LUMINOSITY UPGRADE POSSIBILITIES FOR THE PEP-II B-FACTORY*

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Abstract

PEP-II is an asymmetric e+e- collider[1,2] being constructed in the SLAC PEP tunnel by SLAC, LBNL, and LLNL. The two beams have energies of 3.1 GeV and 9.0 GeV and are made to collide at a single interaction point. PEP-II has a 2200 m circumference. The nominal parameters for PEP-II are listed in Table 1. The High Energy Ring (HER) of PEP-II started commissioning in 1997. The Low Energy Ring (LER) will be commissioned in the summer of 1998. The BaBar detector is to be installed starting January 1999. Studies for increasing the luminosity in PEP-II beyond the design are underway[3]. A brief summary of the possibilities are presented here. Improvements to the integrated luminosity will be implemented gradually. Major luminosity improvements will likely come in two phased upgrades. Several of these possibilities are summarized in Table 1.

1 LUMINOSITY AND TUNE SHIFTS

The luminosity L and tune shifts ξ are given by:

$$L = n N_- N_+ f / 2\pi((\sigma_{x+}^2 + \sigma_{x-}^2)(\sigma_{y+}^2 + \sigma_{y-}^2))^{0.5}$$

$$\xi_{y+} = r_0 N_- \beta_{y+} / 2\pi \gamma_+ \sigma_{y-} (\sigma_{x-} + \sigma_{y-})$$

where $N_{-,+}$ are the bunch charges, n the number of bunches, $\sigma_{x,y}$ are the beam sizes at the IP, $\gamma = E/mc^2$, f is the revolution frequency and r_0 is the classical electron radius. There are three other tune shift equations with + exchanged with - and x exchanged with y. $\sigma = (\varepsilon\beta)^{0.5}$.

2 EMITTANCE CHANGES DURING A FILL

During a typical colliding beam fill the currents are injected and the beams decay over a period of about 1 to 1.5 hours. At the beginning of the fill the beam-beam tune shift limits are all simultaneously reached. However, as the current decay the tune shifts are no longer limited. If the beam emittances are actively reduced during the decaying fill to keep the tune shifts "saturated," then the luminosity will remain higher. The HER has an emittance adjustment range of about a factor of 2.5 and the LER a factor of 4. With this emittance tracking we may get an improvement in the integrated luminosity of a typical fill of about 25%.

* This work was supported by US Department of Energy contract DE-AC03-76SF00515.

3 HIGHER EMITTANCE AND CURRENTS

If the current and emittance of both beams are increased in equal proportions, then the luminosity will increase fractionally with the change. Furthermore, the tune shift values will not change. The maximum luminosity is thus obtained by increasing the current and emittance until the ring can either no longer support the current due to RF, vacuum or instability issues or maintain beam lifetime due to beam tails which exceed the lattice dynamic aperture. The size of the dynamic aperture in PEP-II will be very important as the vacuum system can support additional current from the design values. The vacuum system can support twice the design emittances.

4 REDUCED β*

By reducing the beta functions in the IR the luminosity can be increased. If all the betatron functions in the IR are reduced by the same fraction, then the beam-beam tune shifts all remain unchanged at fixed beam currents. However, the luminosity is increased inversely with the reduced beta value. This result is now a very old one for colliders but still applies directly to PEP-II. We are actively trying to reduce the betatron functions in the IR down to the 1 cm level in the vertical and 30 cm level in the horizontal. This would increase the luminosity by about a factor of about 1.4.

5 HIGH BEAM-BEAM TUNE SHIFTS

Increased beam-beam tune shifts would allow increased beam currents for fixed beam sizes. If all the beam-beam tune shifts increased together, then the two beam currents would increase in proportion and the luminosity would increase as the square of the increase. This result is the strong driving force behind finding 1) better working points in the tune plane, 2) better orbit and coupling control, and 3) better energy transparency conditions. Several examples in Table 1 use higher tune shift values up to 0.06 to increase the luminosity.

6 IR CROSSING ANGLES

PEP-II generates head-on collisions using dipole magnets very near the interaction point. These dipoles separate the two energy beams very quickly to minimize the effects of parasitic beam-beam crossings but produce a large quantity of synchrotron radiation power which affects nearby vacuum chamber designs and detector backgrounds. In order to eliminate these dipoles a beam crossing angle must be introduced. The effects of crossing angles have been carefully studied. The PEP-II design allows for beam crossing angles if they are shown to be desirable. With out changing anything, crossing angles of about +/- 2.5 mrad can be produced. Large crossing angles require rebuilding the interaction region.

7 BUNCH SPACING

The bunch spacing couples directly to the beam emittances. In order to keep the energy transparency conditions satisfied and the beam emittances within an acceptable range (30 to 100 nm), the bunch spacing must be changed to accommodate different beam-beam tune shift values. Below are shown the acceptable bunch spacings in units of RF buckets for various beam-beam tune shift values. We assume here that the luminosity is fixed at the 3 x 10^{33} /cm^2/sec, the vertical betatron function is 1.5 cm and the coupling in 4%. We conclude that for high tune shift values the accelerator prefers to place the current in fewer bunches. This is due to the current squared factor in the luminosity formula.

Tune shift limit	Acceptable bunch spacing
0.02	1 bucket
0.03	2 to 3 buckets
0.04	3 to 6 buckets
0.05	4 to 9 buckets

8 RELAXED ENERGY TRANSPARENCY

Energy transparency for PEP-II calls for equal emittances, equal betas, and equal beam sizes at the interaction point to allow for equal tune shift limits. At PEP-II we will know soon whether the real beam-beam dynamics require these tight constraints. If the sizes of the two beams are allowed to be different, then additional luminosity can be obtained within the present capabilities of PEP-II. For example, if the bunch charge and emittance of the electrons are increased at the same rate and the IP betatron functions are not changed, then all the tune shift values do not change and the luminosity increases approximately as the square root of the fractional current change. Since the HER has a vacuum chamber which can support 3 A, a likely luminosity increase can be obtained with increased HER current up to the maximum acceptable emittance consistent with good beam lifetime. An example of a 40% increase in luminosity with different beam sizes is included in Table 1.

9 TRICKLE CHARGE INJECTION

The PEP-II injection system has been designed so that continuous injection (trickle charging) can be accommodated. Continuous injection would allow the beam currents to remain nearly constant producing luminosity near its peak indefinitely. This would improve the average luminosity by (nearly) eliminating the decaying currents during a normal fill. The presently expected average luminosity during a fill is about 70% of the peak which would increase to about 98% with trickle injection. However, detector backgrounds and radiation damage may be a problem. Initial indications from the HER commissioning up to 750 mA is that with vertical injection, low emittance injected bunches, and enlarged apertures near the detector the backgrounds due to injection are reasonably low.

10 PHASE I UPGRADE TO 10^{34}

A combination of the above improvements as envisioned in the present design can lead naturally to an increased luminosity from 3 x 10^{33} /cm^2 /sec to 1 x 10^{34} /cm^2 /sec with only modest changes. A reference set of parameters are listed in Table 1. The luminosity is raised by increasing the beam currents slightly, increasing the beam-beam tune shifts to 0.045 and lowering the vertical betatron functions at the collision point. The enlarged currents are within the present capabilities of the vacuum chamber design of 3 amperes in both rings (with a few exceptions). The enlarged currents will require somewhat stronger feedbacks. An additional RF station is needed in the LER[5]. The enlarged tune shift would come from improved steering and coupling control in the rings. Studies to reduce the vertical betatron function at the IR are underway. βy^* = 1 cm seems reachable with the present dynamic apertures and the present bunch lengths. The HER was commissioned with a 1.5 cm lattice. As a lower beta* will likely increase the BaBar backgrounds, improved collimation may be needed.

11 PHASE II UPGRADE TO 3 x 10^{34}

A luminosity increase to 3 x 10^{34} /cm^2 /sec requires more substantial changes. A set of parameters are listed in Table 1. The luminosity increase will likely come from 1) a further increase in the tune shift to 0.06, 2) a reduced betay to about 0.75 cm, 3) an increased RF voltage[4,5] to reduce the bunch length to about 0.7 cm, 4) a rebuilt interaction region to allow a crossing angle[6], and 5) an increased beam current beyond 3 amperes in the LER.

A tune shift of 0.06 may be possible as the original PEP and ADONE reached 0.06. This tune shift level would come from a combination of orbit and coupling control, reduced damping time (additional wiggler in the LER), and reduction in the parasitic crossing effects in the IR with crossing angle collisions. A lower beta will likely need a rebuilt IR with closer in quadrupoles. A crossing angle may allow the quadrupoles to be closer and reduce radiation effects. The design may need to be superconducting. The bunch length reduction is made by either momentum compaction changes of the lattices or with increased RF voltage. With RF alone, the voltage would need to be about doubled.

Both rings will support substantially more current. The vacuum system for the HER is designed for 3A and 2A is needed. A few modifications may be needed for the shorter bunches. The LER current of 4.7A is significantly beyond the design of 3A although a safety margin of at least 50% has been included in the present design. Significant new sections of the LER vacuum system may be needed. Also, an improved pressure profile in the interaction region for backgrounds is likely to be required.

REFERENCES

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Table 1 Parameters Sets for PEP-II Luminosity Upgrade Possibilities at 3.1 x 9.0 GeV.

Parameter	Nominal 9x3.1 GeV	Phase I Upgrade (A)	Phase I Upgrade (B)	Relaxed E Transparency	Phase II Upgrade
Tune shift limit x	0.03	0.045	0.06	0.04	0.06
Tune shift limit y	0.03	0.045	0.06	0.04	0.06
Bunches	1658	1658	1658	1658	1658
Beta* y - (cm)	1.5	1.0	1.2	1.2	0.8
Beta* y + (cm)	1.5	1.0	1.2	1.2	0.65
Beta* x - (cm)	50.	33.	40	40	27
Beta* x + (cm)	50.	33.	40	40	22
Luminosity (1/cm^2/sec)	3E33	1E34	1E34	1E34	3E34
I- (A)	0.75	1.11	1.0	2.0	2.0
I+ (A)	2.16	3.20	2.9	3.0	4.7
Emittance x- (nm)	49	49	33	103	53
Emittance x+ (nm)	49	49	33	52	65
Coupling (%)	3	3	3	3	3
N/bunch - (10^{10})	2.1	3.1	2.7	5.8	2.7
N/bunch + (10^{10})	6.0	8.8	8.0	8.4	6.5
RF cavities (HER/LER)	20/6	20/8	20/8	28/8	20/10
Klystrons (HER/LER)	5/3	5/4	5/4	7/4	10/5
Bunch length (cm)	1.1	1.0	1.0	1.1	0.7
Spacing (m)	1.26	1.26	1.26	1.26	1.26