DOUBLE DYNAMIC FOCUSING FOR LINEAR COLLIDERS

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Abstract

Dynamic focusing refers to the use of secondary beams to form final-focus lenses for the primary high energy beams of linear colliders. In double dynamic focusing an initial lens-lens beam collision focuses the lens beams for their collision with the primary beam. This paper describes the techniques for the formation of a uniform lens shape from an initial Gaussian shape, the necesary main- and lens-beam parameters and their scaling, and requirements for a 1 TeV c.m. application. Advantages of this scheme include the complete elimination of the conventional final focus and collimation systems, elimination of beamline elements within the detector, and the promise of looser main-beam linac alignment, energy spread and ground motion tolerances.

1 INTRODUCTION

1.1 Motivation

Our original motivation was a search for a viable final focus system for linear colliders above 1.5 TeV cm. Now our motivation is the complete elimination of the final focus and collimation systems and reduction of backgrounds and cost in all future colliders, including the next linear collider (NLC) [1].

1.2 A simple large momentum-bandpass focusing system

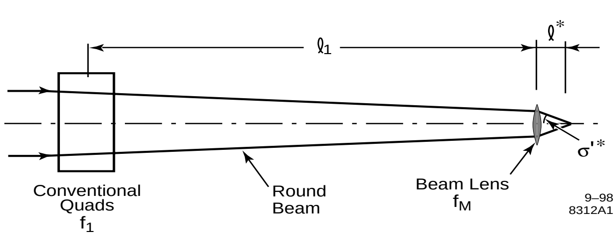

Figure 1. A schematic of a simple final focus system. A very strong lens is placed 1 cm from the IP. The total length is about 4 m.

We will use a secondary beam to create a small strong lens about 1 cm from the IP [2, 3]. Figure 1 shows the full system, with final conventional quads outside the detector at a distance $l_1 \geq 4m$. If the focal length, f_1, of the convential quads is chosen equal to l_1, and the focal length of the beam lens, f_M, is chosen so that a ray originating at the convential quad is focused to the IP, then the final spot size demagnification is $\rho = l^* / l_1$, and

$$\sigma^{*2}(\bar{\delta}) = [\rho^2 + (\lambda^2 - 2\rho)\bar{\delta}^2 + \bar{\delta}^4]\,\sigma_1^2$$

where $\lambda = l_1 / \beta_1$ is the demagnification to the beam lens. If $\lambda < \sqrt{2\rho}$, a condition easily satisfied, the second order term in $\bar{\delta} \equiv \delta / (1+\delta)$ is actually negative. Under these circumstances the bandpass of the system is given by $\bar{\delta}^2 < \rho$, which for a typical demagnification of 1/400 gives $\bar{\delta} < 1/20$, implying a huge momentum bandpass.

1.3 Double dynamic focusing

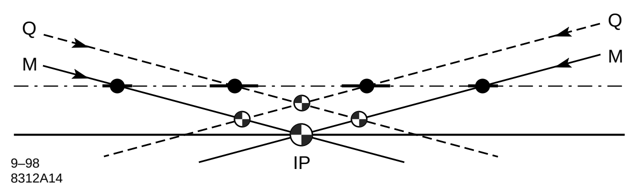

Figure 2. An overview showing the trajectories of the lens beams and main beams. There are three collisions: lens-lens, 2 lens-main and the final main-main. This figure also shows the "crabbing" of the beams and the fact that all beams lie on a common line as they traverse the IP.

Figure 2 shows an overview of the incoming lens and main beams. Because room-temperature colliders must have multi-bunch beams, a non-zero crossing angle is required. Crab cavities are used to twist the bunch so that they pass through each other as if head-on, and by control of their relative phases, they place the bunches along a common transversely-moving line.

The two lens beams must necessarily collide before their interaction with the main beam. This collision can be put to advantage for either aligning the lens bunches or to completely focus the lens beam. It is the latter case which we refer to as double dynamic focusing.

2 LINEAR COLLIDER IP PARAMETERS

With dynamic focusing, arguments for the flat beam geometry are all but eliminated. Round beams are favored because they require lower main-beam bunch charge (facilitating a lower lens-beam energy) and have a larger IP vertical size and β-function. Presumably, for main- linac efficiency, main-beam current is held constant. A lower short-range wakefield is advantageous, but long-range wakes could be worse. Damping ring rf design is changed dramatically. At 1 TeV cm with $n_\gamma = 1$, round IP parameters are $N = 0.7\ 10^9$, $\sigma = 12\,nm$ and $\sigma_z = 60\,\mu m$.

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3 DYNAMIC FOCUSING PARAMETERS

3.1 Lens beam charge per bunch

For a charge $\overline{N}_Q$ in a uniform disk of radius R_Q the focal length is given by $\frac{1}{l*}=\frac{2\overline{N}_Q r_e}{\gamma_M R_Q^2}$. This condition yields $\overline{N}_Q = N_{Q_0}\frac{R_Q^2}{2\sigma_M^2}$ where $N_{Q_0}=\frac{(\gamma\,\varepsilon)_M}{r_e}\xi$, and $\xi=\frac{l^*}{\beta^*}$ is the inverse demagnification from the beam lens to the IP. Since the fraction of the main beam not incident on the uniform disk is given by $\Delta N / N = \exp[-R_Q^2 / 2\sigma_M^2]$, the exponent will lie between 3 and 4.

3.2 Uniform lens distributions

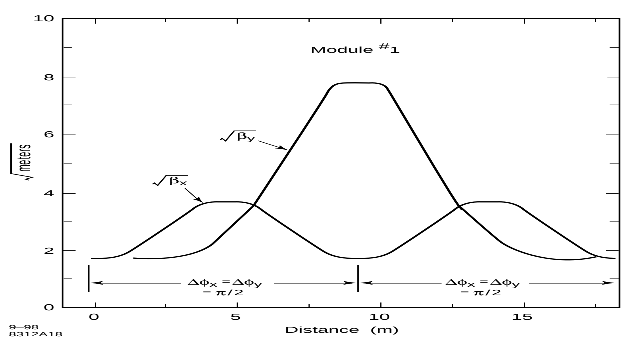

Figure 3. A module for inserting an octupole in a beamline.

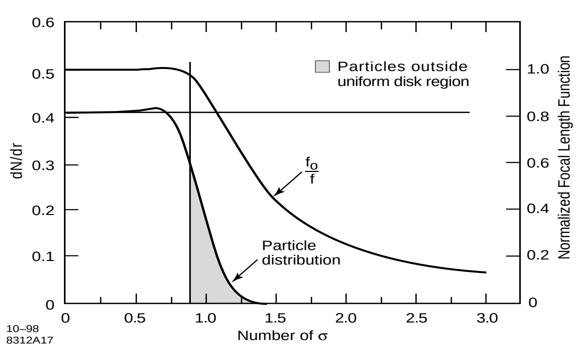

Figure 4. An example of a particle distribution and its focal length function achieved with a 3-octupole system. 85% of the distribution is accurately focused.

A Gaussian distribution can be made almost uniform by using 3 octupoles in 3 similar modules (see Fig. 3), each rotated by 60 degrees from the previous module. An example of a distribution achieved in this way is shown in Fig. 4. The lens-lens collision can further reduce the population in the tails for the main-lens collision.

3.3 Pinch effect

Figure 5 shows the lens beam colliding with the main beam. Each beam focuses the other and the ratio of the focal lengths is the beam-power ratio: $f_M / f_Q = (\gamma\,N)_M / (\gamma\,N)_Q$. The focusing of the lens beam will cause a change in its focal length for the latter part of the main beam. This is improved by arranging that the lens beams diverge when they meet the main beams. See Fig. 6. Ignoring effects of disruption, the luminosity loss due to the change in focal length is about $\frac{\Delta L}{L}\approx\frac{1}{120}\left(\frac{l^*}{f_Q}\frac{\sigma_z}{\beta^*}\right)^2$.

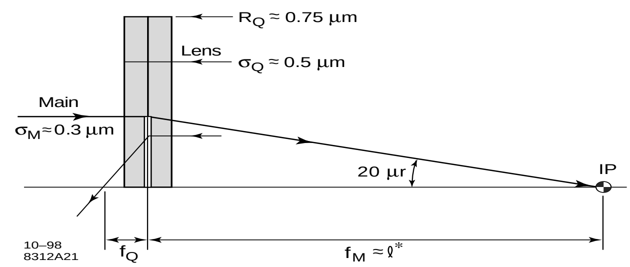

Figure 5. The lens beam, moving to the left, is pinched by the main beam moving to the right.

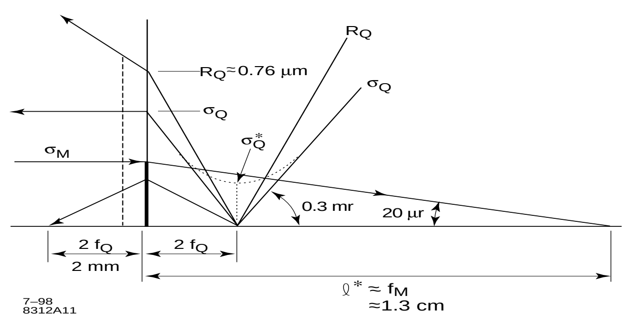

Figure 6. A lens beam which is diverging when it meets the main beam will reduce the pinch effect.

3.4 Parameter summary

Figure 7 summarizes the relationships of the parameters in this problem. $c_p = \sqrt{120\,(\Delta L / L)_p}$ comes from the pinch-loss equation and n_{l^*}, the number of l^* chosen for the focal length of the lens-lens collision, equals 1 for double dynamic focusing and 2 for self alignment. A possible parameter choice for 1 TeV cm [ξ=30, $\gamma_M / \gamma_Q = 100$, D=0.9, and H=3] lies very close to the zero 2nd order chromaticity condition.

These parameter relationships scale well to higher energies, and dynamic focusing appears viable up to 10 TeV cm. At 1 TeV cm it may be possible to put the lens beam in a storage ring. At higher energies a modified scheme including a linac will be necessary. See Fig. 8.

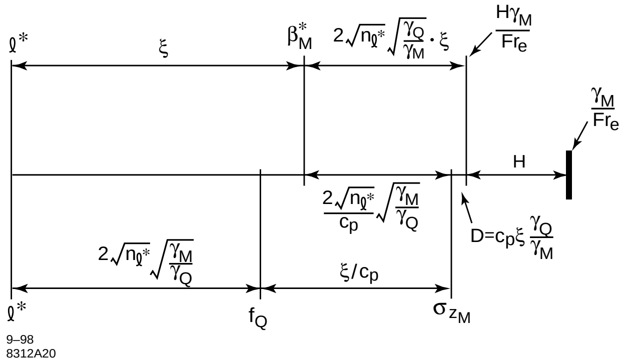

Figure 7. A log-scale diagram showing the relationship of the parameters in a “double” dynamic focusing system. See text.

4 OPTICAL BENCH CONDITIONS

4.1 Jitter

In addition to a uniform lens profile, it is crucial to have small beam jitter because the lens position determines the focal point for the main beam. With the demagnifications assumed, the inter-bunch lens-beam jitter would have to be 1% for the self-aligning case and 0.1% for double dynamic focusing. 1% is the ZDR specification for the NLC damping ring, and appears achievable. 0.1% probably requires a feed-forward loop after extraction from the lens-beam damping ring. Such a scheme is indicated in fig. 8. The main obstacle is the short inter-bunch spacing, presumably at S-band or less. An accurate fast BPM is under study. Lens train alignment can be achieved by using precursor bunches in the lens train.

4.2 The crab cavity

Crab cavity phase tolerance are an order of magnitude tighter with round beam parameters: the relative phases should drift no further than 0.01 degrees X-band. Systems for evaluating the feasibility of this tolerance are being developed.

5 SUMMARY

The prospect of total elimination of the final focus and collimation systems offered by dynamic focusing is very attractive. Additionally backgrounds in the IP region can be dramatically reduced, removing the tension between luminosity and backgrounds present in the SLC operation. Lens-beam energy should be minimnized to reduce cost. The minimum will depend on the lens quality that can be achieved, but appears to be less than 1% of the main beam energy.

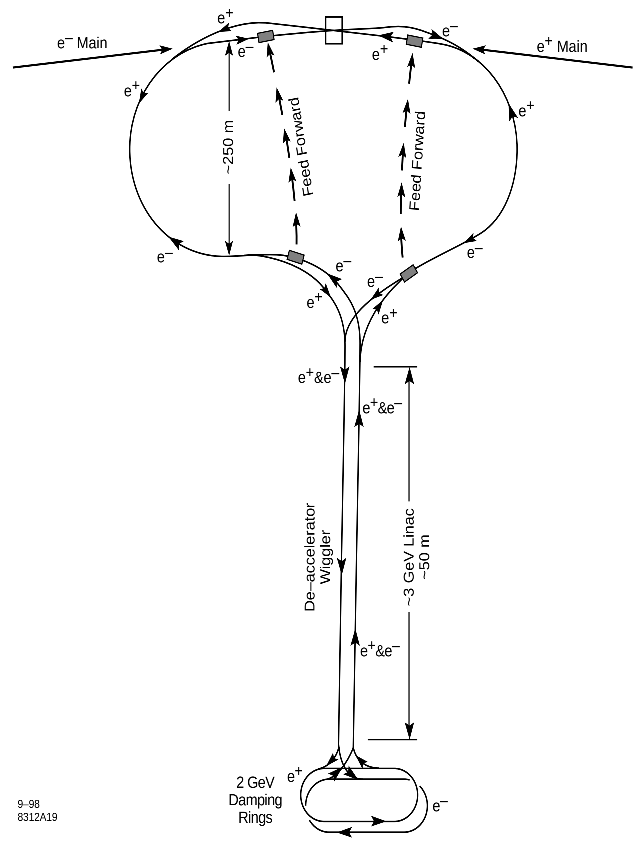

Figure 8. A possible geometry for the lens-beam system. The lens beam is stored in a 2 GeV damping ring between collisions, accelerated to the required collision energy, then decelerated and re-injected into the damping ring. A feed-forward scheme removes bunch to bunch jitter.

6 ACKNOWLEDGMENTS

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