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MESON PRODUCTION IN NN COLLISIONS

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Abstract

Meson production in NN collisions is discussed in conjunction with more basic two-body reactions. In particular, the production of η mesons in both the photo- and hadro-induced reactions are investigated in a combined analysis in order to learn about the relevant production mechanisms for this meson. We consider the nucleonic, mesonic and nucleon resonance currents constructed within an effective Lagrangian approach.

1 Introduction

The primary motivation for studying the production of mesons off nucleons and nuclei is to investigate the structure and properties of the nucleon resonances and, in the case of heavier meson productions, to learn about hadron dynamics at short range. In particular, we still know relatively little about the production mechanism of heavier mesons. Apart from pion production, the majority of theoretical investigations of meson production processes are performed within phenomenological meson-exchange approaches. Such approaches force us to correlate as many independent processes as possible within a single model, if one is to extract meaningful physics information. Here, we concentrate on our investigation of η meson production in both the photo- and hadro-induced reactions. More specifically, we perform a

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combined analysis of the

$$\begin{aligned}
 \gamma + N &\rightarrow N + \eta, \\
 \pi + N &\rightarrow N + \eta, \\
 N + N &\rightarrow N + N + \eta
 \end{aligned}
 \tag{1}$$

reactions. The photoproduction reaction is calculated by considering the s -, u - and t -channel Feynman diagrams plus the generalized contact terms [1] which ensure the gauge invariance of the total amplitude, in addition to accounting for the final state interaction (FSI) effects [2]. The $\pi + N \rightarrow N + \eta$ reaction is calculated in the tree-level approximation including the s -, u -, and t -channels. To the extent that this reaction is dominated by the excitation of the $S_{11}(1535)$ resonance at least for energies close to threshold, this should be a reasonable approximation if one confine oneself to energies not too far from threshold. For higher energies, effects of the $\pi\pi N$ channel becomes important [3]. The $N + N \rightarrow N + N + \eta$ process is calculated in the DWBA approximation, where both the NN FSI and the initial state interaction (ISI) are taken into account [4]. The NN FSI is known to be responsible for the dominant energy dependence observed in the total cross section apart from that due to the phase space. As for the basic meson production amplitude, our model includes the nucleonic, mesonic and nucleon resonance currents which are derived from relevant effective Lagrangians [1, 4]. The free parameters of our model — the resonance parameters, the $NN\eta$ coupling constant, and the cutoff parameter at the photon vertex in the t -channel meson exchange currents — are fixed such as to reproduce the available data in a global fitting procedure of the three reaction processes listed in (1).

2 Results

In this section we discuss the results of our model calculation according to the procedure outlined above. The calculation is basically the same to that reported in [1] for η' , except that here we consider the production of η and that there is an additional reaction channel, $\pi N \rightarrow N\eta$.

2.1 $\gamma p \rightarrow p\eta$

For photoproduction of η off nucleons the amount of available data is considerable, in particular, for proton target. We have available not only the total and differential cross sections over a wide range of energy starting from

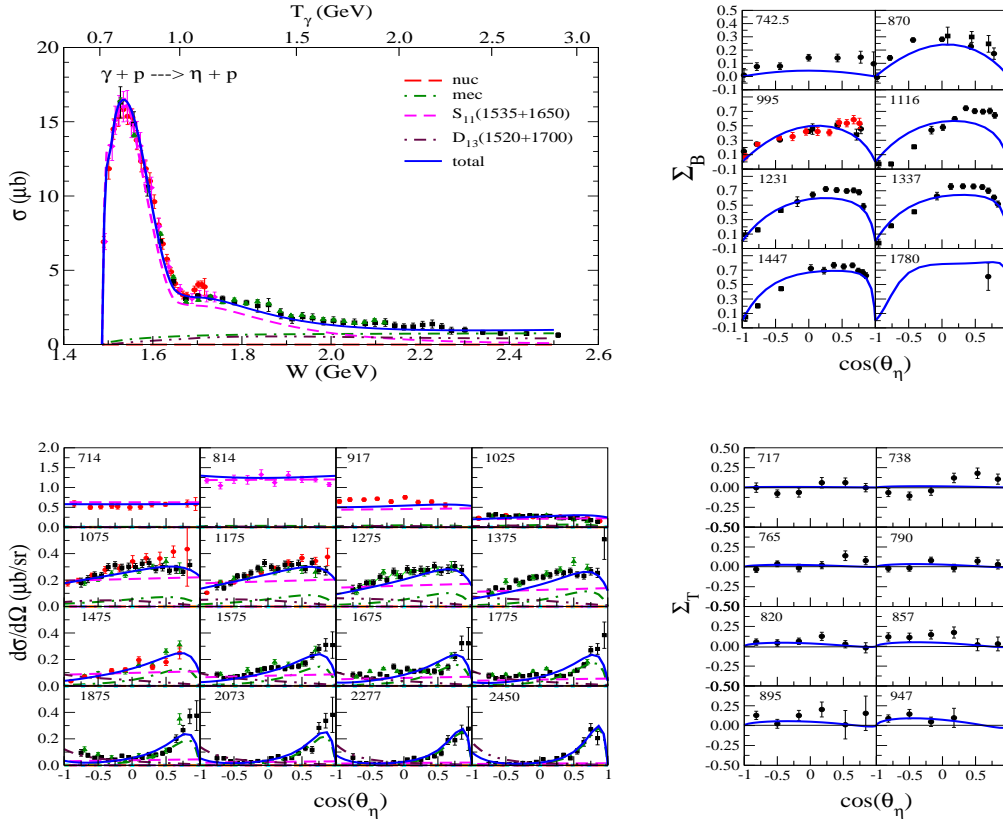


Figure 1: Results for $\gamma p \rightarrow \eta p$. Upper left panel: total cross section as a function of the total energy W of the system. Lower left panel: η angular distribution in the center-of-mass frame. Upper right panel: beam asymmetry, Σ_B . Lower right panel: target asymmetry, Σ_T . The data are from [6].

threshold, but also the beam and target asymmetries. The recent data on neutron target from GRAAL [5] have attracted much interest in this reaction in connection with the possibility of the existence of a narrow (exotic) baryon resonance with mass near 1.68 GeV. Here, we restrict our discussion to the $\gamma p \rightarrow p\eta$ reaction. The results are shown in Fig. 1. As far as the resonance currents are concerned, we follow the strategy adopted in [1] to include the resonances one by one until a reasonable fit is achieved. We found that a reasonable fit quality of $\chi^2/N \approx 3.7$ is achieved by considering the $S_{11}(1535)$, $S_{11}(1650)$, $D_{13}(1520)$, and $D_{13}(1700)$ resonances if only the photoproduction reaction is considered. In a global fit with all the three reaction processes (1) considered, we have $\chi^2/N \approx 5.7$. For the photoproduction process, the inclusion of more resonances did not change the fit quality in any major way.

In particular, we found that no higher spin resonances (D_{15} and F_{15}) were necessary to reproduce the existing data, including the beam asymmetry. However, we were unable to reproduce the measured target asymmetry. This requires a further detailed study. The spin-3/2 resonances are important in reproducing the measured angular distributions in the range of $T_\gamma = 1.07$ – 1.6 GeV and the beam asymmetry. We emphasize that the resonance parameter values in our model are highly correlated with each other and that the existing data are insufficient to establish a unique set of these parameters. The relatively small cross sections measured at higher energies and backward angles constrain the nucleonic current contribution to be very small, so that the $NN\eta$ coupling constant is compatible with zero.

2.2 $\pi^- p \rightarrow n\eta$

As displayed in the upper left panel of Fig. 2, the total cross section for $\pi^- p \rightarrow n\eta$ is nicely reproduced up to $W \approx 1.6$ GeV, where it is dominated by the S_{11} resonances, especially, the $S_{11}(1535)$. We underpredict the measured total cross section at higher energies due to the absence of the $\pi\pi N$ contribution via the coupled channel [3] in our model. The corresponding differential cross section results are shown in the upper right panel of Fig. 2. We note that the model doesn't quite reproduce the structure exhibited by the data at higher energies. The $P_{13}(1720)$ resonance is important in reproducing this structure as illustrated in the lower right panel in Fig. 2.

2.3 $NN \rightarrow NN\eta$

The results for $NN \rightarrow NN\eta$ are shown in Fig. 3. This process is particularly relevant in connection with the role of the ηN FSI. Most of the existing calculations take into account the effects of the NN FSI in one way or another which is well known to influence the energy dependence of the cross section near threshold. Calculations which include the ηN FSI to lowest order reproduce the bulk of the energy dependence exhibited by the data. However, they fail to reproduce the pp invariant mass distribution measured by the COSY-TOF [9] and COSY-11 collaborations [10]. In Ref. [11], it has been emphasized the importance of the three-body nature of the final state in the S -wave in order to account for the observed pp invariant mass distribution. Other authors have suggested an extra energy dependence in the basic production amplitude [12] to reproduce the existing data. Yet another possibility has been offered which is based on a higher partial wave (P -wave) contribution [13]. We observe that all what is required to reproduce the measured pp invariant mass distribution is an extra p'^2 dependence, where

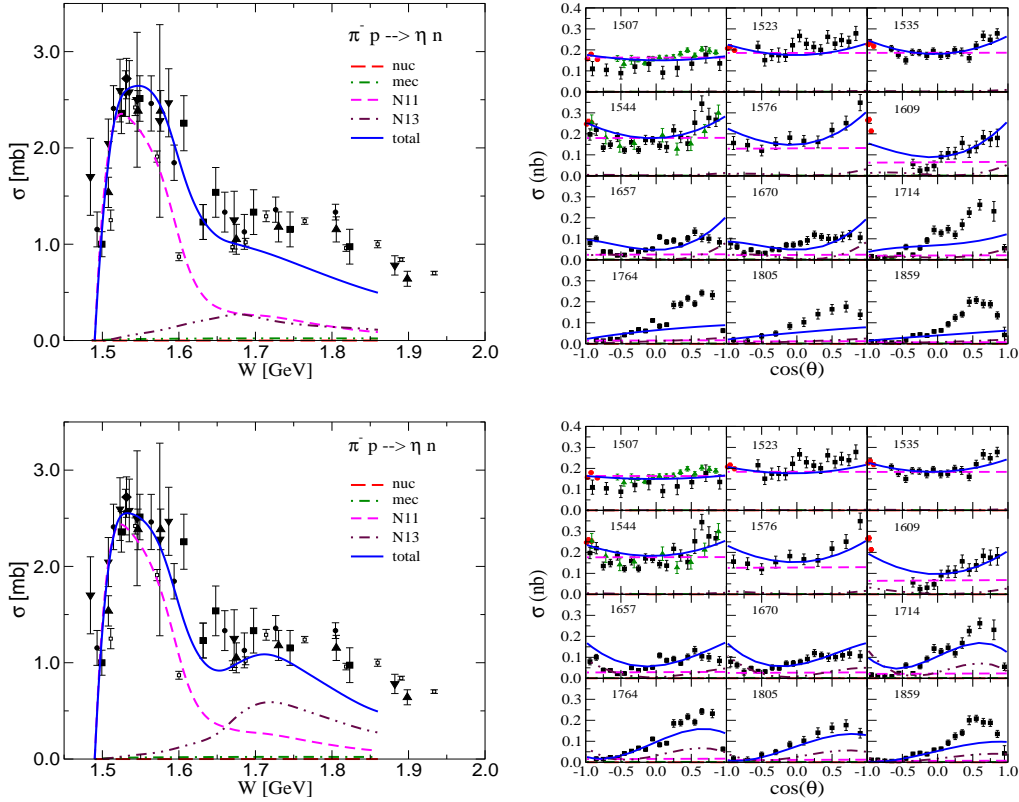


Figure 2: Results for $\pi^- p \rightarrow \eta n$. Upper left panel: total cross section as a function of the total energy of the system W . Upper right panel: η angular distribution in the center-of-mass frame. Here, $N11$ stands for $S_{11}(1535) + S_{11}(1650)$ contribution and $N13 = D_{13}(1520) + D_{13}(1700)$ contribution. Lower panels: same as the upper panels except for the inclusion of the additional $P_{13}(1720)$ resonance, i.e., $N13 = D_{13}(1520) + D_{13}(1700) + P_{13}(1720)$. The data are from [7]

p' denotes the relative momentum of the final pp subsystem. Obviously, this can be achieved either by an S -wave or by a P -wave contribution. Note that the NN P -wave (3P_0) can also yield a flat proton angular distribution as observed in the corresponding data. In any case, as pointed out in Ref. [13], the measurement of the spin correlation functions should help settle the question of the S - versus P -wave contributions in a model-independent way.

Although the model calculation of [13], based on a stronger P -wave contribution, reproduces nicely the shape of the measured pp invariant mass distributions, it underpredicts the total cross section data near threshold

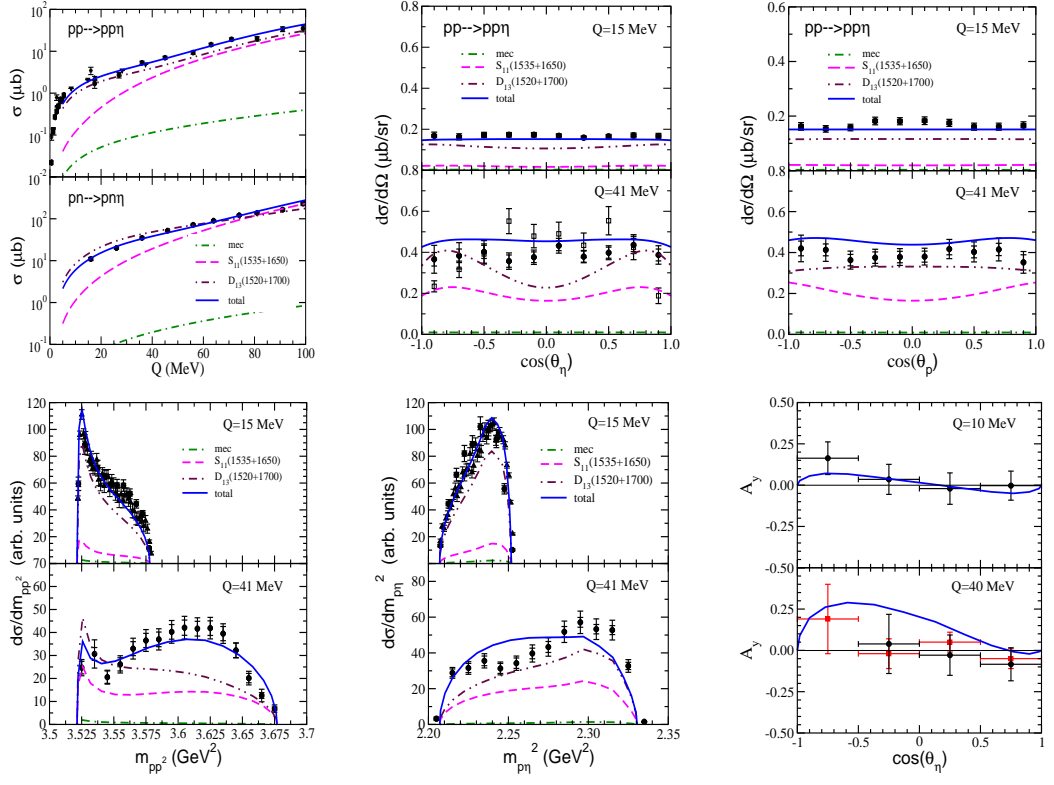


Figure 3: Results for $NN \rightarrow \eta NN$. Upper left panel: total cross section as a functions of the excess energy Q in pp and pn collisions. Upper middle panel: η angular distribution in the overall center-of-mass frame. Upper right panel: final proton angular distribution. Lower left panel: pp invariant mass distribution. Lower middle panel: pn invariant mass distribution. Lower right panel: Analyzing power. The data are from [8–10].

($Q < 30\text{MeV}$). Here we show the new results, based on a combined analysis of the $\gamma p \rightarrow p\eta$, $\pi^- p \rightarrow n\eta$ and $NN \rightarrow NN\eta$ reactions, which reproduce the currently existing data on $NN \rightarrow NN\eta$. The major difference from the previous calculation [13] is a much stronger spin-3/2 resonance contribution. In contrast to the S_{11} resonances, the D_{13} contributions follow more closely the empirically observed energy dependence of the total cross section. It should be emphasized, however, that whether or not the dominance of the D_{13} resonances discussed above is indeed the case still remains to be seen. The reason for this is that, in the present calculation, the coupling constants at the $D_{13}Nv$ vertices ($v = \rho, \omega$) have been fitted to reproduce the $NN\eta$ data. Therefore, the consistency of these coupling constants with

other independent reaction processes involving the $D_{13}Nv$ vertices needs to be checked. For this purpose, processes such as $NN \rightarrow NNv$ and $\gamma N \rightarrow Nv$ are of particular interest.

In Ref. [13], where the dominant η production mechanism is the excitation of the $S_{11}(1535)$ resonance via the pion-exchange, the analyzing power, A_y , exhibits a zero around $\cos(\theta_\eta) = 0$. In the present calculation, where the dominant production mechanism is the D_{13} resonance excitation, the zero of A_y is shifted toward forward angles. Unfortunately, the data are not accurate enough to disentangle these two mechanisms. More accurate data can, therefore, impose more stringent constraints so as to help distinguish the two results.

3 Summary

The progress in the study of meson production processes in NN collisions, both experimentally and theoretically, has reached such a level that it allows us to address certain concrete physics issues, especially, when they are investigated in conjunction with other independent reactions. This has been illustrated here for the specific case of η production where some information on the nucleon resonances may be extracted. In particular, the consideration of meson production processes in NN collisions in conjunction with more basic photo- and (two-body) hadro-induced reactions aiming at a resonance parameters extraction, should help impose more stringent constraints on these extracted parameters. This is especially relevant given the fact that the existing data on meson production (other than pion) in two-body hadronic reactions are rather scarce and of relatively low accuracy. Currently, no facilities are available to improve/extend the corresponding database. On the other hand, the available data on meson production in NN collisions are much more accurate and this database can be and is being expanded especially at the COSY facility.

Acknowledgments

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