Strangeness Electroproduction on the Nucleon at CLAS

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Abstract. High-precision measurements of strange particle production from both proton and neutron targets are a core part of the physics program with the CLAS spectrometer in Hall B at Jefferson Laboratory. Measurements have been carried out at beam energies up to 6 GeV in experiments with polarized beams and polarized targets. This talk will focus on the electroproduction measurements that have been completed, which include cross sections and hyperon polarization observables for K^+Y ($Y = \Lambda, \Sigma^0$) final states over a broad kinematic range in momentum transfer Q^2 and invariant energy W, while spanning nearly the full kaon center-of-mass angular range. These data in the strangeness sector are necessary to better understand the different production mechanisms for Λ and Σ hyperons and to disentangle the different resonant and non-resonant amplitudes in the intermediate state. The usefulness of the CLAS electroproduction data as part of a coupled-channel model fit will be discussed as well as an outlook of this program for the future.

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INTRODUCTION

One of the cornerstones of the physics program in Hall B with the CLAS spectrometer is the N^* program. Measurements that probe the spectrum of nucleon excited states are an important aspect of understanding nucleon structure in this regime of non-perturbative strong interactions in QCD. The large acceptance CLAS spectrometer was designed to measure γN and $\gamma^* N$ cross sections and spin observables over a broad kinematic range for exclusive reaction channels including πN, ωN, ϕN, ρN, ηN, $\eta' N$, $\pi\pi N$, KY, KY^*, and K^*Y. Measurements at electron beam energies up to 6 GeV allow us to probe the relevant degrees of freedom as a function of distance scales up to $Q^2 \sim 5$ GeV^2 over the full nucleon resonance region.

The constituent quark model predicts many more states than have been identified from experiment. This model (e.g. see Ref. [1]) provides predictions for the decay amplitudes to a number of different final states. However, most of our present knowledge of baryon resonances comes from reactions involving pions. This suggests a search for these hadronic states in other reaction channels such as the strangeness production reactions. An important part of the CLAS N^* program involves the investigation of N^* and Δ^* states coupling to strangeness final states through both photo- and electroproduction reactions. Beyond the different coupling constants relative to the pionic channels (e.g. g_{KNY} vs. $g_{\pi NN}$), the study of the exclusive production of $K^+\Lambda$ and $K^+\Sigma^0$ final states has other advantages in the search for missing resonances. As baryon resonances have large widths and are often overlapping, studies of different final states can provide for important cross checks in quantitatively understanding the contributing amplitudes. Also, although the two ground-state hyperons have the same valence quark structure (*uds*), they differ in isospin, such that intermediate N^* resonances can decay strongly to $K^+\Lambda$ final states, while both N^* and Δ^* decays can couple to $K^+\Sigma^0$ final states.

With the development of sophisticated coupled-channel models and advanced single-channel isobar models over the last several years, the initial focus has been on fitting the high-quality available photoproduction data. To date there has been very limited use of the high-quality KY electroproduction data from CLAS. The published electroproduction cross sections and polarization data dominate the world's strangeness physics database in the nucleon resonance region. In this talk I highlight the electroproduction data from CLAS and why it will ultimately be required in the coupled-channel and isobar model fits to fully disentangle which N^* states couple to KY.

RECENT DEVELOPMENTS

With the recently available data for the KY final states from CLAS and elsewhere, there have been renewed efforts on the development of theoretical models. One class are the single-channel, tree-level isobar models. Two recent examples include the hybrid Regge plus resonance isobar model (RPR) [2] and the isobar/multipole model [3]. A number of groups have also developed coupled-channel models [4, 5, 6] or models with simultaneous fits to multiple but independent reaction channels [7, 8]. However, as a combined multi-channel analysis of the photo- and electroproduction reactions is not yet available, isobar models currently represent the best possibility of studying both reactions within the same framework. The recent theoretical analyses have focused solely on the available photoproduction data, but it has been shown that electroproduction observables can yield important complementary insights to improve and constrain the theory. This is relevant as the available multi-channel models that fit to the KY photoproduction data alone have not yielded consistent information on the dominant $N^* \to KY$ couplings.

According to the listings of the Particle Data Group [9], the current knowledge of the $N^* \to KY$ and $\Delta^* \to K\Sigma$ couplings is quite limited. There are only four N^* states listed with decay strength to $K\Lambda$. There are no N^* states and only one Δ^* state listed with decays to $K\Sigma$. For the photocoupling amplitudes that do exist, they have rather large uncertainties. Clearly there is significant room for improvement.

CLAS has provided a wealth of high-quality data for $K^+\Lambda$ and $K^+\Sigma^0$ photoproduction data on the proton. The publications are as follows:

- J. McNabb *et al.*, Phys. Rev. C **69**, 042201 (R) (2004); $d\sigma/d\cos\theta_K^*$, recoil polarization for $K^+\Lambda$, $K^+\Sigma^0$ - W: [1.6,2.3 GeV], $\cos\theta_K^*$: [-0.85,0.95].
- R. Bradford *et al.*, Phys. Rev. C **73**, 035202 (2006); $d\sigma/d\cos\theta_K^*$ for $K^+\Lambda$, $K^+\Sigma^0$ - W: [1.6,2.53 GeV], $\cos\theta_K^*$: [-0.85,0.95].
- R. Bradford *et al.*, Phys. Rev. C **75**, 035205 (2007); beam-recoil polarization (C_x, C_z) for $K^+\Lambda$, $K^+\Sigma^0$ - W: [1.6,2.53 GeV], $\cos\theta_K^*$: [-0.85,0.95].
- M.E. McCracken *et al.*, Phys. Rev. C **81**, 025201 (2010); $d\sigma/d\cos\theta_K^*$, recoil polarization for $K^+\Lambda$ - W: [1.6,2.84 GeV], $\cos\theta_K^*$: [-0.85,0.95].

- B. Dey *et al.*, Phys. Rev. C **82**, 025202 (2010); $d\sigma/d\cos\theta_K^*$, recoil polarization for $K^+\Sigma^0$ - W: [1.69,2.84 GeV], $\cos\theta_K^*$: [-0.85,0.95].

The nearly full angular coverage in θ_K^* and the broad range coverage in invariant energy W, coupled with very fine binning and small overall statistical and systematic uncertainties for the $K^+\Lambda$ and $K^+\Sigma^0$ final states has provided an unprecedented tool for model fits.

The CLAS strangeness physics program in photoproduction for the associated production of ground-state hyperons is based on performing "complete" experiments on both the proton and neutron [11]. The set of experiments for γp has completed taking data and analysis is now underway. The γn experimental program will be finalized when the HD-Ice experiment [12] completes its production run in the first half of 2012.

CLAS *KY* ELECTROPRODUCTION RESULTS

While the CLAS *KY* electroproduction program does not include analysis of a "complete" experiment, and while the statistical precision of the $\gamma^* p$ data are necessarily less than the γp data (due to the requirement of electron detection), the electroproduction data are, in principle, a richer source of information concerning $N^* \to KY$ coupling compared to photoproduction. This results as electroproduction includes both longitudinal and transverse photon polarization coupling to the s-channel N^* and Δ^* states. Utilizing the Q^2 lever arm gives access to the γNN^* transition helicity amplitudes (electrocouplings), the longitudinal and longitudinal-transverse structure functions, and allows for probing the associated N^* electromagnetic form factors. The electroproduction data not only provides supplementary information relative to photoproduction, but also complementary.

To date, only two models have utilized the available CLAS electroproduction data. The RPR isobar model is based on fits to the first sets of CLAS photoproduction data but has been limited to making "predictions" for the CLAS electroproduction data [2]. The only available published model that has actually included the CLAS electroproduction data is the isobar/multipole model from Ref. [3]. Comparison of these models to the CLAS data has shown that the electroproduction data provide for model constraints beyond the photoproduction data, especially with regard to the non-resonant backgrounds and the form factor evolution. In the $K^+\Lambda$ channel, the model agreement is fair overall, but where the longitudinal response has been shown to be significant (higher W and forward θ_K^*), there are notable differences with the data. The overall model agreement with the $K^+\Sigma^0$ electroproduction data is worse. This likely results from the nearly complete lack of knowledge regarding $\Delta^* \to K\Sigma$ coupling, as well as the untested assumption that the N^* resonance set is the same for $K^+\Lambda$ and $K^+\Sigma^0$.

The CLAS publications from electroproduction to date include:

- D.S. Carman *et al.*, Phys. Rev. Lett. **90**, 131804 (2003); beam-recoil polarization (P_x', P_z') for $K^+\Lambda$ - W: [1.6,2.3 GeV], Q^2: [0.3,1.5 GeV^2], $\cos\theta_K^*$: [-1:1].
- P. Ambrozewicz *et al.*, Phys. Rev. C **75**, 045203 (2007); σ_U, σ_L, σ_T, σ_{TT}, σ_{LT} for $K^+\Lambda$, $K^+\Sigma^0$ - W: [1.6,2.4 GeV], Q^2: [0.5,2.8 GeV^2], $\cos\theta_K^*$: [-1:1].

- R. Nasseripour *et al.*, Phys. Rev. C **77**, 065208 (2008); $\sigma_{LT'}$ for $K^+\Lambda$ - W: [1.6,2.3 GeV], Q^2: [0.3,1.5 GeV^2], $\cos\theta_K^*$: [-1,1].
- D.S. Carman *et al.*, Phys. Rev. C **79**, 065205 (2009); beam-recoil polarization (P'_x, P'_z) for $K^+\Lambda$, $K^+\Sigma^0$ - W: [1.6,2.3 GeV], Q^2: [0.3,5.4 GeV^2], $\cos\theta_K^*$ [-1,1].

OUTLOOK AND CONCLUSIONS

Ultimately, the KY photo- and electroproduction data should be fit simultaneously to maximize the constraints on the resonant and non-resonant parameters. The electroproduction data from CLAS represents a valuable asset to theory that has been under utilized. However, several groups are now working toward a combined fit of the γp and $\gamma^* p$ data. These include the Excited Baryon Analysis Center (EBAC) at JLab in their coupled-channel framework [13], the RPR hybrid isobar model [2], and the isobar model developed by the FIU group [14].

The next work to be published in the electroproduction program is the $K^+\Lambda$ recoil polarization (see M. Gabrielyan - these proceedings). There is also a possibility for running with an electron beam on the HD-Ice target, which will be studied in the fall 2011 commissioning beam time. In the longer term, there is a developing baryon spectroscopy program as part of the JLab 12-GeV upgrade with the CLAS12 spectrometer. This will allow for studies of exclusive KY final states in the range of Q^2 up to 10 GeV^2.

In this talk I have reviewed some of the key reasons why the photo- and electroproduction processes of open-strangeness production are important for the investigation of baryonic structure and missing quark model states. I have discussed several aspects of the CLAS strangeness physics program highlighting the breadth and quality of not only our photoproduction data, but also our electroproduction data sets as well. New amplitude-level analyses including the CLAS electroproduction data are called for to more fully unravel the N^* contributions to the KY intermediate state.

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