MEASUREMENT OF THE VECTOR AND TENSOR POLARISATION OF PROTON AND DEUTERON BEAMS

The GEM Collaboration
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Abstract
Measurement of the $d+d \rightarrow ^4He + \eta$ reaction using vector and tensor polarised beam has been performed at COSY using Big Karl magnetic spectrograph. The beam polarisation necessary for obtaining the vector and tensor analysing power for this reaction was measured. The method and the results of the tensor polarisation measurement of the deuteron beam are presented.

1 Introduction

There is a great interest in \(\eta\)-physics in recent years \cite{1}. The completed data set for \(p+d \rightarrow ^3He + \eta\) reaction \cite{2,3} in a wide beam energy range exist but the related channels of \(d+d \rightarrow ^4He + \eta, n+^3He \rightarrow ^4He + \eta\) and \(p+t \rightarrow ^4He + \eta\) are poorly measured. Whereas for the \(p+t\) and \(n+^3He\) collision no data were taken at all due to the problems with neutron beam and triton target, the existing data for the \(d+d \rightarrow ^4He + \eta\) reaction are so far limited to the total and differential cross section at small excess energies (\(Q < 7.7\) MeV) \cite{4–6}.

There are many theoretical models describing the \(p+d \rightarrow ^3He + \eta\) reaction. The two step model proposed by Kilian and Nann \cite{7} was extended by Fäldt and Wilkin \cite{8} to
describe the $d + d \rightarrow {}^4\text{He} + \eta$ reaction. However due to the lack of data the question about the underlying reaction mechanism can not be answered yet.

The GEM collaboration performed an experiment investigating $d + d \rightarrow {}^4\text{He} + \eta$ reaction using unpolarised as well as vector and tensor polarised beams at $Q = 17.5$ MeV. The measurement of the angular dependence of the differential cross section and the analyzing powers for the $d + d \rightarrow {}^4\text{He} + \eta$ reaction allows to extract the partial wave amplitudes directly from the experimental data, not relying on any theoretical model. The energy dependence of absolute values of the partial wave amplitudes together with their phases obtained from the measured observables can be used to determine the reaction mechanism.

The vector polarisation of the beam was measured using a low energy polarimeter placed in the beam line between the cyclotron and the COSY accelerator. The tensor polarisation was measured at the external target station using Big Karl magnetic spectrograph. The tensor polarisation $p_{zz}$ of the deuteron beam was extracted using deuteron-proton backward elastic scattering.

2 Experiment and results

The experiment was performed at the COSY \(^1\) facility in Jülich using the Big Karl magnetic spectrograph [9]. The detector system is schematically shown in Fig. 1. The Big Karl spectograph is equipped with two sets of multi-wire drift chambers (MWDC) for position measurement and two layers of scintillating hodoscopes for time of flight and energy losses information, used for particle indentification. Very good particle separation was achieved as it is seen in Fig. 2.

\[\text{Figure 1: Schematic layout of the detection system of Big Karl used in the experiment. } Q\text{ indicates magnetic quadrupoles lenses, } D\text{ magnetic dipoles.}\]

\(^1\)http://www.fz-juelich.de/ikp/de/
Figure 2: *Time of flight versus energy losses in scintillator layers for the d(d, X) reaction at 1.16 GeV.*

In the measurement of the $d + d \rightarrow \alpha + \eta$ reaction deuteron beam of 1.16 GeV kinetic energy was used. Apart from the unpolarised beam, two different combinations of vector $p_z$ and tensor $p_{zz}$ polarisation were applied:

$$p_z = -\frac{1}{3}, \quad p_{zz} = +1, \quad (1)$$

$$p_z = -\frac{1}{3}, \quad p_{zz} = -1. \quad (2)$$

The vector polarisation $p_z$ was measured with a low energy polarimeter placed in the injection beam line where the deuteron energy is about 76 MeV. Using carbon target, proton elastic scattering was measured with scintillating detectors. The results for both polarisation combinations are: $p_z = -0.32 \pm 0.02$ and $p_z = -0.33 \pm 0.02$, respectively.

The tensor polarisation of the beam was measured using deuteron beam and liquid hydrogen target. The deuterons originating from $d \bar{p}$ backward elastic scattering were measured with Big Karl magnetic spectrograph.

The cross section for $d \bar{p}$ backward elastic scattering can be expressed as:

$$\left[ \frac{d\sigma}{d\Omega}(\theta = 180^\circ) \right]_{pol} = \left[ \frac{d\sigma}{d\Omega}(\theta = 180^\circ) \right]_{unpol} \left[ 1 - \frac{1}{2} T_{20}(\theta = 180^\circ) \right], \quad (3)$$

where tensor polarisation can be written as:

$$p_{zz} = \sqrt{2}t_{20}. \quad (4)$$

In order to determine $p_{zz}$, polarised and unpolarised cross sections as well as tensor analyzing power $T_{20}$ at 180° have to be known. The tensor analyzing power $T_{20}$ at 180° was already determined by the Saclay group [10]. They measured protons from $d \bar{p}$ backward elastic scattering in a broad deuteron beam energy, covering our beam energy at 1.16 GeV. The data points were remeasured with smaller uncertainties by Punjabi et al. [11] and these results are presented in Fig. 3. The cross sections for different polarisation combinations were measured with Big Karl.

The outgoing deuterons were identified using the specific energy losses and time of flight. In order to eliminate background, the deuteron missing mass spectra were analysed.
Figure 3: Tensor analyzing power $T_{20}$ at 180° measured by Ref. [11]. The arrow indicates the beam energy of the present experiment.

Figure 4: Missing mass spectrum for $\vec{d}p \rightarrow pd$ reaction for unpolarised beam (solid line) and two different tensor polarisations of the beam (dashed and dotted lines).

An example of such a spectrum is shown in Fig. 4 for $\vec{d}+p \rightarrow d+X$ process for unpolarised beam and for both polarisations of the beam. From these information the differential cross sections for unpolarised beam and both polarisations were obtained. Using the relation (3) and (4), tensor polarisations were determined: $p_{zz} = +0.81 \pm 0.16 \pm 0.01$ and $p_{zz} = -0.60 \pm 0.11 \pm 0.01$, where the first error is statistical and the second is a systematical one. The results of vector and tensor polarisation measurement are summarized in Table 1.

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| nominal | $p_z$ measured | nominal | $p_{zz}$ measured |
|---------|----------------|---------|-------------------|
| -1/3    | -0.33 ± 0.02   | -1      | -0.60 ± 0.11 ± 0.01 |
| -1/3    | -0.32 ± 0.02   | +1      | +0.81 ± 0.14 ± 0.01 |

Table 1: Results of the vector and tensor polarisations measurement.

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