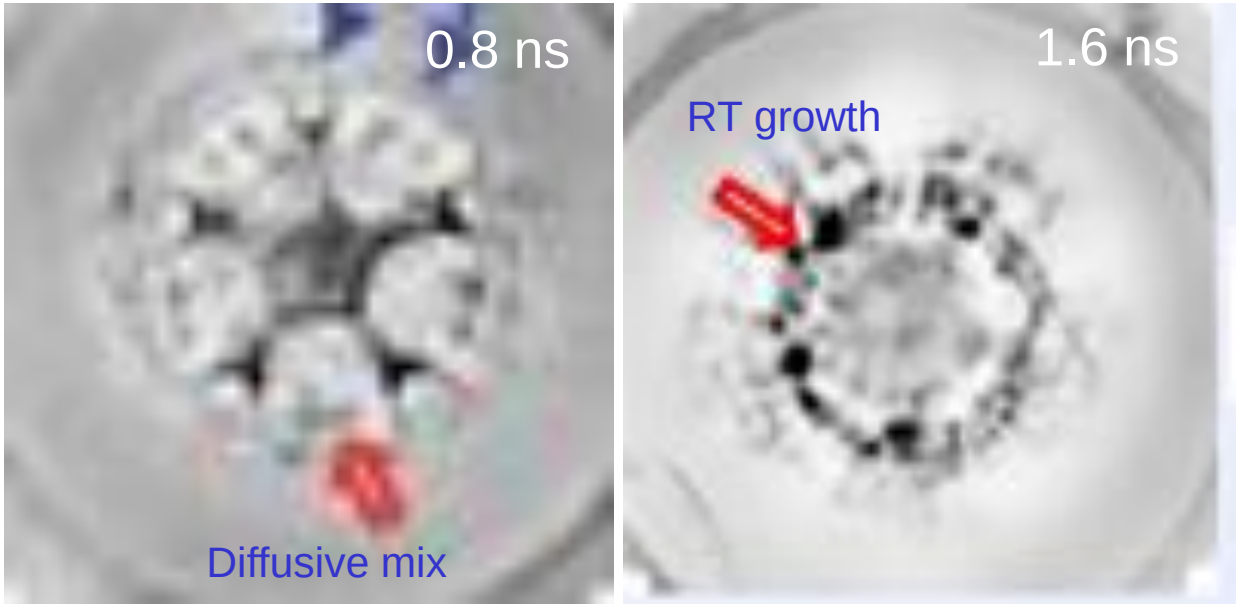
Studying the physics of instabilities and mix at the fill-gas/wall-blowoff interface in ICF experiments

OMEGA data



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MIT

Frontiers of Plasma Science Workshops
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Summary

Time-gated proton radiography reveals the structures and dynamics of material interface

- **Dynamics at material interface are of fundamental importance in ICF**
  - **Unstable interface → the interpenetration of the two materials**
  - **Kinetic ion diffusion → an ambipolar E field and mix**
- **Charged-particle radiography with spatial resolution ~30 μm and temporal resolution ~ 100 ps, could resolve ion diffusion, instability and mixing at the interface**
- **In a broader view, these studies provide physical insight into kinetic effects at material interfaces in other systems, such as HED and Astrophysical plasmas**

Collaborators

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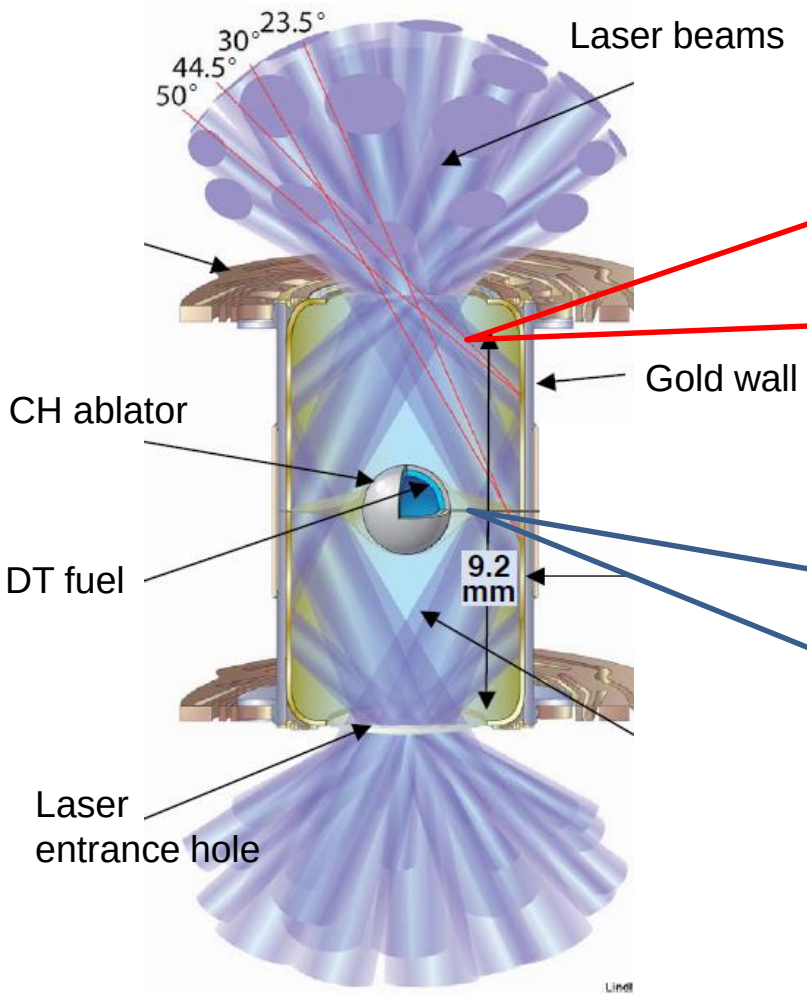
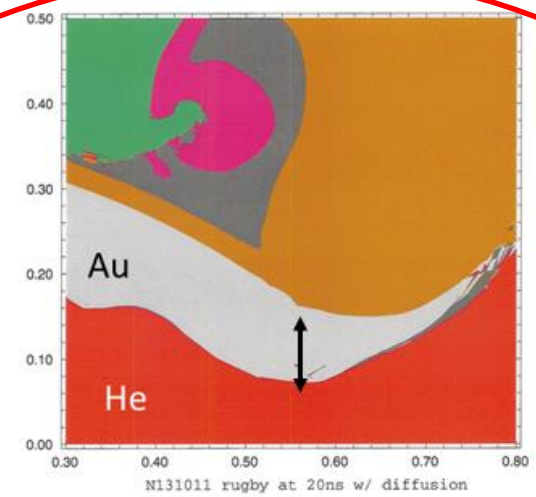
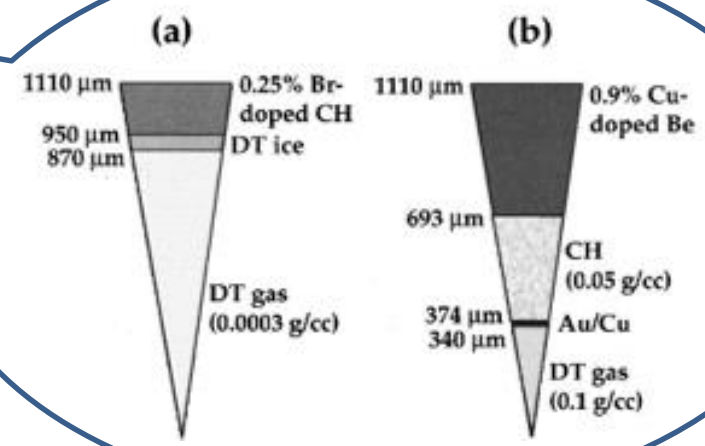
Interfaces are present in hohlraum and capsule of a typical indirect-drive ICF target

NIF Hohlraum

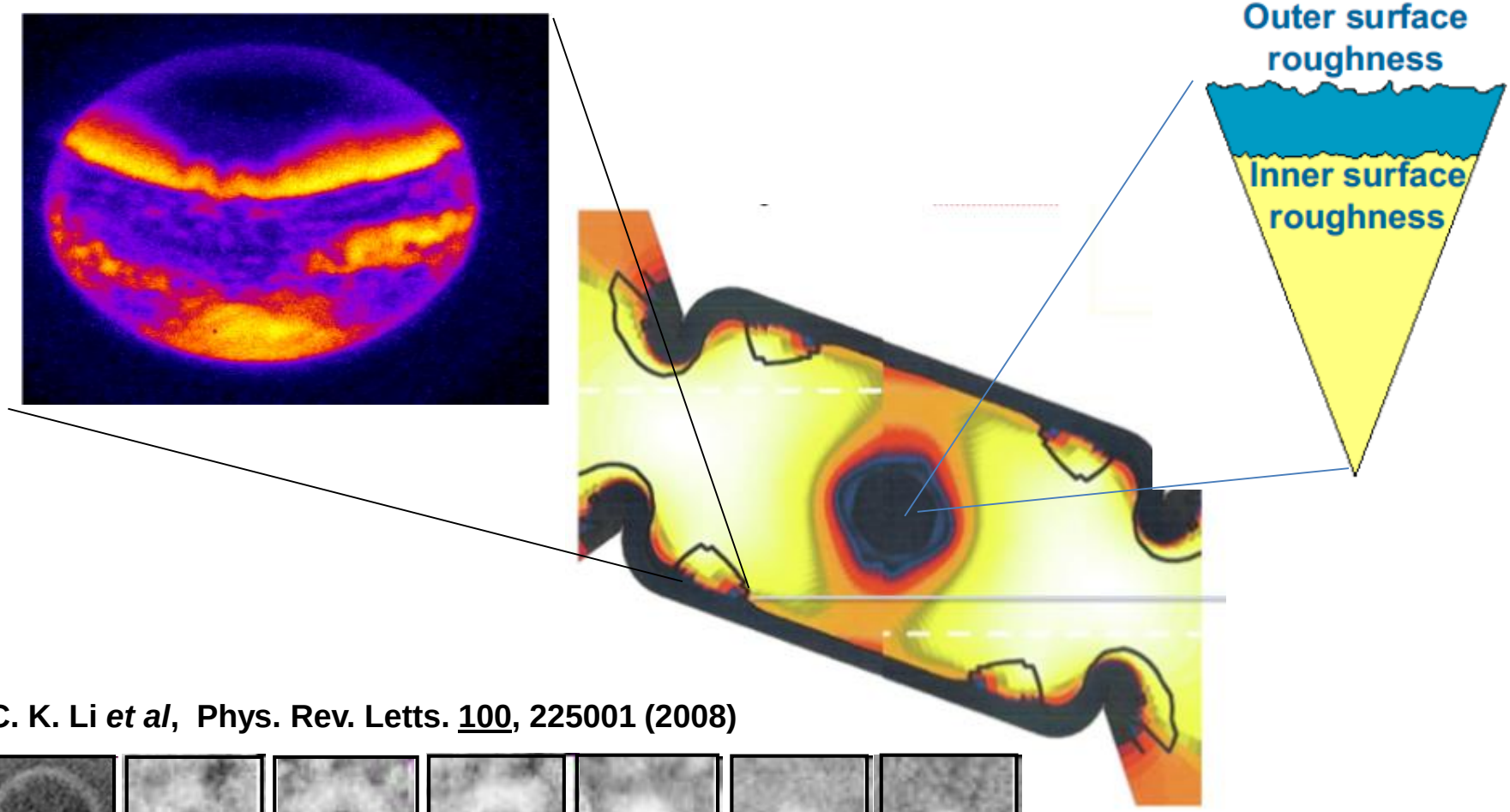




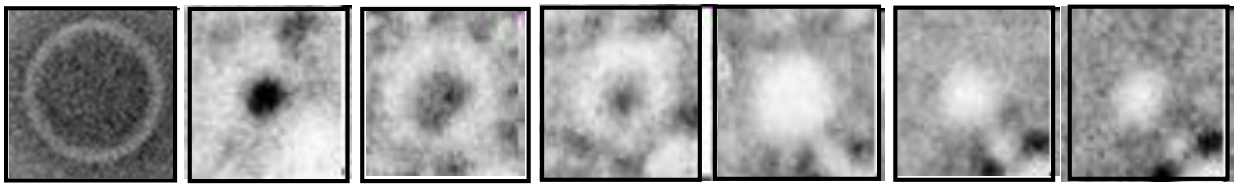
(courtesy of P. Amendt)



Interfaces are hydrodynamically unstable during laser-plasma interactions and ICF implosions, and are affected by fields

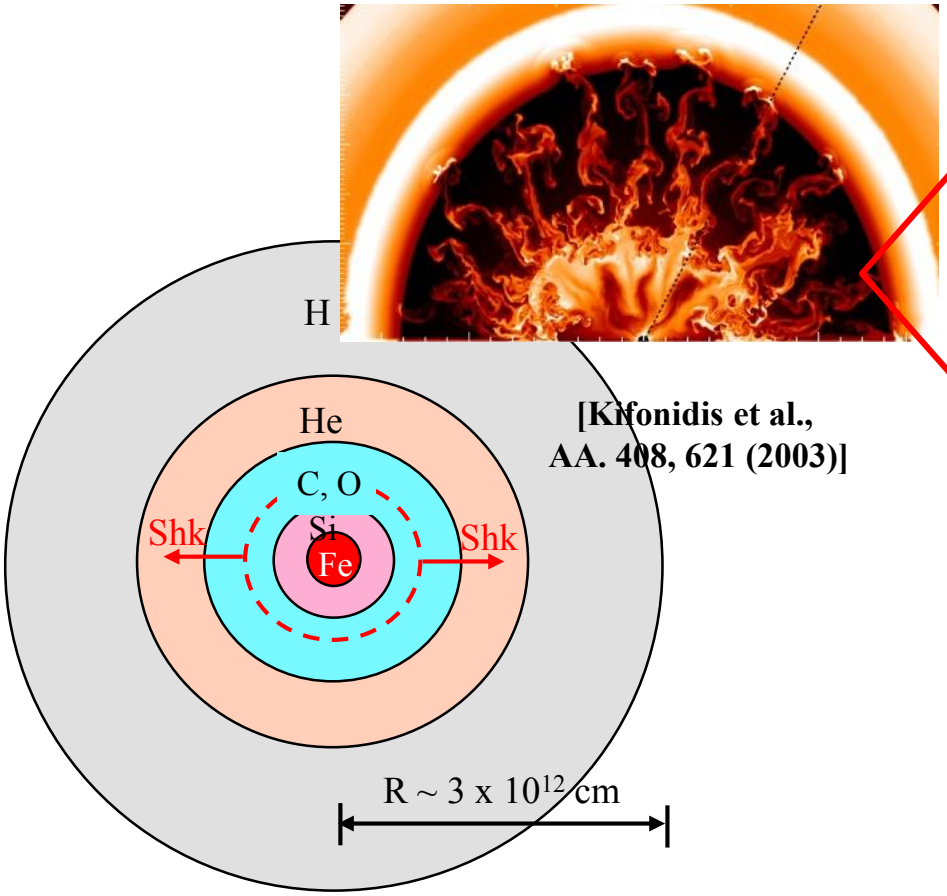


C. K. Li *et al*, Phys. Rev. Letts. 100, 225001 (2008)

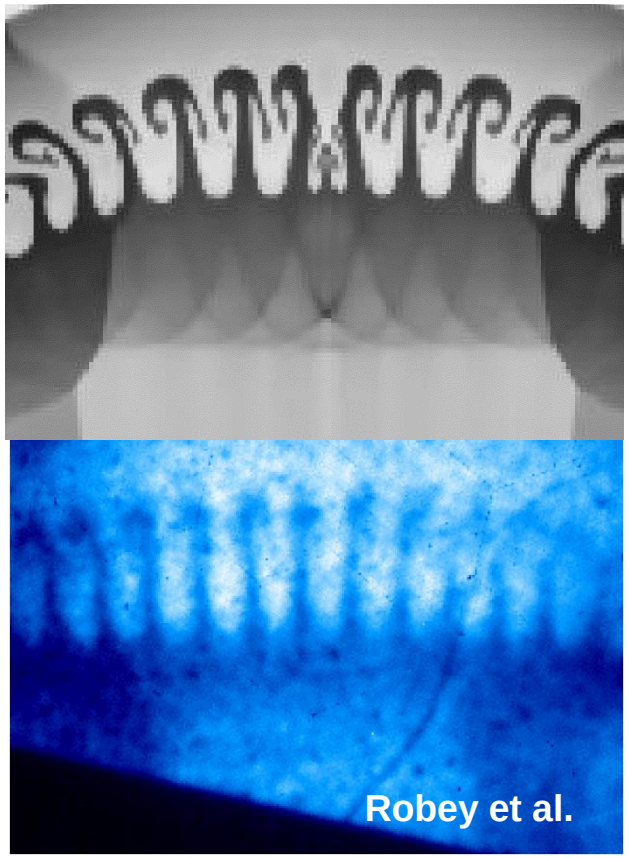


0.0 ns 0.8 ns 1.2 ns 1.4 ns 1.6 ns 1.9 ns 2.1ns

Scaled laboratory experiments provide physical insight into interface dynamics in core-collapse supernovas



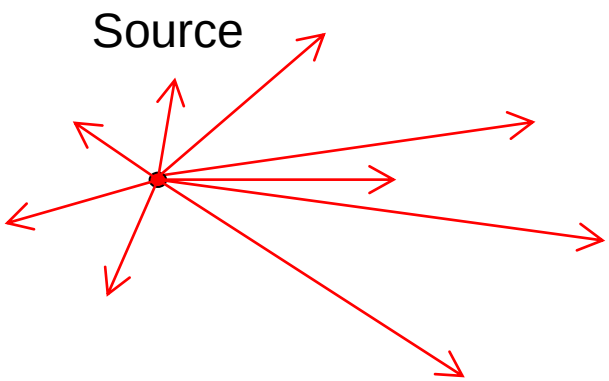
[Kifonidis et al., AA. 408, 621 (2003)]



Kelvin-Helmholtz makes mushrooms on Rayleigh-Taylor spike

H. F. Robey *et al*., Phys. Plasmas **10**, 614 (2003);

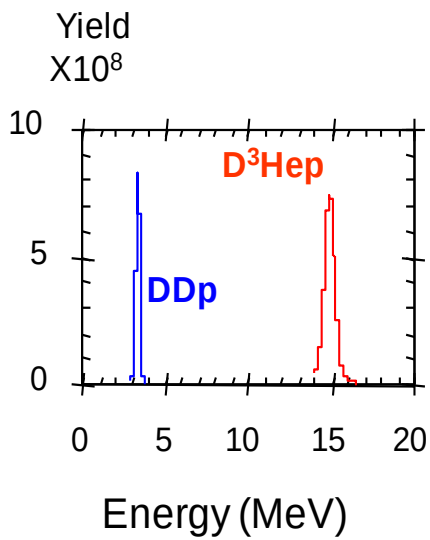
Charged-particles provide direct measurements of fields and instabilities in ICF experiments

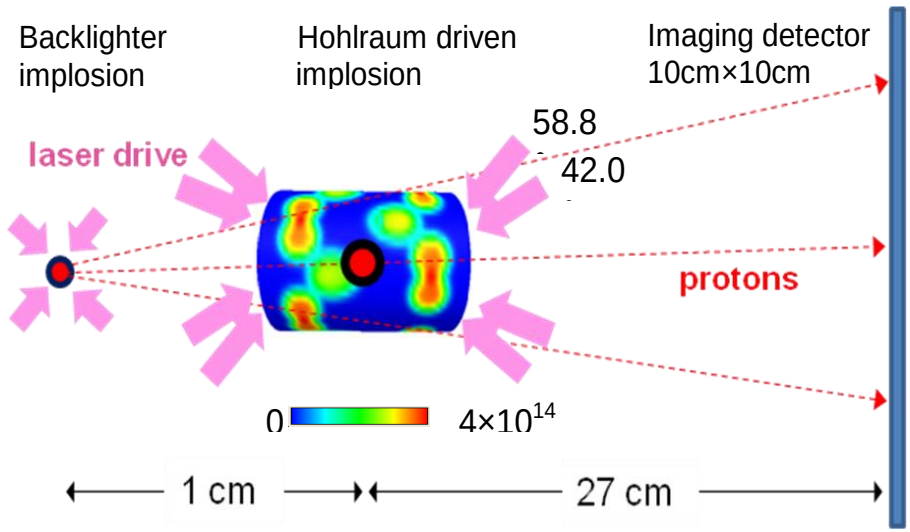


$D + {}^3He \rightarrow {}^4He + p$ (14.7 MeV)

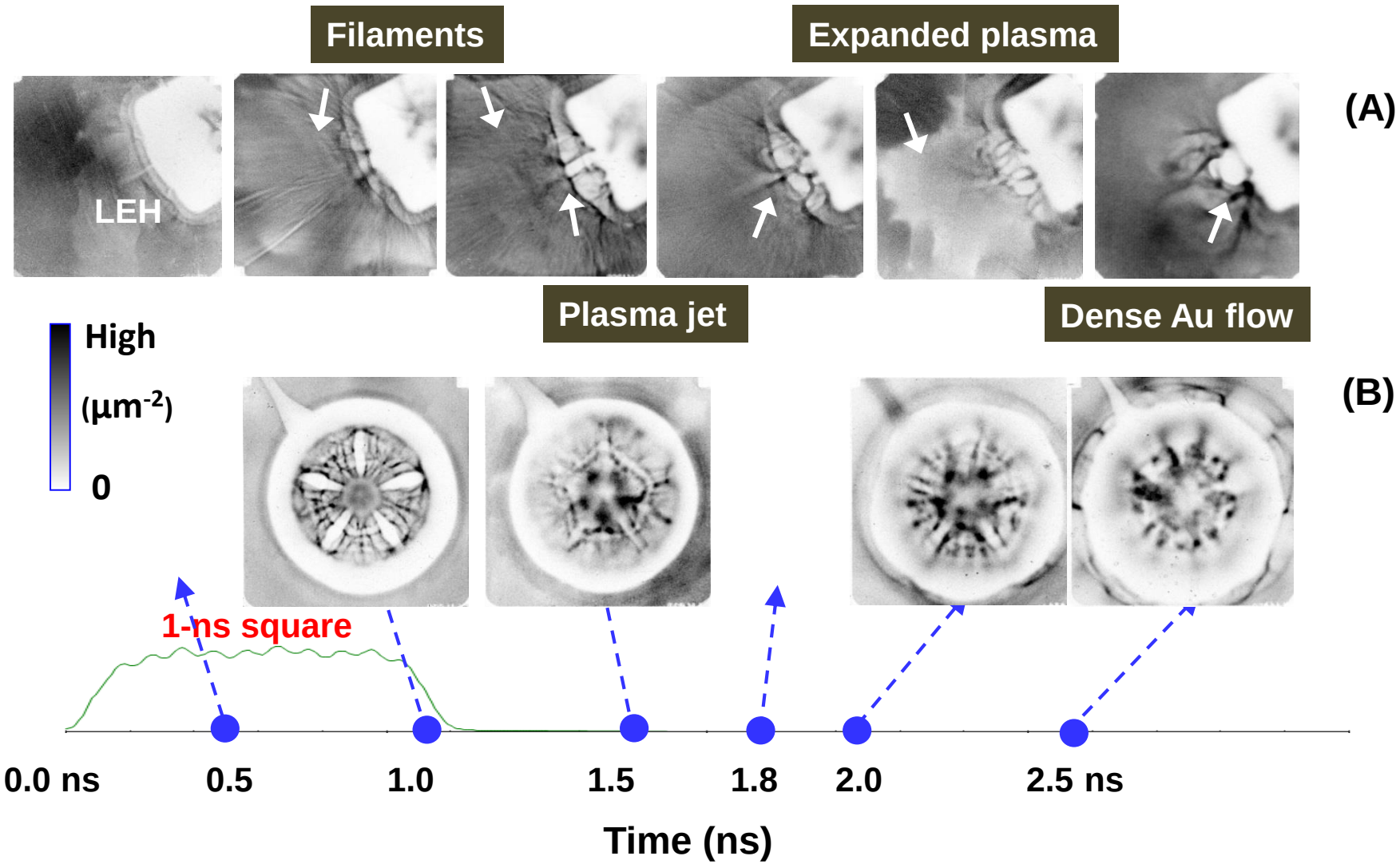
$D + D \rightarrow T + p$ (3.0 MeV)

Spatial resolution: ~ 40 μm (FWHM)
Energy resolution: ~ 3%
Temporal resolution: ~ 80 ps





Proton images reveal the structure and dynamics of current filaments, plasma flow and spontaneous fields at LEHs



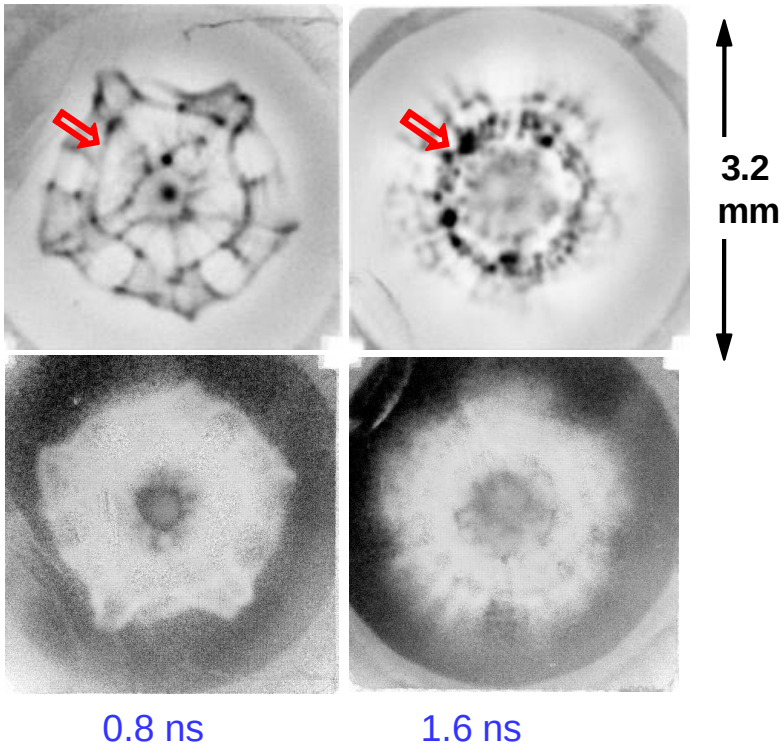
Interpenetration occurs due to the classical Rayleigh-Taylor instability as the lighter, decelerating ionized fill gas pushes against the heavier, expanding gold wall blow-off

Rayleigh-Taylor growth

$$\gamma_{\mathrm{RT}} = \sqrt{2\pi \mathrm{A_t} a k}$$

@ Au-Gas interface

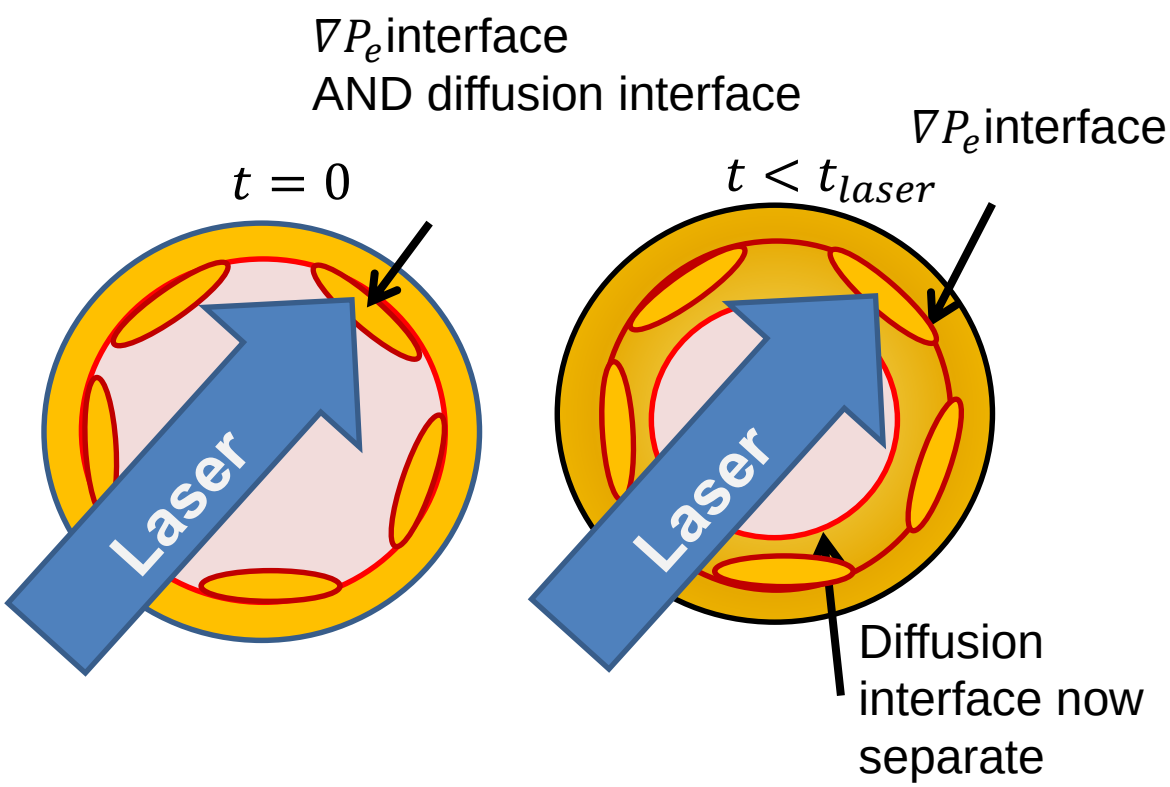
$$\mathrm{A_t} = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \approx 0.54$$

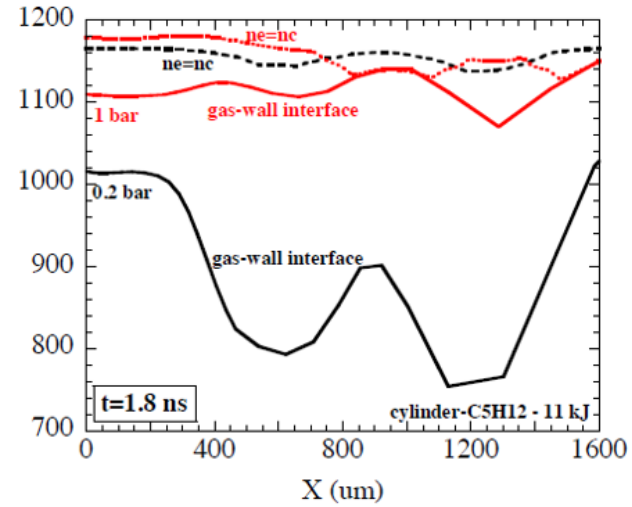


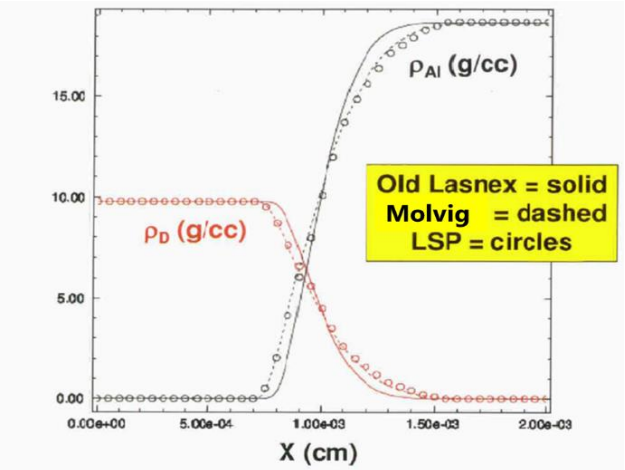
The consequence is a reduced benefit of the gas fill because the enhanced interpenetration (or mixing) between the Au blow-off and the gas plasma leads to high-Z material stagnating earlier in the hohlraum interior

C. K. Li *et al*, Phys. Rev. Letts. 108, 025001 (2012)

Simulations suggest two E-fields are present which are associated with (1) the laser hitting wall (2) the diffusion interface.





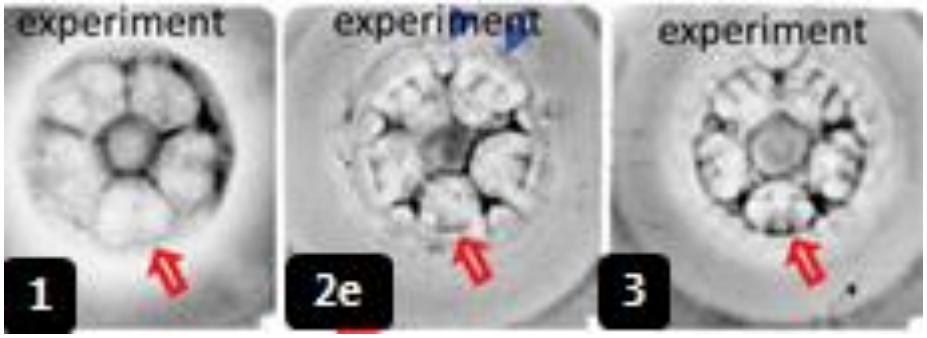


S.C. Wilks *et al*, to be submitter (2015)

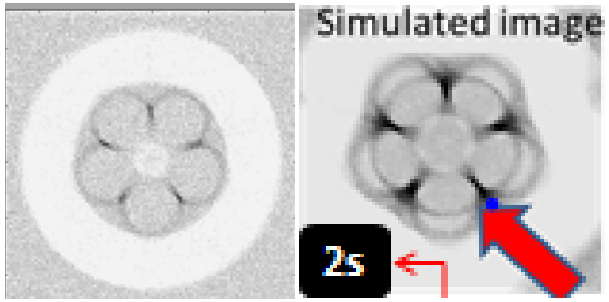
Recent simulations reproduce OMEGA experiments remarkably well, providing physical insight into the kinetic effects at Au/gas interfaces

OMEGA experiments

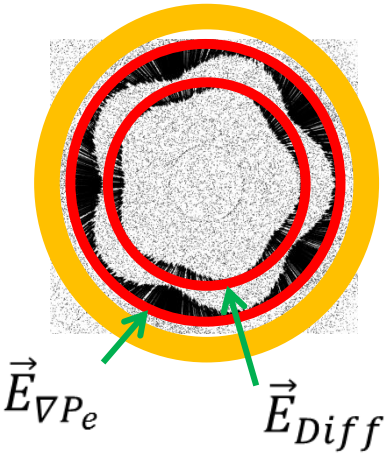
Measured images
PRL 2012

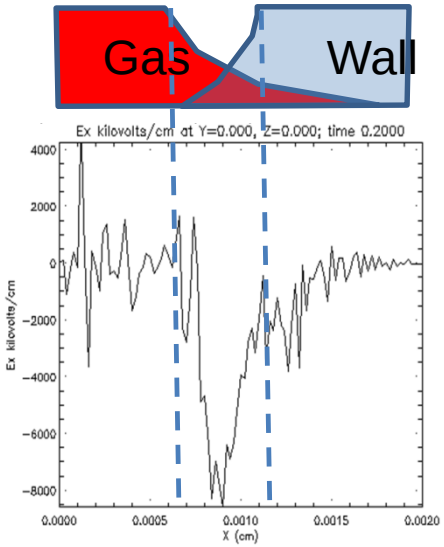


Simulated images
By S. Wilks



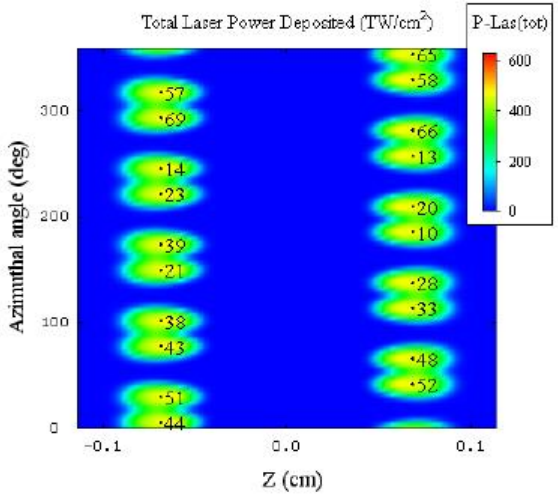
On axis view of $\vec{E}$

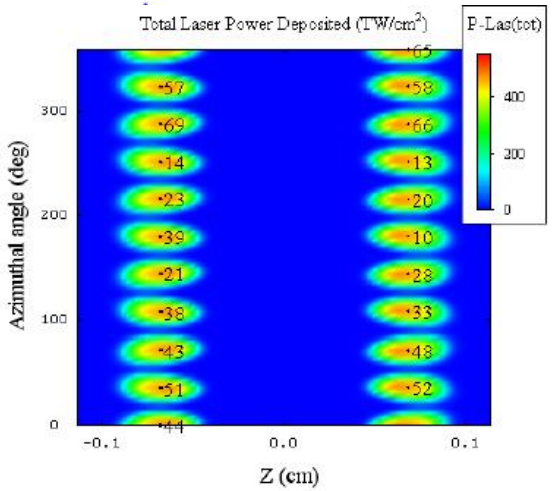




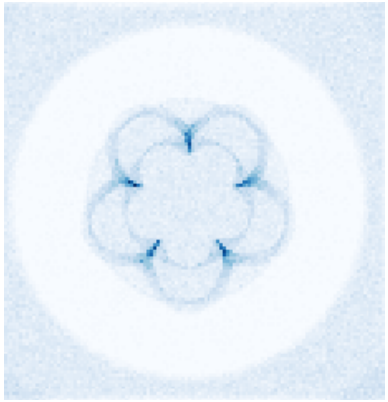
- **1** At early times, diffusion-related field and wall ∇P_e fields are in same spot.
- **2e** As time proceeds, diffusion field moves inward faster than overdense wall.
- **2s** Simulations with both E-fields included can capture these features.
- **3** Once laser is off, diffusive field dominates.

A new experiment has been designed to break the E/B degeneracy and obtain quantitative information of the diffusive mix

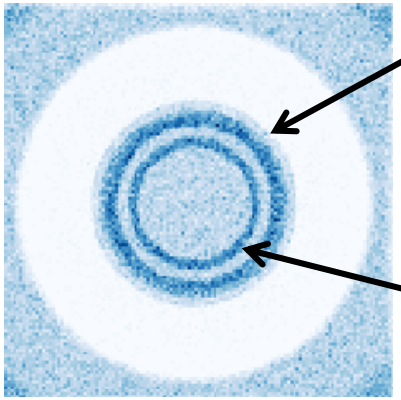




Modeling: old images



"Predicted" new images



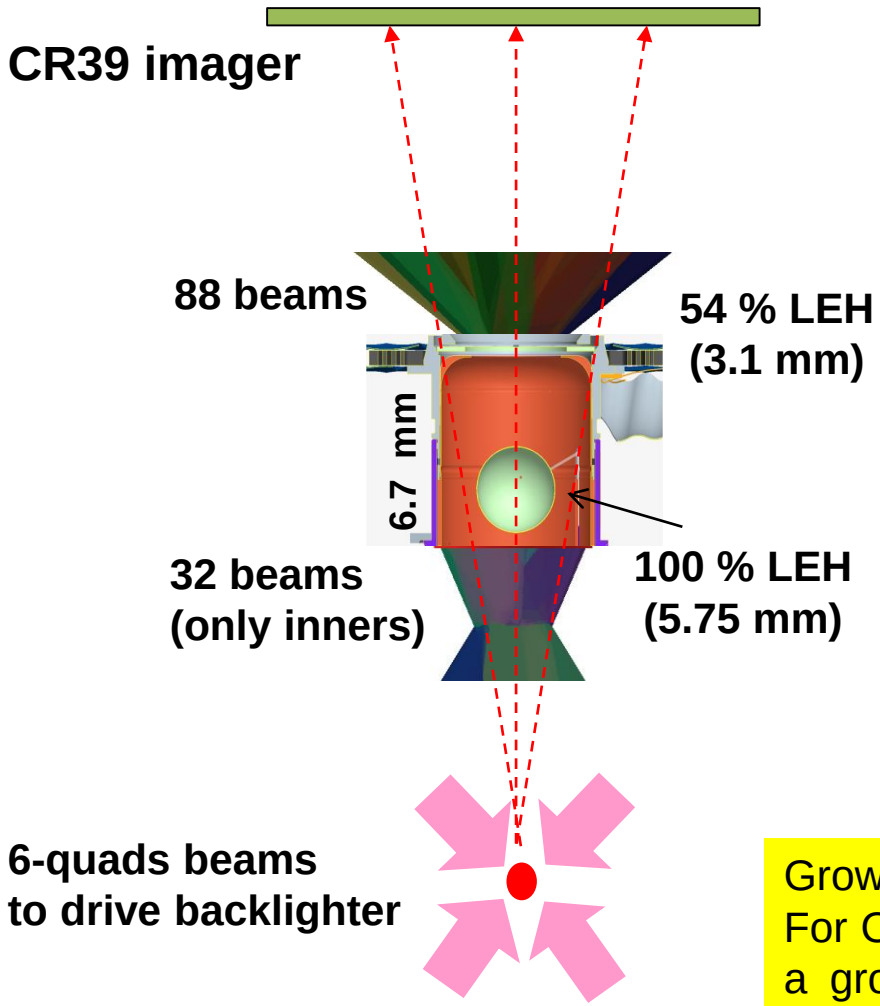
∇P_e feature

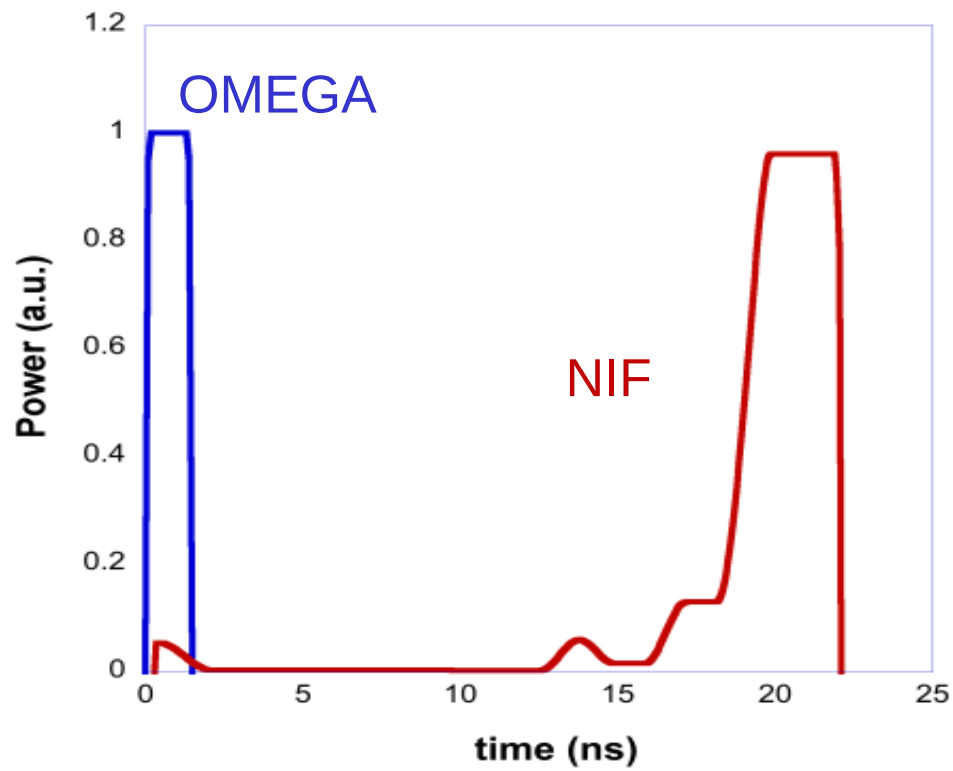
Diffusive E feature

$$\vec{E}_{hohl} = (\nabla P_e)_r \hat{r} + \cancel{(\nabla P_e)_\theta} \hat{\theta}$$

S.C. Wilks *et al*, to be submitter (2015)

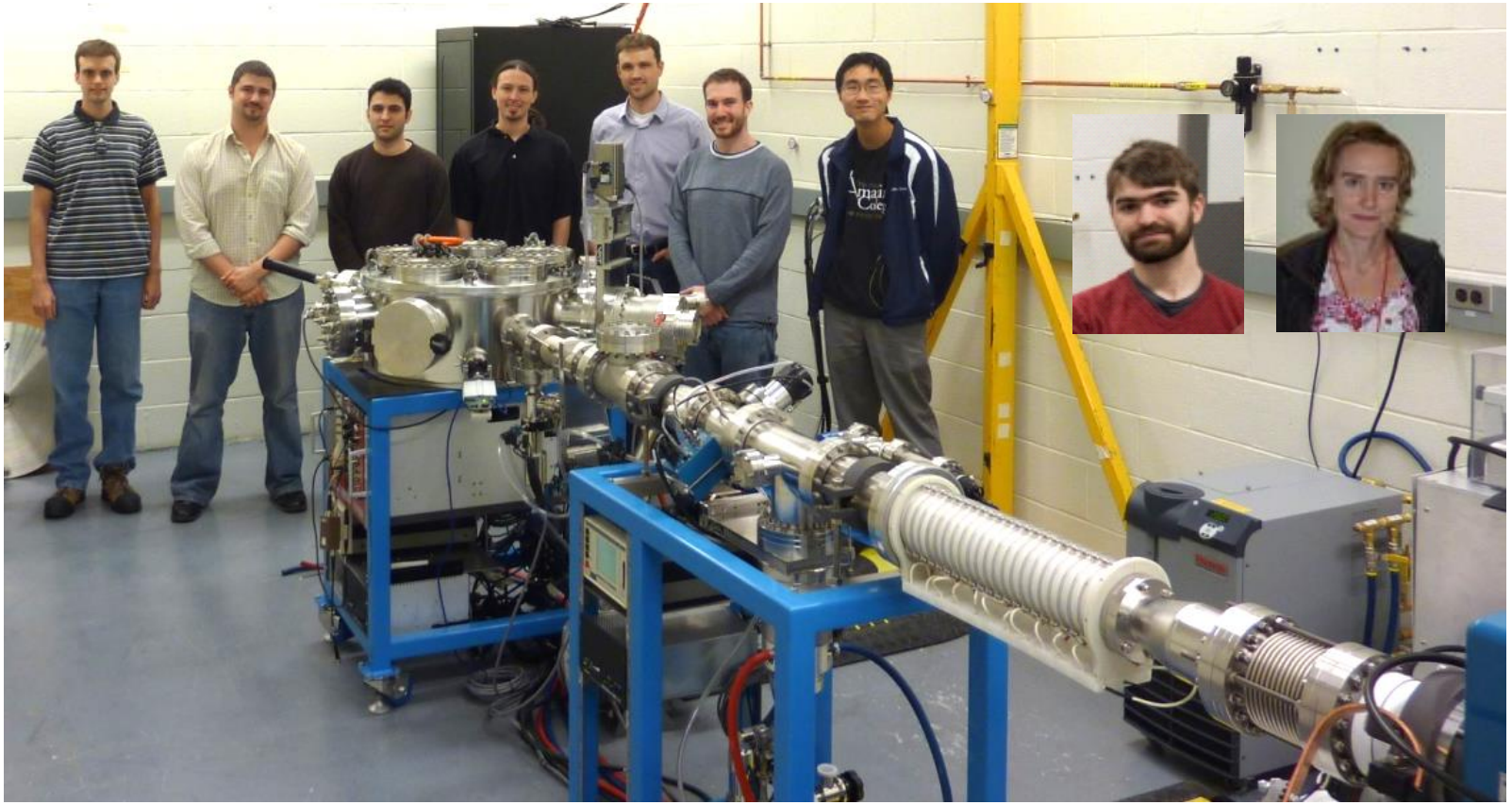
New experiments are being planned for backlighting the ViewFactor indirect-drive implosions at the NIF





Growth of Rayleigh Taylor instabilities:
For OMEGA experiment, after 1 ns the amplitude has a growth ~ 15. Using the same conditions for NIF, imply a very huge amplitude growth after 22 ns.

The MIT-HEDP Accelerator Facility is used for HED diagnostics development



$$D + D \rightarrow t\ (1.01\ \text{MeV}) + p\ (3.02\ \text{MeV})$$

$$D + {}^{3}He \rightarrow {}^{4}He\ (3.71\ \text{MeV}) + p\ (14.63\ \text{MeV})$$

Summary

Time-gated proton radiography reveals the structures and dynamics of material interface

- **Dynamics at material interface are of fundamental importance in ICF**
  - **Unstable interface → the interpenetration of the two materials**
  - **Kinetic ion diffusion → an ambipolar E field and mix**
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