A COOLED GENERALIZED MULTIPLE TARGET SYSTEM TO CREATE POSITRONS FOR A COMPACT TUNABLE INTENSE GAMMA RAY SOURCE*

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Abstract

A compact tunable gamma ray source has many potential uses in medical and industrial applications. One novel scheme to produce an intense beam of gammas relies on the ability to create a high flux of forward directional positrons, which are produced by an electron beam on a high Z target. Presented is an innovative system which allows for a nearly arbitrary targeting geometry that supports multiple targets, whose optimal design is driven by the physics of the positron production processes, while naturally supporting cooling of the targets.

INTRODUCTION

The overall schematic for the strategy reported earlier [1] to produce a compact tunable intense beam of gammas is shown in Figure 1. It consists of an electron beam impinging on a high-Z (W) target to pair produce positrons and electrons. This target is followed by a dipole to create dispersion for the desired positrons (wrong signed particles are bent the other way, while neutrals continue straight ahead), and a wedge of low Z material to take advantage of the dispersion in order to mono-chromatize the beam of positrons. This beam of quasi-mono-chromatic positrons are then bent by a second dipole to separate the neutral and wrong signed particles created in the wedge from the desired positrons and direct the positrons onto a low Z target to annihilate with electrons, thus producing a mono-energetic beam of gammas. In this paper, the simple single target setup in [1] is replaced with an advanced new multiple target system that allows for a nearly arbitrary geometry whose optimal design is driven by the physics of the positron production processes, while naturally supporting cooling of the targets.

KEY CONCEPTS FOR ENHANCEMENTS

The scheme to generalize the target geometry and realize enhanced performance is driven by delivery of the electrons in a pulsed beam and a spinning target housing structure that is in synch with the pulsed beam. Figure 2 illustrates the layout where a preliminary study is presented below to arrive at an optimal configuration that is driven by the physics of positron production by electrons on a high Z target. After a preliminary optimal configuration is derived, an example rotating structure illustrated. All simulations were generated in g4beamline [2].

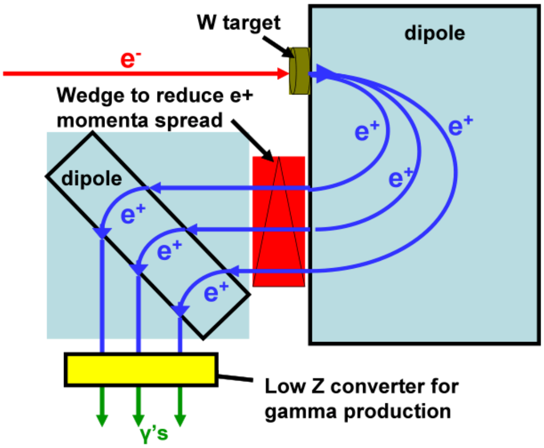

Figure 1: Layout in an earlier study [1] for production of a beam of intense mono-energetic gammas. This paper advances the W target configuration.

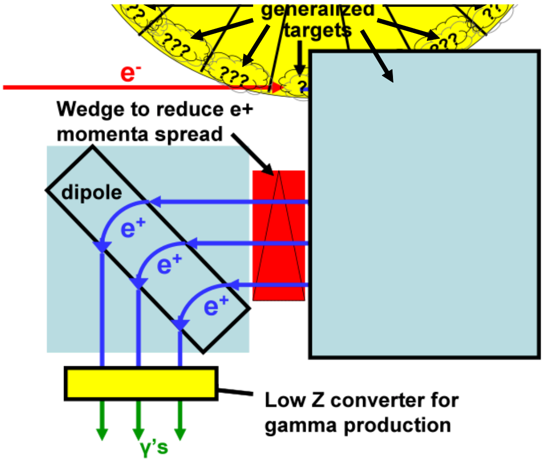

Figure 2: Layout of study reported here that has a spinning target housing to support generalized target geometry and cooling. The repeated generalized target configuration is indicated by the question marks in the clouds.

The study for the optimized multiple target system started with the optimized single target for the 100 MeV electron beam [1], ignoring the increase in the neutron background. Figure 3 shows the transverse positions and polar angles of electrons, positions, and gammas exiting the backside of the optimized 5 mm thick W target placed at the entrance of a dipole with B = 0.667 T. It is readily

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apparent that the gammas are much more forward travelling than the electrons and positrons, inviting a target configuration to be designed to take advantage of this.

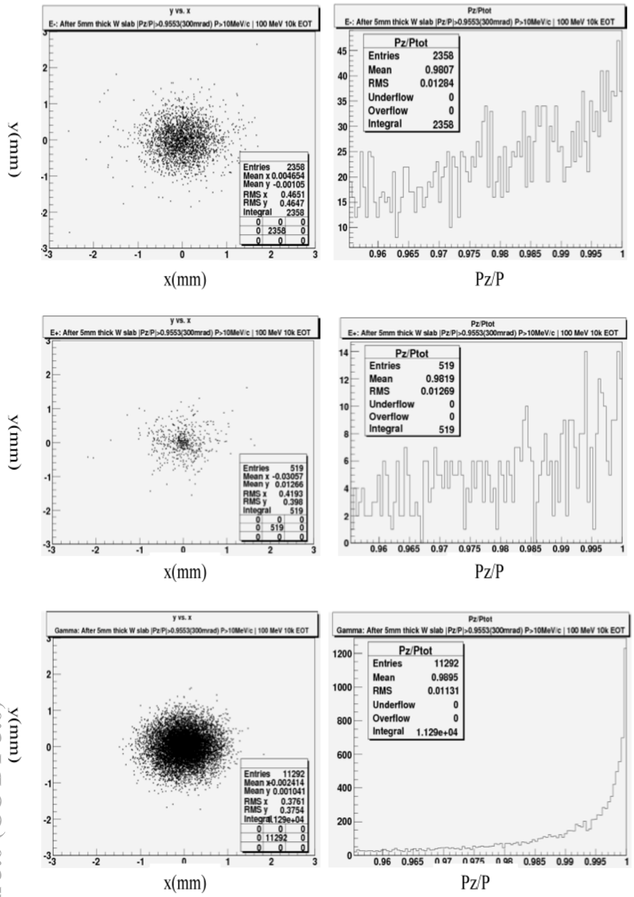

Figure 3: Transverse position and directions of electrons (top), positrons (middle), and gammas (bottom) exiting a 5 mm thick W target hit by 100 MeV electrons. The distributions were produced from 10,000 electrons on the W target and have the following cuts applied to the appropriate particle: |Pz/P| > 0.9553 (300 mrad) and P > 10 MeV/c.

Driven by the results in Figure 3, the strategy to increase the production of useful positrons is to place a second W target of radius 1 mm (or similar size) behind the primary target so that the gammas will interact with it and produce more positrons. This second target needs to be at a distance far enough from the primary target to allow the good positrons already produced in the first target to spread out due to the larger transverse directions (compared to gammas) as well as the bend in the dipole field of 0.6667 T and miss the second target to minimize their loss. But, this second target also needs to be close enough to the focal point, which is the dipole entrance and hence closer to the first target. Figure 4 shows fractions of good positrons that would be potentially lost in a circular second target (radius of 1mm) as a function of the location of its front face. Good positrons are defined to be those that are produced in the first W target, sweep through the dipole, and traverse the wedge with resultant 8 < P < 12 MeV/c and Pz/P < 0.9553 (300 mrad). Figure 4 also shows the rate of gammas that are potentially useful in creating positrons as a function of the location of the front face of the second target.

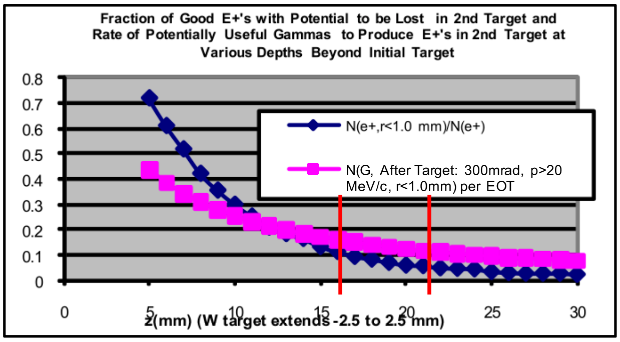

Figure 4: Fraction of good positrons and rate of potentially useful gammas from the 5 mm thick W target that traverse a circular aperture of radius 1 mm at various longitudinal locations. Good positrons are those that have 8 < P < 12 MeV/c and Pz/P < 0.9553 (300 mrad) after the wedge.

Guided by the expected loss of good positrons and enhanced production from gammas, a preliminary investigation was made of the second target at two depths: 1) 17 mm where we expect a loss of 10% of initial good positrons and 2) 22 mm where we expect a loss of 5%. Additionally, the study was expanded to observe possible increase in positron production by using electrons that exit the primary target with reduced momenta to be subjected to an extension of the secondary target that is in the mid-plane path. In particular, the secondary target extended into the mid-plane parallel to the face of the dipole. (An extension radially inward would likely be pursued in future studies.) Thus, the study involved secondary targets of two basic shapes:

1. A disk with radius 1 mm and varying thickness.
2. A wide solid box (referred to as "wide box") with height (parallel to dipole field) 2 mm, varying length (parallel to initial electron direction), and width arbitrarily large to intercept electrons in the mid-plane of any momentum. The edge of the wide box furthest away from the rotating structure's center is displaced 1 mm away from that structure, so that the transverse extent is in common with a disk with radius 1 mm placed on the axis of the initial electrons.

We also studied a second target of square cross-section in the z=17 mm case, referred to here as a "box," which presents a transverse face of 2 mm x 2 mm and does not extend into the mid-plane. Hence, the difference between the wide box and box is due to the interaction of the degraded electrons with the extended mid-plane target. The difference between the box and disk also addresses the effect of the cross section difference between a circle with radius 1 mm and a square with 2 mm sides.

The study varied the lengths of the second targets to find an optimum and Figure 5 displays the results. It is seen that the wide box secondary target with length 3 mm placed closer to the primary target (z=17 mm with 10% initial e^+ loss vs. z=22 mm with 5% initial e^+ loss) that also makes use of mid-plane degraded electrons provides the highest yield of useful positrons within the configurations studied here. Note that the yields in Figure 5 were obtained using a dipole with gap height of 186 mm; the baseline study [3] used gap height of 50 mm.

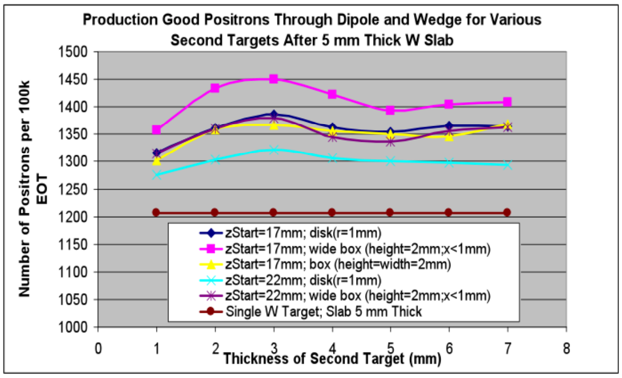

Figure 5: Production yields of good positrons (8<P<12 MeV/c and Pz/P < 0.9553 (300 mrad)) after the wedge for various secondary target configurations after the 5 mm thick W primary target. Note that these yields were obtained using a dipole with gap height of 186 mm; the baseline study used gap height of 50 mm.

Table 1 provides absolute yields of good positrons per 100 MeV electron on the double target system as well as relative yields with respect to the single optimized target. There is a 20% enhancement of good positrons for the wide box (that extends the second target into the mid-plane to make use of the degraded electrons) over the single target configuration. The difference between the wide box and box shows that 6.9% of the enhancement of good positrons is due to the extension into the mid-plane. Comparing the box (2 mm x 2 mm) to the disk (radius = 1 mm), the onset of decreasing positron yield is observed as expected by the limited radial size of the gammas and its forward travel direction as shown in Figure 3.

Table 1: Comparison of Production of Good Positrons from 3 mm thick Secondary Targets at z=17 mm.

Configuration	$N(e^+)$/EOT	$N(e^+$ w/ 2 targets) / $N(e^+$ w/ 1 target)
Wide Box	0.01450	1.20133
Box	0.01367	1.13256
Disk	0.01387	1.14913

Now that a preliminary optimized multiple target system for generating positrons useful for gamma production has been derived, a potential rotating structure that houses the multiple targets is illustrated. Figure 6 shows multiple views of such a structure that uses two rotating disks to support the targets. There is much freedom in designing the support structure and what is shown is just one example. What are fixed in this particular configuration are the targets shown in yellow; the support structure in white would be designed with real world considerations taken into account.

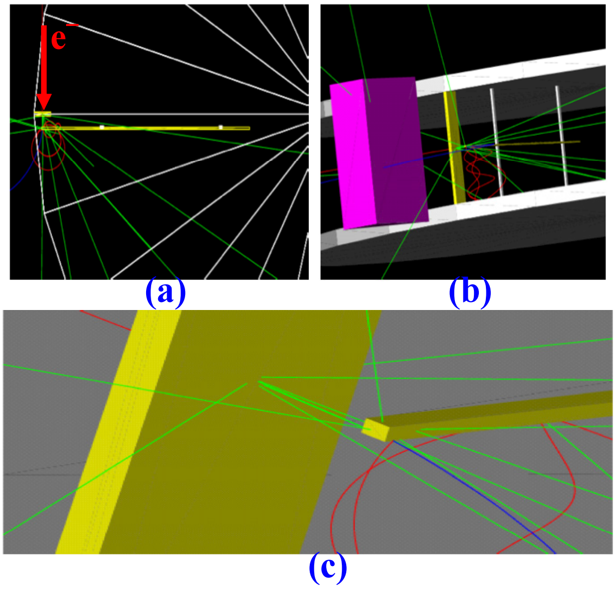

Figure 6: Event displays of double target configuration with supporting structure. Top view through transparent support disks (a), solid oblique view (b), and solid close up view (c) of the same event producing a good positron (blue track) in the second target. Note that the dipole is not shown for sake of clarity. Support structure, including the rotating disks, are in white, the W targets are in yellow, and the Be wedge is purple.

SUMMARY & FUTURE

A preliminary optimized multiple target system has been derived to create useful positrons for purpose of downstream generation of intense gamma rays. The increase in performance is ~20% and the added cost is likely to be small compared to the cost of the total system that includes a 100 MeV accelerator. So, regardless of whether a single target setup would require cooling, implementing an optimized multiple target system provides a cost effective performance enhancement. Full optimization of the multiple target arrangement is yet to be done, but what was described here reveals the novel concept and gives a glimpse of its possibilities.

REFERENCES

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