COLLIMATION APERTURE FOR THE BEAM DELIVERY SYSTEM OF THE INTERNATIONAL LINEAR COLLIDER*

F. Jackson, STFC Daresbury Laboratory, Warrington, U.K.

Abstract

The beam delivery system (BDS) of the international linear collider (ILC) must provide efficient removal of beam halo particles which would cause unacceptable detector background. The collimation aperture or 'collimation depth' is designed such that synchrotron radiation from the halo emitted in the final doublet passes cleanly through the detector interaction region. The ILC BDS collimation depth for several different detector scenarios is evaluated using a semi-analytical technique.

INTRODUCTION

The ILC BDS[1] collimation system has a betatron collimation section followed by a energy collimator. The betatron collimation system has two collimators separated by $\pi/2$ betatron phase advance in the x and y planes.

Collimator wakefields dilute the BDS emittance and are strongly dependent on the collimator apertures. Thus the collimation depth must be estimated early in the BDS design so that wakefield effects can be evaluated. The collimation depth is also crucial in the physical design of the collimators.

The key criterion in determining the collimation depth is that synchrotron radiation (SR) from the collimated beam halo, as it passes through the final doublet, does not hit any aperture near the interaction region (IR). There are several types of aperture near the interaction point (IP) in the ILC machine-detector interface. These include the final doublet aperture, the beampipe itself which becomes narrow at the IP, forward calorimeters, backscattering masks, and extraction quadrupole apertures.

In the geometry of the BDS design (14 mrad crossing angle) no magnets are shared between incoming and extracted beams, and the beam passes through the centre of all these apertures. However in the alternative small or zero crossing angle designs the extracted beams must pass through the apertures of the opposing final doublet, in addition to the other apertures listed above.

The geometry and position of the IR apertures may vary according to the detector layout. There are several detector concepts for the ILC known as SiD, GLD, LDC, and the '4th concept' [2]. These detectors vary in size and so affect the layout of the final doublet and IR apertures, and hence influence the collimation depth.

COLLIMATION DEPTH CALCULATION

A semi-analytical algorithm was developed at Saclay [3] to calculate the collimation depth for a two-phase collimation system like ILC BDS. The basic approach is given below.

The phase space corners of a beam halo $x_i^h = (x, x')^h$, collimated at $n_x\sigma_x$, at any a given point in the final quadrupole doublet can be calculated as

$$x_i^h = (R^{-1})_{ij} \, x_j^{IP} \tag{1}$$

where $x_j^{IP} = n_x(\pm\sigma_x^*, \pm\sigma_{x'}^*)$, R is the transfer matrix from the given point to the IP, σ_x^* ($\sigma_{x'}^*$) is the IP beam size (divergence). An identical equation holds for y.

The phase space corners of the SR profile emitted from this point - the 'SR envelope' - at distance L from the emission point is then

$$x_i^{SR} = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix} x_j^h \tag{2}$$

A circular aperture of radius r placed at distance L from the emission point, puts the following constraint on the SR fan size

$$(x^{SR})^2 + (y^{SR})^2 \le r^2 \tag{3}$$

When (3) is expanded using equations (1) and (2), this constraint becomes an ellipse of collimation depth solutions in n_x, n_y.

The analysis above must be repeated over all emission points in the final doublet to find the overall collimation depth ellipse. The critical emission point in the FD depends on the IP beam parameters, the quadrupole strengths, the aperture sizes and distances.

The collimation depth solution in n_x, n_y is non-unique, but the values taken are usually those that maximise the collimation phase space acceptance i.e. which give $x^{SR} = y^{SR}$.

It may be the case that, with several IR apertures and many emission points, the overall solution boundary in n_x, n_y consists of overlapping or intersecting ellipses, as will be seen later.

The method described assumes linear transport not only within the final doublet, but between the spoilers and the final doublet. In practice the collimators aperture may have to be reduced further to achieve the required SR clearance. In addition, this method does not take into account halo energy spread or the effect of the detector solenoid, which may affect the halo dynamics and thus the collimation depth. An ideal machine with no misalignments is also assumed.

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COLLIMATION DEPTHS FOR ILC BDS

The ILC baseline final doublet and detector configuration has several different scenarios. The current IR design incorporates a 'push-pull' scheme – a single IP shared by two different detector concepts which can be interchanged.

Within the push-pull scheme, final doublet and extraction line optics have been designed for the SiD, LDC and GLD detector concepts. Each design has a different L* (distance from the final quadrupole to the IP) and L_{ext}* (distance from the IP to the first extraction quadrupole).
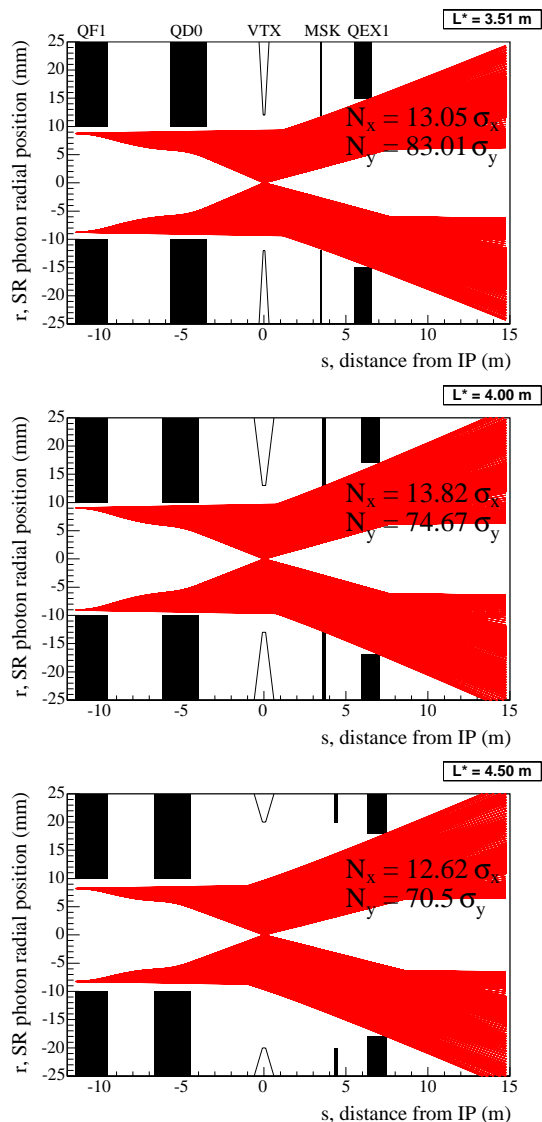

Figure 1: Collimation depths for the baseline ILC final doublet schemes. L* = 3.51 m SiD (top), L* = 4.0 m LDC (middle), L* = 4.5 m GLD (bottom). The final doublet quads QF1 and QD0, the vertex detector VTX, the backscattering mask MSK and the first extraction quad QEX1 are shown.

In the push-pull scheme each detector would carry it's own final quadrupole and first extraction quadrupole. The next-to-final quadrupole and second extraction quadrupole would be part of the fixed BDS beamline which is shared by the two detectors.

The collimation depths have been calculated for the three IR configurations, using nominal IP parameters of $\beta_x(\beta_y)$ = 21 mm (0.4mm), $\varepsilon_x(\varepsilon_y)$ = 2.04×10^{-11} m.rad (8.18×10^{-14} m.rad). The detector parameters (vertex detector and mask geometry) were taken from the detector online documents [4]. The resulting SR fans from the phase space corners of the collimated halo through the IRs are plotted in Figure 1.

It is noticeable from Figure 1 that the apertures of the extraction quadrupole and the mask almost impose the same constraint on the SR fan, except in the L*=4.5 m, GLD case. In addition, the QD0 and QF1 apertures provide only a small margin of clearance for both the SR fan and the halo itself. The 'constraint space' for one case, L* = 3.51 m, SiD, is illustrated in Figure 2.
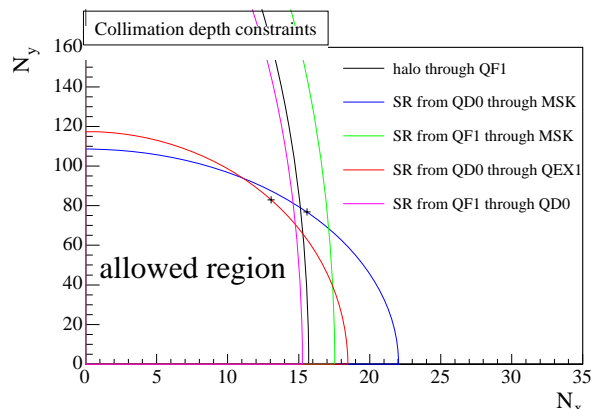

Figure 2: Collimation depth constraints for the L* =3.51 m, SiD, IR design. The allowed region of collimation depths which provides IR SR clearance is lower left inner area of the axes enclosed by the intersecting ellipses. The crosses denote the N_x, N_y values on each ellipse that maximise the collimated halo area.

It is clear that several constraints intersect to define the allowed region, so that removing one constraint alone (for example increasing the mask aperture) does not significantly affect the collimation depth. It is also clear that the collimation depth in each plane can be increased at the expense of the other plane. This flexibility is important since collimator wakefield effects may be inherently larger in one plane.

The collimation depth is also calculated for the alternative 2 mrad crossing angle final focus scheme[5], for L* = 4.5 m. Since the extracted beam does not pass through the centre of the mask and the opposing final doublet, the circular constraint in equation (3) must be reconsidered. One method is to define a virtual aperture centred on the extracted beam, whose edge is aligned with the physical aperture (more details are given in [6]). This gives a conservative estimate of the collimation depth. The results for the GLD scheme are given in Figure 3. It might be assumed that the 2 mrad scheme collimation depths would be tighter than the baseline 14 mrad, since

the off-axis SR fan passes closer to the apertures. However the crucial apertures are different in the 2 mrad design; the extraction quadrupole aperture is no longer relevant, and the first apertures the extracted beam sees are the vertex detector, the mask, the final quadrupole of the opposite FD. Since the vertex detector and mask are very large in the L*=4.5, GLD scheme, and superconducting QD0 has a large aperture, then the SR fan has in fact much more space to pass cleanly. Consequently the collimation depths are looser. But for the LDC and SiD detectors, whose mask apertures are much smaller, the collimation depths are likely to be tighter.
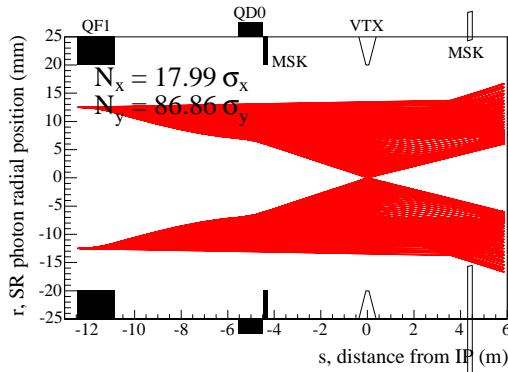

Figure 3: Collimation depths for the alternative 2 mrad crossing angle scheme with L* = 4.5 m.

CONCLUSION

The collimation depths for the baseline ILC BDS schemes are in the range 12.5-13.0 σ_x and 70-85 σ_y for the nominal IP beam parameters. This equates to spoiler full gaps of approximately 3 mm and 1.3 mm in horizontal and vertical planes.

The dependence of the collimation depths on L* appears weak; as L* increases by 30%, the vertical collimation depth decreases by 15%, and the horizontal dependence is weaker. This is due to the larger extraction apertures in the larger L* designs which partly accommodate the wider SR fans.

The alternative 2 mrad BDS design shows looser collimation depths for L*=4.5 m and the GLD, but for other detectors the collimation depths are likely to be tighter.

The collimation depths are determined by several different IR constraints of similar severity. Thus, increasing one aperture alone would not significantly increase the collimation depth; a complete redesign of the IR and all its apertures would be required to loosen collimation requirements.

In all future linear collider BDS designs, collimator wakefields in the vertical plane are predicted to dominate the emittance dilution [7], and cause unacceptably large luminosity loss. Consequently, octupole halo-folding has been incorporated into the ILC BDS design from an early stage (the method was inherited from the previous NLC design [8]). The results here indicate that the vertical collimation apertures can be increased at the expense of

tightening the horizontal apertures. A rough calculation can be made; the emittance dilution varies with the square of the collimator kick factors, which have at least a linear dependence on the collimator apertures. Therefore a 20% increase in vertical spoiler gap results in 44% less emittance dilution. The corresponding reduction in horizontal spoiler aperture and resulting horizontal emittance dilution may be of little concern, since the horizontal emittance dilution is much smaller than the vertical.

The results here have addressed nominal IP parameter sets only. Other scenarios, such as high luminosity running, require smaller beam sizes and thus larger beam divergences through the IR. Larger beam divergences increase the divergence of the SR fan and thus demand smaller collimation depths. While final focus optics designs do not yet exist for high luminosity running, it is estimated that the collimation depths would need to be approximately 40% tighter.

ACKNOWLEDGEMENTS

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