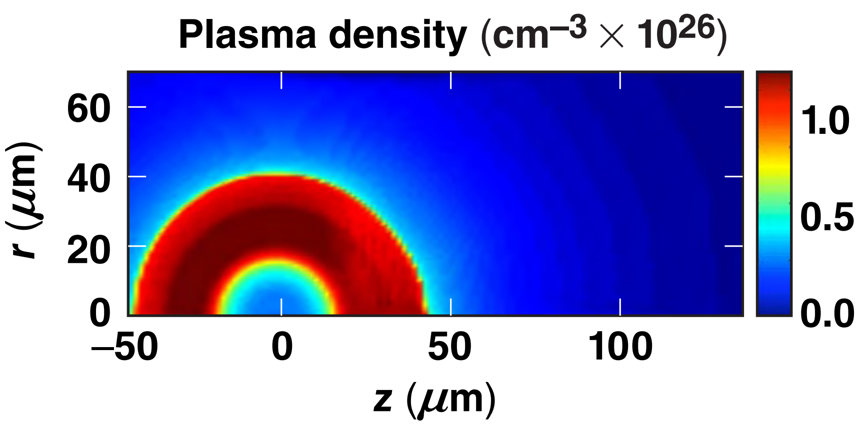
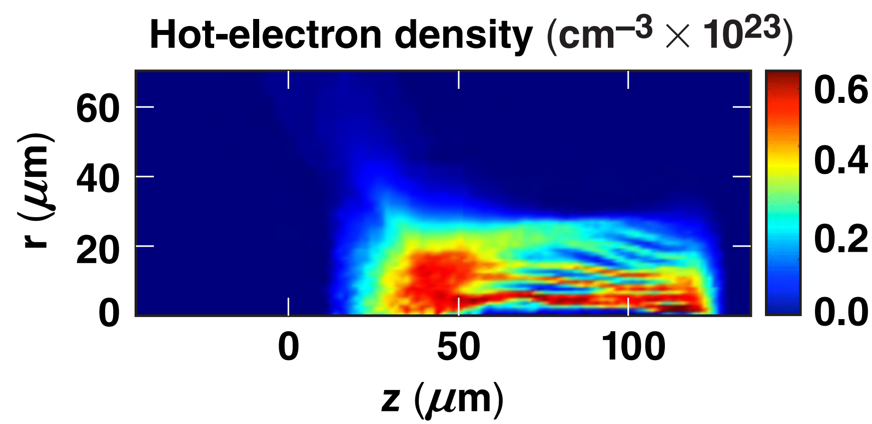
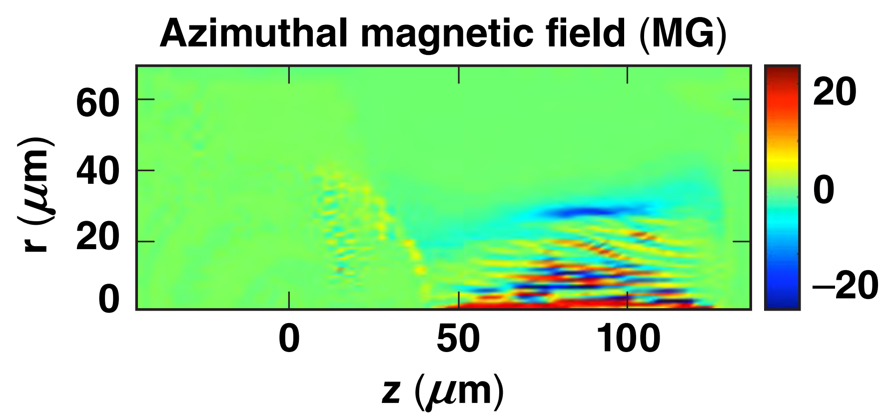
Integrated Simulation of Fast-Ignition ICF





300-kJ fuel assembly
e-beam: $\langle E \rangle = 2.2$ MeV, $\Delta E_{th} = 0.3 \langle E \rangle$,
$r_{FWHM} = 30$ μm, $t = 2.5$ ps,
opening half angle = 20°



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Summary

We have coupled the hybrid PIC code *LSP*[1] and the fluid code *DRACO*[2] to perform an integrated fast-ignition simulation

- *LSP*[1] is used to simulate the transport of hot electrons in the dense plasma of fast-ignition targets.
- *DRACO*[2] is used to simulate the implosion, ignition, and burn.
- Preliminary results show ignition of optimized spherically symmetric targets[3] by a 35-kJ, 2-MeV Gaussian electron beam.
- Beam collimation by the resistive magnetic field reduces the energy required for ignition.

[1]D. R. Welch *et al*., Phys. Plasmas 13, 063105 (2006).
[2]P. B. Radha *et al*., Phys. Plasmas 12, 056307 (2005).
[3]R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).

Collaborators

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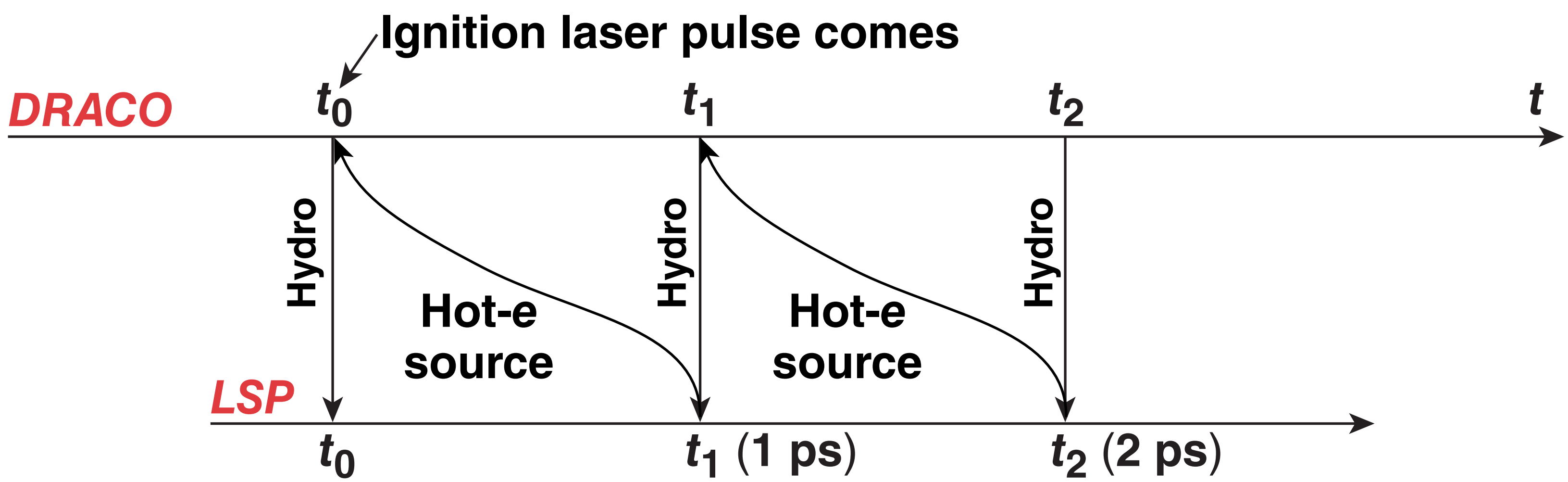
LSP is used to simulate the hot-electron transport and energy deposition, while *DRACO* is used to simulate the target hydrodynamics and burn

- *DRACO*
  - 2-D cylindrically symmetric hydrodynamic code
  - includes all the necessary physics required to simulate ignition and burn of the imploded capsules
  - does not simulate the hot-electron transport and energy deposition
- *LSP*
  - 2-D/3-D implicit-hybrid PIC code
  - implicit solution for the electromagnetic fields and implicit particle push
  - hybrid fluid-kinetic description for plasma electrons
  - intra- and interspecies collisions based on Spitzer rates (have been corrected to include relativistic effects)
  - does not simulate fusion reactions and α-particle transport
  - uses ideal gas equation of state

LSP is used to generate a hot-electron source term in the temperature equation solved by *DRACO*



- *LSP* generates the time history of hot-electron-energy deposition in plasma to be used in *DRACO*
- Hydrodynamic profiles in *LSP*: electron and ion temperatures, densities, and velocities are periodically updated according to *DRACO* results (fluid species). Electromagnetic fields and hot-electron distributions (kinetic species) are not changed.

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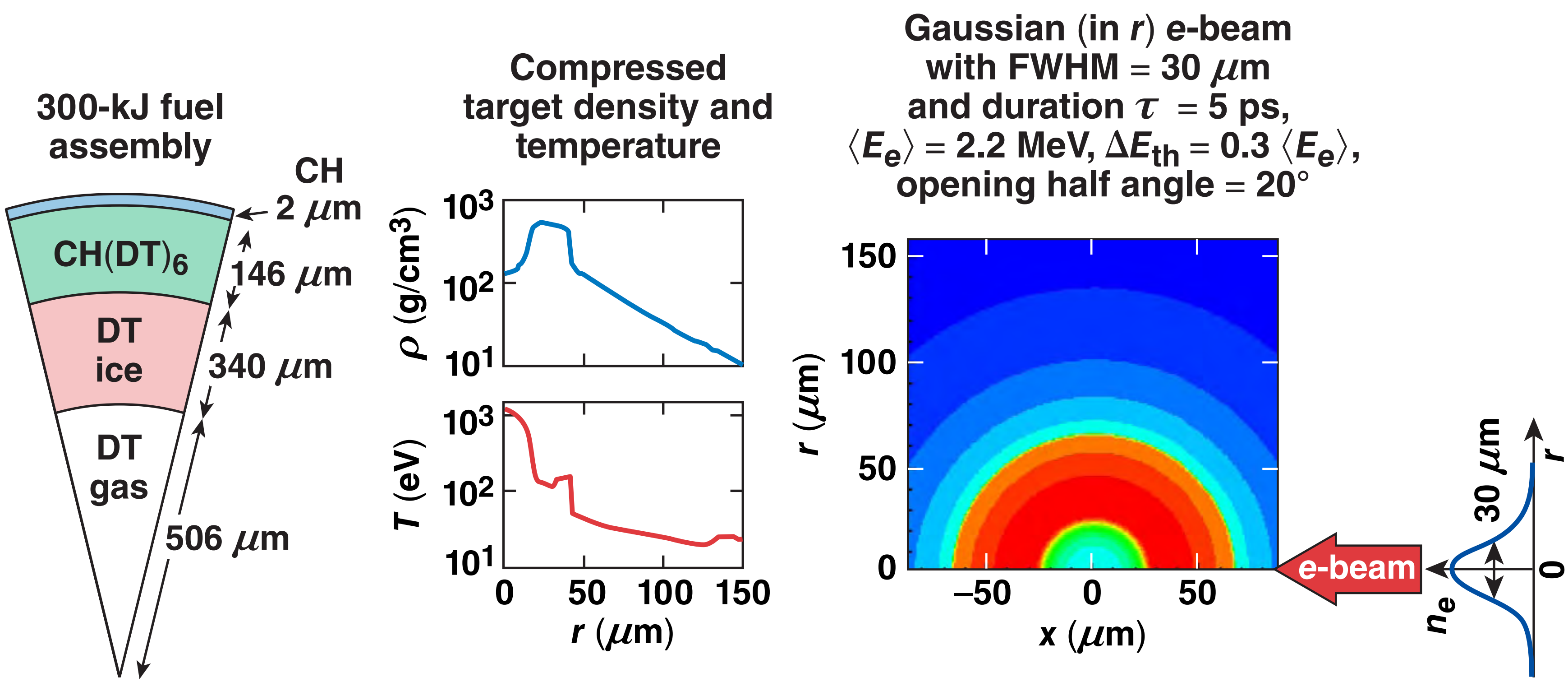
In the integrated simulation, an imploded optimized fast-ignition target* is heated by a 2.2-MeV, r_0 = 30-μm electron beam



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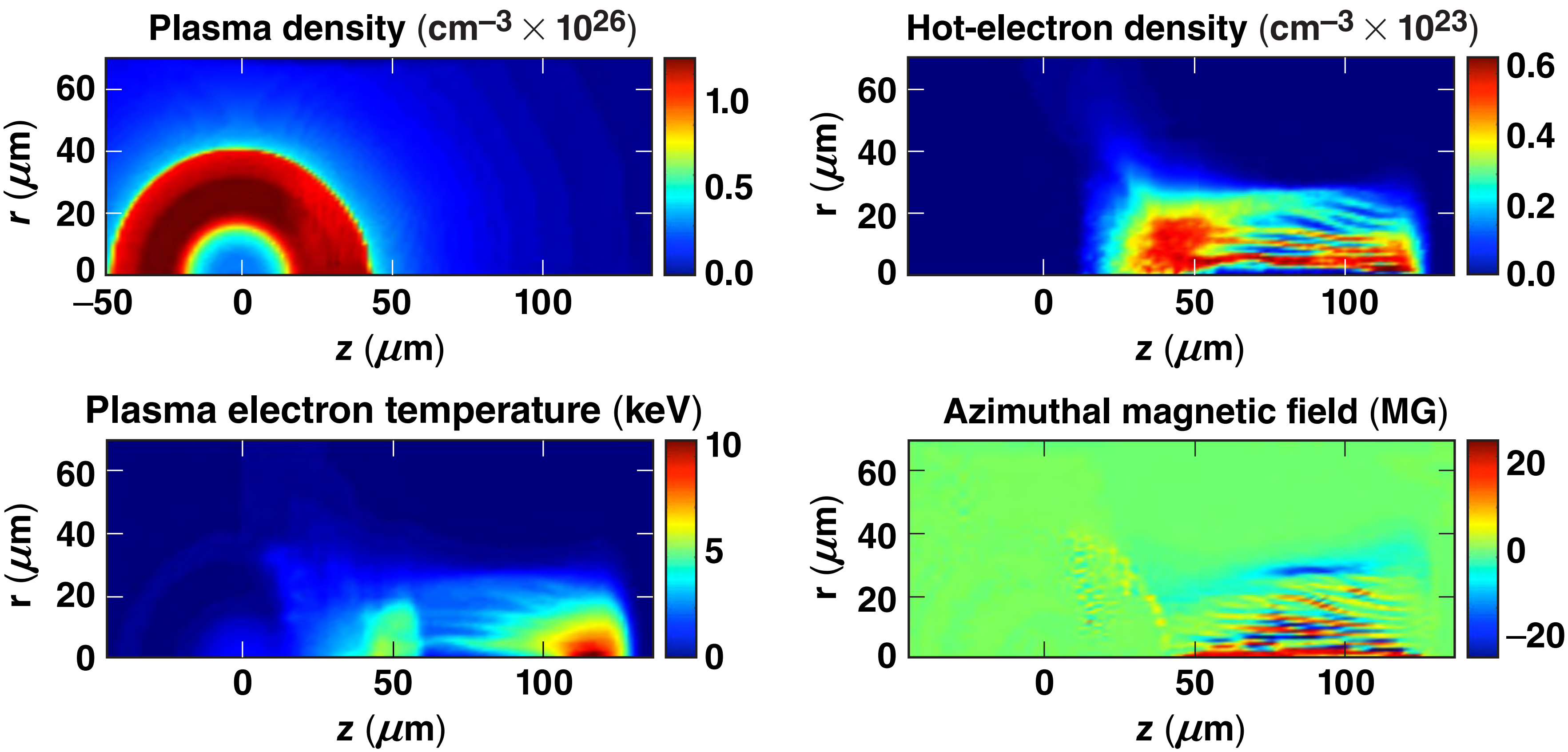
*R. Betti and C. Zhou, Phys. Plasmas 12, 110702 (2005).

LSP simulations show resistive filamentation of the e-beam;[1,2] the magnetic field helps to collimate the beam

Snapshots at t = 2.5 ps after the beginning of the e-beam



[1]L. Gremillet *et al*., Phys. Plasmas 9, 941 (2002).
[2]J. J. Honrubia and J. Meyer-ter-Vehn, Nucl. Fusion 46, L25 (2006).

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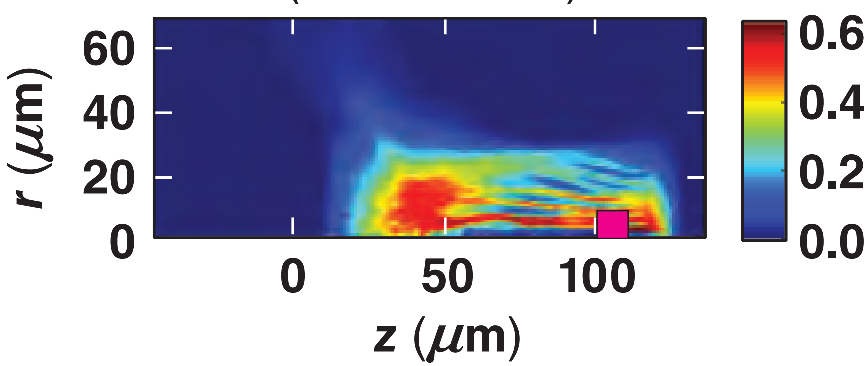
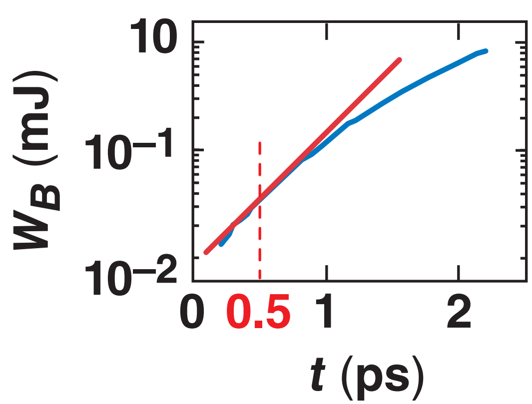
The resistive-filamentation instability growth rate in the simulation is in agreement with theoretical predictions[1]

Electron-beam density at $t = 2.5$ ps
($cm^{-3} \times 10^{23}$)



Magnetic-field energy in the region ■



$\Gamma^{sim} = 1.4 \times 10^{12}\ s^{-1}$

(From Ref. 1)
Linear instability growth rate

$$\Gamma^{theory} = \frac{2}{\tau_d \gamma_b}\left(\frac{\beta_b}{\beta_b^{th}}\right)^2,$$

where the magnetic diffusion time

$$\tau_d = \mu_0 c^2 \Big/ \left(\eta \omega_b^2\right);$$

$\Gamma^{theory} \approx 1.7 \times 10^{12}\ s^{-1}$
at $t = 0.5$ ps

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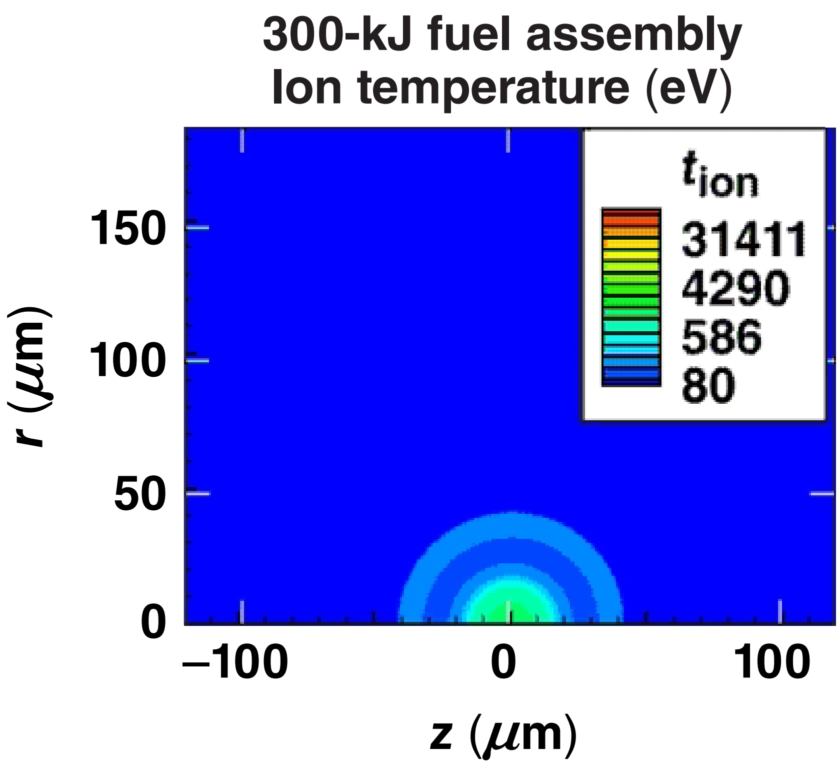
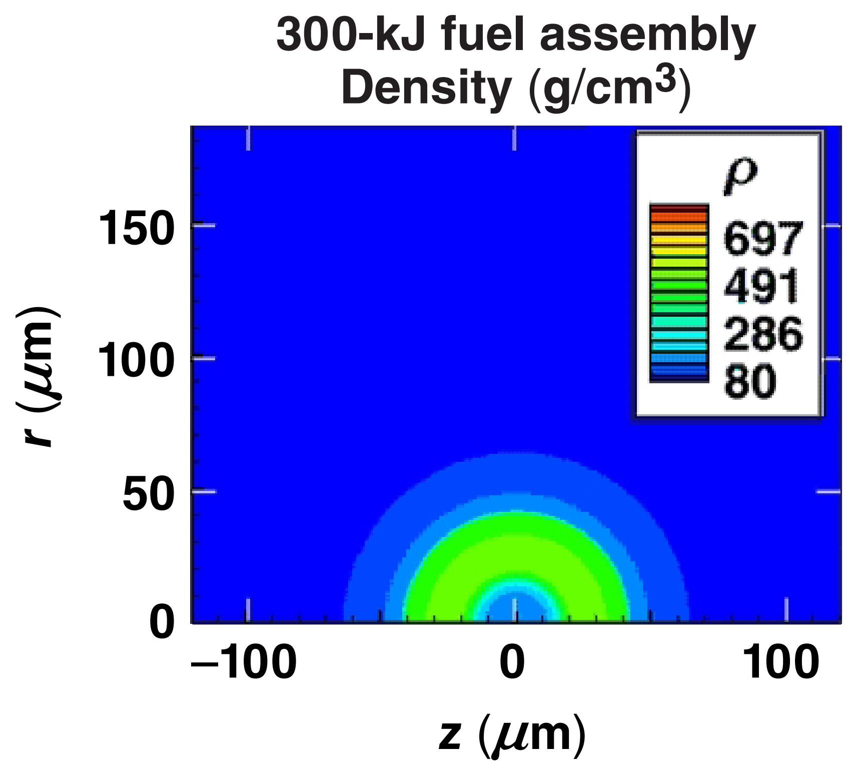
[1]L. Gremillet *et al*., Phys. Plasmas 9, 941 (2002).

Ignition is triggered by a 35-kJ electron beam in the integrated simulation





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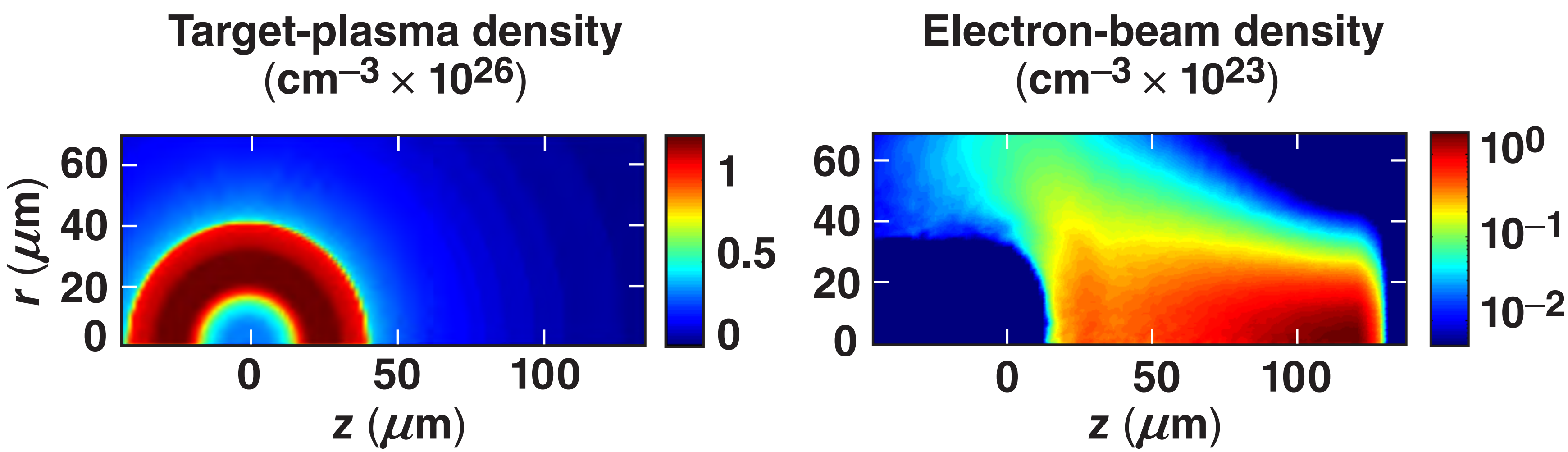
Simulation with the magnetic field artificially suppressed predicts a minimum energy for ignition of 100 kJ for the same e-beam properties



Beam collimation by the resistive magnetic field reduces the energy required for ignition.

Summary/Conclusions

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