Measuring the Photoproduction of $K^{+*} K^{+} \Xi^{-}$ States from a Proton Target

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Introduction and Objectives

The GlueX experiment in Hall D of Jefferson National Lab was created to further investigate strongly interacting systems of quarks. In the Standard Model, the quanta of the strong interaction are gluons, the study of which is known as Quantum Chromodynamics, or QCD.

One of the aims of the GlueX experiment is to explore QCD-inspired models of hadrons. Most models predict many more excited baryon states than have been observed. Additionally, cross sections of some production modes of the ground state cascades have yet to be published.

The poster being presented explores the unpublished reaction: $\gamma\, p \rightarrow K^{+*} K^{+} \Xi^{-}$.

Detector

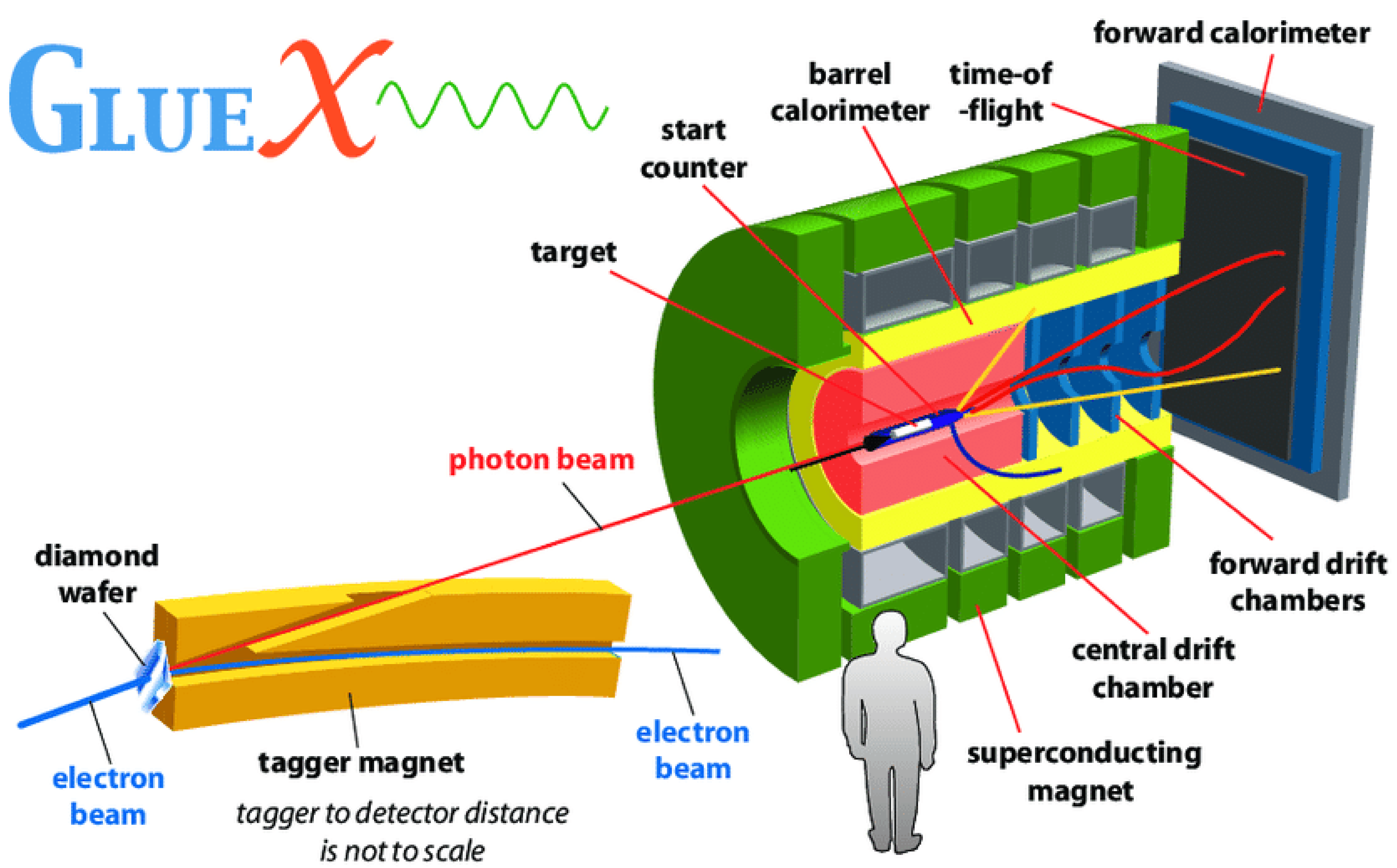

Fig 1. Hall D's detector apparatus.

Hall D utilizes a 12 GeV electron beam to facilitate photoproduction. The energy levels of the produced photons and hadrons are then measured and stored in a data tree with over 31 million events.

Using CERN's ROOT framework, the data tree was then analyzed and categorized into various histograms for each decay reaction. Using a C++ script, these end products were then reconstructed into the intermediate products.

Results

By correlating one pair of products against another, events corresponding to this reaction mechanism can be statistically isolated from the products of other background reactions:

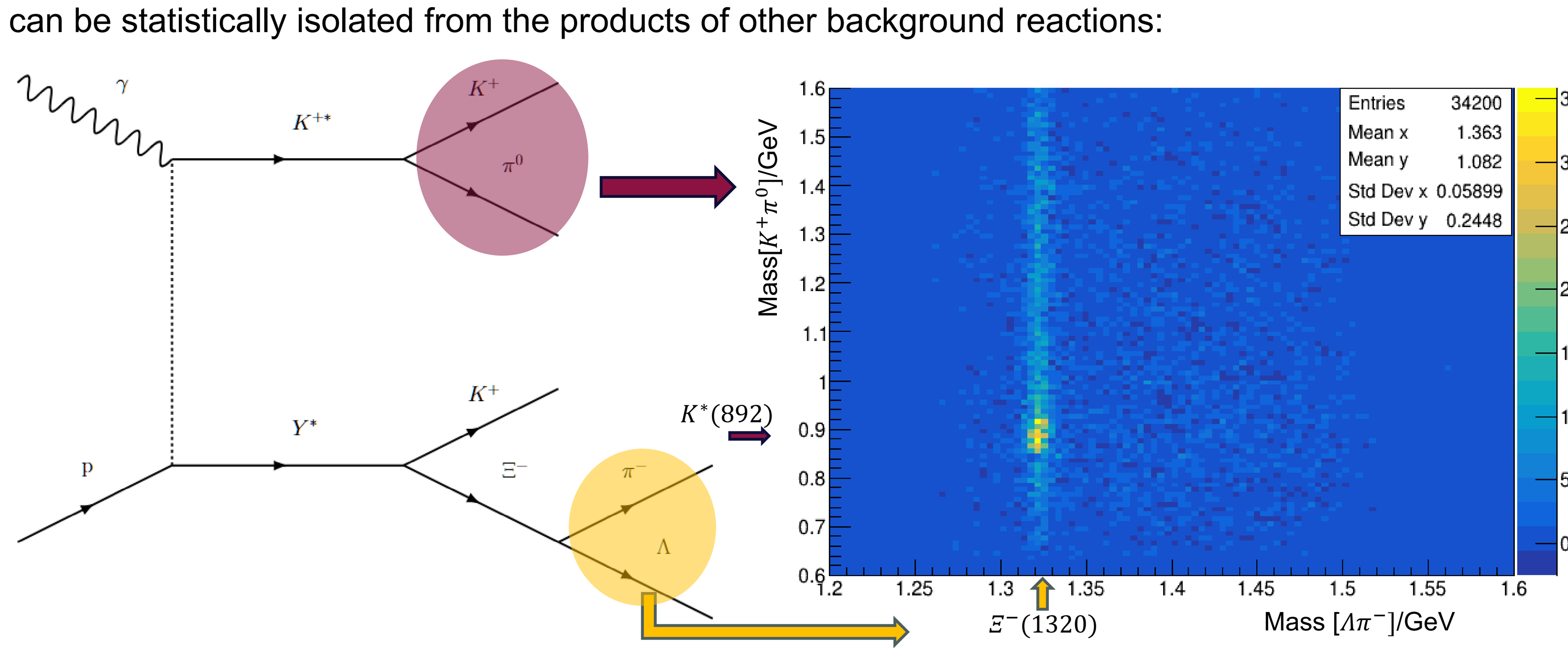

Fig 2. Feynman diagram (left) and Comparison of $K^{+}\pi^{0}$ states to $\Lambda\pi^{-}$ states (right).

Results (Cross Section)

Scattering cross sections can be calculated using the equation

$$\sigma = \frac{Y}{Nt\epsilon}, \text{ where}$$

- Y is the yield from fitting routine.
  - Accidental subtraction (out of time weighted by $-1/6$)
- t is the number of scattering centers (protons per barn of target).
- N is the number of incident photons.
- ϵ is the detector efficiency determined by the Monte Carlo simulation $\left(\frac{Y_{\text{seen}}}{Y_{\text{thrown}}}\right)$.

Projecting the above 2D histogram onto the y-axis, then fitting the estimated signal with a Gaussian distribution, and the background with a polynomial, yields:

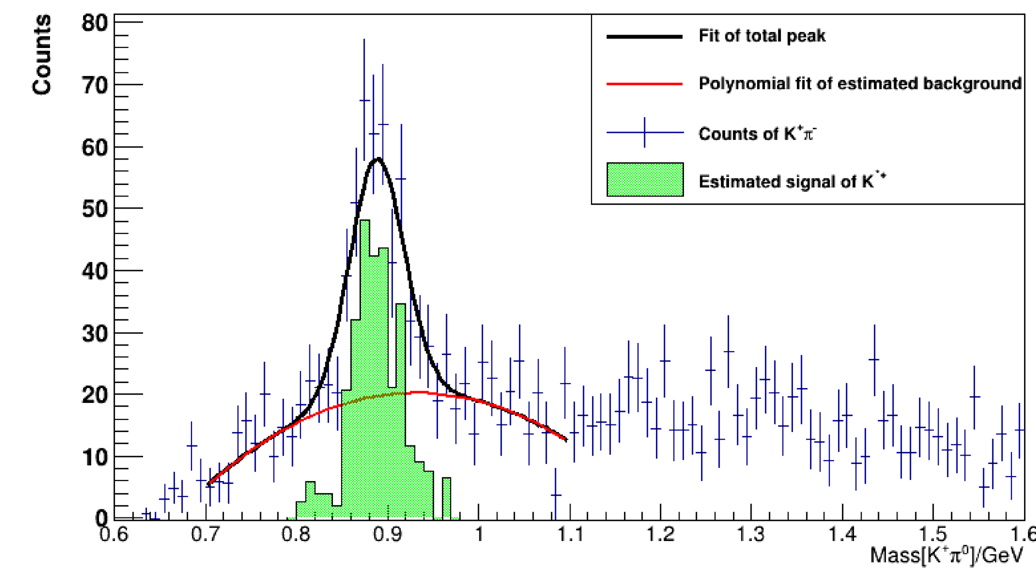

Fig 3. K^{+*} histogram corresponding to a bin center of 1322 MeV for the mass of the invariant $\Lambda\pi^{-}$

These projections and analysis were repeated for each energy bin of the $\Lambda\pi^{-}$ system, then compiled into a single 1D histogram. The result is a plot that may be fitted using a Gaussian with mean 1322.27 $\pm$ 0.28 MeV (PDG value of Ξ^{-} [1] is 1321.71$\pm$0.07) and a standard deviation of 5.59 $\pm$ 0.26 MeV.

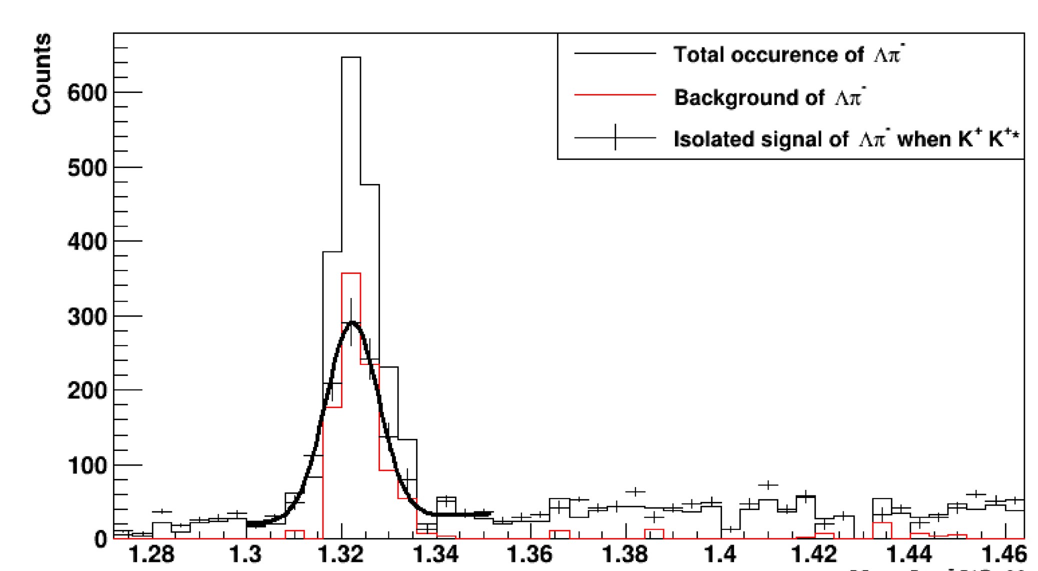

Fig 4. K^{+*} counts per corresponding $\Lambda\pi^{-}$ mass

A Monte Carlo simulation of this reaction was run with the same incident photon energies, propagated with a fixed *t*-slope and all other decays distributed as phase space. The resulting products were then passed through a series of cuts to compensate for detector resolution and geometry. Using the equation above, cross sections for each energy bin were calculated, as seen in Fig. 5.

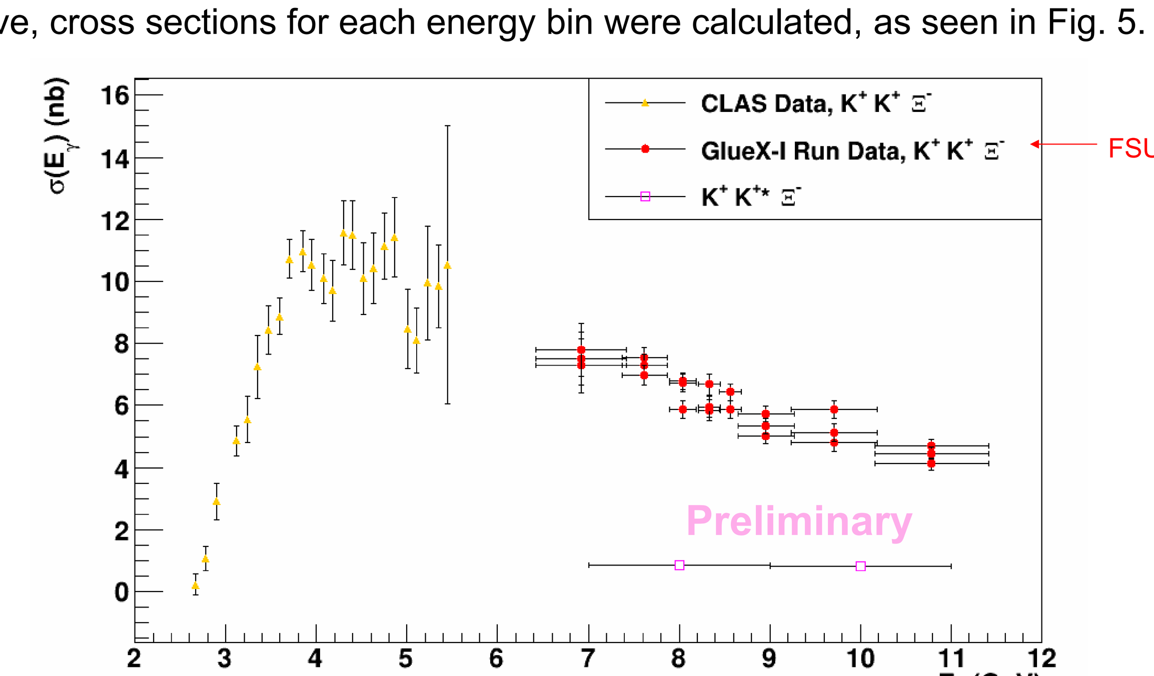

Fig 5. Total cross section of $K^{+*} K^{+} \Xi^{-}$ compared to its background reactions

Results (Background to Ξ^{-*})

To ensure that the events included in this analysis are not statistically more attributable to other decay sequences, the $K^{+}\pi^{0}$system can be plotted against $\Lambda\pi^{-}\pi^{0}$, where invariant mass of $\Lambda\pi^{-}$ is restricted to be near the $\Xi^{-}(1320)$. The vertical or horizontal bands would indicate particle states decaying to those products. For example, the horizontal stripe in Fig. 6 indicates a K^{+*} decaying into $K^{+}\pi^{0}$ instead of a Ξ^{-*} decaying into $\Lambda\pi^{-}\pi^{0}$. The events attributable to K^{+*} serve as a background to the Ξ^{-*}.

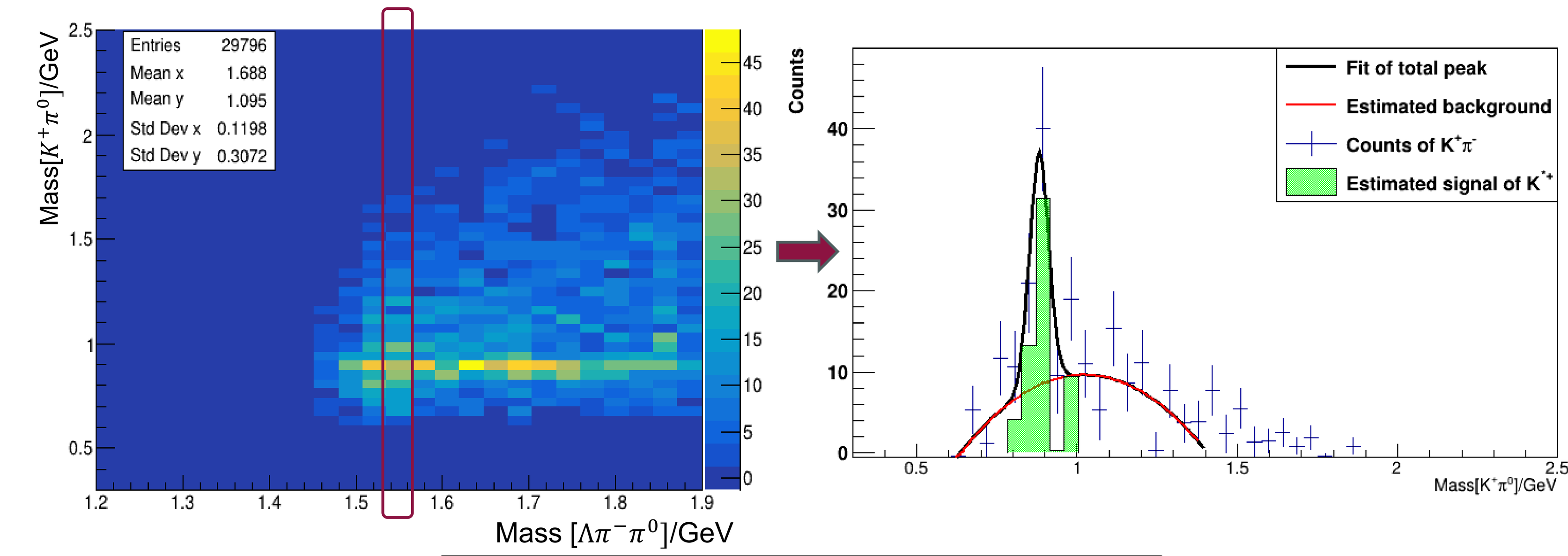

Fig 6. Comparison of $K^{+}\pi^{0}$states to $\Lambda\pi^{-}\pi^{0}$ states

Following the same compiling process for each energy bin as before results in a graph with no definitive peak, as in Fig. 7. From this, it can be concluded that there are no discernible background features counting towards Ξ^{-*} events ($\Xi^{-*} \rightarrow \Xi^{-}\pi^{0}$, where $\Xi^{-} \rightarrow \Lambda\pi^{-}$).

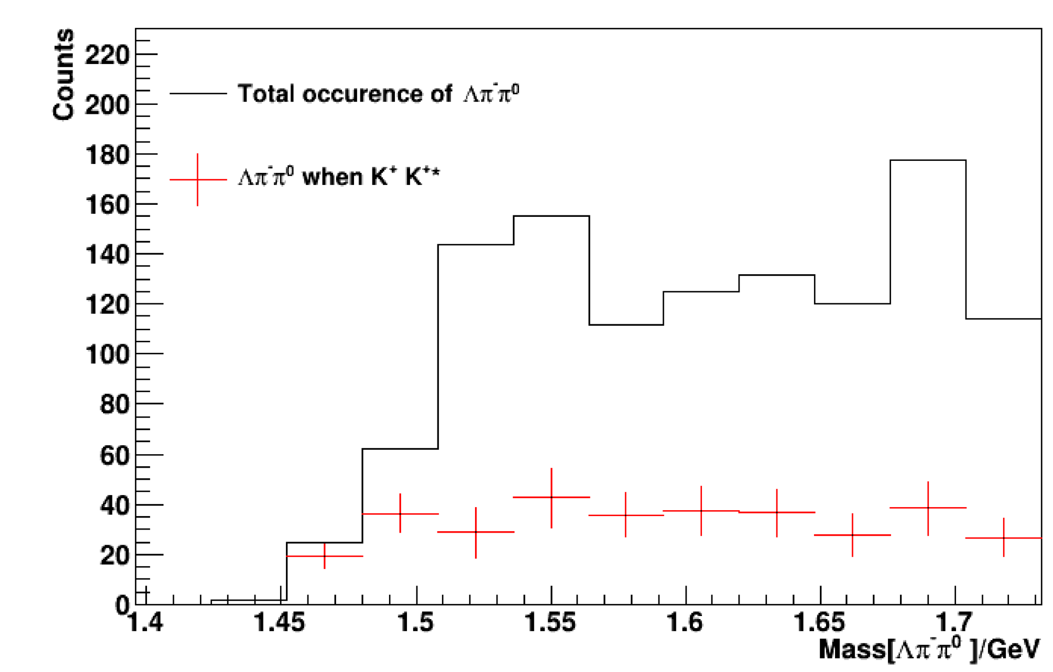

Fig 7. Comparison of K^{+*} counts to corresponding Ξ^{-} mass

Conclusions

There are two mechanisms that produce the same final products:

$$\gamma\, p \rightarrow K^{+*}\, Y^{*}$$
$$K^{+*} \rightarrow K^{+}\, \pi^{0}$$
$$Y^{*} \rightarrow K^{+}\, \Xi^{-}$$

$$\gamma\, p \rightarrow K^{+}\, Y^{*}$$
$$Y^{*} \rightarrow K^{+*}\, \Xi^{-}$$
$$K^{+*} \rightarrow K^{+}\, \pi^{0}$$

At the detector level, these are indistinguishable, as there are no outstanding qualities to discern each K^{+} particle.

This analysis has successfully calculated a preliminary cross section for the reaction $\gamma\, p \rightarrow K^{+*} K^{+} \Xi^{-}$, and provides a measure of the background for the reaction $\gamma\, p \rightarrow K^{+} K^{+} \Xi^{-*}$.

Literature Cited

[1] S. Navas *et al.* (Particle Data Group), Phys. Rev. D 110, 030001 (2024)