
CERN

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Investigation on Convergence Properties: Single Pinch

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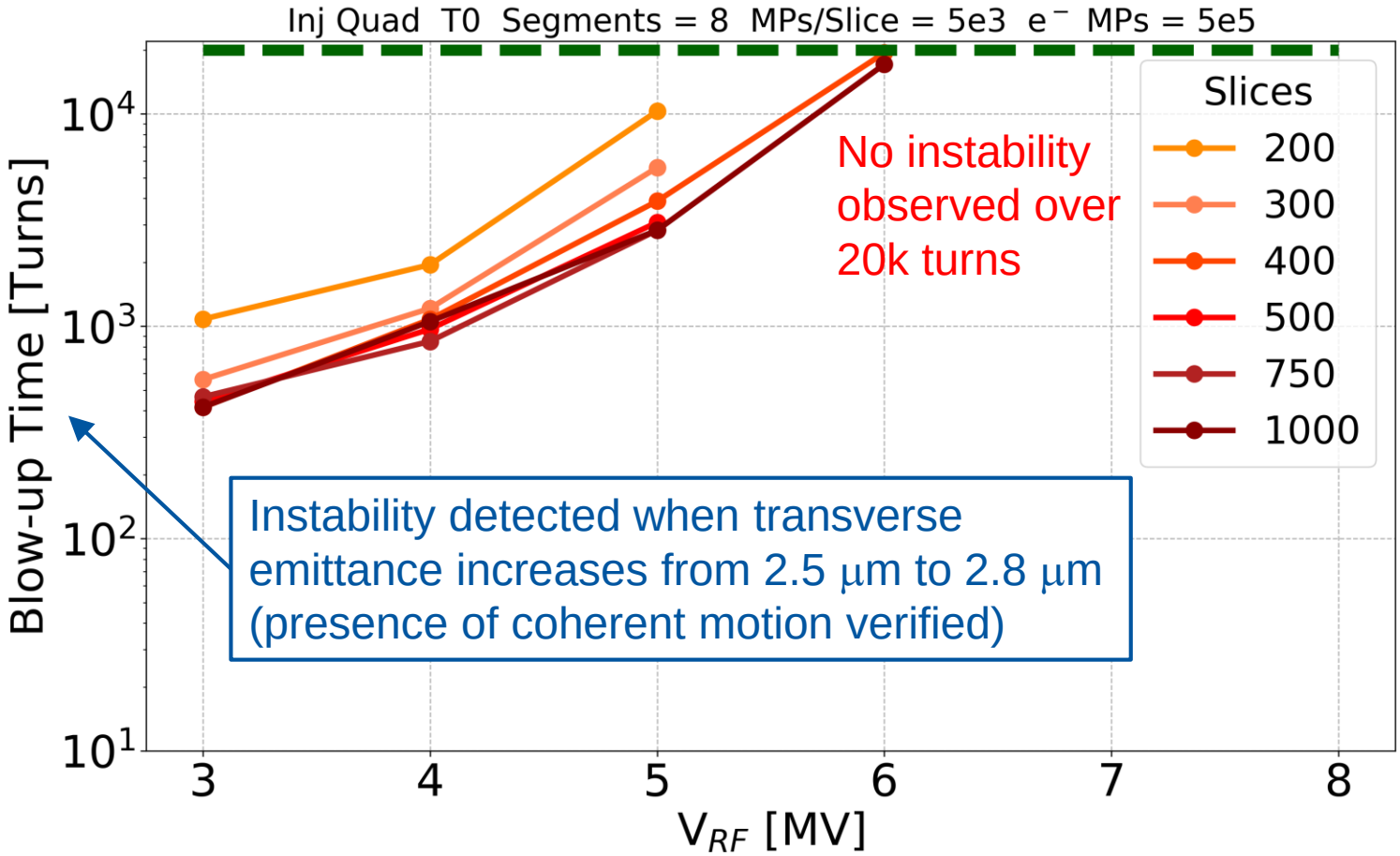
Acknowledgements: K. Paraschou

Introduction: Simulation Parameters

- $\varepsilon_{nx} = \varepsilon_{ny} = 2.5\ \mu m$
- $\beta_x = 92.7$ m and $\beta_y = 93.2$ m
- Energy: 450 GeV
- Magnetic Field (Arc Quadrupoles): 12.1 T/m
- Electron density: from build-up simulation
- SEY: 1.30 - 1.40
- Bunch Intensity: 1.2e11 - 2.3e11 protons per bunch
- Scan: σ_t (0.341 - 0.254 ns) / RF voltage (3 - 8 MV)

Convergence Studies: Slices



- Old setting 150 slices is not adequate
- With 200 slices the bunch is more stable, why?

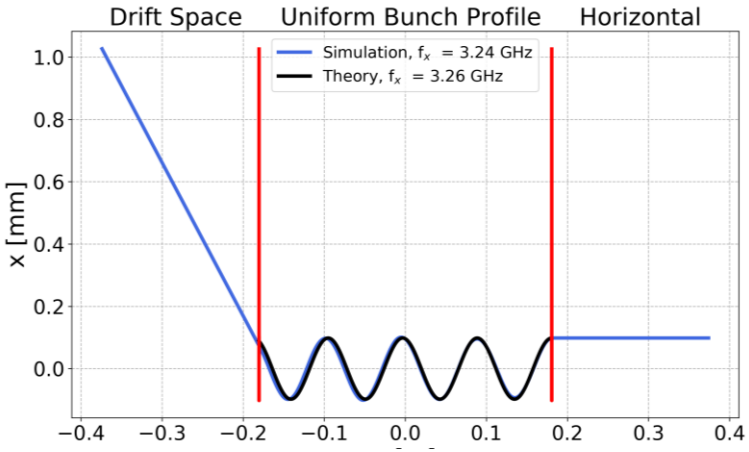
Electron Oscillations

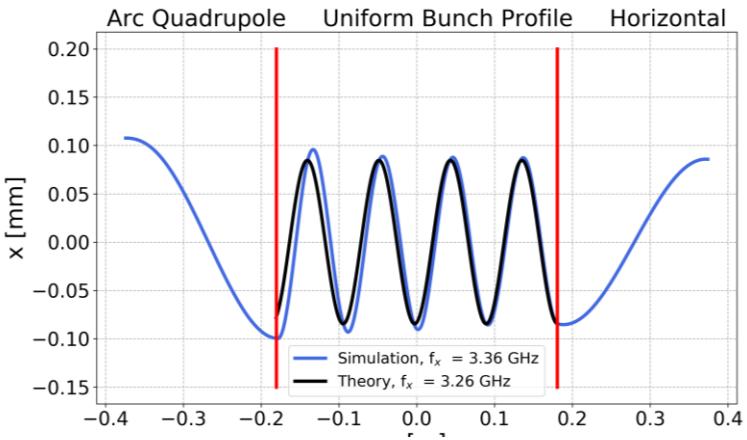
Analytical treatment in drift space (which works reasonably well also in the case of quadrupole and dipole) with uniform and Gaussian longitudinal profiles in **[2].**

Drift Space

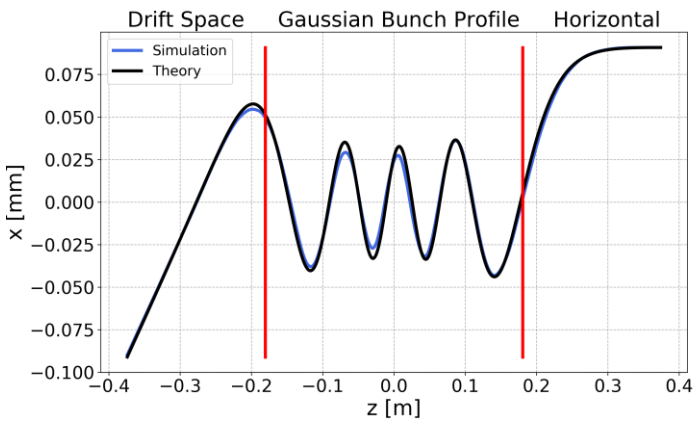
Quadrupole

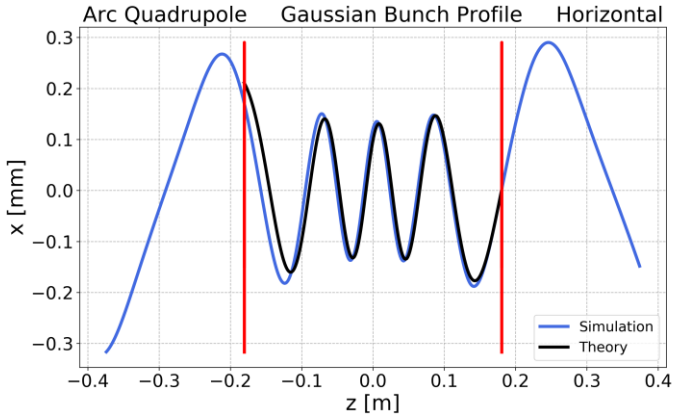
Uniform





Gaussian





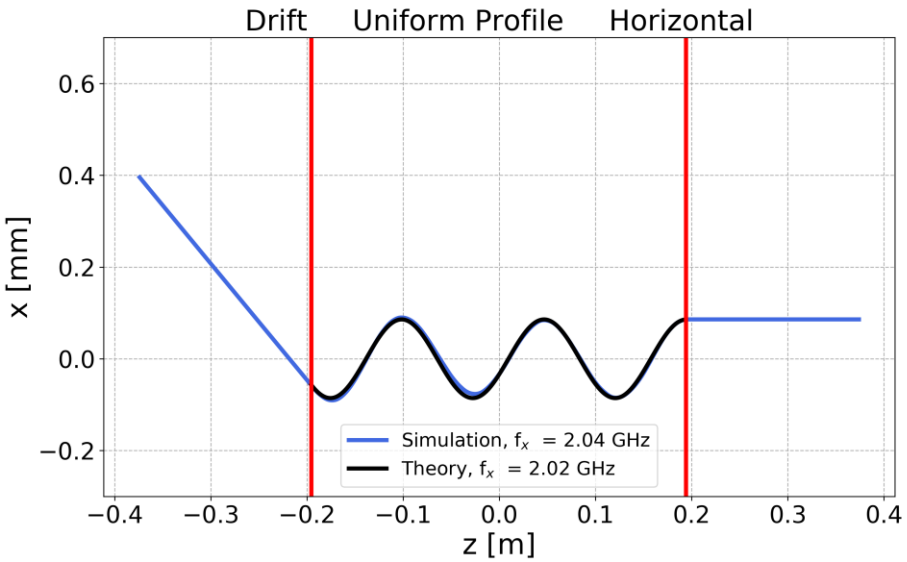
[2] L.Sabato, "Analysis Electron Motion Within the Beam", EC meeting #65 – February 22, 2019

Drift Space
Uniform Longitudinal Profile

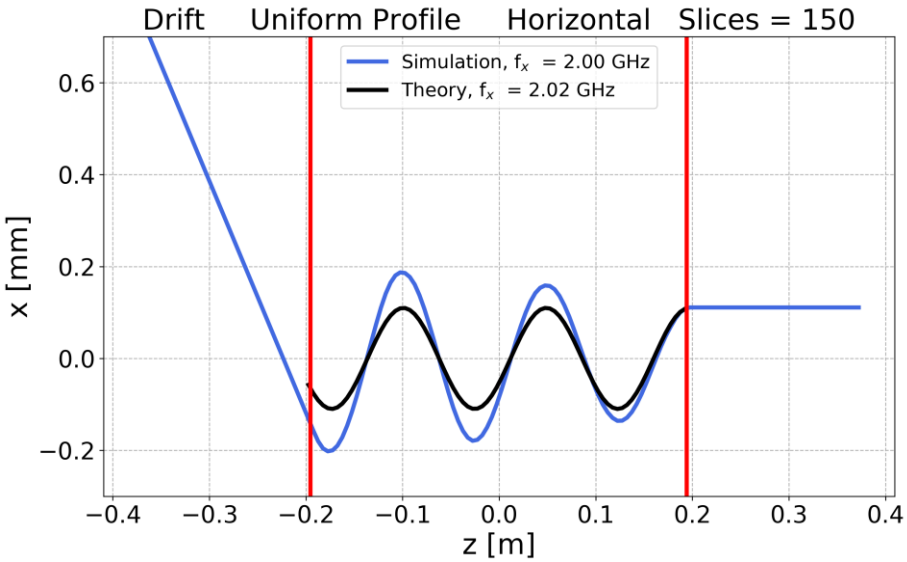
Electron Oscillations: Drift - Uniform

$A_{x\mathrm{goal}} = 0.1$ mm $A_{y\mathrm{goal}} = 0$ mm at bunch start

Slices = 500



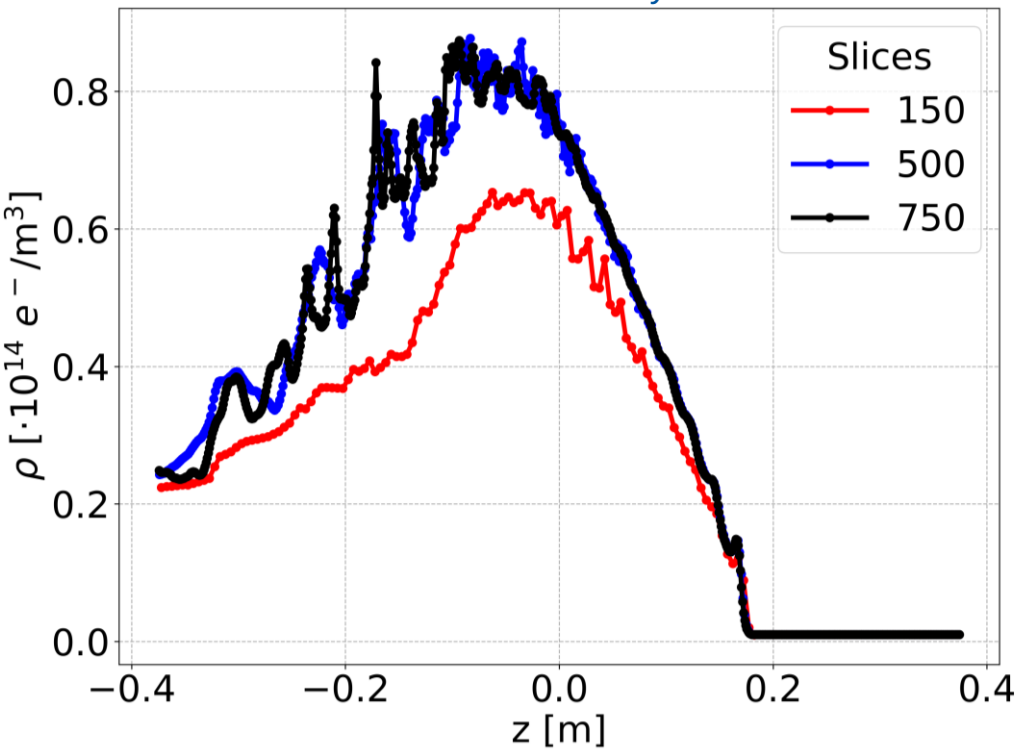
Slices = 150



- In the case 150 slices: the oscillation amplitude increases along the bunch passage
  ➔ electrons more distant from the centre

Electron Oscillations: Drift - Uniform

Electron density average ($|y| < 0.25\sigma_y$ and $x = 0$) along the bunch



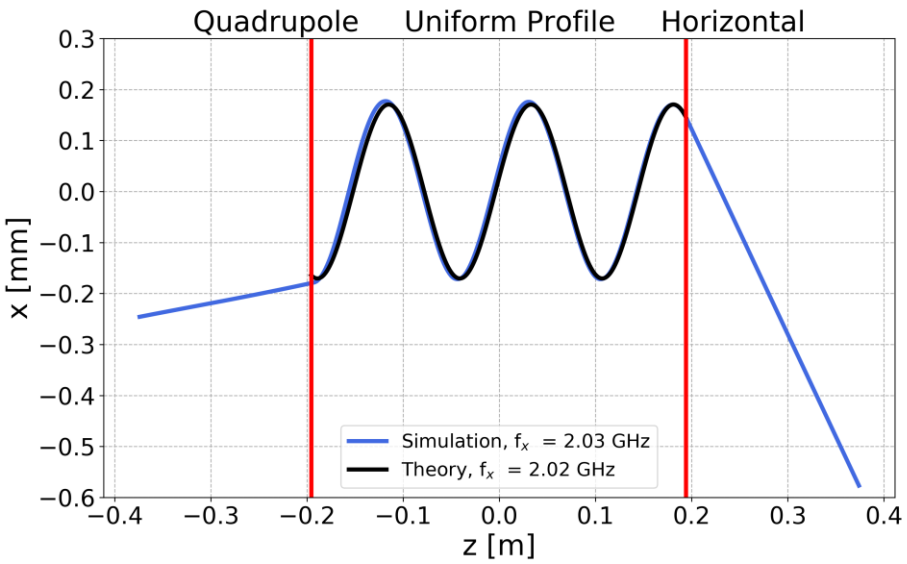
- 150 slices are not enough

Quadrupole
Uniform Longitudinal Profile

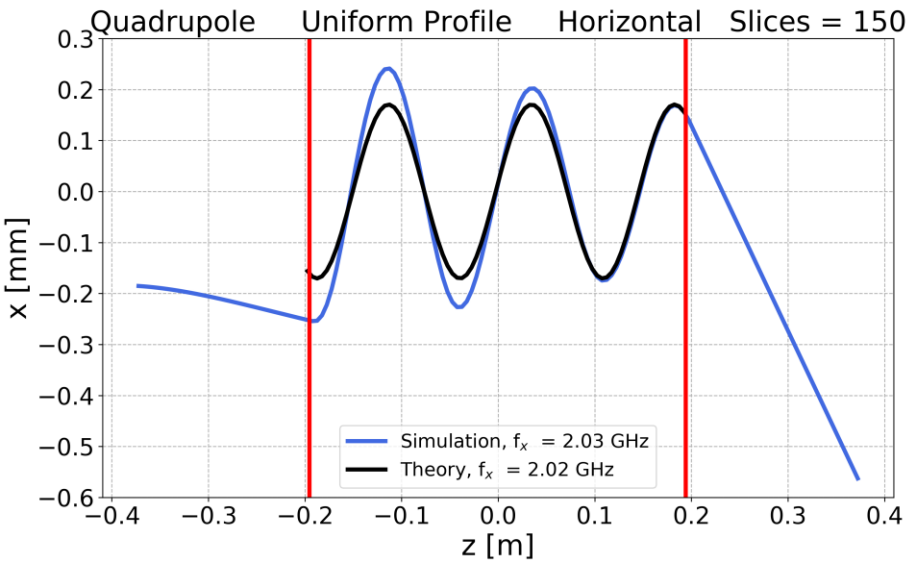
Electron Oscillations: Quad - Uniform

$A_{x\mathrm{goal}} = 0.1$ mm $A_{y\mathrm{goal}} = 0$ mm at bunch start

Slices = 500



Slices = 150



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Electron Oscillations: Quad - Uniform

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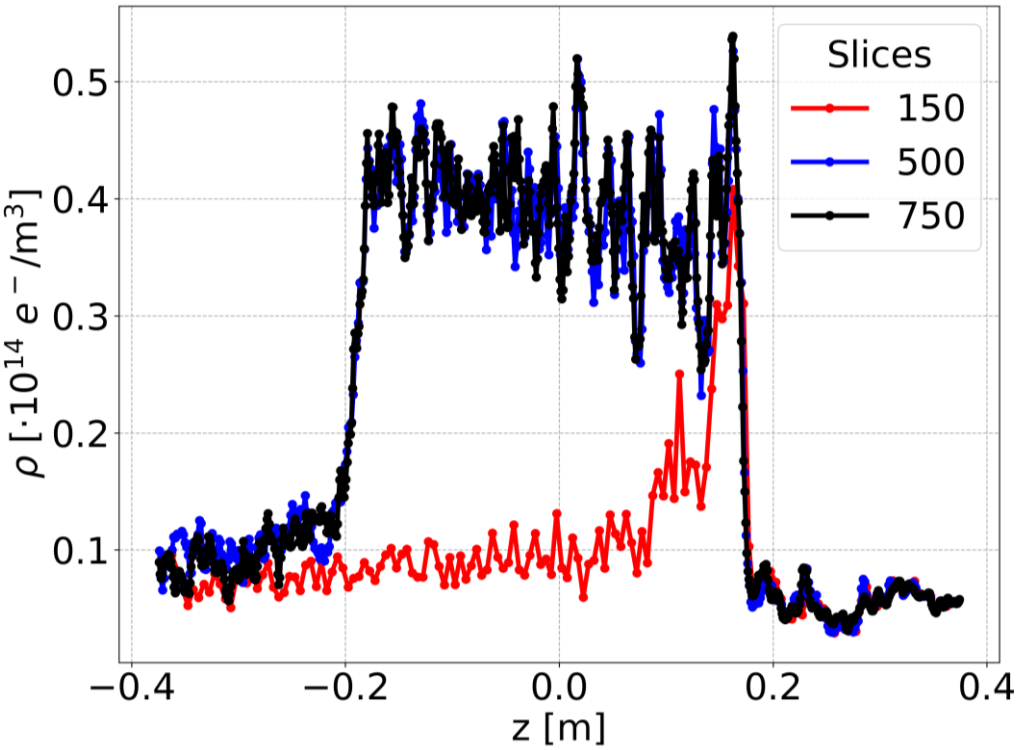
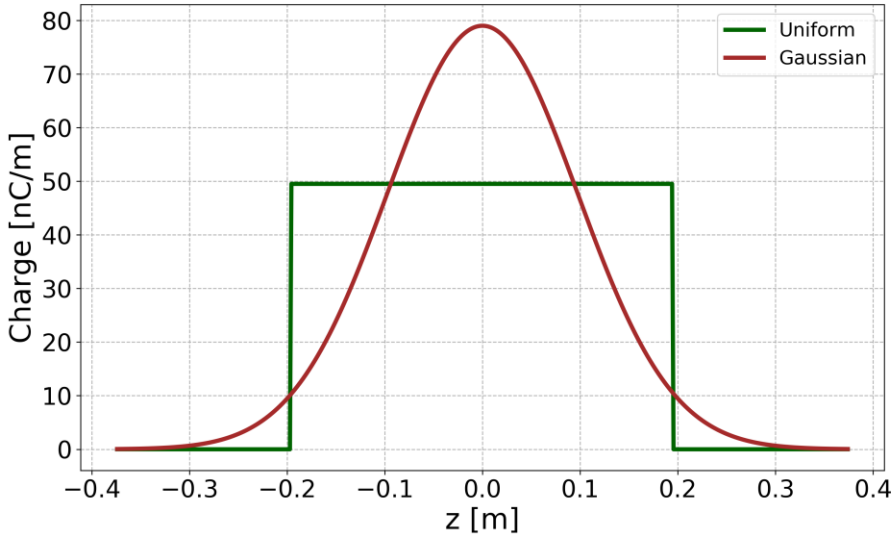


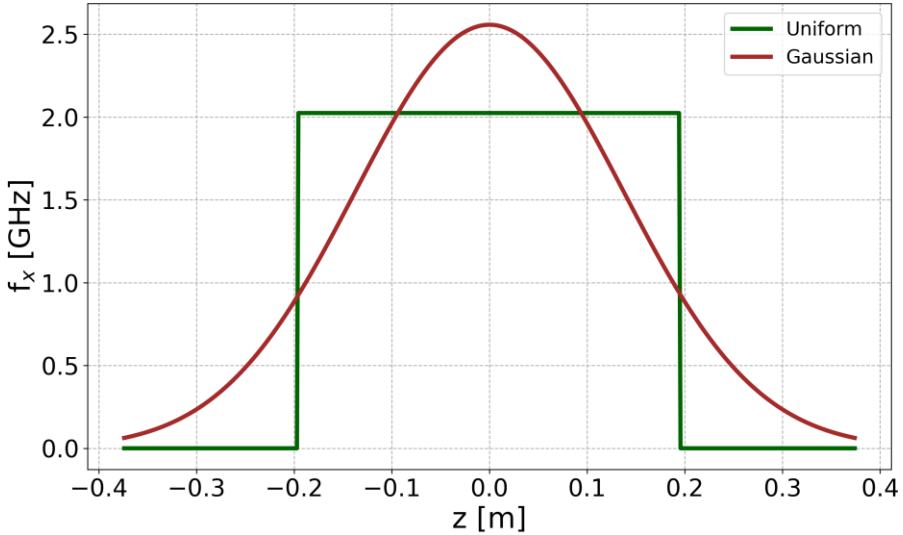
- 150 slices are not enough
- In this case the electron density evolution is completely wrong

Drift Space
Gaussian Longitudinal Profile

Electron Oscillations: Gaussian



$$\lambda_z(z) = \frac{q_e N_b}{\sqrt{2\pi}\sigma_z} e^{-\frac{z^2}{2{\sigma_z}^2}}$$

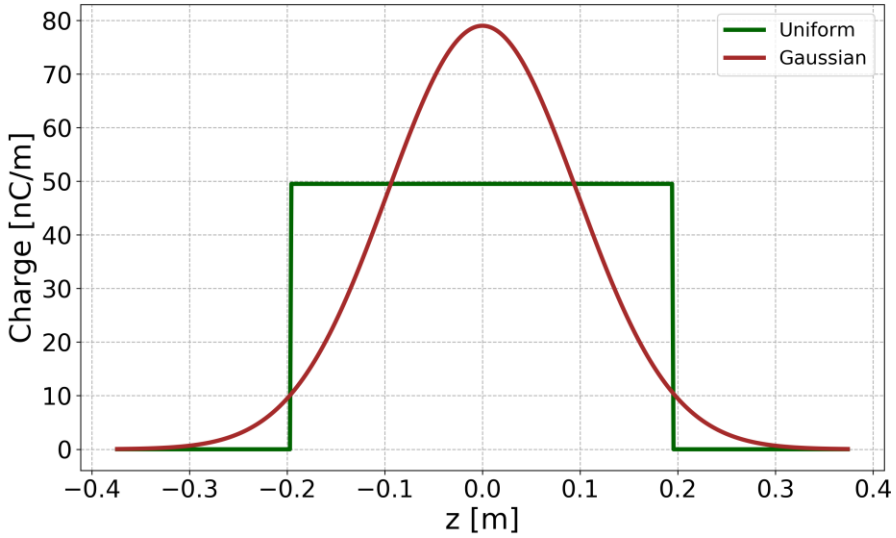


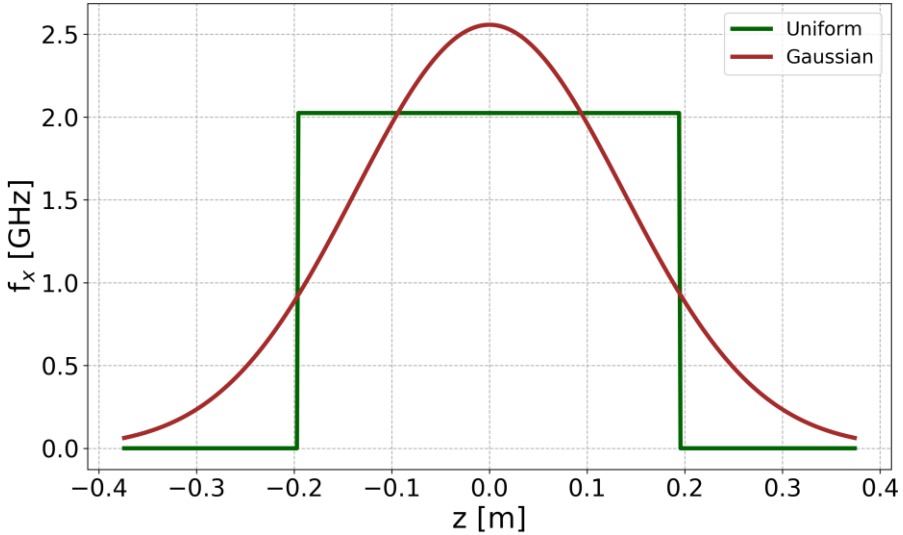
- The local frequency increases in the centre of the proton bunch

$$f_x(z) = \frac{1}{2\pi}\sqrt{\frac{q_e \lambda_z(z)}{2\pi\varepsilon_0 m_e \sigma_x(\sigma_x + \sigma_y)}}$$

[2] L.Sabato, "Analysis Electron Motion Within the Beam", EC meeting #65 – February 22, 2019

Electron Oscillations: Gaussian





- The local amplitude decreases in the centre of the proton bunch:

$$A_x{}^2 = x_0{}^2 + \left(\frac{v_{x0}}{2\pi f_x}\right)^2$$

$$A_x{}^2 = x_0{}^2 + \frac{v_{x0}{}^2}{\frac{q_e \lambda_z(z)}{2\pi\varepsilon_0 m_e \sigma_x(\sigma_x + \sigma_y)}}$$

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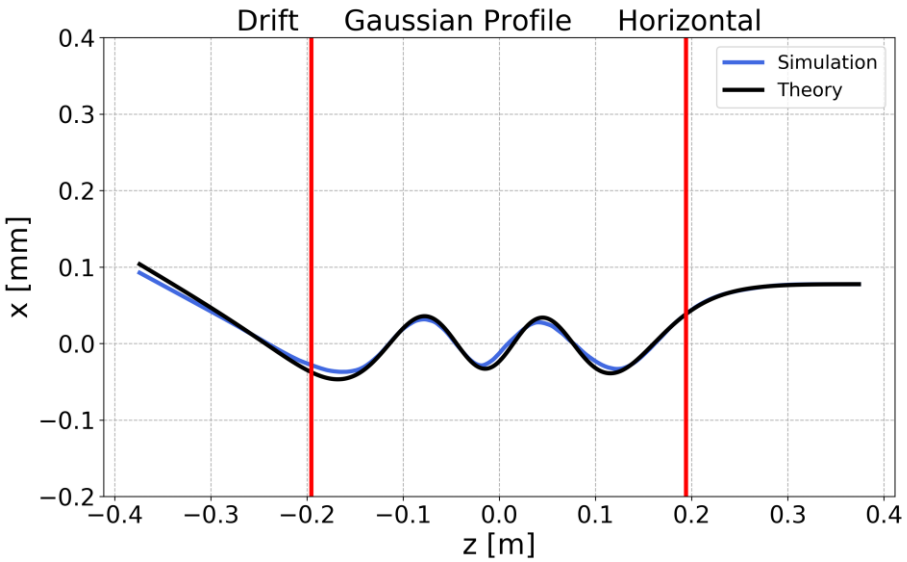
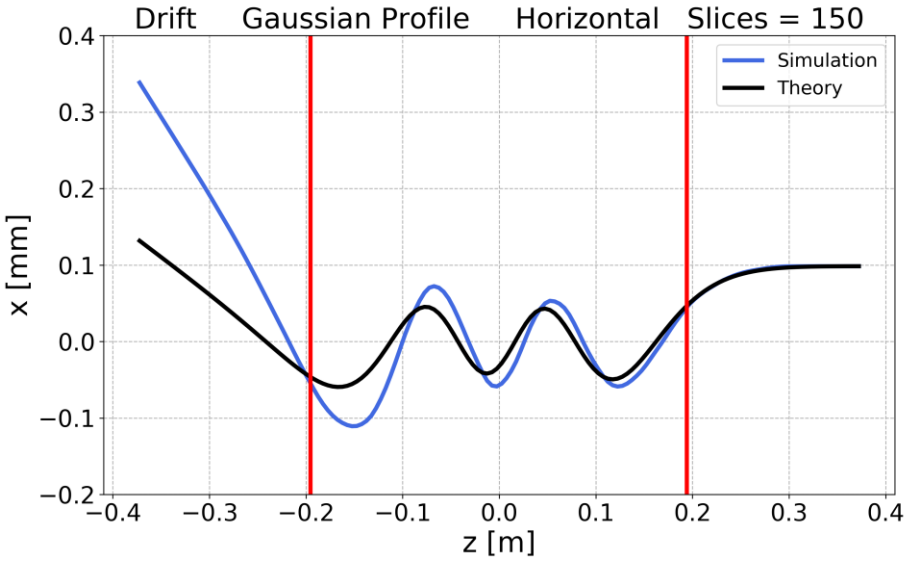
Electron Oscillations: Drift - Gaussian

$A_{x\text{goal}} = 0.1$ mm $A_{y\text{goal}} = 0$ mm at bucket start

Slices = 500



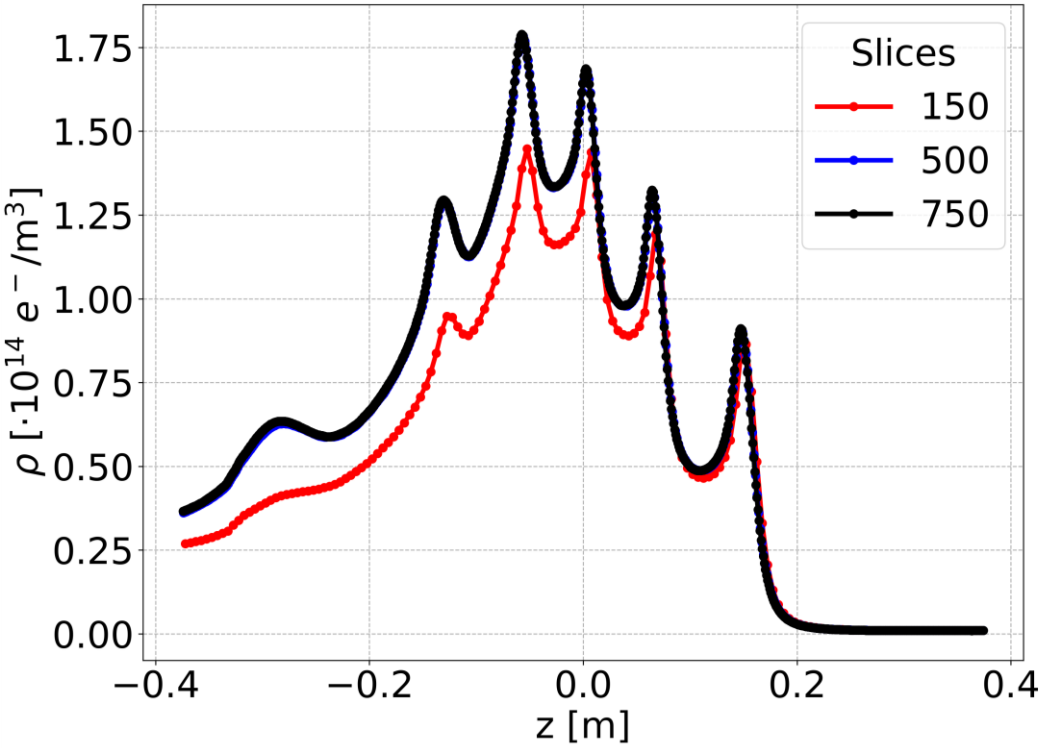
Slices = 150



- In the case 150 slices: the oscillation amplitude increases along the bunch passage
  ➔ electrons more distant from the centre

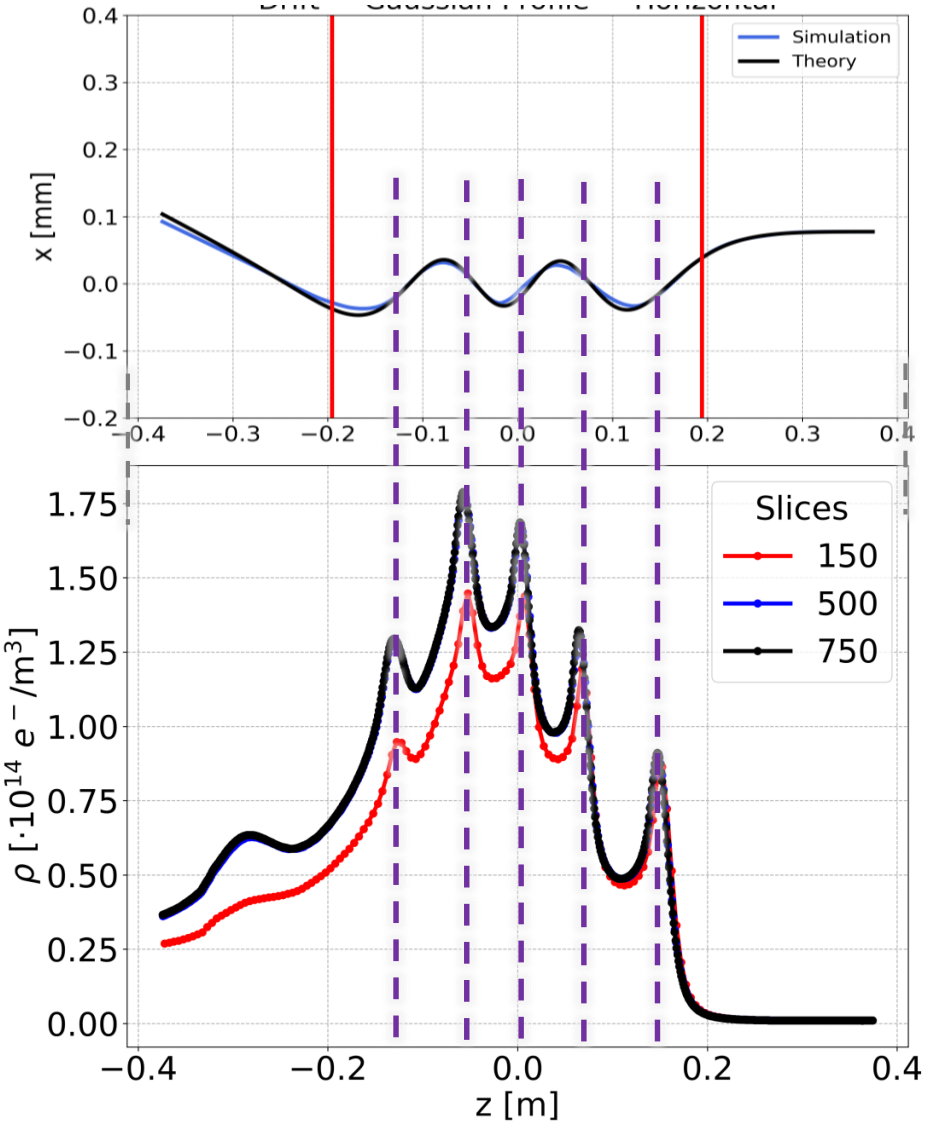
Electron Oscillations: Drift - Gaussian

Electron density average ($|y| < 0.25\sigma_y$ and $x = 0$) along the bunch



- 150 slices are not enough

Electron aussian



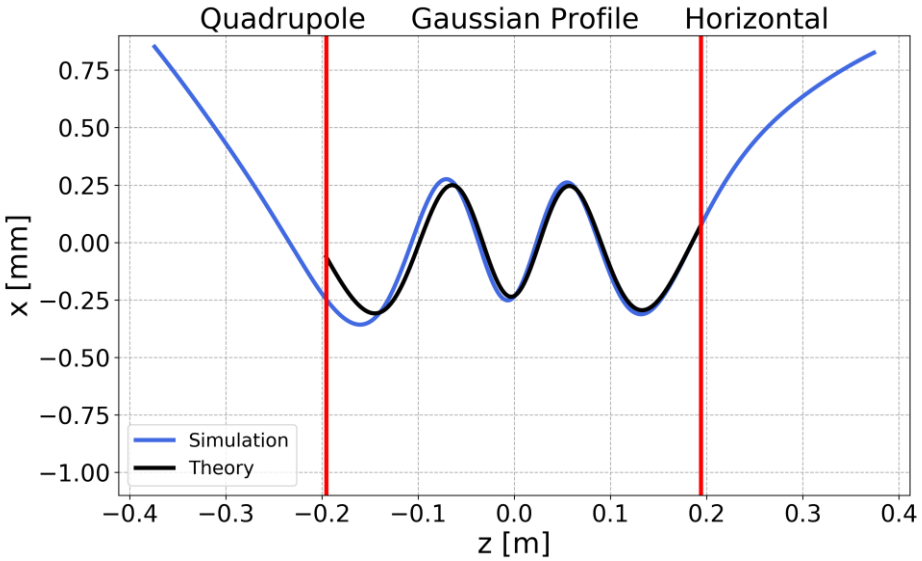
- The peaks are around the zeros of the single electron oscillations (they are closer at the bunch centre and farther at the bunch head and tail, because the electron oscillation frequency is smaller)

Quadrupole
Gaussian Longitudinal Profile

Electron Oscillations: Quad - Gaussian

$A_{x\text{goal}} = 0.1$ mm $A_{y\text{goal}} = 0$ mm at bunch start

Slices = 500



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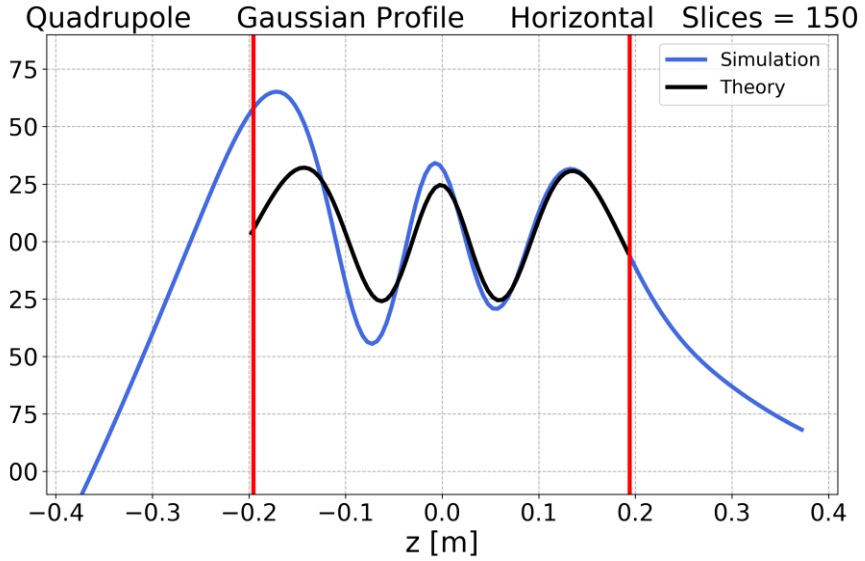
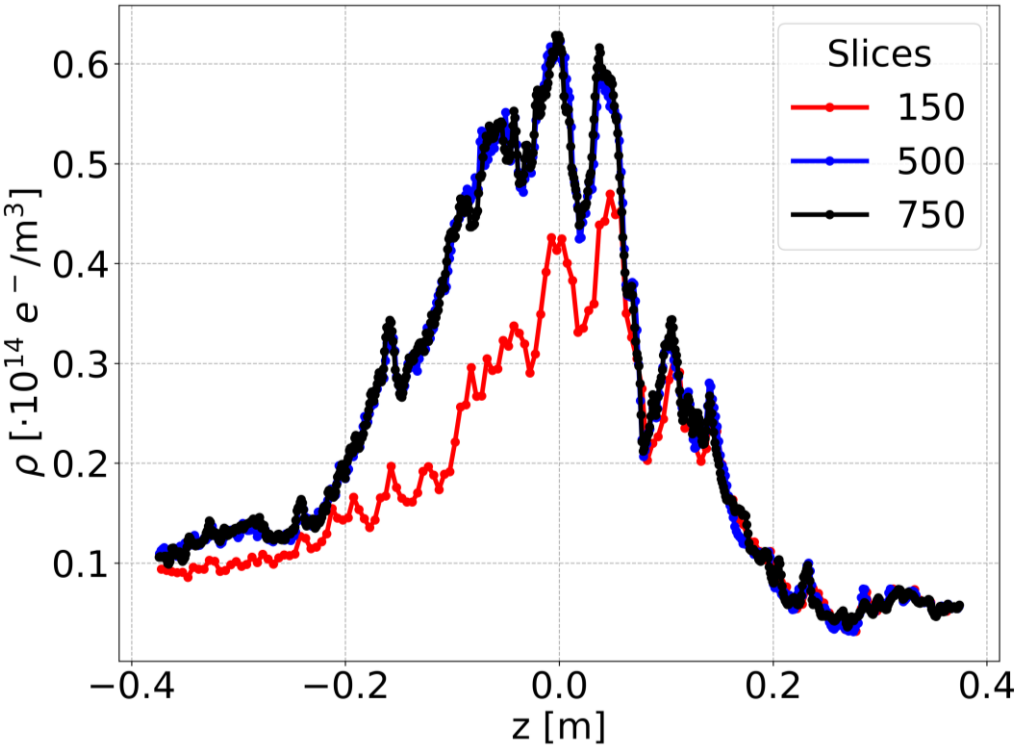


- In the case 150 slices: the oscillation amplitude increases along the bunch passage ➔ electrons more distant from the centre

- The discrepancy that is still observed is due to the magnetic field, which is neglected in the theoretical calculation

Electron Oscillations: Quad - Gaussian

Electron density average ($|y| < 0.25\sigma_y$ and $x = 0$) along the bunch



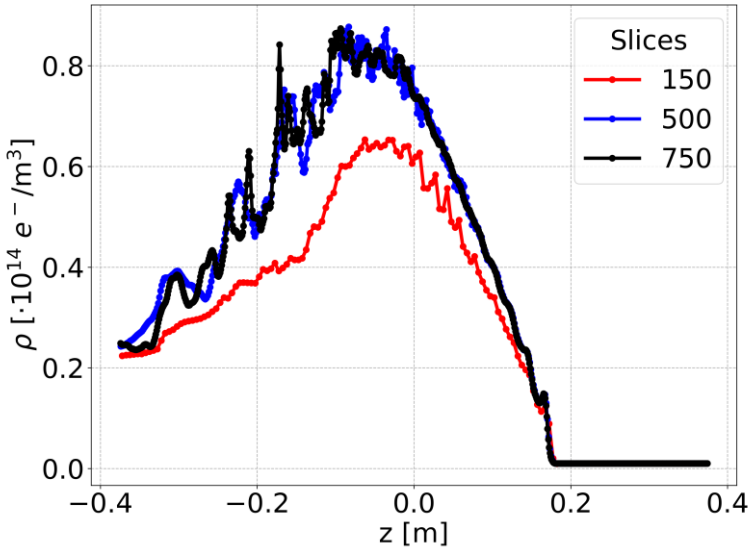
- 150 slices are not enough
- Smaller electron density peak (around 20%) during the pinch ➔ bunch more stable

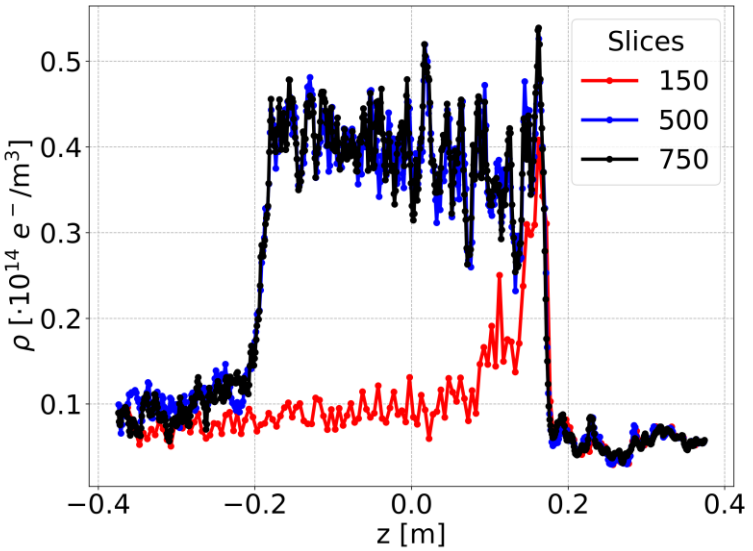
Electron Oscillations: Summary

Drift

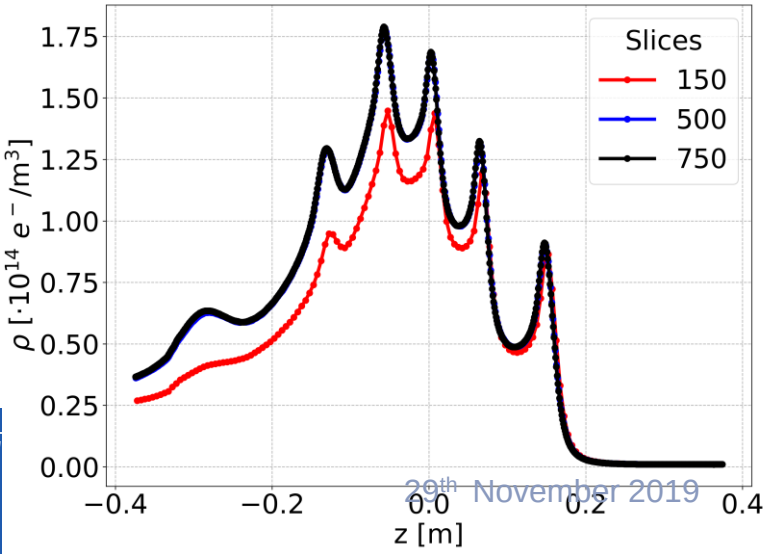
Quadrupole

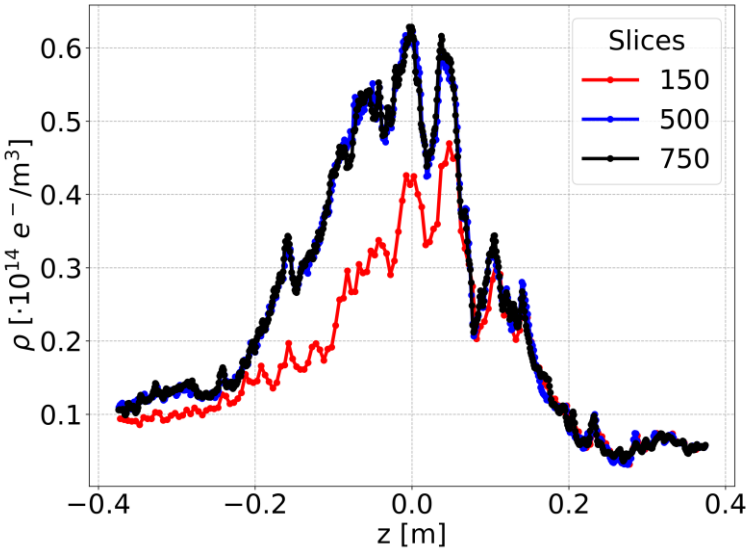
Uniform





Gaussian





Conclusions

- Choosing a number of slices not sufficient:
  - oscillation amplitude increases along the bunch passage
  - electrons more distant from the centre
  - smaller electron density peak
  - bunch more stable

- From the convergence studies at injection, 500 slices are enough for:
  - single passage simulations (for the pinch)
  - multi passage simulations (from large instability convergence studies)

Thanks for your attention