A COMBINED SYMMETRIC AND ASYMMETRIC B-FACTORY WITH MONOCHROMATIZATION

A.N. Dubrovin and A.A. Zholents

Institute of Nuclear Physics, 630090 Novosibirsk, USSR

Abstract. A new approach to the design of a high luminosity electron-positron collider is considered. The distinctive feature of the approach is the use of a large dispersion function at the collision point. This fact allows us to have a high luminosity as well as a good monochromaticity of electron-positron collision energy. The application of the approach to the B-factory design is considered. We receive the luminosity of 5×10^{33} $cm^{-2}s^{-1}$ and c.m. energy spread of 1 MeV in a case of asymmetric 6.5x4.3-GeV beams. The symmetric variant with beam energies of 4.7x4.7-GeV will have the luminosity of $2\times10^{33} cm^{-2}s^{-1}$ and c.m. energy spread of 60 keV. Two variants differ mainly in the ways of the beam final focusing and in the method of the beam separation after collision.

I. INTRODUCTION

B-factory is a high luminosity electron-positron collider intended for operation in the c.m. energy W = 9.5 - 13 GeV. Design motivations are specified mainly by the desire for observation of *CP* violation in the B-meson system. Precise measurements of rare decay modes of $\Upsilon 1S$, $\Upsilon 2S$, $\Upsilon 3S$ resonances, B-mesons and B-barions are also considered as the primary goal.

The luminosity requirements for definitive *CP* violation measurement are minimized by having a moving c.m. at the peak of $\Upsilon 4S$, which implies two rings with unequal beam energies. In spite of the relatively wide width of $\Upsilon 4S$ resonance a monochromatization is used here for better resolution of B-meson masses. We would expect to run the rings with the minimum asymmetry 6.5 GeV on 4.3 GeV that allows a good *CP* violation measurement [1], although a more costly choice 7 GeV on 4 GeV is also possible.

$\Upsilon 1S$, $\Upsilon 2S$, $\Upsilon 3S$ resonances are very narrow. Only few percents of the luminosity are used for generation of these resonances. The monochromatization is the only way to increase the useful luminosity here. We found that best results for the monochromatization level can be obtained in a symmetric variant of a B-factory. Maximum c.m. energy is also available easier in this case.

Our studies show that asymmetric rings have a potential to higher luminosity than symmetric rings. But there is no actual demonstration that it is true. If that fails, we would use the familiar symmetric mode 5.32 GeV on 5.32 GeV for *CP* violation measurements. Thus, our design provides for asymmetric and symmetric operations. A requirement flexibility is achieved for a machine with one interaction point and two almost identical rings in the arcs. Two long straight sections are used for implementation of all distinctions in the variants (see Fig.1).

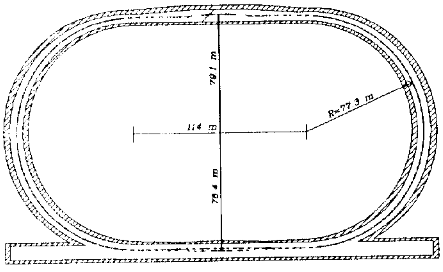

Fig.1 A layout of a B-factory

II. BASIC PRINCIPLES

We usually employ the term *monochromatization* in two senses. In the narrow sense the monochromatization means the reduction of the c.m. energy spread of e^+e^- collisions. In the wide sense it means a collection of certain principles of a collider design. They were already publicized in Refs.2-5. Here we emphasize only some of them.

a) *Large dispersion at the interaction point* (IP) *in one direction* (*e.g.* D^*_x) *and small beta functions in two directions* β^*_x, β^*_y.

The function $H = (D^*_x)^2/\beta^*_x$ should be large to provide for a good energy resolution, σ_W :

$$\sigma_W = W\left[\left(\epsilon_{x1} + \epsilon_{x2}\right)/H\right]^{1/2} \qquad (1)$$

where ϵ_{x1}, ϵ_{x2} are horizontal beam emittanses.
(In the case of the vertical dispersion D^*_y one should substitute vertical dispersion and beta functions in H and vertical emittances in Eq.(1).)

An excitation of the synchrobetatron resonances in beam-beam effects is not seemed now a severe problem since there are suppressions of most resonances obliged to the effect of smallness of betatron oscillation amplitudes relative to the total transverse beam size at the IP [6].

b) *Very small emittances.*

Large emittances are not more needed for high luminosity since beam spots at the IP are mainly determined by beam energy spreads.

c) *Small synchrotron tunes even for very short bunches.*

The main reason for this is a small momentum compaction factor obtained due to the storng focusing in standard cells needed for small emittances.

d) *The very possibility to imply the chromaticity correction inside (or very close to) final focusing quads.*

It means that less sensitivity of a dynamic aperture to high beta functions in the final focus than in the conventional case is achieved.

e) *The independence of the energy resolution on energy spreads inside the beams.*

It means that a possible beam energy spread blowup due to the microwave instability is not more very dangerous. Moreover it can be accomplished by a gain in the luminosity if bunchlengthening is compensated with the implementation of an additional rf voltage.

III. ASYMMETRIC VARIANT

A. Layout

The layout of experimental and utility sections of a B-factory in the asymmetric variant is shown in Fig.2. The high energy beam (*HEB*) enters the experimental section (ex.s.) in a top position and leaves it in a bottom position. Then in the utility section (ut.s.) the *HEB* moves from the bottom to the top. An ongoing low energy beam (*LEB*) moves in a similar fashion in the opposite direction. The interaction region in the ex.s. and straight sections with rf cavities in the ut.s. lie in the middle plane.

Trajectories in the horizontal plane are mirror symmetrical relative to the line connected the IP and the central point of the ut.s. Such symmetry in the ex.s. is important for generation of the large dispersion at the IP by the same bends that used for the orbit separation. Due to the stronger bends the beamline of the *LEB* in the ex.s. is longer than the beamline of the *HEB*. It is compensated in the ut.s., so the circumferences of both rings are equal.

The *LEB* orbit deviation from a central line in the ut.s. is made in two steps with the wiggler magnets in

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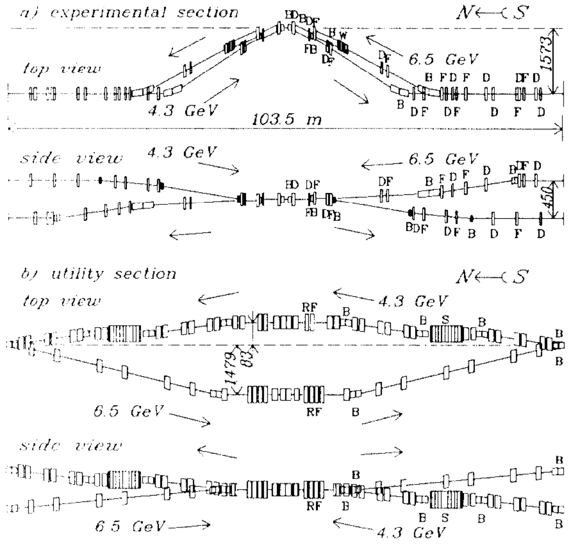

Fig.2 The layout of the experimental and utility sections of a B-factory in the asymmetric variant. B - bending magnet, F,D - quads, W - dipole-quadrupole wiggler, S - dipole wiggler.

between. An idea is to have two vertically separated x rays of wiggler radiation passed by the rf cavities. Their absorption should be made at a large distance as it is foreseen in the machine layout (see Fig.1).

B. Orbit separation and final focus design

An attractive feature of the asymmetric variant is the possibility to use magnets for a fast orbit separation. We begin the separation with the bending magnet and a common vertically focusing quad. The lens focuses too much the *LEB* and doesn't focus enough the *HEB*. This effect has to be compensated and it is done by a double lens (see Fig.3) [3] with the different gradient sign in two centers. The orbit separation at the entrance of the double lens should be sufficient for its installation. Therefore an additional magnet is placed between the main and compensating lenses and the main lens is placed offset. After the double lens there is enough orbit separation for independent beamlines. With this scheme we manage to get the fast orbit separation at the first parasitic crossing (2.1 m from the IP) that is equivalent to 18 horizontal sigma.

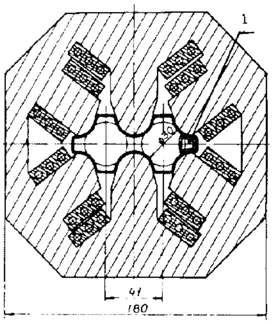

Fig.3 Double quadrupole. 1-SR absorber

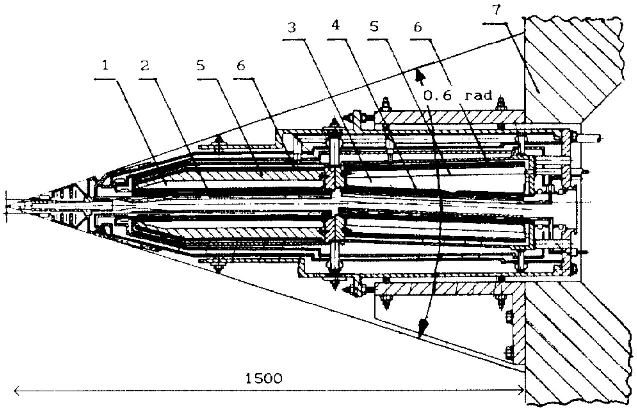

Fig.4 The arrangement of accelerator elements inside the detector. 1- bending magnet iron, 2- magnet superconducting coils, 3- iron of the Panofsky quad, 4- superconducting coils of the quad, 5 - iron of the screening solenoid, 6 - solenoid coils, 7 - iron of the detector.

Since the first bending magnet and the first quad are placed inside the detector they need screening from the outer longitudinal field. It is done by their installation inside the iron shield with compensating superconducting coils around (see Fig.4). With the goal of the compact design of the magnet and quad they have superconducting coils and their irons are frozen at the helium temperature [5]. The quad is designed according to the Panofsky scheme.

A serious problem for a B-factory in the asymmetric variant is the IP beampipe masking from a synchrotron radiation (SR). A solution of this problem is described in the separate report of this conference [7].

IV. SYMMETRIC VARIANT

A. Beam optics and orbit separation

For the symmetric variant of a B-factory the final focus beam optics were designed to provide for $\beta_x^* \ll \beta_y^*$ and a large D_y^* with the opposite signs for each beam. So, nearest to the IP quad in the final doublet is the horizontal focusing quad while the second quad is the vertical focusing one. Therefore similar to Dubna-INP tau-charm factory design [8] we placed the first electrostatic separator ES1 between the quads to produce the initial horizontal separation (see Fig.5).

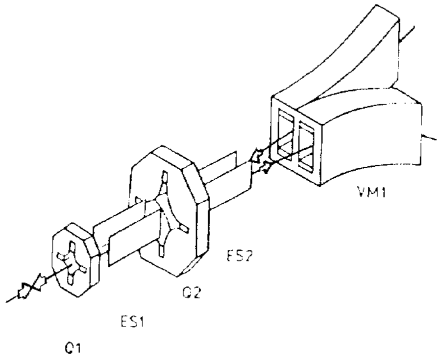

Fig.5 A schematic drawing of orbit separation scheme in the symmetric variant of a B-factory. Q1,Q2 - quads, ES1,ES2 - electrostatic separators, VM1 - magnets.

Then the separation is increased in the second quad and in the second electrostatic separator ES2.

Thus at the entrance into two vertical magnets VM1 placed in 8.2 m from the IP the horizontal orbit separation reaches 30 mm, then magnets turns beams vertically in opposite directions. They have a common iron pole of 3 mm thickness in between, that is enough for magnetic fields of ±0.5 kG. The horizontal beta function near the magnets falls already down to the values about 8 m, so the required horizontal aperture for 30 horizontal sigma at the entrance of VM1 is equal to 5 mm.

A small horizontal beta function is also favorable for beam-beam effects at parasitic crossing. Although we are thinking to have initially the first parasitic crossing in the place where beams are totally separated into two independent vacuum chambers, but the very possibility to place it closer to the IP is a very attractive for further improvements.

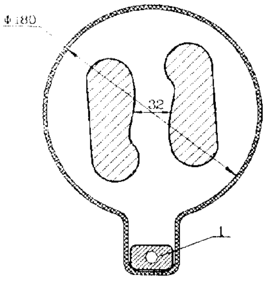

Fig.6 Electrostatic separator ES1. 1-SR absorber

A designed value of the electric field in separators is 30 kV/cm. In addition the separator ES1 is made to provide for a sextupole gradient of 3 kV/cm^3. It is needed for a simultaneous chromaticity correction in both rings in the case of dispersions of different signs. A schematic drawing of this separator is shown in Fig.5.

The evident benefit to begin with the horizontal orbit separation is the very possibility to through the SR from vertical bends between the electrostatic plates and to absorb it on the hidden SR absorber.

B. Layout

The layout of the ex.s. and ut.s. of a B-factory in the symmetric variant is shown in Fig.6. Beamlines of the rings are symmetric relatively to the horizontal and vertical planes. The requirement to have the rings in arcs in the top and bottom positions similar to the asymmetric variant force us to make additional transitions of the trajectories in the south part of the ex.s. It makes the ex.s. geometrically asymmetric relative to the IP while the beam optics remain almost symmetric.

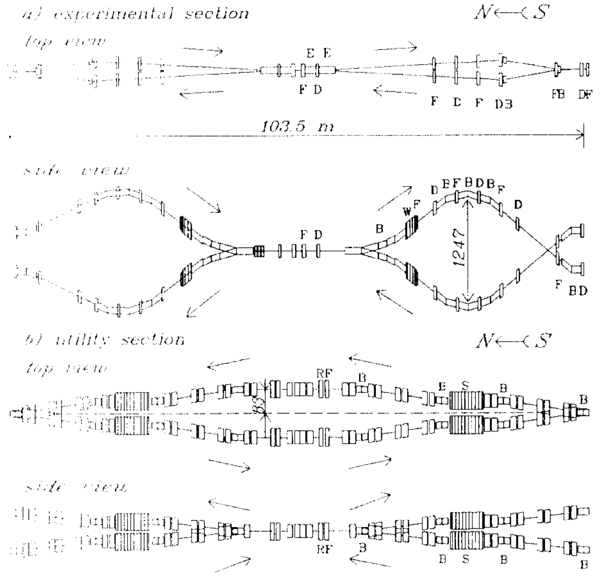

Fig.7 The layout of the experimental and utility sections of a B-factory in the symmetric variant. B - bending magnet, F,D - quads, W - dipole-quadrupole wiggler, S - dipole wiggler, E - separators.

V. STANDARD CELLS

Each arc of a B-factory is filled with 50 identical standard *FODO* cells for every ring. The standard cell (s.c.) is designed to satisfy the required flexibility to different variants and to different beam energies. Two bending magnets can be potentially placed between two neighboring lenses of the s.c. They can be easily removed and installed. Therefore when the ring is operated at the beam energy below 5.32 GeV there are only two magnets in the s.c. placed symmetrically between the lenses. At the higher energies there are all four magnets. Orbit lengthening on 17 mm in the regime with two magnets is compensated by the length of the beamline in the ut.s.

There are at least two purposes for such a trick. One is to manage with better damping at lower energies another is the lowering of the synchrotron radiation at higher energies.

Since the beam emittances in all variants of a B-factory are very small the required aperture in s.c. is 25 mm in the horizontal direction and 15 mm in the vertical direction. Therefore all magnetic elements of the standard cell can be made very compact. We designed the s.c. magnet with the gap of 26 mm and the s.c. quad with the internal diameter of 34 mm.

VI. ACCELERATOR PARAMETERS FOR A B-FACTORY

Parameter	Asymmetric		Symmetric
beam energy, [GeV]	4.3	6.5	4.7
circumference, [m]	714	714	714
beam current, [A]	1	0.7	0.6
N [10^{11}] (e/bunch)	0.9	0.6	2
bunch spacing, [m]	4.2	4.2	15.6
horiz. emittance, [nm·rad]	4	5	3
vert. emittance, [nm·rad]	0.25	0.25	0.06
energy spread [10^{-3}]	1	1	1.1
damping time, $\tau_x/\tau_y/\tau_s$, [ms]	14/8/11	11/6/11	9/6/7
SR energy loss, [MeV/rev]	1.5	2.7	2
momentum compaction [10^{-3}]	1.6	1.6	1.1
bunch lenght, σ [mm]	7.5	7.5	7.5
betatron tunes, Q_x/Q_y	33/21	29/18	37/25
synchrotron tune, Q_s	0.023	0.023	0.019
rf frequency, [MHz]	1000	1000	1000
number of SC cavites	6	6	4
cavity voltage, [MV]	4.5	7	4.5
maximum rf power, [MW]	2.4	2.4	1.6
crossing param., β^*_x/β^*_y, [cm]	60/1	60/1	1/25
crossing param., D^*_x/D^*_y, [cm]	40/0	40/0	0/±42
beam-beam tune shifts, ξ_x	0.012	0.012	0.035
ξ_y	0.05	0.05	0.011
IP beam spot sizes, σ_x [mm]	0.4	0.4	0.006
σ_y [mm]	0.0016	0.0016	0.45
luminosity, [10^{33}cm^{-2}s^{-1}]	5		2
c.m. energy spread, σ_W, [MeV]	1		0.06
Υ1S generation rate, [kHz]			2.5

A designed luminosity and c.m. energy spread at different energies of interest and for a symmetric variant of a B-factory are shown below.

beam energy, [MeV]	5011 (Υ2S)	5178 (Υ3S)	5320
luminosity, [10^{33}cm^{-2}s^{-1}]	2.5	3	3
c.m. energy spread, σ_W, [MeV]	0.075	0.08	0.09

VII. REFERENCE

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