DESIGN OF BEAM EXTRACTION LINE FOR TESLA

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Abstract

In the TESLA superconducting linear collider project, collisions occur at zero crossing angle. 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 must be 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.

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

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 be nearly 0.1 %; the part of the beam which is not transported to the dump should be intercepted by

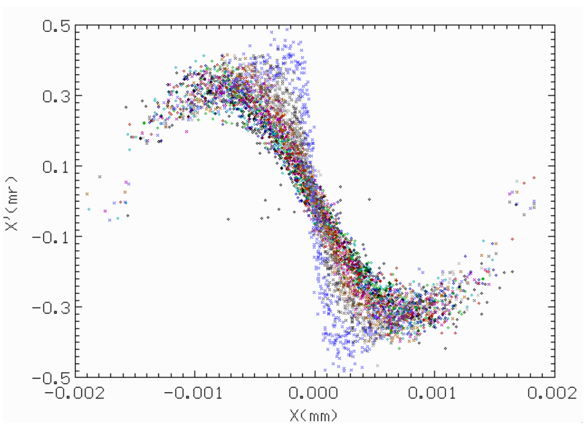


Figure 1: Beam horizontal phase space at the IP.

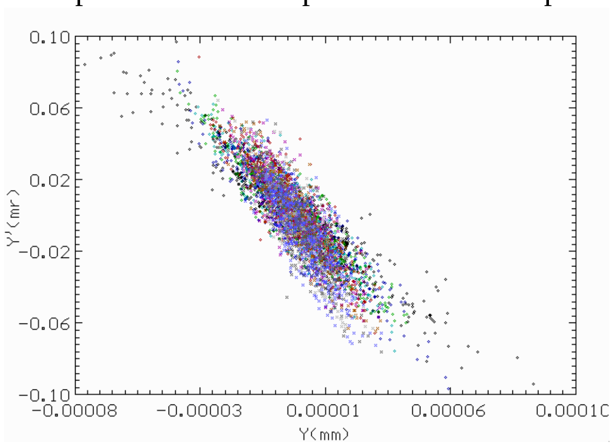


Figure 2: Beam vertical phase space at the IP.

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 15 mrad at the dump. All these requirements must also be fulfilled in the case of beam position errors at the IP. The beam-beam effect gets larger for vertical beam offset.

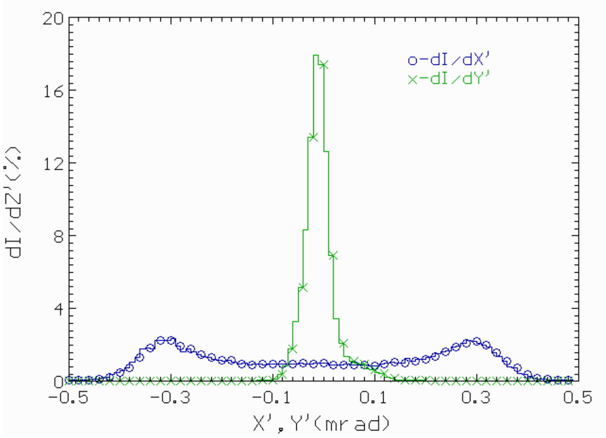


Figure 3: Angular beam distribution at the IP.

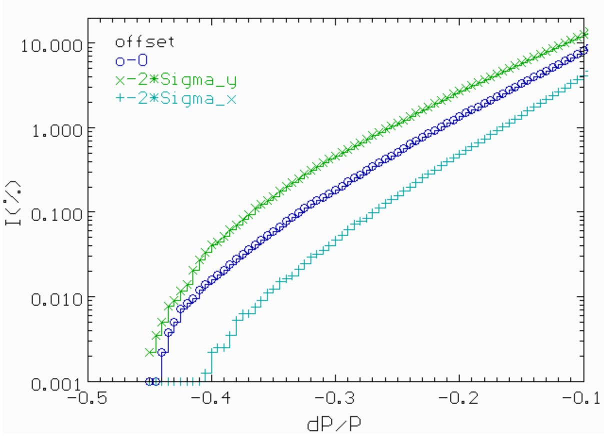


Figure 4: Beam distribution versus momentum.

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

2 SPENT BEAM EXTRACTION

The layout of the extraction system is shown in Fig.5 with the beam optics functions for 250 GeV energy. 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 lense of the beam line are septum quadrupoles: the two upper poles are replaced by a plate of magnetic material playing the 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 nearly 0.1 % of the beam intensity and is defined by the beam distributions on the collimator surface, shown in Fig.6.

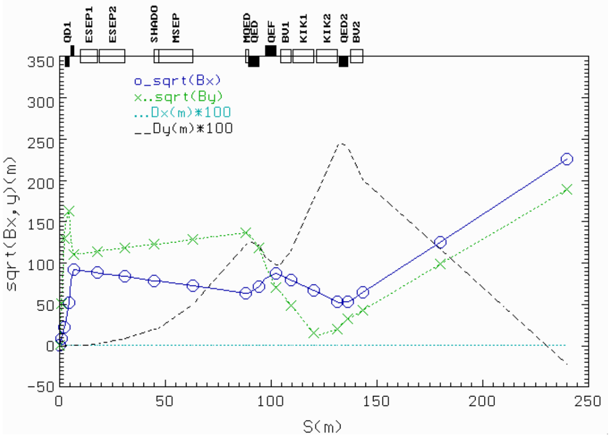


Figure 5: Layout of the beam extraction line.

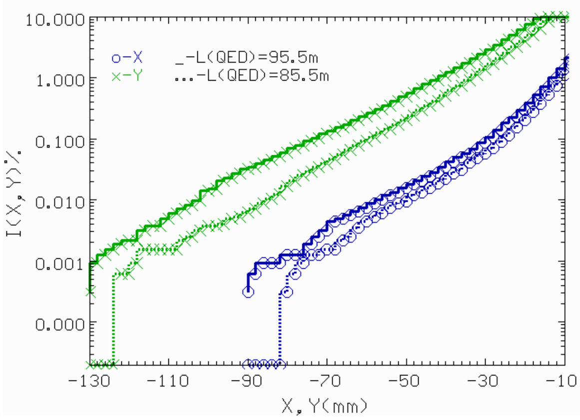


Figure 6: Beam distribution at the entrance of the mirror quadrupoles QED.

On the other hand, the dump must be able to sustain, during the accelerator commissioning and tuning phases, the power deposited by non-colliding low emittance beams on a localized spot of about $\sigma_x \times \sigma_y \sim 0.4mm^2$. Therefore two 10 m 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 80^0 C[4].

To get the necessary 15 mrad gradient of the beam axis relative to the earth surface, a vertical bending magnet is installed.

The choice of structure and layout of the beam line was made so that at the chosen position of QED and given coordinate of dump 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 and the apertures and the electromagnetic parameters of all elements would remain in reasonable technically accepted limits. To realize such an approach, a careful analysis of the beam cross section along the channel depending on its structure and element parameters was made. Because of the large momentum deviation of particles in spent beams and their complex distribution on transverse phase planes in IP, this analysis is more convenient and easier to do, using a matrix method for studding of particles motion. The following variants were considered: without focusing elements, with one, two and three lenses. Their close comparison shows, that in all variants the main influence on the beam size, when there are particles with a large momentum deviation ($\Delta p/p_0$ = - 0.3 and more), is rendered by products of matrix element M12 on the angular deviation of particles, which in all cases is significant more than product of M11 on coordinate deviations. The second important factor, causing increase of beam size in the vertical plane, is the occurrence of the dispersion in it because of the presence of bending magnets. The main source of the dispersion and accordingly increased beam sizes on the dump is the magnet ensuring necessary inclination of the beam on the dump.

Variant	KIK1		KIK2		BV(2)		DUMP	
	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY
	mm	mm	mm	mm	mm	mm	mm	mm
0 Lenses	88	97	98	117	111	210	220	1620
1 Lens	169	60	242	58	340	60	1150	745
2 Lenses	124	64	98	110	71	130	550	503
3 Lenses	112	50	90	77	94	73	420	286

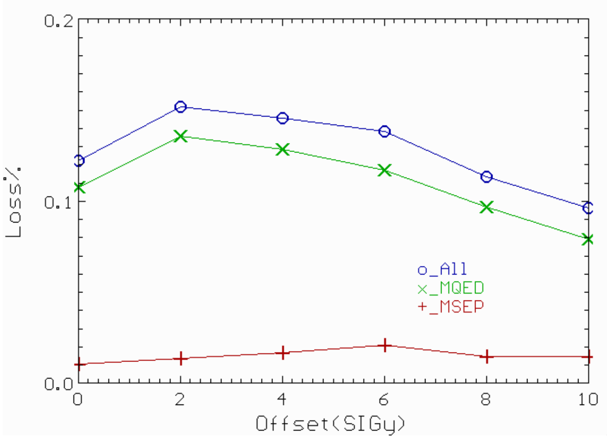
Table: 2 Beam sizes in main line elements for various variants of channel layout.

In the table 2, for comparison, the spent beam sizes in main line elements are given for various above mentioned variants of channel layout. These data are got for the case, when the beam is transported from IP to the dump with an efficiency about 99.9 %. The losses are localized on the collimator (~0.1%), on the dump and an insignificant part (about 0.01 %) on the septum-magnets shadow. The sizes are estimated taking into account the possible beams offset in IP. Calculations show that an offset of $2\sigma_y$ in the vertical plane has the most effect on the beam dimension. All our calculation were done for the collimator jaw coordinates X=-35 ÷ +35 mm, Y=-65 ÷ +10 mm.

From the given data it is clear, that in a variant without lenses the beam is too big on the dump in the vertical plane, in variant with one lens QED, focusing in the vertical plane, the beam has inadmissible sizes in horizontal plane. Using a further focusing in the horizontal plane by a lens QEF, it is possible to get on the dump the beam dimensions close to the required ones (QEF must, also as QED, be a quadrupole septum). However to have some reserve for the beam expansion at the electromagnetic cascade formation in the dump, to some reducing of the necessary apertures in main elements of the channel and lower in comparison with the previous variant gradient in the lens QED it is reasonable to use an additional focusing in vertical plane by the lens of QED2.

An additional profit of QED2 using is that one can more decrease the vertical dispersion by dividing the main bend magnet in two parts and install it between them. This consequently decrease the beam sizes on the dump and aperture in magnet elements.

As one can see from table 2 in the last variant, the beam sizes on the dump satisfy the necessary requirements with a significant reserve, whereas the necessary apertures in all elements of channels can be provided without doubts. As it follows from fig.4, if there is a vertical offset between the beams in IP, the beam particles momentum deviation increases, that naturally can cause additional losses in the channel. In fig.7 the dependencies of losses on the collimator, on the septum magnet shadow and total ones as a function of vertical beams offset are represented.



. Figure 7: Losses versus offset.

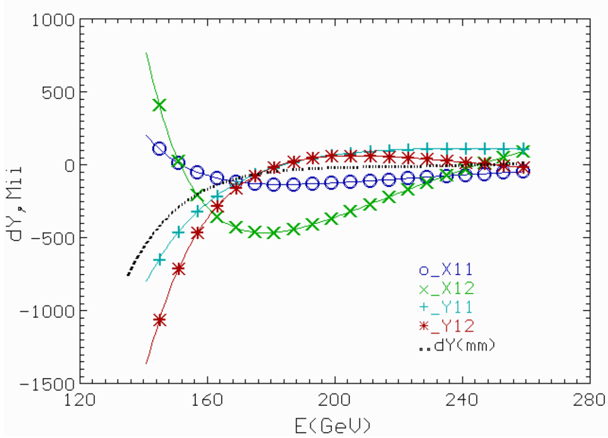


Figure 8: Displacement and matrix elements at the dump

It follows, that the most losses on the collimator take place at the offset about $2\sigma_y$. Namely for this offset the sizes of the element apertures were defined. An analysis shows that a beam position error and horizontal offset in IP does not cause additional losses.

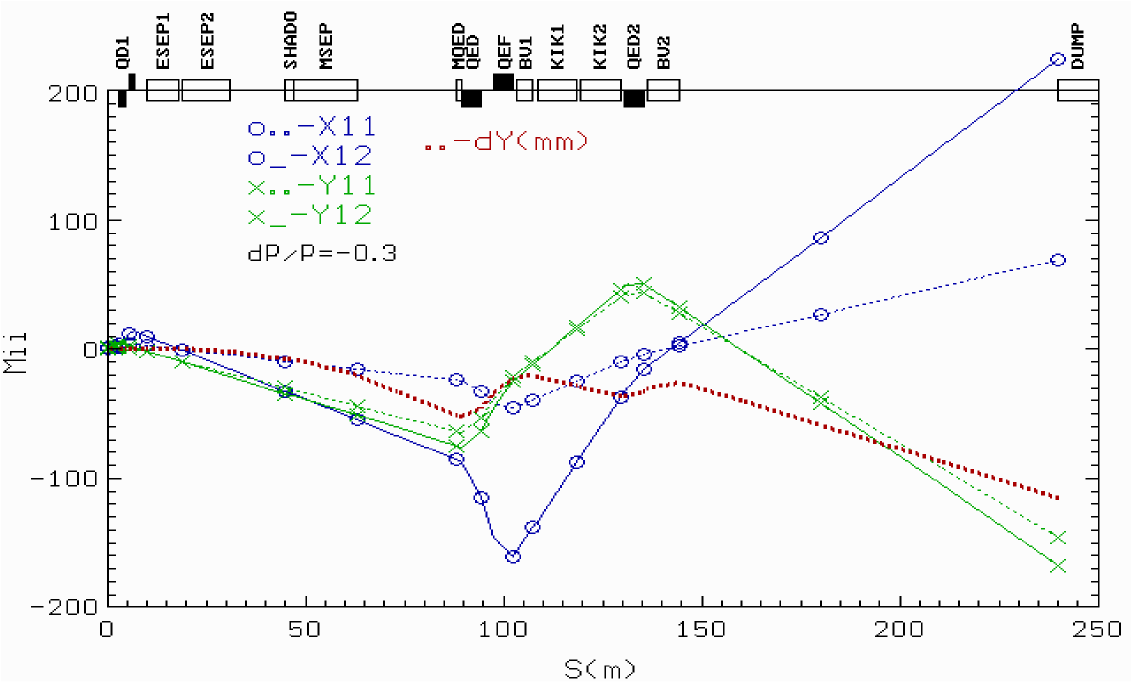


Figure 9: Displacement and matrix elements along the channel (3Lenses).

In fig.9 the variation along the channel of transfer matrix elements and the beam sizes because of the dispersion are shown, and in fig.8 the dependence of the same values versus beam particles energy at the dump entrance are given.

From this date and taking into account the energy distribution of the beam particles (see fig.4) it follows, that due the optimization of the line structure and parameters of its elements, the influence of the dispersion in the bending magnets on the beams size is considerably suppressed. As a result, the main number of particles are concentrated in the nucleus of the beam and only a small part of them, having a energy less than 160 GeV, are distributed on the periphery. The transverse particle distribution on dump entrance, given in fig.10, confirms this conclusion. The same distributions for not interacted beam, presented in fig.11, shows, that its sizes is larger than minimally admitted.

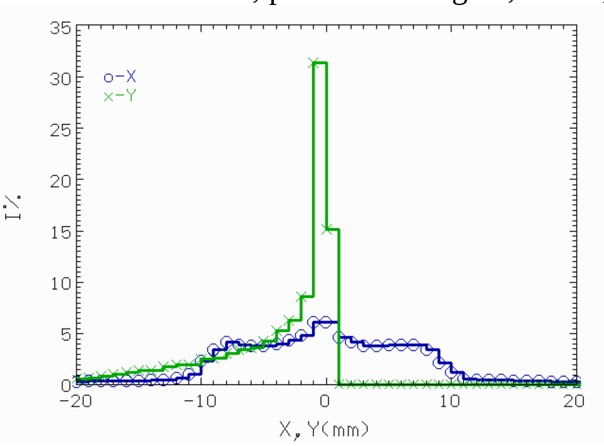


Figure 10: Disrupted beam profiles at the dump.

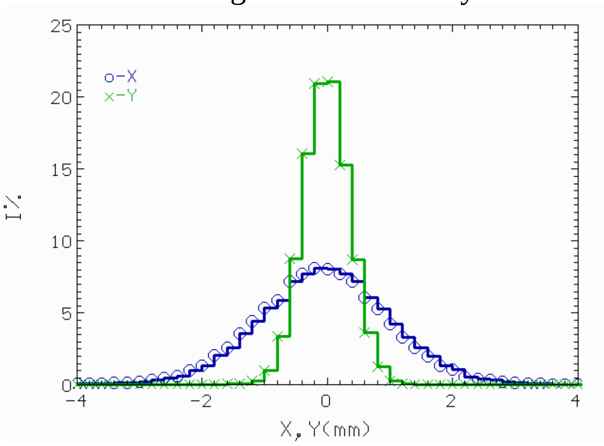


Figure 11: Low emittance beam profiles at the dump

In table 3 the efficiency of beam transport and the beam dimensions in main channel elements and on the dump as a function of different coordinates of collimator's jaws are presented. In the third column the efficiency corresponds to the beams interaction without offsets and in the fourth one if the offset in the vertical plane is $2\sigma_y$. Using this table, it is possible to choose the necessary apertures of the elements and dump cross section, depending on the tolerable losses.

MQED		I_{all}		KIK1		KIK2		BV2		DUMP	
$\pm X_c$	Y_{min}	dy=0	dy=2σ	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY	ΔX	ΔY
mm	mm	%	%	mm	mm	mm	mm	mm	mm	mm	mm
15	50	0.83	1.16	50	49	44	77	56	73	260	120
25	60	0.25	0.35	82	50	78	77	80	73	360	240
35	65	0.12	0.15	112	50	90	77	94	73	420	286
40	70	0.08	0.10	128	50	100	77	97	73	500	325

Table: 3 Efficiency of beam transport and dimensions of main channel elements.

3 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 ~ 15 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 large vertical dispersion. The main part of all spent beam losses are localized on the collimator and on the main dump, whereas the rest of the beam line after collimator is free from radiation.

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