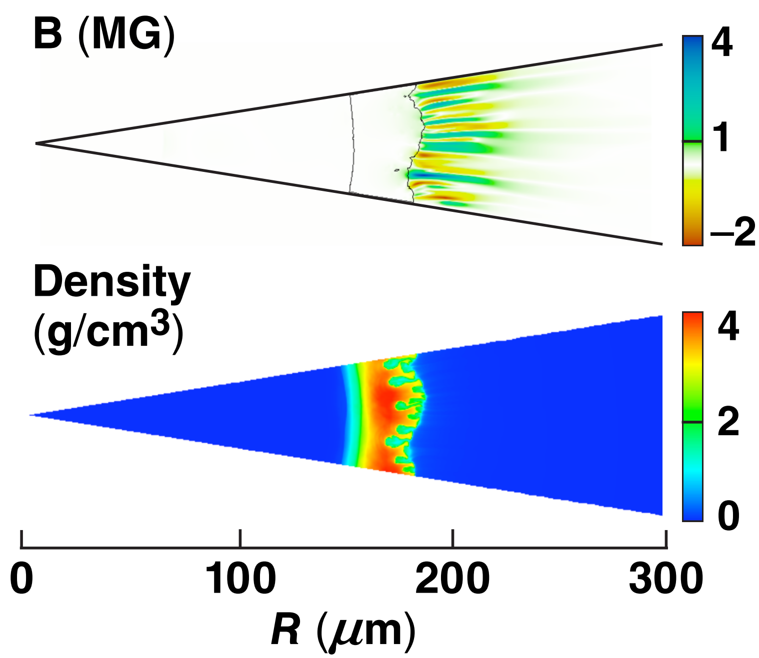
Simulations of Self-Generated Magnetic Fields in Implosion Experiments on OMEGA

Magnetic fields at a perturbed CH–D interface



I. V. Igumenshchev
University of Rochester
Laboratory for Laser Energetics

52nd Annual Meeting of the
American Physical Society
Division of Plasma Physics
Chicago, IL
8–12 November 2010

Summary

Nonuniformities in directly driven ICF targets generate magnetic fields that affect target performance

- Self-generated magnetic fields are developed at perturbed ablation surfaces and material interfaces. These fields are not dynamically important ($P_m << P_g$), but suppress heat fluxes.
- Magnetic fields of several MG originate in plasma corona from various sources of nonuniformities
  - laser imprint: the fields developed at material interfaces can increase perturbations and reduce the laser drive
  - dust particles: the field effects significantly modify perturbations induced by the particles
- Magnetic fields up to 30 MG are generated at peak compression in hot spots of cryogenic targets and up to 100 MG in hot spots of warm targets

Collaborators

V. N. Goncharov, P. M. Nilson, and T. C. Sangster

University of Rochester
Laboratory for Laser Energetics

C. K. Li and R. D. Petrasso

MIT–Plasma Science and Fusion Center

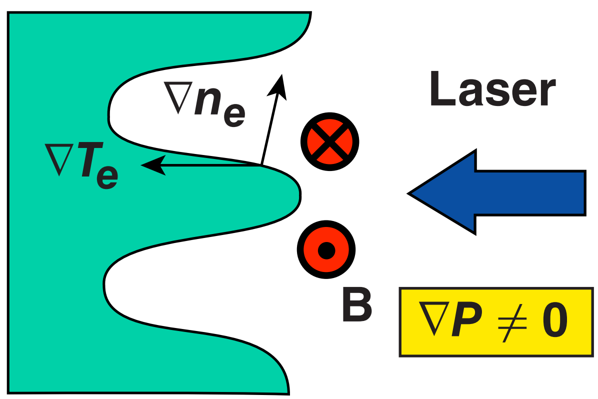
M. G. Haines

Imperial College

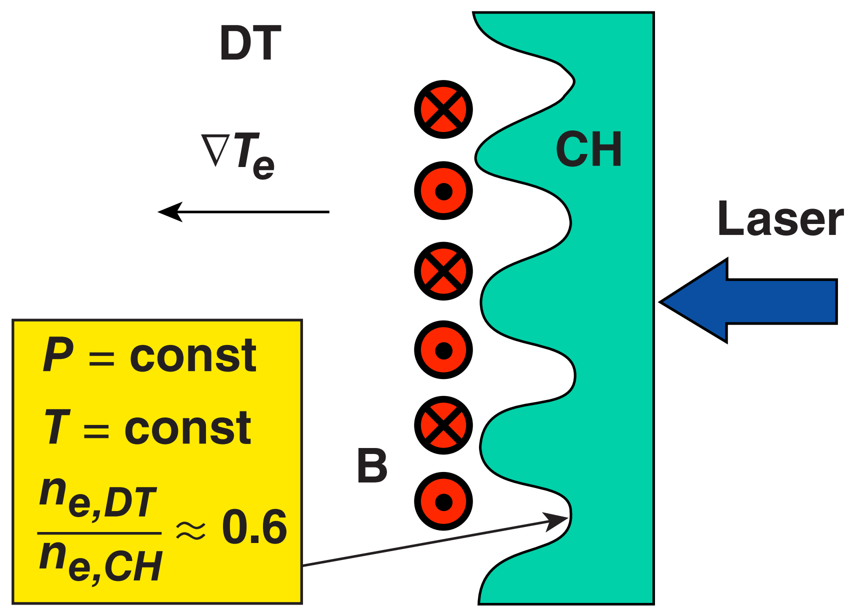
Magnetic fields are generated mainly at perturbed ablation surfaces and material interfaces

$$\begin{bmatrix}\text{Field} \\ \text{growth} \\ \text{rate}\end{bmatrix} = -\frac{c}{en_e}\nabla n_e \times \nabla T_e$$

R-T unstable ablation surface*



CH–DT interface inside thermal conduction zone



The field strength is limited by magnetic diffusivity.

TC9058

*A. Nishiguchi, Jpn. J. Appl. Phys. 41, 326 (2002).

Self-generated magnetic fields and magnetic-dependent heat fluxes are calculated using the Braginskii formulation*

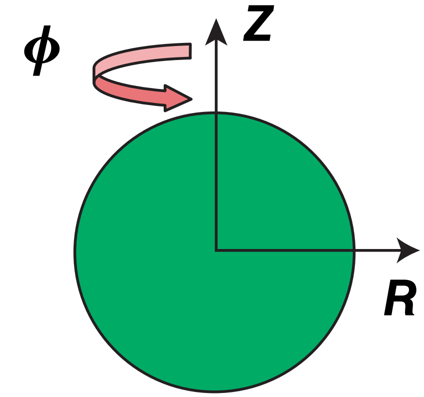
- The induction equation:

$$\frac{\partial \vec{\mathbf{B}}}{\partial t} = \nabla \times \left(\boldsymbol{V} \times \vec{\mathbf{B}}\right) + \frac{c}{e}\left[\nabla \times \frac{\nabla P_e}{n_e} - \nabla \times \frac{\left(\nabla \times \vec{\mathbf{B}}\right) \times \vec{\mathbf{B}}}{4\pi n_e} - \nabla \times \frac{\vec{\mathbf{R}}_T + \vec{\mathbf{R}}_u}{n_e}\right]$$

- The electron heat flux: $\vec{q}_e = \vec{q}_T^{\,e} + \vec{q}_u^{\,e}$

The field affects the heat flux when $\Omega_{Le}\tau_e \geq 1$.

- The MHD equations with thermal conduction terms are solved using the modified 2-D hydrocode *DRACO***



- Assumptions of axisymmetry

$$\partial/\partial\phi = 0,\ V_\phi = 0$$

$$B_R = B_Z = 0,\ B_\phi \neq 0$$

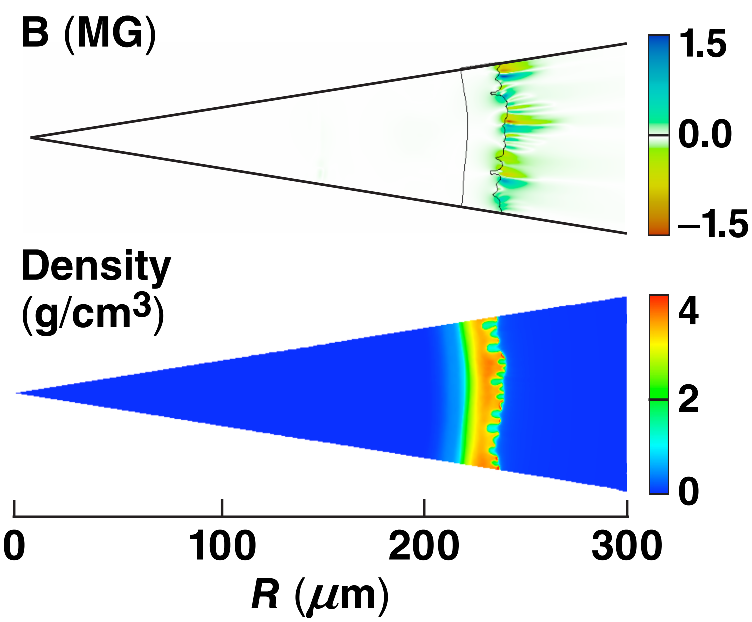
TC9057

*S. I. Braginskii, in Reviews of Plasma Physics (Consultants Bureau, NY, 1965).
**P. B. Radha *et al.*, Phys. Plasmas 12, 032702 (2005).

Perturbations from laser imprint are the source of self-generated magnetic fields

Cryogenic target in the middle of the main pulse: magnetic fields at CH ablation surface*

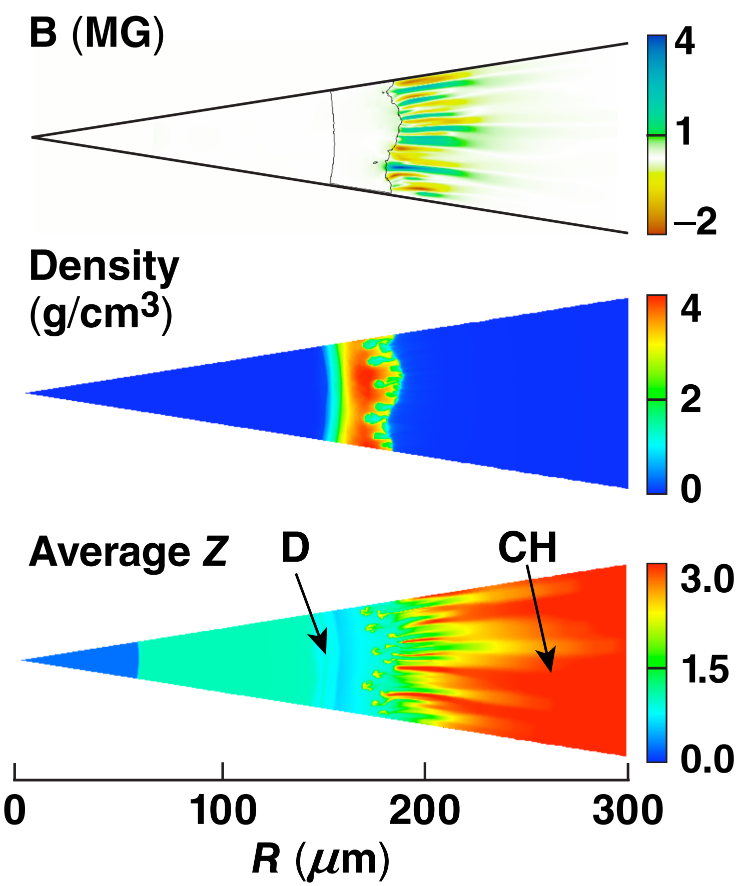
t = 3.2 ns



These fields at ablation surface have a small effect on target performance.

CH is all ablated: magnetic fields at CH–D interface

t = 3.5 ns

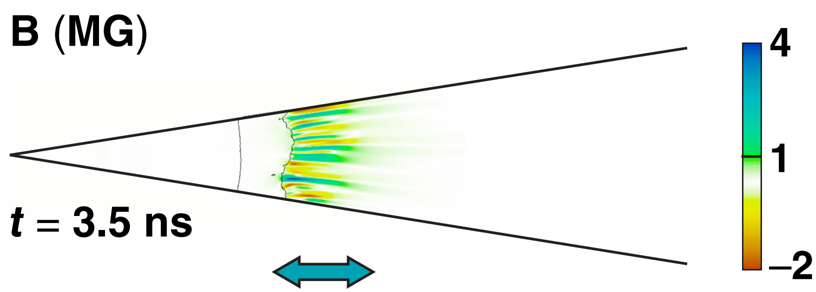


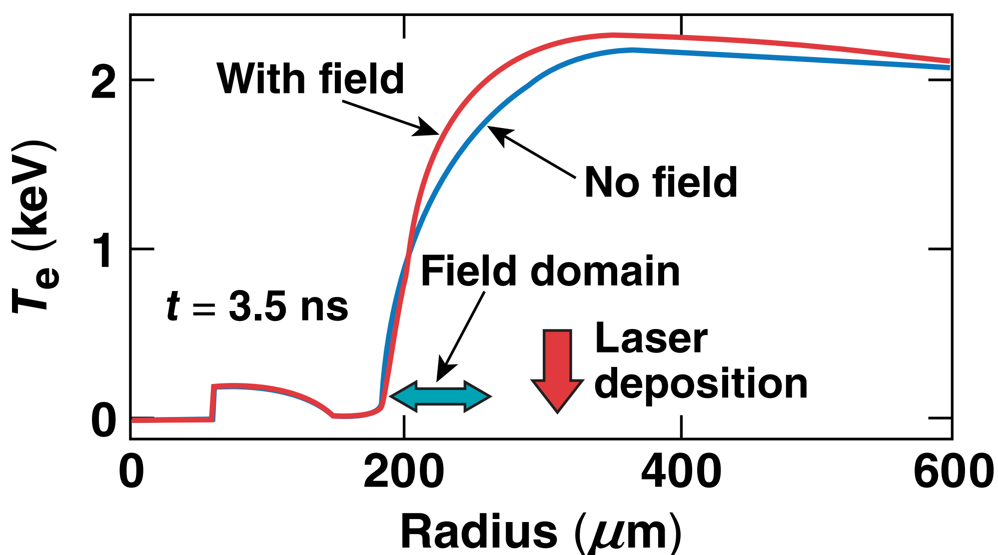
*J. R. Rygg *et al.*, Science 319, 1223 (2008).

TC9059

Radially extended magnetic fields at perturbed CH–D interface efficiently suppress the inward heat flux

The temperature change in the corona due to magnetic fields





- The laser drive is reduced due to suppression of the heat flux
- The fields enhance perturbations with *L*-modes ~20, which are the most dangerous modes at the deceleration phase

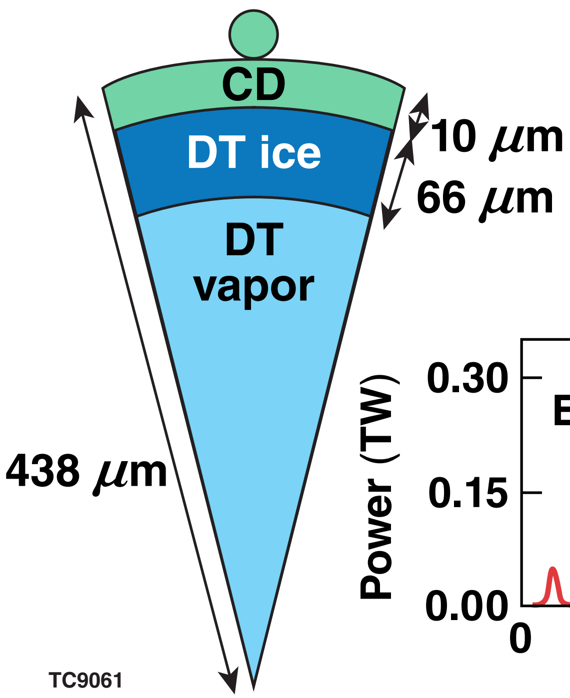
For best performance, plastic shells should all be ablated only after the end of the laser pulse.

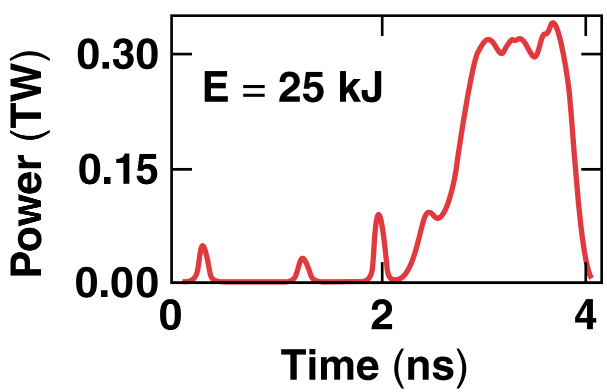
TC9060

Dust particles on the target surface are the source of localized MG field structures

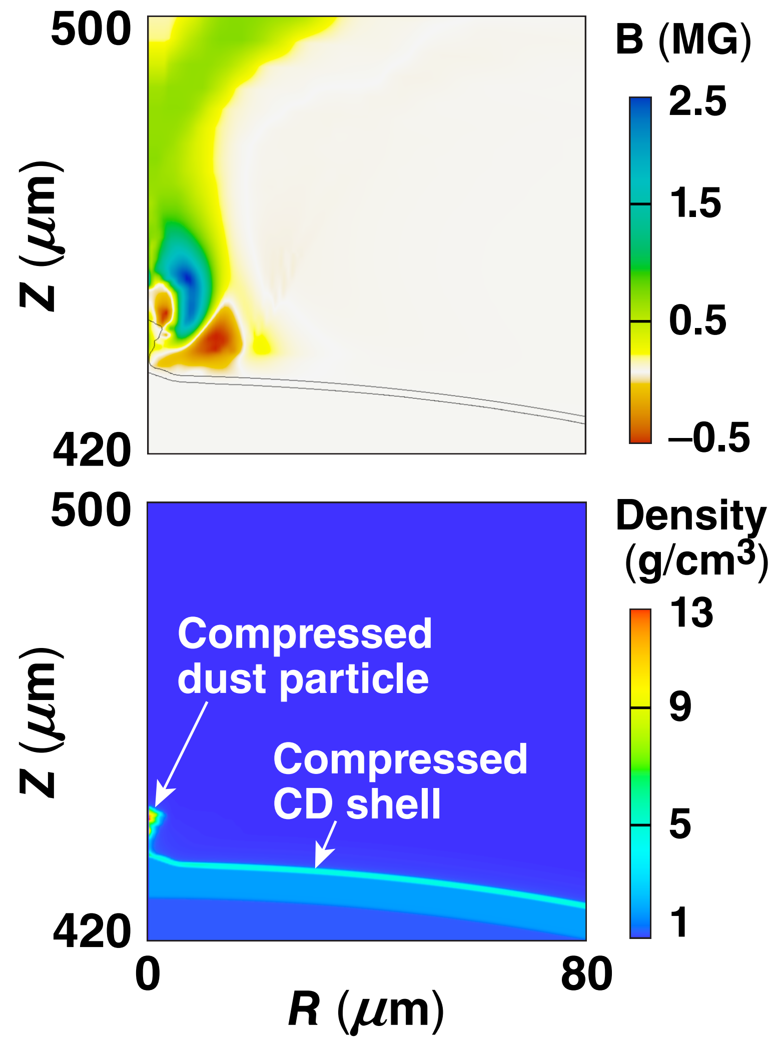
- The surfaces of warm and cryogenic targets are typically contaminated by several tens of ~10-μm-sized dust particles

Cryogenic DT target
with a 10-μm dust particle



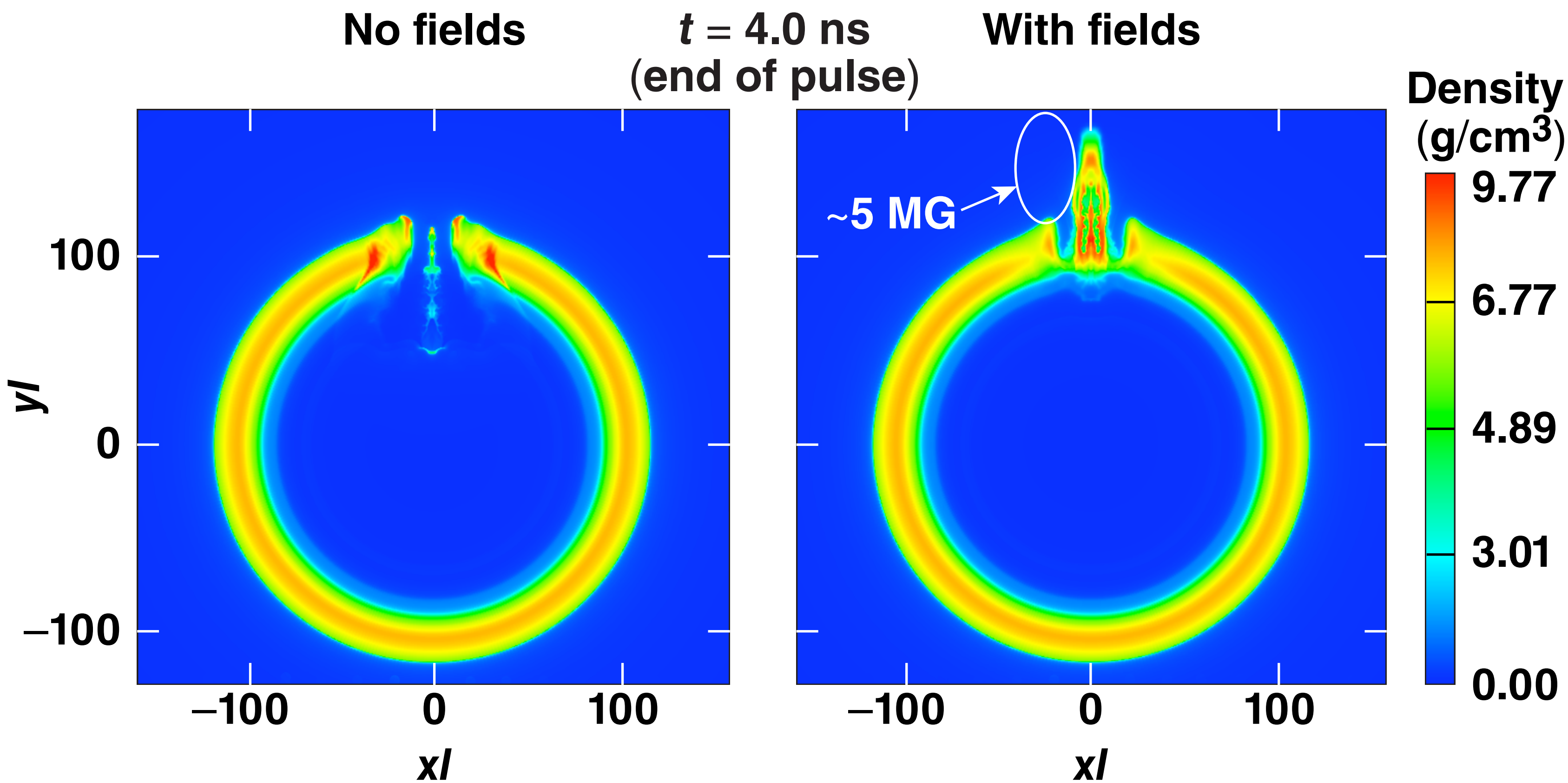


Magnetic structure at t = 200 ps



TC9061

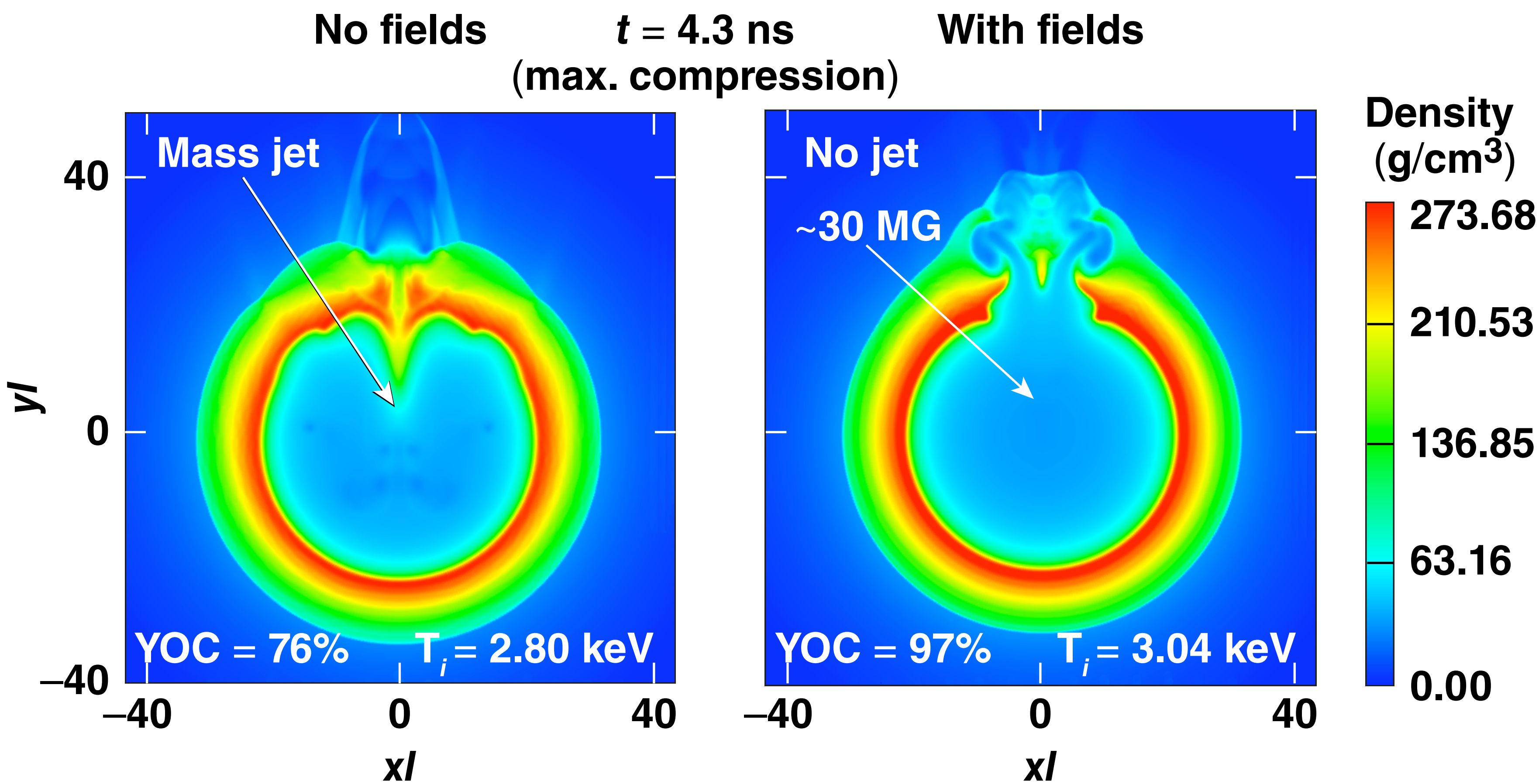
Perturbations induced by a 10-μm dust particle evolve differently with and without magnetic fields



- *R-T* instability develops a hole and some mass is injected inside the shell
- Magnetic fields thermally isolate the perturbed area resulting in a locally reduced drive

TC9062

Simulations predict that magnetic fields will reduce the damage to hot spots from dust particles



- Up to 30-MG fields are generated in hot spots of cryogenic targets
- Larger fields up to 100 MG are generated in hot spots of warm targets due to the presence of plastic–fuel interfaces

Summary/Conclusions

Nonuniformities in directly driven ICF targets generate magnetic fields that affect target performance

- Self-generated magnetic fields are developed at perturbed ablation surfaces and material interfaces. These fields are not dynamically important ($P_m << P_g$), but suppress heat fluxes.
- Magnetic fields of several MG originate in plasma corona from various sources of nonuniformities
  - laser imprint: the fields developed at material interfaces can increase perturbations and reduce the laser drive
  - dust particles: the field effects significantly modify perturbations induced by the particles
- Magnetic fields up to 30 MG are generated at peak compression in hot spots of cryogenic targets and up to 100 MG in hot spots of warm targets