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Emulsion scanning systems for double-strangeness nuclei

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Abstract

Nuclear emulsion is so far the best detector to investigate double-strangeness nucleus including double Lambda hypernucleus, which is a nucleus made up of two lambda hyperons in addition to nucleons. Two types of scanning system are being developed to search for more events of double Lambda hypernucleus rapidly. One is a system for automated Xi$^-$ hyperon tracking. The other is "Overall scanning", high-speed scanning and image recognition for vertex-like-shapes from microscopic images of the tracks in nuclear emulsion plates.

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1. Nuclear emulsion for double Lambda hypernucleus

1.1. Double-strangeness nucleus

The double-strangeness nucleus including double Lambda hypernucleus is one of the most important subjects to investigate baryon-baryon interaction. Baryon-baryon interaction is the origin of various nuclear phenomena and a basic concept in nuclear physics. Lambda-Lambda interaction is especially important as the doorway to study hyperon-hyperon interaction. Since scattering experiment between two hyperons is impractical due to their short lifetime, mass measurement of double Lambda hypernuclei is a unique way to study the interaction.

Nuclear emulsion, which is the photographic solid tracking detector, has performed essential roles for investigation of double Lambda hypernuclei. Fine spatial resolution of nuclear emulsion makes visible a chain of weak decays of double Lambda hypernucleus. It is a tiny characteristic shape, having 3 vertexes at the rest point of

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Xi⁻ hyperon. Then, its mass and species are determined by the masses of daughter particles and their kinetic energies. For this purpose, dedicated thick nuclear emulsion plates have been employed. The thickness of the double side emulsion plate is formed with 40 μm base and two 450 μm emulsion layers on its both sides.

1.2. KEK-PS E176, E373 and J-PARC E07

So far, two emulsion experiments for double-strangeness nuclei, named KEK-PS E176 and E373, were carried out. In the E176, a chain of weak decays of double Lambda hypernucleus was observed among nearly 80 stopping events of Xi^- hyperons. Furthermore, the E373 detected 7 double Lambda hypernuclei among about 700 stopping events. Via an event named "Nagara", Lambda-Lambda interaction in ${}^{6}_{\Lambda\Lambda}He$ is known to be weakly attractive. Aoki et al. (2009), Nakazawa and Takahashi (2010) and Ahn et al. (2013) described the details of these experiments.

We have been preparing for a new experiment, J-PARC E07, which has the statistic 10 times larger than that of the E373. The main detector is emulsion stack, which consists of 12 thick plates and 2 thin plates on the both sides of the stacked thick plates. The Thinner plates are used to connect tracks from Silicon Strip Detectors to the emulsion stack.

Fig. 1 shows a schematic diagram of the hybrid method and location of a double Lambda hypernucleus for the E07. First, a K^+ meson via 'p' (K^-, K^+) Xi^- reaction in a diamond target is detected by a spectrometer placed on the downstream side of the experimental apparatus. Then, the Silicon Strip Detector tags Xi^- hyperon and predicts the incident point in an emulsion stack. The Xi^- track will be detected in the first emulsion plate with a microscopic observation. Finally, double Lambda hypernuclei will be found at some Xi^- stopping points in the emulsion layer. The E07 aims to detect about 10 nuclear species of double Lambda hypernuclei. The E07 will start operation on the first half of 2016.

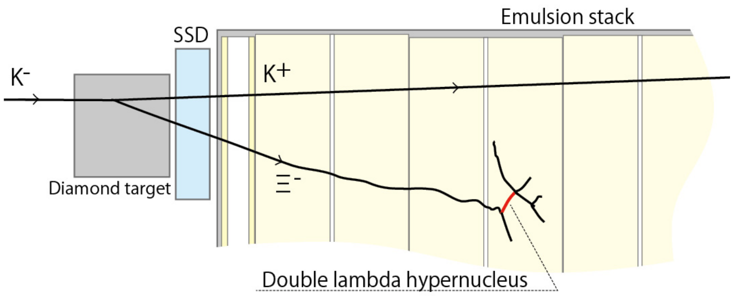

Fig. 1. A schematic diagram of the hybrid emulsion method for J-PARC E07.

2. Scanning systems

2.1. Automated Xi^- hyperon tracking

In the E07, fully automated Xi^- tracking system will be launched for the location of double Lambda hypernucleus. The number of tracks should be followed is more than $4*10^4$, which is several times larger than that of the E373. In the previous experiment, the tracking work was performed with eyes and manual operations for several years. It is necessary to accomplish the location work with the fully automated system for Xi- hyperon tracking within a few years. Therefore, we are developing a dedicated tracking system with advanced image processing techniques.

A key technique for fine position correction between adjacent emulsion layers is employed by pattern matching of beams across the boundary of emulsion layers. Accuracy of 1.4±0.8 μm will be achieved. This accuracy is enough for plate-to-plate connection on the condition with background-free.

The main task is algorithm development for the track following in the emulsion layers. The tracking algorithm is as follows. At first, the following track is focused at the center of a microscopic view field. Then, the microscope system takes a picture of the area along the direction ahead of the track for 10 μm. The system predicts the focusing point on the next picture to find the track. Then the system decides whether the track exists or not in the predicted area. If the track is detected, it takes the next picture and repeats the same procedures till the stopping point. It works successfully for some tracks in an E373's emulsion plate.

2.2. Overall scanning

On the other hand, another new scanning method named "Overall scanning" is being developed to search for alpha decays. Searching of alpha decays is essential for range-energy calibration in nuclear emulsion since the kinetic energies of nuclear fragments are estimated from their ranges. The searching work was performed with visual observation by microscopes before. Because their sources, which are natural radioisotopes with micro amounts such as Thorium and Uranium, are distributed randomly in an emulsion layer. Therefore, Overall scanning is developed to accelerate such searching works.

A computer-controlled optical microscope scans the emulsion layers exhaustively and a high-speed and high-resolution camera takes the microscopic images of the tracks. Then, a dedicated image process picks out vertex–like shapes which consist of several black tracks. Details were described by Yoshida et al. (2014).

Moreover, 10 times more double Lambda hypernucleus events might be detected by Overall scanning than by the hybrid method. The hybrid method was the best way to access double Lambda hypernuclei with minimal emulsion scanning. However, the detection efficiency of Xi^- hyperon by the hybrid method is estimated as about 10% due to the tagging efficiency of a K^+ meson by the spectrometer. Therefore, some double Lambda hypernucleus produced by Xi^- hyperon which is not triggered do exist in the emulsion stacks. Some of new hypernuclear events could be detected by Overall scanning. Actually, during test operation, we detected an event with twin single-hypernuclei and several candidates of double Lambda hypernuclei from the about 22mL volume of E373's emulsion so far.

3. Conclusion

New scanning systems are being developed to obtain larger statistics for double Lambda hypernuclei; A system for automated Xi^- hyperon tracking and Overall scanning. R&D are now ongoing by use of E373's emulsion plates.

Fully automated system for Xi^- hyperon tracking is essential for the location of double Lambda hypernucleus. Now, the key technologies are almost established and the development is ongoing for robust, highly reliable operations. Elemental functions are being integrated in the microscope system which is controlled by a computer.

Overall scanning is used to detect alpha decays and more hypernuclear events, which are distributed randomly in emulsion layers. The system is in operation and detected a typical twin single-hypernuclear event and several candidates of double Lambda hypernuclei so far.

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