On the ILC positron source TeV upgrade option

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Abstract:

As the positron source of the ILC is located at the end of the electron main linac, its drive beam energy will be coupled with the center mass energy of the collider. Lowering the field in the RDR undulator will keep both the positron yield to be about 1.5 and the polarization of captured positron beam to be about 30% for Ecm=350GeV and 500GeV. For the TeV upgrade, the helical undulator will be driven by ~500GeV electron beam. Simulation studies have been carried out at both DESY/University of Hamburg and ANL to explore the options of the ILC undulator based positron source for the TeV upgrade.

Assumptions and constrains

Studies have shown that the ILC positron source target system will be activated and need a sophisticated remote handling system. Relocating the target system will thus result in additional civil constructions, relocation of the down stream beamline elements and probably reoptimization of beamline lattice too. To minimize the cost and change in the existing positron source subsystem, we assume that the location of target station will be fixed at its current position.

Without the above constrain, the simplest solution would be using the same RDR undulator and pushing the target system further down stream to allow the photon beam to spread out just enough to reduce the peak energy deposition down to a manageable level. A simple scaling leads us to a doubled drift distance (800m) from the end of the undulator to the target.

Goal and considerations

It is desired to achieve ~30% polarization for the captured positron beam without using photon collimator. But for the beginning we ignore this and just keep the requirement on the captured yield of 1.5 positrons per electron.

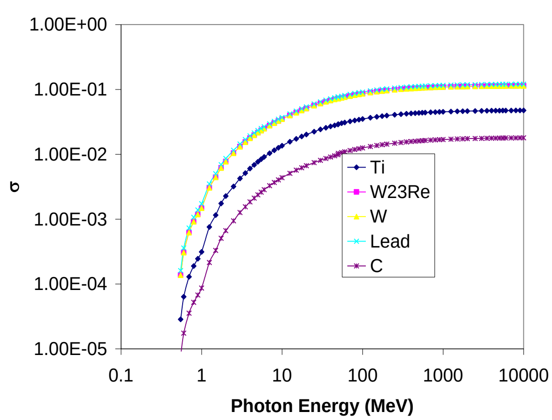

Figure 1. Pair production cross section

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Figure 1 shows the pair production cross section of several target material candidates. In order to minimize the number of positrons produced by less favored photons and to achieve a higher polarization of the captured positron beam without photon collimator, one would like to have 1st harmonics critical (cut-off?) energy to be around 10MeV and definitely below 100MeV. This keeps also the energy spread of the positron beam small: In principal, the positrons produced from the pair production can have energies from ~1MeV up to the energy of the incoming photon. Higher the photon energy, higher the energy spread of positron beam will be.
In equation (1) the photon number spectrum for helical undulator is given.

$$\frac{dNph}{dE}\left[\frac{1}{m\,MeV}\right] = \frac{10^6 e^2}{4\pi\varepsilon_0 c^2 h^2}\frac{K^2}{\gamma^2}\sum_1^\infty \left(J_n'(x)^2 + \left[\frac{\alpha_n}{K}-\frac{n}{x}\right]^2 J_n(x)^2\right) \qquad (1)$$

where:

$$\begin{aligned}
\alpha_n^2 &= \left[n\frac{\omega_1(1+K^2)}{\omega} - 1 - K^2\right] \geq 0 \\
x &= 2K\frac{\omega}{\omega_1(1+K^2)}\alpha_n \\
J_n &= Bessel \quad functions \\
K &= 0.934 * B[T] * \lambda_u[cm] \\
E_1 &= \hbar\omega_1 = \hbar\frac{4\pi\gamma^2 c}{(1+K^2)\lambda_u}
\end{aligned} \qquad (2)$$

As shown in equation (2), the 1st harmonic critical energy is proportional to the square of drive beam energy. Increasing the drive beam energy to 500GeV for the TeV upgrade will quadruple the 1st harmonic critical energy compared with 250GeV drive beam for the same undulator. To bring the 1st harmonic energy back down, we can increase the undulator period length and/or increase K. However, an increased K will increase the higher order harmonics contents and thus waste photon energies. The better option is to increase the length of the undulator period.

Numerical simulation results

Figure 2 shows the yield and polarization of the positron source for different undulator period lengths. The length of the undulator is fixed to 231m and the optical match device(OMD) used in the simulation is a quarter wave transformer (QWT). As shown in figure 2, for a fixed K=1 and fixed 231m length of undulator, an undulator with

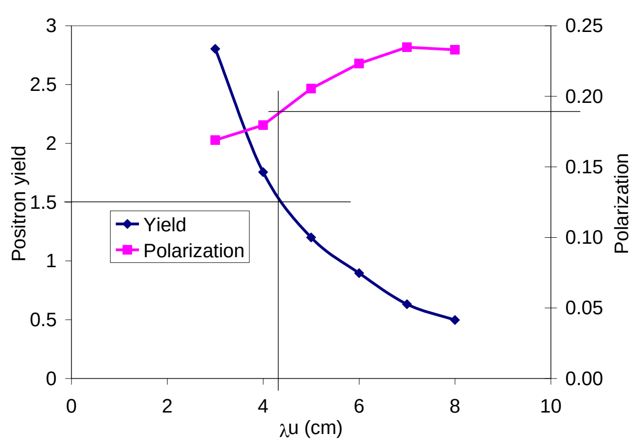

Figure 2. Yield and Pol of 231m long undulator driven by 500GeV electron beam using QWT as OMD

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period of 4.3cm will give us the desired positron yield of 1.5. The simulation for K=1 and undulator period length of 4.3cm has shown that the yield will increase to 2.62, if a flux concentrator (FC) is used as OMD. Thus only a 132m long undulator will be needed.

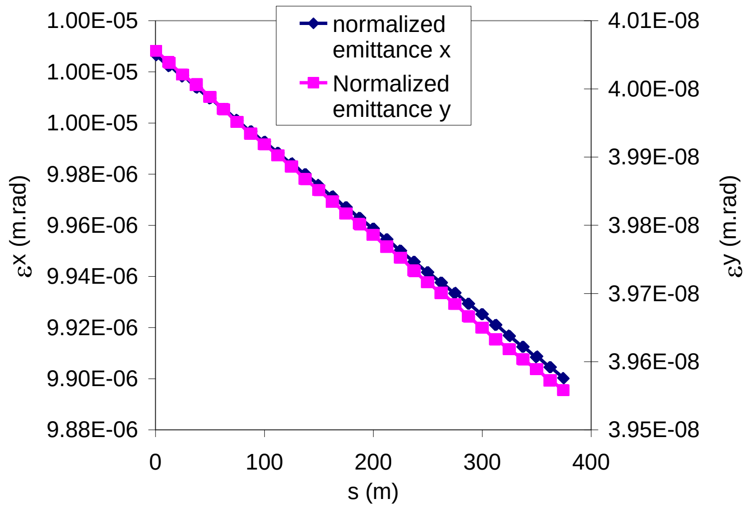

Figure 3. The emittance evolution of 500GeV drive electron beam passing through an undulator with K=1 and λu=4.3cm

We also studied the impact of the undulator to the drive electron beam parameters. The results are shown in figure 3 for the emittance and in figure 4 for the energy and energy spread. The results in figure 3 show that without Quad BPM misalignment error, the drive beam emittance will be damping down when passing through the undulator. The results in figure 4 indicate that the drive electron beam energy spread will increase almost linearly from ~0.2% to ~0.23% with about 400m long undulator beamline

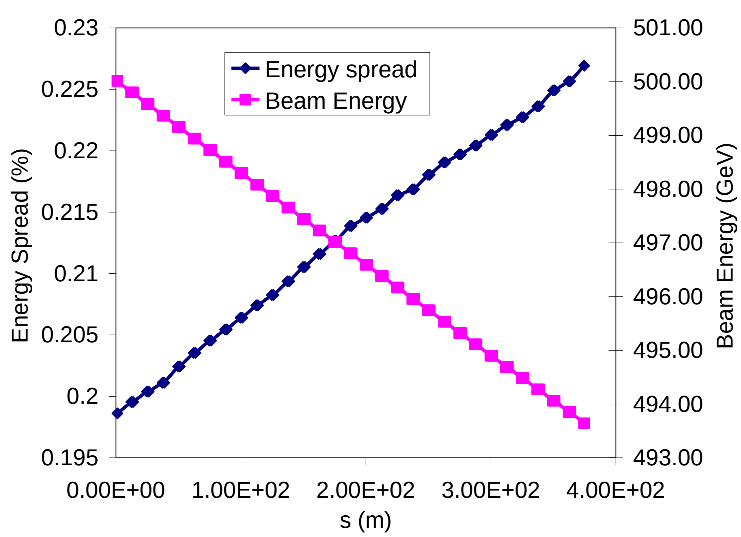

Figure 4. The energy and energy spread of 500GeV drive electron beam passing through an undulator with K=1 and λu=4.3cm

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Preliminary results on polarization

As shown in figure 2, the polarization of the proposed source is just about 20%. In order to achieve a higher polarization for the positron source, a photon collimator has to be applied. We also need to compensate the number of photons dumped in the collimator by using a longer undulator or increase the field of undulator. A preliminary study result is given in figure 5 where we scanned the photon collimator iris for undulator with fixed K=1.5 and 4 different undulator period length. The result shows that the polarization does not improve much with increasing undulator period length. However, high positron polarization requires a small collimator iris so that a large fraction of the photon beam is absorbed in the collimator. Hence, the criteria of choosing the undulator parameters will depend on other parameters like energy depositon in the target and impact on the drive electron beam. More detailed studies and optimizations are needed in order to upgrade the positron source with higher polarization for a TeV ILC.

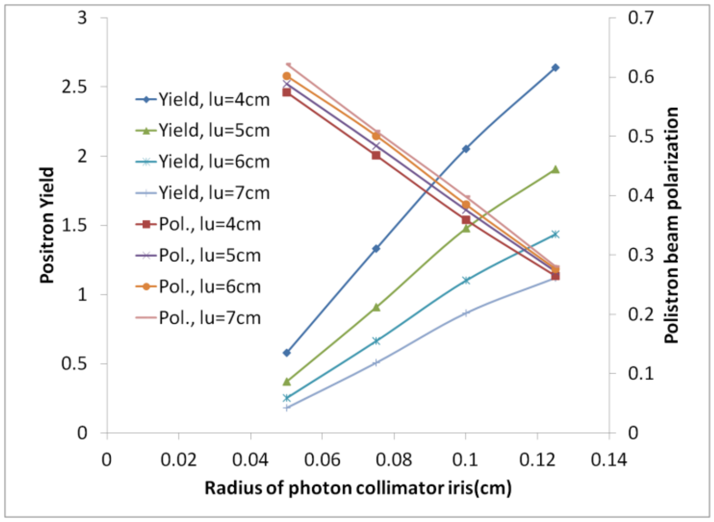

Figure 5. Yield and polarization of positron source with 500GeV drive beam and different photon collimator iris settings for undulator with K=1.5 and λu=4,5,6 and 7cm. The length of undulator in this set of data is 147m long and a TDR FC is used as OMD

Summary

Simulation studies on the ILC positron source option for TeV upgrade have been carried out at both DESY/University of Hamburg and ANL. Preliminary results have shown that to upgrade to TeV ILC, the ILC undulator based positron source can be upgraded to take the ~500GeV drive beam by using an undulator having K=1 with lu=4.3m period without changing other part of positron source system. There is no technical difficulty to build a longer period undulator with K=1.

More detailed studies and optimizations are needed for TeV upgrade with highly polarized positron source.

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