LEDS2023

Half-wavelength velocity bunching

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Outline

- ❖ Ångström Laser
- ❖ Velocity bunching
- ❖ Half-wavelength bunching
- ❖ Conclusions & perspectives

Ångström Laser @ FREIA

Aiming for a compact X-ray coherent source

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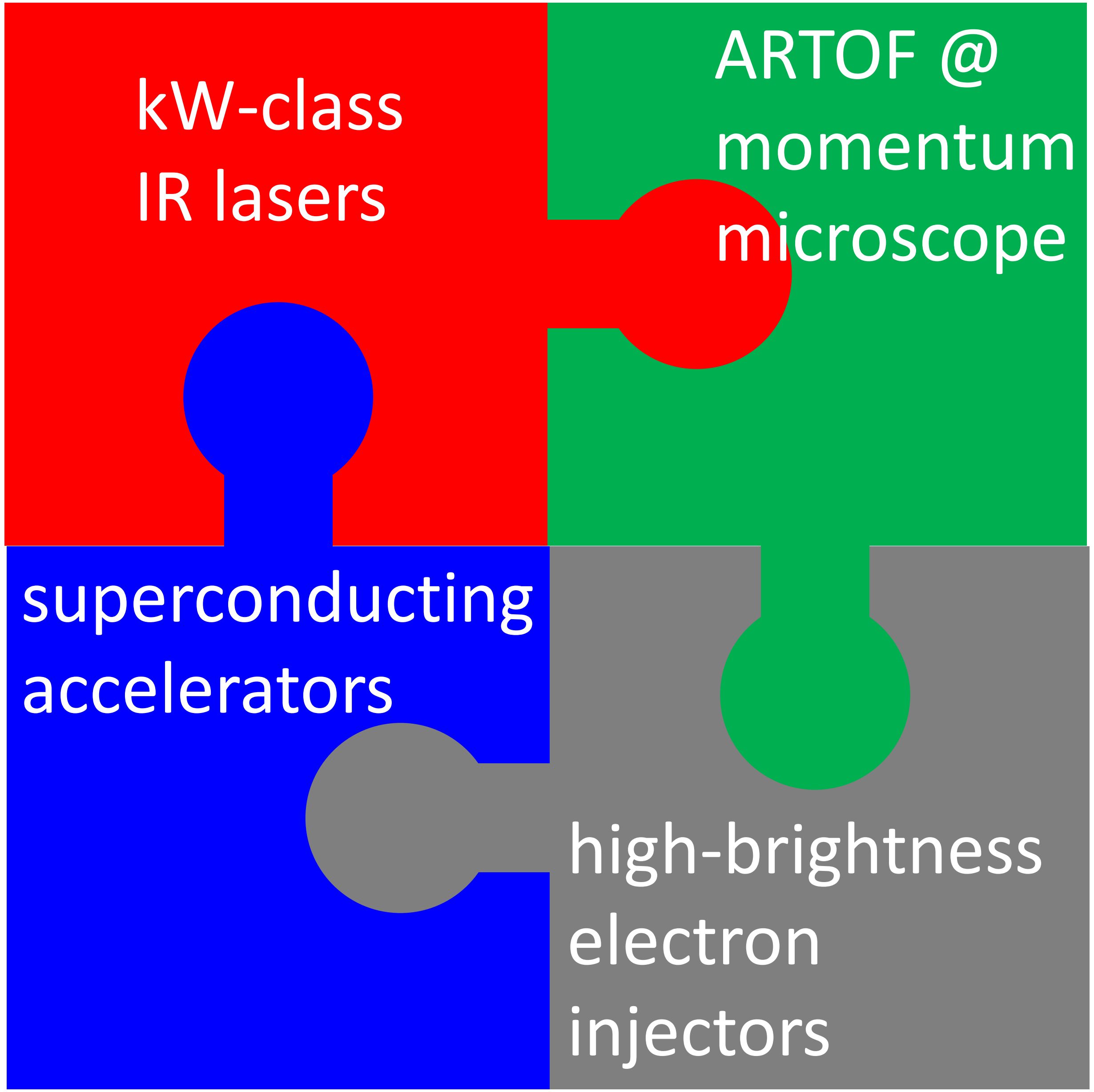
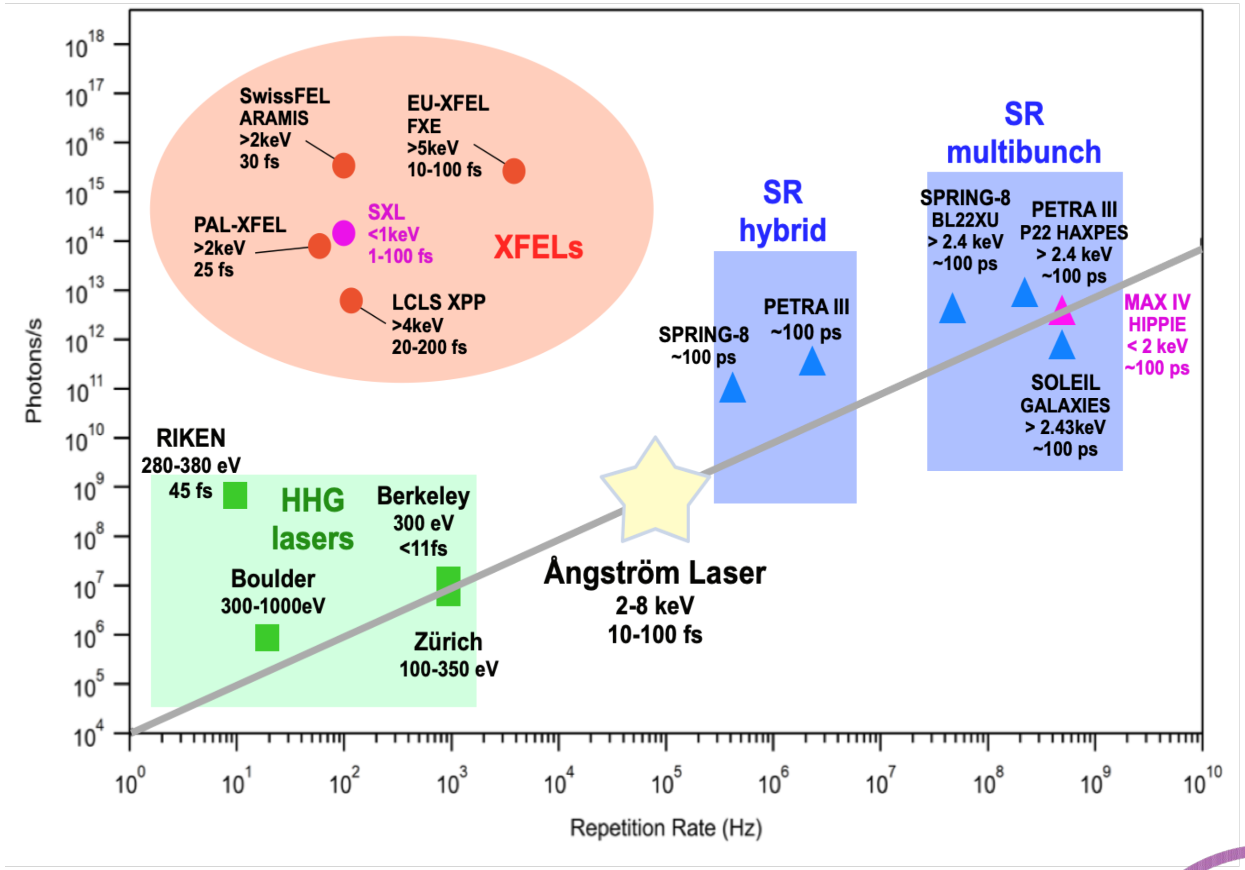
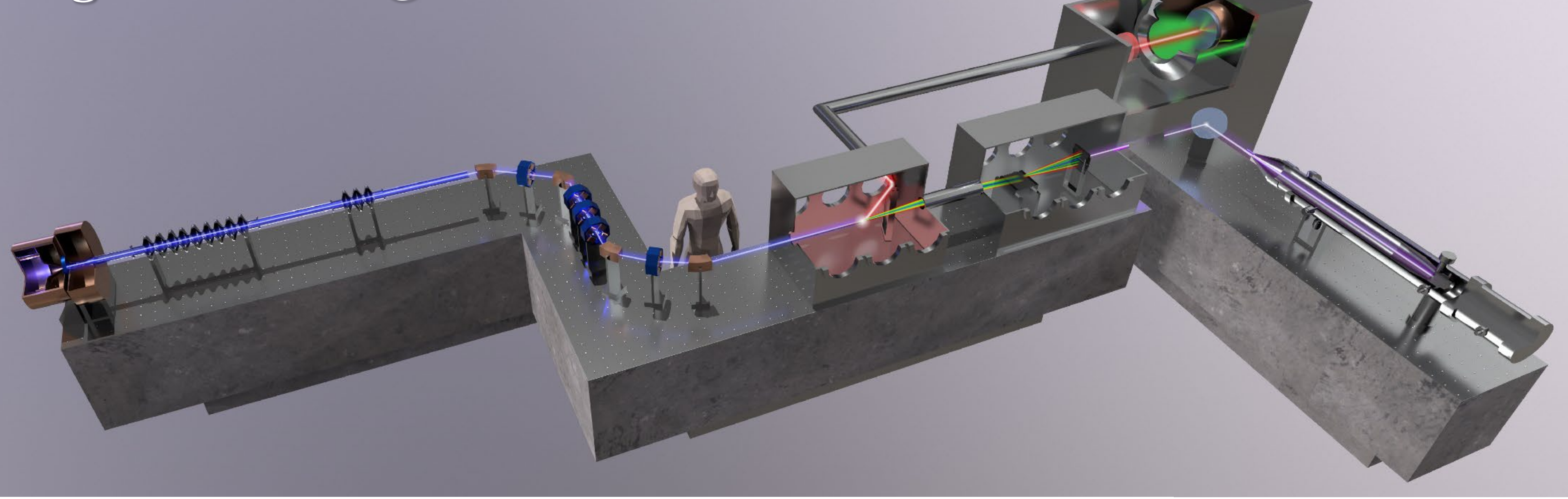




Ångström Laser @ FREIA



X-ray output parameters	Optical undulator	Broadband beamline (at the sample)	Mono-beamline (at the sample)
X-ray energy range	2-13 keV	2-13 keV	2-8 keV
X-ray energy bandwidth	1 %	1 %	~0.02 %
X-ray pulse duration (FWHM)	< 200 fs	< 200 fs	< 200 fs
Flux (s^{-1}) at 100 kHz repetition rate	10^{10}	10^{9}	10^{7}-10^{8}
X-ray spot size (FWHM)	8.0 μm	35 μm	41 μm

Ångström Laser @ FREIA

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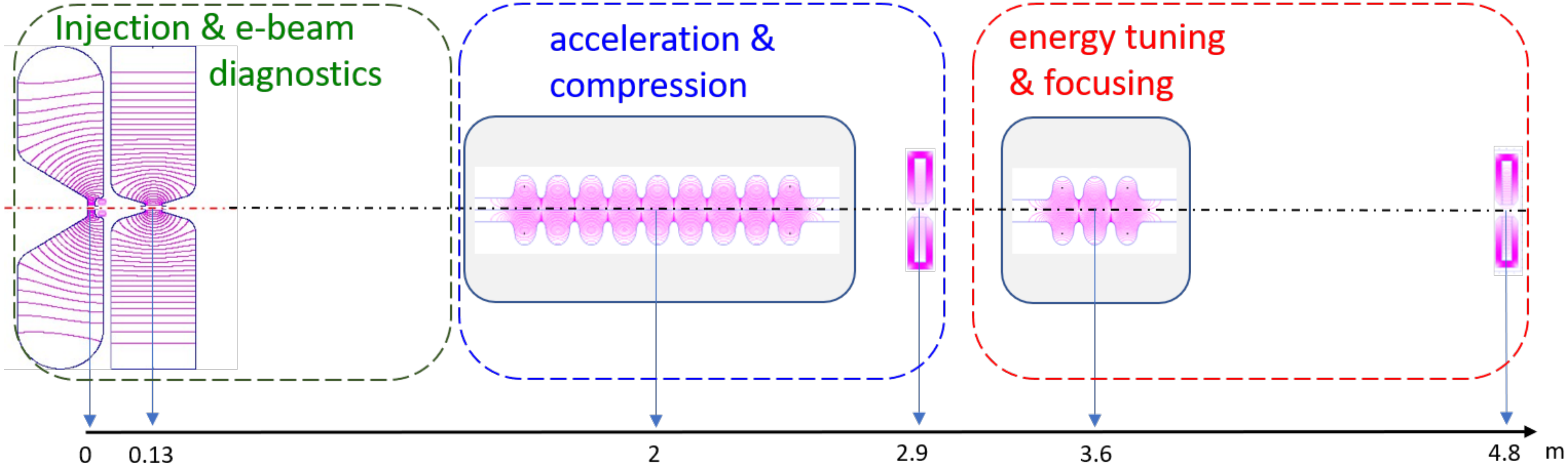

Injector:
- energy: 1 MeV
- energy spread: 9.7 keV
- x-beam size: 240 um
- z-beam size: 770 um
- duration: 2.66 ps
- x-emittance: 65 nm
- z-emittance: 0.4 keV mm

TESLA module:
- 16 MeV
- 30 keV
- 1000 um
- 70 um
- 0.23 ps
- 230 nm
- 0.4 keV mm

Tuning & focusing:
- 10-22 MeV
- 30-80 keV
- 3-5 um
- 50 um
- 0.1-0.2 ps
- 100-200 nm
- 0.8-1 keV mm

Velocity bunching

S. G. Anderson *et al.*, Phys. Rev. ST Accel. Beams **8**, 014401 (2005)

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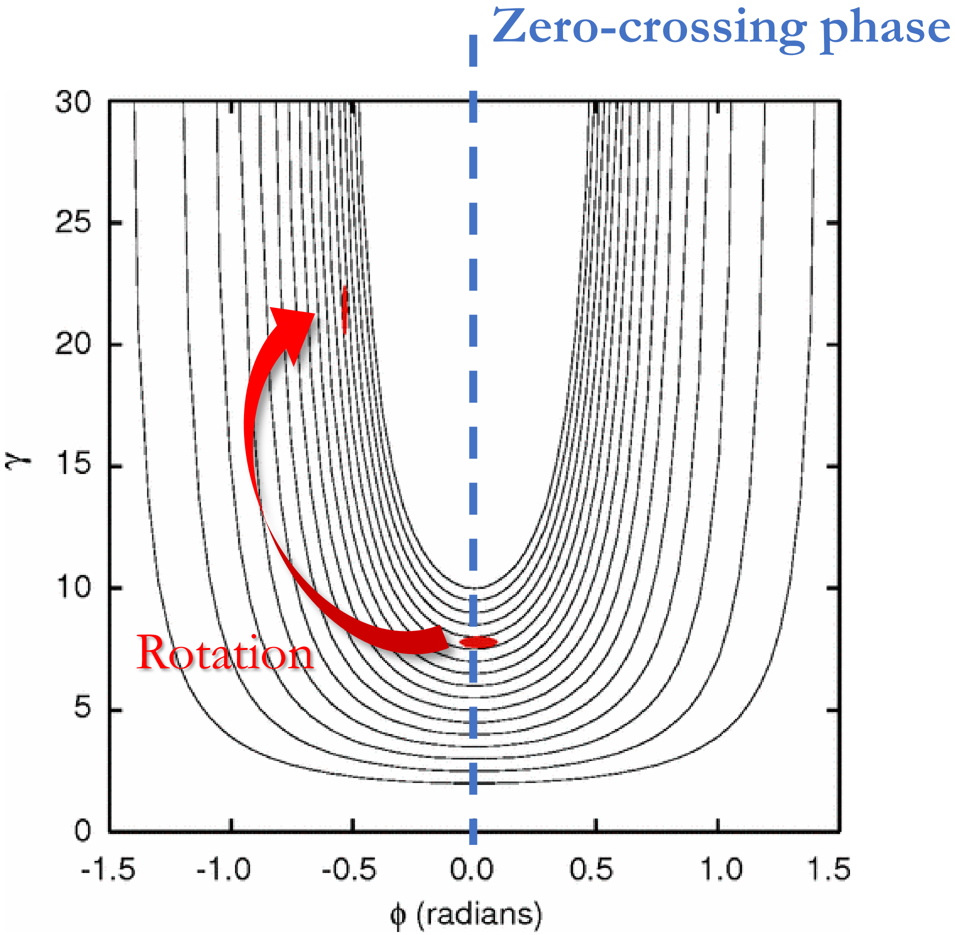
Longitudinal phase space in rf field



Zero-crossing injection
+
$\beta_e < \beta_r$

Chirped and accelerated

Phase of the wave seen by the electron

$$\phi = kz - \omega t - \phi_0 \quad \text{where} \quad \beta_r = \frac{v_r}{c} \quad \text{and} \quad k = \frac{\omega}{\beta_r c}$$

The Hamiltonian is

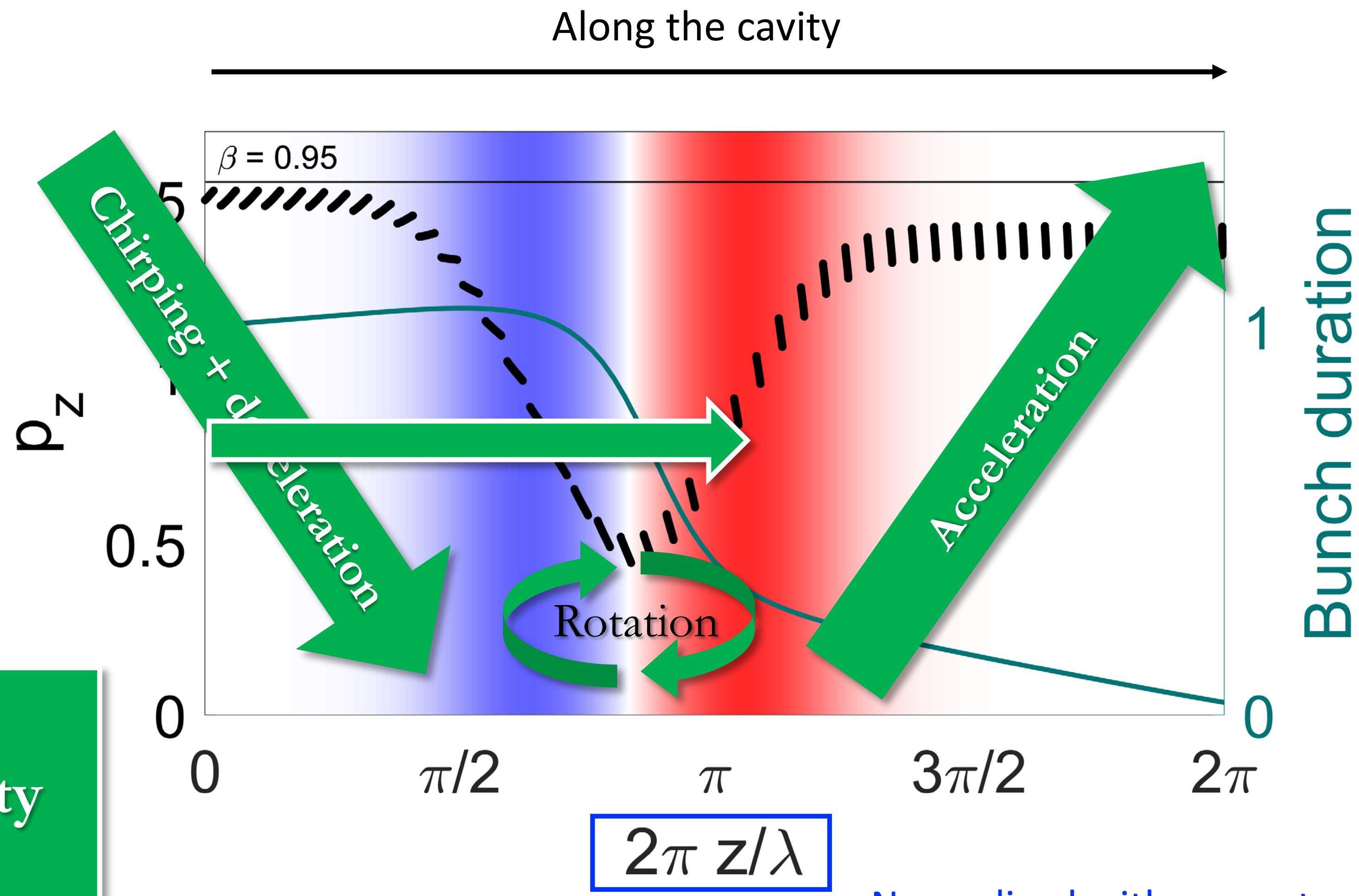
$$H = \gamma - \beta_r\sqrt{\gamma^2 - 1} - \underbrace{\alpha \cos\phi}_{\text{RF field}}$$

PRO: Both compression and acceleration take place within the same accelerator section

Half-wavelength bunching

- Decelerating field
- Accelerating field

1-D Longitudinal phase space portrait



Normalized with respect to the cavity wavelength

All happens in half of the cavity wavelength

Half-wavelength bunching:

1-cell simulation

Instantaneous electric field

Electron phase

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Half-wavelength bunching:
9-cell simulations

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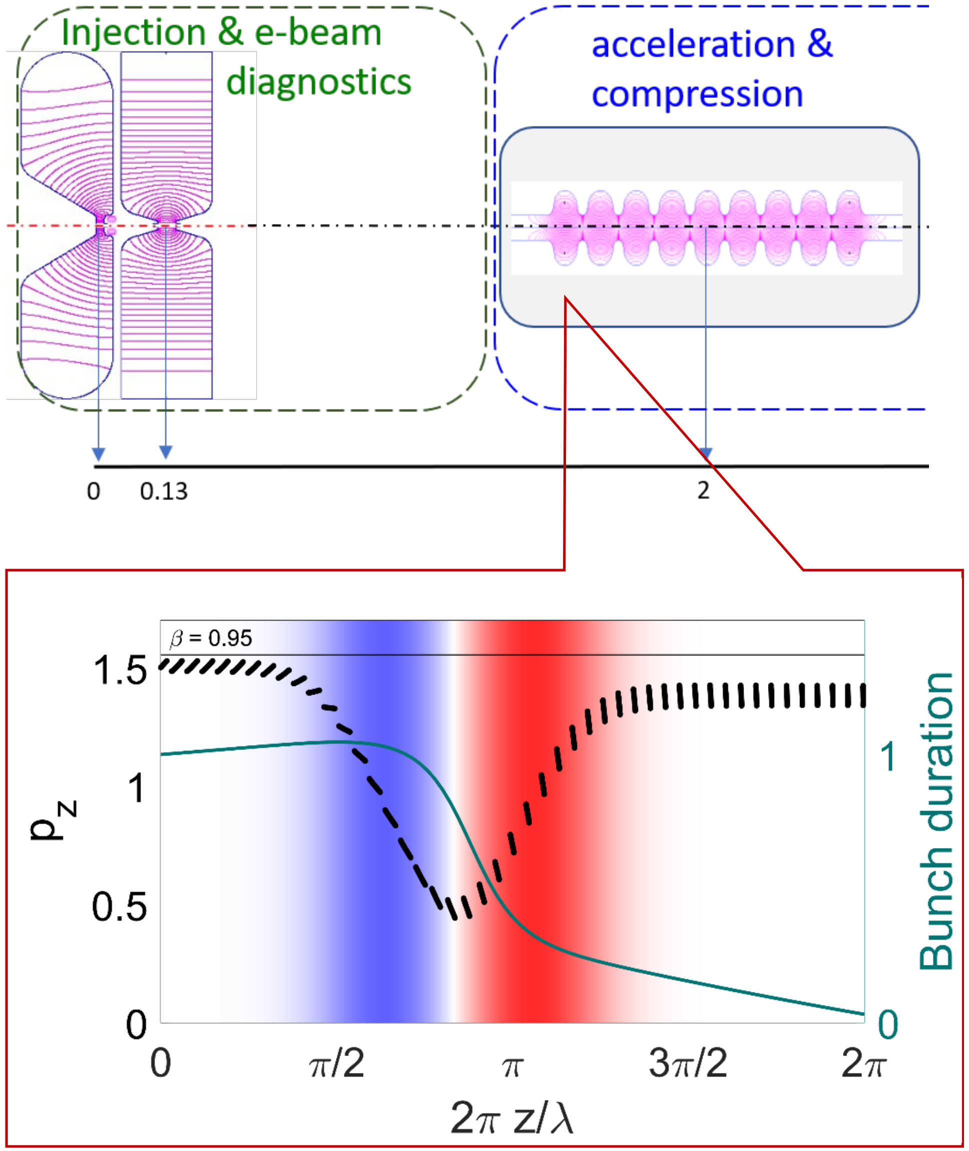

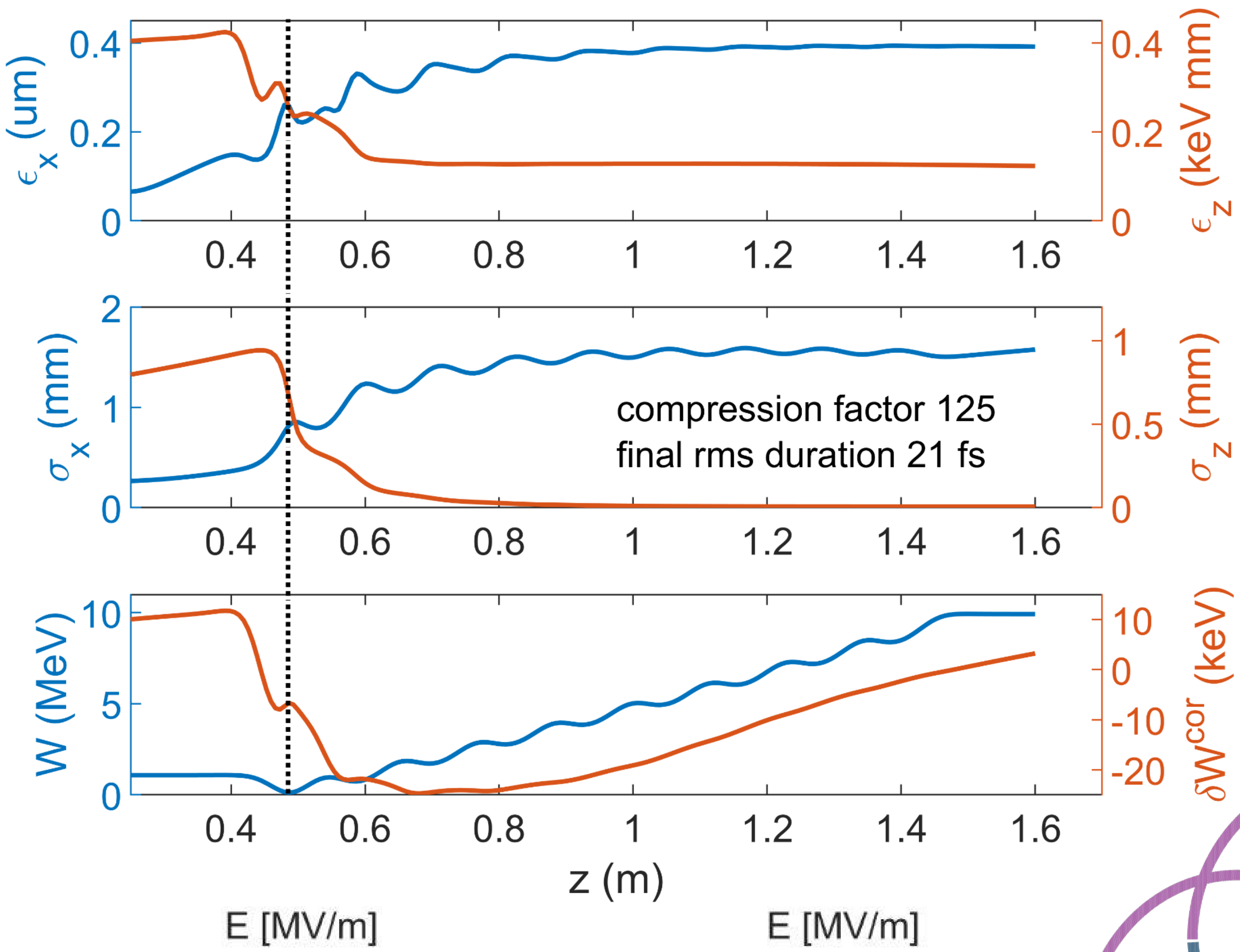

Half-wavelength bunching:

9-cell simulations

Instantaneous electric field

Electron phase

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Half-wavelength bunching:
9-cell simulations

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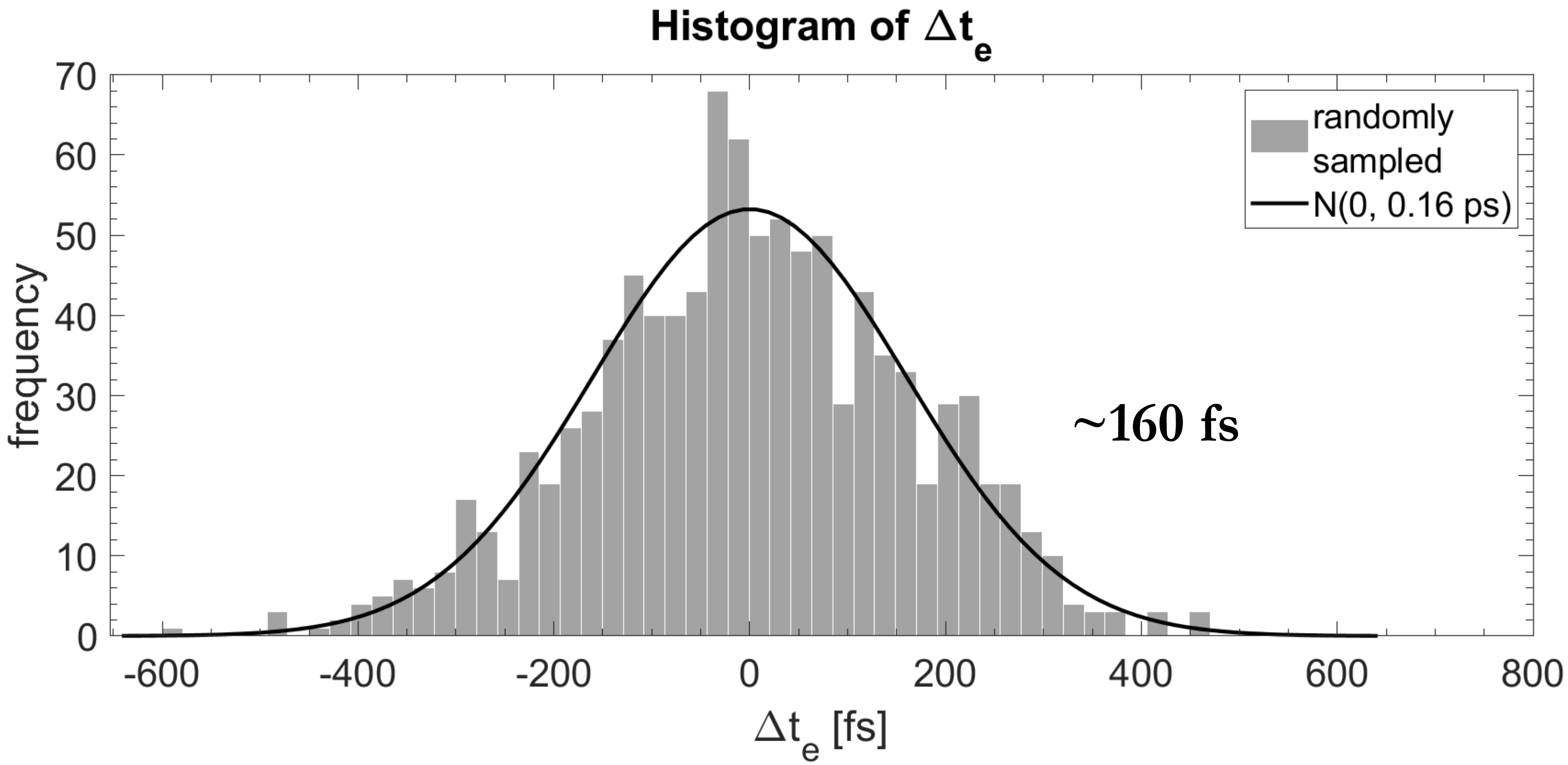
We study the dependence of bunch arrival time on gaussian jitter of parameters



Standard deviation for the noise

$$\sigma_E = 0.05\%$$
$$\sigma_\gamma = 0.05\%$$
$$\sigma_\phi = 0.05^o$$

The time jitter can be reduced down to 16 fs if the accelerator stability is pushed to the state-of-the-art regime

$$\sigma_t^2 \ [\mathrm{fs}^2] \approx \left(\frac{1.12\ \sigma_E}{\mathrm{kVm}^{-1}}\right)^2 + \left(3.8\frac{\sigma_\gamma}{10^{-4}}\right)^2 + \left(29.6\frac{\sigma_\phi}{0.01^o}\right)^2$$

Conclusions & Perspectives

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- ✓ We showed an interesting regime of non-adiabatic temporal compression
- ✓ The discovered mechanism of compression, which is another mode of velocity bunching, opens the door for obtaining very high electron densities in the phase space
- ✓ A 3-ps 16-pC 1-MeV electron bunch is compressed to 21 fs rms and accelerated to 12 MeV in a TESLA superconducting cavity
- ✓ We discussed the performance and stability of a 9-cell cavity

- ❑ Experimental proof-of-principle
- ❑ Employ this mechanism for UED and ICS

Thank you for your attention!

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Back-up slides

Inverse Compton Scattering

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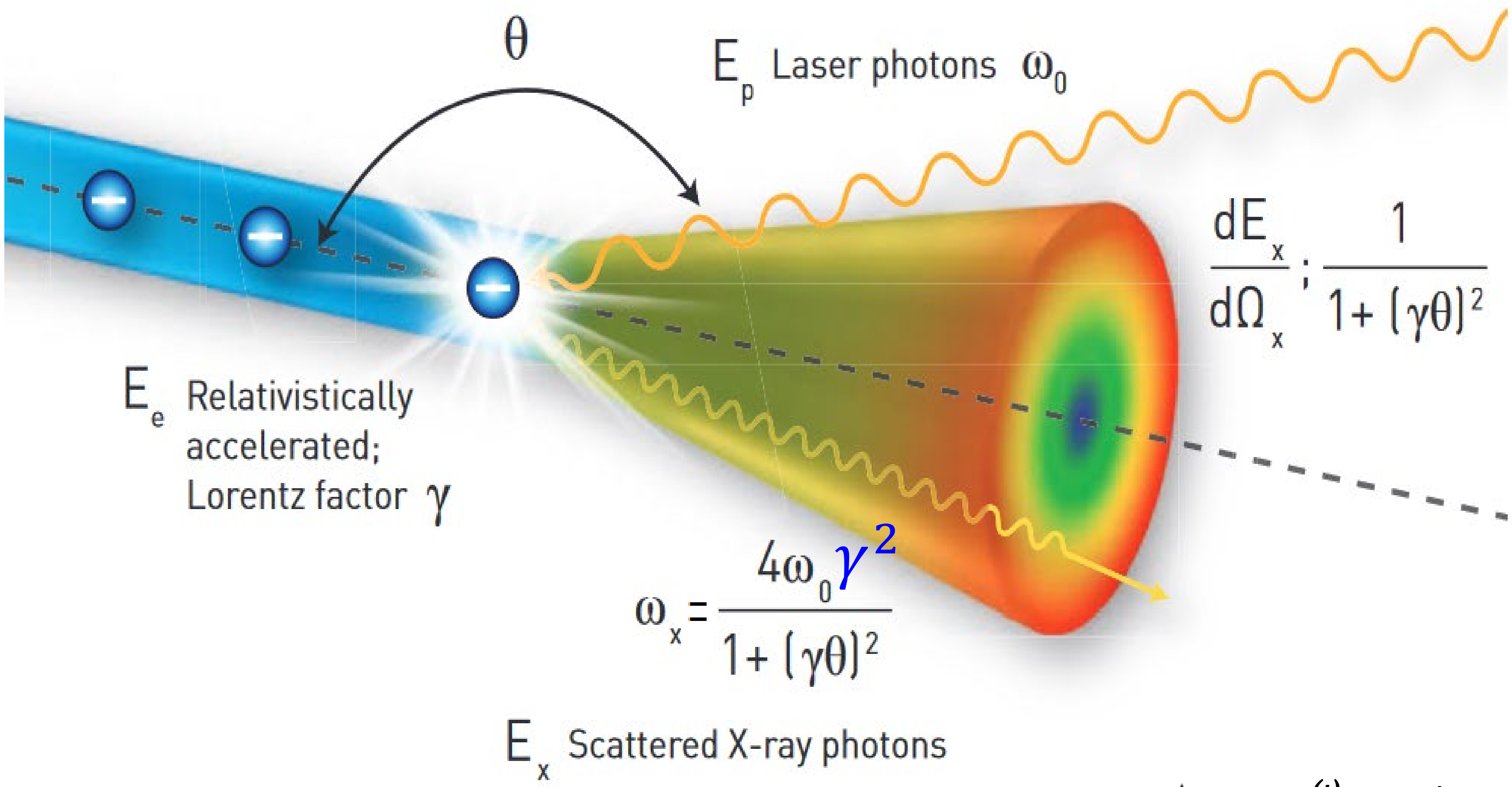
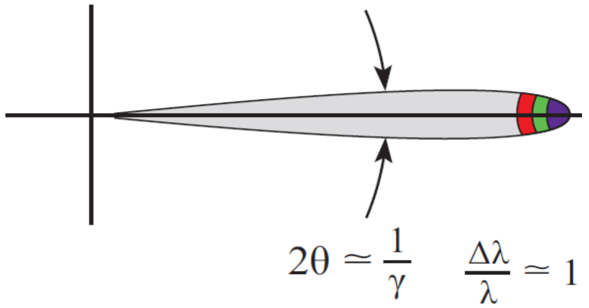
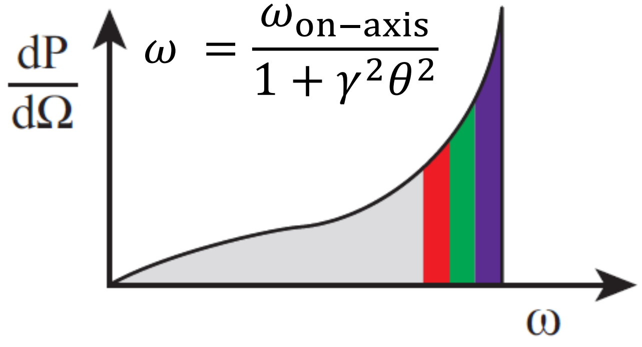
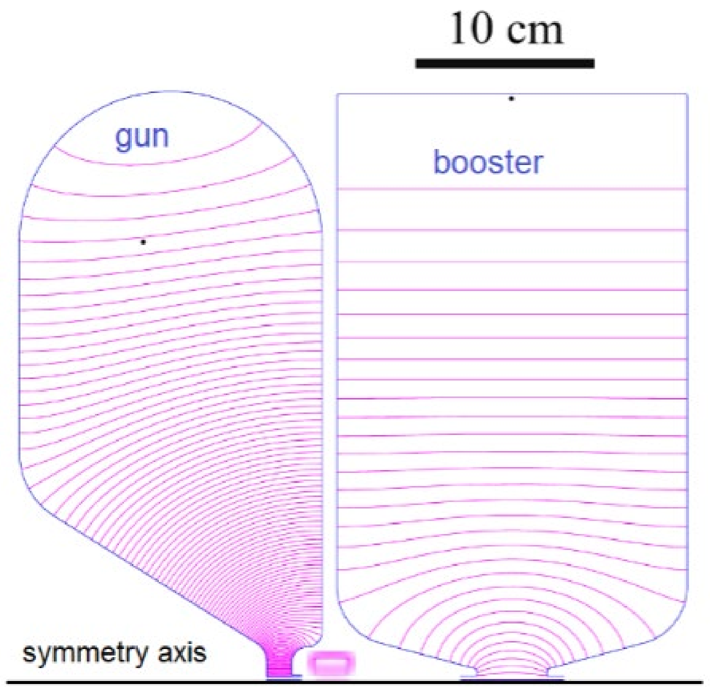
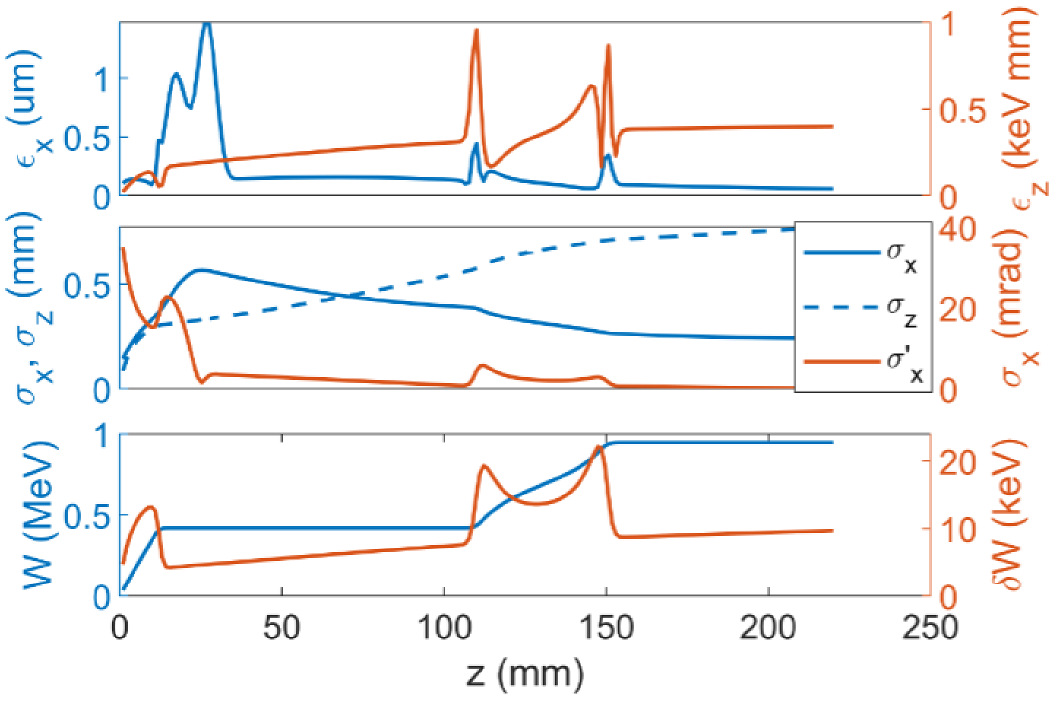






Gun + Booster





Parameter	Symbol	Value	Units
Peak accelerating field	E_{acc}	35	MV/m
Emission phase	-	0	degrees
Charge	Q	16	pC
Energy	W	130	meV
Energy spread	δW	80	meV
rms x-bunch size	σ_x	107	μm
rms bunch duration	σ_t	30	fs
rms x-beam divergence	σ'_x	2.47	mrad
rms thermal x-emittance	ε_x	44	nm

Parameter	Symbol	Value	Units
Charge	Q	16	pC
Energy	W	420	keV
Correlated energy spread	δW	5.3	keV
rms x-beam size	σ_x	2	mm
rms z-beam size	σ_z	0.46	mm
rms x-beam divergence	σ'_x	24.4	mrad
rms normalised x-emittance	ε_x	57	nm
rms normalised z-emittance	ε_z	0.24	keV mm
ratio of x and y emittances		0.99	

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Half-wavelength bunching:
9-cell simulations

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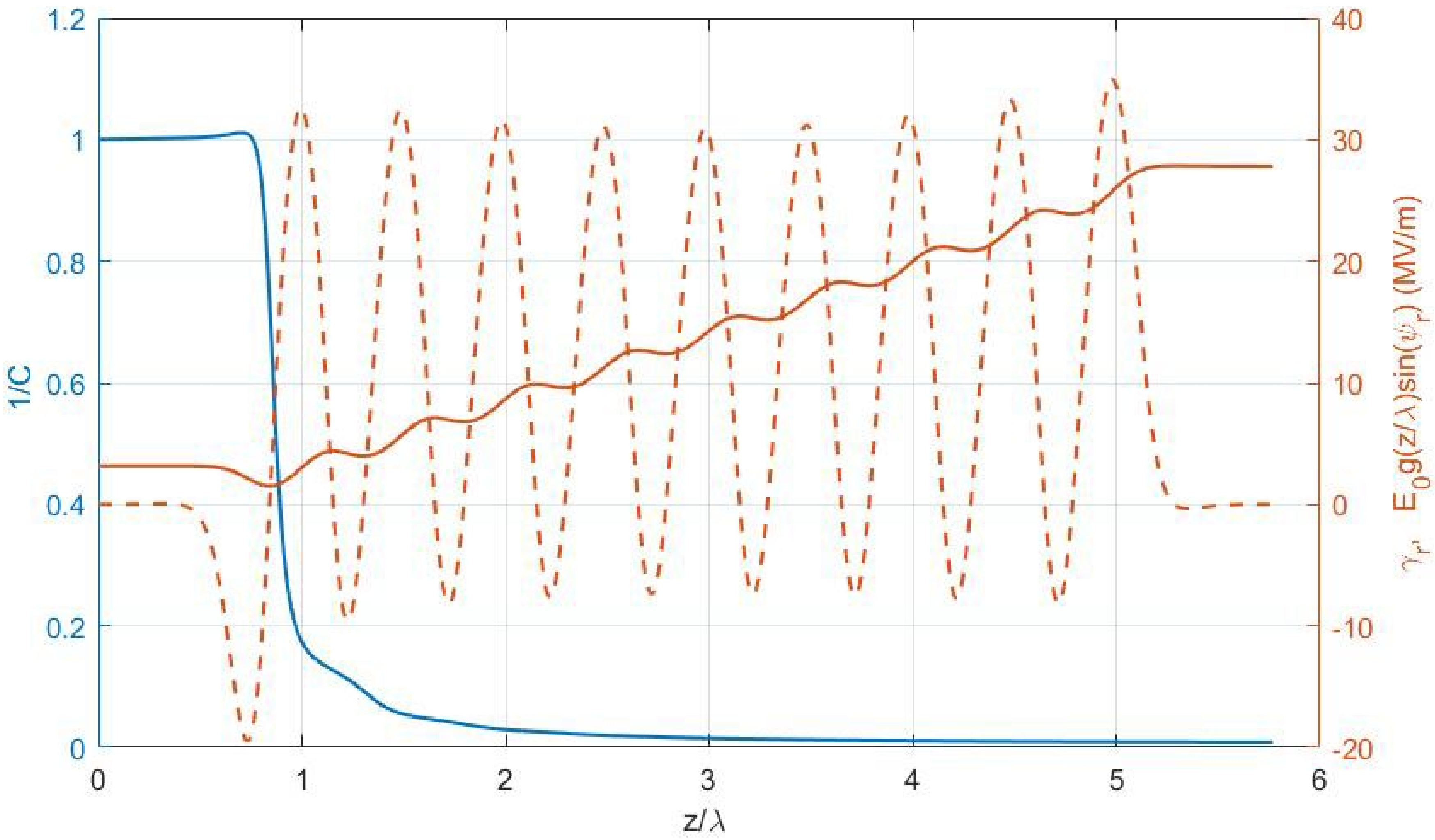

Simulations

Code used: ASTRA
Charge: 16 pC
Number of particles:

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