

Polarimetry for a storage-ring electric-dipole-moment measurement

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Abstract. These proceedings summarize the progress which has been made within the Jülich Electric Dipole Moment Investigations (JEDI) Collaboration on deuteron beam polarimetry for a storage-ring electric-dipole-moment (EDM) measurement. The design of a dedicated EDM polarimeter requires a precise database for optimization purposes. To address this need, a measurement of a deuteron-carbon scattering database has been performed with the forward part of the WASA-at-COSY detector. Preliminary results for vector analyzing powers and unpolarized differential cross sections for different deuteron beam energies are presented.

1 Introduction

Understanding the origin of the matter-antimatter imbalance in the universe is one of the grand challenges of modern physics. One of the necessary conditions is the violation of CP symmetry. Predictions given by the Standard Model fail to explain the observed preponderance of matter by orders of magnitude. Therefore, new sources of CP violation, coming from outside the Standard Model, are needed. They can be seen in Electric Dipole Moments (EDM) of elementary particles.

The principle of an EDM measurement for charged particles like protons or deuterons is based on the observation of the time development of the minuscule vertical-polarization buildup of the beam initially polarized along the particle momentum due to the interaction of a finite EDM with the particle-frame radial electric field in the storage ring. The key challenge is a sensitive and efficient determination of the small change of the polarization.

2 Requirements for EDM polarimetry

In a storage ring EDM measurement, the beam polarization is measured continuously exploiting the scattering of the beam particles at forward angles on a thick (few cm) carbon target. Knowing the vector analyzing power A_y , the polarization p_y can be calculated by comparing scattering rates to the left L and right R for two vector polarization states, i.e., up (+) and down (-), using the cross ratio asymmetry:

$$\epsilon = \frac{3}{2} p_y A_y = \frac{r - 1}{r + 1}. \quad (1)$$

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where $r^2 = (L_+R_-)/(L_-R_+)$. For a value of the proton EDM of the order of $10^{-29} e \cdot \text{cm}$ the required sensitivity of the polarization-buildup measurement should be as low as $\Delta p_y A_y \sim 10^{-6}$. The statistical uncertainty of the polarization buildup is proportional to $1/(\sqrt{N}|A_y|)$, where N stands for the registered number of events in the polarimeter. Minimizing this uncertainty requires maximizing the so-called Figure of Merit (FoM), defined as $\text{FoM} = d\sigma/d\Omega A_y^2 \sin \theta \propto N A_y^2$. Besides high efficiency and analyzing power, an important feasibility requirement for an EDM experiment is that systematic uncertainties of the polarization measurement are correctable to the same level as statistical ones. In [1] it has been shown that it is possible to correct polarization measurements in real time to levels below one part in 10^{-5} .

To fulfill the challenging requirements for a EDM measurement, a new polarimeter, based on LYSO scintillator modules with SiPM readout, is under development. The design of such a device requires a solid database for optimization purposes. The next paragraph describes the activity of the JEDI collaboration in this area.

3 Deuteron-carbon database

3.1 Experiment

The beamtime dedicated to the deuteron-carbon database measurement at COSY took place in November 2016. The data have been taken with the forward part of the WASA-at-COSY detector [2] at seven different kinetic energies of the beam E_d , between 170 MeV and 380 MeV, and five different nominal vector and tensor beam-polarizations (p_y, p_{yy}) , i.e., $(0, 0)$, $(2/3, 0)$, $(-2/3, 0)$, $(1/2, -1/2)$, $(-1, 1)$. In addition to a carbon ribbon target, a CH_2 target has been used for the normalization based on the deuteron-proton elastic-scattering reaction. The goal of the experiment is to obtain the analyzing powers and differential cross-sections for the deuteron-carbon elastic scattering as well as other background reactions, e.g., deuteron breakup. The final result will serve as an input to simulations of various polarimeter designs.

The forward detector of WASA used in the measurement is presented in Fig. 1. It consists of several layers of "pizza-shaped" plastic scintillators, i.e., two layers of the Forward Window Counter (FWC), one layer of the Forward Trigger Hodoscope (FTH), five layers of the Forward Range Hodoscope (FRH), and four planes of the tracking detector — the Forward Proportional Chamber (FPC). The thin scintillators (FWC and FTH) are mostly used for triggering purposes, while energy losses measured in the thicker layers of FRH are predominantly used for energy reconstruction and particle identification. The detector provides full coverage in the horizontal angle ϕ and covers the azimuthal angle θ between 3° and 18° .

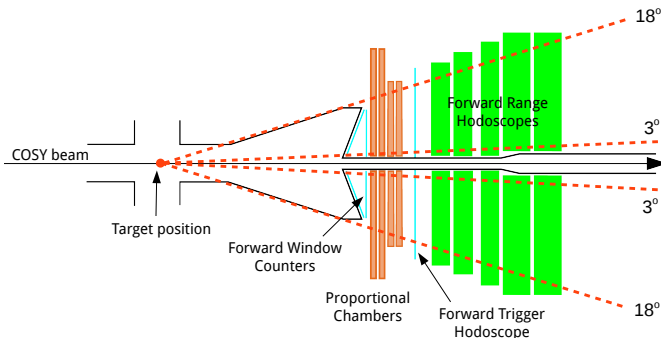


Figure 1. Forward detector of the WASA facility used in the database experiment. The main detector components and the target position are described. The coverage in the azimuthal angle θ is marked.

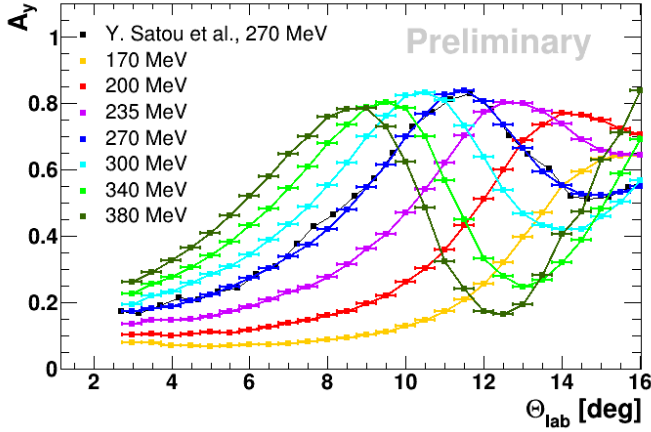


Figure 2. Preliminary vector analyzing powers for the elastic dC scattering reaction measured at different kinetic energies of the deuteron beam at WASA. The reference data from [3] at $E_d = 270$ MeV is presented in black.

3.2 Data Analysis and results

The ejectiles coming from the deuteron-carbon interactions are identified using the correlation between energy losses in the FTH and FRH detector layers ($\Delta E - \Delta E$ method). To obtain the vector analyzing power A_y for the elastic dC scattering, the events with deuterons originating from this reaction have been selected using a 2-dimensional cut on the correlation between energy losses in the last FRH layer reached by the particles (stopping layer) and the layer before it. A_y has been calculated by comparing scattering rates to the left and right for the (+) = (2/3, 0) and (-) = (-2/3, 0) polarization states using the cross ratio asymmetry from Eq. (1). The polarization p_y has been determined by scaling the spectra measured at $E_d = 270$ MeV to the reference data from [3]. The average polarization obtained in this way, $p_y^{\text{prel}} = 0.43$, has been used to extract A_y for all other measured datasets. The result is presented in Fig. 2.

In addition to the analyzing powers, the unpolarized differential cross sections $d\sigma/d\Omega$ for dC elastic scattering have been determined, so far for two E_d energies, namely 200 MeV and 270 MeV. The number of elastically scattered deuterons has been extracted from the energy losses spectra from the stopping FRH layer, using particle identification based on the $\Delta E - \Delta E$ method. The geometrical acceptance and cut efficiency have been estimated using the GEANT3 simulation of WASA. The luminosity has been calculated with deuteron-proton elastic scattering registered with the CH_2 target. The reference data for this reaction at 200 MeV and 270 MeV are [4] and [5–7], respectively. It is important to notice that the discrepancy in the available world results for deuteron-proton elastic scattering for 270 MeV in the kinematic region as measured with WASA is of the order of 40%. For the purpose of this analysis, the differential cross section from [6] has been chosen for normalization. Fig. 3 shows the preliminary differential cross section for $E_d = 270$ MeV and 200 MeV. Only statistical uncertainties have been presented. For comparison, the results from [3] and [4] for dC elastic scattering have been also plotted. A detailed investigation of systematical uncertainties is in progress. In Fig. 4 the preliminary Figures of Merit have been presented.

4 Outlook

The investigation of the complete database of deuteron-induced reactions from a carbon target is under way. In addition to differential cross sections and vector analyzing powers, further activity will include also the determination of tensor analyzing powers. Furthermore,

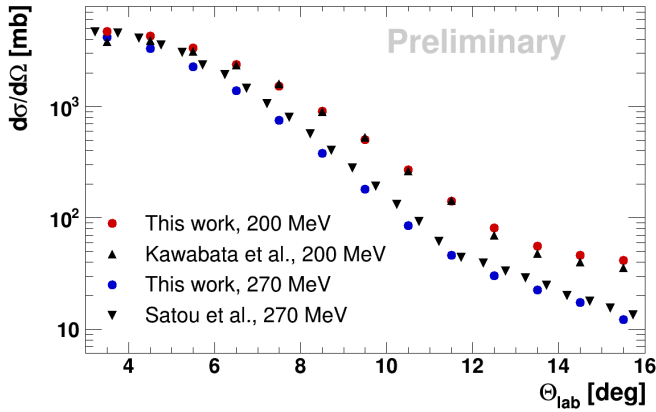


Figure 3. Preliminary differential cross section for the dC elastic scattering reaction. Blue dots show the result for $E_d = 270$ MeV, red dots for $E_d = 200$ MeV. The results obtained for these energies from [3, 4] are marked with black triangles.

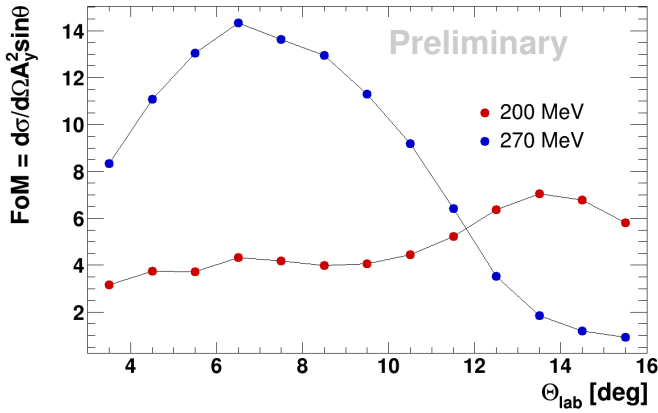


Figure 4. Preliminary Figure of Merit for the dC elastic scattering reaction. Blue dots show the result for $E_d = 270$ MeV, red dots for $E_d = 200$ MeV.

a new experiment on proton-carbon database took place in August 2018, and data analysis has started. Ultimately, these data will be used to produce realistic Monte Carlo simulations of detector responses for a polarimeter designed for an EDM search using a storage ring.

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