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A Tau - Charm - Factory at Argonne

Preliminary Assessment of the Physics Case and the Argonne Site

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Executive Summary

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.

A τ - charm - factory (τcF) 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 $1 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$. Once operational, the facility will produce large samples of τ pairs, charmed 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. These measurements are likely to be of crucial importance for a complete understanding of the dynamics of both the quark and the lepton sectors of the Standard Model. While unexpected results might lead to extensions of the Standard Model, other measurements will be essential ingredients for future developments in theories such as lattice gauge theory or heavy quark effective theory.

The Advanced Photon Source (APS) at Argonne National Laboratory, a 7 GeV positron storage ring for synchrotron radiation, is scheduled to be commissioned in 1995. The APS accelerator complex consists of a 450 MeV linac, a 7 GeV booster synchrotron, and a storage ring for production of synchrotron radiation.

A τcF at Argonne would use the injector system (linac and booster) of the APS for injection of both the electrons and the positrons. The collider ring would be located either within or in proximity to the outside of the APS ring. Some modifications to the existing APS complex would be necessary to serve the τcF. The APS injector system would be adequate for the required luminosity of a τcF provided the e^+ current can be increased by a factor of four. Several options are available to do so.

The use of the APS injector system could result in significant cost savings and makes Argonne an attractive site for a τcF. The existing infrastructure at Argonne, the local expertise in construction of both electron storage rings and collider detectors, the possibility of sharing operation costs between the APS and the τcF, and Argonne's experience with user-oriented facilities are further advantages of the site.

The total cost of the facility was estimated by comparison with previous designs of τcFs, the recent proposals for the B - factories, and experience at the APS. The cost would be approximately 125 M$ including one state-of-the-art detector costing 50 M$. Construction of the facility could commence in two years and be completed around the year 2000.

Interest in the U.S. and European HEP community for a τcF is rather strong as indicated by the large participation at past τcF workshops. Discussions with several experts in the field further supported this evidence of strong interest.

In conclusion, the committee has assessed the physics case, the advantages of the

Argonne site, and the interest in the HEP community for a τcF. It recommends serious consideration of a τcF as a long term HEP project for Argonne.

I. Introduction

This document is the result of a first investigation of the physics case, the Argonne site, and the interest in the HEP community for a τcF. It is based on the work done by an ad-hoc committee that was formed in October 1993 within the Argonne HEP division. The purpose of this document is to serve as a basis for further discussions about a τcF at ANL with the laboratory management, the APS division, and the DOE.

The τcF is an e^+e^- collider running at a E_{CM} between 3.0 and 5.0 GeV and with a very high luminosity of at least 1×10^{33}cm^{-2}s^{-1}. Fig. 1 shows the R - value, the ratio of hadron events to muon pair events, as measured by DELCO[1] in this energy range. The thresholds for the production of charmonium, τ pairs, and charmed mesons are indicated by arrows. 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[2] in Table I for one year running at the design luminosity. The table shows that a τcF produces a factor of five more charmed mesons and τ pairs, and is unique in producing high rates of charmonium states.

In the past, several e^+e^- colliders ran in this energy range, the most notable being SPEAR at SLAC, DORIS at DESY, and BEPC in Bejing. They ran or run at comparatively low luminosities of a few 10^{31}cm^{-2}s^{-1} and measure the collision products with, by today's standards, low resolution detectors.

In 1989 SLAC held a first international workshop on τcFs. Shortly afterwards, a proposal emerged to build such a machine in Spain. Despite the strong interest in the HEP community, the project was cancelled by the Spanish administration in December 1992 for budgetary reasons. After its demise, a further workshop was held in Marbella, Spain in June 1993. Some 100 physicists attended and unanimously endorsed the need for a high luminosity τcF.

II. Physics Case

Depending on the beam energy setting, the τcF will be optimized to study physics with τ leptons, with charmed mesons, or with charmonium states. The following is a short overview of the physics topics. The projected sensitivities are taken from Ref. 3(4) 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. Thus, 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.

Furthermore, a detailed scan around the τ pair production threshold will yield a high precision measurement of the τ lepton mass, to approximately 100 MeV. To minimize the systematic uncertainties, backgrounds to the τ pair sample will be studied by running the collider at a center-of-mass energy below the production threshold for τ pairs.

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,[3] and the sensitivity to be achieved at a B - factory.[4]

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 due mostly to: a) the unique possibility to control the systematic errors by running above and below the production threshold, b) the absence of charmed meson backgrounds, and c) the high and background free efficiency for identification of τ pairs. In conclusion, only a τcF can reach for the τ lepton the level of high precision measurements already obtained for the lighter leptons, the electron and the muon.

B) Charmed 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[2]. 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.

1. CKM Matrix Elements–Semileptonic Decays

Semileptonic decays of heavy mesons, $M_i \to M_f \ell \nu_\ell$, provide values of the elements of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix. Examples are $D^\circ \to K^- e^+ \nu_e$ and $D^\circ \to \pi^- e^+ \nu_e$ which yield the elements V_{cs} and V_{cd}, respectively. Unitarity in the three generation Standard Model constrains V_{cs} to 0.1% and V_{cd} to 1%. However, they are presently determined experimentally only to 10% accuracy.[5] At the τcF, the semileptonic branching ratios could be measured to better than 1% accuracy,[6,7] resulting in a precise extraction of the CKM matrix elements.

2. Purely Leptonic D Decays

The branching ratio for purely leptonic decays of $D^\pm$ and $D_s^\pm$ mesons can be computed exactly in the Standard Model:

$$BR\left(D_{d,s}^+ \to \ell^+ \nu_\ell\right) = \tau_{D_{d,s}^+} \frac{G_F^2}{8\pi} f_{D_{d,s}}^2 \; M_{D_{d,s}^+} \; | V_{cd,cs} |^2 \; M_\ell^2 \left(1 - \frac{M_\ell^2}{M_{D_{d,s}^+}^2}\right)^2 .$$

Quantities f_D and f_{D_s} are the weak decay constants that measure the wave function at the origin, the overlap of c and d (respectively, c and s) quarks in the D^+ (D_s^+) mesons. These constants are used in predictions of second-order weak processes, such as mixing and CP non-invariance, and non-leptonic decays. Values of the weak decay constants can be calculated with lattice methods. Verification of these calculations with data on f_D would permit more confident extrapolations to f_B which is experimentally inaccessible but needed for predictions of $B\bar{B}$ mixing and CP non-invariance in the B system.

Estimated branching ratios (based on the assumption $f_D \simeq 200$ MeV) are $BR(D_s^+ \to \tau^+ \nu_\tau) \simeq 3\%$, $BR(D_s^+ \to \mu^+ \nu_\mu) \simeq 3 \times 10^{-3}$, and $BR(D^+ \to \mu^+ \nu_\mu) \simeq 3 \times 10^{-4}$. Fermilab experiment E-653 has accumulated 70 events of $D_s \to \mu \nu_\mu$ and

15 events of $D_s \to \tau\nu_\tau$, corresponding to a statistical uncertainty of $\pm12\%$ on f_{D_s}.[8] With one year's accumulation of data at a τcF, each of the three branching ratios listed above could be measured to about 2% accuracy.[7,9]

3. Rare Decays and New Physics

Lepton-flavor violating decays such as $D^\circ \to e^\pm\mu^\mp$ are forbidden in the Standard Model with massless neutrinos. Quark flavor-changing neutral-current decays may occur, but their rates are highly suppressed; examples are $D^\circ \to \ell^+\ell^-$, $\nu\bar{\nu}X$, and γX. Rare D decays are potentially sensitive to new interactions beyond those of the Standard Model such as technicolor, substructure, or horizontal gauge bosons. Tagging and precisely constrained mass measurements at the τcF suppress backgrounds permitting a sensitivity[7,10] to branching ratios of $O(10^{-8})$. Fermilab experiment E-653 will report limits[8] of $\simeq 2\times10^{-4}$ for decays $D^\circ \to \pi^\circ\mu^+\mu^-$, $K^\circ\mu^+\mu^-$, and $\rho^\circ\mu^+\mu^-$. Fermilab experiment E-789 is expected to set[11] 90% CL limits of 5×10^{-6} for $D \to e^+e^-$, $\mu^+\mu^-$, $e\mu$. Thus, the τcF promises an improvement of some three orders of magnitude.

4. Mixing, $D^\circ \leftrightarrow \bar{D}^\circ$

Meson mixing has been observed in the $K^\circ - \bar{K}^\circ$ and $B^\circ - \bar{B}^\circ$ systems where the second order flavor transition is associated with a quark of charge $-1/3$, the s and b quarks. The rate for $D^\circ - \bar{D}^\circ$ oscillations is expected to be quite small in the Standard Model, but the reliability of this prediction is subject to significant uncertainties. The usual mixing parameter, integrated over time, is

$$r_D \equiv \frac{BR\left(D^\circ \to \bar{D}^\circ \to \bar{f}\right)}{BR(D^\circ \to f)}.$$

The simplest quark box diagram calculation leads to the expectation[12] $r_D \simeq 10^{-7}$, but long distance effects[13] associated with $K\bar{K}$ and $\pi\ \pi$ intermediate states could boost this to $r_D \simeq 10^{-3}$. Recent applications of heavy quark effective theory (HQET) contradict the expected long distance enhancement[14]. The suppression of r_D is specific to the structure of the Standard Model. Various extensions (supersymmetry, E6 models, $\cdots$) enhance

r_D. Thus, measurements of r_D would probe the reliability of standard calculations as well as open windows on non-standard flavor changing processes. Signatures of mixing are like-sign dileptons from dual semileptonic decays $\left(D^\circ \bar{D}^\circ \to \ell^\pm \ell^\pm X\right)$ or dual identical hadronic decays such as $D^\circ \bar{D}^\circ \to (K^\pm \pi^\mp)(K^\pm \pi^\mp)$. Doubly-Cabibbo-suppressed decays may also lead to dual identical hadronic decays, but these can be separated at a τcF through studies of the correlations[15] in $D^\circ \bar{D}^\circ$, $D^\circ \bar{D}^\circ \gamma$, and $D^\circ \bar{D}^\circ \pi^\circ$. In $D^{*+} \to D^\circ \pi^+$, the charge of the π tags the flavor of the parent D $\left(\text{vs.}\bar{\text{D}}\right)$, a self-tagging feature exploited by Fermilab experiment E-691 and the Cornell CLEO collaboration. Currently the CLEO collaboration has observed a wrong-sign signal based on a sample of $1.8 fb^{-1}$; by 1998, their expected integrated luminosity of $20 fb^{-1}$ should permit a limit of $r_D \lesssim 2 \times 10^{-3}$. Fermilab experiment E-691 has published[16] a limit $r_D < 3.7 \times 10^{-3}$ at 90% CL. Its successor,[17] E-791, should reach $r_D \lesssim 10^{-3}$ to 1.5×10^{-3}, whereas E-831/P-829 could attain $r_D \lesssim 5 \times 10^{-4}$ to 8×10^{-4}. At a τcF, mixing at the rate $r_D \simeq 2 \times 10^{-5}$ could be observed with one year's accumulated data.[7,18] This sensitivity could bring the limit down to the level expected in the Standard Model.

5. CP Non-Invariance

In the three generation Standard Model, CP non-invariance arises from the single complex phase of the three-by-three CKM mixing matrix. Present observations are limited to the K meson system. These are in accord with expectations, but the interpretation of CP non-invariance is far from unambiguously established. The phenomenon could be a signal for physics beyond the Standard Model. As in the case of mixing, the Standard Model generates very small CP violating asymmetries in the D system,[15] generally expected to be smaller than the $\Delta S = 2$ $(\epsilon_K \simeq 10^{-3})$ asymmetry of the K system but larger than the direct CP violating asymmetry in the $\Delta S = 1$ transition $(\epsilon'_K \simeq 10^{-6})$. Predictions depend on an understanding of final-state strong-interaction phases.[15] Physics beyond the Standard Model, such as an extended Higgs sector or non-minimal supergravity, could lead to asymmetries at the 1% level. A rate difference between $D^\circ \bar{D}^\circ (\ell^+ X) f$ and $\bar{D}^\circ D (\ell^- X) f$, with f a CP eigenstate such as K^+K^-, would provide an unambiguous signal of CP non-invariance, either direct or involving $D\bar{D}$ mixing. A CP violating asymmetry of about 1% could be measured[18] in an accumulation of one year of data on $D\bar{D}^o\gamma$.

CP violating asymmetries should be present also in charged $D^{\pm}$ decays. Further detailed studies are warranted to establish whether some of these decays are more promising alternatives. Although our initial survey suggests that observation of CP non-invariance in the D system is a long-shot, it remains an alluring possibility. A τcF might allow exploration of the dynamics of CP non-invariance in a system that is distinct from, yet complementary to, the K and B systems (charge 2/3 vs. charge $-1/3$ quark).

6. Charmonium

The charmonium system itself provides valuable insight into bound state dynamics in QCD and decays of charmonium states into light mesons are an important source of information on hadron spectroscopy.[2] In one year of operation at 3.10 GeV, a τcF would produce $\sim 2\times10^{10}$ J/ψ's, three orders of magnitude greater than the current data sample. The radiative decay $J/\psi \rightarrow \gamma\eta_c$ would yield 2×10^8 η_c's. Operated at 3.69 GeV, the τcF would provide 4×10^9 ψ''s per year, resulting in secondary production of 3×10^8 of each type of χ_c ($J = 0,1,2$) through the radiative decay $\psi' \rightarrow \gamma\chi_c$. We anticipate that the τcF would complete the study of charmonium spectroscopy through confirmation of the existence and properties of the $^1P_1$ (3526) and η_c' (3590) states, as well as discovery of the missing $^3D_2$ and $^1D_2$ states. Excited ψ^* states above $D\bar{D}$ threshold are poorly determined. At a τcF, their decays into D, D^*, and D^{**} states would yield important tests of heavy quark effective theory (HQET).

The existence of glueballs and hybrid mesons is suggested by QCD, but these states have proved elusive owing to the absence of clear-cut signatures to distinguish them from the $q\bar{q}$ states of the non-relativistic quark model. With its high statistics and low background, a τcF would provide the best opportunity to identify and determine the quantum numbers of states that do not fit in $q\bar{q}$ nonets. A systematic high statistics search for gluonia and hybrids could be made in the gluon-rich environment of J/ψ and η_c decays at a τcF. Examples are $J/\psi \rightarrow \gamma gg$; $J/\psi \rightarrow ggg$; and $\eta_c \rightarrow gg$.

III. The APS and the τcF

The main emphasis of this preliminary study was to determine whether the match between the capabilities of the APS injector and the requirements of a τcF was sufficiently close as to warrant further consideration. The APS is scheduled for commissioning in 1995, with the injector complex operational in mid 1994. Table III gives the parameters for the APS injector.

The recent Spanish τcF design[19] is considered in the following as point of reference. The τcF is an e^+e^- collider capable of operating at c.m. energies in the 3-5 GeV range. The high peak luminosity of $10^{33}\text{cm}^{-2}\text{s}^{-1}$ is obtained by using separate e^+ and e^- rings with multiple bunches circulating in each ring. The luminosity lifetime is 2 hours. The Spanish facility is shown schematically in Fig. 2, and a parameter list is given in Table IV.

The following (mutually interdependent) technical issues were identified as the most important in adapting the APS injector to accommodate a τcF:

- e^- injection
- e^+e^- extraction to τcF
- siting
- intensity/rep rate
- effects on APS operation

There are a number of possible approaches to the first three of these points. The scenario with the smallest impact on the APS in terms of modifications to the existing lattice involves running the injector in bipolar mode, i.e. using existing injection and extraction beam and reversing the polarity of magnets and kickers. An e^- transfer line would be added to bypass the Positron Accumulator Ring. The transfer line from the injector synchrotron to the τcF could then be routed through the APS storage ring building, making use of the existing shielding and services. The τcF itself would then be sited on the APS infield (Fig. 3). It may also be useful to consider a new extraction system for more convenient τcF siting in the bipolar option.

This approach requires new or upgraded magnet power supplies and modifications to the injection/extraction kicker supplies to provide polarity reversal capability. There are some concerns about the potential impact of this scheme on the reproducibility of APS injector operations. It is also possible that the polarity switch over time might be undesirably long when the APS is operated in "topping off" mode (see below). Nevertheless, the overall simplicity of this approach makes it worth keeping under consideration.

Monopolar mode, where magnet polarity is not changed and the electrons are injected and extracted in the opposite direction from positrons, would require considerable modifications to the APS injector. This scheme requires new injection and extraction systems (with modifications to the injector lattice), and a more substantial investment in a new e^- beam. Siting of the τcF for this scheme may be either inside or outside the APS synchrotron ring (Fig. 3).

In terms of machine intensity, the designed e^+ yield/pulse is smaller by a factor of $\simeq 4$ from the Spanish τcF injector, limited by the present APS e^+ source. A number of options are available for circumventing this limitation, e.g. an upgraded e^+ source, stacking several bunches from the injector, more bunches in the τcF, etc. The current delivered by the APS injector is still very high, such that a τcF fill could be performed in as little as 2 minutes.

Civil construction required for a τcF in the APS infield would probably disturb alignments of both the booster and the APS storage ring, making τcF construction outside the APS ring preferable. If new injection and extraction sections are installed in the injector synchrotron, construction and commissioning will lead to some down time, but should not affect the performance of the APS.

The estimated APS beam lifetime is $\simeq 10$ hours, and initially the ring will be filled at this interval. The injector will be free during the period between fills for τcF use. In the long term, the APS plans to operate in a "topping off mode" that will require continuous use of the injector by the APS. Given the long APS beam lifetime it does not appear that a few minutes interruption of the topping off operation every 2 hours for a τcF fill would be a major problem for APS users.

It is not entirely straightforward to use the APS injector to serve the τcF. Impact on APS operations will be a major concern. Nevertheless, based on the general requirements for the Spanish τcF injector, it appears that there are no major technical obstacles to proceeding with a detailed ANL τcF design.

IV. Detector

Excellent detector performance is required along with the high machine luminosity to achieve the physics goals of a τcF. This sensitivity can be accomplished using a large data sample with low backgrounds and small systematic biases. An initial detector design,[20] shown in Fig. 4, combines the good momentum resolution and charged-particle identification from a solenoidal magnetic detector with the excellent energy resolution of crystal calorimetry. This design is based on conventional and well-understood detector technology.

The physics goals of a τcF set strict requirements on the detector design, as given in Table V. Since the τ leptons and charmed mesons are produced close to threshold, a vertex detector is not used and a simple beam pipe design can be made. The detector, however, must accommodate quadrupole magnets needed for tight beam focussing near the interaction region. Precise momentum measurements within a solid angle of over 90% of 4π with a minimum of multiple scattering is required for the ν_τ mass sensitivity and many other measurements. Time-of-flight scintillation counters located between the tracking detector and the calorimeter together with dE/dx measurements by the tracker will allow a separation of π's and K's over the entire momentum range. Clean studies of the leptonic and semi-leptonic D decays, among others, impose the following constraints on the electromagnetic calorimeter: precise measurements of the e and γ energies, high detection efficiency, fine granularity, good e-hadron separation, low energy detection thresholds, and hermeticity. Finally, a hadron calorimeter will serve as muon tracker and improve the detection efficiency for neutrons and K_L^0's. Precise measurements of all particles is crucial for determining the missing energy attributable to neutrinos.

The HEP division at ANL has considerable expertise with large detector systems, for example, HRS at PEP, CDF at Fermilab, ZEUS at DESY, and the Soudan detector. In particular, the division has extensive experience in calorimetry, the most recent examples being the design and construction of the ZEUS barrel calorimeter and the design of the calorimeters for SDC at SSCL and the STAR detector at RHIC. Additional experience includes the construction of wire chambers and the acquisition and analysis of large data sets.

V. Cost and Schedule

We have roughly estimated the cost of a τcF by using the lattice of the Spanish design in comparison with the designs of CESR-B and PEP-II, and by using the experience gained with the construction of the APS. The circumference of the τcF and the APS injector synchrotron are similar. However, with two rings, the τcF requires significantly more magnets and a better vacuum system. Likewise, the τcF is similar to, but smaller in size and runs at lower beam energy than, the B - factories. Costs can be scaled according to the number of magnets, the length and the quality of the vacuum system, and the amount of RF power required. The costs of transfer lines have been evaluated for several different concepts and ring locations. Since the cost for beam lines in a tunnel 10 - 15 ft underground is only 5 k$/m, long transfer lines to a fairly remote location could be considered. Some modifications to the APS injector are required to accelerate electrons, as discussed in Section III.

The construction schedule can be estimated based on the APS experience. Assuming that construction of components and buildings could begin a year from approval, the installation of components could begin about two years from approval, followed by testing and commissioning. A realistic schedule would be ultimately determined by the funding profile.

The total cost for the facility including a 50M$ detector is about 125 M$. The facility could be operational about four and a half years after approval.

The use of the existing APS injector saves the cost of a separate τcF injection system, estimated[21] as 33M$, which is approximately equal to the cost of the APS injection system. In addition, it would be highly desirable to utilize the design and construction experience of the APS accelerator scientists and engineers, who may become available in a few years following the commissioning of the APS.

VI. Conclusions and Recommendations of the Committee

After evaluating the scientific and technical matters that are described above, the committee 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. APS site: The construction and operation of a τcF collider at ANL using injected electron and positron beams from the injector of the Advanced Photon Source (APS) is likely to offer important site-specific advantages in terms of reduced construction and operating costs, as well as the availability of some major "infrastructure" elements. The latter include electron accelerator expertise, proven capability in collider detector design and construction, and an excellent laboratory tradition in the operation of large user-oriented research facilities for the entire outside scientific community.

3. Interest in the HEP community: The high level of potential user interest evidenced at the τcF workshops at SLAC in 1989 and at Marbella, Spain in 1993 appears to continue. There is no doubt that a τcF constructed on a prompt schedule would be fully subscribed and effectively used by the US and international HEP communities. The detector design and construction would involve the outside HEP community from the beginning of the τcF project.

4. 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.

The above conclusions led our committee to make the following action recommendation: that Argonne give further serious consideration to a τcF as a long term HEP project.

VII. Future Actions

As stated at the beginning, this report is mainly directed toward the Argonne leadership and staff, in order that a definitive decision can be made on whether Argonne should proceed with a more detailed study of a τcF machine. Such a decision is required to enable further progress on the design of a τcF at Argonne. An affirmative decision to proceed would then require (at least) the following activities:

1. Identifying a leader and a working group for a detailed τcF study.
2. Forming an accelerator design task force which includes APS accelerator scientists, in order to determine decisively the overall technical feasibility and practical implications of using the APS as an injector for the τcF.
3. As the above studies are completed, holding a major workshop to further define and update the τcF physics case and to assess again the depth of the HEP user community interest and support.
4. Keeping the HEP community and the DOE informed of progress on these studies.

When the above activities and studies are complete, a decision to prepare a τcF construction proposal for submission to the DOE will be necessary. A reasonable target date for such a decision would be early 1995.

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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} ($\mathcal{L} = 2 \times 10^{32} cm^{-2} s^{-1}$) for the Z factory and 10 fb^{-1} ($\mathcal{L} = 1 \times 10^{33} cm^{-2} s^{-1}$) 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 Parameters of the injector for the APS.

IV List of parameters of the Spanish τcF.

V Detector requirements for specific measurements in the τ and charm sector from Ref. 14.

Figure Captions

1. The hadronic cross section ratio, R, in the τ-charm threshold region. The ratio $R = \sigma(e^+e^- \to \text{'hadrons'})/\sigma(e^+e^- \to \mu^+\mu^-)$, where 'hadrons' include both $q\bar{q}$ and $\tau^+\tau^-$ events.
2. Schematic of the Spanish τcF.
3. Planview of the APS complex. The insert shows the Spanish τcF to the same scale.
4. The basic configuration of a τcF detector from Ref. 14.

Comparison of Particle Production Rates

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 I

Comparison of Measurements and Sensitivities in τ Physics

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

Table II

Parameter	Value
Circumference (m)	366.923
Revolution Time (μs)	1.224
Injection Energy (GeV)	0.45
Nominal Energy (GeV)	7.0
Maximum Energy (GeV)	7.7
Repetition Time (s)	0.5
Acceleration Time (s)	0.25
No. of Super Periods	2
No. of Cells	40
No. of Bending Magnets	68
Magnetic Field at: Injection (T)	0.0447
Extraction (T)	0.6960
Tunes, υ_x/υ_y	11.713/9.760
Transition Gamma	10.112
Betatron Damping Time at 7 GeV (ms)	2.7
Natural Emittance at 7 GeV (m)	1.321×10^{-7}
Energy Loss Per Turn at 7 GeV (MeV/turn)	6.33
Synchrotron Damping Time at 7 GeV (ms)	1.35
Bunch Length, σ_τ, at 7 GeV (ps)	61
Energy Spread, σ_E/E, at 7 GeV	1×10^{-3}
Average Beam Current (mA)	4.8
Energy Gain per Turn (keV)	32.0
RF Parameters	
Frequency, f (MHz)	352.962
Harmonic Number, h	432
Voltage, V, at 7 GeV (MV)	8.3
Synchrotron Frequency, f_s, at 7 GeV (kHz)	21.3

Table III

Energy	E	2.5	GeV
Circumference	C	376.99	m
Bending radius	ρ	12	m
β-function at IP	β_x^*	0.2	m
	β_y^*	0.01	m
Betatron coupling	κ^2	0.045	
Betatron tunes	Q_x	$\simeq 10.8$	
	Q_y	$\simeq 9.4$	
Momentum compaction	α	0.0189	
Natural emittance	ϵ_x	281	nm
Energy spread	σ_ϵ	5.66×10^{-4}	
Energy loss per turn	U_0	0.288	MeV
Damping times	τ_x	35	msec
	τ_y	22	msec
	τ_ϵ	9	msec
RF frequency	f_{RF}	1.489	GHz
RF voltage	V_{RF}	5	MV
Radiation power	P_{rad}	0.309	MW (2 beams)
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	6.1	mm
Total beam current	I	537	mA
Particles per bunch	N_b	1.75×10^{11}	
Beam sizes at IP	σ_x^*	232	μm
	σ_y^*	$\simeq 10$	μm
Beam-beam parameter	ξ_y	0.04	
Luminosity	L	1.2×10^{33}	$cm^{-2}sec^{-1}$

Table IV

Experiment	Detector emphasis				
	Charged particles	Photons	$\pi K p$ i.d.	$e\mu$ i.d.	Hermeticity
τ physics:					
ν_τ, τ masses	•	•	•	•	•
$\tau \to l\nu_l\nu_\tau$ spectra		•		•	•
Precise branching ratios		•	•	•	•
Second class currents		•		•	•
Weak hadronic current	•	•	•	•	•
τ electric dipole moment		•	•	•	•
Rare decays	•	•	•	•	•
D, D_s physics:					
V_{cs}, V_{cd} (semileptonic decays)		•	•	•	•
f_D (pure leptonic decays)		•		•	•
Hadronic decays (CA, CS, DCS)	•	•	•		
$D^o\bar{D}^o$ mixing, CP violation	•		•	•	•
Rare decays	•			•	•
$J/\psi(3.10)$, $\psi'(3.69)$ physics:					
Spectroscopy ($c\bar{c}$, gg, hybrid, uds)	•	•	•		
Rare decays		•	•	•	•

Table V

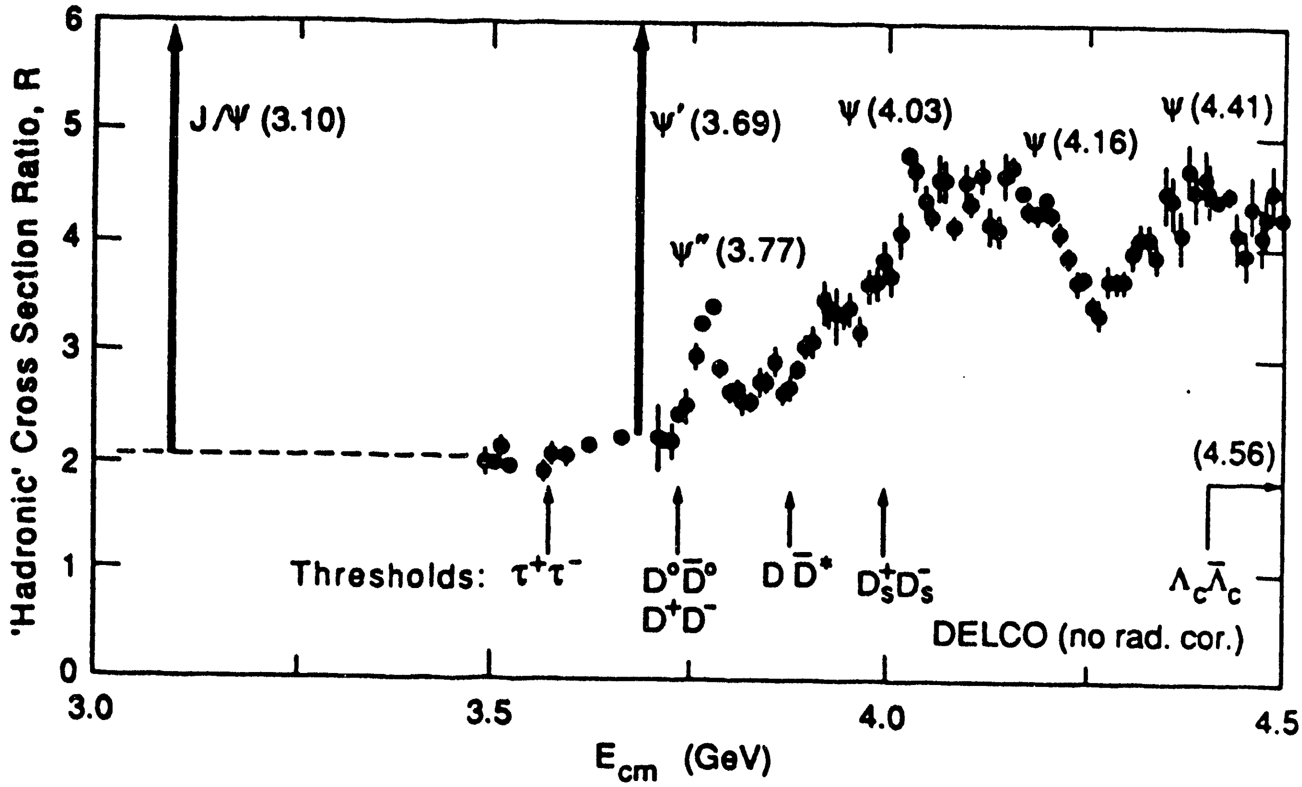
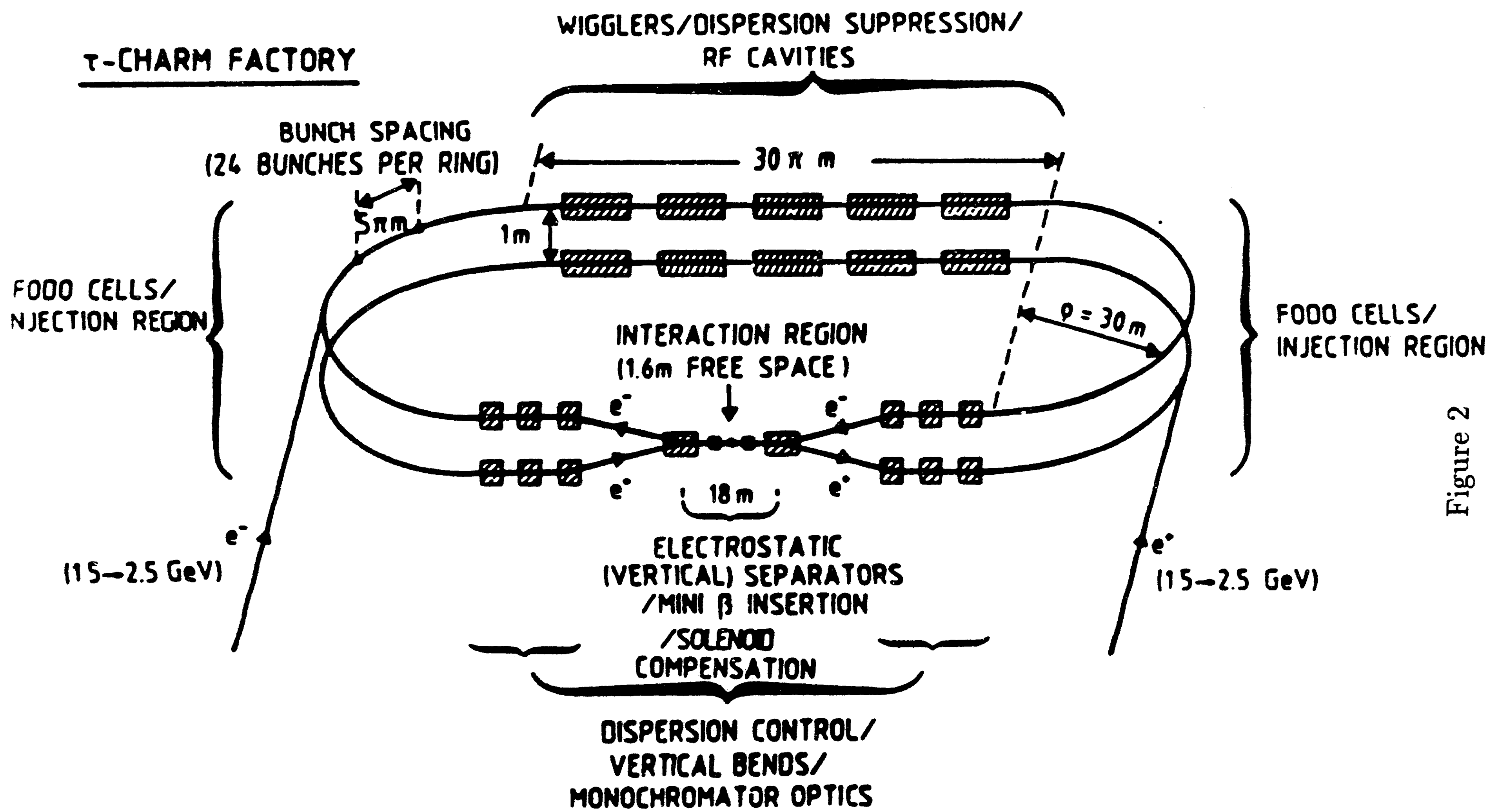

'Hadronic' Cross Section Ratio, R
J/Ψ (3.10)
Ψ′ (3.69)
Ψ″ (3.77)
Ψ (4.03)
Ψ (4.16)
Ψ (4.41)
(4.56)
Thresholds: τ⁺τ⁻
D°D̄°
D⁺D⁻
D D̄*
D⁺ₛD⁻ₛ
Λ_c Λ̄_c
DELCO (no rad. cor.)
E_cm (GeV)
3.0
3.5
4.0
4.5
0
1
2
3
4
5
6

Figure 1



τ-CHARM FACTORY
WIGGLERS/DISPERSION SUPPRESSION/
RF CAVITIES
BUNCH SPACING
(24 BUNCHES PER RING)
5πm
30 π m
1m
FODO CELLS/
INJECTION REGION
ρ = 30 m
FODO CELLS/
INJECTION REGION
INTERACTION REGION
(1.6m FREE SPACE)
e⁻
e⁻
e⁺
e⁺
18 m
e⁻
(1.5→2.5 GeV)
e⁺
(1.5→2.5 GeV)
ELECTROSTATIC
(VERTICAL) SEPARATORS
/MINI β INSERTION
/SOLENOID
COMPENSATION
DISPERSION CONTROL/
VERTICAL BENDS/
MONOCHROMATOR OPTICS

Figure 2

PLAN VIEW OF THE ADVANCED PHOTON SOURCE

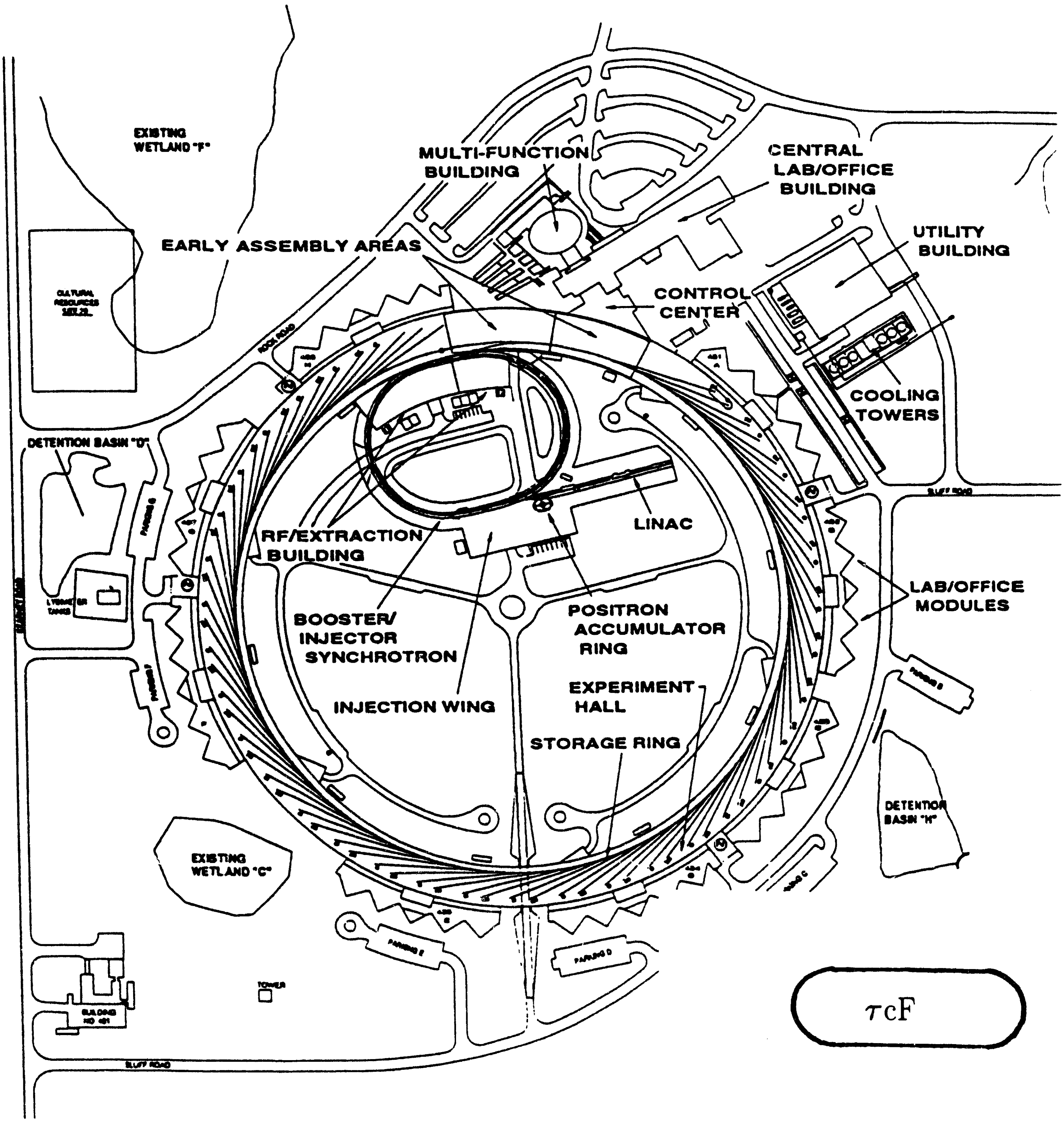


Figure 3

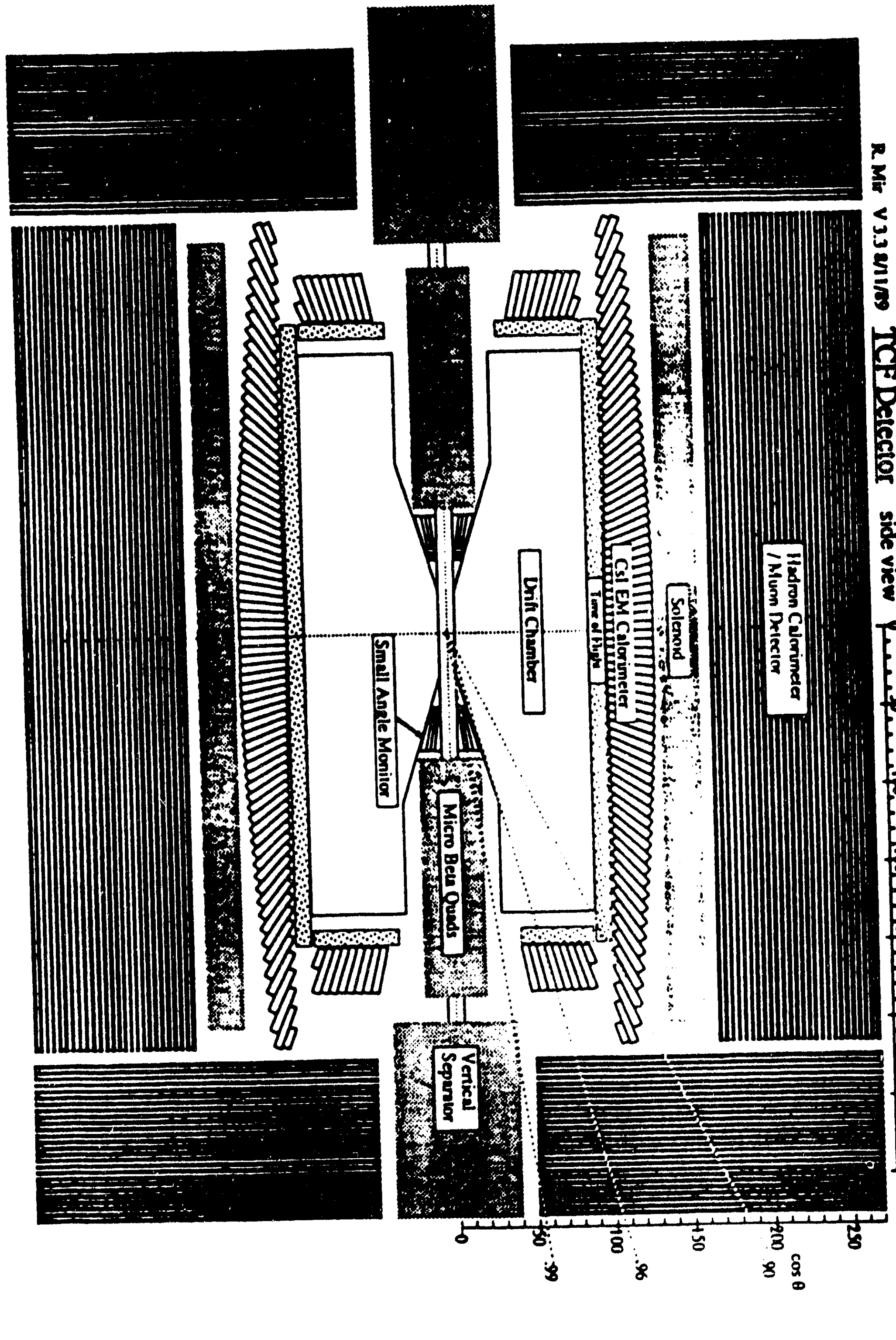

TCF Detector side view
Hadron Calorimeter / Muon Detector
Solenoid
CsI EM Calorimeter
Time of Flight
Drift Chamber
Small Angle Monitor
Micro Beta Quads
Vertical Separator
cos θ
cm

Figure 4

END

DATE
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3/24/94