Extraction of the Spent Beam into the TESLA Beam Capture Section.

A.Drozhdin

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1 Introduction

At the TESLA parameters of the beam ($E = 250GeV, N = 5.14 * 10^{10}$ particles per bunch with 8000 bunches per second) synchrotron radiation emitted in magnetic field along the accelerator and especially in the interaction point (beamstrahlung) cause irradiation and heating of collider equipment. This strongly effects to the choice of extraction system parameters and the design of elements.

Simulations of the spent beam particles and synchrotron radiation loss were done using the STRUCT code[1], where the quantum effect of synchrotron radiation is taken into account. Synchrotron radiation is generated randomly along the trajectory of particles in the magnetic field. Full scale beam line aperture simulation is performed in this calculations.

2 Simulation of Loss at Disrupted Beam Extraction into the Beam Capture Section.

The space between two doublets downstream the interaction point (IP) is used to provide the bending of the outgoing (spent) beam into the disrupted beam capture section (Figure 1). A combination of an electrostatic separator and a septum-magnet is proposed to extract the spent beam out of the beam line vacuum pipe[2, 3]. The $20m$ long separator consists of electrostatic and magnetic deflectors combined in the same unit, to provide deflection of outgoing beam and not to effect to the incoming beam. A magnetic field of 200 gauss, and corresponding to this field, an electrostatic field of about $60KV/cm$ were accepted for this design.

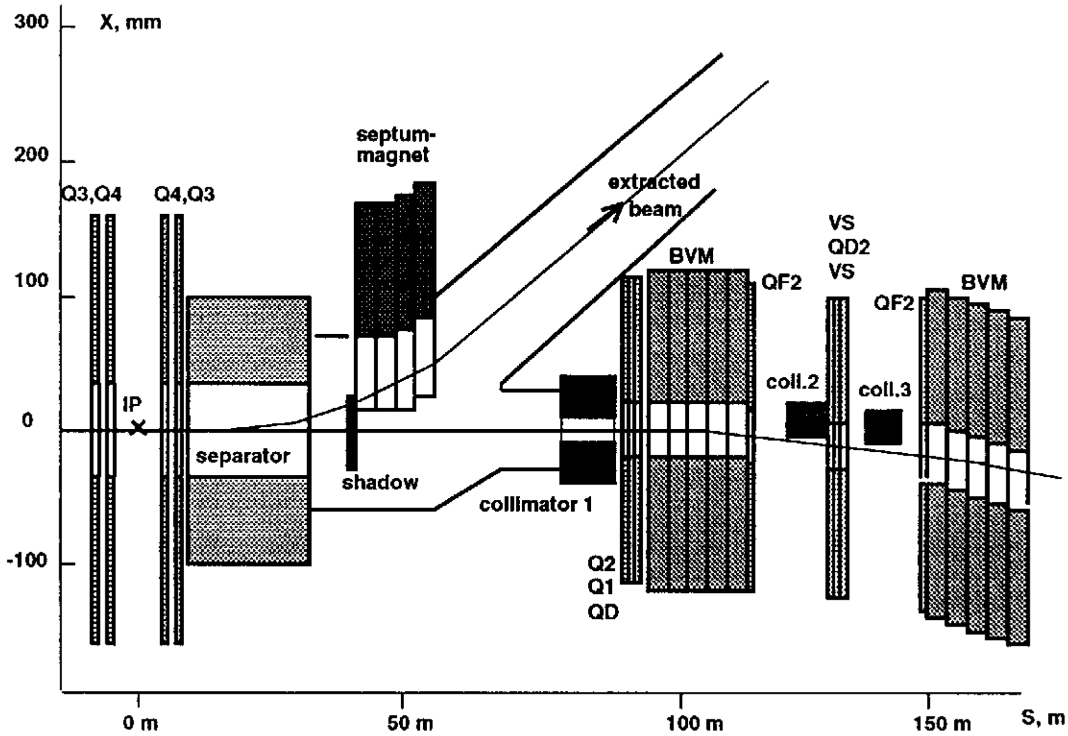

Figure 1: The TESLA beam extraction system.

The aperture of the separator should be large enough for the beamstrahlung photons and disrupted beam passage without loss. The septum-magnet consist of four units which gradually increase in aperture. A low level magnetic field ($0.08T - 0.12T$) allows to decrease the septum thickness to $2mm$. An aluminum shadow is placed at the upstream end of the septum-magnet to protect the septum from beamstrahlung photons and outgoing beam particles. An $80mm$ diameter beam pipe, downstream the septum-magnet, permits to clean the disrupted beam from large amplitude particles.

Simulations of the particles and synchrotron radiation loss were done here using disrupted beam and beamstrahlung photons, emitted from the interaction point[4, 5], as a source for the tracking.

The distribution of the disrupted beam loss and, emitted by the spent beam synchrotron radiation are shown in Figure 2 and Figure 3. About 4% of the outgoing beam are lost along the beam line, and 0.1% in the septum. The beamstrahlung photon loss distribution in the septum and shadow is shown in Figure 4.

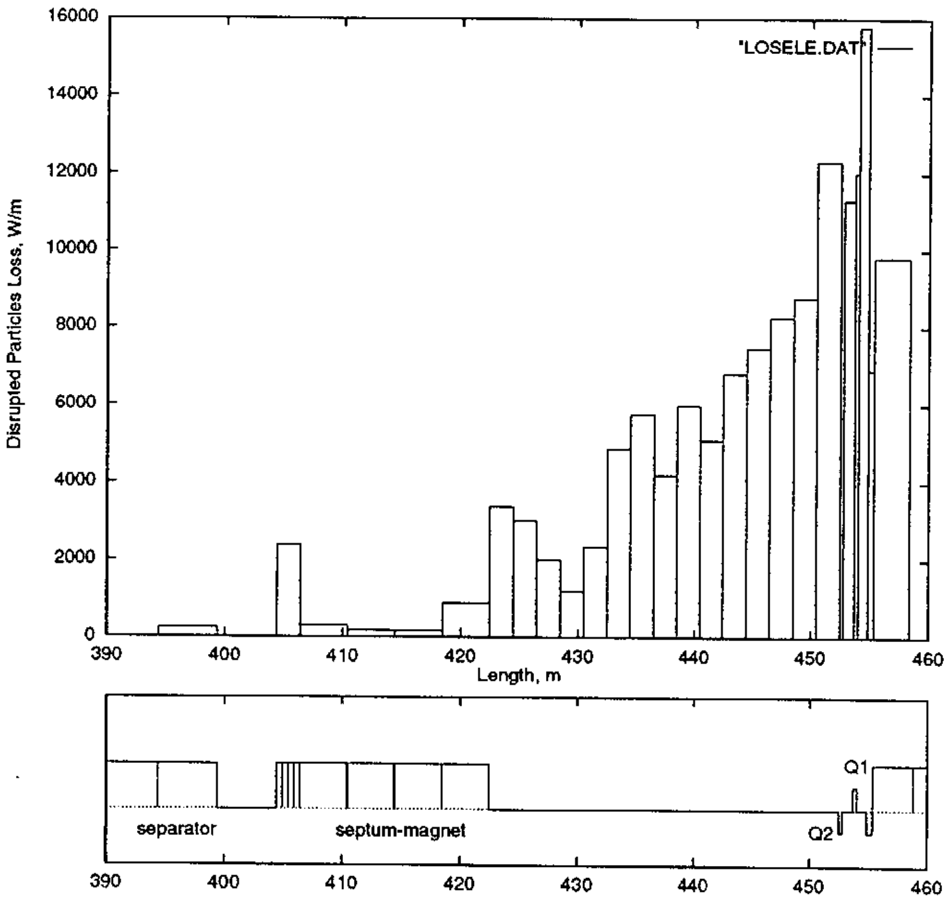

Figure 2: Disrupted particles loss distribution.

The power, intercepted by the septum is about $0.3kW/m$ from the disrupted beam loss and about $3kW/m$ from beamstrahlung photons loss. The $2m$ long shadow intercepts about $50kW$ in total. The cross section of this unit can be made as shown in Figure 5, to increase the heat conductivity from the hot region of shadow to the cooling water.

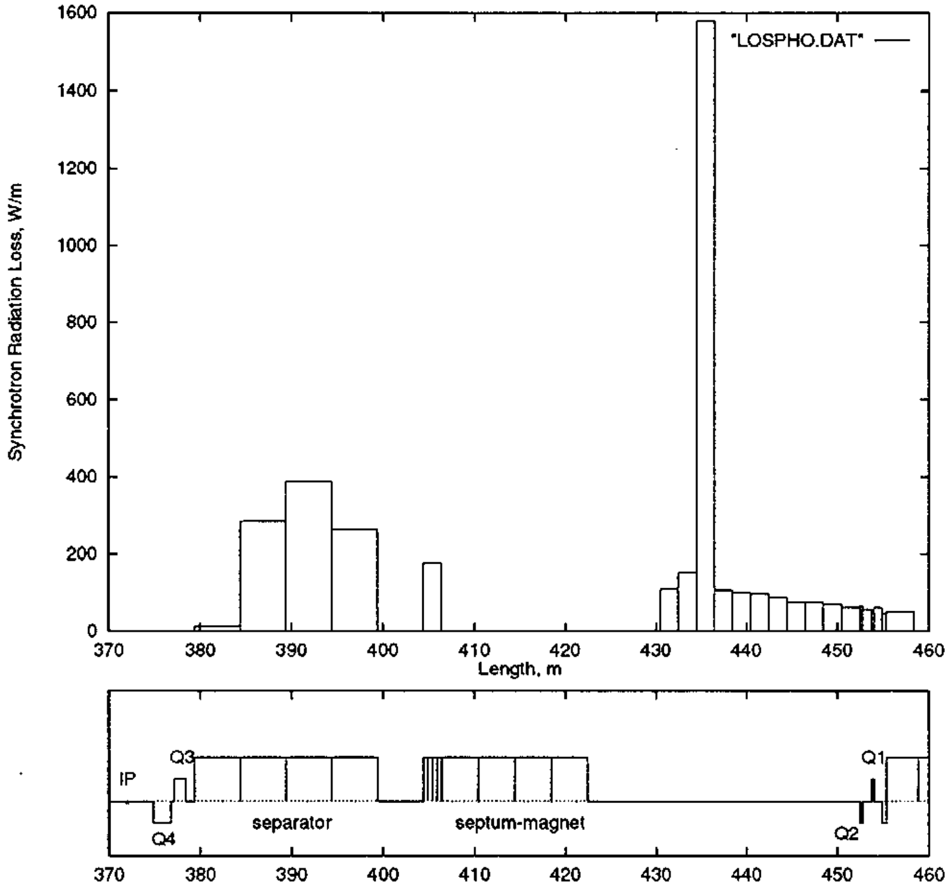

Figure 3: Synchrotron radiation loss emitted by the spent beam.

Distance between the outgoing and incoming beams is equal to 14.5 mm at the entrance of septum-magnet. The optimal septum position was found to be in $7mm$ from the incoming beam orbit, where the disrupted electrons energy loss is approximately equal to the beamstrahlung photons energy loss. The beamstrahlung photons and disrupted beam particles energy intercepted by the shadow are presented in Figure 6. The maximum density of intercepted power is equal to $2kW/mm^2$ for beamstrahlung photons and $1kW/mm^2$ for electrons.

The power, intercepted by the extraction line beam pipe, varies from $3kW/m$ to $12kW/m$.This pipe should be cooled with water.

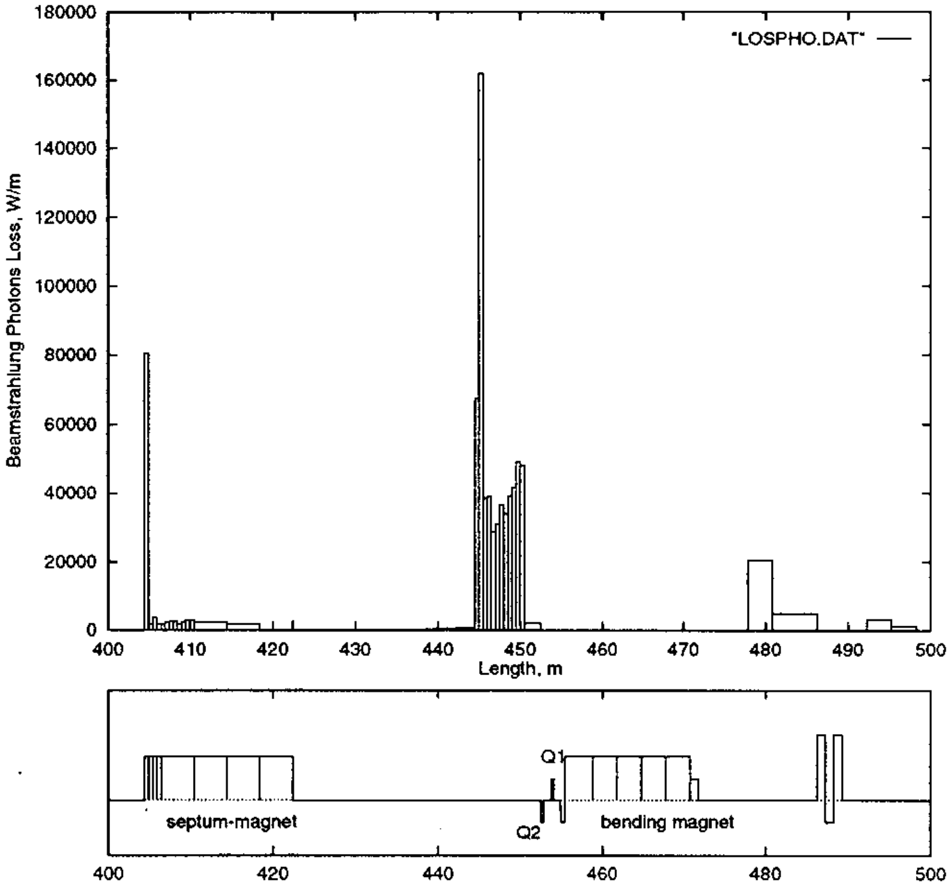

Figure 4: Beamstrahlung photons loss distribution.

As an option, a small aperture magnet (with vertical aperture of about $4-6mm$) instead of septum-magnet was suggested to be used for the spent beam extraction. Compared to the septum-magnet it has an advantage, because the extracted beam passes close to the iron poles with no current in them. In the case of septum-magnet the beam passes close to the copper septum with current and cooling water. Therefore beam loss is much more critical for the septum-magnet compared to the small aperture magnet. But the small aperture magnet has two disadvantages. The first one is four times low thermal conductivity of iron compared to copper and aluminum (iron - $0.69J/(sec * cm * K)$, copper - 3.92, aluminum - 2.40). The second

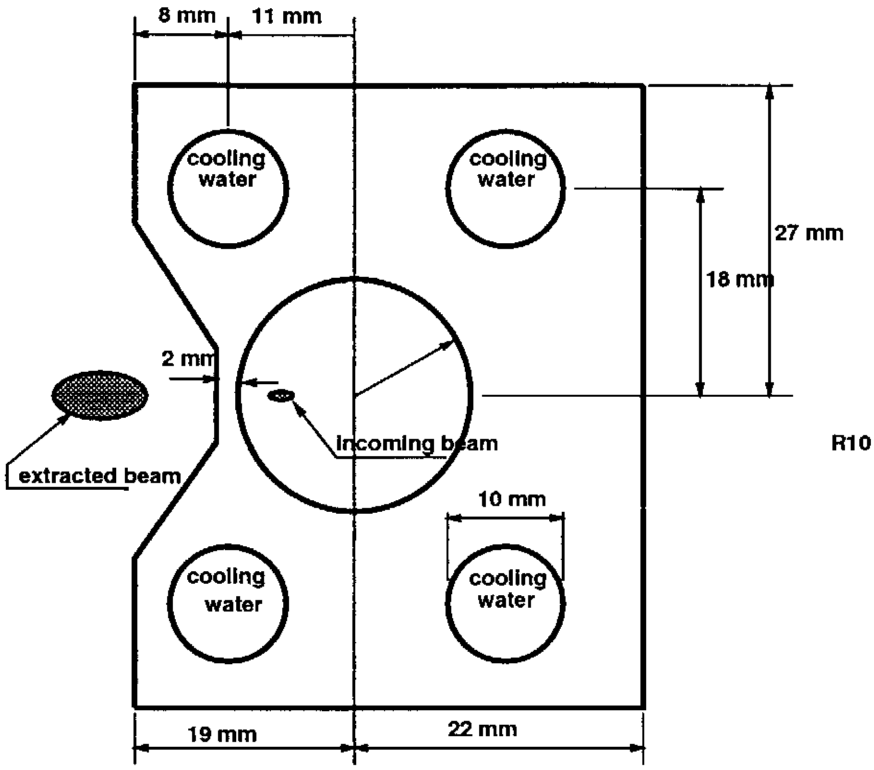

Figure 5: Cross section of the septum-magnet shadow.

disadvantage is the magnetic field outside the gap at the incoming beam line, that can disturb the incoming beam bunches.

In the small aperture magnet case it is necessary to cool the magnet poles with cooling water. An aluminum shadow with a length of $2m$, placed at the entrance of this magnet, can be used to deposit and dissipate the most part of the disrupted particles and beamstrahlung photons energy.

In both cases (septum-magnet and small aperture magnet) a precise investigation and design of the magnet and shadow should be performed.

A sufficient decrease of the septum-magnet and shadow heating is possible by moving them downstream by about $25m$ away from the IP. The distance between the outgoing and incoming beams is equal to 34 mm at the entrance of septum-magnet in this case. The optimal septum position is in $17mm$ from the incoming beam orbit. The beam loss and beamstrahlung photons loss distributions at the septum-magnet and at the small aperture magnet

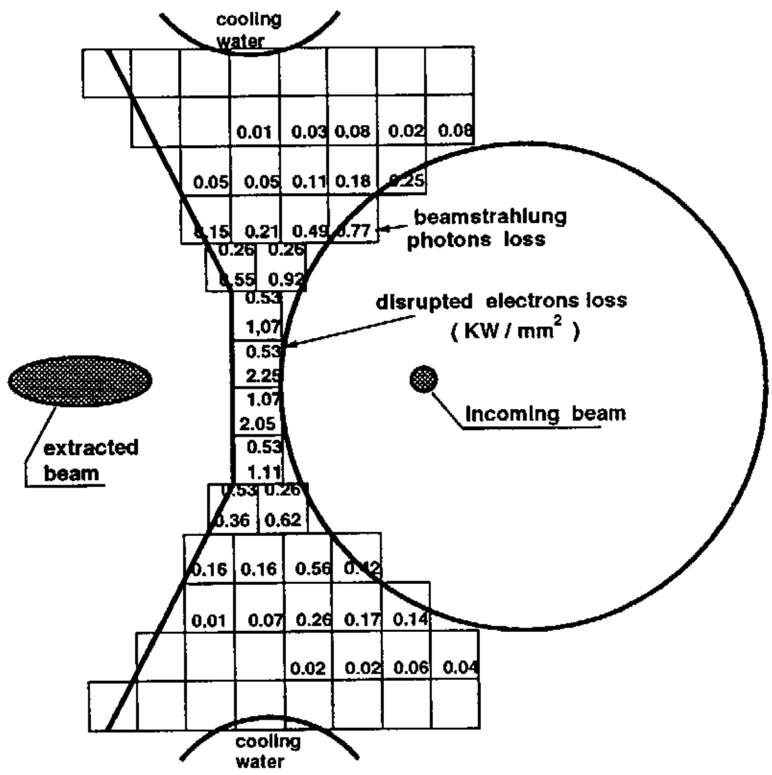

Figure 6: Beamstrahlung photons and disrupted beam particles power intercepted by the septum-magnet shadow ($26m$ between the first doublet and shadow).

shadows are shown in Figure 6, 7 and Figure 8, 9 for the distances $26m$ and $51m$ between the first doublet $(Q3, Q4)$ and the septum-magnet (or small aperture magnet) shadow. The densities of power intercepted by the septum-magnet and small aperture magnet shadows are approximately equivalent for the $26m$ distance between the first doublet and the shadow and are equal to $3kW/mm^2$. If the distance is increased to 51 m the loss density at the septum-magnet shadow decreases to about one sixth from $3kW/mm^2$ to $0.5kW/mm^2$.

About 15% of the intercepted energy are deposited in the body of the aluminum shadow, and 85% of energy are dissipated as secondary low energy electrons, positrons and photons[6]. Some part of this secondaries can effect to the additional heating of septum-magnet (small aperture magnet) downstream the shadow.

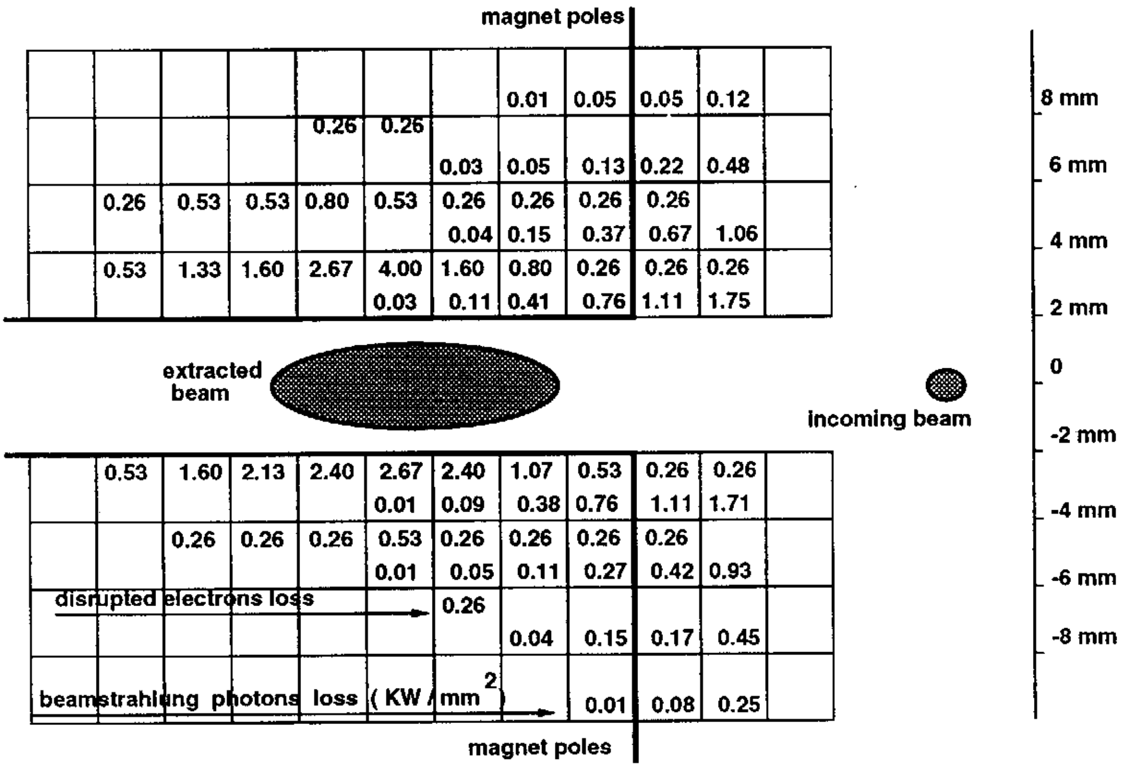

Figure 7: Beam loss and beamstrahlung photons loss distributions at the small aperture magnet shadow ($26m$ between the first doublet and shadow).

The heating of the small aperture magnet aluminum shadow by the collider bunch train is equal to $25K$, and the same overheating for the septum-magnet shadow is equal to $5K$ for the increased distance between the doublet and shadow. So, it is preferable to use a septum-magnet in the spent beam extraction scheme for the increased distance between the doublet and shadow.

This displacement of magnets require to increase the drift space between the first and the second final focus doublets from $74m$ to $115m$. Increasing of the drift space permit to reduce the electrostatic field of the separator to $45kV/cm$ and simultaneously to increase the extracted beam displacement at the second doublet location from 140 mm to 230 mm, that is necessary to pass over the beam line quadrupoles freely.

Parameters of the spent beam extraction system and energy, intercepted by the beam line elements for the increased distance between doublet and

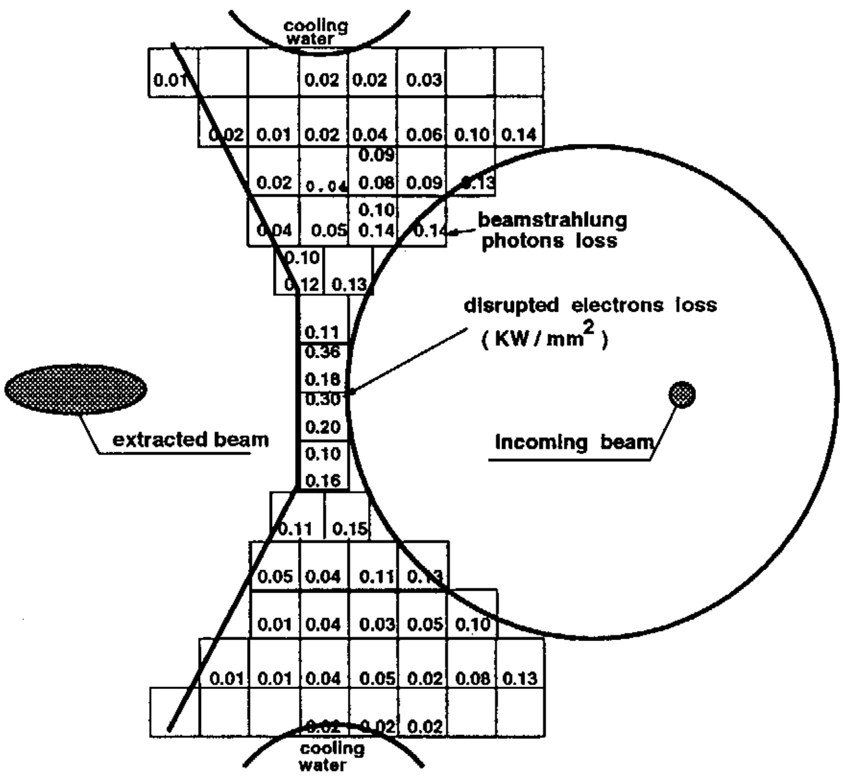

Figure 8: Beam loss and beamstrahlung photons loss distributions at the septum-magnet shadow ($51m$ between the first doublet and shadow).

septum-magnet are presented in Table 1.

The separator field stability effects to the beam position in the interaction point and, therefore, to the luminosity. The beam orbit displacement in the vicinity of the IP for $\Delta B/B = 10^{-3}$ in the different units of the separator is shown in Figure 10. The horizontal beam size in the IP (σ_x^*) is equal to $0.001mm$. Because of that, the separator field stability must be kept at the level of $\Delta B/B = 10^{-4}$ to permit a displacement of the beam to the amount not more than a half size of the beam. That will give a possibility to use a feedback system for a beam position control in the IP.

One separator unit, that fails, upstream or downstream the IP causes a large displacement of the beam (Figure 11). This leads to a 15 mm displacement at the downstream end of the septum-magnet but does not cause radiation and heating problems in the extraction line because incoming beam's

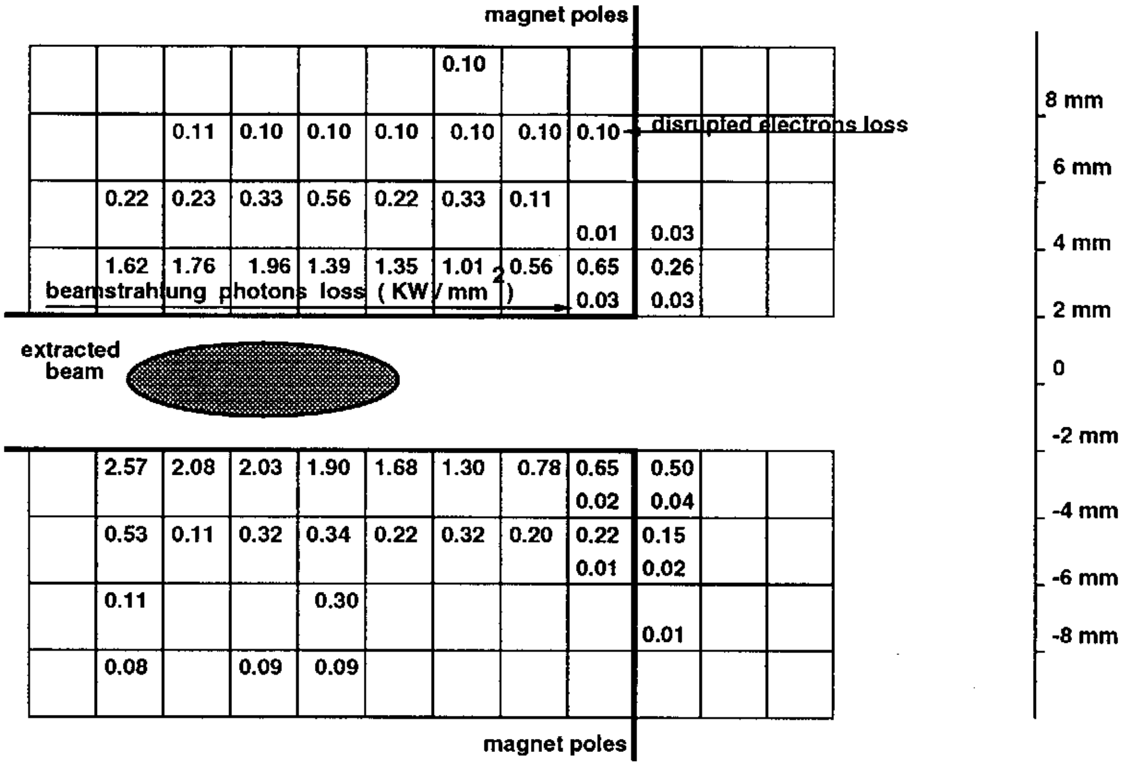

Figure 9: Beam loss and beamstrahlung photons loss distributions at the small aperture magnet shadow ($51m$ between the first doublet and shadow).

do not interact in the IP, and there are no disrupted beams in this case (extracted beam has a small size).

3 Conclusion.

Simulation of the disrupted beam particles and synchrotron radiation loss are done for the TESLA spent beam extraction system. The possibility to minimize the extraction equipment heating to an acceptable level is shown. This requires to increase the drift space between the final focus doublets from 74 m to 115 m, and an aluminum "shadow" is necessary for the septum-magnet protection.

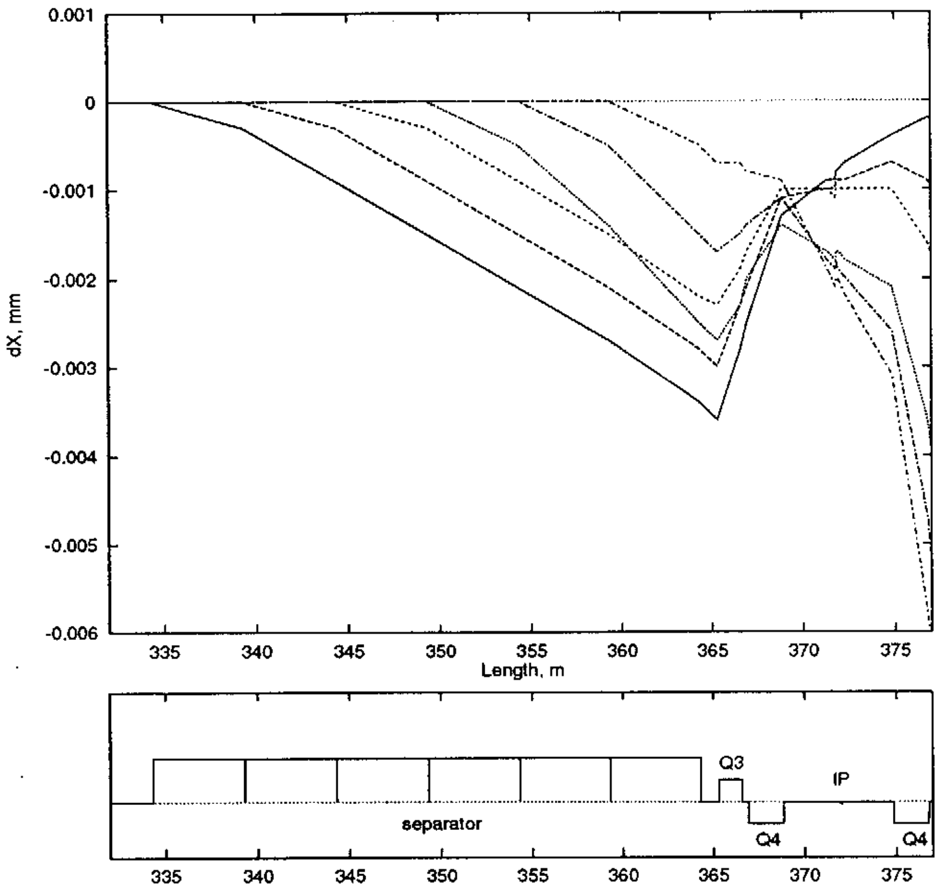

Figure 10: Beam orbit displacement in the vicinity of the IP at $\Delta B/B = 10^{-3}$ in the different units of separator.

4 References.

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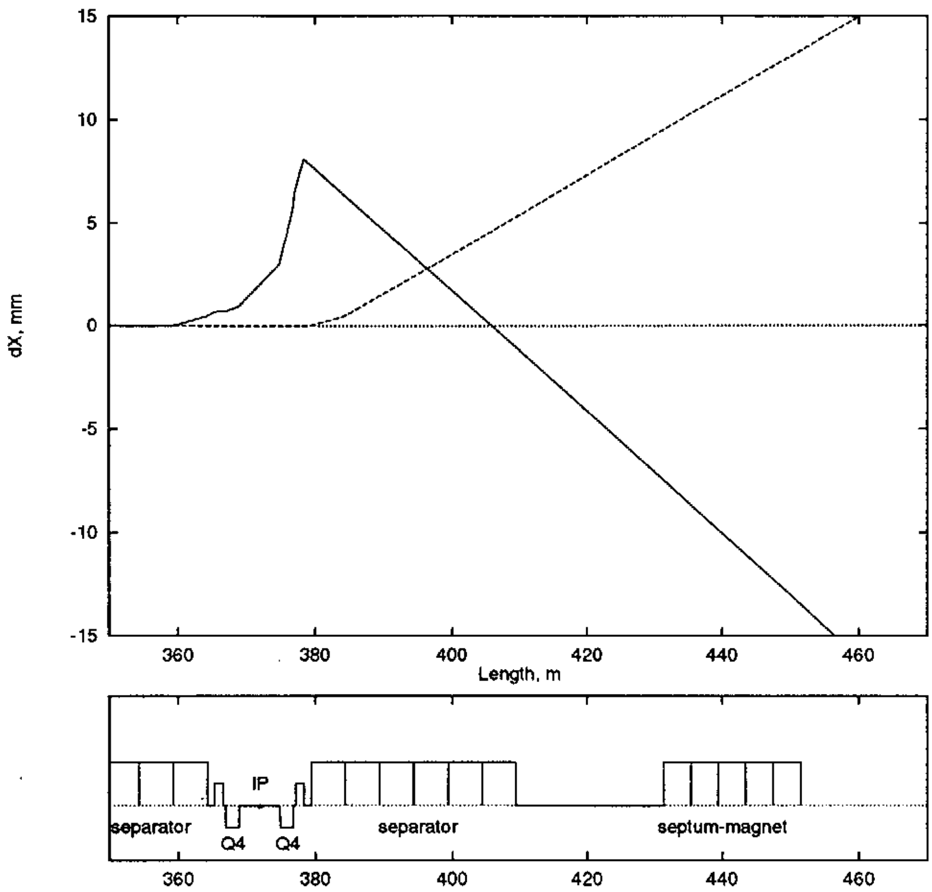

Figure 11: Beam orbit displacement if one separator module fails, upstream or downstream the IP.

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Table 1: Parameters of the beam extraction system, and power, intercepted by the beam line elements.

Element	Length	Aperture hor X ver	Gradient, Magn.Field	Beamstrahl. Photon Loss	Disrupted Electrons	Synchr. Radiat.
	m	mm X mm	T/m, T	kW/m	kW/m	kW/m
separator	15	50 X 80	0.016-0.01 T,	-	-	0.15-0.40
	15	80 X 80	31-50 kV/cm	-	0.13	0.15-0.40
shadow	2	d=2 mm		5	2	0.12
Septum-Magnet(SM):				septum	sept+back	septum
module 1	4	80 X 30	0.08	1	0.3	0.02
module 2	4	80 X 30	0.10	1	0.3	0.02
module 3	4	110 X 30	0.12	1	0.3	0.02
module 4	4	110 X 30	0.12	1	0.3	0.02
module 5	4	130 X 30	0.12	1	0.3	0.02
extracted beam pipe downstream SM						
0 m		d 150			3.5	0.001
10 m		d 150			5.0	0.120
20 m		d 150			7.0	0.080
30 m		d 150			7.0	0.110
circulating beam pipe downstream SM						
10 m		d 60		0.2		
20 m		d 60		0.6		
collimator 1	8	d 16		50.		
collimator 2	6			20.		
collimator 3	6			3.5		
quad Q4	1.920	d 48	250			
quad Q3	1.274	d 48	250			
quad Q2	0.300	d 30	322			
quad Q1	0.300	d 30	322			
quad QD	0.500	d 30	73.2			
quad QF2	1.000	d 30	73.2			
quad QD2	1.000	d 30	73.2			
dipole BMV	15.442	30 X 20	0.0304			
sextupole VS	1.000	d 30				