The τ-charm Factory Storage Ring
Initial design and parameters

John Jowett (CERN)

History of τcF machine design

Design requirements

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History of τcF machine design

January 1987 Informal working group on CERN Ski Club bus.

May 1987 Jasper Kirkby proposes a τ-charm Factory as an experiment on the CERN site. Storage ring integrated with detector design. Exploits LEP pre-injector system and existing infrastructure.

J. Kirkby, "A τ-charm Factory at CERN", *Proc. International School of Physics with Low-Energy Antiprotons, 2nd course,* Erice 1987, CERN-EP/87-210.

Autumn 1987 First version of machine design completed—many discussions at Geneva English School bus stop.

Concept for micro-β quadrupoles from Tom Taylor (CERN).

J.M. Jowett, "Initial design of a τ-charm Factory at CERN" CERN LEP-TH/87-56 (1987).

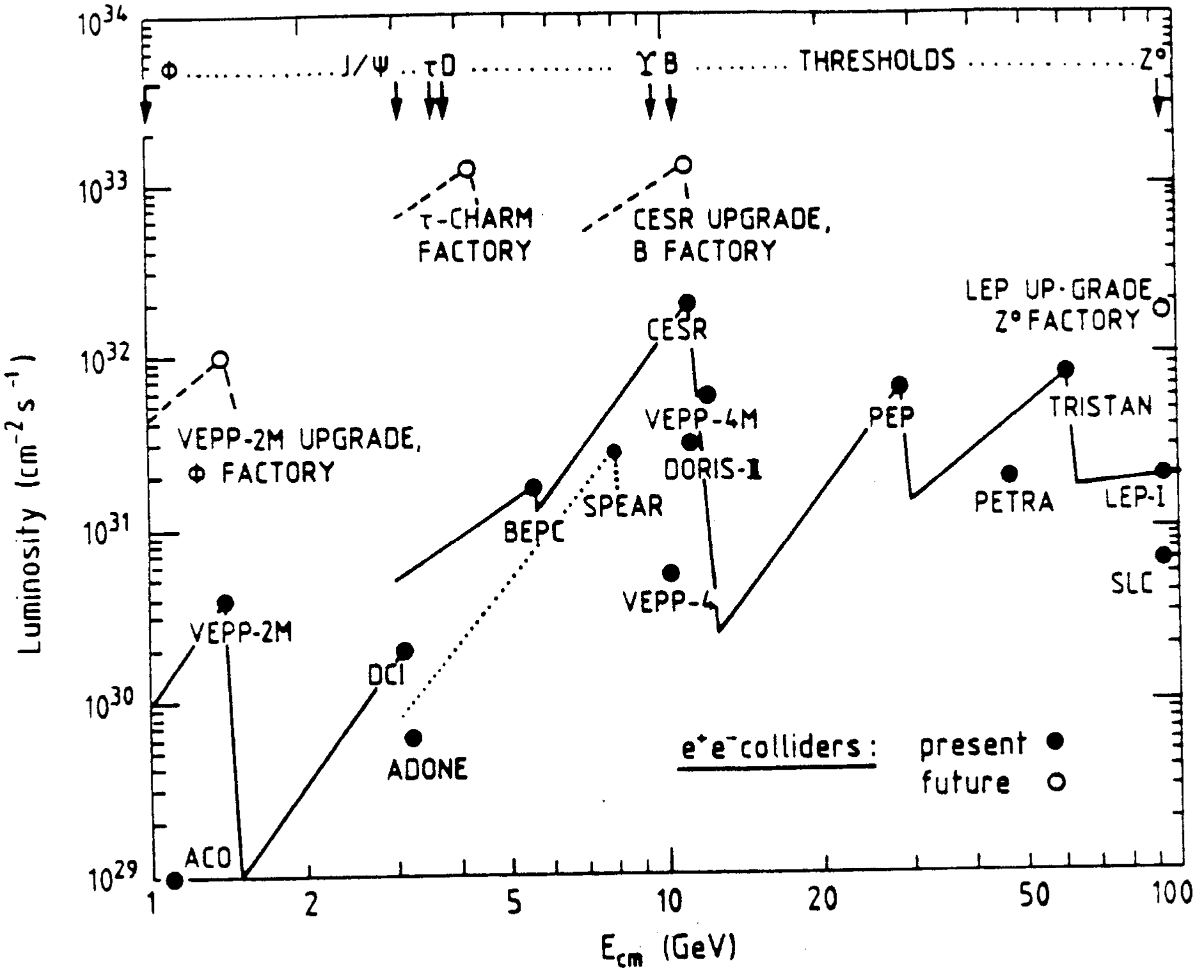
January 1988 Ski-bus working group re-convenes.

June 1988 Improved storage ring design presented.

J.M. Jowett, "The τ-charm Factory storage ring", 1st European Particle Accelerator Conference, Rome, CERN/LEP-TH/88-22 (1988).

1988 Jasper Kirkby continues to promote the idea, interest emerges from particle physicists—but not enough machine designers—in several places.

1989 New input from several directions—this workshop.
Carrying coals ...



Luminosities achieved or hoped-for with various e^+e^- storage rings

figure by J. Kirkby

Design requirements

Wanted:

- Centre of mass-energy $\sqrt{s} = 3\text{–}5$ GeV.
- Luminosity $L \simeq 10^{33}\,\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ at top energy.
- Comparable luminosities at the lower energies.

Concessions:

- High bunch frequency (20 MHz) OK.
- Quadrupoles close (80 cm) to IP.
- Beam pipe getting "large" inside detector.

Initial design adopted double storage ring with a single interaction point. Vertical separation scheme used to ensure head-on collisions.

(Similar to some B-factory ideas.)

Design approach

Luminosity formula:

$$L_0 = \frac{k_b I_b^2}{4\pi e^2 f_0 \sigma_x^* \sigma_y^*}$$
$$= \frac{k_b I_b^2}{4\pi e^2 f_0 \epsilon_x \sqrt{\beta_x^* \beta_y^*}} \left(\kappa + \frac{1}{\kappa}\right).$$

"Unperturbed" beam-beam tune-shift parameter:

$$\xi_{yo} = \frac{(I_b/ef_0) r_e \beta_y^*}{2\pi (E_0/m_e c^2)(\sigma_x^* + \sigma_y^*)\sigma_y^*}.$$

Maximum luminosity by arranging

$$\xi_{yo} = \xi_{xo}$$

with the largest possible current ⇒ "optimal coupling"

$$\kappa = \sqrt{\frac{\epsilon_{yc}}{\epsilon_{xc}}} = \sqrt{\frac{\beta_y^*}{\beta_x^*}}.$$

Bunch current determined by

$$I_b = \frac{2\pi e f_0 (E_0/m_e c^2) \epsilon_x \xi_{yo}}{r_e}$$

$$\Longrightarrow L_0 = \frac{\pi k_b (1+\kappa^2) f_0 (E/m_e c^2)^2}{r_e^2 \beta_y^*} \epsilon_x \xi_{yo}^2.$$

Luminosity at high intensity

Near beam-beam limit, ϵ_{yc} is blown up somewhat.

Take into account with simple prescription: unperturbed ξ_{yo} set to $\xi_{yo} = 0.06$; then beam-beam effect reduces the effective value to saturated $\bar{\xi} \simeq 0.04$.

More realistic value for luminosity:

$$L = L_0 \frac{\bar{\xi}(\xi_{yo})}{\xi_{yo}},$$

$$L = \frac{\pi k_b (1+\kappa^2) f_0 (E/m_e c^2)^2}{r_e^2 \beta_y^*} \epsilon_x \xi_{yo} \bar{\xi}(\xi_{yo}).$$

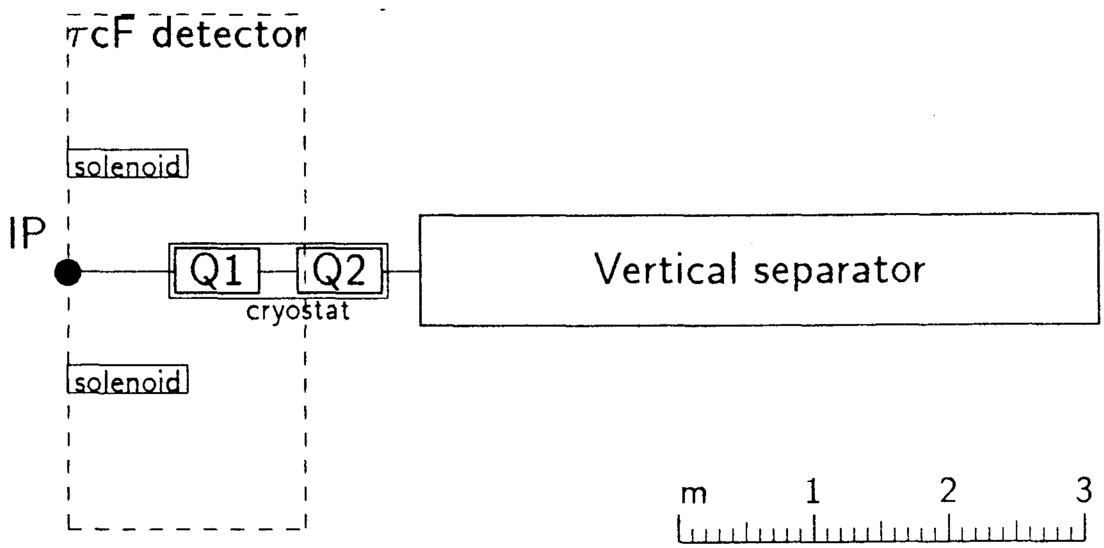
Numerically, with bunch separation $S_b = c/f_0 k_b$,

$$[L/\mathrm{cm}^{-2}\mathrm{sec}^{-1}] = 1.09 \times 10^{38} \frac{(1+\kappa^2)[E_0/\mathrm{GeV}]^2[\epsilon_x/\mathrm{m}]}{[S_b/\mathrm{m}][\beta_y^*/\mathrm{m}]}.$$

Next we must evaluate parameters β_y^* and S_b which are critical in determining the performance of the machine. Then we will know the emittance which is required.

Micro-β insertion and separation scheme

Original design used doublet focussing to achieve $\beta_y^* = 1\,\mathrm{cm}$ with two superconducting quads protruding into detector.

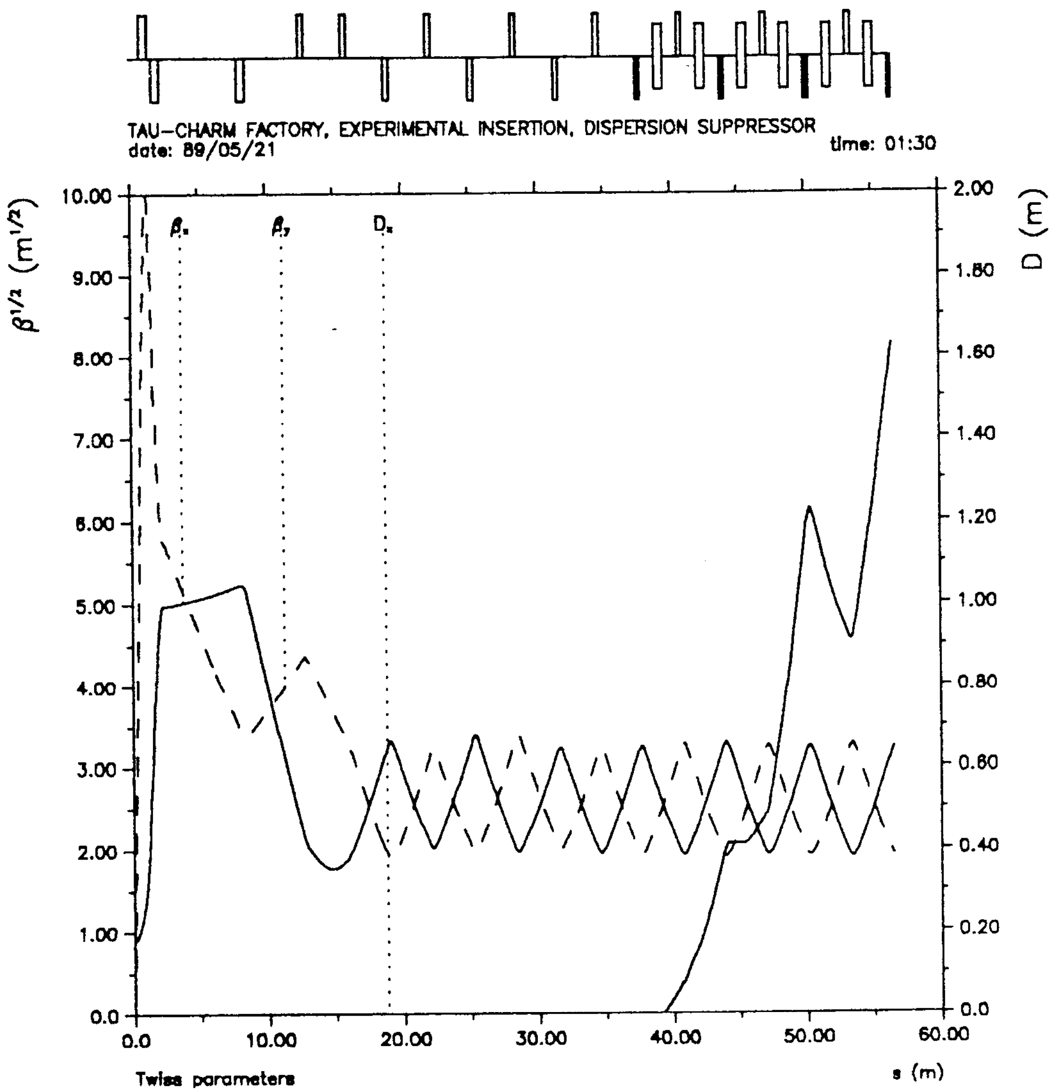


Lower limit on S_b set by the accumulated length of the micro-β insertion and the separation scheme which follows it.

τcF detector design allows closest quadrupole at $L_1 = 0.8\,\mathrm{m}$ with an outer radius not greater than 20 cm.

We can envisage (idea of Tom Taylor) a pair of 0.6 m long iron-free superconducting quadrupoles (Q1 and Q2) whose coils can be separately rotated inside their common cryostat to compensate the betatron coupling induced by the 4 tesla detector solenoid.

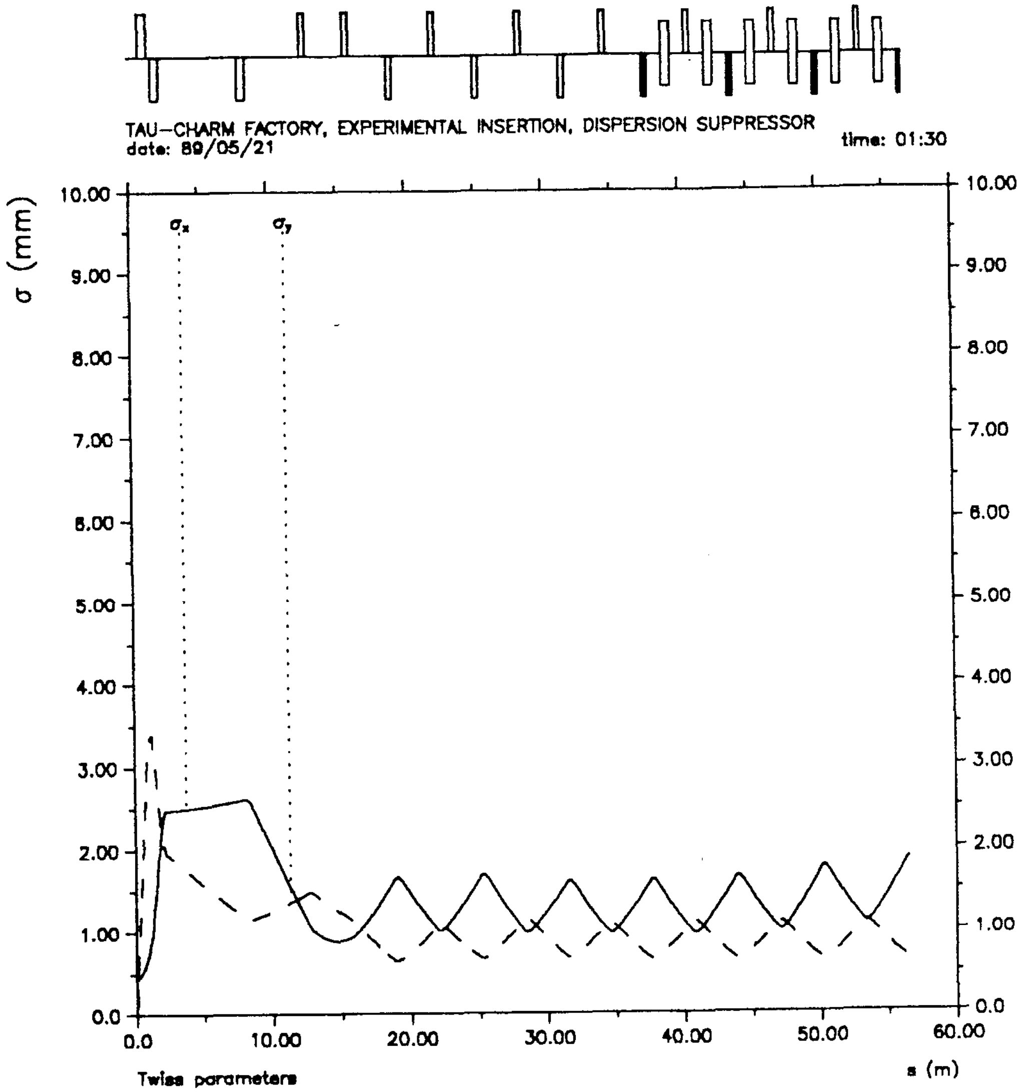
Total length of (half) insertion is 7.6 m including generous 5 m for electrostatic separator plates (VSEP).



Optics of the experimental insertion and dispersion suppressor (doublet focussing)

Maximum quadrupole strength $|K| = 2.8\,\mathrm{m}^{-2}$
$\Rightarrow$field gradient $dB/dx \simeq 24\,\mathrm{T\,m}^{-1}$ at 2.5 GeV.

Design quad for $30\,\mathrm{T\,m}^{-1}$, take half-aperture 50 mm
$\Rightarrow$max field in winding $B_{Q1} \simeq 2.5\,\mathrm{T}$
should be achievable without a cold bore.



**Beam sizes (vertical with full coupling)
for doublet micro-β scheme.**

Separation scheme

Vertical electrostatic separator plates separate beams and avoid parasitic interactions between bunches of the opposing beams.

Limit on the electric field: $E_y \leq 2\,\mathrm{MV\,m^{-1}}$.

Simulations done for LEP (S. Myers) found separation criterion

$$\Delta y \gtrsim 2\sigma_x = 2\sqrt{\epsilon_x \beta_x}.$$

Satisfied comfortably with $S_b \simeq 15\,\mathrm{m}$ (safety margin).

Aspects requiring study:

Backgrounds collimators, masks, etc., geometry?

Heating of plates by irradiation, parasitic mode losses. Outgassing, breakdown.

Coupling impedance this machine must have a very low Z.

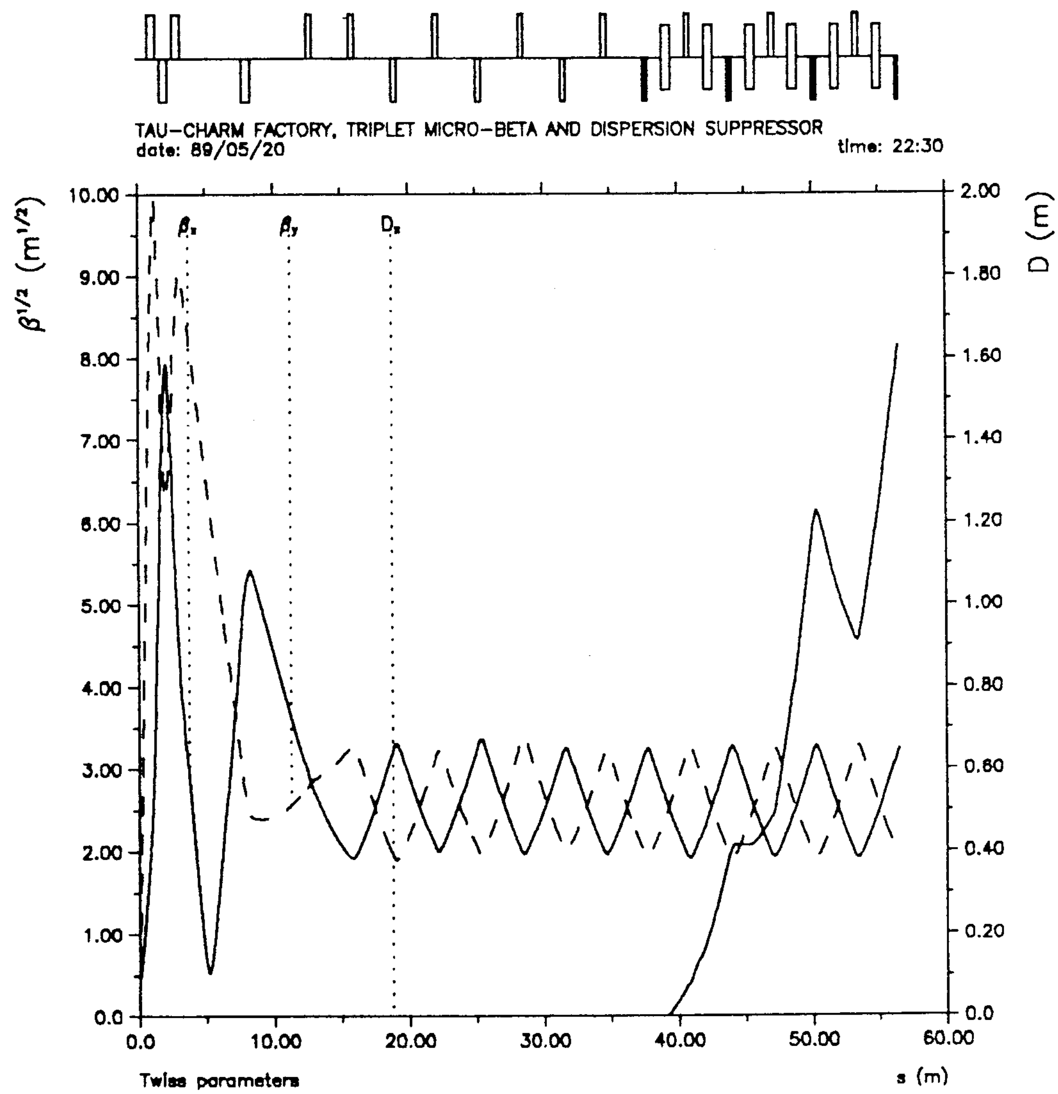
Amplification scheme for initial separation angle by downstream magnetic separation with quadrupoles and weak bending magnets.

RF-magnetic separators should also be considered.

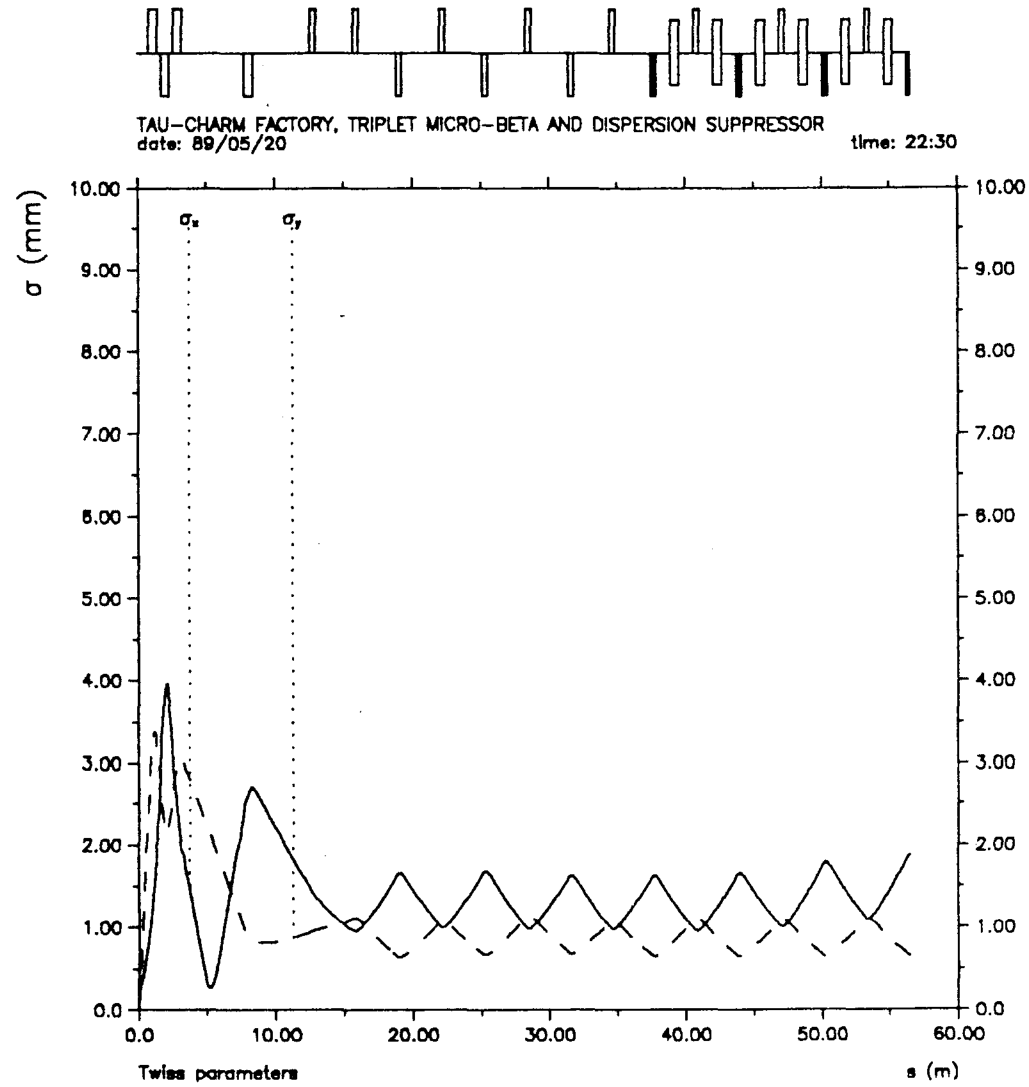
Triplet focussing

Initial design had too small a ration $\beta_y^*/\beta_x^* = 0.01/0.8$.

Reduced to $\beta_y^* = 1\,\text{cm}$, $\beta_x^* = 20\,\text{cm}$.



Extra quadrupole before separator, separator length reduced to 4 m.

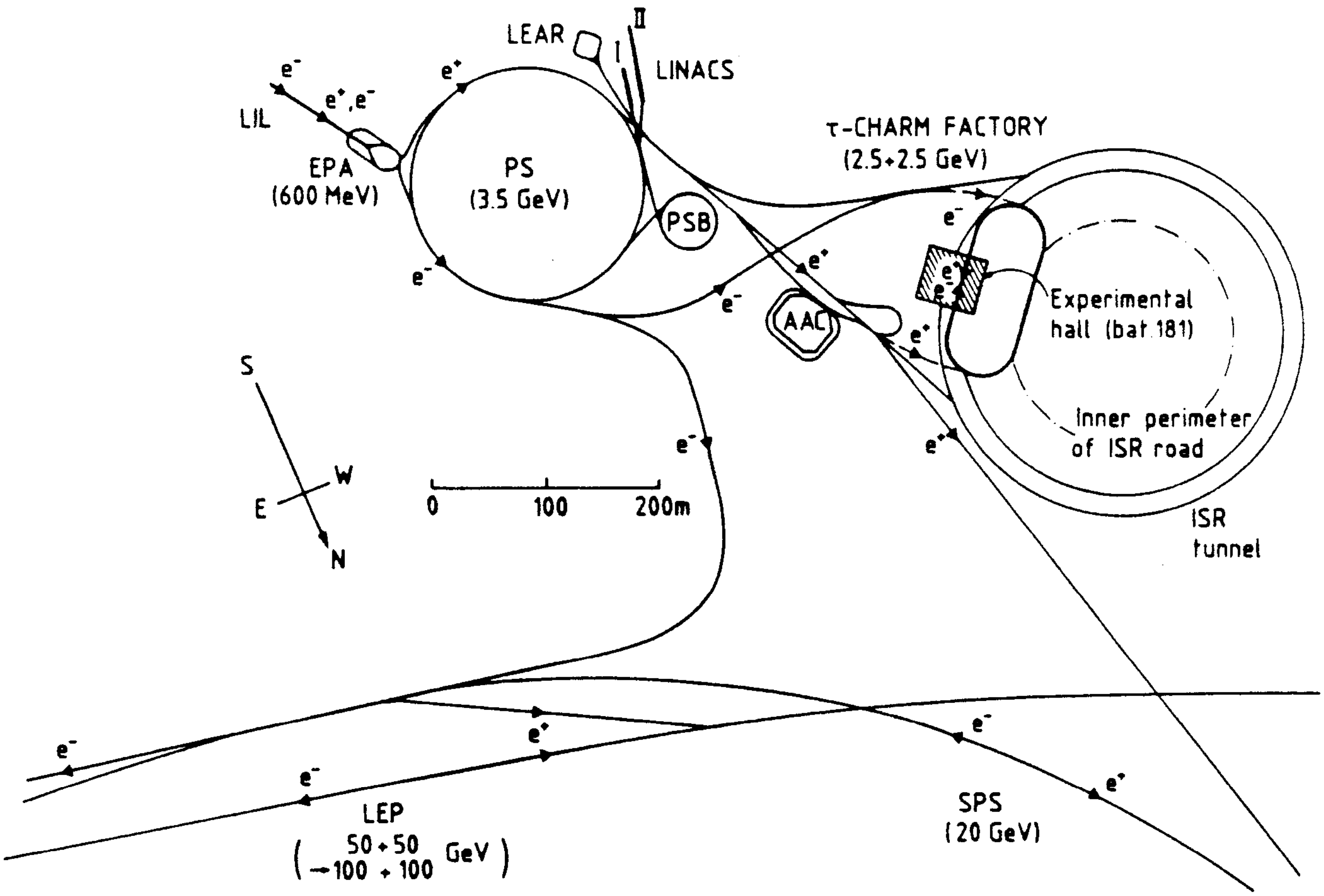


Larger horizontal beam size in Q2.

Injection and geometry

Initial design was largely determined by injection scheme using LEP Pre-Injector (LIL, EPA, PS) which can supply beams at all the operating energies of the τcF.

Avoiding ramping is very important!



Possible layout on the CERN site

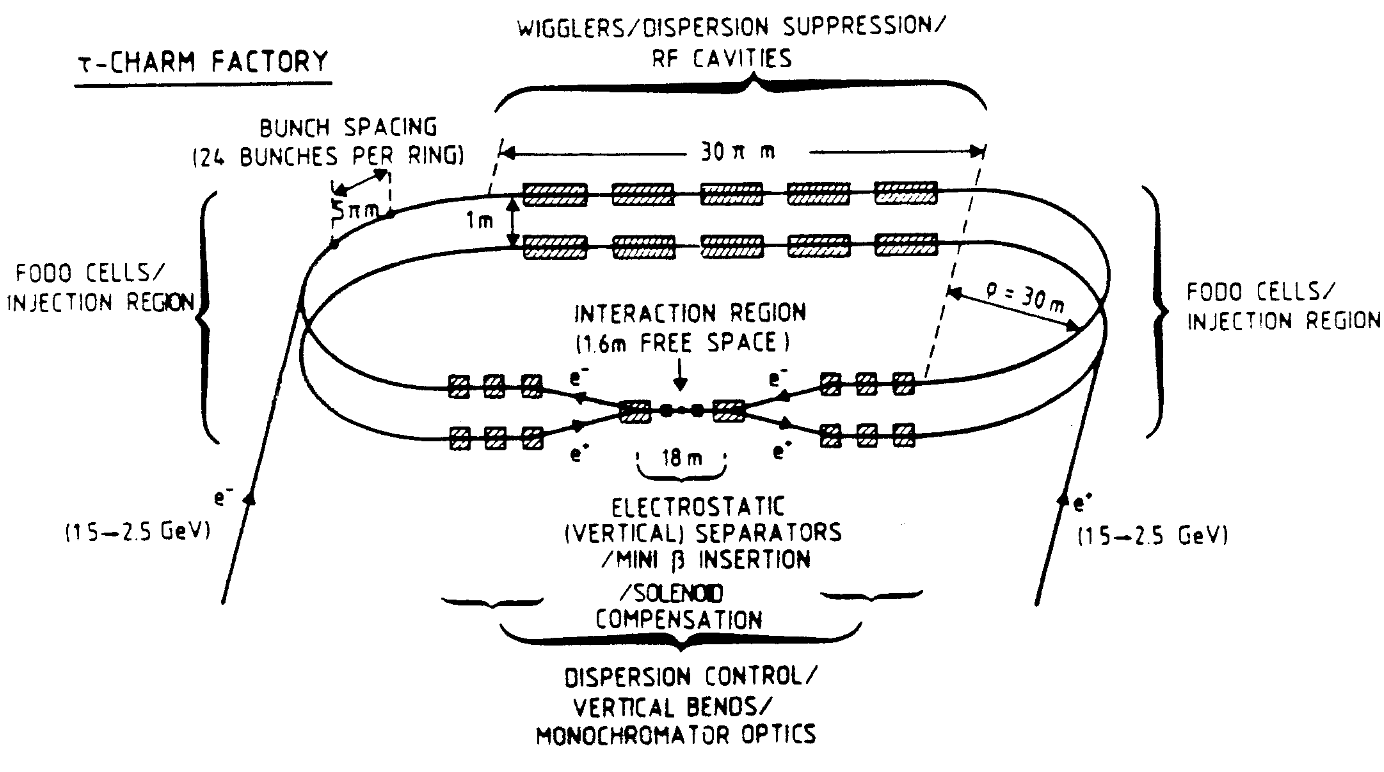
Choice for bunch separation and circumference:

$$S_b[\tau cF] = \frac{S_b[PS]}{5} = 15.708\,\text{m}.$$

Circumference $C[\tau cF] = 3C[PS]/5$ allowing efficient injection into each of 24 τcF bunches in 3 cycles of the CPS.

Smaller circumferences are possible, but we preferred to keep flexibility in the optics.

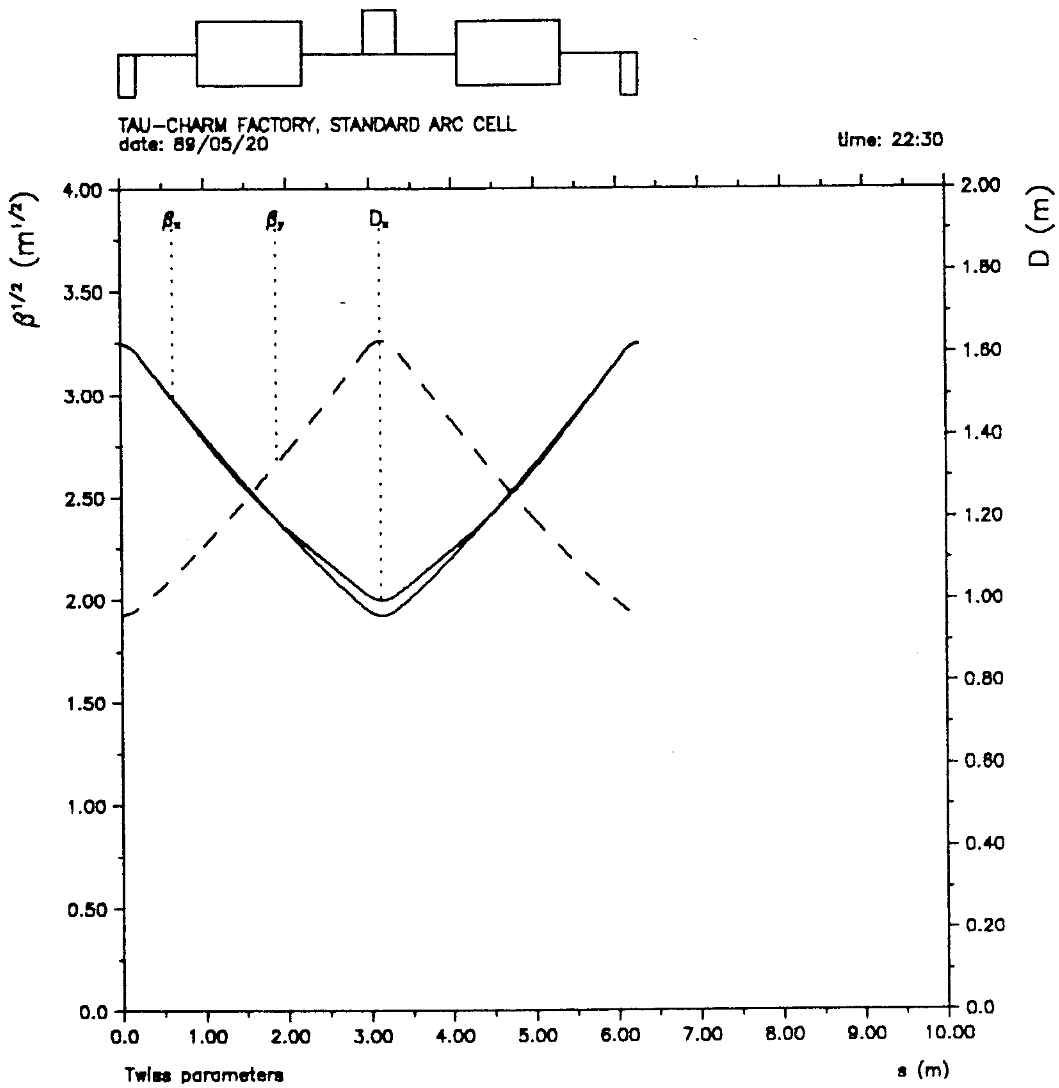
Some 15–21 CPS cycles needed to reach design intensity.
Fast injection kickers, rise to flat top and fall in $2T_b \simeq 104$ nsec.



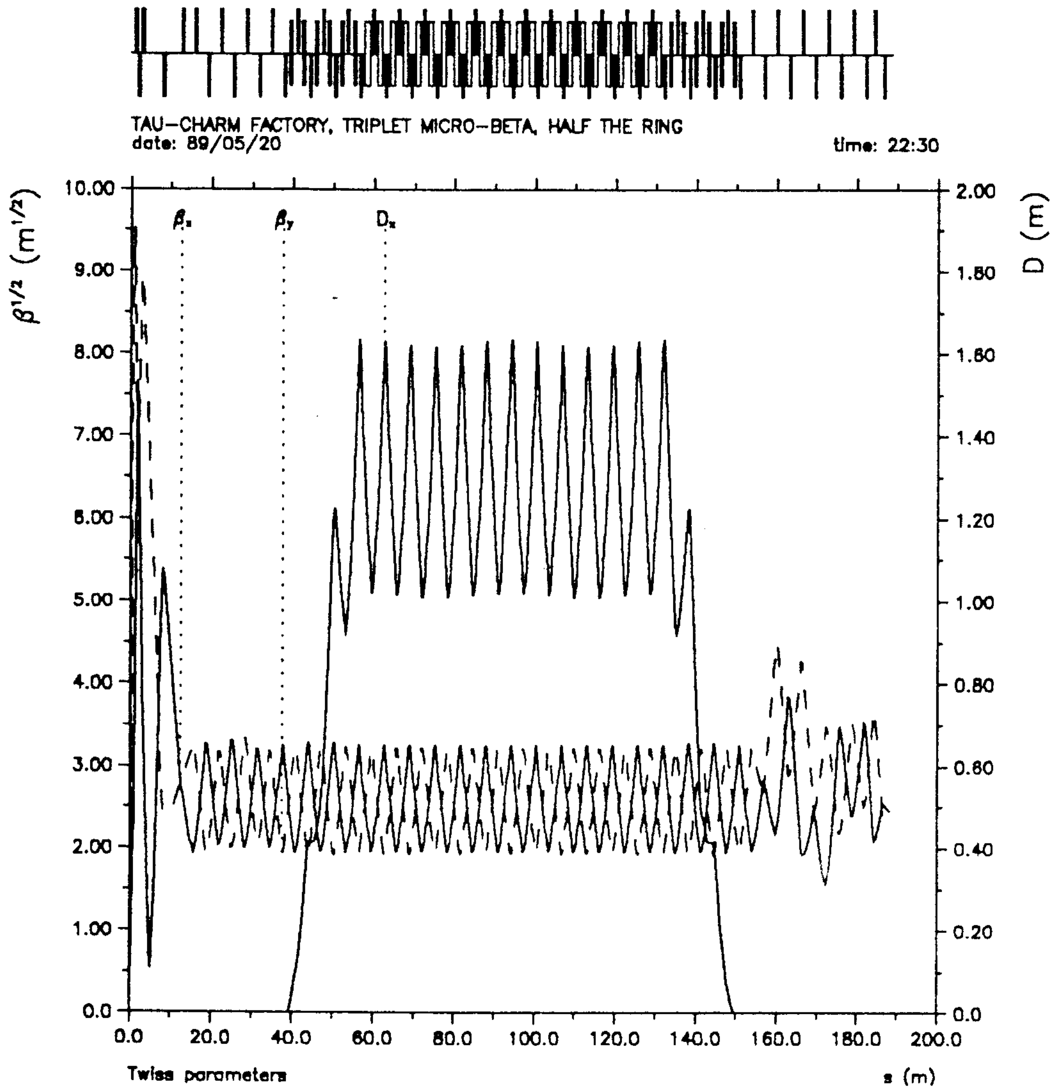
Schematic design of the storage rings

Optics

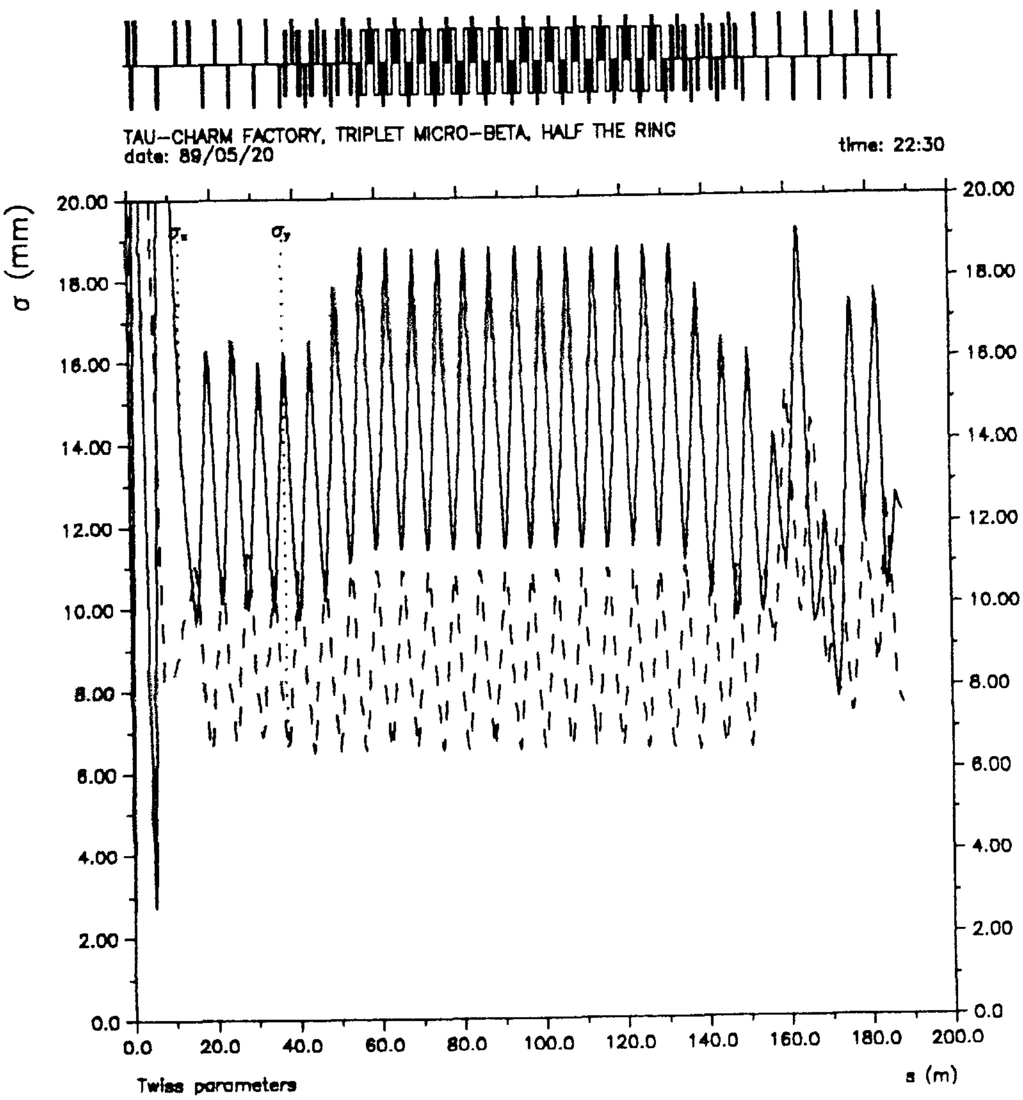
- Bending radius $\rho = 12\,\mathrm{m}$ small to provide rapid damping between beam-beam collisions.
- τcF lattice built from modules with basic length $1/60$ of circumference.
- Each arc contains 12 normal FODO cells with bending angle $\theta = \pi/15$, phase advance $\mu = 60°$.
- Four dispersion suppressors, each consisting of 3 cells with $\theta = \pi/30$.
- Experimental straight section contains matching cells, separation scheme and the micro-β insertion. Space kept for weak vertical bending magnets, electrostatic separators, skew-quadrupoles, etc. Try to maintain flexibility to adjust η at IP for monochromator scheme.
- Utility straight section (also dispersion-free) has several matching cells (Q-adjustment, control of optical functions etc.), space for the RF system, wigglers etc.
- Need to add injection insertions.
- Variation of J_x (damping partition number) by use of Robinson wigglers $\Rightarrow$ keep emittance constant ($L \propto E$). Also reduces energy spread (shorter bunches).



Optics of arc cell



Optics of half the ring



Beam sizes in half the ring

RF system

Initial design proposed to use Cornell/CEBAF type 1.5 GHz superconducting cavities.

Advantages:

- High frequency and voltage to shorten bunches.
- Shape gives lower coupling impedance and higher mode losses than with copper cavities.
- Available "off the shelf" (almost).

Disadvantages/unknowns:

- Cryogenics (but we have it for the SC quads anyway).
- Input power couplers for $> 150\,\mathrm{kW}$ per beam in radiation power alone.
- Higher-order mode couplers for high beam current and small bunch separation.

Needs study ...

Bunch-lengthening can be avoided if $|Z/n|$ is small.

Coupled-bunch instabilities $\Rightarrow$ need feedback systems (narrow-band scheme of Kohaupt?).

Bunch-lengthening

Imperative to keep $\sigma_z \lesssim \beta_y^* = 1\,\mathrm{cm}$.

Natural bunch length $\sigma_z = 6\,\mathrm{mm}$ as $I \to 0$.

Boussard criterion for absence of turbulent bunch-lengthening:

$$\frac{I_p|Z/n|}{2\pi(E/e)\alpha_c\sigma_\epsilon^2} \lesssim 1(1.6)$$

where peak current in bunch is $I_p = ecN_b/\sqrt{2\pi}\,\sigma_z \simeq 550\,\mathrm{A}$. From this parameter list $\Rightarrow$ $|Z/n| \lesssim 0.2\,\Omega$ (we had higher α_c in earlier versions).

Can we design vacuum chamber and RF system to get such a low impedance?

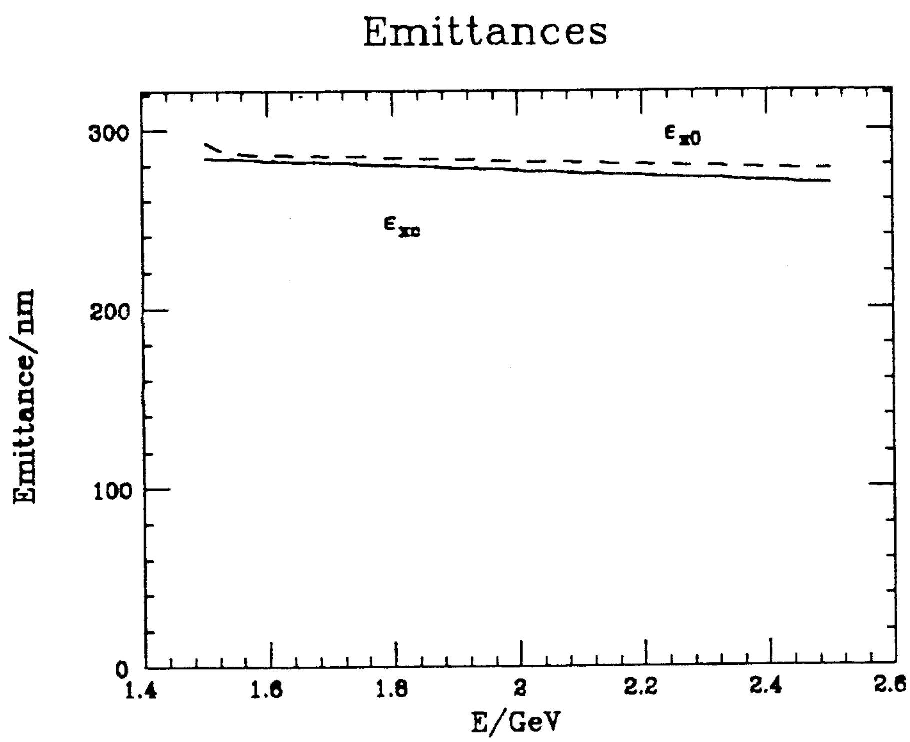
- small number of *superconducting* cavities,
- very smooth chamber

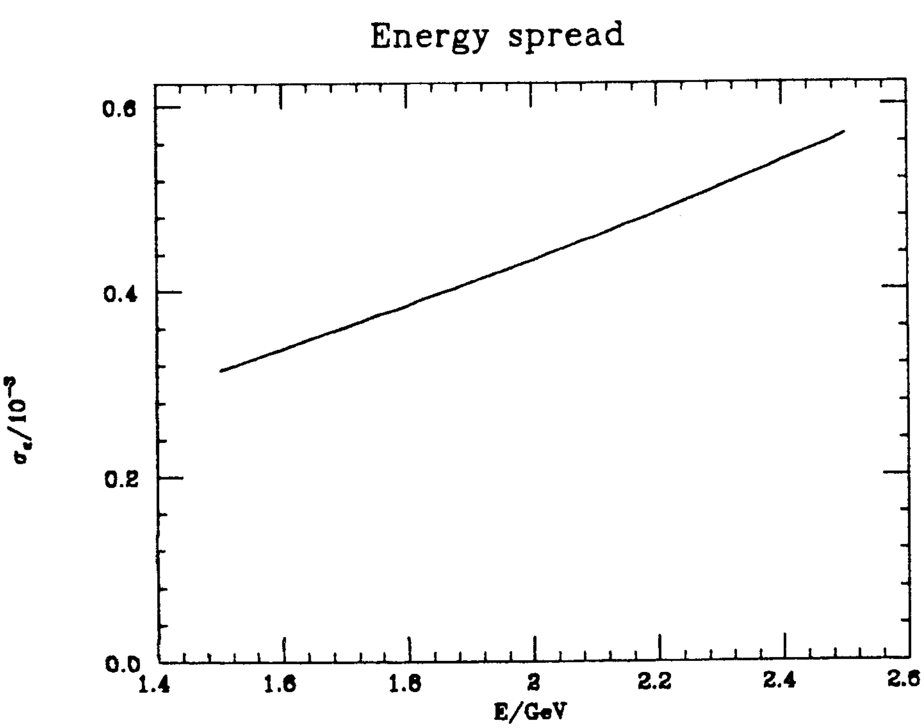
At lower energies, N_b/E is constant
$\Rightarrow$ need to keep $\sigma_z\sigma_\epsilon^2$ constant
$\Rightarrow$ controlled blow-up with wigglers *or* simply allow bunch to lengthen itself.

Parameter list at top energy

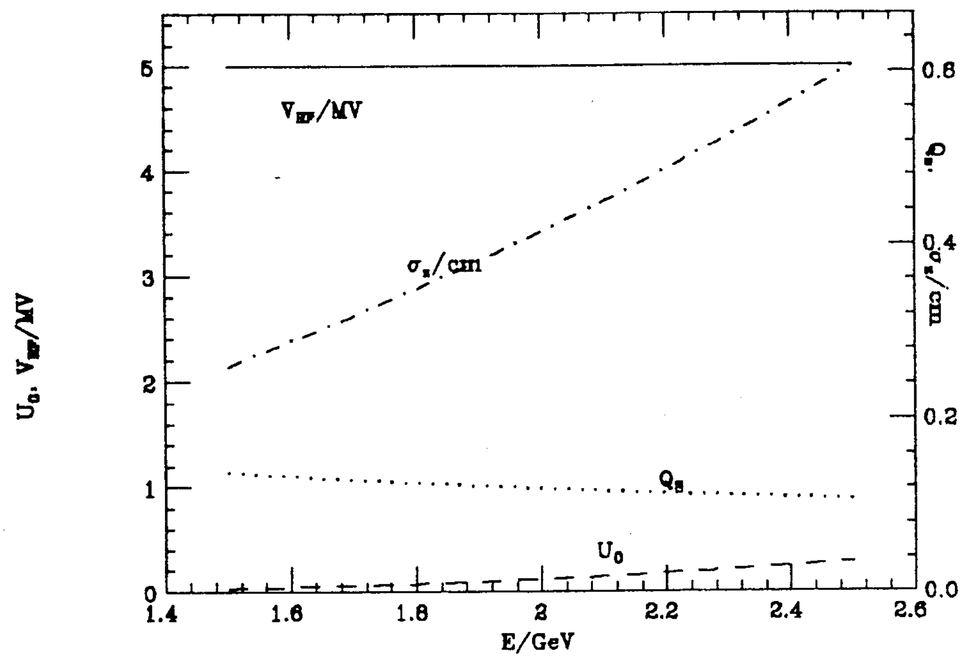
Energy	E	2.5	GeV
Circumference	C	376.99	m
Bending radius	ρ	12	m
β-function at IP	β_x^*	0.2	m
	β_y^*	0.01	m
Betatron coupling	κ^2	0.045	
Betatron tunes	Q_x	$\simeq 10.8$	
	Q_y	$\simeq 9.4$	
Momentum compaction	α	0.0189	
Natural emittance	ϵ_x	281	nm
Energy spread	σ_ϵ	5.66×10^{-4}	
Energy loss per turn	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}	$\mathrm{cm}^{-2}\mathrm{sec}^{-1}$

Variation of parameters with energy

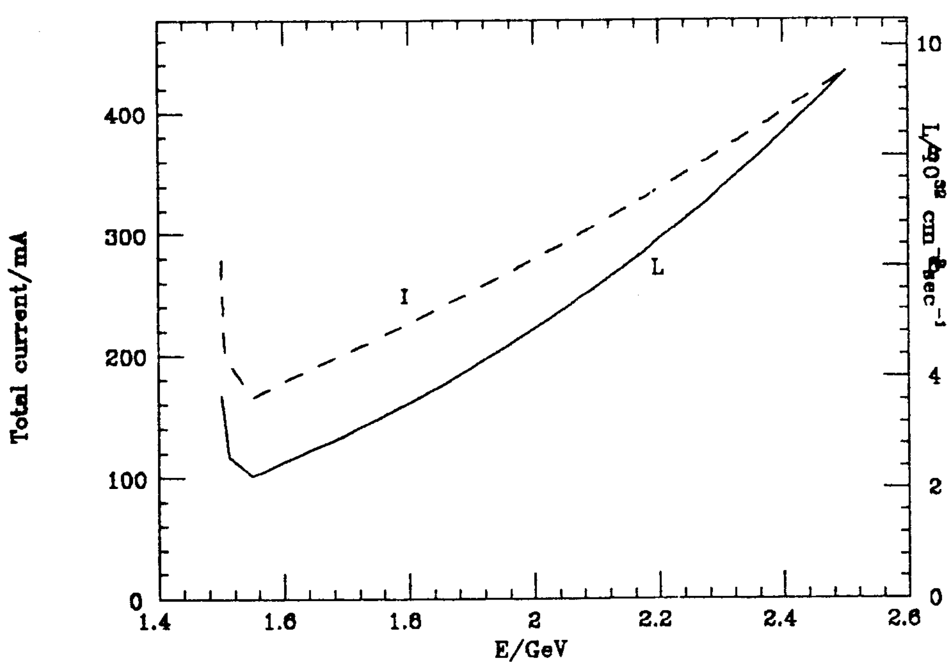




Longitudinal parameters



Beam current and luminosity



Conclusions

- Exploiting the best of current technology and experience, the τcF design luminosity appears feasible.
- The design needs more work, especially on the separator scheme and instabilities. That's what we're here for ...
- New or unconventional ideas (crab crossing, round beams, monochromator schemes, ...) should also be considered—there has to be a first time!
- The τcF has many of the same problems as hadron supercolliders on a smaller scale—it could serve as a test-bed.
- Efficient, high-performance injection system is vital!