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φN photoproduction coupled with the KΛ* channel

Received: date / Accepted: date

Abstract We present in this talk a recent investigation on φ photoproduction, emphasizing the rescattering effects of the KΛ* channel near the threshold region. We discuss the results of the differential cross section and the angular distributions.

Keywords φ photoproduction · Rescattering effects of KΛ*
the rescattering equation can be written as

\[ M_{\gamma N \rightarrow \phi N}(p,p';s) = M_{\gamma N \rightarrow \phi N}^{\text{Born}}(p,p';s) + \int d^4q \frac{\omega + E}{(2\pi)^3 2\omega E} M_{\gamma N \rightarrow K^+ A^*}(p,q;s) \frac{1}{s - (\omega + E)^2 + i\epsilon} M_{K^+ A^* \rightarrow \phi N}(q,p';s), \]

which is a Blankenbecler-Sugar (BbS) equation. The amplitude \( M_{\gamma N \rightarrow \phi N}^{\text{Born}} \) contains the diagrams of pomeron- and meson-exchanges. The second part of Eq. (1) in the right-hand side denotes the rescattering amplitude of the \( K^+ A^* \) channel. Both \( M_{\gamma N \rightarrow K^+ A^*}(p,k;s) \) and \( M_{K^+ A^* \rightarrow \phi N}(k,p';s) \) are the off-mass-shell extended amplitudes for the \( \gamma p \rightarrow K^+ A^* \) and \( K^+ A^* \rightarrow \phi p \), respectively. \( \omega \) and \( E \) correspond to the off-mass-shell energies of the \( K^+ \) and the \( A^* \) in the intermediate states. \( s \) is a Mandelstam variable, i.e. the square of the total energy \( s = (E_\gamma + E_p)^2 \).

Since it is quite complicated to deal with Eq. (1) in a full coupled-channel formalism, we will first concentrate on the imaginary part of Eq. (1), which can be easily derived by the two-body unitarity relation (Landau-Cutkosky rule). In this case, we need only the on-mass-shell amplitudes. The full calculation of Eq. (1) is under investigation and will be presented elsewhere. The imaginary part of the BbS equation is written as

\[ \text{Im} M_{K^+ A^* \rightarrow \phi N}^\text{rescatt.} = -\frac{1}{8\pi} \frac{r}{\sqrt{s}} \int \frac{d\Omega}{4\pi} M_L(\gamma p \rightarrow K^+ A^*) M_L^\dagger(K^+ A^* \rightarrow \phi p), \]

where \( r \) is the magnitude of the \( K^+ \) on-mass-shell three momentum. For detailed formalism, we refer to the recent work [5].

3 Results

We now present the results for the rescattering effects of the \( K A^* \) coupled channel on \( \phi \) photoproduction. Figure 1 draws the results of the total cross section for \( K^+ A(1520) \) photoproduction, based on Ref. [3]. The experimental data are well reproduced. Employing the \( \gamma p \rightarrow K^+ A(1520) \) amplitude, we are able to consider the \( K A^* \) rescattering in \( \phi \) photoproduction.

In Fig. 2 we show each contribution to the differential cross section \( d\sigma / dt \) for \( \phi \) photoproduction in log scale. The dashed curve with P represents the pomeron-exchange contribution. The pomeron governs typically the general \( E_\gamma \) dependence, in particular, in the high energy region, while the \( t \)-channel effects designated by T contribute to the differential cross section almost equally along \( E_\gamma \). The \( K A(1520) \) rescattering effects start to arise from the threshold drastically till around 2 GeV, then fall off fast. Thus, the interference of all these three contributions make it possible to describe the bump-like structure around \( E_\gamma = 2.3 \) GeV.

The angular distributions of the \( \phi \rightarrow K^+ K^- \) decay in the \( \phi \) rest frame allow one to get access to the helicity amplitudes experimentally [8, 9]. They were measured by the LEPS collaboration at forward angles \( (-0.2 < t + |t|_{\text{min}}) \) in two different energy regions: \( 1.97 < E_\gamma < 2.17 \) GeV and \( 2.17 < E_\gamma < 2.37 \) GeV [1]. Here, \( |t|_{\text{min}} \) denotes the minimum four-momentum transfer from the incident photon to the...
Fig. 1 Total cross section for the $\gamma p \rightarrow K^+\Lambda(1520)$ process. The experimental data taken from Ref. [7].

Fig. 2 (Color on-line) Differential cross section as a function of the photon energy $E_\gamma$ in a log scale. The thick solid curve depicts the result with all contributions included. The solid curves with the symbols $P$, $R$, and $T$ denote the Pomeron contribution, $K\Lambda^*$ rescattering effects, and the $t$-channel contribution of $\pi$- and $\eta$-exchanges.

In this talk, we focus on the one-dimensional decay angular distribution $2\pi W(\phi - \Phi)$, since it illuminates the effects of the $K\Lambda^*$ coupled channel. The $2\pi W$ is defined as

$$2\pi W(\phi - \Phi) = 1 + 2P_\gamma P_\Lambda^* \cos 2(\phi - \Phi),$$

where $\phi$ is the polar and azimuthal angles of the decay particle $K^+$ in the $\phi$ rest frame. $\Phi$ stands for the azimuthal angle of the photon polarization in the center-of-mass frame. $P_\gamma$ denotes the degree of the polarization of the photon beam. The definition of $P_\Lambda^*$ can be found in Ref. [5]. In Fig. 3 we compare the results of the $2\pi W(\phi - \Phi)$ with the experimental data. Note that since the photon energy $E_\gamma = 2.07$ GeV is small, the pomeron does not come into play. Interestingly, the $K\Lambda^*$ rescattering effects turn out to be crucial in describing $2\pi W(\phi - \Phi)$. The $t$-channel contribution interferes destructively with the $K\Lambda^*$ effects.
Fig. 3 (Color on-line) The decay angular distributions for $-0.2 < t + |t|_{\text{min}}$. The experimental data are taken from Ref. [1].

4 Summary and outlook

In the present talk, we briefly reviewed a recent investigation on the $K\Lambda^*$ coupled-channel effects in addition to the conventional approach of Pomeron-, $\pi$-, and $\eta$-exchanges. We found that the $K\Lambda(1520)$ rescattering effects play a crucial role in describing the bump-like structure near $E_\gamma \approx 2.3$ GeV of the LEPS experiment. The angular distribution of the $\phi$ also was well explained by the inclusion of the $K\Lambda(1520)$ coupled channel.

In this work, we have considered only the imaginary part of the $K\Lambda(1520)$ rescattering effects. However, the real part will be as equally important as the imaginary one. The corresponding investigation is under way and will soon appear elsewhere.

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