Electron-Cloud Effects in the TESLA and CLIC Positron Damping Rings

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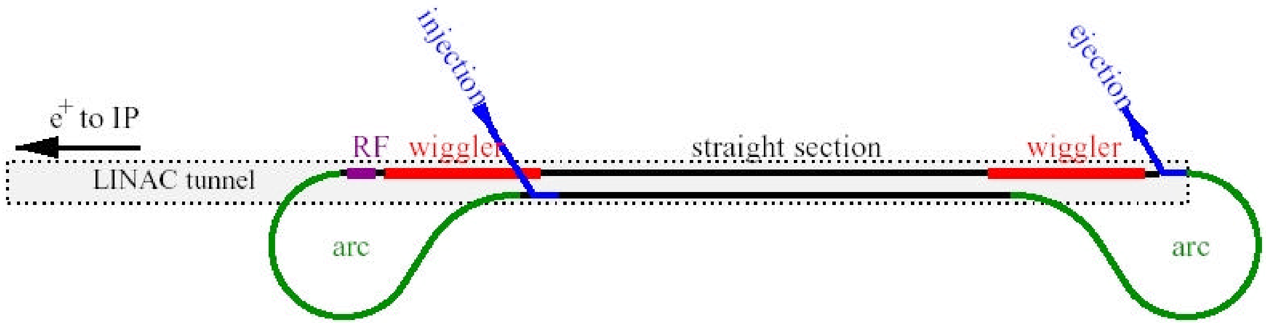
Outline

- The TESLA Damping Ring
- The CLIC Damping Ring
- Simulations: Electron cloud build-up
- Single Bunch Instabilities
  - Broad Bunch Impedance Model
  - Strong head tail instabilities
- Conclusion

The TESLA DR



	TESLA DR	
Parameter		
energy	5	GeV
circumference	17000	m
rev. freqency	17.6	kHz
current	160	mA
# bunches	2820	-
N / bunch	2	E+10
bunch spacing	**20**	**ns**
Emittance x/y	0.82 / 0.002	nm
Qx / Qz	72 /44	-
Qs	0.07	-
sz	6	mm

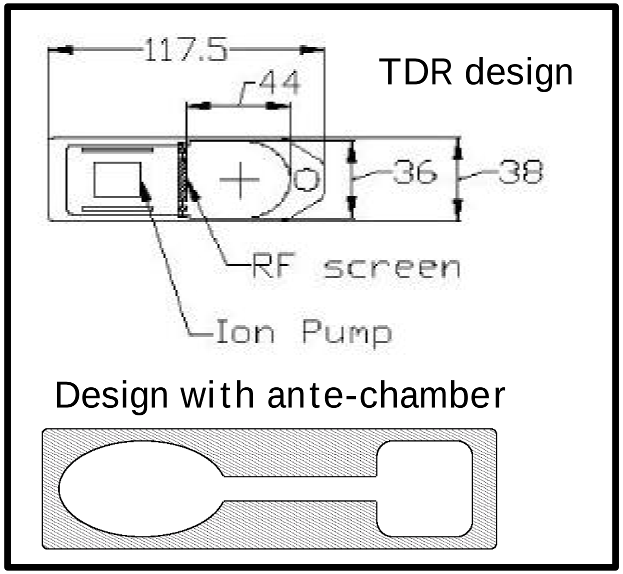
Dogbone shape, integrated in the main linac tunnel.

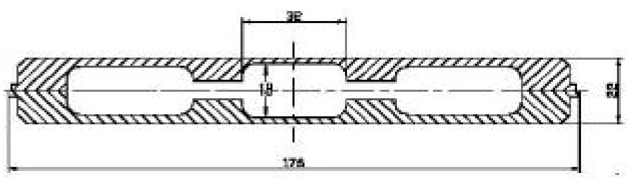
main sections:

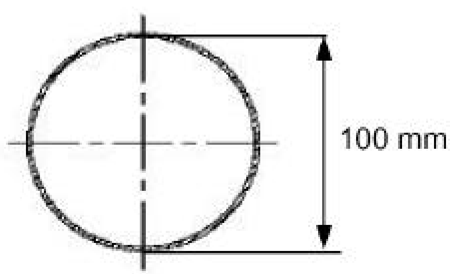
•arc	1900 m	11 %
•straight	14560 m	86 %
•wiggler	540 m	3 %
	17 km	100 %

arc: dipole field 0.2 T
wiggler: peak field 1.6 T

TESLA DR vacuum chamber







	horz. semi axis /mm	vert. semi axis /mm		horz. beam size / µm	vert. beam size / µm
Arc	22	18		103	7
Straigth	50	50		346	346
Wiggler	16	9		93	5

photo-electrons / m / e+

Arc: a) 0.124 (Y = 0.1)

b) 0.0124 (Y = 0.01, ante-chamber)

Wiggler: 0.104 (Y = 0.01, ante-chambers)

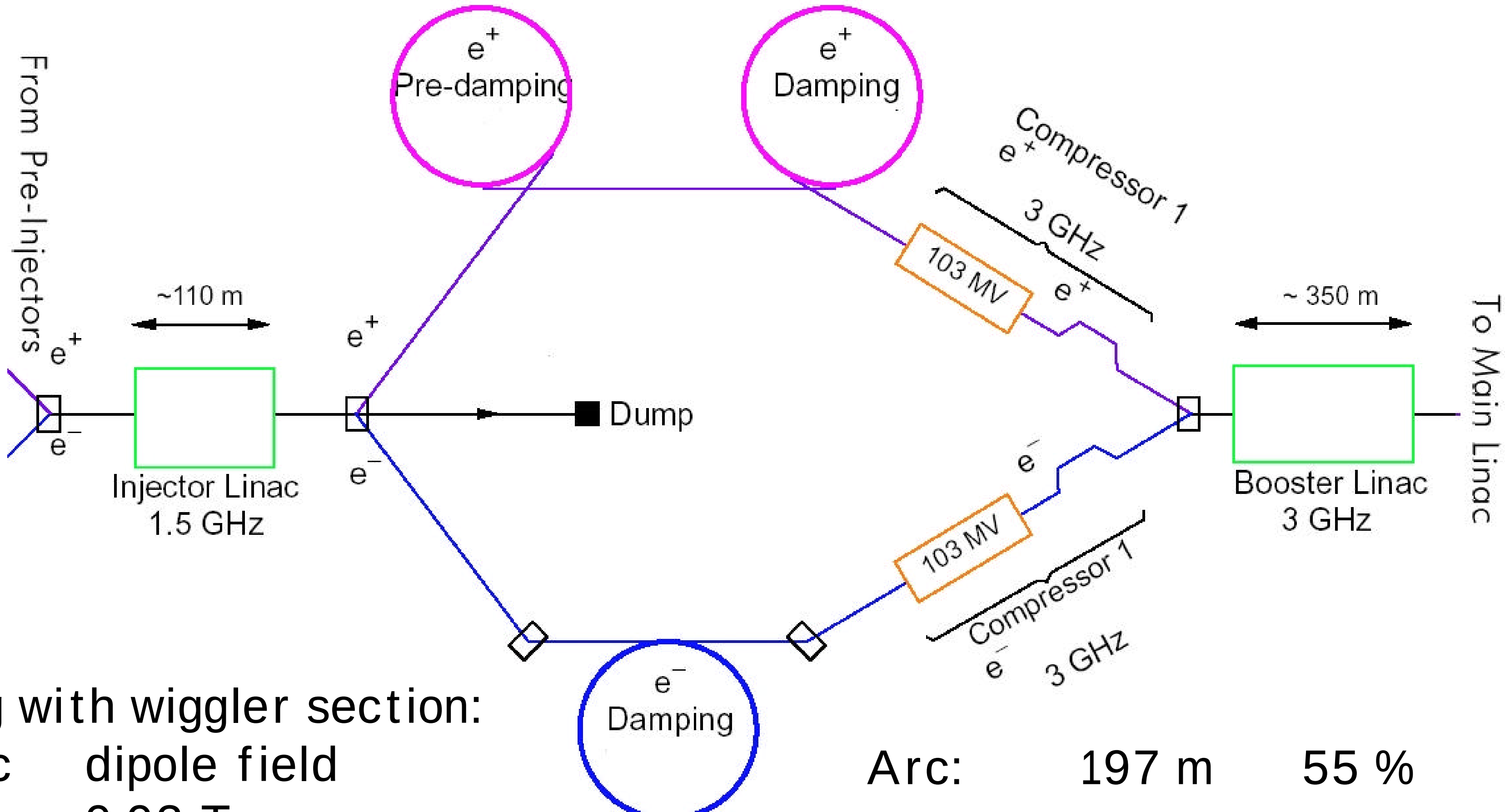
Straight: ionization

4×10^{-9}

scattered synchrotron light

0.0001 (Y = 0.1)

The CLIC Damping Ring



Ring with wiggler section:

- Arc dipole field 0.93 T
- Wiggler peak field 1.76 T

Arc:	197 m	55 %
Wiggler:	160 m	45 %
	357 m	100 %

CLIC e+ DR: parameter and vacuum chamber

Parameter	CLIC DR	
energy	2.4	GeV
circumference	357	m
rev. freqency	839	kHz
#bunch trains	9	
current	9 x 103	mA
# bunches / train	154	-
N / bunch	0.5	E+10
bunch spacing	**0.667**	**ns**
Emittance x/y	0.131 / 0.002	nm
Qx / Qz	72 /34	-
Qs	0.004	-
?z	1.3	mm

Assumed chamber design
(similar to TESLA DR)
Arc:

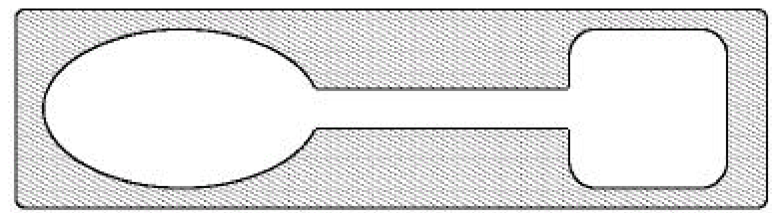


photo-electrons / m / e+
0.058 (Y=0.01 ante-chamber)

Wiggler:

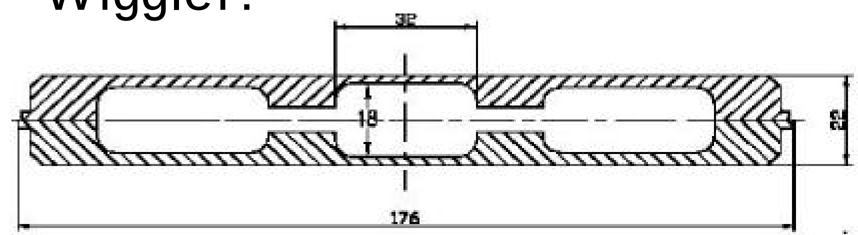
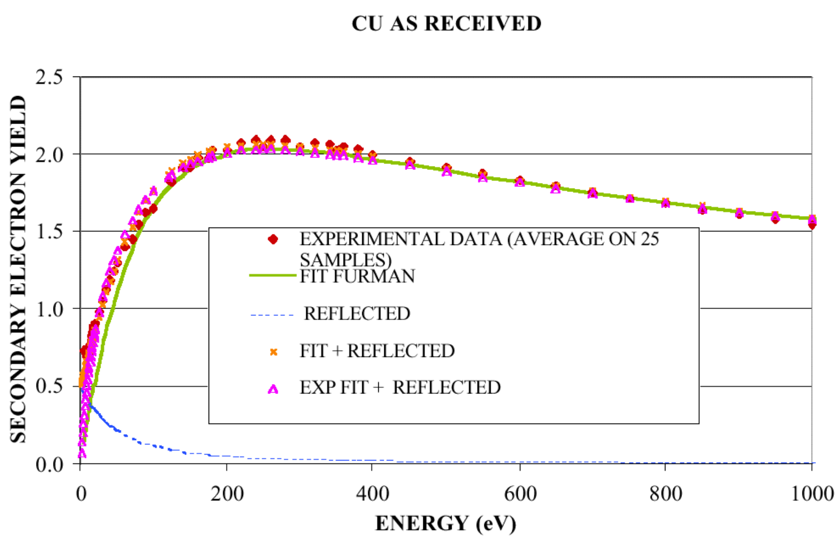


photo-electrons / m / e+
0.109 (Y=0.01 ante-chamber)

Simulations: Electron cloud build-up

Electron build-up code: **ECLOUD**
CERN,
D. Schulte, F. Zimmermann et al.

Secondary Emission Yield (S.E.Y.)
N. Hilleret et al. , CERN



simulation: (1 m of chamber)
- macro electrons
- periodic boundary conditions in z
- external magnetic fields
- space charge fields
- image charges
- secondary emission

maximum Yield δ_{max}
at energy E_{max} of
primary electron
E_{max}~ 300 eV

$$d(E) = d_{\max} \frac{s\,(E/E_{\max})}{(s-1)+(E/E_{\max})^{s}}$$

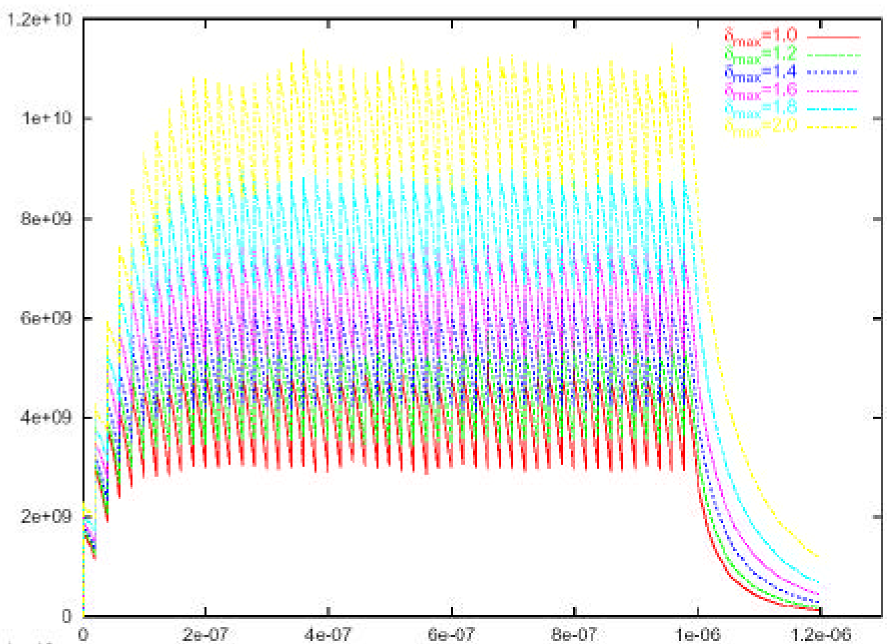
After processing:

Cu	1.4
Al	2.2

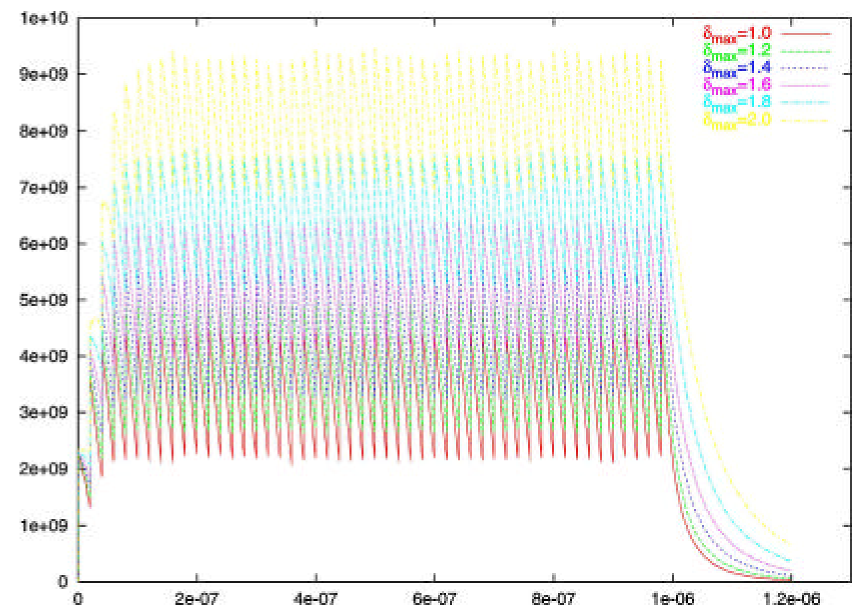
Simulation: TESLA DR arc

Ecloud population per meter (line density)
in the arc
for different secondary emission yields:

bending magnet of the arc
0.124 photoelectrons per positron / m



Field free region of the arc
0.124 photoelectrons per positron / m

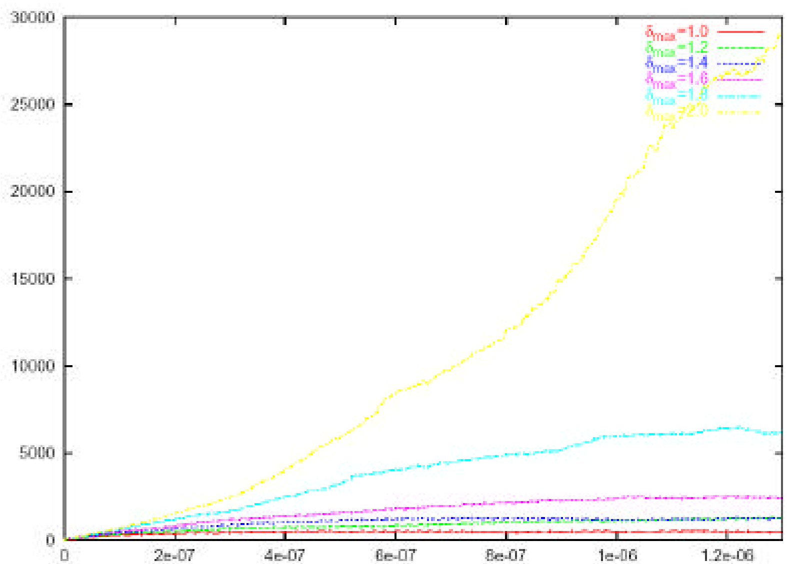


Simulation: TESLA DR straight

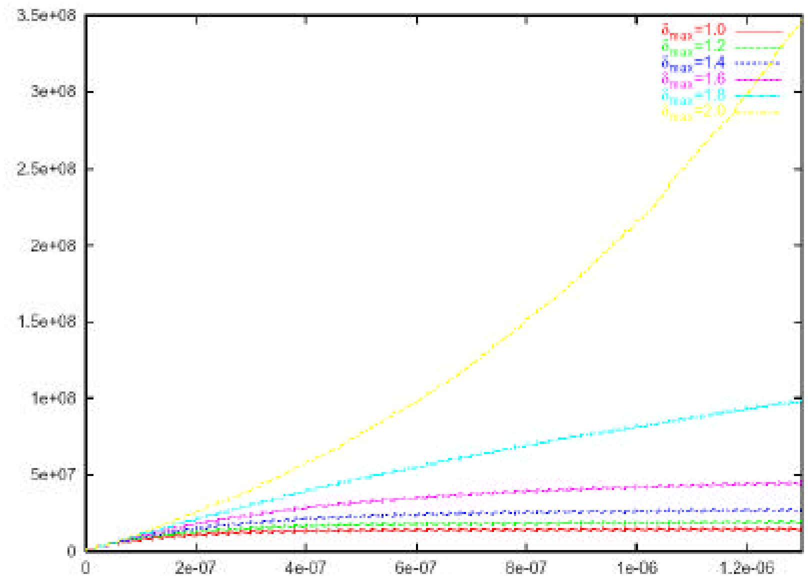
Ecloud population per meter (line density)
in the straigth section
for different secondary emission yields:

$\delta_{max} < 1.6$ => almost no electron cloud

primary electrons created by ionization
4×10^{-9} electrons per positron / m



electrons created from scattered synchrotron ligth
0.0001 photoelectrons per positron / m



Simulation: TESLA DR wiggler

Different models for the wiggler field:

a) dipole

b) $B_r = \sum c_{mn} I'_m (nk_z r) \sin(mf) \cos(nk_z z)$

$$B_f = \sum c_{mn} \frac{m}{nk_z r} I_m (nk_z r) \cos(mf) \cos(nk_z z)$$

$$B_z = -\sum c_{mn} I_m (nk_z r) \sin(mf) \sin(nk_z z)$$

c)

$$B_y = B_0 \cosh\left(\frac{2p}{l} y\right) \cos\left(\frac{2p}{l} z\right),$$

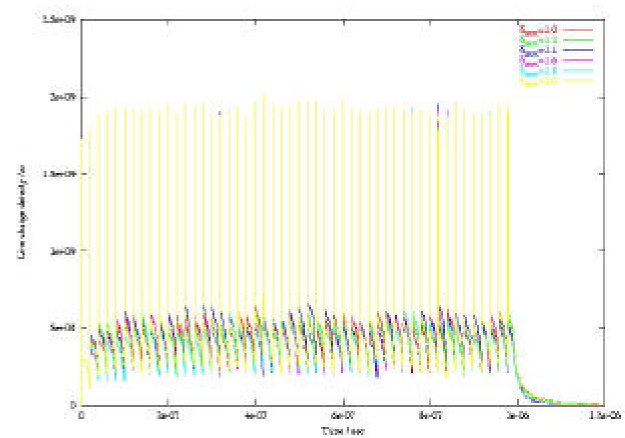
$$B_z = B_0 \sinh\left(\frac{2p}{l} y\right) \sin\left(\frac{2p}{l} z\right)$$

b) and c) have been recently implemented in ECLOUD 2.4

Wiggler field, ante chamber:
0.1038 photoelectrons per positron / m

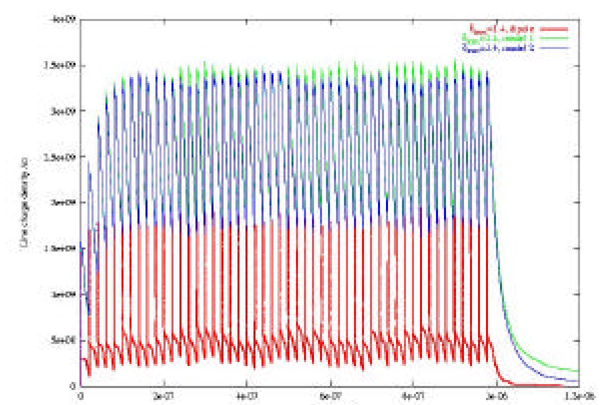
Ecloud population per meter (line density), δ_{max} = 1.0 ... 2.0

dipole:



δ_{max} = 1.4

dipole
model b)
model c)



Simulation of the TESLA DR

Results for the central volume density of the cloud

Arc: $0.5 \ldots 4.0 \times 10^{12}\ m^{-3}$ depending on δ_{max}

Straigth: $< 1.0 \times 10^{8}\ m^{-3}$ for $\delta_{max} < 1.6$

Wiggler: $0.1 \ldots 6.0 \times 10^{12}\ m^{-3}$ depending on δ_{max} and on the model

Neutralization cloud density:

Arc: $2.7 \times 10^{12}\ m^{-3}$

Straight: $0.4 \times 10^{12}\ m^{-3}$

Wiggler: $5.8 \times 10^{12}\ m^{-3}$

→ **Improvements of the vacuum chamber design:**

Arc: Cu plated chamber $\delta_{max} = 1.4$
Ante chamber
cloud $\sim 0.75 \times 10^{12}\ m^{-3}$

Straigth:
Cu plated chamber
cloud $< 1.0 \times 10^{8}\ m^{-3}$

Wiggler: (R&D needed)

understand the different models

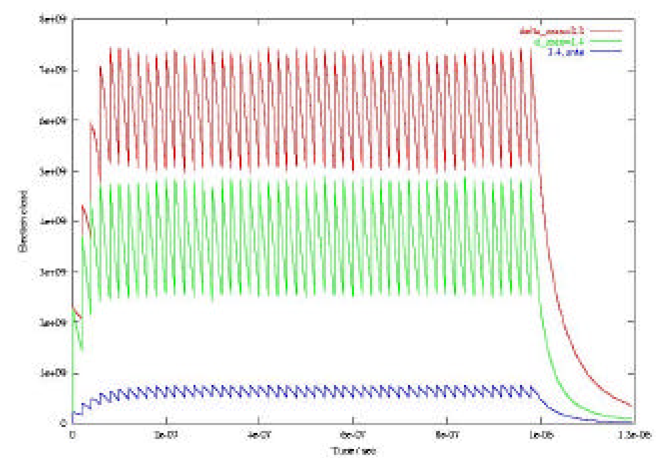
Cu plated chamber or TiN coated chamber ?

Arc: Ecloud population per meter (line density)

$\delta_{max} = 2.2$

$\delta_{max} = 1.4$

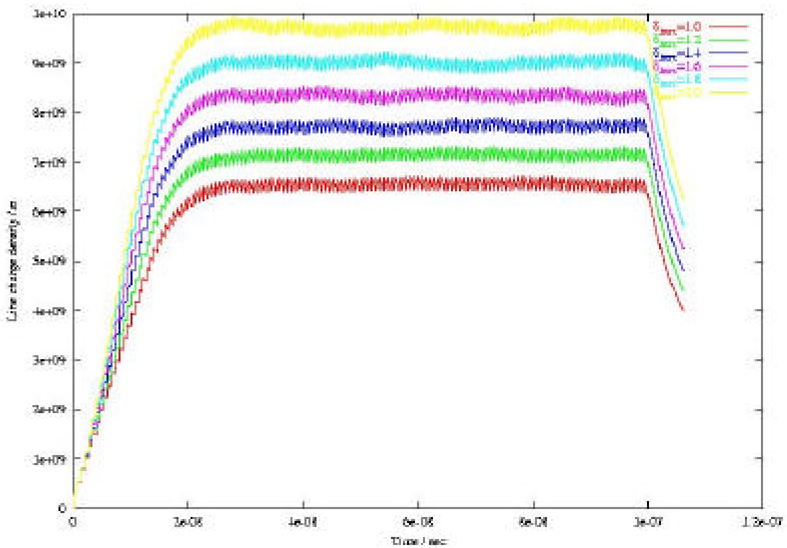
$\delta_{max} = 1.4$ ante ch.



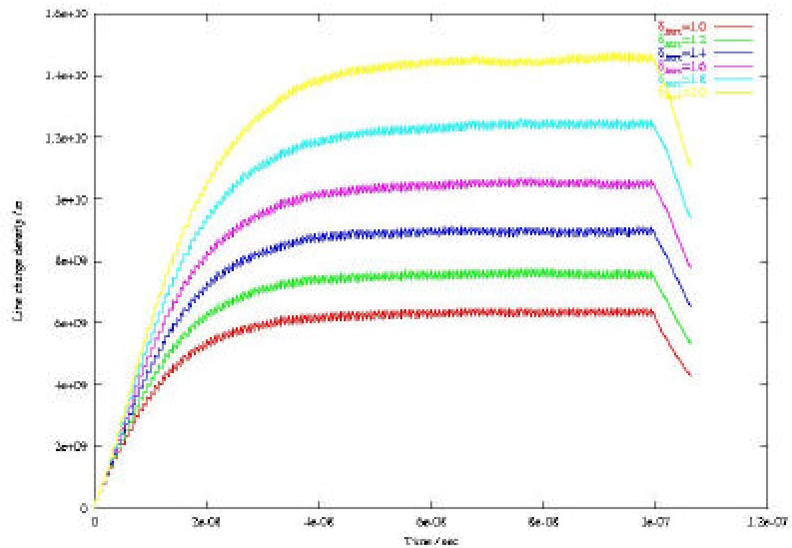
Simulation CLIC DR: arc

Ecloud population per meter (line density)
in the arc
for different secondary emission yields:

bending magnet of the arc
0.0576 photoelectrons per positron / m



Field free region of the arc
0.0576 photoelectrons per positron / m

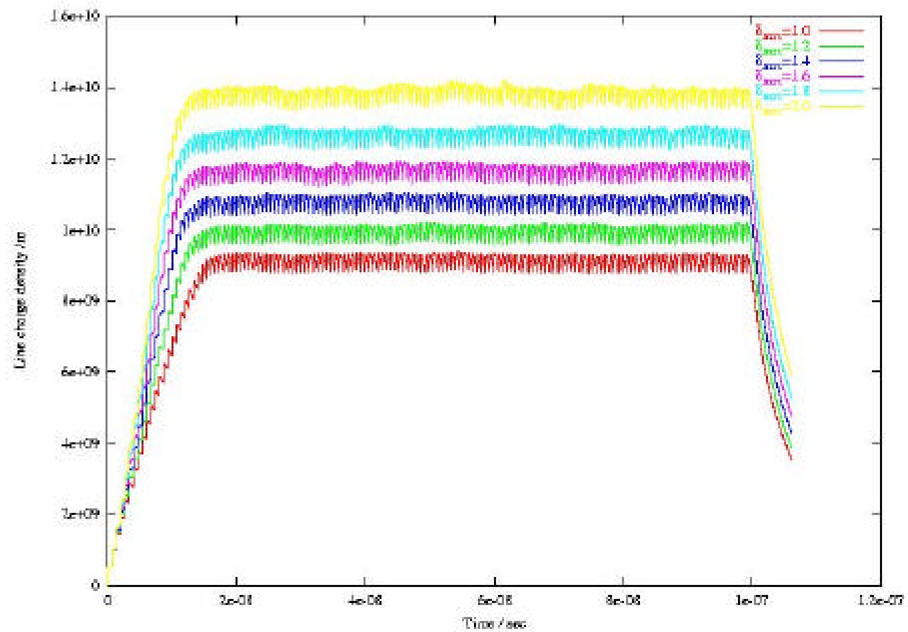


Simulation CLIC DR: wiggler

Ecloud population per meter (line density)
in the arc
for different secondary emission yields:

wiggler: dipole model (constant field)
0.109 photoelectrons per positron / m

work in progress:
other wiggler model



Simulation of the CLIC DR

Results for the central volume density of the cloud

Arc: ~ 95 x 10^{12} m^{-3} δ_{max} = 1.0 ... 2.2

Wiggler: ~ 330 x 10^{12} m^{-3} δ_{max} = 1.0 ... 2.2
dipole field model

Neutralization cloud density:

Arc: 20.1 x 10^{12} m^{-3}

Wiggler: 43.4 x 10^{12} m^{-3}

→ Local volume densities are higher than the Neutralization densities probably due to strong pinch effects.

The wiggler section dominates the ecloud effects

Single Bunch Instabilities

Broad Band Resonator Model
(Ohmi, Zimmermann, Perevedentsev
CERN-SL-2002-011 AP)

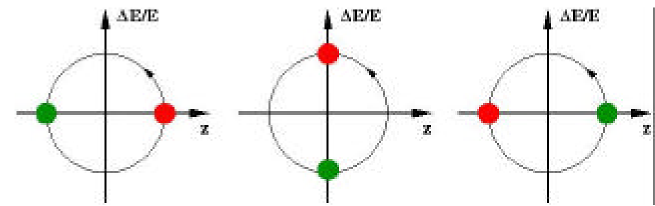
$$W_1(s) = \hat{W}_1 \; \sin(w_c \tfrac{s}{c}) \;\; \exp(-\tfrac{1}{2Q_r} w_c \tfrac{s}{c})$$

$$\hat{W}_1 = \frac{g}{r_e c^3} \frac{1}{l_{beam}} w_b{}^2 \, w_c \, C$$

From simulations
cloud density

beam intensity

Strong Head Tail Instability,
two particle model



The strong head-tail mode
is stable, if

$$Y = \frac{1}{mc^2 g} e^2 N \frac{W_\perp}{C} \frac{p}{2} \frac{c^2}{w_b \, w_s} < 2$$

$$W_\perp(s_z) = \int_0^\infty dx \;\; g(s_z - x) \, W_1(x)$$

TESLA DR: Single Bunch Instabilities

Comparison: Wakefield from the ecloud / Wake for strong head tail instability threshold

	Arc	Straight	Wiggler	**TEASLA DR**
Length / m	1900	14560	540	17000
worst case scenario				
cloud charge density / 10^{12} m^{-3}	2.7	0.4	5.8	0.85
effective wake field / threshold wake	0.577	0.59	0.359	**1.526**
pessimistic scenario				
cloud charge density / 10^{12} m^{-3}	0.75	0.01	5.8	0.28
effective wake field / threshold wake	0.161	0.014	0.359	**0.521**

worst case scenario: neutralization density in all sections

pessimistic scenario: improved chamber design in the arc
and the straigth section,
neutralization density in the wiggler

=> below instability threshold

CLIC DR: Single Bunch Instabilities

Comparison: Wakefield from the ecloud / Wake for strong head tail instability threshold

	Arc	Wiggler	**CLIC DR**
Length / m	197	160	357
scenario 1: neutralization density			
cloud charge density / 10^{12} m^{-3}	20.1	43.4	30.5
effective wake field / threshold wake	0.39	0.72	**1.11**
scenario 2: simulation			
cloud charge density / 10^{12} m^{-3}	95.0	350.0	209
effective wake field / threshold wake	1.8	5.8	**7.6**

scenario 1: neutralization density in all sections

=> at ~ instability threshold

scenario 2: local volume densities from simulations

Main problem: strong pinch effects

=> above instability threshold

Conclusion

- TESLA DR, dogbone shape, long straigth section
- CLIC DR, arc length ~wiggler length
- ECLOUD 2.4 has been used to calculate the cloud density
- Simulation TESLA DR: improvements in the vacuum chamber design:
  - arc and straight: Cu plated chamber
  - arc: ante chamber
- Simulation CLIC DR: large central volume densities predicted
- Single bunch instabilities: Broad band impedance model, strong head tail instabilities
  - TESLA DR: below threshold with improved vacuum chamber design
  - CLIC DR: main problem; pinch effect, further R&D needed