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CAPTURE AND POLARIZATION OF POSITRONS IN A PROPOSED NLC POLARIZED POSITRON SOURCE*

Y.K.Batygin and J.C.Sheppard, SLAC, Stanford, CA 94309, USA

Abstract
A proposed NLC polarized positron source utilizes a 150 GeV electron beam passing through a helical undulator. The resulting flux of polarized photons is converted in a thin positron production target. Spin polarized positrons are captured using a high field flux concentrator followed by an accelerator section immersed in a solenoidal field. Positron tracking through the accelerating and focusing systems is done together with integration of spin precession. Optimization of the collection system is performed to insure high positron yield into the 6-dimensional acceptance of the subsequent pre-damping ring while keeping the high value of positron beam polarization.

INTRODUCTION

The original proposal on polarized positron production specifically for linear colliders was made in Ref. [1]. It incorporates an idea to utilize a helical undulator to produce circularly polarized photons which, being directed onto the target, create polarized positron-electron pairs. A proposed NLC polarized positron source includes a helical undulator, a production target followed by a short solenoid with a strong magnetic field (flux concentrator), a 250 MeV linac with 0.5 Tesla focusing solenoids and a 1.76 GeV booster linac with quadrupole focusing. Parameters of the positron injector are summarized in Table 1. Collected positrons are cut by a 6-dimensional acceptance of the positron pre-damping ring (PPDR). At the injection point into pre-damping ring, the positron beam is cut transversely by the transverse acceptance of 0.03 π m-rad and in energy spectrum to 2%, which corresponds to energy interval of 40 MeV. The ultimate goal of the collector system is to provide the highest number of positrons within the 6-dimensional acceptance of the pre-damping ring keeping longitudinal polarization of the beam as high as possible.

Table 1. NLC polarized positron injector parameters.

Parameter	Value
Electron beam energy	150 GeV
Electrons/Bunch	$8 \cdot 10^9$
Bunches / pulse	192
Pulses/sec	120
Undulator type	Helical
Undulator Parameter, K	1
Undulator Period	1 cm
First Harmonic Cutoff En.	10.7 MeV
$dN\gamma/dL$	2.6 photons/m/e$^-$
Undulator Length	132 m †
Photon Collimator Trans.	0.5
Target Material	Ti-alloy
Target Thickness	0.5 R.L.
Yield (N_+/N_γ)	$2.9 \cdot 10^{-2}$ ‡
Capture Efficiency	0.2
Positrons/Pulse	$1.5 \cdot 10^{12}$
Positrons/Bunch	$8 \cdot 10^9$
Positron Polarization	0.6

† Length for unity gain e$^+$/e$^-$; ‡ Yield for cut spectrum

POLARIZED POSITRON TRACKING

Positron tracking from the target to end of 1.9 GeV linac is performed using BEAMPATH [2]. The initial positron distribution after interaction of photon beam with a 0.5 RL Ti target was calculated using the EGS4 program [3], adapted for polarized beams [4, 5]. Particle tracking was accompanied with integration of the Thomas-BMT equation [6], describing the precession of the spin vector $\vec{S}$:

$$\frac{d\vec{S}}{dt} = \frac{e\vec{S}}{m\gamma} \mathrm{x} [(1+ \quad g\gamma)\vec{B}_{\perp} + (1+g)\vec{B}_{II} + (g\gamma + \frac{\gamma}{1+\gamma}) \frac{\vec{E} \mathrm{x} \vec{\beta}}{c}] ,(1)$$

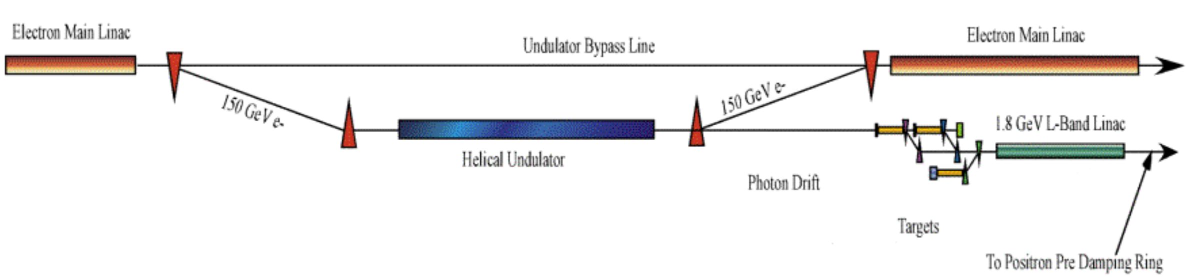

Fig. 1. NLC polarized positron injector layout.

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Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
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Table 2.Yield of positrons with respect to incident γ –flux.

Energy of 1st harm. cutoff, MeV	Positron yield at the target, $N_{e+,target}/N_\gamma$	Positron capture at 1.9 GeV, $N_{e+,1.9GeV}/N_{e+,target}$	Positron yield at 1.9 GeV, $N_{e+,1.9GeV}/N_\gamma$	Positron polarization, $<P_z>$
10.7	0.029	0.20	$5.8 \cdot 10^{-3}$	0.59
30	0.11	0.058	$6.4 \cdot 10^{-3}$	0.59
60	0.17	0.026	$4.4 \cdot 10^{-3}$	0.59

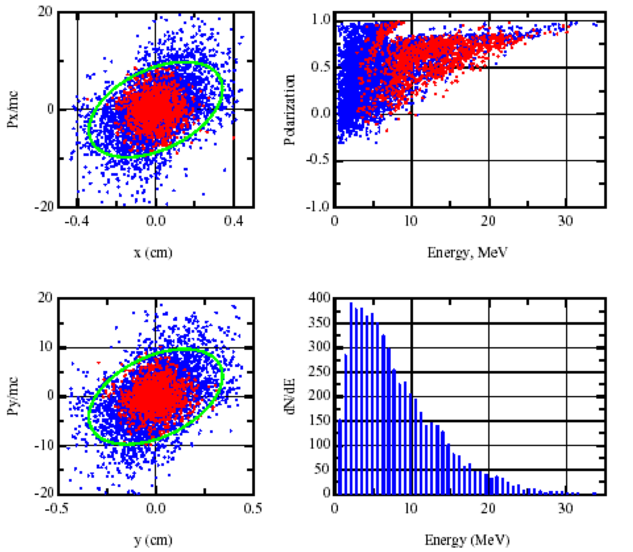

Fig. 2. (Blue) initial distribution of positrons generated by 10.7 MeV γ-flux, (red) positrons accepted at 1.9 GeV, (green) area of 0.03 π m rad.

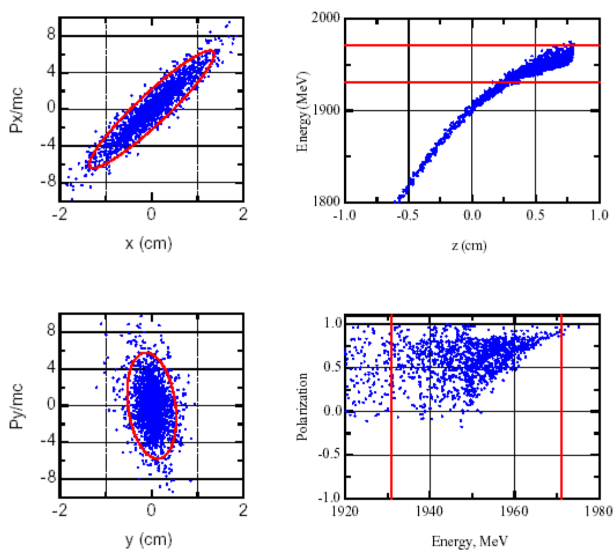

Fig. 3. (Blue) distribution of positrons at 1.9 GeV, (red) emittance area of 0.03 π m rad and ΔE/E=2%.

where g is the anomalous magnetic moment of the positron, $\vec{E}$ is the electrical field, and $\vec{B}_\perp$ and $\vec{B}_{II}$ are components of the magnetic field perpendicular and parallel to particle velocity. Initially the spin vector of each positron is pointed along the momentum vector. During beam transport, the spin vector precesses, resulting in the depolarization of the beam. We define the longitudinal polarization as an average of the product of the longitudinal component S_z and the value of polarization, P, over all positrons:

$$< P_z >= \frac{1}{N} \sum_{i=1}^{N} S_z^{(i)} P^{(i)} \ . \qquad (2)$$

The initial value of longitudinal polarization is $< P_z >$ = 0.43. Polarization of the final beam depends strongly on the energy of accepted particles and is typically in contradiction with the value of positron capture. Below, several different schemes of positron injection are considered.

POSITRON BEAM DYNAMICS

Figs. 2, 3 illustrate dynamics of the positron beam created by a K=1, helical undulator spectrum of photons with a first harmonic cutoff energy of 10.7 MeV (note: only the first 4 undulator radiation harmonics are included) [7]. Initial beam after the target has an energy spread of 0-30 MeV and normalized, rms emittance of 0.0095 π m-rad (see Fig. 2). The target is followed by a flux concentrator [8], which is a solenoid with a sharp increase in magnetic field up to peak value of 5.8 Tesla at a distance of 5 mm from the target and an adiabatic decrease of the field over a distance of 15 cm. An additional magnetic field of 1.2 Tesla at the target is required to confine the emitted positron beam with its large momentum spread.

The flux concentrator is followed by a 250 MeV linac with an effective accelerating gradient of 25 MeV/m and transverse focusing by a 0.5 Tesla solenoid field. After acceleration to 250 MeV, positrons are accelerated in a linac with quadrupole focusing and an accelerating gradient of 15 MeV/m. During acceleration, high energy particles are placed on the top of accelerating field.

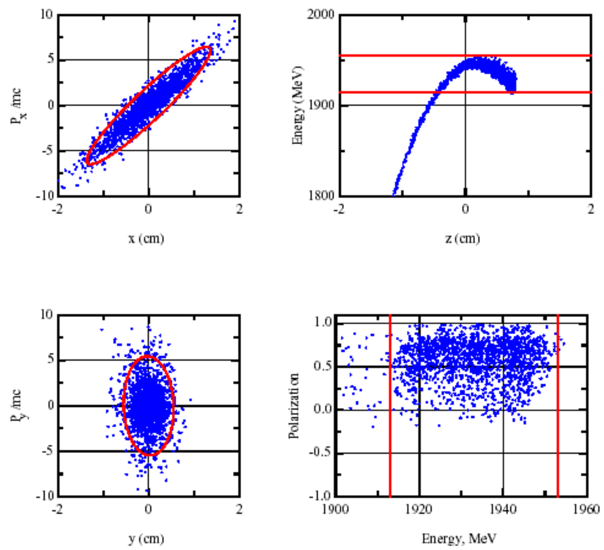

Fig. 4. (Blue) 1.9 GeV distribution of positrons at RF phase in linac φ = -11.5°, (red) emittance of 0.03 π m rad and ΔE/E = 2%.

This gives the possibility to retain the original particle energy distribution and not to mix high energy, high polarized positrons with low energy, low polarized positrons. At the energy of 1.9 GeV, 20% of the initial positrons are within the 6-dimensional phase space acceptance with an average polarization of $< P_z > = 0.59$.

To provide higher positron transmission, the high-energy positrons might be shifted in RF phase with respect to peak of RF voltage. Fig. 4 illustrates results of positron capture simulation in case the RF phase shift in 1.76 GeV linac is selected to be φ = - 11.5°. The value of RF phase shift is adjusted in such a way that the energy difference in head particles and top-energy particles is within the interval of ΔE/E = 2%. It provides the value of positron capture of 26% while beam polarization is kept as high as $< P_z > = 0.56$.

Increasing of the energy of incoming photons results in wider energy spectrum of outgoing photons. Table 2 contains results of capture of positrons created by the K=1, helical undulator spectrum with first harmonic cutoff energies of 10.7 MeV, 30 MeV and 60 MeV. According to EGS4 simulations, the distribution of positron polarization as a function of energy remains qualitatively the same, but is scaled to a wider energy interval. The fraction of captured positrons is 0.058 for positrons generated by the 30 MeV cutoff γ –flux, and 0.026 for that generated by the 60 MeV cutoff γ –flux. These values are substantially smaller than the value of capture of positrons created by 10.7 MeV γ- flux. However, the target conversion rate from photons to positrons increases with the energy of incoming photons. From Table 2 it follows that the value of position yield at 1.9 GeV is of the order of $(4...6)\cdot 10^{-3}$ and is a weak function of energy of γ - flux.

Table 3. Capture and polarization of positrons obtained from 10.7 MeV γ–flux.

	After target	End of 1.9 GeV linac, B_{target}=1.2T	End of 1.9 GeV linac, B_{target}=6.4T
Fraction of positrons within $\varepsilon_x,\varepsilon_y<0.03\ \pi$ m rad, ΔE= ± 20MeV	0.72	0.20	0.29
Positron polarization, $<P_z>$	0.43	0.59	0.55

OPTIMIZATION OF POSITRON TRANSMISSION

According to design, the positron production target is surrounded by tapered solenoidal magnetic field of B_t= 1.2 Tesla followed by a strong magnetic field of flux concentrator with a total peak field of B_{FC} = 6.4 Tesla. The sharp change in magnetic field at the injection is a barrier for low-energy positrons. Transverse momentum of the particle after injection is

$$p_\varphi = p_{\varphi o} + \frac{er}{2}(B_{FC} - B_t)\ . \qquad (3)$$

Assuming an initial value of azimuthal momentum is $p_{\varphi o}$ = 0 and beam radius of r = 2 mm, the value of azimuthal momentum after injection is p_φ = 3.1 MeV/c. Total particle momentum in magnetic field is conserved, which means that low-energy particles with smaller energy are reflected from the target. This gives the idea that if target is placed inside magnetic field of flux concentrator, this barrier is removed and more positrons can be captured. Simulations indicate that it results in significant increase (up to 29%) of the value of positron capture (see Table 3).

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