The peak structure observed in the $K^- + {}^3\mathrm{He} \to \Lambda + p + n$ reaction at J-PARC implies production of a K^-pp bound state

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Atomic nuclei are many-body bound systems of nucleons, i.e., protons and neutrons, due to the attractive interaction between them, which we call the nuclear force. The nuclear force takes place by the exchange of mesons such as pion between nucleons, as Yukawa predicted in 1935. After the discovery of pion in 1947, more than 150 mesons have been discovered and listed in the Mesons Summary Tables published in the Review of Particle Physics.

Inside ordinary atomic nuclei, mesons are not explicit degrees of freedom but exist only as "virtual" states which bind nucleons (Fig.1). However, one may theoretically consider a situation that a meson really exists in an atomic nucleus as an explicit degrees of freedom and composes an exotic bound state together with nucleons, which we call "a mesic nucleus". Study of mesic nuclei has a potential to extend physics of atomic nuclei, because it strongly reflects the meson-nucleon interaction in addition to the nuclear force.

We expect that mesic nuclei exist if the interaction between a constituent meson and a nucleon is attractive enough. Among mesons, K^- has been attracting more attention for the last decade because it was predicted that the interaction between K^- meson and proton is strongly attractive and hence there exists a bound state of a K^- meson and two protons, often called as "a K^-pp bound state". Based on this prediction, there have been many theoretical studies on the properties of the K^-pp bound state as well as experimental searches for it.

In order to discover this K^-pp bound state in experiments, a facility where a large number of strange quarks can be generated is necessary. For this reason, we performed the E15 experiment at J-PARC (Japan Proton Accelerator Research Complex), in which we observed the $K^-{}^3\mathrm{He} \to \Lambda pn$ reaction by applying 3.4×10^9 K^- particles with momentum 1 GeV/c on the ^{3}He target [1]. In the J-PARC E15 experiment, we found a peak structure in the Λp invariant-mass spectrum near the K^-pp threshold (2.37 GeV) as shown in Fig.2. Since the peak exists near the K^-pp threshold, this could be a signal of a K^-pp bound state.

Furthermore, we performed a theoretical calculation of the $K^-{}^3\mathrm{He} \to \Lambda pn$ reaction to investigate the origin of the peak structure observed in the J-PARC E15 experiment [2]. We took into account a scenario that a K^-pp bound state is generated and decays into Λp, and calculate the Λp invariant-mass spectrum of the reaction. The numerical result is shown with the red thick line in Fig.2. From the comparison, the signal in the J-PARC E15 experiment is qualitatively reproduced by the assumption that a K^-pp bound state is generated in the reaction. This implies an existence of a K^-pp bound state in the J-PARC E15 experiment.

We note that the E15 data shown in Fig.2 were accumulated in May 2013 as the 1st run. The E15 2nd run was completed in Dec. 2015, in which we accumulated about 30 times more data than that in the 1st run. Right now we are analyzing these E15 2nd run data to conclude more clearly the peak structure of the spectrum and the existence of a K^-pp bound state, which is a new form of atomic nuclei composed of a K^-meson together with nucleons.

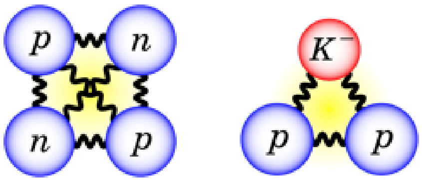

Fig.1 (Left) Bound state of two protons (p) and two neutrons (n) as a ^{4}He nucleus. (Right) Bound state of a K^- and two protons as a kaonic nucleus. In both figures, the wavy lines represent interaction between particles by the exchange of "virtual" mesons.

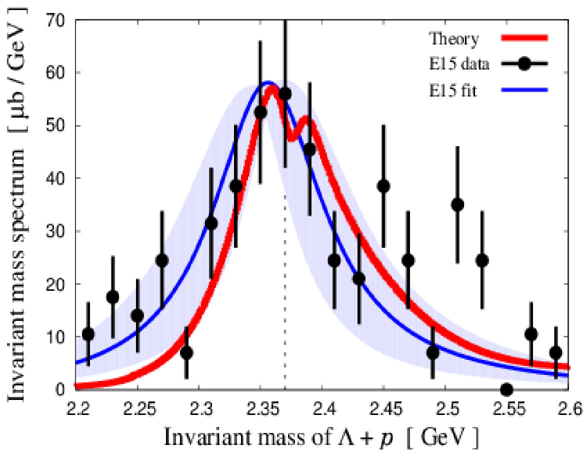

Fig.2 Spectrum for the Λp invariant mass in the $K^-{}^3\mathrm{He} \to \Lambda pn$ reaction. Red thick line represents the theoretical result in the assumption that the K^-pp bound state is generated. Black dots and blue band are experimental data and fit to them, respectively. Note that the experimental results are scaled so as to compare with the theoretical one. The vertical dotted line denotes the K^-pp threshold.

References

[1] Y. Sada *et al.*, Prog. Theor. Exp. Phys. **2016**, 051D01 (2016).

[2] T. Sekihara, E. Oset and A. Ramos, Prog. Theor. Exp. Phys. **2016**, 123D03 (2016).