Exploration of automated data processing for mass production of nuclear data at RIBF

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Since the secondary beam produced by the RIBF generally contains various nuclides, it is possible to acquire data on non-rare events systematically. However, systematic nuclear data acquisition at RIBF has not been realized due to the lack of data acquisition capability and workforce for data analysis. If data calibration can be automated, the latter will be solved. For the automation of data calibration, advanced statistical inference methods could be used. In this study, the Markov chain Monte Carlo method was employed for a part of particle identification analysis in a secondary beam experiment, and the results were comparable to those of the conventional analysis method.

# Introduction

Data-intensive science has been proposed as the fourth paradigm of scientific research following experimental, theoretical, and computational sciences. In data-intensive science, a large amount of data, obtained by advanced data acquisition and processing and simulation techniques, are aggregated, and statistical inference is used to develop data-driven scientific research.

The RI beam experiment at RIBF1) has the advantage of developing such a data-intensive science. The secondary beam used in RIBF generally contains many different nuclides. Therefore, in principle, it is possible in an experiment at RIBF to obtain rare events that the experimental proposer aims for and systematically obtain non-rare nuclear reaction data simultaneously. Such non-rare data may include isotope production and elastic scattering cross sections. The systematic acquisition of such data and the development of scientific research based on the aggregated data is consistent with the direction of data-intensive science.

However, in practice, the data acquisition and data processing capacity of RIBF is limited in two aspects: data acquisition systems and workforce. First, to measure rare events efficiently, data from non-rare events are usually excluded from the acquisition at the trigger level. Also, data on common events that cannot be excluded are rarely published because the data alone have little academic impact, despite the effort required to analyze it. Even if a non-collaborator would like to analyze the data and extract systematic features from them, it is not easy to actually analyze the data because of the need for detailed information on the experimental conditions, such as the operating conditions of the detector and the magnetic field settings of the electromagnets, which vary from experiment to experiment.

The latter of these two limitations can be overcome by automating the data calibration. In order to realize the automation of data calibration in RIBF, modern statistical inference methods could be applied. In this report, an attempt to apply the Markov chain Monte Carlo method (MCMC) to the particle identification analysis for secondary beams is introduced.

# Data Analysis

At the BigRIPS particle separator2) at RIBF, secondary beam particles are identified on an event-by-event basis from time-of-flight (TOF), magnetic rigidity (, and energy loss information obtained by using beamline detectors (the TOF-- method)2). In this study, MCMC was applied to the determination of ion-optical transfer matrix elements, which is the part of the analysis. The first-order ion-optical transformation between two focal planes is given by

Here, and are the positions and angles in the horizontal plane at the initial and the final focal planes, and is the deviation of from the central value and defined by the following equation:

The coefficients , , and are referred to as first-order transfer matrix elements. In the conventional method, first-order transfer matrix elements are determined by linear fitting procedure, and the effect of higher-order transfer matrix elements are adjusted by the empirical method so as to improve the resolution of mass-to-charge ratio (). On the other hand, the new method using MCMC has the potential to determine higher-order transfer matrix elements directly from measurement data.

In this study, a dataset taken in the spallation reaction measurement on was used for the analysis. In this dataset, beam particles distribute only in limited phase-space. At first, and distributions were fitted with the Gaussian mixture model (GMM) implemented in *scikit-learn*3), an open-source machine learning library, and the events corresponding to was extracted. Figure 1 shows the clustering result using GMM. Then, the first-order matrix elements were estimated using MCMC with a probabilistic programming language *Stan*4). Finally, ’s for all events in the dataset were calculated using the estimated matrix elements. Figure 2 shows the correlation of ’s obtained using MCMC to that obtained in a conventional analysis method.

Figure Correlation between and TOF and clustering result using GMM.

Figure Correlation of obtained using MCMC (vertical axis) and a conventional analysis method (horizontal axis).

# Summary

An analysis method employing MCMC was applied to the analysis with a limited dataset, and similar results to the conventional analysis method were obtained. In the future, further development, such as the introduction of higher-order matrix elements and application to more general datasets, will be done to achieve automated data calibration.

References

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