Simulation of $^3$He(d,p)$^4$He reaction and recent results of the experimental investigation of dp breakup reaction

To cite this article: M Janek et al 2016 J. Phys.: Conf. Ser. 678 012032

You may also like

- Clinical impact of time-of-flight and point response modeling in PET reconstructions: a lesion detection study
  Joshua Schaefferkoetter, Michael Casey, David Townsend et al.

- Data-driven respiratory gating based on localized diaphragm sensing in TOF PET
  Kyungsang Kim, Mengdie Wang, Ning Guo et al.

- Research on UWB-Based Indoor Ranging Positioning Technology
  Wei Jing and Huaxing Bian
Simulation of $^3\text{He}(d,p)^4\text{He}$ reaction and recent results of the experimental investigation of $dp$ breakup reaction

M Janek$^1$, P K Kurilkin$^2$, G Tarjanyiova$^1$, V P Ladygin$^2$, Yu V Gurchin$^2$, A Yu Isupov$^2$, J-T Karachuk$^3$, A N Khrenov$^2$, A K Kurilkin$^2$, A N Livano$^2$, G Martinska$^4$, S M Piyadin$^2$, S G Reznikov$^2$, S P Merts$^2$, P N Batyuk$^2$, A A Terekhin$^2$ and I E Vnukov$^5$

$^1$Physics Department, University of Zilina, Univerzitna 1, 01001 Zilina, Slovakia
$^2$Veksler and Baldin Laboratory of High Energies, Joint Institute for Nuclear Research, Joliot-Curie 6, 141980 Dubna, Moscow region, Russia
$^3$Advanced Research Institute for Electrical Engineering, Splaiul Unirii 313, Bucharest, Romania
$^4$Institute of Physics, University of P. J. Shafarik, Park Angelinum 9, 04001 Kosice, Slovakia
$^5$Belgorod State University, Pobedy 85, 308015 Belgorod, Russia

E-mail: janek@fyzika.uniza.sk

Abstract. The feasibility study for the measurements of the polarization observables in the $^3\text{He}(d,p)^4\text{He}$ reaction for DSS project using a part of the BM@N setup have been performed. Deuteron beam with energy of 1.5 GeV, magnet, 12 stations GEM tracker and TOF wall were used in simulations in order to obtain momentum resolution and to prove the separation of the secondary protons and deuterons. Summarized results of the $dp$ breakup reactions with detection of two protons in coincidence for some kinematic configurations at energies from 300 to 500 MeV obtained in Nuclotron are presented.

1. Short introduction

Short range correlations (SRC) of nucleons in nuclei is the subject of intensive theoretical and experimental works during last decade. They can be considered as the drops of cold dense nuclear matter [1] with density five times larger than density in the centre of nucleon. One of the tools to study spin structure of SRC is the measurements of the cross section, tensor analyzing power $T_{20}$ and spin correlation parameter $C_{yy}$ in the $d^3\text{He} \rightarrow p(0^+)^4\text{He}$ reaction [2] at the energies between 1000 and 1750 MeV using polarized $^3\text{He}$ target [3] and extracted polarized deuteron beam from new polarized ion source [4] at Nuclotron.

2. The $d^3\text{He} \rightarrow p^4\text{He}$ reaction at extracted beam at Nuclotron.

One of the goals of the $d^3\text{He} \rightarrow p^4\text{He}$ reaction study at Nuclotron is to understand the reason of the behaviour of the tensor analyzing power $T_{20}$ in $dp$ backward elastic scattering [5]. Other goals are related to the accumulation of the data on polarisation observables, full determination of the matrix element of the reaction in the model independent way and the study of the short-range spin structure of the deuteron and non-nucleonic degrees of freedom. The experiments...
performed at RIKEN at the energies below 270 MeV have shown that the polarization correlation coefficient, \( C_{//} = 1 - 1/(2\sqrt{2})T_{20} + 3/2C_{x,y} \), for the \( ^3\text{He} \rightarrow p^4\text{He} \) reaction can be a unique probe to the D-state admixture in deuteron [2]. In the one nucleon exchange approximation, the expression for \( C_{//} \) is proportional to the D-state fraction in deuteron as \( C_{//} = 9/4u^2/(4u^2+w^2) \) where \( u \) and \( w \) are the S- and D-state wave functions of deuteron in momentum space.

Experiment is planned to be carried out with extracted deuteron beam of Nuclotron at the BM@N area at energy range of 1.0 - 1.75 GeV. The possibility of the \( ^3\text{He} \rightarrow p^4\text{He} \) reaction study is investigated using GEANT4 and ROOT simulation package. There are serious requests on beam size and emittance in the target crossover point. In Fig.1 beam size in vertical and horizontal direction at crossover points F3, F4, F5 and F6 is shown. Deuteron beam hits the \( ^3\text{He} \) target which is placed in the one of the focuses of the beam transportation line of Nuclotron. The length of polarized \( ^3\text{He} \) target is 30 cm. Scattered protons and deuterons, as well as primary deuterons pass along transportation beam line with magnetic elements tuned for the optimal momentum of the secondary protons \( \sim 75\% \) of the initial deuteron beam momentum. The simulation has been performed for the initial deuteron kinetic energy \( T_d = 1.5 \) GeV and 30 cm of the \( ^3\text{He} \) target cell using the GEANT4 toolkit. The software model reflects only substantial parts of BM@N setup. In the first variant of simulation \( ^3\text{He} \) target has only been used while in the second one the quartz radiator of 2 mm thick was added as a TOF start counter. The hadronic interaction of the secondary particles with the target, air and start counter was simulated using GEANT4 with using QBBC physics list with the Binary Cascade model. Quartz radiator spreads the size and the number of particles in the secondary beam due to additional multiply scattering on it in comparison with the first variant, however, the number of these events is quite small for both cases. The further simulation has been performed for the setup with quartz radiator. The momentum of the secondary protons has been taken within 7% around the momentum of proton coming from the binary \( d^3\text{He} \rightarrow p^4\text{He} \) reaction. The momentum reconstruction of particles is based on the information derived from 12 GEM stations placed in the inhomogeneous magnetic field defined by a field map. The simulation has been performed at different field map scale factors: half of the magnetic field value and at maximal one. At this stage the BM@N setup with 12 stations of GEM tracker situated in the magnet can provide the momentum resolution of \( \sim 1.5 - 2\% \). The time difference between mRPC and start detector will be used to separate protons from the background deuterons. At base line of \( \sim 24 \) m the signal protons and background deuterons are separated by \( \sim 20 \) ns. Additional improvement of the momentum resolution can be done by removing of the additional material along the beam line as well as by the increasing of the space resolution of the tracking detectors.

Thus, the BM@N setup can be used as for the studies of the short-range spin structure of the deuteron via deuteron fragmentation processes, \( dA \rightarrow pX \) and \( dA \rightarrow \pi^-X \), with the momentum resolution provided by the 12 stations GEM tracker [6].
3. **Deuteron breakup reaction investigated on Carbon and CH$_2$ targets.**

The experimental data accumulation for a large region of the phase space is requested, because in various region different effects, such as relativistic effects, non nucleonic degrees of freedom, three nucleon forces and also coulomb effects can be investigated. Deuteron breakup on nuclei have rich phase space therefore is interesting to investigate final states. Motivation to study three nucleon forces can be, e.g., observed discrepancy between experimental data and theoretical calculations based on nucleon-nucleon and three nucleon potentials in case of the dp breakup measured at 19 MeV [7] and 130 MeV [8].

The $dp$ breakup reaction is investigated at intermediate energies from 300 - 500 MeV of deuteron energy with eight $\Delta E - E$ scintillation detectors [9]. Special setup of the detectors has been chosen in the experiment performed at 2014. Four detectors have been placed at certain position in the vicinity of the target to follow inverse kinematics of the reaction in which relativistic effects can play a role [10]. Polyethylene and Carbon targets enclosed in a spherical hull made from stainless steel are used to obtain $dp$ reaction via subtraction of Carbon spectra from Polyethylene. Mean axis of the detector pass through the target and with incoming deuterons create the angle $\theta$. Angle between detectors in plane perpendicular to the direction of the deuteron beam is denoted by $\phi_{12}$ and it is fixed to 180°. Solid angle of each of detector is 4.6°. Angles $\phi$ and $\theta$ of the first and second detector specify a detector configuration.

Calibration coefficients (function) have been obtained by calibration procedure which used amplitude and time difference information from PMT’s and known values of proton energies of $pp$-quasi elastic reaction. Cross check of obtained calibration coefficients has been done in $dp$ quasi elastic reaction configuration where except deuterons also protons from $dp$ breakup exist. In Fig. 2 distribution of excitation energy for the case of $dCH_2$ and $dC$ reactions when deuterons from $dp$ quasi elastic reaction reach the detector at mean angle of 27°. Second arm is at angle of 43°. Azimuthal difference between arms is 180°. Clear peak in $dCH_2$ spectra around zero value is caused by $dp$ elastic events. The result confirms also obtained missing mass spectra if deuteron and proton is assumed to reach detector arms.

![Figure 2. Distribution of excitation energy for the case of $dCH_2$ (non shaded spectra) and $dC$ (shaded spectra) reactions when deuterons from $dp$ quasi elastic reaction reach the detector at mean angle of 27°. Second arm is at angle of 43°. Azimuthal difference between arms is 180°.](image)

The kinematical variable $S$ corresponds to the arc-length along the kinematical variable $S$, with zero point chosen at the minimal value of deposited energy in the second arm. The number of breakup events in an interval $S - \Delta S/2$, and $S + \Delta S/2$ was obtained by projecting the events on a line perpendicular to the S-curve. The statistical error associated with the background subtraction is roughly given by $\Delta N_{dp} = \sqrt{N_{CH_2} + \Delta^2 N_C}$, where the $\Delta$ is normalization coefficient of Carbon target. Preliminary result for the $\Delta S = 10$ MeV and for the arm’s polar angles of $\theta_1 = 25°$, $\theta_2 = 34°$ and azimuthal angle between them $\phi_{12} = 135°$ at 300 MeV is presented in Fig. 3.
4. Conclusions

The feasibility study of the measurements of the polarization observables in the $d^3He \rightarrow p^3He$ reaction at 1500 MeV by means of Geant4 simulation with using a part of the BM@N setup and start counter of the TOF system $\sim$20 m upstream the analyzing magnet has been performed. Perfect separation of the secondary protons and deuterons is demonstrated. Partial improvement of the deuteron beam emittance can be done by removing unnecessary equipment along the transportation line. Mentioned experiment can be performed as a part of the commissioning of the BM@N setup in the complete configuration. Momentum resolution at current stage is $\sim 2\%$ due to software tracking system recognition. Feasibility study shows that BM@N setup can be used for the studies of the short-range spin structure of the deuteron via deuteron fragmentation processes with the momentum resolution provided by the 12 stations GEM tracker.

The Geant4 simulation has been performed to give insight into $dp$ breakup reaction via $dCH_2 \rightarrow ppX$ and $dC \rightarrow ppX$ reaction at 300, 400 and 500 MeV mainly for detector configurations used in experiment. Obtained energy and missing mass spectra have been compared with experimental one. Excitation energy for the case of deuteron proton quasi elastic scattering at detector configuration which satisfy $dp$ quasi elastic reaction is obtained as a cross check for obtained calibration coefficients (function). Preliminary result of $S$ variable is obtained after background subtraction at 300 MeV for the arm’s polar angles of $\theta_1 = 25^\circ$, $\theta_2 = 34^\circ$ and azimuthal angle between them $\phi_{12} = 135^\circ$ is presented.

Acknowledgments

The work has been supported in part by the VEGA 1/0556/16 and RFBR grant 13-02-00101a.

References

[1] L. Frankfurt, M. Sargsian, M. Strikman 2008 *Int.J.Mod.Phys.* A23 2991
[2] T. Uesaka et al. 1999 *Phys.Lett.* B467 199
[3] T. Uesaka et al. 1998 *Nucl.Instr. and Meth. in Phys.Res.* A402 212
[4] V.V. Fimushkin et al. 2008 *Eur.Phys.J.* ST 162 275
[5] V. Punjabi et al. 1995 *Phys.Lett.* B350 178
[6] V.P. Ladygin et al. 2014 *PoS BaldinISHEPPXXII* 098
[7] J. Ley et al. 2006 *Phys. Rev. C* 73 064001
[8] S. Kistryn et al. 2003 *Phys. Rev. C* 68 054004
[9] S. M. Piyadin et al. 2011 *Physics of Particles and Nuclei Letters* 2 V.8 107
[10] H. Witala, J. Golak, R. Skibinski, W. Glocle, W. N. Polyzou and H. Kamada 2011 *Few-Body Syst.* 49 61
[11] M. Janek, B. Trpisova, S. M. Piyadin and V. P. Ladygin 2014 *Physics of Particles and Nuclei Letters* 4 V.11 552559

Figure 3. Preliminary result of $S$ variable (MeV) is obtained after background subtraction at 300 MeV for the arm’s polar angles of $\theta_1 = 25^\circ$, $\theta_2 = 34^\circ$ and azimuthal angle between them $\phi_{12} = 135^\circ$. 