JLab Hall A Winter Collaboration Meeting, Jan 26—27, 2023

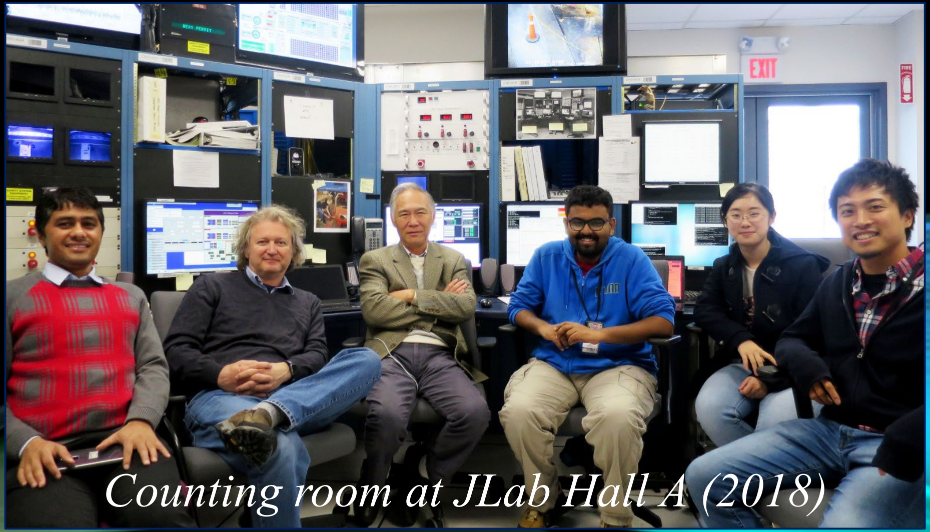
Strangeness production in tritium by electron scattering

Kyoto University, Japan

Toshiyuki Gogami

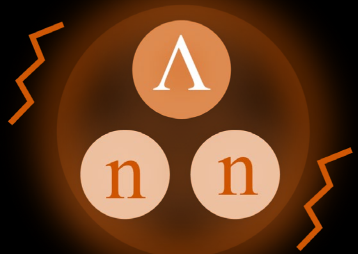
Jan 26, 2023

GRADUATE SCHOOL OF SCIENCE
FACULTY OF SCIENCE
KYOTO UNIVERSITY



Counting room at JLab Hall A (2018)

- ✓ HRS-HRS @ Hall A
- ✓ Tritium target
- ✓ $(e,e'K^+)$
- ✓ Oct—Nov 2018



PTEP Progress of Theoretical and Experimental Physics
JPS The Physical Society of Japan

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

K N Suzuki, T Gogami, B Pandey, K Itabashi, S Nagao, K Okuyama, S N Nakamura, L Tang, D Abrams, T Akiyama, D Androic, K Aniol, C Ayerbe Gayoso, J Bane, S Barcus, J Barrow, V Bellini, H Bhatt, D Bhetuwal, D Biswas, A Camsonne, J Castellanos, J-P Chen, J Chen, S Covrig, D Chrisman, R Cruz-Torres, R Das, E Fuchey, K Gnanvo, F Garibaldi, T Gautam, J Gomez, P Gueye, T J Hague, O Hansen, W Henry, F Hauenstein, D W Higinbotham, C E Hyde, M Kaneta, C Keppel, T Kutz, N Lashley-Colthirst, S Li, H Liu, J Mammei, P Markowitz, R E McClellan, F Meddi, D Meekins, R Michaels, M Mihovilovič, A Moyer, D Nguyen, M Nycz, V Owen, C Palatchi, S Park, T Petkovic, S Premathilake, P E Reimer, J Reinhold, S Riordan, V Rodriguez, C Samanta, S N Santiesteban, B Sawatzky, S Širca, K Slifer, T Su, Y Tian, Y Toyama, K Uehara, G M Urciuoli, D Votaw, J Williamson, B Wojtsekhowski, S A Wood, B Yale, Z Ye, J Zhang, X Zheng

Progress of Theoretical and Experimental Physics, Volume 2022, Issue 1, January 2022, 013D01, https://doi.org/10.1093/ptep/ptab158

Published: 06 December 2021 **Article history** ▾

https://doi.org/10.1093/ptep/ptab158 *(see also here)*

PHYSICAL REVIEW C
covering nuclear physics

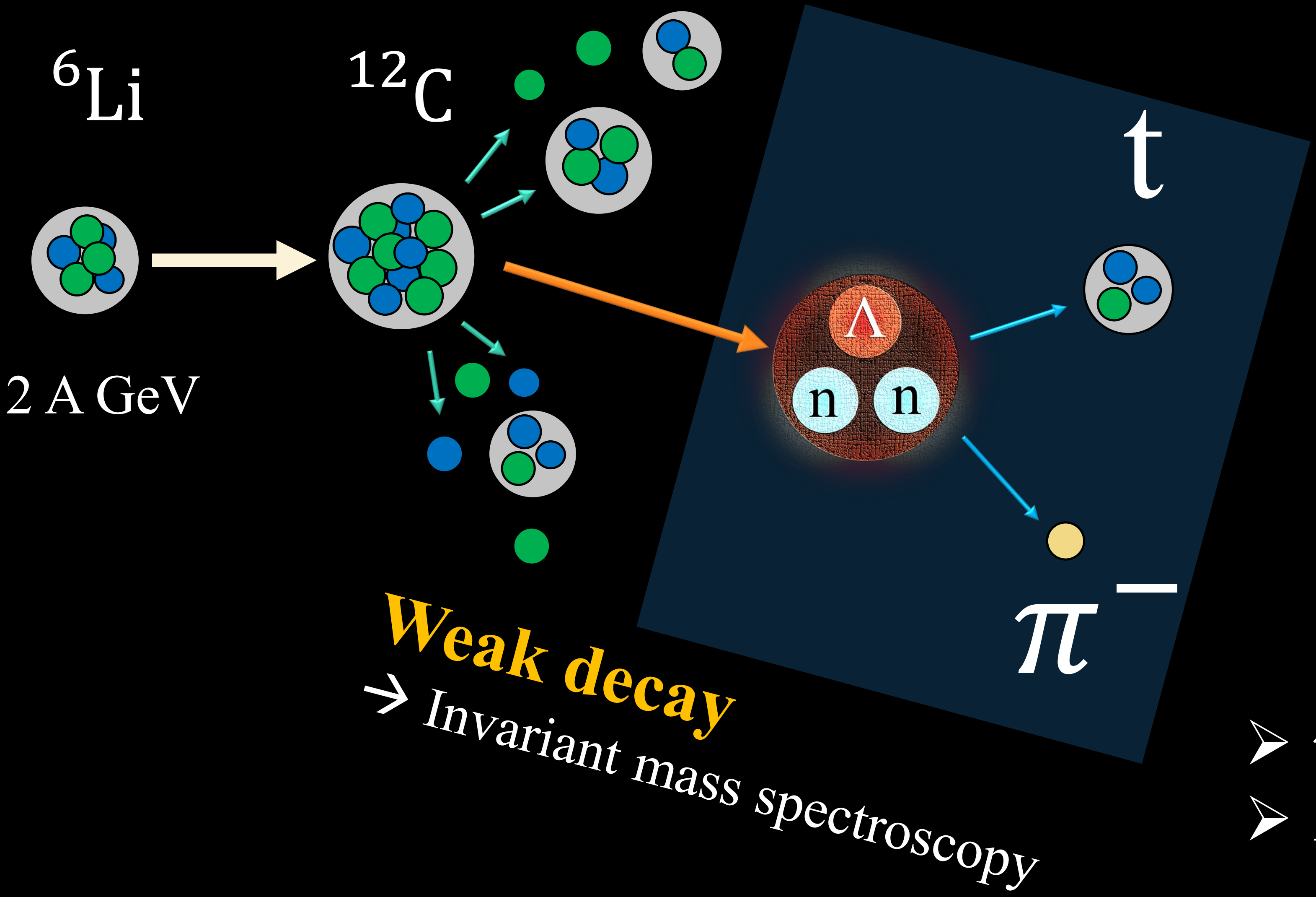
Letter

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

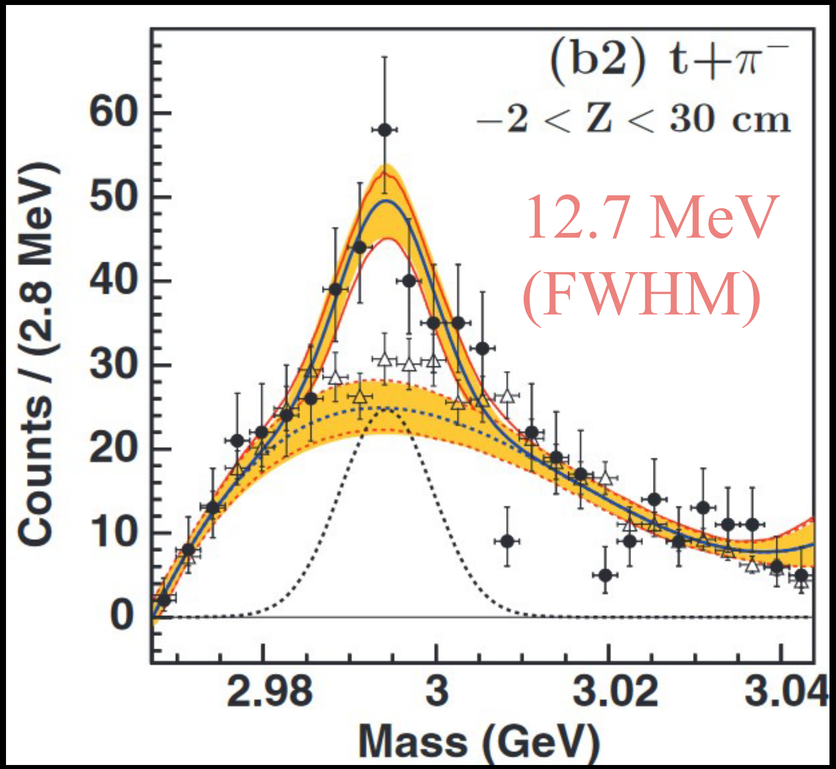
B. Pandey[1], L. Tang[1,2,*], T. Gogami[3,4], K. N. Suzuki[4], K. Itabashi[3], S. Nagao[3], K. Okuyama[3], S. N. Nakamura[3], D. Abrams[5], I. R. Afnan[6], T. Akiyama[3], D. Androic[7], K. Aniol[8], T. Averett[9], C. Ayerbe Gayoso[9], J. Bane[10], S. Barcus[9], J. Barrow[10], V. Bellini[11], H. Bhatt[12], D. Bhetuwal[12], D. Biswas[1], A. Camsonne[2], J. Castellanos[13], J-P. Chen[2], J. Chen[9], S. Covrig[2], D. Chrisman[14,15], R. Cruz-Torres[16], R. Das[17], E. Fuchey[18], C. Gal[5], B. F. Gibson[19], K. Gnanvo[5], F. Garibaldi[11,20], T. Gautam[1], J. Gomez[2], P. Gueye[1], T. J. Hague[21], O. Hansen[2], W. Henry[2], F. Hauenstein[22], D. W. Higinbotham[2], C. Hyde[22], M. Kaneta[3], C. Keppel[2], T. Kutz[17], N. Lashley-Colthirst[1], S. Li[23,24], H. Liu[25], J. Mammei[26], P. Markowitz[13], R. E. McClellan[2], F. Meddi[11], D. Meekins[2], R. Michaels[2], M. Mihovilovič[27,28,29], A. Moyer[30], D. Nguyen[16,31], M. Nycz[21], V. Owen[9], C. Palatchi[5], S. Park[17], T. Petkovic[7], S. Premathilake[5], P. E. Reimer[32], J. Reinhold[13], S. Riordan[32], V. Rodriguez[33], C. Samanta[34], S. N. Santiesteban[23], B. Sawatzky[2], S. Širca[27,28], K. Slifer[23], T. Su[21], Y. Tian[35], Y. Toyama[3], K. Uehara[3], G. M. Urciuoli[11], D. Votaw[14,15], J. Williamson[36], B. Wojtsekhowski[2], S. Wood[2], B. Yale[23], Z. Ye[32], J. Zhang[5], and X. Zheng[5] (Hall A Collaboration)

https://doi.org/10.1103/PhysRevC.105.L051001

nnΛ ($^3_\Lambda n$) measurement at GSI

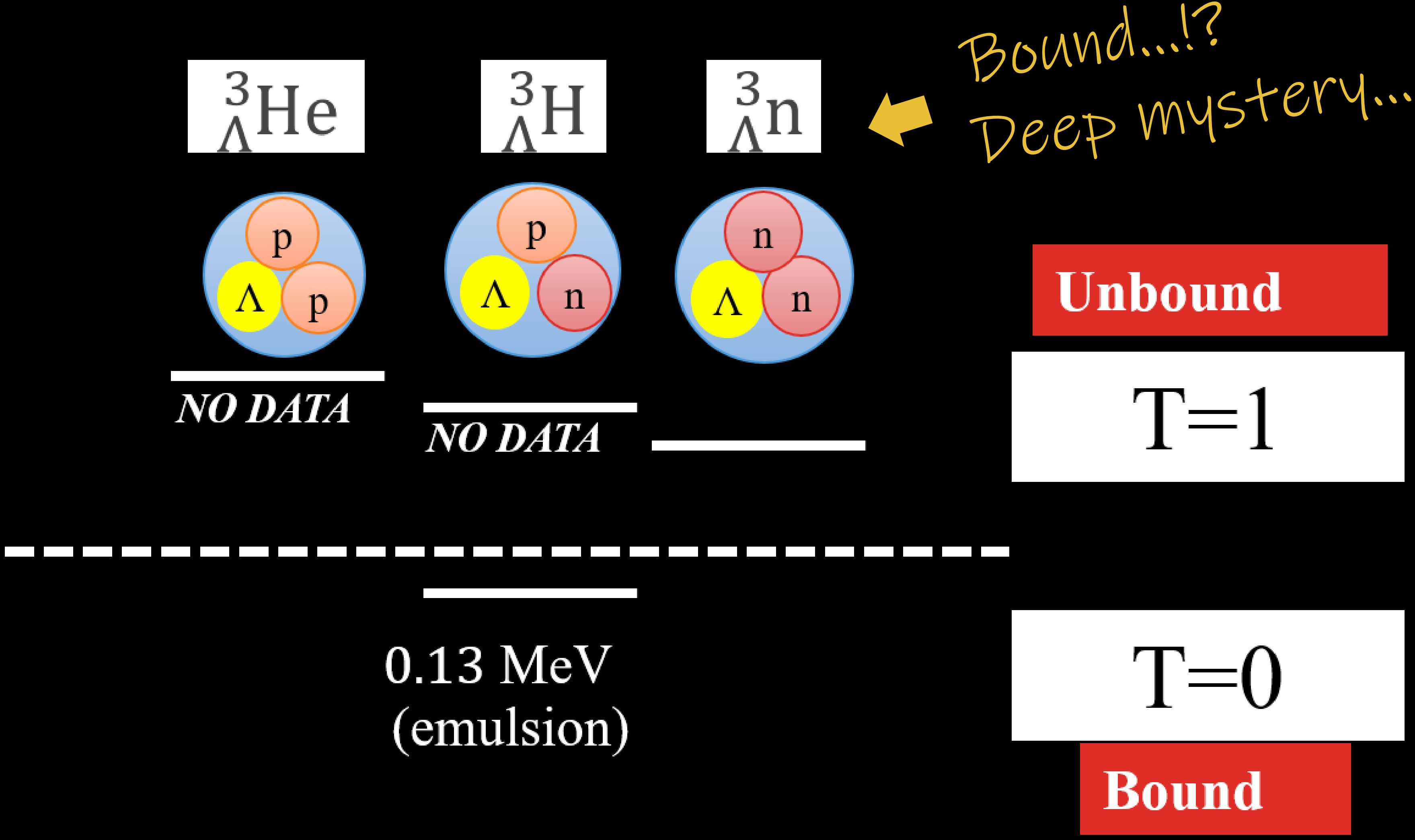


C. Rappold et al., PRC 88, 041001(R) (2013)



- $\tau = 190^{+47}_{-35}$ ps
- $B_\Lambda = -0.5 \pm 1.1 \pm 2.2$ MeV

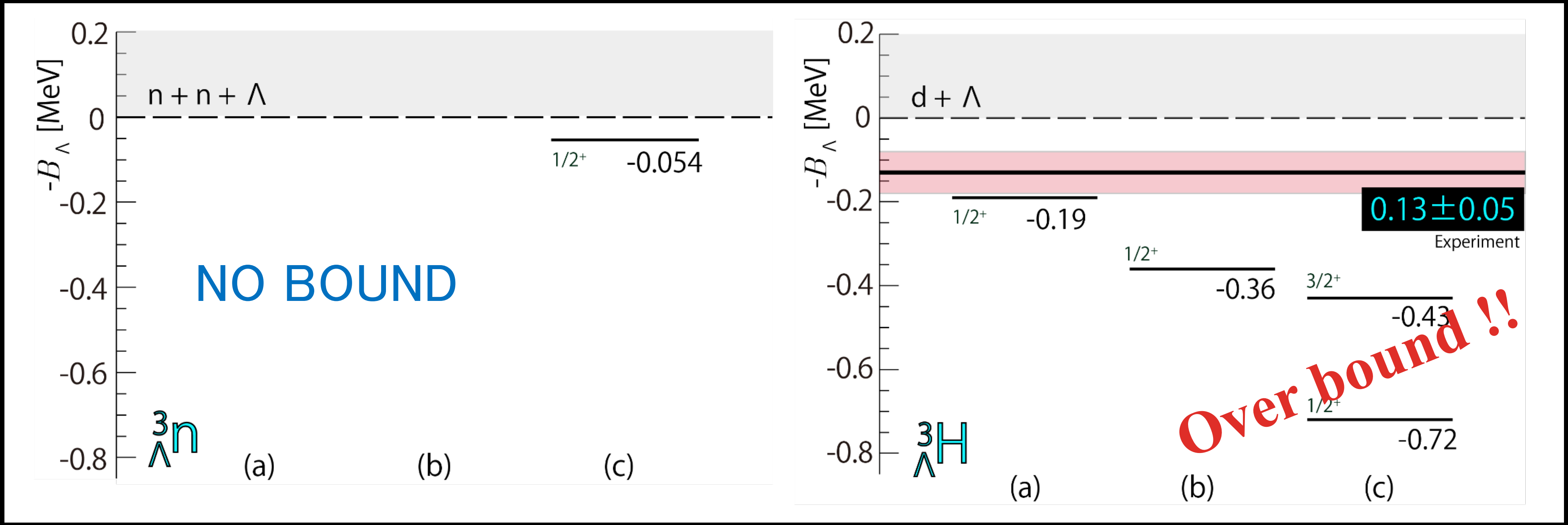
Three-body system with Λ



Can the $nn\Lambda$ be bound?

E. Hiyama, S. Ohnishi, B.F. Gibson, and Th. A. Rijken, Physical Review C 89, 061302(R) (2014).

AV8 ***NN*** + NSC97f ***YN*** potentials



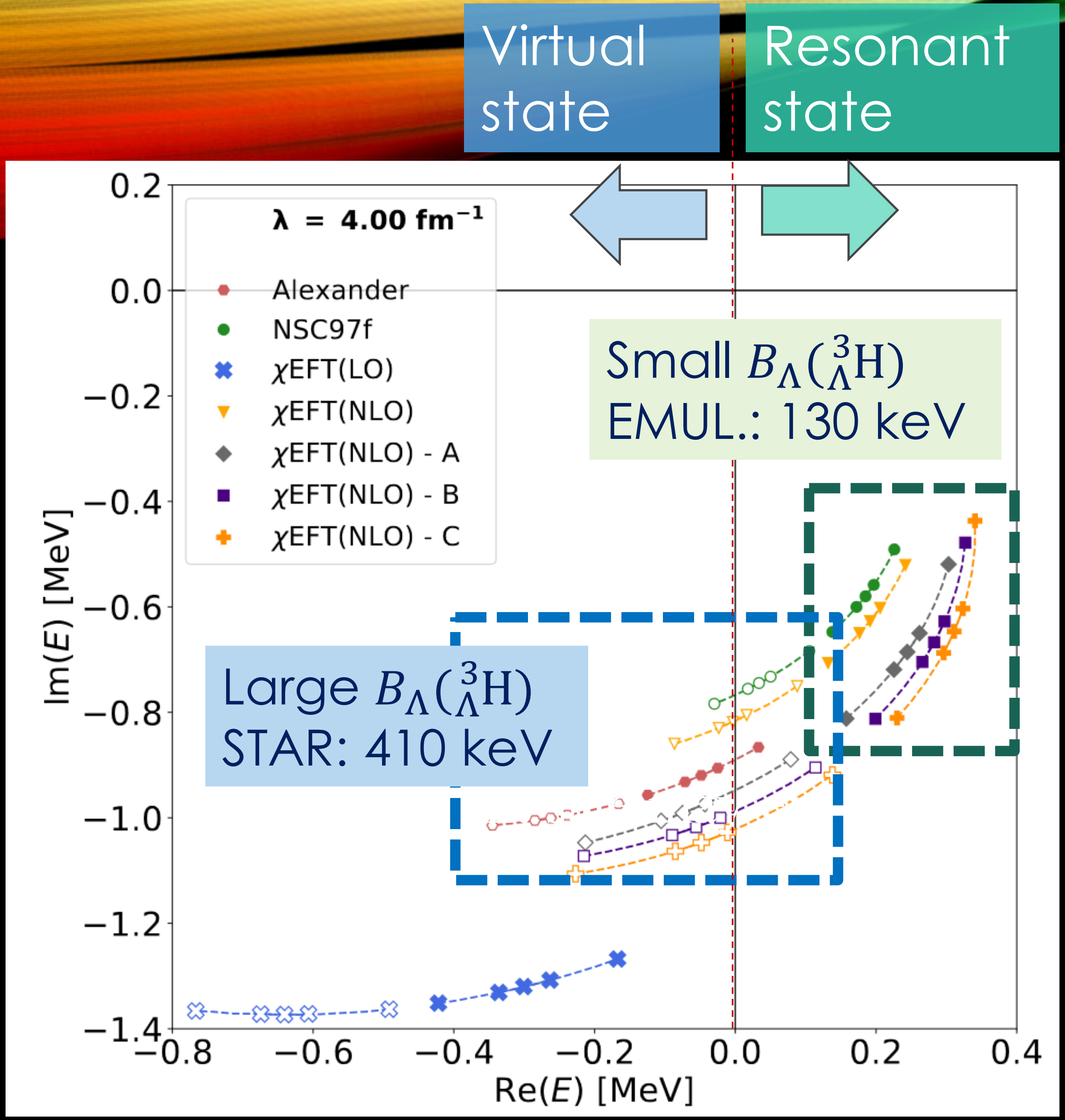
(a) $^3V^T_{\Lambda N-\Sigma N} \times 1.0$

(b) $^3V^T_{\Lambda N-\Sigma N} \times 1.1$

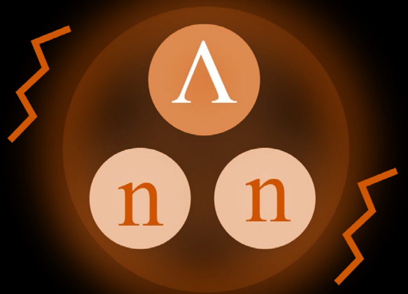
(c) $^3V^T_{\Lambda N-\Sigma N} \times 1.2$

Tensor component of the ΛN-ΣN coupling was varied.
→ **No solution was found** to make the $nn\Lambda$ bound maintaining the consistency with the $^3_\Lambda$H ($^4_\Lambda$H, $^4_\Lambda$He) data.

Resonant nnΛ state



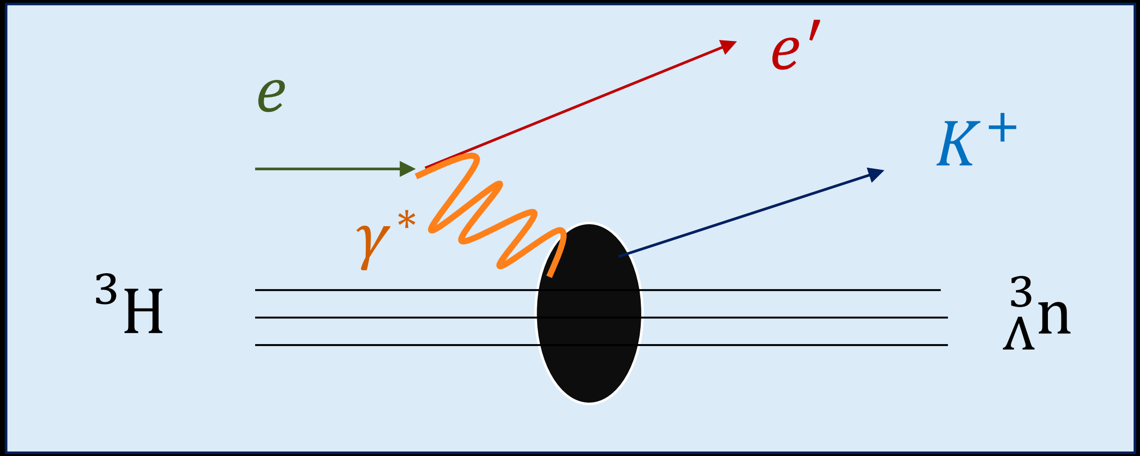
M. Schäfer et al., PRC 105, 015202 (2022)



nnΛ

- ✓ Resonant state may exist
- ✓ Energy + width → nΛ Interaction
- ✓ Strongly related to $B_\Lambda(^3_\Lambda\mathrm{H})$
  → E12-19-002 (HKS)

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



Unti-strange quark

Strange quark

Missing-mass measurement at JLab

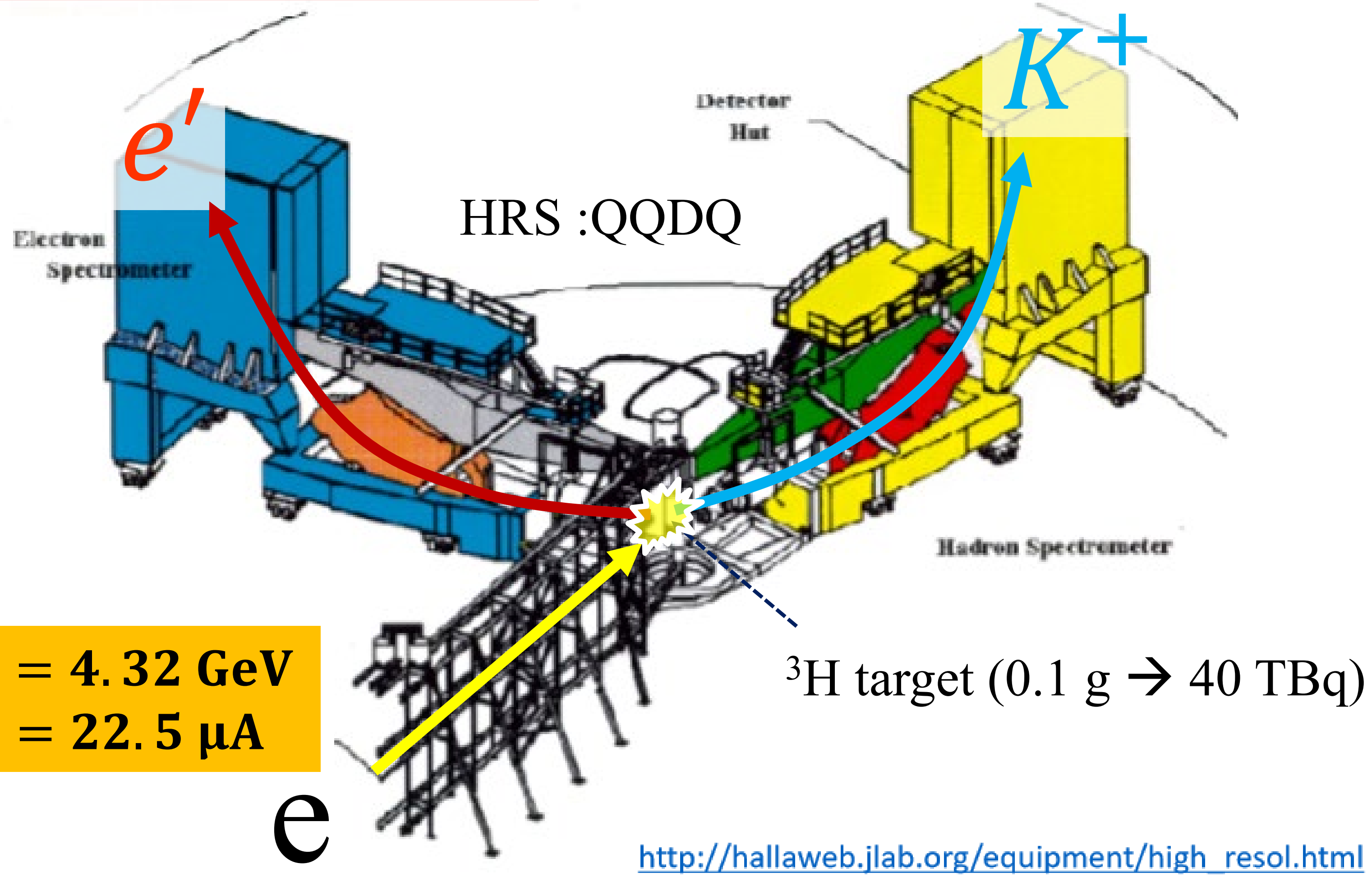
➔ **Sensitive to both bound and resonant states !!**

c.f.) Invariant mass spectroscopy is sensitive to only bound state

Experimental setup at Hall A

$p_{e'} = 2.22\ \mathrm{GeV}/c \pm 4.5\%$
$\theta_{ee'} = 13.2°$

$p_K = 1.82\ \mathrm{GeV}/c \pm 4.5\%$
$\theta_{eK} = 13.2°$

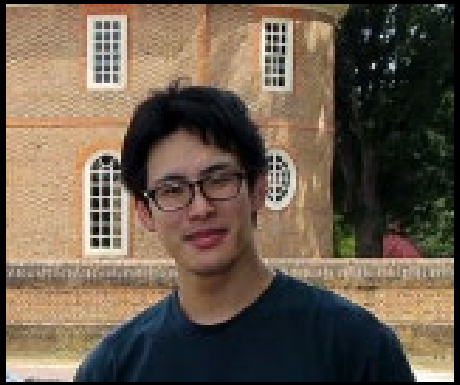


$\boldsymbol{E_e = 4.32\ \mathrm{GeV}}$
$\boldsymbol{I_e = 22.5\ \mu A}$

http://hallaweb.jlab.org/equipment/high_resol.html

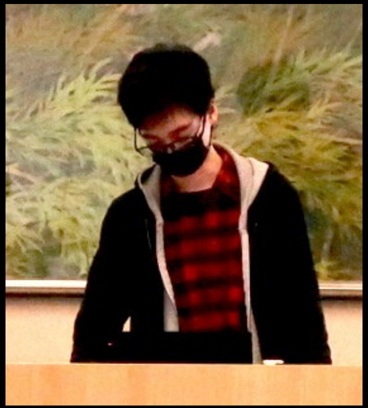
ANALYSES

Analyses by Ph.D. Students
→ 3 out of 5 earned Ph.D.



Dr. K. Itabashi
FY2021
→ KEK

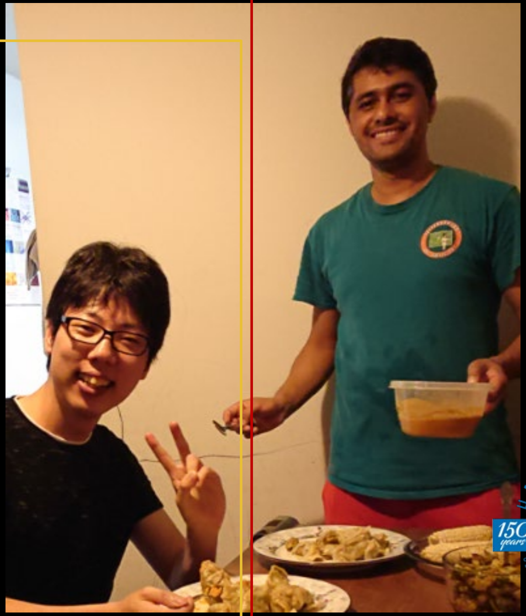
K. Okuyama
(FY2023)



T. Akiyama
(FY2023)

東北大学

Tohoku Univ., Japan



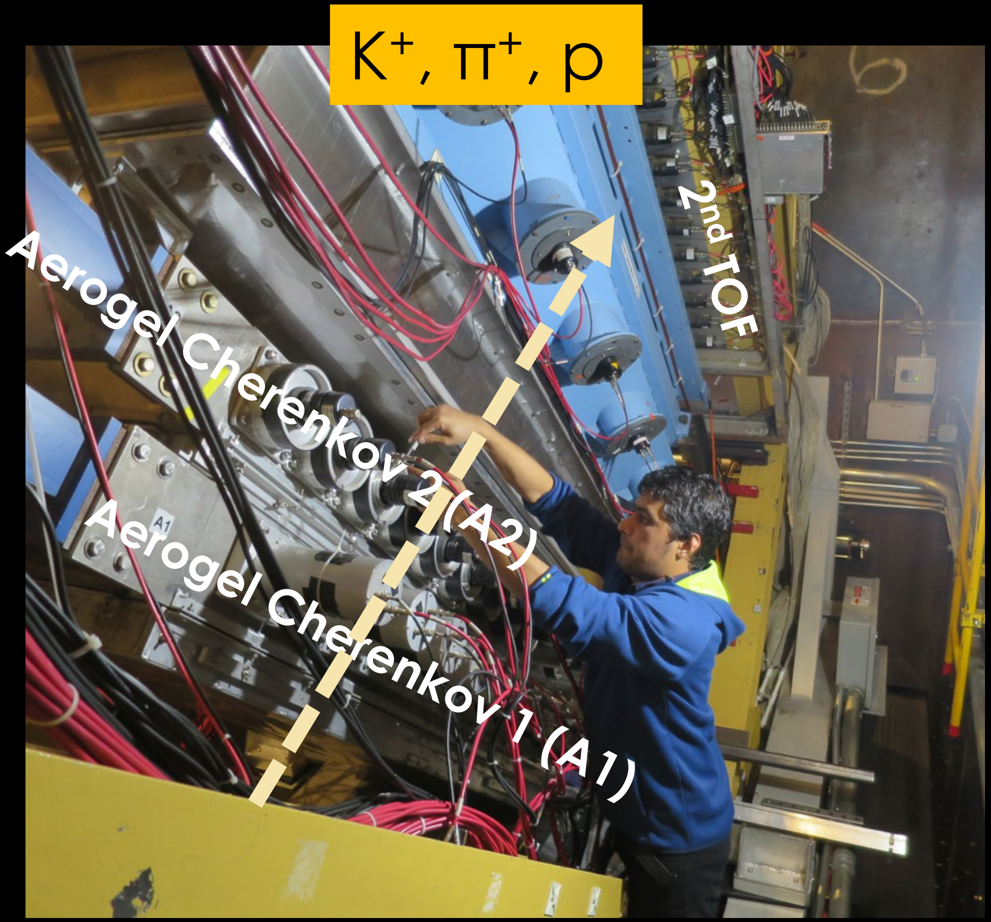
Dr. K.N. Suzuki
FY2021
→ Company

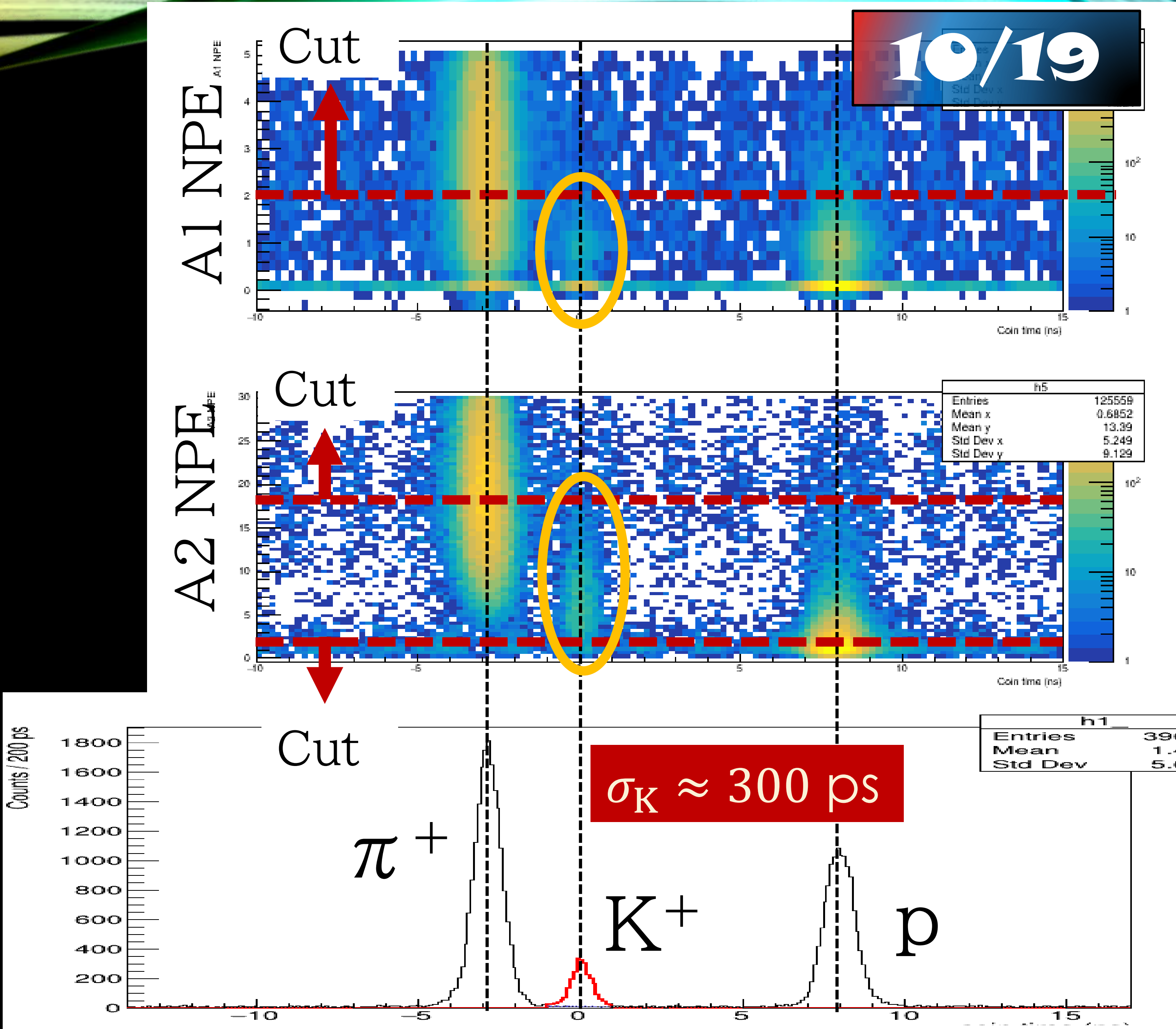
Kyoto Univ., Japan

Dr. B. Pandey
2021
→ VMI

Hampton Univ., US

K^+ identification



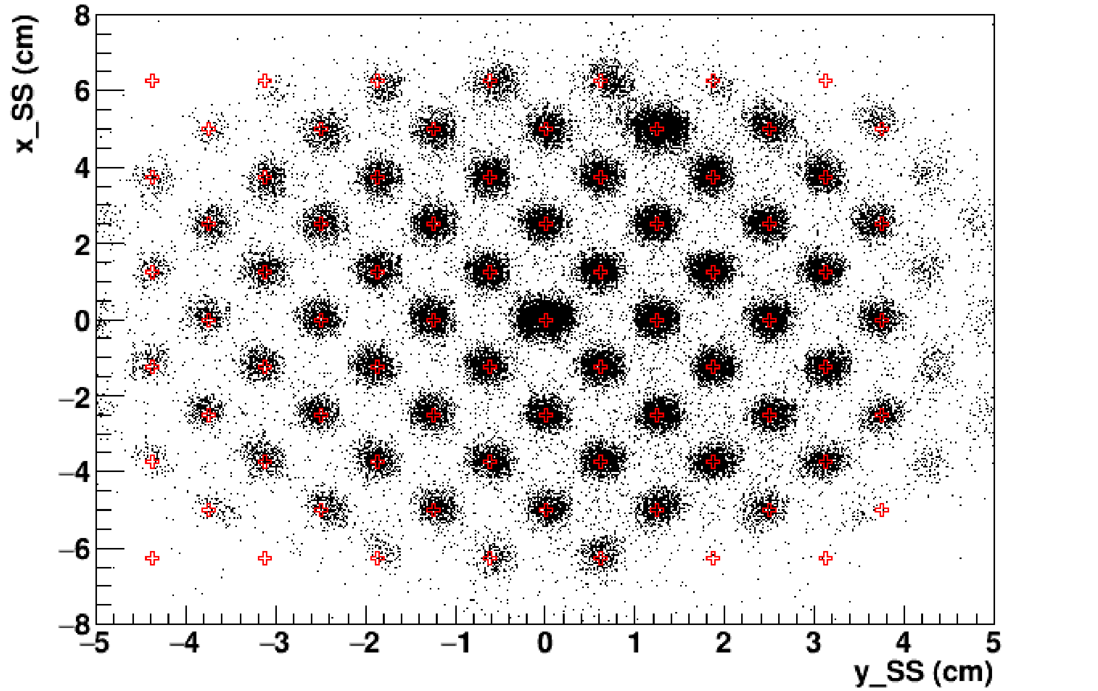


Timing consistency between L and R assuming m_K → Coin time (ns)

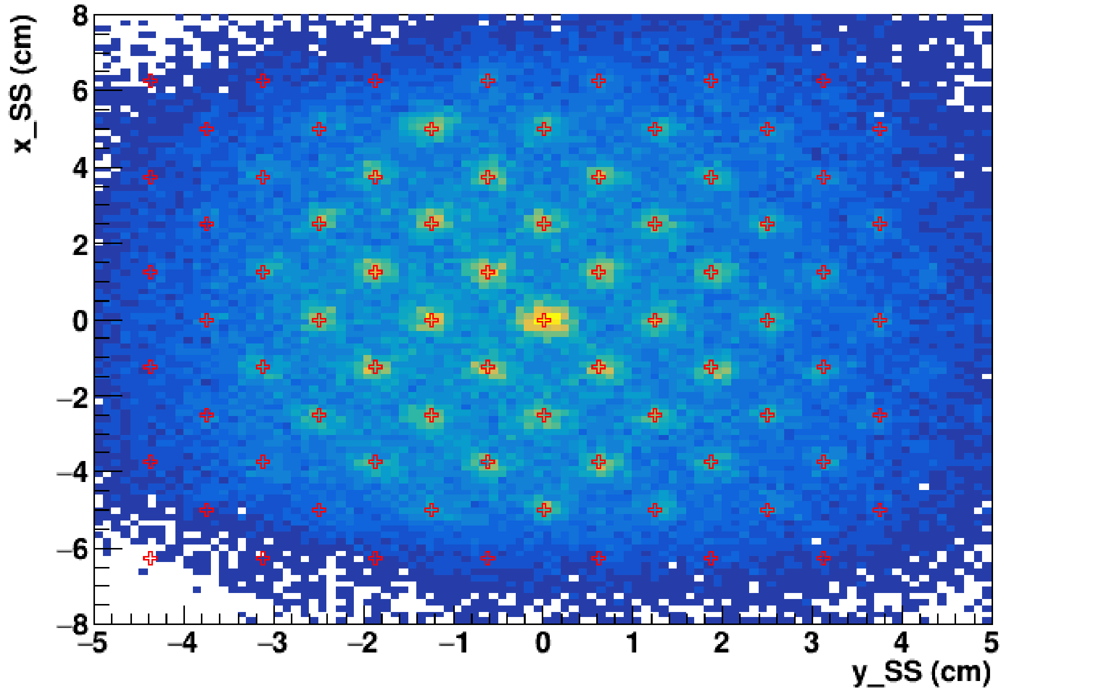
Angle calibration by using sieve slits

The 4th order polynomial

Sieve slit pattern (LHRS)

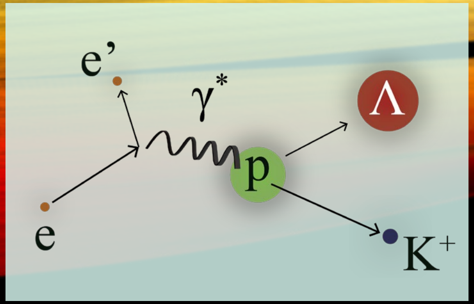


Sieve slit pattern (RHRS)



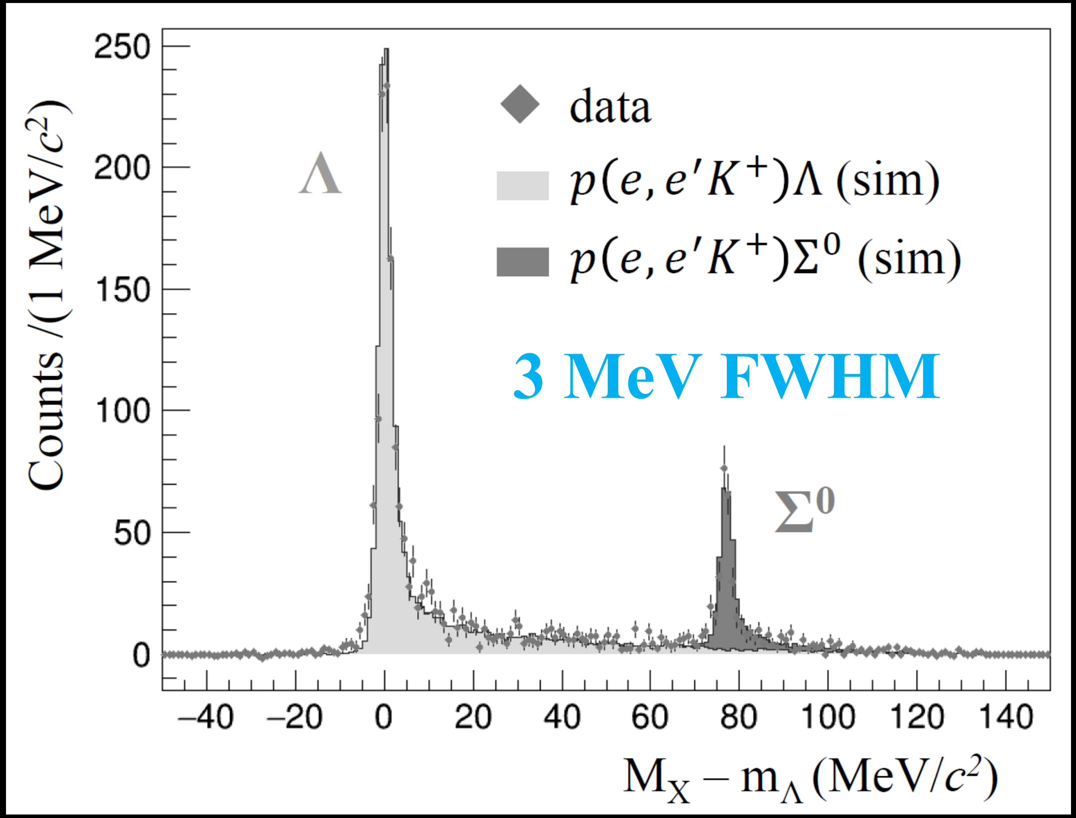
e'

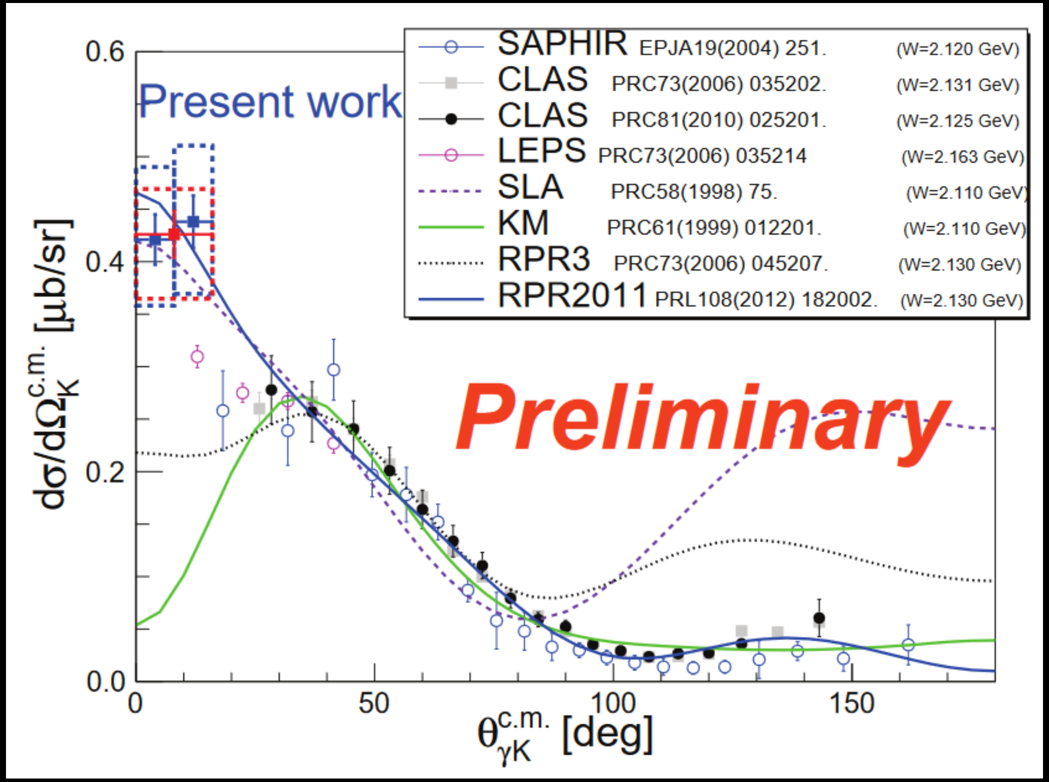
Hadrons



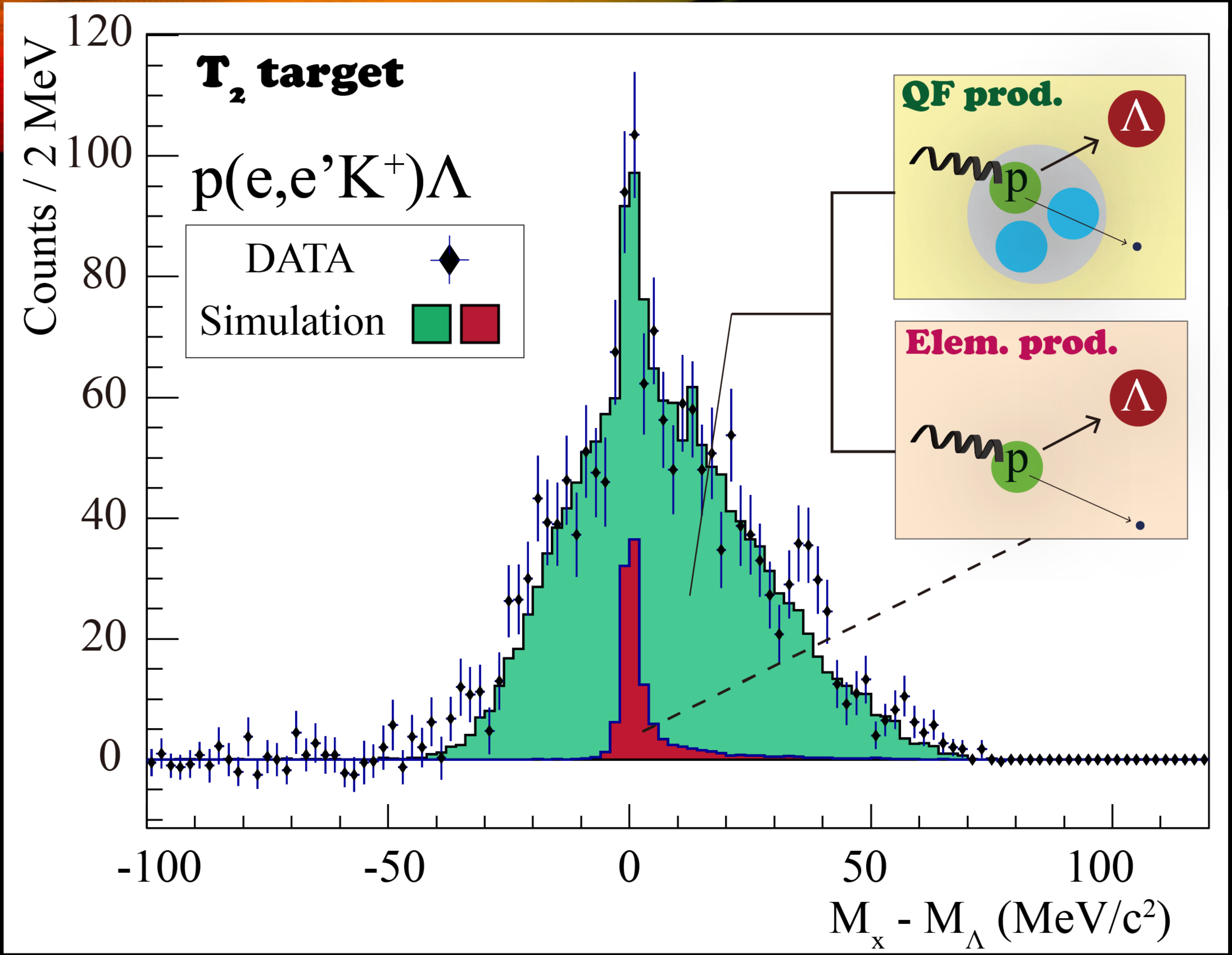
Energy calibration by Λ and Σ

K. Okuyama et al., EPJ Web. Conf. 271, 02003 (2022)





- Calibration with well known masses
- Geant4 simulation is consistent with data

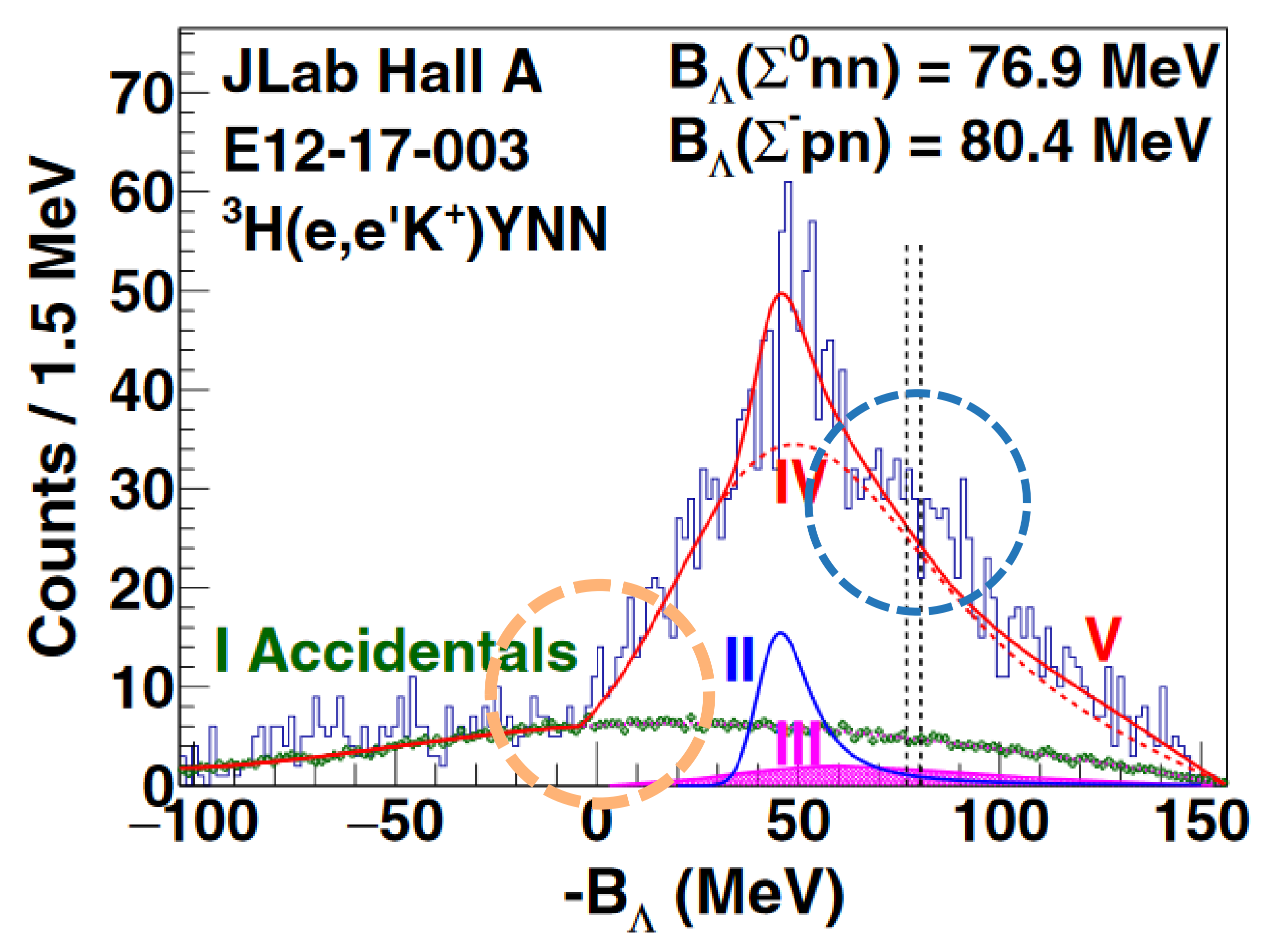


H_2 in T_2 target

A few % of H_2 compared to T_2

Significance study from count-base spectrum

B. Pandey et al., Phys. Rev. C 105, L051001 (2022)



Binding energy:

$B_\Lambda = (2M_n + M_\Lambda) - M_x$

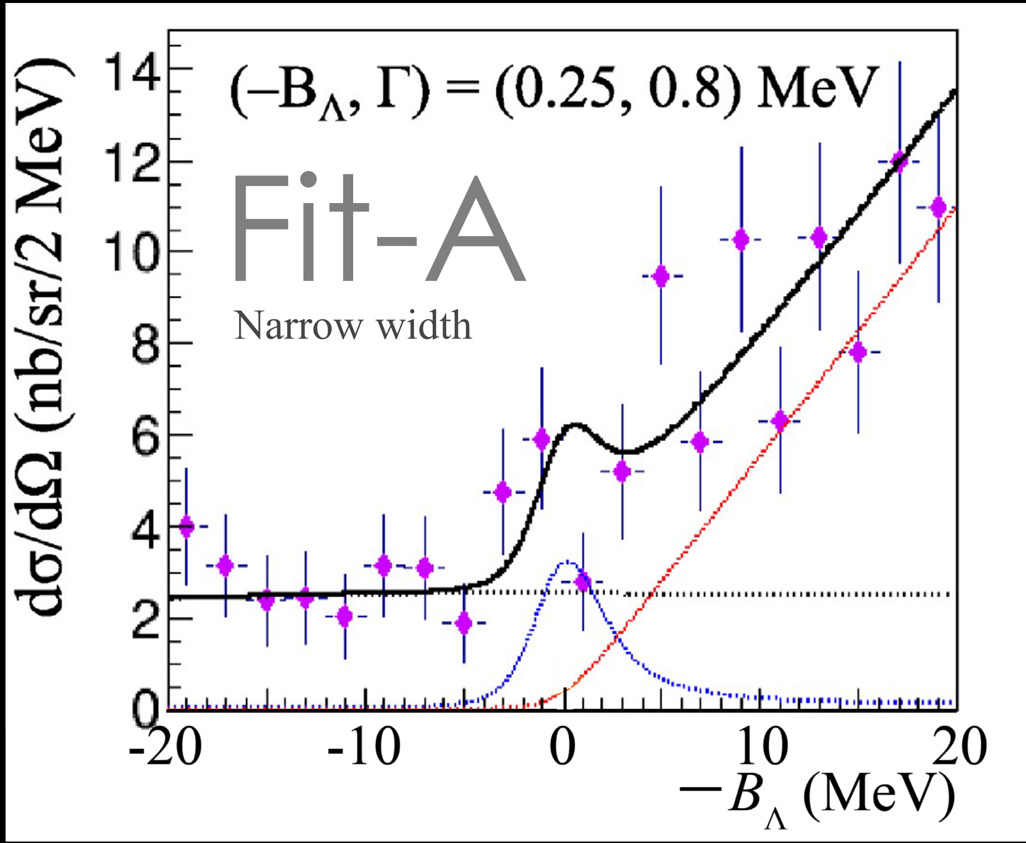
No significant peaks: YNN

But, there is excess.

- K.N. Suzuki et al., PTEP **2022**, 1, 013D01 (2022)
- TG et al., WPJ Web Conf. **271**, 02002 (2022)

Cross section

Fit by unbinned max. likelihood



Fit	A	B
YN Int.	Nijmegen89(*1)	Minesota(*2)
$-B_\Lambda, \Gamma$ (/ MeV)	0.25, 0.8	0.55, 4.7
$\left(\frac{d\sigma}{d\Omega_K}\right)$ [/(nb/sr)]	**11.2** $\pm 4.8\,(\text{stat.})^{+4.1}_{-2.1}\,(\text{sys.})$	**18.1** $\pm 6.8\,(\text{stat.})^{+4.2}_{-2.9}\,(\text{sys.})$
Significance (stat. only)	2.3	2.7

(*1) H. Kamada, K. Miyagawa, and M. Yamaguchi, EPJ Web Conf. 113, 07004 (2016).
(*2) V. B. Belyaev, S. A. Rakityansky, and W. Sandhas, Nucl. Phys. A 803, 210–226 (2008).

Final state interaction (Λn int.)

K. Itabashi e al., WPJ Web Conf. 271, 02006 (2022)

QF distribution analysis
→Λ-n interaction

Influence factor due to FSI

$$\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{FSI}} = \mathrm{I}(\vec{k}_{\Lambda n})\left(\frac{d\sigma}{d\Omega}\right)_{\mathrm{w/oFSI}}$$

I(k) depends on
- scattering length
- effective range

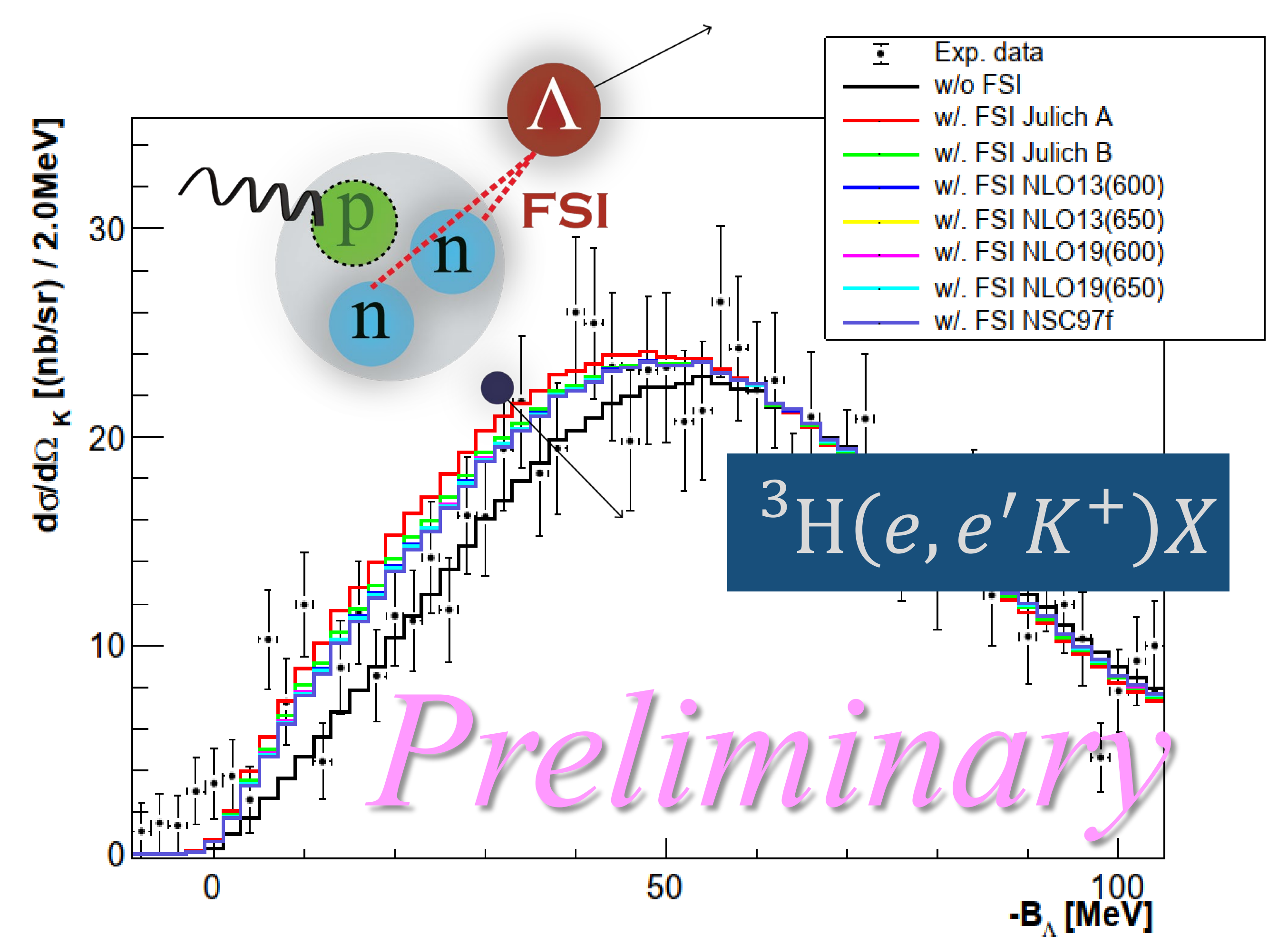
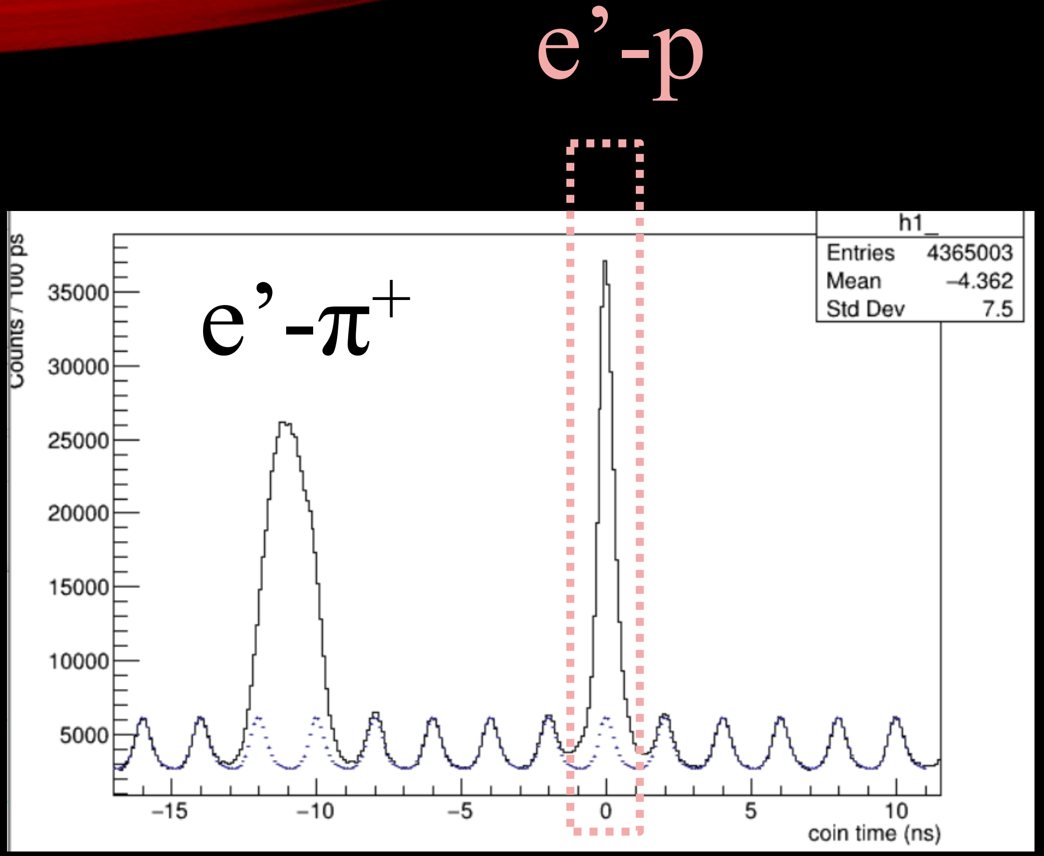
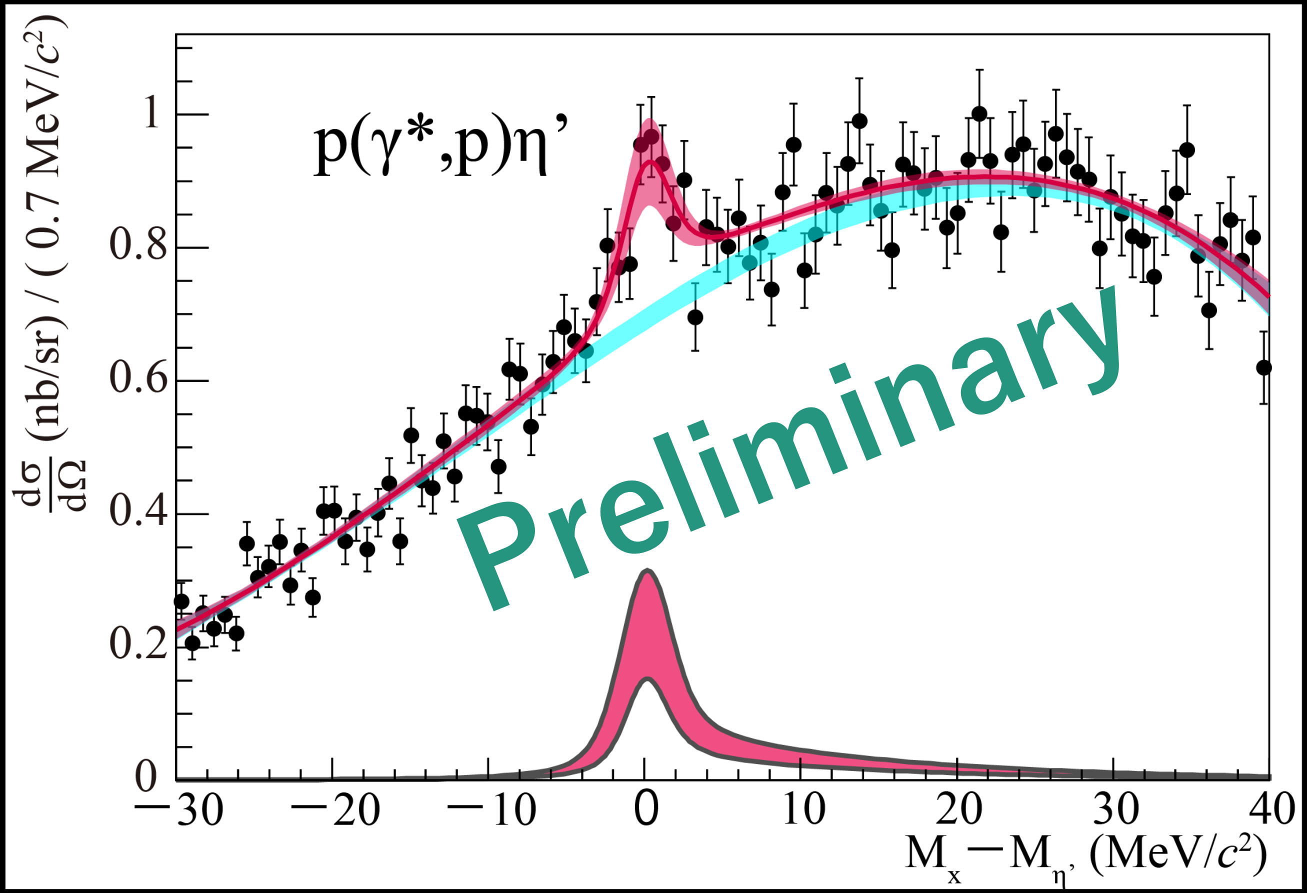


Figure from K. Itabashi (KEK)

$p(\gamma^*, p)\eta'$ reaction cross section



Coincidence time (ns)

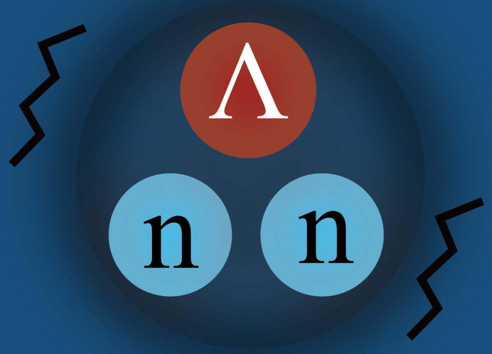


This channel is being analyzed by T. Akiyama (Tohoku Univ.)

SUMMARY

nnΛ search experiment (E12-17-003, 2018)

- The existence of nnΛ bound state is a deep mystery
- Resonant state may exist (theory)
- ^{3}H(e,e'K^{+})nnΛ @ Hall A
  - Sensitive to both bound and resonant states → **very unique**



Results and on-going analyses

1. nnΛ; ***no prominent peak was observed. But, there is excess from background.***
   1. Production cross section [K.N. Suzuki et al., PTEP **2022**, 1, 013D01 (2022)]
   2. Peak search with a count-base spectrum [B. Pandey et al., Phys. Rev. C 105, L051001 (2022)]
   3. nΛ FSI from the QF shape [K. Itabashi e al., WPJ Web Conf. 271, 02006 (2022)]
2. Others
   1. Λ / Σ^0 electro-production [K. Okuyama et al., EPJ Web. Conf. 271, 02003 (2022)]
   2. η' electro-production [link to hypnucl. collab. meeting 2022]

THANK YOU FOR YOUR ATTENTION

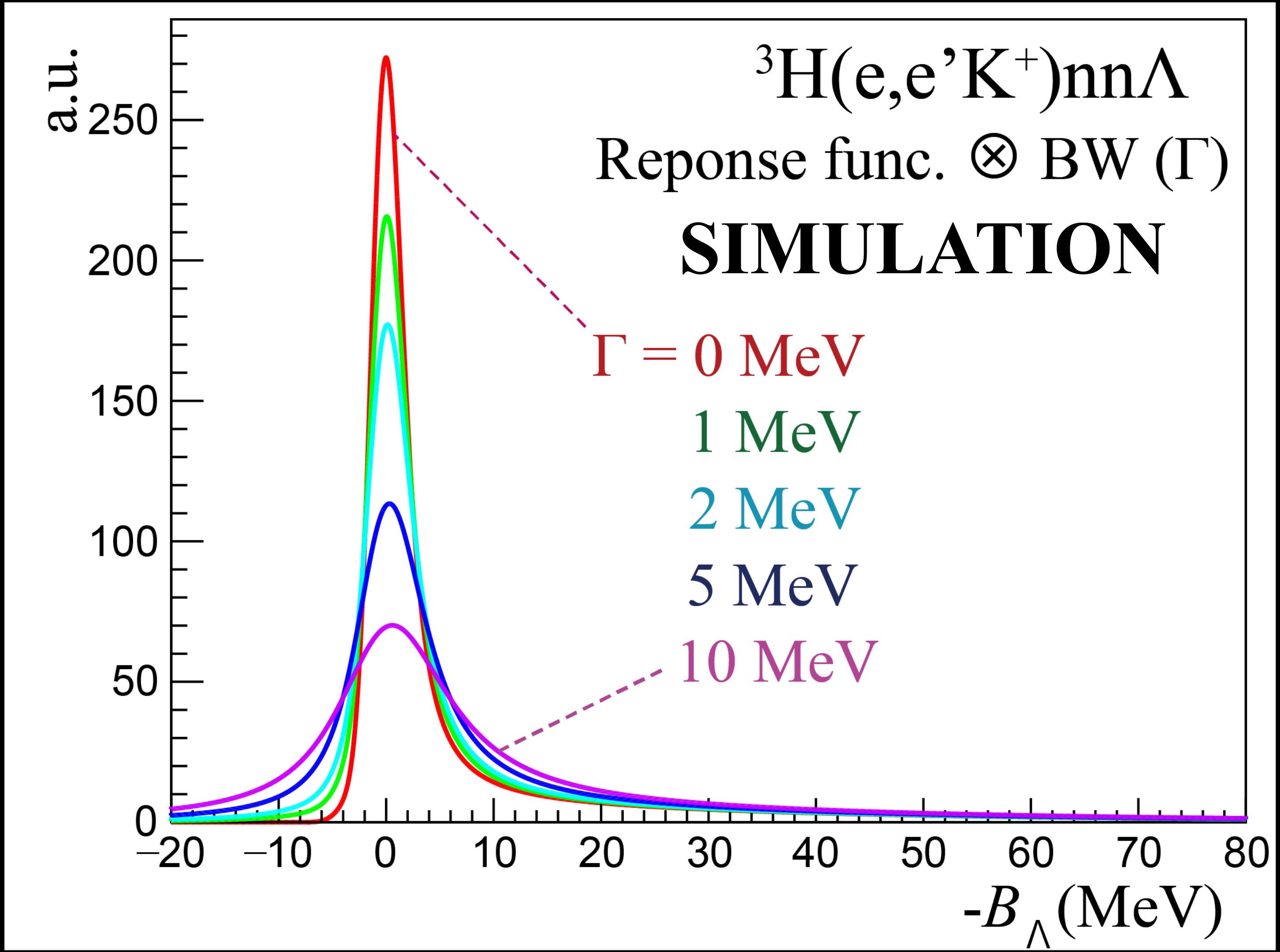
Hypernuclear workshop 2023 on March 3rd @JLab
← will be announced soon

BACKUP

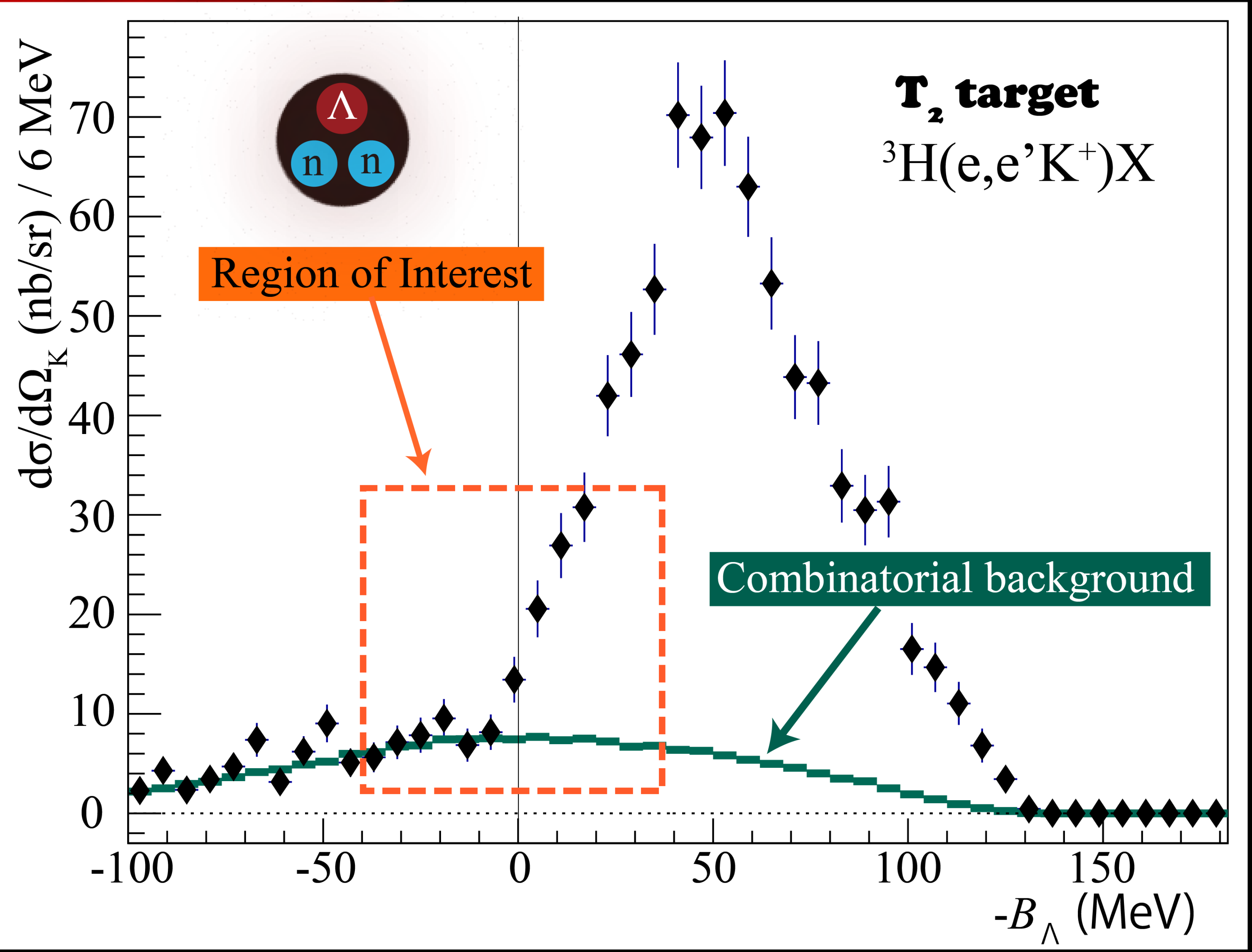
Response function ⊗ BW

1. **Response function (RF)**
 ✓ Geant4 simulation

2. **Signal function**
 ✓ RF convoluted by Breit Wigner



Cross section spectrum



Unbinned maximum likelihood fit

($-20 < B_\Lambda < 20$ MeV)

Probability density function (PDF):

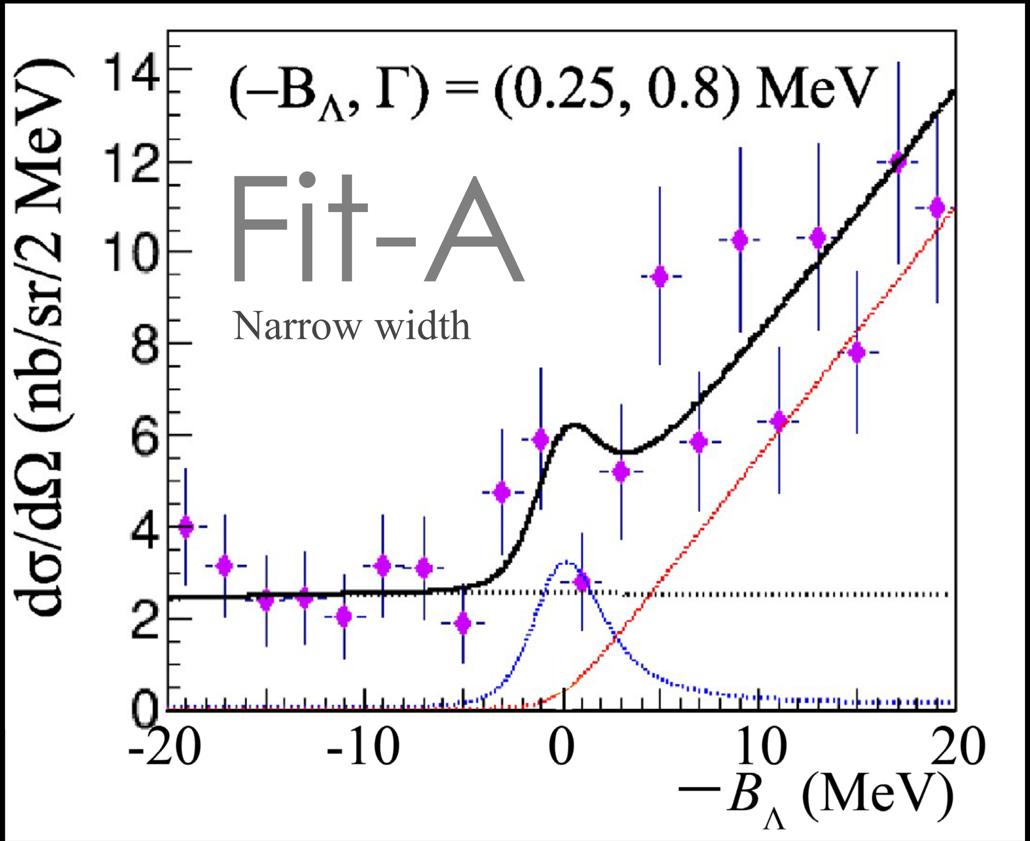
1. Response function (RF)
   - Geant4 simulation
2. Decay width
   - Breit Wigner

(1–2: Next page)

3. QF shape ($-B_\Lambda > 0$)
   - Unknown
     → Linear function ⊗ RF
4. Combinatorial background
   - Data → the 4th order polynomial

Fit result (typical cases)

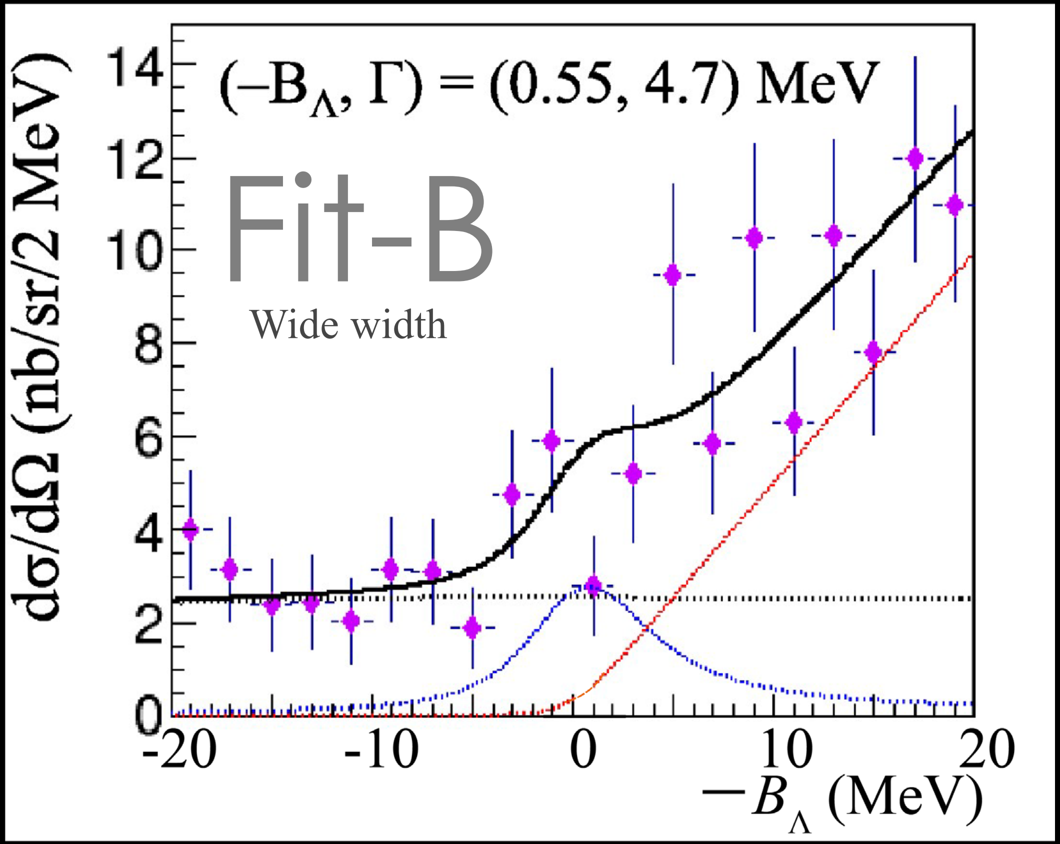
Kamada (2016): YN int. = **Nijmegen89**



$$\left(\frac{d\sigma}{d\Omega_K}\right)_{\text{Fit A}} = \mathbf{11.2} \pm 4.8\,(\text{stat.})^{+4.1}_{-2.1}\,(\text{sys.})$$

2.3 σ (only stat.)

Belyaev (2008): YN int. = **Minesota**



$$\left(\frac{d\sigma}{d\Omega_K}\right)_{\text{Fit B}} = \mathbf{18.1} \pm 6.8\,(\text{stat.})^{+4.2}_{-2.9}\,(\text{sys.})$$

2.7 σ (only stat.)

1-D SCAN

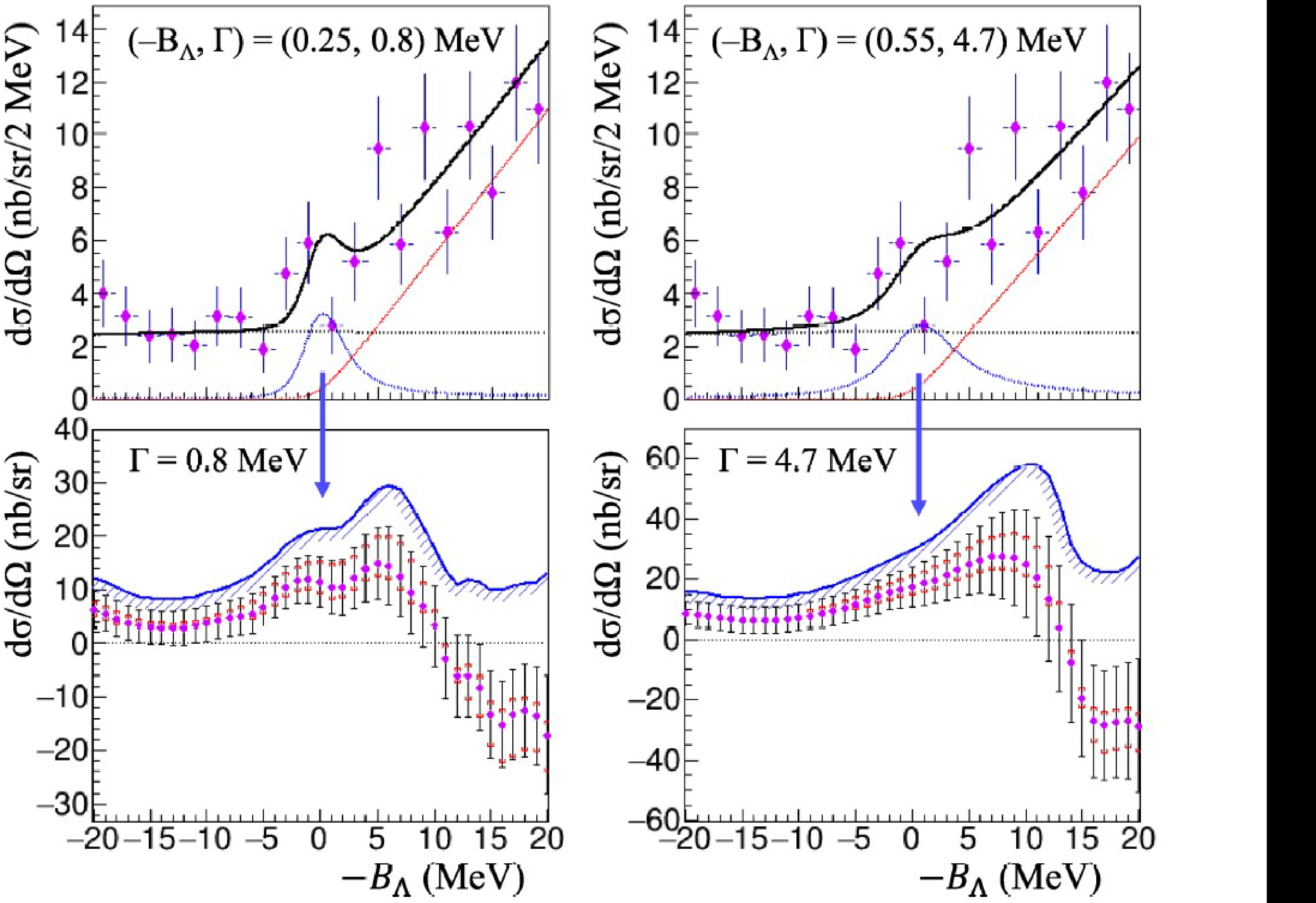
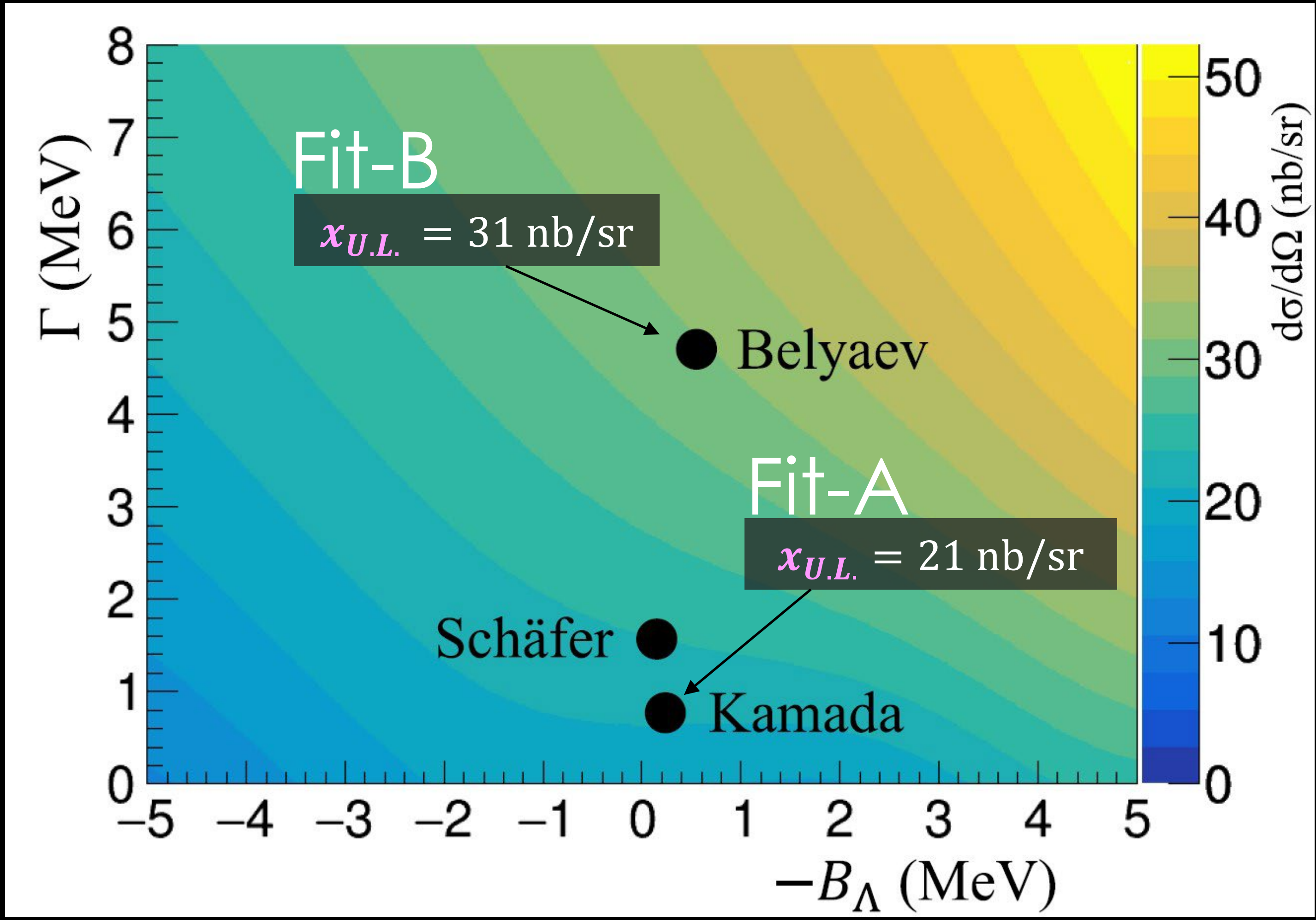


Fig. 11. The differential cross-section as a function of $-B_\Lambda$ (MeV). Spectral fits were done by assuming $(-B_\Lambda, \Gamma) = (0.25, 0.8)$ MeV and (0.55,4.7) MeV respectively, which are predictions adopted from Refs. [8,12]. Each panel shows the differential cross-section of exceeded events over the assumed QF distribution as a function of an assumed peak center.

Upper limit at 90% C.L. (2-D scan)



Upper limit $x_{U.L.}$:

$$\frac{\int_0^{x_{U.L.}^{\text{stat.}}} g(x)dx}{\int_0^{\infty} g(x)dx} = 90\%$$

where, $g(x)$ is a Gaus.

⇩

$$x_{U.L.} = x_{U.L.}^{\text{stat.}} + sys.err.$$

Theoretical calculations to be compared with the results are awaited !!