RECENT MEASUREMENTS OF THE BEAM-BEAM INTERACTION AT PEP-II*

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Abstract

The beam-beam interaction is one of the performance limitations at PEP-II. The peak luminosity in PEP-II has reached $4.6 \times 10^{33}/cm^2/s$ with 800 bunches with a positron current of 1.77 A and an electron current of 1.07 A. The beam-beam tune shift limits have exceeded 0.07 horizontally and 0.03 vertically. A model of the luminosity with current using the measured beam sizes has been developed. Studies are underway to increase the luminosity toward $2 \times 10^{34}/cm^2/s$ and beyond by increasing the number of bunches, raising the beam currents, lowering the betas at the interaction points, and shortening the bunch lengths[1].

Table 1 PEP-II Collision Parameters as of May 2002.

IR Parameter	Design	Present operating
C-M energy (GeV)	10.58	10.58
Crossing angle (mrad)	0	<0.1
Luminosity (x10^{33})	3.0	4.60
Number of bunches	1568	800
HER current (mA)	750	1070
LER current (mA)	2140	1770
Beam-beam parameter (y+/-)	0.03/0.03	0.058/0.031
Beam-beam parameter (x+/-)	0.03/0.03	0.065/0.081
βy*/βx* (cm/cm) (e+)	1.5/50	0.9/35
βy*/βx* (cm/cm) (e-)	1.5/50	1.25/50
Optimum coupling (%)	3.0	2 to 6
Emittance (nm-rad) y/x	1.5/49	3/30+,2/50-
IP beam sizes (microns) y/x	4.7/157	5/140
Σy/x (microns)(Low current)	6.7/222	9/170
Injection top-off time (min)	3	3
Injection full fill time (min)	10	30
Detector solenoid field (T)	1.5	1.5
Int. luminosity in 8 hr pb-1	45	109
Int. luminosity in 24 hr pb-1	135	309
Int. luminosity / week pb-1	785	1846
Int. luminosity / month pb-1	3300	6653
Total Int. luminosity fb-1	--------	95

1 PEP-II CONDITIONS

The peak PEP-II luminosity was achieved using 800 bunches with 1770 mA of positrons and 1070 mA of electrons. Other parameters are shown in Table 1. The bunches were spaced every four RF buckets in 35 short trains of 23 bunches each. There is a 5% ion clearing gap. The one-bunch mini-gaps expel captured low energy e- in the e+ beam. The beta x and y at the collision point were 50 cm and 1.25 cm, respectively. The first few e^+ bunches in each mini-train is under filled by about 10% to avoid blowing up its respective e^- bunch by the beam-beam force. Those e^+ bunches not enlarged as much by the ECI as the other e^+ bunches further along the train [2,3].

2 BEAM-BEAM TESTS

Along the bunch train the luminosity shows a general variation which is caused by the relative LER-HER RF phase shift along the train. See Figures 1 and 2. This variation was predicted in early project planning and the general slope can be compensated. The fast ripples along the train are a result of parked cavities that are

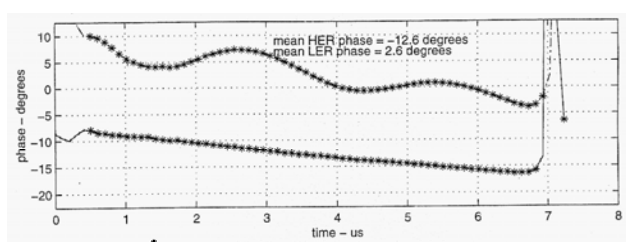

Figure 1. The variation of the bunch RF phase along the bunch train for the LER top and HER bottom. Note the three degrees relative variation in the LER.

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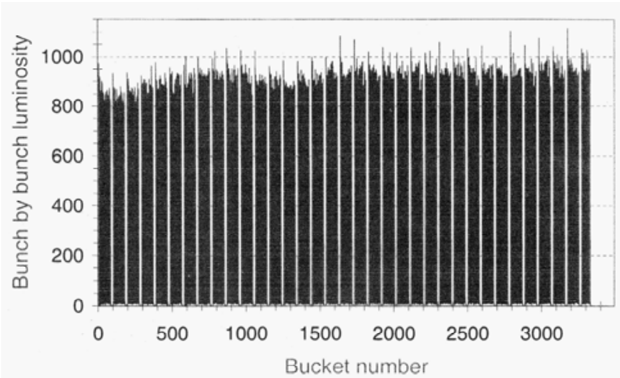

Figure 2. The measured luminosity in each bunch along the bunch train. Note that the luminosity dips where the LER RF phase has maxima.

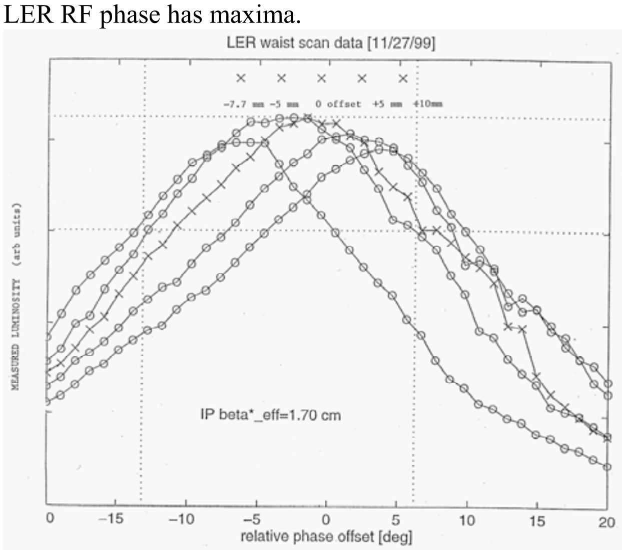

Figure 3. Variations in luminosity with HER RF phase as a function of location of the LER vertical beta waist.

not powered but will be in Fall 2002.

As seen from these RF phase measurements, centering the vertical betas in the IR is very important. Tests were made to center the minima of the IR y beta functions at the collision point by moving the waists with the IR quadrupoles while measuring the luminosity using the rf relative phase. See Figure 3. The waists were found to be very nearly centered to a few mm.

Several coasting beam fills with BaBar were tried with a bunch pattern having every other bucket filled. This bunch spacing is the design pattern (called the "by-2" pattern) having potential parasitic crossing effects. With full colliding currents and the by-2 bunch pattern the nominal peak luminosity was nearly achieved (90-95%) in a few hours. The main effect was to shift the vertical tune by about 0.01. This bodes well for the future for obtaining higher luminosity with more bunches.

The transverse sizes of the positron beam are enlarged at high currents by the electron cloud instability (ECI) from multipacting electrons, as is now commonly seen in several accelerators. A solenoid capable of 30 gauss has been wrapped on the straight section and arc vacuum chambers to suppress these electrons. A length of about 1500 m has been wound resulting in a luminosity increase of order 70% over the past year and a half. With the present solenoids the e+ beam size enlargement starts at about 1500 mA with four bucket spacing and is seen in both the vertical and horizontal planes.

The beams at the interaction point were measured to be tilted by about 2 degrees relative to the machine axis. Vertical beam-beam scans were performed as a function of relative x offset of the two beams and the vertical centers of the scans were plotted versus the x position to reveal the tilt. There were also hints from the out of plane beam-beam deflection scans that the two beams were slightly tilted relative to each other.

The luminosity was measured as a function of the product of the beam currents as shown in Figure 4. From the non-linearity, some of the beam sizes must increase with current. The HER electron beam sizes were measured as a function of the product of the beam currents as shown in Figure 5. The e- vertical size enlarges at low currents from the beam-beam effect. This continues until the electron cloud effect enlarges the positron beam as seen in Figure 7 and relaxes the beam-beam forces on the HER electrons. The LER positron sizes continue to increase above 1500 mA, thus, stopping the growth of the electron tune shifts as are shown in Figure 6. The positron tune shifts in Figure 8 continue to increase with current as the electron beam sizes are relatively constant with further current changes.

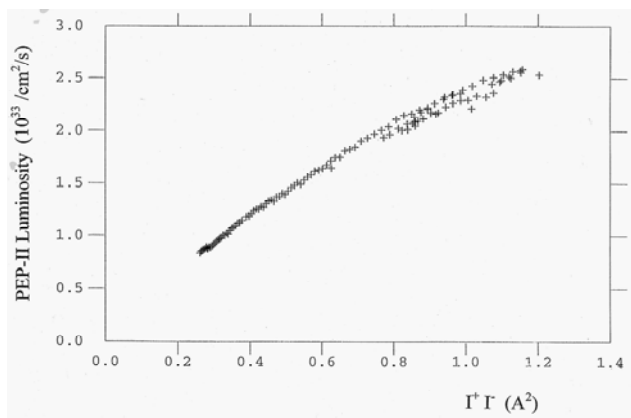

Figure 4. PEP-II luminosity versus the product of the beam currents. Note that the luminosity deviates from an ideal square law due to the enlargement of the beam sizes.

3 CONCLUSIONS

PEP-II is operating at a luminosity of 4.6 x10^{33}/cm^2/s. Beam-beam effects are definitely seen but are sometimes masked by the electron cloud effect in the LER. The electron cloud enlarges the e+ beam starting about 1500 mA with the by 4 pattern. The derived tune shift values (limits) are 0.031 for e- vertical and 0.081 for e- horizontal and 0.058 for e+ vertical and 0.065 for e+ horizontal. Detailed size measurements have started which will help resolve subtle enlargement effects. Energy transparency conditions appear to be quite weak as PEP-II violates the ratio of beam currents, emittance ratios, beta* ratios and damping time equality but the luminosity and tune shifts remain good.

4 REFERENCES

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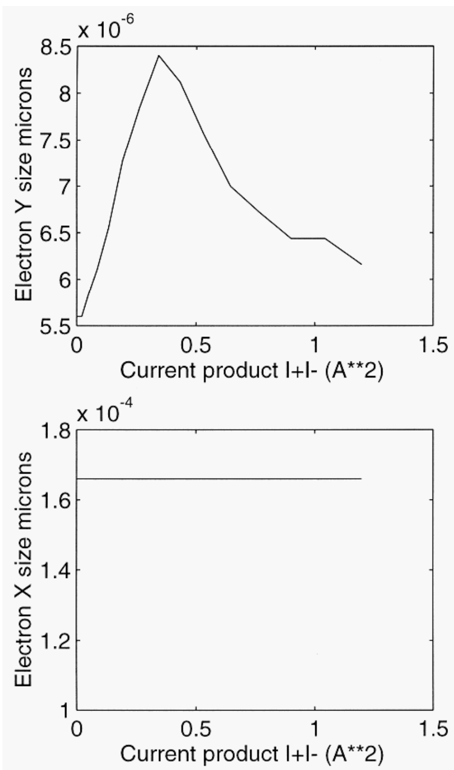

Figure 5. Measured HER electron beam sizes as a function of the product of the beam currents.

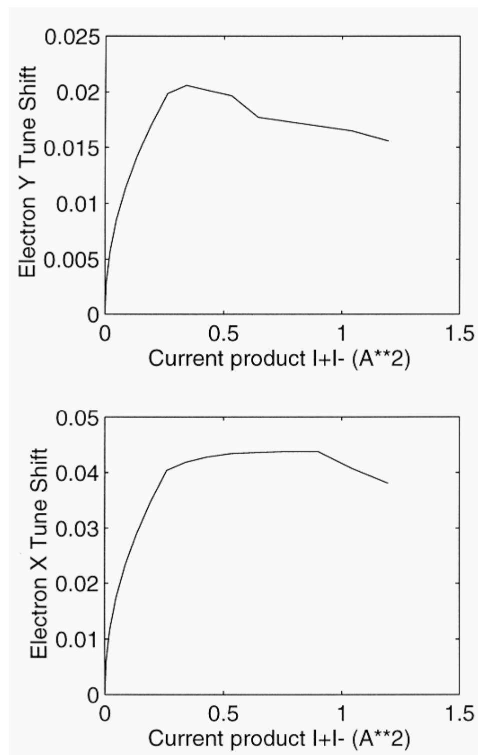

Figure 6. Derived beam-beam tune shift parameters versus current for HER electron.

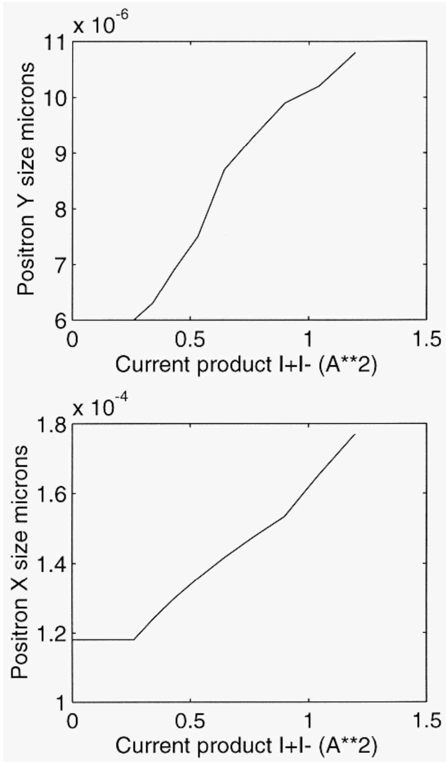

Figure 7. Measured LER positron beam sizes as a function of the product of the beam currents.

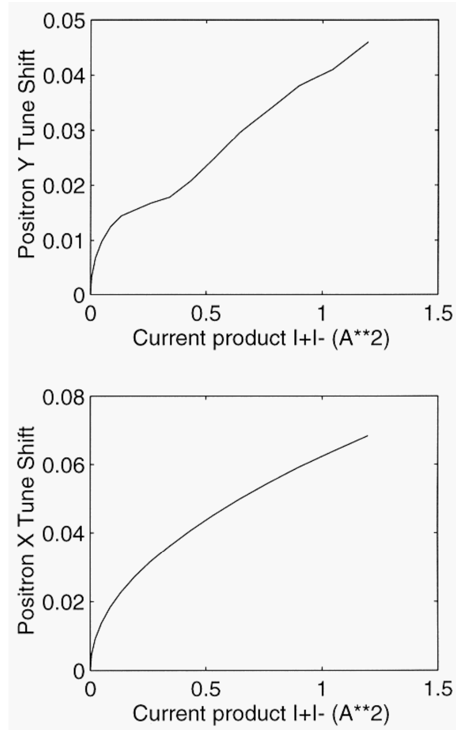

Figure 8. Derived beam-beam tune shift parameters versus current for LER positrons.