

PRODUCTION OF η MESONS IN PROTON-PROTON COLLISIONS CLOSE TO THRESHOLD

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A brief experimental overview on the close-to-threshold η 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 η 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 ^{1,2,3,4,5}. The existing data, gathered utilizing different experimental techniques are in excellent agreement with each other ^a. Theoretical considerations of the excitation function led in most cases to the conclusion that close-to-threshold production of the η mesons in proton-proton collisions proceeds predominantly via the excitation and deexcitation of the negative parity $S_{11}(1535)$ resonance ^b. Despite the very good

^aDue 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 ⁶

^bFor an overview of theoretical models see section 7.3 of ¹⁰ and references therein.

agreement between different theoretical models as far as the leading η 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.⁸, 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 η meson emission in the centre-of-mass system at excess energies of $Q=15$ ³, 15.5 ⁴, 37 ², and 41 MeV³ showed rather flat distributions. It is concluded from these data that in the lower excess energy range the η meson is mainly produced in the s -wave, while at higher excess energies the influence of the p -wave starts to play an important role⁹. The contribution from the d -wave seems to be negligible. Also the proton's angular distributions of the centre-of-mass emission angle^{3,4} show an isotropic behaviour. At $Q=15$ MeV the data indicate dominance of the ${}^3P_0 \rightarrow {}^1S_0s$ transition distorted slightly by the contribution from the ${}^1S_0 \rightarrow {}^3P_0s$. At $Q=40$ MeV there is visible an additional presence of the ${}^1D_2 \rightarrow {}^3P_2s$ transition⁹. 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^{4 c}. This effect has not been explained theoretically yet.

1.3. Invariant mass distributions

The high statistics production of η mesons in proton-proton collisions at $Q = 15.5$ MeV allowed to perform a Dalitz plot analysis of the 3-body final state⁴. 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.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 $Q=4.5$ MeV⁴, where one expects the presence of S -waves only. A three-body calculation performed by Fix and Arenhövel¹² 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

^cWhich is in line with the result by¹¹

parametrization of the reaction amplitude proposed by Deloff¹³ 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 harmonics¹⁴, 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 η 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 $Q=40$ MeV¹⁵. The data, within their rather large error bars, are consistent with zero, which indicates the absence of higher-than- s partial waves in η 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 $(0.003 \pm 0.004)\mu\text{b}$ and $(-0.005 \pm 0.005)\mu\text{b}$, 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 bars⁵.

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^d it was proposed to measure the spin correlation function^e for the $\bar{p}\bar{p} \rightarrow pp\eta$ reaction at COSY¹⁸. 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 detector¹⁹, 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 η meson^{9,10}. 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.

^dStatus of the analysis will be reported in¹⁶.

^eTheoretical predictions for the C_{xx} values are given for instance in^{9,17}.

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