ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI001

DESIGN OF A HIGH LUMINOSITY TAU/CHARM FACTORY

M.E. Biagini, R. Boni, M. Boscolo, A. Chiarucci, R. Cimino, A. Clozza,
A. Drago, S. Guiducci, C. Ligi, G.Mazzitelli, R. Ricci, C. Sanelli, M. Serio,
A. Stella, S. Tomassini, INFN-LNF, Frascati, Italy
G. Schillaci, M. Sedita, INFN-LNS, Catania, Italy
S. Bini, F. Cioeta, D. Cittadino, M. Del Franco, A. Delle Piane, E. Di Pasquale,
G. Frascadore, S. Gazzana, R.Gargana, S.Incremona, A. Michelotti, L. Sabbatini,
Consorzio N. Cabibbo Laboratory, Rome, Italy
N. Carmignani, S.M. Liuzzo, P. Raimondi, ESRF, Grenoble, France
M. Pivi, IMS Nanofabrication, Vienna, Austria
R. Petronzio, Rome II Tor Vergata University, Rome, Italy

Abstract

The design of the *SuperB* B-Factory [1] has been inspiration for several other proposals and is the base of the SuperKEKB new design. SuperB was a state-of-the art accelerator for which new ideas were developed, such as the "*Large Piwinski Angle and Crab Waist Sextupoles*" (*LPA&CW*) collision scheme, super-squeezed beams, and polarized electron beam. The same design criteria were applied to a high luminosity Tau/Charm Factory designed by the INFN-LNF Laboratory in Frascati in collaboration with the Consortium Nicola Cabibbo Laboratory. The target luminosity is 10^{35} cm^{-2} sec^{-1} at 4.6 GeV in the center of mass. The possibility to extend the Linac for a SASE-FEL facility was also taken into account. A Conceptual Design Report [2] was published in September 2013. Since the design of an intermediate energy e^+e^- collider with high peak luminosity is still of interest for many laboratories worldwide, in this paper the design principles and the project features are summarized.

TAU/CHARM DESIGN

The principles of operation of last generation high luminosity colliders are the *LPA&CW* collision scheme, successfully tested at the Φ-Factory DAΦNE in Frascati [3,4], with small beam emittances and smaller beam sizes at the Interaction Point (IP). The design presented here is based on symmetric energy beams, allowing for an easier Final Focus design with respect to the Super B-Factories one. The beam parameters have been chosen in order to have a peak luminosity of 10^{35} cm^{-2} sec^{-1} at the Tau/Charm threshold and upper. At lower center of mass energies a lower luminosity, but still an order of magnitude higher than that of present colliders operating in the same energy range, can be achieved with a suitable choice of parameters. As an example, in Table 1 is a list of beam parameters relevant to achieve such a luminosity, for the energy of 2 GeV/beam. The emittance, bunch length and energy spread of such intense bunches are dominated (and increased) at these energies by the Intra Beam Scattering (IBS) mechanism. For this reason the numbers in Table 1 include an estimation of this effect, as well as the luminosity reduction factor due to the horizontal crossing angle. It has to be noted that these parameters are not pushed to the limit, and the design can tolerate beam currents up to 2.5 A, allowing for a factor of 2 increase in luminosity.

Table 1: Tau/Charm Main Parameters @ 2 GeV

Parameter	Units	
Luminosity	cm^{-2} sec^{-1}	10^{35}
Beam energy	GeV	2
Circumference	m	341
X-angle (full)	mrad	60
Piwinski angle	rad	10.84
Beam-beam tune shift (x,y)		0.004,0.089
IP β (x,y)	cm	7, 0.06
IP σ (x,y)	μm	19, 0.09
Emittance x (Natural/IBS)	nm	2.85/5.13
Coupling factor	%	0.25
Bunch length (Natural/IBS)	mm	5/6.9
Damping times (x,y)	msec	35, 49
RF Frequency	MHz	476
Number of bunches		530
Num. particles/bunch		2.34×10^{10}
Beam current	A	1.75
Beam power	MW	0.16

To get high luminosity with a relatively low bunch density, in order to keep under control the IBS emittance growth, it has been chosen to fill all buckets, with a bunch distance of 2.1 nsec, keeping a 2% gap to avoid the ion trapping in the electron ring. These values require an efficient bunch-by-bunch feedback system, like the one already developed for DAΦNE and PEP-II, a proper choice of the RF parameters and very effective mitigations for the e-cloud instability. It is worthwhile to note that the amount of energy losses in the Tau/Charm is

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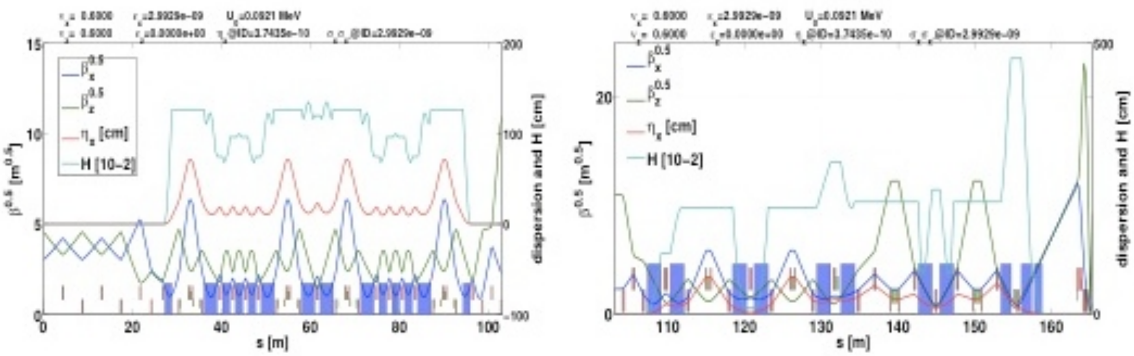

Figure 1: Optical functions and $\mathcal{H}$ function in one Arc (left) and in the Final Focus (right).

very low. Transverse damping times are different in X and Y due to the presence of a gradient dipole in the ARC cell. For the operation at lower beam energy the use of wiggler magnets is mandatory to increase the damping.

The *LPA&CW* collision scheme is beneficial for beam-beam effects. Due to the effective suppression of beam-beam induced resonances it allows for increasing the value of ξ_y by a factor of about 3 as compared with the ordinary head-on collision. Accordingly, the same factor can be gained in the luminosity. For the Tau/Charm design beam-beam tune shifts are on the safe side: the horizontal is negligible, due to the features of the LPA scheme, the vertical ξ_y is lower than 0.1 for the baseline parameters, a value much lower than those routinely achieved at the B-Factories PEP-II and KEKB.

The layout of the Tau/Charm Main Rings (MR) is shown in Fig. 3 (right). A long Final Focus (FF) section brings the two beams to collision at the IP. Opposite to the IP a long straight section provides space for the injection cells, RF cavities, feedback kickers, tune trombone cells, and a Siberian Snake section (in the electron ring only) to longitudinally polarize the electrons at the IP. The two straights are connected by Arc cells providing the low emittance needed. The vertical separation necessary on the opposite side of the IP can be made in different ways: the possibility of slightly tilting the two rings in the vertical plane (2 mrad) seems the easiest one. The Arc cells lattice is based on a 7-bend achromat scheme: among the possible lattice designs, this one has the best ratio between dipole length/total length, and it provides the smallest emittance and has the minimum number of sextupoles with the smaller integrated gradient (because of the large dispersion and betas). The use of a quadrupole gradient (vertical focusing) in some of the cell dipoles reduces the emittance by a factor 1.5 and simultaneously increases the natural bunch length by about a factor 1.25. The dipoles have a curvature radius of 15m, which is the best compromise between short damping time and high average polarization. Optical functions and $\mathcal{H}$ function in the MR (left) and FF (right) are shown in Fig. 1.

A special care has been devoted to the optimization of the non-linear effects both in the arcs and in the FF. In the Arc cells 3 families of interleaved sextupoles (2 SD and 1 SF) at about 180 degrees of phase are used to correct for the cells chromaticity. The sextupoles pairs generate X and Y tune shift versus J_x and J_y (amplitudes). A pair of octupoles cancels the X tune shift dependence from J_x. The Y tune shift from J_y is canceled by having a proper value of α_y at the X sextupoles (or a proper R_{43} matrix element between them). The cross term is very small and can be zeroed by choosing the proper z-location for the octupoles. As result the ARCs optics is virtually linear for several hundreds beam sigmas (x, y, $\Delta E/E$). The dipoles in the FF have fields very close (between 80-100%) to the ARC ones in order to maximize the polarization. The length of these dipoles is as long as possible in order to maximize the dispersion across the sextupoles. Further lengthening of the dipoles would increase the FF $\mathcal{H}$ function and the FF contribution to the overall emittance. The emittance in the Arcs only is about 2.4 nm, including the FF the overall Ring emittance goes up to 2.8 nm.

In the FF the main sextupoles, in phase with the Final Doublets, are paired. Off-phase (in-phase with the IP) sextupoles correct for the third order chroma-ticity; their residual geometric aberrations are very small. A third sextupole further reduces them. The Dynamic Aperture (DA) reduction due to the Final Doublets (FD) fringe fields and the Crab Sextupoles is a well-known issue of this kind of FF designs, and the compensation of such effects has required a dedicated study. Fringe fields are very weak third order non-linearities, ultimately related to the fact that the magnetic fields do satisfy the Maxwell equations. However in Super Flavor Factories their effect is very large and strongly reduces the DA, due to the strong FD quadrupoles and the high beta functions. The DA has been evaluated by tracking particles for 512 turns, taking into account the effect of hard edge fringe fields in all quadrupoles and the effects of the truncation of the Hamiltonian of drift spaces to higher orders. In Fig. 2 the effect of the fringes is shown: it is clear that the main limitation comes from the FF doublets fringing fields, but this can be corrected, and the DA almost restored to the ideal case, with 3 octupoles in the doublet (green curve). The DA in this case is about ±60 σ_x (IBS ε_x, no coupling) and 80 σ_y (IBS ε_y, full coupling).

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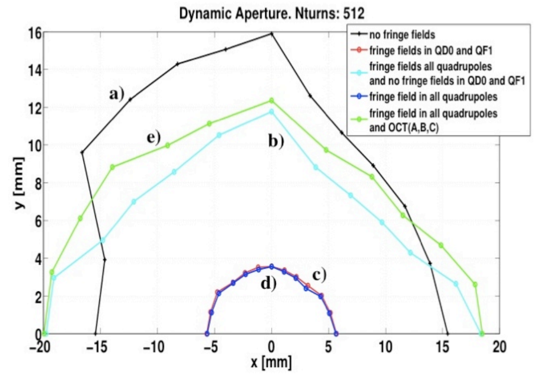

Figure 2: DA with a) no fringes, b) fringes in Arcs only, c) fringes in FF doublets only, d) fringes in all quads, e) fringes in all quads and octupoles correction.

Lifetime (Touschek dominated) and backgrounds have been studied, as well as IBS and e-cloud effects. An extensive work has been performed for the design of all magnet types (including 8 different dipoles, 3 quadrupoles, 2 sextupoles, 1 wiggler). Engineering studies on the MR and Damping Ring (DR) mechanical components, including alignment and vibrations studies, have been performed.

The control system is based on !CHAOS, a new software infrastructure under test at DAΦNE. Infrastructures, civil engineering, vacuum, diagnostics, RF, fluids, cryogenics, electrical engineering and Health, Safety and Environment are also described in [2].

INJECTION COMPLEX

The layout of the Tau/Charm complex is shown in Fig. 3. The injection system consists of a polarized electron gun, a Positron Source, e^- and e^+ Linac sections, a DR and Transfer Lines connecting these systems to the MR. The charge per bunch per pulse required to replace the lost particles at the maximum luminosity is ~100 pC but the system is designed to provide 200 pC in order to have a good safety margin. The electrons are accelerated through three Linacs, L1, L2 and L3, up to 2.3 GeV and then transported to the Electron Ring with a transfer line. A pulsed magnet is used to bypass the positron source. Positrons are produced by 0.6 GeV high current e^- bunches on a W target with a conversion efficiency of about 3%, and stored in the DR for 40 ms, corresponding to 4.5 damping times, in order to reduce the beam emittance. At the DR exit a bunch compressor reduces the length of the positron bunches in order to accelerate them in the linac L3 without producing a large energy spread that would not be acceptable for MR injection. The three Linacs are based on S-band, SLAC type, accelerating sections operating at a repetition frequency of 100 Hz. The injection repetition cycle is 40 ms for each beam, corresponding to 25 Hz. The timing scheme allows to accelerate two beam pulses for a SASE FEL facility, during the store time of the positrons in the DR, without affecting the injection rate for the Tau/Charm.

Figure 3: Tau/Charm complex including Main Rings, Injection complex and FEL facility (left). MR layout (right).

CONCLUSIONS

The design of a high luminosity Tau/Charm Factory has been carried out. A Report [2] gives details on all the related aspects, including machine and injection complex design, accelerator technical systems, conventional facilities. This work provides the basis for a Technical Design Report, and it can be useful for any medium energy lepton collider aiming at reaching high peak luminosity.

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