A mini linac based positron source

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We have installed in Saclay a demonstration setup for an intense positron source in November 2008. It is based on a compact 6 MeV electron linac to produce positrons via pair production on a tungsten target. A relatively high current of 0.15 mA compensates the low energy, which is below the neutron activation threshold. The expected production rate is 4 10^{11} fast positrons per second. A set of coils is arranged to select the fast positrons from the diffracted electron beam in order to study the possibility to use a rare gas cryogenic moderator away from the main flux of particles. A first part of the commissioning of the linac has been performed. First attempts at measuring the fast positron flux are underway. This setup is part of a project to demonstrate the feasibility of an experiment to produce the $\bar{H}^+$ ion for a free fall measurement of neutral antihydrogen ($\bar{H}$). Its small size and cost could be of interest for a university laboratory or industry for materials science applications.

1 Motivation In order to produce slow neutral antihydrogen atoms suitable for a free fall measurement, Walz and Hänsch proposed to use the $\bar{H}^+$ ion in order to collect ultra cold atoms [1]. This ion can be cooled down to µK temperatures (i.e. m/s velocities). The excess positron can then be laser detached in order to recover the neutral $\bar{H}$ atom. The temperature achieved in cooling of the $\bar{H}^+$ ion gives the main systematic error. Collecting 1000 events should provide a 2% measurement error on g.

We proposed a way to prepare such ions using interactions of antiprotons with a dense target of positronium (Ps) [2,3]. The charge exchange process $\bar{p} + Ps \rightarrow \bar{H} + e^-$ is followed by $\bar{H} + Ps \rightarrow \bar{H}^+ + e^-$. Taking into account measured and calculated cross-sections [4,5], if 10^7 antiprotons interact with a density of 10^{12} cm^{-3} Ps atoms, 1 $\bar{H}^+$ ion is produced, together with 10^4 $\bar{H}$ atoms. The Ps density may be obtained by sending of the order of 10^{11} slow e^+ onto a converter such as the one we developed [6] in less than a lifetime of the orthopositronium. The following discusses how we intend to achieve such slow positron fluxes.

2 Positron production with an electron linac In [7] we proposed the idea to use a low energy electron accelerator in order to achieve the high positron rates needed. The low energy induces low positron production rates that can be overcome with a high average current. The energy is also below the neutron activation threshold, which may be an important issue when considering the heavy regulations associated with radioactive installations.

We have purchased a small industrial linear accelerator from Linac Technologies [8]. Its nominal kinetic energy and average current are 5.5 MeV and 0.2 mA. The maximum repetition rate is 200 Hz with a bunch length fixed at 4 µs. The magnetron peak power is 1.9 MW. The total power consumption is 35 kVA. The acceleration length is 21 cm after which the beam diameter is 1 mm, increasing to 1 cm at 80 cm from the end of the acceleration section. The overall dimensions are roughly 1 m x 1 m x 0.8 m (Fig. 1).

Simulations, performed with the GEANT3 software [9], predict rates of 5 10^{11} e^+ s^{-1} when the beam hits a 200 µm thick target at 5 degrees incidence angle. 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. The average exit angle with respect to the beam is large, of the order of 50 degrees and even larger for the lowest positron energies.

The average positron energy is 800 keV, with a large spread as the distribution extends from ~ 0 to 3 MeV [10].

3 Electron linac commissioning The RF cavity requires temperature regulation at ± 0.5 degree. A demineralised water cooling system is then added to the setup.

Figure 1 A view of the linac housing. The top part contains the magnetron and circulator, the bottom part holds the RF cavity.

The beam energy distribution has been simulated with the PARMELA software [11], showing that a sharp peak is obtained at the nominal energy of 5.5 MeV with a long tail extending down to very low energies (Fig. 2). More than 90% of the flux is above 5 MeV.

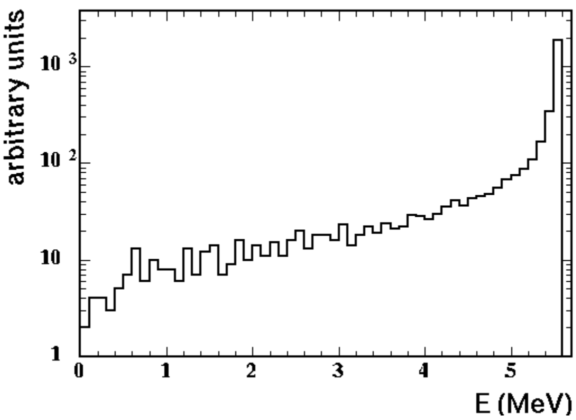

Figure 2 Electron energy distribution from the linac as simulated by the PARMELA software.

An aluminium block shaped as a trapezoid, thus of varying thickness, was placed after the beam exit window downstream the beam line. When moved at uniform velocity in front of the beam, it presents a linearly varying thickness of matter. A sensitive film, placed behind this block receives a dose that depends on the thickness in front of it. After irradiation, the film transparency is analyzed as a function of this thickness of matter, providing an estimate of the beam energy. A maximum energy of 5.53 MeV was measured as expected. The beam spot was also measured with a sensitive film at 80 cm from the end of the RF section. The long axis of its elliptic shape is 1 cm wide also as expected. The intensity was measured with a Faraday cup in air at 200 Hz repetition rate. It was also measured with a thin target (see section 4) in vacuum at various repetition rates. The shape of the current pulse does not vary significantly from pulse to pulse. The average current thus depends only on the repetition rate. An average charge of the order of 50 nC per pulse was deduced from these tests. The average current is around 10 µA when run at 200 Hz. This relatively low current is due to the use of a simple filament as a cathode for these first tests. An impregnated cathode is foreseen for the final commissioning in January 2009, with a 10-fold expected improvement.

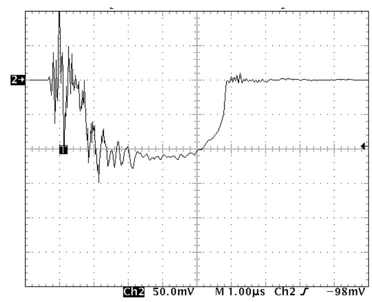

Figure 3 Pulse on the thin target (50 mV/1 µs per division)

4 Fast positron selection If a tungsten moderator of 10^{-4} efficiency is placed after the primary target, a flux of order 10^{7} slow e^{+} s^{-1} is expected.

We have also prepared a set of transport coils and a dipole in order to separate the electrons from the fast positrons. A moderator based on solid Ar, Kr or Ne at cryogenic temperatures can then be placed away from the diffracted electron flux [3,10]. We estimate an efficiency at least 10 times higher after including transport losses due to the large beam size. In order to test this idea, the setup comprising the linac, the coils with their support, and the vacuum chamber has been installed inside an 8 m x 5 m x 3 m concrete shielding against X rays. The temperature regulated water cooling system which is used for the linac is scaled to also cool the coils. Ventilation is installed to evacuate the ozone formed inside the shielding.

We are currently setting up a measurement of the fast positron flux before going on with the slow positron beam line installation.

5 Outlook Such a source may be adapted to the needs of materials science research by transforming the pulse time structure for instance with a trap and additional buncher to obtain sub ns bunches each with few positrons, a variable bunch spacing and a high repetition rate. We also plan to adapt a high field Penning trap to the linac time structure in order to accumulate up to 10^{11} positrons for antihydrogen production [2,3].

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