Simulations of the ILC positron source with 120 GeV electron drive beam

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The International Linear Collider (ILC) baseline design includes an undulator-based positron source. The accelerated electron beam will be used for the positron generation before it goes to the collision point. For the whole ILC energy range the source has to generate 1.5 positrons per electron. However, the efficiency of positron production goes down with decreasing electron drive beam energy. This effect can be compensated to some extend by the choice of undulator parameters and an optimized capture section. This simulation study considers, for the range of electron beam energies down to low values of 120 GeV, the feasibility of achieving the required positron yield. In particular, the optimum parameters for the undulator and capture section of the source at 120 GeV electron beam are presented.

1 INRODUCTION

The baseline design of the International Linear Collider (ILC) is focused on center-of-mass energies of 500 GeV and 350 GeV; operation at low energies and upgrade to energy of 1 TeV is foreseen. The undulator based positron source placed at the end of the main electron accelerator uses the main electron beam for the positron generation. The discovery of a Higgs boson with 126 GeV mass at the Large Hadron Collider suggests a staged approach in building the ILC. Starting with a Higgs factory at a center-of-mass energy of 250 GeV as first phase of the ILC project requires a proper working of the positron source. However, the efficiency of the undulator-based source goes down rapidly at lower drive beam energies. Therefore, in this work, the positron yield and polarization have been calculated for a 120 GeV electron beam and different settings of the undulator and positron capture system.

2 POSITRON GENERATION

The positrons are produced in a thin metal target by multi-MeV photons generated by the electron main linac beam in an helical undulator. The generated positrons are focused first in a flux concentrator (FC) and after that they are captured and accelerated in RF cavities. At energies 125 MeV the positrons are separated from the electrons and photons. The positron beam is accelerated further to 5 GeV and injected into the damping ring (DR).

To simulate the positron production and capture, the Geant4-based code named PPS-Sim has been used [1]. The simplified models of all source parts up to 125 MeV point have been implemented in PPS-Sim. The DR acceptance is emulated at 125 MeV as a series of cuts: the sum of x and y normalized emittances $\epsilon_{nx} + \epsilon_{ny} < 0.07$ rad m; the energy spread is less ±37.5 MeV; the longitudinal bunch size Δz is less 34 mm. According to the ILC requirements [2], the source should have 50% safety margin. That means the source has to deliver to the DR 1.5 positrons per electron going through the undulator.

Due to relatively low conversion efficiency of photons into e^+e^- pairs (below one percent at low drive beam energy), the undulator has to be long enough. ILC design reserves a space for 231 meters of active undulator (magnet) length. The total length of the undulator lattice is about 320 meters. The space between the end of the undulator and the target is 412 meters. The period of undulator is 11.5 mm and the highest K value is 0.92. The prototype of undulator module has been developed and tested at Daresbury [3].

The efficiency of e^+ generation in Ti6Al4V target of different thicknesses is shown in Fig. 1 for a 120 GeV electron beam and an undulator K value of 0.92. The positron yield after the target, normalized per electron going through the undulator, is shown in Fig. 1 by the blue curve. The yield reaches a maximum value of 5.6 e^+/e^- at the target thickness of 14 mm. This thickness is equal to 0.4 radiation length. Though the yield after the target is much higher than 1.5, the quality of positron beam (high divergence angles and big emittance) results in significant positron losses on the way to the DR. The green curve in Fig. 1 shows the yield after the target that fits into the DR emittance acceptance.

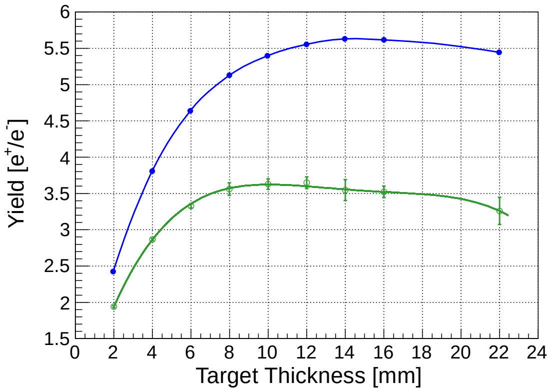

Figure 1: Yield after target without any cuts (blue curve) and with DR emittance acceptance cut (green curve) versus thickness of target. $E_{e^-} = 120\,\text{GeV}$, 231 m undulator with $K = 0.92$ and 11.5 mm period.

Figure 2 shows the yield at 125 MeV point with all DR acceptance parameters (emittance, energy spread and longitudinal bunch size Δz) taken into account . To see impact of Δz cut on the yield, two different Δz cuts (34 mm and 9.6 mm) were applied. The tighter 9.6 mm cut was selected due to historical reasons. Some of our previous simulations were done with a bunch length cut that is equivalent to the electric field phase of ± 7.5 degree at 1.3 GHz.

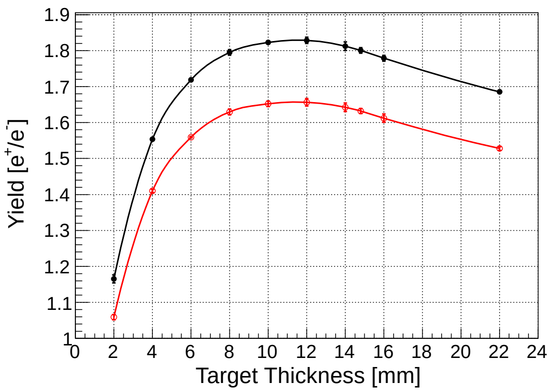

Figure 2: Yield at 125 MeV vs target thickness for 34 mm bunch length cut (black curve) and 9.6 mm (red curve).

The comparison of the yield values in Fig. 1 and Fig. 2 indicates that the positron losses between the target and DR is about 70%. The complete optimization of positron capture and transport system is out of scope of this paper but some of the characteristic tendencies will be shown in the next sections.

3 POSITRON CAPTURE

For positron capture after the target, a pulsed flux concentrator (FC) was chosen as a magnetic focusing device of the ILC source. The ideal field inside the FC along the symmetry axis z is described by the following function: $B(z) = B_0/(1 + g\,z)$, where B_0 is the initial (highest) field close to the entry face of the FC and g is the taper parameter.

The variation of g for the fixed fields at start and end of the FC requires adjusting of the FC length. The impact of the taper parameter on the positron yield is relatively small, as shown in Fig. 3 for g values between 0.03 and 0.075 mm^{-1} and a B field changed from 3.2 T to 0.5 T.

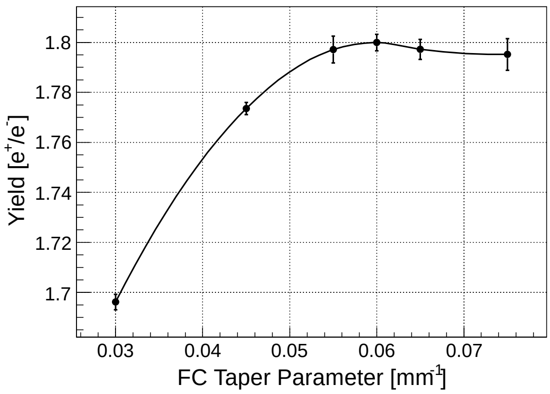

Figure 3: Yield vs taper parameter of flux concentrator.

The yield dependence on the initial field B_0 for $g = 0.06\ \text{mm}^{-1}$ (9 cm length of FC) is shown in Fig. 4. This figure and all other figures below includes simulation results for two bunch length cuts (34 mm shown in black and 9.6 mm shown in red). The current development of the FC in LLNL [4] having a maximal field of 3.2 T will perfectly fit to the source operation at 120 GeV.

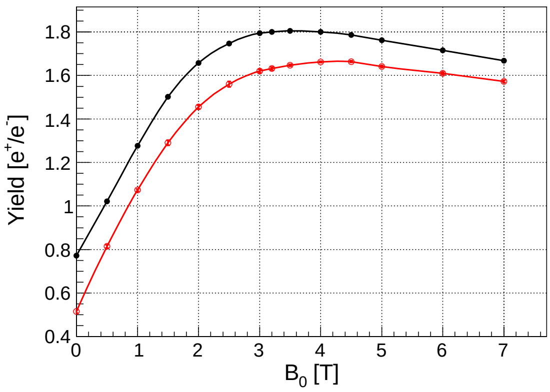

Figure 4: Yield vs initial field of flux concentrator.

The reduction of the electron beam energy increases the photon spot size on the target. For the case of using the full available length of the undulator with highest K (0.92) and 120 GeV e^- beam, the average radius of photons is about 5 mm. Therefore, the proper choice of the aperture size of the FC (R_{FC}) becomes important. Figure 5 shows the yield versus different R_{FC}. A significant fraction of positrons will be absorbed in the FC with radii less than 8.5 mm. The small aperture reduces the source efficiency and increases the heat load in the FC.

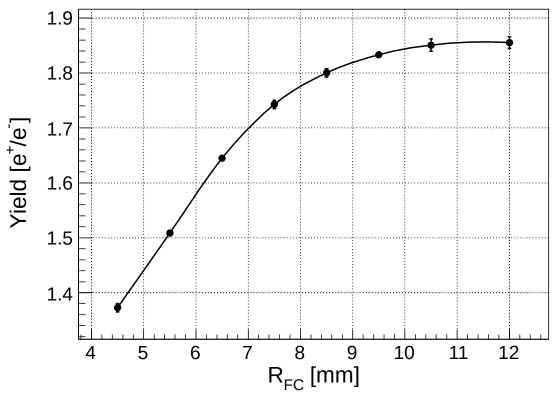

Figure 5: Yield vs initial (entry) aperture radius of FC. $E_{e^-} = 120\,\mathrm{GeV}$, $K = 0.92$, $B_0 = 3.2$ T.

4 POSITRON POLARIZATION

The polarization of a source without photon collimator can be increased by a reduction of the undulator field. For a source with a fixed undulator length, the efficiency of photon generation is smaller in the case of using a lower-field (lower-K) undulators. For example, the reduction of K from 0.92 to 0.76 results in a reduction of the undulator photon yield from 1.95 to 1.39 positrons per electron and meter of undulator. The higher cut-off energy of the first harmonic E_1 (for example, $E_1 = 6.44$ MeV for $K = 0.92$ and $E_1 = 7.54$ MeV for $K = 0.76$) can not compensate the reduction of photon yield. The positron yield dependence on K is in Fig. 6 (left plot) for two different longitudinal bunch length cuts 34 mm (black curve) and 9.6 mm (red curve). The positron polarization is about 31% at 1.5 e^+/e^- yield, see the right plot in Fig. 6.

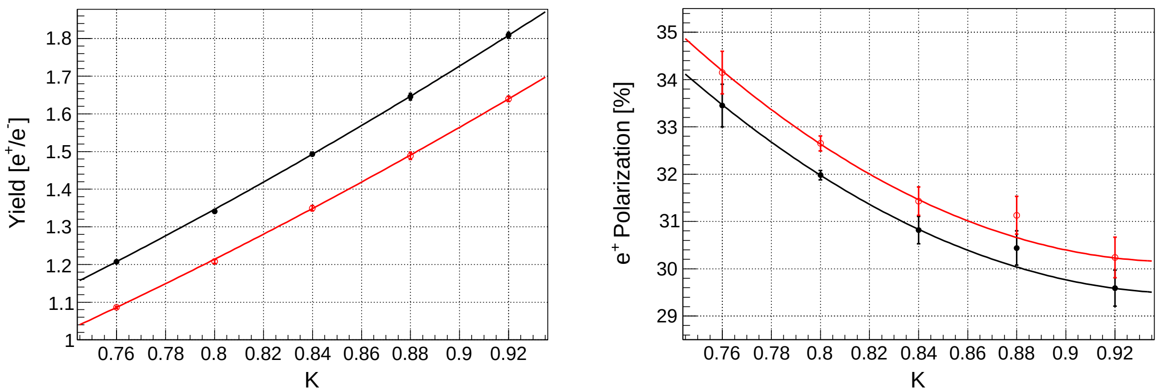

Figure 6: Positron yield (left) and polarization (right) vs undulator K value.

Another more efficient way to increase the polarization of positrons is to apply a photon collimator upstream the target. The e^+ yield and polarization for different aperture radii of collimator R_{col} are shown in Fig. 7. The highest e^+ polarization at 120 GeV is approx. 40% with 3.5 mm radius of the collimator and an undulator K of 0.92. The polarization without collimator is about 30%.

5 SUMMARY

At 120 GeV electron drive beam energy, the positron source based on a 231 m helical undulator with 11.5 mm period and a K value of 0.92 generates 5.6 e^+/e^- in a $0.4X_0$ thick Ti6Al4V target. The choice of a pulsed flux concentrator with 3.2 Tesla peak field on axis and a radius of entry aperture increased to 8.5 mm provides the required 1.5 e^+/e^- at the end of the positron source. The highest polarization without photon

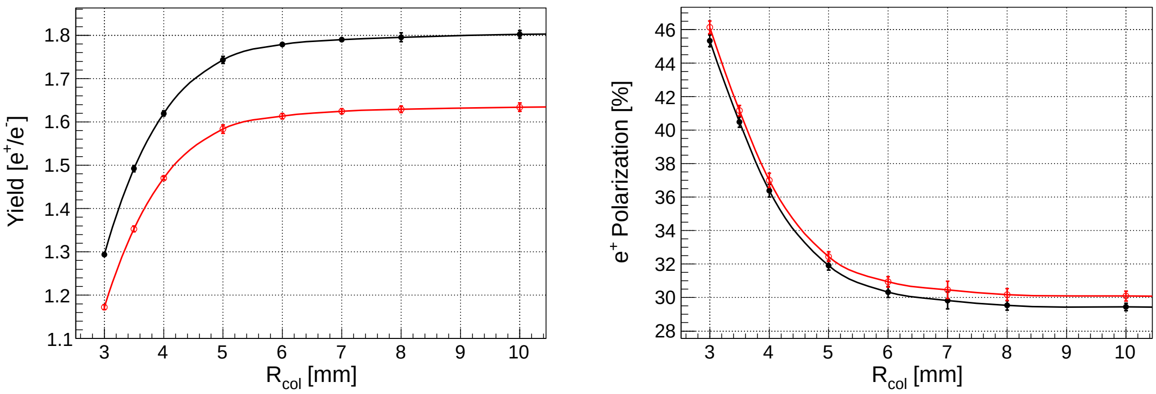

Figure 7: Positron yield (left) and polarization (right) vs aperture radius of photon collimator.

collimator between the undulator and target is 31% at slightly reduced undulator K value of 0.84. To get 40% polarization a photon collimator with 3.5 mm radius is needed.

References

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