UNDULATOR BASED POSITRON SOURCE OPTIMISATION FOR CLIC *

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Abstract

CLIC will need of order 10^{14} positrons per second to achieve its specified luminosity [1]. An undulator based scheme has been proposed as one of the options for the positron source to meet this challenge. As CLIC may operate over a wide range of energy (from 0.5 TeV to 3 TeV centre of mass), there is a large scope to push the performance of the whole system to reach high efficiency. We report on the undulator parameters and optimisation of components of the source, focusing on the undulator, and the adiabatic matching device. In addition to maximising the positron yield, the polarisation of the positron beam is also considered.

INTRODUCTION

An undulator-based scheme has long been the baseline choice for the positron source for the International Linear Collider [2]. A source of this type has the benefits of producing a beam with an emittance smaller than could be obtained from a conventional source achieving the same production rate, whilst limiting thermal load and activation of the production target; and also allows for the possibility of producing a polarised positron beam by use of a helical undulator. However, an undulator-based source has the disadvantage of coupling the positron production to the high-energy electron beam. To avoid this disadvantage and still retain the possibility of producing a polarised positron beam, studies for CLIC have recently focused on a positron source based on a small electron storage ring [3], in which collisions (Compton scattering) between the electrons and photons from a laser are used to produce gamma rays; the gamma rays are then incident on a target in which positrons are generated by pair production.

However, the Compton-based source is still a novel idea with many technical challenges. It is therefore of value, despite the disadvantages associated with coupling the positron production to the high energy electron beam, to consider the use of an undulator-based positron source for CLIC. Some previous studies [4] have indicated the feasibility of such a configuration. Here, we present the results of some recent simulations from the undulator to the entrance of the positron linac following the target and adiabatic matching device. We focus attention on the positron yield and polarisation: our goal is to define a parameter set that optimises these parameters, taking account of cost issues and engineering constraints, and considering also the plan to operate CLIC in stages, with collision energy increasing from 0.5 TeV initially, to an ultimate goal of 3 TeV.

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Table 1: Undulator Parameter Options. Yield and polarisation are calculated taking capture RF and damping ring acceptance into account.

	Option 1	Option 2
Electron energy in undulator	150 GeV	250 GeV
Undulator period	11.5 mm	11.5 mm
Deflection parameter	0.92	0.92
Undulator length	100 m	32 m
Average photon energy	10.5 MeV	29.7 MeV
Power deposition in target	3.3 kW	1.8 kW
Positron yield	1.5	1.5
Positron polarisation	33%	24%

UNDULATOR PARAMETERS

Key parameters for the undulator include the energy of the electron beam, and the field strength, period, and overall length of the undulator itself. All these parameters affect the yield (positrons produced from the source per electron in the undulator) and the positron beam polarisation. Optimisation is complicated by the fact that there are several possibilities for the CLIC upgrade from 500 GeV collisions to 3 TeV collisions: for example the upgrade could be achieved either by extending the length of the linac, or (in principle) by increasing the linac gradient. In the upgrade, the undulator for the positron source could be relocated, or replaced.

The upgrade options, and their impact on the undulator optimisation, were discussed in [5]. A high electron beam energy has the advantage of providing a higher yield; however, the polarisation is reduced, and the photon energy is increased, which can make design and operation of components downstream of the undulator more difficult. Yield is also improved by reducing the undulator period; however, there is a lower limit of around 10 mm for a superconducting helical undulator, set by the difficulty of winding the coils. A higher magnetic field also improves the yield; but here, there is an upper limit set by the maximum magnetic field that can be produced without quenching the coils.

The most likely upgrade scenario for CLIC is an extension of the linac, with relocation of the undulator for the positron source. That allows a range of options for the electron beam energy, and other parameters. Two options for reasonable choices for the undulator parameters, considering technical performance and cost issues, are shown in Table 1. Note that although in principle, a yield of just one

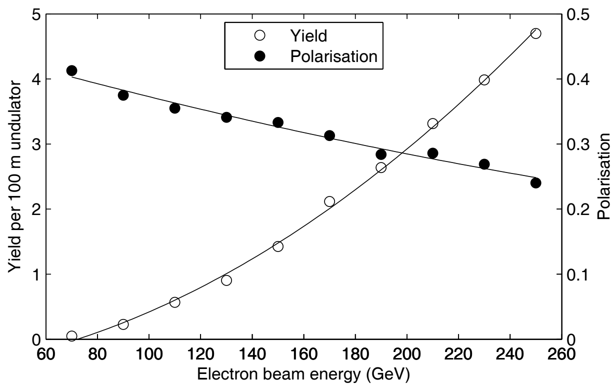

Figure 1: Positron yield and polarisation as functions of the electron beam energy in 100 m helical undulator.

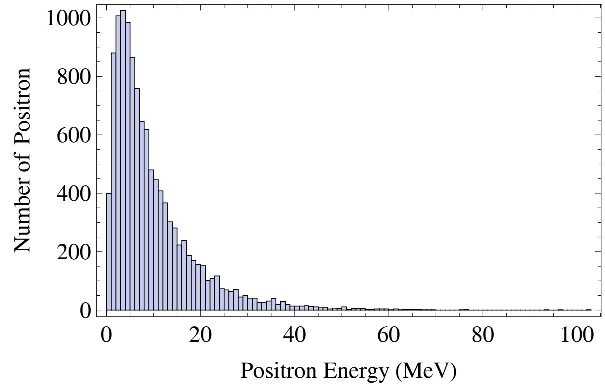

Figure 2: Positron energy spread immediately after the target, for undulator parameters Option 1.

positron per electron in the undulator is sufficient, a higher yield is needed in practice because of losses between the positron source and the interaction point.

In principle, either option could be used at each stage (for collision energy 500 GeV, or 3 TeV). Option 2 allows for a shorter undulator because of the better yield from a higher electron beam energy; however, the polarisation is lower. The precise requirements for polarisation for the physics studies at CLIC need to be understood.

Fig. 1 shows how the positron yield (per 100 m of undulator) and polarisation vary as functions of the electron beam energy between 70 GeV and 250 GeV, for fixed undulator period ($\lambda_u = 11.5$ mm) and deflection parameter ($K = 0.92$), defined in the usual way by $K = 93.4\,B[\mathrm{T}]\,\lambda_u[\mathrm{m}]$.

ADIABATIC MATCHING DEVICE

Photons from the undulator strike a target, and generate positrons by pair production. The positrons are accelerated by a linac, in which transverse focusing is provided by a uniform solenoid field of strength 0.5 T. To minimise losses, the beam at the entrance to the rf section should have a transverse phase space correctly matched to the solenoid field, which means that the phase space distribution will simply rotate as the beam moves along the solenoid, without any variation in transverse size. A beam will be correctly matched to a solenoid of field strength B_s if, at the entrance to the solenoid, the beam is characterised by a beta function with value: $\beta = 2\frac{B\rho}{B_s}$, where $B\rho$ is the beam rigidity. For the case of the positron source, it is difficult to specify the beam rigidity, since the energy distribution is very wide. However, taking an 'average' value using a typical distribution, it is found that the transverse phase space distribution would generally be matched to a solenoid field much larger than 0.5 T. Therefore, an optical component is needed to transform the phase space at the exit of the target, to the phase space matched to the 0.5 T solenoid in the first accelerating section. An adiabatic matching device (AMD) achieves this transformation, by providing a solenoid field that varies smoothly with distance z from the target:

$$B(z) = \frac{B_0}{1 + gz},$$

where g is a constant "taper parameter". Key parameters for the AMD are the initial field B_0, the value of the taper parameter, and the physical aperture. Because of the nature of the positron distribution from the target (in particular, the very wide energy spread), it is not possible to achieve a perfect match between the target and the solenoid in the linac. Optimisation of the parameters to achieve a low rate of lost positrons (i.e. a good transfer efficiency) is best done by simulation. Tracking studies can also be used to investigate the effect of the AMD on the polarisation of the beam, although the impact is expected to be small because the polarisation is predominantly in the longitudinal direction.

One difficulty with an AMD is that it produces a high magnetic field on the target. The target has to rotate at high speed to spread the energy deposition from the photon beam, and the magnetic field from the AMD then leads to large eddy currents, which create an additional thermal and mechanical load on the target. For this reason, the baseline configuration for the ILC [2] specifies a pulsed flux concentrator for matching the beam from the target to the first accelerating section: this simplifies the engineering issues, but at the cost of a lower transfer efficiency compared to an AMD. For CLIC, an AMD may be more practical, because the different time structure of the beam allows for a significantly lower rotation speed of the target wheel. Other options for the capture optics include a quarter-wave transformer.

Fig. 2 shows the energy distribution for the positrons produced from the target, using the Option 1 parameter set shown in Table 1 for the undulator. Fig. 3 shows the horizontal phase space for the positrons immediately after the target. Higher energy positrons tend to have lower values for the transverse co-ordinates and momenta.

Fig. 4 shows the variation in capture efficiency with initial field strength and taper parameter, with fixed aperture

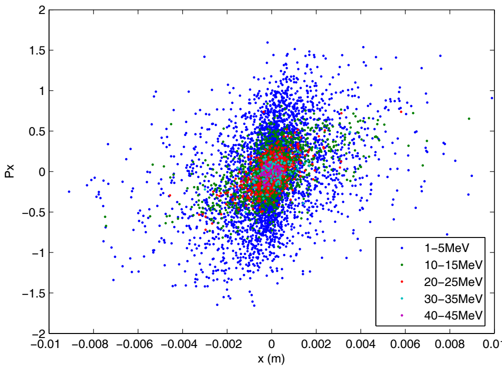

Figure 3: Positron transverse phase space immediately after the target, for undulator parameters Option 1.

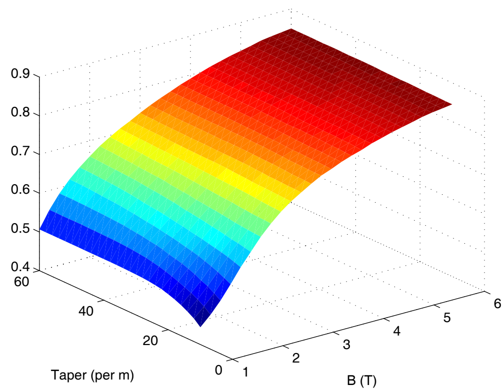

Figure 4: Positron transfer efficiency through the AMD, as functions of the AMD initial field and taper parameter, for undulator parameters Option 1.

of 30 mm for the AMD, and electron beam energy in the undulator of 150 GeV. While there is a strong dependence on field strength, the effect on the capture efficiency from changes in taper parameter is small. As expected, the beam polarisation is not significantly affected by the AMD. Specifying nominal values of 6 T for the initial field strength, and 30 m^{-1} for the taper parameter results in a transfer efficiency of 94%, and polarisation at the end of the AMD of 24%. The total length of the AMD is 366 mm.

Increasing the electron beam energy in the undulator to 250 GeV leads to a small reduction in transverse size and divergence in the positron beam from the target; but the energy spread is significantly larger. As a result, the loss rate is larger than for the case of electron beam energy 150 GeV, though the dependence on AMD initial field and taper parameter has a very similar shape. The AMD has a somewhat larger impact on the beam polarisation: Fig. 5 shows the positron polarisation as a function of the initial field strength and taper parameter. With the nominal parameters given above, the transfer efficiency with 250 GeV electron beam is 87%, and the polarisation is 18%. Note that acceptance limitations in the systems downstream of the AMD leads to loss of some positrons from the beam, and an *improvement* in the polarisation.

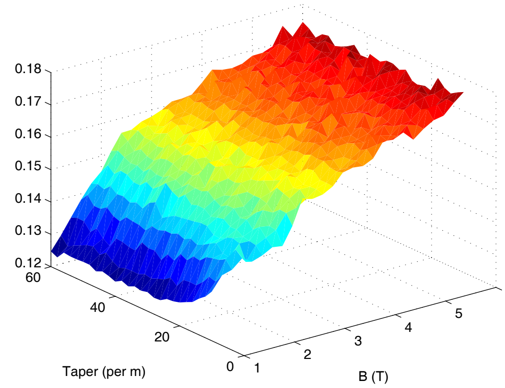

Figure 5: Positron polarisation at the exit of the AMD, as functions of the AMD initial field and taper parameter, for undulator parameters Option 2.

CONCLUSIONS

An undulator-based scheme appears to be a viable option for the CLIC positron source. There is a wide range of parameter options for the undulator, with electron beam energies in the range 150 GeV to 250 GeV providing good positron yield for reasonable undulator period and deflection parameter. A higher energy allows for a shorter undulator; however, the polarisation is reduced, and there is a higher photon energy, that increases the energy spread of the positrons from the target.

An AMD provides matching of the phase space from the target to the first accelerating section. With a high initial field (6 T), there is a good transfer efficiency; however, the eddy currents induced in the target by the field from the AMD make the engineering of this system very challenging. For this reason, alternative options for the matching device should be explored, although these are likely to lead to a reduction in transfer efficiency.

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