AIP Conference Proceedings

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Cite as: AIP Conference Proceedings **950**, 268 (2007); https://doi.org/10.1063/1.2819047

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Dynamics of the η meson production in proton-proton collisions

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Abstract. We briefly describe the present knowledge about the mechanism of the η meson production in the collisions of nucleons. We stress the role of the spin degrees of freedom and discuss a possibility of investigations of the spin observables for the $\vec{p}p \to pp\eta$ reaction using the WASA-at-COSY apparatus and the vertically polarized proton beam of COSY.

Keywords: Analysing power, Madison convention, Meson production, WASA-at-COSY
PACS: 24.10.-i, 24.10.Lx, 25.75.Dw

INTRODUCTION

In the low energy regime of the Quantum Chromodynamics, the interaction between quarks and gluons cannot be treated perturbatively and so far the understanding of the processes governed by the strong forces is unsatisfactory. Therefore, it is essential to carry out measurements involving the production and decay of hadrons and to interpret them in the framework of the effective field theory. Here we would like to concentrate on the production of the η meson, the basic pseudoscalar meson with isospin equal zero. We will discuss briefly η production in the framework of the meson exchange model which is presently the only theoretical approach for the production of mesons heavier than the pion.

DYNAMICS OF THE $pp \to pp\eta$ REACTION

A precise data set [1, 2, 3, 4, 5, 6, 7, 8] on the total cross section of the η meson production in the $pp \to pp\eta$ reaction allowed to conclude that the reaction proceeds through the excitation of one of the protons to the $S_{11}(1535)$ state which subsequently deexcites via emission of the η meson. The crucial observations were a large value of the absolute cross section (forty times larger than for the η' meson) and isotropic distributions [7, 9] of the angle of the η meson emission in the reaction center-of-mass system. More constraints to the theoretical models [10, 11, 12, 13, 14, 15, 16, 17] have been deduced from determination of the dependence of the η meson production on the isospin of the colliding nucleons [18]. The experiments performed by the WASA/PROMICE collaboration [18] revealed a strong isospin dependence. All together, the confrontation of predictions based upon different scenarios, involving exchanges of various mesons, with

CP950, *Meson Physics at COSY-11 and WASA-at-COSY,* edited by A. Kupść, P. Moskal, and M. Wolke

the so far determined unpolarised observables and with the first results on the analysing power indicate the dominance of the exchange of the π meson in the production process [19, 21]. This conclusion is in line with the predictions of Nakayama et al. [15] and also recent calculations of Shyam [22]. Yet, the implications seem to be contra-intuitive due to the very large momentum transfer, between the interacting nucleons, needed to create the η meson near threshold. A poor data base of the polarisation observables allows however only for the qualitative conclusions and in order to establish quantitatively contributions from various production processes and to determine possible interference terms more precise measurments of the spin observables are needed.

Independently of the theoretical framework used, for an unambiguous understanding of the production process relative magnitudes from the partial waves contributions must be well established. The measurement of the analysing power would enable to perform the partial wave decomposition with an accuracy by far better than resulting from the measurements of the distributions of the spin averaged cross sections. This is because the polarisation observables can probe the interference terms between various partial amplitudes, even if they are negligible for the spin averaged distributions. More importantly, in case of the $pp \rightarrow ppX$ reaction, as pointed out in reference [23, 24], the interference terms between the transitions with odd and even values of the angular momentum of the final state baryons are bound to vanish for the cross sections. This characteristic is due to the invariance of all observables under the exchange of identical nucleons in the final state. Due to the same reason there is no interference between s and p-waves of the η meson in the differential cross sections [24]. However, s-p interference does not vanish for the proton analysing power, and thus the precise measurements of A_y could provide the first indications of the comparatively small p-wave contribution [24], unreachable from the spin averaged observables.

ANALYSING POWER

Analysing power (A_y) one can understand as a measure of the relative deviation between the differential cross sections for the experiments with and without polarized beam normalized to the beam polarization P:

$$A_y = \frac{1}{Pcos\phi} \frac{\sigma(\xi) - \sigma_0(\xi)}{\sigma_0(\xi)}, \tag{1}$$

where ξ denotes a set of independent kinematical variables defining uniquely the reaction. For the determination of the analysing power e.g. of the η meson at a given value of the polar angle θ_η it is required to measure a left-right asymmetry of yields of the η meson in any plane turned by the angle ϕ with respect to the laboratory coordinate system. Thus, A_y can be determined from the measurement of the appropriate yield asymmetries according to the following formula:

$$A_y(\theta) = \frac{1}{Pcos\phi} \frac{N_+(\theta,\phi) - N_-(\theta,\phi)}{N_+(\theta,\phi) + N_-(\theta,\phi)} \tag{2}$$

The signs of the yields must be defined according to the Madison convention [25] which tells that if the vector product of the beam and particle momenta is parallel to the polarisation vector, then the yield is taken with the positive sign (N_+) and correspondingly with negative sign (N_-) if this is antiparallel. Thus, depending of the direction of the polarisation vector the particles scattered to the left and to the right will be counted with different sings as it is schematiclally depicted in figure 1.

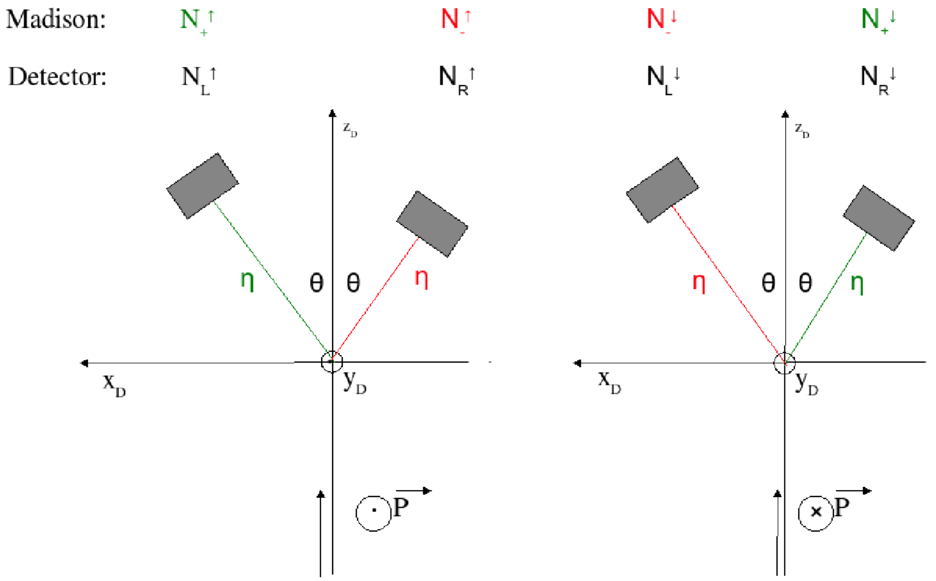

FIGURE 1. Schematic description of the Madison convention.

STUDIES OF A_y WITH THE WASA-AT-COSY DETECTOR

For the measurements of the beam analysing power of the $\vec{p}p \to pp\eta$ reaction we plan to use the WASA-at-COSY experimental setup [26] working as an internal target facility at the cooler synchrotron COSY [27, 28]. A vertically polarised proton beam [29], will be stored and accelerated in the COSY ring. The direction of the polarisation will be flipped from cycle to cycle. The beam of hydrogen pellets cross the circulating COSY beam in the center of the WASA detector. Protons from the $pp \to pp\eta$ or $pp \to pp\pi\pi$ reactions are registered in the Forward Detector and the photons from η and pion decays are detected in the electromagnetic calorimeter. For the identification of the η meson both the invariant mass of the decay products and the missing mass to the outgoing protons is used.

The large acceptance of the WASA detector allows for the determination of the asymmetry of the η meson production as a function of the polar and the azimuthal angle. Figure 2 demonstrates that whole angular range is covered even at excess energies far from the threshold.

The axial symmetry of the setup together with the possibility of flipping the spin directions of the COSY beam allows to reduce significantly systematical uncertainties

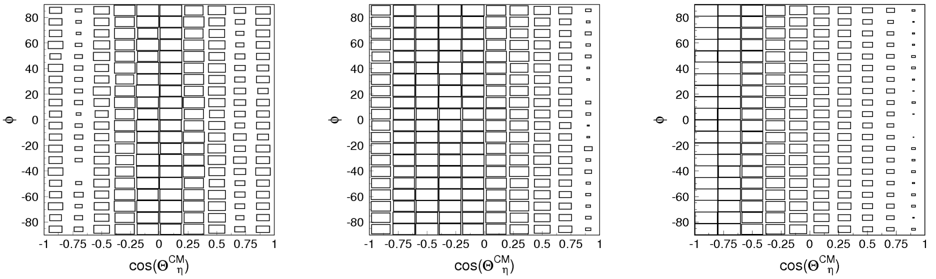

FIGURE 2. Geometrical acceptance for $pp \rightarrow pp\eta$ reaction. From left to right: angular coverage of the WASA detector for excess energies 10 MeV, 50 MeV and 100 MeV.

in comparison to the previous measurements [21]. For example, in order to diminish the influence of the systematical errors of the acceptance and the detection efficiency the asymmetry is determined as a geometrical mean of the yields for the both spin orientations and is corrected for the corresponding luminosities:

$$N_- = \sqrt{\frac{N^{\uparrow}{}_R}{\varepsilon_R L^{\uparrow}} \frac{N^{\downarrow}{}_L}{\varepsilon_L L^{\downarrow}}}, \quad N_+ = \sqrt{\frac{N^{\uparrow}{}_L}{\varepsilon_L L^{\uparrow}} \frac{N^{\downarrow}{}_R}{\varepsilon_R L^{\downarrow}}} \tag{3}$$

The production yields N_L and N_R will be extracted from the pp missing mass spectra reconstructed for each of the studied angular bins separately. Substituting equations 3 into formula 2 one obtains a relation for the analysing power which is free of the uncertainty due to the estimate of the luminosity and the efficiencies.

Determination of the beam polarisation and the control of the systematics is achieved by measurement of the asymmetries for elastically scattered protons since the precise values of the analysing powers are available [31]. The accuracy of these results of 1.2% will allow to control the systematic error of the polarisation determination to about 1%.

ACKNOWLEDGMENTS

We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 programme (Hadron Physics, N4:EtaMesonNet, RII3-CT-2004-506078), the support of the Polish Ministry of Science and Higher Education under the grants No. PB1060/P03/2004/26, 3240/H03/2006/31 and 1202/DFG/2007/03, and the support of the German Research Foundation (DFG).

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