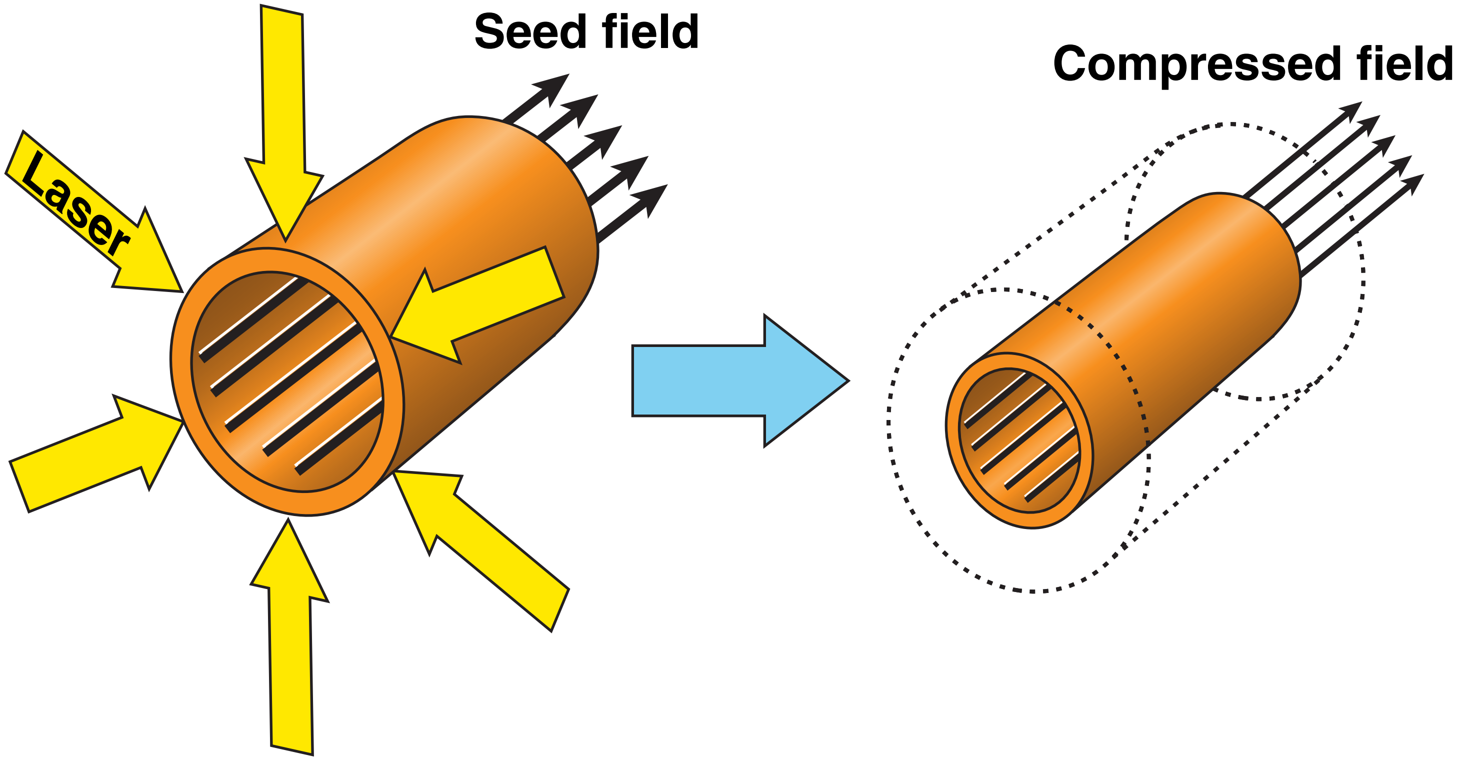
Theory and Simulation of Laser-Driven Magnetic-Field Compression



N. W. Jang
University of Rochester
Laboratory for Laser Energetics

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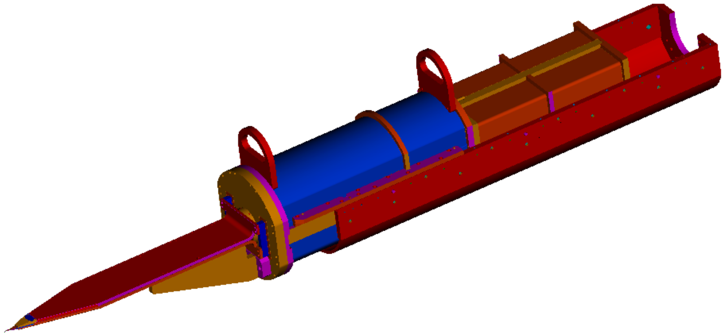
Summary

Magnetic fields can be compressed to ultrahigh intensities through laser-driven implosions

- A seed axial magnetic field of 0.15 MG inside an imploding laser-driven cylindrical target can be compressed to ultrahigh intensities (≥10 MG).
- A high-intensity magnetic field has a variety of physical implications, including
  - improvement of the hot-spot energy confinement through magnetic insulation
  - improvement of collimation of fast electrons for fast ignition
  - study of magnetic collimation of plasma jets
- A compact Pulsed-Power System for Magnetized Target Experiments on OMEGA* is complete to conduct magnetic-field compression experiments scheduled for 9 November 2006.



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*O. V. Gotchev, JO2.00012

Collaborators

R. Betti

O. V. Gotchev

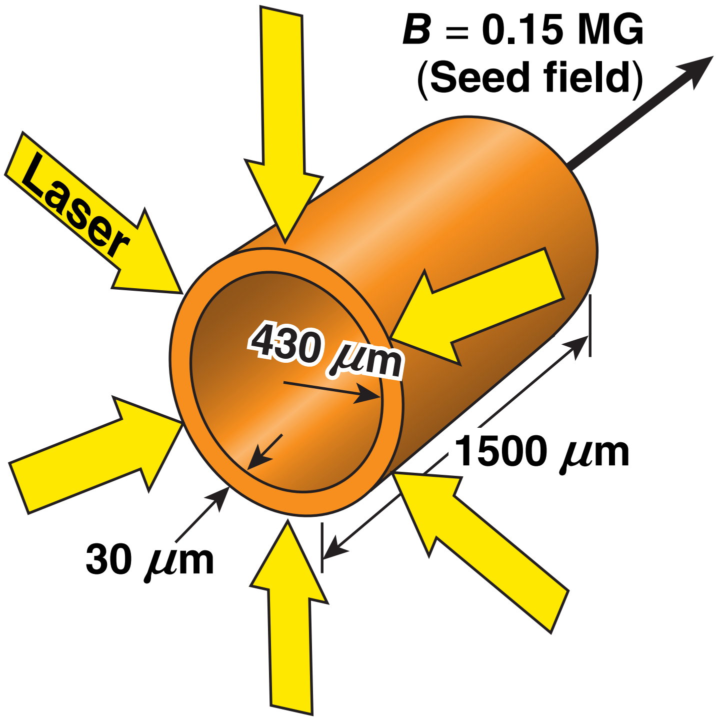
J. P. Knauer

D. D. Meyerhofer

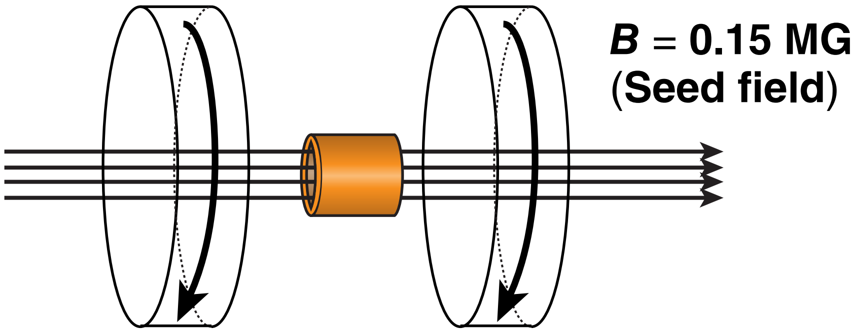
University of Rochester
Laboratory for Laser Energetics

A cylindrical target with a seed field is driven by 40 OMEGA laser beams

- The targets were simulated with three different core materials: (1) DD gas at 3 atm (2) vacuum, and (3) 10-mg/cc-density CH foam core



Cylindrical plastic shell simulated with *LILAC-MHD*



Seed-field generator in the formation of two-turn coils*

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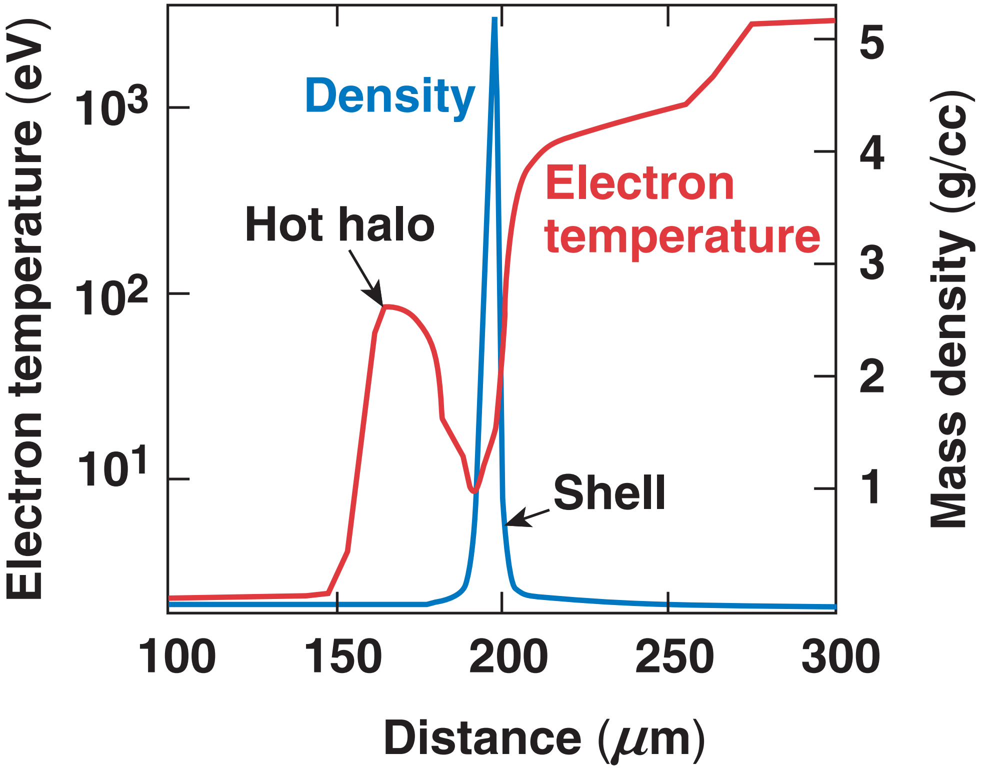
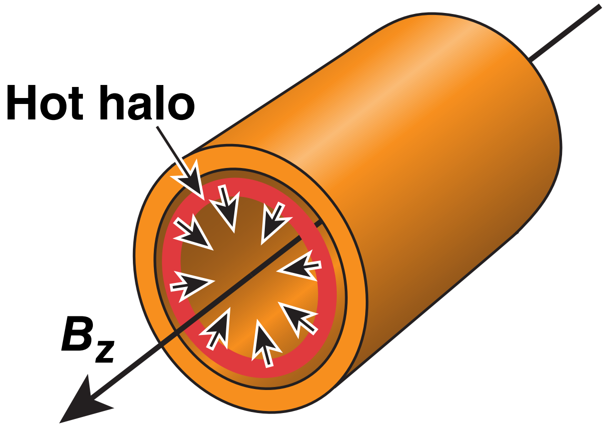
*O. V. Gotchev, JO2.00012

The seed field is trapped by the inner layer of hot-shocked plasma with a high temperature ahead of the shell

$$\eta = 1.65 \times 10^{-5} Z_{\text{eff}} T_e^{-3/2}$$





The hot-halo layer prevents the diffusion of the magnetic field in the radial direction.

Resistive MHD equations were added to the 1-D hydrocode *LILAC*

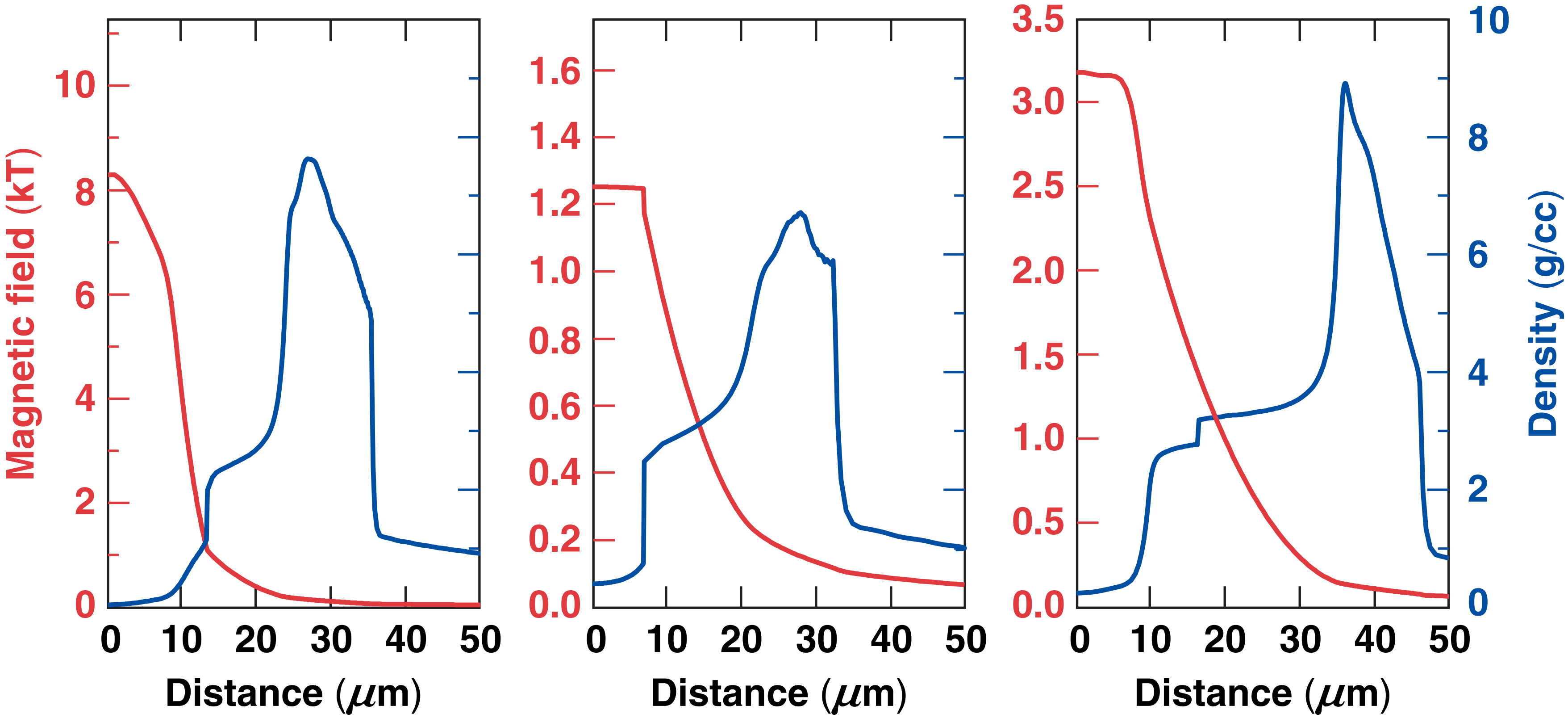
- Use the existing program *LILAC* to simulate the target implosion.
  - *LILAC* is based purely on radiative hydrodynamics
  - modifications are required to build in the effects of the magnetic field. This code will be referred to as *LILAC-MHD*.

- Resistive *MHD* equations added to *LILAC* are
  - magnetic-field diffusion: $\partial_t \vec{B} = \nabla \times (\vec{V} \times \vec{B}) + \nabla \cdot \eta \nabla \vec{B}$
  - magnetic diffusivity calculated from temperature and density

- Contributions of magnetic field to existing hydrodynamics are
  - ohmic heating ηJ^2 is added as a source of heat
  - electron and ion thermal conductivity are reduced by the modification factor determined by gyrofrequencies and collision rates
  - magnetic pressure $B^2/2\mu$ added to the hydrodynamic pressure

The magnetic field at peak compression reaches a magnitude greater than 10 MG

Stagnation profiles



Target with
3-atm DD gas
(t = 3.73 ns)

Target with
vacuum core
(t = 3.68 ns)

Target with
CH foam core
(t = 3.30 ns)

Only a fraction of the initial magnetic flux is trapped and compressed

- Assuming there is no diffusion, the hypothetical maximum field can be calculated by conservation of the magnetic flux.

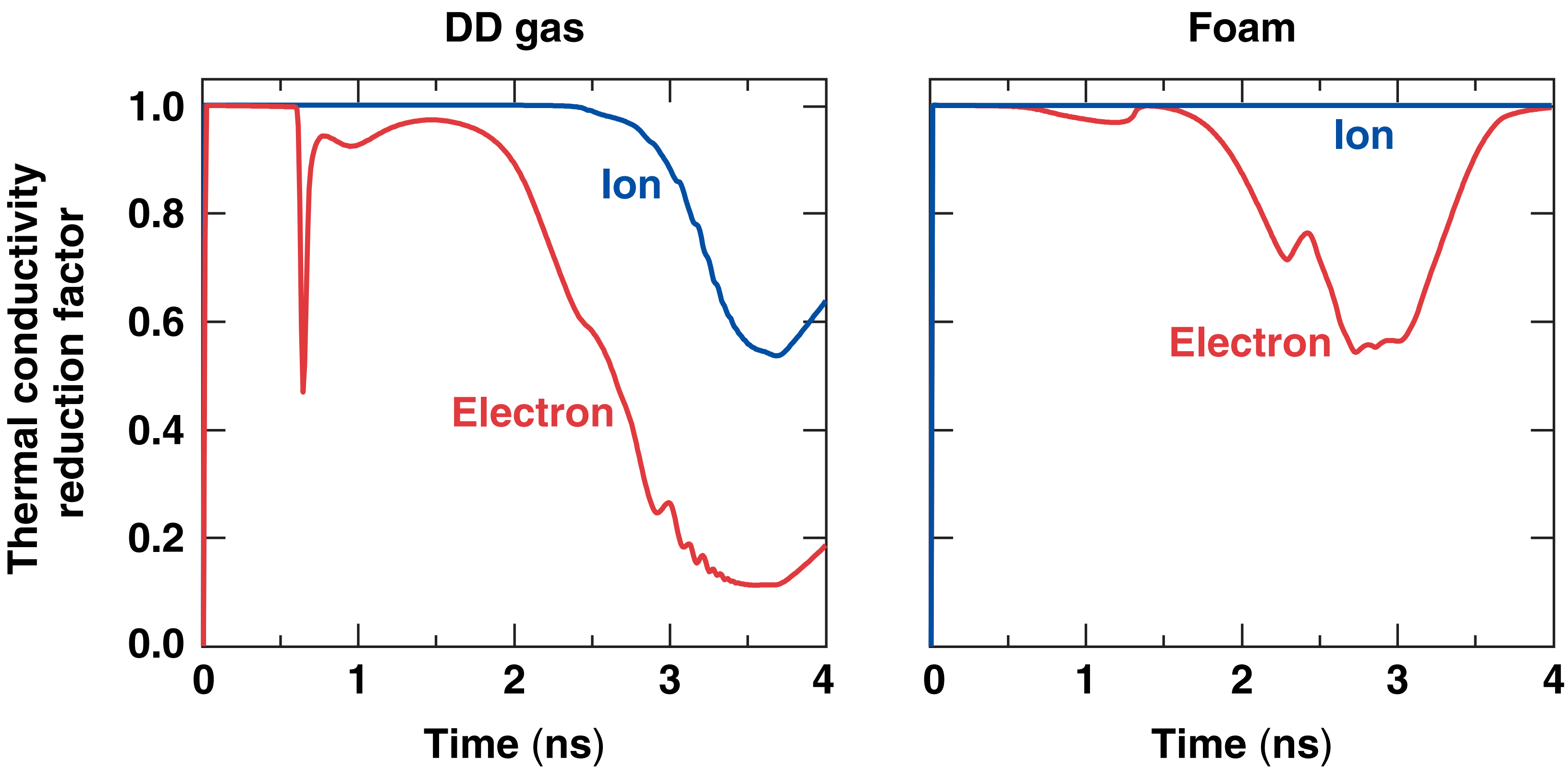
	Peak compression radius (μm)	Without diffusion (MG)	Simulated maximum field (MG)	Fraction trapped
DD gas	13	14.2	8.3	0.58
Vacuum	7	48.9	1.3	0.03
Foam	15	10.6	3.7	0.30

With the magnetic field, the thermal conductivities become highly anisotropic

$$\frac{\kappa_{\perp}}{\kappa_{\parallel}} = \frac{1}{1 + \left(\omega_{\text{ce,ci}} / \nu_{\text{e,i}}\right)^{2}}$$

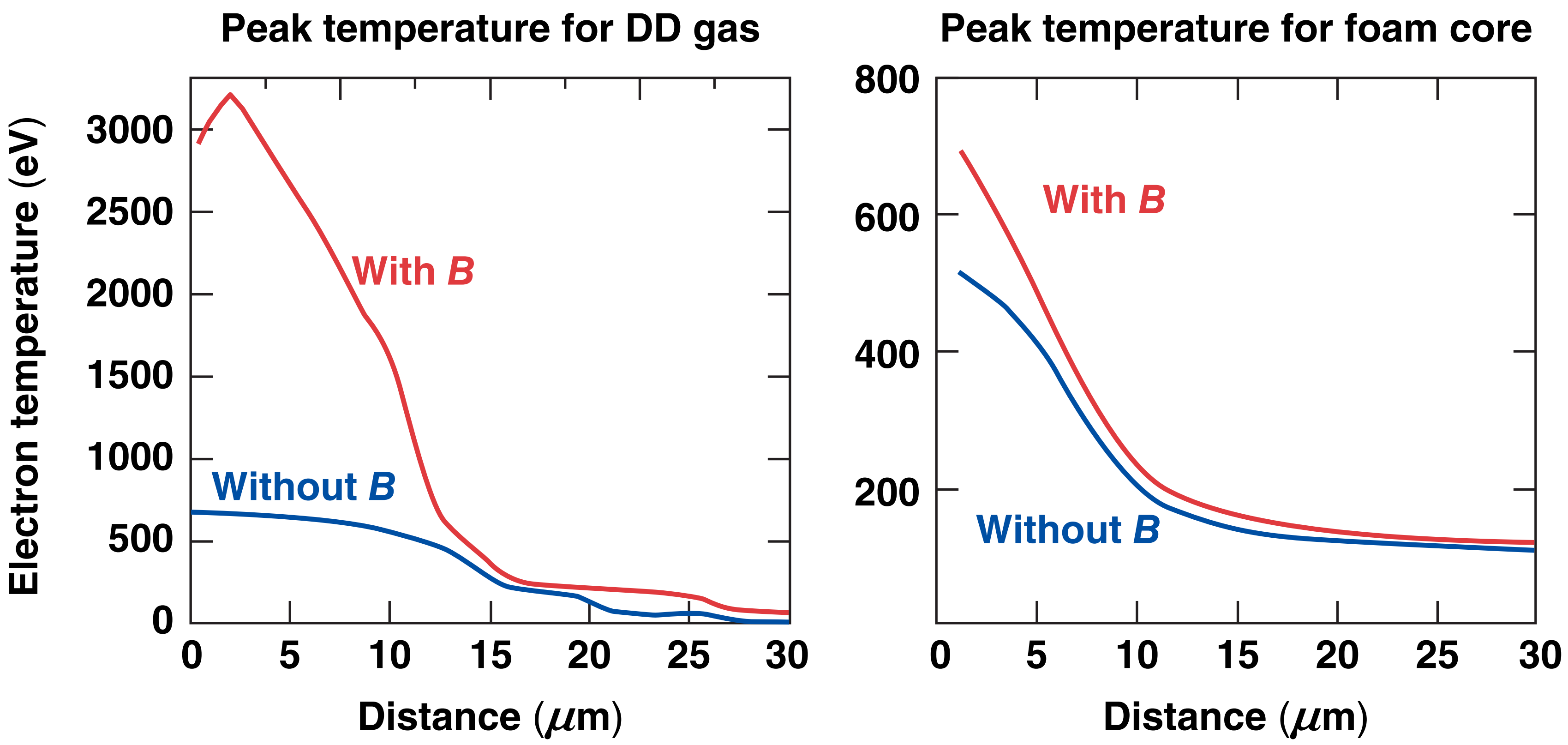
$\omega_{\text{ce,ci}}$: electron and ion gyrofrequencies

$\nu_{\text{e,i}}$: electron and ion-collision rates



Because of the thermal insulation, the hot-spot temperature increases significantly

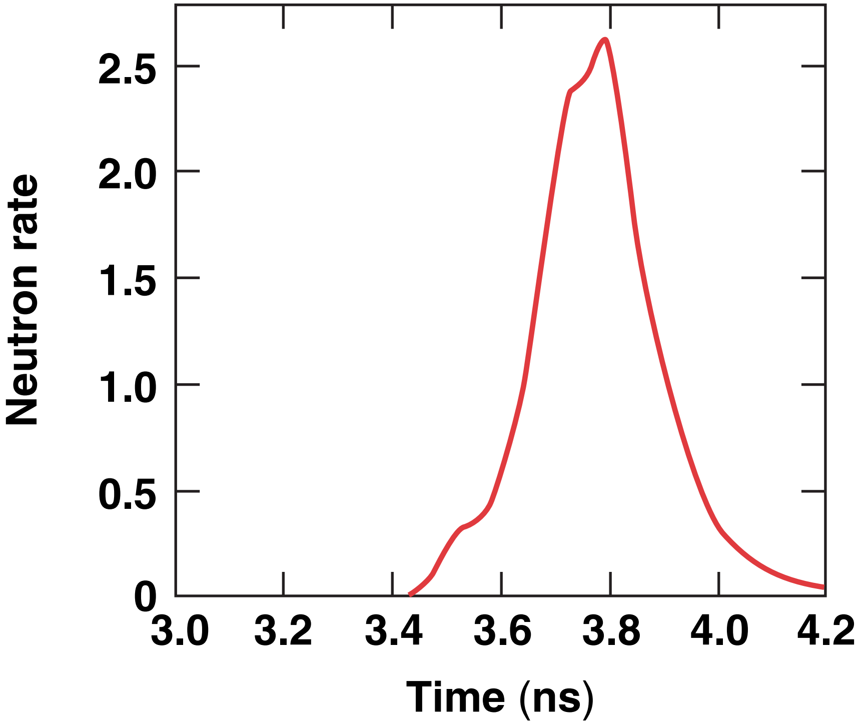
- The temperature over 1 keV in the hot spot is maintained for over 1.2 ns for DD gas.



Peak temperature for DD gas

Peak temperature for foam core

With enhanced energy confinement, the 1-D neutron yield is one order of magnitude higher



	Neutron yield
Without magnetic field	1.65×10^8
With magnetic field	1.02×10^6

Summary/Conclusions

Magnetic fields can be compressed to ultrahigh intensities through laser-driven implosions

- A seed axial magnetic field of 0.15 MG inside an imploding laser-driven cylindrical target can be compressed to ultrahigh intensities (≥10 MG).

- A magnetic field of high intensity reduces thermal conductivity and improves energy confinement.

- A compact Pulsed-Power System for Magnetized Target Experiments on OMEGA* is complete to conduct magnetic-field compression experiments scheduled for 9 November 2006.

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*O. V. Gotchev, JO2.00012