

Multiple-Slice Simulations of Coherent Electron Cooling Performance with Low Beam Current

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COOL'25 - The 15th International Workshop on Beam Cooling
and Related Topics
October 26 - 31, 2025

- 1 Introduction
- 2 Design
- 3 Implement
- 4 Predict
- 5 Verify
- 6 Summary

1 Introduction

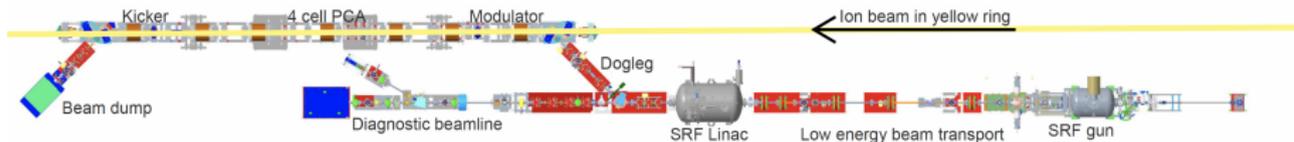
2 Design

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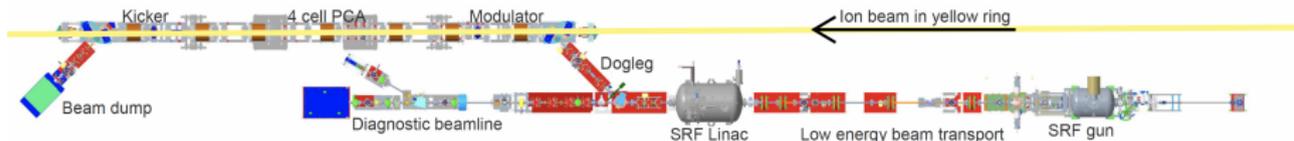
5 Verify

6 Summary



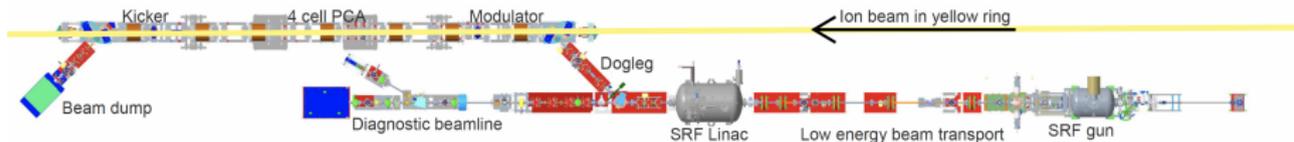
(a) CeC system layout

- Design: CeC simulation including modulator, plasma cascade amplifier (PCA), kicker - search for proper beam parameters.



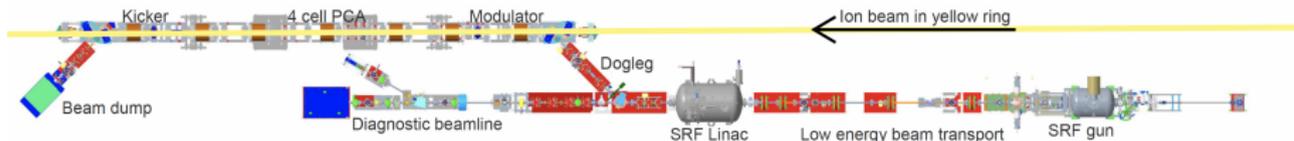
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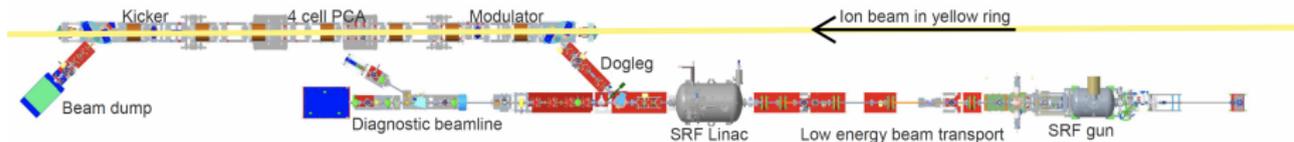
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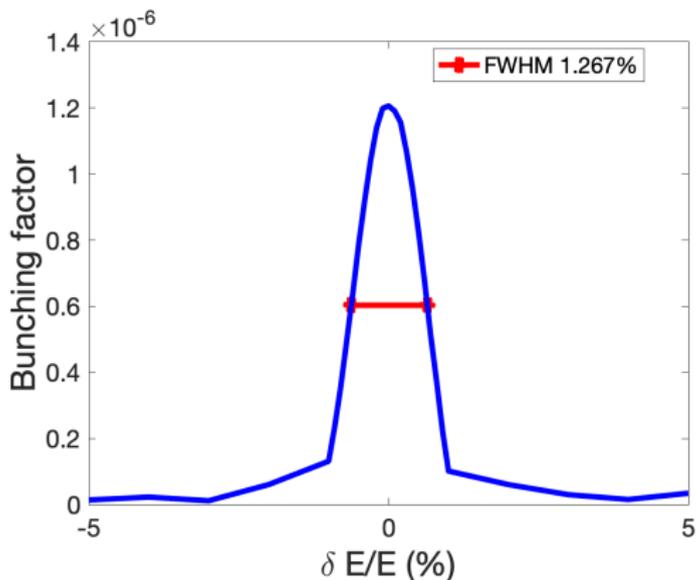
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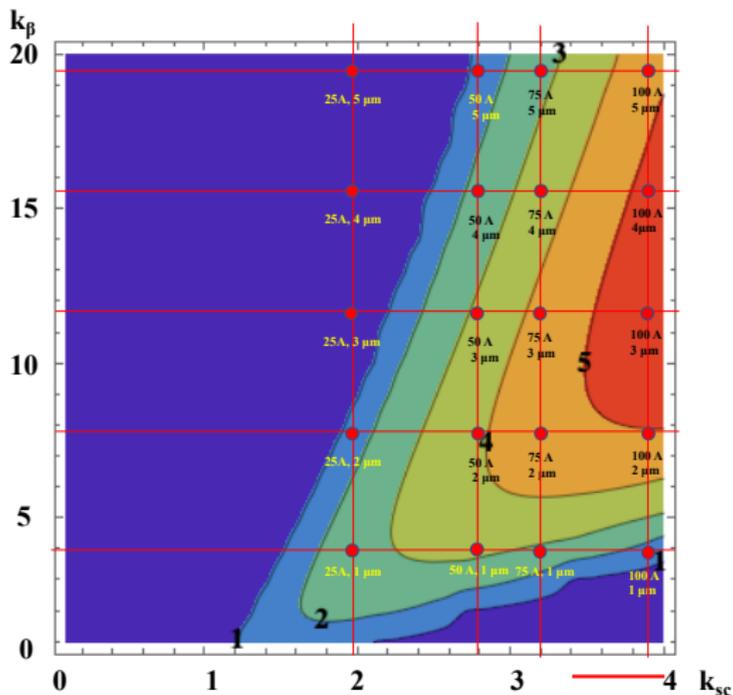
(a) PCA-based CeC

Modulator and kicker: match electron beam with ion beam in space, time, and energy.

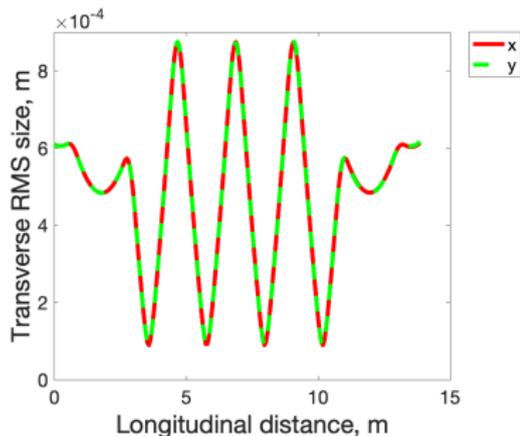


(a) Bunching factor amplitude of the density modulation induced by a single ion for various energy differences between the electron beam and the ion.

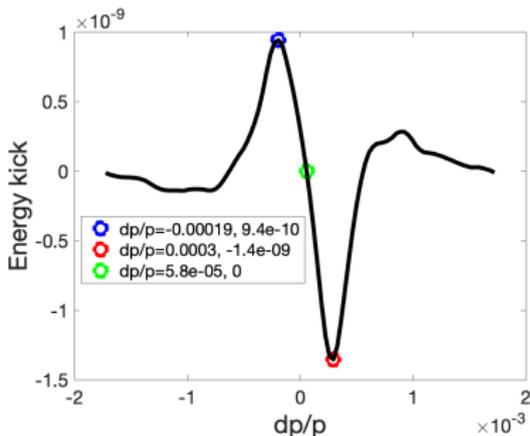
Amplifier: optimize beam parameters for high PCA gain.



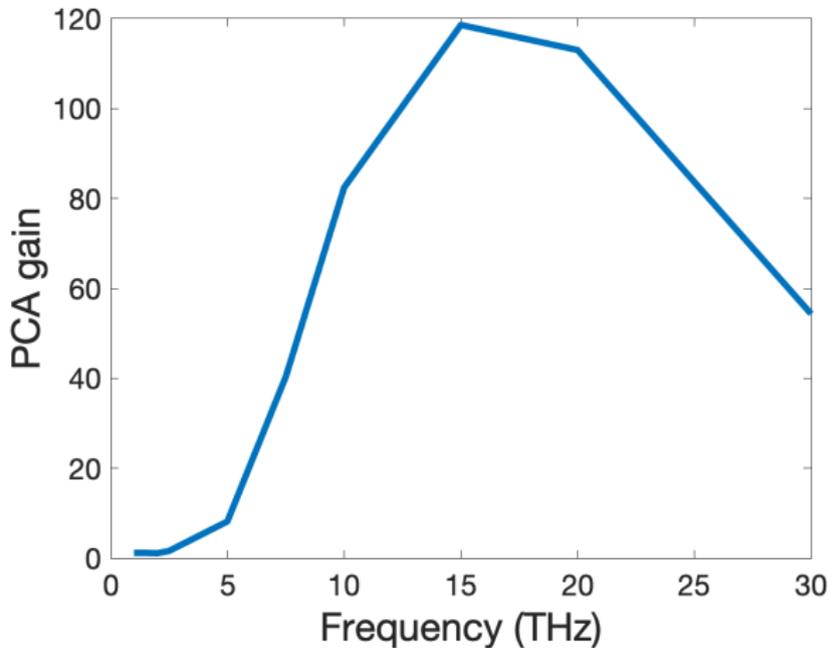
(a) Contour plot of the absolute value of the growth rate in a PCA cell.



(a) Evolution of the transverse RMS beam size

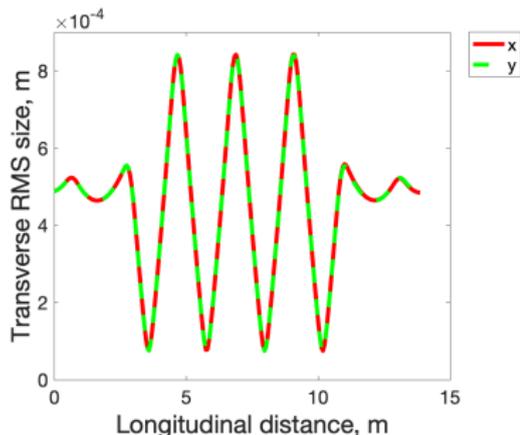


(b) Energy kick to ions

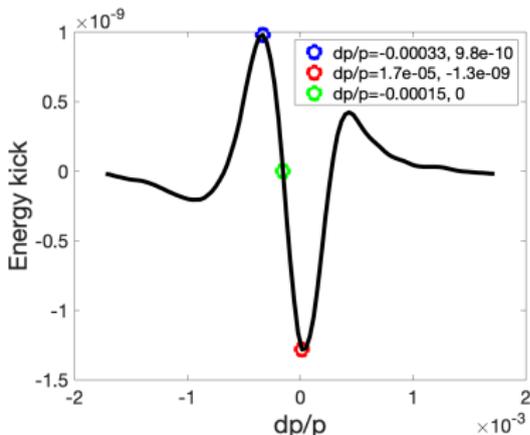


(a) Spectrum of PCA amplification

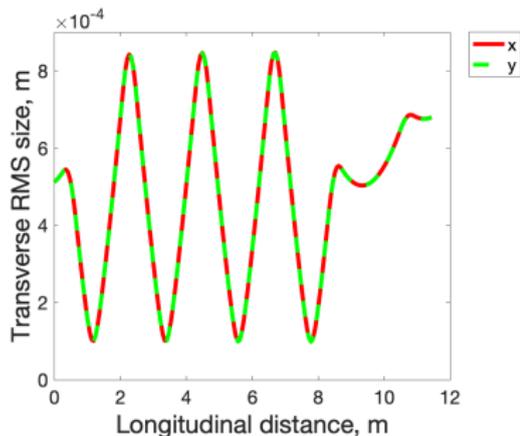
Beam current 50 A, normalized RMS emittance $1.5 \mu\text{m}$



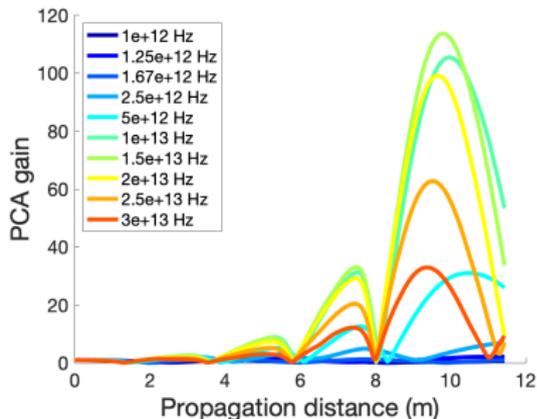
(a) Evolution of the transverse RMS beam size



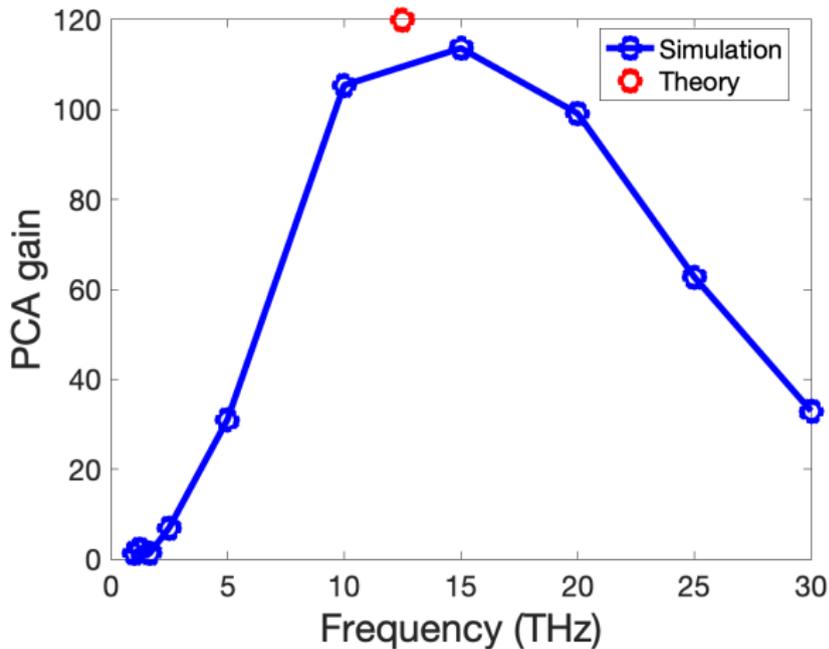
(b) Energy kick to ions



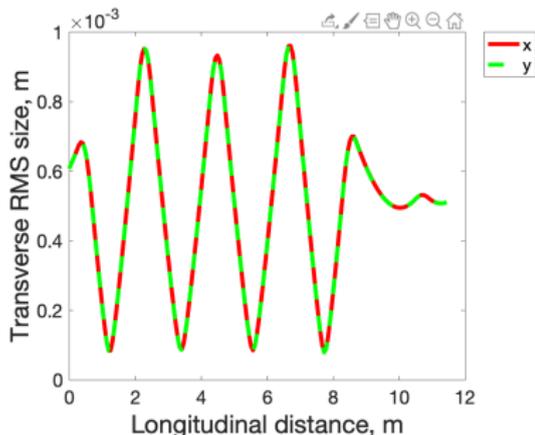
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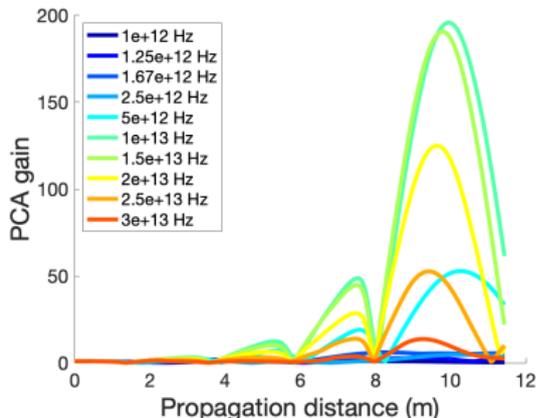
(b) Evolution of PCA gain for various frequencies



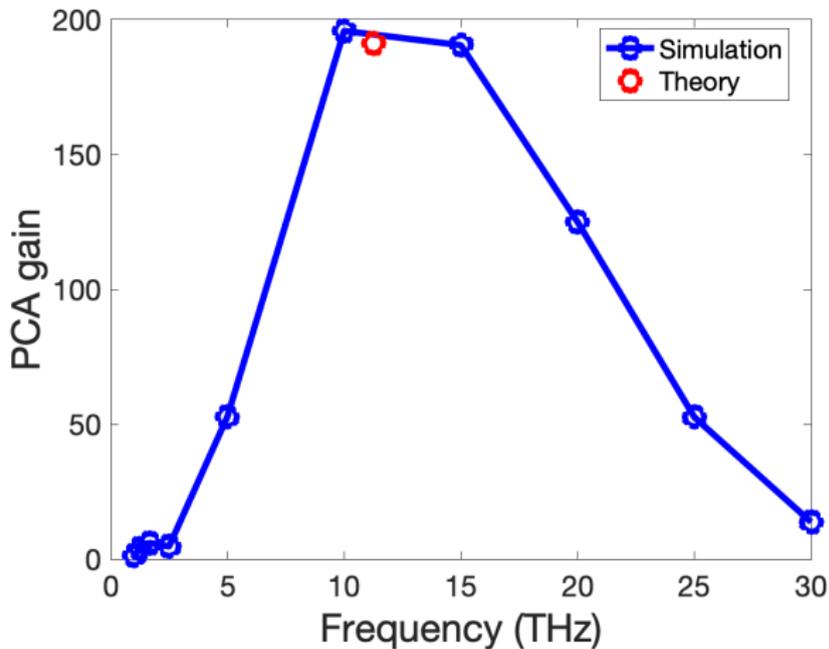
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(a) Spectrum of PCA amplification

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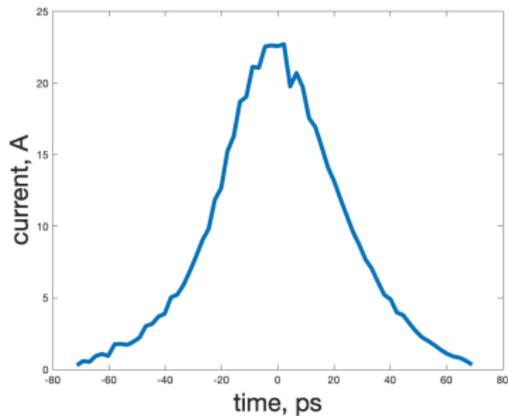
4 Predict

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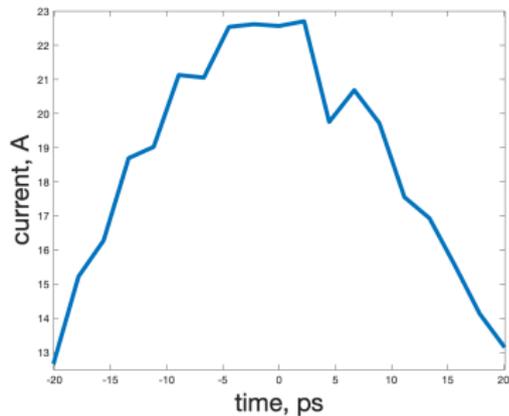
6 Summary

- Low beam current provides better chance to achieve key performance parameter (KPP).
- Detailed beam dynamic simulations are presented by Yichao Jing.
- We present the beam parameters at the entrance of modulator.

Beam current

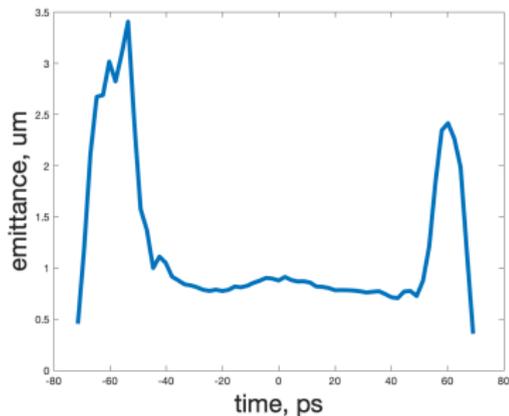


(a) Entire beam

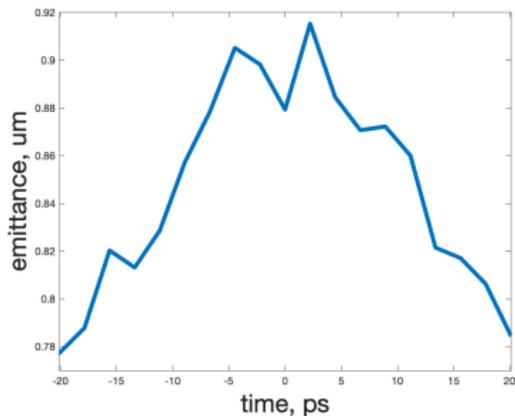


(b) Central beam

Normalized RMS emittance

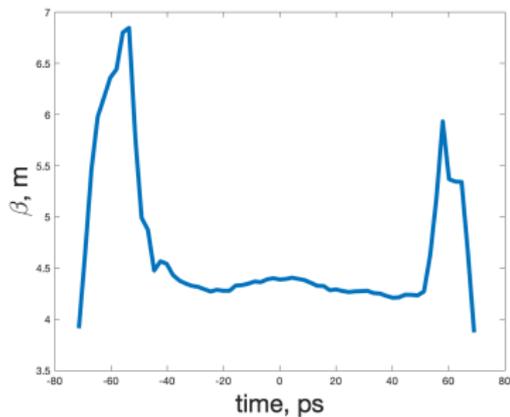


(a) Entire beam

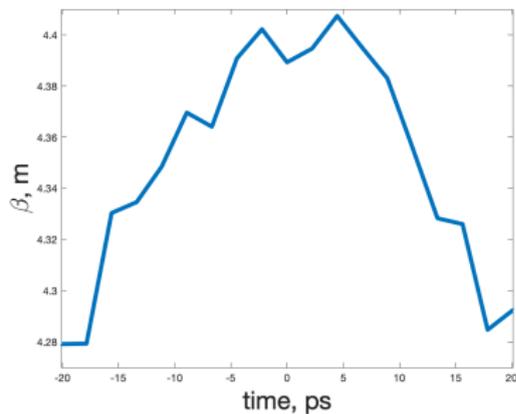


(b) Central beam

β function

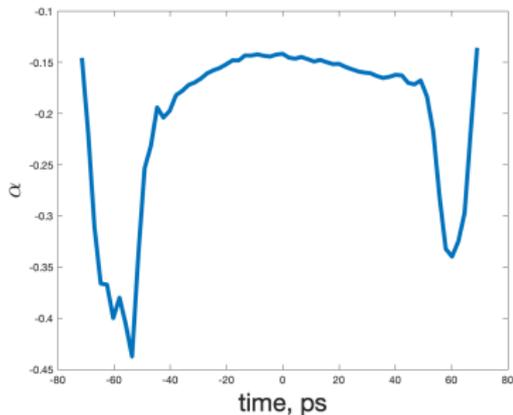


(a) Entire beam

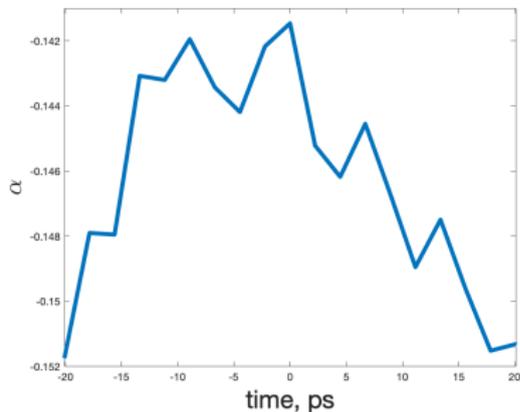


(b) Central beam

α function

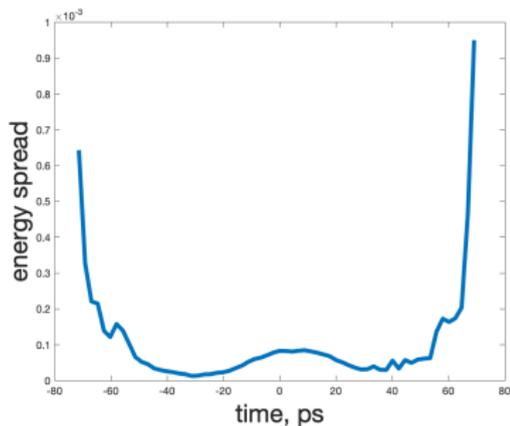


(a) Entire beam

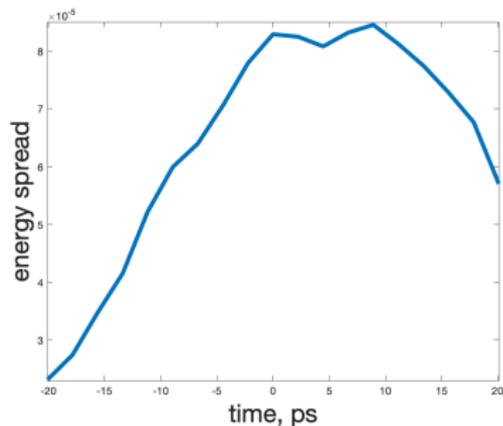


(b) Central beam

RMS energy spread



(a) Entire beam

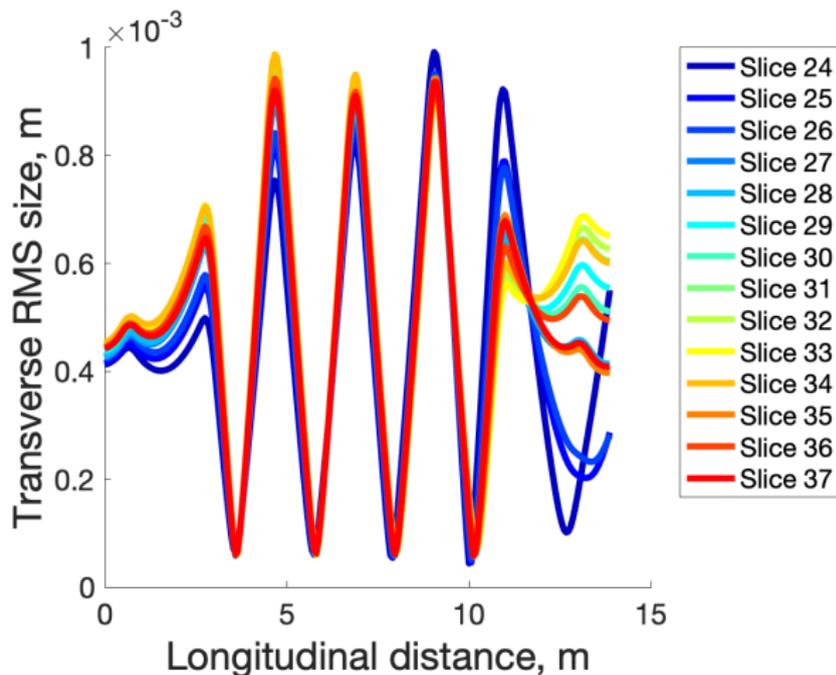


(b) Central beam

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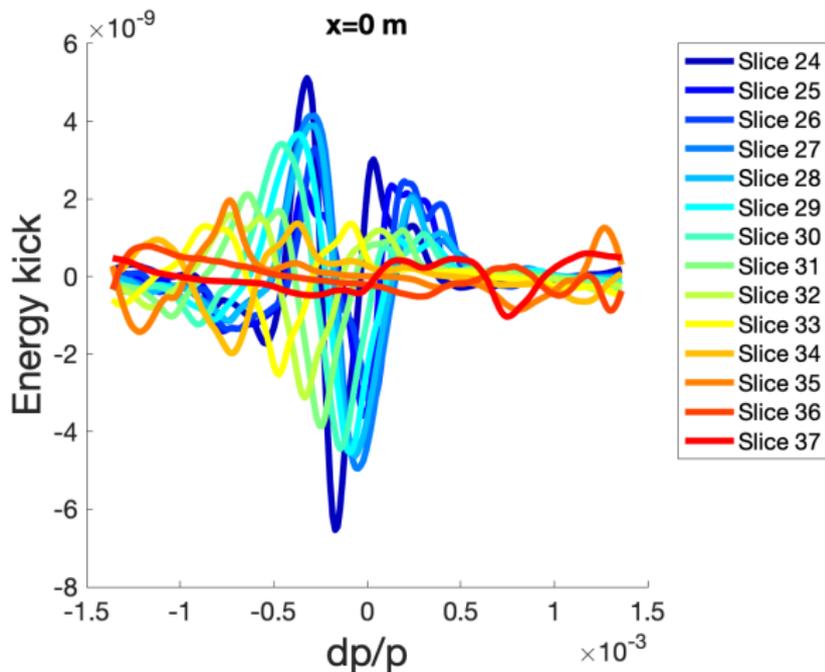
- Simulate multiple slices of the central beam, with slice duration 2.3 ps.
- Three PCA lattices - currents (A) of solenoids 1 to 7
 - Setup 1 (40.51, -80.68, 84.6, -84.6, 84.6, -80.68, 40.51), high PCA gain.
 - Setup 2 (40.51, -80.68, 83.8, -83.8, 83.8, -80.68, 40.51), relax solenoids 3,4,5 for less delay due to transverse motion, PCA gain is slightly reduced.
 - Setup 3 (50, -82, 86.9, -86.9, 86.9, -82, 50), PCA gain is slightly reduced due to larger beam waist in PCA.
- Track cooling force to ions with reference / off-reference energies
- Track cooling force to ions with / without transverse offsets
- RMS size of ion beam is 1 mm with Gaussian distribution. Take weighted sum of cooling force at transverse offsets with corresponding 2D Gaussian distribution probability density function, to quantify overall cooling force.

Setup 1



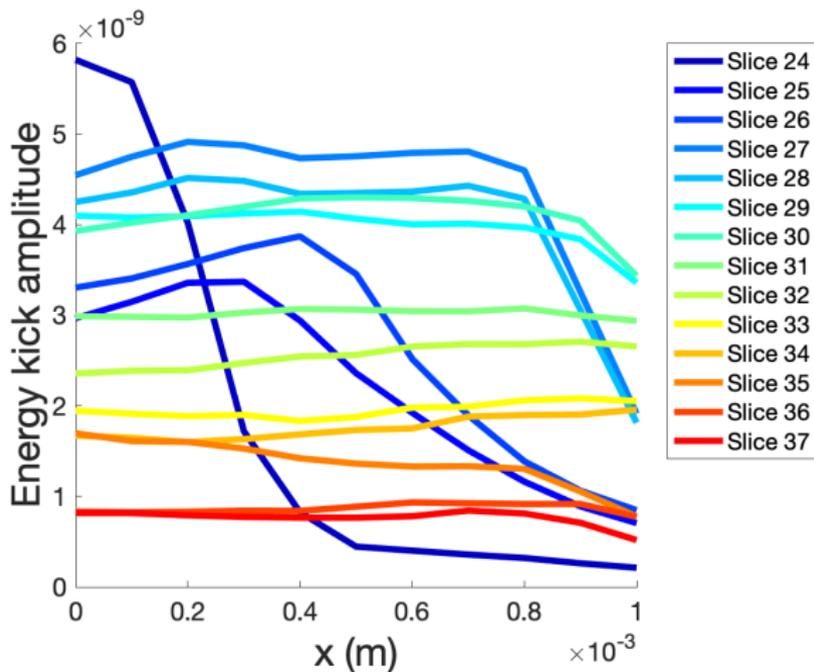
(a) Evolution of the transverse RMS beam size

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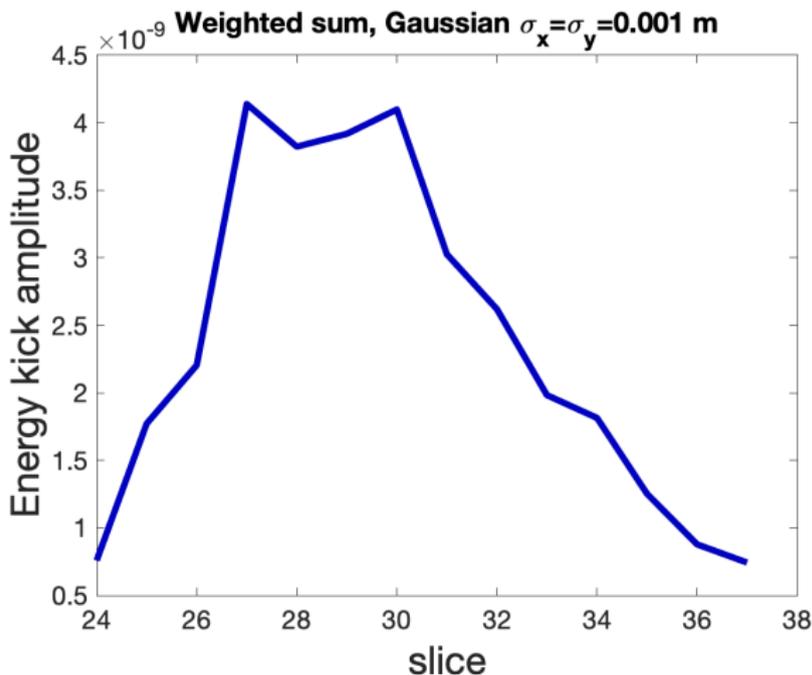
(a) Cooling force to ions without transverse offsets

Setup 1



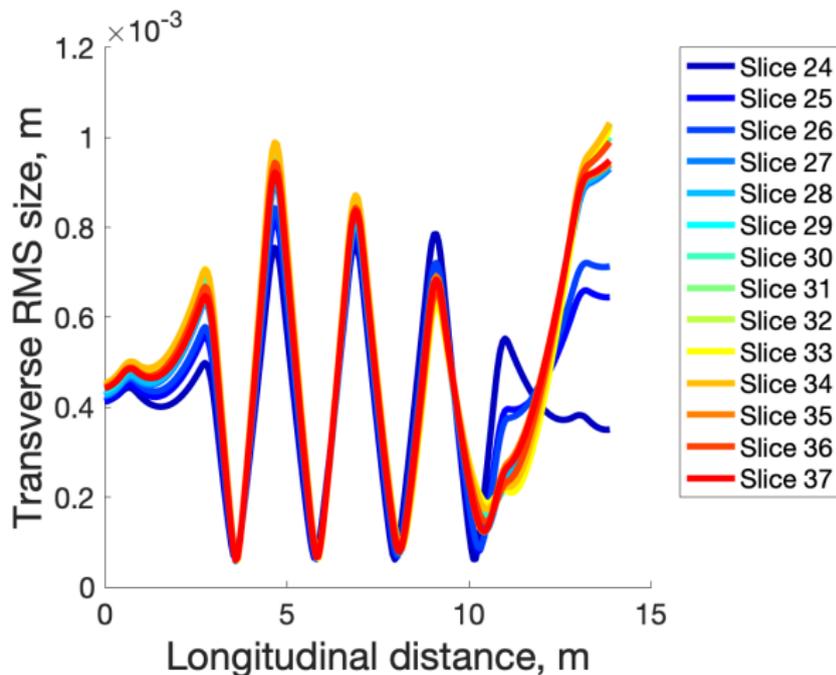
(a) Cooling force amplitude to ions with transverse offsets

Setup 1



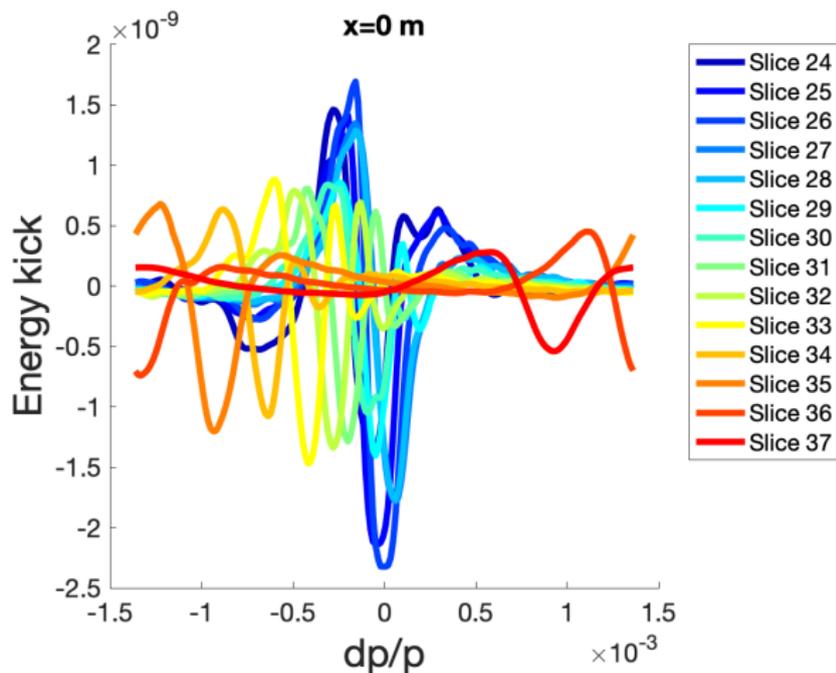
(a) Weighted sum of cooling force amplitude with 2D Gaussian distribution probability density function

Setup 2



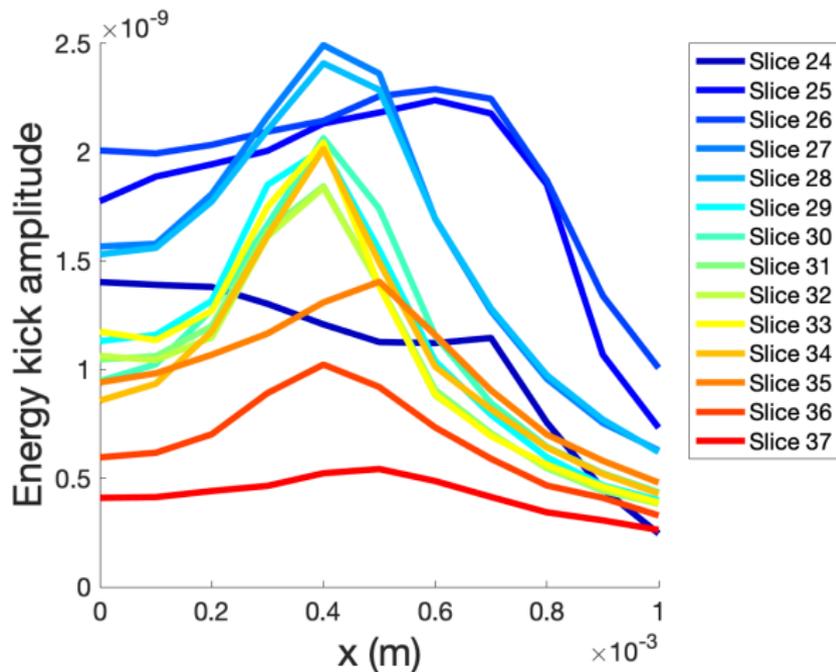
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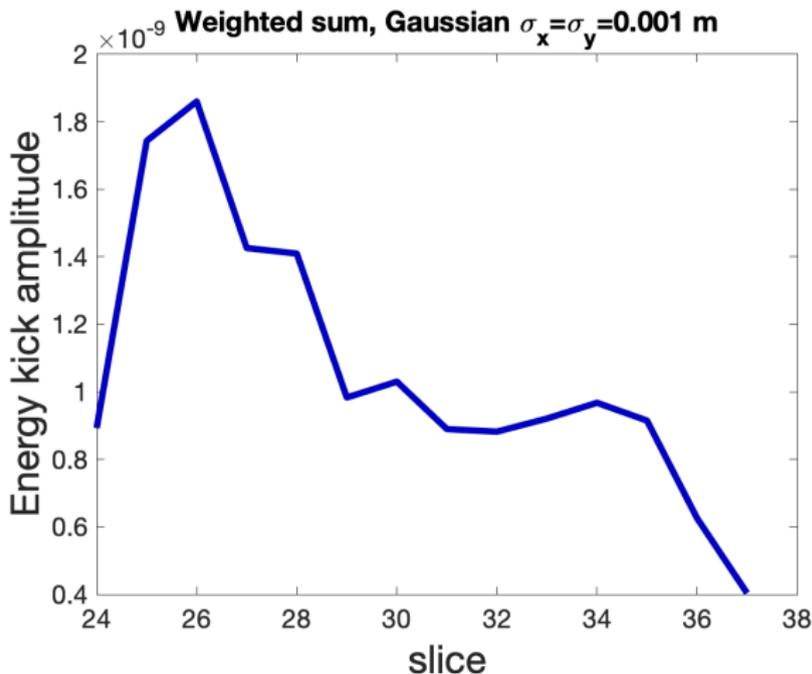
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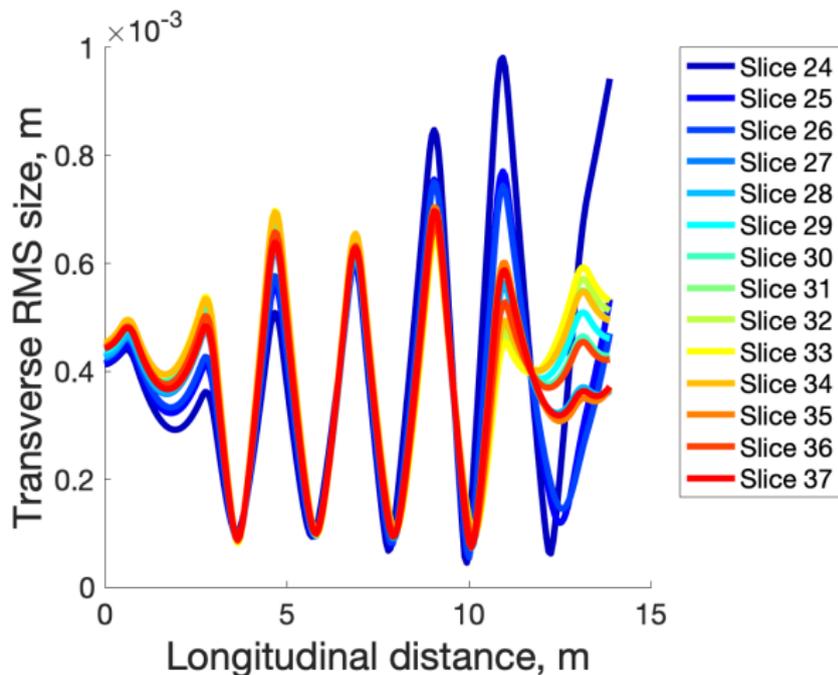
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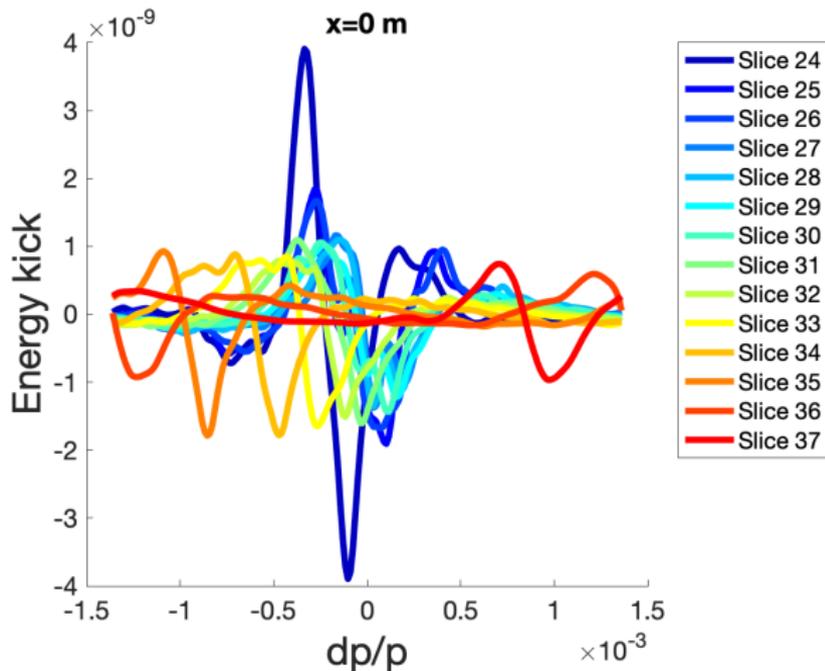
(a) Weighted sum of cooling force amplitude with 2D Gaussian distribution probability density function

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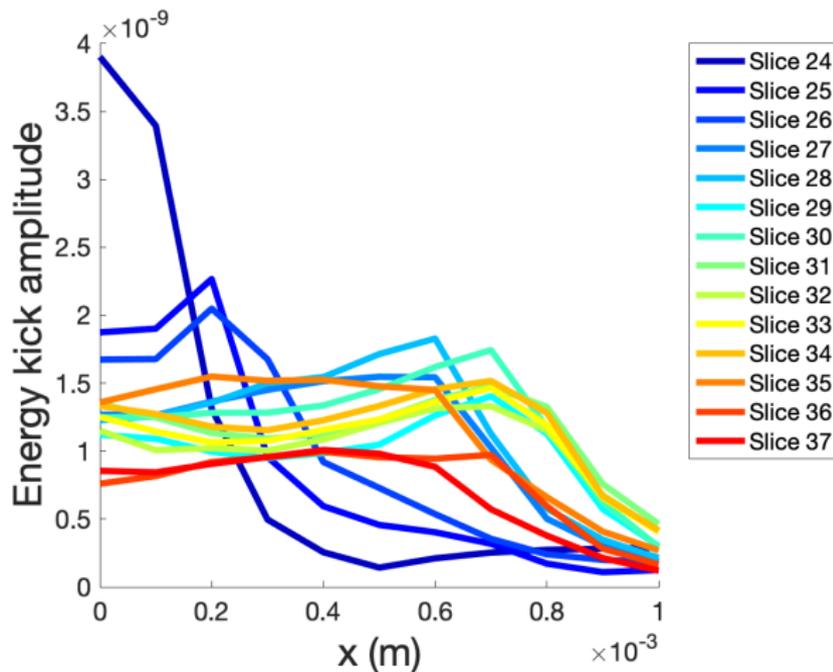
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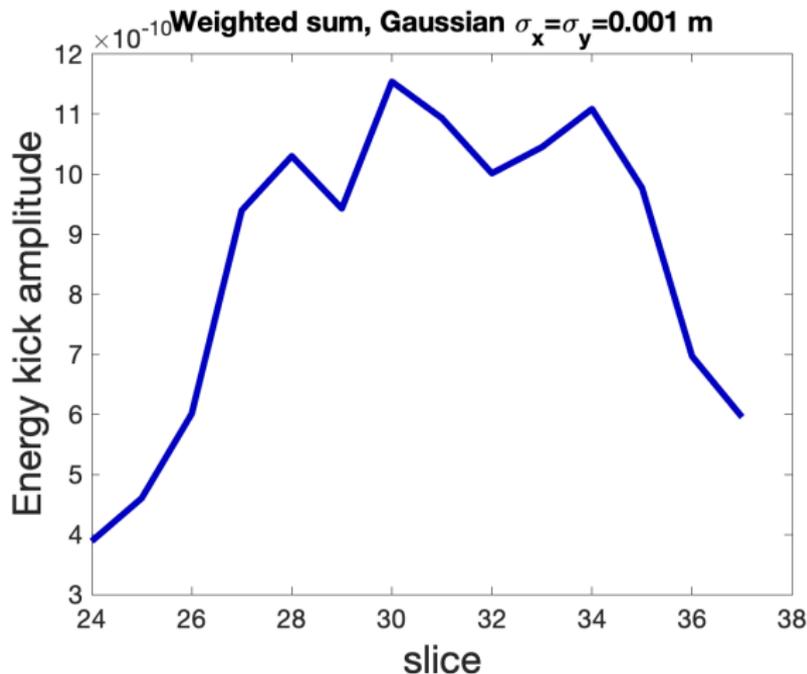
(a) Cooling force to ions without transverse offsets

Setup 3



(a) Cooling force amplitude to ions with transverse offsets

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(a) Weighted sum of cooling force amplitude with 2D Gaussian distribution probability density function

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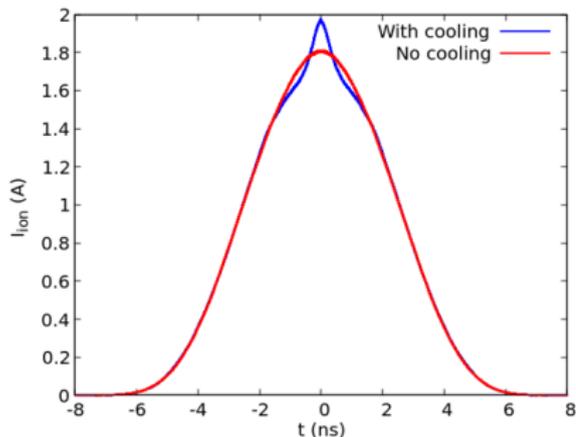
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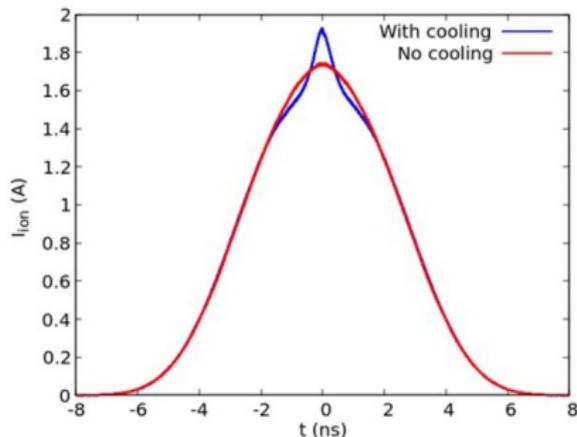
6 Summary

- Track ion beam evolution with / without the presence of CeC.
- Detailed simulations are presented by Gang Wang.
- We present the results for ion beam intensity $8e + 8 / 2e + 8$ after 4 / 8 minutes of cooling, using slices from setup 1.

Ion intensity $8e + 8$, with electron beam slice 24-30

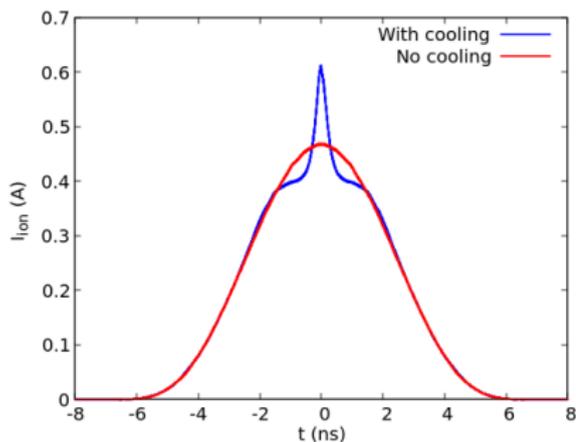


(a) After 4 minutes

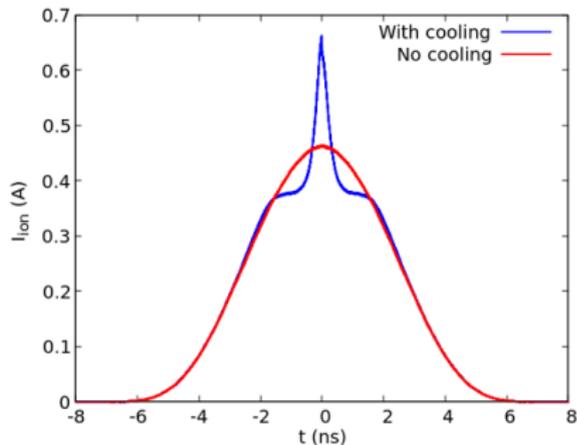


(b) After 8 minutes

Ion intensity $2e + 8$, with electron beam slice 24-30

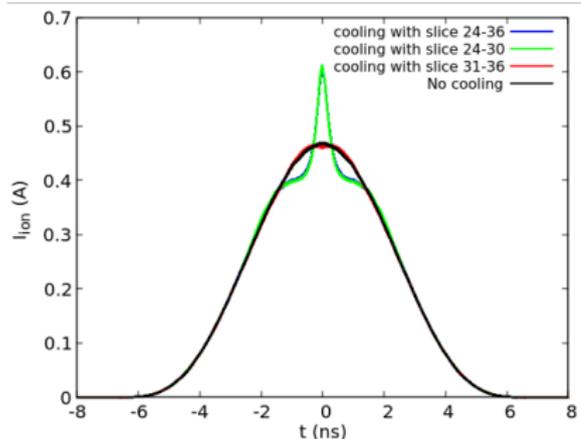


(a) After 4 minutes

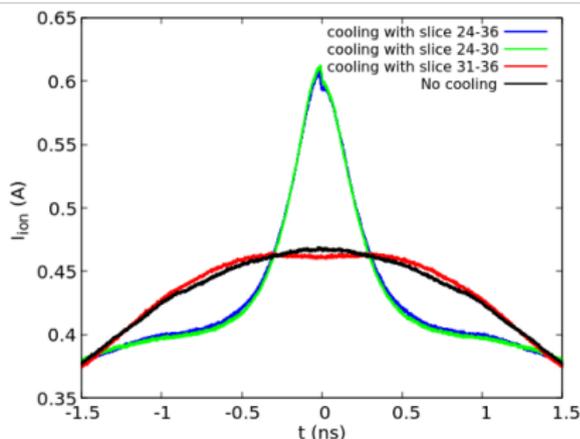


(b) After 8 minutes

Ion intensity $2e + 8$



(a) After 4 minutes



(b) After 4 minutes, zoom in

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- Beam parameters of low peak current for PCA-based CeC have been established. PCA gain spectrum has been simulated, and agrees well with theoretical prediction.
- Beam dynamic simulation has achieved required beam parameters at the entrance of modulator. Low emittance, low energy spread, uniform β function and α function, round beam.
- CeC simulation has predicted strong cooling force because of good quality beam from beam dynamic simulation. Three PCA lattices have been designed.
- Ion tracking simulation has confirmed observable cooling on ion beam with the presence of CeC.

Thank You