

Precision Spectroscopy of Lambda Hypernuclei with Electro-photo production

Tohoku University

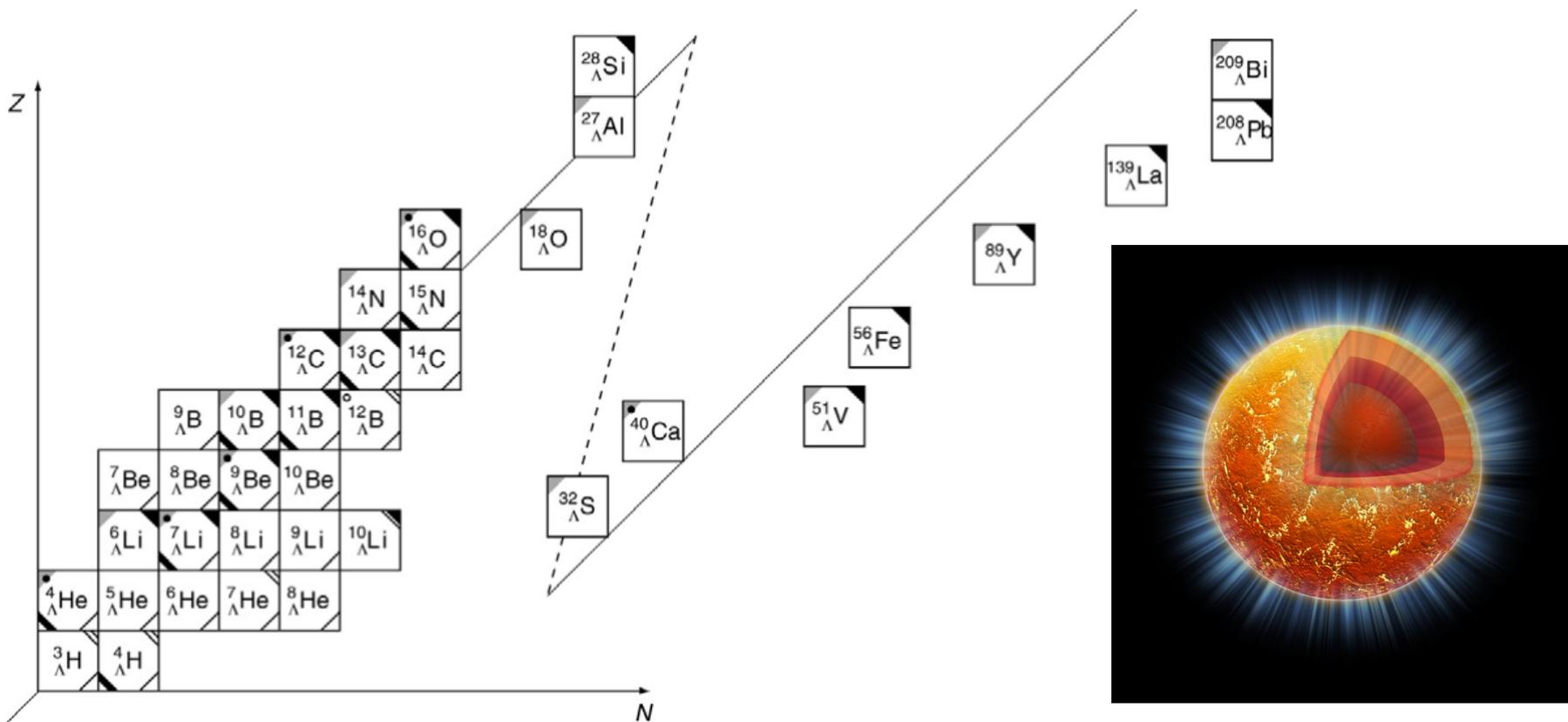
Sho Nagao

2019/12/05

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Λ Hypernuclei

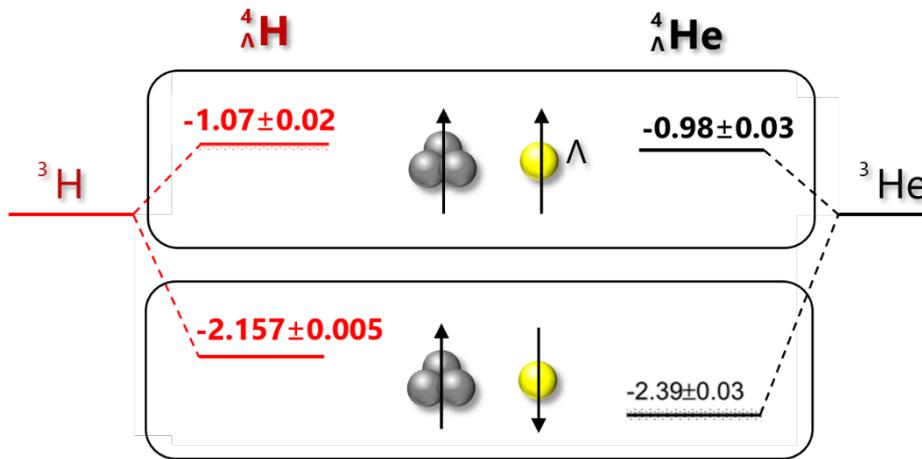


- Study of the ΛN , ΛNN interactions
- Good probe deep inside of nuclei

Mass determination with a few 10 keV ~ several 100 keV

Λ N symmetry breaking force

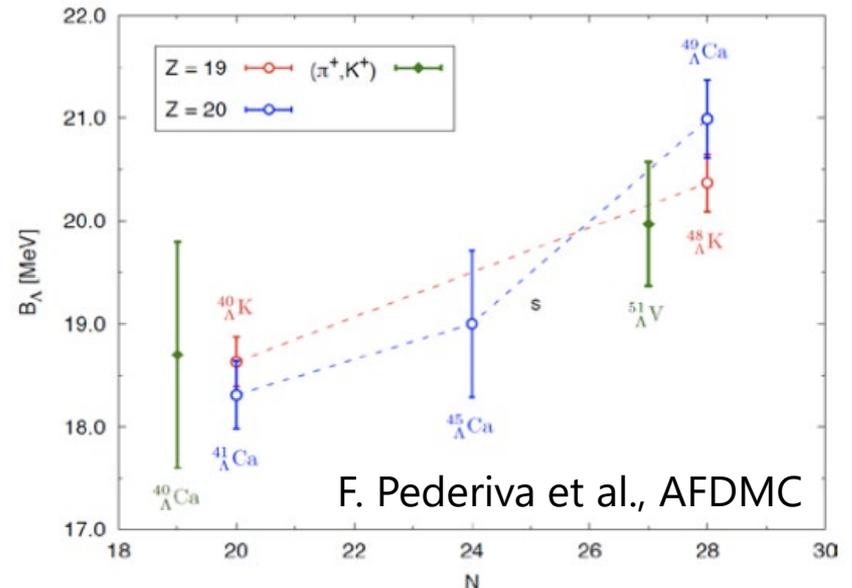
CSB effect on $A=4$ system



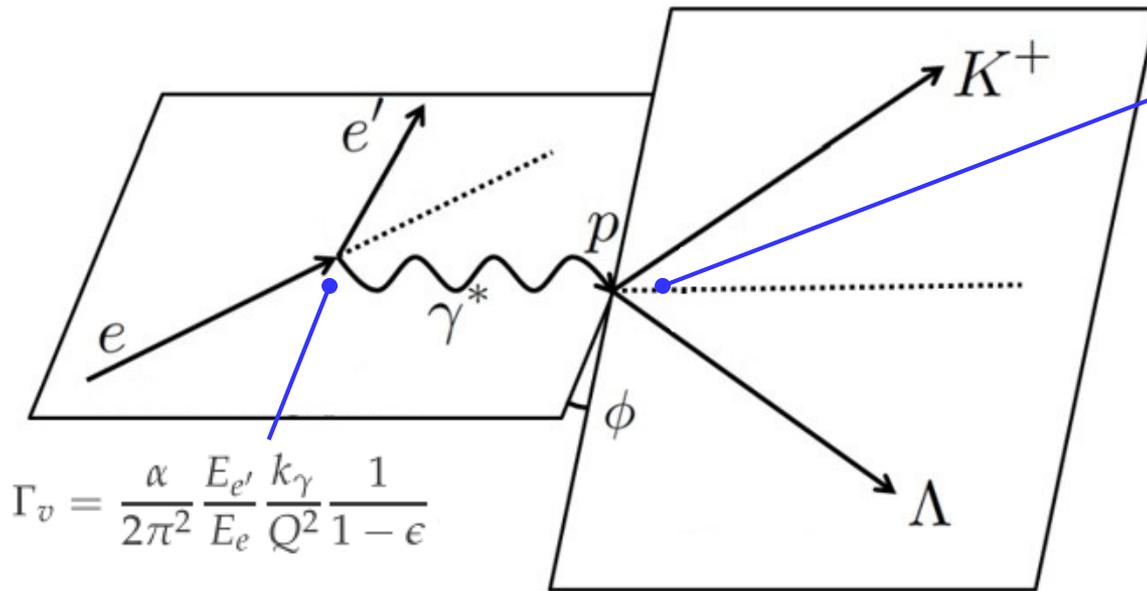
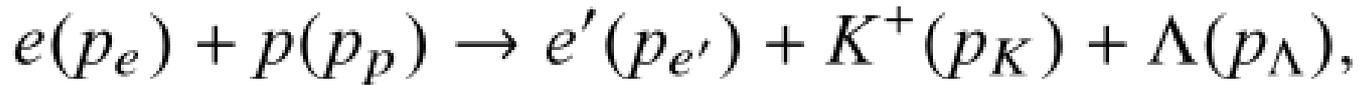
- Spin dependent of Λ N CSB on $A=4$ system.
- Small CSB on p-shell hypernuclei

- B_{Λ} shift on isotope Hypernuclei in quantum MC assuming isospin dependence Λ NN force.
- No experimental data points about isospin dependence in medium-heavy or heavy hypernuclei

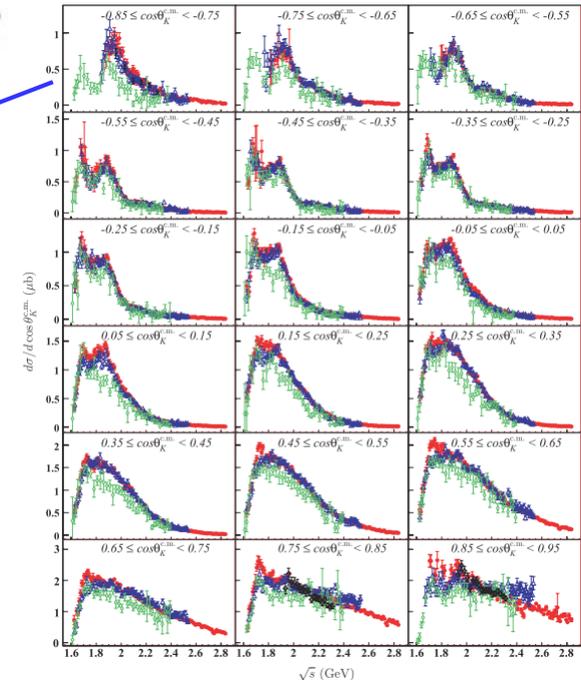
Isotope dependence in mid-heavy hypernuclei



Λ production with EM interaction



$$\Gamma_v = \frac{\alpha}{2\pi^2} \frac{E_{e'}}{E_e} \frac{k_\gamma}{Q^2} \frac{1}{1-\epsilon}$$



PRC81 (2010) 025201.

- proton converts to Λ
Study of iso-mirror, neutron-rich hypernuclei
- Well understandable elementary process
 $E_\gamma = 1.1 \sim 1.5$ GeV, forward θ_K
- ~ 400 MeV/c momentum transfer

(e,e'K⁺) reaction spectroscopy at JLab

nn Λ (JLab E12-17-003)

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

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

Decay pion spectroscopy at MAMI

B_{Λ} of $^3_{\Lambda}\text{H}$

Lifetime measurement at ELPH

lifetime of $^3_{\Lambda}\text{H}$

(e,e'K⁺) reaction spectroscopy at JLab

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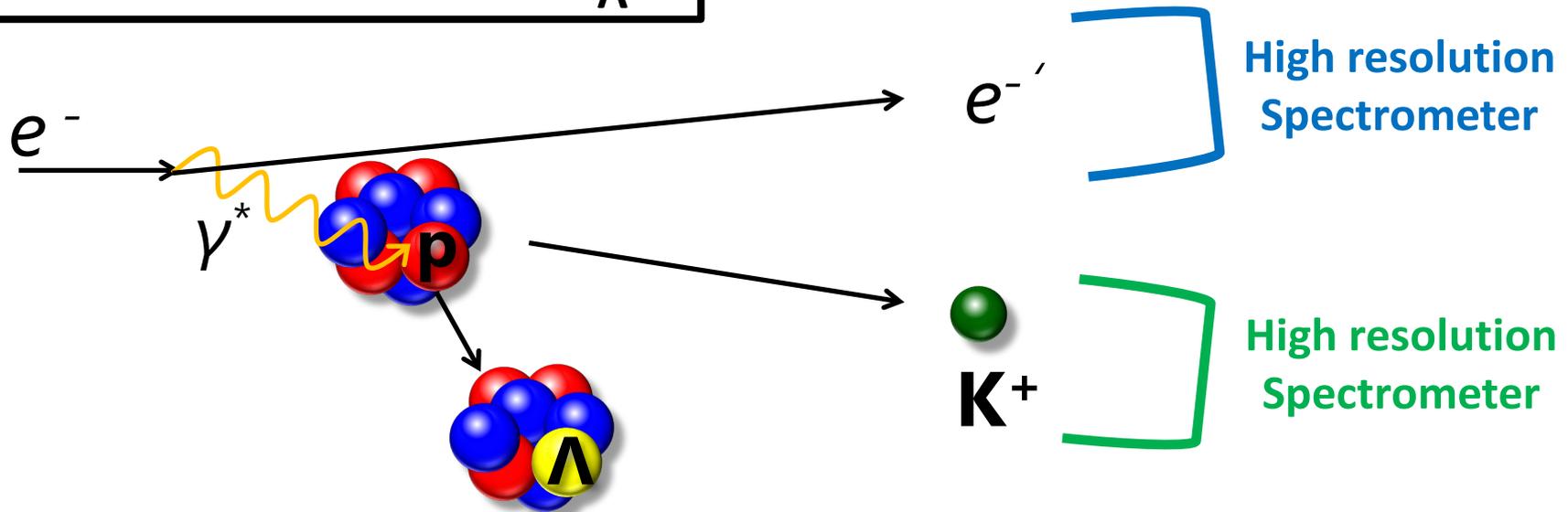
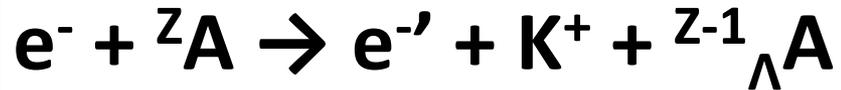
Decay pion spectroscopy at MAMI

B Λ of ³ Λ H

Lifetime measurement at ELPH

lifetime of ³ Λ H

(e,e'K⁺) reaction spectroscopy



Missing mass spectroscopy

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

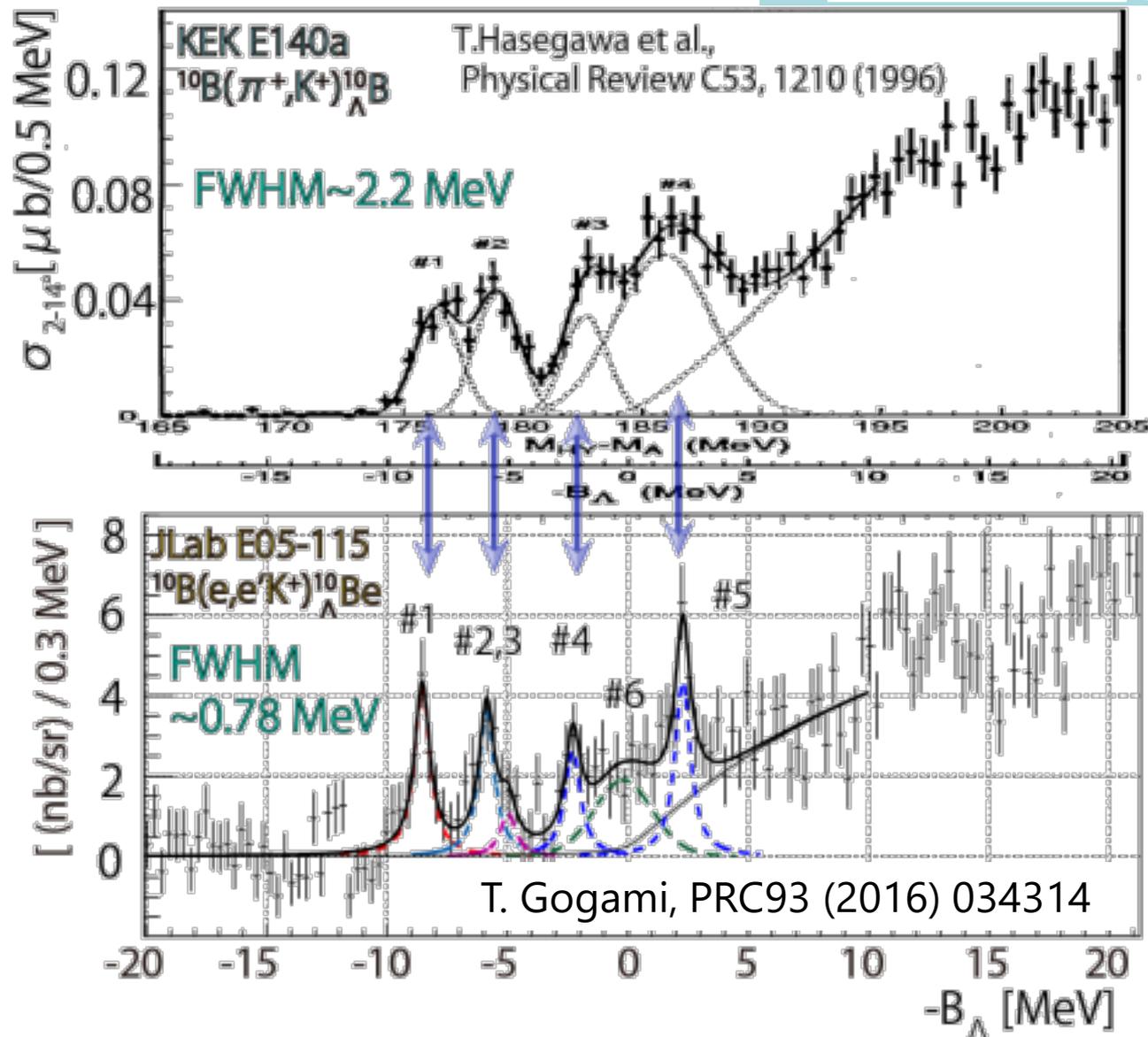
High resolution (sub MeV)

high quality primary electron beams, less stuff target

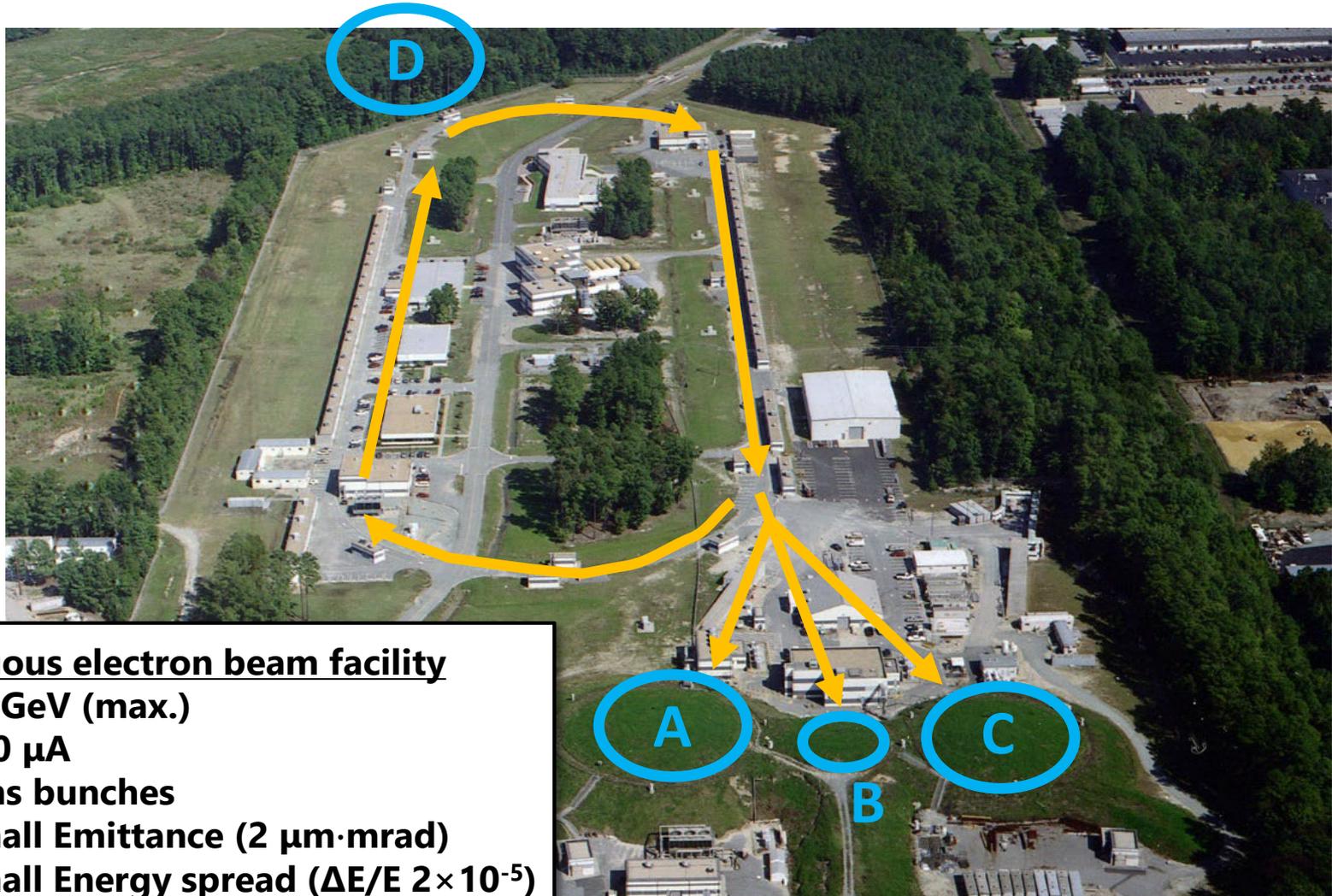
High Accuracy (100 ~ a few 100 keV)

Absolute calibration with Λ & Σ masses

High resolution spectroscopy



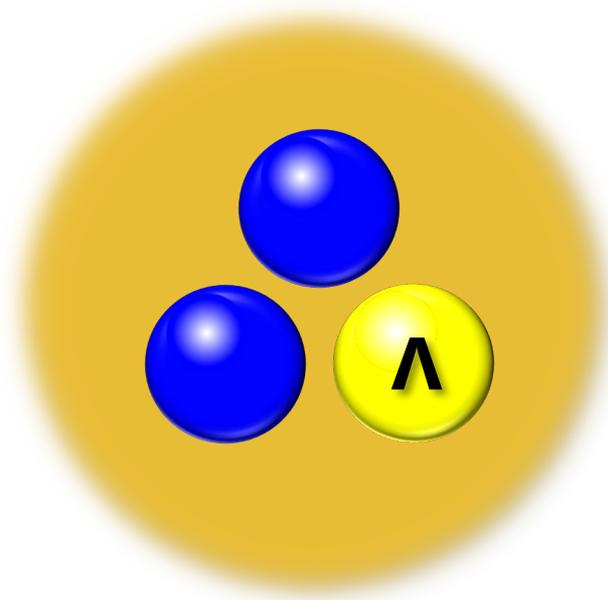
CEBAF (Jefferson Lab)



Continuous electron beam facility

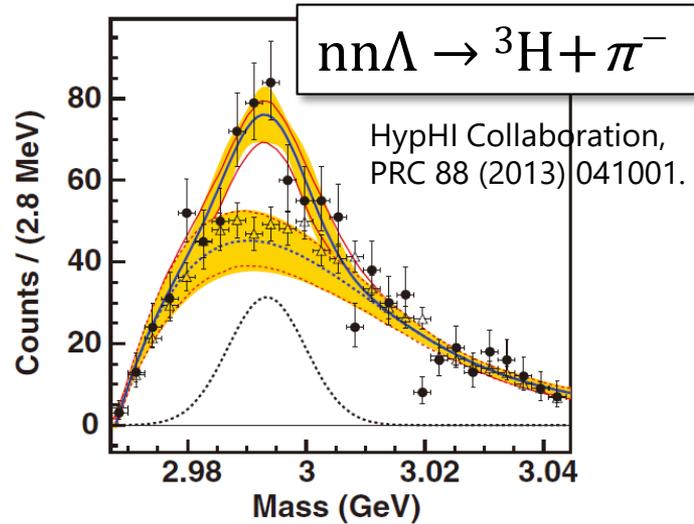
- 12 GeV (max.)
- 100 μA
- 2-ns bunches
- Small Emittance ($2 \mu\text{m}\cdot\text{mrad}$)
- Small Energy spread ($\Delta E/E 2 \times 10^{-5}$)

Search for $nn\Lambda$ state (JLab E12-17-003)



nn Λ state exist or not ?

Experiment



$$\tau = 190_{-35}^{+47} \text{ ps}$$

Λ NN interaction ?

More attractive Λ n force ?

\Rightarrow E12-15-008 approval
data taking in last year

Theory

Unbound

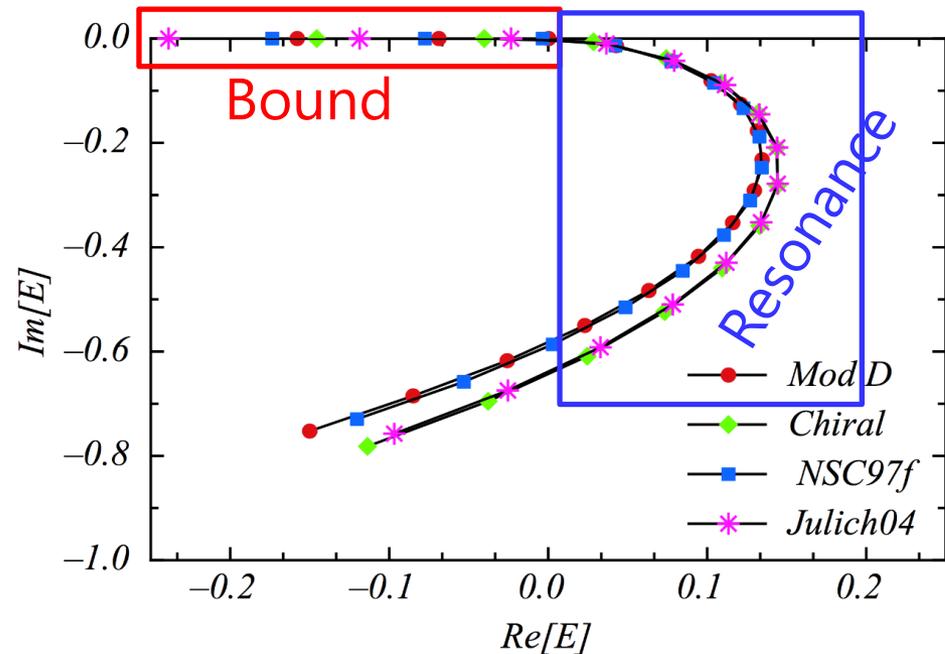
E.Hiyama *et al.*, PRC 89 (2014) 061302.

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

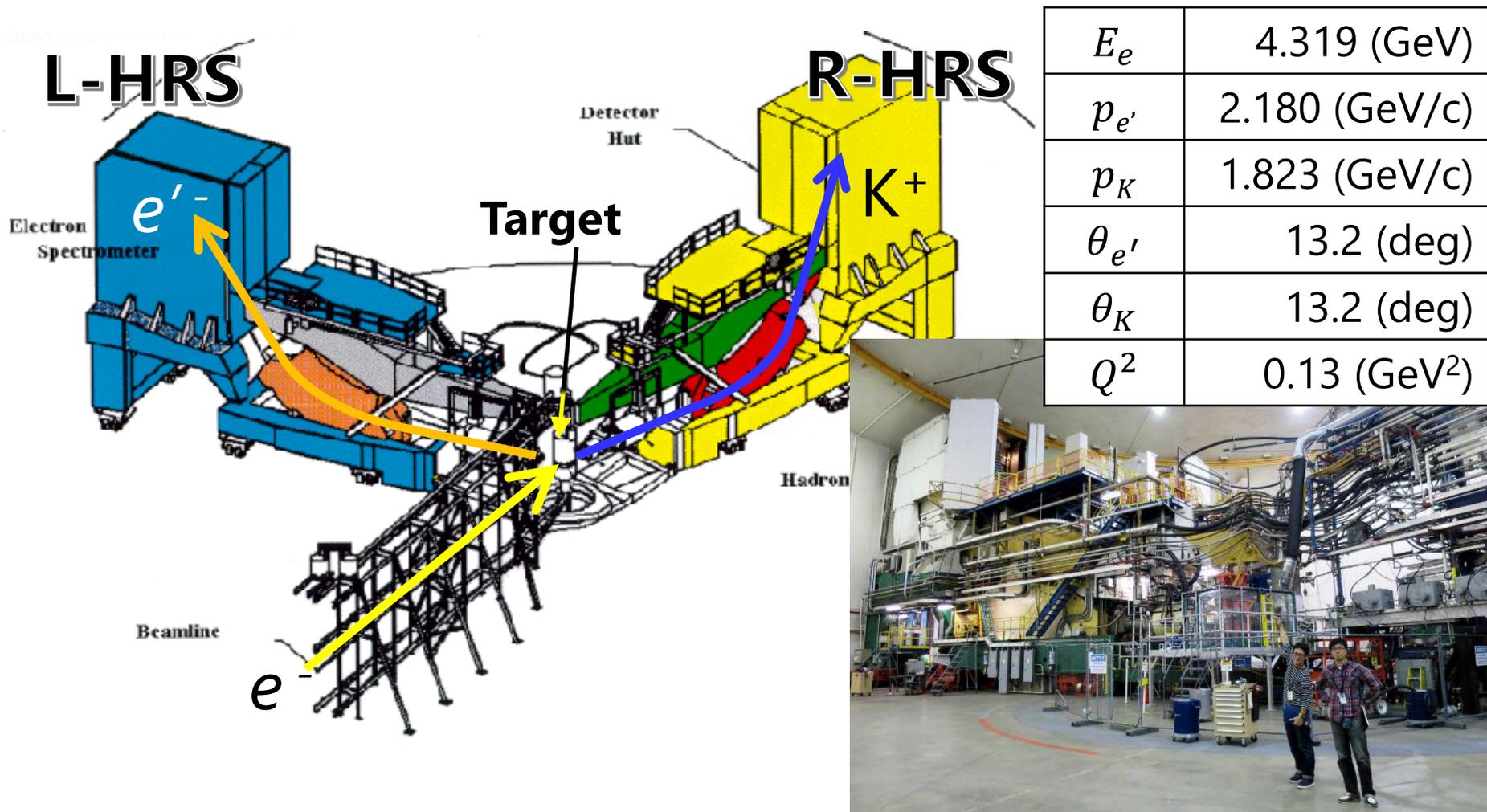
Resonance

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

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



Apparatus



2-HRS system (standard equipment) at Hall-A.

Tritium Target Cell

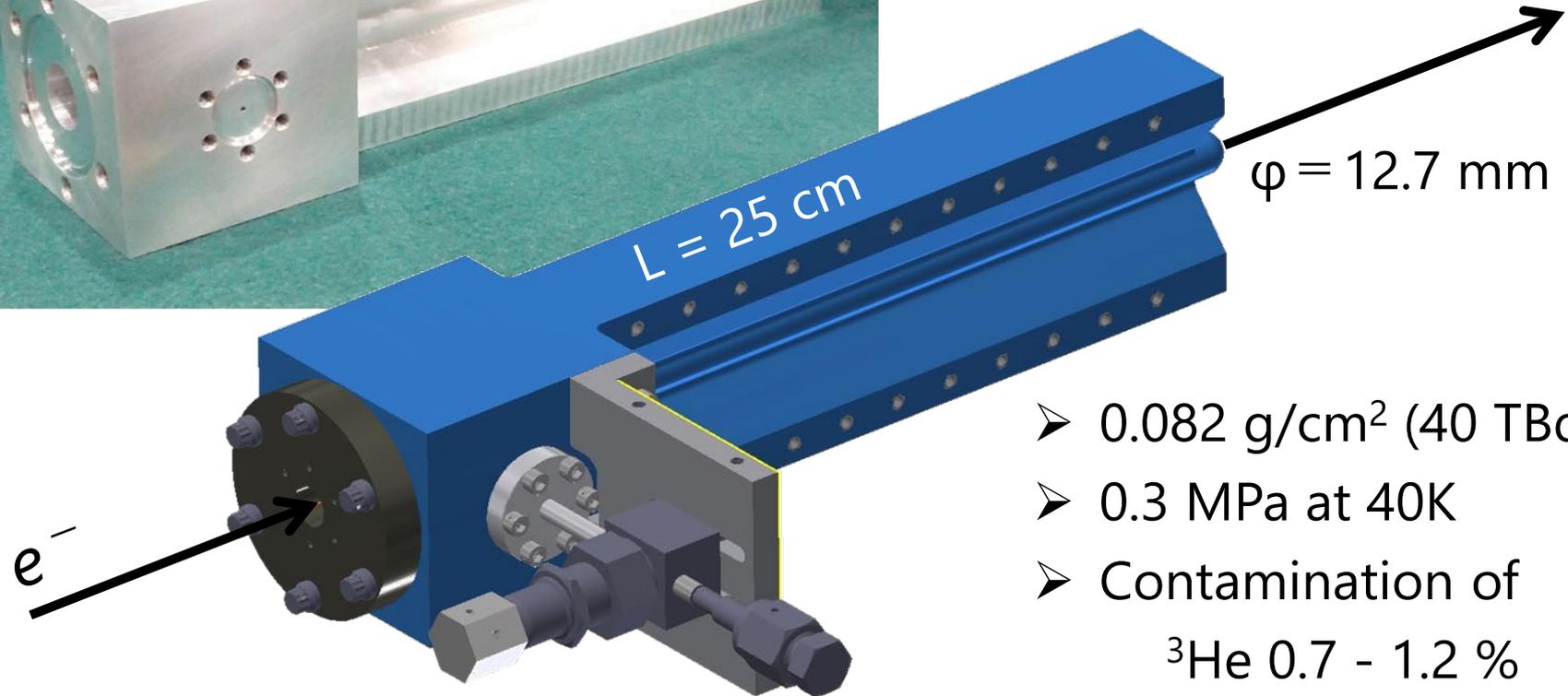
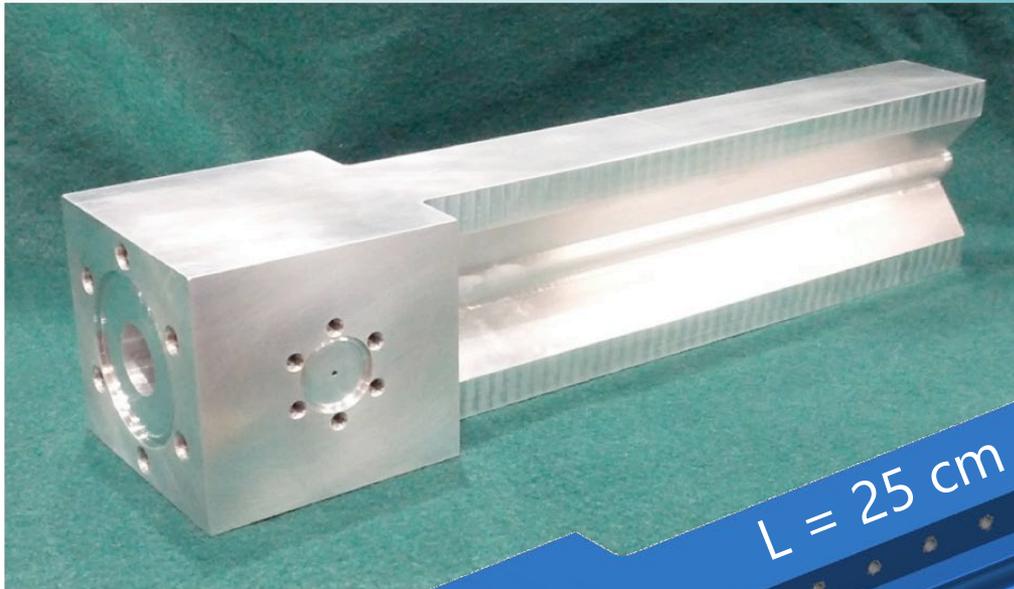
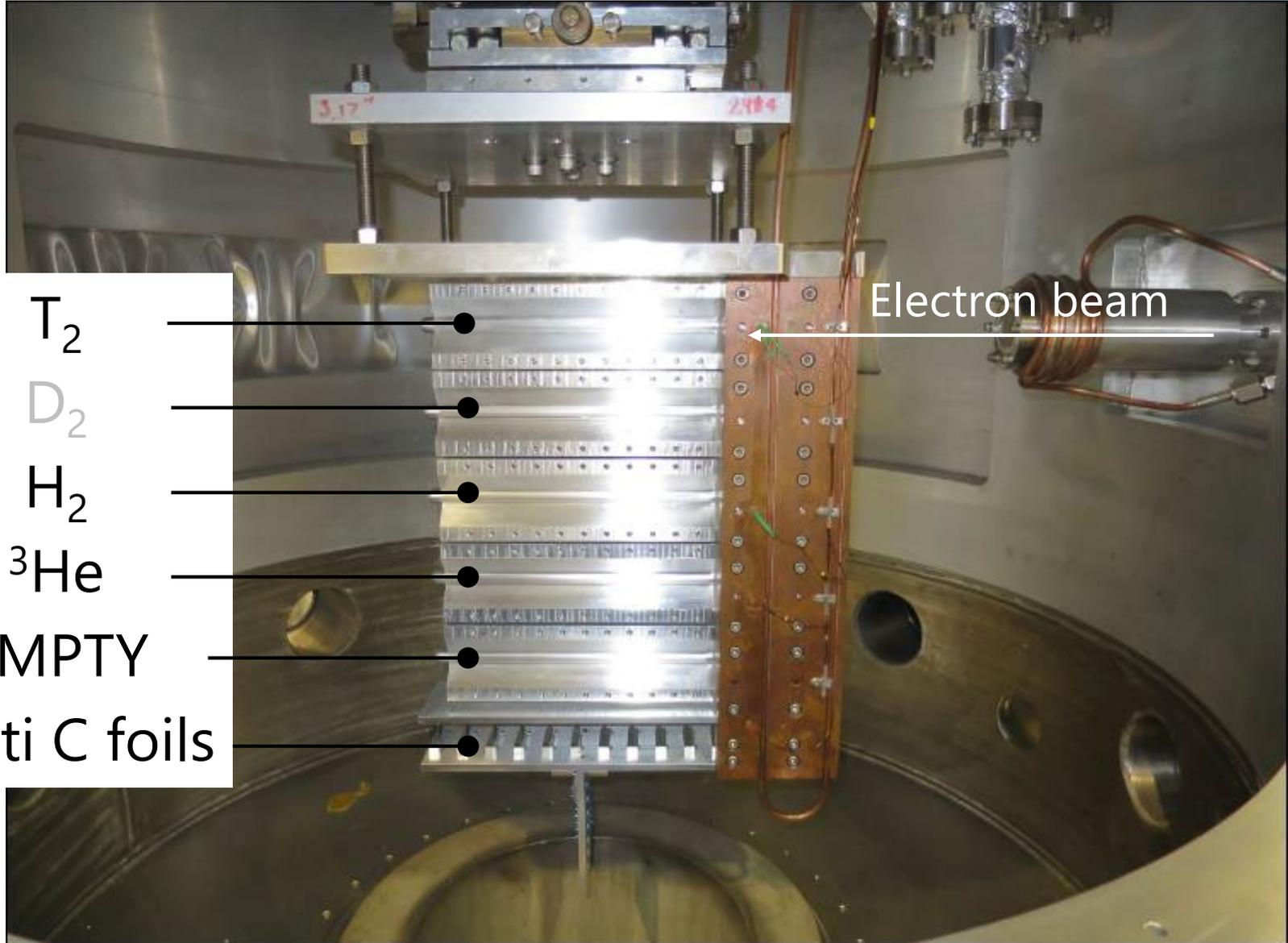


Figure taken from Dave's slide (2015).

- 0.082 g/cm^2 (40 TBq)
- 0.3 MPa at 40K
- Contamination of
 ^3He 0.7 - 1.2 %
 H_2 2%
Al window

Targets



T₂

D₂

H₂

³He

EMPTY

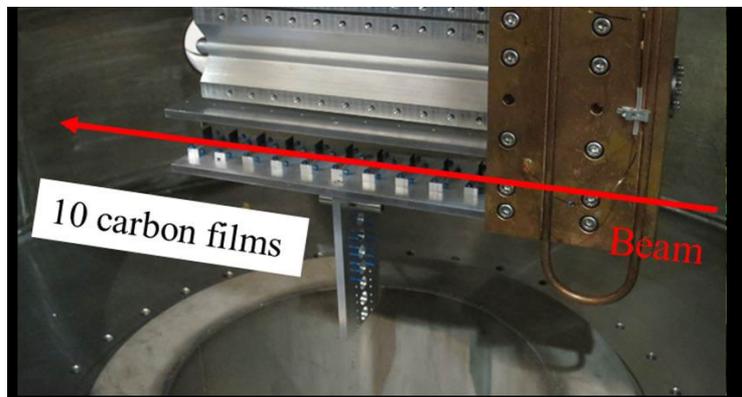
Multi C foils

Electron beam

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

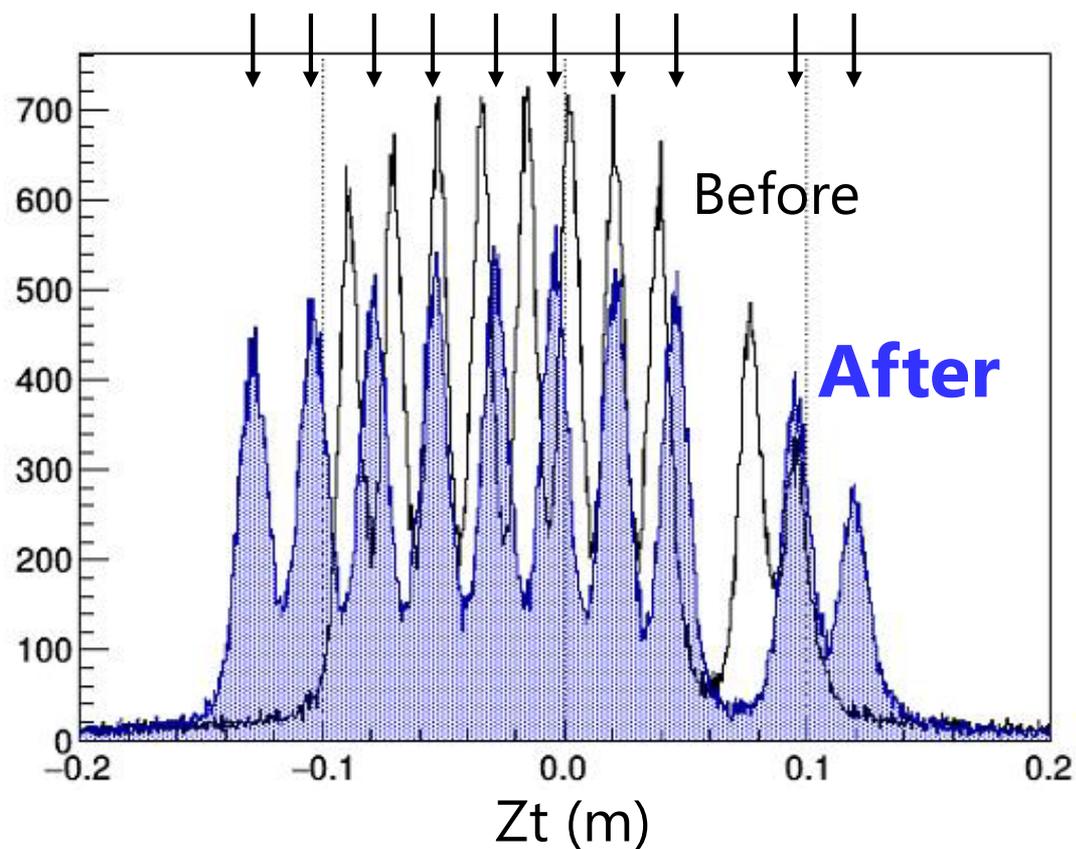
1. Vertex
2. Angle
3. Momentum

Vertex reconstruction

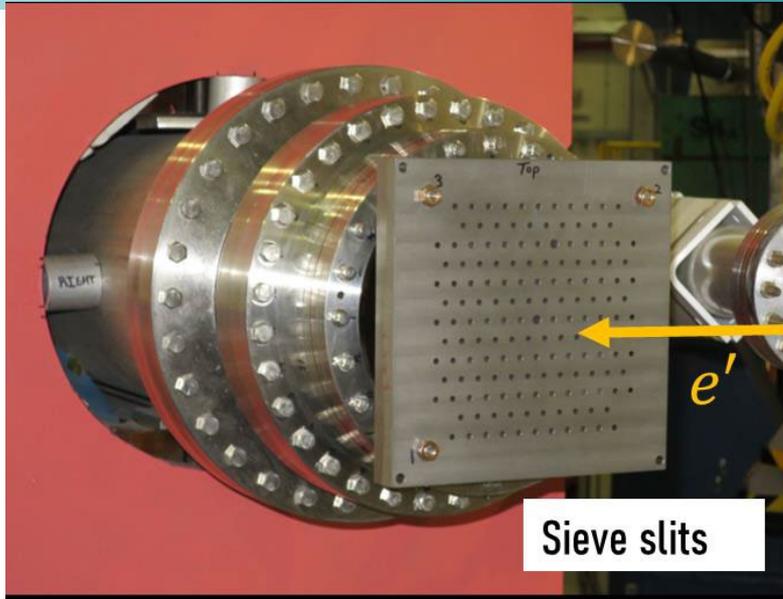


- First (e,e'K⁺) experiment with a long target.
- Calibration of the vertex reconstruction is necessary.
- Better vertex reconstruction after the matrix tuning.

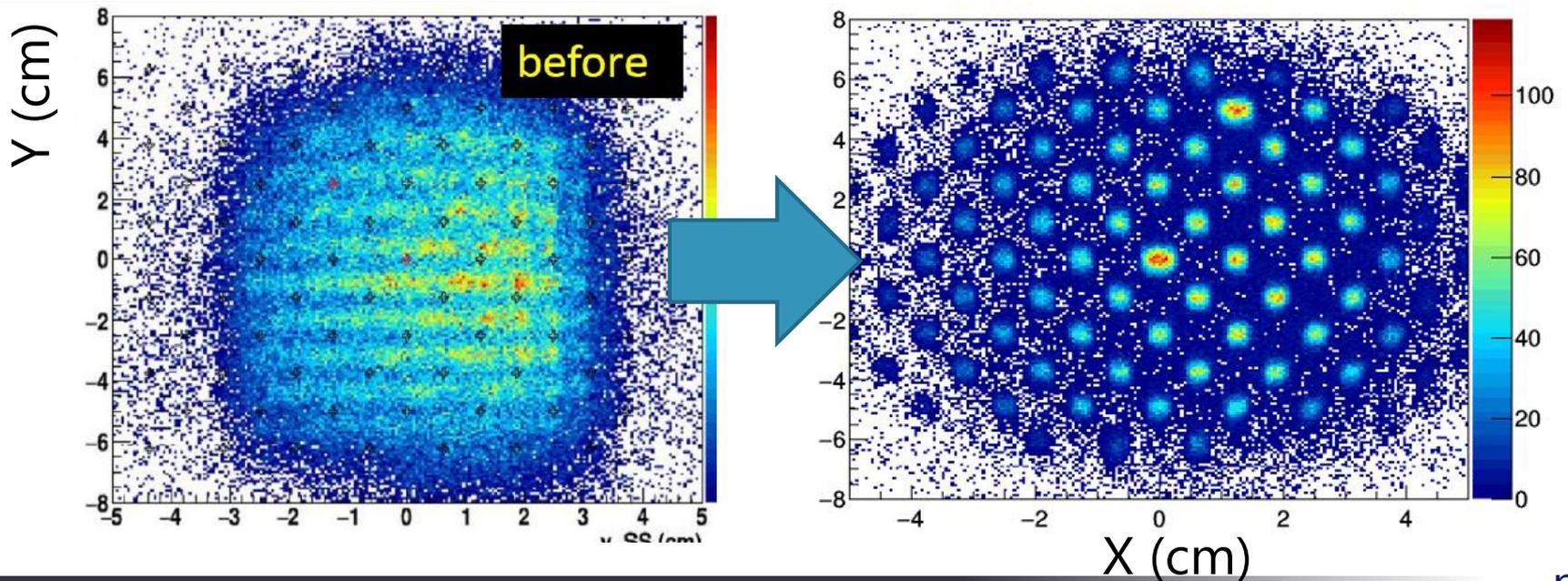
Target position @ Multi-foil target



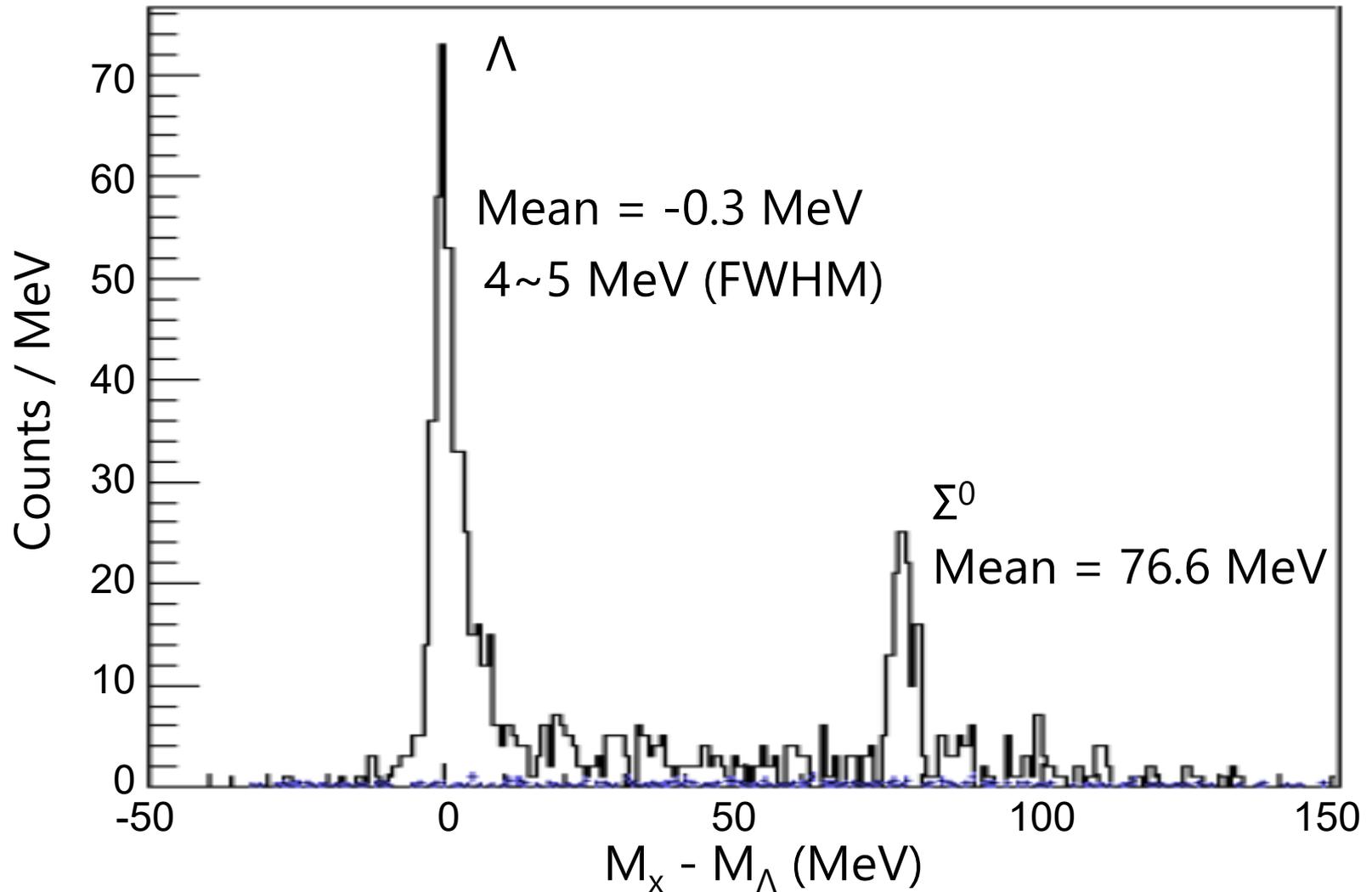
Angular reconstruction



- Angular correction with the sieve collimator.
- Clear holes after tuning.

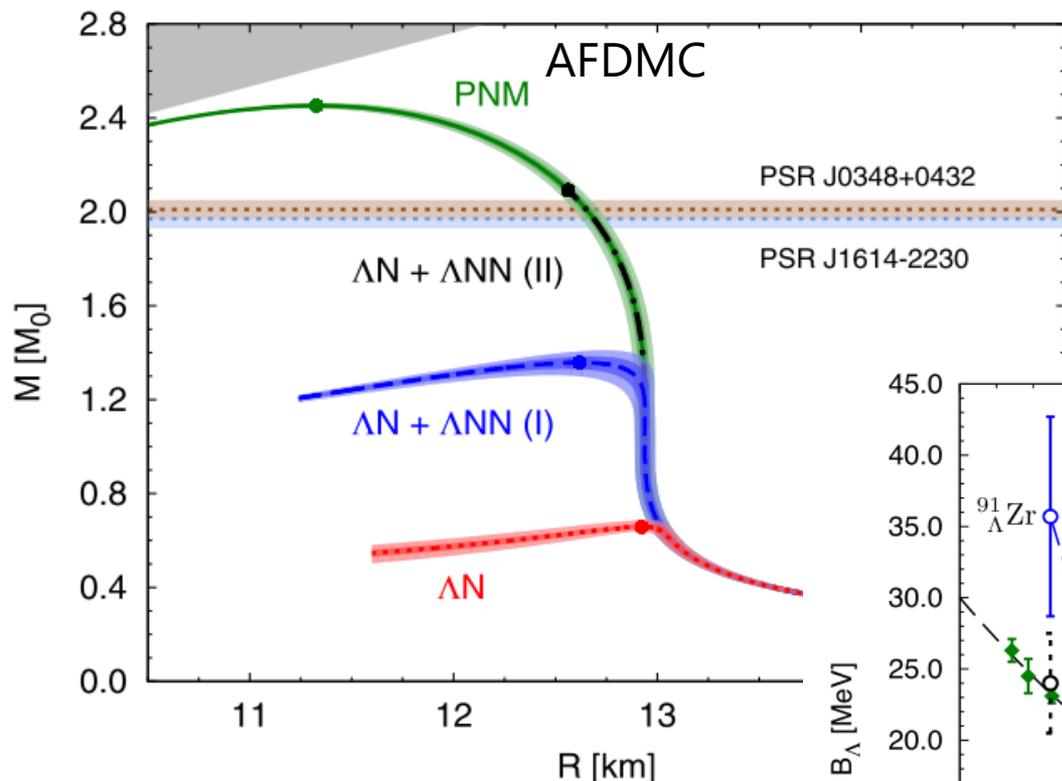


Momentum reconstruction



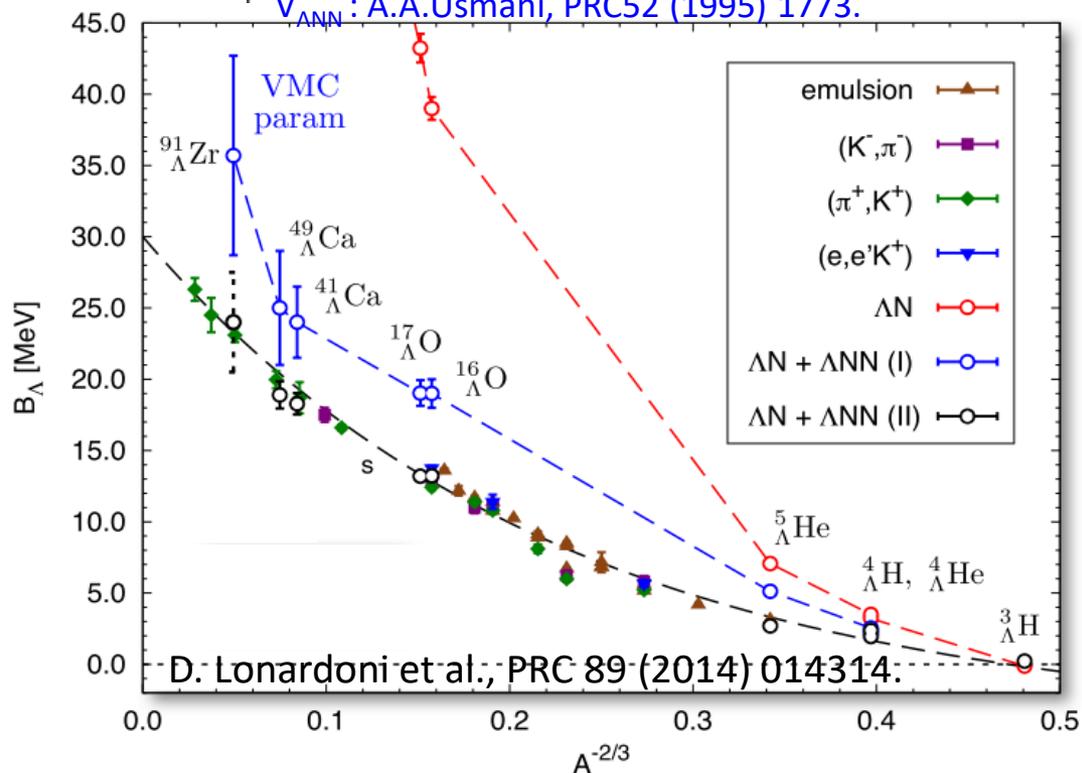
Spectroscopy of
Medium-heavy Λ K isotope
(JLab E12-15-008)

Λ NN interaction & neutron star



Repulsive Λ N force plays an important role in $2M_{\odot}$ neutron star.

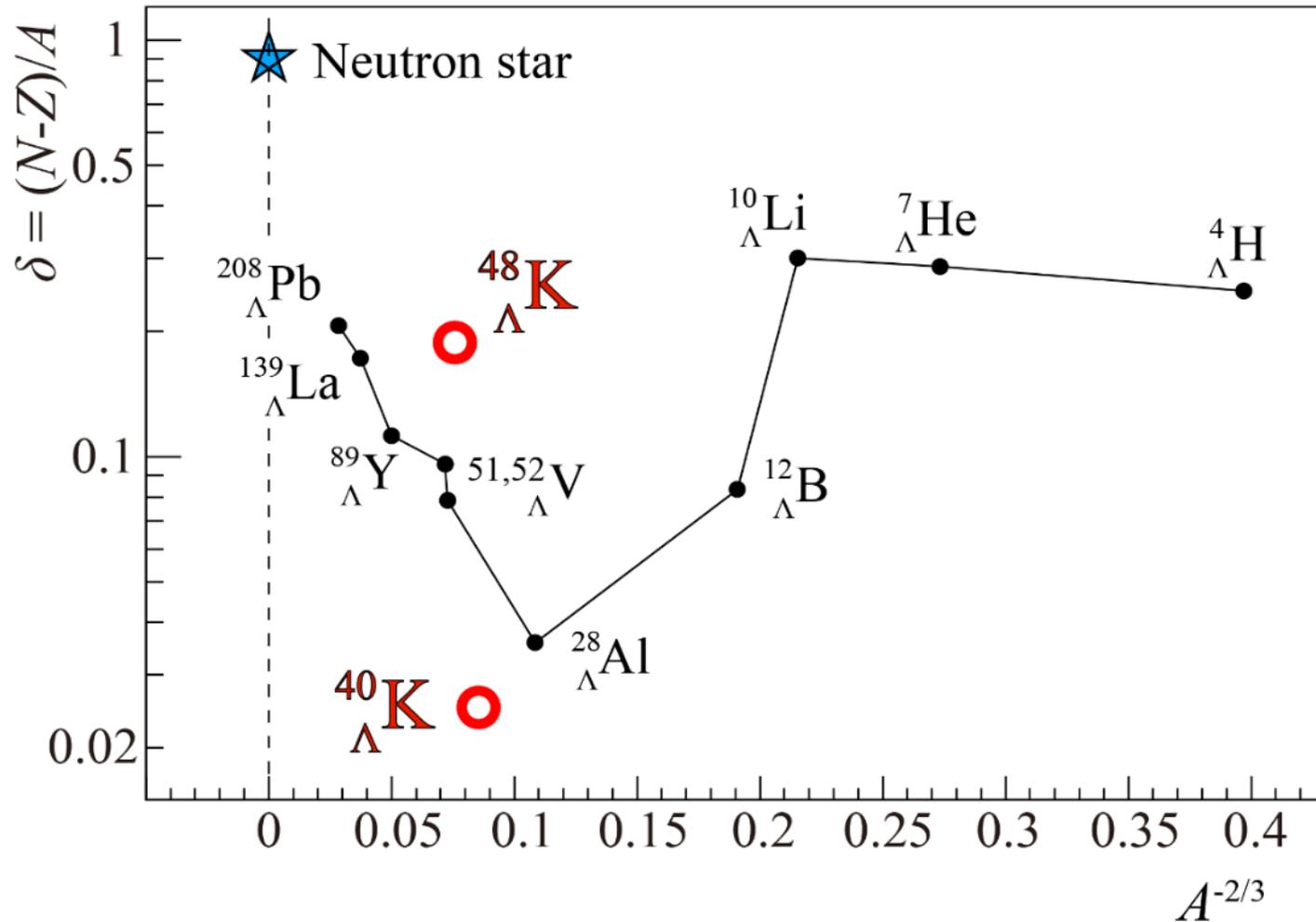
$V_{\Lambda\Lambda}$: A.A.Usmani, PRC52 (1995) 1773.



D. Lonardoni et al., PRC 89 (2014) 014314.

D. Lonardoni et al., PRL114 (2015) 092301.

Isospin dependence of Λ NN interaction



Discussion of interaction is only on A dependence.
No data for isotope dependence.

Overview of Λ K spectroscopy

Determination of $^{40,48}\Lambda\text{K}$ B_Λ with high precision.

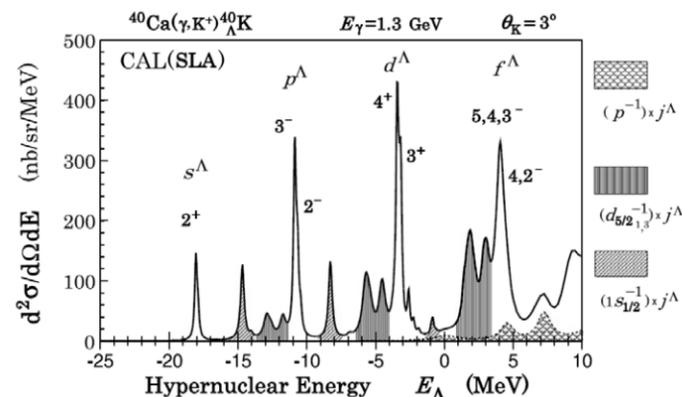
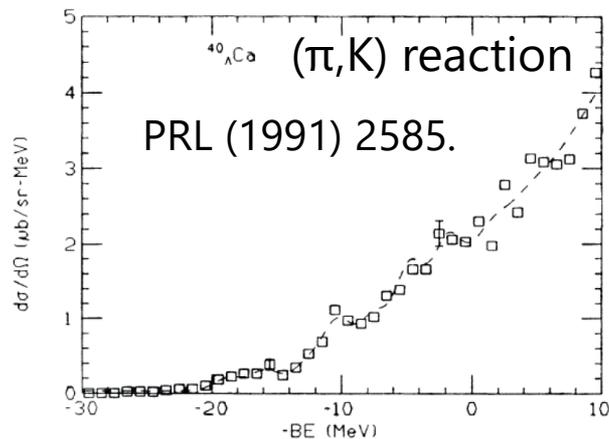
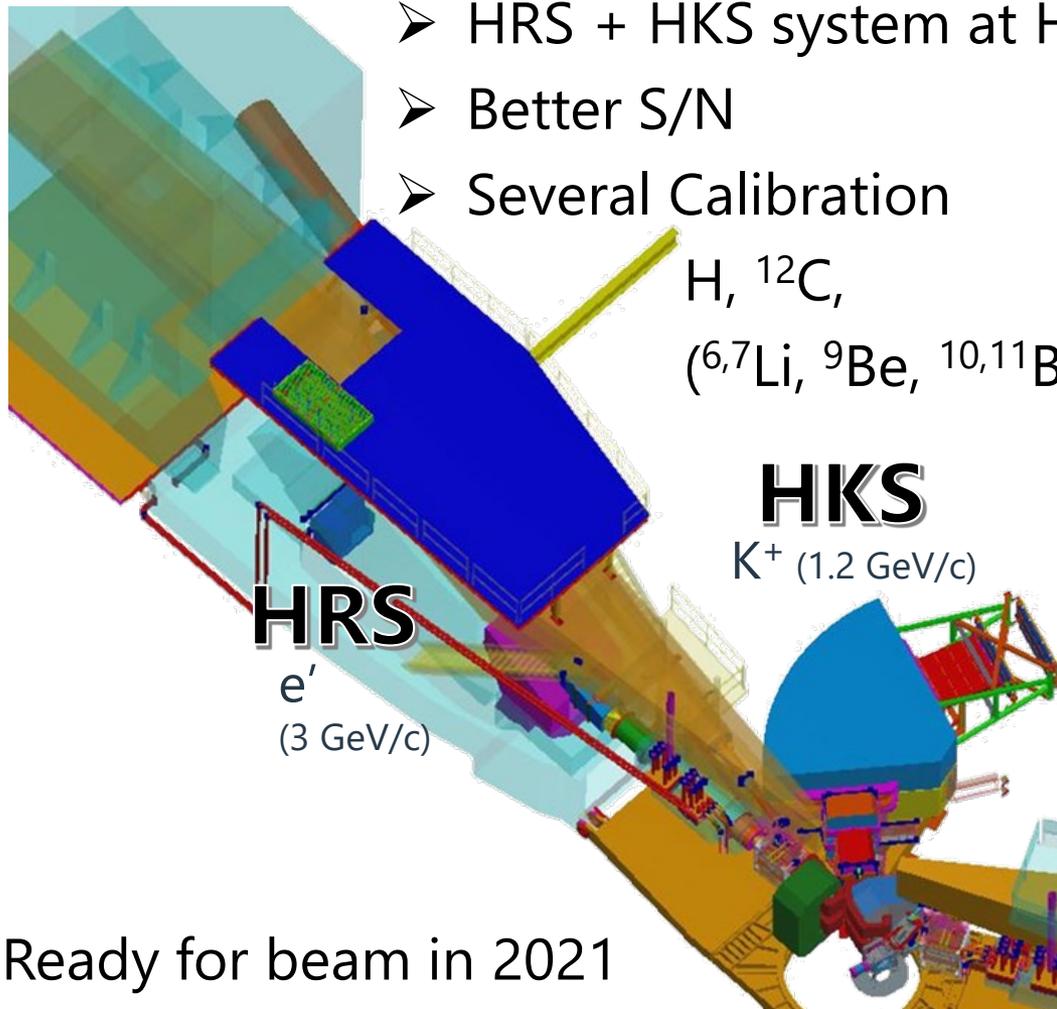
- HRS + HKS system at Hall-A
- Better S/N
- Several Calibration

H, ^{12}C ,
($^6,^7\text{Li}$, ^9Be , $^{10,11}\text{B}$)

HKS
 K^+ (1.2 GeV/c)

HRS
 e'
(3 GeV/c)

Ready for beam in 2021



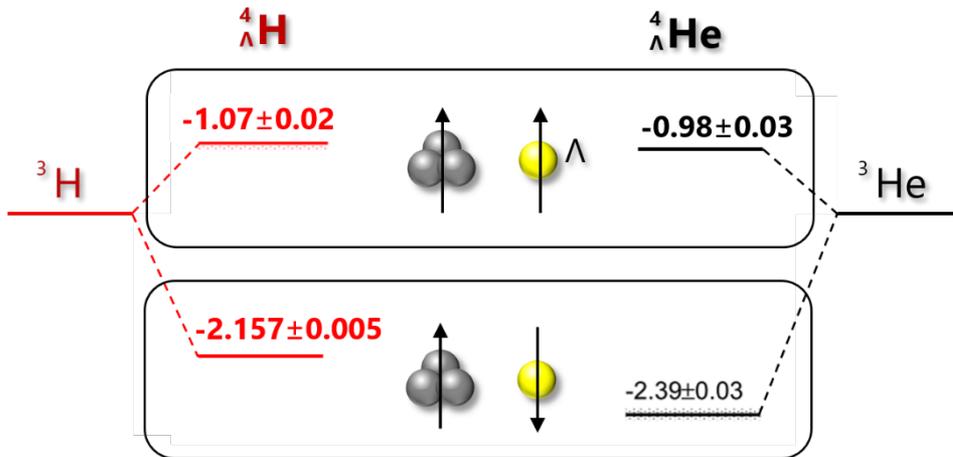
arXiv:1212.0337v1

Spectroscopy of Hyper-hydrogens (JLab C12-19-002)

Motivation

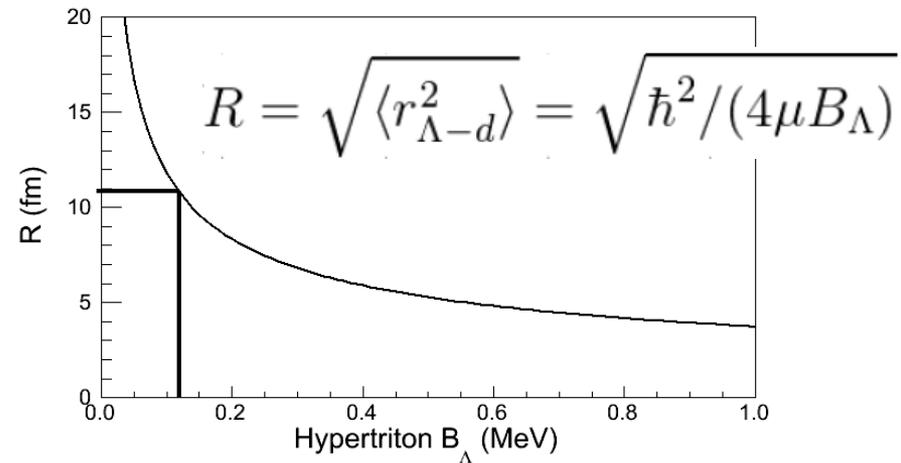
Λ -N CSB

Good Symmetry in nn - pp
 Not good Symmetry in Λn - Λp



Hypertriton lifetime

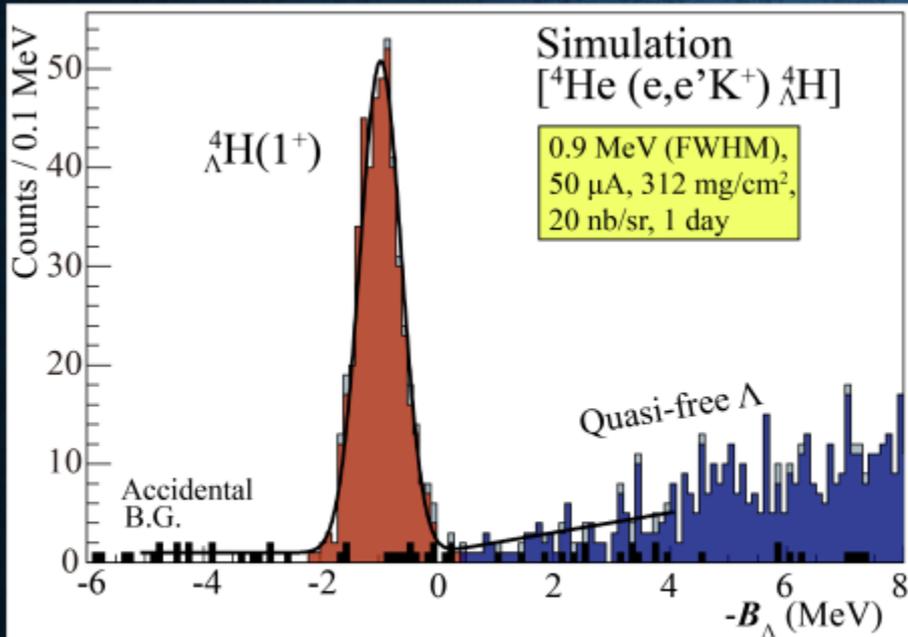
Shallow $B_{\Lambda} \Leftrightarrow$ Short? lifetime



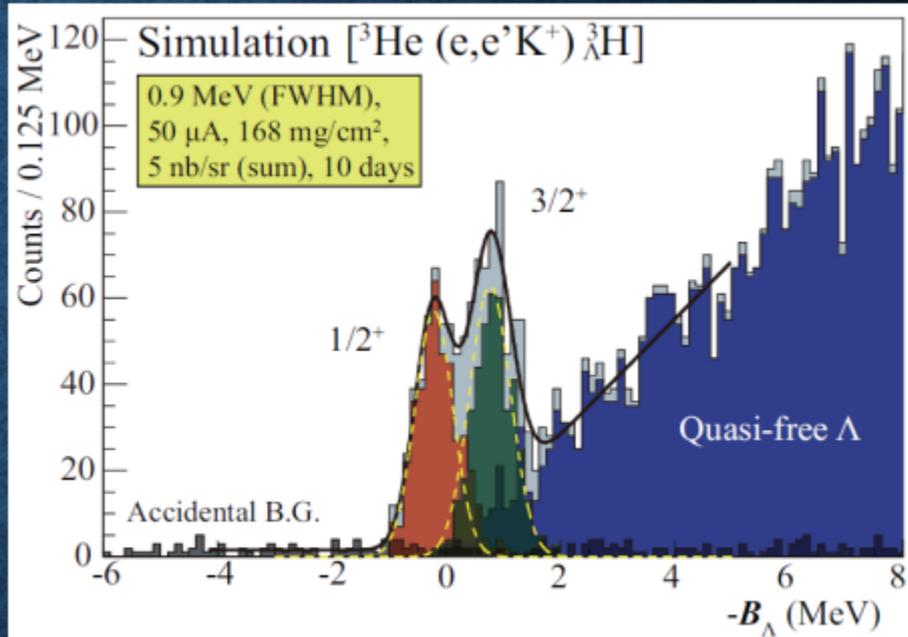
Measurement of B_{Λ} of ${}^4_{\Lambda}\text{H}(1^+)$ & ${}^3_{\Lambda}\text{H}$

B_{Λ} measurement with the $(e,e'K^+)$ reaction

Presentation by T.Gogami



$$\Delta B_{\Lambda}^{\text{stat.}} = \pm 20 \text{ keV}$$



$$\Delta B_{\Lambda}^{\text{stat.}} = \pm 70 \text{ keV}$$

Using same setup with $_{\Lambda}\text{K}$ experiment.

(e,e'K⁺) reaction spectroscopy at JLab

nn Λ (JLab E12-17-003)

^{40,48} Λ K (JLab E12-15-008)

^{3,4} Λ H (JLab C12-19-002)

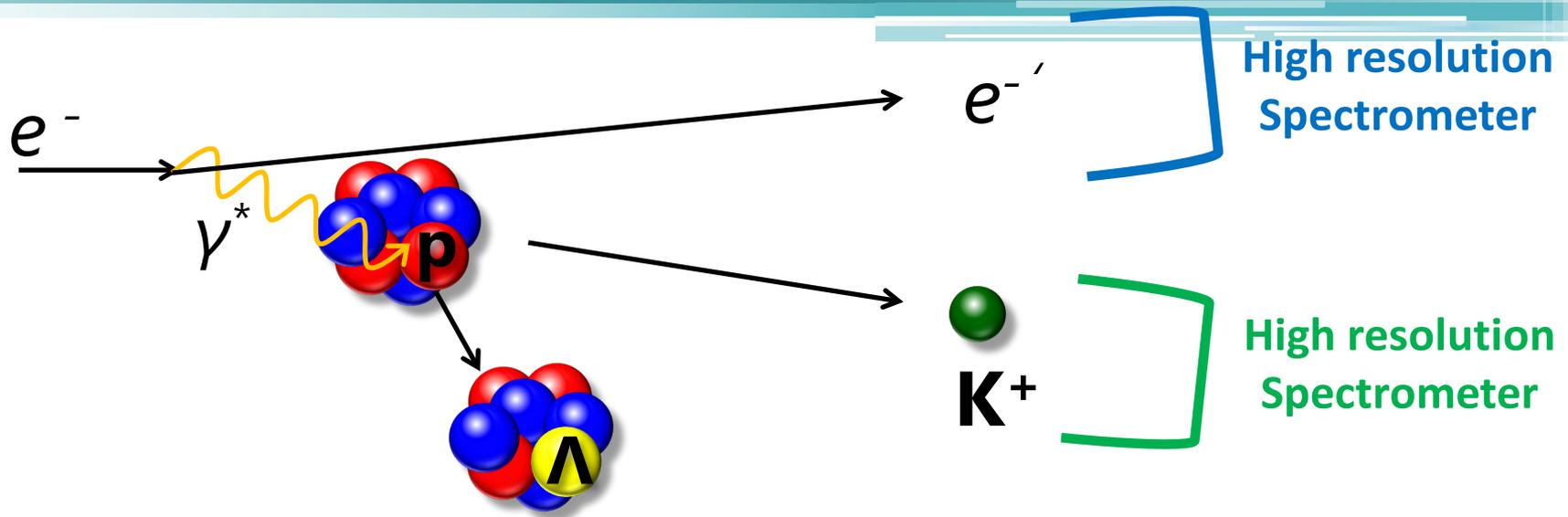
Decay pion spectroscopy at MAMI

B Λ of ³ Λ H

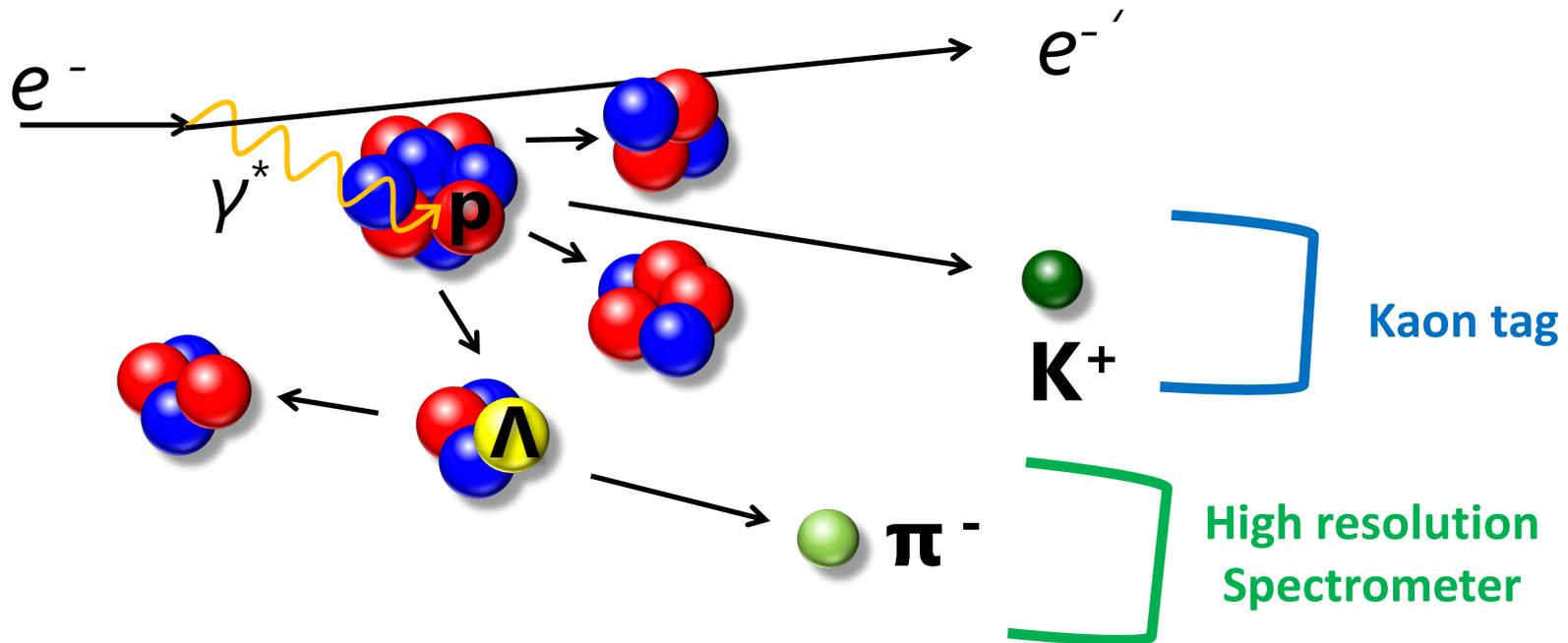
Lifetime measurement at ELPH

lifetime of ³ Λ H

Decay pion spectroscopy



Decay pion spectroscopy



$$M_{\text{HYP}} = \sqrt{M_{\text{nucl}}^2 + p_{\pi^-}^2} + \sqrt{M_{\pi^-}^2 + p_{\pi^-}^2}$$

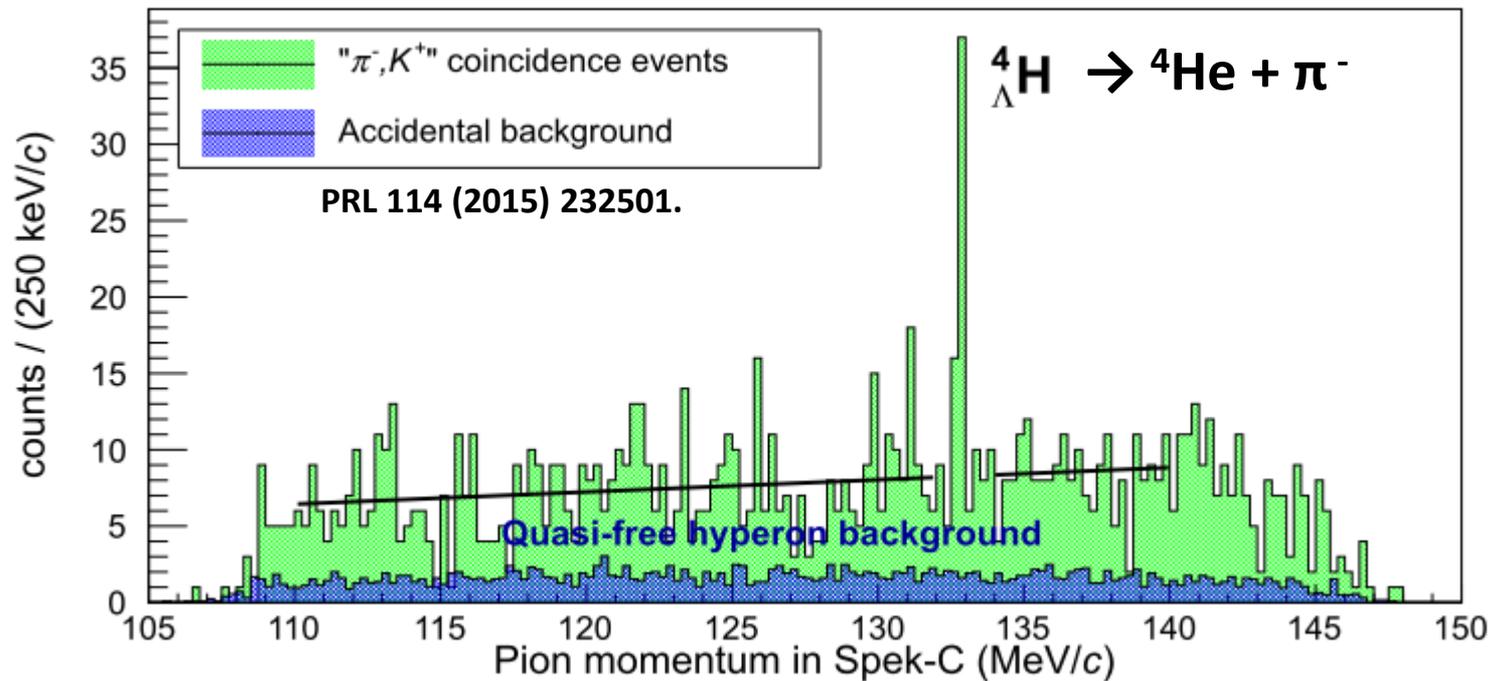
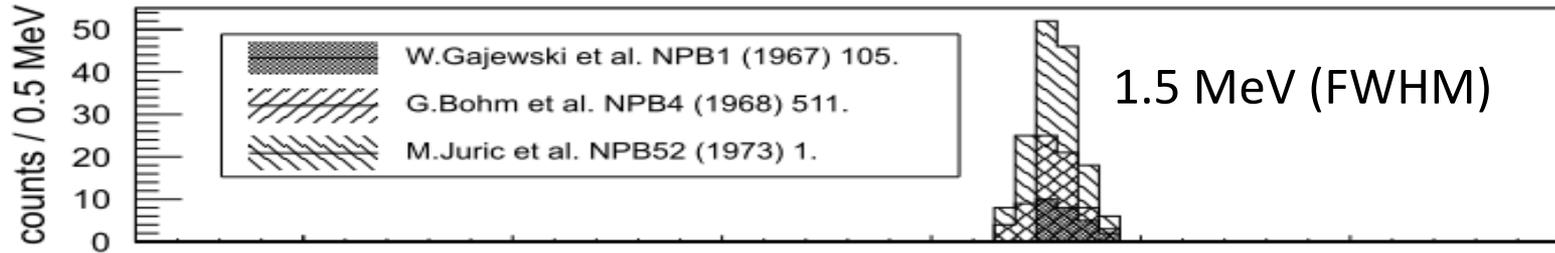
High resolution (100 keV)

10^{-4} spectroscopy with 100 MeV/c pion

High Accuracy (100 keV)

Spectrometer calibration with elastic scattering

Result of ^9Be target



(e,e'K⁺) reaction spectroscopy at JLab

nn Λ (JLab E12-17-003)

^{40,48} Λ K (JLab E12-15-008)

^{3,4} Λ H (JLab C12-19-002)

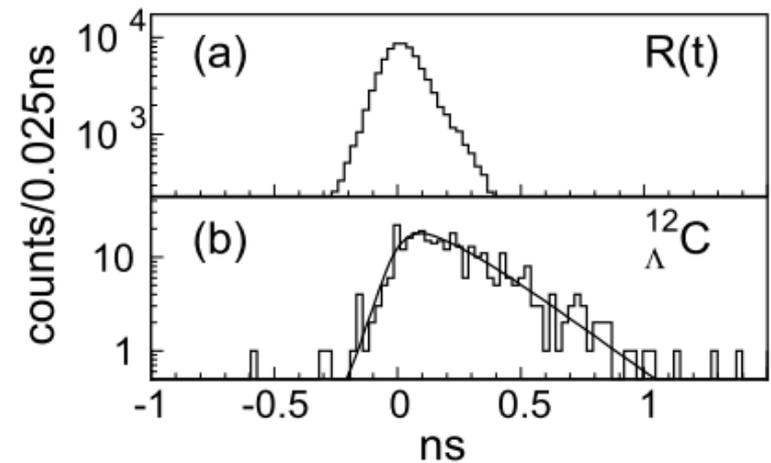
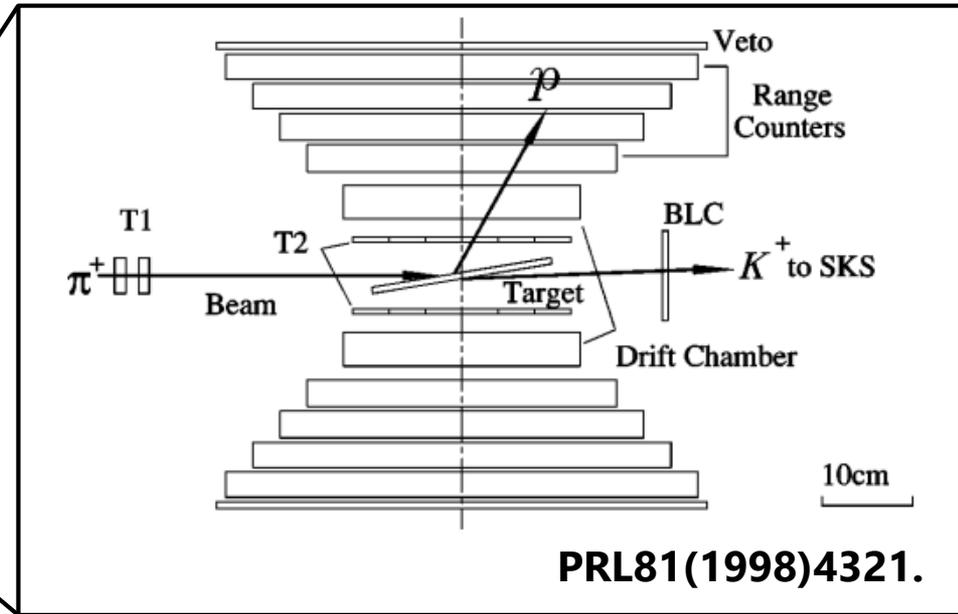
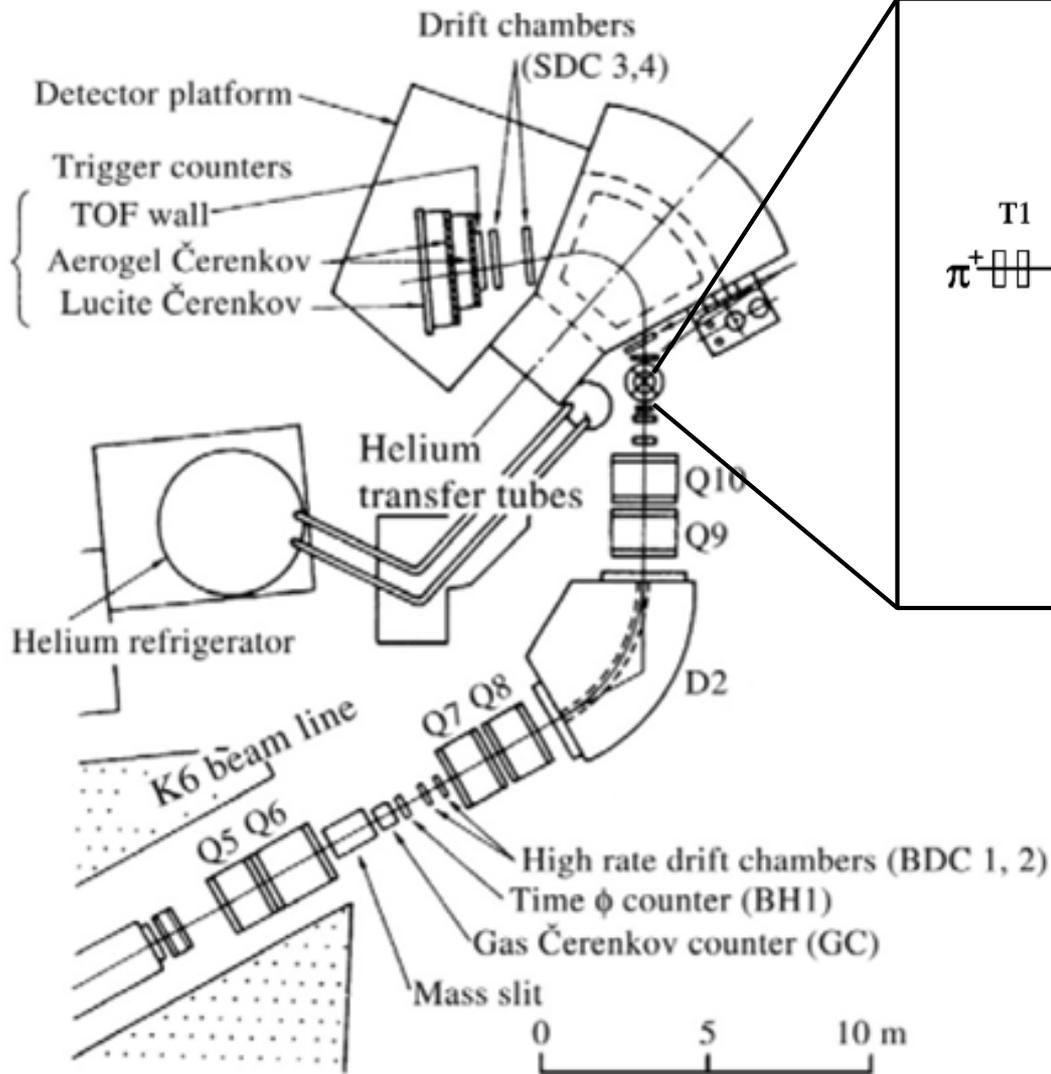
Decay pion spectroscopy at MAMI

B Λ of ³ Λ H

Lifetime measurement at ELPH

lifetime of ³ Λ H

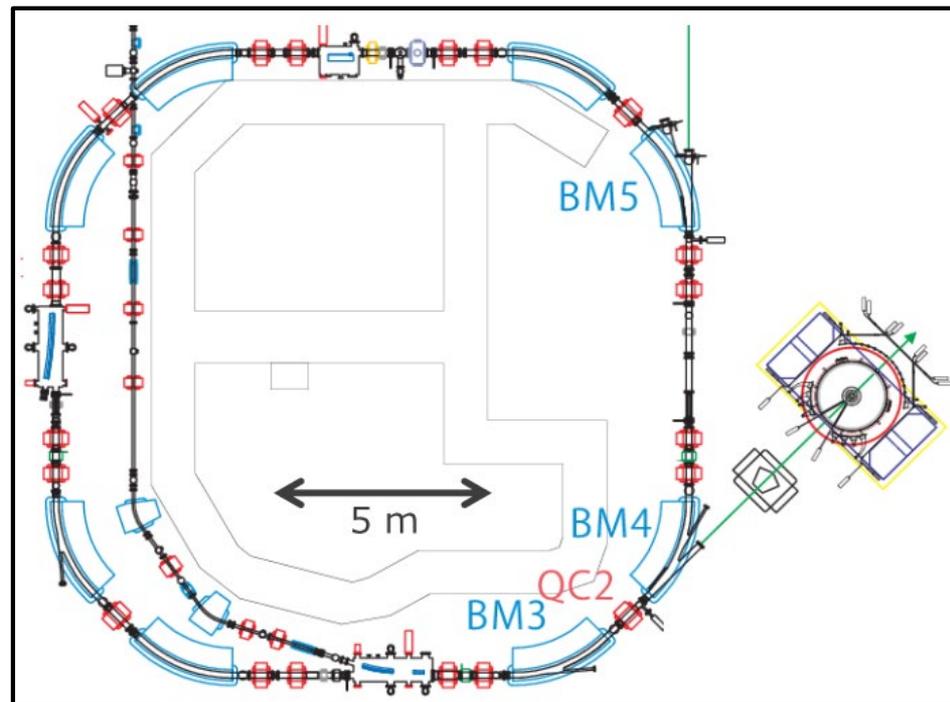
Lifetime measurement with the (π^+, K^+) reaction



Prog. Part. Nucl. Phys. 57 (2006) 564.

Lifetime measurement with the (γ, K^+) reaction

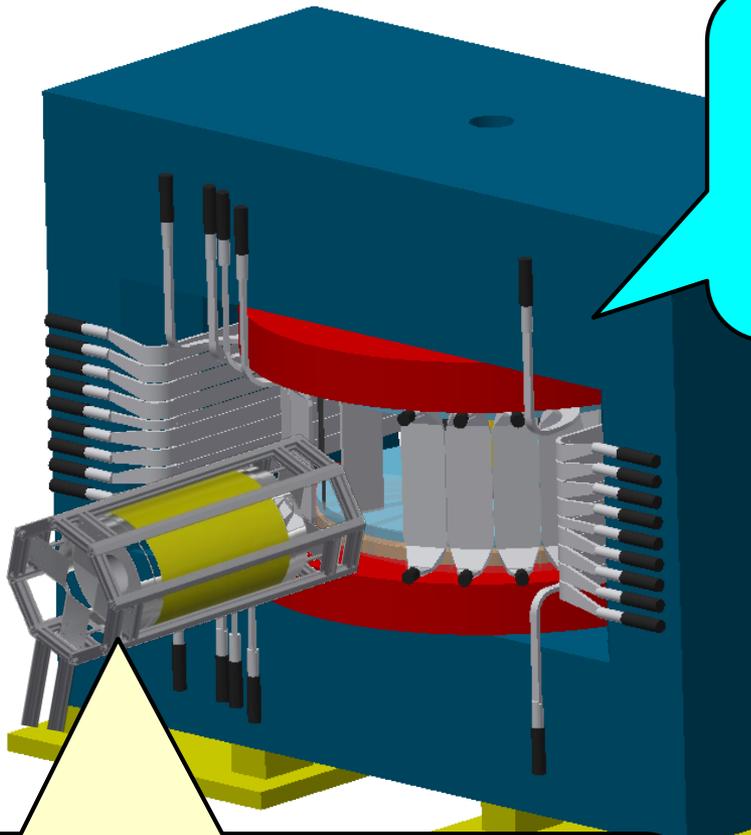
Photon beam line at ELPH Tohoku



Lifetime measurement with the (γ, K^+) reaction

NKS2

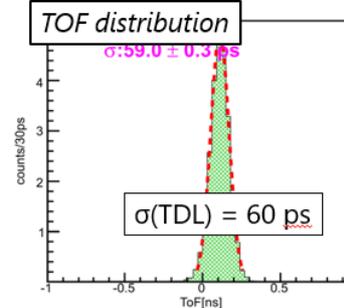
- Forward K^+ Spectrometer
- $\sim 10\%$ K^+ detection
- $\Delta p/p \sim 1\%$



4π Decay counter

- Detecting decay particle
- Good time resolution

Fast timing detector (TDL)



4π good time resolution detector

- $\Phi = 9 \text{ cm}$, $L = 20 \text{ cm}$
- 48 x scintillator bar
 - $5 \times 5 \times 20 \text{ mm}^3$ each
- 48 x 2-series connection SiPM
 - MPPC S13360-3050CS

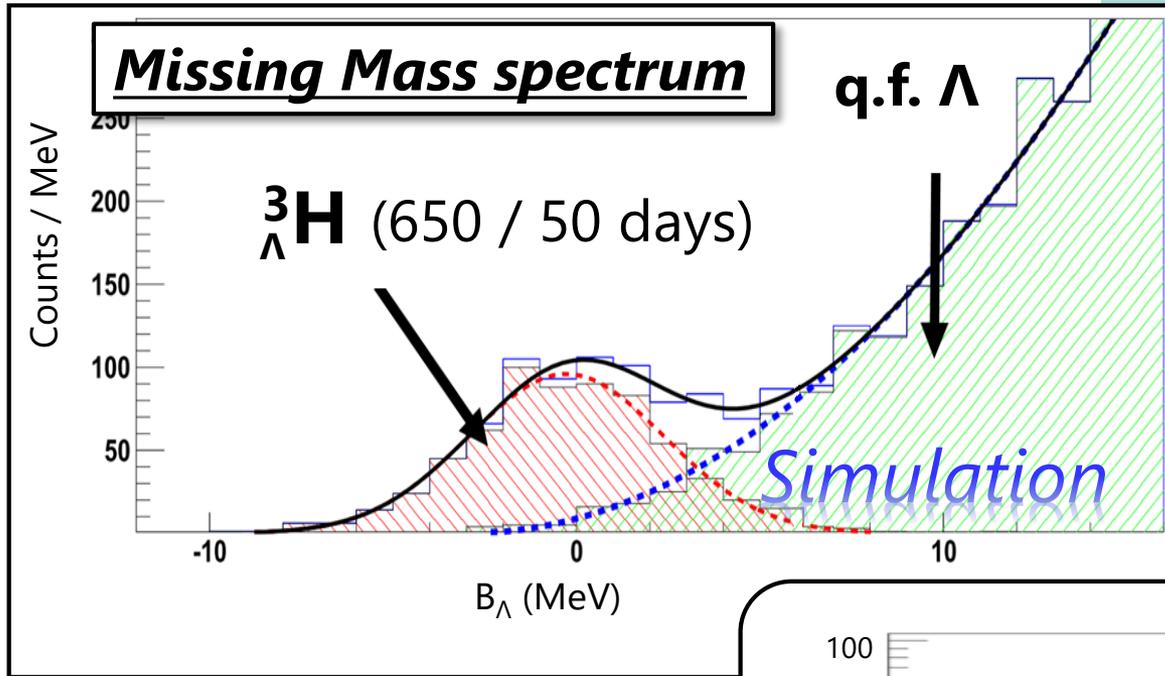
MPPC & Mounter

4ch diff. Amp. card

Constructed Dec.2018



Direct lifetime measurement of ${}^3_{\Lambda}\text{H}$



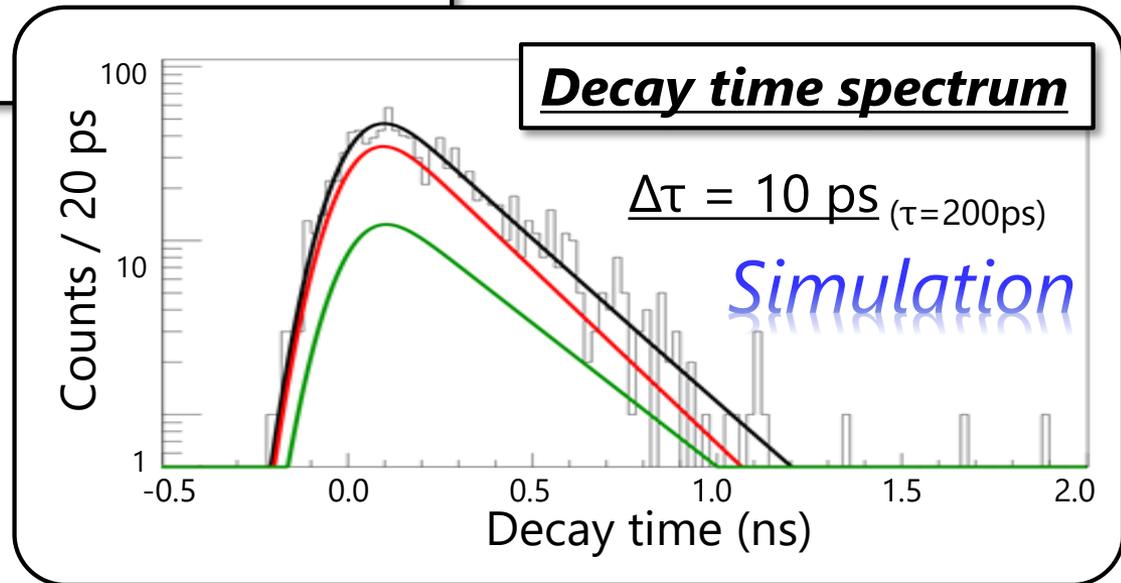
${}^3_{\Lambda}\text{H}$ ID on MM

- $\rightarrow {}^3\text{He} + \pi^{-}$
- $\rightarrow p + d + \pi^{-}$
- $\rightarrow {}^3\text{H} + \pi^0$
- $\rightarrow \text{Non-MWD}$

Evaluating decay time spectrum after selecting π^{-} .

10 ps precision will be expected.

Ready for run in 2021.



(e,e'K⁺) reaction spectroscopy at JLab

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B_{Λ} of $^3_{\Lambda}\text{H}$

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lifetime of $^3_{\Lambda}\text{H}$