Reconstruction of Protons Paths in CR-39 for Radiography Experiments

H. Rinderknecht, D. Casey, N. Sinenian, F. H. Séguin, C. K. Li, J. Frenje, R. D. Petrasso

MIT PSFC

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Introduction & Motivation

Abstract

Recent mono-energetic proton backlighter experiments on the dynamics of laser-plasma interaction and shell implosions in the high energy-density regime have revealed high intensity magnetic and electric fields. A new diagnostic method is suggested, utilizing CR-39 as a two-stage particle detector. By reconstructing incident particle trajectory in addition to measuring energy and fluence, radiography techniques may strongly constrain the strength and location of fields in capsule implosions, hohlraum implosions, and other high-energy-density plasmas of interest.

This work was performed in part at the LLE National Laser User's Facility (NLUF), and was supported in part by US DOE, LLNL, LLE, and FSC at U. Rochester.

Proton radiography with CR-39 provides unique diagnostic for EM fields in HED environments

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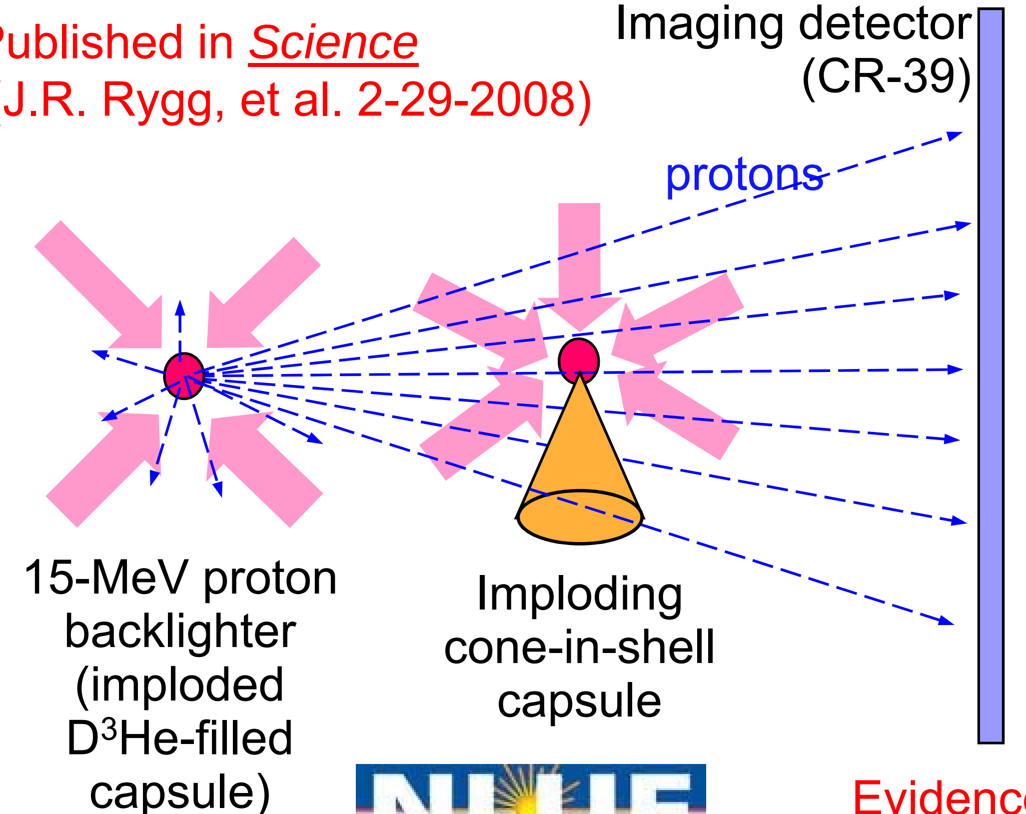
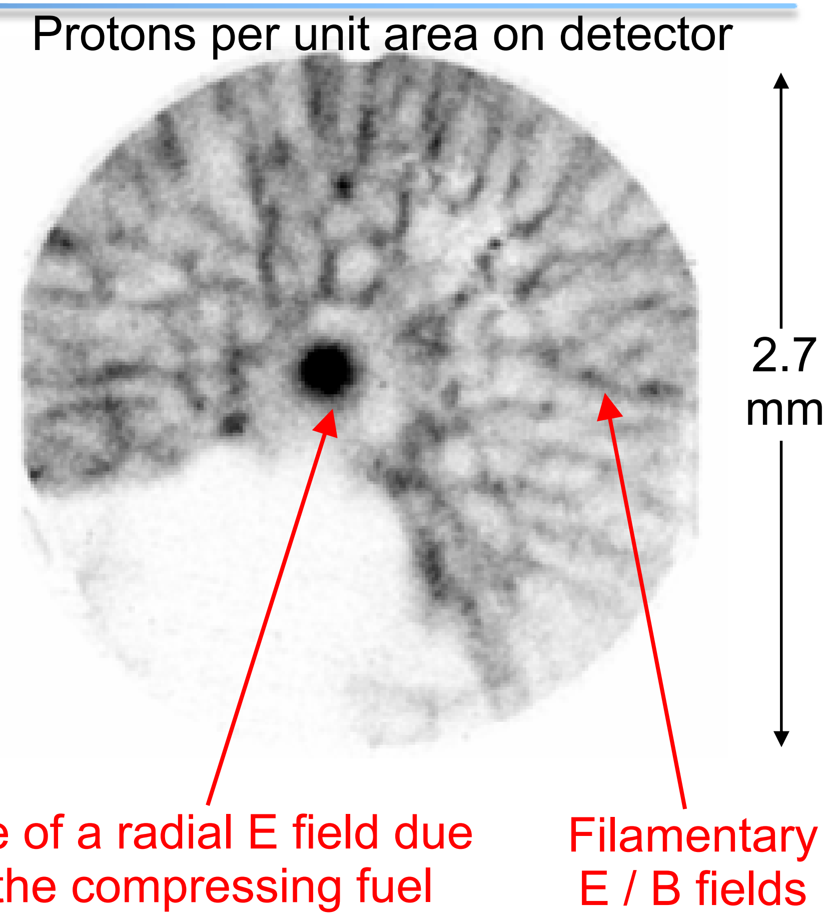
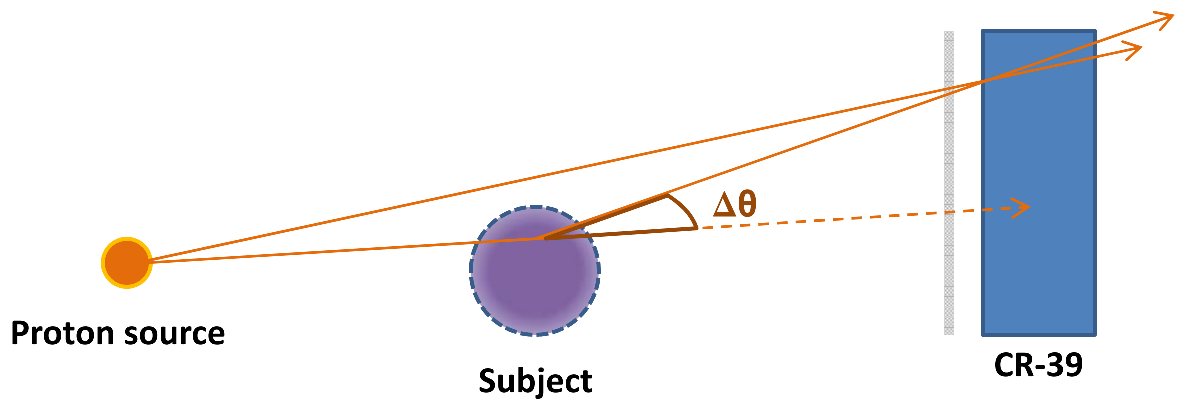




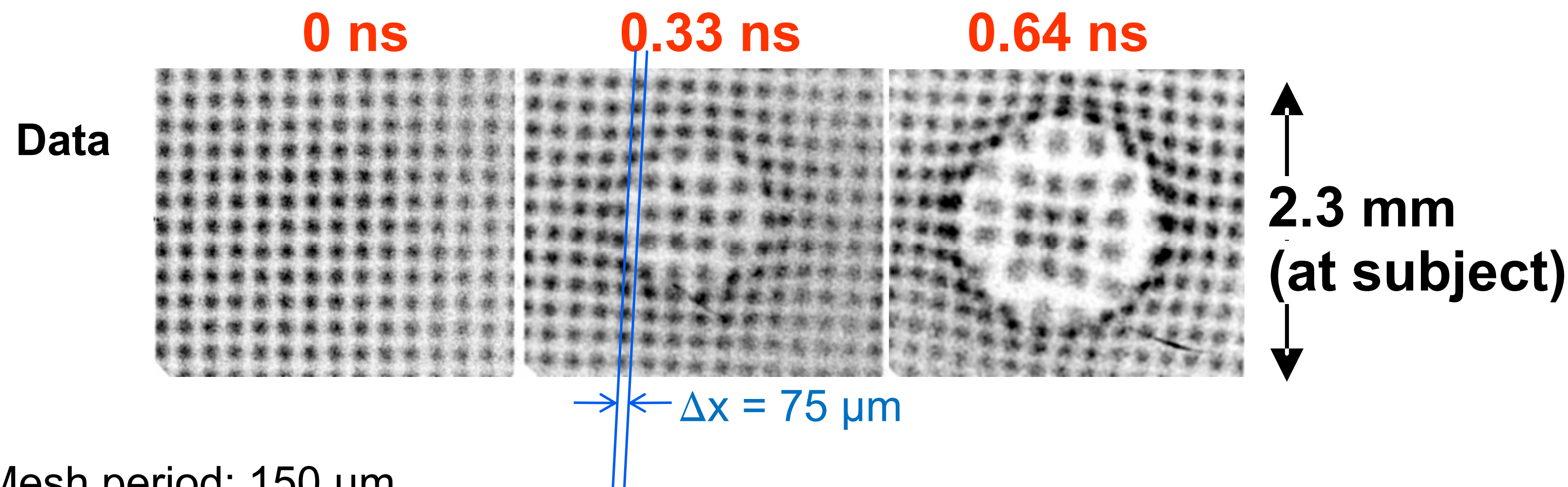
Reconstruction of incident angle of protons on film could yield additional information to constrain observed fields

Physics



- High-energy proton products of a backlighter capsule implosion (~3 and 15 MeV) traverse large EM fields associated with HED plasmas
- Lorentz force perturbs proton path slightly: $\Delta v \approx \vec{a}\Delta t = \frac{q\Delta t}{m}\left(\vec{E} + \vec{v} \times \vec{B}\right)$
- Path contains information about 3D field structure experienced by the proton

Mesh experiments demonstrate size of effects to be studied



Mesh period: 150 μm
Backlighter-Detector distance D_{BD} ~ 30 cm; CR-39 size = 10 cm

To measure deflection ~ 75 μm on grid (1/2 period) requires angular resolution:

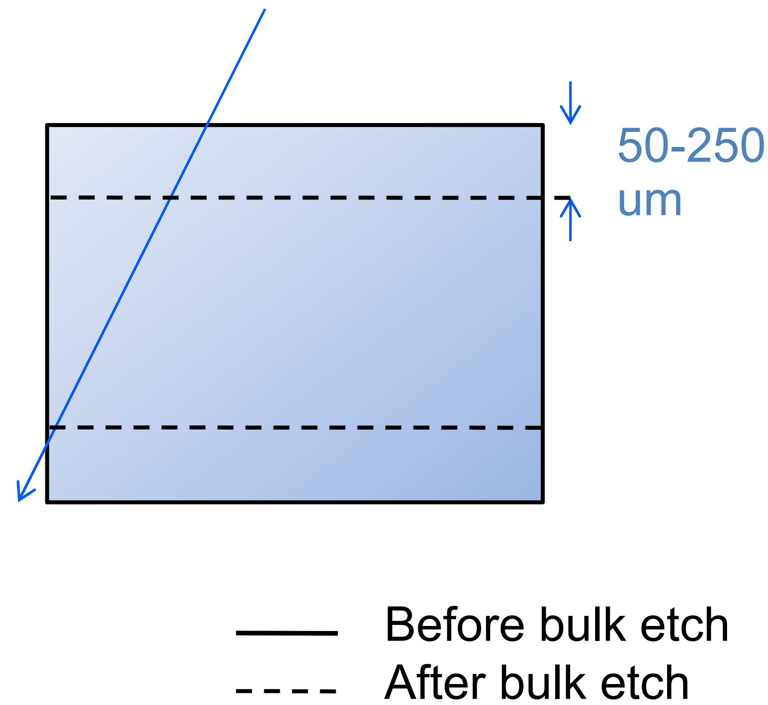
$$\sin\theta = \frac{\Delta x}{D_{BD}} = \frac{\text{displacement}}{\text{field of view}} \times \frac{\text{CR39 size}}{\text{detector distance}} = \frac{75\ \mu\text{m}}{2.3\ \text{mm}} \times \frac{10\ \text{cm}}{30\ \text{cm}} \approx 0.011$$

Deflections of interest are $\gtrsim$ 1 degree

Experimental and Analytical Methods

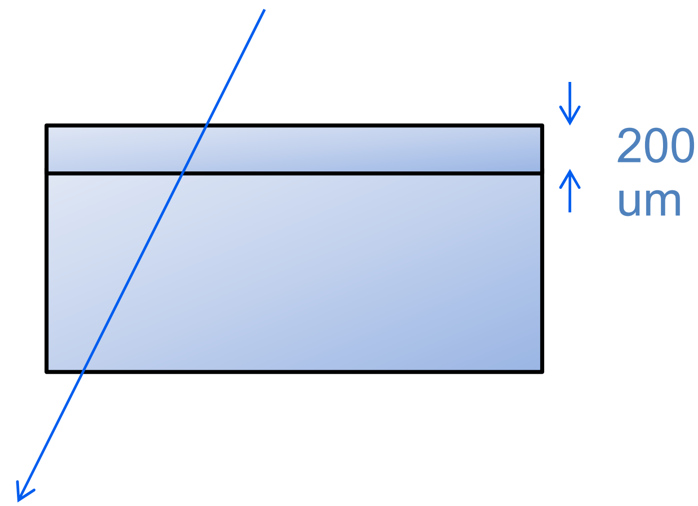
Potential Methods: bulk etching

- Etch radiography CR-39, scan & record tracks
- Submit CR-39 to aggressive etch, removing some substantial thickness of material and erasing the results of the previous etch
- Re-etch CR-39 to reveal tracks, scan & record
- Properly align scans, find coincidences and determine angles-of-incidence for each proton
- Analyze statistically to evaluate field structure

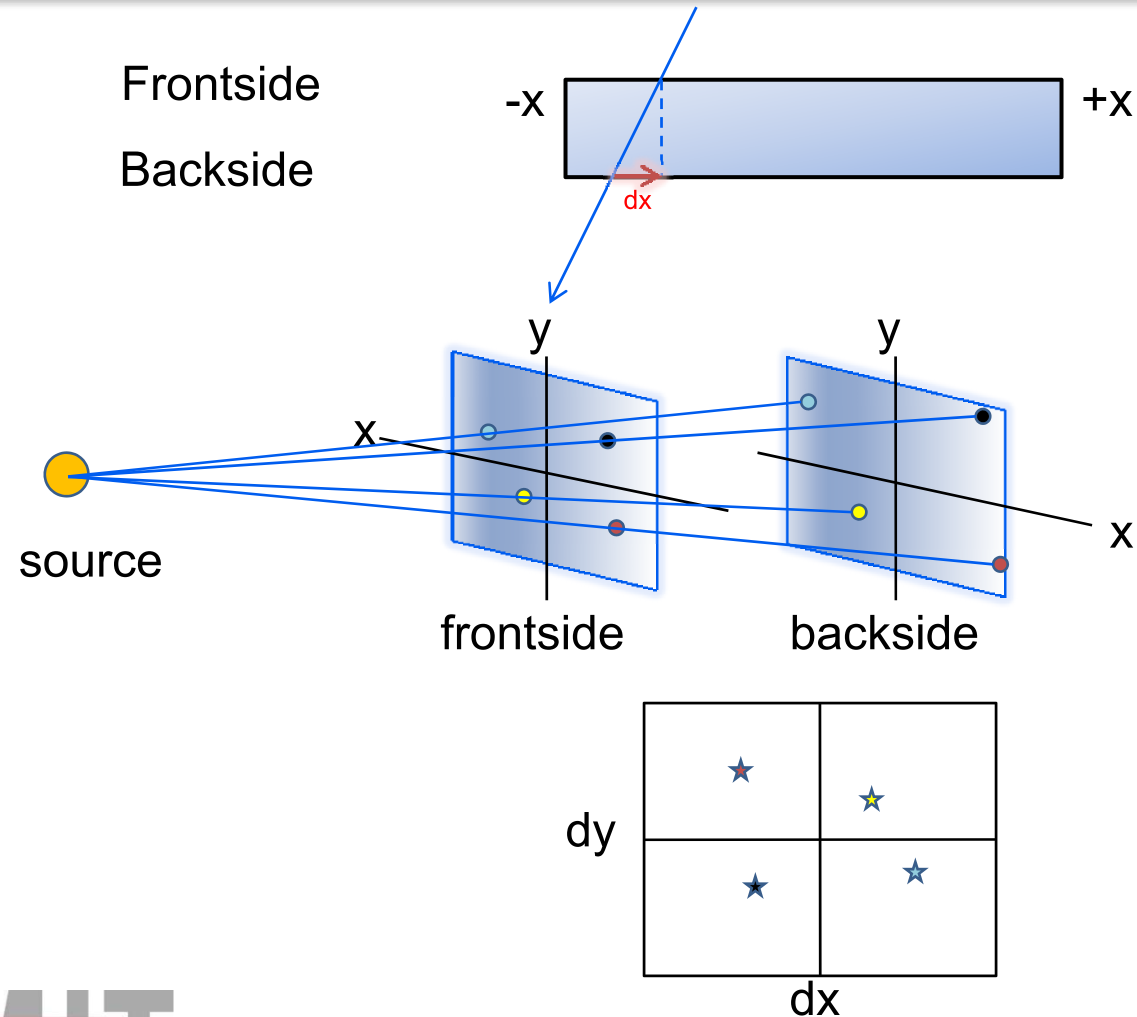


Potential Methods: Thin CR-39

- Radiograph using a stack of thin (~200 um) and thick CR-39
- Scan and record tracks on both sides of thin CR-39, making note of the coordinates of distinctive features
- Properly align scans, find coincidences and determine angles-of-incidence for each proton
- Analyze statistically to evaluate field structure



Angles are measured by comparing coincident tracks between two scans**



Frontside coordinates are adopted. Coincidence angles are measured as (dx,dy):

$$dx = x_{front} - x_{back}$$

$$dy = y_{front} - y_{back}$$

A particle angling to (+x) onto the CR-39 has dx < 0; a particle angling to (+y) onto CR-39 has dy < 0.

Results are presented as a contour plot or histogram in (dx,dy) space, for a given region on the CR-39.

**Coincidence Counting code developed by D.T. Casey; see "Diagnosing Areal Density using the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF" OLUG workshop, 04/29/09

Sources of Error

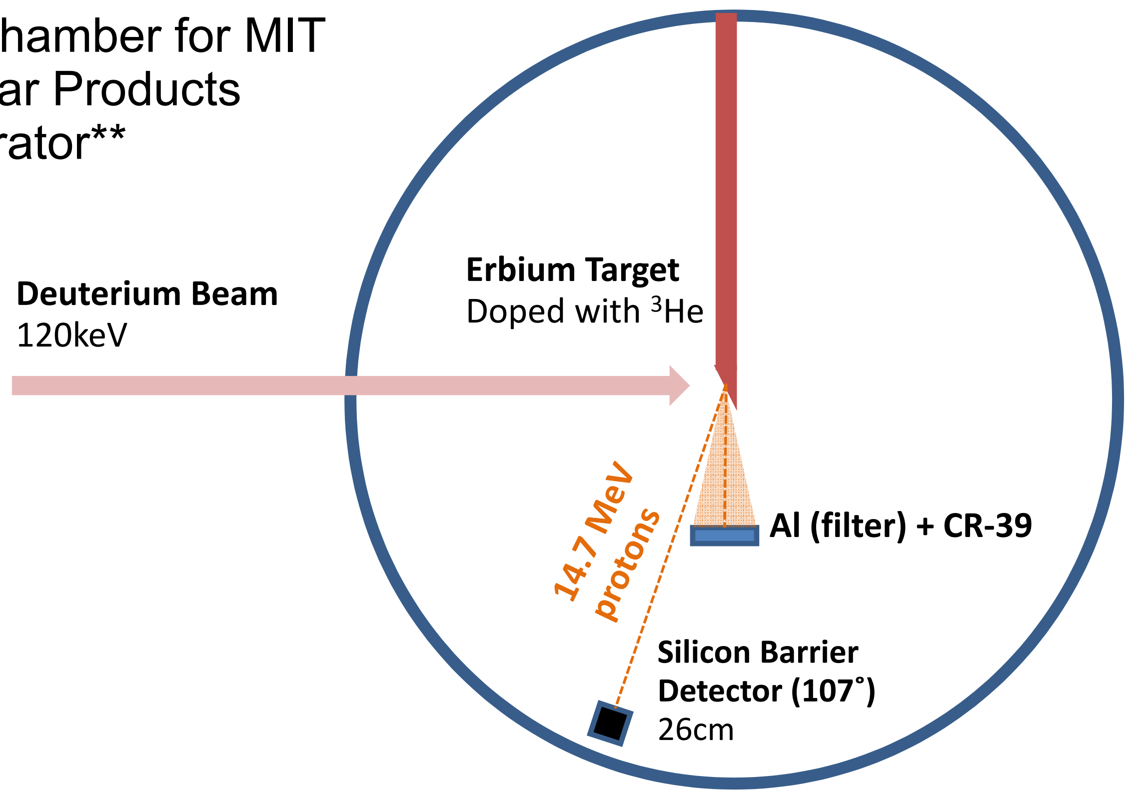
- Source size error (d_{source} ~ 100 um)
- Scattering in subject
- Scattering in filters & CR-39
- Alignment error between scans
- Difference in coordinate systems between
- Thickness variation due to etching or manufacture.

Scattering in filters & CR-39 contribute to error of centroid in (dx,dy) space for a given track sample

Simulation & Data

An experiment was designed to test thin CR-39 and bulk etch methods

Test chamber for MIT Nuclear Products Generator**



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**see poster: N. Sinenian, et al., "The MIT Nuclear Products Generator for ICF Diagnostics Development at OMEGA / OMEGA EP and the NIF" OLUG workshop, 04/29/09

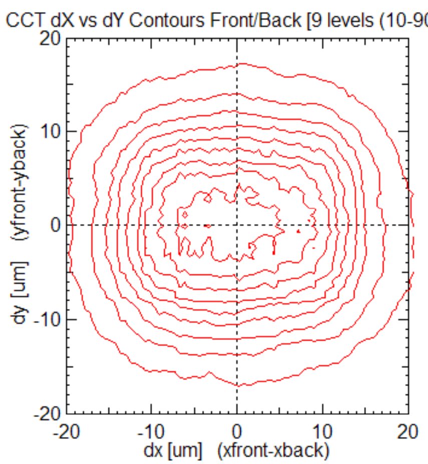
Results of experiment for surfaces separated by 200 μm were simulated using Matlab

Source size: 2.5 mm width

Scattering in plastic: (gaussian) 8 um width

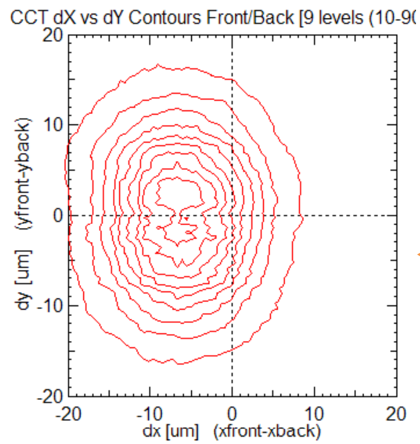
Number of particles: 10,000

entire piece

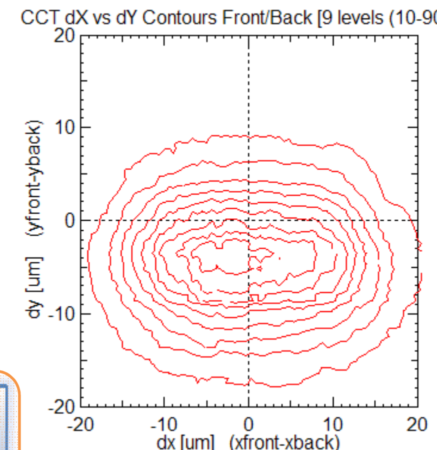


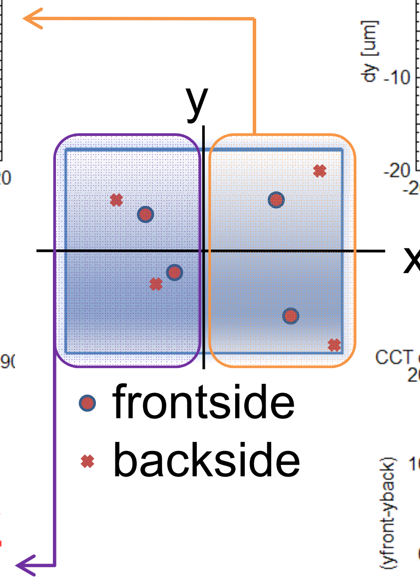
For higher x → peaks shift **left**
For higher y → peaks shift **down**

x > 0

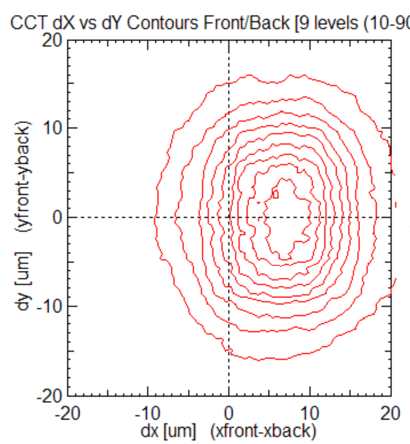


y > 0

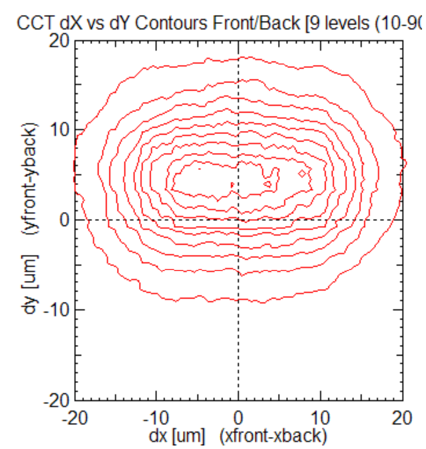




x < 0



y < 0

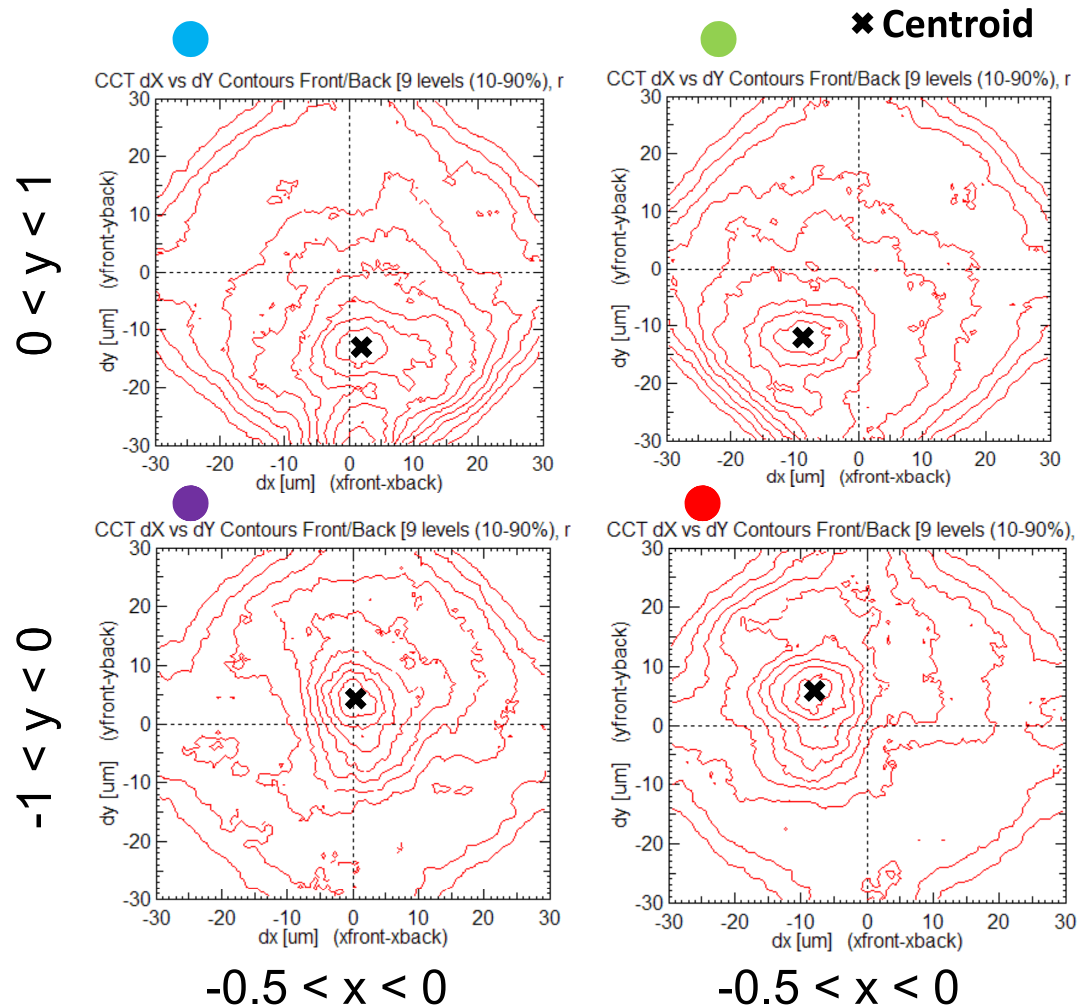


Data from 200 μm CR-39 has accurate angular effects

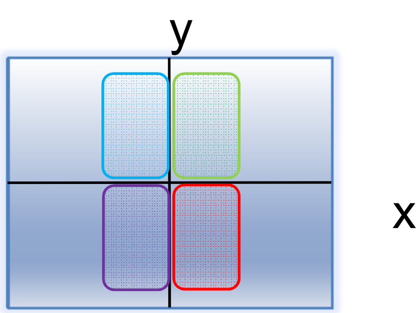
Piece ID: HR1B
Shot date: 04/22/09
Dimensions: x: {-1.69,1.69},
y: {-2.34,2.37}
Distance from target: 12.3 cm.
Filtering: 1080 μm Al

Data exhibits the expected behavior in both X and Y

Measured angular difference: **5.02±0.57°/cm**
Actual difference: **4.67°/cm**



Map of regions on CR-39



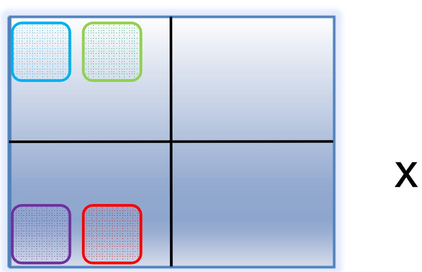
Data from bulk-etched CR-39 exhibits unexpected trends

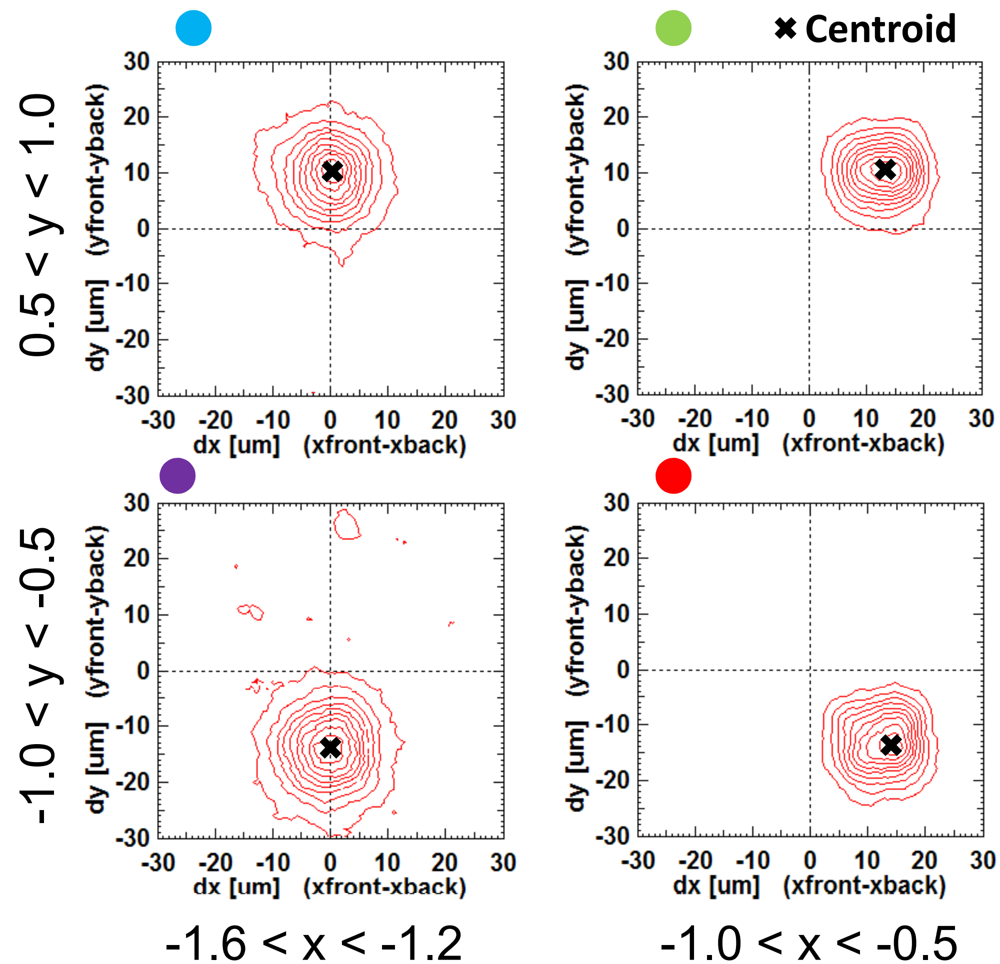
Piece ID: rc543
Shot date: 03/05/09
Dimensions: x: {-1.6,1.6}, y: {-1,1}
Distance from target: 24 cm.
Filtering: 5 steps decreasing from –x to +x
Due to filtering, tracks were only visible for {-1.6 < x < -0.5}

Data has clear *opposite* trend from what is expected.

This is consistent with uniform change in size of CR-39 during bulk-etch processing

Map of regions on CR-39





Trustworthy reference marks on CR-39 would allow for adjustment of coordinates after bulk etch

Thin CR-39 vs bulk etching techniques

Thin CR-39	Bulk etching
✓ No additional processing between scans → greater confidence in equivalence of coordinate systems	✓ "Thick" CR-39 has more consistent response to protons over a large range of energies
✓ Easier to characterize thickness between scanning planes	✓ Easier to acquire in good quality
✗ Hard to acquire with good noise properties	✗ Extra etching steps → less confidence in equivalence of front/back coordinates (requires clear, small fiducials)
✗ Limited proton response (< 5 MeV) forces very restrictive range of operation	✗ Uneven bulk etching introduces additional errors in depth across the piece

Summary & Future Work

Future Work

- Robust bulk etching experiments to determine effect of processing on exposed CR-39
- Establish effective fiducial method (small laser mark on CR-39)
- Field successful proof-of-concept experiment in MIT Nuclear Products Generator
- Field diagnostic with proton radiography on OMEGA

Summary

- A new process for proton radiography with path reconstruction is investigated for improved constraint of observed HED field structures
- Two methods for performing such measurements are tested and compared, using thin CR-39 and bulk etching normal CR-39.

Some Important References

Papers:

F.H. Seguin, et al., "Spectrometry of charged particles from Inertial Confinement Plasmas" Rev. Sci. Instrum. 74 975 (2003)

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

S. Cacenjar, et al., "<ρR> measurements in laser-produced implosions using elastically scattered ions" J. Appl. Phys. 56 (7) (1984).

S.C. McDuffee et al., "An accelerator based fusion-product source for development of inertial confinement fusion nuclear diagnostics," Rev. Sci. Instrum. 79 (2008) 043302.

Posters:

N. Sinenian, et al., "The MIT Nuclear Products Generator for ICF Diagnostics Development at OMEGA / OMEGA EP and the NIF" OMEGA Laser User's Group workshop, April 29th 2009.

D.T. Casey, et al., "Diagnosing Areal Density using the Magnetic Recoil Spectrometer (MRS) at OMEGA and the NIF" OMEGA Laser User's Group workshop, April 29th 2009.