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# Cross section investigation in dp breakup reaction at the intermediate energies

**M Janek<sup>1</sup>, V P Ladygin<sup>2</sup>, Yu V Gurchin<sup>2</sup>, A Yu Isupov<sup>2</sup>, J-T Karachuk<sup>3</sup>, A N Khrenov<sup>2</sup>, P K Kurilkin<sup>2</sup>, A N Livanov<sup>2</sup>, O Mezhenska<sup>4</sup>, S M Piyadin<sup>2</sup>, S G Reznikov<sup>2</sup>, A A Terekhin<sup>2</sup> and I E Vnukov<sup>5</sup>**

<sup>1</sup>Physics Department, University of Zilina, Univerzitna 1, 01001 Zilina, Slovakia

<sup>2</sup>Veksler and Baldin Laboratory of High Energies, Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia

<sup>3</sup>Advanced Research Institute for Electrical Engineering, Splaiul Unirii 313, Bucharest, Romania

<sup>4</sup>Institute of Physics, University of P. J. Shafarik, Park Angelinum 9, 04001 Kosice, Slovakia

<sup>5</sup>Belgorod State University, Pobedy 85, 308015 Belgorod, Russia

E-mail: [janek@fyzika.uniza.sk](mailto:janek@fyzika.uniza.sk)

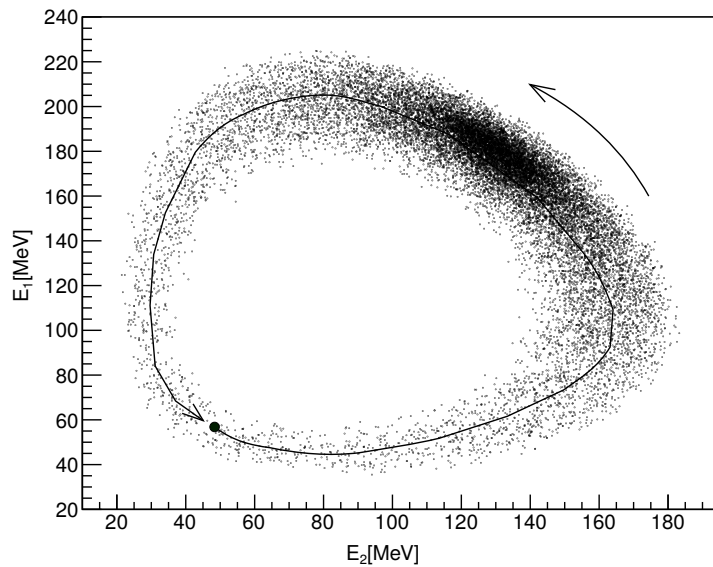
**Abstract.** The dp breakup reaction has been investigated by the scintillation detectors placed at the vicinity of Internal Target Station (ITS) of Nuclotron. Data have been obtained at the angles of  $19^\circ - 54^\circ$  in the laboratory frame at the deuteron energy of 300 - 500 MeV in a various detector configurations in which the sensitivity to the three nucleon correlations and relativistic effects are assumed. Preliminary results of the five fold differential cross section for particular detector configurations of the dp breakup reaction at 400 MeV of deuteron energy have been obtained.

## 1. Introduction

Spin structure of the  $np$  SRCs has been investigated via the measurements of the tensor analyzing power  $A_{yy}$  in deuteron inclusive breakup at various energies in the wide regions of the longitudinal  $x_F$  and transverse proton momentum  $p_T$  [1]. The  $A_{yy}$  data demonstrate the dependence on two internal variables,  $x_F$  and  $p_T$  or their combinations. However none of used approach [2],[3] describe the data. Relativistic effects for the  $nd$  elastic scattering cross section at 70 MeV and 250 MeV were investigated in [4]. It was found that relativistic effects contribution is located mainly at backward angles, but their contribution is not large enough to fill discrepancy between experimental data and theory, even in the case when standard three nucleon forces [5] are used. For the  $d(n,np)n$  breakup reaction at 200 MeV large relativistic effects were observed in configuration where one arm is fixed and second arm scans the angular range. The contribution which comes from relativistic effects can reach up to 60%.

The goal of the Deuteron Spin Structure (DSS) experimental program is to obtain the information about two and three nucleon forces, including their spin dependent parts, from  $dp$  elastic scattering at the energies between 300 – 2000 MeV and  $dp$  breakup reactions with registration of two protons at deuteron energies of 300 – 500 MeV [6].





**Figure 1.** Energy correlation in corresponding detector arms at angles of  $35^\circ$  and  $43^\circ$  and deuteron energy of 400 MeV obtained by phase space simulation. Black curve represents kinematic  $S$ -curve on which events are projected.  $S$  is increasing in anti-clockwise direction.

## 2. Deuteron breakup reaction investigation using unpolarized beam

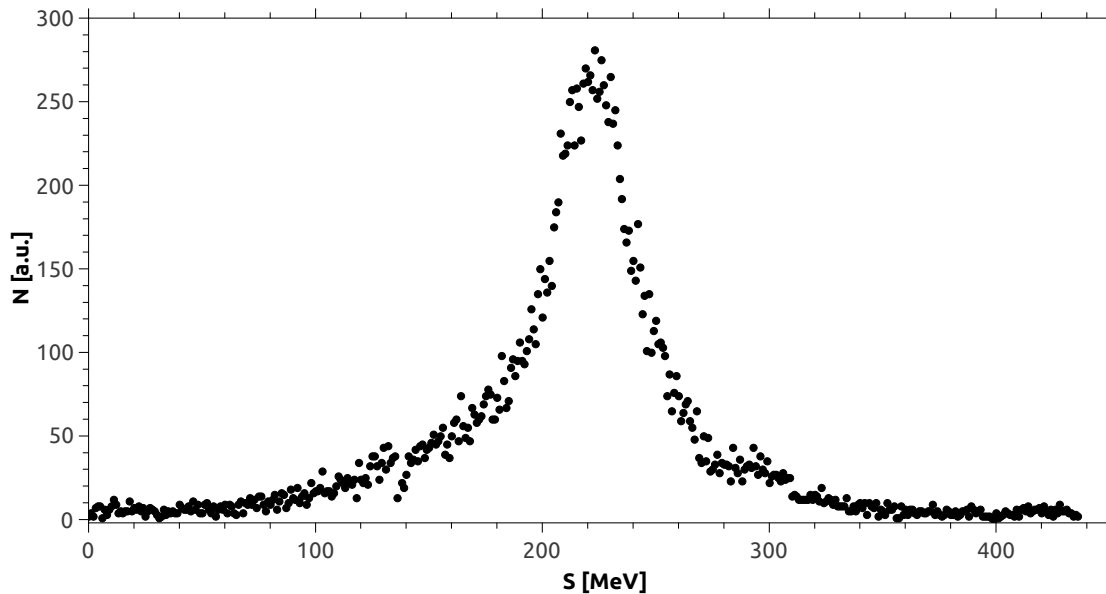
In this paper  $dp$  breakup reaction has been investigated at 400 MeV of deuteron energy. Polyethylene and Carbon targets are enclosed in a spherical hull of Internal Target Station [7]. The  $dp$  breakup reaction is investigated by the simultaneous registration of two protons by two detectors which works in coincidence. Effect on protons is obtained by subtracting Carbon spectra from Polyethylene one. Details of the  $\Delta E - E$  detector construction can be found in [8]. Reasonable agreement was obtained in comparison of energy spectra and missing mass distributions of  $dp$  breakup reaction between experiment and GEANT4 simulation which give us opportunity to handle with the signal and background in more flexible way [9]. The stability of amplitude of all photomultiplier tubes (PMTs) were monitored during all data acquisition. Detailed description of LED system of PMTs can be found in [8]. Assuming linear dependence of amplitudes on particle energy, calibration coefficients for particular  $\Delta E$  and  $E$  detector are obtained by solving the set of linear equations. Detectors have been placed under  $pp$  quasielastic kinematics at  $90^\circ$  cms at 300 MeV, 400 MeV and 500 MeV, where energies can be calculated from kinematics. Good agreement between experimental and simulated energy plots is observed. Detector energy resolution is  $\sim 11$  MeV. Detailed information about calibration procedure can be found in [10].

## 3. Cross section evaluation

Energy correlation in corresponding detector arms at angle of  $35^\circ$  and  $43^\circ$  and deuteron energy of 400 MeV obtained by phase space simulation is shown in Figure.1. The kinematic variable  $S$  corresponds to the arc-length along the kinematic curve with zero point chosen closest to axis origin. Black curve represents kinematic  $S$ -curve on which events are projected.  $S$  is increasing in anti-clockwise direction.

Part of presented data of  $dp$  breakup data was obtained at 200 MeV/n in 2014 follows inverse kinematics of the reaction in which relativistic effects can play a role [4]. The  $dp$  breakup data have been obtained under condition when one arm is fixed and second scans the angular interval allowed by mechanics. In our case one arm was fixed at polar angle ( $\theta_2$ ) of  $43.0^\circ$  and second was placed at angle ( $\theta_1$ ) of  $27.0^\circ$ ,  $31.0^\circ$ ,  $35.0^\circ$ ,  $39.0^\circ$  and  $43.0^\circ$ .

Data of kinematic  $S$ -curve are calculated with energy step ( $\Delta S$ ) of 5 MeV for the detector



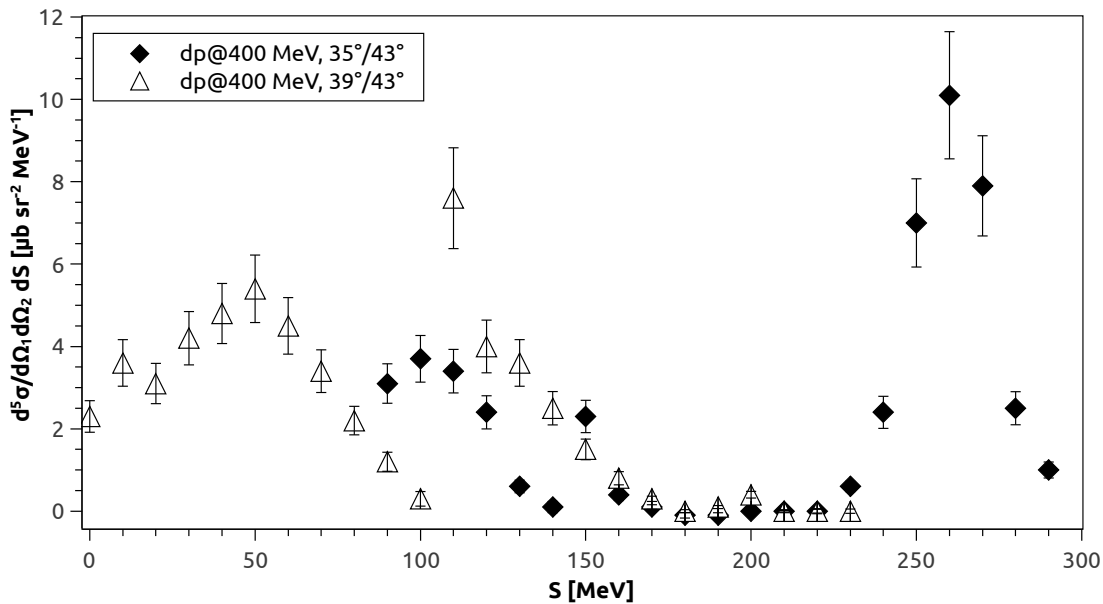
**Figure 2.** Kinematic  $S$  - distribution in corresponding detector arms at angle of  $35^\circ$  and  $43^\circ$  and deuteron energy of 400 MeV. Data have been obtained by phase space simulation.

arms placed at polar angles of  $\theta_1 = 35.0^\circ$  and  $\theta_2 = 43.0^\circ$  and  $\theta_1 = 39.0^\circ$ , and  $\theta_2 = 43.0^\circ$  and azimuthal angle between arms of  $179.2^\circ$  at deuteron energy of 400 MeV. The  $S$  is increasing in anti-clockwise direction. The number of breakup events in an interval  $(S - \Delta S/2, S + \Delta S/2)$  was obtained by projecting the events on the  $S$ -curve.

Kinematic  $S$  distribution in corresponding detector arms at angles of  $35^\circ$  and  $43^\circ$  and deuteron energy of 400 MeV is shown in Figure.2. Data have been obtained by phase space simulation. One can see peak with mean value of  $\sim 220$  MeV.

Number of useful events, beam intensity, detector solid angle and normalization coefficient are needed to calculate five fold differential cross section. Firstly, normalization coefficient have to be fixed. Number of useful events is obtained by projection on the  $S$  - curve and corrected by detector efficiency. Relative strong energy dependence of  $\Delta E$  efficiency is observed. Efficiency of  $E$  - detector is  $\sim 99\%$ . Beam intensity is obtained in a relative way by additional two scintillator counters placed right after the hull of ITS. Solid angle for particular configuration is obtained by Monte Carlo simulation in ROOT package. Then, normalization coefficient is calculated using number of useful events, relative beam intensity, detector solid angle and cross section of known reactions. In our case  $dp$  elastic scattering at 300 MeV and  $pp$  quasielastic reaction at 300 MeV, 400 MeV and 500 MeV were measured. Deviation of calculated normalization coefficients from four measured reactions are not larger then 15% with respect to their mean value. Then five fold differential cross section for  $dp$  breakup reaction for particular configuration is calculated.

Preliminary results of the five fold differential cross section of  $dp$  breakup reaction investigated at 400 MeV for the case of detector arms placed at the angles of  $35^\circ$  and  $43^\circ$ ,  $39^\circ$  and  $43^\circ$  are shown in Figure.3. Only statistical errors are shown.  $S$ - variable interval is cut due to detector acceptance. Preliminary data show some structures at the vicinity of  $\approx 100$  MeV and  $\approx 260$  MeV. Peak obtained in experimental spectra is shifted to the larger values in contrast to pure kinematic one.



**Figure 3.** Preliminary results of the five fold differential cross section of  $dp$  breakup reaction investigated at 400 MeV for the case of detector arms placed at the angle of  $35^\circ$  and  $43^\circ$  and  $39^\circ$  and  $43^\circ$ , respectively. Only statistical errors are shown. Range of presented data are limited by detector acceptance.

#### 4. Conclusion

Preliminary results of the five fold differential cross section of  $dp$  breakup reaction investigated at 400 MeV for the case of detector arms placed at the angles of  $35^\circ$  and  $43^\circ$ , and  $39^\circ$  and  $43^\circ$  have been obtained. Some structures are observed at  $\approx 100$  MeV and  $\approx 260$  MeV. The next step is to process data at remaining angles.

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