UPDATE ON THE ILC POSITRON SOURCE STUDY AT ANL*

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Abstract

We present an update on the ANL ILC positron source study. We examined the impact of different drive beam energies on the positron yield and polarization for the ILC RDR baseline undulator. The e^+ yield is found to drop rapidly as the drive beam energy is reduced. We studied different undulator parameters for their effect on the positron yield and polarization when working at lower drive beam energies. Using a lower K (B field level) can increase the photon energy, but it is still very difficult to bring the yield up for low drive beam energies. For 250 GeV drive beam options, we studied the RDR undulator performance as a function of K. Instead of powering off some sections of the undulator, one can also consider lowering the B field to bring the positron yield back to the desired 1.5 e^+/e^-. We also studied the liquid lead target option for the ILC positron source and performed a comparison of the energy deposition for W and Ti targets.

INTRODUCTION

In the ILC RDR (reference design report) [1], a helical undulator with K=0.92 and λ_u=1.15 cm with a 150 GeV drive beam has been chosen to be the baseline undulator. Since there is a requirement that physics runs must be possible for every energy above $\sqrt{s} = 200GeV$ and with some luminosity for calibration runs needed at $\sqrt{s} = 91GeV$ [1], it is necessary that we examine the impact of different drive beam energies on the positron yield and polarization for ILC RDR baseline undulator.

In the RDR baseline the undulator is inserted in the middle of the electron main linac beam line where the electron beam has an energy of 150 GeV under nominal conditions. Since the machine is required to be able to run at an energy as low as $\sqrt{s} = 91GeV$, while the positron yield will drop significantly when the drive beam energy is reduced as shown in this paper, it was suggested that the undulator been moved to the end of electron main beamline . Here the nominal beam energy is 250 GeV and a study of RDR undulator performance at this drive beam energy is also required. We also did a more detailed simulation of a liquid lead target and compared a Ti target and a tungsten target with respect to the accumulated energy deposition at their best performing thicknesses.

SIMULATION RESULTS

The simulation was based on the codes EGSnrc [2] and PARMELA [3]. We used EGSnrc with our numerical model of the helical undulator to simulate the process of photon radiation of the drive beam in the helical undulator to positron production in Ti target. We then use PARMELA to track the positrons till the end of positron capture where the positron beam energy is about 125 MeV. The yield and polarization of the captured positron beam is then evaluated with damping ring 6-D acceptance window of $A_x + A_y \leq 0.09$ m and $\Delta E\times\Delta z \leq (\pm 25\ \mathrm{MeV})\times(\pm 7.5^0)$. The details regarding the numerical procedure can be found in ref. [4].

Drive Beam Energy Comparison

With the ILC RDR undulator driven with a 150 GeV electron beam, the length of undulator required for achieving a yield of 1.5 is 137 m if a flux concentrator (FC) is used as OMD and 231m when a quarter wave transformer (QWT) is used as OMD. We made a comparison of drive beam energies for both scenarios.

Using the FC as OMD

As shown in Figure 1, a 137 m long ILC RDR undulator with FC as OMD will give us a yield of 1.5 and

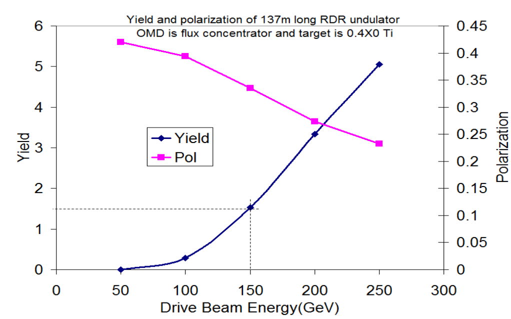

Figure 1: Yield and polarization of the 137 m long ILC RDR undulator with a flux concentrator (FC) as the optical matching device (OMD). Drive beam energy varies from 50 GeV to 250 GeV

the polarization of the captured positron beam will be about 33%. When the drive beam energy is reduced to 50 GeV, the yield is almost zero. When the drive beam energy increases to 250 GeV, the yield is about 5 and the polarization is about 22%.

Table 1: Energy lost from different drive beams using FC as OMD.

Drive beam energy	Energy loss per 100 m	Energy loss for 1.5 yield
50 GeV	225 MeV	N/A
100 GeV	900 MeV	6.37 GeV
150 GeV	2 GeV	2.7 GeV
200 GeV	3.6 GeV	2.21 GeV
250 GeV	5.6 GeV	2.27 GeV

The energy loss from the drive beam is given in Table 1. For a given undulator length, a lower energy drive

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beam will lose less energy because the photons generated will be at lower energy. But for the same positron yield of 1.5, a higher energy drive beam tends to lose less energy. When the drive beam energy goes even higher, the energy spread of positrons produced will be even larger and the capture efficiency will drop, resulting in a higher energy loss for a given positron yield.

Using QWT as the OMD

When QWT is used as OMD, in order to achieve a positron yield of 1.5 at 150 GeV drive beam energy, a 231 m long undulator is required. With this fixed length of undulator and capture optics, we simulated different

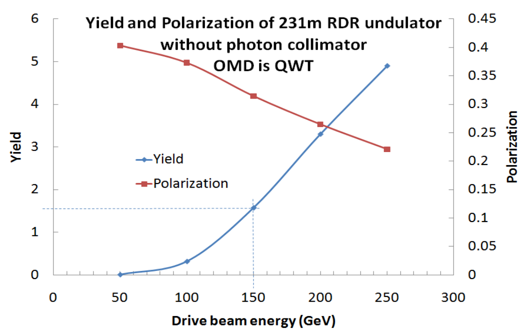

Figure 2: Yield and polarization of a positron source with 231 m long ILC RDR undulator using QWT as OMD.

scenarios with drive beam energy varying from 50 GeV to 250 GeV. The results for yield and polarization are given in Figure 2 while the results of drive beam energy loss are given in Table 2.

Table 2. Energy lost from different drive beam using QWT as OMD

Drive beam energy	Energy loss per 100 m	Energy loss for 1.5 yield
50 GeV	225 MeV	N/A
100 GeV	900 MeV	9.9 GeV
150 GeV	2 GeV	4.6 GeV
200 GeV	3.6 GeV	3.7 GeV
250 GeV	5.6 GeV	3.96 GeV

As shown in Figure 2 and Table 2, the QWT behaves very similar to the case of using the FC except that the drive beam will lose more energy for a given 1.5 positron yield because of the lower capture efficiency from the QWT.

End of Linac Operation

As shown in the previous section, the positron yield can go beyond 3 when drive beam energy is over 200 GeV. Moving the undulator to the end of the linac will then enable us to upgrade the positron source to have a higher polarization without the need to install more undulator modules. Also note that the positron yield will drop significantly when the drive beam energy is lowered, so it was suggested that the undulator be moved to the end of linac where the nominal beam energy is 250 GeV.

There are two ways to reduce the positron yield back to 1.5 when the drive beam energy is higher than 150 GeV. The straightforward method is to turn off some sections of undulator. The other is to lower the current supplied to the undulator to reduce K of undulator. Lowering K will reduce the number of photons produced and also produce more photons on the 1st harmonic which will help to improve the polarization of the resulting positron beam. As shown in Figure 3, a yield of 1.5 can be achieved by lowering K down to about 0.45. The corresponding polarization of the positron beam is about 30%.

Assuming a set of photon collimators can be inserted and replaced easily, then operating the ILC positron source with ~60% polarization and a yield of 1.5 when the drive beam energy is over 200 GeV is another option for end of linac operation.

As shown in Figure 4, with the 231 m long ILC RDR

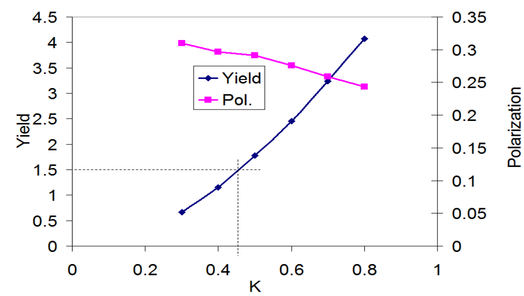

Figure 3: Yield of the positron source with 231 m long ILC RDR undulator with a 250 GeV drive beam and a QWT as OMD.

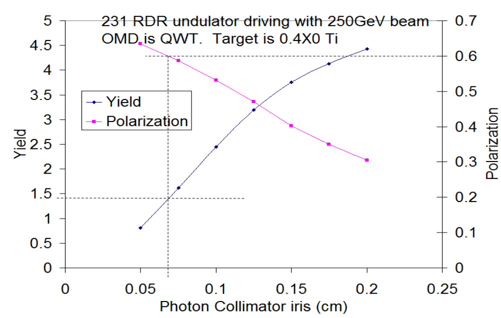

Figure 4: Yield and polarization of 231m ILC RDR undulator driving with 250 GeV electron beam.

undulator driven with a 250 GeV electron beam, 0.4 X_0 Ti target and QWT as OMD, a yield of ~1.5 and polarization of ~60% can be achieved by applying a photon collimator with an iris ~0.7 mm in radius. The same simulation run for a 200 GeV drive beam shows that this goal can be achieved with a photon collimator with an iris ~1.2 mm in radius.

Liquid Lead Target

A liquid metal target for the ILC positron source was proposed by A. Mikhailichenko for an undulator based source [5] and adapted by M. Kuriki for the ILC conventional positron source [6]. Here we present an detailed simulation for undulator based ILC positron source using a liquid lead target.

In this set of simulation, we used the 100 m long ILC RDR undulator driven with 150 GeV electron beam. The target consists of 0.5 X_0 liquid lead 500 m away from the undulator. The OMD we used is an AMD peaking at 6 T on target and decreased down to 0.5 T adiabatically in 14 cm. From the simulation, the capture efficiency is about 30% and the positron yield is 2.09 for a 100 m undulator. The energy deposition per captured positron is

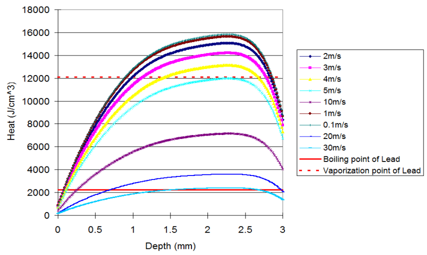

Figure 5: Accumulated energy density deposited in a 0.5 X_0 liquid lead target for different pumping speeds.

about 54.8 MeV. From the ILC RDR [1], the number of electrons per bunch is $2x10^{10}$. Given the required yield of 1.5, the captured positrons will be $3x10^{10}$ per bunch and then the per bunch energy deposition will be about 0.263 J. Using the ILC bunch repetition rate of 5 Hz, the nominal bunch train parameters (2625 bunches per train with a bunch to bunch separation of 369 ns), and the speed at which the liquid Pb is flowing, we did a calculation on the accumulation effect of energy deposition in target and the results are given in Figure 5. As shown, the liquid lead will reach its boiling point even for a 30 m/s pumping speed. But if we taken into consideration the latent heat for vaporization, pumping speeds higher than 5 m/s will keep the lead in the liquid state at its 2022 K boiling point.

Table 3: Comparison of W and Ti target

1.5 Yield, ($3x10^{10}$ e^+ captured), RDR undulator	Ti target (density=4.5 g/cm^3)				W target (density=19g/cm^3)			
	Thickness for highest yield (X_0)	Energy deposition per bunch (J.)	Average power (KW)	Peak energy density (J/cm^3)	Thickness for highest yield (X_0)	Energy deposition per bunch (J.)	Average power (KW)	Peak energy density (J/cm^3)
150 GeV drive, FC	0.3	0.4535	5.95	380	0.6	0.4260	5.59	2400
250 GeV drive, FC	0.5	0.4697	6.16	360	0.6	0.2087	2.74	2100
150 GeV drive, QWT	0.3	0.7493	9.83	610	0.6	0.8051	10.57	4550
250 GeV drive, QWT	0.5	0.8693	11.41	660	0.6	0.4468	5.86	4400

W target and Ti Target Comparison

Tungsten has higher cross section for pair production than Titanium which will naturally leads to a higher conversion rate at the target. In order to quantitatively compare these two materials, we did a set of simulations of these two materials with FC and QWT for different target thicknesses at 150 GeV and 250 GeV. We then compared these two target material at their best performing thickness.

For 100m long RDR undulator, 150GeV drive beam, using FC as OMD, W target gives the highest yield of ~1.57 when the thickness is 0.6X0 while Ti target gives its highest yield of ~1.12 when the thickness is 0.4X0 or 0.3X0. If QWT is used as OMD, the highest yield is 0.84 for W target and 0.67 for Ti target.

For 100m long RDR undulator, 250GeV drive beam, using FC as OMD, W target gives the highest yield of ~5.3 when the thickness is 1X0. But it only dropped to ~5.2 when the thickness is 0.6X0, thus 0.6X0 is chosen for W target. For Ti target, highest yield is ~4.0 when the thickness is 0.5X0. If QWT is used, the highest yield is ~2.46 for W target and 2.16 for Ti target.

The energy deposition is compared in Table 3.

SUMMARY

We studied the impact of modified drive beam parameters on the ILC RDR positron source. The results have shown that the positron yield of the undulator has a very strong dependence on the drive beam energy. For end of linac operation, we considered both lowering the K of the undulator to bring the yield back to 1.5 and using photon collimator to operate the source at a yield of 1.5 and 60% polarization. Results show that yield of 1.5 when driven by 250 GeV beam can be achieved by lowering the K down to about 0.45. The corresponding polarization of positron beam is about 30%. The yield of ~1.5 and polarization of ~60% can be achieved by applying a photon collimator with iris of ~0.7 mm in radius for 250 GeV drive beam and ~1.2 mm in radius for a 200 GeV drive beam. We also studied the liquid lead target for ILC positron source in detailed simulations and compared W and Ti targets for their best performing thicknesses at 150 GeV and 250 GeV.

ACKNOWLEGMENT

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