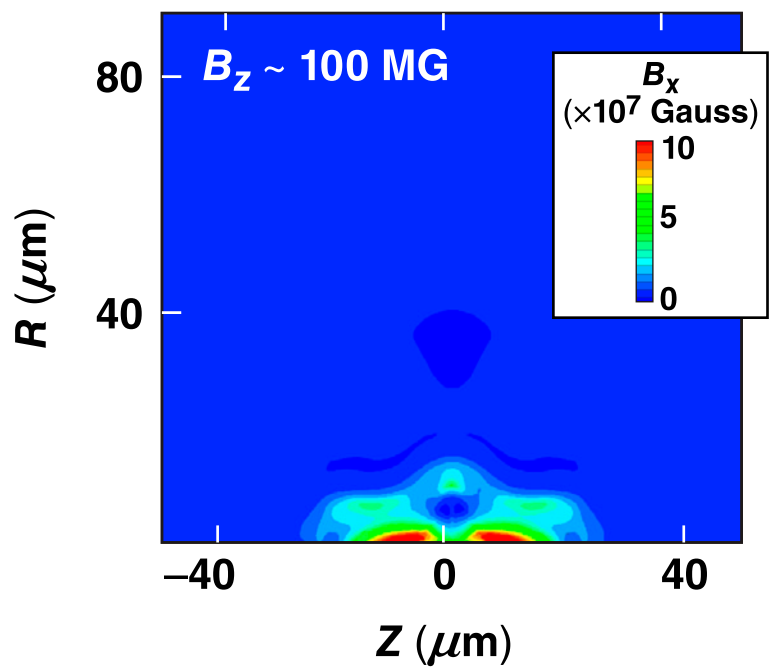
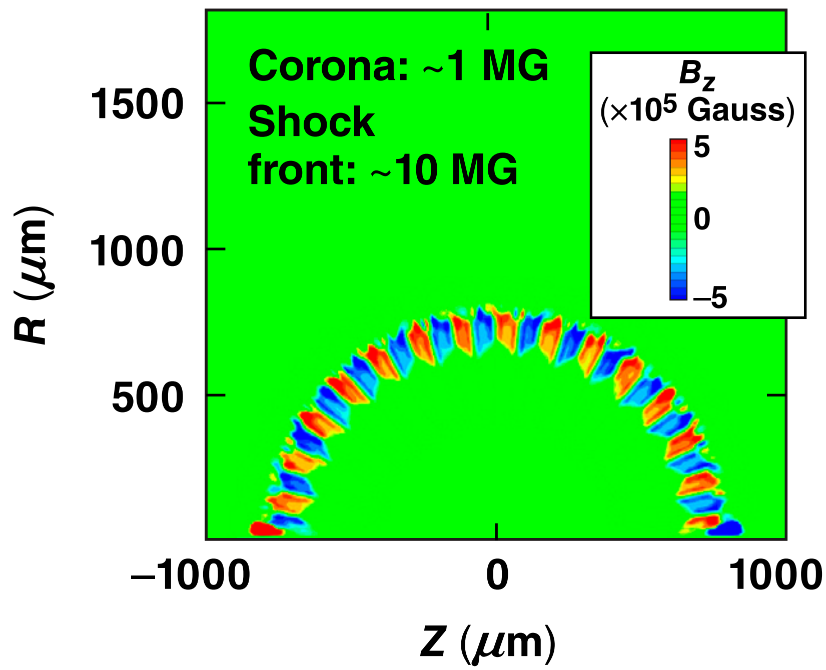
Effects of External and Self-Generated Magnetic Fields on Laser-Driven Implosions

Compression of applied B-field



Self-generated B-field



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Summary

Compression and self-generation of magnetic fields for laser-imploding targets are modeled with the *DRACO*/MHD code

- An external magnetic field of <100 KG can be compressed to hundreds of mega-Gauss at the implosion stagnation with an ~15 kJ laser driver
- Noticeable effects of the compressed magnetic field on target hydrodynamics are demonstrated
- For nonuniformly irradiated implosions, simulations predict self-generation and amplification of the *B*-field by a number of MHD-related processes
- The magnetic field initially generated at the critical surface can reduce the laser imprinting on the ablation surface

Collaborators

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Magnetized laser implosions are simulated with the hydrocode *DRACO* modified to solve the MHD equations

- The hydrodynamics are solved with the ALE (arbitrary Lagrangian/Eulerian) hydrocode *DRACO*,[1] that includes all relevant implosion physics
- The Lorentz force, anisotropic heat fluxes (*B* dependent[2]), and Joule heating are added to *DRACO*
- The magnetic field is obtained by numerically solving the MHD equations with anisotropic (*B* dependent[2]) coefficients

[1] P. B. Radha *et al*., Phys. Plasmas 12, 056307 (2005).
[2] S. I. Braginskii, in Reviews of Plasma Physics, edited by Acad. M. A. Leontovich (Consultants Bureau, New York, 1965).

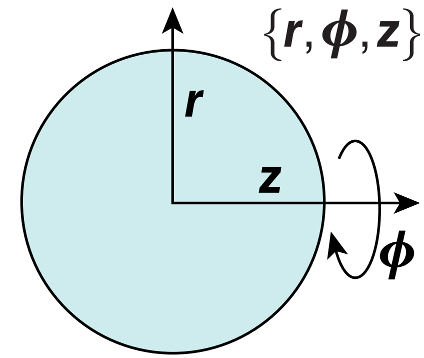
TC8708

A_ϕ/B_ϕ representation of the magnetic field in cylindrical geometry simplifies the simulations

$$\vec{B} = B_\phi \vec{e}_\phi + \vec{\nabla} \times \left(A_\phi \vec{e}_\phi \right)$$

Assumptions:

$$\frac{\partial}{\partial \phi} = 0, \; v_\phi = 0$$



- A_ϕ and B_ϕ are evolved independently for isotropic MHD. The source term goes in only the equation for B_ϕ
- For anisotropic MHD, B-field compression is described by the equation for A_ϕ

$$\frac{\partial A_\phi}{\partial t} = \left[\left(\vec{v} \times \vec{\nabla} \times \vec{A} \right) - \frac{c}{e} \left(\frac{\vec{R}_j + \vec{R}_T}{n_e} \right) \right] \cdot \vec{e}_\phi$$

Diffusion

$$\vec{R}_j = \alpha_\perp (B) \vec{j} / e n_e$$

and self-generation of the B-field by the equation for B_ϕ

$$\frac{\partial B_\phi}{\partial t} = \left[\vec{\nabla} \times \left(\vec{v} \times \vec{B} \right) - \frac{c}{e} \vec{\nabla} \times \left(\frac{\vec{R}_T + \vec{R}_j}{n_e} \right) + \frac{c}{e} \vec{\nabla} \times \left(\frac{\vec{\nabla} p_e}{n_e} \right) \right] \cdot \vec{e}_\phi$$

Nernst

$$\vec{R}_T = -\beta_\wedge^{uT} (B) \left[\vec{b} \times \vec{\nabla} T_e \right]$$

- The heat flux includes magnetic inhibition and the diamagnetic component

Inhibited h.f. — *h.f. along B* — *Double perpendicular h.f.*

$$\vec{q}_T = -\kappa_\perp (B) \vec{\nabla} T_e - \left[\kappa_\parallel - \kappa_\perp (B) \right] \vec{b} \left(\vec{\nabla} T_e \cdot \vec{b} \right) - \kappa_\wedge (B) \left[\vec{b} \times \vec{\nabla} T_e \right]$$

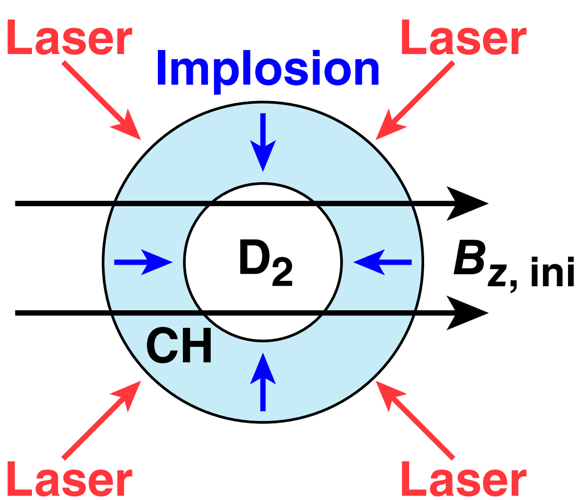
TC8716

DRACO/MHD simulations of: (a) *B*-field compression, and (b) *B*-field self-generation in spherical implosions

Imploding targets: R_{pellet} = 410 μm, R_{shell} = 20 μm, P_{D_2} = 3 atm

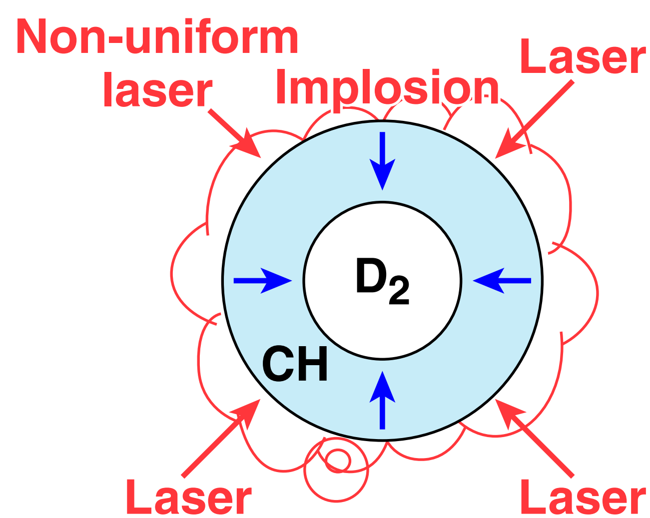
Laser: T_{pulse} = 1 ns, Energy = 15 kJ

(a) Field compression



Uniform irradiation
$B_{z,\,ini}$ = 30,000 Gauss

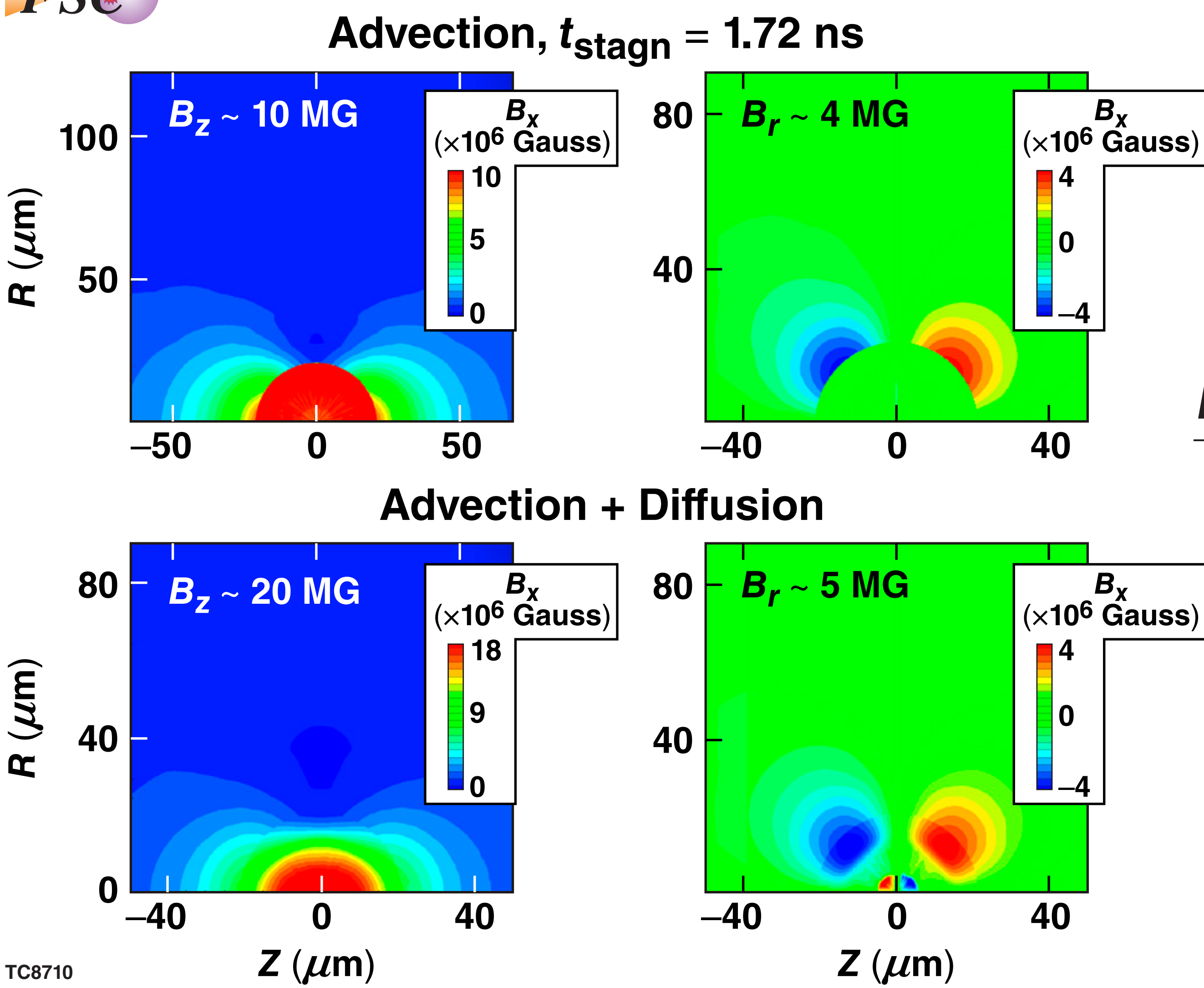
(b) Self-generation of *B*



Nonuniform irradiation
Relative amplitude ~ 3%,
$Length_{ini}$ ~ 86 μm

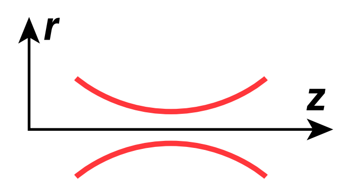
TC8709

Compression of a magnetic field for isotropic MHD shows that magnetic diffusion enhances the peak magnetic field



B_{ini} = 0.03 MG

$$\frac{B_{max}}{B_{ini}} \sim \frac{r_{ini}^2}{r_{fin}^2} \sim 500$$



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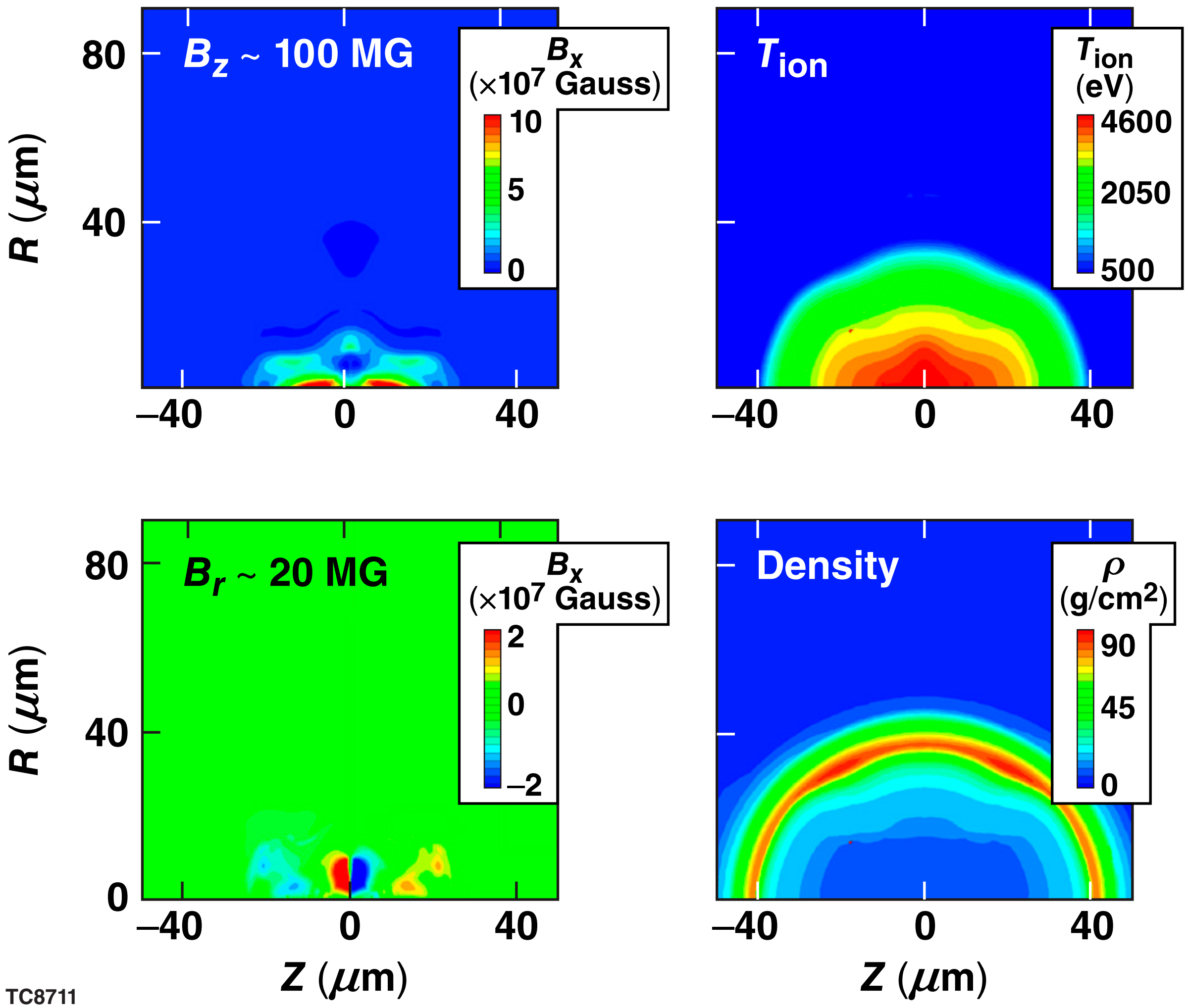
Compression of *B* by advection, diffusion, and anisotropic thermal transport leads to the ultra-high *B*-field that influences the implosion hydrodynamics



- Ions are heated ~30% more due to thermal-heat-flux inhibition by the compressed magnetic field
- Adv+Diff+ATT lead to enhancement ~20% of the neutron yield
- TT redistributes *B*

TC8711

A self-generated *B*-field for nonuniformly irradiated laser implosions are produced by many different mechanisms

1. *Grad N* × *Grad T* as a source — *Vorticity in conducting fluid*

2. Tidman instability[1] (linear) due to

$$\vec{q_T} = -\kappa_\wedge(B)\left[\vec{b} \times \vec{\nabla} T_e\right]$$

Heat flows into the region of large T

3. Hot-spot amplification (nonlinear) due to

$$\vec{q_T} = -\kappa_\perp(B)\vec{\nabla} T_e$$

Heat does not flow from the region of large B

4. RT instability — *Field around conducting protrusions*

5. Converging shock-front instability

6. Joule heating amplification — *Cold boundaries are heated by MHD current*

TC8712

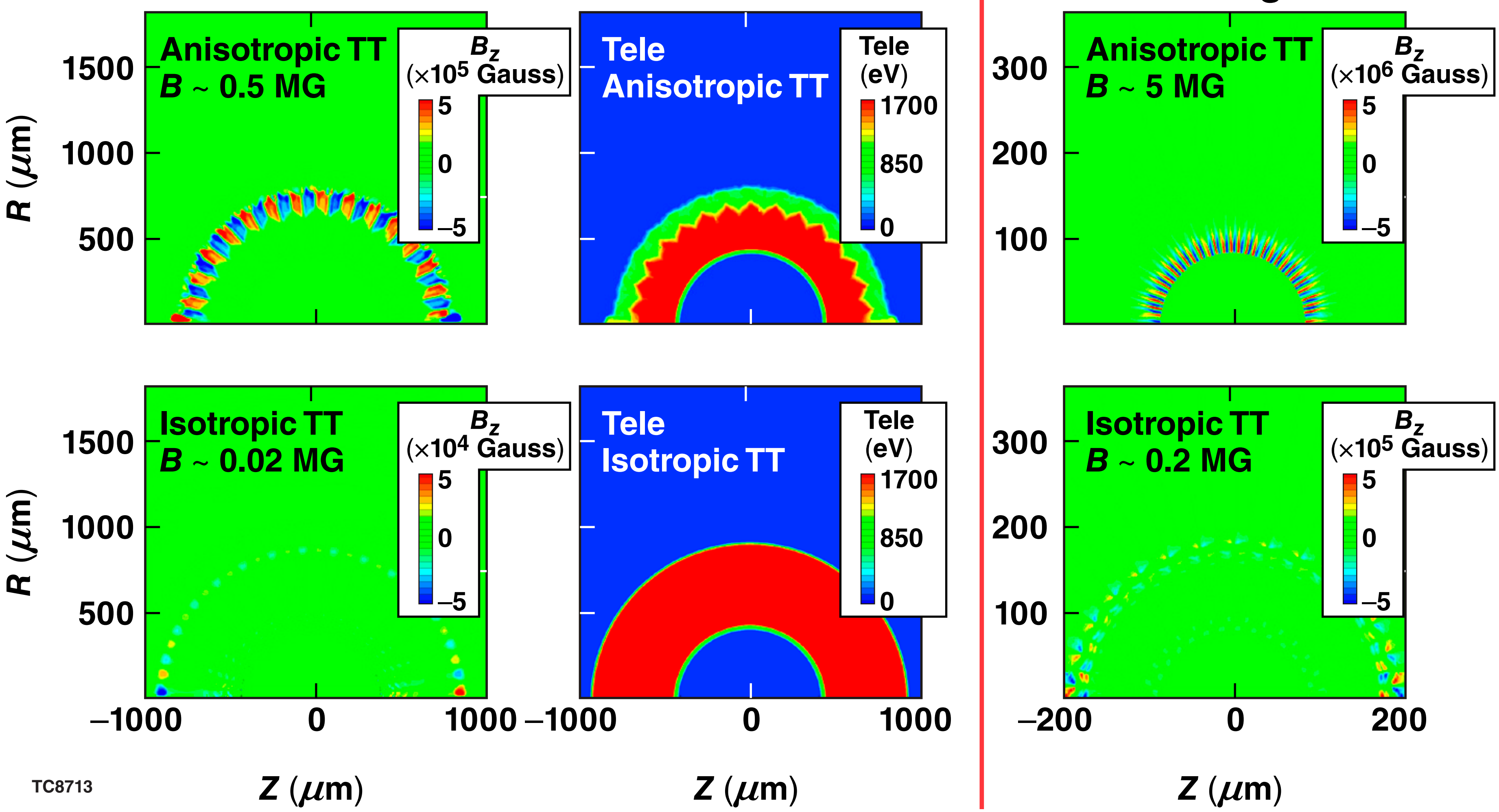
[1] D. A. Tidman and R. A. Shanny, Phys. Fluids 17, 1207 (1974).

Self-generated B-fields at the corona edge and shock front in a gas are highly enhanced by field-inhibited thermal transport

$$\vec{q_T} = -\kappa_\perp(B)\vec{\nabla} T_e \text{!!!}$$

B-field at the edge of the corona

B-field at the shock front in the gas



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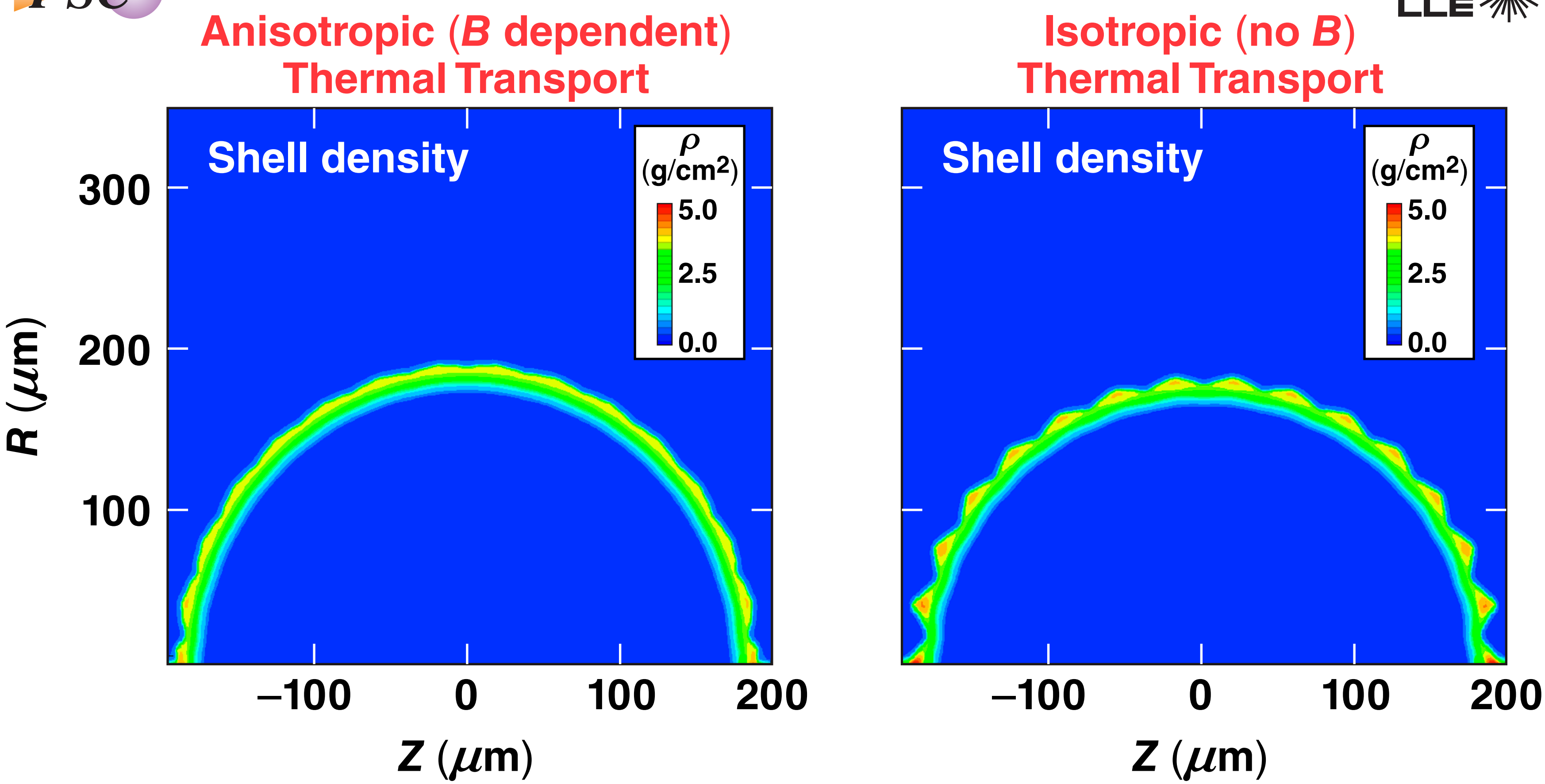
The self-generated magnetic field leads to a reduction of imprinting of laser irradiation nonuniformities on an ablation surface



- The effect is due to an enhanced lateral heat transport induced by a self-generated magnetic fields at the initial stage of implosion.

$$\vec{q_T} = -\kappa_\wedge(B)\left[\vec{b}\times\vec{\nabla}T_e\right]$$

TC8714

Summary/Conclusions

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