Charge symmetry breaking of a hypernucleus $^{4}_{\Lambda}$He

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It has been known for a long time that nuclei of equal mass and with inverted proton and neutron numbers (mirror nuclei) exhibit very similar properties. These similarities are due to a characteristic of the nuclear force called charge symmetry. A question to answer is whether this symmetry holds also for hupernuclei which include a Λ particle.

In the past, an experiment to study $^{4}_{\Lambda}$He gamma rays measured a mass difference between 1^+ and 0^+ states of 1.15±0.04 MeV. The mass difference is very similar to that for $^{4}_{\Lambda}$H of 1.09±0.02 MeV. This measurement indicated that charge symmetry holds for these hypernuclei [1]. However, these experiments had rather poor energy resolution, signal-to-noise ratio, and gamma-ray statistics.

In order to improve the data quality, we proposed a new experiment E13, where we irradiate K^- beams on a ^{4}He target, produce $^{4}_{\Lambda}$He, and measure the gamma ray from its exited state as shown in Fig. 1 [2]. The reaction is $K^- + {}^4\mathrm{He} \rightarrow {}^{4}_{\Lambda}\mathrm{He}^* + \pi^-$, $^{4}_{\Lambda}\mathrm{He}^* \rightarrow {}^{4}_{\Lambda}\mathrm{He} + \gamma$. For extremely intense K^- beams at J-PARC (typically 3 x 10^5 / spill), we developed the gamma-ray detector system Hyperball-J, shown in Fig. 1. We included a mechanical cooling system of Ge crystals to reduce radiation damage due to high beam rates, and employed $PbWO_4$ counters with fast response time (~10 ns) to reject background, such as a Compton scattering and high energy photons from π^0 decay with high particle rates. We also suppressed background reactions by identifying the incident K^- beam particle and the produced π^- with aerogel Cherenkov counters and time-of-flight detectors shown in Fig. 1.

In April 2015, as the first experiment after recovering from the radiation accident at J-PARC Hadron Experimental Facility, we performed the E13 experiment for 5 days with 2.3x10^{10} K^- beams at 1.5 GeV/c. We succeeded to measure gamma-ray energy spectra with a very high energy resolution of 5 keV (FWHM), i.e. a factor of 20 improvement compared to the past experiment. The measured gamma-ray energy spectrum after the (K^-, π^-) event selection is shown in Fig. 2. We observed the peak corresponding to the transition of $^{4}_{\Lambda}$He from the 1^+ excited state to the 0^+ ground state. The energy is determined to be 1.406±0.002 (stat.) ±0.002 (syst.) MeV, which excludes the previous experimental data of 1.15±0.04 MeV.

By comparing the resulting energy levels in $^{4}_{\Lambda}$He and $^{4}_{\Lambda}$H, as shown in Fig. 3, a very large charge symmetry breaking of 320 keV is confirmed. This result implies that there is a difference between the Λn interaction and Λp interaction, depending strongly on their spin states. The present work provides important data to understand the strong interaction between baryons, and has triggered new theoretical studies on this problem.

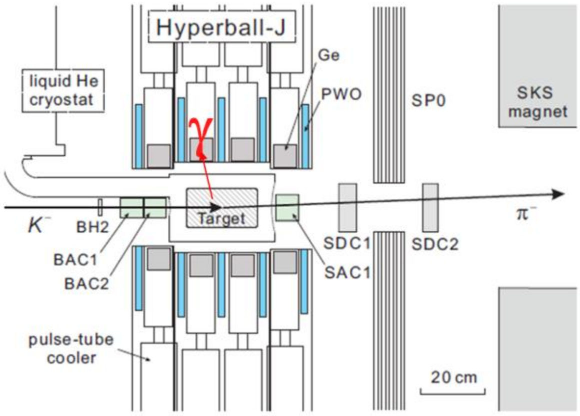

Fig. 1: The experimental setup of E13 [2]. The K^- beam is injected to the ^{4}He target. The incident K^- and the produced π^- are identified with the aerogel Cherenkov detectors BAC2 and SAC1. The gamma rays emitted from the target are detected with the Hyperball-J Ge detectors.

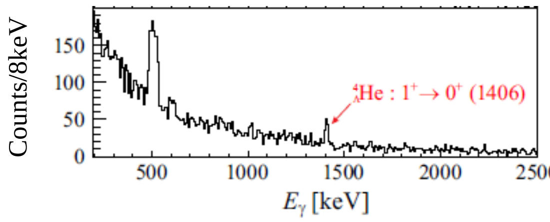

Fig. 2: Gamma-ray energy spectra from $^{4}_{\Lambda}$He requiring (K^-, π^-) reactions [1].

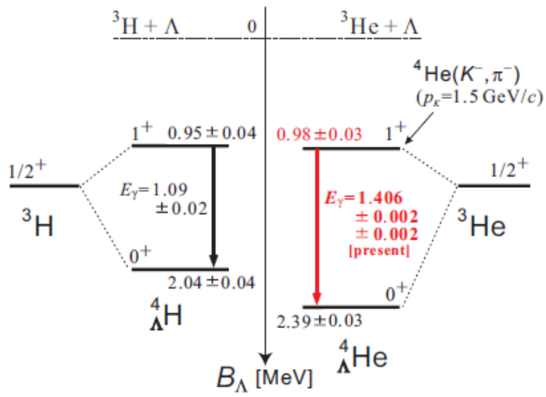

Fig. 3: Energy levels of mirror nuclei $^{4}_{\Lambda}$H and $^{4}_{\Lambda}$He [2].

References

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