THE τ-CHARM FACTORY STORAGE RING

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Abstract We present the main design features of the e^+e^- storage ring for the recently proposed τ-charm Factory. It is designed to operate at collision energies $\sqrt{s}$ = 3–5 GeV with a peak luminosity $L \simeq 10^{33}\,\mathrm{cm^{-2}sec^{-1}}$. The double storage ring is fully integrated with the single detector; the micro-β insertion ($\beta_y^* \simeq 1\,\mathrm{cm}$) includes superconducting quadrupoles protruding into the detector volume. A bunch length $\sigma_z \simeq 7\,\mathrm{mm}$ is achieved with a 1.5 GHz RF system. Bunches of opposing beams collide head-on and bunches of the same beam are separated by 15.7 m. The ring has two straight sections, one for the detector and separation scheme, and one for RF systems, wigglers and other utilities. In consequence, there are fewer constraints on the dispersion at the interaction point than in other colliders. This facilitates luminosity enhancements and the implementation of a monochromator optics by purely magnetostatic means. The existing LEP pre-injector system (LIL, EPA, PS) could fill the τ-charm Factory very rapidly, avoiding the need for ramping.

1 Introduction

Great increases in luminosity—some *two or three* orders of magnitude—over existing or planned machines are possible in the centre-of-mass energy range $\sqrt{s} \simeq$ 3–5 GeV) which includes the J/ψ, ψ', ψ'', ... resonances and the threshold for production of $\tau^+\tau^-$ lepton pairs.

A recent proposal [1] has highlighted the physics potential of an e^+e^- collider working in the energy range of 1.5–2.5 GeV per beam and providing a luminosity of around $10^{33}\,\mathrm{cm^{-2}sec^{-1}}$. This proposal envisages a τ-charm Factory (τcF) composed of a detector fully integrated with its own dedicated storage ring. A large fraction of the cost of such an experimental system would be saved by building it at CERN where (among other things) it could exploit the high-performance e^+e^- source and pre-injector system which has been built for LEP.

Here we summarise the design of the storage ring component of the τcF. The general approach to designing a high-luminosity collider has many points in common with that employed in some B-factory schemes [2,3]. The τcF has two rings with a separation scheme to permit operation with many bunches. Bunches collide head-on at the single interaction point to avoid the well-known difficulties with crossing-angles. Monochromator optics can be implemented to provide very narrow energy resolution. An initial design study along these lines was given in [4]. However the lattice layout and optics have been substantially revised for the present paper and the design luminosity has increased.

The luminosity of the τcF is estimated with [5],

$$L = \frac{\pi c(1+\kappa^2)(E/m_ec^2)^2}{r_e^2 S_b \beta_y^*}\epsilon_x\xi_{yo}\bar{\xi}(\xi_{yo}). \qquad (1)$$

which provides a self-consistent set of beam-parameters taking account, albeit in a simple way, of the luminosity reduction due to increase of vertical emittance at high values of the beam-beam tune-shift parameter. Here the bunch separation, S_b, is clearly a critical parameter. For the basic τcF configuration, we assume

Energy	E	2.5	GeV
Circumference	C	376.99	m
Bending radius	ρ	12	m
β-function at IP	β_x^*	0.8	m
	β_y^*	0.01	m
Betatron coupling	κ^2	0.012	
Betatron tunes	Q_x	$\simeq 9.3$	
	Q_y	$\simeq 9.4$	
Momentum compaction	α	0.0189	
Natural emittance	ϵ_x	249	nm
Energy spread	σ_ϵ	5.84×10^{-4}	
Energy loss per turn	U_0	0.287	MeV
Damping times	τ_x	29	msec
	τ_y	22	msec
	τ_ϵ	10	msec
RF frequency	f_{RF}	1.489	GHz
RF voltages	V_{RF}	5	MV
RF power	P_{RF}	$\lesssim 1.5$	MW
Synchrotron tune (RF2)	Q_s	0.106	
Stable phase angle	ϕ_s	3.3°	
Number of bunches	k_b	24	
r.m.s. bunch length	σ_z	6.2	mm
Total beam current	I	498	mA
Particles per bunch	N_b	1.63×10^{11}	
Beam sizes at IP	σ_x^*	443	μm
	σ_y^*	$\simeq 8$	μm
Beam-beam parameter	ξ_y	0.04	
Luminosity	L	1.6×10^{33}	$\mathrm{cm^{-2}sec^{-1}}$

Table 1: Parameters and performance of τ-charm Factory

that the horizontal and vertical dispersion functions vanish at the interaction point: $\eta_x^* = \eta_y^* = 0$. However a monochromator scheme [6] can be implemented by making η_y^* non-zero with opposite signs for the two beams. Dispersion at the interaction point (IP) can also be used to enhance luminosity [7,3]. The coupling, $\kappa = \sqrt{\epsilon_{yc}/\epsilon_{xc}}$, the total ($\kappa = 0$) horizontal emittance, ϵ_x, and the "unperturbed" ξ_{yo} appearing here are evaluated by the usual formulae valid at low intensity. See [4] for further details. The disparity between these "unperturbed" values and their real values at high ξ_{yo} is taken care of by the function $\bar{\xi}(\xi_{yo})$ which saturates at a value $\xi_s = 0.04$ for $\xi_{yo} \simeq 0.06$. With "optimum coupling", $\kappa = \sqrt{\beta_y^*/\beta_x^*}$, this provides maximum luminosity. A parameter list for the τcF at top energy is given in Table 1.

2 Micro-β optics and bunch separation

A micro-β quadrupole doublet is used to focus the beams and achieve $\beta_y^* = 1\,\mathrm{cm}$ at the collision point. This requires bunch lengths $\sigma_z \lesssim 7\,\mathrm{mm}$ or so. The lower limit on S_b in (1) is set by the accumulated length of the micro-β insertion and the separation scheme which follows it. The design of the τcF detector allows *both* the quadrupoles to protrude into the detector provided they

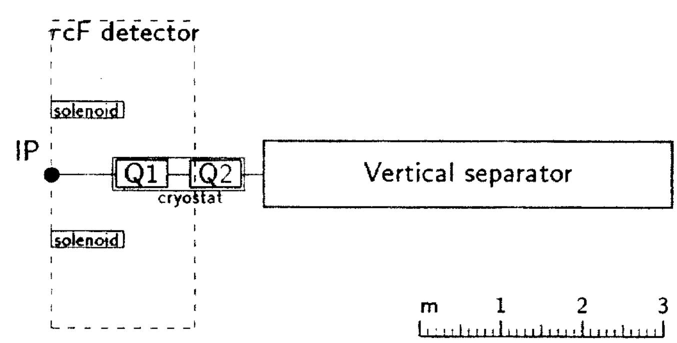

Figure 1: Layout (to scale) of micro-β insertion

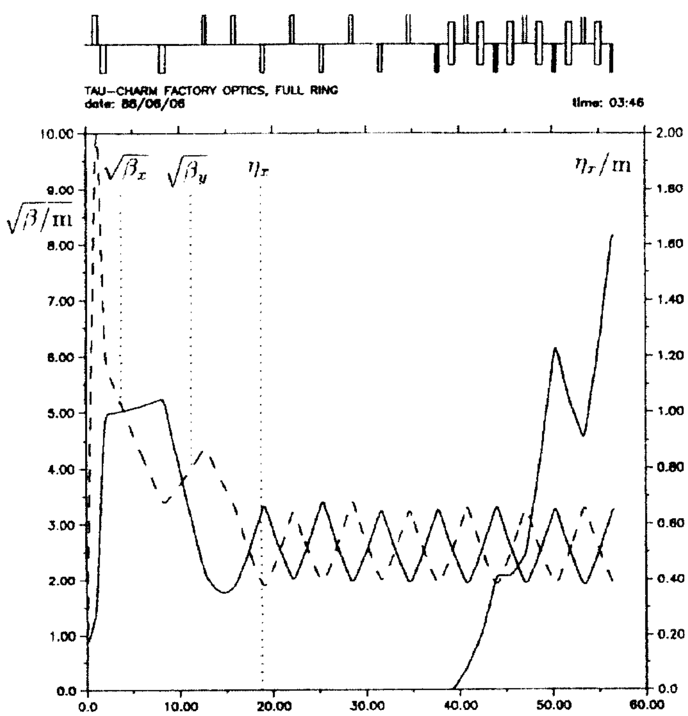

Figure 2: Optics of the experimental insertion

come no closer than $L_1 = 0.8\,\mathrm{m}$ to the interaction point [1] and have an outer radius not greater than 20 cm.

Figure 1 shows the layout of the collision region with the detector (dimensions according to [1]) and its superconducting solenoid. Present technology lets us envisage [8] a pair of 0.6 m long iron-free superconducting quadrupoles (Q1 and Q2) whose coils can be separately rotated inside their common cryostat as part of the scheme to compensate the betatron coupling induced by the 4 tesla detector solenoid. The total length of one half of the micro-β insertion is 7.6 m, which includes a generous 5 m for the electrostatic separator plates (VSEP).

The optics of the experimental insertion and dispersion suppressor is shown in Figure 2 (the vertical separation is not included). The maximum quadrupole strength required $|K| = 2.8\,\mathrm{m}^{-2}$. corresponding to a field gradient $dB/dx \simeq 24\,\mathrm{T\,m}^{-1}$ at 2.5 GeV. Designing the quadrupole for $30\,\mathrm{T\,m}^{-1}$ and taking a half-aperture of 50 mm, the maximum field in a practical winding is $B_{Q1} \simeq 2.5\,\mathrm{T}$ and should be achievable without a cold bore.

Vertical separator plates are used to separate the beams and avoid parasitic interactions between bunches of the opposing beams. We put a conservative limit on the electric field between separator plates: $E_y \leq 2\,\mathrm{MV\,m}^{-1}$. Simulations done for LEP [9] established the separation criterion

$$\Delta y \gtrsim 2\sigma_x = 2\sqrt{\epsilon_x \beta_x}. \tag{2}$$

at the point where the bunches pass. This is already satisfied at the mid-points of the separators for an emittance given by Table 1 but we shall take $S_b \simeq 15\,\mathrm{m}$ for safety.

Studies are necessary in order to ensure that heating of the plates by synchrotron radiation and parasitic mode losses of the high current beams do not give rise to outgassing and a higher breakdown rate. The separator design is important also with respect to detector backgrounds and coupling impedance to the beam. The initial separation angle provided by the plates must be amplified further downstream by magnetic separation with quadrupoles and weak bending magnets [2]. The alternative of RF-magnetic separators [2] can also be considered.

3 Ring geometry and optics

If located at CERN, the τcF could take advantage of the LEP Pre-Injector system. Sufficiently intense beams of electrons and positrons can be supplied by the CPS [10] at all the operating energies of the τcF.

Since $S_b[\tau\mathsf{cF}]$ is of the order of 15 m, close to 1/5 of the separation of lepton bunches in the CPS [10], we are led to

$$S_b[\tau\mathsf{cF}] = \frac{S_b[\mathsf{PS}]}{5} = 15.708\,\mathrm{m}. \tag{3}$$

The circumference $C[\tau\mathsf{cF}] = 3C[\mathsf{PS}]/5$ is chosen to allow efficient injection into each of the 24 τcF bunches in 3 cycles of the CPS [4]. A scheme with $C[\tau\mathsf{cF}] = 251.32\,\mathrm{m}$ and the same bunch separation is also possible but the larger circumference gives greater flexibility in the optics.

The CPS presently supplies 2–3 $\times\ 10^{10}$ particles per pulse so some 15–21 CPS cycles, are needed to reach design intensity. Damping rates in the τcF are fast enough for injected bunches to damp down to the equilibrium orbit before further bunches arrive.

Fast injection kickers, capable of rising to a flat top and falling in twice the bunch separation time, $2T_b \simeq 104\,\mathrm{nsec}$, will be required.

The bending radius $\rho = 12\,\mathrm{m}$ is chosen fairly small to provide rapid damping between beam-beam collisions.

The τcF lattice is built from modules, each having a basic length equal to 1/60 of the circumference. Each arc contains of 12 normal FODO cells with bending angle $\theta = \pi/15$ and phase advance $\mu = 60°$ in both planes. In addition there are two dispersion suppressors, each consisting of 3 cells with $\theta = \pi/30$.

The experimental straight section contains some matching cells, the separation scheme and the micro-β insertion as shown in Figure 2. Space is available for the weak vertical bending magnets, electrostatic separators, skew-quadrupoles, etc. There is enough flexibility to adjust dispersion values at the interaction point for the purposes of a monochromator scheme.

The utility straight section (also dispersion-free) opposite contains several matching cells (for tune-adjustment, control of optical functions etc.) with space for the RF system, wigglers etc. A standard missing-magnet injection scheme can be incorporated into the middle of one arc of each ring.

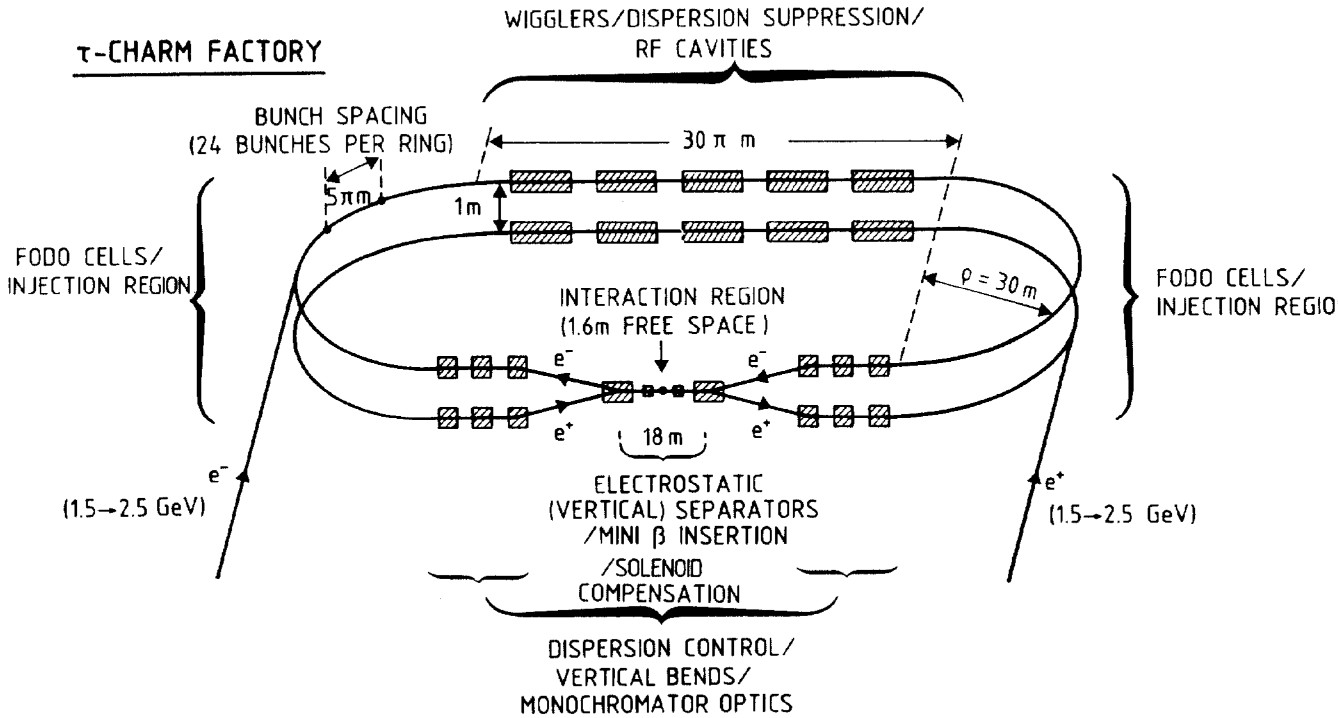

Figure 3: Schematic design of the storage ring

Variation of damping partition numbers by means of Robinson wigglers [11,12,4] is used to keep the emittance constant and make $L \propto E$ at energies below 2.5 GeV. This has the bonus of also reducing the energy spread and helping to produce short bunches.

4 RF system

Two 5-cell 1.5 GHz cavities are installed in the utility straight section of each ring. The high frequency provides the short bunches necessary for the micro-β scheme and has harmonic number $h = 1872$. Superconducting cavities for this frequency are well developed and would be very suitable for the τcF because of their low coupling impedance.

An auxiliary 500 MHz system might be used to facilitate injection.

5 Beam current limits

The design current, $I \simeq 500\,\mathrm{mA}$, of the τcF is comparable with currents now routinely obtained in some light sources. Impedance minimisation is crucial. The usual criterion [13] for the absence of turbulent bunch-lengthening shows that with an effective (at the high bunch frequencies) longitudinal impedance $|Z/n| \lesssim 0.4\ \Omega$, the bunches will not lengthen significantly at top energy. With a very smooth, rather wide vacuum chamber and the superconducting cavities, this value seems to be attainable. At lower energies, $I \propto E$ so the bunches may lengthen but are unlikely to exceed their length at top energy.

In a many-bunch machine, coupled-bunch instabilities are likely to occur. A conventional feedback system capable of acting upon each bunch independently can cure them but the bandwidth necessary $\Delta f \gtrsim c/2S_b \simeq 10\,\mathrm{MHz}$ may be excessive. However lower bandwidth alternative schemes exist [14] and would be preferable.

Acknowledgements I thank A. Hofmann, J. Kirkby, S. Myers, and T.M. Taylor for many helpful discussions.

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