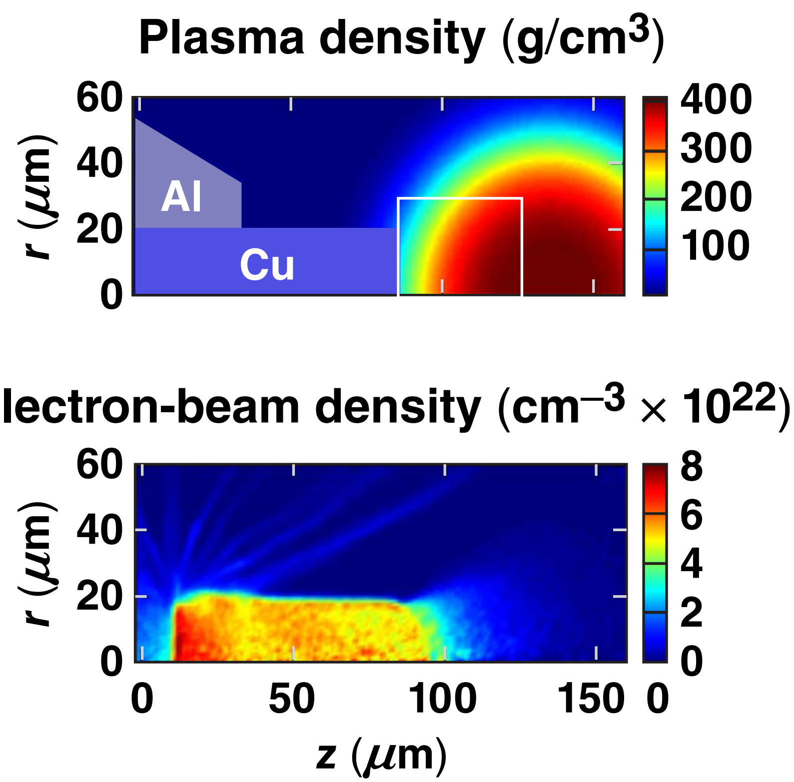
Controlling the Divergence of Laser-Generated Fast Electrons Through Resistivity Gradients in Fast-Ignition Targets



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Summary

Divergence of high-energy electron beams can be controlled through resistivity mismatch in fast-ignition targets*

- *LSP*** simulations predict collimation of high-energy electron beams by resistivity gradients
- Four cases have been modeled
  - Cu cone
  - Al cone with Cu insert in the cone tip
  - Al cone with a Cu wire attached to the cone tip – most effective
  - Cu-lined diamond cone

Collimation by resistivity gradients increases the coupling to the core.

*A. P. L. Robinson and M. Sherlock, Phys. Plasmas 14, 083105 (2007).
**D. R. Welch *et al*., Phys. Plasmas 13, 063105 (2006).

TC9073a

Collaborators

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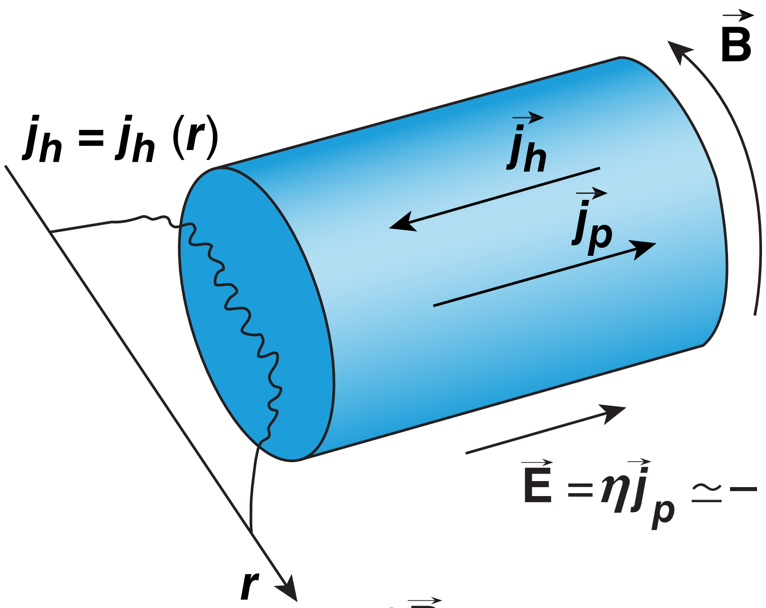
Self-generated resistive magnetic fields can control divergence of electron beams in plasmas*

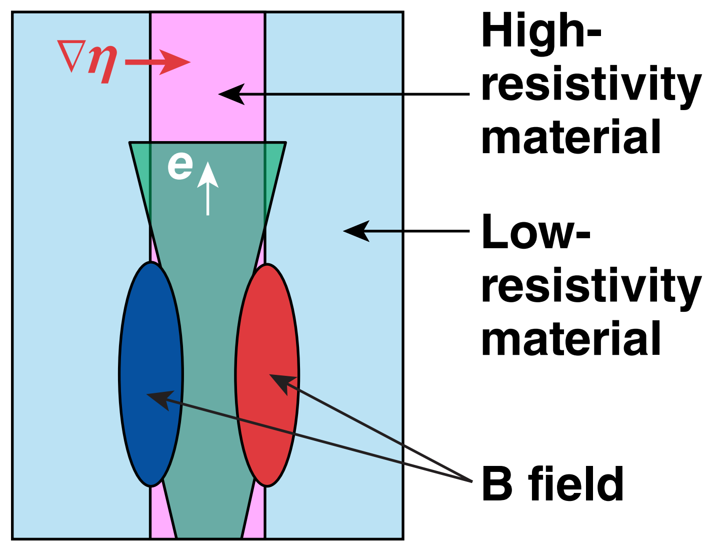


$$\vec{E} = \eta \vec{j}_p \simeq -\eta \vec{j}_h$$

$$\frac{\partial \vec{B}}{\partial t} = -\nabla \times \vec{E}$$

$$\frac{\partial \vec{B}}{\partial t} = \eta \nabla \times \vec{j}_h + \nabla \eta \times \vec{j}_h$$

- **Electron collimation by B fields generated by resistivity gradients***



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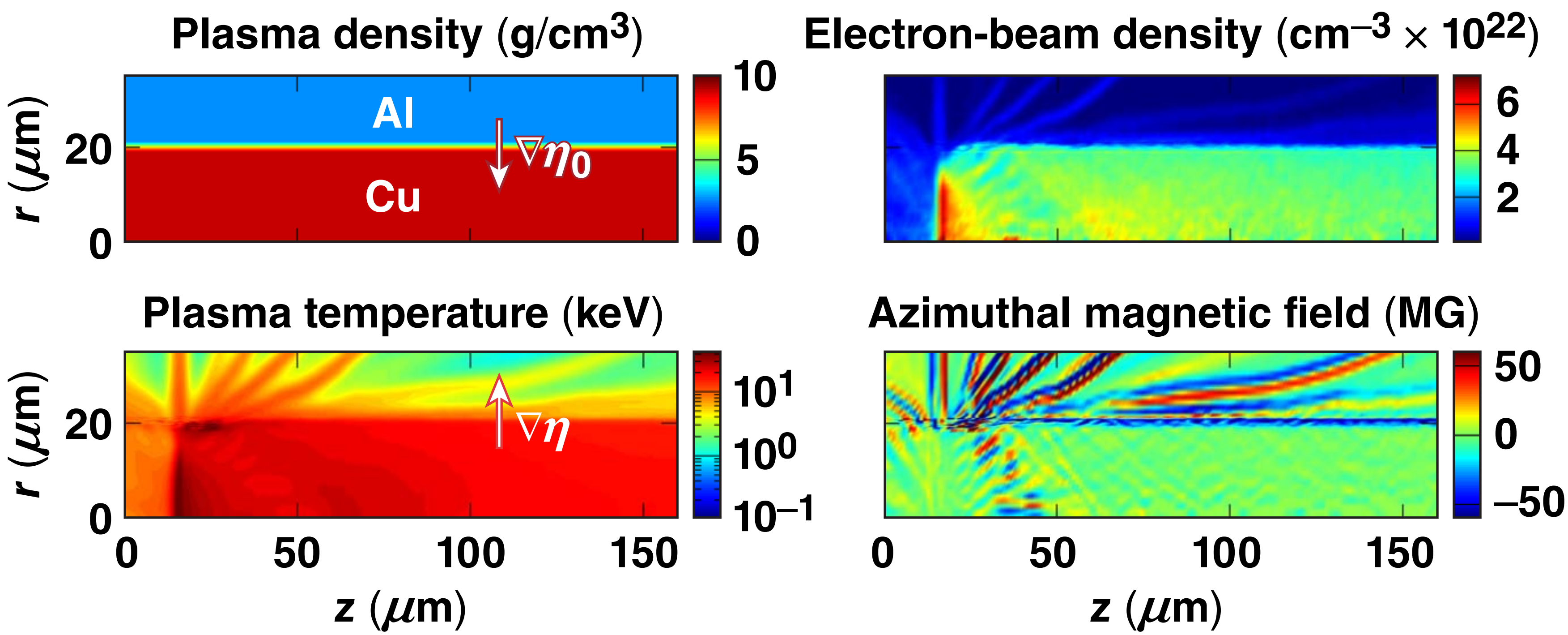
*A. P. L. Robinson and M. Sherlock, Phys. Plasmas 14, 083105 (2007).

A thin Cu fiber embedded in Al effectively collimates a highly divergent 15-kJ electron beam in the *LSP* simulation

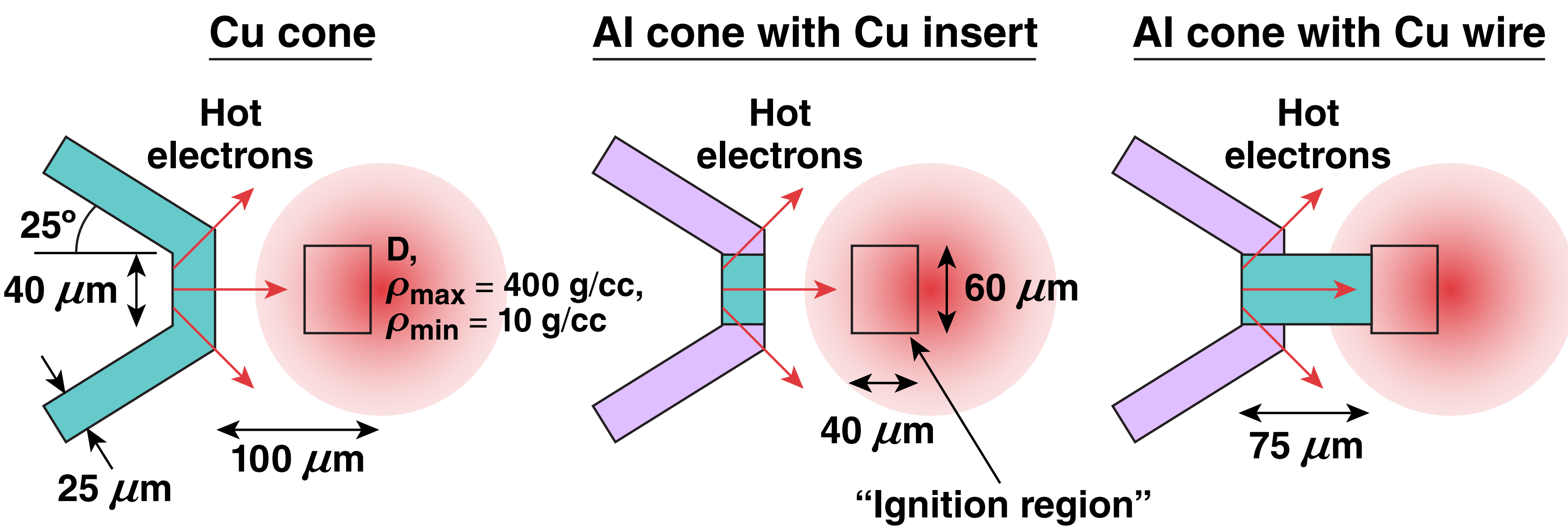
- Simulation for a 7-ps, 2-MeV mean-energy, 67° half-angle electron beam



- Even though $\nabla\eta$ changed direction due to fiber heating, collimation is maintained because $|\eta\nabla \times \vec{j}_h|$ becomes greater than $|\nabla\eta \times \vec{j}_h|$

Collimated electrons contain 65% of the beam energy.

Electron transport in fast-ignition targets using materials with different resistivities has been modeled with *LSP*



- Electron beam: E_{tot} = 40 kJ, τ = 10 ps, r_0 = 20 μm, T_{hot} = 1.6 MeV, $\theta_{1/2}$ = 67°
- Ionization and radiative cooling are modeled
- Energy coupled to the "ignition region" is calculated and compared in the simulations

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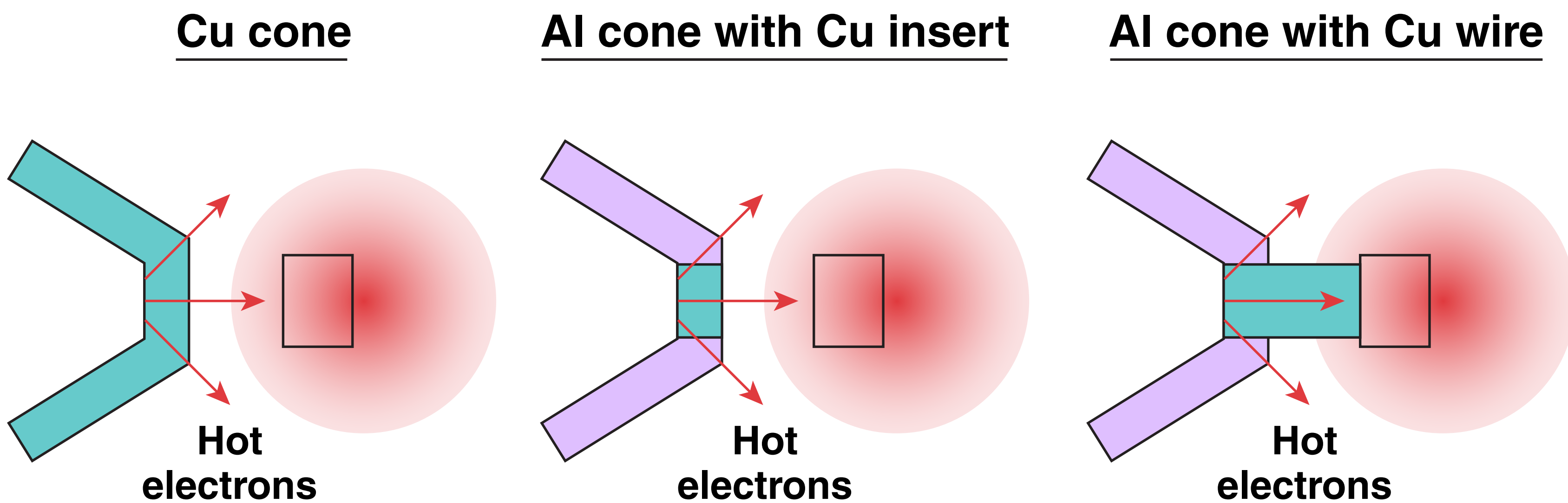
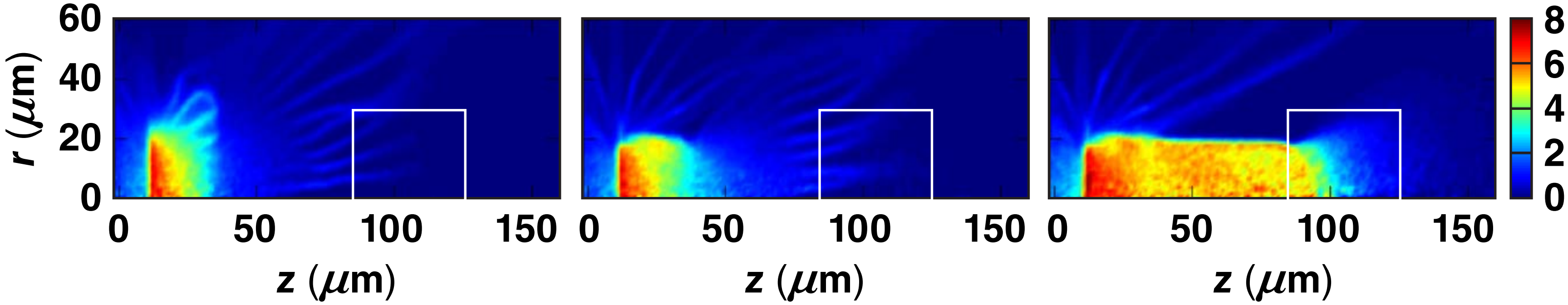
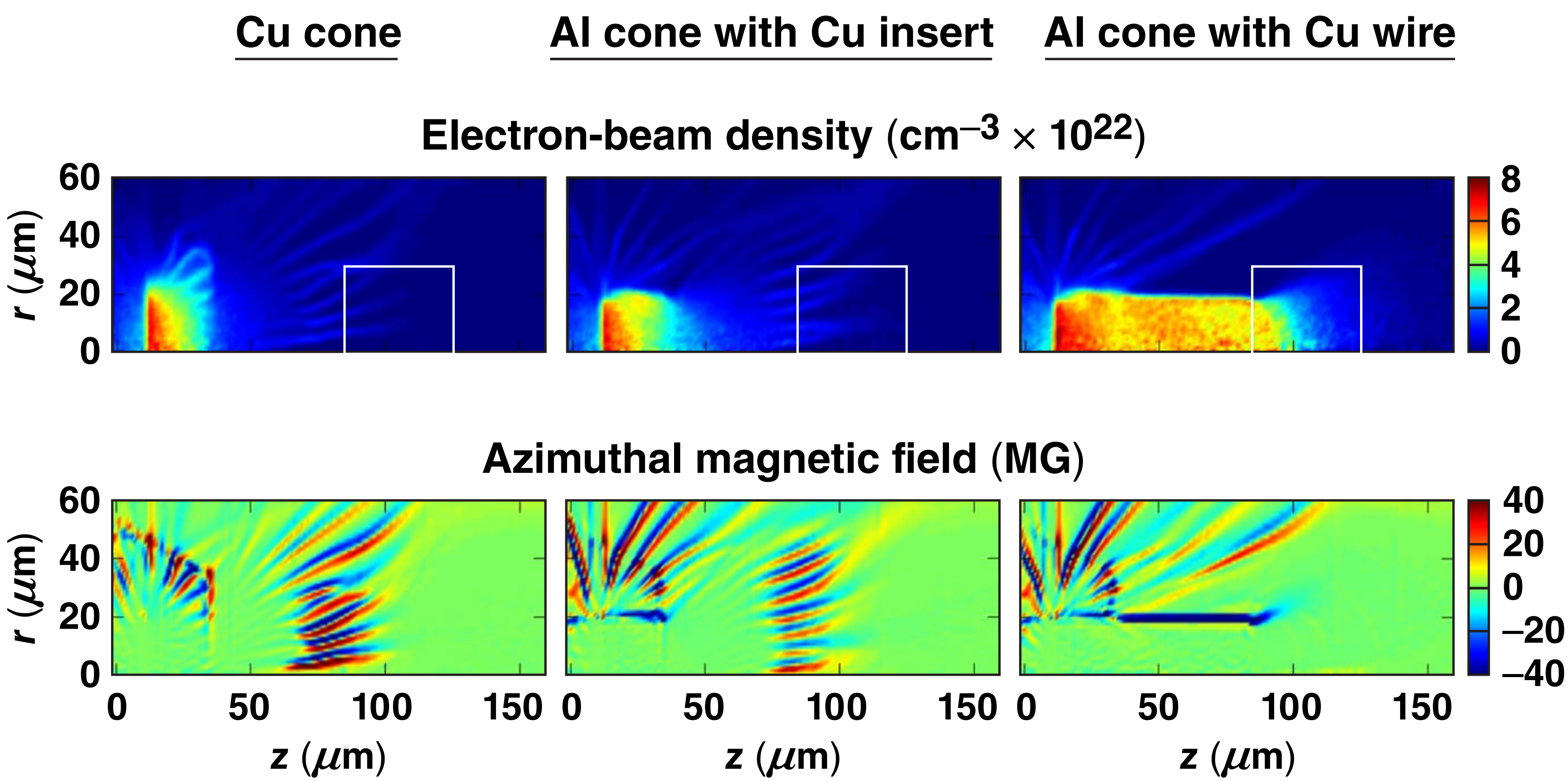
Electrons are effectively collimated by resistivity gradients in the cone tip and in the wire



Electron-beam density ($cm^{-3} \times 10^{22}$) at the time of peak power



Hot-electron divergence is controlled by a resistive magnetic field



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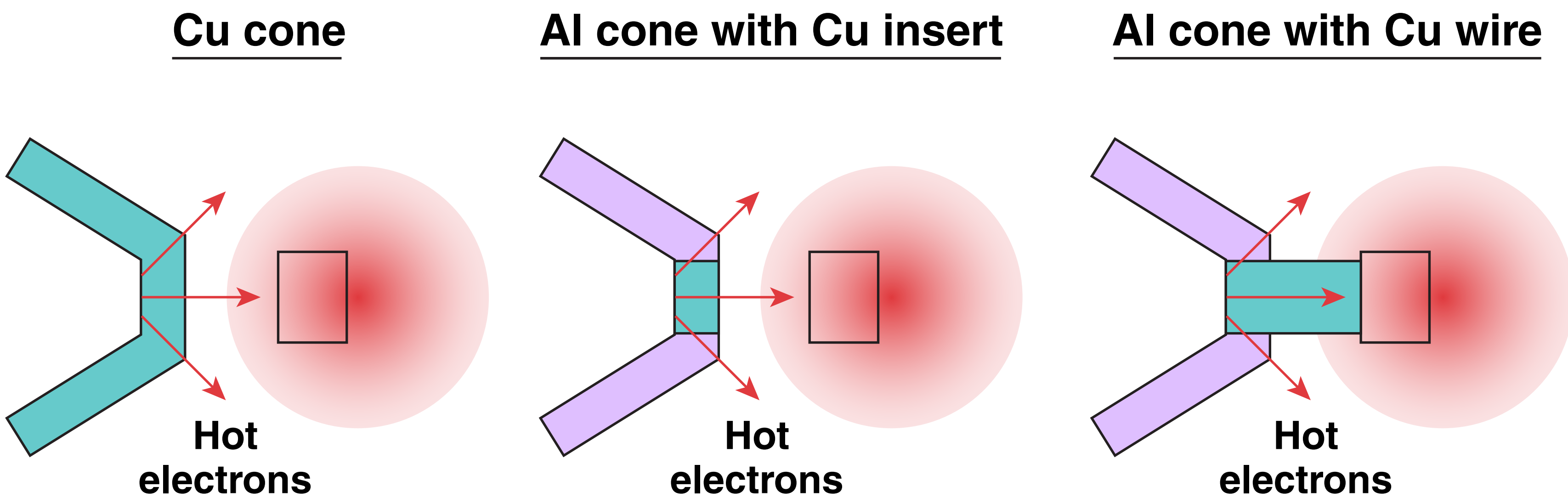
Resistive collimation significantly improves electron coupling to the core

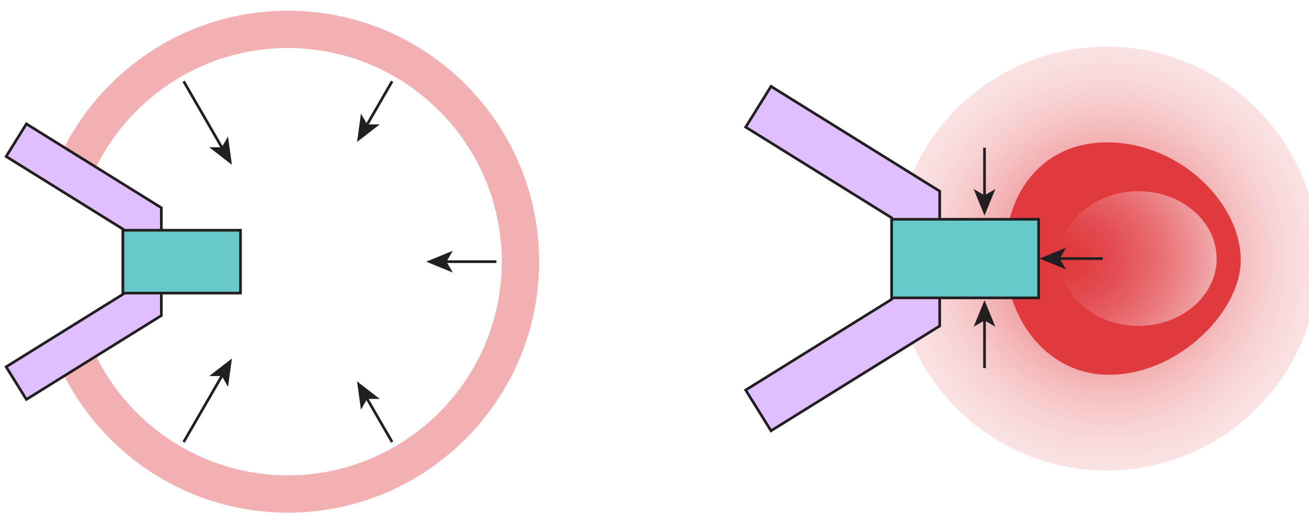


Energy coupled to the "ignition region"		
2.7 kJ (7%)	4.5 kJ (11%)	18 kJ (45%)

- Resistive collimation can be especially useful for targets with thick cone tips

Hydrodynamic simulations are required to determine survivability of the wire during the implosion

- The wire is compressed radially and longitudinally during the implosion
- Asymmetric implosions may be advantageous
  - to protect the wire and the cone from the pressure build-up in the central hot spot
  - to facilitate ignition because of a larger fuel density and larger ρR in front of the wire



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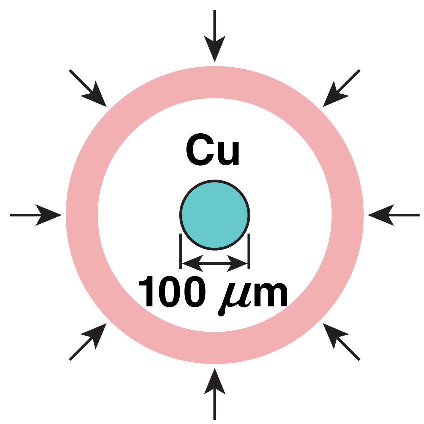
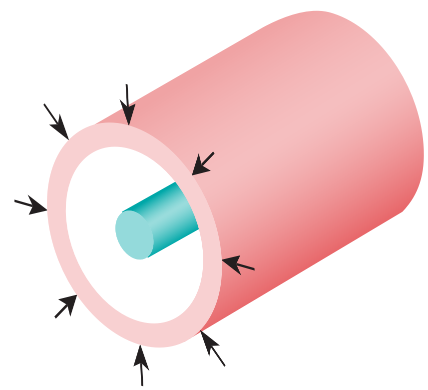
1-D *LILAC** simulations of capsule implosion on a copper sphere and a copper cylinder predict the compressed copper properties





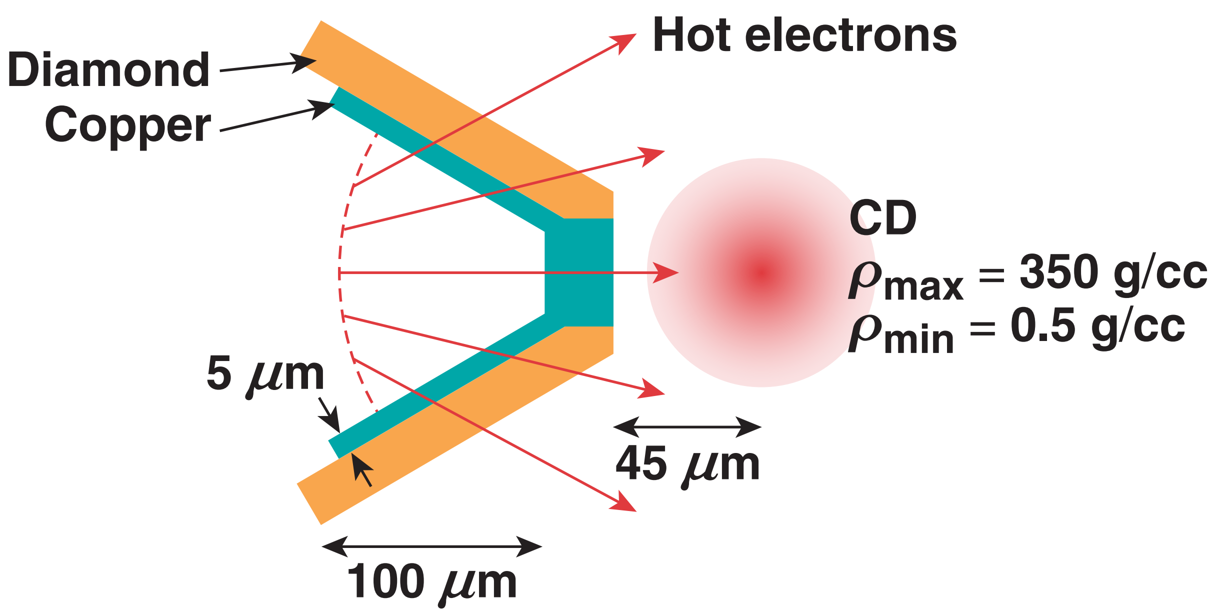
	Diameter (μm)	Density (g/cm^3)	Temperature (eV)	Cu resistivity ($\Omega \times$ m)	DT resistivity ($\Omega \times$ m)
Cu sphere	26	500	600	7×10^{-8}	10^{-9}
Cu cylinder	26	150	275	2×10^{-7}	10^{-8}

- Simulations use a 200-kJ DT target design for direct-drive fast ignition**
- Increased stopping power in a compressed copper may require using higher-energy electrons for ignition (2 to 5 MeV)

*J. A. Delettrez *et al*., Phys. Rev. A 36, 3926 (1987).
**R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).

TC9407

Electron collimation by a high-resistivity material at the inner-cone surface has been modeled



- Diamond cone with Cu tip and Cu inner layer
- Cu pre-plasma: $\rho = 0.02\ \rho_{solid}$ with 1.5-μm exponential gradient length at the cone surface
- Electron beam: E_{tot} = 300 J, τ = 10 ps, r_0 = 14 μm, T_{hot} = 1 MeV, $\theta_{1/2}$ = 67°

Hot-electron collimation in a Cu-lined cone is not as effective as in the wire

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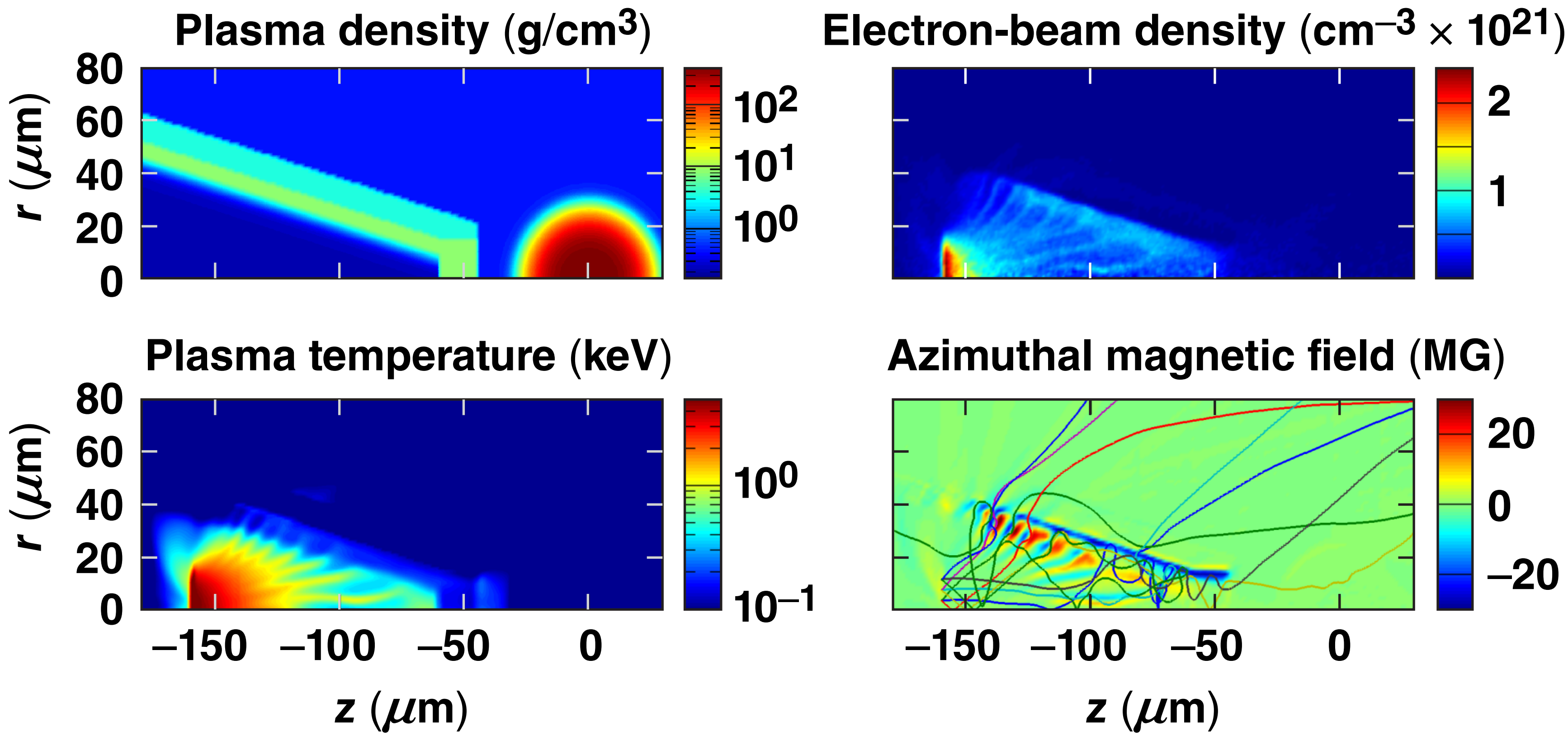
- Simulation results at t = 5 ps



Electrons collimated to the cone tip contain 17% of the beam energy.

TC9409

Summary/Conclusions

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