In this article, we present a brief review of the discoveries of kinds of antimatter particles, including positron ($e$), antiproton ($\bar{p}$), antideuteron ($\bar{d}$) and antihelium-3 ($^3\bar{\text{He}}$). Special emphasis is put on the discovery of the antihypertriton ($\bar{\Lambda}$) and antihelium-4 nucleus ($^4\bar{\text{He}}$, or $\alpha$) which were reported by the RHIC-STAR experiment very recently. In addition, brief discussions about the effort to search for antinuclei in cosmic rays and study of the longtime confinement of the simplest antimatter atom, antihydrogen are also given. Moreover, the production mechanism of anti-light nuclei is introduced.

**Keywords** antimatter, $e$, $\bar{p}$, $\bar{d}$, $^3\bar{\text{H}}$, $^3\bar{\Lambda}$, $^3\bar{\text{He}}$, $^4\bar{\text{He}}$

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### 1. Introduction

The ideal of antimatter can be traced back to the end of 1890s, when Schuster discussed the possibility of the existence of antitokens as well as antimatter solar system by hypothesis in his letter to Nature magazine [1]. However, the modern concept of antimatter is originated from the negative energy state solution of a quantum-mechanical equation, which was proposed by Dirac in 1928 [2]. Two years later, Chao found that the absorption coefficient of hard $\gamma$-rays in heavy elements was much larger than that to be expected from the Klein–Nishima formula or any other [3, 4]. This “abnormal” absorption is in fact due to the production of the pair of electron and its anti-partner, so-called positron. Therefore Chao’s experiment is the first indirect observation of the first anti-matter particle, namely positron, in the history. Another two years later, Anderson observed positron with a cloud chamber [5]. Antimatter nuclei such as $\bar{d}$, $^3\bar{\text{H}}$, $^3\bar{\text{He}}$ have been widely studied in both cosmic rays [6–8] and accelerator experiments [9–15] for the purposes of dark matter exploration and the study of manmade matter such as quark gluon plasma (QGP) respectively, since the observation of anti-proton ($\bar{p}$) [16] in 1955. The possibility of the anti-gravity behavior between matter and antimatter has been discussed somewhere else [17]. The recent progress regarding the observation of antihypertriton ($\bar{\Lambda}$) [18] and antihelium-4 ($^4\bar{\text{He}}$, or $\alpha$) [19] nucleus in high energy heavy ion collisions [20–22] reported by RHIC-STAR experiment as well as the longtime confinement of antihydrogen atoms [23] based on an antiproton decelerator facility by CERN (the European Organization for Nuclear Research) ALPHA collaboration have already created a lot of excitation in both of the nuclear and particle physics community. All of the measurements performed above have implications beyond the fields of their own. For example, the study of hypernucleus in heavy ion collisions is essential for the understanding of the interaction between nucleon and hyperon (YN interaction), which plays an important role in the explanation of the structure of neutron star. Furthermore, as we learned from heavy ion collisions, the production rate for $^4\bar{\text{He}}$ produced by colliding the high energy cosmic rays with interstellar materials is too low to be observed. Even one $^4\bar{\text{He}}$ or heavier antinucleus observed in the cosmic...
rays should be a great hint of the existence of massive antimatter in the Universe. Finally, the successful trap of antihydrogen atoms leads to a precise test of the CPT symmetry law, as well as a measurement of the gravitational effects between antimatter and matter in the future.

In this article, we present a review of kinds of antimatter particles experimentally, based on the time schedule of their first time observations. The paper is arranged as follows: In Section 2, we will take a look back to the discoveries of positron and antiproton. In Section 3, the first time observations of antideuteron and antihelium-3 will be discussed. Section 4 presents a brief review of the formation and observation of $^3\Lambda$ through their secondary vertex reconstructions via decay channel $^3\Lambda \rightarrow ^3\mathrm{He} + \pi^+$ with a branch ratio of 25% in high energy heavy ion collisions. In Section 5, we have discussion of the particle identification of $^4\mathrm{He}$ nucleus by measuring their mass value directly with the fully installed detector Time Of Flight (TOF) at RHIC-STAR. In Section 6, we discuss the effort of searching for antimatter nuclei in cosmos. In Section 7, the long time trap of antihydrogen atoms performed by ALPHA experiment is introduced. In the last section, we have a discussion on antimatter nuclei production mechanism. Finally we give a summary and outlook.

2 Observation of positron

In 1930, Chao performed a few $\gamma$-ray scattering experiments on different elements [3, 4]. $\gamma$-rays from Th C after being filtered through 2.7cm of Pb were used as the primary beam. Al and Pb were chosen as the representatives of the light and the heavy elements. For Al the $\gamma$-scattering is, within experimental error, that predicted by the Klien–Nishima formula which assumes that the removal of the energy from the primary beam is entirely due to Compton scattering of the extranuclear electrons. However, for Pb additional scattering rays were observed. The wavelength and space distribution of these rays are inconsistent with an extranuclear scatterer [3, 4]. Later on, this abnormal absorption was identified as the outcome of the process of electron-positron pair production. Therefore this experiment was also the first experimental indication of the first anti-matter particle, positron, in the observation history for the antimatter.

Two years later, Anderson identified 15 positive tracks by photographing the cosmic rays with a vertical Wilson chamber in August, 1932 [5]. The unknown particles were recognized as the predicted antimatter electron (positron) after an analysis of their energy loss, ionization, as well as their curvatures in the chamber. Figure 1 shows that, a positron reduces its energy by passing through a 6 mm lead plate in the cloud chamber. The track length from the upper part of the cloud chamber can only be interpreted with the observation of positron.

3 Observations of antiproton, antideuteron and antihelium-3

Physicists had expanded their understanding of the natural world, and took into consideration that every particle should have their antimatter partner after the discovery of positron. They were able to expand their knowledge of antimatter with the development of the technology of accelerators, while the development of Time-of-Flight detector system played an important role in the following identification of antimatter particles. In the year 1955, Chamberlain and Segrè from University of California reported their observation of antiprotons based on the Bevatron facility [16]. Antiprotons were produced and scattered into the forward direction by projecting a bunch of proton beam to the copper target at Bevatron. By observing the times of flight for antiprotons, this experiment made more sense by the fact that the electronic gate time is considerably longer than the spread of observed antiproton flight times. The electronic equipment accepts events that are within $\pm 6$ millimicroseconds of the right flight time for antiprotons, while the actual antiproton traces recorded show a grouping of flight times to $\pm 1$ or 2 millimicroseconds. Figure 2(a) and (b) depict a histogram of meson flight times and that of antiproton flight times, respectively. Accidental coincidences account for many of the sweeps (about 2/3 of the sweeps) during the runs designed to detect antiprotons. A histogram of the apparent flight times of accidental coincidences is shown in Fig. 2(c). It will be noticed that the accidental coincidences do not show the close grouping of flight times characteristic of the antiproton or meson.