Search for the deeply bound K^-pp state from the semi-inclusive forward-neutron spectrum in the in-flight K^- reaction on helium-3[†]

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The existence of a strongly attractive force between antikaons ($\bar{K}$) and nucleons in isospin 0 channels leads to the prediction of the formation of deeply bound kaonic-nuclei.[1] The investigation of these exotic states will provide unique information that will reveal the sub-threshold $\bar{K}N$ interaction. However, their existence has not been conclusively established to date.

The simplest kaonic nucleus is theoretically considered to be the so-called K^-pp state, consisting of a negative kaon and two protons.[a] We searched for this state by using an in-flight K^- reaction in the J-PARC E15 experiment at the K1.8BR beam line.[2] The first physics data acquisition was performed in May 2013, with 5×10^9 kaons at 1 GeV/c on a liquid ^{3}He target.

Figure 1 shows the semi-inclusive neutron spectrum at $\theta_n^{lab} = 0°$. Forward neutrons were detected with a plastic scintillation counter array placed $\sim$ 15 m away from the target and their momenta were reconstructed by the time-of-flight method. At least one charged particle was tagged in a cylindrical detector system (CDS) surrounding the target to determine the reaction vertex. The K^0-tagged spectrum, shown in the inset of Fig. 1, is attributed to the quasi-free charge-exchange reaction, and demonstrates that the detector resolution and the missing-mass scale are well understood.

The observed yield in the deeply bound region, corresponding to K^-pp binding energies greater than 80 MeV, was in good agreement with the evaluated backgrounds originating from 1) accidental hits and neutral particles other than neutrons, 2) reactions on the target cell, and 3) neutrons produced via charged Σ decay. Therefore, mass-dependent upper limits on the production cross section were determined in the missing-mass range from 2.06 to 2.29 GeV/c^2 for a $K^-pp \to \Lambda p$ isotropic decay. They were determined to be 30–180, 70–250, and 100–270 μb/sr, for natural widths of 20, 60, and 100 MeV, respectively, at 95% confidence levels. The upper limits obtained were one-order-of-magnitude smaller than the theoretical calculation performed by Koike and Harada for the deeply bound K^-pp case.[3] The ratios of the upper limits to the cross sections of the quasi-elastic channels are (0.5–5)% ($K^-n \to K^-n$) and (0.3–3)% ($K^-p \to K^0n$). These ratios are rather small compared to the sticking probability of the usual hypernucleus formation.
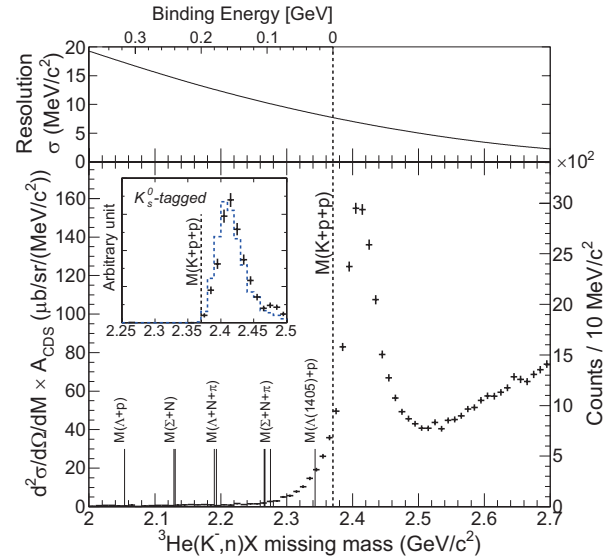

Fig. 1. ^{3}He($K^-, n)X$ semi-inclusive missing-mass distribution (below) and experimental resolution (above). The CDS tagging acceptance (A_{CDS}) is not corrected. The K^-pp binding threshold is indicated by a dotted line and other related mass thresholds are indicated by solid lines. The inset shows the K_s^0-tagged spectrum compared with the simulation (blue dotted line).

In the loosely bound region, we observed a large yield which cannot be explained elementally processes. The cross section of this excess above the background is $\sim$ 1 mb/sr, assuming loosely bound K^-pp formation. This is about the same yield as that given by Koike and Harada,[3] but much greater than the value given by Yamagata-Sekihara et $al.$[4] In spite of the observed large yield, the structure near the threshold suggested in the theoretical spectral functions cannot be identified from only this semi-inclusive measurement. For further investigation of the origin of the sub-threshold structure, an exclusive analysis of the forthcoming dataset is required.

References
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a) More generally, it is expressed as $[\bar{K} \otimes \{NN\}_{I=1,S=0}]_{I=1/2}$ with $J^\pi = 0^-$.