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PHOTOPRODUCTION OF KAONS*

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A new isobar model for photoproduction of $K\Lambda$ on the proton was constructed utilizing the data from CLAS, LEPS, and GRAAL collaborations. In the model, nucleon and hyperon resonances with spin 3/2 and 5/2 in the intermediate state are included using a consistent formalism in which only the physical degrees of freedom contribute to the invariant amplitude. These higher-spin resonances were shown to play an important role in data description. The model describes well the data in the third resonance region in full range of kaon angles. Results of the model are also compared with the hybrid Regge-plus-resonance model constructed recently. Predictions of the models in the very-forward-angle region, important for calculations of the hypernucleus cross sections, are also briefly discussed.

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1. Introduction

The phenomenological analysis of kaon electromagnetic production on the nucleon in the resonance region provides information about baryon properties and their interactions which is so far still difficult to obtain directly from QCD. A study of the reaction mechanism using the effective field theoretical approach, that comprise the basic ingredients of QCD, can shed more light on the baryon spectrum. Indeed, photoproduction of kaons allows to learn more on the existence and properties of the "missing" resonances, the states predicted by the quark models but yet not seen in the π and η productions. Moreover, a correct description of the elementary production is important in obtaining reliable predictions of the excitation spectra in electroproduction of hypernuclei [1, 2].

A very successful method of modeling kaon production is based on an effective Lagrangian with only hadronic degrees of freedom. Since above the kaon-production threshold other channels (πN, ηN) are opened and they

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couple to the kaon channel via the meson–baryon interaction, we should treat all these channels simultaneously to ensure unitarity. In the coupled-channel models [3], the meson–baryon re-scattering effects in the intermediate states are included, however, results are spoiled with additional uncertainty due to the lack of information about the processes like the $K^+\Lambda$ elastic scattering. This insufficiency can be avoided if the re-scattering effects are neglected assuming that their contribution is included to some extent by means of effective values of the coupling constants fitted to data. This simplifying assumption was adopted in numerous single-channel isobar models, *e.g.*, Saclay–Lyon (SL) [4], Kaon-MAID (KM) [5], and Gent-Isobar [6], that play important role in description of the production process and, in particular, in the calculations of the hypernucleus electroproduction [1].

Another approach, suited also for description at energies above the resonance region up to $E_\gamma \approx 16$ GeV, is the hybrid Regge-plus-resonance model (RPR) [7]. This model combines the Regge model, appropriate to description above the resonance region ($E_\gamma > 4$ GeV), with elements of the isobar model eligible for the low-energy region.

In quark models for photoproduction [8], resonances are implicitly included as excited states and, therefore, a number of free parameters is relatively small. Another asset of this approach is a natural description of a hadron structure which has to be modeled phenomenologically via form factors in the isobar models. However, the quark models are too complicated for their further use in the calculations of hypernucleus electroproduction.

Recently, we constructed a new isobar model for single-channel description of kaon photoproduction [9]. Here, we only briefly mention some features of the model and show results to illustrate a quality of description. We also show and discuss results with our recent fit of Regge-plus-resonance model.

2. Isobar and Regge-plus-resonance models

In the resonance region, the invariant amplitude can be split into the resonant and non-resonant (background) parts. The former creates the real resonant patterns observed in energy-dependent data, whereas the latter is a smooth function of energy. The resonant part gets contributions merely from exchanges of the nucleon resonances (the s-channel Feynman diagrams) and the background consists of contributions from the Born terms and exchanges of kaon (t-channel) and hyperon (u-channel) resonances.

Since the kaon-production threshold is quite high, $\sqrt{s} = 1.609$ GeV, contributions of higher-spin nucleon and hyperon resonances are important. However, it is known that a formalism for baryon fields with higher spin is problematic due to presence of non-physical lower-spin components in the

Rarita–Schwinger (RS) field. In our model, we therefore utilized a new consistent formalism developed recently [10] to ensure contributions only from the physical degrees of freedom. The consistency is provided by a requirement that the interaction Lagrangians are invariant under the local gauge transformation of the Rarita–Schwinger field. This requirement makes the corresponding vertexes transversal to the momentum of exchanged particle which then provides contributions only from the highest-spin components in the RS off-mass-shell propagator [9].

The RS gauge invariance brings another important aspect, particularly that the contributions of higher-spin resonances are regular which is especially important for the hyperon exchanges. In kaon production, the Mandelstam variable u can acquire zero values which made including spin-$\frac{3}{2}$ hyperon resonances in the inconsistent formalism problematic due to divergence in the RS propagator connected with the spin-$\frac{1}{2}$ components. But in the consistent formalism, these components do not contribute and, therefore, the spin-$\frac{3}{2}$ hyperon resonances could be included in our model as well as the nucleon resonances with spin $\frac{3}{2}$ and $\frac{5}{2}$ [9].

In the isobar model, the short-range physics, missing in the effective Lagrangian, is included via additional momentum dependence in the interaction vertexes, hadron form factors (hff). Their role, however, is also to suppress the contributions of the Born terms and to reduce a too strong momentum dependence in exchanges of the higher-spin resonances [9]. As the standard dipole form is not strong enough, we considered also the multidipole, Gauss and multidipole-Gauss forms. The hadron form factors were included by a gauge-invariant technique [9].

In the Regge-plus-resonance model, the non-resonant part of the amplitude is modeled by exchanges of two degenerate K and K^* trajectories with only three parameters. The resonant part is described by exchanges of nucleon resonances like in the isobar model [7]. A smooth transition from the resonant into the high-energy (Regge) region is assured by strong hffs of Gaussian or multidipole-Gauss type. The model, therefore, describes data for energies up to $E_\gamma \approx 16$ GeV. Another asset of RPR is absence of the large Born contributions in the non-resonant part of amplitude which makes an important difference in dynamics of the RPR and isobar models.

3. Results

The free parameters in the isobar model, the coupling constants and cut-off parameters in the hadron form factors, were fitted to differential cross sections ($W < 2.4$ GeV) and hyperon polarizations ($W < 2.2$ GeV). We considered many combinations of the nucleon and hyperon resonances and chose two best variants BS1 and BS2 with $\chi^2/\text{n.d.f.} = 1.64$ [9]. In both models, the set of selected nucleon resonances is very similar to that chosen in the Bayesian analysis with the RPR model [7]. This suggests that the present data can already fix well the resonant part of amplitude and reasonable spectroscopic conclusions can be drawn. We confirm, *e.g.* importance of the missing resonances $P_{13}(1900)$ and $D_{13}(1875)$ for the description of data in the $K^+\Lambda$ channel but, in our analysis, $P_{11}(1880)$ was replaced by $F_{15}(1860)$ recently included in the Particle Data Group tables.

The models differ significantly in the choice of hyperon resonances, contributing to the non-resonant part, and in a form of hff. The main asset of the presence of spin-$\frac{3}{2}$ hyperon resonances is reduction of the coupling constants of spin-$\frac{1}{2}$ hyperon resonances which, in general, tend to be large. The higher-spin resonances play a role in dynamics mainly at backward angles. The uncertainty in description of the non-resonant part, which is quite complicated in the isobar model, motivated us to fit the data also with the RPR model, in which the background is given in a simpler form. With the isobar and RPR models we achieved a good description of data as shown in Figs. 1 and 2 for the differential cross section and hyperon polarization. We show only the results of BS1 as predictions of both models are very similar.

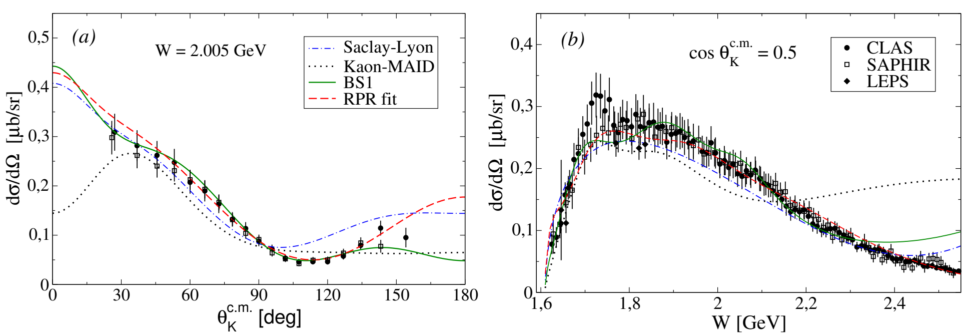

Fig. 1. Results of isobar and Regge-plus-resonance models for the angular (a) and energy (b) dependence of the cross sections in $p(\gamma,K^+)\Lambda$ are compared with data from CLAS [11], SAPHIR [12], and LEPS [13].

The BS1 and RPR models differ mainly at the backward angles both for the cross section and hyperon polarization. The decreasing angular dependence of the cross section for small angles is provided with the kaon-trajectory exchange in the RPR model whereas it is given by the proton and spin-$\frac{1}{2}$ hyperon exchanges in the isobar model. The BS1 model describes the data well only up to the energies to which it was fitted, $W = 2.4$ GeV (cross section) and 2.2 GeV (polarization), but the RPR model is consistent with the data also above the resonance region, see Figs. 1 (b) and 2 (b). The Saclay–Lyon and Kaon-MAID models were not fitted to the polarizations.

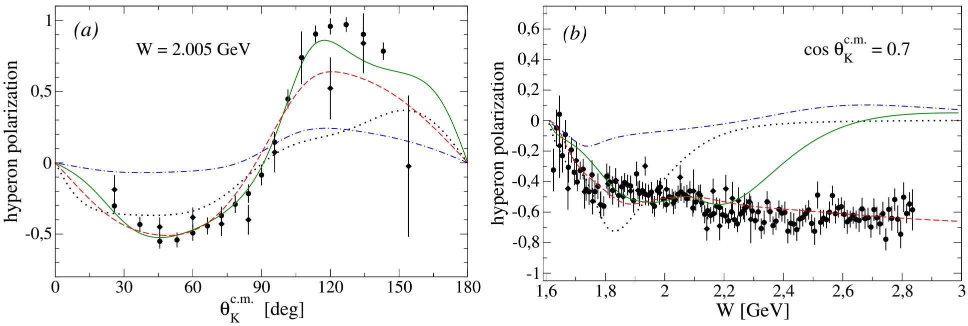

Fig. 2. Hyperon polarization in $p(\gamma, K^+)\Lambda$ calculated with the same models as in Fig. 1 is compared with CLAS data [11].

In Fig. 3, we show prediction of the models for very small kaon angle. Due to the lack of data in this kinematical region, the models cannot be determined precisely which is especially apparent for energies above 1.6 GeV. This kinematical region is very important for calculations of the cross sections in electroproduction of hypernuclei [1]. The nucleus–hypernucleus transition form factors cause the elementary amplitude contribute effectively only for very small angles. The hypernucleus data can be, therefore, used to test the isobar and RPR models in the very small-angle kinematical region.

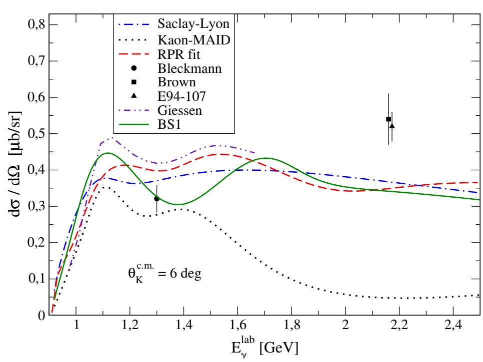

Fig. 3. The cross section for very small kaon angle is shown as predicted by the single-channel isobar and Regge-plus-resonance models and by the multi-channel Giessen model [3]. The available data are for photoproduction (Bleckmann) and electroproduction with very small virtual-photon mass (Brown and E94-107).

4. Summary

The isobar models BS1 and BS2 were constructed using a consistent description of the higher-spin resonances. The presence of spin-$\frac{3}{2}$ hyperon resonances is a novel feature of the isobar model and these resonances were found to play important role in a description of the non-resonant part of amplitude. The set of selected nucleon resonances agree well with the result of Bayesian analysis with the Regge-plus-resonance model. The fit with the RPR model also provides a good description of data in the resonance region and above this region which demonstrates that the data, especially the forward-angle cross sections, can be described successfully assuming different structure of the non-resonant part of amplitude.

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