EXCITED NUCLEON STATES FROM η' PRODUCTION REACTIONS: $\gamma N \rightarrow \eta' N$, $NN \rightarrow NN\eta'$, AND $\pi N \rightarrow \eta' N^*$

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We have performed a combined analysis of the free and quasi-free $\gamma N \rightarrow \eta' N$, $NN \rightarrow NN\eta'$, and $\pi N \rightarrow \eta' N$ reactions based on an effective Lagrangian approach. Considering spin-1/2 and -3/2 resonances, we found that a set of above-threshold resonances $\{S_{11}, P_{11}, P_{13}\}$, with fitted mass of about $M_R = 1925, 2130$, and 2050 MeV, respectively, and the four-star sub-threshold $P_{13}(1720)$ resonance reproduce best all existing data for the η' production processes in the resonance-energy region considered in this work.

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1. Introduction

The η' production reactions are of great interest in the study of nucleon resonances. So far our knowledge of most of the nucleon resonances is mainly due to the study of πN scattering and/or π photoproduction off the nucleon. Since the η' meson is much

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heavier than the π meson, the η' production processes near threshold, therefore, are well suited for investigating high mass resonances in low partial waves. Furthermore, η' photoproduction reactions provide opportunities to study those resonances that couple only weakly to pions. This may help in providing a better understanding of the so-called “missing resonances” problem.

Here we report our recent work on a combined analysis of η' production reactions: $\gamma N \rightarrow \eta' N$, $NN \rightarrow NN\eta'$, and $\pi N \rightarrow \eta' N$.¹ We use an effective Lagrangian approach, where the dynamical content of η' photoproduction and $\pi N \rightarrow \eta' N$ reactions is summarized in Fig. 1. For η' quasi-free photoproduction processes, we account for the Fermi motion of the nucleon by folding the cross section of the free process with the momentum distribution of the nucleon inside the deuteron. The analysis of the $NN \rightarrow NN\eta'$ reaction is done within the distorted wave Born approximation in which both the initial- and final-state NN interactions are taken into account explicitly. The full $NN \rightarrow NN\eta'$ amplitude reads

$$A = (1 + T_f G_f) J (1 + G_i T_i), \quad (1)$$

where T_i (T_f) denotes the NN T -matrix interaction in the initial (final) state, G_i (G_f) the corresponding two-nucleon propagator, and J the basic η' production mechanisms depicted in Fig. 2.

Fig. 1. Feynman diagrams contributing to $\gamma N \rightarrow \eta' N$ (left) and $\pi N \rightarrow \eta' N$ (right). R and N denote the intermediate resonances and nucleon, respectively.

Fig. 2. Basic production mechanisms for $NN \rightarrow NN\eta'$. N and R denote the intermediate nucleon and resonances, respectively. M incorporates exchanges of π , η , ρ , ω , σ and a_1 for the nucleon graphs and π , ρ and ω for the resonance graphs.

2. Results

As our approach is phenomenological, we consider the minimum number of resonances that allows us to reproduce the available data with acceptable fit accuracy. In particular, we restrict ourselves to spin-1/2 and -3/2 resonances since the existing cross section data alone cannot constrain the resonance parameters unambiguously once the higher spin resonances are added into our model. If one only considers the CBELSA/TAPS free photoproduction data,² a good fit can be obtained with only one resonance. By contrast, for the CLAS free photoproduction data,³ a good fit requires at least three resonances, and we found that any one of the above-threshold three-resonance sets $\{P_{11}, P_{13}, D_{13}\}$, $\{S_{11}, P_{11}, P_{13}\}$, and $\{S_{11}, P_{13}, D_{13}\}$ can reproduce the data equally well. As have been discussed in Ref. 1, this ambiguity can be completely removed and only the set $\{S_{11}, P_{11}, P_{13}\}$ remains acceptable once we include η' quasi-free photoproduction⁴ and $NN \rightarrow NN\eta'$ reactions⁵⁻⁹ in our analysis. In addition, we found that to obtain a good description of the data for $NN \rightarrow NN\eta'$, we need an additional *below*-threshold resonance whose inclusion has no bearing on the quality of any of the results for other reactions considered in our work. Finally, we have achieved a good overall description of all reaction processes considered in our work with a (minimum) set of three above-threshold resonances, $\{S_{11}, P_{11}, P_{13}\}$, with the masses of about $M_R = 1925, 2130$, and 2050 MeV, respectively, and one below-threshold P_{13} resonance. These above-threshold resonances may be tentatively identified with the corresponding $S_{11}(1895)^{**}$, $P_{11}(2100)^*$, and $P_{13}(2040)^*$ resonances as listed in PDG.¹⁰ The values of our fitted resonance masses and widths are listed in Table 1. Note that the CLAS data constrains the mass and width of the above-threshold resonances quite well. See Ref. 1 for values of other parameters and a detailed discussion. As an illustration of the quality of our fit, we show in Fig. 3 the differential cross sections for the free $\gamma p \rightarrow \eta' p$ reaction. One sees the data are reproduced quite well. See Ref. 1 for more figures showing the other fitted observables.

Table 1. Resonance mass and width (in MeV) obtained from a combined analysis of the photon- and hadron-induced reactions. Values in columns 3-5 correspond to the fit results for the CLAS free proton data³ and the CBELSA/TAPS free² and quasi-free⁴ proton data, respectively. Values in boldface were kept fixed during the fitting procedure. See Ref. 1 for values of other parameters.

		free p		quasi-free p
		CLAS	CBELSA/TAPS	
$P_{13}(1720)$	M_R	1720	1720	1720
	Γ_R	200	200	200
$P_{13}(2050)$	M_R	2050 ± 4	2045 ± 7	2048
	Γ_R	140 ± 10	52^{+184}_{-52}	51^{+241}_{-51}
$S_{11}(1925)$	M_R	1924 ± 4	1926 ± 10	1925
	Γ_R	112 ± 7	99 ± 23	145 ± 45
$P_{11}(2130)$	M_R	2129 ± 5	2123 ± 23	2126
	Γ_R	205 ± 12	246 ± 54	170 ± 178

Fig. 3. Differential cross sections for $\gamma p \rightarrow \eta' p$. Numbers in parentheses denote the photon lab energy and the total energy of the system, with the upper number pair pertaining to CLAS data³ (filled circles) and the lower one to CBELSA/TAPS data² (empty squares). Solid and dashed lines are our results fitted to CLAS and CBELSA/TAPS data in a combined analysis.

3. Summary

We have performed a combined analysis of the reactions $\gamma N \rightarrow N\eta'$, $NN \rightarrow NN\eta'$, and $\pi N \rightarrow \eta' N$. All of the currently available data in the resonance energy region considered in our work have been nicely reproduced. Considering only spin-1/2 and -3/2 resonances, we have found that the data are reproduced with a minimum of four resonances, i.e. $P_{13}(1720)$, $S_{11}(1925)$, $P_{11}(2130)$, and $P_{13}(2050)$. The $P_{13}(1720)$ is a four-star resonance listed in PDG,¹⁰ and the later three resonances can be tentatively identified with the two-star $S_{11}(1895)$, one-star $P_{11}(2100)$, and one-star $P_{13}(2040)$ as listed in PDG.¹⁰

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