AD-7/GBAR status report for the 2018 CERN SPSC


Abstract: We report on the installation of the first components of the GBAR (Gravitational Behaviour of Antimatter at Rest) experiment in the AD hall.

1- Introduction

In 2017 we started to install parts of the apparatus in the AD-7 experimental zone: the electron linear accelerator, the primary target, the positron extraction line and the drift tube decelerator for antiprotons. The bunker for radiation shielding from the linac was completed and a first laser hut was built. The Penning-Malmberg traps for positrons were also brought to CERN as well as the reaction chamber. Details on the motivation and functional principles of GBAR can be found in the original 2011 proposal [GBAR-SPSC-2011] and the subsequent annual reports to the SPSC [GBAR-SPSC].

2- Layout

The current layout of the GBAR experiment in the AD Hall is shown in Figure 1, while the experimental zone is shown in Figure 2.
Figure 1 – Layout of the GBAR experiment. The LNE50 ELENA transfer beam line comes from the bottom right of the figure. The antiprotons will then enter the drift tube decelerator to enter the reaction chamber. The positron beam line exits from the bunker (bottom left) and enters first the Buffer Gas trap followed by the high field trap and the reaction chamber.

Figure 2 – View of the experimental zone from the visitor’s gallery. The positron beam enters from the right into the buffer gas trap which is followed by the high field trap (in blue). The drift tube decelerator is located in its Faraday cage under the laser hut that will host the laser system to excite positronium.
3- Linear electron accelerator

The electron accelerator is composed of several elements (as can be seen in Figure 3). The accelerating structure, made at NCBJ, is injected with electrons using a triode gun, while the RF power is provided by a 10 MW klystron from Thalès and brought to the structure with a wave guide filled with SF6. A solid-state modulator from Scandinova operates the klystron. A circulator protects the klystron from reflected RF power. The structure is evacuated with small ion pumps to maintain a vacuum better than $10^{-7}$ mbar when operating. Two water chillers maintain the temperature of the klystron and of the accelerating structure. A YAG screen allows to view the beam spot. Installation started in February 2017 with all final elements except for the gun and accelerating structure (Figure 4) that are temporary and can reach a third of the nominal current but allow to test the rest of the setup.

![Figure 3– Schematic of the 9-MeV electron linac.](image)

A major issue with this linac is safety because it will produce intense gamma radiation when the beam hits the target. A radiation shield was installed by CERN/EN consisting of blocks of concrete and iron. An interlocked access door prevents entry inside the bunker when the accelerator is ON. When the linac is running at a very low repetition rate of 2.5 Hz access is possible in the experimental zone. But when it is running above this frequency, i.e. up to full power with a repetition rate of 300 Hz, access to the experimental zone is prohibited by another interlocked access door. Extensive documentation was produced as requested by the safety divisions.

After delays due to an excessive water pressure that destroyed the heat exchangers of the chillers and leaks in the wave guide that had to be replaced, the first tests were conducted in October (Figure 5) under supervision from a team of the Radiation Protection division. The beam energy was measured
with a magnetic spectrometer to provide reference curves of energy vs klystron high voltage or cathode grid voltage and to choose a safe operating point during the first tests in 2017 at an energy of 8.3 MeV.

**Figure 4** – Picture of the temporary accelerating structure on its stand.

**Figure 5** – Left: Waveforms of the first electron beam on October 17. The top yellow curve shows the reflected RF wave. The middle blue curve shows the beam current after 15 kV acceleration at the cathode. The bottom red curve comes from the beam current monitor located after acceleration at 8.3 MeV. Right: Beam spot as seen on the YAG screen.
The final accelerating structure (Figure 6) has been produced at NCBJ and has been tested, equipped with its electron gun, to sustain and accelerate beam with 300 mA peak current at an energy of 7.5 MeV. The final tests will be performed, using a magnetic spectrometer, to determine the electron exit energy.

![Figure 6 – Final accelerating structure after baking in NCBJ.](image)

### 4- Positron production

The water-cooled tungsten target system (Figure 8) for creating positrons includes a stack of tungsten meshes for moderation. The slow positrons are transported in a vacuum tube around which a solenoid is wound to produce a magnetic field of 8 mT (Figure 7). Positrons are thus transported outside the bunker where they hit a removable metallic target and annihilate producing 511 keV gamma rays. These are detected using an NaI crystal detector, a PbWO₄ crystal and a thick plastic scintillator, as well as energy analysed with a retarding voltage grid.

![Figure 7 – Sketch of the (vertically mounted) electron linac inside the GBAR bunker followed by the positron (tungsten) target/moderator and positron beamline leading to the experimental area (right).](image)
Figure 8 – Left: view of the positron beam line exiting the bunker and the two positron traps. Right: Target system surrounded by coils and followed by solenoid transport.

Figure 9 – Left: gamma ray detectors at the exit of the bunker. Red arrow shows the plastic scintillator; blue is for PbWO4 and orange for NaI. Right: transport to the traps; Bottom: first positron annihilation signals.
The first positrons were seen on November 17. With the linac running at a repetition rate of 100 Hz, peak current of 100 mA and pulse duration of 2.9 µs, signals collected (Figure 9) correspond to a number of $3.7 \times 10^4$ e+/pulse, i.e. $3.4 \times 10^6$ per second. The repetition rate was kept at 100 Hz in order to control outgassing of the target. After several shifts of continuous beam operation, we believe outgassing is now performed and we may proceed to higher repetition rate in 2018. It is difficult to extrapolate this positron rate to the parameters of the final structure since there may be non-linear effects such as loss of moderation efficiency with temperature, or creation of defects under high irradiation. It remains to be seen how the system behaves under such high load. Also, the moderator is not optimised and may be improved. The energy spread was measured and found to be 1.3 eV (standard deviation), which is adequate for the operation of the buffer gas trap. This trap was tested successfully with the beam at Saclay on its two stages including using the rotating wall technique.

Tests of the positron traps and the measurement of hydrogen production could not be fully conducted because the linac in Saclay has to undergo substantial maintenance. Since the linac at CERN starts to work, and has much higher performances prospects, it was decided to stop the tests in Saclay and continue them at CERN. The positron traps have been moved from Saclay to CERN in October and are going to be installed during the first months of 2018 together with the reaction chamber (Figure 10).

**Figure 10** – Reaction chamber with magnetic shield (purple).

5- **Post-ELENA Antiproton decelerator and trapping**

The 100-keV antiproton beam delivered by ELENA will be decelerated electrostatically before entering a drift tube, the potential of which is switched to ground during transit. The system was brought from Orsay and installed at CERN (Figure 11). The electrodes have been conditioned to 100 kV and the drift tube switches from 100 kV to ground. The pressure within the vacuum chamber reached $5 \times 10^{-9}$ mbar. This is sufficient for the passage of antiprotons within the reaction chamber. However, it is not enough since it would pollute the ELENA ring where antiprotons stay several seconds. We have identified several weak points that are going to be addressed during the first months of 2018 in order to be ready for accepting first H ions from ELENA and later antiprotons.
Recently our collaborators from Korea have obtained a superconducting magnet with active shielding that can reach 7 T and is suitable for trapping antiprotons (Figure 12). The hardware to make this a Penning-Malmberg trap has been ordered. This device will be placed between the drift tube decelerator and the reaction chamber when proven to trap electrons and protons.

6- Capture and cooling of antihydrogen ions

Design work and simulations for the capture, cooling and free-fall part of the experiment have progressed nicely. In Figure 13, a sketch of the switchyard to separate the antiprotons from the antihydrogen ions is shown. This item should be installed downstream of the reaction chamber.
In Figure 14 the current version of the free-fall chamber is shown, which houses the H\(^+\) capture trap and the precision trap for dropping the neutralized H. In addition to holding excellent vacuum, the chamber must provide a homogeneous magnetic field and a quantisation axis for the Raman side-band cooling scheme, as well as access ports for four laser beams.

Simulations show that a mixture of Be\(^+\)/H\(_2\)^+ or Be\(^+\)/HD\(^+\) allow a shorter capture time of the anti-ion than pure Be\(^+\), with H\(_2\)^+ being more efficient at energies lower than the eV. Large Be\(^+\) crystals have been obtained and also made hollow in order to minimise uncontrolled photo-detachment of H\(^+\) (Figure 15).
Figure 15 – Photographs of cold Be\(^+\) crystals with 4500 ions trapped (top), and a hollow crystal is formed (bottom).

Experiments to trap and cool H\(_2\)^+ ions have started in Paris that can serve as exercise for \(\bar{H}^+\) since this is the closest ion in mass of the same charge. Collaboration with MPQ on Be\(^+\)/Sr\(^+\) sympathetic cooling has started because the mass ratio of 88/9=9.8 is close to that of Be\(^+\)/\(\bar{H}^+\). In Mainz, an improved loading of Be\(^+\) has been achieved using resonant pulsed ionisation with a Ti:sapphire or pulsed non resonant ionisation with a Minilite Nd:YAG. Spectroscopy of mixed crystals of Be\(^+\) and Ca\(^+\) was performed (Figure 16).

Figure 16 – Rabi flops on axial COM mode of mixed Be\(^+\)/Ca\(^+\) crystal.

7- Detector system

The first of four planes of a time-of-flight detector system has been made at Seoul National University (Figure 17) and brought to CERN. With a time resolution of better than 80 ps, it is possible to distinguish annihilations occurring at the top of the free fall chamber from those at its bottom or from cosmic rays.
Several double planes of micromegas chambers were tested at ETHZ. The efficiency reaches better than 96% per plane with an increased gap of 10 mm and a change of gas mixture to AR/CF4/Isobutane (96/2/2).

*Figure 17 – Time-of-flight detector made by the SNU group.*

8- Plans 2018

The final structure of the electron linac is scheduled to be installed and commissioned in February. The drift tube decelerator vacuum will be improved in the meantime in order to be ready to receive H\(^+\) ions from ELENA in March and antiprotons when available. The positron traps and reaction chamber should also be installed during the first semester. A proton gun will be installed before the drift tube to perform experiments to test the matter equivalent of the reactions. The aim is to be ready to produce an antihydrogen beam during the second semester and hopefully to produce and detect anti ions.

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References

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