# Simulations of Cooling Rate for Coherent Electron Cooling With Plasma Cascade Amplifier

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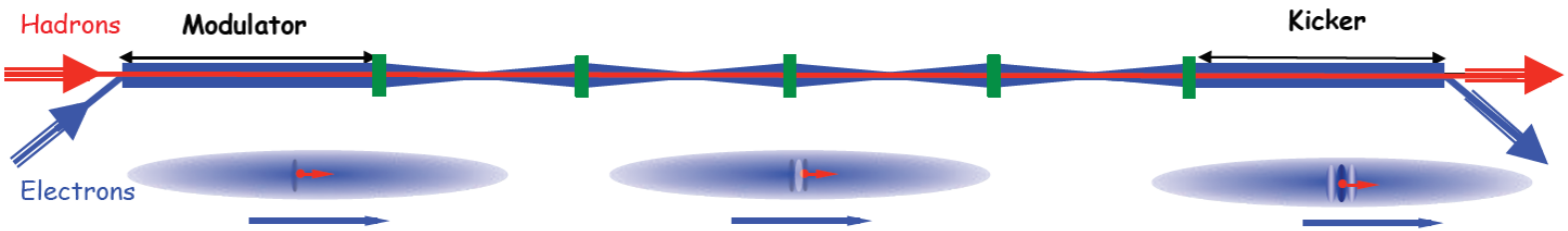
# Introduction

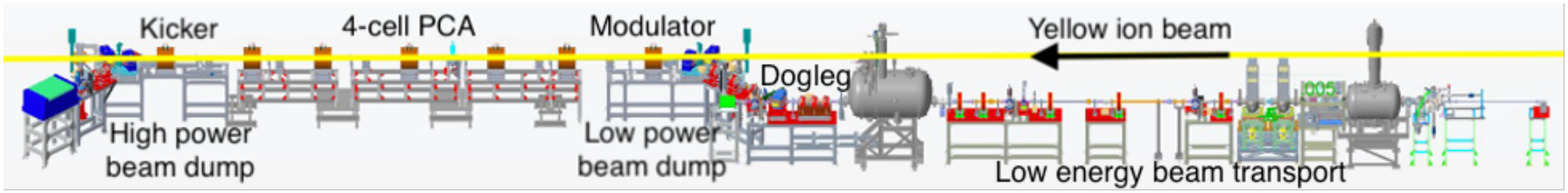
- Coherent electron cooling (CeC) is the most promising technique for the rapid cooling of high-energy high-intensity hadron beams in the Electron-Ion Collider (EIC) at Brookhaven National Laboratory (BNL).
- Modulator, amplifier, kicker.




(a) CeC with plasma cascade amplifier (PCA)

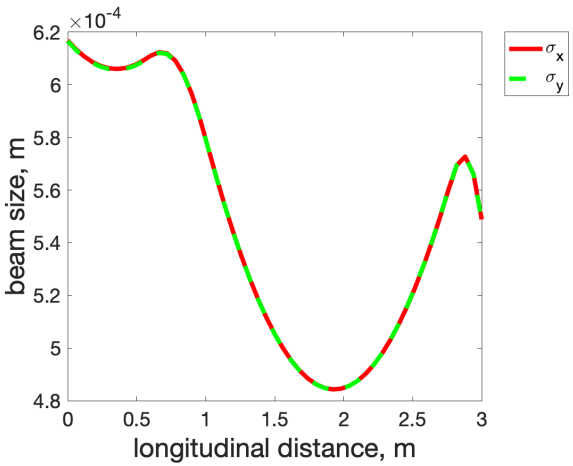
- The SPACE code is a parallel, relativistic, three-dimensional (3D) electromagnetic (EM) Particle-in-Cell (PIC) code.

# Evolution of transverse beam size

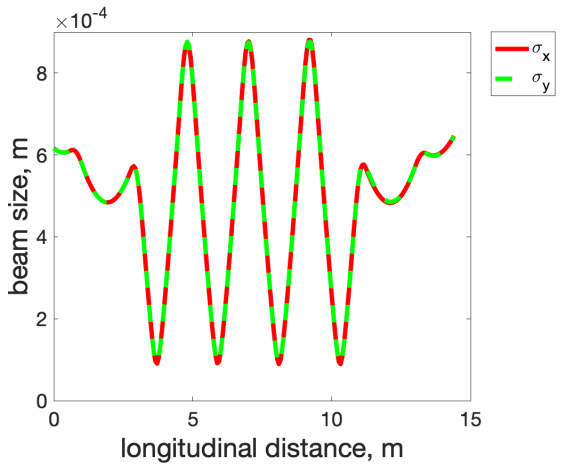



(a) PCA-based CeC system installed at BNL RHIC

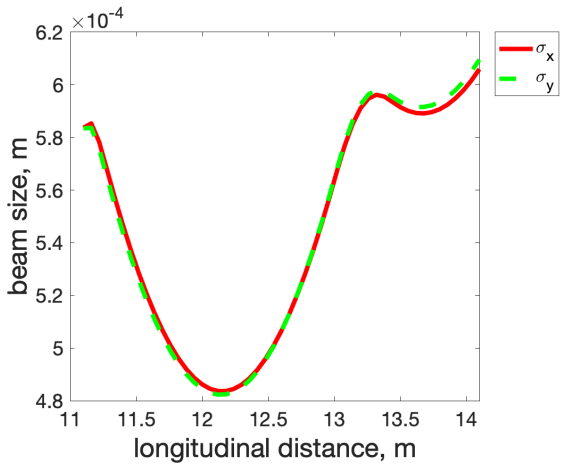
- Modulator 3 m, PCA 8 m (4 cells of 1.8 m, 2.2 m, 2.2 m, 1.8 m), kicker 3 m.




(a) Modulator



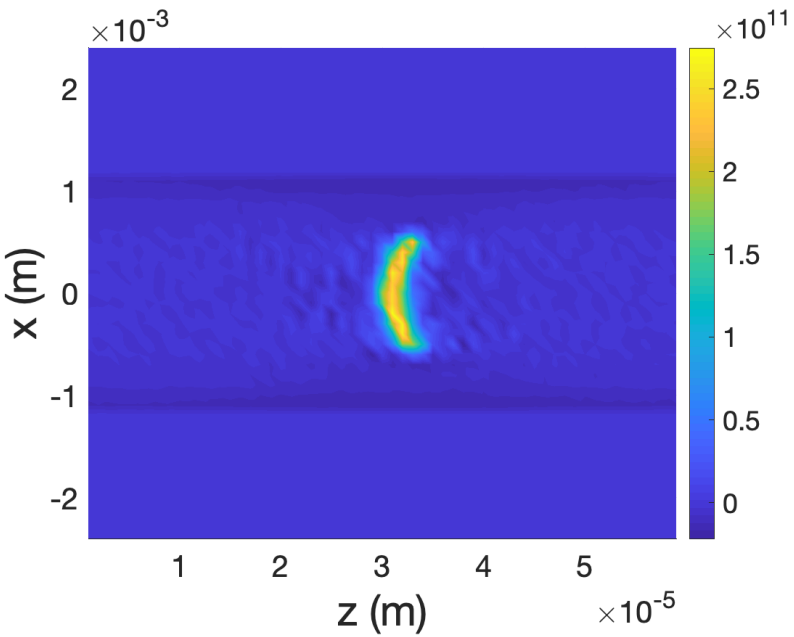

(b) CeC system



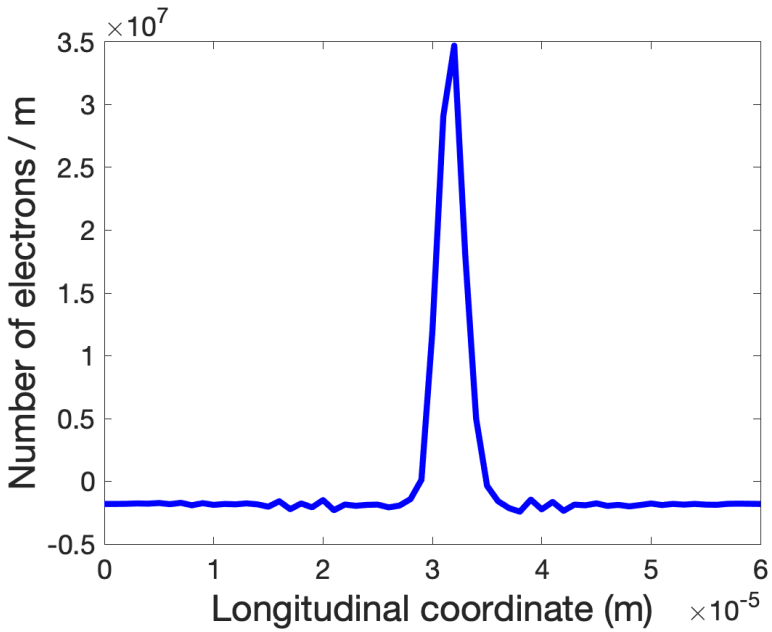

(c) Kicker

# Modulator, density modulation

- Co-propagate the electron beam with a single gold ion $Au^{+79}$.
- The electron beam has 0.1% higher energy than the ion to compensate the delay in the PCA.



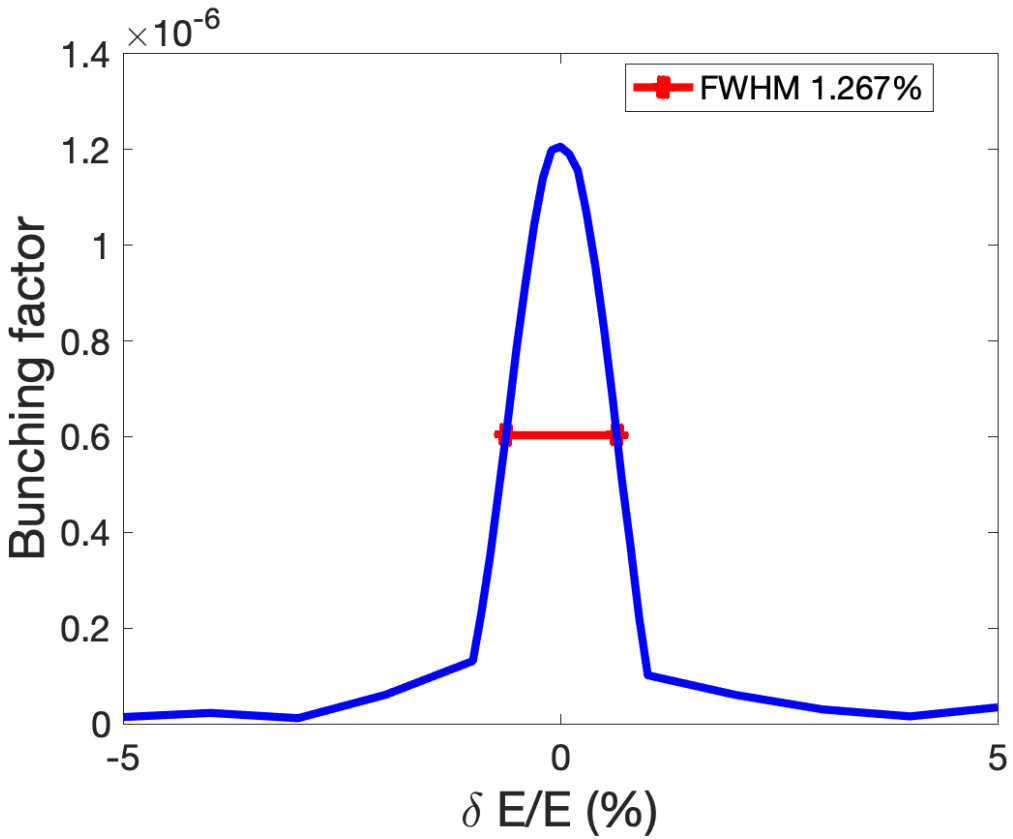

(a) 2D plot



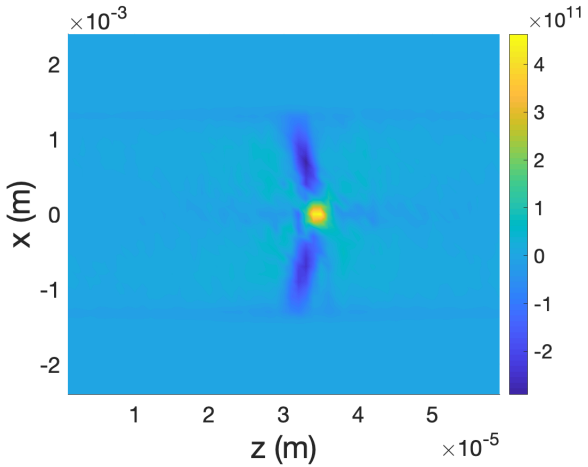

(b) 1D plot

# Modulator, effect of energy difference

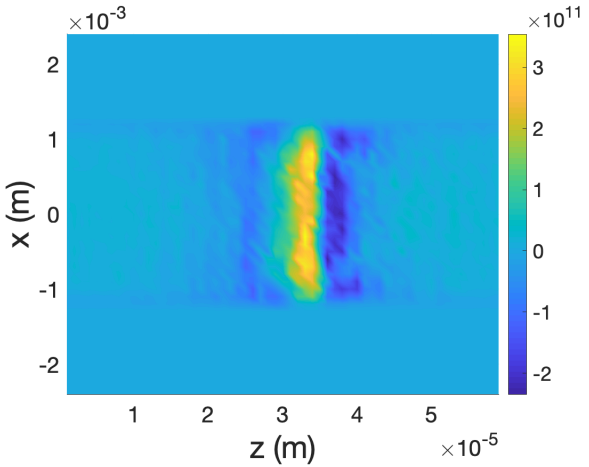
$$b \equiv \frac{1}{N_\lambda} \sum_{k=1}^{N_\lambda} e^{i \frac{2\pi}{\lambda_{opt}} z_k}, -\frac{\lambda_{opt}}{2} \leq z_k \leq \frac{\lambda_{opt}}{2},$$



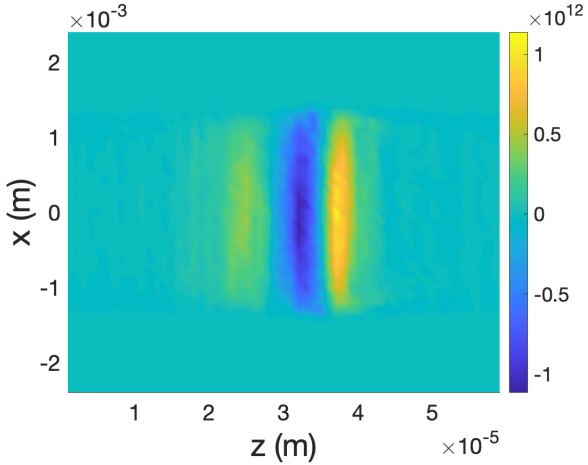
# PCA, evolution of density modulation



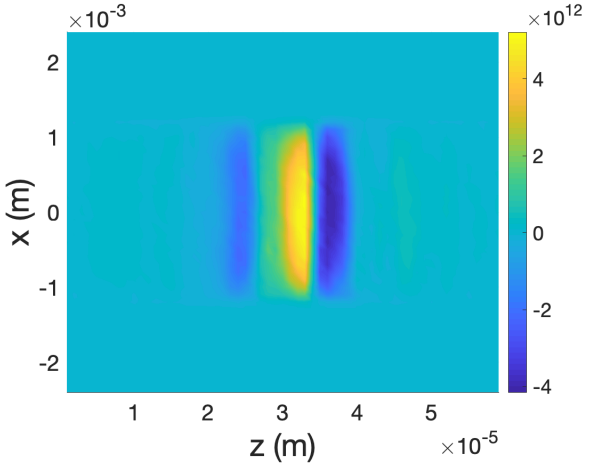

(a) 1st cell




(b) 2nd cell



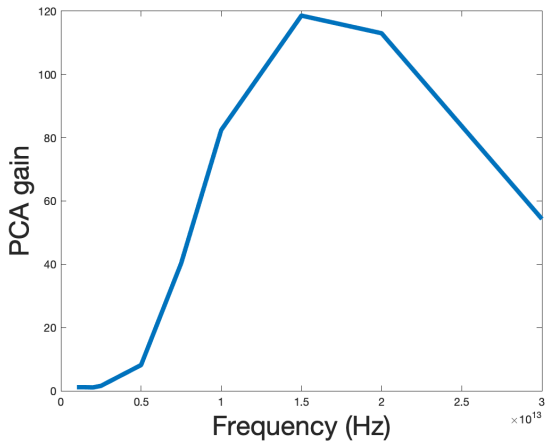

(c) 3rd cell



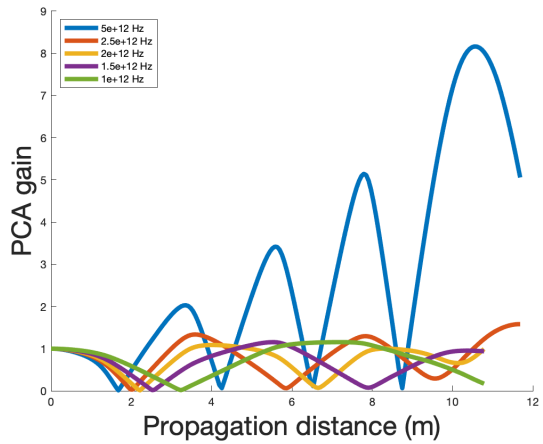

(d) 4th cell

# PCA, amplification at different frequencies

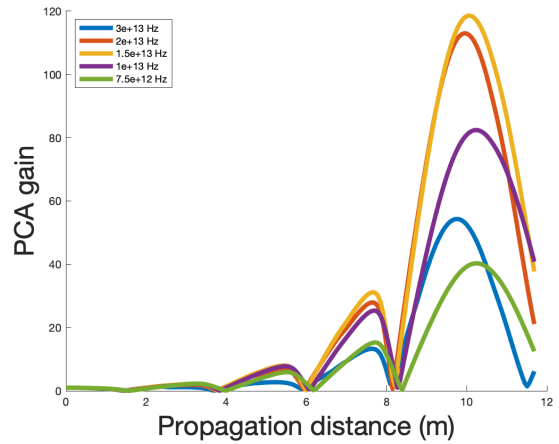
- Track the evolution of density modulation at different frequencies through the PCA section.




(a) Spectrum



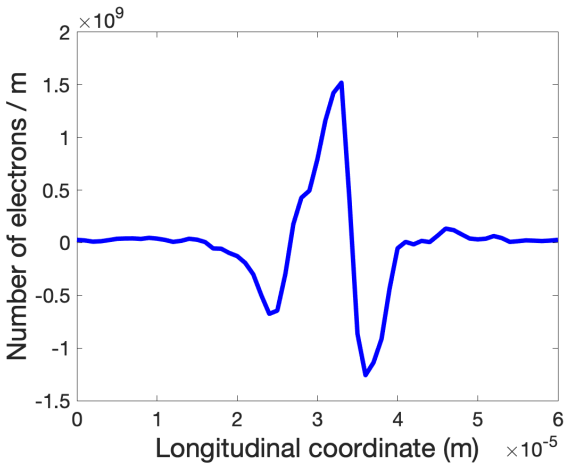

(b) Low frequencies



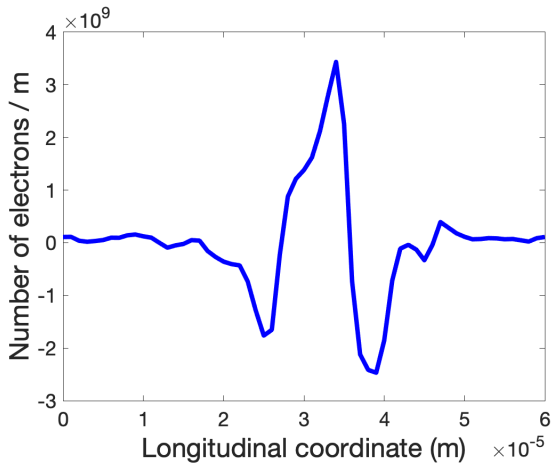

(c) High frequencies

# Kicker, evolution of density modulation

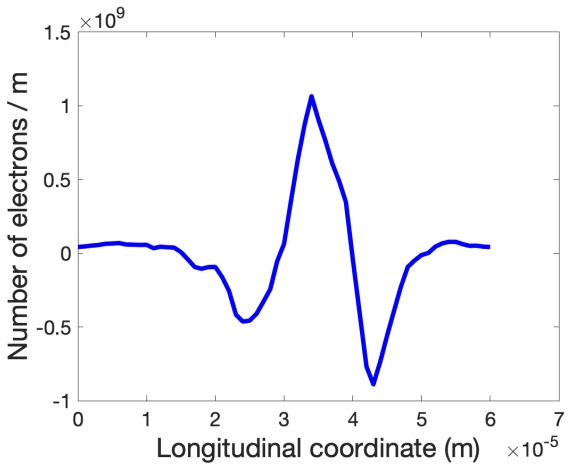
- Track the evolution of the amplified density modulation in the kicker section.




(a) Entrance



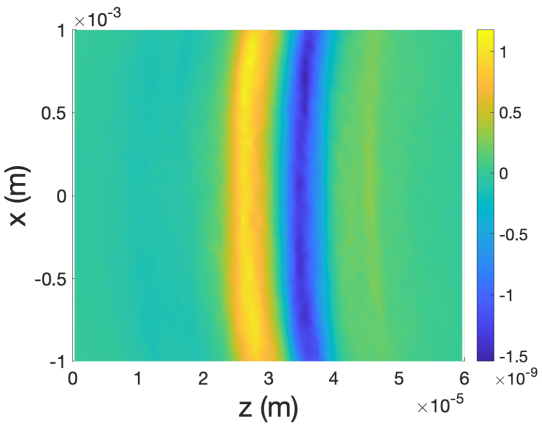

(b) Middle



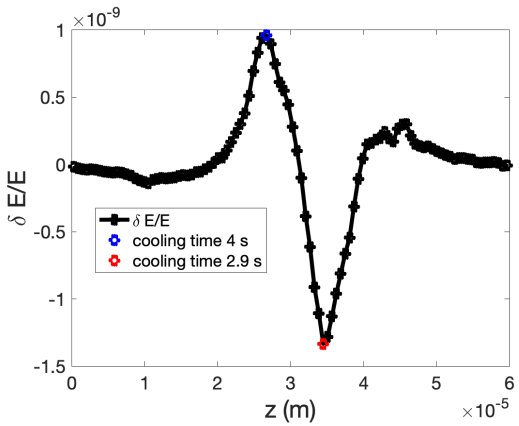

(c) Exit

# Kicker, cooling force

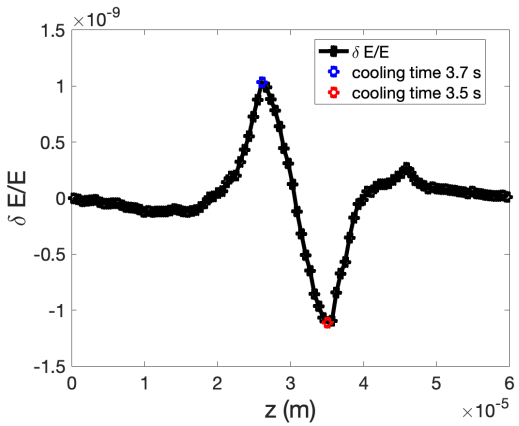
- Track the energy kick received by ions at different locations in the kicker section.
- Demonstrate sufficiently short local cooling time.




(a) 2D plot




(b) Ion without offset




(c) Ion with x offset 0.4 mm

# Conclusion

- Present simulation studies of the PCA-based CeC system, including the modulator, the PCA, and the kicker.
- Simulate the modulation process for various energy differences between the electrons and the ions in the modulator.
- Obtain the amplification of density modulation at different frequencies in the PCA.
- Predict the local cooling time for ions in the kicker.

Thank You