Electron-cloud instability in the CLIC damping ring for positrons

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TWIICE workshop, 16.01.2014

Introduction

- Electron cloud can lead to coherent beam instability (see talk of G. Rumolo)
  - Coupled bunch instability → feedback
  - Single bunch instability → emittance growth faster than radiation damping, feedback difficult due to bandwidth (see talk of K. Li)

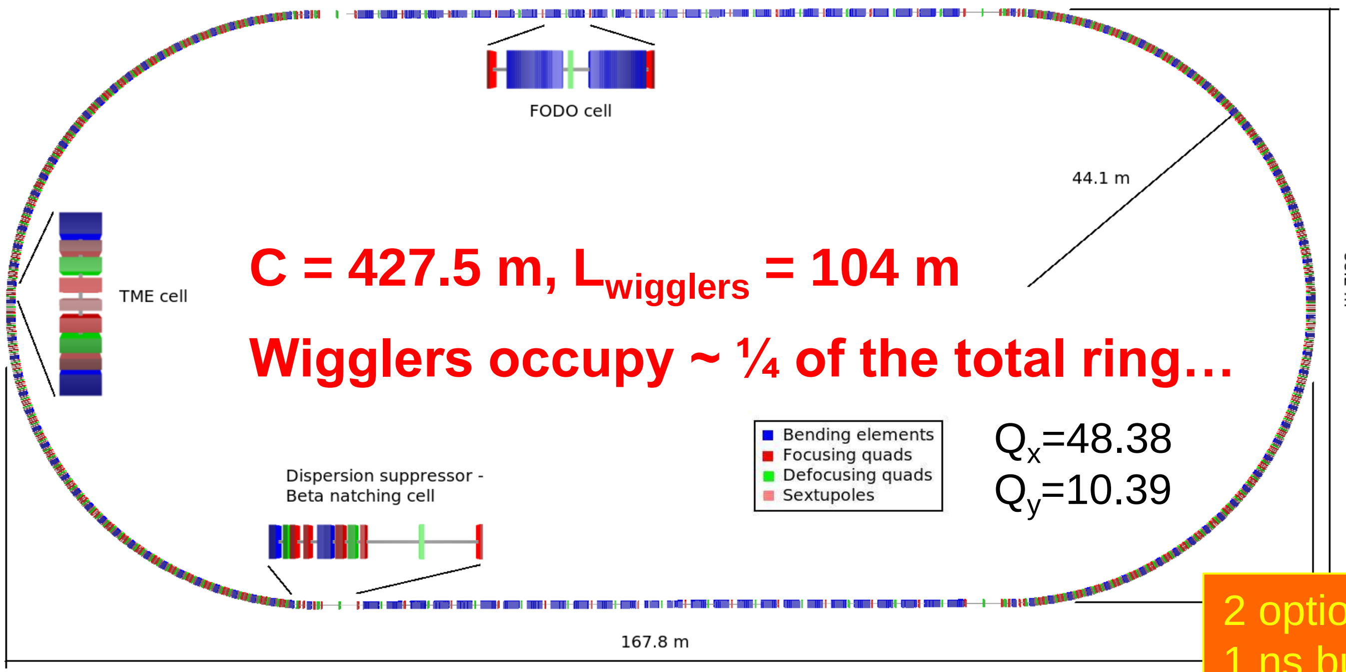
- Single bunch electron cloud instability depends on
  - electron density
  - optics (beta functions)
  - synchrotron tune
  - chromaticity
  - transverse emittance
  - bunch length

… needs to be studied in detail

- Here: study of single bunch instability for superconducting wigglers

CLIC damping rings

See talk of
F. Antoniou



C = 427.5 m, $L_{wigglers}$ = 104 m

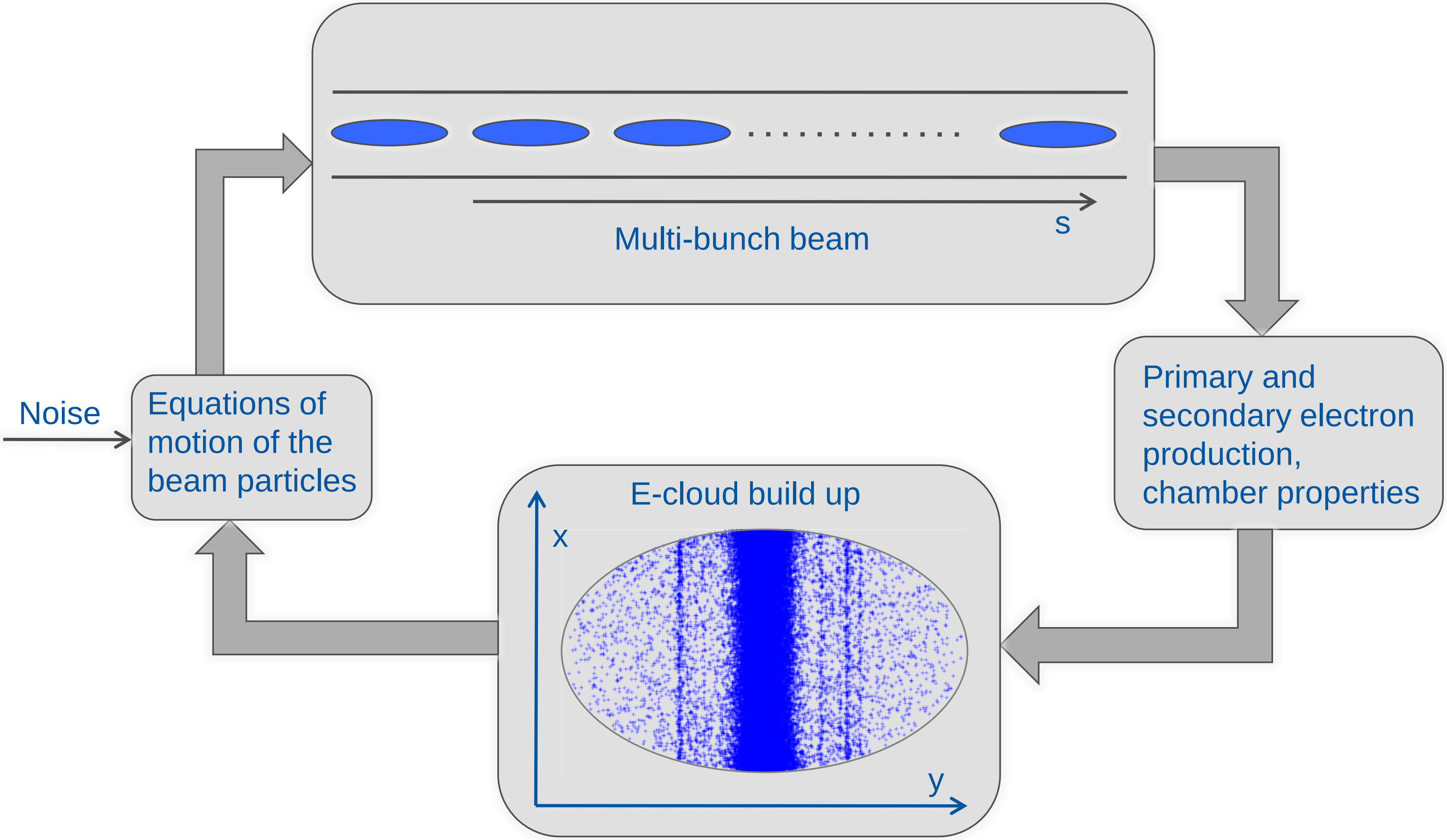
Wigglers occupy ~ ¼ of the total ring…

Q_x=48.38
Q_y=10.39

2 options: 0.5 ns or
1 ns bunch spacing

Description	Symbol	Value
Beam energy	E_0 [GeV]	2.86
Normalized transverse equilibrium emittances	$\varepsilon_{n,x,y}$ [nm]	500, 5
Average beta and dispersion functions (Wigglers)	$b_{x,y}$, D_x [m]	4.2, 9.8, 2.6 x 10^{-5}
Bunch length (rms)	σ_z [mm]	1.6
Synchrotron tune	Q_s	6.5 x 10^{-3}

Electron cloud simulations



Multi-bunch beam

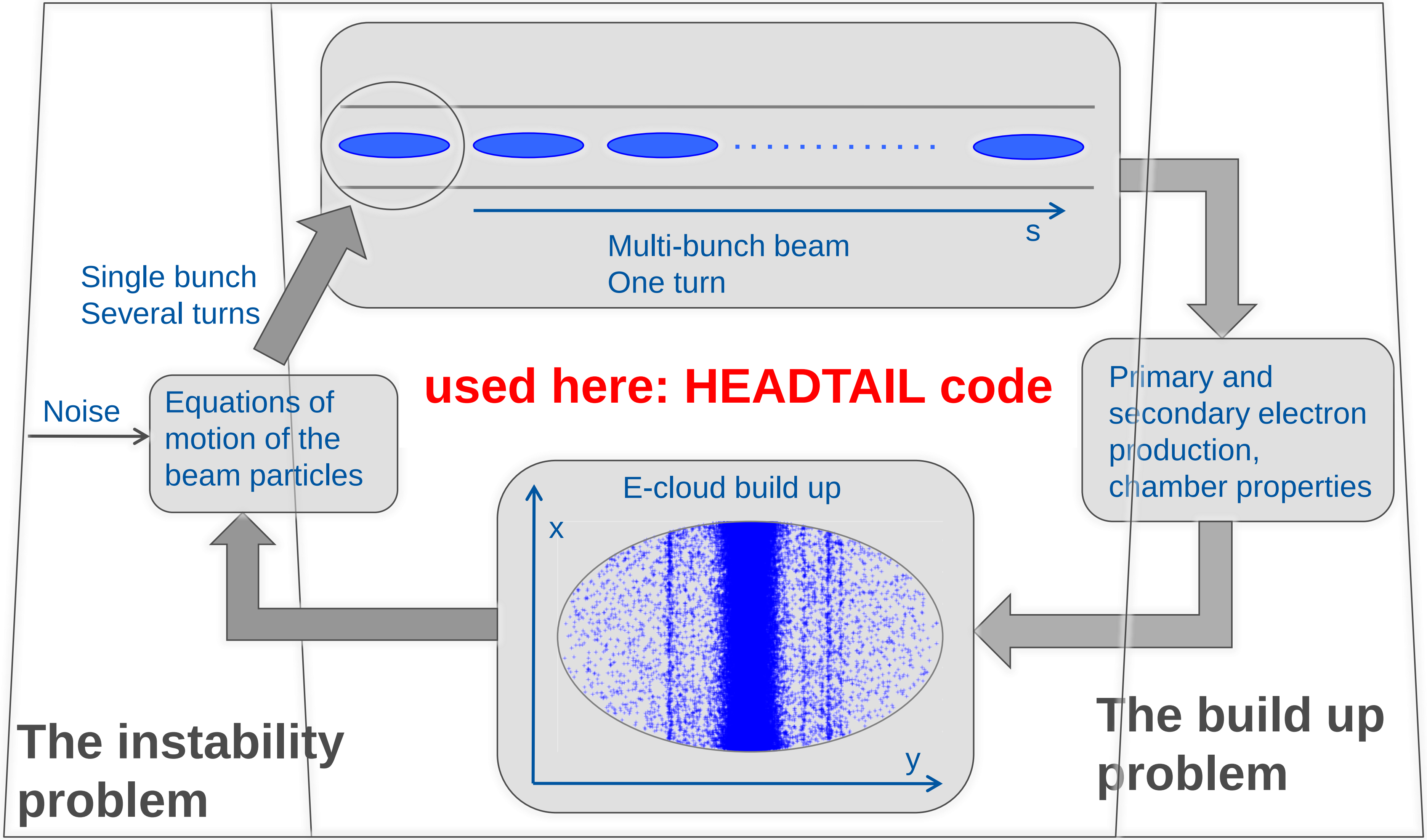
Primary and secondary electron production, chamber properties

E-cloud build up

Equations of motion of the beam particles

Noise

Electron cloud simulations: splitting the problem



Multi-bunch beam
One turn

Single bunch
Several turns

Noise

Equations of motion of the beam particles

used here: HEADTAIL code

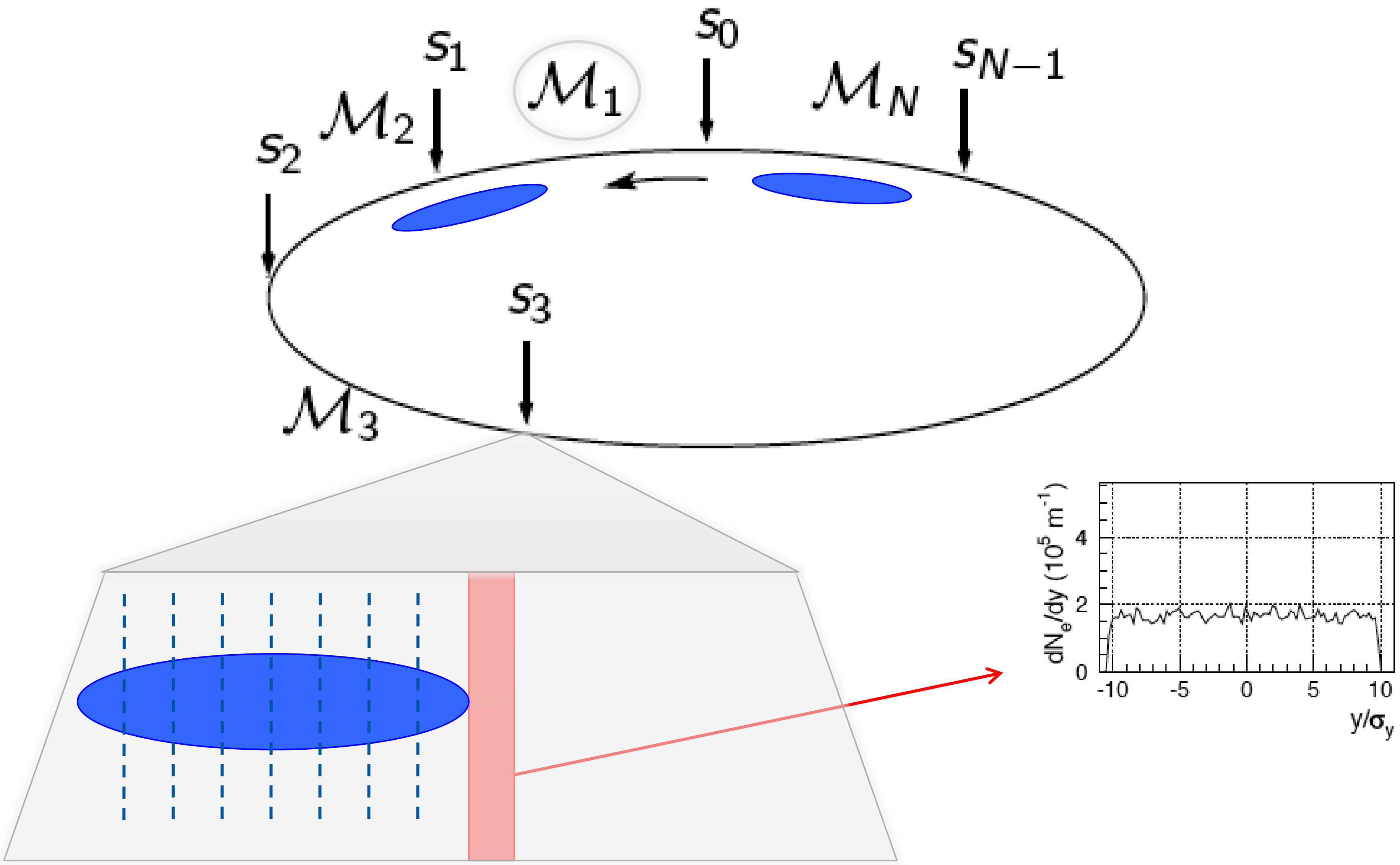
Primary and secondary electron production, chamber properties

E-cloud build up

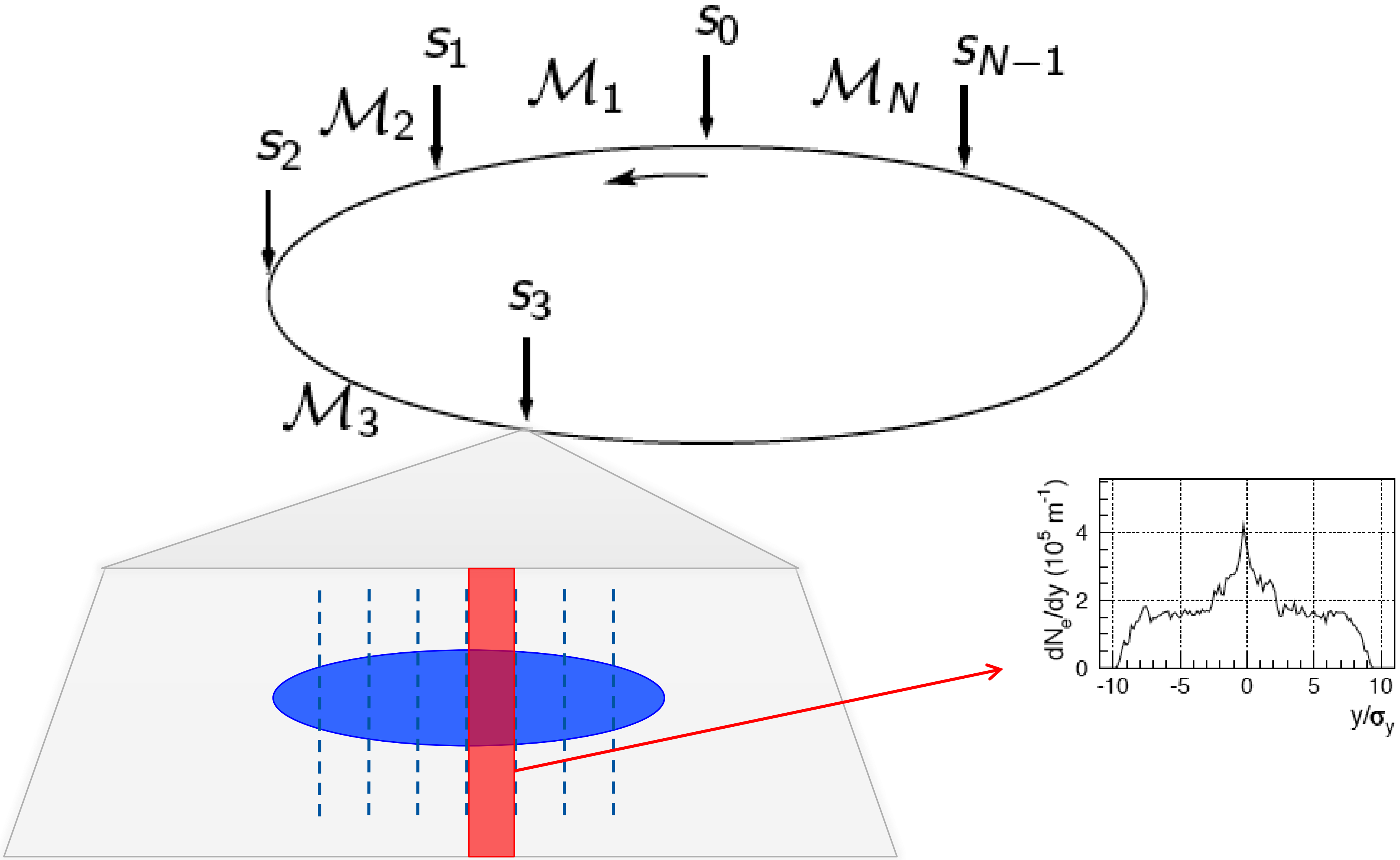
The instability problem

The build up problem

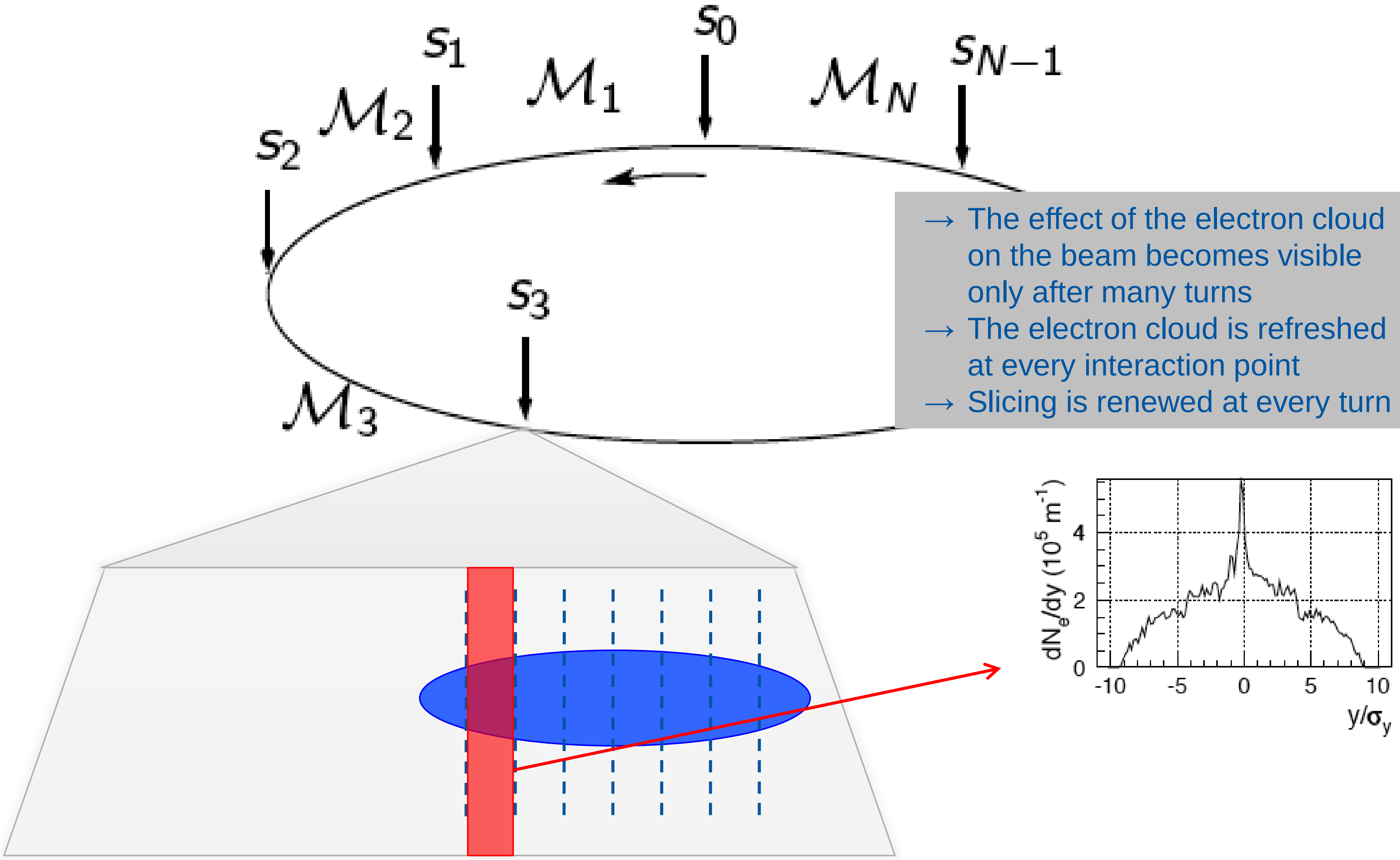
The HEADTAIL code: simulation principle



The HEADTAIL code: simulation principle



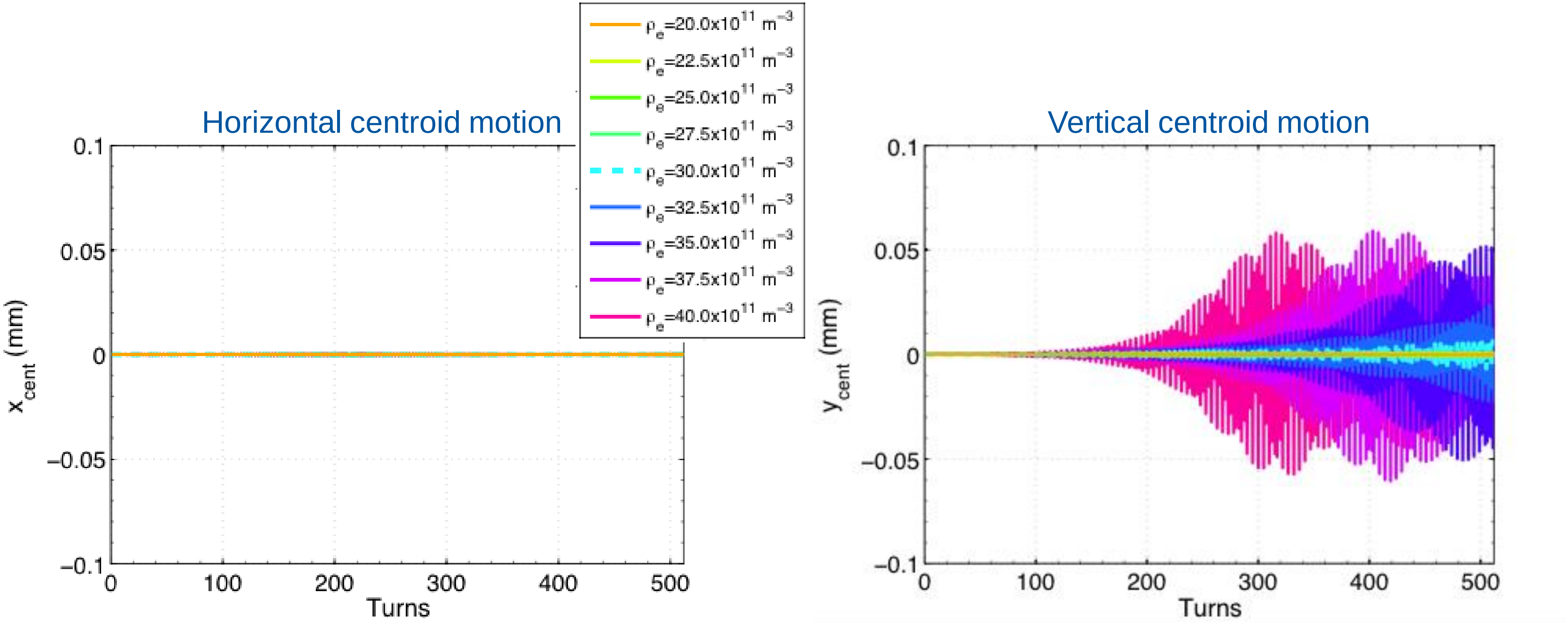
The HEADTAIL code: simulation principle



→ The effect of the electron cloud on the beam becomes visible only after many turns
→ The electron cloud is refreshed at every interaction point
→ Slicing is renewed at every turn

Instability threshold for e-cloud in wigglers

- Simulations with uniform electron density
- Electrons in magnetic dipole field (→ no horizontal motion in HEADTAIL)
  - No (single bunch) instability in horizontal plane

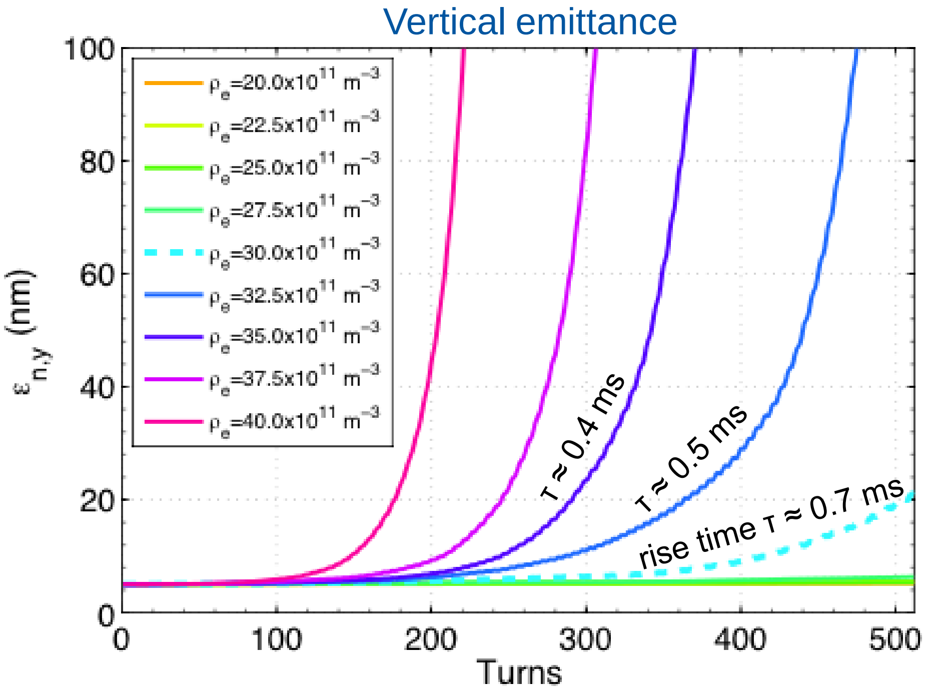


Horizontal centroid motion

Vertical centroid motion

Instability threshold for e-cloud in wigglers

- Simulations with uniform electron density
- Electrons in magnetic dipole field (→ no horizontal motion in HEADTAIL)
  - No (single bunch) instability in horizontal plane
  - Strong growth of vertical emittance ($\varepsilon_{n,y}$) above threshold

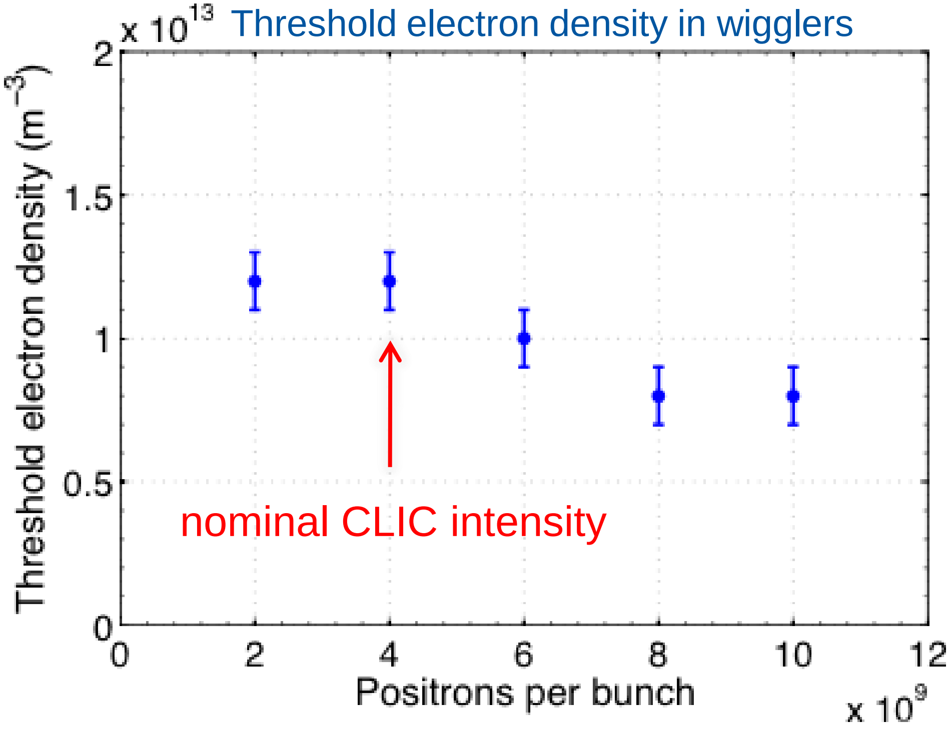

Vertical emittance

⇒ fast growth compared to vertical damping time (2 ms)

⇒ local electron densities of 1.2×10^{13} m^{-3} in wigglers (25% of circumference) drive beam unstable

Dependence on bunch intensity

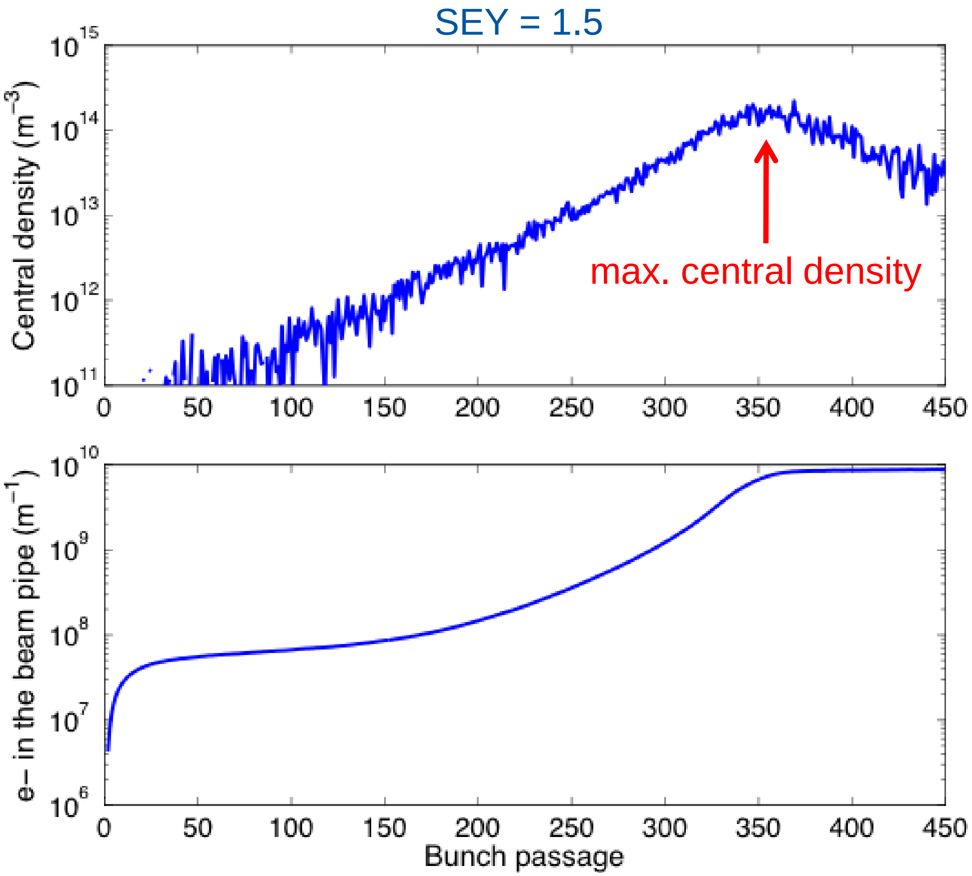
- Simulations with uniform electron distributions
- Weak dependence of instability threshold on bunch intensity
  - Studied in view of future optimization of CLIC parameters



⇒ Similar threshold electron density for the studied range of positron bunch intensities …

Using electron distributions from PyECLOUD

- PyECLOUD simulation for generation of macroparticle distribution
  - 1 ns bunch spacing



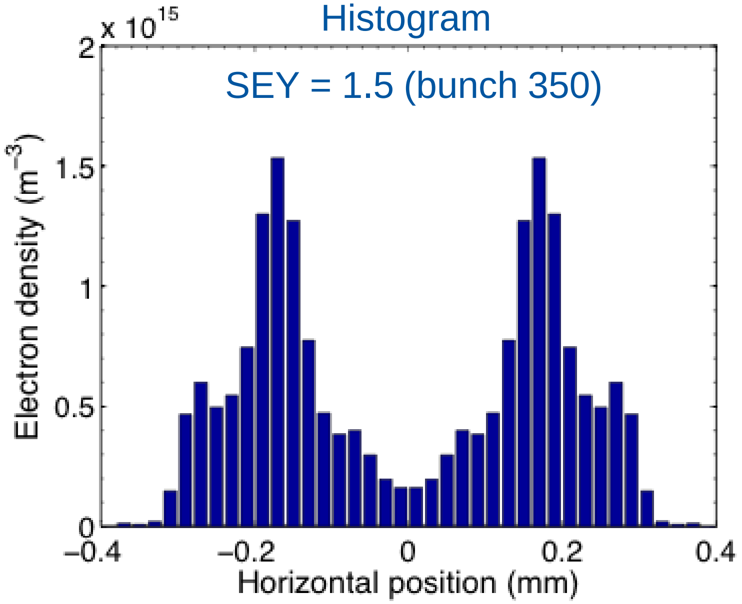
See talk of G. Iadarola

⇒ Using distribution (just before bunch passage) with maximum central density = most critical for instability

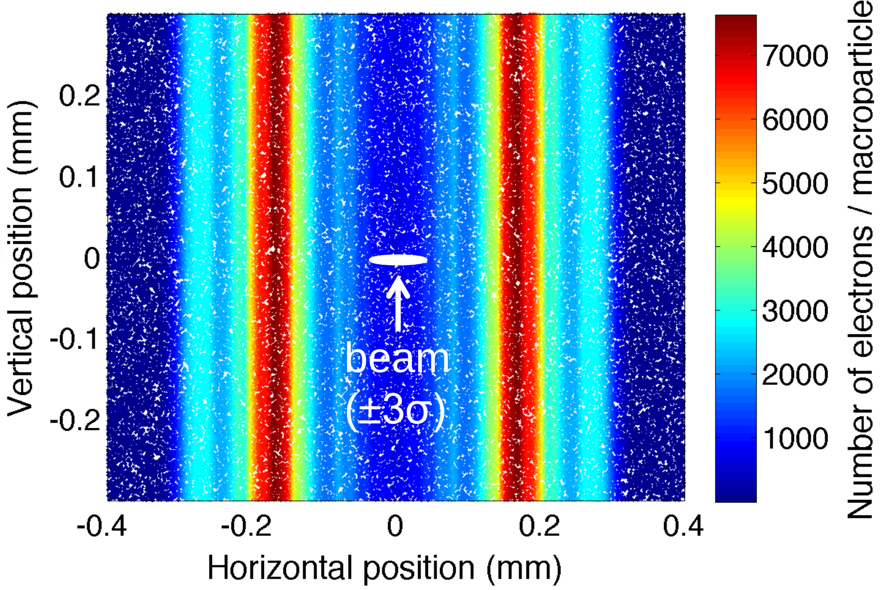
Using electron distributions from PyECLOUD

- PyECLOUD simulation for generation of macroparticle distribution
  - 1 ns bunch spacing
  - Generation of uniform spatial distribution with variable charges/weights

Histogram

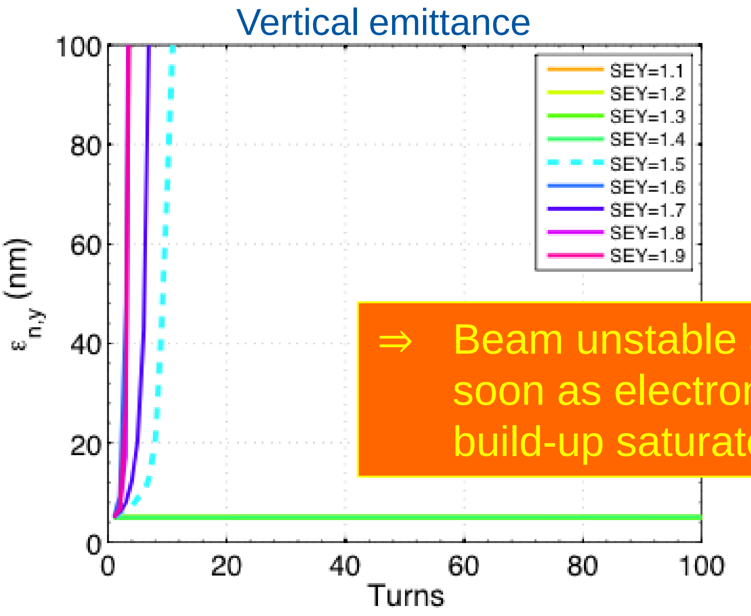


Electron distribution

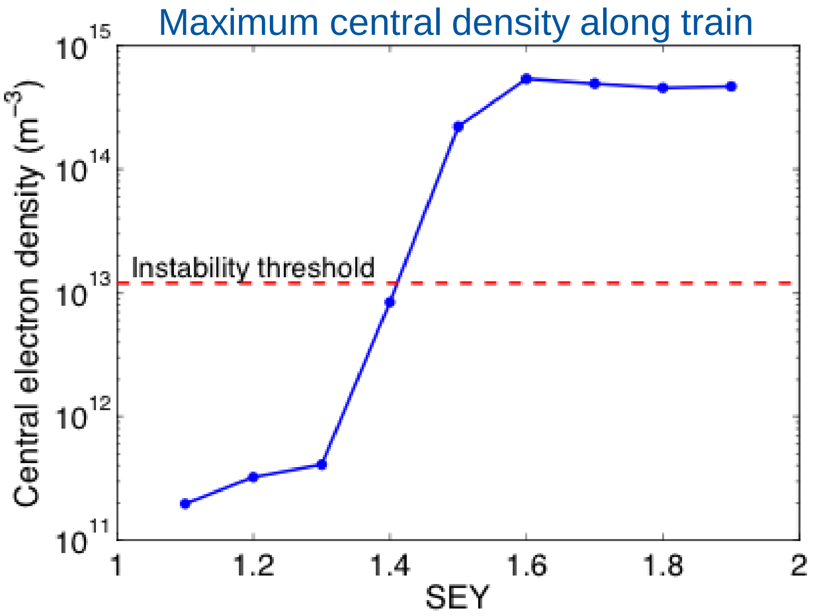


Using electron distributions from PyECLOUD

- PyECLOUD simulation for generation of macroparticle distribution
  - 1 ns bunch spacing
  - Generation of uniform spatial distribution with variable charges/weights
- HEADTAIL simulations with distributions from PyECLOUD
  - Bunch passages with maximum central density along the train


Vertical emittance

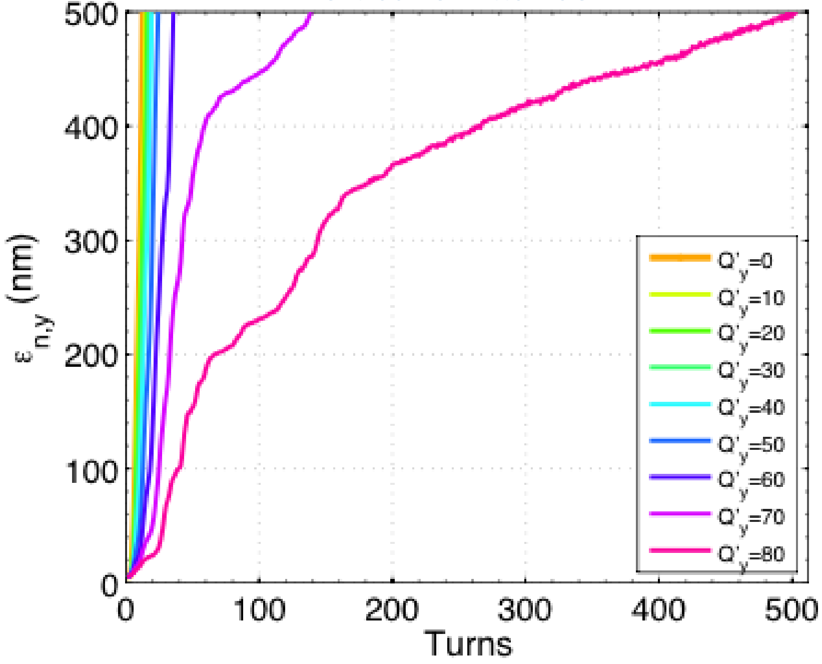
⇒ Beam unstable as soon as electron build-up saturated


Maximum central density along train

Mitigation with chromaticity?

- Increasing vertical chromaticity is one of the measures against e-cloud instability
- Simulation for uniform e-cloud distribution
  - $\rho_e = 4 \times 10^{13}$ / m^3 (equivalent to $\rho_e = 1.6 \times 10^{14}$ / m^3 in the wigglers)

Vertical emittance



⇒ Even very high chromaticity not sufficient for beam stability (+ incoherent effects)

Summary and conclusions

- Electron cloud instability simulations with HEADTAIL
  - Decoupled from build-up simulations (computing power)
  - Semi-self consistent by using electron distribution from build-up code
  - Only single bunch instability

- Simulations for wigglers with uniform e^- distribution
  - Threshold density in wigglers ≈ $1.2 \times 10^{13} / m^3$
  - Emittance growth rate fast compared to damping times
  - Little dependence on bunch intensity
  - Mitigation by chromaticity not sufficient

- Simulations for wigglers using distribution from PyECLOUD
  - Beam is unstable for all SEY values above build-up threshold (i.e. SEY>1.4)
  - Need to suppress e-cloud build-up!