Measurement of Coulomb-assisted nuclear state in "IBUKI" event at J-PARC E07

M. Fujita[1)], H. Ekawa[2)], T. Hashimoto[1)], S. Hasegawa[1)], S.H. Hayakawa[1)], Y. Ichikawa[1)], K. Imai[1)], A. Kasagi[3)], K. Nakazawa[3)], T. Nanamura[1,4)], M. Naruki[1,4)], H. Sako[1)], S. Sato[1)], T. Takahashi[5)], H. Tamura[1,6)], K. Tanida[1)], T.O. Yamamoto[1)], J. Yoshida[6)], M. Yoshimoto[3)], and the J-PARC E07 collaboration.
1): Hadron Nuclear Physics Gr., JAEA 2): RIKEN 3): Gifu Univ.
4): Kyoto Univ. 5): KEK 6): Tohoku Univ.

A baryon is a fermion consisting of three quarks. Nucleons (N), protons and neutrons, are baryons formed of only up and down quarks. The interaction between nucleons has investigated using a lot of data obtained scattered experiments. On the other hand, baryons consisting of strange quarks, such as Λ, Σ, and Ξ, are called hyperons (Y). Strangeness nuclear physics which investigates the YN and YY interactions is one of the important topics for understanding the baryon-baryon interaction. Due to the short lifetime of hyperons (τ~200 ps), it is difficult to perform scattered experiment. Therefore, the YN and YY interactions have been investigated using hypernuclei which are nuclei containing hyperons. As one of approaches to the ΞN interaction, the nuclear emulsion experiments[1,2] and the mass spectroscopy of hypernuclei[3,4] have been performed. It is that the interaction is attractive, however, no exact information was obtained on its strength and potential form because of low statics and limited resolution of their detectors.

To obtain more experimental data, we performed a nuclear emulsion experiment (J-PARC E07[5]) using a newly developed analysis method, called a counter-emulsion method. In this method, the Ξ^- production reaction was identified by the magnetic spectrometers, and the position where the Ξ reached on emulsion was predicted by tracking detectors. It shortened the time for the image analysis compared with the conventional method searching by eyes. As a result, we have achieved 10 times the statics of the previous experiment.

In the experiment, Ξ^-s were produced via the (K^-, K^+) reaction in a diamond target and they were stopped at a nuclear emulsion located downstream of the target. Since the Ξ^-s have a negative charge, they are captured by atoms of C, N, O, Br, and Ag in the emulsion, then they form Ξ^- atoms. The Ξ^- potential and energy states for the case of the ^{14}N-Ξ system are shown in Fig. 1. Firstly, the Ξ^- is in the outer orbit where the Coulomb interaction is dominant as shown in the dotted line and it forms atomic state. Ξ^- transits to inner orbits with X-ray emission, then it is bound and makes a nuclear state due to the strong ΞN interaction. Finally, the Ξ^- is absorbed in a nucleus, namely, reacts as $\Xi^- p \rightarrow \Lambda\Lambda$ and it can produce twin Λ hypernuclei or a double Λ hypernucleus. We reported on the double Λ hypernuclear event "MINO" in 2018[6]. For the strong interaction potential $U(r)$, an optical potential is employed, $U(r) = V(r) + iW(r)$, and the real and the imaginary parts are written in $V(r)$ and $W(r)$, respectively. The energy levels depend on the strength of $V(r)$. The strength of an imaginary part $W(r)$ shows the probability of Ξ^- absorption into the nucleus and effects to the energy width (Γ) of the states as well. We also detected X rays from the Ξ atom using a germanium detector array to measure the energy levels and widths.

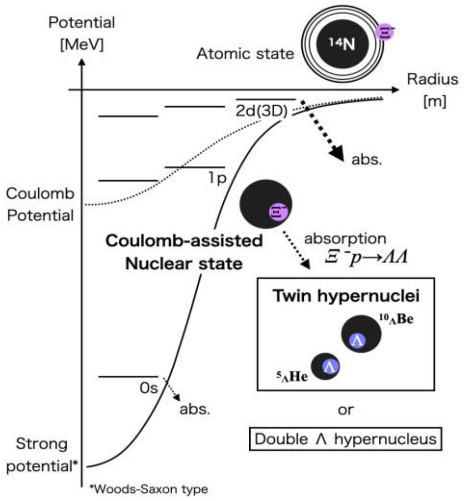

Fig. 1 Sketch of the ΞN potential and energy levels.

Newly observed a twin hypernuclear event "IBUKI" is reported[7], and it was interpreted as the event in which the Ξ^- is absorbed in ^{14}N nucleus, then decays to $^{10}_{\Lambda}$Be and $^{5}_{\Lambda}$He hyper nuclei. The B_Ξ, the binding energy of the Ξ^-, was obtained to be 1.27 ± 0.21 MeV. It represents that this is observation of the Ξ^--^{14}N bound system. In addition to Coulomb interaction, considering the strong interaction with reference to the Ehime potential[8], the B_Ξ in Ξ^--^{14}N system of nuclear *0s*, *1p*, and *2d* states are obtained as 5.93 MeV, 1.14 MeV and 0.174 MeV, respectively. Therefore, IBUKI event, the B_Ξ of 1.27 MeV, is considered to be the *1p* state. The contribution of the strong interaction is almost zero at the *2d* (atomic *3D*) state, while both interactions are comparable at the *1p* state, that is, the Coulomb and strong force are resulting in the energy of 0.39 and 0.75 MeV. The IBUKI is the first observation of the Coulomb-assisted nuclear *1p* state. According to the theoretical calculation which assumed $W(r)$ value based on the previous data, the probability of absorption from the s, *p*, and *d* states are estimated to be 0.00-0.07%, 0.2-5.6%, and 47.9-75.7%, respectively. The fact that a Ξ^- was not absorbed at the *d* state but reached to the *p* state in the IBUKI event suggests that the strength of the ΞN-$\Lambda\Lambda$ coupling is weaker, in other words, $W(r)$ is smaller than our expectation.

References

[1] S. Aoki *et al.*, Nucl. Phy. A **828** 191(2009).
[2] J. K. Ahn *et al.*, Phys. Rev. C **88**, 014003 (2013)
[3] T. Fukuda *et al.*, Phys. Rev. C 58 1306 (1998).
[4] P. Khaustov *et al.*, Phys. Rev. C **61** 054603 (2000).
[5] K. Imai *et al.*, Proposal fpr J-PARC E07 experiment
[6] S. H. Hayakawa *et al.*, Annual Report of ASRC 2018
[7] S. H. Hayakawa *et al.*, Phys. Rev. Lett. **126**, 062501 (2021)
[8] M. Yamaguchi *et al.*, Prog. Theor. Phys. **105**, 627 (2001)