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A New Target Concept for Production of Slow Positrons *

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Abstract

Slow positrons in the energy range up to a few keV are useful for material sciences and surface studies. The Advanced Photon Source (APS) linear accelerator (linac) was designed to produce 8-mA of 450-MeV positrons. A 200-MeV, 1.7-Ampere electron beam impinges on a 7-mm-thick (2 radiation lengths) tungsten target, resulting in bremsstrahlung pair production of electrons and positrons. The existing target was optimized for high energy positron production, and most slow positrons produced by the electron-gamma shower remain trapped inside. The linac could also be used to produce slow positrons, and a modified target could increase the low energy positron yield. Use of a multilayer or segmented target reduces self-absorption by the target, and thus more fully utilizes the incident beam power for slow positron production. A slow positron yield of 10^9/sec is expected from the existing incident electron beam. Multilayer targets could probably be used by other accelerator-based slow positron sources to improve slow positron yield without increasing the incident beam power. Two variations of a multilayer target concept are presented and discussed in this paper.

I. Introduction

High energy and low energy (slow) positrons are generally produced using the same type of target [1, 2, 3, 4]. High energy electrons impinge on a single block of heavy metal such as tungsten or tantalum which is two to three radiation lengths thick. If high energy positrons are desired, a pulsed solenoid is placed just downstream of the target to capture positrons of the desired energy. If slow positrons are desired, an annealed tungsten vane system is used as a moderator to thermalize the positrons. The slow positrons are then extracted from the moderator, reaccelerated to a certain energy, time modulated, and transported to the user's location.

Positron production yield is proportional to the beam power absorbed by the target, but the incident high energy electron beam loses only part of its energy in passing through a target of 2 or 3 radiation lengths. Increasing the target thickness would absorb more of the incident beam power, but would increase the number of positrons trapped inside the target. A 200-MeV electron beam passing through a 2-radiation-length-thick target still exits the target at about 80 MeV, and can still be used to produce more positrons. We feel it is possible to use a multilayer target instead of a single thick block target to improve slow positron production. Segmentation of the target effectively increases the absorbed incident beam power and reduces positron reabsorption. Simulation results using the electromagnetic shower program EGS4 [5, 6, 7] indicate that slow positron yields can be increased one order of magnitude without increasing the incident beam power if a segmented target is used in place of a solid block. Positrons produced in each zone of a multilayer target must still be moderated and collected, which is beyond the scope of this paper.

II. Single Block Target

EGS4 [5, 6, 7] was used to simulate electron-positron pair production from a single block tungsten target. The incident beam energy was fixed at 200 MeV, and the target thickness was varied from 1 to 5 radiation lengths (3.5, 7.0, 10.5, 14.0, and 17.5 mm). Figure 1 shows the total positron yield as a function of energy for different target thicknesses. The maximum yield for a single block target occurs at 2 radiation lengths. The yield of 8-MeV positrons is higher with a 10.5-mm-thick target; however, the transverse positron distribution after the target is also a function of target thickness, increasing from 1 mm at 1 radiation length to 6 mm at 5 radiation lengths as shown in Figure 2. The diameter of the positron distribution from a 10.5-mm target is almost a factor of 2 larger than for a 7-mm target. Fast positrons are captured by a pulsed solenoidal coil just downstream of the target, and since its axial field decreases rapidly away from the axis, the capture efficiency for fast positrons decreases with increasing spot size. We have used the 2-radiation-length target as the optimum thickness for fast positron production at 200 MeV [3, 4], and we compare multilayer target results to it.

III. Multilayer Target

The transverse distribution of the positrons may not be as stringent a factor in slow positron production as in high energy positron production. A multilayer or segmented target will be more efficient for slow positron production, since we can more fully utilize the incident beam power. Use of multiple thin layers will also reduce positron reabsorption by the target. Two multilayer target concepts have been simulated to date. The target material was tungsten in both simulations, and the incident beam energy was fixed at 200 MeV. The shower output from the first target layer becomes the incident beam for the second target layer, and so on.

A. Five-Layer Target

We first simulated a five-layer target. Each tungsten layer was 3.5 mm thick, and layers were separated by 6.5 mm of vacuum. The total length of the target was

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5 cm. The exiting electron beam energy was less than 20 MeV after passing through the 5th target layer, and was not useful for further positron production.

Figure 3 shows positron yields in each zone of the five-layer target as a function of energy, and Figure 4 shows the transverse distribution of positrons in the five-layer target. The transverse distribution is larger in the multilayer case because of the effective difference in incident beam energy. The total number of positrons in each zone is compared to that from the single block target for the same target thickness, as shown in Figure 5. The positron yield in each zone is a little higher than the single block target case except in zone 1. The positron energy range is printed in the figure. Positron energy spectra for the five-layer target are quite similar to those of the single block target. The total positron yield in the five-layer case is about 4.6 times more than the highest yield in the single target case.

B. Nine-Layer Target

A nine-layer target was also simulated. The tungsten thickness of each layer was 2 mm, and layers were separated by 3 mm of vacuum. The total target length was 4.5 cm. The simulation results indicate that the nine-layer target is better than the five-layer target, as shown in Fig. 5 and 6. The total positron yields are maximum in zone 3, which corresponds to a 6-mm target thickness. Low energy positron rates peak in zones 4 and 5. This is in the same range of target thickness as for the five-layer target, but is higher than the single block target. The total yield of forward positrons in the nine-layer target is 8.2 times more than the highest single block target yield.

C. Contribution from Backscattering

The positron yield resulting from backscattering off of the next target layer must also be taken into account in a multilayer target. The transverse distribution of backscattered positrons in the five-layer target is shown in Figure 7, and is not significantly different from the distribution of forward positrons in the same region. The number of slow positrons produced by backscattering is quite small, equivalent to 3%, 10%, 12%, and 10% of the forward positron yield from the 2nd, 3rd, 4th, and 5th target layers. The average ratio is about 8.7%. The backscattered positron energy is much less than the forward positron energy and is usually less than 10 MeV for both the five-layer and nine-layer targets.

When the contribution from backscattered positrons is included, the total positron yield for a five-layer target will be five times more than for a single target. The backscattering contribution in the nine-layer target varies from about 4% of the forward contribution in the second layer to a maximum of 12.4% in the 8th layer. The average ratio of backscattered positrons to forward ones is about 9%. After adding the contribution of backscattered positrons, the total positron yield in the nine-layer target is about one order of magnitude higher than for the single block target.

IV. Conclusion

A multilayer target may increase the total slow positron yield up to one order of magnitude over the yield from a standard single block target with no increase in the incident beam power. This is accomplished by increasing the absorbed incident beam power and reducing positron absorption by the target. The energy spectrum of forward positrons in the multilayer case is not dramatically different from the spectrum in a single block target, and the transverse distribution of positrons is only a little larger than for a single block target. Backscattered positrons contribute about 9% to the total positron yield. Moderation and collection of these positrons is still required, and details of how that is done must be taken into consideration prior to designing an actual target.

V. Acknowledgement

We would like to acknowledge Dr. L. Emery for discussions and for his assistance in this work.

VI. References

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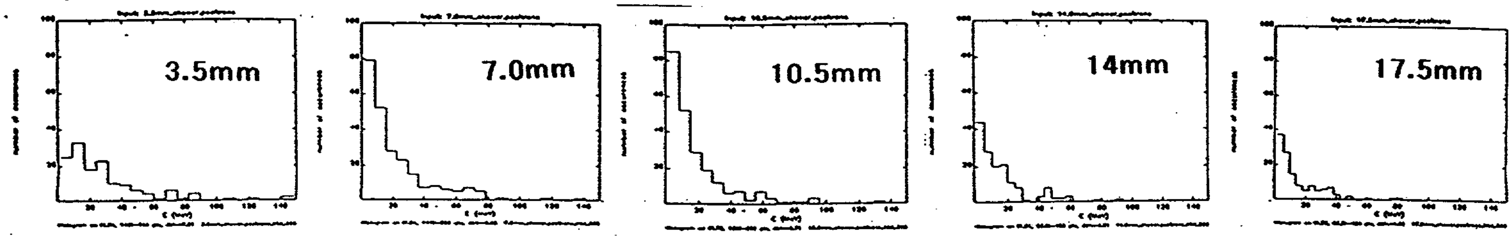

Fig. 1. Single block total positron yields.

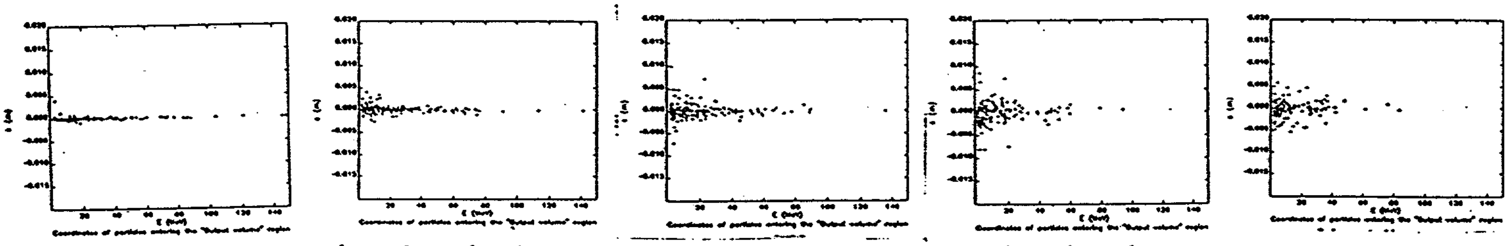
Fig. 2. Single block transverse positron distributions.

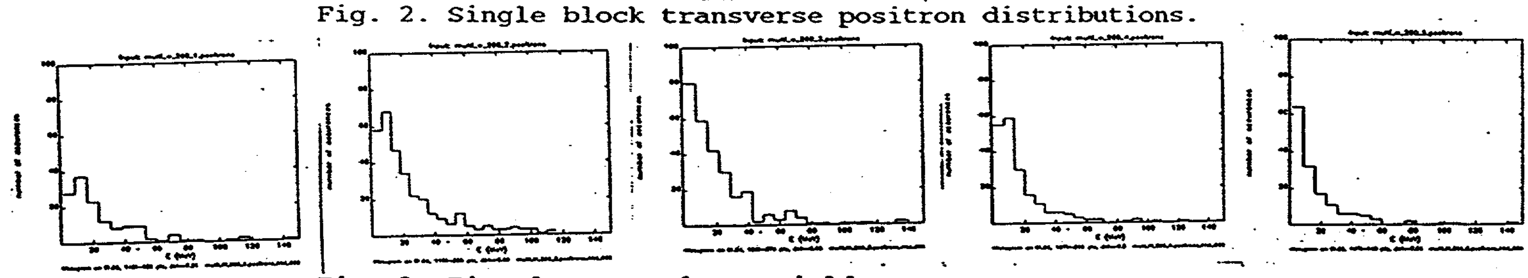
Fig. 3. Five-layer positron yield per zone.

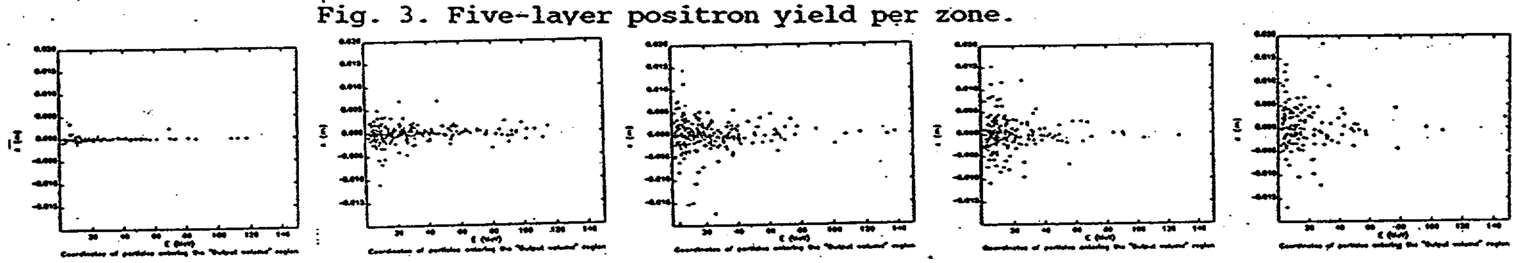
Fig. 4. Five-layer transverse positron distributions.

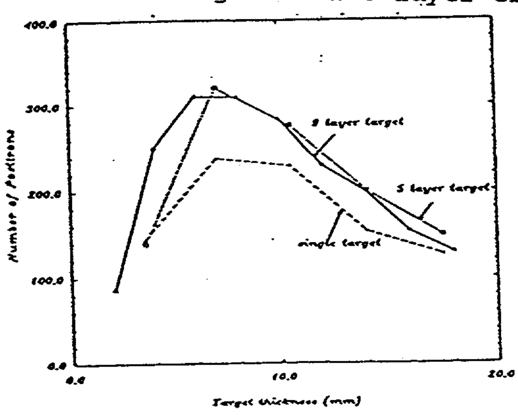

Fig. 5. Comparison of multilayer total positron yields to single block yields

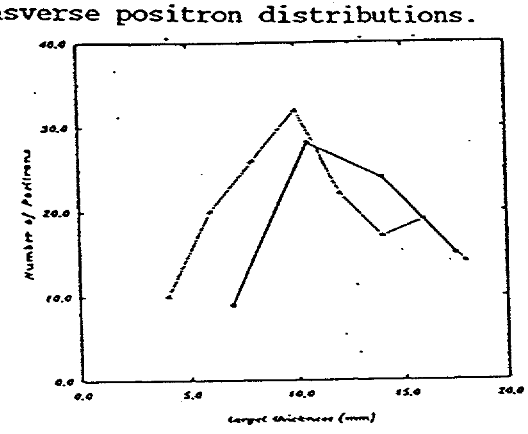

Fig. 6. Comparison of backscattering positron yield in multilayer cases.

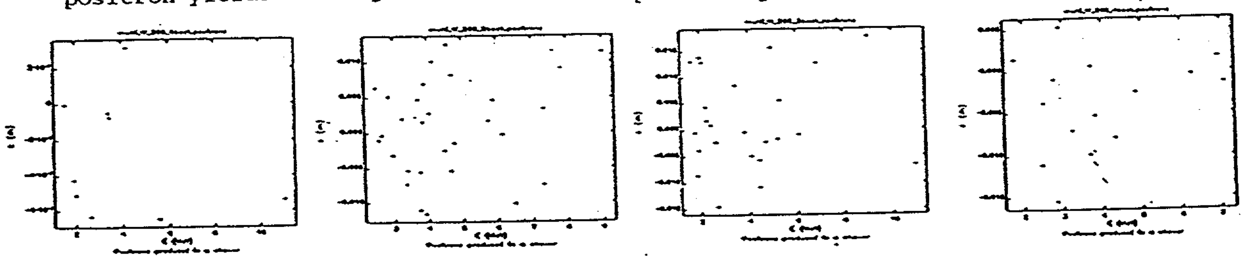
Fig. 7. Five-layer backscattering - transverse distribution.