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Vector meson-baryon dynamics in photoproduction reactions around 2 GeV

A. Ramos[1,a] and E. Oset[2]

[1] *Departament d'Estructura i Constituents de la Materia and Institut de Ciències del Cosmos, Universitat de Barcelona, Martí i Franquès 1, 08028 Barcelona, Spain*
[2] *Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Aptdo. 22085, 46071 Valencia, Spain*

Abstract. We investigate the role of vector mesons and coupled-channel unitarization on photoproduction reactions off the proton at energies around 2 GeV. We explain the sudden drop on the $\gamma p \to K^0\Sigma^+$ cross section, observed recently by the CBELSA/TAPS collaboration, by a delicate interference between amplitudes having $K^*\Lambda$ and $K^*\Sigma$ intermediate states modulated by the presence of a nearby N^* resonance produced by our model, a feature that we have employed to predict its properties. We also show the importance of coupled-channel unitarization in the $\gamma p \to K^{*0}\Sigma^+$ reaction, measured recently by CBELSA/TAPS and CLAS with conflicting results.

1 Introduction

The use of effective Lagrangians combined with unitarizing techniques has proven to be a very efficient tool to understand a variety of problems in hadron physics. The most impressive example is the coupled channel unitary approach for the interaction of pseudoscalar mesons with baryons using chiral Lagrangians, generating $J^P = 1/2^-$ resonances, the most emblematic example being the $\Lambda(1405)$, which has been shown to be built from two nearby poles [1–7].

The interpretation of recent data of photoproduction reactions in a center-of-mass energy region of around 2 GeV requires these coupled channel models to explore the relevance of vector mesons in the dynamical generation of resonances. A nucleon resonance around 1970 MeV and width around 65 MeV, coupling mostly to $K^*\Lambda$ and $K^*\Sigma$ states, was reported in [8] and confirmed in later works considering the simultaneous effect of both pseudoscalar-baryon and the vector-baryon channels[9, 10]. We report here on a theoretical approach [11] that, thanks to the incorporation of vector mesons, gives an explanation to the features observed by the CBELSA/TAPS collaboration in the $\gamma p \to K^0\Sigma^+$ cross section [12, 13] , namely a peak around $\sqrt{s} = 1900$ MeV followed by a fast downfall around $\sqrt{s} = 2000$ MeV, which are not reproduced by resonant-type analyses [14, 15]. We also study the $\gamma p \to K^{*0}\Sigma^+$ reaction, measured by CLAS at Jefferson Lab [16] and CBELSA/TAPS at ELSA [17], finding that the use of a properly unitarized vector meson-baryon amplitude accounts for a sizable amount of the cross section, without the need for the exchange of a κ scalar meson [18] or s-channel Δ contributions [19].

[a] e-mail: ramos@ecm.ub.edu

2 The $\gamma p \to K^0\Sigma^+$, $\gamma n \to K^0\Sigma^0$ reactions

The role of coupled-channel unitarization is particularly significant for the neutral meson production reaction $\gamma N \to K^0\Sigma$ because the tree-level t-channel and Kroll-Rudermann terms are zero, while the s-channel and u-channel terms are small. The basic mechanisms of our model [11] are depicted in Figs. 1 and 2, where one can see the photon conversion into ρ^0, ω, ϕ, followed by the $\rho N, \omega N, \phi N$ interaction leading to the relevant vector-baryon ($V'B'$) channels, which we restrict to be $K^*\Lambda$ or $K^*\Sigma$, since those are the ones to which the resonance around 1970 MeV couples most strongly. The vector-baryon unitarized amplitudes are taken from the work of Ref. [8], which builds the required interaction Lagrangians from the hidden gauge formalism. Finally, the intermediate $V'B'$ states get converted via pion exchange to the $K^0\Sigma$ final state.

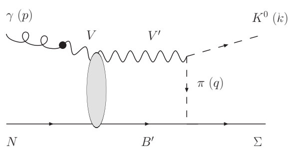

Figure 1. Mechanism for the photoproduction reaction $\gamma N \to K^0\Sigma$.

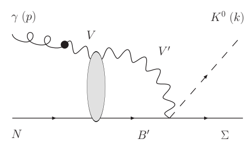

Figure 2. Kroll-Ruderman contact term, added to the mechanisms of Fig. 1 to preserve gauge-invariance.

The results shown in Fig. 3, obtained by retaining different intermediate channels, demonstrate that there is a destructive interference between the $VB \to K^*\Sigma, K^*\Lambda$ amplitudes, which are of similar

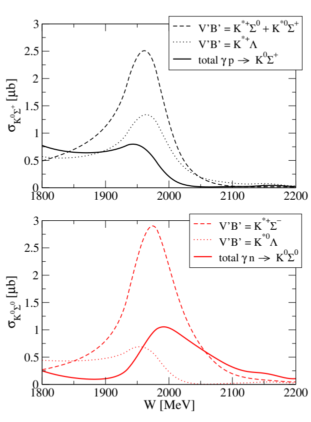

Figure 3. Contributions to the $\gamma p \to K^0\Sigma^+$ (upper panel) and $\gamma n \to K^0\Sigma^0$ (lower panel) cross sections.

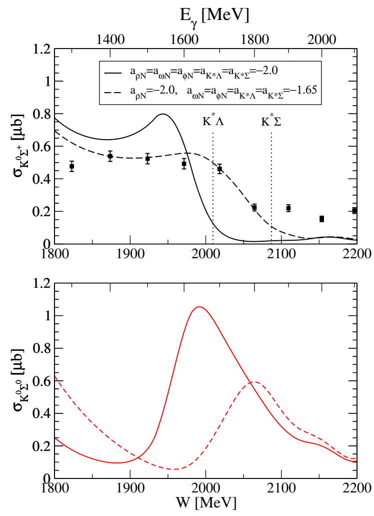

Figure 4. Comparison of the $\gamma p \to K^0\Sigma^+$ cross section, obtained with two parameter sets, with the CBELSA/TAPS data of Ref. [13] (upper panel). Predictions for the $\gamma n \to K^0\Sigma^0$ cross section using two parameter sets (lower panel).

size and shape in the case of the $\gamma p \to K^0\Sigma^+$ reaction. This produces an abrupt downfall of the cross section, right at the position of the resonance generated the employed VB interaction model. In contrast, the $\gamma n \to K^0\Sigma^0$ cross section retains the peak at the position of the resonance. The downfall of our $\gamma p \to K^0\Sigma^+$ cross section (solid line) appears 60 MeV below the energy at which the experimental cross section presents the abrupt drop, as can be seen in the upper panel of Fig. 4. Since this structure is sensitive to the position of the resonance, we can obtain a prediction of its properties by adjusting the parameters of our model to reproduce the CBELSA/TAPS data. The fitted result, shown by a dashed line in Fig. 4, moves the resonance up to 2030 MeV, lying then above the $K^*\Lambda$ threshold and becoming almost twice wider than in the original model. We note that two resonances of negative parity around this region of energy, $N^*(2080)(3/2^-)$ and $N^*(2090)(1/2^-)$, appeared in earlier versions of the PDG, and that a $(3/2^-)$ state around 2080 MeV has been found to explain SPring 8 LEPS data on the $\gamma p \to K^+\Lambda(1520)$ reaction in [20]. Our model could be further tested with a measurement of the neutral $\gamma n \to K^0\Sigma^0$ cross section, a prediction of which is shown in the lower panel of Fig. 4 for the two different parameter sets.

3 The $\gamma p \to K^{*0}\Sigma^+$ reaction

The $\gamma p \to K^{*0}\Sigma^+$ reaction, producing a neutral K^{*0}, is also sensitive to the loop terms of a unitarized coupled-channel approach, as that depicted in Fig. 5 (top). A tree level contribution may also come from the K-meson exchange diagram depicted in Fig. 5 (bottom), which involves an anomalous PVV coupling. This tree level term is insufficient to reproduce the cross section, a fact that motivated the search of other mechanisms, such as the exchange of a scalar κ meson in [18], or an s-channel Δ resonance contribution in [19]. Our results are shown in Fig. 6, where we can see that the contribution of the loop diagram (dashed line) already provides a sizable amount of the cross section, while the addition of the anomalous contribution (solid line) brings the results to be comparable with the experimental data. Given the discrepancies between the two data sets, we cannot refine further our model.

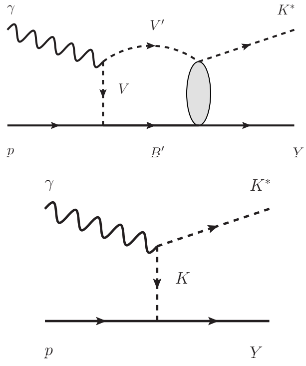

Figure 5. Mechanisms for the photoproduction reaction $\gamma p \to K^{*0}\Sigma^+$ involving normal VVV couplings (top) and anomalous PVV ones (bottom).

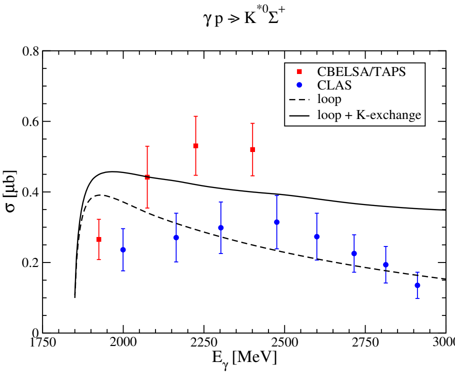

Figure 6. Total cross section for the $\gamma p \to K^{*0}\Sigma^+$ reaction as a function of the photon lab energy, as obtained from the loop terms (dashed line), or including the additional anomalous K-exchange term (solid line). Experimental data are taken from the CLAS [16] or CBELSA/TAPS [17] collaborations.

In any case, our results clearly show that the unitarized loop contributions, omitted in previous works [18, 19], are an essential ingredient of the model and must be taken into account before invoking the need for other mechanisms.

4 Conclusions

We have presented a theoretical study of the $\gamma p \to K^0\Sigma^+$ and $\gamma p \to K^{0*}\Sigma^+$ reactions around an energy $\sqrt{s} = 2000$ MeV, at which a vector-meson baryon interaction model predicts a N^* resonance coupling strongly to $K^*\Lambda$ and $K^*\Sigma$ states. Our results show that the interaction of vector mesons with baryons, implemented through a unitarized coupled channel scheme, is crucial to reproduce the size and shape of these reactions. Further studies, involving also polarization observables, are currently under investigation.

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