Photoproduction of Hyperon Resonances on Hydrogen

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Abstract.

We present the current status of our work on the extraction of cross sections and polarizations for photoproduction of hyperon resonances on a hydrogen target ($\gamma p \rightarrow K^+ Y^*$) using existing data from the CEBAF Large Acceptance Spectrometer (CLAS). The cross sections and polarizations will be used for a simultaneous theoretical analysis of hyperon ground state and hyperon resonance production. Thus far we have identified the hyperon resonances $\Sigma^0(1385)$, $\Lambda(1405)$, and $\Lambda(1520)$ through missing mass and invariant mass cuts in various decay channels, such as $\Lambda\pi^0$, $\Lambda\pi^+\pi^-$, $\Sigma^0\pi^0$, $\Sigma^+\pi^-$, $\Sigma^-\pi^+$, pK^- and nK^0 . We have not yet seen the resonances $\Lambda(1600)$, $\Sigma(1660)$, $\Lambda(1670)$, $\Sigma(1670)$ and $\Lambda(1690)$, although they need to be included for the analysis of the hyperon ground state production.

INTRODUCTION

Strangeness production has been studied in the reactions $\gamma p \rightarrow KY$ to the hyperon ground states, the $\Lambda(1116)$ and $\Sigma(1193)$, for almost 40 years [1]. In some theoretical models [2] the exchange of a virtual hyperon resonance in the u -channel has been included in order to reproduce the measured cross sections and polarizations for the production of the hyperon ground states. Various hyperon resonances, with their corresponding coupling constants, have been considered as candidates for the propagator in the u -channel for hyperon ground state production. The actual contribution of the hyperon resonance in the u -channel is only poorly known. Some models do not include any hyperon resonance [3] [4].

In our approach, actual photoproduction data for hyperon resonances on hydrogen will be used to determine the contributions of the hyperon resonances in the u -channel to $\gamma p \rightarrow KY$ by fitting the data for $\gamma p \rightarrow KY$ and $\gamma p \rightarrow KY^*$ simultaneously. The inclusion of the measured hyperon resonance data will constrain the coupling constants for the u -channel in the reaction $\gamma p \rightarrow KY$.

We are analyzing existing data from the CEBAF Large Acceptance Spectrometer (CLAS) for photoproduction on hydrogen with a special emphasis on the extraction of hyperon resonance data, $\gamma p \rightarrow KY^*$, at photon energies between the corresponding thresholds and 2.4 GeV. Data up to 3.1 GeV will be available soon. Our goal is to obtain as complete a set of hyperon resonance data as possible for use in a new theoretical analysis of the photoproduction mechanism of hyperons and hyperon resonances on hydrogen.

ISOBAR MODELS

The cross sections and polarizations for the reactions $\gamma p \rightarrow KY$ can be compared with the predictions from isobar models. The Feynman diagrams for the reaction $\gamma p \rightarrow K^+ \Lambda$ are shown in Fig. 1. The s -, t - and u -channel diagrams can be grouped into Born and resonance exchange poles. Every vertex within a diagram is parametrized by a coupling constant. The kaon-hyperon-nucleon coupling constants g_{KYN} and g_{KY^*N} are of particular interest. Typically they are obtained from a fit to the cross section and polarizations of $\gamma p \rightarrow KY$ and the resulting χ^2/N is used to select the best fitting hyperon resonance candidate. By using the data from the reaction $\gamma p \rightarrow KY^*$ as a constraint we hope to improve the significance of the fit.

FIGURE 1. Feynman diagrams of an isobar model for the reaction $\gamma p \rightarrow K^+ \Lambda$.

PRELIMINARY RESULTS

Fig. 2 shows the missing mass spectrum for a measured K^+ . In addition to the $\Lambda(1116)$ and $\Sigma(1193)$, the unresolved resonances $\Sigma^0(1385)$ and $\Lambda(1405)$ are seen as well as the $\Lambda(1520)$.

It is clear that the signal-to-background ratio needs to be improved. In addition, a method to separate the $\Sigma^0(1385)$ and $\Lambda(1405)$ resonances has to be developed.

The shaded areas in this and the following figures indicate the energy regions corresponding to the full width at half maximum of the resonances according to the compilation of the Particle Data Group (PDG) [5].

FIGURE 2. Missing mass spectrum m_X for $\gamma p \rightarrow K^+ X$.

We next required the detection of a proton in addition to that of a K^+ . This allows us to focus on the reaction $\gamma p \rightarrow K^+ \Lambda(1520)$ because the $\Lambda(1520)$ can decay into pK^- (the branching fraction is 45% for $\Lambda(1520) \rightarrow N\bar{K}$). The corresponding spectrum is shown in the left panel of Fig. 3. The K^- can be treated as missing particle or, if available, be included in the analysis.

The center panel of Fig. 3 shows the spectrum obtained by requiring the detection of a K^+ as before, and the K^- in addition to the proton in the decay channel $\Lambda(1520) \rightarrow pK^-$. The signal-to-background ratio and the resolution in the invariant mass spectrum is significantly improved in comparison with the missing mass spectrum in the left panel of Fig. 3.

The right panel of Fig. 3 shows the result for the decay channel $\Lambda(1520) \rightarrow nK^0$, followed by $K^0 \rightarrow \pi^+\pi^-$. The K^0 is identified by cutting on the invariant mass of the decay pions in the K^0 mass region. The detection of pions from the decay of the neutral kaon serves as an additional criterion for the event identification.

Besides the decay channel $Y^* \rightarrow N\bar{K}$ we can also analyse the decay of $Y^* \rightarrow \Sigma\pi$.

FIGURE 3. Left panel: missing mass spectrum m_X for $\gamma p \rightarrow K^+ X$ with identified proton and missing K^- from $\Lambda(1520) \rightarrow p K^-$. Center panel: invariant mass spectrum $m_{(p,K^-)}$ for $\gamma p \rightarrow K^+ \Lambda(1520)$, detecting p , K^+ and K^- . Right panel: missing mass spectrum m_X for $\gamma p \rightarrow K^+ X$, with identified K^0 and missing neutron from $\Lambda(1520) \rightarrow n K^0$, K^0 identified via cut on invariant mass of decay pions ($K^0 \rightarrow \pi^+ \pi^-$).

FIGURE 4. Missing mass spectra m_X for $\gamma p \rightarrow K^+ X$, in particular $\gamma p \rightarrow K^+ Y^*$ with detection of the decay $Y^* \rightarrow \Sigma^+ \pi^-$ followed by $\Sigma^+ \rightarrow n \pi^+$ decay (left panel) and with detection of the decay $Y^* \rightarrow \Sigma^- \pi^+$ followed by $\Sigma^- \rightarrow n \pi^-$ (right panel).

Presented in Fig. 4 are the spectra that were extracted with the requirement of the detection of the decay $Y^* \rightarrow \Sigma^+ \pi^-$ followed by $\Sigma^+ \rightarrow n \pi^+$ (left panel) and the detection of the decay $Y^* \rightarrow \Sigma^- \pi^+$ followed by $\Sigma^- \rightarrow n \pi^-$ (right panel). The $\Sigma^\pm$ decay neutron was missing, while the 4-momentum of the decay $\pi^\pm$ was measured. The events in these spectra are primarily from the photoproduction of the Y^* resonances $\Lambda(1520)$, $\Sigma(1385)$, and $\Lambda(1405)$ in the $\gamma p \rightarrow Y^* + K^+$ reaction.

We have also seen the decay channel $Y^* \rightarrow \Sigma^0 \pi^0$ by detecting γ 's. However, the acceptance for this decay channel is lower because of the high γ multiplicity and the minimum gamma energy requirement of 100 MeV for the CLAS shower detector.

FIGURE 5. Missing mass spectrum m_X for $\gamma p \rightarrow K^+ \Sigma^0(1385)$ with $\Sigma^0(1385) \rightarrow \Lambda \pi^0$.

The decay channel $\Sigma^0(1385) \rightarrow \Lambda \pi^0$ is important for the separation of the reactions $\gamma p \rightarrow K^+ \Sigma^0(1385)$ and $\gamma p \rightarrow K^+ \Lambda(1405)$ (see Fig. 5). The decay channel $\Lambda \pi^0$ is prohibited for $\Lambda(1405)$ because of isospin conservation. We will use this decay channel to determine the cross sections for $\gamma p \rightarrow K^+ \Sigma^0(1385)$ first and then subtract them from the combined cross sections for the decay channel $\Sigma^0(1385)/\Lambda(1405) \rightarrow \Sigma^0 \pi^0$ in order to extract the cross sections for $\gamma p \rightarrow K^+ \Lambda(1405)$.

FIGURE 6. Yields for $\gamma p \rightarrow K^+ \Lambda(1520)$ as a function of photon energy E_γ and the angle $\Theta_{K^+}^{CMS}$ between the photon and the K^+ .

The yields for $\gamma p \rightarrow K^+ \Lambda(1520)$ are shown in Fig. 6 as a function of the photon energy E_γ and the angle $\Theta_{K^+}^{CMS}$ between the photon and the K^+ . They need to be corrected for the detector acceptance and normalized to the photon flux in order to obtain cross sections.

The plots in Fig. 7 show the spectra of the missing mass m_X for the reaction $\gamma p \rightarrow K^+ \Lambda(1520)$ for different photon energies E_γ (columns) and different values of $\cos \Theta_{K^+}^{CMS}$ (rows). The background very much depends on the parameters E_γ and $\Theta_{K^+}^{CMS}$.

CONCLUDING REMARKS

Several hyperon resonances including $\Sigma^0(1385)$, $\Lambda(1405)$ and $\Lambda(1520)$ have been identified through missing mass and invariant mass cuts in various decay channels, such as $\Lambda \pi^0$, $\Lambda \pi^+ \pi^-$, $\Sigma^0 \pi^0$, $\Sigma^+ \pi^-$, $\Sigma^- \pi^+$, $p K^-$ and $n K^0$. Eventually,

FIGURE 7. Missing mass spectra m_X for $\gamma p \rightarrow K^+ X$, with measured proton from the decay $X \rightarrow p K^-$, for different values of E_γ (columns) and $\theta_{K^+}^{CMS}$ (rows). A clear peak is seen due to the $\Lambda(1520)$. The values of E_γ are given in the spectra in the top row, the values of $\theta_{K^+}^{CMS}$ are given in the spectra in left-most column. The plots for the angle intervals $(-0.6, -0.2)$ and $(0.2, 0.6)$ were left out in this figure.

cross sections and polarizations will be extracted for all reactions and the results will be compared with theoretical models for hyperon ground state and resonance production. For a successful theoretical analysis, it is important to achieve as complete a set of hyperon resonance measurements as possible in the appropriate mass region with a minimum of background contribution. For each hyperon resonance production channel the results from various decay channels are going to be used as consistency check of the cross sections using the known branching ratios.

A detailed background study is in progress to include the effects from particle misidentification, uncertainty in missing masses, wrong combinations of decay products and, most important, reflections from other reactions (reflections are contributions from other reactions as a result of particle misidentification or incorrect combinations of decay particles). The background study will be performed with GEANT simulations as well as with simple calculations using the particles' 4-momenta and their measurement errors. This analysis will significantly reduce the uncertainties in the cross sections and polarizations and is considered as a complementary technique to side-band subtraction which is the method used for estimating background underneath a peak from the yields on each side of the peak.

GEANT simulations will be used to determine the acceptance of CLAS for each reaction and decay channel. Because of the hyperon recoil polarizations and the detector design, the distribution of the decay particles will be asymmetric and therefore affect the acceptance of CLAS for the individual reaction. Unfortunately, little is known about the polarization of the hyperon resonances. Therefore we will have to go through multiple iterations of simulations and acceptance corrections. The corrected polarizations are the input for the next iteration. The large variety of decay channels allows us to study very closely the detector acceptance as well as the background contributions from other reactions.

It will be important for theoretical analyses of hyperon ground state production to include the hyperon resonances at energies above the $\Lambda(1520)$ resonance, in the 1.6 to 1.7 GeV region. Additional CLAS photoproduction data on hydrogen, up to a photon energy of 3.1 GeV, are currently being analyzed by the CLAS collaboration.

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