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PEP-II Status and Outlook*

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Abstract

PEP-II/BABAR are presently in their second physics run. With machine and detector performance and reliability at an all-time high, almost 51 fb^{-1} have been integrated by BABAR up to mid-October 2001. PEP-II luminosity has reached $4.4\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and our highest monthly delivered luminosity has been above 6 pb^{-1}, exceeding the performance parameters given in the PEP-II CDR by almost 50%. The increase compared to the first run in 2000 has been achieved by a combination of beam-current increase and beam-size decrease. In this paper we will summarize the PEP-II performance and the present limitations as well as our plans to further increase machine performance.

1 PERFORMANCE SUMMARY

Initially, the startup in 2002 was somewhat slower than expected due to difficulties with the rf systems, esp. the low-level rf loops. This held down peak and average luminosity and is reflected in the monthly luminosity, which lagged behind the year-2000 performance for several months (Fig. 1). Continuous machine tuning, vacuum improvements and the addition of more beam-pipe solenoids in the Low Energy Ring (LER) conspired in raising the machine luminosity as did a gradual increase in beam currents. The evolution of the peak luminosity over the year is shown in Fig. 2. Our best achieved machine parameters are summarized in Table 1.

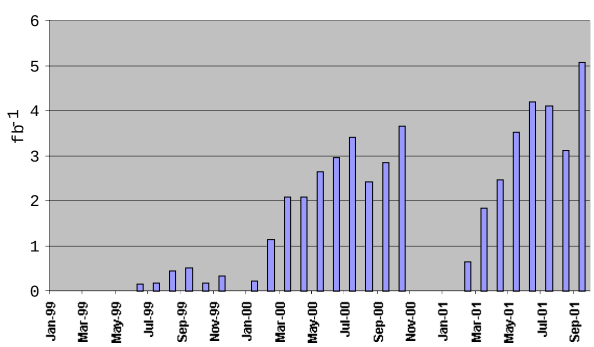

Figure 1: Luminosity by month.

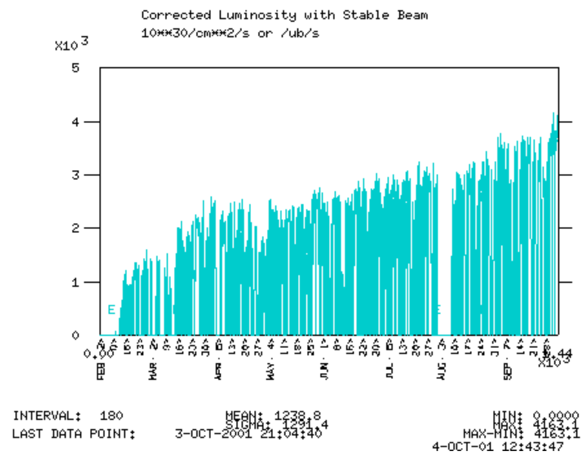

Figure 2: Peak luminosity (delivered).

	Design		Achieved (delivery)	
Energies e– / e+ (GeV)	8.973	3.119		
Currents e– / e+ (A)	0.75	2.14	**0.93**	**1.63**
Single beam currents (A)			0.95	2.10
Number of bunches	1658		**728**	
Bunch currents e– / e+ (mA)	0.45	1.29	**1.24**	**2.09**
Bunch spacing (m)	1.26		2.52	
IP spot size σ_x^* / σ_y^* (μm)	155	4.7	147	5
Luminosity ($\times10^{33}$/cm^2/sec)	3.0		**4.21**	
Tune shift horiz. e– / e+	0.03	0.03	0.059	0.069
Tune shift vert. e– / e+	0.03	0.03	0.027	0.055
Integrated lumi. / day (pb^{-1})	135		**262**	
Integrated lumi. / week (pb^{-1})	785		**1613**	
Integrated lumi. / 7 days (pb^{-1})	785		**1677**	
Integrated lumi. / month (fb^{-1})	3.3		**5.08**	
Beam crossing angle	0 (head-on)		0 (head-on)	

Table 1: PEP-II machine parameters.

2 KEY IMPROVEMENTS

Everything else being equal, luminosity is proportional to the ratio of beam current over beam size, which determines the *specific luminosity, i.e.* luminosity per bunch normalized to current. Plotting the luminosity *vs* the beam-current product for three different 24-hr periods, Fig. 3, shows the increase in luminosity for given beam current product

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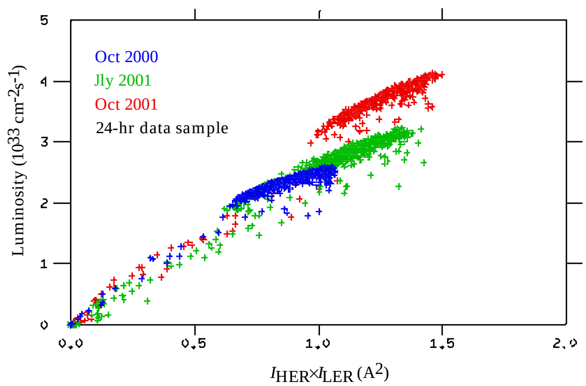


Figure 3: Luminosity *vs* bunch-current product (762 bunches).

achieved by the end of this run. The key improvements that contributed to this increase in specific luminosity have been:

- The addition of beam-pipe solenoids in the LER
- Steering the orbits of both rings flat
- Removing beta beating in the HER
- Improved diagnostics allowing better tune management

Detailed beam-beam studies have been undertaken and are described at another place in these proceedings[1]

2.1 *Beam-pipe solenoids*

At the beginning of the run, only the six LER straight sections were wrapped with solenoid windings to ameliorate the effect of the electron cloud.[2] During the course of this run we have added solenoids to the exposed parts of the vacuum chambers in Arcs 1, 3, 7 and 11. While the effect of the arc solenoids has been expected to be less than that of the straight-section solenoids due to the antechambers' reduction of secondary-electron yield, indication is that the beam size has been further reduced, thus increasing luminosity. At the time of this writing, the Arc-5 solenoids are completed and operational and installation of the Arc-9 solenoids is complete.

2.2 *Steering*

Several attempts to steer the beam orbit flat during the Y2k run were of limited success since the resulting orbit changes in the regions up- and downstream nearby to the BABAR detector led to changes in the compensation of the BABAR solenoid due to the local sextupoles. As a result, luminosity tended to be lower after steering than before. In 2001 a new feature was added to the control system allowing us to exclude a certain region (*e.g.* the interaction region) from steering, thus maintaining the orbit in that region.[3] In this way the global beam orbit was reduced in both rings and the dispersion in the LER (which was particularly large) reduced from $\approx$ 200 mm rms to about 60 mm rms without too much change of the machine coupling. This lead to a significant increase ($\approx 10\%$) in luminosity. Fig. 4 shows the LER orbit after steering.

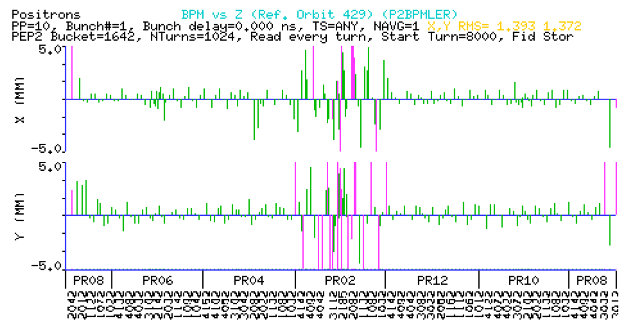


Figure 4: LER orbit after steering.

2.3 *Magnet Lattices*

Progress was made in 2001 in analyzing the lattice functions of the LER using a new algorithm.[4] Operationally, a significant beat in the HER β_x function was uncovered which led to somewhat higher-than-design β_x at the IP; this was gradually tuned out during delivery.[5] Attempts were made to lower the β functions at the IP from their present 50 cm and 1.25 cm in x and y, resp. This proved unsuccessful in that operation and luminosity of the machine was not improved and therefore was backed out.

An attempt to move the horizontal machine tune closer towards 0.5 to increase the dynamic β reduction at the IP demonstrated that the machines indeed can run with high beam current at such a working point, however, strong beta beating in the LER prevented us from reaching good luminosity.[6]

2.4 *Rf Performance*

During the Y2k run, an endemic failure of capacitors in the HV power supplies for the klystrons was encountered that led to the replacement of most capacitors in the supplies during the winter 2000/2001 downtime. In 2001, the major limitations encountered were high trip rates in the HER stations at the upstream end of the straight sections and poor performance of the LER low-level rf (LLRF) loops, both limiting the beam currents. The trip rate in the HER was ameliorated by lowering the total the rf voltage to 10.6 MV and redistributing it, thus lowering it to 2.0 MV in the first station in each straight section (2.2 MV in the other three). To address the LLRF problems a task force was set up with members of both the rf and the longitudinal feedback groups, which tracked down a number of configuration and other issues, gradually improving the performance and stability of the system.[7] An outstanding issue is our inability to run the LER with all three rf stations operating: at full voltage the bunches become too short, increasing heating observed in the vertex chamber which already limits our beam current (see below). If we maintain lower total voltage, the rf systems become unstable at high beam current and the stations trip.

2.5 Backgrounds

Background spikes caused by the trapping of particulates in the HER beam were the primary limitation in achieving good integrated luminosity at the beginning of the Y2k run. The background spike rate decreased during that run and no significant increase in background spikes was experienced during the startup in 2001. Fig. 5 shows the daily trip rate for this run and the Y2k run.

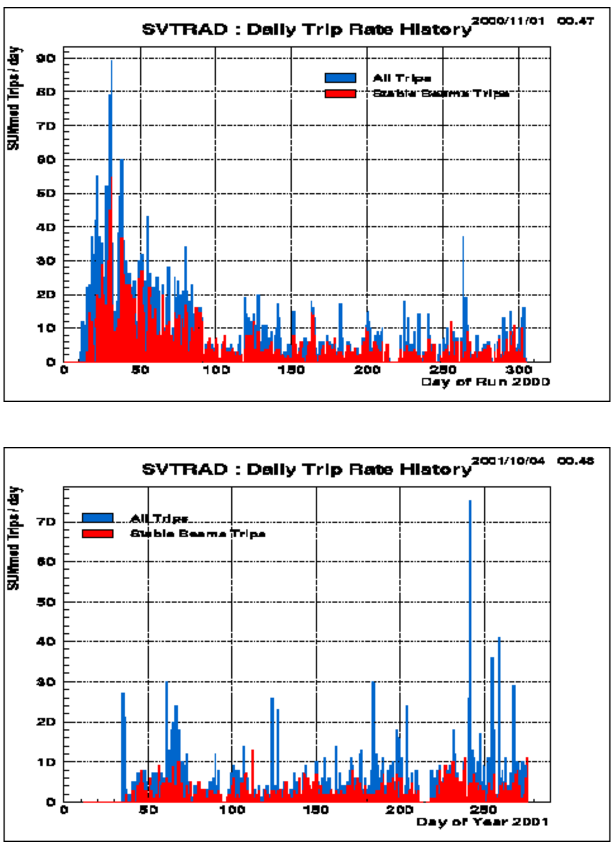


Figure 5: Background aborts per day for 2000 (top) and 2001 (bottom) run.

2.6 Beam Diagnostics

Interferometric vertical beam-size measurement has been added to the HER, and both HER and LER interferometers are now operating routinely.[8] A new gated camera installed at the LER[9] allows bunch-by-bunch beam size measurements which allows us to determine the beam-size evolution along a fill, thus fine-tuning the fill pattern. It has also helped to analyze the apparent flip-flop behavior we have seen at high beam currents, where certain bunches can produce much less luminosity than others, see Fig. 6. When this phenomenon is observed during operation, the LER x tune is usually moved far down, lowering the luminosity, until the low-luminosity bunches have "snapped back," then the tune can be moved back to the normal, high-luminosity point. Using the gated camera it has been determined that such bunches in the LER have much smaller vertical beam size than regular bunches (Fig. 7). Because the bunch currents are about equal everywhere, this leads us to conclude that the HER beam size for these bunches has become very large. It is thought that moving the LER x tune towards lower values increases the LER x beam size—thus lowering the beam-beam strength—until the HER bunches have a chance to shrink to their normal size.

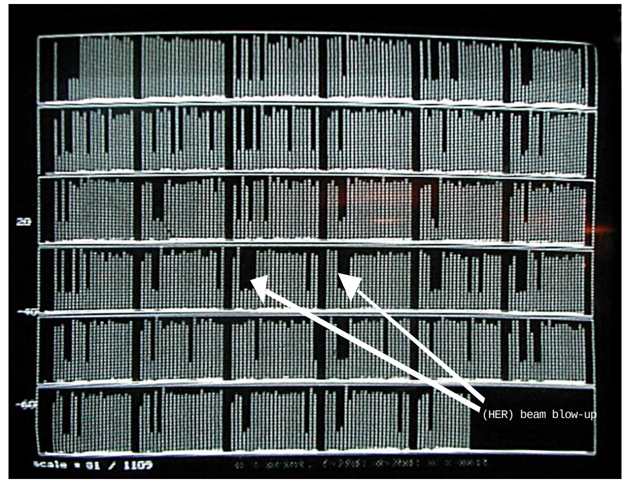


Figure 6: Bunch-by-bunch luminosity.

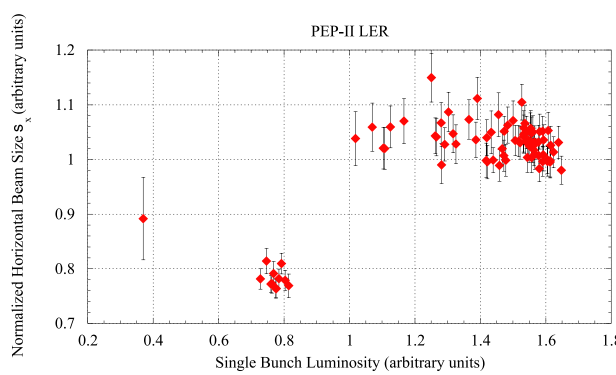


Figure 7: LER horiz. beam size/bunch *vs* luminosity/bunch

2.7 Vertex-Chamber Heating

A section of the vertex chamber buried deeply in the BABAR detector has been subject to higher-than-expected heating for quite some time. In order to find the source of the heat, a number of experiments and measurements have been done, determining the dependence of the temperature rise on:

- both beam currents,
- the beam-to-beam phase,
- the bunch pattern,
- the bunch length, and
- the time constant of the temperature variation.

These measurements indicate that the heat arises mainly from HOM heating with fairly broadband characteristics: Beam-current dependence is predominantly quadratic, lower rf voltage leads to less heating although not as much as one would expect and the temperature rise is relatively insensitive to the bunch pattern. Moderate sensitivity to the beam-to-beam phase indicates a resonance at about 5.4 GHz (Fig. 8).[10]

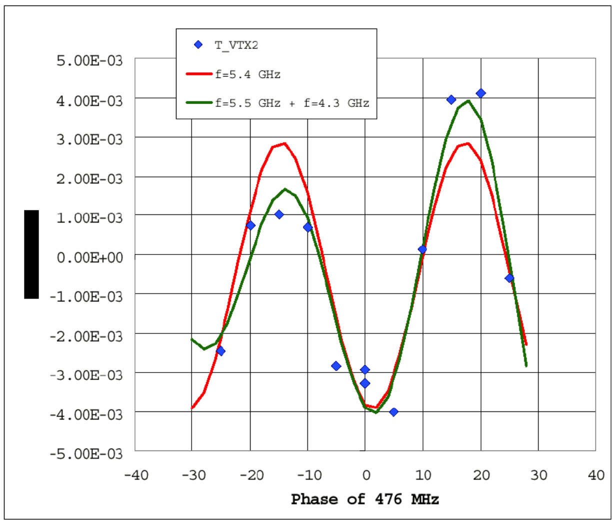


Figure 8: VTX chamber heating *vs* rf phase between HEB and LEB. The red curve is a fit of a single sine wave at 5.4 GHz, the green curve that of two sine waves, one at 4.3 and one at 5.5 GHz.

Intensive analysis using an ANSYS model of the region has allowed us to reproduce the temperature rise and thermal time constant ($200 \ldots 250$ s), from which it is deduced that most likely a short bellows is heated up to several hundred °F.[11] A partial source for the energy is thought to be HOM power generated at the crotch where the HER and LER vacuum systems join.[12] The crotches on the two sides of BABAR are of different design; on the "hot" side, a vertical "knife-edge" separates the chambers, while on the side experiencing much less heating the transition to two chambers is done with a long taper. The sharp transition causes electromagnetic energy to be reflected and parts of it dissipated in the short bellows. We are building a new crotch chamber to replace the one believed to cause the heating. Another part of the energy may stem from a mode trapped at the s.r. masks just next to the bellows. These masks cannot be replaced; to deal more efficiently with the heat generated by this source we will install additional cooling at the bellows.

3 DEVELOPMENTS

3.1 Magnet Lattice

Magnet lattices lowering β_x to 35 cm and β_y to 1.0 cm have been developed and already tried out once; these will be fully commissioned in 2002 to further increase luminosity without raising the beam currents. Using the new lattice-analysis we expect to also commission the low horizontal tune soon The ultimate goal is to bring both ring tunes close to 0.5, realizing significant predicted gains in luminosity due to the dynamic β-effect.[13] Fig. 9 shows results of a luminosity *vs* tune scan using a beam-beam simulation code[14].

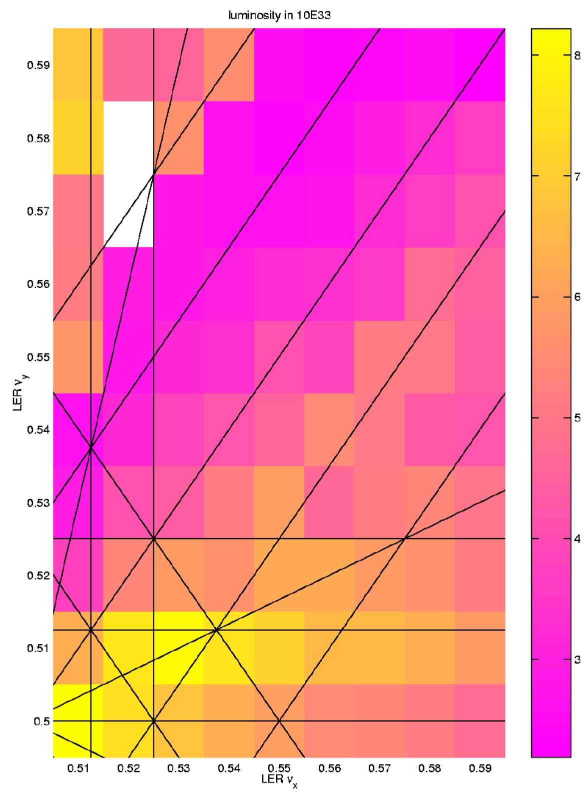


Figure 9: Luminosity *vs* working point (simulation); both rings have equal tunes.

3.2 Bunch-by-Bunch Feedback Systems

The longitudinal and transverse kickers used in the bunch-by-bunch feedback systems are nearing the limits of their beam-handling capacity. Twice a feedthrough on one of the longitudinal kickers was destroyed due to excessive heating. As a short-term measure new feedthroughs have been designed and are being built that use a 7/16 DIN connector with improved power-handling capability compared to the SC connectors in use now. Design of a new longitudinal kicker, based on the over-damped rf cavity structure used at LFN Frascati and other accelerator laboratories, has started in a collaborative effort together with Frascati, these units are expected to be installed in the summer of 2002.[15]

The transverse feedback kickers show higher than expected temperatures on the strip-line electrodes. They are monitored by optical pyrometers, and while the pyrometric measurements have a large uncertainty attached to them (in part due to the necessity of using windows), temperature rise of the kicker body and the feedthroughs is consistent with power dissipation on the order of 100 W. Dissipated on the (aluminum) electrodes, 100 W would cause them to heat up well beyond 100 °C (212°F). Design of a new transverse kicker structure will start early in 2002.

3.3 Rf Stations

An upgrade plan is in place to add rf stations, keeping up with the demand of higher beam currents. Two new stations will be added to the HER in the summer of 2002. These will have two cavities per 1.2 MW klystron rather than four because it is power rather than voltage that is required for higher beam current. This upgrade is sufficient to support a max. beam current of about 1.5 A in the HER. The moderate rise (3 MV) in rf voltage will shorten the bunches commensurate with the reduction in $\beta_y^\star$ we anticipate. The three rf stations installed in the LER at present are sufficient to support beam currents up to 3.8 A.

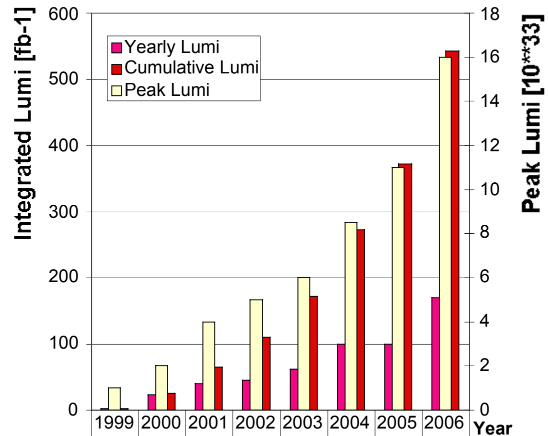
3.4 Abort Kicker Gap

In both rings 5% of the circumference is without beam to allow sufficient time for the beam-abort kickers to rise to their full field. This is necessary to prevent beam aborts from creating beam spillage into the BABAR detector. An unwanted side effect of this gap in the beam is a significant phase transient along the fill of about $\pm 13°$ at 1.6 A beam current in the LER. Even though the transients in the two beams are fairly similar, preventing too much movement of the collision point, the transient causes the gain of the bunch-by-bunch feedback systems to vary along the fill, decreasing significantly for the portions of the beam close to the gap. This is especially serious for the longitudinal feedback system, which detects at $6 \times f_{rf}$. With increasing beam current this effect will become stronger, eventually preventing the bunch-by-bunch feedback systems from working properly.

New beam-abort kickers are being readied presently to be added to the existing installation. This allows shortening the rise time of the beam-abort kickers by a factor of two, thus reducing the required length of the kicker gap in the beam correspondingly.

4 OUTLOOK

The cumulative effect of the improvements outlined above is expected to raise the luminosity of PRP-II significantly. Present projections call for an integrated luminosity delivered to BABAR of about 500 fb^{-1} by the end of the year 2006, see Fig. 10.



	1999	2000	2001	2002	2003	2004	2005	2006
Yearly Lumi	2	23	40	45	62	100	100	170
Cumulative Lumi	2	25	65	110	172	272	372	542
Peak Lumi	1	2	4	5	6	8.5	11	16

Figure 10: PEP-II Luminosity projection.

5 ACKNOWLEDGMENT

I am indebted to M. Sullivan, the PEP-II Run Coordinator, for much of the material used in this talk.

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