Positron Source Simulation and Capturing Optics Studies at ANL

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We report on the simulations of the ILC positron source and capturing optics carried out at Argonne National Lab. These efforts include: numerical simulation of both the undulator-based and conventional positron sources for the ILC from the target to damping ring; investigation of the conventional approach of AMD; and simulation of the positron source emulator.

1. INTRODUCTION

Numerical simulations have become the fastest and most effective way of studying, designing, and optimizing most engineering projects. For the ILC positron source, this means we can study the properties of the positron (e+) beam before the real beamline is constructed, thus avoiding cost overruns and construction delays. The goal of this study is to model as many practical issues as possible by studying the e+ beam in a virtual environment that is as close to reality as possible. We believe that systematic numerical simulations are vital for such a large scale project like the ILC positron source.

Capitalizing on our experience with high-current, high-brightness beam dynamic simulations, we believe that we can assist the ILC project by performing numerical simulations of the e+ source beamline. The software packages we have used in our simulation efforts include EGSnrc[1] and PARMELA[2]

2. CONVENTIONAL POSITRON SOURCE

In collaboration with SLAC, we have carried out simulations on the conventional e+ source. We study the e+ yield as a function of parameters like target thickness, drive beam energy, and transverse beam size. In this paper, we define e+ yield to be the ratio of the number of captured e+ to the number of e- in the drive beam.

In the model, the electron beam strikes a target made of W23Re and we track the e+'s created from the surface of target through the beamline. The beamline consists of the adiabatic matching device (AMD), pre-accelerator linacs surrounded by focusing solenoids, and superconducting linacs with quadrupole focusing. The beam energy is about 120MeV after the pre-accelerator and 5GeV after the superconducting linacs. The e+ damping ring requirements set the acceptable phase-space window for the captured e+'s as +/- 7.5^0 with 1% energy spread. Applying this window to the e+ beam at the end of superconducting linacs, we then obtained the information of captured e+'s.

2.1. Yield vs. target thickness and drive beam energy

To study the e+ yield as a function of the drive beam energy and target thickness, we varied the drive beam energy from 2GeV to 10GeV in steps of 2GeV, and the target thickness from 1 to 8 radiation lengths steps of 1 radiation length. After post processing the output of these 40 runs, we found that the optimum target thickness increased with the drive beam energy; the higher the drive beam energy, the thicker the optimum target, and the higher the e+ yield. After normalizing the yield to the drive beam energy (e+ per GeV), it turns out that the best normalized yield occurs for a target thickness of 4 radiation lengths at an energy of 2GeV. This means that to achieve the required e+ beam intensity with a lower drive beam energy, the drive beam intensity would need to be increased and visa-versa for a higher beam energy. So from the point of view of maximizing e+ yield, high drive beam energy and thick targets are desirable. Interestingly, the incident beam power on the target is approximately constant (for target thickness greater than 4 radiation lengths) since the increase in beam intensity is offset by the decrease in beam energy. On the other hand, the total energy deposited in the target increases rapidly with target thickness, thus making lower drive beam energy desirable. After considering all of these factors, the best working point seems to be drive beam energy of 2~4GeV and a target thickness of 4~5 radiation lengths.

2.2. Yield vs. drive beam spot size

We also studied the e+ yield as a function of drive beam spot size for each energy/thickness combination above. The yield increases as the spot size ( ) decreases, but saturates for <0.5mm. To maximize the yield, should be less than 0.5mm, but to minimize the deposited energy, should be large.

3. UNDULATOR BASED POSITRON SOURCE

For the undulator-based e+ source, we followed the TESLA TDR design[3] but with a lower drive beam energy (150GeV.) The target is a titanium plate with a thickness of 1.42cm. In our beam dynamics model, the capturing optics consist of the AMD, 15 pre-accelerator linacs, 36 cryomodule-1 (one superconducting linac + one quadrupole doublet) modules and 20 crymodule-2 (8 superconducting linac + one quadrupole doublet) modules.

In the 1st stage of our study, we used undualtor parameters K=1.5, B=1.76T [3] and lowered the drive beam energy to 150GeV. We ignored the direction and polarization of the helical undulator radiation, but imported the complete spectrum into EGS. EGS simulations show that about 7% of the photon beam energy is deposited in target and 80% is transmitted through the target which causes radiation problems downstream. Simulations also show a charge excess of e- to e+ of about 60%; thus the total beam is not neutral and is visible to instruments like ICT and BPM.

PARMELA beam dynamic simulations show that the capture rate is about 27% assuming the acceptance window at the damping ring is +/-7.5^0 in RF phase and $\varepsilon_x + \varepsilon_y \leq 0.048\pi\ m.rad$. Post processing of the simulation data indicates that for 3 nC of captured e+, the power deposited into the beamline due to lost particles is 16 kW. Most of the lost power will be deposited into the first few pre-accelerator linacs, within 10 meters of the target. Some of the particles will be back fired into the target and cause an additional 0.5 kW of power deposit in the target.

In the 2nd stage of our study, we adopted the ILC undulator parameters K=1, u=1cm and 150GeV drive beam energy; implemented a more accurate numerical model with the effects of undulator length, collimator parameters, drive beam profile; and considered a strong AMD field inside the target. We found that the AMD field inside the target only creates a negligible perturbation on the e+ phase space distribution exiting from the target surface and thus excluded it from the final model. Using this model, we studied: the yield for different drive beam energy; the yield and polarization for different collimator settings; the yield and polarization for different photon spot size on the target with fixed collimator settings; and the yield and polarization contribution from different radiation harmonics.

Limited by the space available here, we only present a brief summary of our simulation results with the details to follow in a subsequent report. Our results show (1) A higher drive beam energy produces a higher e+ yield. For the ILC baseline helical undulator, the best yield, with a polarization satisfying the ILC requirements, is about 0.9 e+ per e- per 100 meter of undulator length. (2) The e+ yield decreases rapidly when the photon beam rms spot size increases beyond 1.5mm. (3) There is an optimum collimator location and aperture for a given acceptance angle that maximizes e+ yield. Consider the case where the acceptance angle of collimator is fixed at 3.85 rad and the target is located immediately after the collimator. We simulated the e+ yield and polarization while changing the photon beam spot size on the target between 0.2mm to 3.2mm, while keeping the acceptance angle fixed. (This was held fixed by simultaneously changing both the location and iris of the collimator.) It was found that the polarization of the captured e+ beam fluctuated around 61% but the e+ yield has a maximum at about 0.92 when the photon beam has a rms spot size of about 1.4mm. (4)Higher order harmonics contributed significantly to the total e+ yield.

We also did some investigation of the positron separation optics and have a preliminary design already.

4. OTHER ACTIVITIES

4.1. Electron Emulator of Positron Source

The idea behind the electron emulator is to use a low-cost, simple e- beam, with the same phase-space distribution as the e+ beam, to study the complicated e+ capture optics and thus speed up the overall commissioning process. Our plan is to launch a low energy e- beam (compared to a e+ beam energy of 150GeV for the undulator-based and 6GeV for conventional sources) onto a specially designed target that scatters the e- beam into a phase space distribution very similar to that of the e+ beam generated by the gamma rays.

We considered several combinations of target material, target thickness, and electron beam energy with EGS in order to match the energy, energy spread, and angular distribution of the scattered e- beam with the e+ beam produced by the gamma ray shower. By bombarding a beryllium target having a thickness of 30cm with an electron beam energy of 120MeV, we found the resulting e- beam phase space to be very close to the e+ phase space distribution. This appears to be a very promising scheme for emulating the e+ source.

4.2. Adiabatic Matching Device

We also did some preliminary engineering analysis of the adiabatic matching device using a normal conducting solenoid. Our preliminary design consists of a main solenoid made of Bitter magnet, bypassing iron and several accessory solenoids. It is operating in DC mode and needs about 1.5MW to provide 5T on target surface. Further study and optimization might lower the power consumption.

References

[1] http://www.irs.inms.nrc.ca/EGSnrc/EGSnrc.html

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[3] Klaus Flottmann, Investigation toward the development of polarized and unpolarized high intensity positron sources for linear colliders, DESY 93-161