PEP-II STATUS AND FUTURE PLANS*

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Abstract

The PEP-II B-Factory at SLAC has reached a luminosity of $4.6\times10^{33}/cm^2/s$ and has delivered 94 fb^{-1} of data to the BaBar physics detector by the end of May 2002. PEP-II has delivered over 309 pb^{-1} in 24 hours and over 6.35 fb^{-1} in one month. The accelerator physics issues for these performance levels include electron cloud, beam-beam effects, parasitic beam-beam collisions, and RF beam loading. Upgrades to PEP-II are underway to increase the luminosity to 2 to $4\times10^{34}/cm^2/s$ by FY2007. The accelerator physics effects that must be dealt with during these upgrades include RF loading, multi-bunch feedback, IR beta function, bunch length reduction, and interaction region vacuum chamber upgrades.

Table 1: PEP-II parameters at peak luminosity

Parameter	**PEP-II LER**	**PEP-II HER**
Energy (GeV)	3.1	9.0
Vertical tune	36.552	23.638
Horizontal tune	38.650	24.582
Current (mA)	1775	1060
Bunch charge ($\times10^{10}$)	10.2	6.1
RF klystrons/cavities	3/6	5/20
Number bunches	800	800
Lumin. ($\times10^{33}/cm^2/s$)	4.6	4.6
β_y* (mm)	9	12.5
β_x* (cm)	35	50
Emittance (x/y) (nm)	43/7	48/1.6
σ_z (mm)	13	12
Lum hourglass factor	0.81	0.81
Crossing angle (rad)	0	0
IP Horiz. size (μm)	123	155
IP Vert. Size (μm)	7.9	4.5
ξ_x	0.065	0.081
ξ_y	0.058	0.031

*Supported by US DOE contracts DE-AC03-76SF00515 and DE-AC03-76SF00098.

1 STATUS

PEP-II has been providing colliding beams for the BaBar detector since May 1999 [1-7]. The present run started in January 2001 and will end at the end of June 2002. There will be a four month down this summer-fall with beam starting again in November 2002. During the recent run, colliding beams occupied 80% of the time, 10% for repairs, and 10% for machine development and accelerator physics studies. About 87% of the data logged by BaBar was on the Upsilon 4S resonance and 13% off-resonance about 40 MeV lower. PEP-II has briefly operated at the Upsilon 3S. The highest luminosity in PEP-II is $4.6\times10^{33}/cm^2/s$ with the corresponding parameters listed in Table 1. The beam sizes of the LER are enlarged at this peak luminosity by about 40%. The peak luminosity recorded in each month is shown in Figure 1 and the total integrated luminosity in Figure 2. The present delivered luminosity to BaBar is 94 pb^{-1}.

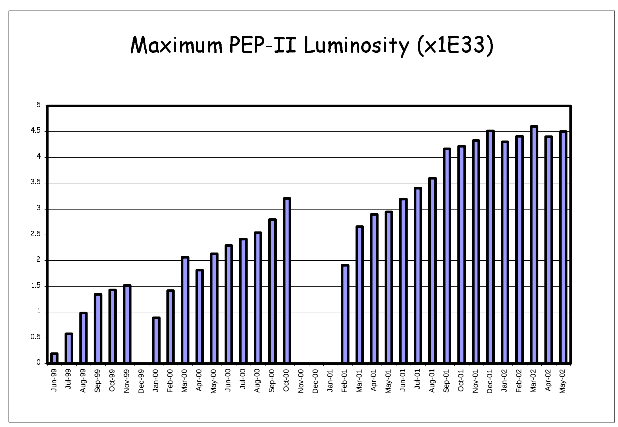

Figure 1 Peak luminosity each month since May 1999.

2 BEAM-BEAM INTERACTION

At low currents, the luminosity increases as the product of the electron and positron bunch charges. At higher currents the beam sizes enlarge due to beam-beam and electron cloud effects, reducing the luminosity increase with current. Most of the beam size blowup is in the positron beam and in both x and y planes. The HER and LER bunch charges are appropriately balanced to produce near equal beam-beam effects. If the LER bunches are relatively too high in current, then the HER lifetime is reduced but its transverse dimensions do not change much

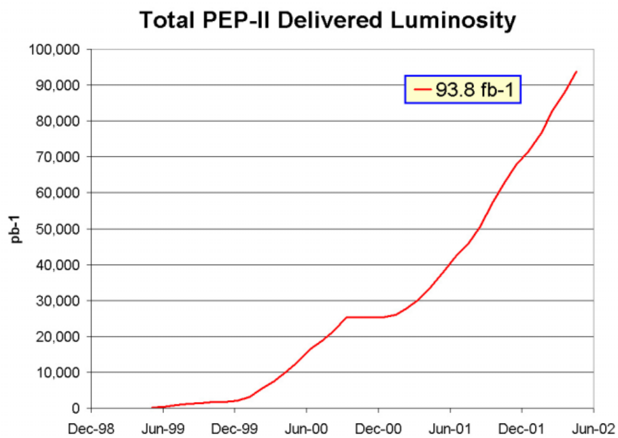

Figure 2 Delivered integrated luminosity to BaBar.

i.e. it has a beam-beam tail effect. If the HER bunches are too high in current then the LER bunch sizes enlarge and eventually the lifetime is affected, i.e. it has both core and tail beam-beam effects. At the highest luminosity, the beam-beam parameters for present collisions are listed in Table 1. PEP-II has been operating with 800 bunches with a bunch every fourth RF bucket. There is very little effect of ECI as seen in Figure 3.

Recently as a test, PEP-II has been operated with bunches every two RF buckets but with mini-gaps after about 24 bunches. A plot of the luminosity over the whole train is shown in Figure 4. There are clear signs of ECI

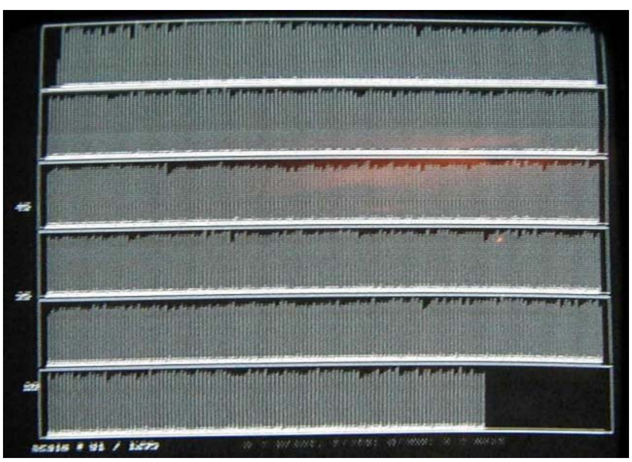

Figure 3 Bunch luminosity along the train with every 4th RF bucket filled and a 5% ion gap at the end of the train.

with higher luminosity at the beginning of the mini-trains than at the end. The first and last bunches have only one parasitic collision instead of two as in all the other bunches in this bunch pattern. The parasitic crossing effects are largest in the vertical plane where the vertical betas are much larger than the horizontal betas at the parasitic collisions displaced 63 cm from the IP on both sides. In the near future bunch patterns with fewer parasitic collisions will be tried. Examples are x2x4 with a mini-gap every 4 to 10 bunches.

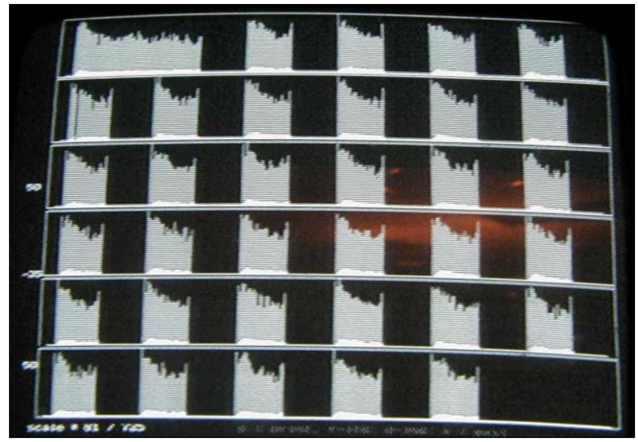

Figure 4 Luminosity in each bunch with every 2nd RF bucket filled and with 24 bunch mini-trains.

The high beam currents in each ring load the RF cavities which, because of the 5% bunch gap, cause the bunch RF phases to shift along the train. In Figure 5 are shown the RF bunch phases along the train for the HER and LER beams. The linear phase shift in the HER is expected. The additional slow ripples in the LER beam phases are due to two parked cavities that are not powered. If both HER and LER phases move together then their collision location does not move relative to the nominal collision point. However, here the LER phase moves differently from the HER by about 5 degrees at 476 MHz. The corresponding IR collision location moves half as far or about 4.4 mm. Since the β_y*s are about 9 to 12 mm, then these shifts cause the collision point to move a large part of β_y*. Thus, the beam-beam geometrical hourglass effect and the tune shifts are enhanced. A few percent reduction in the luminosity and beam lifetimes are seen at the largest phase excursions along the train. During the 2002 summer shut down new abort kickers will be installed allowing the 5% abort gap to be reduced to 2.5 % reducing the phase transients.

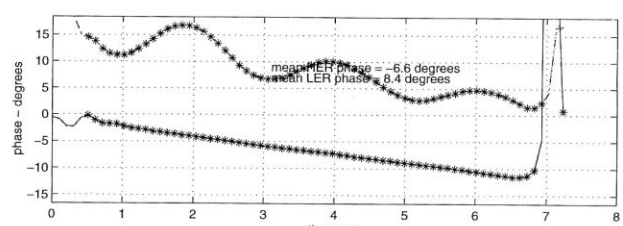

Figure 5 RF phase transients along the bunch train. LER above and HER below. The IP position moves only half as much as the phase difference.

3 ELECTRON CLOUD INSTABILITY

The Electron Cloud Instability (ECI) has been very evident in the LER positron beam from early days. The ECI effects come from e+ bunch interaction with free electrons from photo-electron emission but primarily from multipacting driven by the bunches. The vacuum chamber shapes are important. In the LER arcs the chambers are aluminum with ante-chambers. The straight sections have cylindrical stainless-steel chambers. The interaction region has copper octagonal chambers. To suppress ECI, solenoids have been wound on the drift vacuum chambers in all three regions. Without the solenoids, the ECI effect appeared at a few hundred mA. The solenoids produce about 25 to 35 gauss fields. All the solenoid winding was completed in January of 2002. With the solenoids, the ECI blowup of the LER single beam is essentially not present with a bunch spacing of 4 RF buckets (476 MHz) with current up to 1800 mA. The ring has a 5% ion gap that is clear of bunches.

In the future PEP-II will need to operate with bunches every second RF bucket to provide 1600 bunches for collisions. With two-bucket spacing the ECI effect has reappeared as seen in Figure 4 along the short mini-trains. The cures for this new regime of ECI are under study. Possibly, higher solenoid fields will help.

4 INTERACTION REGION HEATING

At the interaction point of PEP-II there is a Be chamber surrounded by a precision silicon strip detector SVT of BaBar. The Be chamber is double-walled with water cooling between. At present, the water removes about 1 kW of HOM and I^2R heat load. This 60 cm long chamber is connected to the nearby B1 dipole magnet chamber with a two convolution bellows on each end. Since these bellows are in the center of BaBar there was little or no space for water-cooling lines and very little instrumentation. The temperature of these bellows is the present limit on beam operation with heat coming from local beam I^2R losses and transverse beam excited modes at 5.6 GHz. A power of about 60 W are absorbed by these bellows mostly in TE modes. The temperature rise of the bellows convolutions is about 300 degrees C believed to be the engineering limit. Higher luminosity calls for increasing the beam currents, lowering β_y*, and reducing bunch lengths. All of these changes will increase local heat loses. In the summer of 2002, the IR support tube will be removed and extra cooling (air) added, new instrumentation will be added to the Be chamber bellows, a new Q2 crotch chamber with lower HOM generation will be installed, and new higher power Q2 bellows will be installed. The hope is to increase the power capability a factor of four to allow a factor of about four increase in luminosity. The final cooling assembly is under study but a factor of three is already in hand as shown in Figure 6.

5 FUTURE PLANS

PEP-II has an upgrade plan that is leading towards a luminosity of 2×10^{34} in FY2006 and possibly to 4×10^{34}. Combining the equations for luminosity and the vertical tune shift, one derives the traditional luminosity scaling

$$L = 2.17 \times 10^{34} (1 + r) \xi_y \left(\frac{EI}{\beta_y^*} \right) \ \text{cm}^{-2}\text{sec}^{-1} \qquad (1)$$

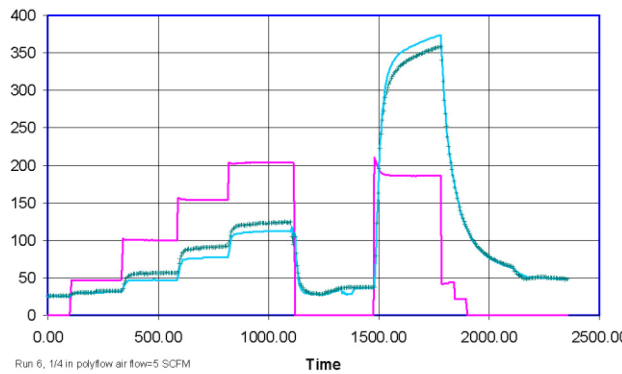

Figure 6. Be bellows temperature rise (deg C) (upper curves right) with heater current (center) with (left) and without (right) 5 CFM air cooling during lab bench tests.

equation with r the y to x aspect ratio (~0.02), E the beam energy, I the beam current, and β_y* the vertical beta at the collision point. In order to get a factor of four above the present luminosity (to 2×10^{34}), the currents will be raised about a factor of two, the tune shifts increased about 10% and β_y* reduced a factor of two to about 7 mm. The number of RF stations in the LER will be increased from two to four in order in achieve about 4.0 A. The number of RF stations in the HER will be increased from five to eight allowing a current of 1.7 A. The β_y* can be decreased to about 7 mm using the present IR quadrupole configuration, although somewhat increased backgrounds are expected. The chromatic corrections will be more difficult but early tests indicate an acceptable dynamic aperture. To achieve 4×10^{34} the β_y* must be lowered to about 4.5 mm and additional RF stations added to the HER and LER. The lower β_y* will likely require that additional quadrupoles be moved closer to the collision point for the LER. These additional quadrupoles would likely be permanent magnets and replace part of the inner B1 permanent magnet dipoles which would be shortened. In order to shorten the bunches to reduce the hourglass effects, lower alpha lattices would be needed in the HER and LER or higher harmonic RF cavities to increase the effective RF voltage. The details of the 4×10^{34} upgrade will be evaluated in the next six months.

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