Investigation of the mechanisms of spallation reactions

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The knowledge of the mechanism of spallation reactions induced by protons and pions on various atomic nuclei is crucial for unerstanding of many physical phenomena as, e.g., the modification of nuclear content of cosmic rays during their propagation through the interstellar space, evolution of heavy stars, etc. [1]. It is also crucial in many technical applications as, e.g., accelerator driven subcritical reactors as well as in radioactive waste transmutation [2], construction and application of spallation neutron-sources [3]. Thus, the knowledge of spallation cross sections is indispensable for understanding of these physical phenomena and for technical applications. Since some of the important targets and/or product nuclei are unstable it is necessary in such a case to rely on theoretically estimated spallation cross sections.

While modern theoretical models of spallation reactions reproduce most of the main properties of the data, there are still observed significant deviations of the model predictions from the data. This concerns both, total production cross sections [4] and differential cross sections ($d\sigma/d\Omega dE$) [5–9] for the proton-nucleus collisions in broad range of the proton beam energy (from 0.175 GeV to 2.5 GeV). Such deviations are mainly observed for light charged particles LCP, i.e. p, d, t, ^{3}He and ^{4}He and intermediate mass fragments IMF, i.e. Li, Be, B ... particles lighter than fission products emitted at forward scattering angles. This indicates a presence of some non-equilibrium processes which are not involved in the standard models of the spallation reactions. It has been reported [5–9] that introducing a phenomenological contribution from fast, hot moving source improves significantly description of data (cf. Fig. 1).

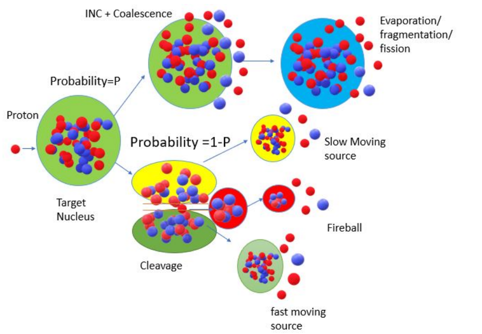

FIG. 1: Possible modes of the spallation reactions. The proton of the beam impinging from the left on to the target nucleus initiates with probability P the intranuclear cascade of nucleon-nucleon and pion-nucleon collisions (present day models) or may induce with probability 1-P a cleavage of the target nucleus into three excited groups of nucleons: the smallest - fireball and two larger - the fast and slow moving sources (possible preequilibrium processes).

In order to investigate such missing mechanism in the present-day models it is planned to perform theoretical analysis of available data on proton and pion induced reactions on broad range of target nuclei (from C up to Au) in the beam energy range up to about 2.5 GeV. A pilot experiment has been already done using the PROTEUS cyclotron of the Cyclotron Centre Bronowice (CCB) at low proton beam energy of 0.23 GeV. Results of this experiment are promising and may be used to analyze the background for upcoming experiment.

The KRATTA (Krakow Triple Telescope Array) [10] detection systemwas used to measure the energy, angle of emission and isotopic composition of ejectiles. The KRATTA

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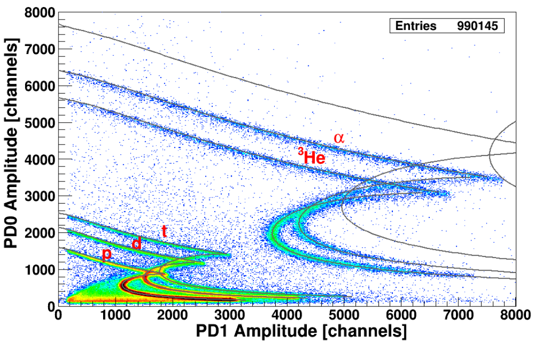

FIG. 2: The ΔE-E map for PD0 and PD1 of the KRATTA detector. PD0 is the signal from first photodiode and PD1 is the sum of signals from the second photodiode and first scintillation detector. The lines supperimposed on to the scatter plot represent different ejectiles and are determined using the ATIMA range-energy tables [10].

detector is consisted of three PIN photodiodes (PD0, PD1, PD2) and two CsI(Tl) crystal scintillation detectors. The thickness of all photodiodes is the same (500 ± 15 μm) whereas thicknesses of the first and the second CsI(Tl) crystals are 2.5 cm and 12.5 cm, respectively. The first photodiode serves to obtain ΔE signal while the second photodiode reads also light signal from the first CsI(Tl) crystal what enables to determine total energy E. The example of identification spectra for proton at energy 230 MeV on Carbon target is shown in Fig. 2. It is also possible to get ΔE-E map using light signal from thin and thick CsI crystals.

It is planned to investigate proton induced spallation reactions using the beam from the PROTEUS cyclotron of the CCB in the proton energy range 0.07 - 0.23 GeV. The single $d\sigma/d\Omega dE$ and coincidence spectra $d\sigma/d\Omega_1 dE_1 d\Omega_2 dE_2$ of LCP and IMF will be measured on various target nuclei (Al, Ni, Ag, Au). The coincidence cross sections together with inclusive differential cross sections should provide stringent constraints to the existing models of the spallation reactions. The main goal of this experiment is to investigate experimentally the hypothesis presented above i.e. the presence of the fast moving source contribution to the reaction mechanism by providing the inclusive and exclusive (coincidence) data which can allow to significantly improve the present understanding of the interaction of protons with atomic nuclei.

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