Status of the Linac based positron source at Saclay

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Abstract. Low energy positron beams are of major interest for fundamental science and materials science. IRFU has developed and built a slow positron source based on a compact, low energy (4.3 MeV) electron linac. The linac-based source will provide positrons for a magnetic storage trap and represents the first step of the GBAR experiment (Gravitational Behavior of Antimatter in Rest) recently approved by CERN for an installation in the Antiproton Decelerator hall. The installation built in Saclay will be described with its main characteristics. The ultimate target of the GBAR experiment will be briefly presented as well as the foreseen development of an industrial positron source dedicated for materials science laboratories.

1. Introduction
One of the fundamental questions of today’s physics concerns the action of gravity upon antimatter. A difference between the free fall of matter and antimatter in the gravitational field of Earth would signal a violation of the Weak Equivalence Principle. There are indirect limits on its validity with antimatter. However these are model dependent or controversial [1]. Projects to detect the free fall of charged antiparticles, in the gravitational field of the Earth, all failed because of the difficulty to shield the apparatus against electromagnetic fields [2]. No experimental direct measurement has ever been successfully performed with antimatter particles. The GBAR experiment, recently accepted by CERN, proposes a direct measurement with antihydrogen atoms, $\text{H}^+$ [3], as suggested by J. Walz and T. Hänsch [4]. This ion can be cooled down to a few µK, by sympathetic cooling with ordinary laser-cooled ions. Velocities less than 1 m/s could be reached for a quasi-vertical free fall. An R&D program has been launched at IRFU (CEA/Saclay) to demonstrate the feasibility of the production of antihydrogen with the use of a cloud of positronium (Ps) atoms (the bound state of an electron and a positron). This target, when bombarded with antiprotons, should allow combining its positrons with the incoming antiprotons and create $\text{H}$ atoms and $\text{H}^+$ ions.

2. The electron linac
In order to produce the high positron rate needed by the GBAR experiment the use a 10 MeV / 2 mA has been foreseen. As a demonstrator for the positron production setup patented by CEA a small
electron linac derived from a commercial industrial machine (Fig 1) has been purchased. Using the proper HF power source its nominal kinetic energy and average current were given to be 5.5 MeV and between 0.1 and 0.2 mA. The repetition rate is 200 Hz with bunch length of 4 µs. The acceleration length is 21 cm after which the beam diameter is 1 mm. The initial commissioning of the linac performed with a filament emitting electrons showed a beam current of 0.007 mA for energy of 5.5 MeV. An impregnated cathode as electron emitter has been installed to increase the beam current. Using it the electron beam reached the expected value of 0.14 mA. Nevertheless energy measurement was not possible in that new configuration as the beam had to exit the vacuum through a thin titanium window to dump on an aluminium wedge used to measure the energy and the beam would have burned this titanium window.

As the positron production was lower than what had been simulated using a 5.5 MeV electron beam the full measurement of the electron beam characteristics had to be undertaken. This has been done using a compact beam analyzer. This device has been installed in the linac bunker and replaced temporarily the positron source.

This beam analyzer consists of a 180° bending magnet and a fast readout system based on optical fibers. It provides a bunch time analysis of the electron energy as can be seen on figure 2. One can state that for a nominal bunch length of 4 µs the effective high power emission has duration of 2.5 µs during which the beam energy reaches 4.3 MeV. Reducing the cathode emitting current leads to an increase of the peak energy. Fig. 3 shows the beam energy dependence as a function of the emitted cathode current for two repetition rates. This energy dependence as a function of the beam current reflects a beam loading effect.

In parallel calculation of the voltage gradient within the accelerating cells were done showing already critical values (locally near 20 MV/m). A further increase of the HF power source would have led to electrical breakdown within the cells. Therefore we decided to work with a lower than the expected beam current to optimize the energy and the positron production rate.

3. The positron source
The positrons are produced in a tungsten target by pair production. The setup shown in Fig.4. consists of a magnetic selector that extracts the positrons emitted after the water cooled target from the remaining electron flow. These positrons are then directed on the pad detector shown on Fig.5. It consists of aluminum pads connected to current measurement devices and protected by a thin metallic
grid that can be kept at various voltages. Using this detector allowed to adjust the magnetic configuration to optimize the positron capture.

The average positron energy emitted from the W target has a mean value of 800 keV and ranges from 0 to 3 MeV, which is advantageous concerning moderation efficiency, compared to positrons generated by a higher energy electron beam. Based on the 0.2 mA beam of 5.5 MeV energy simulations, performed with the GEANT3 software, predict rates of $5 \times 10^{11} \text{e}^+ \cdot \text{s}^{-1}$ when the beam hits a 200 µm thick target at 5 degree incidence angle. This small angle provides greater heat transfer and positron emission in vacuum while keeping an effective target thickness for the incoming electrons. At such low incident energies the positrons are emitted almost isotropically from the target (with 2/5 of these positrons emitted backwards from the incident beam direction).

4. The moderator

Although the design is adapted to a neon cryogenic moderator the initial low energy positron measurements have been performed using a more conventional tungsten mesh moderator. The tungsten meshes have been placed after the positron production target and the magnetic field configuration of the positron source adjusted for low energy positron transport. The measurement of the low energy positron production rate can only be performed outside of the biological shield because of the high level of RF noise near the electron linac and the very low signal of moderated positrons. A 13 m long transport line consisting of a vacuum tube in which a continuous magnetic field (0.5 to 1 mT) is established by coils wound directly on the tube has been installed to guide the positrons outside of the biological protection.

Trials have been made to optimize the number of tungsten grids for moderated positron production.

![FIGURE 3](image.png)  **FIGURE 3.** Beam energy (in MeV) as a function of the beam peak current (1 nVs = 200 µA) for 50 and 100 Hz repetition rate.

The optimum value is around 12 grids as shown on Fig.6. An accelerating voltage is applied across the tungsten mesh grids to extract the positrons towards the extraction line.

The positron detection is done indirectly once they are converted to 511 keV annihilation gamma rays. An aluminum target is inserted in the vacuum tube and used as a target to produce the gamma rays. The gammas are then detected using a BGO scintillator and photomultiplier.

![FIGURE 4](image.png)  **FIGURE 4.** The positron source with the electron/positron separator
5. Future: the gbar project and positron sources for materials science.

The GBAR experiment[5] or “Gravitational behavior of anti-matter at rest” is the basic motivation for the development of an intense compact positron source. This experiment has been accepted by CERN in May 2012. It will produce anti hydrogen atoms and ions during interaction of antiprotons on a positronium target. A very high flux of positrons is needed to produce enough positronium for those interactions. A target value of $2.8 \times 10^8$ slow positrons per second is needed, to be compared to the actual $3.2 \times 10^6$ s$^{-1}$ achieved. Nevertheless the efforts invested in the development of this positron source will be made available for research in materials science. Compact non-radioactive slow positron sources are now available with slow positron production rates of $1.5 \times 10^7$ s$^{-1}$ for the low flux system and $4 \times 10^7$ s$^{-1}$ for high flux system. A company will soon be created to commercialize these products.

6. Conclusion

CEA-IRFU has developed an innovative compact linac based positron source for the need of a fundamental experiment dedicated to the gravity behavior of anti-matter. This device works now efficiently after several years of fine tuning. As consequences the GBAR experiment has been approved by CERN and optimized positron sources will be made commercially available for materials science analysis.

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