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

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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 is developed to improve the performance of the BDS collimation system. Primary considerations are the phase relationships between collimation systems and the final focus, and the overall bandwidth of the system.

INTRODUCTION

The design of an efficient collimation system will be crucial to the ILC BDS, as previous experience with the Stanford Linear Collider (SLC)[1] has confirmed.

The present ‘baseline design’ for the ILC BDS[2] and its collimation systems is based on the BDS design of the previous ‘Next Linear Collider’ (NLC) project[3]. The design includes a betatron collimation section followed by an energy collimator. The collimators consist of thin ‘spoilers’ followed by thick absorbers to provide halo scattering and absorption. The ILC bunch spacing permits the use of ‘survivable’ spoilers (surviving impact by errant bunches), whereas the NLC spoilers were consumable.

The NLC collimation performance was found to provide effective halo removal in tracking simulations[4]; however the current ILC collimation performs less well, requiring tighter spoiler apertures to compensate[5].

In the current BDS lattice design, the horizontal and vertical betatron phase advances (denoted $\Delta\mu_x$ and $\Delta\mu_y$ hereafter) between the spoilers and the interaction point (IP) are not exact. In addition, the *bandwidth* (the energy range over which the beam transport is well behaved) could be improved. The aim of the studies here was to restore the correct phase advances in the lattice, while improving the bandwidth.

Only the lattice design for the 20 mrad crossing angle configuration at 250 GeV beam energy is considered here. The lattice used is that developed in 2005 and taken from the online repository[6]. It should be noted that the most recent lattice design (2006) was not used here (there have been no changes to the collimation system design in [6]).

ILC BDS COLLIMATION DESIGN

Description

For general details on many aspects of collimation system design, refer to the full documentation of the NLC scheme[7].

The betatron collimation section includes two spoilers, named SP2 and SP4 for historical reasons. SP2 and SP4 are separated by *x* and *y* phase advances of 0.25 and 0.75 ($\pi/2$ and $3\pi/2$, in units of 2π). The betatron spoiler apertures are nominally set at the collimation depth, which has been estimated as $9.6\sigma_x$, $74.0\sigma_y$ [8].

The energy spoiler (SPEX) is located downstream of SP2/SP4 at a high dispersion point. The nominal energy acceptance is $|\delta p|<1.5\%$, equivalent to an *x* aperture of 4.5mm. Ideally, no *y* aperture is required for the SPEX.

The spoiler parameters are summarised in Table 1. For an ideal collimation system the phase advance between the betatron spoilers and the interaction point (IP) should be 0.25*n* (*n* integer).

Spoiler	Aperture (mm)	Phase Advance to IP
SP2/SP4	x: 2.15 ($9.6\sigma_x$) y: 1.15 ($74.0\sigma_y$)	$\Delta\mu_x$: 2.76 (SP4→IP) $\Delta\mu_y$: 2.34 (SP4→IP)
SPEX	x: 4.5 ($|\delta p|<1.5\%$) y: OPEN	$\Delta\mu_x$: 2.38 $\Delta\mu_y$: 1.75

Table 1. Nominal ILC BDS spoiler parameters.

Performance

The tracking code MERLIN[9] was used to study the primary collimation efficiency of the lattice from linac exit to final doublet entrance. The spoilers were treated as perfect ‘hard-edges’ (all particles hitting a spoiler were stopped, generating no secondary particles). The tail-folding octupoles were turned off. A halo of 25,000 particles of 250 GeV energy was generated at the linac exit. A ‘1/r’ distribution[4] was used with dimensions $5\sigma_x$-$13\sigma_x$, $36\sigma_y$-$93\sigma_y$ and Gaussian energy spread of ±1% rms. The halo population was chosen to enable fast simulations; the realistic halo population for the ILC may be as large as 10^7[7].

Using the nominal spoiler apertures a substantial number of particles (1343, or 5.4% of the initial halo) lie outside the collimation depth at the FD entrance. When SP2, SP4 and SPEX are tightened to $8\sigma_x$, $74\sigma_y$ (see Table 2), only 24 (0.1%) particles lie outside the collimation depth. Figure 1 illustrates these results.

Using the tight spoiler settings effectively means the SPEX is used as a secondary betatron spoiler in x and y, and this narrow aperture will lead to the undesirable effects of increased wakefields and emittance dilution.

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Spoiler	**Aperture (mm)**
SP2/SP4	*x*: 1.79 (8.0σ_x) *y*: 1.15 (74.0σ_y)
SPEX	*x*: 0.8 (|δp|<0.27%, 8.0σ_x) *y*: 1.93 (74.0σ_y)

Table 2. Tight spoiler apertures required to obtain good collimation efficiency in ILC BDS.

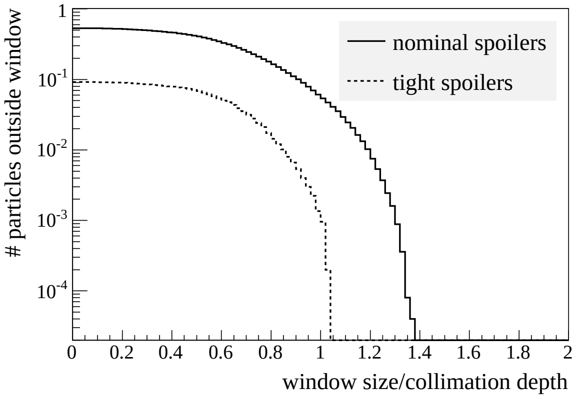

Figure 1. Current ILC BDS collimation performance for nominal and tight spoiler apertures. Number of halo particles (normalised to initial halo population) outside rectangular *x*-*y* window at FD entrance is plotted as a function of the window size. The window size is normalised to the size of the collimation depth.

COLLIMATION OPTIMISATION

The ideal BDS lattice should provide exact collimation phase advances and good bandwidth simultaneously. In practice, improving one of these aspects may result in deterioration in the other.

The approach here was to restore the *x* and *y* phase advances between SP4 and the IP; a method called ‘phase matching’ here. Since there are many different solutions with exact phase match, the bandwidth was measured for each solution; the optimal lattice was then simply that with the best bandwidth. The final focus (including collimation sections) bandwidth was considered here, rather than the bandwidth of the entire BDS.

The bandwidth was defined here as the change in IP Twiss parameters $\gamma_{x,y}$ for ±1% beam energy deviation (δp). If γ increases with $\pm\delta p$ then the IP beam/halo divergence will not be well behaved for off energy particles. The γ vs. δp behaviour at the IP closely follows the β vs. δp behaviour at the FD entrance; thus by optimising the IP γ bandwidth one can improve the IP beam/halo divergence and the FD beam/halo size simultaneously.

A single bandwidth figure of merit was defined as

$$G = \frac{\Delta^{+}\gamma_x}{\gamma_{x,0}} + \frac{\Delta^{-}\gamma_x}{\gamma_{x,0}} + \frac{\Delta^{+}\gamma_y}{\gamma_{y,0}} + \frac{\Delta^{-}\gamma_y}{\gamma_{y,0}}$$

where $\Delta^{+}\gamma$ ($\Delta^{-}\gamma$) is the *positive* change in γ for δp=+1% (δp=-1%) and γ_0 is the γ value at δp=0. Negative values of $\Delta^{+}\gamma$ and $\Delta^{-}\gamma$ were ignored (set to zero). Thus a *G* value of zero for a given lattice means the γ function decreases with $\pm\delta p$ in both planes, i.e. the IP divergence is well behaved. The current ILC BDS lattice has a *G* value of 0.35.

The phase matching was performed using the MAD implementation of the BDS lattice[6]. A matching section consisting of 7 quadrupoles and a variable length drift space was used to phase match the betatron collimators and the IP, keeping the twiss parameters at these locations fixed. The phase match constraints in *x* and *y* were chosen to be $\Delta\mu_{x,y}$ = 2.25, 2.5, 2.75, 3.0, 3.25, 3.5, giving 36 combinations in total.

For each $\Delta\mu_{x}$, $\Delta\mu_y$ constraint the MAD fit was attempted 100 times, varying the 7 input quadrupole strengths and drift length on each attempt. In the case that several solutions were found for one $\Delta\mu_{x}$, $\Delta\mu_y$ constraint, the solution with the lowest *G* value was retained.

Figure 2 shows the *G* values for all 36 $\Delta\mu_{x}$, $\Delta\mu_y$ phase match constraints. No obvious pattern emerges in the phase combinations with the best bandwidth. The solution with the lowest overall *G* value was μ_x=3.00, $\Delta\mu_y$=2.25 (*G*=0.41).

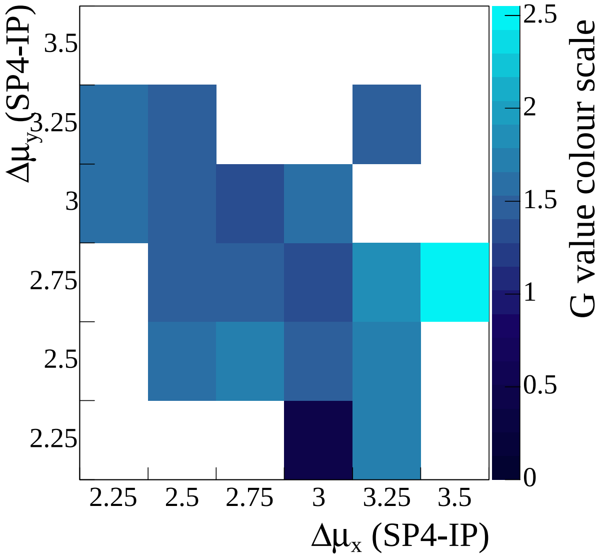

Figure 2. *G* value (denoted by colour) for the phase matching combinations in the optimisation routine. White denotes failure to achieve the phase match.

OPTIMISED COLLIMATION PERFORMANCE

The halo tracking exercise described above was repeated using the ‘optimised’ lattice with $\Delta\mu_x$=3.00, $\Delta\mu_y$=2.25, for both nominal and tight apertures. The SPEX phase was not constrained by the optimisation procedure, and the phase advance from SPEX to IP was 2.62 in *x* and 1.66 in *y*.

For the nominal apertures, 404 particles (1.6%) of the halo lie outside the collimation depth at the FD entrance. For the tight apertures, 14 particles (0.06%) lie outside the collimation depth. This performance is shown in Figure 3.

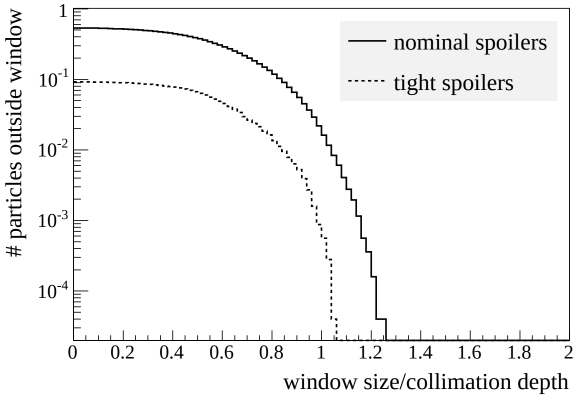

Figure 3. ‘Optimised’ ILC BDS collimation performance. For general description see Figure 1.

COMPARISON OF CURRENT AND OPTIMISED COLLIMATION PERFORMANCE

The results above (Figures 1 and 3) show that for tight spoiler apertures there is little difference in the collimation performance between the current and optimised lattice designs. Both designs provide good collimation efficiency, judged at the level of statistics in this study.

The improvement in collimation performance of the optimised lattice is noticeable when nominal spoiler apertures are used (see Figure 4). The optimised lattice shows a marked improvement in the number of halo particles lying outside the collimation depth. However, the absolute performance is still poor and this design could not be used without implementing a smaller SPEX aperture.

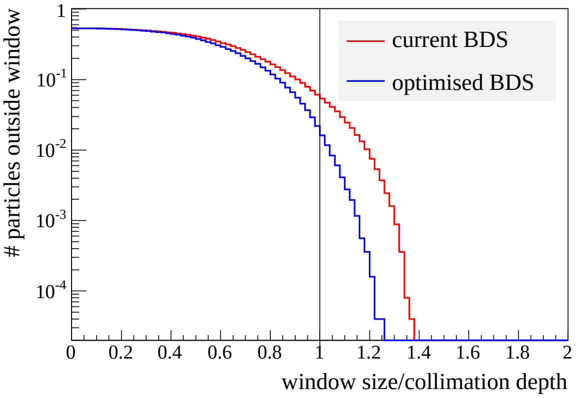

Figure 4. Comparison of current and ‘optimised’ ILC BDS collimation performance, for nominal spoiler apertures. For general description see Figure 1.

CONCLUSIONS

This preliminary study of optimisation shows it is possible to restore exact collimation phase advances to the BDS design, while maintaining reasonable bandwidth. The overall collimation efficiency is improved, in that the number of particles outside the collimation depth is reduced. Thus the method of optimising the lattice with regard to the bandwidth parameter G is useful. However it is important to note that the optimised lattice obtained here would still require tight spoiler apertures to achieve excellent collimation efficiency.

In the optimised lattice, the SPEX is not in phase with the betatron spoilers and the FD (in either *x* or *y*), and future optimisation strategies may profit by addressing this issue.

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