SLAC-PUB-14122

RECOMMENDATION FOR THE FEASIBILITY OF MORE COMPACT LC DAMPING RINGS*

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Abstract

As part of the international Linear Collider (ILC) collaboration, we have compared the electron cloud (EC) effect for different Damping Ring (DR) designs respectively with 6.4 km and 3.2 km circumference and investigated the feasibility of the shorter damping ring with respect to the electron cloud build-up and related beam instabilities. The studies for a 3.2 km ring were carried out with beam parameters of the ILC Low Power option. A reduced damping ring circumference has been proposed for the new ILC baseline design SB2009 [1] and would allow considerable reduction of the number of components, wiggler magnets and costs. We discuss the impact of the proposed operation of the ILC at high repetition rate 10 Hz and address the necessary modifications for the DRs. We also briefly discuss the plans for future studies including the luminosity upgrade option with shorter bunch spacing, the evaluation of mitigation techniques and the integration of the CesrTA results into the Damping Ring design.

INTRODUCTION

Collective effects are prominent among the criteria to be considered when selecting the damping ring circumference and setting specifications for the vacuum system. In the beam pipe of the positron damping ring of the Linear Colliders (ILC and CLIC), an electron cloud may be first produced by photoelectrons and ionization of residual gases and then increased by the secondary emission process [2, 3].

The baseline configuration currently specifies a 6.4 km circumference for the ILC DRs. The international collaboration has formed a working group to (i) address the risks of electron cloud effects when reducing the baseline damping ring circumference from 6.4 km to 3.2 km and (ii) give recommendation on mitigations. We compared the instability thresholds and the electron cloud formation assuming 6 ns bunch spacing in both configurations. In fact, the Low Power option [1] envisions half the damping ring length with half the number of bunches, i.e. same bunch spacing, while the luminosity is recovered with increased focusing, i.e. smaller beta functions, at the interaction point.

We summarize the simulation results for the build-up and the related single-bunch instabilities obtained by the international collaborative working group effort by studying different damping ring lattice designs. The main parameters for the lattices are listed in Table 1 and a layout, which is similar in the two DR options [4, 5], is shown in Figure 1. The nomenclature (DCO4, DSB3) is designed to provide a means of referring to the lattices that is objective, and not coloured by any associations.

Table 1. ILC Damping Ring parameters.

DR Version	DCO4	DSB3
Circumference (m)	6476.4	3238.2
Number of bunches	2600	1300
Beam energy (GeV)	5	
Bunch population	2×10^{10}	
Bunch length (mm)	6	
Bunch spacing (ns)	6	
Number of bunches per train	45	
Number of bunches per train gap	15	
Emittance horizontal (nm·rad)	0.45	0.53
Emittance vertical (pm·rad)	2	
Momentum compaction	1.62×10^{-4}	1.33×10^{-4}
Tunes Qx, Qy	71.11,71.4	57.22,33.09
Synchrotron tune	0.036	0.0166
Chamber radius arcs/straights (mm)	25	
Chamber radius wigglers (mm)	23	
Antechamber full height (mm)	10	

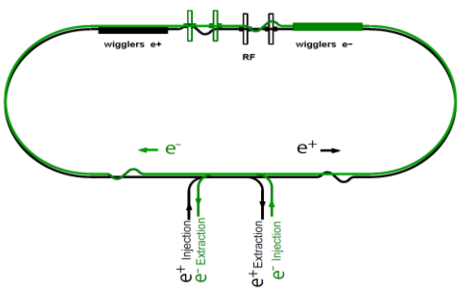

Figure 1. Layout of the ILC damping rings.

SIMULATION CAMPAIGN

The different reference lattices were analyzed with the same techniques and assumptions applied to each. The methodology was as follows:

* Work supported by the Director, Office of Science, High Energy Physics, U.S. DOE under Contract No. DE-AC02-76SF00515, DE-FC02-08ER41538 and by National Science Foundation NSF Contract No. PHY-0734867.
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• Pertinent parameters were compiled, including beam sizes in arcs, wiggler, and straights, bunch spacing, tunes, beta functions, chamber dimensions, and lengths of regions with magnetic fields.

• Electron cloud build-up was simulated for different regions (bend, wiggler, drift, quadrupole, sextupole regions) in the rings, considering actual sets of beam parameters and for different secondary emission yields.

• A common secondary emission yield model was used. Predictions of electron cloud build-up in the damping rings using POSINST (M. Furman, M. Pivi, M. Venturini et al.), ECLOUD (F. Zimmermann, G. Rumolo et al. CERN) and CLOUDLAND (L. Wang) simulation codes were compared.

• Single-bunch instability thresholds of fast head-tail TMCI-like instability and wake fields were estimated by CMAD (M. Pivi) and PEHTS (K. Ohmi) codes.

• Coherent and incoherent tune shifts induced by the electron cloud were computed and compared.

The codes used are the same codes in use at CesrTA [6]. Machine studies are ongoing at CesrTA Cornell, CERN SPS, KEKB and DAΦNE that will benchmark the codes with experimental data; so far, the results of the build-up simulation codes are generally consistent with experimental data assuming certain surface properties. Some discrepancy in quadrupole fields remain under investigation [6].

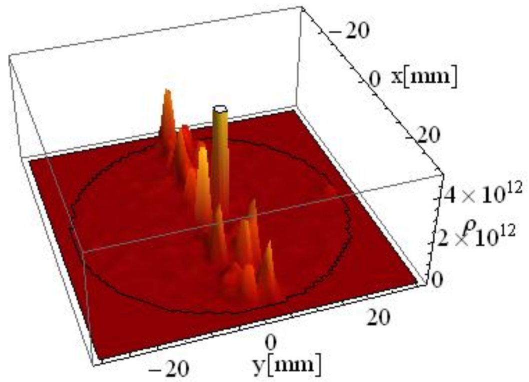

Figure 2. Snapshot of the cloud distribution in a bend magnet for SEY=1.4 and with an antechamber in the 6 km DCO4 ring calculated via ECLOUD simulation.

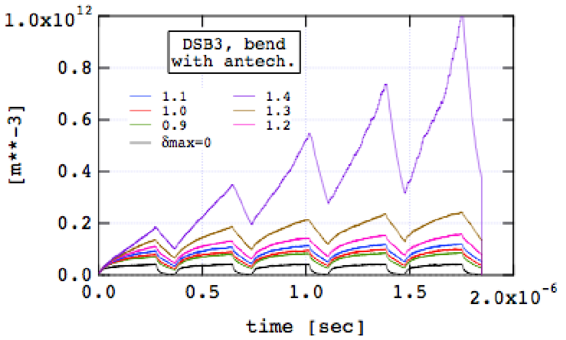

Figure 3. Average cloud density in a bend magnet for various secondary electron yield values with an antechamber in the 3 km DSB3 ring calculated via POSINST simulation.

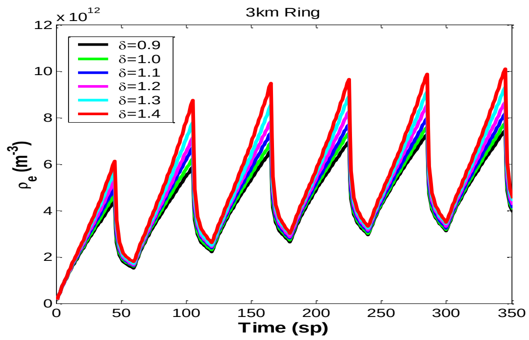

Figure 4. Cloud density in a quadrupole field with an antechamber in DSB3 as calculated with CLOUDLAND.

Photoelectron estimate and future development

As part of these studies, we calculated the effect of the antechamber protection and analytically estimated an average photon absorption of 98% [7,8,9]. Also we assumed photon reflectivities of 20% or 90%. Generally, the photon production per meter is greater in the shorter ring. In the next simulation phase, we will use accurate predictions for photoelectron production in the DRs from simulations by SYNRAD3D a code under development at Cornell and ANL [10].

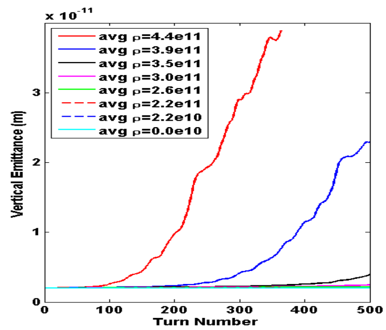

Figure 5. Beam emittance in DSB3 lattice with different cloud densities. The instability threshold is at $3.5{\times}10^{11}$ e/m^3 according to CMAD simulation.

Simulation results

Typically, electron cloud build-up codes compute the interaction between a dynamical cloud and the beam, usually rigid, and deal with the presence of a vacuum chamber. Instability codes assume an already formed cloud and mutually kick cloud electrons and beam particles during their interaction computed at several locations in the ring.

Careful estimates were made for the secondary electron yield (often referred to in the literature as secondary emission yield SEY or δ, with a peak value δ_{max}) threshold for electron cloud build-up and the single-bunch instability threshold as a function of beam current and surface properties for the different DR designs.

As examples, Figure 2 shows a snapshot of the electron cloud density at saturation in a bend magnet of the 6.4 km ring while Figure 3 and Figure 4 show the build-up of the electron cloud density in bend and quadrupole magnet regions of a shorter 3.2 km ring assuming 98% of photons are intercepted by the antechambers.

The single-bunch instability threshold of about 3.5×10^{11} e/m^3 in the 3 km ring is shown in Figure 5. The threshold for the 6 km ring is found at 1.7×10^{11} e/m^3, consistent with the same average cloud density.

The simulated central electron cloud density obtained by build-up simulations for different peak secondary yields, integrated over each ring is then compared to the instability thresholds for the different DR configuration options in Figure 6. Preferably, the cloud density should be several factors below the instability threshold. Notably in the figure, an antechamber design is important to suppress the electron cloud build-up. Furthermore, in a shorter ring, both larger instability threshold and cloud densities are found with respect to a larger ring. Thus, the risk level for adopting a reduced 3km Damping Ring while maintaining the same bunch spacing is low.

In preparation of the Technical Design Phase-II, the working group will investigate shorter bunch spacing, recommend possible mitigations and integrate the CesrTA results into the damping ring design [6].

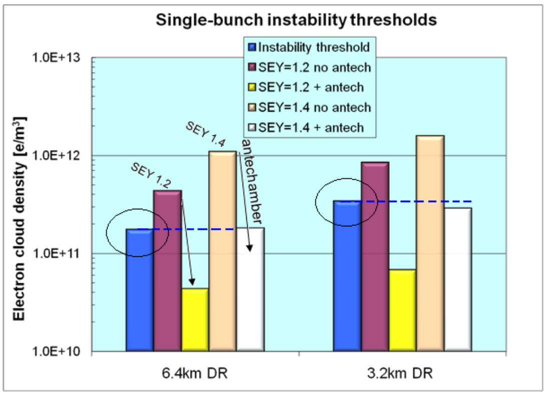

Figure 6. Simulated instability thresholds (blue) in the 6 and 3 km rings compared to the equilibrium cloud density for peak secondary yields δ_{max}=1.4 and 1.2 with (98% photon absorption) and without (0%) an antechamber. The cloud density is the central near-beam cloud density.

Table 2. High repetition rate operations, 3km ring.

DR Version	**SB2009**	**10 Hz**
Circumference (m)	3238	3238
Energy loss turn (MeV)	4.4	8.4
RF Voltage (MV)	7.5	13.4
Beam Power (MW)	1.9	3.6
Number of RF cavities	8	16
B wiggler (T)	1.6	2.4
Wiggler period (m)	0.4	0.28
Total wiggler length (m)	78	75

The acceptable surface secondary electron yield SEY may strongly depend on issues such as beam jitter and incoherent emittance growth below the instability threshold, which have not been thoroughly investigated yet. Furthermore, refined photoelectron rate estimates by 3D simulations will better define the max acceptable SEY.

HIGH REPETITION RATE 10HZ DAMPING RING OPERATIONS

The ILC repetition rate is 5 Hz. A 10 Hz repetition rate has been proposed to increase the luminosity at low beam energy. This requires half the damping time for the positron ring to damp the vertical emittance by 5 orders of magnitude. Assuming high repetition rate in a 3-km ring, we increased the wiggler field to reduce the damping time and reduced the wiggler period to recover the equilibrium emittance, as in Table 2. Since the energy loss per turn increases, the number of RF cavities is also doubled, with commensurate cost increase. This appears to be a reasonable option for the 3.2 km configuration [11].

In a 6-km ring, increasing the field in a ~200 m long wiggler section causes radiation downstream of the wiggler section to increase considerably and a new protection system design is needed; in a 3-km ring the radiation level at 10 Hz would be comparable to the actual level in the 6-km ring at 5 Hz.

SUMMARY

We have investigated the feasibility of shorter damping rings. With respect to the RDR baseline [3], the electron cloud risk level for adopting a reduced 3-km damping ring while maintaining the same bunch spacing is low.

However, reducing the positron ring circumference to 3-km eliminates the back-up option of 12 ns bunch spacing, i.e. safer e- cloud regime, and may reduce the collider luminosity margins. In the event that effective electron cloud mitigations cannot be devised for a 3-km damping ring, an option of last resort would be to add a second positron damping ring.

Furthermore, a 10Hz repetition rate has been proposed to increase luminosity at low beam energy. This appears to be a reasonable option for the 3.2 km configuration.

ACKNOWLEDGEMENTS

We thank M. Harrison, T. Raubenheimer, C. Adolphsen, M. Ross and the CesrTA collaborators for very useful discussions.

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