τ-charm Factory Workshop Machine Physics Summary

K.L. Brown, T. Fieguth and J.M. Jowett

Designing a τ-charm Factory to meet the requirements of the experimentalists raises a number of challenging problems in accelerator physics. This was reflected in a set of particularly productive sessions in the Accelerator Physics Working Groups. The summary which follows is intended as a guide to help the reader find his way through the more detailed material reproduced in these proceedings. We have tried to list the participants after the headings summarising the work of the accelerator physics subgroups but it should be borne in mind that the composition of the subgroups varied in time and there was a good deal of overlap among them.

1 Machine Physics Plenary Session

A design for a τcF storage ring was worked out in 1987–88 by J.M. Jowett in collaboration with J. Kirkby at CERN and this was presented in plenary session. This came to be referred to as the "Initial Design". A central idea here was to exploit the existing LEP Pre-injector system, potentially an excellent injector for a τcF. Although this injection scheme imposes certain numerical constraints, the design of the τcF machine itself can, to a large extent, be abstracted out of its site-specific context.

The collider is conceived as a pair of vertically separated storage rings with a *single* common experimental straight section where the bunches collide *head-on*. Orbit separation is arranged by electrostatic separators just beyond the micro-β quadrupoles.

Attaining luminosities in excess of $10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ requires a large number of bunches, k_b, a small β-function at the interaction point (IP), β_y^*, and a large emittance, ϵ_x. The high bunch frequency, $f_b = f_0 k_b$, is obtained by means of the double ring and separation scheme; a micro-β scheme using superconducting quadrupoles embedded in the detector provides the small β_y^*; an RF system design using a small number of high-frequency superconducting cavities provides the short bunch length σ_z needed for the micro-β to work; finally, the optics design provides a large emittance which can nevertheless be *varied* from its natural value (by means of Robinson wigglers) in order to maximise performance at different beam current levels.

Although some specifics of the Initial Design (e.g. the precise value of the circumference) were determined by requirements of compatibility with the CERN injector, it formed a basis for many of the studies carried out in the workshop. Also, many parameters were evaluated at a beam energy of 2.5 GeV whereas there is now broad agreement that 2.2 GeV would be a suitable upper limit for the τcF. This would allow the machine to be better optimised to run just above the τ-production threshold where there is the greatest demand for a high integrated luminosity.

Ideas for a τ-charm Factory in KEK were presented by S. Kamada. This double ring design is an outgrowth of the KEK design of a B-factory in the Tristan Accumulation Ring tunnel and is based on the same hardware.

An alternative approach to the problem of increasing the bunch frequency f_b was described by G.A. Voss who adapted and extended the "crab-crossing" idea of R. Palmer, K. Oide and K. Yokoya. In this scheme the bunches collide at an angle but are "tricked into believing" that they collide head-on. Special cavities effect a suitable rotation of the bunches prior to collision. Thus, the problem of synchro-betatron resonances associated with collisions at an angle might be elegantly circumvented. The current *per bunch* can be reduced although the *total* beam current (in a larger number of bunches) must be increased if luminosity is to be gained. The results of experimental tests of this idea are eagerly awaited and it is to be hoped that some can be carried out soon, perhaps at PEP or PETRA.

Another fundamental limit to the luminosity attainable is, of course, the beam-beam limit. R. Siemann gave arguments and simulation results suggesting that a higher beam-beam limit can be reached with round beams instead of the flat ones that are used in most of the existing colliders.

Here, again, empirical test is necessary and results should come from a forthcoming experiment at CESR.

2 Working Group on Optics Design

Coordinator: J.M. Jowett

Participants: K.L. Brown, M.H. Donald, T. Fieguth, A. Garren, K. Halbach, A. Harvey, R.H. Helm, S. Johnson, S. Kamada, N. Kroll, M. Lee, H. Nesemann, J. Niederer, K. Oide, R. Servranckx.

Most of the micro-β optics designs discussed in the workshop were based on conventional or superconducting quadrupole magnets. However K. Halbach pointed out the range of alternatives now available through ingenious use of combinations of conventional, superconducting and permanent magnets.

Chromatic correction and dynamic aperture of the Initial Design lattice were studied by R. Servranckx. Although the dynamic aperture was found to be somewhat marginal for the lattice as it stood, straightforward variations of the arc optics (number and length of the basic FODO cells) were shown to provide adequate stable phase space. The choice of a betatron phase advance of 60° per cell was confirmed. All these calculations were made with the utility and experimental straight sections of the Initial Design, including a triplet micro-β optics giving $\beta_y^* = 1\,\text{cm}$. In the space of a workshop, it is clearly impossible to carry out a systematic study of the effects of errors, variations of the micro-β focussing, more elaborate sextupole schemes, etc., but the results for the ideal lattice were sufficiently good that we expect no serious problems here.

Another lattice design was presented by K. Oide. This had a number of interesting features leading to a very large dynamic aperture. Among them we note the use of a non-interleaved sextupole scheme and a short distance from the IP to the sextupoles. Although this lattice was designed to exploit a *horizontal* crab-crossing scheme, its benefits are independent of the separation scheme used.

Electrostatic separation schemes were studied by M. Donald, A. Garren, S. Kamada and K. Oide. They compared the schemes proposed for the

Initial Design and the KEK design which requires very flat beams and consequently a very fine betatron coupling compensation. By removing some of the conservatism inherent in the Initial Design, they reduced the bunch spacing from 15.7 m to 7.3 m.

Replacing the straightforward electrostatic separation by crossed electric and magnetic fields, N. Kroll presented an alternative scheme in which identical separations would be achieved but with the synchrotron radiation from vertical bending directed away from the IP.

In the Initial Design it was proposed to use Robinson wigglers to adjust emittance and maximise luminosity. J.M. Jowett reviewed how these worked. Taking the parameters of the Robinson wigglers which are used in the CERN PS, he showed that they would be a modest addition to a τcF and would allow the beam-beam limit to be more closely approached, e.g., at lower energies or in the event that the current storable was insufficient to reach the beam-beam limit with the natural damping partition.

More work needs to be done to establish whether it is possible to implement a monochromator scheme in a τcF. A possible difficulty is the correction of the coupling due to the detector solenoid. A solution to this problem may necessitate the incorporation of compensating solenoids before the final-focus quadrupoles (as in the ARGUS detector at DORIS).

Among present or past rings, DORIS II most closely approaches the operating conditions of a τcF. H. Nesemann reviewed the experience with this machine, pointing out where important lessons could be learnt. Operation was rather smooth although performance depended critically on parameters such as the working point. Tuning was nearly always necessary after the topping-up of beams which took place about once an hour.

The question of how many interaction points should be allowed for in a τcF was discussed. We would argue that the additional complication and costs (both financial and in terms of luminosity per IP) of having a second IP militate in favour of sticking to a single one. However this view is not universally held.

Another round of parameter studies is necessary to adjust the τcF design to the reduced top energy. This is not expected to affect the above conclusions significantly.

3 Working Group on Beam Current Limitations

Coordinator: J.M. Paterson/K. Bane

Participants: F. Decker, S. Kamada, S. Kheifets, N. Kroll, L. Merminga, H. Nesemann, K. Oide, R.D. Ruth, M. Sands, J. Seeman, K. Thompson, A. Vlieks, G.A. Voss, P.B. Wilson, M. Zisman.

The beam current stored and, hence, the ultimate performance of most e^+e^- storage rings is limited by single- or multi-bunch collective effects and the τcF is certainly no exception in this regard. Close attention was therefore paid to the estimation of instability growth rates and what may be done to reduce them.

In the Initial Design it was recognised that operation of the micro-β optics required r.m.s. bunch lengths $\sigma_z \simeq 1\,\text{mm}$ and that this, in turn, required a large RF voltage slope $\omega_{\text{RF}} V_{\text{RF}}$ and low longitudinal impedance $Z/n \simeq 0.2$–$0.4\,\Omega$. This led to the proposal to use high-frequency superconducting cavities of the Cornell/CEBAF design.

R.D. Ruth verified the impedance requirements and also showed that the transverse mode-coupling (or fast head-tail) instability would not be encountered with the τcF parameters. The question of whether such low Z/n values were attainable was considered by K. Bane and P. Wilson. Impedance budgets for the vacuum chamber components and various possible RF systems showed that a room-temperature system was ruled out for short bunch lengths and that the impedance requirements could be met with a careful vacuum chamber design and, preferably, the so-called "single-mode" superconducting cavities.

Calculations of growth rates of coupled-bunch instabilities were made by K. Thompson using frequencies and impedances of the modes of the 1.5 GHz cavities obtained by 'phone from J. Bisognano at CEBAF. She found that there could be multi-bunch instabilities with growth times $\tau \lesssim 1\,\text{msec}$ with the 0.5 A total current of the Initial Design. Similar results were found by M. Zisman. Discussions concluded that one would probably need *both* a feedback system and new approaches to damping or controlling the modes in the cavities.

Multi-bunch collective effects are likely to be more severe if a ring design based on the crab-crossing concept is chosen. Here the higher luminosity, lower single-bunch current and other advantages are gained at the expense of a much higher *total* beam current (a few amperes in the Voss design).

Single-ring e^+e^- colliders do not normally suffer from positive ion trapping by the electron beam since the counter-circulating positrons conveniently neutralise the potential. The electron ring of a double-ring collider does not enjoy this benefit (except in the interaction region which is common to the two rings). Ion trapping can give rise, in a somewhat unpredictable way, to nonlinear resonance excitation, reduced lifetime and backgrounds. There was discussion of possible cures by leaving gaps in the bunch pattern or by installing clearing electrodes in the vacuum chamber. The latter option could be expensive or increase the chamber impedance. It is acknowledged that this is a difficult problem requiring further attention.

Ideas for an oscillating bunch length lattice, allowing σ_z to be very short at the interaction point but longer elsewhere, were presented by J. Seeman.

At the end of the workshop, a much improved crab-crossing design was found by S. Kheifets, J.M. Paterson and G. Voss. With a larger horizontal crossing angle they managed to dispense with the additional separation, reduce the parasitic beam-beam tune-shifts and relax tolerances.

4 Working Group on RF and Vacuum System

Coordinator: M. Allen

Participants: J. Rees, H. Schwarz, G.A. Voss, A. Vlieks.

The choice of RF frequency was discussed in some detail. The high frequency superconducting system (1.5 GHz) of the Initial Design helps to get a short bunch length with low impedance since the system need comprise only a few cells.

On the other hand, at lower frequencies (350 MHz), high power sources are more readily available. Such a system (either normal or superconducting) could be compatible with a design based on crab-crossing.

The high beam currents in the τcF will lead to heating of the vacuum chamber components by synchrotron radiation and parasitic mode losses. The vacuum chamber must be designed with suitable cooling.

5 Working Group on Injection System

Coordinator: R. Miller

Participants: W. Barletta, F.J. Decker, H. Hoag, C. Kim, G. Loew, P. Morton, E. Nelson, H. Nuhn.

This group considered the question of the beam-production systems, the injection insertion in the main τcF ring, filling times and costs.

Three basic setups for the injector were considered:

- A simple linac with a 1 μsec pulse.
- A linac, with positron accumulation and damping ring, followed by a SLEDded linac.
- A linac, with positron accumulation and damping ring, and a booster synchrotron.

Here, the 3 proposals are arranged in order of cost, complexity and rapidity of filling.

An interesting variation on the 3rd scheme involving a superconducting damping ring was proposed by W. Barletta.

In the Initial Design of the τcF, the radial betatron damping time is rather long in the lower part of the energy range because its natural E^{-3} dependence is exacerbated by the reduction of the corresponding damping partition number by the Robinson wigglers. For this reason, the option of injection into synchrotron phase space, where damping is faster, may be preferred. A reduction of the bending radius and circumference (which will be consequences of the reduction in top energy) would also help here.

6 Working Group on Control System Design

Coordinator: M. Lee

Participants: P. Morton, J. Niederer

Keeping average luminosity close to peak luminosity by frequent (e.g., every 30 min) topping up from the injector makes heavy demands on the τcF control system. It is clear, for example, that routine operation will have to be under computer control to a much greater extent than we are used to. Manual control of injection, setting-up of beams and luminosity maximisation would simply be too slow.

Modern design and development tools ought to help build and manage an adequate control system and resolve the conflicts between various desiderata, e.g., the requirement of high luminosity tends to make a system more complex while the traditional requirement of high reliability is most readily attained by simplification.

7 Conclusions

Overall conclusions from the machine design part of the workshop were that all, or nearly all, of the ingredients for a τ-charm Factory with average luminosity $\gtrsim 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ exist. The challenge is to assemble them into a working machine. On top of this, several exciting new ideas for even greater luminosities, most notably the "crab-crossing", moved several steps closer to realisation at the workshop.

If a τ-charm Factory project is to succeed then—like any particle "factory", whose very *raison dêtre* is the provision of high luminosity—it must not fall far short of its design performance. Such machines cannot redeem themselves simply by virtue of having opened up a new energy region. It follows inexorably that there is no room for compromises or shortcuts: careful and thorough design and engineering will be mandatory throughout the a project.