Kaon electromagnetic production: constraints set by new data

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Abstract

The CLAS data on the photo-production of $K^+$ off the proton are utilised to study reaction mechanism of the process in frame of the isobaric approach. The missing $D_{13}$ resonance is shown to be important for successful description of the data in the whole kinematical region. Constructed models provide satisfactory predictions for the process.

1 INTRODUCTION

Many attempts to describe the electro-magnetic production of $K^+$ have been made in the last decades. Most of the models have, however, problems with a reasonable description of new experimental data collected in JLab and Bonn [1]. Among the models which can still provide a satisfactory prediction in comparison with new data are the latest isobaric ones, Saclay-Lyon [2, 3], Kaon-MAID [4], and Janssen et al [5].

With the very latest data on the photo-production of $K^+$, provided by the CLAS [6] and SAPHIR [7] Collaborations, which reveal clearer and more pronounced resonance structure, one can test the models more thoroughly and learn more about the reaction mechanism of the process, e.g. a relevance of the “missing” $D_{13}$ resonance can be addressed or manifestations of other exotic objects can be looked for.

A good understanding of the electro-magnetic production of $K^+$ off the nucleon is also necessary before more complex calculations of the hypernucleus production are performed (see contribution by T. Motoba). In this respect a reliable prescription for the elementary amplitude is desirable at very small kaon lab angle ($\theta_{lab}^K < 10$ deg) since particularly this kinematical region contributes dominantly to production rates of the hypernuclei.

In this note we limit ourselves to an analysis of the CLAS data set. Our aim is to find an isobaric model being in a better agreement with the CLAS data than the older modes are. We shall in addition try to answer the questions whether the data necessitate an introduction of the $D_{13}$ resonance in models and which role does play the $N^*(1710)$ resonance, a possible candidate for the penta-quark [8].

2 FORMALISM OF ISOBARIC MODELS

In our analysis we utilise the isobaric approach which uses the Feynman diagrammatic technique limited to the exchange of one particle or resonance [1, 2]. The hadron structure in the strong vertexes is taken into account by means of the dipole type form factors [5] introduced in the gauge-invariant way as proposed by Davidson and Workman [9].
Besides the Born terms and two kaon resonances, $K^*(891)$ and $K_1(1273)$, we consider exchanges of nucleon: $S_{11}(1650)$ (N4), $P_{11}(1710)$ (N6), and $P_{13}(1720)$ (N7), and hyperon: $S_{01}(1670)$ (Y2), $S_{01}(1800)$ (Y3), $P_{01}(1600)$ (Y4), $P_{01}(1810)$ (L5), and $P_{11}(1660)$ (S1) resonances. Moreover, we consider also the $D_{13}(1895)$ one predicted by the quark model and already assumed in the Kaon-MAID model [4] but reliably not observed yet. The spin 3/2 and 5/2 resonances are treated in the method used in [2] without off-shell effects [3].

Parameters of the models, the coupling constants and cut-offs of the hadron form factors, were fixed via fitting the differential cross section and polarization to the CLAS data set which consists of 918 data points for the cross section and 220 points for polarization. The two main coupling constants were always kept in the limits of the 20% broken SU(3) symmetry: 

$$-4.4 \leq g_{KN\Lambda} \leq -3.0$$

and

$$0.8 \leq g_{KN\Sigma} \leq 1.3.$$ 

Values of the cut-off masses were also confined:

$$0.6 \leq \Lambda \leq 2.0 \text{ GeV}.$$ 

3 DISCUSSION OF RESULTS AND CONCLUSIONS

The Saclay-Lyon models SL [2] and SLA [3] describe satisfactorily the old data except at $\theta^m_K > 130$ deg and $E^\text{lab}_\gamma > 1.5$ GeV [1]. The models include nucleon resonances with spin up to 3/2 (SLA) and 5/2 (SL) and many hyperon ones. Even though the $\chi^2$ improved after re-adjustment of the parameters, 398 $\rightarrow$ 5.7 (SL) and 412 $\rightarrow$ 7.2 (SLA), the models do not predict any resonant structure above 1.2 GeV. They are able to describe the global behaviour of the data except at $E^\text{lab}_\gamma > 2$ GeV and small kaon angle where they over-predict the cross sections. This is improved when the hadron form factors (h.ff.) are included in the models which results, e.g., in $\chi^2 = 4.13$ for SLA and damping the cross section at $E^\text{lab}_\gamma > 1.7$ GeV and small kaon angle. Absolute values of some hyperon coupling constants of the model with the h.ff., however, tend to be large ($\approx 9$) and their uncertainty due to the fitting procedure is also big ($\approx 100$-$130\%$). Predictions of the polarization are not good with these re-fitted Saclay-Lyon models.

The Kaon-MAID model [4] includes in addition to the Born, $K^*$, and $K_1$ terms only the nucleon resonances N4, N6, N7, and $D_{13}$. We have chosen three modifications of the model which differ in the resonance content: M1 - without $D_{13}$; M2 - all the above resonances; M3 - without N6. In these models the h.ff. of Davidson-Workman type are assumed with independent cut-offs for the Born and resonant terms. The $\chi^2$ for the models are:

$$2.85 \text{ (M1)}, 2.70 \text{ (M2)}, \text{ and } 3.40 \text{ (M3)}.$$ 

The coupling constants acquire reasonable values. Results for the differential cross sections and polarizations are presented in Fig.1 in comparison with the CLAS and SAPHIR data. The model M1 predicts no resonant structure in the cross section above 1.2 GeV at forward and backward kaon angles but it does predict a second maximum at 1.3 GeV and around $\theta^m_K = 105$ deg. Good results are provided by the model M2 except for forward angles where it predicts lower cross sections around 1.3 GeV than the CLAS data suggest. At the first maximum ($E^\text{lab}_\gamma \approx 1.15$ GeV) the model M3 gives smaller cross sections at forward angles ($\cos(\theta_K) = 0.85$) whereas it gives larger values at backward angles ($\cos(\theta_K) = -0.55$) than the M2 model. The model M2 without the N6 resonance displays a similar but still more pronounced pattern (dash-dotted line). The effects were not seen, however, when we omit N6 and add two hyperon resonances (Y2, L5) or (Y2, Y4). Then the first peak can be modelled satisfactorily too. On the contrary, the N6 resonance alone is not able to mimic the peak sufficiently even though various hyperon resonances are added (Y2, Y4, L5, S1). An absence of N6 in the model M2 results in the opposite sign for polarization around 1.15 GeV and large angle ($\cos(\theta_K) = -0.5$). The model M1 predicts different behaviour of the polarizations in comparison with the models M2 and M3. All models do not predict proper
values for the polarizations above 1.7 GeV and small kaon angle (Fig. 1 right panel).

In Figure 2 the best models of those we tried with hyperon resonances are shown. In addition to the resonances contained in M2 these models include: Y2 and L5 (model H1); Y2 and Y3 (model H2). Here a common cut-off for all terms is assumed in the h.f.f. Those versions of the model in which the Y2 resonance is replaced by Y3, Y4 or S1 provide very similar results. The $\chi^2$ for the models H1 and H2 are 2.55 and 2.74, respectively. Predictions of these models for the cross sections differ around the first and second maximum (Fig. 2). This illustrates that the resonance pattern is sensitive to a choice of the hyperon resonances too (Y3 and L5 have almost equal mass but opposite parity). Both models fail to describe the polarization above 1.8 GeV and small kaon angle like the model M2 (see top part of the right panels in Figs. 1 and 2).

Results of the models without $D_{13}$ (dotted and dash-dotted lines in Fig. 2) show a significance of the $D_{13}$ contribution to the cross section in energy region 1.3 - 1.8 GeV for all angles. This observation and that for the model M1 suggest importance of $D_{13}$ for a proper description of the cross section at the second maximum. A particular shape of the structure can be, however, influenced by a presence of hypernuclear resonances. In Figure 2 it is shown that $D_{13}$ also dominates the polarizations for $E_{\gamma}^{lab} > 1.5$ GeV in the models.

The hyperon coupling constants for the H1 and H2 models are large with big error bars like they are for the re-fitted Saclay-Lyon models. Small cut-off parameters, 0.73 GeV (H1) and 0.88 GeV (H2), mean that soft h.f.f. are present in these models.

We conclude that in the isobaric models, in which the off-shell effects connected with the spin 3/2 resonances are not assumed, the $D_{13}$ resonance has to be included to describe the resonant structure of the cross sections correctly. This resonance can mimic the second maximum at all angles in interference with the background which need not include the hyperon resonances. A presence of the $N^*(1710)(N6)$ resonance in the models makes description of
the cross section easier at the first maximum but it is not necessary to include this resonance in the models.

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