

## COMMISSIONING OF THE PEP-II LOW-ENERGY RING\*

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### Abstract<sup>\*†</sup>

The newly constructed PEP-II Low-Energy Ring (LER) is designed to store up to 3 A of 3.1 GeV positrons. It was built as a collaboration between SLAC, LBNL, and LLNL [1]. The ring was completely installed and under vacuum on July 10, 1998. First stored beam was obtained on July 16, and first evidence for electron-positron collisions between LER and HER (High-Energy Ring) beams was observed on July 23, marking the formal completion of the PEP-II project. To date, three commissioning runs have occurred, the first in July 1998 (3 weeks), the second during October–December 1998 (7 weeks), and the most recent during January–February 1999 (5 weeks). During these runs various problems were uncovered and corrected, and the stored beam current has increased from 1 mA to 1160 mA. In this paper, the final LER configuration is described and results of the commissioning runs are presented. The LER is making steady progress toward its operating current of 2.16 A.

### 1. INTRODUCTION

The PEP-II LER is being commissioned by a team of physicists from SLAC and LBNL. Table 1 gives the main LER parameters. The ring (see Fig. 1) is sixfold symmetric, with six FODO arcs (having 90° phase advance per cell in both planes) of 255 m connected by six straight sections of 110 m. Ring areas are designated according to the clock, with straight sections having even numbers (Regions 12, 2, 4, 6, 8, 10) and arcs odd numbers; beam direction is counter-clockwise. Optical elements are mirror symmetric about an axis between the centers of Region 8 and Region 2.

Functional units of the ring are contained in the straight sections, as indicated in Fig. 1. Except in Region 2, the

Table 1. PEP-II LER main parameters.

Energy [GeV]	3.1
Circumference [m]	2200
Emittance, $y/x$ [nm-rad]	1.5/49
Beta function at IP, $y/x$ [cm]	1.5/50
Beam-beam tune shift	0.03
RF frequency [MHz]	476
RF voltage [MV]	3.2
Bunch length, rms [mm]	12
No. of bunches	1658
Total current [A]	2.16
Energy loss per turn [MeV]	0.65

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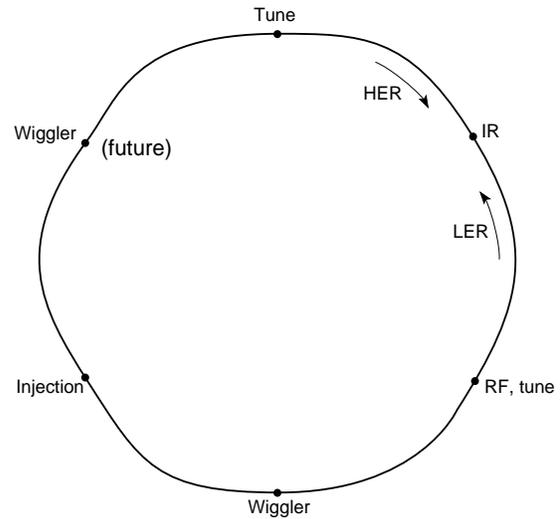


Fig. 1. Functional layout of the LER.

LER is 89 cm above the HER; in the IR the LER beam is transported downward to the plane of the HER and then restored to its normal elevation at the downstream end. A description of the lattice is found in Ref. [2].

To reach high currents with stable beam, bunch-by-bunch feedback systems operating in the time domain are employed to combat longitudinal [3] and transverse [4] instabilities. Diagnostics devices use designs common to the HER [5].

### 2. JULY 1998 RUN

The LER was fully under vacuum (with a few significant leaks) on July 10, 1998; injection activities commenced immediately thereafter. Considerable time was spent beforehand to check out power supplies and polarities of more than 900 magnets, with the result that only one magnet wiring error was discovered with the beam. In view of the limited commissioning time available before detector installation, and the limited optics adjustment range available from the permanent magnet IR quadrupoles, the nominal collision lattice was used from the outset.

To minimize radiation dose to the “background” detectors at the interaction point (IP), a dipole string immediately upstream of the IP was initially turned off and the DC injection bump magnets were tuned for on-axis injection (incoming orbit 45 mm above the LER median plane). Two hours after the beam first arrived at the injection point it had reached the upstream side of Region 2, nearly 1.1 km downstream. Over the next few days the beam was tuned through the complicated IR and

steered to get multiple turns. A 1 mA beam was stored on July 16, as observed with a beam position monitor (BPM) button attached to an oscilloscope and a DC current transformer (DCCT).

The main goals for this initial run were to store 50 mA of positrons, to begin characterizing the lattice and beam orbit, to commission the pulsed magnets (injection and abort kickers), and to commission key diagnostics devices, such as the BPM and beam loss monitor (BLM) systems [5] and the DCCT. By the end of the run, the total beam current had reached 53 mA and the single-bunch current had reached 5 mA (the latter being about four times higher than the design value).

Agreement between the model and measured beta functions was reasonable; differences at the IR quadrupoles were about 50%. The measured natural chromaticity of the ring was about 10% higher than expected in both planes. We ascribe this to the orbit offset in the strong LER sextupoles. (In Region 2, orbit deviations at the sextupoles were initially 15 mm, though the rms orbit in the arcs was below 5 mm. This was ultimately traced to a 3.6% error in the polynomial for the “long bends” in Region 2.)

After storing the beam and correcting the orbit, it was observed that the orbit was not centered. Vertically, it was high by about 1 mm and radially it was offset toward ring center by about the same amount. The first offset was attributed to field from circulating currents in the cable tray above the ring (later verified by post-run measurements). The second offset was ascribed to an error of 4 mm in the 2200 m circumference.

The main difficulty during this run was poor lifetime—only 3 minutes—even at low beam current. The lifetime was insensitive to steering and tunes, and was shown to be unrelated to RF acceptance. Because of the high pressure in a few locations, vacuum was hard to eliminate as the cause of the poor lifetime. However, a few “suspicious” orbit bumps were found to be necessary in Arc 11, and the BLMs nearby had elevated count rates. After the run ended, a visual inspection of the Arc 11 chamber interior showed a folded-over RF gasket that occluded much of the beam aperture. Due to poor lifetime scrubbing was minimal; only 0.5 A-hr was accumulated during the run.

### 3. OCTOBER 1998 RUN

During the shutdown, considerable work was done to improve the ring vacuum. Major leaks were found and repaired, though a few small ones remained. For this run, the goals were to store a beam current of 250 mA and to reach a lifetime of 1 hour at 150 mA. Other important goals included correcting the rms orbit below 1 mm and commissioning the newly installed synchrotron light monitor along with the longitudinal and transverse feedback systems.

Comparison between HER and LER orbits showed that

both rings were too large by about the same amount and a 1 kHz reduction in the RF system master oscillator frequency was made to center the orbit. (To keep the rings phase-locked to the SLAC linac, a corresponding  $-6$  kHz adjustment was made to the linac frequency.) Subsequently, the LER rms orbit was corrected to less than 1 mm in both planes. (The vertical orbit was corrected, despite the cable tray current, with an algorithm that does not minimize corrector strengths.) Later, it became apparent that the LER (and HER) showed mm-scale orbit motion near the IP resulting from thermal motion of the magnet supports along with thermal flexing of various IR beam pipes, which causes slight magnet motion. (At high beam currents, various HER IR thermocouples show significant, though not extreme, temperature increases. This is due to two effects: synchrotron radiation fans from upstream HER dipoles striking uncooled stainless steel portions of the HER vacuum chamber, and strong LER synchrotron radiation fans from the B1 separation dipoles near the IP illuminating the upstream HER beam pipes.) The orbit change in each ring is correctable with a single corrector near the IP and we implemented orbit feedback loops to control the motion. This behavior should improve when *BABAR* comes on line due to changes in the vacuum chambers (bellows added to provide a “frangible link”) and better thermal stabilization with the detector present.

To improve the beam quality for collisions, we decoupled the ring with the global skew quadrupoles. Once the beam was well centered in the sextupoles, it was routinely possible to reach a closest tune approach of  $\leq 0.001$ . Dispersion steering was also done, reducing the residual vertical dispersion in the arcs to about 10 mm.

Both the longitudinal and transverse feedback systems were made operational during this run. The beam was longitudinally stable up to about 300 mA but did show evidence for some “mode-0” oscillation amplitude, driven by the RF system. (The so-called woofer link between the longitudinal feedback and RF systems had not yet been implemented.) The transverse feedback system also showed no evidence for strong coupled-bunch motion aside from the resistive-wall instability. The newly installed LER synchrotron radiation monitor proved very useful in diagnosing beam instabilities as the current was increased, but its mirror is distorted sufficiently to prevent a good determination of the vertical beam size.

During the run, the beam lifetime measured at low current ( $\approx 1$  mA) reached 100 minutes; a beam lifetime of 63 minutes at 150 mA was also reached. By the end of the run in December, a beam of 415 mA was stored, and scrubbing of the vacuum chamber reached 20 A-hr.

### 4. JANUARY 1999 RUN

This period marked the final commissioning period before *BABAR* comes on line. The main goal was to reach a high beam current, 1100 mA, with beam stability sufficient for

luminosity-producing collisions. (Maximum beam current was limited by the interim Q2 vacuum chambers; these are now being replaced to permit full-current operation.) As seen in Fig. 2, the beam current increased steadily during the run; a stored positron beam current above 1 A was reached on February 12. At the end of the run, 1160 mA was stored in the LER, making it presently the world's highest current positron ring. The integrated current has reached 153 A-hr. Unfortunately, there was an accidental vent in one arc (not beam related) one week prior to the end of the run. After resuming operation, the lifetime recovered to its earlier value (1 hour at 700 mA) but did not further improve. During collision tests, a 680 mA LER beam colliding with a 350 mA HER beam produced a measured luminosity of  $5.2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ .

The woofer link from the longitudinal feedback system to the RF system was commissioned and it reduced the mode-0 motion to below  $0.01^\circ$ . This was important in reaching the highest beam currents. Evidence was seen for true longitudinal coupled-bunch motion at high currents; the growing modes are mainly consistent with expectations based on measured RF cavity modes.

At high currents, we find that the pressure readings of the vacuum pumps increase markedly (see Fig. 3). The observed effect is sensitive to the fill pattern, with a larger number of bunches showing less increase. All pumps exhibit such behavior, with the straight sections being worse. The increase is clearly a real pressure rise, as the beam lifetime decreases and the background detectors in Region 2 show a corresponding increase and the same bunch pattern dependence. We believe the pressure rise is due to a pressure-bump phenomenon in which secondary electrons (or possibly ions) desorb gas locally from the chamber walls. There is evidence that scrubbing alleviates the effect, since the arcs show less pressure rise than the straight sections, and the upstream part of a straight section (which is illuminated by synchrotron radiation) is better than the downstream part that has no scrubbing.

### 5. SCHEDULE AND PLANS

The next run will be from May–August 1999. For the LER, the main goals will be to continue scrubbing, to

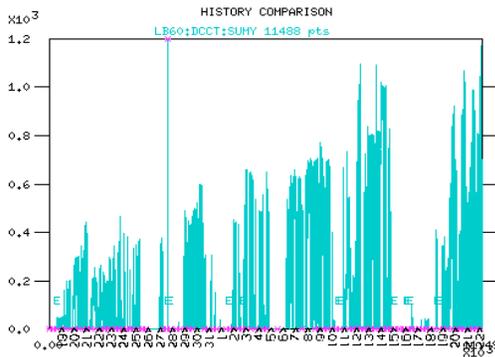


Fig. 2. LER beam current vs. time during run.

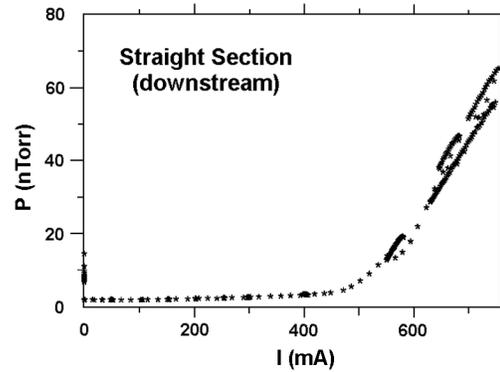


Fig. 3. Pressure in straight section vs. beam current.

reduce detector backgrounds (with improved injected beam quality, with collimators, and possibly with a solenoidal field to suppress the anomalous pressure rise), and to continue optimizing the luminosity. During this run we hope to reach a luminosity of  $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ .

### 6. SUMMARY

LER commissioning is well under way, following in the footsteps of the very successful HER program. Thus far, there have been few surprises. We see no large instabilities, no major misalignments or aperture restrictions, and component heating is modest. Scrubbing is proceeding well, though we have a recurring problem with small leaks at the arc chamber flange joints.

### 7. ACKNOWLEDGMENTS

LER performance thus far is a testimony to the care with which ring components were fabricated and installed. The engineering and technical staffs of PEP-II deserve the credit for this. Equally important to rapid commissioning are the skill and effort of our colleagues on the LER Commissioning Team; successes reported here are theirs.

### 8. REFERENCES

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