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Nuclear Breakup and Coulomb Dissociation of ^9C Nucleus Studied at RIBF RIKEN

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The ^9C breakup was studied during the SAMURAI29R1 experiment through inclusive and exclusive measurements at energies around 160 A MeV for ^9C , in order to evaluate the astrophysical S_{18} factor for the inverse process $^8\text{B}(p,\gamma)^9\text{C}$ at energies in the region of astrophysical interest. The radiative proton capture on ^8B is important in the hot pp chains, in explosive Hydrogen burning ($ppIV$ and $rapI$), at temperatures between $0.05 < T_9 < 1\text{K}$, as possible alternative paths across the $A=8$ mass gap. Another goal of this experiment was a detailed study of the breakup reaction mechanism. During the experiment the nuclear breakup process was studied using a *natural C target* with $425\ \mu\text{m}$ thickness and the Coulomb dissociation by using a *natural Pb target* with $150\ \mu\text{m}$ thickness. The reaction products were tracked simultaneously using a system of position sensitive Si detectors and in total 1024 output channels were read out by using new dual gain preamplifiers (DGP) specially designed for the experiments of the HI-p collaboration.

The SAMURAI29R1 experiment was carried out during the SAMURAI 18Oxygen 2018 Spring campaign and it is part of the HI-p collaboration together with another three experiments.

Performances of the setup used and first results of the analysis are presented.

KEYWORDS: nuclear breakup, photodissociation, silicons, HINP

1. Introduction

The main motivation for studying the proton breakup reaction of the ${}^9\text{C}$ nucleus is the astrophysical impact of its inverse reaction, the radiative proton capture on the ${}^8\text{B}$ nucleus. The ${}^8\text{B}(p,\gamma){}^9\text{C}$ reaction was proposed [1] as a possible bypass to the 3α -process in low metallicity massive stars, in order to produce the fuel for the CNO cycles by a sequence of proton ($pp - III$ and $pp - IV$ in hot pp -chains of Hydrogen burning) and rapid alpha capture reactions ($rap - I$ branch) on nuclei close to the proton drip line.

The thermonuclear energies relevant for nuclear astrophysics are below the Coulomb barrier, where the reaction cross-sections are very small. To measure such cross-sections is even more complicated when radioactive nuclides are involved. In order to bypass the experimental difficulties inherent to the direct measurements, different indirect methods were implemented in nuclear astrophysics for measuring the capture cross-sections [2].

Another fact that motivates to study the ${}^9\text{C}$ breakup is the large spread of the experimental results for the determined astrophysical S-factor, obtained in the previous experiments [3].

2. Indirect methods in nuclear astrophysics

During the NP1412-SAMURAI29 experiment two indirect methods were used: nuclear breakup and Coulomb dissociation with the goal of performing inclusive and exclusive measurements of the breakup reaction cross-section of ${}^9\text{C}$ nucleus in nuclear and Coulomb fields.

As it was already proven, the ${}^9\text{C}$ has the last proton weakly bound and its breakup in a nuclear field is a strong peripheral process. From the momentum distributions and the absolute one proton removal cross-section, the Asymptotic Normalization Coefficient (ANC) of the radial wave function of the last nucleon will be extracted. The method was used successfully in the past to evaluate astrophysical S-factors for other reactions like: ${}^7\text{Be}(p,\gamma){}^8\text{B}$, ${}^{22}\text{Mg}(p,\gamma){}^{23}\text{Al}$, ${}^{23}\text{Al}(p,\gamma){}^{24}\text{Si}$, all these are documented in [4–7]. During this experiment, a natural C target of $425\ \mu\text{m}$ thickness was used to study the nuclear breakup.

The Coulomb dissociation was proposed as an indirect method in nuclear astrophysics more than 30 years ago to evaluate the reaction cross-section for the radiative capture processes. The method proposes to measure the inverse reaction of the radiative capture in a field of virtual photons created by the fast projectile moving in the strong Coulomb field of a target [8, 9] with high atomic number Z , like the Pb target of $150\ \mu\text{m}$ used during our measurements. In order to determine the radiative capture reaction cross-section, the Detailed Balance principle [8] will be used and it will be necessary to disentangle the contribution of different multipoles to the reaction cross-section.

3. Experimental setup

The kinematically complete measurement for the breakup reaction of ${}^9\text{C}$ was performed at RIBF in RIKEN by using the SAMURAI spectrometer [10]. During the SAMURAI Oxygen18 Spring Campaign, all the experiments used as primary beam the neutron-rich ${}^{18}\text{O}$ nucleus accelerated to 230 AMeV energy, using in the last stage of the RI beam acceleration the SRC [11], with a beam intensity higher than 400 pA. The proton-rich ${}^9\text{C}$ secondary beam was obtained and separated by using the two-stages in-flight RI beam separator BigRIPS [11], where at the F0 focal plane the primary beam hit a 2mm thick Be target. Then, for a better separation of the secondary beam at F1 and F5 two Al degraders of 8 mm and 2mm thickness, respectively were placed. After these beamline systems, the secondary beam composition was: ${}^9\text{C}$ - 87%, ${}^8\text{B}$ - 2.9% and ${}^7\text{Be}$ - 10%. For the beam PID measurement during the beam transportation along the BigRIPS line to the SAMURAI experimental area, two plastic scintillators at F3 and F7 with 3mm thickness were used.

The detection setup used to achieve the goals of the experiment, during the physics measurements, consisted of two parts: the standard SAMURAI detectors and a new Silicon strip detectors system placed between the target and SAMURAI spectrometer entrance. By using this detection configuration it was possible to perform inclusive and exclusive measurements of the ${}^9\text{C}$ breakup. In Fig. 1 the experimental setup is shown. The standard SAMURAI detectors used were, starting from the SAMURAI upstream area to the downstream side: two plastic scintillators for triggering, energy loss and timing (SBT1&2), two beam drift chambers for ${}^9\text{C}$ position tracking (BDC1&2), two pairs of silicon GLAST detectors, a drift chamber (FDC0) used for space phase reconstruction of the resulting fragments, two arrays of plastic scintillators hodoscopes (HODF24 & HODP16) that were installed at the exit window of the SAMURAI spectrometer for measuring the time of flight and energy loss of the reaction products, and two drift chambers used to track the resulting protons (PDC1&2). As in all experiments of this campaign, the SAMURAI magnetic spectrometer was used to analyze the rigidity of the products, together with the detectors in order to reconstruct the momentum distributions of the beam and of the resulting fragments. The standard SAMURAI detectors are detailed in Ref. [12]. The production of the relatively clean proton-rich ${}^9\text{C}$ secondary beam from neutron-rich ${}^{18}\text{O}$ primary beam was the notable success of this experiment.

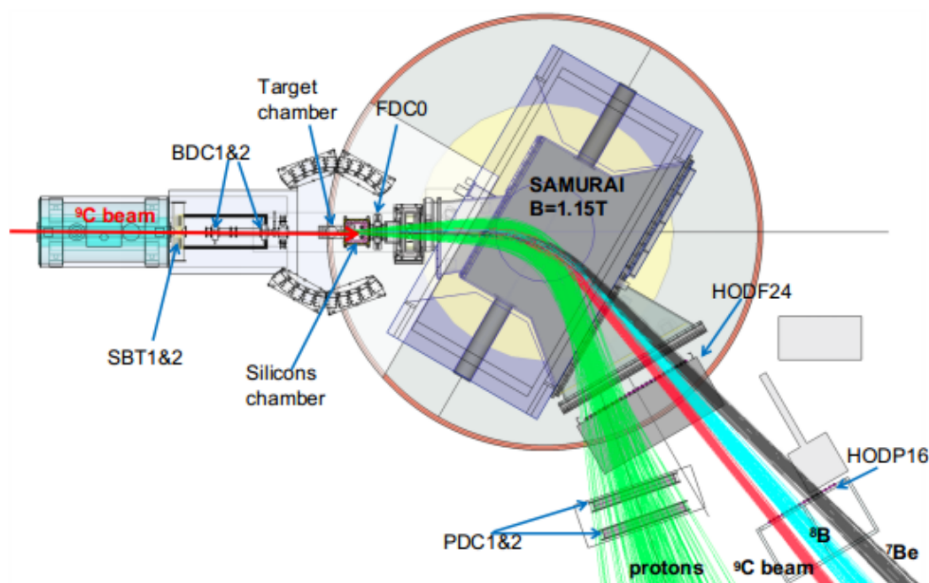


Fig. 1. Top-view of the SAMURAI experimental hall and the trajectories of the reaction products are drawn.

One of the novelties of this experiment was the system of 4 position sensitive silicon strip GLAST detectors and the associated electronics. Each of the silicon detector has 128 strips ($4 \times 128 = 512 \text{ strips}$) and together with the new dual gain preamplifiers (DGP) assured the simultaneous tracking of the reaction products: protons and heavy reaction residues. In this manner a total of 1024 output signals were detected and processed. This was possible due to the high dynamic range of the DGP, sensitive in the same time to the proton and fragments energy loss in the silicon detectors. By using the information obtained from the silicon detectors processed signals together with the HODF24 and PDCs signals it is possible to reconstruct the momentum of the produced protons. More details about the silicon system can be found in Ref. [13, 14]. Fig. 2 shows that the combination of the two detection parts can distinguish between protons and the light nuclei simultaneously detected.

The data analysis results will be reported in a forthcoming paper.

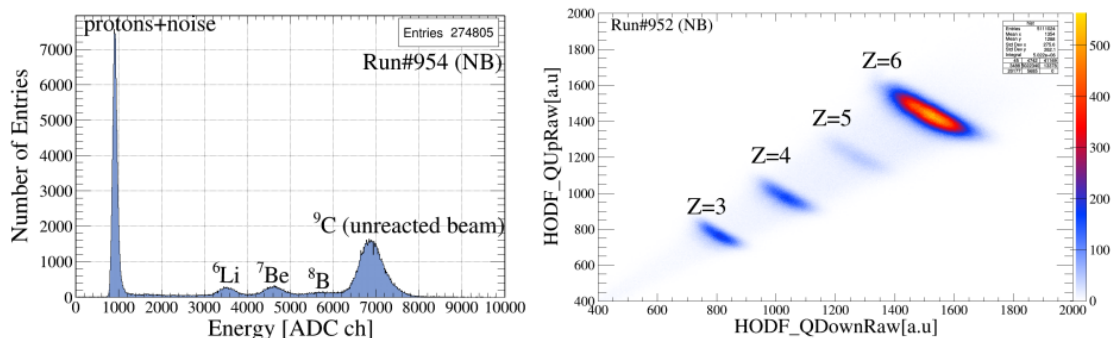


Fig. 2.: The left part shows the reaction products measured with the silicon detectors, comprising nuclei with $Z=1$, $Z=3$, $Z=4$, $Z=5$ and $Z=6$. The right figure shows the same nuclei detected in the hodoscope HODF24

4. Conclusions

The NP1412-SAMURAI29R1 experiment was successfully carried out. We have demonstrated the separation of the protons and fragment signals in the silicon detectors system and the possibility to reconstruct the trajectories using these complex exclusive measurements.

We observed the one and two protons removal channels on both intended targets and on other components of the setup (e.g first pair of the silicon detectors).

The combination between the breakup measurements in nuclear and Coulomb fields is being used because complementary information can be extracted. Thus the exclusive measurements are intended to check the reaction mechanism and to improve the reliability of the nuclear astrophysics conclusions.

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