ELECTRON-DRIVEN POSITRON CAPTURE SIMULATION FOR ILC

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Abstract

ILC (International Linear Collider) is a next high-energy physics project to study the Higgs property as detail as possible and new phenomena beyond standard model. In ILC, the positron beam is produced by converting gamma rays from undulator radiations. To obtain gamma rays as undulator radiation, the electron beam for collision (more than 100 GeV) is used. This positron generation scheme is a totally new approach. From project point of view, it is desirable to have a technical backup as a replacement of the undulator scheme. We propose an ILC positron source based on the conventional electron driven scheme. In this scheme, positron beam is generated from electromagnetic shower in a heavy target material where electron beam is injected. By manipulating the beam time structure to relax the heat load on the production target, the scheme can be feasible technically. In this study, positron capture in the electron driven scheme is simulated from the positron production to the positron DR (Damping Ring), to demonstrate that an enough amount of positron can be generated and captured with a controllable heat load on the target.

INTRODUCTION

ILC is a e- and e+ linear collider for high energy physics to study an Higgs sector and new particles, such as SUSY particles. It is based on the Super-conducting accelerator with its CME (Center of Mass Energy) 500 GeV in the first phase. Technical Design Report of ILC has been published in 2013 [1]. In the report, positron is generated by undulator method. In this method, the driver electron beam passes through undulator and generates high energy gamma ray. The gamma ray impinges on Ti-alloy target and is converted to positron through pair-creation process. For an efficient conversion, the gamma ray energy is required at least more than 10 MeV, which needs 130 GeV drive electron beam energy with 10 mm undulator period. A dedicated electron beam for the positron generation is not realistic. High energy electron beam more than 100 GeV is shared between the collision and the positron generation. Therefore, time structure of the positron generation is fixed. This is a totally new approach as positron source and a demonstration of the system prior to the real construction is desirable, but it is practically difficult hence the demonstration require an accelerator comparable to ILC. In positron creation for ILC, heat load of the target is the biggest issue. In the undulator method, the target has to be rotated at 100 m/s tangential speed to avoid any damage in ultra high vacuum environment. The technology of such a rotating target is not fully established. By considering the risk control of a project, it is necessary to have a technical backup for a positron source of the ILC to reduces unknown technical risks related to this totally new approach.

Conventional positron generation, electron-driven positron source, for ILC has been proposed [2]. In this proposal, several GeV electron beam impinges on a W-Re target and positron is generated by Bremsstrahlung. This method requires several GeV electron beam and a dedicated electron driver is reasonable. The time structure of positron generation is determined freely. Heat load of the target is relaxed by stretching a pulse length of a bunch-train with 300 Hz linac. This relaxation enable rotating target speed to only 5 m/s. Possible target destruction is still the biggest issue. According to SLC experience, Peak Energy Deposition Density (PEDD) given by incident electron beam has to be less than 35 J/g [2].In this report, we study a design of the positron source to achieve enough amount of positron for ILC keeping PEDD less than the limit.

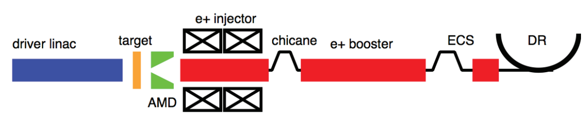

Figure 1: Layout of the ILC electron-driven positron source.

CONCEPT OF POSITRON SOURCE

ILC electron driven positron source is described in this section. The layout is shown in Fig. 1. It consists of electron linac, conversion target, AMD (Adiabatic Matching Device) for transverse momentum suppression, positron injector with focusing solenoid for positron capturing up to 250 MeV, chicane to remove electron and energy large deviated positron, positron booster up to 5 GeV, and ECS (Energy Compressor Section). Our goal is transferring an enough amount of positron to DR, whose dynamic aperture is $\gamma A_x + \gamma A_y < 0.07$ m in the transverse phase space and $z < \pm 35$ mm and $\delta < \pm 0.0075$ in longitudinal phase space, where γ is Lorenz factor, A_x and A_y are action values, and δ is relative energy deviation. As a design criteria, 50% margin on the number of positron in DR acceptance is required. Number of positron in each bunch at IP (Interaction Point) should be same as that of electron, 2.0×10^{10}. Therefore, 3.0×10^{10} positrons in the acceptance is required. The electron beam energy and bunch intensity of the driver linac is typically 6 GeV and 2.0×10^{10}, respectively. The target has typically 14 mm thickness.

Peak field of AMD is typically 5 Tesla and the field is smoothly connected to the solenoid field (0.5 Tesla) at the positron injector. AMD magnetic field is generated by Flux Concentrator, which should be similar to that designed for Super-KEKB factory at KEK, Japan [3]. The positron in-

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Table 1: A typical parameter set. Aperture is given in radius.

Parameter	Value	Unit
Drive Beam energy	6.0	GeV
Beam size	4.0	mm (RMS)
AMD peak field	5.0	Tesla
RF Gradient	25	MV/m
Injector L-band RF aperture	20	mm
Booster L-band RF aperture	17	mm
Booster S-band RF aperture	10	mm
Solenoid	0.5	Tesla

jector linac is composed of L-band NC accelerators up to 250 MeV with 0.5 Tesla solenoid field. After the injector, chicane section is placed to remove electron and positron with a large energy deviation. The positron booster is composed of L-band and S-band NC accelerators as a result of optimization which will be mentioned in the next section. The positron is accelerated by the booster linac up to 5 GeV. After the booster, ECS (Energy Compressor System) is placed. The DR acceptance for z is wide in comparison to that for δ, because the energy spread by RF curvature assuming L-band or S-band acceleration with 75 mm bunch length is much larger than 1.5%. Phase space rotation by ECS in the longitudinal phase space improves the positron distribution so as to match the DR acceptance. In other words, ECS optimizes the capture efficiency.

POSITRON CAPTURE SIMULATION

Results of the particle tracking simulations are represented in this section. Positron generated by the electron injection to W-Re target is simulated by GEANT4. The data used in this simulation are almost same as those in Ref. [2]. The data are imported to GPT [4] to perform the tracking simulation in the positron injector. After the chicane, the particle tracking is simulated by SAD [5]. As a typical example, these tracking are simulated with parameters as shown in table1.

Positron generated in the target is captured by AMD and solenoid. In the injector, not only positron but also electron are captured. Therefore, beam loading is as twice as that only with positron capture. Quantifying the beam loading effect will be studied as next issues. After the injector, chicane section is placed. Fig. 2 shows the particle distributions of before (green) and after (red) the chicane section in the longitudinal phase space ($z - \delta$). In this figure, longitudinal position shift for lower energy particles can be seen. This shift is owing to the dispersion. Capture efficiency is slightly improved with the chicane between the injector and the booster linac. Aperture at the beginning of booster linac is 17 mm, because further increment of the aperture does not increase the positron yield [6]. The longitudinal phase space distribution after ECS is shown in Fig. 3. The particle distribution is rotated by 90 deg. with ECS. The positron distribution after ECS is examined with DR acceptance; positron exists in or out of the DR acceptance.

Number of accepted positron is counted as yield which is defined as ratio of the accepted positron with number of injected electrons to the target.

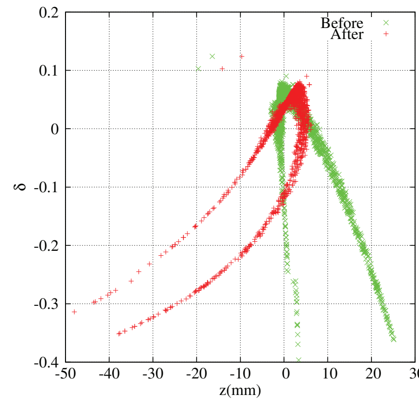

Figure 2: Particle distribution in longitudinal phase space at the end of the injector (green) and chicane (red).

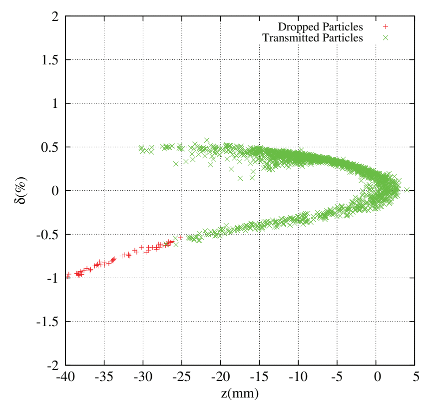

Figure 3: Particle distribution in longitudinal phase space at the end of the ECS. Green plot shows positron accepted by DR aperture and red plot shows dropped positron.

Fig. 4 shows the yield as a function of AMD aperture for three kinds of peak field. The target end is located at 5 mm upstream from where AMD field is peaked. Larger aperture gives better yield, but aperture more than 8 mm does not give any large gain. For the peak field, 5 Tesla shows the best among them at the 8 mm aperture. According to this result, 5 Tesla peak field with 8 mm aperture is an optimum.

By considering cost effectiveness, S-band accelerator is better than L-band. Up to now, our tracking is simulated with L-band structure. Here, we evaluate the yield by replacing the L-band with the S-band. The result is shown in Fig. 5. There are totally 40 cells of the lattice in the booster linac. In the figure, the yield is estimated when the L-band structures after the cell, which is described in horizontal axis, are replaced with the S-band. This figure shows that the yield is decreased when we replace large number of cells with S-band. As we mention later, the yield 1.28 gives an enough amount of positron in the DR acceptance. In this case, 26 and later cells can be replaced with the S-band. This means that the booster linac consisted of 62 L-band and 54 S-band make the yield 1.28.

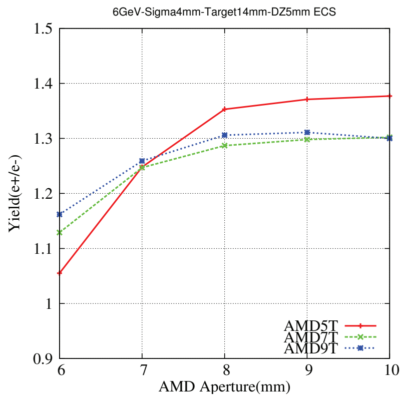

Figure 4: Yield as a function of AMD aperture for 5 Tesla (red), 7 Tesla (green), and 9 Tesla (blue) peak field. Aperture is given in radius.

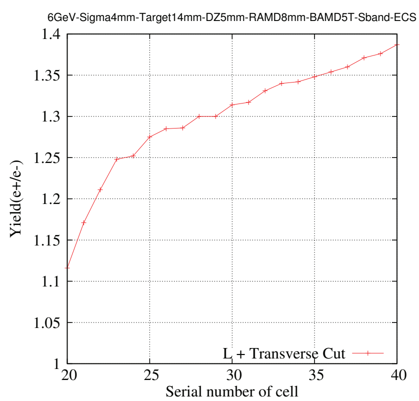

Figure 5: Yield as a function of cell number where L-band ends.

Finally, the drive electron beam and target configuration is optimized. By changing the drive beam energy, target thickness, and the spot size of the electron beam in rms, PEDD and energy deposition per bunch are varied. To compare performances of different configurations with each other, the bunch intensity of the drive electron beam is varied so as to give the same number of positron in the DR acceptance, $3.0 \times 10^{10}/bunch$, i.e. these conditions are normalized by the number of captured positron. In Fig. 6, some kinds of target and beam configurations are showed in PEDD (horizontal axis) and energy deposition per bunch (vertical axis). The numbers associated with each plots show the drive beam energy, target thickness, and the beam spot size, respectively. As a practical limit, PEDD should be less than 35 J/g to prevent any target destruction, then some conditions (right side of the vertical red line in the figure) are excluded. For the energy deposition per bunch, there is no clear threshold, however, the lower is better from technical point of view. Among these configurations, 6 GeV driver beam energy, 14 mm target thickness, and 4 mm rms spot size is the best. In this configuration, the drive beam intensity is 2.3×10^{10} electron per bunch. The yield is 1.25 which gives 3.0×10^{10} positrons per bunch in DR. PEDD is 27 J/g which is below than the practical limit.

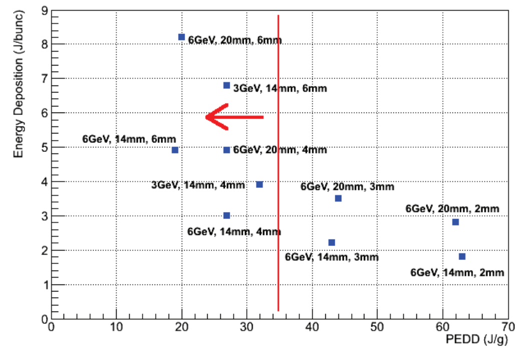

Figure 6: PEDD (J/g) and energy deposition per bunch in some configurations.

SUMMARY

We simulate a start-to-end particle tracking for the electron-driven positron source for ILC. According to this simulation, 3.0×10^{10} positron per bunch is captured in DR with PEDD 27 J/g which is below the practical limit by SLC, 35 J/g. The spot size of electron beam on the target is 4 mm (RMS) and the bunch intensity of the driver linac is 2.3×10^{10} electrons per bunch. AMD peak field is 5 Tesla with 8 mm aperture and the target end is located 5 mm upstream from where AMD field is peaked. The injector linac is consisted of L-band with 20 mm aperture and with 0.5 Tesla solenoid-focusing. The chicane section, which remove electron and positron with a large energy deviation, has slight impact on the capture efficiency. The booster linac is consisted of a hybrid of L-band and S-band structures, which have 17 mm and 10 mm aperture, respectively. ECS optimizes the capture efficiency by rotating positron distribution in longitudinal phase space.

The effect of beam loading in the positron injector will be carefully studied because the beam loading could be heavy by electrons, which give the similar beam loading since they are captured in the opposite phase compared with positron case in RF. Technical detail design for ILC should be completed in three years as global ILC schedule. After evaluating some issues, especially the beam loading effect, we will start the detail design of the electron-driven positron source for ILC.

ACKNOWLEDGEMENT

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