STAR experiment reports the discovery of anti-strange matter

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The STAR experiment (http://www.star.bnl.gov), composed of 54 collaborating institutions from 13 countries: Brazil, PR China, Croatia, the Czech Republic, France, Germany, India, Korea, the Netherlands, Poland, Russia, the United Kingdom and the United States of America, has reported[1], the evidence of the most massive antinucleus discovered to date. The new antinucleus is a negatively charged state of antimatter containing an anti-proton, an anti-neutron and an anti-lambda particle. It is also the first anti-nucleus containing an anti-strange quark.

All terrestrial nuclei, made of protons and neutrons (which in turn contain only up and down quarks), have a zero value for the quantum number 'strangeness'. The strangeness could be non-zero in the core of collapsed stars; so the present measurements will help us distinguish between models that describe these exotic states of matter[2]. Since the discovery of hypernuclei in 1952, many major laboratories have dedicated experiments for hypernuclear studies, with on-going and future facilities at GSI and MAMI C in Germany, DAΦNE in Italy, J-PARC in Japan, JINR in Russia and JLab in USA. These experiments in the near future could confirm the observations reported by STAR.

About a hundred million collisions between gold nuclei using the Relativistic Heavy Ion Collider (RHIC) Facility in Brookhaven National Laboratory, USA, were searched in the antimatter analysis. The new antinucleus was identified via its characteristic decay into a light isotope of anti-helium and a positively charged pion. Invariant mass distribution showing the hypertriton and the anti-hypertriton signals over the combinatoric background is given in Figure 1. Altogether, 70 candidates of the anti-hypertriton and 157 hypertritons were found. The measured masses and the lifetimes were about 2.99 GeV/c^2 and 182 ± 27 ps (statistical error) for both the nuclei respectively.

This discovery has added a new dimension to the standard periodic table of elements that is arranged according to the number of protons, which determine the chemical properties of each element. We now have a 3D chart of the nuclides as shown in Figure 2. In addition to the N-axis corresponding to the number of neutrons, which may change in different isotopes of the same element, the third axis represents strangeness, S, which is zero for all naturally occurring matter. Anti-nuclei lie at negative Z and N in the above chart, and the newly discovered anti-strange nucleus now extends the 3D chart into the new region of strange antimatter. The new discovery of strange antimatter with an anti-strange quark (an anti-hypernucleus) marks the first entry below the plane.

The findings also pave the way towards exploring violations of fundamental symmetries that occurred in the early universe, making possible the very existence of our world. Collisions at RHIC fleetingly produce conditions that existed a few microseconds after the big

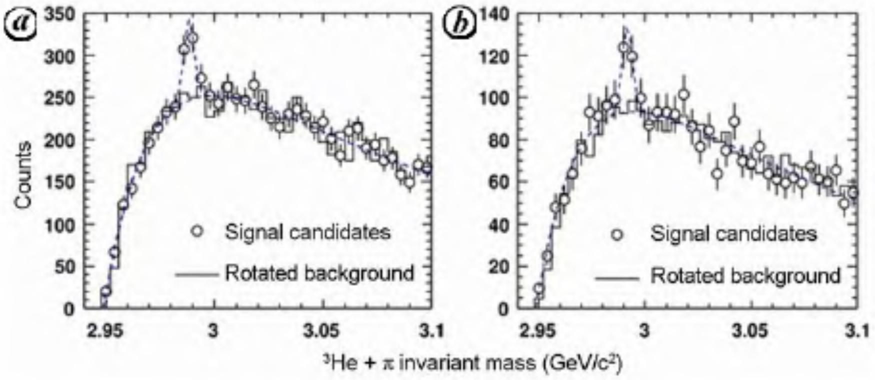

Figure 1. ***a***, Invariant mass distribution of the daughter ^{3}He + π. Open circles represent the signal candidate distributions, and solid black lines are background distributions. The blue dashed lines are a combination of the signal and background. ***b***, Same as ***a***, for the anti-hypertriton candidate distributions.

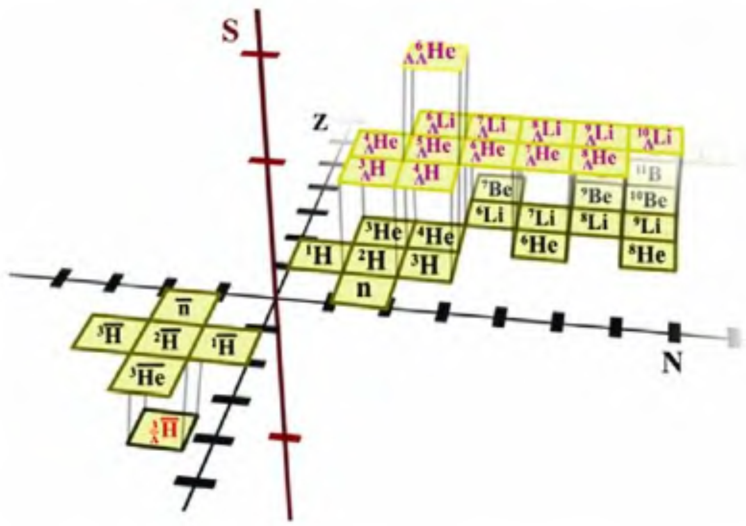

Figure 2. A chart of the nuclides showing extension into the strangeness sector. Normal nuclei lie in the (N, Z) plane. Anti-nuclei lie in the negative sector of this plane. Normal hypernuclei lie in the positive (N, Z) quadrant above the plane. The anti-hypertriton reported by STAR extends this chart into the strangeness octant below the anti-matter region in the (N, Z) plane.

bang. In both nuclear collisions and in the big bang, which started the universe, as we know it, quarks and anti-quarks emerge with equal abundance. At RHIC, among the collision fragments that survive to the final state, matter and anti-matter are still close to equally abundant, even in the case of the relatively complex antinucleus and its normal matter partner featured in the present study. In contrast, antimatter appears to be largely absent from the present-day universe.

Understanding precisely how and why there is a predominance of matter over anti-matter remains a major unsolved problem of physics. A solution will require measurements of subtle deviations from perfect symmetry between matter and anti-matter, and there are good prospects for future anti-matter measurements at RHIC to address this key issue. Furthermore, the present discovery demonstrates that the anti-nucleus production mechanism, known as statistical coalescence, holds over a wider range of conditions than had previously been tested. This in turn has implications for novel ideas related to the structure of nuclear matter[3] and for cosmic-ray experiments searching for new physics like dark matter[4].

STAR is poised to resume antimatter studies at top RHIC energy with greatly enhanced capabilities, and expects to increase its data by about a factor of ten in the next few years, allowing even heavier exotic nuclear states to be discovered and studied.

Recent theoretical studies motivate a search for the onset of quark gluon plasma by studying the evolution of the baryon-strangeness correlation as a function of collision energy[5]. Our measurements provide a natural and sensitive tool to extract this correlation since the coalescence process for a nucleus requires its constituents (lambda and nucleons) to be in proximity in phase space. The results indicate that the phase-space population for strangeness is similar to that for light quarks at RHIC, in contrast to the situation at the AGS. In 2010, RHIC has started a systematic scan over beam energies ranging from low values (near AGS energies ~centre-of-mass energies of 5 GeV) up to the top RHIC energy (centre of mass energies of 200 GeV). Although anti-hypernucleus production and RHIC luminosity both decrease dramatically towards lower beam energy, the coalescence probability for hypernucleus production increases, largely compensating for the decreasing luminosity. This lower beam energy scan[6] should allow the trend with collision energy to be determined more accurately, and should lead to quantitative comparisons with models.

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