Measurement of the spin-correlation coefficients $A_{x,x}$ and $A_{y,y}$ in the quasi-free $np \to \{pp\}_s\pi^-$ reaction near threshold at ANKE-COSY

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Abstract

A kinematically complete double-polarization measurement of the quasi-free $np \to \{pp\}_s\pi^-$ reaction near threshold has been performed using the ANKE spectrometer at COSY-Jülich. Here $\{pp\}_s$ represents a two-proton system with an excitation energy less than 3 MeV. The transversely vector polarized deuteron beam and the internal polarized ANKE hydrogen target were used to determine the spin-correlation coefficients $A_{x,x}$ and $A_{y,y}$. Events from the quasi-free $np \to d\pi^0$ reaction were recorded simultaneously and used for both beam and target polarimetry. In addition, the product of the beam and target polarizations could be estimated from the $A_{y,y}$ coefficient. The storage cell within the polarized target was the main source of background events. Dedicated runs, with no gas in the cell and with the cell filled with N_2 gas, were taken to study the backgrounds. The data analysis procedure and the initial results of the experiment are presented.

1 Introduction

Chiral perturbation theory (χPT) allows accurate calculations for hadronic reactions but its extension to the $NN \to NN\pi$ reactions requires new high precision experimental information in the near-threshold region. Of particular interest are the $np \to \{pp\}_s\pi^-$ and $pp \to \{pp\}_s\pi^0$ processes in the 350 MeV region, with the formation of a $^1S_0$ proton pair (diproton) in the final state, here denoted by $\{pp\}_s$. Measurements of the spin-correlation coefficients $A_{x,x}$ and $A_{y,y}$, taken in conjunction with values of the vector analyzing power A_y and the differential cross section $d\sigma/d\Omega$, will promote further development of χPT in this sector and lead to the determination of the strength parameter d, the so-called low energy constant (LEC) of the $4N\pi$ contact operator [1].

The most direct way to access the LEC is by measuring the cross section and spin-correlation coefficient $A_{x,x}$ in the $np \to pp_s\pi^-$ process. At low energies

$$(1 - A_{x,x})\, d\sigma/d\Omega \sim |\delta|^2 k^2 \sin^2\theta \quad \text{and} \quad A_{y,y} = 1, \tag{1}$$

where δ is a p-wave amplitude involving the $4N\pi$ contact interaction [2]. Given that the angular dependence is known in Eq. (1), only the value of $(1 - A_{x,x})d\sigma/d\Omega$ at 90° has to be extracted from the measurements.

2 Experimental setup

The experiment was performed in 2011 at the Cooler Synchrotron (COSY) of the Forschungszentrum Jülich. The synchrotron produced a vector polarized deuteron beam with kinetic energy 706 MeV which interacted with the internal polarized hydrogen cluster target. This target consisted of an Atomic Beam Source (ABS), a storage cell, and a Lamb-shift polarimeter [4]. The density of the polarized hydrogen gas in the cell was 1.34×10^{13} cm^{-2}. The cell material (20 μm of aluminium and 5 μm of teflon) gave rise to the most significant background, the shape of which in the missing-mass spectra was obtained from dedicated measurements with N_2 in the cell and with the empty cell. The reaction products were registered with the Forward and Positive Detectors (FD and PD) of the ANKE magnetic spectrometer [3].

3 Polarimetry

Polarimetry was done using the quasi-free $np \to d\pi^0$ reaction. For independent determination of the beam and target polarizations for spin orientation up and down, samples of data were taken with unpolarized beam or target. The process was selected by demanding a deuteron and proton spectator in the FD. These pairs were identified on the basis of the time of flight (TOF) differences [5] and the process confirmed through the missing mass in the reaction. Scaling the SAID A_y predictions [6] to fit the experimental asymmetries of Figs. 1 and 2, values for the ABS and beam polarizations could be deduced.

4 Vertex reconstruction

As a long storage cell (39 cm) was used at the experiment the longitudinal coordinates of the interaction points were distributed along the

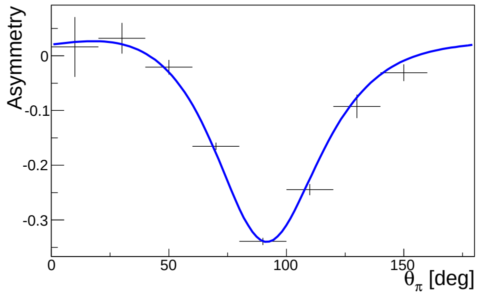

Figure 1: Determination of the ABS polarization, $P_{\rm ABS} = 69 \pm 2\%$

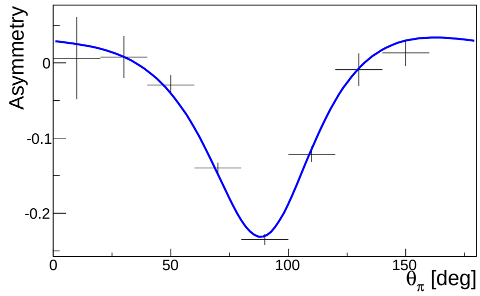

Figure 2: Determination of the beam polarization, $P_{\rm beam} = 50 \pm 2\%$

cell. To improve the accuracy of reconstruction momenta one could do the reconstruction of the longitudinal vertex coordinates. For this aim, the trajectories of the protons and their arrival times were fitted in a single procedure. Determination of the vertex allows to reconstruct properly the kinematics and to enhance the background rejection criteria, employing the TOF information.

The results presented below were obtained with the vertex reconstruction procedure.

5 Experimental results

The final diprotons from the $dp \to \{pp\}_s p_{\rm spec}\pi^-$ process were detected in the PD and the spectator proton ($p_{\rm spec}$) in the FD. The reaction was selected from the missing mass of the three protons and a cut of $E_{pp} < 3$ MeV was imposed on the diproton excitation energy.

The asymmetry can be written in terms of $\Sigma_1 = N_{\uparrow\uparrow} + N_{\downarrow\downarrow}$ and $\Sigma_2 = N_{\uparrow\downarrow} + N_{\downarrow\uparrow}$ as

$$\xi = \frac{\Sigma_1 - \Sigma_2}{\Sigma_1 + \Sigma_2} = PQ(A_{xx}\sin^2\phi + A_{yy}\cos^2\phi) \qquad (2)$$

and this was fitted to the experimental data to yield $A_{y,y}$ and $A_{x,x}$.

Quite generally $A_{y,y} = 1$ for all θ_π and the results are consistent with a constant. Equating this constant to unity gives an independent determination of the product PQ. $A_{y,y} = 1$ was then imposed on the fit to get more precise values of $A_{x,x}$.

The results for $A_{x,x}$ are presented in Fig. 3. Using the cross sections determined earlier [7], the values of $(1 - A_{x,x})\, d\sigma/d\Omega$ are shown in Fig. 4 as a function of θ together with the $\sin^2\theta$ fit of Eq. (1). This gives $(1 - A_{x,x})\, d\sigma/d\Omega(90^o) = (0.097 \pm 0.023)$ μb/sr, to be compared to a model-dependent value of 0.052 μb/sr obtained by fitting cross section and analyzing power data [7].

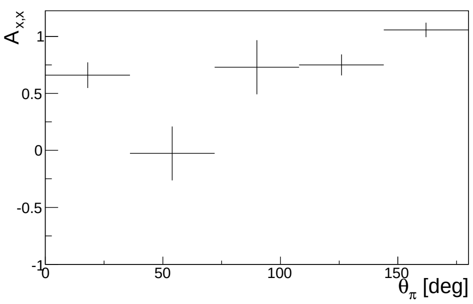

Figure 3: $A_{x,x}$ for $pd \to pp\pi^- + p_{sp}$ process at 353 MeV.

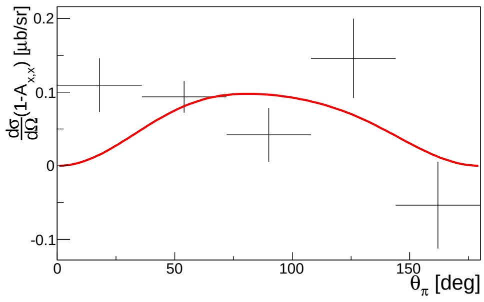

Figure 4: $(1-A_{x,x})d\sigma/d\Omega$ for the $pd \to pp\pi^- + p_{sp}$ process at 353 MeV fitted with $\sin^2\theta_\pi$.

6 Acknowledgements

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