A Preliminary Design for a Tau-Charm Factory*

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Abstract

A Tau-Charm Factory (τcF) with a luminosity of 10^{33} /cm^2/s has been studied to determine the parameters and feasibility of such a facility. We have primarily looked at a system with a circumference of around 380 m, monochromatic optics, superconducting RF, distributed vacuum pumping and electrostatic bunch separation at the single interaction point. A candidate lattice has been developed and we have begun to determine the specifications of magnets and other components

I. Introduction

A Tau-Charm Factory, (τcF), is a high luminosity e^+e^- collider operating near the J/Ψ and τ production threshold, which requires center of mass energies from 3 to ~ 6 GeV. Such a machine would enable a new level of precision in several physics areas such as the tau neutrino mass, rare tau decays, charm decay constants, rare charm meson decays, neutral D^o meson mixing and charmonium, with high statistics and well understood backgrounds [1]. Such studies, particularly the searches for rare processes such as CP violation, require the highest possible luminosities.

We have made a preliminary design study of the feasibility and cost of constructing such a facility. As described below, we have aimed our lattice design work toward the goal of a simple lattice with monochromatic collision optics. The design is not complete or totally self consistent, however critical and high cost components have been examined in some detail. This paper describes the options considered and the initial conclusions of our study.

II. Parameters

Following other work, this design uses two rings separated vertically, with one interaction region between them [2]. The operational characteristics of the machine are determined by the design of the interaction region and the machine lattice in the arcs.

The goal of producing a luminosity of >10^{33} /cm^2/s based on realistic beam parameters and components can be accomplished in a number of ways. In this design two options have been considered for the interaction region: the monochromatic collision optics [3], in which the beams collide in a region with opposite non-zero vertical dispersions so that the sum of the energies of the two beams is constant; and the standard optics, in which the beams are not dispersed. In the past, it has been assumed that the luminosity for the monochromatic optics was necessarily lower than that for the standard, high luminosity optics. We have shown that, with proper tuning, one may be able to obtain similar luminosities with either optics, thus the need for the difficult retuning might be avoided [4]. We have chosen the monochromatic optics for our design.

The lattice capable of producing the desired luminosity is described in reference [4]. The shape of the rings is determined by the long straight section required by the interaction point optics and the beta and dispersion matching sections which couple the magnet arcs to the IP. The straight section on the opposite side of the ring is used for injection, RF, beam dumps and other functions. The lattice optics are designed to maximize the luminosity at the energy of the J/Ψ while providing beam energy resolution at the IP comparable to $\Gamma_{J/\Psi}$ = 0.088 MeV and large dynamic aperture with realistic components. The primary parameters are summarized below.

Collider Ring Parameters

General		
Center of mass energy	3.0 - 6.0	GeV
Luminosity	10^{33}	/s /cm^2
Current	0.86	A
Electrons (positrons)	$1.8 \cdot 10^{11}$	/bunch
Approximate circumference	385	m
Bend radius	11.7	m
Bunch spacing	~10	m
Momentum compaction, α	0.036	
Bunch length	0.01	m§
Natural emittance, ε_x, ε_y	250 / 3.8	nm§
Beam energy spread, σ_E / E	$3.8 \cdot 10^{-4}$	§
Interaction Point		
Beta functions, β_x*, β_y*	0.01 / 0.03	m
Dispersion, D_y*, (D_x*= 0)	±0.4	m
Beam beam tune shifts, $\xi_x = \xi_y$	0.026	
RF System		
RF frequency	~500	MHz
Required RF voltage turn	3	MV§
Maximum radiated power / beam	530	kW
Cavities	1	/ring§

§ all parameters evaluated at 1.5 GeV, (table and text)

The lattice of the arcs consists of FODO cells with a cell length of 7.4 m and a phase advance of 60^o per cell. The dipole magnets operate at 0.71 T and the magnet length is 2.3m. Horizontal dispersion is eliminated in the straight sections by removing the third and fourth magnets from each

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end of the arcs.

At the collision point the optimized orbit parameters are β_x^* = 0.01 m, β_y^* = 0.03 m, and D_y^* = ±0.4 m for the two beams. Head-on collisions are assumed, with electrostatic separators near the interaction point producing the initial beam separation. With electrostatic fields of 24 kV/cm at 1.5 GeV, the beams are separated by ~20 σ, at 5 m from the IP, thus a bunch to bunch separation of ~10 m seems adequate.

The proposed lattice can be made to preserve e+/e- polarization with the addition of spin rotators in the straight sections. The injectors must be able to produce polarized positrons to exploit this capability.

To reach higher luminosities it might be necessary to consider the addition of crab crossing cavities and modification of the IP line to permit off axis collisions. This would permit smaller bunch spacings than the ~10 m required for electrostatic separation.

III. Vacuum Chamber

The vacuum chamber determines the stability of the beams as well as the required aperture of the magnets. Synchrotron radiation from the beams in the arcs produces a large heat load on the chamber as well as radiation induced gas desorption. The gas load is given by the relation $Q_{gas} = 24.2\, E\, I\, \eta$ [Torr L/s], where E is the beam energy in GeV, I is the beam current in Amps and η is the desorption constant [5].

Aluminum, copper and stainless steel chambers were considered. Copper seems preferable because it has good vacuum properties, $\eta = 2 \cdot 10^{-6}$ molecules/photon, but aluminum is cheaper and is more easily extruded. We have tried to produce a simple and compact cross section which requires minimal modification to the basic extrusion. Slots will be cut between the beam chamber and the pumping chamber and the structure could then be bent horizontally at a 11.7 m radius using the techniques developed for the vacuum chamber of the Advanced Photon Source (APS) [6]. In normal operation, the chamber would be cooled by water in the outside cooling channel. Heating for bakeout will be accomplished using hot water in the cooling passages.

An arrangement of slots with a conductance of 500 - 1000 l/s will be made parallel to the beam direction. Pumping will be provided by non evaporable getter (NEG) tapes such as SAES ST707 [7]. Three of these tapes 1.5 cm wide will provide ~500 L/s m of pumping, which should be sufficient to produce a vacuum of ~$4 \cdot 10^{-9}$ Torr in the arcs, giving a gas scattering lifetime of ~7.5 hours.

Synchrotron radiation near the interaction point causes backgrounds in the detectors as well as heating of the components and perhaps large photocurrents in the electrostatic separators. Masking of these components requires absorbers near the electrostatic separators and IP.

IV. Magnets / Power Supplies

In this design the interaction point quadrupoles have a large gradient and large aperture and therefore must be superconducting.

The design of a 5 cm, warm bore, high gradient, (80 T/m at 3 GeV), superconducting quadrupole would follow the LHC quad designed by Ostojic, Taylor and Kirby and built by Oxford Instruments [8]. The quadrupole would use a NbTi conductor and would have a maximum field on the condutor of only about 5 T.

Conventional magnets were based on designs developed for the APS. In order to study the dependence of cost on the gap, two gaps were considered. Dipoles with gaps of 6 and 8 cm were considered along with quadrupoles of 3.5 an 5 cm radii. The dipoles will be made with laminated C shaped cores and the quads will have demountable laminated cores.

Power supplies for all components would be conventional. All dipoles will be connected in series, as will be the quadrupoles. Shunt power supplies around each quadrupole would permit ±10% tuning capability.

V. RF Acceleration

The cw RF system is required to replace ~600 kW of lost synchrotron power per ~1 A beam and provide longitudinal focusing to keep $\sigma_z \sim \beta_x^* \sim 1$ cm, while presenting the minimum possible impedance to the beam.

A superconducting RF system operating near 500 MHz is a natural choice. At this frequency, a voltage of 2.8 MV/turn is required to bunch the beam to 1 cm at 1.5 GeV, and recent data from Cornell show that 3 MV could be provided by one cavity per ring [9]. A system of coupling out and damping higher order modes has been developed along with a geometry that minimizes wake fields. High power rf windows which can transmit the ~400 kW required by one beam are available at this frequency [9]. High luminosity operation above 1.5 GeV would require more than one cavity to maintain the bunch length and beam energy and these could be added when necessary.

The beam current is limited by the radiated power that can be replaced by the RF system, so it is desirable that more than the minimum power is available. Tubes producing more than 1 MW are available below 500 MHz from a number of sources.

Cryogenic heat loads for the RF system, ~100 W /cavity, and the superconducting quadrupoles on the opposite side of the ring, ~50 W, plus piping, would be 300 - 400 W for a system with one rf cavity per ring.

VI. Injector Options / Injection

The optimum filling frequency can be found by maximizing the average luminosity as a function of refilling interval. The lifetime of the beams in the machine, τ_t, is limited to about 90 min. at high luminosity, primarily by inelastic e^+e^- collisions and the Touschek effect, and the filling time should be expected to be about τ_f = 2.5 min. The frequency of injection for maximum overall integrated luminosity would then require refilling after operational periods of about $\sqrt{\tau_t \tau_f}$ ~ 15 min. Thus, the injector will be running about 10 - 15% of the time. Topping up the bunches to save injection time might be possible, and it might significantly increase the integrated luminosity if it were done while maintaining the beams in collision.

A high current injector for the τcF would consist of a ~200 MeV electron linac, a positron target, a ~450 MeV positron linac, a positron accumulator ring to store and damp positrons from many electron bunches and a rapid cycling synchrotron with an acceleration frequency of about 5 - 10 Hz [10]. Such a system should be capable of accelerating $2 \cdot 10^{10}$ polarized e^+ /pulse to 2.5 GeV at a frequency of 5 Hz with low losses.

VII. Conventional Facilities

In order to estimate the overall cost and size of such a facility, we have made preliminary estimates of the space required for different systems together with a possible plan of the facility. The collider requires the equivalent of 3 m of earth in order to shield against a worst case beam loss. This seems most easily provided if the rings are underground. We have assumed that the detector, control areas, counting room, power supplies, and assembly areas, as well as injection beamlines and RF could all be in one building. The detector is self shielding, however the storage rings will require some local concrete shielding in the building. One structure, roughly 20 by 60 m should be sufficient for all activities. The injection system would be located in other structures.

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