Field Measurements from Reconstructions in OMEGA Hohlraum Experiments

Jacob Pearcy*, Graeme Sutcliffe*, Tim Johnson*, Patrick Adrian*, Andrew Birkel*, Brandon Lahmann*, Ben Reichelt*, Neel Kabadi*, Justin Kunimune*, Dan Barnak#, Archie Bott^, Chikang Li*
* Massachusetts Institute of Technology Plasma Science and Fusion Center
^ Princeton Plasma Physics Laboratory
# Laboratory for Laser Energetics

Deflection field reconstruction of proton radiographs can be used to quantify electromagnetic fields in hohlraums

Background

- Proton radiography is good for visualizing field configurations, but its measurements can be difficult to quantify
- The question of how electromagnetic fields affect hohlraum evolution has been difficult to answer in laser experiments
- Recent developments in radiography analysis[1] allow the recovery of certain electromagnetic field information
- My work has been in refining these reconstructive methods and applying them to laser-driven hohlraum experiments at OMEGA

[1] A. F. A. Bott, C. Graziani, P. Tzeferacos, T.G. White, D. Q. Lamb, G. Gregori, A. A. Schekochihin. "Proton imaging of stochastic magnetic fields." Journal of Plasma Physics 83, 905830614 (2017)

Given radiograph + initial flux distributions, we can infer a deflection field

- If proton tracks don't cross, proton coordinates are directly related to image flux via a simple equation ("Kugland image-flux relation")[2]
- Reconstruction process is undertaken by recasting Kugland relation as log-parabolic Monge-Ampere equation and solving[3]
- So long as the no-crossing condition is satisfied throughout the image, each radiograph has a unique deflection field solution

[2] N. L. Kugland, D. D. Ryutov, C. Plechaty, J. S. Ross, and H.-S. Park. "Invited Article: Relation between electric and magnetic field structures and their proton beam images." Rev. Sci. Instrum. 83, 101301 (2012)

[3] M. M. Sulman, J. F. Williams, R. D. Russell. "An efficient approach for the numerical solution of the Monge–Ampère equation." Applied Numerical Mathematics 61, 298-307 (2011)

3 MeV image is very useful for *qualitative* verification of results

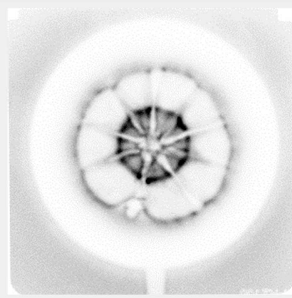
- Extract information from 14.7 MeV image alone by imposing a relationship between the deflections caused by electric fields and magnetic fields;

$$\vec{w}_{tot} = \vec{w}_B + \vec{w}_E = (1-f)\vec{w}_{tot} + f\vec{w}_{tot}$$

- We then test different values for the "field fraction" f by using the inferred electric and magnetic fields to predict 3 MeV proton images
- These 3 MeV proton images are then compared to the actual 3 MeV proton data

Reconstruction Process: Summary

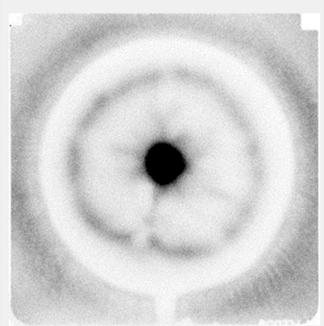
1. Choose data to analyze (typically 14.7 MeV proton image)
2. Specify or infer initial proton flux
3. Select region of analysis (excluding physical obstruction)
4. Iteratively solve the log-parabolic Monge-Ampere equation in this region
5. Recover deflection fields from the solution to 4.
6. Choose a relationship between E and B to test
7. Use the inferred fields to predict 3 MeV images, and compare to actual data



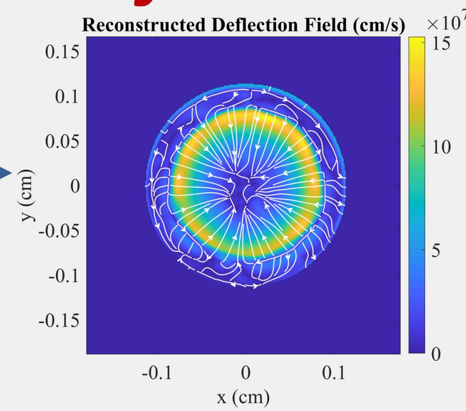
14.7 MeV proton data

OM181127

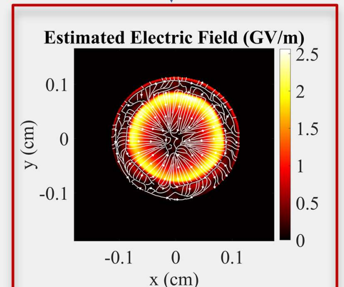
3 MeV proton data

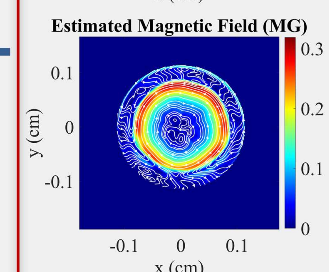


Reconstruct deflection field



Postulate relationship between electric and magnetic fields





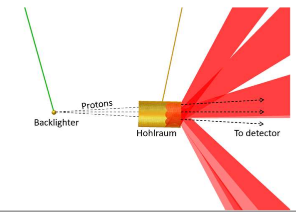
Generate 3 MeV proton image to compare to data

Synthetic 3 MeV proton image

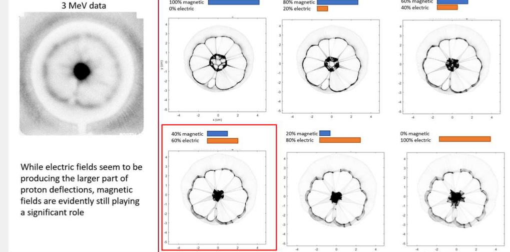
Comparison validates field postulate

Experimental Configuration Used: OM181127

- 10-beam symmetric and 9-beam asymmetric (1 dropped beam) hohlraum drive
- 1 ns laser pulse on hohlraum; probe time for 14.7 MeV ranged between 1.3 ns and 1.7 ns
- Most data taken with laser drive on the opposite side of the hohlraum from backlighter

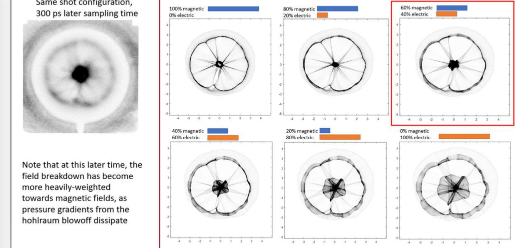


3 MeV data



While electric fields seem to be producing the larger part of proton deflections, magnetic fields are evidently still playing a significant role

Same shot configuration, 300 ps later sampling time



Note that at this later time, the field breakdown has become more heavily-weighted towards magnetic fields, as pressure gradients from the hohlraum blowoff dissipate

We reconstructed certain electromagnetic field information inside of laser-driven vacuum hohlraums

- We infer approximate field strengths of ~3e9 V/m and ~0.5 MG
- In our hohlraum experiments, results indicate that electric fields and magnetic fields are both important contributors to proton deflections – neither seems heavily dominant
- Field fraction seems to change over time, with an apparent tendency to become more magnetic later in the evolution of the hohlraum plasma
- Complex structure of the hohlraum fields indicates a need for further experimentation and modeling efforts

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MIT PhD students work on NIF diagnostics (2nd DTn[1], WRF/SRF[2], PRAD[3], MRS-t[4], PTOF[5]) and fundamental physics (hohlraum x-rays[6] and fields)

[1] poster by Patrick Adrian
[2] poster by Tim Johnson
[3] poster by Graeme Sutcliffe
[4] poster by Justin Kunimune
[5] poster by Neel Kabadi
[6] poster by Ben Reichelt

NIF&PS