Simulations for experimental studies of breakup reactions on neutron-deficient isotopes relevant to the astrophysical *rp*-process

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Our experimental program aims to investigate explosive nucleosynthesis in the *rp*-process occurring in type I X-ray bursts related to the most frequent type of stellar explosions in the Galaxy[1]. Indispensable experimental information related to resonant structures in most sensitive proton-capture reactions with extremely neutron-deficient isotopes will result in the advancement of the existing X-ray burst models by providing a reliable nuclear-data input[2]. A particular focus of this research is to obtain spectroscopic information about proton-unbound excited states in ^{66}Se and ^{58}Zn, which are expected to be involved in the breakout from the waiting-point nuclei ^{64}Ge and ^{56}Ni through the sequential two-proton capture[3]. Single-neutron removal reactions from ^{67}Se and ^{59}Zn at 250 MeV/nucleon beam energy will be deployed to populate the states above one- and two-proton separation energy in ^{66}Se and ^{58}Zn, respectively. Proton decay in-flight of these highly excited states will then be measured in complete kinematics using High-Resolution (HR) 90° mode of the SAMURAI magnetic spectrometer[4] in combination with the existing tracking systems and the custom-designed Si-strip detectors for simultaneous detection and tracking of heavy ions and protons.

The conceptual design of the setup was examined by detailed Geant4 simulations, aiming to achieve an experimental resolution of about 100 keV (sigma) for a single resonance and a total detection efficiency of at least 20%. The multidimensional parameterization and fit algorithm was developed to reconstruct the total momentum of every particle and eventually the proton-fragment relative energy E_{rel} in their rest frame. Compromising the resulting E_{rel} resolution, detection efficiency, and construction cost, an appropriate experimental configuration was worked out after systematical variation of the setup parameters such as the geometry and location of the tracking detectors, target thickness, magnetic field strength, *etc.* In addition, specific simulations were performed to study the effect of δ-electrons on the measurements by the Si trackers. In particular, the interference with a proton signal is studied together with various options to suppress this effect by placing compact kick-off magnets between the Si-trackers, by adjusting the relative distance between the detectors, and/or by track discrimination using track information in the proton-tracking system after the magnet. Based on these studies, the minimum requirements for the design of a vacuum chamber for the Si trackers (*i.e.*, its size, position relative to the target, and internal locations of the detectors) were specified and the following conclusions were drawn:

(1) The HR-mode is suitable for the heavy-ion-proton (HI-p) experiments with beam energies ranging from 200 to 250 MeV/nucleon.
(2) The value of acceptance×efficiency in the HR-mode can be comparable to that of the standard "Day one" configuration ($\simeq$40% for one-proton decay with E_{rel}=1 MeV and beam energy of 250 MeV/nucleon).
(3) The HR-mode provides a better mass (momentum) resolution ($\simeq$1/1500) for heavy ions.
(4) The momentum resolution for protons and E_{rel} resolution can be determined mainly by the straggling in the target and by the position resolutions of the proton-tracking detectors.
(5) E_{rel} resolution (sigma) of approximately 100 keV can be achieved at E_{rel}=1 MeV along with the beam energies between 200 and 250 MeV/nucleon.

These results together with the LISE++ simulations were used in the experimental proposal that was reviewed and approved by the 14th NP-PAC in June 2014. In a similar way, feasibility studies and experimental optimizations were performed for other potential HI-p experiments involving one- and two-proton breakup of ^{9}C, ^{28}S, ^{32}Ar, ^{34}Ca, ^{35}K, ^{36}K and ^{36}Ca. A common setup configuration for all HI-p experiments was figured out and presented by the collaborators in the 15th NP-PAC. Thus, we intend to perform a total of four HI-p experiments in the next two years, ideally as campaign-type measurements, which will provide a wealth of experimental data that can significantly enrich our knowledge and understanding of nucleosynthesis in type I X-ray bursts.

References

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