A Tau-Charm Factory at BEPC

(Preliminary design and parameters)

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INTRODUCTION

Decisive progress in particle physics will require the exploration of two complementary fronters: high-energy and high-precision.

China is a developing country with limited economic power and at present there is no possibility to build a very large collider.

We have made a good starting point in the area of τ-charm physics research since the BEPC put in operation. In order to develop the physics research in this area, China has been thinking to build a τ-charm Factory in the BEPC site.

Considerable economies can be achieved by siting the τ-charm Factory (τcF) at BEPC. The injector system (linac) of BEPC can be used for the injector of the τcF and there are substantial opportunities to use hardware and existing buildings and other infrastructure for BEPC.

The collider rings would be located at the east site of the BEPC linac, where there are no any buildings except the conference hall. The site is about 190m long and 80m wide, which is very suitable to the shape of the τcF.

If the proposal to build the τcF in the BEPC site is approved, the BEPC storage ring will be changed as a dedicated sychrotron radiation facility.

Fig.1 shows the general layout of the τcF on the BEPC site. Fig.2 shows the schematic design of the storage ring.

The Design Goals

(1) maximum peak luminosity of 10 $^{33}cm^{-2}s^{-1}$ at the energy of 2.0GeV;

(2) rings capable of operating over the range $1.5 \leq E \leq 3.0$GeV;

(3) first-stage operation of the collider at 10 $^{33}cm^{-2}s^{-1}$ with a conservative design;

Subsequent operation of the collider with several upgrade options:

- monochromator optics to reduce the center-of-mass energy spread from 1 MeV to 0.1 MeV at the J/ψ resonance.
- longitudinal beam polarization.

(4) reliable operation.

General Description

Luminosity, assuming optimum coupling

$$L=\frac{I\gamma\xi_y}{2er_e\beta_y^*}(1+\frac{\sigma_y^*}{\sigma_x^*})$$

For flat beam, the luminosity

$$L\sim (I\xi_y/\beta_y^*)E$$

The strategy, adopted to achieve high luminosity is common to many other Factory designs: high current, multibunch and separate rings.

Comparison of the BEPC storage ring at E=2.0 GeV

	BEPC	τcF
Number of bunches K_b	1	32
Bunch separation S_b(m)	240.4	11.48
Particles/bunch N	2.16×10^{11}	1.32×10^{11}
Bunch Current I_b(mA)	45	17.16
Current/beam I(mA)	45	550
β-function β_y^*(cm)	6	1
Bunch length σ_z(cm)	4.5	<1.0
B-B parameter ξ	0.04	0.04
Luminosity L ($cm^{-2}s^{-1}$)	1.5×10^{31}	1.0×10^{33}

Comparison τcF with BEPC, the improvements in luminosity are due to:

(1) Increased beam current, with multi-bunch the improvement in I is 550mA:45mA, i.e. a factor 12.2;

(2) Using micro-β scheme to decrease the β-function, the improvement in β_y^* is 1cm:6cm, i.e. a factor 6.

These factors combine to give an overall luminosity increase over BEPC of about 74. So it's possible to design a τcF with a luminosity of $10^{33} cm^{-2} s^{-1}$ using known collider design principle.

The design luminosity would be expected energy dependnce as E^2 below 2.0 GeV.

The average luminosity would be maintained at 70~ 75% of the peak luminosity.

The Lattice Design and the Storage Ring

The collider consists of two rings, one above the other, with one interaction point (IP). Each ring is 61.4m wide and 143.4m long with a circumference of 367.5m.

There are 32 bunches with about 1.32×10^{11} particles per bunch, the total current per beam is 550 mA and the bunch separation is 11.5m.

Fig.3 shows the lattice of half of one ring.

One long utility straight section contains the wigglers and RF cavities. The opposite straight section is about 48m long and contains the interaction point, micro-β insertion and electrostatic vertical separators, the vertical separation and RF cavity section.

(1) Interaction region

As shown in the Fig.4, the interaction

region contains micro-β insertion, e^+ e^- orbits separation section and the β-function matching section. A superconducting micro-β quadrupole doublet is used to achieve low β-function at IP.

After the head-on collision at IP, the orbits of e^+ and e^- are gradually separated by an electrostatic separator ES, two vertical septum magnets BV1 and BV2, and a vertical bending magnets BV3. The two rings are vertically separated 1.46m. The two beams are separated by 2.5 σ_x for standard mode and $11\sigma_x$ for monochromator scheme in the parasitic interaction point which is 5.74m ($S_b/2$) away from the IP.

Six quadrupoles are used to finish focusing and vertical dispersion matching between BV2 and BV3. The quad. Q_7 will be switched off and Q_8 will be changed polarity in the monochromator scheme.

(2) Arc region

The arc region consists of seven non-standard FODO cells in which more inde-

pendent power supplies of quad.s would be used to adjust beam parameters. The experience of BEPC shows that the non-standard cells make the lattice very flexible. Each bending magnet gives the bending angle of 7.5^0. One bending magnet is missed in the sixth cell and replaced by a Robinson wiggler.

The emittance control strategies include: changing the phase advance per cell, adjusting the maximum dispersion D_x and using Robinson wigglers and damping wigglers. The emittance can be varied from maximum 550nm (2.0 GeV) to 10nm (1.55 GeV).

Fig.5 and Fig.6 show the lattice of the storage ring.

Instability Control

(1)Multibunch instability

The coupled-bunch instabilities in the τcF are a potentially serious problem due to large currents of about 550mA, distributed into 32 bunches spaced by 11.5m.

The important mean to control this instability is to reduce the impedance of the RF system.

A superconducting cavity would be better than warm cavity to control the multibunch instability. Such a cavity can provide a large accelerating voltage gradient which leads to reduce the number of cavities, and therefore results in a lower machine impedance. Furthermore a superconducting cavity has a large aperture, which reduces the parasitic impedance due to higher order modes(HOM).

Even if the HOM's in the accelerating cavities are heavily damped there are some unstable modes which have a rise-time faster than the natural damping time. Therefore, a powerful active feedback system is necessary.

(2)Bunch lengthening

In order to match a very low β_y^* value, the length σ_z should be:

$$\sigma_z \leq \beta_y^*$$

The most important topic is to minimize the longitudinal impedance $|Z/N|$ so that short bunch length could be maintained.

The Keil-Schnell-Boussard criterion for the absent of turbulent bunch-lengthening gives a relation between $|Z/N|$ and I

$$\mathrm{I}_b \leq \frac{\sqrt{2\pi}\sigma_z \alpha_p (E_0/e)\sigma_\epsilon{}^2}{R|Z/N|}$$

Applying this at top energy, we find

$$|Z/N| \leq 0.32\ \Omega$$

To achieve this value will require that all vacuum system components, including RF cavities, kickers, separators and vacuum bellows must be designed to minimize the cross-sectional variations. The transition between different size chambers will have to be very smooth and gradual. The bellows and pump-out ports will be shielded.

The careful design of a smooth vacuum chamber and the use of RF cavities with a smoothed shape make it possible to have a low impedance of 0.32 Ω.

Injection Scheme

The BEPC injector system would be improved in order to be adequate for the required luminosity of the τcF.

The linac of BEPC would be upgraded as a full energy injector of the τcF in order to finish the positron injection in 5 minutes and to get higher average luminosity.

The repetition rate of the linac would be increased to 50 Hz.

The electron energy on the e^+ target would be upgraded from now 150 MeV to 300 Mev with the 65 MW klystrons.

A high current electron gun would be developed to increase the electron strength on the e^+ source.

The injection scheme consists of producing a train of 3 or 4 micropulses to be injected simultaneously in the storage ring bucket equally spaced on one train.

The expected injection parameters are following.

No. of e^+ per beam to be stored	4.2×10^{12}
Injection repetition rate (pps)	50
Electron energy on the e^+ target	300MeV
No. of e^- per pulse on the target	4×10^{10}
The positron yield (e^+/e^-,GeV)	0.025
No. of micropulses	4
The filling efficiency	20%
The full fill time (minute)	4.9

Engineering Design and R & D Program

Although the design of the τcF is based on known accelerator technology and on existing collider design principles, some challenging work remains to be done in details. the engineering design and R & D phase are required.

(1) Some of machine physics issues of τcF will be studied in the BEPC storage ring.

(2) Detailed design of superconducting magnets and specific wiggers.

(3) Careful design of superconducting RF cavity and vacuum chamber are necessary to avoid high order oscillation modes.

(4) Development of low-impedance vacuum chamber, separator and kicker.
Detailed estimates and measurements of the impedance due to the various components of the machine.

(5) Design a fast and powerful feedback system for controlling multibunch instabilities.

The R & D program and construction of the τcF would be done on the collaboration with other laboratories.

The Schedule and Preliminary Cost Estimate

The timescale is to complete the R & D in 2 or 3 years and the estimated construction period is ~4 years after the approval.

The use of the BEPC injector system and existing infrastructure and facilities at BEPC would be much cheaper than at "green field".

Preliminary cost estimte for Beijing TcF

(M RMB)

(1)	Civil construction:	170
(2)	Storage ring	363
	Superconducting quad.s	18
	Convential magnets	70
	RF system	120
	Vacuum system	75
	Mechanical system	15
	Beam diagnostic and control system	65
(3)	Injector upgrading	35
(4)	Detector	300
(5)	Unpredictable cost	100
	Total cost	968

CONCLUSIONS

A τ-charm Factory with a C.M. energy of 4 GeV and a luminosity per interaction region of $10^{33} cm^{-2} s^{-1}$ is feasible on a rather conventional basis of multibunch head-on collision scheme together with a micro-β insertion.

To reach such a goal with limited risk, it is essential to incorporate the advanced experience of different improved technological achievements made on most successful machines.

Some challenging work on the design of the τ-charm Factory need to be studied in details.

Parameters of Beijing τcF

	Quantity	Sign	unit	Standard	Monochromator
	Beam engery	E_0	GeV	2.0	1.5
△	Circuference	C	m	367.5	367.5
	Bending radius	ρ	m	9.93	9.93
△	β-function at IP	β_x/β_y	m	0.2/0.01	0.01/0.15
	Dispersion at IP	D_y^*	m	0.0	0.35
	Momentum compaction	α_p		0.022	0.008
△	Natural emittance	ε_x	nm	251	10 (J_x=2)
	Vertical emittance	ε_{yc}	nm	12	2
	Energy spread	σ_ε		5.4×10^{-4}	8×10^{-4}
	Energy loss per turn	U_0	keV	142.6+wiggler	45+wiggler
	Transverse damping	τ_x/τ_y	ms	17/34 (wiggler)	20/52 (wiggler)
△	RF frequency	f_{RF}	MHz	499.58	499.58
△	RF Voltage	V_{RF}	MV	9.00	2.70
	Numbers of bunches	k_b		32	32
△	Bunch spacing	S_b	m	11.5	11.5
△	Total current/Beam	I	mA	500	215
	Particles/Bunch	N		1.32×10^{11}	5.14×10^{10}
	RMS bunch length	σ_z	cm	1.00	0.78
	Longitudinal broadband impedance	$\lvert Z/n \rvert$	Ω	0.32	
	Beam-Beam parameter	ξ_x/ξ_y		0.04/0.04	0.031/0.015
	Beam life time	τ	hr	4.8	1.5
	Transvers Betatron tune	Q_x/Q_y		11.192/10.192	13.12/8.47
	Synchrotron tune	Q_s		0.098	0.068
	Natural Chromaticity	Q'_x/Q'_y		-26.6/-32.0	-35.9/-44.5
△	Luminosity	L	$cm^{-2}s^{-1}$	1×10^{33}	2.2×10^{32}
△	CM energy spread	σ_E	MeV	1.53	0.105

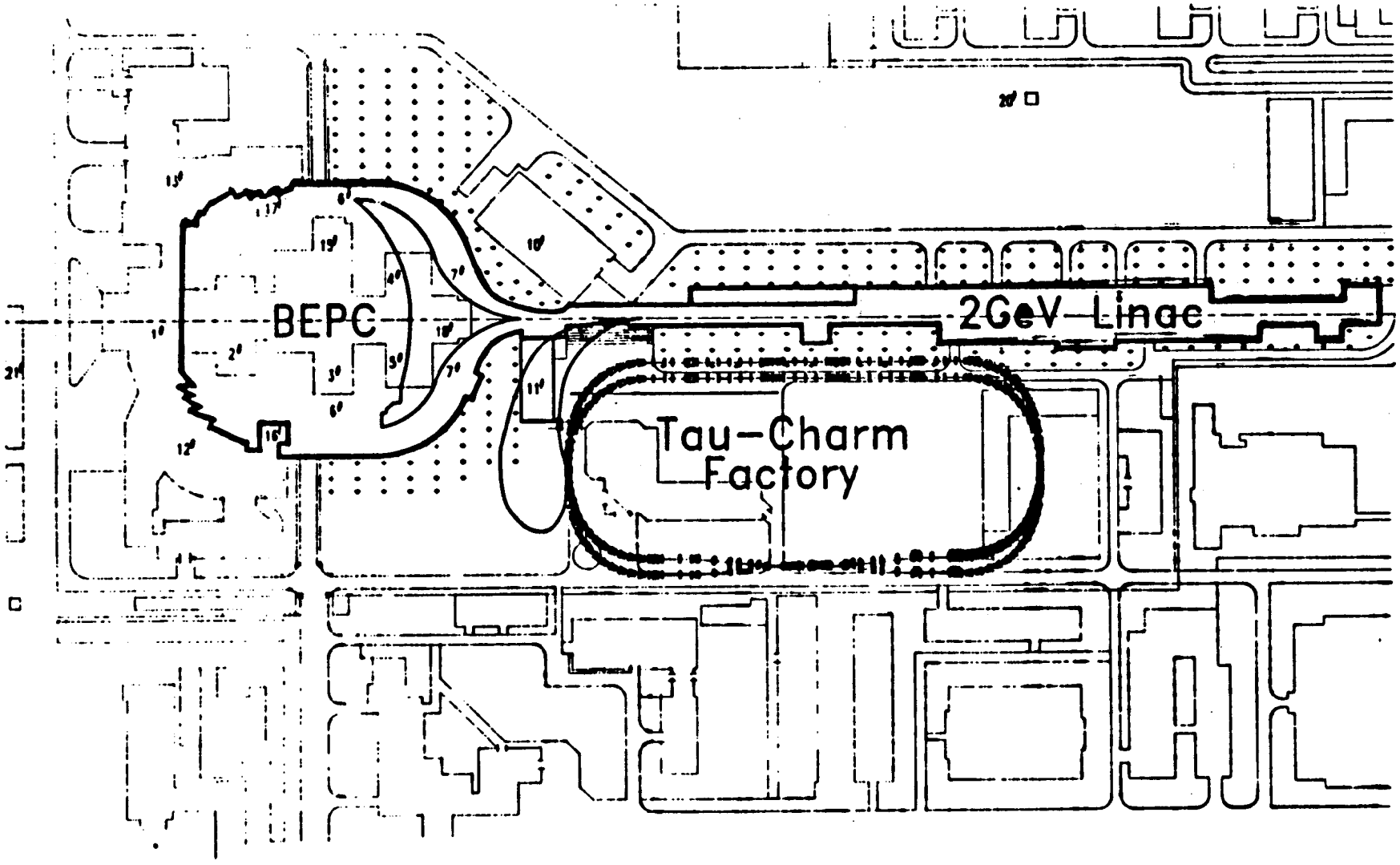

Fig 1. General layout of the TcF on BEPC site

long axis : 143.49 m
Minor axis : 61.42 m

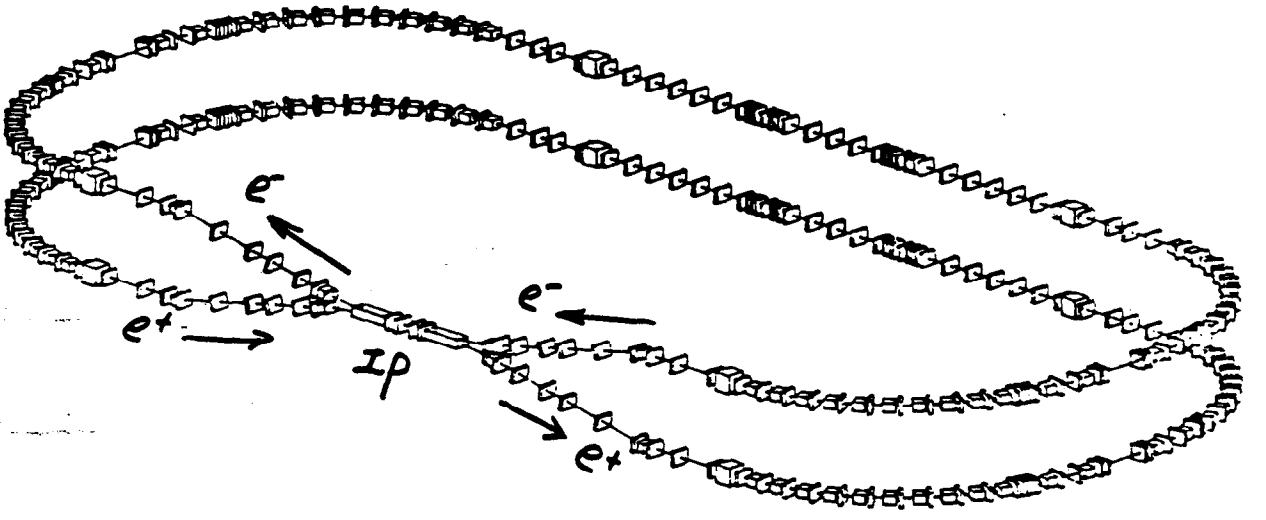

Fig.2 Schematic layout of the storage ring of Beijing τcF

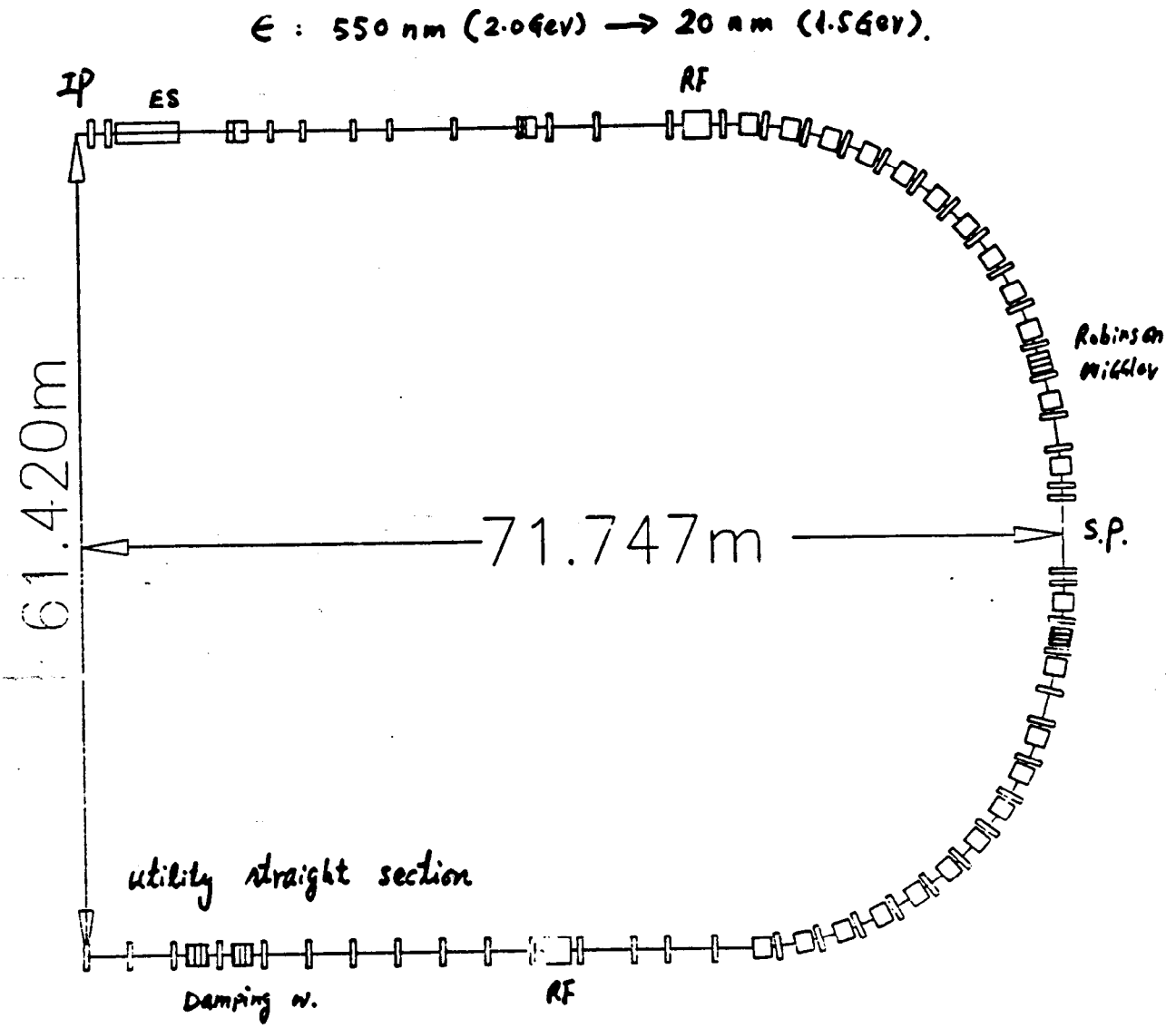

Fig.3 Schematic layout of the storage ring of Beijing τcF

micro-β insertion (2 superconducting quads)

$e^+ e^-$ separation (ES, BV1, BV2, BV3)

β-function matching ($Q_3 - Q8$)

first parasitic interaction point is 5.74m away from IP.

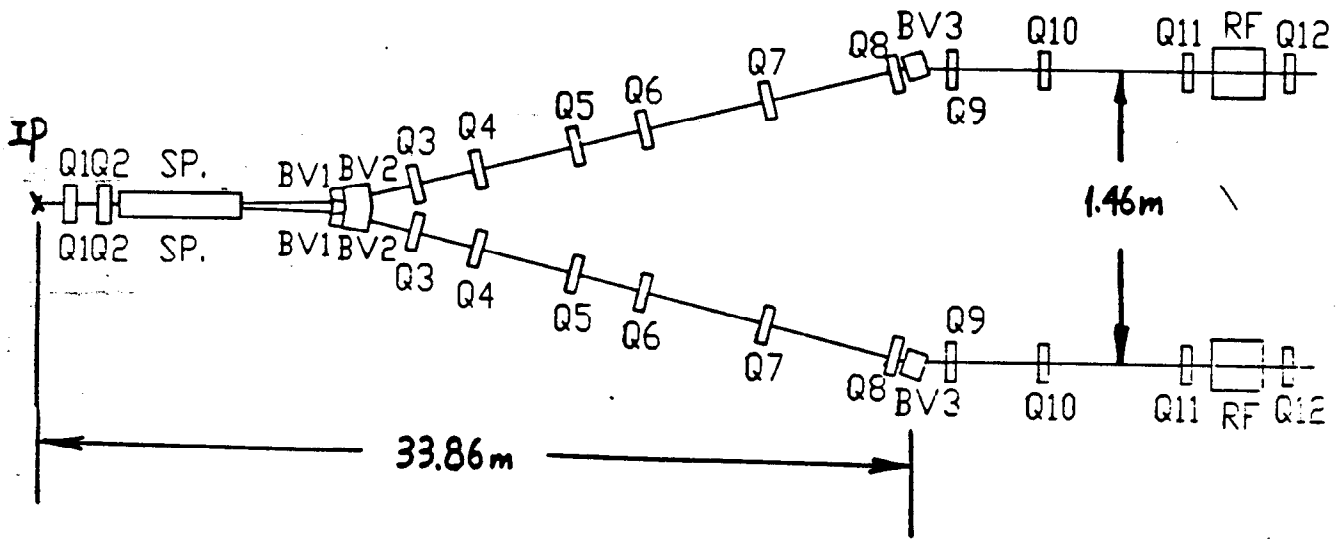

Fig.4 Interaction region

(micro-β, e^+e^- separation, β-function matching)

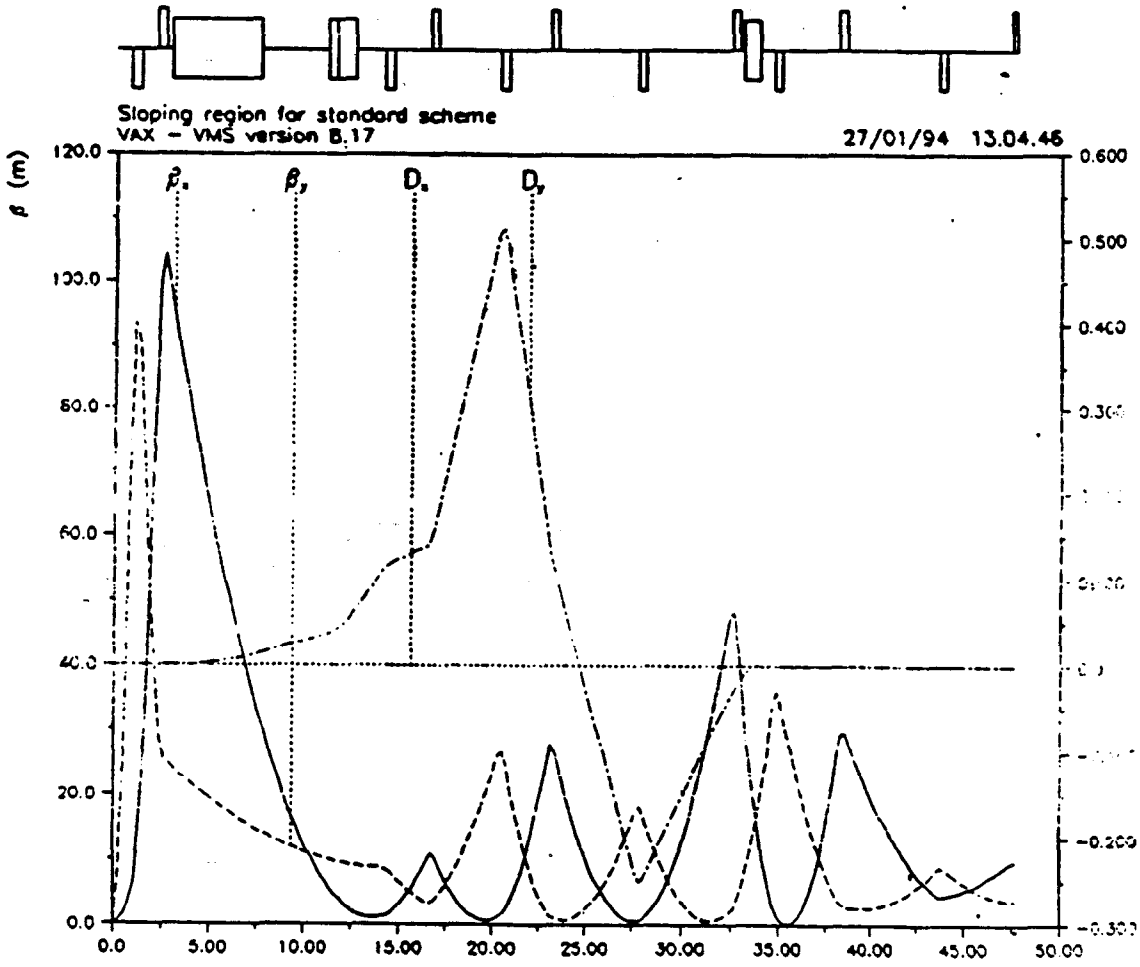

Fig.5a The lattice of the interaction insertion (standard optics)

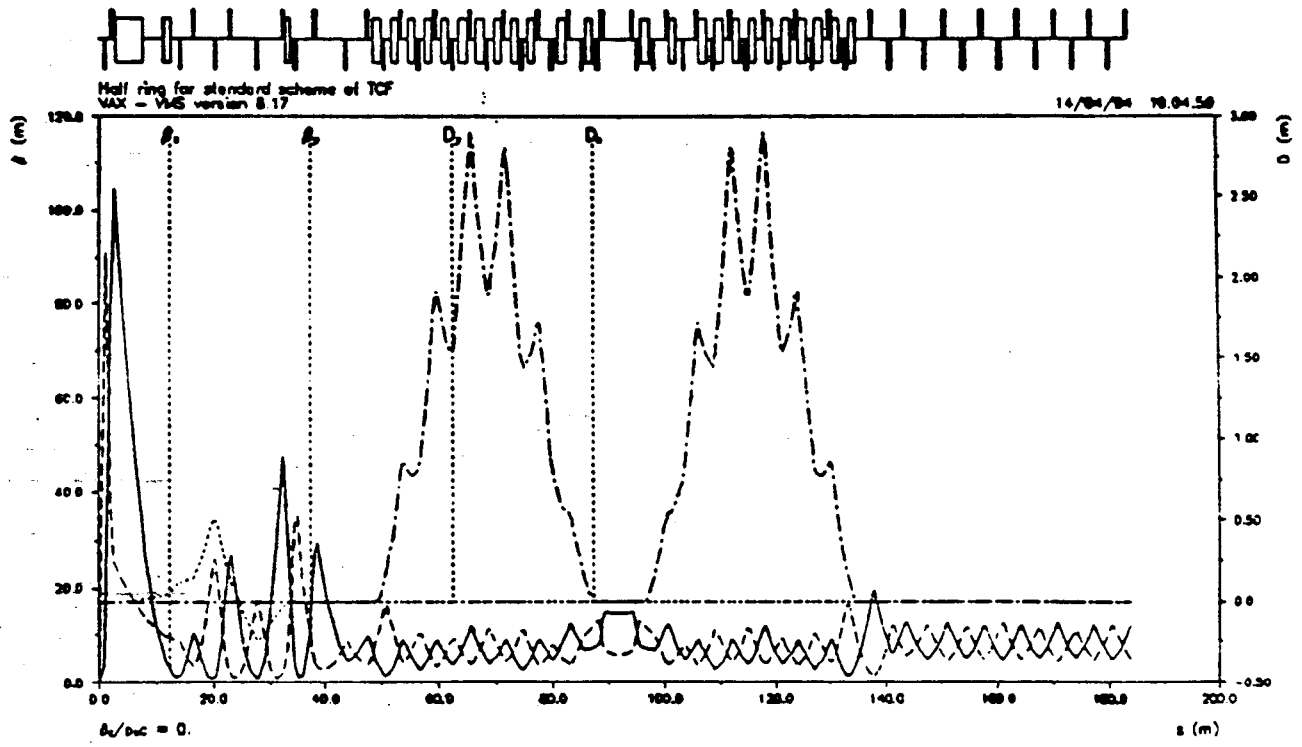

Fig5. The lattice of half of one ring (standard mode)

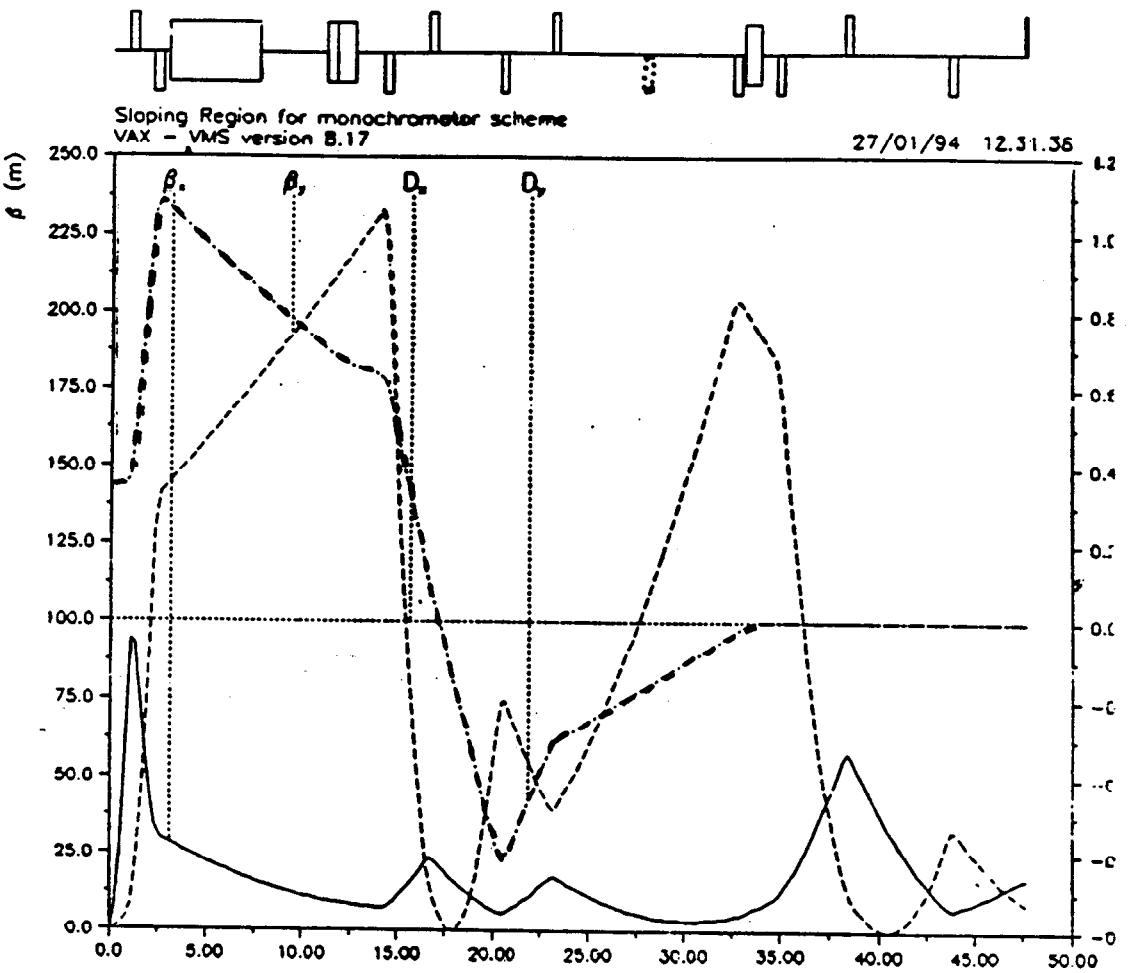

Fig.6a The lattice of the interaction insertion (monochromator optics).

$D_y^* = 0.35\,m$, $D_x^* = 0$

Q1. Q2. Q8 : changing polarity

Q7: switching off.

low ϵ (10 nm)

$\beta_x^* = 1\,cm$, $\beta_y^* = 15\,cm$

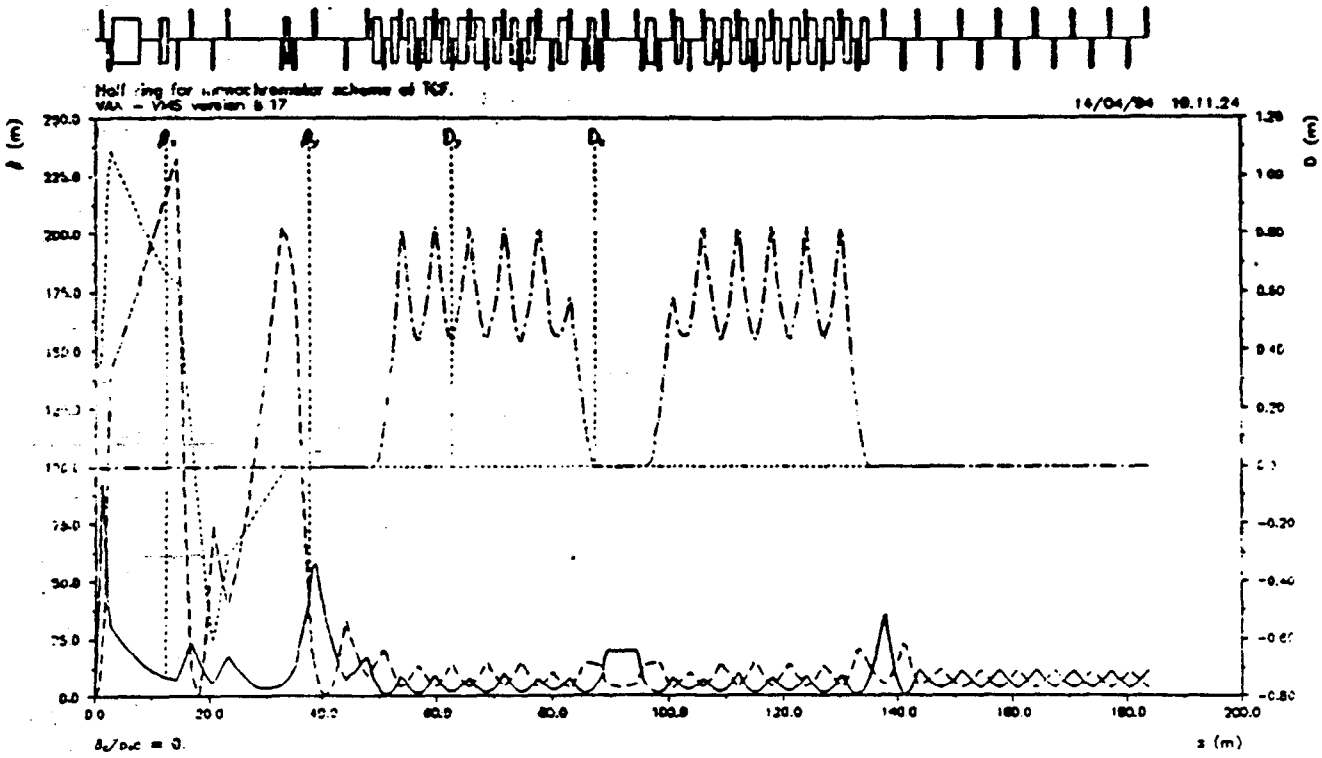

Fig.6 The lattice of half of one ring (monochromator mode)