Efficiency-Corrected Yields of $K\Lambda_{1520}$ Channel in Search of High Mass Nucleon Resonances

Rebecca Osar (Arizona State University)

Abstract: In nuclear physics, there is a discrepancy between theory and experiment concerning the number of existing nucleon resonances. Current models predict far more states than have been observed. In particular, few searches have found excited nucleon resonances in energy ranges over 2.2 GeV in the $K\Lambda$ channel. To investigate this problem, efficiency-corrected yields of the reaction $ep \rightarrow eK^+\Lambda_{1520} \rightarrow epK^+K^-$ in the center-of-mass energy range 2.1–4.5 GeV are constructed utilizing Jefferson Lab's CLAS12 detector. This paper presents the results of the analysis in the search for high-mass nucleon resonances in the $K\Lambda$ channel between 2.1–4.5 GeV.

Motivation

Resonances

- Unstable particles have often decay before hitting detectors in an experiment
- Parent particles can be reconstructed using the energies and momenta of the daughter particles
- The parent particle—or *resonance*—leaves a peak in the mass spectrum

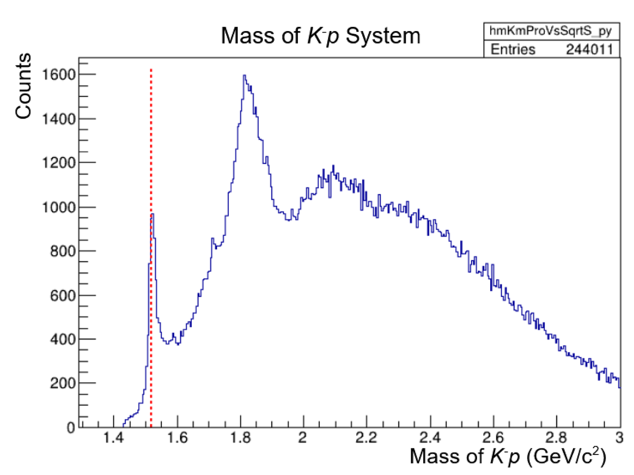

Figure 1: Mass of the K^-p system showing a Λ resonance at 1520 MeV.

The "Missing Resonance" Problem:
Theory predicts far more excited nucleon resonances than have been observed

The $K\Lambda$ Channel

- Nucleon resonances are predicted in the $K\Lambda$ channel up to 3 GeV[1]
  - Few resonances have been observed over 2.2 GeV in this channel[2]
- Data from JLab show a strong Λ_{1520} signal, with center-of-mass energy W between 2.1–4.5 GeV (Fig. 1)
- The signal can be extracted to uncover the resonance spectrum into $K^+\Lambda_{1520}$

$$ep \rightarrow eN^*$$
$$\hookrightarrow K^+\Lambda_{1520}$$
$$\hookrightarrow K^-p$$

Equation 1: Possible reaction with a nucleon resonance N^* in the $K\Lambda_{1520}$ channel.

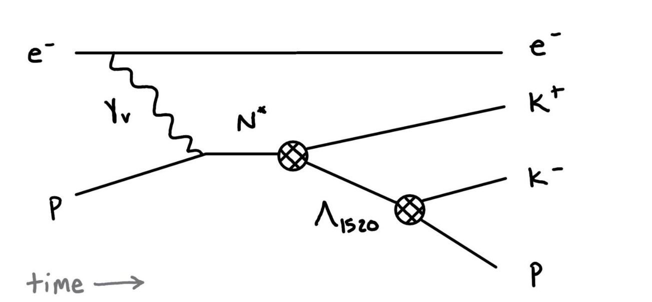

Figure 2: Diagram of the reaction in Eq 1.

Experimental Facilities at Jefferson Lab

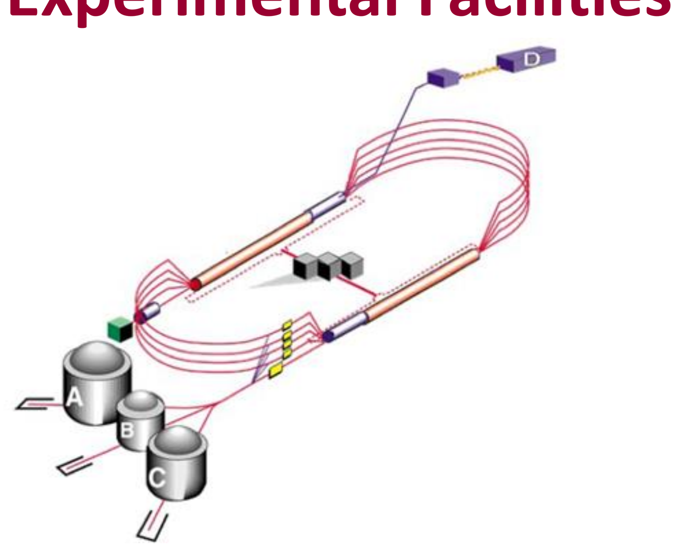

Figure 3: CEFAB Large Acceptance Spectrometer (CLAS12), located in Hall B.

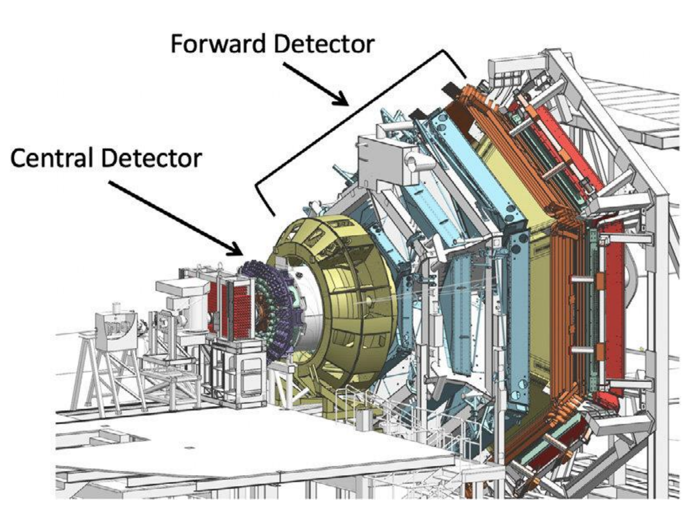

Figure 4: Continuous Electron Beam Accelerator Facility (CEFAB) and the four experimental halls.

CEFAB

- Racetrack accelerator connected to four halls (A, B, C, and D)
- Accelerates electrons up to 12 GeV for fixed target experiments

CLAS12

- Proton target
- Central and forward detectors capture a greater angular range
  - Forward $5° < \theta < 35°$
  - Central $35° < \theta < 125°$

Run Group A (RGA) 2018 Data

- Collides an 11 GeV electron beam on a proton target
- Reaches CM energy up to 4.6 GeV
- Contains runs with negative or positive inbending
  - Negative inbending means negative particles are curved towards the beampipe

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Methods

Event Selection

To cut out background from events of interest, several selection cuts were implemented on the data.

- Particle ID and detector hits
  - The event must have exactly:
    - 1 e in the forward tagger
    - 1 K^+ and 1 K^- in the forward detector
    - 1 p in the forward or central detector
- Missing mass, energy, and transverse momentum
  - A "missing" energy-momentum 4-vector was found by subtracting the 4-vector of the final particles from the initial particles
  - A Gaussian plus a second-order polynomial was fit over each distribution
  - Cuts were made 3σ from the Gaussian mean

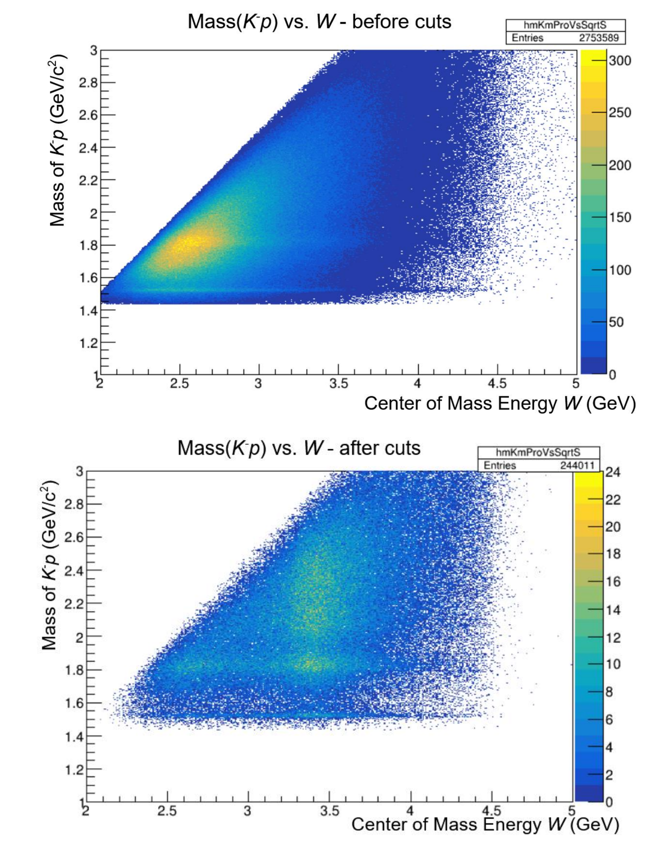

Figure 5: Effects of missing cuts—only 9% of events were kept.

Yields

The 2D histogram of Mass(K^-p) (final state of Λ) vs. W of the K^+K^-p (final state of N^*) are used to extract the signal, or *yields*, of the Λ_{1520} (Fig. 6). The plot of yields vs. W (Fig. 7, right) shows the resonance spectrum.

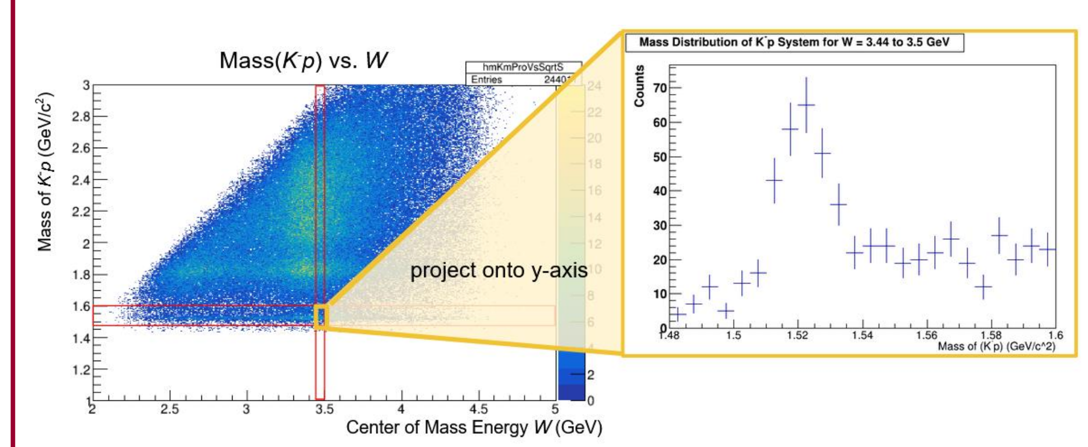

Figure 6: The x-axis was divided into bins 60 MeV wide and projected onto the y-axis between 1.48–1.60 GeV. The peak at 1.52 GeV is the Λ_{1520}

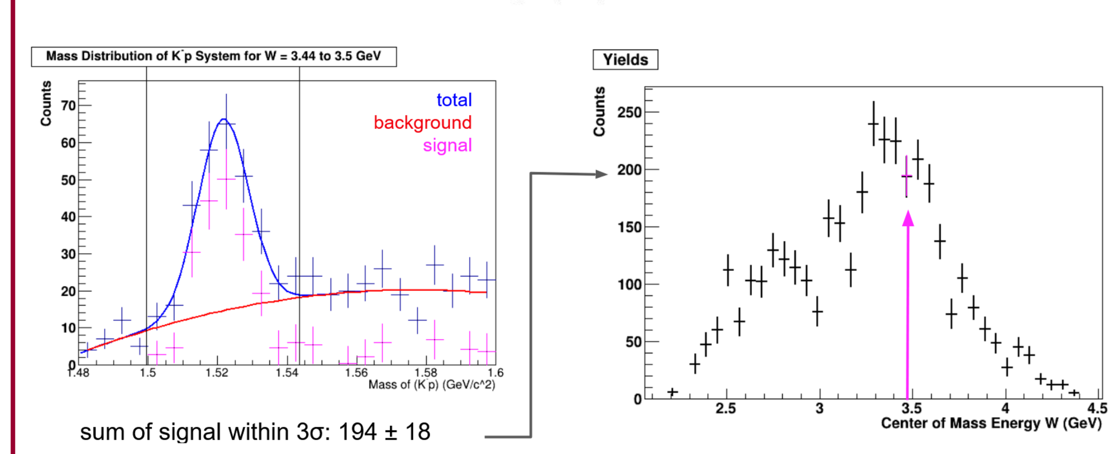

Figure 7: Each bin of the $M(K^-p)$ spectrum was fit with a Gaussian plus a second-order polynomial (blue). The background polynomial (red) was subtracted from the total to give the signal (pink). The signal was summed within 3σ from the mean (shown by black vertical bars) to find the yield for that bin (right).

Efficiency Correction

Some features may appear in the spectrum that are a result of detector efficiency or selection criteria. Monte Carlo (MC) simulated data can be used to correct yields

- Generated events were reconstructed using JLab's MC software
- Reconstructed events were pushed through the selection code
- The cut reconstructed data ("seen" events) were divided by the generated data (thrown events) to get the efficiencies
- Yields were divided by efficiencies to correct

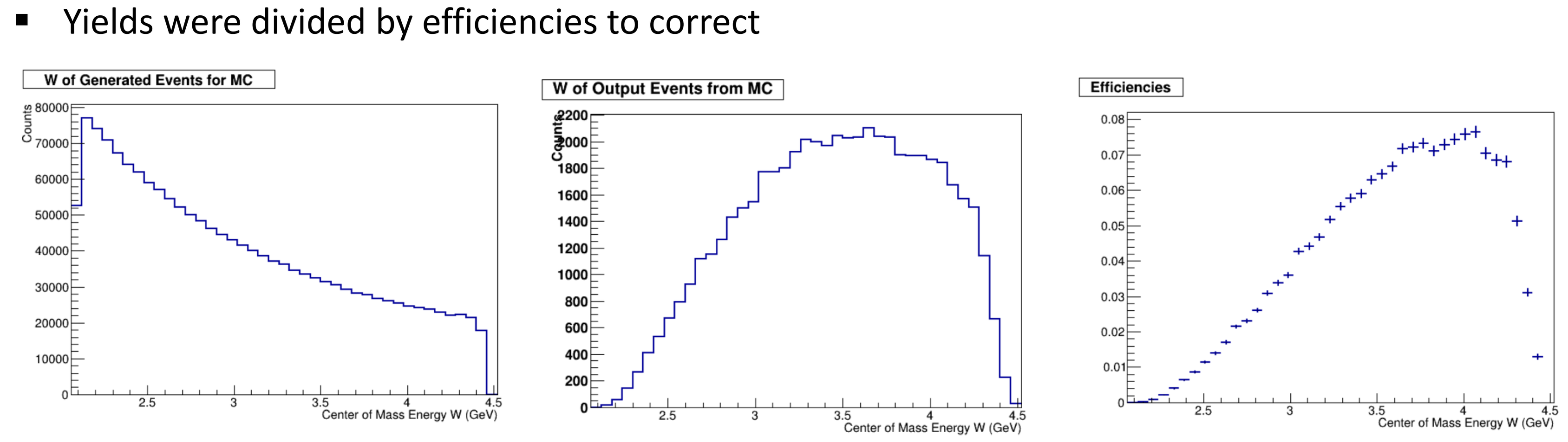

Figure 8: Generated events (left), reconstructed events after event selection (middle), and efficiencies (right) as a function of W. The middle plot is divided by the left plot to get the efficiencies.

Results

2018 Combined Dataset

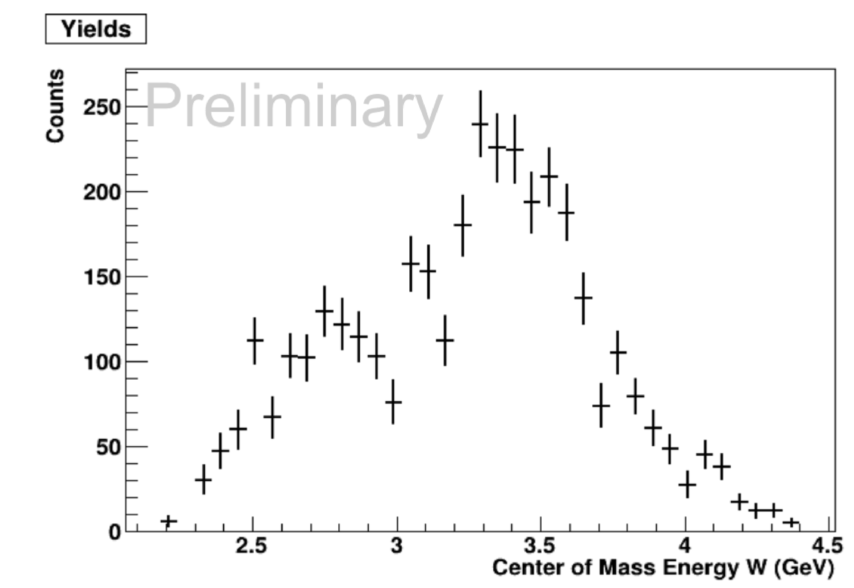

Figure 9: Yields of the RGA 2018 combined dataset. To combine, the data and the MC files were added. The yields were extracted after the data was combined to improve statistics in the fitting routine.

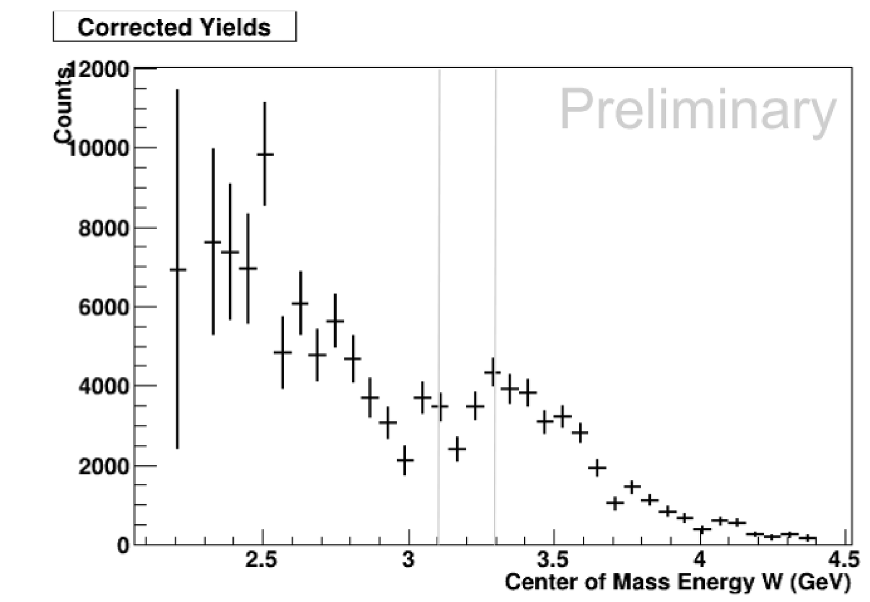

Figure 10: Efficiency-corrected yields of the RGA 2018 combined dataset. After correction, the energy spectrum shows features near 3.1 and 3.3 GeV.

2018 Individual Datasets

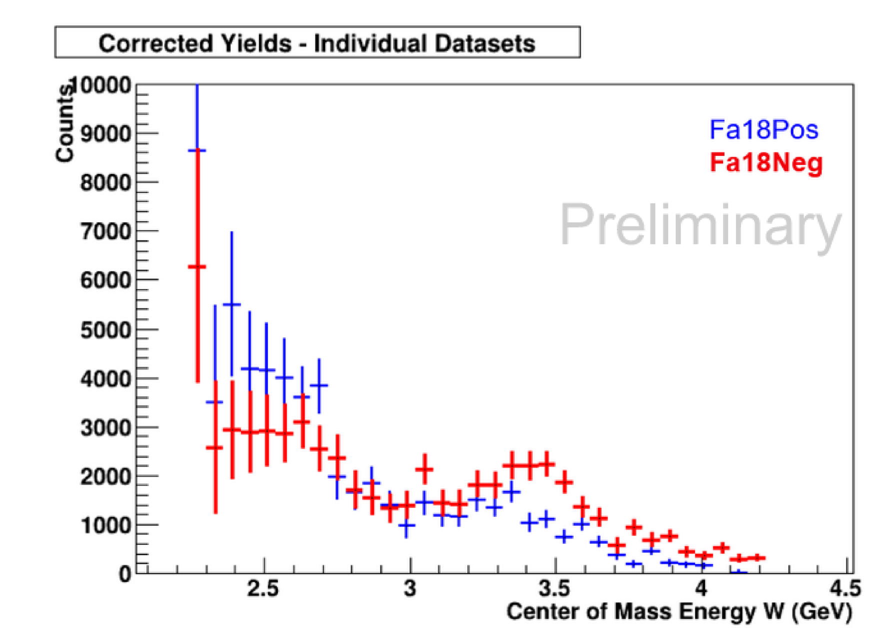

Figure 11: Efficiency-corrected yields of the RGA 2018 data, positive (blue) and negative (red) inbending datasets, respectively. After correction, the feature at 3.1 was narrowed, and the feature at 3.3 GeV was suppressed.

Conclusions

- Some features exist in the spectrum around 3.1 and 3.3 GeV
- Further study is required to investigate the features in the resonance spectrum
- **Next Steps:**
  - Investigate the newly cooked 2019 data
  - Improve the yield extraction fitting routine

References

1. S. Capstick et al., Phys. Rev. D, **58**, 0704011-1 (1998).
2. V. Buckert et al., Phys. Rev. D, **98**, 030001 (2019).