Towards Measuring the Ground State Hyperfine Splitting of Antihydrogen – A Progress Report

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Abstract We report the successful commissioning and testing of a dedicated field-ioniser chamber for measuring principal quantum number distributions in antihydrogen as part of the ASACUSA hyperfine spectroscopy apparatus. The new chamber is combined with a beam normalisation detector that consists of plastic scintillators and a retractable passivated implanted planar silicon (PIPS) detector.

Keywords Antihydrogen · Precision Spectroscopy · CPT · Field-Ioniser · PIPS

1 Introduction

The combined symmetry of charge, parity and time (CPT symmetry), is one of the most fundamental requirements in the standard model of particle physics. Up to now no violation of the CPT symmetry has been observed.

One way of constraining CPT violating parameters in the standard model extension [1] is by comparing spin changing transitions in matter and antimatter [2,3]. Since the first production of cold antihydrogen [4,5] which is the simplest atomic system built completely of antimatter, experiments were planned to test the CPT invariance in the matter-antimatter regime.

The ASACUSA collaboration at the CERN Antiproton Decelerator (AD) facility aims to test the CPT invariance by comparing the ground state hyperfine splitting of hydrogen and antihydrogen in a Rabi like experimental setup [6]. In a first step the ASACUSA collaboration already succeeded in producing antihydrogen and proving the feasibility of detecting antihydrogen in a field free region [7].

2 The ASACUSA Antihydrogen Beamline

The ASACUSA antihydrogen beamline consists of two distinct parts. The first part is the antihydrogen production apparatus which is used to produce a cold and polarised beam of antihydrogen. The second part is the spectroscopy beamline for measuring the ground state hyperfine transitions in antihydrogen.

2.1 Antihydrogen Production

Decelerated antiprotons are ejected from the AD into the ASACUSA experimental area. After injection the particles get further decelerated and are captured in a penning type capture trap called MUSASHI [8]. Inside of the so-called double CUSP trap [9,10] antihydrogen is formed in a mixing process. The produced antihydrogen is neutral and can therefore escape the trapping fields. By the magnetic cusp field geometry the low-field seeking (LFS) anti atoms (negative magnetic moment) are then focused [11] towards the spectroscopy beamline.

2.2 Spectroscopy Beamline

For measuring the transition frequency of ground state antihydrogen the spectroscopy apparatus is the central part of the experiment [12,13]. The LFS traverse
the microwave cavity. If the resonance condition is met a spin flip occurs by the induced hyperfine transition that converts a LFS into a high-field seeking state (HFS). After the microwave cavity the anti atoms reach the superconducting sextuple analyser magnet. If the resonance condition is met, the HFS get defocused by the magnetic field gradient whereas the LFS get focused onto the antihydrogen detector. By tuning the microwave cavity, a resonance scan can be recorded for inferring the ground state hyperfine splitting of antihydrogen. In Fig. 1 a schematic overview is shown.

The effectiveness and performance of the spectroscopy beamline was tested separately with a beam of cold polarised hydrogen [14].

3 A Combined Field Ioniser and Beam Normalisation Chamber

The spectroscopy process described above depends on two important conditions. First the antihydrogen atoms have to be in ground state and second the production rate has to be either constant or closely monitored. The production rate, but also the distribution of the principal quantum number [15] are strongly dependent on the mixing conditions in the double CUSP trap.

In order to solve these issues a new vacuum chamber was developed and mounted in-between the microwave cavity and the double CUSP trap. The interior of the chamber contains two planar parallel copper grids with a transparency for antihydrogen of 95% for each grid. An electric potential difference of 20 kV (± 10 kV per grid) can be applied. The grids are mounted with a distance of 10±0.5 mm. This translates to a minimal principal quantum number n≥12 (∼16 kV/cm) to be ionised when traversing the field ionisation region [7].

In addition to the field ioniser an active beam blocker with a total diameter of 35 mm, a thickness of 300 µm, and with an active surface area of 300 mm² was developed and finally installed in 2014. In general, a beam blocker is required for precision spectroscopy as the superconducting sextuple has a vanishing B field in the centre that would allow HFS to reach the detector and contribute to the background. The beam blocker is built of a passivated implanted planar sili-
con (PIPS) detector (Canberra PD300-300CB) that is glued onto a ceramics disc. Together with plastic scintillators surrounding the vacuum chamber the PIPS detector can be used for beam normalisation by taking the coincidence signal between the plastic scintillators and the PIPS detector. In case the field ioniser is used for measurements, the PIPS detector is mounted on a pneumatic actuator that can retract the detector completely from the beam pipe. A photograph of the chamber components is shown in Fig. 2.

3.1 Antiproton Commissioning

For commissioning the field ioniser and beam normalisation chamber a slowly extracted beam of antiprotons was created in the MUSASHI trap during the ASACUSA beamtime 2015. The extraction energy was set to 150 eV. A major challenge was imposed by the small opening of the aperture separating the MUSASHI trap from the double CUSP trap. For this reason, the double CUSP magnet was required to stay powered, as a tune from MUSASHI to double CUSP was already optimised for the 150 eV antiprotons. The defocusing effect of the two cusp regions in the magnetic field were counteracted by setting the trap electrodes in these regions to -150 V.

In Fig. 2 the response of the beam normalisation system is shown. In the top graph the antiprotons could reach the PIPS detector and produce a coincidence signal in the PIPS detector and in the outer plastic scintillators. The bottom graph shows the same measurement but this time the active beam blocker has been retracted from the beam. As a consequence, the antiprotons cannot reach the PIPS detector, and all recorded coincidence events have to be considered as random coincidences. It can be seen that in the latter case almost no coincidence signal is produced. Following this observation, it can be concluded that the PIPS detector and plastic scintillator coincidence system is suitable to serve as a means
Table 1: Summary of mean number of recorded events in 20 seconds after the start of slow extraction cycle from the MUSASHI trap. Furthermore, the number of extraction cycles is recorded.

| PIPS in beam | mean integrated counts in 20 s | PIPS detector | plastic scintillators | # of runs |
|--------------|-------------------------------|---------------|-----------------------|-----------|
| PIPS removed | 756±331                       | 9948±4836     | 1021±422              | 7         |
|              | 6±2                           | 80±12         | 706±144               | 9         |

for beam normalisation. In Table 1 the recorded mean numbers of antiproton annihilations are summarised.

4 Summary and Outlook

In 2014 a new vacuum chamber was designed. It houses a field-ioniser that is capable of ionising antihydrogen atoms with a principal quantum number as low as n=12 and a PIPS detector as active beam blocker that can be used for beam normalisation measurements during data taking.

The new chamber will be used during the upcoming beamtime 2016 for measuring the principle quantum number distribution for antihydrogen produced in the double CUSP trap. The beam normalisation detector is prepared, and was successfully tested for data taking.

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