MagGiver: Mapping of the GBAR Magnetic Field

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1 Context of this summer camp

The Gravitational Behaviour of Antihydrogen at Rest (GBAR) experiment aims to measure the free-fall acceleration of neutral antihydrogen $\bar{H}$ [1] in Earth's gravitational field ($\bar{g}$ hence the acronym [2]), in order to test Einstein's weak equivalence principle on antimatter. This principle states that the trajectory of a test particle is independent of its composition and internal structure when subjected only to gravitational interaction [3].

The originality of GBAR lies in the production of $\bar{H}$: by creating the ion $\bar{H}^+$, which can be cooled with electromagnetic traps, the excess positron can be photodetached to produce a very slow-moving $\bar{H}$, which cannot be achieved by competing experiments.

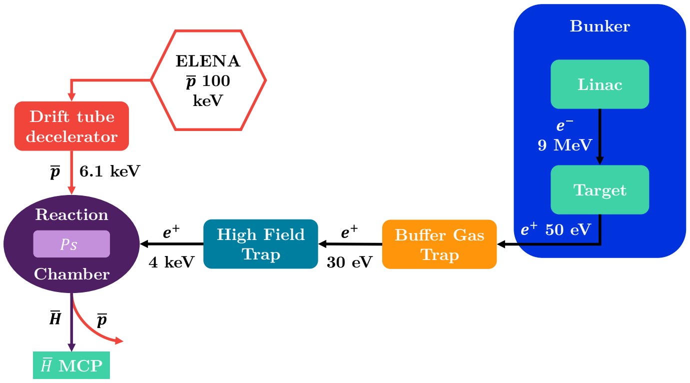

Figure 1: Diagram of the experiment. Source: [4]

The production of resting antihydrogen atoms ($\bar{H}$) in GBAR occurs in the reaction chamber (in purple in figure 1) by directing antiprotons ($\bar{p}$) onto a positronium cloud[1] (Ps), which is produced by directing a positron beam (e^+) onto nanoporous silica. The reaction is governed by [4]:

$$\bar{p} + Ps \longrightarrow \bar{H} + e^- \tag{1.1}$$

[1]the bound state of an electron and its antiparticle, the positron

where $\bar{p}$ is an antiproton, Ps is positronium, $\bar{H}$ is antihydrogen, and e^- is an electron.

Downstream of the reaction chamber, antiprotons that have not reacted with the positronium cloud are deflected using an electrostatic field, allowing only antihydrogen atoms that have not reacted with the positronium cloud to pass through, as described by reaction (1.2):

$$\bar{H} + Ps \longrightarrow \bar{H}^+ + e^- \tag{1.2}$$

Antihydrogen ions ($\bar{H}^+$) are then trapped and cooled to photodetach the excess positron, resulting in neutral and resting antihydrogen ($\bar{H}$). With isolated and resting antihydrogens, measuring their free-fall time in Earth's gravitational field becomes possible.

However, the group faces a challenge: the low rate of positrons reaching the reaction chamber complicates the formation of the positronium cloud (the number of e^+ reaching the chamber is about 5%), impacting the production of antihydrogen atoms.

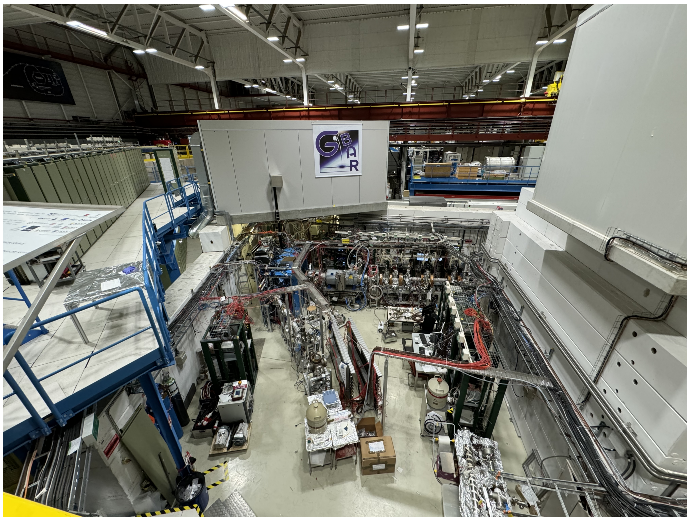

Figure 2: Overview of the GBAR experiment.

One can notices here that a lot of components are likely to generate magnetic fields.

Internal simulations by the GBAR group revealed the sensitivity of the positron (e^+) and antiproton ($\bar{p}$) beamlines to stray magnetic fields (approximately $1G$ for $\bar{p}$ and $0.1G$ for e^+). This sensitivity could partly explain the low rate of positrons reaching the reaction chamber.

The goal of this summer camp is to develop and deploy a real-time magnetic field mapping tool in the GBAR experimental area to attempt to correlate positron beam deviations with stray magnetic fluctuations.

(Perhaps include photos of the experimental site to show the magnetic clutter, highlighting the The Antiproton Decelerator (AD).)

2 MagGiver

The main idea of MagGiver is to use inexpensive magnetic field detectors and deploy them around the experimental zone to compare the actual magnetic field with the simulation results. This helps verify if the actual positron beam deviations are due (or mainly due) to residual magnetic fields around the zone.

2.1 Features

The main feature of MagGiver is to measure the magnetic field around the GBAR zone. It also includes:

- A calibration pack to calibrate the sensors used
- Built-in temperature compensation for the MMC5603 magnetic sensor
- A visualization tool
- A flexible Arduino API allowing the inclusion of additional sensors in MagGiver
- Documentation available on the GBAR GitLab hosted by the Conseil Européen pour la Recherche Nucléaire (CERN)

2.2 How it works

MagGiver is designed to operate with a specific architecture described in the documentation. Here are the basic steps to show how easy it is to use:

- Upload the Arduino script to the Arduino UNO board that you will use
- Mount a multiplexer on the board
- Connect the sensors to the multiplexer (make sure they are supported by MagGiver)
- Connect the board to your computer
- Run the acquisition script and voilà

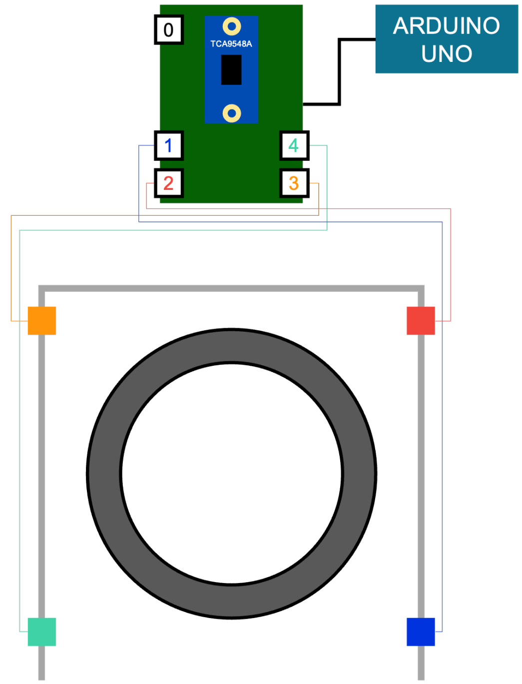

Figure 3: MagGiver hardware setup. Colored squares: sensors, U-shape: profiles, Concentric circles: GBAR vacuum chamber.

3 Few results

In this section, we present some measurements taken using the MagGiver tool. These measurements were collected over a 13-day period in the GBAR positron line experiment zone.

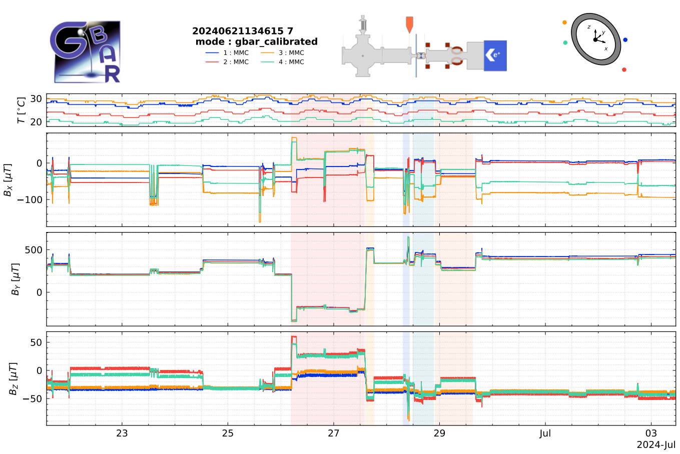

Figure 4: 13 days of measurement. On top: position of a measurement plane in the GBAR positron line, at right: positions of the sensors within this plane.

As observed in Figure 4, there are significant variations in the magnetic field intensities in the GBAR experiment zone over the 13-day period. These measurements highlight the necessity of monitoring the magnetic field due to frequent magnetic events.

The consistent changes in the magnetic field suggest the influence of external factors or experimental activities within the GBAR setup. Monitoring these changes is necessary for ensuring the accuracy and stability of the experiments conducted in this area.

Future work will involve further analysis of these variations to identify specific sources and to improve the overall stability of the experimental conditions.

4 Conclusion

I am very happy to have been selected for the CERN summer camp. The experience has been great, both because of the wonderful environment and the interesting lectures. Even though I worked in a field that is not my main area of expertise, this time at CERN has confirmed my decision to pursue research in particle physics.

The hands-on experience and the knowledge I gained were very valuable. While I am more interested in theoretical physics and simulation, this camp has strengthened my passion for particle physics and my desire to contribute to our understanding of the universe.

Thank you to everyone at CERN who made this experience possible. I am excited to continue my journey in particle physics, inspired and motivated by my time here.

Références

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A Acronyms et abbreviations

CERN Conseil Européen pour la Recherche Nucléaire

AD The Antiproton Decelerator

GBAR Gravitational Behaviour of Antihydrogen at Rest