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A Complete Low-Energy Polarized Proton-Deuteron Breakup Experiment[1, 2]

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Abstract—An experiment at low energy will be done at the COSY cooler synchrotron and storage ring in order to study the three-particle final states of proton-deuteron scattering reactions measuring a complete set of single and double spin observables over large areas of phase space. The physics objective is to test the predictive power of chiral effective field theory at an energy where convergence is guaranteed and few previous measurements exist. A direct comparison between theoretical predictions and experimental data will be enabled by the use of the so called sampling method.

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1. INTRODUCTION

The main objectives for the planned study [1] are twofold; to provide a rich testing ground for the modern theory of nuclear forces, the chiral effective field theory [2], and to study the effects of three-nucleon interactions in this framework. Additional significant motivation worthwhile special attention is the fact that the proton deuteron breakup scattering process constitutes both the background and an obvious potential source of symmetry breaking observables in planned experimental tests of fundamental symmetries [3–4].

The high-precision nucleon-nucleon (NN) potentials [5] created in the nineties successfully reproduced the NN scattering data with a chi-square close to one. However the quantitative success was not on a par with a corresponding increase of the physics understanding given the 40–50 fitted parameters inherent in the phenomenology. A major advancement in theoretical nuclear physics was achieved with the concept of effective field theories [6] that led to the development of the *chiral* effective field theory (EFT) based on the approximate spontaneously broken chiral symmetry of QCD utilizing the proper degrees of freedom in hadronic interaction energies given by pions and nucleons. One advantageous feature of chiral EFT is that three- and few-nucleon interactions enter consistently at increasing order providing a model independent theoretical interpretation of few-body forces whereas previously models for 3N forces were add-on features for the NN potentials. As was shown clearly in [7] the latter approach led to contradicting conclusions in the comparison of data and theory, see [8] for a recent comprehensive review.

[1] Talk at the 20th International Symposium on Spin Physics (SPIN2012), JINR, Dubna, September 17–22, 2012.

[2] The article is published in the original.

2. EXPERIMENT AT COSY

The cooler synchrotron and storage ring COSY at Forschungszentrum Jülich provides polarized proton and deuteron beams up to momenta of 3.7 GeV/*c*. The experiment will use proton beam energies in the range 30 to 50 MeV. Deceleration of the proton beam from the COSY injection energy 45 MeV has been successfully tested [9].

Double spin observables can be measured with the recent addition of the PAX facility situated in a low-β section of the ring. Polarized hydrogen and deuterium gas targets are produced by a thin (5 μm) teflon storage cell fed by a vector and/or tensor polarized atomic beam source (ABS). A Breit-Rabi Polarimeter (BRP) together with a Target Gas Analyzer (TGA) are installed for the calibration of the target polarization. The spin alignment of the polarized target gas is maintained by guide fields of the order of 1 mT generated by Helmholtz-like coils surrounding the target scattering chamber, one coil for each spatial direction x, y and z with the possibility of simultaneously powering more than one coil. In conjunction with a polarized proton beam either vertically or longitudinally polarized, all 22 independent polarization observables in spin-half spin-one collisions can be accessed [1].

A detection setup is being designed made up of three layers of double sided silicon strip sensors arranged in a barrel type configuration for large azimuthal coverage. Total acceptances for breakup of eight and five percent for 30 and 50 MeV proton beam energies respectively, were deduced by GEANT4 simulations of the setup. With the characteristics of the experiment and the total cross sections taken into account, aiming at a statistical uncertainty of 0.002 in the determination of the observables, a total of eight weeks production running is required including two beam energies and using both vertical and longitudinal beam polarization. The precision capacity of our

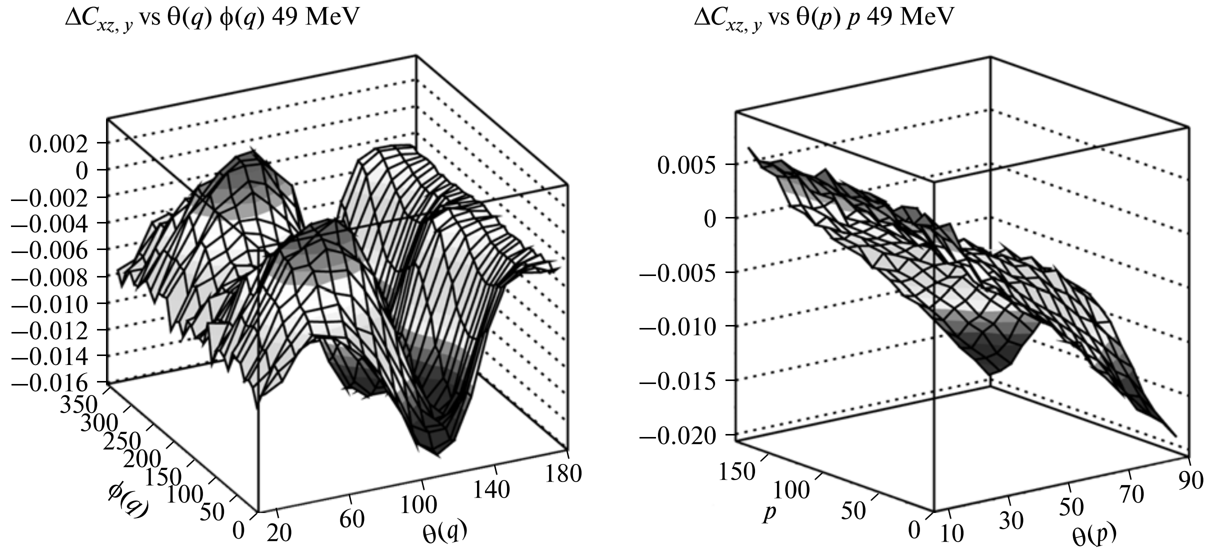

Fig. 1. Profile histograms of the *difference* between 3N+NN and pure NN theoretical predictions at N2LO using cutoff $\Lambda =$ 550 MeV, of the tensor-vector correlation coefficient $C_{xz,y}$ at 49 MeV beam energy; as function of the azimuthal and the polar angle of the neutron in cm (*Left*), as function of the relative momentum between the two outgoing protons in center-of-mass and its polar angle (*Right*).

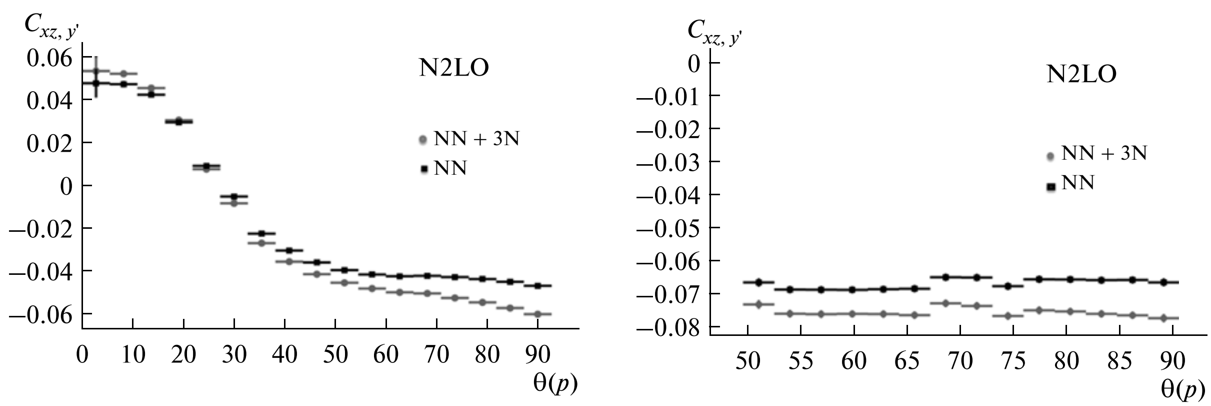

Fig. 2. Profile histograms of $C_{xz,y}$ at 49 MeV proton beam energy (3N+NN red) (NN black) as function θ_p integrated over other independent variables with cuts on θ_q (*Left*), θ_q, θ_p and p plus geometrical cuts of the planned setup (*Right*).

experimental setup was recently shown to be of the order of 10^{-3} for a measured asymmetry [10]. Experimental details can be found in [1].

2.1. Sensitivity Studies

In preparation for the measurements sensitivity studies of spin observables were done using the sampling method [11] on pre-calculated theory grids spanned by more than 4×10^6 kinematical configurations[3]. In Figs. 1 and 2 the tensor-vector correlation coefficient $C_{xz,y}$ is studied, an observable of interest also for the TRIC experiment. Isotropically generated proton deuteron breakup events were used as kinematical input for a multidimensional linear interpolation on the grid. The adopted analysis technique provides convenient access to selected theoretically interesting parts of phase space. The aim for the planned experiment is to measure most of the spin observables in *pd* breakup with large coverage in order to offer a large data set for testing the predictive power of the chiral EFT and to remedy the confused state concerning the nature of three-nucleon interactions.

[3] The theoretical grids were created by A. Nogga.

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