PRODUCTION OF $\eta$ MESONS IN PROTON-PROTON COLLISIONS CLOSE TO THRESHOLD

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A brief experimental overview on the close-to-threshold $\eta$ meson production in proton-proton interactions is presented and the available observables in measurements with unpolarized and polarized beam and target are discussed.

Keywords: eta, close-to-threshold meson production, eta-N interaction, analysing power.

1. Measured observables

The still not well established production mechanism of the $\eta$ meson as well as its interaction with protons can be investigated via measurements of the following observables available in proton-proton scattering:

1.1. Total cross section

Measurements of the total cross section for the $pp \rightarrow pp\eta$ reaction have been performed at various excess energies in many laboratories worldwide\textsuperscript{1,2,3,4,5}. The existing data, gathered utilizing different experimental techniques are in excellent agreement with each other\textsuperscript{a}. Theoretical considerations of the excitation function led in most cases to the conclusion that close-to-threshold production of the $\eta$ mesons in proton-proton collisions proceeds predominantly via the excitation and deexcitation of the negative parity $S_{11}(1535)$ resonance\textsuperscript{b}. Despite the very good

\textsuperscript{a}Due to limited space we are not presenting here the figure of the excitation function for the $pp \rightarrow pp\eta$ reaction. For an overview picture see for instance Fig. 8a in\textsuperscript{6}.

\textsuperscript{b}For an overview of theoretical models see section 7.3 of\textsuperscript{10} and references therein.
agreement between different theoretical models as far as the leading $\eta$ creation mechanism is concerned, there are a lot of discrepancies when trying to explain which out of the considered exchanged mesons plays the dominant role in the excitation of the $S_{11}$. As it was shown by Nakayama et al.\cite{5}, both pseudoscalar and vector meson exchanges result in equally well descriptions of the excitation function for the $pp \rightarrow pp\eta$ reaction close to threshold.

1.2. Angular distributions

Measurements of the close-to-threshold angular distributions of the $\eta$ meson emission in the centre-of-mass system at excess energies of $Q=15, 15.5, 37, 41$ MeV\cite{8} showed rather flat distributions. It is concluded from these data that in the lower excess energy range the $\eta$ meson is mainly produced in the $s$-wave, while at higher excess energies the influence of the $p$-wave starts to play an important role\cite{9}. The contribution from the $d$-wave seems to be negligible. Also the proton’s angular distributions of the centre-of-mass emission angle\cite{3}\,\cite{4} show an isotropic behaviour.

At $Q=15$ MeV the data indicate dominance of the $^3P_0 \rightarrow ^1S_0 s$ transition distorted slightly by the contribution from the $^1S_0 \rightarrow ^3P_0 s$. At $Q=40$ MeV there is visible an additional presence of the $^1D_2 \rightarrow ^3P_2 s$ transition\cite{9}. Contributions from the other partial waves were found to be of minor importance. In contradiction to these results, the emission plane of the $pp \rightarrow pp\eta$ reaction was found to be anisotropic\cite{10}. This effect has not been explained theoretically yet.

1.3. Invariant mass distributions

The high statistics production of $\eta$ mesons in proton-proton collisions at $Q = 15.5$ MeV allowed to perform a Dalitz plot analysis of the 3-body final state\cite{4}. Surprisingly, beside the clear enhancement seen in the lower range of the invariant mass distribution of the $pp$ subsystem, originating in the strong proton-proton final state interaction, the presence of a wide bump in the upper range of this plot has been observed. Different approaches have been applied in order to explain the origin of this wide bump. Nakayama et. al.\cite{9} described the distribution by introducing $P$-waves in the $pp$ subsystem. This approach, although in agreement with the shapes of both $pp$ and $p\eta$ invariant masses, fails when explaining the shape of the excitation function for the $pp \rightarrow pp\eta$ reaction in the range below $Q=40$ MeV. It is also worth to mention that an indication of such a bump was also seen in the $pp$ invariant mass distribution at $Q=4.5$ MeV\cite{11}, where one expects the presence of $S$-waves only. A three-body calculation performed by Fix and Arenhövel\cite{12} could also describe the bump in the $pp$ invariant mass at $Q=15.5$ MeV well, however it fails in explaining the origin of the peak in the low range of $pp$ invariant mass. It also doesn’t reproduce the shape of the $pp$ invariant mass at $Q=41$ MeV. The $p\eta$ invariant mass distributions were not described in this approach. Solution based on the

\footnote{Which is in line with the result by\cite{11}}
parametrization of the reaction amplitude proposed by Deloff resulted in a good description of the $pp$ and $p\eta$ invariant masses at $Q=15.5$ MeV. However, it fails at $Q=40$ MeV. Another model proposed by the same author, based on a three-particle pair-wise approach via the hyperspherical harmonics, led to a good description of $pp$ and $p\eta$ invariant mass distributions at $Q=15.5$ MeV. Solutions at $Q=40$ MeV as well as the excitation function were not discussed in frame of this model.

1.4. Analysing power

Polarisation observables should provide a more detailed information on the dynamics of the $\eta$ meson creation in hadronic collisions, due to their sensitivity to the interference terms between $Ps$ and $Pp$ waves. The first attempt to measure the proton analysing power for the $\bar{p}p \rightarrow pp\eta$ has been undertaken by the COSY-11 group, with a set of data at $Q=40$ MeV. The data, within their rather large error bars, are consistent with zero, which indicates the absence of higher-than-$s$ partial waves in $\eta$ production at $Q=40$ MeV. The $Ps$ and $Pp$ interference term as well as the sum of the $(Pp)^2$ and $SsSd$ interference terms were extracted in the analysis and are equal to $(0.003 \pm 0.004) \mu$b and $(−0.005 \pm 0.005) \mu$b, respectively. In particular, this may indicate that there is no interference between the $Ps$ and $Pp$ waves. Recently, the DISTO collaboration has obtained the set of $A_y$ data at excess energies far from threshold, which surprisingly also turned out to be consistent with zero within the error bars.

2. Prospectives

Beside the upcoming data from the COSY-11 collaboration for the proton analysing power in the $\bar{p}p \rightarrow pp\eta$ reaction at $Q=10$ and $37$ MeV it was proposed to measure the spin correlation function for the $\bar{p}p \rightarrow pp\eta$ reaction at COSY. The latter would be possible at an external target station at COSY with a frozen spin target. For a high efficiencies in the $pp\eta$ event separation the WASA detector, which will be moved to COSY in the near future, would be at best suited. The spin correlation function is an model-independent direct measure of the contribution of the $3P_0 \rightarrow 1S_0s$ transition in the creation of the $\eta$ meson. Performing this experiment in the range of the excess energies, where the only contributions to the production amplitude are those from the $3P_0 \rightarrow 1S_0s$ and $1S_0 \rightarrow 3P_0s$ transitions, one will be able to extract contributions from the both transitions in this excess energy range.

\[\text{d} \text{Status of the analysis will be reported in}^{[16]} \]

\[\text{e} \text{Theoretical predictions for the } C_{xx} \text{ values are given for instance in}^{[9,11]} \]
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