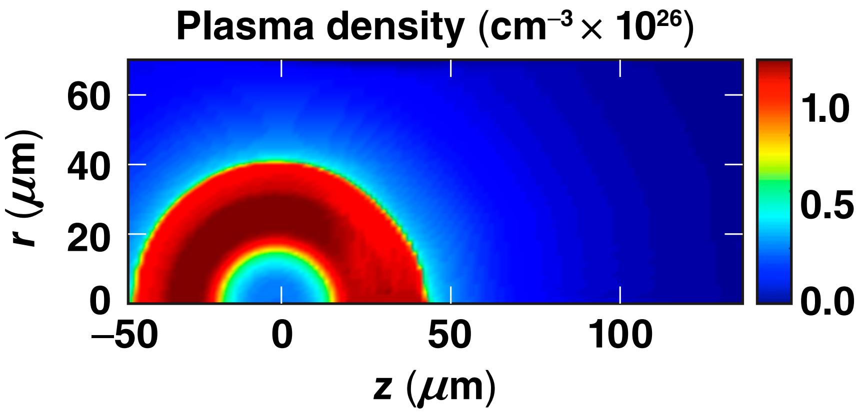
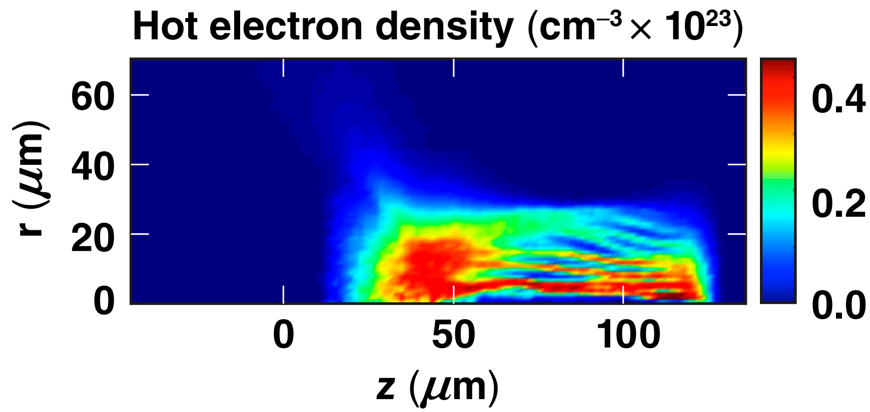
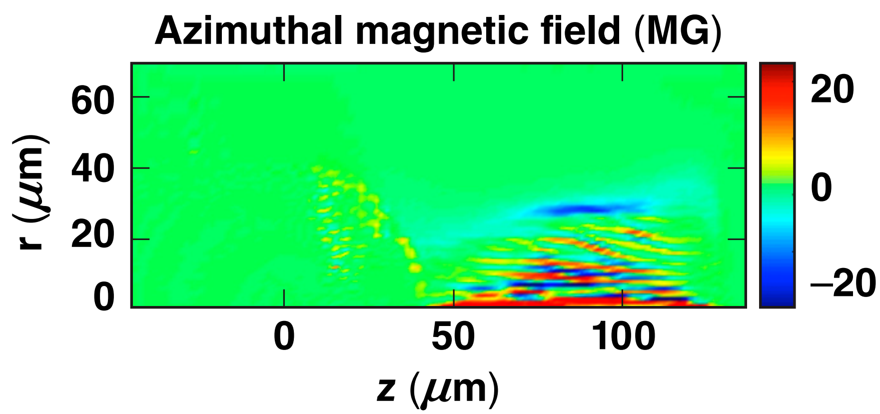
Integrated Simulation of Fast-Ignition ICF





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 simulations show the importance of resistive filamentation and ignition of optimized spherically-symmetric targets[3] by a 35 kJ, 2 MeV Gaussian electron beam
- We plan to simulate the whole fast-ignition experiment when the cone-in-shell target capability will be available in *DRACO* (under development)
- Similar projects are under development at LLNL, ILE (Osaka University, Japan), and Universidad Politecnica de Madrid (Spain)

[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).

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Collaborators

K. S. Anderson

R. Betti

V. Gotcheva

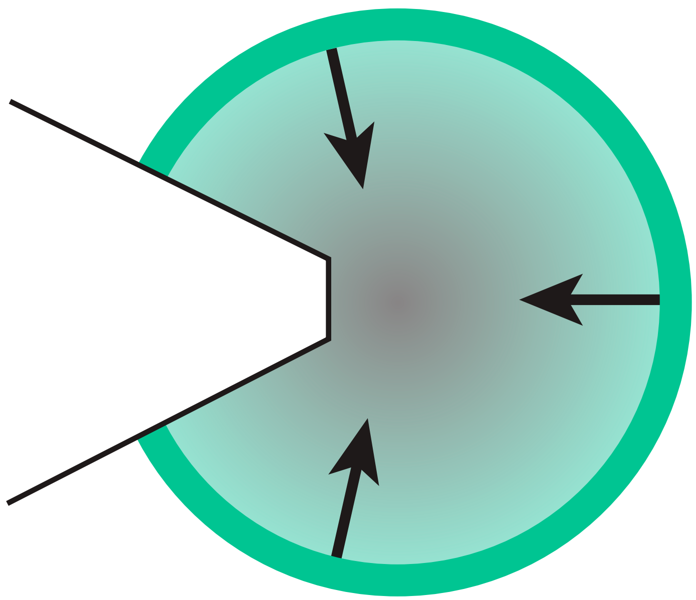
J. Myatt

J. A. Delettrez

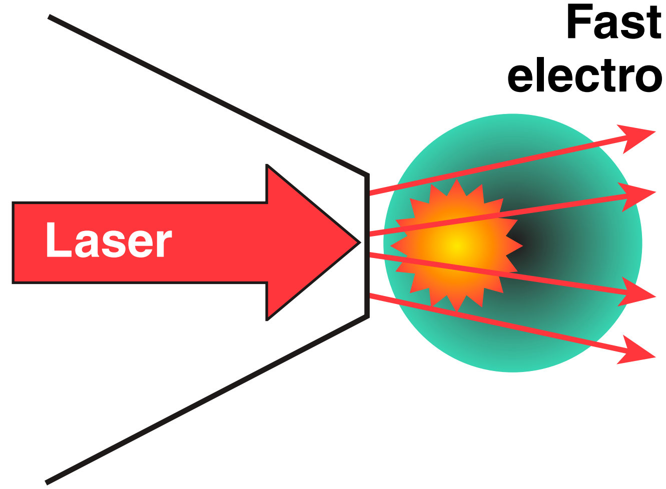
S. Skupsky

We plan to simulate the whole fast-ignition experiment including implosion of cone-in-shell targets and transport of hot electrons from the inner cone surface to the dense core

Implosion



Ignition



- The generation of hot electrons by a PW laser pulse will be described based on the results obtained by others*

*Y. Sentoku *et al.*, submitted to Phys. Rev. Lett.
S. C. Wilks *et al.*, Phys. Rev. Lett. 69, 1383 (1992).

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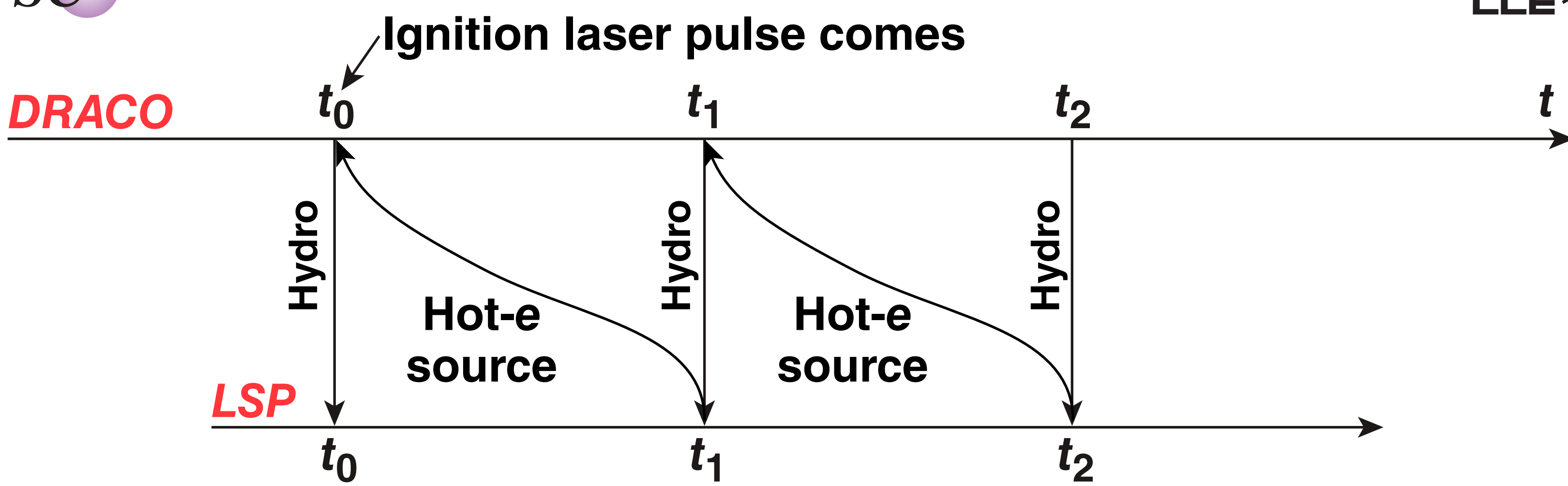
In the integrated simulation we use *LSP* to simulate the hot-electron transport and energy deposition and use *DRACO* to simulate the target hydrodynamics, ignition, and burn

- *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

In the integrated simulation *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.
- In *LSP*, multiple species are used for hot electrons with different energies to model the energy dependence of the stopping power and scattering coefficients

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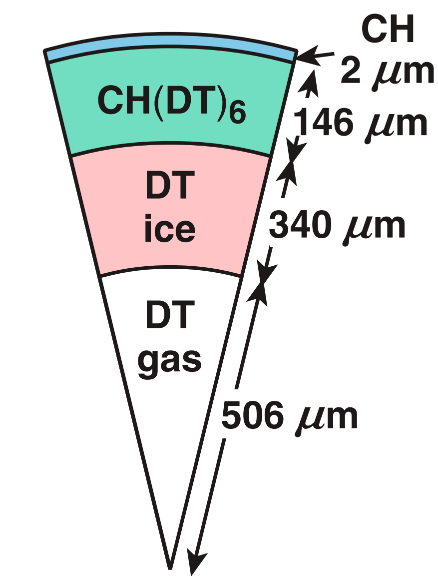
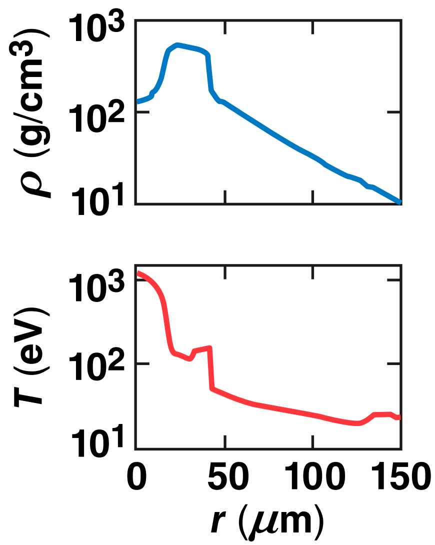
In the integrated simulation an imploded optimized fast-ignition target* is heated by a 2.2-MeV, r_0 = 30-μm electron beam

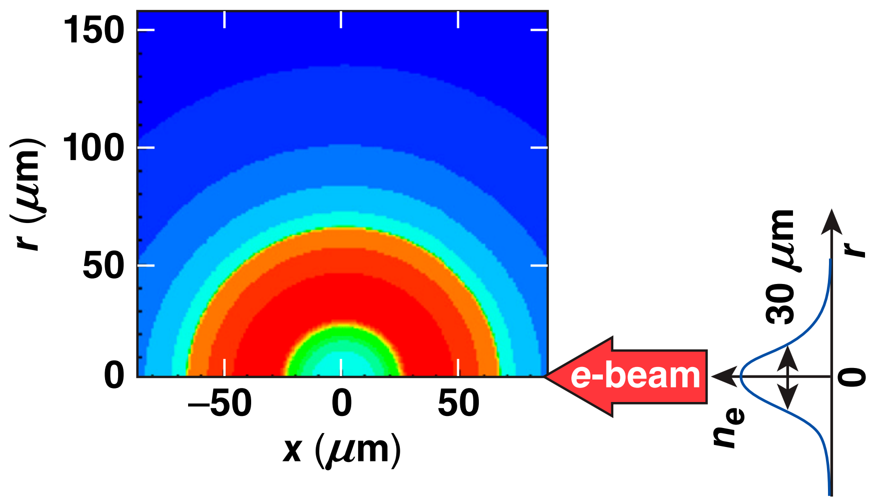
300-kJ fuel assembly



Compressed target density and temperature



Gaussian (in r) e-beam with FWHM = 30 μm and duration τ = 5ps, $\langle E_e \rangle$ = 2.2 MeV, ΔE_{th} = 0.3 $\langle E_e \rangle$, opening half angle = 20°



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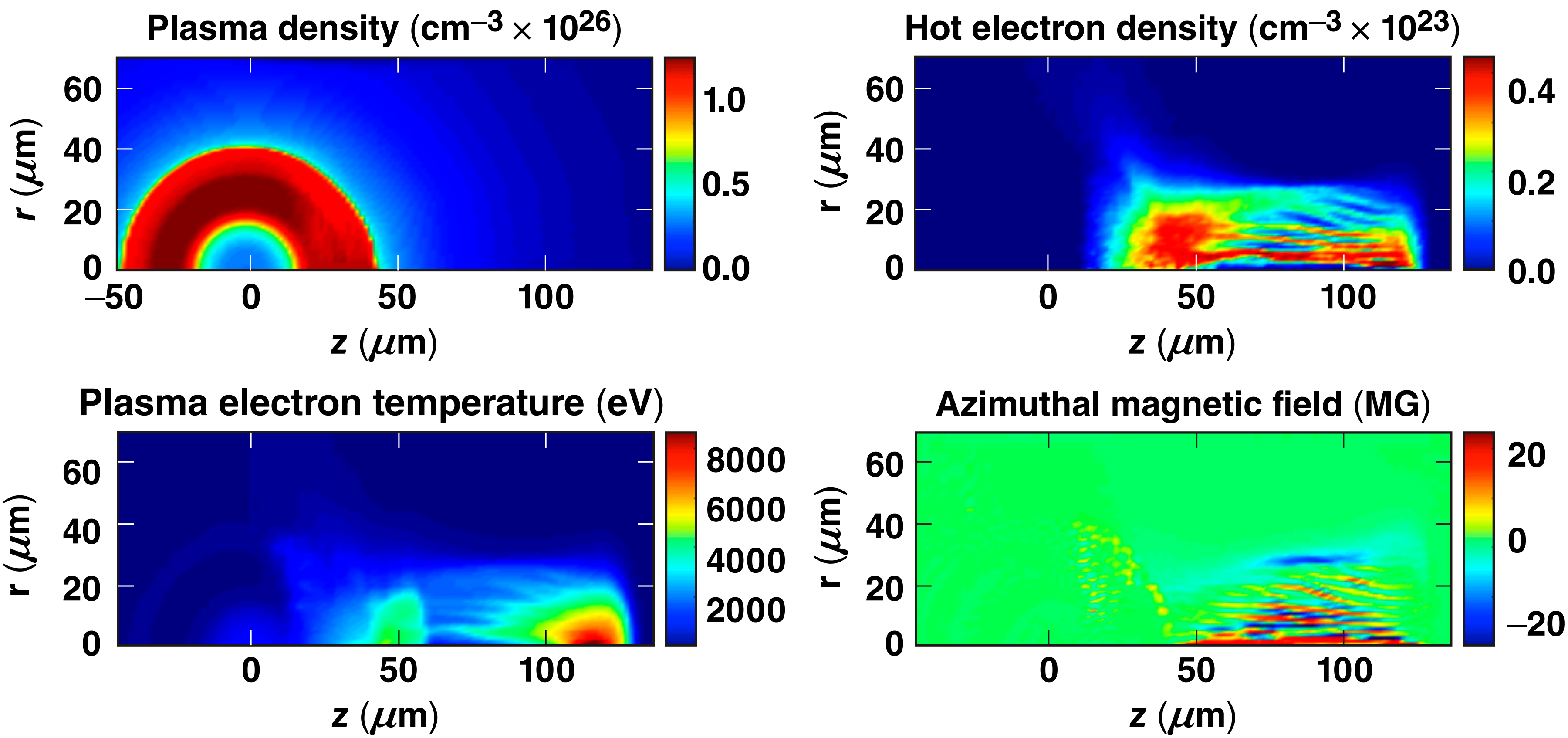
*R. Betti and C. Zhou, Phys. Plasmas <u>12</u>, 110702 (2005).

LSP simulations predict resistive filamentation of the electron beam[1,2]

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



The linear instability growth rate $\gamma \simeq 4 \times 10^{12}$ s^{-1} is in agreement with Ref. 1.

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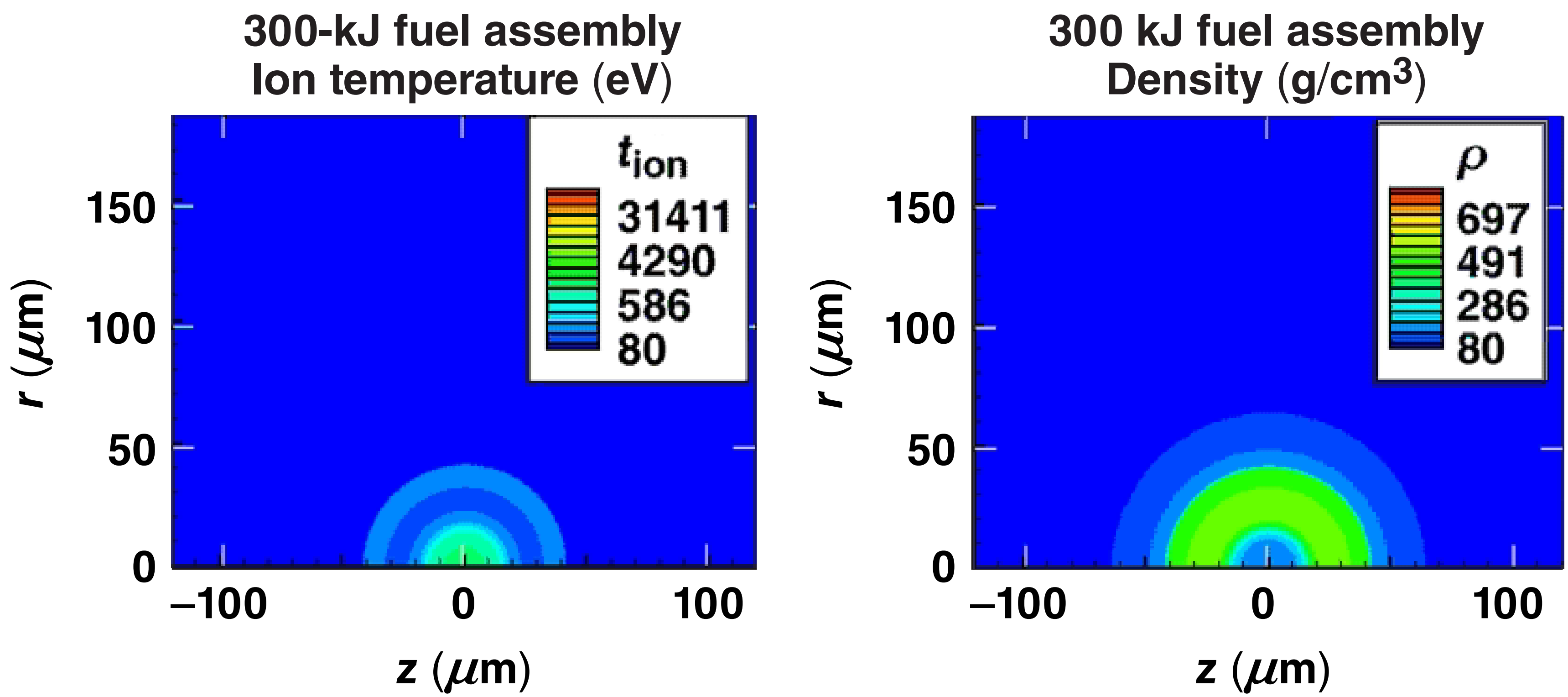
[1]L. Gremillet *et al.*, Phys. Plasmas 9, 914 (2002).
[2]J. J. Honrubia and J. Meyer-ter-Vehn, Nucl. Fusion 46, L25 (2006).

Ignition is triggered by a 32-kJ electron beam in the integrated simulation



[1]A. A. Solodov *et al*., Phys. Plasmas 14, 062701 (2007).
[2]C. K. Li and R. D. Petrasso, Phys. Rev. E 70, 067401 (2004).

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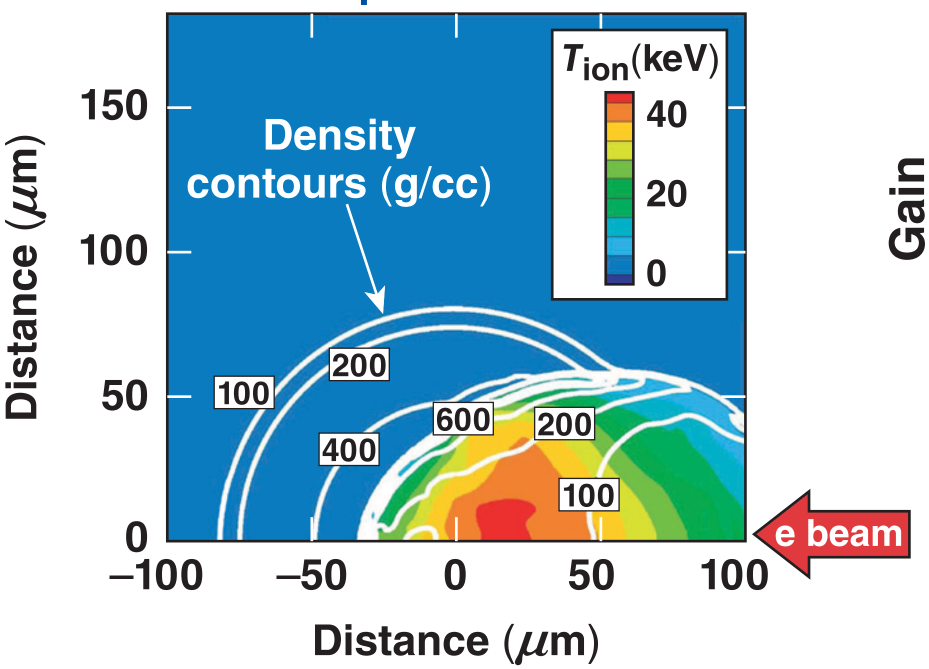
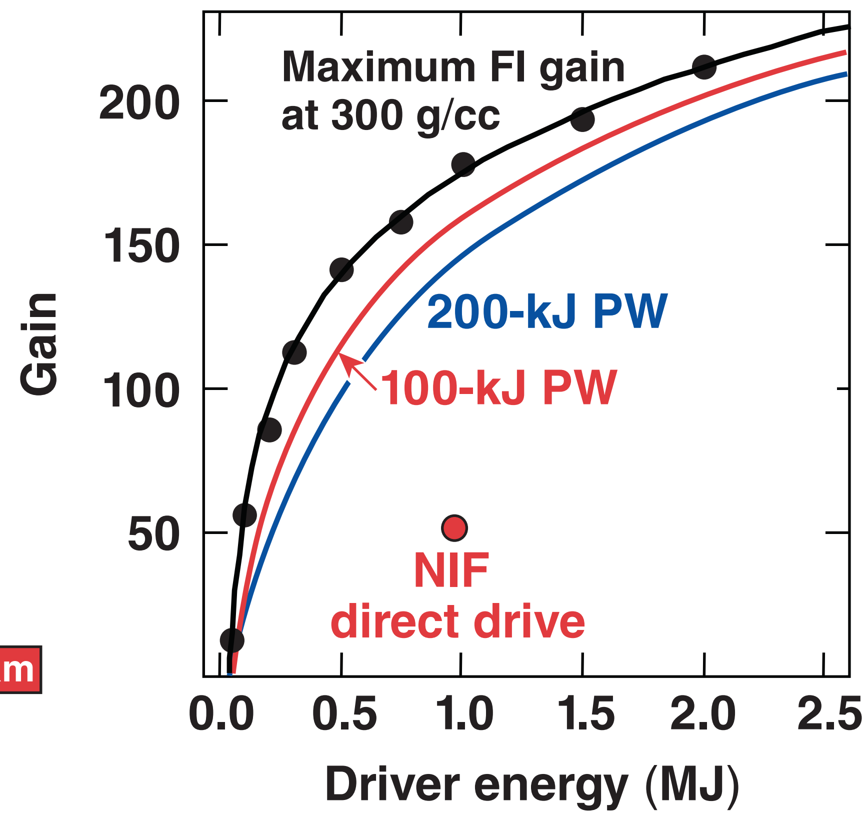
Previous hydrodynamic simulations of fast-ignition[1] (Atzeni-like) predicted the minimum energy for ignition of 17 kJ using 2-MeV, r_0 = 20-μm collimated electron beams

2-D *DRACO* simulation of ignition and burn[1] by 17-kJ, 2-MeV, 20-μm, 10-ps collimated e-beam.

Straight-line electron transport model.[2, 3]





[1]A. A. Solodov *et al*., Phys. Plasmas 14, 062701 (2007).
[2]J. A. Delettrez *et al*., Plasma Phys. Control Fusion 47, B791 (2005).
[3]C. K. Li and R. D. Petrasso, Phys. Rev. E 70, 067401 (2004).

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Summary/Conclusions

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

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