Updates to the International Linear Collider Damping Rings Baseline Design

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On behalf of

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Introduction

- A new baseline for the ILC design, first proposed by the ILC Global Design Effort (GDE) project managers at the LCWA09, Albuquerque September 2009, was approved just before the ALCPG11 meeting, held in March 2011 in Eugene, OR
- The new baseline foresees to operate the ILC with half the number of bunches with respect to the Reference Design Report (RDR) value
- This allows to reduce the damping ring circumference by a factor 2 maintaining the same current

	New Baseline	**RDR**
Number of bunches	1312	2625
Circumference (km)	3.2	6.4
Particles/bunch	$2\ 10^{10}$	$2\ 10^{10}$
Bunch spacing (ns)	6.2	6.2
Current (A)	0.39	0.39

Lattice Selection

- Leading up to ALCPG11, a lattice evaluation process was initiated in order to select a new baseline lattice. Three different lattices were compared:
  1. **DSB lattice, with an arc cell similar to that proposed for the SuperB collider**
  2. **DMC lattice, based on FODO cells,**
  3. **DTC lattice based on a TME-style cell.**

1. S. Guiducci, M. E. Biagini, “A Low Emittance Lattice for The ILC 3 Km Damping Ring”, IPAC’10
2. D. Wang, J. Gao, Y. Wang, “A New Design for ILC 3.2 km Damping Ring Based on FODO Cell”, IPAC’10
3. D. Rubin, “DR 3.242 km DTC Lattice”, Damping Ring Technical Baseline Review, LNF 7-8 July 2011, http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=5183

Lattice Requirements

- The layout is a racetrack
- structure of straight sections, similar to that of the DCO4 lattice used as a baseline for the 6.4 km ring.
- Except for the number of bunches, the parameters of the injected and extracted beams are the same as the RDR
- The target momentum compaction value is in the range from $2 \cdot 10^{-4}$ to $3 \cdot 10^{-4}$.
- Moreover the lattice has to satisfy the requirements for 3 different configurations:
  - **5 Hz “baseline" operation with 1312 bunches**
  - **a 10 Hz operating mode to allow low energy operation of the main linac**
  - **a luminosity upgrade configuration that envisions a return to 2625 bunches per main linac pulse**

Nominal parameters of beams

injected into damping rings

	Baseline	Luminosity upgrade	10 Hz mode
Train rep. rate	5 Hz	5 Hz	10 Hz
Number of bunches/train	1300	2600	1300
Number of particles/bunch	$2x10^{10}$		
e^+ max. transverse amplitude A_x+A_y	0.09 m.rad		
e^+ max. energy error δ_{max}	±0.5%		
e^+ max bunch length	±34 mm		
e- normalized injected emittance	45 μm		
e^- rms relative injected energy spread	0.1%		

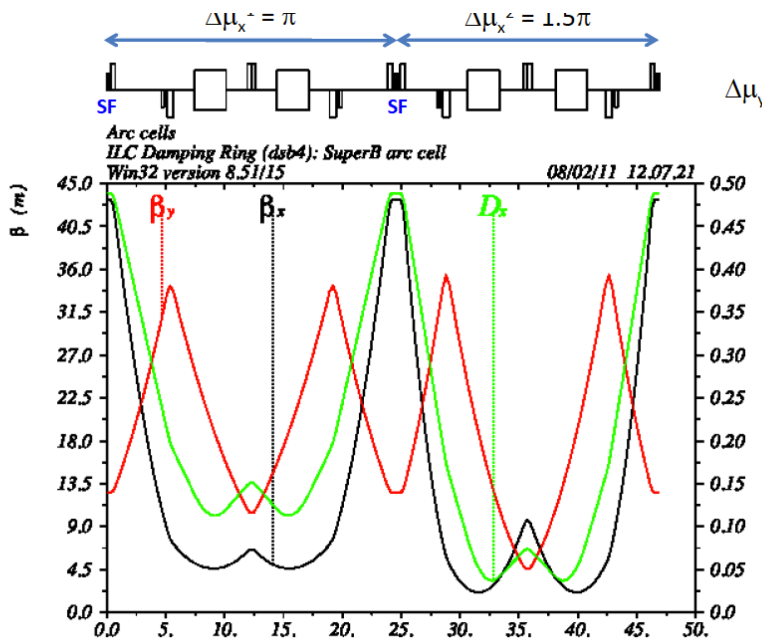
Now ± 1%

extracted from damping rings

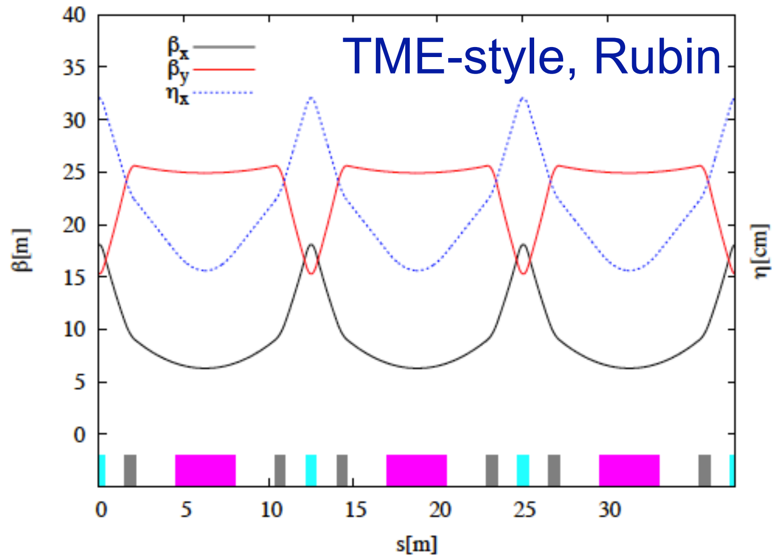
	Baseline	Luminosity update	10 Hz mode
Train rep. rate	5 Hz	5 Hz	10 Hz
Number of bunches/train	1300	2600	1300
Number of particles/bunch	$2x10^{10}$		
Energy	5 GeV		
Horizontal emittance	$<8.0\ 10^{-10}$ m.rad		
Vertical emittance	$2.0\ 10^{-12}$ m.rad		
rms relative energy spread	<0.15%		
rms bunch length	6 mm		
e^+ Vertical damping time	24 ms	24 ms	13 ms
e^- Vertical damping time	24 ms	24 ms	18 ms
Horizontal/vertical jitter	$<0.1\sigma_x/\sigma_y$		

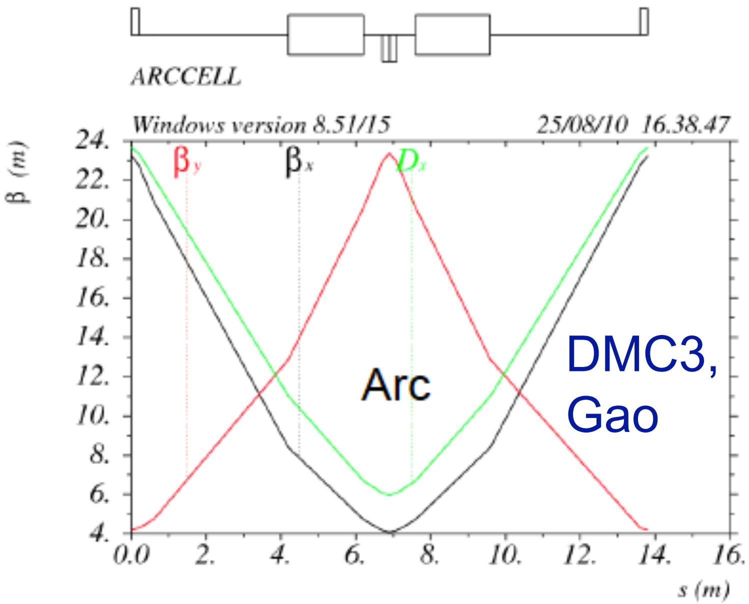
Same as RDR except for the number of bunches

Lattice Comparison



DSB3, Guiducci



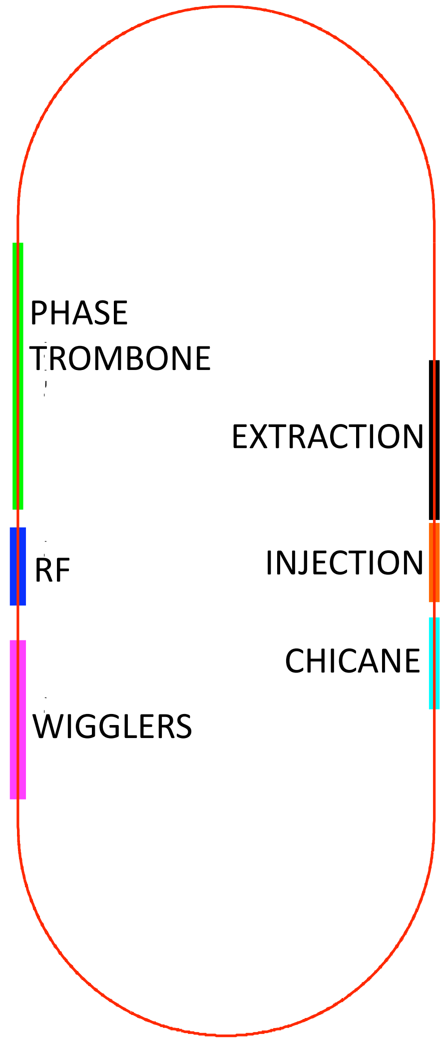


- All 3 lattice styles can satisfy momentum compaction target.
- However, none presently have sufficient dynamic aperture.
- Some technical differences between lattices which may affect final choice.

Lattice Selection

- Leading up to ALCPG11, a lattice evaluation process was initiated in order to select a new baseline lattice. Three different lattices were compared:
  - **DSB lattice, with an arc cell similar to that proposed for the SuperB collider,**
  - **DMC lattice, based on FODO cells,**
  - **DTC lattice based on a TME-style cell.**
- A consensus was reached, on the basis of design completeness, that the DTC lattice should be designated as the baseline. The DSB and DMC lattices are being maintained as alternatives (June 28 2011, DR phone meeting) https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/TeleConference#Tuesday_28_June_2011

DTC01 Layout



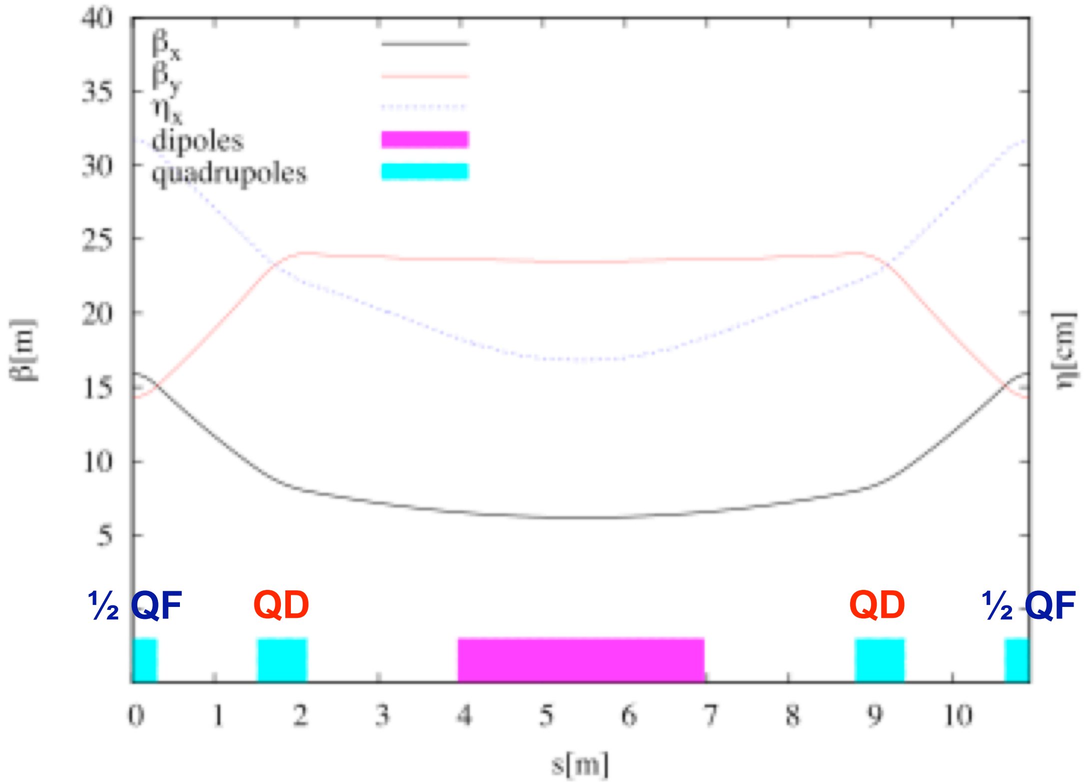
1. Circumference = 3242.9m, 712m straights
2. ~ 6 phase trombone cells
3. 54 – 1.92m long wigglers
   wiggler period = 32cm
   12-poles
   B_{max} = 2.1T
4. Space for 16 RF cavities
   Cryostats for upper and lower positron rings are interleaved

D. Rubin, "DR 3.242 km DTC Lattice", Damping Ring Technical Baseline Review, LNF 7-8 July 2011, http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=518

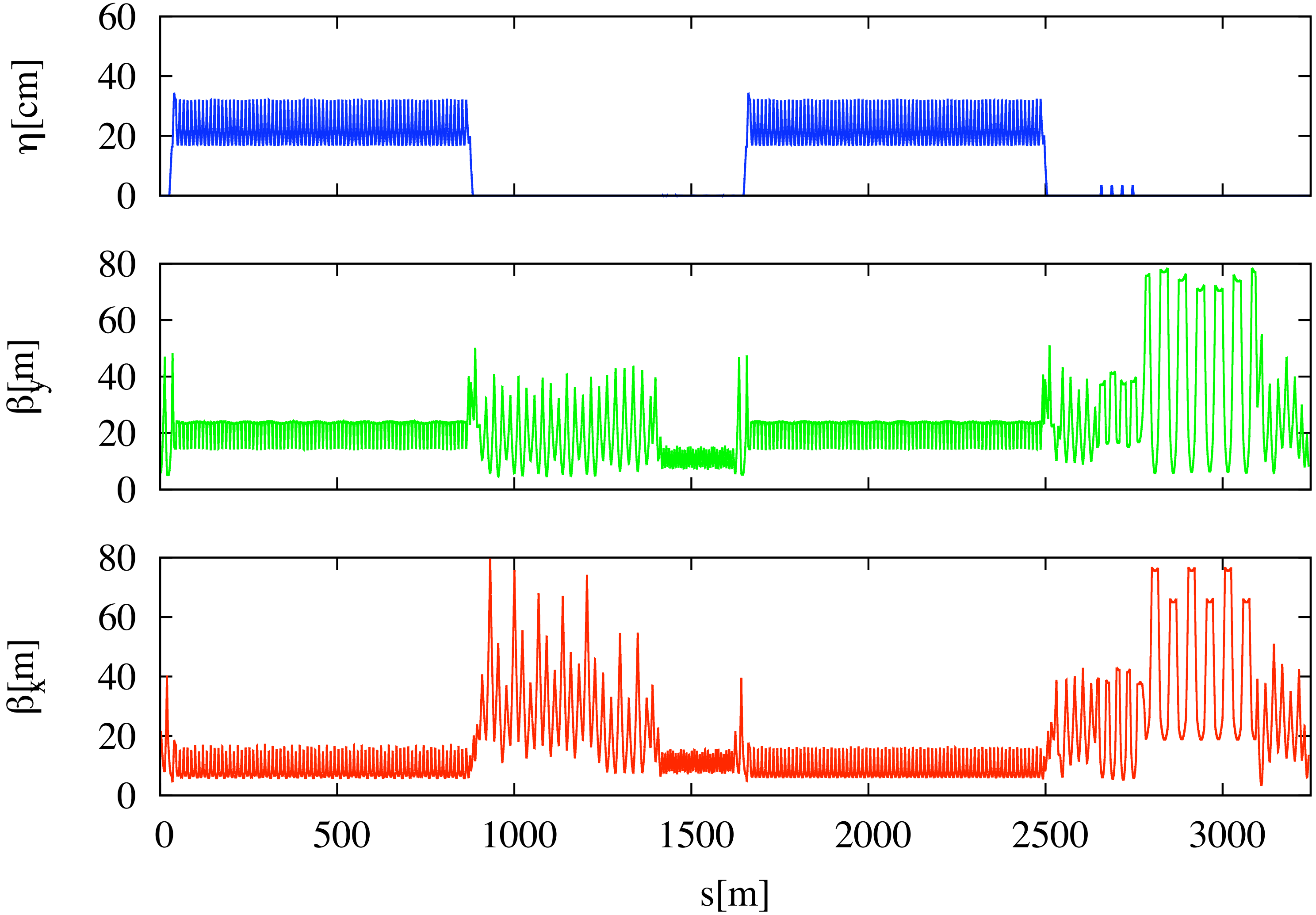
Arc cell - FDBDF

Cell length = 10.93m
Bend length = 3.0m
75 cells/arc

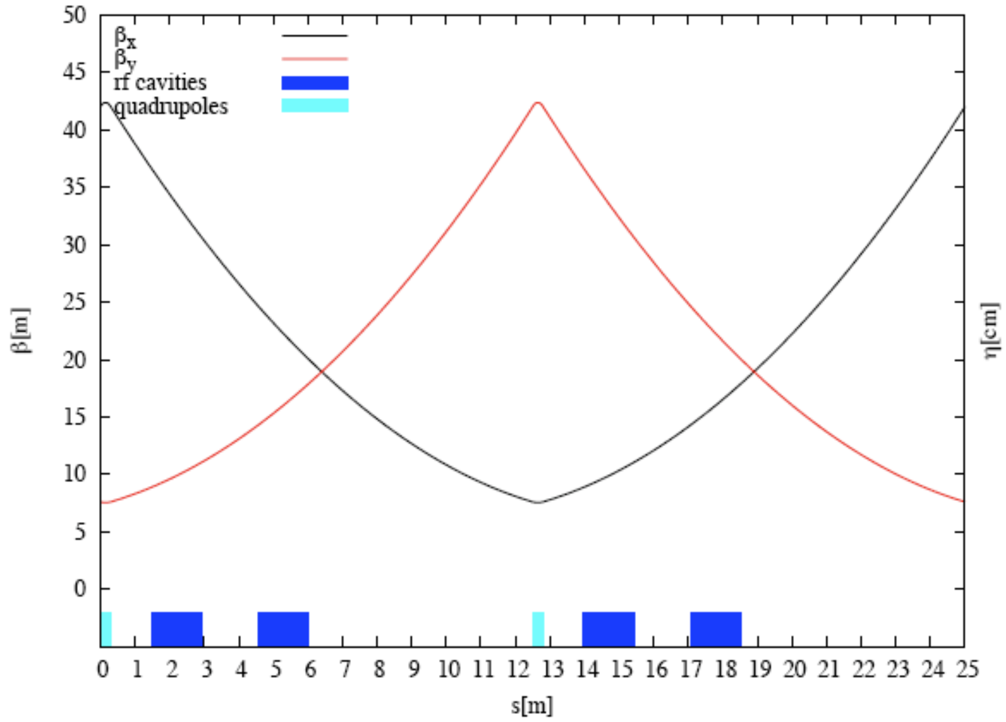
There is some flexibility to vary emittance and momentum compaction by adjusting the arc cell focusing, but typically this comes at the expense of dynamic aperture



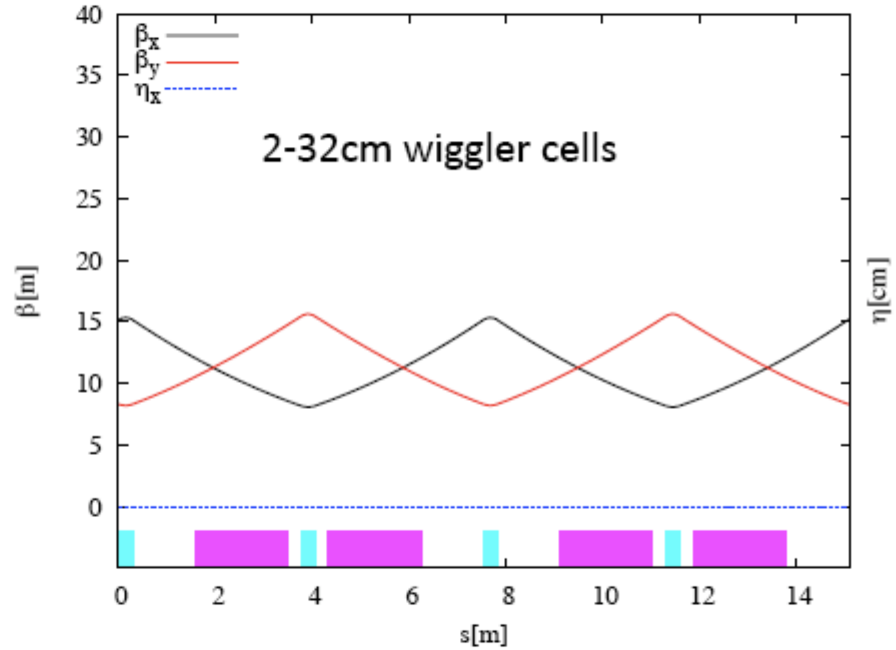
DTC01 Lattice Functions



RF and Wiggler

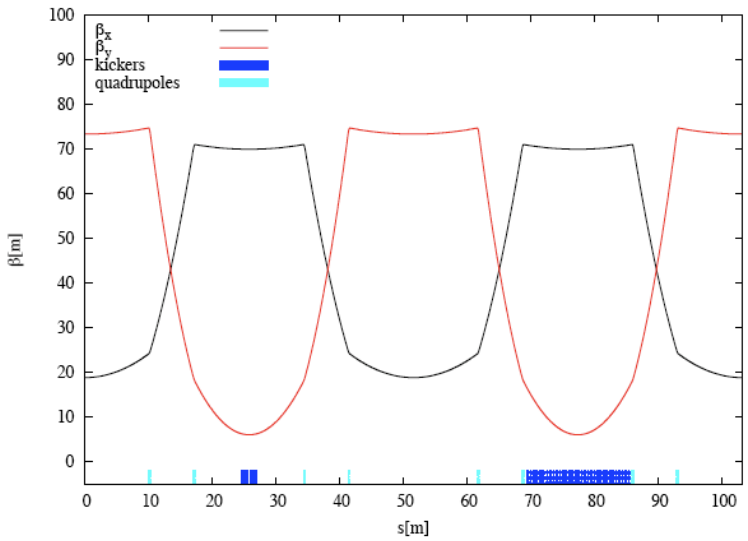


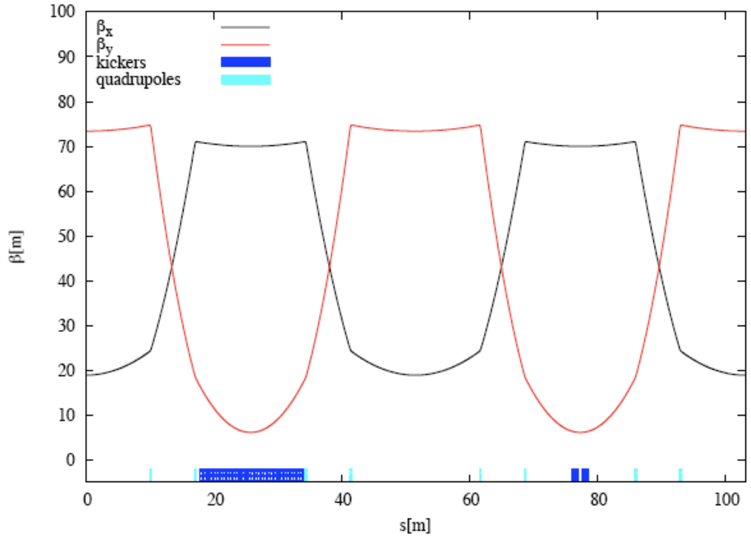
The superferric wigglers are based on the CESR-c design with relatively few but rather long periods to simplify fabrication and to minimize cubic nonlinearity.

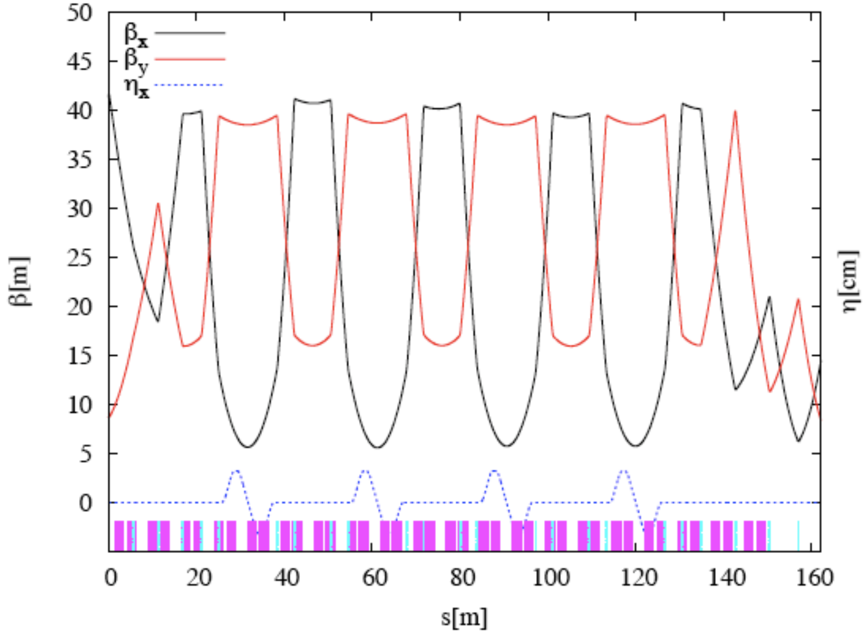


The RF voltage is dictated by the requirement of a 6mm bunch length.
For the baseline 10 single-cell 650 MHz superconducting cavities are needed to satisfy power and voltage requirements.
For the other two configurations, requiring nearly twice the beam power, 12 cavities are needed to keep the coupler power reasonably low.
There is space for 16 cavities in the lattice

Injection/Extraction

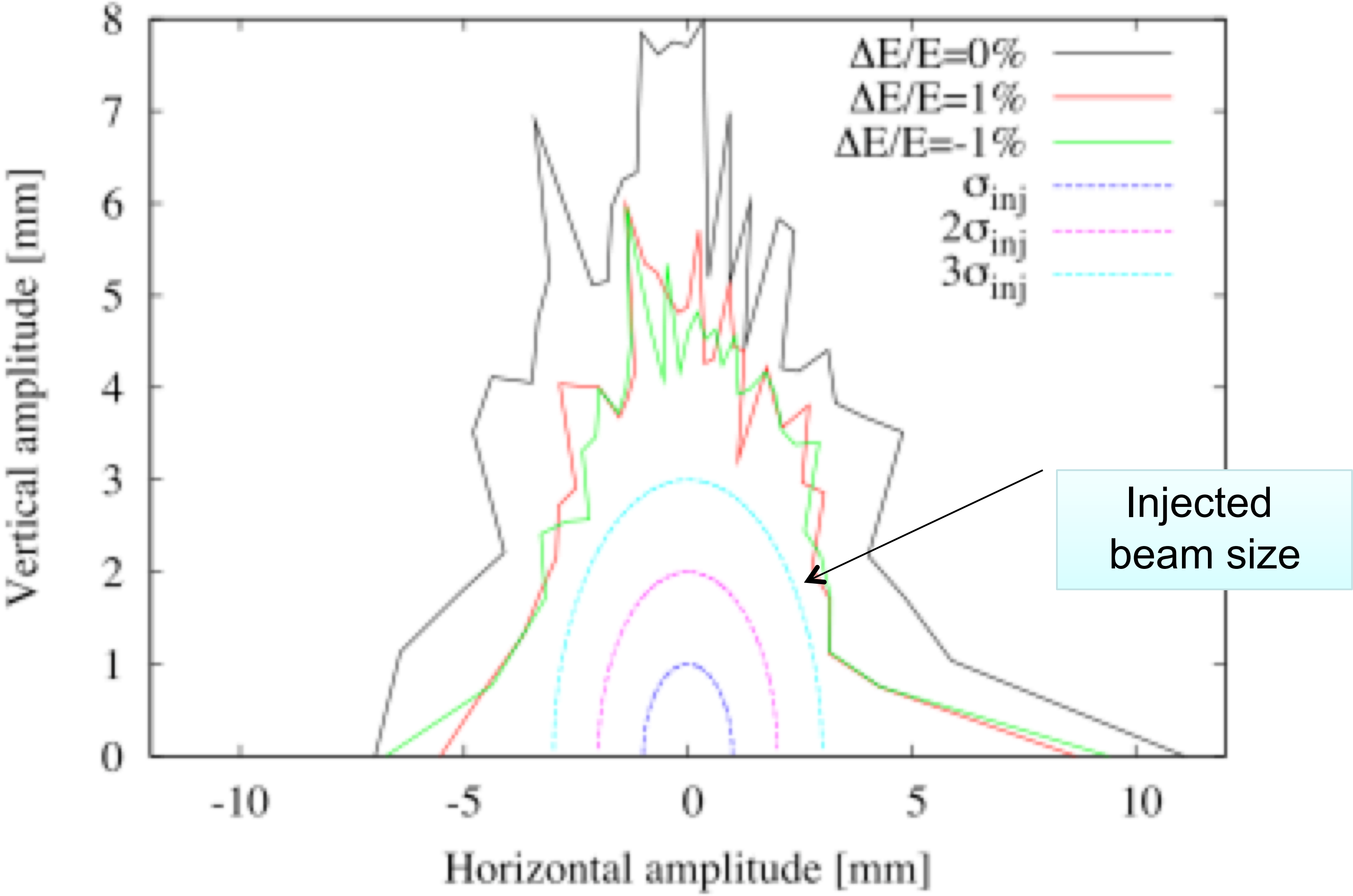






and Circumference Changing Chicane

Dynamic aperture – 10Hz



DTC Parameters

Parameter	**5 Hz Baseline**	**10 Hz**	**Luminosity upgrade**
Energy [GeV]	5	5	5
τ_X[ms]	24.1	13.5	24.1
τ_Z[ms]	12.0	6.7	12.0
σ_z[mm]	6	6	6
σ_δ[%]	0.11	0.134	0.11
$\alpha_p(x10^4)$	3.3	3.3	3.3
$\gamma\varepsilon_x[\mu m]$	5.4	5.2	5.4
RF [MHz]	650	650	650
RF[MV]	14	19.7	14
ξ_x/ξ_y	-51/-43	-51/-44	-52/-43
$B_{wiggler}[T]$	1.5	2.1	1.5
ΔE/turn[MeV]	4.5	8.0	4.5
$Sext[m^{-3}]$	3.3/-4.2	3.3/-4.3	3.3/-4.2
I [A]	0.39	0.39	0.78
Beam power[MW]	1.7	3.1	3.5
No. of RF cavities	10	12	12

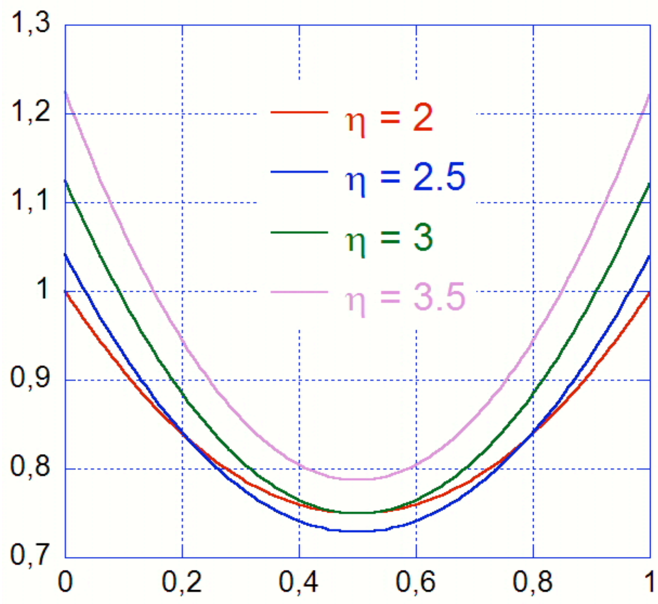
10 Hz Operation

- The damping ring has a pulsed time profile with beam injection/ extraction times of 1 ms. Full beam current is stored for 100 ms and then extracted, the ring is then empty for the next 100 ms before the next injection cycle.
- Half the damping time is necessary to achieve the same extracted vertical emittance. This is achieved by increasing the wiggler field from 1.5T to 2.1T
- One of the main concerns is the operation of the superconducting cavities in a regime of large, periodic and rapidly changing beam loading.
- Superconducting cavity tuning actuators have limited speed and excursion, so that it is quite difficult to follow, in real time, the rapidly changing beam loading conditions
- The simplest approach to overcome this difficulty requires keeping cavities tuned at a certain fixed resonant frequency

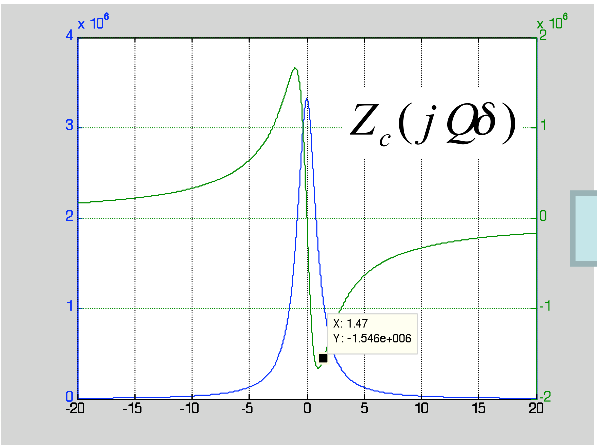
Cavity operation at fixed detuning. Case $\eta \geq 2$

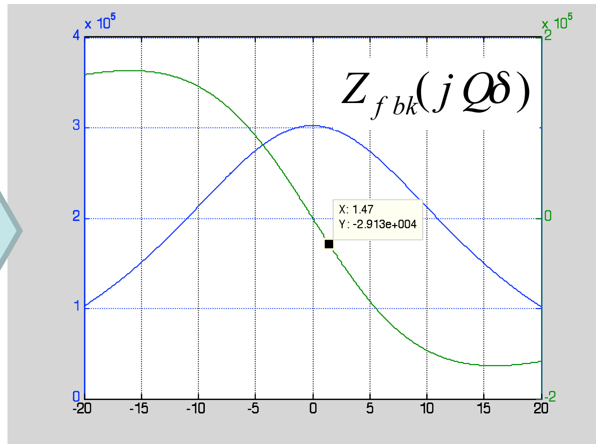
Optimal choice of Q_{ext} and ψ parameters allows limiting the required generator power overhead.

For instance, it is possible to run the system with an overvoltage factor $\eta = 3$ at the cost of only 12.5 % of increased RF power.



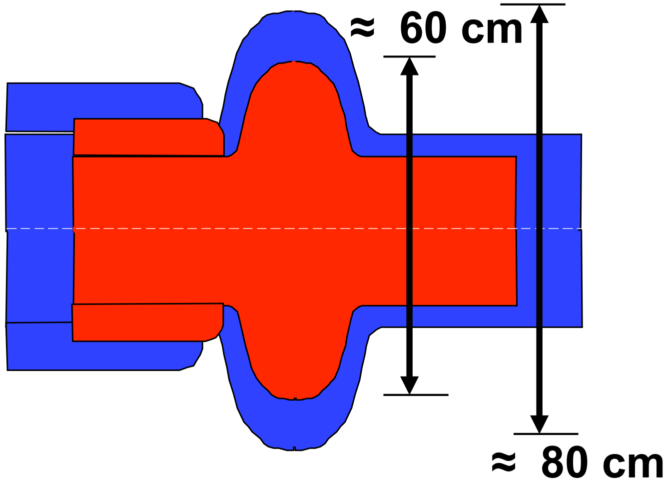
First Robinson limit and direct RF feedback cure

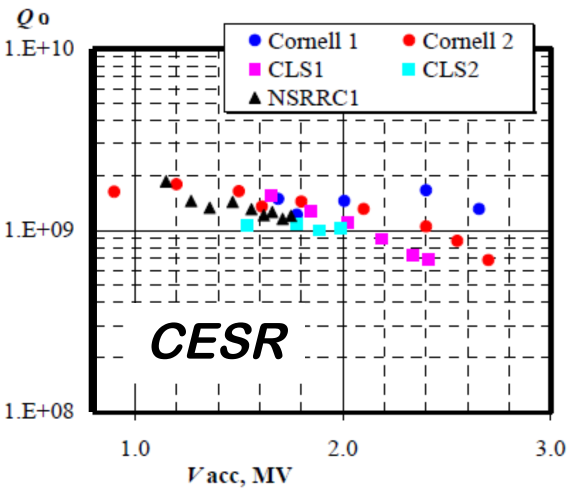


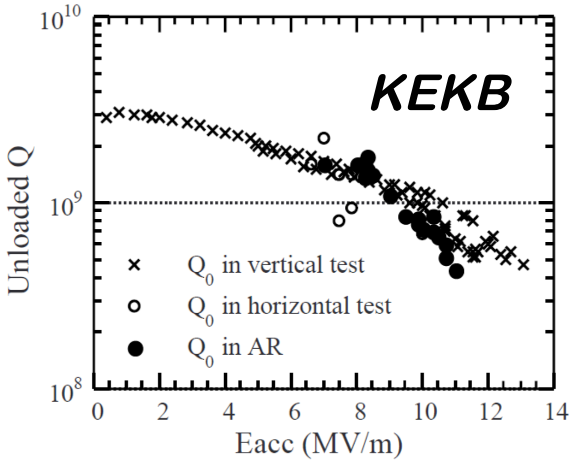


Impedance reduction of two orders of magnitude can be obtained (negligible frequency shift)

- ***The specifications of a new 650 MHz sc cavity may be estimated by scaling dimensions and parameters of the 500 MHz sc cell.***







Frequency	500 MHz	650 MHz
Active cavity lenght	0.30 m	0.23 m
R/Q (CESR cell)	89 Ω	89 Ω
Operating tempature	4.5 K	4.5 K
Static losses	≤ 30 W	≈ 30 W
Accelerating gradient	> 8 MV/m	≈ 7.5 MV/m
Q_0 [x10^9]	≈ 1.0 @ 7 MV/m ≈ 1.5 @ 5 MV/m	≈ 0.6 @ 7 MV/m ≈ 1.0 @ 5 MV/m

DR RF System specifications (scaling from 500 MHz cryo-modules)

Parameter	10 Hz	5 Hz (Baseline)	Lumiosity upgrade
RF frequency	650 MHz		
Total RF voltage [MV]	19.7	14	14
Overvoltage factor	2.46	3.11	3.11
Cavity R/Q [Ω]	89		
Cavity active length [m]	0.23		
Number of cavities	12	12	12
Cavity RF voltage [MV]	1.64	1.17	1.17
Cavity average gradient [MV/m]	7.1	5.1	5.1
Cavity input power [kW]	260	146	293
Ideal input coupling Q_{ext} [$\cdot 10^3$]	116.5	104.6	52.3
Input coupler Q_{ext} [$\cdot 10^3$]	65		
Cavity tuning	fixed, $\tan\psi \approx 1.2$ (#)	stationary	stationary
RF Reflected power @ nominal beam current	8.91 %	5.76 %	1.19 %
Total RF power [MW] (*)	3.40	1.86	3.55
Number of klystrons/ring	6	6	6
Klystron power [kW]	650 kW (including ≈10 % overhead)		
Operating temperature [K]	4.5		
Q_0 (x10^9) @ operating gradient	0.6	1	1
Cryo-RF losses per cavity [W]	50	15	15
N. of cryomodules per ring	12	12	12
Static cryo-losses [W]	30		
Total cryo-losses per ring [W]	960	540	540

Configuration satisfying all the 3 operating modes

- Efficiency of standard refrigerators:

  @ 4.5 K ≈ 0.3 %

- Wall-plug power per refrigerator per ring

  ≈ 320 kW

(*) HOM Power not included

(#)

$$\tan\psi = \frac{1}{\sqrt{\eta^2 - 1}}\left(1 + \frac{\eta}{2}\frac{I_{b_{\max}}(R/Q)Q_{ext}}{V_c}\right)$$

Beam dynamics issues

For the **3.2km** ring we have:

- same number of particles per bunch
- same bunch spacing
- i.e. the same beam current

we expect essentially the same behaviour as for the **6.4km** ring.

The effects of the fast ion instability in the electron ring and the electron cloud instability in the positron ring, which are the main concerns, have been evaluated for the **3.2 km** ring during the baseline selection procedure.

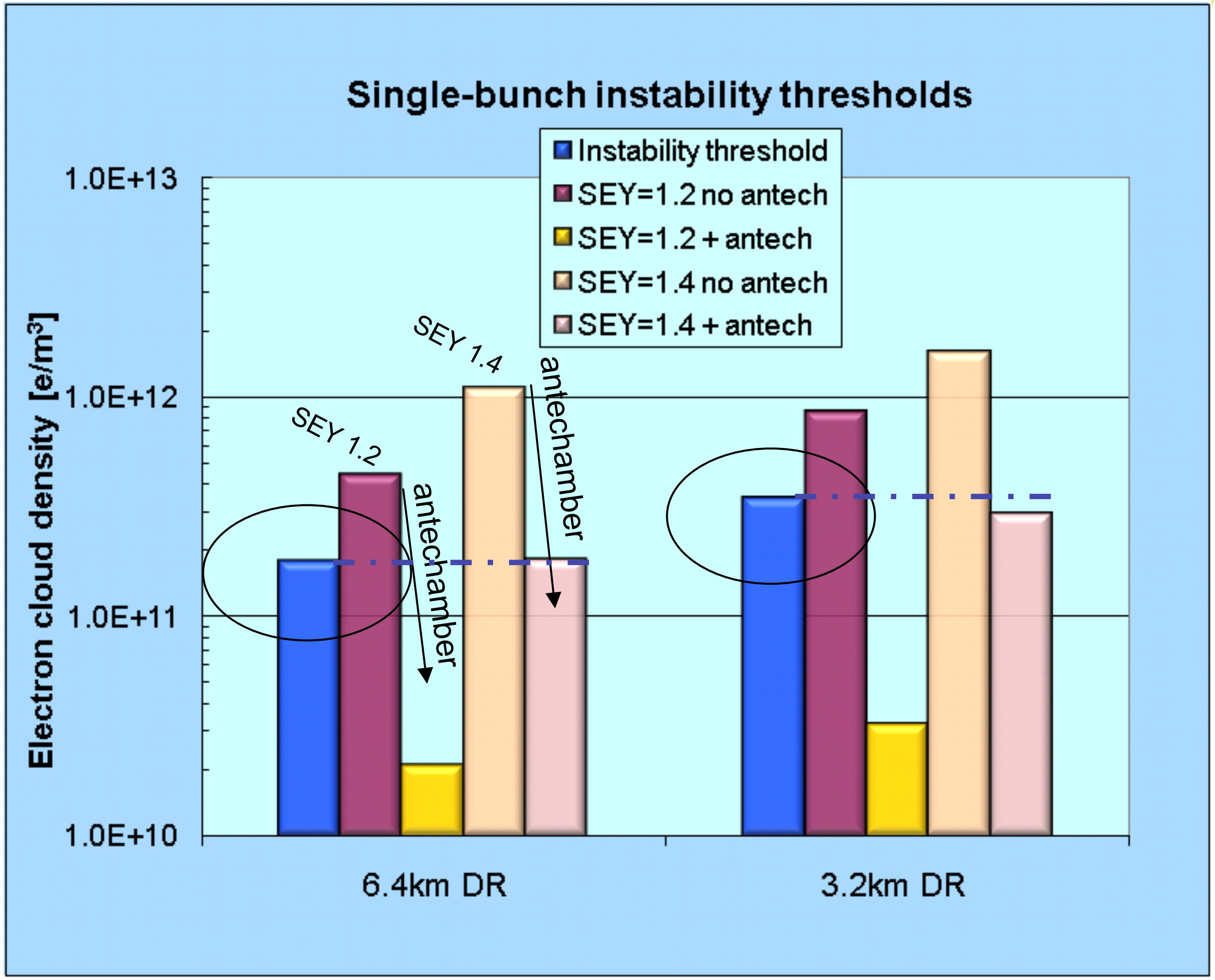
The initial evaluation of the fast ion instability effects was performed using the DSB lattice. The conclusion is that the instability can be kept under control by adopting a fill pattern with bunch trains separated by gaps and by using a bunch-by-bunch fast feedback system.

See the poster on Wednesday: Guoxing Xia, "Ion Instability Study for the ILC 3 Km Damping Ring",WEP103

E-cloud working group

- The first task of the working group was to compare the electron cloud effect for two different DR designs with 6.4 km and 3.2 km circumference, respectively
- The instability thresholds and the electron cloud formation were compared assuming 6.2 ns bunch spacing and the same beam current in both configurations
- Both ring configurations were found to exhibit very similar performance and the 3.2 km ring was found an acceptable baseline design choice

Compare thresholds for 6 km and 3km DR



Simulation Campaign 2010: compiled data of build-up simulations compared with the simulated beam instability thresholds. Overall ring average cloud densities are shown for the 6 km and 3 km rings. The surface Secondary Electron Yield (SEY) determines the cloud build-up and density level.

E-cloud working group

- The main working group deliverables are recommendations for the electron cloud mitigation techniques to be incorporated into each region of the positron ring
- Baseline and alternative mitigation recommendations were selected at a working group meeting during the ECLOUD10 Workshop held at Cornell on October 2010. Input from the workshop participants was included in the evaluation.
- *See the poster on Tuesday:* M. Pivi et al. "Recommendation for Mitigations of the Electron Cloud Instability in the ILC", **TUPC030**

Summary of Mitigation Plan

Mitigation Evaluation conducted at satellite meeting of ECLOUD`10
(October 13, 2010, Cornell University)

EC Working Group Baseline Mitigation Recommendation				
	Drift*	Dipole	Wiggler	Quadrupole*
Baseline Mitigation I	TiN Coating	Grooves with TiN coating	Clearing Electrodes	TiN Coating
Baseline Mitigation II	Solenoid Windings	Antechamber	Antechamber	
Alternate Mitigation	NEG Coating	TiN Coating	Grooves with TiN Coating	Clearing Electrodes or Grooves

*Drift and Quadrupole chambers in arc and wiggler regions will incorporate antechambers

- Preliminary CESRTA results and simulations suggest the possible presence of *sub-threshold emittance growth*
  - Further investigation required
  - May require reduction in acceptable cloud density ⇨ reduction in safety margin
- An aggressive mitigation plan is required to obtain optimum performance from the 3.2km positron damping ring and to pursue the high current option

S. Guiducci, M. Palmer, M. Pivi, J. Urakawa on behalf of the ILC DR Electron Cloud Working Group

High current operation

- For the ”luminosity upgrade” mode, twice the number of bunches need to be stored in the DR with 3.1 ns bunch spacing, doubling of the current in the rings
- This poses a particular concern for the positron DR due to the effects of the electron cloud instability.
- In the event that the electron cloud mitigations that have been recommended are insufficient to achieve the required performance for this configuration, we have allowed for the possibility of installing a second positron ring in the same tunnel.
- The tunnel layout and diameter are designed to accommodate this possibility.

Conclusions

- The baseline lattice for the 3.2km circumference ILC damping ring has been selected.
- The lattice satisfies all requirements for the layout, the injected and extracted beam parameters, and the various operating modes.
- The main beam dynamics issues related to the electron cloud instability have been evaluated and the required mitigation recommendations have been made.
- The lattice is ready to be the basis for the Technical Design Report work.