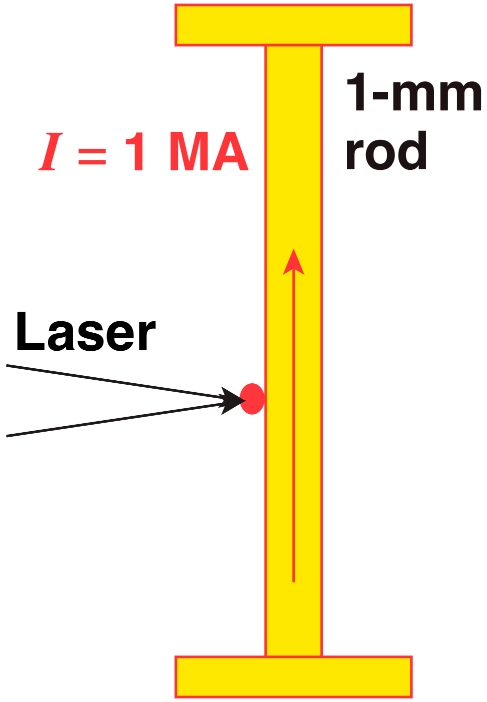
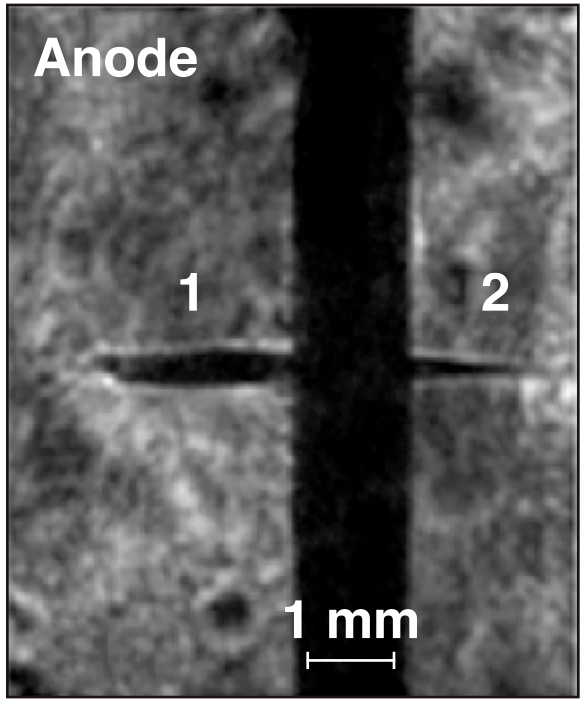
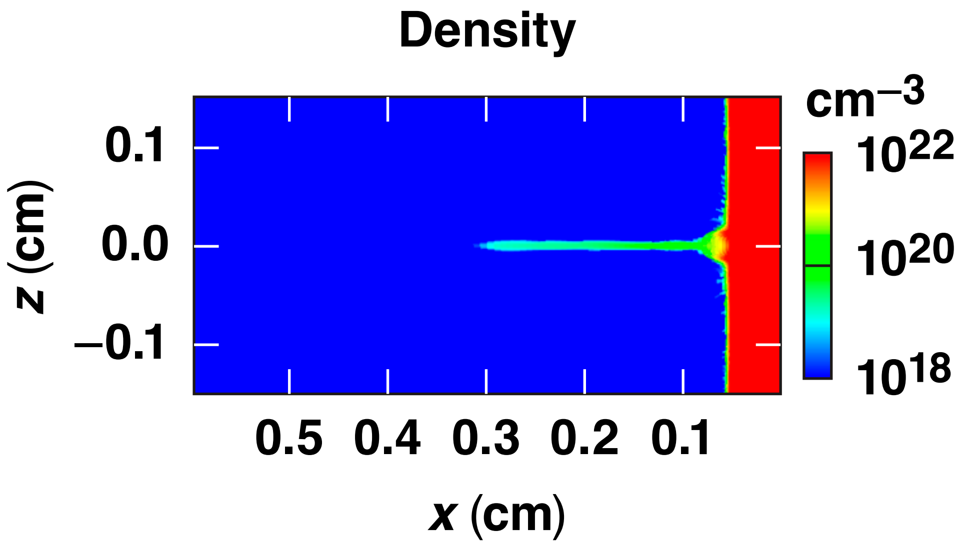
Modeling of a Laser-Generated Plasma in a MG Magnetic Field







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Summary

The confinement of a laser plasma in a strong magnetic field has been observed in the simulations with *HYDRA*

- In the cylindrical geometry, disk-type density structures are generated because of the coupling of laser light to the target in azimuthal magnetic fields
- Resistive magnetohydrodynamics (MHD's) are used for modeling and the role of other terms in Ohm's law is assessed
- At early time the thermal pressure in the expanding plasma is greater than the magnetic pressure, which explains the radial expansion of the disk-type structure at later times
- As the plasma disk expands, the magnetic fields inside the disk can reach a magnitude comparable to the external azimuthal magnetic fields

Collaborators

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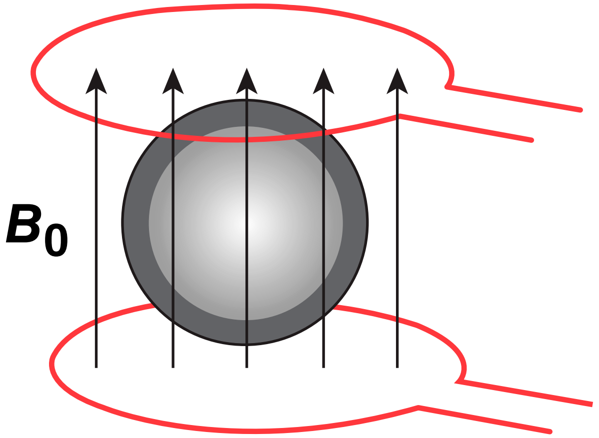
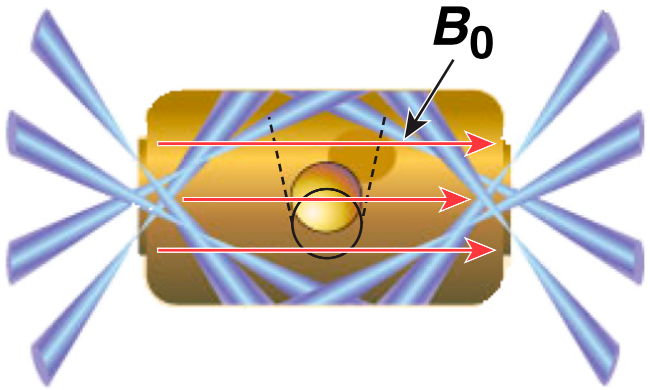
Inertial confinement fFusion (ICF) platforms are incorporating magnetic fields to aid in path toward ignition

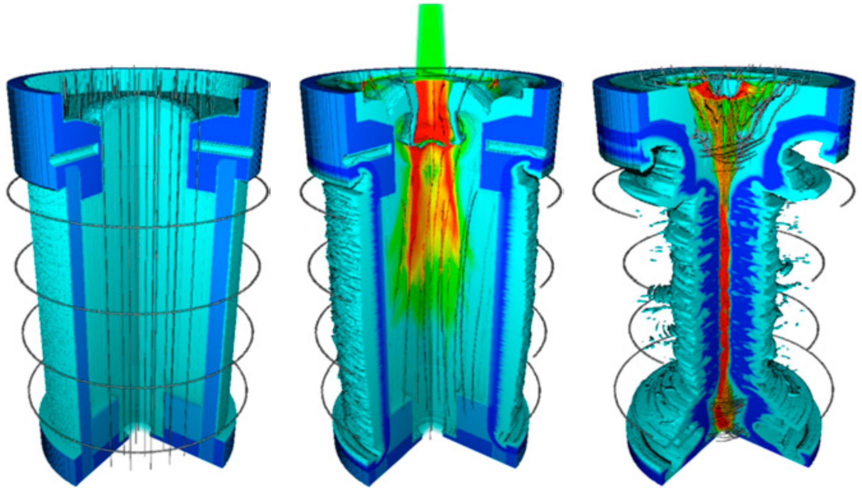
- Multiple concepts in development at Lawrence Livermore National Laboratory, Sandia National Laboratories, and the Laboratory for Laser Energetics
- All magneto-inertial fusion concepts have some interaction of magnetic fields and laser plasmas
- By coupling pulsed-power machines with high-energy lasers, the effect of magnetic fields on ICF targets can be better understood



MagLIF (SNL)



MIFEDS (LLE)



Magnetic NIF (LLNL)

MagLIF: magnetized liner inertial fusion MIFEDS: magneto-inertial fusion electrical discharge system

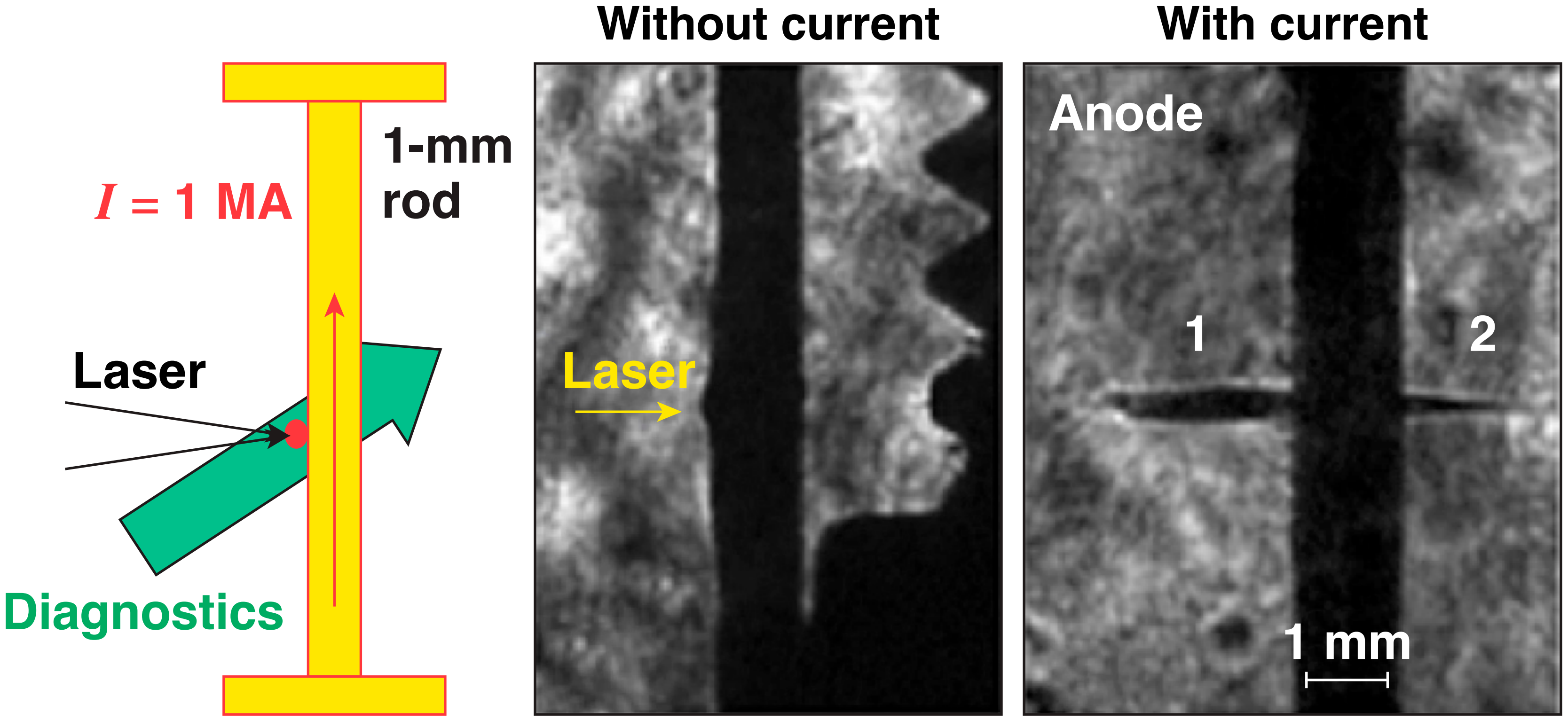
D. J. Strozzi *et al.*, Lawrence Livermore National Laboratory, Livermore, CA, Report LLNL-CONF-672979 (2015).

M. Hohenberger *et al.*, Bull. Am. Phys. Soc. 56, BAPS.2011.DPP.YI3.2 (2011).

M. R. Gomez *et al.*, Phys. Rev. Lett. 113, 155003 (2014).

Disk-type plasma structures have been observed in recent experiments in magnetic fields

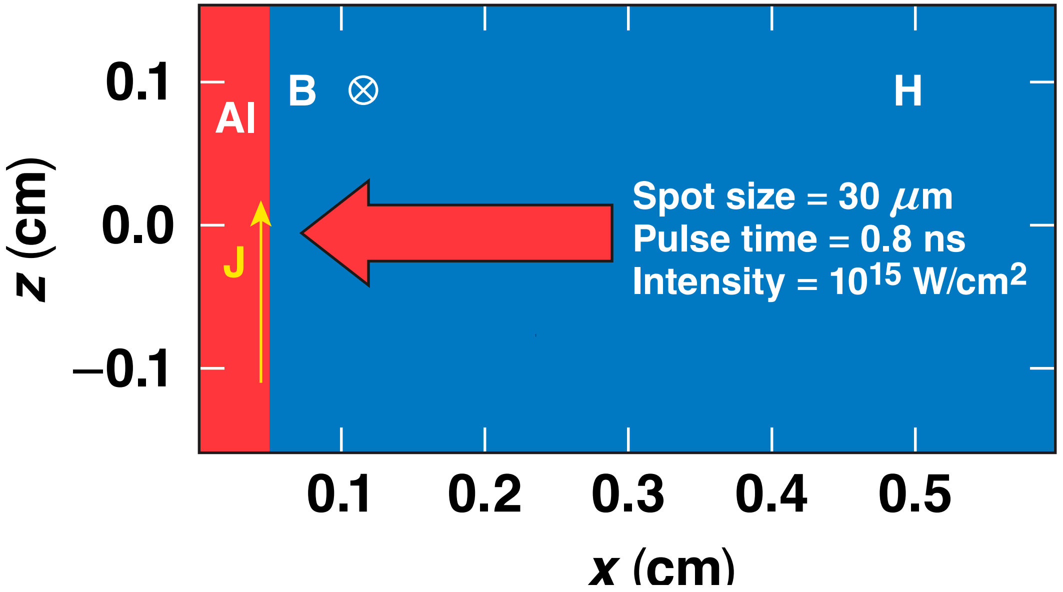
- Experiments were done at the University of Nevada, Reno coupling the Zebra Pulsed-Power Machine and Leopard Laser
- Using a current of about 1 MA, magnetic fields generated near the rod were about 3 MG = 300 T
- The laser was focused to a spot of 30 μm with an intensity of ~3×10^{15} W/cm^2 for ~1 ns
- UV shadowgraphs with the current in the rod show the disk plasma, not present without the current with a measured electron density of 2×10^{19} cm^{-3} and electron temperature of 400 eV



V. V. Ivanov *et al*., Plasma Phys. Control. Fusion 59, 085008 (2017).

The model in *HYDRA* uses resistive MHD in 2-D *r–z* geometry

- **Momentum equation** $\rho_m \frac{D\vec{U}}{Dt} = \rho_q \vec{E} + \vec{J} \times \vec{B} - \nabla \overleftrightarrow{P}$
- **Heat flow** $\vec{q}_e = -\overleftrightarrow{\kappa} \cdot \nabla T_e - \overleftrightarrow{\beta} \cdot \vec{J}$
- **Induction** $\frac{\partial \vec{B}}{\partial t} = -c\vec{\nabla} \times \vec{E}$
- **Ohm's law** $\vec{E} = \underbrace{\boxed{\frac{-\vec{U} \times \vec{B}}{c}}}_{\text{Induction}} + \underbrace{\boxed{\frac{\vec{J} \times \vec{B}}{cen_e}}}_{\text{Hall}} - \underbrace{\boxed{\frac{\nabla \overleftrightarrow{P}_e}{en_e}}}_{\text{Bierman}} + \underbrace{\boxed{\overleftrightarrow{\eta} \cdot \vec{J}}}_{\text{Resistive (diffusion)}} - \underbrace{\boxed{\frac{k}{e}\overleftrightarrow{\beta} \cdot \nabla T_e}}_{\text{Electrothermal}}$



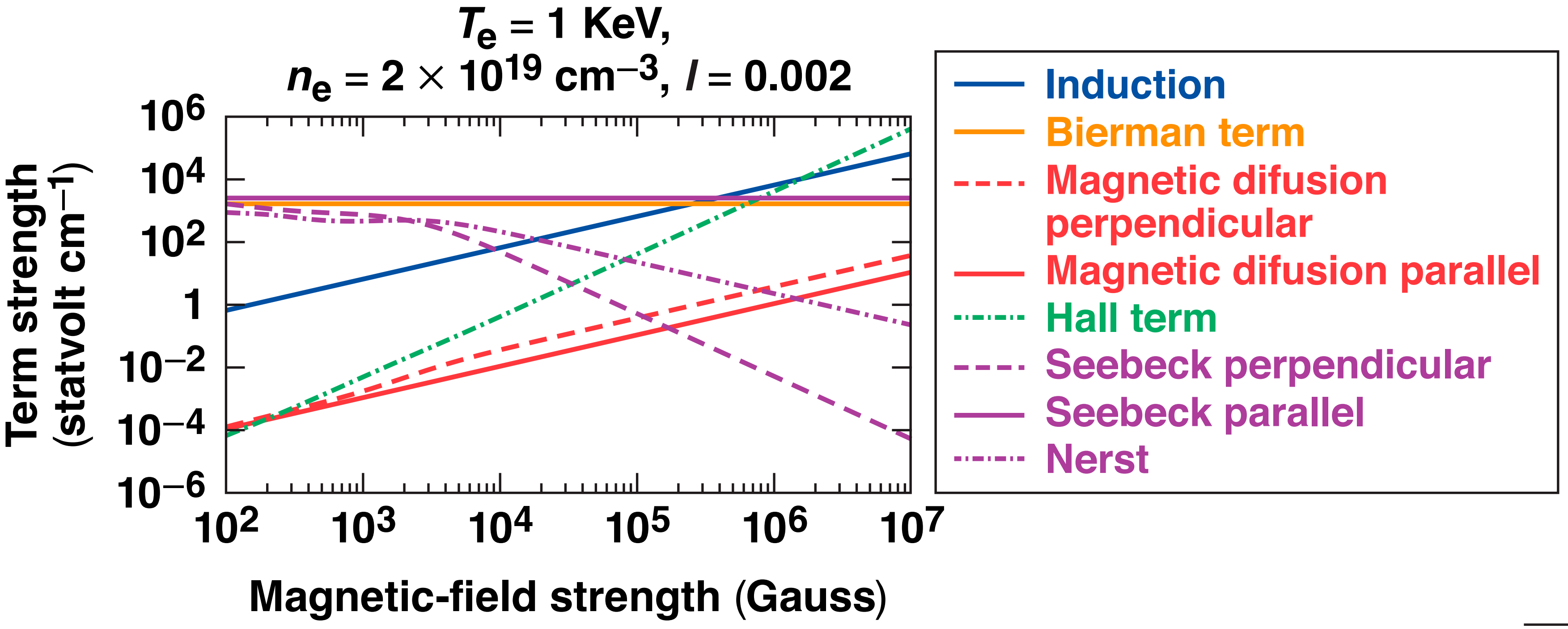
Spot size = 30 μm
Pulse time = 0.8 ns
Intensity = 10^{15} W/cm^2

S. I. Braginskii, in Reviews of Plasma Physics, edited by Acad. M. A. Leontovich (Consultants Bureau, New York, 1965), Vol. 1, p. 205.
J. R. Davies *et al.*, Phys. Plasmas 22, 112703 (2015).

The relative importance of different terms in the Ohm's Law has been evaluated

$$\vec{E} = \overbrace{\boxed{\frac{-\vec{U}\times\vec{B}}{c}}}^{\text{Induction}} + \overbrace{\boxed{\frac{1}{en_e}\left(\frac{1}{c}\vec{J}\times\vec{B} + \frac{\alpha_\wedge}{en_e|B|}\vec{J}\times\vec{B}\right)}}^{\text{Hall}} - \overbrace{\boxed{\frac{\nabla\overleftrightarrow{P}_e}{en_e}}}^{\text{Biermann}} + \overbrace{\boxed{\frac{1}{(en_e)^2}\left(\alpha_\perp J_\perp + \alpha_\parallel J_\parallel\right)}}^{\text{Diffusive (resistive)}} - \overbrace{\boxed{\frac{1}{en_e}\left(\beta_\perp\nabla_\perp T_e + \beta_\parallel\nabla_\parallel T_e\right)}}^{\text{Seebeck (electrothermal)}} - \overbrace{\boxed{\frac{\beta_\wedge}{en_e}\left(\hat{b}\times\nabla T_e\right)}}^{\text{Nerst (electrothermal)}}$$

$$\frac{\partial\vec{B}}{\partial t} = -c\vec{\nabla}\times\vec{E}$$

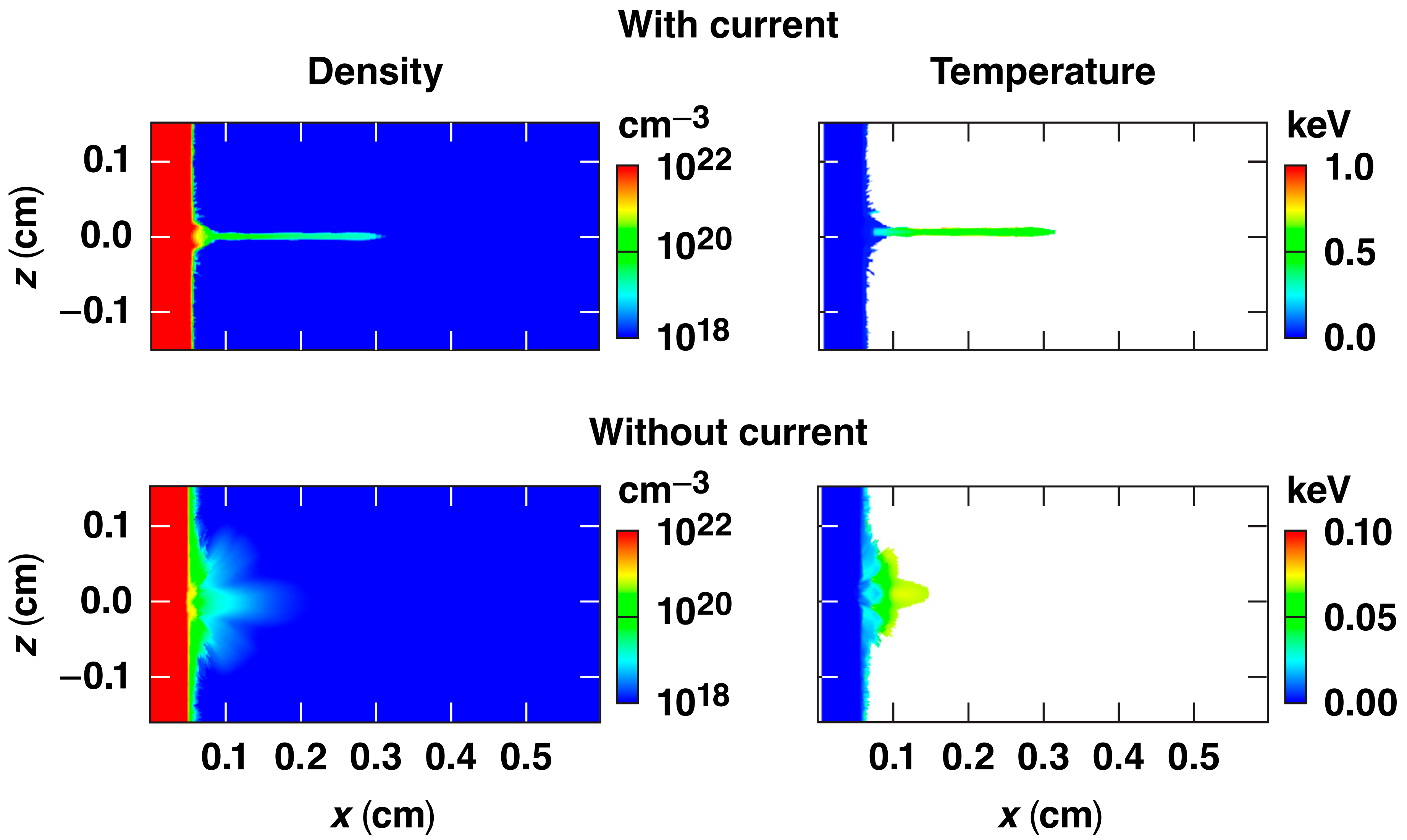


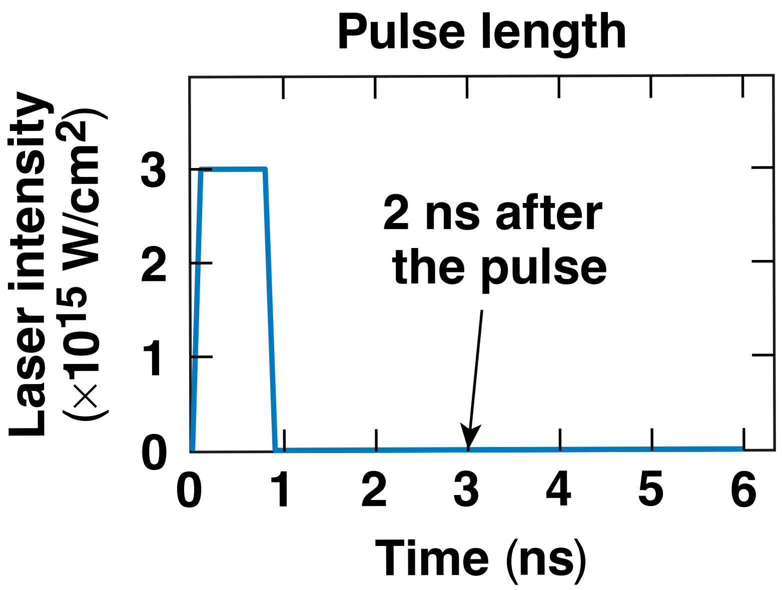
- The induction term dominates
- The plasma parameters
  - electron density $n_e = 2 \times 10^{19}$ cm^{-3}
  - electron temperature T_e = 1 keV
  - scale length l = 0.002 cm = 20 μm

TC14533

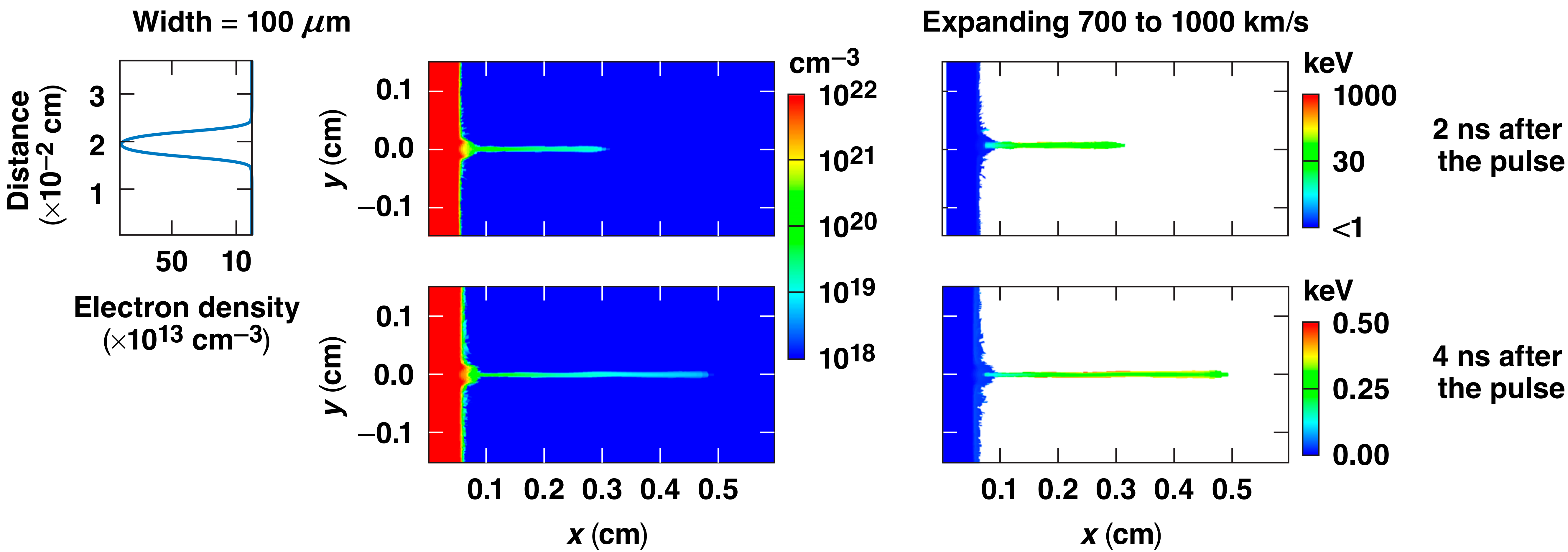
J. Koning, Bull. Am. Phys. Soc. 59, BAPS.2014.DPP.UP8.85 (2014).

Disk-type plasma structures have been observed in simulations with the current in the rod





With time, the plasma disk expands in the radial direction

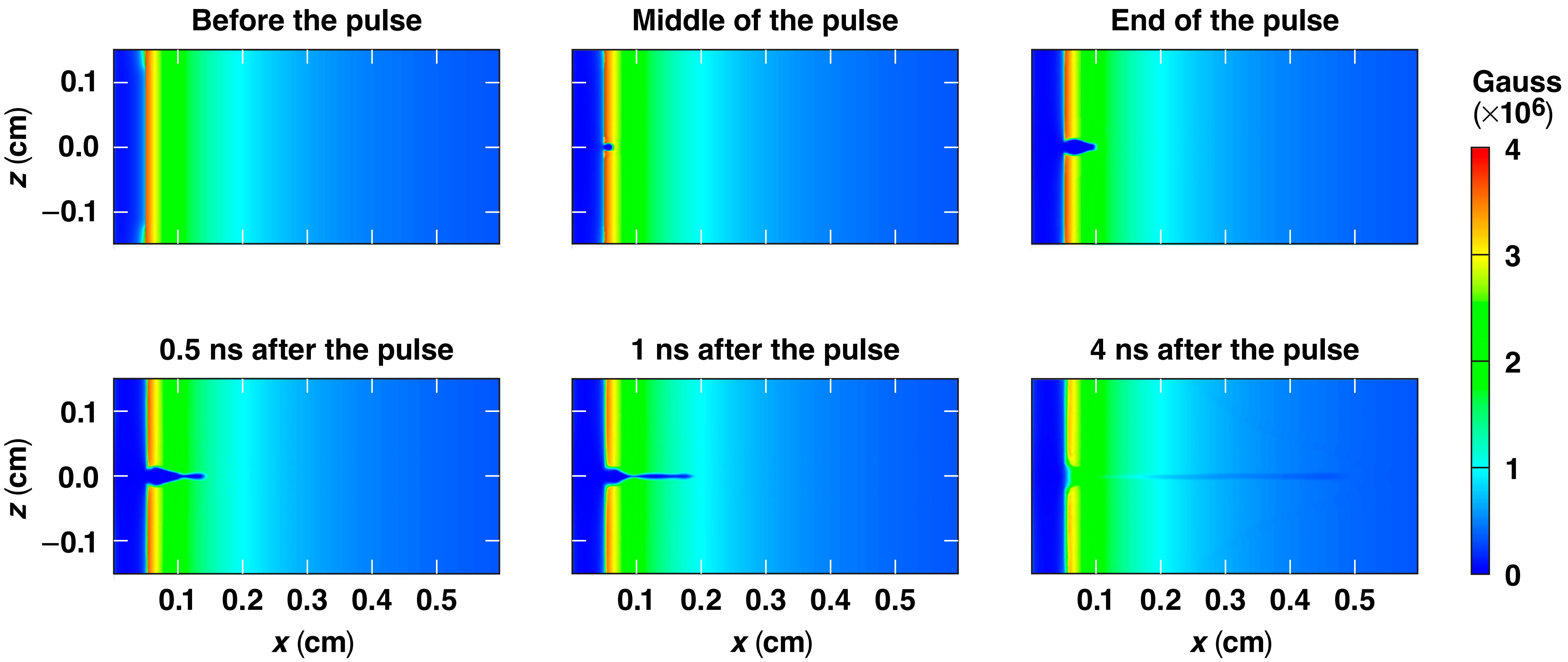

Width = 100 μm

Expanding 700 to 1000 km/s

2 ns after the pulse

4 ns after the pulse

The magnetic-field evolution follows the evolution of the disk



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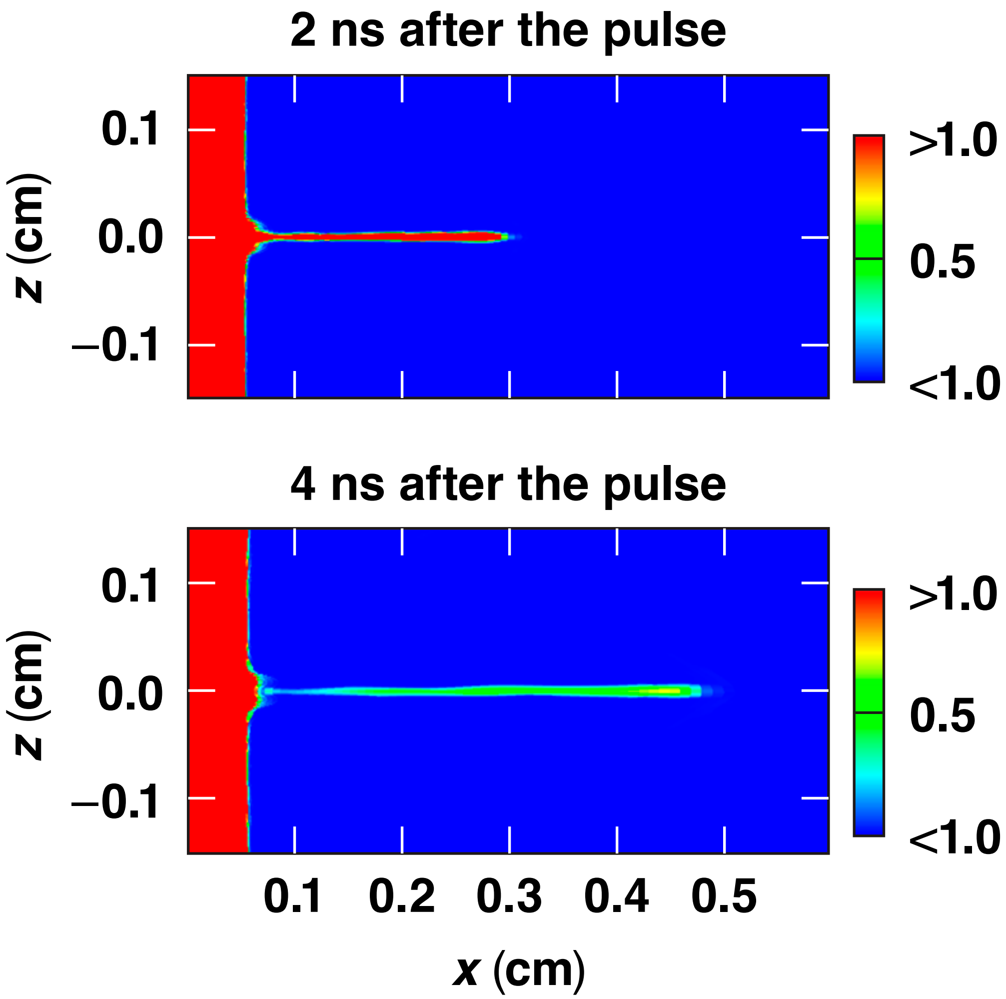
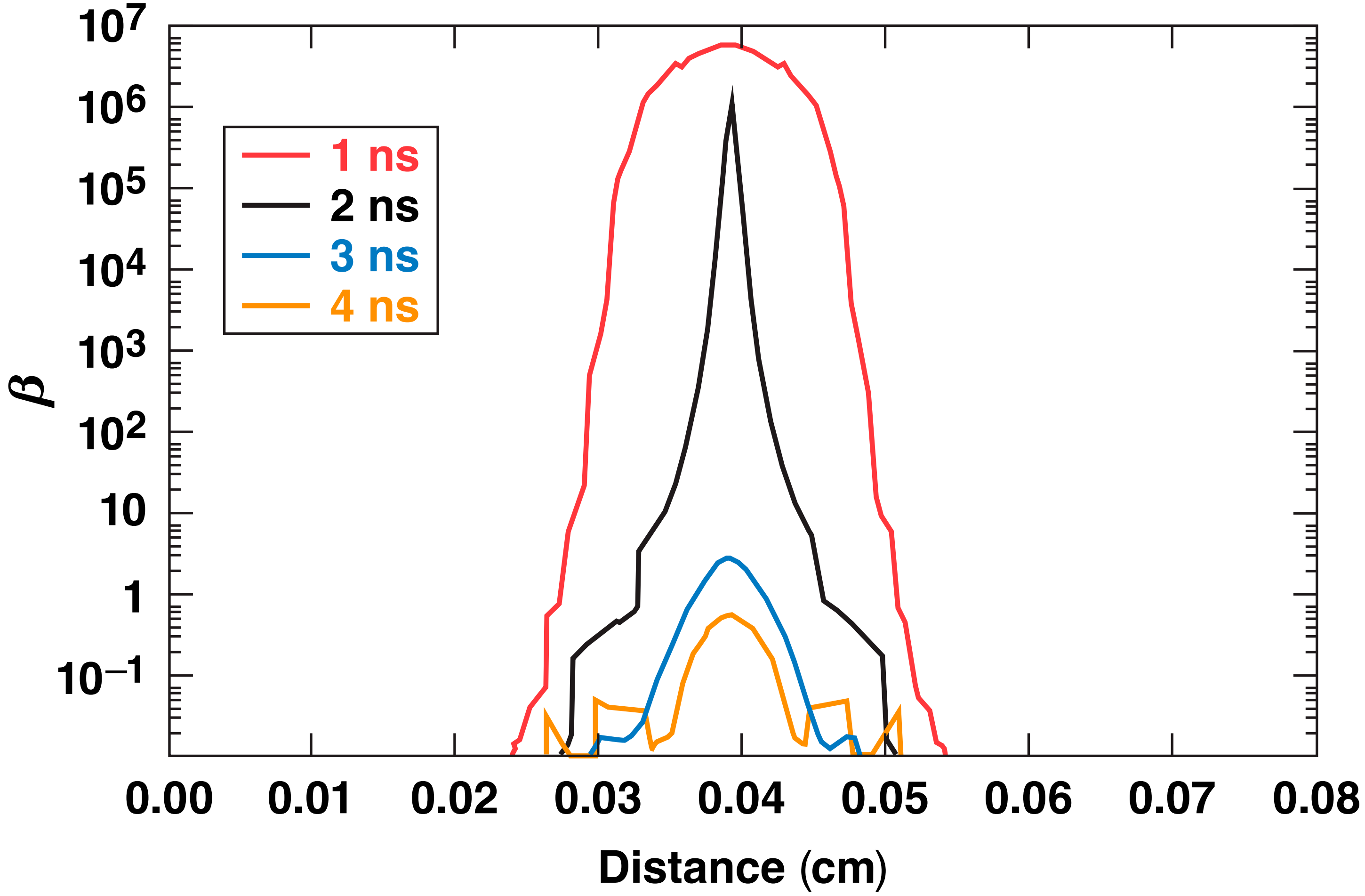
The profile of the plasma pressure parameter β in the axial direction illustrates the localization of the plasma disk





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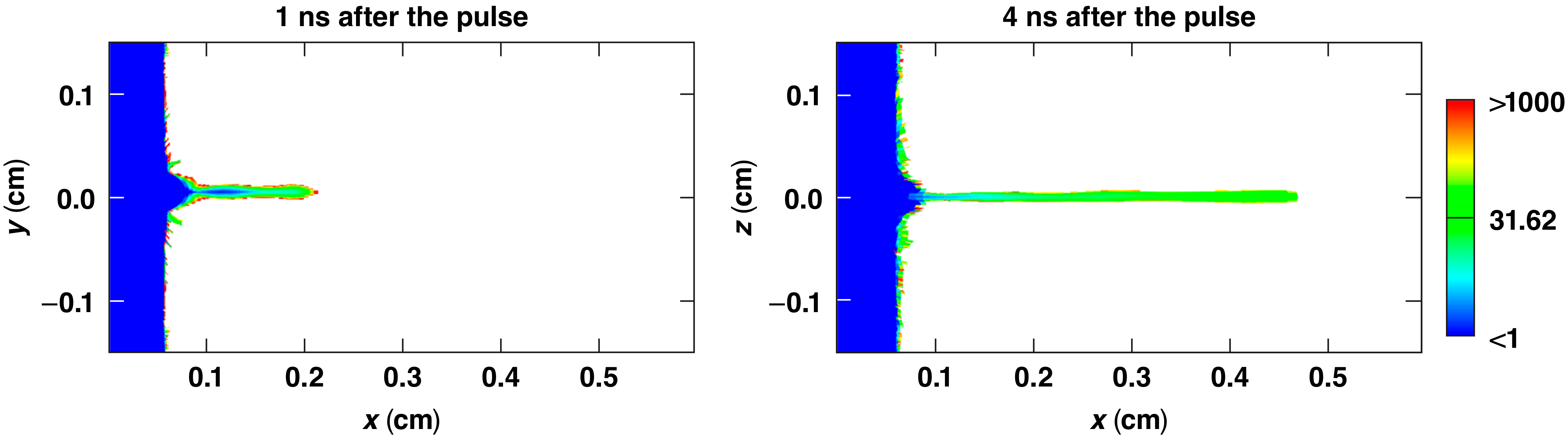
The Hall parameter in the plasma characterizes the influence of the magnetic fields on the transport in plasma



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The mean free path and Larmor radius change by many orders of magnitude in the modeled plasma