# DESIGN OF THE SYNCHROTRON-LIGHT MONITORS FOR PEP-II*

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### *Abstract*

The PEP-II collider has a 2-A, 3-GeV positron ring (the low-energy ring, LER) 1 m above a 1-A, 9-GeV electron ring (the high-energy ring, HER). The beam size and pulse duration will be measured using visible synchrotron radiation (SR) from arc bending magnets. Light will be extracted horizontally by a grazing-incidence, water-cooled mirror which must withstand a power of 50 (LER) or 200 W/cm (HER) along an SR fan with a height of 1.5 (LER) or 0.7 mm (HER) FWHM. A shallow longitudinal slot in the mirror will allow the hot core of the synchrotron fan to pass beyond the mirror to a separate absorber downstream, while the broader visible and near UV emission is reflected. Although the mirror must withstand the full heat load, image-quality surface flatness is required only when the beam is properly aligned with the slot.

## 1 DESCRIPTION OF PEP-II

The PEP-II B Factory[1] is a 2.2-km, two-ring, $e^+e^-$ collider under construction at the Stanford Linear Accelerator Center (SLAC) in the tunnel of the original PEP single-ring collider. The project is a collaboration with the Lawrence Berkeley and Lawrence Livermore National Laboratories (LBNL and LLNL). To produce B mesons with nonzero momentum in the lab frame, the rings have different energies; both require large currents for high luminosity. The 2.1-A, 3.1-GeV positron ring runs 1 m above the 9-GeV, 1-A electron ring. Both rings are designed for a maximum current of 3 A. At one collision point, the LER comes down to the height of the HER, and the two beams collide with zero crossing angle. Table 1 lists several PEP-II parameters.

The HER will be ready for commissioning first, in 1997, since it reuses the PEP-I magnets (but with a new, low-impedance, vacuum chamber). LER commissioning will follow one year later. The BABAR detector will be installed in 1999. Since both rings will use similar diagnostics, their development is proceeding on the HER schedule. Plans for the synchrotron-light beam-profile monitors are described below.

## 2 SYNCHROTRON-LIGHT MONITOR

Synchrotron radiation (SR) in the visible and near ultraviolet (600–200 nm) will be used to measure beam profiles in both transverse dimensions and, with a streak camera, in the longitudinal direction. A measurement of each ring will be made in the middle of Arc 7; this is a high-dispersion point for the HER and a low-dispersion point for the LER. A second HER measurement will later be added near the start of the arc, where the dispersion is low. No suitable high-dispersion bend is available in the LER.

The high SR power on the first mirror (M1), due to the high current (3 A maximum) in each ring, presents a major challenge. Unlike a synchrotron light source, the design offers limited access to SR. There are few ports, to keep the impedance of the ring low. The arcs are in narrow tunnels that do not permit backing the mirror away to reduce the heat load. The beam will be incident on the mirror at 4° to grazing, reducing the maximum power along the SR stripe to 200 W/cm in

Table 1. PEP-II Parameters.

| Parameter | HER | LER | Unit |
|---|---|---|---|
| Circumference | 2199.318 | | m |
| Revolution frequency | 136.312 | | kHz |
| Revolution time | 7.336 | | µs |
| RF frequency | 476 | | MHz |
| Harmonic number | 3492 | | |
| Number of full buckets | 1658 | | |
| Bunch separation | 4.20 | | ns |
| Luminosity | $3 \times 10^{33}$ | | $cm^{-2} \cdot s^{-1}$ |
| Center-of-mass energy | 10.58 | | GeV |
| Current | 0.99 (3 max) | 2.16 (3 max) | A |
| Energy | 9.01 (12 max at 1 A) | 3.10 (3.5 max) | GeV |
| Betatron tunes $(x,y)$ | 24.617, 23.635 | 38.570, 36.642 | |
| Synchrotron tune | 0.0449 | 0.0334 | |
| Emittances $(x,y)$ | 49.18, 1.48 | 65.58, 1.97 | nm·rad |
| Bend radius in arc dipoles | 165 | 13.75 | m |
| Critical energy in arc dipoles | 9.80 | 4.83 | keV |

the HER, and 50 W/cm in the LER. We first describe the arrangement for the HER.

## 2.1 SR Monitor for the High-Energy Ring

HER arcs (Fig. 1 (a)) are almost entirely occupied by magnets. A 5.4-m dipole fills most of each 7.6-m half cell, with a quadrupole, corrector and sextupole taking up much of the rest. The intense SR fan is dumped on the water-cooled outer wall of the chamber. The first mirror, mounted in the vacuum chamber on the arc's outer wall (Fig. 2), reflects the light horizontally across the chamber to the downstream inner corner. The mirror is rotated so that its upstream edge is slightly recessed behind the opening in the chamber wall, which then shades the mirror edge. The downstream end sticks slightly into the chamber, shading the leading edge of the chamber as it resumes downstream of the mirror. Thus, by reflecting back into the chamber rather than outward, we avoid a much higher heat load at edges that would otherwise be normal to the beam.

At 200 W/cm, the mirror cannot be cooled sufficiently to obtain adequate flatness for good imaging. Instead, we make use of the fact that the SR fan at the 9.8-keV critical energy is 15 times narrower than the visible fan we want to image. A 4-mm-high slot will be cut across the mid-plane of the mirror to a maximum depth of 5 mm. The x-ray fan fits into the slot when the electrons are traveling on axis, while the visible beam reflects from the mirror surfaces above and below. Because of grazing incidence, the x rays never reach the bottom of the slot as they traverse the full 7-cm length of the mirror. Instead, they continue past the mirror to dump their heat into a thermally separate absorber just downstream (Fig. 2). Since the x-ray heat load is not deposited onto the mirror, it remains flat for good imaging. The residual heat load of 1 W/cm$^2$, due largely to scattered SR, causes a temperature variation across the surface of less than 1°C.

However, the electrons will not always be correctly positioned. In this case, we do not demand that the mirror be suitable for imaging, but only that it not exceed its yield strength. We can then steer the electrons back to their proper orbit and wait briefly for the mirror to cool and become flat. Both the mirror and the dump are made of Glidcop® (copper strengthened with a dispersion of fine aluminum-oxide particles) with water-cooling channels, following techniques[2] developed for the Advanced Light Source at LBNL. A thin film of polished nickel serves as the mirror's reflective surface. An ANSYS thermal analysis of a beam hitting the mirror 2.5 mm above the top of the slot shows that the temperature for a 3-A HER beam rises from 35°C to 160°C, and the stress rises to 90% of yield.

## 2.2 Imaging and Diffraction

After this first mirror, the light reflects downward from a 45° mirror (M2) and passes through a fused-silica window to exit the beamline vacuum and enter an argon-filled optics chamber below the HER dipole. Fig. 1(b) shows the imaging scheme, which is designed to compensate for the effect of the slot. In geometric optics, a slot or aperture placed in the plane of a lens (like a camera iris) serves only to restrict uniformly the amount of light reaching the image plane without otherwise affecting the image. Here, instead of making M1 a focusing mirror with a slot across the middle, we keep M1 flat and have the first focusing mirror F1 image M1's slot onto the second focusing mirror F2, which then images the beam onto a CCD camera.

We also consider two effects of diffraction. Table 2

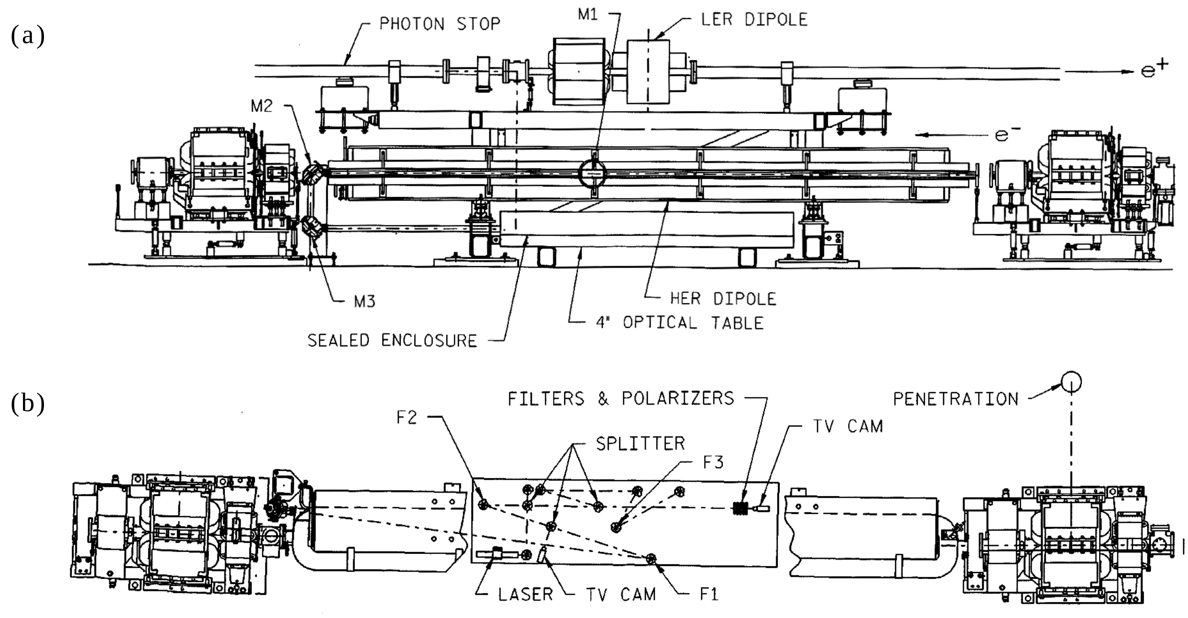


Figure 1. HER and LER beamlines in the middle of Arc 7 in (a) an elevation view and (b) a plan view, showing path of the synchrotron light. For clarity, only the HER optics are shown in the sealed optics chamber below the HER dipole.

**Table 2.** Resolution of the SR Profile Monitor for Measurements at 300 nm. Here, the diffraction spot size, $0.26(\rho\lambda^2)^{1/3}$, uses a larger experimental coefficient rather than the calculated value of 0.21. The image size is given by the quadrature addition of the source size and the diffraction size.

| | **HER Mid-Arc** | **HER Start of Arc** | **LER Mid-Arc** |
|---|---|---|---|
| Radius of curvature in dipole [m] | 165 | 165 | 13.75 |
| Diffraction spot size $\sigma_d$ [μm] | 64 | 64 | 28 |
| Electron/positron beam size $\sigma_y$ [μm] | 179 | 199 | 217 |
| $\sigma_y$ / $\sigma_d$ | 2.8 | 3.1 | 7.8 |
| Image size $\sigma_{image}$ [μm] | 190 | 209 | 219 |
| $\sigma_{image}$ / $\sigma_y$ | 1.06 | 1.05 | 1.01 |

shows the loss in resolution due to the small vertical dimension of the beam. To reduce this effect, the light at all three emission points is taken near horizontally defocusing quadrupoles, where the beams are large vertically. For a point source, diffraction from the slot narrows the image of the beam somewhat at the half maximum point, and creates tails, but the effect is small for our 4-mm slot. However, when this pattern is convolved with a narrow ($\sigma_y/\sigma_d = 2$) Gaussian electron beam, the tails disappear and the distribution broadens by 6% over the full width at half maximum without a slot. The increase is less with PEP's broader beams.

The beams are imaged onto CCD video cameras, and a computer with a frame grabber determines the transverse beam size. We put the optics and cameras inside the PEP tunnel under the HER dipole (with the dipole iron serving as shielding) in order to get good resolution from a short, stable optical path with few surfaces. In the middle of Arc 7, the collected HER and LER light beams are split, with only half used for this local imaging. The other half of the light will be sent upwards through a 10-m penetration to an optics room at ground level, where we can make more elaborate measurements with expensive equipment, such as the streak camera, away from radiation in the tunnel. Fig. 1(b) shows both optical paths for the HER beam.

### *2.3 SR Monitor for the Low-Energy Ring*

In the LER, the SR diverging from the beam downstream of each dipole enters an antechamber; 2/3 of these photons strike a water-cooled photon stop 6 m beyond the bend (see Figure 1(a)). The remainder, emitted in the downstream part of the bend, do not deviate enough from the positron orbit to hit this photon stop but instead continue to the next one. Their intensity is then lower, since they have diverged more, but their broad visible fan is clipped passing through the narrow antechamber of the intervening magnets. Consequently, we choose the light from the closer dipole. The maximum SR power incident on a mirror at a 4° grazing angle is 50 W/cm—well below that of the HER. To get the photons out, we take a 15-mm-wide vertical slice out of the photon stop, and let this light pass through to a mirror similar to the HER mirror, inclined at 4° and with a central slot. The light is deflected horizontally, but this time away from the positron orbit, since the photon stop shades the leading edge of the mirror. A 45° mirror then sends the beam down to the common optics box below the HER dipole.

## REFERENCES


* Supported by the U.S. Department of Energy under contracts DE-AC03-76SF00515 for SLAC and DE-AC03-76SF00098 for LBNL.



[1] *PEP-II: An Asymmetric B Factory*, Conceptual Design Report, LBL-PUB-5379, SLAC-418, CALT-68-1869, UCRL-ID-114055, UC-IIRPA-93-01, June 1993.

[2] DiGennaro, R., and Swain, T., *Nucl. Instrum. Methods* **A291**, 313–318 (1990).


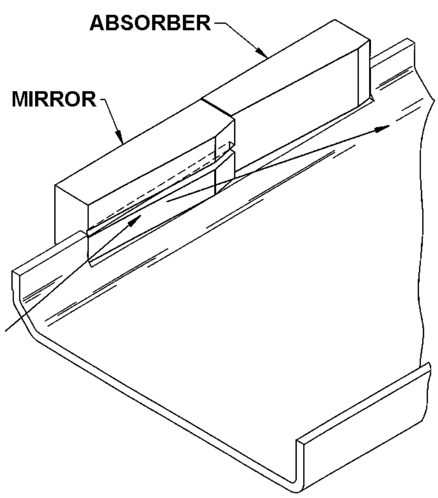


Figure 2. The slotted first mirror and the x-ray absorber, both mounted in the HER chamber wall.