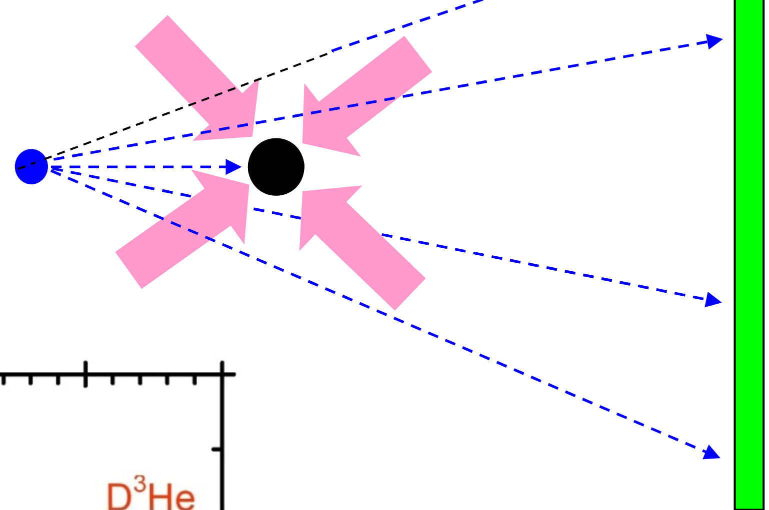
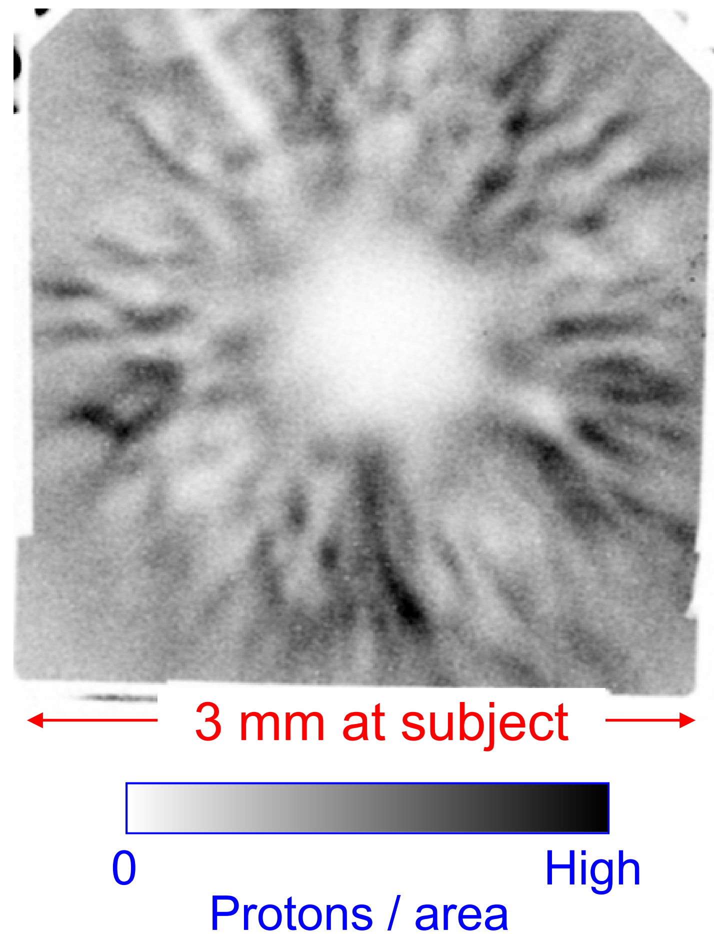
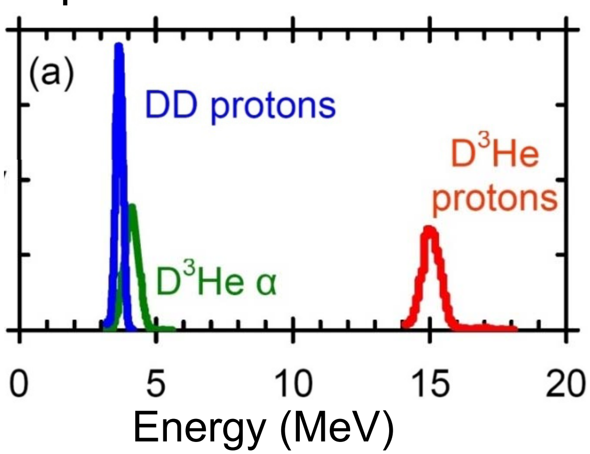
Observation and characterization of coronal filamentation in direct-drive ICF



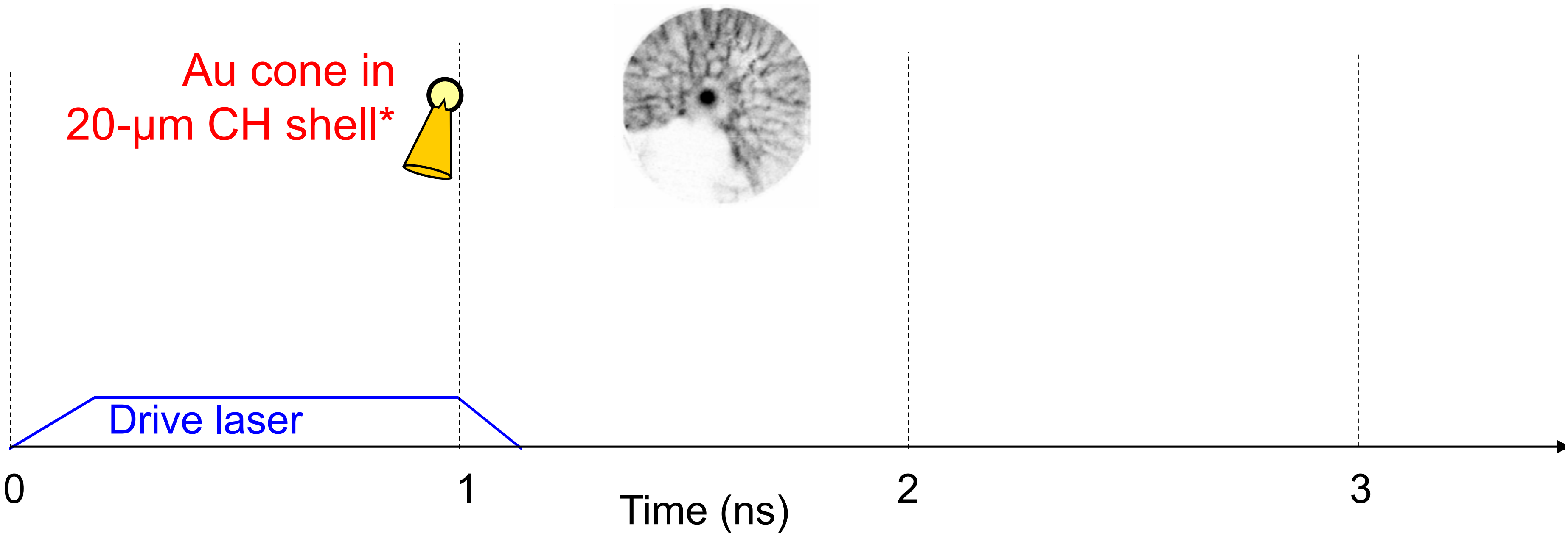
Radiograph made with monoenergetic, 3-MeV p



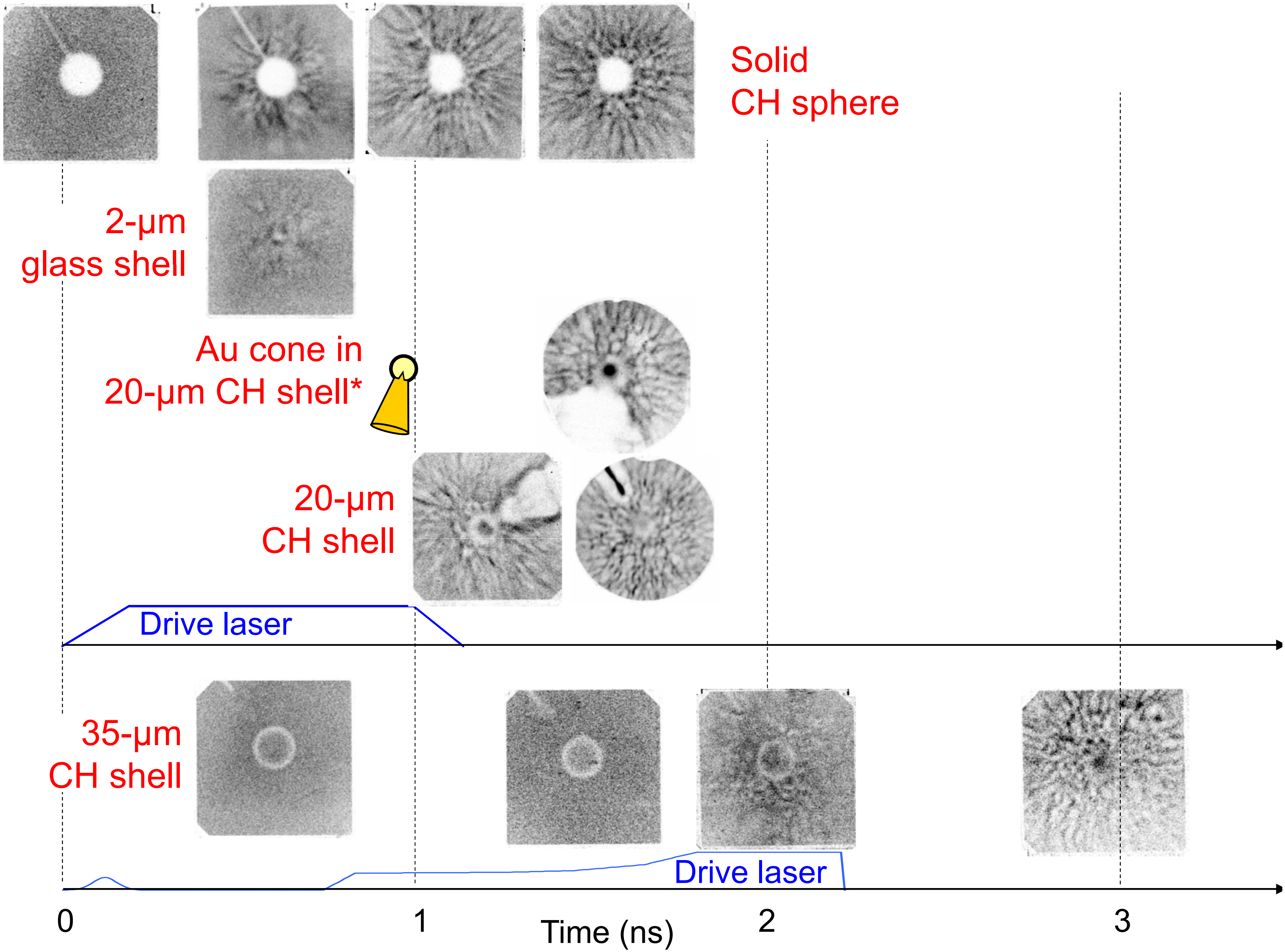
Backlighter spectrum



15-MeV-proton radiography has demonstrated that filaments are endemic in direct-drive implosions

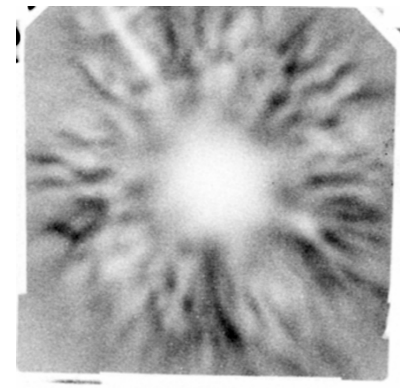


*Rygg *et. al*, ***Science*** (2008)


Solid
CH sphere
2-µm
glass shell
Au cone in
20-µm CH shell*
20-µm
CH shell
Drive laser
35-µm
CH shell
Drive laser
0
1
Time (ns)
2
3

Summary:

1. Radial striations in the images correspond to



   - Current filaments (~ 2 kA toward capsule)
   - Surrounded by *B* ~ 10 T
   - With separation near critical surface ≈ 100 μm

2. The filaments and fields

   - Appear during the laser pulse – could affect drive efficiency
   - Expand with the corona, with features frozen in for hundreds of ps

Collaborators

MIT

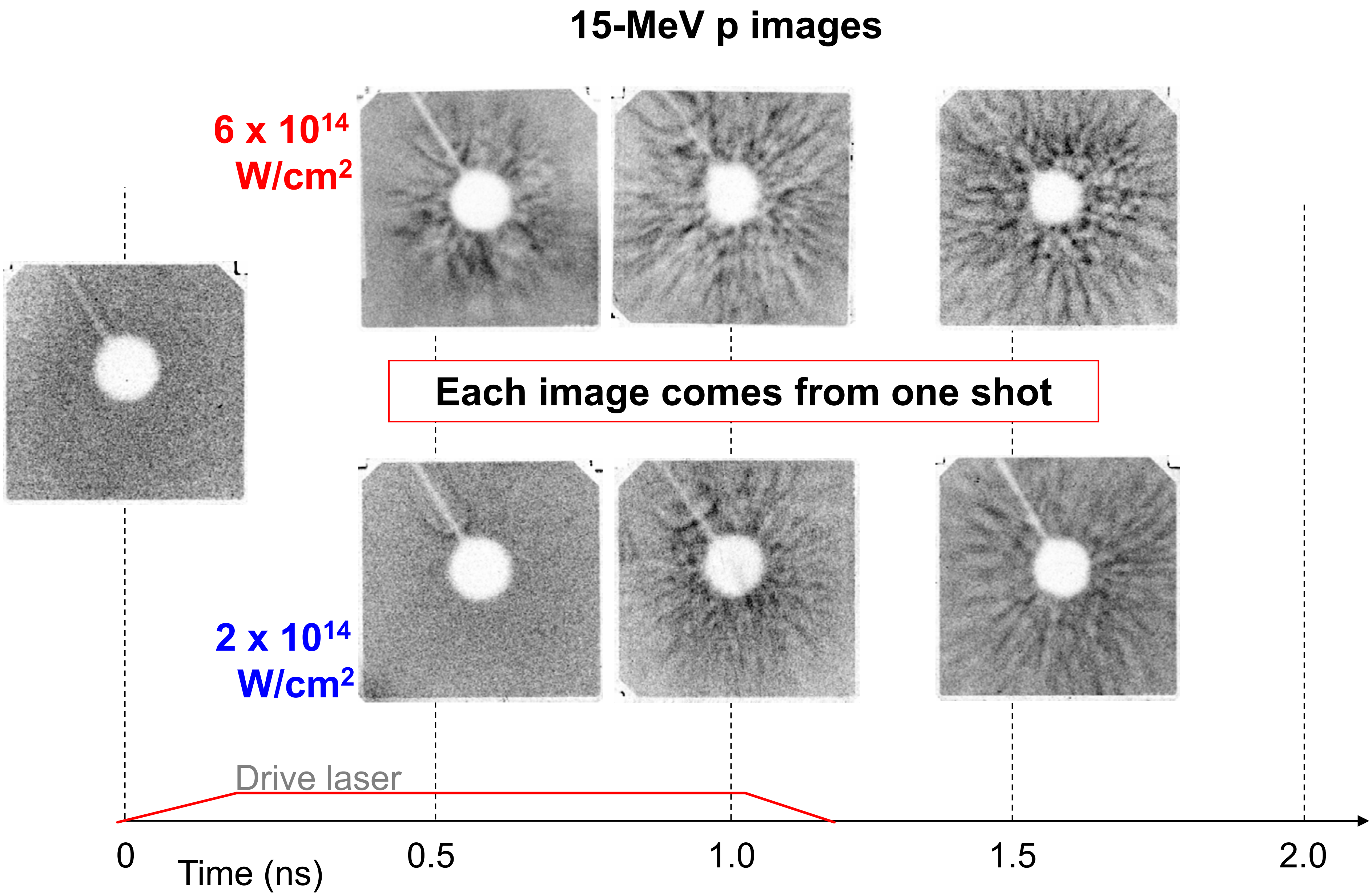
C.K. Li
J. Frenje
M. Manuel
H. Rinderknecht
N. Sinenian
J.R. Rygg*
R. Petrasso

U of R – LLE

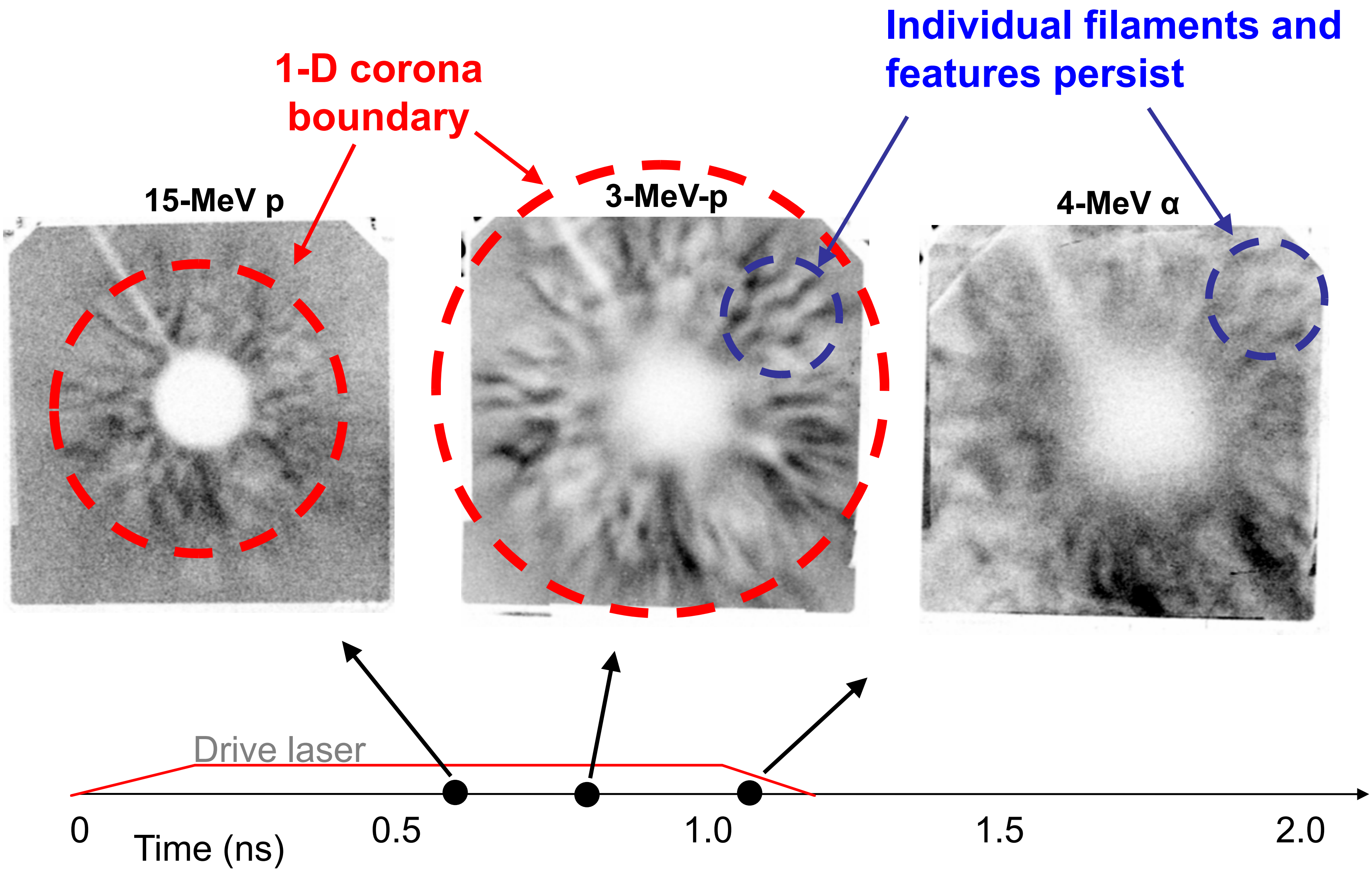
R. Betti
J. Delettrez
J. Knauer
F. Marshall
D. Meyerhofer
V. Smalyuk

*Currently at *LLNL*

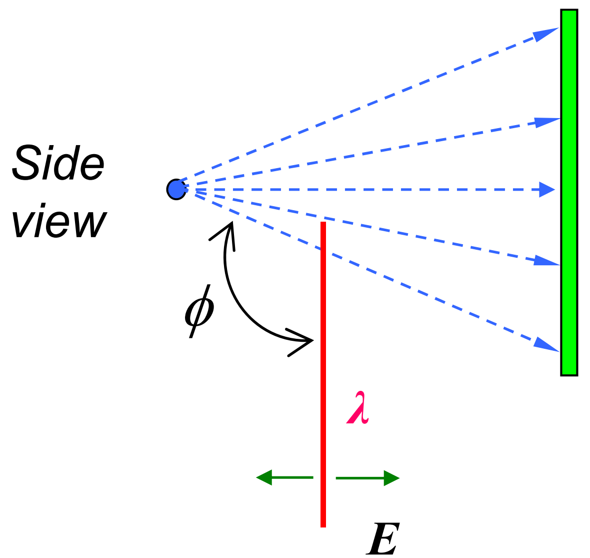
Radiographs were made of solid CH targets (860-µm diam.) driven with two different laser intensities

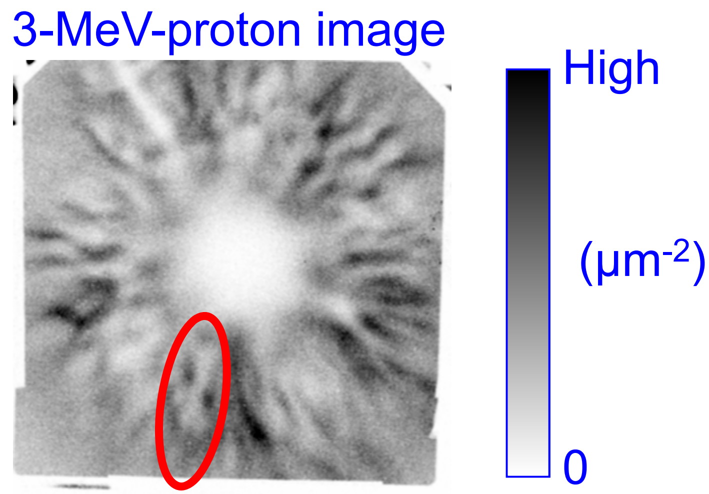


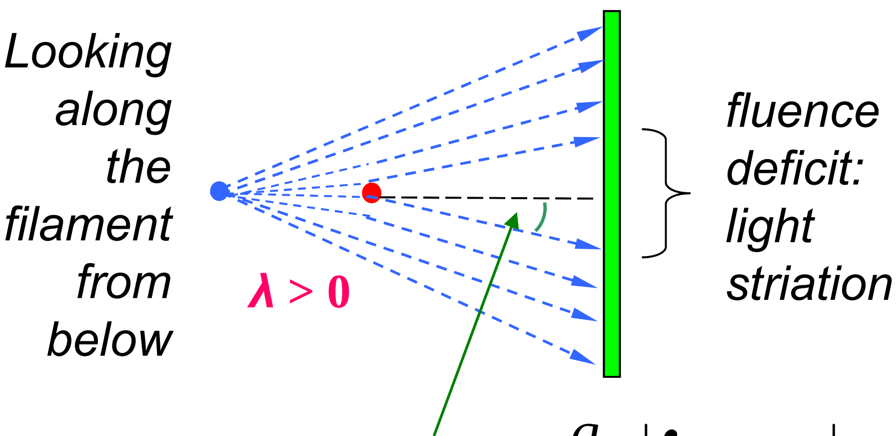
Each shot has images from different particles that sample fields at different times

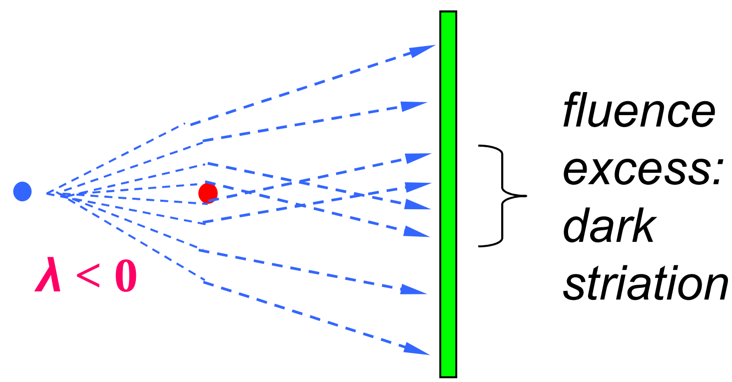


E fields could cause image striations





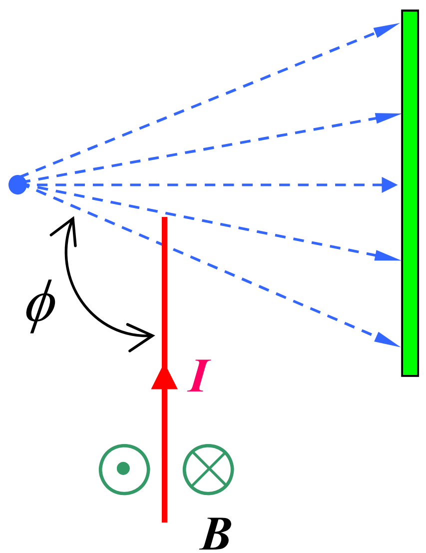




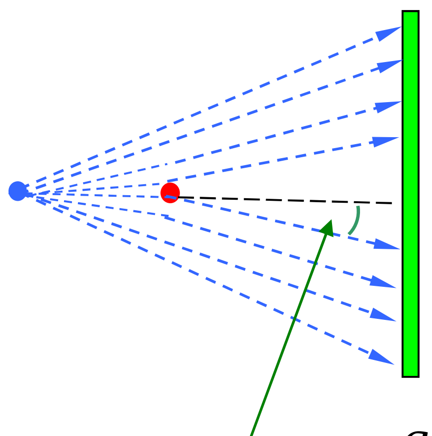
$$\Theta_{i,E} = \frac{q_i}{2\varepsilon_i}\left|\int E \times d\ell\right| \propto \frac{q_i}{\varepsilon_i}\frac{\lambda}{\sin\phi}$$

B fields could cause image striations

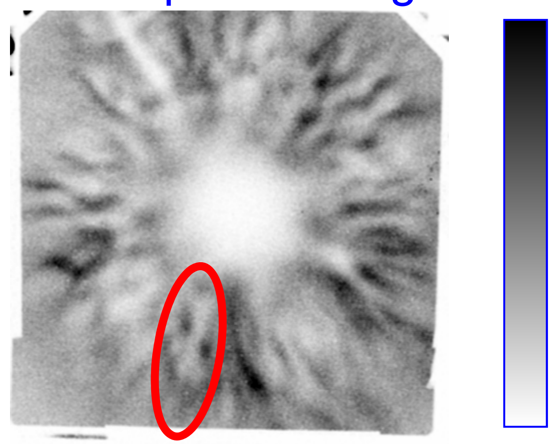
Side view



Looking along the filament from below

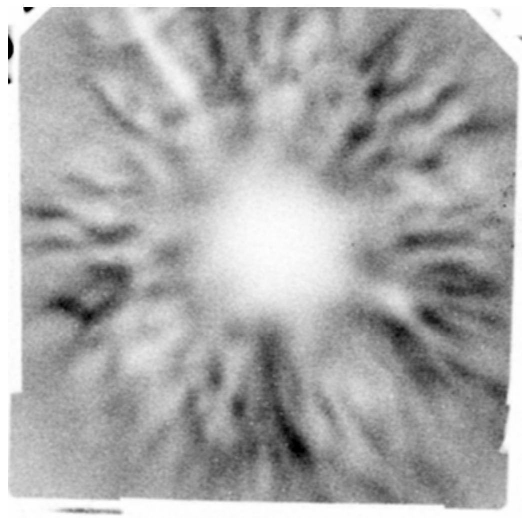


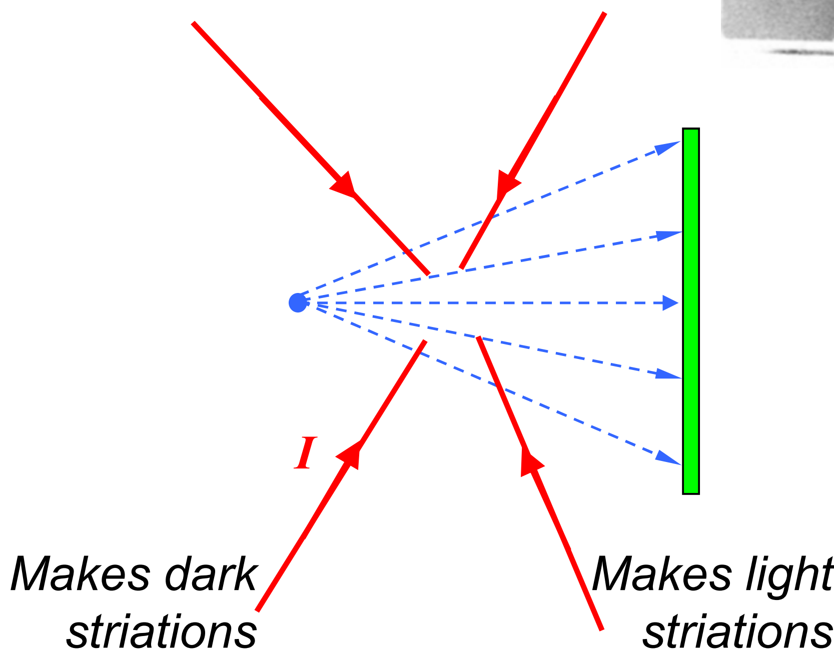
3-MeV-proton image

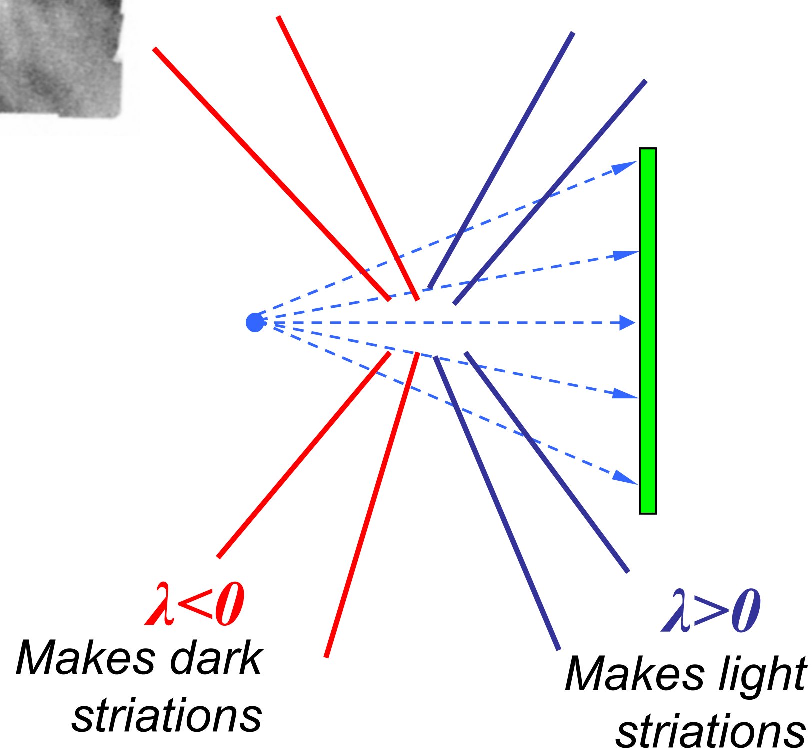


$$\Theta_{i,B} = \frac{q_i}{\sqrt{2m_i\varepsilon_i}}\left|\int B \times d\ell\right| \propto \frac{q_i}{\sqrt{m_i\varepsilon_i}}\frac{\cos\phi}{\sin\phi} I$$

Light striations appearing "in front of" dark ones makes *B* more natural than *E*







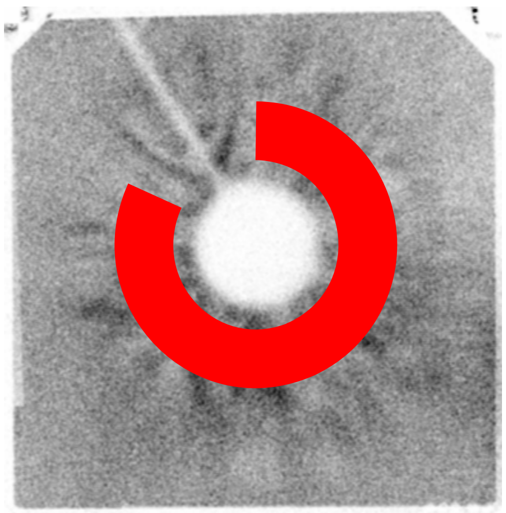
Deflections due to *E* and *B* fields scale differently with the energy, mass and charge of the imaging particle

$$\Theta_{i,E} \propto \frac{q_i}{\varepsilon_i} \qquad\qquad \Theta_{i,B} \propto \frac{q_i}{\sqrt{m_i \varepsilon_i}}$$

- If we could accurately measure deflection angles for a filament with different imaging particles, we could see whether they scaled according to *E* or *B.*

- This is very difficult, because
  - The deflections are small and hard to quantify, especially for 15-MeV protons.

For small deflection angles, a similar scaling applies to measured image modulation due to filaments



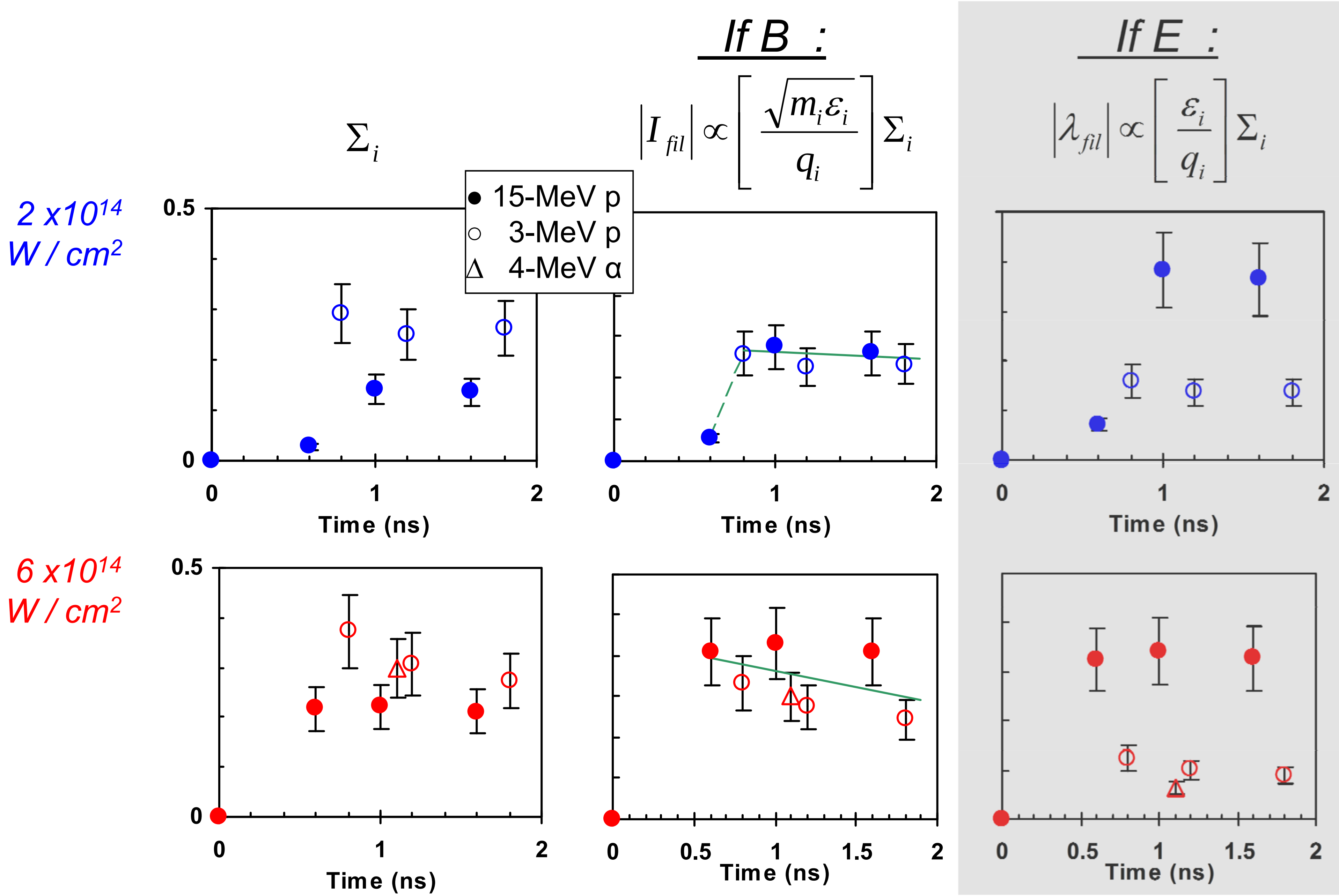
Define an image region containing filaments but not stalk or capsule.

Define RMS image modulation due to filaments : $$\Sigma \equiv \frac{\sqrt{\sigma_{total}^{\;2} - \sigma_{stats}^{\;2}}}{\langle fluence \rangle}$$

If B: $$\Sigma_i \propto \frac{q_i}{\sqrt{m_i \varepsilon_i}} \sqrt{N_{fil}} \left| I_{fil} \right| \quad \Rightarrow \quad \left| I_{fil} \right| \propto \left[\frac{\sqrt{m_i \varepsilon_i}}{q_i} \right] \Sigma_i$$

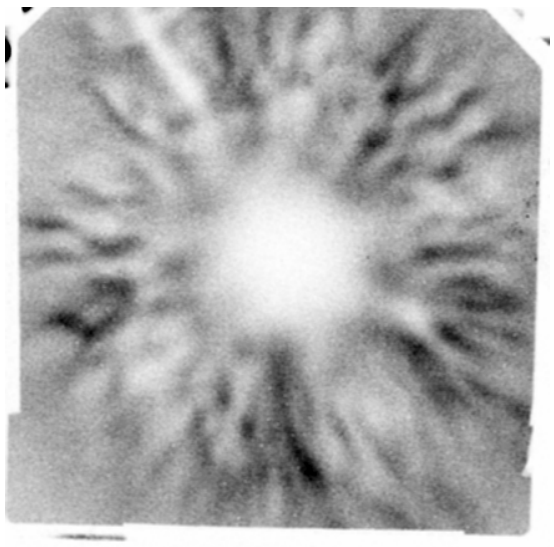
If E: $$\Sigma_i \propto \frac{q_i}{\varepsilon_i} \sqrt{N_{fil}} \left| \lambda_{fil} \right| \quad \Rightarrow \quad \left| \lambda_{fil} \right| \propto \left[\frac{\varepsilon_i}{q_i} \right] \Sigma_i$$

Scaling tests show that image striations are caused by *B*

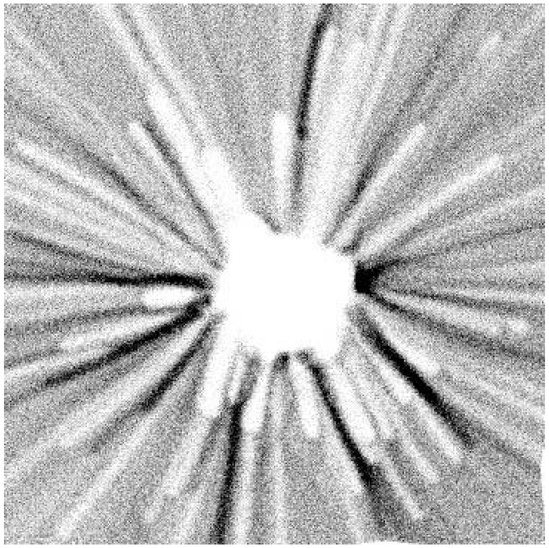


The wavelength (filament-to-filament separation) can be estimated by comparison with simulations

Data

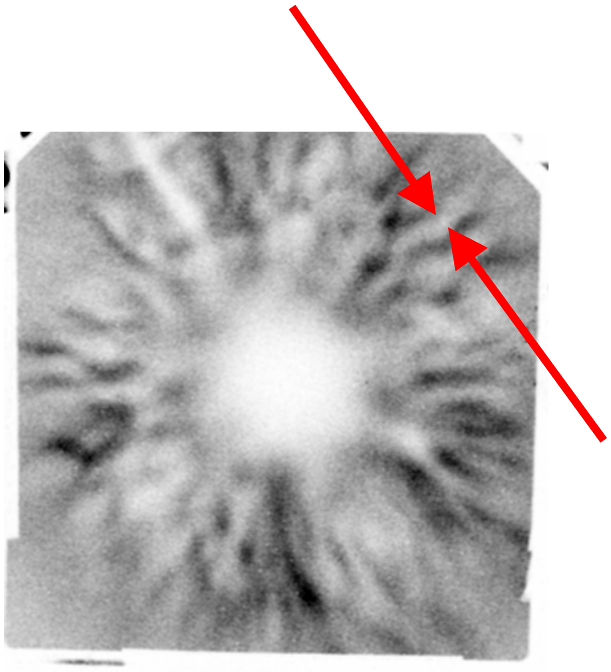


Monte-Carlo simulation
for 200 filaments over 4π



~ 200 filaments distributed over 4π
means 100-μm separation at the capsule surface

Field strength and filament current can be estimated from striation widths in the lowest-energy images

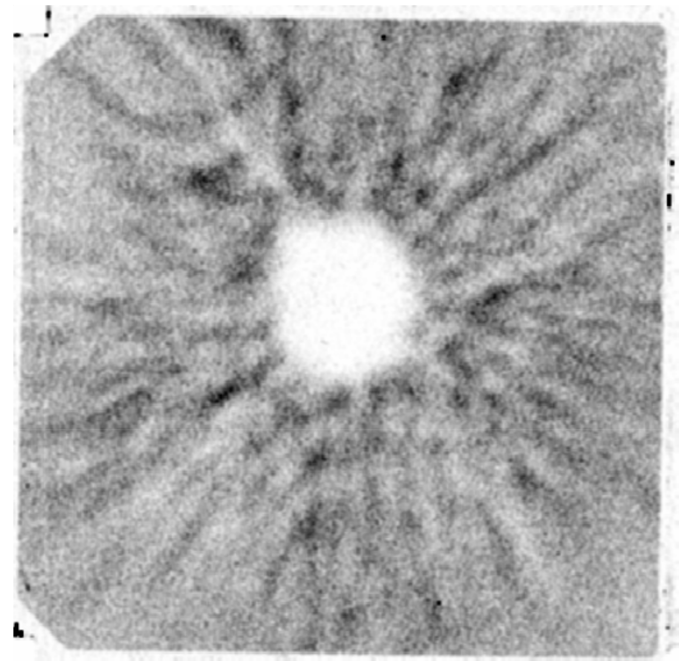


Half width gives a measure of deflection angle

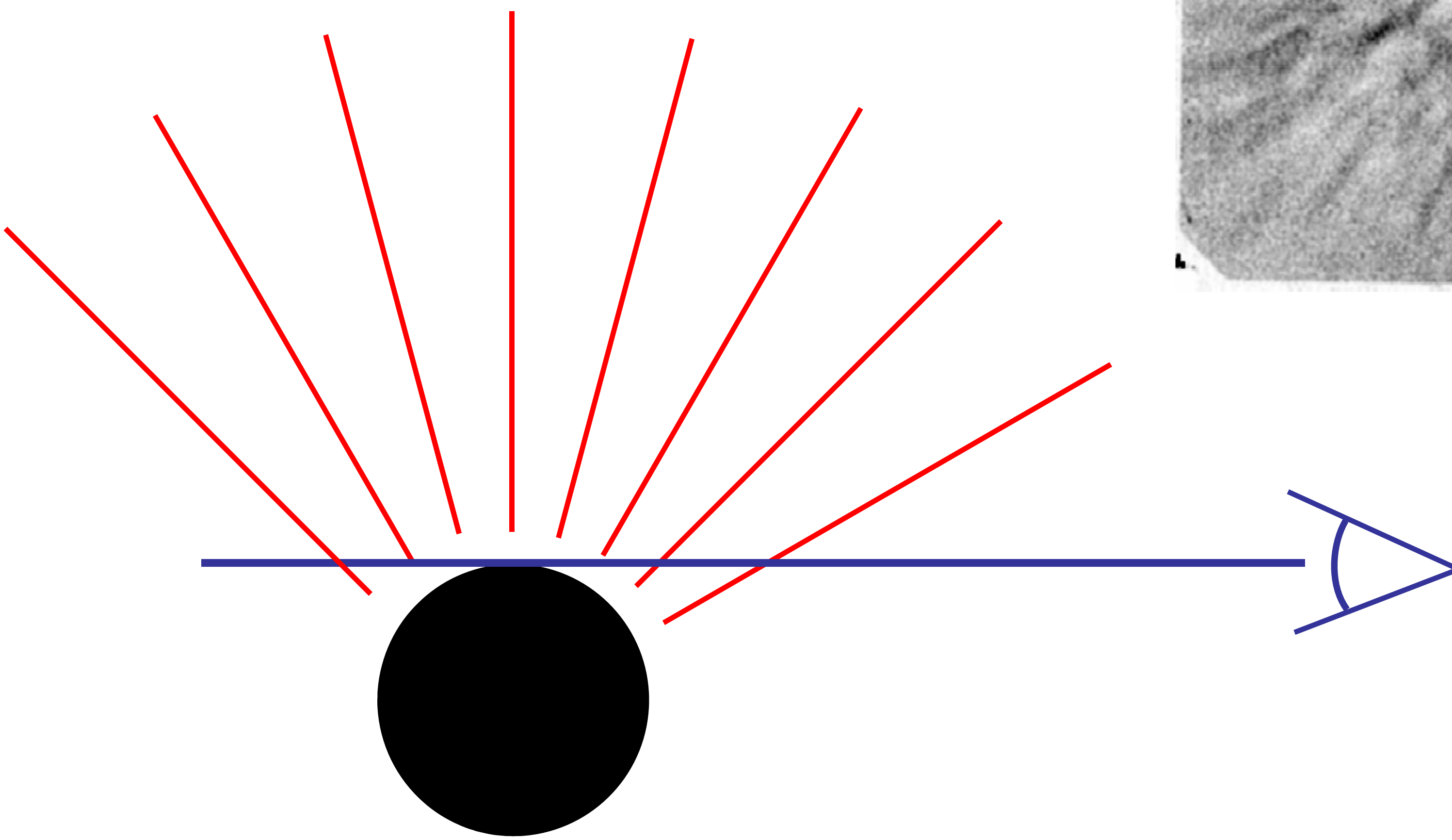
$$\Theta_{i,B} = \frac{q_i}{\sqrt{2m_i\varepsilon_i}} \left| \int B \times d\ell \right|$$

B ~ 10 T

Filaments appear to extend inward to the ablation surface



But we can't prove that
from the images



This is the resulting picture of filament structure at ~1 ns for laser intensity 6 x 10^{14} W/cm^2