BREMSSTRAHLUNG PAIR-PRODUCTION OF POSITRONS WITH LOW NEUTRON BACKGROUND*

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Abstract

Minimization of component activation is highly desirable at accelerator-based positron sources. Electrons in the 8- to 14-MeV energy range impinging on a target produce photons energetic enough to create electron-positron pairs; however, few of the photons are energetic enough to produce photoneutrons. Slow positron production by low-energy electrons impinging on a multilayer tungsten target with and without electromagnetic extraction between the layers was studied by simulation. The neutron background from 14-MeV electrons is expected to be significantly lower than that encountered with higher-energy electron beams. Numerical results are presented and some ideas for a low-activation slow-positron source are discussed.

1 INTRODUCTION

Slow positrons are widely used in materials science and solid state physics research. Positron annihilation techniques are used to characterize vacancy-type defects in metals and alloys. Very low energy positrons are ideal probes for surface crystallography due to their shallow penetration and weak scattering with the atomic ion core.

The use of the Advanced Photon Source (APS) linac beam as a source of slow positrons has been investigated for incident electron beam energies between 200 and 400 MeV [1], [2]. Accelerator studies indicate that the electron linac is capable of producing about 13kW of incident beam power [3]. Simulation studies to optimize the target indicate that for those incident-electron energies, a high slow-positron yield can be obtained.

Activation of components in the area near the target is a potentially serious problem at positron sources. Component activation can be reduced if the input beam energy is low enough such that the cross section for photoneutron production is still quite low, yet high enough to create electron-positron pairs. In this paper, we study the production of slow positrons using electrons with energies between 8 and 14 MeV.

Monte Carlo simulation results of low-energy electrons impinging on a multilayer tungsten target are described. Positron production rates with and without electromagnetic extraction between target layers are compared. Some ideas for a low-background positron source are discussed.

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2 CHOICE OF ELECTRON BEAM ENERGY

Several factors influence the choice of the incident electron beam energy for a slow-positron source with minimal neutrons. One factor is the efficiency with which the incident beam creates positrons, the other is the neutron yield. For high productivity, most of the incident electron beam should penetrate the target. The number of backscattered electrons increases exponentially with decreasing electron energy, as can be seen in Fig. 1. As shown in the figure, there is essentially no backscattering for energies above

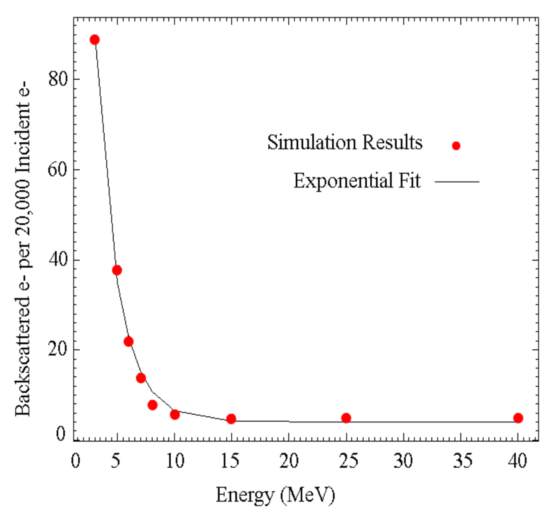

Figure 1: Number of backscattered electrons versus incident beam energy with a superimposed exponential fit.

8 MeV. At 3 MeV, about 0.5% of the incoming particles are backscattered, thus reducing overall efficiency. In our simulations, we chose an energy range between 8 and 14 MeV for the primary electron beam.

The neutron yield per incident electron in a high-Z target is low for energies below 14 MeV. The photoneutron cross-section for tungsten is about 400 mb for 14-MeV photons and becomes negligible for photons of 6-MeV energy and lower [4]. For one radiation-length-thick targets, measurements indicate that there are 2.5×10^{-4} neutrons per 14-MeV electron [5]. Shown in Fig. 2 is the photon energy distribution from 20000 14-MeV electrons impinging on a 1.2-mm tungsten target. An energy cutoff of 1.0 MeV has been applied to the distribution prior to histogramming. Photons below 1.0 MeV are incapable of e^+e^- pair production. The distribution peaks at 1.5 MeV and has a standard deviation of 2.4 MeV. Less than 9×10^{-2} photons per electron have energies greater than 6 MeV.

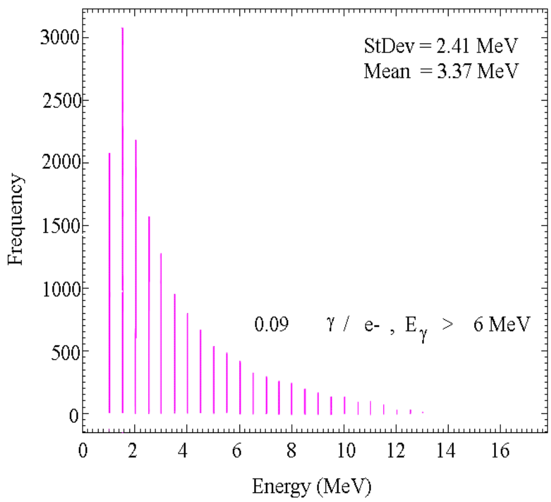

Figure 2: Photon energy distribution from 14-MeV electrons on a 1.2-mm tungsten target.

3 SIMULATION RESULTS

Our simulations were performed with the program EGS4 [6], together with a C-language user-interface code, "shower" [7]. We studied the positron-production efficiencies of single-block and multilayer targets at several energies. Optimized multilayer targets are able to produce more positrons than single-block targets for a fixed incoming beam energy. For multilayer targets, we examined the production rates with and without electromagnetic extraction between target layers.

The forward positron production as a function of single-block tungsten target thickness is shown in Fig. 3 for 8-MeV and 14-MeV electrons. For the higher-energy beam, the production peaks around target thicknesses of 2.5 mm. The production from the 8-MeV beam roughly follows a similar curve. The variations seen in the figure are within the statistical fluctuations of the Monte Carlo process. The number of positrons increases by a factor of 4.5 for a 1.75 increase in beam energy. For target thicknesses greater then 2.5 mm, many positrons are lost in the material decreasing the yield.

Figure 4 shows the forward positron production for a three-layer tungsten target of 1.2-, 0.6-, and 0.6-mm-long segments, respectively. The incident electron beam energy is 14 MeV.

In the figure, circles indicate the number of positrons produced when no electromagnetic field is applied between layers, and squares indicate the production when electromagnetic extraction is applied. In the latter simulations, the total output lepton distribution from each segment was removed and only the photon distribution was used as input to the simulation of the following segment. This possibly leads to an underestimation of the positron count after the second and third layers. In practice, energetic electrons would not be removed by the applied field, though the total beam divergence would be increased, and they could contribute to the positron creation through bremsstrahlung. As shown in the figure, photons produce 68% of the total positron count in the second segment, and 89% in the third segment.

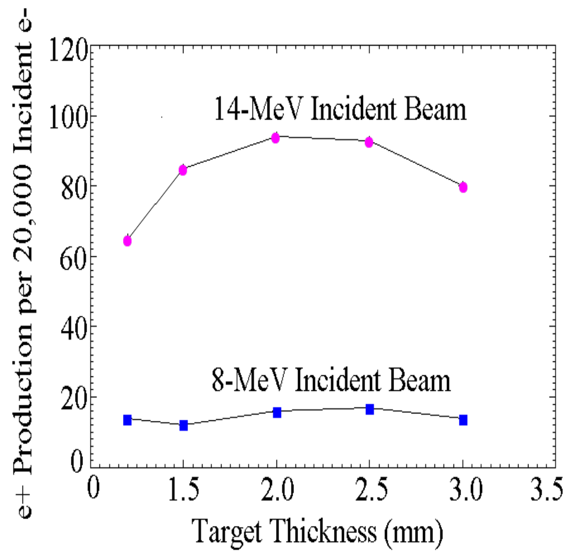

Figure 3: Positron production as a function of target thickness for two electron energies.

We used our high-energy simulation results as a guide to optimize the multilayer target for a 14-MeV incident beam. Specifically, we analyzed the positron production as a function of target thickness and the output electron and photon mean energy variations to determine the optimal segment thicknesses of a multilayer target. At 400 MeV, the best target configuration is a 10.5-mm-long, five-layer target. The 10.5-mm length is determined by the optimized single-block target length.

The highest production differentials between layers occur when there is a 25% variation in thickness from the first to the second layer and none or a small variation in thickness between the last two layers. The output electron mean-energy change from layer to layer is also a factor. Yield is best when the energy decreases by about 50% in the first two layers, and by 30% to 10% in the last layers. These observations, together with the single-block target results at low energies, led to a three-layer target with segment thicknesses of 1.2, 0.9 and 0.9 mm, respectively, as a candidate for an optimized low-energy target. Further simulations showed that the positron production is increased by 26% when the last-segment is 0.6-mm long. For the optimized 1.2-/0.9-/0.6-mm target, the total number of positrons whose energies are ≤ 6 MeV is $1.3e \times 10^{-2}$ per incoming 14-MeV electron.

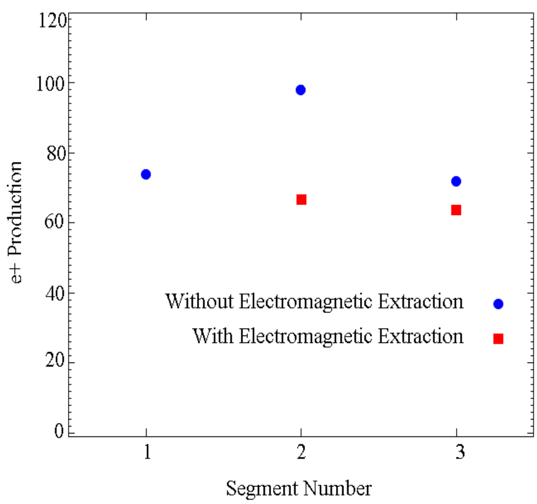

Figure 4: Comparison of the number of positrons produced by 14-MeV electrons on a three-layer target, with and without electromagnetic extraction between layers.

4 OPTIONS FOR A LOW-ENERGY POSITRON SOURCE AT APS

The linac's DC thermionic electron gun has been supplemented by a thermionic rf gun [8], and additional thermionic and low-emittance photocathode rf guns will soon be installed. These guns will be able to handle the task of storage ring injection, thus allowing the DC thermionic gun to be used for other purposes.

The DC gun is currently being re-packaged for greater space efficiency. The gun, together with its buncher and accelerating structure, could be located in the linac tunnel under the rf photocathode gun girder. Assuming good beam optics, at least 13 kW of beam power could still be obtained at 150 MeV. If used to produce a low-energy, high-power beam, the gun and its associated rf structures could operate semi-independently of the APS. The bunchers and accelerating structure could receive rf power from the output load of one of the linac accelerating structures. We estimate that the linac could produce a few kW of beam power in low-energy mode. Available beam power in such a low-energy machine could be significantly increased by changing from pulsed to CW operation, and using superconducting rf structures.

5 CONCLUSIONS

A slow-positron source with reasonable slow-positron yield and with a relatively low neutron background could be constructed. For an incident 14-MeV electron beam, we estimate that a flux of 10×10^7 positrons per second can be achieved, assuming a conservative moderation efficiency of 10×10^{-3}.

Plans are now underway to measure the positron and slow positron yields at another local facility with beam characteristics similar to what we have considered in this paper. Use of low-energy electrons to drive a slow positron source has the advantage that it could be a semi-independent setup. Various configurations for such a source have been investigated. Some options allow operation of the slow positron source in parallel with other APS operations, while operation of other configurations is more constrained.

An additional advantage of the low-energy driver is that extraction and guide voltages for the unmoderated positrons can be lower, since they are produced at lower energies. The disadvantages are lower positron production rates per incident electron. The beam power and thus the positron production rate can be improved by increasing the electron current. At high power and low energy, target ablation will likely be a problem. Detailed thermal analysis must be carried out, and careful monitoring of the target and support structures must be envisioned.

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