A Possible Observation of Λnn Continuum Structures and a Bound ΣNN State using the (e, e'K^+) Reaction

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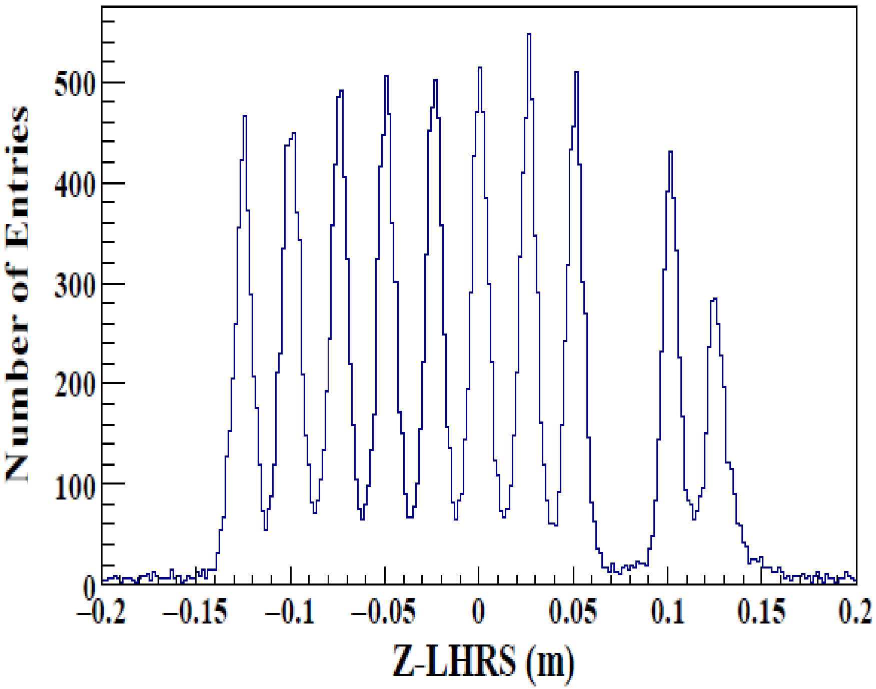
HAMPTON UNIVERSITY

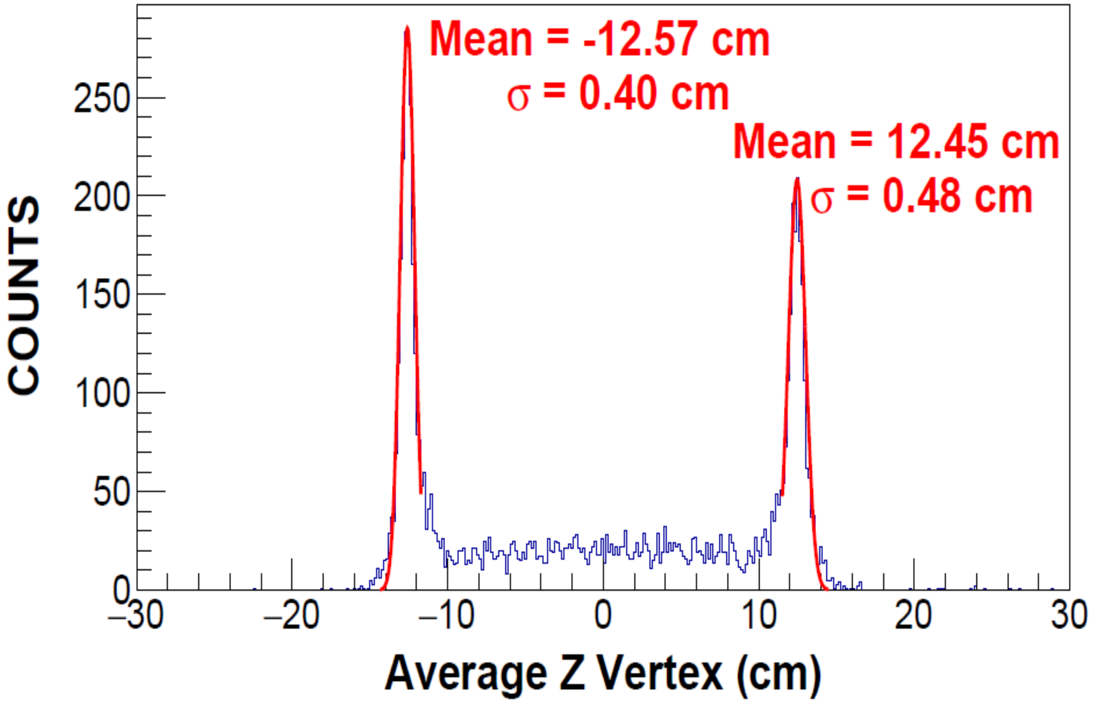
Jefferson Lab EXPLORING THE NATURE OF MATTER

Outlines:

- Z vertex optimization
- HRS angle optimization
- Coincidence time optimization
- Initial momentum optimization
- Simulation
- Al data involved in the matrix tune
- Physics analysis
- Conclusion
- Acknowledgment

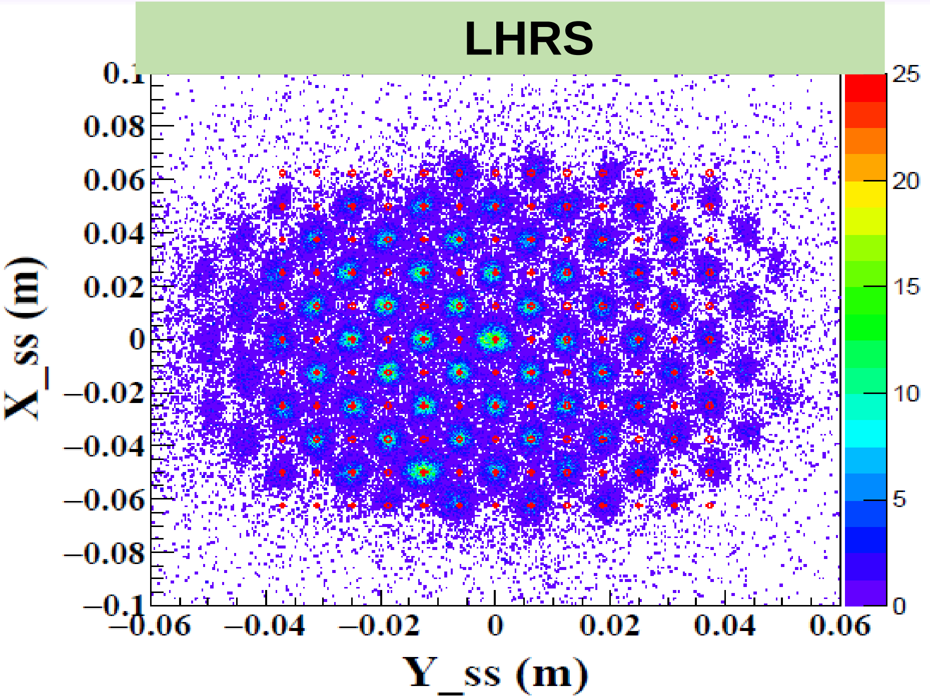
Z-vertex with Optimized Matrix:

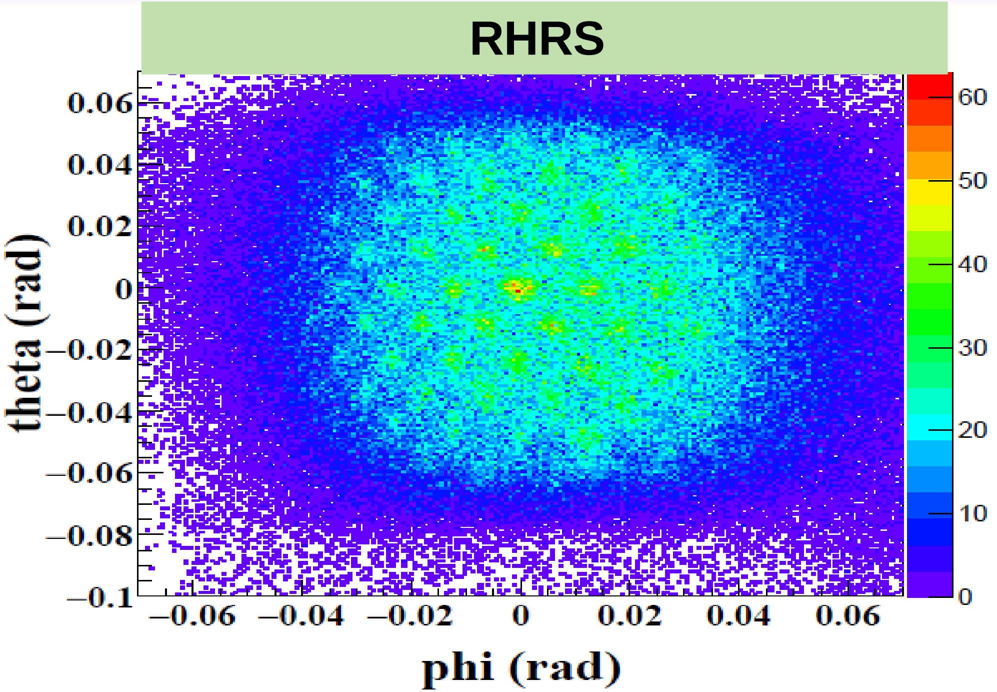




- Each *z*-vertex was optimized separately with the single arm trigger data.
- For the e' and K^+ coincidence data, the average of the two independently reconstructed *z*'s from LHRS and RHRS was used as average *z*.
- A *z*-vertex resolution of about σ = 4.5 mm was achieved.
- For physics analysis, the average *z*-vertex ranging from -10 cm to 10 cm was used.

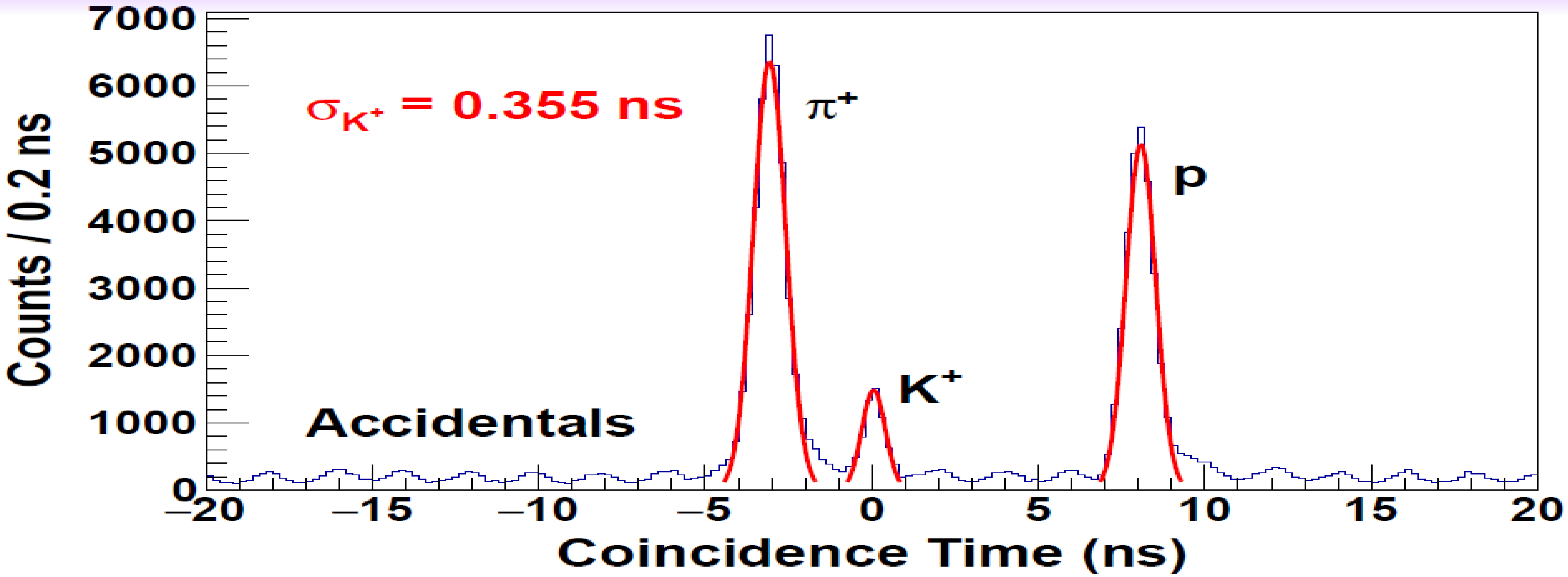
Reconstructed angles with Optimized Matrices:





- For the LHRS, the thickness of the SS plate was sufficient to stop the electrons that did not pass through the SS holes.
- For the RHRS, the thickness of the SS plate was unable to prevent the heavy particles (such as π^+'s and protons) that did not pass through the SS holes.
- A large number of hadrons punching through the SS plate and could reach to the focal plane.
- Therefore, a huge background can be seen between the RHRS SS holes.
- With the optimized matrices, the angular resolution of ~3.2 mrad for θ & ~1.1 mrad for Φ was achieved.

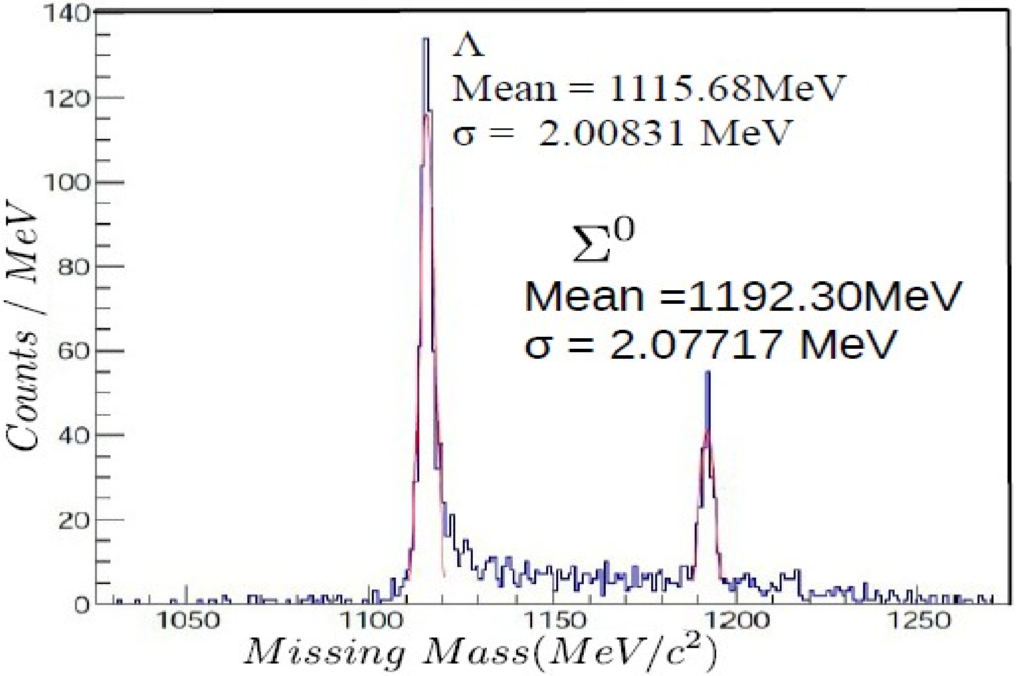
Coincidence Time Spectrum:



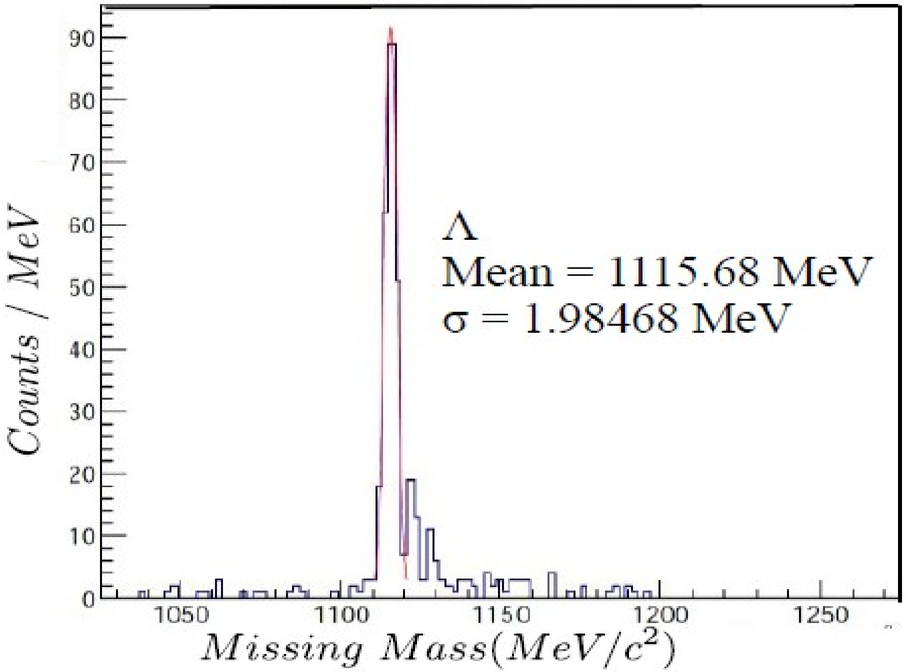
- Different hadrons have different CT, therefore CT can be used as a powerful tool to remove the unnecessary hadrons in the RHRS.
- For physics analysis a coincidence time gate of ± 1 ns was used to select the coincidental K^+'s.
- The small accidental peaks were formed by the accidental coincident events from π^+'s & protons.
- The accidental events within the ± 1 ns coincidence time window cannot be identified and removed. These events will form a background distribution in the physical mass spectroscopy.

Initial Momentum Optimization:

H/H Kinematics

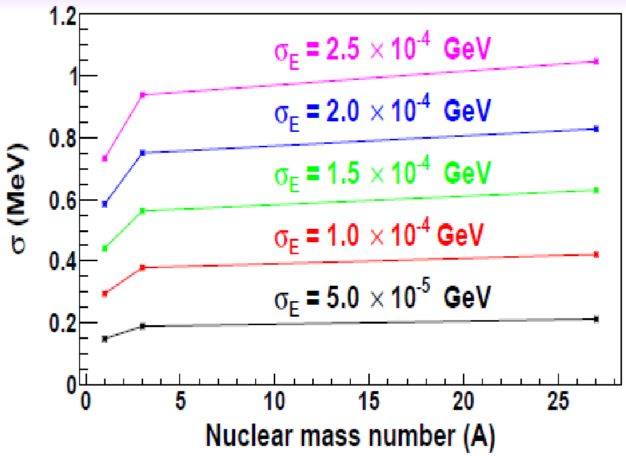


H/T Kinematics

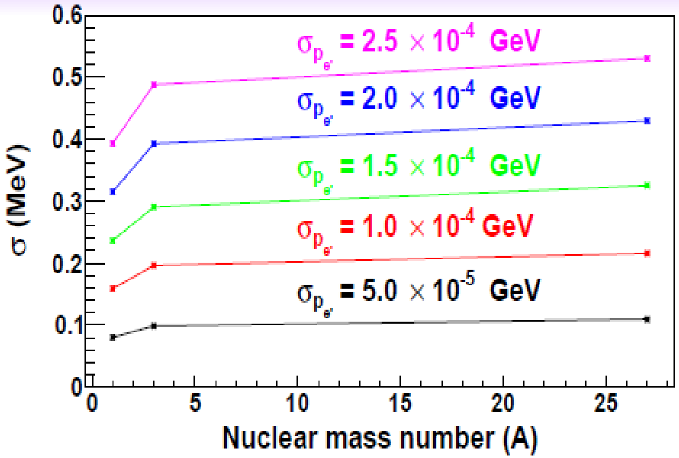


- The HRS momentum matrices were optimized with the known masses of Λ and Σ^0 .
- With the optimized matrices, the peak width of Λ and Σ^0 was reached about 2 MeV (σ).
- Further tune did not improve the optics quality.
- Two problems were recognized: (i) the time jitter for the RHRS VDC (solved by software correction) (ii) the dependence on the residual angular uncertainties.

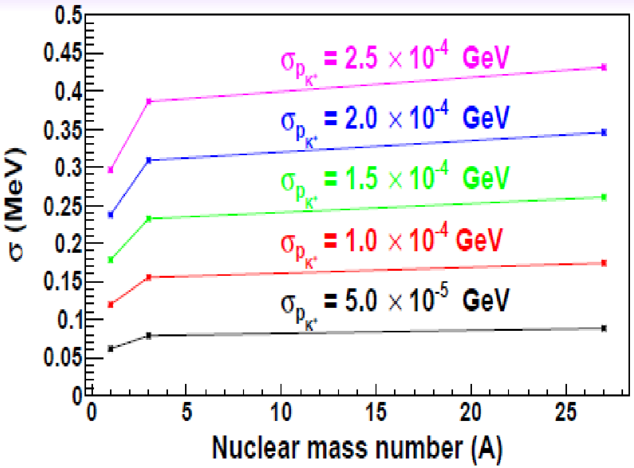
Monte Carlo Simulation:



Beam Energy is smeared at different level of uncertainties



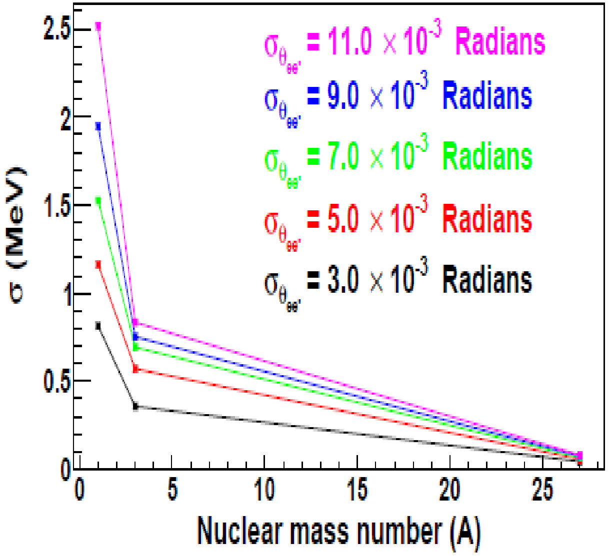
LHRS momentum is smeared at different level of uncertainties



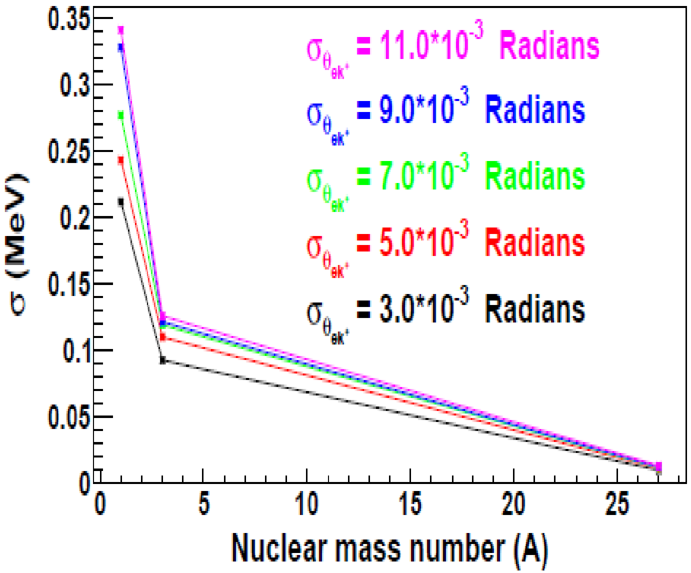
RHRS momentum is smeared at different level of uncertainties

- A Monte Carlo (MC) simulation was performed to study the missing mass resolution achievable by this experiment and to make a prediction to the missing mass resolution for the A = 3 system.
- The simulation investigation has two parts.
- In the first part, the events were generated randomly according to the experimental conditions by evaluating the real data.
- The second part studied the missing mass resolution by introducing uncertainties from the beam energy, HRS momentum and HRS angles.
- It was found that the uncertainty contributions from beam energy and HRS momentum are dominated for heavy mass system (that is the resolution for light mass system is less sensitive than that of heavier one).

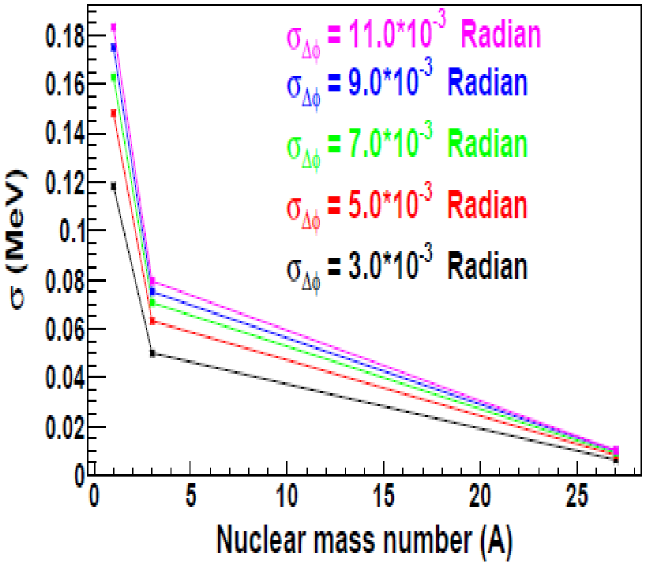
Monte Carlo Simulation Continue:



e' scattering angle is smeared at different level of uncertainties



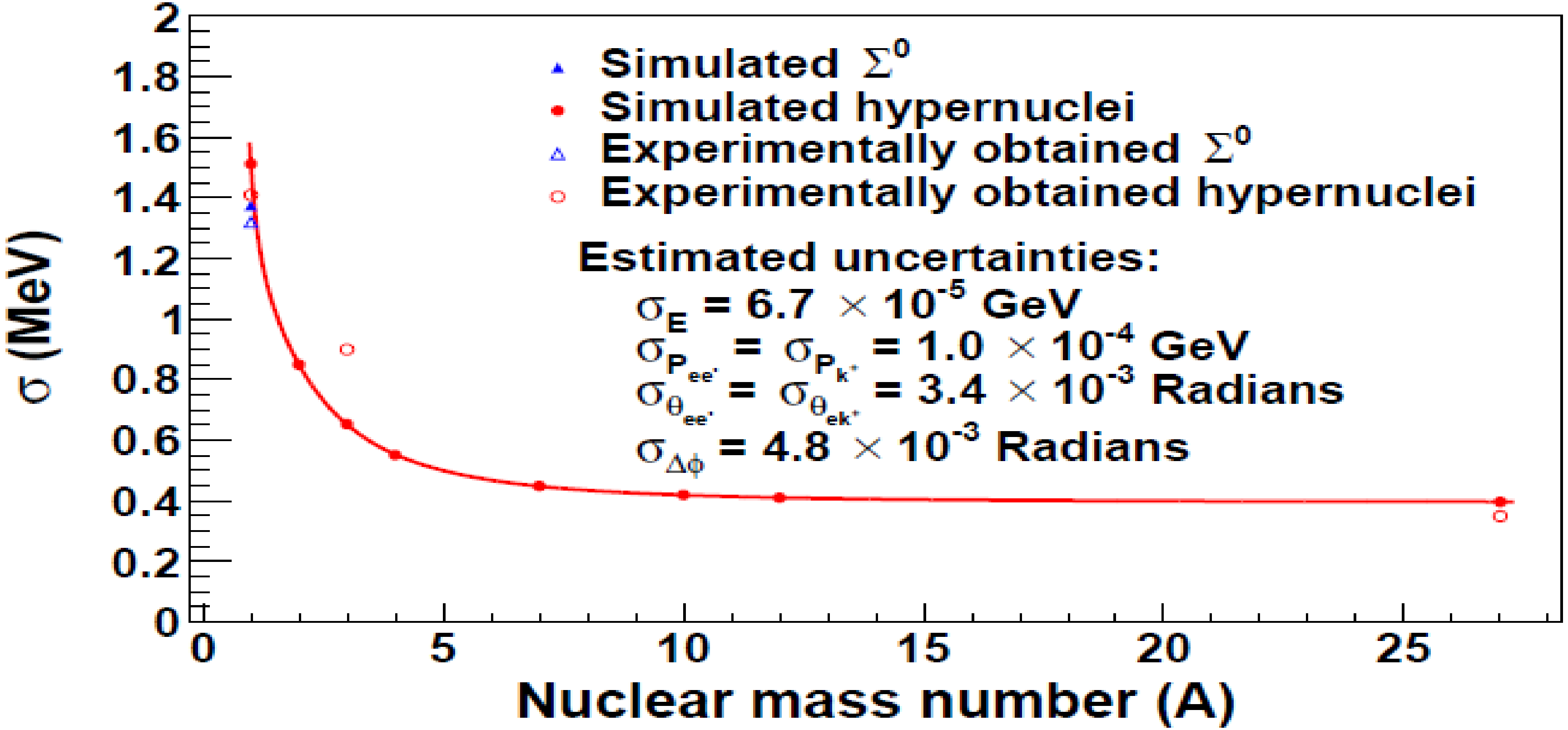
K$^+$ *reaction angle is smeared at different level of uncertainties*



Reaction plane angle (Δφ) is smeared at different level of uncertainties

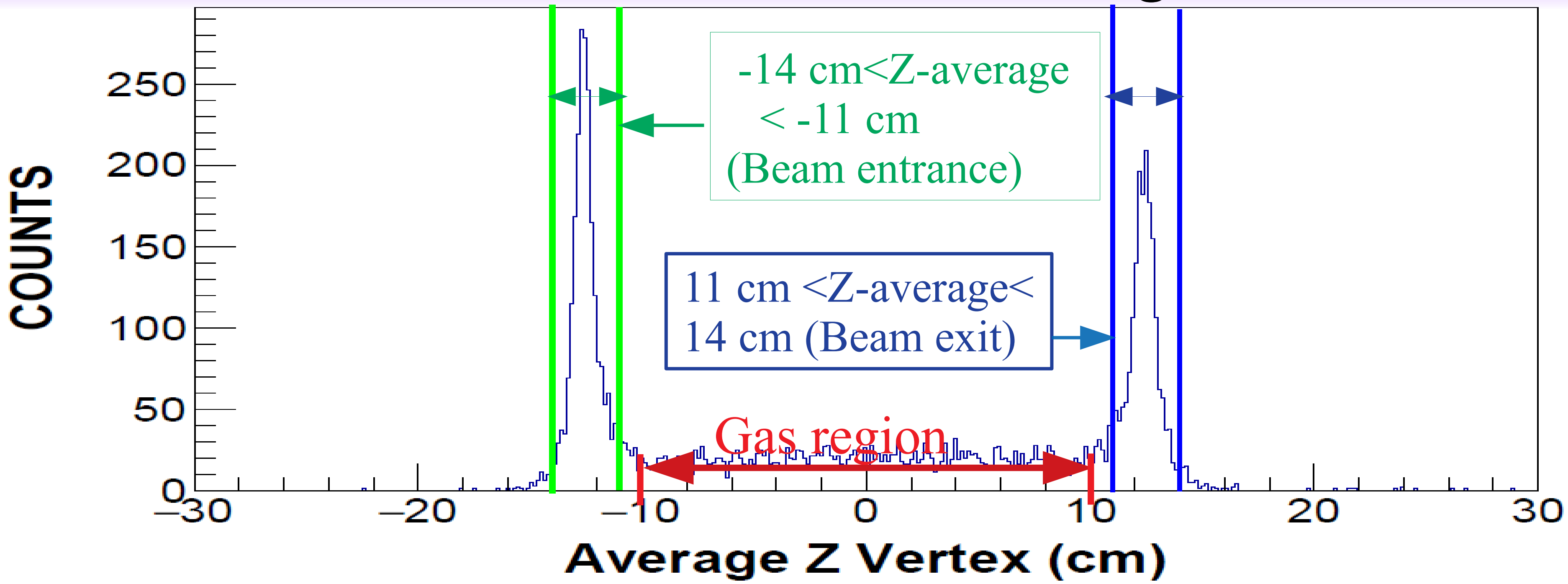
- The A dependence for all these three contributions shows a common feature that the light mass system (especially A= 1) are much more sensitive to the angular uncertainty.
- The e' scattering angle has dominant uncertainty contributions because the mass of the scattered electron is much lighter than that of K$^+$.

Monte Carlo Simulation Continue:



- The result suggested that in order 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 Λ and Σ^0 masses.

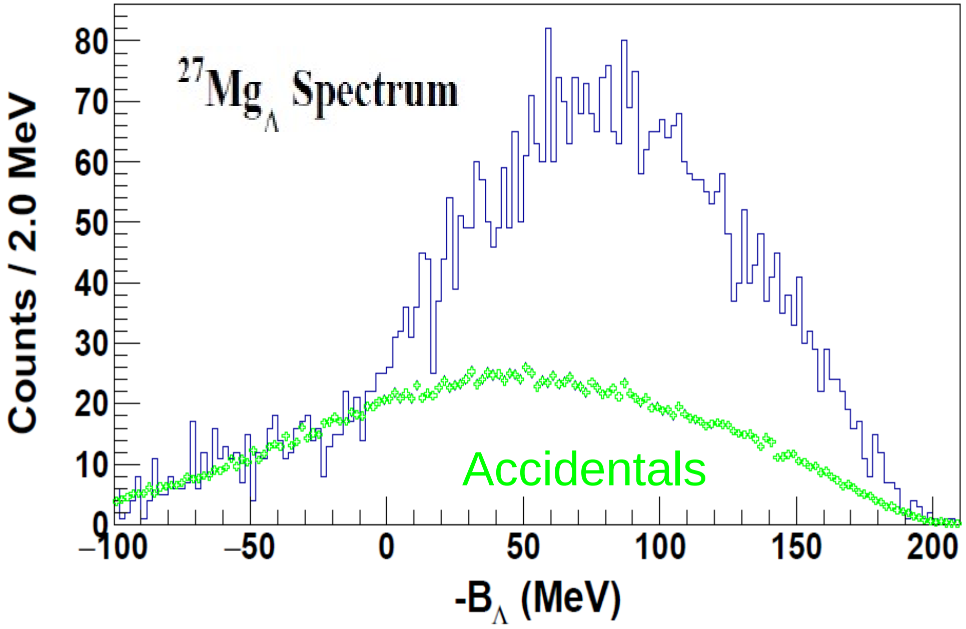
Al is Considered as a Target:

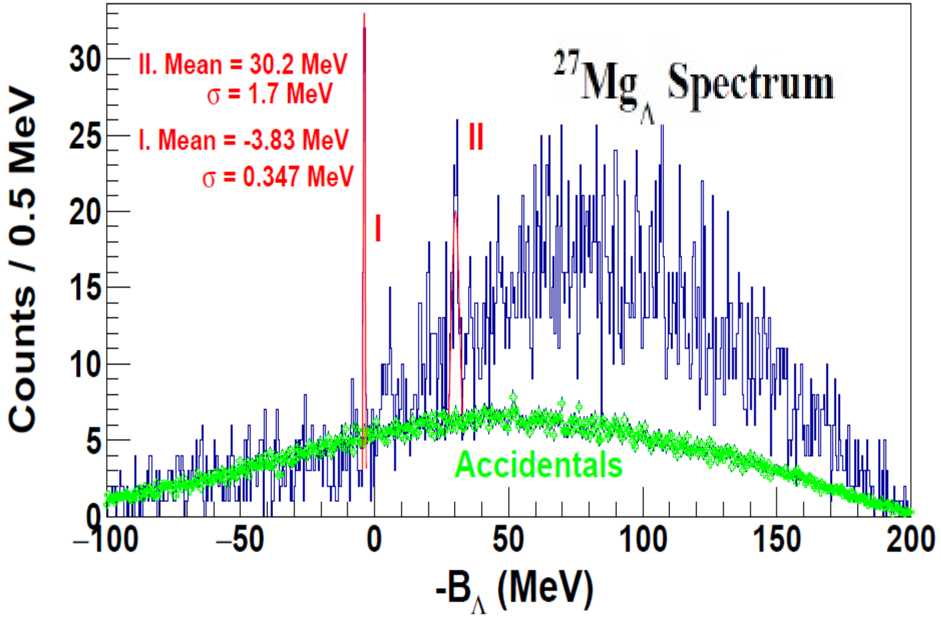


- The target cell was made of 7075 aluminum alloy (~ 90% ^{27}Al, ~5.6 % Zn, ~2.5% Mg, ~1.6% Cu and ~ 0.3% other metals) in which ^{27}Al was dominant.
- The main role of the ^{27}Al was try to find the best possible state which is sufficiently heavy so that momentum Matrix will not be suffered from the angular uncertainty and the Λ and Σ^0 will play the role of boundary conditions.
- The events from the beam entrance and beam exit Al windows were selected and combined together to produce the $^{27}{}_{\Lambda}$Mg hypernuclei.

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

Before Al data involve in Tune	After Al data involve in Tune

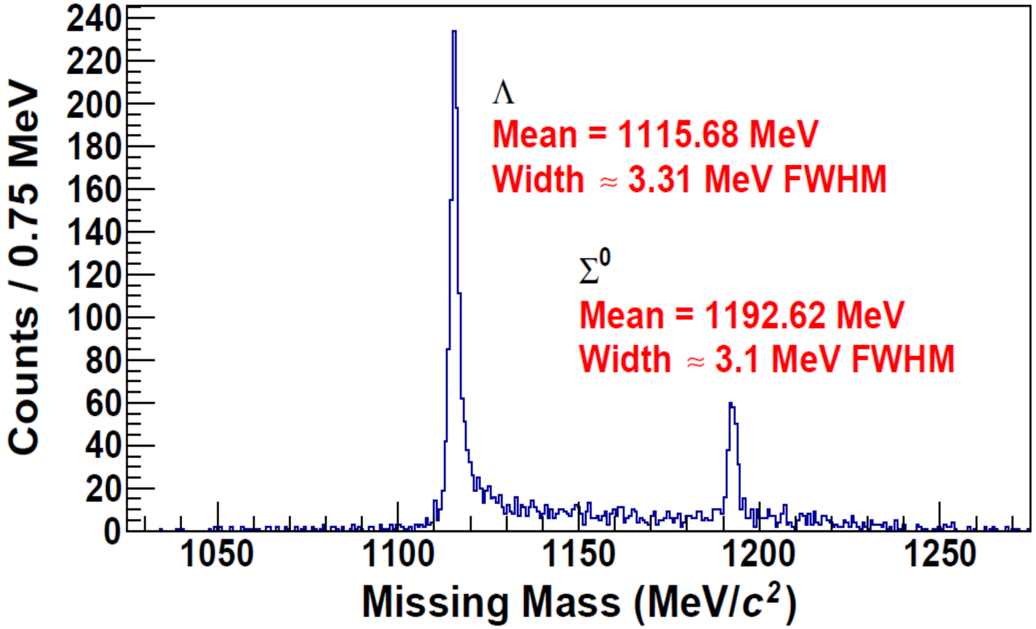




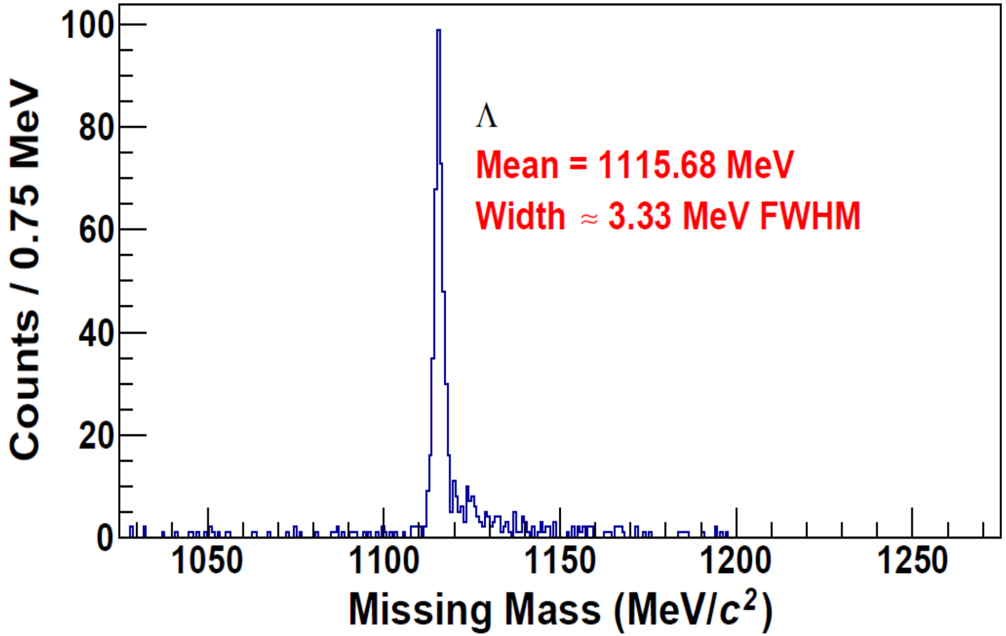
- To involve the Al data in the matrix tune, a peak search test was performed to find the events from the possible single particle state.
- Only the events from the bound state were involved in the matrix tune.
- The resolution of the first Al peak agreed well with the simulation.
- The distribution formed by the green crosses represent the accidental background shape.

Missing Mass Spectrum:

H/H Kinematics

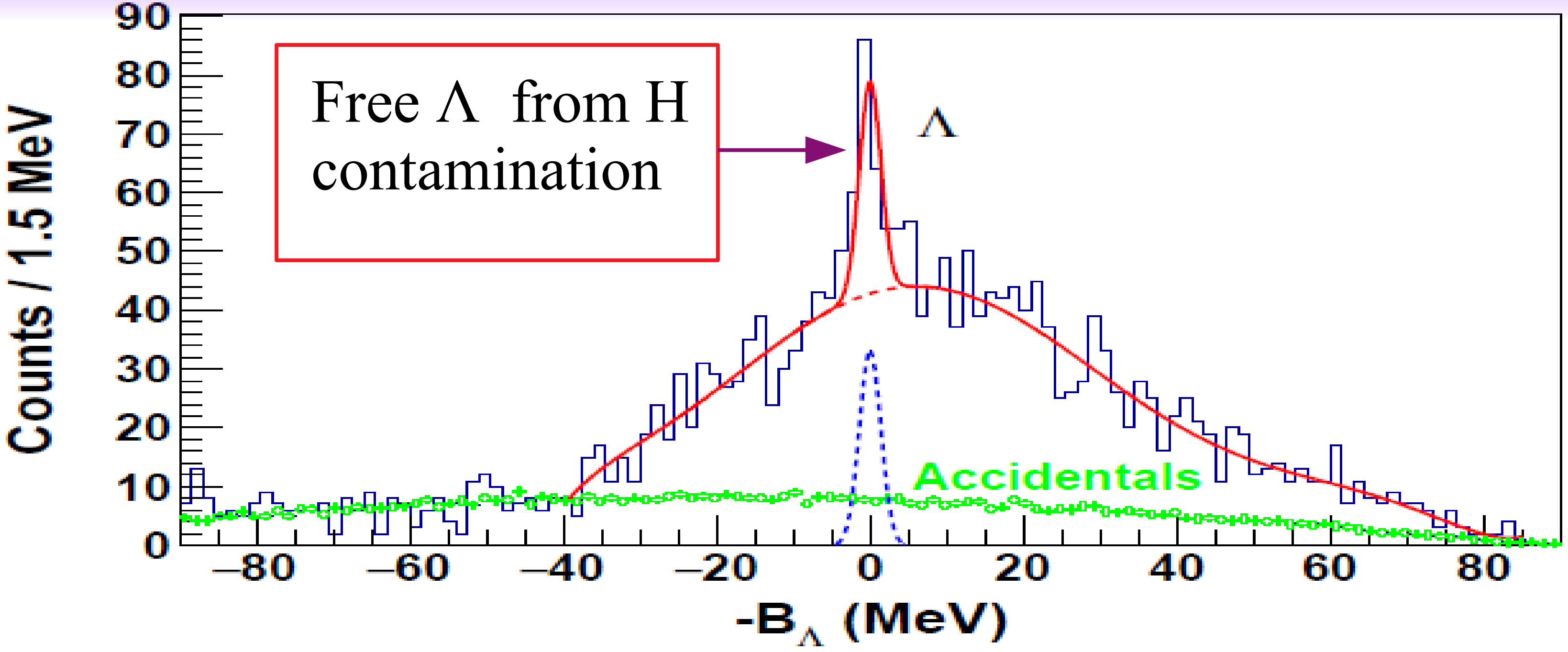


H/T Kinematics



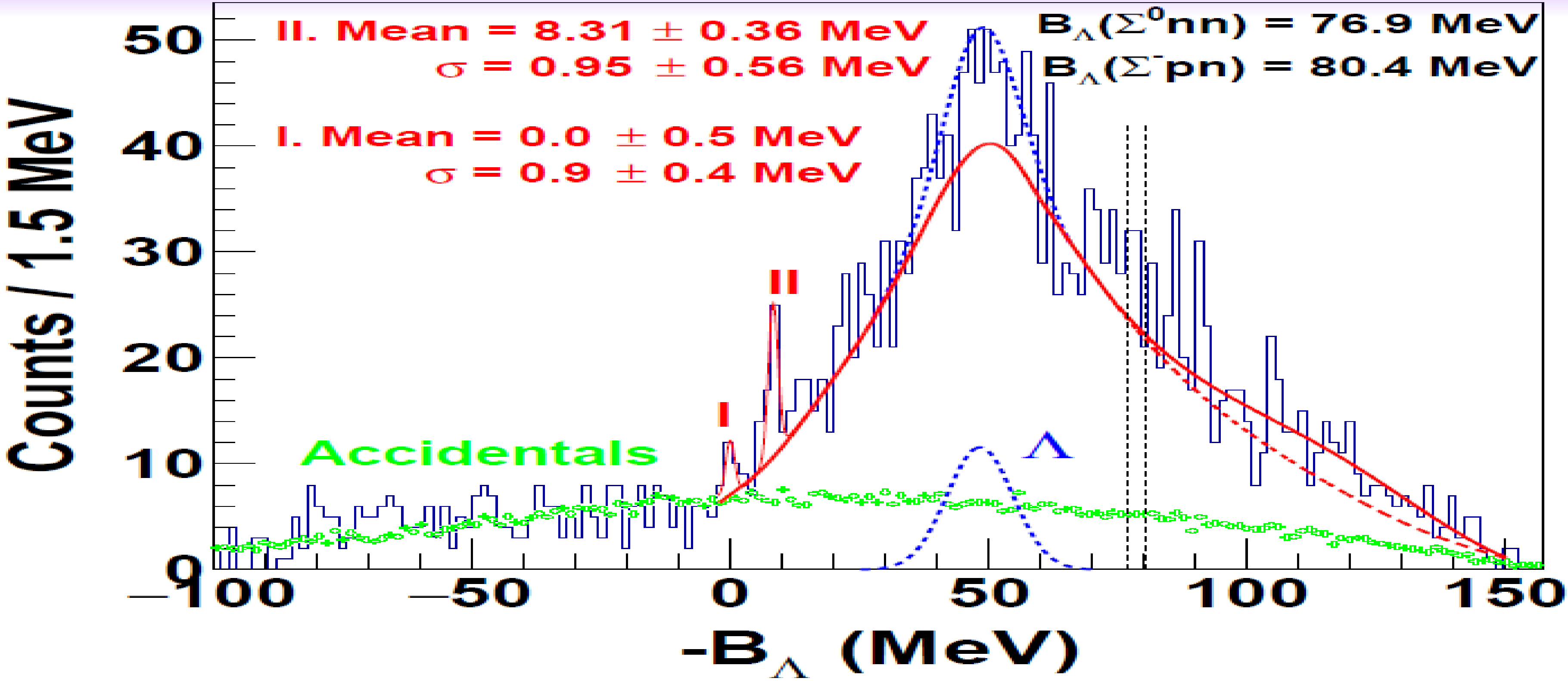
- These are the important data sets used for the absolute missing mass calibration.
- The Λ and Σ^0 landed at their known masses with a separation of 76.94 MeV/c^2 (Nominal separation = 76.96 MeV/c^2).
- Achieved resolution of Λ and Σ^0 agreed with the simulation.
- Systematic uncertainty for the missing mass (binding energy) found ~ 100 keV.

Hydrogen Contamination Test:



- The previous tritium experiment (E12-11-112) reported that about 2% of H was present in the tritium gas.
- To confirm this, the tritium data were then analyzed by H kinematics, the clear peak at B_Λ = 0 MeV verifies the presence of H in the tritium gas.
- The total no of free Λ's were estimated & found ~ 100 counts which corresponds to 2% of H.
- This peak is expected in the Λnn spectrum (with ~100 counts) with a broader width.

Mass Spectroscopy of ${}^{3}_{n}\Lambda$:



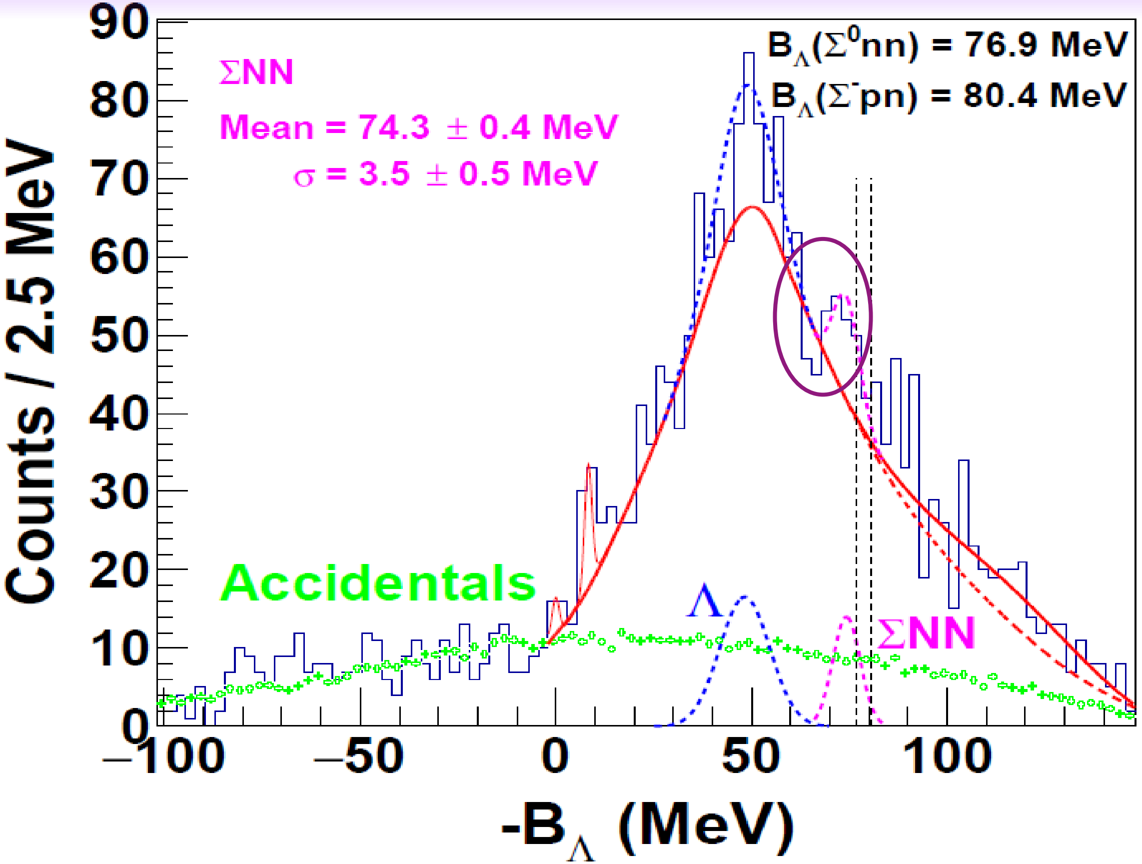
- The 1st peak is possible to be the expected resonance. However, the statistics is very low.
- For the 1st peak, the cross section and st. significance are found ~ 1.3 nb/sr and ~ 2.1 respectively.
- For the 2nd peak, cross section & st. significance are found ~ 3.66 nb/sr and ~4.5 respectively.
- The 2nd peak at such higher excitation was not expected, therefore, its origin is unclear.

Mass Spectroscopy with Higher Bins:

- For the ΣNN peak, the cross section and statistical significance are found ~ 8 nb/sr and ~ 3.1 respectively.

- The bound A = 3 and 4 Σ hypernuclei were predicted long ago, however only an A = 4 Σ hypernuclei (${}^{4}_{\Sigma}He$) was observed by the experiment using the ${}^{4}He(K^{-},\pi^{-})$ at BNL-AGS.

- Jefferson Lab also studied these hypernuclei, however no such visible spectrum was found above the QF distribution.



- For this experiment, the Σ^0 production threshold is lower which indicates that the observed enhancement may likely be a bound ${}^{3}_{\Sigma}n$ hypernuclei.

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 two resonance states of $^{3}_{\Lambda}n$ and one bound state of $^{3}_{\Sigma}n$ were 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 = 0.67 MeV. Thus, the natural width is about 0.6 MeV.
- However, due to low statistics the precision does not permit sufficient constrain in determination of the Λ-n Interaction.

Acknowledgements:

Financial Support:

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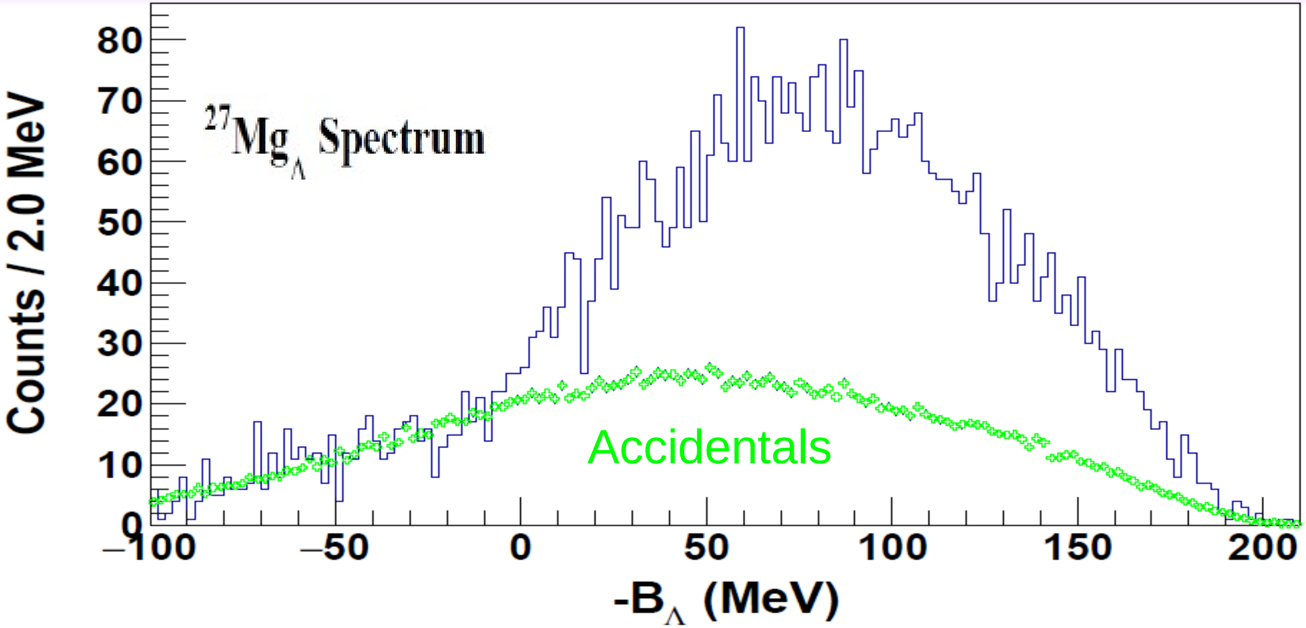
Collaborators:

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

Thank you

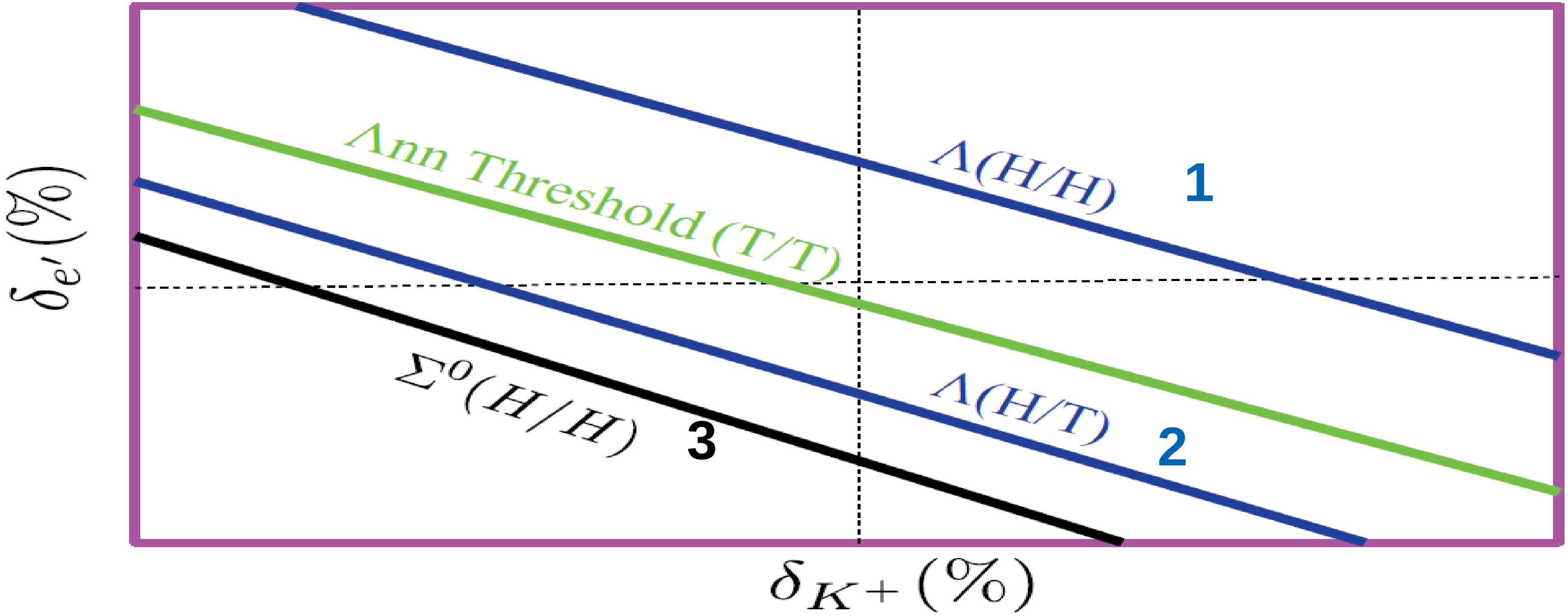
Backup slides

Test Tune with the Al Data:



- To involve the Al data in the matrix tune, a peak search test was performed.
- For the test tune different regions of the spectrum were selected and then the selected regions were tested to see the events from a possible a single particle state.
- Since the selected region did not have sufficient events, therefore a sufficiently high statistical weight was given to the Al events so that they have a dominant contribution.
- When such a location was found the spectroscopy of $^{27}{}_{\Lambda}Mg$ in the threshold region appeared improving. At the same time the width of Λ and Σ^0 also improved slightly.

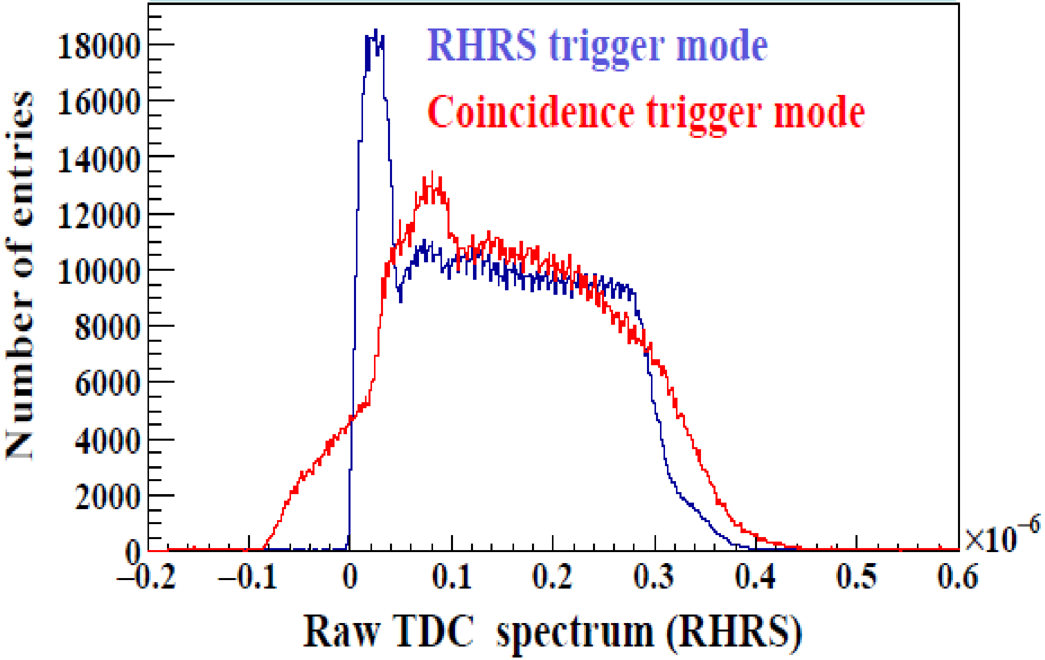
Kinematic Space for e,e'K$^+$ Experiment:



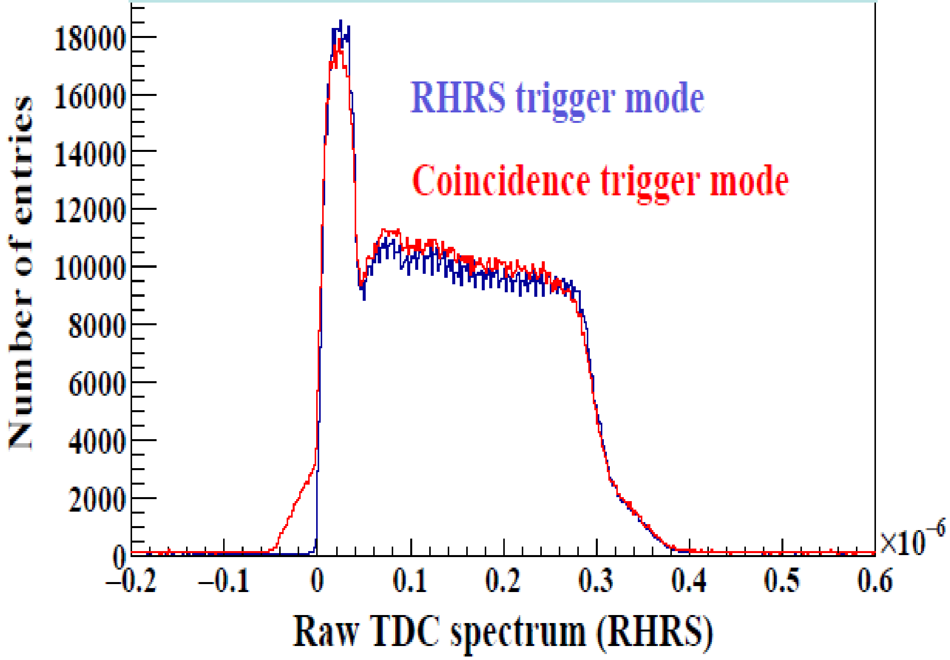
- The momentum calibration is the two dimensional correlation.
- There are only three data point to calibrate the momentum matrices.
- There is large kinematic gap between the two Λ correlation lines.
- The optics quality may not be uniform in the gap region.

Time Jitter Correction:

Before time jitter correction



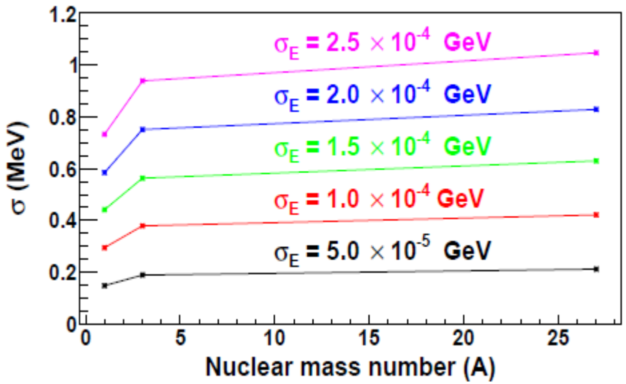
After time jitter correction



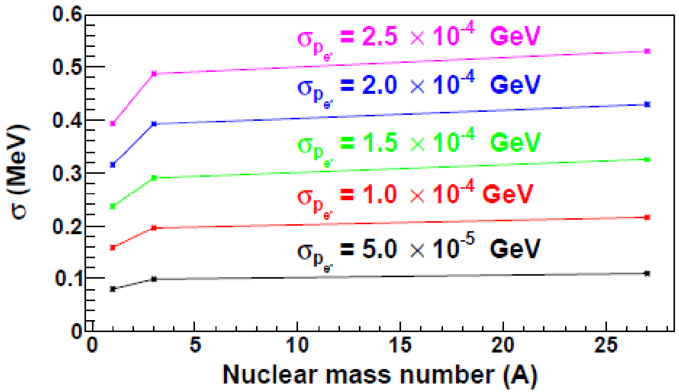
- For the coincidence events at the right arm, the VDC's drift time was found having a time jitter and affecting the momentum optimization as well as the missing mass resolution.
- This problem was minimized by applying a software correction on an event-by-event base to the raw TDC data.

Monte Carlo Simulation:

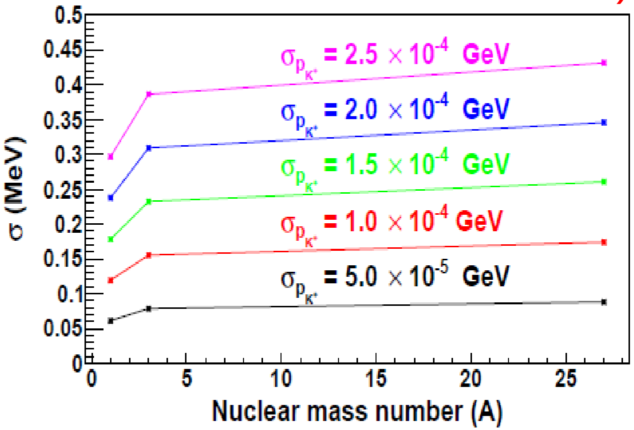
- A Monte Carlo (MC) simulation was performed to study the missing mass resolution achievable by this experiment and to make a prediction to the missing mass resolution for the A = 3 system.
- The simulation was done by assuming the identical experimental conditions and it has two parts.
- In the first part, the events were generated randomly according to the identical experimental conditions by evaluating the real data.
- The second part studied the missing mass resolution by introducing uncertainties from the beam energy, the momentum from LHRS (e') and RHRS (K^+), and the scattering angle (θ) in spherical coordinates for e' and K^+ , and the angle (φ - φ') between the scattering and reaction planes.
- It was found that the uncertainty contributions from beam energy and HRS momentum are dominated for heavy mass system (that is the resolution for light mass system is less sensitive than that of heavier one).



Beam Energy is smeared at different level of uncertainties



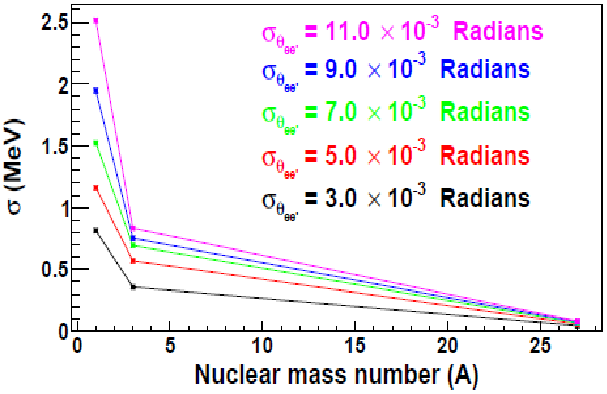
LHRS momentum is smeared at different level of uncertainties



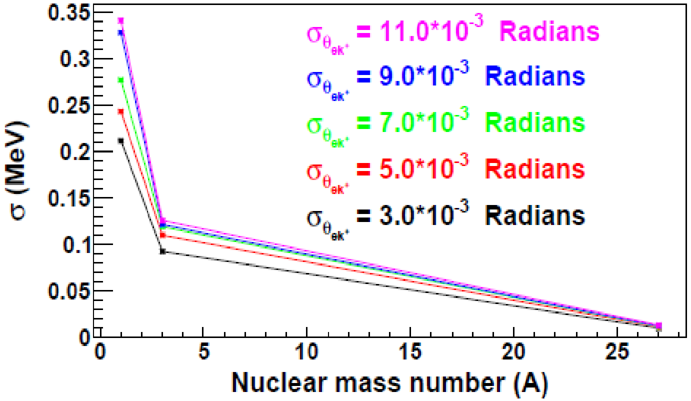
RHRS momentum is smeared at different level of uncertainties

Monte Carlo Simulation Continue:

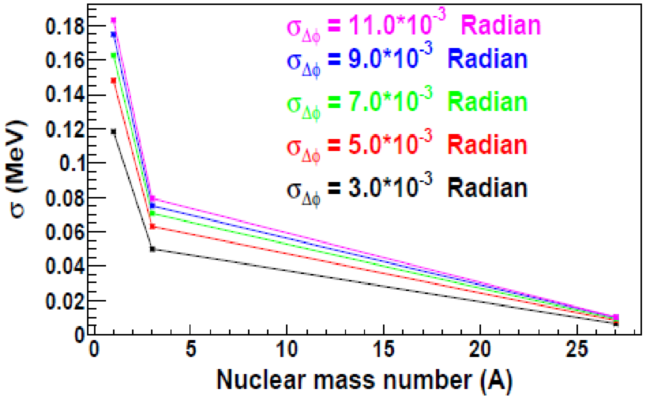
- The uncertainty contributions from e' scattering angle, the K^+ reaction angle, and the reaction plane angle, are dominated for the light mass system especially for A = 1.



e' scattering angle is smeared at different level of uncertainties



K^+ *reaction angle is smeared at different level of uncertainties*



Reaction plane angle (Δφ) is smeared at different level of uncertainties

- The A dependence for all these three contributions shows a common feature that the light systems are much more sensitive to the angular uncertainty.
- The e' scattering angle has dominant uncertainty contributions because the mass of the scattered electron is much lighter than that of K^+.
- The result suggested that a heavy system need to be involved in the momentum matrix optimization in order to reach the best achievable resolution under this experimental condition.