
Conference contribution :

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Towards a test of the Weak Equivalence Principle of gravity using anti-hydrogen at CERN

D. Banerjee[2], F. Biraben[7], M. Charlton[11], P. Cladé[7], P. Comini[1, 2], P. Crivelli[2], O. Dalkarov[6], P. Debu[5], L. Dodd[11], A. Douillet[7#], G. Dufour[7], P. Dupré[10], S. Eriksson[11], P. Froelich[14], P. Grandemange[**], S. Guellati[7], R. Guérout[7], J. M. Heinrich[7], P.-A. Hervieux[4], L. Hilico[7#], A. Husson[1], P. Indelicato[7], S. Jonsell[15], J.-P. Karr[7#], K. Khabarova[6], S.K. Kim[16], Y. Kim[17], N. Kolachevsky[6], N. Kuroda[12], A. Lambrecht[7], A.M.M. Leite[5], L. Liszkay[5], P. Lotrus[5], D. Lunney[1], N. Madsen[11], G. Manfredi[4], B. Mansouli[5], Y. Matsuda[12], A. Mohri[13], G. Mornacchi[**], V. Nesvizhevsky[3], F. Nez[7], P. Pérez[5], C. Regenfus[2], J.-M. Rey[5], J.-M. Reymond[5], J-Y Roussé[5], S. Reynaud[7], A. Rubbia[2], Y. Sacquin[5], F. Schmidt-Kaler[8], N. Sillitoe[7], M. Staszczak[9], H. Torii[12], J. M. Heinrich[7], B. Vallage[5], M. Valdes[4], D.P. van der Werf[5, 11], A. Voronin[6], J. Walz[8], S. Wolf[8], S. Wronka[9] and Y. Yamazaki[10]

[1] Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Orsay, France,
[2]Eidgenössische Tech. Hochschule Zürich (ETH Zürich), Zürich, Switzerland,
[3]Institut Laue Langevin, Grenoble, France,
[4] Institut de Physique et Chimie des Matériaux de Strasbourg, Strasbourg, France,
[5] Institut de recherche sur les lois fondamentales de l'Univers (IRFU), CEA Saclay, France
[6] P.N. Lebedev Institute of Physics, Moscow, Russia,
[7] Laboratoire Kastler Brossel, UPMC-Sorbonne Universités, CNRS, ENS-PSL Research University, Collège de France, Paris, France,
[8] Johannes-Gutenberg-Universität, Mainz, Germany,
[9] National Center for Nuclear Research, Otwock-Swierk, Poland,
[10] Institute of Physical and Chemical Research, Wako, Japan,
[11] Swansea University, Swansea, United Kingdom,
[12] Institute of Physics, University of Tokyo, Komaba, Japan,
[13] Kyoto University, Kyoto, Japan,
[14] Uppsala University, Uppsala, Sweden,
[15] Stockholm University, Stockholm, Sweden,
[16] Seoul National University, Seoul, Korea,
[17] Institute for Basic Science, Daejon, Korea,
[**] CERN, Switzerland,
[#] also at Université d'Evry, Comue Paris-Saclay, Evry, France
francois.nez@lkb.upmc.fr

***Abstract*—The aim of the GBAR (Gravitational Behavior of Antimatter at Rest) experiment is to measure the free fall acceleration of an antihydrogen atom, in the terrestrial gravitational field at CERN and therefore test the Weak Equivalence Principle with antimatter. The aim is to measure the local gravity with a 1% uncertainty which can be reduced to few parts of 10^{-3}.**

***Index Terms*—Gravitation, Antimatter.**

I. INTRODUCTION

To date, the controversial behavior of antimatter in the gravity field (see [1] and references therein) has never been accurately tested. To avoid stray effects from electric or magnetic fields, the antimatter species has to be neutral. The possible candidates are antineutrons ($\overline{\mathrm{n}}$) [2], antihydrogen ($\overline{\mathrm{H}}$) [3] [4] and positronium (Ps) (i.e. e^+ e^-) atoms [5]. One attractive feature of $\overline{\mathrm{H}}$, which is made of one antiproton ($\overline{\mathrm{p}}$) and one positron (e^+), is the possibility of laser cooling. However, cooling $\overline{\mathrm{H}}$ in the 1S ground state is still challenging as there is no powerful laser available at 121nm to drive the 1S-2P transition [6]. The originality of GBAR experiment, which has been approved by the CERN committee [7], is to circumvent this difficulty by producing $\overline{\mathrm{H}}$ at rest from the photo-detachment of one of the positrons of the anti-ion ($\overline{\mathrm{H}}^+$) (that is $\overline{\mathrm{p}}$ e^+e^+) as presented in [8]. Indeed $\overline{\mathrm{H}}^+$ ions can be efficiently cooled in electromagnetic traps .

II. PRINCIPLE OF THE EXPERIMENT

This complex experiment can be divided into three challenging parts :

- production of $\overline{\mathrm{H}}^+$ ions,
- cooling of $\overline{\mathrm{H}}^+$ ions,
- free-fall of an anti-hydrogen atom.

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The $\overline{\mathrm{H}}^+$ ions are produced by two consecutive reactions using excited Positronium atoms (Ps*):

$$\overline{\mathrm{p}} + \mathrm{Ps}^* \rightarrow \overline{\mathrm{H}}^* + \mathrm{e}^- \quad (1)$$
$$\overline{\mathrm{H}}^* + \mathrm{Ps}^* \rightarrow \overline{\mathrm{H}}^+ + \mathrm{e}^- \quad (2)$$

in which $\overline{\mathrm{H}}^*$ stands for anti-hydrogen in an excited state.

Nowadays, efficient production of Ps atoms from a positron (e^+) beam sent on a nanoporous silica sample can be achieved [9]. As the total efficiency of the two reactions is not very high, large quantities of e^+ and $\overline{\mathrm{p}}$ are still needed. The experiment is carried out at CERN, on the Antiproton Decelerator and ELENA ring, using an intense linac based positron source.

III. DEVELOPMENTS

There is an intense activity on the GBAR project both from the theoretical and experimental sides. A careful theoretical study has been done on the systematic effects arising from the anti-hydrogen detector which can interfere with the free fall signal [10][11]. Possible schemes for a determination of the local gravity at the level of 10^{-3} with the GBAR apparatus have also been proposed [12][13][14][15].

The cooling of $\overline{\mathrm{H}}^+$ will be challenging as its temperature has to be decreased over eleven decades, from 200 eV to the neV range. It will be done in several steps, the last one being ground-state cooling of a $\mathrm{Be}^+/\overline{\mathrm{H}}^+$ ion pair. Simulations of the cooling have been performed, and the lasers needed for ions pair cooling are under development [16].

The beam line is also under construction see [17] and references therein. The cross sections of the two consecutive reactions (1) and (2) have been calculated to optimize the production of $\overline{\mathrm{H}}^+$ [18] and more recently, the cross section of the first reaction has been recalculated [19].

It was shown in [18] that, depending on the antiproton energy, the production of $\overline{\mathrm{H}}^+$ should be optimized with Ps atoms excited in 3D state or in 2P state. The velocity distributions of the Ps atoms cloud produced in nano-porous silica is very wide [20] and references therein. Therefore, in order to maximize the Ps excitation efficiency, one possibility is to use a two-photon transition to get rid of the first-order Doppler effect, as proposed for the 1S-3D transition [22]. Alternatively one can build a large line-width laser [20] or an optical frequency comb to excite the 1S-2P transition at 243 nm [21].

Currently, a laser chain for the two-photon excitation of the 1S-3D line of Ps, at 410 nm, has been built and characterized [22]. It is based on the same principle as the laser used for muonic hydrogen spectroscopy [23] excepted that the oscillator cavity is a ring cavity instead of a linear one. The cross section of reaction (1) will be measured in the near future.

A general overview of the project and of recent advances in the development of the experiment will be given at the conference.

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