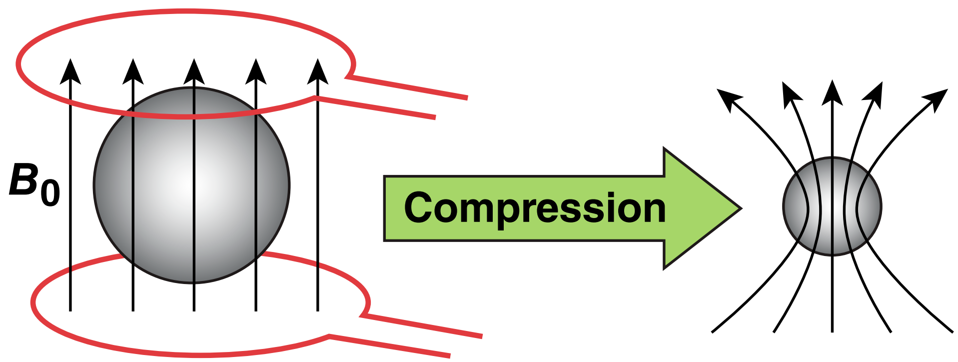
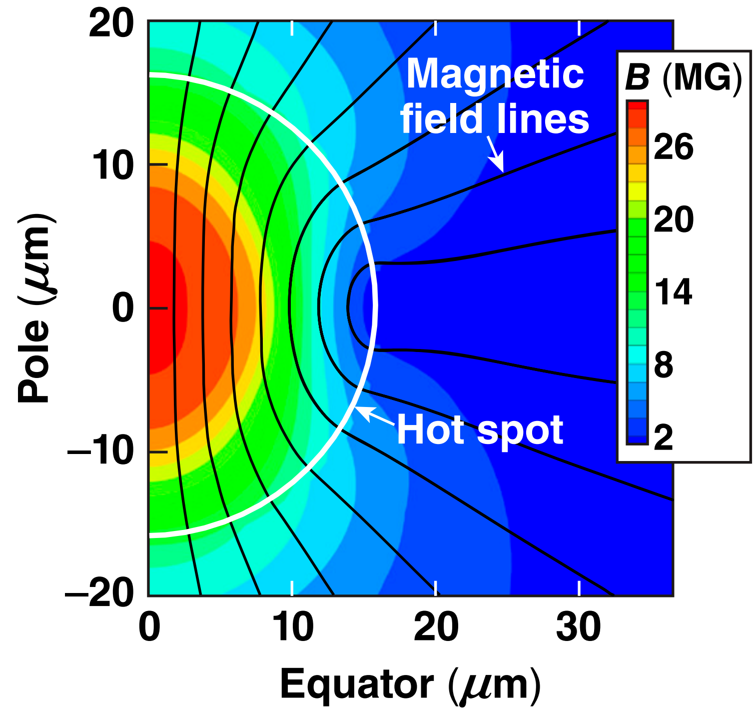
Experiments and Simulations of Laser-Driven Magnetized ICF Targets on OMEGA





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Summary

A 500-fold *B*-field amplification has been shown in 2-D *B*-field compression simulations to agree with magnetized spherical implosion experiments

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Massachusetts Institute of Technology

- 2-D magnetic-field compression was implemented into the 1-D *LILAC* hydrocode
- Simulations of spherical implosions on OMEGA show 500-fold magnetic-field amplification
- A 50-kG seed field was amplified to ~25 MG

Collaborators

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A strong magnetic field in the hot spot improves the ignition condition

- Neutron yield is a strong function of *T* and the ignition energy is inversely proportional to the no-burn neutron yield

  $Y_n \sim p^2 T^2$ for 2 ~ 5 keV, $E_{ign}^{kin} \sim 1/Y_n^{no\ burn}$

- Electron heat-flux perpendicular to magnetic-field lines is reduced by a factor of more than 30 for $B \gtrsim 25$ MG

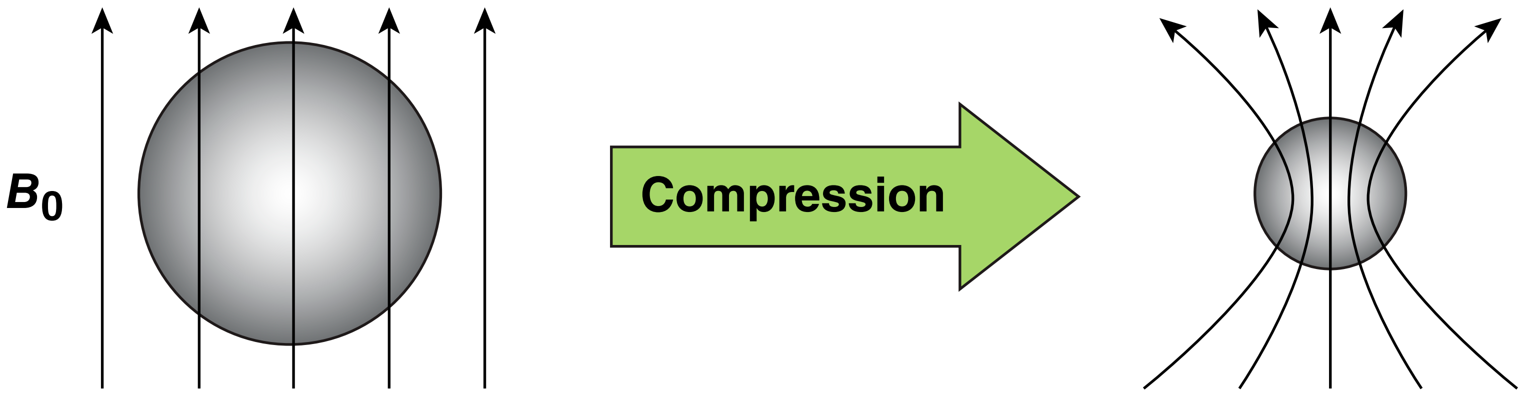
  $\kappa_\perp \sim B^{-2}$, $\kappa_\perp \sim 0.03\ \kappa_\parallel$

- A 30% neutron-yield enhancement and a 15% ion-temperature increase have been measured in the first spherical implosions of magnetized targets on OMEGA*

- A 2-D model is implemented in the 1-D simulations to calculate the spherically compressed magnetic field

*G. Fiksel, UO8.00008 and M. Hohenberger, YI3.00002; P. Y. Chang *et al*., Phys. Rev. Lett. 107, 035006 (2011).

A strong magnetic field can be obtained by compressing a seed field with a spherical imploding target

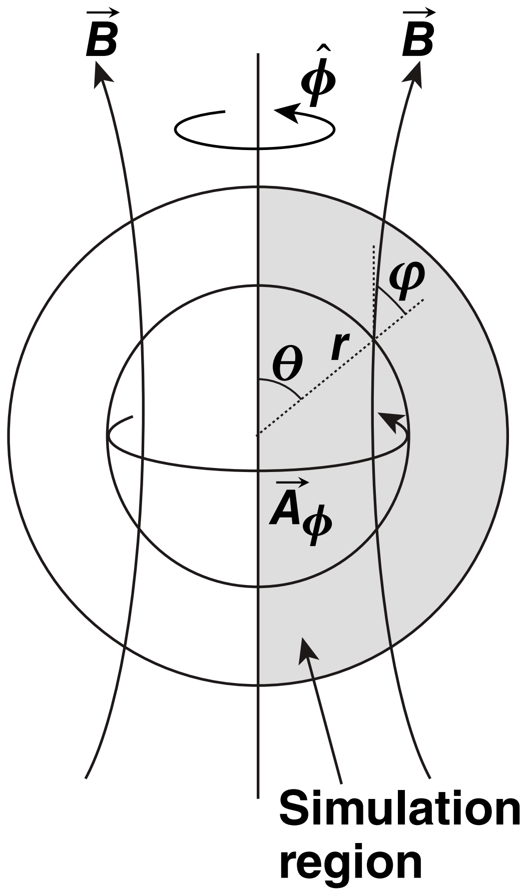


- If compression is faster than magnetic diffusion, then the flux is conserved

$$B_{ideal} = \frac{r_0^2}{r^2} B_0,\ CR = 20 \text{ to } 30 \rightarrow B_{ideal}^{comp} = 400 \text{ to } 900\ B_0$$

- The magnetic pressure is much smaller than the thermal pressure (average hot spot $\beta \sim 1000$). Gross shell hydrodynamics are 1-D and not affected by *B* fields
- Hot spot temperature increases as a reult of the suppression of heat conductivity perpendicular to the *B*-field. Heat losses persist parallel to the field lines in this open field-line configuration

The 2-D resistive MHD model is incorporated into the 1-D *LILAC* hydrocode



***LILAC* hydrocode**

1-D hydro quantities: $\rho, P, T, V_r, \eta, \ldots$

2-D resistive magnetic-diffusion subroutine

$$\frac{\partial \vec{A}_\phi}{\partial t} = \underbrace{\vec{v}_r \times \left(\nabla \times \vec{A}_\phi\right)}_{\text{Convection}} - \underbrace{\eta \nabla \times \left(\nabla \times \vec{A}_\phi\right)}_{\text{Diffusion}}$$

2-D quantities:

$$\vec{B} = \nabla \times \vec{A}_\phi,\ P_B = \frac{B^2}{8\pi}$$

$$\vec{j} = -\frac{c}{4\pi}\nabla^2 \vec{A}_\phi$$

$$\kappa \approx \kappa_\parallel \left[\cos^2\varphi + \frac{\sin^2\varphi}{(\omega_e \tau_e)^2}\right]$$

Average of 2-D quantities

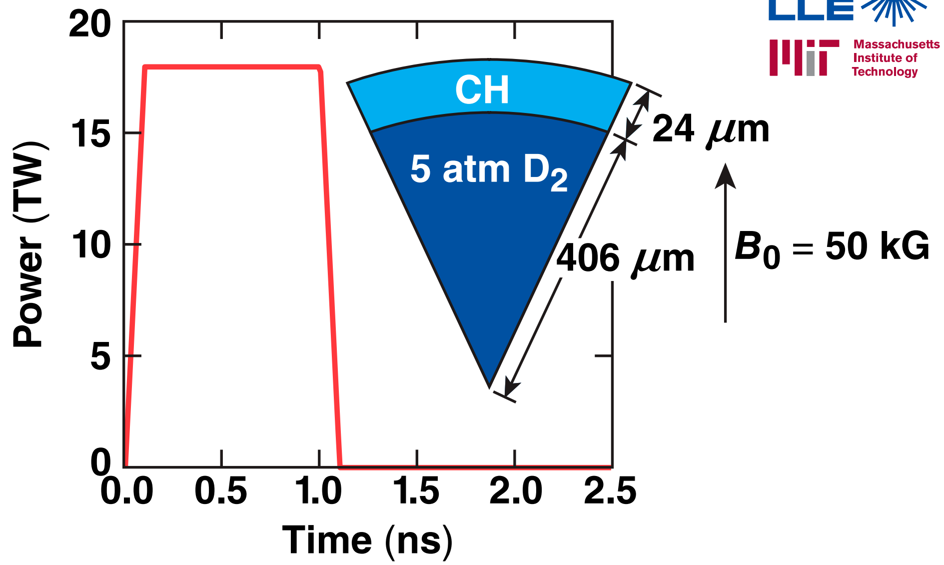
$\kappa,\ P_B,\ \vec{j}$

TC9727

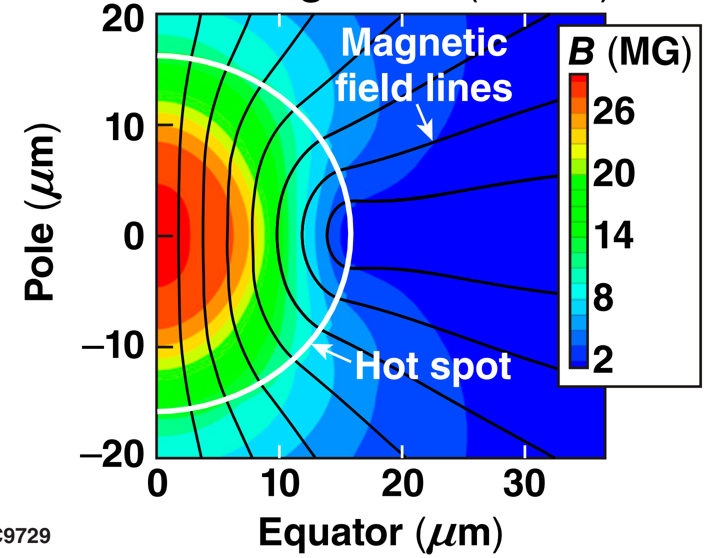
Simulations of implosion experiments show that a seed field of 50 kG is compressed to more than 25 MG in the hot spot

Experimental condition:

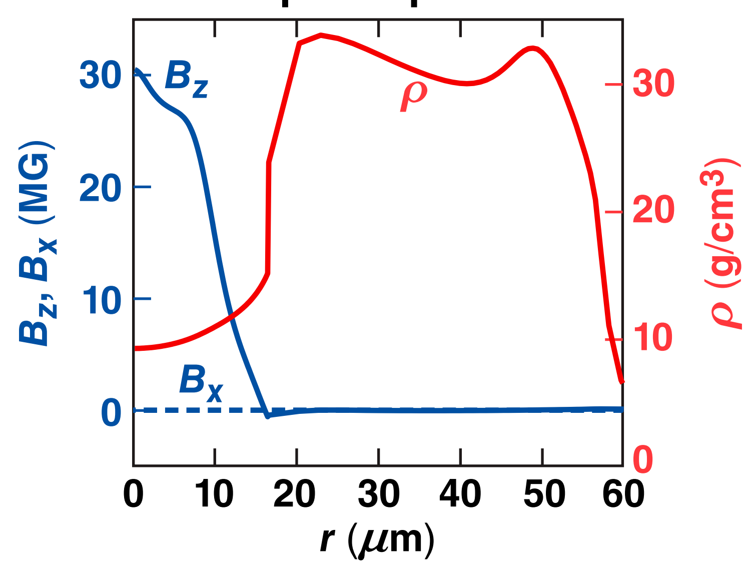
- 1-ns square pulse
- Laser energy: 18 kJ



Simulation results at stagnation (2.1 ns)

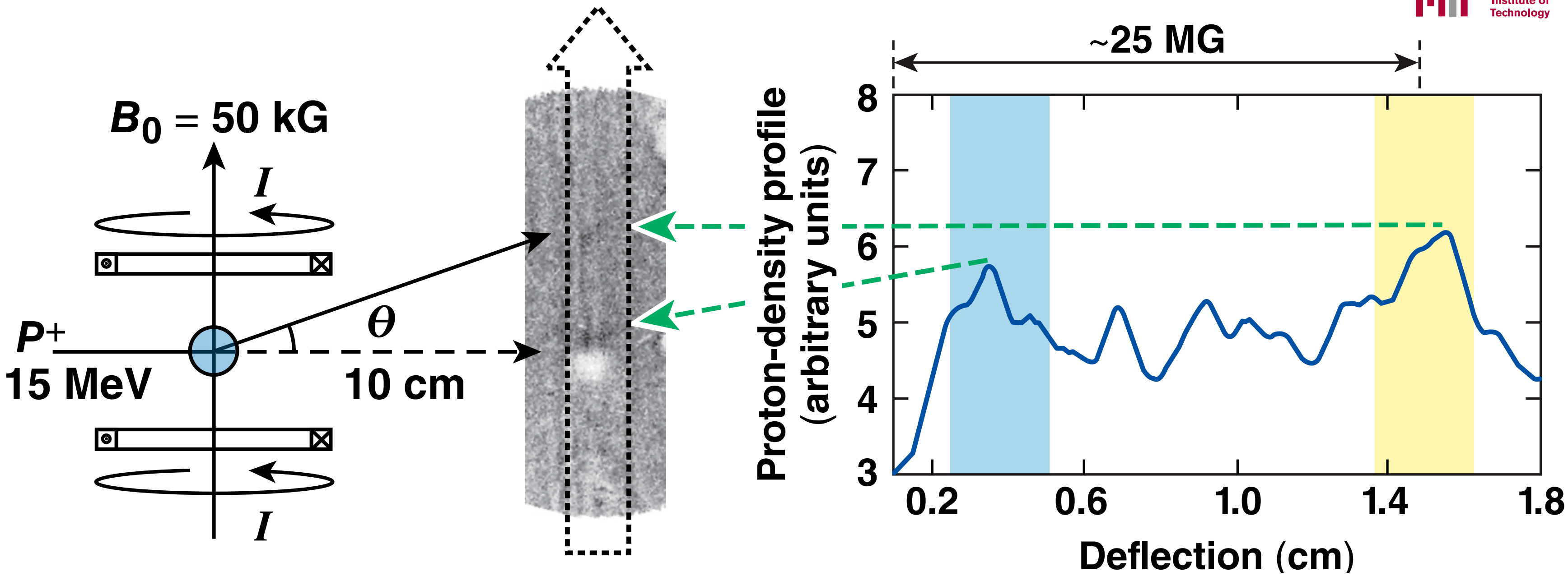


Equator plane



TC9729

B field measurements show good agreement with the simulation results



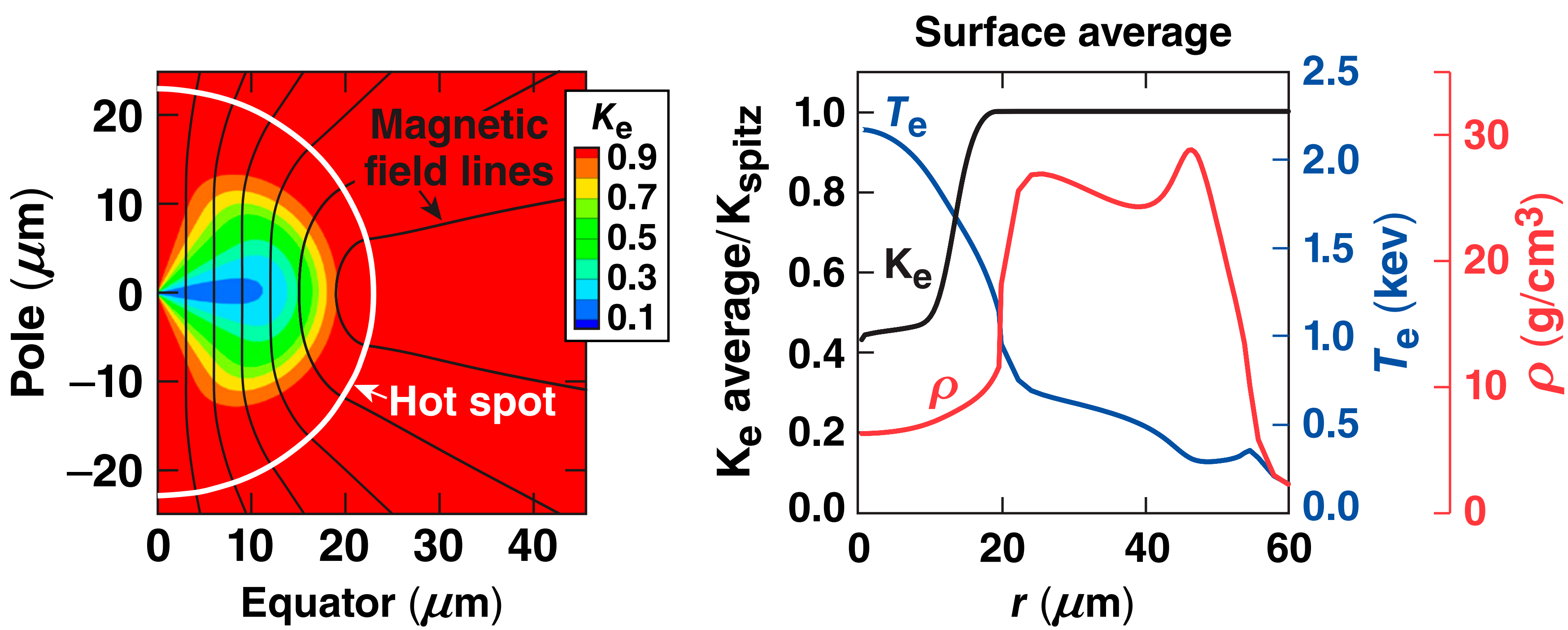
- The displacement gives an average magnetic field of ~25 MG using the 16-μm hot-spot radius from the *LILAC* simulation

$$\int \mathbf{B} \times d\mathbf{r} = \frac{\sqrt{2m_p E_p}}{q} \tan\theta = 860 \text{ MG } \mu\text{m}$$

TC9003a

A strong magnetic field in the hot spot reduces the average heat conductivity by a factor of 2

- Heat conduction suppression at stagnation (2.1 ns)



TC9851

The 1-D *LILAC* simulation predicts lower T_i and neutron yield than experimentally measured

	$B_0 = 8T$ (sim)	$B_0 = 8T$ (exp)
$\Delta N/N$	+15%	+30%
$\Delta T_i/T_i$	+8%	+15%

- 1-D simulations with the 2-D *B*-field model can provide overall reduction in thermal losses but inaccurate heat fluxes [because $T = T(r, \theta)$ while $T = T(r)$ in the code]
- 2-D *DRACO* is being extended to solve the resistive MHD equations

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