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Dynamics of the near threshold η meson production in proton-proton interaction

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Abstract. We present the results of measurements of the analysing power for the $\vec{p}p \to pp\eta$ reaction at the excess energies of Q = 10 and 36 MeV, and interpret these results within the framework of the meson exchange models. The determined values of the analysing power at both excess energies are consistent with zero implying that the η meson is produced predominantly in s-wave.

PACS. 14.40.-n Mesons – 14.40.Aq π, K, and η mesons – 13.60.Le Meson production

1 Introduction

From the precise measurements of the total cross section for the η meson production in the $pp \to pp\eta$ reaction in the close-to-threshold region [1,2,3,4,5,6,7,8] it was concluded [9,10,11,12,13,14,15,16,17] that this process proceeds through the excitation of one of the protons to the $S_{11}(1535)$ state, which subsequently deexcites via the emission of the η meson and a proton. However, there are plenty of possible scenarios of the excitation of $S_{11}(1535)$ resonance. In fact, exchange of any of the π, η, ω, or ρ mesons may contribute to the resonance creation. Considering the cross sections itself doesn't answer the question which out of these mesons give the significant contribution to the production amplitude.

Some constraints may be deduced from the investigations of the isospin dependence of the total cross section for the $NN \to NN\eta$ reaction [18]. The ratio of the total cross sections for the η meson production in proton-neutron collisions to the analogous cross section with proton-proton colliding in the initial state was found to be about 6.5 in the close-to-threshold region, which revealed strong isospin dependence of the production process. This means 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 a factor of 12, suggesting [19] that the isovector meson exchange - the π or ρ meson exchange - is the dominant process leading to the excitation of the S_{11} resonance. However, the relative contributions of the pseudoscalar π meson and vector ρ meson still remain to be determined.

Here, the measurements of the polarization observables can assist, because the predictions of the one boson exchange models [16,17] with respect to the analysing power are sensitive to the type of the exchanged meson.

COSY-11 collaboration performed two measurements of the analysing power function at the beam momenta of p_{beam} = 2.010 GeV/c and 2.085 GeV/c, which for the $\vec{p}p \to pp\eta$ reaction correspond to the excess energies of Q=10 and 36 MeV, respectively. Here we would like to briefly summarize the results of these measurements and present the main conclusions we could have drawn from our studies.

2 Results

In the measurements the COSY-11 detection setup [20, 21,22] has been used, along with the vertically polarized proton beam, which polarization was flipped from cycle to cycle in order to reduce the systematic uncertainties. For the detailed description of the experimental apparatus, method of measurement and analysis, the reader is referred to [23].

The tested predictions of the analysing power of reference [16] were based on the assumption of the ρ meson exchange dominance and the proton asymmetries taken from the photoproduction of the η meson [26]. In the case of the calculations of reference [17] the exchanges of all mesons have been taken into account in the framework of the relativistic meson exchange model of hadronic interactions and it was found in this model that the contribution from the pion exchange is the dominant one.

Fig. 1 shows the experimentally determined values of the analysing power A$_y$ for the $\boldsymbol{pp} \rightarrow pp\eta$ reaction confronted with the theoretical predictions of the pseudoscalar [17] and vector [16] meson exchange dominance models. The χ^2 test of the correctness of these models have been performed and the reduced values of the χ^2 were found to be equal to 0.54 (corresponding to the significance level of $\alpha_{psc} = 0.81$) and 2.76 ($\alpha_{vec} = 0.006$), for pseudoscalar and vector meson exchange dominance models, respectively.

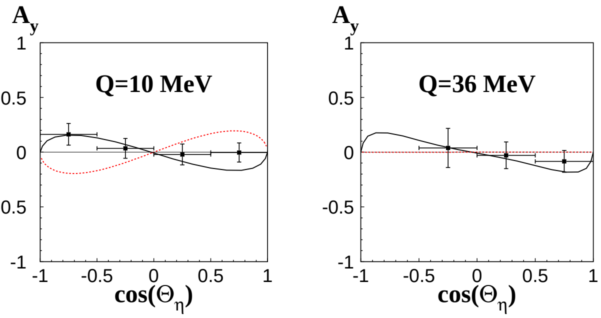

Fig. 1. Analysing power A$_y$ for the $\boldsymbol{pp} \rightarrow pp\eta$ reaction as a function of cosine of the polar angle of the η meson production in the overall center-of-mass system for Q=10 MeV (left panel) and Q=36 MeV (right panel). Full lines are the predictions based on the pseudoscalar meson exchange model [17] whereas the dotted lines represent the calculations based on the vector meson exchange [16]. In the right panel the dotted line is consistent with zero. Shown are the statistical uncertainties.

In the vector meson exchange dominance model [16] the angular distribution of the analysing power is parameterized as a function of the polar angle of η meson production in the center-of-mass system with the following equation:

$$A_y(\theta_\eta) = A_y^{max,vec} \sin 2\theta_\eta, \qquad (1)$$

where the amplitude A$_y^{max,vec}$ is a function of the excess energy Q, shown as a dotted line in the left panel of Fig. 2.

We have estimated the values of A$_y^{max,vec}$ comparing the experimental data with predicted shape utilizing a χ^2 test [23,24,25]. Determined experimental values are shown in Fig. 2 (left) along with the theoretical predictions according to the vector meson exchange dominance model [16]. Analogously, the confrontation of the experimentally determined amplitude A$_y^{max,psc}$ with the predictions of the pseudoscalar meson exchange dominance model [17] are shown in Fig. 2 (right). Predictions of the model based on the π mesons dominance are fairly consistent with the data, whereas the calculations based on the dominance of the ρ meson exchange differ from the data by more than four standard deviations. However, the latter calculation used the proton asymmetry (T) in eta photoproduction [26], within the framework of the vector meson dominance model [27], as the basis of their estimate. It should be noted that it has proved hard to reconcile the experimental value of T with the results of photoproduction amplitude analyses [28].

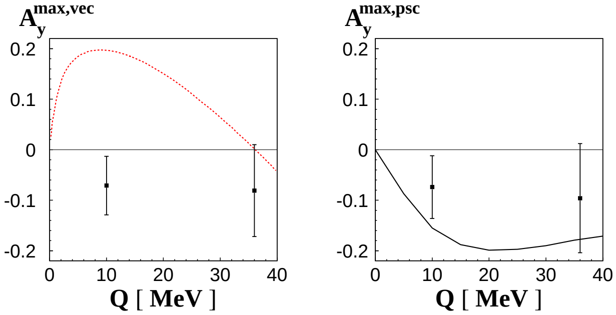

Fig. 2. Theoretical predictions for the energy dependence of the amplitude of A$_y^{max}$ confronted with the amplitudes determined experimentally at the excess energies of Q=10 and 37 MeV for the vector (left) and pseudoscalar (right) meson exchange dominance model.

3 Conclusions and outlook

Taking into account the χ^2 analysis of the analysing power for the pseudoscalar and vector meson exchange models we have shown that the predictions of the pseudoscalar meson exchange dominance [17] are in line with the experimental data at the significance level of 0.81. On the other hand, the assumption that the η meson is produced solely via the exchange of the ρ meson [16], leads to the discrepancy between the theoretical predictions and experimental data larger than four standard deviations. It must be stated, however, that the production amplitude for the ρ meson exchange was determined based on the vector meson dominance hypothesis and the photoproduction data [26]. At this point it is also worth mentioning that the recent calculations of the η meson production in the NN collisions performed in the framework of the effective Lagrangian model [29] also indicate the dominance of the pion exchange.

The analysing power values for both excess energies are consistent with zero within one standard deviation. This is in line with the results obtained by the DISTO [30] collaboration in the far-from-threshold energy region. Such a result may indicate that the η meson is predominantly produced in the s-wave.

4 Future perspectives

Recently, the proposal for the measurement of the analyzing power function [31] with the WASA-at-COSY apparatus [32] has been presented and awaits recommendation of the COSY Programme Advisory Committee. Measurements are planned with about 50 times better statistics which should enable the error bars from Fig. 1 to be reduced of circa 7 times.

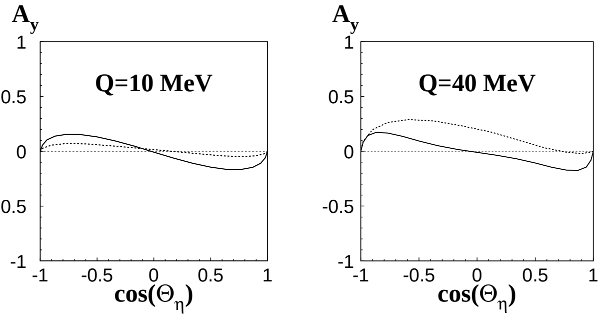

Fig. 3. Predictions of the dependence of the analyzing power function on the intermediate resonance type [33].

Fig. 3 presents the dependence of the analyzing power as a function of the cosine of the polar angle of the η meson emission in the center-of-mass system on the intermediate resonance type [33]. Solid line are the calculations of the pseudoscalar meson exchange model performed under assumption that only $S_{11}(1535)$ resonance contributes to the η meson production amplitude, whereas the dotted line represent the predictions of the same model, including $D_{13}(1520)$, $S_{11}(1535)$, $S_{11}(1650)$, and $D_{13}(1700)$ resonances. Therefore, the improvement in the measurement accuracy would enable to investigate the influence of other-than-$S_{11}(1535)$ resonances upon the production amplitude.

Measurements of the analysing power A_y with much higher statistics may also allow the model independent partial wave decomposition with an accuracy by far better than resulting from the measurements of the distributions of the spin averaged cross sections. This is because the polarization observables can probe the interference terms between various partial amplitudes, even if they are negligible for the spin averaged distributions. More importantly, in case of the $pp \rightarrow ppX$ reaction the interference terms between the transition with odd and even values of the angular momentum of the final state baryons are bound to vanish for the cross sections [34,35]. This characteristic is due to the invariance of all observables under the exchange of identical nucleons in the final state. Due to the same reason there is no interference between *s* and *p*-waves of the η meson in the differential cross sections [35]. However, *s*-*p* interference does not vanish for the proton analysing power, and thus the precise measurements of A_y could provide the first determination of the comparatively small *p*-wave contribution [35], unreachable from spin averaged observables.

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