PEP-II/AP Note 2-92
ESG Tech Note 210

FURTHER ASSESSMENTS OF THE BEAM-BEAM EFFECT FOR PEP-II DESIGNS APIARY 6.3D AND APIARY 7.5

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October, 1992

ABSTRACT

We continue our studies of the effects of the beam-beam interaction for the APIARY 6.3D and APIARY 7.5 designs of PEP-II for a variety of conditions. We focus primarily on the effect of the collisions at the parasitic crossing points, although we also consider the effects of the nominal beam-beam parameter ξ_0 having a value of 0.05 instead of the nominal value of 0.03. Our studies are based on strong-strong multiparticle tracking simulations. We conclude, quite consistently, that APIARY 7.5 offers a significantly higher "margin of comfort" than APIARY 6.3D on account of the increased separation of the beams at the parasitic collision points. We also conclude, not surprisingly, that if a higher-than-nominal value for ξ_0 is desired, it is safer to decrease the nominal beam emittance than to increase the bunch current, although this latter approach is more effective. Our simulations quantify, to an extent, the trade-offs between the "safety" and the "effectiveness" of these two approaches. Simulations for a positron-beam synchrotron tune of 0.04 and 0.05 show qualitatively similar results.

1. Introduction

In a previous note[1] we presented a fairly extensive assessment of the beam-beam effect on the luminosity performance of PEP-II for the interaction region (IR) design APIARY 6.3D, described in detail in the CDR[2]. In this note we continue this assessment, and extend it to the APIARY 7.5 design, described in the Design Update[3] (DU). We present here 11 cases; all these studies are based on strong-strong multiparticle simulations with the code TRS[4] on the NERSC Cray-2S/8128 computer. Simulations with another code have also been carried out[2,3,5] for both IR designs; the two codes yield results in good qualitative agreement.

In this note we focus on a comparison between the two designs. Accordingly, we vary fewer parameters but perform more detailed simulations than in our first note. As before, however, the

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primary parameter of our focus is the separation d between the beams at the first parasitic collision (PC). Although there are several PCs on either side of the interaction point (IP) (six in APIARY 6.3D and four in APIARY 7.5), it is the first PC that dominates. Accordingly, we neglect all but this first PC in all our simulations (an analytic estimate of the effects of the "outer" PCs was carried out in lowest-order approximation for APIARY 7.5 in the DU[3]). We also focus on the nominal beam-beam parameter ξ_0, whose value is specified to be 0.03 in the PEP-II design. In our beam-beam studies, however, we also allow ξ_0 to take on the value 0.05 in order to assess how much margin the two IR designs allow when the beam-beam interaction is "pushed."

From the beam-beam perspective, and within the approximations we are forced to make in our present simulations, there are only two differences between the APIARY 6.3D and APIARY 7.5 designs:

(a) the PC separation d is 2.8 mm in APIARY 6.3D, while it is 3.5 mm in APIARY 7.5, and

(b) the lattice functions at the PC, and the phase advances from the IP to the PC, are slightly different in the two designs.

Without a doubt it is the increased value of d in APIARY 7.5 that has the larger impact on performance. In keeping with our adopted strategy in these studies, we take d to be a free parameter that we vary independently of all others. In the limit $d \to \infty$ all effects of the PCs disappear, and only those from the primary collisions at the IP remain. Our main goal, then, is to assess the relative weakness of the PCs for the nominal value of d, under several circumstances, described in detail in Sec. 3. As in our previous note, all the results presented here are in the form of plots of beam blowup factors σ/σ_0 *vs.* $d/\sigma_{0x,+}$. This latter variable is the PC separation normalized to the local nominal horizontal beam size of the low-energy beam (LEB). The nominal APIARY 6.3D design implies a value $d/\sigma_{0x,+} = 7.57$, while APIARY 7.5 implies $d/\sigma_{0x,+} = 9.64$. As mentioned above, however, in the blowup plots shown below we vary $d/\sigma_{0x,+}$ by varying d while keeping all other parameters fixed.

Our main conclusion is that APIARY 7.5 offers a significantly wider comfort margin than APIARY 6.3D due to the increased PC separation. We also conclude, not surprisingly, that if a higher-than-nominal value for ξ_0 is desired, it is safer to decrease the nominal beam emittance than to increase the bunch current, although this latter approach is more effective due to the quadratic dependence of the bunch current in the luminosity formula. Almost certainly the optimal way to increase ξ_0 involves a combination of these two methods, plus changing other parameters; such an optimization falls outside the scope of these studies, and is not addressed here. Our results quantify, within the inherent accuracy of our methods, the "comfort margin" of the IR designs, and the trade-offs between the "safety" and the "effectiveness" of the two simplest approaches to increase ξ_0 mentioned above.

We also conclude that there is no qualitative difference in the results of a simulation for APIARY 7.5 when the synchrotron tune is $\nu_{s+} = 0.0403$ or $\nu_{s+} = 0.05$.

In most cases presented here we have looked at a working point such that the fractional parts* of the tunes are (ν_x, ν_y) = (0.64, 0.57) for both beams, following the results of previous tune scans.[2,3,6] However, we also present results for two other working points, namely (0.28, 0.18) and (0.57, 0.64). We conclude that the choice (0.64, 0.57) is clearly better than the other two from the perspective of luminosity performance. While more extensive tune scans remain to be carried out, including unequal working points for the two beams, we believe that a fine search around (0.64, 0.57), with slight differences for the two beams, will reveal an even better operating point.

Section 2 describes the basic assumptions we have made in these studies. A detailed explanation of the parameters used, and the results obtained, in each of the 11 cases is presented in Sec. 3. A comparative assessment is presented in Sec. 4. Section 5 collects our conclusions.

2. Assumptions

All basic lattice and nominal beam parameters are listed in Tables 1 (APIARY 6.3D) and 2 (APIARY 7.5). The actual values of the parameters used in each of the 11 cases are variants of these, and are stated in Sec. 3. A detailed explanation of all our assumptions is described in Ref. 1. Here we summarize further assumptions that need clarification, or that are peculiar to this note:

2.1 Lattice

We consider only the linear approximation to the lattice, which is therefore fully described by the tunes, the lattice functions at the IP and PCs, and the intervening phase advances. In both designs, and in both rings, the PCs are optically symmetric about the IP; thus the lattice functions and phase advance from the IP are the same. We imagine the lattice divided up into two “short” arcs, from the IP to each of the two PCs, and one “long” arc, from one PC to the other (see a sketch below). The lattice functions and phase advances $\Delta\nu$ are listed in Tables 1 and 2; these phase advances remain fixed even when the tune is changed. The phase advance of the “long” arc is therefore adjusted to be $\nu-2\Delta\nu$, where ν is the tune of the entire ring. As mentioned above, we have chosen three working points for our simulations, which are listed in Sec. 3 in each case. It should be emphasized that these tunes and phase advances correspond to the “bare machine,” *i.e.*, in the absence of the beam-beam interaction.

The RF wavelength, λ_{RF}, is 0.6298 m, and we consider only the nominal value for the bunch spacing, namely $s_B = 2\lambda_{RF} = 1.2596$ m. Therefore the first PC occurs at a distance of 0.6298 m from the IP.

2.2 Primary beam-related parameters

The nominal beam-beam parameter ξ_0 is 0.03 in cases “A” and 0.05 in cases “B” (all four beam-beam parameters are equal). In going from a given case “A” to the corresponding case “B” we have either increased the number of particles per bunch by a factor of 5/3 at fixed emittance, or have decreased the emittance by a factor 3/5 at fixed bunch current. In the first case the

* Within our approximations, the integer part of the tune does not enter.

nominal luminosity $\mathscr{L}_0$ increases by a factor $(5/3)^2$ but in the second case $\mathscr{L}_0$ increases by a factor 5/3. The actual values of $\mathscr{L}_0$ in each case are stated in Sec. 3 below.

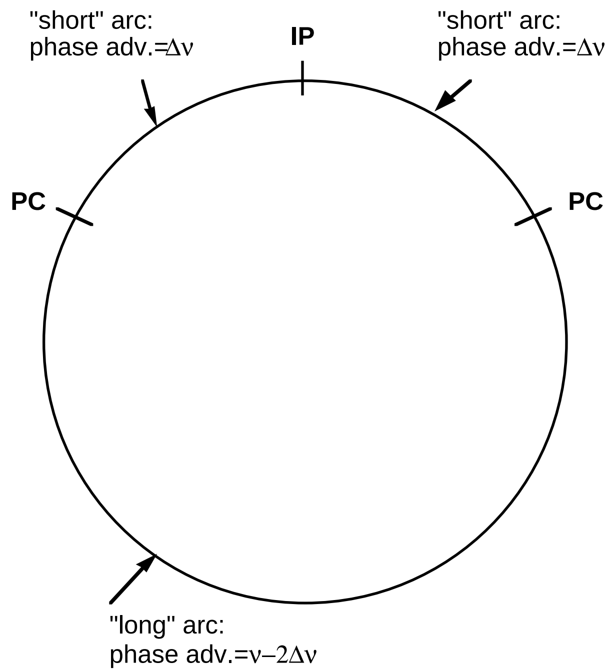

Fig. 1. Sketch of either ring showing the phase advances of each arc.

2.3 Other parameters

The numbers of particles per bunch, nominal emittances, rms beam sizes and rms angular divergences at the collision points are determined by the lattice functions, collision frequency, and the primary parameters ξ_0 and $\mathscr{L}_0$. These are all listed in Tables 1 and 2. The beam energy E, bunch length σ_ℓ, rms energy spread σ_E/E and synchrotron tune ν_s are different for the two beams, but are held fixed at their specified CDR values throughout our studies.

In the nominal cases, specified by the parameters in Tables 1 and 2, the number of particles per bunch are determined assuming that there are no gaps in the bunch population. The actual PEP-II design, however, calls for an ion-clearing gap of 88 bunches in each beam, corresponding to ~5% of the maximum possible bunch population (one bunch every other bucket). If we wanted to take the gap into account in the beam-beam simulations, we would have to increase both the number of particles per bunch and the nominal emittances by ~5% in order to keep ξ_0 and $\mathscr{L}_0$ at their specified values of 0.03 and 3×10^{33} cm^{-2} s^{-1}, respectively. We believe that this change would imply negligible modifications in our results.

We note that, when the number of particles per bunch are increased from their nominal values by a factor of 5/3 at fixed emittance, the total beam current of the LEB reaches 3.6 A, which exceeds the maximum value allowed by the vacuum chamber design. We have studied this high-bunch current option only as a way to assess the effects of a relatively strong beam-beam dynamics, and not as a realistic option for PEP-II in its current conception.

In all but one of the simulations presented here the synchrotron tune of the LEB is ν_{s+} = 0.0403, as indicated in Tables 1 and 2. This value is consistent with the other parameters listed, such as a peak voltage V_{RF} = 8.0 MV and a momentum compaction factor $\alpha = 1.15 \times 10^{-3}$. These values predate the CDR, and have been used in all the beam-beam simulations presented here and earlier,[1–3,5–7] including those in Sec. 4.4 (“Beam-Beam Issues”) of the CDR and the DU. However, although the LER lattice design has not yet been finalized, the CDR and the DU assume elsewhere that $\alpha = 1.5 \times 10^{-3}$. As a result, the peak RF voltage is specified to be 9.5 MV instead of 8.0 MV (the rms bunch length σ_ℓ is taken to be 1 cm, and the rms energy spread σ_E/E is taken to be 1×10^{-3}, as we do here and in all previous simulations). The corresponding value of the synchrotron tune of the LEB is closer to 0.05 than 0.0403. We present below the results of one simulation for APIARY 7.5 in which we compare the results for ν_{s+} = 0.0403 with those for ν_{s+} = 0.05, with all other parameters remaining fixed. The results are qualitatively similar.

2.4 Simulation details

The details of the code TRS[4] are explained in detail in Ref. 1. In all 11 cases presented here we have chosen 256 “superparticles” per bunch, five slices to represent the thick lens effects in the beam-beam interaction, and have run the simulations for 25,000 turns, or about five damping times. With these choices, each run (*i.e.*, each point in any of the blowup plots) takes ~22 min CPU time on one of the NERSC Cray-2S/8128 computers. In this regime, the CPU time scales approximately linearly with the number of superparticles per bunch, the number of thick-lens slices, and the number of turns. We have not yet attempted any kind of optimization in structuring or in compiling the program to take advantage of the Cray architecture.

Although the damping times are nominally specified to be τ_+ = 5,014 and τ_- = 5,040 turns, in most simulation runs we have set them equal, namely $\tau_+ = \tau_-$ = 5,014 turns. In practice, however, the difference in the results between a simulation with τ_- = 5,040 turns and one with τ_- = 5,014 turns is insignificant.[1]

3. Details of study cases

As indicated above, we have run the simulation for 25,000 turns in all cases. The beam blowup plotted in all figures is the average over the final 2,500 turns of the run. Table 3 provides a summary of the parameters that are varied in the 11 cases. The exact values of the input parameters for each case are listed on the right margin of the corresponding figure. These values supersede those in Tables 1 or 2 if there is any discrepancy (such as in the damping times, as explained above). Here we provide a detailed case-by-case explanation:

3.1 Case 6A (Fig. 2)

This is the nominal CDR case (APIARY 6.3D IR design), with ξ_0 = 0.03 and $\mathcal{L}_0$ = 3 $\times 10^{33}$ cm^{-2} s^{-1}. The working point is (ν_x, ν_y) = (0.64, 0.57) for both beams. A complete list of parameters is found in Table 1. In the simulation, the horizontal and vertical damping times were taken to be the same for both rings, namely $\tau_+ = \tau_-$ = 5,014 turns instead of the nominally specified values τ_+ = 5,014, τ_- = 5,040 turns.

3.2 Case 6B (Fig. 3)

This is a high-current version of case 6A, with ξ_0 = 0.05 and $\mathcal{L}_0$ = 8.33 $\times 10^{33}$ cm^{-2} s^{-1}. The higher value for ξ_0 is achieved in this case by increasing $N_\pm$ by a factor of 5/3 relative to case 6A, keeping the nominal emittances fixed. The rest of the parameters are listed in Table 1.

3.3 Case 7A1 (Fig. 4)

This is the nominal DU case for the APIARY 7.5 IR design with ξ_0 = 0.03 and $\mathcal{L}_0$ = 3 $\times 10^{33}$ cm^{-2} s^{-1}. The working point is (ν_x, ν_y) = (0.64, 0.57) for both beams. The parameters are listed in Table 2. The actual damping times used in the simulation are those on the right margin of the figure.

3.4 Case 7B1 (Fig. 5)

This is a high-current version of case 7A1, with ξ_0=0.05 and $\mathcal{L}_0$ = 8.33 $\times 10^{33}$ cm^{-2} s^{-1}. As before, the higher value for ξ_0 is achieved by increasing N_+ and N_- by a factor of 5/3 from case 7A1, keeping the nominal emittances fixed. Besides this change, the rest of the parameters are the same as in case 7A1.

3.5 Case 9A4 (Fig. 6)

This is another APIARY 7.5 case, similar to case 7A1 except that the working point is (ν_x, ν_y) = (0.28, 0.18) for both beams.

3.6 Case 9A5 (Fig. 7)

This case is similar to case 9A4 (APIARY 7.5) except that the working point is (ν_x, ν_y) = (0.57, 0.64) for both beams.

3.7 Case 11A4 (Fig. 8)

This case is similar to 6A (APIARY 6.3D) except that the working point is (ν_x, ν_y) = (0.28, 0.18) for both beams.

3.8 Case 11A5 (Fig. 9)

This case is similar to 11A4 except that the working point is (ν_x, ν_y) = (0.57, 0.64) for both beams.

3.9 Case 12B (Fig. 10)

This is a low-emittance version of case 6A (APIARY 6.3D). As in case 6A, ξ_0 has the higher-than-nominal value of 0.05; unlike case 6B, however, this value for ξ_0 is now achieved by reducing all four nominal emittances by a factor 3/5 from case 6A at fixed bunch current. Correspondingly, the four nominal beam sizes are a factor $\sqrt{3/5}$ smaller. The resultant luminosity is a factor 5/3 larger than in case 6A, namely $\mathscr{L}_0 = 5 \times 10^{33}$ cm^{-2} s^{-1}, instead of 8.33×10^{33} cm^{-2} s^{-1} in case 6B. The rest of the parameters are listed in Table 1. It should be noted that the nominal value of the normalized PC separation is in this case $d/\sigma_{0x,+} = \sqrt{5/3} \times 7.57 = 9.77$.

3.10 Case 20B (Fig. 11)

This is the APIARY 7.5 analog of case 12B, *i.e.*, the low-emittance, nominal-current version of case 7A1, with $\xi_0 = 0.05$ and $\mathscr{L}_0 = 5 \times 10^{33}$ cm^{-2} s^{-1}. Other parameters are listed in Table 2. In this case, the nominal value of the normalized PC separation is $d/\sigma_{0x,+} = \sqrt{5/3} \times 9.64 = 12.44$.

3.11 Case 7A2 (Fig. 12)

This is the same as case 7A1 (APIARY 7.5) except that the synchrotron tune ν_{s+} of the LEB is 0.05 instead of 0.0403.

4. Discussion of the results

We now compare the results for these 11 cases by looking at the plots for the beam blowup factors σ/σ_0 *vs.* the normalized PC separation, $d/\sigma_{0x,+}$. As mentioned above, in these plots we vary d while keeping all other parameters fixed. The actual design value of d (or $d/\sigma_{0x,+}$) is indicated by an arrow in all plots.

4.1 APIARY 6.3D vs. APIARY 7.5 (Fig. 13)

In comparing any blowup plot for APIARY 6.3D with the corresponding one for APIARY 7.5 (*i.e.*, same working point and same value of ξ_0), one sees that the qualitative shapes of the curves are the same. This is clear in Fig. 13, and also in comparing Figs. 14 and 15, and Figs. 16 and 17. The reason for this similarity is simple: as pointed out in the Introduction, the only relevant differences between the two designs are (a) the value of d, and (b) the value of the lattice functions at the PC. Since d is a free variable in the blowup plots, the only remaining difference is (b), which is minor.

Fig. 13 compares cases 6A with 7A1 and 6B with 7B1. In each case, the arrows indicate the nominal PC separation. For these values of d, the vertical beam blowup of the LEB is ~10–20% for $\xi_0 = 0.03$ and ~60–80% for $\xi_0 = 0.05$. The resultant dynamical values for the luminosity, are: $\mathscr{L} \sim 2.6 \times 10^{33}$ cm^{-2} s^{-1} for 6A, $\mathscr{L} \sim 2.9 \times 10^{33}$ cm^{-2} s^{-1} for 7A1, $\mathscr{L} \sim 5.3 \times 10^{33}$ cm^{-2} s^{-1} for 6B, and $\mathscr{L} \sim 5.9 \times 10^{33}$ cm^{-2} s^{-1} for 7B1.

As seen in Fig. 13, the important difference between APIARY 6.3D and APIARY 7.5 is that this latter design provides a greater margin of comfort because the nominal value of $d/\sigma_{0x,+}$ is significantly larger than the "threshold" value of $d/\sigma_{0x,+}$ below which there is onset of substantial beam blowup. One can see that this "threshold" value is $d/\sigma_{0x,+}$ ñ 6 for $\xi_0 = 0.03$ and $d/\sigma_{0x,+}$ ñ 8 for $\xi_0 = 0.05$.

4.2 Comparison of three working points (Figs. 14 and 15)

Fig. 14 shows a comparison of beam blowup for three different working points for the APIARY 6.3D design. Clearly the working point (0.64, 0.57) is better than either (0.28, 0.18) or (0.57, 0.64). Previously[1] a wider, but less accurate, tune scan was performed, that led to the choice (0.64, 0.57). Fig. 14 presents a detailed confirmation for three points of that tune scan.

Fig. 15 presents the same comparison for APIARY 7.5 as does Fig. 14 for APIARY 6.3D, with a similar conclusion. In comparing any given case in Fig. 14 with the corresponding one in Fig. 15, one reaches the same conclusion about the increased margin of comfort for APIARY 7.5 mentioned in Sec. 4.1 above.

4.3 High current, nominal emittance vs. nominal current, low emittance (Figs. 16 and 17)

In order to assess how the PEP-II design might perform if a luminosity larger than 3×10^{33} cm^{-2} s^{-1} were desired, we compare four cases with $\xi_0 = 0.05$ rather than 0.03. Fig. 16 shows a comparison between the APIARY 6.3D cases 6B and 12B. Fig. 17 presents the corresponding comparison for the APIARY 7.5 cases 7B1 and 20B.

All four cases have $\xi_0 = 0.05$; as explained above, however, this higher-than-nominal value of ξ_0 is achieved by scaling different parameters from the nominal cases ($\xi_0 = 0.03$). In cases 6B and 7B1, the bunch currents are scaled from the nominal case by a factor of 5/3 at fixed nominal emittance, while in cases 12B and 20B the emittances are scaled by a factor of 3/5 at fixed bunch current. It should be noted that, even though ξ_0 has the same value in these four cases, *the nominal luminosity does not*: cases 6B and 7B1 have $\mathscr{L}_0 = 8.33 \times 10^{33}$ cm^{-2} s^{-1}, while cases 12B and 20B have $\mathscr{L}_0 = 5 \times 10^{33}$ cm^{-2} s^{-1}. The reason for this difference is, of course, that $\mathscr{L}_0$ scales quadratically with N but only linearly with ε_0^{-1}.

From this comparison we see that the shapes of all four blowup curves are qualitatively similar. The "bottom" cases (12B and 20B), however, provide a greater margin of comfort than the "top" cases (6B and 7B1) because the nominal value of $d/\sigma_{0x,+}$ is larger. However, this increase in safety margin is achieved at the expense of luminosity, which is larger for 6B and 7B1.

4.4 LEB synchrotron tune 0.0403 vs. 0.05 for APIARY 7.5 (Fig. 18)

As mentioned above, we have used $\nu_{s+} = 0.0403$ in all beam-beam simulations to date. The CDR and the DU, however, specify $\nu_{s+} = 0.05$. Fig. 18 compares the simulations for cases 7A1 and 7A2, whose only difference is the value of the synchrotron tune of the LEB. Although there is slightly less blowup for $\nu_{s+} = 0.05$, the results are qualitatively similar.

5. Conclusions

(1) Clearly the APIARY 7.5 design provides a greater degree of comfort than APIARY 6.3D on account of the larger PC separation. This conclusion is consistently reached by comparing any APIARY 7.5 case with the corresponding APIARY 6.3D case. Presumably, this increased degree of comfort translates into increased reliability of operation. We say “presumably” because the present beam-beam simulations do not encompass all the beam dynamics that will be operative in the real machine (or in more detailed simulations).

(2) The working point (0.64, 0.57) seems quite comfortable. Undoubtedly, more refined tune scans near this point will reveal better choices for the working point. We also have evidence[7] that better performance is achieved if the working points of the two rings are slightly different in such a way as to compensate for the beam-beam effects from the PCs, which affect the two beams differently.

(3) If a higher-than-nominal luminosity is desired, it is safer to decrease the beam emittance than to increase the bunch current, although the latter approach has the advantage of being more effective in increasing luminosity.

(4) There is no qualitative difference in the results when the synchrotron tune of the LEB is changed from 0.0403 to 0.05.

6. Acknowledgments

We thank M. Zisman for valuable editorial comments. We are grateful to NERSC for supercomputer support.

7. References

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TABLE 1
APIARY 6.3D PRIMARY PARAMETERS
Nominal CDR case; $\mathscr{L}_0 = 3 \times 10^{33}$ cm^{-2} s^{-1}; ξ_0=0.03

	LER (e^+)	HER (e^-)
$\mathscr{L}_0$ [cm^{-2} s^{-1}]	3×10^{33}	
C [m]	2199.32	2199.32
E [GeV]	3.1	9.0
s_B [m]	1.2596	1.2596
f_c [MHz]	238.000	
V_{RF} [MV]	8.0	18.5
f_{RF} [MHz]	476.000	476.000
ϕ_s [deg]	170.6	168.7
α	1.15×10^{-3}	2.41×10^{-3}
ν_s	0.0403	0.0520
σ_ℓ [cm]	1.0	1.0
σ_E/E	1.00×10^{-3}	0.616×10^{-3}
N	5.630×10^{10}	3.878×10^{10}
I [A]	2.147	1.479
ε_{0x} [nm-rad]	91.90	45.95
ε_{0y} [nm-rad]	3.676	1.838
β^*_x [m]	0.375	0.750
β^*_y [m]	0.015	0.030
σ^*_{0x} [μm]	185.6	185.6
σ^*_{0y} [μm]	7.426	7.426
τ_x [turns]	5,014	5,040
τ_y [turns]	5,014	5,040

TABLE 1 (contd.)
APIARY 6.3D IP AND PC PARAMETERS
Nominal CDR case; $\mathscr{L}_0 = 3 \times 10^{33}$ cm^{-2} s^{-1}; ξ_0=0.03

	LER (e^+)		HER (e^-)	
Δs [cm]	62.9816			
d [mm]	2.82			
	IP	1st PC	IP	1st PC
$\Delta\nu_x$	0	0.1643	0	0.1111
$\Delta\nu_y$	0	0.2462	0	0.2424
β_x [m]	0.375	1.51	0.750	1.30
β_y [m]	0.015	25.23	0.030	13.01
α_x	0	–2.42	0	–1.06
α_y	0	–29.25	0	–18.74
σ_{0x} [μm]	185.6	372.4	185.6	244.4
σ_{0y} [μm]	7.426	304.5	7.426	154.6
$\sigma_{0x'}$ [mrad]	0.495	0.646	0.248	0.274
$\sigma_{0y'}$ [mrad]	0.495	0.353	0.248	0.223
d/σ_{0x}	0	7.570	0	11.538
ξ_{0x}	0.03	–0.000544	0.03	–0.000234
ξ_{0y}	0.03	+0.009097	0.03	+0.002345
$\xi_{0x,tot}$ a)	0.0289		0.0295	
$\xi_{0y,tot}$ a)	0.0482		0.0347	

a) The total nominal beam-beam parameter is defined to be $\xi_{0,tot} \equiv \xi_0^{(IP)} + 2\xi_0^{(PC)}$.

TABLE 2
APIARY 7.5 PRIMARY PARAMETERS
Nominal DU case; $\mathcal{L}_0 = 3 \times 10^{33}$ cm^{-2} s^{-1}; ξ_0=0.03

	LER (e^+)	HER (e^-)
$\mathcal{L}_0$ [cm^{-2} s^{-1}]	3×10^{33}	
C [m]	2199.32	2199.32
E [GeV]	3.1	9.0
s_B [m]	1.2596	1.2596
f_c [MHz]	238.000	
V_{RF} [MV]	8.0	18.5
f_{RF} [MHz]	476.000	476.000
ϕ_s [deg]	170.6	168.7
α	1.15×10^{-3}	2.41×10^{-3}
ν_s	0.0403	0.0520
σ_ℓ [cm]	1.0	1.0
σ_E/E	1.00×10^{-3}	0.616×10^{-3}
N	5.630×10^{10}	3.878×10^{10}
I [A]	2.147	1.479
ε_{0x} [nm-rad]	91.90	45.95
ε_{0y} [nm-rad]	3.676	1.838
β^*_x [m]	0.375	0.750
β^*_y [m]	0.015	0.030
σ^*_{0x} [μm]	185.6	185.6
σ^*_{0y} [μm]	7.426	7.426
τ_x [turns]	5,014	5,040
τ_y [turns]	5,014	5,040

TABLE 2 (contd.)
APIARY 7.5 IP AND PC PARAMETERS
Nominal DU case; $\mathscr{L}_0 = 3 \times 10^{33}$ cm^{-2} s^{-1}; ξ_0=0.03

	LER (e^+)		HER (e^-)	
Δs [cm]	62.9816			
d [mm]	3.498			
	IP	1st PC	IP	1st PC
$\Delta\nu_x$	0	0.1645	0	0.1112
$\Delta\nu_y$	0	0.2462	0	0.2424
β_x [m]	0.375	1.433	0.750	1.279
β_y [m]	0.015	26.46	0.030	13.25
α_x	0	–1.680	0	–0.840
α_y	0	–41.988	0	–20.994
σ_{0x} [μm]	185.6	362.9	185.6	242.4
σ_{0y} [μm]	7.426	311.9	7.426	156.1
$\sigma_{0x'}$ [mrad]	0.495	0.495	0.248	0.248
$\sigma_{0y'}$ [mrad]	0.495	0.495	0.248	0.248
d/σ_{0x}	0	9.639	0	14.429
ξ_{0x}	0.03	–0.000336	0.03	–0.000150
ξ_{0y}	0.03	+0.006200	0.03	+0.001553
$\xi_{0x,tot}$ [a)]	0.0293		0.0297	
$\xi_{0y,tot}$ [a)]	0.0424		0.0331	

a) The total nominal beam-beam parameter is defined to be $\xi_{0,tot} \equiv \xi_0^{(IP)} + 2\xi_0^{(PC)}$.