Stability with electron cloud

A. Romano, G. Iadarola, G. Rumolo

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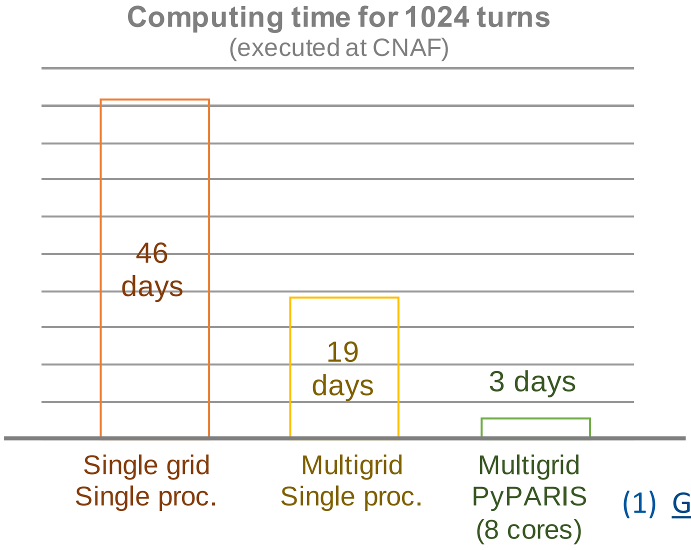
PyECLOUD-PyHEADTAIL simulation

Understanding of EC phenomena heavily relies on PyECLOUD-PyHEADTAIL simulations

- Simulations are very demanding in terms of time and computational resources → multi-scale problem
  - ➢ in space: small beam (~100 um) in a big chamber (4 cm)
  - ➢ in time: 1 ns for the e- motion, 1 to 10 s for instability development
- Recent work has been focused on increasing the performance of the simulation tools (1)
  - ➢ "telescopic" grid introduced in the Particle in Cell solver
  - ➢ exploit parallel computing through a new parallelization layer (PyPARIS)

→ Allowed gaining new insight on scenarios that were previously inaccessible!



(1) G. Iadarola et al, "THPAB043 (2017)

HCP cluster at INFN-CNAF

- Typical simulation study requires hundreds of CPUs (8-16 CPUs per job) and 3-4 week to simulate 10^4 turns
  - HPC cluster at INFN-CNAF (in Bologna) extensively used for this purpose
- New HPC cluster dedicated to CERN studies [(1)]
  - 12 nodes running in LSF (32 cores each) → 384 CPUs with hyper-threading enable
  - Simulations running steadily since June ☺

HOST_NAME	STATUS	JL/U	MAX	NJOBS	RUN	SSUSP	USUSP	RSV
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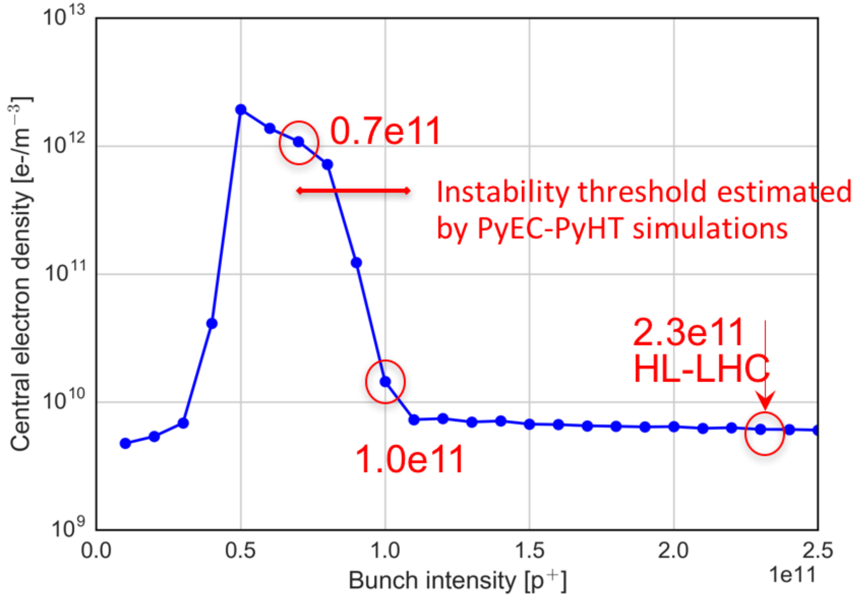
hpc-201-11-06-a	closed	-	64	64	64	0	0	0
hpc-201-11-06-b	closed	-	64	64	64	0	0	0

(1) A. Falabella, "HPC Cluster at CNAF: a brief introduction", ABP-CWG meeting #18

Lessons learned from LHC 1/2

- EC in **dipoles** is **not** expected to drive instabilities both at injection and flattop energy
  - the onset of instability development in dipoles depends on the electron density seen by the beam[1]→ in the present conditioning state of the LHC estimated density below the instability threshold
  - however the situation changes significantly when the bunch intensity decreases w.r.t. the nominal parameters → observations of instabilities in collisions consistent with our simulation studies [2] ☺



(1) H. Bartosik et al., "BENCHMARKING HEADTAIL WITH ELECTRON CLOUD INSTABILITIES OBSERVED IN THE LHC", ECLOUD12

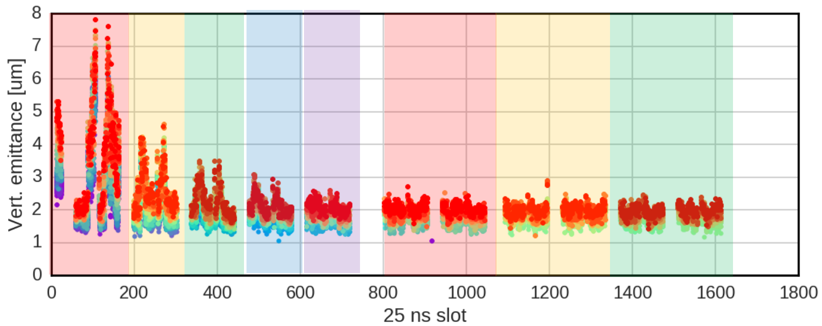
(2) A. Romano et al., "Instabilities in stable beams", presentation at the ½ -day internal review of LHC performance limitations during run2

Lessons learned from LHC 2/2

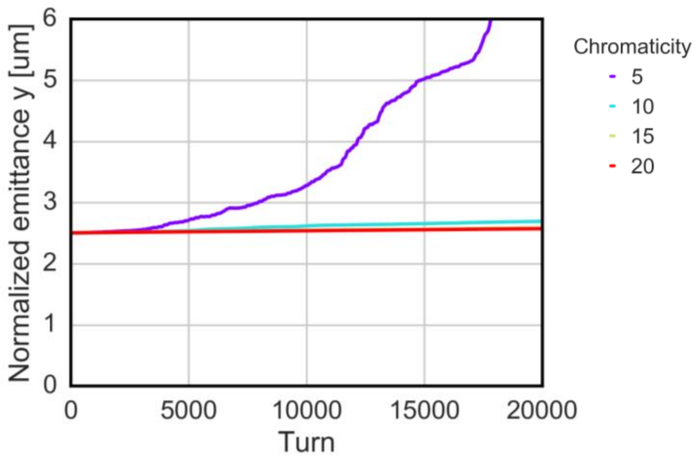
- EC in **quadrupoles** alone is a key driver of instabilities at the LHC **injection** energy [1]
  - simulations allowed explaining instabilities observations → large chromaticity values, relatively high octupoles current and a fully functional feedback system were needed to reach a satisfactory emittance preservation
  - instability suppressed when increasing the beam energy up to 6.5 TeV due to the increased beam rigidity

Bunch-by bunch emittance measurements

Oct [A] Chromaticity	6.5 5/5	13 5/5	13 10/10	13 15/15	26 15/15	52 15/15	52 10/15	52 20/15



Simulation studies



(1) A. Romano et al., “Electron cloud induced instabilities in the LHC”, presentation at the Joint Ecloud-PyHEADTAIL Meeting

Instability simulations for the HL-LHC

- The interaction of a single bunch with an EC has been simulated in the dipole and quadrupole magnets separately
- The parameters used are listed below

Parameters	Value @ 450 GeV	Value @ 7 TeV
N_b (p/bunch)	0.6-2.4 x 10^{11}	0.6-2.4 x 10^{11}
$\varepsilon_{x,y}$ (μm)	2.0	2.5
σ_z (cm)	10.4	9.0
B (T, T/m)	0.53, 12	8.3, 188.2
V_{400MHz}	8	16
$\langle\beta_x\rangle$, $\langle\beta_y\rangle$	92.7, 93.2	92.7, 93.2

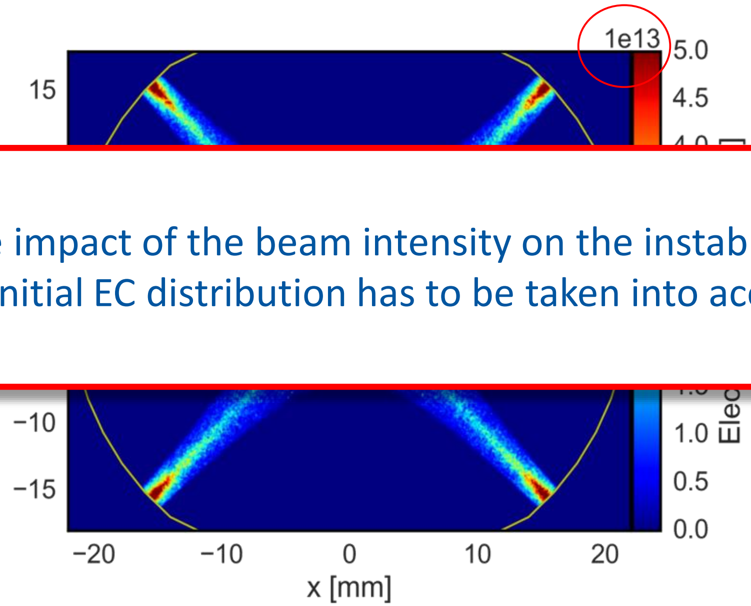
Pre-squeezed optics → we can scan the beta function to study the impact of the ATS scheme ….

EC induced instability: quadrupole magnets

- Due to electron trapping from magnetic field gradients EC density at the beam location can be very high

- The EC pinch dynamics in the quadrupoles can be very sensitive to the initial phase space distribution again due to the trapping effects

  - ➢ a realistic initial distribution of electron in the quadrupoles from build-up has to be used to assess the threshold for the coherent instability → self-consistent simulations with build-up [1]

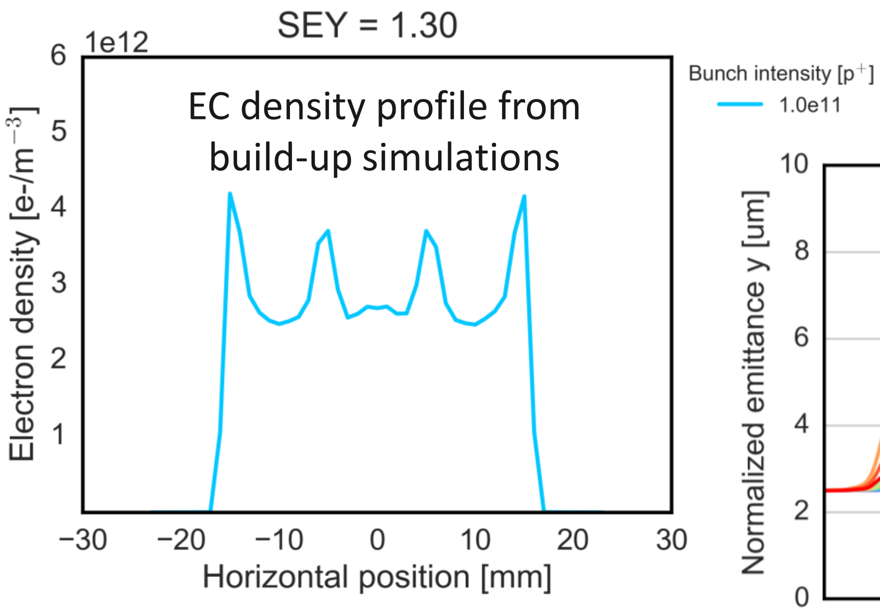


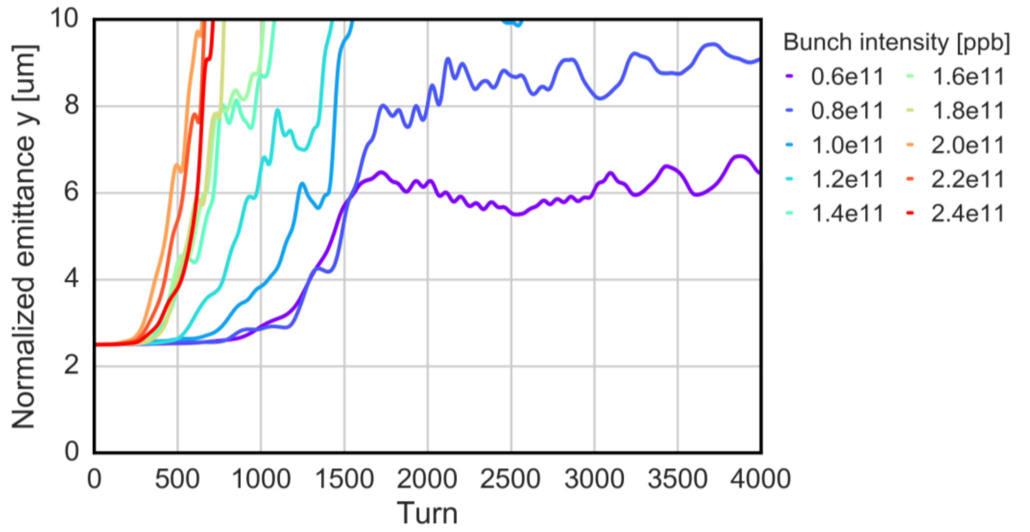
We want to study the impact of the beam intensity on the instability development → Which initial EC distribution has to be taken into account?

(1) G. Iadarola et al., "EFFECT OF ELECTRON CLOUD IN QUADRUPOLES ON BEAM INSTABILITY", IPAC15

Impact of the initial electron distribution

- At first we wanted to investigate separately the effect of the intensity increase on the instability mechanism for the same initial EC distribution
  - ➢ EC distribution computed for N_b =1.0e11 and then used it as input for a set of instability simulations → realistic distribution from build-up but not self-consistent with intensity
  - ➢ Instability rise-time is much faster for higher beam intensities





(Realistic total length of quadrupoles, NO chromaticity, NO octupoles, NO damper)

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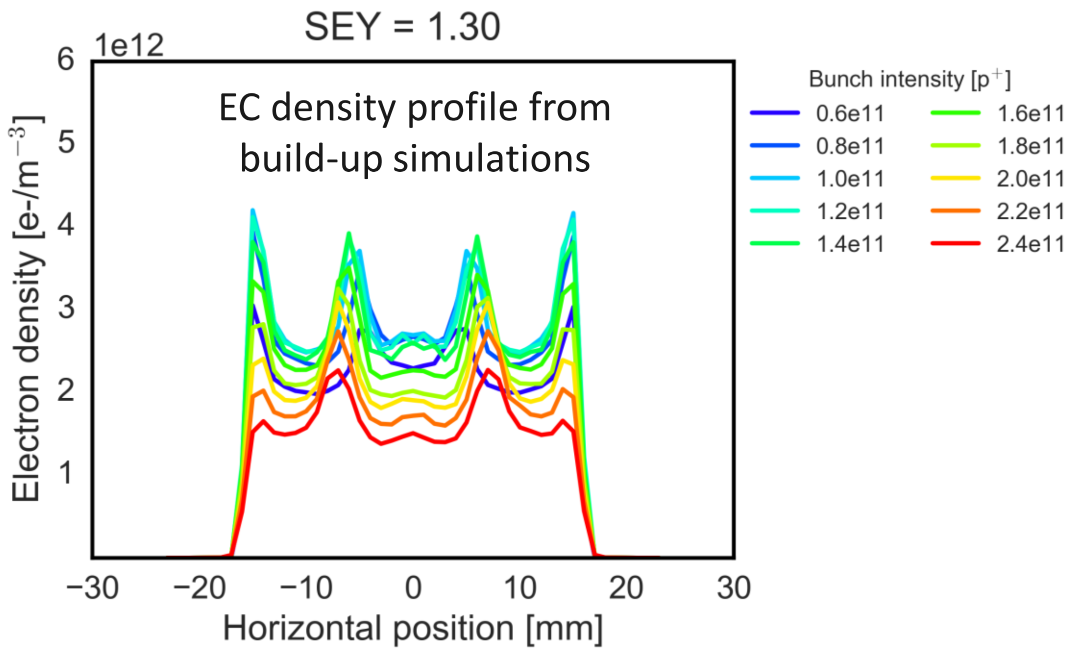
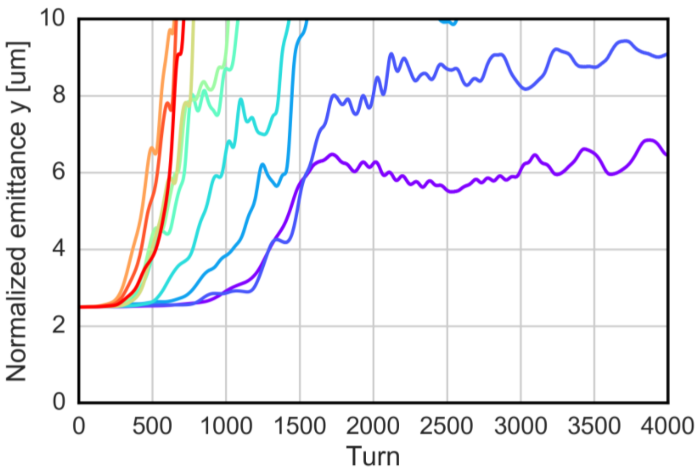
  - ➢ EC distribution computed for N_b =1.0e11 and then used it as input for a set of instability simulations → realistic distribution from build-up but not self-consistent with intensity
  - ➢ Instability rise-time is much faster for higher beam intensities
- However, the EC density profile estimated for different bunch intensity shows that for increasing bunch intensities, the electron density decreases significantly all over the chamber

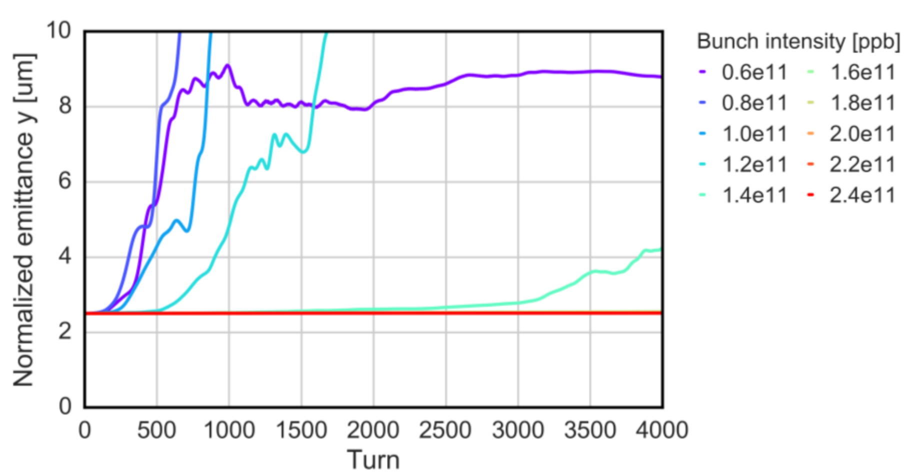


Impact of the initial electron distribution

Initial distribution from build-up assuming N_b = 1.0e11→ same input for all cases



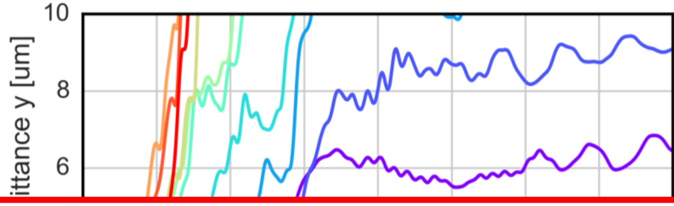
Initial distribution from build-up computed "ad-hoc" for each bunch intensity (self-consistent)



- The electron density is overestimated (up to a factor 2) when using the same EC distribution (computed for N_b =1.0e11) as input for a set of instability simulations
- Relying on self-consistent simulations
  - Instability observed for lower bunch intensity → larger EC density in the chamber
  - For higher bunch intensity the e- density is not sufficient to drive the bunch unstable

Impact of the initial electron distribution

Initial distribution from build-up assuming N_b = 1.0e11 → same input for all cases



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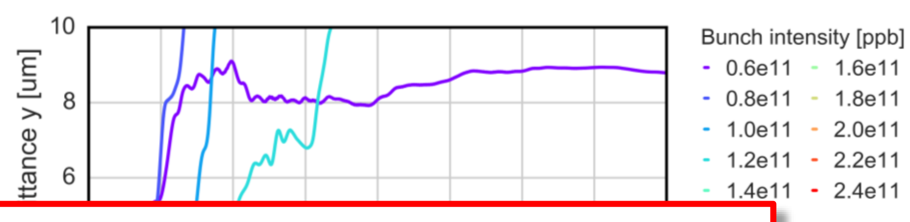

- To estimate correctly the instability threshold we need run self-consistent simulations with bunch intensity → initial EC distribution computed "ad-hoc" for different bunch intensities and used as input for instability simulations
- In these conditions the increase of the bunch intensity has a beneficial impact on the beam stability

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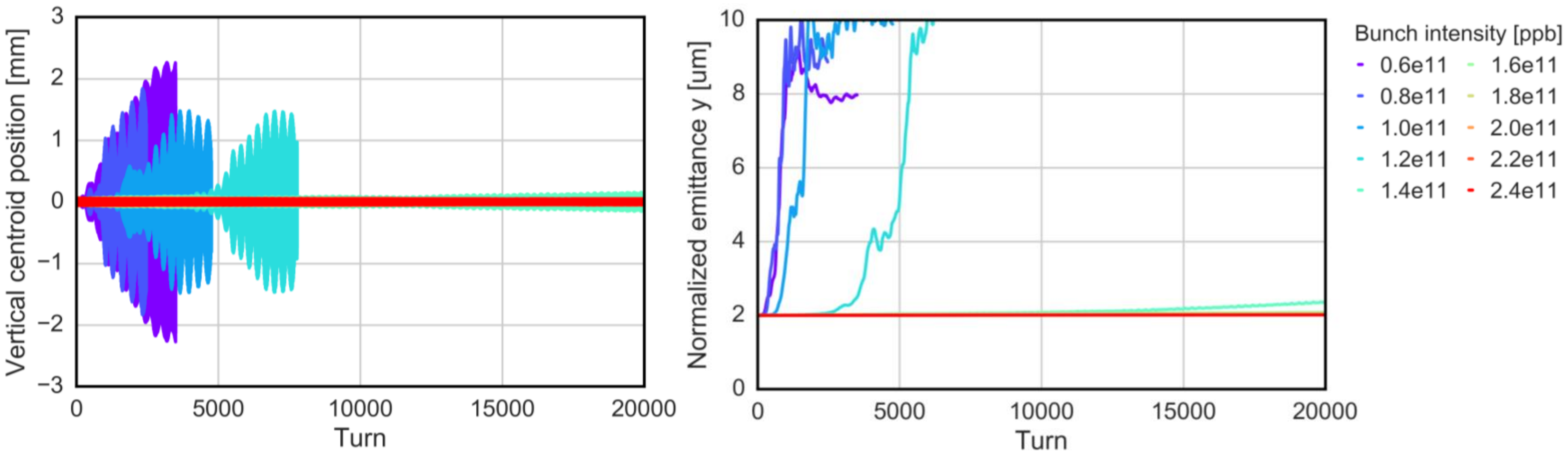
- Relying on self-consistent simulations
  - Instability observed for lower bunch intensity → larger EC density in the chamber
  - For higher bunch intensity the e- density is not sufficient to drive the bunch unstable

Arc quadrupoles @ 450 GeV: only EC

- Instability observed in both planes, consistently with the symmetry of the e-cloud dynamics in the quadrupoles
- Unlike LHC, EC in quadrupoles is not expected to drive instabilities at injection within the beam intensity upgrade foreseen by HL-LHC (N_b=2.3e11 p/bunch) → provided that intensity dependence from build-up simulations is confirmed experimentally

EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	OFF	0/0	0



(similar behaviour in the horizontal plane)

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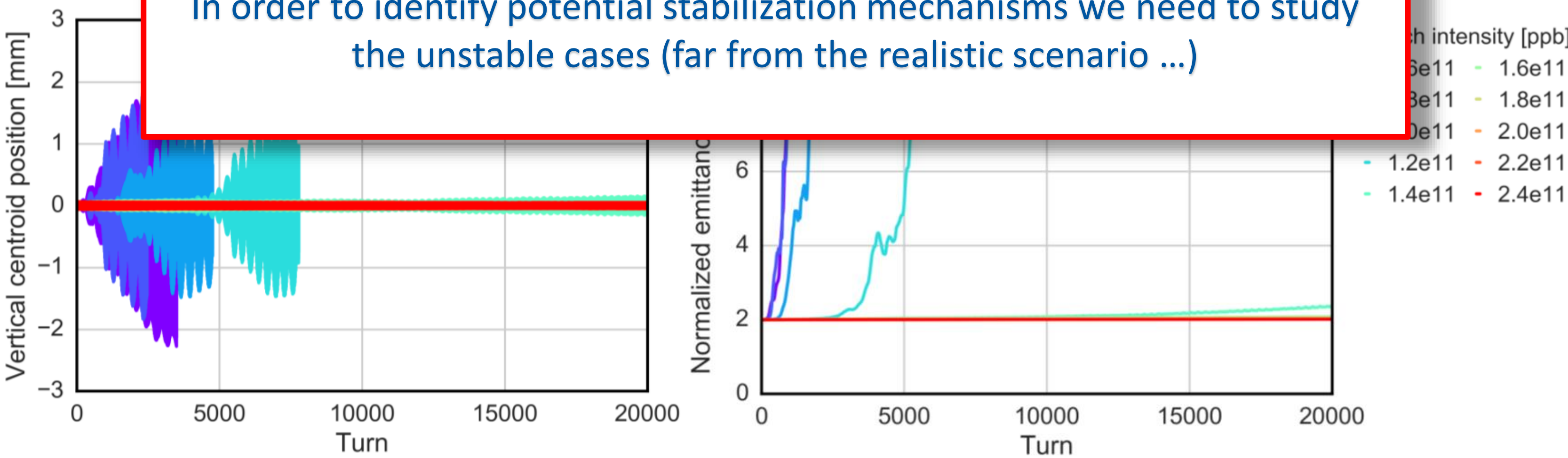
In order to identify potential stabilization mechanisms we need to study the unstable cases (far from the realistic scenario …)



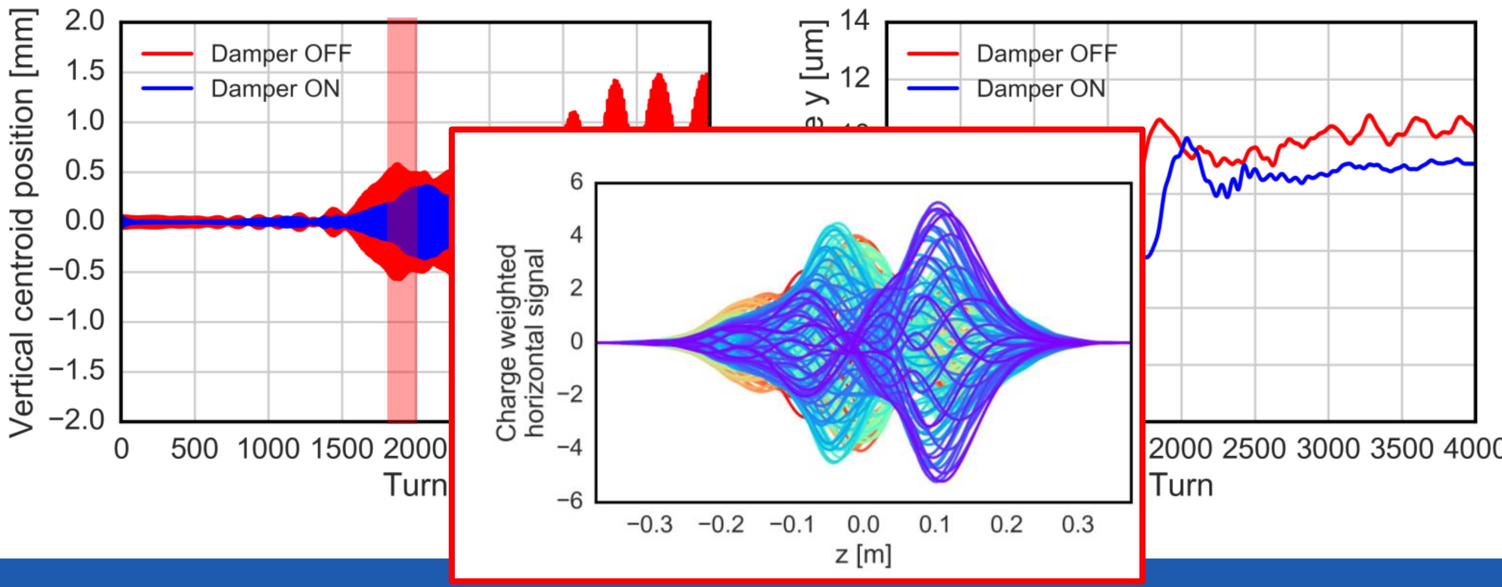
(similar behaviour in the horizontal plane)

Arc quadrupoles @ 450 GeV: transverse feedback effect

- Feedback system helps in reducing the centroid oscillation but not the emittance growth
  - Higher order modes excited → cannot be damped by the traditional damper
  - Consistent with the machine observation during the scrubbing run → higher damper gain helped to mitigate fast losses

EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	ON	0/0	0

N_b = 1.0e11 ppb

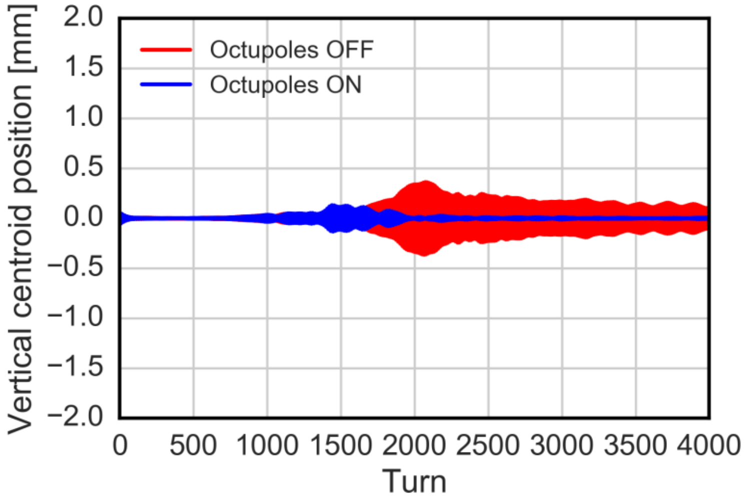


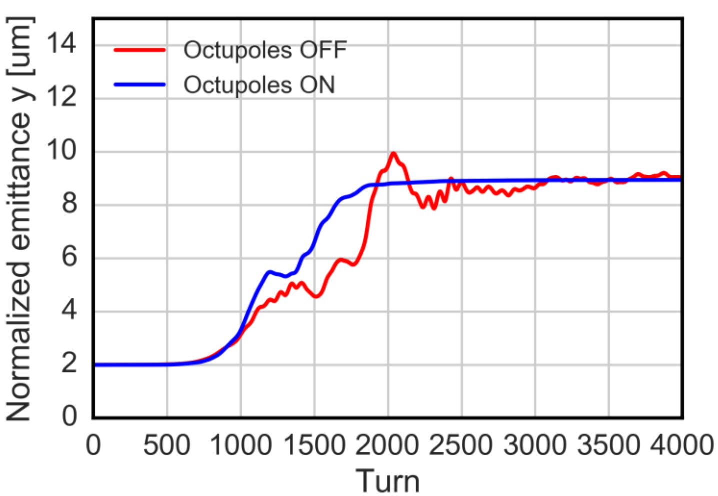
Arc quadrupoles @ 450 GeV: octupoles effect

- Mild stabilizing effect of octupoles alone → emittance growth still visible
- Octupoles might be less effective due to the smaller beam emittance → next step: detailed emittance and octupole scan

EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	ON	0/0	26 A

N_b = 1.0e11 ppb





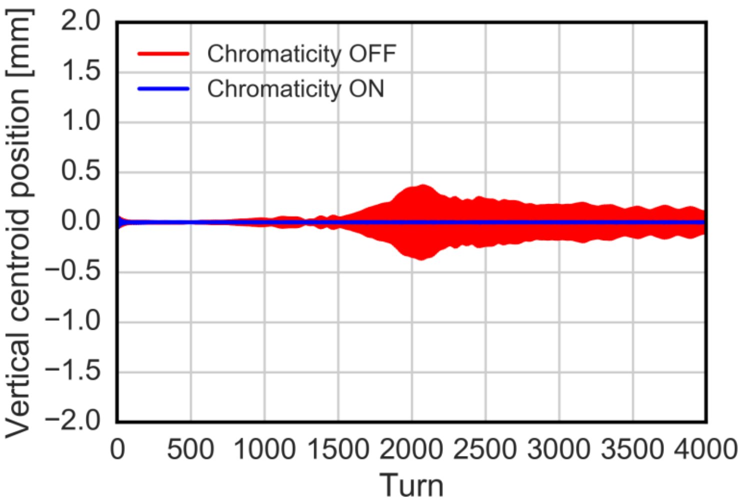
(similar behaviour in the horizontal plane)

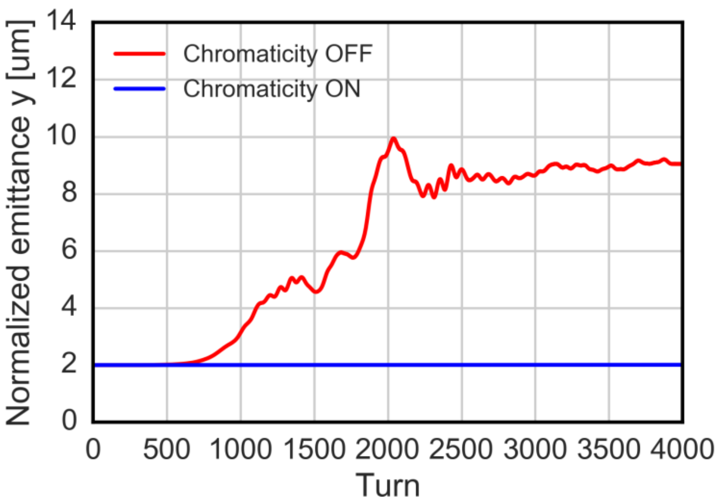
Arc quadrupoles @ 450 GeV: chromaticity effect

- Strong impact on the emittance growth and on the bunch oscillation as well
  - Large chromaticity values can ensure the beam stability

EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	ON	20/20	0

N_b = 1.0e11 ppb



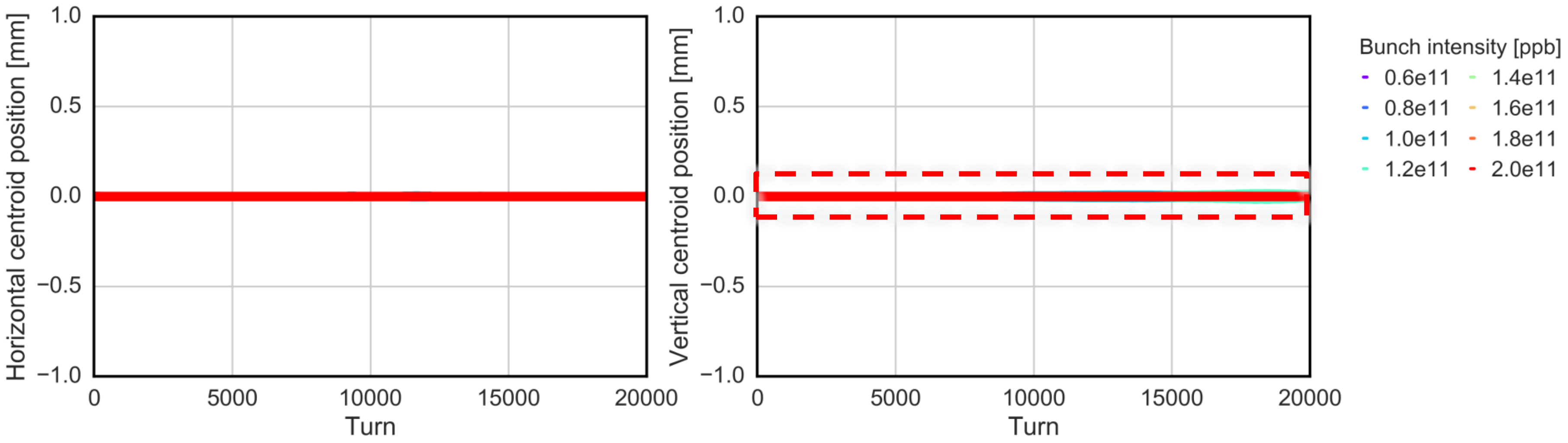


(similar behaviour in the horizontal plane)

Arc quadrupoles @ 7 TeV: only EC

- For bunch intensities larger than 2.0e11 the multipacting process does not occur for SEY=1.30
- Strong stabilizing effects of the increased beam energy → effect of the increased beam rigidity

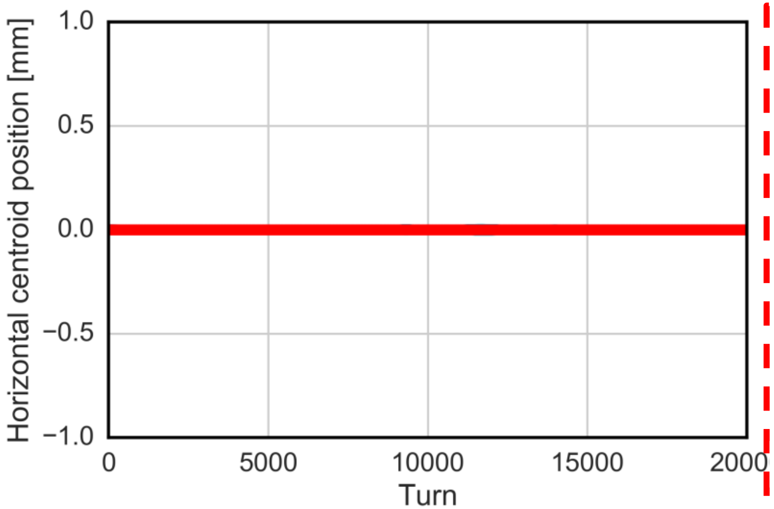
EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	OFF	0/0	0

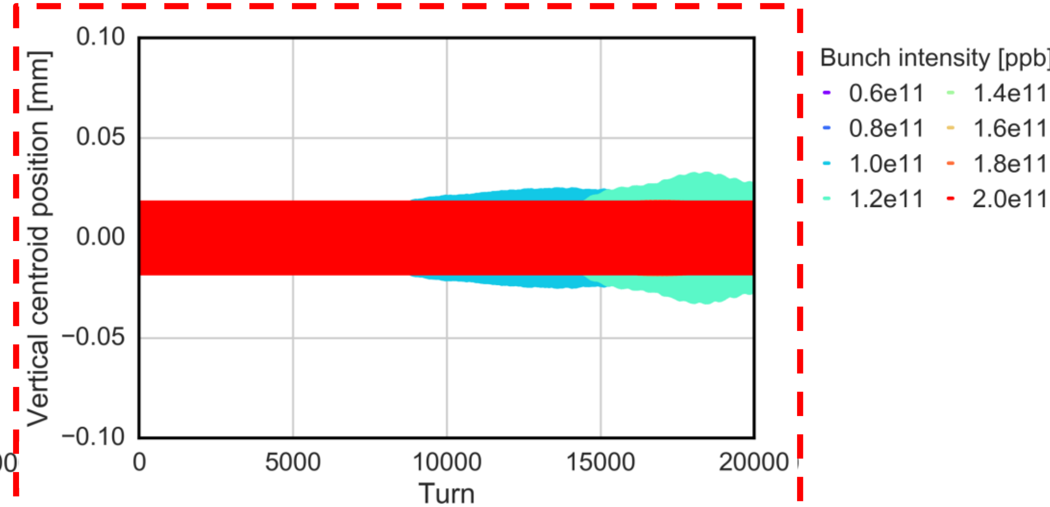


Arc quadrupoles @ 7 TeV: only EC

- For bunch intensities larger than 2.0e11 the multipacting process does not occur for SEY=1.30
- Strong stabilizing effects of the increased beam energy → effect of the increased beam rigidity
- Few unstable cases around LHC-like intensities can be observed in only the vertical plane, developing after 10k simulated turns → to be simulated together with damper, chromaticity and octupoles
  - EC in quadrupoles should not be an issue in HL-LHC

EC in quads	Damper	Chromaticity	Octupoles current
SEY 1.3	OFF	0/0	0



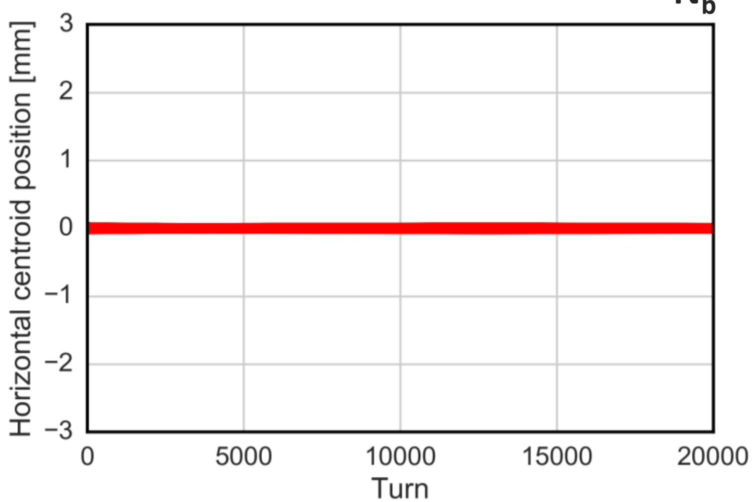


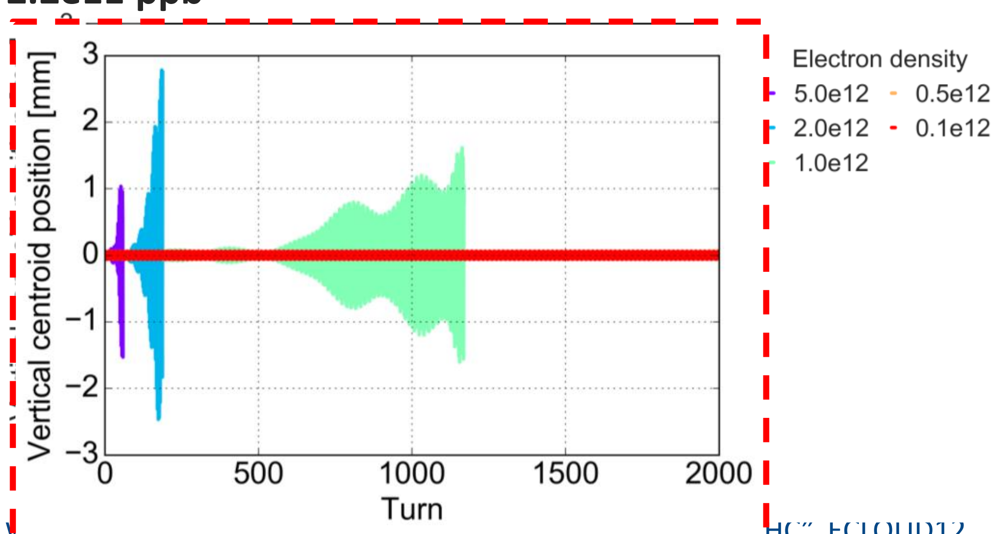
Arc dipoles @ 450 GeV: a first look

- EC distribution is initialized uniform within the dipole chamber and its density is scanned → good approximation[1]
- Instabilities observed only in the vertical plane
  - fast rise-time for large e- densities
  - instability threshold at around 1e12 e-/m^3

EC density in Dip	Damper	Chromaticity	Octupoles current
1e11-5e12	OFF	0/0	0

N_b = 2.2e11 ppb





(1) H. Bartosik et al., "BENCHMARKING HEADTAIL W… HC", ECLOUD12

Arc dipoles @ 450 GeV: a first look

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- Instabilities observed only in the vertical plane
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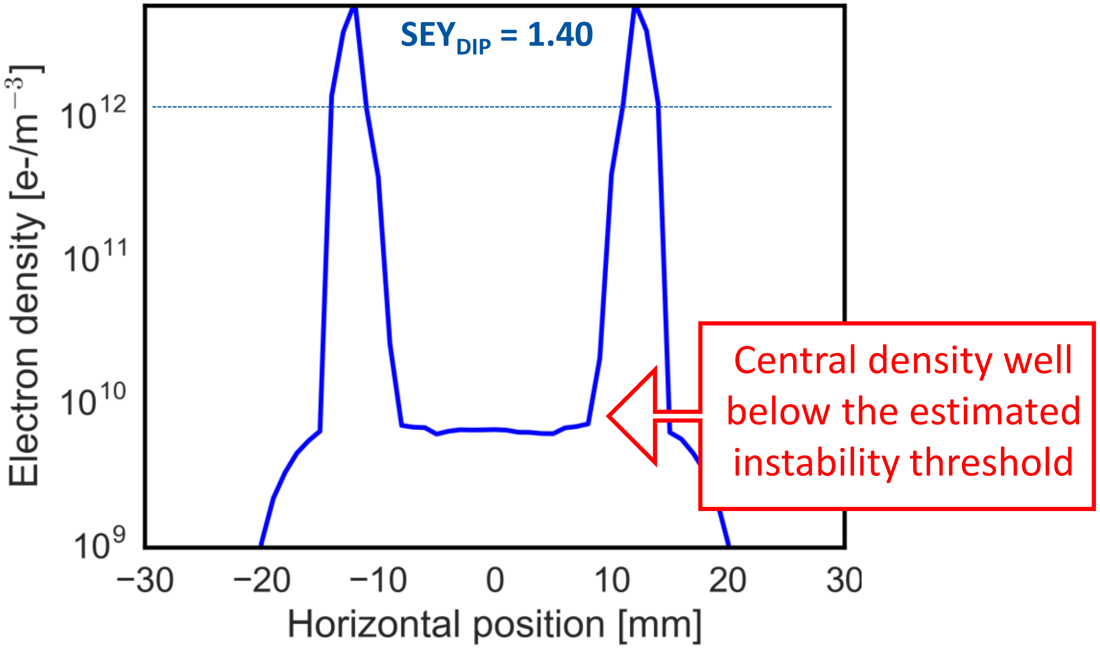
Estimated e- density from PyECLOUD build-up simulations



(1) H. Bartosik et al., "BENCHMARKING HEADTAIL WITH ELECTRON CLOUD INSTABILITIES OBSERVED IN THE LHC", ECLOUD12

Conclusions

- Simulation results show that the beam intensity increase foreseen by the HL-LHC has a beneficial impact on the beam stability

- Unlike LHC, the EC in quadrupoles in HL-LHC is not expected to drive the beam unstable both at injection and flattop energy → provided that intensity dependence from build-up simulations is confirmed experimentally
  - However potential mitigation strategies have been investigated → strong stabilizing effect from large chromaticity (20/20) and mild effect from octupoles and damper
  - Next steps → scan in beam emittance, octupoles current, chromaticity and beta function

- Preliminary studies in dipoles show that the EC density in the beam chamber is well below the estimated instability threshold → EC induced instabilities are not expected

Thanks for your attention!