$\pi N \to \eta N$ process in a χQM approach

Jun He[*], Xianhui Zhong[+], Bijan Saghai[*], Qiang Zhao[+]

[*]Laboratoire de recherche sur les lois fondamentales de l'Univers, DSM/DAPNIA/SPhN, CEA/Saclay, 91191 Gif-sur-Yvette, France
[+]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049, P.R. China

Abstract

A chiral quark model approach is used to investigate the $\pi^- p \to \eta n$ process at low energies. The roles of the most relevant nucleon resonances in $n \leq 2$ shells are briefly discussed.

1 Introduction

The $\pi^- p \to \eta n$ reaction provides a suitable probe to investigate the structure of low-lying nucleon resonances as well as the ηN interaction.

Recent high precision data released by the BNL Crystal Ball Collaboration [1] has revived the interest in that process. The impact of those data on the meson-baryon interactions has been emphasized by the SAID Group [2]. Extensive theoretical efforts are also being deployed *via* coupled-channel formalisms, such as the K-matrix approach [3], meson-exchange model [4], chiral model [5], T-matrix [6], and dynamical formalism [7].

We have extended to the $\pi N \to \eta N$ process a comprehensive and unified approach [8] to the meson photoproduction, based on the low energy QCD Lagrangian in terms of quarks degrees of freedom. This latter formalism has been developed and proven [9] to be successful in investigating $\gamma p \to \eta p, K^+\Lambda$ and $\gamma N \to \pi N$ reactions. In this approach, only a few parameters are required. In particular, only one parameter is needed for the nucleon resonances to be coupled to the pseudoscalar mesons. All the resonances can be treated consistently in the quark model.

2 Theoretical frame

In the chiral quark model, the low energy quark-meson interactions are described by the effective Lagrangian

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

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

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

with $\xi = \exp{(i\phi_m/f_m)}$, where f_m is the meson decay constant. ψ and ϕ_m are the pion and quark fields, respectively.

The η meson production amplitude can be expressed in terms of Mandelstam variables, $\mathcal{M} = \mathcal{M}_s + \mathcal{M}_u + \mathcal{M}_t$.

The s- and u-channel transitions are given by:

$$\mathcal{M}_s = \sum_j \langle N_f|H_\eta|N_j\rangle\langle N_j|\frac{1}{E_i+\omega_\pi - E_j}H_\pi|N_i\rangle, \tag{3}$$

$$\mathcal{M}_u = \sum_j \langle N_f|H_\pi\frac{1}{E_i-\omega_\eta - E_j}|N_j\rangle\langle N_j|H_\eta|N_i\rangle, \tag{4}$$

where ω_π and ω_η are the energies of the incoming π-meson and outgoing η-meson, respectively. H_π and H_η are the standard quark-meson couplings at tree level. $|N_i\rangle$, $|N_j\rangle$, and $|N_f\rangle$ stand for the initial, intermediate, and final state baryons, respectively, and their corresponding kinetic energies are E_i, E_j, and E_f.

Given that the a_0 meson decay is dominated by $\pi\eta$ channel [11], we consider the a_0 exchange as the prominent contribution to the t-channel,

$$\mathcal{M}_t = \sum_j \frac{g_{a_0\pi\eta}g_{a_0qq}m_\pi^2}{t^2 - m_{a_0}^2}\langle N_f|\overline{\psi}_j\psi_j\vec{a}_0|N_i\rangle. \tag{5}$$

where m_{a_0} is the mass of the a_0 meson.

With the above effective Lagrangian and following the procedures used in Ref. [8], we obtain the amplitude in the harmonic oscillator basis [10].

3 Results and discussion

Using the formalism sketched above, we have investigated the cross-section for the $\pi^- p \to \eta n$ process. In our model, non-resonant components include nucleon pole term, u-channel contributions (treated as degenerate to the harmonic oscillator shell n), and t-channel contributions due to the a_0-exchange.

The resonant part embodies the following n=1,2 shell nucleon resonances:

- n=1: $S_{11}(1535)$, $S_{11}(1650)$, $D_{13}(1520)$, $D_{13}(1700)$, and $D_{15}(1675)$,
- n=2: $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $P_{13}(1900)$, $F_{15}(1680)$, and $F_{15}(2000)$.

Here we use the Breit-Wigner masses and widths given in the PDG [11]. For meson-nucleon-nucleon couplings we adopt $g_{\pi NN}$=13.48 and $g_{\eta NN}$=0.81.

Our results for the differential cross-section are depicted in Fig. [1] for pion incident momenta P_π^{lab} = 0.718, 0.850, and 1.005 GeV, corresponding to the total centre-of-mass energies W = 1.507, 1.576, and 1.674 GeV, respectively.

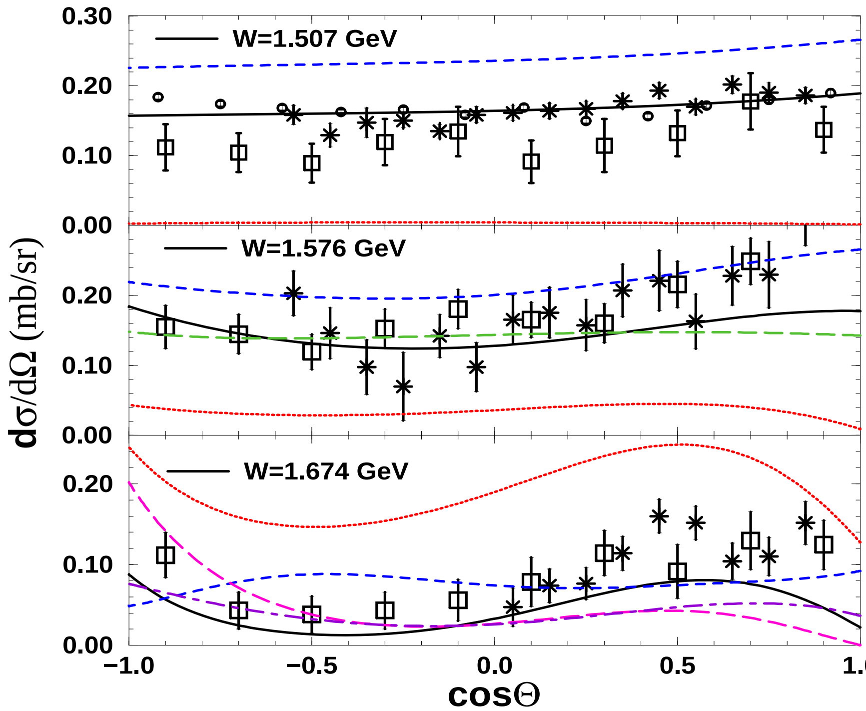

Figure 1: Differential cross-section for $\pi^- p \to \eta n$. The curves appearing in all the three boxes are: full model (solid black), the $S_{11}(1535)$ switched off (dotted red), and the $S_{11}(1650)$ switched off (dashed blue). In the middle box: the $D_{13}(1520)$ switched off (long dashed green). In the lower box: the $P_{11}(1710)$ switched off (long dashed magenta) and without the n=2 shell contributions (dot-dashed violet). Data are from Prakhov *et al.* [1] (circles), Richards *et al.* [12] (squares), and Deinet *et al.* [13] (stars).

We get a good agreement with the data at those energies (full curves). In order to single out the importance of various resonances, at each energy we show results while one *significant* resonance is switched off. The $S_{11}(1535)$

plays a crucial role in this energy range. At the lowest energies it has a constructive effect, while at the highest one its contribution becomes destructive. The $S_{11}(1650)$ has a (much) smaller and destructive effect. The role of the $D_{13}(1520)$, shown at W=1.576 GeV, is merely to produce the right curvature. At the highest energy, although the overall contribution from n=2 shell is rather small, the $P_{11}(1710)$ produces significant effects. This point was emphasized in our recent work [10], and led us to adopt here a reversed sign for that resonance *from the beginning*. That sign change for the $P_{11}(1710)$ could be an indication, e.g. for the breakdown of the non-relativistic constituent quark model or for unconventional configurations inside that resonance. More investigation is needed to underpin the origins of this novelty.

References

[1] S. Prakhov *et al.*, *Phys. Rev. C* **72**, 015203 (2005).

[2] R. A. Arndt, W. J. Briscoe, I. I. Strakovsky, R. L. Workman, *Phys. Rev. C* **74**, 045205 (2006).

[3] G. Penner and U. Mosel, *Phys. Rev. C* **66**, 055211 (2002); V. Shklyar, H. Lenske, U. Mosel, *Phys. Lett. B* **650**, 172 (2007).

[4] A. M. Gasparyan, J. Haidenbauer, C. Hanhart, J. *Phys. Rev. C* **68**, 045207 (2003).

[5] T. Inoue, E. Oset, M. J. Vicente-Vacas, *Phys. Rev. C* **65**, 035204(2002).

[6] S. Ceci, A. Svarc, B. Zauner, *Phys. Rev. Lett.* **97**, 062002 (2006).

[7] A. Matsuyama, T. Sato, T.-S.H. Lee, *Phys. Rept.* **439**, 193 (2007).

[8] Z. Li, H. Ye, M. Lu, *Phys. Rev. C* **56**, 1099 (1997).

[9] B. Saghai and Z. Li, *Eur. Phys. J.* **A11**, 217 (2001); B. Saghai, nucl-th/0408054; B. Saghai *et al. Eur. Phys. J. A* **31**, 512 (2007); Q. Zhao *et al.*, *Phys. Rev. C* **65**, 065204 (2002).

[10] Xian-Hui Zhong, Qiang Zhao, Jun He, Bijan Saghai, nucl-th/0706.3543.

[11] W. M. Yao *et al.*, *J. Phys. G* **33**, 1 (2006).

[12] W. B. Richards *et al.*, *Phys. Rev. D* **1**, 10 (1970).

[13] W. Deinet *et al.*, *Nucl. Phys. B* **11**, 495 (1969).