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Abstract

We report here the results of the calibration of the polarimeter POMME for vector polarized deuterons at an energy of 1.8 GeV. The results show that inclusive deuteron-carbon scattering has substantial vector analyzing power even at this high energy. The results obtained on two analyzers, carbon, which is generally used and a lighter material, paraffin, are found to be similar.

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1 Introduction

The polarized deuteron beam of the Saturne National Laboratory has been extensively utilized in nuclear structure studies using inelastic deuteron scattering at high excitation energies [1]. The polarimeter POMME, based on inclusive scattering on a carbon target, has been previously calibrated for incident deuteron energies up to 700 MeV [2]. The knowledge of the analyzing power for deuterons at higher energy is especially important in view of experiments where the polarization of an outgoing deuteron from the reaction has to be measured, such as in the study of baryonic resonances excited in the reaction $(\vec{d}, \vec{d}')$. We show here that the effective analyzing powers are sufficiently large and that a polarimeter with 2π azimuthal angular acceptance, like POMME, can still be used up to at least 1.8 GeV to measure the vector polarization of deuterons. In contrast, the tensor analyzing powers measured in this experiment are too small to be useful. A comparison is made between carbon and paraffin analyzers. The analyzing powers are found to be similar, although it was expected that the analyzing power of paraffin would be higher because of its hydrogen content.

2 Experimental method

A description of the polarimeter POMME has been published by Bonin *et al.* [2, 3], so here we limit ourselves to a brief description of its main characteristics. Three front proportional wire chambers determine the trajectories of the deuterons incident on the analyzer. The front chamber's dimensions are 50×50 cm^2 and their resolution is better than 2 *mm*. Two kinds of analyzers were used: a 34.8 cm thick carbon block with a density of 1.7 g/cm^3; and a 40 *cm* thick paraffin block, of density 0.95 g/cm^3. The scattered particles were detected by three rear chambers which have dimension of 100×100 cm^2. Their resolution is approximately 3 *mm*; the detection efficiency of the chambers in POMME is typically 92%. The trigger of the polarimeter is defined by an ensemble of overlapping scintillators placed closed to the focal plane just before the analyzer (Fig.1).

In the previous calibration at deuteron energies below 700 MeV, an iron absorber was placed behind the rear chambers in order to stop protons coming from deuteron break up in the carbon analyzer. A wall of scintillators detected the transmitted deuterons and was included in the trigger. At low energy this is an efficient way to select elastically scattered deuterons; it increases the effective analyzing powers, as demonstrated first by Garcon *et al.* [4]. It turns out that at the present energies the difference between the proton and deuteron energy loss in the iron is not sufficient to make a selection, so in this experiment the last plane was not in the trigger. Moreover, this avoids the possible false asymmetries arising from any dependence of the efficiency of the counters on the hit position of the particle.

In the present calibration, POMME was placed at the focal plane of the spectrometer

SPES4. The polarized deuteron beam of the Saturne synchrotron was incident directly on the polarimeter. The lowest possible intensity from the machine (about 10^8 particles per beam burst) was further reduced to approximately 10^4 particles per burst with the help of beam slits and by defocalizing the last quadrupoles of the spectrometer.

The polarized deuteron beam of Saturne has vector and tensor polarization components ρ_{10} and ρ_{20} along the vertical axis [5]. Radio frequency transitions are applied in the ion source to produce nuclear polarization. Different transitions are combined to obtain either 2 states (only vector polarized), or 4 states of polarization (vector and tensor polarized), changing the sign of the components at each beam cycle (approximately every 3 s). The polarization of the deuteron beam was measured by a low energy polarimeter, located just at the exit of the source [5]. With the four state beam the vector polarization was $\rho_{10} = 0.41 \pm 0.02$ and the tensor polarization was $\rho_{20} = 0.62 \pm 0.02$. For the purely vector polarized beam $\rho_{10} = 0.79 \pm 0.02$.

3 Analysis and results

The data analysis was carried out as described in more detail in [2]. The chambers were mechanically aligned with a precision of $\simeq 1$ mm, but a software procedure allowed to align on particle trajectories at the level of 0.1 mm. The incoming and outgoing deuteron trajectories were reconstructed using the chamber information. Geometrical conditions on the reaction vertex are required. A cone test was also applied, to insure that no asymmetry was introduced by the finite solid angle of the detectors downstreams of the analyzer. This is especially important in the case of an extended polarimeter. For each beam polarization state (i) a two-dimensional distribution of $N^{(i)}(\theta, \phi)$ was created, where θ and ϕ are the polar and the azymuthal angles of scattering. The angular ranges were $0^o \leq \theta \leq 15^o$ and $-180^o \leq \phi \leq 180^o$, with bins of 1^o and 10^o for θ and ϕ, respectively. Appropriate combinations of the events from beam bursts with different polarization admixtures were formed to obtain purely vector and purely tensor distributions. For example, to obtain the vector analyzing power we define a vector ratio as:

$$R_V(\theta, \phi) = \frac{N^{(2)}(\theta, \phi) - N^{(3)}(\theta, \phi)}{N^{(2)}(\theta, \phi) + N^{(3)}(\theta, \phi)} \tag{1}$$

where

$$N^{(2)}(\theta, \phi) = N_0(\theta)[1 + \sqrt{2}\rho_{10} iT_{11}(\theta) cos\phi] \tag{2}$$

$$N^{(3)}(\theta, \phi) = N_0(\theta)[1 - \sqrt{2}\rho_{10} iT_{11}(\theta) cos\phi] \tag{3}$$

The data for R_V were then fitted with:

$$R_V(\theta, \phi) = A_1(\theta)\ cos\phi \tag{4}$$

The vector analyzing power is then related to the coefficients A_1 of the fit by:

$$iT_{11}(\theta) = \frac{A_1(\theta)}{\sqrt{2}\,\rho_{10}} \tag{5}$$

A similar analysis was carried out to obtain the tensor coefficients T_{20} and T_{22}.

The results of the calibration are shown as a function of the polar angle in Fig. 2, for the carbon (open circles) and paraffin (triangles) analyzers. The actual value of the efficiency, the average analyzing power and the figure of merit are given in Table I. The vector analyzing powers are relatively large, for the carbon analyzer as well as for the paraffin; the maximum value occurs at ($4^o - 10^o$) and the useful angular range is ($2^o - 15^o$). The 2-state and 4-state beam measurements were in good agreement. Therefore they were combined to obtain the final results. The tensor analyzing powers are also shown in Fig. 2 and their average values are given in Table I. They are both compatible with zero. At lower energies only T_{22} was noticeably different from zero [2].

The reported errors are statistical only. The systematic errors can be evaluated to be ±2%. They originate mainly from the uncertainty on the beam polarization. The errors coming from experimental asymmetries (eventual misalignment of the chambers or trajectory reconstruction) are canceled by the method used for the analysis which takes into account the beam spin flip. However they would affect a polarization measurement at the order of ±1%.

The polarimeter efficiency ϵ is defined as the ratio between events useful for polarization and events incident on the polarimeter. It depends on the cross section of the reaction as well as on the geometry and on the efficiency of the detection.

The performance of a polarimeter is usually expressed in terms of the figures of merit, $\mathcal{F}_{ij}$ (where (ij) are the tensorial indices). These depend on the polar angle θ and are functions of the efficiency ε and of the analyzing powers, T_{ij}. They are defined as

$$\mathcal{F}_{ij}^2 = \int \varepsilon(\theta)\, T_{ij}^2(\theta)\, d\theta \tag{6}$$

The integration is over the angular domain where the polarimeter is efficient. The figures of merit determine the number of events, N_{inc}, necessary to obtain a given uncertainty in a polarization measurement. For example, the statistical error in a measurement of the vector polarization, ΔP_y, can be expressed as

$$\Delta P_y = \sqrt{\frac{2}{N_{inc}\mathcal{F}_{11}^2}} \tag{7}$$

The values of the efficiency, the average analyzing power and the figure of merit reported in Table I show that the average vector analyzing power for the paraffin is about 20% higher than for the carbon. The integrated efficiency is 30% higher for the carbon analyzer than for paraffin, as expected from the larger number of carbon nuclei in the graphite analyzer. When combined in equation (6) these two quantities result in almost equal coefficients of merit for carbon and paraffin. About 40% of the events have a scattering angle smaller than

1.5°; these events are mostly due to Coulomb multiple scattering and therefore carry little analyzing power. Also about 30% of the carbon events (and 22% for paraffin) are rejected since they do not correspond to a single track in the rear chambers. They do not arise from an inclusive reaction with one charged particle in the forward direction, but rather from other processes such as multiple nuclear interactions or reactions with neutral particle production.

4 Conclusion

The new results presented here indicate that it is possible to use a polarimeter with 2π azimuthal acceptance like POMME, for deuteron vector polarization measurements up to at least 1.8 GeV. The vector figure of merit at 1.8 GeV is half as large as the one obtained for 575 MeV deuterons in ref. [2]; it is also three fourth of the value observed for protons of the same energy, for a similar carbon thickness [6]. A polarimeter based on the d,p elastic reaction [7] is under study and should give better performances, in particular for the tensor figures of merit.

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Table I. Efficiency, average analyzing powers and figures of merit for carbon and paraffin analyzers, calculated in the scattering angle range $2^o \leq \theta \leq 15^o$.

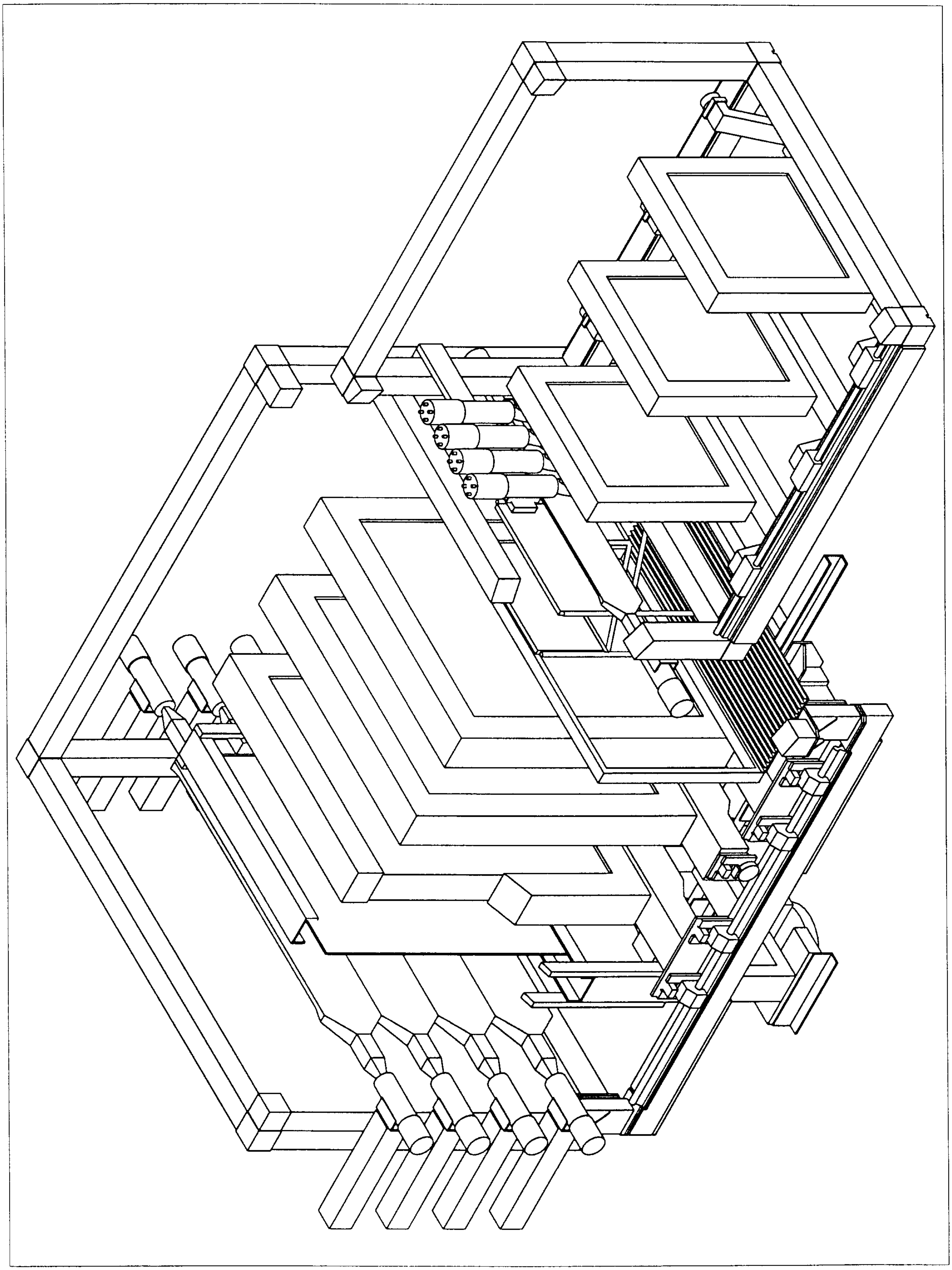
	$Carbon$ (34.8cm)	$Paraffin$ (40cm)
Efficiency	0.1403 ± 0.0002	0.1072 ± 0.0002
$< iT_{11} >$	0.087 ± 0.004	0.103 ± 0.004
$< T_{20} >$	-0.002 ± 0.006	0.012 ± 0.009
$< T_{22} >$	-0.034 ± 0.033	-0.031 ± 0.040
F_{11}	0.0326 ± 0.0015	0.0334 ± 0.0013
F_{20}	0.0008 ± 0.0023	0.0039 ± 0.0029
F_{22}	0.0127 ± 0.0124	0.0100 ± 0.0135

Figure caption

Figure 1. Overview of POMME.

Figure 2. Efficiency and analyzing powers iT_{11}, T_{20} and T_{22} for carbon (open circles) and paraffin (triangles) analyzers.

Fig 1



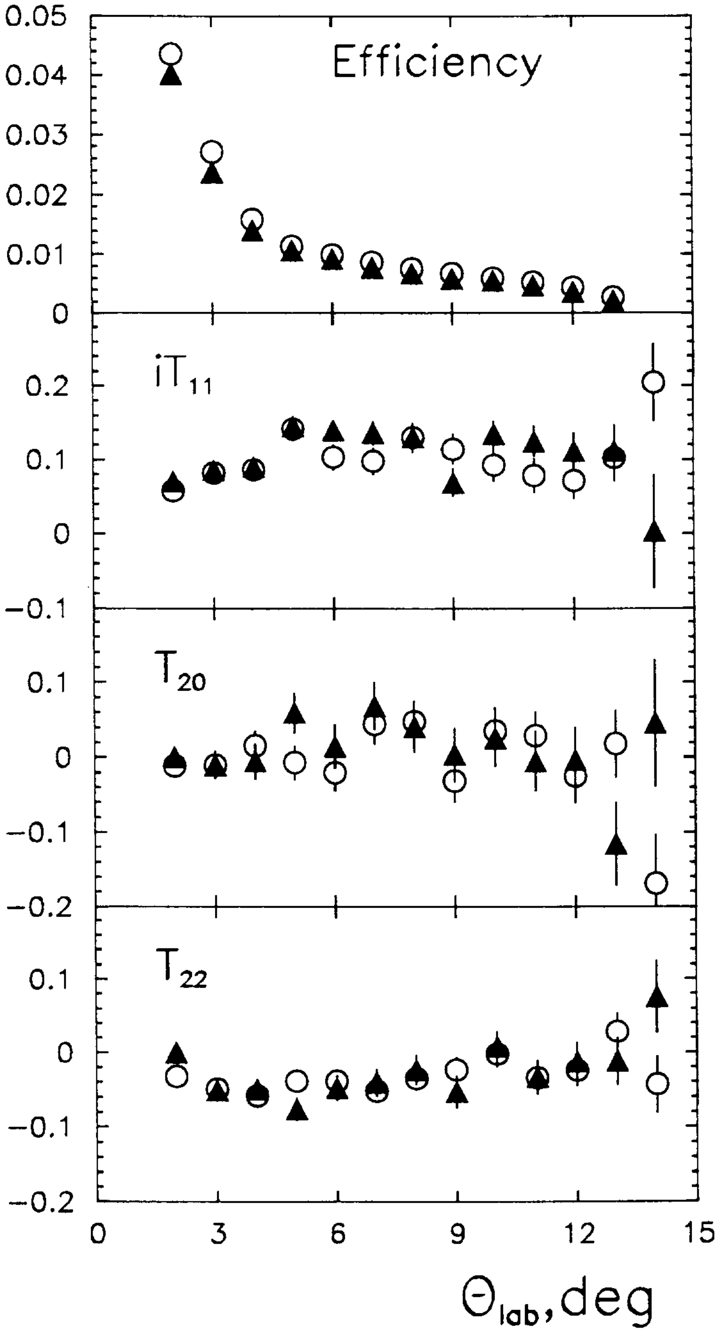

Efficiency
0.05
0.04
0.03
0.02
0.01
0
iT$_{11}$
0.2
0.1
0
−0.1
T$_{20}$
0.1
0
−0.1
−0.2
T$_{22}$
0.1
0
−0.1
−0.2
0
3
6
9
12
15
Θ_{lab}, deg

Fig 2