A Versatile TBA Lattice for a Tau-Charm Factory with and without Beam Monochromatization

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Abstract

Optics for a high luminosity e^+e^- collider at a CM energy of 4 GeV with and without monochromatization of beams and achromatic TBA cells in the arcs have been carefully studied, including chromaticities correction, dynamic apertures and beam lifetime.

1 LUMINOSITY AND BASIC PARAMETERS CHOICES

The choice of the basic parameters has been done in two steps considering successively a standard optics and a monochromator optics.

In the case of a standard optics we will use a conventional flat horizontal beam collision optics without dispersion at the interaction point, IP. From [1] we can deduce that high luminosity will be obtained with $\beta_y^* \simeq 0.01$ m, a minimum bunch spacing $S_b \simeq 12$ m, and a large emittance ϵ_x, provided the necessary beam current, I_b, can be achieved. At 2.0 GeV per beam, to obtain $L = 10^{33}$ cm^{-2} s^{-1}, the emittance has to attain the value $\epsilon_x = 3.0\ 10^{-7}$ m rad.

In the case of beam monochromatization, positrons with energy $E_0(1+\varepsilon)$ colliding with electrons at $E_0(1-\varepsilon)$ and vice-versa are needed. In that case the CM energy resolution, σ_w, is reduced while the effective luminosity is increased [2]. This will be achieved by means of opposite vertical dispersions at IP for the two beams ($D_{y+}^* = -D_{y-}^* = D_y^*$). If we consider the introduction of vertical dispersion as the only modification of the usual flat beam scheme ($\sigma_x^* \gg \sigma_y^*$, $\beta_x^* \gg \beta_y^*$), it has been shown in [3] that this procedure leads to a gain factor λ in the energy resolution and a loss in total luminosity by the same factor. If we take a horizontal flat beam with finite vertical dispersion at the IP, the vertical beam size is dominated by the beam energy spread σ_ϵ, ($\sigma_y^* \simeq \sigma_\epsilon D_y^*$). Consequently the beam space charge parameter $\xi_y \ll \xi_x = \xi_{max}$. The reduction in luminosity can be compensated by a reduction of β_x^* [4]. For practical reasons a small β_x^* supposes a larger β_y^*. This inversion is only valid if we keep $\xi_x = \xi_{max}$, and that supposes a reduction in horizontal emittance ($\sigma_x^* \ll \sigma_y^*$). Under these conditions we can achieve a factor λ in energy resolution without loss in total luminosity. According to beam-beam studies using finite dispersion at the IP [5], and assuming $D_y^* \neq 0$ and $D_x^* = 0$, we get a condition on the vertical beam-beam parameter $\xi_y \simeq 0.015$, together with a normal condition on the horizontal beam-beam parameter $\xi_x \leq 0.04$. Let's assume that $\beta_x^* = 0.01$ m and $\xi_x = 0.04$. At $E_0 = 2.0$ GeV per beam for keeping the luminosity at the level of $1.0\ 10^{33}$ cm^{-2} s^{-1} with a colliding frequency $k_b f_r$=25 MHz, the number of particles per bunch must be N_b=1.2 10^{11} and the horizontal emittance $\epsilon_x \leq 2.2\ 10^{-8}$ m rad. We can conclude in the case of an optimized monochromator optics, that the parameters choice is very different from the case of a standard optics.

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2 DESIGNING A VERSATILE COLLIDER

The Tau-Charm Factory (TCF) is a double ring with head-on collisions and electrostatic vertical separation scheme. In the following we describe the three main parts of the accelerator: the arcs, the insertion region (including the low-β insertion and the slopes) and the utility straight section.

2.1 *Arcs and emittances*

Most of TCF designs have used conventional FODO cells in the arcs. The passage from low to high emittance is obtained by means of a special design of the standard arc cells. The emittances can be further reduced or increased with the help of Robinson, damping or emittance wigglers [4] [6].

In our study the original idea is based on low emittance lattices designed for the 3^{rd} generation synchrotron radiation storage rings. At 2.0 GeV these emittances are typically of the order of 10^{-8} m rad.

These lattices are constructed from basic achromatic cells. In this context, achromatic means that the dispersion function is zero at the entrance and exit of the cells. Two parallel studies with two kinds of cells, namely Double Bend Achromat (DBA) and Triple Bend Achromat (TBA) have been made [7]. The procedure followed in both studies is the same. We can deduce from [8] that the TBA lattice gives better performances than the DBA lattice. So in the following we will concentrate on the TBA lattice only.

In the first part of the study we have designed the low-emittance arc ($2.0\ 10^{-8}$ m rad) essentially by choosing the right number of TBA cells. The change from low to high emittance ($3.0\ 10^{-7}$ m rad) is achieved by displacing and increasing the β_{xmin} in the magnets. To get these conditions we decrease the strength of the quadrupoles in the achromat and allow the dispersion to be non-zero at the ends of the module, to achieve a large contribution to the emittance. The optics of high and low emittance versions of these basic modules,matched with the codes BETA and MAD, are shown in figure 1. The dispersion for the high emittance case is finally suppressed at both extremities of each arc by a special matching of the last module, as shown in figure 1(b).

2.2 Interaction region

In this study the interaction region is designed in a more conventional way. It is essentially composed of a micro-β insertion and a separation scheme.

To achieve in the two modes of operation a low-β ($\beta_x^* \simeq 0.01$ m with monochromatization, $\beta_y^* \simeq 0.01$ m in the standard case) we use a superconducting doublet. The distance between the first superconducting quadrupole and the IP is kept at 0.8 m to locate the detector and to match easily both optics. However the distance between the first and second quadrupoles has been reduced from 1.0 to 0.5 m [4] [6] to avoid the growth of the high β-function, which is responsible for the high chromaticity in this kind of lattices.

The passage from monochromatization to standard scheme has been obtained freezing the location of the superconducting doublet and vertical dipoles and having additional quadrupoles in the sloping region. The figure 1 shows the optics for the two modes of operation.

2.3 Utility insertion

The double ring scheme has only one crossing point, hence the opposite insertion is made of two long straight sections corresponding to the two rings, with an equivalent length to the sloping insertion region.

The straight section is made of regular FODO cells without dipoles, leaving enough space to house RF cavities, beam instrumentation devices and additional sextupoles. These sextupoles will help the correction of chromaticities if necessary. The quadrupoles of this region are used to adjust the tunes (Q_x, Q_y) and make other compensations.

2.4 Collider performances

The performances for the TBA lattice are given in table 1. In this table we have included also the values of natural chromaticities, $Q'_{x,y}$, the strength of sextupoles, (SF, SD), and the maximum stable betatron amplitudes, $A_{x,y}$. To calculate the chromaticities and the sextupoles strengths we have used the HARMON module of MAD. To estimate the quality of this correction we have tracked the particles with δ=0 during 10^3 turns with MAD. We have obtained the maximum stable betatron amplitudes in both planes, i.e. A_x(with A_y=0) and A_y(with A_x=0), where $A_{x,y} = \frac{(x^*,y^*)^2}{\beta^*_{x,y}}$, as a function of sextupoles positions and tunes (Q_x, Q_y). To adjust the tunes we have used the quadrupoles of the FODO cells in the utility insertion. For the best configuration we have then tracked the particles, with δ=0 and $\delta \neq 0$, to obtain the dynamics apertures. These have been finally obtained using a faster tracking code, RACETRACK.

The performances of an improved case, from the point of view of dynamic aperture are also included in table 1 (3^{rd} column). In this case we have two additional sextupoles families in the utility insertion, where we have made $D_x \neq 0$, to help the correction of chromaticities.

In all cases the rings were considered to be perfect, without any closed orbit or field errors. However the synchrotron radiation damping has not been included.

	TBA M-LE	TBA S-HE	TBA S-HE ($D_x \neq 0$)	
E_0	2.0	2.0	2.0	GeV
ρ	6.31	6.31	6.31	m
σ_ϵ	$6.81\ 10^{-4}$	$6.81\ 10^{-4}$	$6.81\ 10^{-4}$	
C	387.0	387.0	387.0	m
$k_b f_r$	27.89	27.89	27.87	MHz
κ	0.067	0.033	0.033	
ϵ_x	$1.9\ 10^{-8}$	$2.9\ 10^{-7}$	$2.7\ 10^{-7}$	m rad
ϵ_y	$1.3\ 10^{-9}$	$9.5\ 10^{-9}$	$9.1\ 10^{-9}$	m rad
β_x^*	0.01	0.3	0.3	m
β_y^*	0.15	0.01	0.01	m
D_y^*	0.32	0.0	0.0	m
ξ_x	0.04	0.04	0.04	
ξ_y	0.035	0.04	0.04	
N_b	$1.2\ 10^{11}$	$1.1\ 10^{11}$	$1.0\ 10^{11}$	
I	0.55	0.47	0.50	A
L	$1.1\ 10^{33}$	$8.4\ 10^{32}$	$8.0\ 10^{32}$	$cm^{-2}s^{-1}$
λ	15.8	1.0	1.0	
σ_w	0.1	1.9	1.9	MeV
Q_x	18.4	11.5	10.9	
Q_y	10.7	15.1	14.5	
Q'_x	-40.9	-32.6	-31.8	
Q'_y	- 41.9	-40.4	-39.8	
SF	53.3	41.0	37.9	T/m
SD	-80.3	-46.7	-44.5	T/m
A_x	30	12	21	$\sigma^*_{x\beta}$
A_y	84	68	67	$\sigma^*_{y\beta}$
V_{RF}	2.0	12.0	12.0	MV
h	612	612	612	
σ_b	$5.8\ 10^{-3}$	$6.0\ 10^{-3}$	$6.1\ 10^{-3}$	m
ϵ_{RF}	0.024	0.024	0.023	
ϵ_E	0.018	0.022	0.021	
τ_{tr}	166.0	4813.6	4679.7	min
τ_{bb}	400.5	410.4	404.2	min

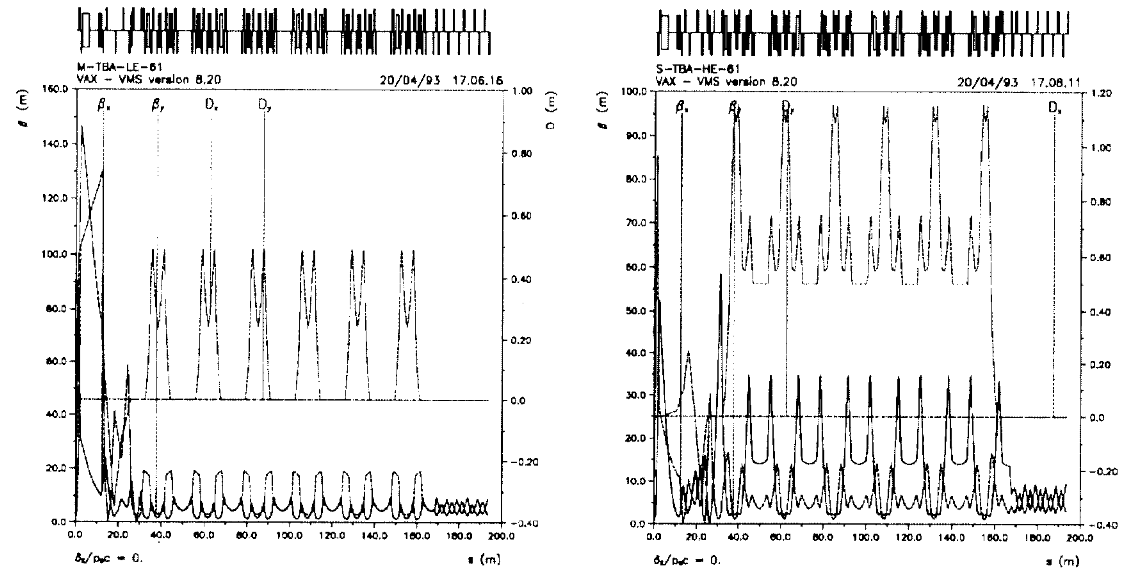
Table 1: Performances of the TBA lattice in the two modes of operation.

3 BEAM LIFETIME

In a TCF the two main contributions to the lifetime are the Touschek effect and the beam-beam bremsstrahlung.

The Touschek effect is important at low and medium energies, with flat beams and low emittance. Hence in the monochromatic case the beam lifetime comes essentially from this effect.

To compute the Touschek lifetime, τ_{tr} [9] it is necessary to know the energy acceptance of the machine, ϵ_E. Both



(a) Monochromatization.

(b) Standard.

Figure 1: Optics along one superperiod of the TBA lattice.

energy acceptance and Touschek lifetime have been calculated using a numerical code [10] which takes into account the jumps in particle energy from this effect all around the ring.

In a very high luminosity machine the beam lifetime may also come from beam-beam inelastic collisions (e^+e^- bremsstrahlung). The lifetime due to this effect, τ_{bb}, has been calculated with the usual formula [11]. The energy acceptance at IP, ϵ_E^*, is calculated with the code [10], and found to be equal to the RF acceptance, ϵ_{RF}. The results are summarized in table 1.

4 CONCLUSION

From this feasibility study we can conclude that a single ring geometry can include both monochromatization and standard schemes with the same luminosity, 1.0 10^{33} cm^{-2} s^{-1} at E_0 =2.0 GeV.

Concerning the arcs, we have observed that TBA cells, although non-conventional for a collider, are more flexible than FODO arcs. Hence we can change from low (2.0 10^{-8} m rad) to high (3.0 10^{-7} m rad) emittance by simple detuning of the optics without additional quadrupoles in the arcs and without wigglers.

The beam lifetimes have been considered also. In the standard mode beam-beam bremsstrahlung is the dominant loss mechanism. However in the monochromatic mode the high beam density causes the Touschek effect to dominate.

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