Recent development of laser wakefield accelerator at NCU

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24.11.2023 CHiP

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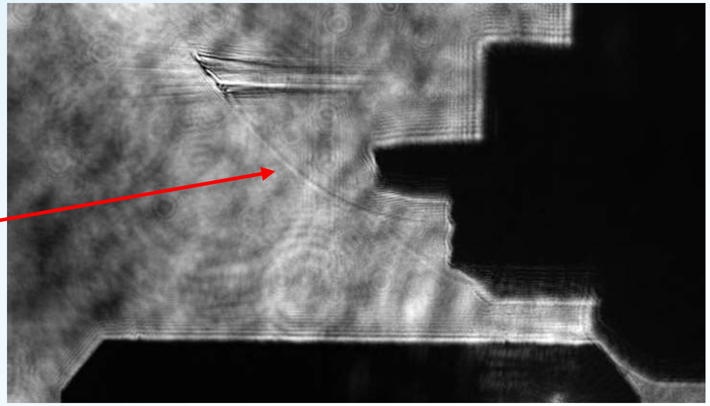
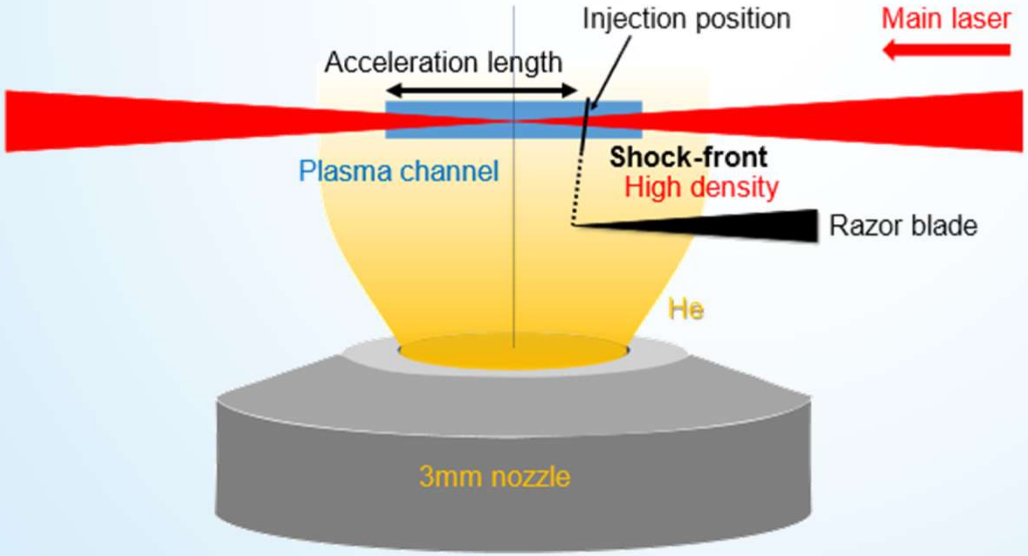
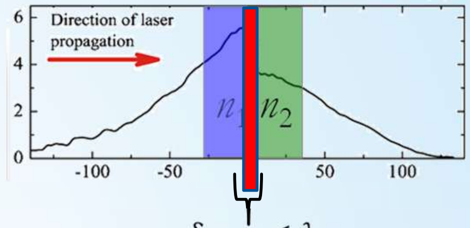
Principle of shock-front injection

Shock wave

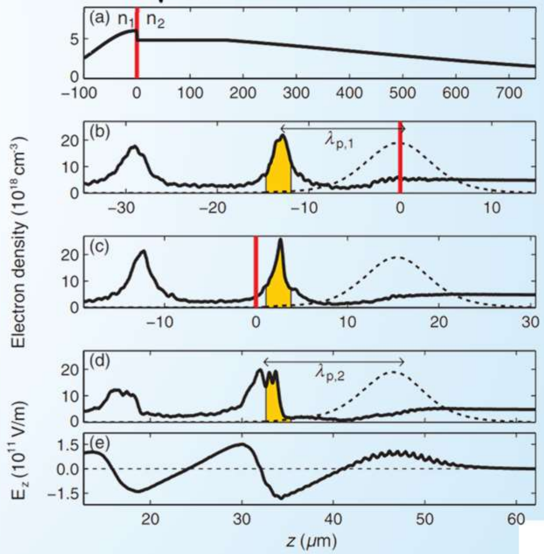






$\delta_{trans} < \lambda_p$

$$\lambda_p \propto \frac{1}{\sqrt{n_e}} \Rightarrow \lambda_{p,1} < \lambda_{p,2}$$



Phys. Rev. Lett. 110, 185006 (2013)
Phys. Rev ST- Acc and beams 13,091201 (2010)

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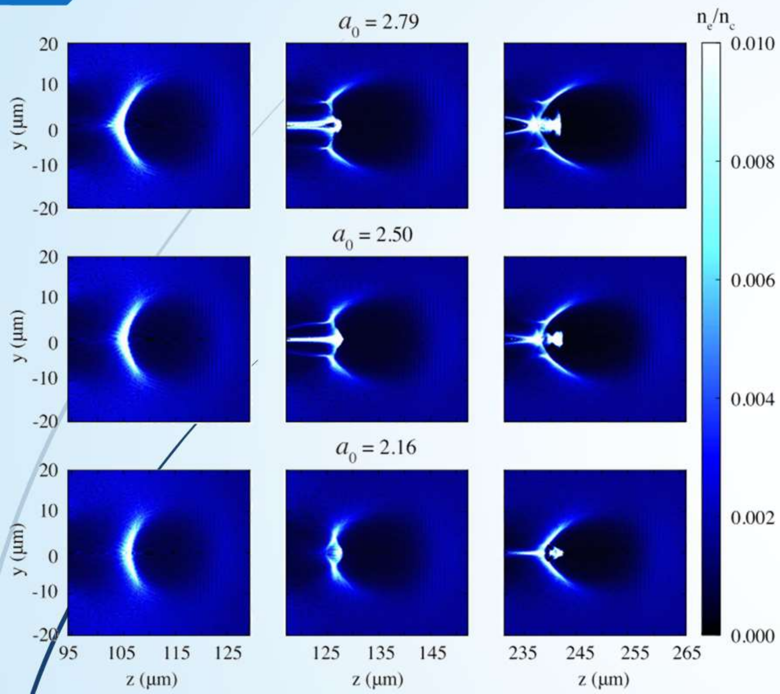
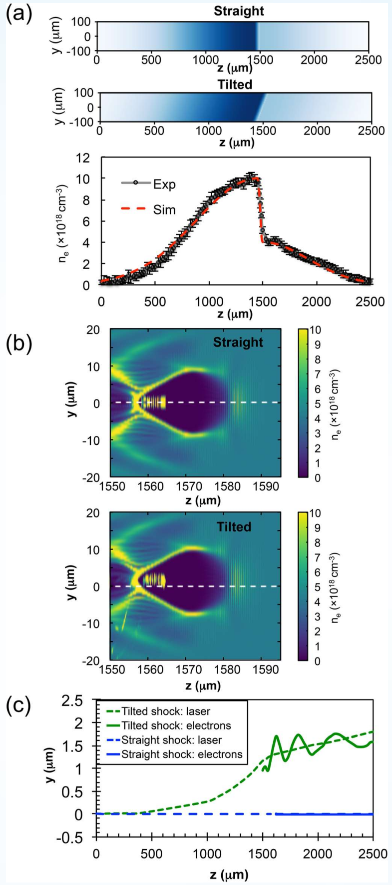
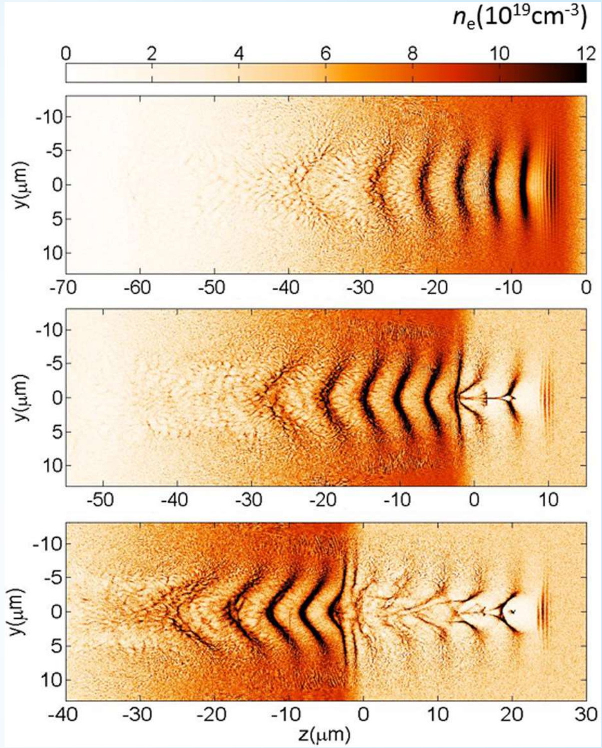


F Massimo et al 2018 Plasma Phys. Control. Fusion 60 034005



Physics of Plasmas 25, 043107 (2018)

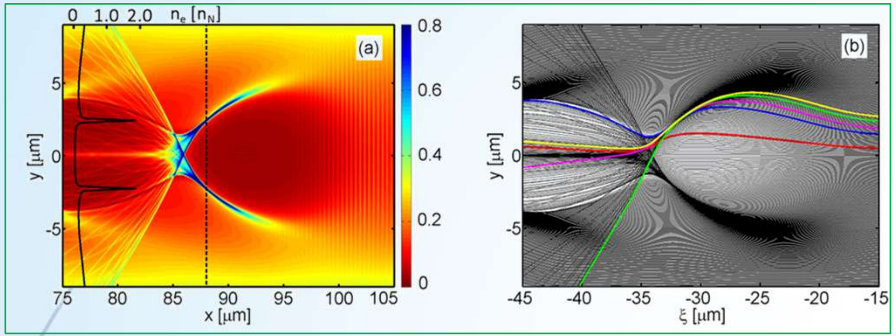


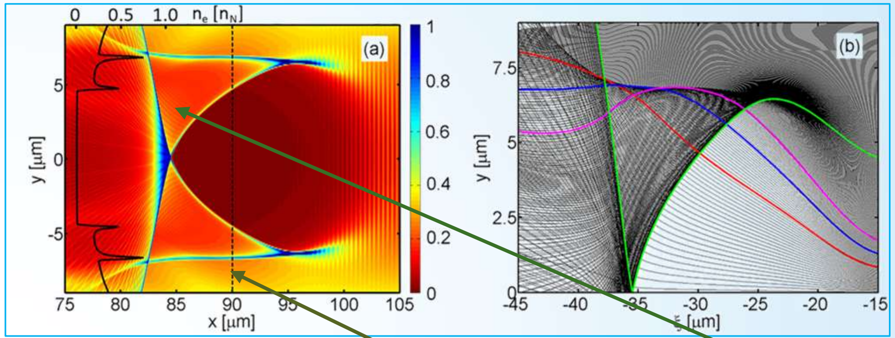
Physics of Plasmas 24, 083106 (2017)

Transverse Structure of the Wakefield

a_0=1.8

a_0=3.6





Tail wave

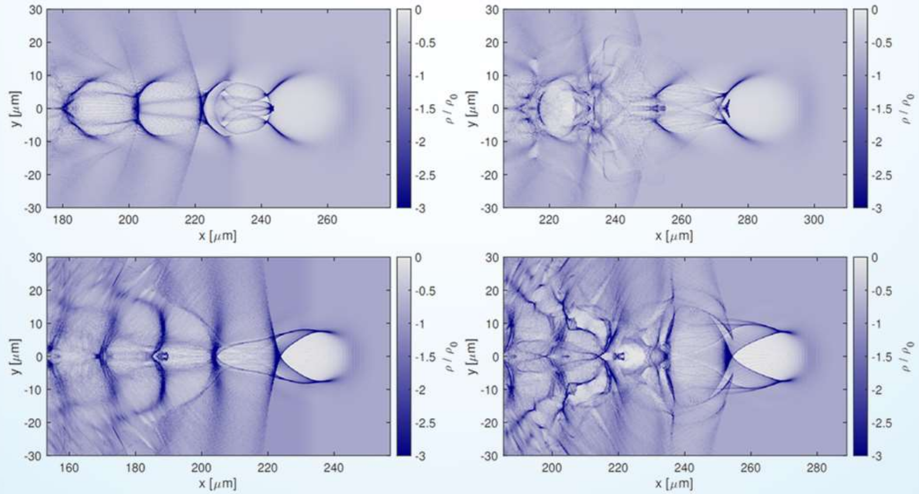
Lateral wave

Physics of Plasmas 23, 103112 (2016)

pondermotive force

"Beam loading" injection

Tail wave injection



a_0=2.9

a_0=4.4

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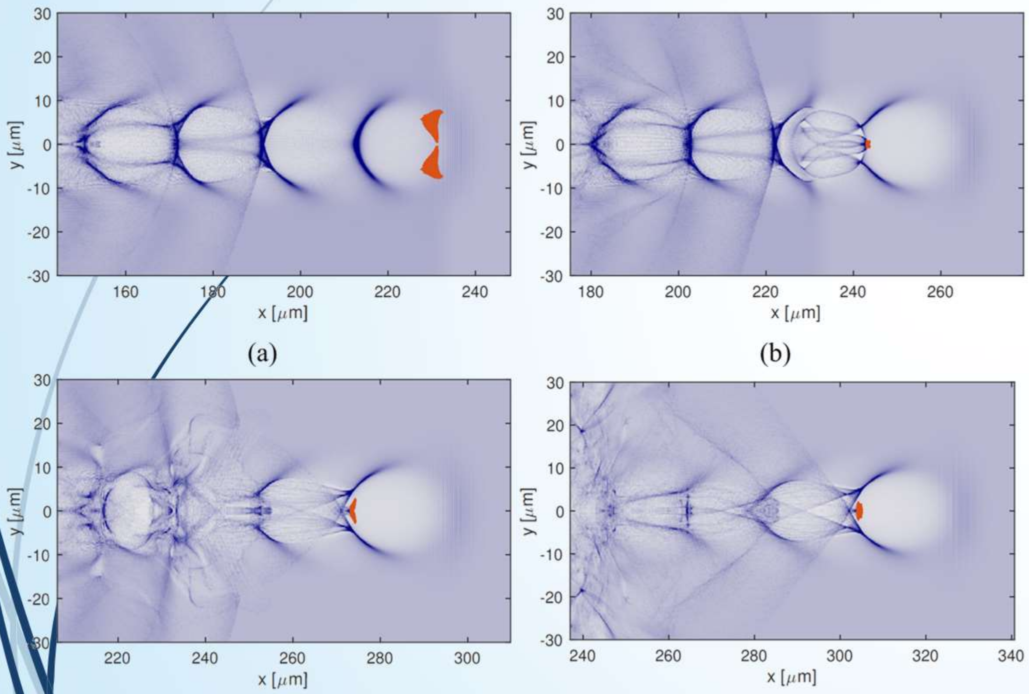
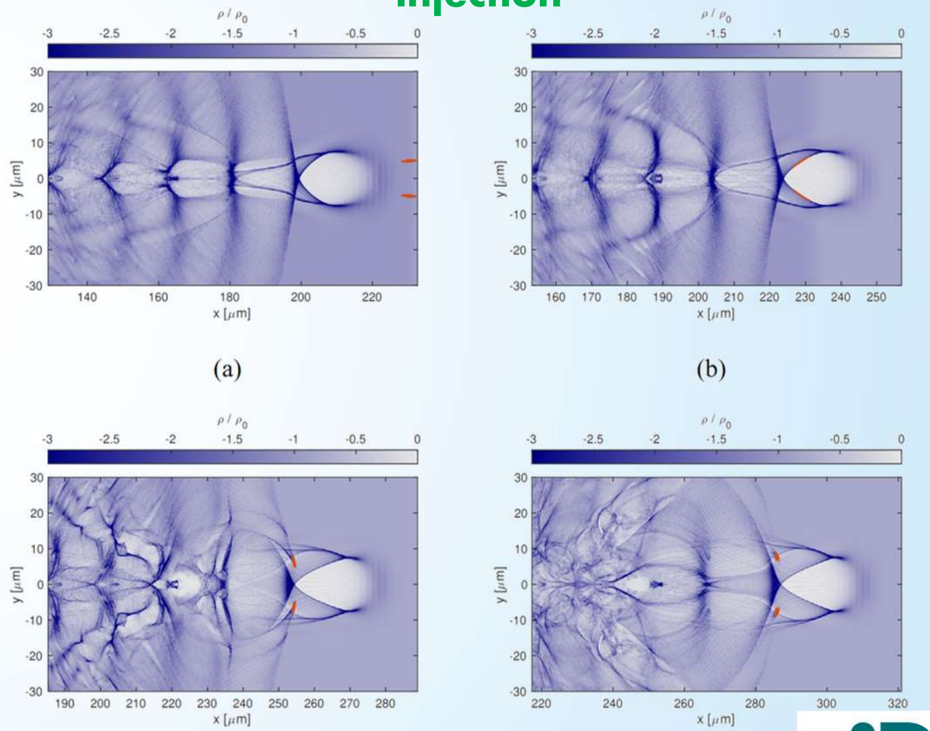
Source of the Injected Electrons

"Beam loading" injection



Tail wave injection



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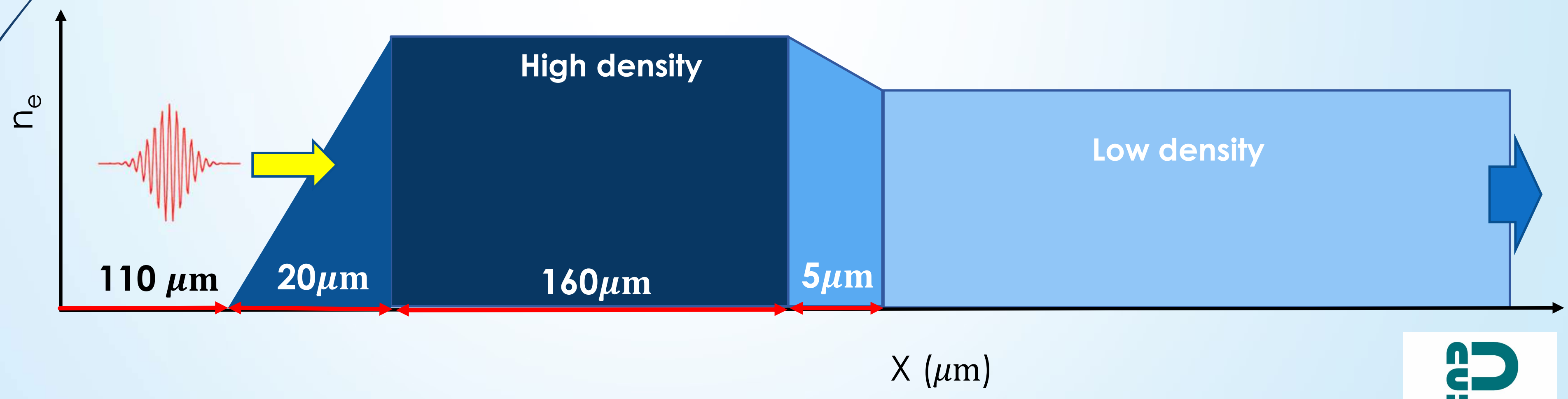
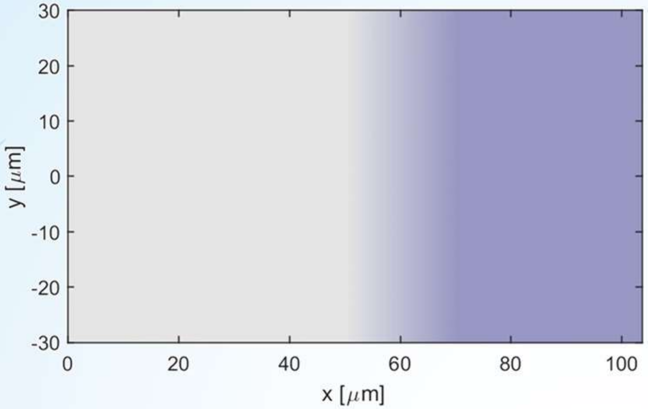
Simulation Setting

Laser wavelength = 810 nm
Duration = 42.43 fs
W_0 = 8-10 μm
a_0 = **2-4.3**
Focal position = 292.5 μm
VORPAL/OSIRIS

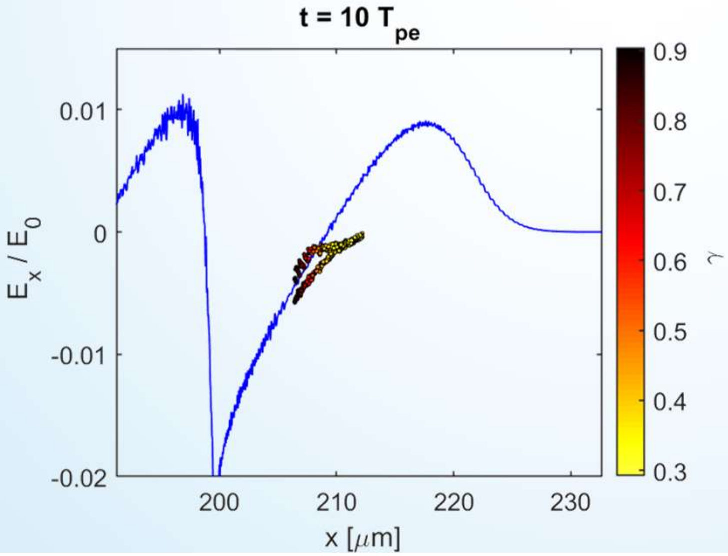
Laser evolution pedestal = $4.73 \times 10^{24}\ \mathrm{m}^{-3}$
Acceleration plateau = $3.87 \times 10^{24}\ \mathrm{m}^{-3}$



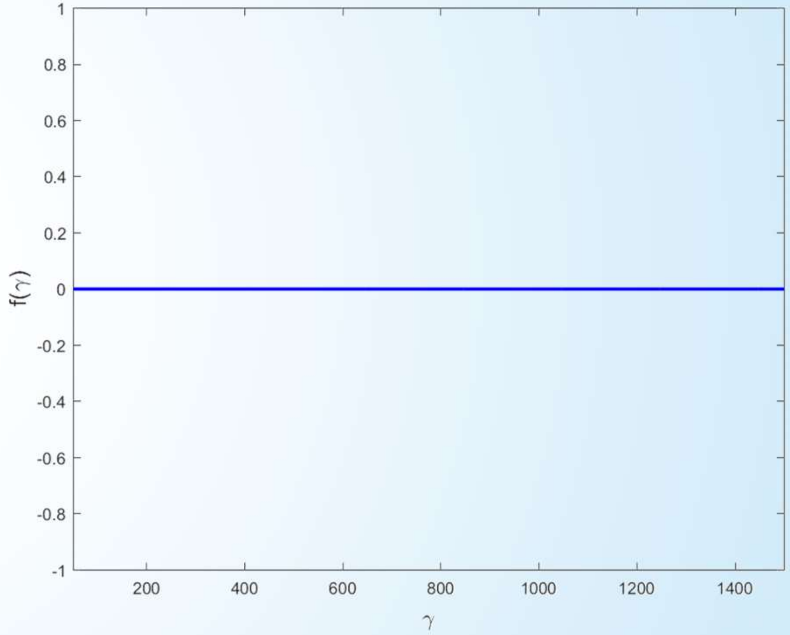
Electron density



Longitudinal E-field



Spectrum



$\Delta E < 10$ MeV

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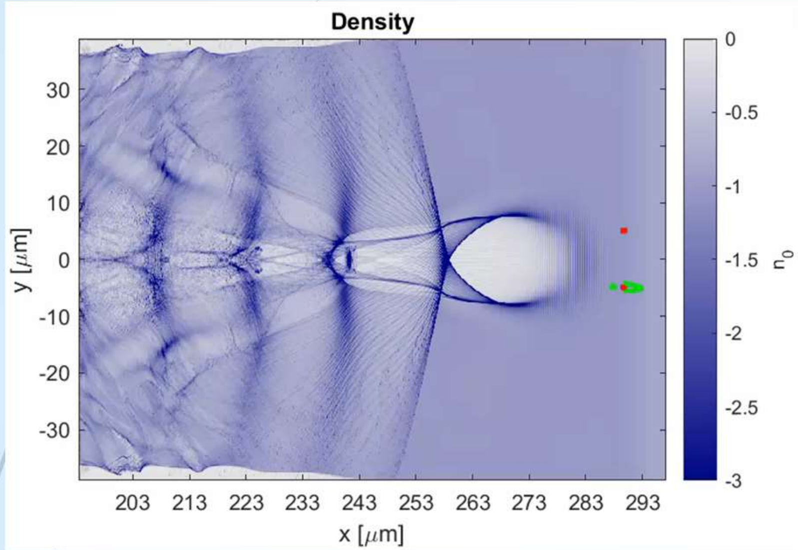
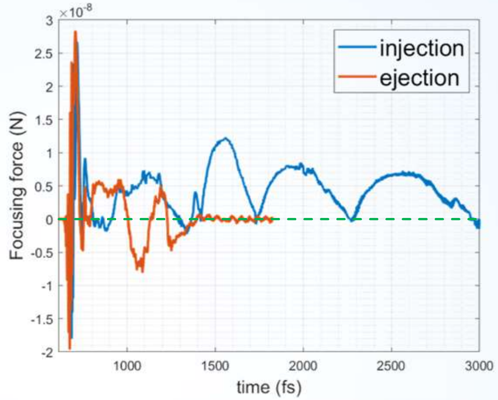
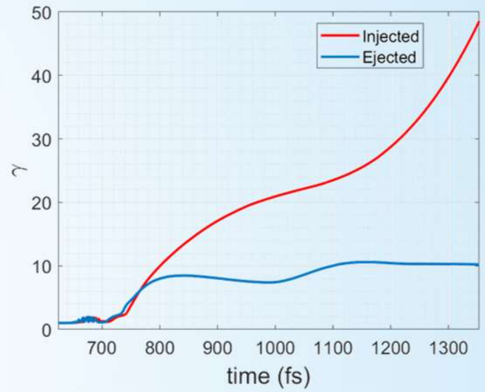
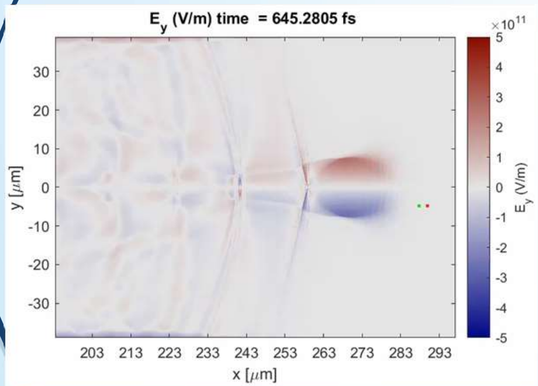
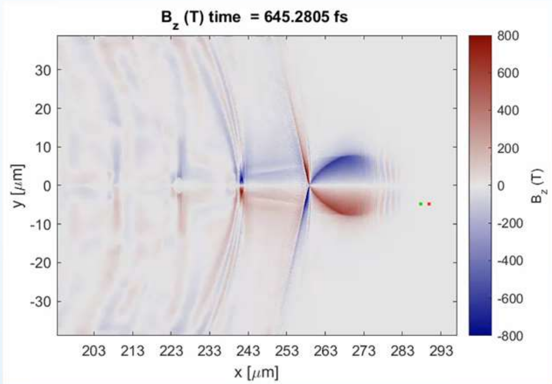
Injection v.s. Ejection

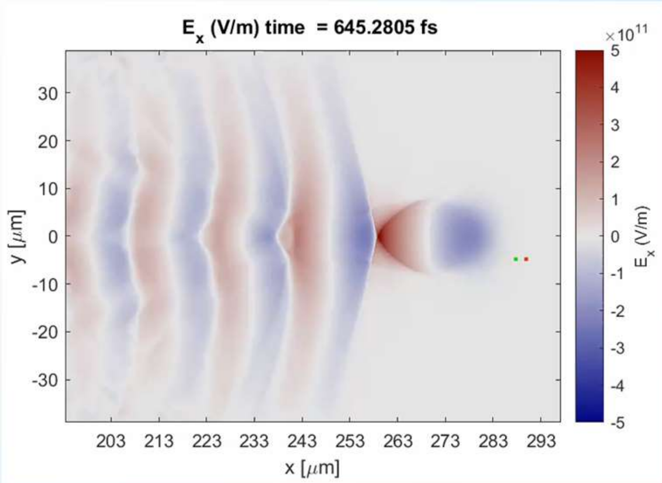












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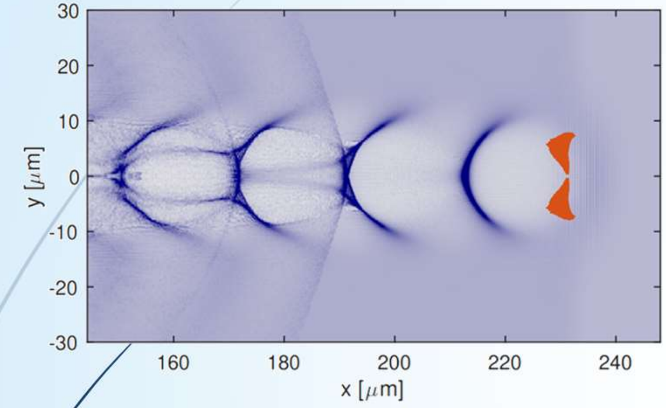
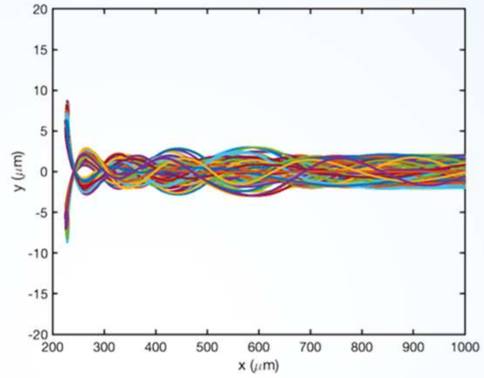
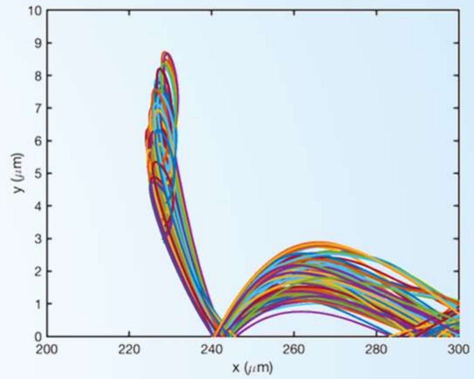
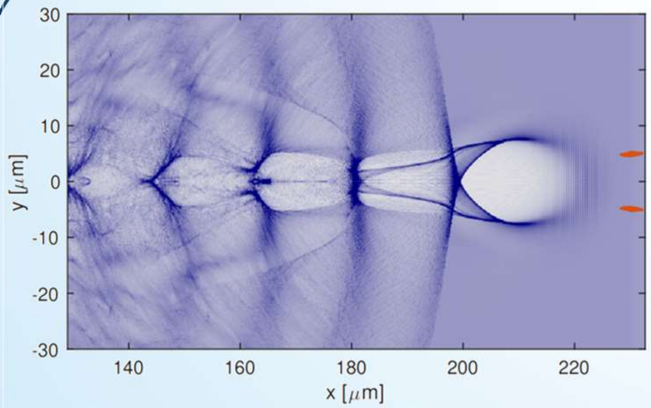
“Beam loading” injection

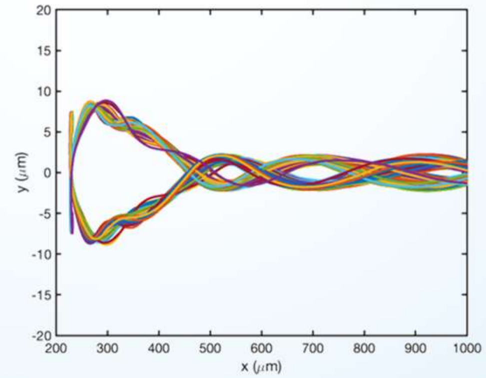


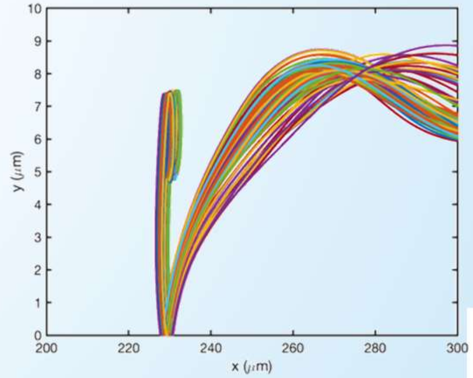




Tail wave injection







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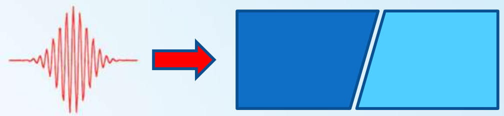
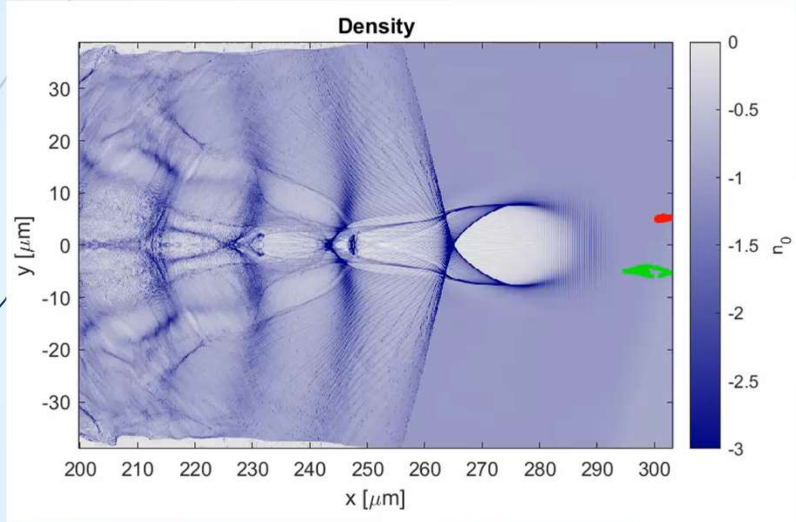
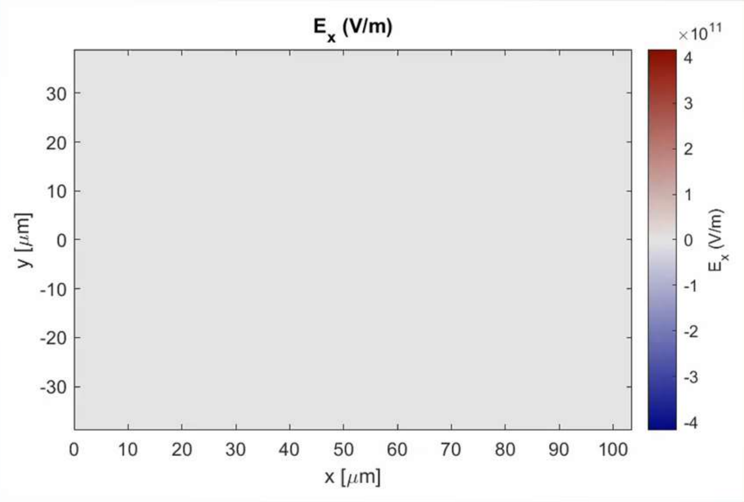
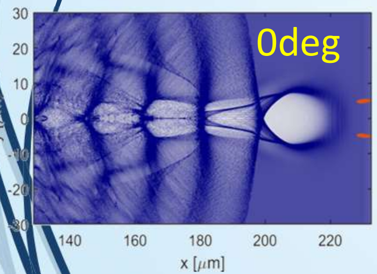
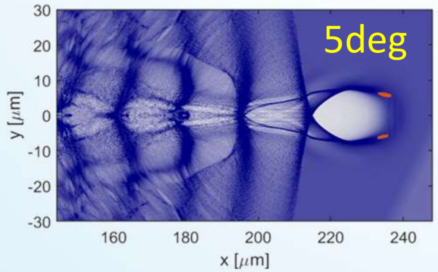
Adding Tilted Shock Front

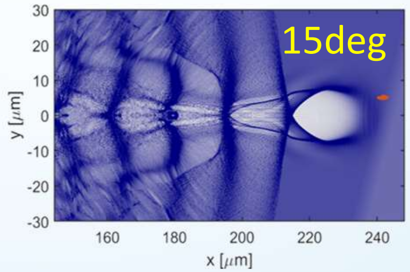


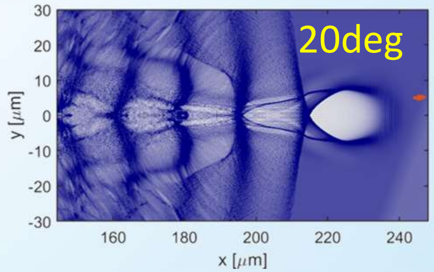












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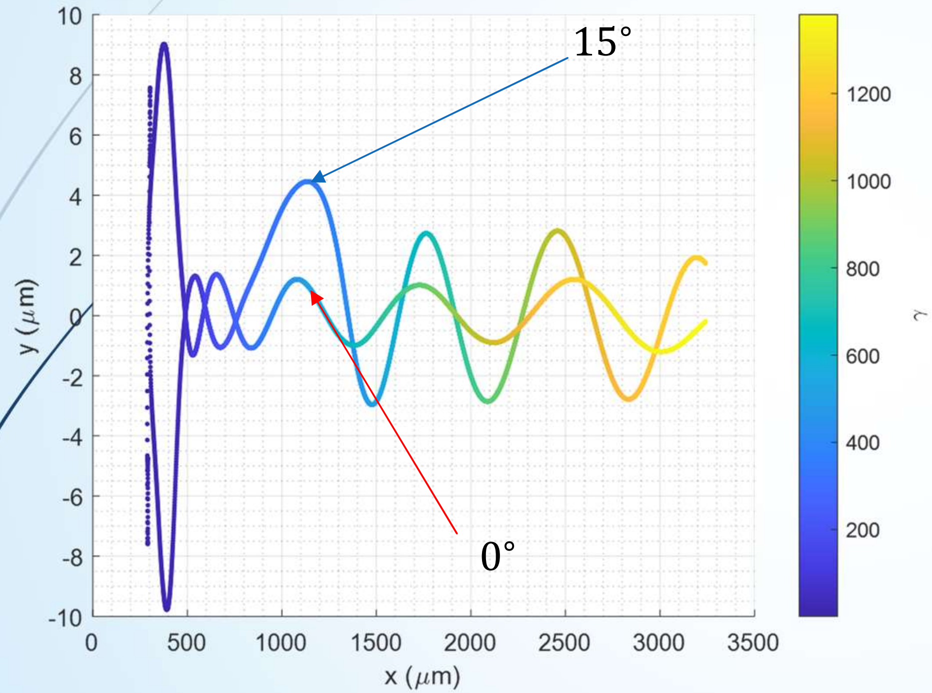
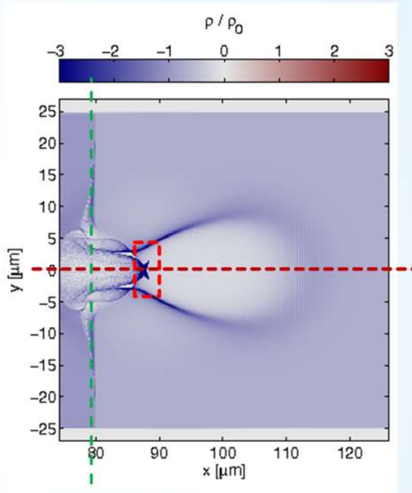
0° and 15° Trajectories

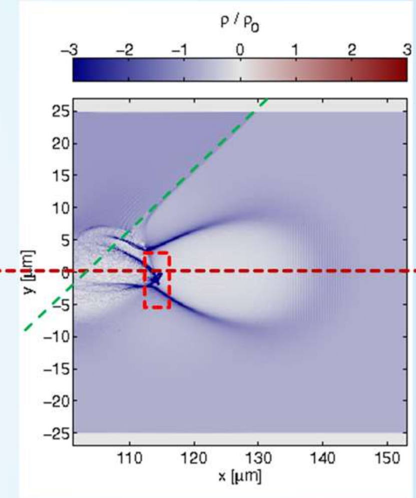


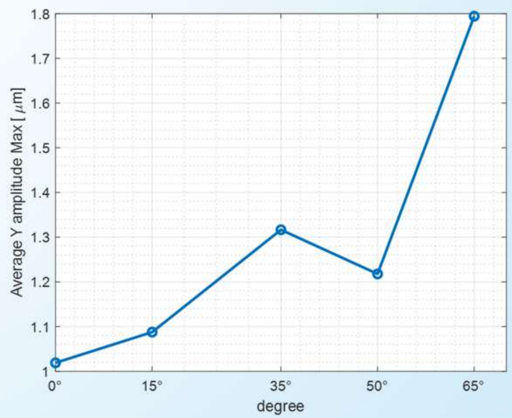
"Beam loading" injection

Normal Shock front



Tilted Shock front





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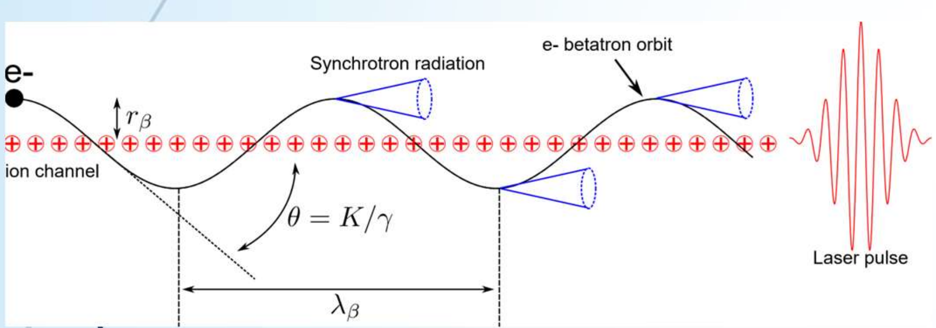
Laser-driven Betatron Radiation



SCALING LAWS

- Betatron frequency: $\omega_\beta = \omega_p / \sqrt{2\gamma}$
- Transverse momentum: $a_\beta \propto \sqrt{\gamma n_e} r_\beta$
- Divergence: $\vartheta = a_\beta / \gamma$
- Critical photon energy: $E_c \propto \gamma^2 n_e r_\beta$
- Efficiency: $N_{phot/cycle} = \alpha a_\beta$

- Wavelength:

$$\lambda_h = \frac{\lambda_\beta}{h 2\gamma_e^2}\left(1 + \frac{a_\beta^2}{2} + (\gamma_e \varphi)^2\right) = \frac{\sqrt{3}\pi c}{h\omega_p \gamma_e^{3/2}}\left(1 + \frac{a_\beta^2}{2} + (\gamma_e \varphi)^2\right)$$

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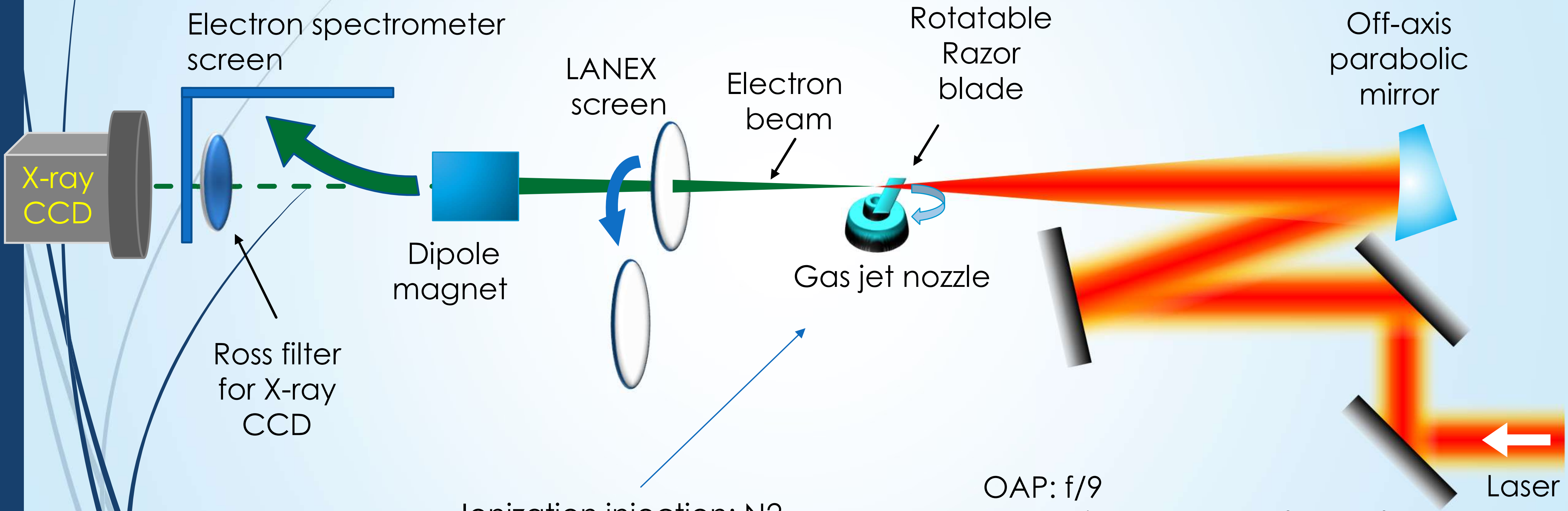
Enhancement of Betatron Radiation



Ionization injection: $N2$
Self-injection: He
Shock-front injection: He

OAP: f/9
Focus size: 9-11.5 μm (FWHM)
a_0=2.75~4

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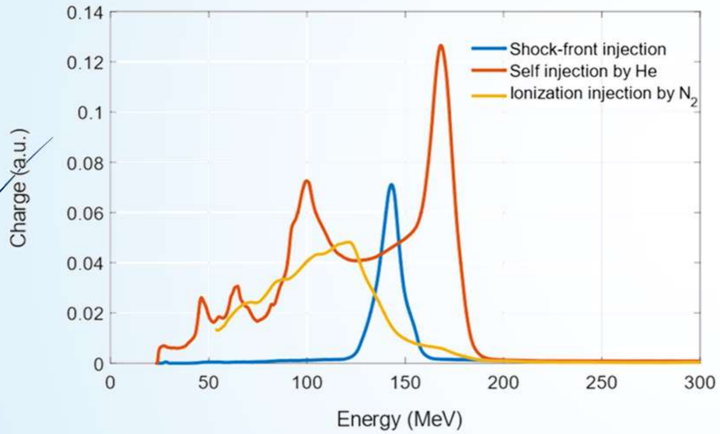
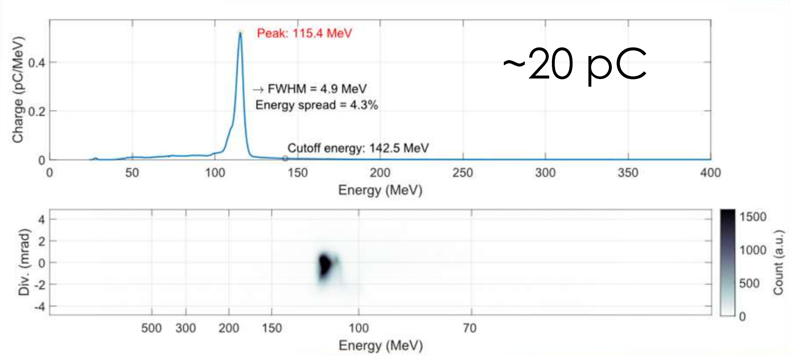
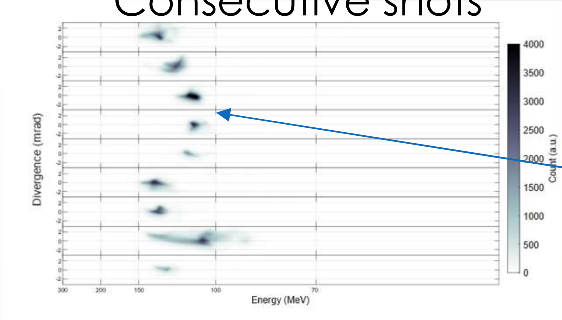
Comparison of injection mechanism by NCU 100TW laser system





Consecutive shots



Due to PID oscillation

Injection method	Electron density (cm^{-3})
Ionization injection (N_2)	2.0×10^{18} (neutral)
Self-injection (He)	$8.5 \times 10^{18} - 1.0 \times 10^{19}$
Shock-front injection (He)	3.7×10^{18}

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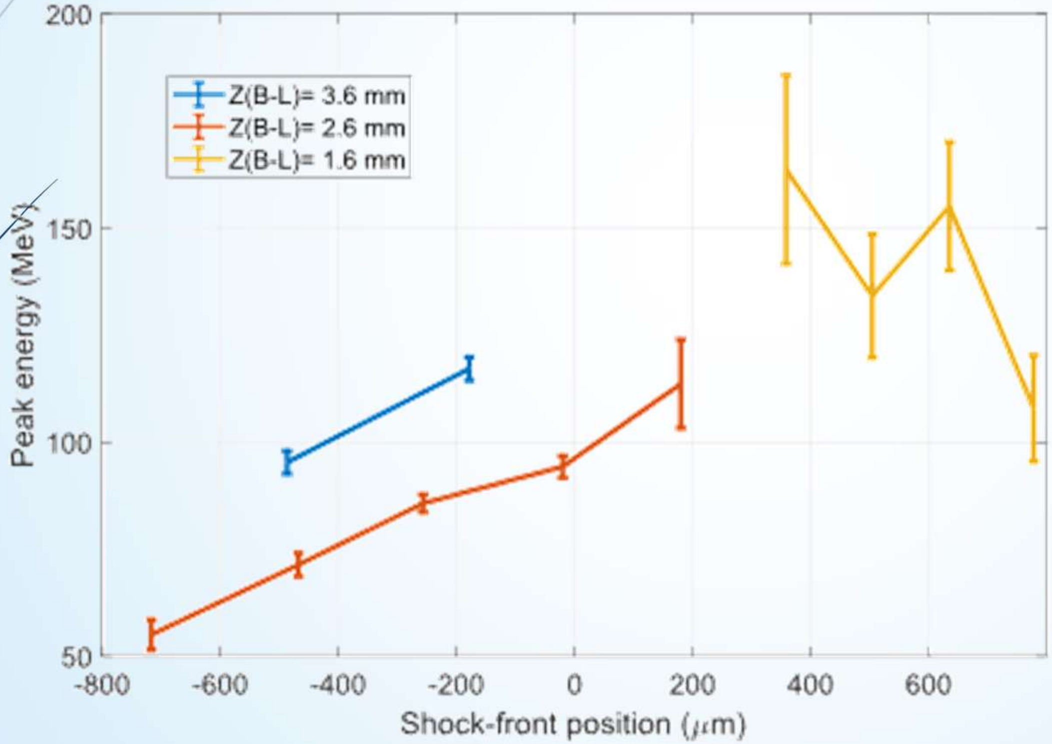
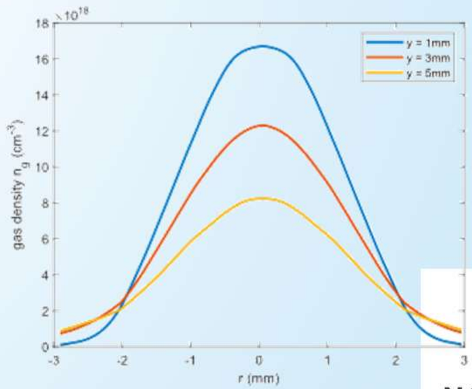
Tunable monoenergetic electron beams



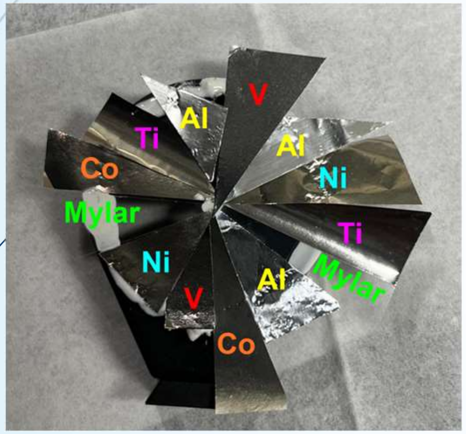
Classical wavebreaking limit field:

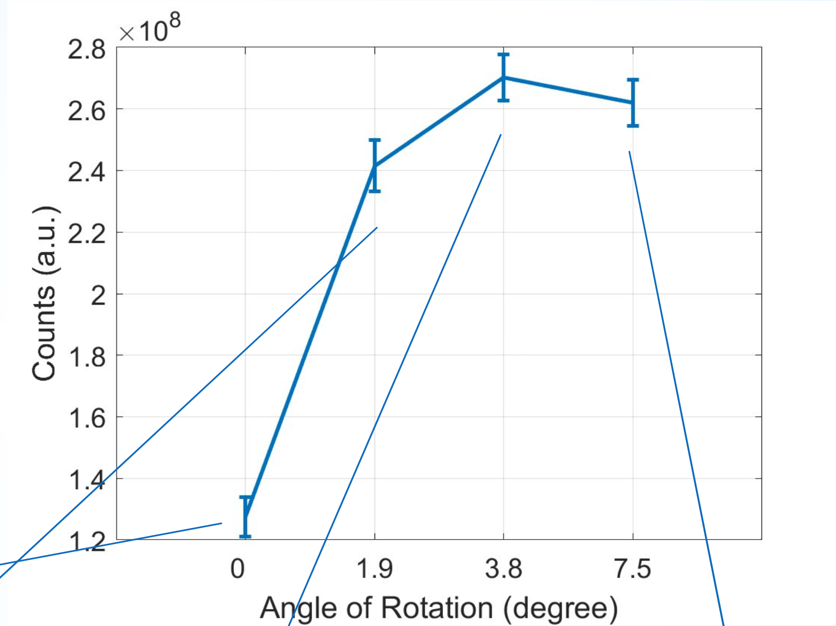
$\sim 96 \times \sqrt{n_0(\mathrm{cm}^{-3})}\ (\mathrm{V/m})$
$= 185\ \mathrm{GV/m}$

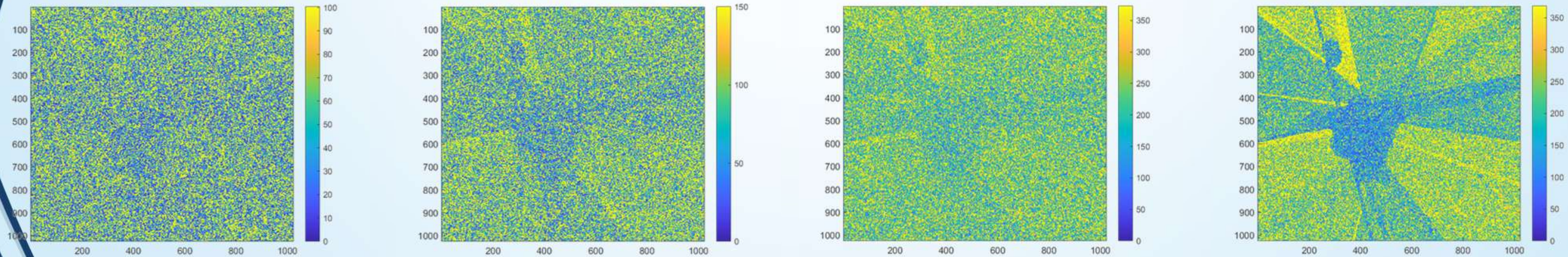
Observed
96.5-281 GV/m



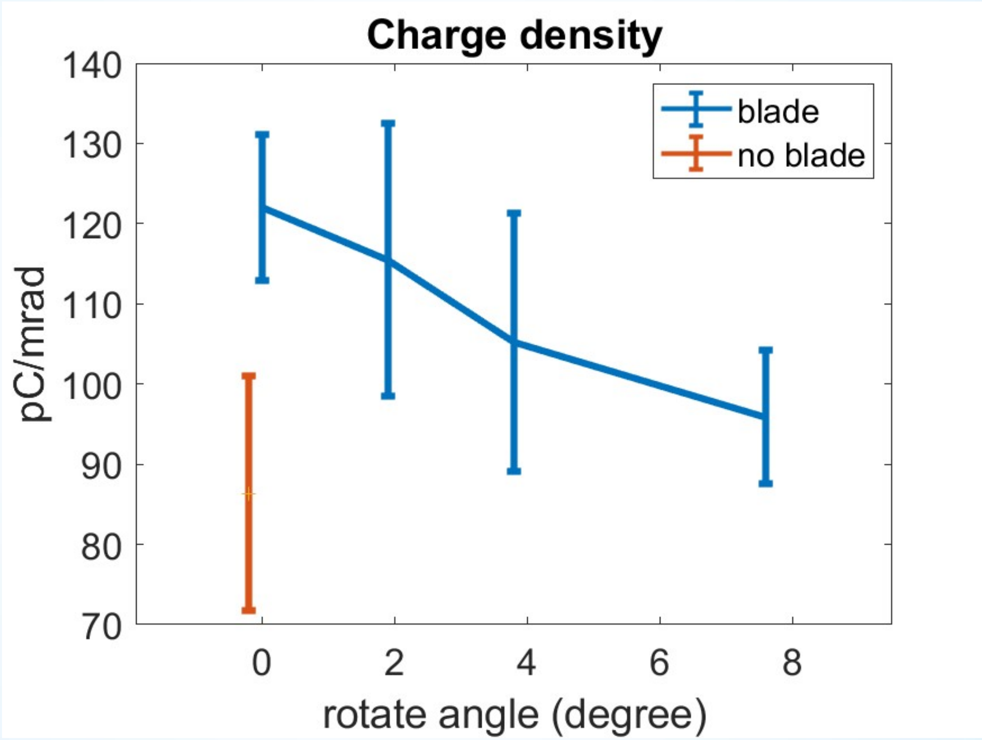
Enhancement of Betatron Radiation by Ionization-Enhanced Shock-Front Injection







Enhancement of Betatron Radiation by Ionization-Enhanced Shock-Front Injection



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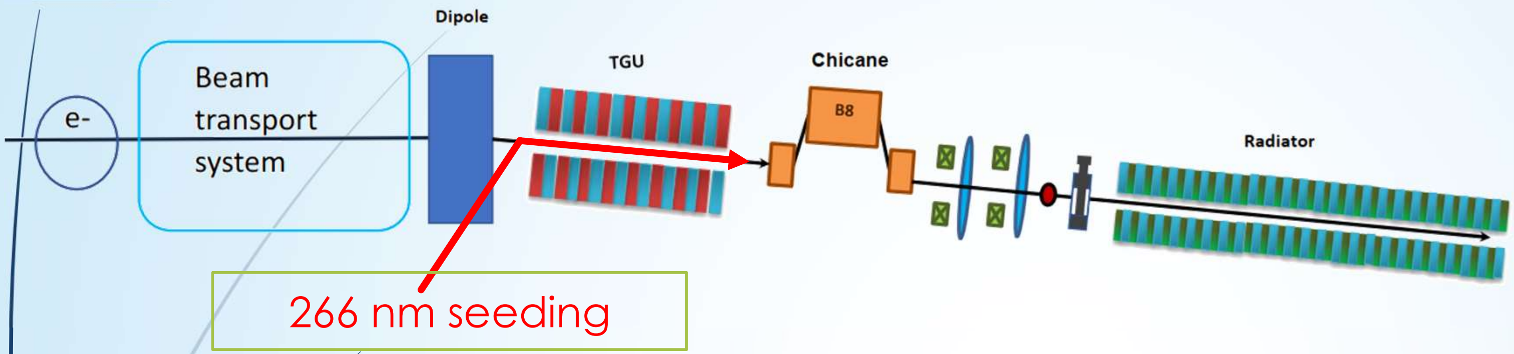
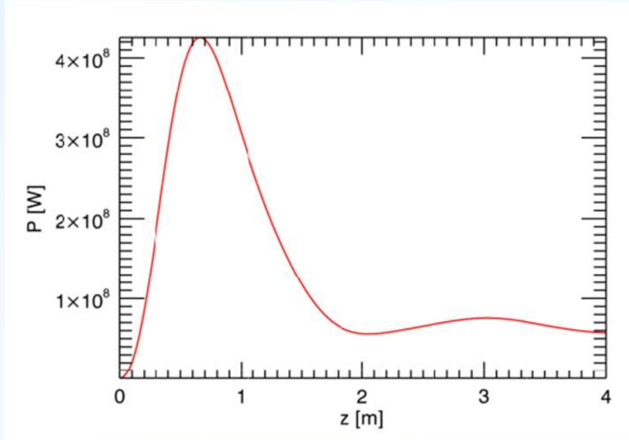
Plan of High-Gain Harmonic-Generation FEL in NCU





Electron Beam Parameters	
Electron beam energy [MeV]	250
Beam size, rms [μm]	90
Normalized emittance [mm-mrad]	0.5
Peak current [A]	3000
Energy spread [%]	0.5/1/2
Bunch length[fs]	5

Seed Laser Parameters	
Wavelength[nm]	266
Peak power[MW]	200
Rayleigh length[m]	5

Undulator Parameters	
Radiator period [mm]	20
Radiator type	planar
Radiator parameter, K	1.496/1.075
Operating field, B_0 [T]	0.57
Radiation wavelength [nm]	88/66
Modulator period [mm]	50
Modulator Type	planar
Modulator parameter, K	1.756
Operating field, B_0 [T]	0.376
Radiation wavelength [nm]	266

- Energy spread <1%
- Normalized emittance < 0.5 mm mrad
- Energy > 200 MeV
- Charge > 30 pC
- Seeding: 266 nm
- EUV: 66.7 nm

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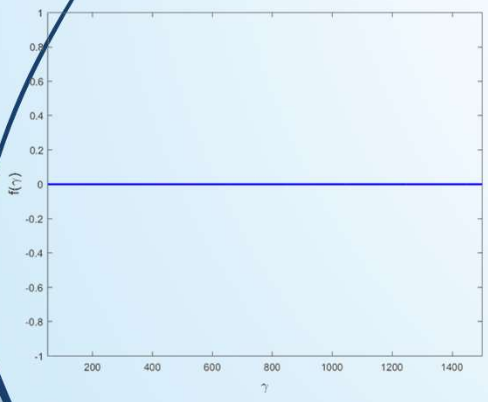
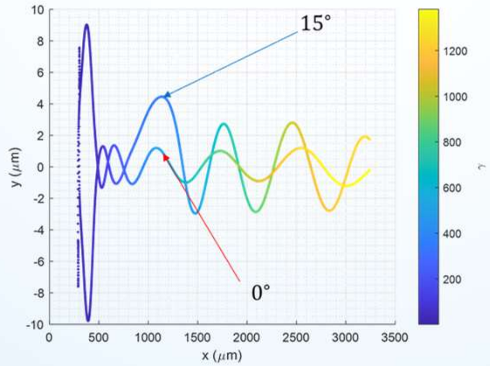
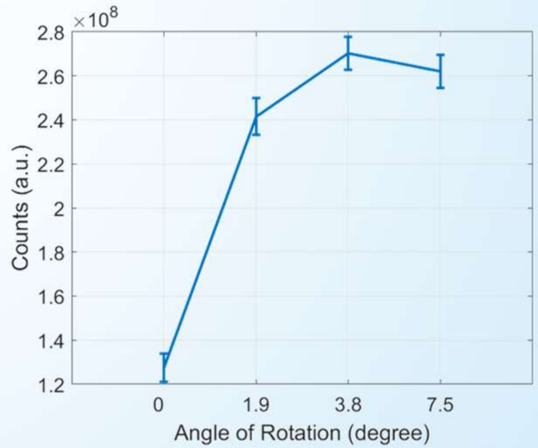
Summary

- Monoenergetic electrons are generated by the tail-wave injection
- Tilted shock front leads to one-side injection and increases the amplitude of the betatron oscillation
- Preliminary results show the possibility of the enhancement of the X-ray brightness







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Thanks For Your Attention!!

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National Science and Technology Council

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NSRRC

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