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Partial wave analysis of $(\gamma/\pi)N \rightarrow \eta N$ reactions within a coupled channel unitary Lagrangian approach*

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Abstract. The recent Crystal Ball measurements of the eta-meson photoproduction on the proton are analyzed within an unitary coupled-channel Lagrangian approach. The dip observed in the reaction cross section at 1.68 GeV is explained in terms of the interference between the $S_{11}(1535)$ and $S_{11}(1650)$ states. Additional contributions from the P_{11} partial wave are also important. No strong indication for the narrow P_{11} state with a width of 15 MeV is found. Predictions for the double-spin asymmetry C_z are presented and discussed.

1 Introduction

Combined study of pion- and photon-induced reactions provides an important information on the dynamic of baryon resonances. This is an essential issue not only for the reaction theory but also for understanding of the internal structure of hadrons. One of the main question here is whether the nucleon resonance spectra summarized in the Particle Data Group (PDG) [1] is complete or not.

The recent measurements of the eta- meson photoproduction on the quasi-free neutron (γn) demonstrate two resonance-like structures in the total cross section at c.m. energies 1.53 and 1.67 GeV respectively [6–9]. While the first peak corresponds to the well known $S_{11}(1553)$ state the nature of the second one is unclear [2,12,4,5]. The authors of [2] predict a narrow P_{11} state with a width of 15 MeV and the mass of 1.67 GeV whereas the Giessen group [12] explains this phenomena in terms of the $S_{11}(1650)$ and $P_{11}(1710)$ resonance excitations. The third explanation has been given in [5] where the authors argued that the additional structure could be related with a cusp effect due to the $K\Lambda$ and $K\Sigma$ channels.

If it is granted that the second peak observed in the γn scattering is due to the narrow (exotic) state one may expect a similar effect in other eta-production reactions at same energies, e.g in gamma-proton and pion-nucleon scattering. However the situation in the photon-induced reaction on the proton (γp) is completely opposite to the γn scattering. The recent high-precision measurements from the Crystal Ball/MAMI collaboration [10] demonstrate a dip in the eta production cross section but not a resonance-like peak. This raises three questions. The first one is whether the dip reported in the ηp cross section and resonance-like signal observed in ηn are originated from the same degrees of freedom or not. If yes, then does the dip in ηp and resonance-like effect in ηn have their counterparts in $\pi N \rightarrow \eta N$ reaction? And the third question: is one of these phenomena (or both) can be attribute to the excitation of a narrow or exotic state?

To investigate these possibilities we perform an updated partial wave analysis of $\gamma p \rightarrow \eta p$ and $\pi^- p \rightarrow \eta n$ reactions including the recent high precision measurements from [10]. Here main results are summarized; more details on can be found in [11].

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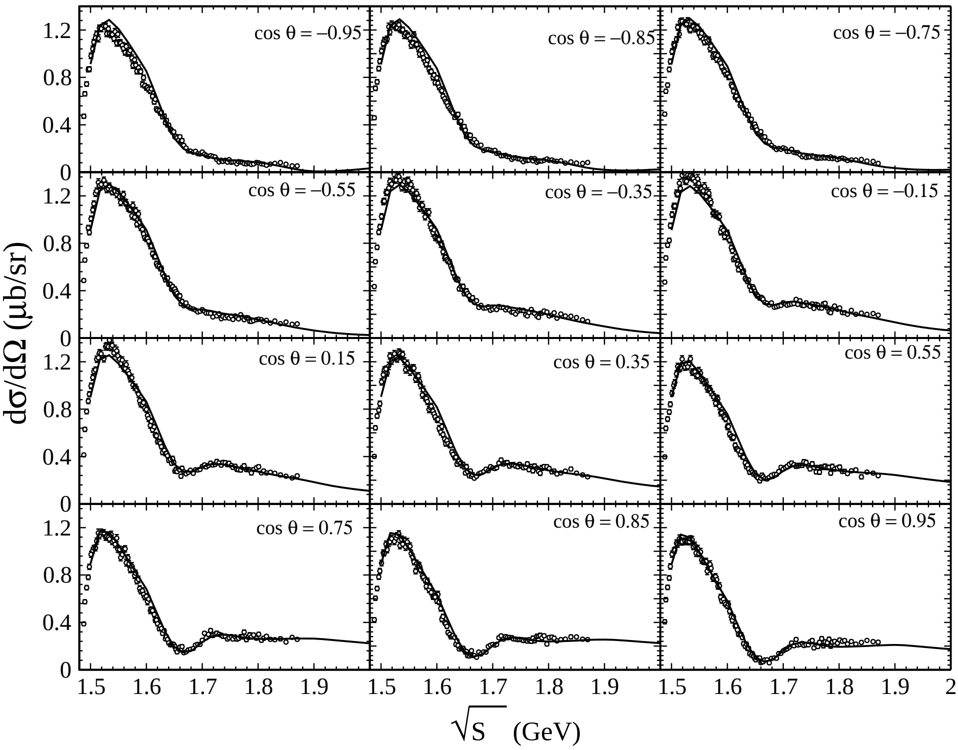

Fig. 1. Calculated differential $\gamma p \to \eta p$ cross sections in comparison with the experimental data from [10] .

2 Giessen Model

A unitary effective Lagrangian model is developed to solve a coupled-channel problem for pion- and photon-induced reactions [11–17]. It is based on solving Bethe-Salpeter equation

$$T(\sqrt{s}, p, p') = K(\sqrt{s}, p, p') + \int \frac{d^4q}{(2\pi)^4} K(\sqrt{s}, p, q) G_{BS}(\sqrt{s}, q) T(\sqrt{s}, q, p') \quad (1)$$

in the K-matrix approximation where p (k) and p' (k') are the incoming and outgoing baryon (meson) four-momenta, $T(\sqrt{s}, p, p')$ is a coupled-channel scattering amplitude, G_{BS} is a meson-nucleon propagator and $K(\sqrt{s}, p, p')$ is an interaction kernel. The quantities $T(\sqrt{s}, p, p')$, G_{BS}, and $K(\sqrt{s}, p, p')$ are multidimensional matrices where the elements of each matrix stand for the different scattering reactions $(\gamma/\pi)N \to \pi N$, $2\pi N$, ηN, $K\Lambda$, $K\Sigma$, and ωN.

The interaction kernel in Eq. (1) is derived from the Lagrangians given in [11–17]. The resonance parameters were allowed to be varied during the fit. The description of the database and details of the calculations are given in [11].

2.1 Results and discussion

The results of the calculations for the $\gamma p \to \eta p$ reaction are presented in Fig. 1. The first peak comes from the excitation of the $S_{11}(1535)$ resonance. The dip at 1.68 GeV is due to the destructive interference between the $S_{11}(1535)$ and $S_{11}(1650)$ states. Though the effect from the $P_{11}(1710)$ state is only minor, the contribution from this resonance produces a rapid change in the M_{1-} photoproduction multipole, see [11]. The coherent sum of all partial waves leads to the more pronounced effect from the dip at forward angles. We also corroborate our previous findings [12] where a small effect from

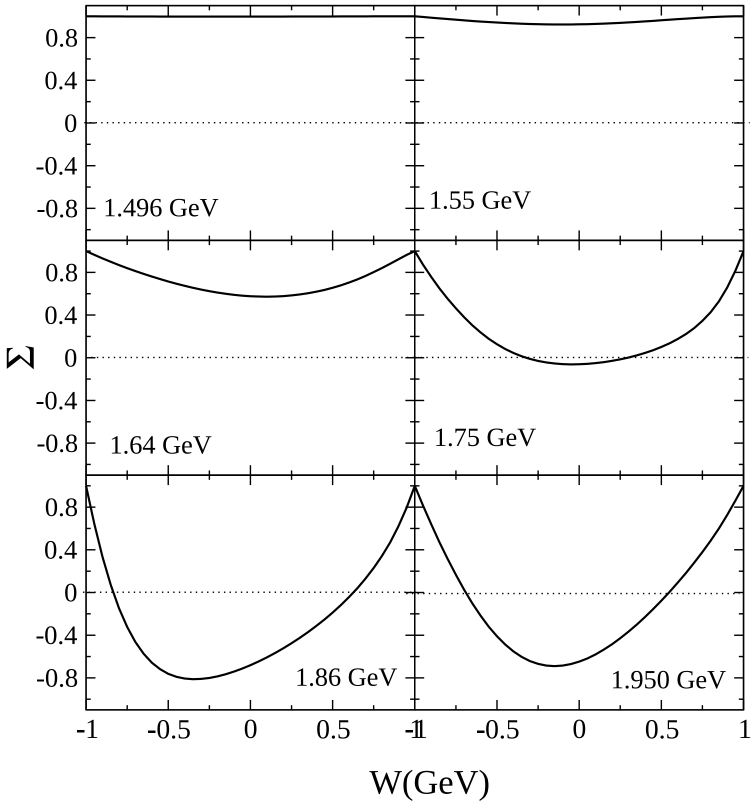

Fig. 2. Calculated differential $\gamma p \to \eta p$ cross sections in comparison with the experimental data from [10].

the ωN threshold was found. The opening of the ωN channel leads to a small cusp effect at the energy W=1.72 GeV which lies almost 50 MeV higher than the dip position. This conclusion is opposite to that drawn in [18] where the authors conclude on importance of this effect for description of the dip at 1.68 GeV. Also no any strong indications for a narrow state are found in the present analysis of the Crystal Ball/Taps data.

The measurement of the double spin observable C_z might be very useful to pin down the mechanism of the eta -photoproduction. This quantity measures a spin transfer from the initial photon to the final nucleon. If the reaction entirely proceeds through the S_{11} resonance excitation this observable is $C_z = +1$ and does not depend on scattering angle in the c.m. frame. One other hand contributions from the P_{11}-wave induce a spin flip and C_z behaves like $1 - 2\sin^2(\theta)$. Hence $C_z\ (90^0\ ) = -1$ which denotes the spin flip in case of the purely P_{11}-resonance contribution. Therefore, for example, experimental study of C_z would shed light on the parity of the possible resonance state observed at 1.68 GeV in the $\gamma n \to \eta n$ scattering.

In Fig. 2 the C_z asymmetry calculated for the $\gamma p \to \eta p$ photoproduction is shown as a function of the c.m. scattering angle. In the energy region 1.49 ... 1.55 GeV the reaction proceeds through the $S_{11}(1535)$ state excitation. As a result the calculated asymmetry is almost one for all scattering angles. Close to the dip position the magnitude of the S_{11} wave decreases and the contributions from other partial waves - P_{11}, D_{13} start to influence C_z. Above 1.7 GeV the asymmetry changes its sign for scattering angles close to 90^0. At these energies the transition amplitude represents a coherent sum of many partial waves. This leads to the rotation of the spin of the final proton at moderate scattering angles. However the tensor part of electromagnetic current does not contribute at forward and backward scattering angles and the spin of the final proton is aligned along the z-axis for forward and backward scattering.

2.2 Conclusion

Pion- and photon-induced reactions are studied to investigate the mechanism of the eta-meson photoproduction on the proton. The dip observed in the recent Crystal Ball measurements is explained in terms of the interference between the $S_{11}(1535)$ and $S_{11}(1650)$ states. Additional contributions from P_{11} wave makes the dip to be more pronounced for forward scattering angles. No strong indication for a narrow $P_{11}(1680)$ state with the 15 MeV width is found. Thought the ωN threshold plays an important role at energy W=1.72 GeV it does not responsible for the dip structure at 1.68 GeV.

The measurement of the double spin asymmetry would provide an additional test for the present model calculations and would help to pin down the reaction dynamics further.

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