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η photoproduction in the resonance energy region ☆

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Abstract

The η production in the nucleon resonance energy region is studied within the unitary coupled-channels effective Lagrangian approach of the Giessen model. We demonstrate that the second peak recently observed in the cross section of η photoproduction on the neutron at $\sqrt{s} = 1.66$ GeV can be explained in terms of coupled-channel effects due to $S_{11}(1650)$ and $P_{11}(1710)$ resonance excitations.
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Most of the information about the electromagnetic properties of nucleon resonances comes from the analysis of pion photoproduction data. However, since we have to expect that not all of the resonances couple equally strong to the πN channel other production and decay scenarios must be investigated. Such a complementary information on resonance spectra can be obtained from the study of reactions with $K\Lambda$, ηN, ωN, etc. in the final state. Recently, $K\Lambda$ photoproduction has attracted considerable attention [1–4] in prospects of searching for 'hidden' states predicted in [5–7]. The η production on the neutron might be of particular interest for the search of narrow 'hidden' states predicted by some quark models [8,9]. Due to the isoscalar nature of the η meson this reaction selects only isospin-$\frac{1}{2}$ channel which also simplifies the analysis. The previous experimental studies of γd scattering [10,11] have shown that η photoproduction on the neutron at c.m. energies up to $\sqrt{s} = 1.6$ GeV is governed by the excitation of the $S_{11}(1535)$ resonance. Recently, the GRAAL [12] and CBELSA-TAPS [13] collaborations reported on their preliminary $\gamma n \to \eta n$ data which has been extracted from the analysis of γd scattering. Although these measurements need to be confirmed a striking and unexpected result of these findings is that the integrated neutron cross section has an additional maximum at c.m. energy around $\sqrt{s} = 1.66$ GeV. To our knowledge a consistent explanation of this phenomenon is pending.

The central question is whether the observed structure comes from the excitation of an unknown baryonic state. In [14] the existence of a narrow resonance with the mass $M = 1.675$ GeV and strong coupling to the ηn final state has been predicted. The contribution from this resonance has been proposed [15] as an explanation of the peak seen in the preliminary $\gamma n^* \to \eta n$ GRAAL data [12] at $\sqrt{s} = 1.6 \ldots 1.7$ GeV. However, before any conclusion can be drawn the conventional mechanisms in the η photoproduction both on the proton and on the neutron has to be investigated in detail. In this Letter we present a first attempt for a multichannel analysis of ηp and ηn reactions within the Giessen Model, a unitary coupled-channel approach taking into account constraints from the other scattering channels. The Giessen model [16–18] has been developed for the simultaneous analysis of the pion- and photon-induced reactions up to about 2 GeV. In [4,19] an updated solution of the coupled-channel problem has been obtained to $\pi N \to \pi N, 2\pi N, \eta N, \omega N, K\Lambda, K\Sigma$ and $\gamma N \to \gamma N, \pi N, \eta N, \omega N, K\Lambda, K\Sigma$ reactions at energies from the threshold up to 2 GeV. At that time the η photoproduction on the neutron was beyond the scope of the calculations. Since the hadronic resonance parameters have been extracted in [4,19] the extension of the model to $\gamma n \to \eta n$ is in principle straightforward if the neutron helicity amplitudes of all resonances

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Table 1
Parameters of resonances considered in the present work. First line: parameters obtained in the present calculations. Second line: parameters are taken from our previous analysis [19]. In square brackets the sign of the ηNN^* coupling relative to the πNN^* coupling is given. Third line: values from PDG; in brackets estimated errors are given. NG — no average value in PDG is given. Helicity amplitudes are given in units of 10^{-3} GeV$^{-1/2}$

N^*	Mass	Γ_{tot}	$\Gamma_{\pi N}$	$\Gamma_{\eta N}$	$A^p_{1/2}$	$A^n_{1/2}$	$A^p_{\frac{3}{2}}$	$A^n_{\frac{3}{2}}$
$S_{11}(1535)$	1526	136	34.4	56.2[+]	95	−74	–	
	1526	136	34.4	56.1[+]	92	−13	–	
	1535(10)	150(25)	45(10)	53(7)	90(30)	−46(27)	–	
$S_{11}(1650)$	1664	133	71.9	2.5[−]	57	−9	–	
	1664	131	72.4	1.4[−]	57	−25	–	
	1655(15)	165(20)	72(22)	6(3)	53(16)	−15(21)	–	
$P_{11}(1440)$	1517	608	56.0	–	−84	138	–	
	1517	608	56.0	–	−84	138	–	
	1440(30)	325(125)	65(10)	–	−65(4)	40(10)	–	
$P_{11}(1710)$	1723	397	1.7	41.5[+]	−50	24	–	
	1723	408	1.7	43.0[+]	−50	68	–	
	1710(10)	150(100)	15(5)	6(1)	9(22)	−2(14)	–	
$P_{13}(1720)$	1700	152	17.1	0.1[+]	−65	3	35	−1
	1700	152	17.1	0.2[+]	−65	1	35	−4
	1725(25)	225(75)	15(5)	4(1)	18(30)	1(15)	−19(20)	−29(61)
$P_{13}(1900)$	1998	369	24.5	5.4[−]	−8	12	0	23
	1998	404	22.2	2.5[−]	−8	−19	0	6
	1900	NG	26(6)	14(5)	−17	−16	31	2
$D_{13}(1520)$	1505	100	56.5	1.2[+]	−15	−64	146	−136
	1505	100	56.6	1.2[+]	−13	−70	145	−141
	1520(5)	112(12)	60(5)	0.2(0.04)	−24(9)	−59(9)	166(5)	−139(11)
$D_{13}(1950)$	1934	855	10.5	0.1[−]	11	26	26	−55
	1934	859	10.5	0.5[−]	11	40	26	−33
	2080	NG	NG	4(4)	−20(8)	7(13)	17(11)	−53(34)
$D_{15}(1675)$	1666	148	41.1	0.1[+]	9	−56	21	−84
	1666	148	41.1	0.3[+]	9	−56	21	−84
	1675(5)	146(16)	40(5)	0(1)	19(8)	−43(12)	15(9)	−58(13)
$F_{15}(1680)$	1676	115	68.3	0.0[+]	3	30	116	−48
	1676	115	68.3	0.0[+]	3	30	116	−48
	1685(5)	130(10)	68(3)	0(1)	−15(6)	29(10)	133(12)	−33(9)
$F_{15}(2000)$	1946	198	9.9	2.0[−]	11	9	25	−3
	1946	198	9.9	2.0[−]	11	9	25	−3
	2000	490(130)	8(5)	NG				

would be known. The electromagnetic properties of most of the discovered states were extracted only from the analysis of the pion photoproduction data. Hence, the uncertainties of the extracted parameters would bring a large ambiguity to such a calculation.

A very important example relevant for the case at hand are the electromagnetic properties of the $S_{11}(1535)$ resonance. Because of the strong coupling of this state to ηN, the amplitude ratio $R = A^n_{1/2}(S_{11}(1535))/A^p_{1/2}(S_{11}(1535))$ defines a balance between η meson photoproduction on the neutron and the proton at energies close to this resonance mass. The various analyzes of pion photoproduction find this ratio being spread over a wide range $R = -0.3 \ldots -1$ (see the Particle Data Group (PDG) [20] and references therein). On the other hand the combined studies of the ηp and ηn photoproduction data [21–24] seems to agree on the value $R \approx -0.8$. Hence, one can hope that the multichannel analysis of the πN- and ηN-channels maximally constrains the resonance parameters, thereby a solid conclusion on the reaction mechanism and resonance parameters can be drawn.

The aim of this Letter is as follows. We repeat our previous calculations [4,19] but taking into account presently available ηn data to constrain the couplings $N^* \to \gamma n$. Using the hadronic parameters from [19] we predict the angular distribution and beam asymmetry for $\gamma n \to \eta n$ scattering in the energy region where the second peak in the ηn data is observed.

In [19] ηn data were not included in the fit. In the present calculation we include the experimental data on the ratio $(d\sigma/d\Omega)_n/(d\sigma/d\Omega)_p$ of neutron to proton η photoproduction cross sections from [25]. These data cover the energy region 1.5–1.6 GeV but with large statistical errors. We include these data in our fit but multiply the original error bars by the factor of $\frac{1}{3}$. Above 1.6 GeV we include the preliminary data points of the total cross section $\gamma n \to \eta n$ from [26]. Starting from our best solution to the pion- and photon-induced reactions we perform an additional fit varying only the helicity decay amplitudes and ηNN^*-couplings of the isospin-$\frac{1}{2}$ resonances keeping all other parameters fixed. The obtained parameters are shown in Table 1 in comparison with the results from [19]. The variation of the ηNN^*-couplings leads in general to a modification of total widths of the resonances and affects the description of $\gamma p \to (\pi/\eta)p$ reaction. Hence a variation of the $A^p_{1/2}$ amplitudes was also allowed. However, only tiny changes in the proton helicity amplitudes are observed, indicating the reliability

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