Transfer reactions and silicon detector testing with the ELISSA prototype

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1 Motivation

Testing of the X3 detectors from Micron Semiconductor Ltd. [1] at ELI-NP with α-source using a conventional read-out chain based on charge-sensitive Mesytec MPR-16 preamplifiers showed better results than those published for similar arrays (ANASEN or ORRUBA). Now we propose to perform more complex tests using deuteron beams and three targets: ^{12}C, ^{24}Mg, and ^{197}Au. The proposal has primarily the aim of testing part of the ELISSA array developed by an ELI-NP and INFN-LNS collaboration and develop the data acquisition system. The proposed tests will evaluate the technical capabilities of our detectors and identify the problems.

The single particle spectroscopic factor is introduced in the context of shell model and measures the occupancy of nuclear orbitals generated by a mean field. It is an important value to calculate the cross sections of low-energy nuclear reactions using the practical nuclear reaction models, especially for the reaction involving the process of single particle excitation. On the other hand, the neutron and proton capture reactions play a key role in the astrophysical s-, p-, r-, and rp-processes, whose reaction rates are the necessary inputs to calculate the nucleosynthesis for these astrophysical processes. To determine the cross section and reaction rates for these capture reactions at the low energy range of astrophysics interest, nuclear reaction models considering both of the compound capture and direct capture mechanisms have been developed. The spectroscopic factor is a crucial input in these reaction models. In particular, the spectroscopic factor is related to the resonant parameter which is used in Breit-Wigner formula and Hauser-Feshbach model to determine the cross section for compound capture reactions. Meanwhile, to calculate the cross section of direct capture reaction, the perturbative theory is usually employed, in which the spectroscopic factor is a key input to determine the matrix element in the calculation form. Experimentally, the neutron transfer reaction via A(d,p)B reaction channel has been widely used to extract the neutron spectroscopic factor. More specifically, the experimental angular distributions of A(d,p)B reaction are analyzed within the theoretical framework like Distorted Wave

Bonn Approximation. Furthermore, according to the properties of nuclear mirror state between nucleus A + n and nucleus A + p, the proton spectroscopic factor could also be studied from the nuclear structure information of A + n obtained by A(d,p)B reaction. In this proposal, the measurements of transfer reactions ^{12}C(d,p)^{13}C and ^{24}Mg(d,p)^{25}Mg are suggested. The neutron spectroscopic factors for n+^{12}C=^{13}C and n+^{24}Mg=^{25}Mg can be extracted by the analysis of the experimental angular distributions for these transfer reactions. The nuclear structure of the mirror states p+^{12}C=^{13}N and p+^{24}Mg=^{25}Al can also be studied, and the corresponding proton spectroscopic factors can be determined as well. Eventually, these proton spectroscopic factors will be used to calculate the astrophysical reaction rates for the important proton capture reactions ^{12}C(p,γ)^{13}N and ^{24}Mg(p,γ)^{25}Al.

2 Experiment description

We propose to study the transfer reactions at incident deuteron energies between 1 MeV and 10 MeV using one ring of the proposed ELISSA array. The primary goal is to measure deuteron-induced cross-sections for several transfer reactions. The deuteron beam with a spot size of about 1.5 mm^2 will impinge on the target at a maximum current of 5 nA (10 MeV deuterons). The produced protons will be detected using an array of twelve position sensitive silicon strip detectors (see Figure 1). A Faraday Cup will be mounted behind the array to measure the intensity of the deuteron beam.

One ring with 12 silicon detectors X3 will be located in the forward direction. These detectors are position sensitive, 1000 μm-thick resistive strip detectors. The geometrical coverage over a polar range is from 45° to 85° at full coverage along the azimuthal angle. The beam tests will be carried out using a read-out chain based on charge-sensitive MPR-16 preamplifiers from Mesytec. The front side of the X3 detector is divided into four position sensitive strips resulting in eight signals. Sixteen signals from the front sides of the two X3 detectors, as well as the bias voltage of the detector, are fed to one MPR-16 preamplifier board, which will be placed outside the vacuum chamber.

3 Simulations

A deuteron beam of 7–10 MeV will be hitting a ^{12}C target of 100 μg/cm^2 thick. The 9 MV tandem can produce deuteron beams up to 18 MeV, but the E_{beam} limit of 10 MeV was chosen based on the proton stopping energy in silicon. The region over the polar angles θ between 70°–170° has already been studied [4] , therefore the measurements between 0° and 80° are the most relevant. Figure 2 shows the results of the reaction simulated with the VIKAR code using the proposed experimental setup. The first three excited

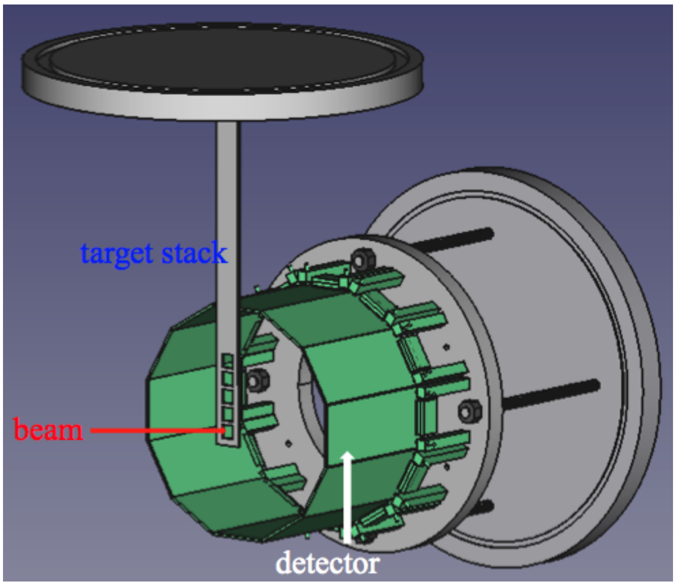

Figure 1: CAD simulation of the experimental setup inside the reaction chamber: twelve X3 silicon strip detectors in a cylindrical configuration, target ladder approximately 5 cm far from the center plane of the detectors.

state proton groups from the ^{12}C+d reactions [3] over polar angles θ at the energy of the deuteron beam of 10 MeV are clearly separated.

Such simulations were also carried out for the reaction ^{24}Mg(d, p)^{25}Mg. This reaction was studied in the 1960s. There are several recent experiments [5, 6], in which the energy of the deuteron beam was up to 2 MeV, and the theta angles were from 90 degrees and 165 degrees. We would like to repeat these measurements as the experimental data of the differential cross section are often discrepant.

4 Summary

We ask four days of beam time (12 UT) to calibrate and measure the energy and position resolution of the X3 detectors. The position calibration procedure will consist of using a mask with equally spaced slits in front of the X3 detectors. Moreover for a better position and energy calibration we also request a ^{7}Li beam onto a ^{12}C target in order to measure the kinematic distribution of the alpha particles coming from the ^{7}Li+^{12}C$\rightarrow$^{4}He+^{15}N reaction.

For the experiment we will ask for 6 days (18 UT), divided in half for measurements with the ^{12}C target (3 days or 9 UT) and with the ^{24}Mg target (3 days or 9 UT).

The efficiency of the array of detectors obtained in the simulation using

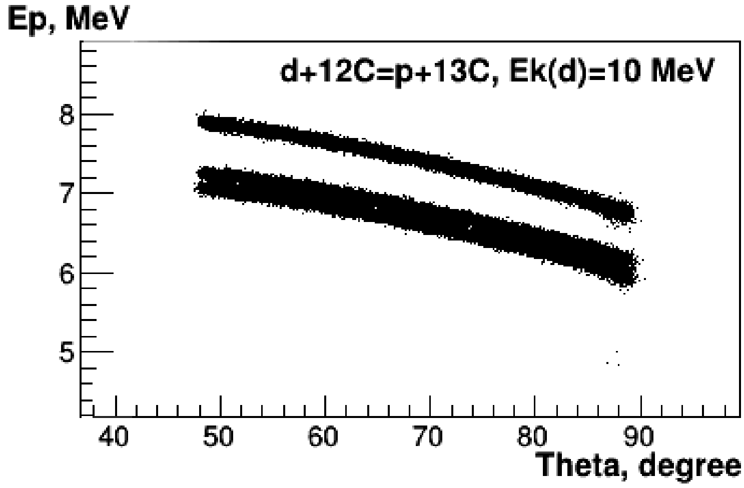

Figure 2: VIKAR simulation of energy distribution of the first three excited state proton groups in the reaction ^{12}C(d, p)^{13}C.

VIKAR will be close to 30 %. The differential cross section is approximately 1 mbarn at the proposed incident energies, so with a target of 100 μg/cm^2 we expect to detect about 10-15 protons every second. It takes about 15 minutes to accumulate the required 400-500 counts/detector (100 counts/strip).

References

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