New data on the differential cross section of the dp-elastic scattering at 2.5 GeV obtained with HADES detector

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New results on the differential cross section in deuteron-proton elastic scattering are obtained at the deuteron kinetic energy of 2.5 GeV with the HADES spectrometer. The angular range of $69^\circ - 125^\circ$ in the center of mass system is covered. The obtained results are compared with the relativistic multiple scattering model calculation using the CD-Bonn deuteron wave function. The data at fixed scattering angles in the c.m. are in qualitative agreement with the constituent counting rules prediction.
1. Introduction

The reaction of nucleon-deuteron elastic scattering is considered both by theoreticians and experimentalists as one of the important tasks in few-nucleon physics. During a long period of time it has been served as a hope to obtain an information about the intermediate- and short-range $NN$ interaction and as a probe of the deuteron structure at small distances. A large amount of the data on the nucleon-deuteron system has been accumulated in last few years on the cross section and also on various spin observables to study the three-nucleon forces effects. As it was shown in 1998 by Henryk Witala et al. [1], the effects of $3NF$ may appear in the cross section minimum region at intermediate energy scattering where the $3N$ interaction are comparable with the $NN$ one.

Several experimental groups have been investigated the cross section and polarization observables in $Nd$ elastic scattering at the energy range $65 - 135$ MeV/nucleon [2–15]. Such activities were stimulated by the observed discrepancy of 30% between the differential cross section data and results of Faddeev calculations [16]. The discrepancy for the differential cross section at these energies are remedied by the inclusion of the $2\pi$-exchange three-nucleon forces ($3NF$) such as TM-3NF [17], UrbanaIX-3NF [18] or TM99 [19] into the calculations [20]. However, the large discrepancies between the experimental data [21–24] and theoretical predictions in the differential cross section minimum are observed even after the $3NF$s inclusion [20, 25] at the energy range $200 - 600$ MeV/nucleon.

On the other hand the experimental data on deuteron-proton elastic scattering at the deuteron kinetic energies $195 - 600$ MeV/nucleon [8, 21, 26–30] are well described by the relativistic multiple scattering model [31, 32].

The transition to higher energies will allow to understand the mechanism of manifestation of the fundamental degrees of freedom at distances of the order of the nucleon size. In this work we present a new data on the differential cross section of $dp$-elastic scattering obtained with the HADES spectrometer [36] at a deuteron beam kinetic energy of 2.5 GeV.

2. Experiment

The High Acceptance Di-Electron Spectrometer (HADES) is operated at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany taking beams from the heavy-ion synchrotron SIS18. HADES is a charged-particle detector consisting of a six-coil toroidal magnet centered on the beam axis and six identical detection sections located between the coil and covering polar angles between $18^\circ$ and $85^\circ$. Each sector is equipped with a hadron-blind ring-imaging Cherenkov (RICH) detector followed by multivare drift chambers (MDCs), two in front and two behind the magnetic field, as well as two scintillator hodoscopes (TOF and Tofino). The lepton identification is provided mostly by the RICH and supplemented at low polar angles with preshower detectors, mounted at the back of apparatus. Hadron identification is based on the time-of-flight and on the energy-loss information from the scintillators and the MDC tracking detector. The schematic view of the HADES spectrometer is presented in Fig. 1. Technical aspects of the detector are described in [36].
In experiment presented here a deuteron beam with a kinetic energy of \( T_d = 2.5 \text{ GeV} \) and an intensity of about \( 10^7 \) particles/s were directed to a 5 cm long liquid-hydrogen cell with a total areal thickness of \( 0.35 \text{ g/cm}^2 \). The main goal of this experimental run was the measuring of the electron-positron pair production properties in \( np \) channel at the same beam energy per nucleon as in case of \( pp \) run. In order to investigate the \( np \) interaction using deuteron beam the HADES setup was upgraded with a Forward Fall (FW) scintillator hodoscope. During this run it was located 7 meters downstream from the target and covered the angular range from \( 0.33^\circ \) up to \( 7.17^\circ \).

The momenta of the produced particles were deduced from the hits in the four drift chamber planes (two before and two after the magnetic field zone) using a Runge-Kutta algorithm [36]. The momentum resolution was 2-3% for protons and pions and 1-2% for electrons, depending on momentum and angle [36].

The \( dp \) elastic events were selected using the information about the angle-momentum correlations for two detected particles and their experimental time difference.

3. Results and discussion

The results on the angular dependence of the \( dp \) elastic cross section at \( T_d = 2.5 \text{ GeV} \) compared with the relativistic multiple scattering model calculations [31, 32] using CD-Bonn deuteron wave function [37] are shown in Fig. 2. The HADES data are marked by red squares. Error bars include both the statistical and systematical uncertainties. The dashed line corresponds to the calculations taking into account single scattering contributions only. The solid and dash-dotted curves are the results of calculation including the single and double scattering term with and without the principal value part of the three-nucleon free propagator, respectively.
The deviations in the description of the angular dependence of the $dp -$ elastic cross section data and theoretical calculations [31, 32] are observed. The results of the calculation taking into account only the single scattering term underestimate the cross section data, while including the double scattering leads to the experimental data overestimation. World $pd -$ elastic scattering data at 1.3 GeV/nucleon [38] are presented by the triangles.

On the other hand, at high energies and large transverse momenta the constituent counting rules (CCR) [33, 34] are working. They predict a $1/s^{n-2}$ dependence of the differential cross section for the binary reaction, where $n$ is the total number of the fundamental constituents involved in the reaction. In the reference [35] it is shown that in hadron interactions with participations of the lightest nuclei $^2$H, $^3$H and $^3$He the scaling behaviour given by relation above is also occurs, specifically, at a beam energy around 1 GeV if the scattering angle is large enough. A regime corresponding to CCR can occur already at $T_d = 500$ MeV [35].

The results on the energy dependence of the differential cross section in $dp -$ elastic scattering at fixed scattering angles of 90°, 100°, 110° and 122° in the c.m. are presented in Fig. 3 and Fig. 4. The HADES data are depicted by the red squares. The world data [27, 38–41] are shown by the open symbols and stars. The lines are the result of the fitting of the world data by the function $\sim s^{-16}$. It can be concluded that the $dp -$ elastic cross section data are well follows the scaling regime $\sim s^{-16}$ in the angular region 90 – 122° in the center of mass system.

4. Conclusion

New results on the angular dependence of the differential cross section in the $dp -$ elastic scattering are obtained with the HADES spectrometer at 2.5 GeV. The angular region of 69 – 125°
Differential cross section of the $dp$-elastic scattering at 2.5 GeV obtained with HADES

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Figure 3: Differential cross section of $dp$-elastic scattering at fixed scattering angle of $90^\circ$ and $100^\circ$ in c.m.s. The HADES results are presented by red square. The world data are marked by open symbols. The curves are the predictions of constituent counting rules.

Figure 4: Differential cross section of $dp$-elastic scattering at fixed scattering angle of $110^\circ$ and $122^\circ$ in c.m.s. The HADES results are presented by red square. The world data are marked by open symbols. The curves are the predictions of constituent counting rules.

in c.m. is covered. The $dp$-elastic scattering data are compared with the relativistic multiple scattering model calculation using CD-Bonn deuteron wave function. The deviation of the data from theoretical calculations is observed. The behavior of the cross section data at fixed scattering angles in the c.m. is in a satisfactory agreement with the constituent counting rules prediction.

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