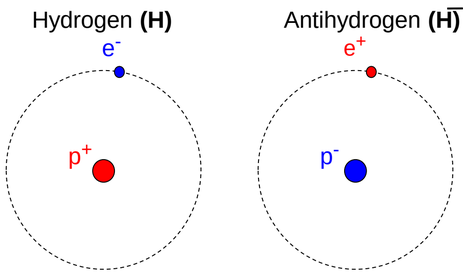
Physic with antimatter: the hyperfine splitting of antihydrogen atoms

ID ABSTRACT 275

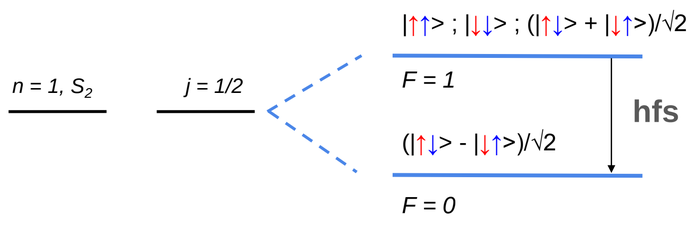
alpha experiment at CERN, Antimatter Factory

Overview

The **ALPHA** experiment (**A**ntihydrogen **L**aser **P**hysics **A**pparatus) at CERN is able to synthesize, confine and study cold atoms of antihydrogen. By precise comparisons of the characteristics of hydrogen and antihydrogen, the experiment hopes to study and test fundamental symmetries between matter and antimatter, (e.g. **CPT** symmetry).



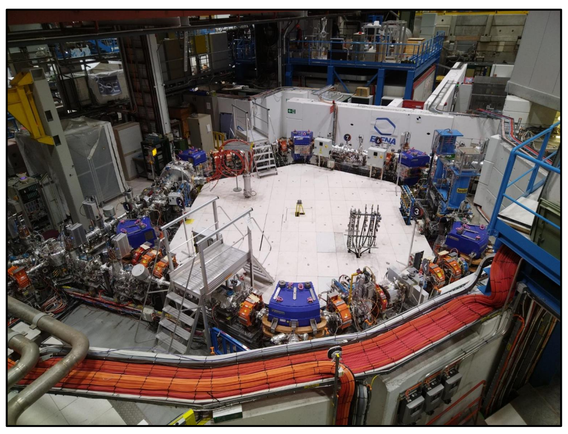
■ At ALPHA is possible to perform spectroscopy measurements, probing the anti-atoms with laser light, testing the CPT invariance of spectral lines, Such as Ly-α or the **hyperfine structure** of anti-matter.



The AD and ALPHA Experiment

The **ALPHA** produces antihydrogen atoms from the physical mixing of two plasma clouds of antiproton and positron. The antiprotons are produced during the scattering of the **PS** proton beam (E ≅ 200 GeV) on a iridium target, then separated from other particles via a magnetic biconical-lent. AD decelerate these antiproton down to 5.3 MeV of kinetic energy, and then they are sent to **ELENA** ring, where they are further decelerated to 100 keV. The antiprotons are finally delivered to the experiments of the Antimatter Factory, where ALPHA is located.

ELENA antiproton decelerator



antiprotons from AD/Elena

p^-

Antiproton magnetic trap (Penning Trap)

anti-proton cooling

Measure and Compress anti-proton plasma size

p^-

e^+

MIXING plasma: Anti Hydrogen Production in ALPHA2.

Measure and compress positron plasma size

positron cooling

Positron Accumulator

e^+

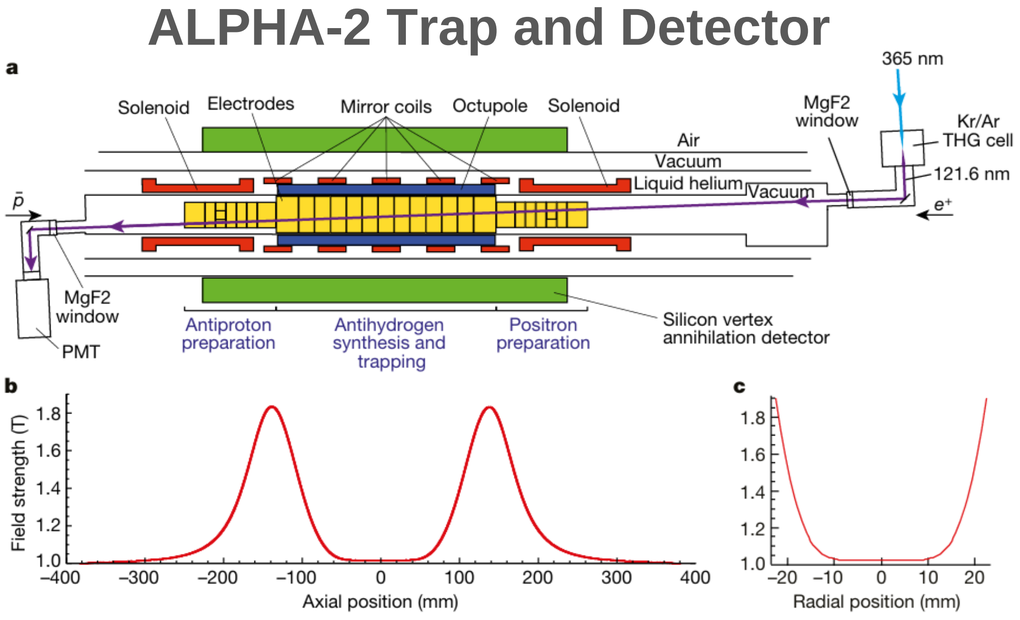
NA^{22} Positron Source

The positrons are produced by the β^+ decay of a Na^{22} source. The emitted positrons typically have an energy range in the hundreds of keV, and therefore need to be slowed down before they can be trapped. At ALPHA, this is accomplished in a multi-stage device known as the Positron accumulator.

Na^{22} source

positron accumulator

ALPHA-2 Trap and Detector



The Hyperfine Splitting Measurement

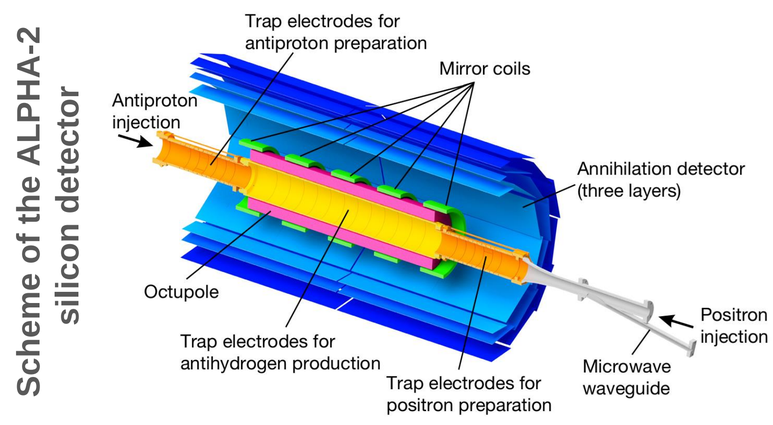
In ALPHA-2 detector, the antihydrogen is produced from the positron and antiproton plasma during the mixing process. Because of its neutrality, the confinement of the anti-hydrogen is achieved exploiting its magnetic moment. By manipulating the axial and transverse magnetic field, a potential wall does not let the antihydrogen to escape the trap.

| **Ground-state hyperfine energy levels.** The energy levels are calculated assuming they are identical to those of hydrogen. The ket notation indicates the positron spin (left; ↓ or ↑) and antiproton spin (right; ⇓ or ⇑) states in the high-field limit. The shaded region illustrates part of the range of fields in the ALPHA-2 antihydrogen trap, with the minimum at 1.03 T.

The confining magnetic field resolves the degeneration of the levels for the 1S orbital. There are 4 different energy levels, which are labeled **a**,**b**,**c**,**d**, which depends on the anti-proton and positron spin orientation. Only the **d** and **c** state can be confined in the magnetic trap.

Once the antihydrogen is produced, it populates equally the **c** and **d** states, and the **b** and **c** annihilate with the electrode wall immediately after the mixing phase

The measurement of the hyperfine splitting consists on determining the frequency difference between the **c** → **b** transition and the **d** → **a** transition. These transitions are induced by illuminating the antihydrogens with micro-wave light. Once an anti-hydrogen shifts to an untrappable state, it is no longer confined and annihilates on the electrode trap walls. The annihilation products are detected by the silicon detector covering ALPHA-2.



Analysis and Simulation

The data collected by ALPHA-2 detectors represents annihilation counts versus frequencies. The Analysis consist on the determination of the onset of the transition (starting frequency). The difference between the two frequencies represents the hyperfine splitting (HFS). The Experiment is repeated a certain number of times, because of the magnetic field drift which shifts the onsets frequencies lineary during the passing of time. To extract the hyperfine splitting, several onset finding algorithms were studied with a Monte Carlo simulation. The hfs is the result of a linear fit of the onsets values, to correct the for the B_{drift}.

Simulated c->b and d->a transition, which are suitable to study the systematic and statistical error of the onset finding algorithms.