International Journal of Modern Physics A

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

R. CZYŻYKIEWICZ[α,β], H-H. ADAM[γ], A. BUDZANOWSKI[δ], D. GRZONKA[β], M. JANUSZ[α], L. JARCZYK[α], B. KAMYS[α], A. KHOUKAZ[γ], K. KILIAN[β], P. KLAJA[α], P. KOWINA[ε], P. MOSKAL[α,β], W. OELERT[β], C. PISKOR-IGNATOWICZ[α], J. PRZERWA[α], T. ROŻEK[β,ζ], R. SANTO[γ], T. SEFZICK[β], M. SIEMASZKO[ζ], J. SMYRSKI[α], A. TÄSCHNER[γ], P. WINTER[β], M. WOLKE[β,η], P. WÜSTNER[θ], W. ZIPPER[ζ]

[α]*Institute of Physics, Jagellonian University, Cracow, PL-30-059, Poland*
[β]*IKP, Forschungszentrum Jülich, Jülich, D-52425, Germany*
[γ]*IKP, Westfälische Wilhelms-Universität, Münster, D-48149, Germany*
[δ]*Institute of Nuclear Physics, Cracow, PL-31-342, Poland*
[ε] *Accelerator Division, Gesellschaft für Schwerionenforschung, Darmstadt, D-64291, Germany*
[ζ]*Institute of Physics, University of Silesia, Katowice, PL-40-007, Poland*
[η]*Svedberg Laboratory, Uppsala, S-75121, Sweden*
[θ]*ZEL, Forschungszentrum Jülich, Jülich, D-52425, Germany*

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 $pp \to pp\eta$ 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 agreement between different theoretical models as far as the

[a]Due to limited space we are not presenting here the figure of the excitation function for the $pp \to pp\eta$ reaction. For an overview picture see for instance Fig. 8a in [6]
[b]For an overview of theoretical models see section 7.3 of [8] and references therein.

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. [9], both pseudoscalar and vector meson exchanges result in equally well descriptions of the excitation function for the $pp \to pp\eta$ 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 MeV [3] 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 role [10]. 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 $^3P_0 \to ^1S_0s$ transition distorted slightly by the contribution from the $^1S_0 \to ^3P_0s$. At Q=40 MeV there is visible an additional presence of the $^1D_2 \to ^3P_2s$ transition [10]. Contributions from the other partial waves were found to be of minor importance. In contradiction to these results, the emission plane of the $pp \to pp\eta$ 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 state [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. [10] 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 $pp \to pp\eta$ 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 [4], where one expects the presence of *S*-waves only. A three-body calculation performed by Fix and Arenhövel [12] could also describe the bump in the *pp* invariant mass at Q=15.5 MeV well, however it fails in explaning 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 parametrization of the reaction amplitude proposed by Deloff [13] 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,

[c] Which is in line with the result by [11]

based on a three-particle pair-wise approach via the hyperspherical harmonics [14], 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 $\vec{p}p \to pp\eta$ has been undertaken by the COSY-11 group, with a set of data at Q=40 MeV [15]. 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 $(0.003 \pm 0.004)\mu$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 [5].

2. Prospectives

Beside the upcoming data from the COSY-11 collaboration for the proton analysing power in the $\vec{p}p \to pp\eta$ reaction at Q=10 and 37 MeV [d] it was proposed to measure the spin correlation function [e] for the $\vec{p}\vec{p} \to pp\eta$ reaction at COSY [18]. 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 [19], 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 $^3P_0 \to ^1S_0s$ transition in the creation of the η meson. Performing this experiment in the range of the excess energies, where the only contributions to the production amplitude are those from the $^3P_0 \to ^1S_0s$ and $^1S_0 \to ^3P_0s$ transitions, one will be able to exctract contributions from the both transitions in this excess energy range.

Acknowledgments

The work has been supported by the European Community - Access to Research Infrastructure action of the Improving Human Potential Programme, by the DAAD Exchange Programme (PPP-Polen), by the Polish State Committe for Scientific Research (grants No. 2P03B07123 and PB1060/P03/2004/26), and by the Research Centre Jülich.

[d] Status of the analysis will be reported in [16].
[e] Theoretical predictions for the C_{xx} values are given for instance in [10,17].

References

1. E. Chiavassa et al., *Phys. Lett.* **B322**, 270 (1994); H. Calén et al., *Phys. Lett.* **B366**, 39 (1996); H. Calén et al., *Phys. Rev. Lett.* **79**, 2642 (1997); F. Hibou et al., *Phys. Lett.* **B438**, 41 (1998); H. Calén et al., *Phys. Rev. C* **58**, 2667 (1998); J Smyrski et al., *Phys. Lett.* **B474**, 180 (2000).
2. H. Calén et al., *Phys. Lett.* **B458** 190 (1999).
3. M. Abdel-Bary et al., *Eur. Phys. J.* **A16** 127 (2003).
4. P. Moskal et al., *Phys. Rev. C* **69**, 025203 (2004).
5. F. Balestra et al., *Phys. Rev. C* **69**, 064003 (2004).
6. P. Moskal et al., *Prog. Part. Nucl. Phys.* **49**, 1 (2002).
7. C. Caso et al., *Eur. Phys. J.* **C3** 1 (1998).
8. C. Hanhart et al., *Phys. Rep.* **397** 155 (2004).
9. K. Nakayama et al., *Phys. Rev. C* **65** 045210 (2002).
10. K. Nakayama et al., *Phys. Rev. C* **68**, 045201 (2003).
11. E. Roderburg et al., *Acta Phys. Pol.* **B31** 2299 (2000).
12. A. Fix and H. Arenhövel, *Phys. Rev. C* **69**, 014001 (2004).
13. A. Deloff, *Phys. Rev. C* **69**, 035206 (2004).
14. A. Deloff, nucl-th/0406069.
15. P. Winter et al., *Phys. Lett.* **B544**, 251 (2002); Erratum-ibid **B553**, 339 (2003).
16. R. Czyżykiewicz et al., Contribution to the COSY-11 Extended Meeting (to be published in Schriften des FZ-Jülich, 2004).
17. M.P. Rekalo et al., *Phys. Rev. C* **55**, 2630 (1997).
18. P. Winter, R. Czyżykiewicz et al., nucl-ex/0406034.
19. J. Zabierowski et al., *Phys. Scripta* **T99**, 159 (2002).