Recent experimental results on electron and ion acceleration at the University of Michigan

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Current Key Collaborators

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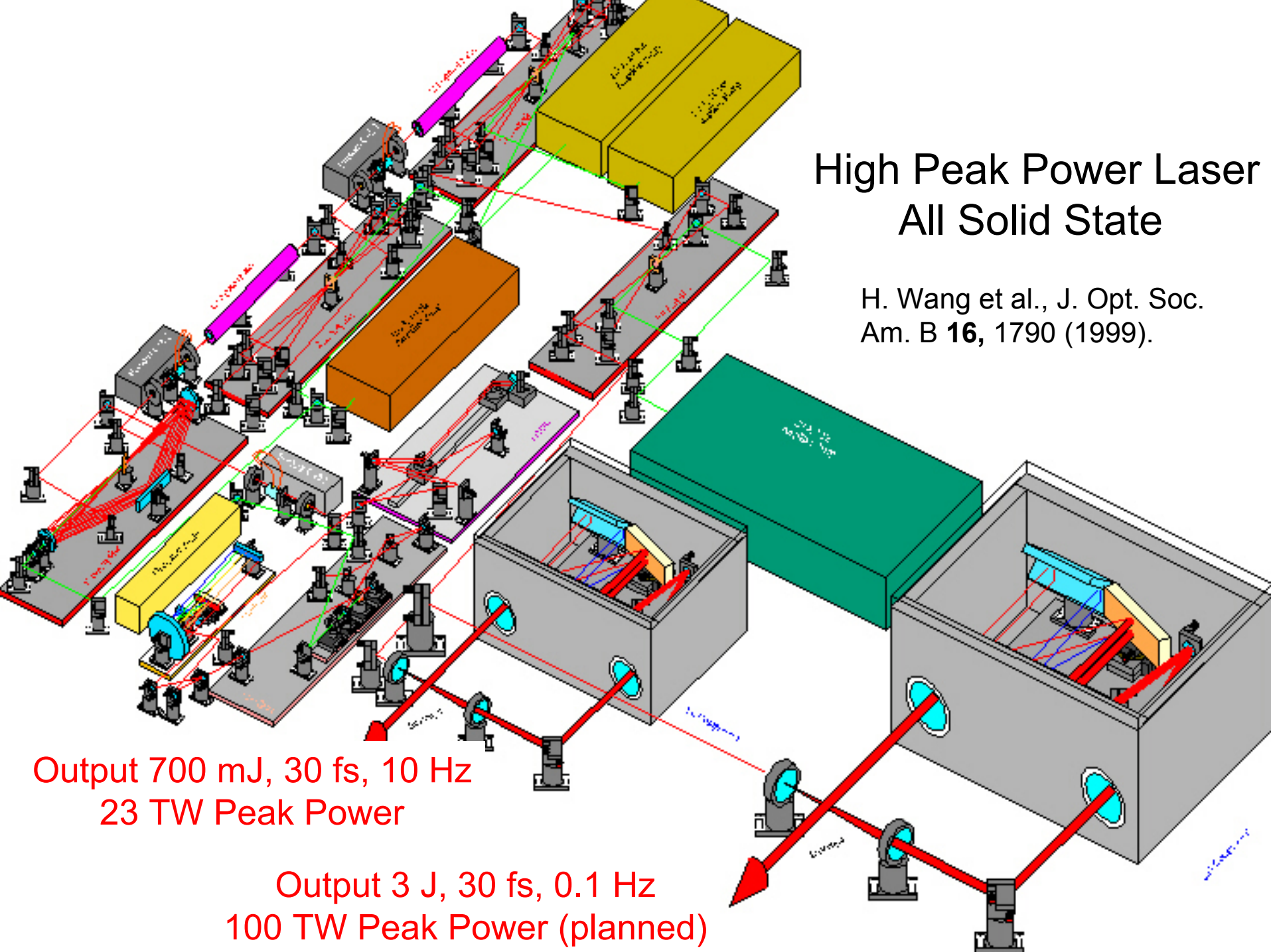
Nominal Laser Parameters

- Flashlamp-pumped Ti:Sapphire/Nd-Glass laser system
  - 1 micron
  - 400 fs
  - 5 J
  - 10 TW
  - 0.003 Hz
  - contrast: 10^{-5}
- Flashlamp-pumped Ti:Sapphire laser system
  - 0.8 micron
  - 30 fs
  - 3 J
  - 100 TW laser (currently at 30 TW)
  - 0.1--10 Hz
  - contrast: 10^{-7}



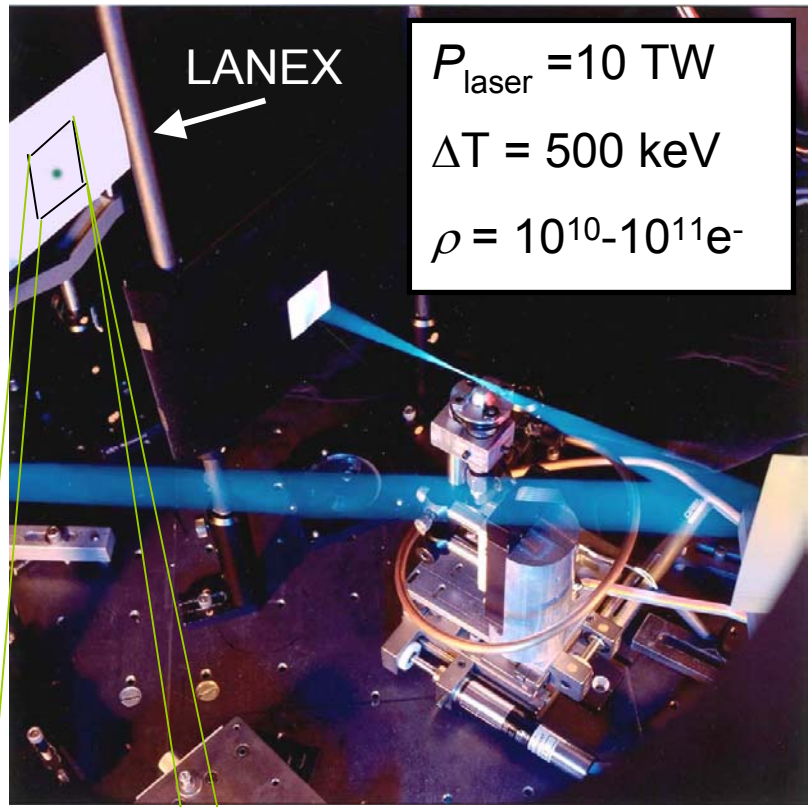
High Peak Power Laser
All Solid State

H. Wang et al., J. Opt. Soc. Am. B **16,** 1790 (1999).

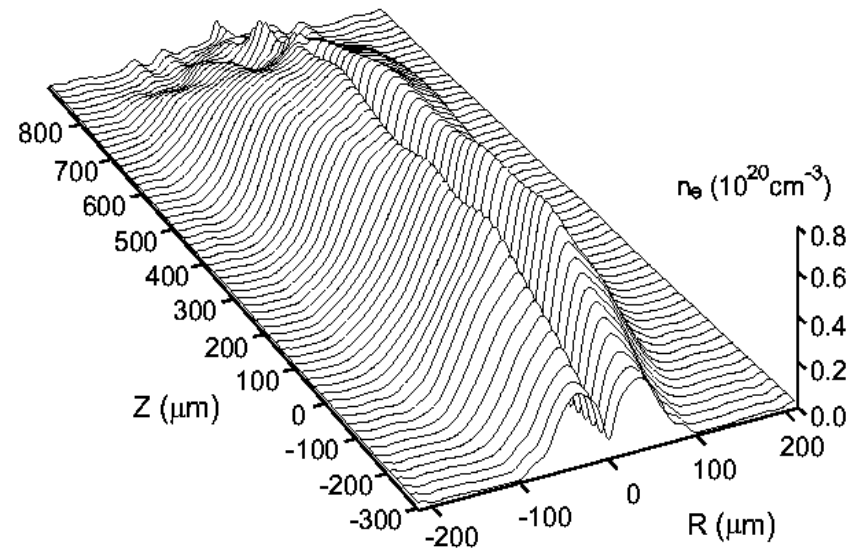
Output 700 mJ, 30 fs, 10 Hz
23 TW Peak Power

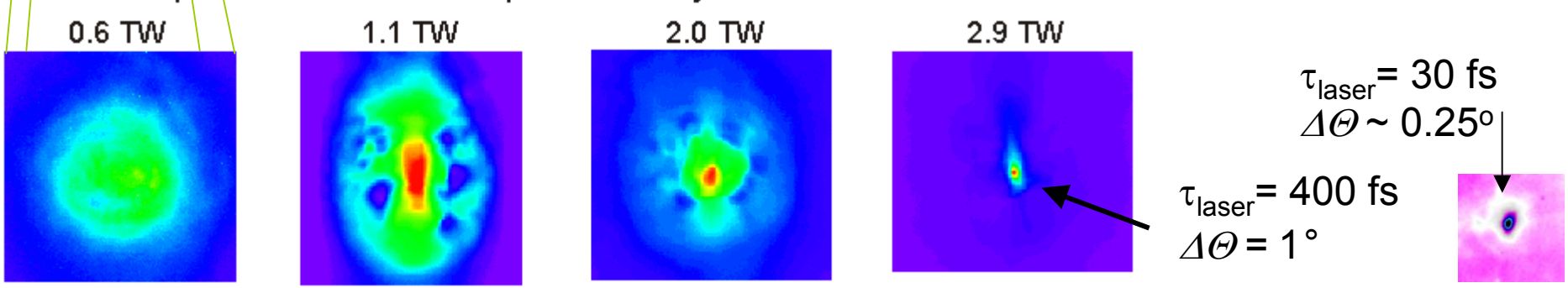
Output 3 J, 30 fs, 0.1 Hz
100 TW Peak Power (planned)

Low-Angular Divergence of Laser-Wakefield Electron Beam



Relativistic self-channeling leads to collimation of the laser beam, which leads to collimation of the electrons.

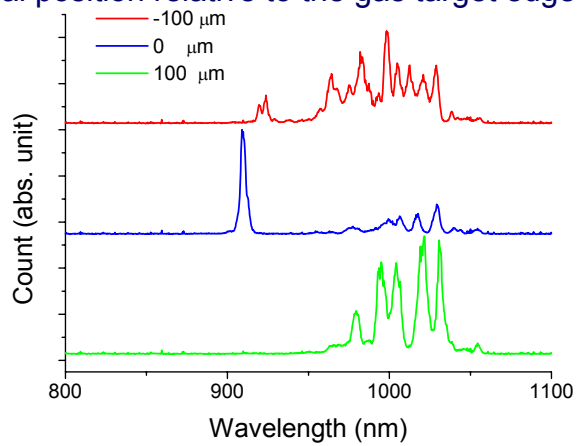




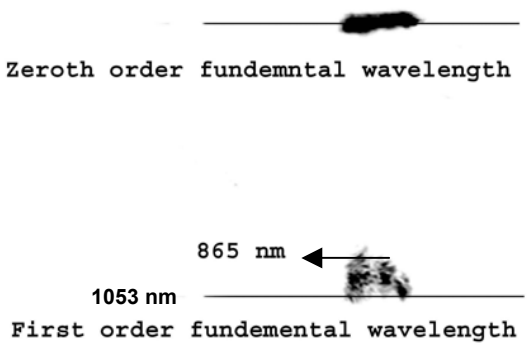
Novel Effects Relevant to Laser-Wakefield Generation

- Stimulated forward Raman scattering found to be seeded by ionization blue-shifted light

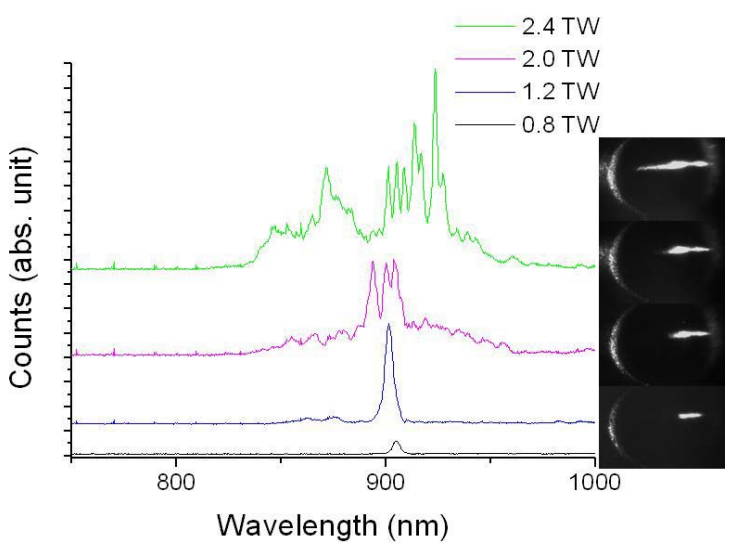
Raman spectra shows 100-um sensitivity to the focal position relative to the gas target edge.

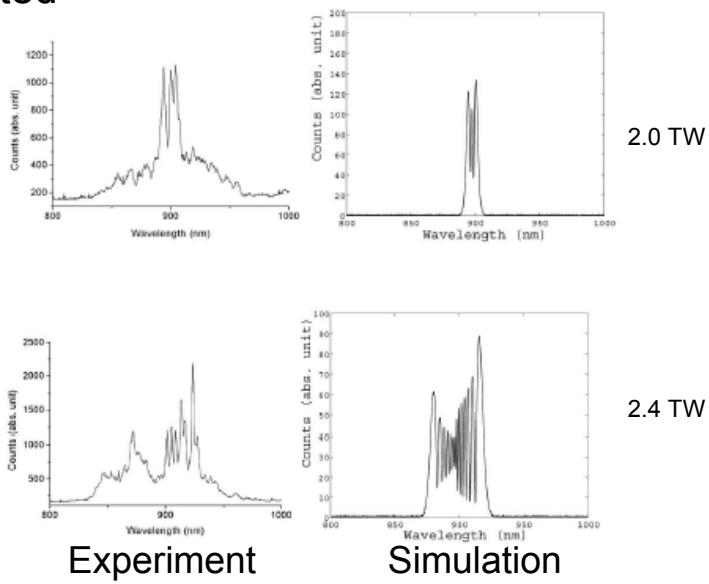


Spectrally and spatially resolved light in the top-view direction shows that the laser spectrum blue shifts as it propagates.



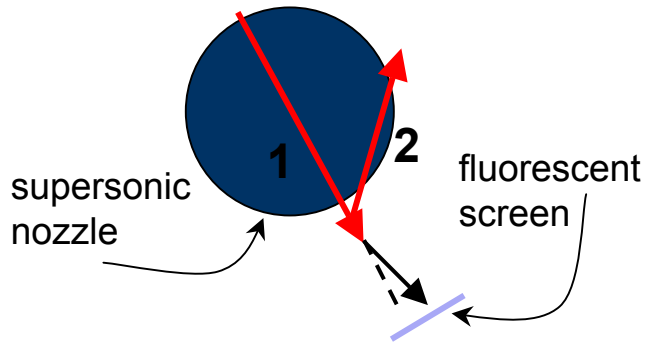
- Raman spectrum found to be cross-phase modulated



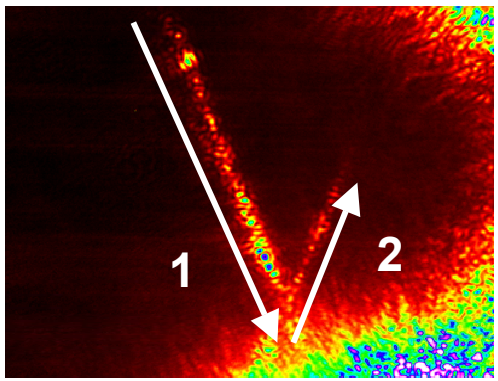


Cross-Correlation Optical Measurement of Electron-Beam Pulse Duration

Direct temporal measurement of a sub-picosecond-laser-accelerated electron beam, by use of ponderomotive deflection by an ultraintense laser pulse

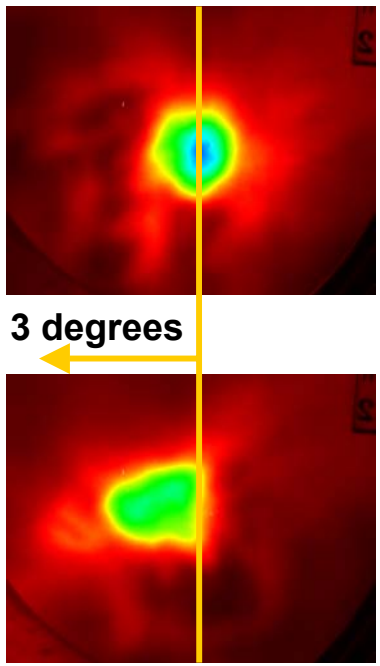


1st laser pulse – accelerates e-beam
2nd laser pulse – deflects e-beam



Channeling of the two laser pulses – the interaction region lies outside the plasma

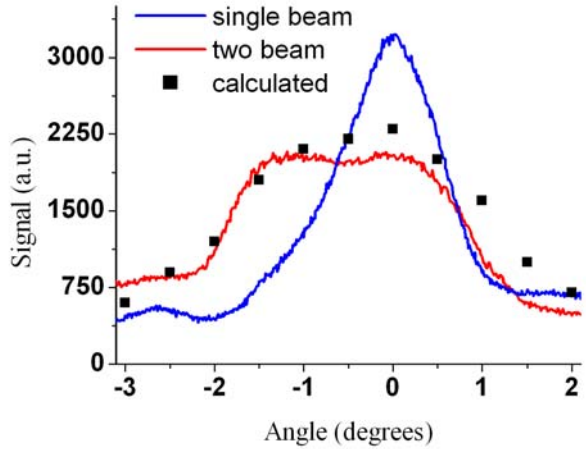
1-beam, undeflected



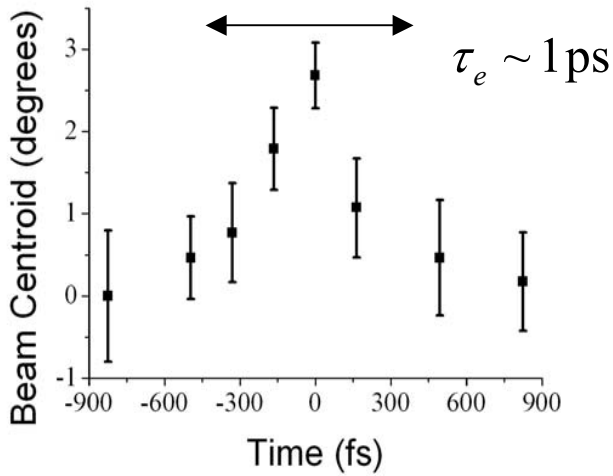
~ 3 degrees

2-beam, zero delay

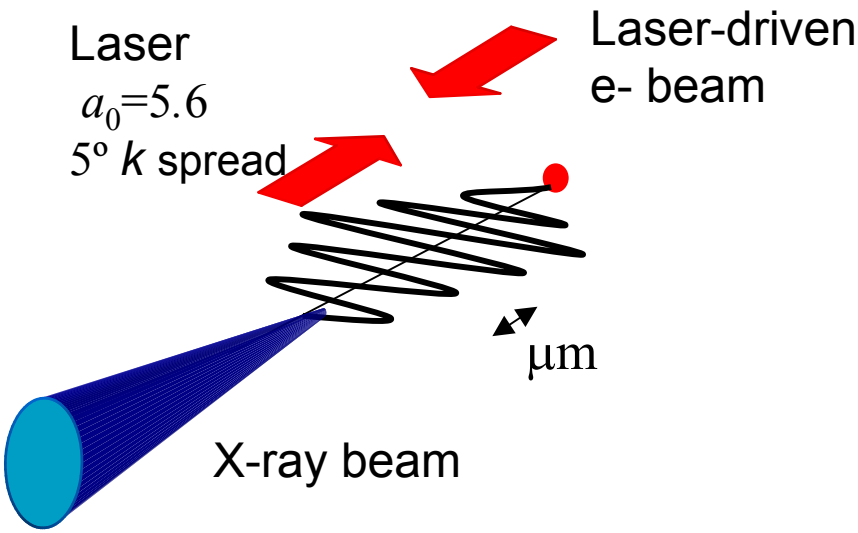
Ponderomotive deflection of electron beam observed on fluorescent screen

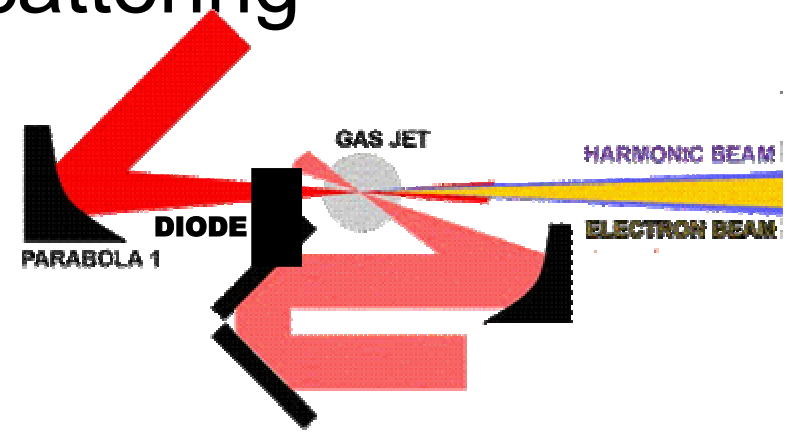


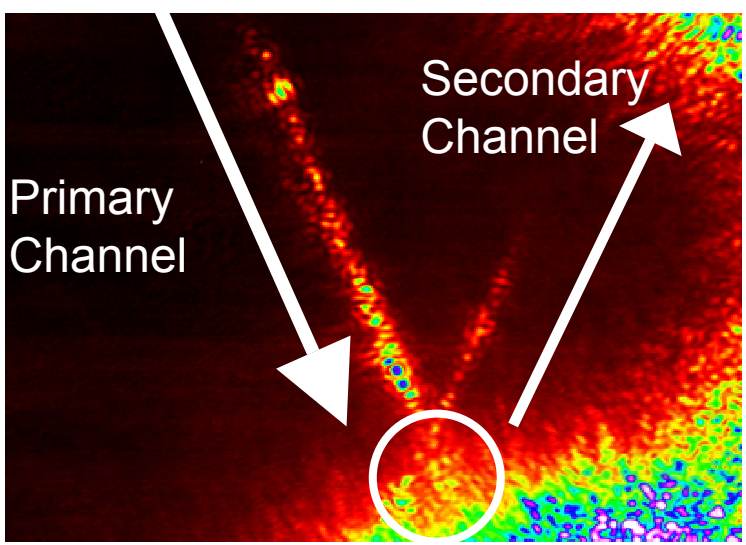
Measurement agrees with calculations that include longitudinal laser fields

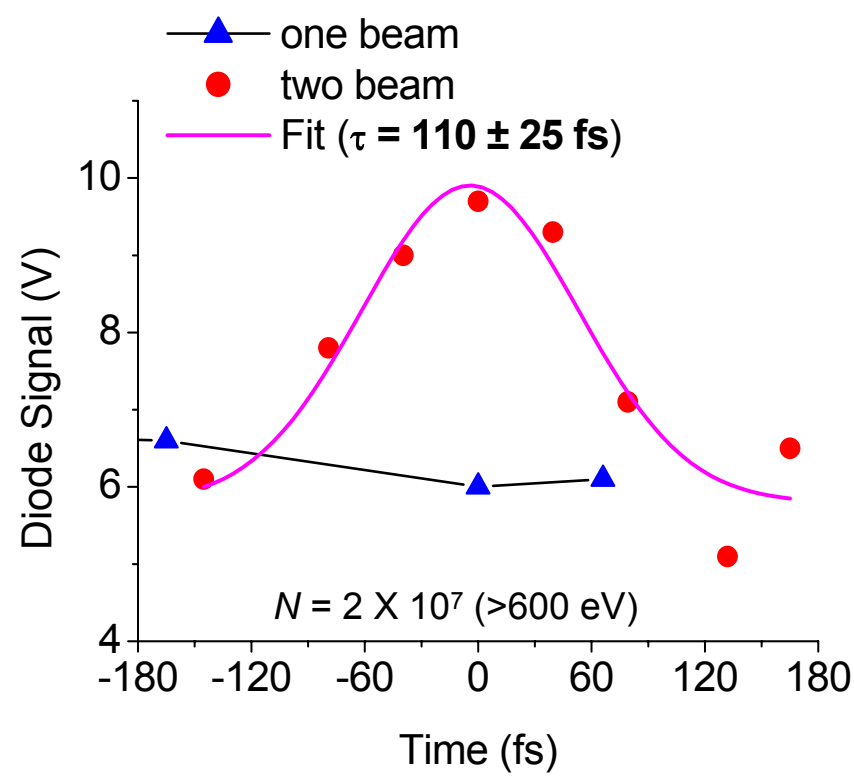


XUV Generation from Counter-propagating Thomson Scattering

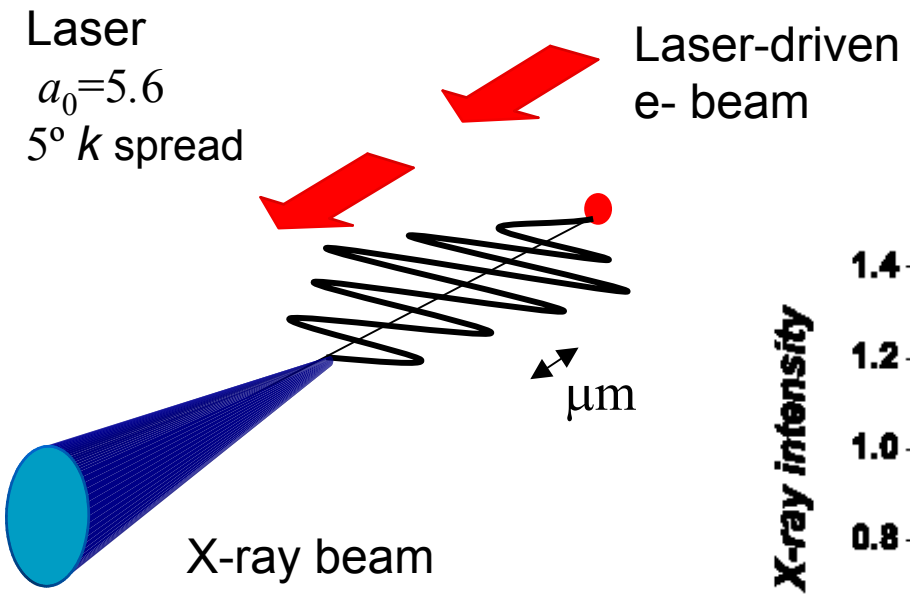


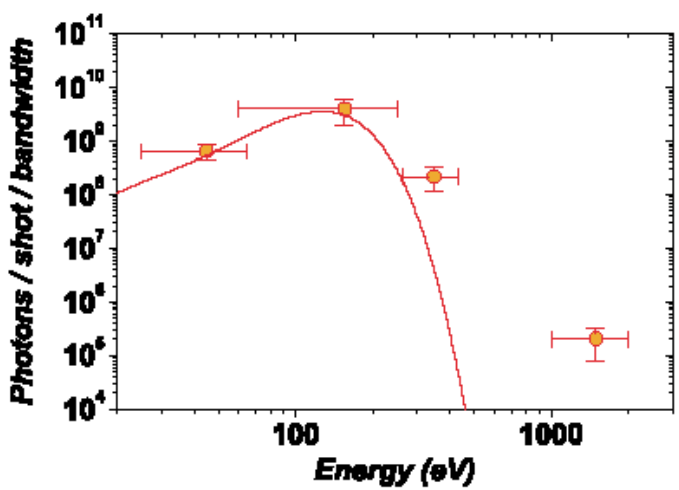


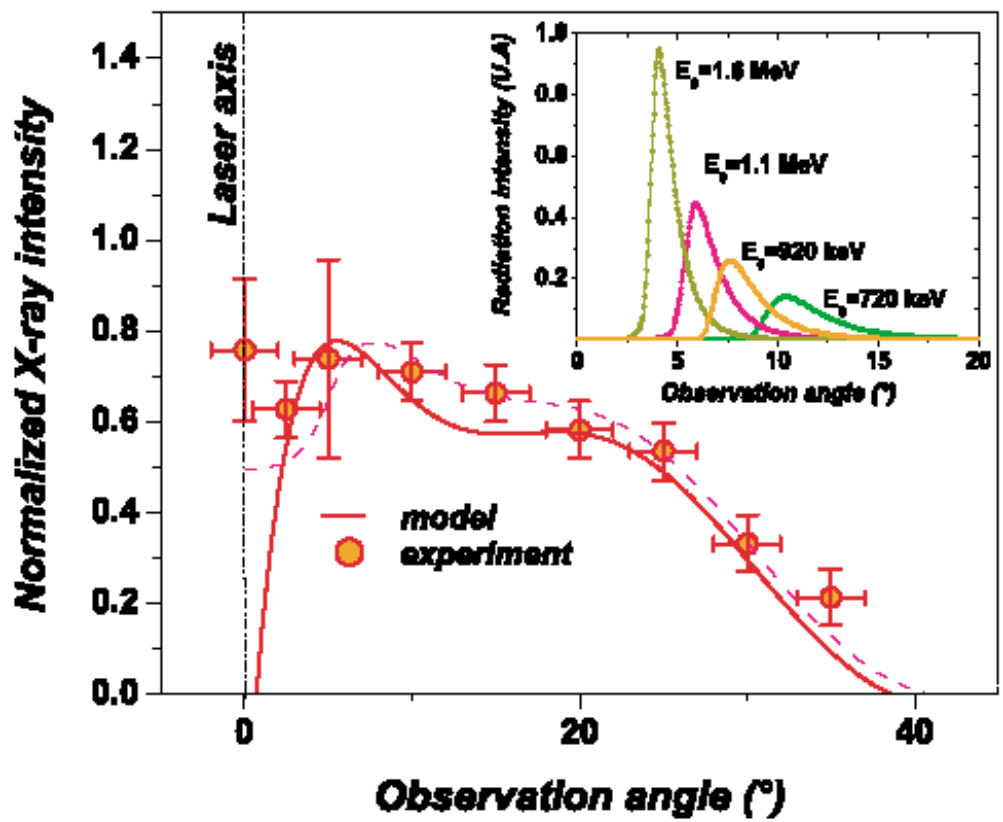




Co-linear Laser Synchrotron X-Rays

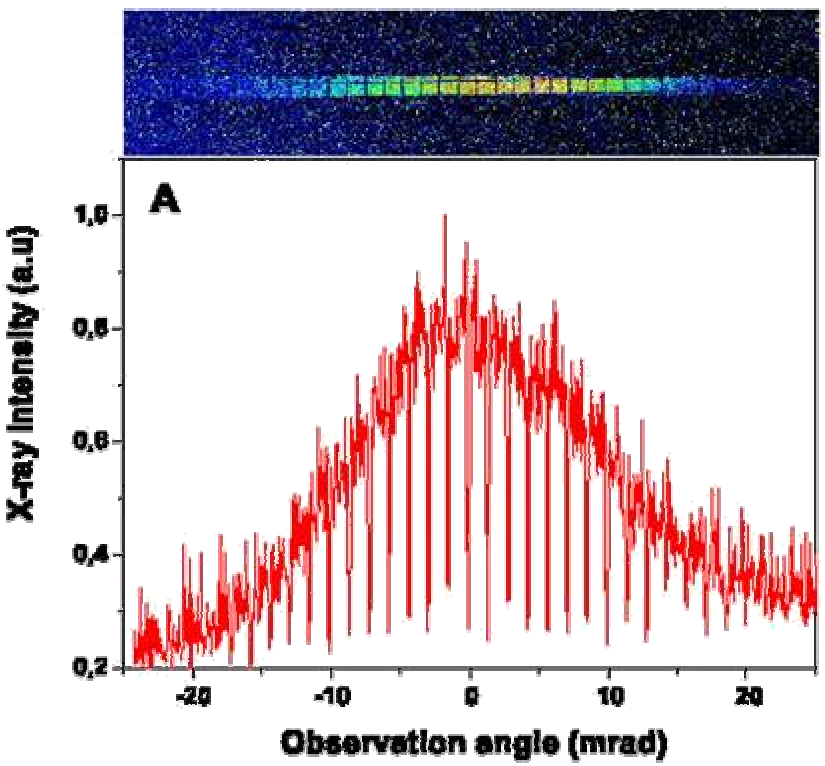


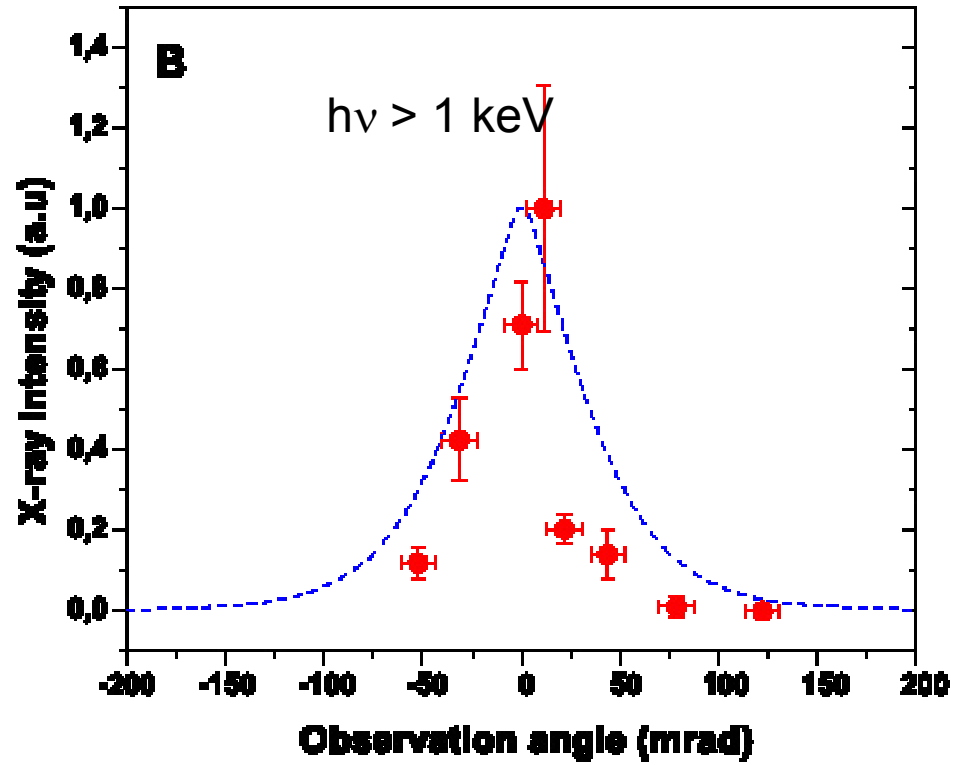




K. Ta Phouc, et al. *Physical Review Letters,* **91**, 195001-1 (2003).

Betatron oscillations in a plasma channel produce a well-collimated x-ray beam

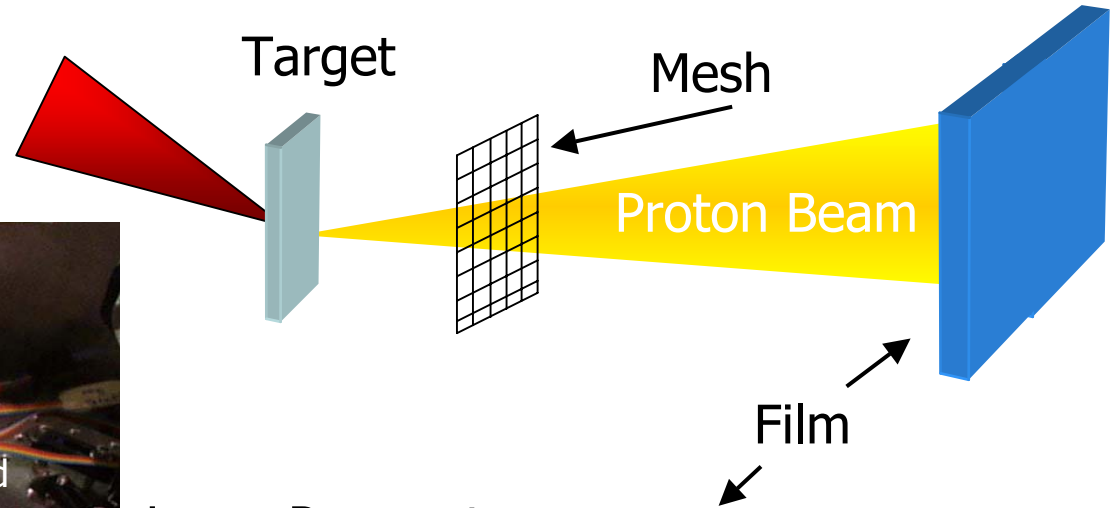


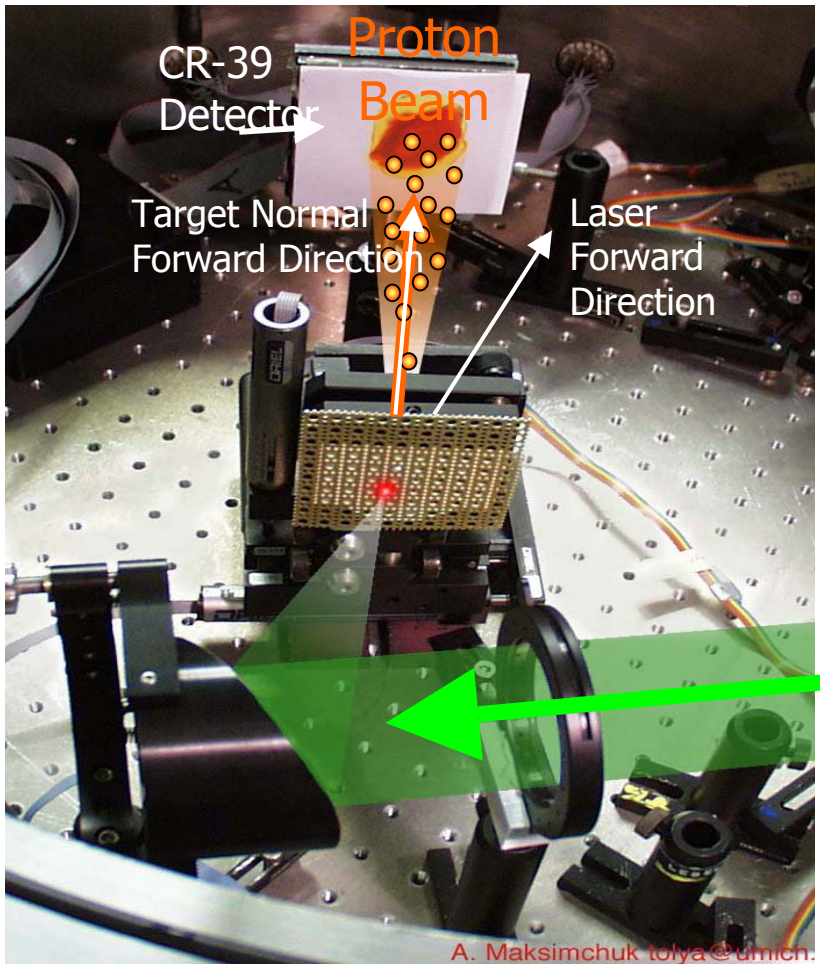


10^{10} photons/shot in a collimated beam
Estimated pulse duration ~ 30 fs
Source size = 20 μm X 20 μm
Brightness = 2 X 10^{22} photons/[$mm^2 \cdot mrad^2 \cdot s \cdot 0.1\%BW$]

A. Rousse *et al.* (in review, Phys. Rev. Lett.).

Laser-Driven Proton Beams Show Excellent Transverse Emittance





Laser Parameters:

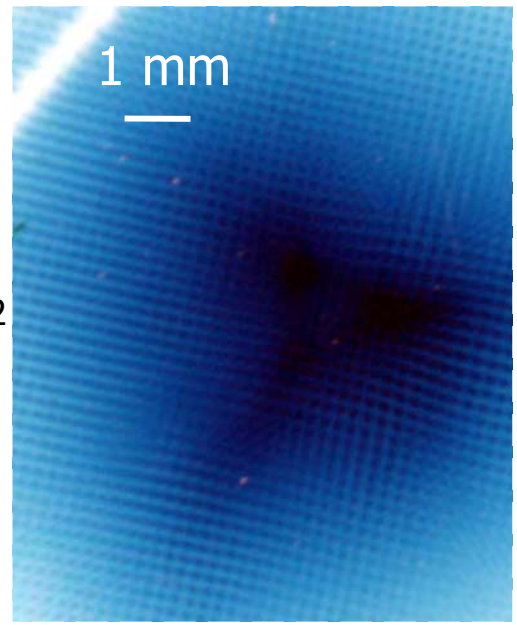
λ=1.053 μm

P < 12 TW

U = 5 J

τ = 400 fs

I =<2x10^{19} W/cm^2

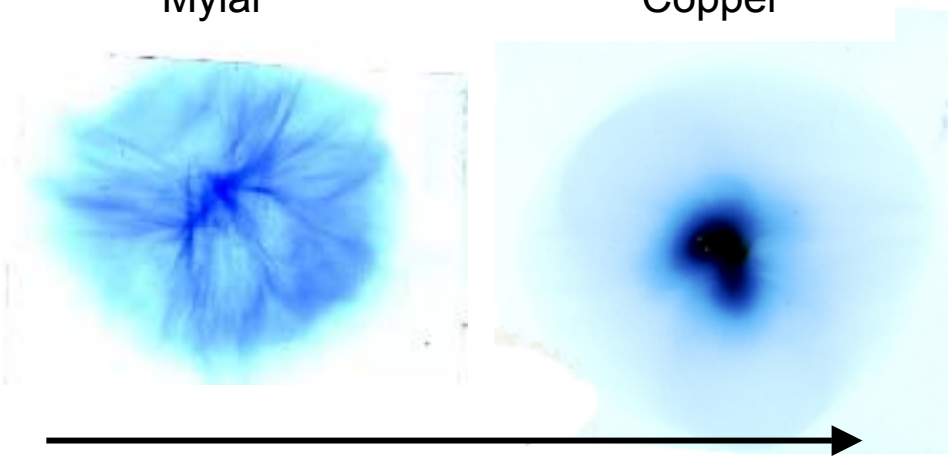


Laser-driven proton acceleration: improved understanding of mechanisms and control

Proton beam spatial profiles (CR-39)

Mylar

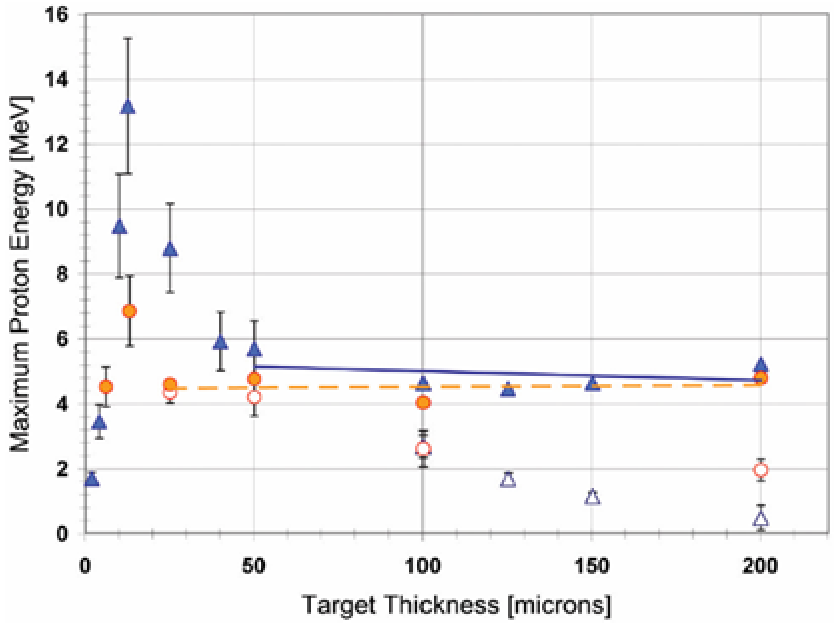
Copper



Conductivity

Smoother beams with increasing conductivity reveals the role of beam instabilities in dielectric materials.

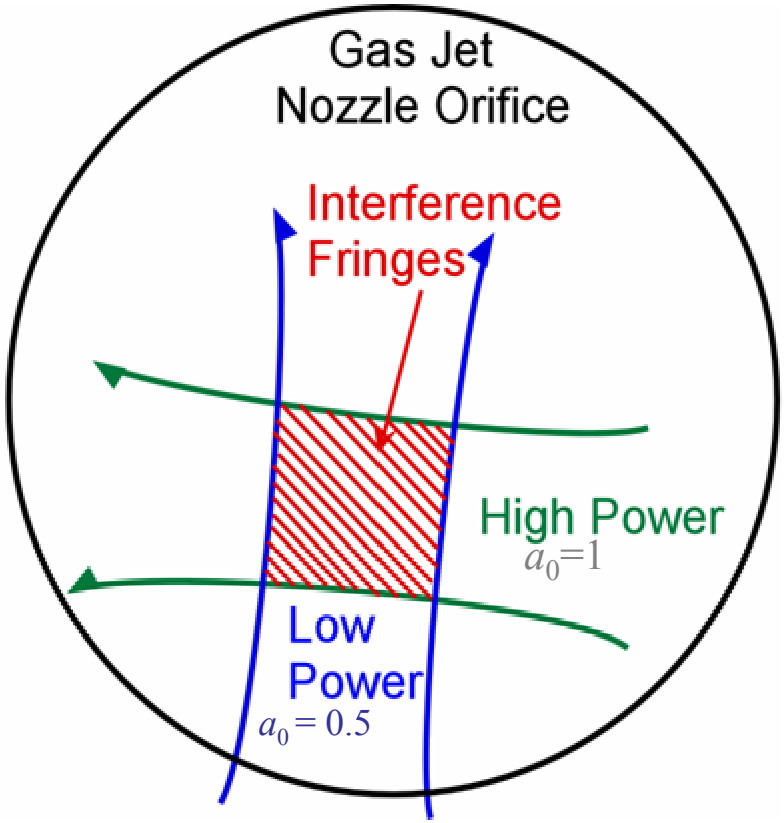
Proton energy vs. target thickness

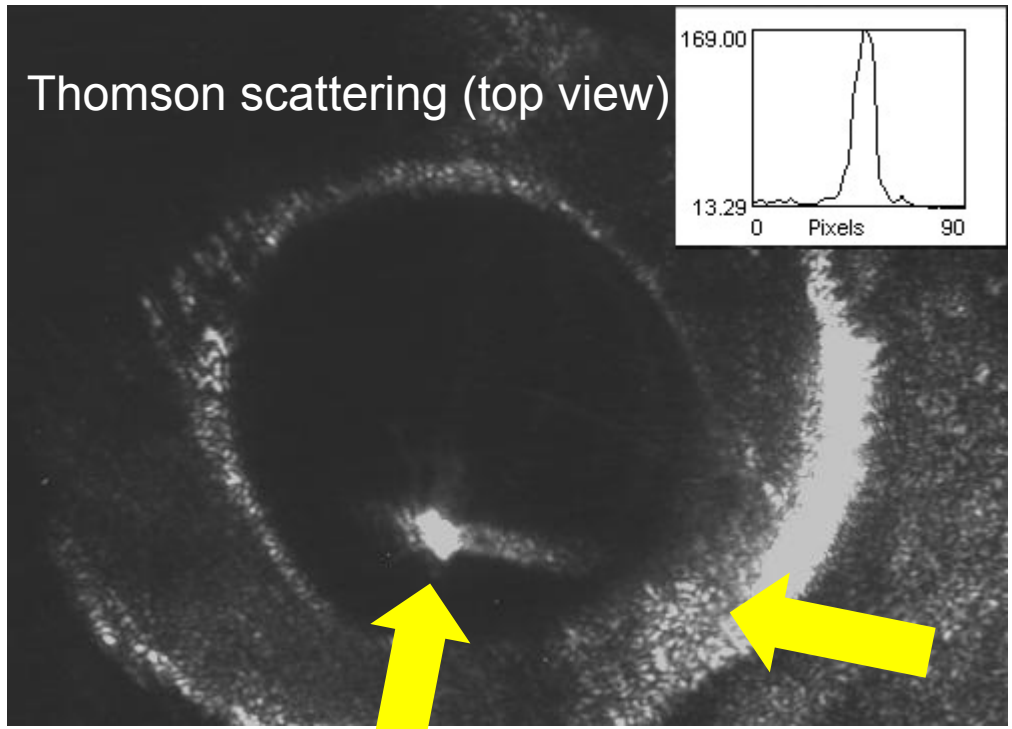


Protons found to originate from both front and rear sides of thin-film targets.

Kirk Flippo's PhD Dissertation, University of Michigan (2004).

An Optical Trap for Relativistic Plasma

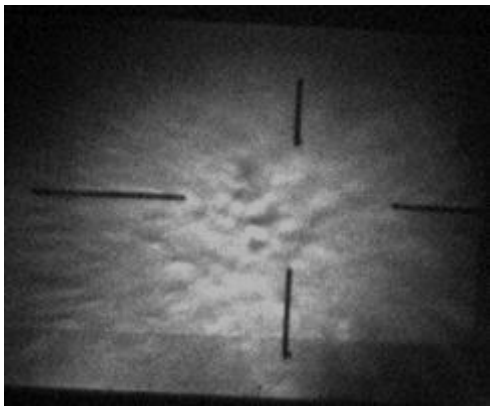




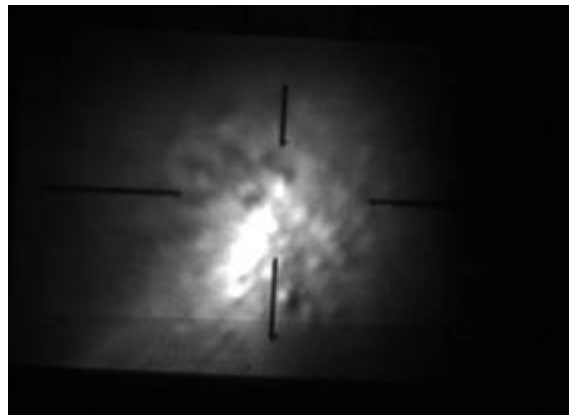
$$P_s / P_0 \sim \delta n / n \sim 10$$

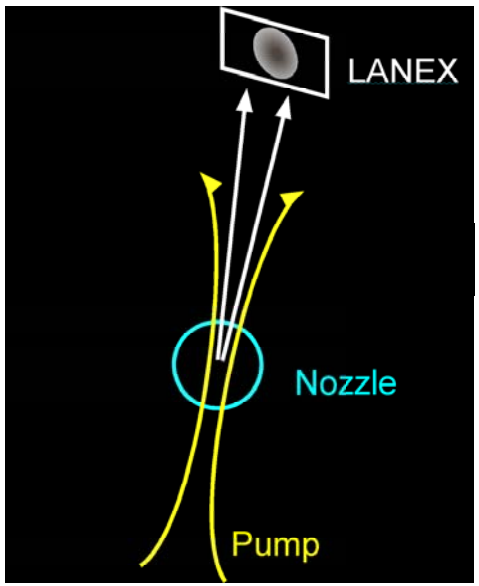
P. Zhang, N. Saleh, S. Chen, Z.M. Sheng and D. Umstadter, *Physics of Plasmas* **10**, 2093 (2003).

Transverse injection pulse decreases e-beam divergence, and transfers energy

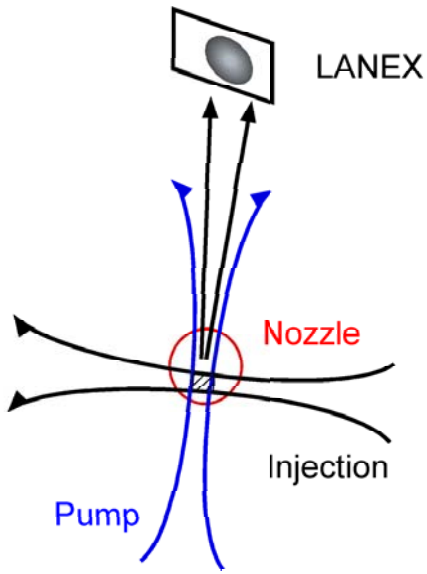


Wide electron beam profile w/o injection, near self-trapping threshold





Electron beam profile narrows with injection



Zhang et al., *Phys. Rev. Lett.* **91**, 225001 (2003).

Summary

- MeV laser-wakefield electron accelerator
  - Guiding and angular-divergence reduction
  - Sub-picosecond electron-beam pulse-duration
  - Stochastic heating and injection of electrons
  - Ionization seeding of plasma waves
  - Relativistic self-modulation
- All-optically-driven femtosecond x-ray sources
- MeV-energy laser-driven proton accelerator
  - Proton origin and beam-uniformity control
- Optical trap for relativistic plasma