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B, τCharm, and φ Factories

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Abstract

Electron-positron collider type particle factories, B-Factory, τCharm Factory, and φ Factory, aim at achieving a high luminosity in a range of 5 x 10^{32}cm^{-2}s^{-1} to 10^{34}cm^{-2}s^{-1}. This goal requires storing large currents, 0.5 A to 5 A, in rings by distributing them into large number of bunches. To avoid unnecessary collisions, all factories adopt two-ring scheme, where electrons and positrons are stored in different rings. One φ Factory, DAΦNE is now being commissioned and two asymmetric-energy B-Factories, KEKB and PEP-II, now under construction, will be completed by the end of 1998. IHEP, Beijing, expects R&D of its τCharm Factory, BTCF, to be approved soon.

1 Introduction

A factory is an accelerator facility that is optimized to produce some kind of particles copiously for high-energy physics studies. All factories now being constructed or planned are electron-positron colliders and named after the particles they produce. B-Factory is tuned to produce B-mesons, τCharm Factory τ-leptons and J/ψ particles, and φ Factory φ mesons. The energy of beams in these factories are mainly determined by the mass of particles they produce. Figure 1 shows the hadronic cross section and expected number of events per year for factories with a luminosity of 10^{33}cm^{-2}s^{-1}. The event rate at B-Factory is two orders of magnitude lower than that of τCharm and φ Factories; therefore, B-Factory demands the highest luminosity among factories, namely, 3 x 10^{33}cm^{-2}s^{-1} to 10^{34}cm^{-2}s^{-1}, whereas that of τCharm and φ Factories is around 5 x 10^{32}cm^{-2}s^{-1} to 10^{33}cm^{-2}s^{-1}. In this paper two B-Factories, KEKB at KEK[1], PEP-II at SLAC[2], τCharm Factory, BTCF at IHEP, Beijing[3], and φ Factory, DAΦNE at Frascati[4], are discussed. Figures 2,3,4, and 5 show layouts of these factories. Table 1 summarizes basic parameters of these factories.

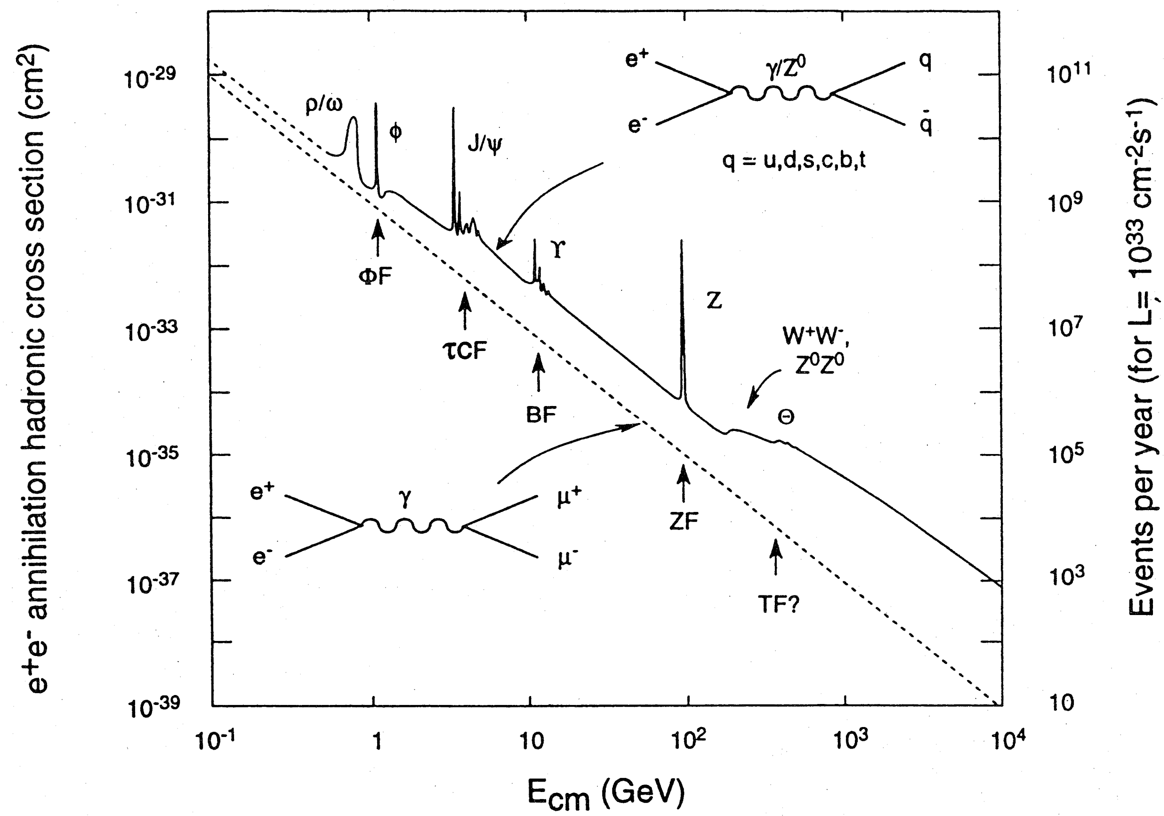

Fig. 1 Cross section and events per year for factories.

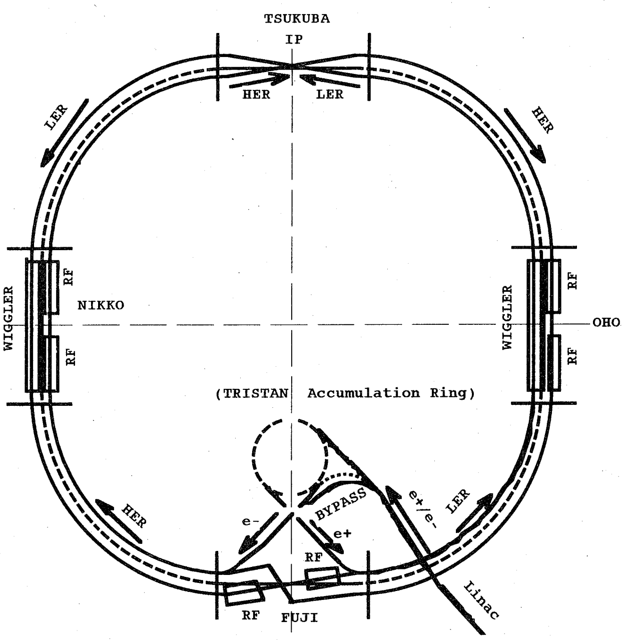

Fig. 2 Schematic layout of KEKB.

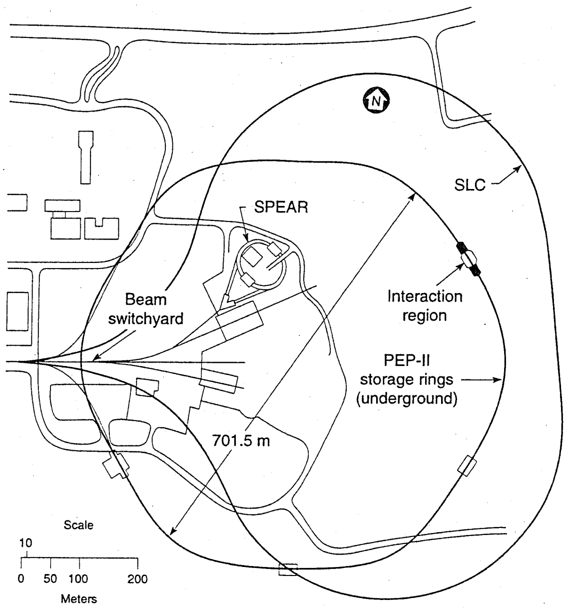

Fig. 3 Schematic layout of PEP-II.

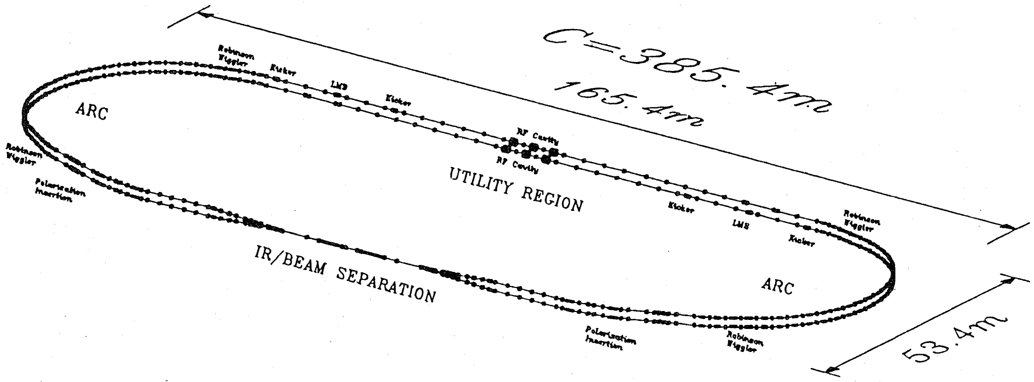

Fig. 4 Schematic diagram of BTCF.

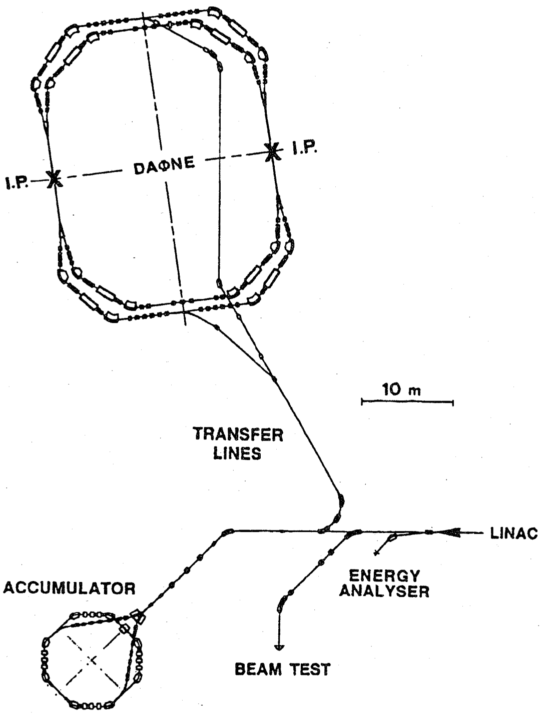

Fig. 5 Layout of DAΦNE and its injector.

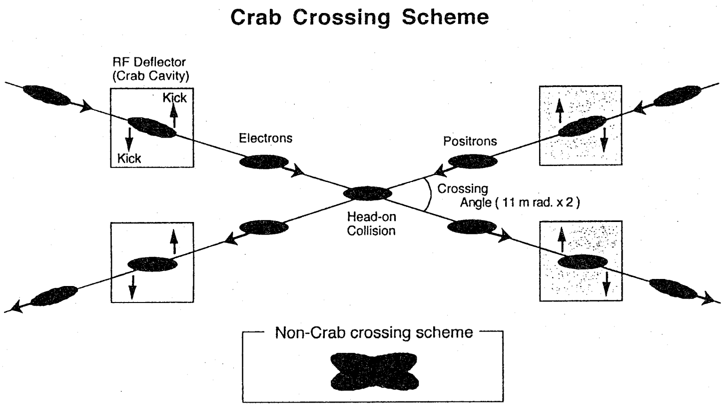

Fig. 6 Principle of crab crossing.

Table 1
Main parameters of factories

	KEKB	PEP-II	BTCF(high luminosity)	DAΦNE
luminosity (10^{33}cm^{-2}s^{-1})	10	3	1	0.5
number of rings	2	2	2	2
number of interaction points	1	1	1	2
symmetric/asymmetric energy collision	asymmetric	asymmetric	symmetric	symmetric
circumference (m)	3016	2199	385	97.7
beam energy (GeV)	8 (e^-)/3.5(e^+)	9(e^-)/3.1(e^+)	1.5-2.5	0.51
total current per beam (A)	1.1(e^-)/2.6(e^+)	1.0(e^-)/2.14(e^+)	0.57	5.24
number of bunches	5000	1658	86	120
bunch spacing (m)	0.59	1.14	3.78	0.81
crossing angle (mrad)	2 x 11	0	2 x 2.6	2 x 12.5
beam-beam tuneshift ξ_x/ξ_y	0.039/0.052	0.03/0.03	0.04/0.04	0.04/0.04
β-function at IP β_x^*/β_y^* (cm)	33/1	50/1.5(e^+) 67/2.0(e^-)	65/1	450/4.5
RF frequency (MHz)	508.887	476	476	368.25
type of cavity[1]	NCC,SCC	NCC	SCC	NCC
detector	BELLE	BaBar		KLOE, FINUDA

1) NCC and SCC stand for normal conducting cavity and superconducting cavity, respectively.

2 High luminosity and large stored current

The luminosity of an electron-positron collider is given by

$$L = 2.2 \times 10^{34} \xi (1+r) \left(\frac{E \cdot I}{\beta_y^*} \right)$$

where L stands for luminosity in cm^{-2}s^{-1}, ξ, beam-beam tuneshift, r, the ratio of vertical beam size to horizontal beam size at the collision point, I, beam current in A, E, beam energy in GeV, and β_y*, beta-value at the interaction point.

All factory designs assume that the beam-beam tuneshift ξ is between 0.03 and 0.05 and β_y* between 1 and 5 cm. They also adopt a flat-beam scheme where r is of the order of a few %. Since the luminosity is inversely proportional to the beam energy, lower-energy factories require higher currents. If, we assume, for example, L=10^{33}cm^{-2}s^{-1}, ξ=0.03, and β_y*=1 cm, and use typical energy of B (5 GeV), τCharm (1.5 GeV) and ϕ (0.5 GeV) Factories, we find that we need to store 0.30 A for B-Factory, 1.0 A for τCharm Factory, and 3.0 A for ϕ Factory. High-energy colliders can achieve higher luminosity with relatively lower currents.

These large currents should be achieved with multi-bunch beam storage in rings. If we store n bunches of electrons and positrons in a ring, these bunches collide at 2 x n points along the ring. Almost all of these collisions except at interaction points are unnecessary. The simplest way to avoid these unnecessary collisions is to use two rings: one for electrons and the other for positrons. All factories adopt this two-ring scheme. Electrons and positrons collide at one interaction point (IP) at KEKB, PEP-II, and BTCF, and at two IPs at DAΦNE.

3 Coupled-bunch instabilities

Under high-current and large number of bunches stored in factories, coupled-bunch oscillation grows quickly, since bunches couple to each other through wakes produced by bunch-environment (RF cavities and vacuum components) interactions. In order to prevent these instabilities, HOM(higher-order mode)-free RF cavities and smooth vacuum components should be used. All factories use single-cell, single-mode cavities, either normal conducting (KEKB, PEP-II, and DAΦNE) or superconducting (KEKB, and BTCF) [5]. KEKB uses normal conducting cavities called ARES [6] for its positron ring, and both ARES and single-cell, single-mode superconducting cavities[7] for its electron ring. In October and November 1996 a prototype superconducting cavity for KEKB was beam-tested at the accumulation ring of TRISTAN[8]. The cavity could store 573 mA at 2.5 GeV. This current is about a half of the KEKB electron ring and the same as that of BTCF.

At KEKB and PEP-II, high stored current in a ring excites coupled-bunch instabilities due to not only HOMs but also fundamental mode of RF cavities. The coupled-bunch instability becomes extremely strong, and the growth time of which is of the order of a few 10 μsec. The mechanism of this instability is the following. An RF cavity should be matched to its power source (klystron) to prevent reflection of RF power. The beam through the cavity excites RF field which is not in phase with the RF field from the power source and destroys the matching condition. By changing the resonant frequency of the cavity by a small amount, Δf, this matching is restored again. This Δf is called the detuning frequency and is inversely proportional to the stored energy of the cavity. At the positron ring of PEP-II, this detuning frequency is nearly equal to the revolution frequency. If the same type of cavities were used also at KEKB, the detuning frequency would become twice as large as the revolution frequency at the positron ring of KEKB. When we increase the stored current in a ring, the peak of the RF impedance approaches to and passes the mode frequency of anti-dampimg coupled-bunch modes; these modes are strongly excited.

To circumvent the instability, KEKB and PEP-II adopt different approaches: KEKB uses large-stored energy cavities ARES to make Δf small compared to the revolution frequency, whereas PEP-II's method is to use direct RF feedback and feedback through a comb filter to lower the impedance of the cavity at the anti-damping coupled-bunch mode frequencies.

The difference of the circumferences of rings of factories make this situation differ from each other. Larger rings (KEKB and PEP-II) have severe problems, whereas this instability is of no concern for BTCF and DAΦNE that has only shorter circumferences, where the detuning frequency is small compared to the revolution frequency.

4 Photo-electron and fast-ion instabilities

Two new types of coupled-bunch instabilities may be serious to B-Factories and τCharm Factory: one is the photo-electron instability(PEI) and the other fast-ion instability(FII).

PEI is a serious concern for positron rings. Positrons stored in a ring emit synchrotron lights, which then hit the inner wall of vacuum ducts and produce photoelectrons. These electrons are attracted by beam potentials and move toward the beam. Although the electrons stay in a vacuum pipe only short period (a few 10 nsec) and are absorbed quickly, continuous production and absorption result in somewhat equilibrium distribution of electrons around the beam. This electron cloud acts as a source of wake and excites a coupled-bunch instability. Vertical oscillation of bunches is excited. The growth time of the instability may be shorter than 1 msec at KEKB. PEI was first observed at Photon Factory ring of KEK[9] and confirmed by an experiment at BEPC by IHEP-KEK collaboration[10].

FII[11,12,13] is a serious concern for electron rings. A bunch train in a ring ionizes residual gas and creates ions. These ions are accumulated rapidly within a bunch train. If a bunch in the head of the train start to oscillate due to some disturbances, the oscillation couples resonantly to that of trailing bunches through ions and grows along the bunch train. In a flat beam case, vertical oscillation of bunches are excited. Linear theory predicts that the growth time of this instability at KEKB and PEP-II is of the order of 1 msec. Note that this instability is different from ion trapping. In factories, ions created by a bunch train are cleared in a bunch gap. Ions are not continuously trapped and the first bunch in the train always sees fresh gas. Two experiments done at LBL[14] and KEK[15] detected this instability.

Bunch-by-bunch beam feedback systems have a capability of damping transverse coupled-bunch instabilities with 1 msec or faster damping time and are expected to cure the instabilities.

5 Asymmetric energy collisions at B-Factories

KEKB and PEP-II, are asymmetric energy electron-positron colliders. The energies of electrons and positrons are different (3.5 GeV positrons and 8 GeV electrons at KEKB and 3.1 GeV positrons and 9 GeV electrons at PEP-II). Electrons have higher energy than positrons in order to avoid ion trapping, which becomes much serious at low energies. Positron ring, therefore, is called low-energy ring (LER) and electron ring high-energy ring (HER).

In symmetric energy collision of 5.3 GeV electrons and positrons, such as at CESR, B-mesons and anti B-mesons are produced at rest and decay at the point where they are created. Identification of B or anti B-mesons is impossible. B-mesons and anti B-mesons produced in an asymmetric energy collider move toward the direction of incoming electrons and travel a few 100 μm before decaying into secondary particles. By detecting these secondary particles, we can identify B and anti B-mesons. This is of vital importance to KEKB and PEP-II that aim at detecting CP-violation effect, which is a subtle difference of behavior between particles and anti-particles. BELLE detector[16] surrounds the IP of KEKB and BaBar detector[17] that of PEP-II.

BTCF and DAΦNE are symmetric energy colliders: the energy of electrons and positrons is the same.

6 Interaction regions

Electrons and positrons are made to collide at IP and should be separated into different rings after the collision. Finite-angle crossing scheme is attractive, since it separates beams naturally. KEKB, BTCF and DAΦNE adopt this scheme. Crossing angles of KEKB, BTCF and DAΦNE are ±11 mrad, ±2.3 mrad, and ±12.5 mrad, respectively. Without crossing at angle, electric separators should be used to separate beams at symmetric energy colliders, and separation dipole magnets at asymmetric energy colliders. PEP-II uses separation dipole magnets and beams collide head-on.

Synchrobetatron resonances may be excited by an finite-angle collision, where beam-beam force felt by a particle in a bunch differs according to not only its transverse position but also its longitudinal position. This dependence on particle's longitudinal position makes transverse and longitudinal motion of bunches couple to each other and excites synchrobetatron resonances.

At KEKB, extensive simulation study showed that there still remained ample areas in a ν_x-ν_y diagram where no reduction of luminosity took place. This is encouraging; however, KEKB people are now developing crab cavities as a fall-back option. Figure 6 illustrates principle of crab crossing[18, 19]. Incoming bunches are tilted by a crab cavity and collide head-on in a center-of-mass frame at IP. Outgoing bunches are tilted-back by another crab cavity. Crab cavities should be superconducting to supply enough voltage necessary for these kicks.

KEKB, PEP-II and BTCF have small β_y* of 1 – 2 cm at IP. To achieve this value, final focus quads should be located inside the detector under the detector solenoid filed. The use of ordinary iron magnets are precluded; either superconducting or permanent magnets should be used. Permanent separation magnets and final focus quads are used in PEP-II, where as superconducting anti-solenoids and final focus quads are installed in KEKB. Anti-solenoids effectively cancel out the solenoid field of the detector and simplify coupling correction. BTCF will use superconducting doublets as its final focus magnets.

7 τCharm Factory, BTCF

Although a few τCharm Factories were ever planned in the world, only one τCharm Factory project, BTCF, Beijing TauCharm Factory at IHEP, Beijing, is alive. Feasibility study of this factory has been completed and the institute expects its R&D to be approved soon. BTCF is planned to have three modes of operation: (1) high-luminosity mode, (2) longitudinal- polarization mode, and (3) monochromator mode. High-luminosity mode tries to reach 10^{33}cm^{-2}s^{-1} at 2 GeV, whereas the longitudinal polarization mode aims at storing longitudinally polarized beams at 1.8-2.0 GeV with somewhat lower luminosity for the search of the CP violation in τ–decays. The monochromator modes aims at increasing the event rate at J/ψ energy (1.55 GeV) by reducing the spread in the center of mass energy. This is obtained by using opposite large dispersion values of two beams at the IP. The luminosity of this mode will be 10^{32}cm^{-2}s^{-1}.

8 ϕ Factory DAΦNE

DAΦNE has two IPs. One IP is surrounded by KLOE[20], the main physics motivation of which is the observation of direct CP-violation in K_L decays, i.e. the measurement of ε'/ε with accuracy in 10^{-4} range. To achieve this goal, a luminosity of 5 x 10^{32}cm^{-2}s^{-1} is required. The other IP of DAΦNE is assigned to a smaller size detector, FINUDA[21], for study of hypernuclei formation and decay.

9 Perspectives

DAΦNE has just started its commissioning and two B-Factories, KEKB and PEP-II, will be commissioned in 1998. BTCF needs a 3-4 year R&D period and the construction will start early next century at the earliest. BTCF will be able to learn experiences gained by DAΦNE, KEKB, and PEP-II and construction will be done on the basis of these factories.

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