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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Investigation of key nuclear reactions in the astrophysical rp-process

研究課題名（英文）Investigation of key nuclear reactions in the astrophysical rp-process

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　3,000,000円

研究成果の概要（和文）：シリコンストリップ検出器とデュアルゲインASICプリアンプを組み合わせた高精度粒子追跡システムの開発と構築が完了しました。 追跡システムは完全に装備されており、天体物理的プロセスに関連する重イオンの陽子分解反応の測定に使用する準備ができています。 SAMURAI分光計のインフラストラクチャーと標準検出器を新しく設計されたシリコントラッカーと共に使用した詳細な実験計画が徹底的に開発され、2018年6月に公式に予定されていた実験を実行するための実験準備が開始されました。 RIBFにおける機械時間委員会は、2019年の春まで暫定的に78Krビームの使用を延期することを決定した。

研究成果の概要（英文）：Development and construction of high-precision particle tracking system using silicon strip detectors coupled with dual-gain ASIC preamplifiers have been completed. The tracking system is fully equipped and ready to be used for the the measurement of heavy-ion proton breakup reactions relevant to the astrophysical rp-process. Detailed experimental scheme using the infrastructure and standard detectors of the SAMURAI spectrometer together with the newly designed silicon trackers has been thoroughly developed and the experimental preparations have been started in order to run the experiment, which was officially scheduled on June 2018. However, due to present beam time limitations at RIBF, the usage of 78Kr primary beam, which is necessary to produce the desired secondary beams of 67Se and 59Zn, machine time committee at RIBF has decided to postpone the usage of 78Kr beam tentatively until spring of 2019.

研究分野：　Experimental nuclear physics

キーワード：　Silicon trackers　Dual-gain preamplifiers　Completed development　Experimental setup　Readiness

１．研究開始当初の背景

In the beginning of this research the experimental proposal was already approved by the NP-PAC committee and the conceptual design of the setup was finalized and validated through detailed Geant4 simulations. An international collaboration was established. First successful beam test of custom designed ASIC preamplifier chips for the silicon detectors was completed. The development of the full scale readout system was started.

２．研究の目的

This study aims to investigate the two most critical reaction rates of the rp-process: ^{57}Cu(p,γ)^{58}Zn and ^{65}As(p,γ)^{66}Se, which are predicted to have a dramatic impact on the light curves and final chemical yields in type I X-ray bursts. Indispensable experimental data for these reactions will enrich our knowledge about origin of heavy elements in the Universe, properties of neutron stars and also will help to answer the question: where is the endpoint of the rp-process?

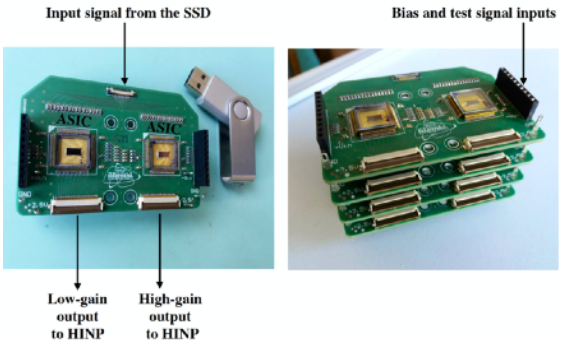
３．研究の方法

The secondary beams of ^{67}Se and ^{59}Zn @ 250 MeV/u are generated from a primary beam of ^{78}Kr. Single-neutron removal reactions from ^{67}Se and ^{59}Zn @ 250 MeV/u on Be target are used to populate unbound excited states in ^{66}Se and ^{58}Zn, respectively. Their proton-decay inflight, corresponding to a time-reversal proton-capture process in stellar environment, is measured in complete kinematics using SAMURAI spectrometer. The key component of the setup is an array of GLAST silicon strip detectors with custom-designed ASIC preamplifiers, operating in a wide dynamic range of input signals for simultaneous detection and tracking of heavy fragments (up top Z=50) and protons. The preamplifiers are coupled to the existing high-density readout system (HINP) provided through by collaboration with the US institutions: Texas A&M university, Washington University and Louisiana State University. Other detectors are standard equipment SAMURAI which have been extensively used in previous SAMURAI experiments

４．研究成果

Mass production of the dual-gain ASIC preamplifiers has been completed. 150 new chips have been constructed which is sufficient to instrument 2400 channels in silicon-strip detectors. The chips were tested and assembled on PCBs which were designed and produced by the collaborative institution Atomki (Hungary). An example of fully assembled PCBs is shown in the Figure 1 below.

Fig.1: Left: Preamplifier board with two assembled ASIC chips showing low- and high-gain outputs. Right: a stack of 4 PCBs as



used to readout silicon detectors.

The newly designed preamplifier boards in combination with the HINP readout system were tested in the parasitic test experiment at HIMAC in December 2017, using light ion cocktail beam. Low-energy signal from Z=1, 2 and 3 particles was clearly resolved in the test experiment.

From January 2018 active preparation for the experiment at RIBF has started. New vacuum chamber, missing electronics and mechanical components for the silicon trackers were constructed. Beam time request for the experiment was submitted and approved by the RNC machine time committee, which tentatively scheduled the experiment on June 2018. Preliminary experimental on-site preparations and the kick-off meeting with collaborators of this experiment has been carried out. However, due to the beam time limitations in this fiscal year, acceleration of the 78Kr beam, necessary to produce secondary ^{67}Se and ^{59}Zn beams, was eventually cancelled by the machine-time committee. The beam time was given only to the SAMURAI experiments using 18O primary beam. Nevertheless, this provided a good opportunity to test the silicon trackers in different experiment (SAMURAI29) which focused on the study of Coulomb and nuclear breakup of proton-rich isotope 9C. The silicon tracker array with the newly

designed readout system was installed in the SAMURAI beam line as shown in the Figure 2:

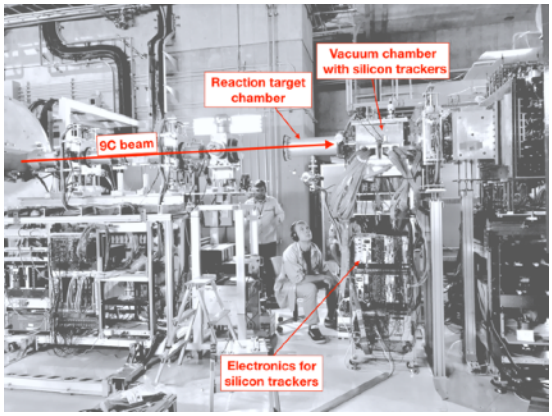


Fig 2: Experimental setup around the target area in SAMURAI29 experiment. Silicon trackers and the preamplifier boards are located inside the vacuum chamber.

SAMURAI29 experiment was carried out from 3rd to 6th of June 2018. The silicons performed well for coincident detection of protons and heavy ions. Figure 3. below shows the secondary beam profile measured in 4 silicon trackers after the reaction target.

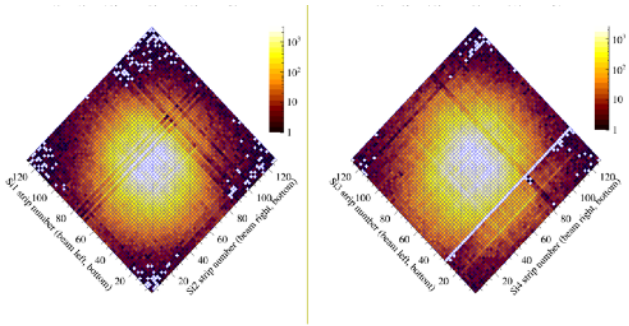


Fig 3: beam profile measured with 4 silicon detectors in SAMURAI29 experiment.

The response of the SSDs with respect to the protons was investigated using pure proton beam at an energy of 150 MeV and in the reactions induced by the target. Figure 4 shows comparison of the energy spectrum for protons in one of the silicons trackers for these two cases.

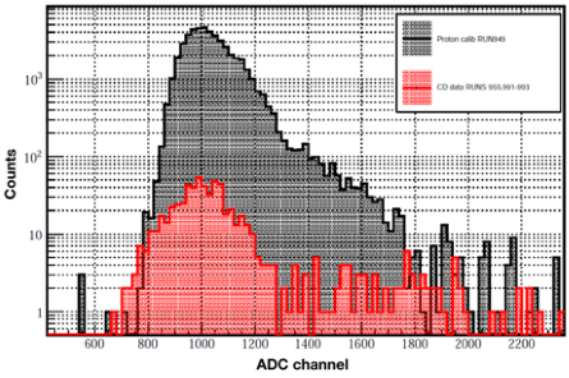


Fig. 4: Energy-loss spectrum of protons in one silicon layers measured with pure proton beam @ 150 MeV (black histogram) and in the Couloumb dissociation measurements (red histogram) where coincidences with heavy-ion hits in the same silicon are selected.

The results of SAMURAI29 experiment demonstrate good performance of the silicons for protons as well as for heavy ions, which were also visible in the data from the low-gain readout of the preamplifiers. This gives further confidence in reliable performance of the detectors for the future measurements of breakup of ^{58}Zn and ^{66}Se (as soon as ^{78}Kr primary beam will become available).

Next opportunity to perform the experiment with ^{78}Kr beam will be in March/April 2019.

５．主な発表論文等

（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　　件）

〔学会発表〕（計　1　件）

1.V. Panin, Invited oral presentation at the KPS 2017 meeting in Daejeon (South Korea) 20th April 2017, Title: “Dissociation of proton-rich nuclei at SAMURAI as a method to study the most critical (p,γ) reaction rates in stellar nucleosynthesis.”

〔図書〕（計　　件）

〔産業財産権〕

○出願状況（計　　件）

名称：
発明者：
権利者：
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番号：

出願年月日：
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○取得状況（計　　件）

名称：
発明者：
権利者：
種類：
番号：
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〔その他〕
ホームページ等

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