JLab Experiment: Searching for The Possible Λnn Resonance

Determining the Unknown Λn Interaction by Investigating the Λnn Resonance

(*E12-17-003: Just completed in November of 2018*)

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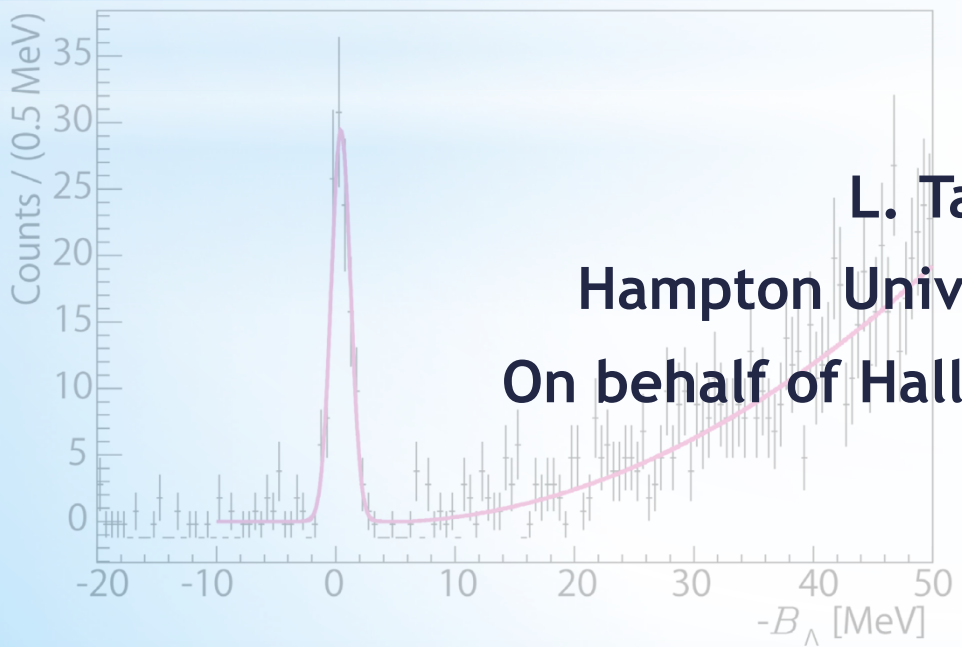
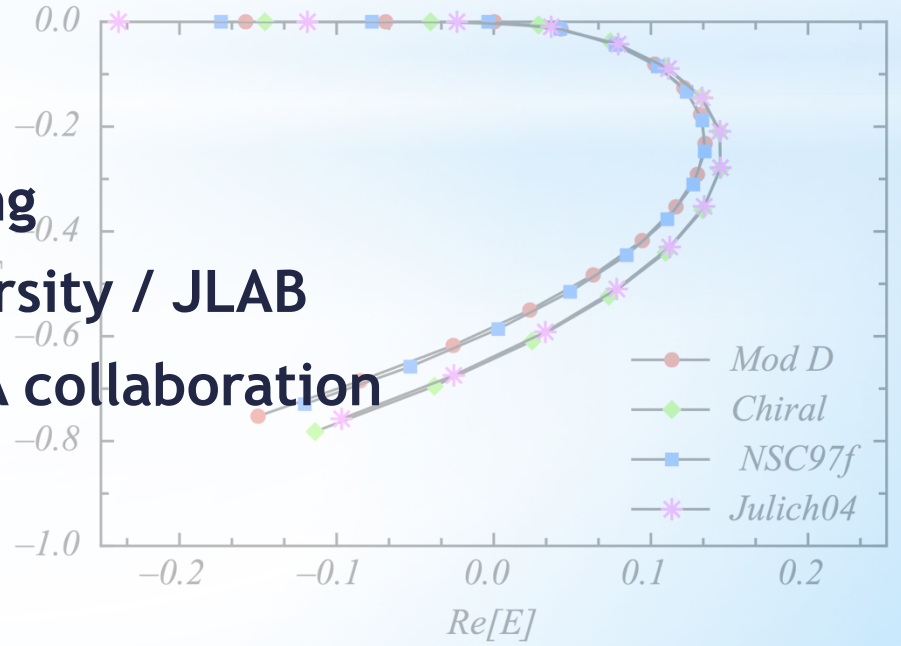
On behalf of Hall A collaboration





INTRODUCTION

- Understanding the baryonic interaction with all flavors is one of the essential goals of nuclear physics.
- For *NN* interaction, there are plenty of scattering data, while for the *YN* and *YY* interactions scattering data are extremely limited or none. Hypernuclei have so far been predominantly used as laboratory to study *these "Strange" (S =-1) baryonic* interactions. *For the JLab program on hypernuclei, we focus on the* ***ΛN*** *interactions.*
- Experimental data from study of hypernuclei have so far made significant contribution in acquiring indirect or supplemental information on the *ΛN* interact.
- However, the standing puzzles (*such as Charge-Symmetry-Breaking and "Hyperon Puzzle" on neutron star's mass*) may urge us looking into more direct ***ΛN*** interaction data.

MODELING THE *B-B* INTERACTION

APPROACH: Combined analysis with input from available ***NN***, ***YN***, ***YY*** scattering data, ***nuclear*** and ***hypernuclear*** data on *BE* and U_Y, plus hadron physics (*Experiments and Theory on flavors, quarks, QCD dynamics*)

N-N Scattering

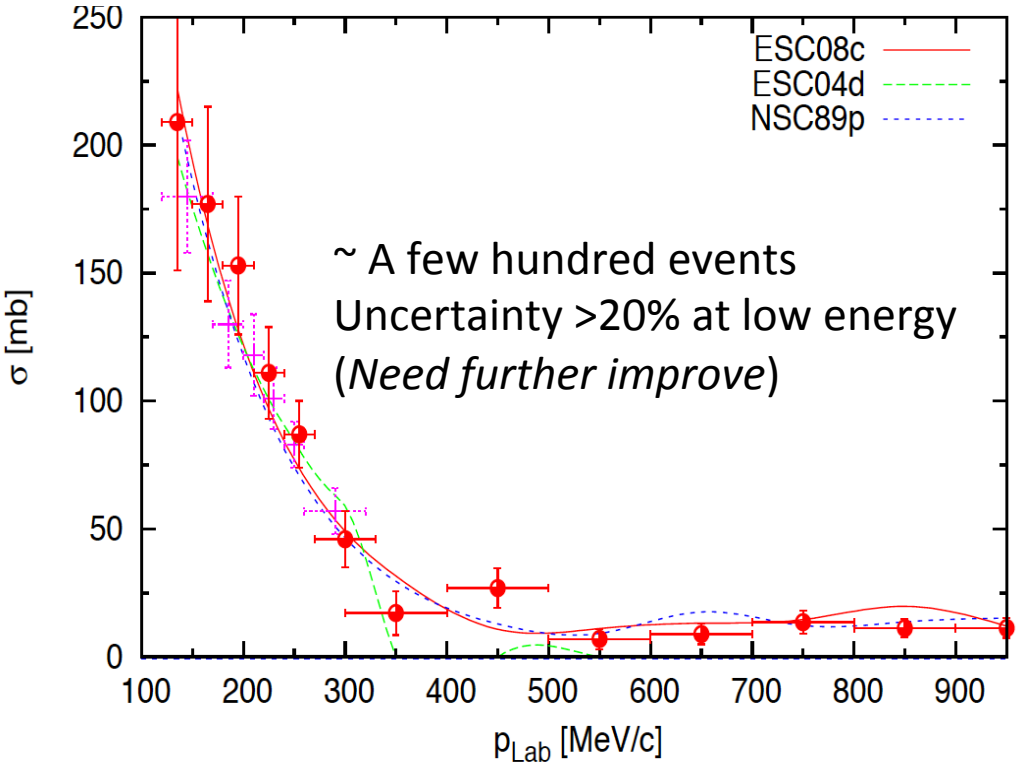
> 4000 events
+ low energy part

This made NN interaction much better understood

Λ-n Scattering

None!

Λ-p Scattering



Based on the ***NN*** interaction, the ***Λn*** interaction is treated to have the same properties as that of ***Λp*** interaction

CHARGE SYMMETRY BREAKING (CSB)

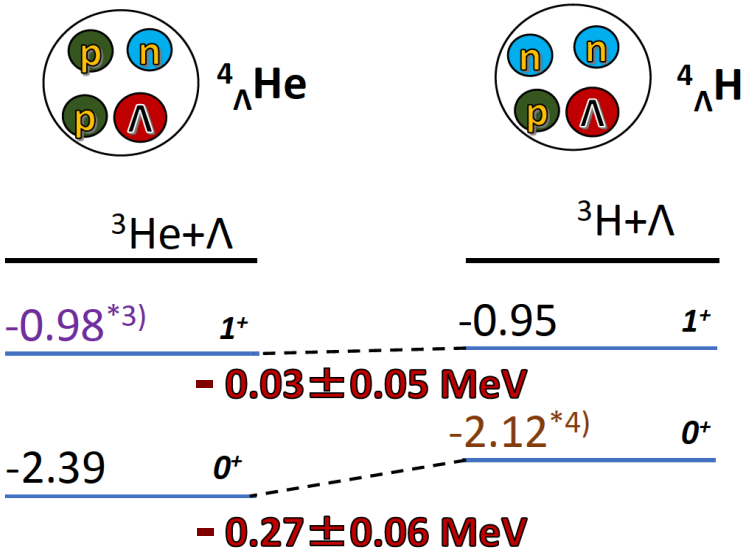
N-N Interaction

$$\Delta B = 0.76384\ (26)^{*1)}\ \text{MeV}$$
$$\Delta B_{em} = 0.683^{*2)}\ \text{MeV}$$

0.081 MeV

*1) J.H.E. Mattauch *et al.*, Nucl. Phys. **67**, 1 (1965).
*2) R.A. Brandenburg *et al.*, NPA **294**, 305 (1978).

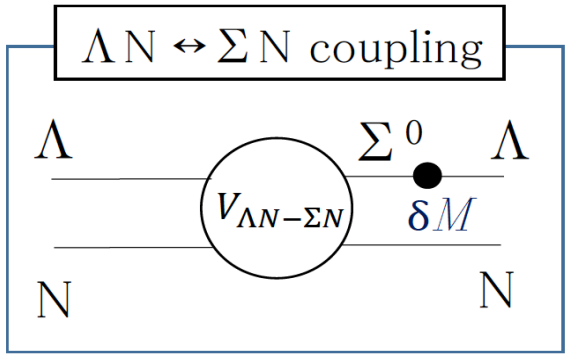
Λ-N Interaction



*3) T.O. Yamamoto *et al.*, Phys. Rev. Lett. **115**, 222501 (2015).
*4) A. Esser *et al.*, Phys. Rev. Lett. **114** 232501 (2015).

This leads to:

1. ***Good approximation w/o CSB.***
2. ***Common for B-B interactions, i.e. Λp and Λn interactions are treated basically identical.***



D. Gazda, A. Gal, Nucl. Phys. A **954**, 161 (2016).

A. Gal, Phys. Lett. B **744** 352 (2015).

Experimental data of *Λn* interaction becomes extremely valuable

POSSIBLE EXPERIMENTAL APPROACHES

- $d(\gamma, K^+)\Lambda n$ reaction: Studying Λn interaction through final state interaction.

  Challenge: Model dependence

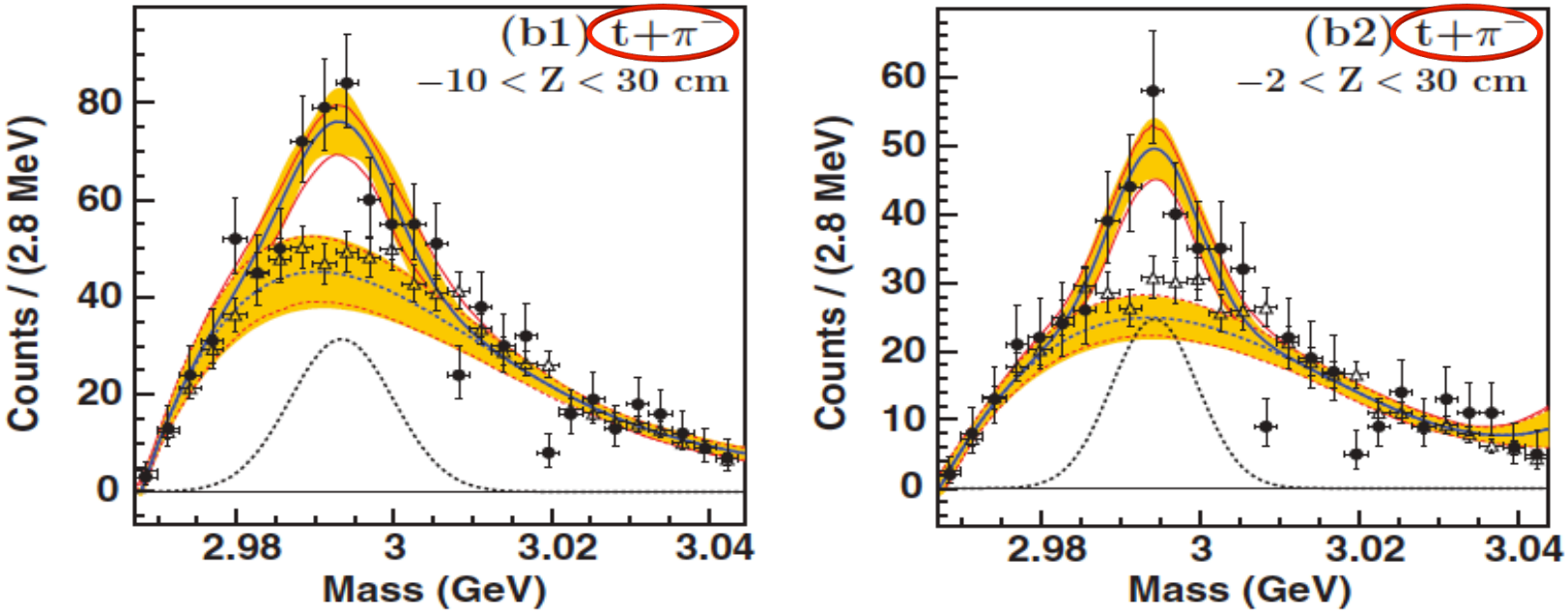
- $d(K^-_{stop}, \gamma)\Lambda n$ reaction: Pure final state interaction.

  Challenge: Limited energy resolution for γ *detection at* ~300 MeV and very high cost

- Possible *Λnn resonance?*

OBSERVATION OF A POSSIBLE *Λnn* SYSTEM

^{6}Li (2A GeV) on ^{12}C target and study the invariant mass of final state particles



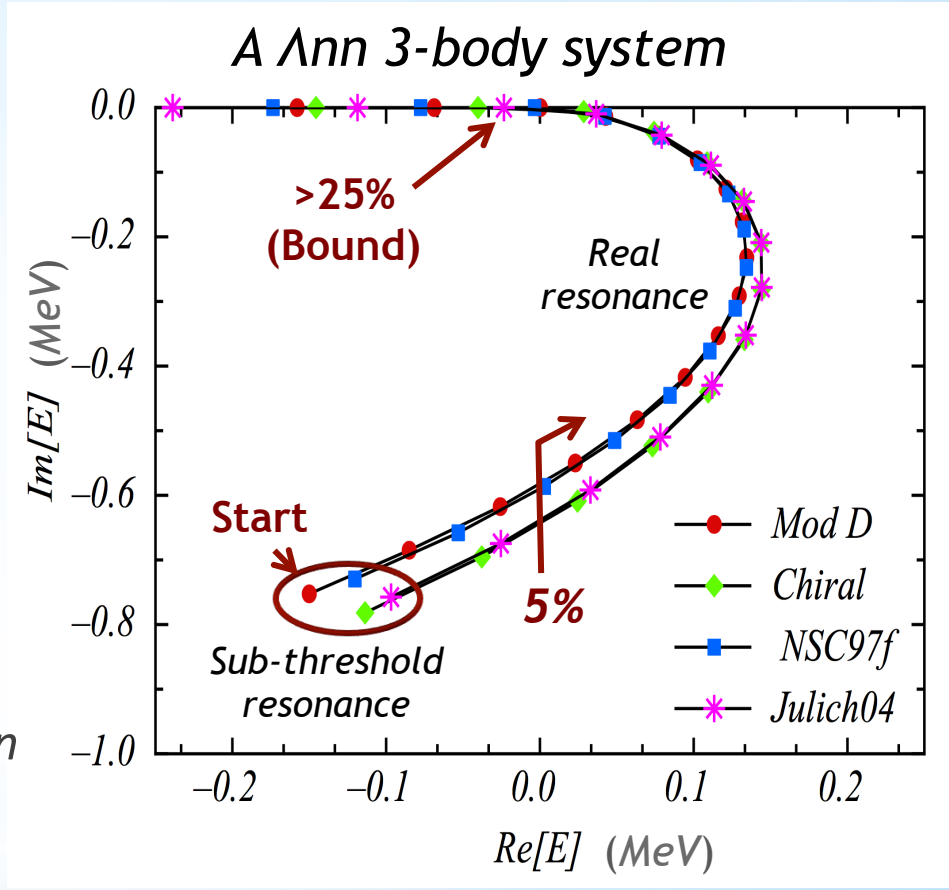
*C. Rappold et al., Phys. Rev. C **88**, 041001(R) (2013)*

- It was claimed to a bound state based on non-mesonic decay and lifetime.
- All theoretical analyses applying the current *YN* interaction modes ruled it out.
- But a few theoretical studies indicated that a physical resonance is possible
  [For example: H. Kamada, *EPJ Web of Conferences **113**, 07004 (2016)*]
- If such a resonance does exists, it may provide us for the first time the experimental information about ***Λn*** interaction.

THEORY INVESTIGATION ON *Λnn* RESONANCE

Iraj R. Afnan and Benjamin F. Gibson, Phys. Rev. C 92, 054608 (2015)

- Pairwise interactions of rank one, *i.e.* separated potentials for *nn* and *Λn* interactions.
- Four different baryonic potential models were used to fit for the effective range parameters of the *nn* and *Λp* interactions from the existing scattering data.
- Solving the *Λnn* Faddeev equations into the second complex energy (*E*) plane and examining the eigenvalue.
- Assume *Λn* and *Λp* interactions are the same to begin. Continuously scaling up *Λn* strength, 2.5% per step, to obtain an eigenvalue spectrum.



➢ By measuring the ***BE*** and ***Width*** of the resonance peak, the *Λn* interaction strength relative to *Λp* interaction can be determined for the first time by an experimental data.

THE JLAB EXPERIMENT E12-17-003

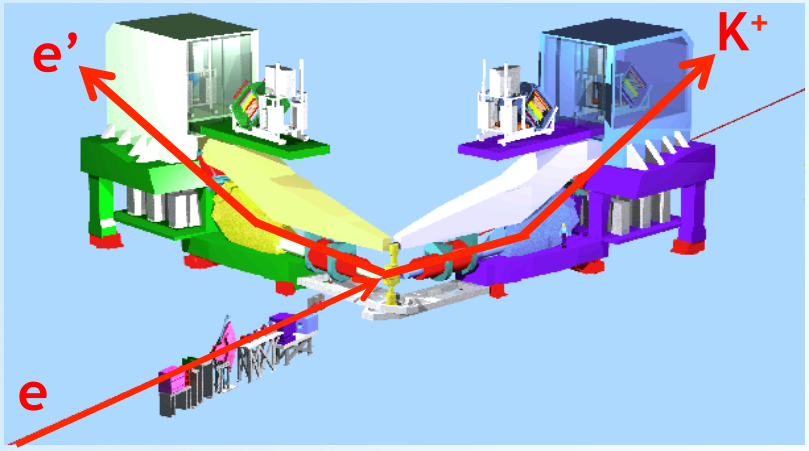
- Production: $^{3}H(e, e'K^{+})(\Lambda nn)$ reaction. It is the best for searching the Λnn state by precision mass spectroscopy.
- Experiment was carried out from Nov. 1 – 25, 2018
- With good CEBAF beam quality ($\delta E/E \approx 10^{-4}$), excellent HRS spectrometer resolutions ($\delta p/p \approx 10^{-4}$ and $\delta\theta \leq 5\,mr$), we hope to achieve:

  $\Delta(BE)_{sys} \approx \pm 0.1$ MeV (absolute mass);

  Energy resolution (peak width) ≈ 2.0 MeV FWHM.

  (The final precision depends on statistics)

EXPERIMENT E12-17-003 IN HALL A



Two HRS spectrometers were used in time coincidence for the (e,e'K^+) reaction:

L-HRS for scattered electrons (e')

R-HRS for reaction kaons (K^+)

Beam Energy: 4.319 GeV

Data were collected with two different kinematics:

H Kinematics: H target

P_K = 1.8231 GeV/c @13.2°

$P_{e'}$ = 2.1000 GeV/c @13.2°

Producing both Λ and Σ^0 for kinematics calibration

T Kinematics: T and H targets

P_K = 1.8231 GeV/c @13.2°

$P_{e'}$ = 2.2180 GeV/c @13.2°

Obtain the Λnn mass spectroscopy from T_2 and reference Λ from H_2 targets

TYPES OF DATA COLLECTED

- **Optics** *(Sufficient)*

Analysis done

- ✓ Thick-Al and dummy targets w/ and w/o raster
- ✓ Multi-foil target w/ and w/o raster, and w/ sieve slits
- ✓ Used to calibrate and optimize various reconstructions

- **Λ and Σ^0 production w/ H kinematics** *(80%, sufficient)*

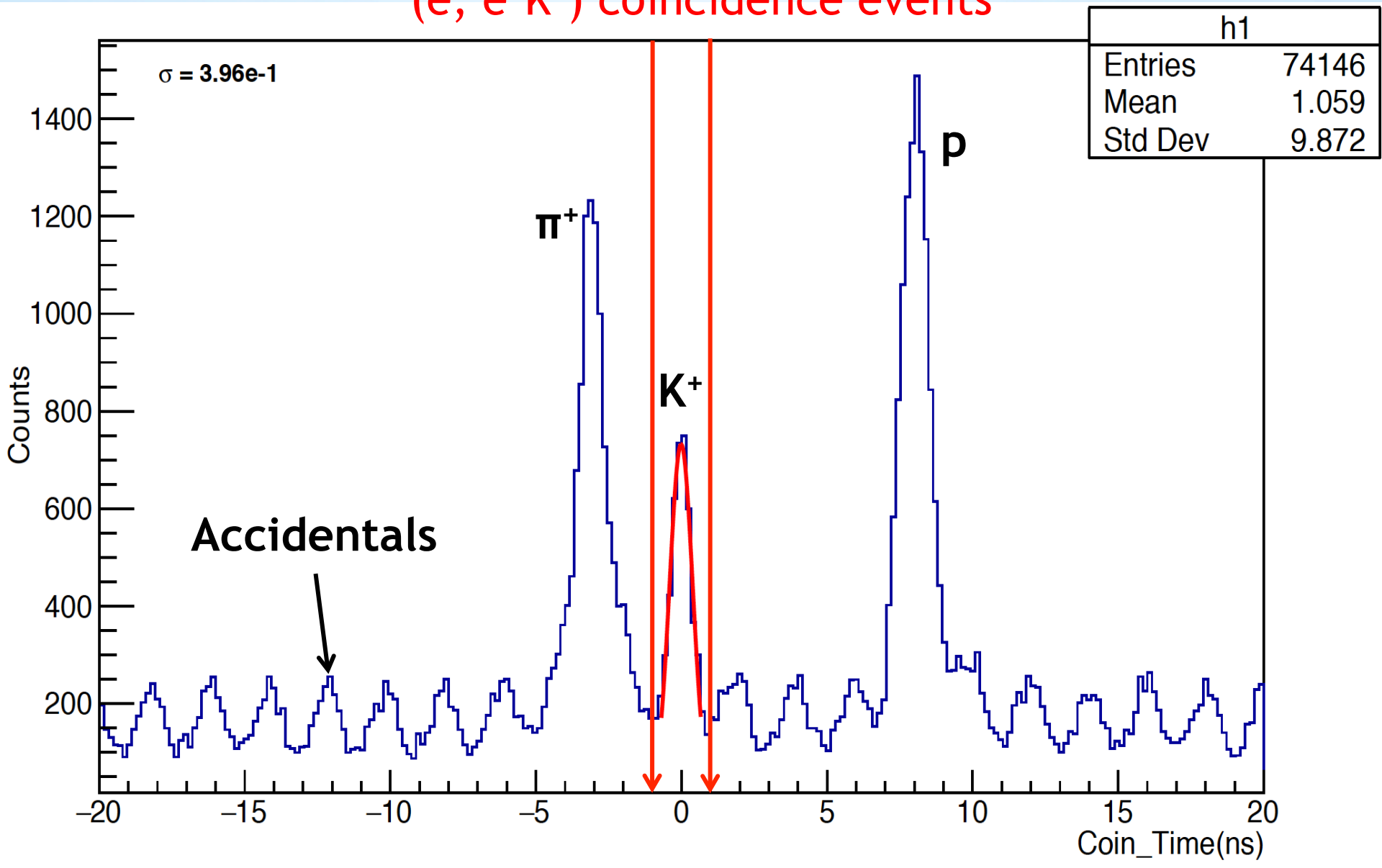
Current analysis

- ✓ Kinematics calibration with known Λ and Σ^0 masses
- ✓ Determine absolute beam E and spectrometer P_0's.

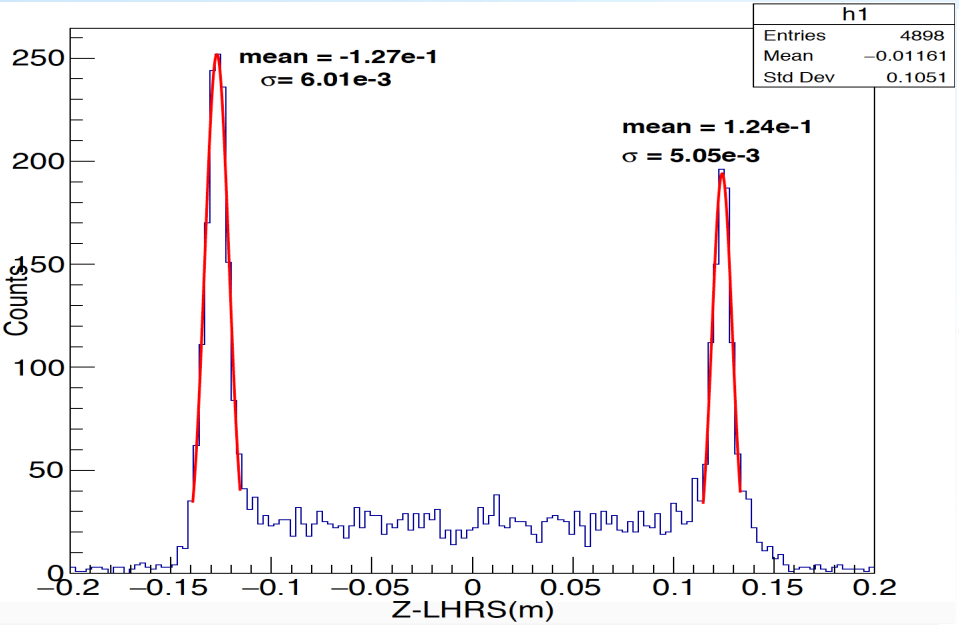
- **Λ production w/ T kinematics** *(Extra, sufficient)*
  - ✓ Check L-HRS scaling between two kinematics
  - ✓ Check the effect of H contamination (~2%)
- **Λnn production w/ T target** *(~85% of proposed)*
- **Λpn production w/ He target** *(Extra)*
  - ✓ Check the effect of possible He contamination

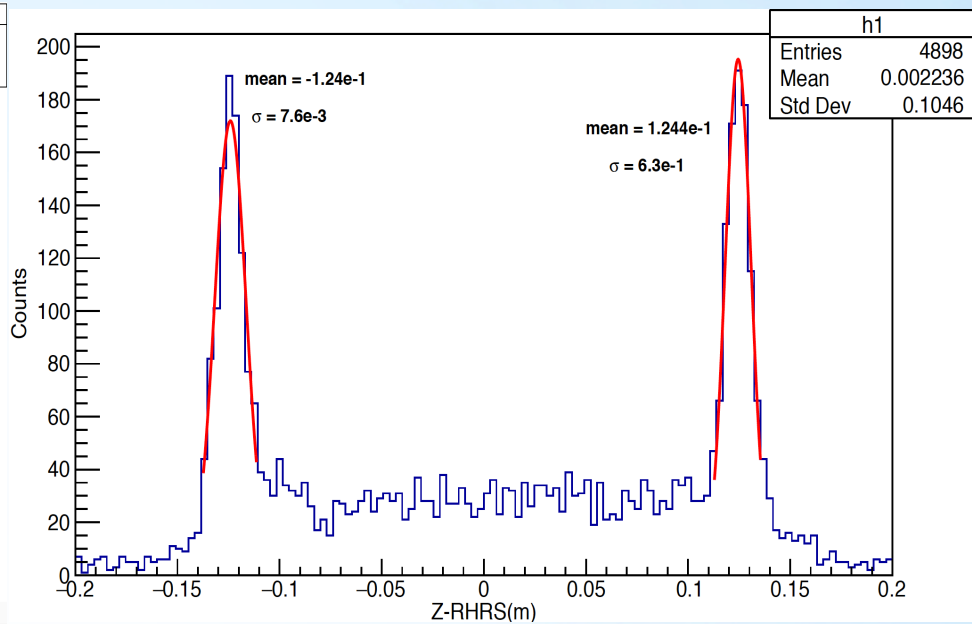
CURRENT ANALYSIS HIGHLIGHTS

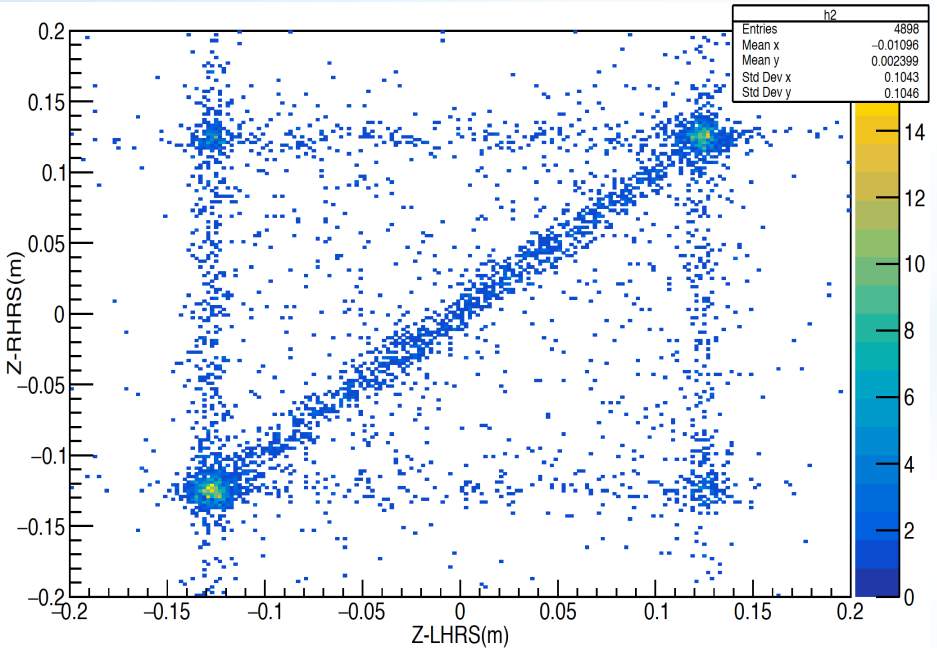
(e, e'K^+) coincidence events

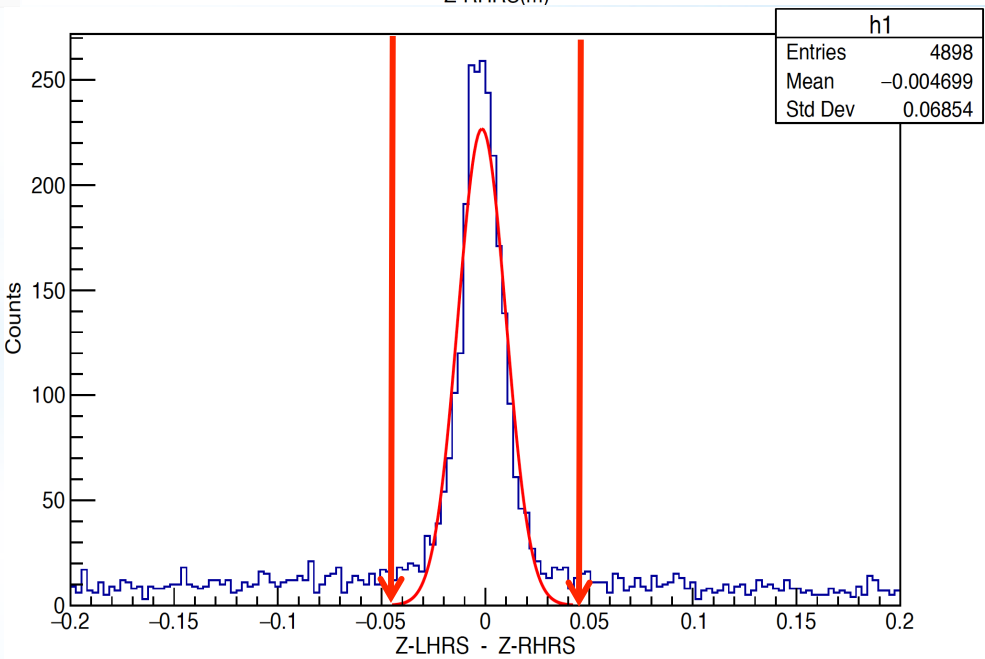


CURRENT ANALYSIS HIGHLIGHTS – *Cont.*

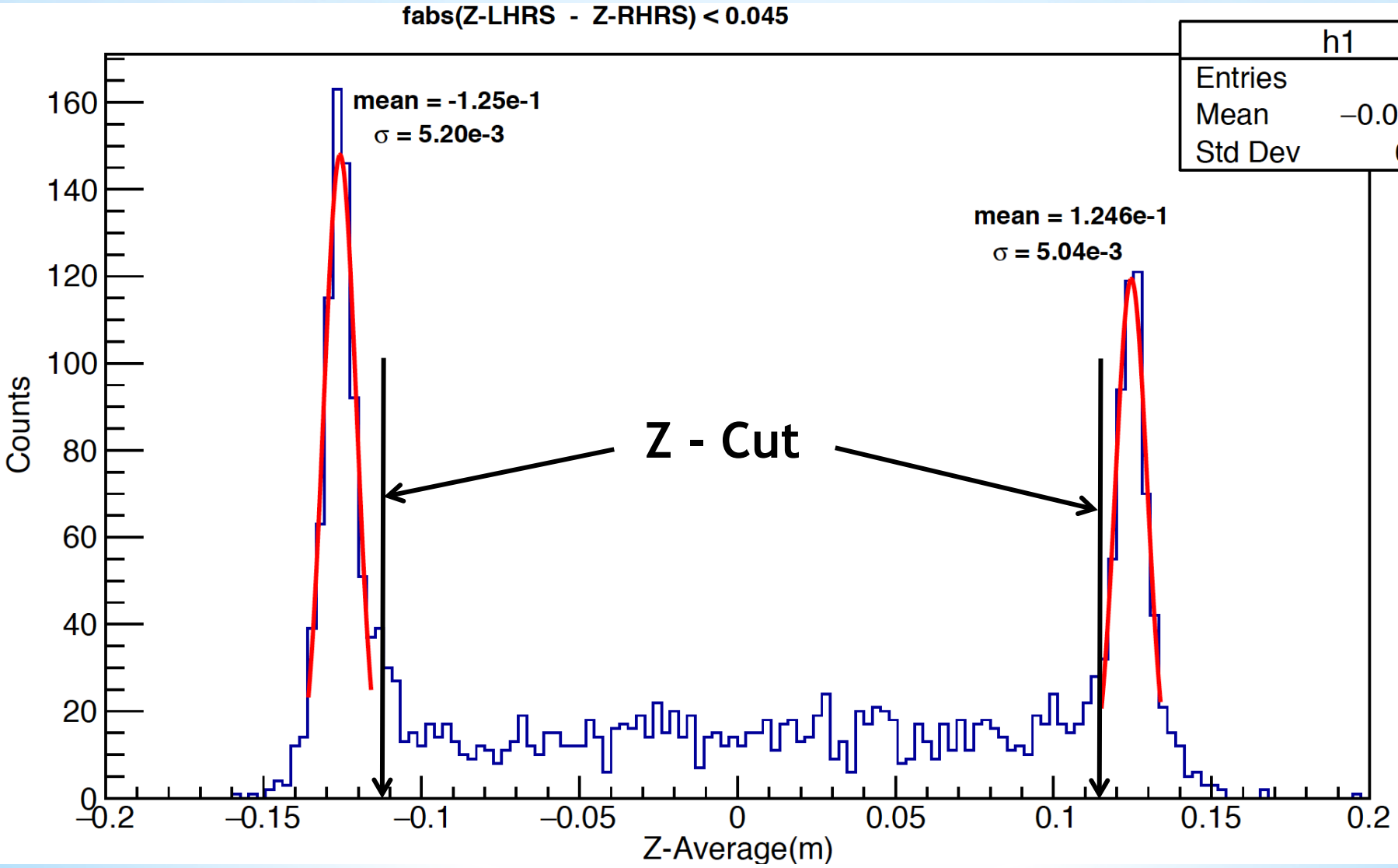






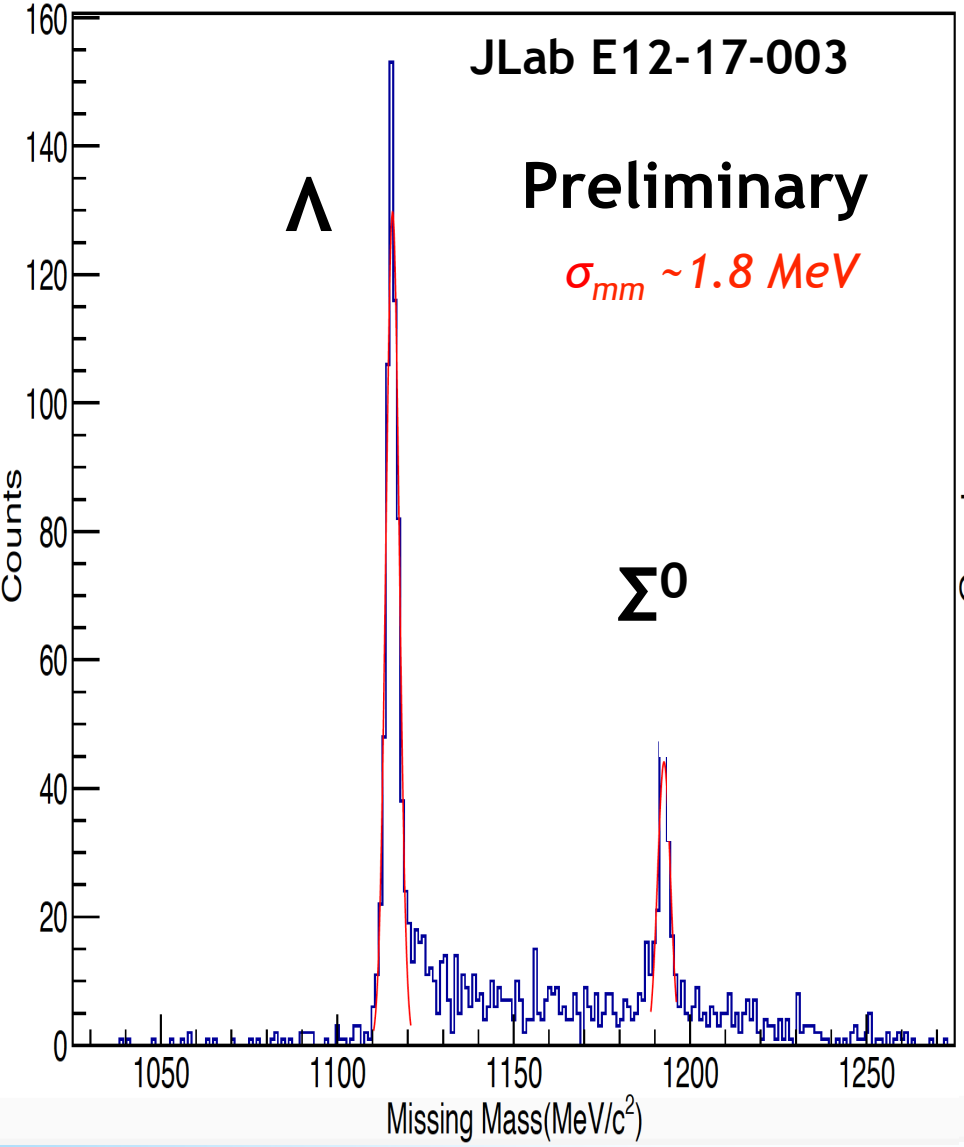


CURRENT ANALYSIS HIGHLIGHTS – *Cont.*

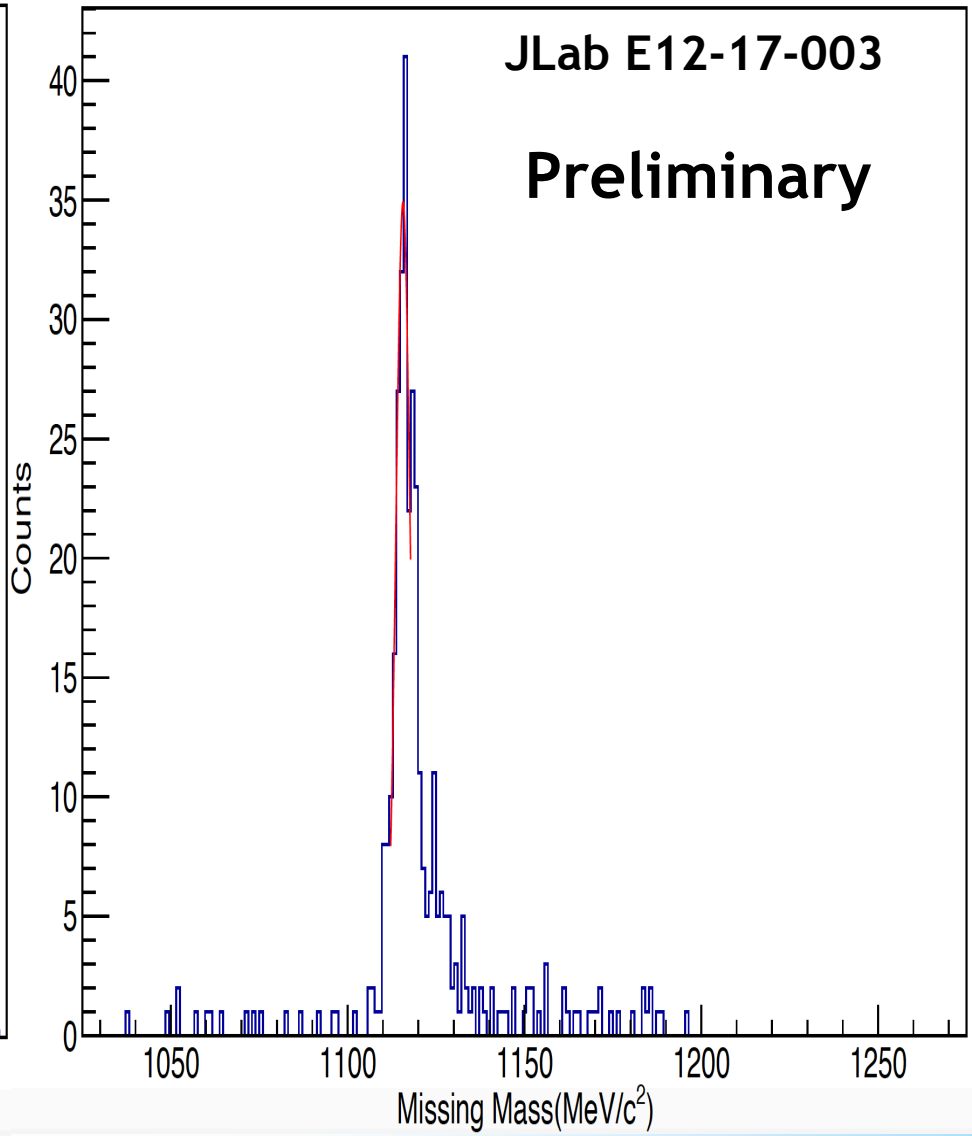


CURRENT ANALYSIS HIGHLIGHTS – *Cont.*

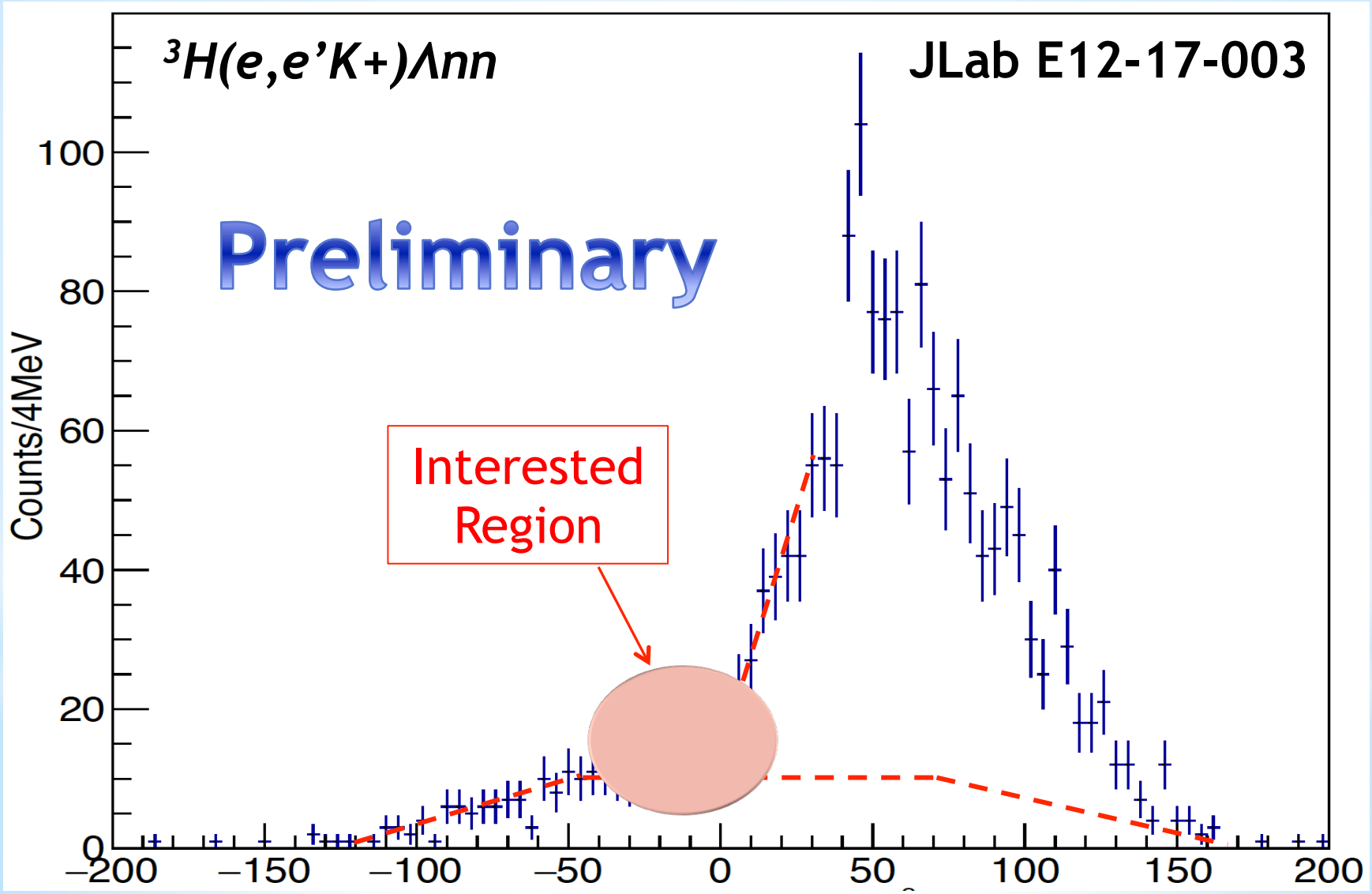
H(e,e'K+)Λ/Σ⁰ w/ hydrogen kinematics



H(e,e'K+)Λ/Σ⁰ w/ trirtium kinematics



CURRENT ANALYSIS HIGHLIGHTS – *Cont.*



SUMMARY

- *Λnn* resonance can be a unique tool to determine the unknown *Λn* interaction.
- The JLab *Λnn* spectroscopy experiment using the (e,e'K^+) reaction has been successfully carried out in Hall A in November of 2018.
- The experiment collected variety of data for careful and detailed calibrations and production
- The spectroscopy from H target has proven good production of Λ and Σ's
- Detailed and careful calibrations are the key part of analysis and are ongoing