A Tau-Charm Factory in the United States*

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As the conclusions of the many presentations made at the Tau- Charm Workshop illustrate, a strong case can be made for the physics program that can be accomplished at a Tau-Charm Facility. This idea is now being taken one step further. A group of physicists and engineers have started a serious effort to design a Tau-Charm Facility for the United States. Our first choice would be to place the Facility at SLAC, but, since it would be built with its own injector and positron source, it could be built at any number of other suitable locations in the U.S. The people who worked hard on the concept (both from the accelerator physics and particle physics points-of-view) and the initial design leading up to the Workshop are given in the first reference.[1]

The Tau-Charm Facility will be a two ring, multi-bunch, electron- positron collider with one interaction point, operating at a peak luminosity of 10^{33} cm^{-2} sec^{-1}. It is anticipated that within a few months after completion of construction, the collider will reach a peak luminosity of 10^{32} cm^{-2} sec^{-1} † and that within the subsequent two years enough experience will be gained to allow the Facility to reach its design luminosity of 10^{33} cm^{-2} sec^{-1}. Two decisions concerning the energy limits of the collider have been made, based on the physics discussions at the Workshop. A center-of-mass energy of 4.0 GeV will be the energy at which the collider will be designed to give the peak luminosity of 10^{33} cm^{-2} sec^{-1}. However, the components of the rings and the injector will be sized to go to higher center-of-mass energies. As the center-of-mass energy, E, increases above 4.0 GeV, the attainable peak luminosity will decrease at least as E^{-3}. The collider will be designed to operate up to 4.4 GeV with somewhat reduced luminosity, and the attempt will be made to carry this energy (with even less luminosity) up to the charmed baryon threshold of 5.2 GeV. Figure 1 shows the data

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† As was emphasized by a number of the physics talks given at this Workshop, experiments that take data at the "turn-on" luminosity of 10^{32} cm^{-2} sec^{-1} already will be able to make new contributions to J/ψ, τ, and D/D_s physics.

taken with DELCO in 1978 during a twelve week run at SPEAR.[2] The structures above 4 GeV have not been investigated at any real statistical level, so that any data taken, even with reduced luminosity, would be of great interest.

In contrast, the new electron-positron collider now being commissioned in Beijing, has a design luminosity of 5×10^{30} cm^{-2} sec^{-1} at a center-of-mass energy of 3.0 GeV. At the time of the Workshop, the collider had reached a luminosity of 2.2×10^{30} cm^{-2} sec^{-1}. At SPEAR, the best average luminosity obtained during normal data-taking conditions was 3×10^{30} cm^{-2} sec^{-1} at a center-of-mass energy of 3.77 GeV. The Tau-Charm Facility will make a very significant increase in the available luminosity for experiments in the tau-charm energy region!

The physics program for which the Tau-Charm Facility will be built will be very rich, both in breadth and depth. It is essential, if this physics potential is to be realized, that the collider be designed so that the average luminosity is maximized. It must be possible to make rapid refills of the two circulating beams at relatively frequent intervals. Thus the Facility will be built with a dedicated injector for both electrons and positrons, with a maximum energy equal to half the maximum center-of-mass energy at which the collider will operate. The decision has been made, based on accelerator physics discussions at the Workshop, that the injector should be a SLAC-type linac and should incorporate a low energy (about 500 MeV) accumulator ring to enhance the injected positron current.

In the initial concept of the collider first proposed by Jowett[3] the beams from the two rings collide head-on, that is, at a zero degree crossing angle. However, an alternate proposal developed at the Workshop by Voss *et al.*,[4] which is based on the "crab-crossing" ideas of Palmer and Oide and Yokoya,[5] would have the beams cross at a small, but finite, horizontal crossing angle. A proposal, first made by Bob Siemann last year at Snowmass[6] and presented at the Workshop, that collisions between round beams rather than the normal flat beams could enhance the luminosity needs further study. More accelerator physics work needs to be done on the Jowett and Voss concepts before the final ring design can be chosen. However, since the two concepts have many elements in common, preliminary design layouts may be started for scoping and estimating purposes. The decision has been made that the collider will be designed with one interaction region that will accommodate a high-quality detector, but with a detector hall that will have a "push-pull" capability and, as a result, allow space for the future construction of a second detector.

How can the high luminosity be achieved? The luminosity of a circular collider with beam energy, E_0, can be expressed in a number of ways, one of which is given here:

$$L \;\alpha\; \frac{\epsilon_x \; \xi_y^2 \; E_0^2}{\beta_y^* \; S_{bunch}}$$

Thus, a high luminosity collider will require:

a large horizontal emittance, ϵ_x;
a large beam-beam tune shift, ξ_y;
many bunches which therefore give a small bunch spacing, S_{bunch};
a small beta function at the interaction point, β_y^*.

The many bunch requirement is most easily met by providing a two ring machine. However, the collider design then has to deal with the problems that arise when beams circulating in two separate rings are brought into collision in a common straight section. The beta function β_y^* can be reduced by moving the interaction quadrupoles on each side of the detector closer to the interaction point. However, the closer the quadrupoles are to the interaction point, the more they interact with the detector design. A small β_y^* has two other ramifications as well. The bunch length of each beam must be kept short (e.g. shorter than β_y^*), and the collider must be designed with a high-frequency RF system.

A pictorial layout of the initial Jowett collider design, but without the electron-positron injector system, is shown in Fig. 2. A site of about 100 by 200 meters will be required for the collider itself. Figures 3 and 4 show simplified drawings of the interaction region for both the Jowett and Voss designs. In the Jowett design, the length of the common straight section in the interaction region (about 15 meters) determines the bunch spacing. Thus the bunches will cross about every 50 nanoseconds. In the Voss design, in principle every available bunch can be filled; if the RF system is designed for 353 MHz, then bunches could collide as often as every three nanoseconds!

Preliminary parameters lists for both the Jowett and Voss designs are shown in Tables 1 and 2.[4,7] Note that the Voss design is more conservative than the Jowett design in the choice of the design value for β_y^* (and thus in the choice for the RF frequency and the r.m.s. value for the bunch length), but the price paid for this conservatism is the number of bunches and the value of the total circulating beam current!

What can be said about the Physics and Detector simulation? Experience from the MARK III experiment at the SLAC Storage Ring SPEAR will be of great benefit! Rates from the MARK III detector can be scaled easily to the Tau-Charm Facility environment. The MARK III limits with particle identification are already understood, and a number of ways are known by which these limits can be improved. Finally, a revised MARKIII Monte Carlo system is now working in the Tau-Charm Facility environment. Calculations have been made, and are continuing to be made to predict the expected signals and backgrounds for a number of the initial experiments, based on a first-order extrapolation to a Tau-Charm Facility detector. The Monte Carlo system then will be used to simulate various detector concepts so that the final detector design will be optimized as much as possible to the requirements of the physics experiments. The important point to be made here is that because of the MARK III experience, these extrapolations to the Tau-Charm Facility environment are relatively risk-free!

The detector is discussed in much more detail in the summary paper by Kirkby[8] and in the individual papers submitted by members of the detector group. The important parameters of the detector are highlighted here. The detector will be built around a solenoidal magnet that gives an axial magnetic field somewhere between 0.8 and 1.2 Tesla at the interaction point. Proceeding outward radially from the beam pipe, the first detector element will be a drift chamber for charged particle tracking that will give a momentum resolution for a particle of momentum, p, and velocity, β, of

$$(\delta p/p)^2 \approx (0.4\% \times p\ (\mathrm{GeV/c}))^2 + (0.3\%/\beta)^2$$

The chamber will be designed to be built with a minimum amount of material so that multiple scattering is minimized. This will be especially important for the data that will be taken to measure the tau neutrino mass.

The detector needs a very good particle identification system for separating charged pions, charged kaons, protons, electrons, and muons using (a) time-of-flight, (b) dE/dx,

(c) an electromagnetic calorimeter, and (d) a muon tracking system. The time-of-flight system and the electromagnetic calorimeter both will be located inside the solenoid. Simulation studies of a number of reactions presented at the Workshop show that significant improvements in detection efficiency and resolution will be obtained if the electromagnetic calorimeter is made from Thallium-doped Cesium Iodide crystals. Measurements with the drift chamber will give the dE/dx information. The muon tracker, which will also incorporate a hadron calorimeter with a thickness of about five interaction lengths, will be used for positive identification of muons by tracking and range, and for detection (in the sense where the detected signal is used as a veto) of neutrons and K_L^0. The entire detector must be designed to cover as much as possible of the complete 4π steradian solid angle in order to maximize the detection efficiencies of charged particles and to minimize the losses of neutral particles. A preliminary sketch of a tau-charm detector is shown in Fig. 5.

We have started the necessary engineering work at SLAC that we expect will lead to a Conceptual Design Report for the project. We have finished a preliminary site investigation complete with civil engineering studies and have identified two of 15 possible sites as meeting our site criteria. For the moment we will continue to work with the two sites to help insure that we have not overlooked something important in preparing our site criteria. Using Jowett's first-order design, we have calculated the preliminary beam-stay-clear dimensions for the vacuum chambers and have specified the preliminary dimensions for the ring bending magnets and quadrupoles. Although the final ring layout most certainly will change, what we have now is adequate for scoping and estimating purposes.

We intend that the Tau-Charm Facility be used not only for particle physics experiments, but also be used to help advance the science of Accelerator Physics. Accordingly, we hope to design the collider with relatively long, flexible, straight sections, with flexible magnet controls (Cornell has already shown the efficacy of this approach), and with space for beam instrumentation and beam manipulation devices. A partial listing of topics that could be investigated in accelerator physics experiments at the Tau-Charm Facility include:

high-current and multi-bunch physics,
bunch-bunch interaction physics,
non-linear physics,
and simulation tests.

We envisage that these experiments would be approved and scheduled through the same program advisory committee that would approve and schedule the high-energy physics experiments on the Tau-Charm Facility. To this end, the program advisory committee should contain several accelerator physicists. The accelerator physics experience gained with the Tau-Charm Facility may very well point the direction to better storage rings and colliders at even higher luminosities.

The Tau-Charm Facility must be designed carefully and conservatively, and constructed with great care and supervision if we are to be able to run the Facility reliably at high luminosity day-after-day. Not only will we need close coordination between the various groups working on the different parts of the collider, but we will also need close cooperation and coordination between the machine designers and the detector designers, many of whom will be working from university positions external to SLAC. If this can be done, then we believe that the Facility should be operating for physics at a luminosity of 10^{32} cm^{-2} sec^{-1} within six months after completion of construction. We expect that we will gain enough operating experience during the following two years to bring the Facility to consistent and reliable operation at a luminosity of 10^{33} cm^{-2} sec^{-1}. Our calendar year would give eight months for particle physics experiments, two months for accelerator physics experiments, one month for scheduled down time, and one month for emergency down time. Maintenance days would be scheduled as needed.

In conclusion, the Tau-Charm Workshop has provided the basis for a Conceptual Design Report for a Tau-Charm Facility, by:

(a) the examination of the physics potential,

(b) studies of storage ring and injector designs,

(c) studies of detector designs based on the physics requirements.

It is our aim to have the Conceptual Design Report completed by the end of 1989, and to submit it to the Department of Energy in January of 1990. To that end, the following U.S. Institutions are currently collaborating on the Conceptual Design Report:

Stanford Linear Accelerator Center

Experimental Groups D and E

Accelerator Theory and Special Projects Group

California Institute of Technology

The University of California at Santa Cruz

The University of Cincinnati

The University of Illinois

The University of Oregon

The University of Washington

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   J. M. Jowett, CERN;
   J. Kirkby, CERN;
   M. L. Perl, SLAC;
   R. H. Schindler, SLAC;
   A. Seiden, U.C. Santa Cruz;
   W. H. Toki, SLAC.

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7. G. A. Voss, J. M. Paterson, and S. A. Kheifets, "Crab-Crossing in a Tau-Charm Facility", Tau-Charm Factory Workshop, SLAC, May 23–27, 1989.

8. Jasper Kirkby, "Detector Group Summary", Tau-Charm Factory Workshop, SLAC, May 23–27, 1989.

Table 1. Preliminary parameter list for the Jowett design of a Tau-Charm Facility.

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
	$\tau\epsilon$	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	1.7×10^{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 2. Preliminary parameter list for the crab-crossing Tau-Charm Facility design of Voss et al.

N	Parameter	Value	Unit
1	Maximum energy	2.2	GeV
2	Maximum current at 2.2 (1.5) GeV	$2 \cdot 6.5$ $(2 \cdot 4.4)$	A
3	Luminosity at 2.2 (1.5) GeV	$4.6 \cdot 10^{33}$ $(2.1 \cdot 10^{33})$	cm $^{-2}$ s^{-1}
4	Circumference	377.4	m
5	Horizontal emittance	$2.5 \cdot 10^{-5}$	cm
6	Horizontal beta function at the IP	100	cm
7	Vertical beta function at the IP	3	cm
8	Coupling factor k	3	%
9	Beam size at the IP $(w \cdot h \cdot l)$	$0.05 \cdot 0.0015 \cdot 2.1$	cm^3
10	Horizontal crossing angle	± 6	mrad
11	Linear tune shift $\Delta Q_x = \Delta Q_y$	0.04	
12	Energy loss at 2.2 (1.5) GeV	174 (38)	keV/turn
13	Synchrotron radiation power at 2.2 (1.5) GeV	$2 \cdot 1100$ $(2 \cdot 162)$	kW
14	Accelerating frequency	353	MHz
15	Accelerating voltage	2	MV/turn
16	Harmonic number	444	
17	Momentum compaction factor	0.026	
18	Natural energy spread at 2.2 GeV	$5.4 \cdot 10^{-4}$	
19	Bunch length at 2.2 GeV	2.1	cm
20	Maximum crab cavity voltage	0.71	MV

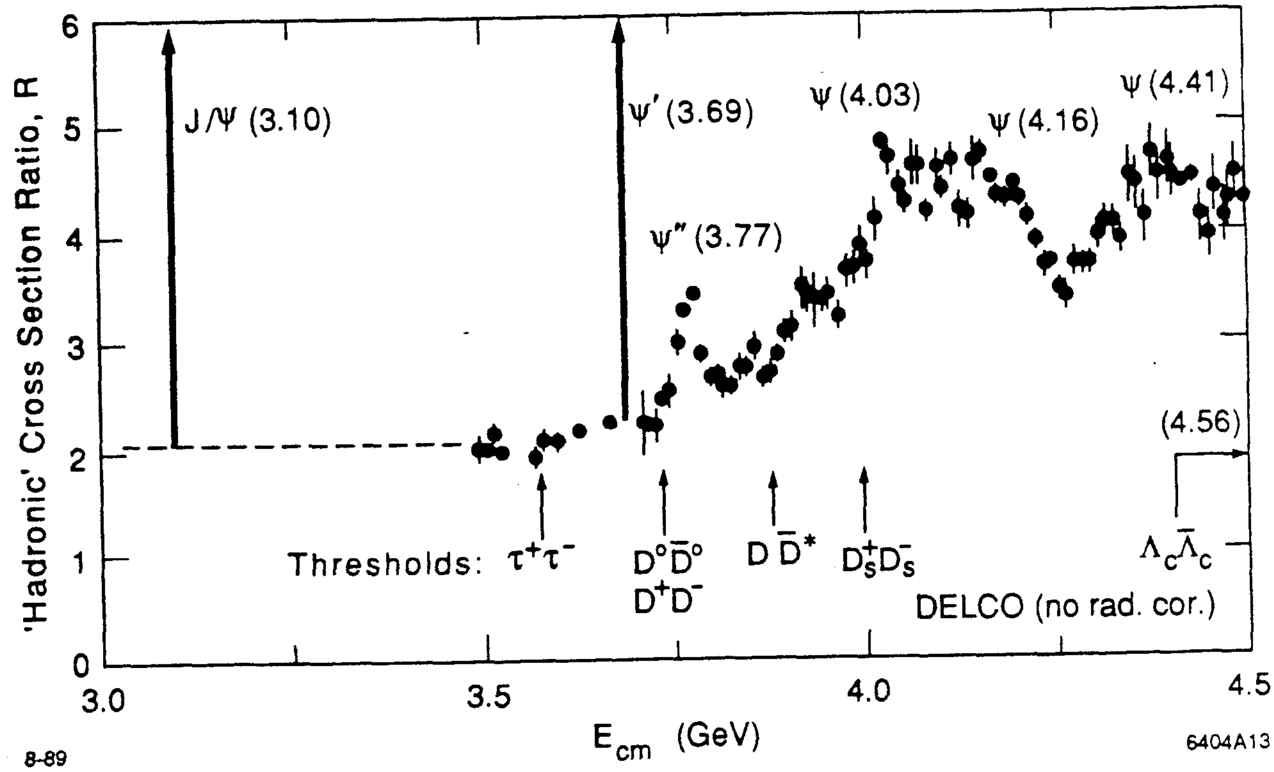


Fig. 1. Values of $R \equiv \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-)$ as a function of the center-of-mass energy. There are approximately 100,000 hadronic events shown on this plot.

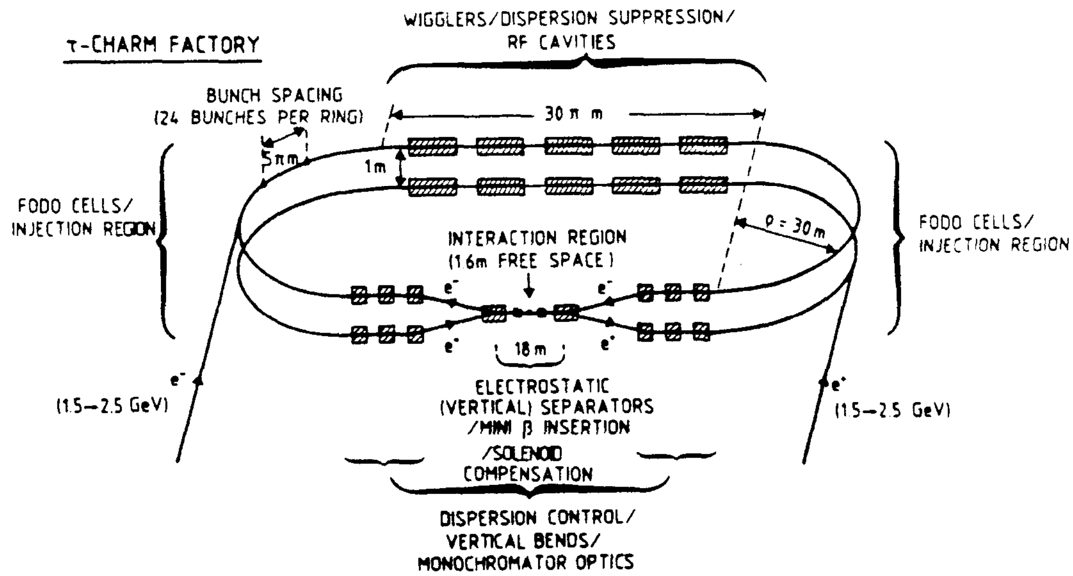


Fig. 2. Schematic design of the storage rings in the initial Jowett design of the Tau-Charm Facility.

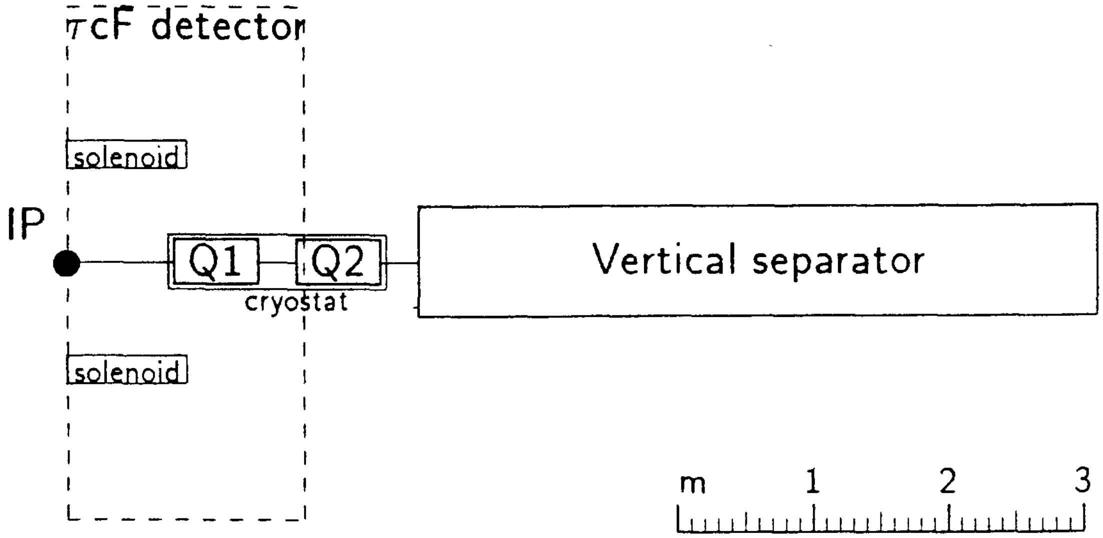
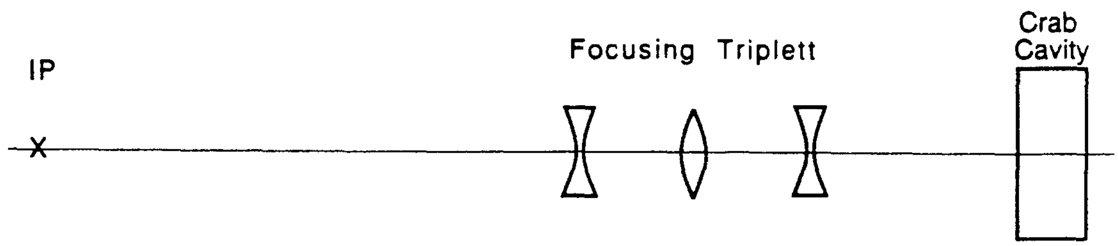


Fig. 3. Interaction region for the Jowett design. Note the two superconducting quadrupoles that protrude into the detector.



IP					Crab Cavity
	Focal length (cm) (horizontal)	f=−113	f=70.5	f=−113	
0	Distance from IP (cm)	200.0	250.0	300.0	510.0
0	Beam-beam Separtation (cm)	2.4	4.06	2.84	3.01
1.0	Horizontal beta function (m)	5.0	13.5	6.35	6.3
0	Hor. betatron Phase Shift (°)	63.0	66.9	70.0	90.0
0.03	Vertical beta function (m)	133.0	87.0	187.0	42.0
0	Vert. betatron Phase Shift (°)	89.1	89.4	89.6	91.2

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Fig. 4. Parameters of the interaction region in the Crab-Crossing design of Voss et al.

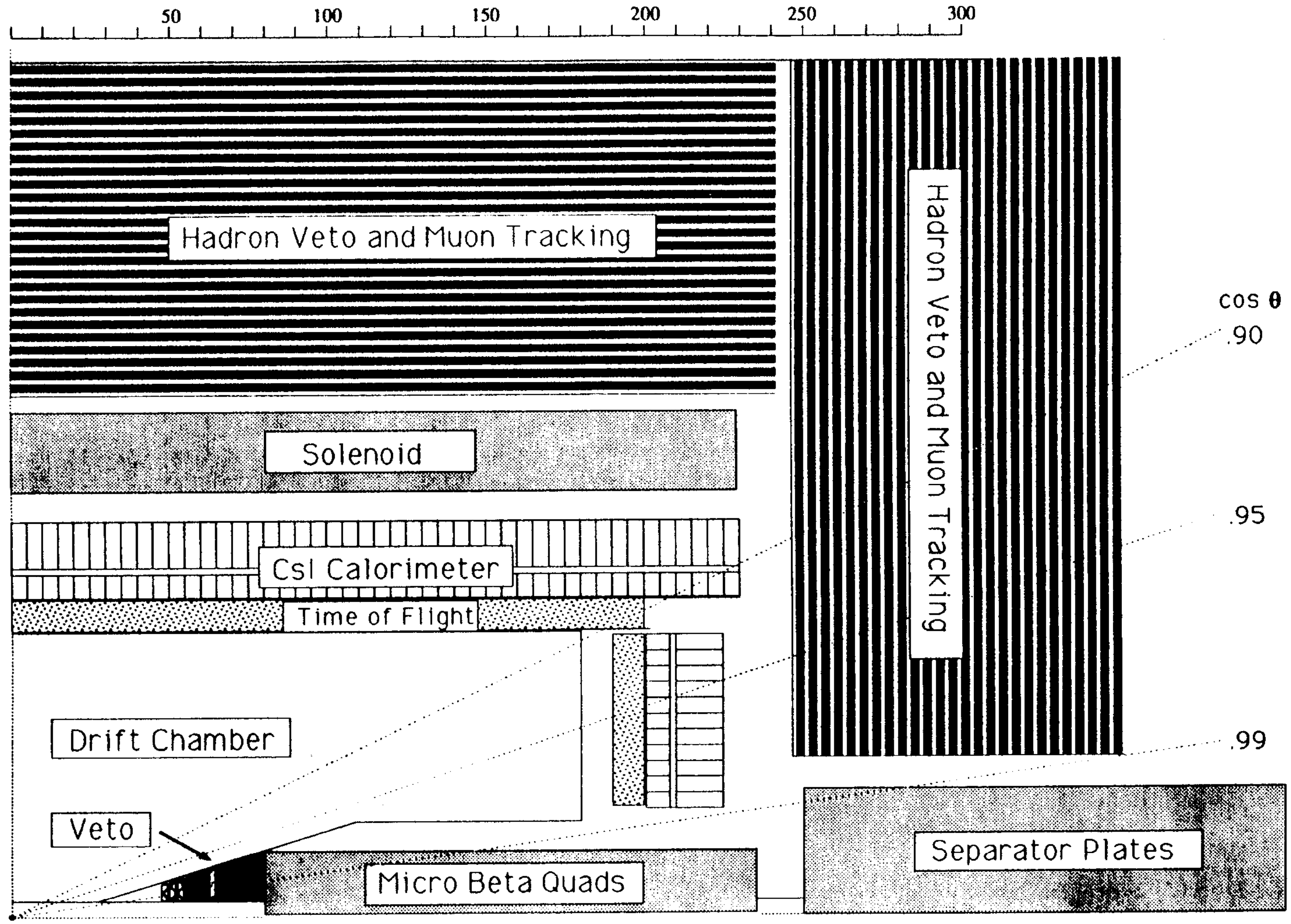

Fig. 5. A preliminary sketch of a tau-charm detector.