Analysis Result of the E12-17-003 Experiment

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Jefferson Lab Experiment: E12-17-003
Data Taken: November 2018

HAMPTON UNIVERSITY

Jefferson Lab EXPLORING THE NATURE OF MATTER

The Data Analysis is Completed:

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Letter

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

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(Hall A Collaboration)

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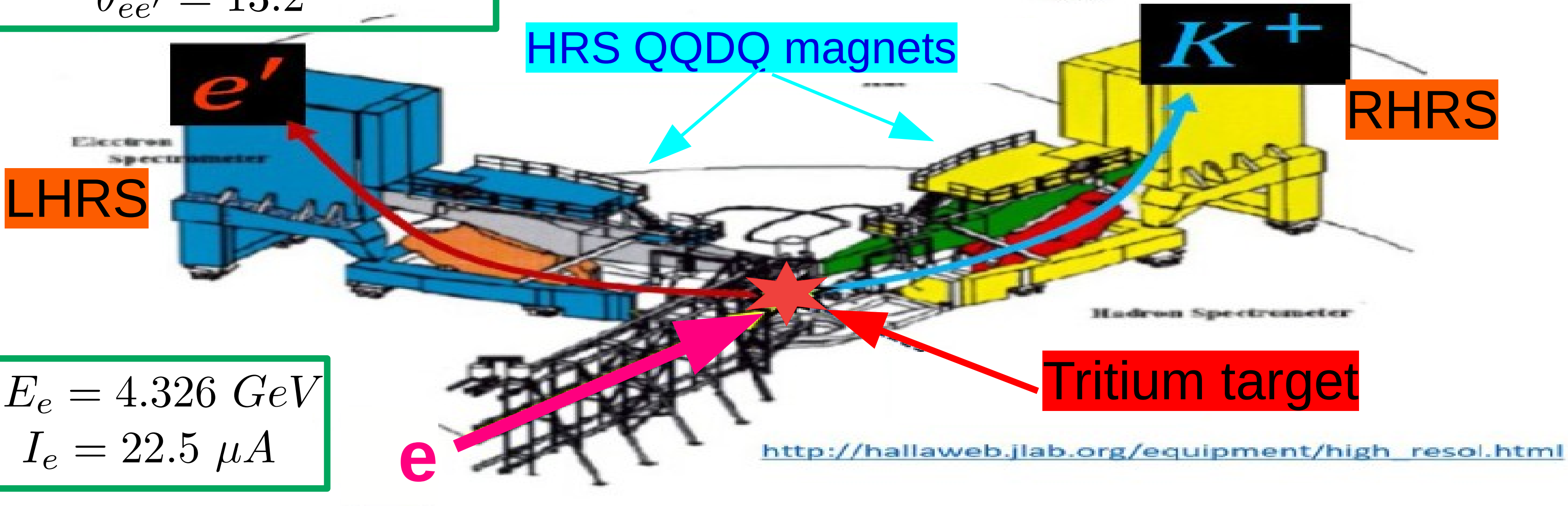
Experimental Setup for the E12-17-003 Experiment:

1. H kinematics
Target: H
p_e = 2.1 GeV/c
→ **Calibration data**

$$p_{e'} = 2.218\ GeV/c \pm 4.5$$
$$\theta_{ee'} = 13.2^\circ$$

2. T kinematics
Target: H, He, T
p_e = 2.218 GeV/c
→ **Production data**

$$p_{K^+} = 1.823\ GeV/c \pm 4.5$$
$$\theta_{eK^+} = 13.2^\circ$$

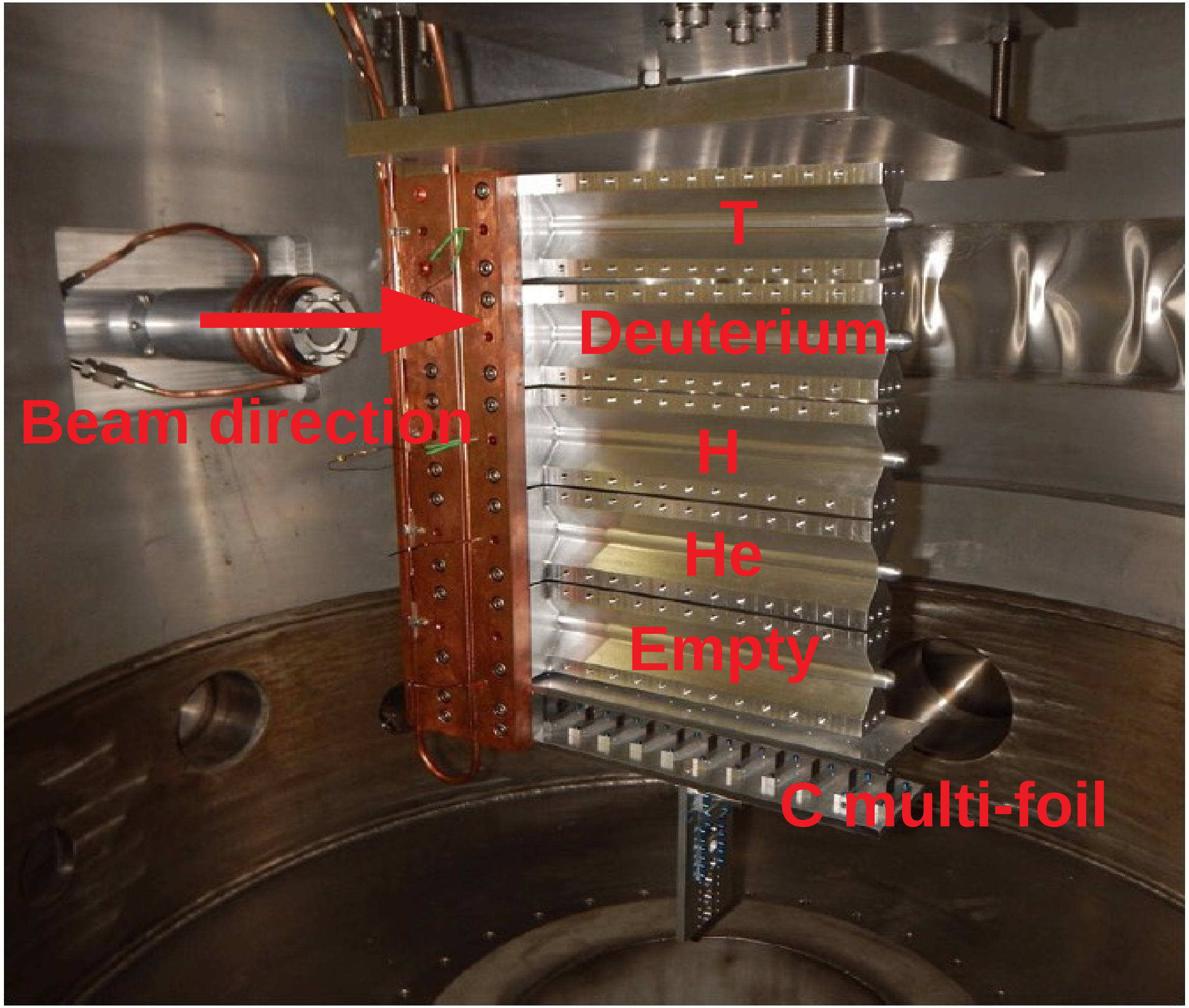


$$E_e = 4.326\ GeV$$
$$I_e = 22.5\ \mu A$$

- The experiment was performed in the experimental Hall A using a tritium target.
- Data were taken with two different kinematics.

The Gas Target System:

- The gas was filled in a cylinder made of 7075 aluminum alloy.
- The length of the cylinder was ~25 cm and diameter ~12.7 mm.
- The target cell has a modular design.
- Since the tritium is radioactive, to minimize the safety hazards associated with the tritium target, a special target system with three layers of confinement was designed during the operation.
- The maximum current allowed to the tritium target was 22.5 μA.



System Optimization:

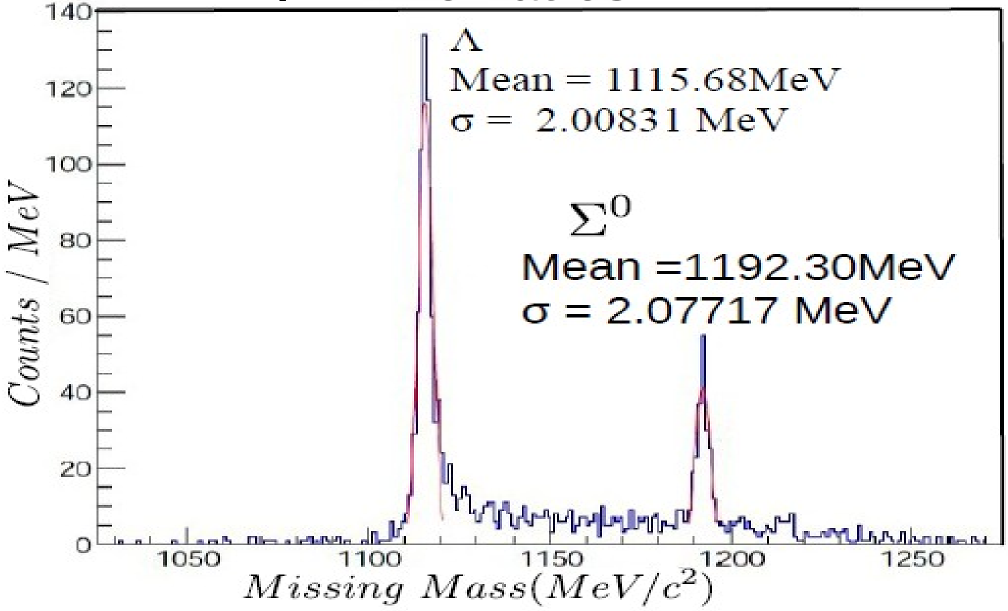
Since the E12-17-003 was a high precision experiment, the whole system was optimized as required by the experiment.

- The Z vertex is optimized with the multi-foil data and a Z-vertex resolution of about 4 mm (σ) is achieved.
- The HRS angles are optimized with the sieve slit data. With the optimized matrices the resolutions for the in-plane and out-of-plane angles were estimated to be about 1.7 mr and 2.4 mr (σ) respectively.
- The coincidence time is optimized for the scattered electrons and emitted kaons. For the kaon peak, the resolution is achieved about 300 ps. With this resolution, the kaons are cleanly separated from rest of the hadrons.

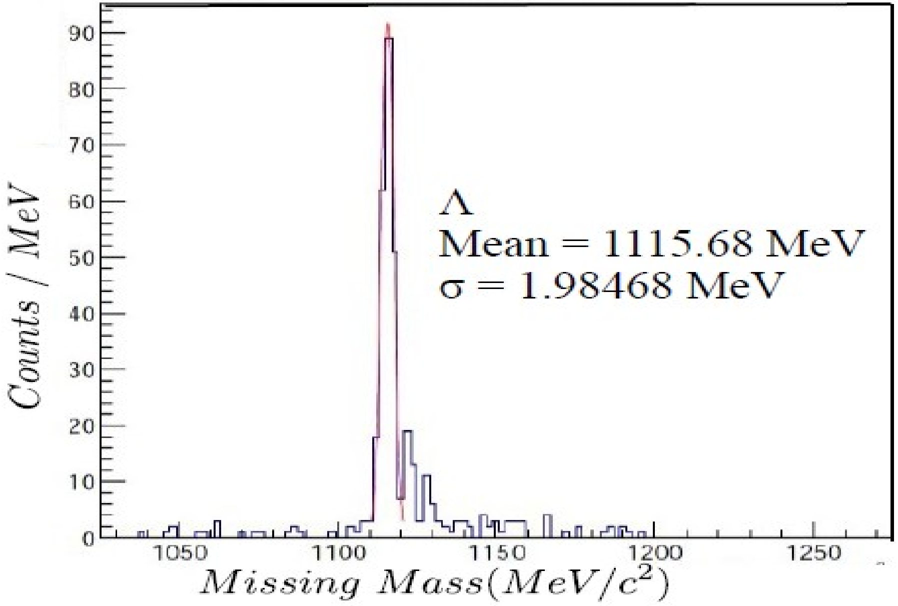
All these optimizations satisfied our experimental requirements.

Initial Momentum Optimization:

H/H Kinematics



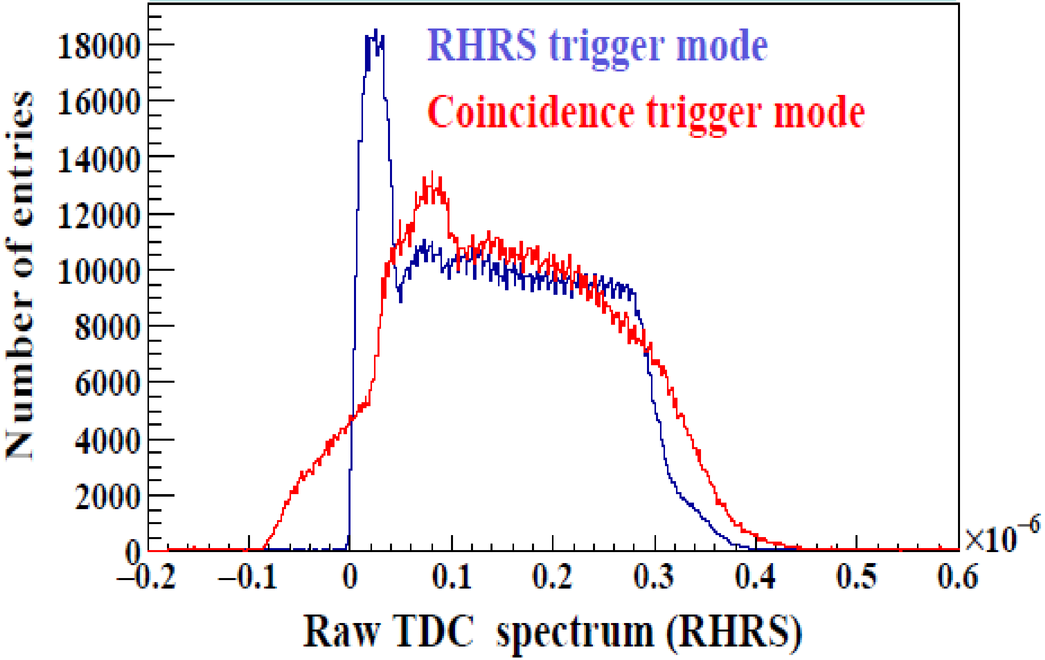
H/T Kinematics



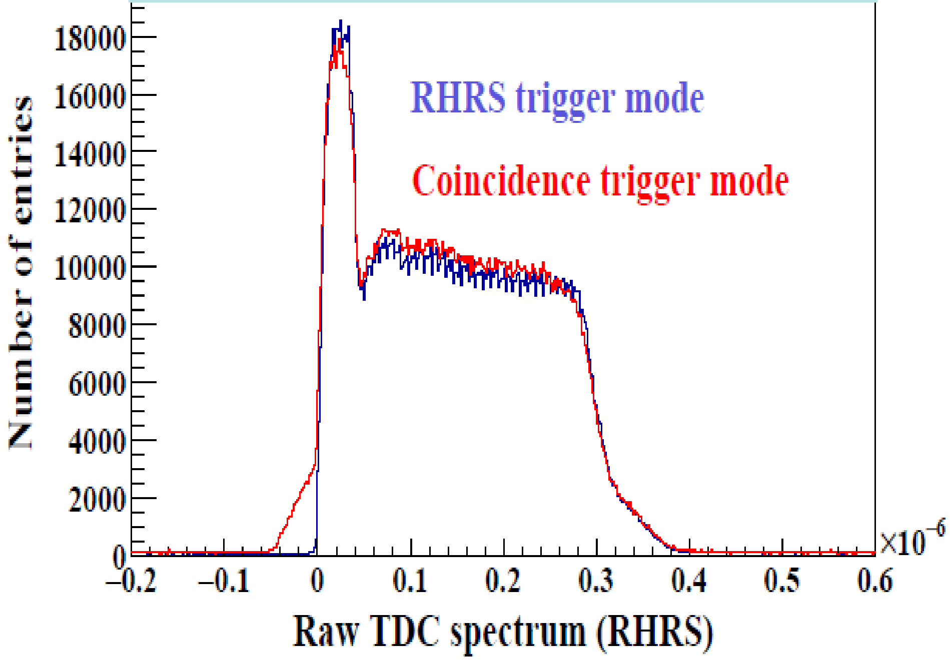
- For the momentum optimization, the known masses of Λ and Σ^0 produced by the (e, e'K^+) reaction were used like the previous hypernuclear experiments at Jlab.
- During the momentum optimization when the resolution of Λ and Σ^0 was achieved about 2 MeV (σ), the further tune did not improve the optics quality.
- **Two problems were recognized:**
  (i) Time jitter for the RHRS VDC.
  (ii) The dependence on the residual angular uncertainties.

Time Jitter Correction:

Before time jitter correction

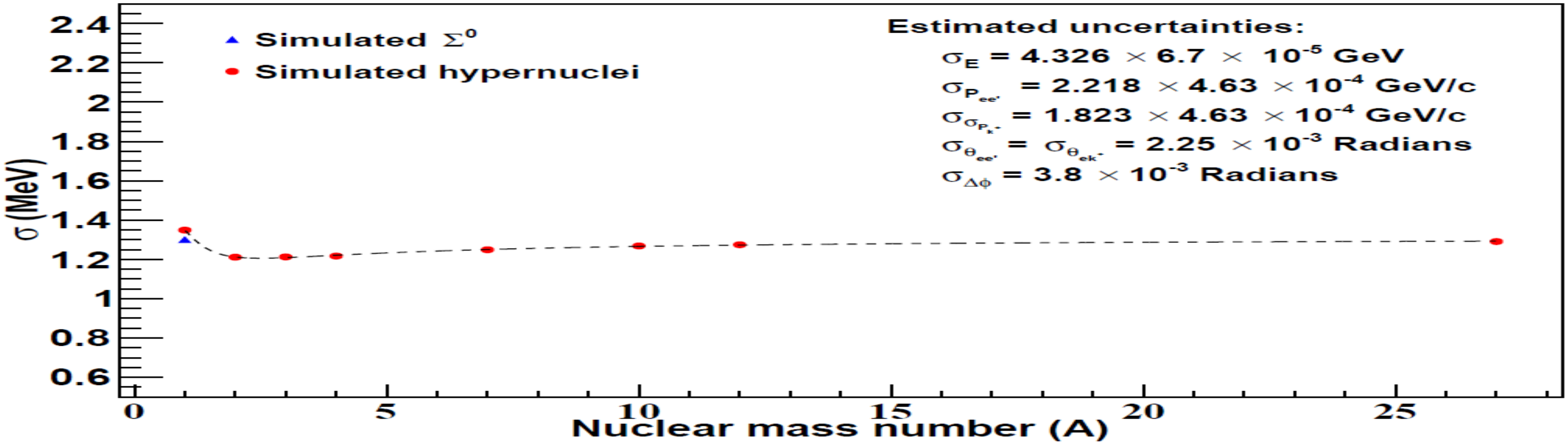


After time jitter correction



- For the coincidence events at the right arm, the VDC’s drift time was found having a time jitter and affecting the momentum optimization as well as the missing mass resolution.
- This problem was minimized by applying a software correction on an event-by-event base to the raw TDC data.

Simulation of A dependence of Missing Mass Resolution:



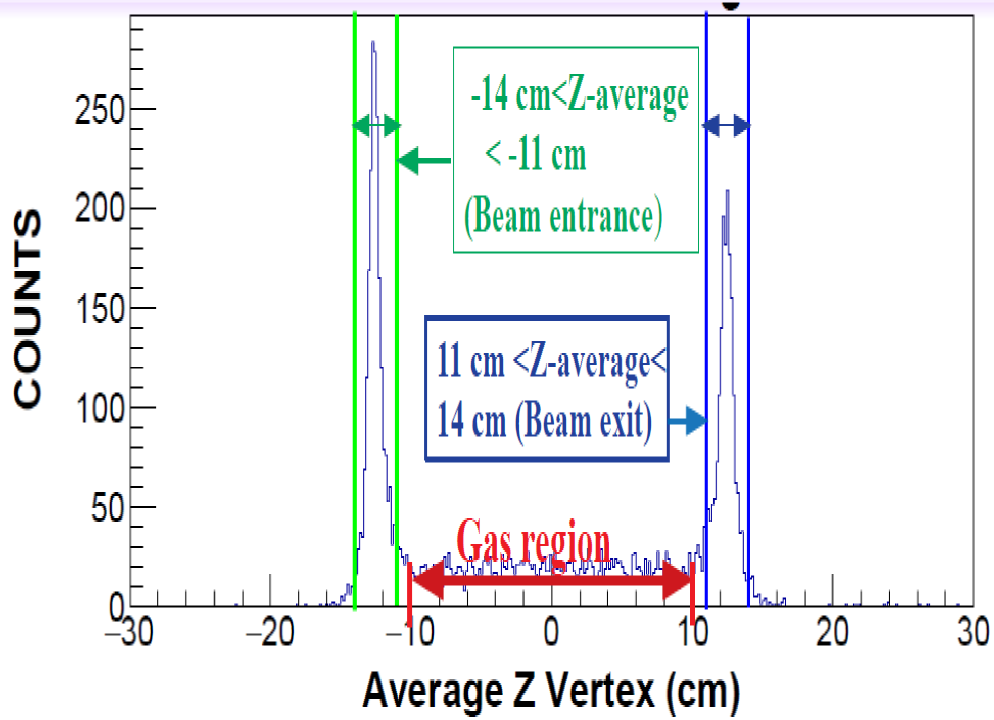
- Using the identical experimental conditions, a simulation of A dependence of missing mass resolution was carried out. The simulation was aimed mainly for the the two reasons:

(i) to study the uncertainty contributions from the beam energy, HRS momenta & scattering angles.

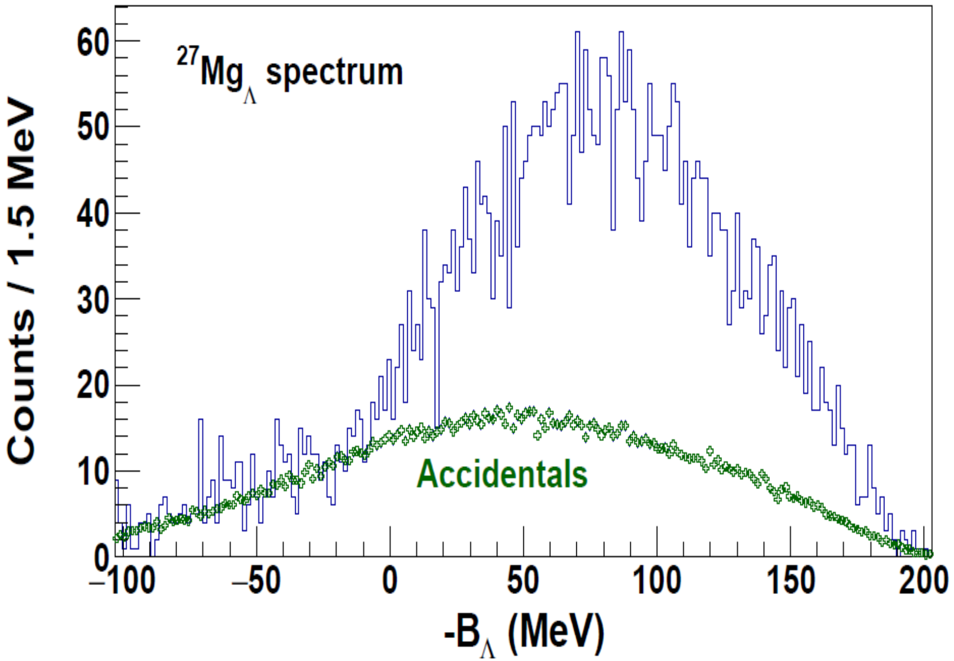
(ii) to predict the missing mass resolution of A = 3 system.

- The scattering angle uncertainties are dominated for a light mass system (A =1), while the energy and momentum uncertainties dominated for the heavy system with A>7.
- The simulation suggested that to reach the best achievable resolution under this experimental condition, a heavy mass system with negligible angular dependence needs to be involved in the matrix tune along with the known masses of Λ and Σ^0.

Al Data Involved in Matrix tune Along with Λ and Σ^0 Masses:



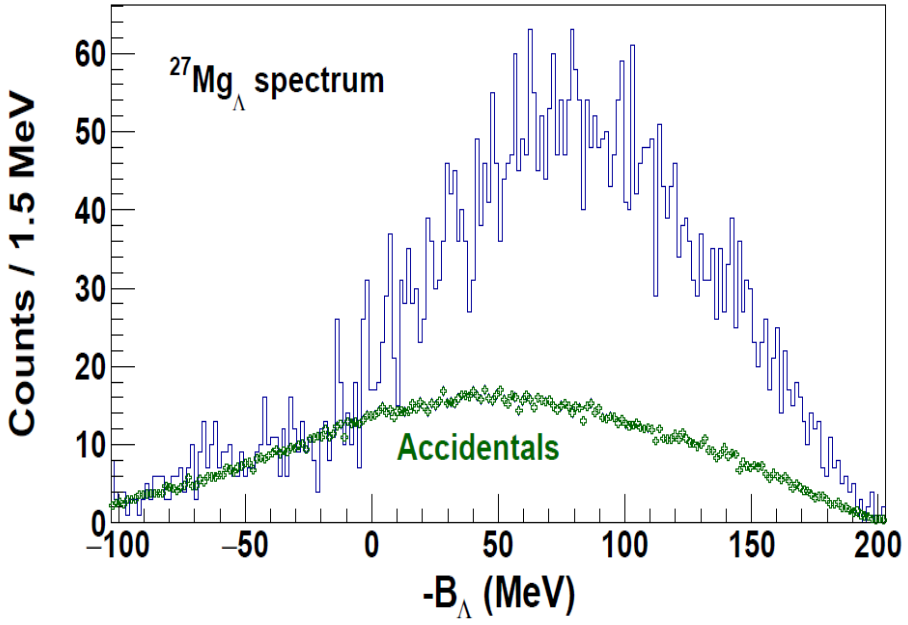
Before Al data involve in Tune



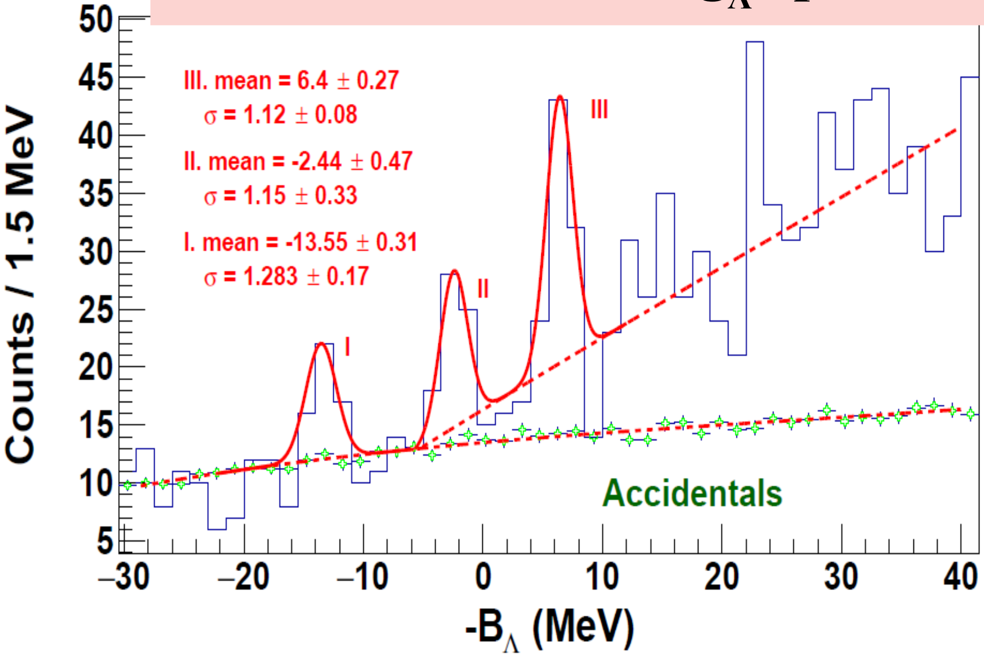
- The only possibility of involving a heavy mass system was the ^{27}Al as the target cell was made of ^{27}Al.
- Events from the beam entrance and exit Al end caps were selected and combined together to produce the $^{27}Mg_\Lambda$ hypernuclei.
- To involve the Al data in the matrix tune, a peak search test tune was performed to find the events from the possible single particle state.

$^{27}Mg_\Lambda$ Spectrum After Al data Involved in Matrix Tune:

After Al data involve in Tune



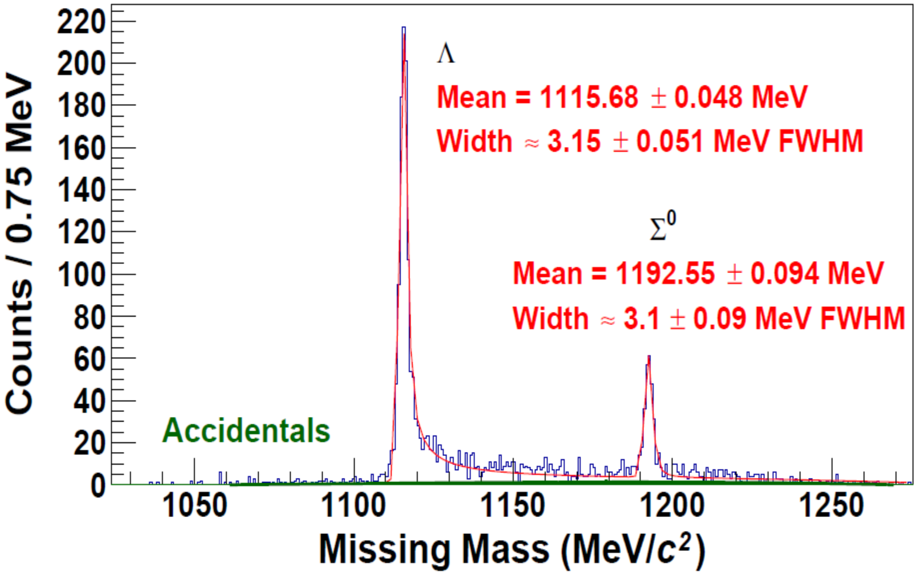
Closer View of $^{27}Mg_\Lambda$ Spectrum



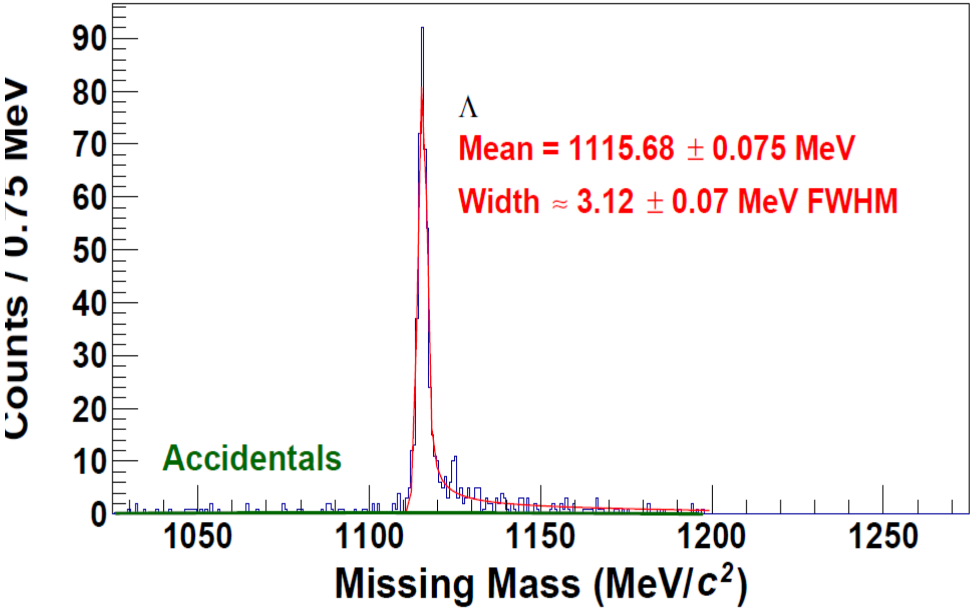
- After the optimization, a few peak structures are appeared in the $^{27}Mg_\Lambda$ spectrum.
- After the optimization, 3 peak structures are appeared, 2 of which are in a bound region.
- The statistical significance of the 1st, 2nd and 3rd peaks are 2.7, 3.57, and 4.18 respectively.
- The resolution of the bound peak agreed well with the simulation.

Missing Mass Spectrum:

H/H Kinematics

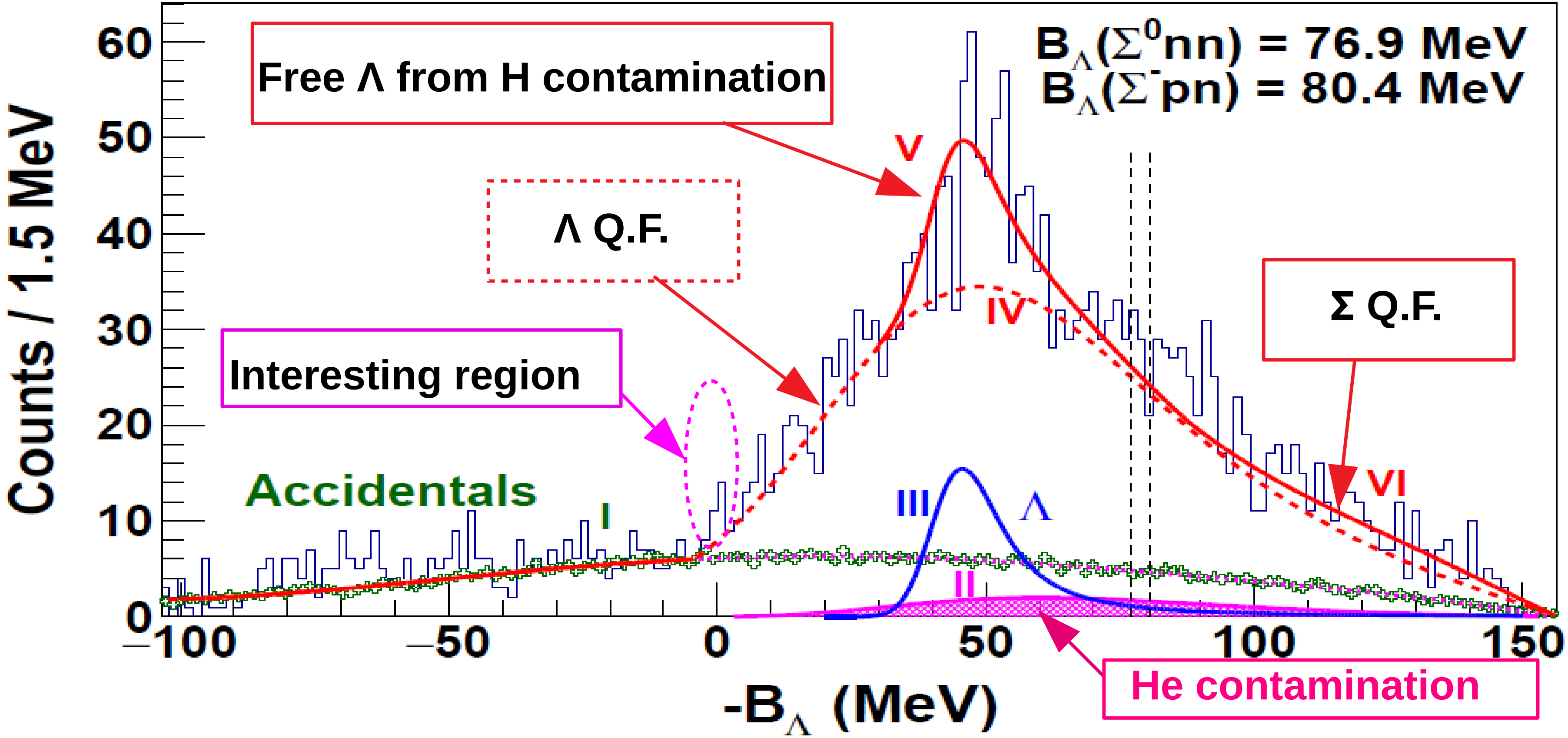


H/T Kinematics



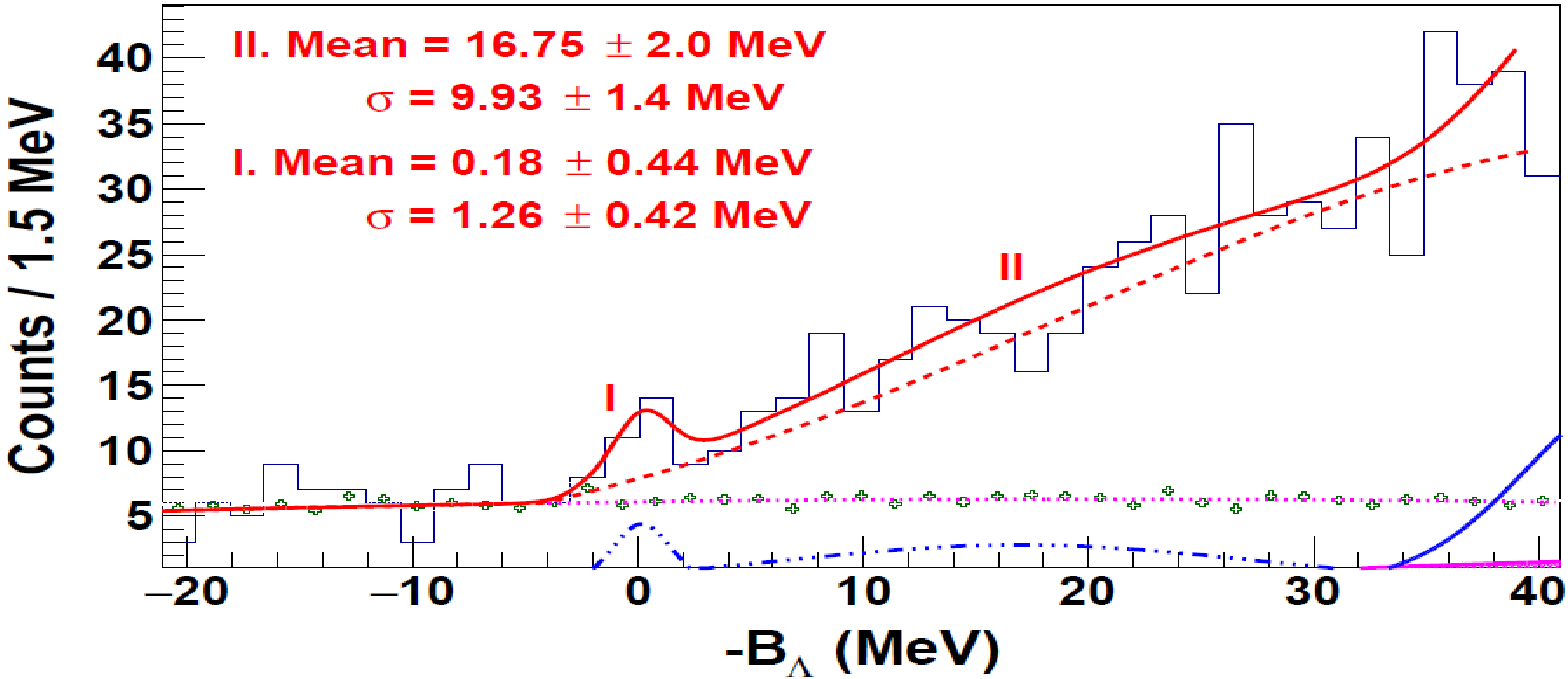
- These are the important data sets used for the absolute missing mass calibration.
- The Λ and Σ^0 landed at their known masses with a separation of 76.87 MeV/c^2 (Nominal separation = 76.96 MeV/c^2).
- Achieved resolution of Λ and Σ^0 agreed with the simulation.
- Systematic uncertainty for the missing mass (binding energy) found ~ 108 keV.

Λnn Spectrum:



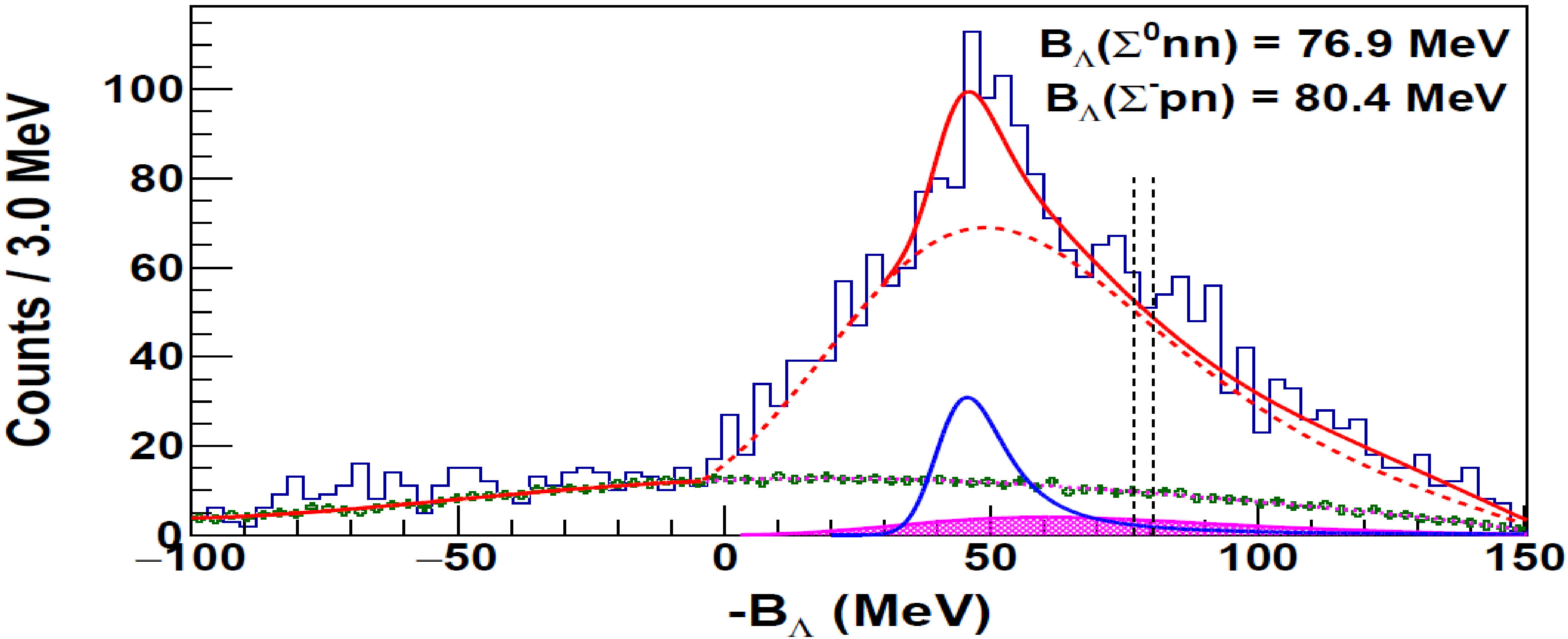
- The threshold mass is defined as the rest mass of Λnn system.
- The Λ and Σ QF distribution functions are obtained by fitting the SIMA simulated data.
- The simulation used the ^{3}He spectral function where the FSI is not included.
- The free Λ curve is obtained by fitting the H data in T kinematics.

Closer view of Λnn Spectrum:



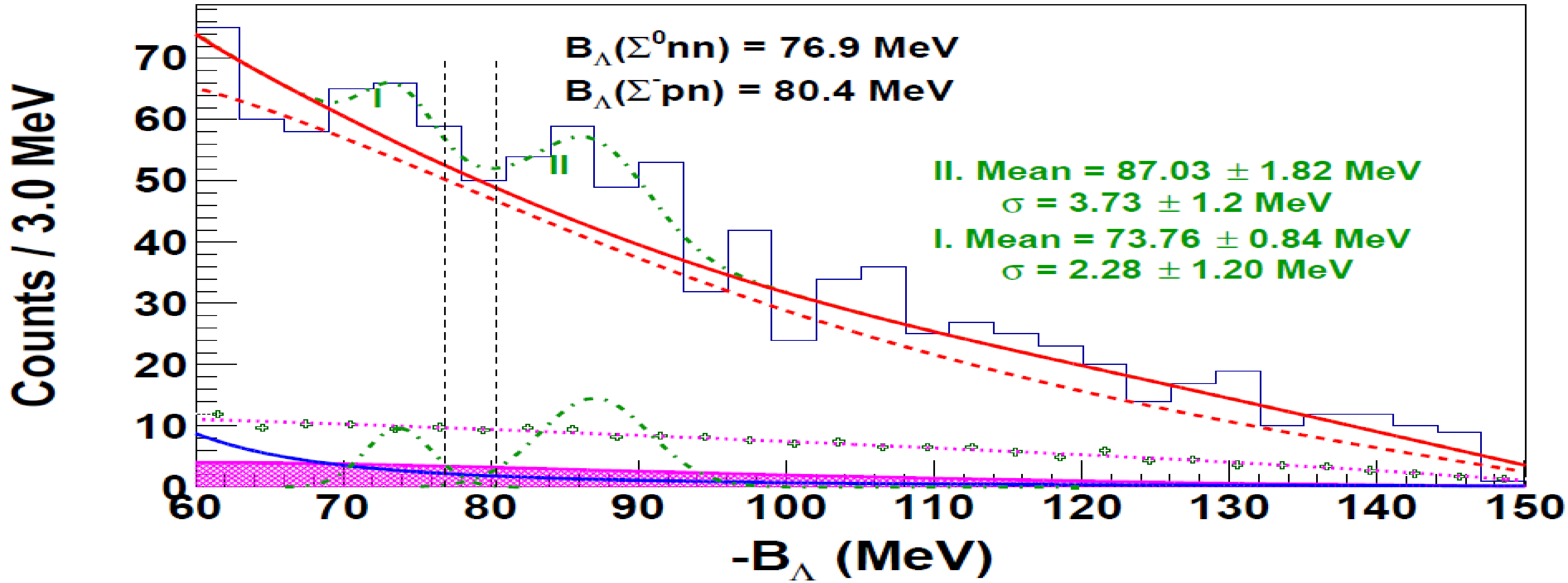
- The 1st peak is possible to be the expected resonance for which the experiment was looking for.
- A simulation predicted the intrinsic missing mass resolution of A = 3 resonance to be σ = 1.21 MeV. Thus, the natural width (Γ/2) is about 0.35 MeV.
- The St. Sig. of the 1st peak is found about 2.7 which is not sufficient to permit a definite identification
- The 2nd gaussian doesn't mean anything, just taking care of extra strength appeared above Λ QF shape.

Mass Spectroscopy with Widerer Bins:



- To reduce statistical fluctuation the Λnn spectroscopy is plotted with the wider bins.
- With the wider bins the excess of events above the Λ QF distribution around the Σ thresholds are observed.

Closer view of the Λnn spectrum with Wider Bins:



- It looks like near the ΣNN threshold lines there are two enhancements.
- The enhancement might be the signature of the ΣNN hypernuclei which has been predicted long ago.
- The st. sig. of the two peaks is 2.2 and 4.6, which is not sufficient to solidly confirm the observed states.
- Since the spectral functions for the ^3H and ^3He are different, the predicted QF distributions may not be accurate and this may affect the interpretation of the observation.

Conclusions:

- The experiment demonstrated that by using the tritium target and (e,e'K^+) reaction, it is possible to observe the 3-body neutral Λ and Σ hypernuclei. However, Hall A system need to be optimized for higher statistics.

- From this experiment one small enhancement near the Λnn thresholds and two enhancements near the ΣNN thresholds are observed. However, to make a definite identification, higher statistics are required.

- A simulation predicted the intrinsic missing mass resolution of A = 3 resonance to be σ = 1.21 MeV. Thus, the natural width is about 0.35 MeV.

- The more details can be found in B. Pandey, L. Tang et al., Phys. Rev. C 105, L051001 (2022).

Acknowledgements:

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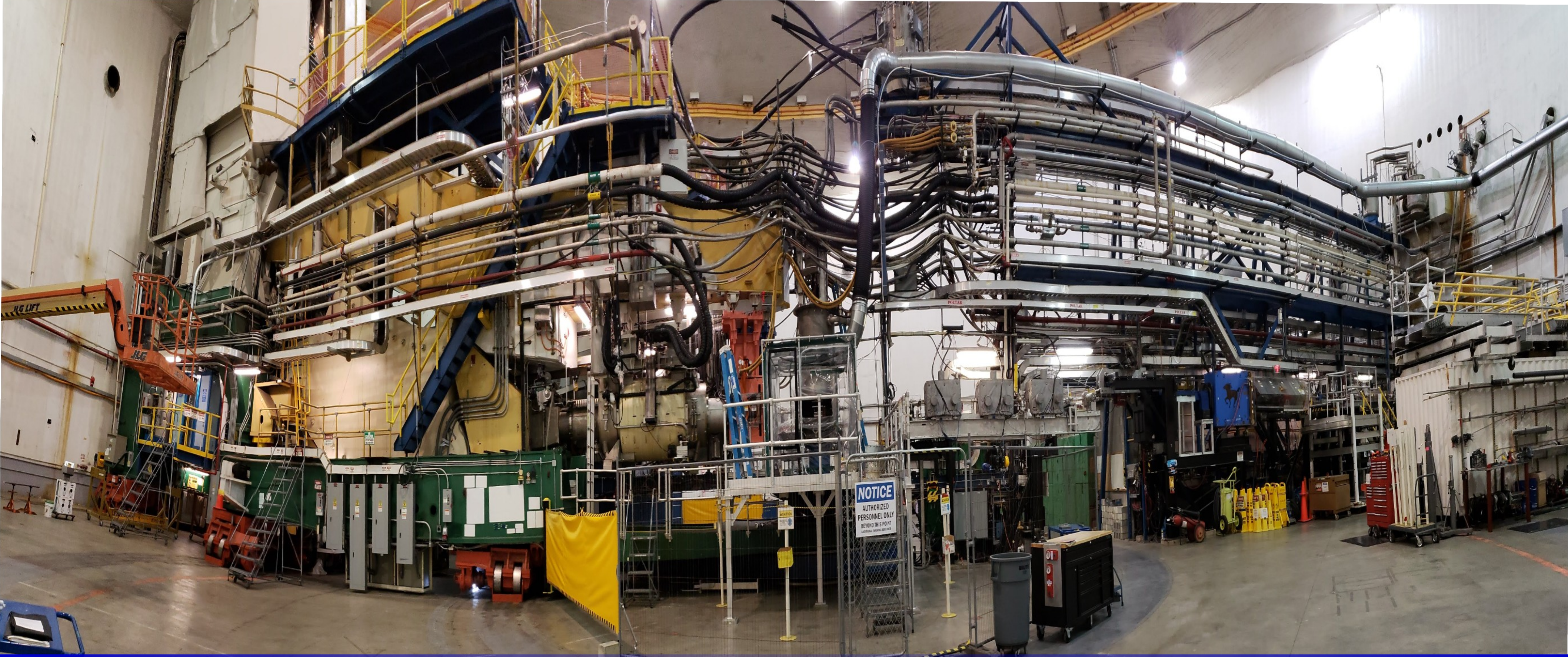
Collaborators:

- The whole HKS collaboration and spokes persons of the experiment
- Jefferson Lab Hall A collaboration, tritium group students and postdocs
- Hall A technical staffs, target group, and accelerator staffs



Thank you