PEP-II: An Asymmetric *B* Factory Based on PEP*

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INTRODUCTION

An Asymmetric *B* Factory to be installed in the PEP tunnel has been under study at SLAC, LBL, and LLNL for several years [1-4]. A mature design for a 9 GeV × 3.1 GeV electron-positron collider with a design luminosity of 3×10^{33} cm^{-2}s^{-1} is presented. Solutions now exist for all the technical problems, including issues related to high currents (e.g., beam instabilities, feedback systems, vacuum chamber design, lifetime degradation, and radiation power dissipation in the interaction region) and those related to the different energies of the beams (e.g., beam separation, beam-beam interaction, and detector requirements). The status of this project, which is being proposed for funding in FY 1993, will be discussed.

MAIN PARAMETER CHOICES

B Factory Physics Requirements

The PEP-II *B* Factory is a two ring e^+e^- collider designed to operate at the $\Upsilon(4S)$ resonance (center-of-mass energy 10.6 GeV). To enhance the study of *CP* violations, different energies for the two beams have been adopted (9.0 GeV for the electrons and 3.1 GeV for the positrons). The important detection requirement is to differentiate and separately identify the decay products of the *B* and the $\bar{B}$ mesons. This means a vertex resolution of about 60 microns, requiring that the inner radius of the vertex chamber be about 2.5 cm. Although the magnitude of the *CP* violation is expected to be large in the *B*-meson system, the cross sections of the important processes are small, so the design luminosity of the *B* Factory is 3×10^{33} cm^{-2}s^{-1}.

Machine Design Strategy

The luminosity of an asymmetric collider is given by [1]

$$\mathcal{L} = 2.17 \times 10^{34} (1+r) \left\{ \frac{I\ E\ \xi_y}{\beta_y^*} \right\}_{+,-} \ \mathrm{cm^{-2}\ s^{-1}} \qquad (1)$$

where r is the aspect ratio, I is the beam current in amperes, E is the beam energy in GeV, ξ_y is the beam-beam tune shift and β_y^* is the vertical beta function in cm. The expression in brackets can be evaluated for either beam.

The basic strategy is to choose single-bunch parameters (Table 1) similar to those obtained routinely in existing storage rings. This ensures that the beam-beam interaction is similar, the machine optics problems are tractable, and the single-bunch instabilities are manageable. New problems are:

1) Interaction region layout (two rings, backgrounds).
2) Vacuum chamber design (high currents).
3) RF and feedback systems (multibunch instabilities).

Design challenges are restricted to high-current and multi-bunch problems, which are either engineering problems or, in the case of the multibunch feedback system, in an area where there have been enormous improvements in the electronics available on the market. This means that, for the most part, no new accelerator physics issues must be addressed that would be less likely to provide definitive solutions.

TABLE 1. PARAMETER LIST

	Electron	Positron	
Energy	9.0	3.1	GeV
Luminosity	3×10^{33}		cm^{-2}s^{-1}
Tune shift ξ	0.03		
No. of bunches	1658†		
Bunch spacing	1.26		m
β_y^*	3.0	1.5	cm
β_x^*	75.0	37.5	cm
Separation	Horizontal		
Beam current	1.48	2.14	A
Bunch current	0.89	1.29	mA
σ_y^*	7.4		µm
σ_x^*	186		µm

†allows for 5% gap for ion clearing

INTERACTION REGION

The interaction region (Fig. 1) has been laid out to be compatible with either a head-on or a crossing-angle configuration [5]. Our initial choice is head-on collisions with flat beams, separated magnetically. This configuration is closest to that of conventional circular colliders so our luminosity estimates are the most reliable. Since the magnetic separation produces synchrotron radiation from which the detector must be shielded, the detector masking is easier with a crossing angle, and this option is maintained for a future upgrade. Permanent magnets are used for the LER focusing; a septum quadrupole is needed for the first HER quadrupole, 4 m from the IP.

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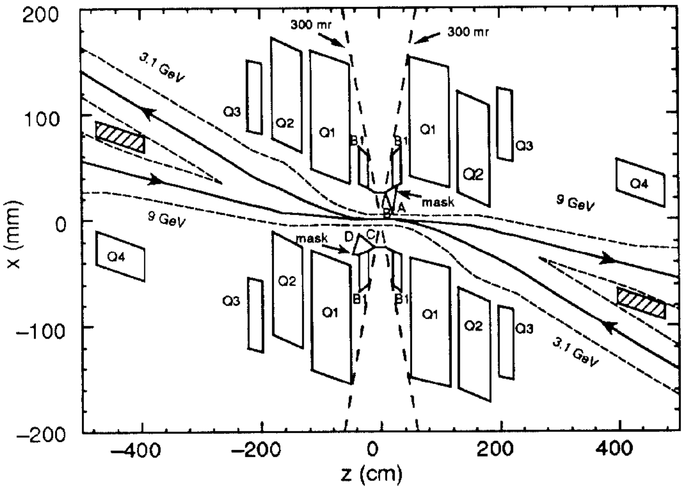
Background conditions are one to two orders of magnitude better with flat beams than with round beams, because the quadrupoles are weaker, the beam angular divergence is smaller (so that the beam size in the quadrupoles is smaller), and the separation angle can be smaller [6].

Completely satisfactory masking solutions for the head-on case have been obtained using an "S-bend" geometry to reduce backgrounds. The synchrotron radiation conditions are acceptable, and particle background rates from bremsstrahlung and beam-gas interactions have been evaluated and demonstrated to be acceptable [7].

FIGURE 1. THE INTERACTION REGION LAYOUT



We now have a detailed layout of the IP region, including all magnets, supports, collimators, and the innermost detector elements. The permanent-magnet bends and quadrupoles for the LER are based on Sm_2Co_{17} (which has the best radiation hardness and temperature stability) and meet all of the aperture and strength requirements. The synchrotron radiation power density on the masks and collimators is reasonable and preliminary engineering designs have been made, including thermal and stress analyses. All of these elements, as well as the vertex detector, fit inside a 31.2-cm diameter support tube that spans the entire detector. All elements will be prealigned within this tube prior to its installation into the detector.

We are studying two different solutions to the septum quadrupole for the HER. We have a detailed design for a superconducting Panofsky septum quadrupole, which would be just outside the detector and is compatible with all of the constraints. We also have a conceptual design for a room-temperature, Collins-type septum quadrupole, which we are in the process of engineering.

RING LAYOUT

The PEP-II *B* Factory will be based on the present PEP ring [8], taking advantage of the existing components and infrastructure. This leads to significant reductions in the cost and the scheduling uncertainties usually associated with conventional construction.

The HER arcs have a completely regular periodic structure containing 12 identical cells [9]. These cells are slightly longer than in PEP (15.125 m instead of 14.35 m) allowing room for vacuum flanges (PEP had only one 14.35-m vacuum chamber per cell). There are two dispersion suppressor cells at the ends of each arc, each slightly longer than the arc cells (16.013 m). The straight sections consist of 8 FODO cells, each 15.125 m long, except in the special straights.

The LER layout is based on that of the HER. The length of the standard period is exactly the same as the HER (15.125 m) and the quadrupoles are stacked vertically to simplify installation. The short (1-m) bend magnets increase the radiation damping. Each bend is placed close to its quadrupole on a common support raft, and is always down-beam from the quadrupole so that its synchrotron radiation strikes the chamber wall downstream of the bend.

The HER magnets are recuperated from PEP: 192 5.4-m dipoles, 20 low-field dipoles, 192 quadrupoles, and 144 sextupoles. All of these magnets will be taken from the PEP tunnel and the coils removed and refurbished. The mechanical shape of every magnet will be measured in an automated measurement facility and some fraction (≈20%) will also be measured magnetically and the results compared with the original data to confirm the validity of the procedure.

The LER magnets (and some HER magnets) are new and will be based on the designs used for the PEP magnets.

VACUUM CHAMBER

The vacuum chamber, which is based on the HERA approach [10], is designed for a maximum current of 3 A, corresponding to ≈10 kW/m or ≈2 kW/cm^2 (PEP was designed for 10 kW/m). A phosphor-bronze alloy with 2% tin is being considered for the beam tube and the pumping channel. An octagonal shape beam chamber with 5 mm walls is completely self shielding. Temperature profiles across the chamber and thermal stresses have been evaluated. The photodesorption rate should be ten times lower than aluminum [11-13]. A copper test chamber will be built this year and its synchrotron radiation outgassing properties confirmed at BNL .

In the HER, lumped ion pumps will be used as well as distributed ion pumps in both bends and quadrupoles. In the LER, only lumped pumps will be used, as there is no magnetic field in the region where the gas load is greatest.

RF SYSTEM

The RF cavities will be powered from 1-MW commercial klystrons at the *B*-Factory frequency of 476 MHz. Each klystron will be attached to two cavities via a circulator. This will require windows capable of transmitting 500 kW, which we are developing. We are also studying the possibility of modifying the present PEP klystron design to produce 500 kW at 476 MHz. If this is successful, the klystrons could be built at SLAC.

The cavity design is such that trapped higher-order modes are strongly coupled to outside loads using waveguides that are beyond cutoff for the fundamental accelerating mode [14]. We are adopting a copper cavity with "noses," similar to the Daresbury and ALS designs. This choice maximizes the cavity shunt impedance and minimizes the RF power required to establish the voltage. A computational method has been developed for estimating the shunt impedance of the fundamental mode in the presence of the waveguide couplers, and this technique is being used to optimize the cavity design. A model (pill-box) cavity has been built to measure waveguide coupling, check the computations, and investigate the practical difficulties involved. Calculations of the higher-order-mode damping and measurements on the model cavity agree, and show that damping of the higher-order modes to a Q of 30 is achievable.

The mechanical design of the cavity is proceeding with calculations of the thermal loading. Other cavity components, such as the tuners and couplers, are also being studied. We have funds for the design and construction of a high-power cavity to investigate the manufacturing issues.

FEEDBACK

The feedback system detects the phase offset of each bunch and feeds back after 90° of synchrotron oscillation (about 7 turns later). A front-end detection circuit has been built to evaluate signal-to-noise capabilities of a fast detection system [15], and a tracking program has been developed incorporating all longitudinal effects (including those of the feedback system) [16]. Analytic calculations and simulations have been performed to understand the effects of limiting the output power of the kicker amplifier.

The results show that our concept works and that only 2 kW are required to stabilize the beams. The front-end detection circuits have demonstrated the capability to measure phase errors of 0.5° at 476 MHz, with 27 dB rejection between adjacent bunches.

SLC AS INJECTOR

The injection system (Table 2) is based on the transfer of single bunches of electrons and positrons on each pulse of SLC into single buckets in each ring [17]. These bunches contain 20% of the total required charge when filling from scratch, but only contain 4% when topping up. Bypass lines will be added to the linac so that the *B*-Factory beams need not traverse the full length of the linac accelerating structure, which would lead to energy jitter and emittance degradation.

Adjustable collimators will be provided in the arcs to limit the acceptance to $\pm 10\sigma$. Adjustable collimators will also be provided in the straight section upstream of the detector, set to $\pm 12.5\sigma$. The physical apertures in the interaction region allow $\pm 15\sigma$ and an additional 2 mm for closed-orbit errors. We have tracked injected particles with large energy and transverse position errors for 20,000 turns in the ring and find no particles being lost in the interaction region.

TABLE 2. INJECTION PARAMETERS

Ring energies			
HER (e^{-})	9 GeV		(10 max, 8 min)
LER (e^{+})	3.1 GeV		(4 max, 2.8 min)
Ring currents			
HER	1.48 A	—	6.9×10^{13} e^{-}
LER	2.12 A	—	9.7×10^{13} e^{+}
Ring particles/bunch (with 5% gap)			
HER			$\approx 4 \times 10^{10}$ e^{-}
LER			$\approx 6 \times 10^{10}$ e^{+}
Linac repetition rate (pps)			60 – 120
Linac current (e$^{\pm}$/bunch/pulse)†			$0.2 - 1 \times 10^{10}$
Time between bunches (ns)			4.2
Ring kicker pulse (start-to-finish)			≤ 300 ns
Topping-off time (from 80 to 100%)			3 minutes
Filling time (from zero)			6 minutes

†*SLC presently operates with* $2 - 3 \times 10^{10}$

SUMMARY

We have a conservative design that achieves all of our goals. Key technical aspects of the design have successfully undergone independent technical reviews. The budget (Table 3) has been evaluated in great detail, and has been validated by the DOE. There is no technical impediment to starting in 18 months and we are aggressively seeking funding.

TABLE 3. BUDGET

ED& I	\$ 32,241,000
M&S and Labor	\$101,537,000
Total	\$133,778,000
Contingency	≈ 25%

Construction time could be 42 months

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