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

Collaboration meeting 2021

K. N. Suzuki

Paper

- This presentation is based on the paper submitted to PTEP
- Accepted on Nov. 22

PTEP

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

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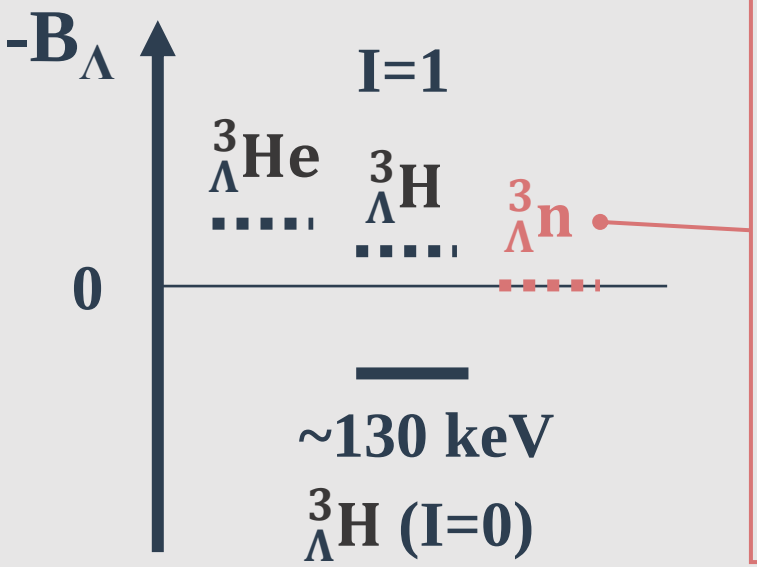
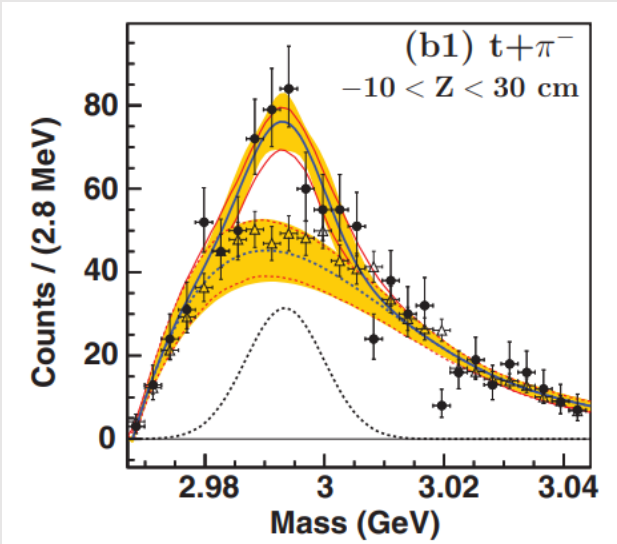
Introduction

Introduction

- ${}^{3}_{\Lambda}$H (I=0) is the only established state in A = 3 hypernuclear system.
- HypHI Collabolation indicated nnΛ signal at GSI in 2013.





C. Rappold et al., Phys. Rev. C. **88**, 041001 (2013)

Theoretical calculation for bound state

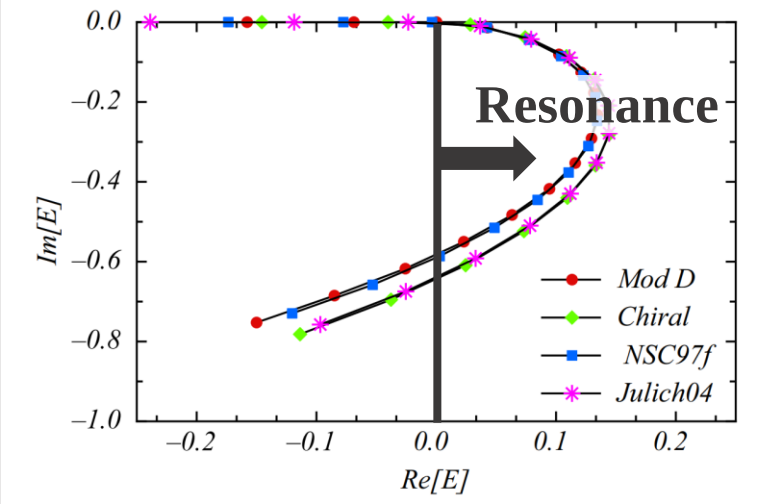
- Almost all calculations have shown that the existence of the bound state is difficult.

Author	Method	YN interaction	Bound	Regards
Downs [12]	variational method	exponential	×	-
Miyagawa [13]	Fadeev	Nijimegen	×	-
Hiyama [14]	variational method	NSC97f	×	-
Gal [15]	Fadeev	Nijimegen	×	-
Garcilazo [16,17]	Fadeev	CCQM	×	-
Ando [18]	coupled integral equation	$\not{\pi}$EFT	△	Efimov state?
Belyaev [19]	hyperspherical harmonics	Minesota	×	V ↑ 50% bound
Afnan [21]	Fadeev	Yamaguchi	×	Λn ↑ 25% bound
Filikhin [22]	Fadeev	NSC97f	×	-
Kamada [23]	Fadeev	Nijmegen	×	YN ↑ 20% bound

Theoretical calculation for resonant state

- Many papers have suggested the existence of the resonant states.
- There are large uncertainties in their binding energies and widths.

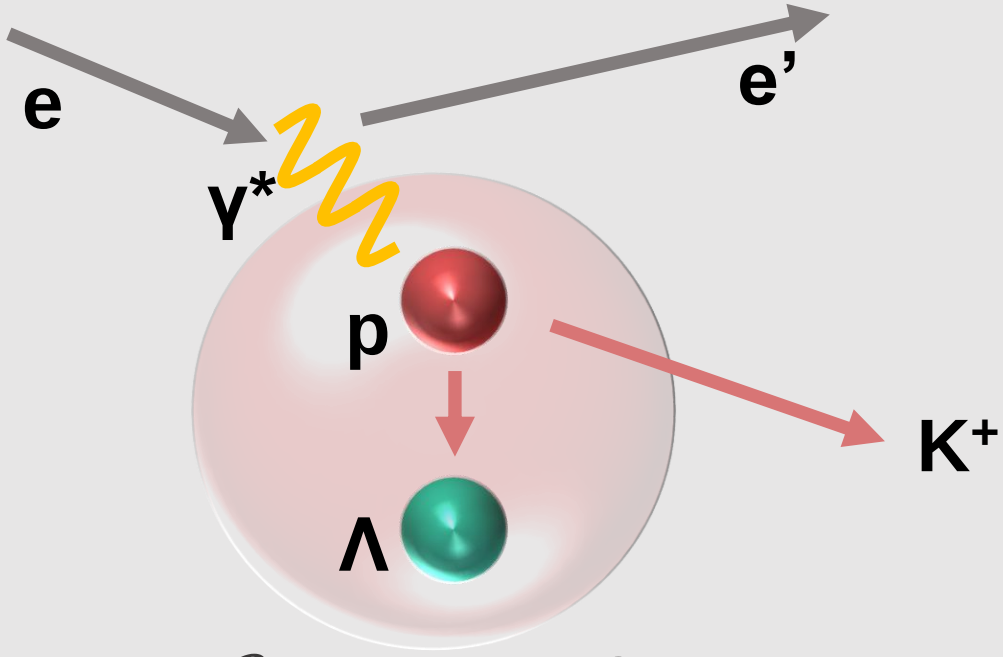
Author	Method	YN interaction	Resonance	Regards
Belyaev [19]	hyperspherical harmonics	Minesota	○	-
Afnan [21]	Fadeev	Yamaguchi	×	$\Lambda n \uparrow$ 5% resonance
Filikhin [22]	Fadeev	NSC97f	○	-
Kamada [23]	Fadeev	Nijmegen	○	-
Schäfer [24, 25]	IACCC, CSM	NSC97f, χEFT	○	-



Iraj R. Afnan and Benjamin F. Gibson. Phys. Rev. C, Vol. 92, p. 054608, 2015

Electro-production of hypernuclei at JLab

- Changing p to Λ ➡ nnp target to nnΛ
- High resolution primary beam ➡ ΔM =1.5 MeV (σ)
- Missing mass method ➡ Sensitive to bound/resonance

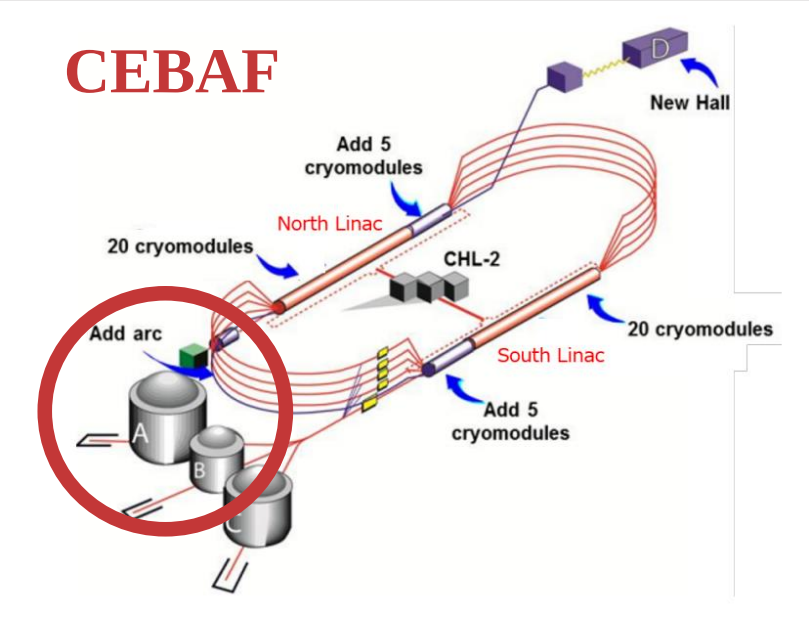


$^{3}\mathrm{H}(\mathrm{e},\mathrm{e}'\mathrm{K})^{3}_{\Lambda}\mathrm{n}$

Experiment

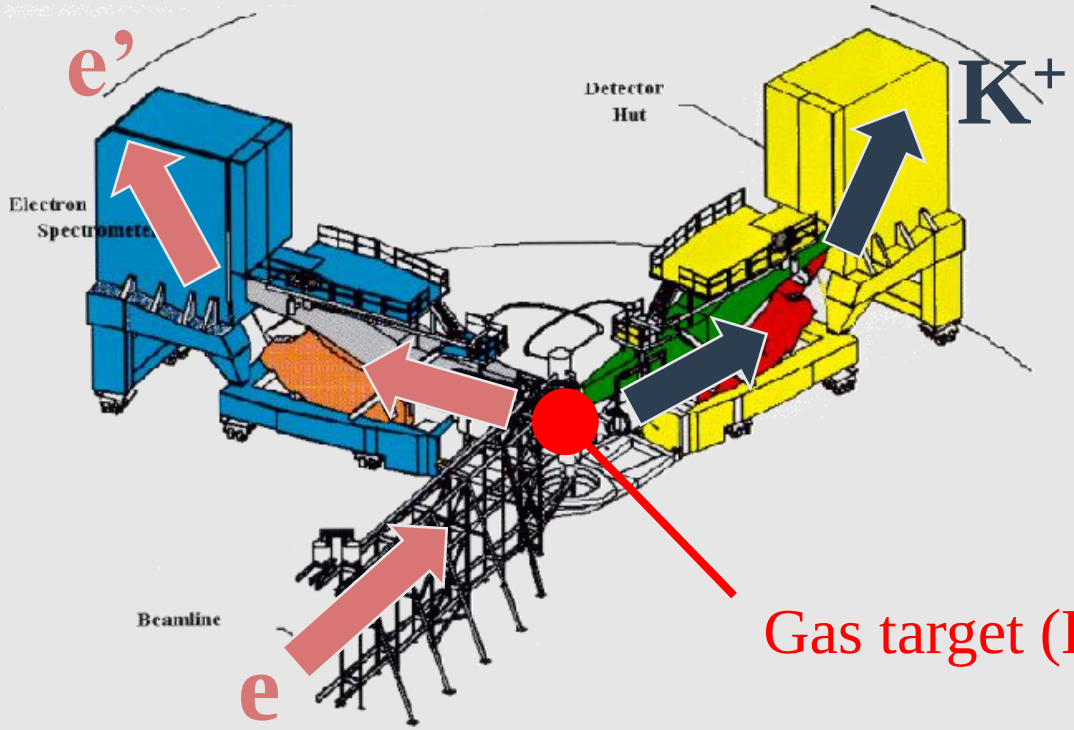
Jefferson Laboratory (Virginia, USA)

- 12 GeV continuous electron beam (Max)
- High Quality Beam
  - $\Delta E/E = 1.0 \times 10^{-4}$ (FWHM)
  - Intensity 100 μA (22.5 μA for T_2)
- Data taken in Nov 2018



High Resolution Spectrometer (HRS)

- $\Delta p/p = 2.0 \times 10^{-4}$ (FWHM)
- Momentum bite / p ~ $\pm$4.5%



Kinematics

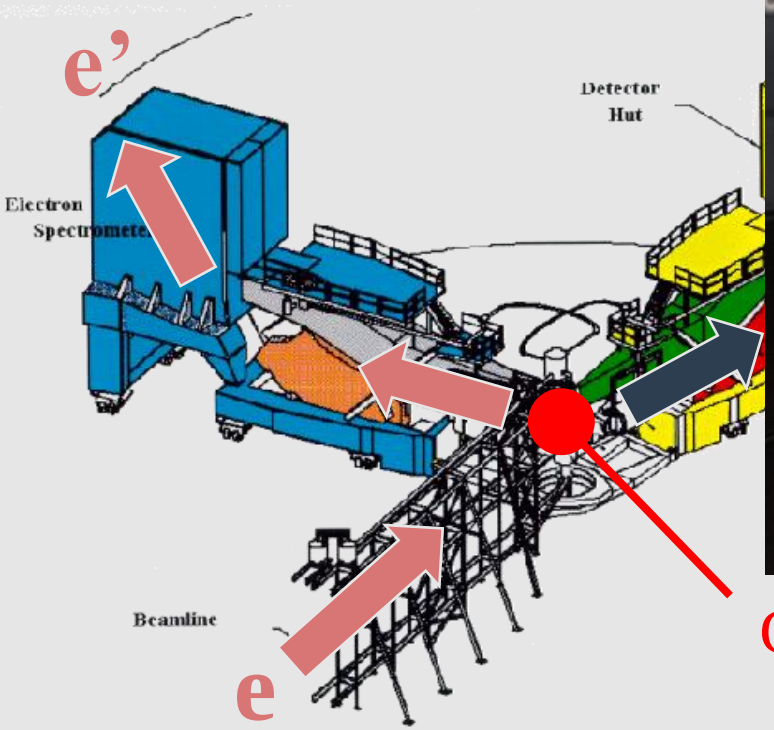
p_e	2.218 GeV/c
p_k	1.823 GeV/c
Q^2	0.506
$\theta_{e\gamma}$	13.2°
$\sqrt{s}$	2.08
ϵ	0.794
ϵ_L	0.091

High Resolution Spectrometer (HRS)

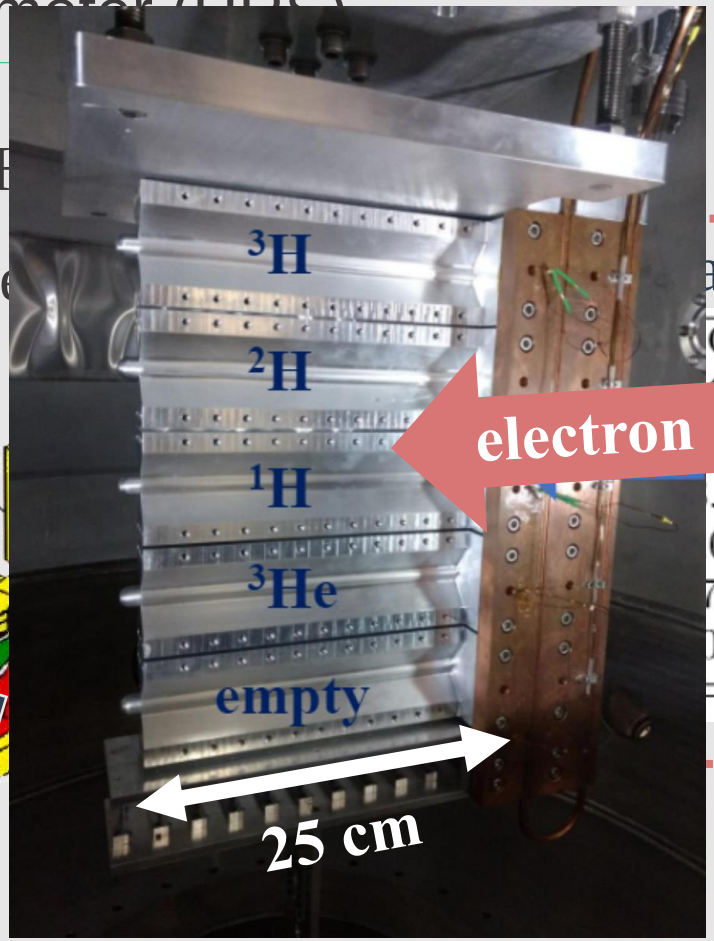
- $\Delta p/p = 2.0 \times 10^{-4}$ (FWH
- Momentum acceptance

atics

	GeV/c
	GeV/c
	06
	.2°
	08
	794
	091



4.32 GeV/*c*

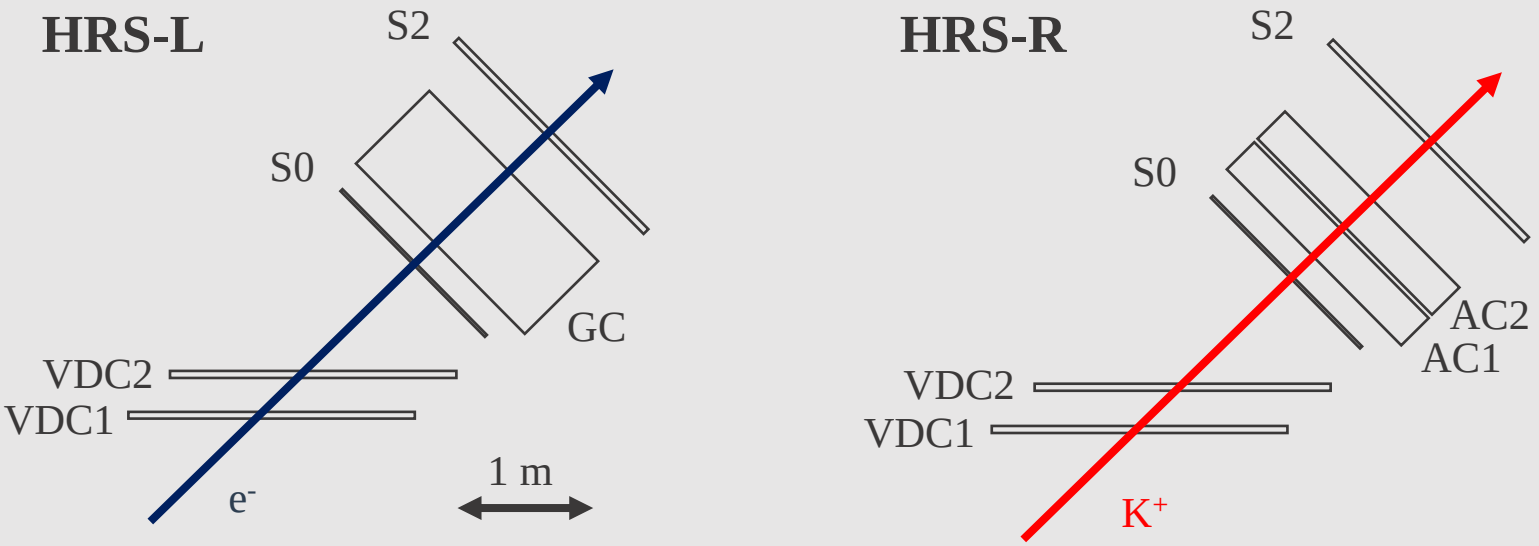


Gas target (H_2, T_2)

S.N. Santiesteban et al., Nucl. Inst. Met A. 940,(2019)

Detectors

- Almost the same configuration
  - Vertical Drift Chamber (VDC)
  - Scintillator (S0 and S2)
- PID is different
  - Gas Cherenkov (HRS-L, π^- rejection)
  - AC1, AC2 (HRS-R, π^+, p rejection)



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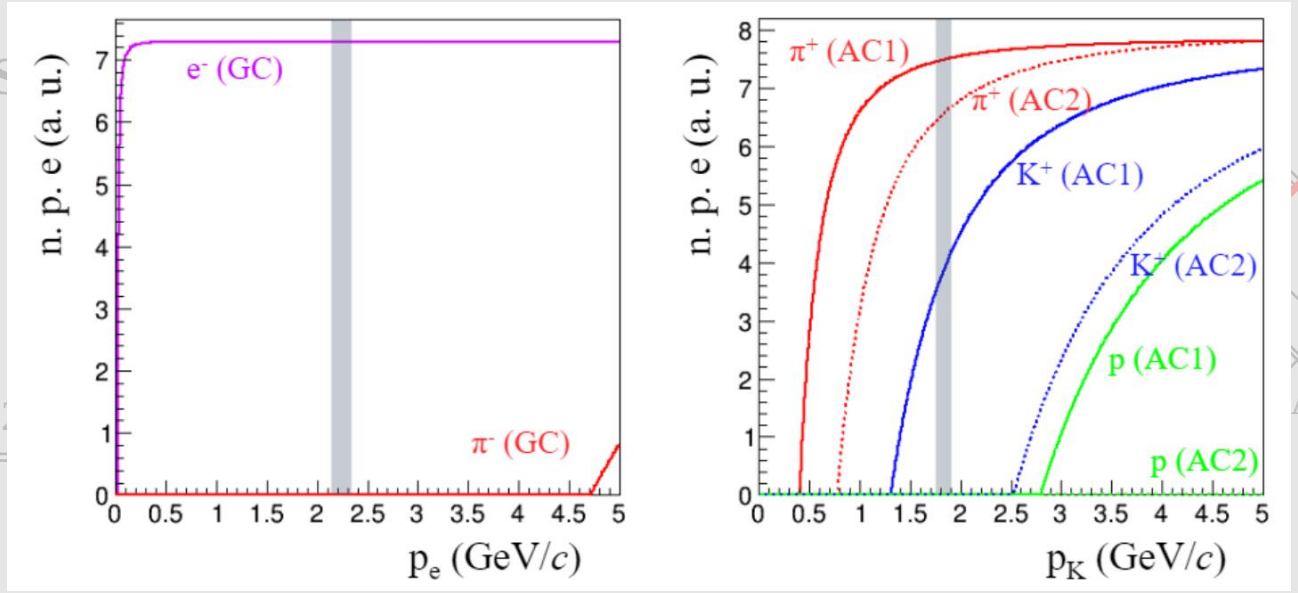


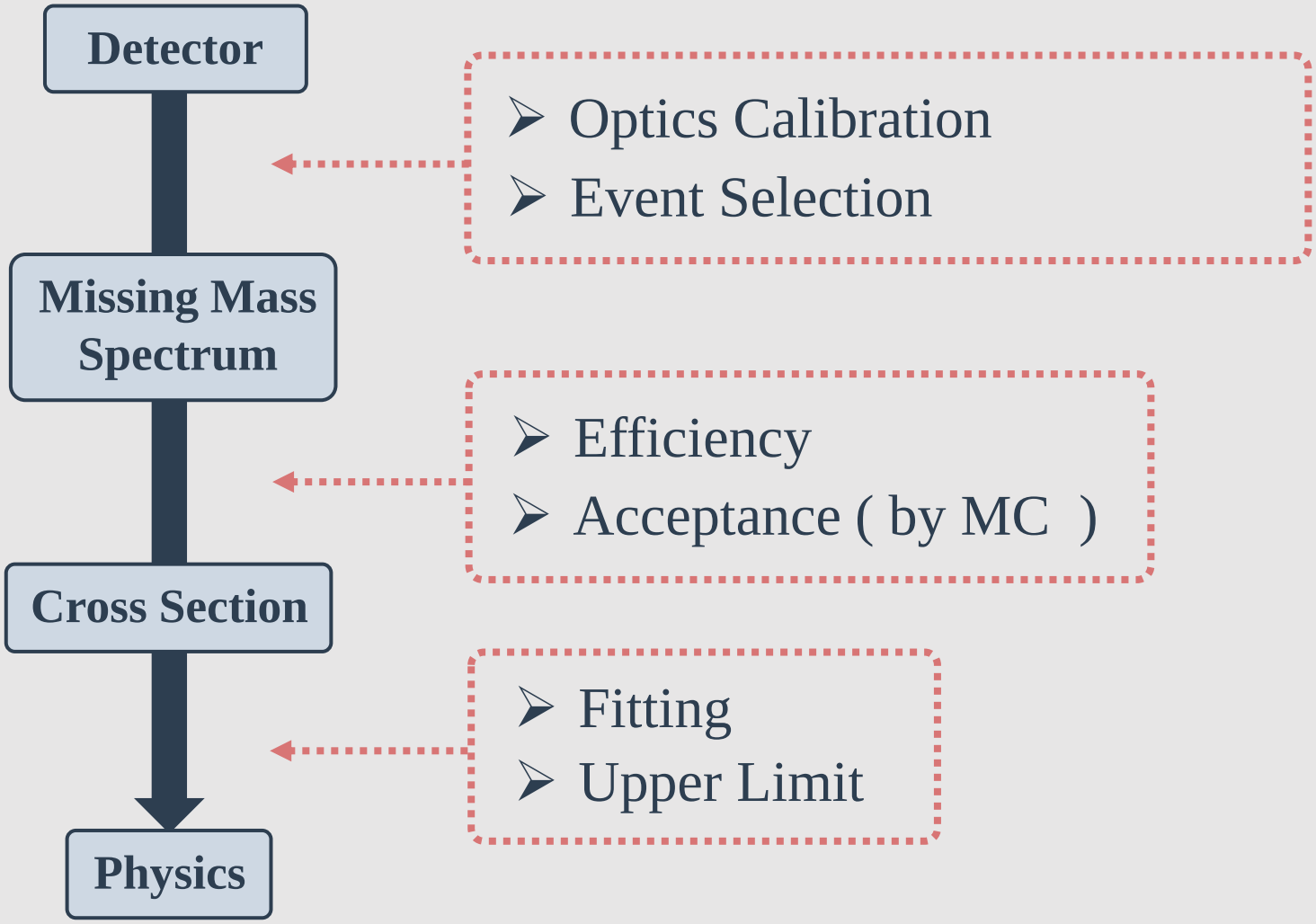
Analysis

Analysis status

The same spectrum has been analyzed in three groups independently.

	This talk		
			
Doctor Candidate	K. N. Suzuki	B. Pandey	K. Itabashi
Focus on	Cross section Upper limit	Peak search	Λn FSI
Acceptance Estimation	Geant4	-	SIMC

Analysis Flow



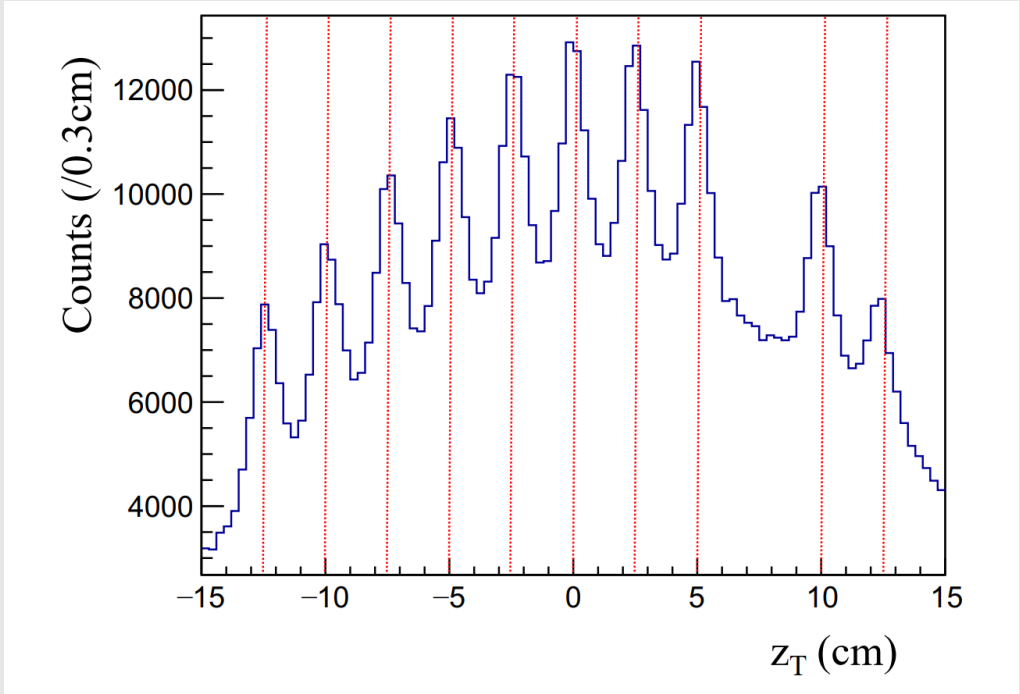
Optics calibration (Vertex)

- Vertex optics were calibrated with the carbon foil data.

z optics

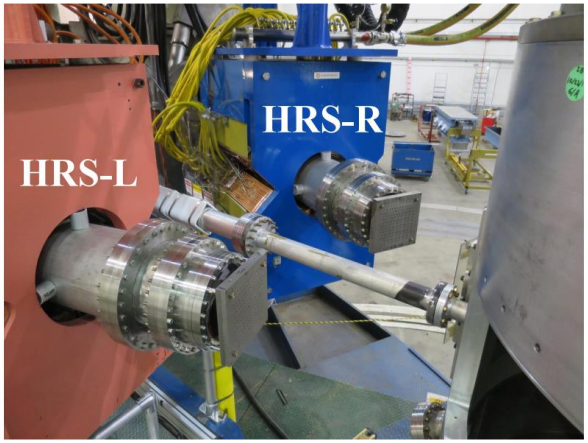
$$z_T = \sum_{a+b+c+d=0}^{n} C_z(a,b,c,d) x^a x'^b y^c y'^d$$

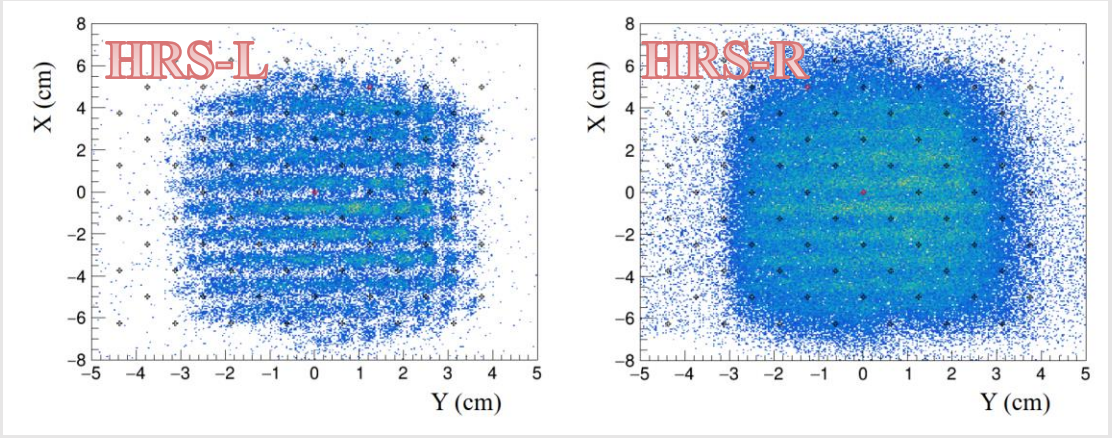
Carbon foil × 10

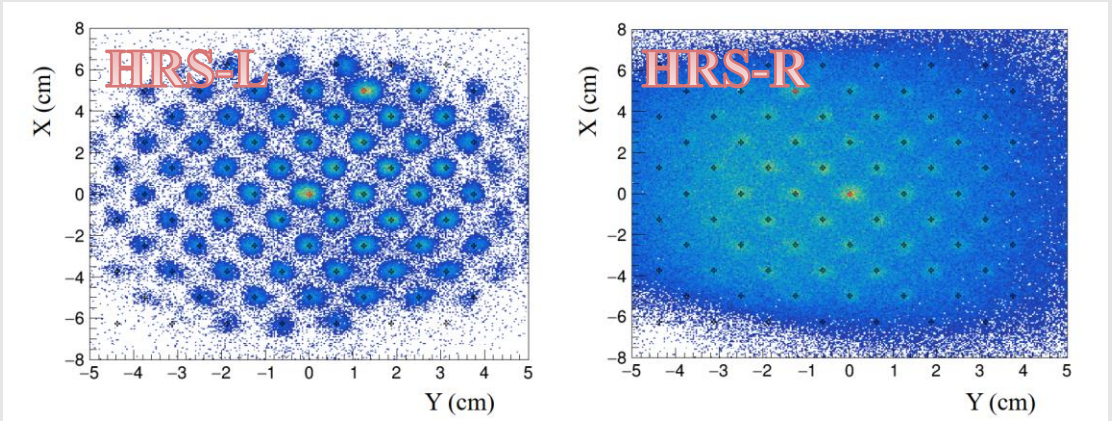


Optics calibration (Angle)

- Angle parameters were calibrated with sieve-slit data

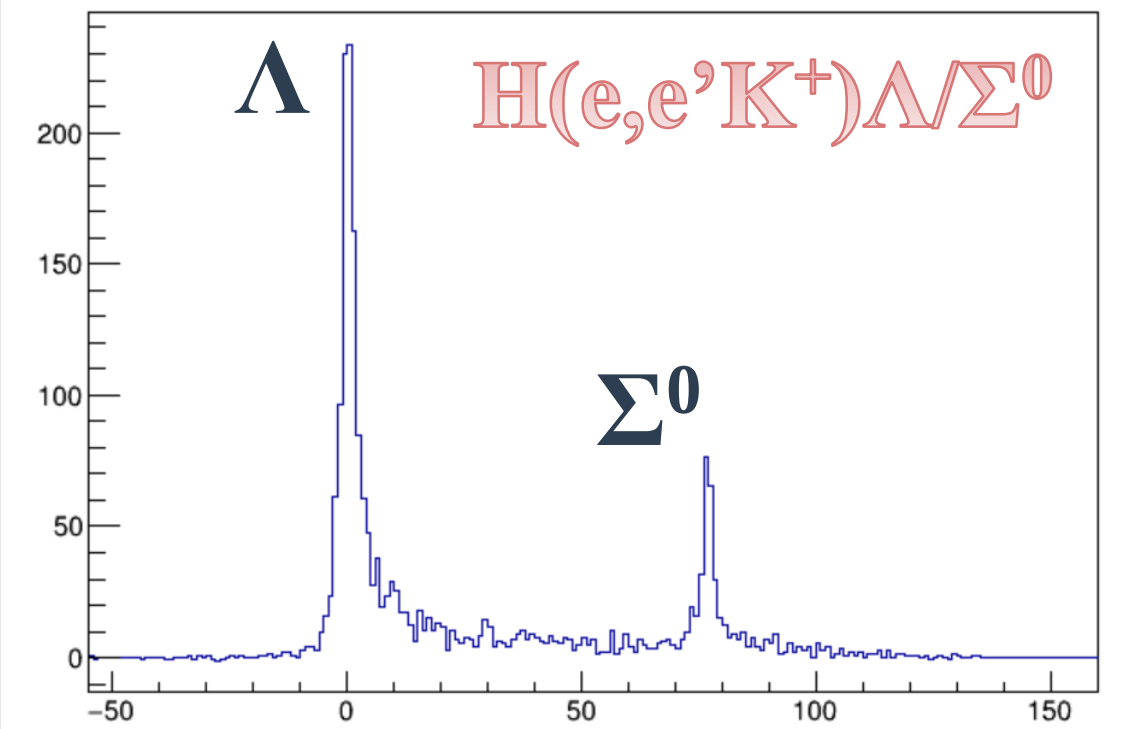






Optics calibration (Momentum)

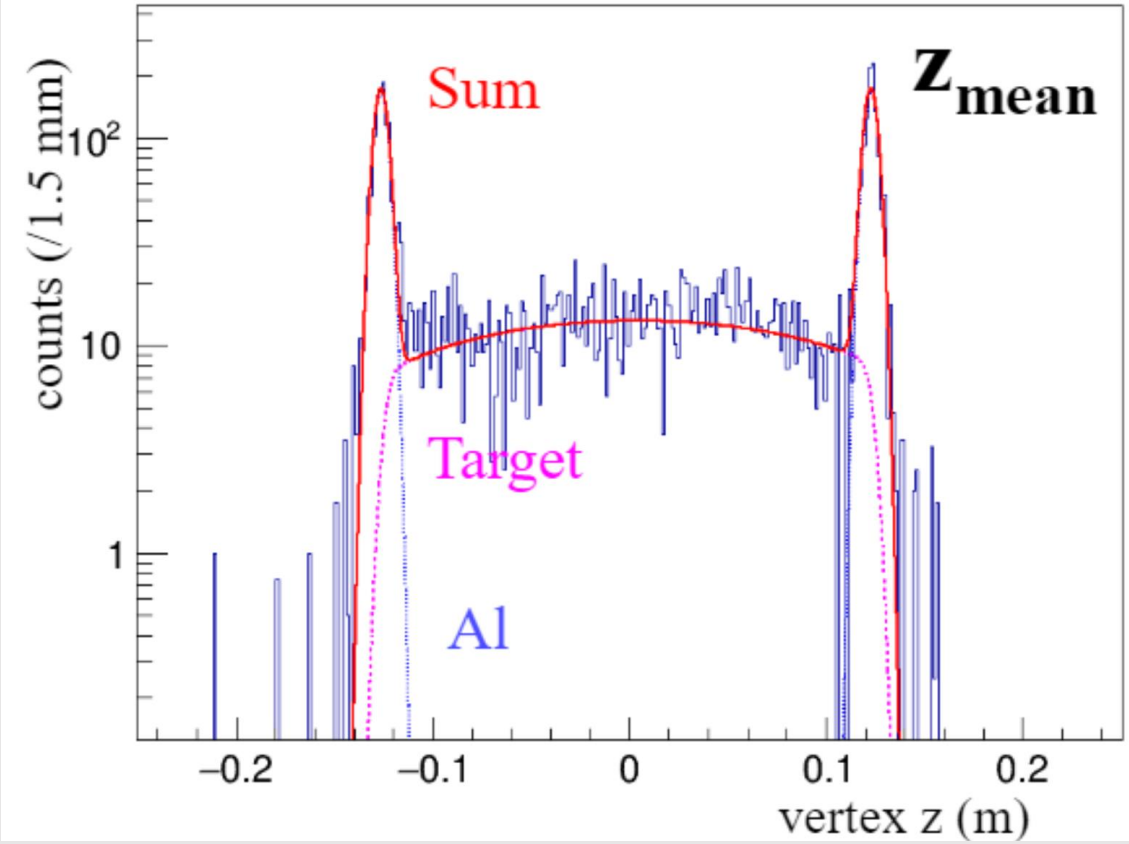
- Momentum parameters were calibrated with $H(e,e'K^+)\Lambda/\Sigma^0$



ΔM =1.3 MeV (σ)

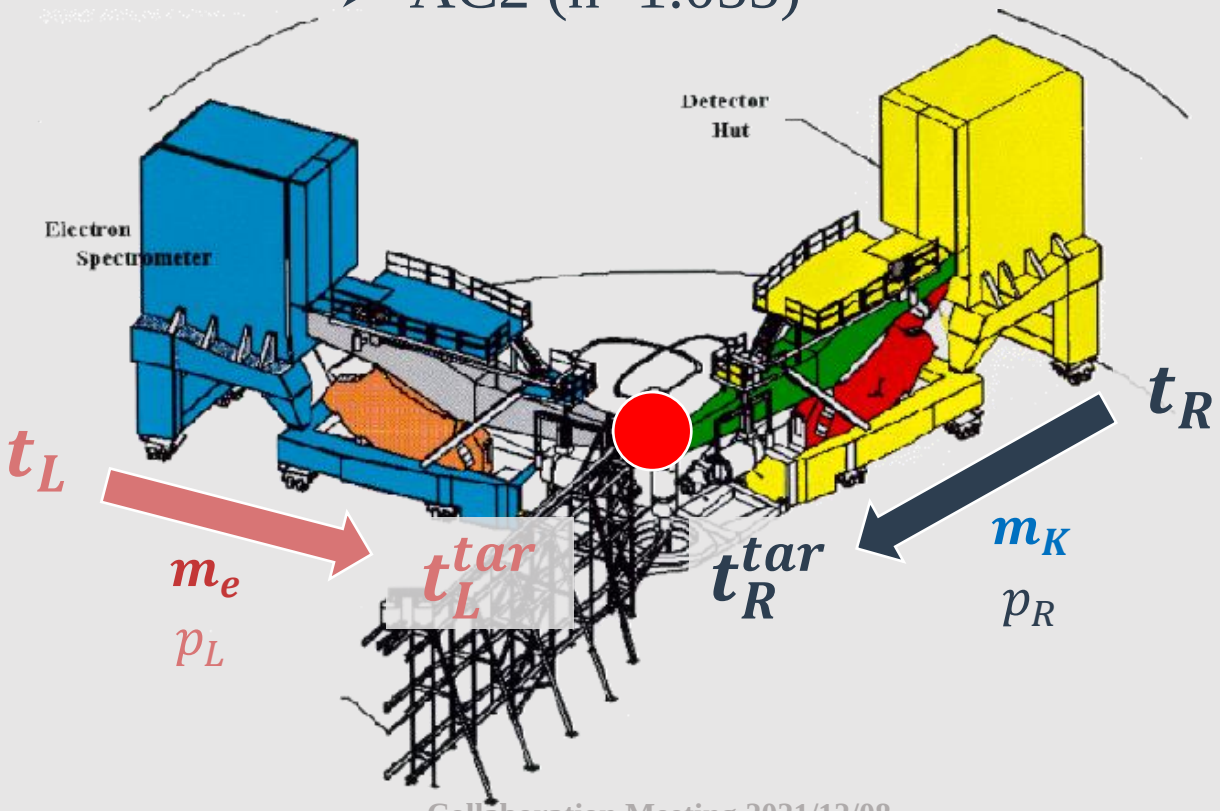
Vertex cut

- There are Al cell contamination in the edge.
- Target region |z| < 0.1 m was selected.



K^+ Selection

- Coincidence time : $t_L^{tar} - t_R^{tar}$
- Aerogel Cherenkov
  - AC1 (n=1.015)
  - AC2 (n=1.055)



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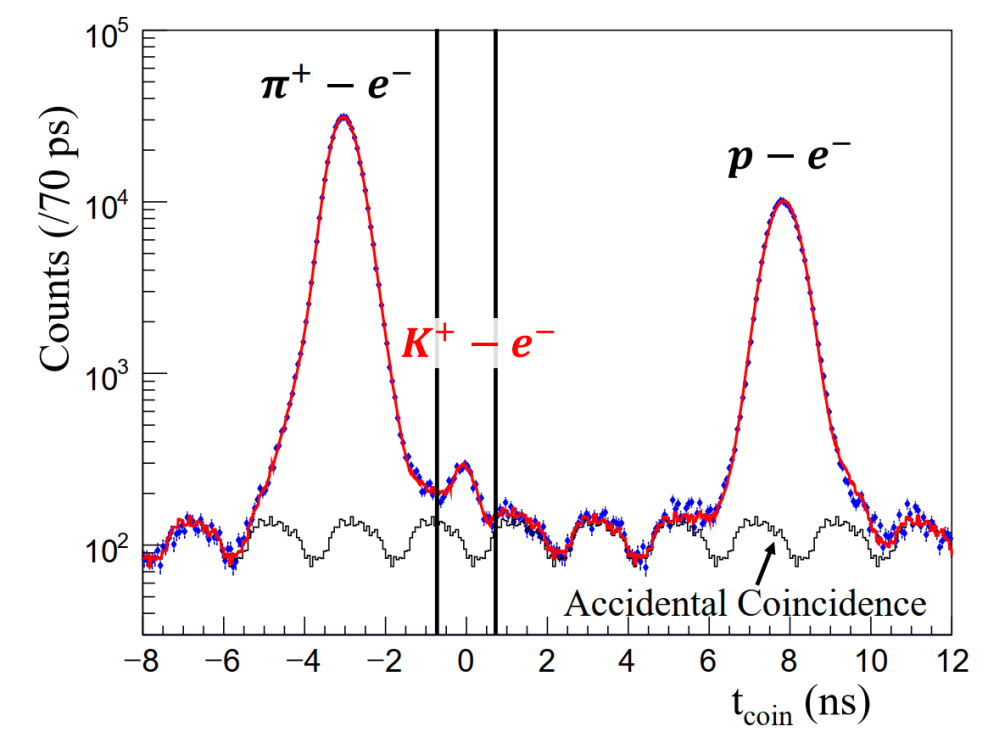

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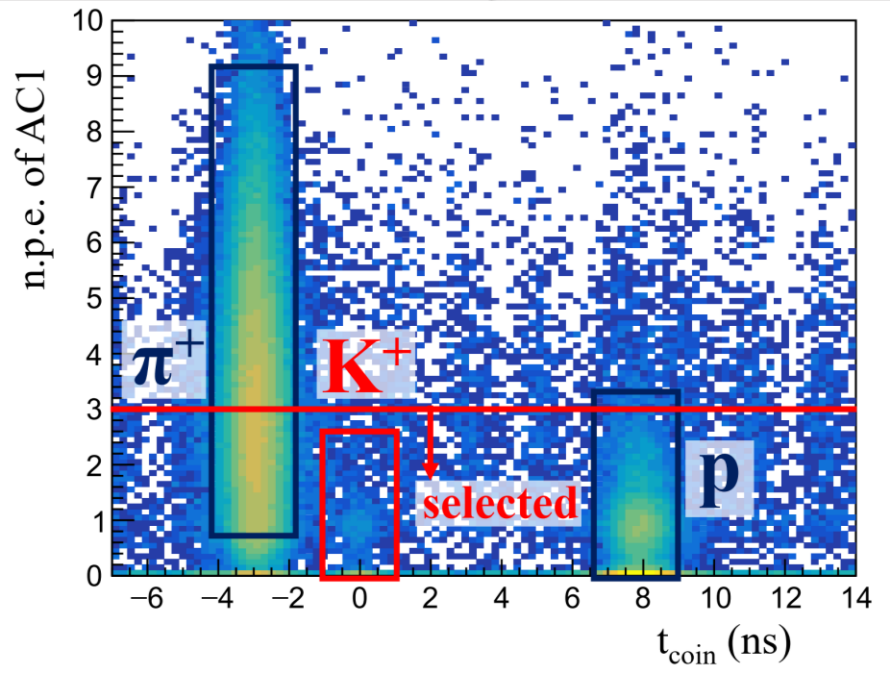
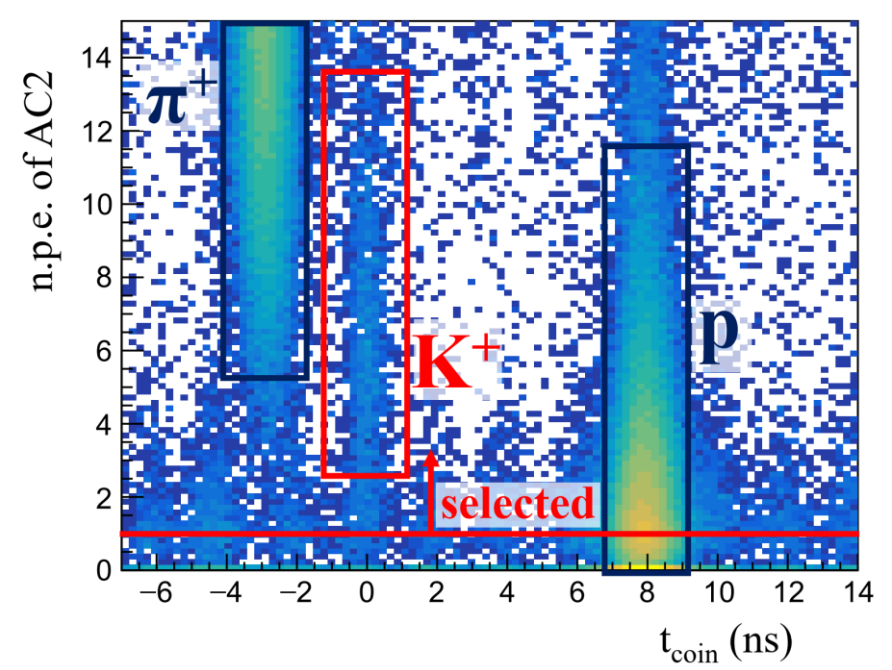
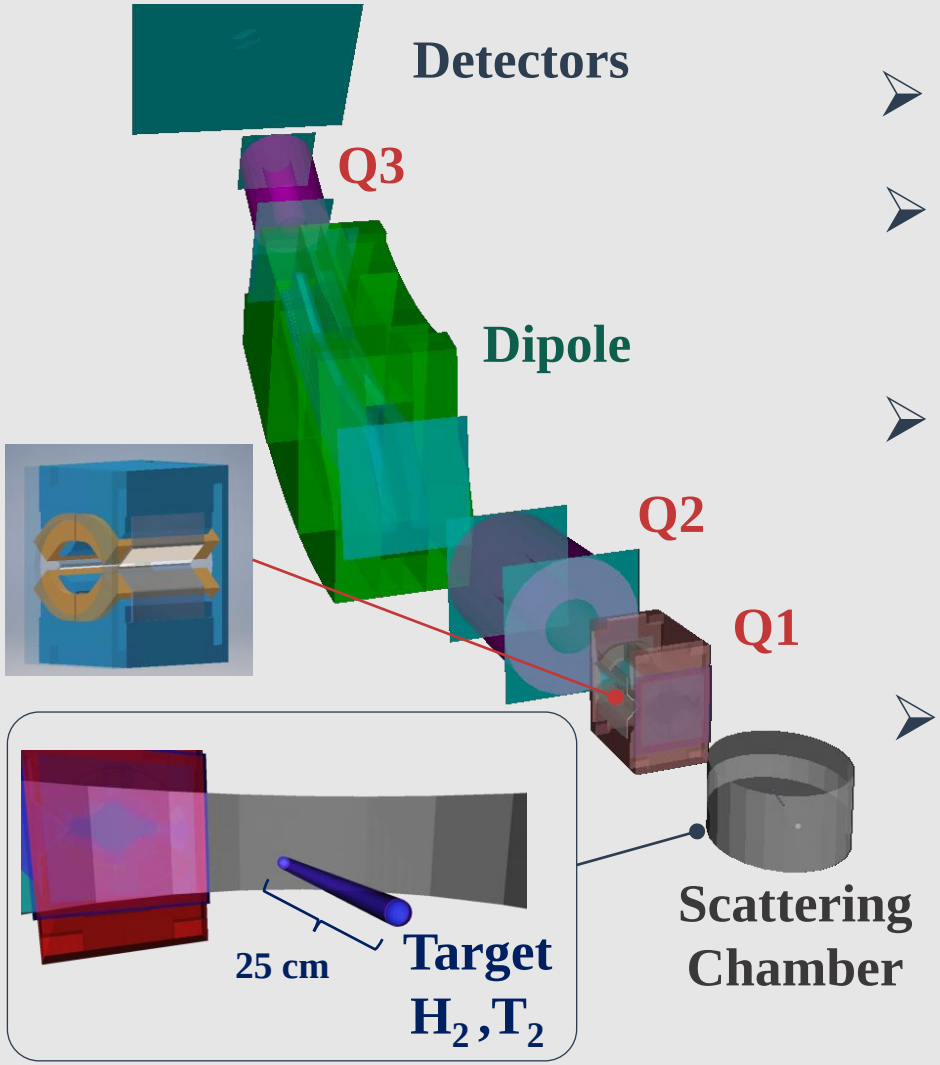


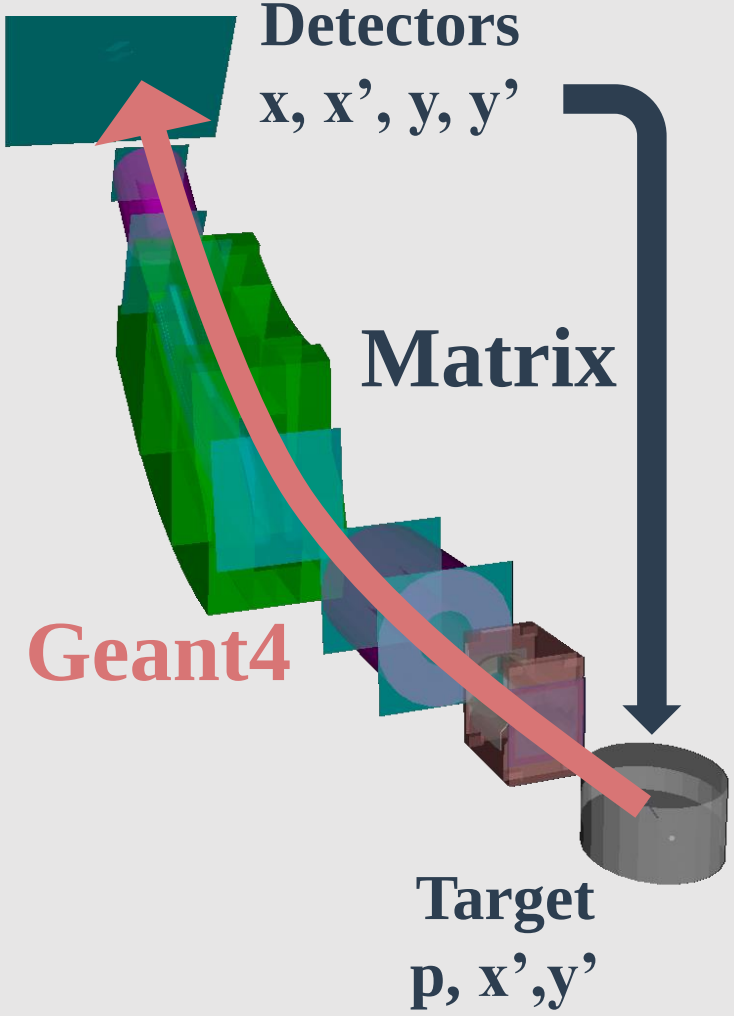


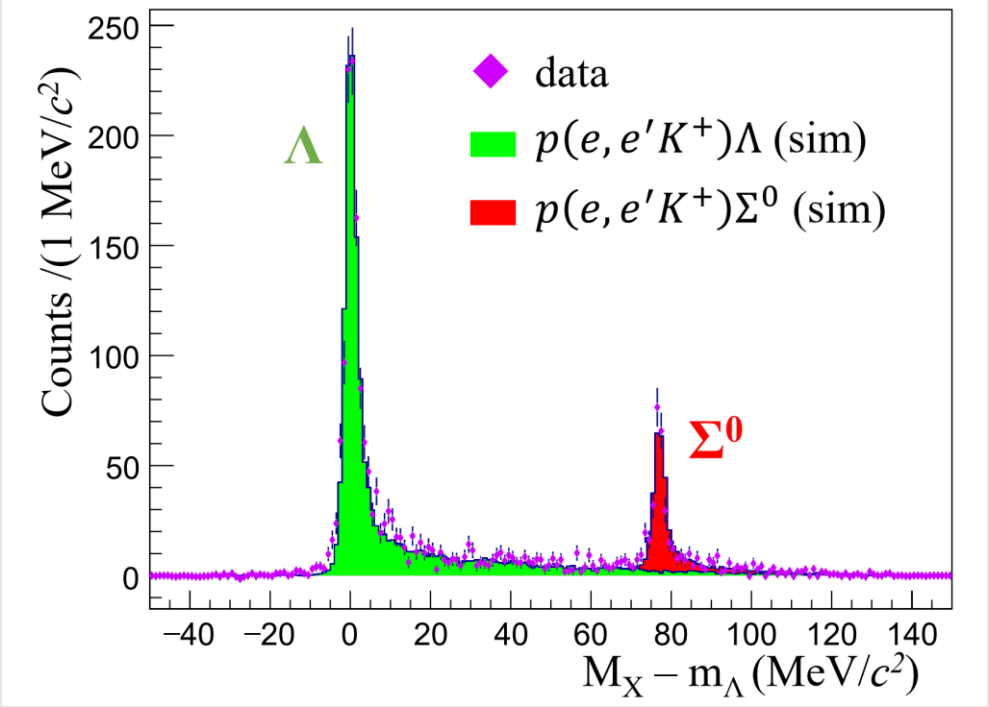
Geant4 Simulator



- Original simulator
- Realistic geometry:
  target cell, Q1 and Dipole
- Magnetic field:
  Dipole → TOSCA
  Quadrupole → Kato-eq.
- Material included:
  Target cell, Air,
  Isolator etc...

Geant4 Simulator





Estimated Resolution

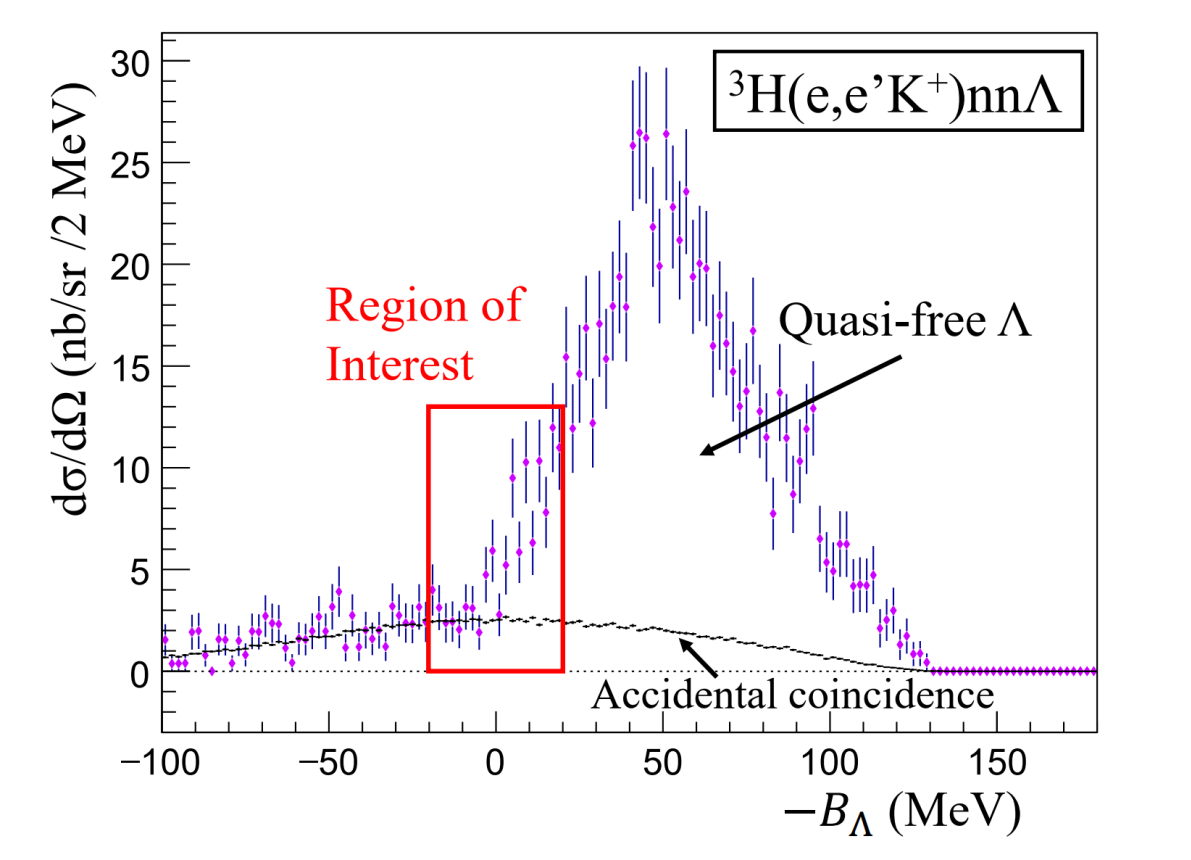
Λ: 1.4 ± 0.1 MeV ➡ nnΛ: 1.5 ± 0.2 MeV

Efficiency

Item	Efficiency or correction factor	Regard
$\epsilon_{\mathrm{track}}$	0.981	Tracking efficiency estimated from the data analysis and a simple MC simulation.
$\epsilon_{\mathrm{decay}}$	0.15 at $p^{\mathrm{cent.}}$	K^+ survival ratio against its decay estimated by Geant4 MC simulation.
ϵ_{T}	0.986	Survival ratio of the tritium gas against its decay with $^3\mathrm{H} \rightarrow ^3\mathrm{He} + \mathrm{e}^- + \bar{\nu}_\mathrm{e}$.
$1/\epsilon_{\mathrm{He}}$	0.97	Correction factor to correct the ^{3}He contamination from the tritium decay. A ratio of Q.F. Λ production from ^{3}H to that of ^{3}He was assumed to be the same as that of the $(e, e'p)$ reaction [40].
ϵ_{DAQ}	0.95	Efficiency of data acquisition system and trigger counters [41].
$\epsilon_{\mathrm{ctime}}$	0.96	Efficiency for the real coincidence selection by the coincidence time (Fig. 6).
$\epsilon_{\mathrm{absorp}}$	0.91 at $p^{\mathrm{cent.}}$	Survival ratio of K^+ against its absorption in materials due to the K^+N interaction. It was estimated by the Geant4 MC simulation.
$\epsilon_{\mathrm{density}}$	0.901	Density-reduction effect of the gas due to the heat by beam irradiation [20].
$\epsilon_{\mathrm{vertex}}$	0.71	z_{diff} and z_{mean} cuts shown in Sec. 3.2.
ϵ_{PID}	0.91	Survival ratio of signals after the particle identification by the gas and aerogel Cherenkov detectors.
$1/\epsilon_\pi$	0.98	Correction factor to correct the π contamination.

Cross section

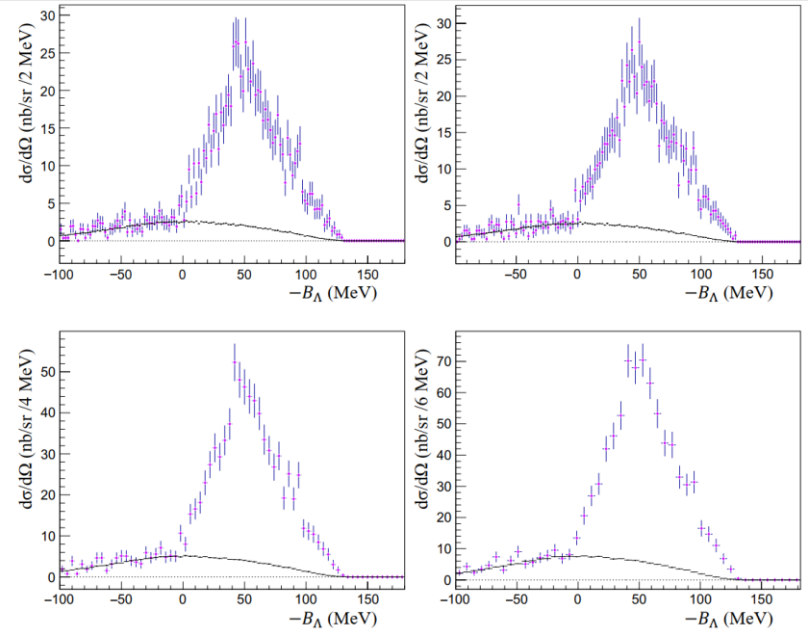
- The cross section of $^{3}H(e,e'K^{+})nn\Lambda$ were calculated with the efficiencies.



Fitting

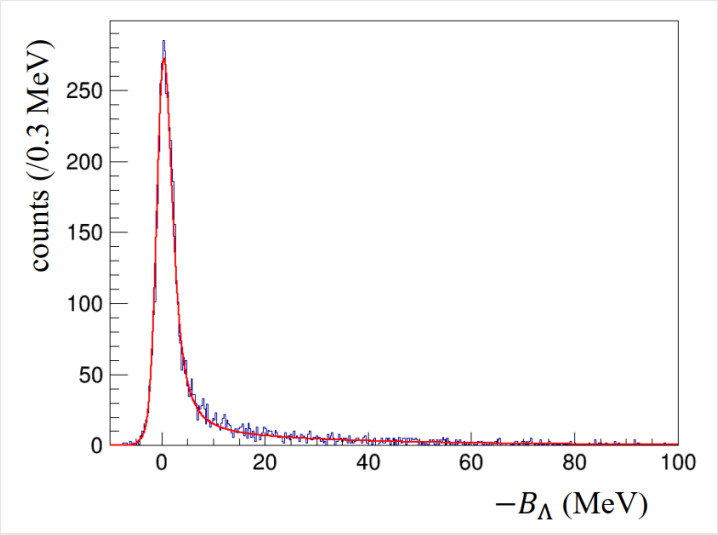
- A systematic error due to the binning effect is large in the threshold region where the number of events is limited
- Fitting was performed with unbinned-maximum-likelihood

$$L(x;\theta) = \prod_{i=1}^{N} f(x_i, \theta)$$

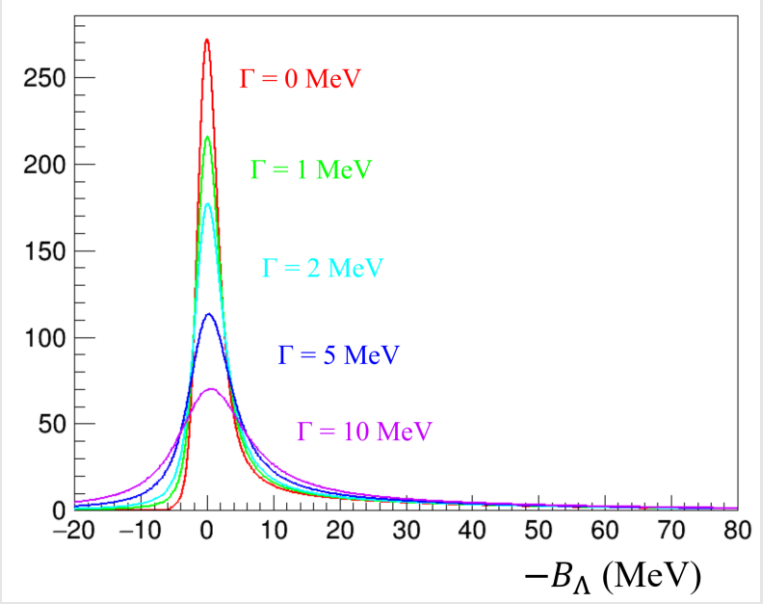


nnΛ Function

- nnΛ signal with Γ = 0 MeV was simulated with the Geant4.
- BW function with finite width Γ was convoluted.

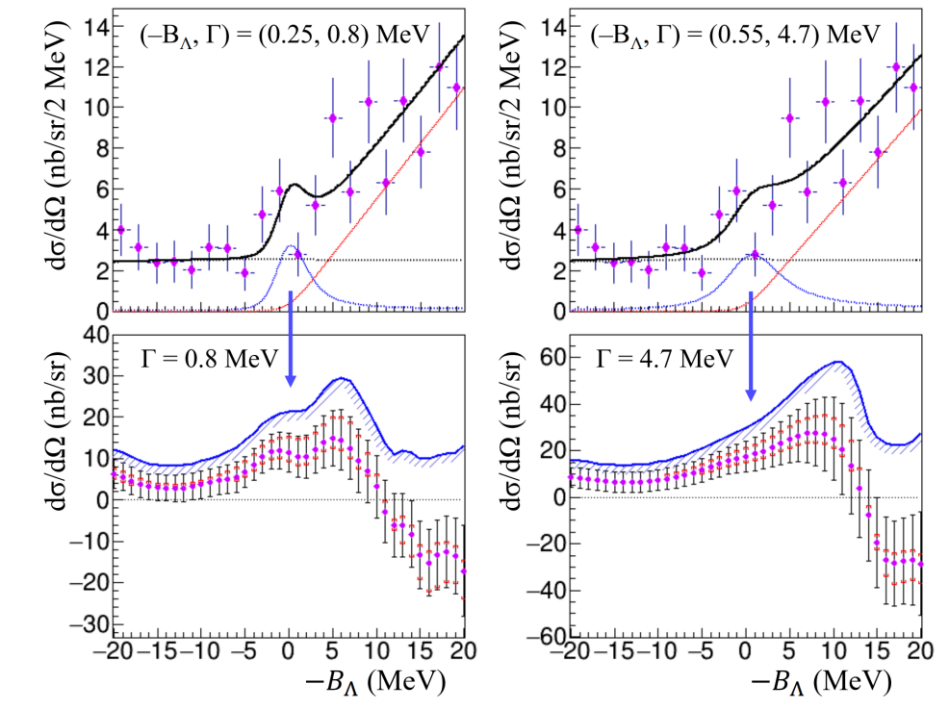


Convolution



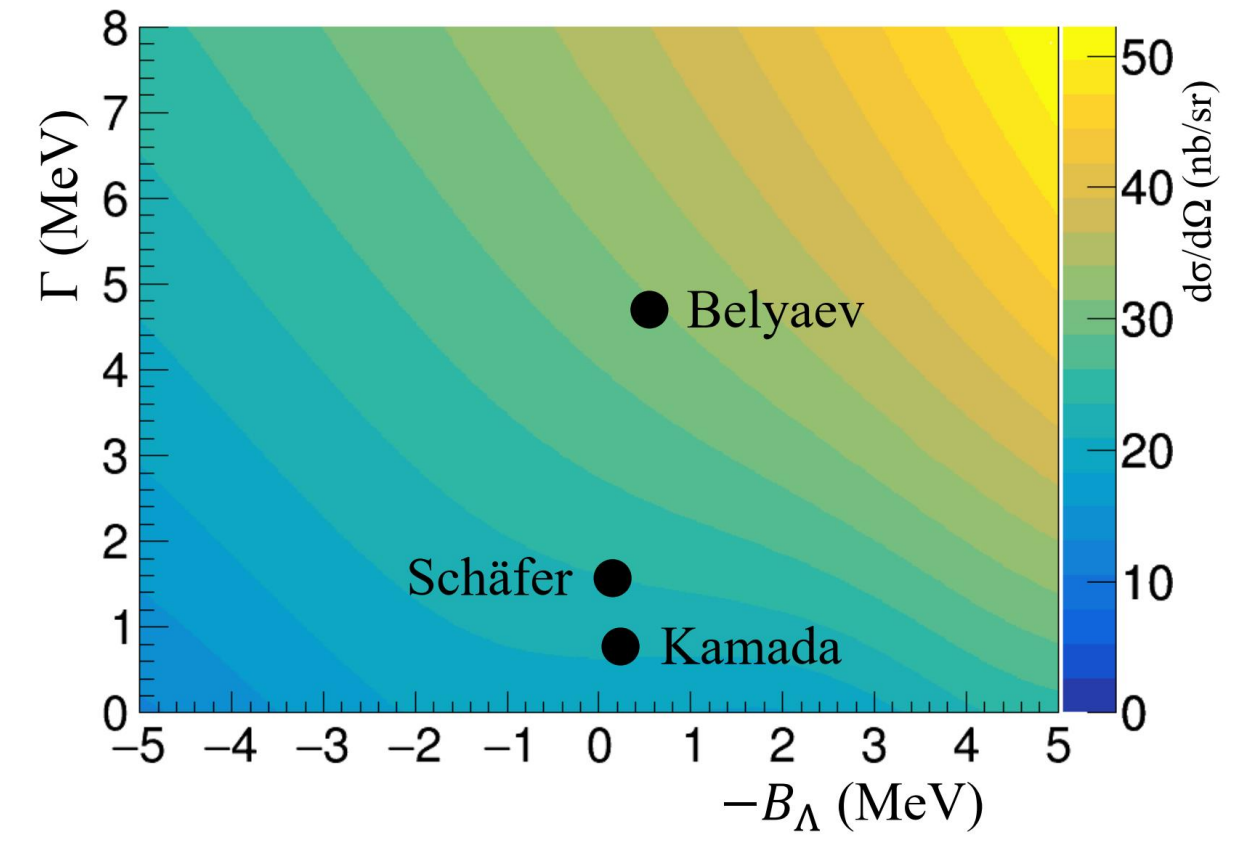
Fitting result

- The upper panels show the result with (B_Λ,Γ) = (0.25,0.8) and (0.55,4.7)MeV.
- No peak structure with a significance exceeding 3σ was found.
- The bottom show the 90% upper limit. (0.25,0.8) MeV : 21 nb
  (0.55,4.7) MeV : 31 nb



Fitting Result

- Two-dimensional scans of B_Λ and Γ for upper limit were performed.



Summary

^{3}H(e,e'K)nnΛ reaction was measured with HRS-L and HRS-R at Jefferson Laboratory HallA in 2018.

- The cross section was obtained with efficiencies and correction estimation.
- No significant peak was observed, and upper limit was estimated.
- This is expected to provide significant information on the nnΛ existence and Λn interaction