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DISCOVERY OF DOUBLE STRANGENESS NUCLEAR SYSTEM BY EMULSION COUNTER-HYBRID EXPERIMENT

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Abstract

E07 emulsion-counter hybrid experiment has been carried out at J-PARC to discover double strangeness nuclei. The scanning work is performed by establishing automatic track following system which has been successfully developed. More than 100 double hypernuclear events are expected from this experiment.

Keywords: emulsion counter hybrid, double strangeness nuclei, automatic track following

Introduction

E07 experiment was performed by Emulsion-counter hybrid method . Double strangeness nuclei are main available sources to study Λ−Λ ιnteraction and Ξ−N interaction. Λ−Λ and Ξ−N interaction are important roles to build EOS of neutron star . They are also linking to add one component as strangeness (S) into 2D nuclear chart to become 3D nuclear chart with proton, neutron and strangeness. Although existences of many double hypernuclei are suggested theoretically, experimental information is so poor. There is only one uniquely identified double hypernuclear event over the world, namely “NAGARA event” which gives Λ−Λ interaction in 6He (helium) to be 0.67 ± 0.17 MeV. Experimental information of these interactions are very limited by number of double-hypernuclear events. Firstly, Danysz et al., had good fortune to detect a sample of double−Λhypernucleus among four candidate events of Ξ− hyperon stopping in nuclear emulsion experiment over five decadesago . In 1991, the existence of double strangeness system was confirmed by E176 experiment which is first generation of emulsion counter hybrid experiment. They found one double hypernucleus by observing nearly 80 Ξ− hyperon stopping evets and they also found two twin single hypernuclear events, gives the Ξ−N interaction. After 10 years later, E373 experiment was carried out to get a greater statistics number of hypernuclear events than that of E176. E373 experiment was second generation of E176but some experimental setups were different and they found NAGARA event among seven double−Λ hypernuclear envents. Therefore, NAGARA event becomes a rule of double lambda hypernuclear event and two twin single hypernuclear events were also observed in E373 experiment. To study systematically the interaction of Λ−Λ and Ξ−N with large number of double hyernuclear events E07 experiment has been carried out at J-PARC. In emulsion experiment, the scanning is heavy work to be able to detect events. Therefore, we have successfully developed new technique namely, “automatic track following system”.

Production of double strangeness nuclear events

As first the Ξ− hyperon is produced by the reaction of K− + “p” → Ξ− + K+. In this reaction, “p” is quasi free proton in Carbon as the diamond target and the incident K− beam is nearly 1.66 GeV/c. The emitted K+ will go to forward direction of incident beam and will carry large momentum and while Ξ− will remains as recoiled one and enters into the emulsion stack as demonstrated in Fig 2.1.

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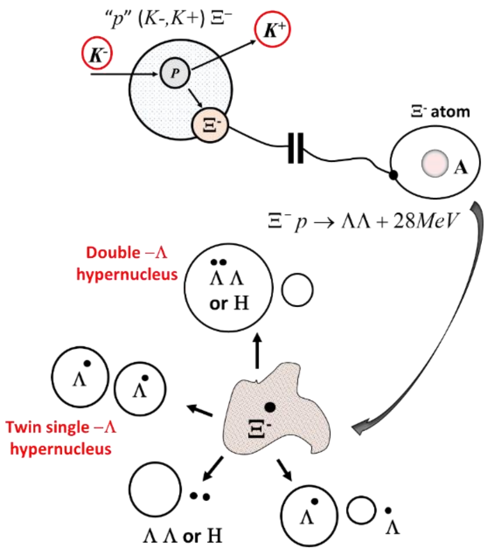

Figure 2.1 Production of double lambda hypernuclear events

When Ξ– hyperon enters into nuclear emulsion, its momentum will loss and it will be at rest due to ionization with atoms in emulsion. Finally, Ξ– hyperon will stop everywhere in emulsion sheet and it will be captured by one atom of emulsion and absorbed by nucleus into inner orbits. The excited Ξ– atom or nucleus will decay into four possible modes such as double Λ hypernucleus, Twin-single Λ hypernucleus, tow free Λ with one normal nucleus and one single Λ hypernucleus with one free lambda and normal nucleus. Among them, double Λ and twin single lambda hypernucleus are our subject.

Experimental setup of E07 Emulsion-counter hybrid experiment

Fig 3.1 is the experimental setups around emulsion stack. The incident K- is the secondary beam with momentum of 1.8GeV/c which is available to produce strangeness (S=2). After K- beam passed through the collimator, it hits the diamond target is mounted in front SSD which is silicon strip detector to record the tracks of X- hyperons emitted from target. SSD gives the estimated positions and angles of X-hyperon candidate tracks. The estimated position and angle of candidates are very important to be continue the following them in nuclear emulsion sheets. Since the position of K- beam is fixed, mover brings the emulsion stack mounted on it to change the irritated position and hence, it works to be able to expose the whole surface of emulsion sheets. The Hyperball-X is mounted at the upstream of diamond target and it has six GM counters which detect X-rays from the capture of X- hyperons to study the X-N interaction. At the downstream of emulsion stack, KURAMA magnet is placed to trace the K+ emitted from "p"(K-,K+)X reaction. At the end of experimental setup, TOF (time of flight) is located to measure the real time of K- and K+ particle and their momentum can be calculated.

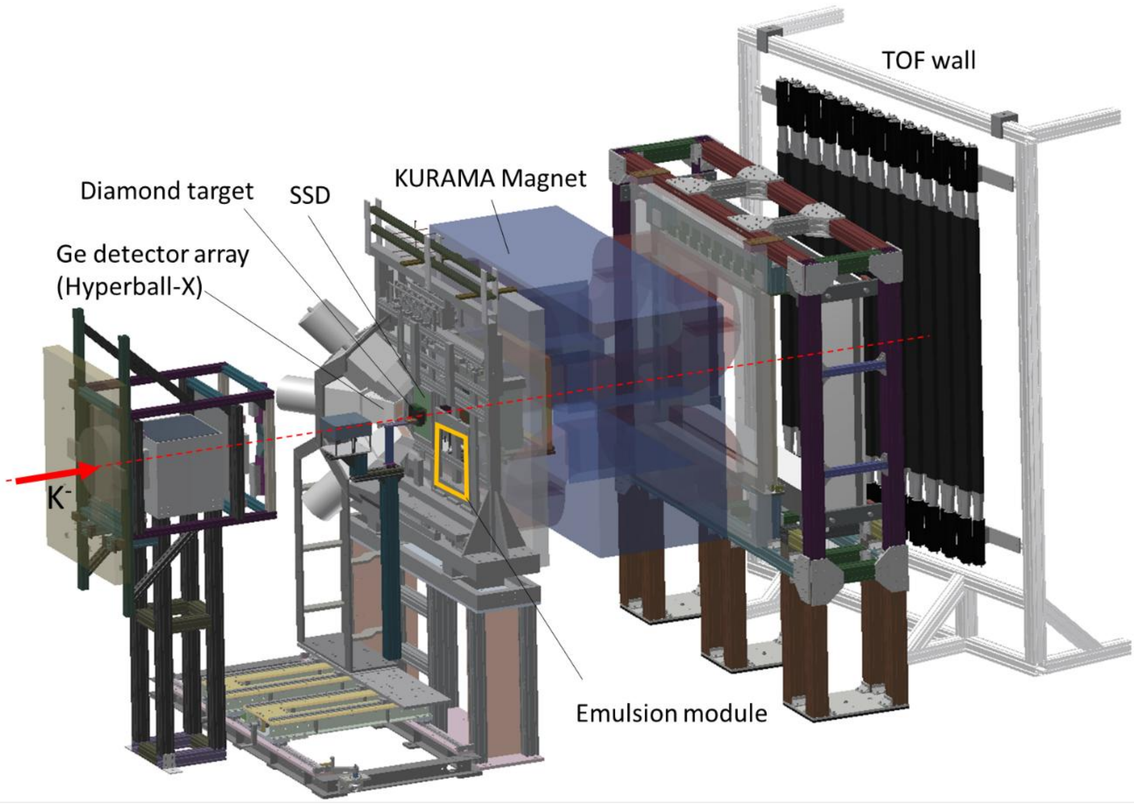

Figure 3.1 Experimental setup of E07 experiment

Nuclear emulsion

Nuclear emulsion is the best one of 3-dimentional detectors. The good ability of this detector is very effective one to detect the short-life particle such as Λ, Ξ, Σ and so on, and their life-time is in order of 10-10 s. Emulsion gel is composed of eight elements as expressed in Table 4.1. In table, it can be seen that nearly eighty percent of composition is Ag+Br- crystals. When charged particles enter in the emulsion, they ionize with Ag+Br- crystals as Ag+ + e– + Br → Ag and Ag+ + e– becomes the latent image. When the emulsion sheet is performed by photographic development, the latent image can be seen as dark grain under microscope. Therefore, the dark grains will appear along the travel of charged particles and the series of dark grains is the track of charged particles. The range of charged particle travelled in emulsion give their kinetic energy by aid of range-energy relation.

Table 4.1 Composition of Nuclear Emulsion

Material	Weight (%)	Mole ratio (%)
I	0.9	0.2
Ag	46.0	24.4
Br	33.2	21.7
S	0.2	0.2
O	6.5	12.2
N	2.9	6.0
C	8.8	19.9
H	1.4	15.4

Automatic track following system

In emulsion counter hybrid method, the estimated position and angles of Ξ− candidates are supplied by SSD detector. By using estimated data, the tracks of Ξ− candidates have to be followed in nuclear emulsion sheet until their stopping points as shown in Fig 5.1. The following of all Ξ− candidates was had work in E373 experiment because they used semi-automatic tracking system. Scanning time was for many years in E373 and besides, the human errors may exist when the track is followed sheet by sheet. We have to follow the Ξ− tracks from 1st sheet to the sheet where it stopped. Therefore, the automatic track following system has been established to reduce following time and to follow the tracks with high accuracy.

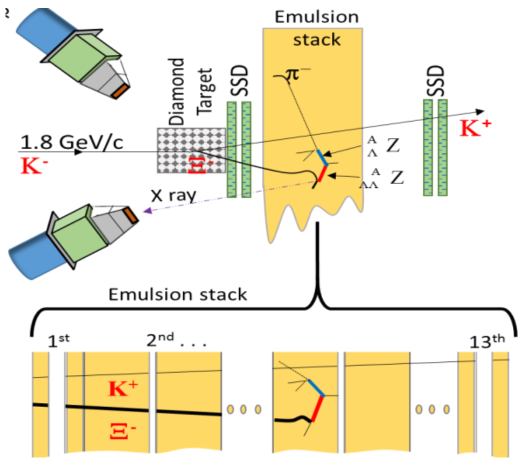

Figure 5.1 Experimental setup of emulsion stack

Automatic track following system was built by computer-aids microscopic system. Fig. 5.2 shows the stage of microscope system. The emulsion plates are set on X-Y stage and a 50-time oil-immersion objective lens with effective field of 110 μm × 130 μm is located in optical Z direction. One CCD camera which is mounted on the top of optic part is employed to seize image through the objective lens and its resolution is 552(H) × 440(W) pixels with 8 bits. The light luminance for optics is supplied from the LED below the X-Y stage. A vacuum pump is connected to X-Y stage to keep the emulsion plates flat on X-Y stage. The white rubber frame (Oil lake) protect the oil for objective lens does not spread outside and to be able to reuse the oil. The motor motion of X-Y stage and optic part in Z direction, the adjustment of light luminance from LED, image taking of CCD camera and data processing are worked together under automatic controlled system.

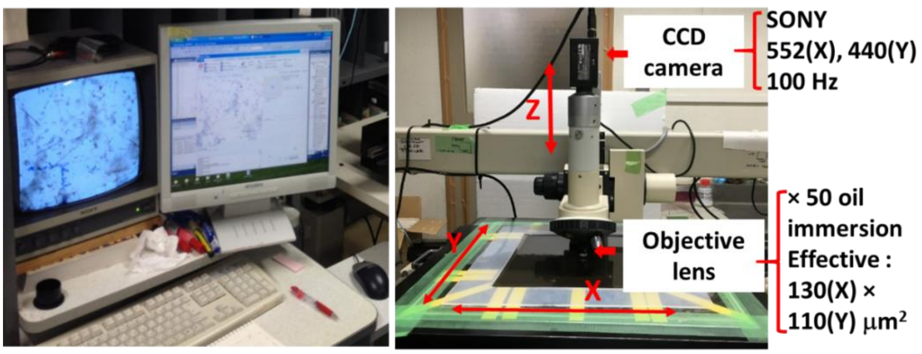

Figure 5.2 Computer aid microscopic system

There are three main parts such as (a) automatic emulsion surface detection, (b) sheet to sheet alignment with K- beam pattern and (c) track recognition and following.

Summary

E07 experiment has been carried by emulsion-counter hybrid method. The automatic track following system has been successfully established with high accuracy. The tracking work will be finished within a few year and we expect to detect more than 100 double hypernuclear events from E07 experiment in near future.

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