Beauty-Factories

A review of proposals

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Abstract

In recent years a number of proposals for B-factories have been made in various parts of the world. The principle of this new type of collider is described, the challenge it presents to accelerator physicists is detailed, the proposed solutions are presented and analyzed.

1 Introduction

The B-factories which are described here are medium energy e^+e^-colliders with luminosities at the limit of what can be reasonably expected using the most modern techniques in accelerator physics.

The collider should be capable to do a variety of physics experiments but it is optimized for one specific experiment: The study of the violation of the CP symmetry in the $B\overline{B}$ system. The two beams of electrons and positrons collide with a center of mass energy of 10.6 GeV, corresponding to the $\Upsilon(4S)$ resonance. The instantaneous decay of the $\Upsilon(4S)$ produces a pair of B mesons. The CP asymmetry is deduced from the difference in the decay time of these two B-mesons. To be able to measure this decay times one gives a '*boost*' to the two mesons by colliding particles with different energies coming from two different rings, so that the decay times are converted into decay distances (of the order of 200 μm). The measurement of the decays are made using a vertex detector which has to be close to the beam to measure accurately the position of the two vertices. The analysis of the kinematics and probable decay times gives an optimum range of energy [1] of the high energy ring between 7 and 12 GeV. A luminosity of $10^{34} cm^{-2} s^{-1}$ would allow to collect in one year the number of events required to measure the asymmetry with a reasonable accuracy.

2 Conditions for high luminosity

Since the basic paper of Sands [2] a number of papers have been published on the equations governing the design of e^+e^-colliders. The conditions listed below correspond to the generally accepted requirements for maximum luminosity L.

1. *Minimum number of parasitic crossings.* A crossing point is called parasitic when it is not used for physics experiments. A large number of bunches with a few parasitic crossings can only be achieved with double ring colliders.

2. *Equal circumference of the two rings.* To avoid exciting coherent motion of the two beams coupled by the beam-beam effect at the interaction point.

3. *Head-on collisions.* To avoid exciting the synchrobetatron resonances which limited the performance of DORIS in its first version.

The luminosity L is optimized using a small number of parameters which characterize separate effects:

- **The beam-beam parameter ξ.**
  Which measures the perturbation induced by one beam on the other at the collision point. All simulation programs results confirm that one should be able to reach the same values of beam-beam parameter in asymmetric and symmetric colliders. The performance predictions for B-factories are based on this conjecture.

- **The beta value at the collision point β^*.**
  Which measures the focusing achieved by the lattice optics at the collision point. It is adjusted at the minimum compatible with the ring optics stability.

- **The average circulating current I.**
  The design aims at the maximum value compatible with beam stability.

3 Interaction region

The energy asymmetry of B-factories imposes to have two beams of different energies focused to the same spot size at the interaction point, using a number of quadrupoles common to both machines before the two beams are distant enough that separate beam optics elements can be installed. The asymmetry brings as an advantage the possibility to separate the beams by purely magnetic deflection. Three different techniques of separation have been proposed:

- *Local dipoles.* Two dipoles situated on each side and as close as possible to the interaction area, deflect the beam in inverse proportion to the energy.
- *Tilted solenoïd.* The Solenoïd field of the detector is tilted with respect to the beam axis in order to provide a transverse dipole field starting at the interaction point and therefore closer to the interaction point.
- *Crossing at an angle.* The two beams cross at an angle and are therefore separated even more efficiently. In order to maintain the head-on crossing the bunches are tilted on their trajectory. This is the so called 'Crab-crossing' scheme.

The general layout of the interaction area is very much a function of the respective position of the two rings which is in general determined by the constraint of an existing ring or tunnel. The position side by side of the two rings has the advantage of letting open the possibility of crab-crossing which is better done in the horizontal plane; it is not adaptable to all tunnel shapes. When a separation in the vertical plane is preferred, it is simpler to place the two rings on top of each other, because flat beams are easier to separate in the vertical plane.

Table 1: B-Factory projects

Lab.	DESY	KEK	Novosib.	LBL-SLAC	CERN-PSI	Cornell
$\mathcal{L}$ ($10^{33} cm^{-2} s-1$)	3	10	5	3	1 - 10	3
Energy (GeV)	3 /9.3	3.5/8	4.3/6.5	3.1/9	3.5/8	3.5/8
$\beta^*(cm)$	1/2[1]	1	1	1.5/3[1]	1	1.5
Circumference (m)	2304	3018	714	2199	963	765
Emittance ϵ_x (nm)	50	19	5	50	90	130
separation plane	Vert.	Horiz.	Horiz.	Horiz.	Vert.	Horiz
Bunch dist. S_b (m)	3.6	0.6	4.2	1.3	3	3.3
I.P. elements[2]	$Q_1^\bullet, Q_2^\bullet, Q_3$	B^*, Q_1^s	B^*, Q_1^s	$B^*, Q_1^\bullet, Q_2^\bullet, Q_3^\bullet$	Q_1^s, Q_2^s, Q_3, Q_4	Q_1^s
Rings Position	Top	Side	Top	Top	Top	Side
Aspect ratio	flat	flat	flat	flat	flat	flat
Collision type	Head-on	Head-on	Head-on	Head-on	Head-on	Crab
Collision upgr.	none	Crab	Monochr.	Crab.	none	none
RF	n.c.	n.c.	n.c./s.c.	n.c.	s.c.	s.c.

[1] *Different values of beta for low and high energy rings*

[2] *Elements common to both beams; a $^\bullet$ indicates a permanent magnet, a ^{s} a superconducting one*

The number of common elements differs considerably from one project to the other as shown table(1). Recent information seems to indicate that most projects converge towards simple schemes with a minimum number of common elements.

3.1 Background and masking

The detector must be protected against several sources of radiation [4] [9]

- *Beam-gas* interaction which produces, all along the machine: photons, positrons and electrons which could finally arrive in the detector area.
- *Beam-wall* interactions of lost particles hitting the wall, with the same effect as above.
- *Synchrotron radiation* produced by the beam interacting with the field of quadrupoles, dipoles and separators.

Each source has to be analyzed in detail, tracking programs determine the properties of particles arriving in the interaction area, scrapers must be designed to scrape this radiation away before it reaches the interaction area, masks of the detector must be placed in the detector area. The interaction of these particles with scrapers and masks must be simulated to determine how much scattered radiation will be produced by the impinging particles. The simulation programs used have recently been checked against measurements (in particular at LEP and DORIS [10] [9]), the agreement is within a factor of two, which is remarkable. The sensitivity to closed orbit errors or misalignments is such that extreme precautions will be required to avoid the destruction of the sensitive part of the detector.

The B-Factory is equipped with a vertex detector so that the vacuum chamber radius at the Interaction Point is only 2.5 cm. The vacuum pipe inside the vertex detector is in general made of beryllium to achieve mechanical stability with a minimum of matter between the collisions and the detection equipment. It must be cooled to evacuate the heat induced by image currents. The large amount of photodesorption induced by synchrotron radiation impinging on protection masks in the vicinity of this small diameter tube raises severe problems of vacuum pumping. Preliminary solutions have been worked out which show there also that the ingenuousness of designers can solve apparently insurmountable problems.

4 RF system

The bunches must be short so that the collisions take place in the center of the waist in the interaction point. The RF-systems must be extremely powerful in order to maintain these short bunches in a machine with large synchrotron radiation losses and a high current circulating beam. The design of the system must moreover take into account the risk of single bunch and multibunch beam instabilities.

The design of the RF system imposes a technical choice between two technologies

- *Superconducting (s.c.) cavities.* Modern s.c. cavities are expected to provide 10 MV/m [11] of accelerating fields with a small coupling to the beam. The technology is however difficult to install in operation and not all laboratories are familiar with the precautions required.
- *Normal conducting (n.c.) cavities.* This conventional technology can be further developed to higher gradients (up to 4 MV/m) and lower coupling to the beam, at the expense of a high power dissipation. These announced performances should be confirmed by power tests in the near future. The obvious advantage of n.c. cavities is their simplicity of operation.

Multibunch instabilities are generated when a coherent pattern of transverse or longitudinal oscillation of all bunches around the ring enters in resonance with a parasitic mode of oscillation of RF cavities (or other similar resonant equipment). The difficulty is that with a large number of bunches there is a large number of such patterns covering a large frequency band and that similarly there are many parasitic Higher Order Mode (HOM) of oscillations of the cavities capable to enter into resonance with the rotating patterns. The solution is to damp the HOM in the accelerating cavities and to install feedbacks acting on all the modes. This is the subject of active R. & D. in several laboratories.

5 Vacuum system

The required performances of the B-factory vacuum system are far beyond what has been achieved or proposed in existing electron storage rings, mainly because of the high circulating current and the corresponding high synchrotron radiation power to be absorbed and dissipated in the arcs. The vacuum system of these colliders should present the following characteristics:

- *Low gas desorption material for the vacuum chamber*
- *Large cooling capacity*
- *Large pumping speed*
- *Low beam environment coupling impedance*
- *Adequate shielding against synchrotron radiation*

Copper vacuum chambers of modern design even though they are not conventional have been selected in most B-factory projects; copper combines a low desorption coefficient, a high thermal conductivity and a good shielding capacity.

6 Status of proposals

The following list concentrates on essential proposals, it is made in approximate chronological order.

- *CERN-PSI:* A joint study [3] was made on request of CERN and PSI management to install an asymmetric B-factory in the ISR Tunnel. The project is at best delayed for several years.
- *LBL/SLAC:* The project, a B-factory installed in the PEP tunnel [4] is presented jointly by a number of laboratories from the West coast. It has been recently proposed to finance the project on operation funds of SLAC with possibly other contributions. A vigorous R.& D. program is supported by the participant laboratories.
- *Cornell:* The Cornell Laboratory proposes to install in the CESR tunnel a B-Factory based on the Crab-crossing scheme [6], and using superconducting cavities. A vigorous R.& D. program on superconducting cavities is underway. The project has not obtained, up to now, support from the NSF, funding agency of the Cornell laboratory.
- *DESY:* A second proposal, called HELENA [5], to be published soon, concerns two rings installed on top of the PETRA ring, in the same tunnel. The project was not, up to now, supported by the laboratory management.
- *KEK:*
  The Japanese project [7] which was for a certain time based on the TRISTAN tunnel, is now returned to the original proposal to install the rings in a dedicated tunnel. uses a crab-crossing scheme. Negotiations with the funding agencies have started. A program of R.& D. is underway with official support.

- *Novosibirsk*
  The Russian project [8] is based on the monochromator idea which aims at improving the energy resolution in the collisions. Formally accepted by USSR authorities, ground breaking for the injector was started, its present status is not known.

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