THz ELECTRON-PULSE TRAIN DYNAMICS IN A MeV PHOTOINJECTOR

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Outline

- Motivations
- Electromagnetic fields in an RF accelerator
- Evolution of an ultra-short electron bunch
- Initial Phase Compensation:

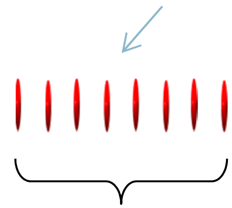
  Generation of an ultra-short electron pulse

  Generation of ultra-short electron-pulse train
- Schemes of initial phase compensation
- Conclusion

Motivations

- **Electron-pulse train:**

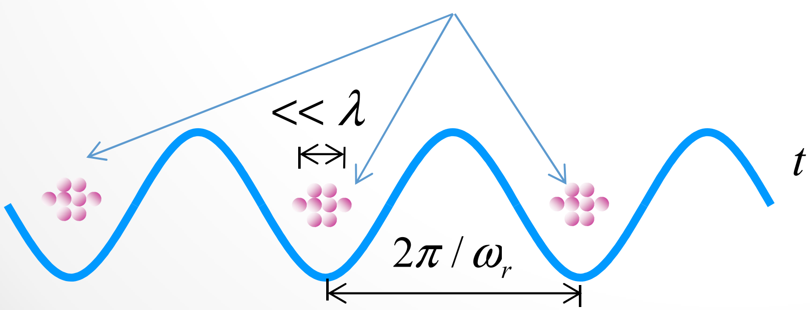
Electron
micro-bunches



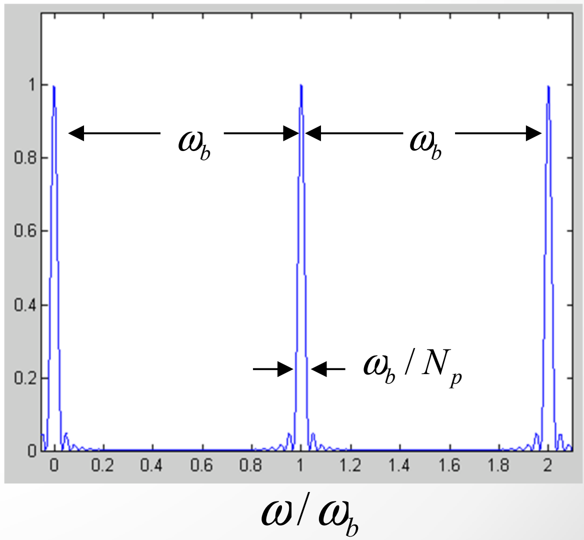
Electron
macro-bunch

Narrow-line coherent radiation

Electron
micro-bunches

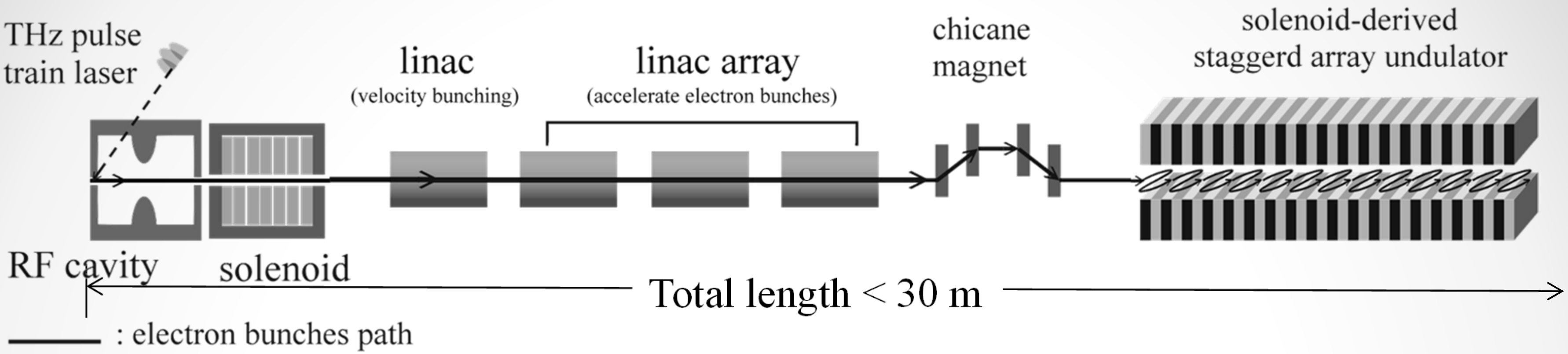


Radiation spectrum



A soft X-ray FEL with 10-time reduced size

(Fu-Han Chao et al., Proceedings, FEL2011)



Beam:

Beam energy = 150 MeV

Peak current = 3.3 kA

Energy spread = 3×10^{-4}

Emittance = 2-mm-mrad

Initial bunching factor = 10 ppm

Undulator:

Period = 5 mm

Gap = 0.8 mm

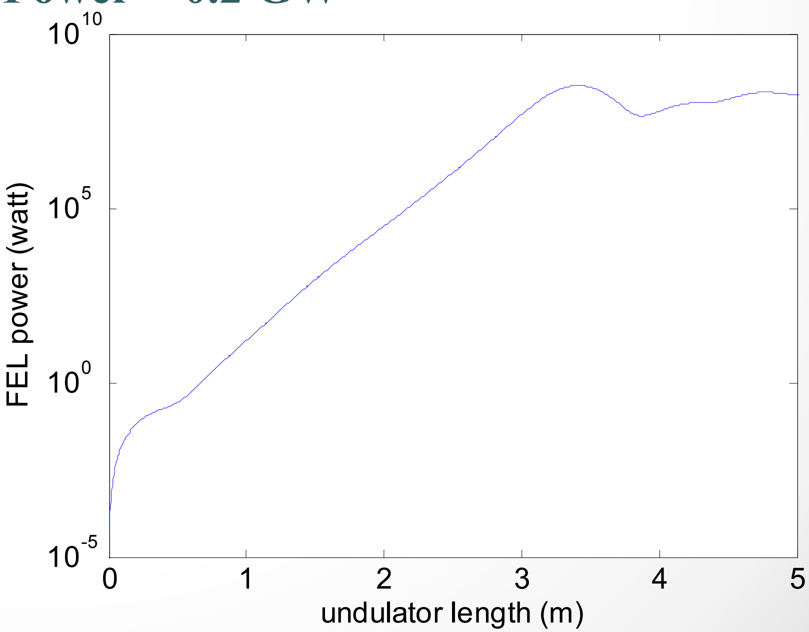
Undulator parameter = 0.4

Length = 3 m

Radiation:

Wavelength = 32.2 nm

Power = 0.2 GW

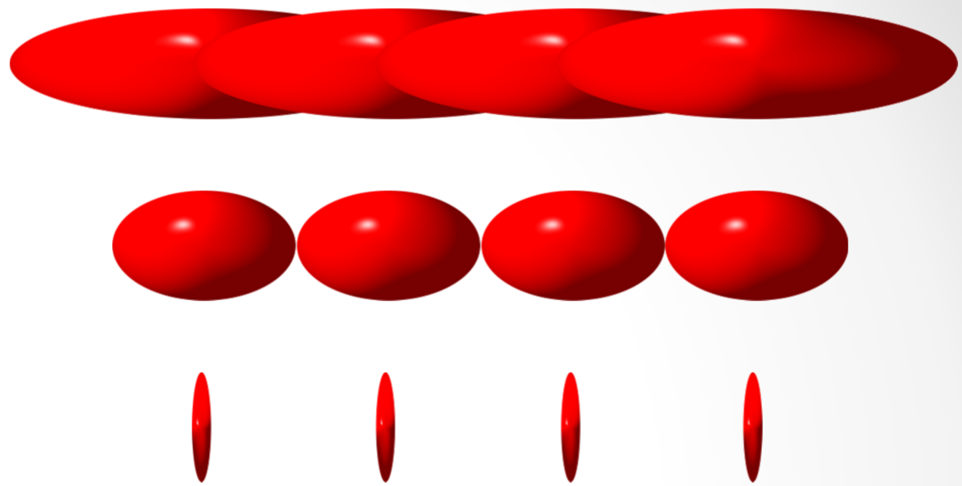


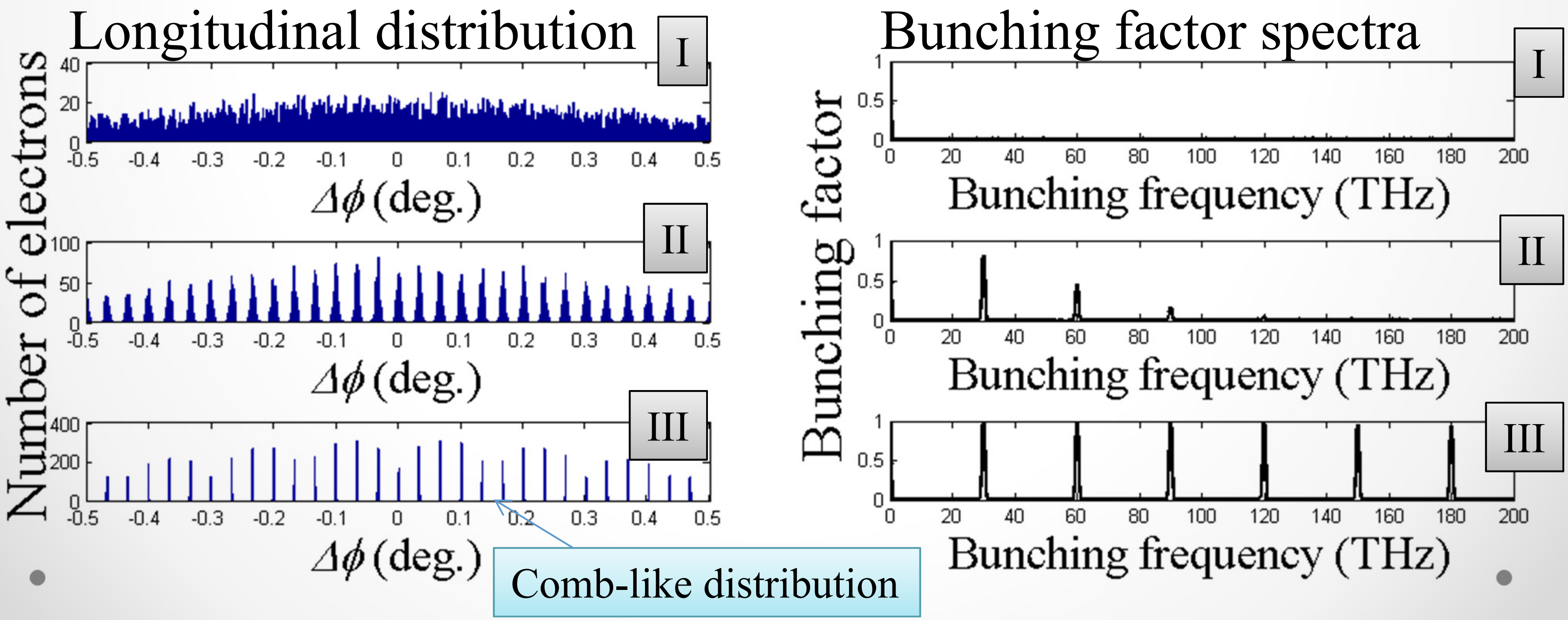
Motivations

I Bunch width>>period

II Bunch width ~period

III Bunch width<<period





Electromagnetic fields in an RF accelerator

- The RF fields in a standing-wave accelerator are **radial-dependent**. The field components of the dominate mode are given by:

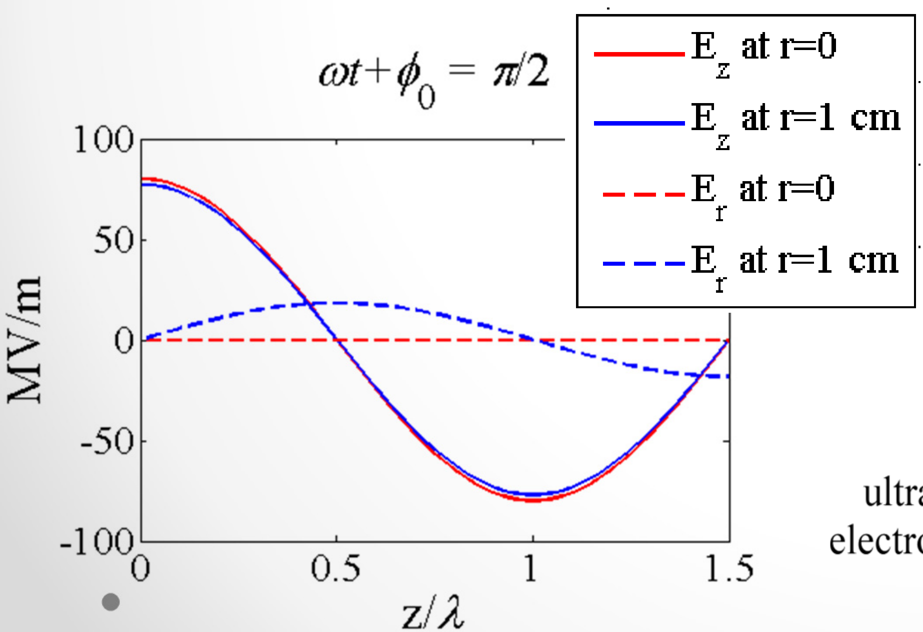
Longitudinal field

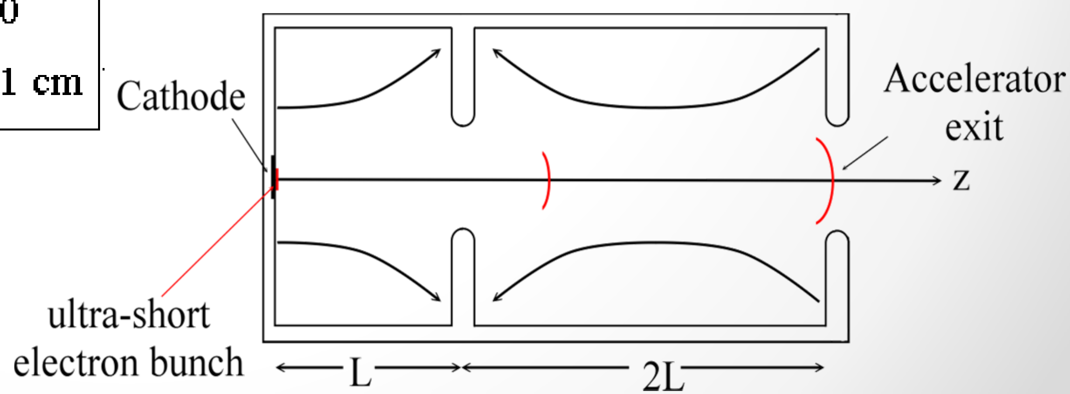
$$E_z(r,z,t) = E_0 J_0(\eta_0 r)\cos(k_0 z)\sin(\omega t + \phi_0)$$

Transverse fields

$$E_r(r,z,t) = E_0 k_0 r \frac{J_1(\eta_0 r)}{\eta_0 r}\sin(k_0 z)\sin(\omega t + \phi_0)$$

$$B_\theta(r,z,t) = E_0 \frac{\omega r}{c^2}\frac{J_1(\eta_0 r)}{\eta_0 r}\cos(k_0 z)\cos(\omega t + \phi_0)$$

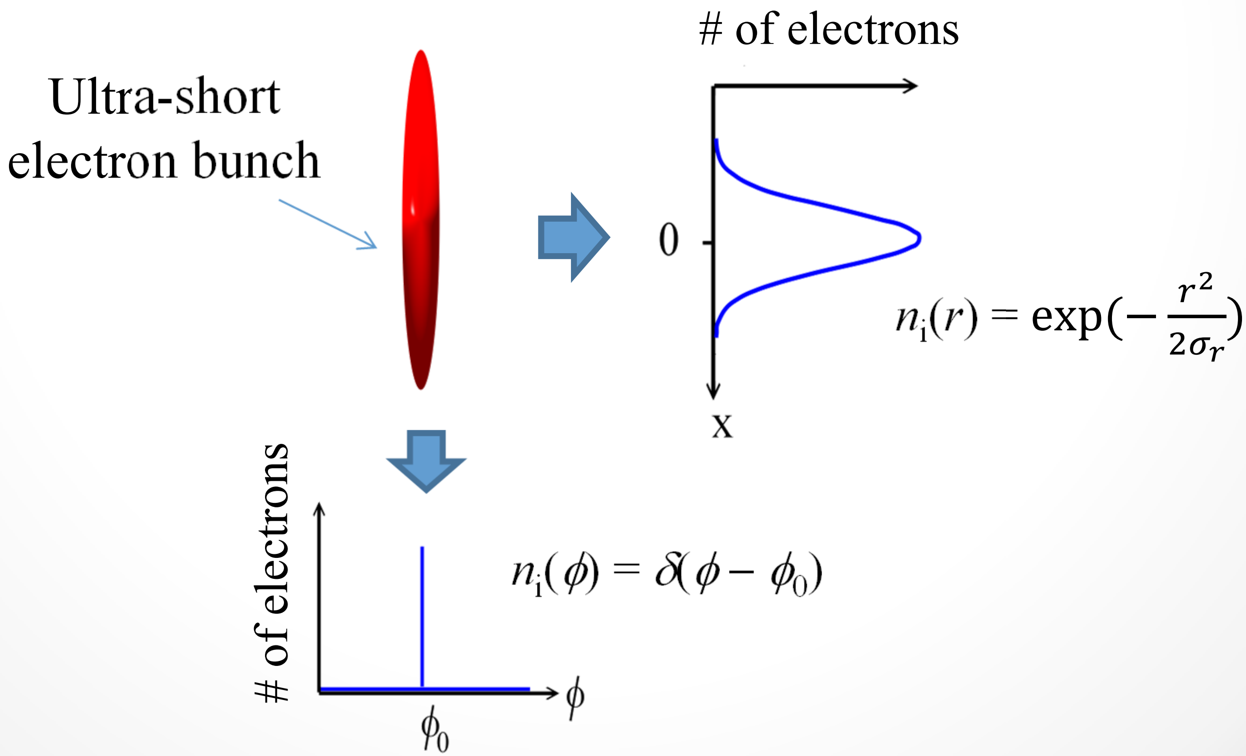




Evolution of an ultra-short electron bunch

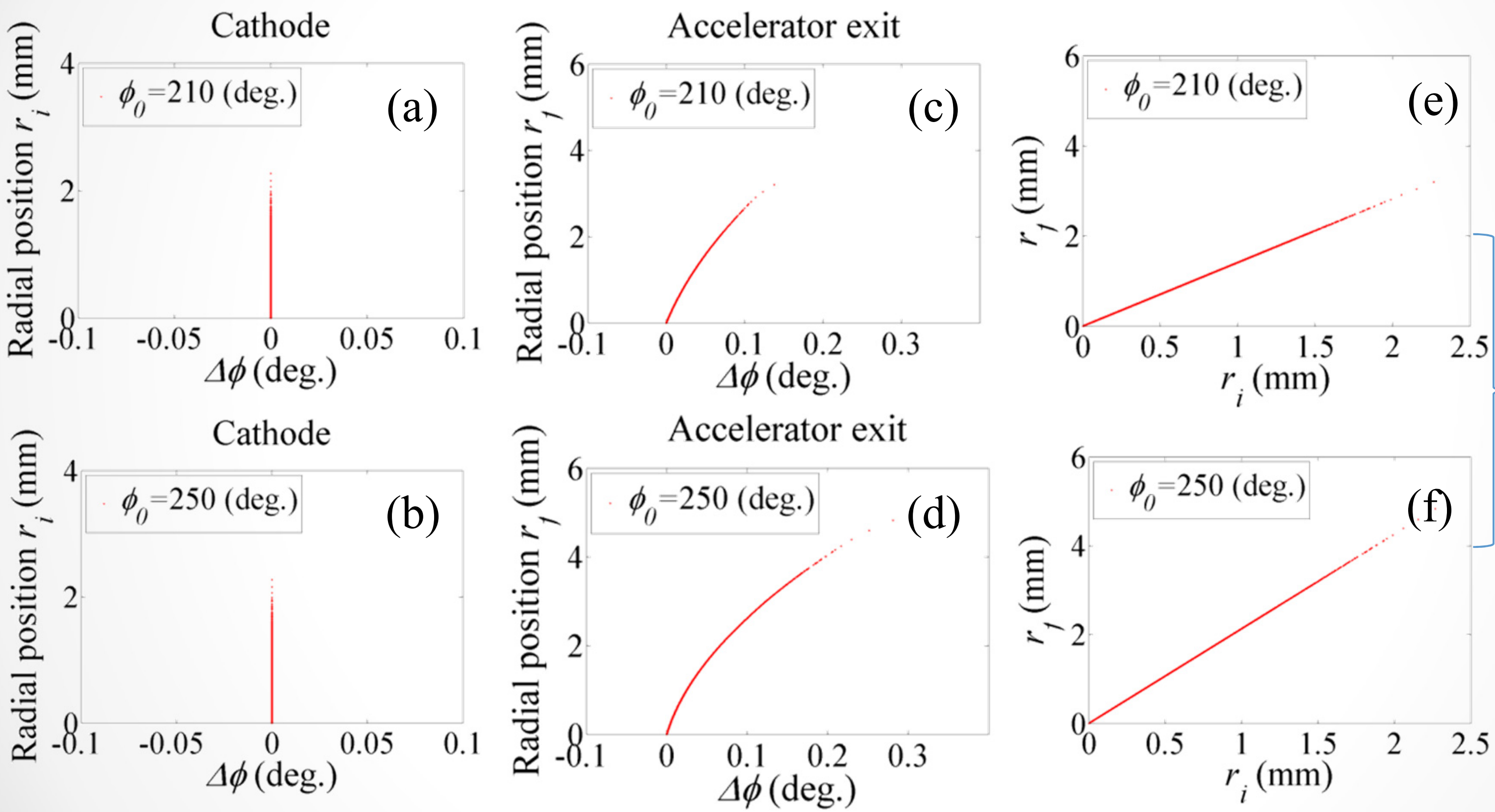
- **Assumptions:**

1. Longitudinal distribution: $n_i(\phi) = \delta(\phi - \phi_0)$ at cathode.
2. Transverse distribution: $n_i(r) = \exp(-\frac{r^2}{2\sigma_r})$, σ_r: RMS bunch radius.
3. No space charge effects.



Evolution of an ultra-short electron bunch

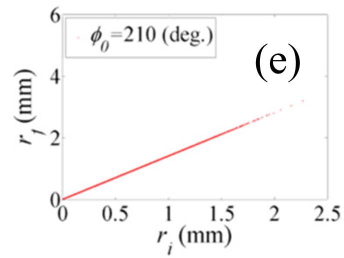
- **PARMELA simulation results (w/o space charge effects)**



$Slope\ M = \frac{dr_f}{dr_i} = const. > 1$

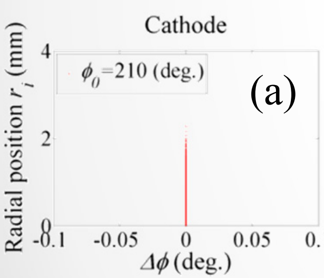
Evolution of an ultra-short electron bunch

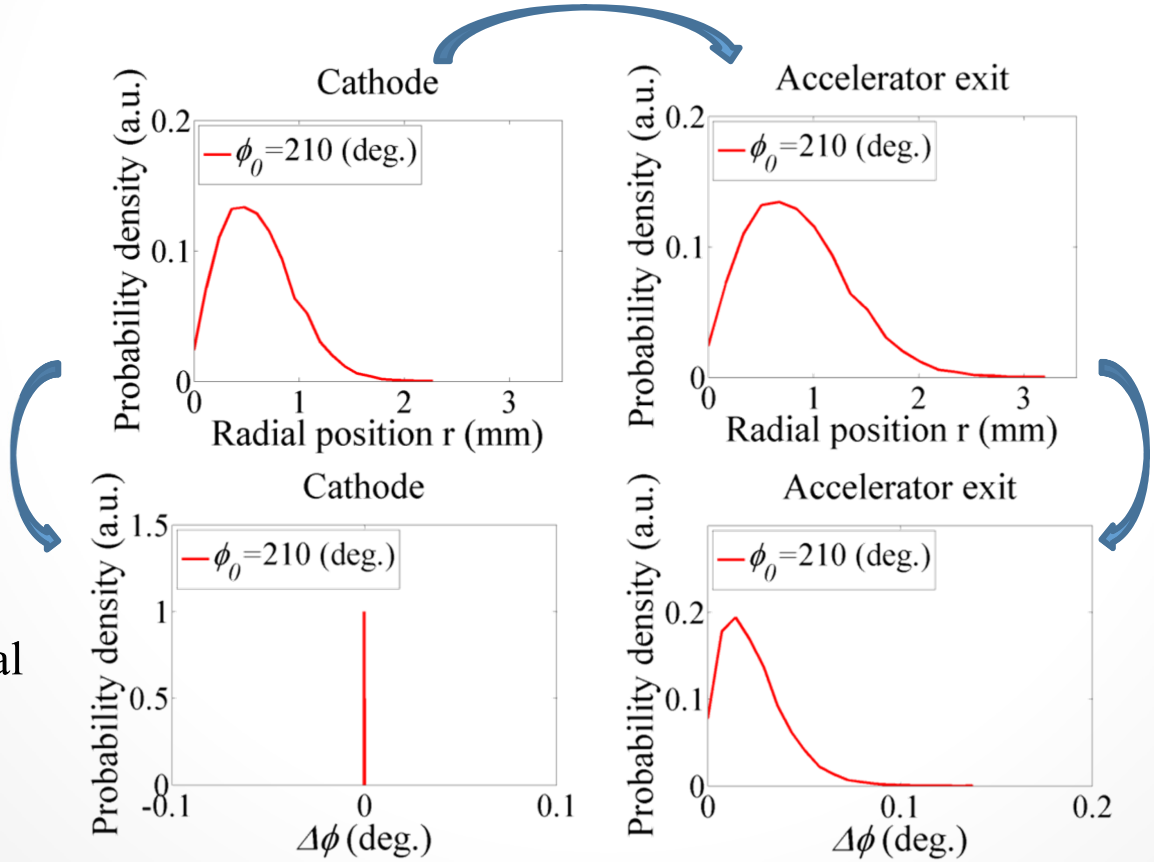
Both the widths and radius of the accelerated electron bunch are broadened!

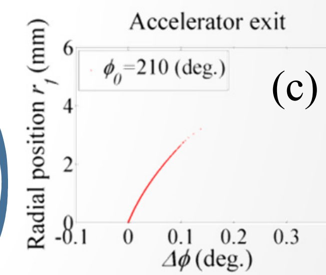


The transverse distribution of electrons is uniformly broadened by *M* times during particle acceleration!

Transverse distribution

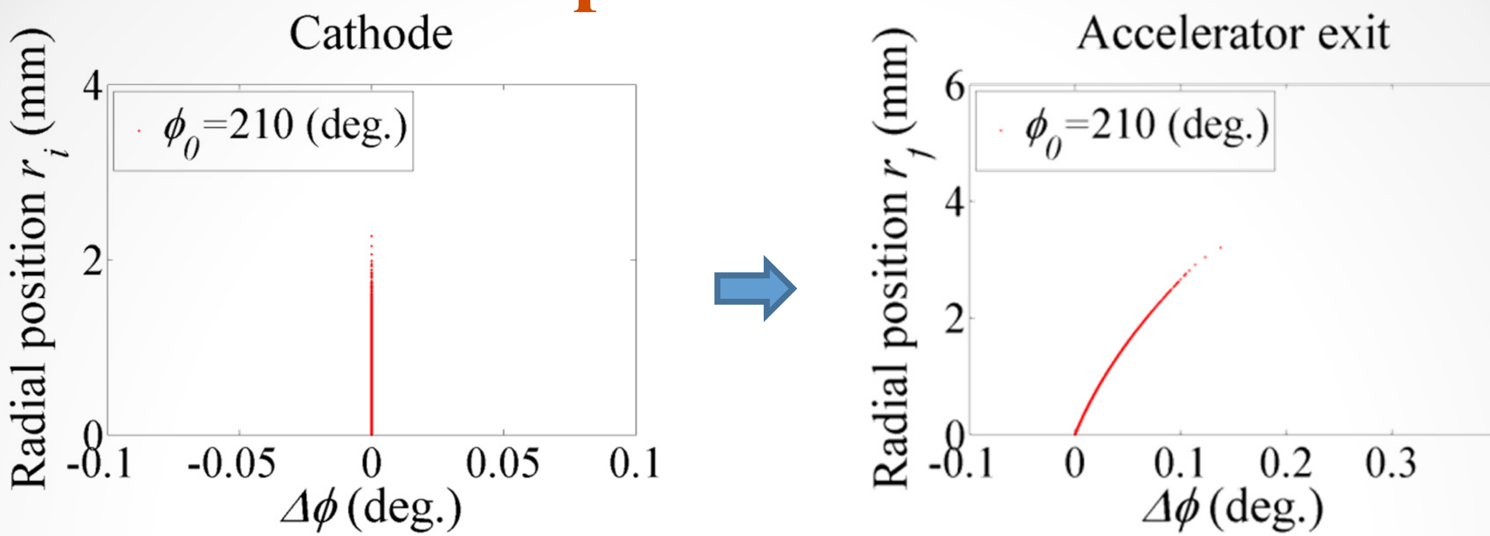






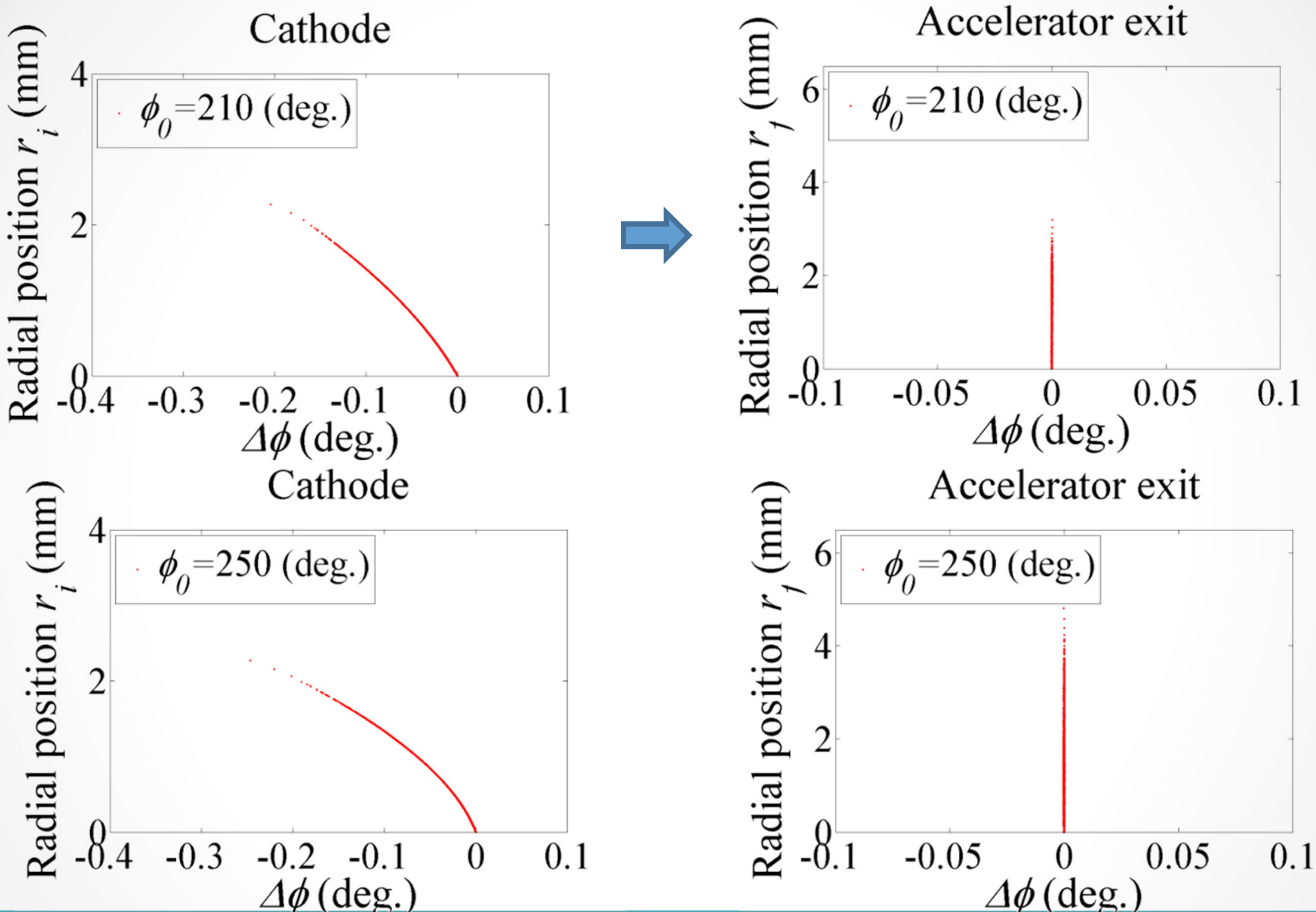
Longitudinal distribution

Initial Phase Compensation



The longitudinal phase spread of the accelerated electrons due to the non-uniform RF fields can be compensated!

Initial Phase Compensation

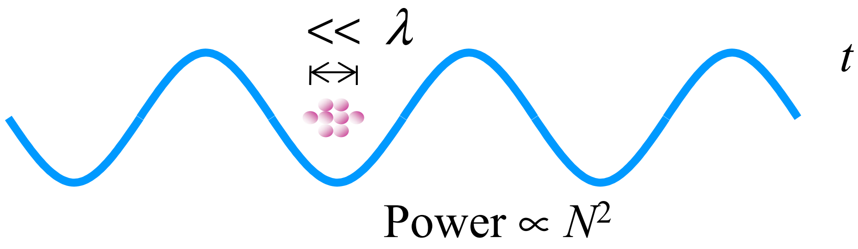


The longitudinal phase spread of the accelerated electrons due to the non-uniform RF fields can be compensated!

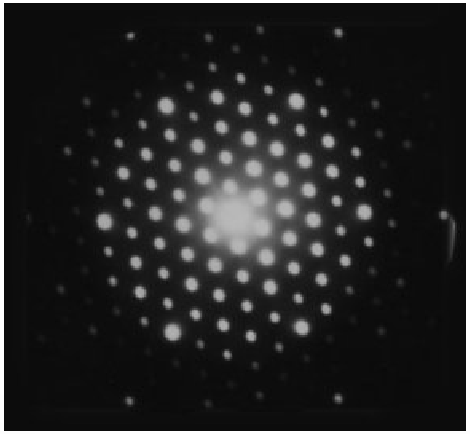
Generation of an ultra-short electron pulse

- **Applications of ultra-short electron pulse:**

1. Coherent radiation

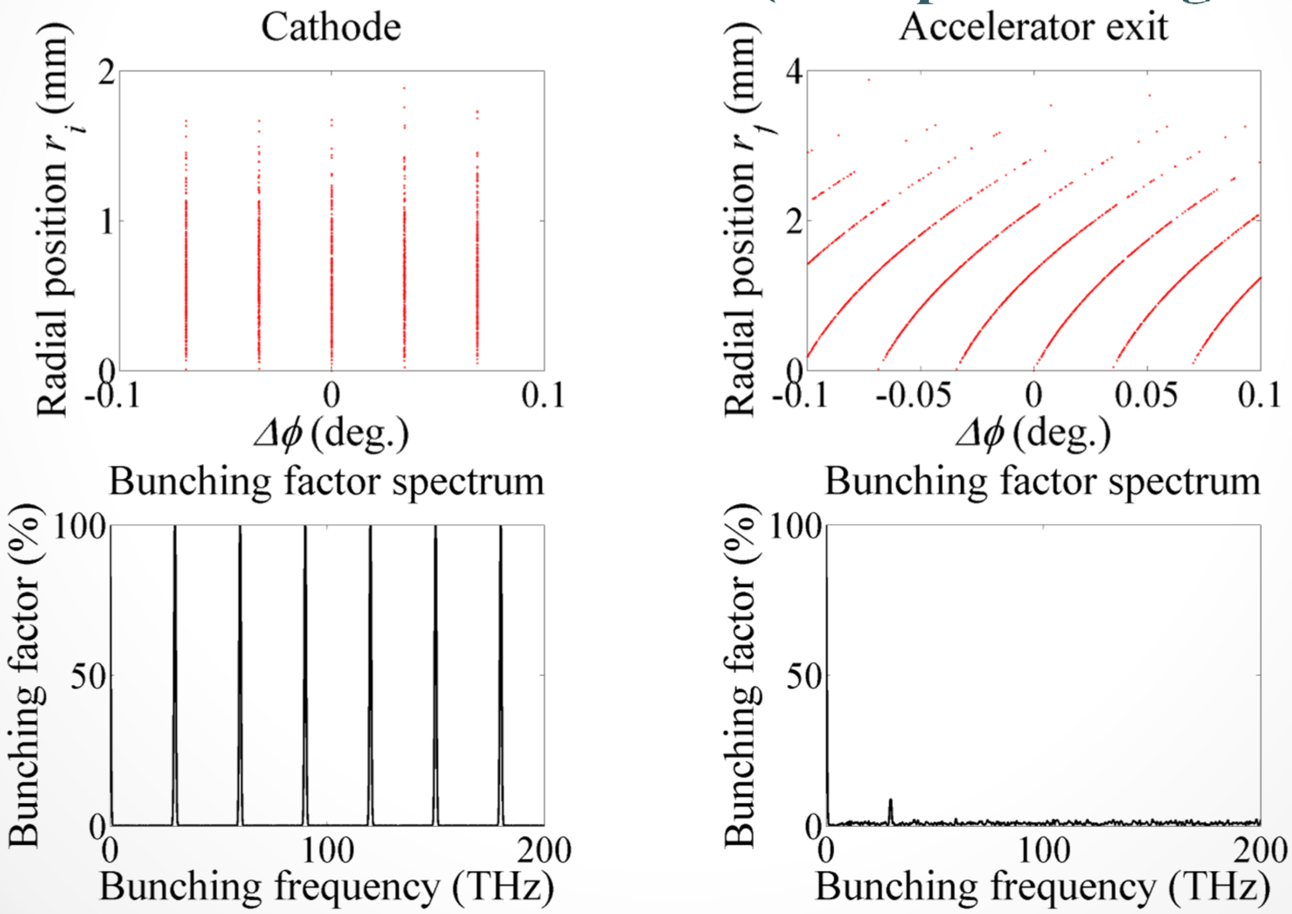


2. Ultrafast electron diffraction (UED) or Ultrafast electron microscopy (UEM)



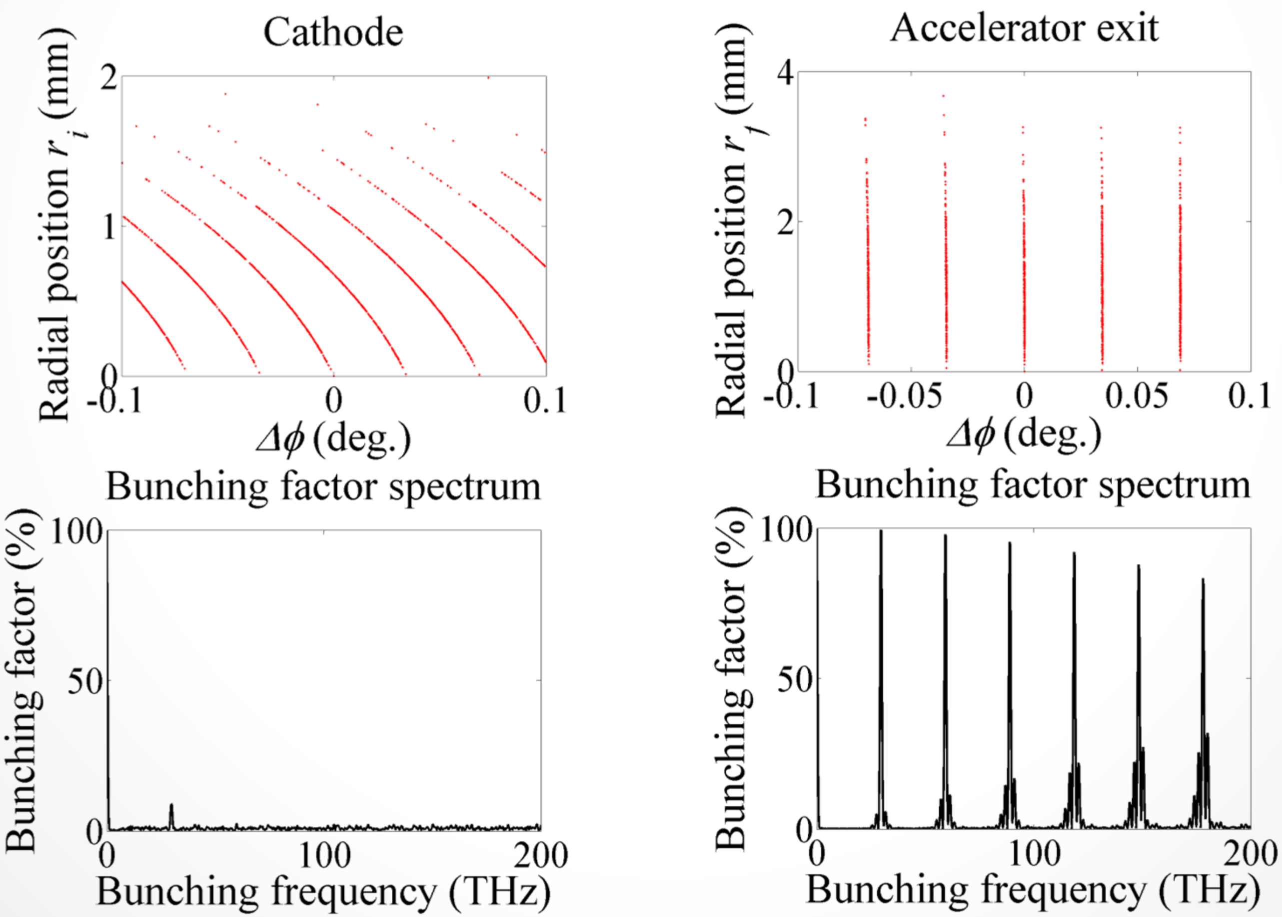
Generation of ultra-short electron pulse train

- **Without initial phase compensation**: The non-uniform RF fields broaden the longitudinal bunch width of the electron micro-bunches and reduce the bunching factor of the accelerated electron-pulse train.
- **PARMELA simulation results (w/o space charge effects):**



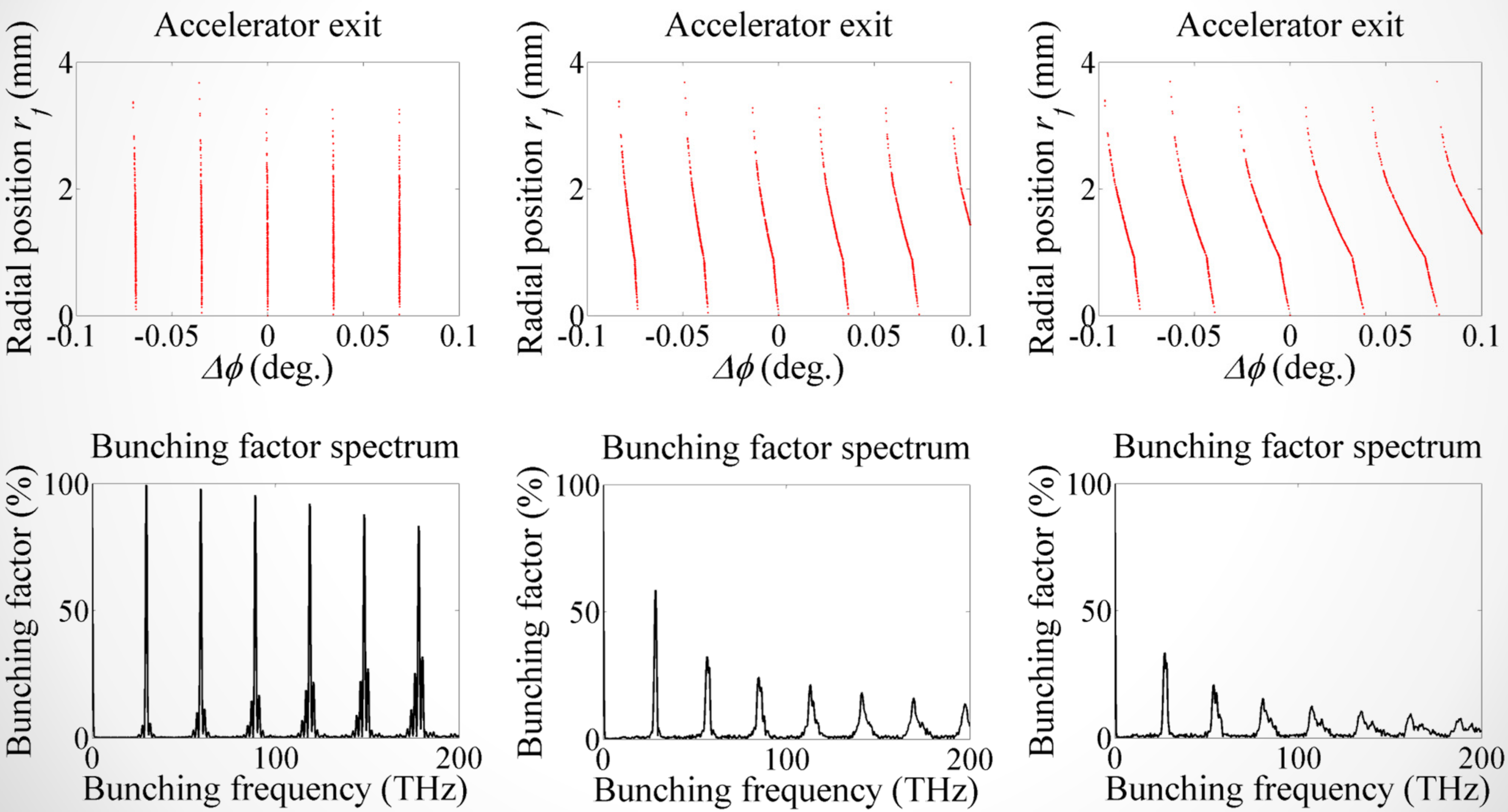
Generation of ultra-short electron pulse train

- **With initial phase compensation:** The debunching of electron micro-bunches can be overcome. An excellent bunching spectrum of an electron-pulse train can be retained at the accelerator exit.



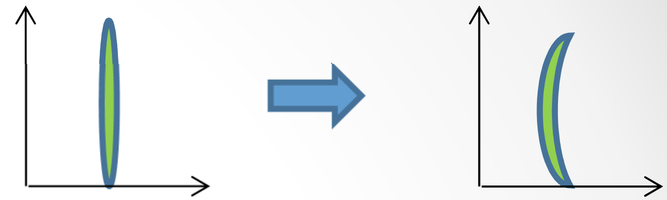
Generation of ultra-short electron pulse train

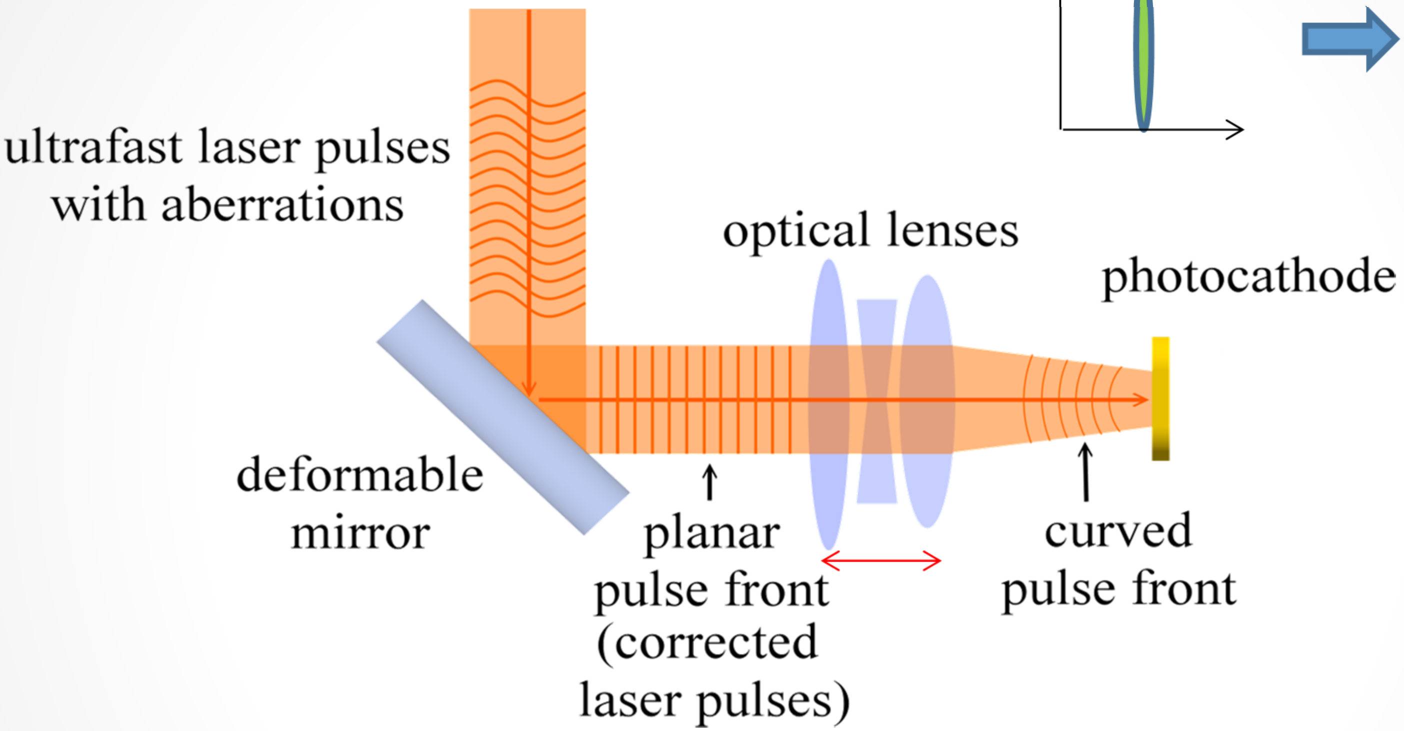
No space charge eff. | **Total charge: 5 pC** | **Total charge: 10 pC**



Schemes of Initial Phase Compensation

1. Adjustable laser pulse front shaping





2. Slightly concave photocathode

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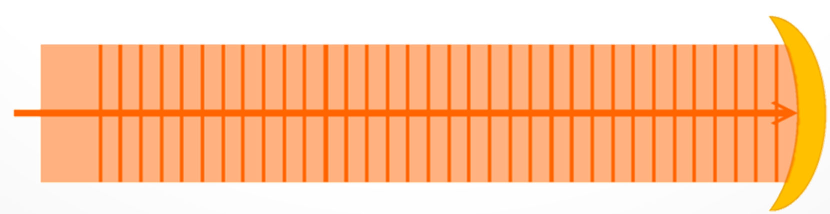

Conclusion

- The non-uniform RF fields broaden the electron bunch width in both the longitudinal and transverse directions during particle acceleration.
- With the non-uniform RF fields, it is hard to retain the width of an accelerated electron pulse in the fs regime.
- We proposed to compensate the phase spread of the electrons by changing the initial phases of the electrons over r.
- With initial phase compensation, the longitudinal bunch width of the accelerated electron bunch could be retained in the fs regime when the space charge effects are not significant.
- It is possible to produce a periodic electron-pulse train with a high bunching factor for a bunching frequency at tens of THz.

Thank you for your attention!