



Interaction Region RF Shield Issues

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The NLC ZDR [1] called for an rf shield in the IR that extended from the end of the final quadrupole towards the IP. In addition, the ZDR specified an rf septum that partially covered the quadrupole exit face. These are illustrated in Fig. 1.

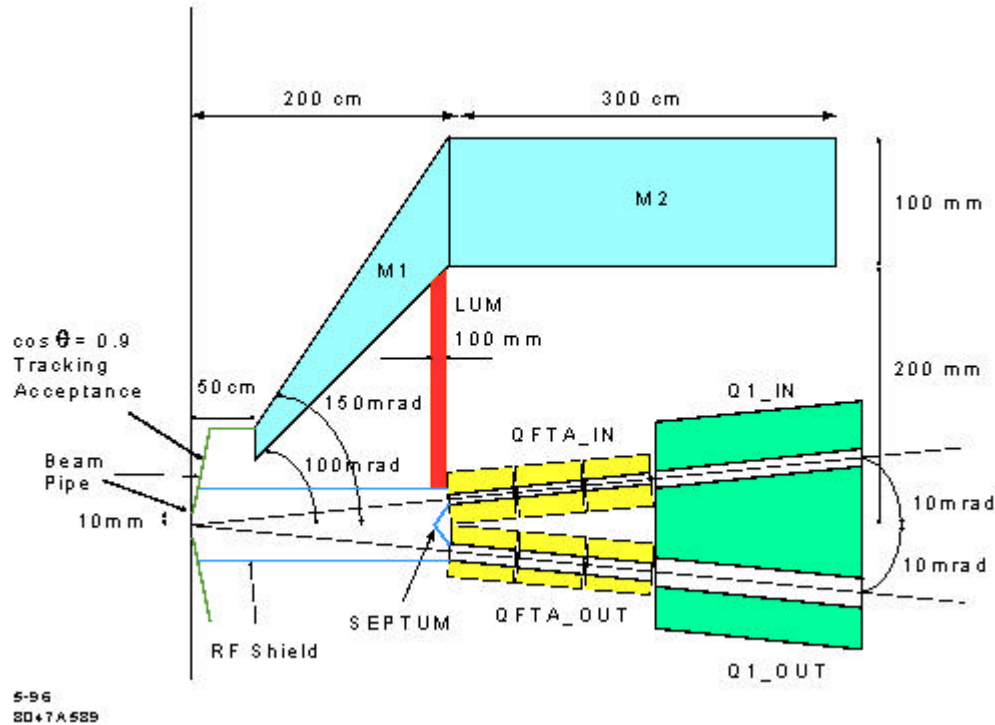


Figure 1. Schematic of the IR from Ref. [1].

The rf shield and septum were proposed to reduce possible wakefield effects in the IR including rf heating as well as beam deflections. However, the rf shield is a significant source of backgrounds due to the scattering of the e^+/e^- pairs from the IP.

There are four issues to consider when discussing the need for an rf shield: parasitic beam-beam collisions, short-range wakefields, multi-bunch wakefields, and heating.

With a crossing angle of 20 mrad, the parasitic beam-beam collisions have a negligible effect – the growth of the kink instability is very small and then additional focusing is not important [2]. Similarly, preliminary calculations of the multi-bunch wakefields, presented in LCC-0025, indicate that the dipole wake is significantly less than 1 V/pC/m at a trailing bunch. The deflection from such a wakefield will be negligible even if it is driven resonantly by the beam.

This is not necessarily true of the beam induced heating. In principal, it might be possible to deposit a few Watts of average power in the IR but this would be most easily dealt with by adding absorbing material to the region.

The last issue is that of the short-range wakefields. Here, the effect can be more important as discussed by Gennady Stupakov in a memo included in Appendix A. Using his expressions for the short-range wakefield, the deflection can be expressed in terms of the incoming jitter at the final quad:

$$\frac{\Delta y^*}{s_y^*} = k \frac{Nr_e}{g} \frac{L^{*2}}{b^*} \frac{\Delta y_q}{s_{yq}}$$

and the corresponding emittance dilution would be:

$$\frac{\Delta g e_y}{g e_y} = \frac{1}{6} \left[k \frac{Nr_e}{g} \frac{L^{*2}}{b^*} \right]^2 \frac{\Delta y_q}{s_{yq}}$$

where $k = 2/a^2$ and a is the chamber radius. For the standard NLC design with $N=1.0 \times 10^{10}$, $E = 250$ GeV, $L^* = 2$ m, $b^* = 100$ μ m, and $a = 6$ mm, the jitter amplification is a factor of 12% and the emittance dilution would be 0.2% for incoming jitter equal to the beam size at the final quad; the expected beam jitter is less than $1/2$ the beam size at the final quadrupole. If the aperture of the final quadrupole simply scales linearly with the L^* , which is necessary to maintain an equivalent aperture in units of the beam size, the jitter amplification and emittance dilution are independent of the L^* .

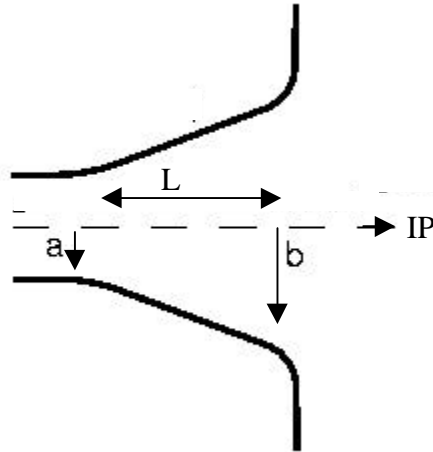


Figure 2. Schematic of the final quadrupole exit.

The amplification could be reduced by adding a taper to increase effective exit aperture of the final quadrupole as illustrated in Fig. 2. In this case, the kick factor would be:

$$\mathbf{k} = \frac{2}{b^2} + \frac{(b-a)^2}{\sqrt{\rho} abL\mathbf{s}_z}$$

where L is the length of the taper which is assumed to be greater than $L > a^2 / \mathbf{s}_z$. The first term decreases with the outer radius b while the second term increases. Then b can be optimized to minimize the kick factor. The outer radius b and the resulting kick factor \mathbf{k} are plotted against the length L in Figs. 3 and 4, respectively.

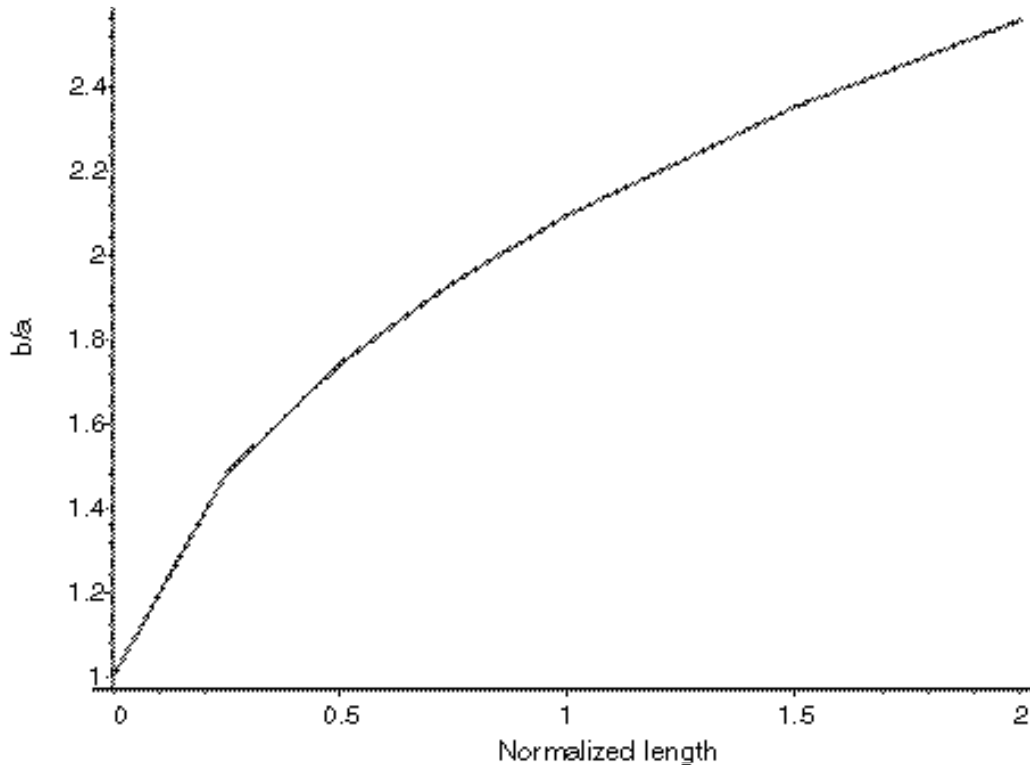


Figure 3. Optimum normalized outer radius b/a versus normalized taper length LS_z/a^2 .

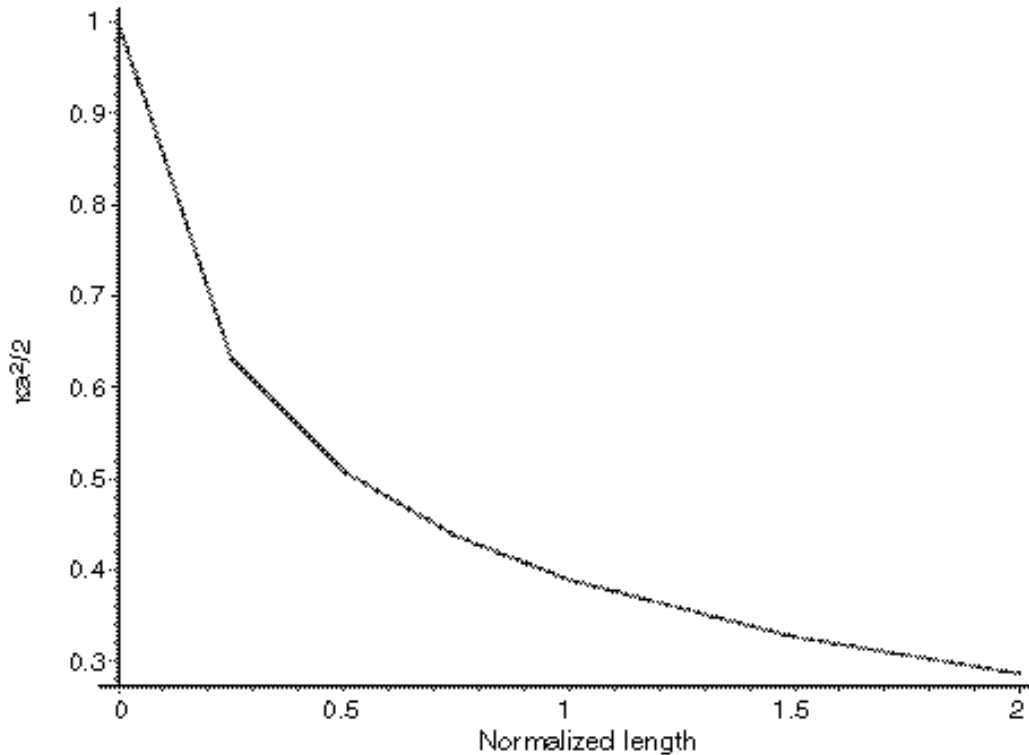


Figure 4. Resulting normalized kick factor $ka^2/2$ versus normalized taper length LS_z/a^2 .

One can see that the kick factor can be reduced by a factor of two by adding a taper out to an outer radius that is roughly 70% larger than the inner radius but there is not as much relative gain beyond this point. For the NLC parameters, this implies a taper length of roughly 30 cm, however, since the wakefield effect is already quite small, we do not think such a taper is necessary.

References

- [1] *A Zeroth Order Design Report for the Next Linear Collider*, T.O. Raubenheimer, ed., SLAC Report-474 (1996).
- [2] P. Chen, K. Yokoya, "Multi-bunch Crossing Instability" SLAC-Pub-4643 (1988).

Appendix A

SLAC MEMORANDUM

May 9, 2000

To: Tor Raubenheimer
 From: Gennady Stupakov
 Re: Estimate of the wakefield at the exit of the final quad in the NLC

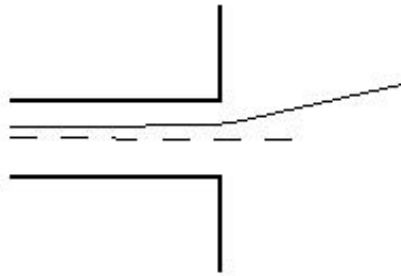


Figure 1: Exit pipe geometry.

In this note I calculate the effect of the wake generated at the exit from the final quad of the NLC.

The wake for the geometry shown in Fig. 2 was computed in Ref. [1]. The average over the bunch deflection angle θ caused by the wake is

$$\theta \equiv \langle y' \rangle = \kappa \frac{N r_e y}{\gamma}, \quad (1)$$

where N is the number of particles in the bunch, r_e is the electrons classical radius, y is the beam offset, and κ is the kick factor,

$$\kappa = \frac{2}{a^2}, \quad (2)$$

with a equal to the pipe radius. The rms spread of the deflection angle within the bunch, $\theta_{\text{rms}} = \langle (y' - \langle y' \rangle)^2 \rangle^{1/2}$, is

$$\theta_{\text{rms}} = \frac{\theta}{\sqrt{3}}. \quad (3)$$

We assume the nominal NLC beam parameters $N = 1.1 \cdot 10^{10}$, $\gamma = 5 \cdot 10^5$, and the pipe radius $a = 6$ mm. This gives

$$\theta = 3.4 \cdot 10^{-9} y \text{ rad}, \quad y'_{\text{rms}} = 2 \cdot 10^{-9} y \text{ rad}, \quad (4)$$

where y is measured in mm. At the NLC IP, which is about $l = 2$ m away from the exit from the pipe, the beam offset will be

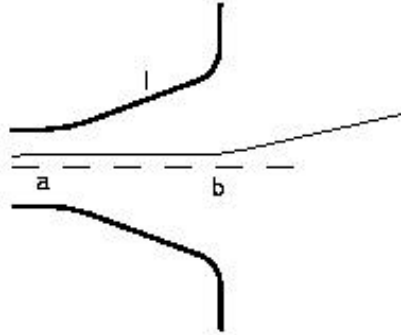
$$\Delta y = l\theta = 6.8y \text{ nm}. \quad (5)$$

The vertical beam size σ_y at the interaction point ($\beta_x = 100 \mu\text{m}$) is about 3.5 nm, and requiring the jitter to be less than a quarter of σ_y , we find the tolerance for the beam offset at the exit from the final quad,

$$y < 130 \mu\text{m}. \quad (6)$$

We can also estimate the emittance dilution due to the kick. The beta function at the exit is approximately equal to $\beta_1 = l^2/\beta_x \approx 4 \cdot 10^4 \text{ m}$. The normalized emittance dilution can be estimated as $\Delta\epsilon = \frac{1}{2}\gamma\theta_{\text{rms}}^2\beta_1 \approx 4 \cdot 10^{-8} y^2 \text{ m rad}$. Again, requiring a tolerable emittance dilution of about 10% of the nominal vertical emittance $4 \cdot 10^{-8} \text{ m}$, we obtain the tolerance for the offset $y < 300 \mu\text{m}$.

Note the scaling of the wake with the pipe radius — it is proportional to a^{-2} . Making the exit pipe radius bigger would quickly loosen the tolerances for the beam jitter.



If we want to taper the exit as shown on Fig. 2, from radius a to radius $b > a$ by making a conical expansion of length l , then the kick factor will be equal to $2/b^2$, however an additional wake generated by the taper needs to be added. This wake was calculated in my paper [2], it gives the kick factor

$$\kappa = \frac{(b-a)^2}{\sqrt{\pi a b l \sigma_x}}. \quad (7)$$

Figure 2: Quad exit with FR shield. One has to keep in mind that in order Eq. (7) to be valid the taper should be long enough, $l_0 > a^2/\sigma_x$ where l_0 is the distance on which the radius doubles from a to $2a$.

References

- [1] F. Zimmermann, K. L. F. Bane, and C. K. Ng, in S. Myers, A. Paheco, R. Pascual, C. Petit-Jean-Genaz, and J. Poole, eds., *Proc. European Particle Accelerator Conference, Sitges, 1996* (IOP, Bristol, 1996).
- [2] Stupakov G.V., *Particle Accelerators* 56(2), 83 (1996).