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# Positron Collection in Linear Collider*

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In the Linear Collider design, the positron capture system includes a positron production target, followed by an adiabatic matching device (solenoid), a pre- linac with solenoidal focusing, and a linac with quadrupole focusing before injection into a positron damping ring. Two schemes for positron production have been studied: (i) a conventional approach with high-energy electron beam interacting with a high-Z target and (ii) polarized positron production using polarized photons generated in a helical undulator by a primary collider electron beam which then interact with a positron production target. The capture efficiencies for both schemes are compared. Various parameters affecting the positron capture are analyzed.

## 1. INTRODUCTION

In the Linear Collider, the positron capture system includes a positron production target, an adiabatic matching device (AMD), and a linac to accelerate positrons up to the injection energy of the positron damping ring. Efficiency of the positron collector is defined by the number of positrons accepted into the damping ring. The ultimate goal of the collector system is to provide the highest number of positrons within the 6-dimensional acceptance of the damping ring. For polarized positrons, the longitudinal polarization of the captured beam has to be as high as possible. Two parameters are important to characterize the efficiency of positron collection. Positron yield, $Y=N_{e+}/N_{e-}$, is a ratio of the number of accepted positrons $N_{e+}$, to the number of primary electrons, $N_{e-}$, used for positron beam generation. Positron capture, $C = N_{e+}/N_{e+,target}$ is a ratio of accepted positrons to the number of positrons produced at the target, $N_{e+,taget}$. The value of positron yield of Y =1.5, is considered a sufficient value for positron source operation in the Linear Collider.

## 2. POSITRON CAPTURE IN CONVENTIONAL SOURCE

### 2.1. Particle Dynamics

A positron beam extracted from the target is characterized by a large emittance and energy spread. The positron beam has to be transformed into the beam with small transverse momentum spread and a larger spot to be matched with the conventional focusing structure of a linac. Transformation is performed in an adiabatic matching device, where the magnetic field slowly decreases from the large value at the target, $B_{max}$ = 6 Tesla, to the nominal value of the focusing field in the linac, $B_o$ = 0.5 Tesla, along the z-direction. After the AMD, particles are accelerated in RF field. Fig. 1 illustrates typical particle distribution at the injection energy of 5 GeV into the damping ring. To calculate positron capture within 6D phase space, first we calculate root-mean-square (rms) Twiss parameters of particle distribution, $\alpha = -<xp_x>/\varepsilon_x$, $\beta = <x^2>/\varepsilon_x$, $\gamma = (1 + \alpha^2)/\beta$, where rms beam emittance is $\varepsilon_x = \sqrt{<x^2><p_x^2> - <xp_x>^2}$. Analogous parameters are calculated for distribution on $y - p_y$ phase plane. Twiss parameters $\alpha$, $\beta$, $\gamma$ define a family of ellipses

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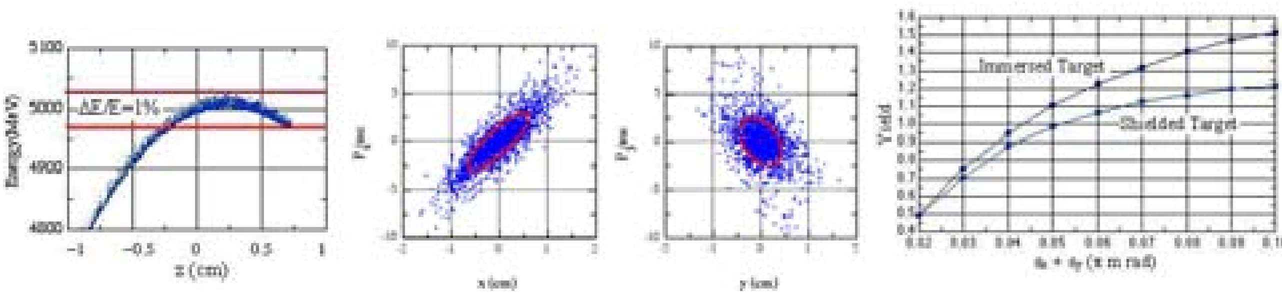

Figure.1. Positron distribution and yield at 5 GeV for conventional source, $\Delta E/E \leq 1\%$.

with the same ratio of semi-axes. The particle with the position $x_i$, $p_i$ belongs to a partial ellipse described by the equation $\gamma x_i^2 + 2\alpha x p_i + \beta p_i^2 = \varepsilon_x^i$, with an analogous expression for $\varepsilon_y^i$. The particle is supposed to be captured transversely, if $\varepsilon_x^i + \varepsilon_y^i$ Š $\varepsilon_{max}$, where $\varepsilon_{max}$ is the transverse phase space area of the damping ring available for the particles. To be accepted into damping ring, particles have to be cut in energy as well. Fig. 1 illustrates positron yield as a function of combined beam emittance for the value of energy cut, $\Delta E/E \leq 1$. As far as positron yield at the target is Y = 13.3, the positron yield of Y= 1.5 at 5 GeV corresponds to the value of positron capture of C = 0.11.

## 2.2. Immersed Target vs Shielded Target

Positron yield strongly depends on position of the target with respect to magnetic field of the AMD. Due to conservation of canonical momentum, $r^2(d\varphi/dt + \omega_L) = \text{const}$, where $\omega_L = eB/(2m\gamma)$ is the Larmor frequency, the particle obtains additional azimuthal rotation in changeable magnetic field of the AMD, $p_\varphi r = p_{\varphi o} r_o - (e/2)\,(r^2 B(z) - r_o^2 B_{target})$, where $p_{\varphi o}$ is the positron azimuthal momentum at the target, $p_\varphi$ is the azimuthal momentum at z, $r_o$ is the particle radius at the target, and r is the current particle radius. For a shielded target, the magnetic field of the AMD changes significantly near the target. Assuming $p_{\varphi o} = 0$, $r = r_o = 0.5$ cm, and $\Delta B = 6$ Tesla, the azimuthal momentum of the particle after passing through a jump of magnetic field is $p_\varphi = 0.5 er\Delta B = 4.44$ MeV/c. This means that a particle emerged from the shielded target parallel to the axis with momentum p < 4.44 MeV/c, cannot be transported through the magnetic field of the AMD. Fig.1 illustrates the difference in positron yield for shielded and immersed target. For the nominal value of the damping ring acceptance, $\varepsilon_x + \varepsilon_y \leq 0.09\ \pi$ m rad, $\Delta E/E \leq 1\%$, the difference in positron yield is around 25%.

## 2.3. Increase of Positron Yield via Bunch Compression

Positron capture is restricted by the curved distribution in longitudinal phase space due to RF acceleration. The energy restriction of $\Delta E/E \leq 1\%$ corresponds to phase width of the accepted bunch of $\Delta\phi = 2 \arccos(1 - \Delta E/E) = 15^o$. An effective way to increase the number of positrons in longitudinal phase space is utilization of a magnetic bunch compressor (chicane) at the intermediate energy. Fig. 2 illustrates particle distribution in longitudinal phase space before and after compression at the energy of 250 MeV. After compression, the number of positrons within $\Delta\phi = 15^o$ is increased significantly, and after acceleration, total number of positrons within 6D phase space is larger than that without compression. Fig. 2 contains results of simulation of positron capture using bunch compression at the energy of 250 MeV. Positron yield is increased by 40% using compression.

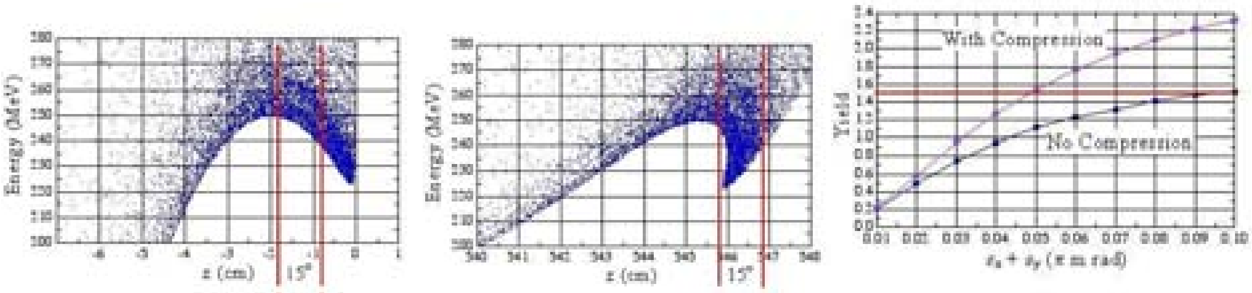


Figure 2. Longitudinal positron distribution before and after 250 MeV compression and positron yield at 5 GeV.

## 3. CAPTURE OF POLARIZED POSITRONS

In contrast with the conventional source, the undulator-generated positron distribution has significantly smaller emittance and energy spread. The initial distribution is correlated in energy, polarization and transverse momentum spread of positrons. The low energy positrons are less polarized and more transversely divergent, while high-energy positrons are strongly polarized and less divergent. There is an inevitable compromise between number of accepted positrons and beam polarization. Collector beamline contains the same elements as the conventional source. Polarized positron tracking is accompanied with integration of the Thomas-BMT equation, describing the precession of the spin vector. 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 of spin vector, $S_z$, and the value of polarization, P, over all positrons, $\langle P_Z \rangle = \langle S_Z^{(i)} P^{(i)} \rangle$. The initial value of longitudinal polarization is $\langle P_Z \rangle = 0.43$. After removing low-energy positrons in the beamline, the polarization of the final beam can reach the value of $\langle P_Z \rangle = 0.6$.

Fig. 3 illustrates the value of polarized positron capture, which is 3-4 times larger than that of conventional source. Variation of the RF field peak with respect to positron bunch results in a larger positron beam capture but with a smaller value of beam polarization.

(a) (b) (c)

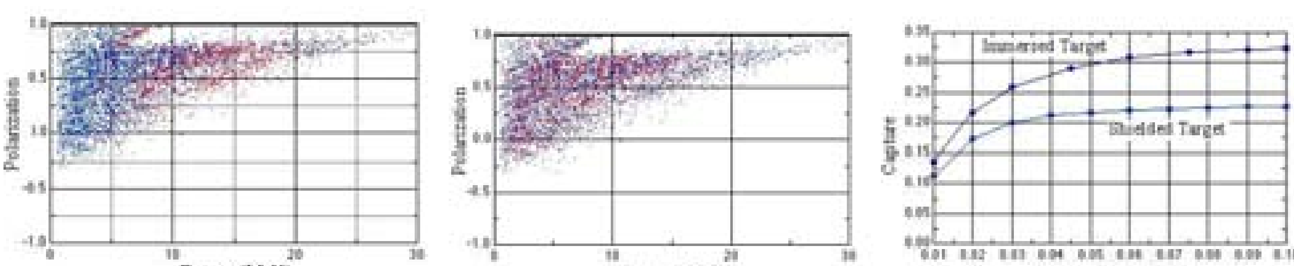


Figure 3. (Blue) (a) Initial positron disribution after shielded target, (b) positron distribution after immersed target, (c) positron yield at 5 GeV within $\Delta E/E \leq 1\%$, (red) positrons accepted into damping ring.