Design of Damping Rings for Linear Colliders

S. Guiducci

LER10

January 12, 2010

ILC DR Requirements

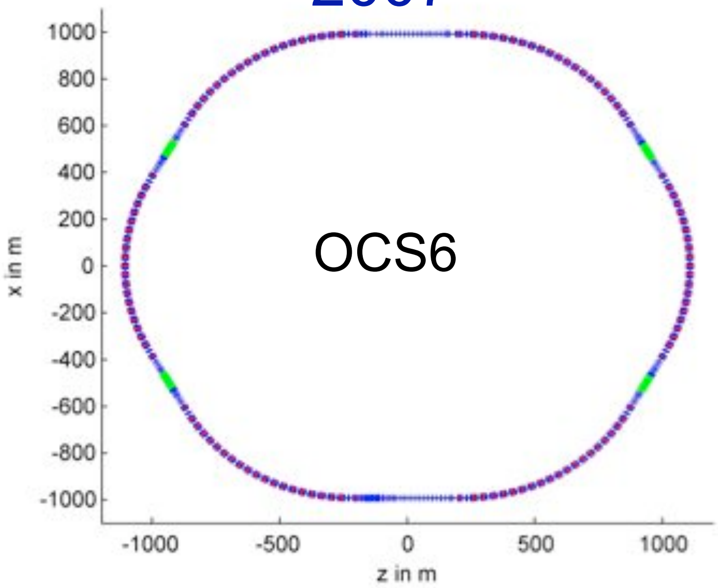
Number of bunches	2625
Number of particles per bunch	2×10^{10}
Repetition frequency (Hz)	5
Normalized e^+ injected emittance $\gamma\varepsilon_{x,y}$ (m)	0.01
Energy acceptance	±0.5%
Normalized horizontal extracted emittance $\gamma\varepsilon_x$ (μm)	< 8
Normalized horizontal extracted emittance $\gamma\varepsilon_x$ (μm)	0.02
RMS relative energy spread	< 0.15%
RMS bunch length (mm)	6

Circumference

- Given by the number of bunches and the minimum achievable bunch distance T_b
- Limits come from:
  - **kickers pulse duration**
  - **Instabilities limiting the maximum stored current, in particular the e-cloud instability in the positron ring**
- Since the first GDE meeting Snowmass 2005:
- T_b (ns) = 20 ⇒ 12 ⇒ 6
- C (km) = 17 ⇒ 2x6.9 ⇒ 6.4 … 3.2 Proposed for SB2009

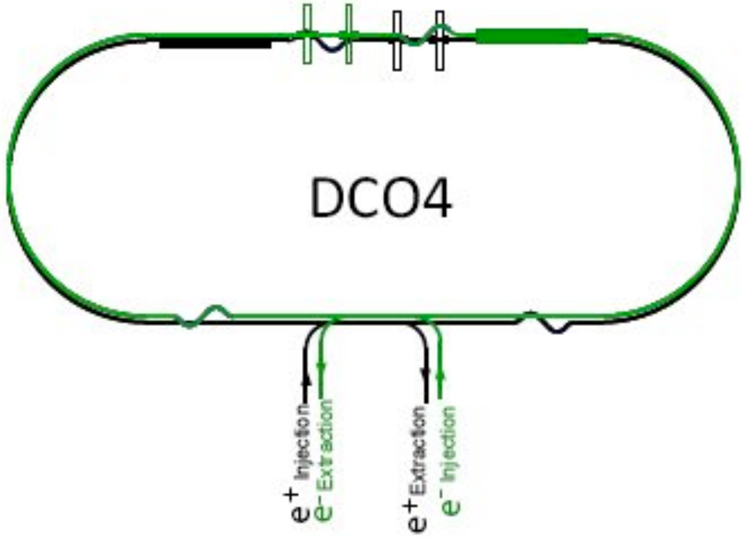
Layout

Hexagonal RDR 2007



C = 6.7 km

Racetrack TILC08



C = 6.4 km

Racetrack layout determined by the most efficient use of tunnel and access shafts, concentrated in two straight sections

Higher ring periodicity helps to increase dynamic aperture

Damping time

- Energy = 5 GeV $\Rightarrow$ no emittance blowup due to space charge effects
- For a 6.4 km ring at 5 GeV wigglers are needed to get the proper damping time
- Beams stored for ~7 τ_d to have extracted emittance ≈ equilibrium emittance
- $\tau_d \leq 200/7 \leq 28$ ms
- Wigglers are also useful in reducing the emittance

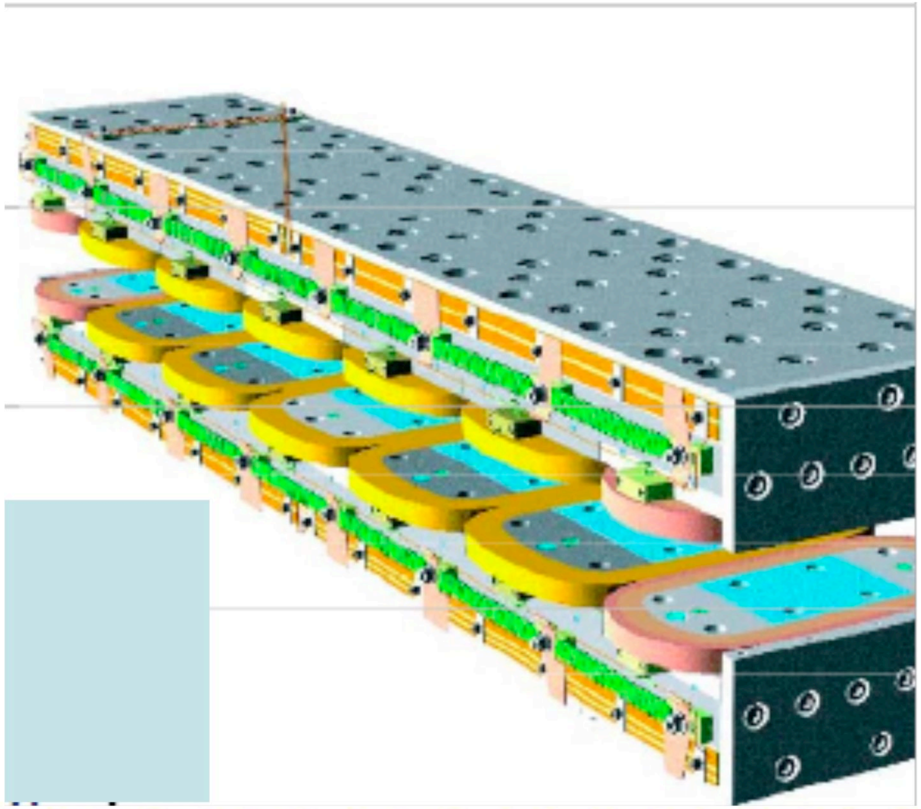
ILC DR wigglers

•Extensively used to reduce damping time and emittance and to mitigate IBS effect

•CESR-c type superconducting wiggler: good aperture, very good field quality and proven performance.

- Number of wigglers 88
- Peak field 1.6 T
- Period 0.40 m
- Unit length 2.45 m
- Vertical aperture 5 cm

•Pole width 20 cm



Lattice Evaluation TILC08, Sendai

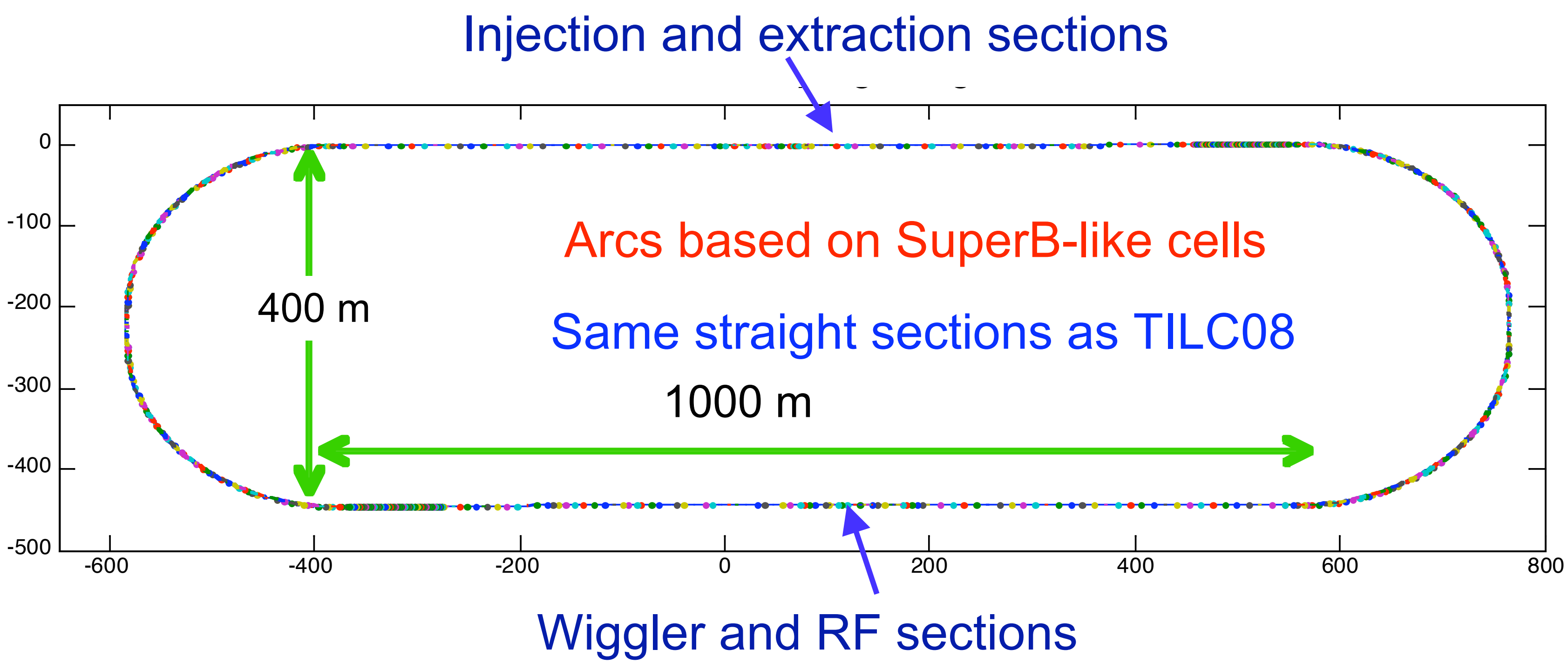
- 4 lattices OCS8, FODO4, FODO5, DCO were evaluated on 8 criteria:
  - Lattice Design and Dynamical Properties
  - Conventional Facilities and Layout
  - Magnets, Supports and Power Supplies
  - Vacuum System and Radiation Handling
  - RF System
  - Injection and Extraction
  - Instrumentation and Diagnostics
  - Control System, Availability and Reliability
- Rankings were very similar, all the lattices were satisfying the requirements
- Differences were driven by items that affect cost, availability and reliability (eg, clustering of major components near the two proposed access shafts)

The DCO lattice was recommended as baseline

SB2009 - 3.2 km ring

- In 2009 it has been studied an ILC parameter set with a reduced number of bunches 1300
- This allows to reduce the DR circumference to 3.2 km
- The bunch separation and the number of particles per bunch remain the same, and the beam current in the ring is the same
- From the view point of beam dynamics we expect essentially the same performance as the 6.4 km ring

Layout of the 3.2km damping rings



- Injection/extraction lines of the two rings are superimposed
- RF cavities: 18 ⇒ 8
- Wigglers: 80 ⇒ 32

http://ilcagenda.linearcollider.org/materialDisplay.py?contribId=516&sessionId=11&materialId=slides&confId=2628

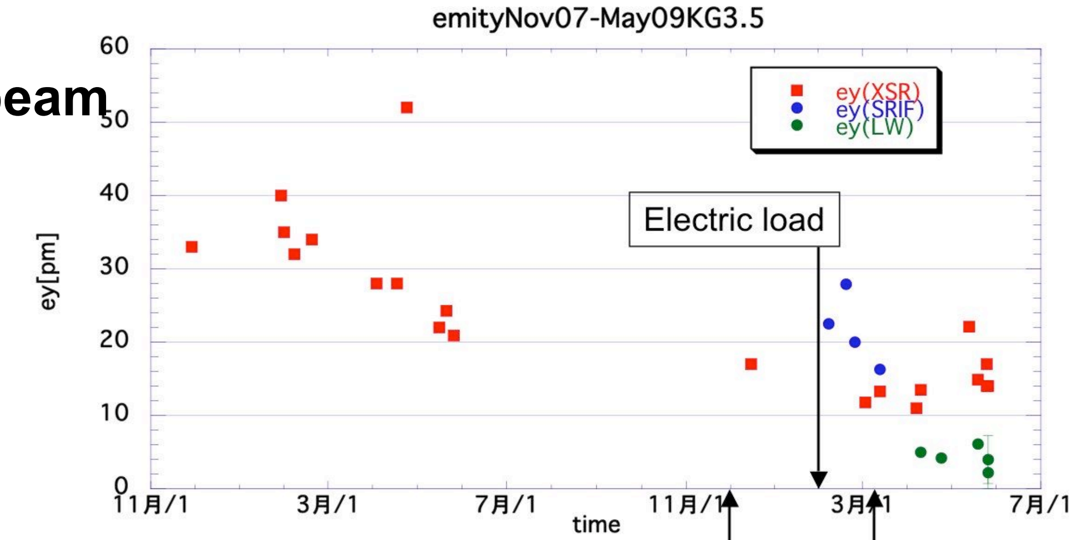
http://ilcagenda.linearcollider.org/contributionDisplay.py?contribId=119&sessionId=27&confId=3461

ILC DR Main Challanges

- Large Acceptance (large e+ injected emittance, no predamping ring)
- Ultra low emittance
- Control of electron cloud effect in positron DR
  - **Vacuum chamber coating**
  - **Solenoids**
  - **Clearing electrodes**
- Control of the fast ion instability in the electron DR
  - **Pressure below 1 nTorr**
  - **Gaps in the ring fill pattern**
  - **Fast feedback systems**
- Developing a very fast rise and fall time kicker for single bunch injection and extraction in the ring.

ILC DR Test facilities ATF

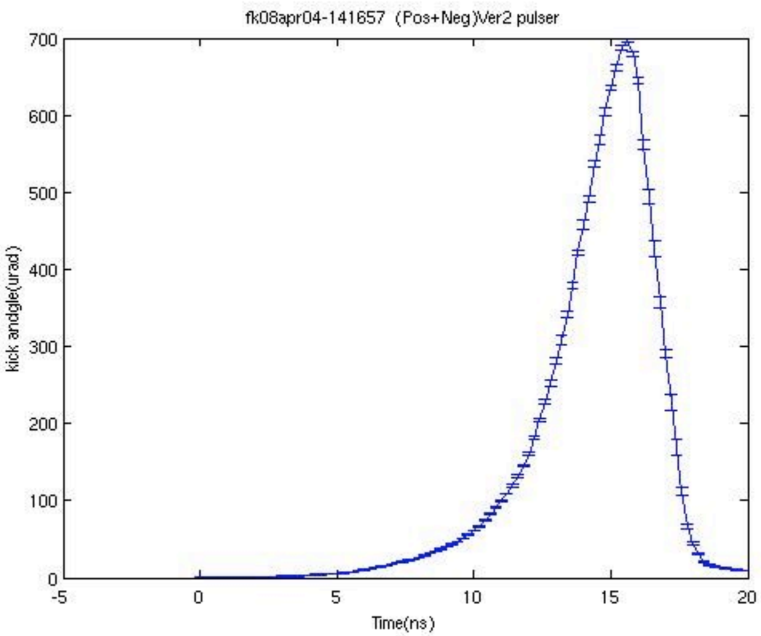
Generation of low emittance beam



2008 spring

2009 spring
I=5-6x10^9

Fast kicker Experiment



Pulse source(FID FPG 10-6000KN)

Maximum output voltage ±10 kV

Rise time @ 10-90% level - < 1 ns

Rise time @ 5-95% level - < 1.2 ns

Pulse duration @ 90% - 0.2-0.3 ns

Pulse duration @ 50% - 1.5-2 ns

Output pulse amplitude stability – 0.5-0.7%

ILC DR Test facilities CesrTA

Attain sufficiently low vertical emittance to enable exploration of

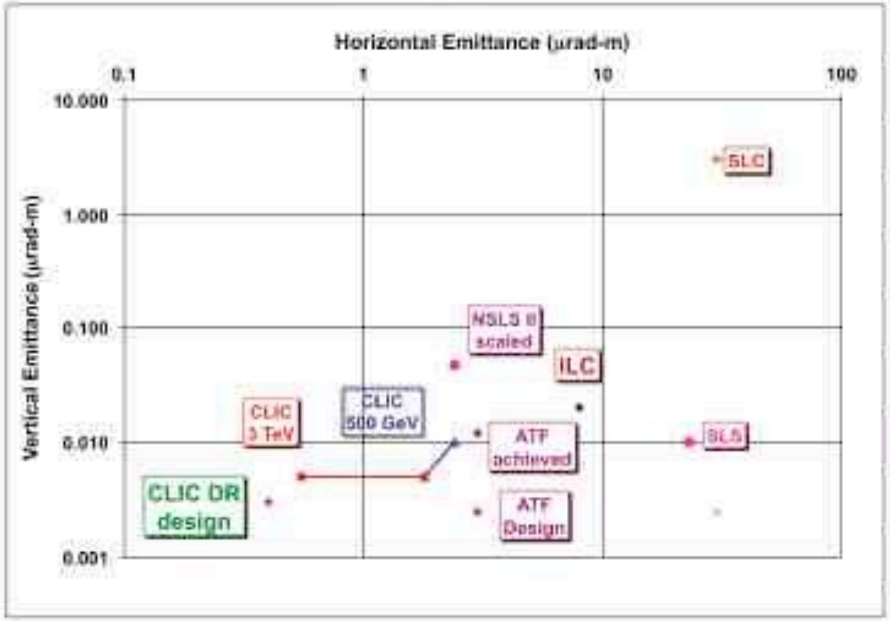
- dependence of electron cloud on emittance
- emittance dilution effect of e-cloud

- Comparisons of EC mitigations:
  - **Environments: Drift, Wiggler**
  - **Chamber Surfaces: Al, Cu, TiN coating, amorphous carbon coating**
- Simulations and Measurements:
  - **Electron densities including Retarding Field Analyzers effects**
  - **TE wave measurements**
  - **Coherent tune shifts for e+ and e-**
  - **3D wiggler simulations**

ECLOUD Working Group goals

- To give a recommendation on the feasibility of a shorter damping ring by comparing the electron cloud build-up and instability for the 6.4km and 3.2km rings with a 6 ns bunch spacing by March 2010, then
- Following the CesrTA program or by ECLOUD'10, to give our recommendation on e- cloud mitigations and evaluate the electron cloud in the shorter 3.2 km ring with a 3 ns bunch spacing.
- Furthermore starting late 2010, to fully integrate the CesrTA results into the Damping Ring design.

DR design goals and challenges



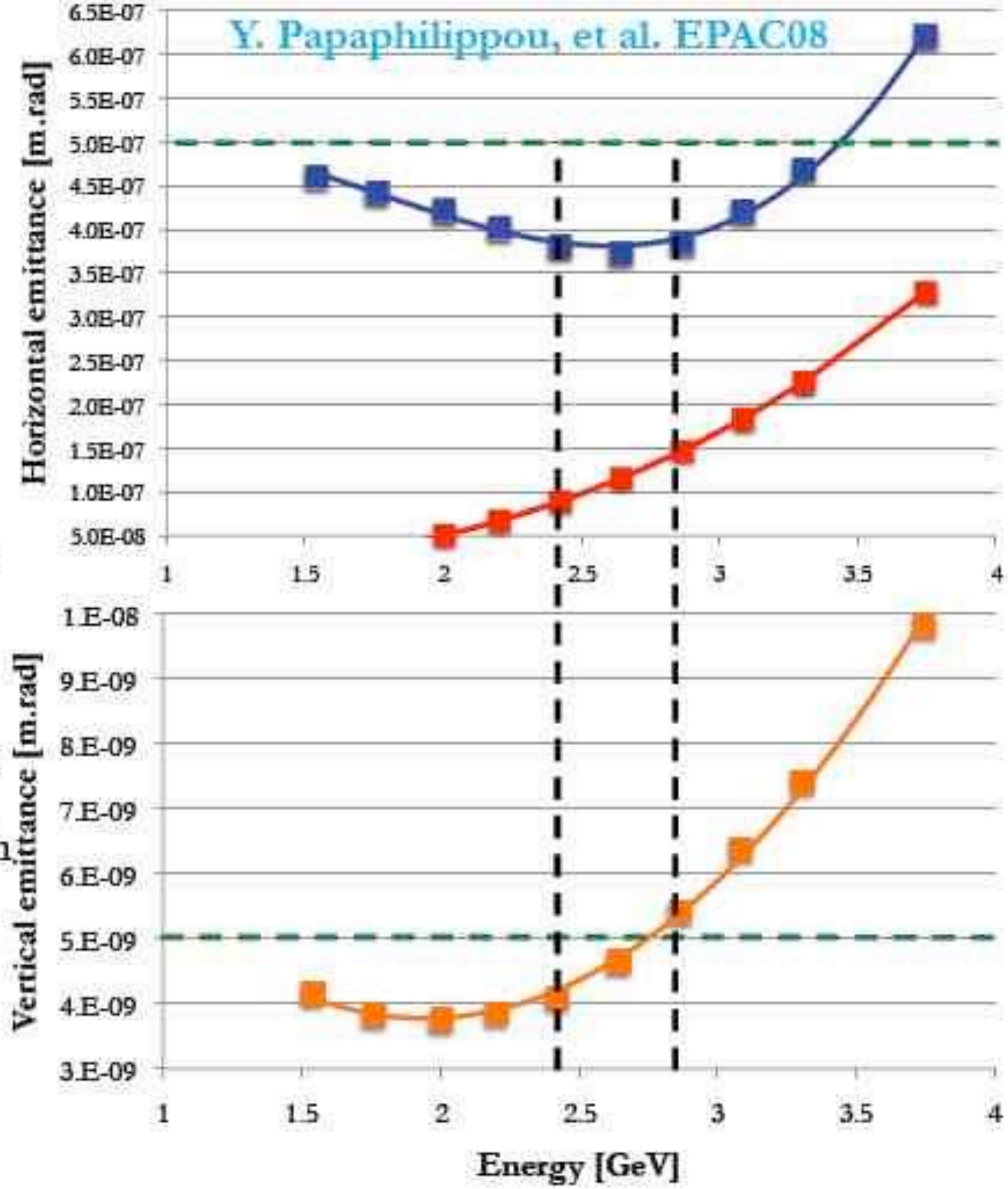
PARAMETER	NLC	CLIC
bunch population (10^9)	7.5	4.1
bunch spacing [ns]	1.4	0.5
number of bunches/train	192	312
number of trains	3	1
Repetition rate [Hz]	120	50
Extracted hor. normalized emittance [nm]	2370	<500
Extracted ver. normalized emittance [nm]	<30	<5
Extracted long. normalized emittance [keV.m]	10.9	<5
Injected hor. normalized emittance [µm]	150	63
Injected ver. normalized emittance [µm]	150	1.5
Injected long. normalized emittance [keV.m]	13.18	1240

- Design parameters dictated by target performance of the collider (e.g. luminosity), injected beam characteristics or compatibility with the downstream system parameters
- Most parameters are **driven** by the main linac RF optimization
- In order to reach ultra-low emittance, CLIC DR design is based on the inclusion **super-conducting wigglers**
- Output emittance is **dominated by Intrabeam Scattering (IBS)** due to high bunch charge density and instabilities may be triggered due to a number of collective effects (e.g. e^--cloud, fast ion instability)

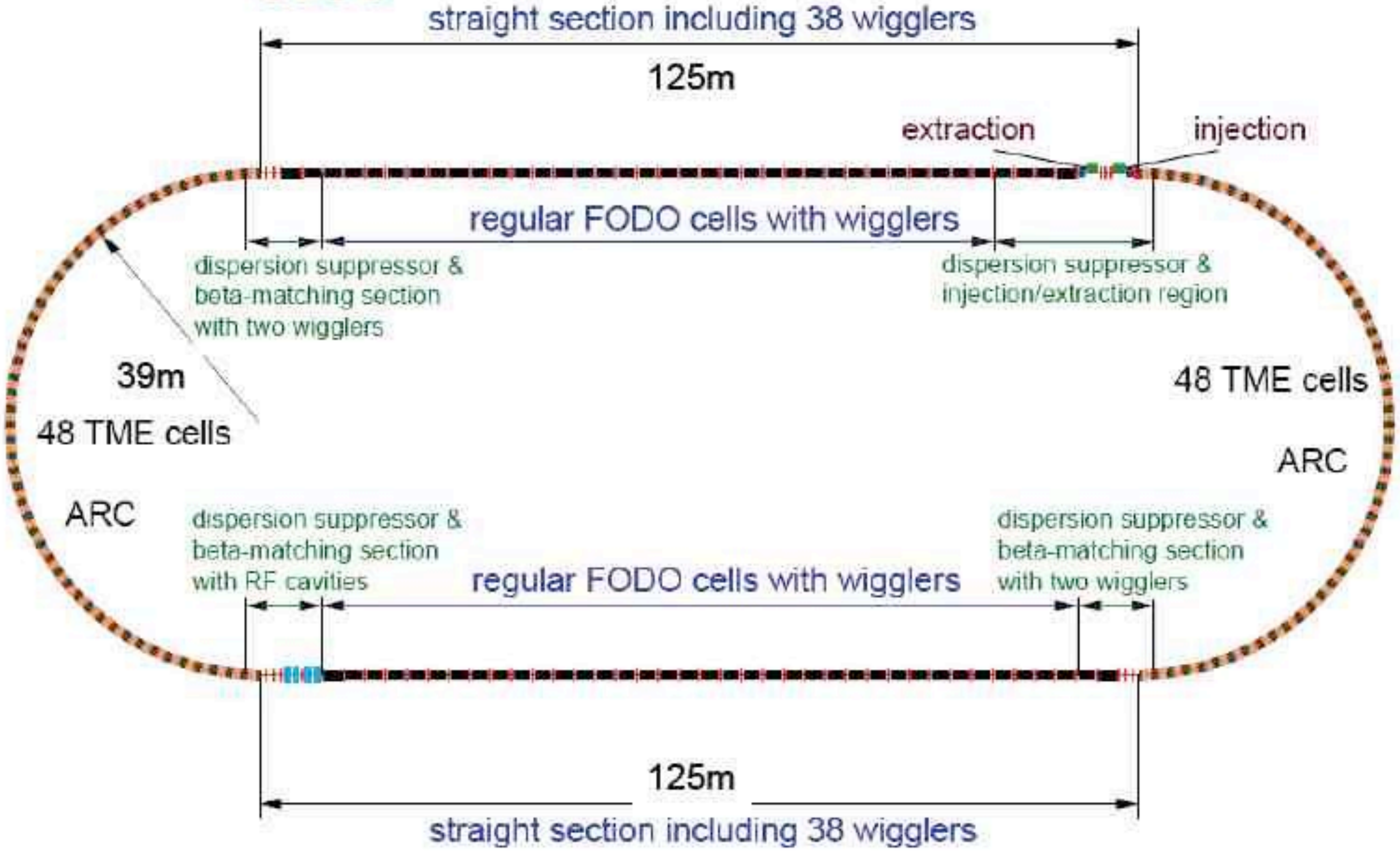
Y. Papaphilippou LCWAS09

Damping ring energy

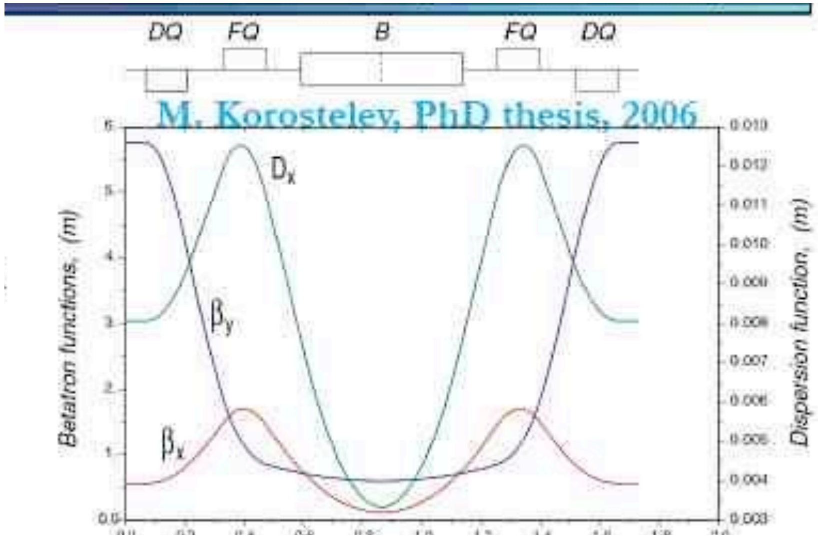
- Scaling of emittances with energy obtained with analytical arguments and numerical integration for including the effect of IBS
- Longitudinal emittance kept constant
- Broad **minimum** for horizontal emittance @ 2-3GeV
- Higher energy reduces ratio between zero current and IBS dominated emittance
- Vertical emittance increases linearly with energy (tighter alignment and low emittance tuning tolerances)
- No significant change in geometrical aperture in terms of beam sizes as lower geometrical emittance at high energy compensates increase of magnet strength
- Increase of energy loss per turn and radiated power increased RF voltage, higher beam loading)
- Collective effects get relaxed (especially space-charge)
- Increase the DR energy to **2.86GeV**



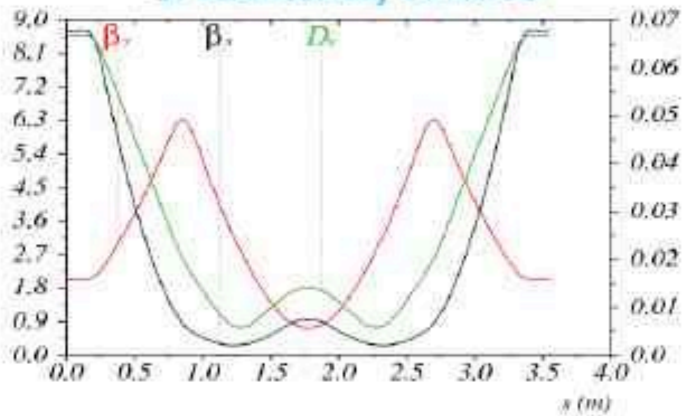
DR layout


straight section including 38 wigglers
125m
extraction
injection
regular FODO cells with wigglers
dispersion suppressor & beta-matching section with two wigglers
dispersion suppressor & injection/extraction region
39m
48 TME cells
ARC
48 TME cells
ARC
dispersion suppressor & beta-matching section with RF cavities
regular FODO cells with wigglers
dispersion suppressor & beta-matching section with two wigglers
125m
straight section including 38 wigglers

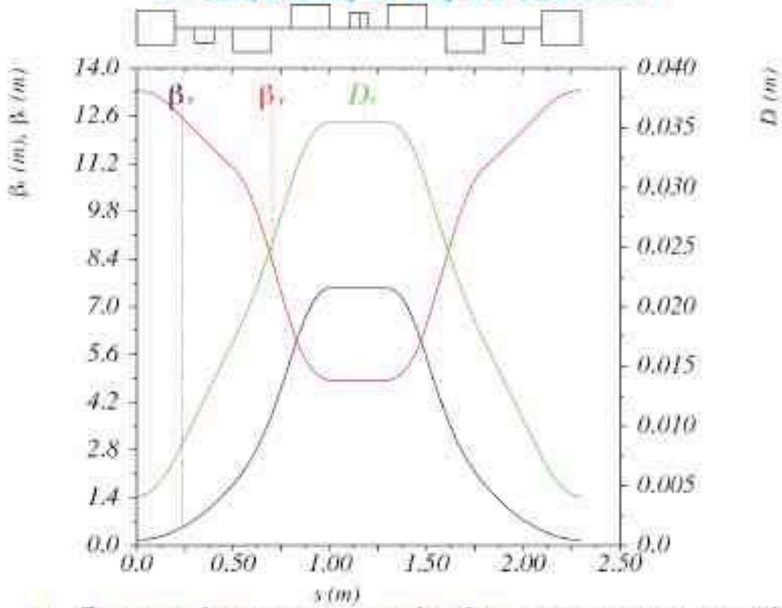
CLIC DR lattice



P. Raimondi, CLIC08

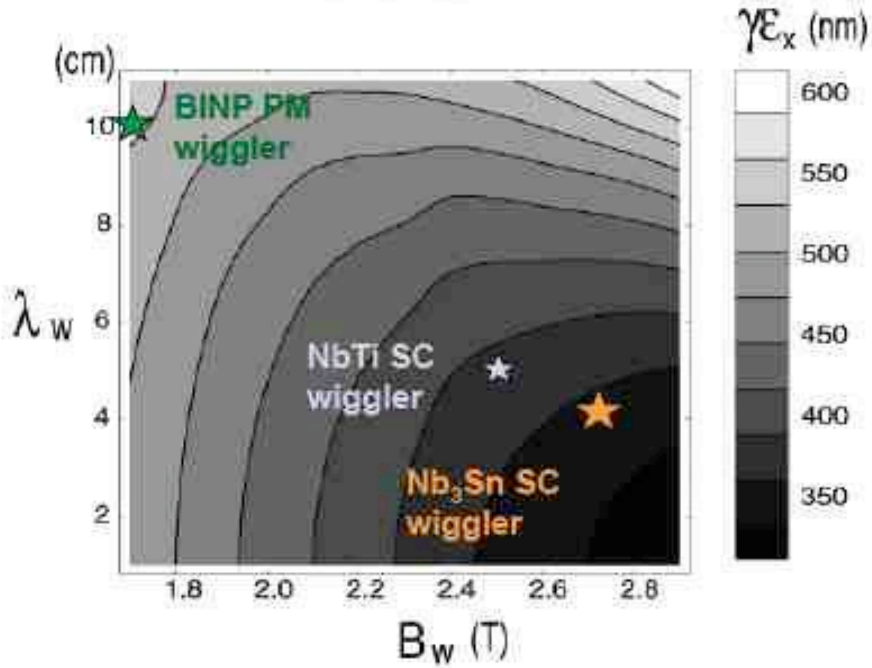


S. Sinyatkin, et al., EPAC 2009



- Increasing space, reducing magnet strengths
- Reducing chromaticity, increasing DA
- IBS growth rates reduced, i.e. zero current equilibrium emittance increased but IBS dominated emittance not changed
- Combined function bends with small gradient (as in NLC DR and ATF)

Wigglers' effect with IBS



Parameters	BINP	CERN
B_{peak} [T]	2.5	2.8
λ_W [mm]	50	40
Beam aperture full gap [mm]	13	13
Conductor type	NbTi	Nb_3Sn
Operating temperature [K]	4.2	4.2

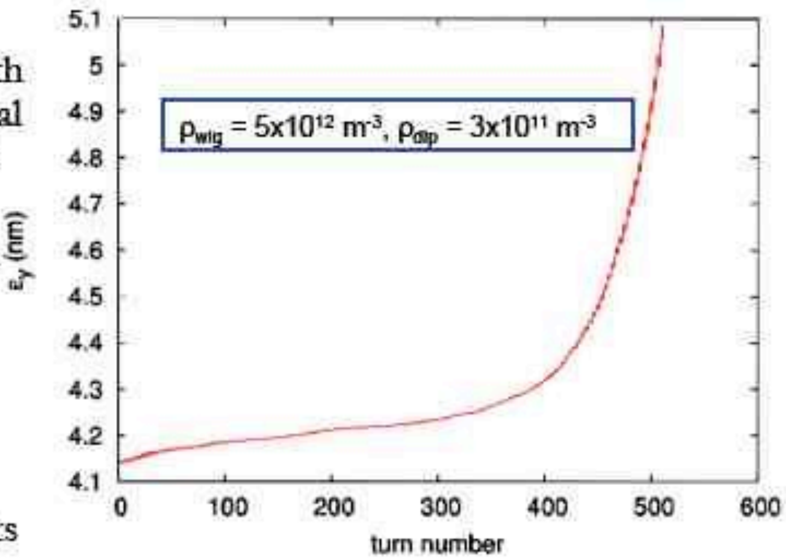
- Stronger wiggler fields and shorter wavelengths necessary to reach target emittance due to strong IBS effect
- Two wiggler prototypes
  - 2.5T, 5cm period, built and currently tested by BINP
  - 2.8T, 4cm period, designed by CERN/Un. Karlsruhe
- Current density can be increased by using different conductor type
- Prototypes built and magnetically tested (at least one by CDR)
- Installed in a storage ring (ANKA, CESR-TA, ATF) for beam measurements (IBS/ wiggler dominated regime)
- Major DR performance item

Collective effects in the DR

G. Rumolo et al., EPAC08

- Electron cloud in the e^+ DR imposes limits in PEY (99.9% of synchrotron radiation absorbed in the wigglers) and SEY (below 1.3)
  - Cured with special **chamber coatings**
- Fast ion instability in e^- DR, molecules with A>13 will be trapped (constrains vacuum pressure to around 0.1nTorr)
- Other collective effects in DR
  - Space charge (large vertical tune spread of 0.19 and 10% emittance growth)
  - Single bunch instabilities avoided with smooth impedance design (a few Ohms in longitudinal and MOhms in transverse are acceptable for stability)
  - Resistive wall coupled bunch controlled with feedback (1ms rise time)
- For CDR
  - Update studies with newest parameter set including 3D photon distribution in wiggler section
  - Estimate impedance of a few key components

Chambers	PEY	SEY	ρ [10^{12} e^-/m^3]
Dipole	0.000576	1.3	0.04
		1.8	2
	0.0576	1.3	7
		1.8	40
Wiggler	0.00109	1.3	0.6
	0.109	1.3	45
		1.5	70
		1.8	80



DR RF system

A. Grudiev, CLIC08

- RF frequency of **2GHz**
  - Power source is an R&D item at this frequency
- High peak and average power of **6.6** and **0.6MW**
- Strong beam loading transient effects
  - Beam power of ~6.6MW during 156 ns, no beam during other 1488 ns
  - Small stored energy at 2 GHz
- Wake-fields and HOM damping should be considered
- A conceptual RF design should be ready for the CDR

CLIC DR parameters	
Circumference [m]	493.05
Energy [GeV]	2.86
Momentum compaction	0.6×10^{-4}
Energy loss per turn[MeV]	5.9
Maximum RF voltage [MV]	7.4
RF frequency [GHz]	2.0

- High energy loss per turn at relatively low voltage (keeping longitudinal emittance at 5keV.m) results in large ϕ_s
  - Bucket becomes non-linear
  - Small energy acceptance
  - RF voltage increased to **7.4MV** (energy acceptance of **2.6%**)
  - As longitudinal emittance is decreased (3.9 keV.m), horizontal emittance increased to **480nm**

Y.P., 02/10/2009 LCWA 2009

ILC/CLIC DR Parameters 2009

	ILC	CLIC
Energy (GeV)	5	2.9
Circumference (m)	3238	493
Bunch number	1300	312
N particles/bunch	$2x10^{10}$	$4.1x10^{9}$
Bunch distance (ns)	6.2	0.5
Average current (mA)	387	125
Bunch peak current (A)	25	21
Damping time τ_x (ms)	24	1.6
Emittance $\gamma\varepsilon_x$ (nm)	5300	390
Emittance $\gamma\varepsilon_x$ (nm)	20	4.9
Momentum compaction	$1.3\ x10^{-4}$	$0.6\ x10^{-4}$
Energy loss/turn (MeV)	4.4	5.8
Bunch length (mm)	6.0	1.4
RF Voltage (MV)	7.5	7.4
RF frequency (MHz)	650	2000
Betatron tunes Q_x, Q_y		
Natural chromaticity x/y	-100 / -63	-149 / -79

Common issues

- Low Emittance Tuning
- Collective effects:
  - **e-cloud**
  - **Fast ion**
  - **IBS**
  - **Impedance related effects**
- Wiggler dominated ring
- Beam diagnostics

Conclusions

- Main issues are related to:
  - **Low emittance**
  - **Short bunch distance**
  - **High current**
  - **Stringent requirements on the stability of the extracted beams**
  - **Beam instrumentation**
- These are common between ILC and CLIC but also with the new SL sources and the new project of ultra high luminosity B-factories
- The objective of this meeting is to exchange experiences and find synergies