ILC DR Working Group on Collective Effect: Electron Cloud

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on behalf of ILC DR Working Group

27-29 March, 2010
LCWS10 & ILC10 Beijing, China

Beam Instability simulation code

- To estimate e- cloud beam instability used CMAD (M. P. SLAC), developed since 2006
- Include full machines lattice from MAD: beta functions, dispersion, chromaticity, etc.
- “Parallel” simulations up to ~100 processors, to deal with many lattice elements and turns (>1000).
- Beam and cloud represented by macroparticles. Particle in cell PIC code.
- 6D beam particle dynamics; 3D electron cloud dynamics in 2D forces.
- e- cloud pinching and magnetic fields included.

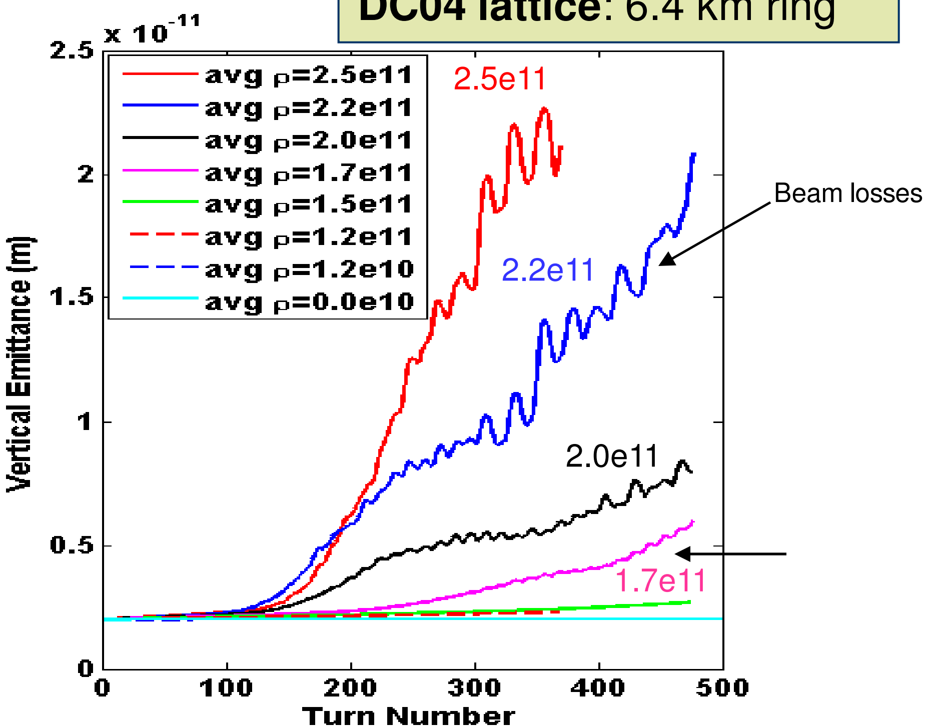
Simulation code

- CMAD: Tracking the beam (x,x',y,y',z,δ) in a MAD lattice by 1st order and 2nd (on/off) transport maps and with electron clouds distributed in the ring.
- MAD8 or X "sectormap" and "optics" files as input
- Apply beam-cloud interaction point (IP) at each element in the lattice.
- Benchmarking with existing codes HEAD-TAIL, WARP/POSINST: very good to excellent.
- Study incoherent emittance long-term growth <u>below</u> threshold: "real or numerical?"

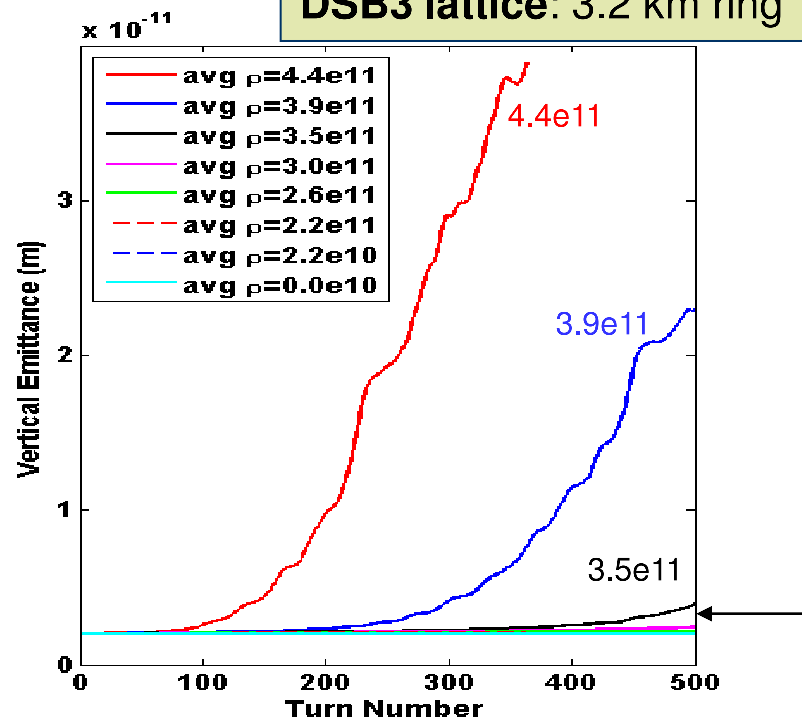
ILC DR instability simulations

- CMAD a tracking and e-cloud beam instability parallel code (M.Pivi SLAC)
- Taking MAD(X) optics file at input, thus tracking the beam in a real lattice and applying the interaction beam-electron cloud over the whole ring
- Assumed cloud in magnetic fields and solenoids (no cloud) in drift regions

DC04 lattice: 6.4 km ring



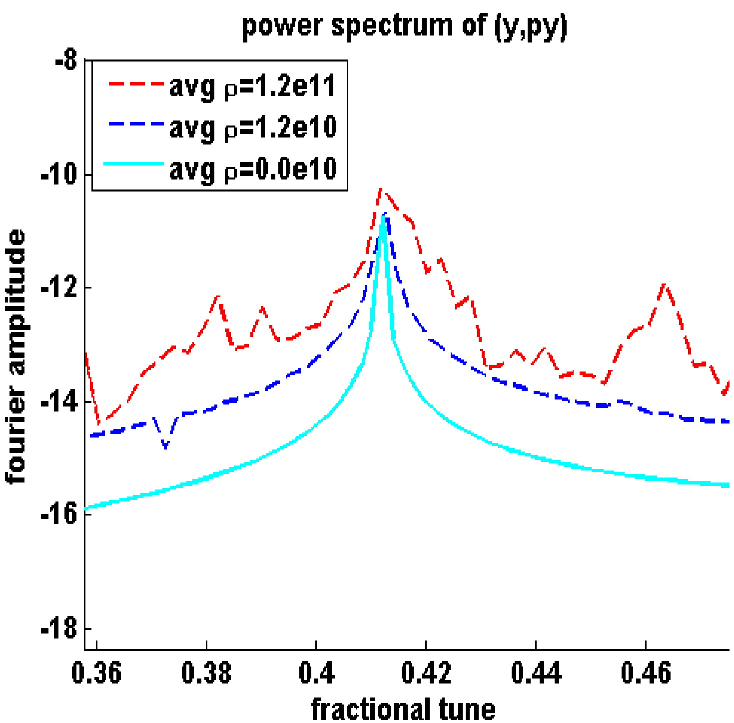
DSB3 lattice: 3.2 km ring

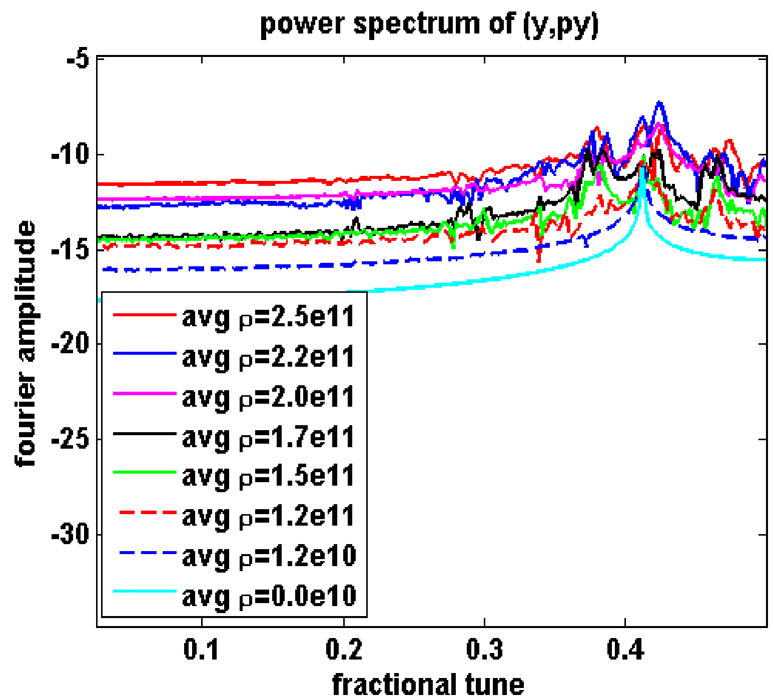


- Finding: lower density thresholds for the 6km ring

ILC DR instability simulations

Tune shift in the 6km DR - DCO4

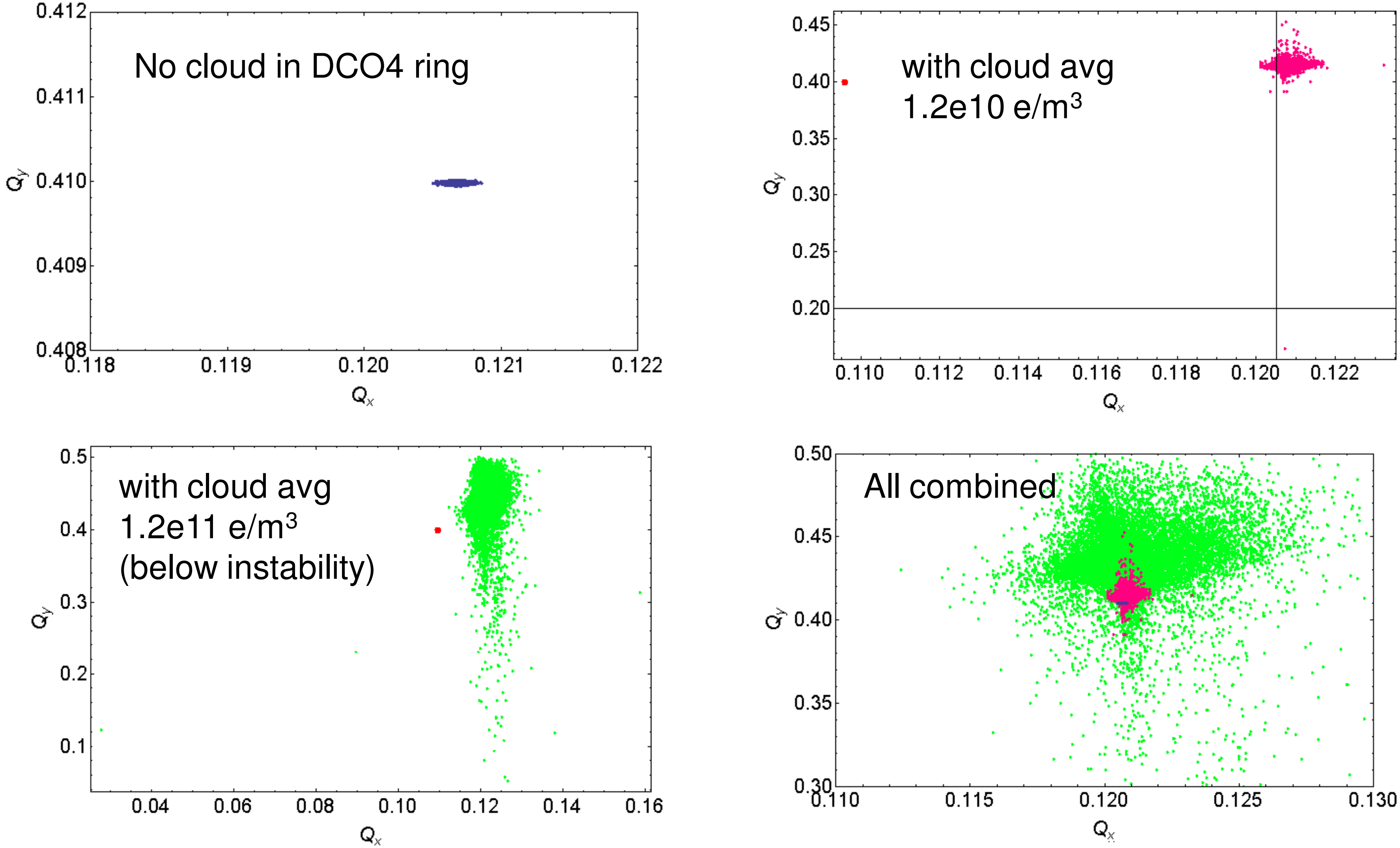




CMAD

Plot the power spectrum of the beam centroid recorded at BPM location

Incoherent tune shift in DCO4 DR



Plotting the tunes of selected particles in the beam

CMAD

Comparing cloud density instability threshold with cloud density from build-up

To compare with beam instability type of simulations, from the build-up simulations we extracted the cloud density defined as:

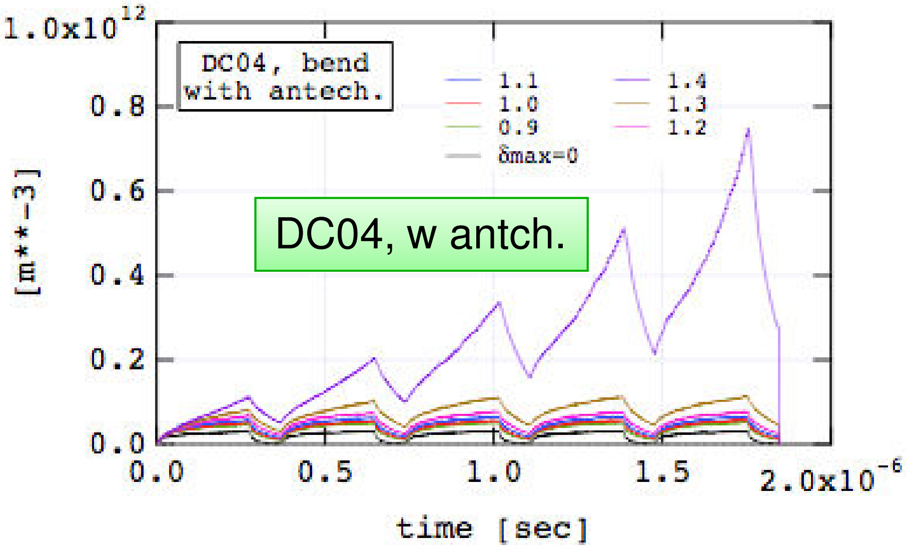
- density at equilibrium after electron cloud build-up
- density NEAR THE BEAM (10 σx, 10 σy)
- density JUST BEFORE electron cloud pinching (head of bunch)

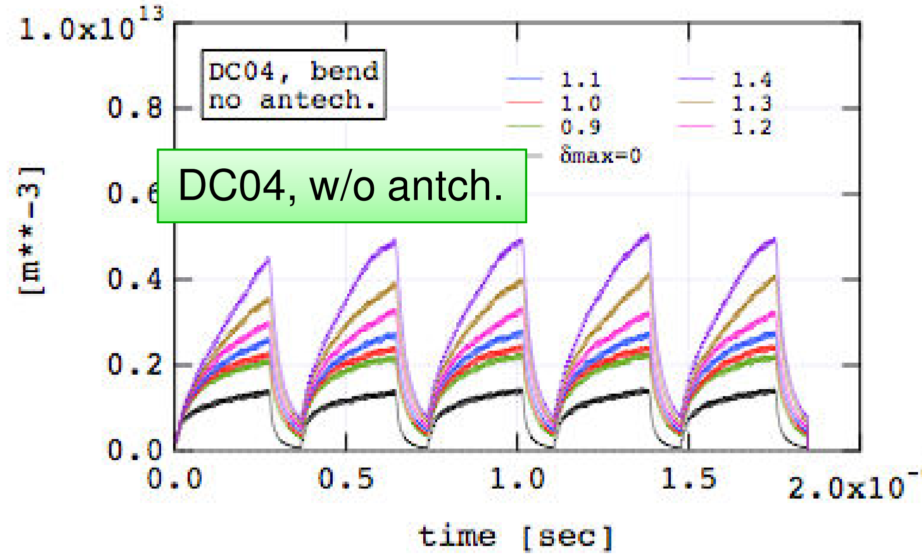
The three conditions above satisfied at once.

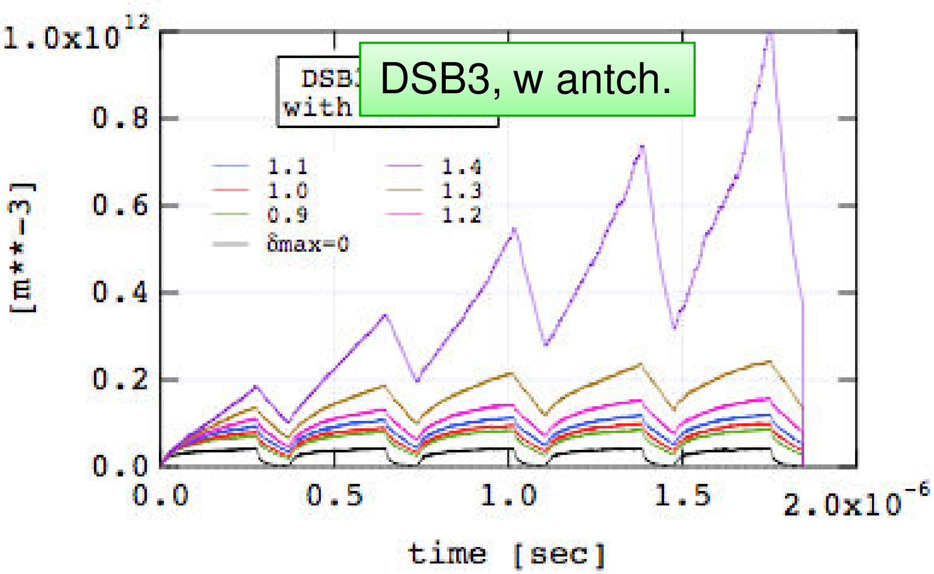
Next showing latest build-up simulations used for the comparison process

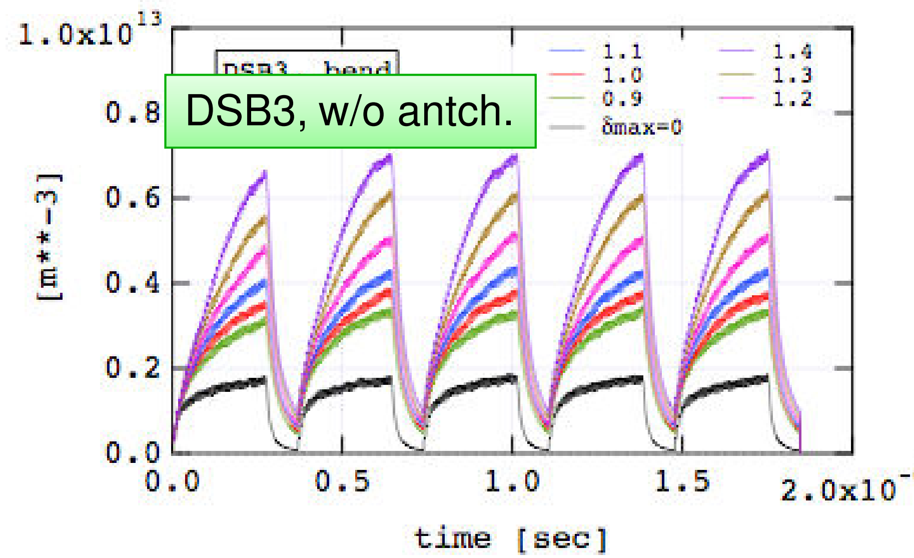
Bending magnet build-up

space-averaged ecloud density









n_e at bunch front within 10 beam σ's [(*)]

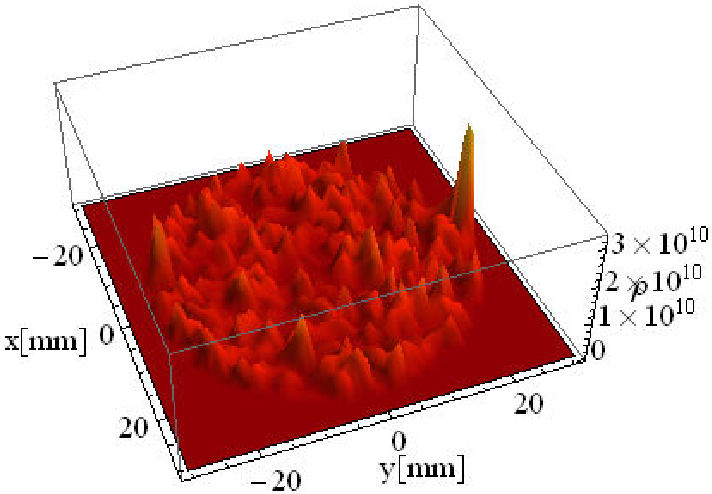
units: 10^{12} m^{-3}

	DC04				DSB3			
	field-free		bend		field-free		bend	
δ_{max}	antch.	no antch	antch.	no antch	antch.	no antch	antch.	no antch
0	0.024	1.2	0.023	1.0	0.034	1.7	0.031	1.3
0.9	0.044	2.3	0.038	1.6	0.063	3.2	0.063	2.4
1.0	0.050	2.6	0.042	1.8	0.070	3.6	0.073	2.6
1.1	0.057	3.0	0.048	1.9	0.081	4.0	0.086	2.9
1.2	0.066	3.4	0.056	2.2	0.94	4.5	0.10	3.4
1.3	0.080	3.9	0.079	2.6	0.11	5.0	>0.2	3.9
1.4	0.10	4.5	>0.3	3.1	0.14	5.6	>0.3	4.6

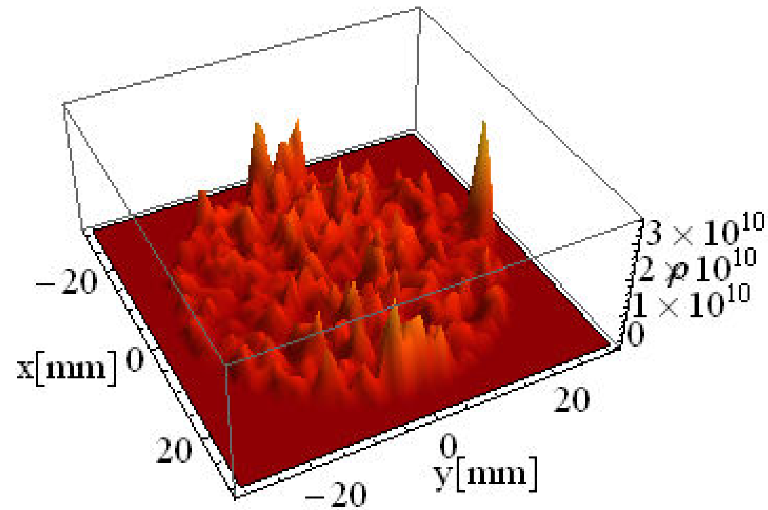
[(*)] Note: these simulated data have large errors (~30-40%) due to statistical noise. Within these errors, there is no difference between the time-averaged density and the instantaneous density at the last bunch in the train

e- cloud “distribution” - 6km ring

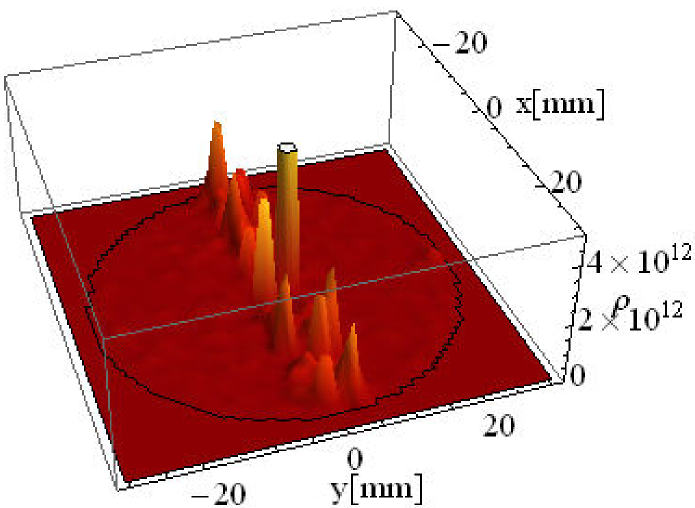
SEY=0.9



SEY=1.2



SEY=1.4



Snapshot of the cloud distribution in dipole “just before” the passage of the last bunch for: R=25%, η=90%

e-cloud density at bunch front within 10 beam σ's (*)

	DC04				DSB3			
	Wiggler		Bend		wiggler		bend	
δ_{max}	**antch.**	**no antch**	**antch.**	**no antch**	**antch.**	**no antch**	**antch.**	**no antch**
0.9	**0.18**	**4.1**	**0.012**	**0.39**	**0.30**	**6.1**	**0.02**	**0.66**
1.0	**0.25**	**4.9**	**0.016**	**0.52**	**0.42**	**7.4**	**0.028**	**0.88**
1.1	**0.33**	**6.3**	**0.018**	**0.59**	**0.55**	**9.5**	**0.03**	**1.00**
1.2	**0.41**	**7.2**	**0.023**	**0.76**	**0.65**	**11.2**	**0.039**	**1.29**
1.3	**>2.1**	**>12.3**	**0.2**	**4.2**	**>3.2**	**>20.3**	**0.34**	**6.14**
1.4	**>3.7**	**>20.5**	**0.4**	**7.6**	**>7.0**	**>31.7**	**0.68**	**9.52**

units: 10^{12} m^{-3}

(*) Note: these simulated data have large errors (~30-40%) due to statistical noise. Within these errors, there is no difference between the time-averaged density and the instantaneous density at the last bunch in the train

Element-averages of Twiss functions, beam sizes and photon rates on the outer vacuum chamber wall

ε_x = 441 pm ε_Y = 2 pm

σ_z = 5.6 mm δ_E = 0.127%

6.4 km (DCO4)

Element	Nr Seg	<Length>	Tot Length	Fraction	<Beta X>	<Beta Y>	<Sig X>	<Sig Y>	<Phot/m/e>
Dipole	5024	0.091	459.1	7.1%	10.5	24.8	0.214	0.007	0.283
Drift	56323	0.096	5397.7	83.3%	21.1	19.4	0.268	0.006	0.146
Wiggler	2251	0.095	214.9	3.3%	10.7	12.1	0.069	0.005	1.515
Quadrupole	3063	0.097	296.1	4.6%	21.6	20.6	0.291	0.006	0.182
Sextupole	1127	0.098	110.0	1.7%	20.1	20.6	0.364	0.006	0.037
Solenoid	0	0.000	0.0	0.0%	0.0	0.0	0.000	0.000	0.000
Octupole	0	0.000	0.0	0.0%	0.0	0.0	0.000	0.000	0.000
Non-dipole	62764	0.096	6019.1	92.9%	20.7	19.2	0.264	0.006	0.195
Non-drift	11465	0.094	1080.2	16.7%	14.6	20.7	0.222	0.006	0.475
Total	67788	0.096	6478.7	100.0%	20.0	19.6	0.261	0.006	0.201

Jim Crittenden and Kiran Sonnad, Cornell U.

ε_x = 525 pm ε_Y = 2 pm

σ_z = 5.3 mm δ_E = 0.118%

3.2 km (DSB3)

Element	Nr Seg	<Length>	Tot Length	Fraction	<Beta X>	<Beta Y>	<Sig X>	<Sig Y>	<Phot/m/e>
Dipole	4332	0.091	393.8	12.2%	3.8	18.7	0.094	0.006	0.914
Drift	26553	0.093	2478.1	76.5%	22.9	23.2	0.149	0.007	0.154
Wiggler	804	0.097	78.2	2.4%	10.7	12.1	0.075	0.005	1.252
Quadrupole	2617	0.091	238.3	7.4%	20.4	20.6	0.213	0.006	0.250
Sextupole	546	0.091	49.5	1.5%	22.0	24.0	0.312	0.007	0.143
Solenoid	0	0.000	0.0	0.0%	0.0	0.0	0.000	0.000	0.000
Octupole	0	0.000	0.0	0.0%	0.0	0.0	0.000	0.000	0.000
Non-dipole	30520	0.093	2844.1	87.8%	22.3	22.7	0.155	0.006	0.192
Non-drift	8299	0.092	759.8	23.5%	10.9	19.0	0.144	0.006	0.690
Total	34852	0.093	3238.1	100.0%	20.1	22.2	0.148	0.006	0.280

The analysis of 23Feb10 used γ/m/e = 0.204 for both drifts and dipoles.
Note the higher ring fraction (factor 1.7) and radiation (factor 3.2) in dipoles for the 3.2 km ring.
This high rate in the dipoles will be mostly compensated for in the horizontal tune shift contribution by the remarkably small average horizontal beta function (3.8 m), as long as the cloud is roughly linear with the rate.

Ecloud in quadrupoles & sextupoles: parameters

Lanfa Wang, SLAC
March 23, 2010

3.2km DR

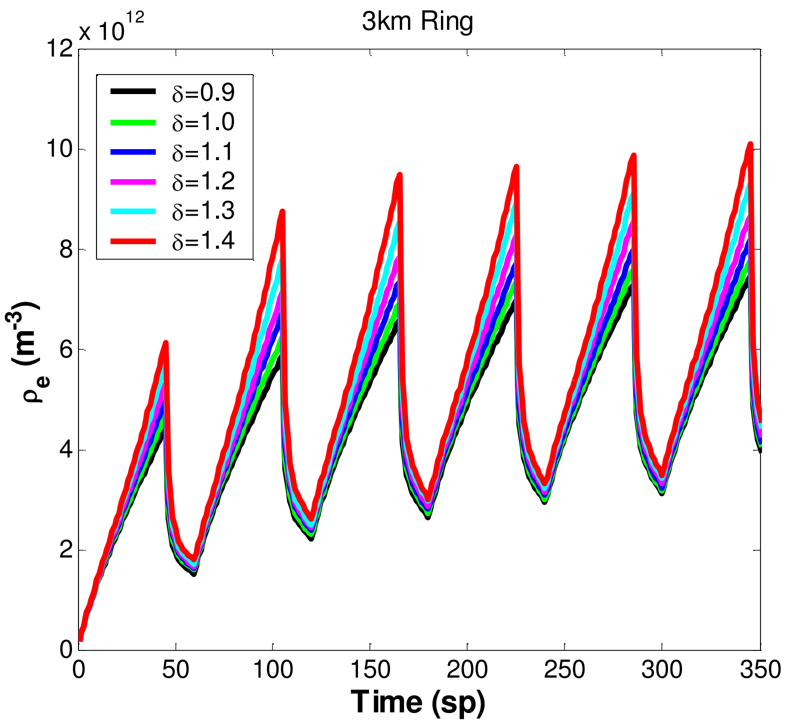
- Field: 7.5T/m
- Length:0.3m
- Pipe radius: 25mm
- SEY: 0.9~1.4
- Beam Size: (270,5) μm

6.4km DR

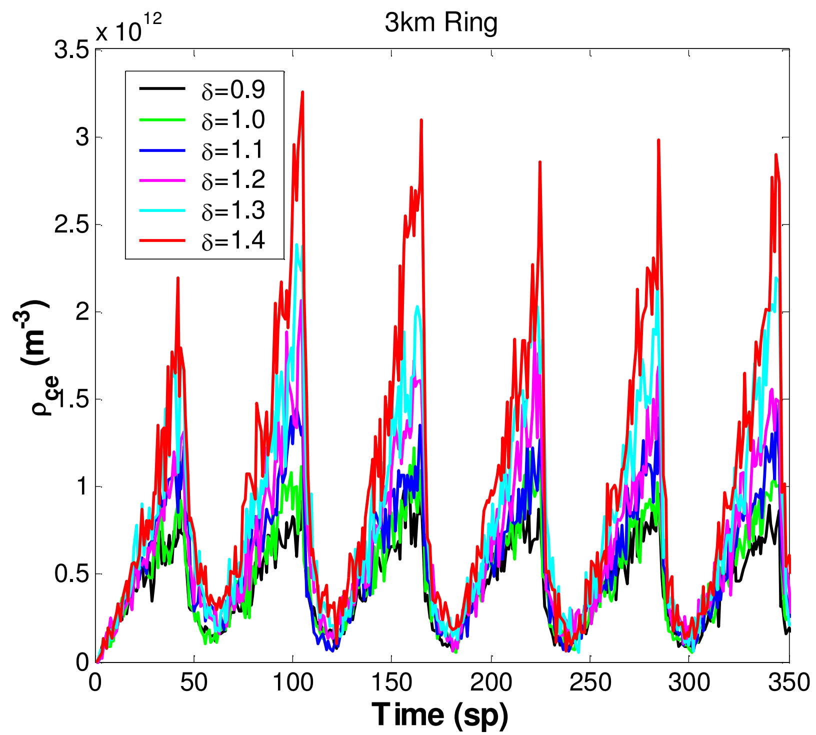
- Field: 12T/m
- Length:0.3m
- Pipe radius: 25mm
- SEY: 0.9~1.4
- Beam Size: (360,6) μm

SEY effect (3km Ring)

Quadrupole: Photon Reflectivity =20%
Antechamber protection =0



Average density build-up

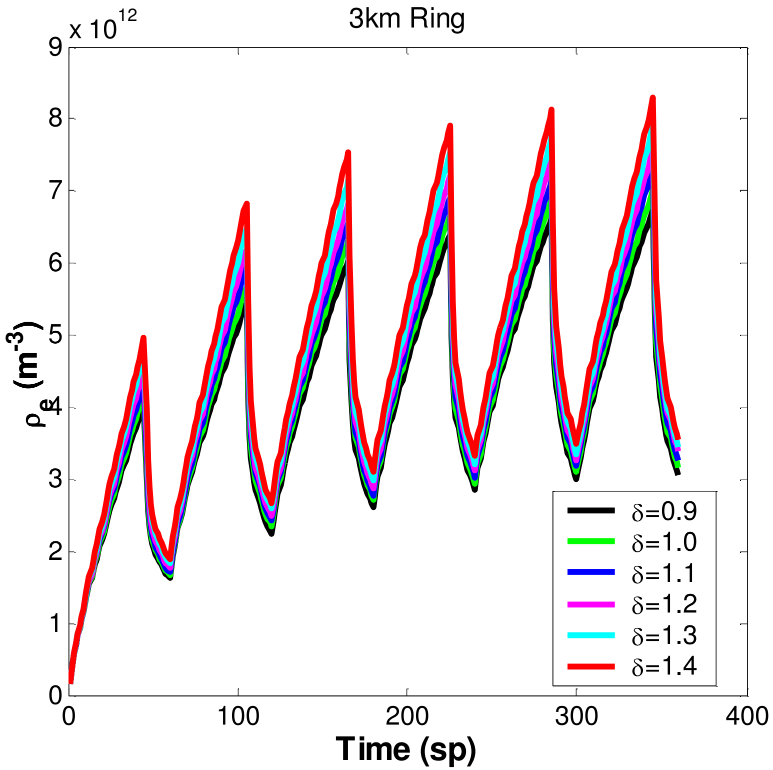


Central density build-up

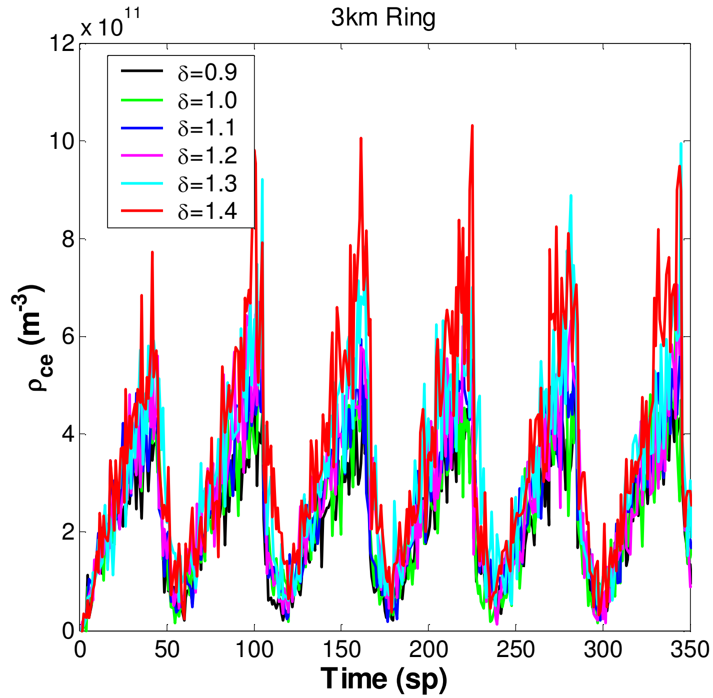
Lanfa Wang, SLAC

SEY effect (3km Ring)

Sextupole: Photon Reflectivity =20%
Antechamber protection =0



Average density build-up

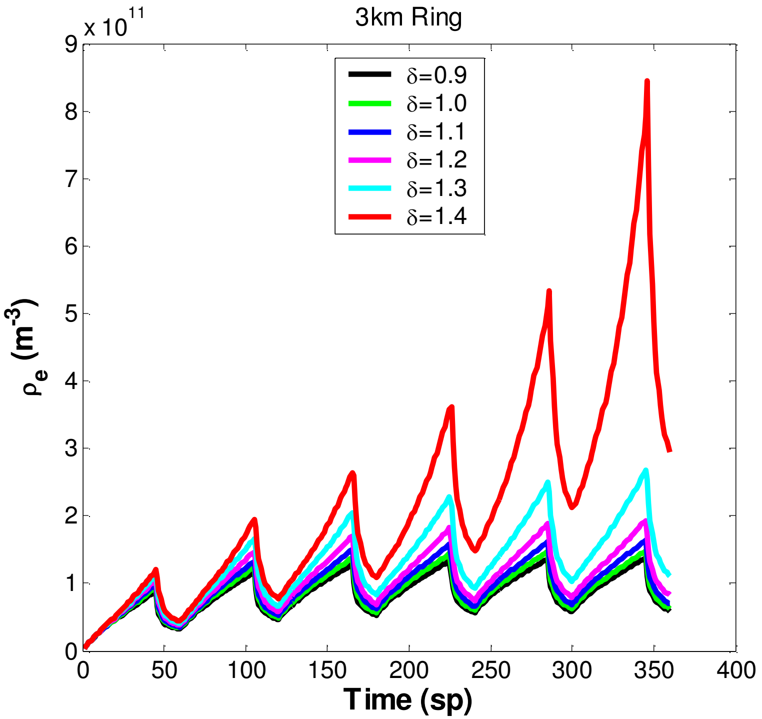


Central density build-up

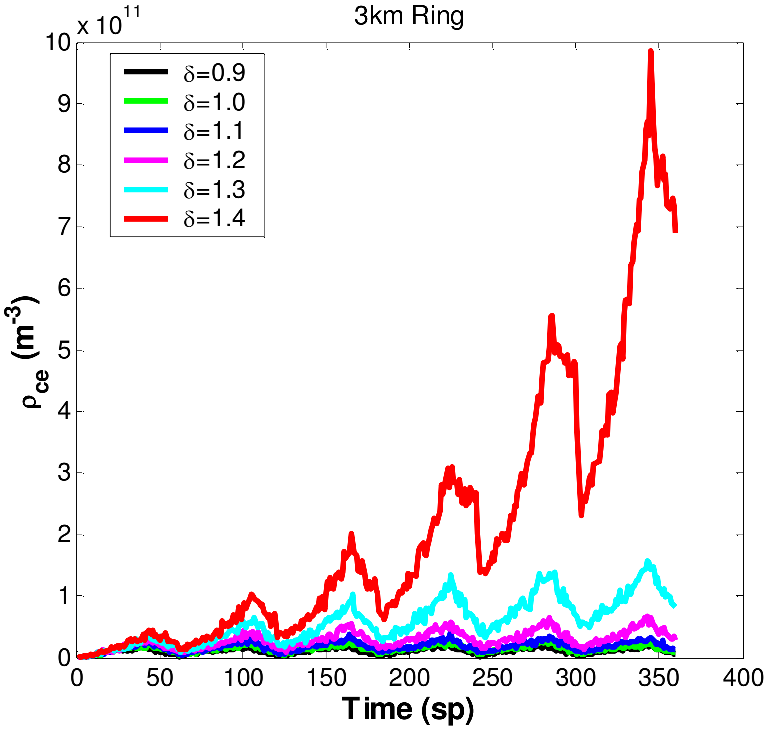
SEY effect (3km Ring)

Quadrupole: Photon Reflectivity =20%
Antechamber protection =98%

Note: ecloud is not saturated for large SEY



Average density build-up

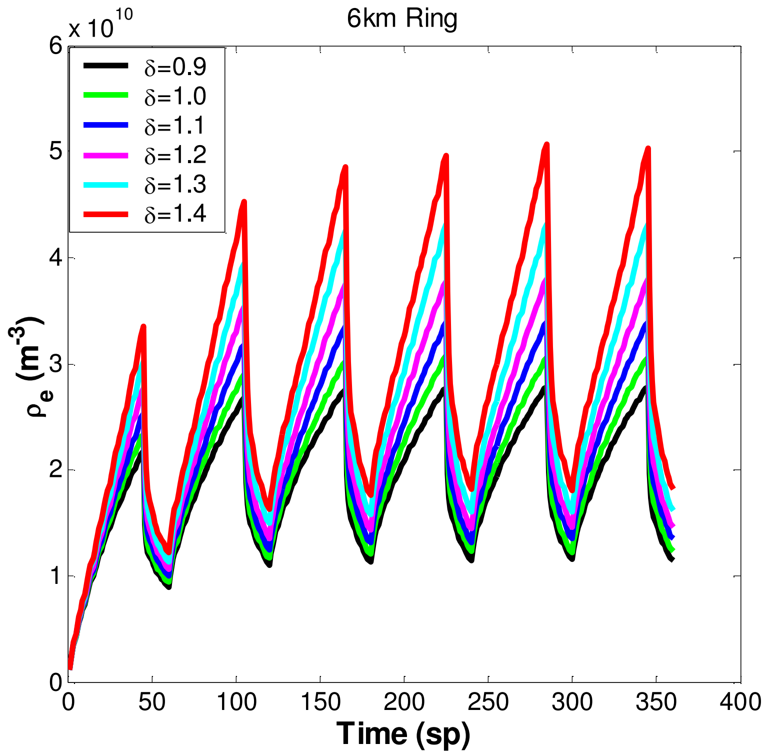


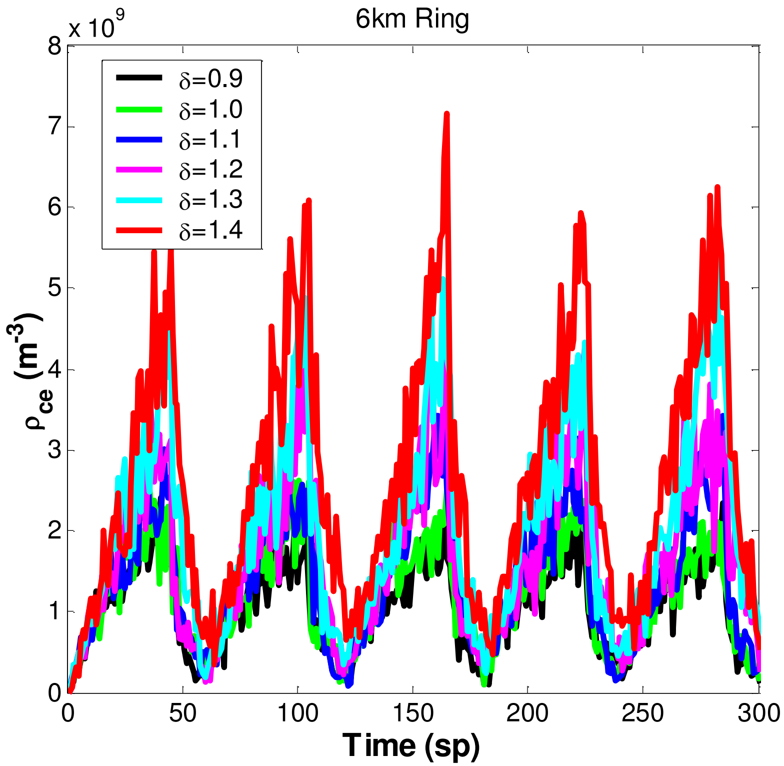
Central density build-up

SEY effect (6km Ring)

Sextupole: Photon Reflectivity =20%

Antechamber protection =98%





Average density build-up

Central density build-up

Photoelectrons production

For these set of simulations:

- Analytic estimates for the synchrotron radiation with antechamber (see O. Malyshev and T. Demma presentations)

- Including next: synchrotron radiation simulations with antechamber, photon reflectivity, photoelectric yield, etc. → Synrad3D

Simulation input parameters for all cases
(mostly from M. Pivi, 17 Nov. 2009 et. seq.)

Beam energy	E_b=5 GeV
Bunch population	N_b=2x10^{10}
RMS bunch length	σ_z=5 mm
Bunch train	45 bunches (spacing t_b = 6.154 ns = 4 buckets)
Gap length between trains	15x4=60 buckets
Fill pattern simulated	5 x (train+gap)
Chamber radius	a=2.5 cm
Antechamber full height (if present)	h=1 cm
Antechamber clearing efficiency	η=98%
Quantum efficiency of chamber surface	QE=0.1
Radiation vertical spot size at wall	σ_y=1 mm
Photon reflectivity	R=0.9 (*)
Peak SEY values explored	δ_{max}=0, 0.9, 1.0, 1.1, 1.2, 1.3,1.4
Electron energy at δ_{max}	E_{max}=296 eV
SEY at E=0	$\delta(0)=0.31x\delta_{max}$

(*) This means that 10% of the photoelectrons are generated localized at the right "edge" of the chamber, *whether or not there is an antechamber* (probably not realistic, but probably not very important for high values of R)

Build Up Parameters for DC04 & DSB3

Beam energy	E_b[GeV]	5
Bunch population	N_b	2.1x10^{10}
Number of bunches	N_b	45 x 8 trains
Bunch gap	*Ngap*	15
Bunch spacing	$L_{sep}[m]$	1.8
Photoelectron Yield	*Y*	0.1
RMS bunch length	σ_z	5
Antechamber full height	*h[mm]*	10
Antechamber protection	η	0%;97%
Fraction of uniformely dist photelectrons	*R*	20%
Max. Secondary Emission Yeld	δ_{max}	0.9;1.0;1.1;1.2;1.3;1.4
Energy at Max. SEY	E_m *[eV]*	300
SEY model	Cimino-Collins $(\delta(0)=0.5)$	

*https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/WebHome/DampingRingsFillPatterns.xls

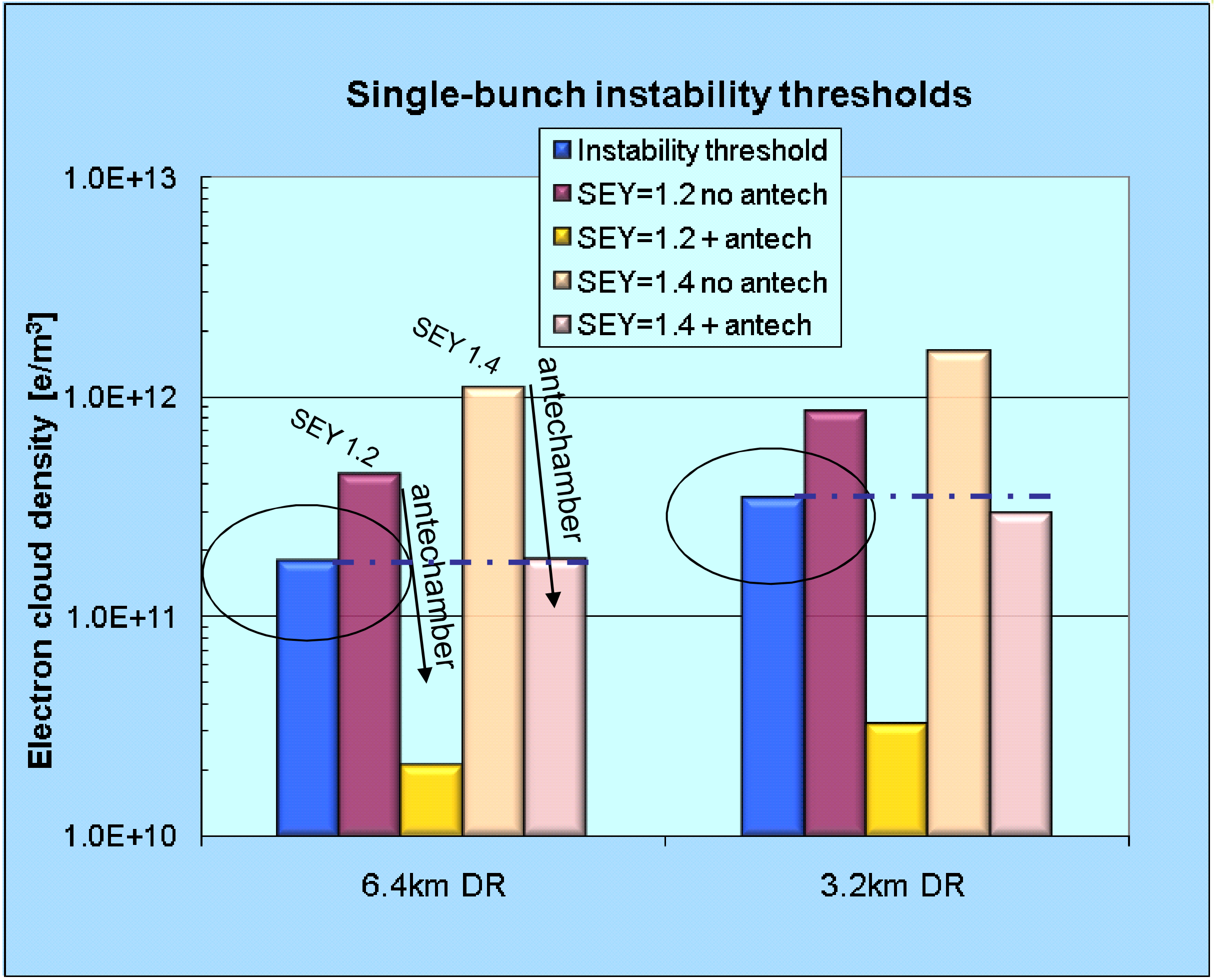
Build Up Input Parameters for CLOUDLAND

ilc-DR 6.4 Km, 6 ns bunch spacing*.

Bunch population	N_b	$2.1\text{x}10^{10}$
Number of bunches	N_b	45 x 6 trains
Bunch gap	$Ngap$	15 bunches (60 buckets)
Bunch spacing	$L_{sep}[m]$	1.8
Bunch length	$\sigma_z\,[mm]$	6
Bunch horizontal size	$\sigma_x\,[mm]$	0.26
Bunch vertical size	$\sigma_y\,[mm]$	0.006
Photoelectron Yield	Y	0.1
Photon rate (e^-/e^+/m)	dn_γ/ds	0. 33
Antechamber protection	η	0%, 98%
Photon Reflectivity	R	20%
Max. Secondary Emission Yeld	δ_{max}	1.2
Energy at Max. SEY	$E_m\,[eV]$	300
SEY model	Cimino-Collins $(\delta(0)=0.5)$	

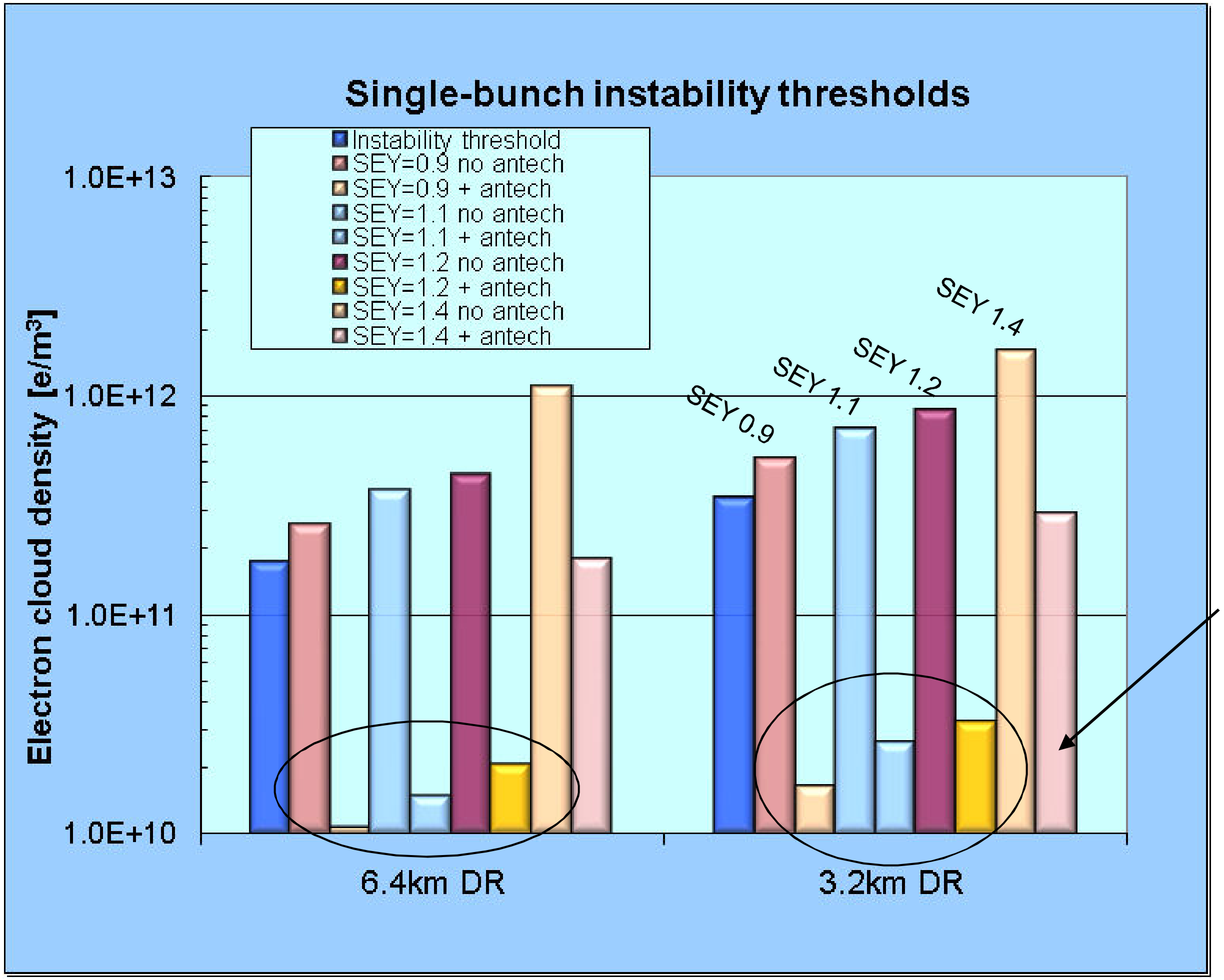
*https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/WebHome/DampingRingsFillPatterns.xls

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.

Compare thresholds for 6 km and 3km DR



Complete set of data. All simulations for antechamber eta=97-98%, but R=0.2 and R=0.9.

Compiled data from build-up simulations and compare against and beam instability thresholds. Showing the overall ring average cloud density for the 6 km and 3km rings

Statistical errors and parameters variation

- Errors in the cloud density near beam 30-40% due to statistical noise

- Lower cloud density when reflectivity R=0.2 instead of R=0.9

- Factor ~4-5 increase in cloud density if antechamber protection is η=90% (instead of η=98%).
  What is our level of confidence on η=98%?

Will be refined by SR simulations

<u>These may set a lower threshold for the acceptable SEY</u>

Summary of Working Group findings

- Given the same current and bunch distance we expect similar or even higher instability threshold for the shorter ring
- Need for antechamber designs either in 6km and 3km DR
- With an antechamber design and train gaps, a SEY 1.1-1.2 offer sufficient margin against beam instability. Need to factor in parameters variation and statistical errors.

Recommendation and Risks Assessment

- With respect to the RDR baseline, the risk level for adopting a reduced 3km Damping Ring while maintaining the same bunch spacing is: Low.

- The acceptable surface Secondary Electron Yield (SEY) may strongly depend on issues not yet thoroughly investigated such as beam jitter and slow incoherent emittance growth. Refined estimations of the photoelectron production rate by simulations will better define the maximum acceptable SEY.

(Cont') Recommendation and Risks Assessment

- 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.