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# Quasi-free Cross Section Measurements at CLAS: $\gamma D \to p\pi^-(p), \gamma D \to K^*(892)^0\Lambda(p), \gamma D \to K^+\Sigma^*(1385)^-(p)$

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Preliminary measurements of the quasi-free differential cross sections of the $\gamma D \to p\pi^-(p)$, $\gamma D \to K^*(892)^0\Lambda(p)$, and $\gamma D \to K^+\Sigma^*(1385)^-(p)$ reactions are shown using data from the Jefferson Lab Hall B CLAS g13 experiment. No experimental cross section data have yet been published on $\gamma D \to K^*(892)^0\Lambda(p)$, and the only published cross section data on $\gamma D \to K^+\Sigma^*(1385)^-(p)$ are at forward angles, where $t$-channel $K^+$ and $K^{*+}$ exchanges are predicted to dominate. These data can be used to contribute to the search for the "missing" $N^*$ resonances, some of which are predicted to have non-negligible couplings to the excited strangeness channels. These cross sections are shown to be sizable compared to the ground-state channels, indicating that it is important to include excited channels in coupled-channels analyses used to extract the $N^*$ resonances. In addition, the $\gamma D \to p\pi^-(p)$ data provide a significant increase to the world statistics, and will be used to study rescattering effects within the deuteron.

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## 1. Introduction

About a dozen $N^*$ states have been well-established according to the Particle Data Group [1], but some relativized quark models [2] predict that many more $N^*$ resonances exist. However, diquark models [3] predict that the $N^*$ spectrum is limited by a correlated quark-pair in the nucleon. Some models of baryon decays [4] predict that some of the unobserved $N^*$ states couple non-negligibly to the strangeness channels. Measurements of the cross sections and polarization observables of strangeness photoproduction reactions on the proton and the neutron can provide additional constraints on the extraction of the $N^*$ resonance parameters, which will provide valuable information on the relevant degrees of freedom within the nucleon.

The CLAS detector [5] was located in experimental Hall B at Jefferson Lab in Newport News, VA. Its torus magnet bent charged particles through drift chambers, time-of-flight scintillator paddles, and other detector components with a large angular acceptance. The CLAS g13 experiment [6] ran between October 2006 and June 2007 with a 40-cm-long liquid-deuterium target located within CLAS. For the data used in this analysis, an $\sim$80% circularly polarized photon beam was produced via bremsstrahlung by a 2.655 GeV electron beam incident on a photon tagger.

## 2. Analysis

Both the $\gamma D \to K^*(892)^0\Lambda(p)$ and $\gamma D \to K^+\Sigma^*(1385)^-(p)$ reactions were studied through their decays to $\gamma D \to K^+\pi^-\Lambda(p)$, with $\Lambda \to p\pi^-$. To select these and $\gamma D \to p\pi^-(p)$ events, particle identification, $\Lambda$ invariant mass, and spectator-proton missing mass cuts were placed. In addition, a missing momentum cut of 200 MeV/c was used to select quasi-free events.

In the $\gamma D \to K^*(892)^0\Lambda(p)$ analysis, $\pm 1\Gamma$ overlap cuts were placed on the $\Sigma^*(1385)^-$ invariant mass peaks to remove the majority of the dominant $\Sigma^*(1385)^-$ background. Approximately 17000 $\gamma D \to K^*(892)^0\Lambda(p)$ events were extracted in 35 bins, and about 100000 $\gamma D \to K^+\Sigma^*(1385)^-(p)$ events were extracted in 170 bins. In addition, approximately 300 million $\gamma D \to p\pi^-(p)$ events were extracted in about 9000 bins.

## 3. Preliminary Results

All of the cross sections from the g13 experiment shown in this paper are preliminary and do not have systematic uncertainties; they are only quoted with statistical uncertainties. Final acceptance studies and systematic uncertainty studies for these channels are currently ongoing. Also, none of them have been corrected for final-state interactions.

The preliminary differential cross section of the $\gamma D \to p\pi^-(p)$ reaction from the CLAS g13 experiment is shown in Figure 1. It is compared against the CLAS g10 experiment results [7], which is quoted without systematic uncertainties or corrections for final-state interactions. These data are compared to the SAID GB11 [8] and the Bonn Gatchina BnGa12-1 [10] predictions. The SAID predictions were obtained from a partial wave analysis including the CLAS g10 data [9], and thus closely match the g10 and g13 data. Discrepancies between the g10 and g13 data are currently being studied.

The preliminary differential cross section of the $\gamma D \to K^*(892)^0\Lambda(p)$ reaction from the CLAS g13 experiment is shown in Figure 2. It is compared against the model prediction by Kim *et al.*

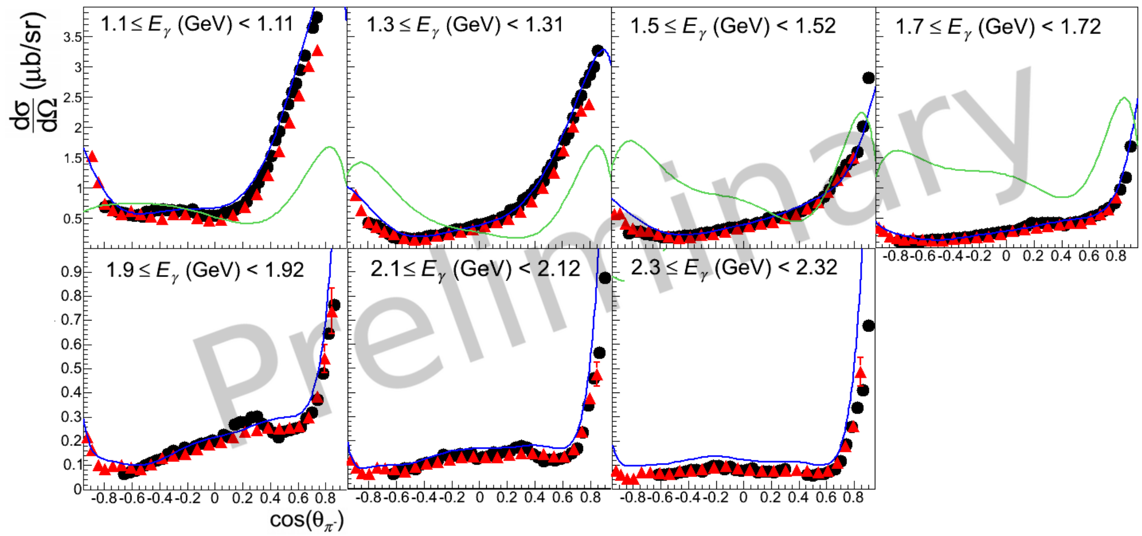



Figure 1: For $\gamma D \to p\pi^-(p)$, the preliminary CLAS g13 (black circles) and CLAS g10 [7] (red triangles) differential cross sections, and the SAID GB11 [8] (blue curves) and Bonn Gatchina BnGa12-1 [10] (green curves) predictions. The uncertainties are smaller than the data markers.

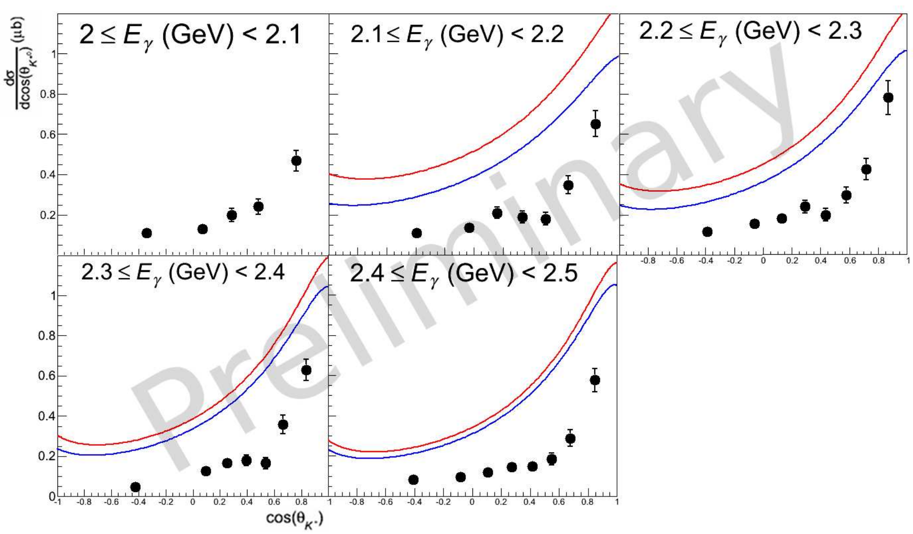



Figure 2: For $\gamma D \to K^*(892)^0\Lambda(p)$, the preliminary CLAS g13 (black circles) differential cross section data and the model predictions by Kim *et al.* [11] with (red curves) and without (blue curves) $N^*$ resonances in the model.

[11], which is based on effective Lagrangians. The model predictions are significantly larger than the data, but both exhibit a strong forward-angle peak, indicating that the reaction is dominated by $t$-channel interactions.

The preliminary differential cross section of the $\gamma D \to K^+\Sigma^*(1385)^-(p)$ reaction from the CLAS g13 experiment is shown in Figure 3. It is compared against the published LEPS results [12] and the model prediction by Oh, Ko, and Nakayama [13]. While the g13 and LEPS results agree within the uncertainties, the model predictions, which are based on effective Lagrangians,

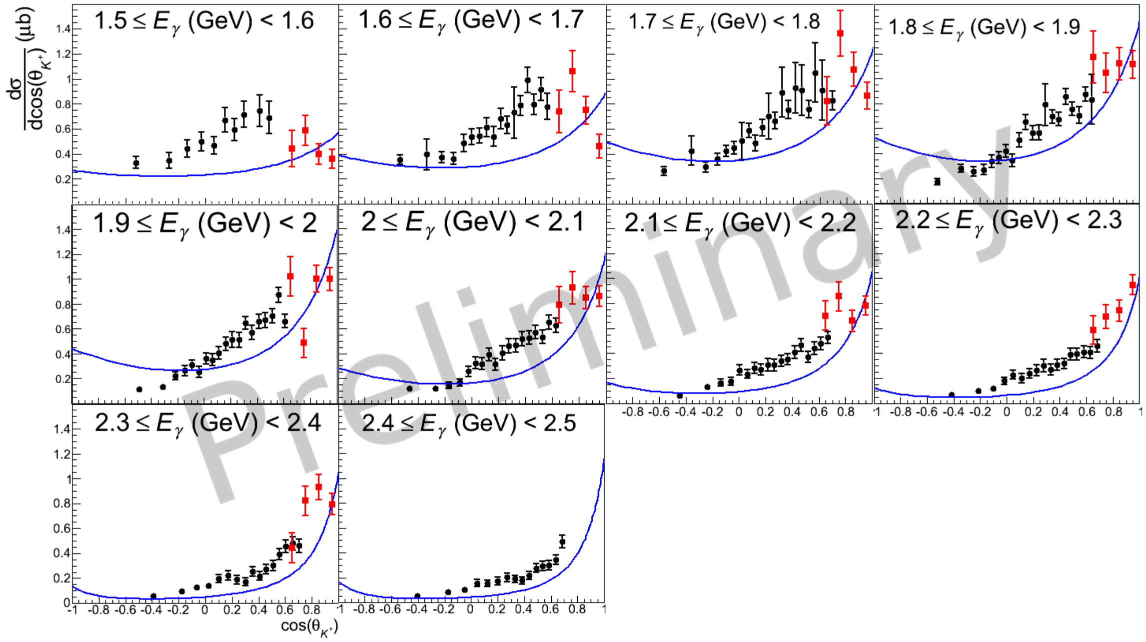


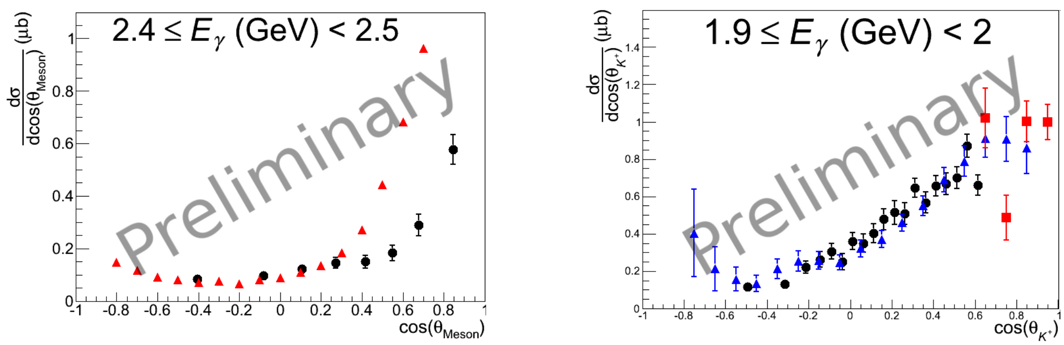

Figure 3: For $\gamma D \to K^+\Sigma^*(1385)^-(p)$, the preliminary CLAS g13 (black circles) differential cross section data, the LEPS data [12] (red squares), and model predictions by Oh, Ko, and Nakayama [13] (blue curves).

are significantly smaller than the g13 data.

The preliminary g13 $\gamma D \to K^*(892)^0\Lambda(p)$ cross section is shown compared against the ground-state $\gamma p \to K^+\Lambda$ cross section [14] in Figure 4a for one of the photon energy bins. Although there are no published data on the $\gamma D \to K^0\Lambda(p)$ cross section, this comparison illustrates that the photoproduction cross section of the excited, $K^*\Lambda$ channel is sizable to that of the ground-state $K\Lambda$ channel, especially at larger angles. As shown in Figure 4b, the LEPS and preliminary g13 $\gamma D \to K^+\Sigma^*(1385)^-(p)$ cross sections are similar to that of the ground-state $\gamma D \to K^+\Sigma^-(p)$ reaction [15] at larger angles. The similar magnitudes of these cross sections indicate that it is important to include these excited channels in the coupled-channels analyses that are used for extracting the $N^*$ resonance parameters.

## 4. Conclusions

Systematic uncertainty studies and final acceptance studies for these CLAS data are currently ongoing. The $\gamma D \to p\pi^-(p)$ cross section will be used to study rescattering effects in deuteron targets. The $\gamma D \to K^*(892)^0\Lambda(p)$ and $\gamma D \to K^+\Sigma^*(1385)^-(p)$ cross sections are important to include in coupled-channels analyses in $N^*$ searches, due to their sizable cross sections compared to the ground state channels. When finalized, these data can be used to contribute to the search for the missing $N^*$ resonances.




(a) CLAS g13 $\gamma D \to K^*(892)^0\Lambda(p)$ (preliminary, black circles) and CLAS g11 $\gamma p \to K^+\Lambda$ [14] (red triangles). There are no published data for $\gamma D \to K^0\Lambda(p)$.

(b) CLAS g13 $\gamma D \to K^+\Sigma^*(1385)^-(p)$ (preliminary, black circles), LEPS $\gamma D \to K^+\Sigma^*(1385)^-(p)$ [12] (red squares), and CLAS g10 $\gamma D \to K^+\Sigma^-(p)$ [15] (blue triangles).

Figure 4: Comparison of the excited state and ground state cross section measurements in one photon energy bin. Their similar magnitudes indicate it is important to include the excited channels in coupled-channels analyses used to extract the $N^*$ resonances.

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