Precision Antihydrogen Annihilation Reconstructions using the ALPHA-g Apparatus

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Introduction

Moments after the Big Bang, matter and antimatter should have been created in equal parts [1]. When a matter particle interacts with its antimatter counterpart, they annihilate. Yet matter has prevailed. How then does our world exist? To understand the baryonic assymetry problem, we develop experiments that compare aspects of matter to antimatter, one such aspect being gravity. Does antimatter fall down like matter, or does it fall up?

Antihydrogen

Antihydrogen, the antimatter equivalent of hydrogen, is the simplest anti-atom as it only requires a positron (e^+) and an antiproton ($\bar{p}$) [2]. Imagine trapping antihydrogen, releasing it, and observing which direction it falls. This will test the theory known as the Weak Equivalence Principle (WEP), where the acceleration due to gravity that a body experiences is independent of its stucture or composition [3].

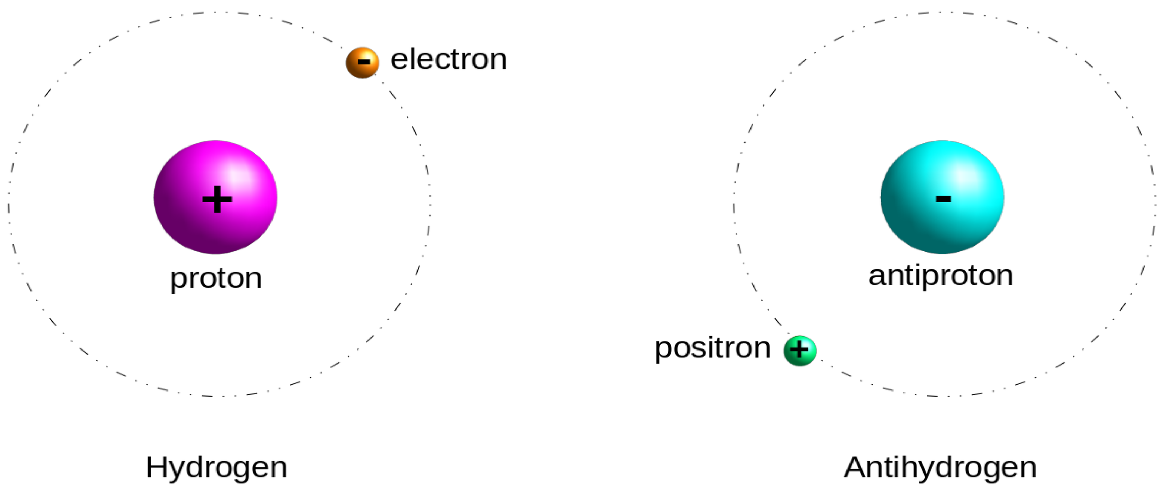

Figure 2. Hydrogen and antihydrogen atoms.

ALPHA

ALPHA (Antihydrogen Laser PHysics Apparatus) is a diverse collaboration of scientists based at the European Organization for Nuclear Research (CERN) using neutral atom trapping techniques to make antihydrogen measurements. Using a Penning trap to capture antiprotons from the Antiproton Decelerator (AD) at CERN, ALPHA has developed techniques to cool and trap positrons and antiprotons and mix them to form antihydrogen [4].

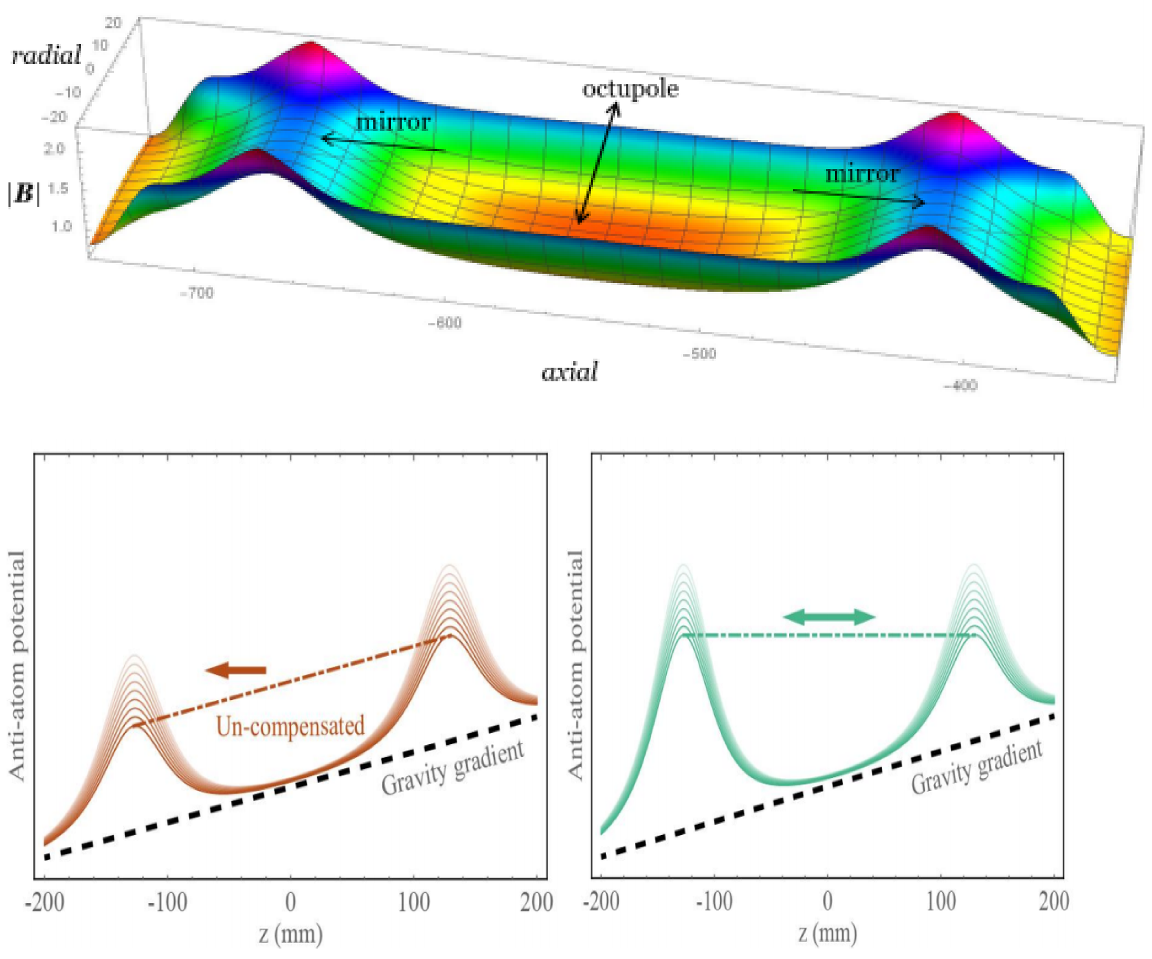

Figure 3. Antihydrogen is held in a magnetic field due to its magnetic moment. A compensated release of the axial confiment is required to account for gravity. This is done in a effort to eliminate a bias for the antihydrogen to fall down due to Earth's gravity. Images made by Chukman So.

ALPHA-g

ALPHA-g is a vertical apparatus where e^+ and $\bar{p}$ are injected into the bottom end of the apparatus into the Penning trap where the particles are mixed to form antihydrogen, which is then magnetically trapped [5]. Following a controlled release, antihydrogen will either fall up or down before it interacts with the walls of the Penning trap and annihilates. When antihydrogen annihilates, it produces on average 3 charged pions. These pions can be tracked using a radial Time Projection Chamber (rTPC), a gas detector 2.3m in length and 40cm in (outer) diameter that envelopes the ALPHA-g apparatus [6]. When an annihilation event occurs, information from the rTPC can reconstruct the resulting particle trajectories, and measure the vertex of the annihilation. The vertical distribution of vertices will determine whether antimatter falls up or down, and result in measurements for the gravitational mass of antihydrogen. ALPHA-g is also fitted with a barrel scintillator surrounding the rTPC that works to reject cosmic ray backgrounds, the largest source of background events for this experiment.

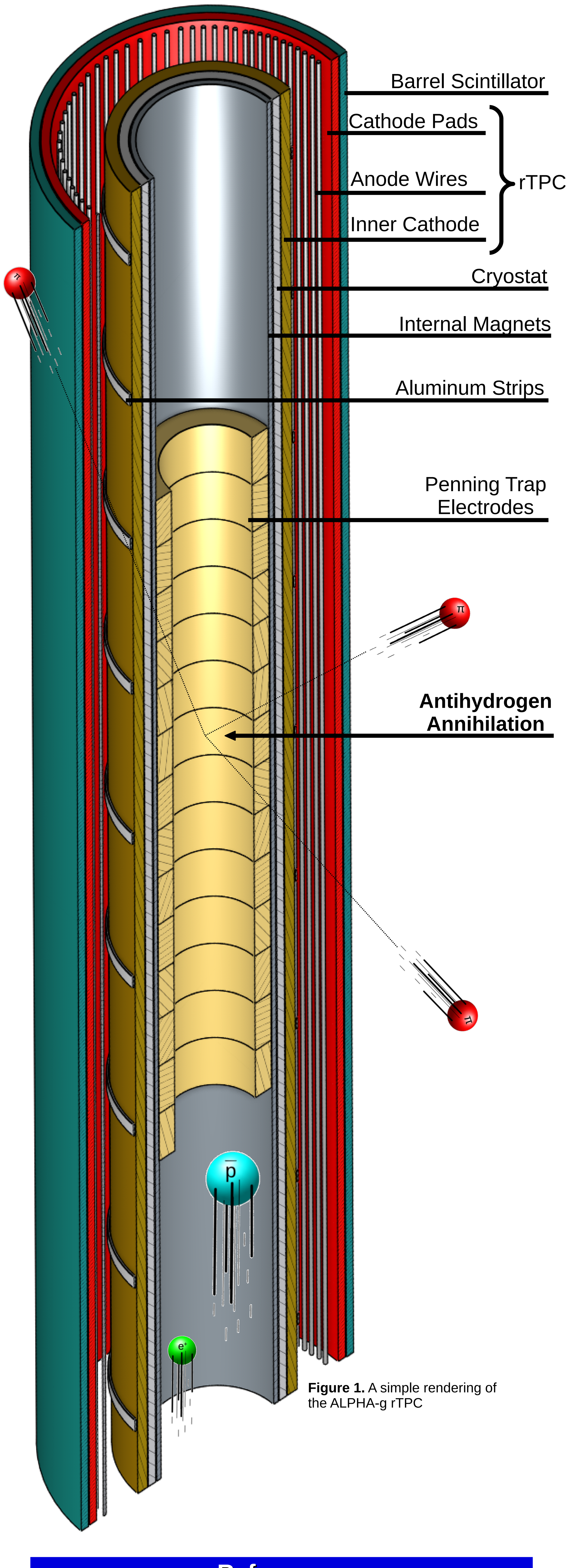

Figure 1. A simple rendering of the ALPHA-g rTPC

Annihilation Simulations

Using toolkits such as GEANT4 and Garfield++, we can simulate annihilation events within ALPHA-g. GEANT4 is used to simulate particle trajectories through matter, and establish the geometry of the detector [7]. Garfield++ inputs the physics necessary to track events in a gas medium, and calculates electric fields [8]. Together, they can accurately simulate the expected annihilation and cosmic events in ALPHA-g. This is all done in an effort to accurately understand the physics data obtained, as we are working with a small number of trapped anti-atoms (on the order of 10 anti-atoms every 5 minutes).

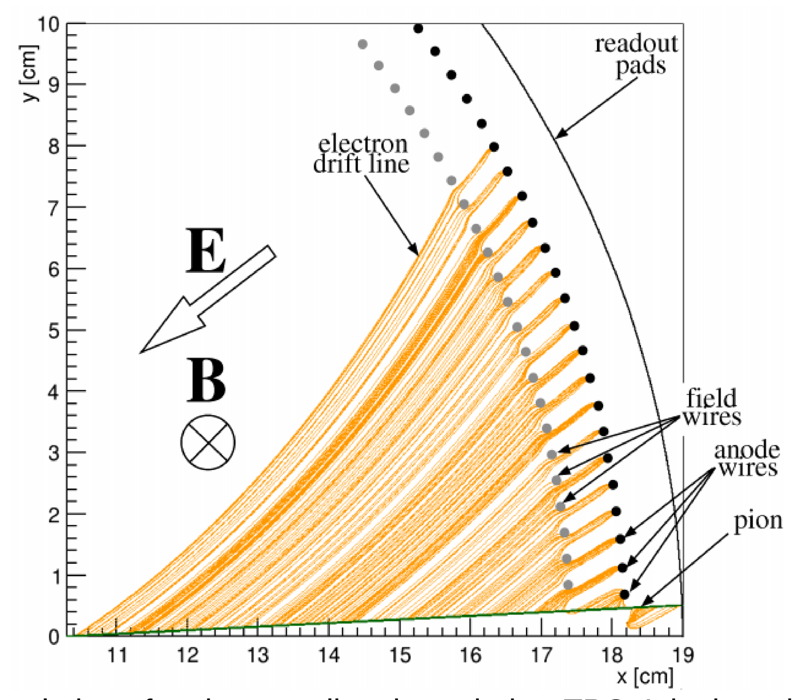

Figure 4. Simulation of a pion traveling through the rTPC. It ionizes the gas, resulting in electrons drifintg towards the anode wires. Image made by Andrea Capra.

Laser Calibration

Another important step is to properly calibrate the detector. This is performed using an ultraviolet laser (λ = 266nm) and a cylindrical quartz rod that directs a plane of light down the length of the detector and interacts with strategically placed aluminum strips. There are 9 aluminum strips (6mm width) placed along the inner cathode of the detector. The work function of aluminum is lower than the photon energy, therefore due to the photoelectric effect as the laser light hits the aluminum, we will see electron emission arrive at the wires of the rTPC at known positions. The electrons hitting the wire and the resulting induced charge at the cathode pads will provide timing and z-position information. In order to not hit the same anode wires along the length of the rTPC, the plane of light is rotated slightly in the z-axis. Ideally 2 electron clouds will hit 2 anode wires.

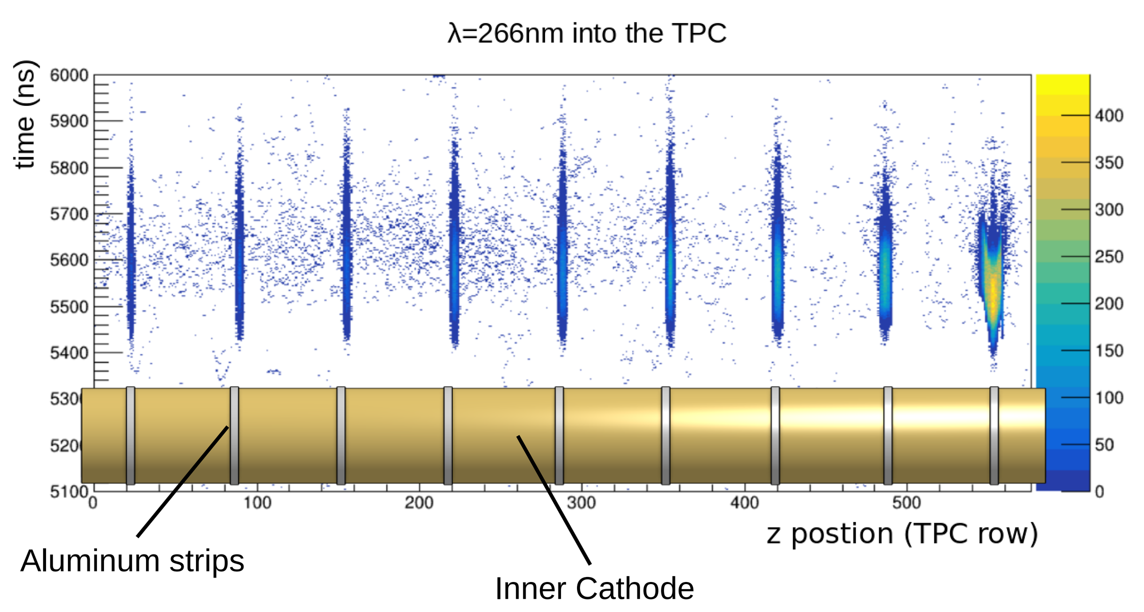

Figure 5. UV light shone inside the rTPC can be seen interacting with all 9 aluminum strips

Conclusion

Quantifying the detector resolution through simulations and calibrating the detector with the laser system are critical to determining the annihilation positions within the detector, and thus calculating the gravity measurements for antihydrogen. The matter-antimatter symmetry problem cannot be easily explained. However, tests of the gravitational mass of antihydrogen are key measurements towards understanding why our Universe is comprised of matter. Using vertex reconstruction methods, the ALPHA-g experiment aims to make the first measurements of the gravitational mass of antihydrogen.

References

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