A Possible Observation of Λnn Continuum Structure and A Bound ΣNN State Using The (e,e'K$^+$) reaction

Report for the Hall A E12-17-003 experiment: Determining the Unknown Λn Interaction by Investigating the Λnn Resonance

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On behalf of Hall A collaboration

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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 baryonic interactions with "Strangeness".
- ✧ *For the JLab program, 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* (*CSB*) may urge us looking into more direct ***ΛN*** interaction data.

SCATTERING DATA FOR MODELING THE *B-B* INTERACTION

N-N Scattering

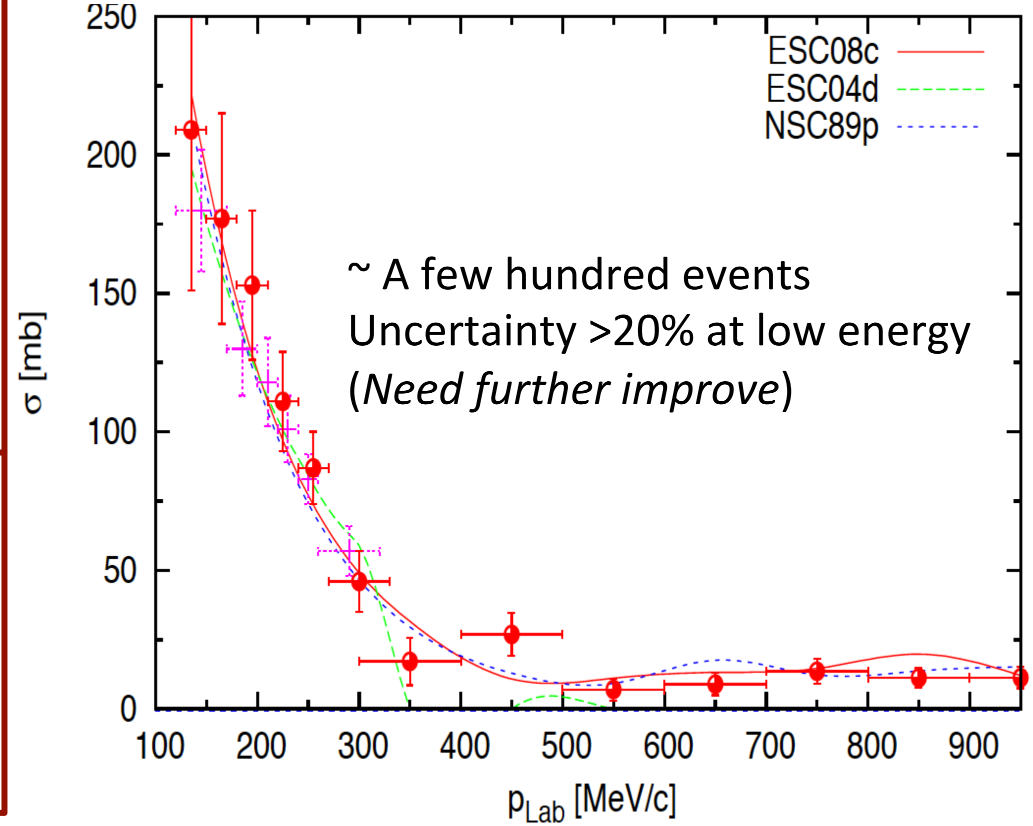
> 4000 events
+ low energy part

This made NN interaction much better understood

Λ-n Scattering

None!

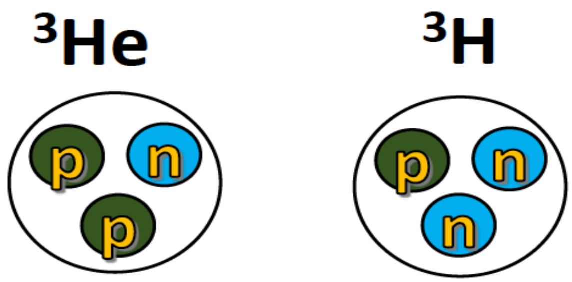
Λ-p Scattering



The ***Λn*** interaction is not determined experimentally, but replies on assumptions based on the limited understanding on the ***Λp*** interaction

CHARGE SYMMETRY BREAKING (CSB)

N-N Interaction

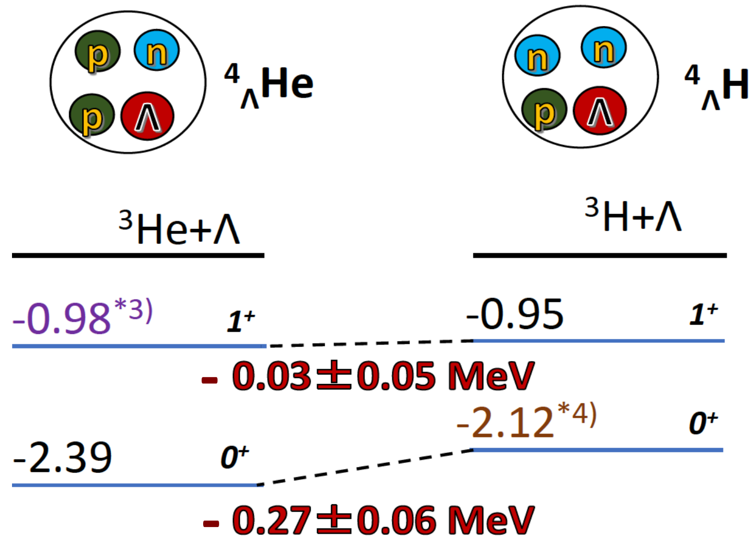


$$\Delta B = 0.76384\,(26)^{*1)}\ \text{MeV}$$
$$\Delta B_{em} = 0.683^{*2)}\ \text{MeV}$$

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).

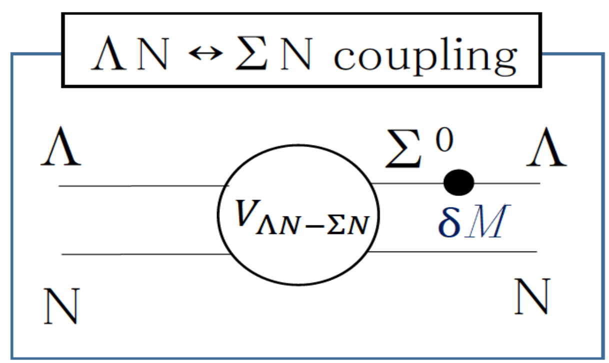
Λ-N Interaction



*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.



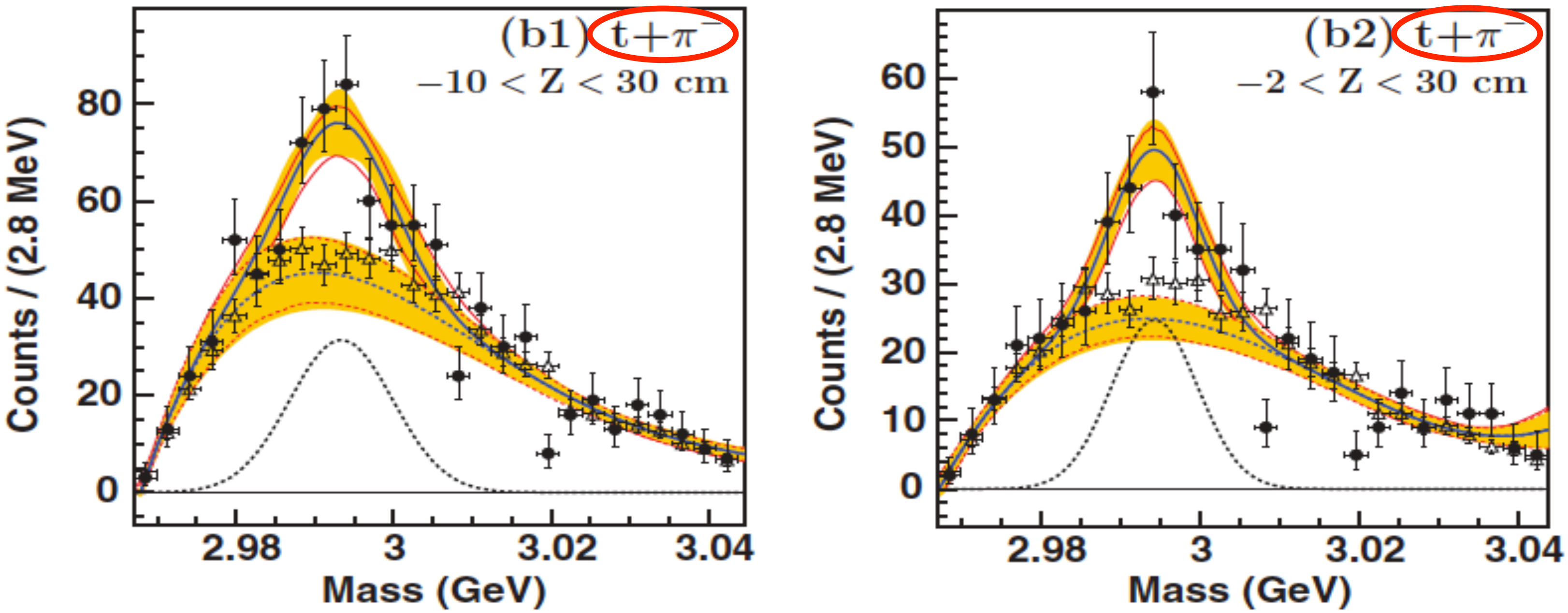
D. Gazda, A. Gal, Nucl. Phys. A **954**, 161 (2016).

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

Experimental data on *Λn* interaction becomes extremely valuable

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)*]

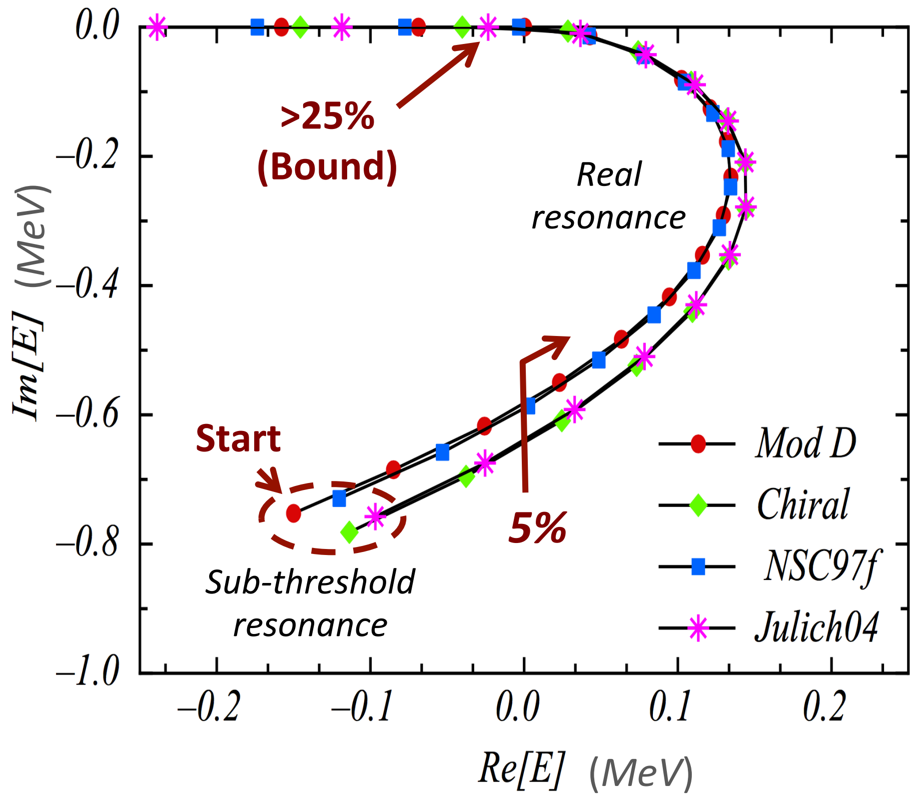
- If such a resonance does exists, it may provide us for the first time the experimental information about ***Λn*** interaction.

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.

A Λnn 3-body system

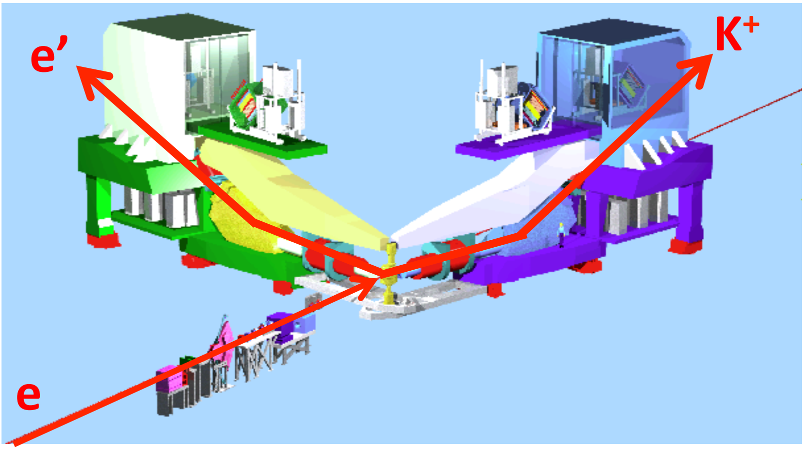


➢ By measuring the ***BE*** and ***Width*** of the resonance peak, the *Λn* interaction strength relative to *Λp* interaction can be determined for the first time by an experimental data.

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.
- Tritium experiments already exist in Hall A at JLab
- Although the experiment was not optimized for the $(e,e'K^{+})$ reaction using the standard HRS-HRS configuration, it was the unique and only chance.
- There was no cross section available, so the possible yield was assumed based on the (*Λpn*) spectrum obtained by the early Hall C E91-016 experiment.

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

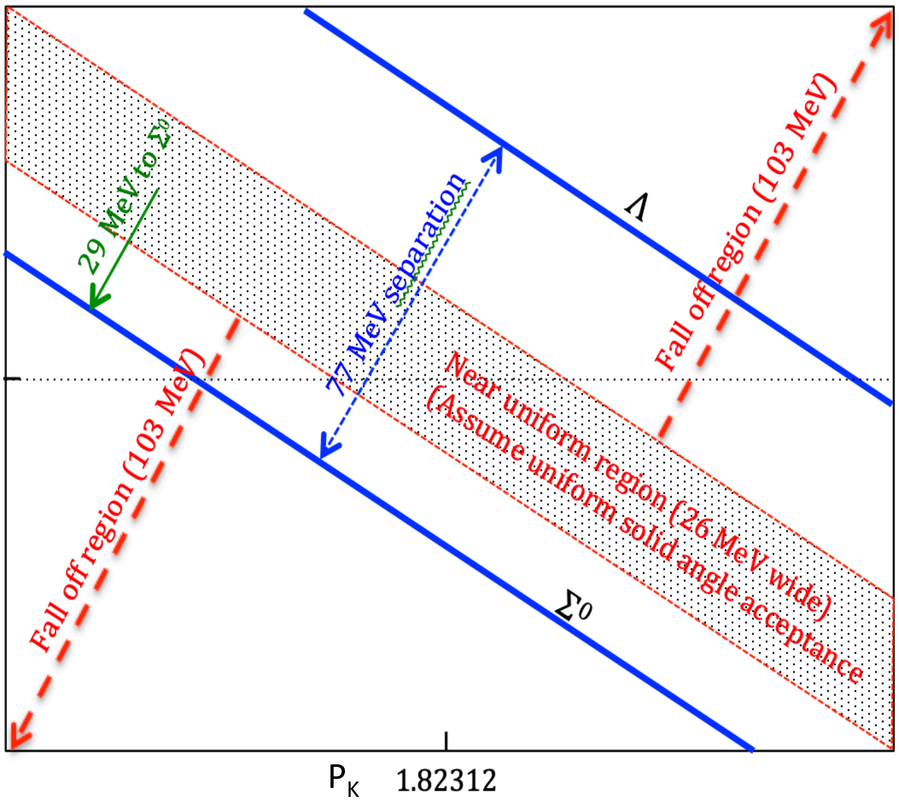
P_K = 1.8231 GeV/c @13.2°

$P_{e'}$ = 2.2180 GeV/c @13.2°

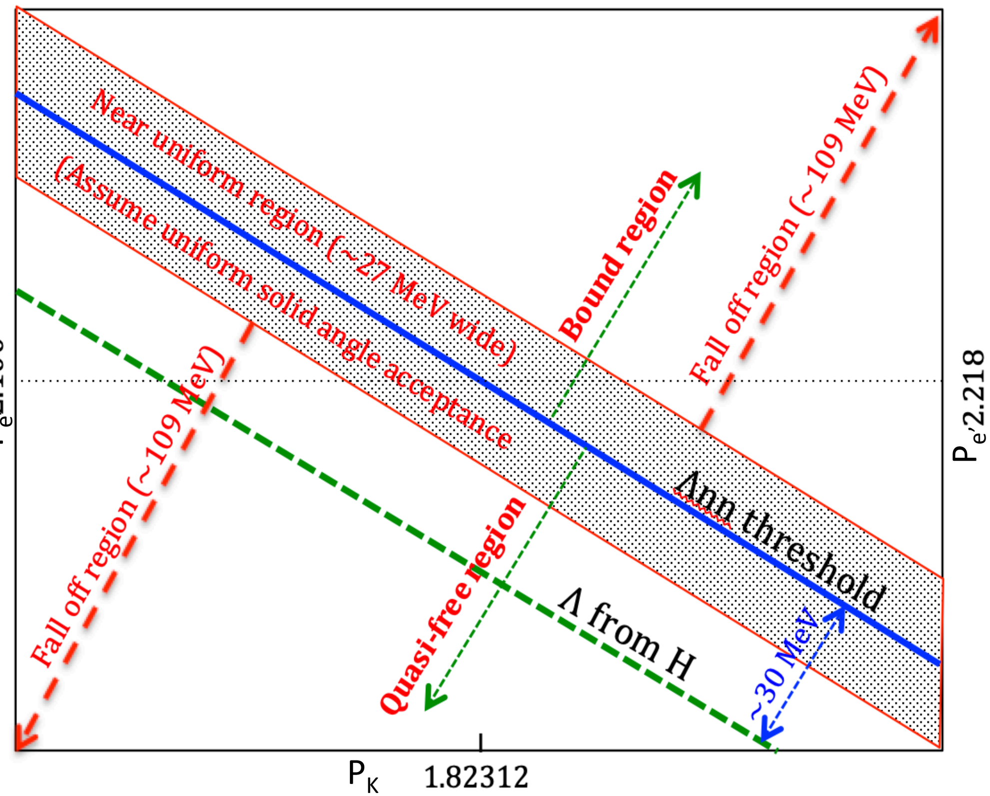
Obtain the Λnn mass spectroscopy from T_2 and reference Λ from H_2 targets

DIFFERENCE OF THE TWO KINEMATICS

H Kinematics

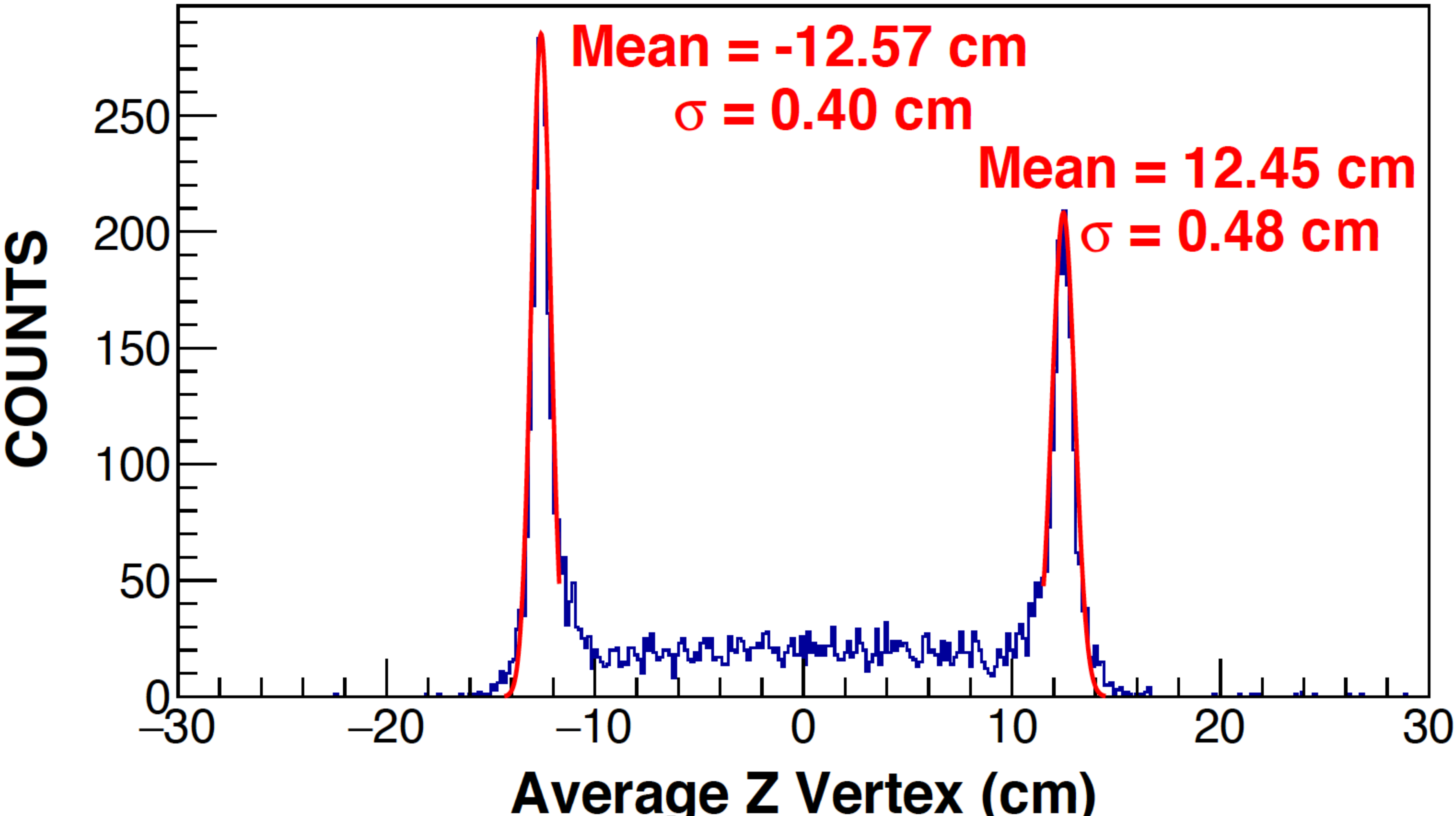


T Kinematics



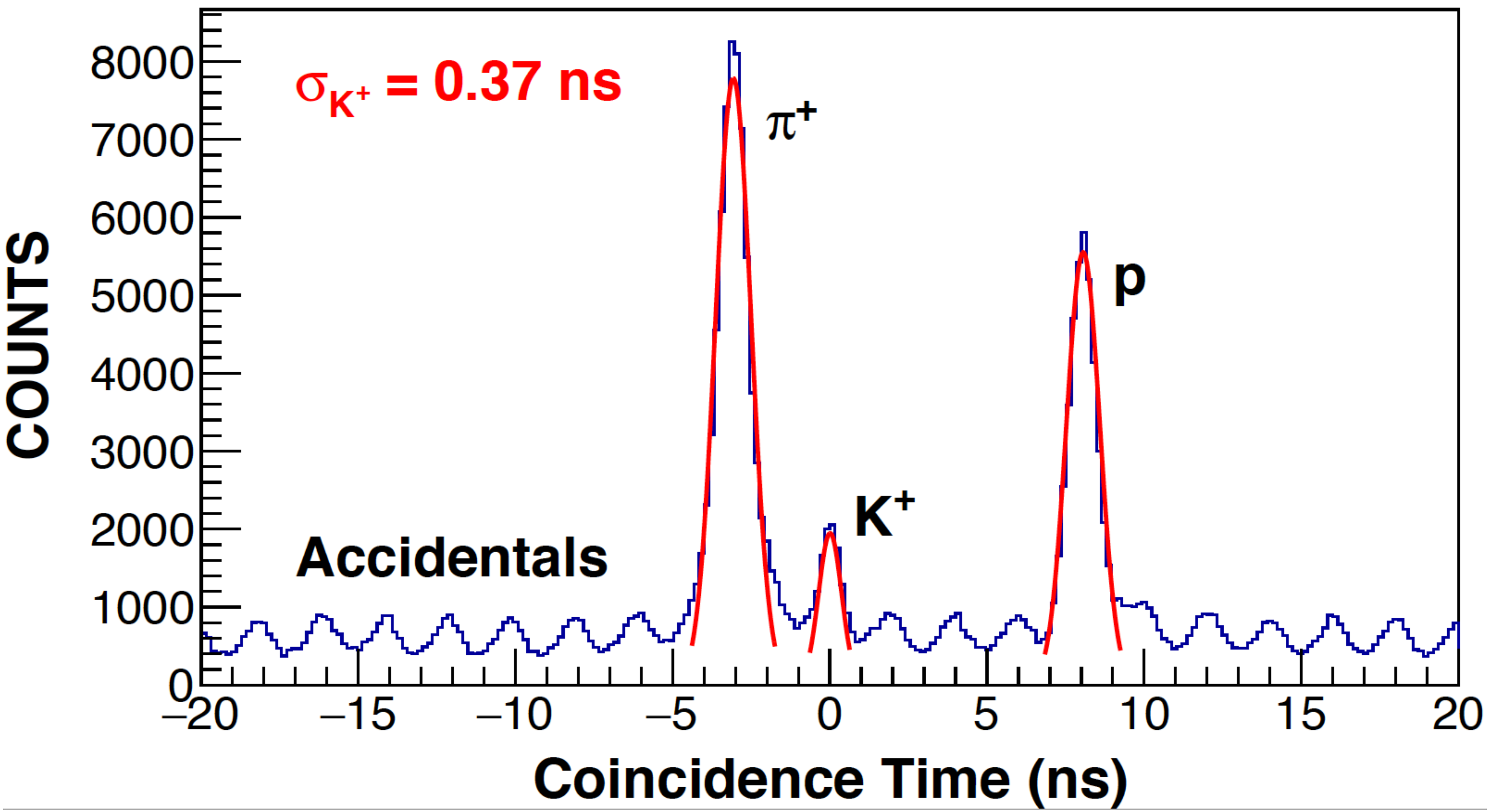
Using the known masses of Λ and Σ^0 to ensure high precision on the absolute missing mass scale (systematic uncertainty of the binding energy of the Λnn resonance)

ANALYSIS RESULTS – *Z-vertex*



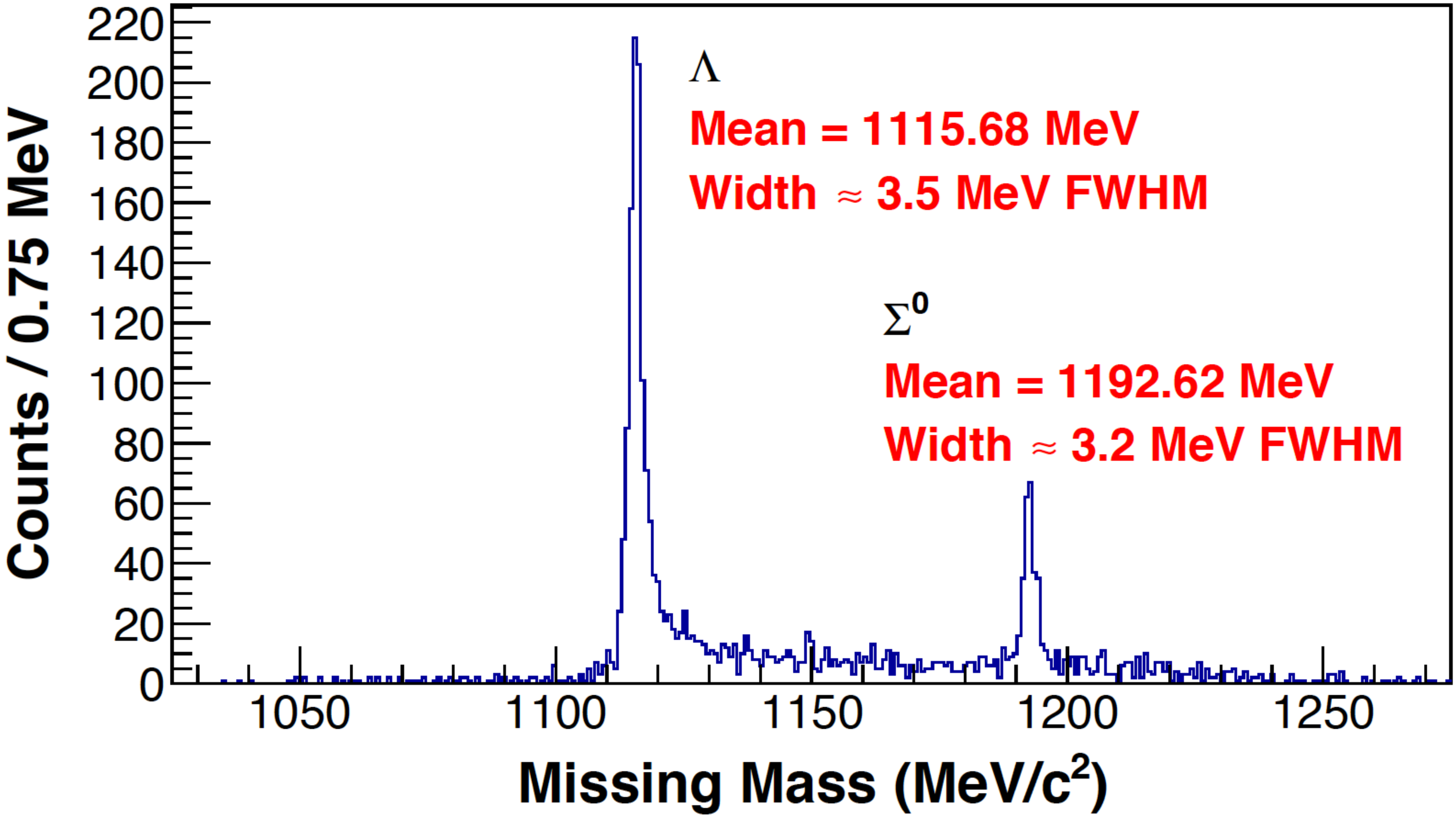
Z-vertex resolution: $\sigma_Z \approx 4.5$ mm

ANALYSIS RESULTS – *Coincidence Time*



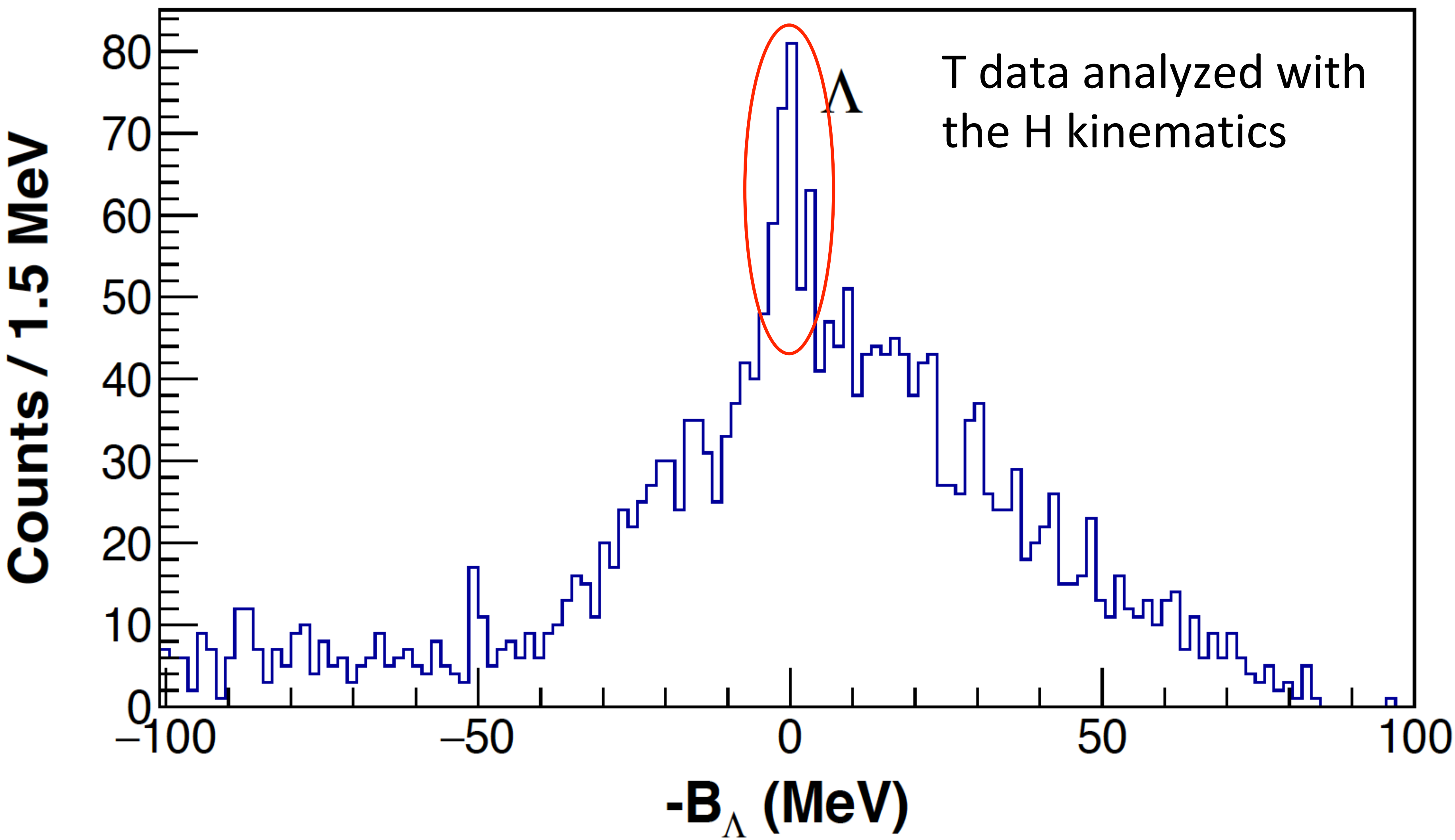
Accidental background are from pions and protons due to inefficiency of the two aerogel detectors

ANALYSIS RESULTS – Λ/Σ^0 Spectrum



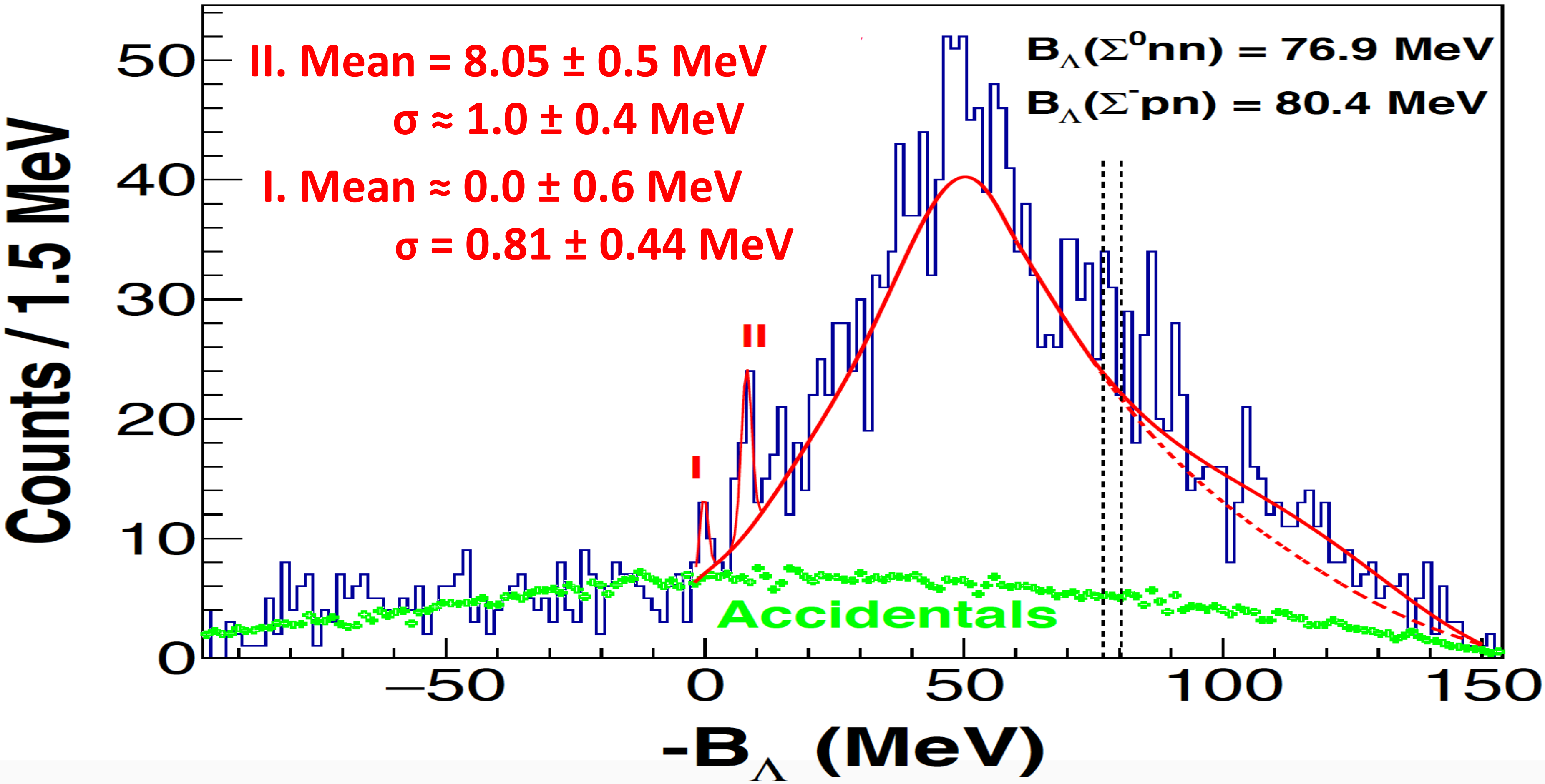
$\Delta M = 76.94\ MeV/c^2$ (nominal: $76.96\ MeV/c^2$)

ANALYSIS RESULTS – *H Contamination*



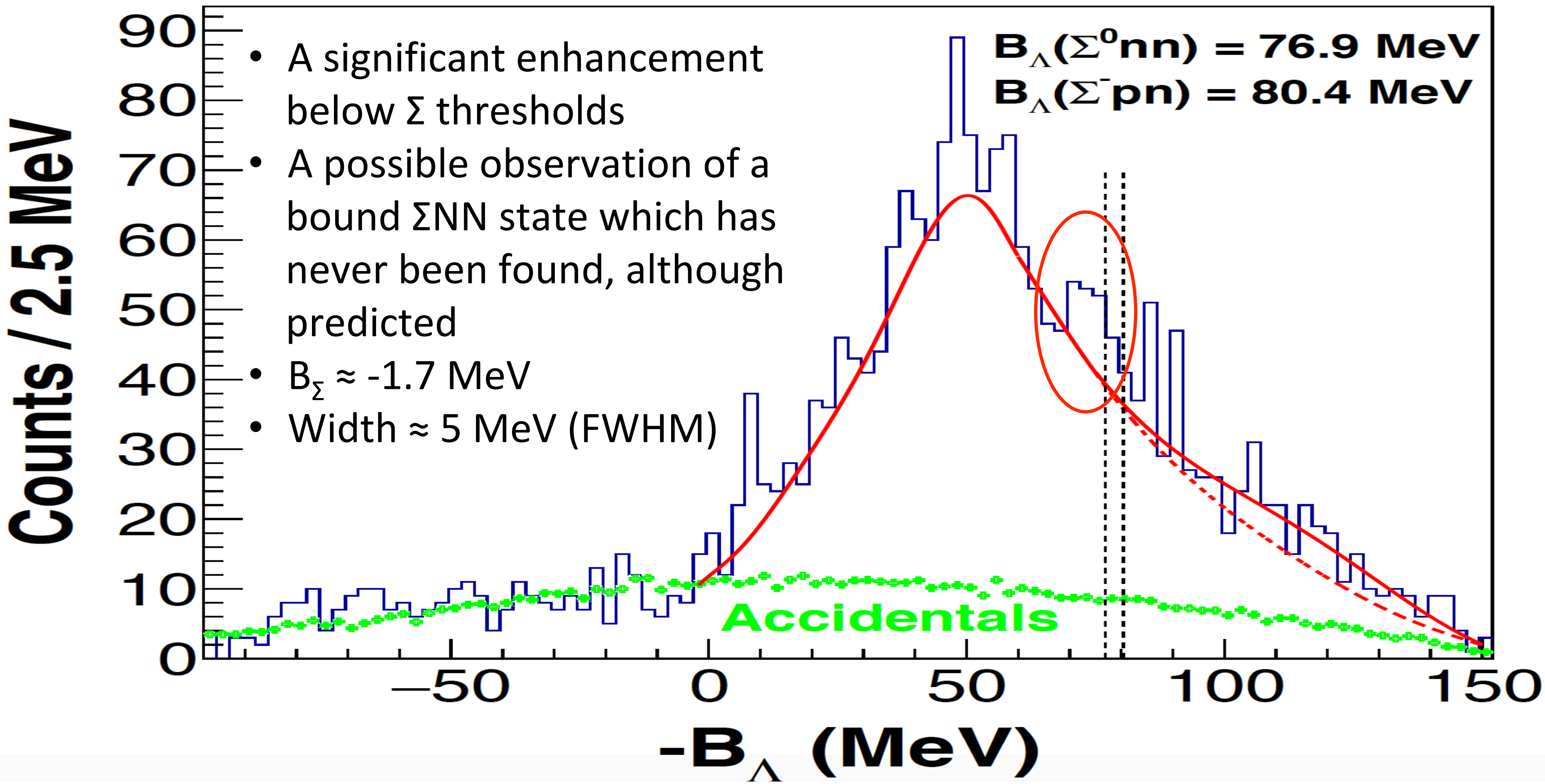
~ 2% H contamination, agreed with other tritium exp.

ANALYSIS RESULTS – *Λnn Resonance*



- The 1st peak: The possible *Λnn* resonance
- The 2nd peak: Unexpected, nature is not clear
- Statistics is not sufficient to make definitive identification

ANALYSIS RESULTS – *Bound ΣNN State*

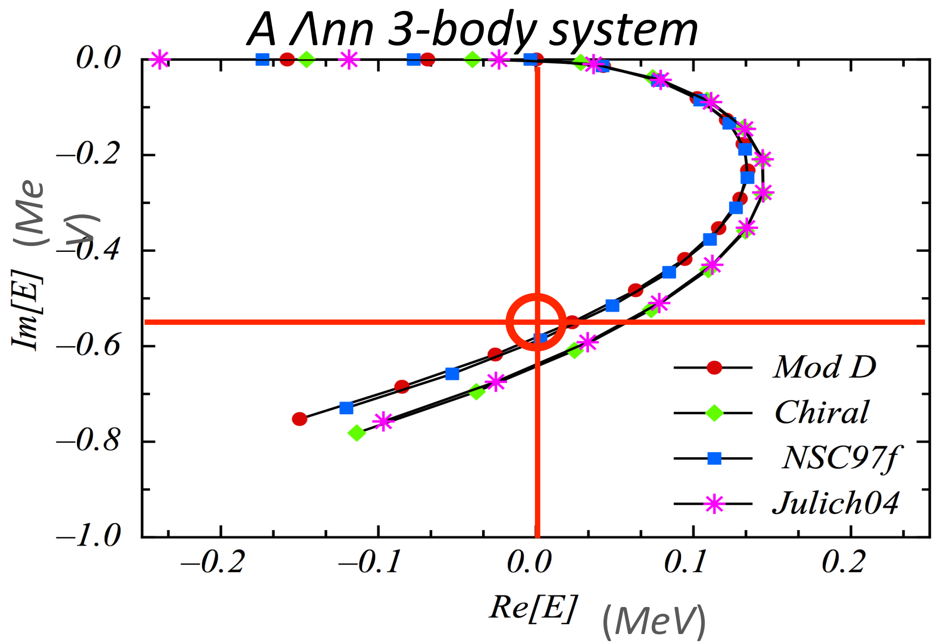


- $^3He(K^-,\pi^-)(\Sigma^+d)$, (Σ^+pn), or (Σ^0pn), not found!
- $^3He(e,e'K^+)(\Sigma^0d)$, (Σ^0pn), or (Σ^-pn), Hall C E91-016, not found!
- $^3H(e,e'K^+)(\Sigma^0nn)$, (Σ^-d), or (Σ^-pn), thus it is possible (Σ^0nn)!

E12-17-003 RESULT SUMMARY

For the Λnn resonance

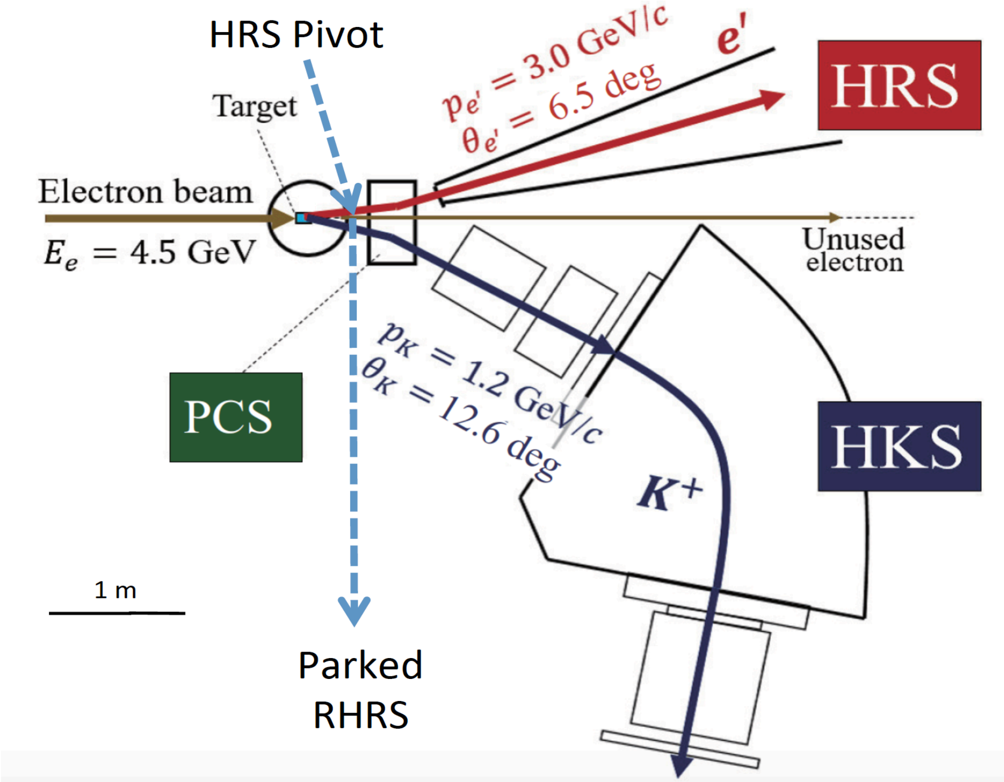
- The possible observation of the resonance is very interesting, but the precision is insufficient for determination of the Λn interaction
- Good statistics is really needed, not only for identification but also for precise measurements



For the bound ΣNN state

- The bound ΣNN state provides important experimental information to study the ΛN − ΣN interaction and its isospin dependence.
- It can also help to understand the CSB.

NEW PROPOSAL – Optimized HKS-HRS



- Smaller e' angle, 7 times gain for the integrated virtual photon flux
- Short HKS orbit, 2.9 times gain on K^+ survival rate
- Excellent KID, 1.6 times gain
- Larger kinematics acceptance, 1.4 times gain
- Shorter target, 0.5 times gain
- Overall gain: **22.7**
- **Yield on the Λnn resonance: ~ 270**
- **Yield on the ΣNN state: > 750**
- **Statistical uncertainty: < ±50 keV**

Required beam time: 204 hours (8.5 days)

T_2	Production	140 hours
H_2	Calibration by *Λ* and *Σ*^{0} known masses	8 hours
Multi-foil-C	Calibration by the ground state of $^{12}_{\Lambda}B$	54 hours
Empty cell	Background from Al end caps	2 hours

SUMMARY

- *E12-17-003 has proven the uniqueness and the success of the (e,e'K^+) reaction at JLab.*
- *The experiment had possible observation of the Λnn resonance and a bound (A = 3) ΣNN state.*
- *Obtained statistics was too small to allow a definitive identification, nor provide information precise enough to determine the Λn and Λ-Σ interactions.*
- *A new proposal was submitted to repeat this experiment with the optimized HKS-HRS system.*