A LUMINOSITY OF 10^{34} CM^{-2} S^{-1} IN THE PEP-II B-FACTORY*

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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 $1.09 \times 10^{34}/cm^2/s$ and has delivered an integrated luminosity of 884 pb^{-1} in one day. PEP-II has delivered, over the past seven years, an integrated luminosity to the BaBar detector of over 375 fb^{-1}. PEP-II operates in continuous injection mode for both beams boosting the integrated luminosity. The peak positron current has reached 2.995 A in 1722 bunches. The electron current has reached 1.78 A. 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 β_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 3.6 times the design and the best integrated luminosity per day is 0.884 fb^{-1}, over 6.8 times the design. The highest luminosity in each month is shown in Figure 2, the integrated luminosity for each month since the startup of PEP-II is shown in Figure 3 and the integrated luminosity for Run 5 in Figure 4.

Figure 1: View of the PEP-II tunnel. The LER beam line is above the HER beam line.

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Table 1: PEP-II June 2006 Parameters

Parameter	PEP-II Design	PEP-II Present
HER Vertical tune	23.64	23.61
HER Horizontal tune	24.62	24.503
LER Vertical tune	36.64	36.59
LER Horizontal tune	38.57	38.505
HER current (mA)	750	1776
LER current (mA)	2140	2950
Number of bunches	1658	1722
Ion gap (%)	5	1.6
HER RF klystron/cav	5/20	10/26
HER RF volts (MV)	14.0	15.6
LER RF klystron/cav.	2/4	4/8
LER RF volts (MV)	3.4	4.35
β_y* (mm)	15-25	9-10
β_x* (cm)	50	40-105
Emittance (x/y) (nm)	49/2	30-50/0.8
σ_z (mm)	11	11-12
Lum hourglass factor	0.9	0.82
Crossing angle(mrad)	0	<0.05
IP Horiz. size Σ (μm)	222	160
IP Vert. Size Σ (μm)	6.7	6.9
HER Horizontal ξ_x	0.03	0.113
HER Vertical ξ_y	0.03	0.062
LER Horizontal ξ_x	0.03	0.027
LER Vertical ξ_y	0.03	0.047
Lumin. ($\times 10^{33}/cm^2/s$)	3.00	10.88
Int. Lum/month (fb^{-1})	3.3	17.04
Total Int. Lum. (fb^{-1})	30/year	> 375 total

The progress in integrated luminosity has come from correcting the orbits, lowering β_y*, moving the fractional horizontal tunes in both rings to just above the half integer (~0.505), and trickle injection of both beams.

RUN 5B STATUS

PEP-II [1-6] has been providing colliding beams for the BaBar detector since May 1999. The present Run 5 started in April 2005 and will end in August 2006. There will be a four month down starting August 2006 for safety checks and installation. During the recent run, colliding beams occupied 68% of the time, 25% for repairs, and 7% 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 10.88×10^{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 20%. Also, the vertical beam size of the HER is enlarged by about 15% at the peak luminosity. Both increases are due to the beam-beam effect. 844 pb^{-1} has been delivered in 24 hours. The present delivered luminosity to BaBar is over 375 fb^{-1}.

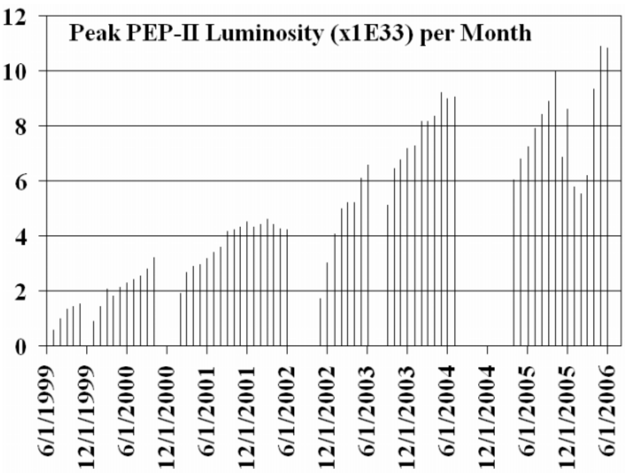

Figure 2: Peak luminosity each month since May 1999. The highest luminosity is 1.088×10^{34}/cm^2/s.

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 moved closer to the half integer (~0.505) and an increase of about 15% 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. Further horizontal beta beats in both rings are under investigation.

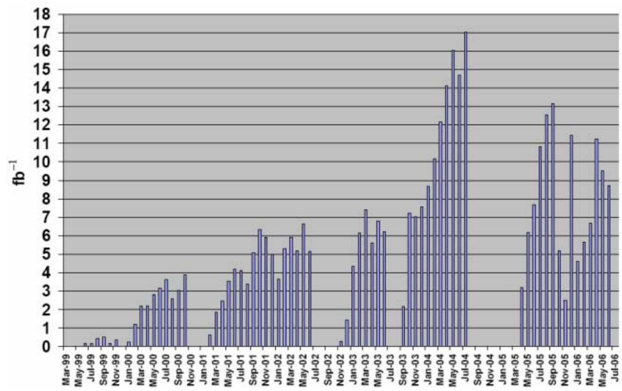

Figure 3: Integrated luminosity per month. PEP-II delivered over 17 fb^{-1} in the month of July 2004.

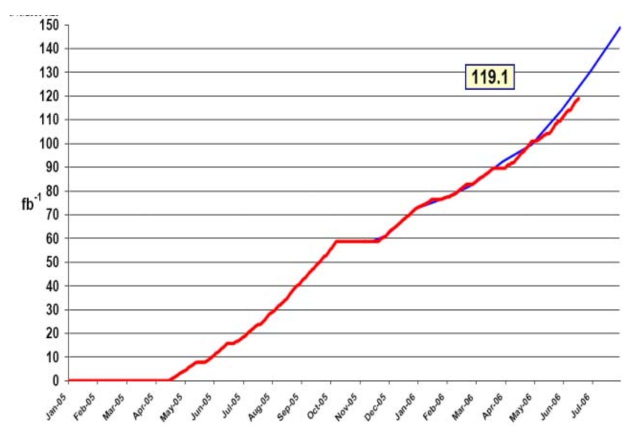

Figure 4: Delivered integrated luminosity to BaBar by PEP-II for Run 5. A total of over 119 fb^{-1} has been delivered from April 2005 to May 2006. The blue curve is the projected luminosity for this run. This projection was made in March 2006.

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 (Δx=3.2 mm). As the β_y* is lowered the parasitic effects will become stronger but so far at most a few percent (<5%) luminosity loss. In September 2004 we filled in all of the mini-gaps to get the maximum number of bunches into the rings.

Beam-beam parameters in the vertical from 0.047 to 0.062 are now routinely achieved in PEP-II that far exceed the design of 0.03.

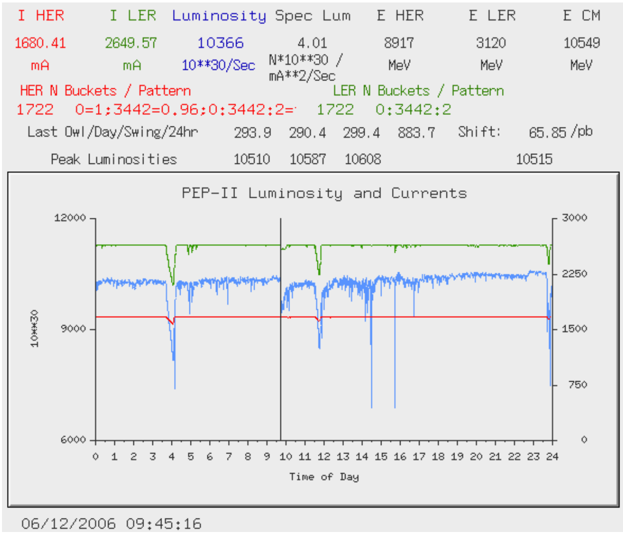

Figure 5: PEP-II's best day showing trickle injection and 844 pb^{-1} of integrated luminosity.

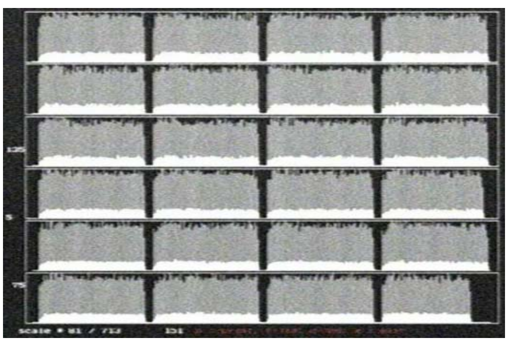

Figure 6: Bunch luminosity along the train with every 2nd RF bucket filled and a 1.8% ion gap at the end of the train. There are mini-gaps of about 12 RF buckets.

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 five 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 three 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 $2.0\text{x}10^{34}$ in FY2008.

$$L = 2.17\times10^{34}(1+r)\xi_y\left(\frac{EI}{\beta_y^*}\right)\ \text{cm}^{-2}\text{sec}^{-1} \qquad (1)$$

with r the y to x aspect ratio (~0.03), 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 2.0 above the present luminosity (to $2.0\text{x}10^{34}$), the currents will be raised about a factor of 1.4, the tune shifts increased about 15% and β_y* reduced from 10 mm to about 8.5 mm. The number of RF stations in the HER will be increased from ten to twelve in order in achieve about 2.2 A. The LER has sufficient RF stations to store 4 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.

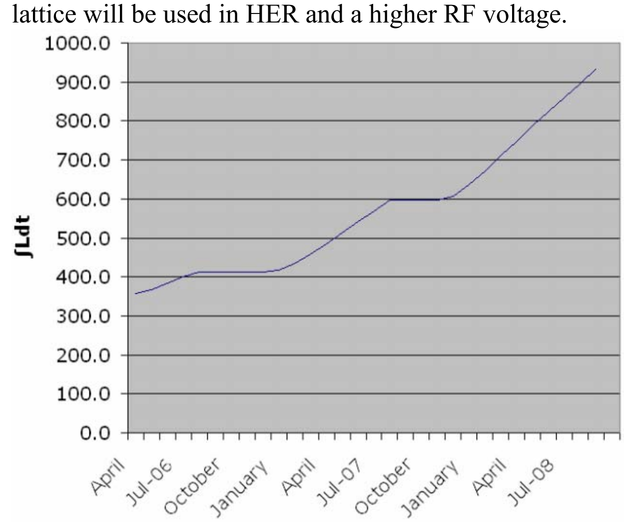

Figure 7: Projected integrated luminosity (fb^{-1}) for PEP-II through September FY2008.

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