Performance of a Compact Final-Focus System for a 30-TeV Muon Collider

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Abstract. A final-focus optics for a 30-TeV round-beam muon collider has been developed. It is based on the novel design approach for linear colliders. Here, we demonstrate that this system promises a very satisfactory performance. In particular, we evaluate the energy bandwidth, sensitivity to the transverse emittance, magnet-position and stability tolerances, and the luminosity for successive turns.

I INTRODUCTION

In response to the results of the 1999 HEMC workshop [1], the parameter sets [2] were revised [3]. Present research efforts focus on a 30-TeV collider, where synchrotron radiation is still moderate. Relevant parameters are summarized in Table 1.

TABLE 1. Parameters of the 30-TeV Muon Collider [3].

parameter	symbol	value
beam energy	E_b	15 TeV
Lorentz factor	γ	142, 000
bunch population	N_b	2.3×10^{12}
transv. emittance [μm]	$\epsilon_{x,y}$	1.9×10^{-10} m
transv. normalized emittance [μm]	$\gamma\epsilon_{x,y}$	27 μm
rms bunch length	σ_z	4.8 mm
IP beta function	$\beta^*_{x,y}$	4.8 mm
IP rms spot size	$\sigma^*_{x,y}$	950 nm
rms energy spread	$\delta_{\rm rms}$	2×10^{-4}

Side constraints for the final-focus optics design are that (1) quadrupole fields remain either below a maximum gradient of 400 T/m or below a peak field of 15 T at 5σ, and (2) the free space from the exit face of the last quadrupole to the IP, l^*, is kept larger than 6 m.

A system was designed by Raimondi following the approach described in Ref. [4]. This system fulfills all the requirements above. Its total length is about 1 km per side. Optical functions are displayed in Fig. 1. For the round beams of the muon collider, the

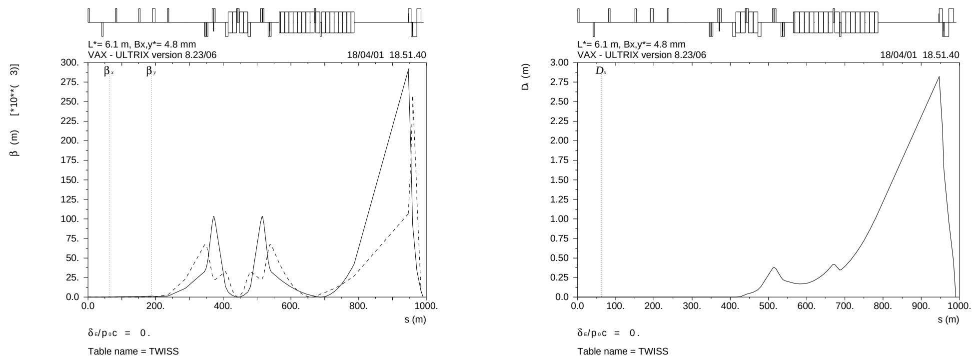

FIGURE 1. Left: Beta functions vs. position; right: dispersion vs. position.

linear-collider final doublet was replaced by a quasi-triplet with equal peak beta functions in both planes.

II PERFORMANCE

The performance was evaluated by tracking with MAD [5] and then computing the luminosity on a grid in the x-y plane at the interaction point, using a routine of the FFADA programme package [6]. The simulated single-pass energy bandwidths for luminosity and rms spot sizes are shown in Figs. 2 and 3. The bandwidth is about ten times larger than the required minimum value of $\delta_{\rm rms} \approx 2 \times 10^{-4}$, so that the final focus could accommodate a larger 6D muon emittance. Figure 4 depicts the dependence of the spot size on the transverse emittance. Nonlinear aberrations become important for emittances about 4 times larger than the nominal value.

To explore the multi-turn behavior, the final focus was complemented by an identical inverse system for the outgoing side, and a rotation matrix was added for tune adjustments. We set the betatron tunes to $Q_x = 4.28$ and $Q_y = 3.31$; the fractional parts correspond to the LHC injection tunes. Figure 5 demonstrates that the excellent tracking performance is maintained on successive turns, although the system had been optimized for a single passage only. We attribute the good multi-turn performance to the locality of the chromatic correction.

Single-pass tolerances on vertical magnet position and field strengths obtained by applying algorithms and routines of FFADA [6,7] are illustrated in Fig. 6. The full bars are ‘jitter’ tolerances, computed from the induced orbit motion at the collision point. Jitter can be corrected within a few pulses using a fast orbit feedback. The open bars are ‘drift’ tolerances referring to increases in the IP spot size. Since the beam-size tuning will be performed less frequently, these tolerances must be met over a longer time scale, *e.g.*, minutes.

The tightest jitter tolerance is about 100 nm, for the second to last quadrupole. The quadrupole magnets upstream of the final triplet are most sensitive to vertical drifts, with

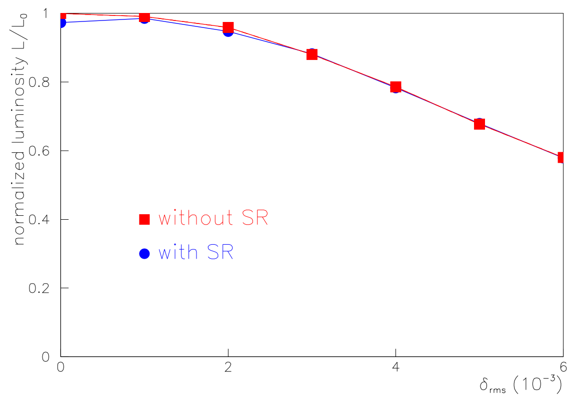

FIGURE 2. Single pass luminosity vs. relative rms momentum spread. The luminosity is normalized to the ideal goemetric luminosity. The two curves refer to simulations with and without synchrotron radiation.

a tolerance of 1 μm. The most challenging field-stability requirements are found for two of the final quadrupoles, for which the field must be stabilized to within 5×10^{-6}.

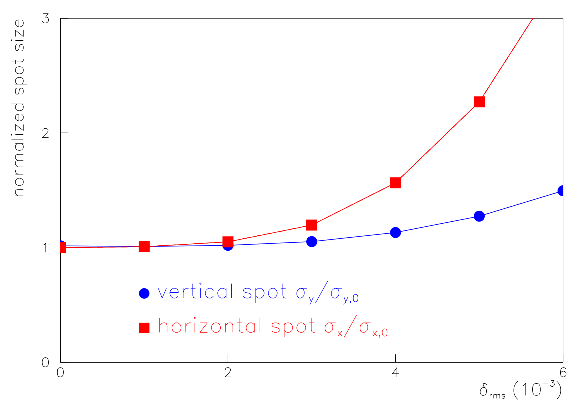

FIGURE 3. Horizontal and vertical rms spot sizes vs. the rms momentum spread for a single pass. Synchrotron radiation was included in the simulation. The spot sizes are normalized to the ideal linear ones, about 950 nm.

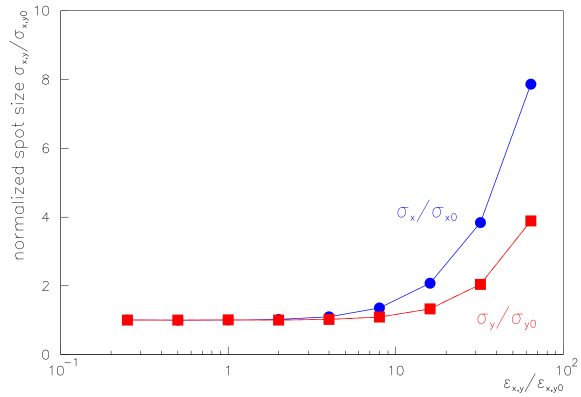

FIGURE 4. Single-pass horizontal and vertical rms spot sizes vs. the transverse emittance in units of the design emittance. The rms energy spread was kept constant at $\delta_{\rm rms} = 10^{-3}$. Synchrotron radiation was included in the simulation. The spot sizes are normalized to the ideal linear ones.

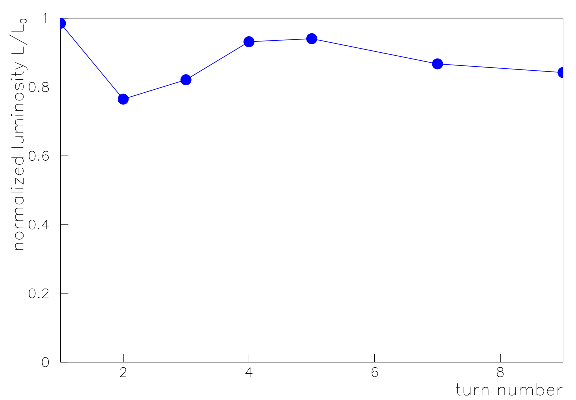

FIGURE 5. Normalized luminosity as a function of turn number simulated for a constant momentum spread of $\delta_{\rm rms} = 10^{-3}$, including synchrotron radiation. The arc is modelled by a simple rotation matrix. The tunes are adjusted to $Q_x = 4.28$ and $Q_y = 3.31$.

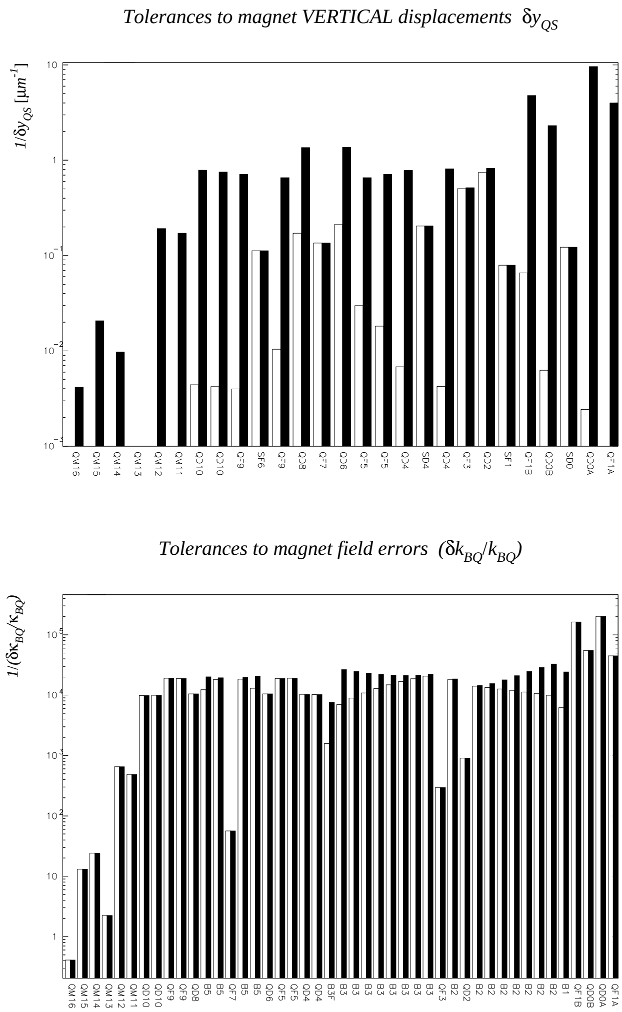

FIGURE 6. Single-pass vertical-displacement (top) and field-strength (bottom) tolerances [7] for quadrupole and sextupole magnets. Each value displayed corresponds to a luminosity loss of 2% per element and per beam. The full bars represent pulse-to-pulse ‘jitter’ tolerances, due to the induced orbit motion. The open bars are ‘drift’ tolerances referring to increases in the IP spot size. The final triplet magnets are on the right.

III CONCLUSIONS

The 30-TeV final-focus system considered in this note performs exceedingly well, up to an rms energy spread of about 2×10^{-3}, *i.e.*, ten times larger than required, and for emittances equal to 4 times the design value. It will maintain the ideal luminosity over multiple turns. Magnet field strengths and tolerances are consistent with present technology.

ACKNOWLEDGEMENTS

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