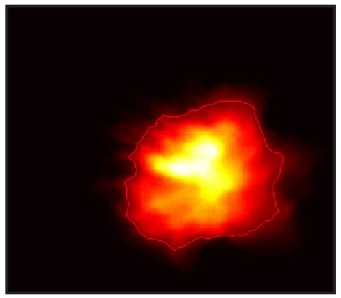
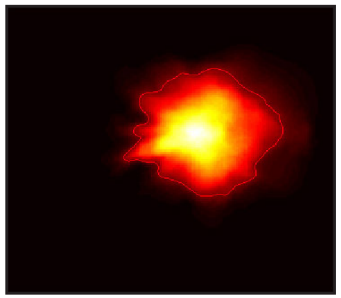
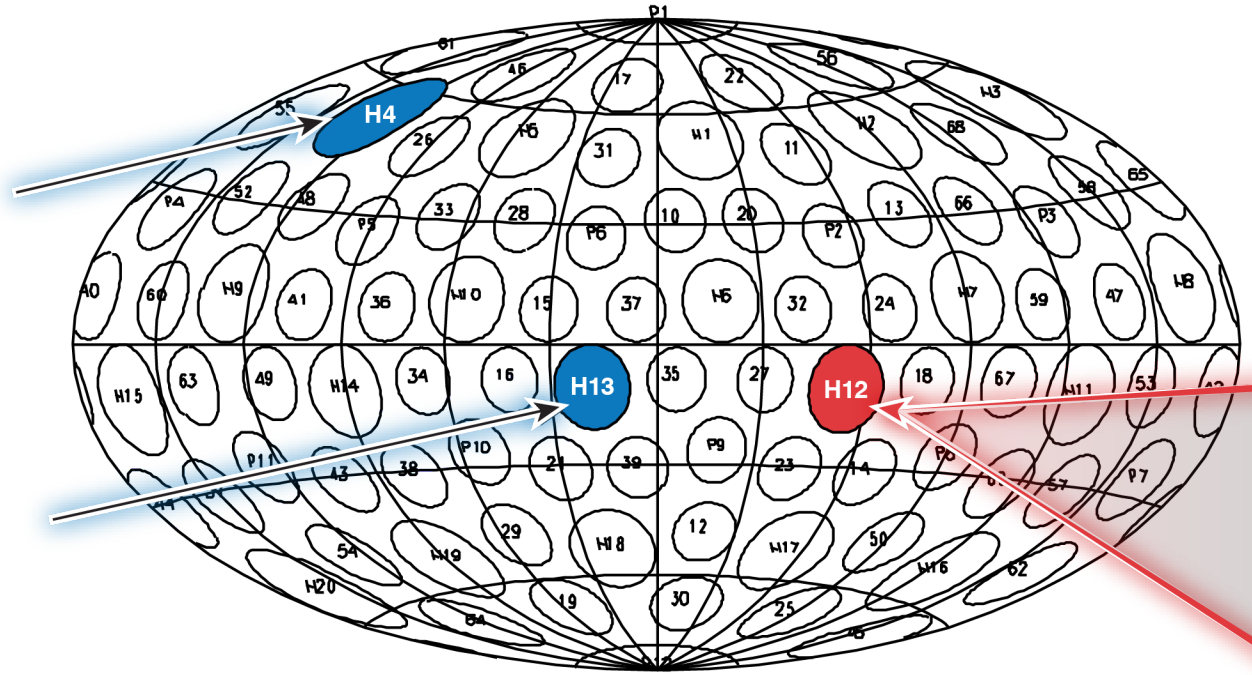
The Third Line-of-Sight Time-Gated X-Ray Imager for OMEGA DT Cryogenic Implosions



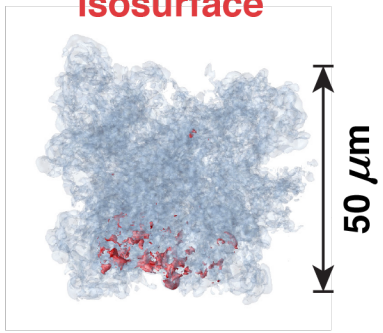


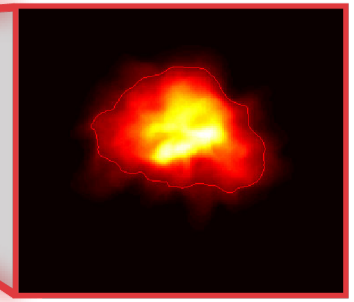
Simulated 3-D x-ray imaging of hot spot



OMEGA Target Chamber

Simulated 1-keV isosurface





K. Churnetski
University of Rochester
Laboratory for Laser Energetics

62nd Annual Meeting of the
American Physical Society
Division of Plasma Physics
9–13 November 2020

Summary

A 3-D view of the hot spot is crucial for understanding the evolution of the hot spot and the multidimensional effects that occur during ICF implosions

- OMEGA currently has two time-gated x-ray imagers: a time-resolved Kirkpatrick–Baez x-ray microscope* and the single-line-of-sight, time-resolved x-ray imager (SLOS-TRXI)**
- A time-gated hot-spot x-ray imager is being developed for use on OMEGA as a third line of sight similar to SLOS-TRXI with ≤5-μm spatial and 20-ps temporal resolutions
- 3-D gated hot-spot x-ray imaging will be used to infer the low-mode structure of the hot spot

In the future, stalk and fill tube jets at stagnation will be studied with the third line of sight.

ICF: inertial confinement fusion

* F. J. Marshall *et al.*, Rev. Sci. Instrum. 88, 093702 (2017).
** W. Theobald *et al.*, Rev. Sci. Instrum. 89, 10G117 (2018).

Collaborators

W. Theobald, K. A. Woo, I. Igumenshchev, R. Ejaz, S. T. Ivancic, A. Kish, M. Michalko, R. C. Shah, R. Spielman, and S. P. Regan

University of Rochester
Laboratory for Laser Energetics

A. Raymond

General Atomics

P. Bell, A. Carpenter, A. McPhee, C. Trosseille, and D. K. Bradley

Lawrence Livermore National Laboratory

J. D. Hares and A. K. L. Dymoke-Bradshaw

Kentech Instruments Ltd.

G. Rochau, L. Claus, and M. Sanchez

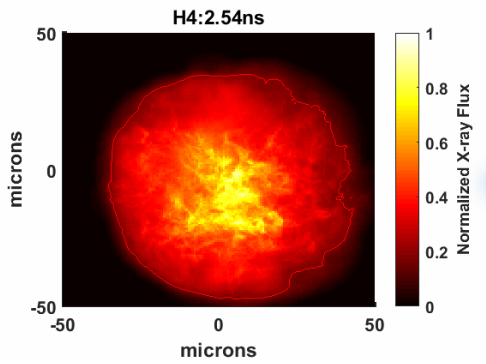
Sandia National Laboratories

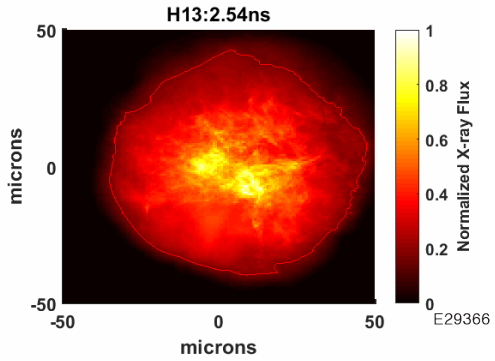
D. Garand

Sydor Technologies

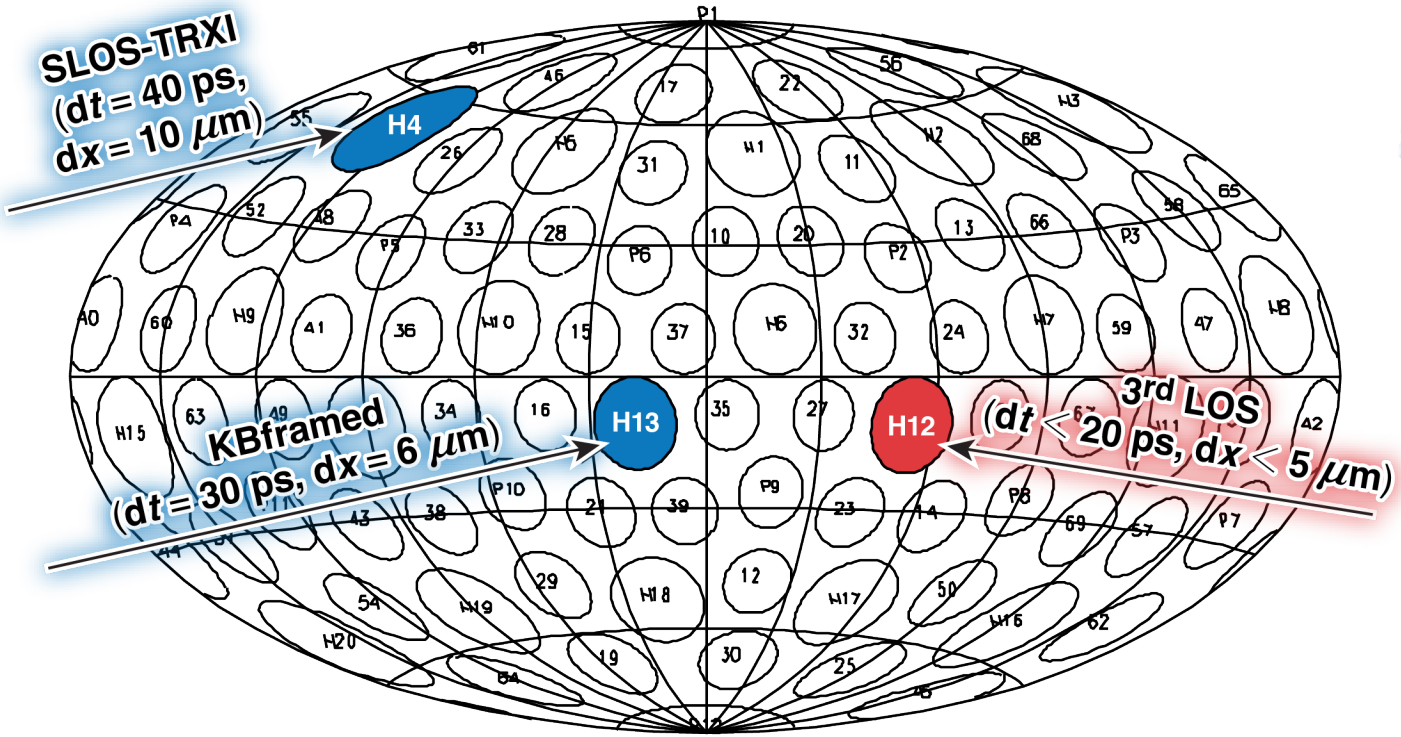
Multidimensional effects on hot-spot formation will be diagnosed with 3-D gated x-ray imaging of the hot-spot plasma

ASTER* 3-D simulation x-ray image

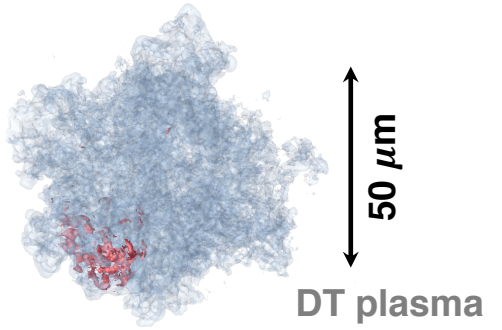


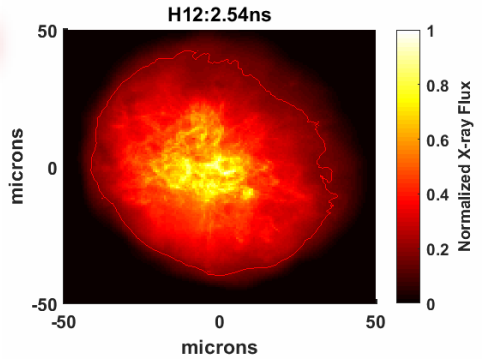


OMEGA Target Chamber



ASTER* 3-D simulation (T_e ~ 1-keV surface)





Three-dimensional gated x-ray imaging of the hot spot will use three quasi-orthogonal lines of sight.

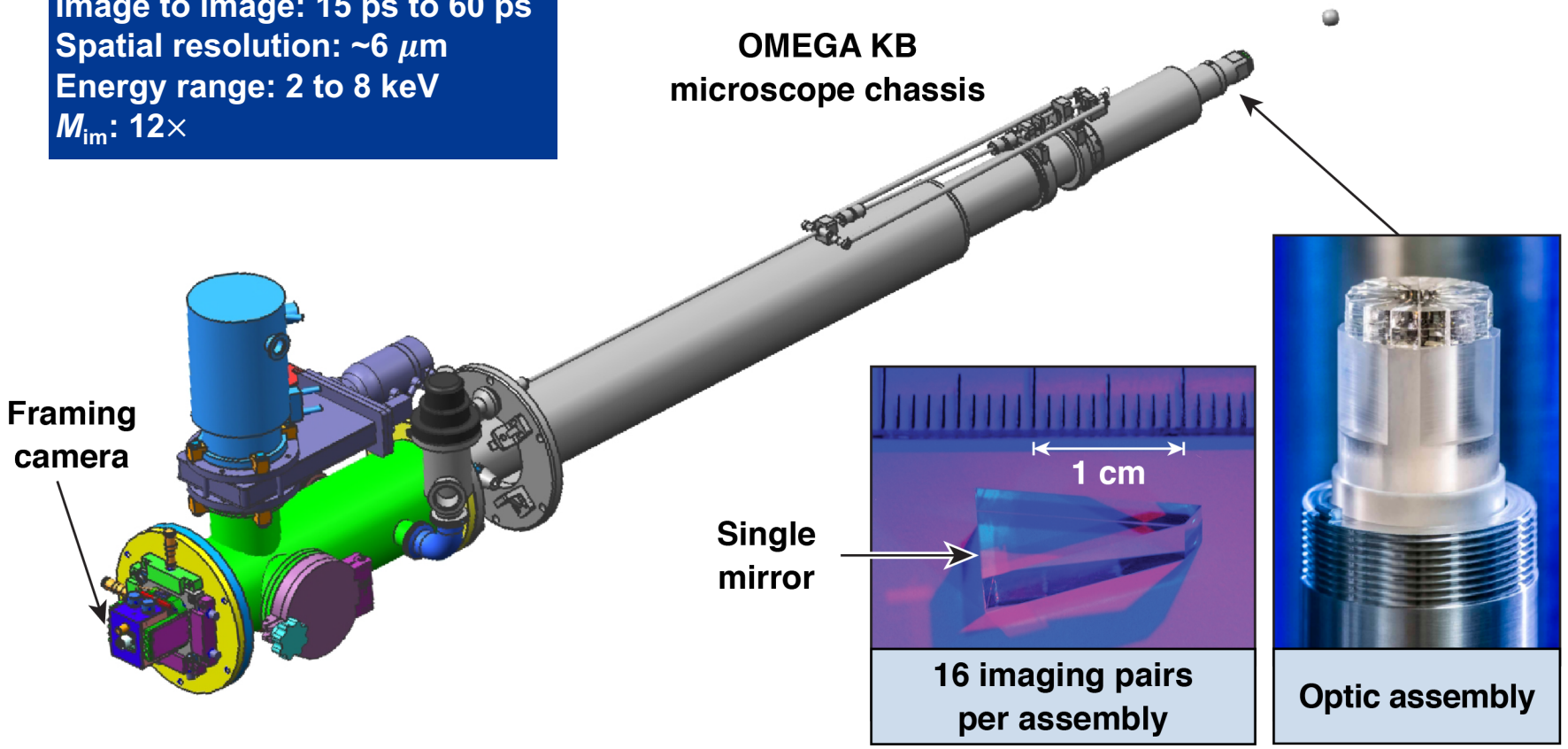
LOS: line of sight

* I. V. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).

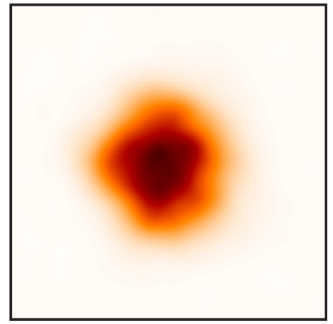
First LOS Time-Gated X-ray Imager

KBframed is a 16-channel Kirkpatrick–Baez (KB) x-ray microscope that provides time-resolved images of the core around stagnation

Gate width: ~30 ps
Image to image: 15 ps to 60 ps
Spatial resolution: ~6 μm
Energy range: 2 to 8 keV
M_{im}: 12×



KBframed core image
OMEGA cryogenic DT target
implosion shot 77064



100 × 100-μm
image regions

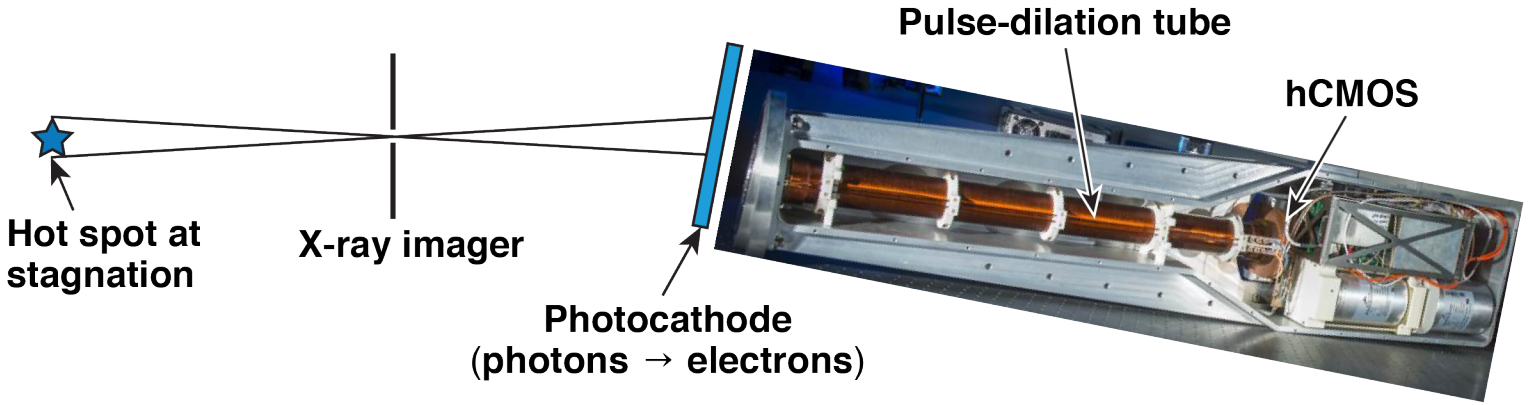
0 Max

Relative x-ray intensity

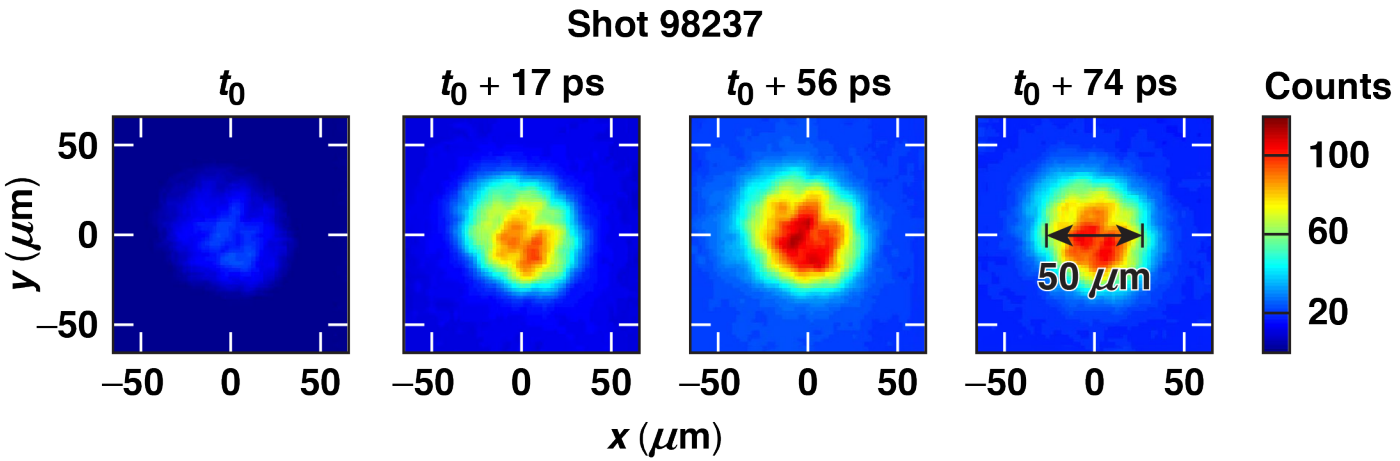
E22996f

F. J. Marshall *et al.*, Rev. Sci. Instrum. 88, 093702 (2017).

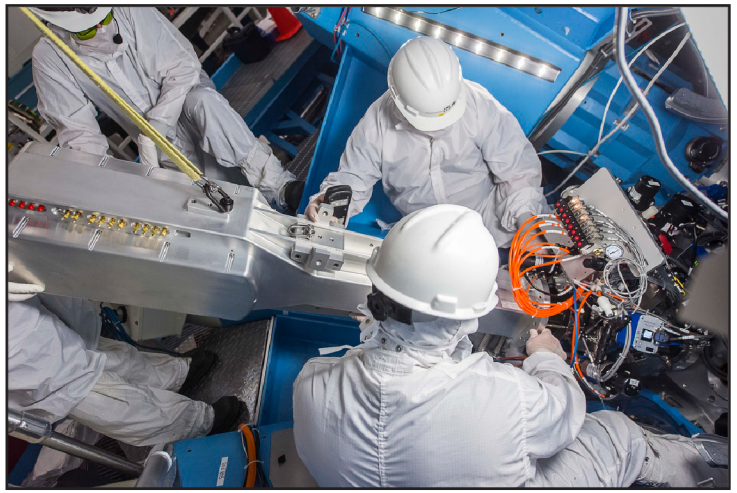
SLOS-TRXI is a fast-gated x-ray camera comprised of an electron pulse-dilation imager and a nanosecond-gated burst-mode hCMOS sensor



Gate width: ~40 ps
Image to image: 17 ps to 39 ps
Spatial resolution: ~10 μm
Energy range: 4 to 9 keV
M_{im}: 12.4×



E29368

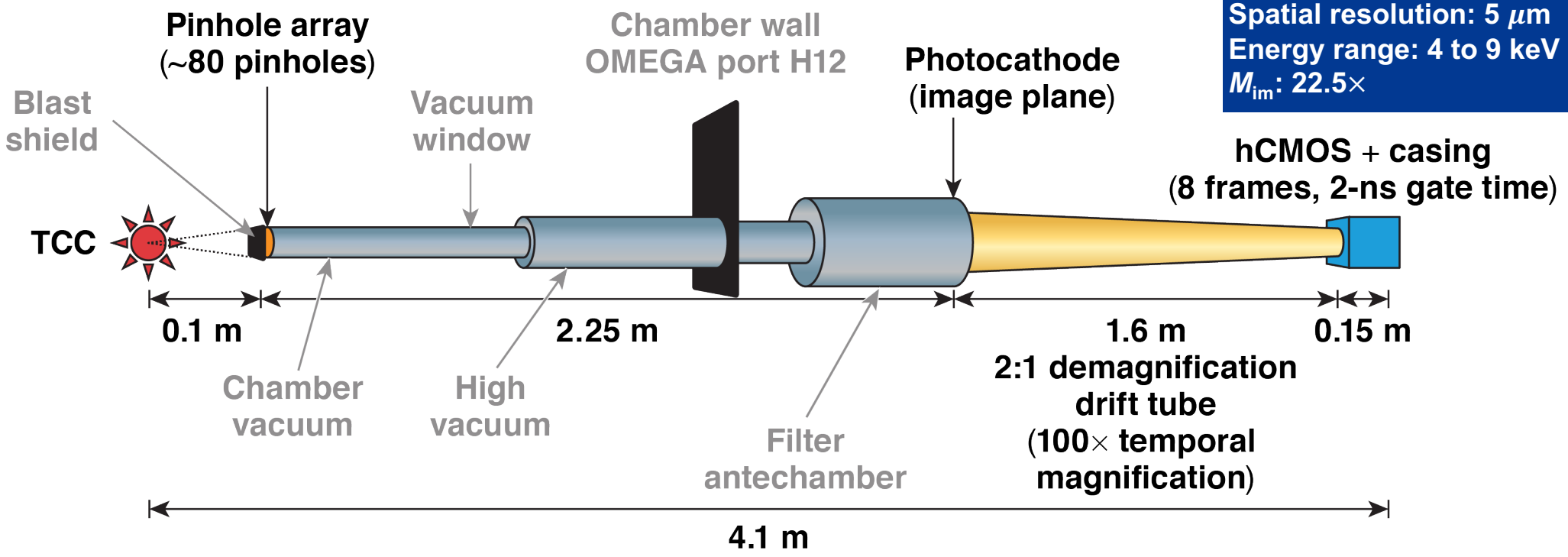


hCMOS: hybrid complementary metal-oxide semiconductor

K. Engelhorn *et al.*, Rev. Sci. Instrum. 89, 10G123 (2018);
T. J. Hilsabeck *et al.*, Rev. Sci. Instrum. 81, 10E317 (2010);
W. Theobald *et al.*, Rev. Sci. Instrum. 89, 10G117 (2018).

The 3rd LOS will follow the SLOS-TRXI concept but will have improved spatial (≤5-μm) and temporal (20-ps) resolutions

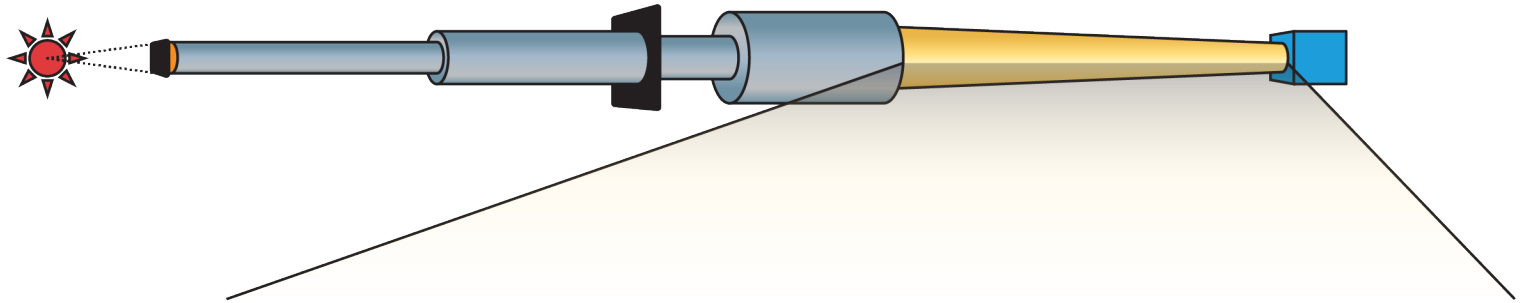
Gate width: ~20 ps
Image to image: 20 ps
Spatial resolution: 5 μm
Energy range: 4 to 9 keV
M_{im}: 22.5×

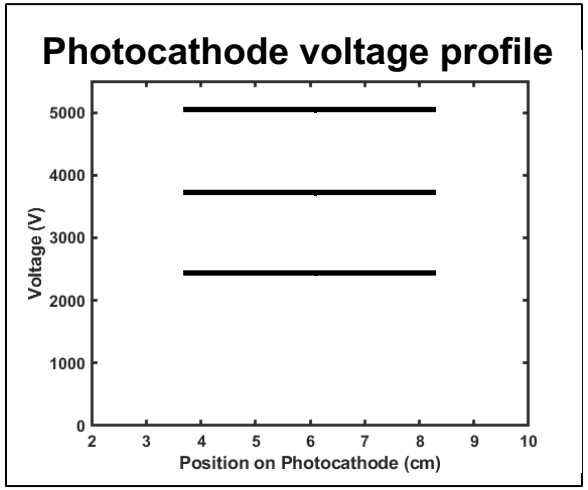


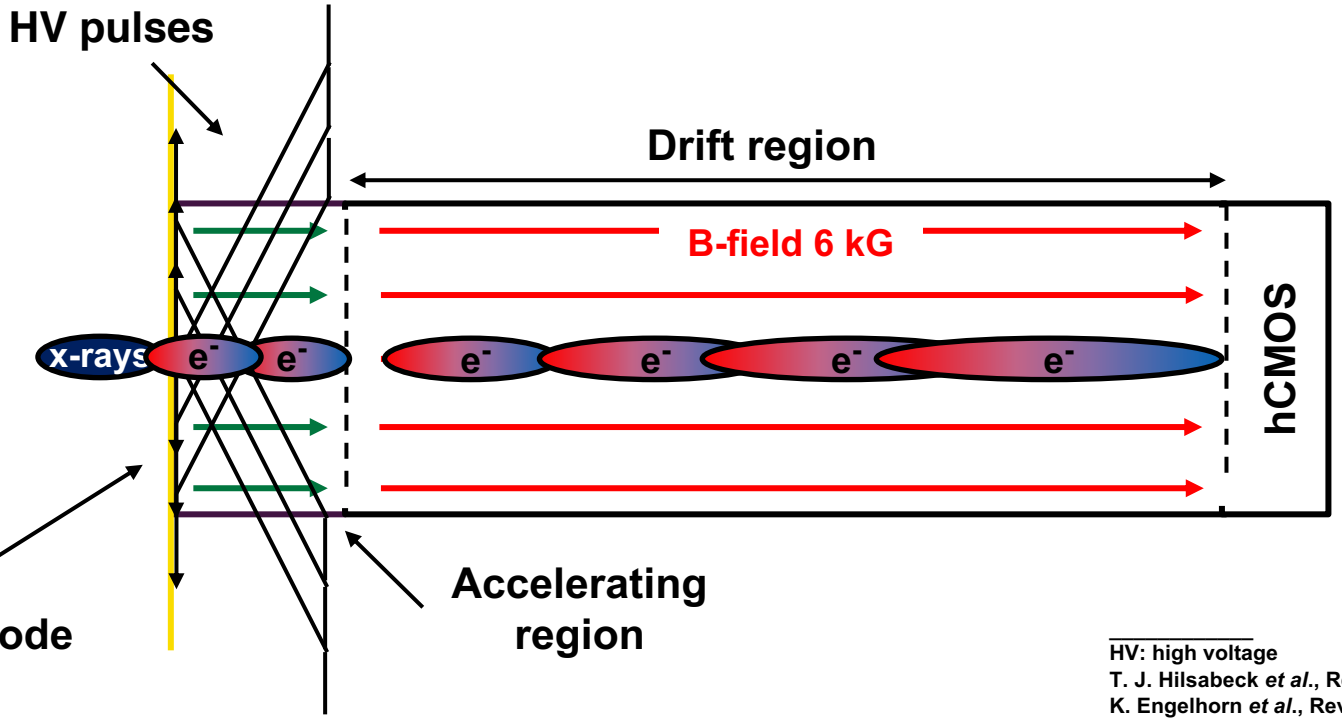
The high spatial and temporal resolutions will allow the 3rd LOS to be used to study the stalk and fill tube at stagnation.

TCC: target chamber center

A time-varying electric field on the x-ray photocathode will magnify the image temporally



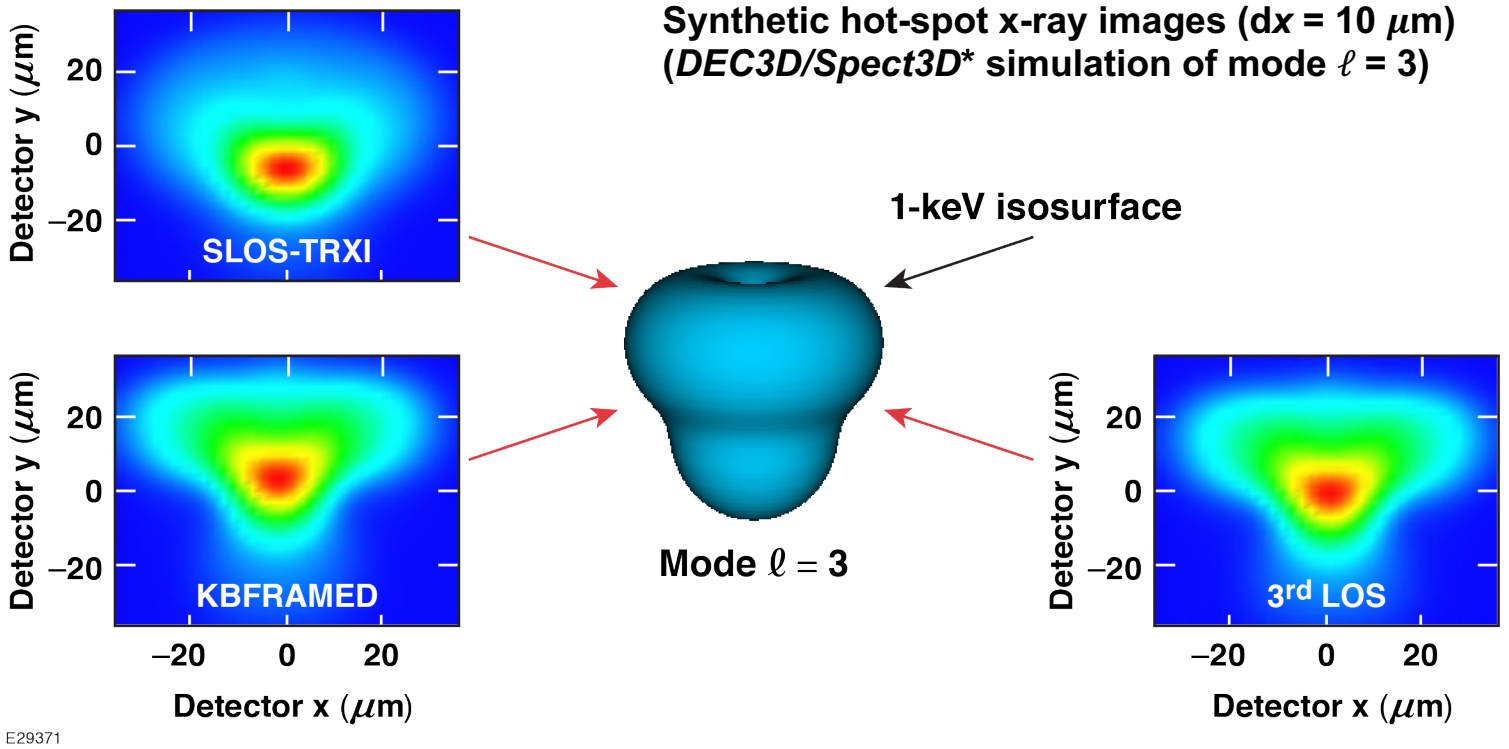




HV: high voltage

T. J. Hilsabeck *et al.*, Rev. Sci. Instrum. 81, 10E317 (2010);
K. Engelhorn *et al.*, Rev. Sci. Instrum. 89, 10G123 (2018).

The 3-D hot-spot x-ray imaging requirements are being developed based on 3-D radiation-hydrodynamic simulations



Preliminary requirements to resolve modes ℓ = 1 to 3 with 3-D view:

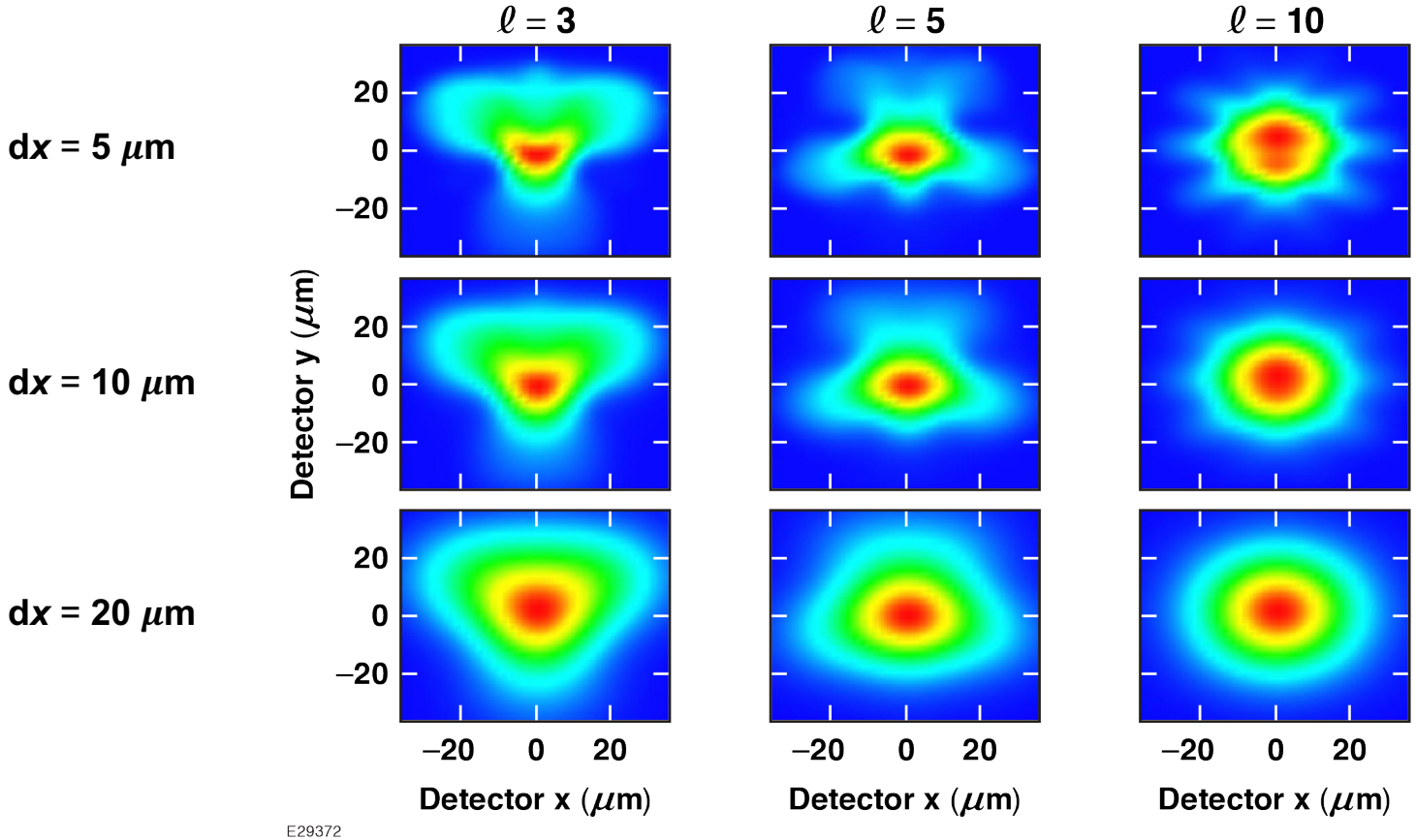
- **Spatial resolution of 5 to 10 μm (hot-spot diameter ~50 μm)**
- **Temporal resolution of 20 to 30 ps (burnwidth ~80 ps)**
- **≥3 diagnostic lines of sight with absolute reference frames**

Machine learning techniques will be applied in the 3-D data analysis.**

* K. M. Woo *et al.*, Phys. Plasmas 25, 052704 (2018);
Spect3D, Prism Computational Sciences Inc., Madison, WI 53711.
VisIt, Lawrence Livermore National Laboratory, Livermore, CA 94550.
J. Delettrez *et al.*, Phys. Rev. A 36, 3926 (1987).

** B. Zirps *et al.*, "A Platform to Infer the Dominant Mode from Experimental X-Ray Images Using the Deep-Learning Convolution Neural Network," to be submitted.

Images for the third line of sight were post-processed for various spatial resolutions and ℓ modes



A 5-μm spatial resolution is needed to resolve mode 10 with a single line of sight.

K. M. Woo *et al.*, Phys. Plasmas 25, 052704 (2018);
SPECT3D, Prism Computational Sciences Inc., Madison, WI 53711.

Summary/Conclusions

A 3-D view of the hot spot is crucial for understanding the evolution of the hot spot and the multidimensional effects that occur during ICF implosions

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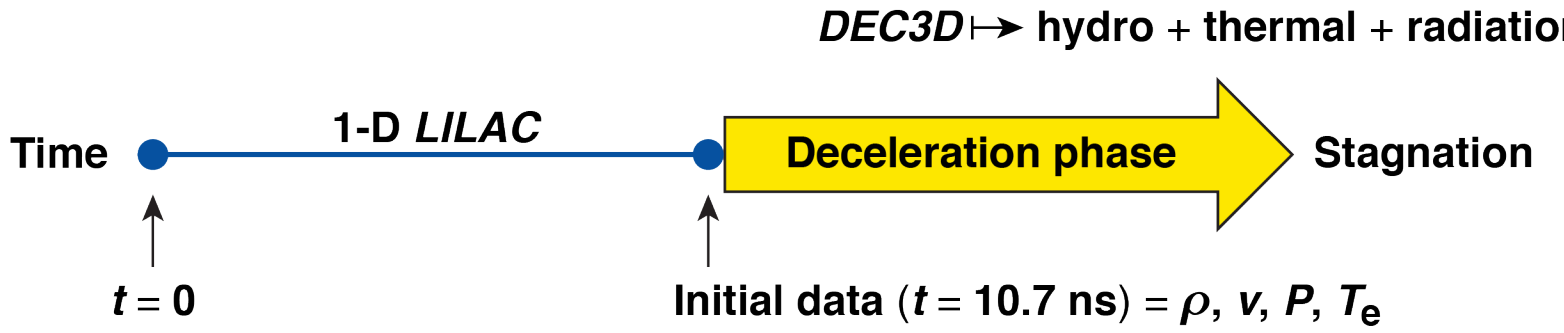
* F. J. Marshall *et al.*, Rev. Sci. Instrum. 88, 093702 (2017).
** W. Theobald *et al.*, Rev. Sci. Instrum. 89, 10G117 (2018).

Velocity perturbation is applied at the beginning of the deceleration phase to study the Rayleigh–Taylor (RT) instability

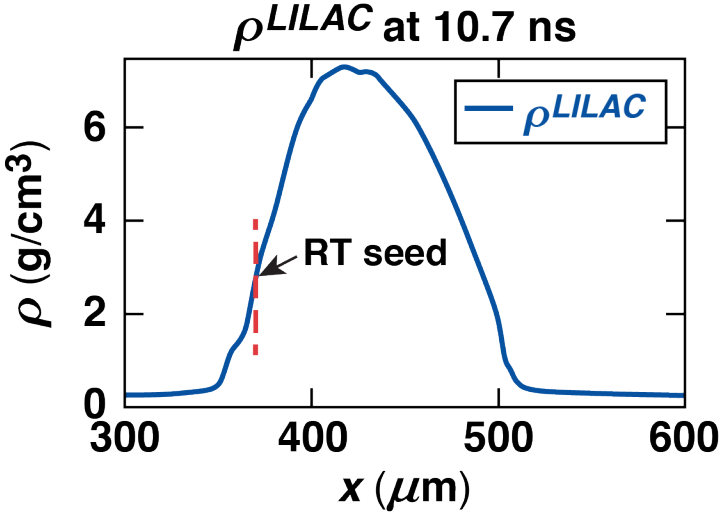


Initial velocity perturbations

$U_{3\text{-D}} = U_{1\text{-D}} + \Delta U Y_\ell^m(\theta, \varphi)$... single mode

$U_{3\text{-D}} = U_{1\text{-D}} + \sum_{\ell,m} \Delta U_{\ell m} Y_\ell^m(\theta + \theta_\ell, \varphi + \varphi_m)$ ... multimode

National Ignition Facility (NIF)-size target



TC12608a

K. M. Woo *et al.*, Phys. Plasmas 25, 052704 (2018).
K. M. Woo, 57th Annual Meeting of the American Physical Society Division of Plasma Physics,Savannah, GA (2015).