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The PEP–II Design*

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ABSTRACT

The Stanford Linear Accelerator Center (SLAC), Lawrence Berkeley Laboratory (LBL), Lawrence Livermore National Laboratory (LLNL) Positron Electron Project–II (PEP–II) is a design for a high-luminosity, asymmetric energy, electron-positron colliding beam accelerator that will operate at the center-of-mass energy of the Υ4S (10.58 GeV). The goal of the design is to achieve a large enough integrated luminosity with a moving center-of-mass reference frame to be able to observe the predicted rare decay modes of the Υ4S that do not conserve charge parity (CP).

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1 Introduction

The beam energies of a B factory differ by at least 4.5 GeV or, equivalently, a B factory has a minimum beam-energy asymmetry of 3.5 GeV and 8 GeV. This energy asymmetry produces a moving center-of-mass reference frame that allows a detector to time-order the decay of the two B mesons produced in the formation of the Υ4S resonant state. The difference in the time-order rate of decay between rare CP eigenstates of matter B mesons and antimatter B mesons is an indication of CP violation. The low event rate of these rare, CP-violating events means a high-luminosity accelerator is needed. The requirement of high luminosity has pushed all proposals for B factories to high beam current designs. The attempt to keep the internal beam-bunch instabilities at the level of present machines, has led to designs that have beams with many bunches (~1000). Due to the many-bunch solution for high luminosity and the energy asymmetry, each beam must be stored in a separate storage ring.

Large beam currents impose several design challenges for any storage ring design. The vacuum in the storage rings must be good enough to insure adequate beam lifetimes (on the order of hours) despite high levels of synchrotron radiation striking the chamber walls. Multibunch instabilities induced by the large beam currents must be controlled. These instabilities are kept in check by making the beam pipe as "smooth" as possible to minimize broad-band impedances, by damping the higher-order modes in the rf cavities to minimize narrow-band impedances, and by using longitudinal and transverse feedback systems to independently measure and correct the position of each bunch in each beam.

The word "factory" implies a steady, high-efficiency machine. To accomplish this, a rapid and efficient injection system is needed in order to maintain the large beam currents at near peak level most of the time. The injection system should be able to top up stored beams and even refill empty storage rings in times much shorter than the lifetimes of the beams.

The interaction region (IR) of a B factory is one of the more complex sections of the machine. The small distance between bunches in each beam, the small spot size at the interaction point (IP), the large beam currents, the fact that this is the place in the accelerator where the two beams are brought into collision, and the presence of a large sensitive detector that surrounds the IP make designing an IR complicated.

In the following sections, we describe design choices made for the PEP–II accelerator that will be built at SLAC, and summarize the present status of the project. This project is a collaboration by the Stanford Linear Accelerator Center, Lawrence Berkeley Laboratory, and the Lawrence Livermore National Laboratory.

2 PEP–II

PEP–II is an upgrade of the original PEP–I accelerator at SLAC [1]. The 2200-m long tunnel that housed PEP–I will be reused; it will contain two storage rings, one on top of the other. Figure 1 shows a schematic of the two rings with two views of how the beams are brought into collision at the IP. The low-energy ring (LER) is above the high-energy ring (HER) everywhere except in the IR. The HER design reuses all of the magnetic components of the original PEP, while the magnetic components of the LER will be new.

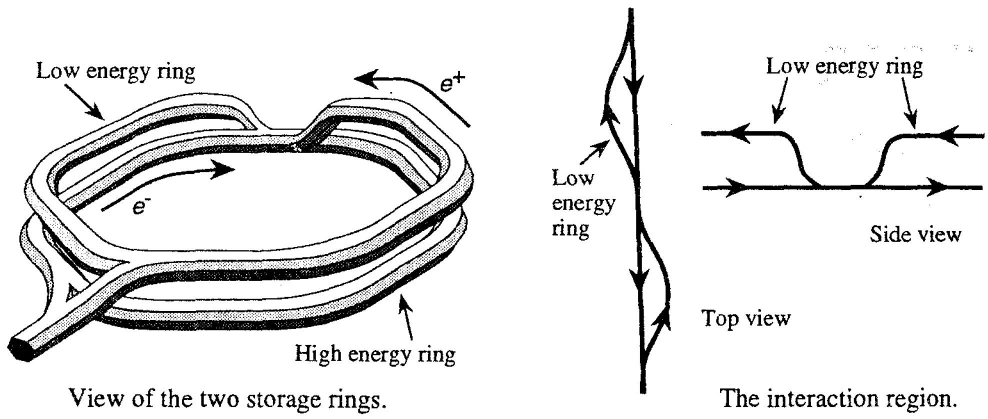

Figure 1. Schematic drawing of the PEP-II*B* factory.

Table 1. Some machine parameters

Parameter	e^+	e^-
Beam energy (GeV)	3.1	9
Beam current (A)	2.15	0.99
β_y^* (cm)	1.5	2.0
σ_x (μm at IP)	156	
σ_y (μm at IP)	6.2	
σ_z (cm)	1.0	
Luminosity ($cm^{-2}\ s^{-1}$)	3×10^{33}	
Tune shift	0.03	
Beam aspect ratio (v/h at IP)	0.04	
Number of beam bunches	1658	
Bunch spacing (m)	1.26	
Beam crossing angle	0° (head-on)	

The PEP–II design employs a 3.1 GeV on 9 GeV energy asymmetry. This larger than minimum asymmetry improves the detection of CP-violating events by boosting the center-of-mass more and improves accelerator flexibility by making it easier to separate the beams. This increased ease of beam separation has made it possible for PEP–II to incorporate a head-on collision design. The beams are magnetically separated by strong permanent magnet dipoles positioned 22.5 cm from the IP.

Table 1 lists some of the parameters of the PEP–II *B* factory. Whenever possible, conservative design parameters have been chosen. For instance, the tune shift is set at 0.03, compared to PEP–I which attained a tune shift of 0.06. A beam aspect ratio of 0.04 again should not be difficult to achieve. This relatively high ratio will also make it easier to overlap the beams at the collision point.

Six straight sections and six arcs in each ring are designated by numbers 1 through 12, with the straight sections labeled 2, 4, 6, 8, 10, and 12. The HER design uses Region 10 for

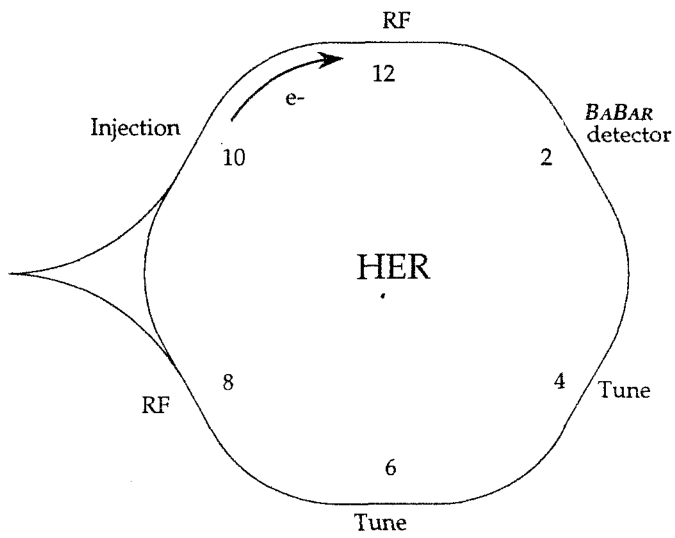

Figure 2. Schematic of the high-energy ring (HER). The six straight sections are labeled by function. The HER is a 60° lattice that has noninterlaced sextupoles with a beta beat in the arcs on either side of the interaction point to provide some local chromaticity correction. In addition, there are interlaced sextupoles in the other four arc regions. The emittance of the ring is controlled by adjusting the dispersion function in these four arcs.

injection into the ring. Regions 8 and 12 house the rf cavities for the HER, and Regions 4 and 6 have sections for adjusting the tune of the ring (see Fig. 2).

All of the old PEP–I machine components have been completely removed from the tunnel. The PEP–I magnetic elements, dipoles, quadrupoles, and sextupoles, will be reused to build the HER. These magnetic elements are presently being tested, refurbished, and remeasured. Presently, 85% of the dipoles are finished and are ready for installation. The dipoles should be completed by February 1995. About 35% of the quadrupoles and 25% of the sextupoles have been refurbished. Half of the quadrupole and all of the sextupole refurbishment, remeasurement, and testing should be finished by late spring of 1995.

Figure 3 shows a layout of the LER ring with the straight sections labeled by function. The LER will use Region 8 as an *injection straight*. Regions 6 and 10 will have wiggler

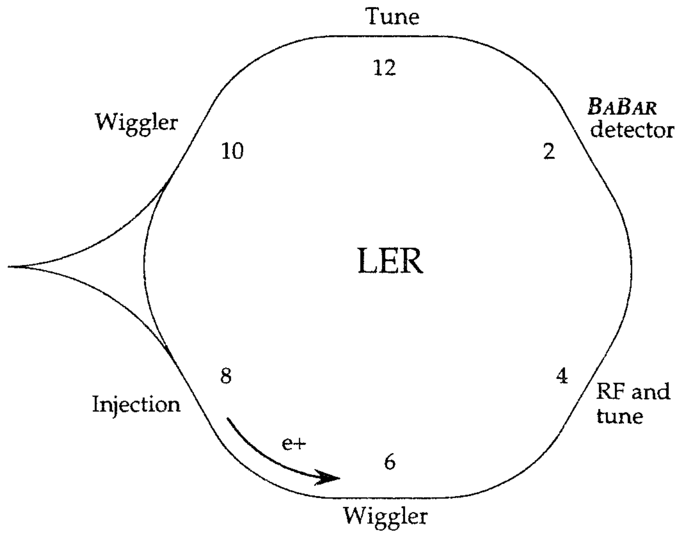

Figure 3. Schematic of the LER ring. The six straight sections are labeled by function.

magnets; Regions 12 and 4 contain sections for adjusting the tune. Region 4 also contains the rf cavities for the LER. The wiggler magnets in Regions 10 and 6 will be used to control the emittance and to shorten the damping time of the LEB. The emittance range with the wigglers is about 30 to 130 nm rad, and the damping time can be adjusted to nearly match the damping time of the HEB. The LER lattice is a 90° lattice with an interlaced sextupole scheme. In addition, the LER design employs a local chromaticity correction scheme in Region 2 near the IP. Most of the current work on the LER has gone into designing and detailing the LER quadrupoles. The quadrupole design is now complete and production of these magnets has started. The dipole design is well advanced, with production scheduled to start in 1995.

3 Injection

A *B* factory requires an efficient and reliable injector to maintain the high beam currents in the storage rings. PEP–II enjoys the advantage of having as an injector one of the most powerful sources of electrons and positrons in the world, the Linear Accelerator at SLAC (linac). The linac can supply more charge/bunch to the *B* factory than is required and the injected bunches

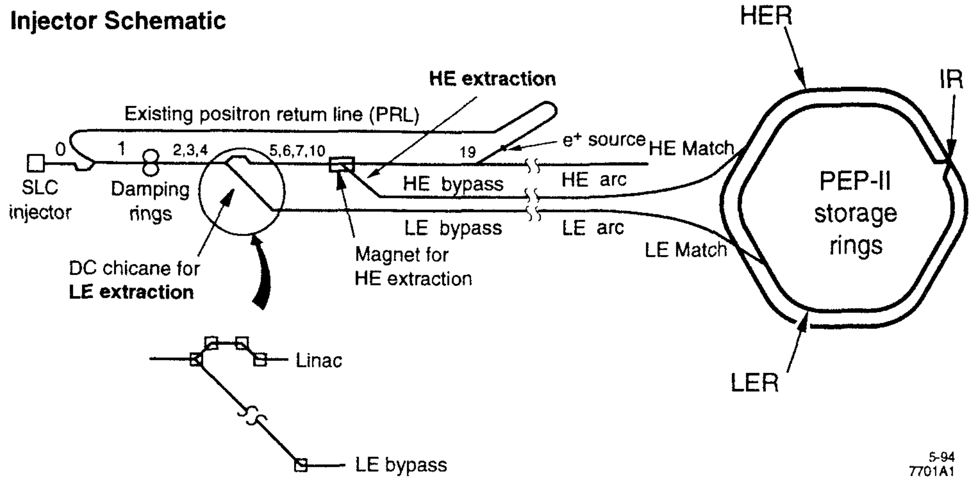

Figure 4. Schematic of the PEP–II injection system. The low-energy and high-energy beams are separately extracted from the SLAC linac, and travel down bypass lines to the PEP–II storage rings.

(both positrons and electrons) have a very small spot size: a result of the damping rings used by the linac in the production of beams for the Stanford Linear Collider (SLC). The electrons and positrons for the *B* factory will be extracted from the linac at the desired beam energy and transported down to PEP–II through dedicated bypass lines. These lines will be installed near the ceiling of the linac tunnel in much the same way that the positrons generated two thirds of the way down the accelerator are transported back to the front of the linac to be injected into the positron damping ring. The injection into the PEP–II rings will be in the vertical plane. Figure 4 shows a schematic of the injector for PEP–II.

The linac routinely delivers low-emittance ($\gamma\varepsilon_x$=4×10^{-5} m-rad) pulses of 2.5×10^{10} particles/bunch to the SLC. PEP–II needs pulses of about 1×10^{10} particles, and the linac emittance is smaller than the stored beam emittance of the *B* factory. The RF frequency of PEP–II has been chosen to be a multiple of the linac frequency, making synchronization of the two machines easier. The injector is designed to fill both rings from zero to full current in six minutes; it will be able to top up both rings in three minutes. The HER and LER bypass lines and the HER extraction line are all scheduled to be installed in spring 1995 during a scheduled accelerator shutdown.

4 Vacuum

The vacuum chambers in both rings of PEP–II will be new. The HER beam pipe is a copper design similar to the copper vacuum chambers in HERA at DESY. The higher Z copper is an excellent shield for synchrotron radiation, as well as being a good thermal conductor. In addition, copper has a lower photon gas desorption rate than aluminum or stainless steel. A low-photon gas-desorption rate is important in keeping the gas load in the vacuum chamber down to a manageable level, especially with the high beam currents of a *B* factory. Detailed designs of HER vacuum components are nearing completion. A prototype arc dipole and quad chamber has been fabricated and detailed production planning is underway with production scheduled to start in the summer of 1995. The first copper extrusions should start arriving in late spring. An electron beam welder has been ordered and should arrive in June 1995.

The LER dipole magnets are 45 cm long, much shorter than the 5.4-m dipole magnets for the HER. The shortness of the LER dipoles has led to the concept of a beam pipe with an antechamber and a discrete photon stop, which should make it easier to get a good vacuum. This concept is similar to that used for the vacuum chambers in the Advanced Light Source (ALS) at LBL. The vacuum chambers will be composed of an aluminum extrusion, with a water-cooled copper bar as the photon stop. The aluminum extrusions are about to be ordered; the first prototype chambers are scheduled to be completed in 1995.

5 RF System

The rf cavities are a major source of narrow-band impedance in a *B* factory. Due to the high beam currents, the higher-order modes in these cavities can couple to the closely spaced beam bunches and drive coupled oscillation modes that destabilize the beam. The PEP–II

Table 2. RF system parameters

Parameter	High-energy ring	Low-energy ring
Radio frequency voltage (MV)	18.3	5.1
Number of klystrons	6	4
Number of cavities	24	8
Gap voltage per cavity (kV)	763	638
Cavity wall power (kW)	83	58
Beam power per cavity (kW)	155	258
Power through the window (kW)	240	330
Klystron power (kW)	1005	687

group has chosen to attack this problem on two fronts: first, by constructing a room-temperature copper cavity that suppresses higher-order modes by coupling the modes out through small waveguides to a ferrite load; and second, by building longitudinal and transverse feedback systems that correct phase and position motion of each of the 1658 bunches on a bunch-by-bunch basis. The waveguides that couple to the cavity are small enough to cut off the fundamental mode, and hence do not damp the accelerating mode of the cavity.

Table 2 lists some of the RF system parameters. The klystrons that supply the rf power to the cavities will be ten new 1.2 MW klystrons. The first prototype klystron is nearly complete and is scheduled to be ready for testing in early 1995. The power from the klystron is distributed to two LER or four HER cavities through the use of magic—Tee power splitters. The power splitters have 1.2 MW waveguide loads to absorb reflected power from the cavities. In addition, a 1.2 MW circulator protects the klystron from any remaining reflected power. The power splitters and circulator have been successfully tested at 500 kW in a way that simulates a 1.2 MW load, and will be tested at full power in spring 1995, shortly after the prototype 1.2 MW klystron is operating.

The design of the rf cavity is complete. The rf power is coupled to the cavity by an iris coupling network with a wave guide window. The first cavity is presently being fabricated and is scheduled to be completed and ready for testing in summer 1995.

6 Feedback

After the rf cavity Higher Order Modes (HOM) have been damped as well as possible, the feedback systems must damp the remaining coupled-bunch instabilities. In fact, the damping and subsequent broadening of the HOM frequencies allows these higher frequencies of the rf cavities to potentially cause instabilities in as many as 100 coupled-bunch modes for each HOM frequency. This has led to a feedback design that corrects each beam bunch independently. This design is very flexible, and can correct any form of position (energy) error in a beam bunch no matter what the source of the error. The small bunch spacing of 4.2 ns means that the overall response of the feedback systems must cover a band of 119 MHz. This leaves out some possible modes near the principal accelerating frequency (476 MHz) that would be too strong for the coupled-bunch feedback system. These will be countered by feedback loops located directly around the cavity-klystron systems.

The longitudinal feedback system detects the phase error of a bunch with respect to the master rf oscillator. The signal is digitized and the information is supplied to a parallel farm of Digital Signal Processors (DSPs). This allows the feedback algorithm to be implemented in software, which provides a great deal of flexibility in producing the correction signal. The transverse feedback system will also employ a similar technique to damp out transverse coupled-bunch instabilities.

The Advanced Light Source (ALS) at LBL is being used to test prototypes of the PEP–II longitudinal and transverse feedback systems. In late 1994, a prototype longitudinal system was installed in the ALS that included a 250 MHz front and back end, a farm of four DSPs, a 10-W power amplifier, and a wideband kicker. This prototype has been very effective in damping coupled-bunch modes in the 84 bunch ALS operating mode and its performance agrees very well with simulations. A 500-W power amplifier will be installed early in 1995. In addition, a full PEP–II prototype feedback system is being assembled, and will be tested at the ALS in 1995. A prototype transverse kicker scheme has been installed in the ALS as well, and has been successfully implemented. Further tests at the ALS and final design details are scheduled to be completed in the first half of 1995.

7 Interaction Region

The interaction region (IR) is one of the more complicated parts of a *B* factory. The two beams must be brought into collision with small spot sizes in order to achieve the required high luminosity. In addition, backgrounds generated by the beams must be held to an acceptable level, so the detector can operate and not suffer degradation from radiation damage.

The detector for the PEP–II *B* factory will be made up of a silicon vertex detector, a drift chamber, a particle identification system, a CsI calorimeter, a 1.5 T magnetic field, and a muon identification system embedded in the magnetic-flux-return steel. The silicon vertex detector will have five layers of silicon wafers and will measure the decay vertices of the *B* mesons. The detector beam pipe will be made of two layers of Be, 0.8– and 0.4–mm thick, with a 2–mm gap for cooling. The inner surface of the pipe is coated with 25 μm of Cu. The Cu layer provides shielding from very low-energy photons and also reduces the resistive wall loss heating. The drift chamber will have a low density gas to minimize multiple scattering in the chamber and will measure the momentum of charged decay particles. The CsI calorimeter measures the electromagnetic energy of the decay particles.

The two major sources of detector backgrounds come from Synchrotron Radiation (SR) and beam-gas bremsstrahlung. The first layer of Si is the part of the detector most exposed to SR. Because it is so close to the colliding beams, it is also most vulnerable to shower backgrounds generated by beam-gas particles striking the beam pipe near the IP. The innermost layers of the drift chamber are also sensitive to beam-gas backgrounds. In general, the CsI and other detector subsystems are relatively insensitive to beam backgrounds because they are generally farther away from the colliding beams. The part of the calorimeter that is near the beam lines (the end cap sections) must be checked to make sure backgrounds are not serious in this region.

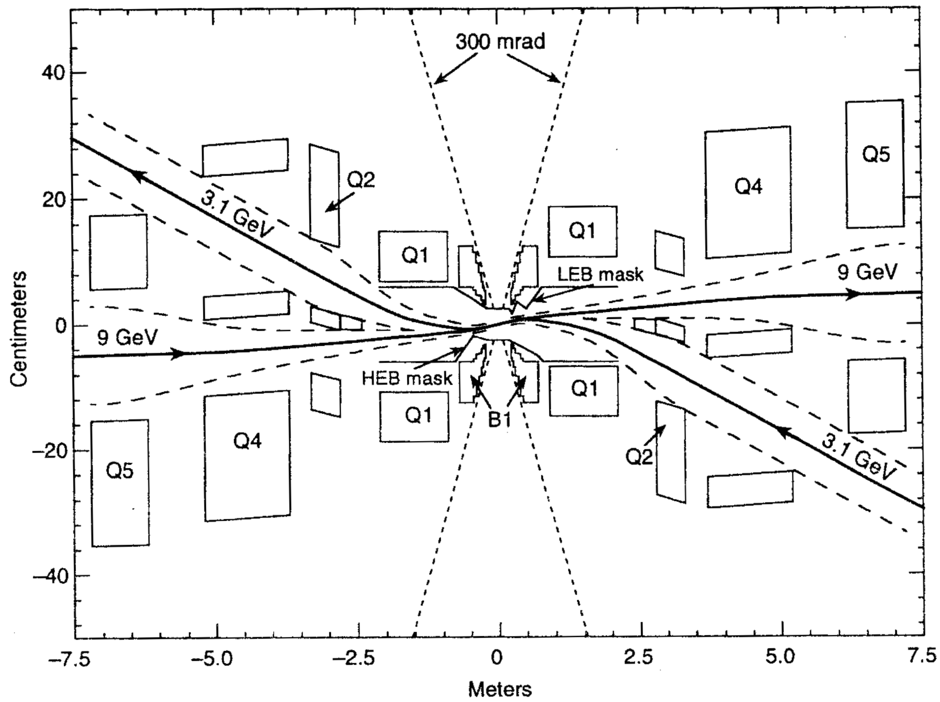

Figure 5. Layout of the interaction region (the vertical scale is greatly exaggerated).

In the PEP–II accelerator design, the beams are separated by a horizontal-dipole permanent magnet (B1, see Fig. 5) positioned 22.5 to 70 cm from the IP. The average field strength of this magnet is about 7 kG. B1 provides enough separation at the first parasitic crossing (63 cm from the IP) to keep the beam-beam effects of all four parasitic crossings negligible. The beam separation at 63 cm is about $11\sigma_x$ of the low-energy beam (LEB), the largest dimension of the two beams at this position. Simulations of the beam-beam effect from parasitic crossings [2] indicate that the beams must be separated by at least 7σ to keep perturbations from parasitic crossings small compared to the beam-beam effect at the collision point.

The beams are further separated by the following quadrupole (Q1). Q1 is a vertically-focusing permanent magnet that is centered on the high-energy beam (HEB) and thereby bends the offset LEB further away in x from the HEB. B1 and Q1 are permanent magnets for two reasons; first, permanent magnets can be strong and still be compact, and second, B1 and Q1 are immersed in the detector solenoidal field. The combination of B1 and Q1 separates the beams enough to permit a septum quadrupole (Q2) to be placed 2.8 m from the IP. Q2 is a horizontally focusing magnet for the LEB and does not influence the HEB. Q1 and Q2 are the final focusing doublet for the LEB. Behind Q2 are two magnets, Q4 and Q5, the primary focusing magnets for the HEB. Figure 5 shows a layout of this region.

Synchrotron Radiation

A strong fan of Synchrotron Radiation (SR) is generated by the LEB as it travels through Q1. The photons from this fan are absorbed on a mask located under the B1 magnet near the detector beam pipe (labeled the LEB mask in Fig. 5). The LEB also generates SR fans when it travels through the two B1 magnets. These essentially overlapping fans throw radiation down the incoming HEB beam pipe (about 5.7 kW), strike the mask in front of the Q2 septum on the LEB outgoing side depositing 3.5 kW of power, and deposit about 1.3 kW of power along the beam pipe in the Q2 magnet of the outgoing LEB.

The HEB is offset by 14 mm in x as it goes through the Q4 magnet. This offset generates a soft bend in the beam and redirects the SR generated by $10\sigma_x$ beam particles in Q5 away from the LEB mask. A little more than half (1100 W) of this soft-bend radiation is absorbed by the HEB mask; most of the other half (~ 800 W) strikes the mask in front of the outgoing Q2 septum for the HEB. The B1 radiation fans generated by the HEB do not strike any nearby surfaces and are absorbed in a radiation dump located about 17 m from the IP along the outgoing HEB beam pipe. Figure 6 shows the SR fans generated near the IP by the LEB and HEB.

The IR is designed so that none of the surfaces near the IP that are struck by direct SR can emit photons that can directly hit the Be detector beam pipe. All SR photons must "bounce" from at least two surfaces before they are able to strike the Be pipe. The only exception to this is the photons that hit the tip of the LEB and HEB masks. These photons can scatter through the tip and then directly strike the detector beam pipe. However, the critical energy of these photons is very low—1.5 keV for the LEB and 6 keV for the HEB—and only the photons that

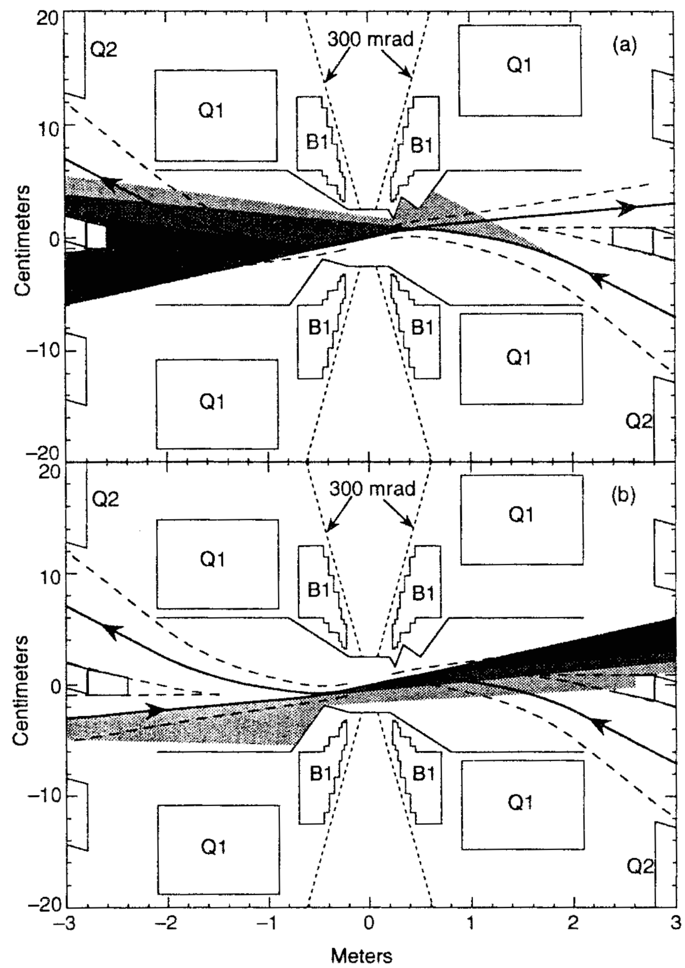

Figure 6. Synchrotron radiation fans near the interaction point generated by (a) the low-energy beam, and (b) the high-energy beam. The fan shading indicates the relative intensity of the fans—the darker the shading, the more intense the radiation.

strike within about 5 μm of the mask tip have a chance of scattering through the tip. Therefore, although the tip-scattered photons dominate the SR background rates for the detector, the rate is not very high. Table 3 shows the expected photon rates for the first layer of a silicon vertex detector. The predicted rates for other layers of a vertex detector are much lower.

Table 3. Occupancy and radiation dose estimates for layer 1 of the silicon vertex detector from synchrotron radiation.

	Occupancy (%)	Limit (%)	Safety factor	Radiation dose per 10^7 sec (krad)	Limit (krad)	Safety factor
Silicon layer 1	0.048	10	209	2.86	200	70

Beam particle backgrounds

There are several possible sources of detector backgrounds directly due to beam particles:

- Beam-gas bremsstrahlung
- Elastic beam-gas scattering (Coulomb scattering)
- Radiative BhaBhas
- Elastic BhaBhas.

In the PEP–II design, the source that dominates detector backgrounds is beam-gas bremsstrahlung, but backgrounds from radiative BhaBhas are a not too distant second. In fact, the radiative BhaBha rate is high enough that high-energy photons emitted along the collision axis can, if detected, produce a very fast, real-time measure of luminosity. Detector backgrounds from beam-gas events occur when either the scattered electron or the produced photon strike the beam pipe near the detector components. Since residual gas molecules produce this source, it is important to have a low vacuum pressure in the beam pipes of the incoming beams. Figures 7a and 7b are plots of the origin of the beam-gas scatter events for those events in which the scattered particles strike the beam pipe within ± 2.2 m of the IP. The four-vectors of the particles that strike the beam pipe are used as input to a GEANT [3] simulation of the beam pipe and detector. A tally is then made of the amount of energy absorbed in particular detector components as well as the number of ionizing tracks that can register as hits in various detector components. Table 4 summarizes the results of this tally for the first layer of the silicon vertex detector and for the drift chamber of the detector.

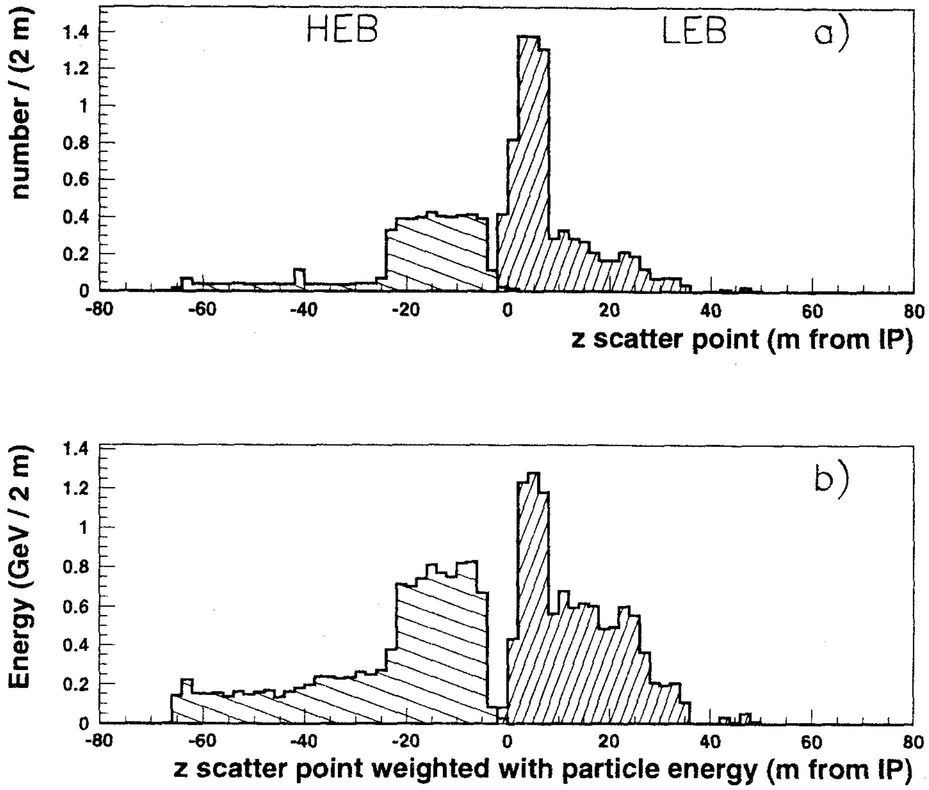

Figure 7. Plot of the z position of the scatter point for beam-gas particles that strike within $\pm$ 2.2 m of the interaction point for both the high-energy and the low-energy beams, with (a) unweighted scatter points, and (b) scatter points weighted by the particle energy.

Table 4. Summary of detector backgrounds from lost beam particles. A one nTorr vacuum and beam currents of 0.99A for the HEB and 2.14A for the LEB is assumed.

	Silicon layer 1		Drift chamber	
	Average	Worst	Average	Layer 1
Occupancy	1.3%	3.3%	0.7%	0.07%
Limit	10–15%	10–15%	10%	10%
Safety factor	7.7	3	14	140
Radiation dose per 10^7 sec	33 krad	270 krad	0.005 C/cm	0.0005 C/cm
Limit	1500 krad	1500 krad	0.1 C/cm	0.1 C/cm
Safety factor	45	5.6	20	200

8 Summary

Building an accelerator that can deliver an integrated luminosity of 30 fb^{-1} per year with factory-like performance is a challenging task. The SLAC, LBL, LLNL PEP–II *B* factory group has taken the word "factory" seriously in the design of the accelerator. As much as possible, conservative parameters have been chosen throughout the machine design. However, the large beam currents needed to obtain the high luminosity and the energy asymmetry needed for the center-of-mass boost push the design beyond present day machines in the following subsystems: the RF, feedback, vacuum, and interaction region. The PEP–II team has addressed these challenges and has developed a robust design for a *B* factory that will be ready in 1998. Table 5 lists some of the major milestones for the PEP–II project.

Table 5. PEP–II Milestones

1994	Winter	PEP–II project funded
1995	Spring	e^- extraction and bypass installed e^+ bypass installed
1995	Fall	e^- extraction through one cell of bypass line
1997	Winter	HER, injection into the first sextant of the ring HER, one turn in the complete ring
1997	Spring	e^+ extraction
1997	Summer	LER, injection into the first sextant of the ring HER, complete RF system
1998	Winter	LER, one turn in a complete ring
1998	Spring	LER, complete RF system
1998	Fall	Collide HER and LER beams

9 References

1. The basic design of PEP–II can be found in "PEP–II an Asymmetric *B* Factory" Conceptual Design Report," CALT–68–1869, LBL–PUB–5379, SLAC–418, UCRL–ID–114055, UC–IIRPA–93–01, June 1993.
2. Eden and Furman, "Further Assessments of the Beam-Beam Effect for PEP–II Designs APIARY 6.3D and APIARY 7.5," PEP–II/AP Note 2–92 (Oct 1992).
3. "Detector Description and Simulation Tool", GEANT Version 3.15 (CERN Program Library W5103, CERN) June 1993.

10 Questions and Answers

QUESTION 1: What maximum energy asymmetry can PEP-II achieve and what modifications would be required to achieve that asymmetry?

ANSWER: PEP-II has been designed to be able to reach an energy asymmetry of 12 GeV on 2.46 GeV with a center-of-mass energy equal to the ϒ5S resonance. The only modifications to the accelerator would be in the interaction region. In particular, the B1 magnets would be considerably weakened because the higher asymmetry makes it easier to separate the beams. In addition, the Q1 magnets would also be made weaker since the lower energy of the LEB would require a weaker field. The rest of the accelerator—from Q2 on out, including the injection system—would remain unchanged.

QUESTION 2: What can be done to get higher luminosity?

ANSWER: Table 6 lists machine parameters for the nominal PEP–II design and for a suggested design with a luminosity of 1×10^{34} cm^{-2} s^{-1}. The high tune shift of 0.06 is needed to keep the beam currents at or below the three-ampere design limit and the 1.25-cm β_y^* is probably the smallest value that is reasonable without greatly increasing the rf voltage. The rest of the high-luminosity design parameters are similar to the nominal design values.

Table 6. Suggested machine parameters for a high luminosity PEP–II.

	Nominal parameters		Possible high-luminosity design parameters	
Beam energy (GeV)	3.1	9	3.1	9
Beam current (A)	2.17	0.99	3.04	1.05
β^*_x (cm)	37.5	50.0	62.5	62.5
β^*_y (cm)	1.5	2.0	1.25	1.25
ε_x (cm)	64.5	48.4	34.9	34.9
ε_y (cm)	2.58	1.94	0.70	0.70
σ_x (μm at IP)	156		148	
σ_y (μm at IP)	6.2		3.0	
Luminosity cm^{-2} sec^{-1}	3×10^{33}		1×10^{34}	
Tune shift	0.03		0.06	
Beam aspect ratio (v/h at IP)	0.04		0.02	
Bunch spacing (m)	1.26		1.26	

QUESTION 3: In the local chromaticity correction scheme for the LEB, why is the x chromaticity correction first?

ANSWER: The maximum β_x and β_y values for the LEB are almost the same, β_x max = 109 m and β_y max = 118 m, so the chromaticity in x and y is about the same. The first open place for a sextupole after Q2 is at about 9 m from the IP. In this area, it was easier to keep β_x large and make β_y small. In addition, a substantial amount of x dispersion has been created by the LEB going through B1 and Q1. One prefers to place a sextupole where dispersion and beta functions are large; hence, it was decided to correct x chromaticity first in the LEB.

QUESTION 4: What are the dimensions of the LEB arc chambers in the region of the beam?

ANSWER: A cross section of the arc chamber of the LEB has an elliptical shape with dimensions of 95 mm in x and 55 mm in y for the beam. These dimensions correspond to half-widths of about 42σ in x and 143σ in y. There is also an antechamber on one side to absorb the synchrotron radiation generated by the dipole magnets.