# PERFORMANCE OF THE PEP-II B-FACTORY COLLIDER AT SLAC *

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*Abstract*

PEP-II is an $e^+e^-$ asymmetric B-Factory Collider located at SLAC operating at the Upsilon 4S resonance (3.1 GeV x 9 GeV). It has reached a luminosity of $9.21 \times 10^{33}/cm^2/s$ and has delivered an integrated luminosity of 710 $pb^{-1}$ in one day. PEP-II has delivered, over the past six years, an integrated luminosity to the BaBar detector of over 262 $fb^{-1}$. PEP-II operates in continuous injection mode for both beams boosting the integrated luminosity. The peak positron current has reached 2.45 A in 1588 bunches. Steady progress is being made in reaching higher luminosity. The goal over the next several years is to reach a luminosity of $2.1 \times 10^{34}/cm^2/s$. The accelerator physics issues being addressed in PEP-II to reach this goal include the electron cloud instability, beam-beam effects, parasitic beam-beam effects, high RF beam loading, shorter bunches, lower $\beta_y$* interaction region operation, and coupling control. Figure 1 shows the PEP-II tunnel.

## PARAMETERS

The present parameters of PEP-II are shown in Table 1 compared to the design. The present peak luminosity is over three times the design and the best integrated luminosity per month is 17.04 $fb^{-1}$, over five times the design. The highest luminosity in each month is shown in Figure 2, the integrated luminosity each month in Figure 3 and the integrated luminosity in Run 5 in Figure 4.

Figure 1. View of the PEP-II tunnel.

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Table 1: PEP-II May 2005 Parameters.

| Parameter | PEP-II Design | PEP-II Present |
|---|---|---|
| HER Vertical tune | 23.64 | 23.622 |
| HER Horizontal tune | 24.62 | 24.520 |
| LER Vertical tune | 36.64 | 36.564 |
| LER Horizontal tune | 38.57 | 38.512 |
| HER current (mA) | 750 | 1550 |
| LER current (mA) | 2140 | 2450 |
| Number of bunches | 1658 | 1588 |
| Ion gap (%) | 5 | 1.8 |
| HER RF klystron/cav | 5/20 | 9/26 |
| HER RF volts (MV) | 14.0 | 15.5 |
| LER RF klystron/cav. | 2/4 | 4/8 |
| LER RF volts (MV) | 3.4 | 4.04 |
| $\beta_y$* (mm) | 15-25 | 11 |
| $\beta_x$* (cm) | 50 | 35-49 |
| Emittance (x/y) (nm) | 49/2 | 31-59/1.4 |
| $\sigma_z$ (mm) | 11 | 11-12 |
| Lum hourglass factor | 0.9 | 0.84 |
| Crossing angle(mrad) | 0 | <0.1 |
| IP Horiz. size $\Sigma$ ($\mu$m) | 222 | 170 |
| IP Vert. Size $\Sigma$ ($\mu$m) | 6.7 | 7.3 |
| HER Horizontal $\xi_x$ | 0.03 | 0.055 |
| HER Vertical $\xi_y$ | 0.03 | 0.046 |
| LER Horizontal $\xi_x$ | 0.03 | 0.053 |
| LER Vertical $\xi_y$ | 0.03 | 0.064 |
| Lumin. ($\times 10^{33}/cm^2/s$) | 3.00 | 9.21 |
| Int. Lum/month ($fb^{-1}$) | 3.3 | 17.04 |
| Total Int. Lum. ($fb^{-1}$) | 30/year | > 262 total |

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The progress in integrated luminosity has come from correcting the orbits, lowering $\beta_y$*, moving the fractional horizontal tunes in both rings to just above the half integer (<0.52), and trickle injection of both beams.

## RUN 5 STATUS

PEP-II [1-7] has been providing colliding beams for the BaBar detector since May 1999. The present Run 5 started in April 2005 and will end in July 2006. There will be a one month down in October 2005 for safety checks. During the recent run, colliding beams occupied 75% of the time, 20% for repairs, and 5% 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. The highest luminosity in PEP-II is $9.21x10^{33}/cm^2/s$ with the corresponding parameters listed in Table 1. The horizontal beam size of the LER is enlarged at this peak luminosity by about 30%. Also, the vertical beam size of the HER is enlarged by about 20% at the peak luminosity. Both increases are due to the beam-beam effect. 710 $pb^{-1}$ has been delivered in 24 hours. The present delivered luminosity to BaBar is over 262 $fb^{-1}$.

The accelerator down from August 2004 to March 2005 dealt with three months of installation work followed by several months of safety training and procedure updates.

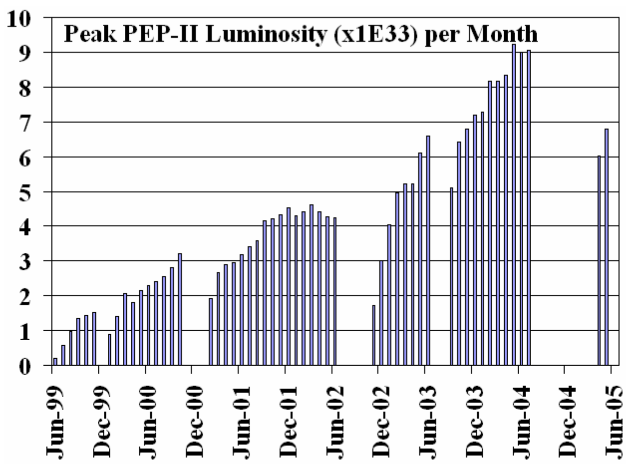


Figure 2. Peak luminosity each month since May 1999. The highest luminosity has reached $9.21x10^{33}/cm^2/s$.

## BEAM-BEAM INTERACTION

At low currents, the luminosity increases as the product of the electron and positron bunch charges. At higher currents the LER-x and HER-y beam sizes enlarge due to beam-beam and somewhat by interaction region parasitic collisions. The HER and LER bunch charges are appropriately balanced to produce near equal beam-beam effects. If there is a miss-balance, flip-flop effects can occur. The horizontal tunes of both rings were recently

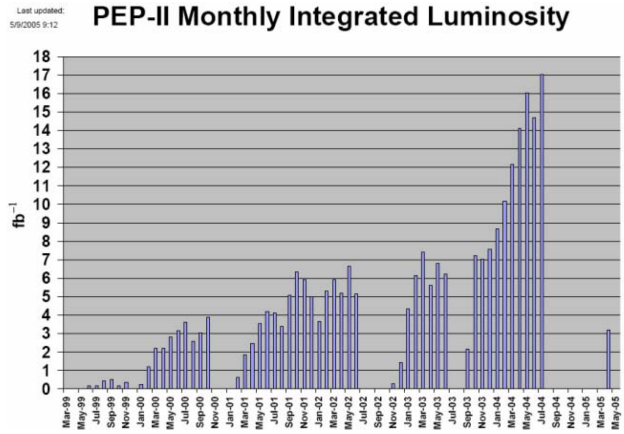


Figure 3. Integrated luminosity per month. In July 2004 PEP-II delivered over 17 $fb^{-1}$.

moved closer to the half integer (~0.51 to 0.52) and an increase of about 10% in luminosity occurred. In order to move the HER to the half integer, the horizontal beta beats in the HER had to be fixed. Moving close to the half integer tune makes any beta beats larger. Computer codes (MIA, ORM, Phase-Advance) have been used to improve the coupling and betas in the rings. The beta beats in both rings are below 50%.

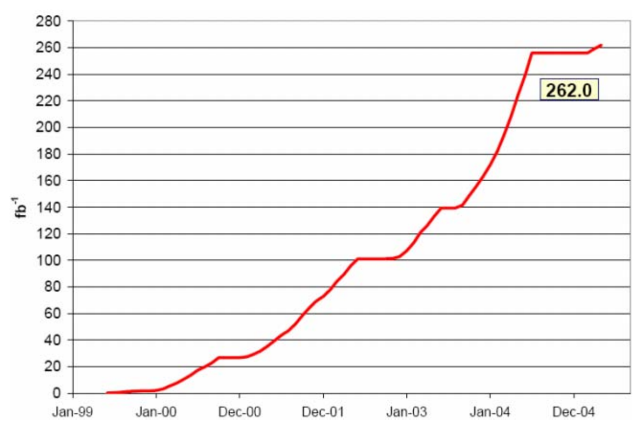


Figure 4. Delivered integrated luminosity to BaBar by PEP-II. A grand total of over 262 $fb^{-1}$ has been delivered from May 1999 to May 2005.

Since October 2003, PEP-II has operated with bunches in every two RF buckets but with mini-gaps of a few RF buckets after about 66 bunches. A plot of the bunch luminosity over the whole train is shown in Figure 6. Over the train, there are no signs of Electron Cloud Instability ECI in the positron beam. The parasitic crossing beam-beam 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 ($\Delta x$=3.2 mm). As the $\beta_y$* is lowered the parasitic effects will become stronger but so far at most a few percent (~5%) luminosity loss. Beam-


Figure 5. PEP-II's best day showing trickle injection and a 710 $pb^{-1}$ integrated luminosity.

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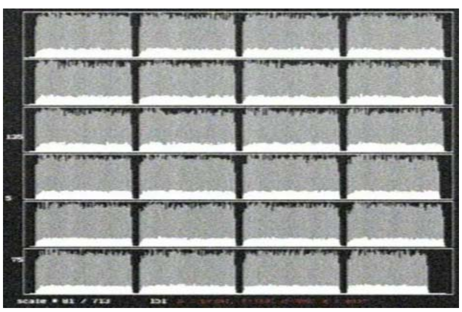

Figure 6. Bunch luminosity along the train with every 2nd RF bucket filled and a 1.8% ion gap at the end of the train. There are mini-gaps of about 3 RF buckets.

beam parameters from 0.046 to 0.065 are now routinely achieved in PEP-II that far exceed the design of 0.03.

## CONTINUOUS (TRICKLE) INJECTION

Continuous injection was made to work in November 2003 when the PEP-II and BaBar teams reduced the backgrounds to an acceptable level to allow BaBar to take data continuously. The improved efficiency for data delivery was about 30% within a few days. Trickle injection for positrons uses about three injection pulses per second from the SLAC linac, resulting in the positron current being stable to about 0.1% with BaBar recording better than 98% of the data. The electron ring at PEP-II proved more difficult and studies continued until March 2004 before trickle injection was successful. About two linac pulses per second is needed to keep the electron current stable to 0.1%. Since March 2004, both PEP-II rings are trickle injected simultaneously with BaBar taking data. So PEP-II has true trickle injection with either beam injected pulse-by-pulse with very steady currents and steady luminosity, see Figure 5. The overall integrated luminosity efficiency jumped 10% with the HER ring and to just over 40% with both rings together.

## FUTURE PLANS

PEP-II has an upgrade plan that is leading towards a luminosity of greater than $2.1 \times 10^{34}$ in FY2007. Combining the equations for luminosity and the vertical beam-beam parameter, one derives the traditional luminosity scaling

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

equation with r the y to x aspect ratio (~0.04), E the beam energy, I the beam current, and $\beta_y$* the vertical beta at the collision point. In order to get a factor of 2.3 above the present luminosity (to $2.1 \times 10^{34}$), the currents will be raised about a factor of 1.5 to 2, the tune shifts increased about 10% and $\beta_y$* reduced from 11 mm to about 8.5 mm. The number of RF stations in the LER will be increased from four to five in order in achieve about 4.4 A. The number of RF stations in the HER will be increased from nine to ten allowing a current of 2.2 A. To shorten the bunch length to reduce the hourglass effects, a lower alpha lattice will be used in HER and a higher RF voltage.

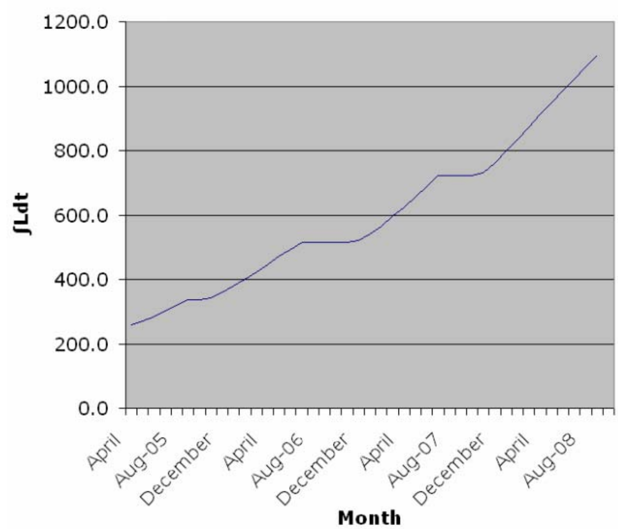


Figure 7. Projected integrated luminosity ($fb^{-1}$) for PEP-II into FY2008.

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