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STUDY OF THE η-MESON PRODUCTION WITH POLARIZED PROTON BEAM*

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The $pp \to pp\eta$ reaction was investigated at excess energies of 15 MeV and 72 MeV using the azimuthally symmetric WASA detector and a polarized proton beam of the Cooler Synchrotron COSY. The aim of the studies is the determination of partial wave contributions to the production process of the η meson in nucleon–nucleon collisions. Here, we present preliminary results of the extraction of the position of the interaction region with respect to the WASA detector and preliminary results on the degree of polarization of the COSY proton beam used in the experiment.

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1. Introduction

In spite of the number of both experimental [1–13] and theoretical [14–22] studies performed so far for measurements of total and differential cross sections for the η-meson production in nucleon–nucleon collisions, the proton–η interaction as well as the mechanism of the η-meson production have not been fully elucidated yet. From the above cited measurements of the η-meson production in pp and pn reactions, we learned that the production occurs predominantly via the $N(1535)$ resonance and that the proton–η interaction is much larger than in the case of proton–π^0 and proton–η' interactions [23, 24]. The knowledge of the η- and η'-meson interaction with nucle-

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ons is crucial for the search of the mesic nuclei which is recently carried out in many laboratories, *e.g.* COSY [25–28], ELSA [29], GSI [30], JINR [31], JPARC [32], LPI [33], and MAMI [34] with the increasing theoretical support *e.g.* [35–46]. Previous studies of the η-meson production in collisions of nucleons revealed that even in the close-to-threshold region higher partial waves and other baryon resonances may contribute to the production mechanism. Moreover, the indication of the contribution of higher partial waves near threshold comes also from the comparison of the invariant mass distribution from the production of $pp\eta$ and $pp\eta'$ systems [47]. Therefore, for an unambiguous understanding of the production process relative magnitudes from the partial wave contributions must be well established. This may be at least to some extent achieved by the measurement of the analyzing power A_y which 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. Up to now, measurements of the analyzing power for the $\vec{p}p \to pp\eta$ reaction were performed by the COSY-11 and DISTO collaborations [48–51]. Due to the lack of statistics and small detector acceptance (in the case of COSY-11 [52, 53]) these first measurements did not allow for unambiguous conclusions about the production mechanisms. Therefore, a high statistics measurement was made with the large acceptance ($\sim 4\pi$) symmetric WASA detector [54]. The experiment was conducted for beam momenta of 2026 MeV/c and 2188 MeV/c [55] which correspond to excess energies of 15 MeV and 72 MeV, respectively. To monitor the degree of polarization, the luminosity and the detector performance, simultaneously the $\vec{p}p \to pp$ reaction was measured. In order to control effects caused by the potential asymmetries in the detector setup, the spin direction of the proton beam was flipped from cycle to cycle.

In the next sections, we briefly describe the experiment and remind the conclusions drawn from simulations studies performed so far [56] and after that we present preliminary results from the studies of the degree of polarization of the proton beam used in the experiment.

2. Studies of A_y with the WASA-at-COSY detector

The axially symmetric WASA detector and the vertically polarized proton beam of COSY have been used to collect a high statistics sample of $\vec{p}p \to pp\eta$ reactions in order to determine the analyzing power as a function of the invariant mass spectra of the two particle subsystems, and as a function of the emission angle of the η meson [57].

For the monitoring of degree of polarization, simultaneously to the $\vec{p}p \to pp\eta$ reaction, the proton–proton elastic scattering reaction has been measured. The estimation of systematic uncertainties of the determination of the degree of polarization of the beam is presented in [56]. Performed analyses revealed that to reach a systematic uncertainty of the polarization smaller than 3%, the position of the center of the interaction region has to be controlled with a precision better than 1 mm. The large statistics of collected data and utilization of methods of vertex reconstruction shown in [56, 58], allowed us to determine the average vertex position with the precision much better than 1 mm. Furthermore, conducted studies show that the beam tilted within the maximum allowed range should have no significant influence on the obtained degree of polarization [56].

2.1. Extraction of the average vertex positions from the experimental data

To find the position of the vertex (v_x, v_y, v_z) in the experiment, methods described in [56, 58] have been applied. The first utilized method is based on the angular dependence of the coplanarity of incoming and outgoing protons, which is defined as

$$C = \frac{(\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_{\text{beam}}}{|\vec{p}_1 \times \vec{p}_2| \cdot |\vec{p}_{\text{beam}}|}\,, \tag{1}$$

where $\vec{p}_1$ and $\vec{p}_2$ corresponds to momentum vectors of scattered protons, and $\vec{p}_{\text{beam}}$ is the beam momentum vector. In order to find the center of the interaction region, coplanarity distributions as a function of ϕ angle simulated with different vertex positions are compared with the experimental one using the χ^2 statistics. For each $C(\phi)$ spectrum, a χ^2 value is calculated according to

$$\chi^2 = \sum_i \frac{\left(M_i^{\text{MC}} - M_i^{\text{exp}}\right)^2}{\left(\sigma_i^{\text{exp}}\right)^2}\,, \tag{2}$$

where i indicates the chosen ϕ range, the M_i^{MC} and M_i^{exp} are the mean values of the coplanarities in a given ϕ range, and σ_i^{exp} is the error of M_i^{exp}. The corresponding distributions of the vertex shift for a given coordinate as a function of time (for twenty exemplary runs) are shown in Fig. 1. Analyses were performed for both data sets: with polarized beam (upper left) and unpolarized beam (upper right).

The second method is based on utilization of the $d(\phi_d)$ distributions as shown in [56]. The resulting experimental spectra of position of a given coordinate as function of time (run number) are shown in Fig. 1 in the lower row (left and right). One can see that for the data with polarized beam, the vertex position is relatively stable with time, however for the data sample collected with unpolarized beam some fluctuations are observed. Nevertheless, both methods give results for v_x and v_y coordinates that differ on the average only by about 0.04 cm. Thus, we may conclude that at the present stage of experimental data analysis, the systematic uncertainty of the determination of the position of the interaction region is equal to about ±0.2 mm which corresponds to an uncertainty of the polarization determination of less than ±1% (see figures in [56]).

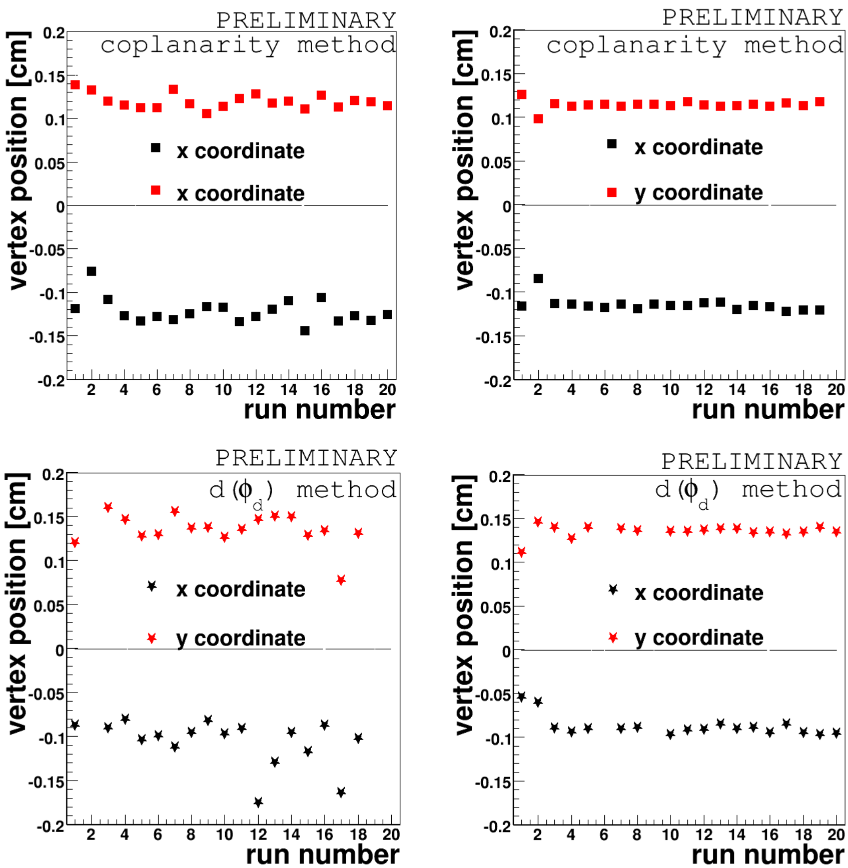

Fig. 1. Distributions of the shift from the nominal value of a given coordinate of the center of the interaction region as a function of time (run number). Plots were made for data collected with an unpolarized beam (left column) and with a polarized beam (right column). The results obtained using the coplanarity method are shown in the upper row. In the lower row, the results obtained using the $d(\phi_d)$-method [56] are presented.

2.2. Extraction of the degree of polarization from experimental data

The method of polarization determination is described in detail in [56]. Therefore, for the sake of completeness, we only briefly recall that the polarization P is extracted by fitting the experimental distributions with the function [56]

$$\epsilon(\theta,\phi) = P(\theta)\, A_y(\theta)\, \cos(\phi)\,, \tag{3}$$

where the asymmetry

$$\epsilon(\theta,\phi) = \frac{N(\theta,\phi) - N(\theta,\phi+\pi)}{N(\theta,\phi) + N(\theta,\phi+\pi)} \tag{4}$$

is calculated separately for each spin orientation of polarized protons, in two ranges of proton scattering angles of 30°–34° and 34°–38°. To obtain A_y at a desired beam momentum and to estimate a systematic uncertainty of this determination, two different functions are fitted to the momentum dependence of A_y measured by the EDDA Collaboration [59] in these angular ranges. The plots used for the extraction are shown in Fig. 2. As a result, two polarizations are extracted for two ranges of the center-of-mass polar angle of the forward scattered proton, and a weighted mean is used as a final polarization for a given spin orientation [56].

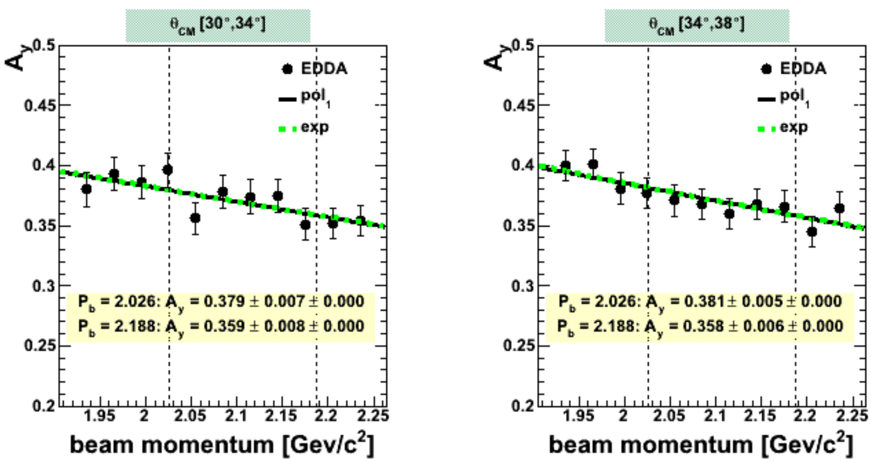

Fig. 2. The $A_y(\theta_{\rm CM}, p_{\rm beam})$ distributions obtained by the EDDA Collaboration. Data points are shown as filled circles. Fitted functions are described in the legend. Dashed horizontal lines mark the two beam momenta for which WASA data were taken. For both beam momenta, evaluated analyzing powers are shown with the statistical and systematic errors respectively.

The polarization for twenty runs (about 5% of data) is shown in Fig. 3. In the left panel, the polarization obtained from data collected with an unpolarized beam is presented and, therefore, should be consistent with zero. In the right panel, the results obtained from the analysis of data gathered with polarized beam are shown. The polarization was calculated for both orientations of proton spin separately. Data points shown in Fig. 3 have been corrected for acceptance determined using the vertex position extracted from the experimental data. For comparison, also the result assuming a nominal center of the vertex region $(v_x, v_y, v_z) = (0, 0, 0)$ is plotted.

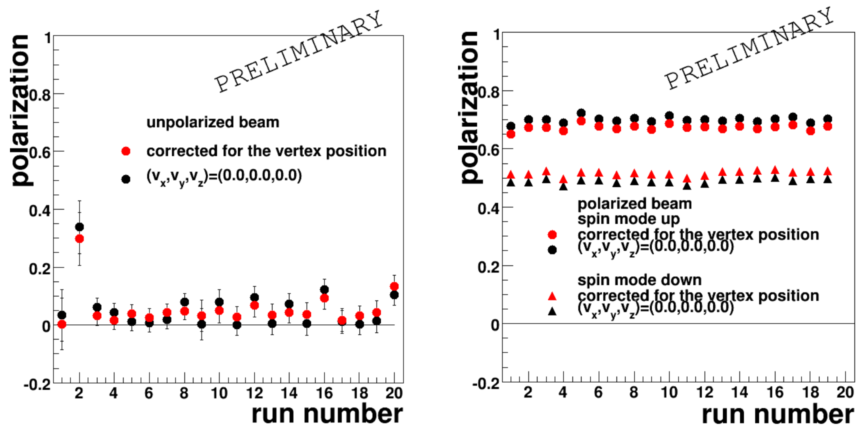

Fig. 3. Distributions of polarization as a function of run number for unpolarized (left) and polarized (right) data (taken at a beam momentum of $p_{\rm beam}$ = 2026 MeV/c). Data points have been acceptance corrected using the default vertex position at $(v_x, v_y, v_z) = (0, 0, 0)$ (black marker) and the vertex position established based on the experimental data (gray/red marker). Results for both polarization modes of the beam particles are shown.

3. Summary

Preliminary results of the extraction of the v_x and v_y coordinates of the center of the interaction region have been shown. At the present stage of analysis, the systematic uncertainty in the determination of the position of the interaction region is equal to about ± 0.2 mm which corresponds to an uncertainty of the polarization determination of less than $\pm 1\%$ (see figures in [56]). The polarization for the measurement with a beam momentum of $p_{\rm beam} = 2026$ MeV/c was determined preliminary to be about 49% and 67% for spin-down and spin-up orientations, respectively. For the measurement with unpolarized beam, a small but non-zero value of polarization (4%) was found even after the correction for the average position of the interaction points. Therefore, further detailed studies of the possible reason of the non-zero polarization for the unpolarized beam are required. However, it should be stressed that in this contribution we show that the collected data are of a high quality with average polarization of about 58%. It was also shown that it should be possible to control the degree of polarization with a systematic precision of about $\pm 1\%$.

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