Coherent Electron Cooling Simulation

Jun Ma

Collider-Accelerator Department
Brookhaven National Laboratory

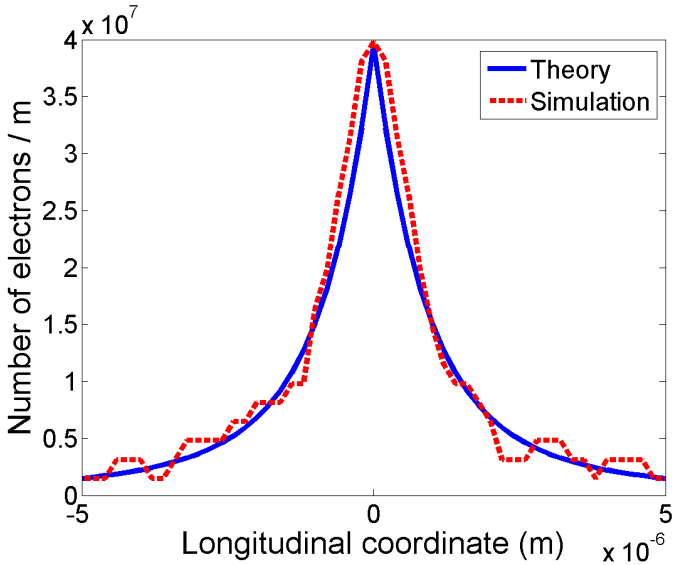
Early Career Scientist Retreat
September 9, 2022

Introduction

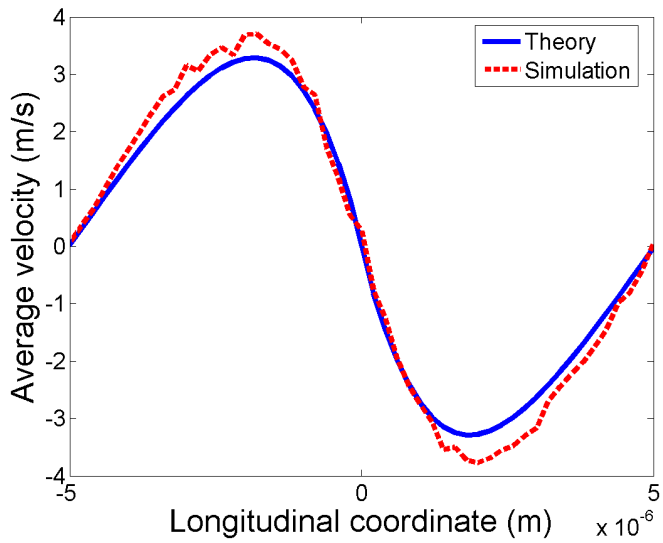
- In the Electron-Ion Collider (EIC), Strong Hadron Cooling (SHC) is needed to reach high luminosity. Present baseline approach for SHC is based on Coherent electron Cooling (CeC).
- A general CeC scheme consists of three main sections:
  - Modulator
  - Amplifier
  - Kicker
- Implementations of amplifier
  - Microbunching instability (MBI) amplifier
  - Free electron laser (FEL) amplifier
  - Plasma cascade amplifier (PCA), ongoing experiment at Relativistic Heavy Ion Collider (RHIC).

Simulation tool, benchmark with theory

- The SPACE code is a parallel, relativistic, three-dimensional (3D) electromagnetic (EM) Particle-in-Cell (PIC) code.

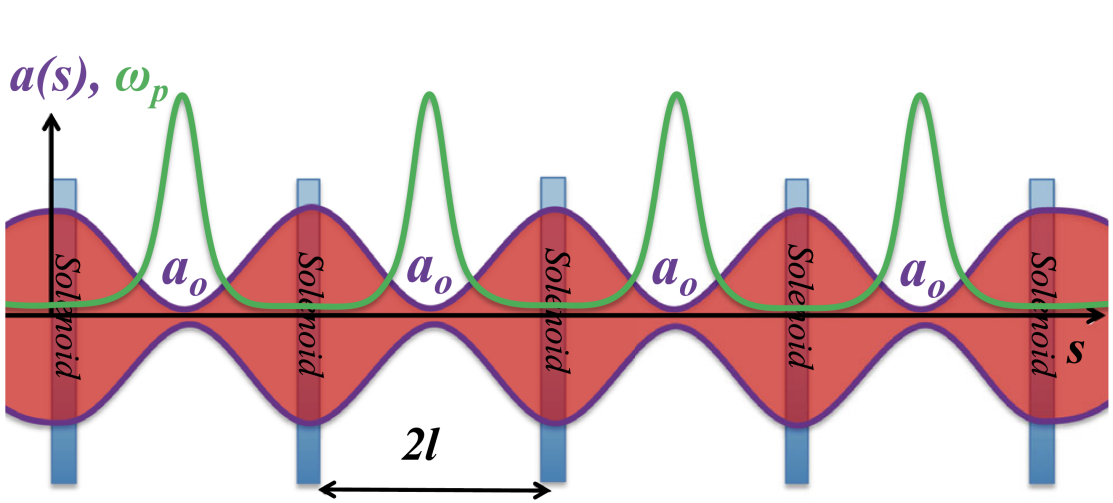


(a) Density modulation

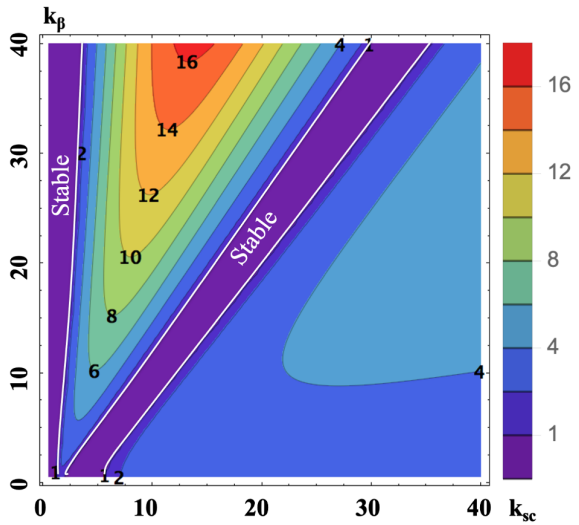


(b) Velocity modulation

PCA theory



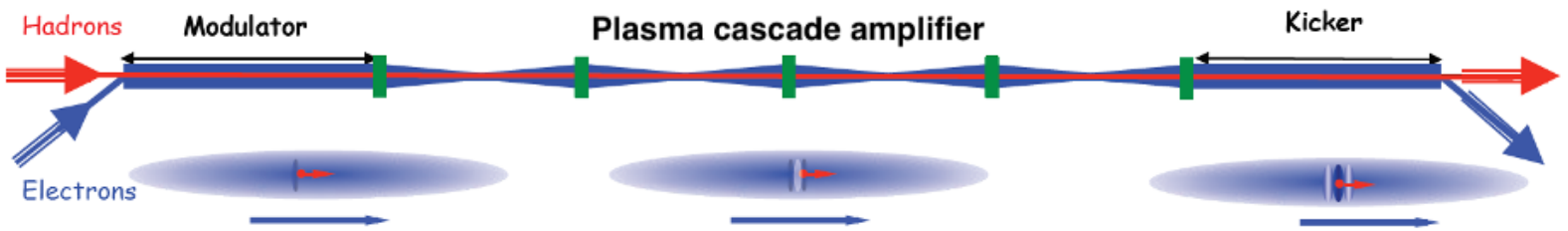
(a) Beam envelope



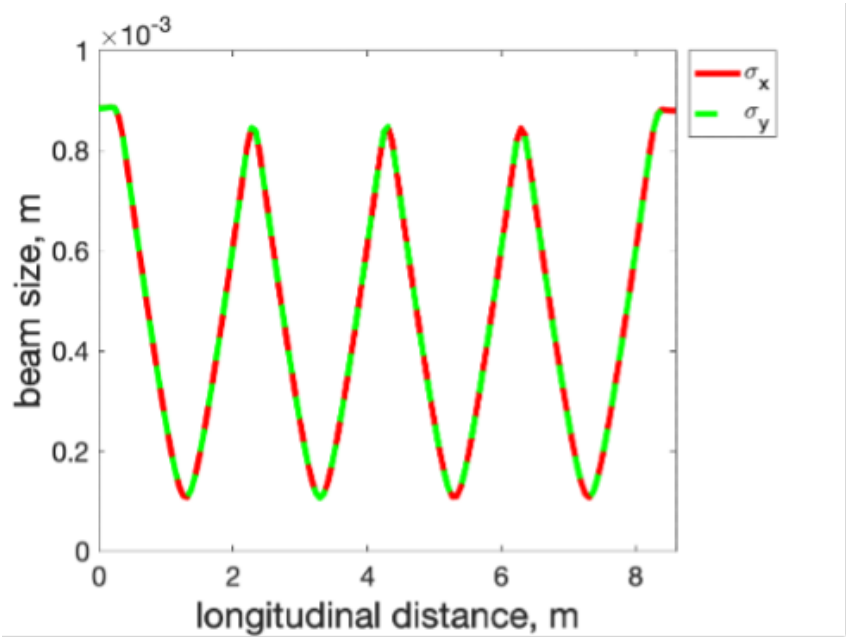
(b) PCA gain in a cell

* V. N. Litvinenko et al., Phys. Rev. Accel. Beams 24, 014402 (2021).

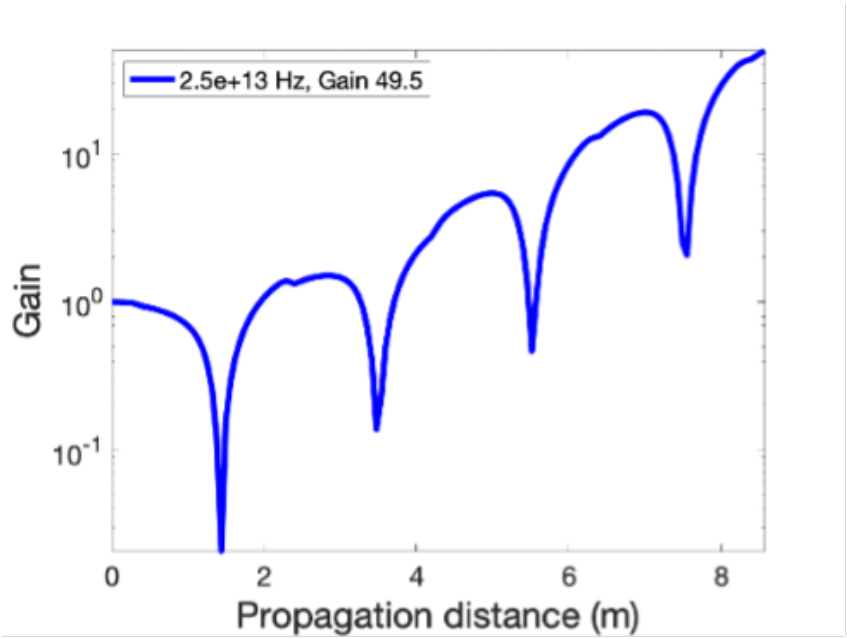
Periodic PCA



(a)

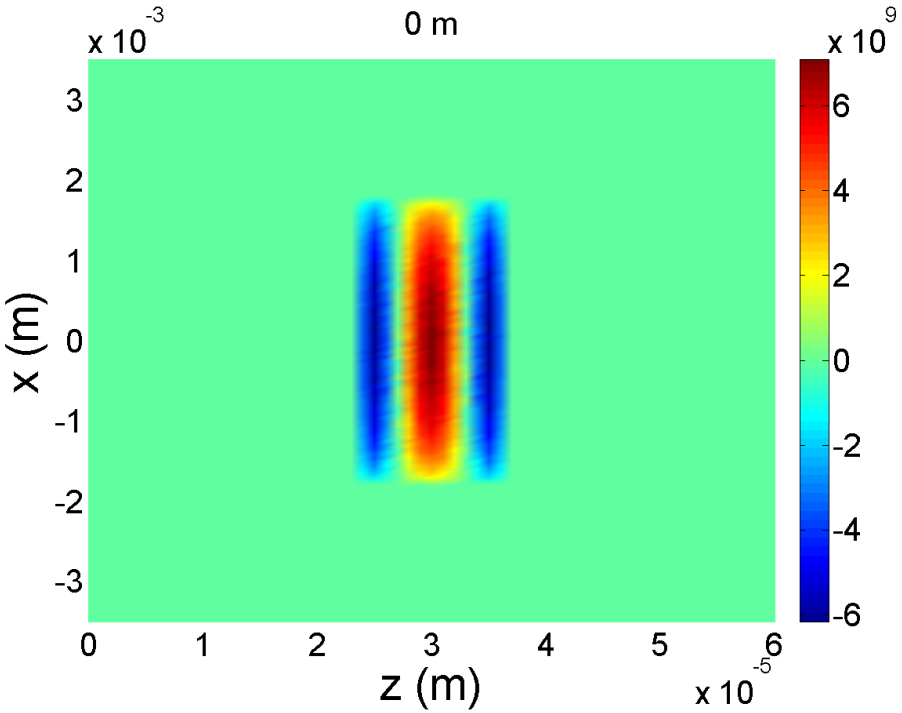


(b) Beam envelope

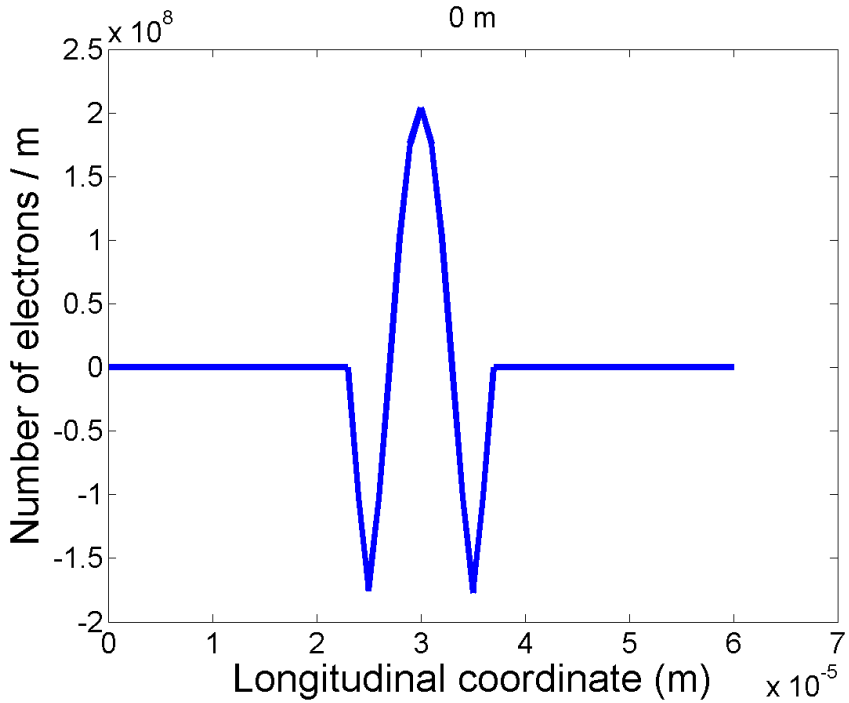


(c) PCA gain

Periodic PCA, evolution of density modulation



(a) z-x plot



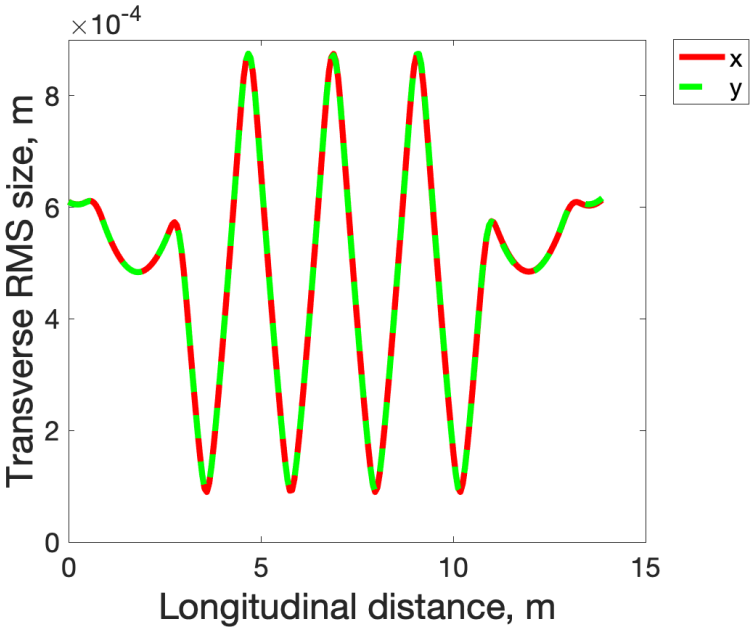
(b) z plot

PCA-based CeC experiment

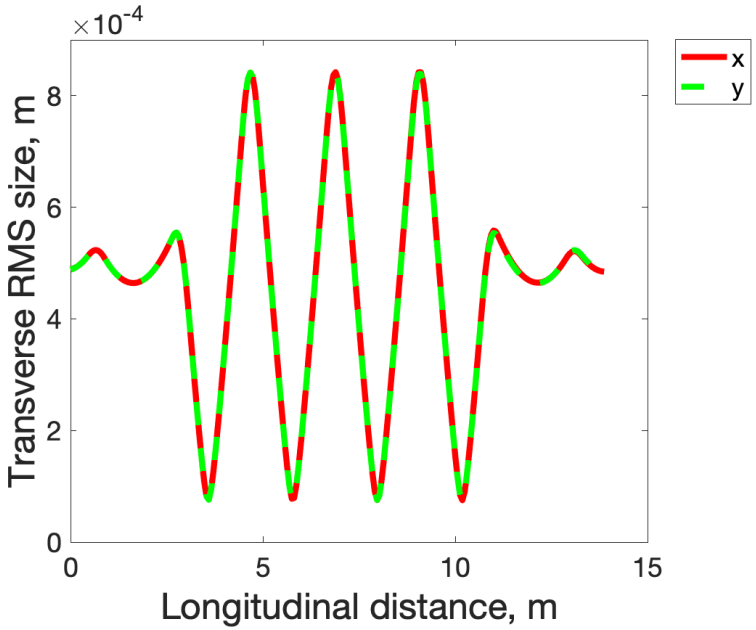
(a) PCA-based CeC layout

- Modulator: 3 m
- 4-cell PCA: 1.8 m, 2.2 m, 2.2 m, 1.8 m
- Kicker: 3 m

PCA-based CeC lattice design



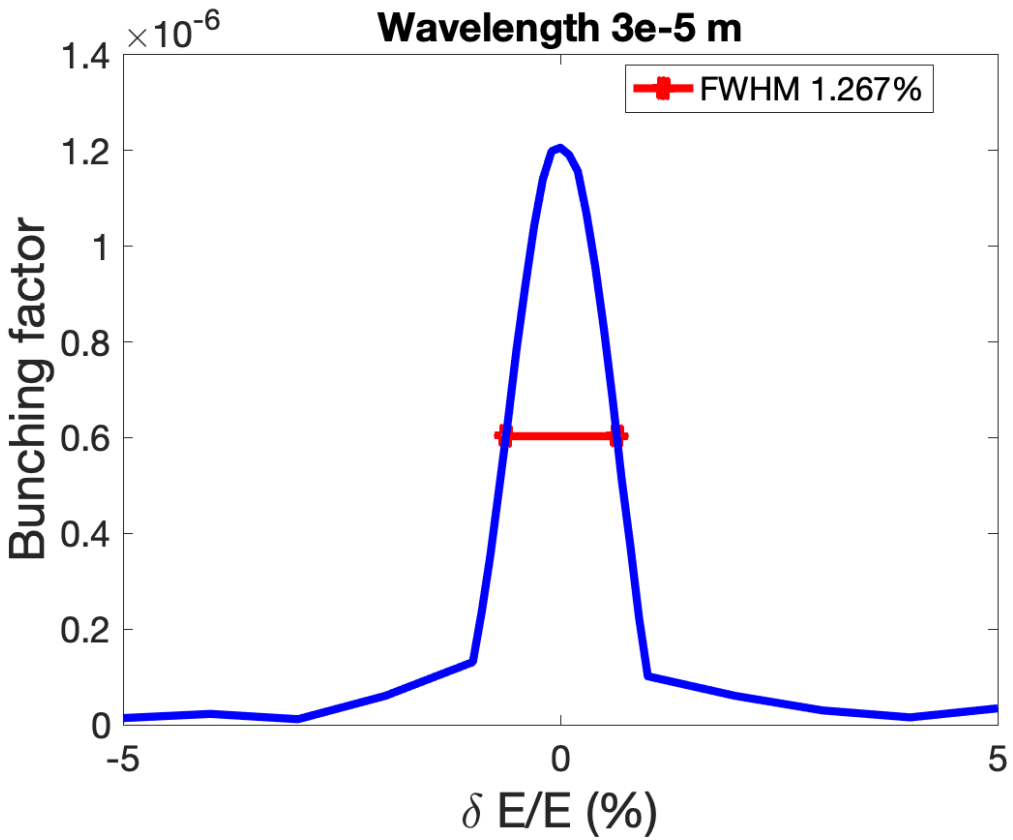
(a) Beam peak current 75 A



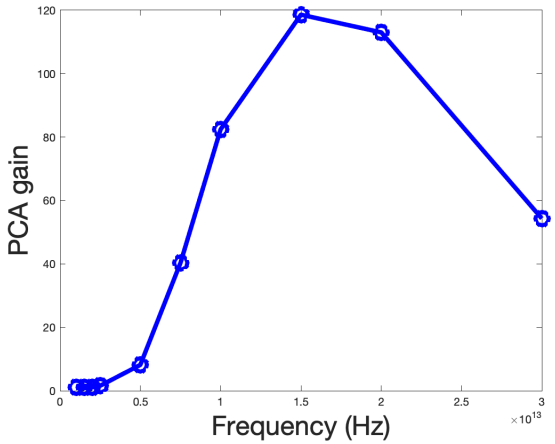
(b) Beam peak current 50 A

Modulator, effect of energy difference

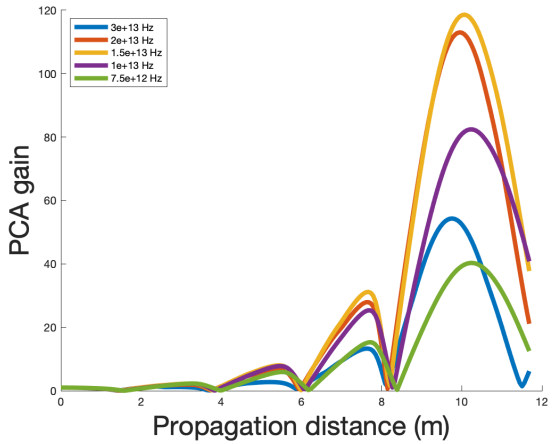
$$b \equiv \frac{1}{N_\lambda} \sum_{k=1}^{N_\lambda} e^{i \frac{2\pi}{\lambda_{opt}} z_k}, -\frac{\lambda_{opt}}{2} \leq z_k \leq \frac{\lambda_{opt}}{2},$$



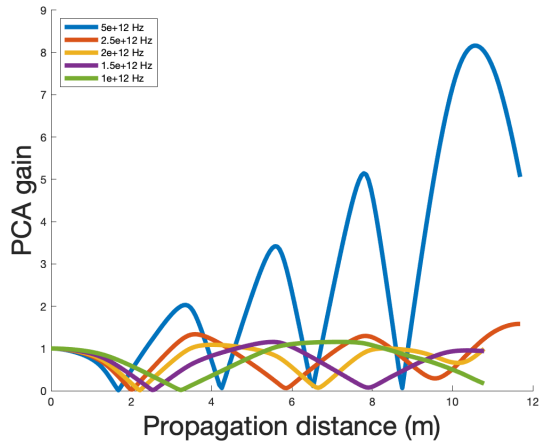
PCA, gain spectrum



(a) PCA gain

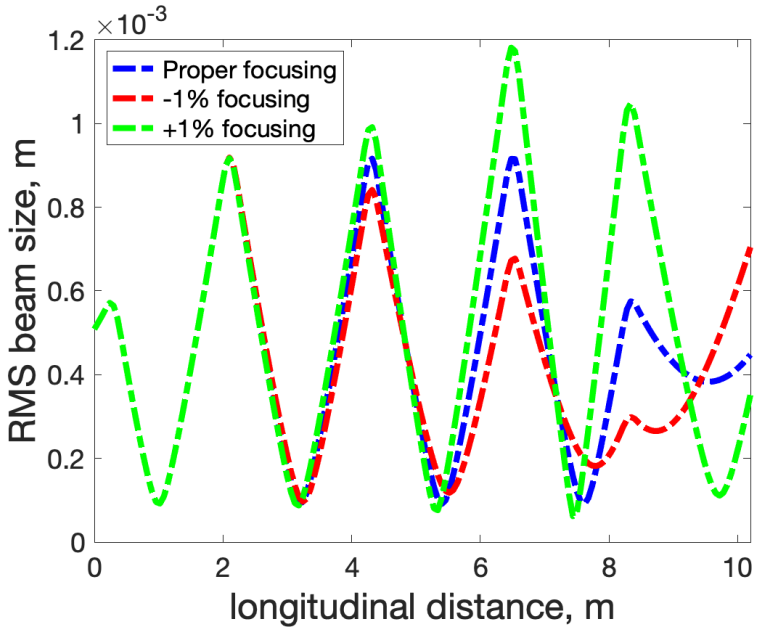


(b) PCA gain

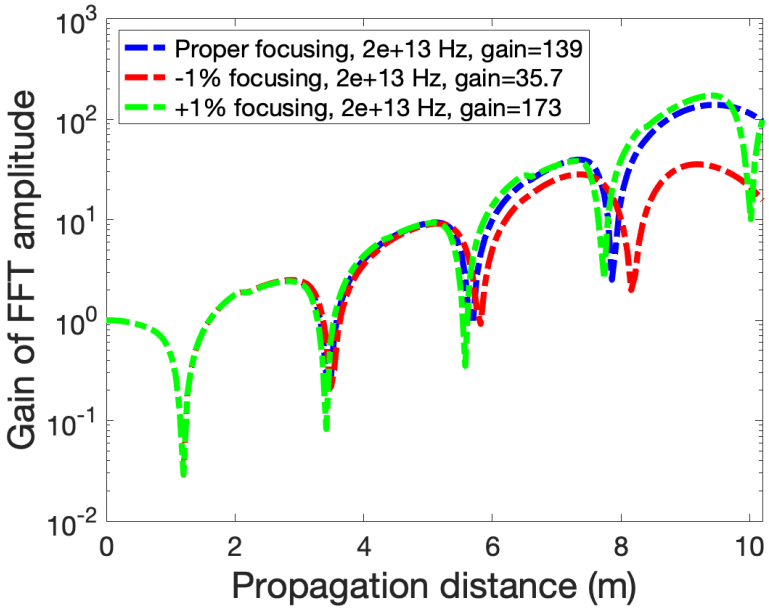


(c) PCA gain

PCA, sensitivity study of focusing

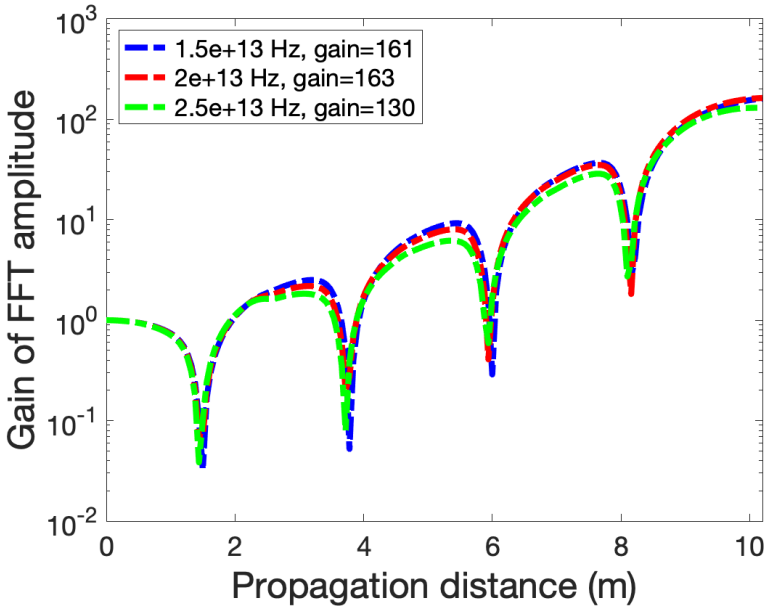


(a) Beam size

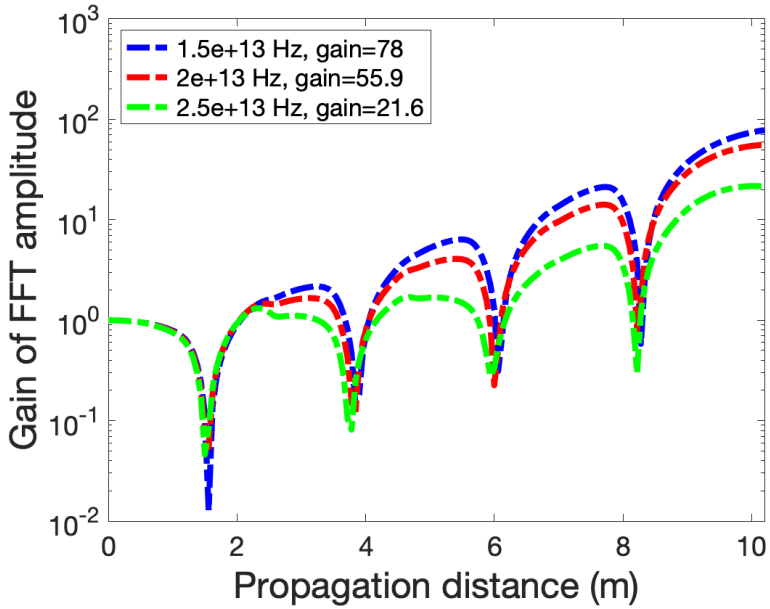


(b) PCA gain

PCA, sensitivity study of emittance

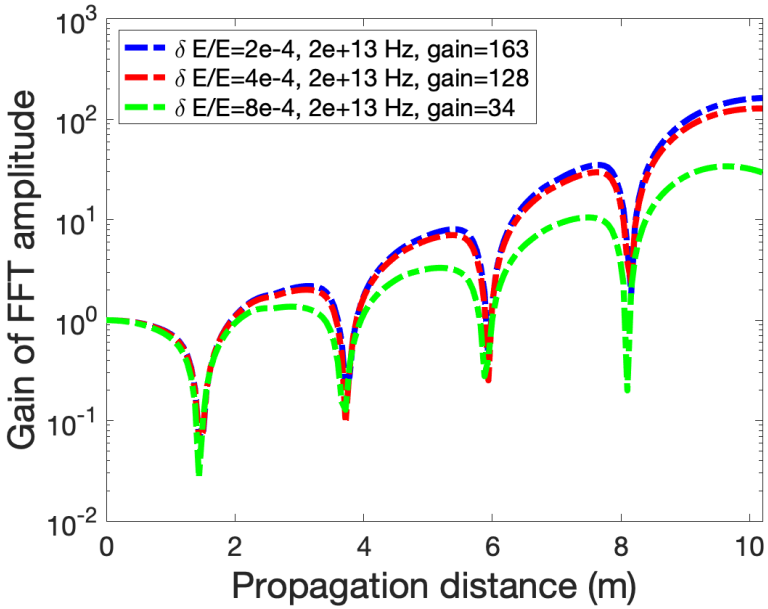


(a) $\varepsilon_{n,KV} = 7\mu m$

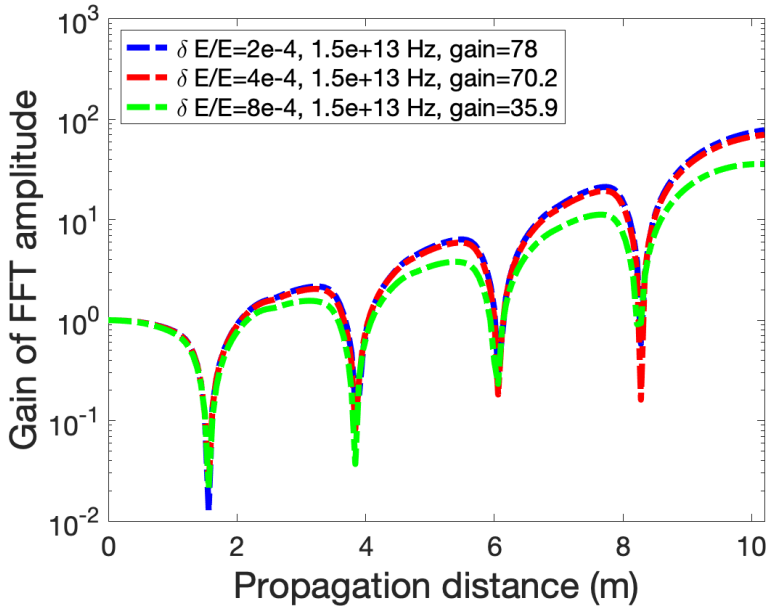


(b) $\varepsilon_{n,KV} = 10\mu m$

PCA, sensitivity study of energy spread

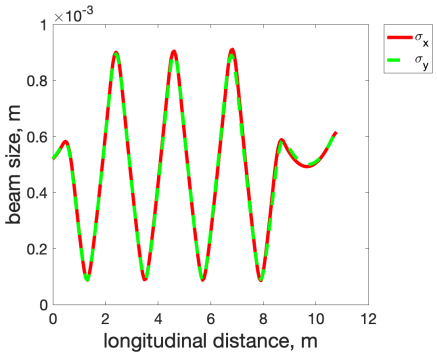


(a) $\varepsilon_{n,KV} = 7\mu m$

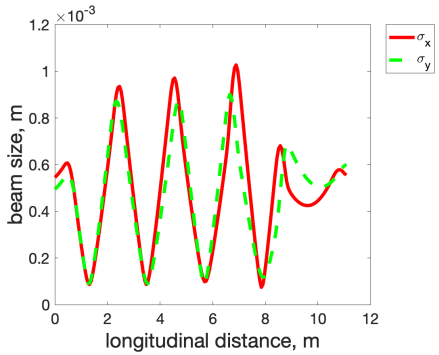


(b) $\varepsilon_{n,KV} = 10\mu m$

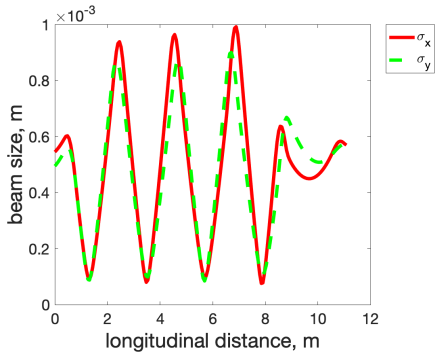
PCA, sensitivity study of transverse symmetry



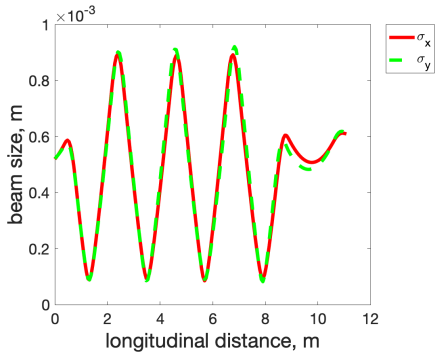
(a) Reference



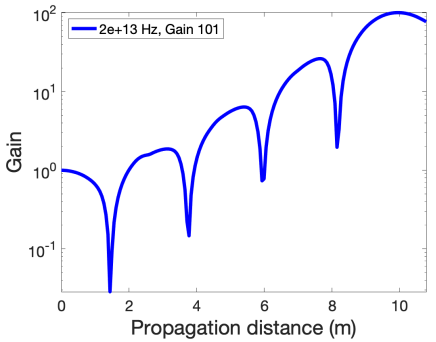
(b) $\Delta\varepsilon$



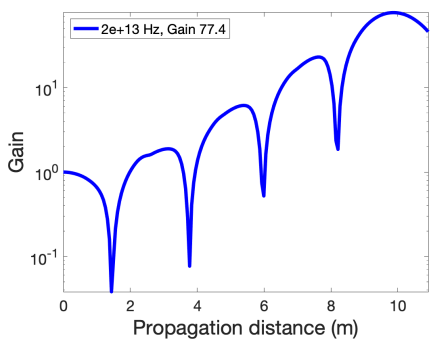
(c) $\Delta\beta$



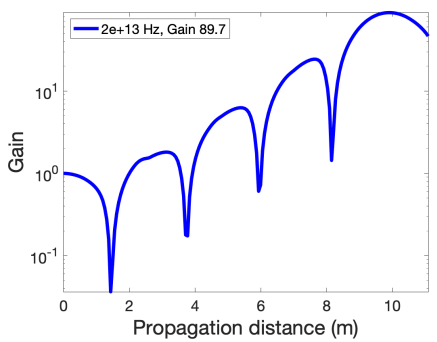
(d) $\Delta\alpha$



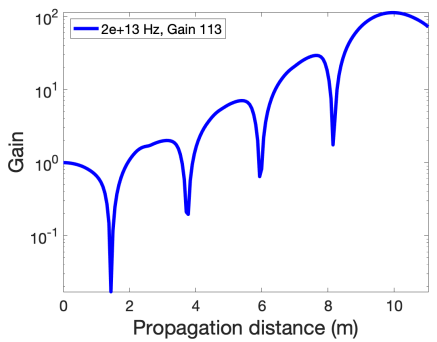
(e) Reference



(f) $\Delta\varepsilon$

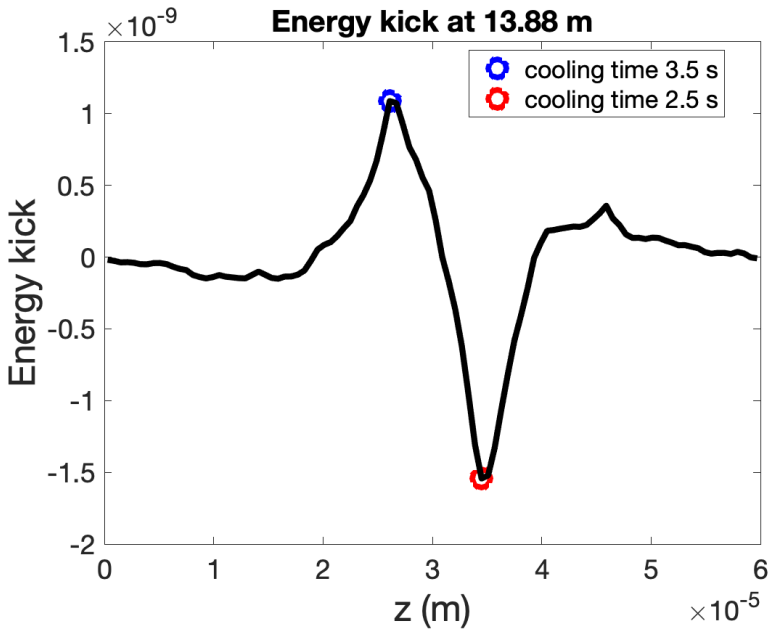


(g) $\Delta\beta$

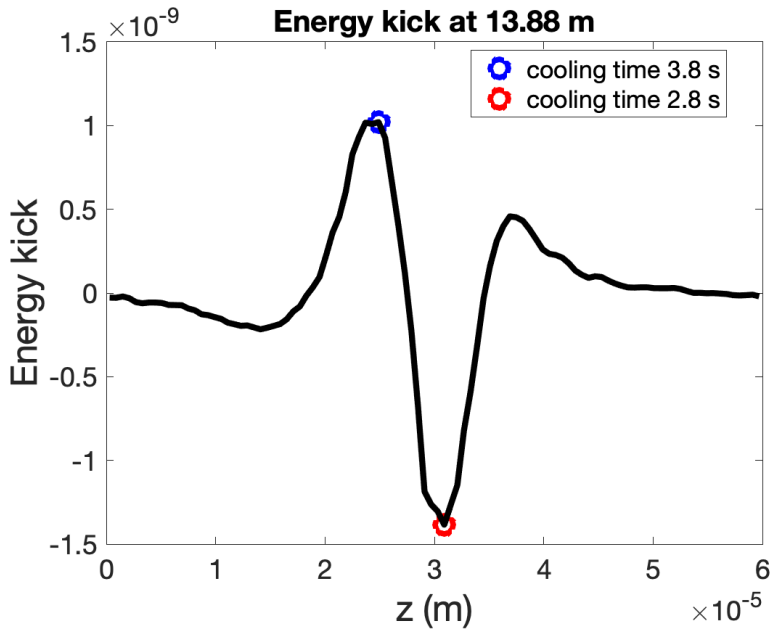


(h) $\Delta\alpha$

Kicker, cooling

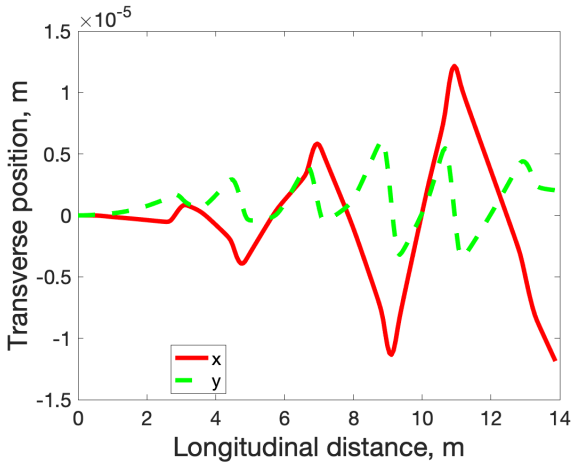


(a) Beam peak current 75 A

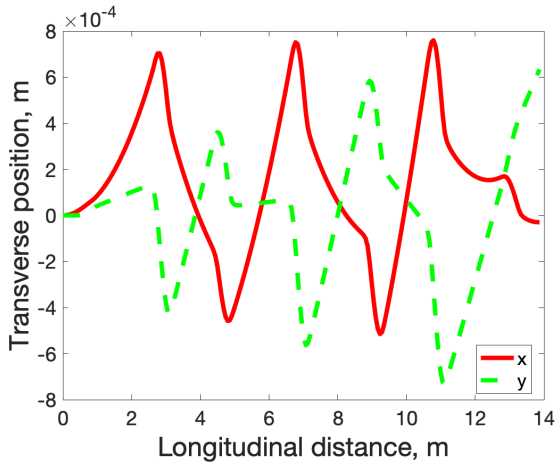


(b) Beam peak current 50 A

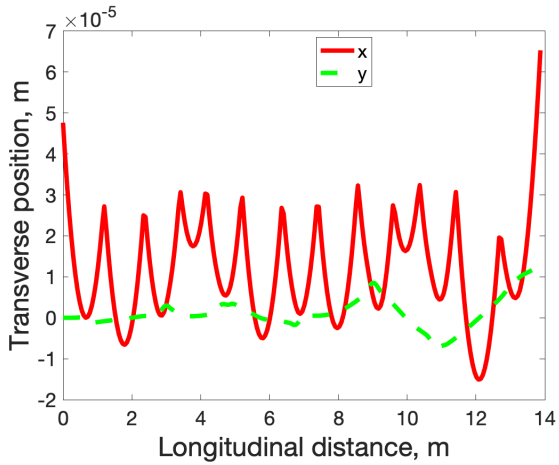
Kicker, effect of earth field



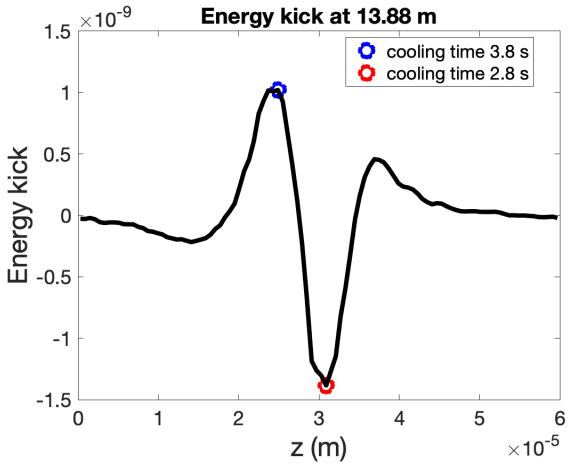
(a) Reference



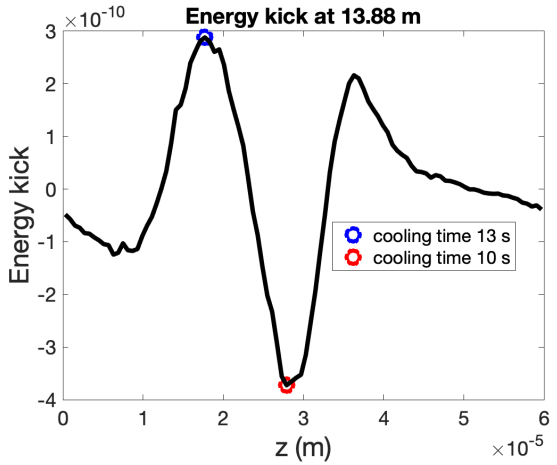
(b) Earth field



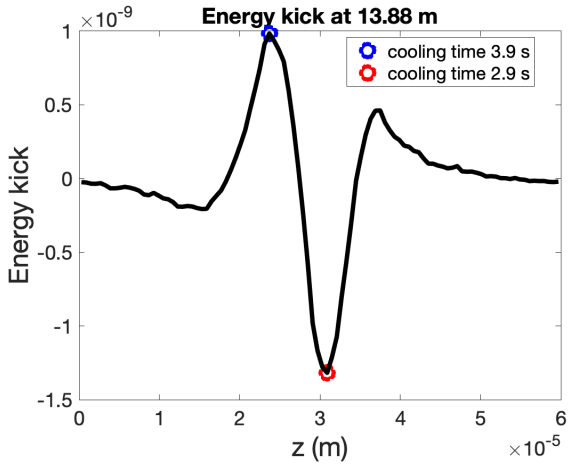
(c) Earth field + correction



(d) Reference



(e) Earth field



(f) Earth field + correction

Summary

- Cooling is needed to reach high luminosity in EIC
- The SPACE code has been benchmarked with theory
- Simulations of PCA-based CeC
  - Lattice design
  - Modulator, effect of energy difference between electrons and ions
  - PCA, gain spectrum, sensitivity study of focusing, emittance, energy spread, transverse symmetry
  - Kicker, cooling performance, effect of earth field

Thank You