Observation of a new double-lambda hypernucleus in J-PARC E07 experiment

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For understanding the baryon–baryon interaction as an extension of the nuclear force, it is essential to investigate on octet baryons in the $SU(3)_{\mathrm{flavor}}$ symmetry. While the nucleon–nucleon interaction has been well studied with rich experimental data, further studies of hyperon–nucleon and hyperon–hyperon interactions are necessary for the information of extended baryon–baryon interaction. It is difficult to produce an intense hyperon beam due to the very short lifetime of hyperons (τ~10^{-10} s, $c\tau$~10^{-2} m). In particular, an experimental investigation around the $S = -2$ sector has been awaited to explore such extended baryon–baryon interaction. A double-Λ hypernucleus, a nucleus having two Λ hyperons, is a good probe to study the ΛΛ interaction. The mass of double-Λ hypernucleus gives us the information of the ΛΛ interaction. One of the best ways to measure the mass of the double-Λ hypernucleus is a nuclear emulsion. The emulsion detects tracks of sequential weak decays of hypernuclei with the position resolution of sub-μm.

The J-PARC E07 experiment was performed to investigate S = -2 hypernuclei at J-PARC K1.8 beam line. Using a K^- meson beam with the momentum of 1.8 GeV/c, Ξ^- hyperons were produced in the quasi-free $p(K^-, K^+)\Xi^-$ reaction at a diamond target. A method using combined information between two spectrometers and nuclear emulsion, called hybrid emulsion method, was conducted by using silicon-strip detectors and one hundred eighteen emulsion modules. The experimental setup around the target is presented in Fig. 1. In total, 1.13×10^{11} K^- beam particles were irradiated to the target.

An impressive double-Λ hypernuclear event named MINO [1] was observed with a newly developed emulsion scanning system. Figure 2 shows a photograph of the MINO event and its schematic drawing. The Ξ^- hyperon came to rest at vertex A, where three charged particles of track #1, #3, and #4 were emitted. The particle of track #1 decayed into three charged particles of track #2, #5, and #6 at vertex B. The particle of track #2 decayed into three charged particles of track #7, #8, and #9 at vertex C. By kinematic analysis, the nuclide of the double-Λ hypernucleus was uniquely identified as a new double hypernucleus of beryllium, $_{\Lambda\Lambda}$Be. The event can be interpreted as one of the following three candidates:

$$^{16}\mathrm{O} + \Xi^- \rightarrow {}^{10}_{\Lambda\Lambda}\mathrm{Be} + {}^{4}\mathrm{He} + t,$$

$$^{16}\mathrm{O} + \Xi^- \rightarrow {}^{11}_{\Lambda\Lambda}\mathrm{Be} + {}^{4}\mathrm{He} + d,$$

$$^{16}\mathrm{O} + \Xi^- \rightarrow {}^{12}_{\Lambda\Lambda}\mathrm{Be}^{*} + {}^{4}\mathrm{He} + p.$$

The binding energies of two Λ hyperons in double-Λ hypernuclei, $B_{\Lambda\Lambda}$, are obtained as 15.05 ± 0.11 MeV, 19.07 ± 0.11 MeV, and 13.68 ± 0.11 MeV, respectively, by assuming Ξ^- capture in the atomic 3D state with the binding energy of the Ξ^- of 0.23 MeV. The most probable interpretation is the production and decay of the $^{11}_{\Lambda\Lambda}$Be nucleus determined from the kinematic fitting method.

The emulsion scanning of the E07 experiment is ongoing. More than 10 events of double-Λ hypernuclei have been observed up to the present. Further events are expected to be observed in the near future.

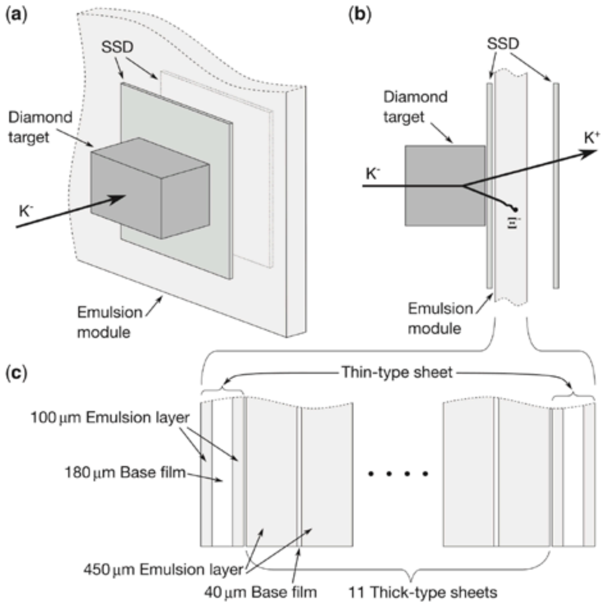

Fig. 1 Schematic view of the experimental setup around a diamond target. The target size is 50 mm (W) × 30 mm (H) × 30 mm (T).

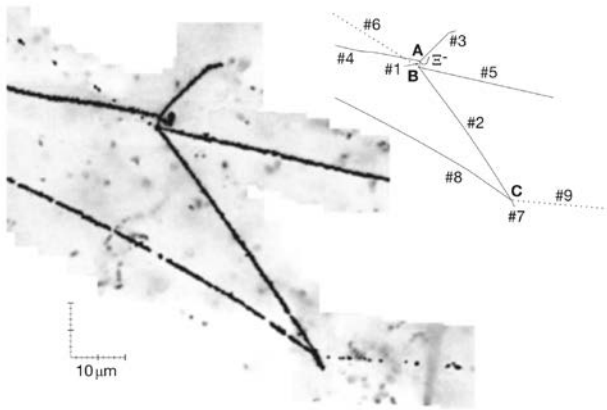

Fig. 2 A photograph of the MINO event and its schematic drawing.

References

[1] H. Ekawa *et al*., PTEP **2019**, 021D02 (2019).