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New NLC Final Focus

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Abstract. A novel design of the Final Focus has recently been proposed [1] and has been adopted now for the Next Linear Collider [2]. This new design has fewer optical elements and is much shorter, nonetheless achieving better chromatic properties. In this paper, the new final focus system is briefly discussed stressing one particular characteristic of the new design – its multi TeV energy reach.

INTRODUCTION

The main task of a linear collider final focus system (FF) is to focus the beams to the small sizes required at the interaction point (IP). To achieve this, the FF forms a large and almost parallel beam at the entrance to the final doublet (FD), which contains two or more strong quadrupole lenses. For the nominal energy, the beam size at the IP is then determined by $\sigma = \sqrt{\varepsilon\,\beta^*}$ where ε is the beam emittance and β^* is the betatron function at the IP (typically about 1–0.1 mm). However, for a beam with an energy spread σ_E (typically 0.1–1%), the beam size is diluted by the chromaticity of these strong lenses. The vertical chromaticity defined as $\xi = \frac{d\beta^*/\beta^*}{dE/E}$ roughly scales as $(L^* + L_q/2)/\beta^*$, where L^* (typically 2–4 m) is the distance from the IP to the FD and L_q is the length of the final quad (assumed vertically focusing). Thus the chromatic dilution of the beam size $\sigma_E L^*_{\text{eff}}/\beta^*$ is very large. The design of a FF is therefore driven primarily by the necessity of compensating the chromaticity of the FD.

In a "traditional" final focus system (SLC [3], FFTB [4] or the new linear collider designs) the chromaticity is compensated in dedicated chromatic correction sections (CCX and CCY) by sextupoles placed in high dispersion and high beta regions. The geometric aberrations generated by the sextupoles are canceled by using them in pairs with a minus identity transformation between them. As an example, the "traditional" design of the NLC Final Focus [2] with $L^* = 2$ m, $\beta^*_x = 10$ mm and $\beta^*_y = 0.12$ mm is shown in Fig.2. The advantage of the traditional FF is its separated optics with strictly defined functions and straightforward cancellation of geometrical aberrations. This makes such a system relatively simple for design and analysis.

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The major disadvantage of the "traditional" final focus system is that the chromaticity of the FD is not locally compensated. As a direct consequence there are intrinsic limitations on the bandwidth of the system due to the unavoidable breakdown of the proper phase relations between the sextupoles and the FD for different energies. This precludes the perfect cancellation of the chromatic aberrations. Moreover, the system is very sensitive to any disturbance of the beam energy in between the sources of chromaticity, whether due to longitudinal wakefields or synchrotron radiation. The bend magnets have to be sufficiently long and weak to minimize the additional energy spread generated and lengthen the system considerably. As a result of all these limitations, the length of the beam delivery system becomes a significant fraction of the length of the entire accelerator, and scaling to higher energies is difficult.

"IDEAL" FINAL FOCUS SYSTEM

Taking into account the disadvantages of the traditional approach, one can formulate the requirements for a more "ideal" final focus: 1) The chromaticity should be corrected as locally as possible. 2) The number of bend magnets should be minimized. 3) The dynamic aperture or, equivalently, the preservation of the linear optics should be as large as possible. 4) The system should have as few elements as possible. It is straightforward, starting from the IP, to build such a system: 1) A Final Doublet is required to provide focusing. 2) The FD generates chromaticity, so two sextupoles interleaved with these quadrupoles and a bend upstream to generate dispersion across the FD will locally cancel the chromaticity. 3) The sextupoles generate geometric aberrations, so two more sextupoles in phase with them and upstream of the bend are required. 4) In general four more quadrupoles are needed upstream to match the incoming beta function (see the schematic in Fig.1).

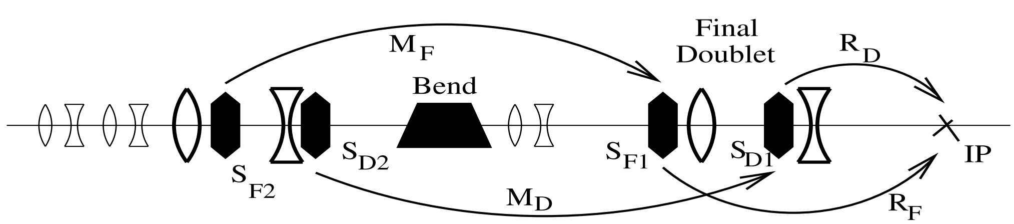

FIGURE 1. Optical layout of the new final focus.

While cancellation of vertical chromaticity is straightforward in the new design, simultaneous cancellation of horizontal chromaticity and second order dispersion produced in the final doublet is more difficult. In spite of this, such a system has a lot of flexibility and it is possible to make it aberration free up to third order and to minimize the forth order aberrations. The angular dispersion at the IP, η', is necessarily nonzero in the new design, but can be small enough that it does not significantly increase the beam divergence.

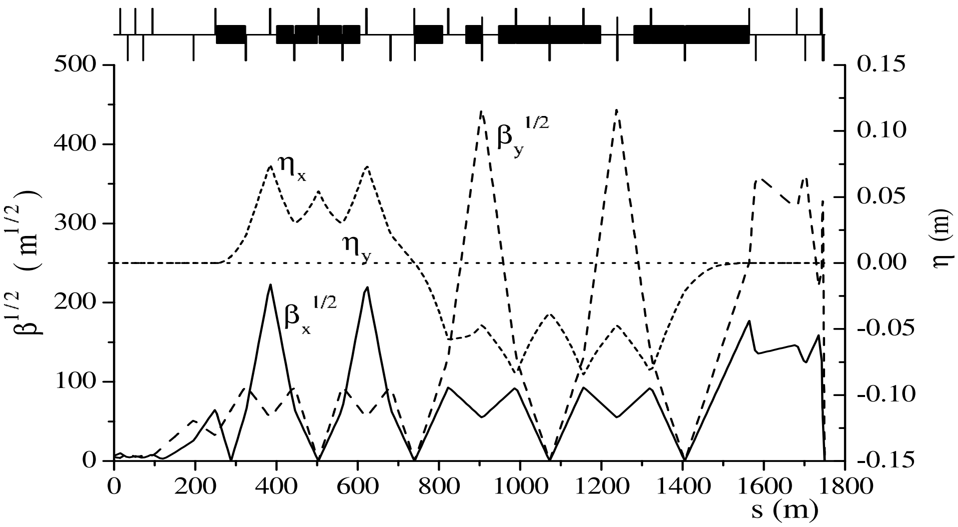

FIGURE 2. Optics of the traditional Final Focus for the Next Linear Collider showing horizontal and vertical betatron (β) and dispersion (η) functions.

The new FF system even in the "minimal" configuration shown in Fig.1 has potentially much better performance than the traditional design. Additional elements can further increase its performance. It can be shown that a system with the same demagnification as the traditional NLC FF, same L^* and comparable optical performance can be built in a length of about 300 m.

The new optics for the NLC design is shown in Fig.3 and the beam parameters are given in Table 1. This system has a few elements beyond the minimal design to further improve the performance. In addition, the new system has an $L^* = 4.3$ m, which is more than twice the original value and will simplify the design of the detector. Although the chromatic correction is larger due to the longer L^*, the

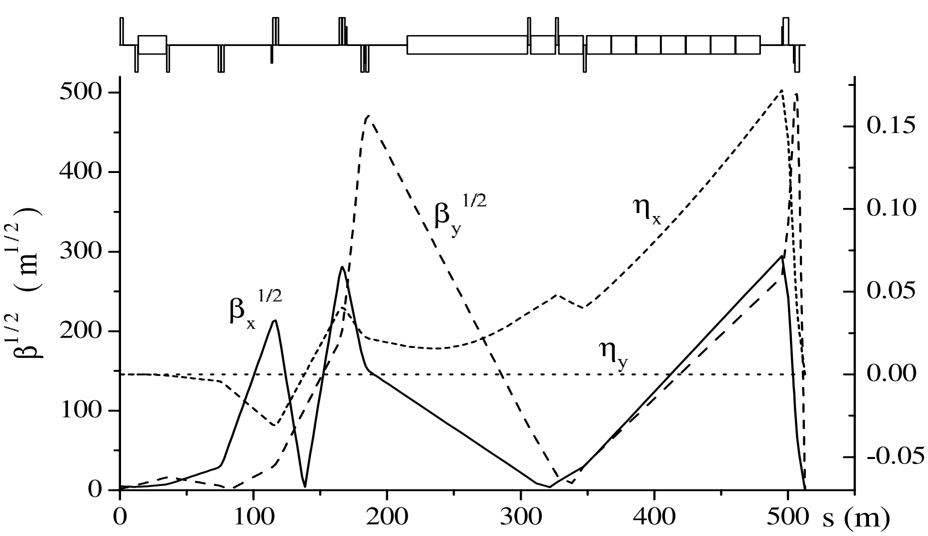

FIGURE 3. Optics of the New Final Focus for the Next Linear Collider.

TABLE 1. Beam and optics parameters.

Beam energy, GeV	500
Normalized emittances $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (μm)	4 / 0.06
Beta-functions β_x / β_y at IP (mm)	9.5 / 0.12
Beam sizes σ_x / σ_y at IP (nm)	197 / 2.7
Beam divergence θ_x / θ_y at IP (μrad)	21/23
Energy spread σ_E (10^{-3})	3
Dispersion' η'_x at IP (10^{-3})	5.4

performance of the system is still better than for the original NLC FF design.

Finally, another major advantage of the new final focus design is that the system scales more easily to higher energies. In the traditional FF, the length of the system increases rapidly with energy because of the need to minimize the synchrotron radiation in the bend magnets. Any energy loss between the pairs of sextupoles breaks the perfect cancellation of aberrations and causes an increase in the IP beam size. The new design has fewer bend magnets and can operate up to a center of mass energy of about 2 TeV. At high energy, the geometrical beam emittance also shrinks which reduces the higher order aberrations and allows further optimization of the tradeoff between sextupole and bend magnet strength. If one takes advantage of this optimization to reduce the bending angle, the FF geometry changes but the change is small, only a few centimeters, and no change is required at low energy. The new FF design can operate from 0.1 to 1 TeV CM with the same bend angle and thus with a fixed beamline geometry. At higher energies, reoptimization of the bend angle becomes necessary. If one were able to achieve even smaller normalized beam emittances at high energy as assumed in [5,6], the new FF design can operate up to 5 TeV CM without increasing its length. The luminosity as a function of energy is shown in Fig.4 for these different assumptions.

CONCLUSION

The recently developed new Final Focus of the Next Linear Collider has better properties than the systems so far considered or built. It is much shorter, providing a significant cost reduction for the collider. The system is compatible with an L^* which is twice as long as that in the traditional NLC FF design, which simplifies engineering of the Interaction Point area. Its favorable scaling with beam energy makes it attractive for multi-TeV operation. We believe that further improvements of the performance of the system are possible.

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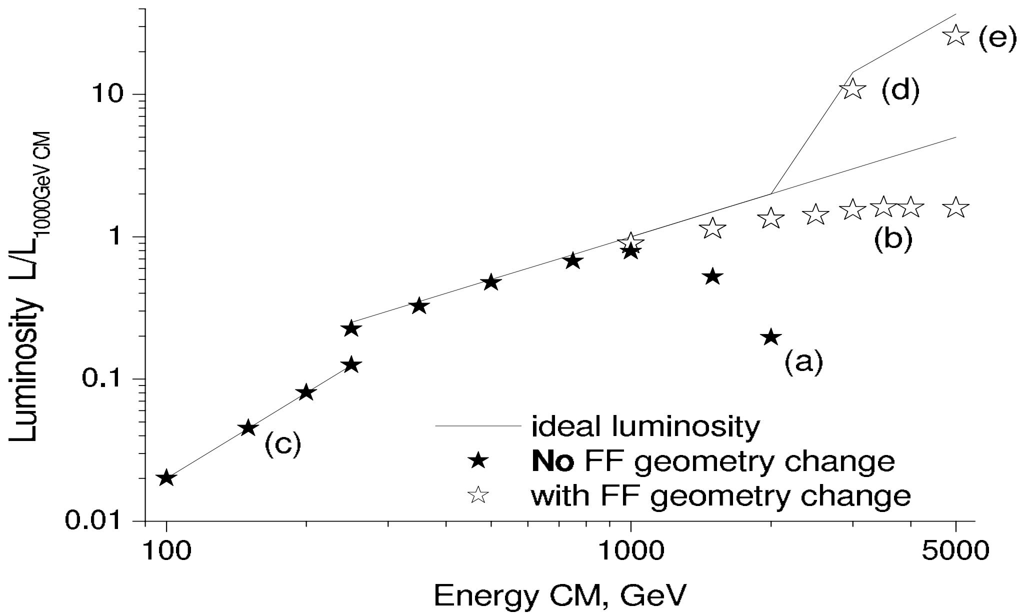

FIGURE 4. Luminosity versus center of mass energy for the new NLC FF. Cases a), b) and c) correspond to parameters from Tab.1, in the case c) the IP beta functions are inversely proportional to the energy to keep beam divergence constant. The case d) correspond to [6] where $\gamma\varepsilon_{x/y} = 68/2 \cdot 10^{-8}$ m, $\sigma_E = 0.2\%$ and $\sigma^*_{x/y} = 43/1$ nm and the case e) to [5] with $\gamma\varepsilon_{x/y} = 50/1 \cdot 10^{-8}$ m, $\sigma_E = 0.2\%$ and $\sigma^*_{x/y} = 31/0.54$ nm. The FF geometry is fixed in cases a), c) and reoptimized in cases b), d) and e). Beam-beam effects are not included.

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