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Study of nucleon resonances in a chiral quark model via η productions

HE Jun(何军)[1;1)] B. Saghai[2]

1 (Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China)

2 (Institut de Recherche sur les lois Fondamentales de l'Univers, IRFU, CEA/Saclay, 91191 Gif-sur-Yvette, France)

Abstract In this report we investigate η-meson productions on the proton via electromagnetic and hadron probes in a chiral quark model approach. The observables, such as, differential cross section and beam asymmetry for the two productions are calculated and compared with the experiment. The five known resonances $S_{11}(1535)$, $S_{11}(1650)$, $P_{13}(1720)$, $D_{13}(1520)$, and $F_{15}(1680)$ are found to be dominant in the reaction mechanisms in both channels. Significant contribution from a new S_{11} resonances are deduced. For the so-called "missing resonances", no evidence is found within the investigated reactions. The partial wave amplitudes for $\pi^- p \to \eta n$ are also presented.

Key words N*, chiral quark model, photoproduction

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1 Introduction

Among meson production processes, which are the important way to study resonances, η production has its unique advantage in several sides. The structure of the low energy resonances $S_{11}(1535)$, which is near the threshold of η production, attracts many attentions, such as, possible pentaquark component[1]. Because the η meson bears zero isospin, all isospin-3/2 resonances are filtered out in this process, which brings convenience to study the nucleon resonances. Besides, by studying η production, one can extract the information of ηN interaction , for which a possible strong attraction between η and N at low energies may lead to popular interesting "η-mesic nuclei"[2, 3].

2 Theoretical frame

As in Ref. [4] we start from an effective chiral Lagrangian[5],

$$\mathcal{L} = \bar{\psi}[\gamma_\mu(\mathrm{i}\partial^\mu + V^\mu + \gamma_5 A^\mu) - m]\psi + \cdots , \qquad (1)$$

where vector (V^μ) and axial (A^μ) currents read,

$$V^\mu = \frac{1}{2}(\xi\partial^\mu\xi^\dagger + \xi^\dagger\partial^\mu\xi) \ , \ A^\mu = \frac{1}{2\mathrm{i}}(\xi\partial^\mu\xi^\dagger - \xi^\dagger\partial^\mu\xi), \ (2)$$

with $\xi = \exp(\mathrm{i}\phi_m/f_m)$ and f_m the meson decay constant. ψ and ϕ_m are the quark and meson fields, respectively. The four components (seagull, s, u and t-channel) for the photoproduction of pseudoscalar mesons or pion nucleon scattering, can be written is as following,

$$\mathcal{M}_{fi} = \langle N_f|H_{f,i}|N_i\rangle + \sum_j \left\{ \frac{\langle N_f|H_f|N_j\rangle\langle N_j|H_i|N_i\rangle}{E_i+\omega-E_j} + \frac{\langle N_f|H_i|N_j\rangle\langle N_j|H_f|N_i\rangle}{E_i-\omega_m-E_j} \right\} + \mathcal{M}_T, \qquad (3)$$

where $N_i(N_f)$ is the initial (final) state of the nucleon, and $\omega(\omega_m)$ represents the energy of incoming (outgoing) photons (mesons). In this work, the wave functions for the intermediate states (resonances) are obtained in the one-gluon-exchange (OGE) model[6] though fitting the PDG value of spectrum.

3 Fitting procedure

Using the CERN MINUIT code, we have fitted simultaneously the following data sets:

1) Observables for $\gamma p \to \eta p$

Differential cross-section: Data base includes 1220 data points, for 1.49< W <1.99 GeV, coming from

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1) E-mail: Junhe@impcas.ac.cn

the following labs: MAMI[7] (100 points), CLAS[8] (142 points), ELSA[9] (311 points), LNS[10] (180 points), and GRAAL[11] (487 points). Only statistical uncertainties are used.

Polarized beam asymmetry: 184 data points, for 1.49< W <1.92 GeV, from GRAAL[11] (150 points) and ELSA[12] (34 points). Only statistical uncertainties are used.

2) Observables for $\pi^-p\rightarrow\eta n$

Differential cross-section: Data base includes 354 data points, for 1.49< W <1.99 GeV, coming from: Deinet[13] (80 points), Richards[14] (64 points), Debenham[15] (24 points), and Brown[16] (102 points), Prakhov[17] (84 points). Uncertainties are treated as Ref. [18]

We also use the PDG values of known resonances[19] as input for masses and widths. Resonances with masses above $M\approx 2$ GeV, treated as degenerate, are simulated by a single resonance.

Here we use the definition χ^2 as,

$$\chi^2=\sum\frac{(V_{\rm ex}-V_{\rm th})^2}{(\delta V_{\rm ex})^2+(V'_{\rm th}\Delta E_{\rm ex})^2}\ . \qquad (4)$$

Here $V_{\rm ex}$, $V_{\rm th}$, and $\delta V_{\rm ex}$ are the standard χ^2 quantities. The additional term is a product of the derivative of the observable with respect to energy ($V'_{\rm th}$), and the experimental energy bin ($\Delta E_{\rm ex}$). For the two interaction χ^2 is 2.05 with 2.27 for the η photoproduction and 1.15 for $\pi^-p\rightarrow\eta n$. So we can say our approach gives a reasonable explanation to the measured observables from threshold up to $W\approx 2$ GeV especially for the latter interaction. If we use the same definition of χ^2 as EBAC@Jlab group[18], we will obtain $\chi^2=1.99$ for $\pi^-p\rightarrow\eta n$, which is close to their values, 1.94. Here we use only 21 adjustable parameters totally for the two η production processes considered compared with 175 parameters used by EBAC group.

4 Results and discussion

The results for the photoprodcution and pion-duced production are given in the Figs. 1, 2.

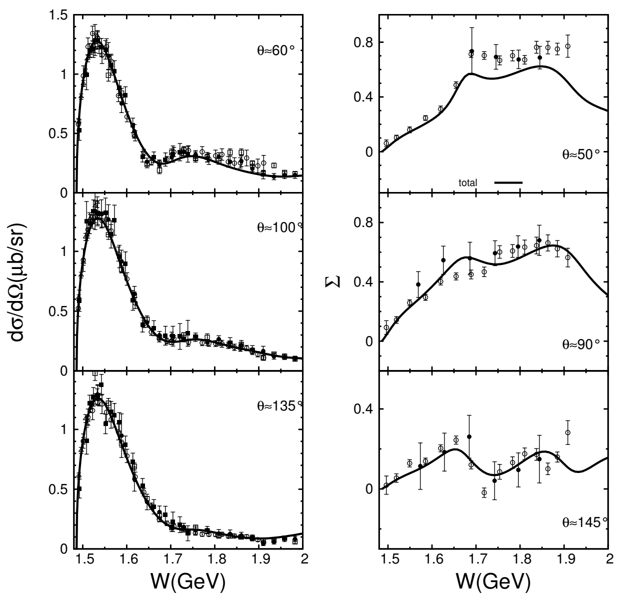

Fig. 1. The differential cross section (left) and beam asymmetry (right) for the η photoproduction.

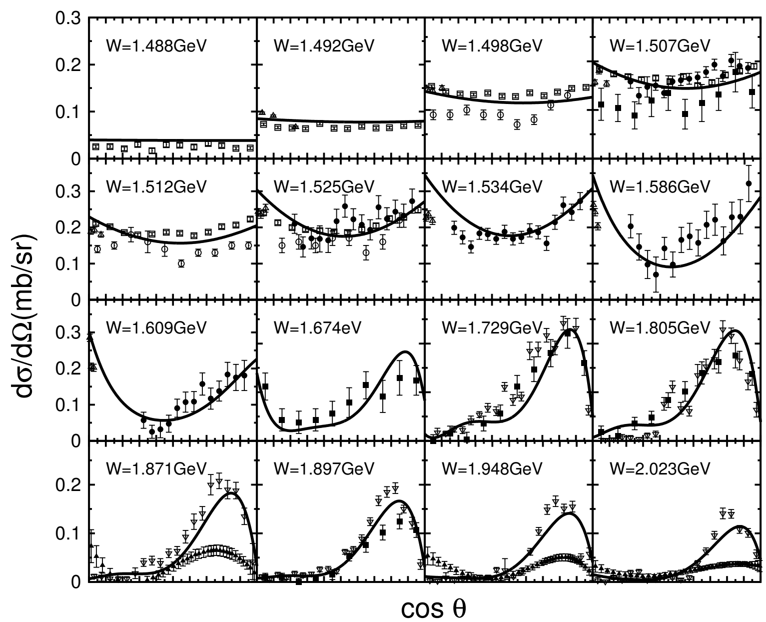

Fig. 2. The differential cross section for the $\pi^-p\rightarrow\eta n$.

For the photoproduction, the variations of differential cross section and beam asymmetry with the energy W at three angles are presented. The differential cross sections are well reproduced except in the region about 1.85 GeV at forwards angle. For the beam asymmetry, the uncertainties of data are larger. In general, our results are acceptable in all energy region and angles.

From Fig. 2 for pion-induced productions the observables are reproduced quite well. In the low energy region, the symmetry curvature, which is from the S_{11} dominance, is reproduced. For the higher energy region, with the decrease of the contribution of S_{11}, the symmetry is destroyed. Here the data is not consistent with each other as in the low energy. In our calculation we adopt the data by Brown et al.[16] not those by Crouch et al.[20] to fit.

As suggested by Isgur, a model which can only describe spectrum can not be identified as a successful model directly[21]. In our work, besides the spectrum is compared with the PDG values the configuration mixings of the wave functions obtained from the spectrum are used to calculate the observables. Here we use OGE model because its wonderful success in description of the spectrum under 2 GeV and the configuration mixings which is successfully used to calculate the decay width and helicity amplitudes[22]. The result of baryon spectrum extracted from the present work is reported in Fig. 3.

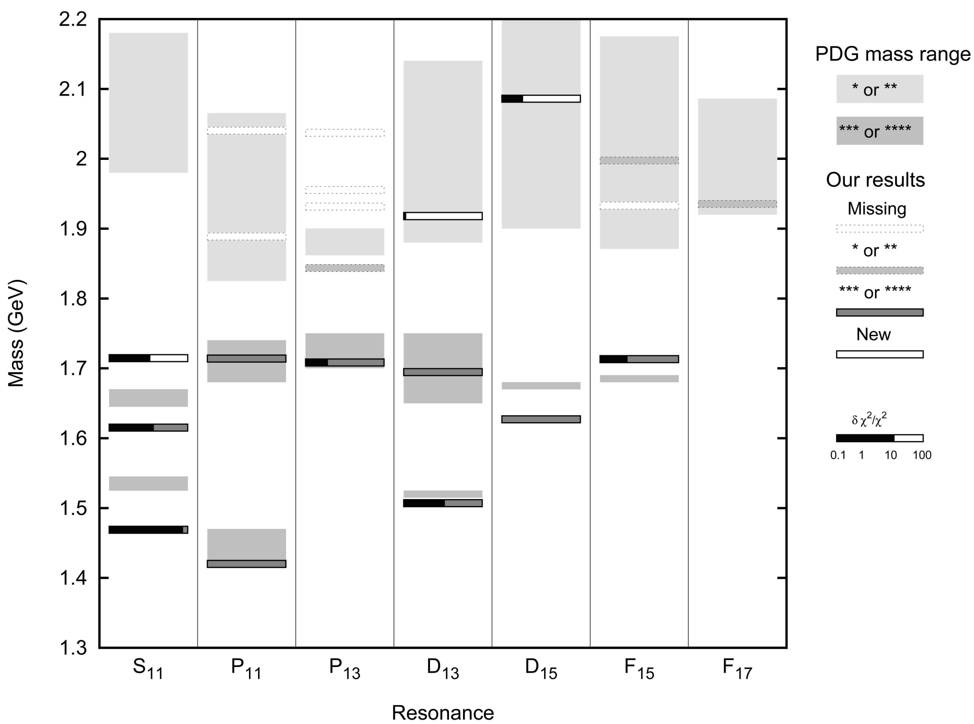

Fig. 3. The spectrum with $\delta\chi^2/\chi^2$ for the corresponding resonances.

Our results are in good agreement with these obtained form the original OGE model by Isgur[6]. The contribution of each resonances is also given in the same figure. The ratios of changes of χ^2 after turning off(on) corresponding resonances and χ^2 for full model, $\delta\chi^2/\chi^2$, are presented in Fig. 3 as black bars for corresponding resonances. Among the twelve nucleon resonances in that energy range, compiled by PDG, five of them are found to play crucial roles in the reaction mechanism, namely, $S_{11}(1535)$, $S_{11}(1650)$, $P_{13}(1720)$, $D_{13}(1520)$, and $F_{15}(1680)$. Five extra resonances generated by the formalism, known as "missing" resonances, turn out to show no significant contributions to the process under investigation. Two new resonances reported in the literature, S_{11} and D_{15}, are found relevant to the photoproduction process; the most important effect comes from the S_{11} resonance. The new resonances are not necessary to reproduce the data for $\pi^- p \to \eta n$ while two more known resonances, $D_{15}(1675)$ and $P_{11}(1440)$ are not negligible in this process.

The partial wave amplitudes for the pion induced production are presented in Fig. 4 and compared with the results from SAID[23].

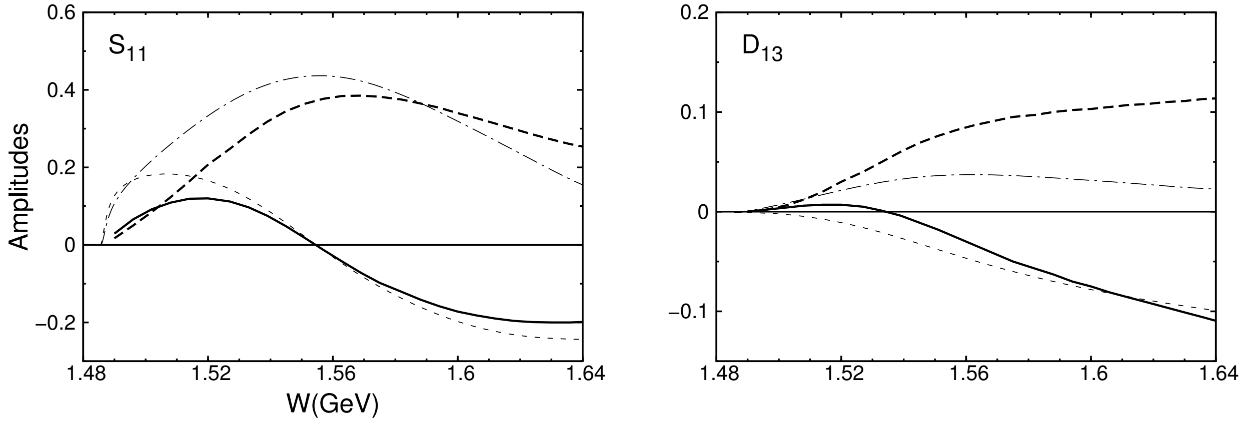

Fig. 4. The amplitudes for $\pi^-p \rightarrow \eta n$, the thick full (dashed) curve shows the real (imaginary) part of amplitudes in current work. The dotted (dash-dotted) curve shows the real (imaginary) part in FA02 by SAID.

Here we present the amplitudes of two partial wave, S_{11} and D_{13}. In general, our results are in agreement with the FA02 solution of SAID.

In this work the two η productions, $\gamma p \rightarrow \eta p$ and $\pi^-p \rightarrow \eta n$, was investigated in a chiral constituent quark approach. In the current work, the significant merit is that the contribution of each known and so-called "missing" resonances is only relevant to the overall parameters. The importance of certain resonance is not extracted from the experimental data though determining its strength by fit as done in the models on the hadron level, but given by the formalism itself. Then we can see clearly that in the considered channels the contribution of "missing" resonances are really neligible in constituent quark model.

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