Physicists discover evidence of rare hypernucleus, a component of strange matter

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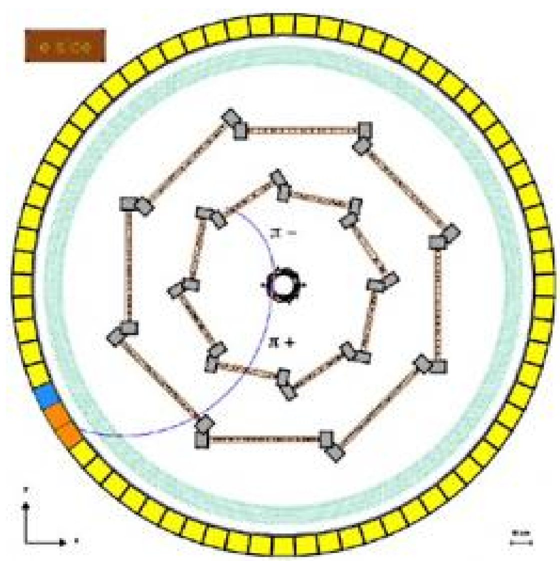

A view of one of the three events found by FINUDA: a schematic frontal view of the apparatus is shown, and the two blue lines represent the two 'pi' mesons moving along opposite bent trajectories in the magnetic field of the apparatus. Image credit: FINUDA collaboration

(PhysOrg.com) -- Physicists in Italy have discovered the first evidence of a rare nucleus that doesn’t exist in nature and lives for just 10^{-10} seconds before decaying. It’s a type of hypernucleus that, like all nuclei, contains an assortment of neutrons and protons. But unlike ordinary nuclei, hypernuclei also contain at least one hyperon, a particle that consists of three quarks, including at least one strange quark. Hypernuclei are thought to form the core of strange matter that may exist in distant parts of the universe, and could also allow physicists to probe the inside of the nucleus.

The particular hypernucleus investigated here, called "hydrogen six Lambda" (${}^{6}_{\Lambda}H$), was first predicted to exist in 1963. Now, in a study published in a recent issue of Physical Review Letters, physicists working in the FINUDA experiment at the Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati (INFN-LNF) in Frascati, Italy, have reported finding the first evidence for the particle. The FINUDA collaboration's analysis of millions of events has turned up three events for the rare hypernucleus.

Strange properties

As its name suggests, ${}^{6}_{\Lambda}H$ is a large type of hydrogen nucleus that consists of six particles: four neutrons, one proton, and one Lambda (Λ) hyperon. Since an ordinary hydrogen nucleus contains one proton and no neutrons, hydrogen nuclei that contain one or more neutrons are sometimes called "heavy hydrogen." The most common types of heavy hydrogen are deuterium (which has one neutron) and tritium (which has two neutrons). Since ${}^{6}_{\Lambda}H$ has four neutrons plus a L hyperon, physicists refer to it as "heavy hyperhydrogen."

The L hyperon, which consists of one up, one down, and one strange quark, does an even more interesting thing to ${}^{6}_{\Lambda}H$: it increases its lifetime from 10^{-22} seconds (the lifetime of the hypernucleus core ${}^{5}H$ without L) to 10^{-10} seconds. When scientists first discovered the L hyperon in 1947, they observed a similarly longer lifetime than predicted for this "strange" object. That observation led to the idea of the existence of the strange quark, with strangeness being the property that causes the quark to live so long.

Detection

Without the L hyperon, it would likely be impossible for physicists to directly observe a hydrogen nucleus with four neutrons, since such a heavy isotope is very difficult to produce and has a very short lifetime. Another hypernucleus, $^{4}{}_{\Lambda}H$, which has two neutrons instead of four, is more easily produced than $^{6}{}_{\Lambda}H$ in similar experiments and has been detected many times. But detecting evidence of $^{6}{}_{\Lambda}H$ is much more difficult. The 27 million collision events analyzed by the FINUDA collaboration represents about one full year of continuous data-taking from an experiment that spanned several years. Theoretically, the formation probability of $^{6}{}_{\Lambda}H$ is at least 100 times smaller than that of $^{4}{}_{\Lambda}H$.

The FINUDA experiment is located at one of the two interaction points of the DAFNE collider at INFN-LNF. As Elena Botta, a lead collaborator in the study, explained, DAFNE produces electron and positron beams. When these beams collide nearly head-on, they produce the phi meson (Φ), which decays with a 50% probability into a charged pair of K and anti-K mesons.

FINUDA's interaction point contains an octagonal prism with eight targets along the sides. When the anti-K meson interacts with a lithium nucleus in one of these targets, it can simultaneously produce a $^{6}{}_{\Lambda}H$ hypernucleus and a π^{+} meson of a particular energy. If scientists detect this particular meson, they've detected a signature of the strange nucleus formation. As Botta explained, $^{6}{}_{\Lambda}H$ production involves a two-step mechanism to decrease the number of protons in the lithium isotope, ^{6}Li, from three to one, which produces hydrogen. Once produced, the neutron-rich $^{6}{}_{\Lambda}H$ hypernuclei slow down inside the target, and after 10^{-10} seconds they decay at rest into a π^{-} meson and a ^{6}He nucleus. The π^{-} meson also has a particular energy, and scientists can easily detect it to give the signature of the decay. So both the formation and the decay of

$^{6}{}_{\Lambda}H$ hypernuclei can be detected by searching for events with the presence of these particular π^+ and π^- mesons.

Strange matter

As the first evidence for $^{6}{}_{\Lambda}H$ hypernuclei, the results could shed light on strange matter, which is hypothesized to exist at the center of ultra-dense neutron stars. The physicists hope to investigate strange matter further by producing strange nuclear systems.

“Hypernuclei can be interpreted as the core of strange matter,” Botta told *PhysOrg.com*. “In particular, the possibility to produce strange nuclear systems containing two Λ particles will allow us to study the interaction between strange particles.”

Hypernuclei could also serve as a useful tool to investigate the current model of nuclear structure, in which protons and neutrons are arranged in a stable configuration.

“The fact that a hypernucleus has a strange quark does give it interesting characteristics compared to normal nuclei, since it allows the component L particle to act as a probe that can go very deep into the nucleus to test the description that the single particle shell model gives of nuclear matter,” Botta said. “In this respect, the study of hypernuclear physics allows us to get information not directly accessible otherwise.”

She added that other hypernuclei with large neutron-to-proton ratios could exist in a stable state, even though ordinary neutron-rich nuclei are theoretically unstable. Neutron-rich hypernuclei seem to be an exception because of the way they modify the structure of a nucleus and increase its lifetime.

During an upcoming experiment at the Japan Proton Accelerator

Research Complex (J-PARC), physicists plan to search for $^{6}_{\Lambda}H$ as well as for other neutron-rich hypernuclei, such as lithium 10 Lambda ($^{10}_{\Lambda}Li$).

More information: M. Agnello, et al. "Evidence for Heavy Hyperhydrogen $^{6}_{\Lambda}H$." *Physical Review Letters* 108, 042501 (2012) DOI: 10.1103/PhysRevLett.108.042501