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MODERN VIEW ON TAU-CHARM FACTORY DESIGN PRINCIPLES

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1 Introduction

Presently two tau-charm factory (TCF) projects with a centre-of-mass energy range 3-5.7 GeV are being studied. The first one aims at CERN-ISR site, so taking advantage of the existing powerful injector, and the second one is directed towards construction at Dubna. These projects have many common features, apart from the site, because of well identified constraints and a strong collaboration between designers.

The requirements for TCF physics, machine and detector have been discussed at many workshops [1],[2], [3],[4],[5]. The numerous requirements for TCF physics put difficult constraints on the machine. They are summarized as follows:

- The peak luminosity must be around the tau-lepton production threshold energy of E$\simeq$2 GeV (E being the beam energy) and higher than 10^{33} $cm^{-2}s^{-1}$;
- The TCF must provide a high average luminosity, of the order of half the peak luminosity;
- High luminosity must be provided in a wide energy range from E$\simeq$1.5 GeV (J/ψ physics) up to 2.85 GeV (charmed baryon physics);
- Around specific energies (i.e. J/ψ resonance and tau pair production threshold) a centre-of-mass energy resolution of 100 keV or less is desirable which requires beam monochromatization;
- Polarized beams simultaneously with monochromatization are also of a special interest.

Up to now there are many proposals on the TCF schemes. The first one proposed by J. Jowett for the CERN site [6] gave the main principles for such a factory. The main requirement that still remains valid is the use of a conservative approach. More detailed studies based on the conventional design have been performed at LAL [7], SLAC [8] and JINR [9]. These designs provide luminosities close to 10^{33} cm^{-2} s^{-1} without monochromatization. Another approach has been suggested to design the TCF on the basis of a monochromator optics [10].

In developing these designs, versatile lattices allowing the different schemes listed above, were proposed [11],[12],[13],[14],[15]. Based on different regular cells in the arcs, they have common ability to change the emittance by 15$\div$20 times, giving easy opportunities to switch from one mode of operation to another.

Crossing angle scheme is also very attractive for a tau-charm collider, since it allows to increase the number of bunches in each ring and, consequently, the luminosity [16],[17],[18],[19].

At present we have three possible phases for the TCF project:
- phase 1 is based on a conventional scheme;
- phase 2 is based on a monochromatization scheme;

- phase 3 is a crossing angle scheme which provides a luminosity of $3 \div 5 \cdot 10^{33}$ cm^{-2} s^{-1}.
The order of priority for phases 2 and 3 can be defined later, but phase 1 remains the first priority on a time schedule.

2 Versatile Scheme Design

2.1 Conventional TCF Scheme with CERN-PS as Injector

It was announced at the Marbella workshop [3] that the European TCF community should reconsider the CERN site. Such a choice using the ISR tunnel and the LEP injector (Fig. 1) is presently seen as the most cost effective and time approach to TCF physics in Europe, resulting both from the existing infrastructure at CERN and from the existing injector.

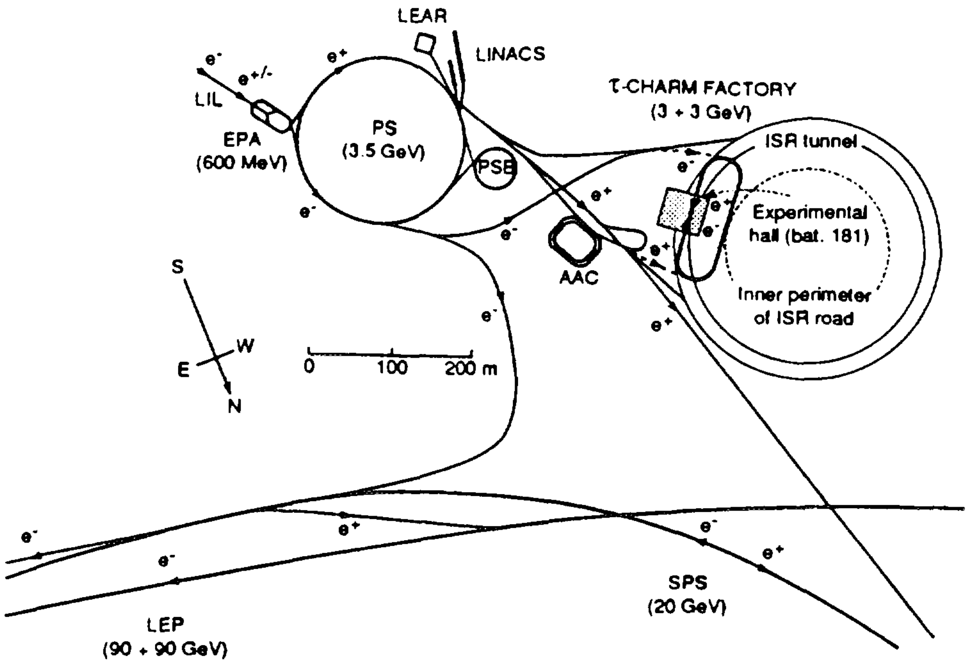

Fig. 1. The layout of the tau-charm Factory on the CERN ISR site, presented at Marbella workshop [3]

Using the CERN-PS as an injector introduces some constraints to the collider design parameters. For instance the TCF circumference must be in relation with that of the PS in order to fill the collider with an even bunch distribution. The value of 359.04 m is the best one. It allows to fill the TCF orbit with 32 bunches in 4 PS cycles giving a bunch spacing large enough to avoid parasitic bunch crossings in the conventional scheme with electrostatic separators. This value for the circumference leads to the following relation between RF frequencies: f(TCF)=21/5 f(PS)$\simeq$480.9 MHz. The harmonic number, q=576, is suitable for the conventional scheme, as well as for the crossing angle one which will be discussed later on.

The TCF operation starts with phase 1. To get the luminosity at the level of $10^{33}cm^{-2}s^{-1}$ at 2.0 GeV, an emittance close to 400 nm is required. In the design prepared for the TCF in Spain[20], as well as for the Dubna lattice[14], regular FODO cells with 60° horizontal phase advance in the arcs are used. The natural emittance generated in the horizontal bending magnets is about 100 nm. The increase of the emittance up to the required value is made by using dipole and Robinson wigglers, located at dispersion suppressors. The parameter list for this conventional scheme, at the energy of 2.0 GeV, is given in Table 1.

2.2 Luminosity versus Energy in Conventional Scheme

A lattice design based on the use of different types of wigglers is very convenient for a collider operating over a wide energy range with a peak luminosity at intermediate energy and a slow decrease at other energies. Two examples are considered below which demonstrate the high efficiency of this approach.

If the accelerator operates below the nominal energy of 2.0 GeV, it is desirable to provide an E^2 luminosity dependence by keeping the emittance constant with the help of wigglers. On the other hand, at energies above the nominal one, for example 2.85 GeV, and constant RF power, it is possible in principle to provide a luminosity which falls down as E^{-3}. To get this luminosity variation it is necessary to keep the beam-beam parameter constant by an appropriate reduction of the emittance, $\epsilon_x \propto E^{-5}$, with wigglers. The dependence of, the TCF luminosity on the energy is shown in Fig. 2.

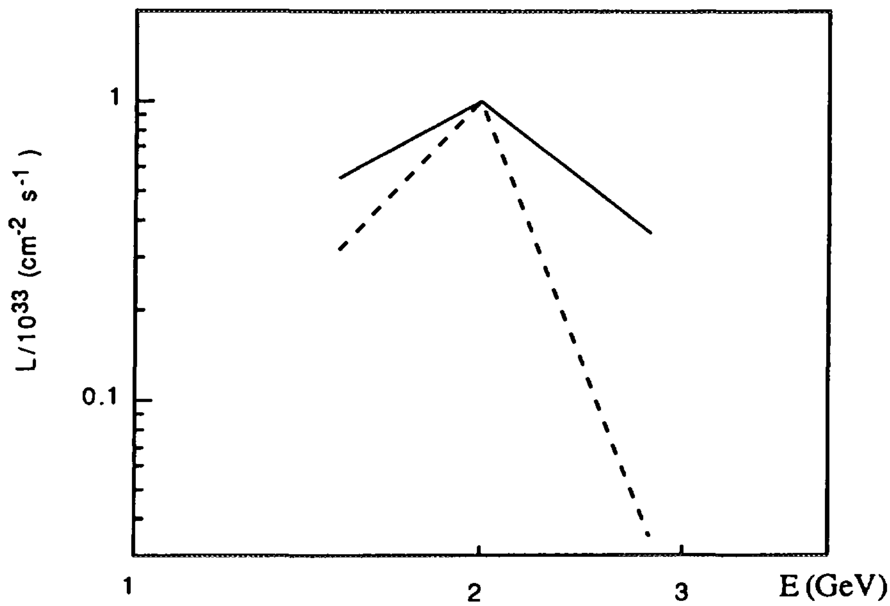

Fig. 2. Luminosity versus energy with constant emittance below nominal energy and constant RF power and beam-beam parameter above nominal energy. Dotted lines show natural luminosity variations without emittanve control.

		Standard scheme	Monochrom. scheme	Cros. angle scheme
Beam energy, GeV	E	2.0	2.0	2.0
Luminosity, $cm^{-2}s^{-1}$	L	$1.0\cdot10^{33}$	$1.0\cdot10^{33}$	$3.6\cdot10^{33}$
C.M. energy resolution, MeV	σ_w	1.8	0.14	1.6
Circumference, m	C	359	359	359
Natural emittance, nm	ε_0	378	17.0	225
Vertical emittance, nm	ε_y	19 *	2 †	5 ‡
Damping partition numbers	$J_x/J_y/J_\varepsilon$	0.58/1/2.42	2/1/1	0.66/1/2.34
Bending radius in arc, m	ρ	10.5	10.5	10.5
Damping times, msec	$\tau_x/\tau_y/\tau_s$	39/23/9	17/34/32	37/24/10
Momentum compaction	α	$1.67\cdot10^{-2}$	$8.43\cdot10^{-3}$	$1.67\cdot10^{-2}$
Energy spread	σ_E	$6.23\cdot10^{-4}$	$7.31\cdot10^{-4}$	$5.59\cdot10^{-4}$
Total current, A	I	0.564	0.537	2.0
Number of particles per bunch	N_b	$1.32\cdot10^{11}$	$1.26\cdot10^{11}$	$0.78\cdot10^{11}$
Number of bunches	k_b	32	32	192
RF voltage, MV	V	8	5	7
RF frequency, MHz	f_{RF}	481	481	481
Harmonic number	q	576	576	576
Energy loss per turn, kV	U_0	211	142	196
Bunch length, mm	σ_s	7.43	8.01	7.13
Bunch spacing, m	S_b	11.2	11.2	1.9
Required long. impedance, Ohm	$\lvert Z_n/n \rvert$	0.24	0.19	0.31
Beta functions at I.P., m	β_x^*/β_y^*	0.20/0.01	0.01/0.15	0.50/0.01
Vertical dispersion at I.P., m	D_y^*	0.	0.36	0.
Beam-beam parameters	ξ_x/ξ_y	0.04/0.04	0.04/0.03	0.04/0.04

Table 1: List of parameters of tau-charm collider

Clearly, wigglers will contribute to give high flexibility to the design, which is very important for the collider operation over the desirable wide energy range.

2.3 Rearrangement to Monochromatization Scheme

To proceed with phase 2 (small energy resolution experiments) it is necessary to switch from the conventional scheme to a monochromator optics. At this moment, the versatile lattice proposed by P. Beloshitsky [14] can be taken for further considerations. To rearrange the conventional scheme into the monochromatization one, it is necessary to change the phase advance in the regular cells from 60° to 90°, to switch-off the dipole wigglers

*for coupling factor κ=0.05
†with wigglers
‡for coupling factor κ=0.05

and to switch-on the Robinson wigglers. The overall procedure leads to a decrease of the emittance down to 15÷20 nm. The location of the arc elements is not changed, but the vertical separation region should be modified. It should be shortened compared with the conventional scheme to generate essentially non-zero vertical dispersion at the interaction point (I. P.) and make optical matching and chromatic correction easier. The orbit length remains practically unchanged meanwhile. The list of parameters of the collider with monochromatization scheme is given in Table 1.

3 Crab-Crossing Design for TCF

3.1 Crab-Crossing Scheme and Versatility

The crab-crossing option is considered here as a possible TCF upgrade that should be implemented in the phase 1 of the project. To change from the conventional scheme to a finite horizontal crossing angle, it is necessary to modify the interaction and the separation regions while keeping the arcs and the long straight section opposite to I. P. untouched. Using the same arcs requires to bring the beam orbits to the same vertical plane, at least at the ends of the insertion region. It puts strong restrictions to optical matching, and the orbits snake in both planes, as shown in the Fig. 3. Consequently, the TCF circumference becomes longer, and the tuning of the RF frequency becomes necessary.

3.2 Optics in TCF Crab-Crossing Scheme

Among the various horizontal crossing angle solutions, the one which uses the first micro-beta insertion quadrupole Q1 (Fig. 3) common for electron and positron beams while separating the other magnetic elements, gives a maximum luminosity with minimum total current [19]. Calculations show that it is possible (and good) to use in the crab-crossing scheme an additional compact permanent quadrupole QPM located just in front of the quadrupole Q1 to help in the vertical focussing and to amplify the horizontal beam separation. As well as quadrupole Q1, quadrupole QPM is common to both beams. The insertion optics has been chosen similar to the Cornell B-Factory proposal [21]. The positions and the lengths of quadrupoles QPM and Q1 are the same as in the conventional design lattice, and have been taken directly from the machine-detector interface considerations, discussed at the Marbella workshop [22]. The long drift space after quadrupole Q1 provides enough horizontal beam deviation to have two vacuum chambers starting at the horizontally focussing quadrupole Q2 which is located 2.3 m from I. P.

The value of the crossing angle, $\phi = \pm 12$ mrad, has been chosen as a compromise between fast beam separation necessary to separate vacuum chambers in quadrupole Q2 and reasonable orbit excursion in quadrupole Q1. After Q1, the deflecting angles become ± 37 mrad and the horizontal distance between the beam axes at the entrance of Q2 is of 118 mm.

According to the TCF parameter list, the ratio of horizontal beam size to the bunch length at I. P. is approximately 4 times bigger than the crossing angle ϕ, probably allowing to avoid synchro-betatron coupling. Nevertheless, special places with appropriate horizontal phase advances $\mu_x = \pm 2\pi \times 1.75$ are foreseen for the RF crab cavity location in

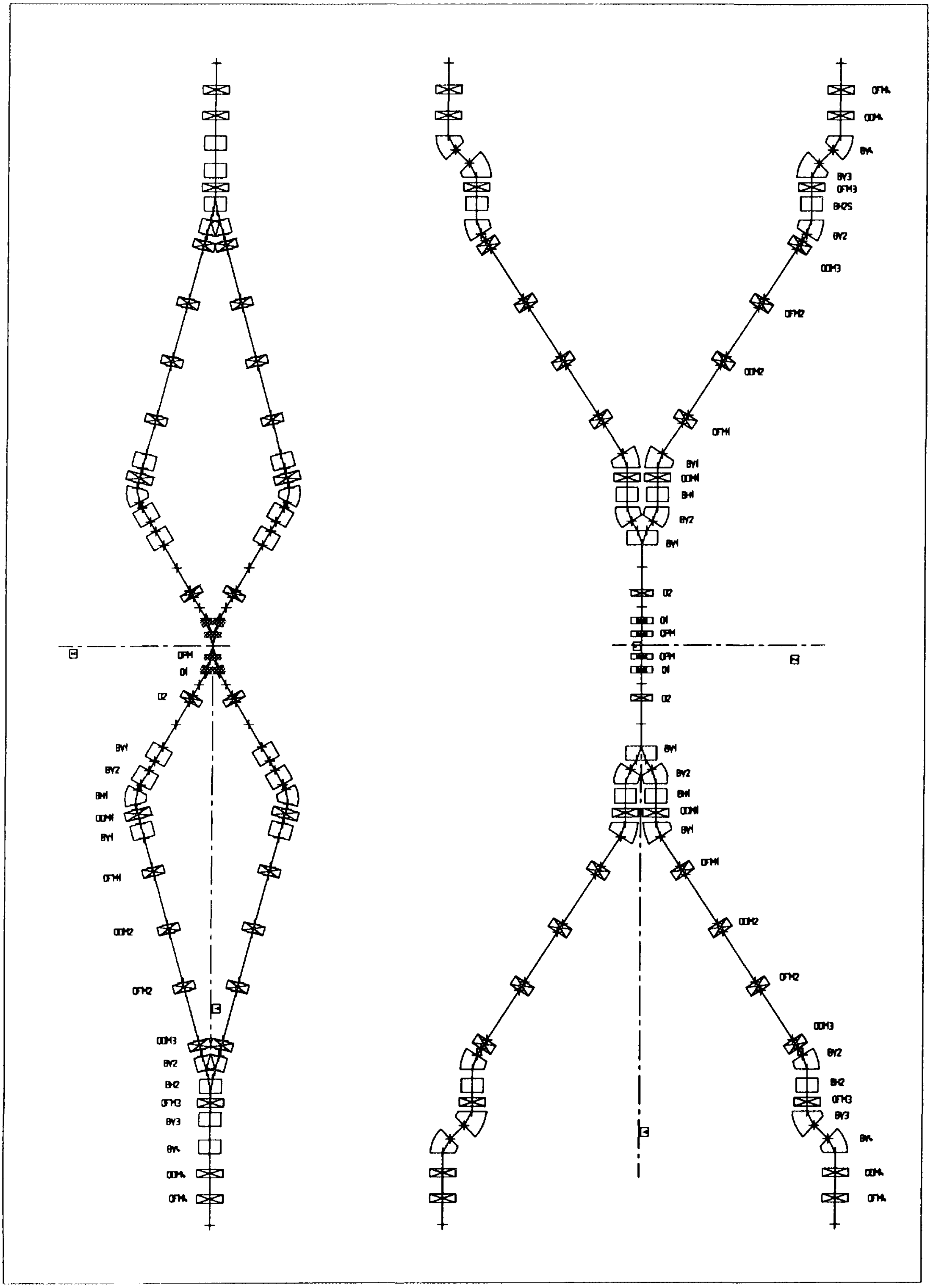

Fig. 3a. Horizontal and vertical interaction region view in crossing angle scheme

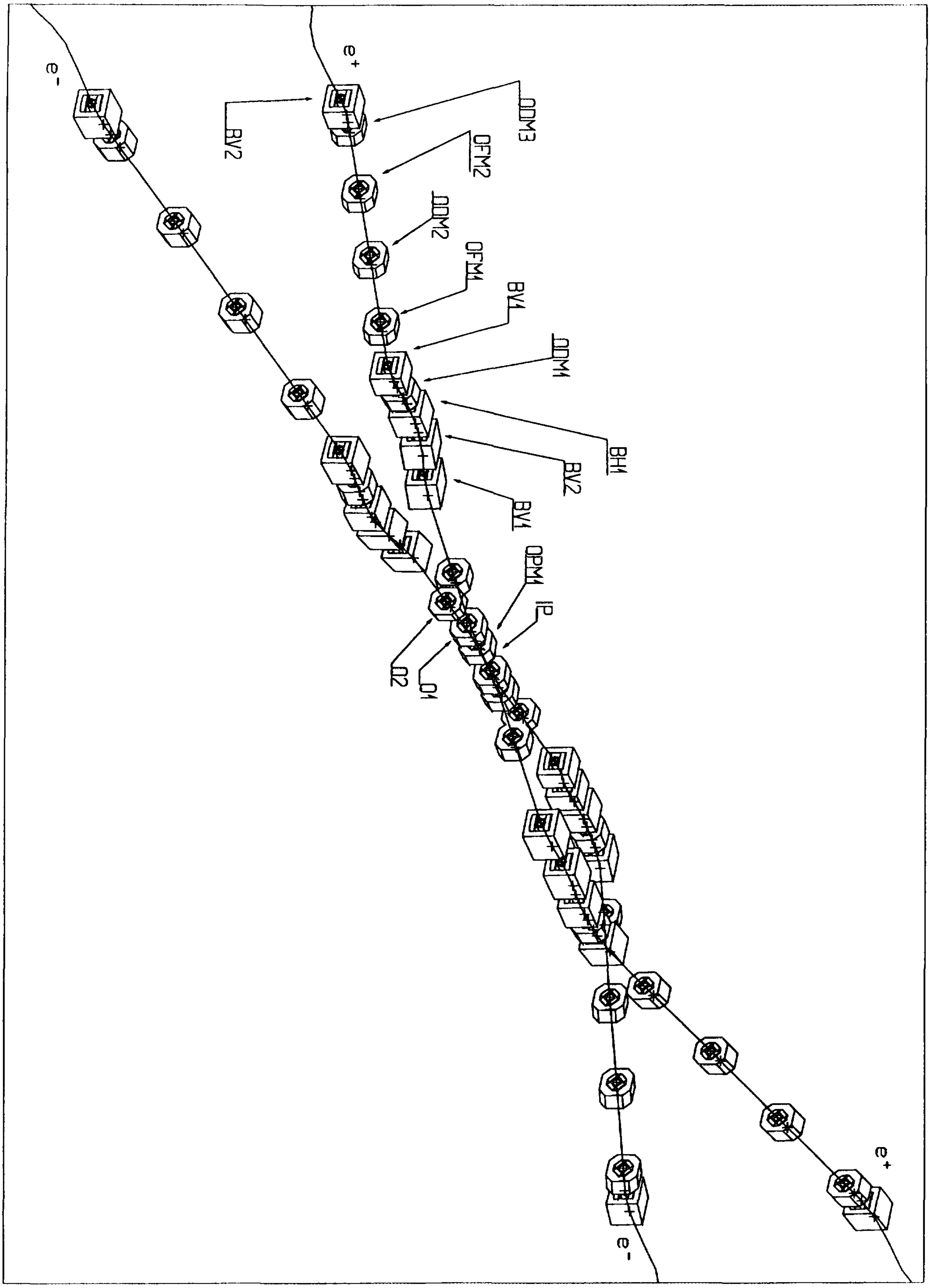

Fig. 3b. Interaction region layout in crossing angle scheme

the optical design. The value of the horizontal beta function at the crab cavity position is 12 m, and 1.0 MV crab cavity voltage is necessary to tilt the bunches.

3.3 Choice of Parameters for Crab-Crossing in TCF

Each 18^{th} RF bucket is occupied when the conventional scheme with CERN-PS as an injector is used. To increase the number of bunches with the crab-crossing scheme, each third RF bucket is filled with particles. A choice for the number of bunches k_b=192 was made as a compromise between the number of parasitic crossings and the bunch current. Four parasitic crossings located symmetrically are obtained in the present case. The ratio between beam axis distance to beam horizontal size, at these points, are $2\Delta x/\sigma_x$=32 and 33 respectively.

The value of β_y^* =0.01 m is the same as in the conventional scheme in order to get high luminosity with relatively small current. This is possible, since no additional problems appear with chromatic correction in the crab-crossing scheme. Final focus chromaticities in this case are very close to those of the conventional one. The results of chromaticity correction in the conventional scheme show [23] that it is possible to get large energy acceptance, $\delta p = \pm 1.8\%$, and hence, good beam lifetime for the 60° lattice.

With the previous number of bunches it is possible to increase the luminosity in principle by factor 6, leading to a total beam current of 3.4 A. However, the safer value of 2.0 A was adopted as the design parameter. For a beam-beam parameter equal to 0.04, an emittance of 223 nm is required, which is quite easy to get with 60° lattice by properly adjusting the wigglers. As a result, a luminosity of $3.6 \cdot 10^{33}$ cm^{-2} s^{-1} is achieved.

4 Conclusions

The Tau-Charm Factory satisfying most of the physics requirements could be designed now on the basis of update work made at various institutes. To perform the different physics programs the TCF design includes a versatile magnet lattice, which provides the different modes of operation (conventional, monochromatatic and crossing angle ones). For further accelerator physics and engineering studies the Dubna TCF design is quite suitable. It provides a luminosity of about 10^{33} cm^{-2} s^{-1} for the first phase, a centre-of-mass energy resolution of 100 keV with monochromatization, and a luminosity of about $3.6 \cdot 10^{33}$ cm^{-2} s^{-1} with a crossing angle scheme.

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