Frequency upshifting in a beam driven quasilinear plasma wake

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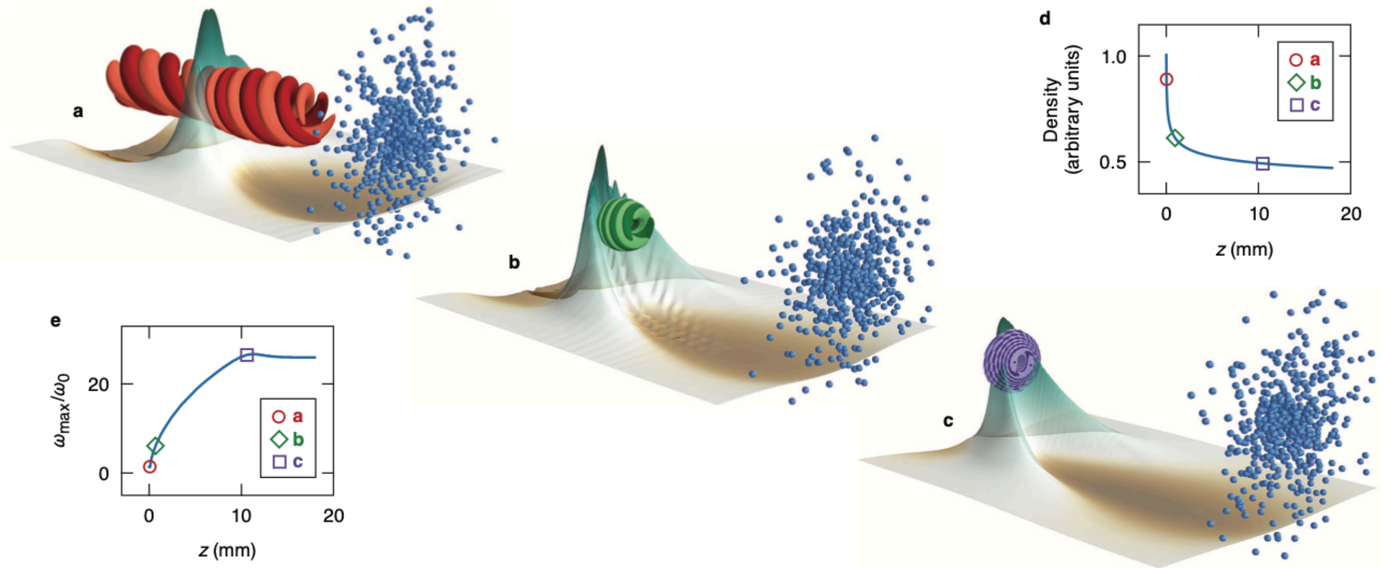


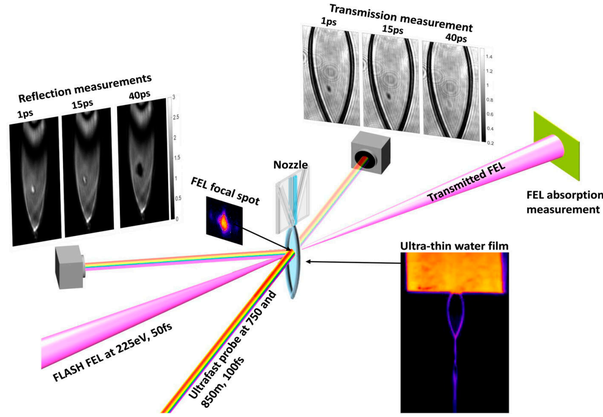
K. Miller et al., ArXiv (2024)

FACET-II PAC meeting 2024

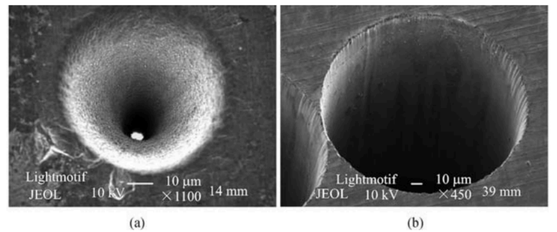
Science justification

Some applications of Extreme Ultraviolet (XUV) light

- Short wavelength ($\lambda < 120$ nm), high intensity radiation
  - High-resolution imaging
  - High-energy-density physics
  - Nanotechnology
- Fine-scale material ablation
  - Nanomachining
  - Spectrometry
  - Photolithography
- Ultrafast pump-probe for AMO physics



Chen et al. *Matter and Radiation at Extremes* **6,** 054401 (2021)



S. Gao, H. Huang, Front. Mech. Eng. 2017, 12(1): 18–32

ASML's XUV lithography machine NXE:3400 for fabricating computer chips

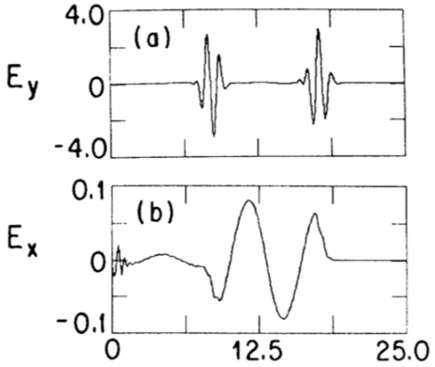
Science justification

Frequency shifting of light with plasma

"Photon acceleration"

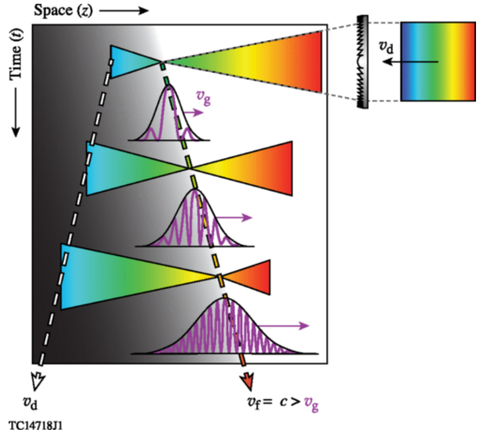
Wilks et al., Phys. Rev. Lett. (1989)

Esarey et al., Phys. Rev. A (1990)

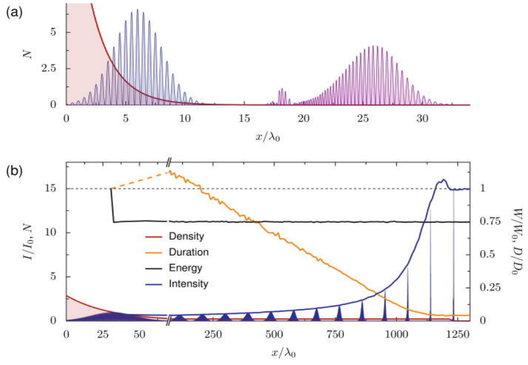


Time varying / Ionization gradients

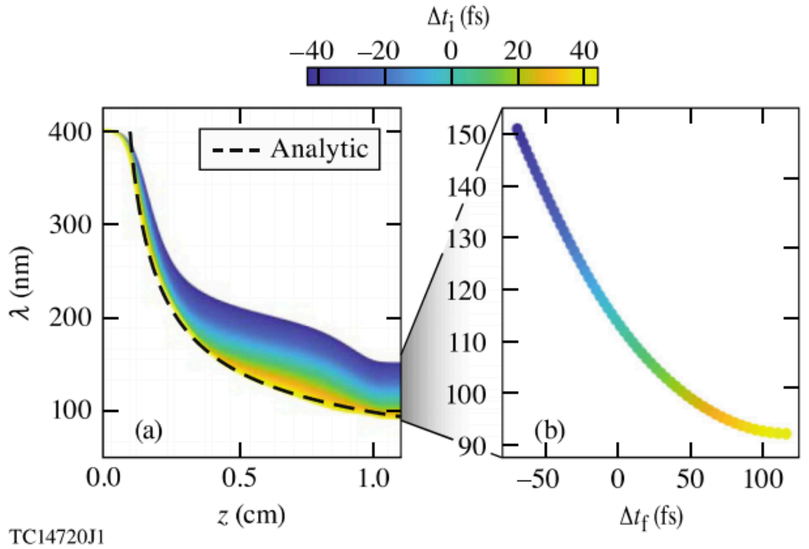
Esarey et al., Phys. Rev. A (1991)



Flying focus Howard et al, Phys. Rev. Lett. (2019)



Edwards et al., Phys. Plasmas (2018)

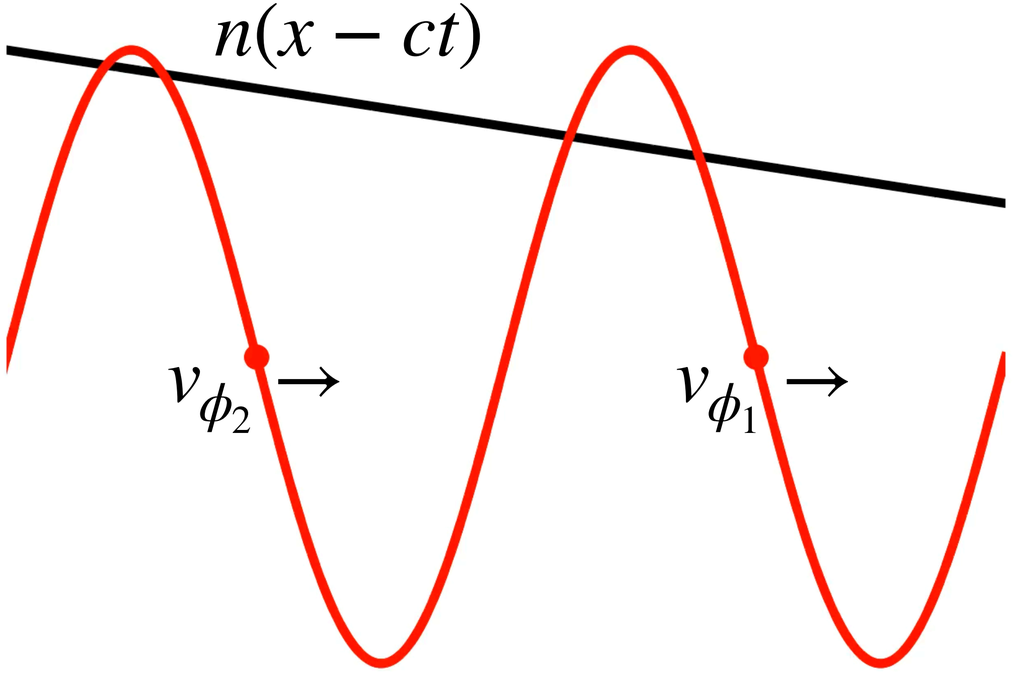


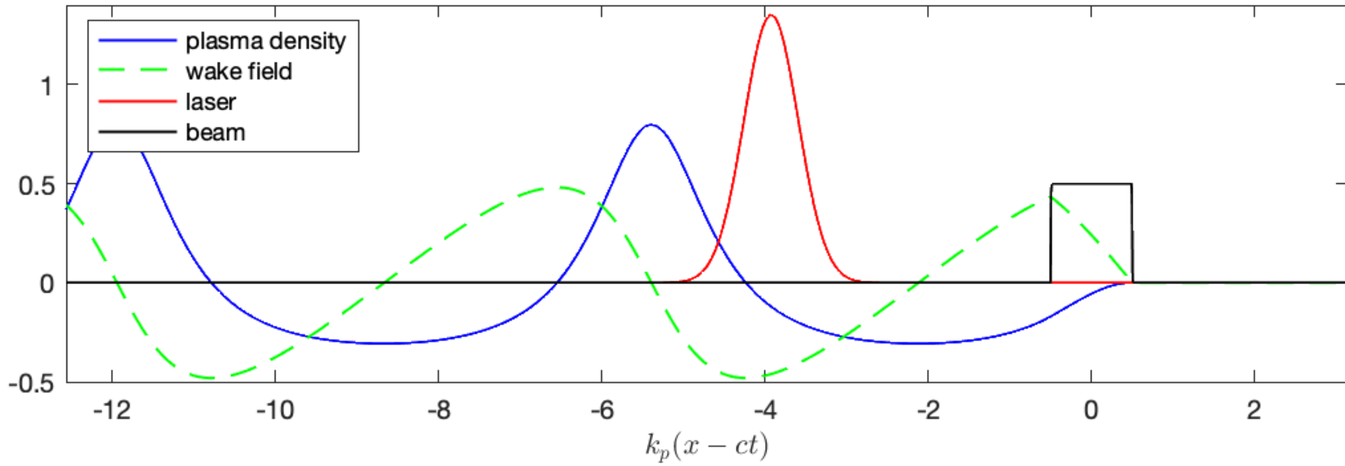
Nie et al., Nature Photonics (2018)

Science justification

“Photon acceleration”

- On a co-moving negative linear density gradient the optical wavelength is compressed
- $$\frac{1}{\lambda}\frac{\delta\lambda}{\delta t} \approx c\frac{\delta\eta}{\delta x}$$
- i.e. the frequency is upshifted
- The density gradient of plasma wave has exactly the co-moving density gradient we want



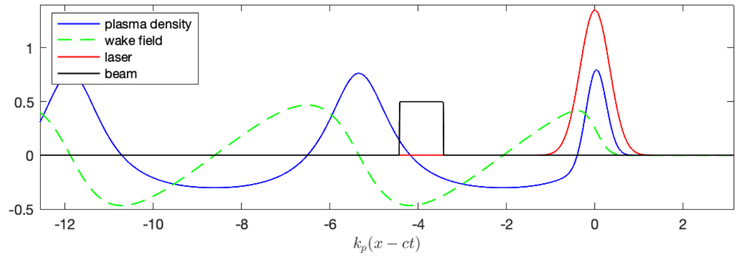


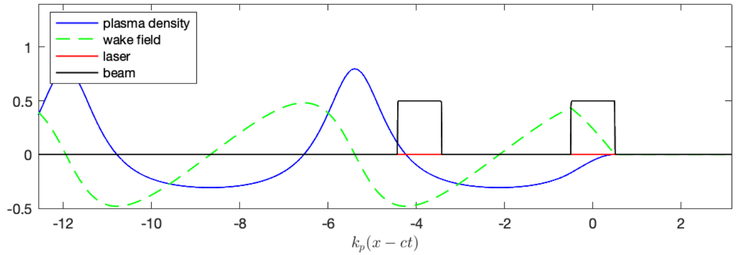
Science justification

Beam driven “photon acceleration”

- In addition to Laser plasma WakeField Acceleration (LWFA) of electrons…

Tajima and Dawson, Laser electron accelerator, PRL 1977



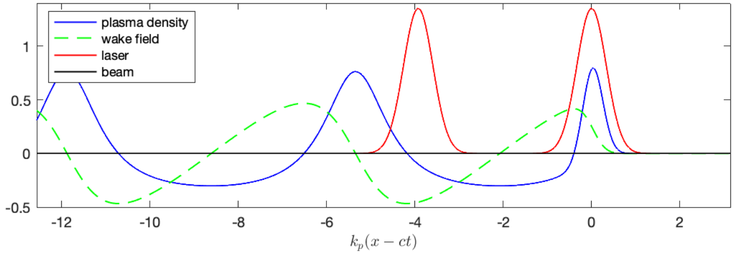


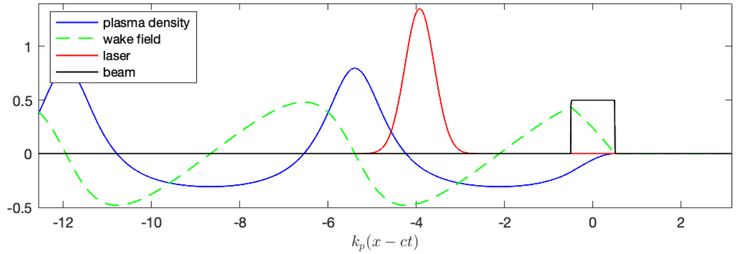
- and beam driven Plasma WakeField Acceleration (PWFA) of electrons…

Chen et al., Acceleration of Electrons by the Interaction of a Bunched Electron Beam with a Plasma, PRL 1985

- Laser plasma Wakefield PHOTON Acceleration (LWPA)…

Wilks et al., Photon accelerator, PRL 1989



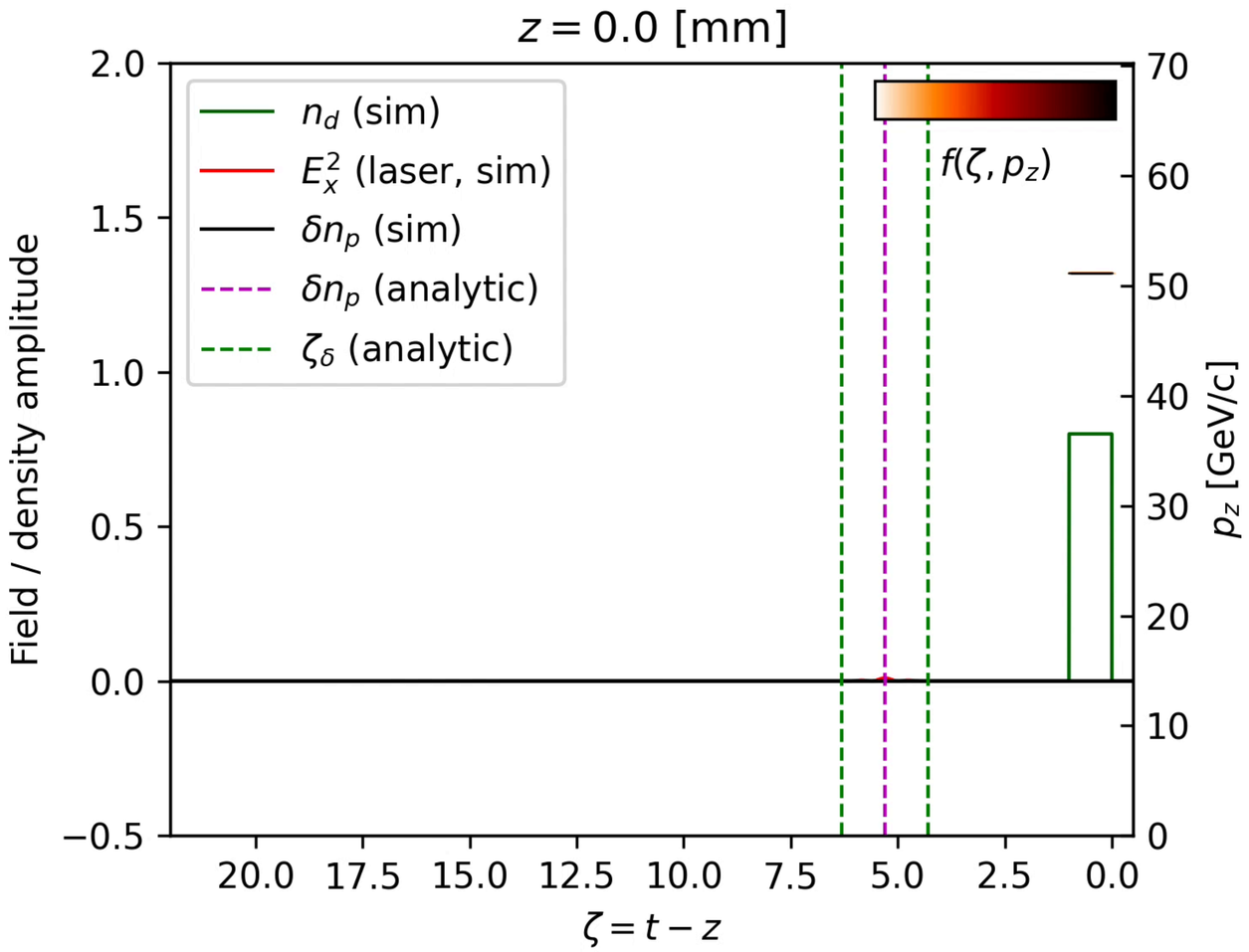


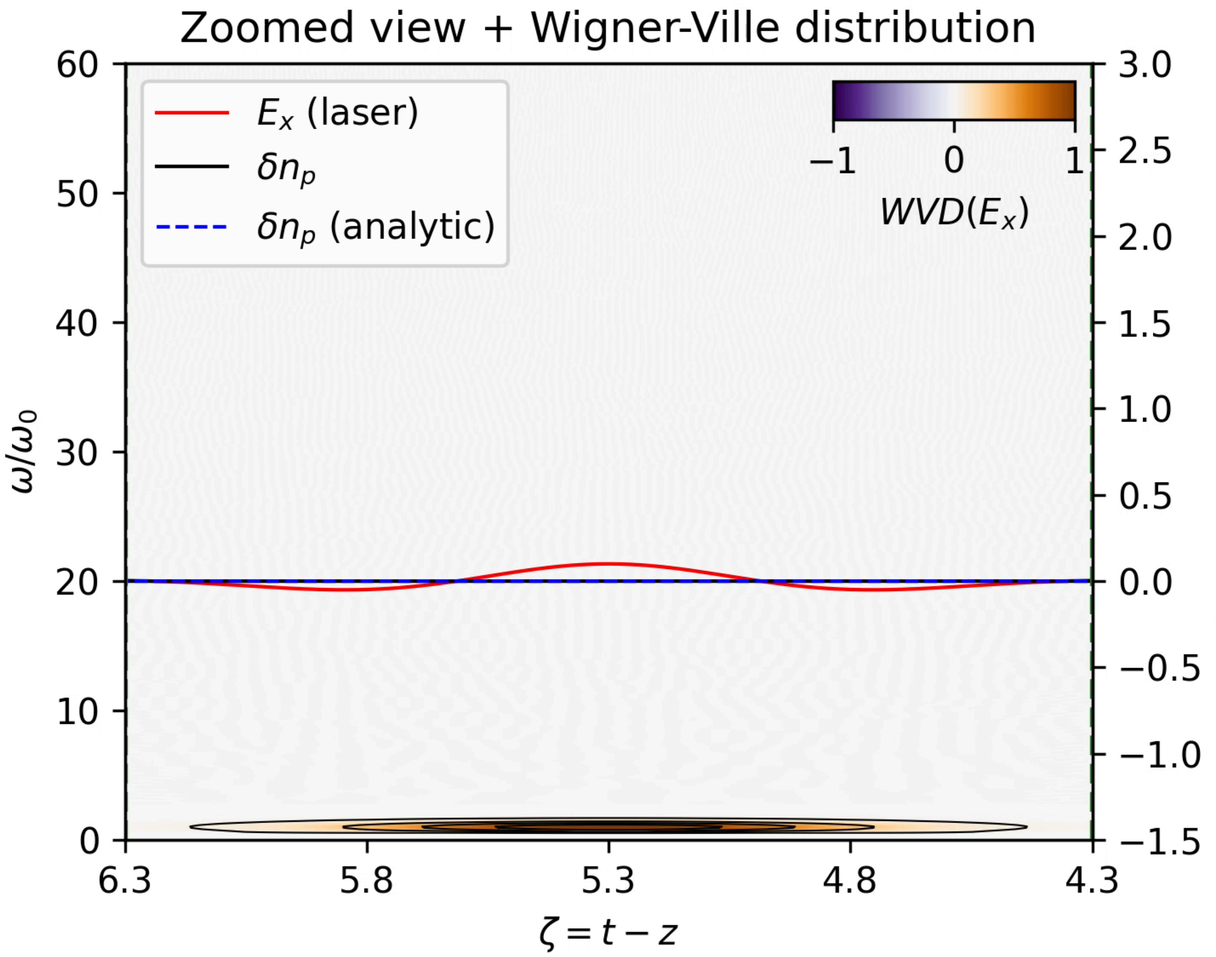
- And Beam driven plasma Wakefield PHOTON Acceleration (BWPA)

Sandberg and Thomas, Photon acceleration from Optical to XUV, PRL 2023

Science justification

1D PIC simulation using phase matched profile



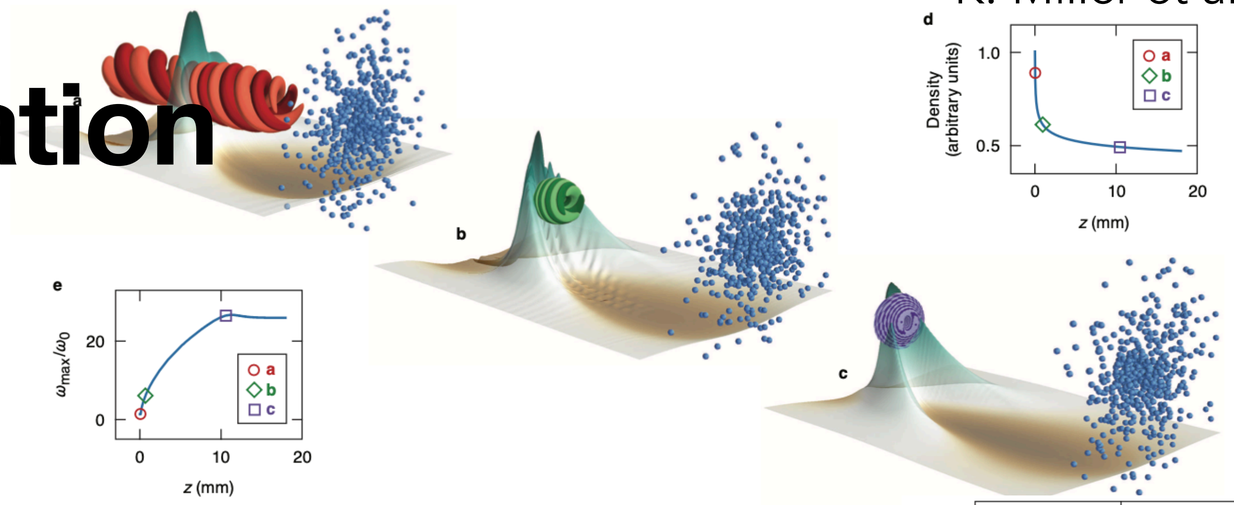


K. Miller et al., ArXiv (2024)

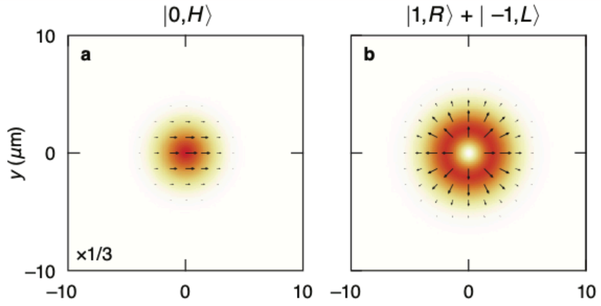
Science justification

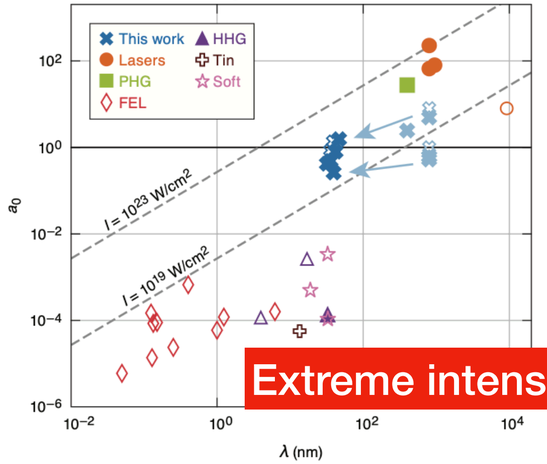
Outlook

- Latest simulation results: ab-initio 3D simulation (quasi-3D particle-in-cell) demonstrates:
  - 25x shift (800 nm → 30 nm)
  - Fully coherent, amplification x10 in energy (100 mJ)
  - Vector vortex light (radially polarized) supported
  - Only weak focusing with plasma lens gets 10^{22} Wcm^{-2}
    - But…. 50 GeV beam



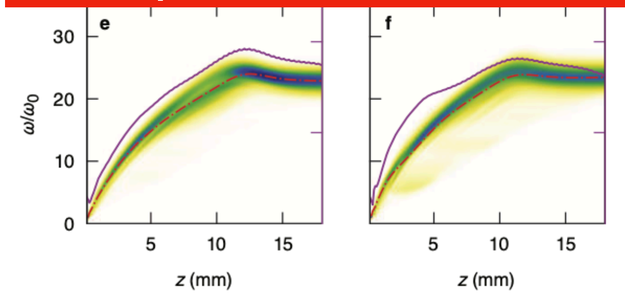
Laser profiles at end of simulation



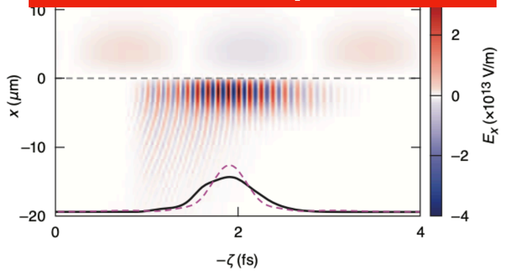


Extreme intensity

Laser spectrum as a function of z



Wavefront is preserved



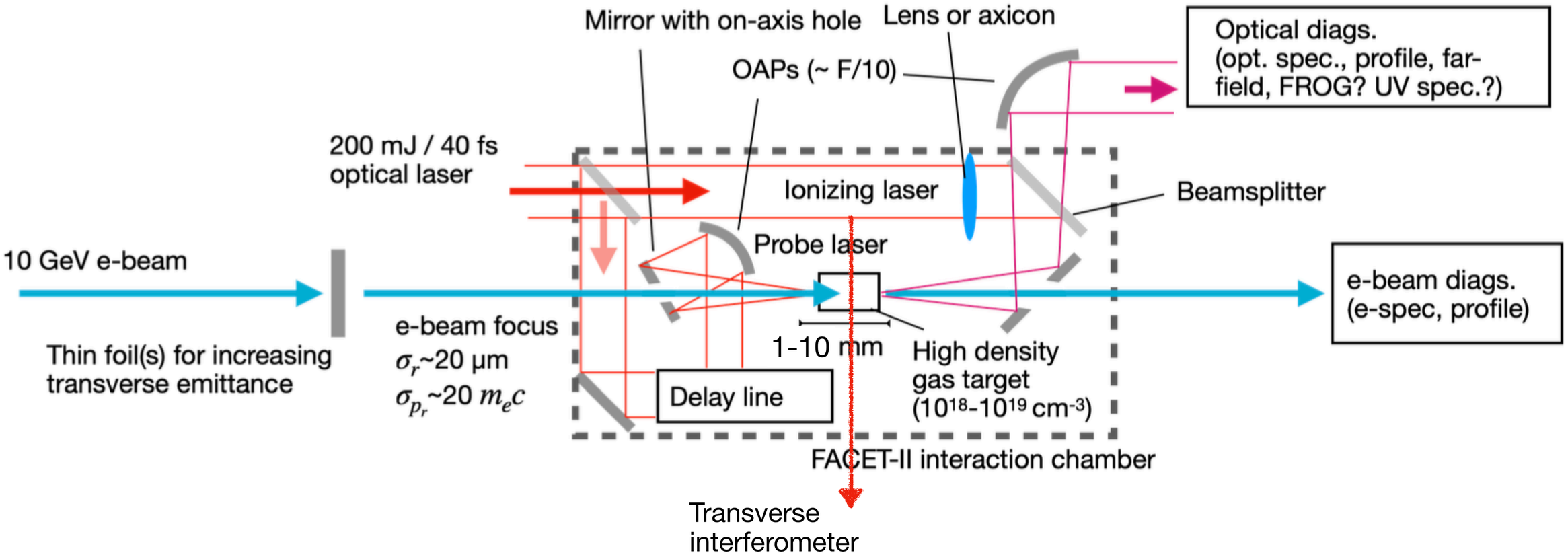
Description of science goals

Overview

- Increase transverse emittance of e-beam
  - Mitigates beam collapse into blowout regime
- Generate quasilinear wake
  - Short (mm scale), uniform high density (10^{18} cm^{-3}) target
- Probe wake with laser through induced frequency shifts - small shifts expected for initial experiments (<<2x)
- Longer term: Develop plasma target for phase matching

Description of science goals

Sketch of possible setup



Beam parameters needed

Electron Beam	
Beam Type	e^-
Beam energy (GeV)	10
Repetition Rate (Hz) (range)	Sync w/ optical laser, 10 Hz
Bunch Charge (nC) (range)	Max (1.5 nC should be ok)
Bunch Length (σ, μm) (range)	Min (<30 µm workable)
Beam Spot size (σ, μm) (range)	20-30 µm
Experimental Laser	
Pulse Energy (mJ) on target at electron beamline (range)	Necessary to ionize plasma + probe pulse. Nominal 200 mJ
Pulse Duration (fs) (range)	<30 fs optimal <100 fs usable

PROPOSERS & REQUESTED FACILITY:

Principal Investigator:	Alexander Thomas
Institution:	University of Michigan
Contact Information:	Phone: 7347636008 Email:agrt@umich.edu
Experiment Members:	TBD + Fitzgarrald + student (UM), Gerstmayer, Streeter (QUB)
Collaborating Institutions:	TBD + Queens U. Belfast, U. Rochester / LLE + collaborators welcome
Funding Source (optional)	
Approximate Duration:	1 year initially, extend on successful demonstration of upshift