Abstract

We present a new version of the EtaMAID model for \( \eta \) and \( \eta' \) photoproduction on nucleons. The model includes 23 nucleon resonances parameterized with Breit-Wigner shapes. The background is described by vector and axial-vector meson exchanges in the \( t \) channel using the Regge cut phenomenology. Parameters of the resonances were obtained from a fit to available experimental data for \( \eta \) and \( \eta' \) photoproduction on protons and neutrons. The nature of the most interesting observations in the data is discussed.

EtaMAID is an isobar model \cite{1, 2} for \( \eta \) and \( \eta' \) photo- and electroproduction on nucleons. The model includes a non-resonant background, which consists of nucleon Born terms in the \( s \) and \( u \) channels and the vector meson exchange in the \( t \) channel, and \( s \)-channel resonance excitations, parameterized by Breit-Wigner functions with energy dependent widths. The EtaMAID-2003 version describes the experimental data available in 2002 reasonably well, but fails to reproduce the newer polarization data obtained in Mainz \cite{3}. During the last two years the EtaMAID model was updated \cite{4, 5, 6} to describe the new data for \( \eta \) and \( \eta' \) photoproduction on the proton. The presented EtaMAID version includes also \( \eta \) and \( \eta' \) photoproduction on the neutron.

At high energies, \( W > 3 \) GeV, Regge cut phenomenology was applied. The models include \( t \)-channel exchanges of vector (\( \rho \) and \( \omega \)) and axial vector (\( b_1 \) and \( h_1 \)) mesons as Regge trajectories. In addition to the Regge trajectories, also Regge cuts from rescattering \( \rho \mathbb{P}, \rho f_2 \) and \( \omega \mathbb{P}, \omega f_2 \) were added, where \( \mathbb{P} \) is the Pomeron with quantum numbers of the vacuum \( 0^+(0^{++}) \) and \( f_2 \) is a tensor meson with quantum numbers \( 0^+(2^{++}) \). The obtained solution describes the data up to \( E_\gamma = 8 \) GeV very well. For more details see Ref. \cite{7}. Energies below \( W = 2.5 \) GeV are dominated by nucleon resonances in the \( s \) channel. All known resonances with an overall rating of two stars and more were included in the fit. To avoid double counting from \( s \) and \( t \) channels in the resonance region, low partial waves with \( L \) up to 4 were subtracted from the \( t \)-channel Regge contribution.

The most interesting fit results are presented in Figs. 1-5 together with corresponding experimental data.

In Fig. 1 the total \( \gamma p \rightarrow \eta p \) cross section is shown. A key role in the description of the investigated reactions is played by three \( s \)-wave resonances \( N(1535)1/2^- \), \( N(1650)1/2^- \),
Figure 1: Total cross section of the $\gamma p \rightarrow \eta p$ reaction with partial contributions of the main nucleon resonances. Red line: New EtaMAID solution. Vertical lines correspond to thresholds of $K\Sigma$ and $\eta'N$ photoproduction. Data: A2MAMI-17 [6].

Figure 2: Total cross section of the $\gamma p \rightarrow \eta'p$ reaction with partial contributions of the main nucleon resonances. Red line: New EtaMAID solution. Data: A2MAMI-17 [6], CBELSA/TAPS-09 [9], and CLAS-09 [10].
and N(1895)1/2−, see partial contributions of these resonances in Fig. 1. The first two give the main contribution to the total cross section and are known very well. An interference of these two resonances is mainly responsible for the dip at \( W = 1.68 \) GeV. However, the narrowness of this dip we explain as a threshold effect due to the opening of the \( KΣ \) decay channel of the \( N(1650)1/2− \) resonance. The third one, N(1895)1/2−, has only a 2-star overall status according to the PDG review [8]. But we have found that namely this resonance is responsible for the cusp effect at \( W = 1.96 \) GeV (see magenta line in Fig. 1) and provides a fast increase of the total cross section in the \( γp \rightarrow η′p \) reaction near threshold (see black line in Fig. 2). A good agreement with the experimental data was obtained for the cross sections of the \( γp \rightarrow η′p \) reaction, Fig. 2. The main contributions to this reaction come from \( N(1895)1/2−, N(1900)3/2^+, \) and \( N(2130)3/2^− \) resonances.

Very interesting results were obtained during the last few years for the \( γn \rightarrow ηn \) reaction. The excitation function for this reaction shows an unexpected narrow structure at \( W \sim 1.68 \) GeV, which is not observed in \( γp \rightarrow ηp \). As an example, the total cross section measured with highest statistics in Mainz [11] is shown in Fig. 3. The nature of the narrow structure has been explained by different authors as a new exotic nucleon resonance, or a contribution of intermediate strangeness loops, or interference effects of known nucleon resonances, see Ref. [12]. In our analyses, the narrow structure is explained as the interference of \( s, p, \) and \( d \) waves, see partial contributions of the resonances in Fig. 3. Our full solution, red line in Fig. 3 describes the data up to \( W \sim 1.85 \) GeV reasonably well and shows a cusp-like structure at \( W = 1.896 \) GeV similar as in Fig. 2 for the \( γp \rightarrow ηp \) reaction. However, the data demonstrate a cusp-like effect at the energy of \( \sim 50 \) MeV below. This remains an open question for our analyses as well as for the final state effects in the data analysis.

Recently, the CLAS collaboration reported a measurement of the beam asymmetry \( Σ \) for both \( γp \rightarrow ηp \) and \( γp \rightarrow η′p \) reactions [13]. At high energies, \( W > 2 \) GeV, the \( γp \rightarrow ηp \) data have maximal \( Σ \) asymmetry at forward and backward directions, see Fig. 4. We have
found that an interference of $N(2120)3/2^-$ and $N(2060)5/2^-$ resonances is responsible for such an angular dependence. The data was refitted excluding the resonances with mass around 2 GeV. The most significant effect we have found by refitting without $N(2120)3/2^-$ (black line) and $N(2060)5/2^-$ (blue line). The red line is our full solution.

The beam asymmetry $\Sigma$ for $\gamma p \rightarrow \eta p$ reaction is presented in Fig. 4 with the GRAAL data [14] having a nodal structure near threshold. Such a shape of the angular dependence could be explained by interference of $s$ and $f$ or $p$ and $d$ waves. However, the energy dependence is inverted in all models. The EtaMAID-2016 solution [5] describes the shape of the GRAAL data for $\Sigma$, but not the magnitude. The new CLAS data [13] can not solve this problem because of poor statistics new threshold. Our new solution describes the $\Sigma$ data well at $W > 1.95$ GeV.

In summary, we have presented a new version $\eta$MAID-2017n updated with new resonances and new experimental data. The model describes the data currently available for both $\eta$ and $\eta'$ photoproduction on protons and neutrons. The cusp in the $\eta$ total cross section, in connection with the steep rise of the $\eta'$ total cross section from its threshold, is explained by a strong coupling of the $N(1895)1/2^-$ to both channels. The narrow bump in $\eta n$ and the dip in $\eta p$ channels have a different origin: the first is a result of an interference of a few resonances, and the second is a threshold effect due to the opening of the $K\Sigma$ decay channel of the $N(1650)1/2^-$ resonance. The angular dependence of $\Sigma$ for $\gamma p \rightarrow \eta p$ at $W > 2$ GeV is explained by an interference of $N(2120)3/2^-$ and $N(2060)5/2^-$ resonances. The near threshold behavior of $\Sigma$ for $\gamma p \rightarrow \eta'p$, as seen in the GRAAL data, is still an
open question. A further improvement of our analysis will be possible with additional polarization observables which soon should come from the A2MAMI, CBELSA/TAPS, and CLAS collaborations. This work was supported by the Deutsche Forschungsgemeinschaft (SFB 1044).

References

[1] W.-T. Chiang, S. N. Yang, L. Tiator, and D. Drechsel, Nucl. Phys. A700, 429 (2002).

[2] W.-T. Chiang, S. N. Yang, L. Tiator, M. Vanderhaeghen, and D. Drechsel, Phys. Rev. C 68, 045202 (2003).

[3] J. Akondi et al. (A2 Collaboration at MAMI), Phys. Rev. Lett. 113, 102001 (2014).

[4] V. L. Kashevarov, M. Ostrick, L. Tiator, Bled Workshops in Physics, Vol.16, No.1, 9 (2015).

[5] V. L. Kashevarov, M. Ostrick, L. Tiator, JPS Conf. Proc. 13, 020029, (2017).

[6] V. L. Kashevarov et al. (A2 Collaboration at MAMI), Phys. Rev. Lett. 118, 212001 (2017).

[7] V. L. Kashevarov, M. Ostrick, L. Tiator, Phys. Rev. C 96 035207 (2017).

[8] C. Patrignani et al. (Particle Data Group), Chin. Phys. C 40, 100001 (2016).

[9] V. Crede et al. (CBELSA/TAPS Collaboration), Phys. Rev. C 80, 055202 (2009).

[10] M. Williams et al. (CLAS Collaboration), Phys. Rev. C 80, 045213 (2009).

[11] (A2 Collaboration at MAMI), D. Werthmüller et al. , Phys. Rev. C 90, 015205 (2014).

[12] (A2 Collaboration at MAMI), L. Witthauer et al. , Phys. Rev. C 95, 055201 (2017).

[13] P. Collins et al., (CLAS Collaboration), Phys. Lett. B 771 , 213 (2017).

[14] P. Levi Sandri et al. (GRAAL Collaboration), Eur. Phys. J. A 51 , 77 (2015).