Electron cloud studies for the CLIC damping rings

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in CLIC Seminar 06.06.2007

- Introduction:
  - CLIC damping ring parameters
  - Faktor2 for e-cloud build-up simulations
- E-cloud build up in CLIC-DR:
  - Arcs and wigglers
  - With and without ante-chamber
  - Dependence on photoemission and secondary emission yields
- Beam instability driven by e-cloud
- Conclusions

Updated list of parameters → last column

Damping rings' parameter evolution

- At injection:
  - $(\varepsilon_x,\varepsilon_y)=(60,1.5)\mu m$
  - $\sigma_s=10mm$
  - $\sigma_\delta=0.5\%$
- No impact to output parameters

PARAMETER	2005	2006a	2006b	2007a	2007b
energy [GeV]	2.424				
circumference [m]	360	365.2			
bunch population [E+09]	2.56+5%			5.20+5%	4.00+5%
bunch spacing [ns]	0.533			0.667	
number of bunches/train	110			311	
number of trains	4			1	
store time/train [ms]	13.3			20	
rms bunch length [mm]	1.55	1.51	1.59	1.49	1.53
rms momentum spread [%]	0.126	0.136	0.130	0.138	0.135
hor. normalized emittance [nm]	540	380	308	443	386
ver. normalized emittance [nm]	3.4	2.4	3.9	4.3	4.1
lon. normalized emittance [eV.m]	4725	5000	4982	4998	4993
(horizontal, vertical) tunes	(69.82, 34.86)	(69.82, 33.80)			
coupling [%]	0.6		0.13		
ver. dispersion invariant [μm]	0		0.248		
wiggler field [T]	1.7	2.5			
wiggler period [cm]	10	5			
energy loss/turn [MeV]	2.074	3.903			
hor./ver./lon./ damping times [ms]	2.8/2.8/1.4	1.5/1.5/0.75			
RF Voltage [MV]	2.39	4.25	4.185	4.345	4.280
number of RF cycles	2			1	
repetition rate [Hz]	150			50	
RF frequency [GHz]	1.875			1.499	

From Y. Papaphilippou, in CLIC-Parameter-WG

More parameters needed for the simulations (I)

Description	Unit	Value
Average β_x dipoles	m	0.5
Average β_y dipoles	m	0.5
Average β_x wigglers	m	4.0
Average β_y wigglers	m	4.0
Number of bends		96
Dipole length	m	0.545
Number of wigglers		76
Wiggler length	m	2
Momentum compaction α		8.02×10^{-5}
Hor. chromaticity Q'_x		2.03
Vert. chromaticity Q'_y		-0.24

From M. Korostelev's design, thanks to Y. Papaphilippou

$\Rightarrow$ Average beta functions together with the emittances define the **average bunch transverse sizes** over tha arcs and the wigglers

$\Rightarrow$ Number and length of dipoles and wigglers define the fraction of the ring covered by those elements and therefore a **scaling factor for the e-cloud density** to be used in instability simulations

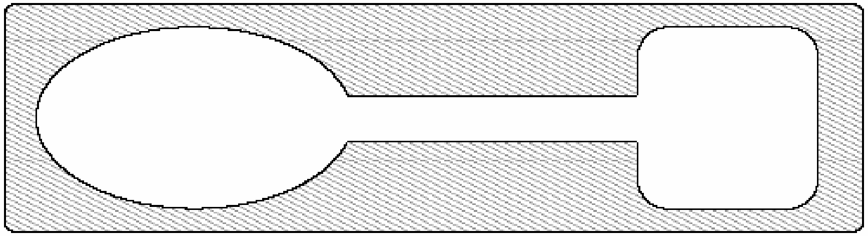
More parameters needed for the simulations (II)

Vacuum chamber dimensions

	CLIC DR Arc	CLIC DR Wiggler
horizontal semi axis /mm	22	16
vertical semi axis /mm	18	9
antechamber-slot half height		3
chamber area /cm^2	12.4	5.8

D. Schulte, R. Wanzenberg, F. Zimmermann, in Proceed. ECLOUD'04

Design of the vacuum chamber with antechamber in the arcs and wigglers



The antechamber absorbs 90 to 99.9% of the synchrotron radiation and gives a photoemission yield in the main chamber 10 to 1000 times lower than in a design w/o antechamber

Photoemission yields

	CLIC DR Arc	CLIC DR Wiggler
N_0 /10^{10}	0.5	0.5
ρ/m	8.67	4.58
dN_γ/dz [/e^+/m]	5.764	10.903
$Y_{\rm eff}$	0.01	0.01
dN_{e^-}/dz [/e^+/m]	0.0576	0.109
$dN_{e^-}/dz^{\rm ion}$ [/$^{e+}$/m]	4×10^{-8}	4×10^{-8}

Description of Faktor2

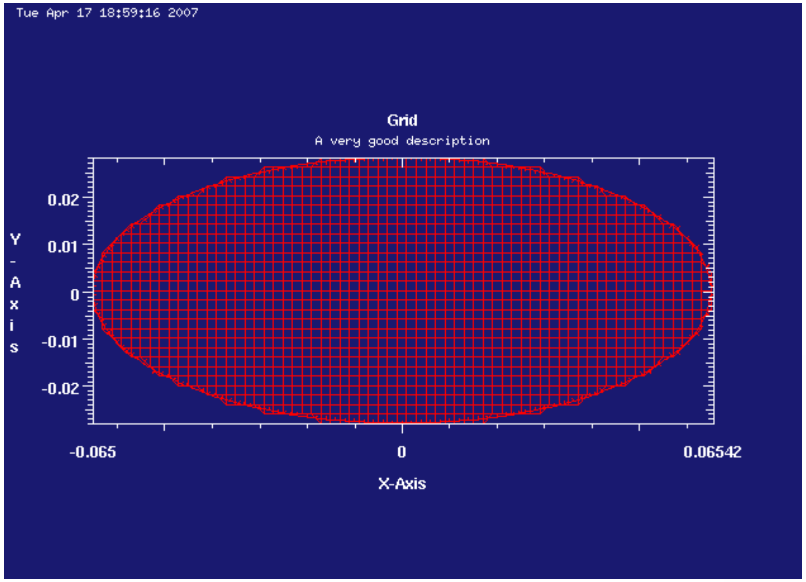
- **Faktor2** is a new code written by W. Bruns that can simulate **electron cloud build up** around positron or hadron beams, or **ion accumulation** around electron beams
- Primary generation of electrons currently can be both from gas ionization and from photoemission

→ **Secondary emission** or **elastic reflection** at the pipe wall

- Both electrons and ions produced from residual gas ionization are tracked in the beam field and in their own space charge field
  - Semianalytical solution (model by D. Schulte) enormously increased the speed of tracking in a dipole field
- EM Boundary conditions on a boundary of arbitrary shape can be assigned
  - Perfectly conducting wall
  - Different potentials (clearing electrodes)
  - E.g., antechambers can be simulated
- The beam does not feel the effect of the electron or ion cloud

Sample result from benchmark with ECLOUD for elliptical chamber in the SPS

→ Presented in CLIC Beam Dynamics Meeting 18.04.2007

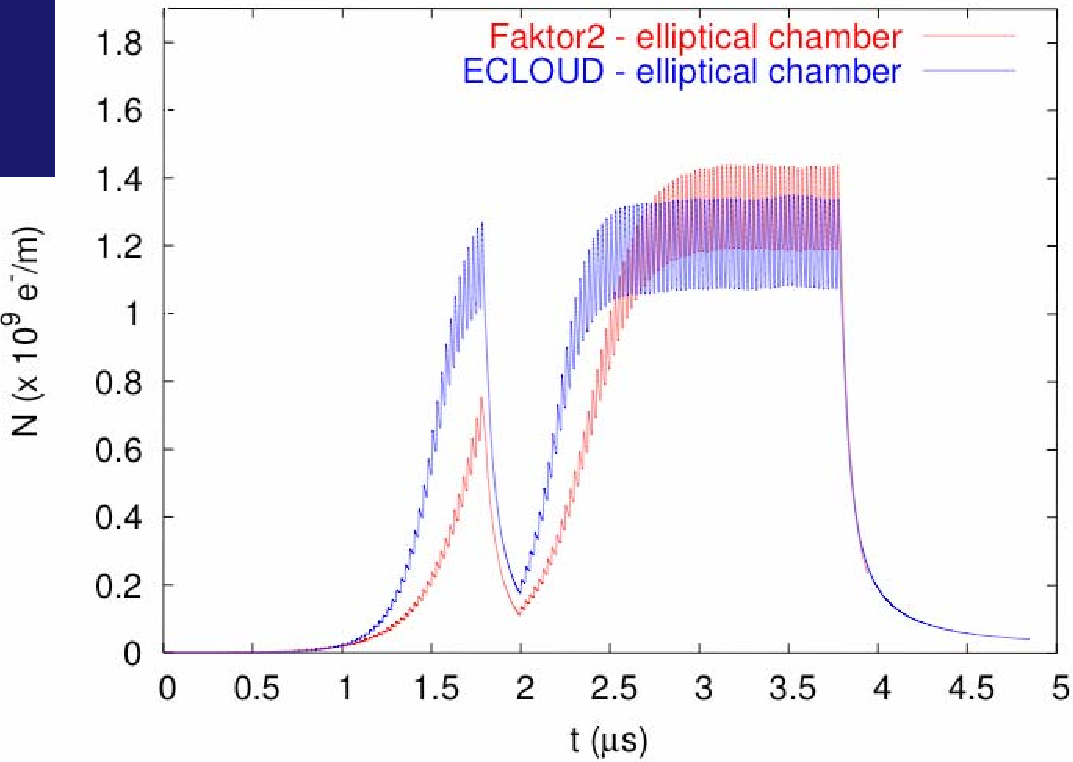


In ECLOUD:

- P_{rg}=*9* nTorr, σ_i=*2* Mbarn
- 2000 pairs per bunch

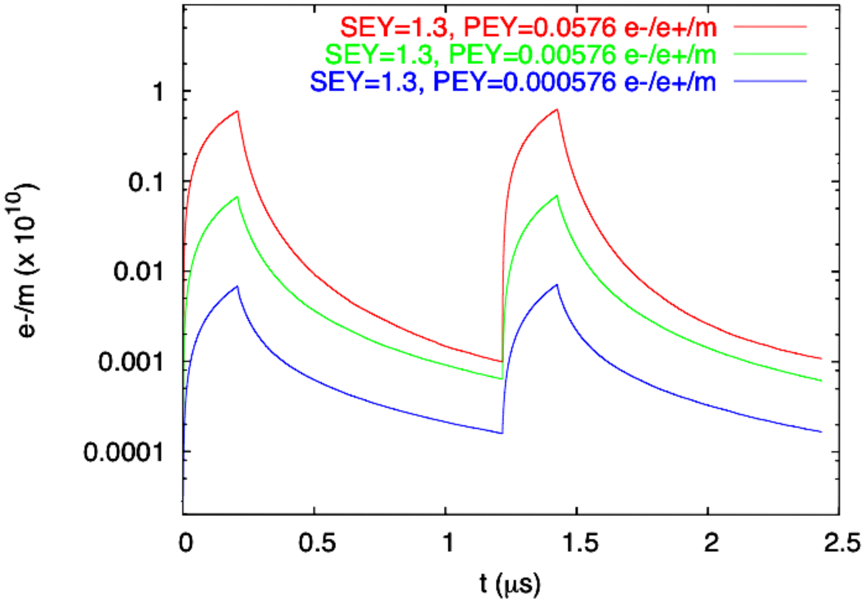
In Faktor2:

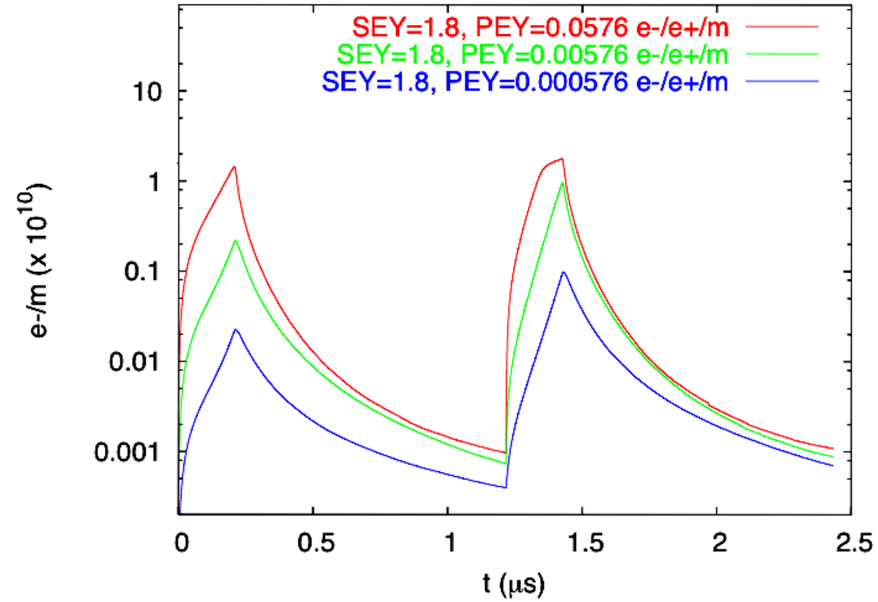
- *0.25 x 10*$^{-6}$ pairs per particle per meter
- 2000 pairs per bunch

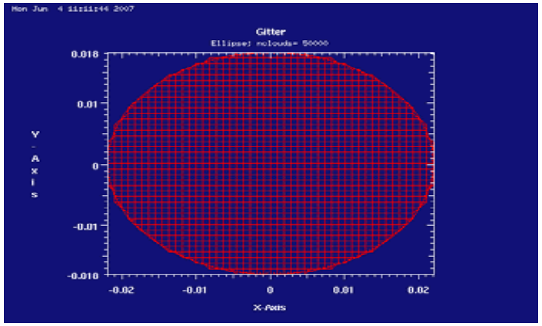


Electron cloud build up in the arcs of the damping ring (I)

Averaged electron density over the chamber cross section (electron line density)





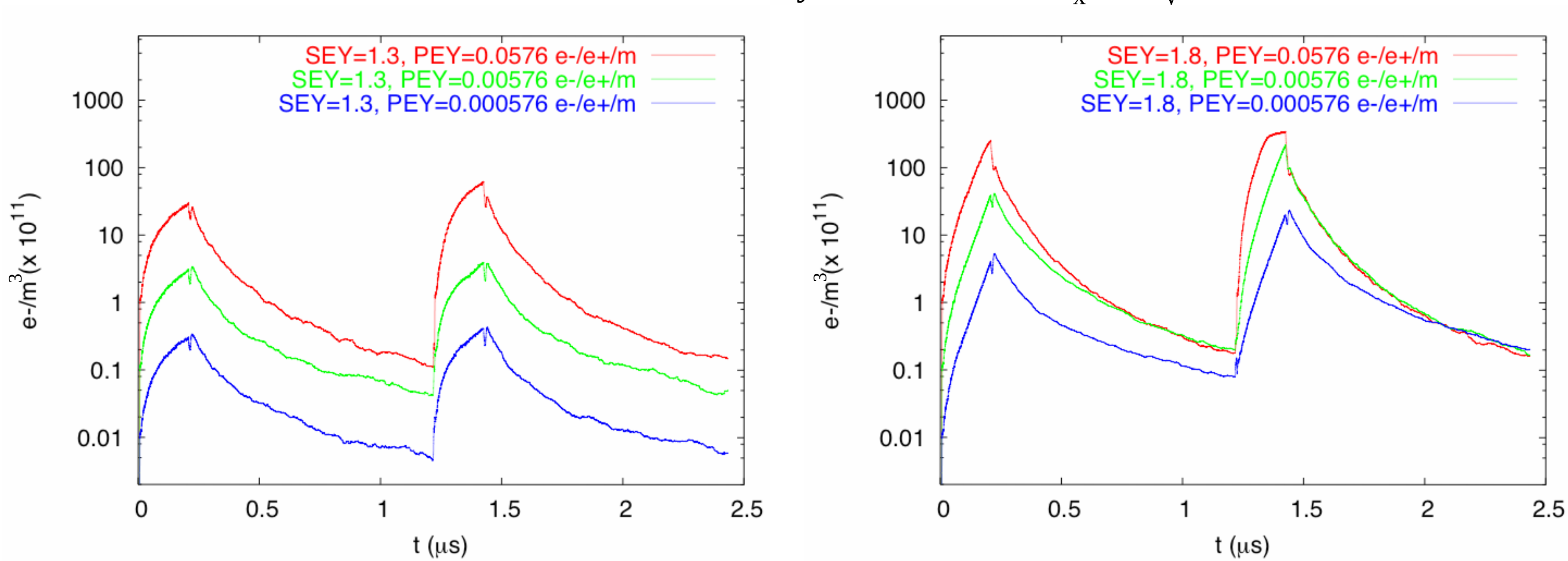


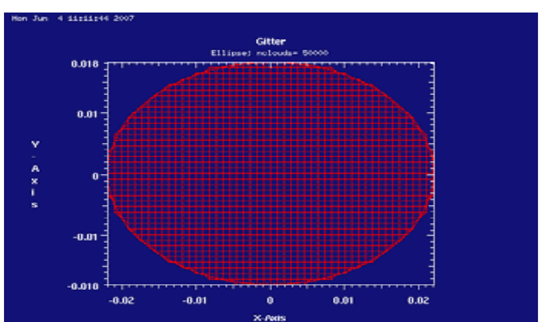
→ 3 different values of the PhotoEmission Yield (PEY) have been used, modeling 90, 99, 99.9% absorption of the radiation into the antechamber

→ The final average density in the chamber (10^8-10^{10} e^-/m) hardly depends on the Secondary Emission Yield (SEY)

Electron cloud build up in the arcs of the damping ring (II)

Central electron density in a radius of $5\sigma_x$ x $5\sigma_y$



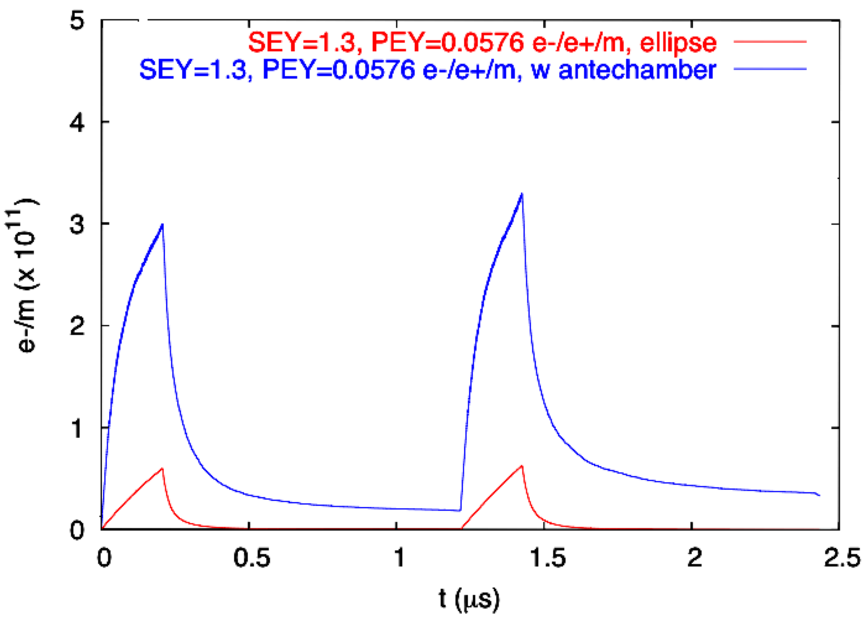


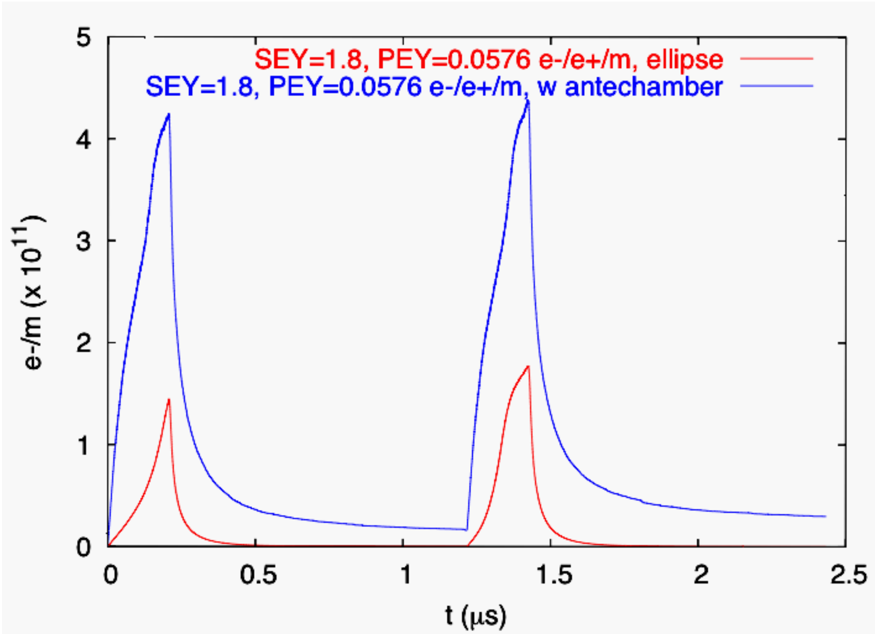
→ The final central density around the beam (10^{11}-10^{13} e^-/m^3) is similar to the averaged density (10^8-10^{10} $e^-/m/0.00124m^2$)

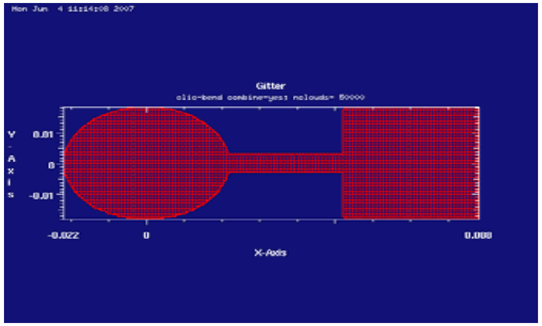
→ However, the central density is the critical parameter to be considered for the beam stability studies.

Electron cloud build up in the arcs of the damping ring (III)

Comparison with full simulations with the antechamber (line density)







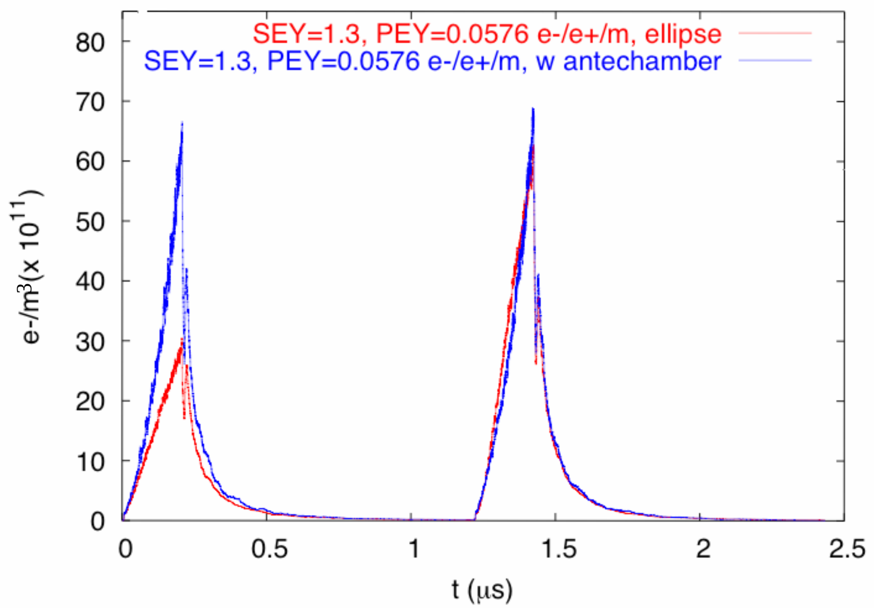
→ The electron production with the antechamber is ~10 times larger because also the electrons in tha antechamber are produced and tracked

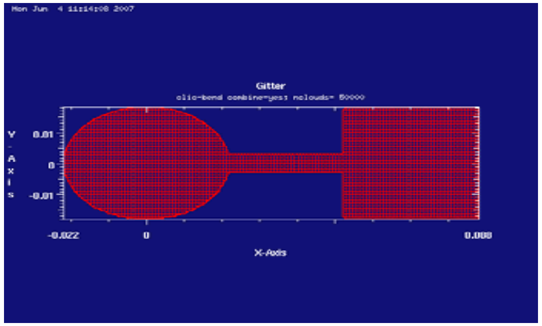
→ However, these electrons remain all confined in the antechamber and hardly feel the beam electric field

→ They move very slowly, therefore they take long time to disappear

Electron cloud build up in the arcs of the damping ring (IV)

Comparison with full simulations with the antechamber (central density)





→ The central densities are similar because they are not affected by the presence of the antechamber

→ Therefore electron cloud density values in the range **2×10^{11} - 4×10^{13} e^-/m^3** can be expected in the arcs of the positron damping ring with the present parameters

Electron cloud build up in the arcs of the damping ring (V)

It seems that mainly there is not much production from secondary emission, why ?..

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Electron cloud build up in the arcs of the damping ring (VI)

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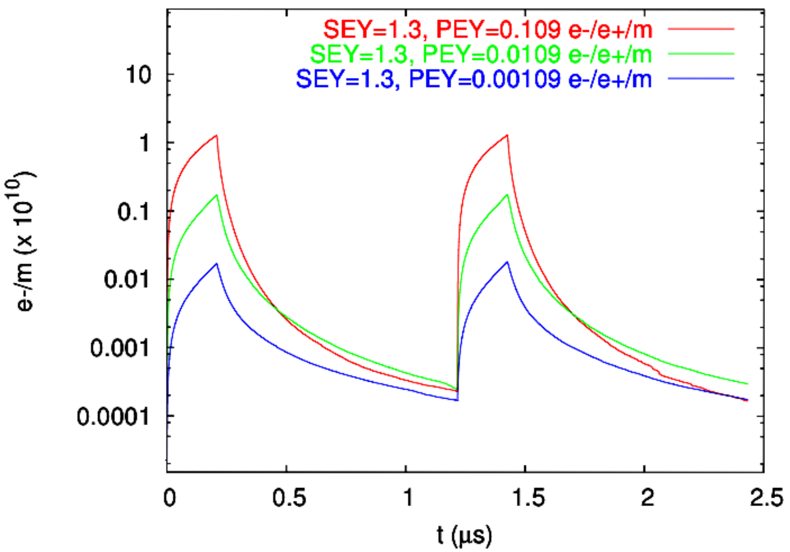
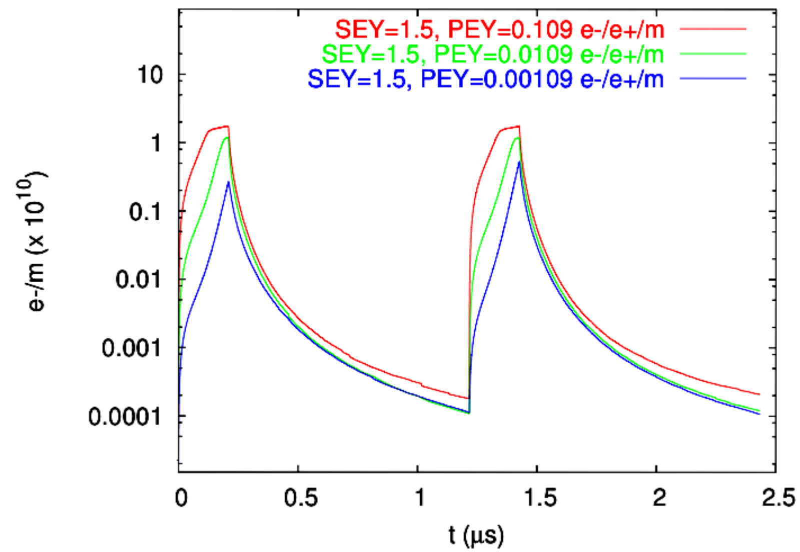
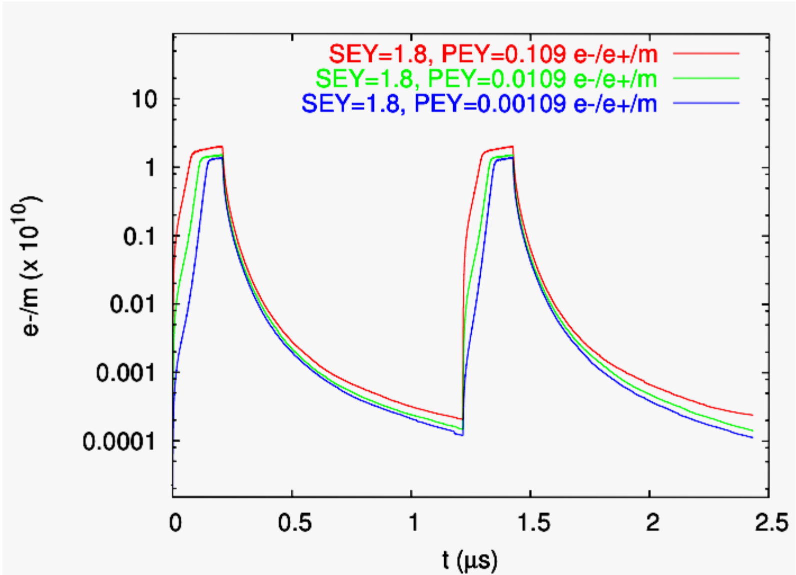
Electron cloud build up in the wigglers of the damping ring (I)

Electron line densities for different PEYs and SEYs





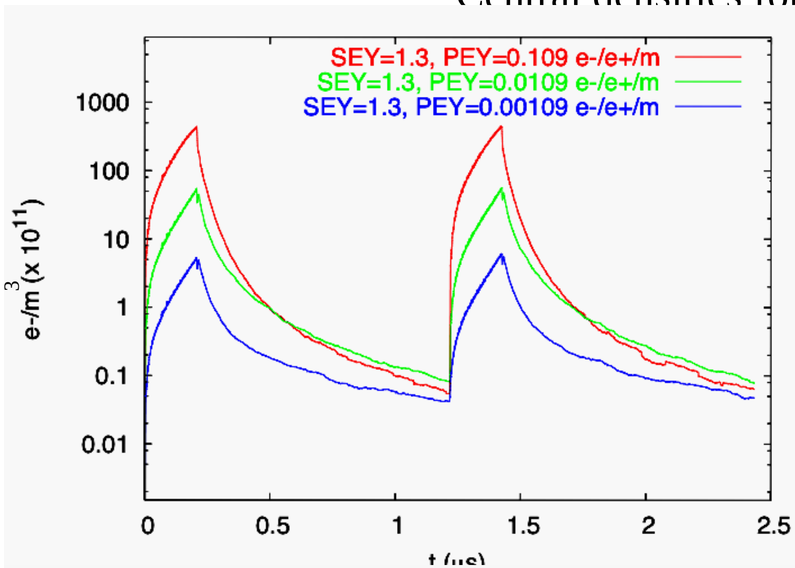


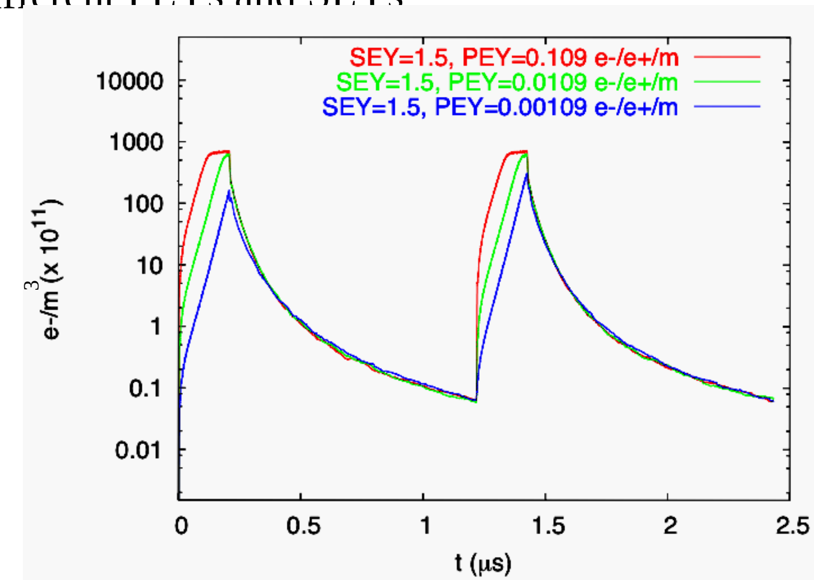
→ In the wigglers there can be multipacting if the SEY is sufficiently high

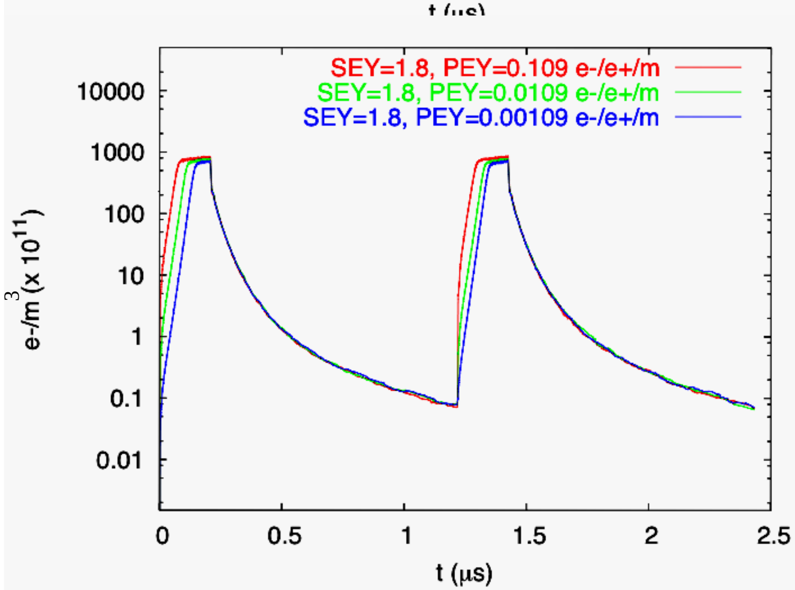
→ For δ_{max}=1.8 the electron line density saturates at ~10^{10} e^-/m independently of the PEY.

Electron cloud build up in the wigglers of the damping ring (II)

Central densities for different PEYs and SEYs







→ The same trend can be observed in the electron central density

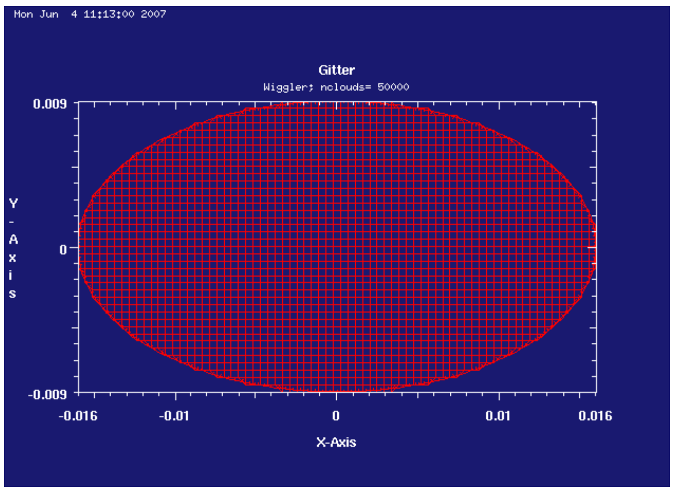
→ Comparing central densities and line densities it is clear that the electron distribution is quite uniform over the pipe cross section

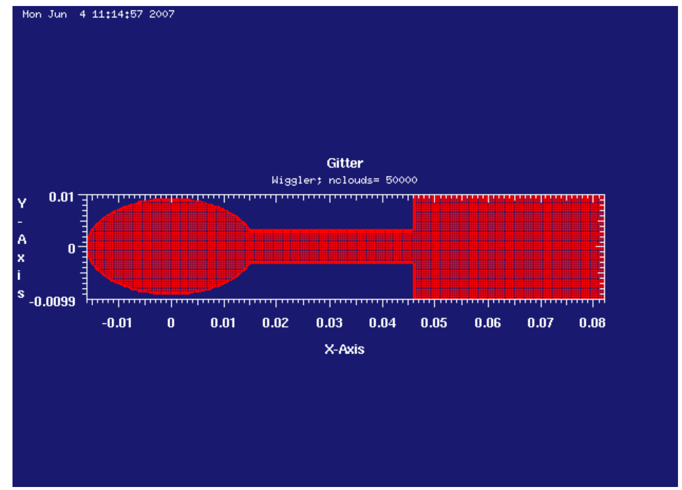
Max central density @SEY=1.8 → 10^{14} e^-/m^3

Max density @SEY=1.8 → 2 x10^{10} $e^-/m/4.5cm^2$

Electron cloud build up in the wigglers of the damping ring (III)

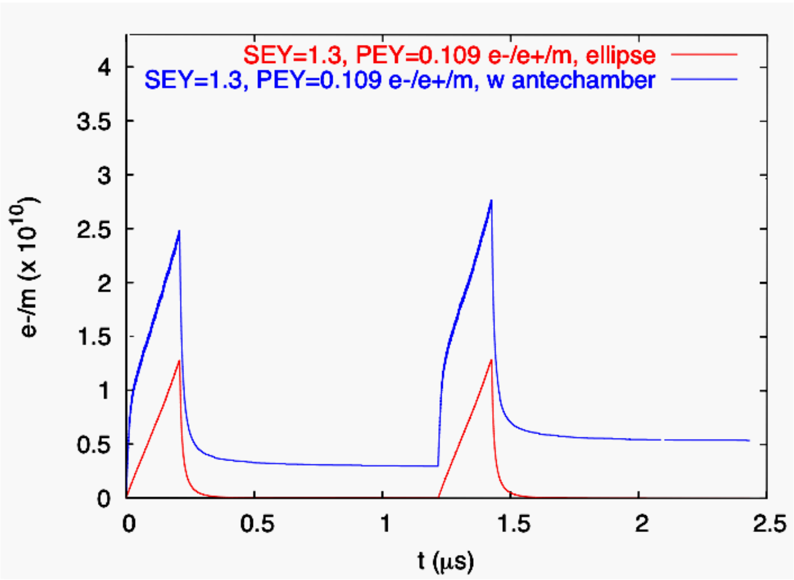
Simulating the full antechamber.....

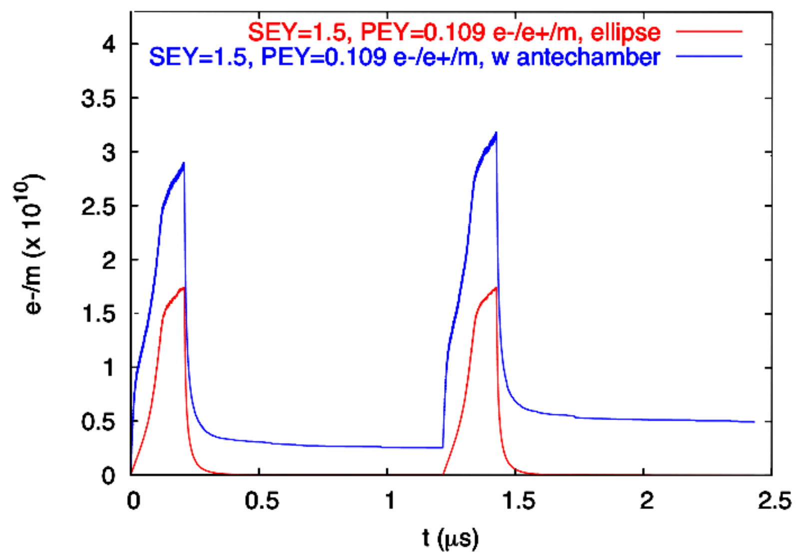


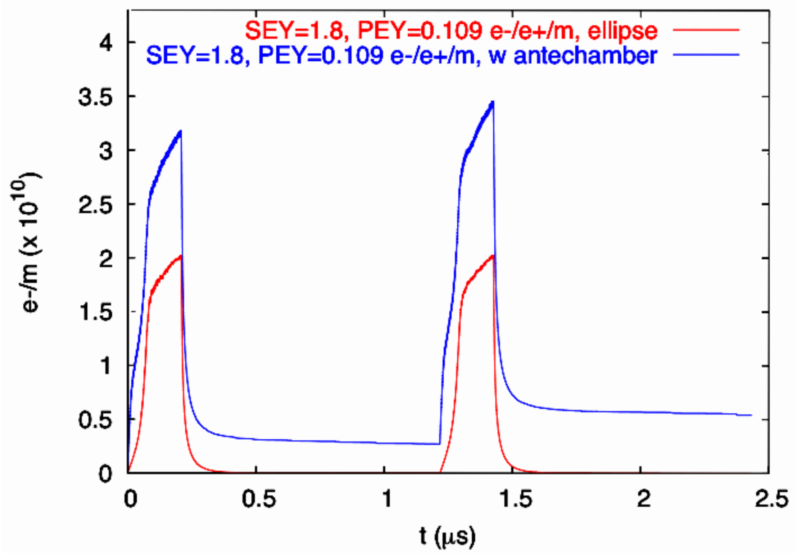


Electron cloud build up in the wigglers of the damping ring (IV)

Electron line densities: comparing cases w and w/o antechamber





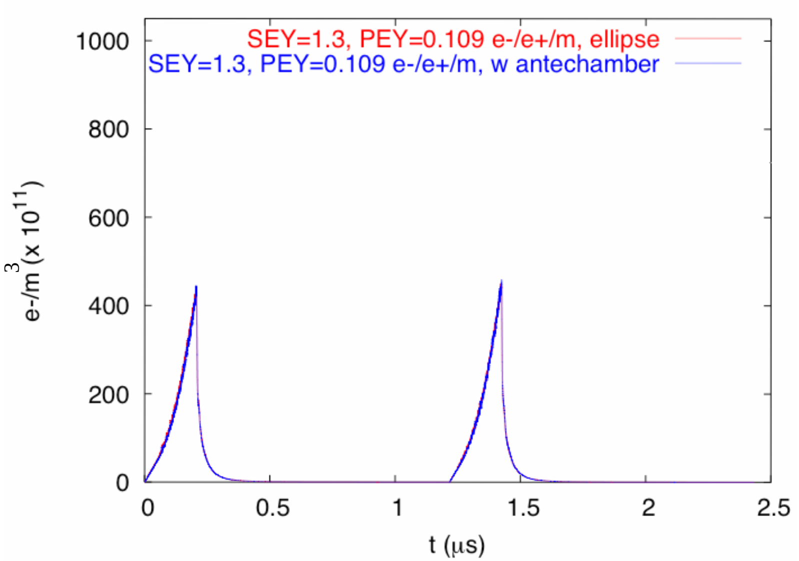


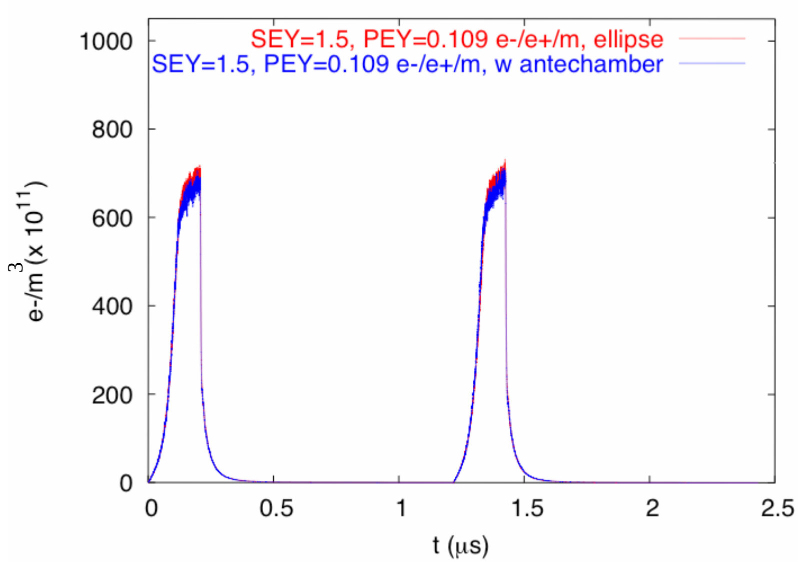
→ The electrons generated in the antechamber result in a much higher line density

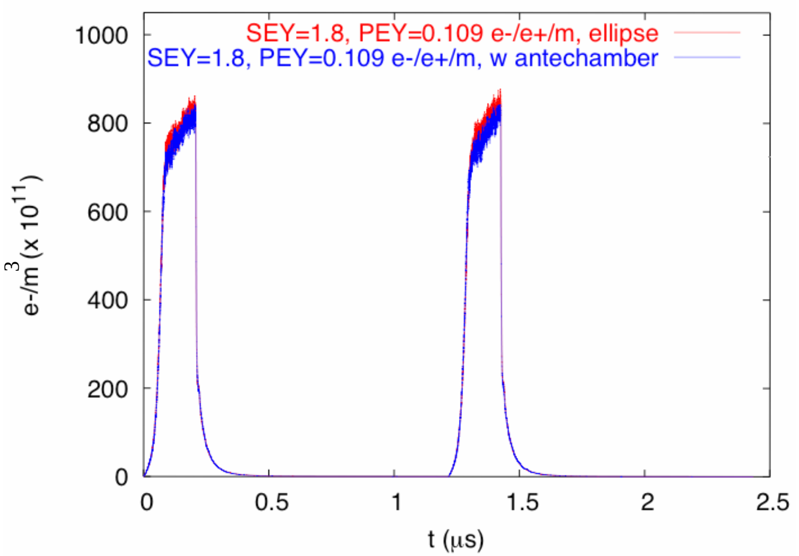
→ These electrons move slowly and cause a slow decay of the elecron cloud: but they do not affect the beam!

Electron cloud build up in the wigglers of the damping ring (V)

Electron central densities: comparing cases w and w/o antechamber







→ The central densities in the two cases can be hardly distinguished

→ In simulations, the antechamber can be neglected and we can track only the electrons inside the main beam pipe.

→ This exercise allowed us to refine the method of re-distribution of the charges in Faktor2 when the number of macroparticles grows too high

Electron cloud build up in the wigglers of the damping ring (VI)

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Electron cloud build up in the wigglers of the damping ring (VII)

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Summary of the density values obtained from build up simulations

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

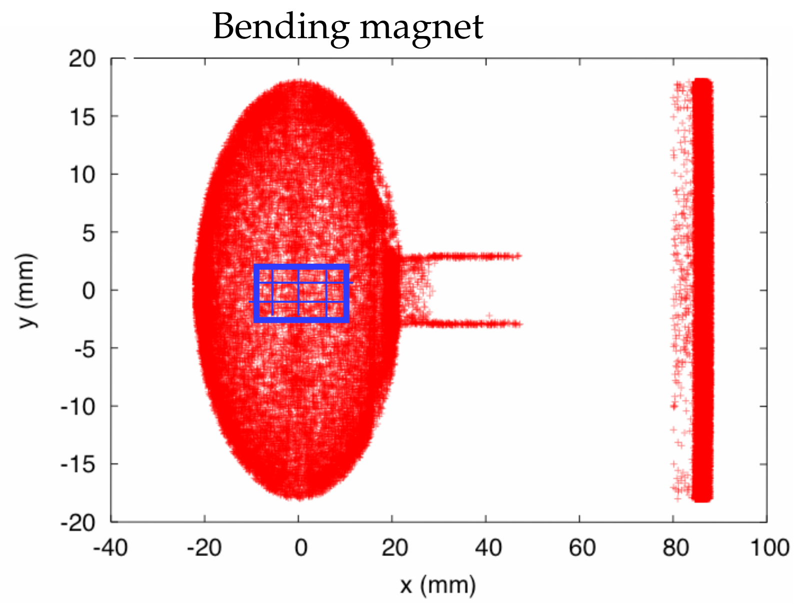
For these values there is basically a negligible electron cloud

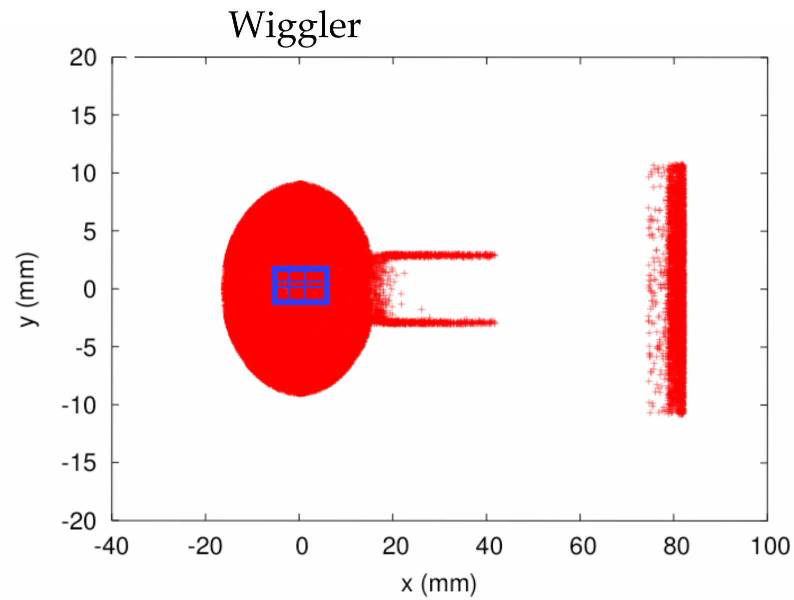
Here the values do not change even with a lower PEY

To model an integrated effect over one turn, these values have to be scaled by:

- **Wigglers** $\Rightarrow$ (total wiggler length)/circumference = (76 x 2)/365 = **0.41**
- **Arcs** $\Rightarrow$ (total arc length)/circumference = (96 x 0.545)/365 = **0.143**

HEADTAIL simulations to check beam stability (I)





→ The **HEADTAIL** code has been modified to accept electron distributions as generated by **Faktor2** as an input

→ The used distribution can be optionally cut into a **small rectangle around the beam** to allow for the simulation of cases in which the beam is much smaller than the beam pipe

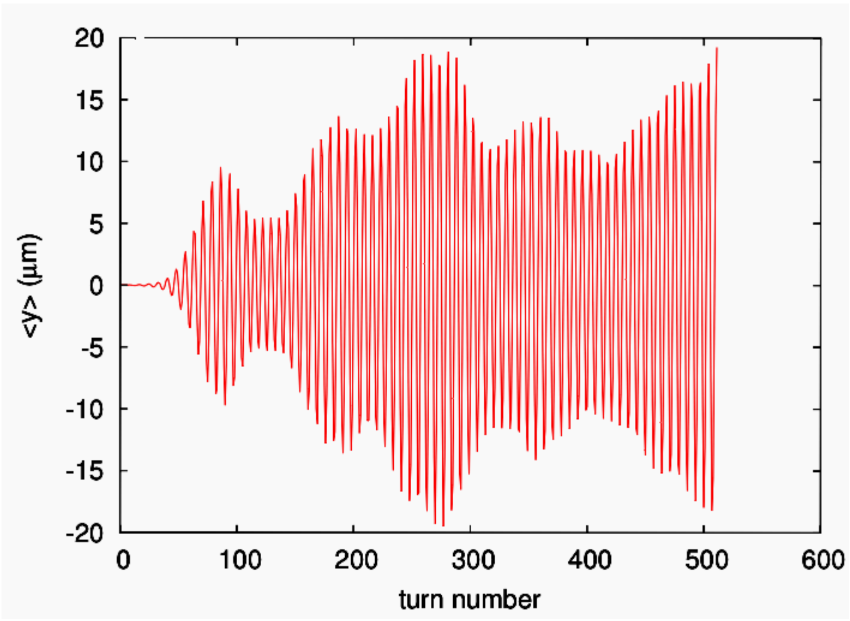
→ **HEADTAIL** has been also modified to allow **the interaction of the bunch with electron clouds with different densities located at places with different beta functions**

HEADTAIL simulations to check beam stability (II)

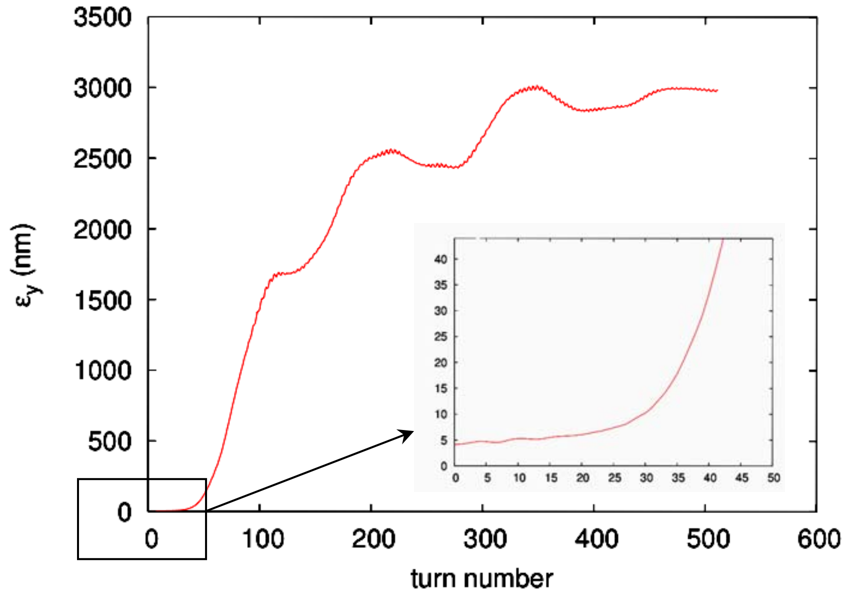
→ We assume the best case in the wigglers as well as in the dipoles:

$\rho_{wig} = 1.8 \times 10^{13}\ m^{-3}$ $\rho_{dip} = 3 \times 10^{11}\ m^{-3}$

→ The beam is strongly unstable



*** Vertical centroid motion**



*** Vertical emittance evolution**

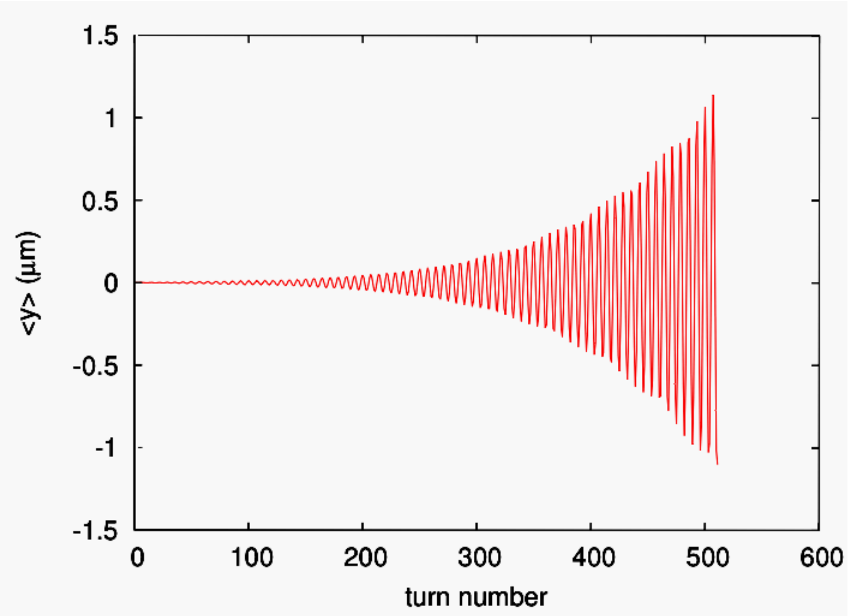
HEADTAIL simulations to check beam stability (III)

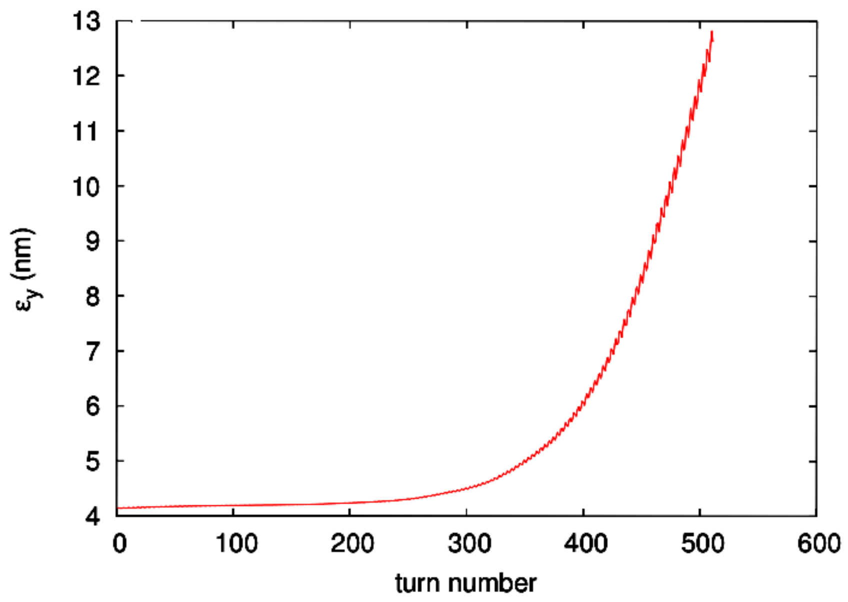
→ We need to lower the e-cloud density below the predicted values to look for thresholds...

→ We take the worst case in the dipoles and equal equivalent e-cloud density in the wigglers

$\rho_{wig} = 5 \times 10^{12}\ m^{-3}$ $\rho_{dip} = 5 \times 10^{12}\ m^{-3}$

→ The beam is still unstable





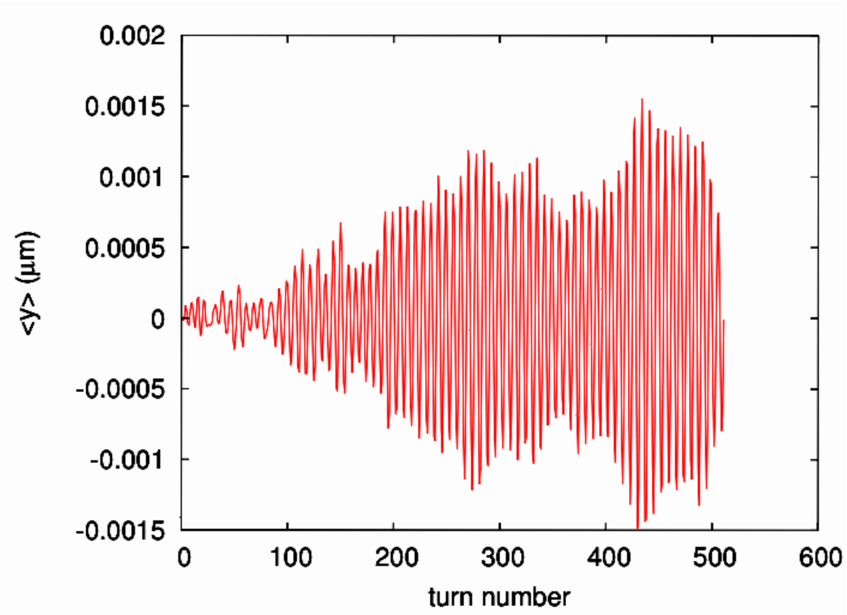
⇒ Exponential growth!

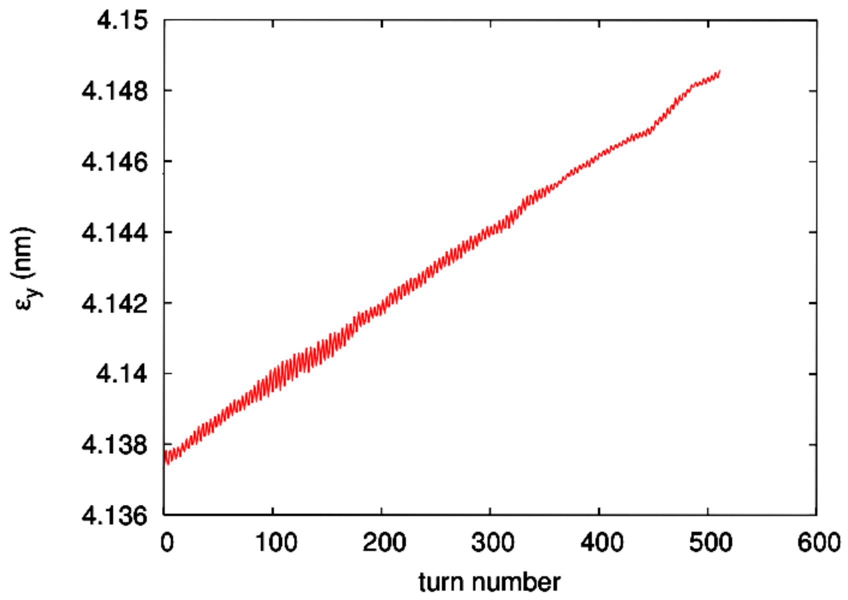
HEADTAIL simulations to check beam stability (IV)

→ We assume the worst case in the dipoles and 5 times lower equivalent e-cloud density in the wigglers

$\rho_{wig} = 1 \text{ x } 10^{12} \text{ m}^{-3}$ $\rho_{dip} = 5 \text{ x } 10^{12} \text{ m}^{-3}$

→ The beam is stable





⇒ Slow incoherent emittance growth?

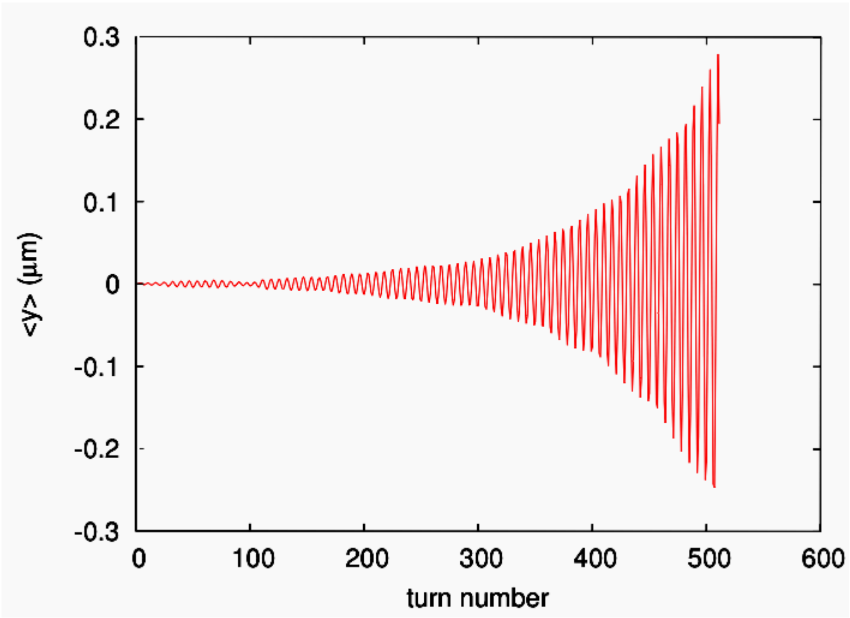
HEADTAIL simulations to check beam stability (V)

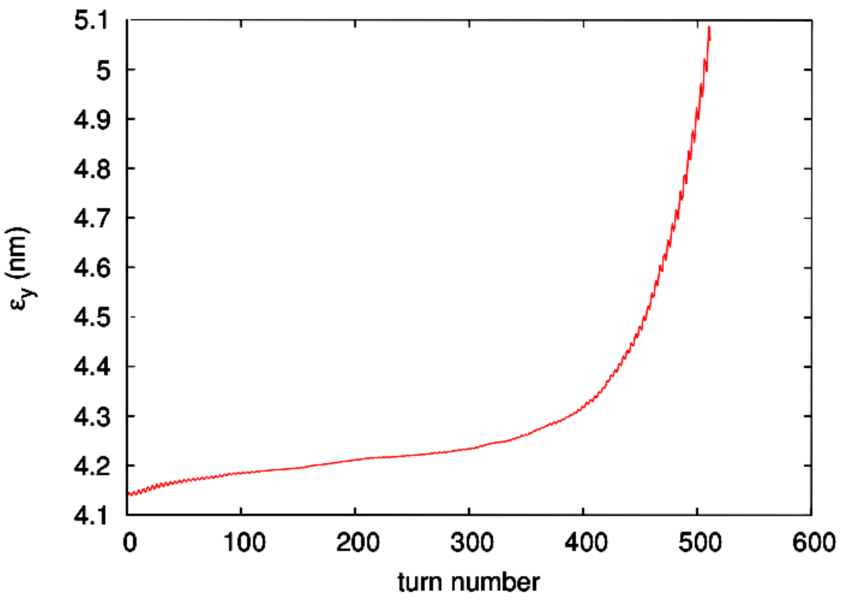
→ If the e-cloud in the dipoles is worst, the threshold in the wigglers is ~3 x 10^{12} m^{-3}

→ And if the e-cloud density in the dipoles was lower ?

$\rho_{wig} = 5 \times 10^{12}\ m^{-3}$ $\rho_{dip} = 3 \times 10^{11}\ m^{-3}$

→ The beam is unstable but it is at the limit ($\rho_{wig} = 3 \times 10^{12}\ m^{-3}$ is stable)





Summary & Outlook

- Using **Faktor2**, we have simulated the **electron cloud build up** in the arcs and in the wigglers of the CLIC-DR
- Simulations have been done with the antechamber and in an ellipse
  - Results are the same because the electrons produced in the antechamber remain confined out of the main pipe
- The electron cloud is low density (both in the arcs and in the wigglers) only when
  - $\boldsymbol{\delta_{max} \leq 1.3}$
  - The antechamber absorbs **99.9% of the synchrotron radiation**
- Using **HEADTAIL** we have studied where the beam becomes unstable
  - Instability simulations show that the beam is unstable in any case if there is electron cloud build up in the wigglers.
  - It has been found that the e-cloud density threshold value in the wigglers for the beam to be stable is 3 to 5 x 10^{12} m^{-3} independently of the dipoles.

⇒ HEADTAIL simulations could be refined using the **sector maps** to transport particles from wigglers to dipoles, so as to have the correct phase advances

⇒ Maybe the electron cloud in the **straight sections** could be relevant too ?

⇒ Check the effect of **nonlinear chromaticity**