Status of the GBAR experiment

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CEA/IRFU

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Outline of the presentation

1. Introduction
2. The GBAR experiment
3. Work progress
4. Future plans

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Motivation

- Prediction: Baryon/Antibaryon Ratio = 1
  All observations Baryon/Antibaryon Ratio ≠ 1
- Maybe gravitation interaction is different?
- What is the theory of quantum gravitation?

Possible exotic solutions:
- Cosmology models which keeps matter-antimatter symmetry but include mechanism which keep them apart;
- SM extension in which gravity depends on the flavor;
- etc.

What can be a good solution to set the problem? **Measurement!**
**Gravitational Behaviour of Antihydrogen at Rest**

- **Goal:** Test the weak equivalence principle for antimatter using antihydrogen atom with at least 1% precision.

- The principle of the GBAR experiment:
  - production of antihydrogen ion $\bar{H}^+ \Leftrightarrow \bar{p}e^+ e^+$;
  - trapping of $\bar{H}^+$ in a Paul trap;
  - sympathetic $\bar{H}^+$ cooling with $Be^+$ down to 10 $\mu$K;
  - photodetachment of an “extra” $e^+$ ($\Delta t < 150$ $\mu$s, $\Delta s < 100$ $\mu$m);
  - measurement of the time of flight of the $\bar{H}$ in the region without magnetic field gradient ($h = 10$ cm $\rightarrow \Delta t = 0.14$ s).

- 1 event gives 37% uncertainty, and 1500 events 1%

- Further goal: $10^{-5}$ precision with the method presented by V.V. Nesvizhevsky (see the talk in the Morning).
The first large part of the experiment is to prepare the antihydrogen ion beam (P. Pérez and A. Rosowsky, NIM A 532 (2004) 523):

\[ Ps^* + \bar{p} \rightarrow \bar{H}^* + e^- \]  \hspace{1cm} (1)

\[ Ps^* + \bar{H} \rightarrow \bar{H}^+ + e^- \]  \hspace{1cm} (2)
The scheme of the GBAR experiment

\[ \bar{p} + Ps^* \rightarrow \bar{H}^* + e^- \]

\[ \bar{H} + Ps^* \rightarrow \bar{H}^+ + e^- \]
The GBAR experiment

The GBAR zone in March 2017
The GBAR zone in November 2018

- summer 2018 - the first GBAR antiproton beam time
ELENA / antiproton deceleration and trapping

- **ELENA - The Extra Low Energy Antiproton ring**
  - C. Carli and the AD/ELENA team(s);
  - beam energy $E = 100$ keV (from 5.3 MeV);
  - beam length 300 ns;
  - four bunches, each with $0.43 \cdot 10^7$ antiprotons at extraction.

- **Antiproton deceleration and trapping:**
  - antiproton deceleration from 100 keV to 1-10 keV;
  - next year: **antiproton trap**.
Electron linear accelerator based positron source

- Electron beam provided by electron linear accelerator:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>9 MeV</td>
</tr>
<tr>
<td>Number of $e^-$/bunch</td>
<td>$6 \cdot 10^{12}$</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>300 Hz</td>
</tr>
<tr>
<td>Beam power</td>
<td>3.2 kW</td>
</tr>
<tr>
<td>Average current</td>
<td>0.18-0.36 mA</td>
</tr>
<tr>
<td>Peak current</td>
<td>0.3 A</td>
</tr>
<tr>
<td>Pulse length</td>
<td>$2 - 4 \mu s$</td>
</tr>
</tbody>
</table>

- Slow positron beam characteristics:
  - positron flux: $4 \cdot 10^7$ positrons/s;
  - (radioactive sources $< 10^7$ $e^+$/s);
  - Goal $3 \cdot 10^8$ $e^+$/s.
Positron trapping and positronium production

→ Positron trapping:
  • 1st trap: buffer gas trap:
    • $N_2$ with $CO_2$ cooling gas;
    • 80 bunches from linac stacked and transferred.
  • 2nd trap: high field Penning-Malberg trap:
    • 5 T magnetic field;
    • $1 \cdot 10^8$ e$^+$ in 100 s;
    • The goal: $3 \cdot 10^{10}$ e$^+$ in 110 s.

→ Positronium production using the mesoporous $SiO_2$ converter:

→ Optimise the system with hydrogen atom and ion production: $Ps^* + p \rightarrow H^* + e^+$, $Ps^* + H \rightarrow H^- + e^+$
**$\bar{H}^+$ cooling**

- **1st step:**
  - a mm scale RF linear trap;
  - capture and sympathetic Doppler cooling of a $\bar{H}^+$ ion in a big $Be^+$ crystal;
  - few mK.
- **2nd step:**
  - miniaturized trap called precision trap;
  - ground state Raman side band sympathetic cooling of a $Be^+/\bar{H}^+$ ion pair in the precision trap;
  - 10 $\mu$K.


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**Dark ion in capture trap ($H_2^+$ or $H_3^+$)**

- **Precision trap.**
Free fall chamber and annihilation detectors

- Antihydrogen annihilation detectors:
  - tracker detectors - MicroMegas detectors 50 cm $\times$ 50 cm; the efficiency better than 96% per plane for charged pion;
  - Time of Flight Detectors build from bars made of scintillator - 170 cm $\times$ 10cm $\times$ 5cm, time resolution 80 ps.
- Magnetic field shield - under investigation.

*Time of Flight Detectors and small MicroMegas detectors.*
Summary and future plans

Summary:

- the GBAR experiment has undergone significant development in the past two years.

Next steps:

- during CERN long shutdown 2 (now):
  - produce hydrogen atom and ion;
  - measure hydrogen Lamb shift;
  - improve the ELENA-GBAR connection using $H^-$ beam;
  - prepare the free fall experiment and test parts of it.

- after long shutdown 2 (spring 2021):
  - the free fall experiment with 1% accuracy using basic method;
  - spectroscopy of the gravitational quantum levels of the $\bar{H}$ atom using method presented by V. V. Nesvizhevsky (see his talk in the morning);
  - measure the antihydrogen Lamb shift.
The GBAR collaboration


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Future plans

**$H/\bar{H}$ Lamb shift**

The measurement plan:

- measurement of a quenched fraction of $H$ as a function of microwave frequency;
- in case of $\bar{H}$ 4 months of data result with 100 ppm on line center and 10% on $\bar{p}$ radius ($\Delta E = \frac{1}{12} \alpha^4 m_r^3 r_\bar{p}^2$);
- the setup is currently being tested with a hydrogen beam;
ELENA - The Extra Low Energy Antiproton ring

- C. Carli and the AD/ELENA team(s)
- Beam energy $E = 100$ keV (from 5.3 MeV)
- Beam length 300 ns
- Four bunches, each with $0.43 \cdot 10^7$ antiprotons at extraction
Future plans

Positron trapping

- Buffer gas trap:
  - $N_2$ with $CO_2$ cooling gas;
  - present trapping efficiency 5 ± 0.5% (goal 20 – 25%);
  - lifetime 0.6 s (stage 1) and 14 s (stage 3);
  - 80 bunches from linac stacked and transferred.

- High field Penning-Malberg trap:
  - 5 T magnetic field;
  - With linac repetition frequency at 100 Hz the number of trapper positrons is $1 \cdot 10^8 \text{ e}^+$ in 100 s;
  - The goal is to accumulate $3 \cdot 10^{10} \text{ e}^+$ in 110 s.
Future plans

Positronium production and general study

- Positronium production using the mesoporous SiO$_2$ converter:
  - Cross section calculations:
    - 1st reaction: H/\BAR{H} excitation to n=3 gives 100 higher cross section;
    - 2nd reaction: there is no agreement between existing calculations - measurement!
  - During the LS2:
    - study Ps density in the target cavity:
    - 1S-3D to measure enhancement of hydrogen atom and ion cross-section.