DESIGN OF BEAM AND BEAMSTRAHLUNG EXTRACTION LINES FOR TESLA

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Abstract

In the TESLA superconducting linear collider project, collisions occur at zero crossing angle. While the outgoing beams are extracted at about 40 m after the interaction point, the beamstrahlung photons travel further upstream along the incoming final focus beam line. Moreover, the option to rapidly dump the spent beams after the collision has been favoured recently to avoid the inconveniencies of large beam losses and beam line activation. For these reasons, the design of the beam and beamstrahlung extraction lines is interplayed with those of the final focus optics and synchrotron radiation masking. We propose a system where the beam extraction is downward and where the beam and beamstrahlung power is dumped at 240 m from the IP. The power deposition along the beam lines and beam transmission to the dump are found to be acceptable.

1 INTRODUCTION

High energy (250 GeV) and intensity ($2.8 \cdot 10^{14}$ sec^{-1}) of beams in the superconducting linear collider TESLA[1] require a careful design of the extraction transport of the spent beam and beamstrahlung, arising from the beam collisions at the interaction point (IP), to the dumps with small losses to avoid the surrounding equipment activation. The solution to this task is complicated because of the large increase in angular and momentum spread due the beam collisions and because the layout of the electron, positron and beamstrahlung extraction lines must be combined with the final focus optics of the incoming beam.

The choice of the extraction systems and beam line structure are driven by the following basic tasks: they must not influence the incoming beam; the relative beam losses from IP to dump should not exceed 0.1 %; the part of the beam which is not transported to the dump should be intercepted by a collimator specially installed for this purpose; the beam diameter on the dump in the case of IP collisions should be smaller than 0.8 m to fit in the dump window, and, without collision, larger than 0.1 mm for a small enough temperature rise of the dump water; the beam sizes in the sweeping kickers should not exceed the apertures of these magnets; the vertical inclination of the beam axis to the horizontal plane should be about 20 mrad at the dump. All these requirements must also be fulfilled in the case of beam position errors and beam-beam offset at the IP. The beam-beam effect gets larger for vertical beam offset.

The spent beam particle distribution in horizontal and vertical phase planes and their angular and energy distributions are shown in Fig.1-4. The effect of

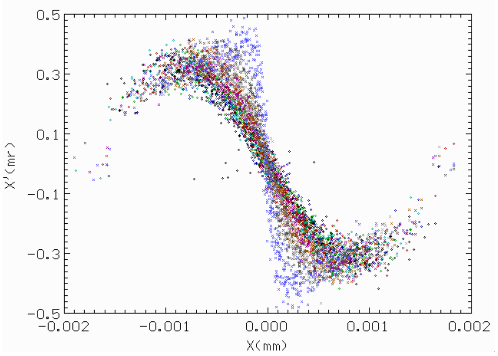

Figure 1: Beam horizontal phase space at the IP.

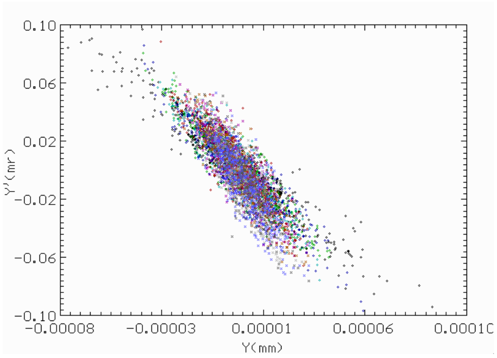

Figure 2: Beam vertical phase space at the IP.

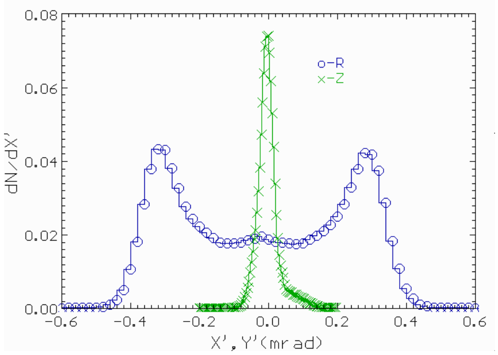

Figure 3: Angular beam distribution at the IP.

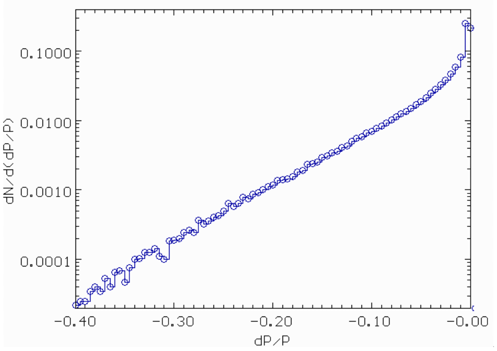

Figure 4: Beam distribution versus momentum.

disruption and beamstrahlung can be inferred by comparing these distributions to the parameters, recalled in Table 1, of the nominal low emittance 250 GeV beam. They are estimated from beam-beam simulations with GUINEA-PIG[2].

Horizontal. Emittance	ε_x	$2 \cdot 10^{-11}$ m·rad
Vertical. Emittance	ε_y	$6.1 \cdot 10^{-14}$ m·rad
Hor. angular spread	θ^*_x	37 μrad
Ver. angular spread	θ^*_y	12 μrad
Relative energy spread	σ_δ	$3\ 10^{-4}$(e+)/$1.8\ 10^{-3}$(e–)

Table 1: Beam IP parameters for TESLA 500.

2 SPENT BEAM EXTRACTION

The layout of the extraction system is shown in Fig.5 with the beam optics functions for 250 GeV energy.

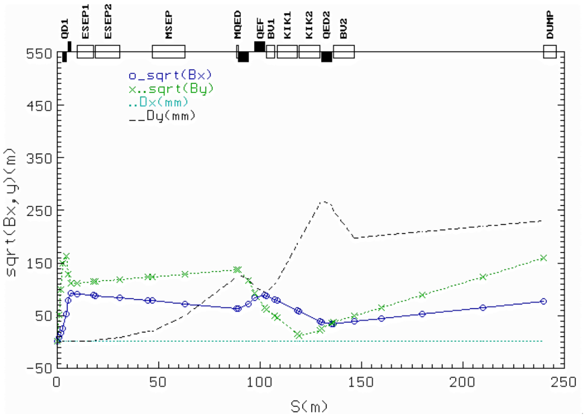

Figure 5: Layout of the beam extraction line.

It contains the following main parts. The 20 m long separator consisting of electrostatic and magnetic deflectors combined in the same unit[3]. The bending of the beam by the magnetic field of the separator is compensated by its electric field for the incoming beam and added for the outgoing beam. The bending angle of the separator in the vertical plane is 0.8 mrad. The main spent beam deflection is executed by the 16 m long septum magnet with gradually increased aperture. The total bending angle, produced by the septum magnet is 2.1 mrad.

To decrease the influence of the dispersion created by the extraction bends, it is reasonable to place the first focusing lens as close as possible to the IP. In order to preserve the necessary separation between the chambers of the incoming and outgoing beams, the first two lenses of the beam line are quadrupole septums: the two upper poles are replaced by a plate of magnetic material playing a role of a magnetic mirror. The first lens is then located 89.5m downstream of the IP. Nevertheless because of the large momentum deviation of particles in the spent beam, the apertures of these elements need to be unacceptable large. Therefore a collimator is placed before the first lens to intercept particles with the lowest momentum. Its aperture is chosen such that it intercept less than 0.1 % of the beam intensity and is defined by the beam distributions on the collimator surface, shown in by Fig.6.

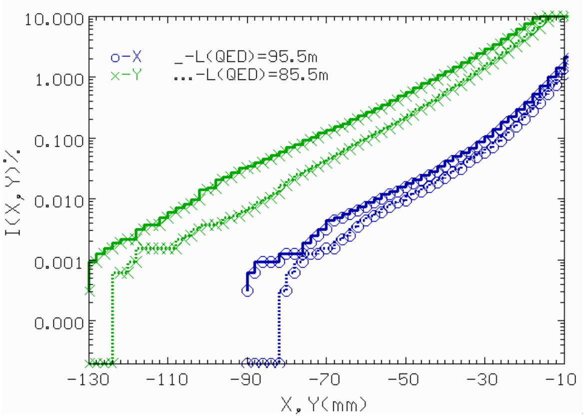

Figure 6: Beam distribution at the entrance of the mirror quadrupole QED.

On the other hand, the dump must be able to sustain, during the accelerator commissioning and tuning phases, power deposited by non interacting low emittance beam on a localized spot of about 400 μm radius (cf. Fig.7). Therefore two 10m long high-frequency kickers are installed in the beam line, each providing beam sweeping along one of the transverse coordinates. As their field are phase shifted by 90^0, the beam on the dump describes a circle of 3 cm radius, large enough for the temperature rise in the dump water not to exceed an allowable limit of 80 K[4].

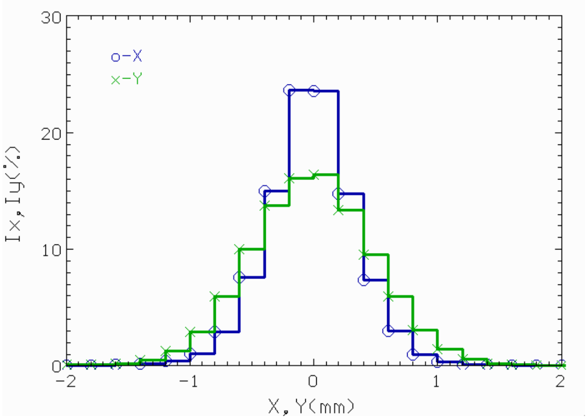

Figure 7: Low emittance beam profiles at the dump.

To get the necessary 20 mrad gradient of the beam axis relative to the earth surface, a vertical bending magnet is installed. It is one of the main sources of vertical dispersion and consequently of beam sizes on the dump. To partially compensate this increase, the magnet is divided in two parts and a vertically focusing quadrupole is placed between them.

In this approach, all spent beam losses are localized in the collimator and on the main dump, whereas the rest of the beam line is free from radiation. The profile of the disrupted and collimated beam is shown in Fig.8, assuming head-on collisions. These profiles are widened in the cases of vertical offset errors at the IP, since deflection angles and energy losses reach higher values.

The beam line is optimized for the most critical offset found to be at $2\sigma_y$. On the contrary, horizontal IP offsets do not increase the phase space of the disrupted beam and thus do not degrade the beam extraction.

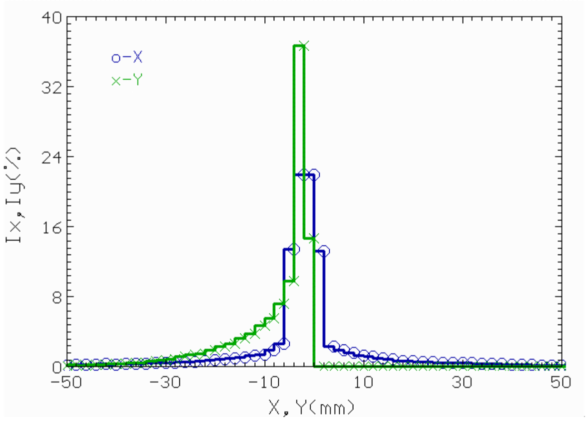

Figure 8: Disrupted beam profiles at the dump.

3 BEAMSTRAHLUNG AND LOW ENERGY CHARGED PARTICLES

In the TESLA head-on collision scheme, 300 kW of beamstrahlung power is emitted from the IP through the incoming beam line. Most of this power must be absorbed by a water collimator in the beam dump area, 240m away from the IP. To provide a free clearance up to this point the final transformer optics is designed[5] with three doublets in such a way that a weak intermediate doublet, at about 150 m from the IP, has a large enough bore aperture of 7 cm radius. As shown by Fig.9, about 40 kW photon power shines through the 1 cm radius beam pipe aperture at the center of the photon collimator and must be collected downstream of the first dipole of the beam line. A circular mask, located at about 20 m from the IP, shields the inner detector from the synchrotron radiation emitted by the far quadrupoles and dipoles. With a 1 cm radius, matched to the 1.2 cm one of the inner detector mask, it intercepts less than 5 W of beamstrahlung power. This scheme allows for a 1.4 cm beam pipe radius at the IP, advantageous for vertex detection.

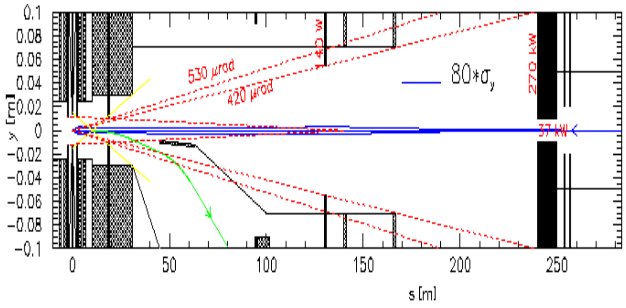

Figure 9: Vertical layout of the final transfomer beam extraction and beamstrahlung collimators. Beamstrahlung power levels on the collimators are given in red. The extration orbit is shown in green.

Although the ±10 m region around the IP is free from spent beam loss, lower energy radiative Bhabhas and e+e– pairs, which experience large disruption at the IP, are over-focussed by the superconducting doublet quadrupoles. The deposited power densities, shown in Fig.10, is however smaller than the 4.7 W/m power limit of the LHC superconducting cables. About 1000 radiative Bhabhas per bunch crossing can be collected on a fast luminosity monitor 8.5 m from the IP. The pairs stopped by the mask at 2m can also be used for this purpose.

4 CONCLUSION

A beam extraction line has been designed for the 500 GeV TESLA linear collider in combination with a 11 MW water dump located 250 m from the IP. It achieves the two antagonistic goals of blowing up the sizes of non-colliding low emittance beams, in order not to vaporize the water, while controlling the beam-beam disrupted beam sizes to fit in the dump window. Extraction is done vertically with a net 20 mrad downward angle at the dump. This angle is generated in steps by electrostatic separators, followed by septum magnets and finally by normal dipoles. Septum quadrupoles with magnetic mirror plates are included to control the beam focussing and the vertical dispersion.

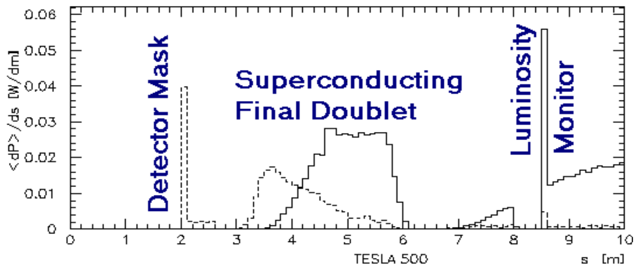

Fig.10: Average power , in units of W/dm, deposited by the radiative Bhabhas (solid) and e+e– pairs (dashed) in the interaction region (IP at s=0).

Beamstrahlung power is extracted with less than 0.2 kW power deposited on the way towards the same dump area. The beamstrahlung water collimator could be combined with the main beam water dump.

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