Title

Beam-Beam Issues in Asymmetric Colliders

Author

Furman, M A

Publication Date

1992-07-01

LBL-32561
UC-414

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

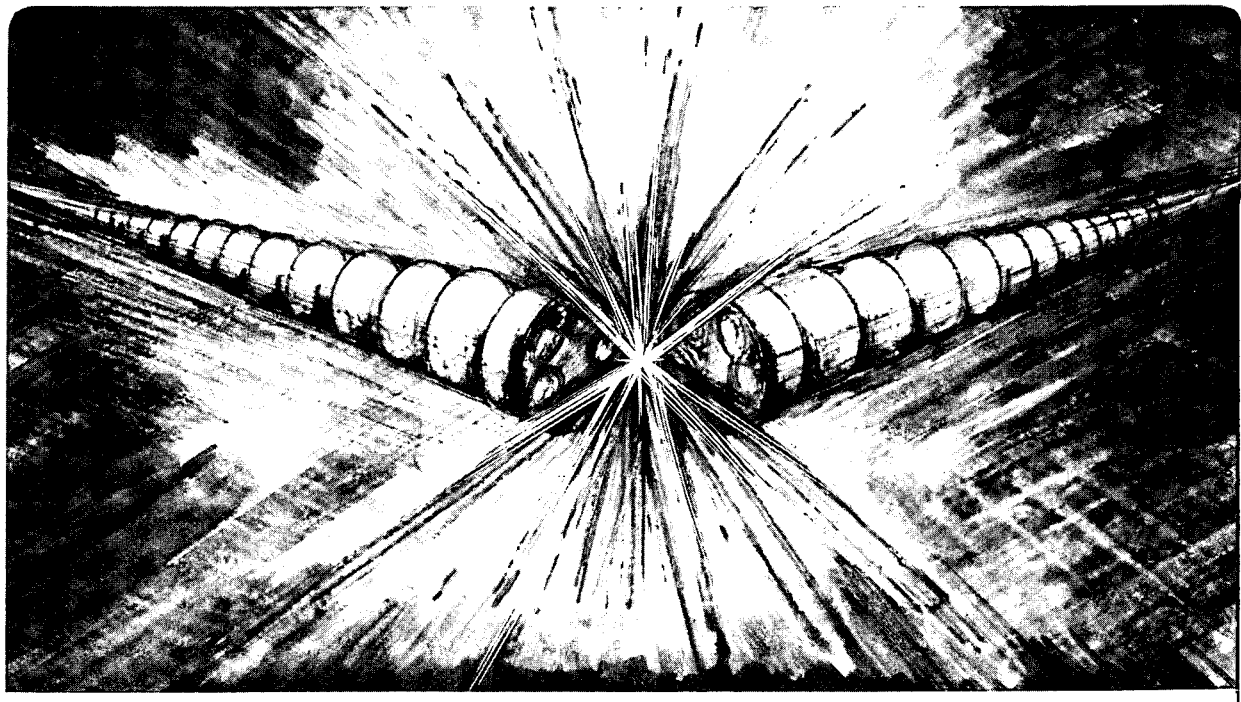
Accelerator & Fusion
Research Division

Invited talk presented at the Conference on B Factories: The State of the Art in Accelerators, Detectors and Physics, Stanford, CA, April 6-10, 1992, and to be published in the Proceedings, and invited talk presented at the Washington APS Meeting, Washington, D.C., April 18-23, 1992, and to be published in the Proceedings

Beam-Beam Issues in Asymmetric Colliders

M.A. Furman

July 1992



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

DISCLAIMER

LBL-32561
UC-414
ESG-205
ABC-77

Beam-Beam Issues in Asymmetric Colliders*

Miguel A. Furman

Accelerator & Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Invited talk presented at the Conference: B Factories: The State of the Art in Accelerators, Detectors, and Physic, Stanford, CA, April 6-10, 1992

and

Invited Talk to be presented at the Washington APS Meeting, Washington D.C., April 18-23, 1992

* Work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

Beam-Beam Issues in Asymmetric Colliders†

Miguel A. Furman
Accelerator & Fusion Research Division
Lawrence Berkeley Laboratory, Berkeley, CA 94720 U.S.A.

ABSTRACT

We discuss generic beam-beam issues for proposed asymmetric e^+-e^- colliders. We illustrate the issues by choosing, as examples, the proposals by Cornell University (CESR-B), KEK, and SLAC/LBL/LLNL (PEP-II).

1. INTRODUCTION

Several institutions around the world have recently proposed building asymmetric e^+-e^- colliders with a design luminosity in the range $10^{33} - 10^{34}$ cm^{-2} s^{-1}, whose primary purpose is the detailed study of the B meson system [1–6]. The design performance of these "B factories" is optimized for a center of mass energy of 10.56 GeV, corresponding to the $\Upsilon(4S)$ resonance; this implies that the energies of the two beams must satisfy $E_+ \cdot E_- = 27.9$ GeV^2. A brief summary of relevant parameters is displayed in Table 1. In all cases the low-energy ring (LER) contains the positron beam, while the high-energy bring (HER) contains the electron beam. From the perspective of the beam-beam interaction, the energy asymmetry is a novel feature for which there is no experience (with the very recent exception of HERA [7]). Since the beams necessarily travel in two different rings, they have, in general, different tunes, emittances, chromaticities, beam-beam parameters, etc, and experience different magnetic errors, impedances, etc. A first beam-beam issue is, therefore: is the energy asymmetry a detrimental effect on the beam-beam dynamics?

The value chosen for the luminosity is significantly higher than in existing (or defunct) e^+-e^- colliders. It is generally believed that the performance of these machines is (or was) limited by the strength of the beam-beam interaction. Almost certainly the same limitation applies to asymmetric colliders. This limitation, coupled with other constraints such as synchrotron radiation masking and the avoidance of single-bunch instabilities, implies that the high luminosity must be achieved by using many bunches, each of which has "normal" bunch current and emittance. Experience shows that the largest achievable dynamical beam-beam parameter is $\lesssim 0.06$. For this reason, all proposed designs have chosen values for the nominal beam-beam parameters in the range $\xi_0 = 0.03 - 0.05$. The combination of high beam current and normal bunch current implies a relatively short bunch spacing s_B, in the range 0.6 m to a few m, which, in turn, implies that the bunches will experience parasitic collisions (PCs) in the vicinity of the interacton point (IP). This raises a second issue: are PCs detrimental to the performance? One way to weaken the strength of the PCs is by means of a crossing angle at the IP. In this case, is the crossing angle detrimental? Other issues must be addressed, that are not peculiar to asymmetric colliders, such as: effects of magnet nonlinearities, injection options, and beam lifetime.

Table 1. Selected parameters

Project	$\mathscr{L}_0$ [10^{33}]	E_+ / E_- [GeV]	β_{y+}/β_{y-} [cm]	σ_ℓ [cm]	ξ_0
BFI	1	3.5 / 8	1 / 1	0.5	0.05
CESR-B	3	3.5 / 8	1.5 / 1.5	1	0.03
DESY	3	3 / 9.3	1 / 2	1	0.04
VEPP-5	5	4.3/6.5	1 / 1	0.75	0.05
KEK	2	3.5 / 8	1 / 1	0.5	0.05
PEP-II	3	3.1 / 9	1.5 / 3	1	0.03

†Work supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

2. BEAM-BEAM ISSUES

2.1 Nominal and Dynamical Quantities

In the absence of the beam-beam interaction, the beam sizes and emittances take on single-beam values, which we call "nominal." We label them with a subscript 0. For example, the nominal vertical beam size of the positron bunch, and the nominal vertical beam-beam parameter of a positron at the center of the bunch are given by

$$\sigma^*_{0y,+} = \sqrt{\varepsilon_{0y,+}\beta^*_{y,+}} \tag{1}$$

$$\xi_{0y,+} = \frac{r_0 N_- \beta^*_{y,+}}{2\pi\gamma_+\sigma^*_{0y,-}(\sigma^*_{0x,-} + \sigma^*_{0y,-})} \tag{2}$$

(similar expressions apply for the remaining three quantities, *mutatis mutandi*). Once the beams are brought into collision, the emittances deviate from their nominal values and reach a new equilibrium value and, as a result, so do all quantities involving the beam sizes, including the beam-beam parameters and the luminosity. These are the "dynamical" quantities, which we denote without the subscript 0.

Obviously a design is specified by nominal quantities, while the performance is determined by dynamical quantities. Designs with different parameters have different costs, risk factors, tolerances and dynamical luminosity $\mathcal{L}$, even if the specified nominal luminosity $\mathcal{L}_0$ is the same. Beam-beam studies must assess the relative merits of different designs.

Another question that beam-beam studies can in principle answer is: what is the beam-beam limit? By this we mean the design with best performance for a given cost (understood in its most general possible sense). Such an investigation is much more difficult than comparative assessments of different designs, and will not be addressed here.

2.2 Formulation of the Beam-Beam Problem

When two bunches collide, only one (or a few) particles hit each other head-on and annihilate; the vast majority of them (typically $10^{10} - 10^{11}$ per bunch) pass through and experience a force from the collective electromagnetic field from the opposing particles. In principle, solving the beam-beam problem amounts to the determination of the charge distribution of the bunches under their mutual and repetitive influence. This amounts to solving Maxwell's and Newton's equations (in the presence of damping and random quantum excitation) simultaneously and self-consistently. This is a formidable problem that will probably never be completely solved.

However, in addition to the experience from symmetric colliders, the solution to the beam-beam problem is known in the limit $\xi_0 \to 0$. In this limit, the beam-beam interaction can be described by an effective thin-lens quadrupole magnet at the IP, which has the peculiarity that it is focusing in both planes. If we call k the effective strength of this quadrupole (k = inverse focal length), and if β_0 is the beta function at the IP, then the solution is such that k is given by

$$k\beta_0 = 4\pi\xi_0 \tag{3}$$

The resultant tune shift $\Delta\nu$, the dynamical beta function β and the dynamical alpha function α immediately before the IP ($\alpha \equiv -\beta'/2$) are given by the equations

$$\cos(2\pi(\nu_0+\Delta\nu)) = \cos(2\pi\nu_0) - 2\pi\xi_0\sin(2\pi\nu_0) \tag{4}$$

$$\frac{\beta}{\beta_0} = \frac{\sin(2\pi\nu_0)}{\sin(2\pi(\nu_0+\Delta\nu))} \tag{5}$$

$$\alpha = (\alpha_0 - 2\pi\xi_0)\frac{\beta}{\beta_0} \tag{6}$$

(the nominal slope α_0 is normally chosen to be zero). There are four such sets of equations for the horizontal and vertical dimensions of either beam. These equations are valid to lowest order in ξ_0 for the particles in the beam core provided that: (1) there is no x-y coupling, (2) the bunch length is small, $\sigma_\ell \ll \beta_0$, and (3) the nominal tune ν_0 is not too close to an integer or half-integer. The beam emittances are not changed in this limit.

If ξ_0 is not small, the solution is not completely understood. In general, however, the effects are unfavorable: the dynamical beam sizes and emittances are usually larger than nominal, so that the dynamical beam-beam parameters and luminosity are smaller than nominal, and the beam lifetime is finite rather than infinite.

2.3 Asymmetry and Transparency

Because no asymmetric colliders exist at present, and because the consequences of the beam-beam interaction are not completely understood for intense beams, it has been argued [8] that a cautious design approach might be to force the beam dynamics of an asymmetric collider to resemble as closely as possible that of a symmetric one. In this way the design can draw upon the experience from single-ring colliders. This situation is achieved by imposing the following "transparency symmetry" conditions:

(i) pairwise equality of nominal beam-beam parameters: $\xi_{0x,+} = \xi_{0x,-}$ and $\xi_{0y,+} = \xi_{0y,-}$

(ii) pairwise equality of nominal beam sizes: $\sigma^*_{0x,+} = \sigma^*_{0x,-}$ and $\sigma^*_{0y,+} = \sigma^*_{0y,-}$

(iii) equality of damping decrements of the two rings

(iv) equality of the tune modulation amplitudes due to synchrotron oscillations: $(\sigma_\ell \nu_s/\beta^*_{x,y})_+ = (\sigma_\ell \nu_s/\beta^*_{x,y})_-$, where σ_ℓ =bunch length and ν_s =synchrotron tune.

These conditions have been arrived at from analytic arguments and by trial and error in simulations. It is known that, in many cases, the predicted performance is better when the above conditions are satisfied than when they are fully violated [9]. An immediate consequence of transparency symmetry is a significant reduction in the number of free parameters, which is certainly a practical advantage for beam-beam studies. This symmetry is generally regarded as a prudent starting point and has been adopted, in an approximate way, by all B factory proposals.

A more rigorous set of transparency conditions have been arrived at [10] by demanding that the short-term single-particle dynamics of the two beams be identical. This implies that the tunes, emittances, beta functions, beam-beam parameters and bunch lengths of the two beams must be pairwise equal. The only freedom left over in this analysis is a trade-off between energy and bunch current such that $(N\gamma)_+ = (N\gamma)_-$. Since this analysis is Hamiltonian, nothing can be stated about the damping decrements. Luminosity performance, apparently, has not been studied under these conditions.

Transparency symmetry implies certain equalities among the beta-functions and emittances [8]. In particular, the expression for the nominal luminosity simplifies to

$$\mathcal{L}_0 = 2.167\times 10^{34}(1+r)\xi_{0y}\left(\frac{EI}{\beta^*_y}\right)_{+,-} \quad [\mathrm{cm^{-2}s^{-1}}] \quad (7)$$

where the energy E is expressed in GeV, the total beam current I in A and the beta function in cm. The subscript +,– means that the expression in parentheses can be taken from either beam, and $r = \sigma^*_{0y}/\sigma^*_{0x}$ is the nominal beam aspect ratio.

3. BEAM-BEAM SIMULATIONS FOR PEP-II

A fair number of multiparticle tracking simulations have been carried out for PEP-II [1,11]. The current design has head-on collisions at the IP with magnetic beam separation in the horizontal plane. As a result of the relatively short bunch spacing, s_B = 1.26 m, the bunches experience a few glancing parasitic crossing collisions (PCs) on their way into and out of the IP. PCs induce effects such as a closed orbit distortion, tune shift, tune spread, and higher-order nonlinear effects. Generally speaking, all these effects are likely to be detrimental if the beam separation d at the PC is too small. For this reason, the beam-beam simulations have looked at this parameter quite closely.

These simulations are "strong-strong," in which the bunches are represented by up to 256 "superparticles" that are initially Gaussian-distributed in 6-dimensioanl phase space. Typically, simulations are run for up to five damping times, or 25,000 turns. Although the particle distributions deviate from Gaussian as time progresses, for the purposes of computing the beam-beam kick on the opposing bunch, the rms beam size is computed at every turn and used in the Bassetti-Erskine formula [12] corresponding to the electric field of a Gaussian distribution. This turns out to be a fairly good approximation for nominal values of the parameters because the actual shapes of the distributions remain quite close to Gaussian.

Thick lens-effects [13] are taken into account by dividing up the bunch into up to five slices in the longitudinal dimension. The simulations include damping and quantum excitation, hourglass and disruption effects, synchrotron oscillations and betatron tune modulation due to synchrotron motion. However, longitudinal forces during the beam-beam collisions are neglected, as are all lattice nonlinearities. Thus the machine is represented by a linear arc.

3.1 Parasitic Crossings Neglected

The simulations show that, if the PCs are ignored, the dynamical behavior is quite close to nominal even when ξ_0 is substantially larger than the specified value 0.03. This is shown in Fig. 1, in which the dynamical luminosity is plotted vs. ξ_0 (the design is such that $\xi_{0x,+} = \xi_{0y,+} = \xi_{0x,-} = \xi_{0y,-} \equiv \xi_0$). The chosen working point is (0.64,0.57) for both beams, and ξ_0 is varied away from its nominal value of 0.03 by varying the bunch current at fixed nominal emittance. Results from two similar but not identical codes [14] are shown (for large values of ξ_0, the results are probably not reliable; also, the two codes differ in the way they handle coherent effects, which are important at high values of ξ_0).

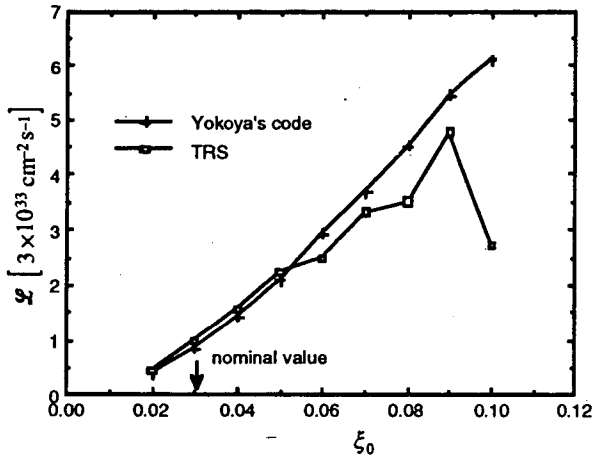


Fig. 1. Dynamical luminosity vs. nominal beam-beam parameter for PEP-II in the absence of effects from PCs.

3.2 Effects of the Parasitic Crossings

An idea of the strength of the PCs is given by the size of the induced beam-beam kick. The beam-beam kick from *each* PC experienced by a positron at the center of the bunch is characterized by beam-beam parameters

$$\xi_{0x,+}^{(pc)} = -\frac{r_0 N_- \beta_{x,+}}{2\pi\gamma_+ d^2}, \qquad \xi_{0y,+}^{(pc)} = +\frac{r_0 N_- \beta_{y,+}}{2\pi\gamma_+ d^2} \tag{8}$$

where d is the separation between the orbits at the PC location. Similar expressions apply for an electron, *mutatis mutandi*. In the current design, APIARY 7.5, each bunch experiences four PCs on either side of the IP. The PCs closest to the IP on either side, however, overwhelm all the others, so that only these two have been considered in the beam-beam studies. For these, the orbit separation is d= 3.5 mm; using the rest of the nominal parameter values, the above expressions evaluate to

$$\begin{aligned} \xi_{0x,+}^{(pc)} &= -0.003, & \xi_{0x,-}^{(pc)} &= -0.0002 \\ \xi_{0y,+}^{(pc)} &= +0.006, & \xi_{0y,-}^{(pc)} &= +0.002 \end{aligned} \tag{9}$$

for *each* of the two PCs. The fact that the vertical beam-beam parameter of the LER is the largest of the four is due to the fact that the vertical beta function is also the largest; this, in turn, is because $\beta^*_{y,+}$ is the smallest.

One example [15] of simulation results including these PCs is shown in Fig. 2, in which the beam blowup factors are plotted against normalized beam separation (TRS code). This particular case corresponds to an earlier design, APIARY 6.3D, for which the nominal beam separation at the PCs is d = 2.8 mm, corresponding to $d/\sigma_{0x,+}$ = 7.6. In this plot $d/\sigma_{0x,+}$ is varied by varying d while keeping all other parameters fixed. It is clear that the vertical σ's blow up more significantly at small PC separation, especially for the LER. This is probably related to the fact that the vertical beam-beam kick from the PC is strongest for the LER, as seen in Eq. (9). The four σ's do not blow up together because the transparency symmetry is not

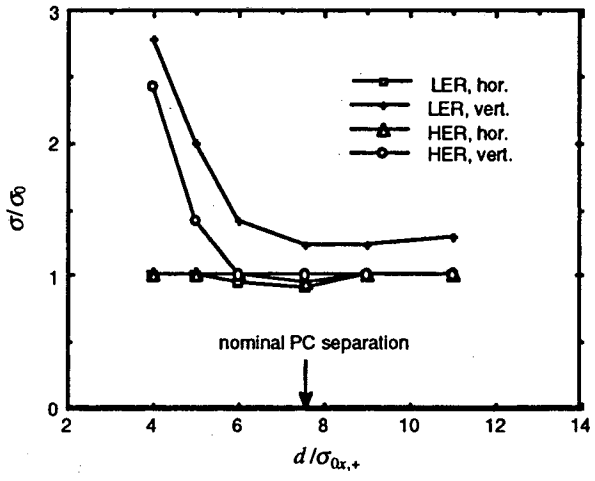


Fig. 2. Beam blowup for PEP-II (APIARY 6.3D) including PCs (TRS code).

only broken by the PCs, Eq. (9), but is also broken at the nominal level due to the difference in the tune modulation amplitudes due to synchrotron motion,

$$\left(\frac{\sigma_\ell V_s}{\beta_x^*}\right)_+ = 1.07\times10^{-3}\,,\left(\frac{\sigma_\ell V_s}{\beta_x^*}\right)_- = 6.97\times10^{-4}$$
$$\left(\frac{\sigma_\ell V_s}{\beta_y^*}\right)_+ = 2.69\times10^{-2}\,,\left(\frac{\sigma_\ell V_s}{\beta_y^*}\right)_- = 1.74\times10^{-2} \qquad (10)$$

If d is increased sufficiently ($d/\sigma_{0x,+} \gtrsim 7$ in this particular case), the effects from the PCs disappear, leaving a remanent LER vertical blowup of ~20–25% due to the main collision at the IP. This implies a ~10% reduction in dynamical luminosity from its nominal value of 3×10^{33} cm^{-2} s^{-1}.

The APIARY 7.5 design has d = 3.5 mm and $d/\sigma_{0x,+}$ = 9.6. Simulation results for the vertical blowup of the LER are shown in Fig. 3 (the remaining three blowup factors are quite close to unity). The onset of significant beam blowup happens in this case for $d/\sigma_{0x,+} \lesssim 5$, which allows a larger margin of comfort in the design than in APIARY 6.3D (the upturn shown by TRS at $d/\sigma_{0x,+}$ = 12 is almost certainly an artifact of not having run the simulation long enough).

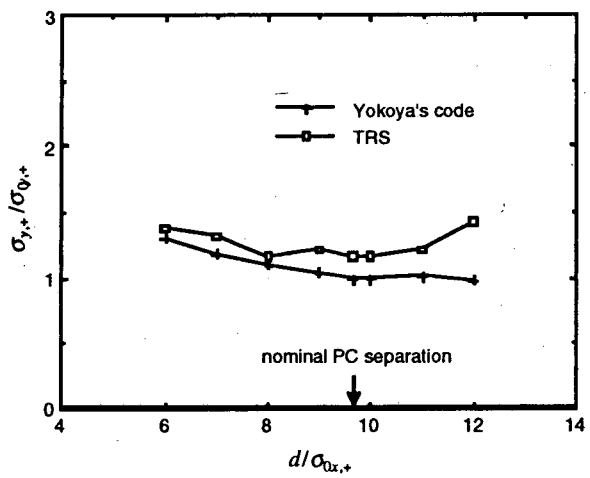


Fig. 3. Vertical beam blowup for PEP-II (APIARY 7.5) including PCs.

3.3 Comments on Transparency Symmetry

From the point of view of beam-beam simulations, PEP-II has been studied more extensively than the other proposed asymmetric colliders. Here are a few questions for transparency symmetry that are tentatively answered within the context of these simulations:

(1) Is transparency symmetry a convenient, prudent starting point for the design? Yes; the symmetry conveniently restricts the numbers of parameters to study, and allows to callibrate predicted performance against the experience available for symmetric colliders. Simulations for PEP-II also show that performance is better under transparent-symmetric conditions than under non-transparent-symmetric conditions [9].

(2) Does transparency symmetry allow reaching the beam-beam limit? Probably not; it is quite possible that luminosity performance can be better for a non-transparent-symmetric configuration than for a symmetric one. In fact, it has been argued on general grounds [16] that, given an asymmetric machine design, the beam-beam limit can only be achieved with asymmetric beam dynamics parameters. Thus, according to this argument, transparency symmetry would preclude attaining the beam-beam limit. However, the same reasoning predicts greater sensitivity to errors and tighter tolerances as the beam-beam limit is approached. Thus it is possible that the ultimate beam-beam limit in an asymmetric collider can be achieved at the price of relinquishing too much flexibility and therefore operational reliability, or of undesirably tight tolerances. Furthermore, it is not known presently how different the luminosity at the beam-beam limit would be compared with what could be achieved in a given transparent-symmetric case. In any case, the consensus for now seems to be that even if luminosity performance can be improved by moving away from transparency, it is still a prudent approach to ensure that the collider design should encompass the transparent-symmetric option.

(3) Is transparency symmetry strictly necessary? Probably not; as pointed out above, the symmetry is not perfect for the PEP-II design even at the nominal level on account of Eq. (10), and it is further broken by other effects such as those from the PCs and magnet errors. Certainly transparency symmetry implies design challenges such as an unnaturally fast damping rate for the LER, which must be achieved by resorting to wigglers and/or strong bending magnets. From this perspective, it would be convenient and economical to dispense with these special devices, or to reduce their scope. This must be balanced against the "prudent approach" metioned above. More research is needed in order to assess the issue.

(4) Does transparency symmetry allow adequate tolerances and safety margins? Yes; other simulations, not presented here, show, for example, that tolerances are not tight on the vertical and horizontal alignment of the beams when they collide at the IP not exactly head-on but slightly off-center. Another example that suggests that the equality of the LER and HER beam-beam parameters may not be strictly necessary for the APIARY 6.3D design is shown by the simulation results in Fig. 4, in which the vertical beam blowup of the two beams are shown as a function of the LER beam-beam parameter ξ_{0+}. In this case ξ_{0+} is varied away from its nominal value of 0.03 under the constraints $\xi_{0x,+} = \xi_{0y,+}$ and $\xi_{0x,-} = \xi_{0y,-}$, with the product $\xi_{0+} \cdot \xi_{0-}$ held fixed at 0.03^2. This is done by changing the number of particles per bunch at fixed nominal emittance such that the product of the bunch currents remains constant. This constraint ensures that the nominal luminosity for all points in Fig. 4 is the same, namely $\mathcal{L}_0 = 3 \times 10^{33}$ cm^{-2} s^{-1}. This simulation is meant only to give an idea of the variation of the dynamics away from transparency condition (i), and not to provide, necessarily, realistic alternatives for the parameters (it should be remembered that transparency condition (iv) is not exactly satisfied, on account of Eq. (10)). The simulations included PCs, and were run for three damping times, with the bunches divided up into three longitudinal slices (TRS code). The horizontal beam blowup for both beams was quite close to unity for all points. The luminosity performance varies smoothly as the beam-beam parameters move away from equality. In fact, these results suggest that the performance is slightly better for $\xi_{0+} = 0.024$, $\xi_{0-} = 0.0375$ than for $\xi_{0+} = \xi_{0-} = 0.03$ (the peak at $\xi_{0+} \approx 0.022$ is probably due to a resonance effect). Fig. 4 further supports the belief that transparency is not a "hair trigger" symmetry.

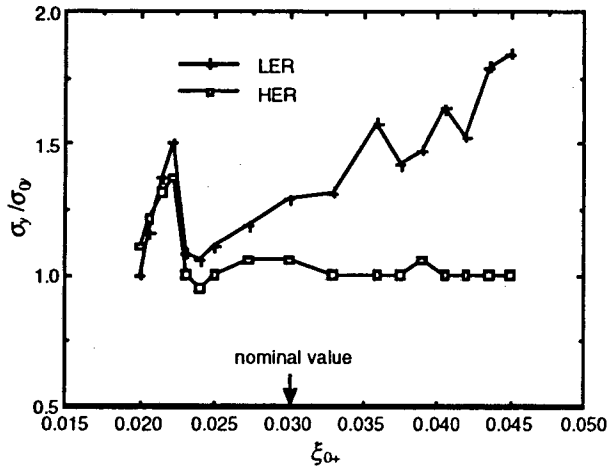


Fig. 4. Vertical beam blowup for both beams for asymmetric beam-beam parameters.

3.4 Injection Issues

At the time of injection the beam is displaced from its nominal orbit by about $8\sigma_0$. If the injection process takes place in the horizontal plane, the injected beam has a chance for a close-to-head-on collision with the stored beam at a PC location before its orbit damps down to nominal. This close encounter is quite strong because of the large beta function. Vertical injection, on the other hand, does not entail this potential problem. Simulations for both cases have been carried out for PEP-II [17]. As a result of these, vertical injection has been adopted.

4. CROSSING ANGLE

The challenge of beam separation in the interaction region has naturally led to the consideration of collisions at an angle. In this case, however, potentially detrimental synchro-betatron resonances appear [18] whose effects must be assessed.

Although the KEK B factory design calls for head-on collisions, the possibility of a small crossing angle has been recently considered [19]. Studies of the beam closed orbit, including the effects of nine PCs on either side of the IP, show that the stability of the coherent dipole mode of the beam is safe for a crossing half-angle $\phi/2 = 2.3$ mrad. In this case the normalized beam separation at the first PC is $d/\sigma_x \approx 9$ for a bunch spacing $s_B = 0.6$ m.

Ongoing experiments at CESR [20] for collisions with a horizontal crossing angle show that there are no significant detrimental effects for half-angles up to $\phi/2 \approx 2.5$ mrad. Certain synchro-betatron resonances that are excited by the crossing angle have been identified and have been shown to be avoidable.

The CESR-B design [5] calls for a relatively large horizontal crossing angle, $\phi/2 = 12$ mrad. The resultant bunch tilt is supposed to be compensated by pairs of "crab cavities" [21]. Since such a compensating mechanism allows for the possibility of large crossing angles, it would void, in principle, all concerns arising from parasitic collisions. The burden is shifted to

proving that such cavities can be built, operated and controlled reliably under actual operating conditions. Present studies seem to show that tolerances are not tight [20].

5. CODES AND ALGORITHMS

So far, lattice nonlinearities have not been included in the strong-strong simulations used in the PEP-II beam-beam studies. However, simulations and experiments at CESR [22] have shown that sextupole magnets do not seem to have a significant effect on luminosity performance. Including lattice nonlinearities in simulation codes does not seem to represent a significant coding effort. However, even without nonlinearities, these simulations can be time-consuming: as an example, a simulation run for 15,000 turns, 256 superparticles per bunch and thick-lens effects described by 3 slices with the code TRS takes ~8 min CPU time on a CRAY Y-MP (the two PCs on either side of the IP included). In this regime, the CPU time scales roughly linearly with the number of superparticles, with the number of turns, and with the number of slices.

The importance of allowing for, and consistently treating, non-Gaussian distributions, has been emphasized. This can be achieved with PIC (particle-in-cell) codes [23,24], which solve Maxwell's and Newton's equations approximately consistently during the beam-beam collision. Some interesting new results have been observed in this type of simulations for round beams and high values of ξ_0 [24]. At present, it appears that an extension along these lines implies a significant complication in the tracking codes and a major increase in the computer time needed. This work remains to be carried out to confirm that, in the parameter regime relevant to B factories, the strong-strong simulation results are not significantly modified.

The coherent mode approach [25] to the beam-beam problem has been used to arrive at a good understanding of the coherent dipole modes of coupled beams, and hence to an understanding of instabilities of closed orbits [26]. It remains an interesting problem to extend this method, with comparable reliability, to higher-order modes, especially for asymmetric colliders. The quadrupole mode, for example, would shed light on beam blowup, and therefore on luminosity performance.

Each of the methods described has strengths and weaknesses, and sheds light on different aspects of the dynamics. It is probably unrealistic to expect any single calculational approach to be developed in the foreseeable future that can reliably predict systematically and quantitatately all aspects of beam-beam dynamics. Each method, however, should be properly callibrated against experimental results.

6. BEAM LIFETIME

A reliable determination of the beam lifetime is by far the most difficult and expensive part of beam-beam studies. It is the least-studied beam-beam issue in B factory proposals. Although interesting analytic work has been done for simplified models [27], studies for realistic, concrete cases remain to be carried out. The core of the beam, which determines the short-term average luminosity, can be studied effectively with strong-strong simulations, as mentioned above. The beam lifetime, on the other hand, is important for the integrated luminosity, and is determined by the dynamics of the tails of the beam.

The beam tails involve particles at large amplitude and very long time scales. Lattice nonlinearities are probably essential, and brute force simulation approaches are thought to be hopeless with present-day computers, at least if one wants results with a reliability comparable to that which can be achieved in beam core studies. Numerical "acceleration" algorithms [28] are promising in this respect, although they need to be tested further for reliability and accuracy. Table 2 summarizes a comparison between the essential dynamics of the beam core and tails.

Table 2. Dynamics of Luminosity and Lifetime

	Luminosity	Lifetime
Relevant region:	beam core	beam tails
Relevant time scale:	~few damping times	many damping times (~100 ?)
Appropriate method/theoretical object of interest:	strong-strong simulations (~100–1000 superparticles)/ quadrupole mode, beam blowup	weak-strong simulations (incoherent approach)/convection currents

7. CONCLUSIONS

(1) The energy asymmetry does not seem to be an issue *per se* for asymmetric colliders, at least when transparency conditions are satisfied. Thus an asymmetric collider does not seem to be qualitatively different from a single-ring, symmetric machine from the perspective of beam-beam dynamics. (2) Present B factory designs do not push the beam-beam physics beyond what has been achieved in existing (or defunct) colliders. However, the relatively short bunch spacing does pose the challenge of potentially strong parasitic collisions. (3) The KEK design is quite aggressive, with a beam-beam parameter of 0.05 and a disruption parameter $D = 4\pi\xi_0\sigma_z/\beta_y^*$ close to a record high of 0.31. The challenge for this design is to present simulations (or other arguments) supporting the possibility of achieving the advertised ultimate luminosity goal of 10^{34} cm^{-2} s^{-1}. (4) If the crab-crossing scheme for CESR-B works reliably under full beam loading conditions, there would appear to be no further significant beam-beam issues remaining. (5) The luminosity performance for PEP-II has been well-studied with simulations which imply an acceptable luminosity performance. The PCs closest to the IP appear to be sufficiently weak. The "outer" PCs need to be taken into account; however, almost certainly these do not pose any significant problems. (6) The beam lifetime should be studied; however, it seems likely that this issue is not qualitatively different from single-ring colliders. For the time being, therefore, one may count on the available experience from existing machines. New simulation algorithms for the beam tails should be refined and callibrated. (7) Multiparticle tracking simulations should be augmented to include the effects from lattice nonlinearities, and callibrated more carefully by comparing to experiment. (8) The interesting ongoing experiments at CESR with crossing angle collisions should be completed and pushed to larger crossing angles, if possible.

8. ACKNOWLEDGEMENTS

I am grateful to Y.-H. Chin, J. Eden, S. Krishnagopal and M. Zisman for valuable discussions.

REFERENCES:

[1] An Asymmetric B Factory Based on PEP, Conceptual Design Report, LBL PUB-5303, SLAC-372, CALT-68-1715, UCRL-ID-106426, UC-IIRPA-91-01, February, 1991.

[2] Accelerator Design of the KEK B Factory, ed. S. Kurokawa, K. Satoh, and E. Kikutani, KEK Report 90-24, March, 1991.

[3] A. N. Dubrovin and A.A. Zholents, in Proc. of 1991 IEEE Particle Accelerator Conference, San Francisco, May 6–9, 1991, p. 2835.

[4] F. Willeke, in Proc. of 1991 IEEE Particle Accelerator Conference, San Francisco, May 6–9, 1991, p. 135.

[5] K. Berkelman et al., CESR-B, Conceptual Design for a B Factory Based on CESR, CLNS 91-1050, February, 1991.

[6] Feasibility Study for a B-Meson Factory in the CERN ISR Tunnel, ed. T. Nakada, CERN 90-02, PSI PR-90-08, March, 1990.

[7] F. Zimmermann, these proceedings.

[8] A. Garren *et al*, Proc. 1989 Particle Accelerator Conference, Chicago, March 1989, p. 1847; Y.-H. Chin, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, Ed. Andrew M. Sessler, AIP Conference Proceedings **214**, 424 (1990); Y. H. Chin, LBL-27665, August, 1989, presented at the XIV Intl. Conf. on High Energy Accelerators, Tsukuba, Japan, August 1989; M. A. Furman, ABC-25/ESG-0163, Feb. 1991 (rev. Sept. 1991).

[9] Y.-H. Chin, Ref. 8.

[10] S. Krishnagopal and R. Siemann, Phys. Rev. **D41**, 1741 (1990).

[11] Y.-H. Chin, Proc. 1991 Particle Accelerator Conference, San Francisco, May 1991, p. 213; J. L. Tennyson, ABC-28, August 1991; J. R. Eden and M. A. Furman, ABC-62/ESG technote 186, May, 1992.

[12] M. Bassetti and G. A. Erskine, CERN-ISR-TH/80-06.

[13] S. Krishnagopal and R. Siemann, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, A. M. Sessler, ed., AIP Conf. Proc. **214**, 278 (1990), and *Phys. Rev.* **D41**, 2312 (1990).

[14] J. L. Tennyson, undocumented code "TRS," 1989; K. Yokoya, undocumaented code.

[15] J. R. Eden and M. A. Furman, Ref. 11.

[16] J. L. Tennyson, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, Ed. Andrew M. Sessler, AIP Conference Proceedings **214**, 130 (1990).

[17] Y.-H. Chin, these proceedings; ABC-51/LBL-31434/ESG-158, October 1991.

[18] A. Piwinski, IEEE Trans. Nucl. Sci. **NS-24**, 1408 (1977).

[19] K. Satoh, these proccedings; K. Hirata, KEK-BF-0089, April 1, 1992.

[20] M. Tigner, these proceedings.

[21] K. Oide and K. Yokoya, Phys. Rev. **A40**, 315 (1989).

[22] G. Jackson and R. Siemann, *Nuclear Instruments and Methods* **A286**, 17 (1990).

[23] 4. J. Koga, Proc. *7th ICFA Workshop on Beam Dynamics*, UCLA, May, 1991; T. Tajima and J. Koga, Proc. *Nonlinear Dynamics and Particle Acceleration*, Tsukuba, Oct. 1990, Y. Ichikawa and T. Tajima, eds., AIP Conf. Proc. **230**, 236 (1991); T. Tajima and J. Koga, *Part. Accel.* **28**, 125 (1990).

[24] S. Krishnagopal and R. Siemann, 1991 Particle Accelerator Conference, San Francisco, May 1991, p. 1071; Phys. Rev. Lett. **67**, 2461 (1991).

[25] K. Hirata, in *Beam Dynamics Issues of High Luminosity Asymmetric Collider Rings*, A. M. Sessler, ed., AIP Conf. Proc. **214**, 175 (1990).

[26] K. Hirata and E. Keil, CERN/LEP-TH/89-76, December, 1989.

[27] J. Tennyson, Physica **5D**, 123 (1982); A. L. Gerasimov, Physica **D41**, 89 (1990); A. Gerasimov and R. Siemann, Proc. *Workshop on Nonlinear Problems in Future Particle Accelerators*, Capri, Italy, 1990, W. Scandale and G. Turchetti, eds., World Scientific.

[28] J. Irwin, Proc. *Third Advanced ICFA Beam Dynamics Workshop*, Novosibirsk, May–June 1989, p. 123; S. Milton, Proc. 1991 Particle Accelerator Conference, San Francisco, May 1991, p. 291.

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
TECHNICAL INFORMATION DEPARTMENT
BERKELEY, CALIFORNIA 94720