ISOSPIN DEPENDENCE OF THE η MESON PRODUCTION IN HADRONIC COLLISIONS*

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Based on recent COSY-11 results of measurements of total cross sections for the quasi-free $pn \to pn\eta$ reaction we determine the isospin I = 0 component of the total cross section for the $NN \to NN\eta$ reaction down to the threshold. We show that the energy dependence of the total cross section ratios $\frac{\sigma_{I=0}(pn \to pn\eta)}{\sigma(pp \to pp\eta)}$ and $\frac{\sigma_{I=0}(pn \to pn\eta)}{\sigma(pn \to d\eta)}$ can be described using the Fäldt and Wilkin analitical parametrization of the nucleon-nucleon final state interaction.

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1. Introduction

Studies on the η meson production in hadronic collisions via different isospin channels have had a large contribution to the understanding of the reaction mechanism [1–3]. From the comparison of the total cross sections for reactions $pn \to pn\eta$ [4–7] and $pp \to pp\eta$ [8–15] it was derived that the production of the η meson with the total isospin $I = 0$ in the initial channel exceeds the production with the isospin $I = 1$ by over an order of magnitude, suggesting [16] the isovector meson exchange to be the dominant process leading to excitation of the S_{11} resonance. This mechanism is considered to be predominant [17–25]. However, relative contributions to the production process of π and ρ meson exchange are still not well settled [26–29].

In this paper we determine contributions of the I = 0 and I = 1 components to the total cross section of the $NN \to NN\eta$ reaction taking into account an entire available data base including our recent cross sections for the $pn \to pn\eta$ reaction determined near the kinematical threshold [5].

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2. $pn \to pn\eta$ and $pp \to pp\eta$ total cross section ratio

Denoting by σ_0 and σ_1 the isospin I = 0 and I = 1 components of the total cross section for the $NN \to NN\eta$ reaction, we can write that:

$$\sigma(pn \to pn\eta) = \frac{1}{2}(\sigma_0 + \sigma_1), \tag{1}$$

and that

$$\sigma(pp \to pp\eta) = \sigma_1. \tag{2}$$

Left panel of Figure 1 shows the ratio of the total cross sections for the $pn \to pn\eta$ reaction to the total cross section for the $pp \to pp\eta$ reaction plotted as a function of the excess energy. It was surprising to observe this ratio to fall down at lower values of Q. However, as explained by Wilkin [30], to large extent, this behavior may plausibly be assigned to the difference in strength of the proton-proton and proton-neutron FSI. Following the reference [31] the parameterization of the isospin I = 0 component of the cross section for the $pn \to pn\eta$ reaction, taking into account proton-neutron FSI, is given by:

$$\sigma_0(pn \to pn\eta) = A\frac{Q^2}{(1+\sqrt{1+Q/\epsilon_{pn}}\ )^2}, \tag{3}$$

where A is a constant, Q is an excess energy, and $\epsilon_{pn} = 2.2$ MeV is the binding energy of the pn bound state [30].

Analogously, the parameterization of the $pp \to pp\eta$ reaction total cross section (pure isospin I = 1) is given by:

$$\sigma(pp \to pp\eta) = B\frac{Q^2}{(1+\sqrt{1+Q/\epsilon_{pp}}\ )^2}, \tag{4}$$

with $\epsilon_{pp} = 0.68$ MeV being the "binding" energy of the pp virtual state [31], and B being a constant. The value of $\epsilon_{pp} = 0.68$ was derived [32] from the fit of formula 4 to the cross sections for the $pp \to pp\eta'$ reaction [33–36] for which the influence from the proton-meson final state interaction can be neglected [37].

Employing equations 4, 3, 2, and 1 one obtains for the cross sections ratio a following closed analytical formula which accounts for the interaction between nucleons [31, 38]:

$$\frac{\sigma(pn \to pn\eta)}{\sigma(pp \to pp\eta)} = 0.5 + C(\frac{\sqrt{\epsilon_{pp}} + \sqrt{\epsilon_{pp}+Q}}{\sqrt{\epsilon_{pn}} + \sqrt{\epsilon_{pn}+Q}})^2. \tag{5}$$

We have fitted the function given by Equation 5 (with C as the only free parameter) to the data in the excess energy range from 0 to 40 MeV where the higher partial waves of the nucleon-nucleon system are suppressed [37]. The result is presented in Figure 1(left) as the solid line, and explains to some extent the observed decrease of the ratio at threshold. The parameter C was found to be 6.85 ± 0.63 and the χ^2 of the fit was equal to 1.6.

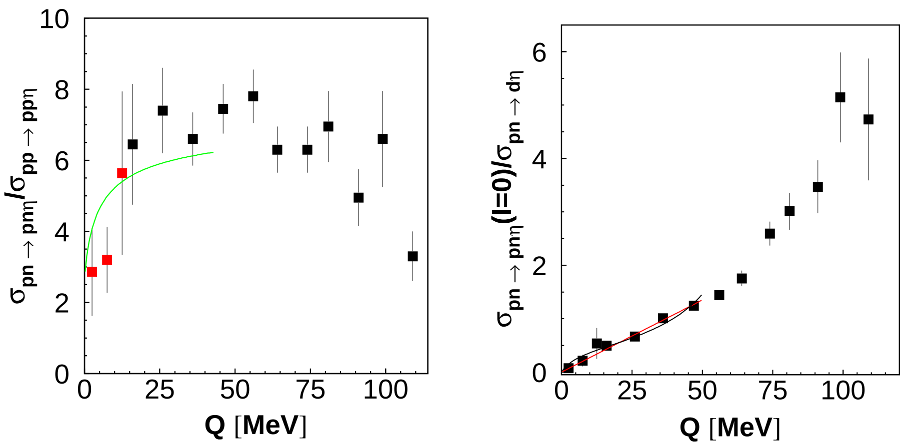

Fig. 1. (left) Ratio of the total cross sections for the $pn \to pn\eta$ and $pp \to pp\eta$ reactions. A superimposed line indicates a result of the fit taking into account the final state interaction of nucleons. (right) Ratio between the $I = 0$ component of the $pn \to pn\eta$ total cross section and the total cross section for the $pn \to d\eta$. A superimposed lines indicate result of fits taking into account the final state interaction of nucleons (black line), and assuming that the ratio of the total cross sections changes linearly with the excess energy (straight line).

A slight bump-like structure observed in the ratio presented in the left panel of Figure 1 – with a flat maximum at the excess energy of about 50 MeV – could be due to the fact that production of the η meson in hadronic collisions proceeds via the intermediate resonance N*(1535) (m(N*) - m_η - $m_{nucleon} \approx 49$ MeV). This may indicate that coupling of this resonance to the neutron–η may be stronger than to the proton-η channel. This interpretation is however controversial since it would imply a strong isospin breaking effects [39].

3. $pn \to pn\eta(\mathrm{I}=0)$ and $pn \to d\eta$ total cross section ratio

The total cross section for the $pn \to d\eta$ reaction is a pure isospin $\mathrm{I} = 0$ since both deuteron and the η meson have isospin equal to zero. In the case of the $NN \to NN\eta$ reaction the $\mathrm{I} = 0$ component of the cross section can be extracted from cross sections for the reactions $pn \to pn\eta$ and $pp \to pp\eta$ employing equations 1 and 2.

In order to compare the production of the η meson associated with the proton-neutron bound state (dη) to its production with the proton and neutron in continuum (pnη) in the way independent of the initial state interaction we have extracted the experimental values of the $\sigma_0(pn \to pn\eta)$ component, and compared them to the total cross sections for the $pn \to d\eta$ reaction. The ratio of these two cross sections is presented in the right panel of Figure 1, plotted as a function of the excess energy Q. An interesting observation is this ratio rises nearly linearly with the excess energy up to circa 60 MeV, and above this value it starts to grow more steeply. This may suggest that from about 60 MeV influence of the higher partial waves in the $pn\eta$ system is more pronounced than in the case of the $d\eta$ system.

According to the reference [24] the low energy cross section for the $pn \to d\eta$ reaction may be parameterized in the following way:

$$\sigma(pn \to d\eta) \approx a\sqrt{Q}(1 + bQ), \tag{6}$$

where parameters a and b are calculated from the nucleon mass, the η and ρ meson masses, and also the ρ meson coupling constant [24]. As the latter is still not well known, and the values of parameters a and b are model dependent [1] we have treated a and b as free parameters of the fit.

Dividing Equation 3 by Equation 6 we get:

$$\frac{\sigma_0(pn \to pn\eta)}{\sigma(pn \to d\eta)} = \frac{DQ^{3/2}}{(1 + bQ)(1 + \sqrt{1 + Q/\epsilon_{pn}})^2}, \tag{7}$$

with D being a constant. We have fitted Formula 7 in the range between the threshold and Q = 50 MeV (see Figure 1 (right)) [2], treating D and b as free parameters of the fit. The fit procedure resulted in $D = 0.35 \pm 0.03 \frac{1}{MeV^{3/2}}$ and $b = -0.013 \pm 0.001 \frac{1}{MeV}$. The value of reduced χ^2 of the fit was equal to 1.4.

[1] In reference [24] they are calculated in the framework of the vector meson dominance one boson exchange model, where the ρ meson exchange current dominates the production amplitude.

[2] This corresponds to the close-to-threshold reaction region, where higher partial waves shouldn't be present, and Formulae 3 and 6 apply.

On the other hand, the assumption that the $\sigma_0(pn \to pn\eta)$ to $\sigma(pn \to d\eta)$ ratio is a linear function of Q in the close-to-threshold region (up to the excess energy of Q = 50 MeV):

$$\frac{\sigma_0(pn \to pn\eta)}{\sigma(pn \to d\eta)} = KQ, \tag{8}$$

yields $K = 0.027 \pm 0.001 \, \frac{1}{MeV}$, with the reduced value of χ^2 equal to 0.3. The best linear function fitted to the experimental data is presented in Figure 1 (right).

One should, however, be careful in interpretation of the cross section ratios presented in Figure 1 due to the rather low energy resolution for measurements of the $pn \to pn\eta$ reaction which was equal to about 5 MeV for the COSY-11 experiment and circa 8 MeV for experiments performed with the WASA/PROMICE detector [**?**].

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REFERENCES

[1] G. Fäldt, T. Johansson, C. Wilkin, *Physica Scripta* **T99**, 146 (2002).

[2] P. Moskal, M. Wolke, A. Khoukaz, W. Oelert, *Prog. Part. Nucl. Phys.* **49**, 1 (2002).

[3] C. Hanhart, *Phys. Rept.* **397**, 155 (2004).

[4] H. Calén *et al.*, *Phys. Rev.* **C58**, 2667 (1998).

[5] P. Moskal *et al.*, *Phys. Rev.* **C79**, 015208 (2009).

[6] P. Moskal *et al.*, *J. Phys.* **G32**, 629 (2006).

[7] P. Moskal, R. Czyżykiewicz, *AIP Conf. Proc.* **950**, 118 (2007).

[8] F. Hibou *et al.*, *Phys. Lett.* **B438**, 41 (1998).

[9] J. Smyrski *et al.*, *Phys. Lett.* **B474**, 182 (2000).

[10] A. M. Bergdolt *et al.*, *Phys. Rev.* **D48**, 2969 (1993).

[11] E. Chiavassa *et al.*, *Phys. Lett.* **B322**, 270 (1994).

[12] H. Calén *et al.*, *Phys. Lett.* **B366**, 39 (1996).

[13] H. Calén *et al.*, *Phys. Rev. Lett.* **79**, 2642 (1997).

[14] P. Moskal *et al.*, *Phys. Rev.* **C69**, 025203 (2004).
[15] M. Abdel-Bary *et al.*, *Eur. Phys. J.* **A16**, 127 (2003).
[16] C. Wilkin, Report No. TSL/ISV-96-0147 (1996).
[17] A. Moalem *et al.*, *Nucl. Phys.* **A600**, 445 (1996).
[18] M. Batinić *et al.*, *Phys. Scripta* **56**, 321 (1997).
[19] J. F. Germond *et al.*, *Nucl. Phys.* **A518**, 308 (1990).
[20] J. M. Laget *et al.*, *Phys. Lett.* **B257**, 254 (1991).
[21] T. Vetter *et al.*, *Phys. Lett.* **B263**, 153 (1991).
[22] B. L. Alvaredo *et al.*, *Phys. Lett.* **B324**, 125 (1994).
[23] V. Bernard *et al.*, *Eur. Phys. J.* **A4**, 259 (1999).
[24] G. Fäldt and C. Wilkin, *Physica Scripta* **64**, 427 (2001).
[25] K. Nakayama *et al.*, *Phys. Rev.* **C65**, 045210 (2002).
[26] K. Nakayama *et al.*, arXiv:0803.3169.
[27] R. Shyam, *Phys. Rev.* **C75**, 055201 (2007).
[28] G. Fäldt and C. Wilkin, *Phys. Scripta* **64**, 427 (2001).
[29] J-J Xie *et al.*, *Phys. Rev.* **C77**, 058202 (2008).
[30] C. Wilkin, private communication (2008).
[31] G. Fäldt and C. Wilkin, *Phys. Lett.* **B382**, 209 (1996).
[32] P. Moskal *et al.*, *Int. J. Mod. Phys.* **A 22** (2007) 305.
[33] A. Khoukaz *et al.*, *Eur. Phys. J.* **A20**, 345 (2004).
[34] P. Moskal *et al.*, *Phys. Lett.* **B474**, 416 (2000).
[35] F. Balestra *et al.*, *Phys. Lett.* **B491**, 29 (2000).
[36] P. Moskal *et al.*, *Phys. Rev. Lett.* **80**, 3202 (1998).
[37] P. Moskal, arXiv: hep-ph/0408162.
[38] G. Fäldt and C. Wilkin, *Phys. Rev.* **C56**, 2067 (1997).
[39] K. Nakayama, comment during this symposium (2008).