Search for Excited Cascade (Ξ^{*-}) Hyperons in the Reaction $ep \rightarrow e'K^+K^+K^-(\Lambda/\Sigma^0)$ Using CLAS12

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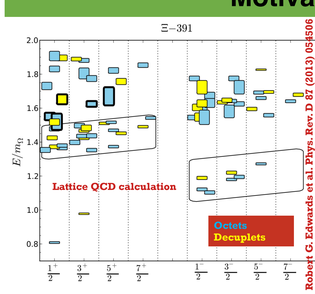
Abstract

Doubly strange cascade hyperons are experimentally underexplored. The CLAS12 Very Strange physics program aims to study the electroproduction of these states. The reaction $ep \rightarrow e'K^+K^+K^-(\Lambda/\Sigma^0)$ is studied with an electron beam energy of 10.6 GeV using CLAS12 RG-A data. Scattered electrons are detected with either the Forward Detector (FD), covering a polar angle range of 5° to 35° to study electroproduction, or with the Forward Tagger (FT) covering a polar angle range of of 2.5^o to 4.5^o to study quasi-real photoproduction. The CLAS12 detector with nearly 4π solid angle coverage is used to detect charged kaons in the final state. Λ/Σ^0 hyperons are reconstructed using the missing mass technique to explore intermediate double strange hyperons (Ξ^{*-}) which decays to K^- and Λ/Σ^0. No statistically significant Ξ^{*-} states other than Ξ^{*-}**(1530)** was found in the $e'K^+K^+$ missing mass spectra in the FD acceptance only. Upper limits on the production cross section for the reaction $ep \rightarrow e'K^+K^+\Xi^{*-}$**(1820)** is being investigated for low-Q^2 and high-Q^2 electroproduction processes.

Motivation

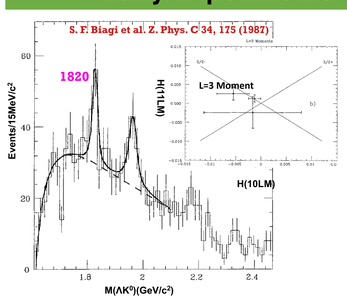


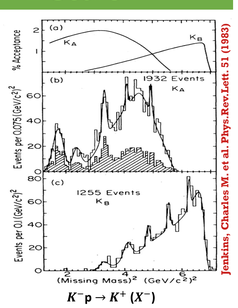
Particle	J^P	Overall status
$\Xi(1320)$	$\frac{1}{2}^+$	****
$\Xi(1530)$	$\frac{3}{2}^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$\frac{3}{2}^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\frac{5}{2}^?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*

2022 PDG update

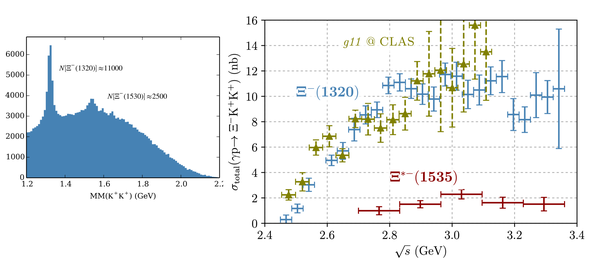
- There are far fewer experimentally observed Cascade states than have been predicted.
- Validate SU(3) flavor symmetry of QCD.
- Advance QCD to understand the physics of the early universe.

Early Experiments on Ξ Search





- Used K^- beam on low sensitivity hydrogen bubble chamber.
- SPS charged hyperon beam at CERN studied Ξ^-N interaction.
- Kaon production using MPS at BNL claimed multiple Ξ states.
- CLAS6 photoproduction data showed $\Xi^-(1320)$ and $\Xi^{*-}(1530)$.



CLAS Collaboration: Guo, L. et al. Phys. Rev. C76, 025208 (2007) / Goetz, J. T. et al. Phys. Rev. C 98, 062201 (2018)

CLAS12 Spectrometer

Forward Detector:
($5^o \leq \theta \leq 35^o$)

- *TORUS magnet*
- *HT Cherenkov Counter*
- *Drift chamber system*
- *LT Cherenkov Counter*
- *Forward ToF System*
- *Preshower calorimeter*
- *E.M. calorimeter (EC)*

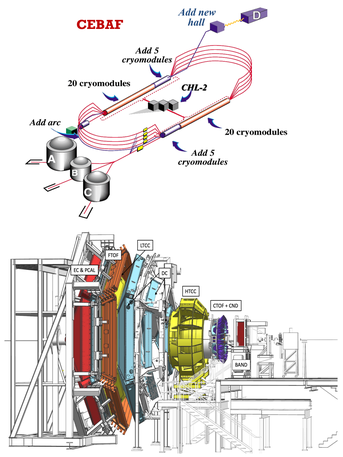
Central Detector:
($35^o \leq \theta \leq 125^o$)

- *SOLENOID magnet*
- *Barrel Silicon Tracker*
- *Central Time-of-Flight*

Upgrades:

- *Micromegas (CD)*
- *Neutron detector (CD)*
- *RICH detector (FD)*

- ***Forward Tagger (FT)***
  ($2^o < \theta < 5^o$)



V. Burkert et al., Nucl. Instrum. Meth. A 959(2020) 163419

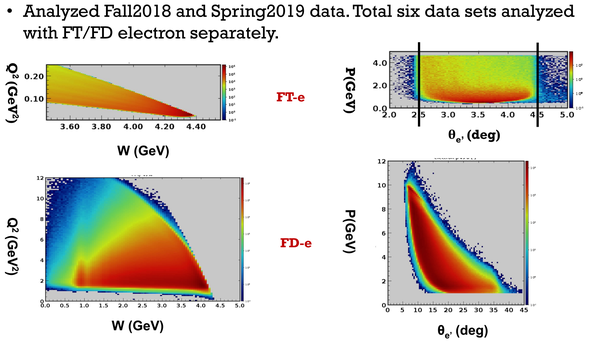
CLAS12 RG-A Experiment

- Electron beam: 10.6 GeV and 10.2 GeV longitudinally polarized electron beam from CEBAF.
- Beam Current: 5 nA to 75 nA.
- Target: 5 cm unpolarized liquid hydrogen (LH2) target.
- The Superconducting Torus and Solenoid Magnet for momentum measurement.
- Forward Tagger on to detect electrons and photons at a very forward polar angle of 2° to 5°.

Data Analysis Strategy

$$ep \rightarrow e'K^+K^+\Xi^{*-}(1820)$$
$$\Xi^{*-}(1820) \rightarrow K^-(\Lambda/\Sigma^0)$$

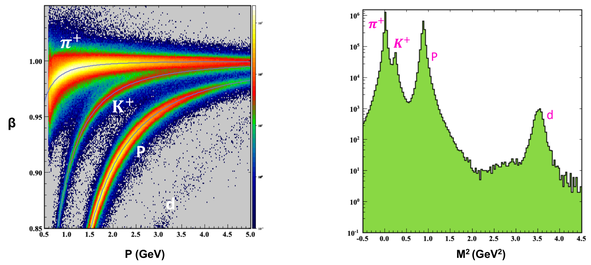
- Scattered electron e' detected in two different regions.
  - Low-Q^2 region to study quasi-real photoproduction - e' detected in the FT system which covers a very forward polar angle range of 2° to 5°.
  - High-Q^2 region to study electroproduction - e' detected in the FD system which covers a forward polar angle range of 5° to 35°.
- Charged kaons detected in the CLAS12 detector (FD) in coincidence with scattered electrons.
- Analyzed Fall2018 and Spring2019 data. Total six data sets analyzed with FT/FD electron separately.



Acknowledgements

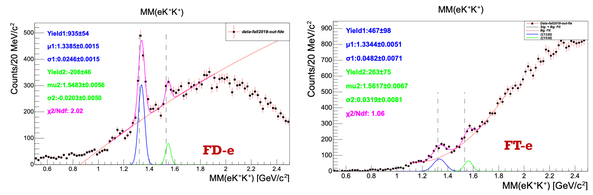
- This work is funded by DOE Grant **DE-SC0013620**

Charged Kaon Selection



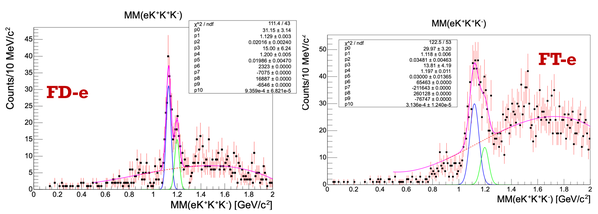
- Kaons detected in FD ($5^o < \theta_{K^\pm} < 35^o$).
- DC fiducial cut.
- $0.4 < P_{K^\pm} < 10.604$ GeV.
- $0.4 < \beta_{K^\pm} < 1.05$.
- $-10 < v^z_{K^\pm} < 1$ cm.
- Momentum dependent vertex time cut.

Missing Mass Spectra

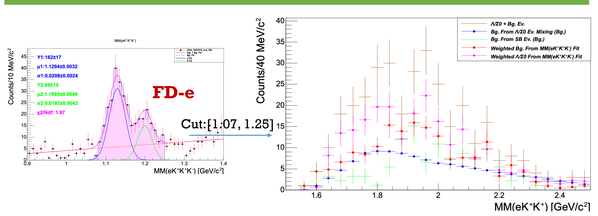


- $\Xi^-(1320), \Xi^-(1530)$ clearly visible (First-time seen from electroproduction data) in the MM($e'K^+K^+$) distributions.
- Smeared Λ/Σ^0 visible in the MM($e'K^+K^+K^-$) distributions.
- Background template modeled with event mixing technique.
- Fit uses Gaussian convolution with polynomial bkgd template.

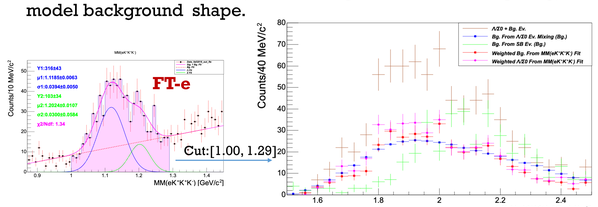
MM = gaus(Λ) + gaus(Σ^0) + C*[bkgd]



Background Shape in the MM($e'K^+K^+$) for $e'K^+K^+K^-$ Events

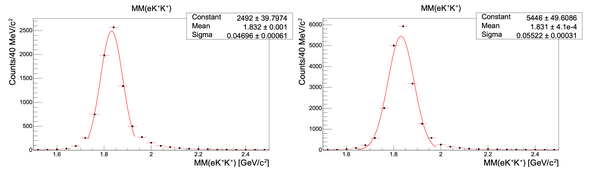


- Used multiple techniques (Event Mixing, Sideband, Fit weighting) to model background shape.



MC Simulation

- Performed GEANT4-based MC simulation for reaction efficiency.
- MC tuning was performed by measuring known Ξ^-**(1320)** width as a function of the momentum smearing factor to derive experimental resolution.
- Ξ^{*-}**(1820)** state experimental mass resolution inferred from MC.

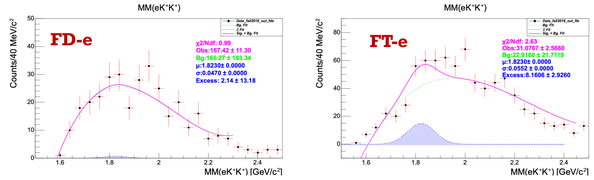


$\sigma_{\Xi^{*-}(1820)}$ = **46.96 MeV (FD-e)** $\sigma_{\Xi^{*-}(1820)}$ = **55.22 MeV (FT-e)**

ep $\rightarrow e'K^+K^+\Xi^{*-}$**(1820)** $\rightarrow e'K^+K^+K^-(\Lambda/\Sigma^0)$

Signal Yield/Statistical Significance

MM = gaus(Ξ^{*-}(1820) fixed μ/σ) + C*[bkgd]



- Allowed only signal strength to fluctuate in the fit.
- Implemented maximum log-likelihood ratio ($\lambda = \frac{max(L(X/H_1))}{max(L(X/H_0))}$) test to determine 95% CL-boundaries for small signals over a background.
- Test Statistics (TS) = -2lnλ.
- Statistical Significance in terms of $\sigma = \pm\sqrt{TS}$.

Preliminary Cross Section Upper Limit for $ep \rightarrow e'K^+K^+\Xi^{*-}(1820)$

- Converted 95% upper-limit yield to upper-limit on the cross section in FT-e $Q^2(10^{-2}$ - 0.3 GeV$^2)$ and FD-e Q^2 $(10^{-1}$ - 0.6 GeV$^2)$ range. Our preliminary result for the upper limit cross section is extracted to be approximately around **2** nb and further work to set on the production cross section of the reaction $ep \rightarrow e'K^+K^+\Xi^{*-}$ as a function of Ξ^{*-} mass is in progress.

Summary

- No statistically significant Ξ^{*-} **(1820)** signal was observed from the preliminary data analysis using CLAS12 Forward Detector acceptance.
- Estimated upper limit on the Ξ^{-*} **(1820)** yield using maximum log-likelihood ratio test method for counts and fit statistics.
- Upper limits on the production cross section for $ep \rightarrow e'K^+K^+\Xi^{*-}$**(1820)** is being investigated for low-Q^2 and high-Q^2 electroproduction processes.