HIGH POWER PHOTON COLLIMATORS FOR THE ILC *

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Abstract

An undulator-based positron source has been chosen as a part of the baseline configuration [1] for the International Linear Collider. A photon collimator placed between the undulator and the target can be used to adjust the size, intensity and polarization of the photon beam impacting the target, and can also protect the target station and limit the activation of downstream components. In this paper, we calculate the energy deposition, temperature change, activation and dose rate for two different designs of the photon collimator.

INTRODUCTION

The International Linear Collider (ILC) requires a positron source capable of producing bunch trains of 2.8×10^{13} positrons at 5 Hz. Each bunch train will be 1 ms in duration, and contain between 2800 and 5600 bunches. For some of the studies proposed for the ILC, a high degree of polarization will be needed. The present ILC baseline design specifies an undulator-based positron source, in which high energy (10 MeV) photons are produced from electrons passed through an undulator; the photons impact a target, in which electron-positron pairs are created. Between the undulator and the target, a photon collimator can be used to control the properties of the photon beam [2], and to provide some protection for the target station.

Issues for the photon collimator include: effectiveness in controlling properties such as beam size and polarization; energy deposition and temperature rise; radiation dose rate and activation; and production of secondaries that may hit the target station. In this paper, we compare two designs for the photon collimator, in the context of all these issues.

PHOTON COLLIMATOR GEOMETRY

Fig. 1 shows two designs for the photon collimator. Each design consists of an inner spoiler, and an outer absorber. Model 1 [3] is 90 cm long and has an outer radius of 6 cm. The materials used for the spoilers and absorber are titanium and copper, respectively. Model 2 [4] consists of a graphite spoiler and tungsten absorber, in thermal contact with an enclosing cylinder of copper. The length is about 18 cm and the outer radius is 4 cm. The inner radius of both collimators can be chosen to optimise the properties of the photon beam.

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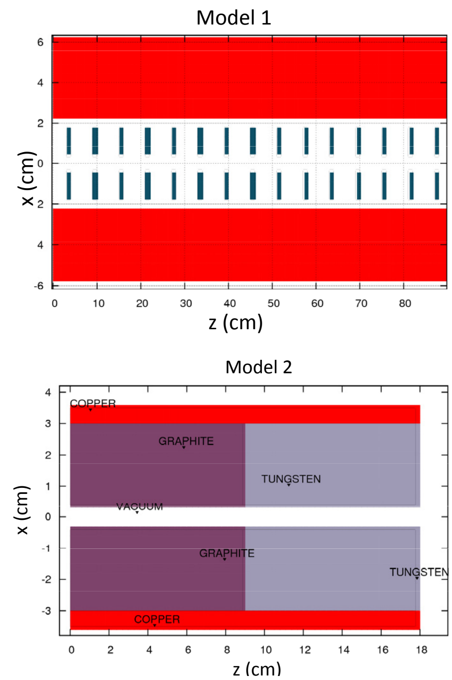

Figure 1: Photon collimator geometries.

COLLIMATOR APERTURE AND POSITRON BEAM PROPERTIES

The polarization of photons generated from a helical undulator is correlated with the angle of the photon trajectory with respect to the undulator axis. Therefore, by adjusting the aperture of the photon collimator, it is possible to control the polarization of the photon beam [2], and ultimately, the polarization of the positron beam produced in the target. A smaller collimation aperture gives a higher degree of polarization, but will also limit the intensity of the photon beam. The optimum aperture will depend on the requirements for the studies to be carried out at the ILC.

Fig. 2 shows simulation results from GEANT4 [5] for the positron yield and polarization as functions of the photon collimator aperture. The values shown are for the positron beam after the capture device following the target. The results for Model 1 and Model 2 are essentially the same. The capture device consists of a longitudinal magnetic field that peaks at the target, and decreases with distance. There are several options being considered; the results shown in Fig. 2 assume a superconducting adiabatic matching device, which provides a peak field of 5 T, and gives a better capture efficiency compared to other (lower field) options. However, operation of a target in fields above 2 T is an issue [6]. The capture device has a certain

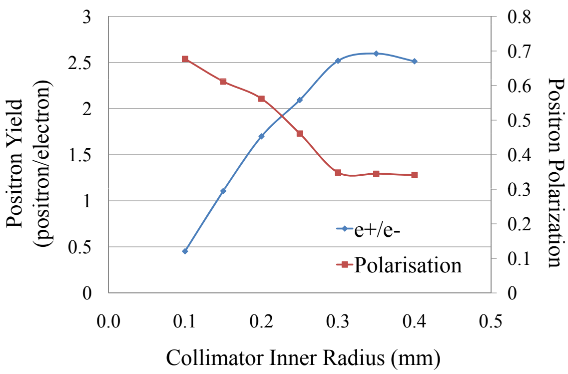

Figure 2: Positron yield and polarization as functions of collimator aperture.

energy and angle acceptance, which means that it will act in some respects like a photon collimator. This can be seen from Fig. 2: when the aperture of the photon collimator is larger than about 3 mm, the yield and polarization become independent of the aperture.

A positron polarization of 70% would be achievable with a photon collimator aperture of 1 mm; but at this point, the positron yield (positrons produced per electron in the undulator) would be less than 0.5, which would severely limit the operational efficiency of the ILC. A polarization of 60% can be achieved with a yield of about 1. In practice, however, a yield of greater than 1 will be required, to allow for positron losses between the capture device and the damping ring injection; the exact requirement for the yield is still to be determined, but a value of 1.5 is probably realistic. Thus, a collimator aperture of around 1.7 mm may be optimal, which would give a polarization of around 55%.

ENERGY DEPOSITION AND HEATING

Ionization losses in the photon collimator will result in energy deposition and temperature rise. Although the collimator will remove only part of the photon beam, the rate of energy deposition could be of order 30 kW; a proper understanding of thermal effects will be important to validate and optimize the design of the collimator. The ILC will operate with pulses of 1 ms duration, and a pulse repetition rate of 5 Hz. Therefore, the temperature rise during a pulse will be essentially determined by the energy deposited during a pulse, while the actual temperate reached will depend on the radiative cooling between pulses.

Fig. 3 shows the temperature rise in the spoilers and absorbers in each collimator model during a machine pulse, obtained from FLUKA [7] simulations. The temperature rise is shown as a function of collimator aperture; also shown, for comparison, is the fraction of photons transmitted. We assume that the absorbed energy is evenly distributed throughout the material. For both models, it is actually the spoilers, rather than the absorbers, that experience the greatest temperature rise. In both cases, the temperature rise appears to be manageable.

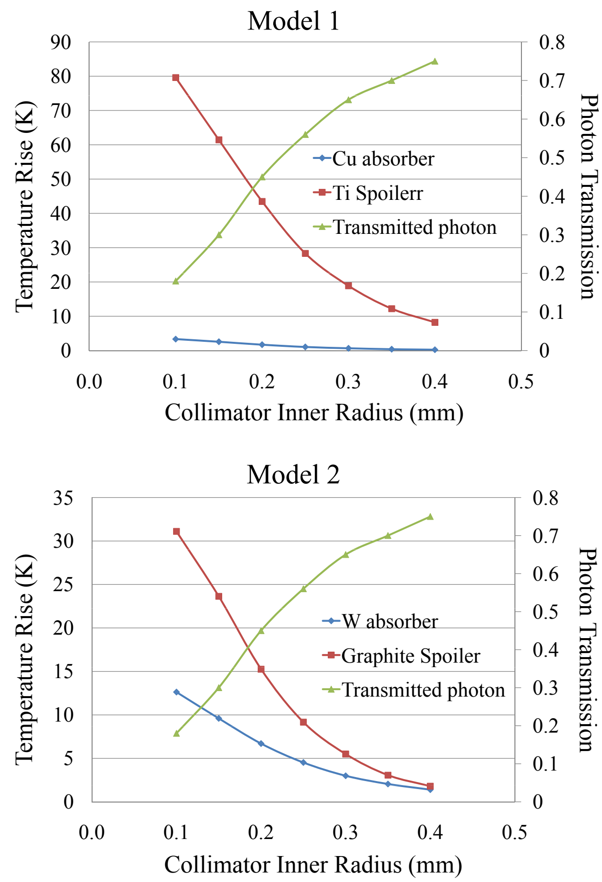

Figure 3: Temperature rise in spoilers and absorbers as a function of collimator aperture. Also shown is the fraction of photons transmitted.

Without convective cooling, the temperature of the collimator may be calculated from the Stefan-Boltzmann law for thermal radiation. Assuming a value of roughly 0.1 for the emissivity of the copper surface, the temperature of the surface in each model will significantly exceed the melting point of copper (1300 K): therefore, convective cooling will be required in both cases.

ACTIVATION

Photons striking the collimator will lead to nuclear activation. To estimate the magnitude of the activation, we calculate the equivalent dose rate immediately after an operational period of 180 days, and one day later. We assume a photon beam intensity of 8×10^{16} photons/second, and a 3 mm aperture for the collimator. Fig. 4 shows the equivalent dose (calculated using FLUKA) for each of the two models immediately after operation, as a function of distance from the collimator; in both cases, the equivalent dose rate can reach 10^9 pSv/second. After one day of cooling, the dose rate falls by an order of magnitude for Model 1. For Model 2, which uses graphite and tungsten for the spoiler and absorber material (rather than titanium used for

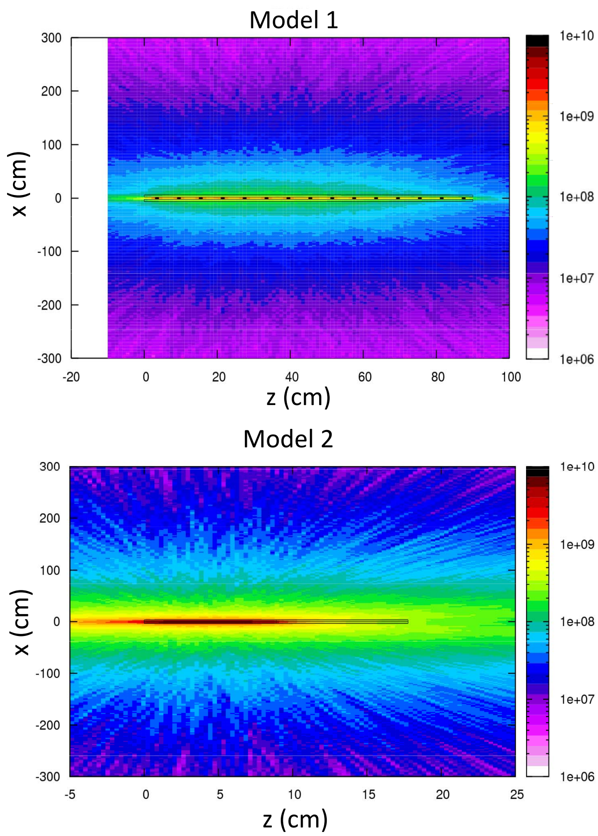

Figure 4: Equivalent dose rate immediately following an operational period of 180 days.

the spoiler material in Model 1) the dose rate falls much more quickly. However, the working environment beside the collimator will be an issue because of its proximity to the target [8]: the photon collimator will be part of the remote-handling system [6].

SECONDARY PARTICLES

Photons striking the collimator can generate secondary particles, which may reach the target station. Although the number of secondaries striking the target station is not expected to be very large, it is still important to understand the likely consequences. Table 1 shows the power of secondary electrons and positrons from the photon collimator, for different collimator apertures.

Table 1: Power (in watts) of Secondary Particles Emitted from the Photon Collimator

aperture	Model 1		Model 2	
(mm)	e^-	e^+	e^-	e^+
1	1090	790	120	77.6
2	582	311	83.3	43.3
3	189	86.9	63.5	9.93
4	44.7	11.3	32.2	2.11

We see that Model 2 has significantly lower power of secondary particles; this is because tungsten is a more effective absorber. For a collimator radius of around 2 mm (giving a positron yield of more than 1.5), a secondary particle power of a few hundreds of watts will be expected for Model 1, and less than 100 W for Model 2.

SUMMARY AND CONCLUSION

A photon collimator between the undulator and target in the ILC positron source can be used to control the intensity and polarization of the photon beam, and hence the properties of the positron beam. By using the AMD capture device that provides the best capture efficiency of the available options, a positron polarization of more than 50% looks achievable with a positron yield of greater than 1.5. This would require collimation of the photon beam with an aperture of around 1.7 mm. Although a positron polarization of 70% is possible in principle (with collimator aperture of 1 mm), the positron yield would be too low for efficient operation of the ILC. Without collimation, the positron polarization will be around 30%. The results for the polarization and yield are effectively the same for the two collimator designs we have considered.

Heat deposition in the collimator is a concern. If they relied solely on radiative cooling, both collimator designs would reach a temperature that is above the melting point of copper. Therefore, the collimator will require additional, convective cooling.

Activation is a further concern. The initial results suggest that after one day of cooling (following 180 days of operation), the equivalent dose rate in the vicinity of the collimator will still be significantly high, at least in Model 1. Further study will be needed to understand the activation and its implications more thoroughly.

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