STUDY OF THE PRODUCTION MECHANISM OF THE $\eta$ MESON
BY MEANS OF ANALYSING POWER MEASUREMENTS

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Information about the production mechanism of the $\eta$ meson in proton-proton collisions
can be inferred by confronting the experimental studies on the analysing power for the $\vec{p}p \to pp\eta$ reaction with the theoretical predictions of this observable. The determined
analysing powers for Q=10 MeV and Q=36 MeV are consistent with zero. Results show
that the predictions of pure pseudoscalar meson exchange model fairly describe the
experimental data, while the predictions of pure vector meson exchange dominance model
disagree with the data at the level of 4.3 $\sigma$.

Keywords: $\eta$ meson; close-to-threshold production; analysing power.

1. Introduction

After a test measurement of the analysing power for the $\vec{p}p \to pp\eta$ reaction at excess
energy Q=40 MeV, two additional measurements at Q=10 and Q=36 MeV have
been done. The experiments have been performed in the Research Center Jülich
(Germany), using the polarised proton beam of the medium-energy storage ring
COSY and a H$_2$ cluster target. For the particle detection the COSY-11 detector
setup has been used. In this experiment the missing mass technique has been
applied in order to identify events in which the $\eta$ mesons have been produced. The
goal of this experiment was to determine the main contribution to the production
mechanism of the $\eta$ meson.

From the near-threshold measurements of the cross sections for the $pp \to pp\eta$
reaction, it was concluded that the production of this meson proceeds via a two-step process, namely the excitation of the S$_{11}$(1535) resonance and its subsequent
Fig. 1. Predictions of the analysing power for the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=10$ MeV as a function of the center-of-mass (CM) polar angle of the $\eta$ meson emission ($\Theta_{CM}$). For the explanations of curves see text.

decay into a proton-$\eta$ pair. There exist, however, many possibilities leading to the excitation of the resonant state of the nucleon in this reaction. The simplest way to answer the question whether the excitation of the $S_{11}(1535)$ proceeds via the exchange of the pseudoscalar- or vector mesons (or exchange of both types of mesons) is the measurement of the analysing power for the $\bar{p}p \rightarrow pp\eta$ reaction. In Figure 1 predictions for two scenarios mentioned above are depicted for the excess energy $Q=10$ MeV.

The solid line in Fig. 1 is a prediction for the pseudoscalar meson exchange model, where the excitation of the $S_{11}(1535)$ resonance is dominated by the exchange of pseudoscalar mesons, whereas the dotted line represents the results of the calculations based on vector meson exchange. Significant differences in the sign and the magnitude of the analysing power predicted basing upon different assumptions show the sensitivity of the analysing power to the production mechanism.

2. Preliminary Results

The experiments have been performed at the beam momenta $p_{beam}=2.010$ and $2.085$ GeV/c, corresponding to the excess energies $Q=10$ and 36 MeV, respectively. Analyzing powers have been determined as functions of the center-of-mass polar angles of the $\eta$ meson emission -- $\Theta_{CM}$. The preliminary results of the data analysis are depicted in Fig. 2.

In order to verify the correctness of the models the reduced $\chi^2$ for both hypotheses have been calculated. In calculations the data point for $Q=36$ MeV and $\cos \Theta_{CM} = -0.75$ has been excluded due to the low statistics and problems with the background evaluation, resulting in large systematical error. The reduced value of the $\chi^2$ for the pseudoscalar meson exchange model was found to be $\chi^2_{pseudoscalar} = 0.68$, which corresponds to the significance level $\alpha_{pseudoscalar} = 0.69$, whereas for the vector meson exchange model $\chi^2_{vector} = 2.85$ resulting in the significance level $\alpha_{vector} = 0.006$. 
Mechanism of the $\eta$ Meson Production

In Ref. 15 the angular distribution of the analysing power is parametrized with the following equation:

$$A_y(\Theta_{CM}) = A_{y}^{max} \sin 2\Theta_{CM},$$

where the amplitude $A_{y}^{max}$ is a function of the excess energy $Q$, and its energy dependence is shown as the solid line in Fig. 3.

Assuming that the predictions of the vector meson exchange model regarding

Fig. 2. Left: Analysing power function for the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=10$ MeV. Right: The same, but for the excess energy $Q=36$ MeV. Vertical bars denote the statistical errors, whereas the horizontal bars are to visualize the ranges of averaging. Full lines are predictions of the pseudoscalar meson exchange model, whereas dotted lines are the predictions of vector meson exchange model. For $Q=36$ MeV prediction of vector meson exchange model is consistent with zero. The size of the vertical axis has been chosen to cover the full range of the allowed values of $A_y$.

Fig. 3. The line denotes the energy dependence of $A_{y}^{max}$ according to the vector meson exchange model. Two points are the experimentally determined values of the $A_{y}^{max}$ for $Q=10$ and 36 MeV.
the shape of the angular dependence of the analysing power are correct, we have estimated the values of \(A_y^{\text{max}}\) comparing the experimental data with the predicted shape utilizing a \(\chi^2\) test. The values of \(A_y^{\text{max}}\) for \(Q=10\) and \(36\) MeV have been determined, and are equal to \(-0.070\pm0.062\) and \(-0.070\pm0.091\), respectively. Results are presented in Fig. 3. The predicted \(A_y^{\text{max}}\) function, is at a distance of 4.3 \(\sigma\) from the data point for \(Q=10\) MeV.

3. Conclusions

Our studies indicate that the predictions of the analysing power within the pure vector meson exchange models can be rejected with significance level of 0.006. On the other hand, predictions of the pseudoscalar meson exchange model, where \(\pi\) meson is the dominant meson in the internuclear exchange are in line with the experimental data with the statistical probability of 69 %. This suggests that the latter scenario is much more probable for the \(\eta\) meson production. However, the interference in the exchange of both types of mesons are not excluded and should be studied theoretically. It is also possible that the mesonic or nucleonic currents contribute to the \(\eta\) meson production more than it has been assumed in both models. Further theoretical analysis of this process is required.

The analysing powers for \(Q=10\) MeV and \(Q=36\) MeV are consistent with zero, within one standard deviation. This may suggest that the \(\eta\) meson is predominantly produced in the \(s\)-wave. This observation is in agreement with the results of the analysing power measurements performed by the DISTO collaboration where, interestingly, in the far-from-threshold energy region the \(A_y\) were found to be consistent with zero within one standard deviation.

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