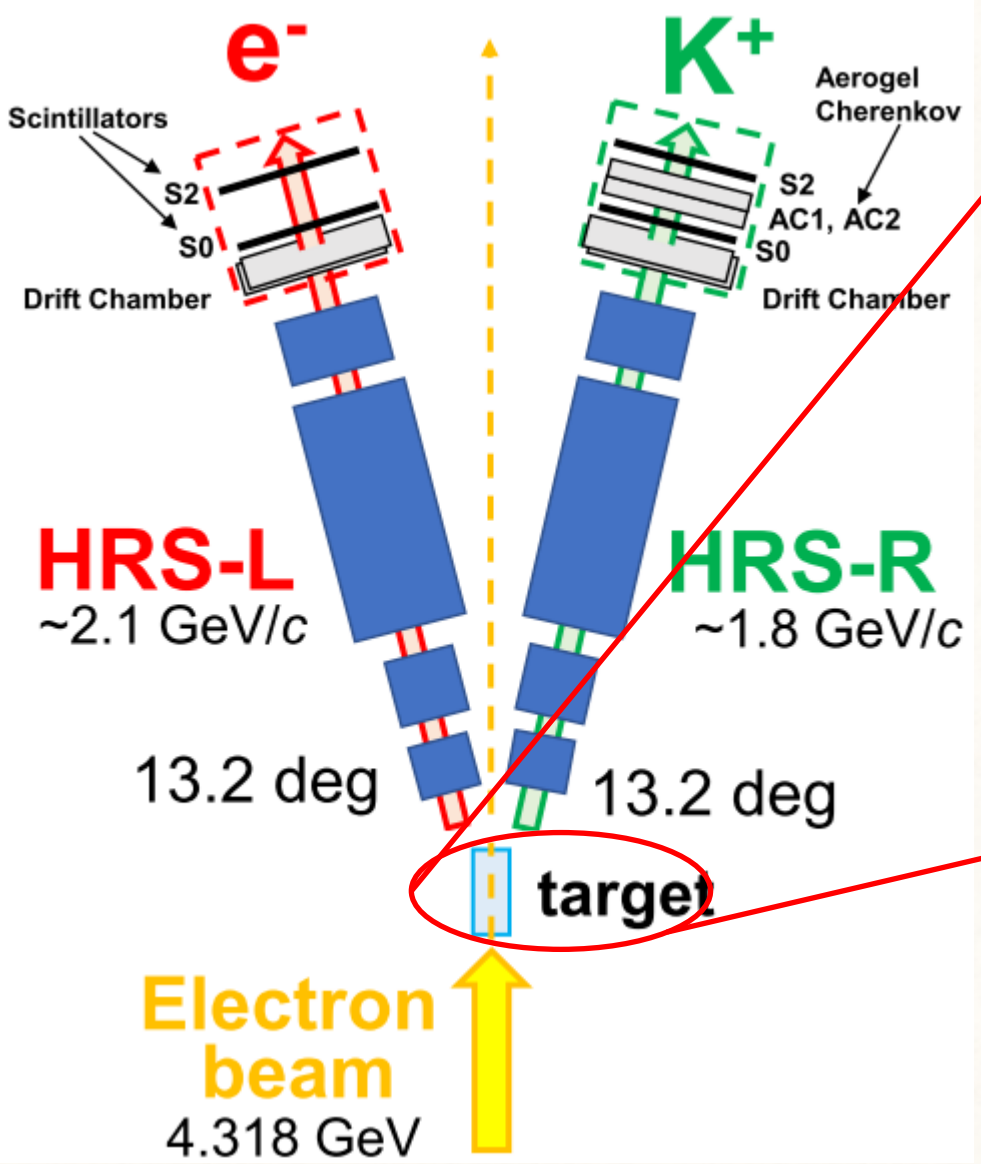


PRC 88 (2013) 041001.



Hypernuclei database (https://hypernuclei.kph.uni-mainz.de/)

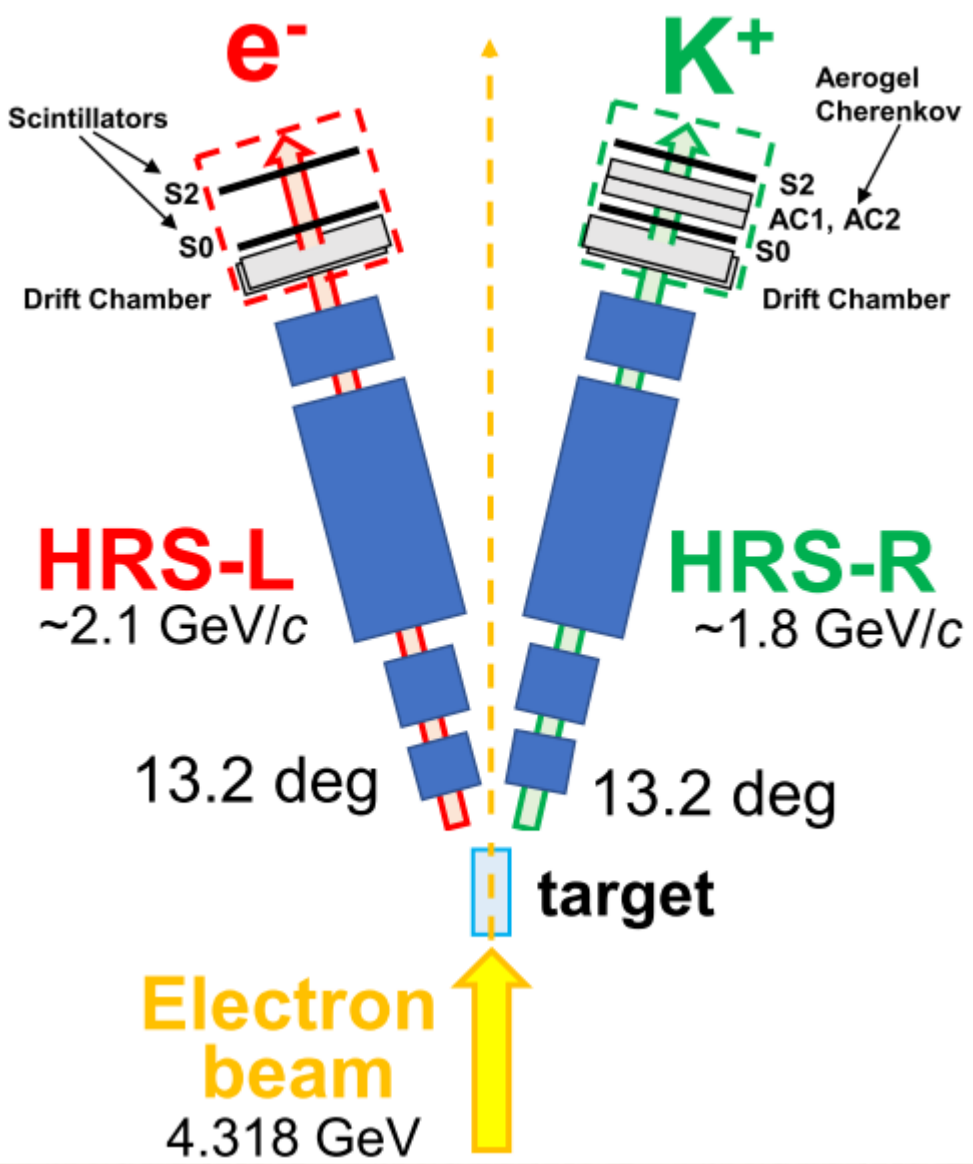
Experiment w/ cryogenic gas T_2 and High-resolution Spectrometers

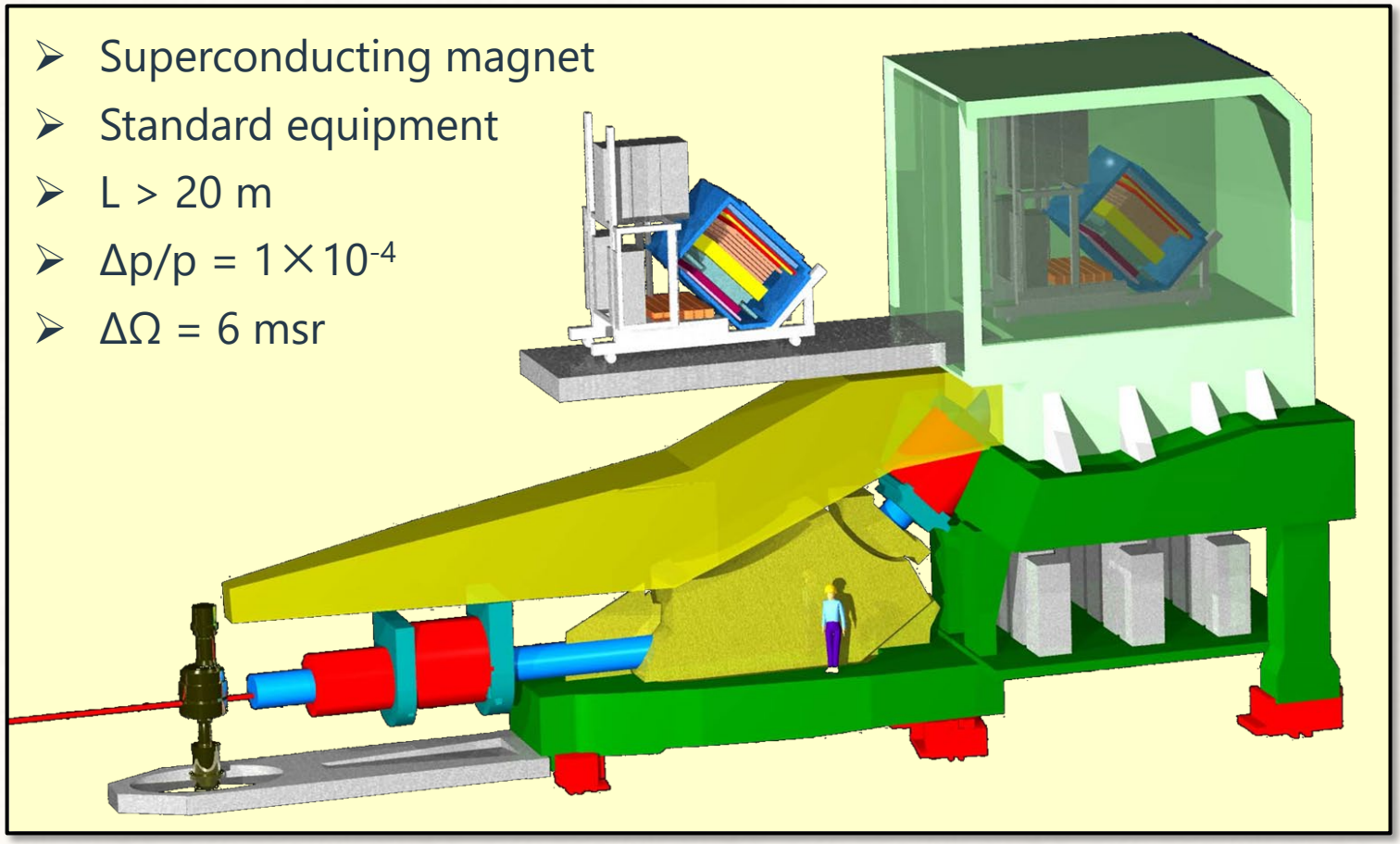


$\underline{T_2 \text{ target}}$
40 K, 85.1±0.8 mg/cm^2, 40 TBq

$\underline{H_2 \text{ target}}$
40 K, 70.8±0.4 mg/cm^2

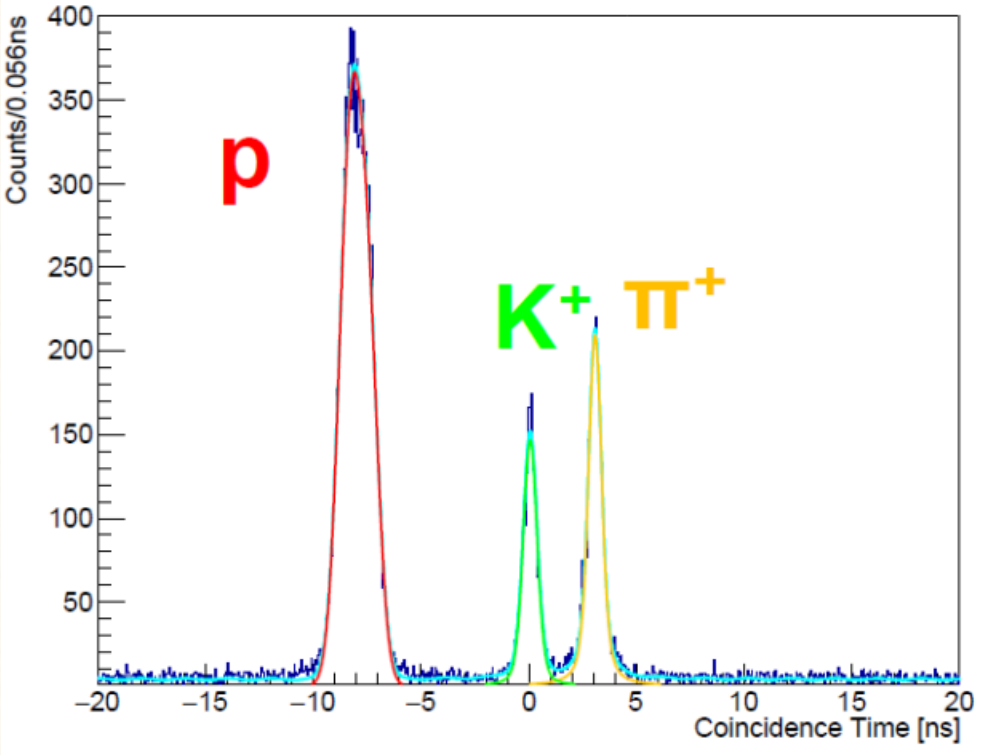
Experiment w/ cryogenic gas T_2 and High-resolution Spectrometers



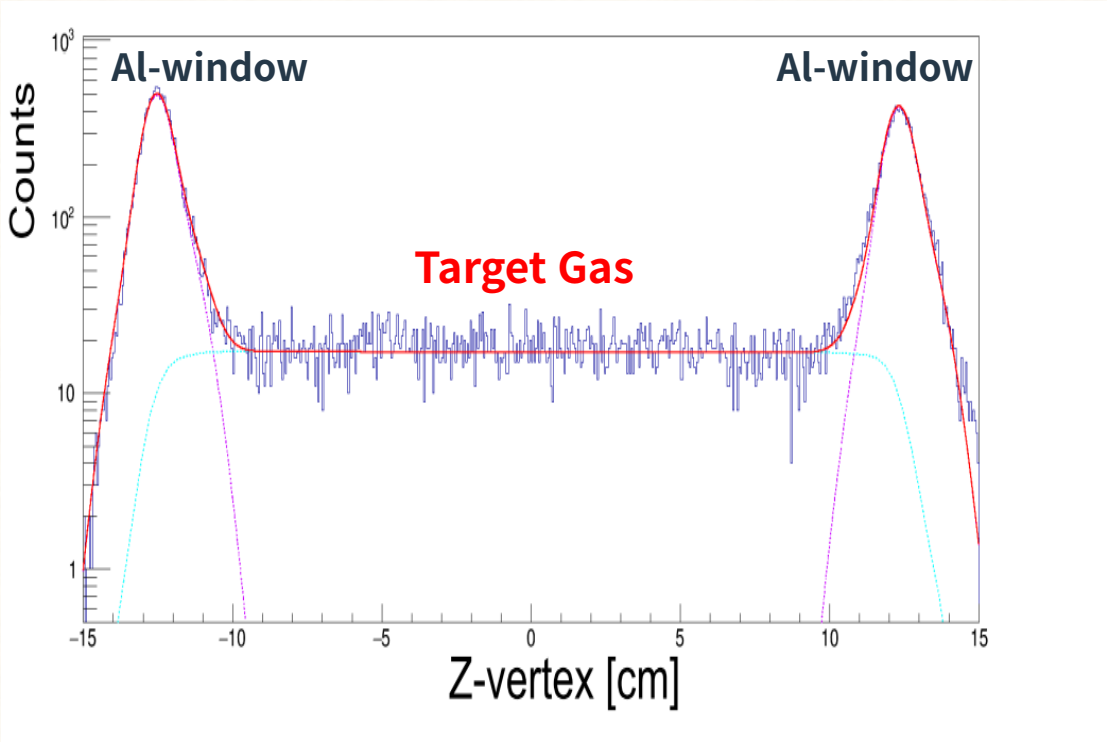


Event Selection

- K^+ is identified on coincidence time of two spectrometers
- K^+ selection with two aerogel-Cherenkov detectors
- Any PID are not necessary for e^-' side

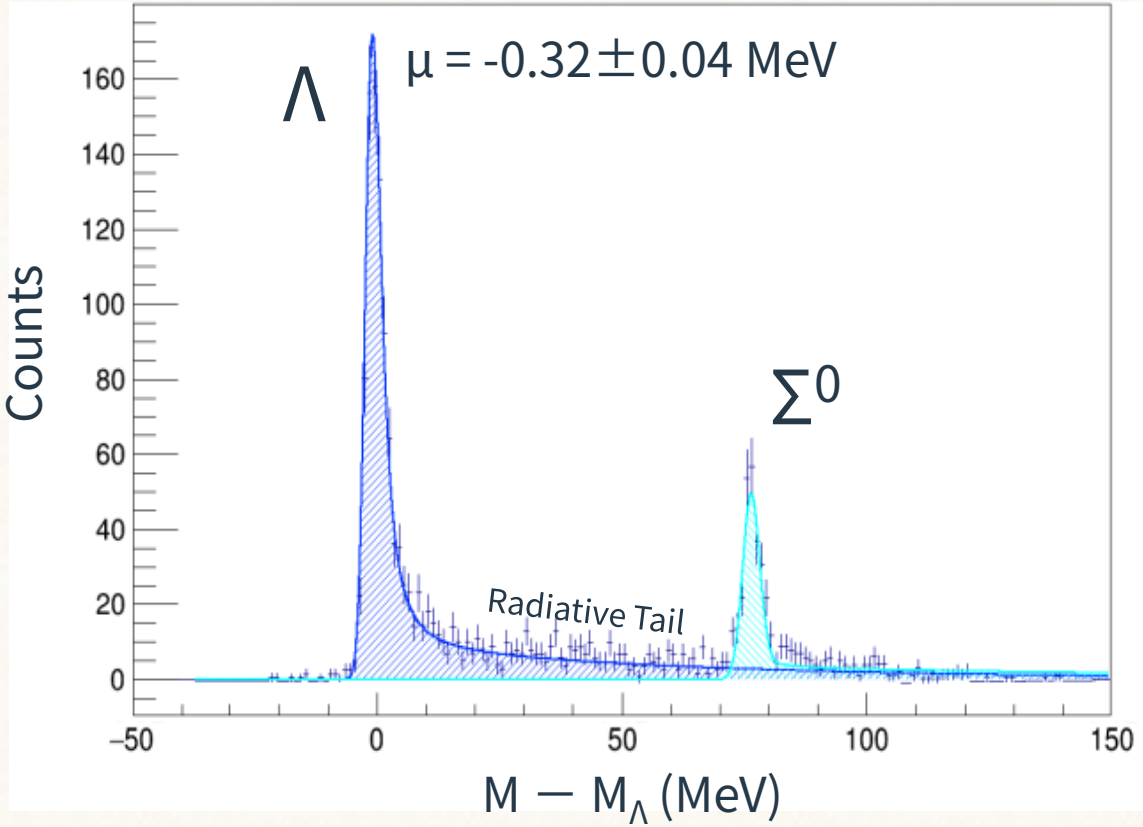


- Reaction points at the target could be measured with < 1 cm resolution on vertex information reconstructed with transfer matrix
- Cryo-gas region and Al-window could be find clearly

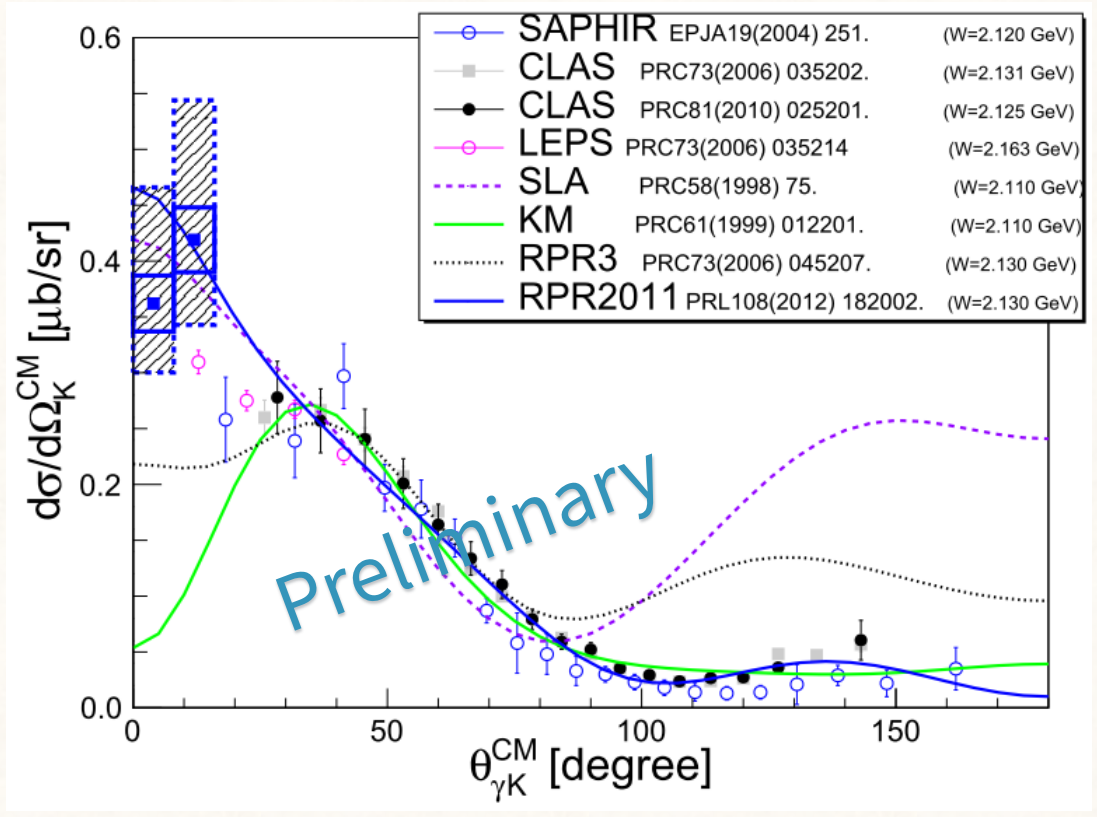


Energy Calibration with H_2 target

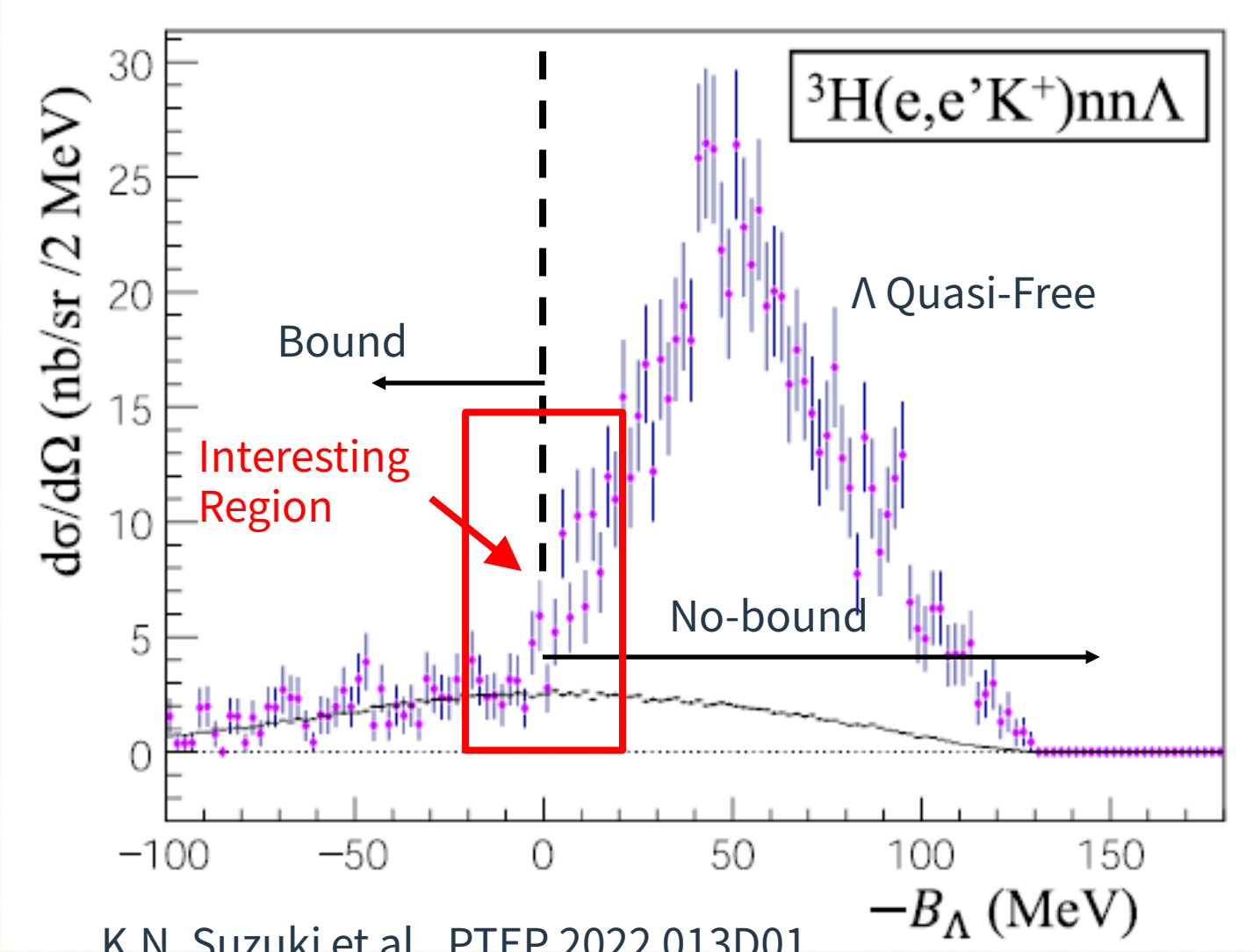
- Mass calibration with $p(e,e'K^+)\Lambda/\Sigma^0$
- Λ Mass resolution is 1.4 MeV (rms)
- Systematic error of peak centroid would be 0.4 MeV



- Measurement of very forward angle with low Q^2 region
- Λ/Σ^0 reaction cross-section at this new kinematical position will be reported.

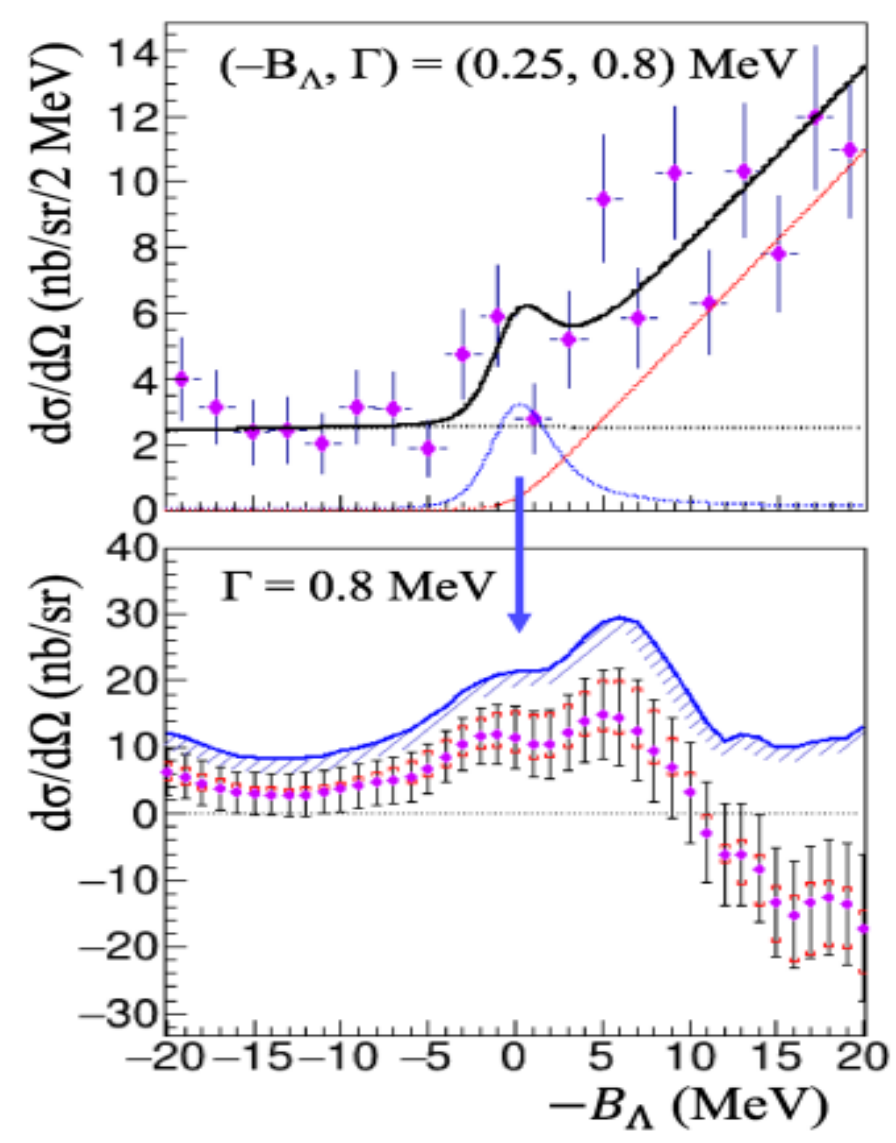


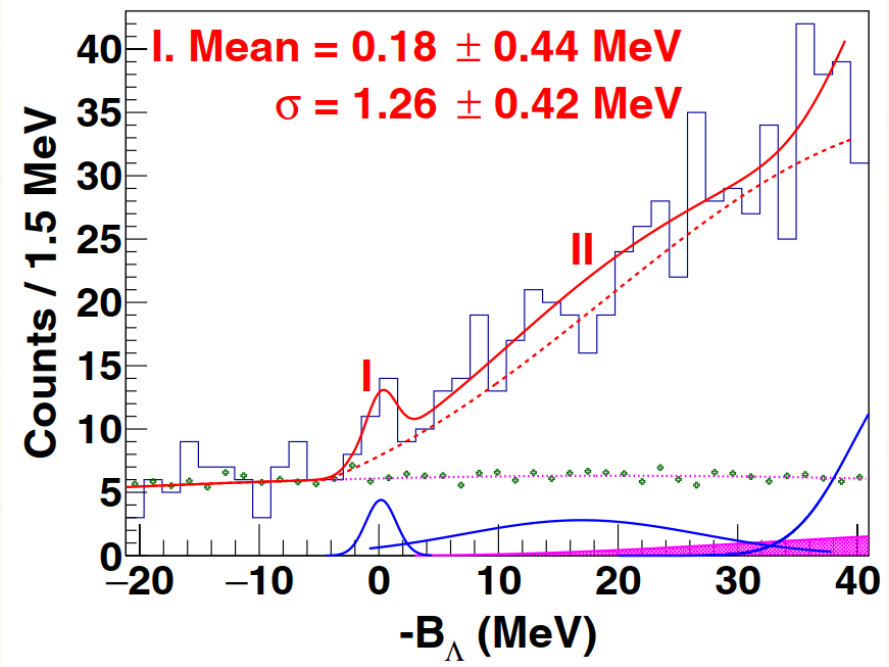
Missing Mass of T_2 target



K.N. Suzuki et al., PTEP 2022 013D01

Remarks





- Expected resolution σ = 1.3 MeV, δE = 0.4 MeV
- No robust peak (2.7σ)
- Upper-limits 21 nb sr^{-1} (90% C.L.)

Future Projects

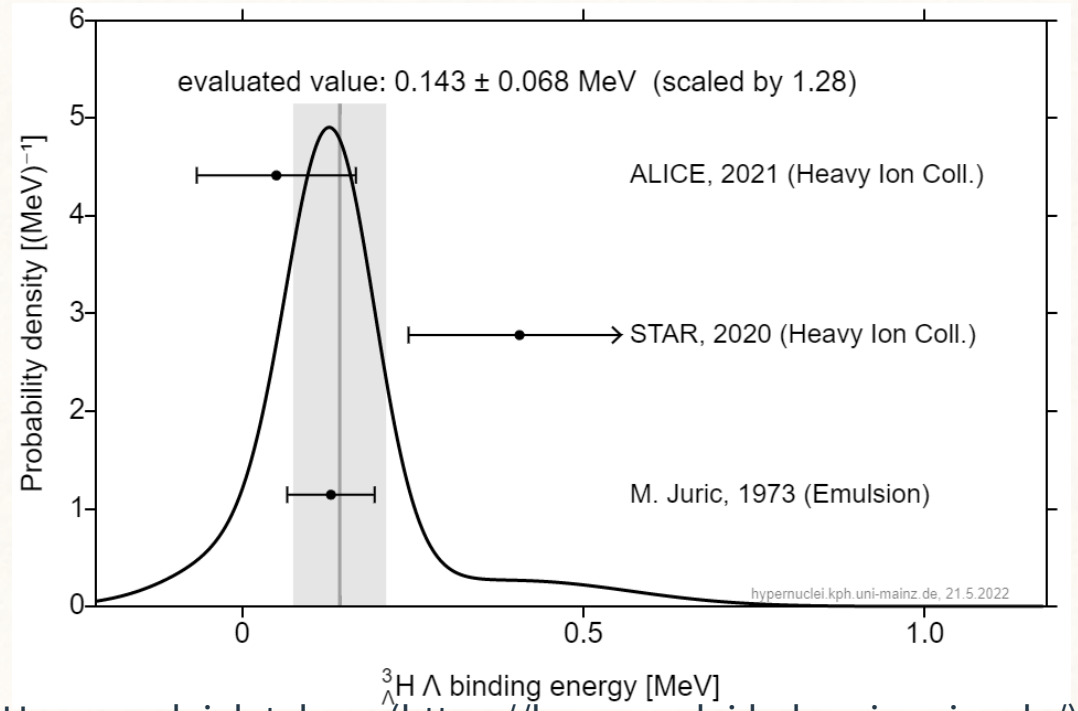
Three experiments are already approved

E12-19-002 Spectroscopy of $^{3,4}_{\Lambda}$H

E12-15-008 Spectroscopy of hypernuclear isotopes $^{40,48}_{\Lambda}$K

E12-20-013 Spectroscopy of $^{208}_{\Lambda}$Ti

$^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H(1^{+}) spectroscopies



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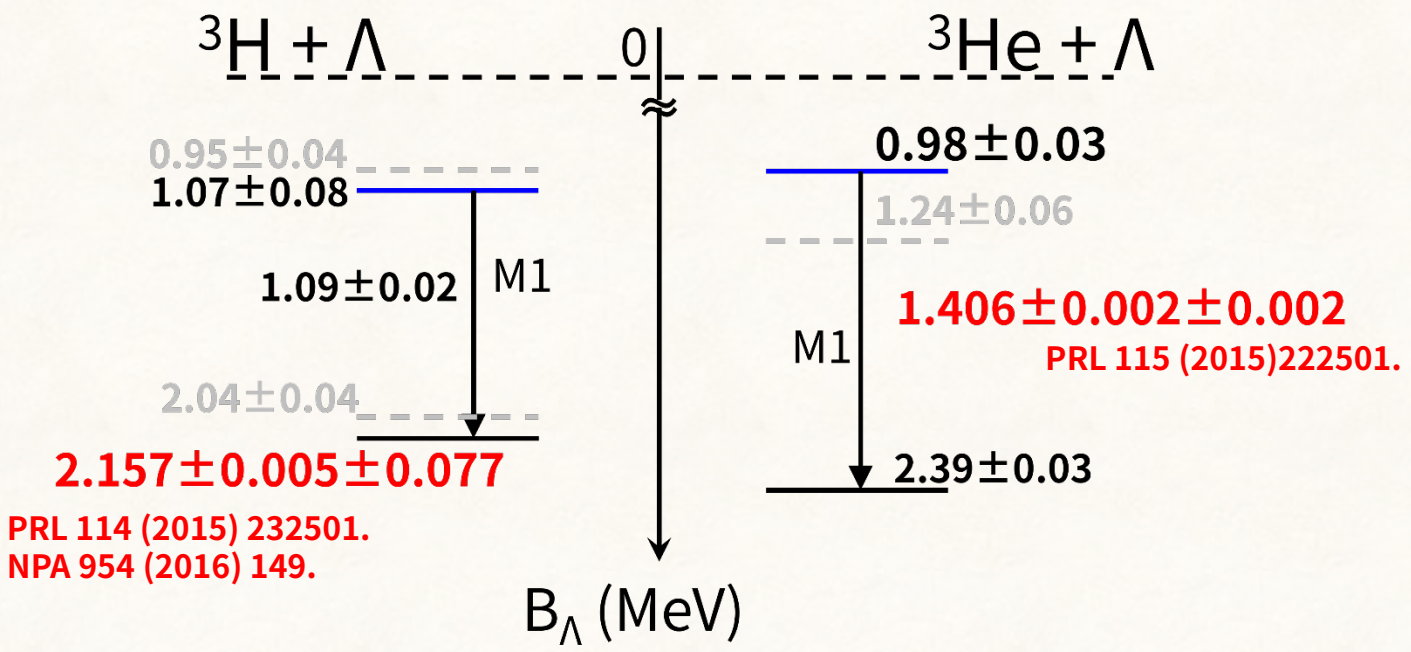
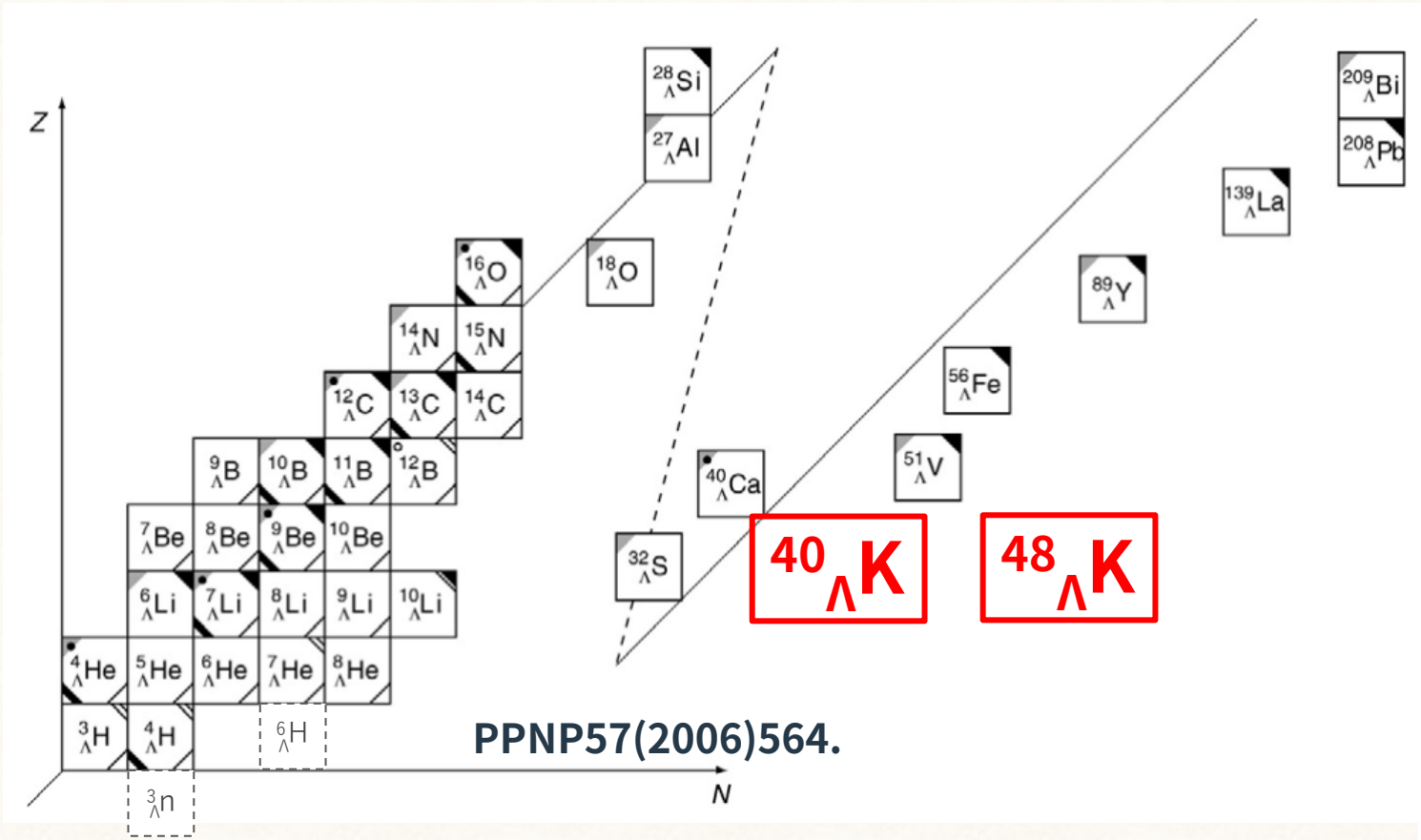


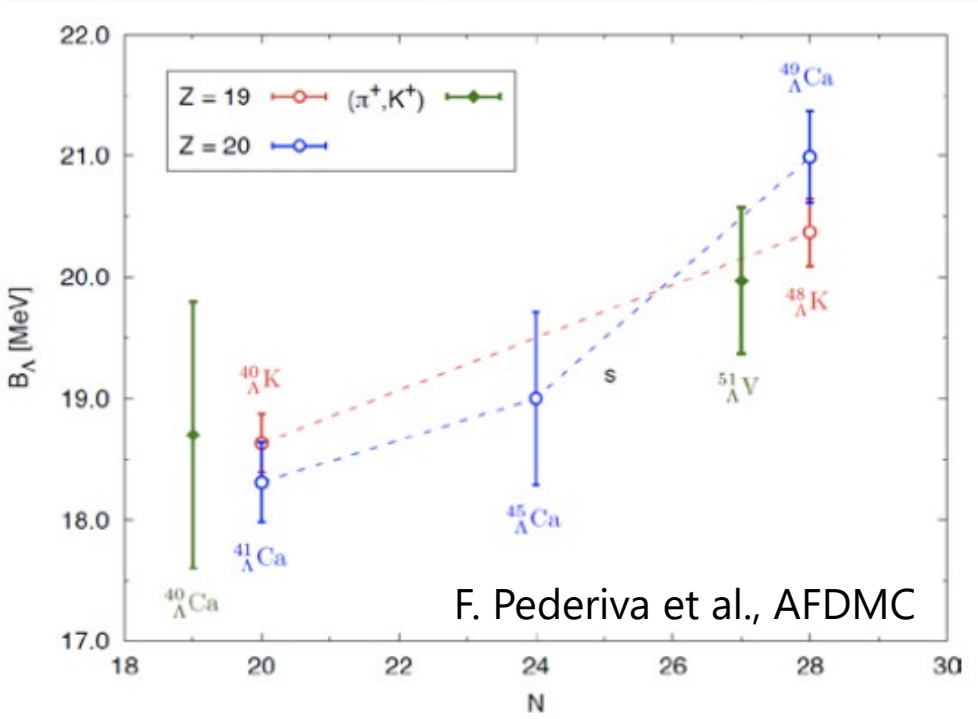
- Precision measurement of $^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H(1^{+}) from ^{3}He and ^{4}He cryo-gas target
- Spectroscopy of $^{3}_{\Lambda}$H will be an independent measurement and resolve a part of hypertriton puzzle
- Measurement of $^{4}_{\Lambda}$H(1^{+}) will be a new data of charge-symmetry-breaking on A=4 hypernuclear system

Spectroscopy of ΛK isotopes



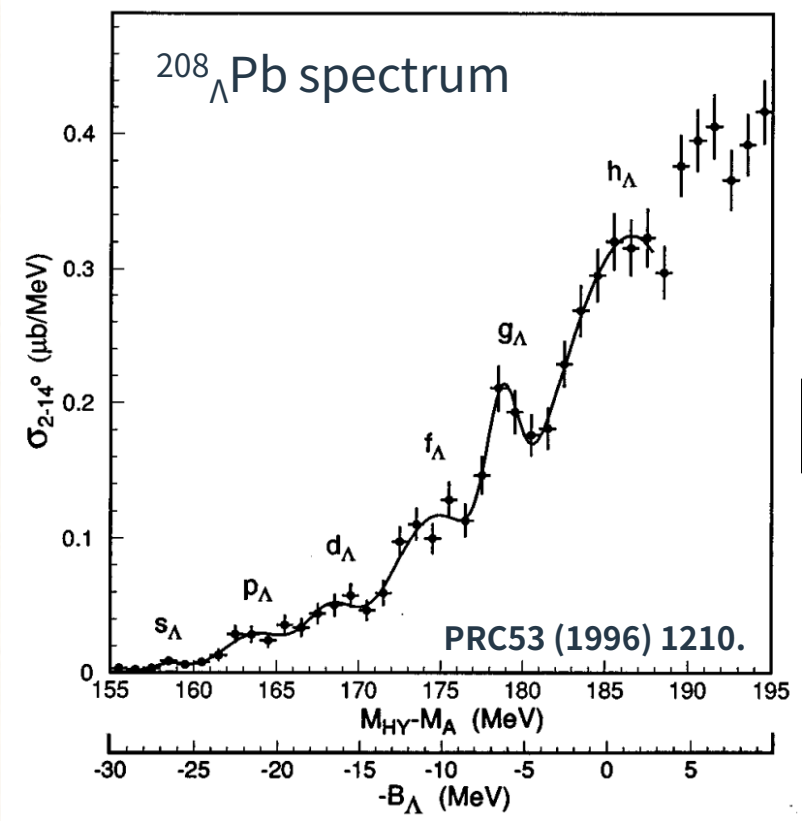
PPNP57(2006)564.

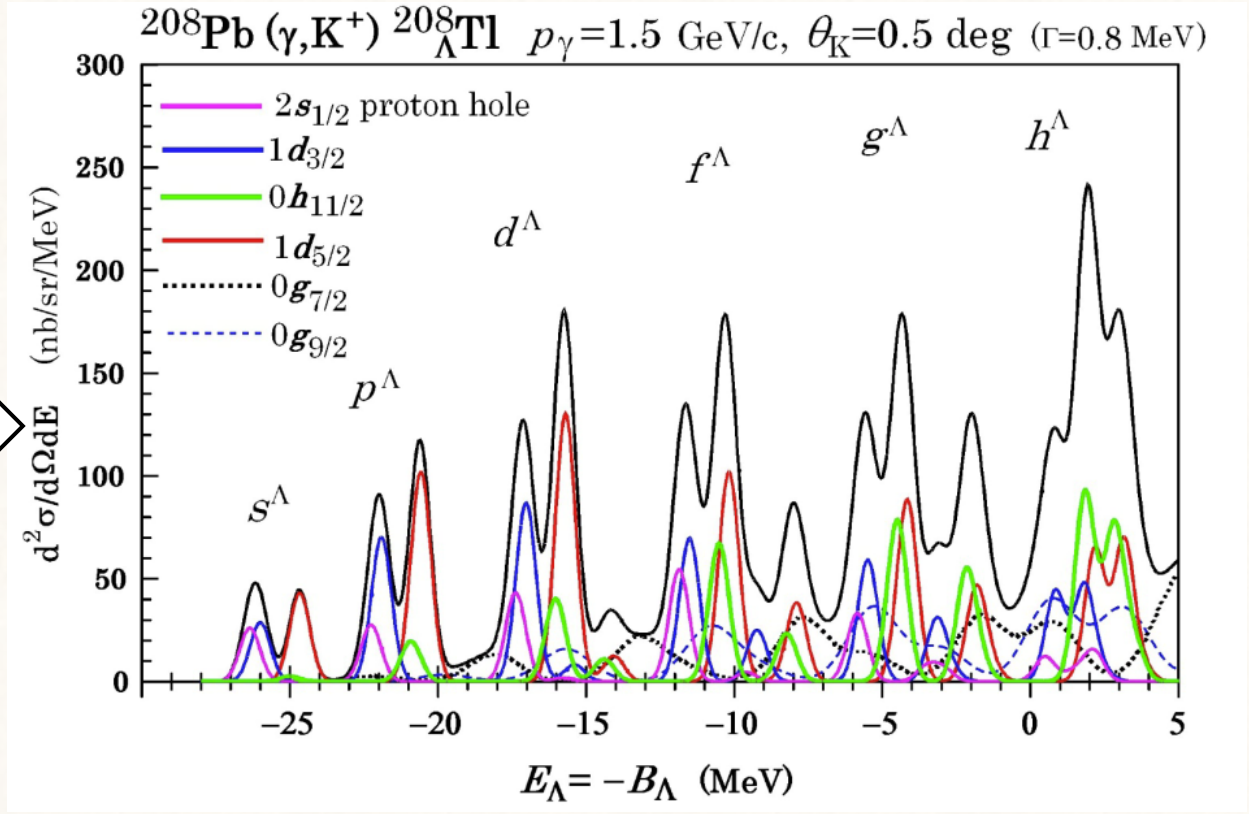
Isotope dependence
in mid-heavy hypernuclei



- Isospin dependence for medium-heavy hypernuclei is really interesting
- B_Λ shift is expected in the quantum MC assuming isospin dependence ΛNN force, while there are no experimental data
- Measurement is important understanding ΛN & ΛNN interaction nuclear medium

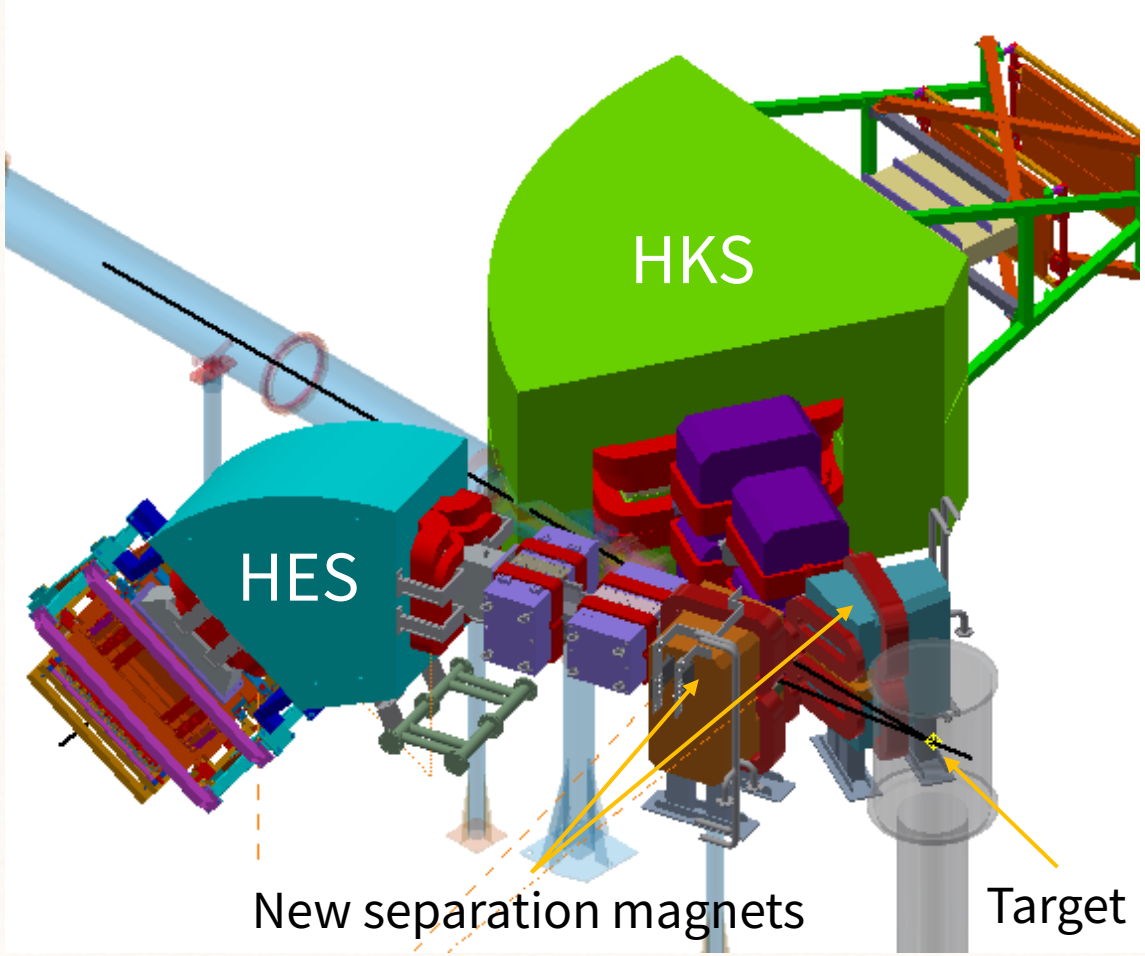
Spectroscopy of heavy hypernucleus



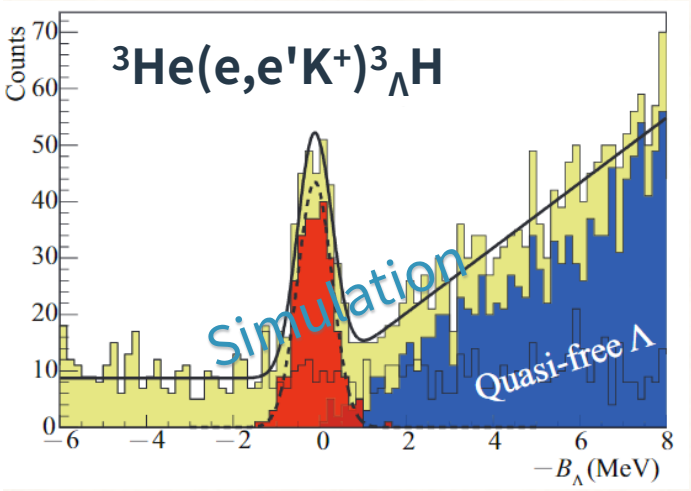


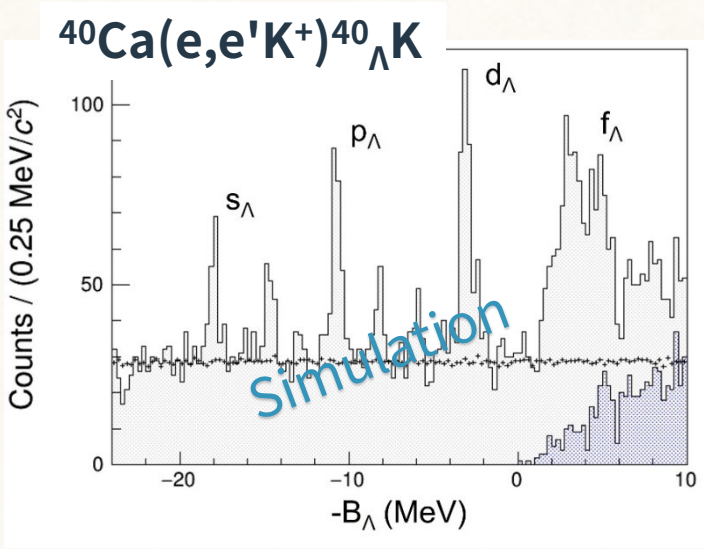
- Current heavy hypernuclear data of (π^+,K^+) reaction does not have enough resolution and accuracy
- Measurement by (e,e'K^+) reaction would identify peaks rather clearly
- Experimentally challenging due to higher rate of bremsstrahlung background

Overview of new experiments



(CH_2, ^{3,4}He, ^{6}Li, ^{11}B, ^{12}C, ^{27}Al, ^{40,48}Ca, ^{208}Pb)





- Two existing high-resolution short arm spectrometer together with new separation magnets
- high-yield and lower-background
- Single rate in spectrometer would be reduced by a factor of a few tens.
- B_{Λ} measurement of ~10 keV precision
- Experiments will be from 2025~

Summary

- Hypernuclear missing-mass spectroscopy have provided information about ΛN interaction nuclear medium
- (e,e'K^+) reaction spectroscopy has good characteristics measuring B_Λ (High-resolution, High-accuracy)
- ^{3}H(e,e'K^+)X experiment has been performed at JLab Hall-A

  No robust peaks
- New three experiments are already approval

  Spectroscopy of $^{3,4}_{\Lambda}$H

  Spectroscopy of hypernuclear isotopes $^{40,48}_{\Lambda}$K

  Spectroscopy of $^{208}_{\Lambda}$Ti