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Simulation of the ILC Collimation System Using BDSIM, MARS15 and STRUCT[*]

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Abstract

The simulation codes BDSIM, MARS15 and STRUCT are used to simulate in detail the collimation section of the International Linear Collider (ILC). A comparative study of the collimation system performance for the 250 × 250 GeV machine is conducted, and the key radiation loads are calculated. Results for the latest ILC designs are presented together with their implications for future design iterations.

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Abstract

The simulation codes BDSIM [1], MARS15 [2] and STRUCT [3] are used to simulate in detail the collimation section of the International Linear Collider (ILC) [4]. A comparative study of the collimation system performance for the 250 GeV machine is conducted, and the key radiation loads are calculated. Results for the latest ILC designs are presented together with their implications for future design iterations.

INTRODUCTION

The ILC is expected to run with $250 - 500$ GeV e+/e- beams with approximately 20 MW power. The Beam Delivery System (BDS) is a key part of the accelerator which should provide precise bunch collisions on a nanometer scale. Two detectors are now under design - with 2 and 14-20 mrad crossing angle. The BDS layouts for these detectors will be referred to as 2 and 20 mrad systems respectively.

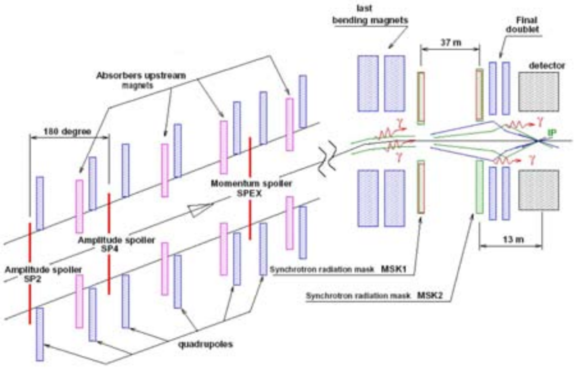

Figure 1: Sketch of ILC collimation system.

Interactions of the beam halo with detector components and the Synchrotron Radiation (SR) it produces can cause a large amount of background in the Interaction Region (IR). The collimation system [5] is designed to scrape the halo away. Due to high beam energy and power the collimation system (see Fig. 1) becomes a critical issue: the collimators can be damaged and the secondary particles produced in beam-collimator interactions can themselves cause noticeable backgrounds. The extraction lines also have collimation systems serving to protect the magnets from radiation loads. These collimation systems are usually referred to as “downstream” and the former as “upstream”.

The upstream collimation system is two-stage. Halo particles that have large transverse deviation or are off-momentum interact with thin primary collimators (spoilers) and are then lost further along in the secondary collimators (absorbers, masks, protection collimators).

To evaluate the performance of the collimation system simulations of power loads on key elements and the secondary particles reaching the detector were performed. To assure reliablility the simulations were performed with several codes:

- BDSIM v0.2 [1] - a Geant4 based extension toolkit for beam line simulations.
- MARS15 [2] - Monte Carlo programs for detailed simulations of electromagnetic and hadronic cascades in 3-D geometrical configurations.
- STRUCT [3]- a program to perform particle tracking and interactions with material of collimators in beam lines.

THE UPSTREAM COLLIMATION SYSTEM

The simulation of the collimation system in the upstream beam delivery optics has been performed by tracking “$1/R^2$” (i.e. falling off as $1/R^2$ in phase space) beam halo as in Fig. 2. For normalisation purposes this has been assumed to constitute 10^{-3} of the main beam.

For both upstream and downstream simulations with BDSIM, secondary particle production via standard electromagnetic processes have been computed with lower limit tracking thresholds set to 10 keV for both charged and neutral particles. Results for the normalised power losses in the 20 mrad BDS as a result of running beam halo in BDSIM are presented in Fig. 3 and power dissipation calculations from MARS15 are shown in Fig. 4. All losses from beam halo are shown to be within tolerable limits and the all halo-related particles pass through the vertex detector aperture.

Beam envelopes for beam halo and corresponding SR can be used to give lower limits on the aperture size of all the elements in the BDS. Results without tail folding octupoles are given in Fig. 5. Using these octupoles causes the envelope of the halo to increase.

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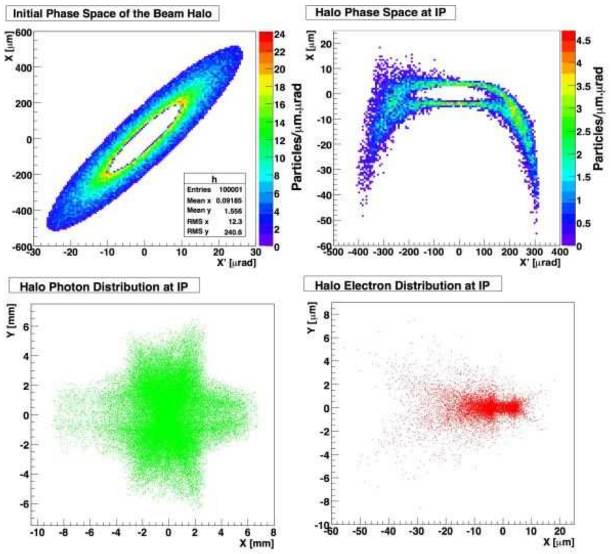

Figure 2: Top left: initial beam halo phase space. Top right: beam halo phase space at the IP. Bottom left: photon spatial distribution at the IP. Bottom right: halo electron spatial distribution at the IP.

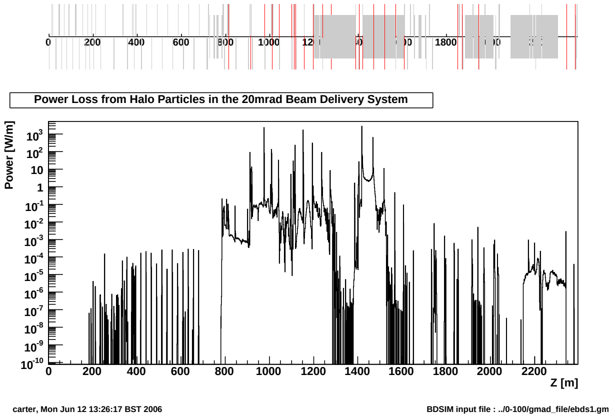

Figure 3: Normalised power losses due to beam halo and corresponding SR along the 20 mrad BDS. Given as a function of distance from the linac.

EXTRACTION LINES

The extraction lines guide the beam and the beamstrahlung from the IR to the beam dumps. The post-collision beams are disrupted and the collimation system here serves to protect the magnets from the radiation loads. The downstream collimation and power losses have been calculated using high statistics for $250-500$ GeV "Nominal" and "High Luminosity" beams [6] with zero and non-zero vertical offsets. In this paper only the 250 GeV Nominal beam losses will be considered (see Fig. 6 and 7). Comparisons with simulations without SR tracking [7] show that in both the 2 and 20 mrad extraction lines the power curves are dominated by the SR losses. Distributions for SR and the core beam in the 2 mrad design have been produced at the entry point to key magnets using STRUCT (see Fig. 8).

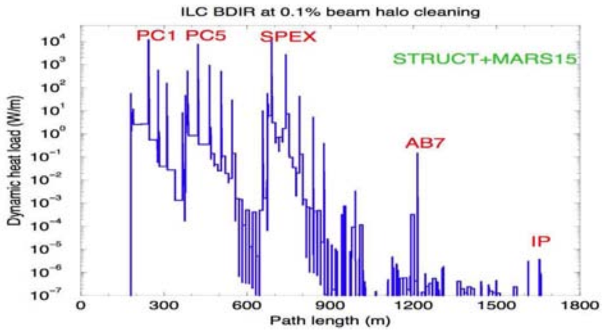

Figure 4: Power dissipation in the 20 mrad BDS using MARS15.

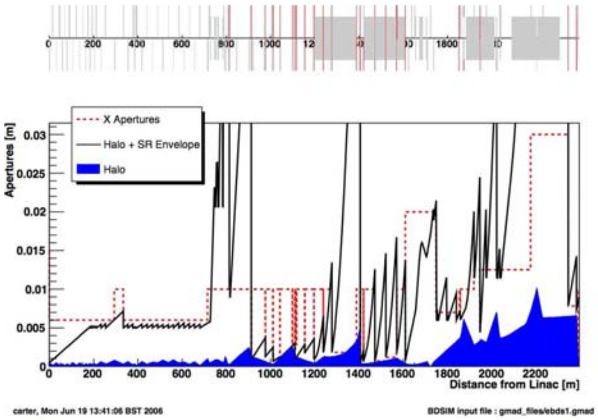

Figure 5: Beam envelope of the halo (shaded region) and the collimated SR (solid line) in the 20 mrad BDS. Horizontal aperture of elements is also plotted (dashed line).

Certain key magnets in the 2 mrad extraction line will use superconducting technology which will set strict limits on any beam power incident upon them in terms of avoiding quenching. The closest quadrupole to the 2mrad IR, QD0, is one such magnet and detailed studies have been conducted in order to fully predict the localised energy load within its NbTi coils. Radiative Bhabhas generated as a result of beam-beam interactions in the detector region provide the largest contribution to this power deposition. These particles, generated using GUINEA-PIG [8], have been tracked in BDSIM and by scoring QD0 into approximately 300,000 volumes comprehensive power deposition maps have been produced (see Fig. 9). Magnet designers of the similar superconducting quadrupoles for the Large Hadron Collider (LHC) have set a maximum localised power deposition of 1.5 mW/g and due to the harsh conditions as a result of the close proximity to the IR, this value has been lowered to 0.5 mW/g for QD0 [9]. Fig. 9 shows that for the 250 GeV nominal machine parameters QD0 suffers a maximum localised power deposition of 1.8 mW/g in the NbTi coils. Simulations with a pre-showering Tungsten liner can reduce the power deposition

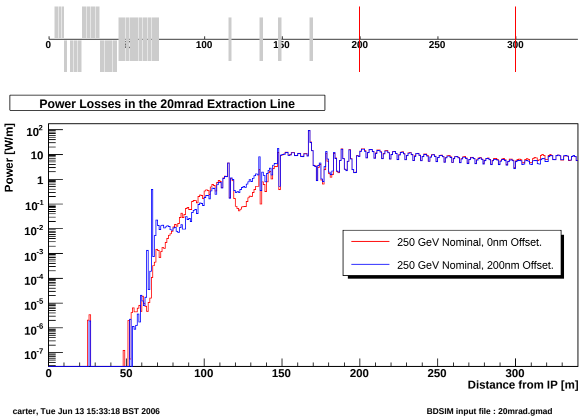

Figure 6: Normalised power losses along the 20 mrad extraction line from disrupted beam and SR. Total integrated power of 1.68 W for 0 nm and 1.66 w for 200 nm.

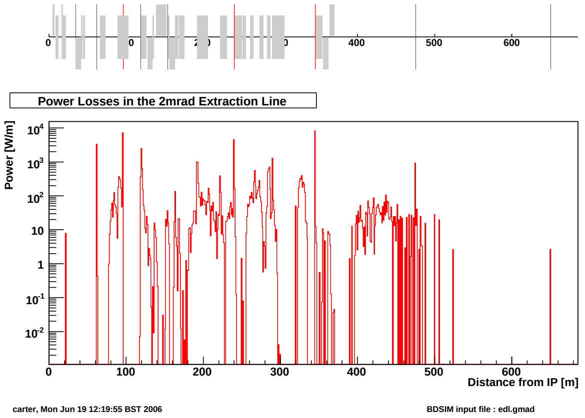

Figure 7: Normalised power losses along the 2 mrad extraction line for 250 GeV nominal disrupted beam with no vertical offset and SR. Total integrated power of 45.8 kW.

levels to below the set threshold for most of the suggested machine parameter sets, but further studies must be carried out in order to fully evaluate the effects on normal beam transport when using this liner.

CONCLUSIONS

By simulating the ILC collimation system performance with different simulation tools and performing benchmarking it was possible to analyse the radiation environment in the beam delivery system with a higher degree of confidence. Both STRUCT and BDSIM codes give similar results. The performance of the upstream collimation system and the 20 mrad extraction line is found satisfactory whereas the radiation loads on the 2 mrad extraction line require further optimization.

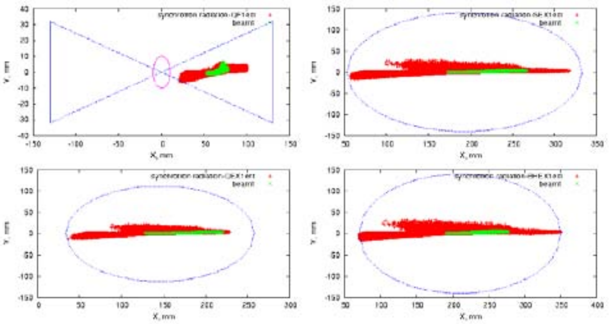

Figure 8: Beam distribution calculated with STRUCT.

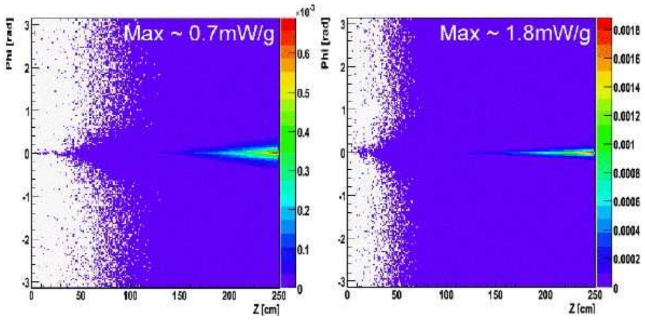

Figure 9: Power deposited into scored rings of superconducting QD0 in the 2mrad extraction line from Radiative Bhabhas generated in the 250 GeV Nominal machine. Left: power into the aluminium beam pipe. Right: first 0.5 cm of the NbTi coils.

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