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Cite as: AIP Conference Proceedings **2182**, 040011 (2019); https://doi.org/10.1063/1.5135843
Published Online: 27 December 2019

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A Possible Low-energy Positron Source at Jefferson Lab

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Abstract. Jefferson Lab is interested in the production of positrons for nuclear physics applications but also has the capability of producing low energy positrons that could be used for positron annihilation studies. Using the LERF accelerator at the Thomas Jefferson National Accelerator Facility, it is possible to produce a high brightness source of very low-energy positrons. The accelerator requirements are well within the capabilities of the installed hardware. For these experiments, we only need run at up to 120 MeV. A challenge is the production of the positrons. The gamma converter must be able to absorb the 50 kW of beam power that the linac delivers. At this low an energy, the converter, though challenging, is feasible. The transport of the low energy positrons from the production target to the next stage, where the energy is reduced even further, must have a very large acceptance to be able to efficiently transport the flux of positrons from the positron production target to the moderator. We propose to accomplish such a transport by means of a guiding solenoidal field with a novel endcap design. Finally, it is in principle possible to produce a spin polarized beam by filtering the positrons at low energy. The layout of the proposed device will be described in this presentation.

INTRODUCTION

As has been pointed out in many presentations in this conference, positron annihilation is a unique probe of materials and surfaces that allow measurements of surface properties not possible with other probes such as electrons or X-rays. Though nuclear decay sources are available for positron annihilation studies, accelerator sources provide higher fluxes and much higher brightness[1]. Spin polarized source can provide even more capability and an accelerator source can produce spin polarized positrons either via production by spin polarized electrons[2] or perhaps via a spin polarized hydrogen converter[3].

THE LOW ENERGY RECIRCULATION FACILITY

The Low Energy Recirculation Facility at Jefferson Lab was originally constructed to study free-electron laser (FEL) systems and was successful in demonstrating record recirculated beam power in an energy recovery linac (ERL) and record power from a free-electron laser[4]. The accelerator system, shown in figure 1, is housed in a heavily shielded underground vault. It consists of a DC photocathode gun providing 350 keV beams to a superconducting booster accelerator that can accelerate up to 9 MeV. This beam is then injected into an energy recovering accelerator system consisting of three superconducting accelerator modules (cryomodules) and two recirculation loops that bring the beam through an FEL and then back to the accelerator for energy recovery. In this energy recovery mode, the ERL has demonstrated up to 1.3 MW of circulating electron beam power. This is far higher than the 192 kW of the installed klystron power. The accelerator is also capable of operating in a non-recirculated mode in which the beam is dumped at high energy. In this case the electron beam power is limited by the klystron power to less than 192 kW and is typically limited by the target and dump to much less than that.

Currently the facility has been modified to carry out cryomodule testing for the LCLS II laser project. This involved removing two of the cryomodules. This reduces the maximum energy and beam power available for positron

The 18th International Conference on Positron Annihilation (ICPA-18)
AIP Conf. Proc. 2182, 040011-1–040011-5; https://doi.org/10.1063/1.5135843
Published by AIP Publishing. 978-0-7354-1929-2/$30.00

production to 45 MeV and 50 kW respectively. Once the cryo-module testing is complete two more modules may be added to bring the maximum energy and power up to >120 MeV and >120 kW. The facility is also being used for isotope production and the generation of positrons is synergistic with that activity.

It is possible to use the electron beam generated by the superconducting linear accelerator of the LERF to generate a beam of positrons with a high flux. A reasonable goal is a flux of 10^{10} positron/sec delivered to a laboratory on the floor above the FEL vault. To produce this flux, one must consider the following: generation and transport of the positron beam, optimization of the positron cooling, radiation shielding, and management of the design, installation and operation of the facility.

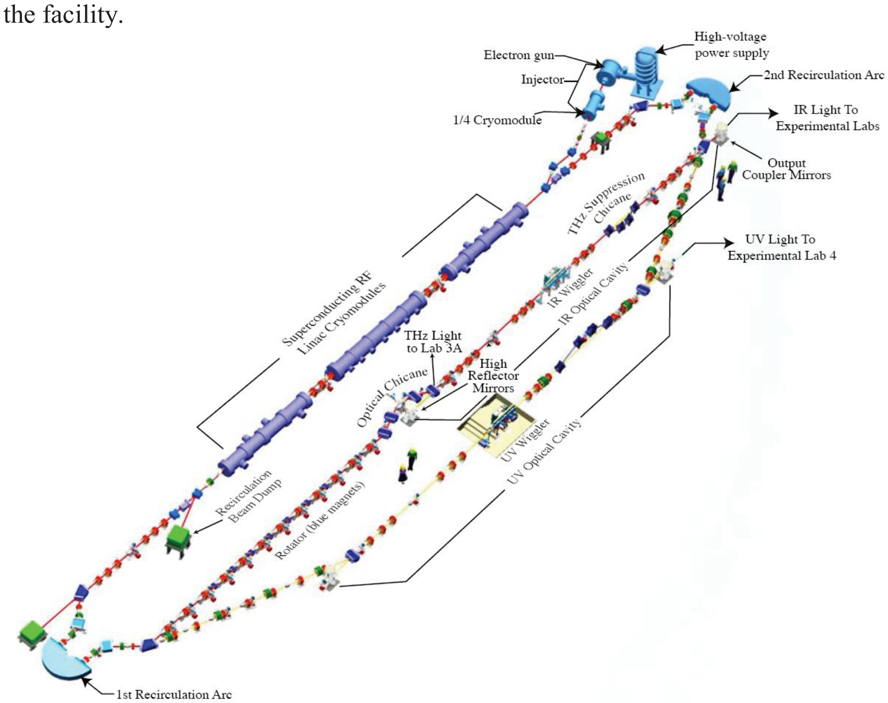

FIGURE 1. Layout of the accelerator at the LERF with two FEL beamlines.
A target for positron production would be just after the first arc

PROPOSED POSITRON GENERATION AND TRANSPORT

As noted in the last section, the LERF linac in fixed-target mode can provide an electron beam at ~120 MeV and up to 1 milliampere of beam current. The electron beam from the LERF linac is very bright and the time structure is quite flexible, allowing either pulsed or CW electron beams. Pulsed operation allows one to use time-of-flight techniques in experiments.

The power available to be deposited into the target by the electron beam to produce sufficient positron intensity is very high, 10's of kW. This can be deposited into a very small volume, but the heat from this must be removed promptly to prevent damage to the target. One must mitigate the power density by rotating a solid target and by rastering the incoming electron beam.

Target design

The target design is described in much more detail in another publication[6]. We found that the positron production for positions with an energy below 600 keV was optimized for a beam energy of 120 MeV and a tungsten target thickness of 6 mm. We would use a 1 mA beam, providing a beam power of 120 kW. The target will be rotated and the electron beam will be rastered to keep the target from melting. A compensation raster will be used to maintain the positron brightness.

Positron Transport

To transport the generated positrons from the target to an experiment we would use a novel high-efficiency Rare Gas Moderator (RGM), such as solid-Neon[5], which is a different moderator type than the ones used in existing linac- and reactor-based facilities. It is experimentally verified that the efficiency of the solid-Neon moderator is more than a factor of 10 higher than the Tungsten moderator (commonly used in existing facilities) with positrons emitted from ^{22}Na. The difference between efficiencies occurs due to the fact that positron diffusion length inside the RGMs is much longer than it is inside metallic moderators.

Using the positron kinetic energy spectrum of the ^{22}Na as a baseline, this design will transport positron with kinetic energy below 600 keV from the converter. It is important to note that cryogenic nature of the RGM mandates that RGM must be positioned away from the high temperature and radiation area around the converter.

Positron capture and the transport line to the moderator

The integrated positron beamline layout is shown in Fig. 2. A driving electron beam from a linac hits the converter target thus producing positrons. We then capture low-energy positrons (T+ below 600 keV) and transport them to the moderator. In the moderator, the positrons lose energy and then a fraction of them are able to escape to the surface as slow positrons with T+ on the order of a few eV. For the transportation of positrons to the moderator we designed an arc-shaped solenoid capture and transport channel. The purpose of this curved transport channel is to transport positrons away from the high radiation area near the converter. The high-energy photons, electrons and positrons are much more collimated than low-energy particles and they will hit the beam dump along a straight path. Corrector dipole magnets are superposed on the channel to allow the positrons to follow the curve.

The extraction of the positrons from the channel to a very low magnetic field area will be achieved by a magnetic field terminator ("plug"). The extraction efficiency from the solenoid channel is enhanced with rapid extinction of the guide field. Otherwise, the lowest energy, and most desirable positron, will follow the diverging field lines into material surfaces and be lost. A simpler version of the magnetic plug has been fabricated and tested and demonstrated a thousand-fold reduction in the fields outside the plug. Further reduction of the field to the mG levels can be achieved with metal shielding.

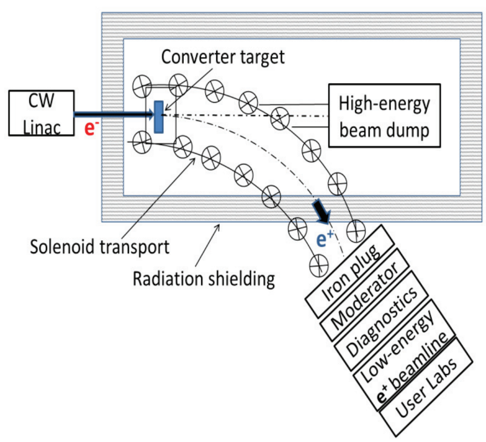

FIGURE 2. Conceptual layout of the positron beamline. Drawing is not to scale.

Transport calculations of positrons were performed with GEANT4-based software. A snapshot from the simulation is shown in figure 3. In this snapshot, we only present the solenoid transport channel, the plug, and the positrons that are able to penetrate through the plug. For the purpose of presenting a clear picture, other particles are eliminated.

Approximately 25% of the positrons that have reached to the iron plug from the tungsten converter are lost while traversing the plug. The kinetic energy spectrum of the positrons that are able to reach to the moderator is shown in Fig. 6b. The positron efficiency on the moderator is calculated to be 6.6×10^{-4} positron/incident electron. With the assumption of 1 mA incident electron beam current, the intensity on the moderator would be about 4×10^{12} positron/s within a transverse spot size of x,y ~ 8 mm *rms* as seen in Fig. 6a. By using 1% efficiency with solid neon RGM, the projected slow positron intensity would be 4×10^{10} slow positrons/sec.

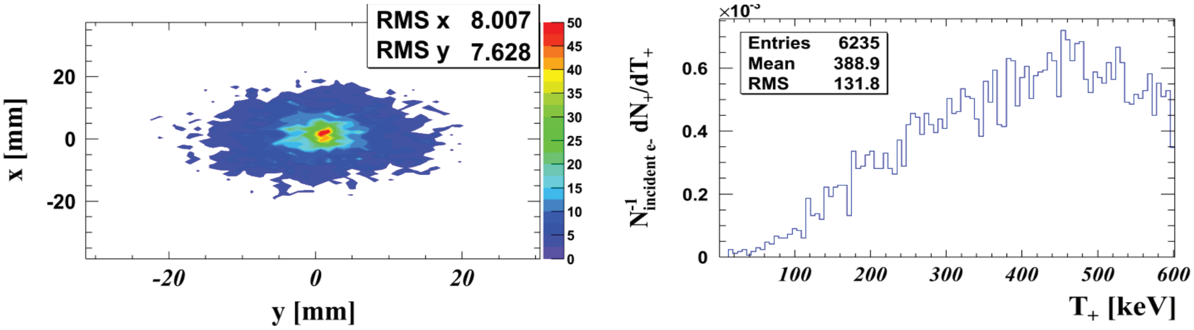

FIGURE 3. (a) The transverse spot profile of the positron beam on the moderator. Here we present positrons with energies below 600 keV. (b) Kinetic energy of the positrons after the iron plug. Positrons shown here have a cut in energy with T+ < 600 keV.

Focusing and Remoderation of Slow Positrons

Moderated slow-positrons will be extracted from the moderator by the electrostatic focusing elements. Electrostatic focusing is dominant for low speed particles in a low magnetic field environment.

It is known that the energy spread of the emitted slow positron from RGMs is higher than W moderators, thus this will result in lower beam brightness. This low brightness can be offset by higher intensity and through further re-moderation in a very thin W foil a process known as brightness-enhancement[7]. The brightness-enhancement will be done as illustrated previously in Figure 2. Although, after the re-moderation process only 5% of the positrons survive, the brightness of the beam will be increased significantly by at least 3 orders of magnitude due to the reduction in the transverse size and energy spread. As it is shown[8], a slow positron micro-beam can be produced with a transverse size of less than 100 μm on a sample.

Since the solenoid captures both positrons and electrons from the converter, the number of electrons that are able to reach to the moderator is a factor of 10 higher than the number of positrons. There is also a small portion with positron and e- energies up to 2.5 MeV that make it to the moderator. The total power of the particles that reach the moderator is about 20 W (when incident e- beam is 120 kW). Simulations with 500 μm thick solid-Neon show that about 10% (~ 2 W) of this power will be deposited in the moderator. With adequate cooling in the moderator, this power can easily be extracted from the system. If the temperature increase in the moderator cannot be prevented due to these electrons, we will implement a small dipole magnet to divert low-energy electrons away from the moderator.

CONCLUSIONS

The Low Energy Recirculation Facility at Jefferson Lab can provide a bright, high power beam for the production of low energy positrons. By using a combination of a rare-gas cryogenic moderator and tungsten final moderator we can provide over 10^{10} positrons/sec. at low energy and can moderate them to 10^7 positrons/sec. with a very small spot size. We should note that polarized positrons are also possible if a polarized hydrogen target is used to eliminate one spin orientation, though the flux would be reduced by a large factor.

ACKNOWLEDGMENTS

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177.

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