E^+E^- FACTORIES*

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Abstract

The achievements of the three main e+e- Factories have been impressive. The KEK B-Factory has achieved a peak luminosity of 1.7x10^{34} cm^{-2} sec^{-1} and the PEP-II B-Factory has reached 1.2x10^{34} cm^{-2} sec^{-1} while the DAFNE Phi-Factory has obtained 1.5x10^{32} cm^{-2} sec^{-1}. Early in the B-Factory running, CP violation in the B meson system was found to be consistent with the prediction of the Standard Model. Now all three factories are integrating as much luminosity as they can in order to look for rare decay channels that may have a rate that differs from the value predicted by the Standard Model and therefore hint at New Physics. There are two newer factories that have started or are about to start. The Tau-charm factory at CESR has been delivering luminosity to the CLEO detector and BEPCII, the newest Tau-charm e^+e^- factory located at IHEP in Beijing, has just started commissioning. I will give a status report on the recent accomplishments of all five factories and will show what these facilities have for plans to further improve performance.

INTRODUCTION

Factory accelerators are lower energy accelerators that concentrate on generating extremely large physics data sets at a chosen center-of-mass energy or over a limited center-of-mass energy range. The two B-factories, KEKB and PEP-II, run almost exclusively at the peak of the Upsilon 4S resonance (10.58 GeV) with asymmetric beam energies in order to observe CP violation in the B meson system. The resonance has a cross-section of about 1.5 nb. In addition, the detectors, BELLE and BaBar, look for rare B decays that might hint at physics beyond the standard model. DAFNE is an accelerator that operates on the peak of the phi resonance (1.02 GeV). The main detector, KLOE, is looking for deviations from the standard model in K meson decays. The two newer factories CESR-c and BEPCII are Tau-charm factories that are in the process of building large data sets of D meson decays in the energy range of 3-4 GeV.

All factories concentrate on maximizing peak luminosity and accelerator uptime in order to deliver the highest possible data rate to the detectors. Since most of the physics is statistics driven, factories must continually improve performance in order to be able to double data sets in a reasonable time frame. The usefulness of a factory diminishes when it takes too long (several years) to significantly increase the data set.

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e^+e^- factories maximize luminosity in as many ways as they can. One way is to use as many bunches as possible in order to increase the collision frequency. This tends to lead to a bunch spacing that is typically between 1-2 m for facilities with separate storage rings. CESR-c is the exception with only one storage ring. However, at CESR-c they have developed a fill with mini-trains of 5 or 6 closely spaced bunches. The close bunch spacing means that the bunches can couple to each other – usually forcing the installation of fast bunch-by-bunch transverse and longitudinal feedback systems to control instabilities.

Factories also increase total beam current as much as possible. Typical beam currents are about 1 A with PEP-II beam currents being higher (1.5-3 A) and CESR-c being lower. These high currents mean large amounts of synchrotron radiation (SR) power and higher-order-mode (HOM) power are present. Both of these sources of power must be controlled as small amounts of either can rapidly heat up un-cooled vacuum components. HOM power effects can also be enhanced by shortening the bunch length – one of the things factories want to do in order to increase luminosity because then one can lower β_y^* . Both PEP-II and KEKB have had vacuum components either heat up or arc due to high HOM power.

The small bunch spacing of factories that have separate storage rings also means that the positron beam is susceptible to electron cloud effects (ECI) and the electron beam is susceptible to ion effects. PEP-II first saw ECI effects when they moved from a by8 bunch pattern (every 8^{th} RF bucket or 5 m bunch spacing) to a by4 bunch pattern (2.5 m spacing) [1]. ECI effects can be mitigated with solenoid windings around the beam pipe. Both KEKB and PEP-II have done this. KEKB performance is still affected by ECI. So far, PEP-II has no apparent effects from ECI. Ion effects in an electron ring can be suppressed by having an ion gap in the bunch train. PEP-II has decreased its ion gap from an original design value of 5% down to 1% of the total ring. It has only seen ion effects when the machine starts up after a down time and vacuum scrubbing is occurring [2].

Factories push on the frontiers of high-beam currents, HOM power issues, fast feedbacks, small bunch spacing and , of course, high luminosity. Recent work on squeezing even higher luminosity, while using about the same beam currents as is in present B factories, by changing how the beams collide holds promise for future e^+e^- factories [3].

B FACTORIES

KEKB

The B Factory in Tsukuba, Japan has produced the highest luminosity of any factory. It also holds all records

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for integrated luminosity. Figure 1 shows a layout of the accelerator and table 1 lists the design and achieved parameters of KEKB [4]. The circumference of the KEKB rings is 3000 m. The high-energy ring (HER) uses room temperature and super-conducting RF. The low-energy ring (LER) uses room temperature RF. The room temperature RF energy is stored in large cavities local to the accelerating cavities. This decouples the klystrons and minimizes the effects of beam loading. The interaction point (IP) has a horizontal crossing angle of ±11 mrads.

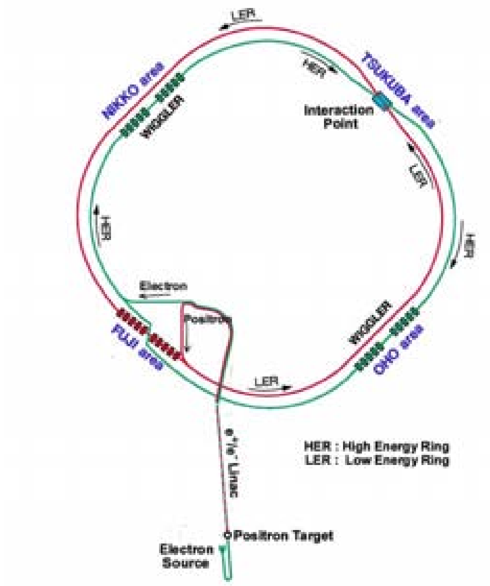

Figure 1. Layout of the KEKB accelerator. The BELLE detector is in the Tsukuba area (upper right).

Table 1. KEKB parameters.

	Design		Achieved	
	e-	e+	e-	e+
Beam energies (GeV)	8.0	3.5		
Currents (A)	1.1	2.6	1.3	1.7
Number of bunches	5000		1338	
Bunch spacing (m)	1.2		2.4	
Bunch currents (mA)	.22	.52	.97	1.2
Beam stored energy (kJ)	90	92	110	59
Luminosity ($\times 10^{33}$/cm^2/sec)	10.0		17.12	
Integrated Luminosity (fb^{-1})			710	
Data set (B mesons)			1.4×10^9	

KEK has worked for several years to develop a crab cavity scheme that rotates the beams such that the bunches collide in a head-on fashion at the IP [5]. Beam-beam simulation code argues that a luminosity increase of as much as a factor of 2 might be attained by crabbing the beams [6]. This last spring KEK installed the cavities and have been re-commissioning the rings with these new cavities [7]. They have demonstrated crabbing at the IP and have achieved reasonably high single bunch luminosity [8].

Figure 2. The crab cavity for the KEKB HER.

KEKB will run in its present state until at least early 2009. They have an upgrade proposal to increase the luminosity of KEKB by a factor of 24 to a peak value of 4×10^{35} cm^{-2} s^{-1} [9].

PEP-II

The PEP-II accelerator at SLAC collides a 9 GeV beam on a 3.1 GeV beam in a head-on collision. PEP-II has achieved a peak luminosity of $1.2\text{x}10^{34}$ cm^{-2} s^{-1} and has the highest beam currents of any accelerator [10]. With nearly 3A of beam current in the positron storage ring it has the largest stored quantity of anti-matter. The rings are 2200 meters in circumference and each ring has 6 arcs and 6 straights. Figure 3 shows a layout of the rings and Table 2 lists the parameters of the accelerator.

The high currents of PEP-II have revealed several issues. Some of these are: bunch-by-bunch stability control, HOM power, RF stability and vacuum chamber heating from SR. The total HOM power is difficult to measure but by carefully accounting for all other power losses in the rings has been calculated to be about 200 kW for the HER and 300 kW for the LER at the PEP-II maximum currents of 1900 mA for the HER and 2900 mA for the LER [11]. Small portions of this power can heat up vacuum components and care must be taken to keep

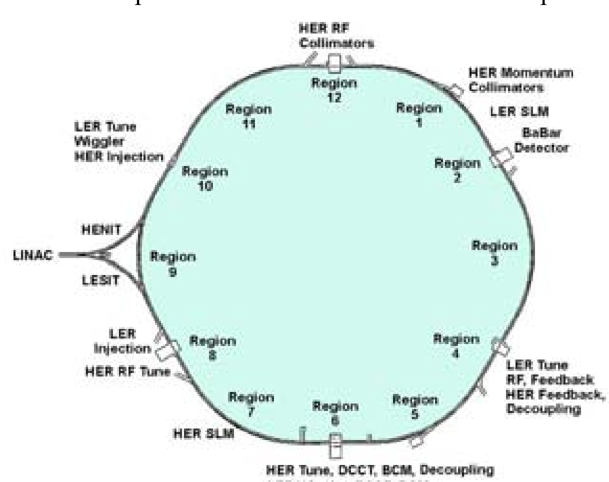

Figure 3. Layout of the PEP-II B-factory. The BaBar detector is located in region 2 (upper right).

the HOM power from getting into un-cooled components. Figure 4 shows the effect of HOM power penetrating behind an RF seal between two vacuum flanges [12].

Table 2. The PEP-II parameters.

	Design		Achieved	
	e-	e+	e-	e+
Beam energies (GeV)	9.0	3.1		
Currents (A)	1.1	2.6	1.3	1.7
Number of bunches	1658		1722	
Bunch spacing (m)	1.26		1.26	
Bunch currents (mA)	.45	1.3	1.1	1.7
Beam stored energy (kJ)	49	49	118	68
Luminosity ($\times10^{33}$/cm^2/sec)	3.0		12.07	
Integrated Luminosity (fb^{-1})			450	
Data set (B mesons)			9×10^8	

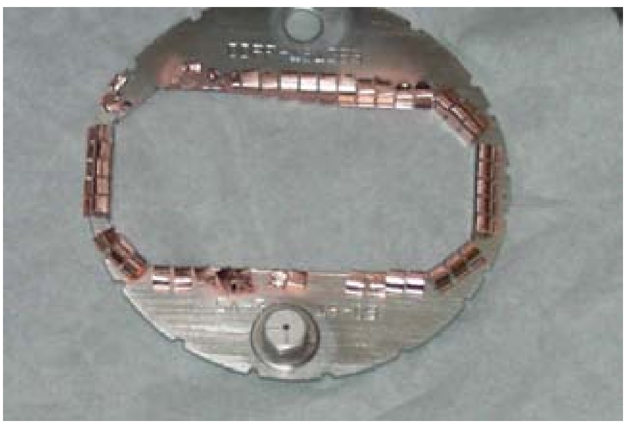

Figure 4. An RF seal designed to bridge the gap between two vacuum flanges. One can see that the stainless steel plate got hot enough to melt the copper (upper left corner) as well as vaporize the sliver plating on the mounting bolts and washers.

PEP-II has added two more RF stations for a total of 11 stations to the HER. This should enable us to increase the HER current to 2.2 A. The LER beam already has enough RF capacity to go up to 4 A with the four stations we have. Other upgrades include a new coupling correction scheme for the LER on either side of the detector that uses permanent magnet skew quads [13] and the capability of converting the HER lattice from a 60 degree lattice to a 90 degree lattice [14]. Both of these improvements aim at lowering the emittance of the beams. PEP-II hopes to achieve a peak luminosity of 2×10^{34} cm^{-2} s^{-1} before it is turned off in Sept. 2008.

PHI FACTORY

DAFNE

DAFNE is the factory that runs on the Φ resonance (1.02 GeV). The Φ resonance has a cross-section of 5000 nb and decays almost exclusively into K mesons. The storage rings are 120 m in circumference and the relatively low beam energy of 0.5 GeV makes beam stability an important issue. Touschek lifetimes also play a large role [15]. Table 3 lists the parameters of DAFNE and Figure 5 shows the layout of the rings.

Table 3. Parameters of DAFNE.

	Design		Achieved	
	e-	e+	e-	e+
Beam energies (GeV)	0.5	0.5		
Currents (A)	5.2	5.2	1.5	1.1
Number of bunches	120		111	
Bunch spacing (m)	0.8		0.8	
Bunch currents (mA)	43	43	14	10
Beam stored energy (kJ)	.85	.85	.24	.18
Luminosity ($\times10^{33}$/cm^2/sec	0.53		0.16	
Integrated Luminosity (fb^{-1})			0.8	
Data set (K mesons)			8×10^9	

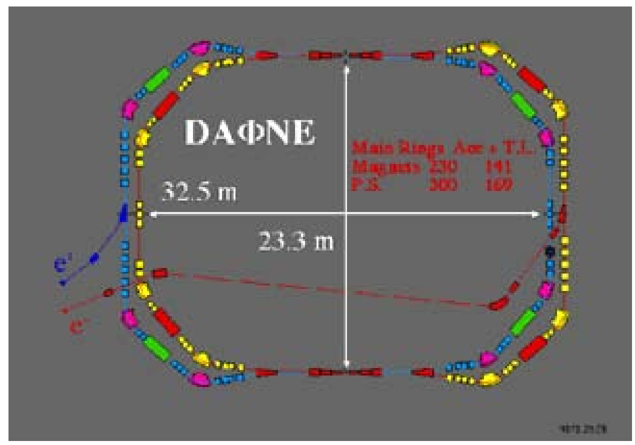

Figure 5. Layout of the DAFNE storage rings. The main detector KLOE is located around one of the collision points at either the top or the bottom of the layout.

DAFNE has improved machine performance by concentrating on the effects of the parasitic crossings. They have moved the beam orbits farther apart at the crossings, they have lowered the β_y^* and they have installed compensating wires between the two beams at the parasitic crossings. DAFNE alternates delivery between several different detectors; KLOE, FINUDA, and a new detector SIDDHARTA. Other upgrades include: improving the wiggler system, bunch-by-bunch feedback systems, improved injection kickers and a new interaction region (IR) with a "crabbed waist" design [16-20]. The new IR design will be the first attempt to build and install a "crabbed waist" IR design. This type of collision is in the design for a Super B-factory with a luminosity that is 100 times higher than the current B-factories [21-23]

TAU-CHARM FACTORIES

There are two factories working in the Tau-charm energy region. CESR, located at Cornell has been running for a couple of years and the other Tau-charm factory, BEPCII, located in Beijing is just starting up.

CESR-c

CESR, the e^+e^- collider at Cornell, has been the pioneer accelerator in the energy region of the Upsilon resonances and laid the foundation for the present day asymmetric-energy B factories. The CESR storage is 768 m in circumference. The CESR team has extended the beam energies from the 5 GeV area down to the Tau-charm region of 1.5 GeV. The extended machine is called CESR-c [24-27]. This was accomplished by adding twelve wigglers to improve the damping time of the lower energy beams. The wiggler design is being studied as a prototype for the wigglers needed in the ILC damping rings [28]. CESR-c has presently achieved half of its design luminosity. Table 4 lists the beam parameters for CESR-c and Figure 6 is a layout of the CESR rings.

Table 4. Beam parameters for CESR-c.

	Design		Achieved	
	e-	e+	e-	e+
Beam energies (GeV)	1.5-2.5			
Currents (A)	.23	.23	.06	.07
Number of bunches	45		24	
Bunch spacing (m)	17		17	
Bunch currents (mA)	3-5		2.5	2.9
Beam stored energy (kJ)	1-1.5		.26	.30
Luminosity ($\times 10^{33}$/cm^2/sec)	0.15-0.5		0.07	
Integrated Luminosity (fb^{-1})	7		0.7	

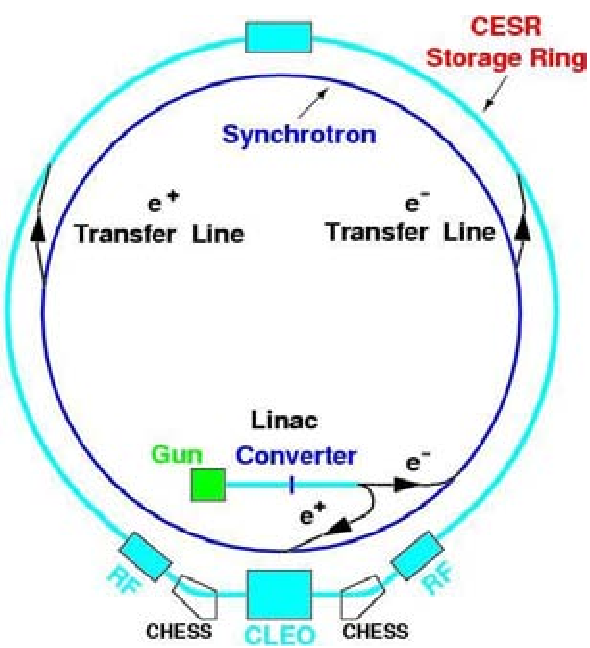

Figure 6. Layout of the CESR storage rings. A synchrotron ring is used to alternately capture and store the electrons and positrons before they are transferred into the main storage ring.

BEPC II

BEPC II is the new accelerator at IHEP in Beijing. They are re-using the tunnel that housed BEPC, a single ring collider in the Tau-charm energy region. BEPC II will have two new separate storage rings with circumferences of 237 m and intends to increase the luminosity to 100 times that of BEPC or 1×10^{33} cm^{-2}s^{-1}. They have started up with a temporary IR beam pipe and have stored both positrons and electrons and have made collisions [29-34]. IHEP plans to install the rest of the IR elements soon. BES III should be ready to roll on line early this fall. Using the electron beam they have been able to produce a synchrotron light source (the other half of the upgrade) to some initial users. Table 5 lists the goals and present status of BEPC II and Figure 7 shows a ring layout.

Table 5. Parameters for the BEPC II factory.

	Design		Achieved	
	e-	e+	e-	e+
Beam energies (GeV)	1.89			
Currents (A)	.91	.91	.15	.20
Number of bunches	93		~100	
Bunch spacing (m)	2.4		2.4	
Bunch currents (mA)	10		1.5	2.0
Beam stored energy (kJ)	0.3		.16	.23
Luminosity ($\times 10^{33}$/cm^2/sec)	1			
Integrated Luminosity (fb^{-1})	Commissioning			

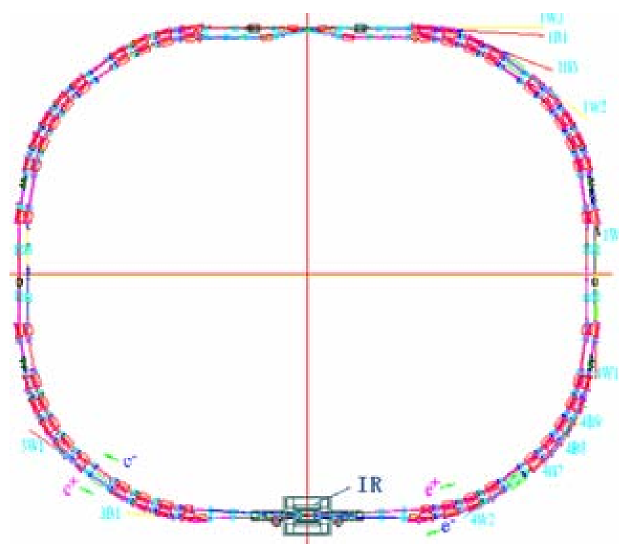

Figure 7. Layout of the BEPCII collider.

BEPC II has a very unusual IR [35]. The final focus magnets are super-conducting and also have to cancel the large detector field solenoid. In addition, the magnets and beam pipe have to accommodate a single e- beam that exits out through the incoming positron beam pipe when the accelerator is used as a light source facility.

SUMMARY

The e^+e^- factories of the world are all producing large data sets in order to look for deviations from the Standard Model in very rare decay channels. A signal can be either an unexpectedly large or an unexpectedly small decay rate. Such a signal can point toward the existence of new forms of matter that are contributing to the given decay rate. It was the decay rates of the K mesons that led to the prediction and subsequent discovery of the charmed quark. In a likewise manner the decay rates of the B mesons led to the prediction that the mass of the, at that time, undiscovered top quark was significantly higher than had been assumed. Recently, a signal from D meson decay has been announced that might be an indication of new physics but that, as of this writing, is not a firm enough result to say whether or not there is anything beyond the Standard Model [36]. They want more data!

e^+e^- factories have extended our knowledge of high-current high-luminosity machines that have a small bunch spacing. Some of the factories are R&D test beds for aspects of future colliders and many of the findings from all of the factories can be used to guide future accelerator development.

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