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The AEgIS experiment at CERN: Probing antimatter gravity

R. Caravita(1), S. Aghion(2)(3), C. Amsler(4), M. Antonello(3)(5), A. Belov(6), G. Bonomi(7)(8), R. S. Brusa(9)(10), M. Caccia(3)(5), A. Camper(1), F. Castelli(3)(11), G. Cerchiari(12), D. Comparat(13), G. Consolati(2)(3), A. Demetrio(14), L. Di Noto(15)(16), M. Doser(1), C. Evans(2)(3), M. Fanì(1)(15)(16), R. Ferragut(2)(3), J. Fesel(1), A. Fontana(8), S. Gerber(1), M. Giammarchi(3), A. Gligorova(4), F. Guatieri(9)(10), P. Hackstock(1), S. Haider(1), A. Hinterberger(1), H. Holmestad(1), A. Kellerbauer(12), O. Khalidova(1), D. Krasnický(16), V. Lagomarsino(15)(16), P. Lansonneur(17), P. Lebrun(17), C. Malbrunot(1)(4), S. Mariazzi(9)(10), J. Marton(4), V. Matveev(6)(18), S. R. Ḿuller(14), G. Nebbia(19), P. Nedelec(17), M. Oberthaler(14), D. Pagano(7)(8), L. Penasa(9)(10), V. Petracek(20), F. Prelz(3), M. Prevedelli(21), B. Rienäcker(1), J. Robert(13), O. M. Røhne(22), A. Rotondi(8)(23), H. Sandaker(22), R. Santoro(3)(5), L. Smestad(24), F. Sorrentino(15)(16), G. Testera(16), I. Tietje(1), M. Vujanovic(1), E. Widmann(4), P. Yzombard(12), C. Zimmer(1), J. Zmeskal(4) and N. Zurlo(8)(25)

(The AEgIS Collaboration)

(1) *Physics Department, CERN - 1211 Geneva 23, Switzerland*
(2) *Politecnico of Milano - Piazza Leonardo da Vinci 32, 20133 Milano, Italy*
(3) *INFN Milano - via Celoria 16, 20133, Milano, Italy*
(4) *Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences Boltzmanngasse 3, 1090 Vienna, Austria*
(5) *Department of Science, University of Insubria - Via Valleggio 11, 22100 Como, Italy*
(6) *Institute for Nuclear Research of the Russian Academy of Science - Moscow 117312, Russia*
(7) *Department of Mechanical and Industrial Engineering, University of Brescia via Branze 38, 25123 Brescia, Italy*
(8) *INFN Pavia - via Bassi 6, 27100 Pavia, Italy*
(9) *Department of Physics, University of Trento - via Sommarive 14, 38123 Povo, Trento, Italy*
(10) *TIFPA/INFN Trento - via Sommarive 14, 38123 Povo, Trento, Italy*
(11) *Department of Physics, University of Milano - via Celoria 16, 20133 Milano, Italy*
(12) *Max Planck Institute for Nuclear Physics - Saupfercheckweg 1, 69117 Heidelberg, Germany*
(13) *Laboratoire Aimé Cotton, Université Paris-Sud, ENS Cachan, CNRS, Université Paris-Saclay - 91405 Orsay Cedex, France*
(14) *Kirchhoff-Institute for Physics, Heidelberg University - Im Neuenheimer Feld 227, 69120 Heidelberg, Germany*
(15) *Department of Physics, University of Genova - via Dodecaneso 33, 16146 Genova, Italy*
(16) *INFN Genova - via Dodecaneso 33, 16146 Genova, Italy*
(17) *Institute of Nuclear Physics, CNRS/IN2p3, University of Lyon 1 - 69622 Villeurbanne, France*

([18]) *Joint Institute for Nuclear Research - 141980 Dubna, Russia*
([19]) *INFN Padova - via Marzolo 8, 35131 Padova, Italy*
([20]) *Czech Technical University, Prague - Bøehová 7, 11519 Prague 1, Czech Republic*
([21]) *University of Bologna - Viale Berti Pichat 6/2, 40126 Bologna, Italy*
([22]) *Department of Physics, University of Oslo - Semælands vei 24, 0371 Oslo, Norway*
([23]) *Department of Physics, University of Pavia - via Bassi 6, 27100 Pavia, Italy*
([24]) *The Research Council of Norway - P.O. Box 564, NO-1327 Lysaker, Norway*
([25]) *Department of Civil Engineering, University of Brescia - via Branze 43, 25123 Brescia, Italy*

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Summary. — The AEḡIS experiment at CERN's Antiproton Decelerator is set up to precisely measure the gravitational interaction between matter and antimatter. For this purpose, antihydrogen will be formed from cold antiprotons and positronium, the hydrogen-like bound state of an electron and a positron. Subsequently, the free-fall acceleration of a cold horizontal beam of antihydrogen will be measured by a deflectometer. The present status, recent experimental progress and the medium-term plan of the AEḡIS experiment are presented.

1. – Introduction

Probing experimentally the antimatter gravitational acceleration with a pulsed beam of cold antihydrogen is the ambitious goal of the AEḡIS collaboration at CERN [1], aiming to use a moiré deflectometer [2] to detect its vertical displacement due to the free-fall with a position-sensitive detector [3]. Pulsed antihydrogen production has not been experimentally achieved yet, and will be realized in AEḡIS with a double charge-exchange reaction between trapped antiprotons ($\bar{\mathrm{p}}$) and laser-excited Rydberg Positronium (Ps) atoms [4] obtained from the conversion of positrons (e^+) in a matter e^+-Ps converter:

$$\begin{array}{rcll} \mathrm{e}^- + \mathrm{e}^+ & \longrightarrow & \mathrm{Ps} & \text{Ps production} \\ \mathrm{Ps} + \gamma_{205\ \mathrm{nm}} + \gamma_{1700\ \mathrm{nm}} & \longrightarrow & \mathrm{Ps}^* & \text{Laser excitation} \\ \bar{\mathrm{p}}^- + \mathrm{Ps}^* & \longrightarrow & \bar{\mathrm{H}}^* + \mathrm{e}^- & \text{Charge exchange.} \end{array}$$

Many progresses towards a first milestone pulsed production of $\bar{\mathrm{H}}$ have been recently pursued by AEḡIS: the preparation of a dense, cold plasma of $\bar{\mathrm{p}}$; the efficient production of Ps by the matter converter designed for cryogenic high-vacuum use; efficient Ps Rydberg laser-excitation.

A sketched scheme of the current setup of the experiment is shown in Fig. 1. A nanoporous silicon positron-Ps converter developed for cryogenic use [7] is placed 1.5 cm above a Malmberg-Penning trap for $\bar{\mathrm{p}}$ storage [6]. Positrons (e^+) implanted with KeV energy are efficiently converted into Ps atoms - immediately re-emitted into vacuum after

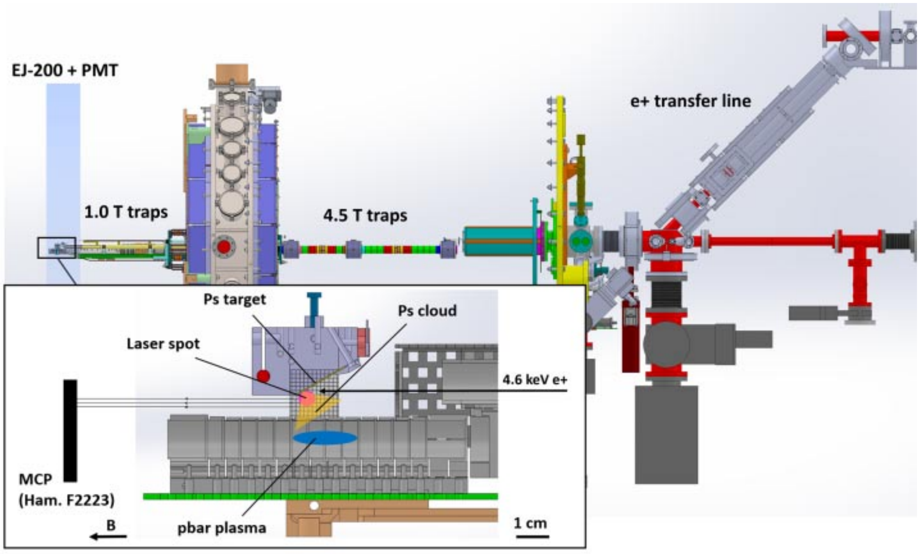

Figure 1. – Cut-open schematic view of the AEgIS experiment, highlighting the most crucial components. Inset: zoom on the antihydrogen production region.

cooling by collisions in the material porosities (electrochemically-etched nanochannels [8]). Two laser pulses are sent from the side of the converter to excite the emitted fraction of Ps first to $n = 3$ (205.045 nm) then to Rydberg levels (1700 nm) [10]. Rydberg Ps atoms, having a lifetime longer than 10μ s, fly towards the $\bar{\text{p}}$ storage trap and produce $\bar{\text{H}}$ by the charge-exchange reaction with the $\bar{\text{p}}$ in the cold plasma.

2. – Antiproton plasma preparation

Abundant cold $\bar{\text{p}}$ were prepared in the final trap based on a procedure constitued by several plasma manipulations. First, $\sim 1\%$ of the $3 \cdot 10^7$ 5.3 MeV antiprotons in each spill of the Antiproton Decelerator were captured and cooled in AE$\bar{\text{g}}$IS catching traps (using a matter energy degrader and electron sympathetic cooling [6]). Subsequently, the mixed $\bar{\text{p}}$ - e^- plasma was radially compressed to high densities, using the rotating-wall technique [11], to $\lesssim$ mm [12]. Finally, the antiprotons were transferred ballistically to the $\bar{\text{H}}$ production trap by applying fast potential pulses on the trap end-caps [13]. Stacking of several $\bar{\text{p}}$ spills was shown possible, allowing $6 - 7 \cdot 10^5$ antiprotons to be stored in the trap with long plasma lifetimes (> 1 h).

3. – Positronium production and Rydberg excitation

In parallel, Ps production and emission into vacuum from the mesoporous silicon targets designed for AE$\bar{\text{g}}$IS was shown to have high ($\sim$ 35%) efficiency [5]. Ps was subsequently laser-excited to the Rydberg levels spanning from $n = 15$ to $n = 17$ [14] with an overall laser excitation efficiency of $\sim 8\%$ [15], demonstrating the proof-of-principle laser excitation for $\bar{\text{H}}$ production. An alternative way to increase the Ps lifetime was also investigated, i.e. Ps laser excitation to the 2^3S metastable state, revealing to be a possible candidate for future inertial experiments on Ps itself [16].

4. – Conclusions

AEgIS entered its data taking period with both antiprotons and positrons at the beginning of 2015. Since then, significant progress towards a first experimental demonstration of pulsed antihydrogen formation was obtained. This experiment, now within reach, is the crucial milestone towards conducting a first gravity measurement on antihydrogen.

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