Towards the elucidation of the hypertriton puzzle

Toward Precise Measurement of the Binding Energy and lifetime of Hypernuclei

An international collaboration led by Takehiko Saito, a chief scientist, from RIKEN and GSI/FAIR facility, and Christophe Rappold, a researcher at the Instituto de Estructura de la Materia, CSIC, has been published in the world-renowned online journal Nature Review Physics, a perspective review on “**New directions in hypernuclear physics**”. The current puzzle of the understanding of the hypertriton is then presented with the current experimental studies that aims to elucidate it.

The hypertriton is composed of a deuterium nucleus and a Lambda particle (Λ particle), and the binding energy due to the force acting between them had been considered to be small for about 50 years based on measurements made until the 1970s. However, recent experiments have shown that the lifetime of hypertritons from formation to decay may be significantly shorter than that predicted by the binding energy. Moreover, in 2020, a publication by the STAR heavy ion collision experiment at Brookhaven National Laboratory in the United States reported that the measured binding energies may be several times higher than the values obtained in those 50 years (Note 1). However, a final conclusion could not be reached because of the large uncertainities, and the mystery of the hypertriton deepened. In order to resolve this discrepancy, C. Rappold and S. Escrig from IEM with their others collaborators are directing the ongoing efforts to resolve this discrepancy, known as the hypertriton puzzle.

First it is important to precisely re-measure the binding energy, and on this purpose C. Rappold and others has developed a machine learning [1] model to analyze data from nuclear emulsion plates irradiated with K meson [2] beams at the Japan Proton Accelerator Research Complex (J-PARC) [3]. The research group has succeeded in visually detecting the production and decay of hypertritons [4]. In this study, the international research group has developed an analysis method that combines physical simulation and machine learning techniques, and demonstrated that it is possible to detect hypertriton formation and decay events from the nuclear emulsion data. The nuclear emulsion plate used to search for the hypertriton was originally used in an experiment to detect another hypernucleus, so the search for the hypertriton was performed among a large number of background events with no hint at all. By March 2021, when the paper was submitted, we had analyzed about 0,2 per thousand (2x10-4) of the total emulsion plate data used in the experiment, and at that time, we had successfully and uniquely identified three cases of hypertritons.

Second, the collaboration has a following-up experiment at GSI/FAIR facility this winter, in which C. Rappold and S. Escrig has an important contribution by building of the micro-vertex detection system and ~~of~~ the full analysis framework. The experiment called WASA-FRS experiment aims to measure precisely the lifetime of the hypertriton along with the test of the existence of the nnLambda state. For this purpose the WASA central detector system is being set up at the mid-focal plane of the fragment separator FRS of GSI for the upcoming FAIR Phase 0 in March 2022. WASA stands for "Wide Angle Shower Apparatus" and is designed to trace the tracks of large numbers of particles that are emitted in energetic nuclear collisions. Thus, the device is a huge, almost closed sphere, equipped with countless measuring instruments. Inside is a superconducting solenoid magnet that must be cooled to four Kelvin with liquid helium.

This research will show that hypertritons can be detected efficiently in large quantities from nuclear emulsion plates and in in-flight spectroscopy experiment. The determination of their binding energy and lifetime with the world's highest precision is expected to contribute to the solution for the "hypertriton puzzle". This research was published in the online edition of the scientific journal, Nature Reviews Physics (September 14, 2021) :

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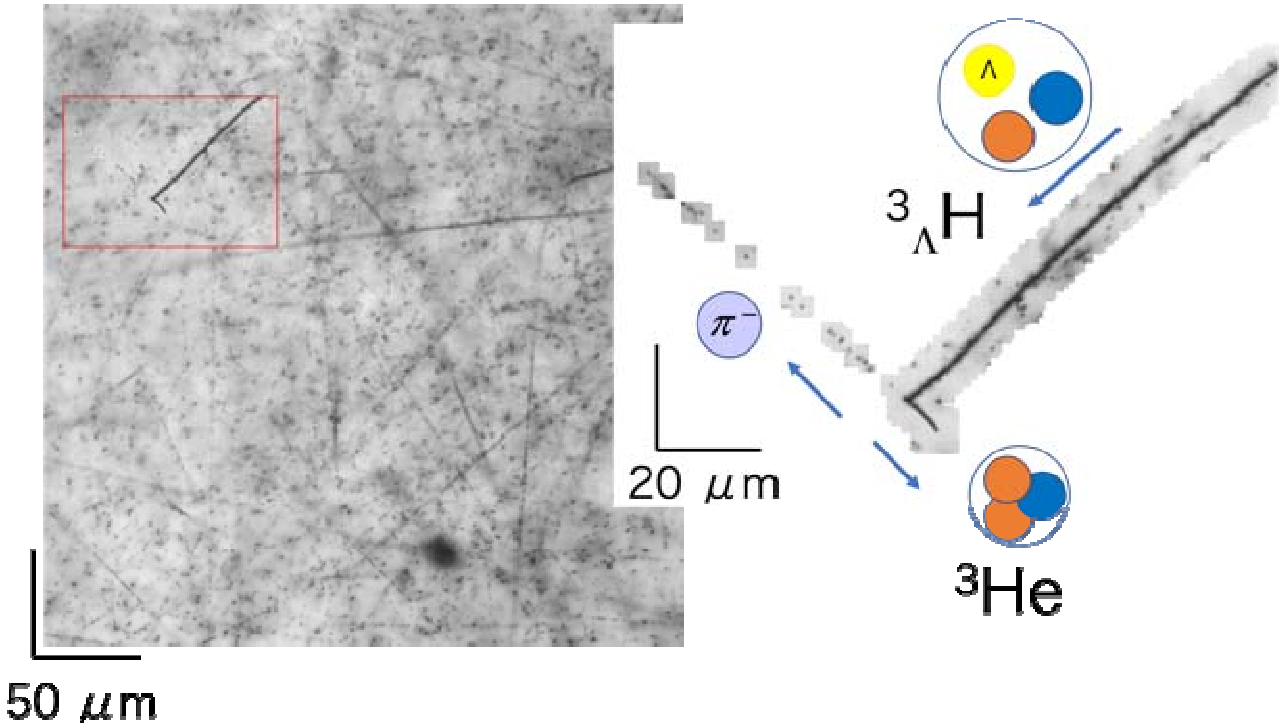

Figure 1: The discovered decay events of hypertritonin the emulsion plate of the E07 experiment

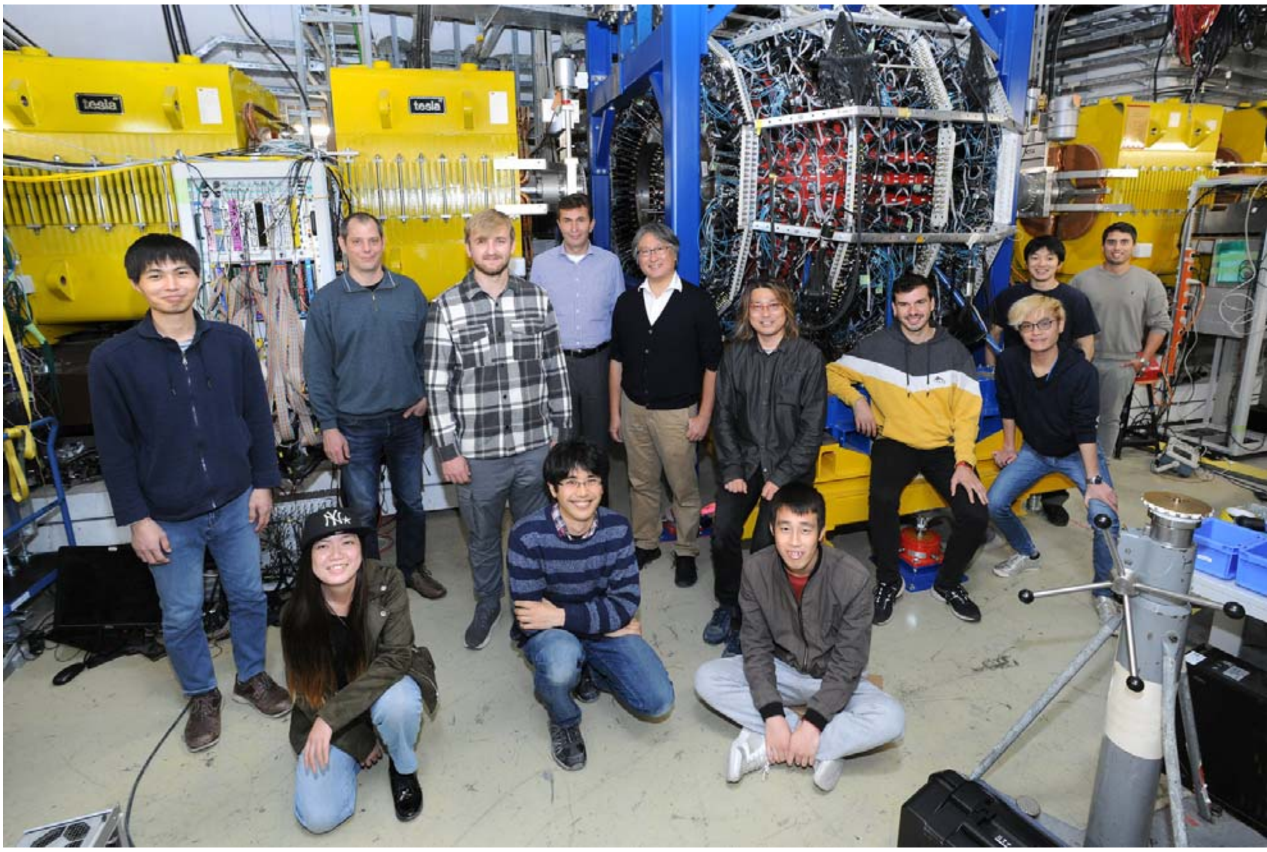

Figure 2: Members of the WASA-FRS collaboration on site at GSI/FAIR to install the WASA detector at FRS

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Supplementary Explanation

[1] Machine Learning, Neural Network

Machine learning is a computer-based data processing technique in which the computer is made to construct a processing method based on a large amount of data and examples of correct answers (training data), rather than a human being programming the processing method in advance. A neural network is a mathematical model used in machine learning that mimics the mechanism of the neural network of an organism's brain. Image processing using neural networks has rapidly improved in performance since around the mid-2010s, and is now being applied in a variety of situations.

[2] K mesons

A meson is a particle composed of one quark and one antiquark. A meson containing a Strange quark is called a K meson.

[3] Japan Proton Accelerator Research Complex (J-PARC)

Japan Proton Accelerator Research Complex (J-PARC) is the collective name for the Japan Proton Accelerator Research Complex (J-PARC), a high-intensity proton accelerator and utilization facilities built in Tokai-mura, Ibaraki Prefecture, Japan. It is jointly operated by the High Energy Accelerator Research Organization (KEK) and the Japan Atomic Energy Agency (JAEA). The secondary particles generated by colliding protons accelerated by the accelerator with nuclear targets are used for research in materials and life sciences, nuclear and particle physics, and industrial applications.

[4] Hypernucleus, Hypertriton

A hypernucleus is an atomic nucleus in which a particle called a hyperon is added to the protons and neutrons that make up a normal atomic nucleus. The hypertriton is the lightest of the hypernuclei and consists of protons, neutrons, and lambda particle (a type of hyperon).