3-Nucleon Force in Proton Polarized Helium-3 Scattering

Feasibility Studies

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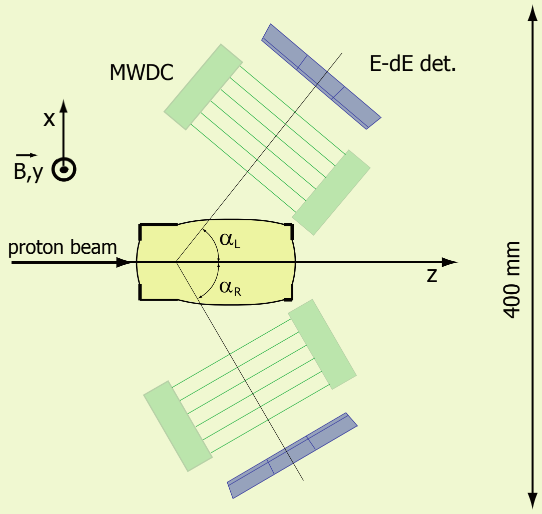
The ultimate goal of the project is the measurement of vector analyzing power and differential cross section for protons scattered on a polarized helium-3 target in elastic scattering and breakup reactions. The experiment is planned to be performed at the Institute of Nuclear Physics PAS in Kraków - Cyclotron Center Bronowice (CCB) with the use of the AIC-144 cyclotron operating at the proton beam energy of 60 MeV in the first phase and around 200 MeV at PROTEUS 235 cyclotron in the second phase. The key idea of this experiment is a precise reconstruction of the reaction vertex, allowing for efficient background reduction, and for accurate knowledge of the reaction kinematics.

This is the extension of current research of our group, focused mostly on three-nucleon (3N) environments, to four-nucleon (4N) systems, a first step from few, towards many body systems. The importance of 4N systems is enhanced by expected larger contribution of 3-nucleon force (3NF) and a possibility to investigate different total isospin contributions to the 3N interaction. The measurement will provide data which will be used to explore three-nucleon forces (3NF) effects in a different environment, what has a potential to give new insight into the problem. Current progress in the theoretical calculations describing 4N systems dynamics is a main motivation to investigate ^{3}He scattering at medium energies.

In order to look into subtle spin effects of the interaction, the project assumes the construction of the helim-3 polarized target together with the dedicated detector setup, and the data acquisition system.

The data will fill gaps in already existing sparse in number and imprecise database at medium energies for the 4N systems and will be used for verification of theoretical approaches. They will also be useful to check the sensitivity to 3NF effects in the 4N environment and also to other dynamical effects.

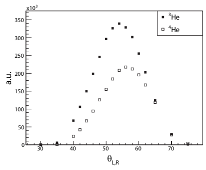


Results of the Monte-Carlo simulation of the detector

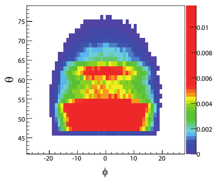
Monte-Carlo simulations of the detector have been performed. Accounted for were:

- experimental cross section for p-^{3}He and p-^{4}He reactions,
- detector geometry and materials,
- measured proton beam lateral distribution and divergence,
- particle dependent energy losses.

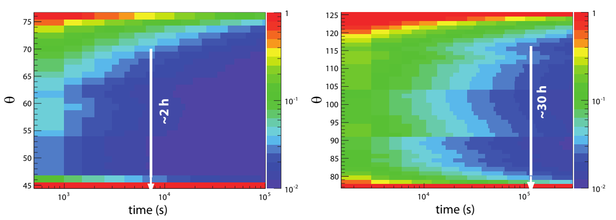
Figure on the right shows total rates expected for p-^{3}He and p-^{4}He elastic scattering for symmetric detector configuration, as a function of detector module inclination angle alpha. Below, the event distribution, as a function of polar and azimuthal angles in LAB frame, for optimal module inclination angle is presented.



Assuming conservatively rather low beam current of 100 pA and uncertainty of helium-3 polarization of the order of 1% one may calculate the time needed to reach given accuracy of analyzing power measurement.
Figures below show this uncertainty as a function of the polar angle in LAB frame and the time of a measurement, for symmetric and maximally asymmetric detector configurations. One may observe that in order to reach total uncertainty of 2% one needs around 2 hours for symmetric, and more than one day for the maximally asymmetric detector configuration (white lines in the plots below).



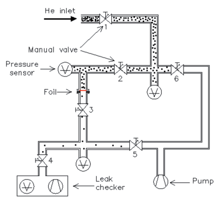
Uncertainty of analyzing power as a function of time of measurement and proton polar angle in LAB

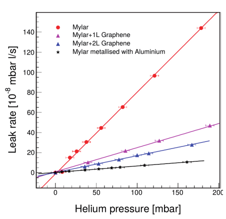


Tests of scattering chamber windows

On their way to the detector particles produced in p-^{3}He scattering cell penetrate through a chamber windows. A compromise has to be found between the thickness, minimum permeability to extremely precious helium isotope, and the strength of these windows. Dedicated studies, including very promising in this context graphene coating, have been performed (on the right).

As a result we consider applying commercially available and much cheaper then graphene coating solution: double-side aluminized 0.01 mm Mylar foil, featuring significantly lower diffusion and able to sustain 2 bar overpressure. (tested for a target cell still without side windows, see below)

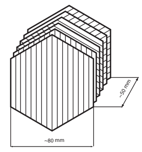


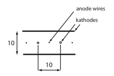


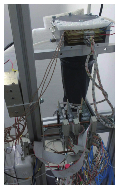
Multiwire Drift Chamber

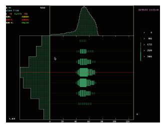
For precise reconstruction of charged particle trajectories a set of two identical Multiwire Drift Chambers, each consisting of six measuring planes, is proposed. Sense wires, arranged as shown beside, an three different directions, will allow for unambiguous reconstruction of even two track in each chamber. Pulse-height information recorded alongside with the drift time will facilitate particle identification, which in case of this experiment reduces to the distinction between protons, deuterons and helium-3 ions.

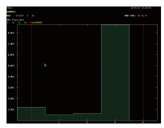
Full size, 3-plane prototype has already been built, and is currently being tested.





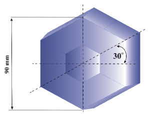


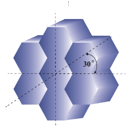




E-dE detector

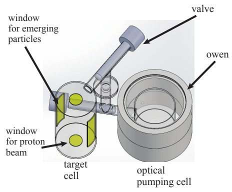
In order to provide fast trigger signal, necessary for MWDC, and to identify detected particles, as well as to reconstruct their total energy, a system of phoswitch scintillator detectors is proposed. Significant decrease of the detection threshold can be achieved by using pulse-height information from the drift chambers and/or application of Pulse Shape Analysis from CsI scintillators instead of phoswitch mode. The later possibility shall be considered in the case of the measurement at higher proton beam energy in order to avoid very thick scintillators. Each module will be read out by a single silicon PM. The final detector geometry is a subject of optimization.





Polarized target

One to the most important component of this experiment is the polarized helium-3 target. In order to obtain and to maintain large nuclear polarization the Spin Exchange Optical Pumping (SEOP) method is proposed. In this method helium-3 nuclei are oriented by spin exchange with optically pumped rubidium atoms. It allows one to achieve relatively high degree of nuclear polarization and acceptable luminosity due to high pressure of helium gas. In order to decuple polarization function from the scattering cell we propose to use a double cell structure (shown below), with heated optically pumped polarizing cell, and scattering cell at room temperature, connected to the polarizing cell via a cold trap - limiting penetration of rubidium vapor to the target area (not shown in the scheme below).



Setup for tests of double cell structure proposed in this experiment (up), and searching for a leak in the glass junction (left side)