BEAM-BEAM COLLISIONS AT THE PEP-II *B* FACTORY*

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Abstract

We describe first beam collisions at the PEP-II *B* Factory, a collaboration of SLAC, LBNL, and LLNL. The beams are brought close to each other in the transverse (x,y) and longitudinal (timing) directions through the use of two shared beam position monitors located 0.72 m from either side of the interaction point (IP). Transverse beam-beam deflection scans and the use of a zero-angle luminosity detector allow us to center the collisions. Beam collisions were also seen by exciting one beam at its tune frequency and observing a response in the other beam at the same frequency. Shifts in betatron tunes have also been measured. To date, the peak measured luminosity attained is $5.2\pm1\times10^{32}$ cm^{-2} s^{-1} with 786 bunches in each beam and with beam currents of 354 mA for the high-energy beam (HEB) and 680 mA for the low-energy beam (LEB).

1 PEP-II

PEP-II [1], an asymmetric-energy two-storage-ring accelerator, is designed to allow the study of the decay channels of the Upsilon (4S) resonance from a boosted center-of-mass system. The boost permits the separation in time of the decay of the matter and anti-matter B mesons the 4S produces thereby allowing one to look for asymmetries in the decay-time distributions of these mesons and hence a violation of CP conservation.

The high-energy ring (HER) was completed first and a beam was stored in the ring in June of 1997. The low-energy ring (LER) and the final interaction region beam pipes and magnets were finished and installed in July of 1998 with beam stored in the LER shortly thereafter. Table 1 lists some of the PEP-II design parameters.

The PEP-II interaction region, shown in figure 1, employs two strong horizontal bending magnets (B1) located ±21 cm from the IP to bring the beams into a head-on collision. On either side of the IP, the beams also pass through a shared quadrupole (QD1) which is centered on the HEB. This design places the LEB off-axis in this shared defocusing quad which further horizontally separates the two beams prior to the beams entering separate vacuum chambers. The next three magnets on either side of the IP are septum quadrupole magnets where one of the beams travels through a field-free region while the other is focused either horizontally or vertically. The first of these magnets (QF2) is a focusing magnet for the LEB and completes the final focus doublet for the LEB. The next two magnets (QD4 and QF5) are the final focus doublet for the HEB with the shared QD1 magnet supplying additional vertical focusing [2].

Table 1. PEP-II IP design parameters.

	HER	LER
Energy (GeV)	8.9732	3.1186
Current (A)	0.75	2.15
β_x^* (m)	0.50	
β_y^* (m)	0.015	
σ_x (μm)	155	
σ_y (μm)	4.7	
Σ_x (μm)= σ_x √2	220	
Σ_y (μm)= σ_y √2	6.6	
ξ_x and ξ_y	0.03	
Revolution freq. (kHz)	136.311	
Bunch spacing (m)	1.26	
Number of bunches	1658	
Bunch luminosity ($cm^{-2}s^{-1}$)	1.8×10^{30}	
Total luminosity ($cm^{-2}s^{-1}$)	3×10^{33}	

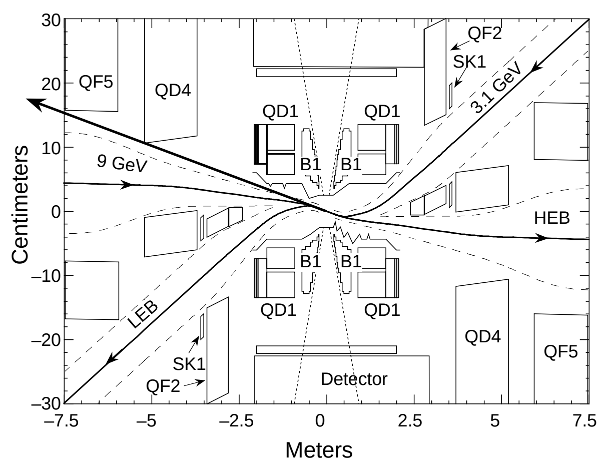

Figure 1. Layout of the interaction region. Note the expanded transverse scale. The large thick arrow leaving the IP denotes the direction of the radiative Bhabha photons used for measuring luminosity.

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Luminosity is measured by detecting radiative Bhabha photons emitted by incoming positrons. The photon travels along the collision axis and exits the beam pipe of the incoming HEB at about 9 m from the IP. The photon is detected in a Pb-shielded fused-silica Cherenkov detector[3,4]. Figure 1 shows the direction of the radiated photons observed by the luminosity detector. Photons emitted by beam-gas bremsstrahlung produce a background for the luminosity detector. However, the strong B1 bending magnets close to the IP restrict this background to beam-gas events generated within ±30 cm of the IP.

2 COLLISION RUNS

Several blocks of time during each running period were dedicated to collision studies.

2.1 July 1998, First evidence for collisions

Our first collisions were attempted on July 23rd and 25th. The low LER beam lifetime (1-2 min.) required constant injection of positrons into the LER. We saw evidence of collisions by scanning one beam through the other transversely and observing beam loss in the LER, indicating that the LEB was being disrupted by the HEB. The LEB lifetime degraded as the beams started to pass through each other, then it recovered when the horizontal scan centered the beams and degraded again while the beams were moving out of collision. We also observed a hint of a collision signature in beam-beam deflection scans. In another test, we transversely excited the HER at one of the tune frequencies and saw the signal transferred to the LER frequency spectrum. We saw no signal in the luminosity detector at this time, however, later analysis indicated that the collision axis was not pointed at the detector.

2.2 Fall 1998 run, November-December

During the fall there were a total of five collision runs each lasting about two days.

On Nov. 10, the first collision run of the fall, we observed a luminosity signal in the detector and saw definite beam-beam deflections. Σ_x and Σ_y, defined as follows:

$$\Sigma_x \equiv \sqrt{\sigma^2_{x^-} + \sigma^2_{x^+}} \text{ and } \Sigma_y \equiv \sqrt{\sigma^2_{y^-} + \sigma^2_{y^+}} ,$$

were both measured by scanning one beam through the other and recording the luminosity signal. Most of the time Σ_x was measured to be close to the design value of 220 μm. However, Σ_y started out high at 40 μm. Throughout the fall running Σ_y was successfully made smaller by improving the optics and decreasing the vertical dispersion in each ring. By the end of the fall run Σ_y was consistently in the range of 11-14 μm.

At the start of each collision run, the collisions were tuned up with a single bunch in each beam. Then, multibunch collisions were tried, first 11 on 11, then 36×36 (60 m spacing), 87×87 (22.7 m spacing) and finally 261×261 (7.56 m spacing). In all multibunch cases, the luminosity scaled with the number of bunches. The highest luminosity for the fall was 8.9×10^{31} $cm^{-2}s^{-1}$.

Much of the time during collisions was spent studying luminosity and beam size as a function of bunch currents. It appears that when the HEB bunch current gets near or above 0.5 mA the LEB lifetime drops significantly and the beam size "blows up" particularly in x. This corresponds to a subsequent roll-off in luminosity as the HEB current is increased past the 0.5 mA per bunch value. We have tried raising the LER bunch current to find a value that upsets the HER, but instead have found that for high LER bunch currents (up to 3 mA) the LER lifetime seems to fall off at lower (about 0.4 mA) HER bunch currents.

Most of one entire collision run (about 5 shifts) was devoted to exploring various tune-plane working points. Each ring was separately moved from the design value to a new working point to see if this improved the luminosity per bunch. No immediate improvement was seen.

A feedback loop designed to keep the beams in collision by optimizing the luminosity signal was also commissioned in December.

The measured luminosity and the luminosity calculated from the beam currents and from two different methods for finding the transverse beam sizes (transverse luminosity scans and beam-beam deflections) yielded consistent results as long as the e^- current was below 0.5 mA/bunch.

2.3 Winter 1999 run, January-February

There were two main collision runs in the winter: Feb. 4-8 and Feb. 19-22. The first run investigated a new working point for the LER that was below the diagonal in the tune plane. This new point proved to be a significantly better place for the LER; it produced the luminosity record of 5.2×10^{32} cm^{-2} s^{-1} with 680 mA of e^+ and 354 mA of e^- in 786 bunches and with a Σ_y of 12 μm.

The last collision run concentrated on lowering Σ_y by systematically reducing the vertical dispersion and coupling in each ring and by vertically aligning the beams at the IP. The result was a record minimum Σ_y of 8.6 μm with a consistent value between 9-11 μm. Figure 2 shows a typical vertical beam scan.

The design fill pattern (1656 bunches) has parasitic crossings (PCs) at ±0.63 m from the IP. In order to study Pcs, fill patterns with PCs (1656×1656 and 1048×1048) were tried. The 1048 fill pattern has every third bunch of the design pattern empty generating a series of mini-gaps around the entire ring. PC effects are not strong. More time is needed to determine if PCs influence the performance of the machine.

3 SOME RESULTS

Here we list some of the results from the collision runs. In most cases we would store a relatively high LEB current

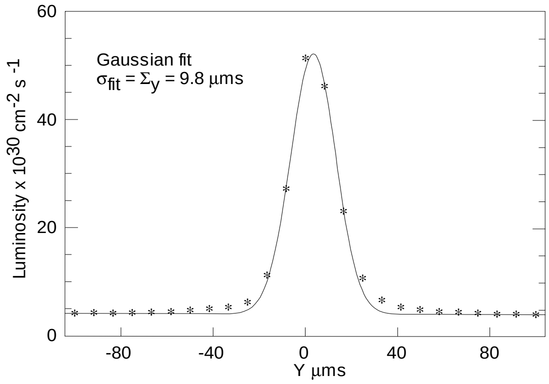

Figure 2. Plot of a typical vertical beam scan. The σ is the fitted Gaussian sigma. The background level is quite low for all measured values of luminosity.

and then start with a low HEB current and record Σ_x, Σ_y and luminosity as a function of increasing HEB current. Figure 3 is a plot of the measured luminosity as a function of increasing HER current and figure 4 shows a plot of the measured Σ_y values throughout the month of Feb. Table 2 compares some of the present accelerator achievements with the design values.

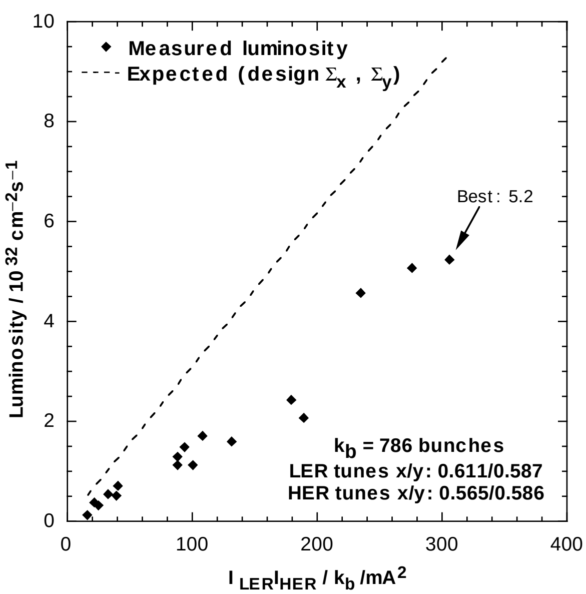

Figure 3. Plot of the measured luminosity as a function of the HER beam current, the LER current being held constant. The dashed line is the expected value for the luminosity based on the design Σs.

Table 2.
Present achievements compared with design values. The coherent beam-beam parameter (Ξ) we define as $\xi/2$.

	Design	Achieved
Σ_x (µm)	220	200-250
Σ_y (µm)	6.6	8.6
Ξ_x (e^+,e^-)	0.015, 0.015	0.0075, 0.017
Ξ_y (e^+,e^-)	0.015, 0.015	0.009, 0.014
L ($cm^{-2}s^{-1}$)	3×10^{33}	5×10^{32}

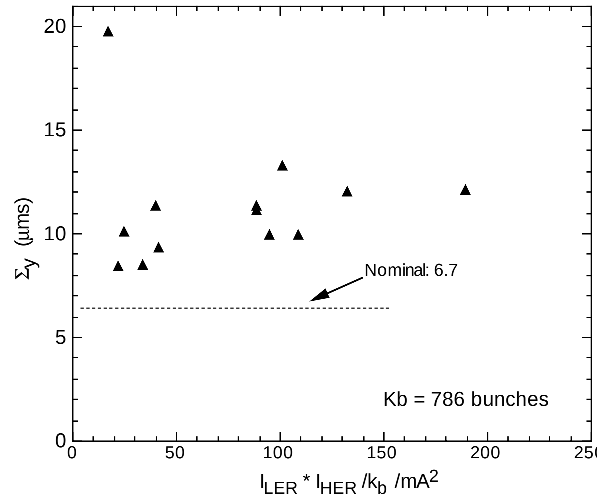

Figure 4. Plot of measured Σ_y values in Feb. for the fill pattern of 786 bunches/beam (2.52 m spacing).

4 SUMMARY

A total of about 20 days have been spent studying collisions at PEP-II. Over a period of 72 hrs in February, PEP-II had an average luminosity of 2×10^{32} $cm^{-2}s^{-1}$. The luminosity achieved is in agreement with calculations based on the beam currents and the measured Σs at the IP. Lowering Σ_y , matching the spot sizes of the two beams at the IP and increasing the beam currents should lead to the design luminosity.

Presently, PEP-II is off for the BaBar detector installation. Startup is scheduled for the first part of May. Initially, in order to keep detector backgrounds low, beam currents will be limited to 500 mA. However, even with this limitation, PEP-II should be able to achieve a luminosity of at least 1-3 $\times 10^{32}$ $cm^{-2}s^{-1}$ on a regular basis.

5 ACKNOWLEDGMENTS

We thank the PEP-II team and SLAC staff for all the work they did to make this accelerator come together so well. We would also like to thank the accelerator operating staff for their tireless efforts to improve the performance of PEP-II during commissioning.

6 REFERENCES

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