POSITRON PRODUCTION 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 directional positrons. These positrons would traverse a dipole and wedge configuration to reduce their momentum spread and be directed onto a target to annihilate with electrons, producing an intense source of gammas. We present in this paper a study for the start of the process that aims to produce an intense beam of directional positrons.

INTRODUCTION

The overall schematic for our strategy 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 target to pair produce positrons and electrons. The high Z target is selected to be tungsten, W, since it has the highest melting point of high Z materials and is a common choice for positron production from a beam of electrons. This target is followed by a dipole to create dispersion for the desired positrons (wrong signed particles bend 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 thenbent 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, we optimize characteristics of the electron beam and the W target.

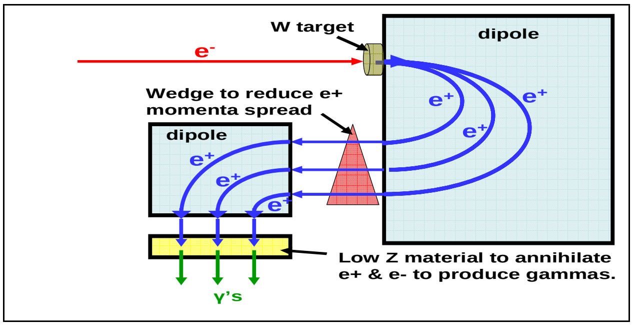

Figure 1: Overall layout for production of a beam of intense mono-energetic gammas. This paper optimizes the electron beam and W target.

GOALS OF POSITRON PRODUCTION

To maximize the use of the dipole/wedge configuration, the electron beam and high Z target should be optimized for maximum number of positrons traveling in the direction of the initial electron beam [1]. Furthermore, the energy range of the final γ's is about 2 to 10 MeV. Based on studies of electron/positron annihilation to produce gammas [2], we will focus our efforts on producing positrons in range of 2 MeV/c ≤ P(e+) ≤ 15 MeV/c.

ELECTRON BEAM PROFILE AND W TARGET GENERAL SHAPE

We begin with a simulation to extract the general features of the electron beam and W target system that is appropriate to produce positrons for our needs. The features under study here are:

1. Electron beam profile: pencil thin or uniform in transverse plane.
2. W target dimensions: radius and thickness.

We imposed cuts on transverse emittance $\varepsilon_T \leq 100\pi$ mm-mrad, where:

$$\varepsilon_T = \rho\theta \tag{1}$$

with

$$\rho = \sqrt{x^2 + y^2} \quad \text{and} \quad \theta = \cos^{-1}(P_z / P) \tag{2}$$

Figure 2 shows the rate dependence of positron production on W target thickness and radius for 20 MeV electrons with a pencil beam profile. We see the trend for higher yield with larger radii, which is consistent with gammas being produced at relatively large angles as shown in Figure 3 and traveling distances in the W target that are shorter than its radiation length of 3.5 mm. For 1 million electrons on target, we expect ~5500 positrons or ~0.0055 e+/(e− on target) within $\varepsilon_T \leq 100\pi$ mm-mrad for radii between 0.3 mm and 2.0 mm. All simulations were performed in G4beamline [3].

Figure 4 shows the rate dependence of positron production on a W target thickness and radius for 20 MeV electrons with a uniform beam profile. The yield decreases with larger radii, which is different from the pencil beam result in Figure 2. where the yield increases with larger radii.This may be understood as follows. Gammas produced at relatively large angles (see Figure 3) travel distances in the target on the order of its radiation length of 3.5 mm. In the uniform beam case, a larger proportion of the gammas are produced at larger radii near the outer edge, which reduces the fraction of gammas that will interact in the target. The lower overall yield is also consistent with this edge effect. However, there is still an

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increase in yield with increasing radii at very small radii, where the edge effect occurs over the entire target. The decrease in yield with increasing radii starts above radius 0.3 mm. For 1 million electrons on target, we expect ~4000 positrons or ~0.0040 e+/(e− on target) within $\varepsilon_T \leq 100\pi$ mm-mrad for radii between 0.2 mm and 0.9 mm.

Comparing yields in Figure 2 for pencil beam to those in Figure 4 for uniform beam we arrive at the following conclusions to use in further studies:

1. The electron beam should have a pencil profile.
2. The W target should have a large radius to allow the wide angle gammas to interact in the target and produce e+'s.

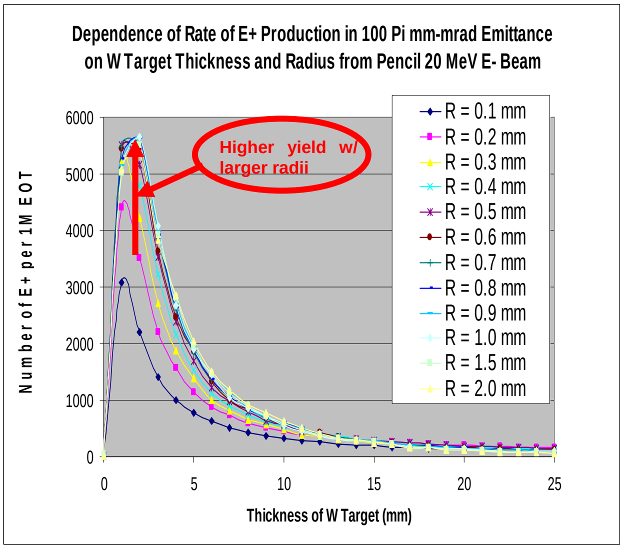

Figure 2: Rate of positron production per million electrons on target (EOT), satisfying $\varepsilon_T \leq 100\pi$ mm-mrad for varied W target thicknesses and radii from a 20 MeV pencil beam of electrons.

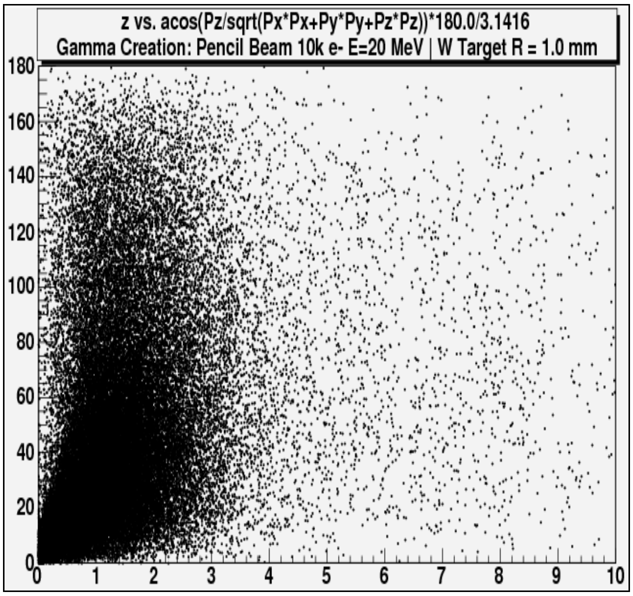

Figure 3: Polar angle (degrees) vs. longitudinal position from start of target (mm) for gammas created in the target.

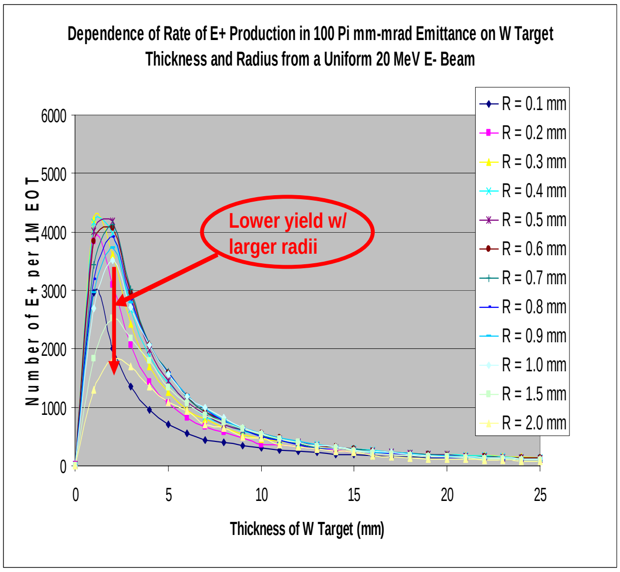

Figure 4: Rate of positron production per million electrons on target (EOT), satisfying $\varepsilon_T \leq 100\pi$ mm-mrad for varied W target thicknesses and radii from a 20 MeV uniform beam of electrons.

OPTIMIZATION OF ELECTRON BEAM ENERGY AND W TARGET THICKNESS

Guided by the initial studies above, we used a pencil beam for the electrons and a large radius W target to optimize the beam energy and W target thickness for maximum number of directional positrons per beam energy and minimal (or acceptable) flux of background neutrons.

In the optimization for e+'s that enter the dipole and wedge, we assume forward traveling positrons within $\theta \leq 300$ mrad will be useful to create a mono-energetic positron beam. Figure 5 shows the rate of positron production with:

- $\theta(e^+) \leq 300$ mrad and
- 2 MeV/c $\leq P(e^+) \leq 15$ MeV/c

When the yields are normalized to power of the 100 MeV electron beam as indicated by the arrows, it is seen that a 75 MeV e- beam is nearly as efficient as a 100 MeV beam.

Given the similar efficiency per unit beam power, we investigated the reduction in the neutron background afforded by operating at a lower energy beam. Figure 6 shows that the kinetic energy of the neutron background increases with target length for 50, 75, and 100 MeV electron beams. The yield of positrons are also shown for electron beams of 50, 75, and 100 MeV. The optimal lengths of the W target are indicated by vertical lines at slightly lower than the maximum yield length, taking into account positron yield and neutron background. Table 1 summarizes and quantifies the results with values for positron rates and total kinetic energy of background neutrons and shows that a 75 MeV e- beam is 97.7% efficient in producing e+'s to that of the 100 MeV beam, while reducing the potential dose of neutrons by ~6%.

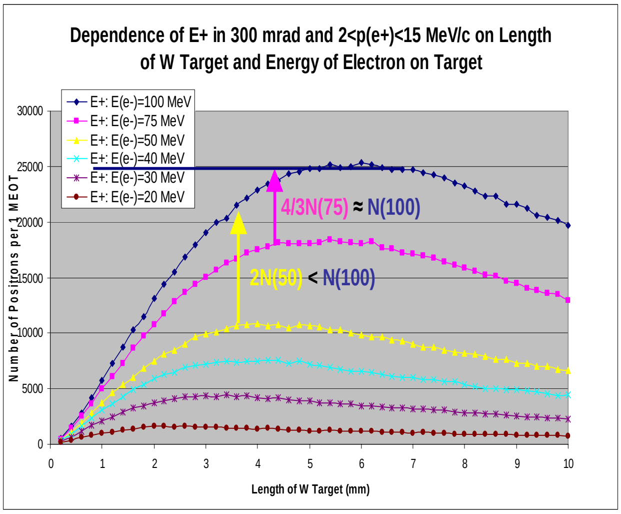

Figure 5: Rate of positron production per million electrons on target (EOT), satisfying θ ≤ 300 mrad for W with radius 14 mm for beam energies 20 MeV to 100 MeV and W target thicknesses 0.2 to 10 mm. The arrows indicate the positron yield normalized to power of 100 MeV electron beam.

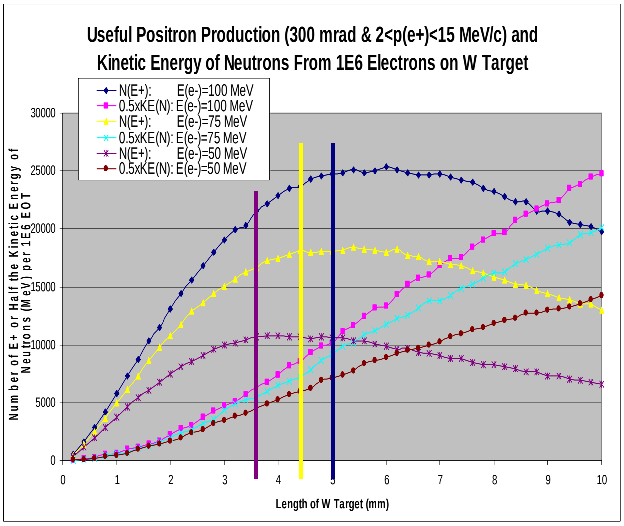

Figure 6: Rate of positron production and kinetic energy of neutron background per million electrons on target (EOT) for 50, 75, and 100 MeV. Note that half the neutron kinetic energy is plotted.

Table 1: Summary of Positron Yields and Neutron Background

†Values for optimal lengths of W target are estimated to be prior to maximum yield for e$^+$'s where it begins to flatten, while total kinetic energy of neutron background grows.

E(e-) (MeV)	†W Target Length (mm)	# e+ per 1e6 EOT	# Neutrons per 1e6 EOT	KE of Neutrons per 1e6 EOT (MeV)	# e+ per 1e6 EOT (scaled to power for 100 MeV)	# Neutrons per 1e6 EOT (scaled to power for 100 MeV)	Energy of Neutrons per 1e6 EOT (GeV) (scaled to power for 100 MeV)
100	5.0	24,757	7,217	20,379	24,757	7,217	20,379
75	4.4	18,137	4,611	14,404	24,183 (0.9768 of 24,757)	6,148 (0.85188 of 7,217)	19,205 (0.9424 of 20,379)
50	3.6	10,705	2,829	9,013	21,410 (0.8648 of 24,757)	5,658 (0.78398 of 7,217)	18,026 (0. 8845 of 20,379)

SUMMARY

We have presented an optimization for a positron source that comprises the front end of a compact tunable gamma ray source. The optimal configuration is a pencil beam of 75 MeV electrons on a large radius (≥ 14 mm) W target of length 4.4 mm. The positron production rate is 97.7% of that of using 100 MeV electrons, and the neutron background dosage is ~6% lower. . Another benefit of a 75 MeV electron beam over a 100 MeV beam is lower cost and smaller space required for the accelerator.

REFERENCES

[1] R. Abrams, et al, contribution MOPEA044 at IPAC2010.

[2] A. Afanasev, et al., contribution MOPEA043 at IPAC2010.

[3] G4beamline, T. Roberts, http://www.muonsinc.com.