5 Production and Spectroscopy of Antihydrogen

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The goal of the ATHENA (AnTiHydrogEN Apparatus [1]) experiment is to produce antihydrogen atoms at low energies, to capture them in a magnetic trap and to compare by 2 photon laser excitation the 1S - 2S energy difference of antihydrogen with the one for hydrogen, in view of testing CPT invariance at the level of about 1 part in 10^{15}.

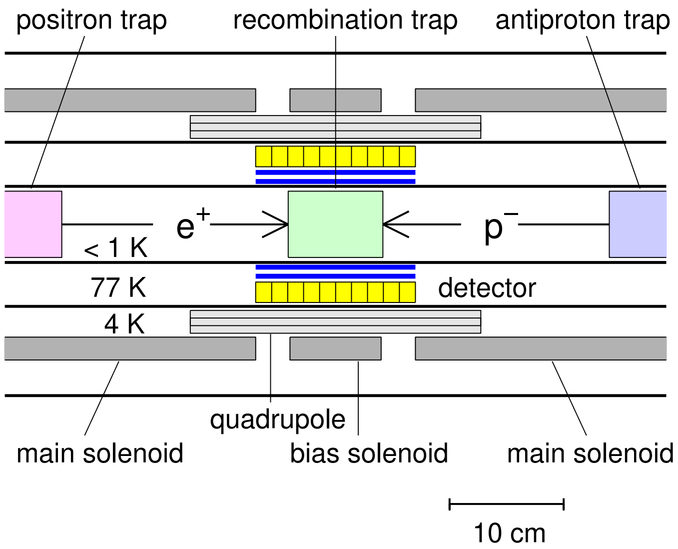

Figure 5.1: *Central part of the ATHENA superconducting solenoid with the recombination trap and the annihilation detector. Parts of the positron trap and the antiproton trap are also shown.*

The apparatus consists of a superconducting solenoid (3 T) with a cold bore to house the antiproton trap, the positron storage trap, and the $\overline{\mathrm{H}}$ trap (fig. 5.1). Antiprotons will be extracted from the Antiproton Decelerator (AD) at CERN, captured in an electromagnetic field configuration known as a Penning trap, and cooled to sub-eV temperatures by electron cooling. Large number of positrons from a ^{22}Na source will be accumulated in a similar field configuration.

One of the major challenges will be bringing the antiprotons and positrons in close contact for a time sufficiently long to allow the antihydrogen formation process to take place. To combine positrons with the antiprotons a nested Penning trap, a series of coaxial cylindrical electrodes with alternating electric fields, will be used.

Once antiprotons and positrons have been recombined, the confinement by the electric forces ceases and the antihydrogen atoms would escape, hit the walls of the recombination trap and annihilate. To confine the produced antihydrogen atoms magnetic gradients interacting with their magnetic moment can be used. This requires superimposing a strong magnetic gradient field onto the constant field necessary for the Penning trap. A combination of quadrupole coils for radial confinement and solenoids for the axial confinement will be used.

In the first phase of the experiment we will study the formation rates of antihydrogen atoms and their capture in a magnetic gradient trap, by observing the annihilation of antihydrogen atoms impinging on the walls surrounding the antihydrogen trap with an appropriate detector. The unambiguous proof of antihydrogen formation will be obtained by detecting the antiproton annihilation products and measuring the annihilation vertex in time coincidence with the two back-to-back 511 keV photons from e^+e^- annihilation.

The Physics Institute of the University of Zürich is responsible for a major part of the antihydrogen annihilation detector (mechanical structure, Si microstrip detector, photodiodes and read out electronics).

5.1 Silicon microstrip detector

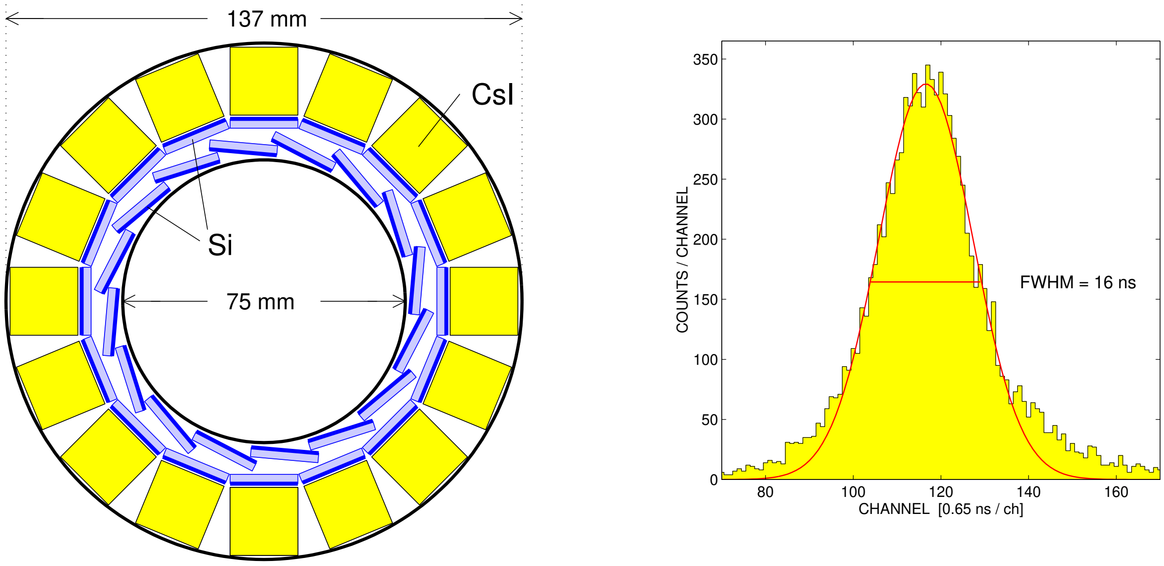

Figure 5.2: *Left: Front view of the ATHENA annihilation detector.*
Right: Time resolution of the Si microstip detector obtained by measuring the time difference of minimum-ionizing particles passing through a fast plastic scintillator and the Si microstrip detector.

The Zurich group is responsible for the design, construction and readout of the microstrip vertex detector surrounding the antihydrogen trap which will signal the annihilation of stored antihydrogen. In 1998 we proposed a design which ensures a large angular coverage and therefore a high detection efficiency. The layout is shown in fig. 5.2. It consists of two cylindrical layers of 16 silicon microstrip modules, 76 and 96 mm in diameter, respectively. The 32 modules contain double sided AC coupled detectors of 160 mm length and 400 μm thickness, with a width of 19 mm. One surface (direction along the detector axis) will be read out through 128 pads and the other ($r\phi$) will be read out by 128 strips (pitch 150 μm). The total number of channels is 8192. These will be multiplexed into 32 analog outputs by 64 readout chips. A similar vertex detector has been built for the Crystal Barrel experiment [2].

We are currently investigating the performance of the detector and the readout chips at 77 K with encouraging results. Good energy and time resolutions are obtained (fig. 5.2).

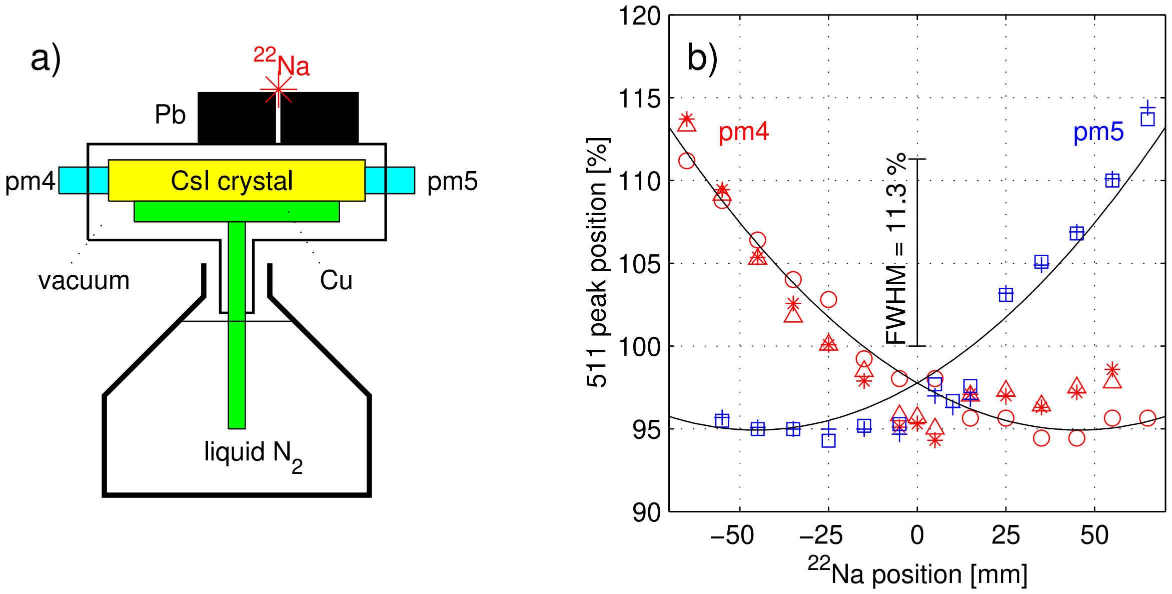

Figure 5.3: *a) Sketch of the apparatus to measure the crystal response (light output and decay time) from 511 keV photons at cryogenic temperatures.Dimensions of crystal:* $2.5 \times 2.5 \times 15.5$ *cm*^{3}. *b) Dependence of light output on the position of the* ^{22}*Na source (0: middle of crystal).*

5.2 Test of CsI crystals

We also provide assistance in developing the crystal detector (main responsibility: University of Pavia) that will detect the annihilation of the positron. We are currently investigating the properties of pure CsI and CsI(Na) at different temperatures with positron sources. An earlier result from the Italian group indicated a substantial increase in light output for pure CsI with decreasing temperature. We have built a test bench at cryogenic temperatures to measure the light output as a function of position z along the crystal (fig. 5.3a) and have succeeded in detecting the 511 keV photons entering 15 cm long crystals at the opposite end to the readout. In the ATHENA experiment we planed to determine z by comparing the amplitudes of signals from both ends of the crystal. However, the energy resolution is not sufficient (fig. 5.3b). Therefore, we will subdivide the crystals along their lengths in 12 elements, each read out by four photodiodes.

The crystals will be manufactured by industry or by the University of Tbilisi. First results on test crystals show good energy resolution and an acceptable decay time at low temperatures (fig. 5.4).

These measurements were done using photomultipiers (Hamamatsu R1450). For the annihilation detector photodiodes have to be used. First crystal tests with photodiodes coupled to the same readout chip as for the Si strips show an acceptable signal to noise ratio (FWHM of 511 keV peak: 25 %).

The detector will be assembled in summer 1999 and first runs with antiprotons from the AD are scheduled in autumn.

References

[1] ATHENA proposal, CERN SPSLC 96-47, http://www.cern.ch/athena/

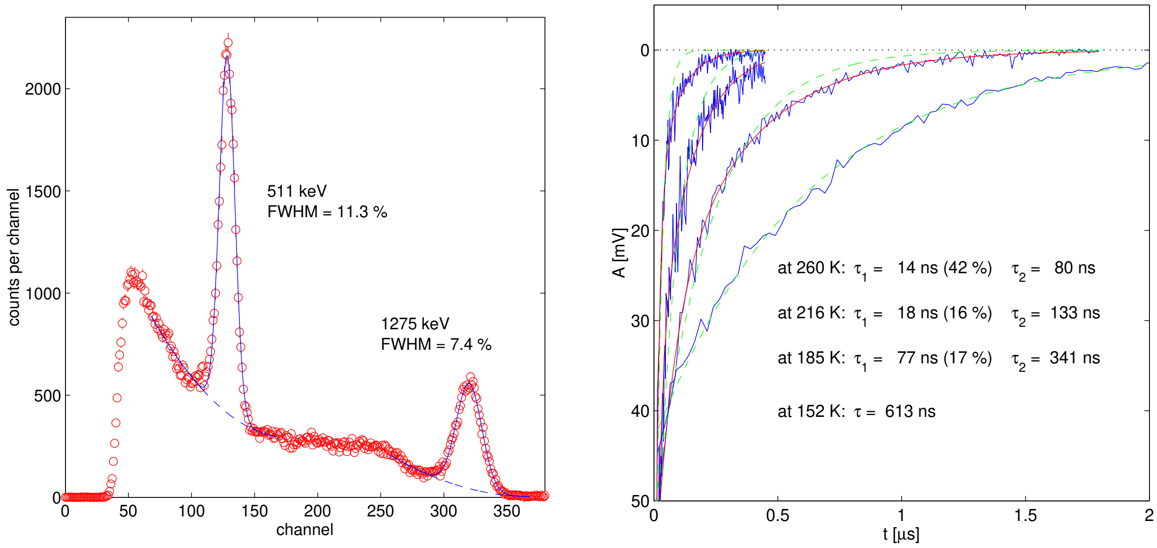

Figure 5.4: *Left: Energy resolution of a pure CsI crystal (University of Tbilisi) measured with a ^{22}Na source at 120 K. Right: Time response of the same crystal at different temperatures. At the three higher temperatures two time components are observed. At the lowest temperature the decay curve can be described by one exponential.*

[2] M. Doser et. al., NIM A412 (1998) 70