COLLIMATION OPTIMISATION IN THE BEAM DELIVERY SYSTEM OF THE INTERNATIONAL LINEAR COLLIDER*

F. Jackson, D. Angal-Kalinin (STFC Daresbury Laboratory, Warrington, U. K); A. Latina, D. Schulte (CERN, Geneva, Switzerland); R. J. Barlow, A. Toader (University of Manchester, Manchester, U. K)

Abstract

The collimation systems of the International Linear Collider (ILC) Beam Delivery System (BDS) must perform efficient removal of halo particles which lie outside the acceptable ranges of energy and spatial spread. An optimisation strategy based on earlier work is applied to the latest version of the BDS lattice. The resulting improvement in collimation performance is studied by halo tracking simulations, and the luminosity performance of the optimised lattice is also examined.

INTRODUCTION

An efficient collimation system will be crucial to the ILC BDS to mitigate detector backgrounds. The BDS collimation system and its evolution is briefly described in [1].

The current lattice design for the nominal ILC parameter set and baseline configuration is not yet optimal for collimation performance. The betatron phase advances between the collimators and the final focussing doublet are not perfect and the lattice bandwidth is not optimal. A method of phase advance restoration and bandwidth optimisation was devised and is described in [1]. This used a set of quadrupoles to restore the phase advances between the betatron collimators and the interaction point (IP). The method described here was developed to restore the phase relationships between the betatron collimators, the energy collimator, and the IP.

The changes to the lattice during optimisation disturb the optical functions in particular locations. The effects of these lattice modifications on beam transport have been checked by luminosity studies.

ILC BDS COLLIMATION OPTIMISATION

BDS Collimation Design

The BDS collimation system is described in a previous paper [1]. It consists of two betatron collimators SP2 and SP4 separated by an effective phase advance of π/2 and located at large transverse beam size, followed by an energy collimator SPEX located at a high dispersion point. The final doublet (FD) and IP are separated by π/2 and the phase relationship between the betatron collimators and the FD is crucial. The lattice used in [1] has undergone numerous modifications and the current version is the '2006e' lattice [2][3], which shall be referred to as the 'original' lattice here. The collimation phase advances for the original lattice are given in **Table 1**. The horizontal and vertical collimation depths for nominal lattice parameters are assumed to be 11.9 σ_x, 70.7 σ_y; these are determined by the requirement that synchrotron radiation from the FD passes cleanly through the interaction region[4]. These collimation depths correspond to full apertures of 2.7 mm and 1.3 mm in x and y for the betatron collimators, while the horizontal full aperture of SPEX (4.5 mm) is nominally set at an energy acceptance of $|\delta p|<1.5\%$.

Optimisation

The goal of the optimisation was to restore perfect phase advances between SP4, SPEX and the IP, while constraining the other optical functions at those locations, and maintaining the fixed π/2 phase advance between SP2 and SP4, FD and IP. Multiple phase matched solutions were attainable, and that with the best IP bandwidth was taken as the optimum lattice. The bandwidth was defined here as the increase in IP beam divergence for off energy particles compared to on energy particles. A bandwidth figure of merit was devised as the relative change in the Twiss γ function for energy deviations of $\delta p=\pm1\%$ [1]. The software MAD[5] was used to model the lattice and perform the phase matching.

The first attempt to optimise the lattice (referred to as 'opt1' here) proceeded as follows. The phase advance between SP4 and SPEX was adjusted using four quadrupoles at the exit of the betatron collimation section. It was found that adjusting the strengths of the quadrupoles alone was not sufficient to achieve phase matching. By varying in addition the longitudinal separations of the quadrupoles a phase match was possible, resulting in an increased lattice length. The phase matching between SPEX and IP was then achieved using the dedicated matching section at the exit of the energy collimation bend (seven quadrupoles at fixed locations). Multiple solutions were obtained for the SPEX-to-IP phase matching, and the solution with the best bandwidth was chosen as the optimal lattice. This was approximately 26m longer than original design due to the increased length in the SP4-to-SPEX matching. This increased length would increase the cost of the BDS.

The second attempt at optimisation (referred to as 'opt2' here) sought to constrain the length of the lattice. The phase matched solution between SPEX and the IP was identical to the first method. However to achieve the SP4-to-SPEX phase matching two additional quadrupoles were added to the exit of the betatron collimation section, and the locations of all six quadrupoles were fixed. The

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phase advances achieved in the first attempt were targeted. Several solutions were obtained and again the solution with the best bandwidth was chosen.

The original and optimised Twiss γ bandwidth at the IP are illustrated in **Figure 1**. The optimised lattices demonstrate improved bandwidth, since the γ values tend to decrease for $|\delta p|>0$. The important phase relationships are shown before and after the optimisation in **Table 1**.

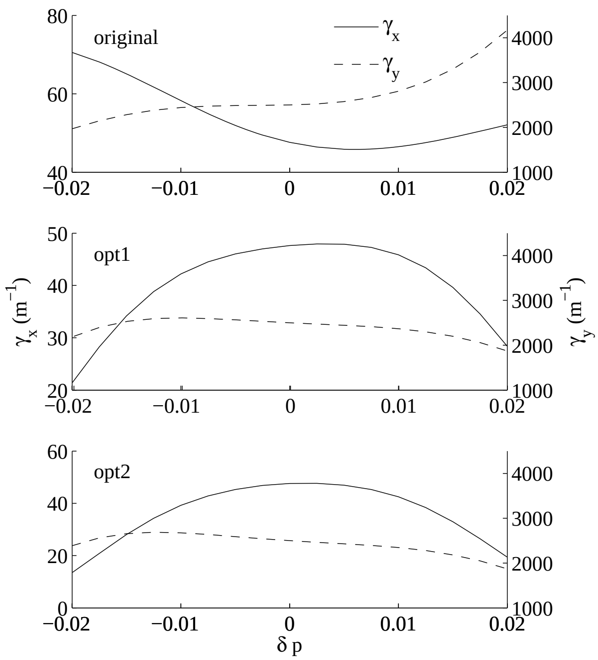

Figure 1: IP Twiss γ values as function of energy deviation, for original and optimised ILC BDS lattices.

Table 1: ILC BDS betatron phase advances between collimators and IP for the original and optimised lattices.. The phase advances *x* and *y* ($\Delta\mu_x$ and $\Delta\mu_y$) are given in units of 2π.

Collimator	Phase Advance to IP	
	Original	**Optimised**
SP4	$\Delta\mu_x$: 2.76 $\Delta\mu_y$: 2.34	$\Delta\mu_x$: 2.25 $\Delta\mu_y$: 2.25
SPEX	$\Delta\mu_x$: 2.38 $\Delta\mu_y$: 1.75	$\Delta\mu_x$: 2.75 $\Delta\mu_y$: 3.25

COLLIMATION PERFORMANCE AND LUMINOSITY STUDIES

The collimation performance of the lattices can be measured using halo tracking simulations. It is also important that the lattices optimised for collimation described maintain good properties for core beam luminosity.

Tools for BDS final focus luminosity optimisation have been developed at CEA Saclay[6]. Using these tools, the beam luminosity as a function of energy was found to be poorer in the optimised lattices compared to the original. However, the original luminosity performance was recovered by adjusting the strengths of the final focus sextupoles.

Figure 2 shows the luminosity performance of the original and optimised lattices, including the sextupole adjustments. It can be seen that the optimised lattices preserve good luminosity performance.

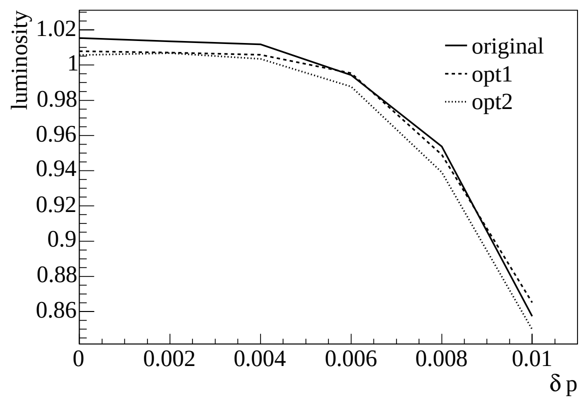

Figure 2: Geometric luminosity (normalised to the design luminosity) as a function of energy deviation for the original and optimised ILC BDS lattices.

The collimation performance of the lattices, including the sextupole adjustments, was studied with the tracking code MERLIN[7]. A halo of 25,000 particles with energy 250 GeV and 1% Gaussian energy spread was generated at the BDS entrance, uniformly distributed in the *x*, *x*', *y*, *y*' coordinates and extending to 1.5 times the collimation depth. The halo was tracked to the entrance of the final doublet, treating the three collimators as perfect absorbers of any incident particle. The collimators were set at first to the collimation depth. A measure of the primary collimation efficiency is the number of particles outside the collimation depth at the final doublet entrance.

The collimation efficiency results are shown in **Figure 3**. The improvement in collimation efficiency in the optimised lattices is clear. However, it can be seen that with spoilers set at the nominal collimation depth the number of particles outside the collimation depth is not negligible (of the order of 1% of the initial halo population) for all the lattices. To achieve much higher collimation efficiency the apertures must be reduced to smaller than the nominal collimation depth. If the collimators' horizontal apertures are reduced to 10 σ_x only a small number of halo particles (of the order of 0.01%) lie outside the collimation depth for the optimised lattices. For the original lattice, these tight horizontal collimator settings only partially improve the collimation efficiency, since the poorer vertical collimation performance dominates.

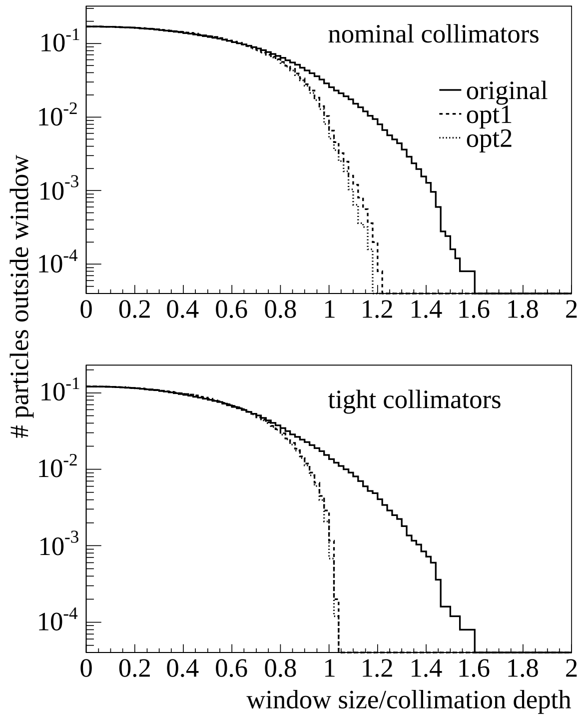

Figure 3: Collimation performance for original and optimised ILC BDS lattices, for nominal (top) and tight (bottom) collimation apertures. The number of halo particles (normalised to initial halo population) outside a rectangular x-y window at the FD entrance is plotted as a function of the window size. The window size is normalised to the collimation depth.

To improve the collimation efficiency of the original lattice vertical apertures would have to be reduced, including perhaps introducing a vertical SPEX aperture. This is particularly undesirable since collimator wakefields are expected to dominate in the vertical plane for the ILC BDS[8], as was the case in the previous NLC BDS design[9].

CONCLUSION

The lattice optimisation here has successfully yielded designs for the BDS with restored collimation phase advances and good bandwidth. These designs apparently provide significant improvement in collimation performance, judged by tracking simulations of primary halo particles. It would be important to verify these simulations with more complicated simulations including secondary particle production and transport at the collimators. The performance improvement should mitigate the need to reduce collimation apertures and thus substantially reduce wakefield effects.

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