Investigation of Electric and Self-Generated Magnetic Fields in Implosion Experiments on OMEGA

Proton radiographs of implosion targets at t = 300 ps

Experiment

Post-processed *DRACO*-MHD simulations

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Summary

Strong electric and self-generated magnetic fields were observed in direct-drive implosions

- Various defects on the surface of implosion targets were applied to enhance the development of self-generated magnetic fields
- Electromagnetic (EM) fields were measured and visualized using proton radiography
- Simulations of EM fields were performed using a *DRACO*-MHD (2-D magnetohydrodynamic code) and show good agreement with measurements
- Both electric and magnetic fields are responsible for the formation of proton images

Collaborators

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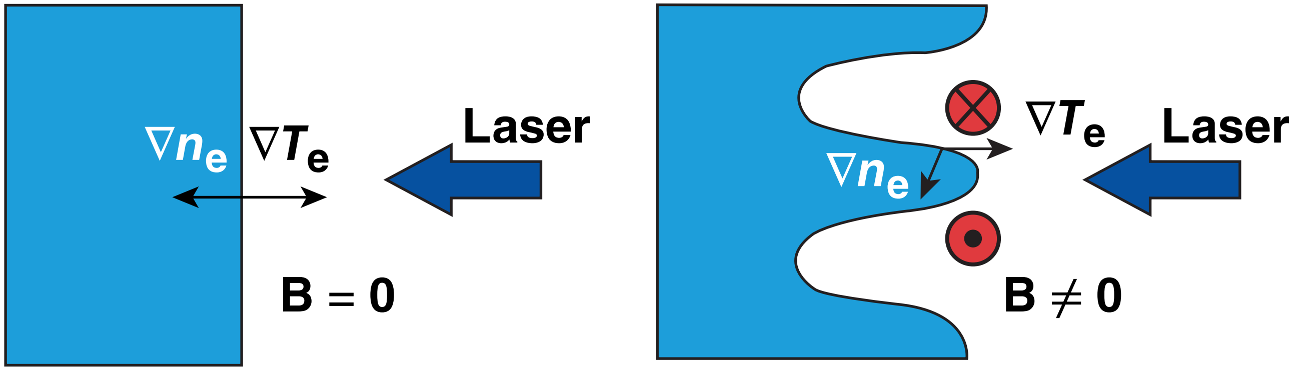
Self-generated magnetic fields can indicate perturbations in implosion targets

Biermann battery process: $\frac{\partial \mathbf{B}}{\partial t} \sim -\nabla n_e \times \nabla T_e$

- No fields when no perturbations

- B fields develop at perturbed ablation surfaces



TC10754

Different mechanisms affecting the B-field dynamics were included in the inertial confinement fusion (ICF) code *DRACO*

Magnetic effects were implemented using the Braginskii formulation*

- **The induction equation:**

Source Pinch Nernst Diffusion

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

- **Nernst:** $\frac{\partial \mathbf{B}_\varphi}{\partial t} = \frac{\partial}{\partial R}\left(V_T \mathbf{B}_\varphi\right), \; V_T = \frac{\tau_e}{m_e} \frac{\beta_1'' x^2 + \beta_0''}{\Delta} \frac{\partial T_e}{\partial R}$ **Convection velocity**

- **Modified heat flux:**

Spitzer Cross gradient Electron current

$$\vec{q}_e = \vec{q}_T^{\,e} + \vec{q}_u^{\,e}$$

- **Cross gradient:** $\left(\vec{q}_T^{\,e}\right)0 = -k_\wedge^e \frac{\partial T_e}{\partial R}, \quad k_\wedge^e \sim \mathbf{B}_\varphi$

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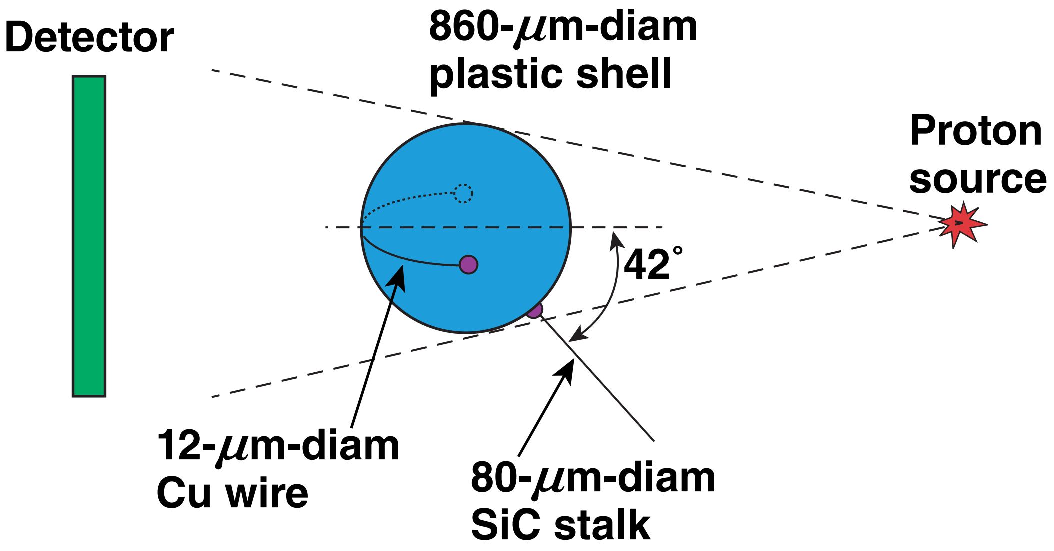
*S. I. Braginskii, in *Reviews of Plasma Physics*, edited by Acad. M. A. Leontovich (Consultants Bureau, New York, 1965), Vol. 1, p. 205.

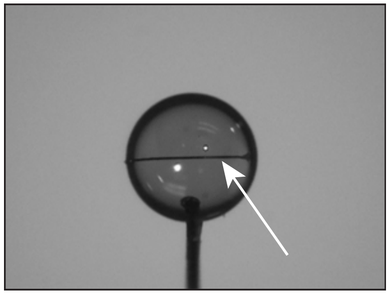
Self-generated magnetic fields were enhanced in implosion experiments using targets with various surface defects

- Surface defects: wire, glue spot, and mount stalk
- EM fields are probed using proton radiography*

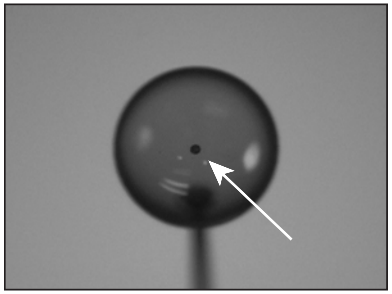


Pre-shot images of targets

With wire



With glue spot



- Implosions use 60 OMEGA beams and the proton backlighter uses one OMEGA EP beam

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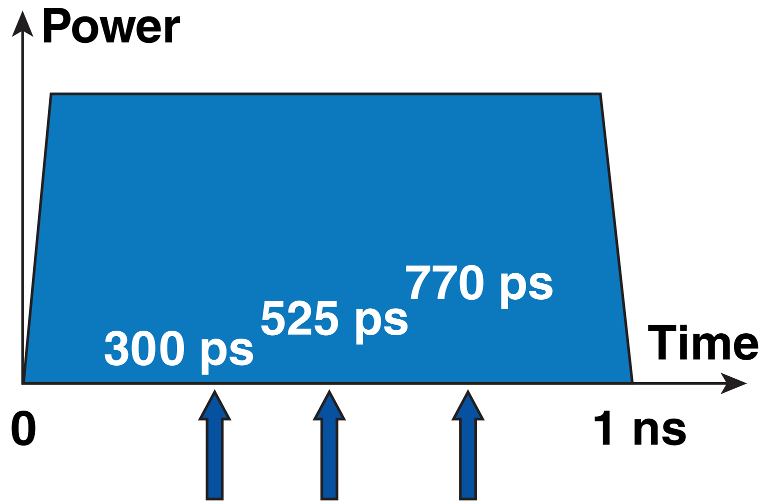
*A. Zylstra *et al*., Rev. Sci. Instrum. 83, 013511 (2012).

The targets were imploded using 28-kJ, 1-ns square laser pulses

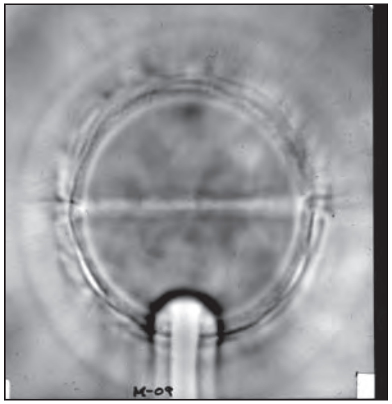
- Proton images were taken at three different times during the laser drive



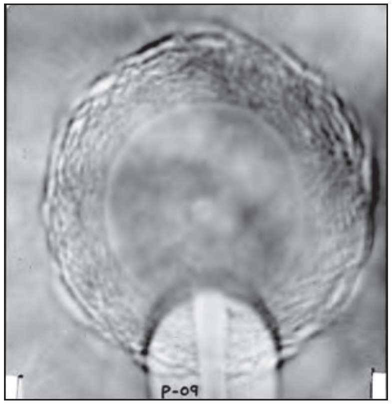
- Image quality degrades at and after 1 ns because of the development of filaments in the corona, which scatter protons (return current instability?)

High-resolution images of implosions with defects were obtained using ~37-MeV backlighting protons

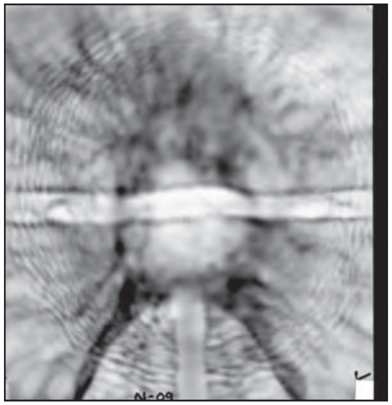
63035
Wire on detector side
***t* = 300 ps**



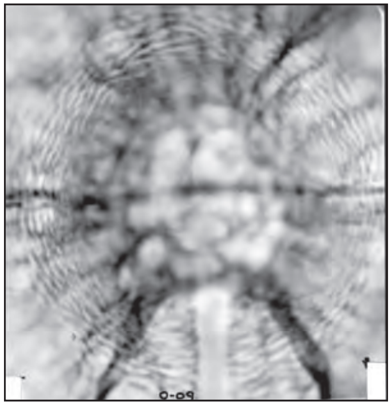
63043
Glue spot on detector side
***t* = 525 ps**



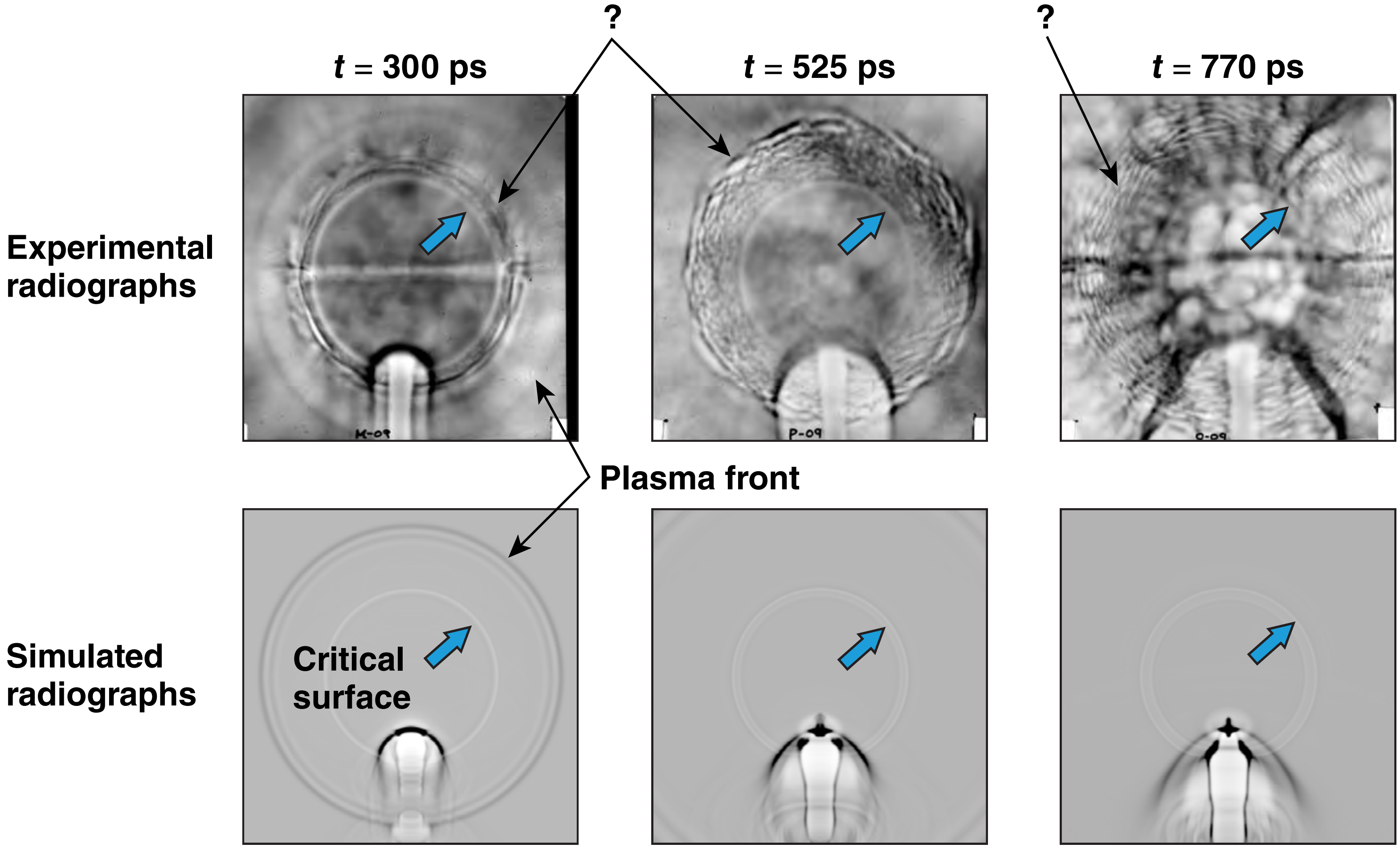
63037
Wire on detector side
***t* = 770 ps**



63039
Wire on source side
***t* = 770 ps**



Protons scattered by electric fields produce images of the spherical plasma front and critical surface



t = 300 ps

t = 525 ps

t = 770 ps

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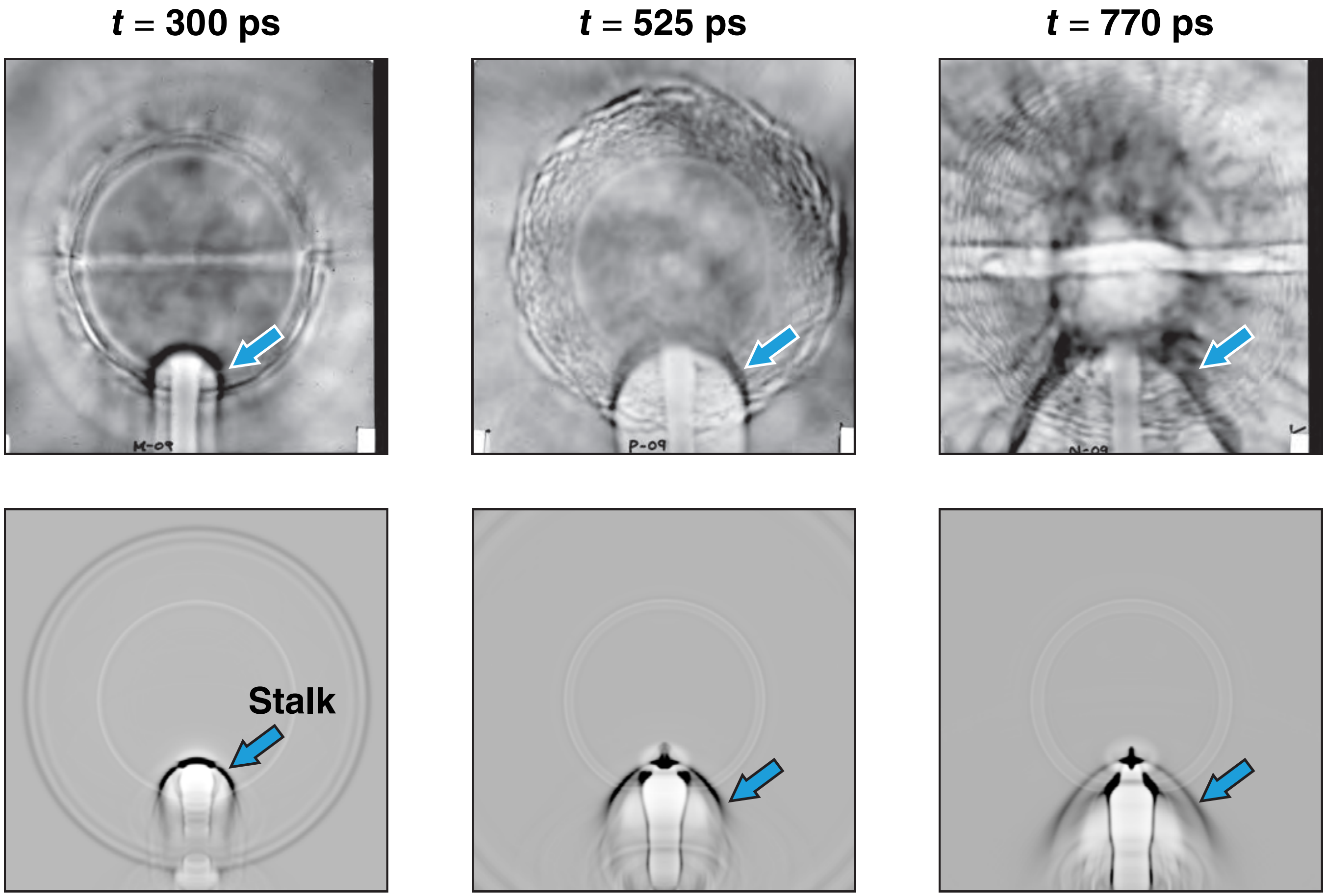
Experimental radiographs

Plasma front

Simulated radiographs

Critical surface

Simulated proton radiographs show the evolution of plasma ablating from the stalk in good agreement with experiments

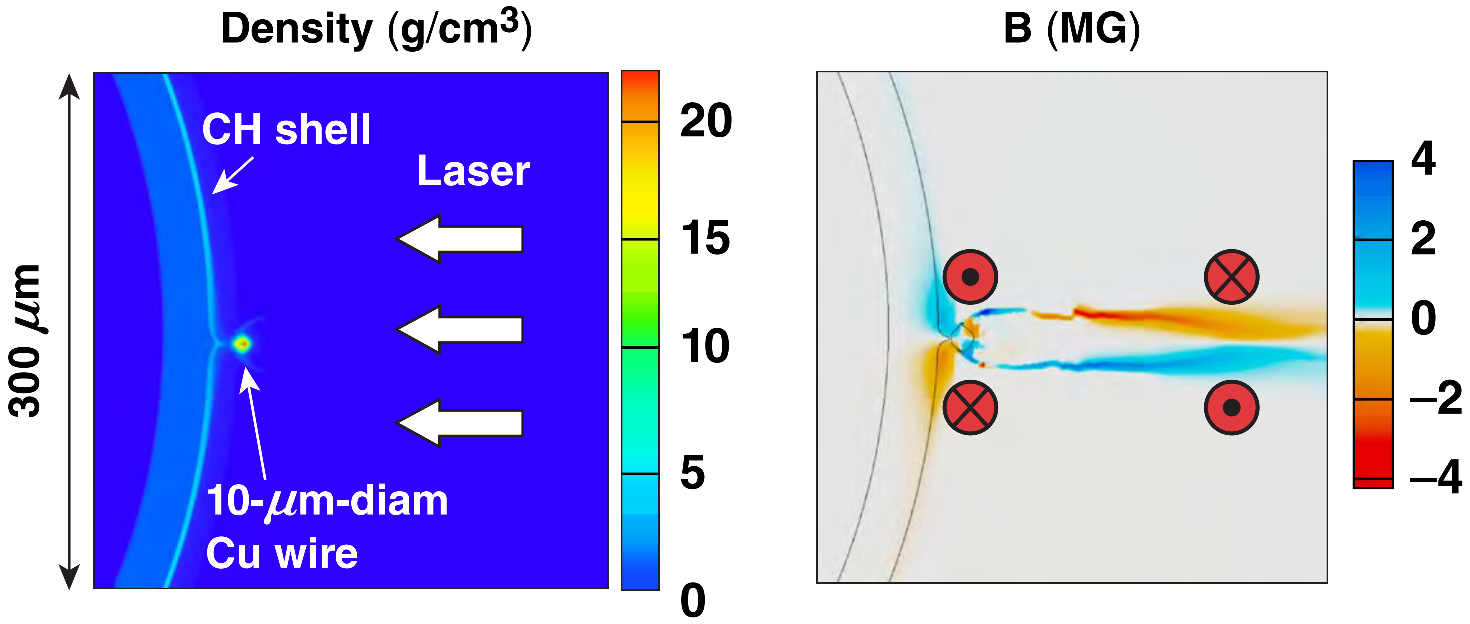


Experimental radiographs

Simulated radiographs

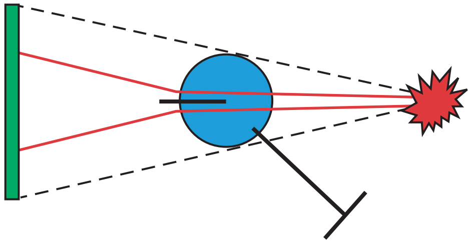
Images of the stalk are mostly caused by B fields

The on-surface Cu wire is ablated and develops an extended plasma tail and B-field structure

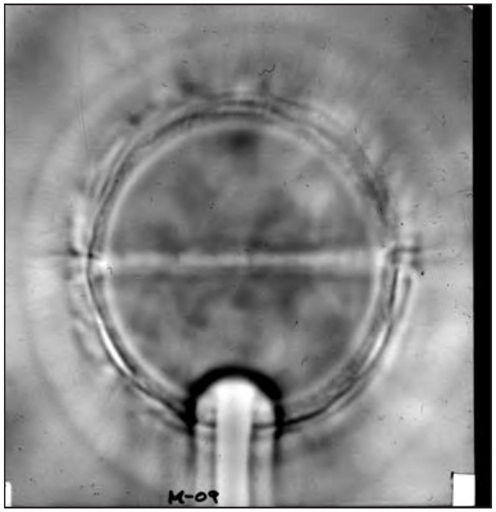


t = 300 ps

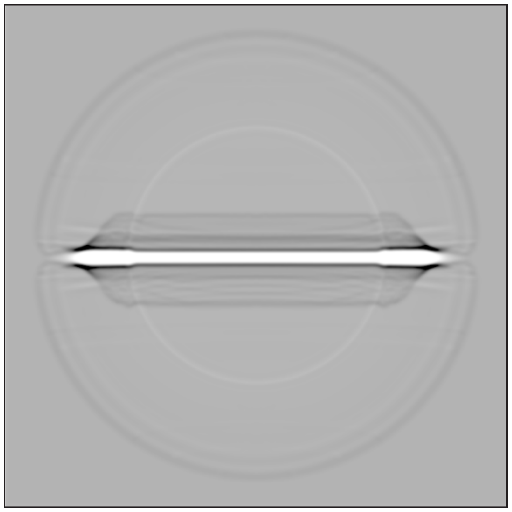
B fields at the tail cause a divergence of backlighting protons and produce a light line on the image



Experiment



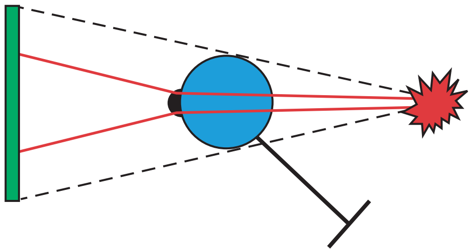
Simulations

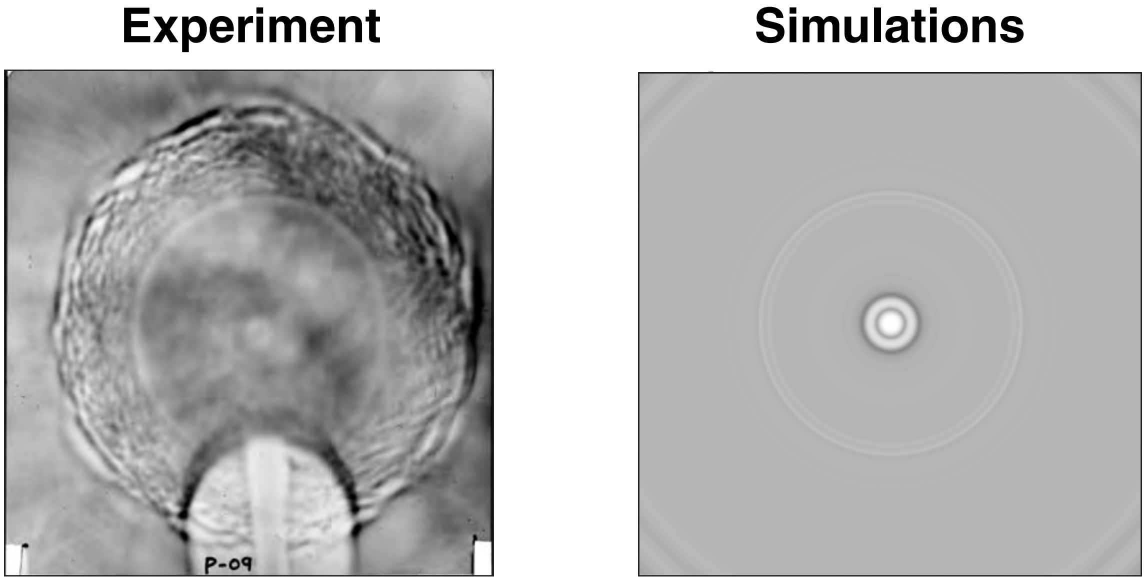


Protons are scattered mostly as a result of B fields

t = 300 ps

Ablation of the glue spot results in the formation of a plasma tail and B fields, which scatter the proton trajectories off producing a light spot in the image





t = 520 ps

- Light spot is larger by a factor of 2 in simulations; this is likely a consequence of overestimation of the plasma tail width in simulations

Summary/Conclusions

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