NEW DESIGN OF THE TESLA INTERACTION REGION WITH $L^* = 5$ M

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Abstract

We study the main implications of increasing the last drift length l^* from 3 to 5 meters, in the TESLA interaction region: namely, the design of a new final focus system with a better chromatic correction, the extraction of the beam after the collision through the opposite doublet, and the new collimation requirements.

INTRODUCTION

Increasing the distance l^* between the final doublet and the interaction point (IP) to $l^* = 5$ m would be beneficial for the TESLA Interaction Region (IR) design. From the accelerator point of view, the superconducting final quadrupoles would move out of the large field (4 T) region of the detector solenoid, thus reducing the need for an optical correction of the solenoid effect on the beam. From the detector point of view, the forward acceptance would increase at low angles, the TPC (Time Projection Chamber) and calorimeter background created in the quadrupole cold mass would reduce, and it would offer the possibility of a lighter mask with a simpler support system.

In counterpart, a longer l^* raises three problems, mainly:

- the correction of the chromaticity created by the last doublet, which is proportional to l^*
- the extraction of the spent beam
- the extraction of the synchrotron radiation generated in the last doublet.

We successively discuss these three points.

THE FINAL FOCUS SYSTEM

By adopting the central idea of the NLC final focus system [1,2,3] – non-zero dispersion in the final quadrupole doublet to correct its chromaticity locally by inserting one sextupole between the quadrupoles – the performance of the chromatic correction can be greatly improved. However the NLC layout as such is not compatible with the TESLA head-on collision scheme. Indeed, a magnet free drift space of about 240 m is necessary to let the beamstrahlung cone be intercepted at the position of the beam dump [4].

Taking advantage of the superior chromatic correction, a new TESLA final focus system with $l^* = 5$ m has been designed, as displayed in Figure 1. Chromo-geometric aberrations are compensated at the second order by two pairs of interleaved sextupoles, each pair acting essentially in one plane. Within each pair, the transfer matrix R in the xy-plane between the sextupole located at the first (x-pair) or second (y-pair) maximum of the beta-functions, and the sextupole located in the last doublet has the form:

$$R = \begin{vmatrix} M & 0 & 0 & 0 \\ R_{21} & 1/M & 0 & 0 \\ 0 & 0 & M & 0 \\ 0 & 0 & R_{43} & 1/M \end{vmatrix},$$

where the non-zero terms are arbitrary. The second order geometric aberrations produced by the two vertical sextupoles are thus cancelled [2]. The dispersion in the doublet results in an angular dispersion $D'_x = 10$ mrad at the IP, to be compared with the 37 μrad beam angular spread. It also creates a sizeable the 2nd order dispersion which is cancelled by including a fifth sextupole at the upstream maximum of the dispersion function.

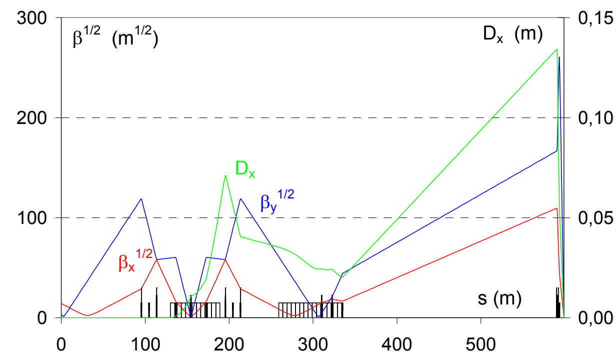

Figure 1: Optics of TESLA final focus with $l^* = 5$ m (NLC-like solution).

By optimizing the beta-waist position at the first dipole family, the horizontal emittance growth generated by synchrotron radiation is minimized to small fraction of the 10^{-11} m nominal emittance for the 400 GeV beam energy (Figure 2).

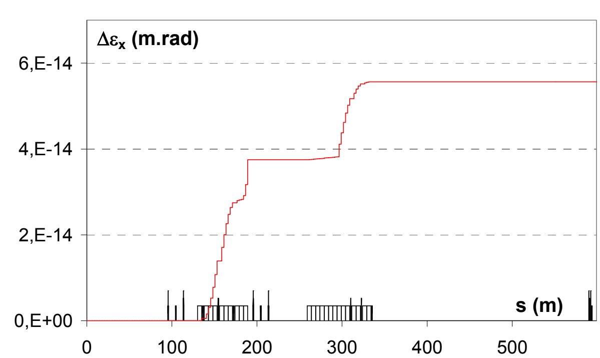

Figure 2: Horizontal emittance growth for the 400 GeV beam energy. Nominal emittance is 10^{-11} m.

An alternative optics solution (Figure 3) has also been studied where the smaller horizontal chromaticity is compensated in an upstream correction section like in the

TESLA TDR[4] design. In this 'hybrid' system, the two sextupole pairs are not interleaved. The IP second-order dispersion is cancelled by an intermediate dispersion bump which also reduces the angular dispersion at the IP to $D'_x = 2.6$ mrad.

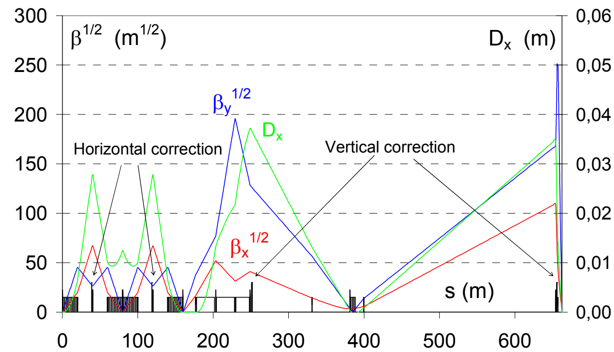

Figure 3: Optics of TESLA final focus with $l^* = 5$ m (hybrid solution).

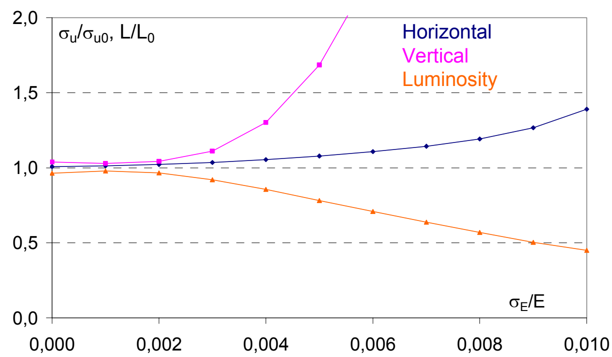

Figure 4: IP bandwidths of the $l^* = 5$m final focus (NLC-like solution).

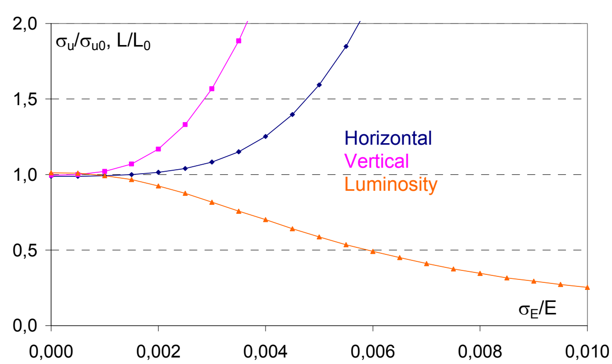

Figure 5: IP bandwidths of the $l^* = 5$m final focus (hybrid solution).

The performance of the NLC-like and hybrid final focus systems are plotted in Figs.4,5 in terms of normalized beam sizes and luminosity (without beam-beam effect) as functions of the beam RMS energy spread σ_E/E. While both systems prevail over the TDR $l^*= 3$m design, the NLC-like system is definitely superior. It is also the shortest and its only drawback is the larger IP angular dispersion D'_x.

THE SPENT BEAM EXTRACTION

The acceptance of the outgoing final doublet to particles originating from the point-like collision at a given angle can be defined by calculating the maximum angle θ_{max} with respect to the beam axis for a particle to hit the doublet aperture as a function of its energy. Due to the doublet polarity, the tightest acceptance occurs when the IP emission is in the horizontal plane. These acceptances are compared in Figure 6 in the cases where $l^* = 3$ and 5 m assuming a doublet aperture diameter of 48 mm and a 4 T solenoid field applied over the first 4.5 m distance. The difference between the two curves is small and the $l^* = 5$ m weaker doublet is actually more efficient in extracting the low energy particles like the $e+e-$ pairs and the $e\pm$ bremsstrahlung. Tracking simulations must be done to confirm this analysis.

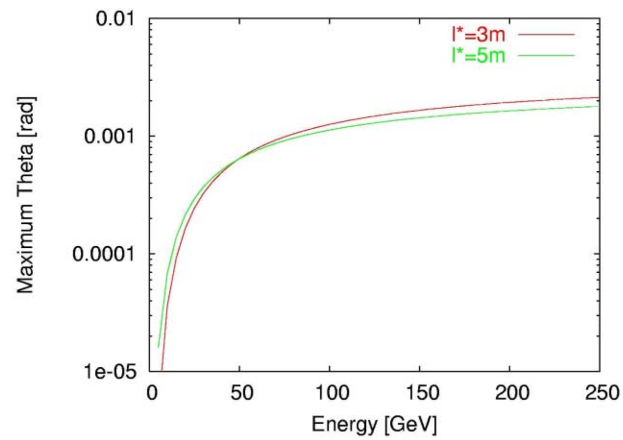

Figure 6: Angular acceptance in the horizontal plane of the outgoing final doublet as a function of particle energy.

THE COLLIMATION REQUIREMENTS

Extraction of the synchrotron radiation from the doublet regions for an incoming beam with a transverse extension of $8.6\ \sigma_x \times 47.5\ \sigma_y$ is shown in Figure 7.

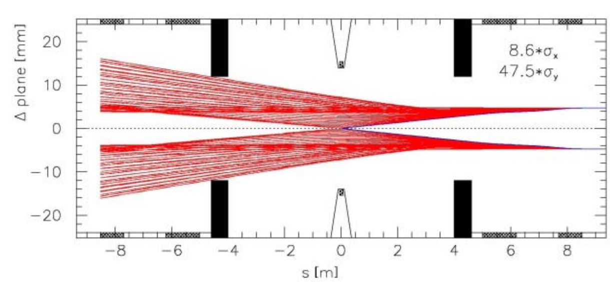

Figure 7: Diagonal stretch of the synchrotron radiation emitted by the final doublet through the opposite inner mask (black) and doublet apertures (hatched).

The collimation depths are set by the aperture and the position of the inner mask. A diameter of 24 mm at most is required to properly shield the vertex detector of 15 mm radius. Moving the mask away from the IP by 2 m along with the doublet is favourable for the detector point-of-view because it increases the low-angle coverage and minimizes the weight of the overall detector mask. But, as shown by Table 1, the collimation requirements are indeed much tighter than in the TDR design. These tight collimation requirements should be met by an improved collimation optics using tail folding by non-linear elements (octupoles) [5].

Table 1: Beam collimation requirements for synchrotron radiation extraction.

	*l**	IP to Mask distance	Number of σ_x	Number of σ_y
TDR design	3 m	2 m	13	81
New design	5 m	4 m	8.6	47.5

The above collimation depths are derived from an analysis [6] which assumes nominal beam phase-space distributions at the IP and ignores the energy dimension. Taking the energy dependence into account is necessary, especially with a non-zero dispersion function in the doublet, but it should rely on realistic rather on ideal beam distributions. Therefore, once the TESLA-TDR collimation section has been matched to the entrance of the NLC-like final focus optics (figure 8), the 5D beam phase-space enclosed by the apertures of the energy and betatron spoilers is transported to the final doublet for on-momentum (figure 9) as well as off-momentum energies.

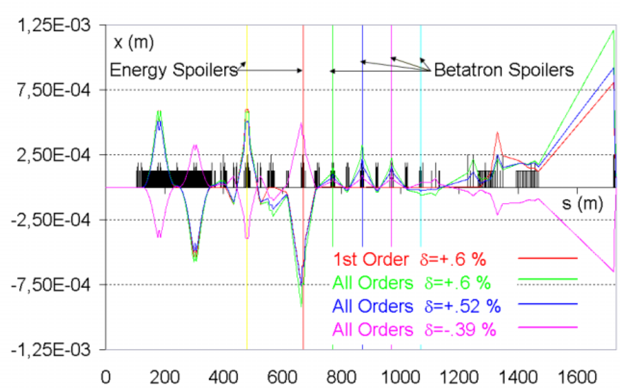

Figure 8: Off-momentum central trajectories through the TESLA beam delivery system.

The importance of doing the off-momentum transport to all orders by scaling the magnet strengths, rather than at the 1st order only, is highlighted by Fig.8 which shows that the higher order dispersion is large in particular in the betatron collimation section. Once the energy collimation depths are set for given apertures of the two energy spoilers, in the present case [–0.52%, +0.39%], the extreme photon rays originating from the phase-space corners (red dots in Fig.9) are plotted through the IR apertures for a dense enough set of energy deviations within the energy window, and the betatron spoiler apertures are fine-tuned until the synchrotron ray pattern reproduces that of figure 7. In the present case, it ended up in closing the one horizontal betatron spoiler in phase with the final doublet by about 30%. A wider energy collimation could result into more sizeable changes of the betatron spoilers.

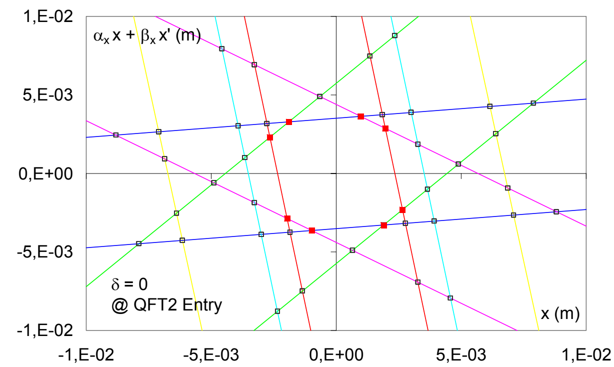

Figure 9: On-momentum horizontal phase-space enclosed by the collimation spoilers. Colours of the slits match those in Fig.8.

CONCLUSIONS

In order to upgrade the IR design of TESLA, the optics of a final focus system with *l** = 5 m has been studied. Two chromatic correction optics inspired by the new NLC final focus have been derived and their performance have been compared and found already superior to the previous *l** = 3m design. The spent beam extraction of the new systems seems more favourable for low energy particles. The collimation depths are more stringent, as expected, and they might require adapting an octupole tail-folding optics into the collimation section. Using the collimation section designed for the TESLA TDR, the impact of energy deviations on the on-momentum aperture settings of the betatron spoilers has been studied by propagating the energy-dependent un-collimated phase-space to the final doublet and checking the synchrotron radiation stay-clear.

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