Characterization of Neutral Trapped Antihydrogen in ALPHA Experiment

M. Ahmadi*, P. Pusa*, D. Joss*, P. Nolan*, D. Wells*, J. Thornhill*, D. Seddon*, J. T. K. Mckenna**, M.Fujiwara**, A. Olin**, K. Olchanski**, L. Kurchaninov**), A. Capra***, S. Menary***), A. Evans****) and ALPHA collaboration.

*) Department of Physics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom

**) TRIUMF, Canada

***) York University, Canada

****) University of Calgary, Canada

*) **corresponding author: mostafa.ahmadi@cern.ch**

Motivation

Antihydrogen is the simplest atomic system composed entirely of antiparticles. This quantum system can be used to test CPT invariance by comparing the spectra of hydrogen and its antimatter counterpart, figure 1. The Antihydrogen Laser PHysics Apparatus (ALPHA) project at the CERN Antiproton Decelerator (AD) aims to confine antihydrogen atoms and perform spectroscopy on the trapped anti-atoms.

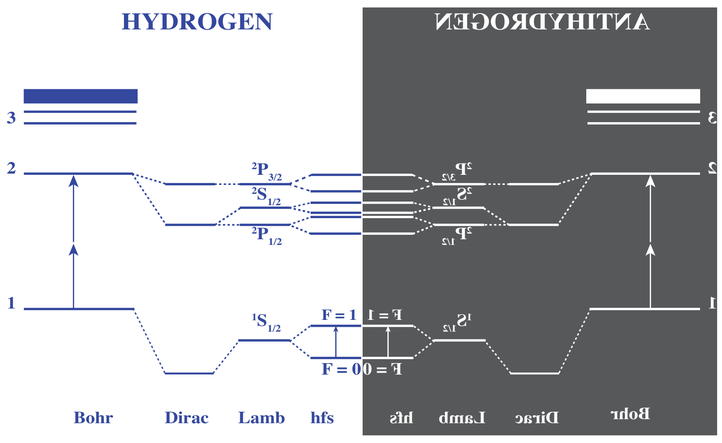

Fig. 1: Schematic illustration of hydrogen and antihydrogen spectra.

Experiment/Apparatus

Antiprotons are produced at the AD and subsequently ejected to the ALPHA apparatus from the left side , figures 2(a) and 2(b) . Positrons are created from a radioactive beta-decay source containing an isotope of Na-22 , not shown in figure 2(a), and ejected to the ALPHA apparatus from the right side.

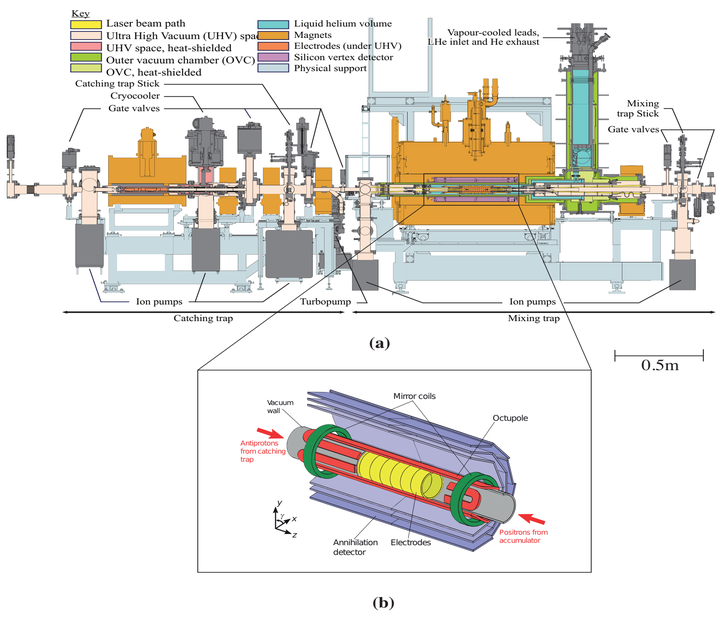

Fig. 2: (a): Cut-away schematic of the ALPHA apparatus. (b): a schematic diagram of the magnetic neutral-atom trap and the surrounding apparatus.

The ALPHA trap is made up of a Penning–type trap to confine the charged particles needed to produce antihydrogen and a set of superconducting magnets consisting of octupole and mirror coils to produce a magnetic bottle in which the neutral antihydrogen atom is trapped, figures 2(b) and 3.

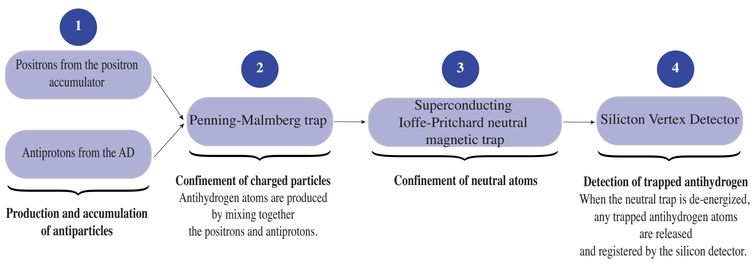

Fig. 3: Flow chart illustrating four steps for producing, trapping and detecting antihydrogen atoms in ALPHA apparatus.

Annihilation Vertex Reconstruction

The production and trapping of antihydrogen is detected by means of a three-layer silicon vertex detector (SVD), figures 4 and 5, which surrounds the trap. An antihydrogen atom which is not trapped in the magnetic bottle will drift to the trap walls, at which point the antiproton will annihilate to form charged pions. The tracks of the charged pions are reconstructed, figure 4, thereby locating the annihilation vertex. Imaging the annihilation vertices also provides a powerful diagnostic of the antihydrogen production mechanism.

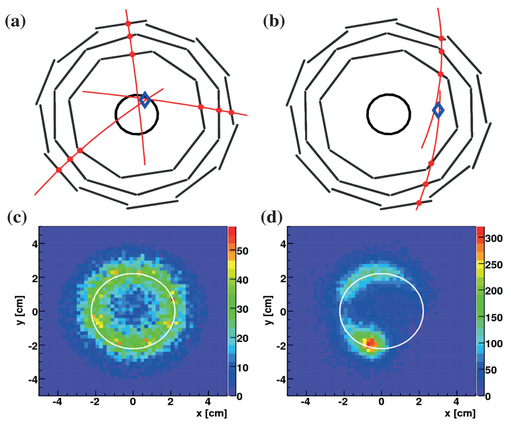

Fig. 4: (a)-(c)Antiproton annihilation reconstruction. (b)-(d) A cosmic event reconstruction.

Silicon Vertex Detector

The SVD, figure 5, was built in Liverpool University. It consists of two halves, each with a 3-layer barrel populated by 10,12 and 14 hybrid modules on the inner, middle and outer layers, respectively. A total of 72 hybrid modules results in the readout of 36,864 channels, an active area of 0.8 m^2 and a solid angle coverage of 77% at the very centre of the trap. A single module is illustrated in figure 6.

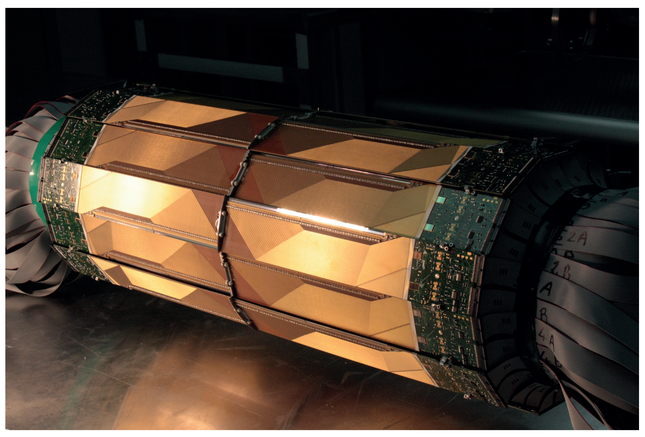

Fig. 5: The Silicon Vertex Detector.

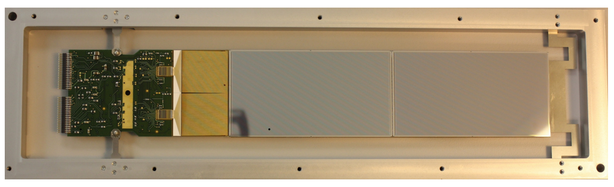

Fig. 6: A silicon hybrid module used in ALPHA detector.

A hybrid module has the following specifications:

- 300 µm p on n double sided strip detector.
- 256 x 128 strips, pitches 229 / 890 µm.
- Sensor size 60mm x 115mm.
- Active 58mm x 112mm.
- N-side externally AC coupled.
- Four Va1Ta 128 channel ASICs.
- Fast trigger shaper (75ns) / slow analogue shaper, (typically 1µs).
- Programmable shaping parameters.
- Dynamic range ±10 MIPs.

SVD Data Acquisition (DAQ)

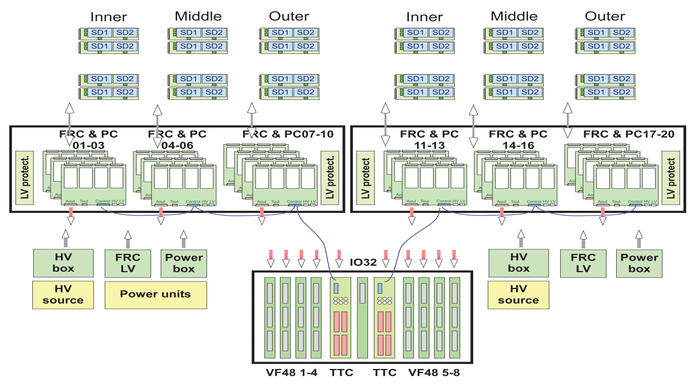

Fig. 7: SVD DAQ system.

Illustrated in figure 7 is a cartoon of the silicon detector DAQ system. A 500Hz readout of the 36,864 channels with a minimum of dead time has been achieved. The DAQ system consists of a set of front-end repeater cards which multiplexe and amplify the analogue and trigger signals from the hybrid modules. The readout process is supervised by a timing and trigger control module, which is also used to form the final trigger decision. Analogue signals of accepted Silicon events are digitized by a custom ADC board which has been developed at TRIUMF.

Recent Milestones

- An improved limit on the charge of antihydrogen from stochastic acceleration[1]
- An Experimental Limit On The Charge Of Antihydrogen[2]
- Resonant Quantum Transitions In Trapped Antihydrogen Atoms[3]
- Confinement Of Antihydrogen For 1,000 Seconds[4]

Future Work

- Precision spectroscopy of antihydrogen
- Gravity measurements

References

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[2] C. Amole et al., Nature Communications 5, 3955 (2014)
[3] C. Amole et al., Nature Communications 4, 1785 (2013)
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Acknowledgments

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