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# Study of double-strangeness nuclear systems with nuclear emulsion

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## Abstract

Double strangeness nuclei such as double-Λ and Ξ hypernuclei have been studied with nuclear emulsion due to its fine position resolution. Recently, we have started an experiment to study Λ-Λ interaction more accurately than that information given by the NAGARA event with ~$10^2$ double-Λ hypernuclei which may provide us understanding free from nuclear medium effect. It is necessary to develop treatment method for huge amount, 2.1 tons of the emulsion gel, even if very pure $K^-$ beams are available at J-PARC. We have developed the base film to support the emulsion, emulsion surface coating method with a special layer of 0.5 μm thick, method for making large-size plate (35.0 x 34.5 $cm^2$) and scanning method, called "*overall scanning*". The first evidence of a deeply bound state of $\Xi^-$-$^{14}N$ system, named KISO, was successfully detected in the test operation of the overall scanning.

*Keywords:* Nuclear emulsion, plate making, double-Λ hypernucleus, Ξ hypernucleus;

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## 1. Introduction

In nuclear physics, the interaction between ordinal nucleons, *N-N*, has been continuously studied for more than 60 years. Its research has provided us three thousand nuclei among seven thousand ones predicted by theory. Regarding

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the hyperon-nucleon (Y-*N*) interaction, where Y is a $\Sigma$ or $\Lambda$ hyperon, its research is steadily progressing. We had a stereoscopic nuclear chart by adding a hyperon inside nuclei. Such single hypernuclei of nearly forty samples are located on the 2nd floor in the chart, so far. To understand hadron-hadron interaction in baryon octet scheme, it is necessary to study double-strangeness systems, e.g. $\Lambda$-$\Lambda$ interaction and $\Xi$-*N* interaction. Because of short lifetime ($\sim 10^{-10}$ s), we input two units of strangeness (S = -2) into nuclei, called double-$\Lambda$ or $\Xi$ hypernuclei, and measure masses via their decay sequence. An effective way to produce S = -2 nuclei is to stop $\Xi^-$ hyperons captured by some nuclei. Since the Q-value of their production is at most 30 MeV through the reaction of $\Xi^- +$ "*p*" => $\Lambda + \Lambda$, nuclear emulsion is the best detector to observe the production and decay of S = -2 nuclei. Since the emulsion scanning procedure took a long time, the NAGARA event was the only clearly identified ($^{6}_{\Lambda\Lambda}$He) event introduced by Takahashi et al. (2001), Nakazawa and Takahashi (2010) and Ahn et al. (2013). Although the NAGARA event suggested the $\Lambda$-$\Lambda$ interaction to be weakly attractive, it is necessary to detect double-$\Lambda$ hypernuclei in other nuclear species than NAGARA to get conclusive information free from nuclear medium effect. Recently, a new hybrid experiment to provide $\sim 10^2$ double-$\Lambda$ hypernuclei has been approved as the E07 experiment at J-PARC. To get such a number of events, we expose a large volume of emulsion with highly pure $K^-$ beams ($K^-/\pi^- \sim 6$). In this paper, a series of mass production of emulsion plates will be introduced. We also discuss the development of the scanning system, which is introduced by Yoshida et al. (2014) in detail.

## 2. Mass production of emulsion plate

In the E373 experiment at KEK-PS, we have detected 7 double-$\Lambda$ hypernuclei among $\sim 10^3$ $\Xi^-$ stopping events and just the NAGARA event was uniquely identified. To detect other nuclear species with S = -2, it is necessary to record $\sim 10^4$ $\Xi^-$ stopping events in the emulsion. Therefore we should process 2.1 tons of emulsion gel, what is nearly 3 times more than the case of E373. To make nuclear emulsion plates with the gel, many kinds of R&D have been made. Three of them are introduced bellow.

### *2.1. Improvement on hydrophilia of emulsion support film (R&D No.1)*

We must use the support film to avoid upswell and strain of the plate during development in the photographic solution and after drying, respectively. We prepared two types of emulsion plate. One is the plate with thin emulsion (100 μm) layers on both sides of polystyrene (PS) film ($t$ = 180 μm) to detect $\Xi^-$ hyperon tracks reconstructed by counter system at the top of the emulsion stack. Another one with thick (500 μm) layers on both sides of thin PS film ($t$ = 40 μm) is intended for the detector of production and decay of S = -2 nuclei. Since original PS-film had no hydrophilia, dried emulsion was easily separated from the film in the process of photographic development. Therefore we applied Corona discharge on both sides of the film.

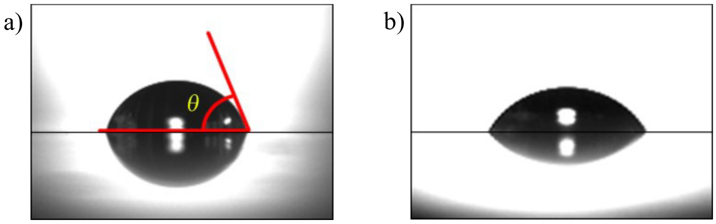

Fig. 1. Contact angle, $\theta$, in a) is larger than that of b) after Corona discharge application on the PS-film.

Corona discharge machine[1] was applied for PS film inside with voltage of 3 kV and feed speed of 20 m/min. However the discharge effect was found to be not uniform over the 1 m wide and 200 m long film being water-soaked. To evaluate the effect of the Corona discharge, therefore, we have measured contact angle, $\theta$, of a water drop (10.0 ± 0.1 mg) with the film as displayed in Fig. 1 a). In Fig. 1 a) before Corona application, the $\theta$ was $(68.5 \pm 0.5)^{\circ}$ by elliptical fitting. Then the discharge machine was applied again with 4 kV and 10 m/min., and

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[1] ONOKOGYO Co., ltd. ; http://www.onokogyo.com