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Recommendation for the Feasibility of more Compact LC Damping Rings

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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 a shorter damping ring with respect to the electron cloud build-up and related beam instability. 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 to considerably reduce 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 mitigations 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 the 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 have 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 configuration options. 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 by a smaller vertical beta function 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, similar for both damping ring options, 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, if present (mm)	10	

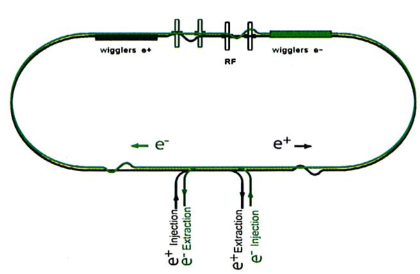

Figure 1. Layout of the ILC damping rings.

SIMULATION CAMPAIGN

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

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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 different simulation codes were compared.

• Single-bunch wake fields and the thresholds of fast head-tail TMCI-like instability were estimated both by simulations and analytically.

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

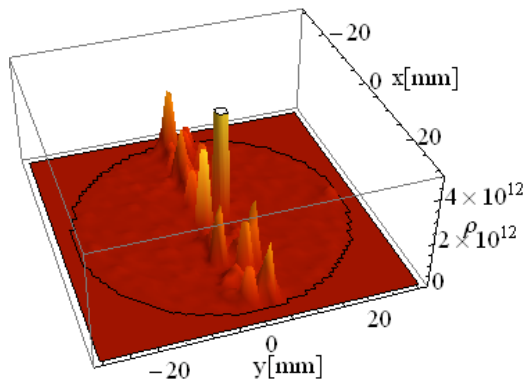

Figure 2. Snapshot of the cloud distribution in bend magnet for SEY=1.4 and with antechamber in the 6 km DCO4 ring by ECLOUD simulations.

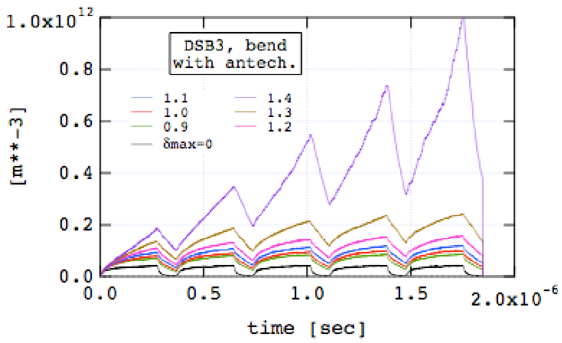

Figure 3. Space averaged cloud density in bend magnet for various SEY and with antechamber in the 3 km DSB3 ring by POSINST simulations.

Typically, simulation codes explore different physics regimes: the cloud build-up or the beam instabilities.

Codes used for the simulations of the electron cloud build-up were POSINST (M. Furman, M. Pivi, M. Venturini et al.), ECLOUD (F. Zimmermann, G. Rumolo et al. CERN) and CLOUDLAND (L. Wang). Single-bunch instability simulation codes used were CMAD (M. Pivi) and for benchmarking PEHTS (K. Ohmi). These are the same codes in use at CesrTA [4].

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 still remains in quadrupoles were part of the R&D effort is concentrating [4].

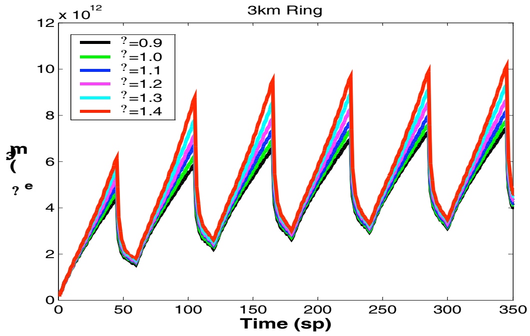

Figure 4. Cloud density in quadrupole with antechamber in DSB3 by CLOUDLAND simulations.

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% [5,6,7]. Aslo we assumed a photon reflectivity 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 [8].

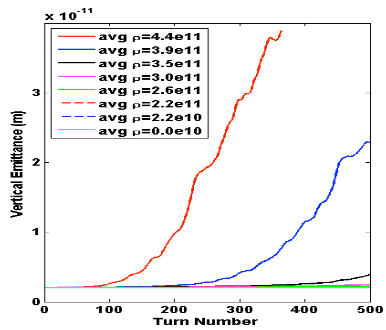

Figure 5. Beam emittance in DSB3 lattice with different cloud densities. Instability threshold at 3.5_10^{11} e/m^{3} by CMAD simulations.

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 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 of the secondary electron yield (sometimes in the literature also referred 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.

Error! Reference source not found. show a snapshot of the electron cloud contour 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 antechambers.

Furthermore, the simulated 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 density obtained by build-up simulations, integrated over the rings is then compared to the instability thresholds for the different DR configuration options in Figure 6. Preferably, the formed cloud density should be several factors below the instability threshold. Also, an antechamber design is important to suppress the build-up. 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 [4].

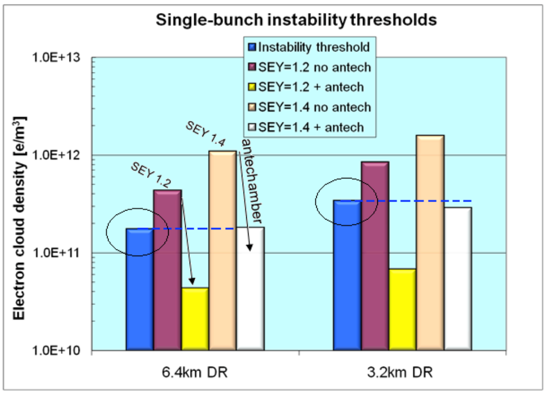

Figure 6. Simulated instability thresholds (blue) in the 6 and 3 km rings compared to the equilibrium cloud density for peak secondary yields δ_{max}=1.4 and 1.2 with (98% photon absorption) and without (0%) antechamber. The cloud density is central near-beam cloud density.

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 slow incoherent emittance growth below the instability threshold, not yet thoroughly investigated. Furthermore, refined photoelectron production rate by 3D simulations will better define the maximum 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 ILC luminosity at low beam energy. Assuming high repetition rate in a 3-km ring, we reduced the wiggler period to reduce the damping time and increased the wiggler field 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 cost increase.

This appears to be a reasonable option for the 3.2 km configuration [9].

In a 6-km ring, high repetition rates cause radiation downstream of wiggler sections to considerably increase 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 6km 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 3km damping ring while maintaining the same bunch spacing is low.

Though, reducing the positron ring circumference to 3-km eliminates the back-up option of 12 ns bunch spacing (safer e- cloud regime) and may reduce the luminosity margins. In the event that effective EC mitigations cannot be devised for a 3km 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.

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REFERENCES

[1] http://ilc.kek.jp/SB2009/SB20091216A.pdf
[2] Contributions in Proc. ECLOUD07 Workshop, 2007
[3] N.Phinney, N.Toge, N.Walker ILC-Report-2007-001
[4] M. Palmer *et al.* In Proc. PAC09 Conf., Canada, 2009
[5] T.Demma https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/TeleConference#Tuesday_23_February_2010
[6] M. Furman and G. Lambertson LBNL-41123, 1998
[7] O. Malyshev, p. 13 of LER10 Workshop CERN, 2010

[8] J. Calvi *et al.* TUPD024, this Proceedings IPAC10
[9] S. Guiducci summary ILC10, Beijing, China, 2010