Mapping *E* & *B* fields in laser-generated plasmas using monoenergetic proton radiogaphly

Fredrick Séguin, MIT, *et al*.

Collaborators

MIT – PSFC	*U of R – LLE*	*LLNL*
C.K. Li	R. Betti	P. Amendt
J.R. Rygg*	J. Knauer	O. Landen
M. Manuel	D. Meyerhofer	P. Patel
J. Frenje	V. Smalyuk	R. Town
N. Sinenian		
D. Casey		
R. Petrasso		

*Currently at *LLNL*

Support

National Laser Users Facility (NLUF)
Fusion Science Center (FSC) at the University of Rochester
DoE – NNSA
Laboratory for Laser Energetics, University of Rochester
Lawrence Livermore National Laboratory

Introduction

Summary

Monoenergetic proton radiography of plasmas and Lorentz-force mapping allow for measurement of field strengths and discrimination between *E* and *B*

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1. Monoenergetic proton radiography provides a method of imaging laser-generated plasmas and their self-generated *E* and *B* fields.
2. Images can be analyzed with the Lorentz equation to determine the type (*E* or *B*), spatial distribution, and strength of such fields.
3. A detailed example is shown for plasma bubbles generated by laser beams incident on a CH foil.
4. Other applications complete or underway include
   - Magnetic reconnection of B fields around colliding plasma bubbles
   - Fields in direct-drive-ICF coronae
   - Fields in indirect-drive-ICF hohlraums
   - Fields generated by R-T instabilities

E and *B* fields in a plasma can be measured by probing with monoenergetic protons

(1) Proton trajectory bending is due to the Lorentz force $F = q\left(E + \frac{v \times B}{c}\right)$,

where q = proton charge and v = proton velocity,
acting over a path length ℓ characteristic of the fields' spatial extent.

(2) If bending by angle Θ is observed and the field is known to be E or B, then

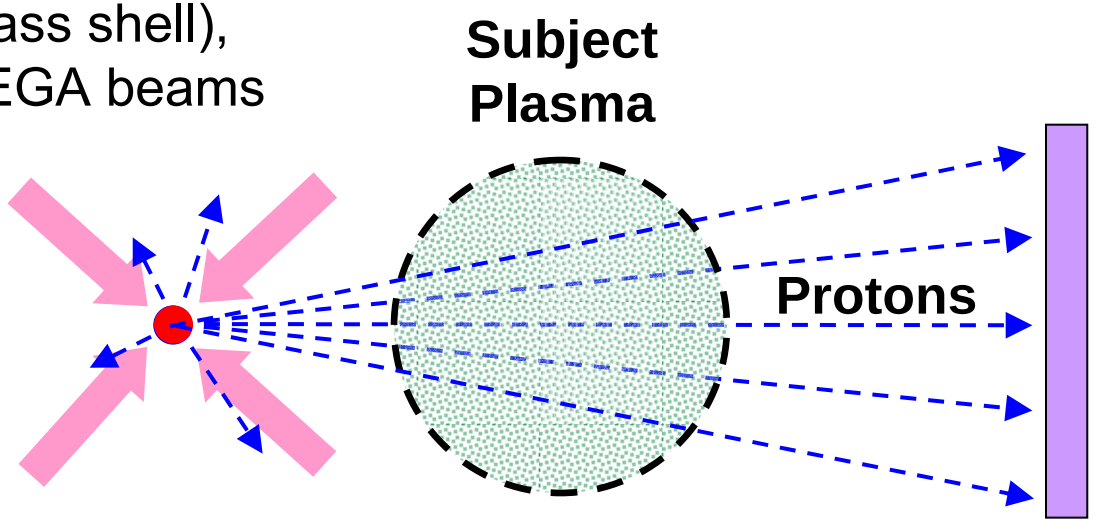
$$\int E \times d\ell \propto \Theta \,/\, (\text{proton energy}) \qquad \text{or} \qquad \int B \times d\ell \propto \Theta \,/\, (\text{proton energy})^{1/2}$$

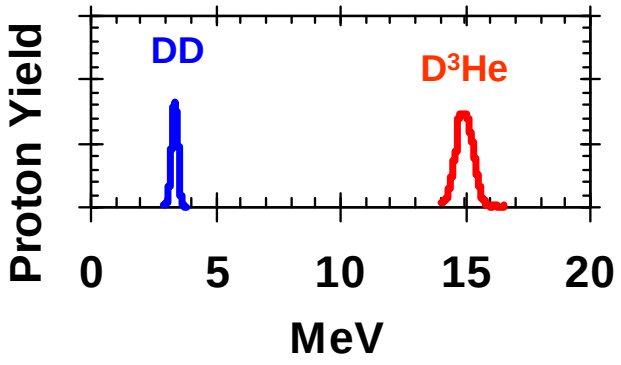
(3) If there is no a priori knowledge of field type, separate Θ components due to E and B can be determined with two independent measurements:

- Measurements on two identical plasmas with the direction of v reversed.
- Measurements on one plasma with protons of two discrete values of $|v|$.
- Measurements on two plasmas identical except for the reversal of E or *B*.
  (This method will be used in the next section)

Monoenergetic proton radiography provides a method of imaging laser-generated plasmas and their *E* and *B* fields

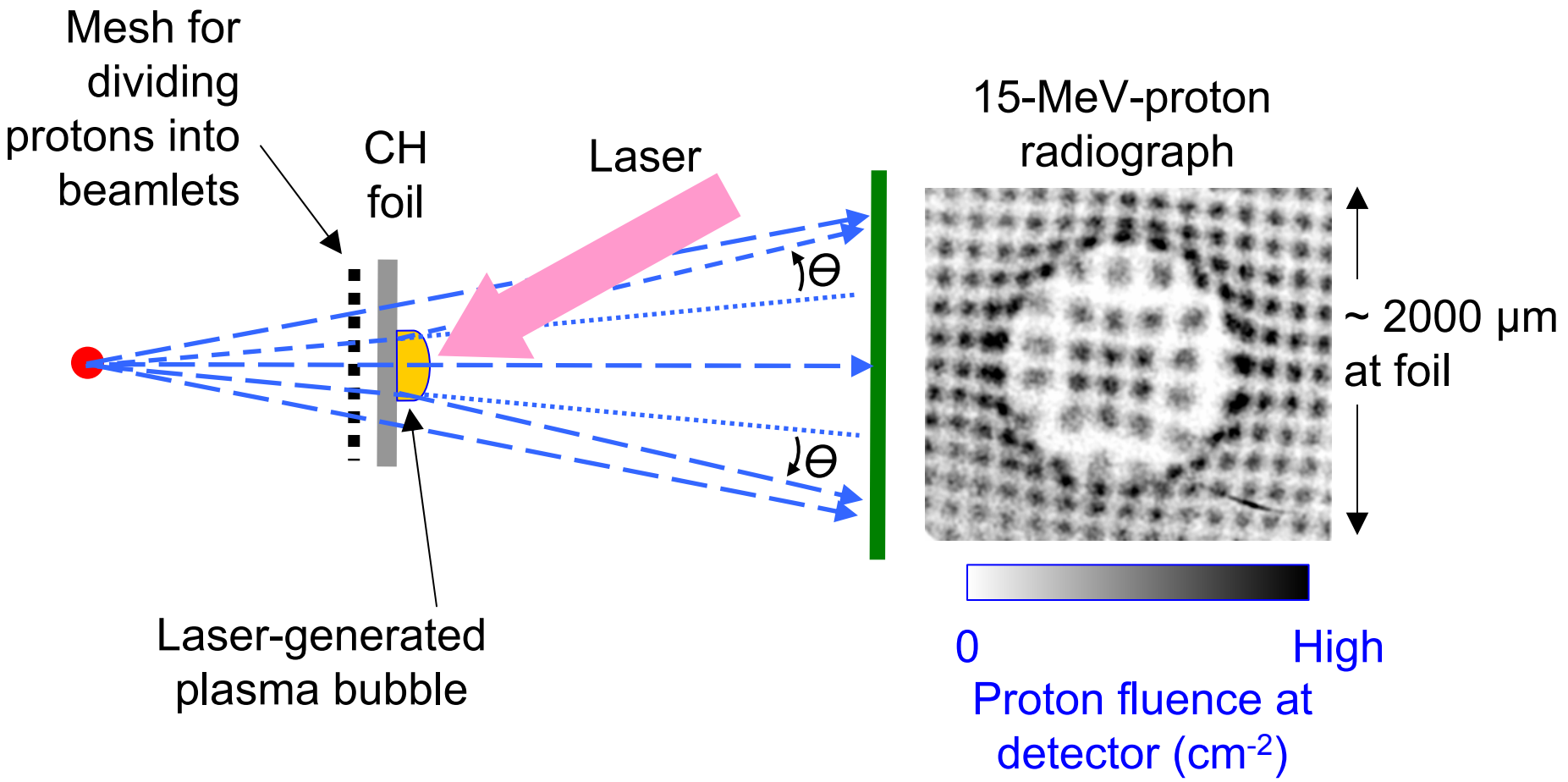
Backlighter capsule
(D^3He in a thin glass shell), driven by 20 OMEGA beams





Imaging detector
(records position and energy of every proton)

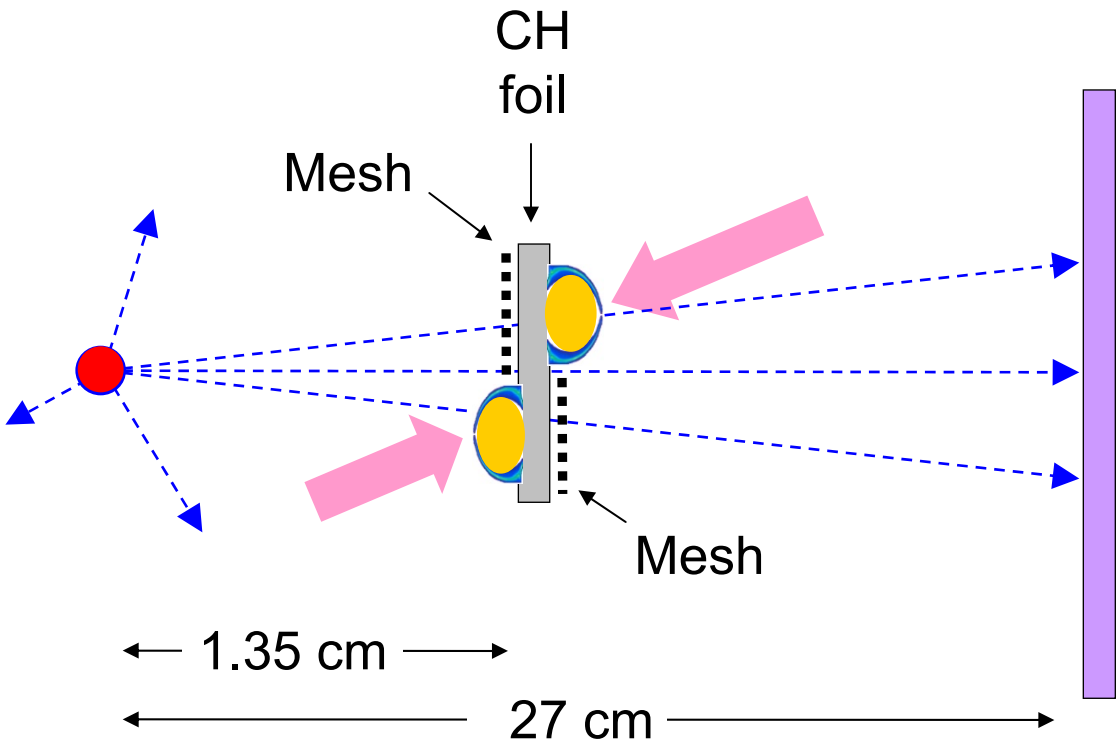
Question: How can we tell whether deflections Θ seen in images of laser-produced plasma bubbles are due to *E* or *B*?



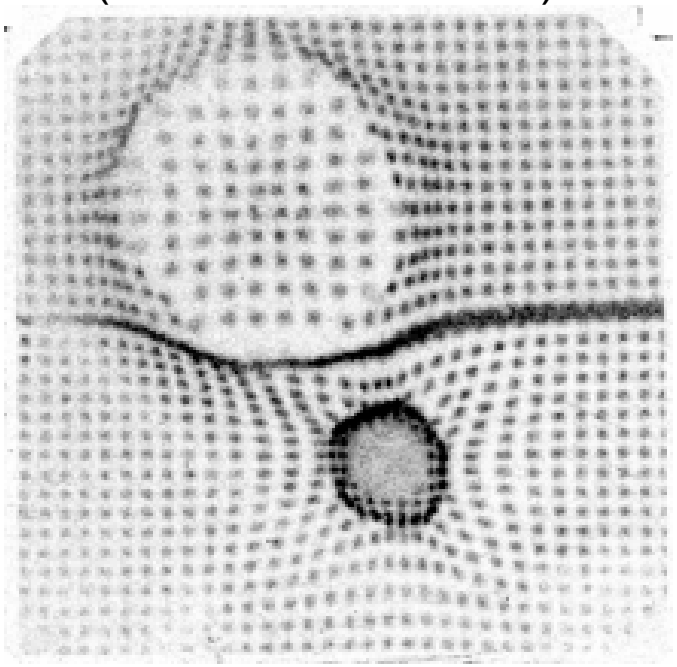
Li *et al.* , PRL (2006)

Map fields in two plasma bubbles

Answer: *E* & *B* can be separated and mapped by imaging two plasma bubbles, identical except for the sign of *B*



15-MeV-proton radiograph*
(OMEGA shot 46535)

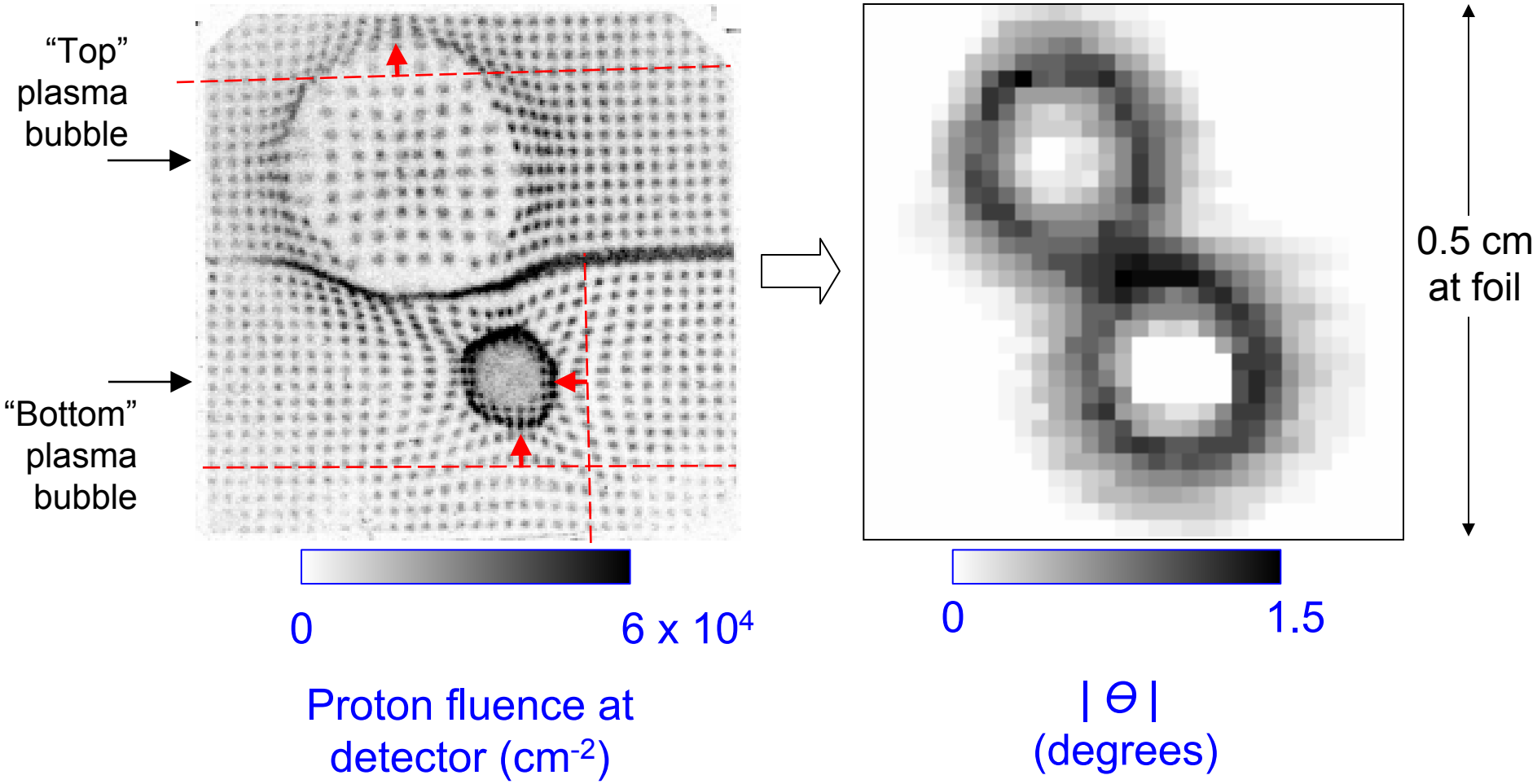


Proton fluence at detector (cm^{-2})

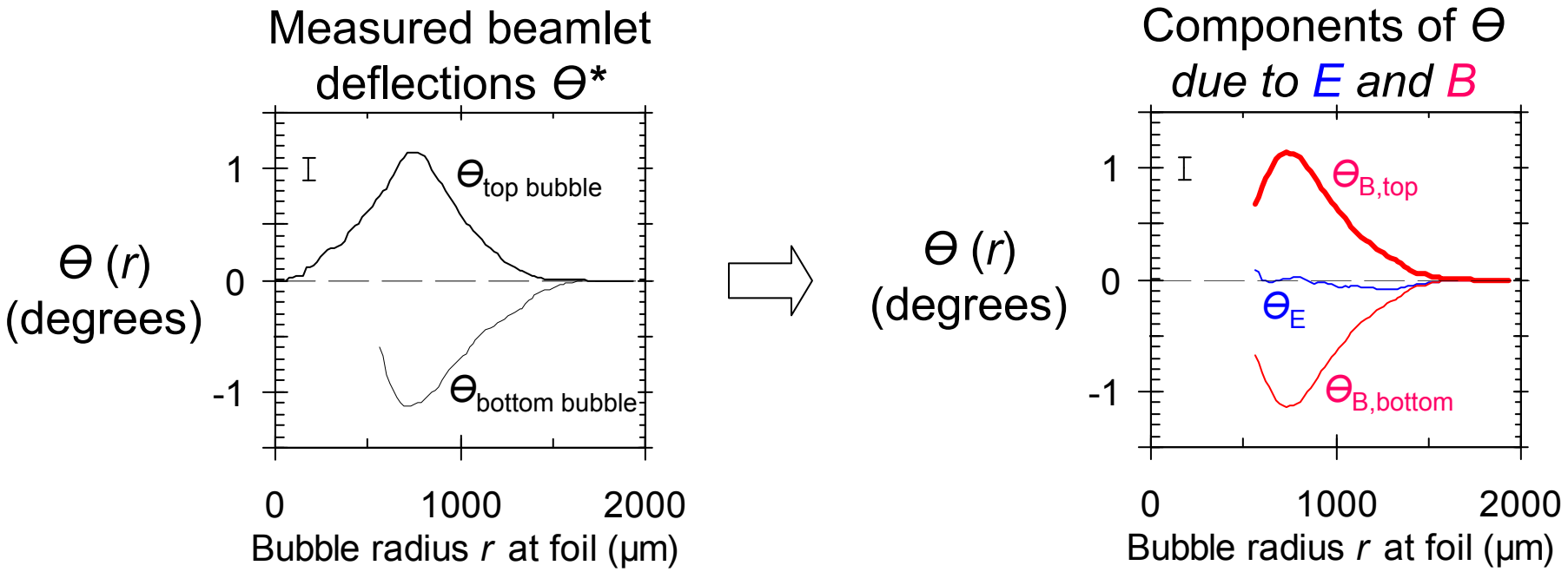
*Oriented as seen from behind the detector, looking toward the backlighter.

Petrasso *et al.*, PRL (2009)

Beamlet displacement in image ⇨ deflection angle Θ at foil



Θ is decomposed into components due to *E* and *B*

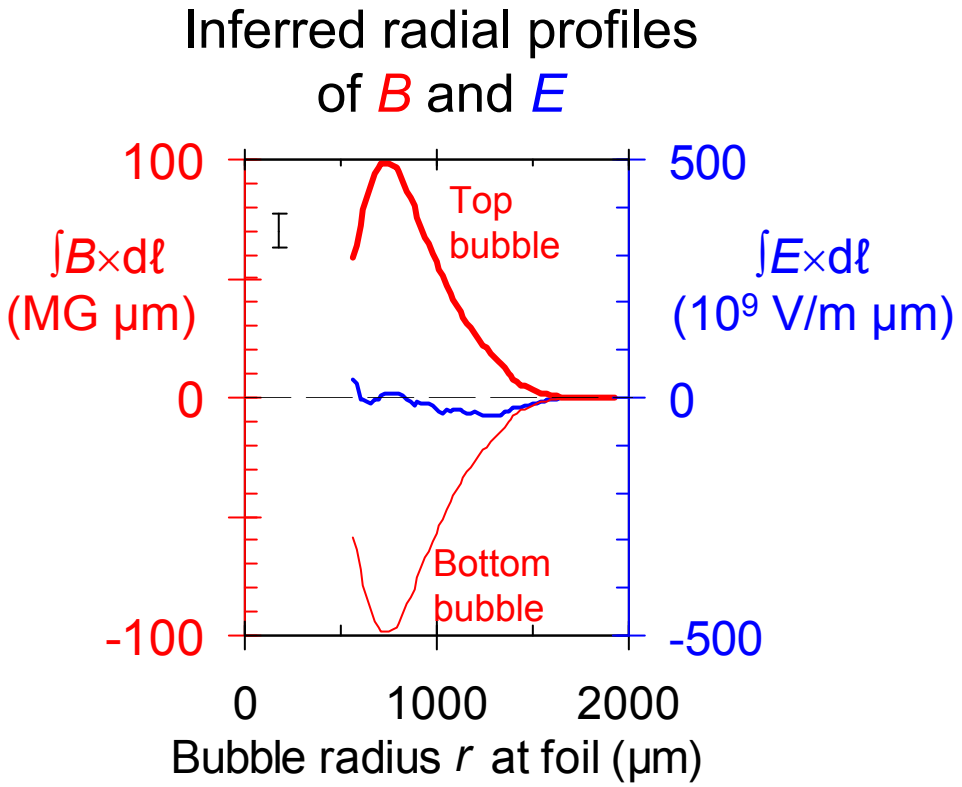


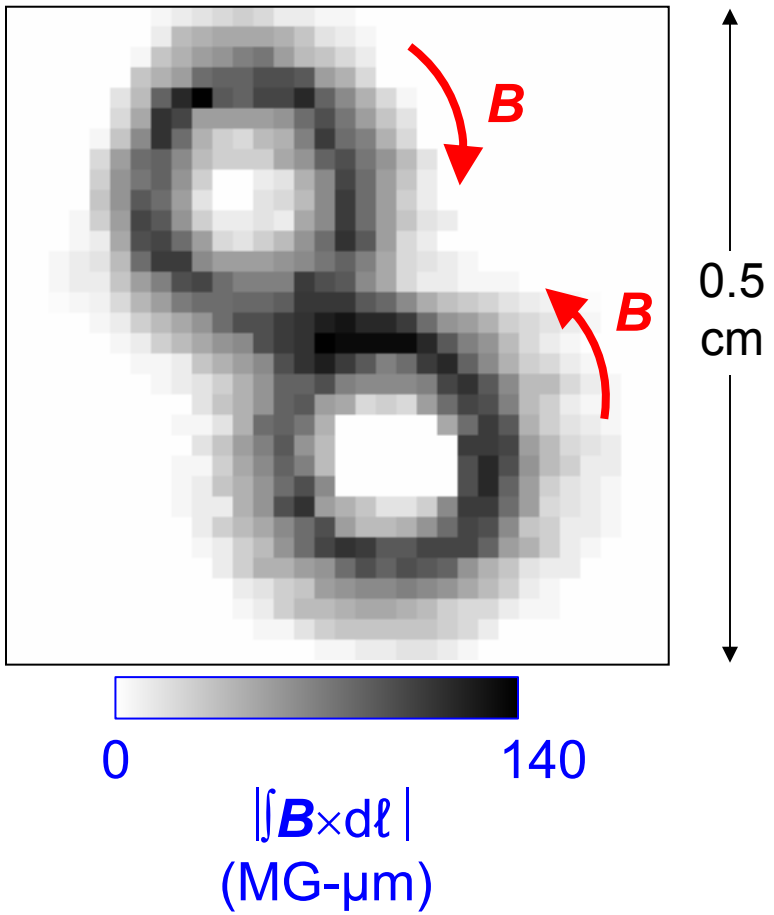
Since *B* is reversed between the bubbles while *E* is not,

$$\left.\begin{aligned}\Theta_{top}(r) &= \Theta_E(r) + \Theta_{B,top}(r)\\ \Theta_{bottom}(r) &= \Theta_E(r) - \Theta_{B,top}(r)\end{aligned}\right\} \Rightarrow \left\{\begin{aligned}\Theta_E(r) &= [\,\Theta_{top}(r) + \Theta_{bottom}(r)\,]/2\\ \Theta_{B,top}(r) &= [\,\Theta_{top}(r) - \Theta_{bottom}(r)\,]/2\end{aligned}\right.$$

*Positive is away from the bubble center, negative toward the bubble center.

The Lorentz equation is used to relate Θ_E to E and Θ_B to B; E is found to be smaller than the measurement uncertainty

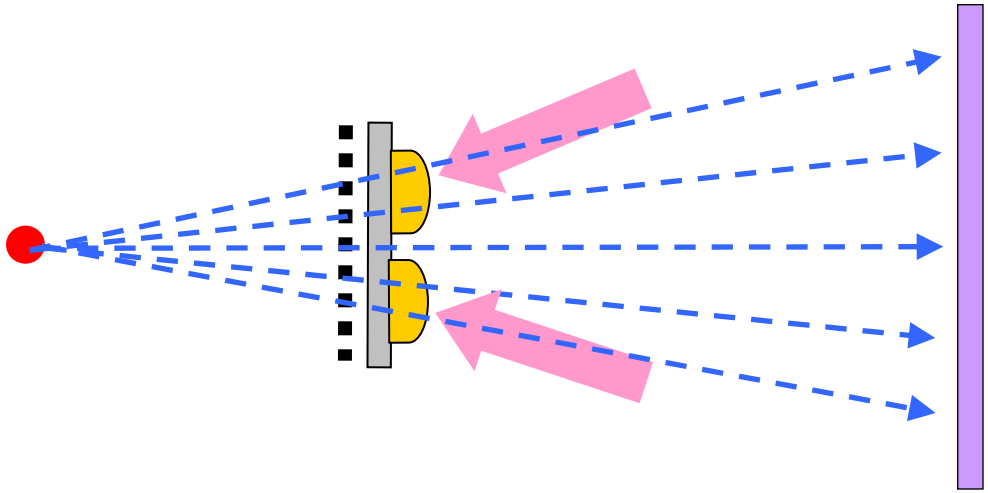




Other applications

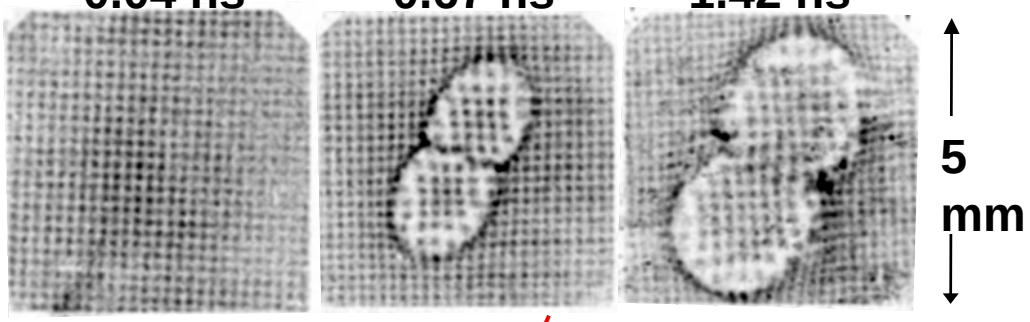
Magnetic reconnection

Magnetic topology is observed to change as two laser-generated bubbles merge and reconnect.

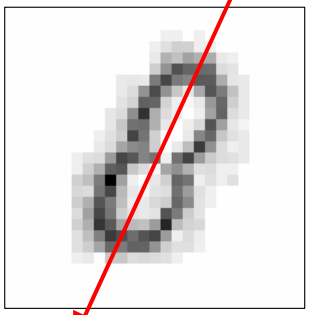


Laser on from 0 – 1 ns

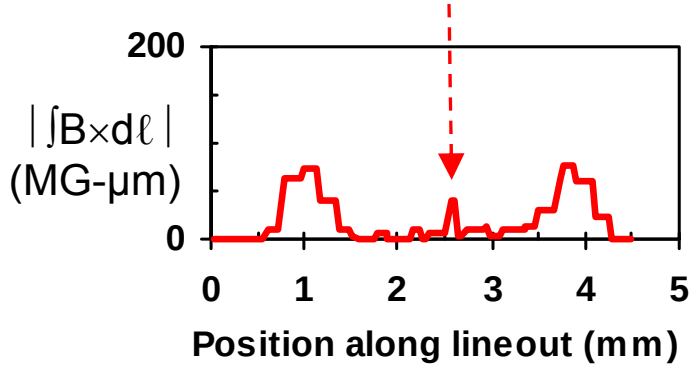
0.04 ns 0.67 ns 1.42 ns



5 mm



Field strength was reduced to ~ 5% where bubbles overlap.

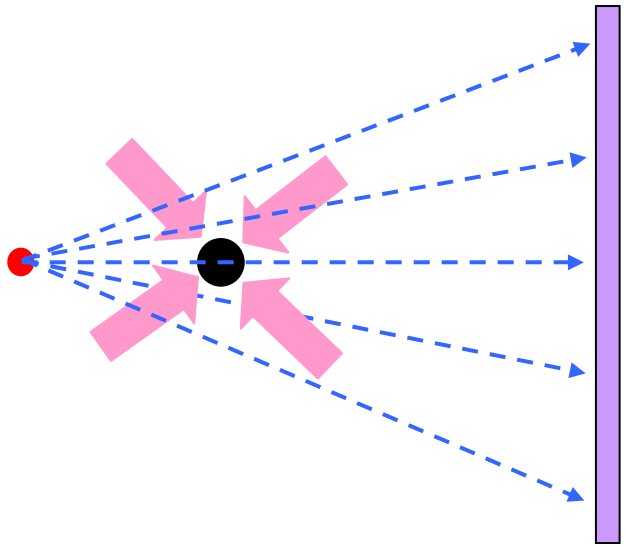


Li *et al.*, PRL (2007)

Rosenberg poster, this session

Direct-drive ICF

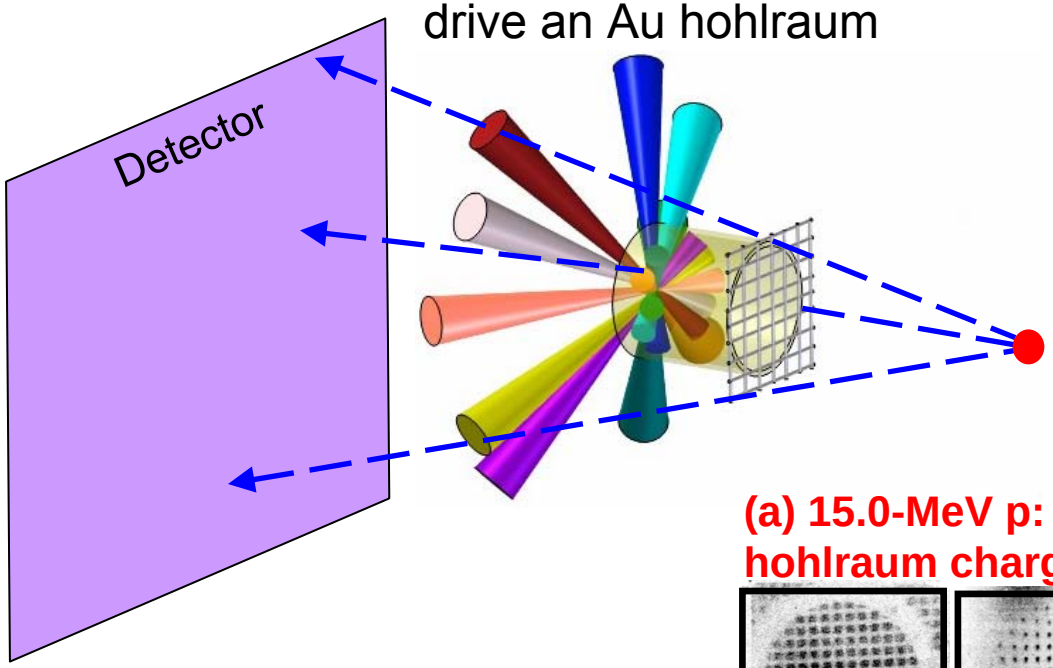
Monoenergetic proton and alpha radiography reveal *E* and *B* fields inside and outside imploding, direct-drive ICF capsules.



Rygg *et al.*, Science (2008)
Li *et al.*, PRL (2008)
Seguin *et al.*, to be submitted

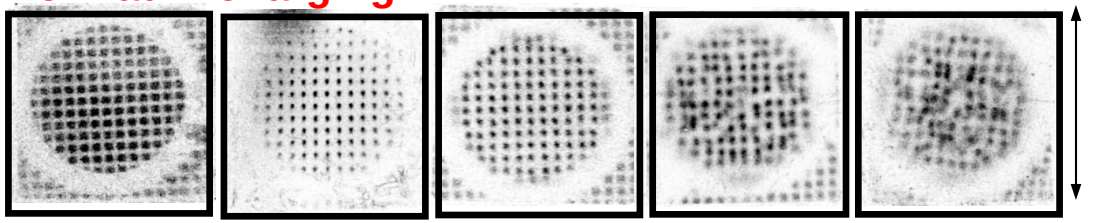
Indirect-drive ICF

10 OMEGA laser beams drive an Au hohlraum

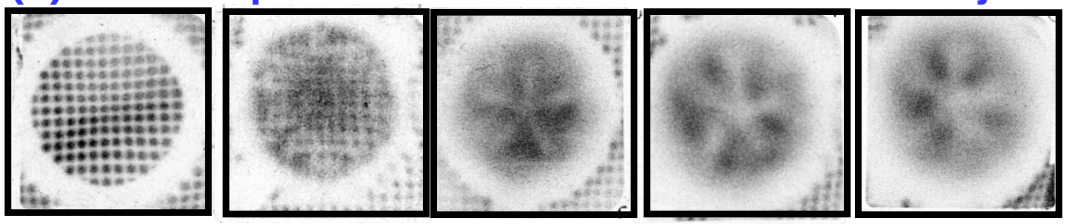


Proton radiographs show dynamics of *E* and *B* fields and Au plasma jets in a laser-driven holhraum.

(a) 15.0-MeV p: distortions show E field and hohlraum charging



(b) 3.3-MeV p: distortions show B fields and Au jets

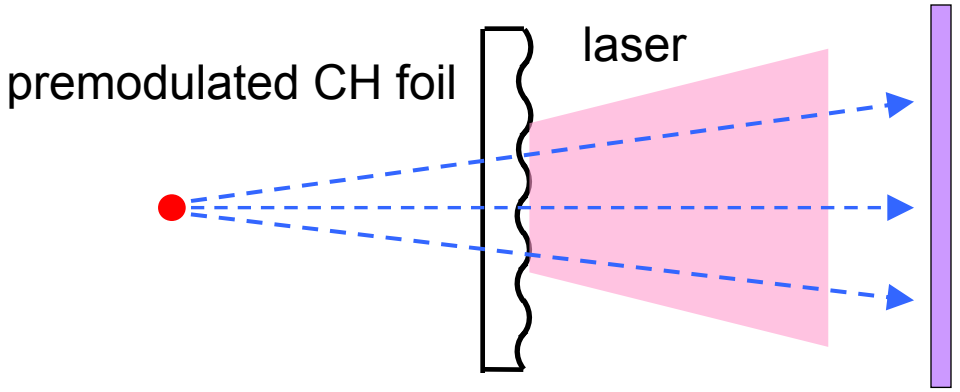


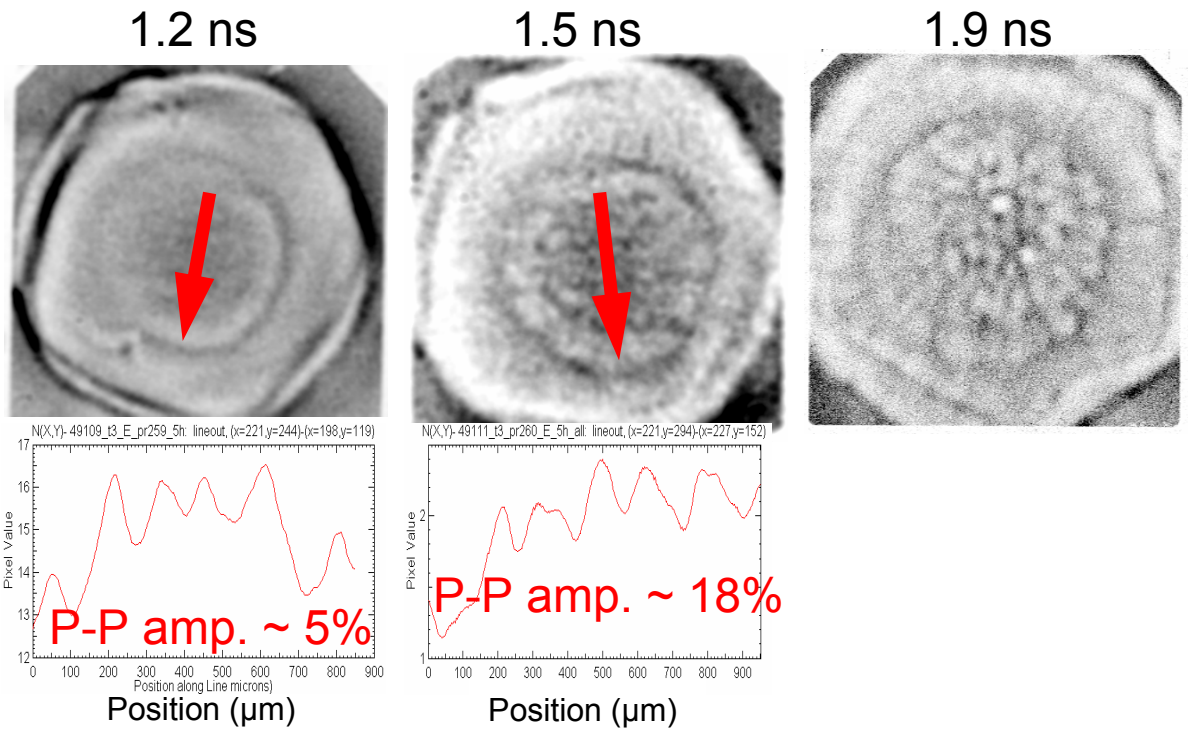
Li *et al.*, PRL (2009)

Li talk, tomorrow

R-T instability

15-MeV radiographs of laser-irradiated, premodulated foils show growing image modulation (reflecting both mass distribution and *B* fields) evolving into cellular structures





Manuel poster, this session