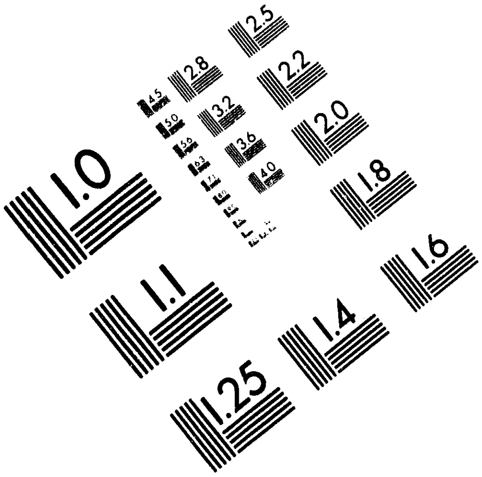

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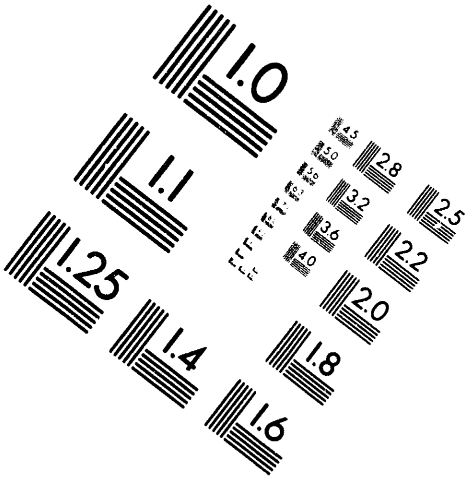

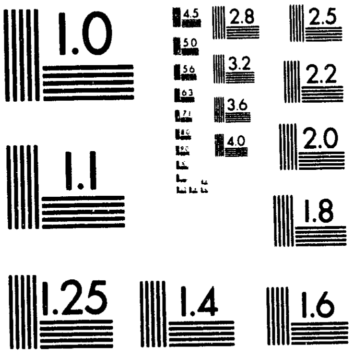

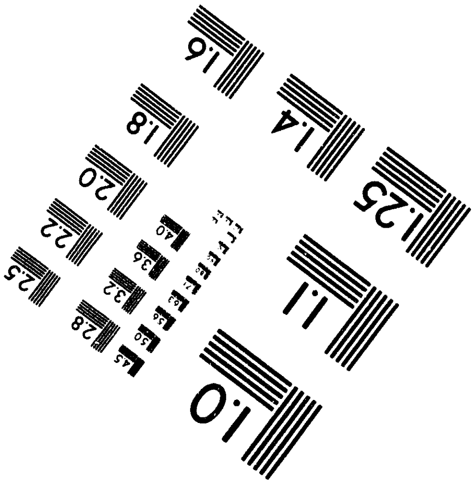

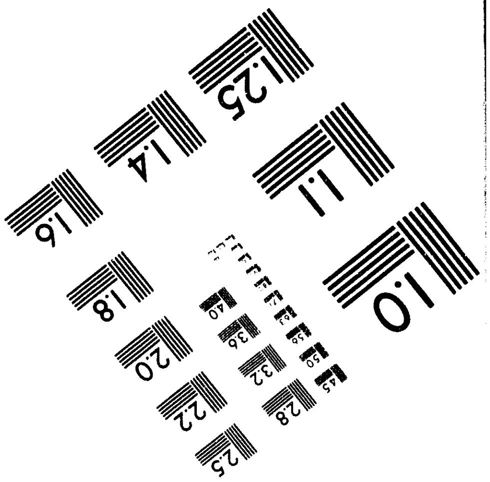

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A Tau - Charm - Factory at Argonne

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Abstract

In this paper we explore the possibility of building a tau-charm-factory at the Argonne National Laboratory. A tau-charm-factory is an e^+e^- collider with a center-of-mass energy between 3.0 GeV and 5.0 GeV and a luminosity of at least $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Once operational, the facility will produce large samples of τ pairs, charm mesons, and charmonium with either negligible or well understood backgrounds. This will lead to high precision measurements in the second generation quark and the third generation lepton sectors that cannot be done at other facilities. Basic physical properties and processes, such as the tau neutrino mass, rare tau decays, charm decay constants, rare charm meson decays, neutral D^0 - meson mixing, and many more will be studied with unique precision.

An initial design of the collider including the injector system is described. The design shows that a luminosity of at least $1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ can be achieved over the entire center-of-mass energy range of the factory.

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I. Introduction

Progress in High Energy Physics (HEP) is achieved on two complementary frontiers, one requiring higher energies to discover new quanta and the other requiring higher precision to find violations of the selection rules of the Standard Model. Whereas the first frontier leads to the need for larger and larger machines, the second frontier requires higher particle production rates and high resolution detectors. Both approaches have been essential to the progress of the field.

The Tau - Charm - Factory (τcF) is an e^+e^- collider running at a center-of-mass energy between 3.0 and 5.0 GeV and with a very high luminosity of at least $1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The energy range covers the thresholds for the production of charmonium, τ pairs, and charm mesons. Running the collider above and below the different thresholds creates data samples with well understood backgrounds and, therefore, results in measurements with very small systematic errors. The number of produced particles compared to a Z - and a B - factory is compiled[1] in Table I for one year running at the design luminosity. The table shows that a τcF produces a factor of five more charm mesons and τ pairs, and is unique in producing high rates of charmonium states. The goal of the Charm2000 workshop was to study experiments capable of collecting 10^8 reconstructed charm mesons. This is clearly within the reach of a τcF.

II. Physics Case

Depending on the beam energy setting, the τcF will be optimized to study physics with τ leptons, with charm mesons, or with charmonium states. The following is a short overview of the physics topics. The projected sensitivities are taken from Ref. 2(3) for the τcF (B - factory).

A) Tau Lepton Physics

The observed properties of the τ lepton are consistent with it being a sequential lepton, a heavier version of the electron and muon, with its own neutrino partner ν_τ. With a mass of 1777 MeV, the τ lepton is the only lepton sufficiently heavy to decay into hadrons, approximately 64% of its decays. This makes it an ideal tool to study hadronic weak interactions under very clean conditions and to search for deviations from the predictions of the Standard Model.

The optimal center-of-mass energy to study the production and the decay of τ leptons is around 3.57 GeV, i.e. below the ψ' resonance and the open charm thresholds. The cross section is large, approximately 1 nb, and, therefore, high statistics data samples of τ pairs may be collected. The decay branching ratios, the Michel parameters, the τ neutrino mass, and the τ dipole moment can be determined with unmatched precision. A search for rare decay modes not expected in the Standard Model can be made to very small branching ratios of the order of 10^{-8}. Other rare decay modes, such as $\tau \rightarrow \eta\pi\nu$, can be measured accurately if occurring at the rate predicted by the Standard Model.

Table II shows a comparison of the status of recent measurements (taken from reports at the 1993 Cornell conference), the projected sensitivity of a τcF as advertised during the 1993 workshop,[2,4] and the sensitivity to be achieved at a B - factory.[3]

The production rate of τ pairs is only a factor five larger at a τcF compared to a B - factory. Nevertheless, the measurements at a τcF are significantly more precise. This advantage is mostly due to: a) the unique possibility to control the systematic errors by running above and below the production threshold, b) the absence of charm meson backgrounds, and c) the high efficiency for identification of background free τ pairs.

B) Charm Meson and Charmonium Physics

The charm quark, c, is the only heavy charge 2/3 quark accessible to precise experiments. Its variety of weak decays (Cabibbo allowed, Cabibbo forbidden, doubly Cabibbo forbidden, rare second-order weak decays, $\cdots$) can be used to probe the interplay of the weak and strong interactions, including precise tests of quantum chromodynamics (QCD) at the interface of perturbative and non-perturbative dynamics[1,4]. Mixing in the $D^\circ - \bar{D}^\circ$ system and studies of CP non-invariance in the charge 2/3 sector would be of great interest, distinct from the studies of $K - \bar{K}$ and $B - \bar{B}$ mixing and related CP non-invariance that involve charge $-1/3$ quarks. In addition, decays of the J/ψ, ψ', and other charmonium systems provide important insight into light meson and gluonium spectroscopy.

With the increase in event rate expected at B factories and high-luminosity investigations at the Z°, the precision attainable in specific rare processes will be limited by backgrounds and systematic uncertainties. At a τcF, adjustment of the beam energy above or below a particular threshold permits measurements of backgrounds directly. Data samples are pure, free from contamination from heavier flavor decays. Near threshold, heavy flavors are produced in simple particle-antiparticle final states (e.g. $D^\circ \bar{D}^\circ$, $D^+ D^-, \cdots$). If the decay of one particle is observed, its companion is tagged cleanly. Operation of a τcF at the ψ'' (3.77 GeV) would yield pure $D^\circ \bar{D}^\circ$ and $D^+ D^-$ states, without contamination from other charm meson or baryon states. At 4.03 GeV, tagged $D_s^\pm$ (cs) states can be studied, while at 4.14 GeV, $D_s^{*\pm}$ states can be investigated via associated production of $D_s^{*\pm} D_s^\mp$. Operation at the J/ψ (3.10 GeV) would provide an intense clean source of gluonic states and light-quark hadrons. Table III shows a compilation of the estimated sensitivity of a τcF in the charm and charmonium sector.

III. Design of the Collider

An initial design of the collider to determine a preliminary set of parameters and the approximate cost of the facility is presented. The design shows that a luminosity in excess of $1 \times 10^{33} \mathrm{cm}^{-2} \mathrm{s}^{-1}$ can be achieved with a center-of-mass energy in the range between 3 and 5 GeV with beam beam tuneshifts less than 0.04.

The operational characteristics of the machine were defined by the design of the interaction region, which determines the charge per bunch and the bunch separation, and by the machine lattice, which determines the equilibrium emittance. The initial parameters assume two rings with a vertical separation of one meter, and one collision point halfway between the rings. The beams will be steered to the collision point using vertical bends, similar to the Spanish/CERN design[5].

The ring is oval, approximately 38 m wide and 100 m long with two zero dispersion straight sections and a circumference of about 300 m. One straight section contains the interaction point and the other is used for injection and RF acceleration. The length of the straight sections is determined by the optics that is required to couple the arcs to the interaction region.

Despite the relatively low beam energy, the large circulating beam currents, approximatively 1.4 A, produce about 400 kW of synchrotron radiation per beam. This high radiation is responsible for the production of considerable gas in the arcs. Following the design of Argonne's Advanced Photon Source (APS)[6], distributed pumping is used to remove this gas. The vacuum chamber is assumed to be a copper extrusion incorporating non evaporable getter (NEG) tapes. Using the parameters of the vacuum chamber, the design of the magnets and power supplies were based on algorithms developed for the APS.

The RF system serves two purpose: replacement of the energy in the beams lost due to synchrotron radiation and reduction of the bunch length. Superconducting cavities provide the required power and voltage in a system which has a large internal diameter. Higher order modes are minimally excited and can be damped.

The parameters of the interaction point are constrained by the nearest quadrupoles, which are located within the detector. These are large aperture superconducting magnets with concentric higher order multipole correctors. The beams are separated by long electrostatic separators. Masking of the synchrotron radiation is somewhat easier than in B - factories[7,8] due to the lower beam energies and the approximate collinearity of the beam.

The storage ring will be provided with a full energy injector. A number of options for the injector system are being considered, including a small synchrotron supplied by an electron/positron linac.

The conventional construction will include the shielding requirements for the beams, a large hall for the detector, the work and assembly areas, the counting house and the run control rooms, as well as buildings housing the power supplies, the refrigeration plant, and the safety systems associated with the storage ring operation. The rings could be located underground and shielded by dirt. Additional shielding will be required for the straight section used for injection and acceleration of the beams and the injection beam lines.

IV. Cost and Schedule

A preliminary survey of the beam optics, the vacuum system, the ring magnets, the power supplies, the RF system, and the interaction point has been completed, permitting some preliminary cost estimates of the systems and identification of the critical issues. The cost estimates are in fair agreement with extrapolations based on existing facilities, but preliminary. The major costs of the collider are associated with the vacuum system, the magnets, and the RF system. The costs of the collider and the detector are roughly equal.

The construction time of the facility is estimated to be about four years from approval, assuming the existence of a fairly complete design.

V. Conclusions

After evaluating the scientific and technical matters that are described above, we reached the following principal conclusions:

1. Physics potential: A τcF will be the most powerful tool anywhere for precise experimental study of the properties of the τ lepton and the charm quark. Its combination of high production rate and low background will provide major advantages compared to similar experiments at B - factory machines, and will be of particular importance for the study of rare decay modes and for sensitive searches for new processes and new states.
2. Collider design and the Argonne site: the Argonne site offers important advantages for the design, construction and operation of a τcF. A conceptual design of the collider including several options for the injector system is in preparation. A document describing the design and the costs is expected to be released within the next few months.
3. Overall assessment: A τcF can be expected to be a unique, powerful, and cost-effective tool in HEP research for many years. Whether such a project could be funded in a timely way at ANL (or anywhere else) is not clear, in view of current budget uncertainties and the abrupt termination of the SSC project by the US Congress. Nevertheless, a τcF would provide excellent research opportunities in a very cost effective way and contribute significantly to the productivity and the vitality of the U.S. HEP community.

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Table Captions

I Comparison of τ-charm data samples at the Z, B and τ-charm factories to be collected in one year of data taking. The quoted numbers correspond to integrated luminosities of 2 fb^{-1} ($\mathcal{L} = 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) for the Z factory and 10 fb^{-1} ($\mathcal{L} = 1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) for the B - and τ-charm factories.

II Comparison of the status of some important measurements in τ physics with the projected sensitivities of both τ-charm and B - factories.

III Estimated sensitivity of a τcF in the charm and charmonium sector.

Table I

Particle	Z Factory	B Factory	τcF
D^0 (single)	1.2×10^7	1.5×10^7	5.8×10^7 (ψ'')
D^+ (single)	0.5×10^7	0.7×10^7	4.2×10^7 (ψ'')
D_S^+ (single)	0.3×10^7	0.3×10^7	1.8×10^7 (4.14 GeV)
$\tau^+\tau^-$ (pairs)	0.3×10^7	0.9×10^7	0.5×10^7 (3.57 GeV)
			2.4×10^7 (3.67 GeV)
			3.5×10^7 (4.25 GeV)
ψ	-	-	1.7×10^{10}
ψ'	-	-	0.4×10^{10}

Table III

Topic	Measurement	Sensitivity
CKM Matrix Elements	V_{cd}/V_{cs}	$\sim 1\%$
Weak Decay Constants	f_D, f_{D_S}	2%
New Physics	Rare Decay Branching Ratios	$O(10^{-8})$
$D - \overline{D}$ Mixing	Semileptonic Decays	$r_D < 2 \times 10^{-5}$
—"—	Hadronic Decays	—"—
CP Violation	Decays into CP Eigenstates	$\sim 1\%$
Absolute Branching Ratios	D Mesons	O(1%)
—"—	D_S, Λ_c, Ξ_c, ... Mesons	O(5%)
Charmonium	Spectroscopy	$O(10^3)$ More Statistics
—"—	Electromagnetic Coupling	—"—
—"—	Gluonium Search	—"—

Table II

	Measurement	1993 Cornell (Dallas)	τcF 1993	SLAC BF 1993
General Properties	m_τ	± 0.3 MeV	± 0.1 MeV	?
	τ_τ	±1.0%	-	±0.3%
	m_{ν_τ}	<32.6 MeV CL=95%	<1 MeV CL=95%	< 5.5 MeV CL=95%
	ρ	± 3.9%	± 0.02%	$\pm\mathcal{O}(0.1)$%
	τ Polarization	± 10%	-	-
	d_τ	-	$< 1 \times 10^{-17}$ecm	?
	Universality	$\mathcal{O}(0.5)$%	0.1%	0.5%
Branching Ratios	$e\nu\nu$	± 0.8%	± 0.1%	± 0.5%
	$\mu\nu\nu$	± 0.9%	± 0.1%	± 0.5%
	$\pi\nu$	± 2.2%	± 0.1%	± 0.5%
	$K\nu$	± 10%	± 0.8%	?
	$\rho\nu$	± 1.3%	?	?
	$3\pi\nu$	± 2.4%	?	?
	$\pi 2\pi^0\nu$	± 3.6%	?	?
	$5\pi\nu$	± 16%	?	?
	$5\pi\pi^0\nu$	± 43%	?	?
Rare Decays	$\pi\pi^0\eta\nu$	$< 1.1 \times 10^{-2}$ CL=95%	$< 10^{-7}$	$< 10^{-6}$
	$e\gamma$	$< 1.7 \times 10^{-4}$ CL=90%	$< 10^{-7}$	$< 10^{-6}$
	$\mu\gamma$	$< 4.2 \times 10^{-6}$ CL=90%	$< 10^{-7}$	$< 10^{-6}$
	3μ	$< 1.7 \times 10^{-5}$ CL=90%	$< 2 \times 10^{-8}$ CL=90%	$< 5 \times 10^{-7}$ CL=90%
	$\pi\eta\nu$	$< 0.9 \times 10^{-2}$ CL=95%	$\sim 1 \times 10^{-5}$	$< 5 \times 10^{-5}$ CL=95%

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