SIMULATION OF A CW POSITRON SOURCE FOR CEBAF*

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Abstract

A positron source for the 6 GeV (and 12 GeV upgrade) recirculating linacs at Jefferson Lab is presented. The proposed 100nA CW positron source has several unique characteristics; high incident electron beam power (100kW), 10 MeV/c incident electron beam momentum, CW incident beam and CW production. Positron production with 10 MeV/c electrons has several advantages; the energy is below neutron threshold activation so the production target and the optical system will not become activated during use; CEBAF requires a very low energy spread, so the absolute energy spread is bounded by the low incident energy. These advantages are offset by the large angular distribution of the outgoing positrons. Results of simulations of the positron production and capture are presented. Energy flow, power deposition and thermal management of the elements present a challenge and are included in the simulations.

INTRODUCTION

Use of positrons for acceleration has been very popular for decades. The International Linear Collider (ILC) design requires a well-defined intensive positron source for a lepton collider [1]. At the Continuous Electron Beam Accelerator Facility (CEBAF), it has also been a desire to produce a positron beam [2]. We propose to produce a high intensity, low energy positron beam with a current $I \geq$100nA and emittance less than or equal to the max admittance of CEBAF(∼200πmm.mrad). A CW electron beam with 10 mA current and 10 MeV/c momentum(similar to JLAB Free Electron Laser (FEL) injector properties) is used to produce positrons on a thin tungsten(W) converter with a thickness of $L_0 = 0.15X_0$. A success of reaching the proposed positron current at CEBAF will advance the Deeply Virtual Compton Scattering (DVCS) program and permit precision measurements of two-photon effects in high energy electron scattering. We also consider the possibility of producing intense low energy moderated positrons for the study and imaging of materials, surfaces, and macromolecules. Our proposed design is; compact in size; does not require a damping ring; maintains the incident beam below photoneutron activation threshold; and is a unique CW source. A thin converter followed by a quadrupole triplet will be a ”momentum selection device”. Almost 99% of electrons, photons and off-momentum positrons will be dumped in the quadrupoles and in a collimator. This compact system can either be coupled to a short SRF or a chicane to separate positrons from electrons After another FODO cell, positrons will be ready for injection into CEBAF.

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SIMULATION RESULTS

We have used various simulation tools to simulate our conceptual design. GEANT4 [3] was used to simulate positron yield and power deposition; for both production and beam transportation, G4BEAMLINE [4] a GEANT4 based simulation program has been used. Optimization of quadrupole-triplet design was necessary to get the highest current per transverse emittance. DIMAD [5] embedded in a genetic algorithm method written in perl was used for this purpose. To analyze the simulation results ROOT [6] was used.

Optimum Production Target Thickness

We consider an electron drive beam of 5-14 MeV/c. We wanted to stay below photoneutron activation threshold [7] to minimize radiation issues. Our first study was optimizing target thickness and incident beam energy. Power deposition and brightness of the positron beam are the two parameters to make the decision on our optimum target thickness. Brightness B is defined as;

$$B = \frac{N(e^+)}{\varepsilon_x * \varepsilon_y} \tag{1}$$

where ε_x and ε_y are rms transverse emittances with correlation defined as;

$$\varepsilon^2_{x,y} = <x^2><x'^2> - <xx'>^2 \tag{2}$$

Here x is the position and x' is the angle of the phase space. Since the low energy positrons have a large transverse emittance, we do not use the small angle approximation:

$$x' = \arctan \frac{p_x}{p_z}. \tag{3}$$

Fig. 1 shows the positron conversion efficiency normalized to deposited power in the W, depending on W thickness for 5, 10 and 20 MeV/c incident electrons . In Fig. 3, the brightness peaks around 3 MeV/c for 10 MeV/c electrons with W(mm)=0.5.

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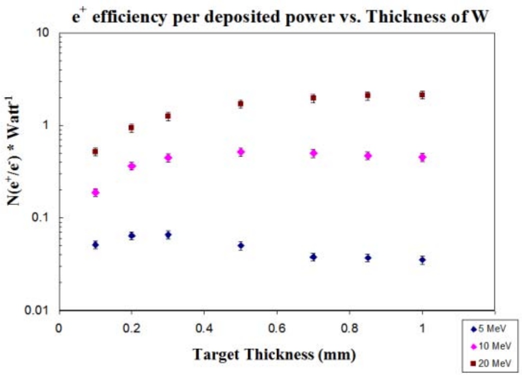

Figure 1: Positron production efficiency per deposited power in the target, as a function of target thickness. Three values of the incident electron energy are shown.

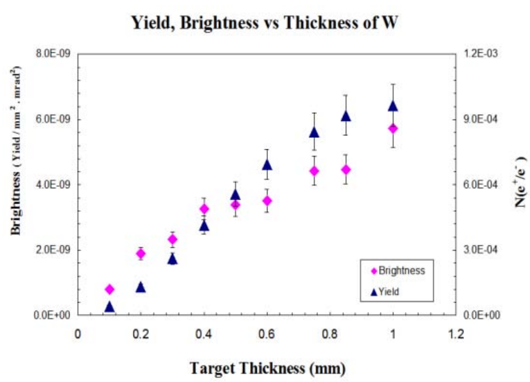

Figure 2: Brightness and positron efficiency depending on target thickness.

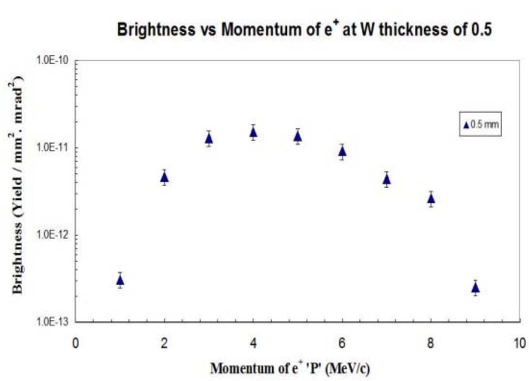

Figure 3: Brightness depending on the positron momentum bins.

Momentum Selection

Since optimization of brightness and preserving time structure are the key motivations; we needed to select positrons of a given central momentum and σ_p. A new technique by P R Sarma [8] gave us an idea to use a quadrupole triplet to select a positron momentum band and to dump the electrons and off-admittance positrons.

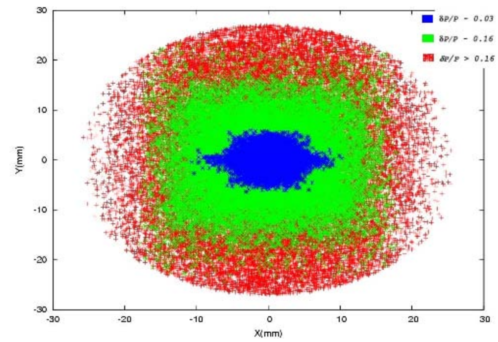

Figure 4: x-y profile right before the collimator. The color key is defined in the text.

Fig. 4 shows how this selection is made. The x-y profile of the positron beam at the entrance to a collimator following the quadrupole triplet is shown for three different positron momentum bands. The dark-blue ellipsoid in the central is for $p(e^+) = $ 3MeV/c$\pm$3%, and the green is all events within a 16% momentum spread. The red outlier shows all off-momentum positrons.

Power Deposition and Quad Values

Power deposition in the target and in other optical elements is a big challenge. Tungsten has the highest melting point among high-Z materials but we will still need active cooling of the target. A water-cooled rotating target is an option. Using the beam parameters of FEL; our driving beam will hit the target with 100 kWatts of power. Quadrupole values were taken from existing FEL quads; gradients have been optimized by DIMAD and genetic algorithm. In Table 1, these parameters and power deposition at tungsten(W), quadrupoles(Q1, Q2 and Q3), collimator(C) and post-collimator(PC) are shown.

Table 1: Quadrupole Parameters and Deposited Energy

Symbol	Gradient	Length	Aperture	Power
	$T.m^{-1}$	mm	mm	kWatt
W	–	0.5	50	22
Q1	1.9	150	27	25
Q2	-0.9	150	27	15
Q3	0.6	150	27	5
C	–	57	5	28
P.C	–	–	–	0.2

Momentum and Phase Space

The positron momentum spectrum and transverse phase space right after the W convertor are shown in Fig. 5(a) and Fig. 5(b). Since the large angle positrons dominate

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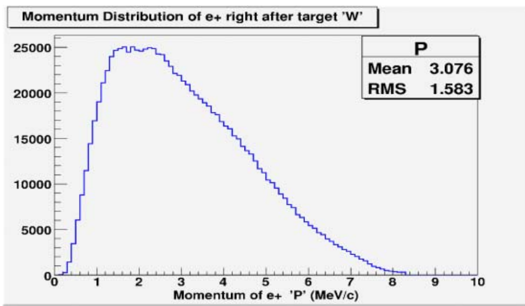
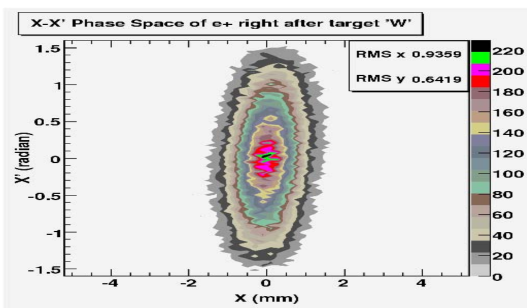
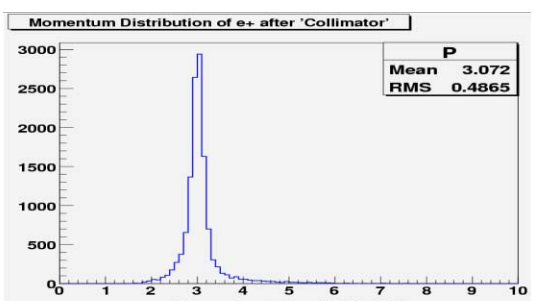
the phase space, we need to select positrons within a transverse emittance of $\approx \varepsilon_{x,y} \sim 100\pi$mm.mrad, this helps us to optimize the quad triplets and size of the collimator. In, Fig. 5(c) and Fig. 5(d), the momentum distribution and transverse phase space of positrons after the collimator are shown. In Fig. 5(c), the momenta sharply peaks at 3 MeV/c as a result of quadrupole's momentum selection.



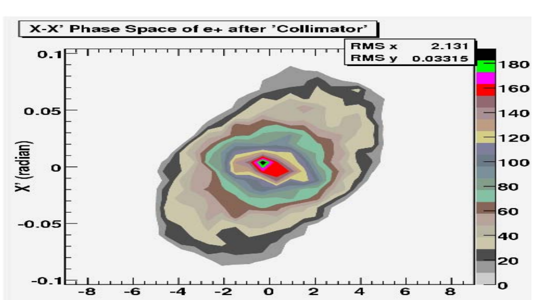
(a) Momentum Distribution.



(b) $X - X\prime$ phase space.



(c) Momentum Distribution.



(d) $X - X\prime$ phase space.

Figure 5: Momentum and Phase space distribution of positrons (a) and (b) after tungsten;(c) and (d) after collimator.

CONCLUSION

The analysis has been made to optimize the production target and quadrupole collection optics for production of a monochromatic bunched CW positron beam from a low energy electron drive beam. Positrons emitted from the target are sprayed all over a large phase-space so that almost 95% of the emitted positrons are dumped in the quadrupoles and at the collimator. This quadrupole optimization has been done using the currently available magnets at JLab. Further and more detailed optimization will be completed, in particular with larger bore magnets. Our results show that shorter but higher field gradient magnets are needed to be built. The quadrupole triplet selects certain momenta as well as works as a beam dump. Assuming 10mA of incoming electron beam; simulations show that we can obtain 20nA of positron current within the admittance and energy$\times$time spread of CEBAF. To get better emittance we are in the process of studying additional quadrupole triplets. Simulations of acceleration of positrons through the SRF cavities are ongoing as well. Power deposition is one of the biggest challenge of this study and needs comprehensive engineering design.

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