3–2 Determination of the Mass of a Ξ Hypernucleus

—New Information to Understand the Structure of Neutron Stars—

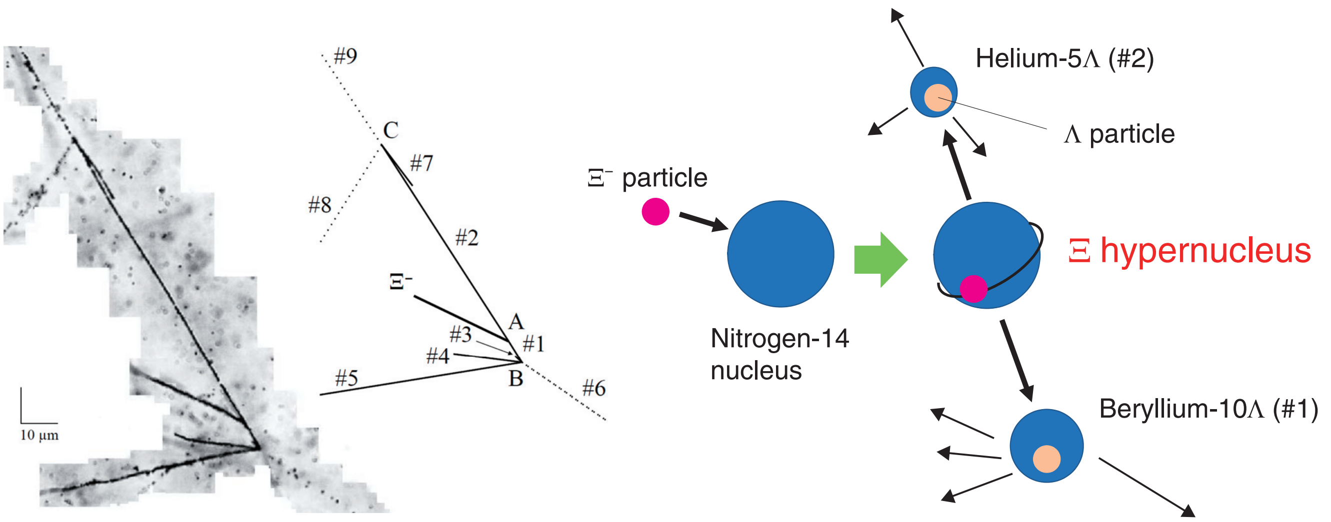

Fig.3-4 Picture (left) and schematic drawing (right) of the new Ξ hypernucleus event
A Ξ⁻ particle is captured by a nitrogen-14 nucleus at point A, forming a Ξ hypernucleus, which then decays into a beryllium-10Λ hypernucleus (#1) and a helium-5Λ hypernucleus (#2). The beryllium-10Λ nucleus decays into several nuclei (#3–#6) and a few neutrons (not seen) at point B, whereas the helium-5Λ nucleus decays into a helium-4 nucleus (#7), a pion (#8), and a proton (#9) at point C.

Although normal nuclei comprise protons and neutrons, special nuclei called hypernuclei containing baryons with strange quarks are known to exist; two such hypernuclei are Lambda (Λ) and Xi (Ξ) baryons. Λ hypernuclei, which contain one strange quark, have been extensively studied, whereas hypernuclei with a Ξ particle, which contains two strange quarks, have been rarely studied.

There are several motivations to study Ξ hypernuclei, one of which is neutron stars. Ξ is one of the particles that could appear in neutron stars, and whether or not it appears depends on the interaction with protons and neutrons. Therefore, it is important to determine the strength of the interaction using ground experiments; high-quality experimental data on Ξ hypernuclei have been long-awaited.

Therefore, we performed an experiment to produce Ξ⁻ (Ξ with a negative charge) particles in abundance using a high-intensity K beam at the J-PARC Hadron Experimental Facility. The produced Ξ⁻ particles were then injected into special picture films, called nuclear emulsions, to record Ξ hypernuclear events. After developing the films, we then used our optical microscope system to search for the Ξ hypernuclear events. We found an event during which a Ξ⁻ particle was absorbed by a nucleus in the emulsion film to form a Ξ hypernucleus, which then broke up into two Λ hypernuclei (Fig.3-4). An extensive analysis demonstrated that the Ξ⁻ was absorbed by a nitrogen-14 nucleus, and the two Λ hypernuclei were beryllium-10Λ and helium-5Λ.

The binding energy of the Ξ⁻ particle was determined as 1.27±0.21 MeV. Assuming only Coulomb interaction between the Ξ⁻ particle and the nitrogen-14 nucleus, the binding energy would be 0.39 MeV; the large difference is due to the strong interaction. Hence, these results allow the strength of this strong interaction to be estimated, thereby helping to clarify the interior workings of neutron stars, which can be considered astronomical-sized nuclei.

Only a part of the data obtained in the experiment has been analyzed; as we continue, we expect to discover more such interesting events. Additionally, we are developing a new analysis method that will enable us to find 10 times as many Ξ hypernuclei. By observing many Ξ hypernuclei events, we will obtain detailed information on the strong interactions involving Ξ particles to clarify how Ξ particle affects the properties of neutron stars.

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Reference

Hayakawa, S. H., Tanida, K. et al., Observation of Coulomb-Assisted Nuclear Bound State of Ξ⁻–^{14}N System, Physical Review Letters, vol.126, issue 6, 2021, 062501, 6p.