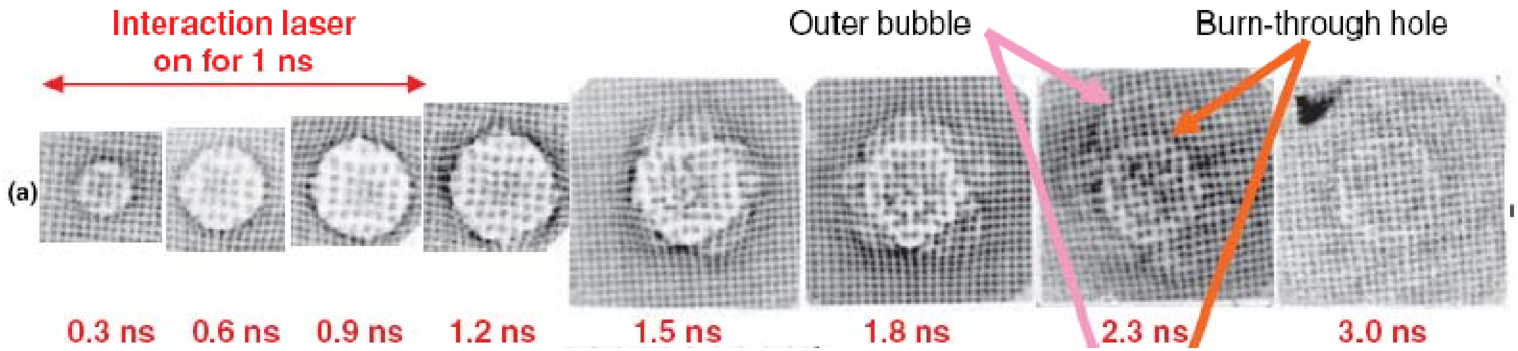
Using Proton Radiography and Thomson Scattering to Study Laser-Generated Plasma Bubbles



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Abstract

We have used Proton Radiography in conjunction with Thomson Scattering to study the evolution of magnetic fields around laser-generated plasma bubbles. In particular, we have investigated dynamics associated with the reconnection of two of these bubbles in planar geometry. These experiments are of notable relevance to the progress of indirect-drive ICF. Additionally, comparison of experimental data to simulation reveals the need for a 3D code to simulate the effects of instabilities in laser-plasma interactions.

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Motivation

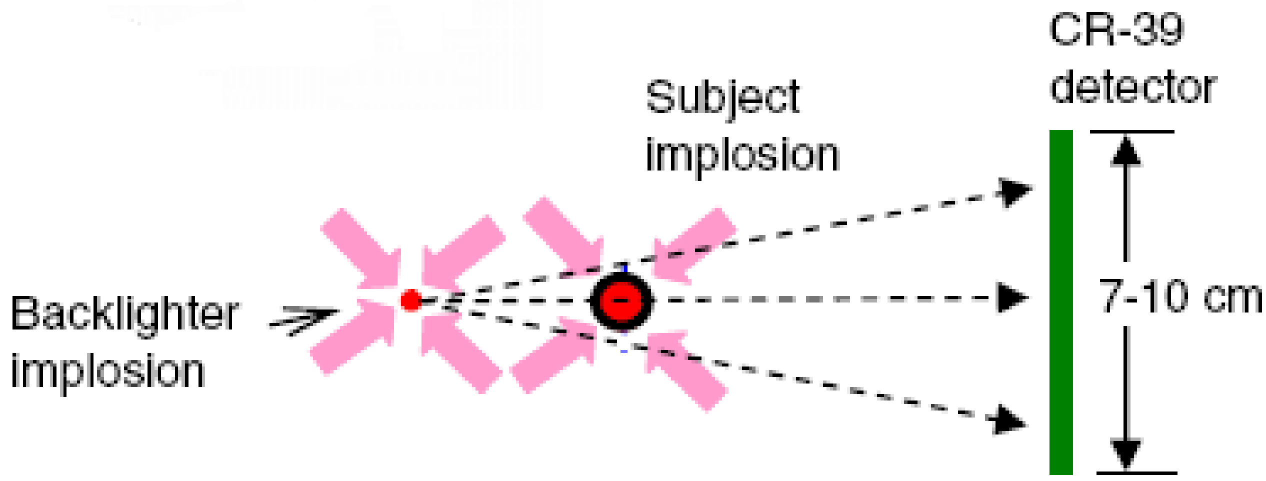
- Diagnosing laser-generated plasmas in ICF-relevant regimes
- Simulating conditions inside ICF hohlraums in laser-foil experiments
- Understanding electromagnetic fields produced during indirect- and direct-drive implosions

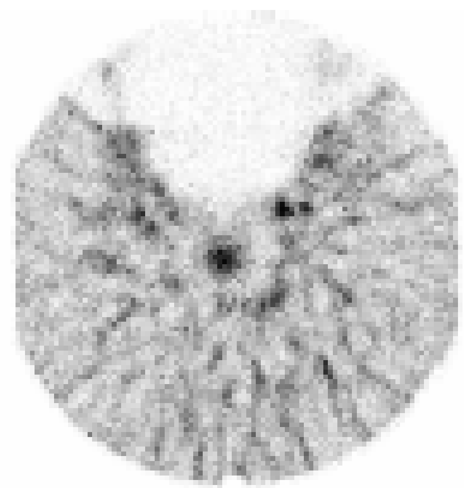
- Proton Radiography provides temporally- and spatially-resolved data on E and B fields
- Thomson Scattering provides data on plasma temperature, which sheds light on field dynamics

Diagnostics and Experiments

Proton Radiography Is Used to Image and Measure Electric and Magnetic Fields

- Monoenergetic DD and D^3He protons are produced in a backlighter implosion
- Image features reflect the deflection of protons due to the Lorentz force: $F = q(E + V \times B)$, <u>where V is known</u>

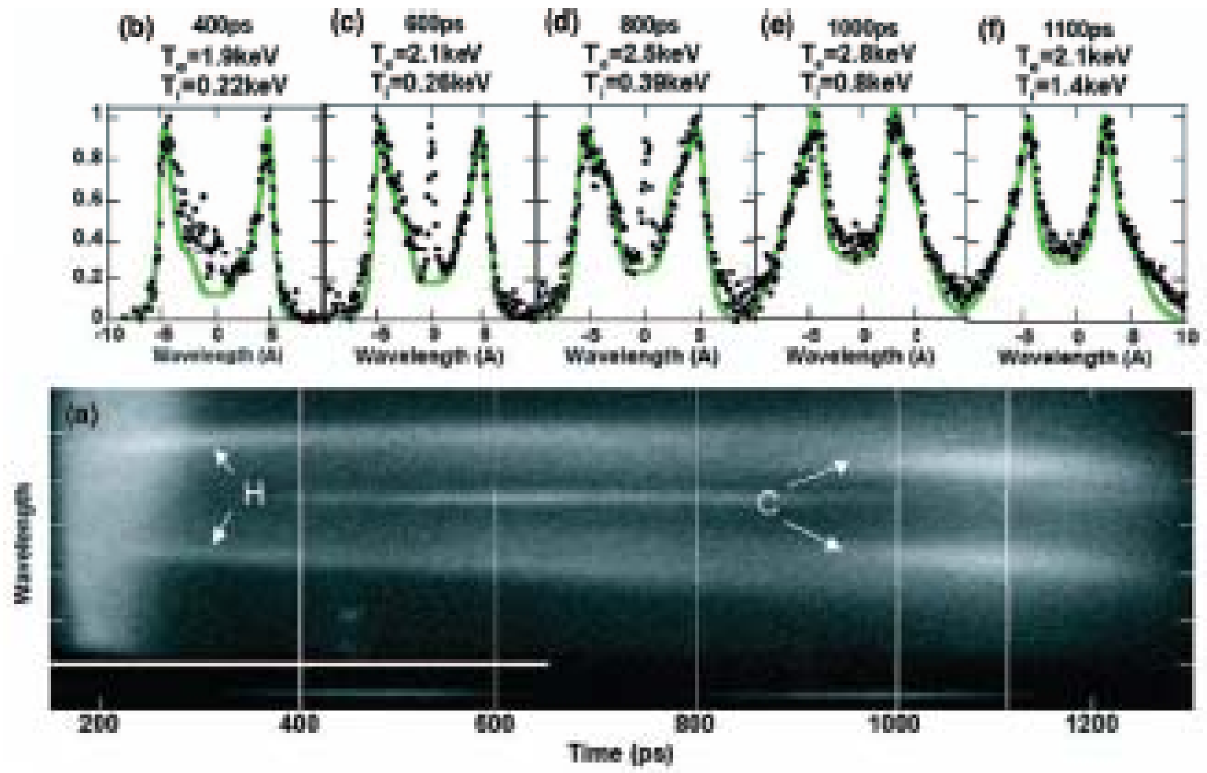




J.R. Rygg *et al.* "Proton Radiography of Inertial Fusion Implosions," Science 319, 1223 (2008)

Thomson Scattering Is Used to Probe Electron Temperatures in Plasma

- A measured spectrum of laser light reflected off ion acoustic waves is fitted to provide Te, Ti, and density

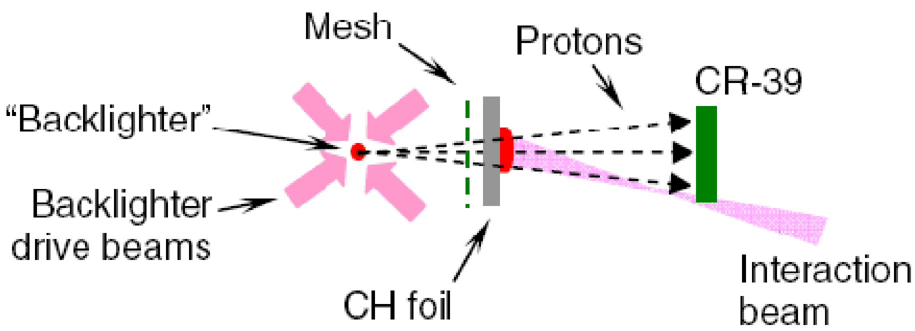


D.H. Froula, *et al.* “Thomson-scattering techniques to diagnose local electron and ion temperatures, density, and plasma wave amplitudes in laser produced plasmas,” RSI 77, 10E522 (2006)

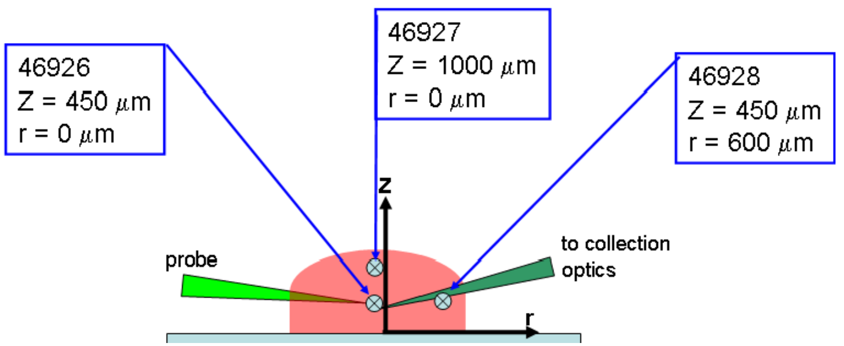
Experiments

- Single bubble – 1 laser on CH foil

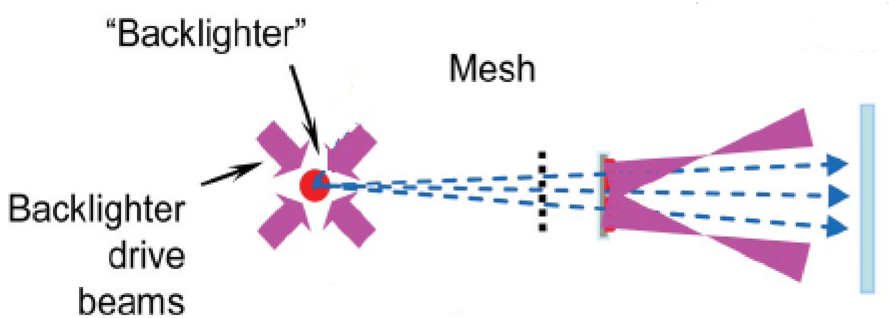
Radiography setup

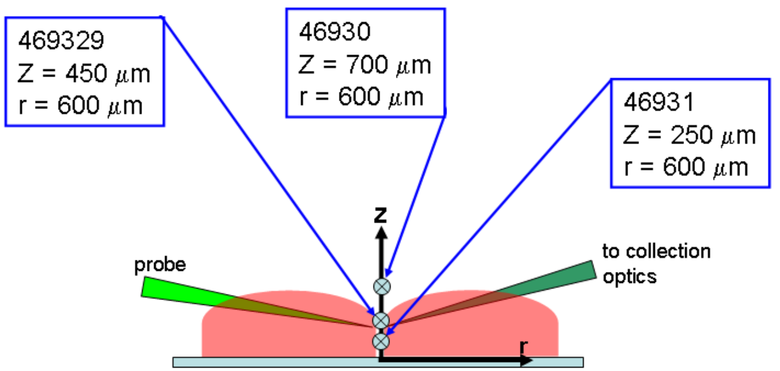


Thomson Scattering regions



- Reconnection – 2 lasers side-by-side

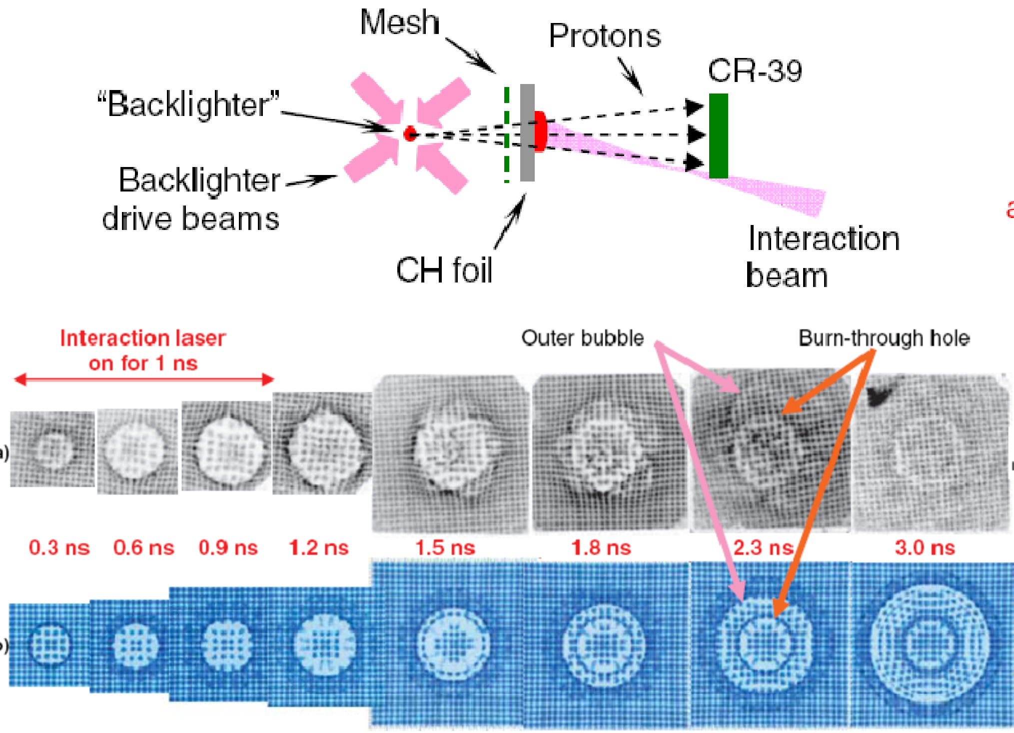


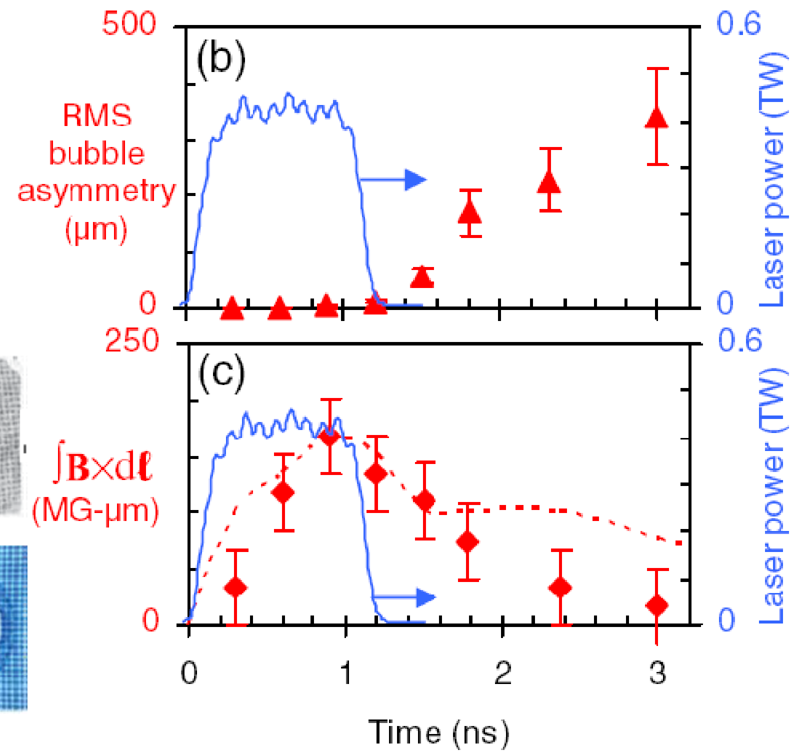


Comparison of Data to Simulation

Proton Radiography Reveals 3D Structures in Laser-Generated Plasma Bubbles

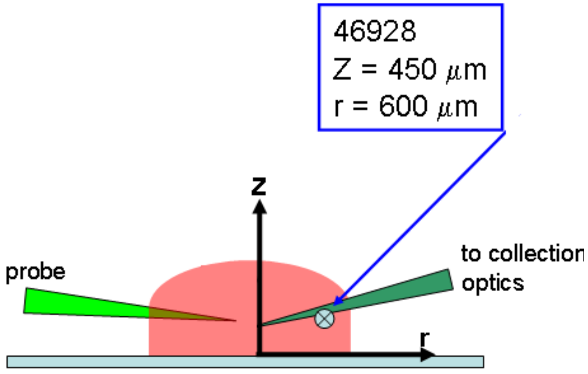
- Asymmetry develops after laser turn-off around t = 1.3 ns
- 2D LASNEX (dashed below right) cannot predict 3D

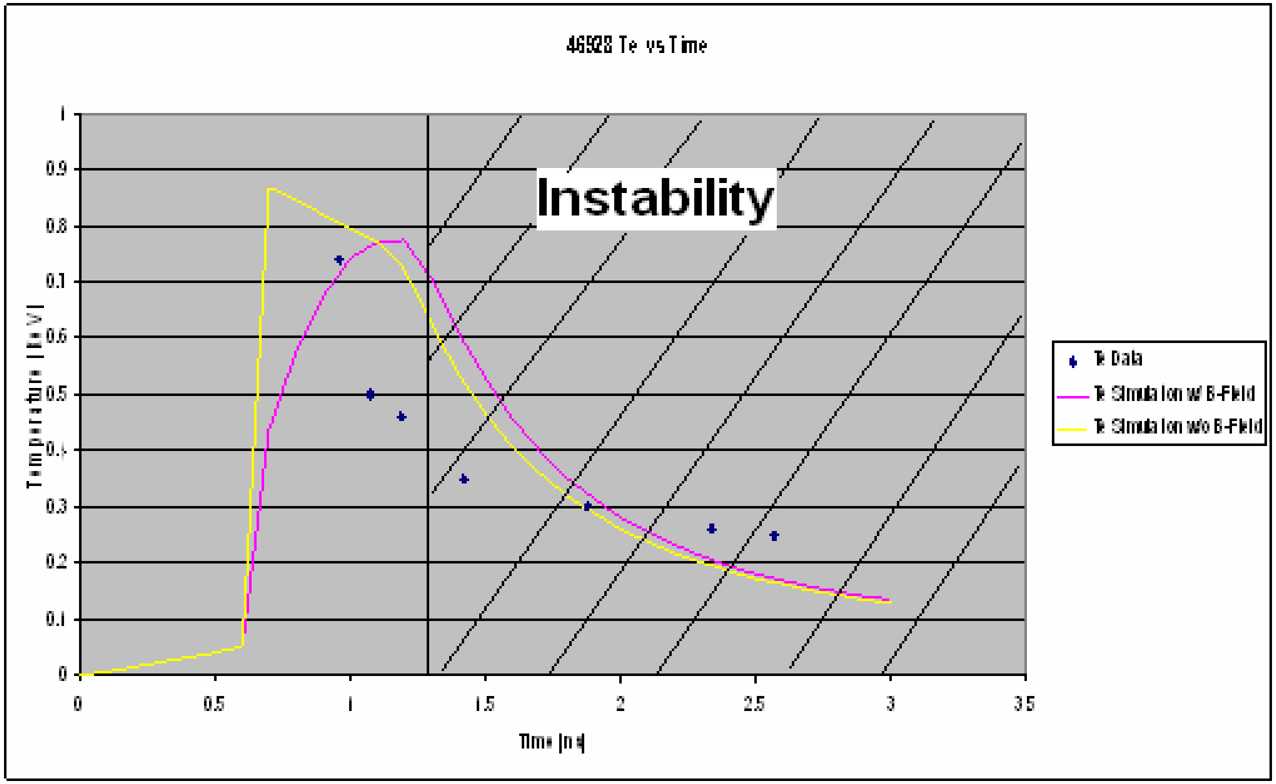




C. K. Li, *et al.* "Observation of the Decay Dynamics and Instabilities of Megagauss Field Structures in Laser-Produced Plasmas," PRL 99, 015001 (2007)

Thomson Scattering Was Used to Measure Electron Temperatures in Laser-Generated Plasma Bubbles





Comparison to Simulation Demonstrates Need for a 3D Hydrodynamics Code

- Proton Radiography shows that 3D instabilities dominate B field decay

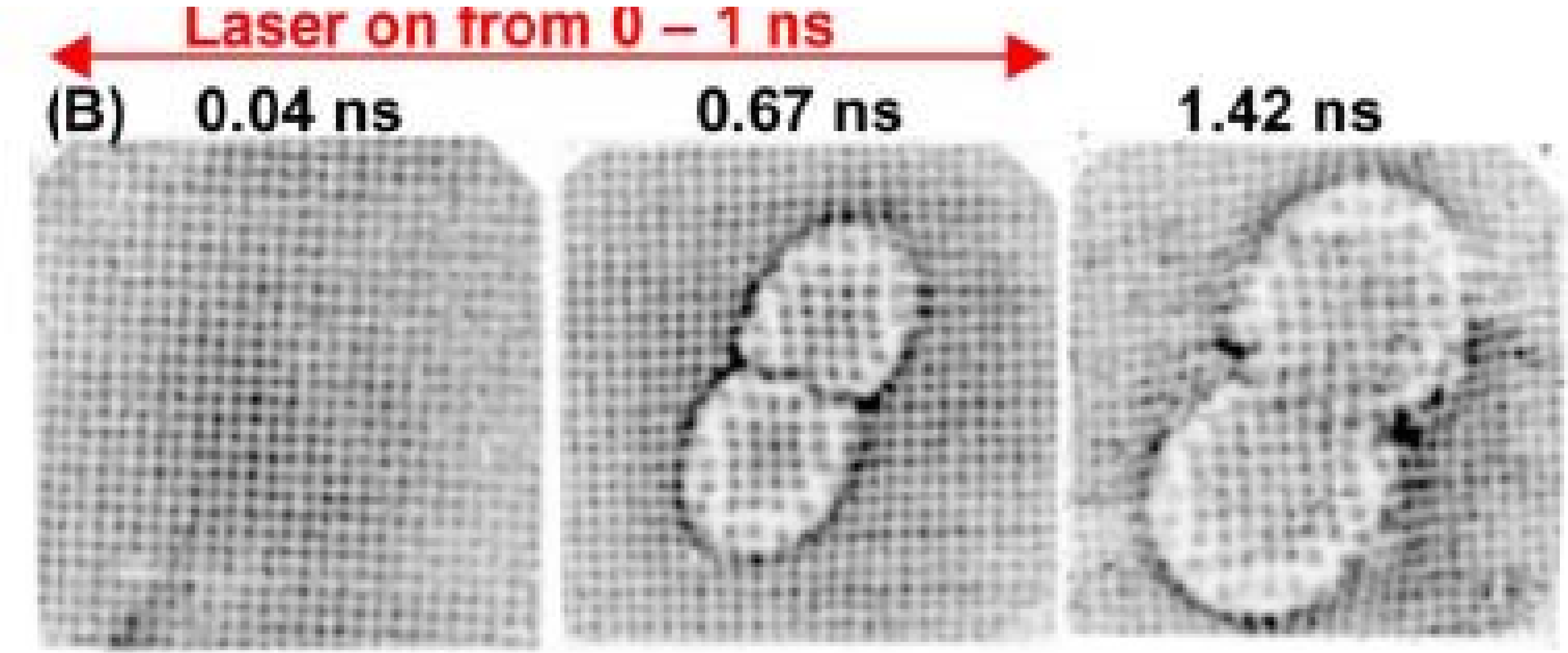
- 2D LASNEX code was benchmarked against laser-generated plasma bubble data
  - Was found to overestimate B when 3D instabilities occur

- 3D simulations would be required to study 3D instabilities and even 2D parameters in the presence of 3D instabilities

Reconnection Data

Proton Radiography Shows Topology Change During Magnetic Reconnection

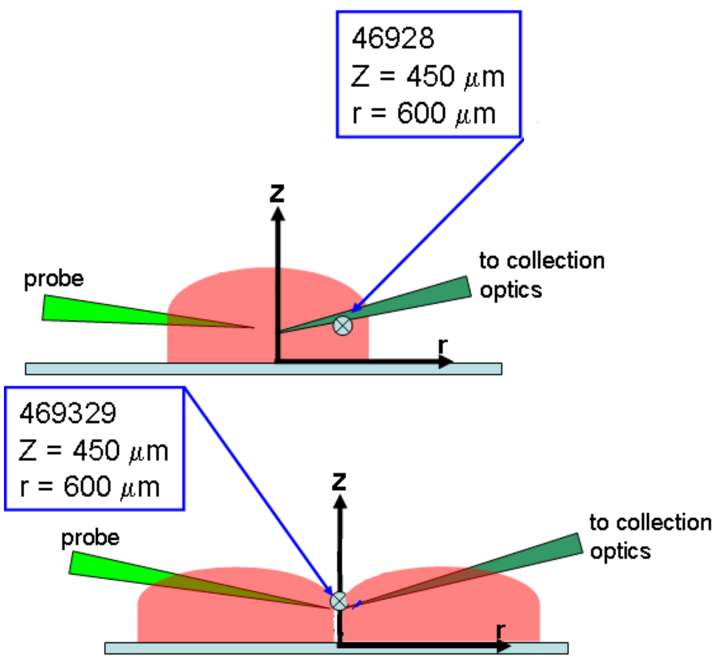
- Hydrodynamics are unaffected because hydrodynamic pressure >> magnetic pressure
  - See slide below

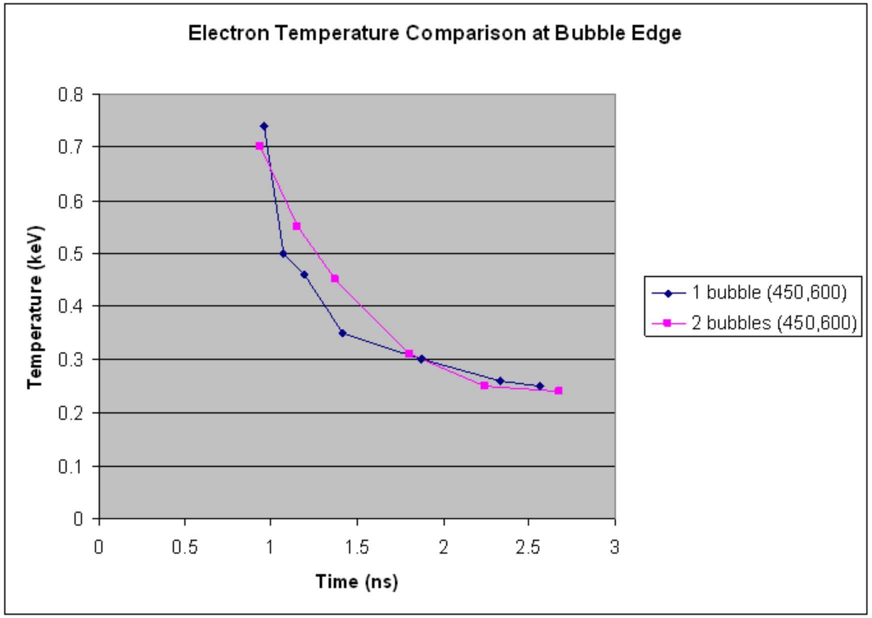


C. K. Li, *et al.* “Observation of Megagauss-Field Topology Changes due to Magnetic Reconnection in Laser-Produced Plasmas,” PRL 99, 055001 (2007)

Thomson Scattering Shows That Reconnection Does Not Affect Temperature

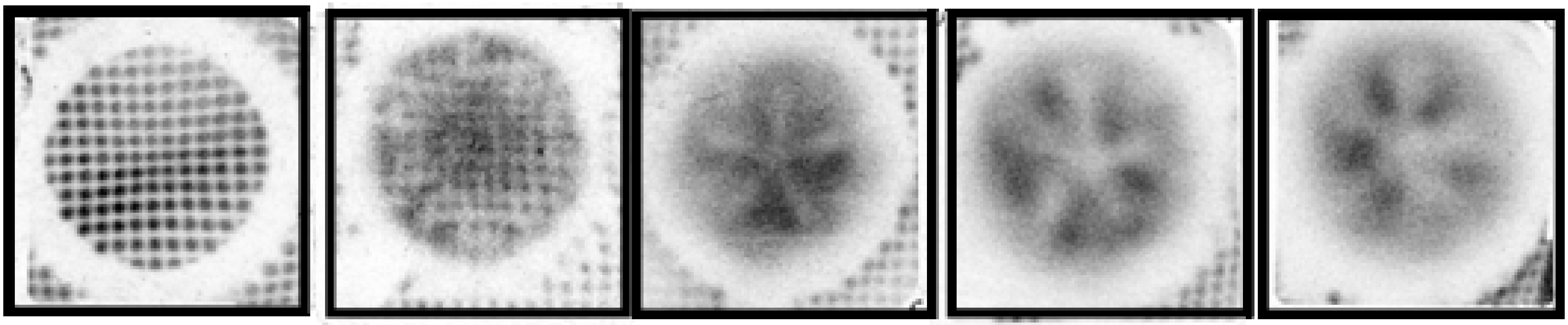
- No difference in Te(t) between single and double bubble





Proton Radiography Shows the Dynamics of Fields and Flows Inside ICF Hohlraums

- Understanding magnetic fields around laser-generated plasmas is crucial for advancing indirect-drive performance
- Interaction of several bubbles through reconnection leads to the creation of jets
- Fields affect electron transport; jets could physically impinge on capsule inside of <u>vacuum</u> hohlraum (below)



C. K. Li, *et al.* PRL (2009)

Summary and Future Work

Questions

- What is the effect of bulk flows or jets on Thomson Scattering data? Can we use TS to diagnose jets?
- How else could Proton Radiography and Thomson Scattering data be used to study plasmas in ICF-relevant regimes?
- How can the Ignition community make use of these experiments?

Future Work

- Answer the questions above!
- May 19 experiments, more Radiography of hohlraums
- Study reconnection of plasma bubbles inside foam-filled hohlraum, closer to real indirect-drive conditions
- Do jets penetrate all the way to the hohlraum center or are they mitigated by the presence of foam or gas?
- Apply Thomson Scattering to hohlraum experiments alongside Radiography

Conclusions

- Proton Radiography has proven to be a useful diagnostic for laser-produced plasmas
- We can use Thomson Scattering to obtain plasma properties which affect B-field dynamics, while B(t) itself is measured using Proton Radiography
- Magnetic fields of laser-generated plasma affect transport around ICF capsules; understanding their development is critical to implosion performance

- There is a need for a 3D code to simulate laser-plasma interactions that give rise to instabilities

Important References

- J.R. Rygg *et al.* “Proton Radiography of Inertial Fusion Implosions,” Science 319, 1223 (2008)
- D.H. Froula, *et al.* “Thomson-scattering techniques to diagnose local electron and ion temperatures, density, and plasma wave amplitudes in laser produced plasmas,” RSI 77, 10E522 (2006)
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- C. K. Li, *et al.* “Observation of Megagauss-Field Topology Changes due to Magnetic Reconnection in Laser-Produced Plasmas,” PRL 99, 055001 (2007)
- P.M. Nilson, *et al.* “Magnetic Reconnection and Plasma Dynamics in Two-Beam Laser-Solid Interactions,” PRL 97, 255001 (2006)
- C. K. Li, *et al.* “(Submitted for Publication)” PRL (2009)