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The GBAR experiment: gravitational behaviour of antihydrogen at rest

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Abstract
The recently recommended experiment GBAR is foreseen to run at CERN at the AD/ELENA antiproton source. It aims at performing the first measurement of the Earth's gravitational acceleration on antimatter by observing the free-fall of antihydrogen atoms. This requires creating anti-atoms at an unprecedented low energy. The different steps of the experiment and their present status are reviewed.

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(Some figures may appear in colour only in the online journal)

Introduction

The GBAR experiment aims at performing the first measurement of antimatter free-fall on the Earth. The project has been submitted to the CERN/SPSC scientific committee (GBAR Collaboration 2011), which recommended it on January 2012. This paper gives an overview of all different and numerous steps of this project. Such a project requires calling upon very different communities in physics. It brings together among the best world specialists from different domains: accelerator, elementary particle, plasma, atomic, nuclear, laser physics and materials science.

Scientific motivation

Investigating the properties of antimatter represents today an active field of research in physics. The fact that the Big Bang model needs an equal production of antimatter and matter in its first stages is a major problem of physics nowadays, since no observation of primordial antimatter in the Universe has been reported up to now. A yet-unexplained property of antimatter regarding fundamental forces is therefore an open question.

The Einstein weak equivalence principle (WEP) states that the trajectory of a test particle is independent of its composition and internal structure when it is only submitted to gravitational forces. This fundamental principle has never been directly tested with antimatter and is at the heart of general relativity. The validity of the equivalence principle for antimatter is a basic scientific question, the interest of which is strongly enhanced by the recent observation of the acceleration of the expansion of the Universe, which leads to fundamental questions on gravitation theories. This discovery has triggered very large projects in astrophysics. The introduction of dark energy to accommodate the observations leads to difficult questions, since it appears as repulsive gravity. In addition, the Universe matter content seems to be dominated by what is called dark matter, but its nature and properties are totally unknown. All these experimental facts suggest that our understanding of gravitation may be very incomplete.

From a theoretical point of view, models such as supergravity may contain components inducing repulsive gravity (see, e.g., the seminal paper of Scherk (1979) and the discussion in Nieto and Goldman (1991)), thus violating the WEP. An extension of the standard model of particle physics, with terms directly violating the Lorentz and CPT symmetries (Kostelecky and Tasson 2011), could accommodate a very large difference between the inertial and gravitational masses of an antimatter particle. A model with negative masses for antiparticles was used to simulate the evolution of the Universe since the Big Bang (Benoit-Levy and Chardin 2012), resulting in predictions for cosmological observables in agreement with measurements. Such a model does not require the hypotheses of dark matter or dark energy, or the inflation episode, to describe the Universe.

It is thus extremely interesting to test antimatter in a gravity field: the GBAR experiment aims at measuring the free-fall acceleration of neutral antihydrogen atoms in the terrestrial gravitational field, which is quoted as $\bar{g}$ in this paper.

Indirect tests of the equivalence principle for antimatter have been obtained by comparing the properties of particles and antiparticles or by arguing about the virtual antimatter content of the nuclei of ordinary matter. Two particle–antiparticle systems have been studied in great detail with this aim: comparison of the decay parameters of K^0 and $\bar{K}^0$ (CP LEAR 1999), and the simultaneous measurement of p and $\bar{p}$ cyclotron frequencies (Gabrielse *et al* 1999). However, all these tests rely upon disputable theoretical hypothesis—refer, e.g., to a review on experiments and theoretical arguments (Nieto and Goldman 1991). One should finally note that some authors have published a limit on the mass difference between neutrinos and antineutrinos from the time arrival of events from the 1987A supernova explosion (Pakvasa *et al* 1989). This limit relies on the possibility that one out of the 19 observed events is due to an electron neutrino, the others being antineutrino diffusions.

Direct tests have been envisaged in the past to measure the free-fall of charged antiparticles (with positrons and antiprotons), but the weakness of gravitational forces makes the protection against electromagnetic influences extremely difficult, which prevented any result. The measurement with antineutrons could not be made because it is very difficult to sufficiently slow them. A discussion of the possibility of testing gravity on positronium shows that it would be very hard to undertake (Mills and Leventhal 2002). The next simplest form of neutral antimatter is the antihydrogen atom.

Principle of the experiment

The basic features of the proposed experiment were expressed in a letter of intent to the CERN SPSC (Pérez *et al* 2007), following the original idea of Walz and Hänsch (2004). The originality of this path is to first produce the ultra-cold $\bar{H}^+$ ion before producing the ultra-cold $\bar{H}$ atom: the ion can be cooled down to μK temperatures (i.e. m s^{-1} velocities), and the extra positron can then be laser detached in order to recover the neutral $\bar{H}$ atom and observe its free-fall (see figure 1 (right)).

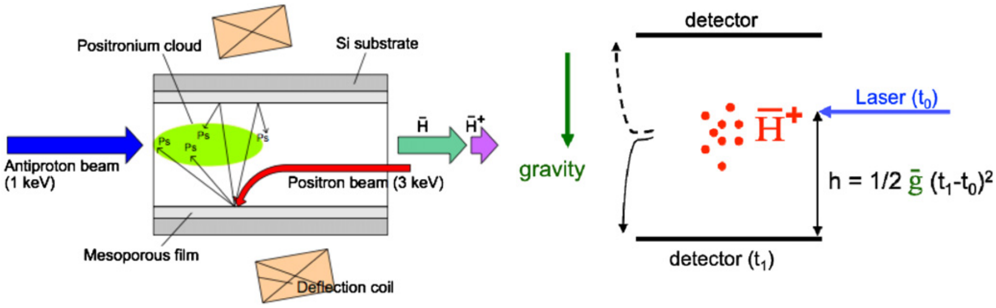

Figure 1. (Left) Principle of $\bar{\mathrm{H}}^+$ production scheme and (right) free-fall measurement.

The experiment aims at the 1% precision in a first step. Our method, however, opens the possibility of performing a spectroscopy of quantum states in the gravitational potential with a much higher precision.

The key point is to obtain anti-atoms with less than 1 m s^{-1} velocity, i.e. to cool them to less than 20 μK. The cooling limit for neutral hydrogen is, due to photon recoil, at 1.3 mK. The proposed path gets around this limitation by producing an intermediate state, the antimatter counterpart of the H$^-$ ion, i.e. $\bar{\mathrm{H}}^+$, which consists of an antiproton, and two positrons. This ion can be cooled to μK temperatures through interactions with positively charged ions according to Walz and Hänsch. The excess positron can then be photo-detached in order to recover the ultra-cold neutral $\bar{\mathrm{H}}$ atom. This process can be set up to minimize momentum transfer in the vertical direction. The very low velocity of the atom leads to a quasi-vertical free-fall, much easier to detect than a horizontal deflection. The falling anti-atom annihilates on a plate, delivering a large signal used to measure the time of flight since the photo-detachment. The distance between the laser beam and this plate being known, this provides a measurement of $\bar{g}$. The temperature achieved in the cooling of the $\bar{\mathrm{H}}^+$ ion gives the main systematic error.

The $\bar{\mathrm{H}}^+$ ion is produced through two charge-exchange processes from interactions of $\bar{\mathrm{p}}$ and $\bar{\mathrm{H}}$ with the same positronium target (Pérez and Rosowsky 2005) (see figure 1 (left)):

$$\bar{\mathrm{p}} + \mathrm{Ps} \rightarrow \bar{\mathrm{H}} + \mathrm{e}^- \tag{1}$$

followed by

$$\bar{\mathrm{H}} + \mathrm{Ps} \rightarrow \bar{\mathrm{H}}^+ + \mathrm{e}^-. \tag{2}$$

From measurements or calculations of the cross-sections for these two reactions (Merrison *et al* 1997, Mitroy 1995), one expects, for 10^7 antiprotons interacting with a 10^{12} cm^{-3} density positronium cloud, the production of one $\bar{\mathrm{H}}^+$ ion, together with 10^4 $\bar{\mathrm{H}}$ atoms. The number of $\bar{\mathrm{H}}^+$ may be enhanced if the positronium cloud is excited into $n_{\mathrm{Ps}} = 3$ states, where its binding energy of 0.76 eV is almost degenerate with that of $\bar{\mathrm{H}}^+$. The model then predicts gains of ~100 in the number of ions. Collecting 1500 events in a few weeks should provide a 1% measurement error on $\bar{g}$.

A future prospect comes from the expectation that $\bar{\mathrm{H}}$ will be reflected from the 'annihilation plate' with nearly 90% probability if launched from a few tens of micrometres above its surface. The phase space of these ultra-cold anti-atoms is comparable to that of ultra-cold neutrons made to bounce on a material surface at the ILL reactor, where quantum states were obtained in the potential composed of gravity and quantum reflection, leading to a spectrum of quantum states (Nesvizhevsky *et al* 2002). The spectroscopy of these 'gravitational' levels should lead to orders of magnitude improvement on the error on $\bar{g}$ (Voronin *et al* 2011).

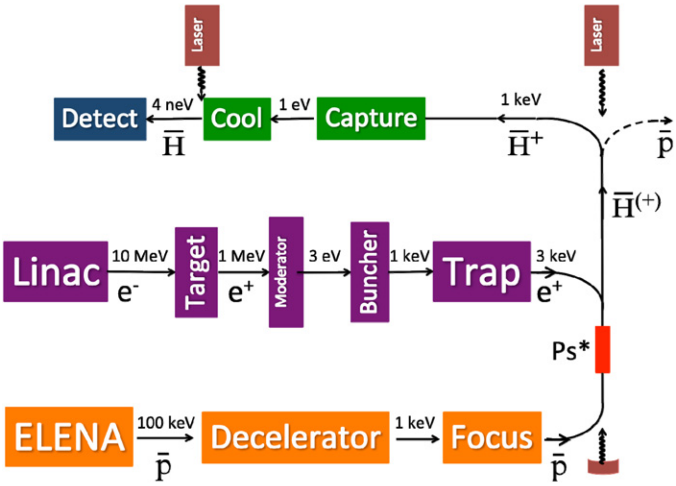

Figure 2. Overall scheme. The high (above keV) values are mean kinetic energies, while the lower ones are dispersions, i.e. temperatures.

Experimental scheme

The antiparticles needed to form the anti-atoms and ions are produced at high velocities because the reactions to create these antiparticles involve the creation of a particle–antiparticle pair and have thus an energy threshold of twice the mass of the electron for e^+ production, and six times the mass of the proton for $\bar{p}$ production, due to conservation of baryon quantum number and of momentum. The production cross-section increases exponentially above this threshold. But the subsequent step to produce an anti-atom or an anti-ion requires velocities of lower orders of magnitude. And, in the last part of the experiment, the measurement of the free-fall requires that the velocity must be of the order of 1 m s^{-1}. The overall scheme then proceeds through a succession of deceleration, cooling or moderation steps.

The steps needed to perform the gravitation experiment are as follows (see figure 2).

- Production of an intense flux of fast positrons (few MeV) from the interactions on a thin tungsten target of a 10 MeV electron beam produced by a small accelerator.
- Selection of the positrons and suppression of the electron and gamma background with a magnetic separator.
- Moderation of the positrons to create the so-called slow positrons of a few eV kinetic energy.
- Accumulation of the positrons inside a high-field Penning–Malmberg trap, where they cool down to a few meV and are then ejected in less than 100 ns onto a mesoporous silica target to form a dense ortho-positronium (o-Ps) cloud.
- Excitation of the positronium to gain a large factor on their cross-section for the production of $\bar{H}^+$.
- Interaction with the very low-energy antiproton beam extracted from the Antiproton Decelerator (AD) followed by the ELENA ring at CERN: this produces $\bar{H}$ atoms and $\bar{H}^+$ ions.
- Accumulation of the $\bar{H}^+$ ions and sympathetic cooling to 10 µK in a Paul trap.
- Photo-detachment of the excess positron by a laser shot at threshold, and measurement of the free-fall of an antihydrogen atom.

On a longer term, a higher precision on the measurement of $\bar{g}$ could be reached with the spectroscopy of gravitational levels of $\bar{\mathrm{H}}$, in a way inspired by the work done with ultra-cold neutrons.

In the following, we describe all the steps of the experiment with their present status (as of January 2012).

Antiproton deceleration

The antiprotons needed to create the antihydrogen ions will be provided by the CERN AD complex, completed by the recently approved ELENA ring (Oelert *et al* 2009) scheduled for operation in 2016. ELENA is foreseen to deliver $\sim 10^7$ antiprotons of 100 keV kinetic energy every 110 s. The antiprotons have to be further slowed down to 1 keV before interacting with the positronium cloud. The beam should also be focused onto the 1 mm diameter tube that will contain the Ps target. This will be done with electric fields in the same way as already achieved with heavy ions at ISOLDE at CERN (Herfurth *et al* 2001, Lunney *et al* 2009). The design and realization of this pulsed drift tube is now under way. Once ready, it will then be transferred to CERN to be adapted to the ELENA ring and tested with H^- ions. Preliminary simulations show that an efficiency as high as 80% is reachable for this step.

Positron production

The production of one $\bar{\mathrm{H}}^+$ ion with the quoted antiproton flux requires its interaction on a positronium cloud of high density, 10^{12} cm^{-3}. Such a density will be provided by a high intensity positronium bunch accumulated beforehand in a trap. The filling of this trap requires the realization of a positron source producing $\sim 3 \times 10^8$ slow positrons per second, which is achievable with a small electron accelerator in the space available.

A prototype positron source has been developed at Saclay as a demonstrator for such a source. A small linac accelerator produces a 5 MeV electron beam sent on a tungsten target, where fast (MeV) positrons are produced. Those fast positrons have to be moderated to a few eV energy, an important parameter in the process. The currently obtained efficiency of 2×10^{-4}, with a set of tungsten meshes as a moderator, may be improved. New arrangement of tungsten meshes will be tested with the present demonstrator. The aimed efficiency is 5×10^{-4}.

Another option based on moderation with solid neon (Mills and Gullikson 1986) is foreseen to bring this value above 10^{-3}. However, this technique is somewhat challenging because, whereas tungsten meshes can be inserted directly after the primary target, the solid neon must be kept at a temperature of 7 K, and thus must be located away from the electrons diffused by the primary target and representing a power of the order of 2 kW. In order to achieve this, the fast positrons must be brought to such remote location with magnetic fields of order 0.2 T as demonstrated in the Saclay prototype. The problem consists then in adapting magnetic fields and maintaining the 7 K temperature in this environment.

The Saclay prototype source (figure 3) is based on a 4.3 MeV/0.11 mA linac running at 200 Hz. For the installation at CERN, it must be replaced by a higher energy linac of 10 MeV and 0.2 mA to gain a factor ~ 13 in slow e^+ rate, and with a repetition rate to be adapted to the frequency at which the Penning trap can accumulate positrons.

Positron accumulation

The aimed Ps density is obtained with $\sim 10^{10}$ positronium confined in a 0.01 cm^3 tube. The Ps is created with 30% efficiency by the conversion of positrons being dumped onto porous silica

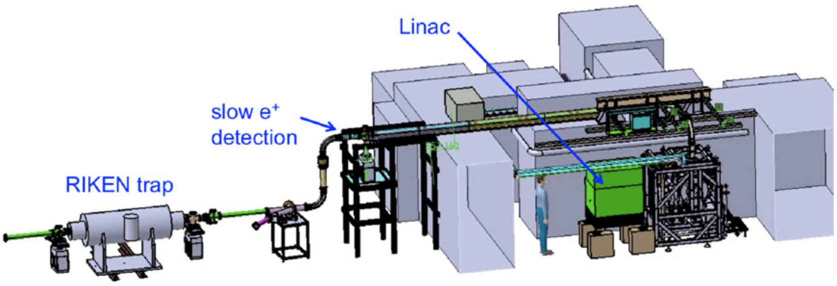

Figure 3. Drawing of the slow positron test bench at Saclay.

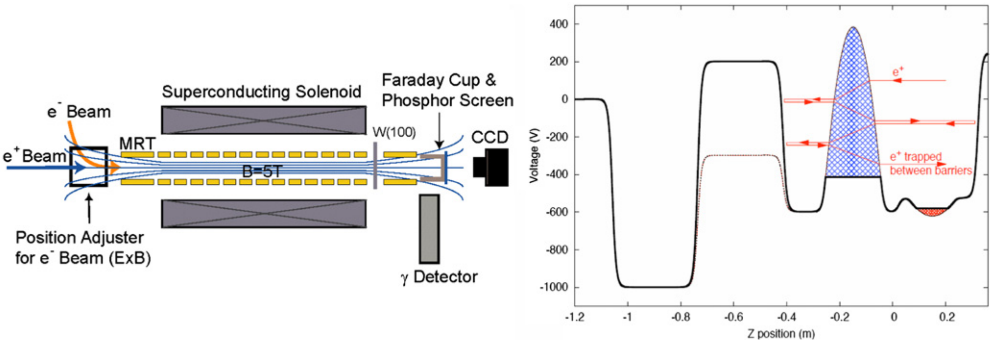

Figure 4. (Left) Sketch of RIKEN's Penning–Malmberg trap and (right) scheme of trapping voltages with e^- cooling.

coated inside a hollow tube (see figure 1 (left)). Thus, $\sim 3 \times 10^{10}$ e^+ are needed. They can be accumulated in a Penning–Malmberg trap during the 110 s between two bursts of antiprotons, via the direct injection of slow positrons from the linac–selector–moderator system into the trap. The Atomic Physics Laboratory of RIKEN has built such a trap (figure 4 (left)) and succeeded to store in it 2×10^{10} electrons in a potential well of 1 kV, and some 10^6 positrons in a nearby well of only 50 V (Oshima *et al* 2004), using a dc source of e^+ based on ^{22}Na. This trap has been shipped to Saclay where it is being connected to the linac-based positron source, and taking advantage of the pulsed beam, the trapping sequence will be adapted to enhance its performance (figure 4 (right)).

The trapping mechanism is partly due to electron cooling in contrast to the standard Surko technique that uses a buffer gas for cooling. The advantage of electron cooling is that, when enough positrons are accumulated, it is easy to remove the cooling electrons with electric fields. In a buffer gas system, two separate traps are needed, and the operations are complicated because the antimatter particles would annihilate with the gas on long time scales. The electron cooling technique has a low efficiency with dc sources because a single pass through the electron cloud is not enough to sufficiently cool the positrons, while with a pulsed source, the e^+ bunch is made to traverse a few thousand times the electron cloud before the next bunch arrives. However, it remains to be proven that the electron cooling technique will work to store a few 10^{10} e^+. When this is done at Saclay, the trap will be transported at CERN and connected to the 10 MeV linac, possibly in 2015.

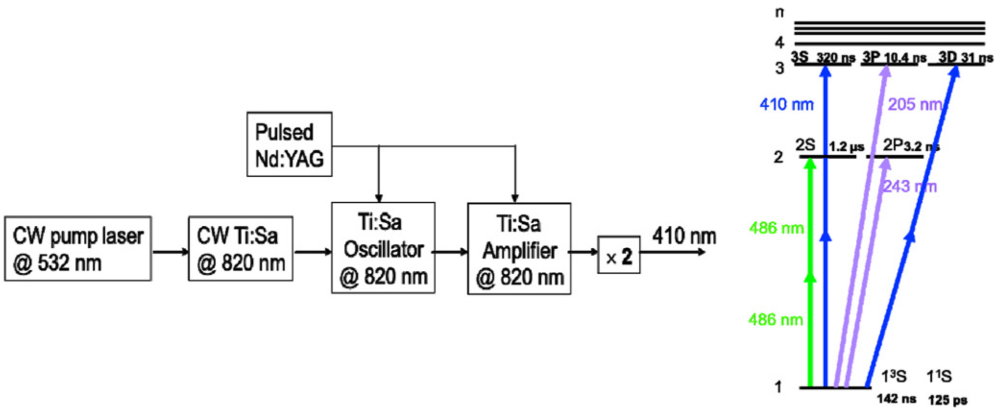

Figure 5. (Left) Positronium excitation laser system, and (right) energy levels.

Positronium production

Positronium can be efficiently formed by the interaction of slow positrons with matter. Several series of porous silica samples have been made and their efficiency to produce o-Ps, the 142 ns long-lived triplet state, have been measured using a low intensity e^+ beam from ETHZ (Crivelli *et al* 2008).

Selected samples were tested at UC Riverside in USA (Cassidy *et al* 2010), where a small Penning trap is available to accumulate 10^7 e^+ and dump them onto the sample in 1 ns, so that the instantaneous flux is about 10^{11} times higher, i.e. close to the foreseen parameters of the experiment (for which a longer extraction, about 100 ns, is sufficient). The results show that the conversion performances are the same at low and high flux. The GBAR Ps target can be made by assembling four pieces of this porous silica to form a tube with a 1 mm^2 section and a length of 1–2 cm. This tube will be tested at Saclay by placing it at the exit of the Penning trap so that the accumulated e^+ plasma can be dumped into it. Ps formation will be tested by counting the annihilation gamma rays produced in the Ps decay using the technique developed at UC Riverside (Cassidy *et al* 2006).

Positronium excitation

When the positronium is in an excited state, the $\bar{H}$ production cross-section from reaction 1 is increased by a factor of around n^4, where n is the principal quantum number of the Ps. However, since the aim is to maximize the $\bar{H}^+$ production, the n value needs to be optimized, as well as the energy of the incident antiprotons, because the $\bar{H}^+$ production proceeds in two steps (reactions 1 and 2). For instance, when Ps is excited to its 2P level, the cross-section for reaction 2 is expected to increase by a factor larger than 100 (Roy and Sinha 2008). Moreover, as the binding energy of $\bar{H}^+$ is expected to be the same as that of H^-, i.e. 0.76 eV, and as this happens to be very close to the excitation level of Ps ($n = 3$), we may expect a resonant enhancement of the production of $\bar{H}^+$ by the exciting part of the Ps to this level. Calculations of this step are underway in the collaboration to help choosing the optimal excitation scheme. In the meantime, another team is devising the laser system to excite Ps to its 3D level instead of the 3S level, because this latter level is more sensitive to photoionization (figure 5). This Ps excitation device will be installed downstream from the Penning trap in order to illuminate

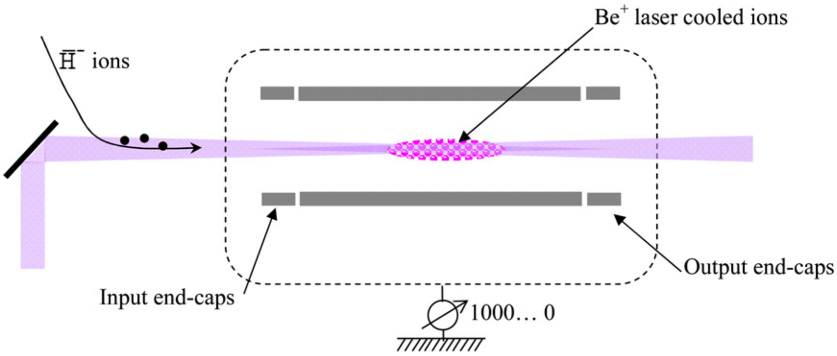

Figure 6. Simplified sketch of the capture and sympathetic cooling trap showing the cooling laser and $\bar{\mathrm{H}}^+$ entrance path.

the tube containing the positronium cloud. This step will be tested at the Saclay facility prior to the transfer to CERN.

$\bar{H}$ and $\bar{H}^+$production chamber

The anti-atoms and ions will be formed in the hollow tube coated with the porous silica material that converts e^+ into o-Ps, itself partly excited, and traversed by the antiproton beam. Thus, three incoming beams must be focused in the tube, and the $\bar{\mathrm{H}}^+$ ions extracted from it and guided towards the apparatus are dedicated to its cooling. The way to achieve this precise beam transport must be compatible with the environment of the antiproton and positron sources. For instance, the e^+ source output is in the fringe field of the 5 T solenoid of the Penning trap, while the Ps target area should be as much as possible in a field-free region. Extensive electric- and magnetic-field calculations, followed by simulations of particle trajectories, are on the way to design and adjust coils and focusing elements that will guide these beams to the target section. The production of anti-atoms takes place during the crossing of the antiprotons, a few tens of ns, compatible with the lifetime of the positronium, about 140 ns.

$\bar{H}^+$cooling

The cooling of $\bar{\mathrm{H}}^+$ ions to 10 µK needs a dedicated development, although the technique has been demonstrated with heavier ions. The incoming $\bar{\mathrm{H}}^+$ ions have a kinetic energy of 1 keV and a ∼20 eV kinetic energy spread that has to be reduced by 10 orders of magnitude. The proposed method relies on sympathetic cooling by laser-cooled Be^+ ions in two steps: first, $\bar{\mathrm{H}}^+$ capture and sympathetic cooling to the mK range by a Doppler cooled Be^+ ion cloud and, second, the Raman side-band cooling of a $\bar{\mathrm{H}}^+/\mathrm{Be}^+$ ion pair in a minitrap down to the quantum regime. The detailed steps are as follows (see figures 6 and 7).

- Prepare a Be^+ ion cloud in the 2 cm long biased linear trap (figure 6) and a single Be^+ ion in the minitrap (figure 7).
- Capture the $\bar{\mathrm{H}}^+$ ion in the biased linear trap.
- Sympathetically cool the $\bar{\mathrm{H}}^+$ ions by a laser-cooled Be^+ ion cloud down to the mK regime.
- Decrease the bias voltage to zero.
- Transfer a single $\bar{\mathrm{H}}^+$ ion to a minitrap to form a $\bar{\mathrm{H}}^+/\mathrm{Be}^+$ ion pair.
- Cool to the quantum regime by the Raman side-band cooling (Monroe *et al* 1995).

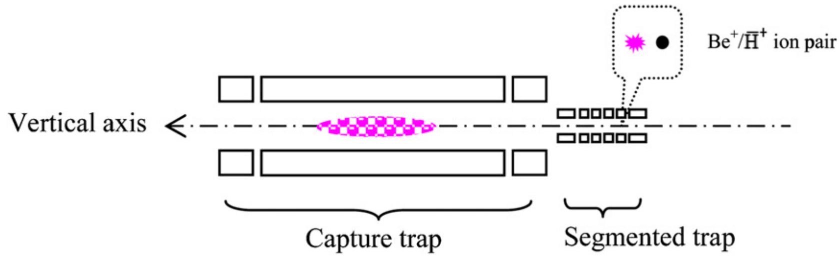

Figure 7. Simplified sketch of the capture trap and the ion-pair segmented trap.

A crystallised Be^+ ion cloud with a few tens of thousands ions can be produced within a few seconds. It can be seen as a highly damped mechanical system that allows opening for a very short time the axial potential for the intake of $\bar{H}^+$ ions. The trap is designed to accommodate for $\bar{H}^+$ ions with an initial 20 eV kinetic energy spread and allows for sympathetic cooling within less than 1 s (Bussmann *et al* 2006). This first cooling step will result in an ion cloud with a shell structure, i.e. an $\bar{H}^+$ ion chain surrounded by Be^+ ions. A cold $\bar{H}^+$ ion will be guided to the minitrap to form an ion pair in a vertical arrangement. An ion pair in a Paul trap has six vibrational eigenmodes that can be tuned in the MHz range. The Raman side-band cooling is a well-established method to remove kinetic energy from all those modes (Monroe *et al* 1995, Hemmerling *et al* 2011). For the GBAR project, the Raman side-band cooling will be applied to prepare the ion pair in the fundamental vibrational mode in the vertical direction. Such a quantum harmonic oscillator exhibits velocity dispersion below 1 m s^{-1}, fulfilling the GBAR requirements.

The proposed protocol will be first worked out using light matter ions, such as H^+ or H_2^+, before being transferred at CERN to be run with $\bar{H}^+$. None of the difficulties raised by the ion manipulation come from antimatter properties. Indeed, because of Coulomb repulsion and extremely small relative kinetic energies involved (in the eV range), the smallest ion-approach distances are in the nm–μm range. No electron/positron orbital overlap that would result in annihilation is expected. As a consequence, all the proposed protocols can be worked out using matter, e.g., H^+ or H_2^+ ions.

$\bar{H}^+$ neutralization

After the cooling process, a laser pulse is produced to detach the extra positron. In order to minimize the momentum kicks on the ion due to the photon absorption and to the subsequent positron emission, the laser wavelength must be set very close to that of the photo-detachment threshold. For instance, if the photon energy is set to 10 μeV above threshold, the atom recoil velocity is 1 m s^{-1}. The cross-section for this process is very low near threshold, but the laser power can be focused on a very small volume, because the ions can be localized to about 10 μm. The detachment rate with a 1 W laser is 100 s^{-1} per ion, more than enough to perform all measurements between two antiproton ejections from the AD. The laser will be shot horizontally, so that only the momentum of the detached e^+ will affect the vertical momentum of $\bar{H}$. In figure 8, the different trajectories drawn are the result of simulation and reflect the dispersion induced during the neutralization. The CW laser can be modulated and therefore can be used to define the start of the free-fall within few tens μs.

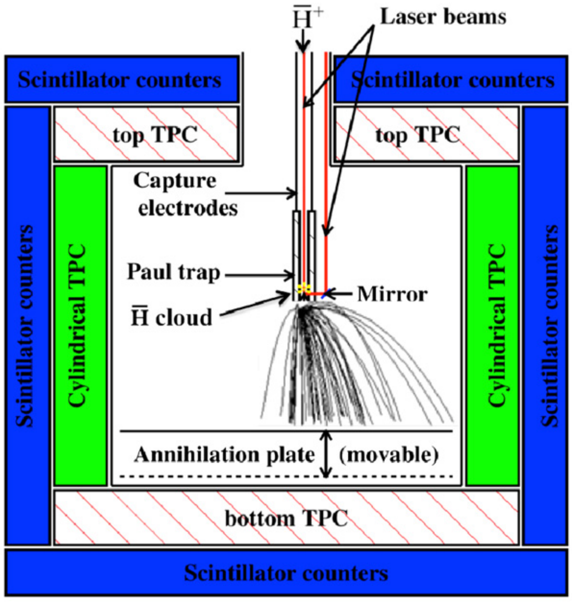

Figure 8. Sketch of side view of the free-fall detection setup.

Free-fall detection

A free-fall 'event' is characterized by the following.

- The photo-detachment laser shot that gives the start time of the free-fall.
- The emission of the positron from the $\bar{H}^+$ion and its subsequent annihilation. Because of the high RF fields in the Paul trap, the positron is ejected with a very high velocity in an unknown direction. The detection of one of the two 511 keV gamma rays from its annihilation could also be used to define the start of the event with a better precision than the laser illumination duration.
- The annihilation of the positron and of the antiproton of the $\bar{H}$ atom at the end of the free-fall. Two 511 keV gammas are emitted, and in 95% of the cases, the proton–antiproton annihilation produces a set of charged and neutral pions, with 99% of the latter decaying into two high-energy gamma rays.

The end of the free-fall time (143 ms for a 10 cm vertical fall if $\bar{g} = g$) can thus be measured with plastic scintillator counters surrounding the vacuum chamber, which are well suited to detect the emitted charged pions and provide the annihilation time with high precision. The present design (see figure 8) includes a set of small time projection chambers placed around the vacuum vessel to reconstruct the annihilation vertex and to eliminate cosmic background from the event topology.

Note that particles ($\bar{p}$, $\bar{H}$, e^+, Ps, γ) accompanying the $\bar{H}^+$ ion at the time it enters the cooling process do not produce background to the free-fall events, since the photo-detachment is triggered after the cooling of the $\bar{H}^+$ ions, which takes more than 1 ms. Note also that any exotic value of $\bar{g}$ giving rise to an annihilation on the vacuum vessel wall would be measured, although with a reduced precision. Finally, additional constraints on the electric and magnetic fields impose some care in the design of the experimental environment (see GBAR Collaboration 2011).

With the expected antiproton rate from AD/ELENA (10^7 antiprotons every 110 s) and using realistic efficiencies at all steps of the experiment, it is expected to get 0.14 free-fall event per pulse, enough to attain the 1% precision on $\bar{g}$ in few weeks.

Collaboration and sharing

The present collaboration includes 14 institutes and 49 physicists and engineers. The development of the fast positron source started at Saclay IRFU, and will continue with the National Centre for Nuclear Research (NCBJ, Otvosk, Poland). The positron moderation involves IRFU, ETH Zurich (Switzerland) and Tokyo University of Science. The positron accumulation is currently being performed at IRFU using a trap provided by the Atomic Physics Laboratory of RIKEN (Tokyo, Japan) with the help of CSNSM (Orsay, France) and IPCMS (Strasbourg, France). The positronium production and excitation is shared between Swansea University (UK), IRFU, ETHZ, IPCMS and Laboratoire Kastler-Brossel (ENS, Paris). The $\bar{\mathrm{p}}$ deceleration and focusing are studied and realized by CSNSM, LKB and Tokyo University of Science. The production of $\bar{\mathrm{H}}$ and $\bar{\mathrm{H}}^+$involves LKB, Swansea, IRFU and IPCMS. The cooling is shared by Johannes Gutenberg-University (Mainz, Germany) and LKB. The free-fall measurement will be realized by JGU, ETHZ, IRFU and Swansea. The collaboration also includes contributors from Institut Laue-Langevin (Grenoble, France) and University of Tokyo (Komaba, Japan).

The installation of the experiment at CERN will start in 2014, and the first beams are expected on phase with the commissioning of ELENA in 2016.

Acknowledgments

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