Towards Antihydrogen Confinement with the ALPHA Trap

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and the ALPHA Collaboration

PANIC 2008
Toward Antihydrogen Confinement in the ALPHA Trap

PAN IC2008 Eilat

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The dream - Antihydrogen Spectroscopy

1s-2s two-photon spectroscopy

- Doppler effect cancels
- High precision in matter sector
- Test of CPT theorem

\[ f(1S-2S) = 2\,466\,061\,102\,474\,851(34)\,\text{Hz} \] - Hänsch group

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The dream - Antihydrogen Spectroscopy

1s-2s two-photon spectroscopy

If antihydrogen can be trapped, any type of spectroscopic measurement can be contemplated

- Doppler effect cancels
- High precision in matter sector
- Test of CPT theorem

\[ f(1S-2S) = 2 466 061 102 474 851(34) \text{ Hz} \] - Hänsch group

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Hbar Formation mechanism:

- Radiative recombination
  - Binding E. deep; Formation rates low, $\sim T^{-0.6}$
- Three-body recombination
  - Binding E. shallow; Formation rate high, $\sim T^{-4.5}$
Remember ATHENA

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Antihydrogen Production

Superimpose Magnetic Trap

\[ U = -\mu B \]

0.7 K/T per Bohr magneton
Plasma stability


\[ P_\theta \approx \frac{e}{2c} B \sum_{i=1}^{N} r_i^2 \]

- Magnetic trap field strongly breaks the symmetry

Radial B field
Octupole vs Quadrupole

- Use Octupole instead of Quadrupole
- Perturbation near axis much reduced
- Need trap walls close to the magnet
Radially, \[ \Delta B = \sqrt{B_s^2 + B_w^2} - B_s \]
Toward Antihydrogen Confinement in the ALPHA Trap

ALPHA Apparatus Overview

Mixing trap

Si tracker

$e^+$

P$ar{b}$
Plasma confinement in Octupole trap

- Antiprotons and positrons in 1.2 T octupole field
- Number of particles measured as a function of storage time
  - Demonstrate compatibility of Charged and neutral trap
FAST TRACK COMMUNICATION

Production of antihydrogen at reduced magnetic field for anti-atom trapping

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Figure 4. Scintillation events as a function of time after the start of mixing, for normal mixing (black) and mixing with heated positrons (red). The time bins are 1 s long. The data are for 10 mixing cycles, normalized to one cycle. The inset is a plot of the first 5 s of the same data, re-binned into 200 ms bins to illustrate the rise time of the antihydrogen production. The uncertainties reflect counting statistics only (1 standard deviation).
Plasma radial control important

- Recall $E \propto en_e r^2$

External rotating RF field exerts torque on plasma $\rightarrow$ radial compression

What’s new?

- Normally need coolant
- Use electrons as a coolant
Annihilation Imaging Capability allows:
- Detection of antihydrogen
- Rapid diagnosis of system
- Ancillary measurements
  (e.g. plasmas in non-uniform B fields)

Essential for ALPHA:
- Antihydrogen trapping detection and spectroscopy
- Need compatibility with the neutral trap
Si Tracker Status

- Oct-Nov 2007
  6 modules *in situ* test
- June 2008
  38 module out of 60
  being commissioned
“Ballistic” particle loss in octupole field due to symmetry breaking

- Annihilations gives unique signatures
  - Enhanced at trap edges
  - 4 hot spots at each end

\[ \Rightarrow \text{Not yet definitive proof of ballistic loss} \]

Result from Oct 07 commissioning
Fresh New Data on Ballistic Loss

Preliminary

Counts

Azimuthal angle (deg)

Axial position (cm)

X-Y Projection (cm)
Fresh New Data on Ballistic Loss

- Preliminary
- Confirms ballistic loss model
- Powerful diagnosis

Axial position (cm)

Counts

Azimuthal angle (deg)

X-Y Projection (cm)
Neutral (Hbar) versus charged (pbar) losses

Preliminary

Hbar annihilations on the walls: uniform phi-distribution
Trapped Antihydrogen Detection Method

- Make antihydrogen in magnetic trap
- Remove charged particles by electric field
- Dump the magnetic trap using fast IGBT switch
- Look for annihilation events from escaping neutrals hitting the trap walls
- Fast dumping crucial to fight the background

Octupole current decay
Characteristic energy scales:

- Plasma energy: space charge \((\propto e n_e r^2) \approx 10\) eV
- Neutral trap depth: \((\mu \Delta B) \approx 0.1\) meV
- Need \(10^{-5}\) control of plasma to make cold enough H\(\bar{e}\)ar!

Optimizations in particle moving and shaking:

- \(\sim 40\) potentials, time scale, particle numbers
- Largely systematic trial and error.

Antihydrogen quantum states:

- Formation process still not well understood
Summary and Prospects

– Antihydrogen trapping and spectroscopy: challenging goal
– ALPHA making progress
  – Nearly all parts constructed within 1st year
  – Si tracker finally coming along
  – Physics results coming out
  – Started campaigns of trapping attempts
  – Exciting time ahead for antihydrogen physics!