Deuteron polarimetry at COSY

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Abstract. The vector P_z and tensor P_{zz} polarizations of a deuteron beam have been measured using elastic deuteron–carbon scattering at 75.6 MeV and deuteron–proton scattering at 270 MeV. After acceleration to 1170 MeV inside the COSY storage ring, the polarizations of the deuterons were remeasured by studying the analyzing powers of a variety of nuclear reactions at the ANKE magnetic spetrometer. The overall precisions obtained were about 4% for both P_z and P_{zz}. One of the motivation for the experimental programme is the direct reconstruction of the spin-dependent amplitudes, including relative phases, of large angle neutron-proton elastic scattering, through the study of the $p(d,2p)n$ charge–exchange reaction up to the highest available deuteron energy at COSY (2.3 GeV).

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INTRODUCTION

The COoler SYnchrotron (COSY) of the Forschungszentrum Jülich (FZJ) [1] accelerates and stores protons up to 2.88 GeV and deuterons up to 2.27 GeV both for experiments internal to the ring and for those using an extracted beam. In the case of protons, an extensive series of successful measurements with polarized beams and targets was carried out with the internal EDDA detector [2] and, has since been used as a polarimeter. COSY is now embarking on a programme of investigations [3] with polarized deuteron beams and polarized hydrogen (and deuterium) storage cell targets [4] at the ANKE magnetic spectrometer [5], placed at an internal target station of the COSY ring. One of the motivations for the ANKE experimental programme is the direct reconstruction of the spin-dependent amplitudes, including relative phases, of large angle neutron-proton elastic scattering, through the study of the $p(d,2p)n$ charge–exchange reaction. In order to accomplish this programme [3], it is a priority to establish polarization standards for the deuteron beams of better than 5%.

BEAM POLARIMETRY

The polarized H^- or D^- ion beam delivered by the source [6], is pre–accelerated in the cyclotron JULIC and injected by charge exchange into the COSY ring. The acceleration of vertically polarized protons and deuterons at COSY is discussed in detail in Ref. [7].

The scheme used to produce the beam consists of eight different states, including one unpolarized state and seven combinations of vector and tensor polarizations. The states and the nominal (ideal) values of the polarizations (P_z and P_{zz}) and relative intensities (I_0) are listed in Table 1. The polarized ion source was switched to a different polarization state for each injection in order to reduce the systematic errors.

TABLE 1. The eight configurations of the polarized deuteron ion source, showing the ideal values of the vector and tensor polarizations and the relative beam intensities, obtained by operating the three radiofrequency transitions. Also shown are the measured vector and tensor polarizations of the deuteron beam with statistical errors. The determinations of $P_z^{\rm LEP}$ were carried out at a momentum of 539 MeV/c using the Low Energy Polarimeter (LEP). The EDDA values of $P_z^{\rm EDDA}$ and $P_{zz}^{\rm EDDA}$ were obtained at 1042 MeV/c, assuming that state–0 was unpolarized. The systematic uncertainties of the polarizations $P_z^{\rm EDDA}$ and $P_{zz}^{\rm EDDA}$, employed in the subsequent analysis, amount to ± 0.04.

Mode	$P_z^{\rm Ideal}$	$P_{zz}^{\rm Ideal}$	$I_0^{\rm Ideal}$	$P_z^{\rm LEP}$	$P_z^{\rm EDDA}$	$P_{zz}^{\rm EDDA}$
0	0	0	1	0.000 ± 0.010	0	0
1	$-\frac{2}{3}$	0	1	-0.572 ± 0.011	-0.499 ± 0.021	0.057 ± 0.051
2	$+\frac{1}{3}$	+1	1	0.285 ± 0.011	0.290 ± 0.023	0.594 ± 0.050
3	$-\frac{1}{3}$	–1	1	-0.302 ± 0.011	-0.248 ± 0.021	-0.634 ± 0.051
4	$+\frac{1}{2}$	$-\frac{1}{2}$	$\frac{2}{3}$	0.395 ± 0.014	0.381 ± 0.027	-0.282 ± 0.064
5	–1	+1	$\frac{2}{3}$	-0.758 ± 0.015	-0.682 ± 0.027	0.537 ± 0.064
6	+1	+1	$\frac{2}{3}$	0.731 ± 0.014	0.764 ± 0.027	0.545 ± 0.061
7	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{2}{3}$	-0.417 ± 0.015	-0.349 ± 0.027	-0.404 ± 0.065

To assist in the optimization of the polarization of the beams inside COSY, a Low Energy Polarimeter (LEP, located in the injection beam line) has been used [8]. The LEP is operated at the COSY injection energy of $T_d = 75.6$ MeV for the polarization measurement via dC elastic scattering. Studies of the cross section and analyzing power A_y for 70 MeV [9] and 76 MeV [10] deuterons suggest that the polarimeter should work best if the detectors are placed to accept polar angles near 40°. Under such conditions the tensor analyzing powers are very small for this reaction so the LEP is only sensitive to the vector polarization of the beam. Taking the two data sets [9, 10] together, we deduce that $A_y(40^\circ) = 0.61 \pm 0.04$ at 75.6 MeV. The results of the P_z measurements with the LEP for the different states are shown in Table I.

The EDDA detector has been used to provide a wealth of high quality polarized pp elastic scattering data over a wide range of energies by using a thin internal target and measuring during the energy ramp of the COSY accelerator [2]. With the same apparatus, the vector and tensor polarizations of the circulating deuteron beam has been obtained by measuring $\vec{d}p$ elastic scattering at $T_d = 270$ MeV, where precise values are known for both tensor and vector analyzing powers [11]. A fit to the data with the polarizations for all eight states being left as free parameters yields $P_z = -0.002 \pm 0.038$ for state–0. Any non–zero result might reflect a residual polarization of state–0 or could be due to an instrumental asymmetry. The EDDA values for the polarizations of the seven states shown in Table I were extracted under the assumption that state–0 is unpolarized. Although supported by direct measurements with the LEP, the uncertainty of about ± 0.04 has to be considered as a systematic uncertainty on all the polarizations

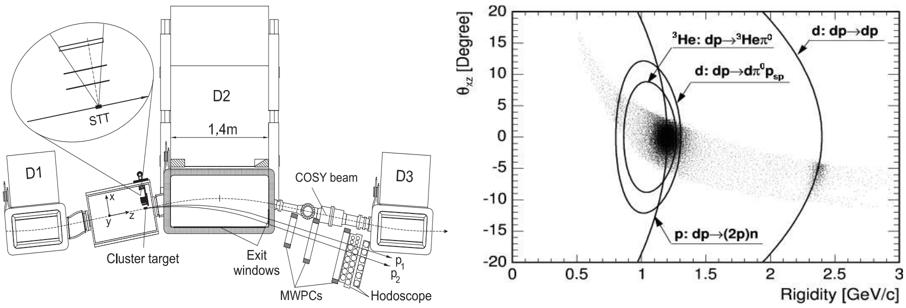

FIGURE 1. The ANKE experimental setup (left) and acceptance for four nuclear reactions (right).

extracted using EDDA. The typical fractions of the ideal vector and tensor polarizations were about 75% and 60%, respectively, though values from the individual polarization states were used in the subsequent analysis of the ANKE results.

After being accelerated in the COSY ring [1], the values of the deuteron beam polarizations provided by EDDA and LEP have been checked by measuring various nuclear reactions at $T_d = 1170\,\text{MeV}$ using the ANKE spectrometer [5]. Fig. 1 shows only those parts of the spectrometer that are relevant for the present experiment. The reactions that were pertinent to this polarization study are: $\vec{d}p \to {}^3\text{He}\,\pi^0$, quasi–free $\vec{n}p \to d\pi^0$ with a fast spectator proton, $\vec{d}p \to (pp)n$ producing a fast pair of protons with low excitation energy, and $\vec{d}p \to dp$ at small angles. Fig. 1 shows the ANKE experimental acceptance for charged particles as a function of the laboratory production angle and magnetic rigidity. From the loci of the kinematics of the four reactions it is seen that all of them had reasonable acceptances over some angular domain. The identifications of these reactions were very clean with the small background ($\leq$ 1–3%).

Using the measurement of the $\vec{d}p \to {}^3\text{He}\,\pi^0$ reaction in the forward direction, where it has a very strong tensor analyzing power signal, we obtained: $A_{yy}(\theta = 0^\circ) = 0.461 \pm 0.030$, to be compared with the precise results from SATURNE $A_{yy}(\theta = 0^\circ) = 0.458 \pm 0.014$ [12]. The quasi–free $\vec{n}p \to d\pi^0$ reaction is only sensitive to the vector polarization of the beam. We find that the analyzing power (see Fig. 2) at different angles is proportional to the SAID prediction for $\vec{p}p \to d\pi^+$ [13]. The analyzing powers from the $\vec{d}p \to (pp)n$ reaction was compared with the impulse approximation predictions using the current SAID *NN* phase shift solution and quantitative agreement has been observed [14]. Elastic deuteron–proton scattering is sensitive to the vector and tensor polarizations of the beam. In Fig. 2 we compare our measurements of A_y and A_{yy} for $\vec{d}p \to dp$ with those of Argonne and SATURNE [15].

Putting all these results together, we obtained that: $A_y(\text{ANKE}) = (1.01 \pm 0.03) \times A_y(\text{Expected})$; $A_{yy}(\text{ANKE}) = (0.99 \pm 0.03) \times A_{yy}(\text{Expected})$ The central values shown here reflect the possible loss of polarization during the acceleration from the EDDA energy to that of ANKE. Though these indicate very little depolarization, one cannot draw tight limits on this effect because of the uncertainties introduced by the calibration of the EDDA polarimeter. Taking the systematic errors of 4% here, we suggest that any polarization loss is below 6% for both the vector and tensor parameters.

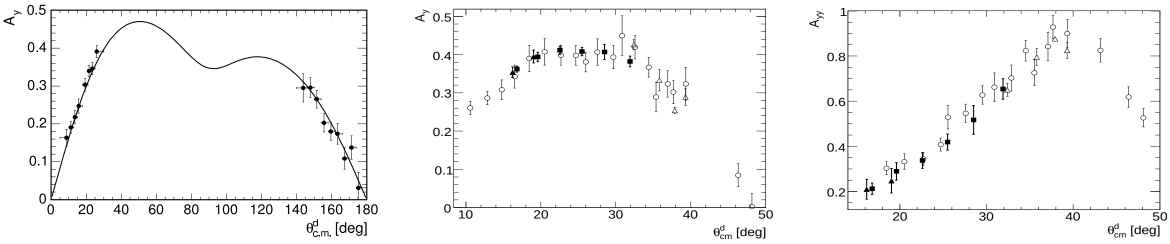

FIGURE 2. left panel: the vector analyzing power for the $\vec{n}p \to d\pi^0$ with the SAID prediction; middle and right panel: the ANKE results (solid symbols) for vector (A_y) and tensor (A_{yy}) analysing powers of the $\vec{d}p \to dp$ reaction together with the Argone and SATURNE data (open symbols) [15]

CONCLUSION

By measuring five analyzing powers in ANKE, we have shown that it is possible to determine both the vector and tensor polarizations of the deuteron beam (typically about 75% and 60% of ideal, respectively) with precisions of about 4% each. Taking these results in conjunction with the values of the polarizations measured with the EDDA polarimeter, we find no evidence for any depolarization effect in the acceleration from EDDA to ANKE. We have also measured the Cartesian analysing powers A_{yy} and A_{xx} for the $\vec{d}p \to (pp)n$ reaction at a beam energy of 1170 MeV, with a small pp excitation energy. Quantitative agreement with predictions based upon an up–to–date phase–shift analysis will allow one to use the charge–exchange data from ANKE for pn studies in more barren regions. For the details of these measurements see refs. [15, 14].

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