Dynamics of few-nucleon systems

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We propose a research program in the domain of few-nucleon systems to be performed with proton beams at the new cyclotron facility of the Cyclotron Center Bronowice. We aim at precise measurements of the differential cross sections of the elastic scattering and the kinematically complete deuteron breakup processes in proton-deuteron collisions. The studies, carried out over a wide range of beam energies, in almost the whole phase space, would provide very rich, worldwide unique data sets for systematic verifications of current and future approaches to describe the interaction details in few-nucleon systems.

We assume that the undergoing negotiations with foreign partners (Swiss laboratories at Uni Basel and PSI, KVI, FZ Jülich) will be successfully completed with decisions of transferring different experimental equipment to Cracow. The main purpose is to obtain the whole detection setup BINA from KVI, which includes liquid target assembly, the detector system (wire chamber and scintillation hodoscope) with the complete electronics.

Below we present the headlines of the planned research. In the first phase, tests with the AIC-144 beam at the old experimental hall are to take place, and, provided their outcome concerning the beam characteristics allows, also certain measurements are performed. Moreover, investigations towards optimization of the system for the second phase are foreseen. The main activity is grouped in the second phase, that is measurements with the optimized setup at the new CCB facility. We consider also possible extensions of the program as the third phase.

1. Stage I

- **Feasibility studies**
  As the first step AIC-144 beam studies at the old experimental hall are considered, with the focus on optimizing beam collimation and beam profiles.

- **Performance tests of detector elements**
  With the optimized beam, tests of specific parts of the detection systems are foreseen. Development of the measuring procedures and methods (e.g. beam energy degradation, precise intensity monitoring) is to be carried out. Upgrade of relevant detector elements is to be performed on the basis of the test results.

- **Measurements**
  If the beam parameters are found to be satisfactory, it is conceivable to perform the elastic scattering and breakup reaction measurements at selected kinematical configurations, with a number of semiconductor telescopes positioned at specific angles in a vacuum scattering chamber; they arrangement should be based on theoretical advises, pointing at the most interesting (showing the highest sensitivity to certain effects) phase-space configurations. Even discrete geometries can be very valuable in studies of e.g. three-nucleon force effects or Coulomb force influences.

2. Stage II

- **Feasibility studies at the new cyclotron**

  The tested previously detector elements and the simple experimental setup will be used to verify and optimize beam properties and investigate background conditions at the experimental station in the new CCB hall. After installation of the BINA setup, performance of all experimental subsystems will be checked (liquid target assembly, detector electronics, the full trigger electronics and data readout/acquisition system, including on-line monitoring software).

- **Elastic scattering in proton-deuteron system**

  Elastic scattering can be investigated with the test scattering chamber (only selected registration angles) and LD_2 target, providing physical results and a benchmark for measurements with the BINA system. Scan over beam energies will allow for relative normalization to the precisely known cross section values at several energies, eliminating in this way systematic uncertainty due to limited precision of the liquid target effective thickness determination.

- **Cross section measurements with BINA**

  After BINA detection system is installed and brought into operation, the measurements of elastic scattering and breakup reactions will be carried out, with an almost complete phase-space coverage (full detection efficiency for charged particles). These studies, performed over wide range (70 – 230 MeV) of proton beam energies, will provide the first (world wide) so consistent and systematic data base for investigating 3N continuum at medium energies.

- **Electromagnetic reactions in 3N system**

  Including detection of gamma-quanta will enable to study also processes of radiative capture, like $p + d \rightarrow {}^3He + \gamma$.

3. Possible extensions ─ stage III

- **New detector for few nucleon systems studies**

  Development of possibly optimal detection system, having all advantages of BINA, but even more versatile and avoiding its shortcomings (lower energy threshold, increased neutron detection efficiency).

- **Four nucleon systems**

  An extension of studies to four nucleon systems, i.e. measurements of two-, three- and, ultimately, four-body exit channels in reactions induced by proton beams on A=3 nuclei.

- **Measurement of analyzing powers in proton-deuteron collisions**

  Demanding and ambitious task is a development of vector and tensor polarized deuterium target (cryogenics, strong magnetic field). International collaboration partners are currently being identified.

- **Proton scattering on light nuclei**

  Studies of proton-induced reactions on light targets, leading to few-body exit channels.