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AN OPTIMIZATION OF POSITRON INJECTOR OF ILC

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Abstract

ILC (International Linear Collider) is a future project of high energy physics. In the current baseline design, positron generation by gamma rays from undulator radiation is assumed. However, this approach is totally new and it is very difficult to demonstrate the system prior to the construction because it requires more than 100 GeV beam as the driver. A conventional positron generation (e- driven) has been proposed as a technical backup option. In this method, the technology is well established, but the issue is to obtain an enough amount of positron with a manageable energy deposition on target. We present a result of a systematic study of capture efficiency defined by DR (Damping Ring) acceptance where the beam emittance is reduced by radiation damping. We performed a start-to-end simulation of the positron source of ILC and found that an enough amount of the positron per bunch is obtained with a manageable energy deposition on the production target.

INTRODUCTION

International Linear Collider (ILC) is a future project of high energy physics. It is an electron and positron linear collider based on the Super-conducting accelerator with its CME (Centre of Mass Energy) 500 GeV in the first phase and 1 TeV in the second phase. The expected luminosity at 500 GeV is $2.0 \times 10^{34} cm^{-2} s^{-1}$. Technical Design Report of ILC has been published in 2013 [1]. The Japanese candidate site has been selected as Kitakami Mt. area, Iwate prefecture and the technical detail design including site specific parts (e.g. access tunnel layout, etc.) is progressed. In ILC, the positron is generated by undulator method. In this method, the driver electron beam generates high energy gamma ray by passing through undulator. The gamma ray is converted to positron by pair-creation process with Ti-alloy target. For the efficient conversion, the gamma ray energy is at least more than 10 MeV which requires 130 GeV drive electron beam energy with 10 mm undulator period. An electron linac dedicated to the driver is not realistic and the electron beam for collision is also used for the positron generation. This is a totally new approach as positron source and a system demonstration prior to the real construction is desirable, but it is therefore practically difficult. By considering the risk control on a project, it is not an ideal situation. Conventional positron generation for linear colliders has been proposed and it is also considered for ILC [2]. In this proposal, several GeV electron beam impinges on a heavy metal target (typically W-Re) and positron is generated by Bremsstrahlung. Possible target destruction is the biggest issue in this case. According to SLC experience, Peak Energy Deposition Density (PEDD) given by incident electron beam has to be less than 35 J/g. Our goal is establishing the positron injector design to achieve enough amount of positron for ILC keeping PEDD less than the limit.

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ILC ELECTRON DRIVEN POSITRON SOURCE

In this section, ILC electron driven Positron source is described. The layout is shown in fig. 1. It consists from electron linac, conversion target, AMD (Adiabatic Matching Device) for transverse momentum suppression, positron injector with focusing solenoid for positron capturing, positron booster up to 5 GeV, and ECS (Energy Compressor Section). Our goal is providing an enough amount of positron to DR whose dynamic aperture is $\gamma A_x + \gamma A_y < 0.07$ in the transverse space and $z < \pm 35mm$ and $\delta < \pm 0.0075$ in longitudinal space, where A_x and A_y are action value, δ is relative energy deviation. As a design criteria, 50% margin on the number of positron is required. Number of positron for each bunch at IP (Interaction Point) should be 2.0×10^{10}, then 3.0×10^{10} positrons in DR acceptance is required.

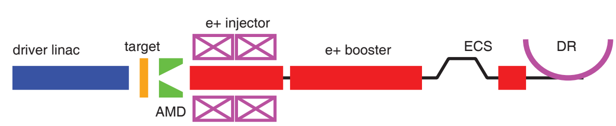

Figure 1: Layout of the ILC electron driven positron source which consists from electron linac, target, AMD, positron injector, positron booster, and ECS.

PEDD gives a practical limit on the positron intensity on the production target. It should be less than 35 J/g according to SLC experience. To compensate PEDD, 63 ms out of 199 ms which is ILC pulse interval is used for positron generation. In the 63 ms, 20 RF pulses are fired in 300 Hz. For each RF pulses, 132 bunches are contained in a form of a triplet where each mini-train contain 44 bunches with 6.15 ns spacing and the mini-train interval is 100 ns [2]. Duration and average beam current of one triplet is about 1 μs and 0.63 A and it is feasible to employ Normal Conducting (NC) RF system for the acceleration. By considering positron capture performance and cost effectiveness, L-band and S-band NC accelerator are employed.

The beam energy and bunch intensity of the driver linac is typically 6 GeV and 2.0×10^{10}, respectively. The target is 14 mm thick rotating target made from W-Re alloy which has a good conversion efficiency. The rotation could be up to 5 m/s tangential speed to suppress PEDD below 35 J/g

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Table 1: A Typical Parameter Set

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 RF aperture	20	mm
Booster RF aperture	17	mm
Solenoid	0.5	Tesla

and spread out the heat load. AMD induces a strong magnetic field along the beam axis. The peak field is typically 5 Tesla and the field is smoothly connected to the solenoid field at the positron injector, 0.5 Tesla. 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 injector linac is composed from L-band NC accelerators with 0.5 Tesla focusing solenoid field. The energy is up to 250 MeV. The positron booster is composed from 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 up to 5 GeV. After the booster, ECS (Energy Compressor Section) is placed. DR acceptance in the longitudinal space is 70 mm in z and 1.5% in δ, respectively. The z acceptance is too wide by considering the δ acceptance, because the energy spread by RF curvature assuming L-band or S-band acceleration and 70 mm bunch length is much larger than 1.5%. Phase-space rotation by ECS in the longitudinal space improves the effective area of the DR acceptance. In other words, ECS optimizes the capture efficiency.

POSITRON CAPTURE SIMULATION

In this section, tracking simulations are presented. Positron generated by the electron injection with W-Re target is simulated by GEANT4 and the data are identical to that in Ref. [2]. The data are imported to GPT to perform the tracking simulation in the positron injector. For the booster up to 5 GeV and ECS, the simulation is performed by SAD. As a reference, the simulations are performed with parameters as shown in Table1.

The particle distribution in longitudinal space at downstream of the positron injector are shown in Fig. 2. The beam energy is 250 MeV. The longitudinal phase space distribution after ECS is shown in Fig.3. The particle distribution is rotated by ECS as recognized. The particle distribution after ECS is examined with DR acceptance and number of accepted positron is counted as yield which is defined as ratio of the accepted positron with number of electron. Fig. 4 shows the yield as a function of AMD aperture for 5 Tesla (solid line), 7 Tesla (dashed line), and 9 Tesla (dotted line) 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 big gain. For the peak field, 5 Tesla shows the best among them. According to this results, 5 Tesla peak field with 8 mm aperture is an optimum.

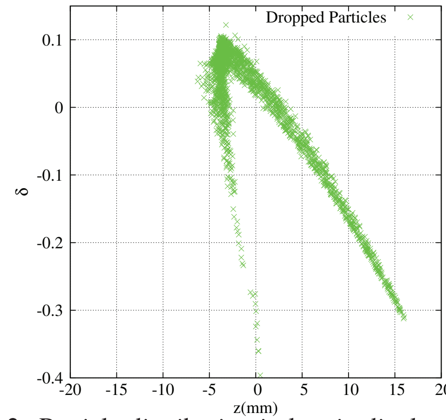

Figure 2: Particle distribution in longitudinal space at the end of the injector where the beam energy is 250 MeV.

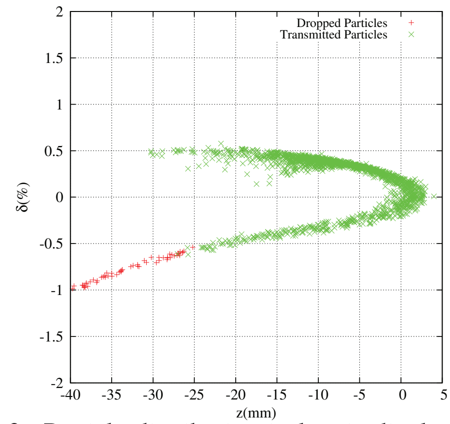

Figure 3: Particle distribution in longitudinal space after ECS.

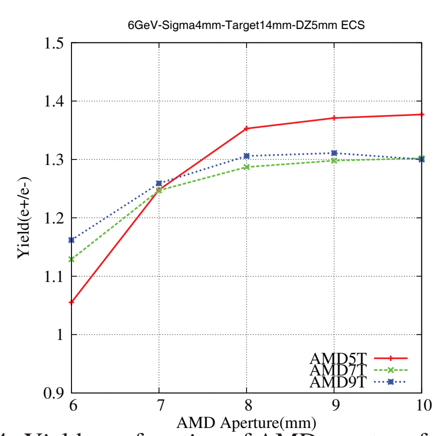

Figure 4: Yield as a function of AMD aperture for 5, 7, and 9 Tesla peak field. 5 Tesla peak field gives the best yield.

Figure 5 shows the yield as a function of aperture of accelerating structure. Larger aperture gives better yield, but the yield is already saturated at 16 mm.

By considering cost effectiveness, S-band accelerator is better than L-band. Up to now, the simulation is performed

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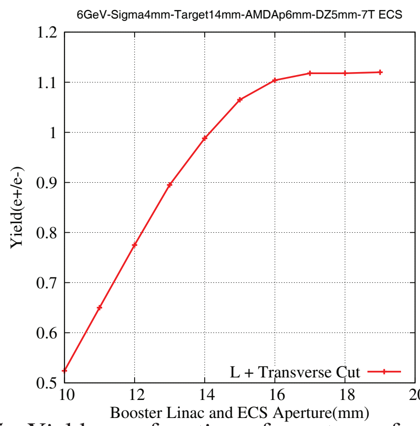

Figure 5: Yield as a function of aperture of accelerating structure.

with L-band structure. Here, we examined the yield by replacing the L-band with the S-band. The result is shown in Fig. 6. There are totally 40 cells of the lattice in the booster linac. In this figure, the yield is estimated when the L-band structures after the cell are replaced with S-band. From this plot, if we replace 28 and later cells with S-band, the yield does chage not so much. Then, as an optimum, the booster linac up to 27 cell is by L-band and 28 cell and later by S-band.

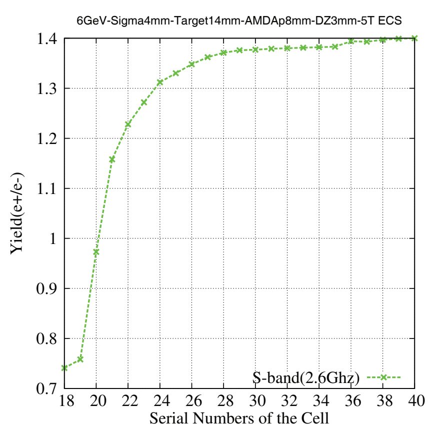

Figure 6: Yield as a function of cell number where S-band starts.

The drive beam and target configuration is optimized. By changing the drive beam energy, target thickness, and the spot size, PEDD and energy deposition per bunch are varied. To compare performance with different configurations, the bunch intensity is varied giving the same number of positron in the DR acceptance, $3.0 \times 10^{10}/bunch$,i.e. the condition is normalized by the number of captured positron. In Fig. 7, various target and beam configurations are plotted in PEDD (horizontal axis) and Energy depostion per bunch (vertical axis). The numbers associated to each points show the drive beam energy, target thickness, and the beam spot size in rms. As a practical limit, PEDD should be less than 35 J/g to prevent any target destruction and some conditions are excluded. For the energy deposition per bunch, there is no clear threshold, howevery, the lower is better from technical point of view. Among these configurations, 6 GeV driver beam energy, 14mm target thickness, and 4 mm rms spot size is the best.

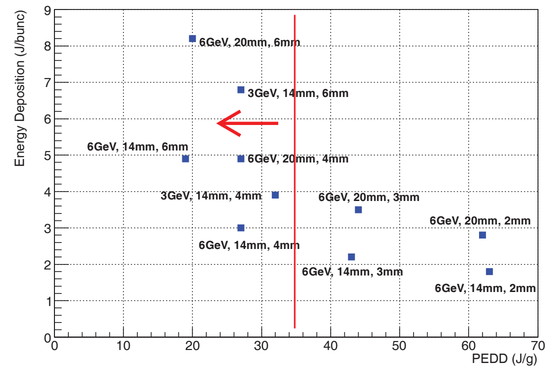

Figure 7: PEDD (J/g) and Energy deposition per bunch with various configurations. 6 GeV drive beam energy, 14 mm target thickness, and 4mm rms spot size is the best.

SUMMARY AND CONCLUSION

We perform a start-to-end simulation for the electron driven ILC positron source. According to the simulation, 3.0×10^{10} positron per bunch is obtained with PEDD 27 J/g which is below the practical limit by SLC, 35 J/g. The spot size 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. The injector linac is L-band with 0.5 Tesla solenoid-focusing. The booster linac is a hybrid of L-band and S-band structures. ECS is important for better acceptance.

ILC is now in a stage of the technical detail design which should be completed in three years. Based on the positron source design desribed in this report, we have to eastablish a technical design to synchronize to the global ILC schedule. Among various issues which should be studied before the technical design, the effect of beam loading, especially in the positron injetor should be carefully studied, because the beam loading in the positron injector can be very heavy by electrons. The electrons give the same beam loading since they are captured in the opposite phase of RF. After confirming various issues, we can start the technical design of the positron source for ILC.

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