ILC-CLIC LET Beam Dynamics Workshop

CLIC Damping Rings and their impact on the RTML

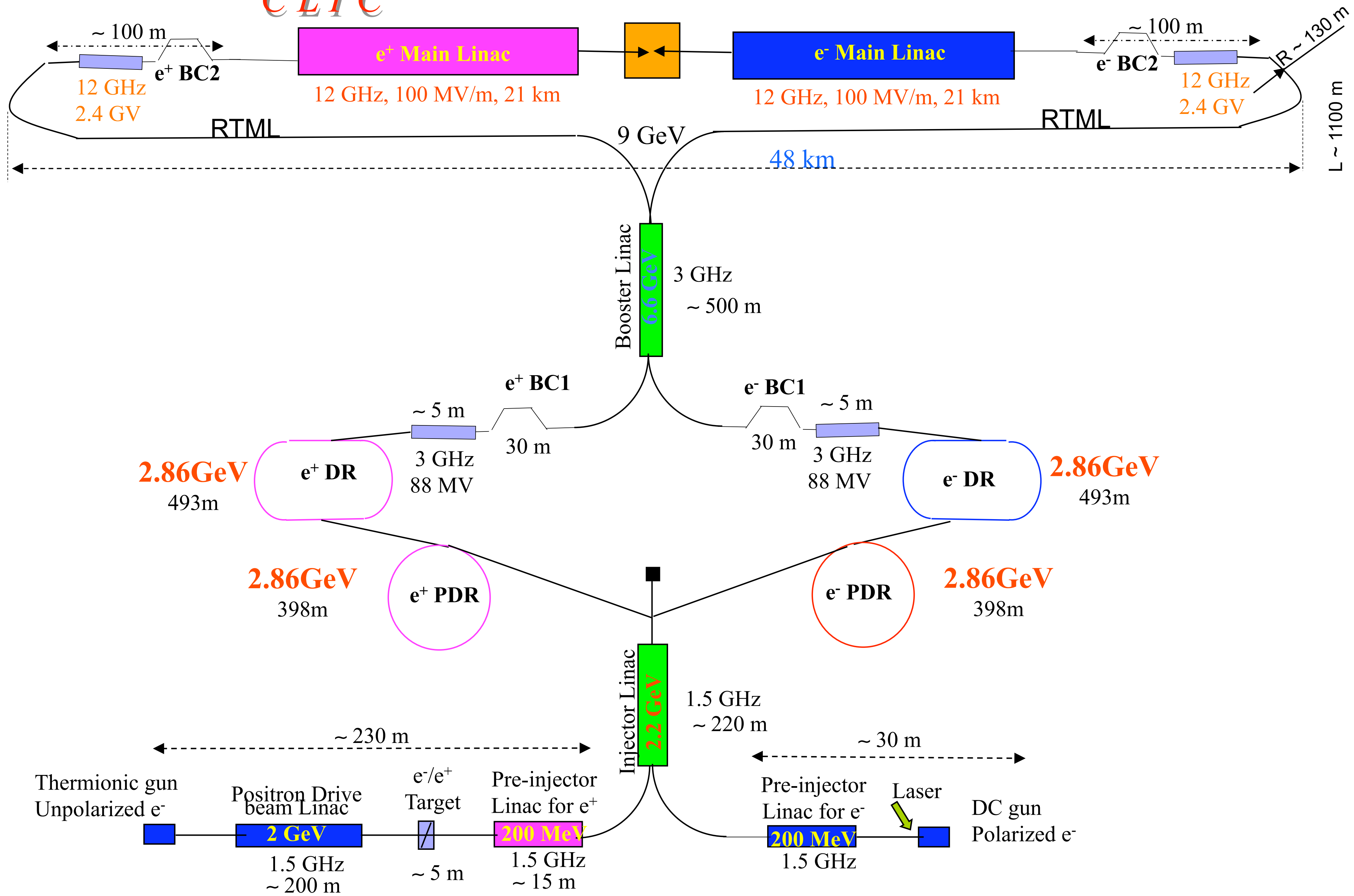
Yannis PAPAPHILIPPOU

June 23rd, 2009

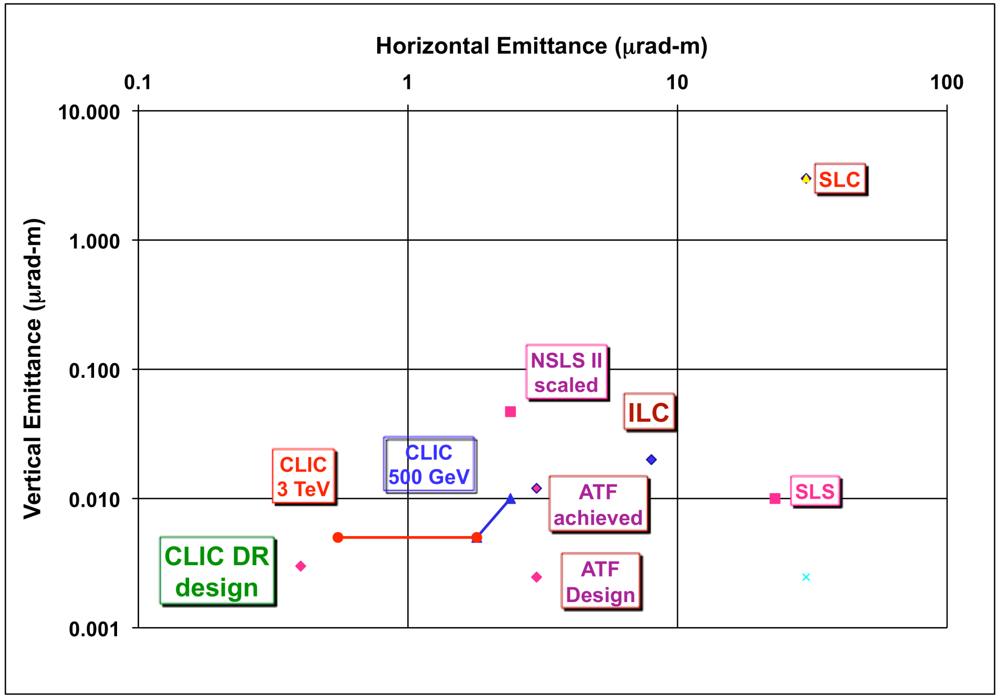
Outline

- CLIC Damping Rings (DR) overview
  - Design goals
  - Layout, optics and parameters
  - Super-conducting wigglers
  - Collective effects
  - RF and kickers
  - DR @ 500GeV
- Summary

Injector complex



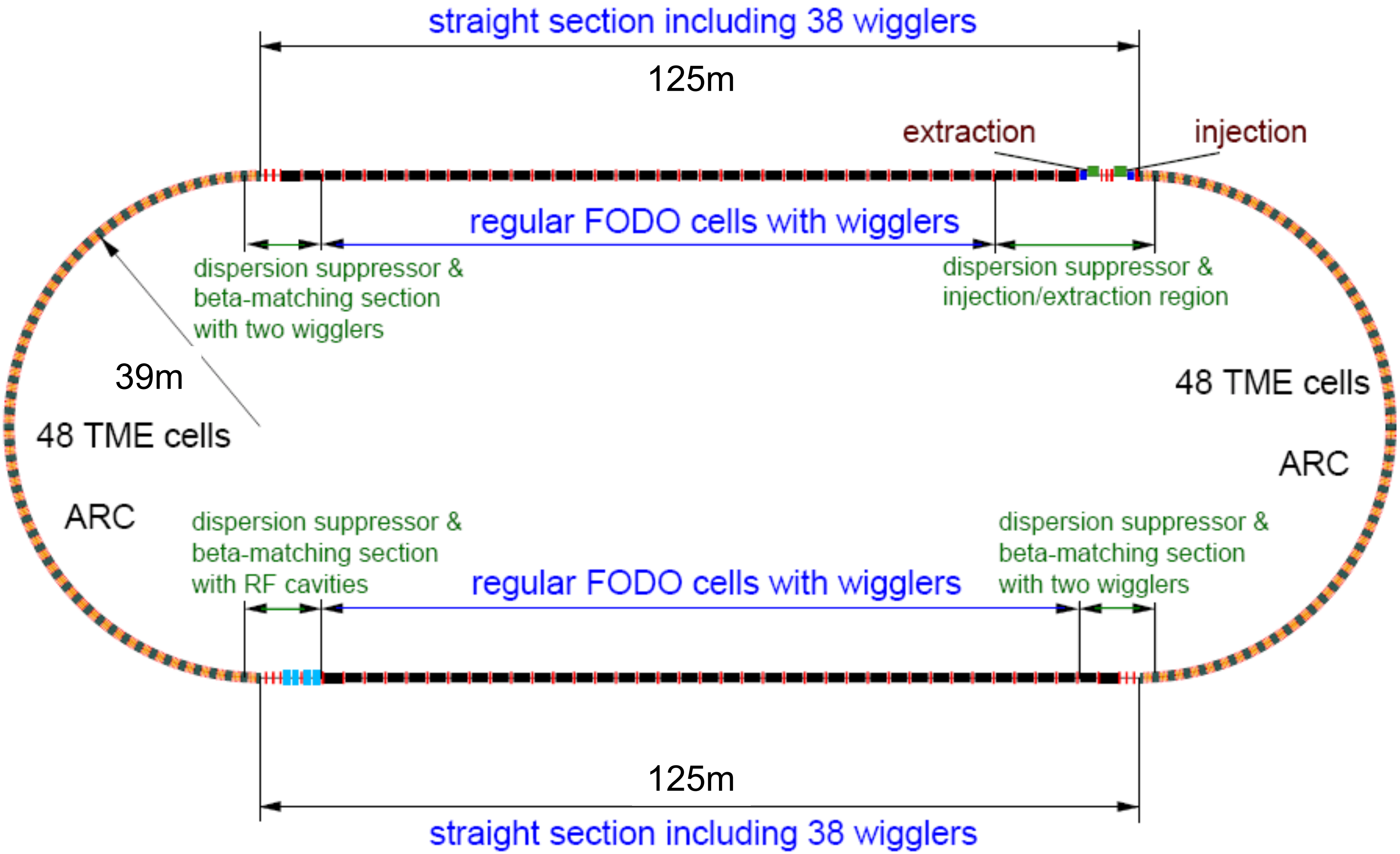
DR design goals and challenges



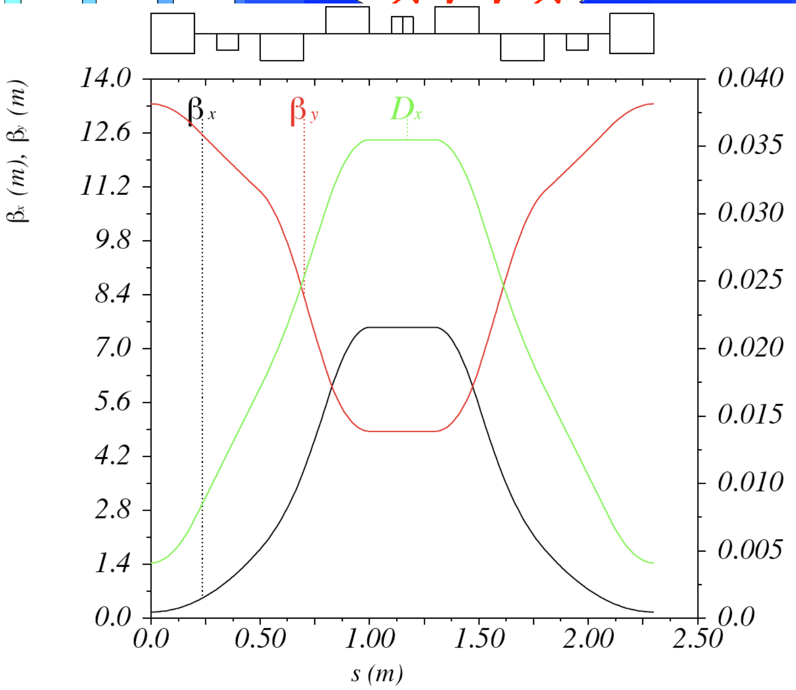
PARAMETER	NLC	CLIC
bunch population (10^9)	7.5	4.1
bunch spacing [ns]	1.4	0.5
number of bunches/train	192	312
number of trains	3	1
Repetition rate [Hz]	120	50
Extracted hor. normalized emittance [nm]	2370	<**500**
Extracted ver. normalized emittance [nm]	<30	<**5**
Extracted long. normalized emittance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

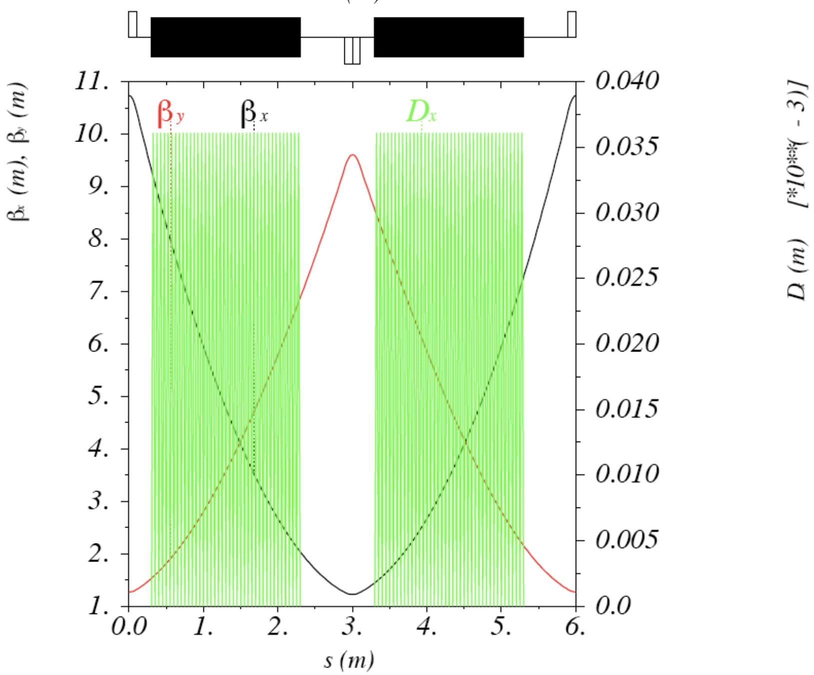
- Design parameters dictated by CLIC target performance (e.g. luminosity), injected beam characteristics or compatibility with the downstream system parameters (RTML)
- Most parameters are **driven** by the main linac RF optimization
- In order to reach ultra-low emittance, CLIC DR design is based on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

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
48 TME cells
ARC
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

DR optics





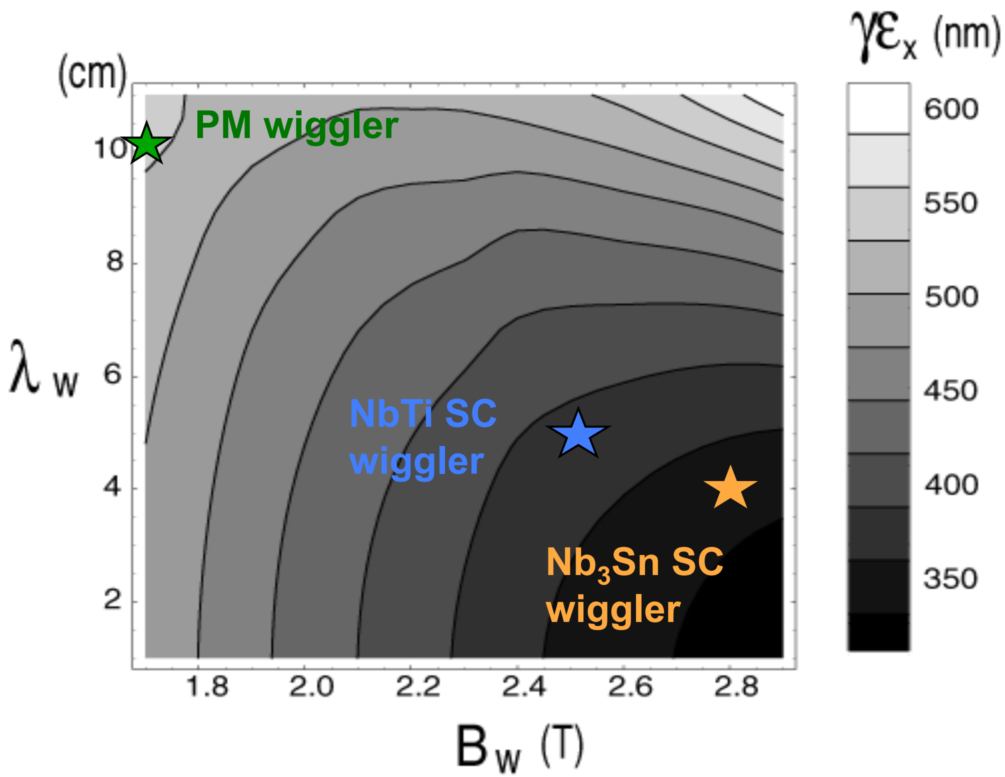
- Two rings of race track shape with ~500m circumference
- Low emittance optics design
  - Minimisation of IBS effect
  - Comfortable dynamic aperture
- Arc formed by 100, 2.3m-long TME cells with combined function dipoles
- Long straight section filled with 6m-long FODO cells incorporating super-conducting damping wigglers
- Maximum beta functions of ~10m and maximum dispersion of ~3.5cm

DR parameters

- Energy of 2.86GeV
  - Energy increase had no impact to RTML
- Low coupling (dispersion invariant)
- High energy loss/turn and required RF voltage
- Low momentum compaction factor (large energy acceptance)
- Fast damping times < 2ms, only one train needed per machine cycle
- IBS grows "zero-current" horizontal emittance by **factor of 2**
- Transverse emittances "just" satisfy the requirement
- Longitudinal beam dimensions controlled with RF voltage

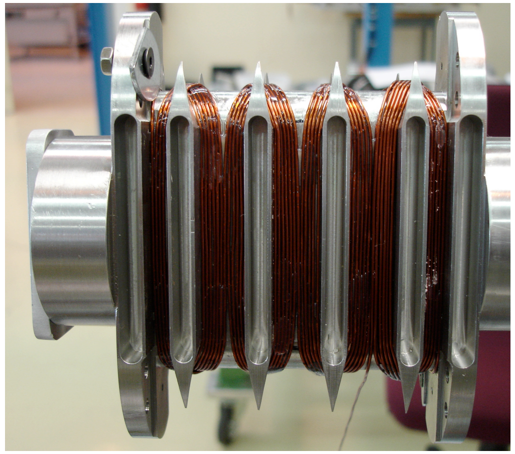
Energy [GeV]	2.86
Circumference [m]	493.05
Coupling [%] / $\langle\mathcal{H}_y\rangle$ [10^{-7}]	0.13 / 2
Energy loss/turn [MeV]	5.9
RF voltage [MV]	7.2
Natural chromaticity hor. / ver.	-149 / -79
Mom. compaction factor [10^{-5}]	6
Damping time x / s [ms]	1.87 / 0.94
Number of arc cells / wigglers	100 / 76
Cell /dipole length [m]	2.30 / 0.4
Bend field [T] / gradient [m^{-2}]	1.27/-1.1
Wiggler field [T] / Wavelength [cm]	2.5 / 4
Bunch population, [10^9]	4.1
IBS growth factor	1.9
Hor. norm. emittance [nm.rad]	**480**
Ver. norm. emittance [nm.rad]	**4.7**
rms bunch length [mm]	1.35
rms energy spread [%]	0.1
Longitudinal emittance [eVm]	3700

Wigglers' effect with IBS



- 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 (NbTi)
  - 2.8T, 4cm period, designed by CERN/Un. Karlsruhe (Nb_3Sn)
- Prototypes built, measured and to be tested in storage rings

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

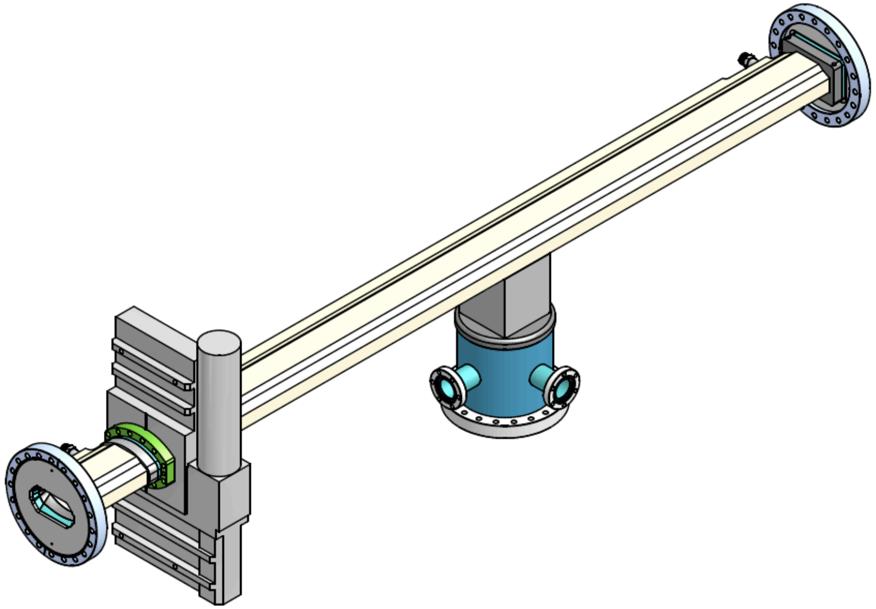


Collective effects in the DR

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 (e.g. NEG, aC)
  - Chamber coated at CERN and to be tested in CESR-TA
- 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 0.2 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)

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

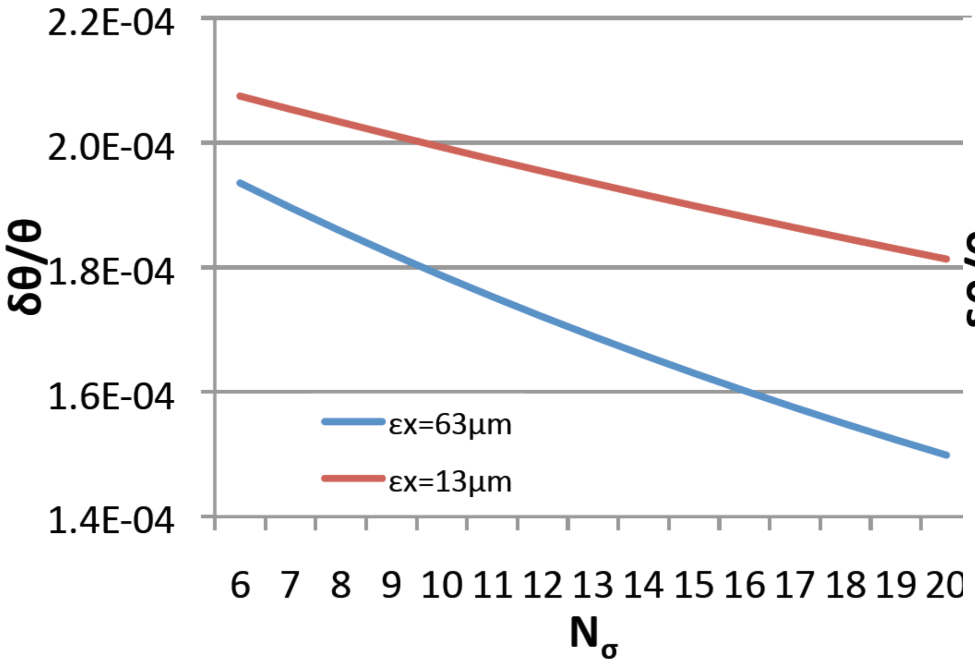
- RF frequency of **2GHz**
  - Power source is an R&D item at this frequency
- High peak and average power of **6.6** and **0.6MW**
- Strong beam loading transient effects
  - Beam power of ~6.6MW during 156 ns, no beam during other 1488 ns
  - Small stored energy at 2 GHz
- Wake-fields and HOM damping should be considered
- RF frequency and peak power can be reduced with an interleaved scheme of 1ns bunch spacing
  - Need of recombination scheme
  - Major impact in upstream and downstream systems

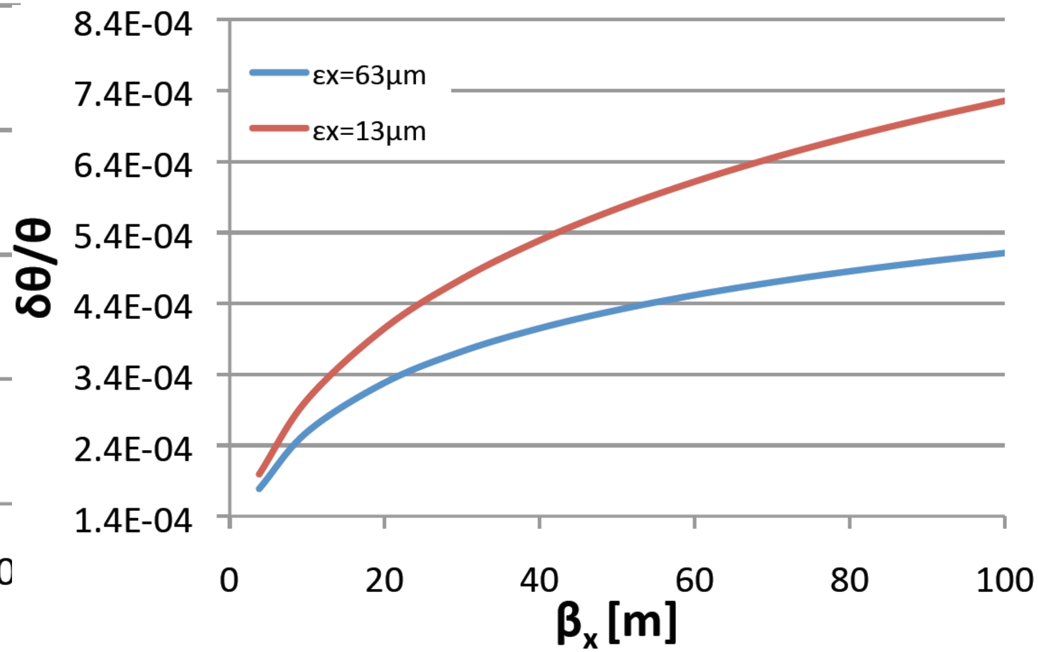
CLIC DR parameters	
Circumference [m]	493.5
Energy [GeV]	2.86
Momentum compaction	0.6×10^{-4}
Energy loss per turn[MeV]	**5.04**
Maximum RF voltage [MV]	**6.5**
RF frequency [GHz]	**2.0**

- 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 **6.5MV** (energy acceptance of **2.6%**)
  - As longitudinal emittance is decreased (3.7 keV.m), horizontal emittance **increased** to **480nm**

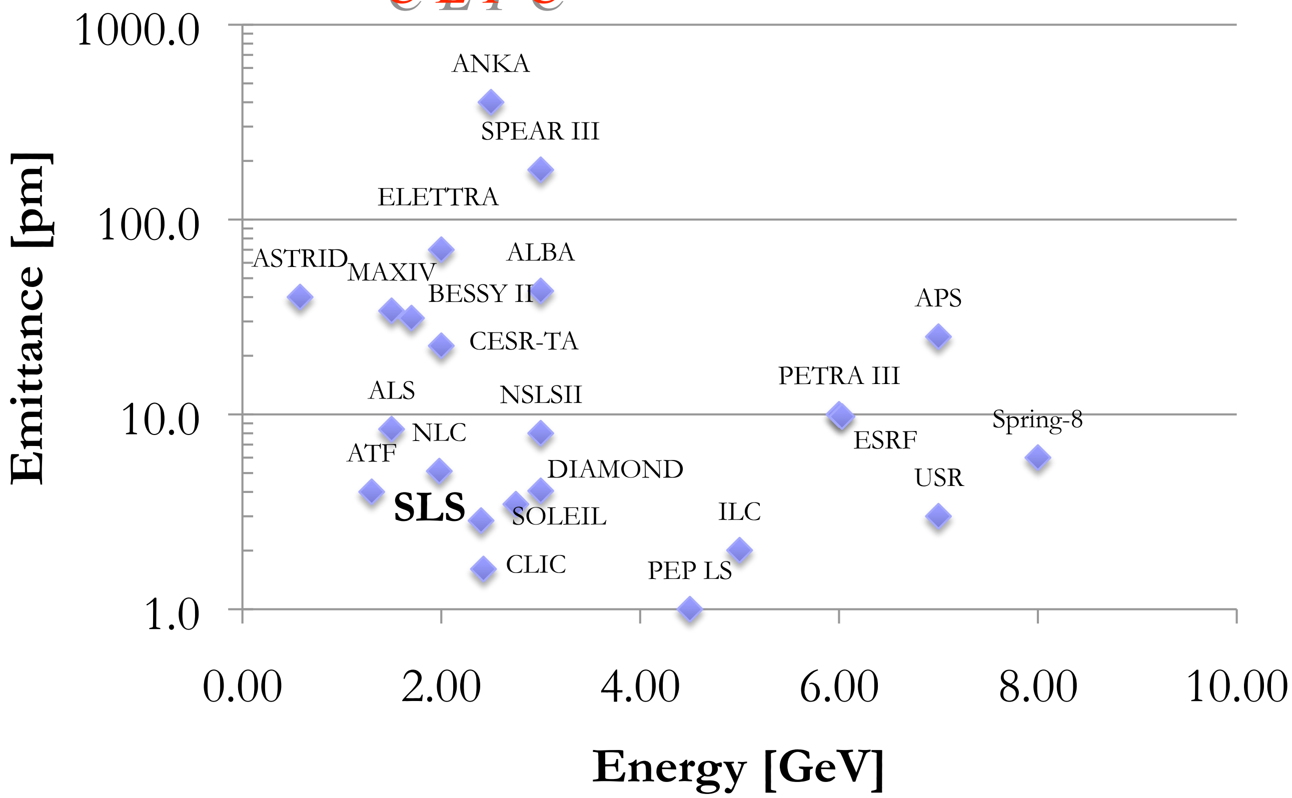
Kicker stability

- Kicker jitter is translated in a beam jitter in the IP.
- Typically a tolerance of $\sigma_{jit} \leq 0.1\sigma_x$ is needed
- Translated in a relative deflection stability requirement as $\dfrac{\delta\theta_{\rm kick}}{\theta_{\rm kick}} \leq \dfrac{\sigma_{\rm jit}}{x_{\rm sep}}$
- For higher positions at the septum (larger injected emittances or lower beta functions) the stability tolerance becomes tighter
- The tolerance remains typically to the order of $\mathbf{10^{-4}}$
- Available drift space has been increased to reduce kicker voltage spec.





Emittances @ 500GeV



NSLSII PARAMETERS	Values
energy [GeV]	3
circumference [m]	791.5
bunch population [10^9]	11.8
bunch spacing [ns]	1.9
number of bunches	700
rms bunch length [mm]	2.9
rms momentum spread [%]	0.1
hor. normalized emittance [μm]	2.9
ver. normalized emittance [nm]	47
lon. normalized emittance [eV.m]	8700
coupling [%]	0.64
wiggler field [T]	1.8
wiggler period [cm]	10
RF frequency [GHz]	0.5

- SLS achieved **~3pm**, the lowest geometrical vertical emittance, at 2.4 GeV, corresponding to ~**10nm** of normalised emittance
- **Below 2pm**, necessitates challenging alignment tolerances and low emittance tuning
- Seems a "safe" target vertical emittance for CLIC damping rings @ 500GeV
- Horizontal emittance of **2.4μm** is scaled from NSLSII parameters, a future light source ring with wiggler dominated emittance and 10% increase due to IBS

Route to 3TeV

- The 3TeV design can be relaxed by **including only a few super-conducting wigglers** (around 10%) and **relaxing the arc cell optics** (reduce horizontal phase advance)
- Another option may be operating a **larger number of super-conducting wigglers at lower field** of around 2T.
- The same route can be followed from conservative to nominal design, considering that some time will be needed for low-emittance tuning (reducing the vertical emittance)
- Considering the same performance in the pre-damping rings, the 500GeV design **relaxes the kicker stability requirements** by more than a factor of 2
- The **dynamic aperture** of the DR should be also more **comfortable** due to the relaxed arc cell optics
- **Energy loss/turn** will be **significantly reduced** (a factor of 4-5) and thereby the **total RF voltage needed**

Bunch charge @ 500 GeV

- Bunch charge of **1.1 x 6.8x10^{9}p** for 354 bunches corresponds to an average current of **350mA** (170mA for the CLIC DR baseline parameters)
- **Damping time** will be inevitably increased to **4-5ms** which is **quite long** for **50Hz** repetition rate
- **Staggered trains** may be needed
- This corresponds to a beam current of at least **700mA**, i.e. good HOM damping design for RF cavities but also lower transients
- Rise time and flat top of kicker should be shortened (factor of 2)
- Absorption scheme has to be reviewed for higher radiation power per wiggler, but lower total power
- All collective instabilities increase with the bunch charge but there is a significant reduction due to the increased emittance (charge density is reduced)
- Total impedance will be lower due to less wiggler gaps and absorbers

Summary

- Revised DR lattice in order to be less challenging with respect to magnets, layout and IBS (key feasibility item)
- DR emittance dominated by super-conducting wigglers
- Collective effects (e-cloud, FII) remain major performance challenges
- RF system present challenges with respect to transients and power source at the DR frequency (true for the whole injector complex)
- Stability of kickers challenging, as for all DRs and even modern storage rings (top-up operation)
- Established conservative and nominal DR parameters for CLIC @ 500GeV
- DR satisfies all requirements from upstream and downstream systems
  - No margin for further emittance reduction at the exit of DR
  - Jitter tolerances for current and timing have to be established