NOVEL DESIGNS FOR UNDULATOR BASED POSITRON SOURCES

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Abstract

At least three proposed future colliders (ILC, CLiC and LHeC) require a positron source with a yield greater than 10^{14} $\mathrm{e}^{+}s^{-1}$. An undulator-based positron source has the potential to provide the required yield. This design generates gamma rays by using a high energy electron beam traveling through a superconducting helical undulator. The gamma rays then pair produce in a titanium alloy target to produce positrons. This is the ILC baseline positron source.

Two drawbacks to the undulator-based positron source are that it couples the positron source to the electron beam operation and that it exhibits a low conversion efficiency of photons to positrons. A self-seeding undulator-based positron source has been proposed[1]. This starts with a low intensity positron beam which travels through the undulator to produce more positrons which are recirculated through the source to increase the intensity until the design yield is achieved. Multiple targets can be added to increase the conversion efficiency of the positron source. In this study I present simulation results for such a design and consider the feasibility of this design at the ILC, CLiC or LHeC.

INTRODUCTION

The idea for an undulator based positron source was proposed in 1979 by Balakin and Mikhailichenko[2]. The premise for this design is that when an electron beam travels through an undulator or wiggler a photon beam is generated due to the motion of the electrons, this photon beam is then used to produce positrons via Bethe-Heitler pair-production in a conversion target. Polarized positrons can be produced by ensuring that the photons incident on the conversion target are circularly polarized, the degree of polarization of the positrons is proportional to the polarization of the photon that produced it.

Undulator based polarized positron sources therefore use a helical undulator to produce photons, the photons with energies closest to those of the harmonic peaks of the spectrum have the highest polarization. The photon spectrum of a helical undulator is a function of the deflection parameter K and the period of the undulator winding λ. A helical undulator based positron source with parameters $K = 0.92$ and $\lambda = 1.15\,\mathrm{cm}$ is the baseline ILC RDR positron source[3].

The ILC RDR source design uses a conversion target 0.4 radiation lengths thick made from Ti6Al4V alloy which spins with a rim speed of $100\,\mathrm{ms}^{-1}$, this will be referred to as an RDR target. These target specifications were chosen to ensure survivability as the heat load on target from a photon beam produced by a 150 GeV drive beam and eddy currents due to the target's rotation in the capture optics' magnetic field is $\sim 20\,\mathrm{kW}$ [4]. This however means that the conversion efficiency of the photons into positrons is $\sim 2\%$ so the majority of the photon beam does not interact and is wasted. The idea of using multiple conversion targets in series is investigated below with a source using ILC RDR design parameters and up to 6 targets being simulated.

A further limitation of undulator based positron sources is the need for a high energy lepton drive beam to produce the photon beam. For $\mathrm{e}^{+}\mathrm{e}^{-}$ colliders such as the ILC this means that the electron and positron arms of the machine are interdependent. For CLiC where the undulator based positron source is a possible upgrade to produce polarized positrons there is no interdependency as there will be a full intensity positron source able to be used as the drive beam for the undulator. The idea of using positrons to create more positrons in a self-seeding positron source suitable for ILC, CLiC and LHeC is also investigated below.

A MULTI-TARGET POSITRON SOURCE

A multi-target positron source has been simulated using PPS-Sim[5] which is an interface to the Geant4[6] libraries. The layout of the multi-target source is shown in Figure 1. The 150 GeV e^{-} drive beam passes through a helical undulator to produce a photon beam. This photon beam is incident on each target in turn producing e^{-} and e^{+} which are captured by an Optical Matching Device(OMD) and then accelerated up to 125 MeV by the capture RF. The e^{+} and e^{-} then enter a dipole magnet to separate them into their respective transfer lines whilst the photons interact with the next target. After travelling through all the targets the photon beam is dumped as are the electrons produced in the targets. The positrons are then accelerated up to 5 GeV for injection to the damping ring.

The simulation of the multi-target source used ILC RDR undulator parameters with a drive beam energy of 150 GeV, an undulator length of 147 m, a Flux Concentrator as the OMD and the photon collimator radius set to 10 cm. Results from simulations with six RDR targets are shown in Figure 2. Positron yield is plotted in terms of positrons within the damping ring acceptance per electron in the undulator($\mathrm{e}^{+}/\mathrm{e}^{-}$), the requirement of the ILC design is to achieve a yield of $\mathrm{e}^{+}/\mathrm{e}^{-} = 1.5$. The yield from each of the first 5 targets is greater than the ILC design yield. Combining the positrons produced in each target into a single bunch in the damping ring the length or deflection parameter of undulator for the ILC positron source can be reduced whilst maintaining the design yield.

The effect of reducing the undulator deflection parameter on positron yield in the damping ring whilst keeping $\lambda =$

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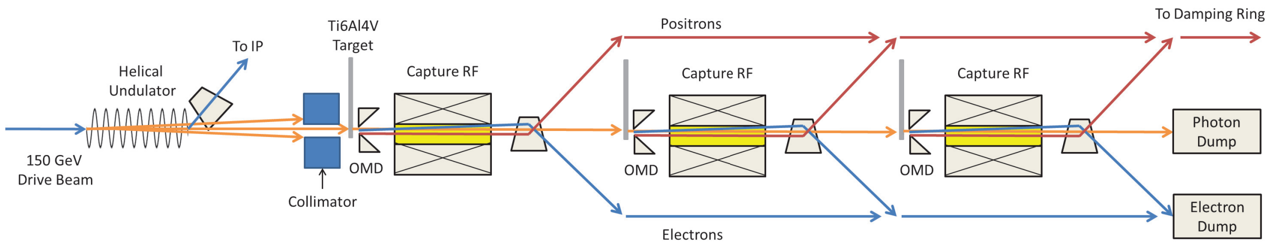

Figure 1: Schematic of a multiple target positron source with 3 conversion targets. Red arrows represent e^+, blue arrows represent e^- and orange arrows represent γ. The Optical Matching Device(OMD) can be a Quarter Wave Transformer(QWT), Adiabatic Matching Device(AMD) or a Flux Concentrator(FC).

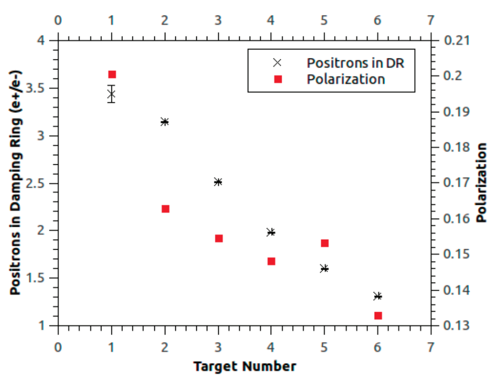

Figure 2: Plot of yield and polarization for 6 targets with $K = 0.92$ and $\lambda = 1.15$ cm.

1.15 cm is shown in Figure 3. As expected as the target number increases the yield from each target decreases. Of interest is the yield of the first and second targets when K is between 0.50 and 0.78 as the yield is in fact higher in the second target compared to the first.

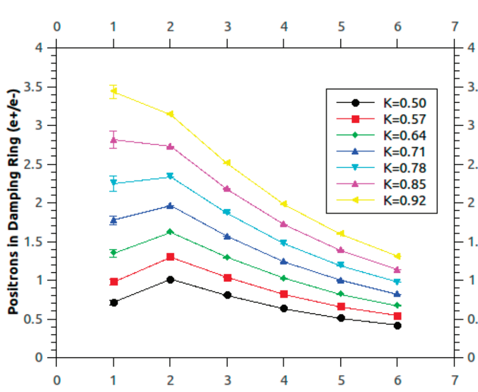

Figure 3: Plot of yield for 6 targets with undulator period $\lambda = 1.15$ cm and varying values of K.

Assuming that the positrons produced in multiple targets can be captured and injected into one bucket in the damping ring the yield and polarization for a 6 target positron source as a function of K is shown in Figure 4. This assumption is a relatively safe one as only positrons that are within the damping ring acceptance are included and the spread in time of arrival of positron bunches from different targets into the damping ring is of the order of picoseconds.

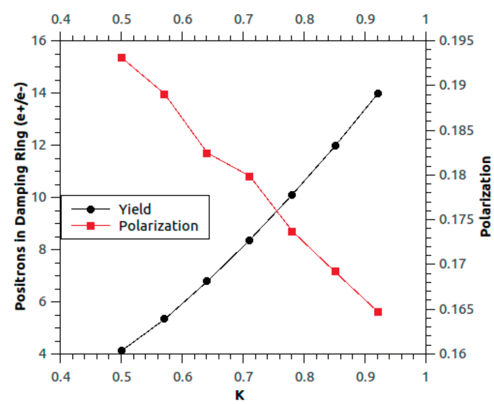

Figure 4: Plot of yield and polarization in damping ring from a 6 target positron source with undulator period $\lambda = 1.15$ cm as a function of K.

This source with 6 RDR targets produces a yield of between 4 and 14 e^+/e^- depending on the choice of K. This means that other parameters of the positron source can be relaxed such as undulator length.

A SELF-SEEDING POSITRON SOURCE

A self-seeding positron source is one which starts with a low intensity positron beam and uses this low intensity beam to produce a higher intensity positron beam. A self-seeding source at the ILC or LHeC would comprise of a conventional positron source and an undulator based positron source. A conventional positron source uses an electron drive beam with energy of about 5 GeV incident on a conversion target made from a high Z material to produce positrons. In a self-seeding source these positrons would then be accelerated up to 150 GeV and pass through an undulator based positron source. The undulator based source acts as a positron amplifier which will produced more positrons than went through the undulator. This process can be repeated until the required yield is met. This type of source has been simulated for the ILC parameters.

The ILC has an auxiliary conventional positron source included to be used during commissioning. This source uses a 6 GeV electron beam and the same RDR target used by the undulator based source. It is able to produce about 2% of the yield of the undulator based source. A self-seeding source at the ILC could use this commissioning source to produce a pulse of positrons which are injected into the damping ring. This pulse would then be accelerated by the positron main linac to 150 GeV before passing through the undulator and then travelling to the IP. Each bunch as it passes through the undulator would produce a photon bunch which would produce a new positron bunch from the RDR target. This new bunch will then fill the bucket in the damping ring that was occupied by the bunch that produced it.

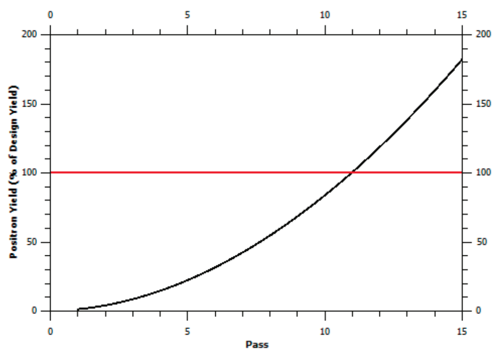

Figure 5: Plot of positron yield as a percentage of the ILC design yield for each pass through a self-seeding positron source with undulator length = 147 m, $K = 0.92$, $\lambda = 1.15$ cm and a drive beam energy of 150 GeV. The red line is the target yield.

Figure 5 shows the result of a simulation of a self-seeding source at the ILC which used ILC RDR undulator parameters with a drive beam energy of 150 GeV, an undulator length of 147 m, the Flux Concentrator as the OMD and the photon collimator radius set to 10 cm as before. The results show that the self-seeding source will reach the design intensity by pass 11, however it will then continue to increase in intensity.

The number of positrons from this self-seeding source design is given by $y = y_0(\alpha\epsilon)^j$ where y is the final number of positrons, y_0 is the initial number of positrons, α is the number of photons produced per positron in the undulator, ϵ is the number of positrons produced within the damping ring acceptance per photon and j is the number of passes through the source. This growth in intensity needs to be controlled by a feedback system to ensure the positron yield will stay as close to the design yield as possible. Two options to control this growth in intensity are to either turn down the current in the undulator and thus lower K or turn off individual undulator modules. The undulator positron source simulated has an efficiency of 0.7% of photons producing positrons within the damping ring acceptance. This means that by reducing K from 0.92 to 0.63 the intensity will stabilise.

A self-seeding positron source at LHeC could be very similar to the one at the ILC however due to the greater yield requirements and restrictions on the energy of the undulator drive beam multiple targets or even sources will be required. Work is currently ongoing to investigate the exact specifications of such a source for LHeC.

A self-seeding source at CLiC could be very different to one at the ILC or LHeC as CLiC already has a full intensity positron source and the aim of an undulator based source at CLiC would be to deliver high polarization. There are two possible options for a self-seeding source at CLiC. One is to optimize the source for polarization and use the full intensity unpolarized positron source as a drive beam for the undulator. This would mean that the positron pulse trains at the interaction point would alternate between unpolarized or highly polarized($\sim 60\%$) and would not require a feedback system as the positrons produced by the undulator source would not pass through it a second time. The other option would be to use the full intensity unpolarized positron source to produce the initial pulse train and then use a similar idea as described for the ILC self-seeding source. However there would be no ramp up time as the positron beam will already be at full intensity. The undulator based source will just need to maintain this yield and polarization. This design will need a feedback system to maintain the yield but all pulses will be polarized.

SUMMARY

A multi-target undulator based positron source may be a viable option for LHeC where a very high positron yield is required as it will produce more positrons than the single target undulator based source with out damaging the conversion targets. Work is continuing on refining simulations of a multi-target undulator based source for the ILC with a higher positron polarization one possible benefit of this design. The self-seeding positron source appears to be a viable concept and work is now needed to optimise the source and ensure stability of the positron yield is possible.

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