Development of high intensity source of thermal positrons
APoS (Argonne Positron Source)

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Abstract. We present an update on the positron-facility development at Argonne National Laboratory. We will discuss advantages of using low-energy electron accelerator, present our latest results on slow positron production simulations, and plans for further development of the facility. We have installed a new converter/moderator assembly that is appropriate for our electron energy that allows increasing the yield about an order of magnitude. We have simulated the relative yields of thermalized positrons as a function of incident positron energy on the moderator. We use these data to calculate positron yields that we compare with our experimental data as well as with available literature data. We will discuss the new design of the next generation positron front end utilization of reflection moderator geometry. We also will discuss planned accelerator upgrades and their impact on APosS.

1. Introduction
Positron spectroscopies have huge unrealized potential in many fields of science, including chemistry, physics, materials science, surface science, biological sciences and nanoscience [1-7]. Advances in the use of positrons have been strongly inhibited by the low intensity of the available sources of thermalized positrons. Higher intensity positron beams are required to utilize new techniques such as positron microprobe, positron holography, to carry out gravitation experiments with antimatter and to do chemistry with antimatter [1]. The development of traps to confine positrons at high densities [2, 8], which have the potential to be portable and thus decouple positron production from positron applications also requires an intense source of positrons to allow accumulation of the high number of positrons in a reasonable amount of time. APosS utilizes a 20 MeV linac accelerator for the pair production of positrons from the x-rays formed by the interaction of high-energy electrons with matter. A conventional W moderator is used for positron thermalization. At APosS we have already demonstrated $3 \times 10^7$ e+/sec slow positron flux [10] and are in the process of an upgrade that we expect to give us $3 \times 10^9$ e+/sec.

The upgrade consists of three parts. First, we directly couple the positron target to the linac, second, we will increase the moderation efficiency of the fast positrons using reflection geometry and monocristalline tungsten moderator and third, we will decelerate the positrons for better moderation efficiency. We are also working on an energy and power upgrade of the accelerator that will contribute to increased intensity of the APosS.
2. Present configuration of the positron beam line and proposed changes

Figure 1 shows the present configuration and the new configuration (yellow lines) of APosS. Presently, we are using positron beam line at table 2. A new positron front end will be installed at table 1. A transport line will connect the new converter/moderator chamber to the existing transport system at the table 2. By eliminating windows between the accelerator and the positron converter, we will be able to deliver maximum power (presently 16 kW) to the positron target without overheating the beam windows.

Figure 1. Present and proposed positron beam lines. On the right is the existing positron line. On the left is the new line design to utilize reflection mode of the moderation. An expansion of the new/existing converter/moderator assembly is shown on the sides.

2.1. Increase of moderator efficiency.

The measured moderation efficiency for a tungsten moderator varies from 10^{-5} to 2 \times 10^{-3} [11-13]. The value depends on geometry (transmission or reflection), crystalline structure (polycrystalline or monocrystalline), form (foil, mesh, fins etc) and thermal treatment. While no systematic study of the moderator efficiencies exists, the efficiencies reported by different authors can be summarized as follows: The efficiency of monocrystalline moderators is higher than polycrystalline moderators and reflection geometry is more favorable then transmission. Our recent calculations are consistent with the advantage of reflection geometry [15]. One can expect an increase of moderation efficiency by more than a factor of five if reflection geometry is used rather than transmission [12, 13]. With reflection geometry, it is possible to use a monocrystalline moderator, while a thin foil is needed to produce moderated positrons in transmission and a thin foil is difficult to obtain in monocrystalline form. Also, one can use higher power beams as the moderator in reflection geometry can be cooled.

2.2. Deceleration of the fast positrons for better moderation efficiency.

In [14, 15] we have calculated the relative moderator efficiency of a foil moderator for different energies of a positron impinged on the moderator. For these calculations, we use EGSnrc Monte Carlo code. It was assumed that the moderation efficiency would be proportional to the number of positrons whose energies were reduced below 2 keV closer to the surface than 1 \mu m. The geometry used for calculation shown on figure 2a. (The results are not dependent on the exact geometry chosen, as the relative distribution of the positrons in this system is independent of energy for positron energies greater than 20 keV.) Using this proxy we have calculated both relative reflection moderation efficiency and transmission moderation efficiency, and results are presented on figure 2b. We have compared those efficiencies with ones calculated if the positron energy spectrum is numerically shifted by 100 keV (to simulate electrostatic deceleration of the positrons). The 100 KeV value was
chosen because one can use a short, double-gap, electrostatic decelerator and 100 kV power sources are commercially available.

Figure 2b shows the relative moderation efficiency calculated for original and shifted energy spectrum of positrons. One can expect 2.5 times increase in moderation efficiency for moderator in reflection mode due to deceleration of the positrons by 100 keV and four times for moderator in transmission mode.

Figure 2. a) Geometry of the moderator used for EGSnrc calculations. The thickness of the W foil is 50 μm. 1 μm layer at the surface was used to calculate relative moderation efficiency for reflection and transmission mode of moderation. b) Histogram of moderation efficiency relative to the original energy spectrum of positrons and moderator in transition mode.

2.3. Impact of the accelerator upgrade.
Traditionally, only high-energy electron accelerators were considered useful for efficient positron production, but recently, even low-energy 10-MeV accelerators have been considered for this purpose [17]. Where is the sweet spot for positron production using electron accelerator? To tackle this question we have used the approach similar to one we used for relative efficiency calculations. Results of the calculations were discussed in [18], and are presented on figure 3a.

Figure 3. a) Relative yield of positrons as a function of the incident electron energy. b) Projected accelerator upgrade parameters.

Because the efficiency of the generation process depends on the number of positrons formed for a given amount of electrical energy impinging on the target, we display our results as positrons per electron per energy. As we see, the yield of total positrons increases virtually continuously (closed
squares) while the number of thermalized positrons appears to approach saturation at about 60 MeV both for reflected moderation (filled circles) or transmitted moderation (open circles).

We are in process of upgrading the accelerator-beam energy (projected electron beam energy presented on figure 3b. As one can see we will be at the sweet spot for efficient slow positron production ~40 MeV. The upgrade will also increase the maximum beam power on the target to 30kW. So improvements in accelerator will allow us to increase positron yield by a factor of 4 without any significant modifications to the positron setup.

3. Summary
We have updated the present status of the APosS and outlined planned upgrades of the facility. We have presented the results of the relative-moderator-efficiency calculations for moderators in transmission and reflection mode and have shown the increase of the positron yield from deceleration of the high-energy positrons.

Planned accelerator upgrades will allow us to increase APosS intensity. We are planning to achieve intensity of \(10^9\) e+/s thermalized positron, with 2 cm beam diameter in 5 μs pulses with 300 Hz repetition rate.

The development of the high intensity positron beam line at APosS will allow one to conduct experiments on densities of antimatter that were not considered as even possible. Techniques like positron microprobe, positron holography and Positron Auger Spectroscopy will benefit from availability of intense positron flux. The highest density traps under design \(N \approx 10^{15}\) [9] can be filled in one day with the upgraded APosS.

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