AN UNDULATOR BASED POLARIZED POSITRON SOURCE FOR CLIC*

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Abstract

A viable positron source scheme is proposed that uses circularly polarized gamma rays generated from the main 250 GeV electron beam. The beam passes through a helical superconducting undulator with a magnetic field of ~ 1 Tesla and a period of 1.15 cm. The gamma-rays produced in the undulator in the energy range between ~ 3 MeV – 100 MeV will be directed to a titanium target and produce polarized positrons. The positrons are then captured, accelerated and transported to a Pre-Damping Ring (PDR). Detailed parameter studies of this scheme including positron yield, and undulator parameter dependence are presented. Effects on the 250 GeV CLIC main beam, including emittance growth and energy loss from the beam passing through the undulator are also discussed.

INTRODUCTION

The undulator based positron source was first proposed by V. E. Balakin and A.A. Mikhailichenko [1]. K. Flottmann completed the study [2]. When an electron beam is passing through an undulator (planar or helical), a photon beam is generated as a result of the motion of the electron beam in the undulator. For a helical undulator, the photons with energies close to the critical energies of each harmonic will have higher circular polarizations. The positrons created by these photons will then in turn have a higher polarization. For this reason, a helical undulator is used in polarized positron sources. The spectrum of helical undulator radiation is a function of both deflection parameter K and undulator period λu. The yield of an undulator based positron source varies strongly with the choice of undulator parameter and the electron beam energy [3]. Generally speaking, lower K might be helpful for the polarization of a positron source because more photons will be in the first harmonic. But for a given period length λu, lower K also means a lower positron yield. For a given CLIC main beam energy, a shorter period length λ_u leads to higher positron yields. But limited by current technologies, the shortest period achievable is about 1 cm with a K maximized around 0.7. After comparison of several sets of undulator parameters, the ILC RDR baseline positron source undulator was chosen to have K=0.92 and λ_u=1.15 cm [4]. Since considerable R&D efforts have been invested in the ILC RDR baseline undulator, one could use the ILC RDR undulator for an undulator based polarized positron source for CLIC. In order to achieve the same ILC goal of a positron yield of 1.5 (Number of e+ over the number of e- passing through the undulator) with 60% polarization with a reasonably short insertion, instead of using a 150 GeV CLIC main beam as in ILC RDR baseline, a 250 GeV CLIC main beam energy is chosen for the CLIC undulator based polarized positron source in this paper. Since K is proportional to the B field of the undulator, by changing the current supplied to the undulator, one can change the parameter K for a given helical undulator. In the following sections, undulator with a fixed period length of 1.15cm and fixed CLIC main beam energy of 250 GeV will be studied with variations in the value of K and the collimator iris.

As stated in [5] and [6], the RF frequency for the CLIC injector complex is 2 GHz and the injector linacs will accelerate beams from 200 MeV up to 2.86 GeV before injecting into the predamping ring. Based on the above predefined parameters, a conceptual layout of the undulator based polarized positron source for CLIC is shown in Figure 1.

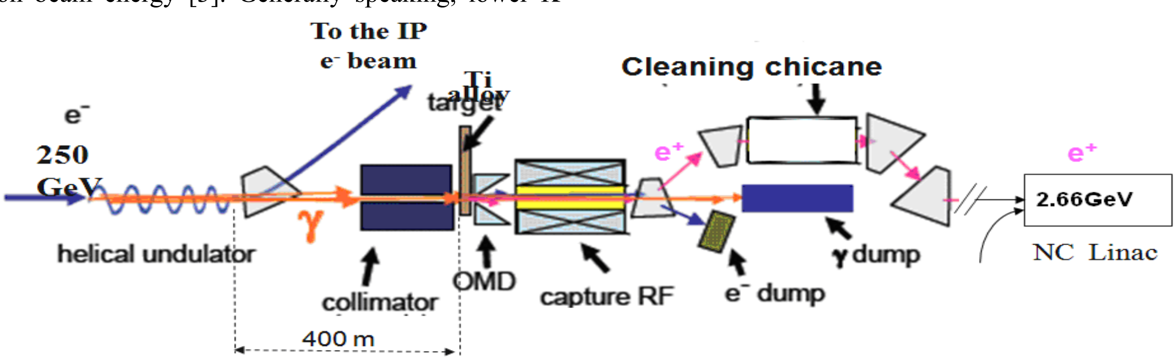

Figure 1: Conceptual layout of an undulator based polarized positron source for CLIC

A 250 GeV drive electron beam passes through the undulator and then is bent back to the electron main linac beamline. The photon beam that is produced will then

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pass through a photon collimator where the unwanted photons are blocked so that only preferred photons are able to strike the target and produce a positron beam with enhanced polarization. An optical matching device (OMD) is then used to focus and match the positron beam into the capturing beamline. The OMD could be adiabatic matching device (AMD) or a flux concentrator (FC).

SIMULATION RESULTS

The simulation was based on the codes EGSnrc [7] and PARMELA [8]. EGSnrc with our numerical model of a helical undulator is used to simulate the process from photon radiation of the CLIC main beam in the helical undulator to positron production in Ti target. PARMELA is then used to track the positrons until the end of positron capture where the positron beam energy is about 200 MeV. The yield and polarization of the captured positron beam is then evaluated with a 6-D acceptance window we used for ILC: $A_x + A_y \leq 0.09$ m and $\Delta E \times \Delta\Phi \leq (\pm 25\ \mathrm{MeV}) \times (\pm 7.5^0)$ and assume particles within this window should be able to transport down to the entrance of the Pre damping ring without losses. The CLIC Pre-Damping ring acceptance window, $A_x + A_y \leq 0.252$ m and $\Delta E \times \Delta z \leq (\pm 86\ \mathrm{MeV}) \times (\pm 3.6\ \mathrm{cm})$ is not used here. A detailed layout of positron transport beam line is needed to actually track the positron from the end of capturing beam line to the Pre-Damping ring injection line. And from there one can then applied the CLIC Pre-Damping ring acceptance window to evaluate the yield and polarization.

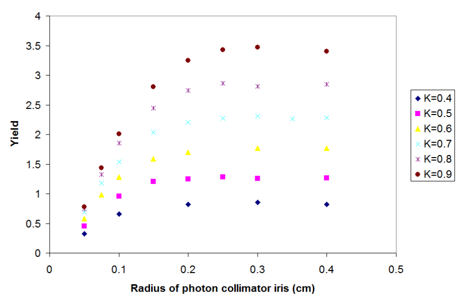

Figure 2: Yield of 100m long undulator using AMD

With AMD

Since CLIC has only 312 bunches per pulse train, the target might be able to rotate at a lower speed and thus using an AMD might be a practical approach. With an AMD as the OMD, undulators with different K and a fixed λ_u=1.15 cm have been evaluated for the yield and polarization with different sizes of the photon collimator. The results are given in Figure 2 and Figure 3.

As shown in Figure 2, if the requirements on polarization is relaxed, using undulator with K=0.6 and λ_u=1.15 cm will give us a yield of 1.5 and the polarization of the captured positron beam is 20% as shown in Figure 3. If the polarization requirement of 60% on the captured e^+ beam is enforced, the iris radius of the photon collimator need to be smaller than 0.5 mm for a drift of only 400 m as shown in Figure 3. The corresponding yield will be smaller than 0.5 for a 100 m undulator. In order to reach 1.5 yield and 60% polarization, one needs to have more than a 300 m long undulator if an AMD with a field taper from 6 T to 0.5 T over 14 cm is used as OMD. A scan of AMD parameters shows that the yield can be increased if one increases the initial B field on the surface of target, but doing this will be impractical because of the concomitant increase in the eddy current associated with the B field on target.

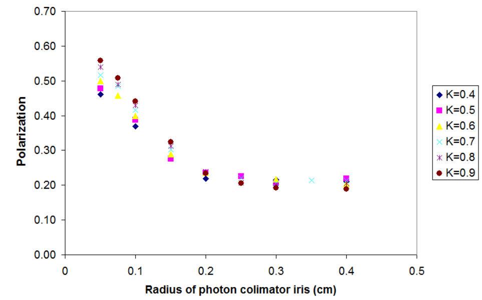

Figure 3: Pol. of a 100 m long undulator using AMD.

With FC

By comparison with the AMD, the FC has the advantage of having a smaller field on the surface of target and thus a reduced the eddy current in target. The CLIC undulator based positron source with FC using a fixed λ_u=1.15 cm and varying K were simulated.

As shown in Figure 4, for the low polarization option, a yield of 1.5 can be achieved easily with K > 0.6 and

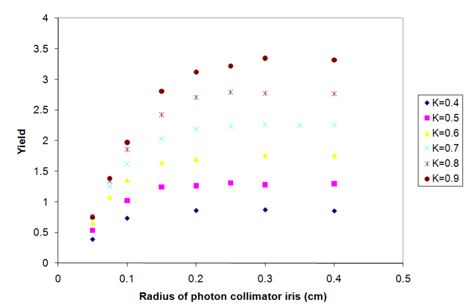

Figure 4: Yield of 100 m long undulator using FC.

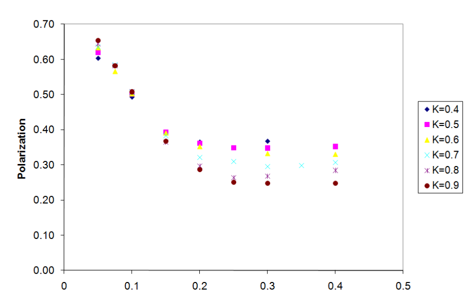

Figure 5: Pol. of a 100 m long undulator using FC.

λ_u=1.15 cm. The polarization of the captured positrons is slightly higher than 30%.

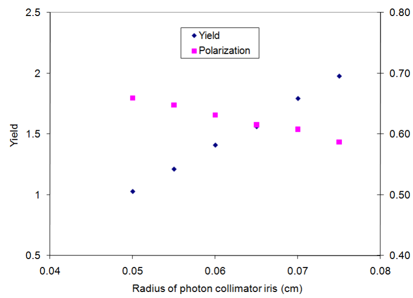

Figure 6: Yield and polarization of a 150 m long undulator with K=0.9, λ_u=1.15 cm.

As shown in Figures 4 and 5, for a CLIC main beam energy of 250 GeV, the highest yield and polarization happens with K=0.9. In order to find the collimator setting for 60% polarization, the collimator iris settings for a 150 m long undulator with K=0.9 and λ_u=1.15 cm were scanned and the results are shown in Figure 6. When the polarization is ~60%, the corresponding yield of captured positron beam is about 1.78 and the photon collimator is 0.7 mm in radius. Based on these results, if operating the undulator with K=0.9 and λ_u=1.15 cm using a photon collimator with an iris 0.7 mm in radius with 0.4 X_0 Ti target located 400 m away from the end of undulator, a yield of 1.5 and polarization of 60% can be reached with a 127 m long undulator.

Compared to the AMD, FC deflects away those positrons with larger divergence angle which usually have lower polarization and thus enhances the polarization of the captured positron beam.

Energy lost from the CLIC main beam

If FC is used as the OMD, in order to have a captured positron yield of 1.5 and polarization of 60%, one need to have a 127 m long undulator with K=0.9 and λ_u=1.15 cm. After a 250 GeV CLIC main beam passes through the 127 m long undulator it will radiate 6.9 GeV into photons. With a photon collimator with an iris of 0.7mm in front of a 0.4X0 Ti target located 400m away from the end of undulator, the total energy of collimated photons is about 4.83 GeV per 250 GeV drive electron. Given the CLIC beam parameters of 312 bunches per train, 4×10^9 electrons per bunch and a repetition rate of 50 Hz, the power carried in the photon flux is about 69 kW and the power collimated is about 48.2 kW.

Effect on the CLIC main beam emittance

For the effect of the helical undulator insertion on the CLIC main beam emittance, our previous study [9] has shown that the change of emittance after an electron beam passes through a helical undulator is:

$$\Delta\varepsilon_n = -\varepsilon_n \frac{|\Delta E|}{E} + (\beta_0 + \frac{L^2}{3\beta_0})\frac{K}{\gamma}\frac{1}{E^2}\frac{\hbar\omega_{\max}}{2}|\Delta E| \quad (1)$$

where $\omega_{\max}$ is the cut off frequency of the first harmonic, L is the length of the undulator, ΔE is the energy lost in the undulator, and E is the energy of injected beam. Using equation (1) and the beam parameters from [5], a simple calculation shows that for a 127 m long undulator with K=0.9 and λ_u=1.15 cm, the horizontal emittance will be reduced by about 16 nm-rad and the vertical emittance will be increased by 1 nm-rad if there isn't any additional optics to control the beam profile. A similar study with ILC undulator based positron source[9] has shown that when proper FODO lattices are used in between undulator modules, both horizontal and vertical emittance of drive electron beam will keep damping down until it meets the equilibrium:

$$\varepsilon_{equilibrium} = (\beta_0 + \frac{L_0^2}{3\beta_0})\frac{K}{\gamma}\frac{1}{E^2}\frac{\hbar\omega_{\max}}{2}|\Delta E| \quad (2)$$

where L_0 is the length of each undulator module.

SUMMARY

Based on the simulation results, the captured yield of 1.5 and polarization of 60% can be achieved by using a 127 m long undulator with K=0.9, λ_u=1.15 cm and a photon collimator with an iris of 0.7 mm with a 0.4 X_0 Ti target located 400 m away from the end of the undulator together with a flux concentrator. A more detailed study with e+ transported down to the injector is needed to be done and reported in the future.

ACKNOWLEGMENT

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