

Analysis of the η meson production mechanism via the $\vec{p}p \rightarrow pp\eta$ reaction

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Abstract. Polarisation observables constitute a powerful tool for establishing the production mechanism of the η meson and for inferring the presence of higher partial waves in the final system. Measurements of the proton analysing power for the $\vec{p}p \rightarrow pp\eta$ reaction have been performed by the COSY-11 group at three different excess energies: $Q=10, 37$ and 40 MeV. Data at $Q=40$ MeV indicate that the η meson is probably produced in partial waves higher than s wave.

INTRODUCTION

Despite the fact that the discovery of the η meson took place over forty years ago [1], its production mechanism still remains an open question. Based on the close-to-threshold total cross section measurements for the $pp \rightarrow pp\eta$ reaction [2, 3, 4, 5, 6, 7], investigations on differential cross sections for this reaction [8, 9, 10, 11, 12, 13, 14, 15] and recently performed measurements of the proton analysing power for the $\vec{p}p \rightarrow pp\eta$ reaction [16, 17], there is a consensus that in the NN collisions the η meson is produced in a two-step process, where in the first stage exchange of one of the pseudoscalar or vector mesons excites the S_{11} resonance and subsequently this resonance decays into a $N\eta$ pair. The $S_{11}(1535)$ resonance seems to play an important role as an intermediate state since it has a large width covering the threshold energy for the $pp \rightarrow pp\eta$ reaction, and it couples strongly to the $N\eta$ system with a branching ratio corresponding to 30-55 % [18].

Although there exists a variety of models based on different assumptions concerning the mechanism of the η production, these models are in quite good agreement with the existing data on close-to-threshold total cross sections for the $pp \rightarrow pp\eta$ reaction [19]. As it was shown in reference [20], the excitation function for the $pp \rightarrow pp\eta$ process

can be equally well described by the intermediate excitation of the S_{11} via the exchange of either pseudoscalar or vector mesons. This implies that more limitations have to be added to the models in order to extract the way the η meson is really being created. One solution would be the verification of different models by means of the polarisation observables. At present there exist two models that predict the energy dependence of the proton analysing power for the $\bar{p}p \rightarrow pp\eta$ reaction [20, 21]. Theoretical forecasts for the two different excess energies $Q=15$ MeV and $Q=40$ MeV are shown in fig.1. There are significant differences between the models visible in both: the relative sign (at lower Q values) and in the magnitude of the proton analysing power. Measurements of this observable might therefore help to establish the adequacy of mechanisms of η meson production.

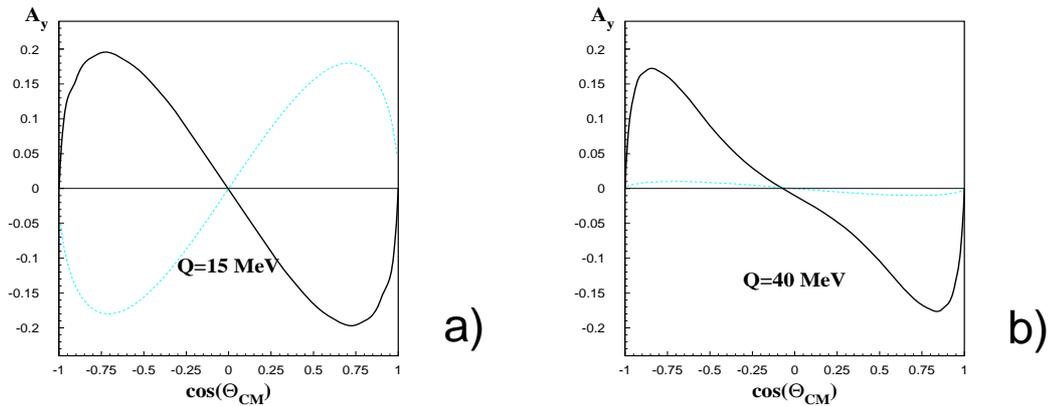


FIGURE 1. Predictions of the angular dependence for proton analysing power at (a) $Q=15$ MeV and (b) $Q=40$ MeV. The solid lines are the predictions of reference [20], whereas the dotted lines represent the calculations according to reference [21]. θ_{CM} is the centre-of-mass polar angle of the η meson.

EXPERIMENTS

There have been, so far, performed three measurements of proton analysing power for the $\bar{p}p \rightarrow pp\eta$ reaction at different excess energies. All these experiments made use of the COSY-11 installation [22], which is an internal detection setup mounted inside the COSY ring¹ [23] in the Research Centre Jülich. Experiments were performed in three separate runs in January '01 (at excess energy $Q=40$ MeV), September '02 ($Q=37$ MeV) and April '03 ($Q=10$ MeV). Data taken during the first run have been analysed and published [16] whereas the data from the two last runs await the full analysis. In the following the results from measurement at the excess energy $Q=40$ MeV will be presented as well as some preliminary estimations for the other runs.

The mentioned COSY-11 detection setup is displayed schematically in fig. 2a. Due to the short lifetime, the η meson cannot be registered in any of the detectors available at COSY-11. Its identification, however, can be performed using the missing mass

¹ Accelerator's name 'COSY' is an acronym of COoler SYnchrotron.

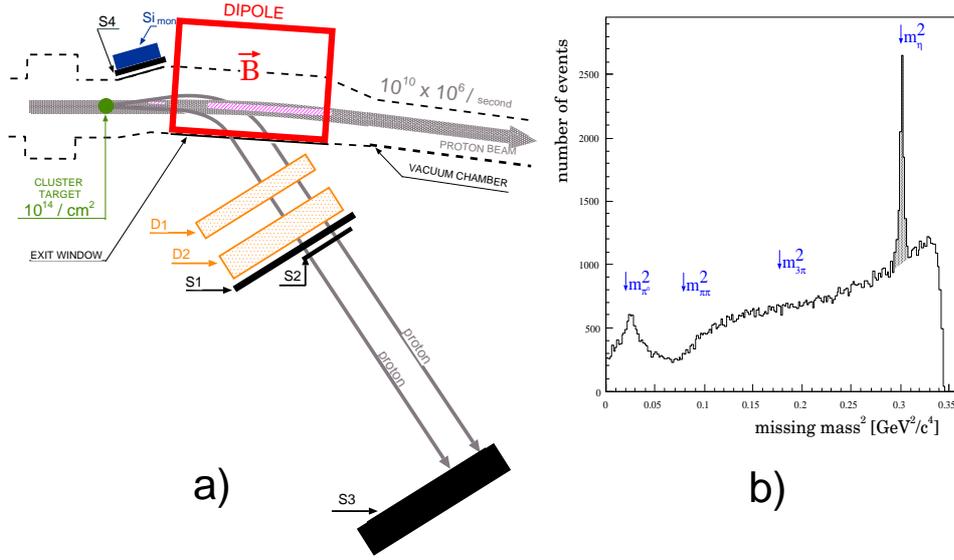


FIGURE 2. (a) Schematic view of the COSY-11 detection setup. D1 and D2 denote the two stacks of drift chambers with 6 and 8 detection planes respectively. S1, S2, S3 and S4 are the scintillator detectors. The time of flight is measured between the S1 scintillator hodoscope and the S3 scintillation wall. Having known the velocity of the particle from the time of flight measurement and the particle’s momentum from the track reconstruction in the magnetic field inside the dipole magnet one is able to reconstruct the particle’s mass. Si_{mon} are the silicon detectors used for the detection of elastically scattered protons. For more details the reader is referred to [22, 24]. (b) Square of the missing mass for events with two protons in the final state. Values indicated by arrows are the literature masses [25] of individual particles or systems of particles. Figure is adapted from [17].

method. Having known the beam and target’s four-momenta, denoted as P_{beam} and P_{target} respectively, and having reconstructed the four-momenta of the two protons in the exit channel (P_1 and P_2), it is possible to determine the square mass of the unregistered particle or system of particles according to the formula:

$$m_X^2 = (P_{beam} + P_{target} - P_1 - P_2)^2. \quad (1)$$

The missing mass spectrum for events with two protons in the exit channel, obtained from the whole measurement at $Q=40$ MeV is shown in figure 2b. A high peak at the value of the η mass square is clearly seen. with about 6000 events inside the peak above the background. The background mainly originates from multi-pion production. The increase of the background in the higher-energy part of the spectrum is a reflection of the increasing acceptance of the detection system in this region. The mass resolution achieved during this measurement was equal to $\sigma_{m_\eta} = 1.6$ MeV/ c^2 .

In order to determine the analysing power² one has at the same time to monitor both the luminosity and the beam polarisation. During the first two measurements we made use of the EDDA experimental setup [26] in order to extract the beam polarisation,

² For detailed calculation of the analysing power, which takes into account the efficiency corrections, the reader is referred to [16].

whereas in the last two runs we monitored the polarisation by means of the COSY internal polarimeter [27] and our own monitoring system, allowing to measure elastically scattered protons in the horizontal and vertical planes.

RESULTS

The analysing power values for the $\bar{p}p \rightarrow pp\eta$ reaction as obtained from the measurement at an excess energy $Q=40$ are presented in figure 3. The range of the η centre-of-mass polar angle has been divided into four bins, with a width of 0.5 in $\cos(\theta_{CM})$. There are about 1000-1500 events in each bin. Figure 3a shows the results of analysis within the framework of the vector meson exchange model [28] for the $\bar{p}p \rightarrow pp\eta$ reaction. The dashed line in this figure represents the η $s + p$ partial wave contribution, the $s + p + d$ waves are represented by the dashed-dotted line, whereas the full model calculations, taking into account also the higher partial waves are shown as a solid line, which is close to the dash-dotted line. It is worth to note that the pure s wave should force A_y to be equal to 0. However, at present level of the measurement's accuracy we are not able to infer any quantitative conclusions.

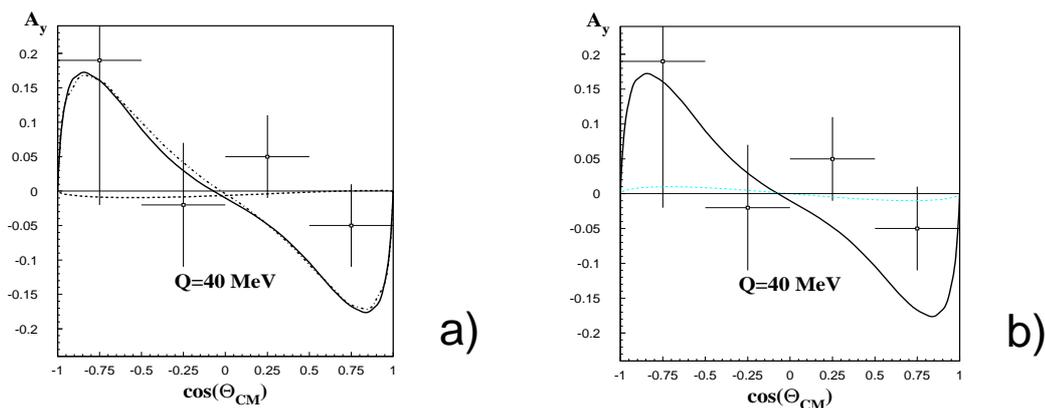


FIGURE 3. (a) Analysing power for the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=40$ MeV. Curves in this figure are adapted from [28]. (b) Comparison of experimental data with predictions of different models. The labelling of curves has been explained in the caption of figure 1.

The interference term between Pp and Ps waves (denoted as G_1^{y0} , where we follow the notation from [29]) as well as the sum of $(Pp)^2$ and $(SsSd)$ interference terms ($H_1^{y0} + I_1^{y0}$) have been calculated and are equal to [16]:

$$G_1^{y0} = (0.003 \pm 0.004) \mu\text{b},$$

$$H_1^{y0} + I_1^{y0} = (-0.005 \pm 0.005) \mu\text{b}.$$

The vanishing value of G_1^{y0} may suggest that there is no interference between Pp and Ps waves in the final state system. Unfortunately, during the first measurement the precision of data was not good enough to disentangle the sum of H_1^{y0} and I_1^{y0} .

OUTLOOK

As can be seen from figure 3b both model predictions lie within 2σ distance from experimental data, therefore at the level of accuracy obtained during the first measurement we are not able to distinguish between two different hypotheses of the η production. Thus further investigations were necessary. During the last two measurements the beam polarisation was increased from about 50% (which was the averaged polarisation during the first run) up to 75-80%. This nice feature, together with the fact that the luminosity integrated over the whole measurement's period was larger by a factor 1.5, should result in about two times better accuracy of the last two measurements. Moreover, the difference between predictions of two mentioned models are the largest at the excess energy $Q=10$ MeV, studied in present experiments, which should additionally help to discriminate one of the reactions models.

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