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DESIGN OF PHOTON MASKS FOR THE ILC POSITRON SOURCE*

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Abstract

A long superconducting helical undulator is planned as baseline to produce polarized positrons at the International Linear Collider (ILC). To protect the undulator walls from synchrotron radiation, masks must be inserted along the undulator line. The power distribution deposited at these masks is studied in order to design the photon masks.

INTRODUCTION

The Technical Design Report (TDR) of the International Linear Collider (ILC) describes two positron sources: the baseline source using a helical undulator, and an e-driven source [1]. The possibility of producing polarised positrons is one of the most important benefits of using a helical undulator as a baseline for the ILC [2]. A high-energy electron beam passes through the helical undulator to generate circularly polarized photons, and these photons then hit a thin metal target. The result is a longitudinally polarized positron beam [3]. The positrons are captured and accelerated to the required energy. The opening angle of the photon beam is determined by the energy of the electron beam; it is proportional to $1/\gamma$. The power deposition along the undulator must be kept below 1 W/m [4]. This can be reached by inserting masks along the undulator line [5].

A previous study for the photon mask design was done in [6] but using different parameters. Here, the actual parameters for ILC250 are taken into account to propose a design for photon masks. Both, ideal and non-ideal (realistic) helical undulators are considered. Further, the effect of adding photon masks on the photons polarization (P_γ) at the target plane is discussed.

POWER DEPOSITED AT MASK

Helical Undulator Synchrotron Radiation (HUSR) code [7] was used to simulate the photon spectrum from a helical undulator. This code takes into account also realistic magnetic fields in the undulator. The uncertainty of the B-field used for the studies here is based on the size of the B-field errors measured from helical undulator prototypes [8]. The general parameters of the helical undulator at ILC250GeV is shown in Table 1 [9].

Table 1: ILC Undulator Parameters

Parameter	**Value**
Centre-of-Mass Energy	250 GeV
Undulator Period	11.5 mm
Undulator K	0.85
Electron Number per Bunch	2×10^{10}
Number of Bunches per Pulse	1312
Pulse Rate	5.0 Hz
Undulator Aperture	5.85 mm
Photon Mask Aperture	4.4 mm
Photon Mask Number	22
Number of Quadrupoles	23
Total Active Undulator Length	231 m
Total Lattice Length	319.828 m

HUSR code is too time-consuming for accurate simulation of the photon spectrum, when the distance between the undulator module exit and observation points is below 25 m. In the 250 GeV center-of-mass energy, 132 helical undulators must be used to produce the required positrons (1.5 e^+/e^-), and 22 photon masks are placed along the undulator line to protect the undulator vessel. Since the photon is produced with an opening angle, it is clear that the highest power deposit would be at the last photon mask. Therefore, only the power deposited at the last mask is shown and studied here, taking into account the power deposited in the previous masks and the electron loss energy along the undulator line ($\simeq$3 GeV).

The ideal undulator deposits 335 W with 2.01 MeV average incident photon energy at the photon mask. With the realistic undulator, the power deposited and the average incident photon energy are 361 W and 2.14 MeV, respectively.

PHOTON MASK DESIGN

The photon mask has to be designed to stop the primary incident photons and the secondary particles. In [9], the saved area for undulator is limited (319.828 m), so the length of the photon masks cannot be longer than 30 cm. To stop photons with incident average energy in MeV range with such short mask photons, the mask material should have small radiation length, high atomic number and high density. One possible material which can be used for the photon mask is copper. It is 1.44 cm, 29 and 8.96 g/cm^3 radiation length, atomic number and density, respectively.

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Figure 1 shows a longitudinal section of the photon mask. The photon mask has a cylindrical geometry of 30 cm length and 15 cm outer diameter. To reduce the wake-fields, the inner radius in the first and last 5 cm of the mask length are tapered (green areas). The inner radius in the first 5 cm is tapered from 0.2925 cm to 0.22 cm, and in the last 5 cm the inner radius is tapered from 0.22 cm to 0.2925 cm which is the beam pipe radius. Between the tapered sections, the inner radius of the photon mask is 0.22 cm (orange area).

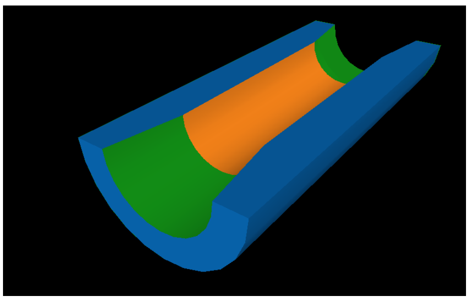

Figure 1: A longitudinal section of the photon mask.

ENERGY DEPOSITION AND HEATING

FLUKA [10] was used to simulate the energy deposition along the photon mask. The incident photons simulated by HUSR for both ideal and realistic helical undulators were used as input to FLUKA.

The Peak Energy Deposited Density (PEDD) as well as the maximum temperature rise at the photon mask were calculated. Figures 2 and 3 show the energy deposited along the photon mask for both ideal and realistic undulator, respectively. Figure 4 shows the maximum energy deposited at the photon mask for ideal and realistic undulators. In both cases, the maximum energy deposited along the mask is at the end of the first tapered part. This means when the mask radius becomes 0.22 cm, the maximum deposited energy at the mask by ideal and realistic undulators will be 0.0022 and 0.0024 (GeV/cm^3/Ph), respectively. This ideal mask can stop $\approx$ 98.5% but the realistic mask can only stop $\approx$ 98%. The PEDDs at the mask in case of both ideal and realistic undulators are 8.07 and 9.03 J/g/Pulse, respectively. The PEDD is useful when calculating the maximum increase in the temperature. The specific heat capacity and density of copper and PEDD are used to calculate the maximum temperature rise. The maximum temperature rises at the mask for both ideal and realistic undulators are 21 and 24 K/Pulse. In both cases, the tolerable energy density as derived from the endurance strength and tolerable instantaneous temperature rise are below the acceptable limit [11]. Therefore the photon masks are safe against damage.

PHOTON MASK EFFECTS

Placing photon masks along the beam-line will affect beam parameters such as the photon power, average energy, and polarisation P_γ. Figures 5 and 6 show the photon spectrum without and with masks, and with a 0.22 cm considered

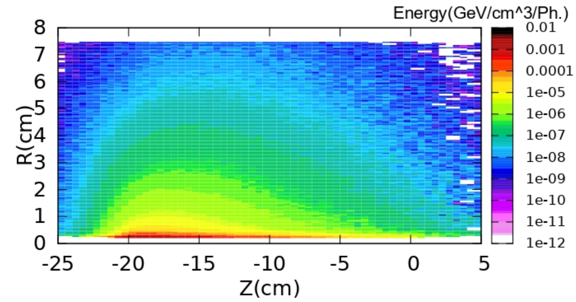

Figure 2: The ideal energy deposited along the mask.

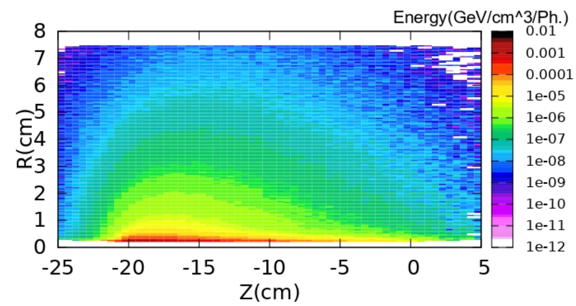

Figure 3: The realistic energy deposited along the mask.

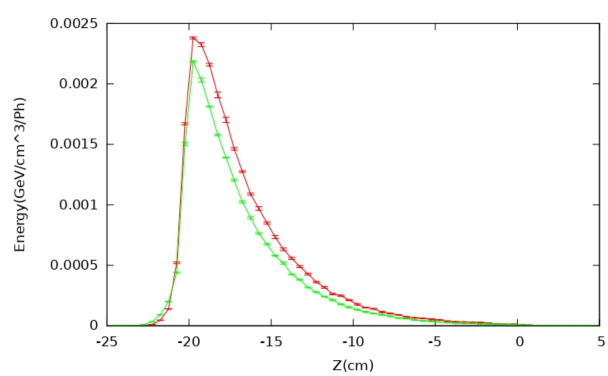

Figure 4: The maxmimum energy deposited at the mask. Green (Red) line represents the ideal (realistic) case.

beam spot radius at the target for both ideal and realistic undulator, respectively. Figures 7 and 8 show the P_γ without and with masks, and a with 0.22 cm considered beam spot radius at the target for both ideal and realistic undulator, respectively.

Table 2 summarises the impact of photon masks on these quantities. Photon masks can increase the photon energy from 7.68 and 7.59 MeV to 7.97 and 7.87 MeV in case of both ideal and realistic undulator, respectively. In addition, photon masks can increase the P_γ from 38 and 37% to 41.32 and 38.7% for both ideal and realistic undulators, respectively.

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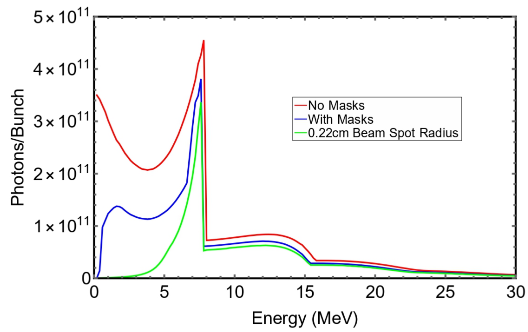

Figure 5: Ideal Photon Spectrum at Target.

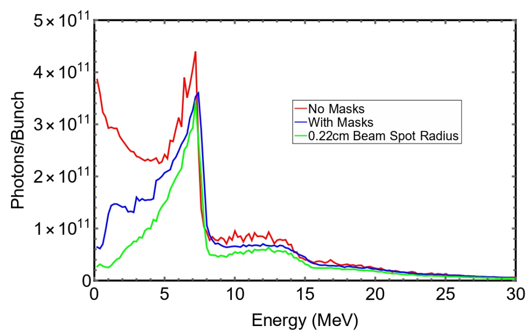

Figure 6: Realistic Photon Spectrum at Target.

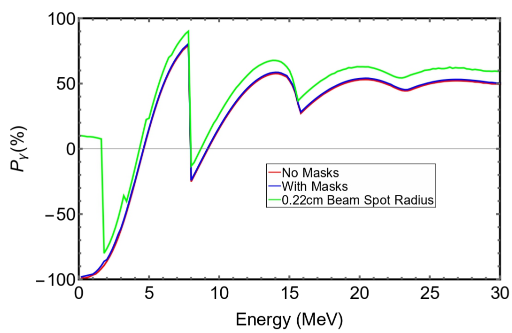

Figure 7: Ideal Photon Polarization (P_γ) at Target.

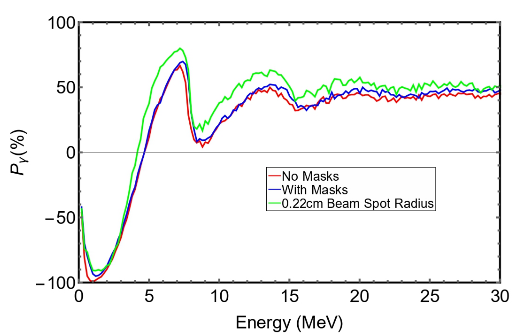

Figure 8: Realistic Photon Polarization (P_γ) at Target.

CONCLUSION

A possible mask design with a high photon absorption efficiency for both ideal and realistic undulators has been studied using copper as a material. Simulation results proved that masks are safe and slightly collimate the photon beam.

Table 2: Power, Average Energy and P_γ at Target for Ideal (Realistic) Undulators Without and With Masks

	Power (W)	Energy (MeV)	P_γ (%)
	Ideal		
No Masks	62.5	7.68	38.1
With Masks	60.2	7.97	41.32
0.22cm Spot	43	10.65	73.76
	Realistic		
No Masks	61	7.59	37
With Masks	59	7.87	38.7
0.22cm Spot	42	10.2	66

It is important to notice that the photon polarization for the realistic undulator is only slightly lower than in case of an ideal device.

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