High resolution mass spectroscopy of hypernuclei with primary electron beams: Recent results and prospects

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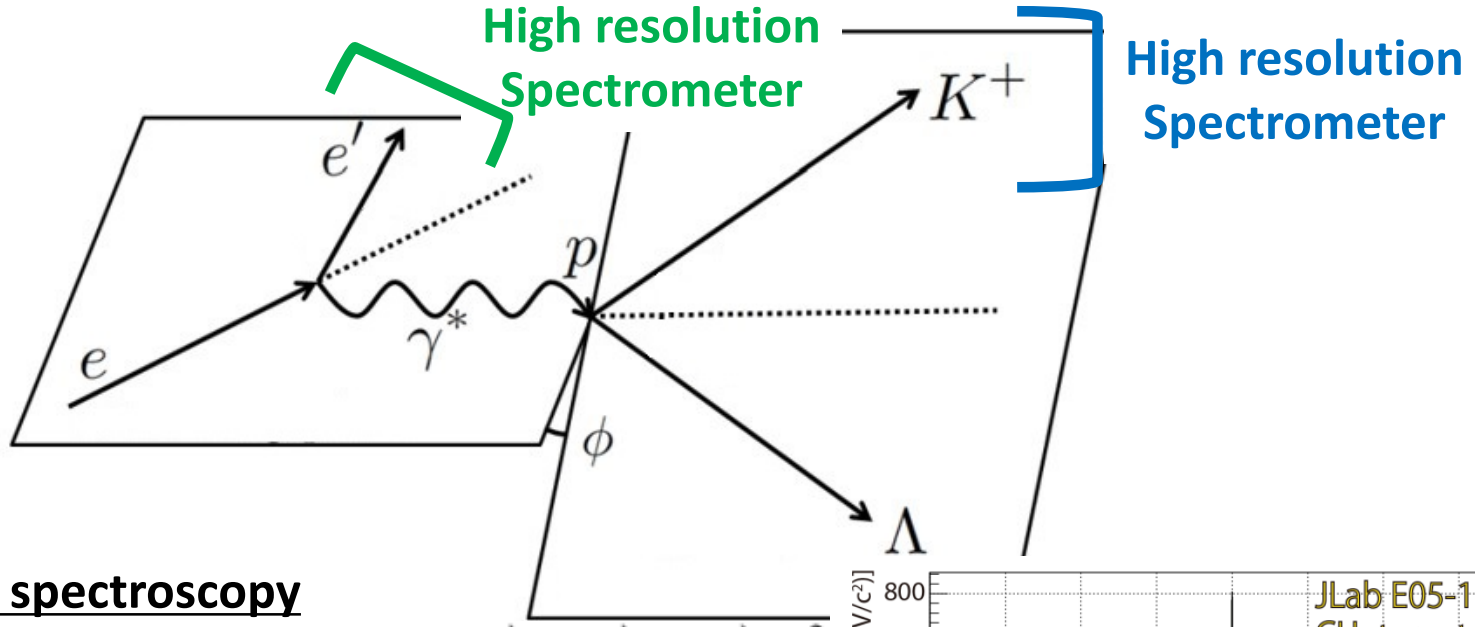
($e,e'K^+$) reaction spectroscopy

$$e(p_e) + p(p_p) \rightarrow e'(p_{e'}) + K^+(p_K) + \Lambda(p_\Lambda),$$



Missing mass spectroscopy

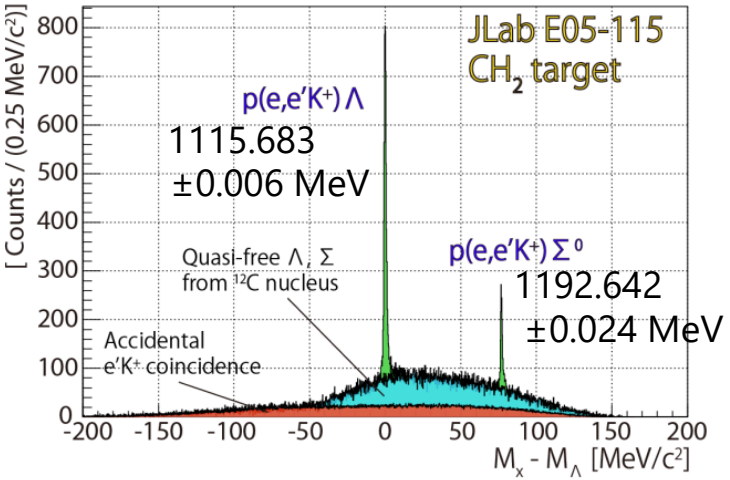
$$M^2_{HYP} = (E_e + M_t - E_{e'} - E_{K^+})^2 - \left(\vec{p}_e - \vec{p}_{e'} - \vec{p}_{K^+}\right)^2$$

- p to Λ

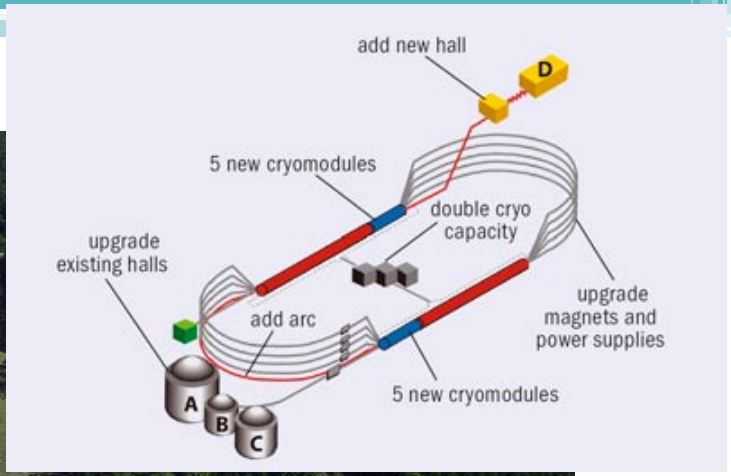
  Absolute energy calibration

- High quality e- beam

  High energy resolution



CEBAF (Jefferson Lab)

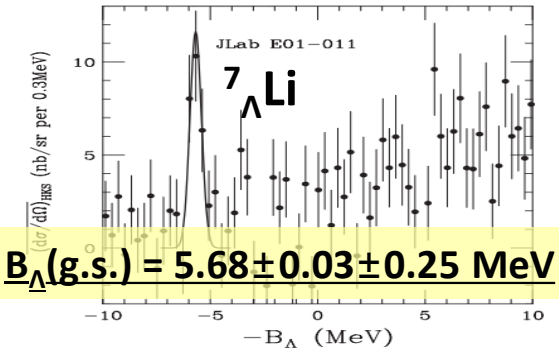


Continuous electron beam facility

- **12 GeV (max.)**
- **100 μA**
- **2-ns bunches**
- **Small Emittance (2 μm·mrad)**
- **Small Energy spread (ΔE/E 2×10^{-5})**

Hypernuclear Projects

S.N.Nakamura *et al.*, PRL110 (2013) 012502.



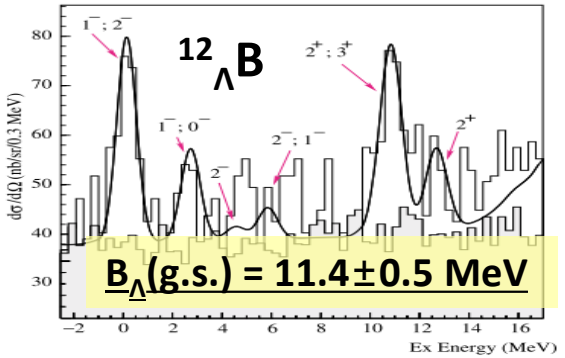
B_Λ(g.s.) = 5.68±0.03±0.25 MeV

E89-009 (2000) : JLab Hall-C

Proof of Principle

Λ, Σ^0, $^{12}_{\Lambda}$B

T.Miyoshi *et al.*, PRL90 (2000) 232502.



B_Λ(g.s.) = 11.4±0.5 MeV

E01-011 (2005) : JLab Hall-C

Light hypernuclei

Λ, Σ^0, $^{7}_{\Lambda}$Li, $^{12}_{\Lambda}$B, $^{28}_{\Lambda}$Al

L.Yuan *et al.*, PRC73 (2006) 044607.

L.Tang *et al.*, PRC90 (2014) 034320.

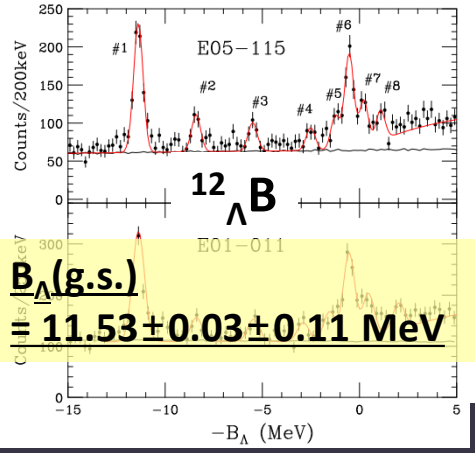
E94-107 (2004-5) : JLab Hall-A

Light hypernuclei

Λ, Σ^0, $^{9}_{\Lambda}$Li, $^{12}_{\Lambda}$B, $^{16}_{\Lambda}$N

F.Cusanno *et al.*, NPA835 (2010) 129.

F.Cusanno *et al.*, PRL103 (2009) 202501.

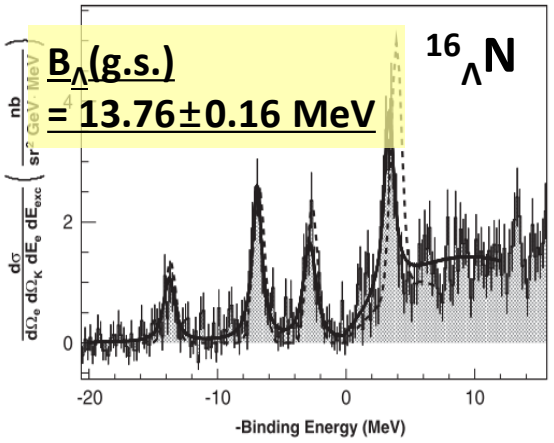


B_Λ(g.s.)
= 11.53±0.03±0.11 MeV

E05-115 (2009) : JLab Hall-C

Light – Medium-heavy hypernuclei

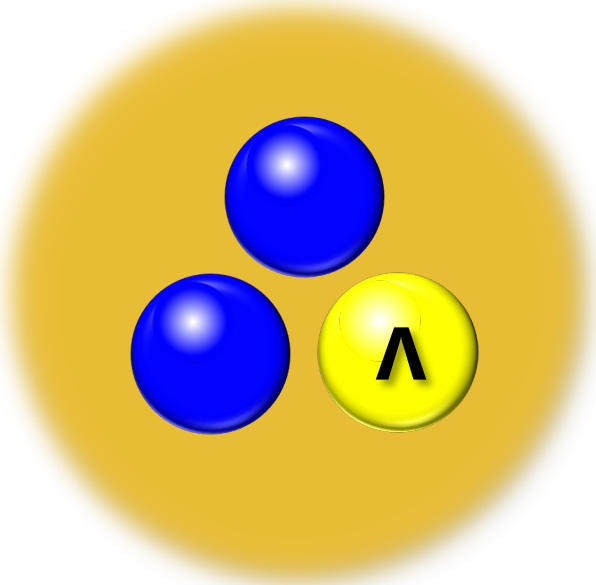
Λ, Σ^0, $^{7}_{\Lambda}$He, $^{10}_{\Lambda}$Be, $^{12}_{\Lambda}$B, $^{52}_{\Lambda}$V



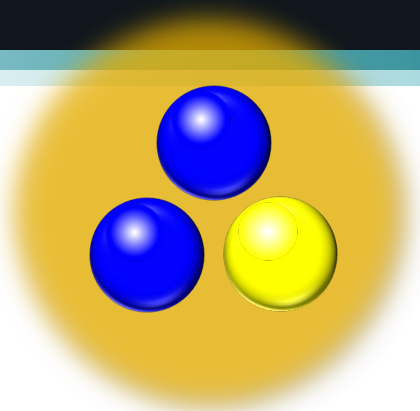
B_Λ(g.s.)
= 13.76±0.16 MeV

Search for nnΛ state

(JLab E12-17-003)



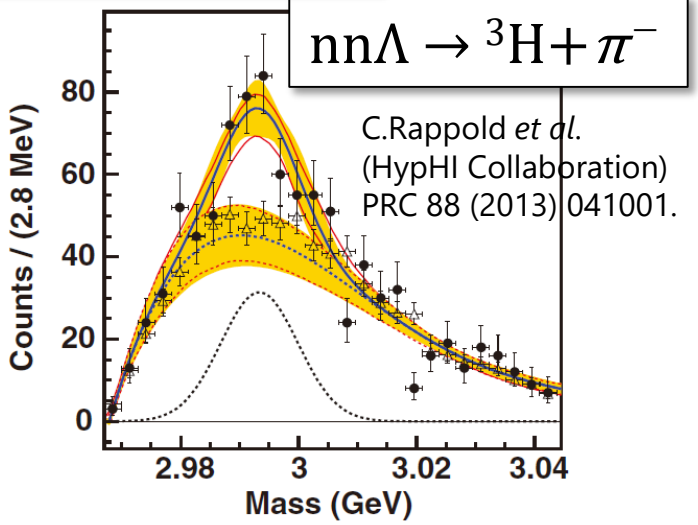
nnΛ state



- T=1 state
- Neutral
- Bound state exists or not ?

Experiment

$$nn\Lambda \rightarrow {}^{3}\mathrm{H} + \pi^{-}$$



C.Rappold *et al.*
(HypHI Collaboration)
PRC 88 (2013) 041001.

Theory

Bound nnΛ : cannot be reproduced

E.Hiyama *et al.*, PRC 89 (2014) 061302.

A.Gal *et al.*, PLB 736 (2014) 93.

Resonance nnΛ state ??

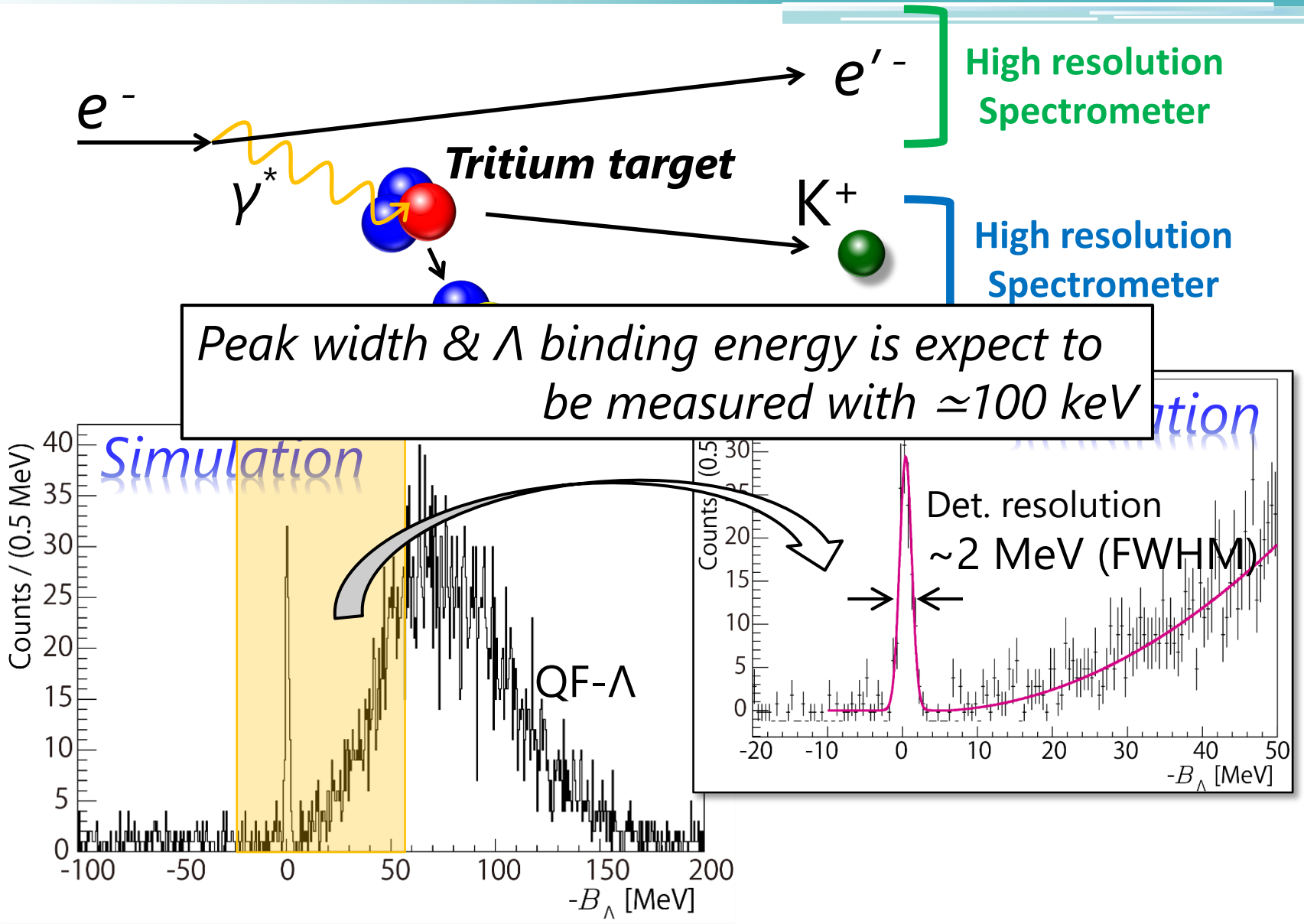
I.R.Afnan *et al.*, PRC 92 (2015) 054608.

H.Kamada *et al.*, EPJ Web Conf. 113 (2016) 07004.

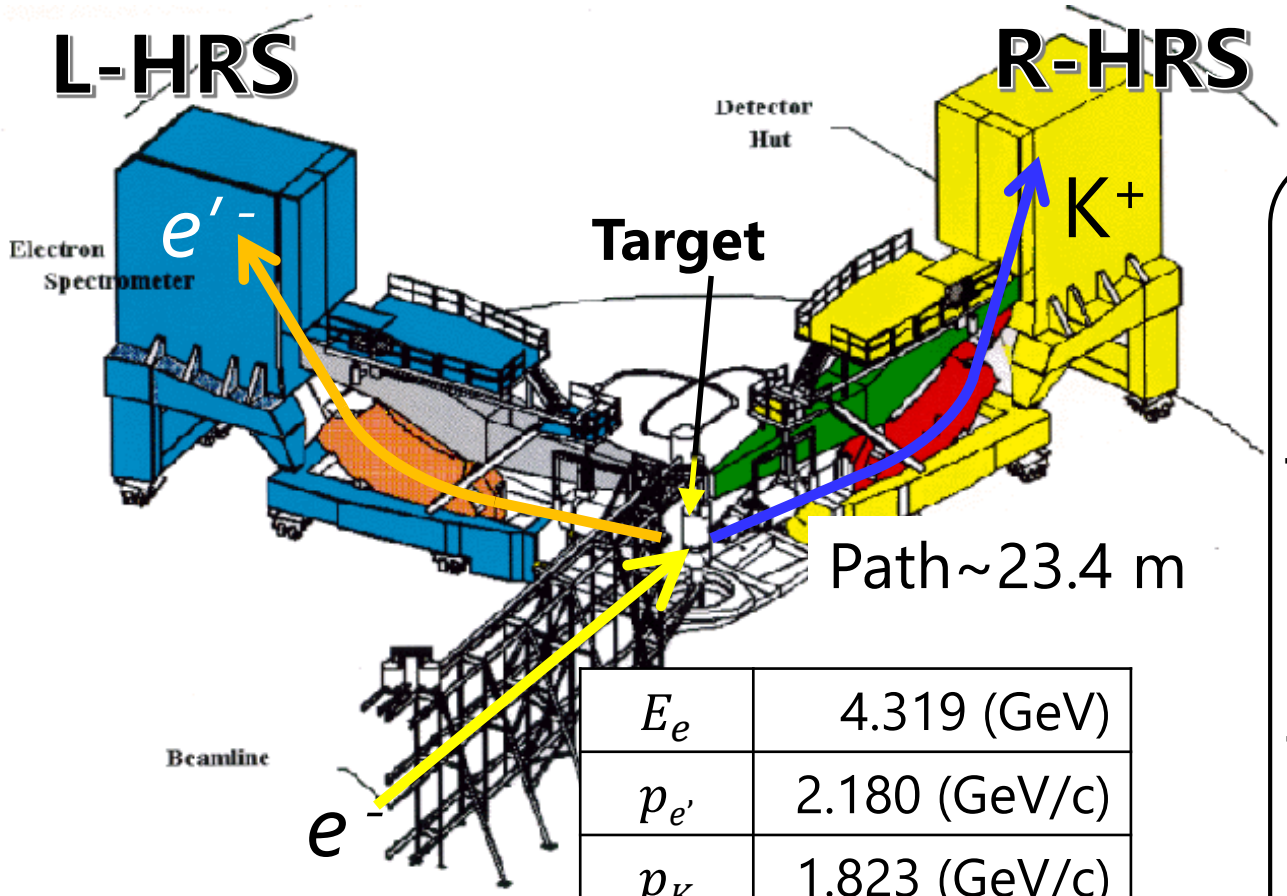
Search for nnΛ state is important investigating Λn interaction.

⇒ *(e,e′K⁺)* reaction spectroscopy

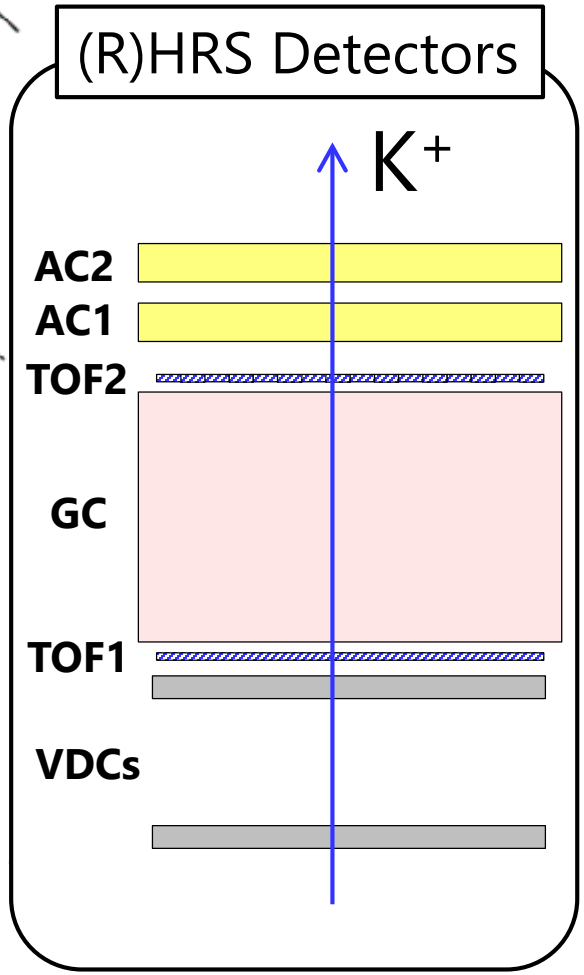
nnΛ search (JLab E12-17-003)



Setup



E_e	4.319 (GeV)
$p_{e'}$	2.180 (GeV/c)
p_K	1.823 (GeV/c)
$\theta_{e'}$	13.2 (deg)
θ_K	13.2 (deg)
Q^2	0.13 (GeV^2)



Tritium Target

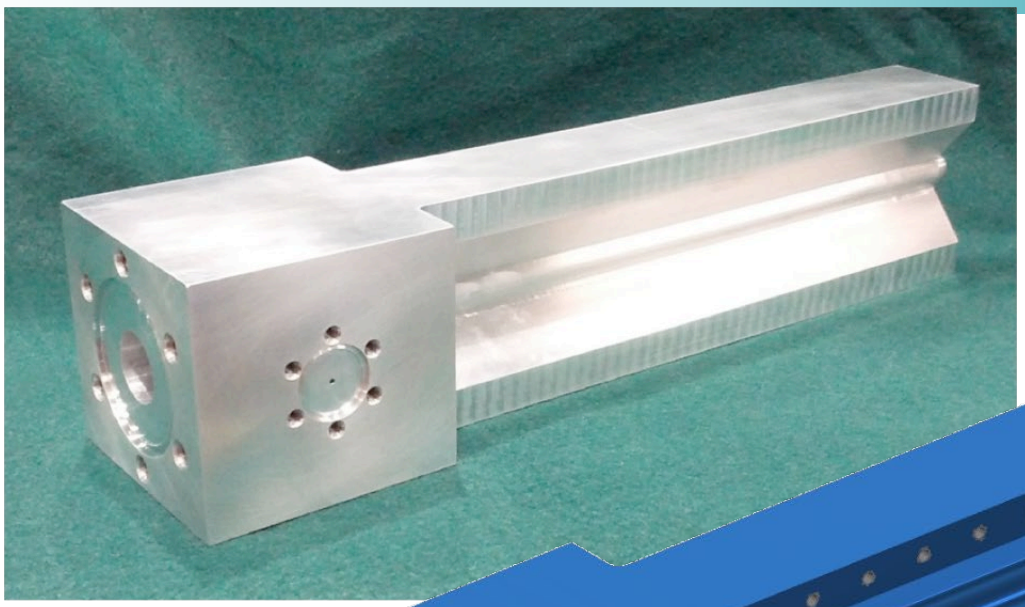
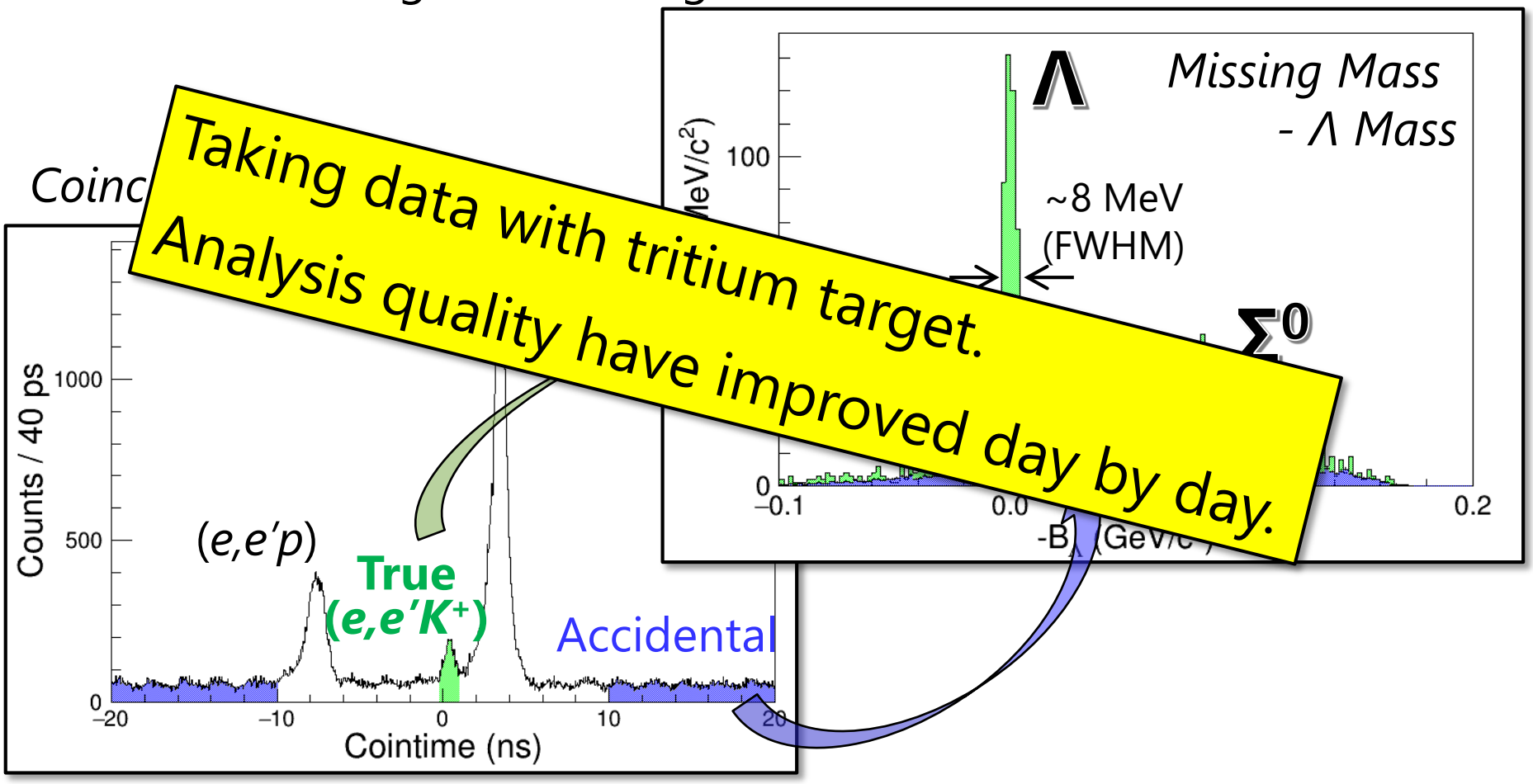


Figure taken from Dave's slide (2015).

- 0.082 g/cm^2 (40 TBq)
- 0.3 MPa at 40K
- 25 cm Length
- Al window

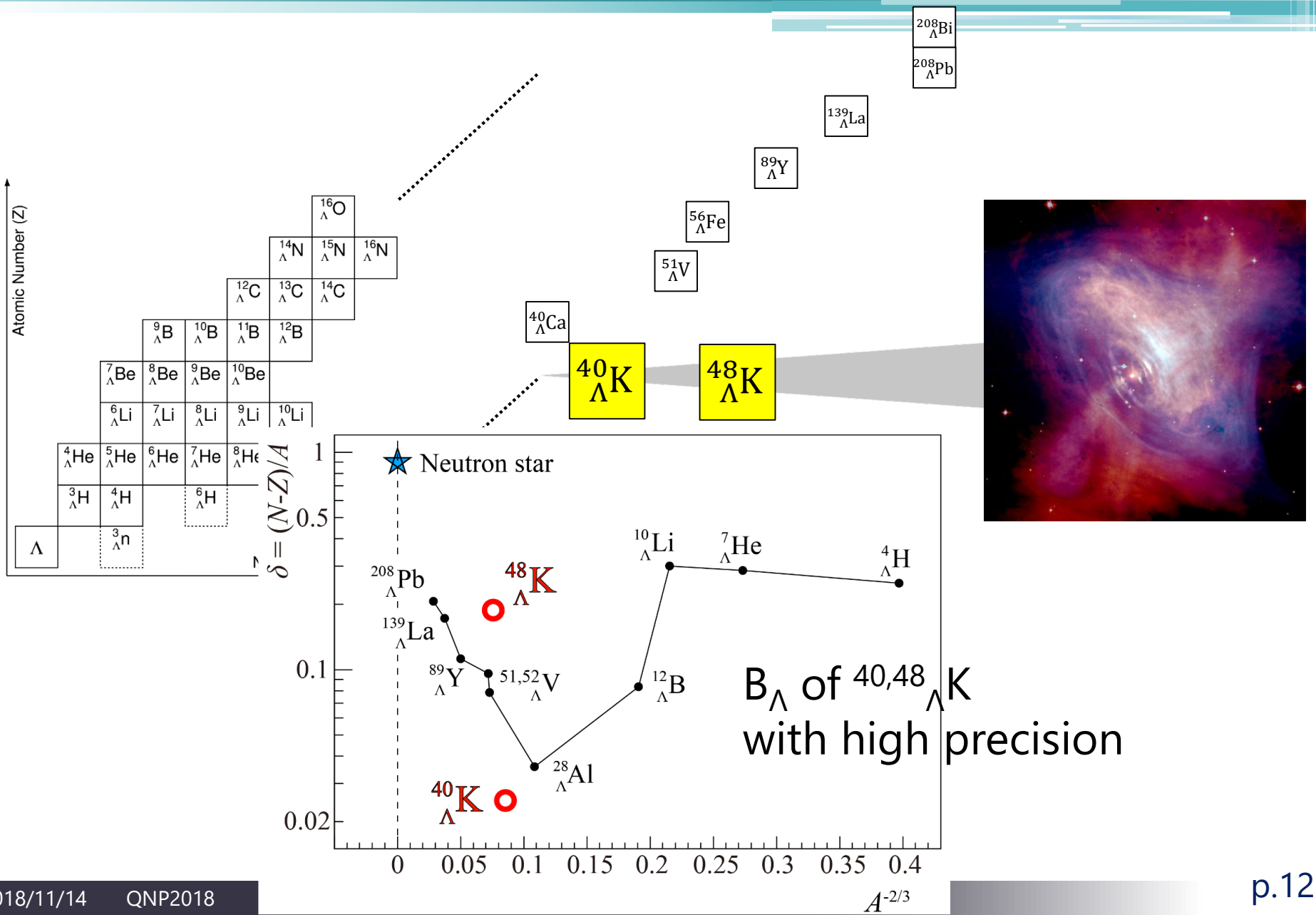
Results of Quick Analysis

- We are taking data from Oct. 31 - Nov. 21 (Now!!)
- We took $p(e,e'K^+)\Lambda$ data first 3 days.
- We are taking data with right condition



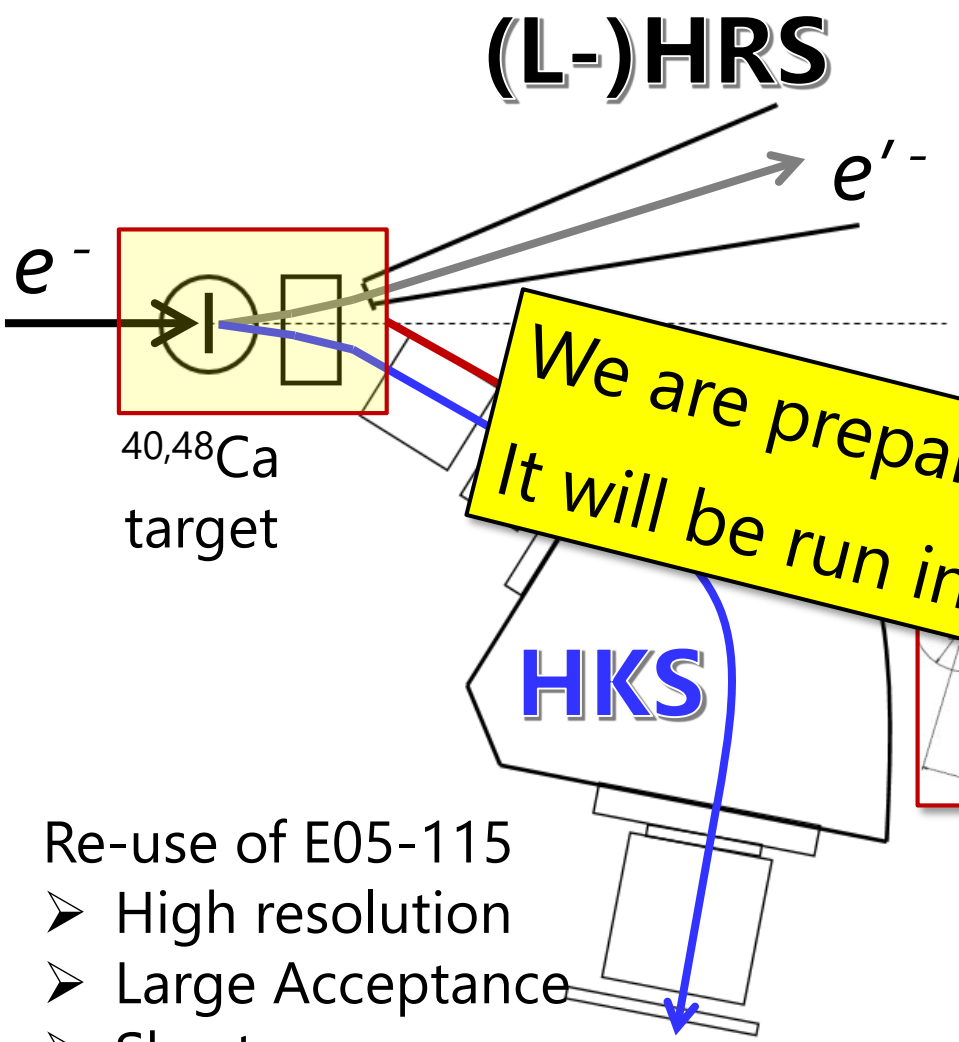
Spectroscopy of
Medium-heavy $_{\Lambda}$K isotope
(JLab E12-15-008)

Isospin dependence of ΛNN interaction



B_Λ of $^{40,48}_{\Lambda}$K with high precision

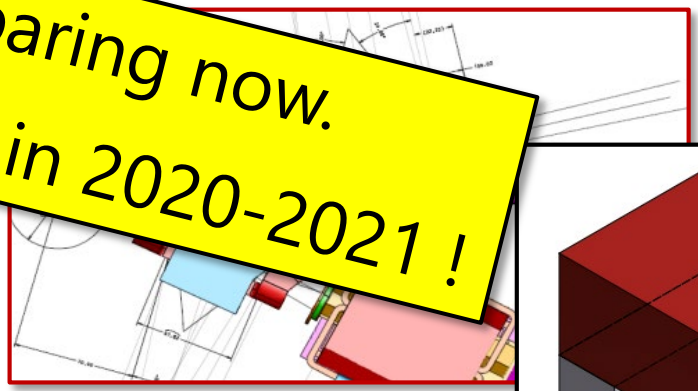
Setup

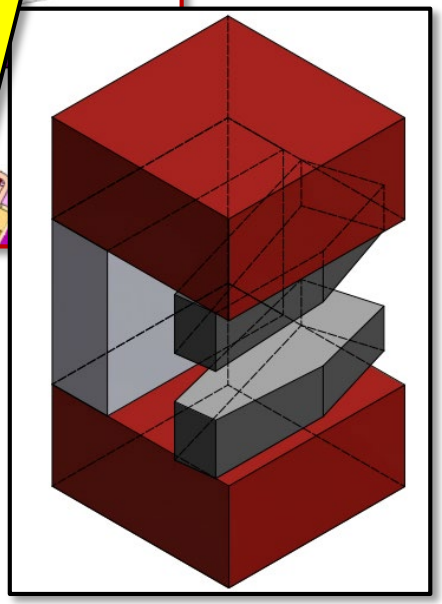


- Higher Yield
  - Forward angles
- Less Background
  - No acceptance at 0 deg

We are preparing now.
It will be run in 2020-2021 !

New Charge Septum Magnet





Re-use of E05-115
- High resolution
- Large Acceptance
- Short arm
- Good KID

Summary

Λ hypernuclear spectroscopy with the (e,e'K⁺) reaction

- High resolution, High precision, Absolute B_Λ
- CEBAF at JLab
- ${}^{7}_{\Lambda}\mathrm{He}$, ${}^{10}_{\Lambda}\mathrm{Be}$, and ${}^{12}_{\Lambda}\mathrm{B}$ (JLab E05-115 [Hall-C])

nnΛ search (E12-17-003) at JLab Hall A

- Study of the Λn interaction
- (e,e'K⁺) experiment with the tritium target.
- Kinematics & Detectors were checked with $p(e,e'K^+)\Lambda$ data
- The experiment is now running.

High resolution spectroscopy of ${}_{\Lambda}$K hypernuclei

- Study of the isospin dependence of the ΛNN interaction
- Design of a new Septum magnet is on going.
- The experiment will be run in 2020-2021