Optical Probing of Underdense Laser–Plasma Interactions Using the Vulcan Petawatt Laser

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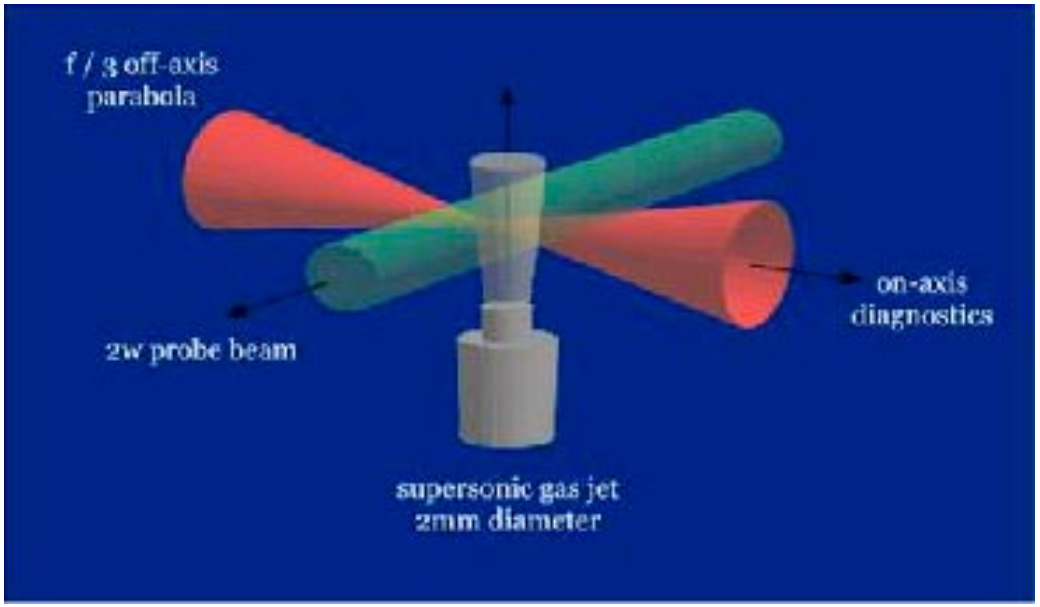

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University of Rochester
Laboratory for Laser Energetics

9th International Workshop
on Fast Ignition Targets
Cambridge, MA
3–5 November 2006

Summary

Underdense laser–plasma interactions have been optically probed on the Vulcan Petawatt Laser Facility

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- Blast-wave formation
  - blast-wave formation has been studied in helium plasmas using 200- to 350-TW, 1-ps laser-pulses
  - a stable-unstable-stable front transition is observed
- Ponderomotive channel formation
  - channel formation has been studied in helium plasmas using 450-TW, 0.65-ps laser-pulses
  - multiple channel formation is correlated to the electron-beam profile generated during the interaction

Collaborators

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CCLRC, Central Laser Facility, Rutherford Appleton Laboratory, Oxon, UK

S. Karsch and J. Schreiber

MPQ, Garching, Germany

On-axis electron acceleration >300 MeV has been previously demonstrated

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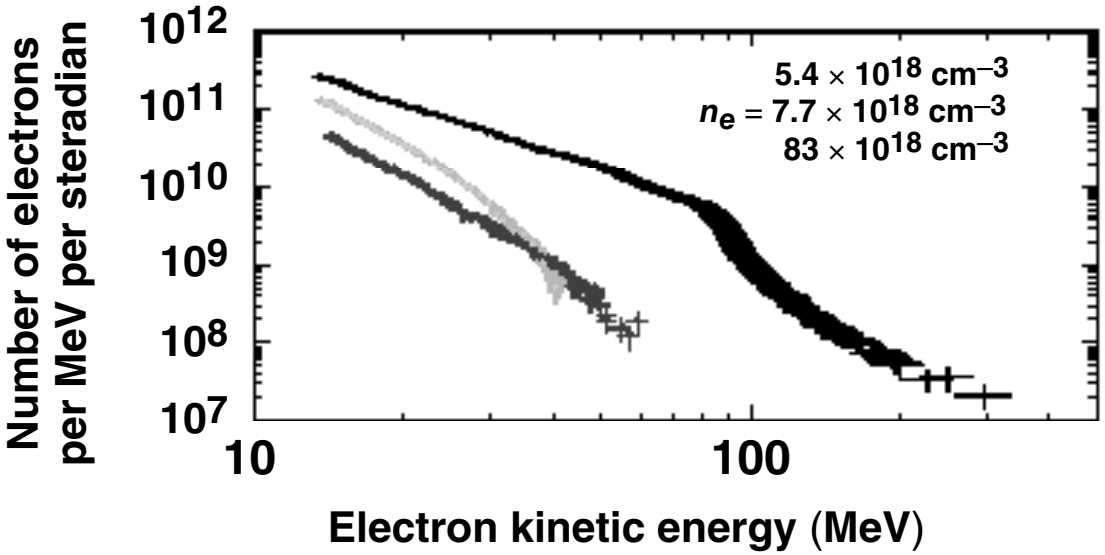
- Three examples of electron energy spectra observed at various background electron densities for laser intensity ~3 × 10^{20} W/cm^2.
  - on-axis electron acceleration
  - direct laser acceleration (DLA) mechanism
  - electron energies > 300 MeV



Mangles *et al.*, Phys. Rev. Lett. 94, 245001 (2005).

Multi-MeV transverse shock acceleration of ions has been previously demonstrated

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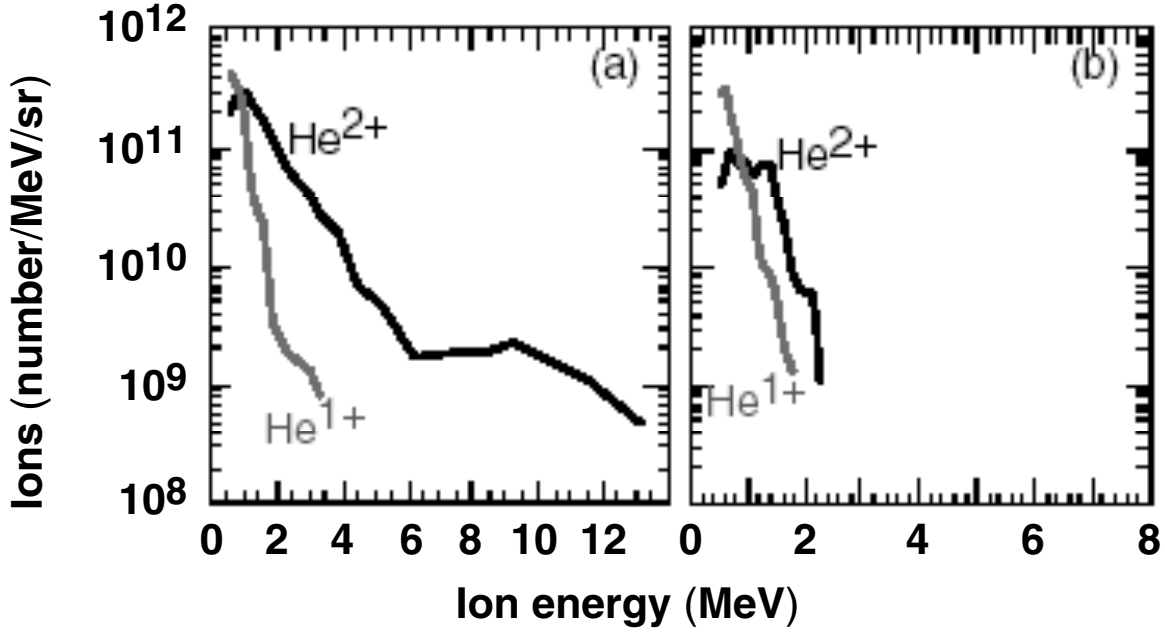
- Energy spectra of helium ions for (a) high density, 1.4×10^{20} cm^{-3}, and (b) low density, 1.7×10^{19} cm^{-3}.
  - transverse ion acceleration
  - shock-acceleration mechanism
  - He ions, $E_{max} \approx 13$ MeV



Wei *et al.*, Phys. Rev. Lett. 93, 15 (2004).

The objective is to study electron and ion acceleration from underdense laser–plasma interactions

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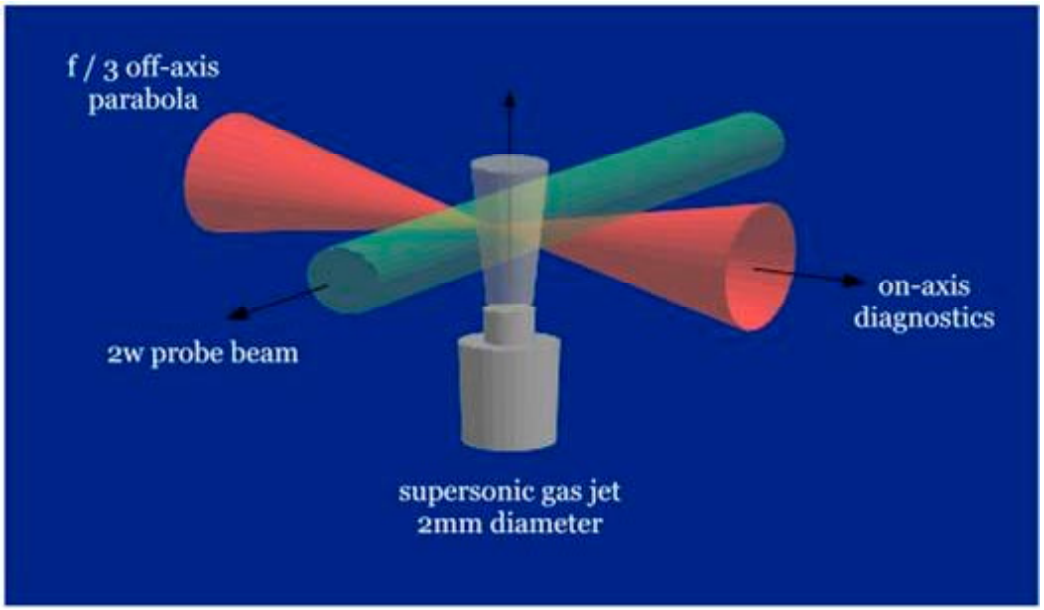
- The Vulcan Petawatt Laser Facility
  - 500 J, 500 fs → 1 PW
  - focused electromagnetic intensities $I = 10^{20–21}$ W/cm^2
  - relativistic regime $a_0 >> 1$
  - $a_0 \approx 40$ for 10^{21} W/cm^2



Experimental setup: target area and diagnostics

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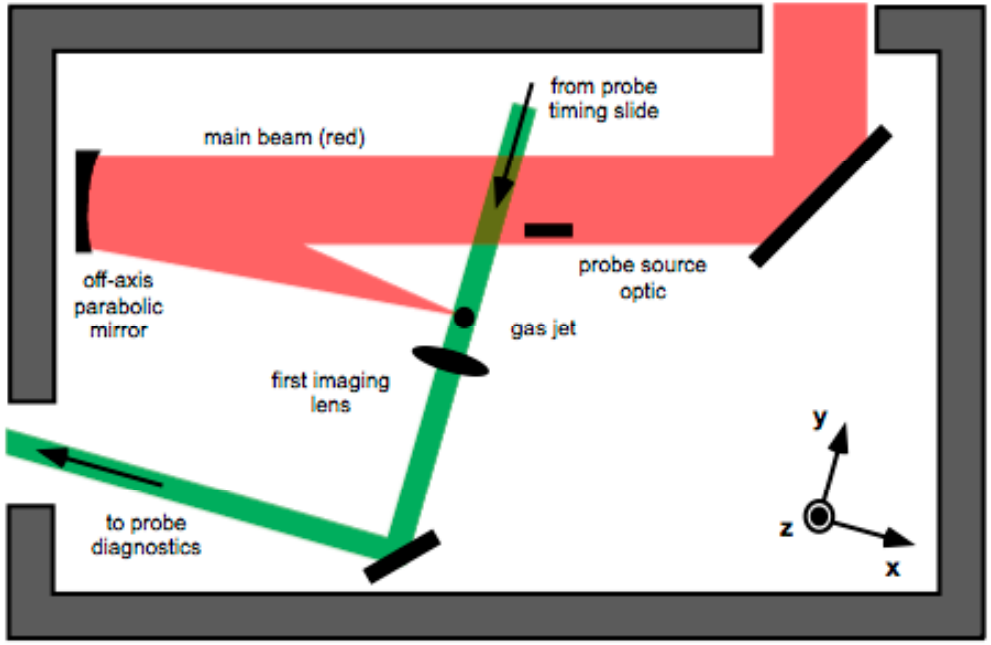

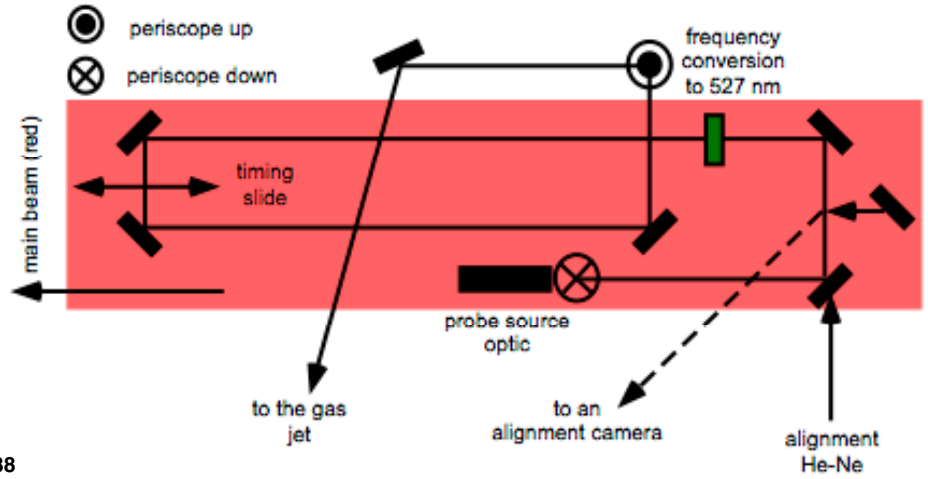

- 527-nm optical probe beam
- Electron spectrometers
- Thomson parabolas
- Filtered radiochromic film stacks
- Probe beam source optics

E15288

527-nm probe beam setup: diagnostic channels

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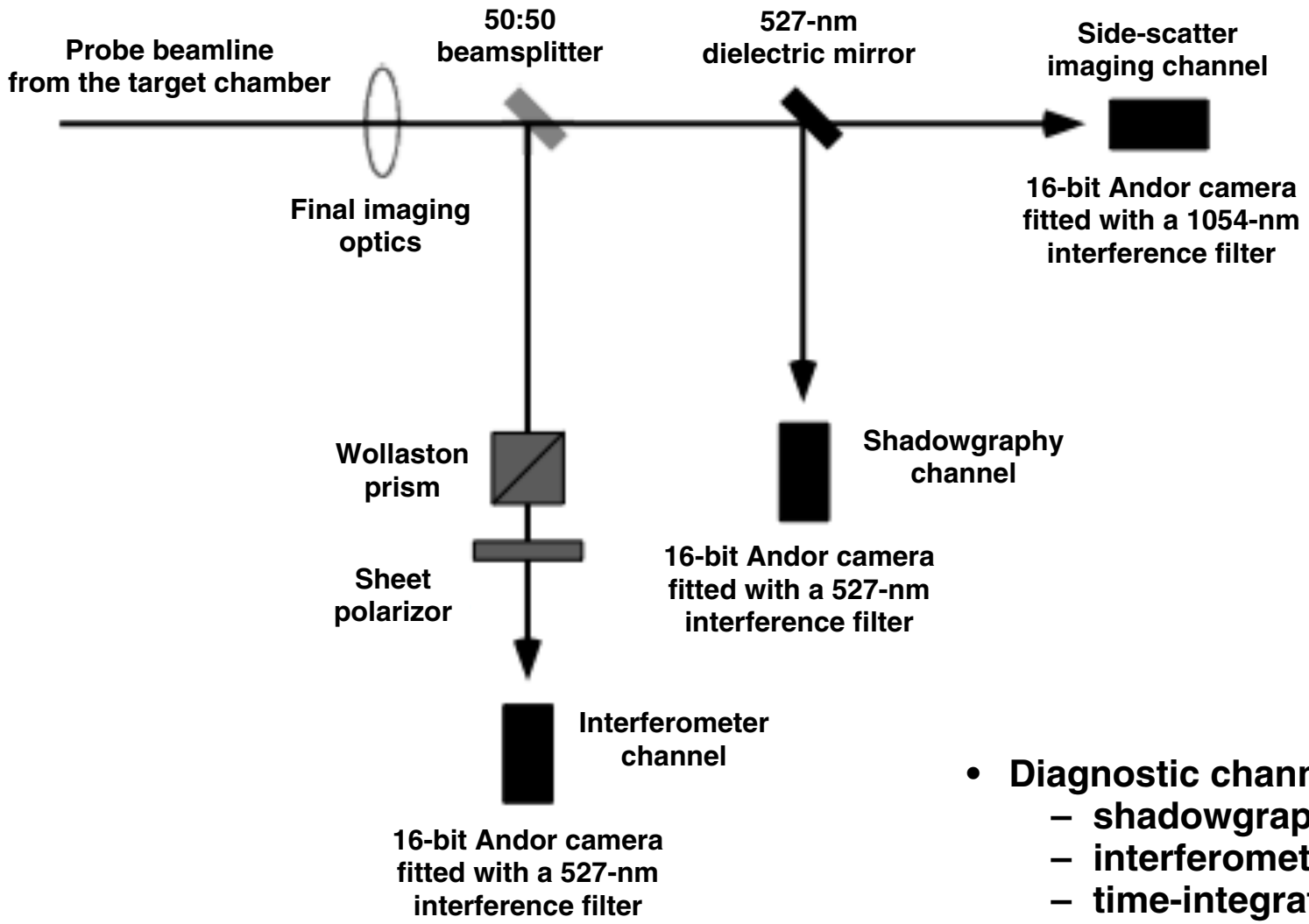

- Diagnostic channels
  - shadowgraphy
  - interferometry
  - time-integrated optical self-emission

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2D3V *OSIRIS* code simulations show the result of a Coulomb explosion in channel and blast-wave formation

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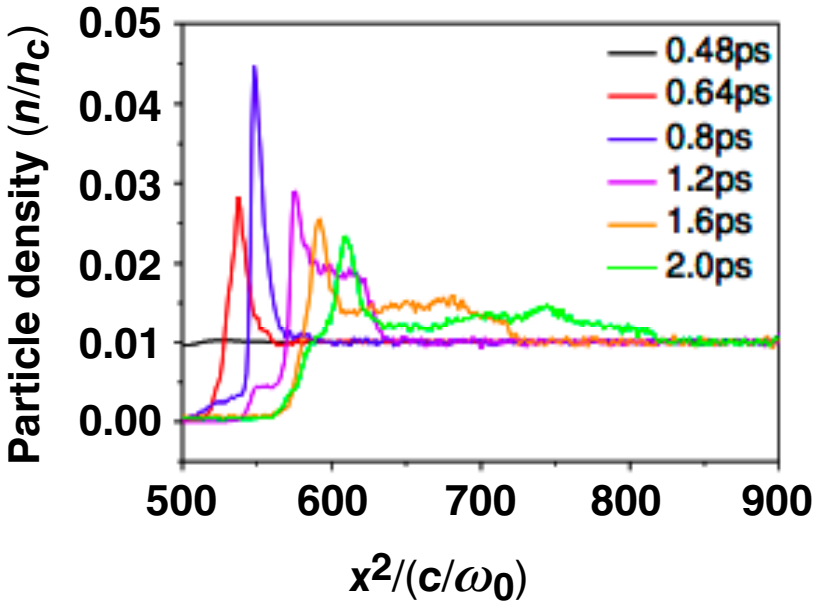
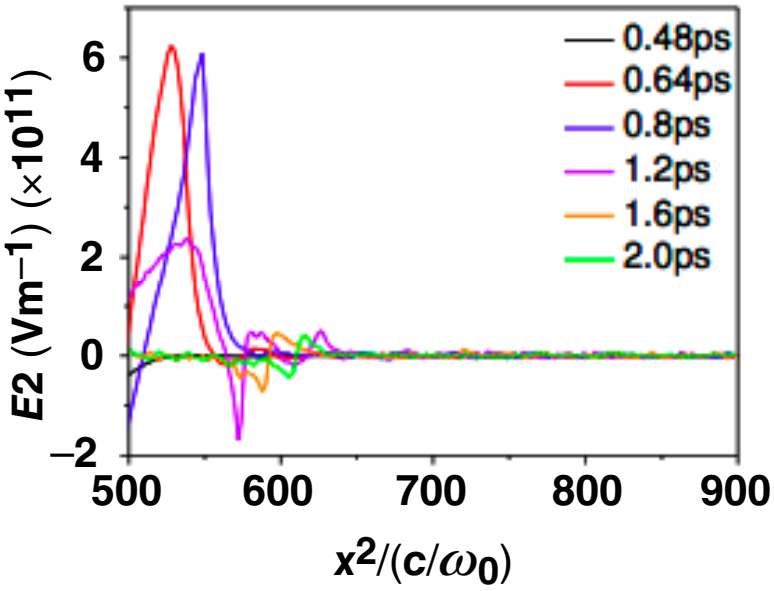
- Laser pulse: 0.65 ps, $a_0 = 15$
- He plasma: $n_e = 0.01\ n_{cr}$

- Temporal evolution of the electron density profile



- Temporal evolution of the radial electric field profile



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200-TW, 1-ps- pulses: Blast front formation in He plasmas at $n_e = 2 \times 10^{19}$ cm^{-3}

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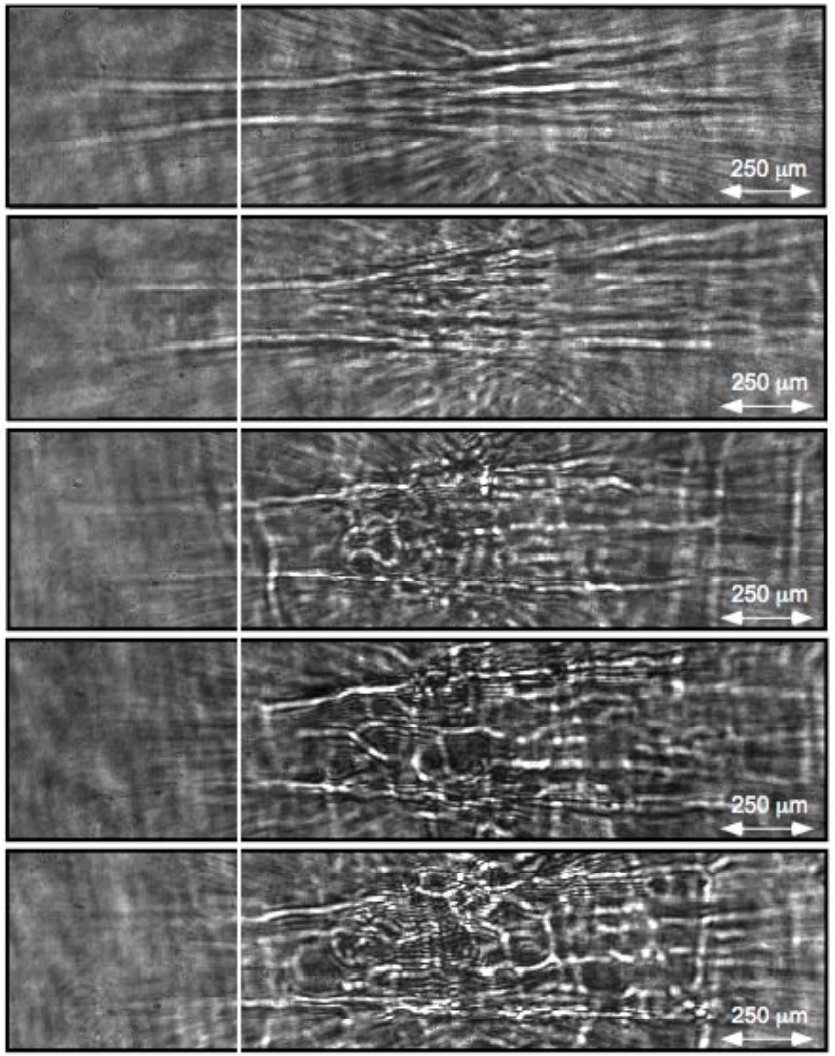

$t = t_0 + 30$ ps

$t = t_0 + 70$ ps

$t = t_0 + 153$ ps

$t = t_0 + 225$ ps

$t = t_0 + 231$ ps

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The front exhibits an unstable phase as it propagates radially that is damped after $t = t_0 + 800$ ps

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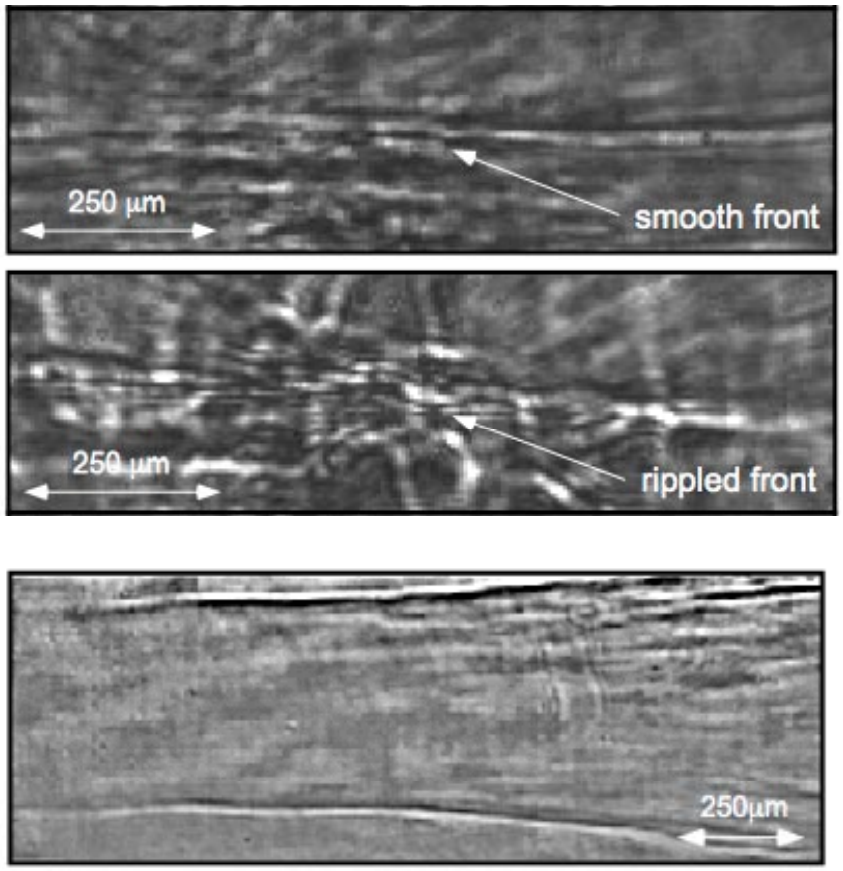

$t = t_0 + 70$ ps

$t = t_0 + 233$ ps

$t = t_0 + 800$ ps

The blast wave is characterized by the deceleration parameter $\alpha = 0.34$ and exhibits front thickness reduction

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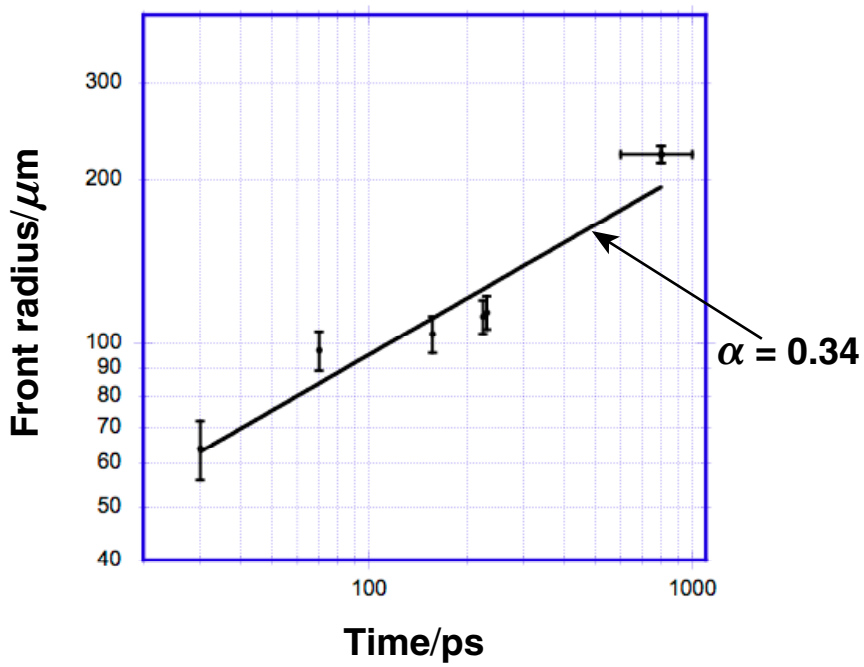
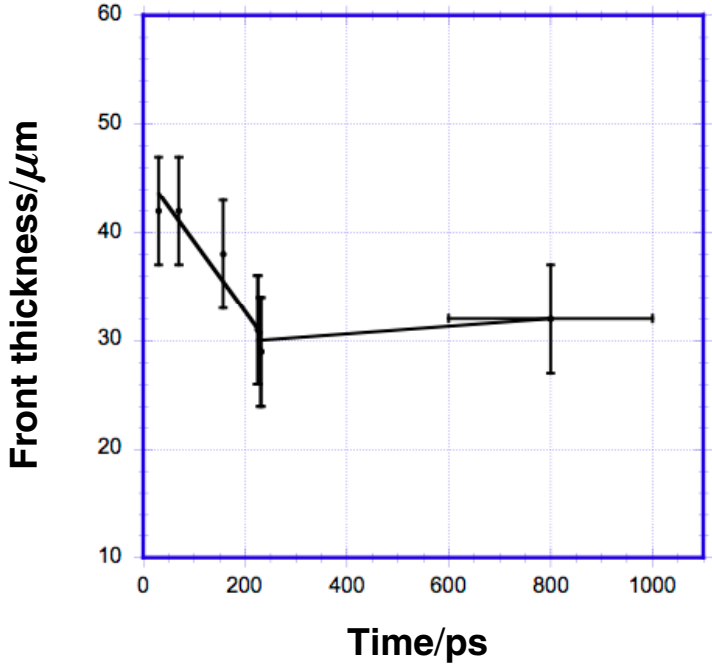
- Temporal evolution of the blast front radius



- Temporal evolution of the blast front thickness



$\alpha = 0.33$: momentum conserving snowplough regime

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350-TW, 1-ps pulses: Blast-wave formation in He plasmas at $n_e = 1.6 \times 10^{19}$ cm^{-3}

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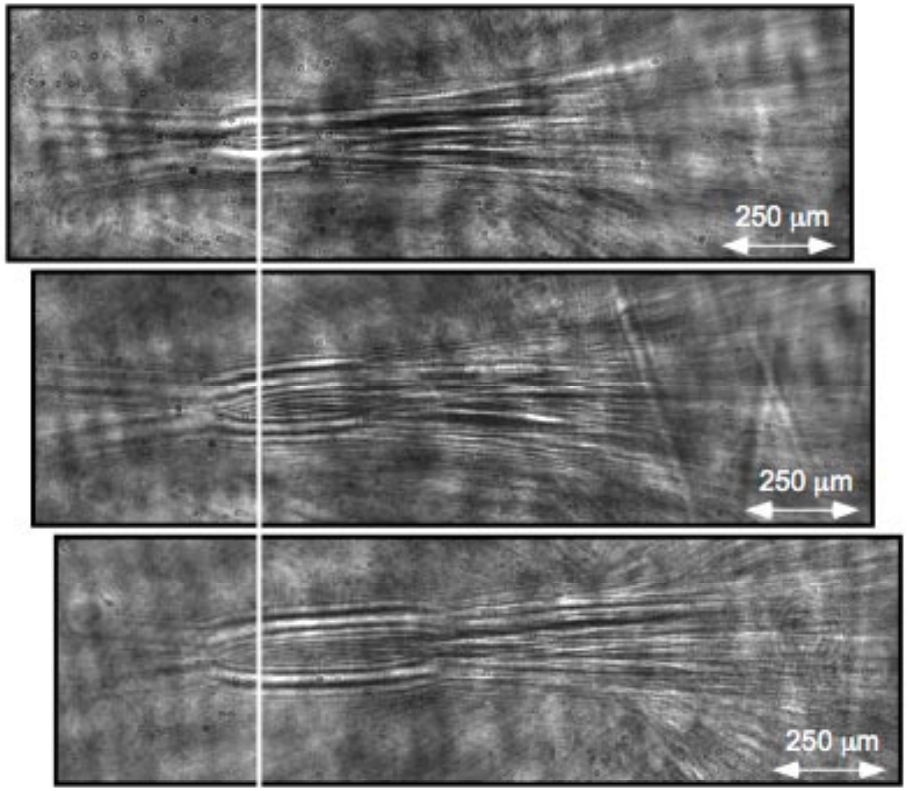
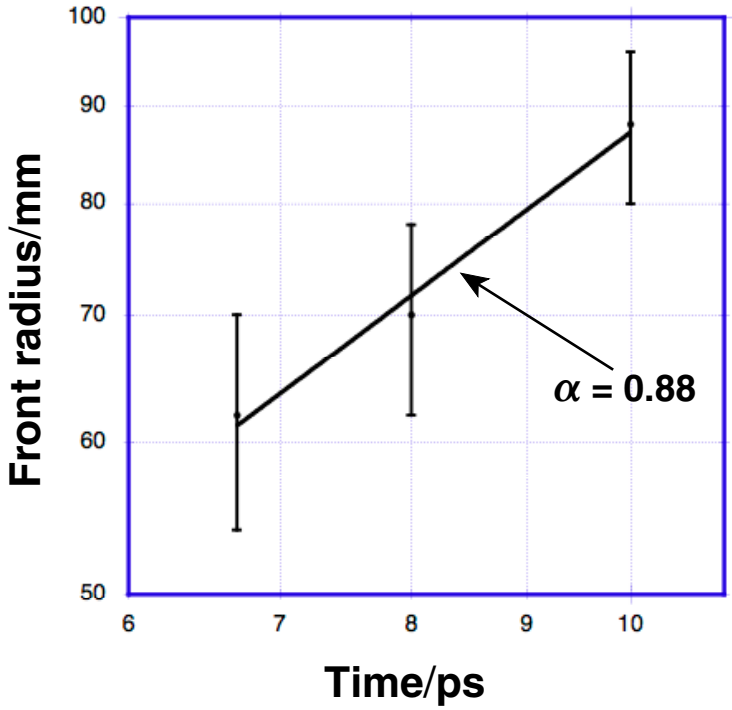
$t = t_0 + 7$ ps (top)
$t = t_0 + 8$ ps (middle)
$t = t_0 + 10$ ps (bottom)



- Temporal evolution of the blast front radius



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450-TW, 0.65-ps pulses: Channel formation in He plasmas at $n_e = 1.5 \times 10^{19}$ cm^{-3}

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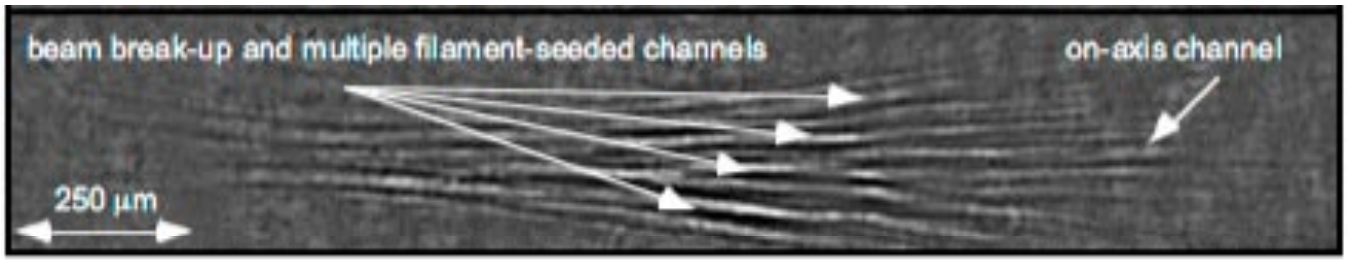
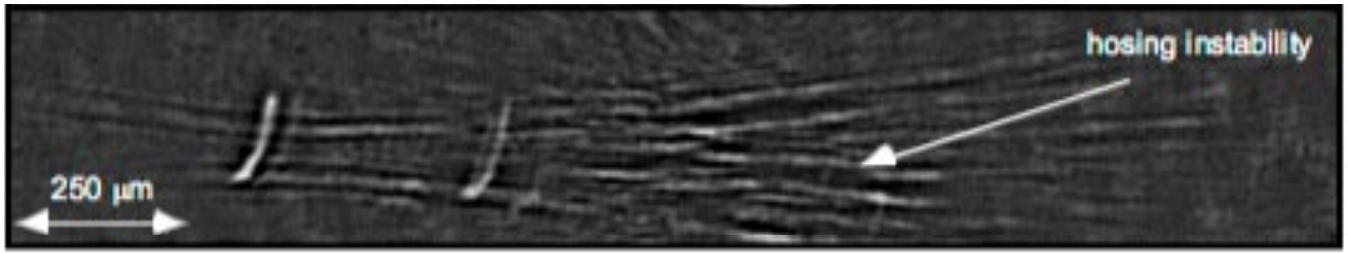


$t = t_0 + 14$ ps



$t = t_0 + 14$ ps

450-TW, 0.65-ps pulses: Multiple-channel formation in He plasmas at $n_e = 2.5 \times 10^{19}$ cm^{-3}

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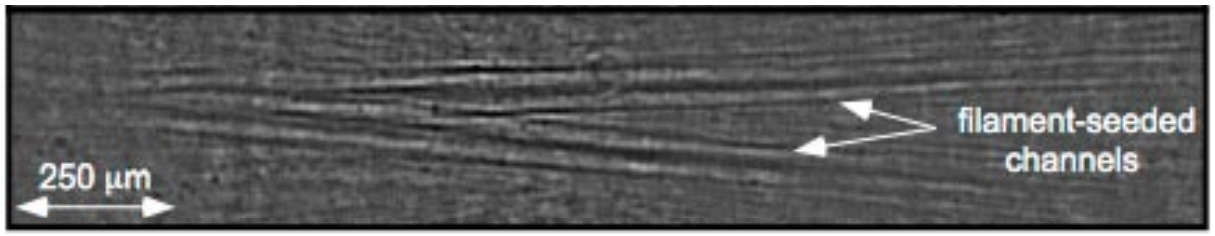
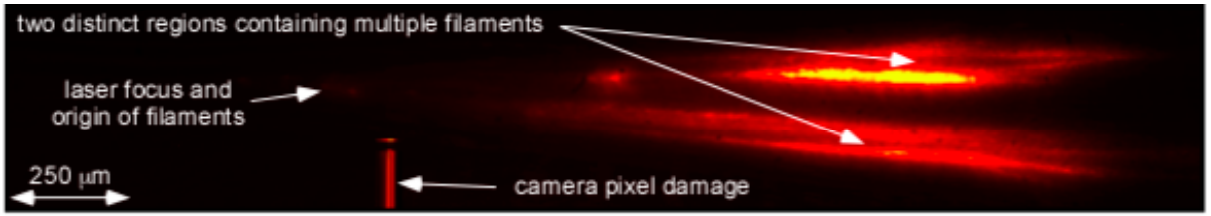


$t = t_0 + 10$ ps



Time-integrated 1.054-μm self-emission

450-TW, 0.65-ps pulses: Channel formation in He plasmas at $n_e = 2 \times 10^{19}$ cm^{-3}

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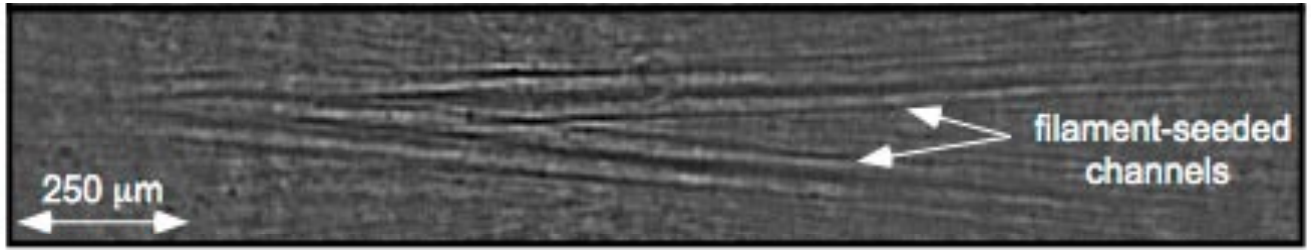
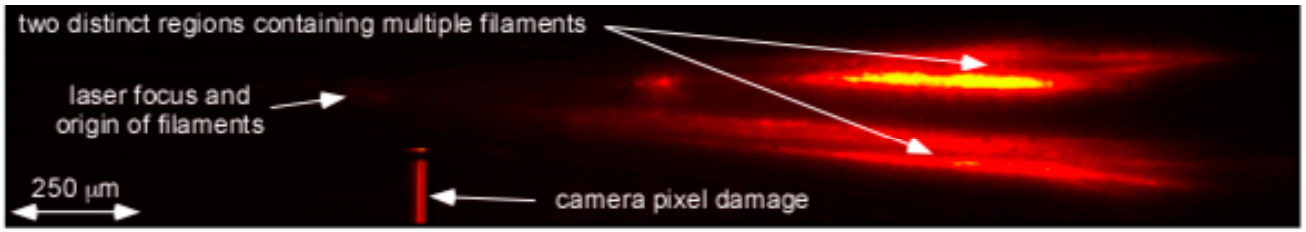


$t = t_0 + 10$ ps



Time-integrated 1.054-μm self-emission

Self-emission occurs from the channel walls.

450-TW, 0.65-ps pulses: Channel formation in He plasmas at $n_e = 2 \times 10^{19}$ cm^{-3}

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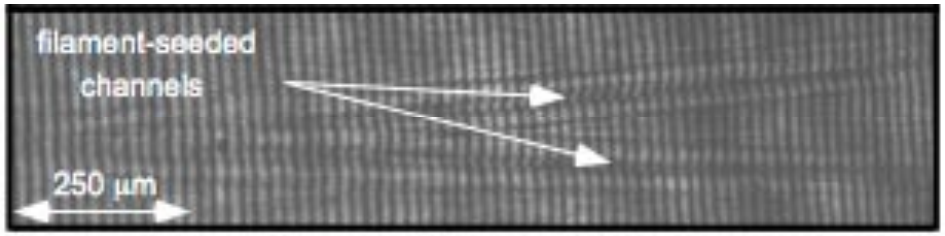
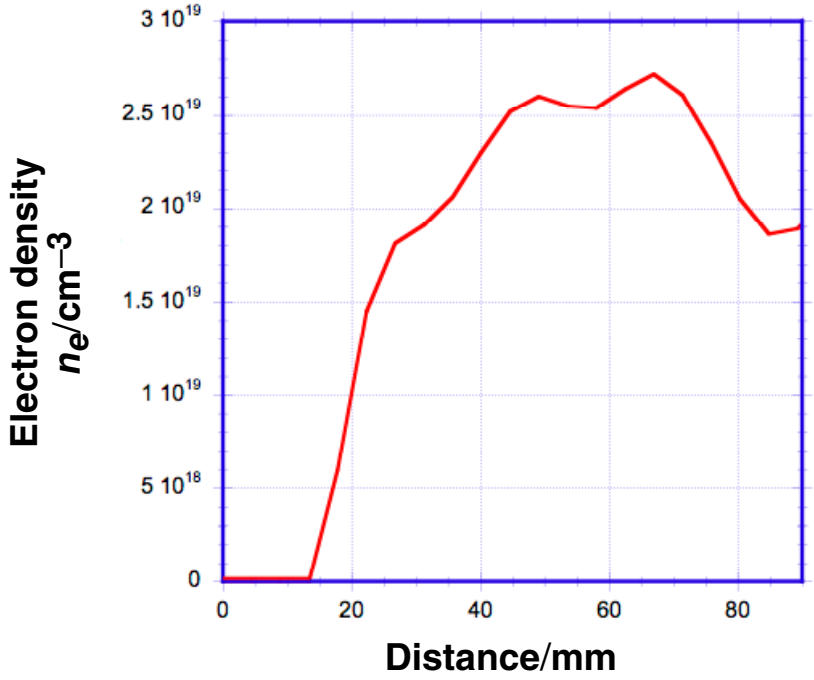


Double-channel interferogram

$t = t_0 + 10$ ps



Radial-channel electron density profile

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Multiple electron beamlets are observed from 450-TW, 0.65-ps laser-pulse interactions in He plasmas

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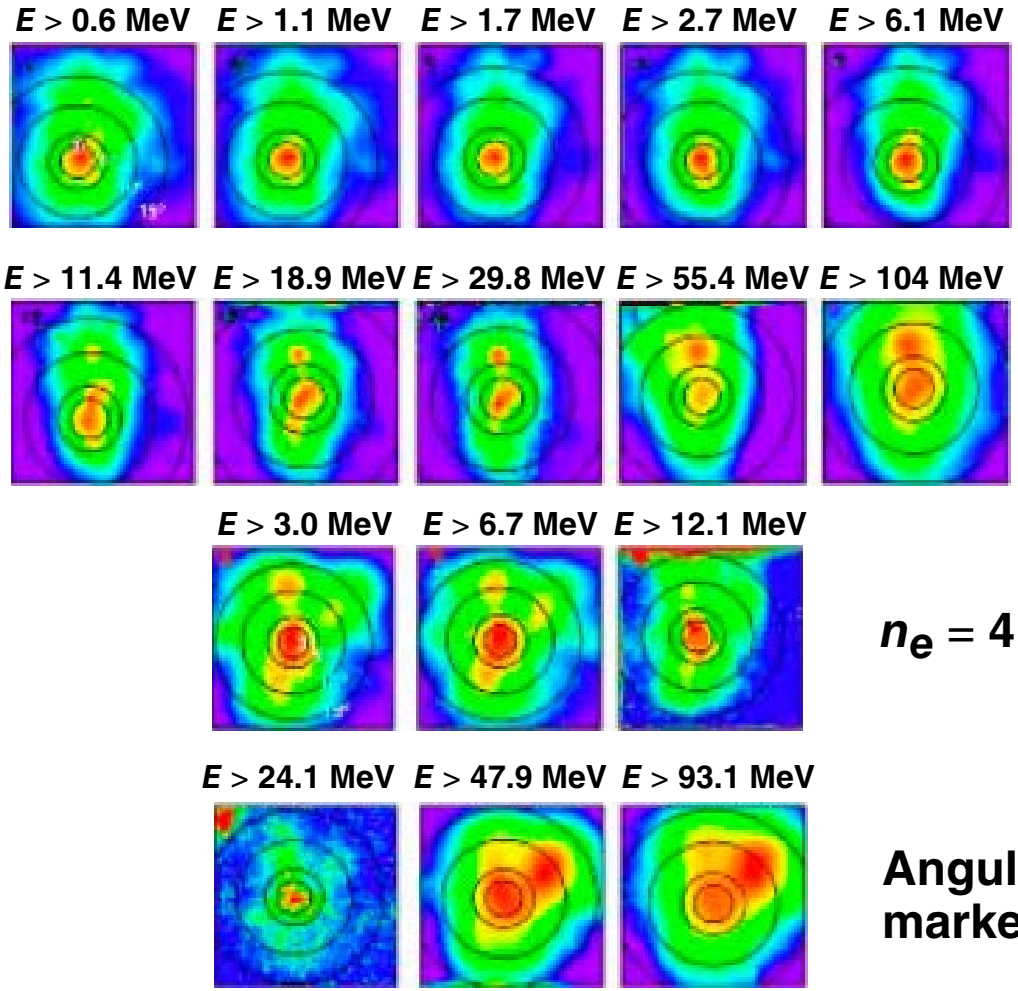

Radiochromic film detector stack

$n_e = 2 \times 10^{19}$ cm^{-3}

$n_e = 4 \times 10^{19}$ cm^{-3}

Angular contours are marked at 3°, 5°, and 15°

E15298

Summary/Conclusions

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