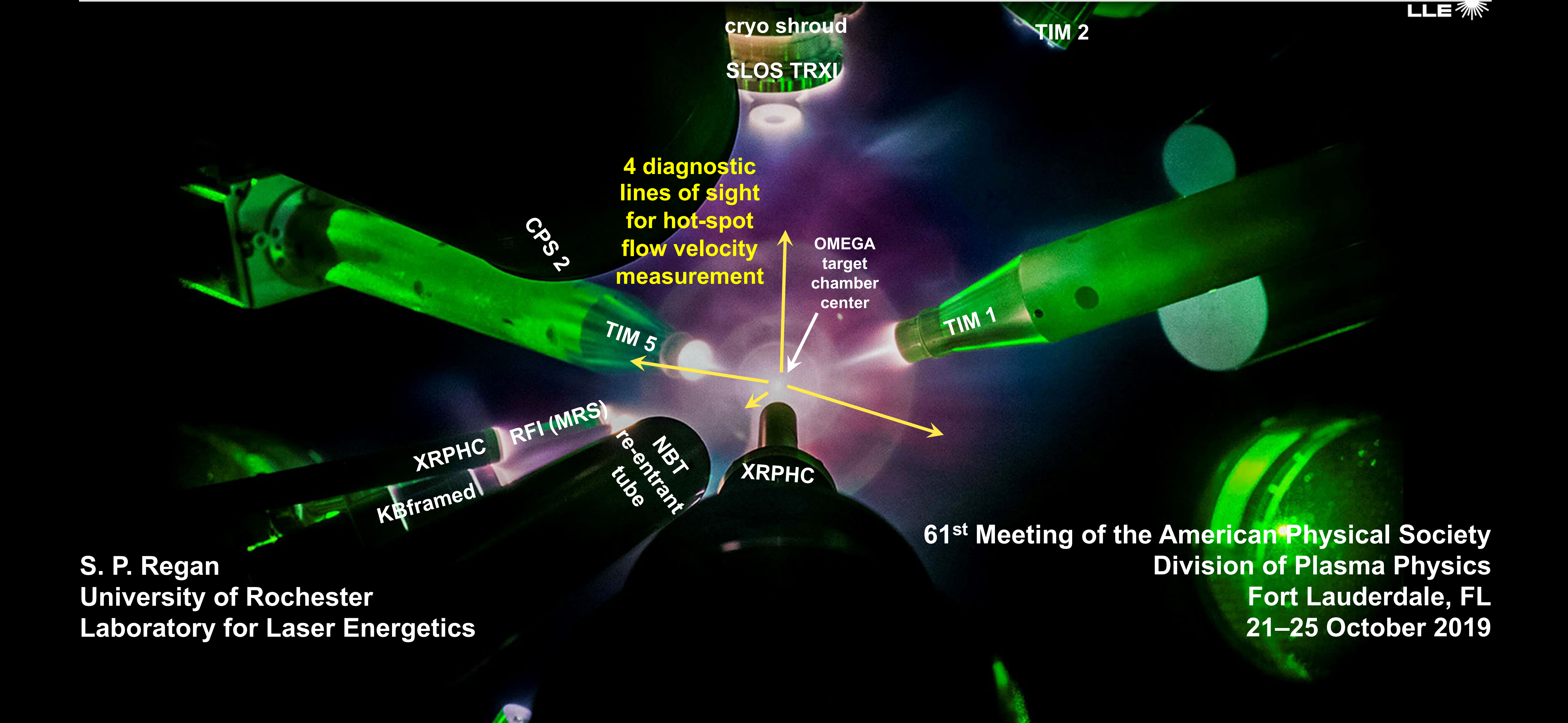
Hot-Spot Flow Velocity in Laser-Direct-Drive Inertial Confinement Fusion Implosions



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Division of Plasma Physics
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3-D nuclear and x-ray diagnostics are used on OMEGA to understand multidimensional effects on laser direct drive implosions

- The 1st and 2nd moments of the primary DT fusion neutron peak are diagnosed with four neutron time-of-flight detectors (3-D nToF)
- 3-D nToF measurements at stagnation indicate a hot-spot flow velocity of 50 to 150 km/s having an inverse relationship with neutron yield
- Comparison of 3-D hot-spot x-ray imaging* with 3-D nToF measurements reveals the hot-spot elongates along the hot-spot flow velocity direction

3-D x-ray and nuclear measurements are essential to diagnose the causes of performance limitations in inertial confinement fusion.

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S. Ivancic *et al.*, UO7.00004, this conference.

Collaborators

S. P. Regan, O. M. Mannion, C. J. Forrest, J. P. Knauer, R. Betti, E. M. Campbell, D. Cao, V. Yu. Glebov, V. N. Goncharov, S. T. Ivancic, F. J. Marshall, P. B. Radha, T. C. Sangster, R. C. Shah, C. Sorce, C. Stoeckl, and W. Theobald

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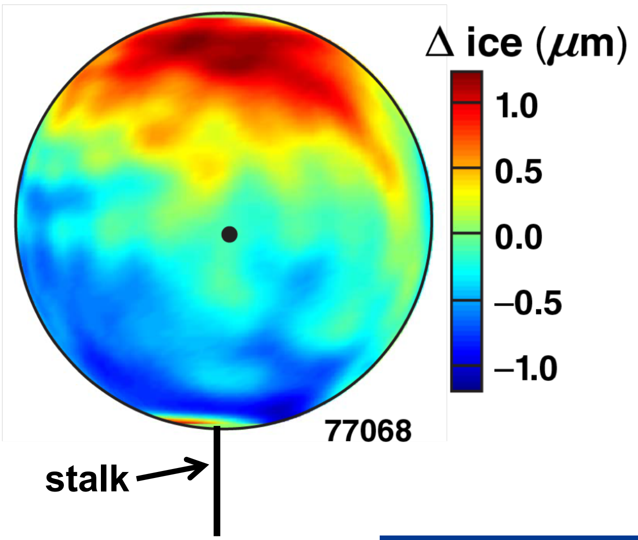
University of Rochester

Multidimensional effects are seeded by many sources of nonuniformity in laser direct drive

Target uniformity, Engineering features (e.g., target stalk)

Ice-shell thickness variation (cryo)



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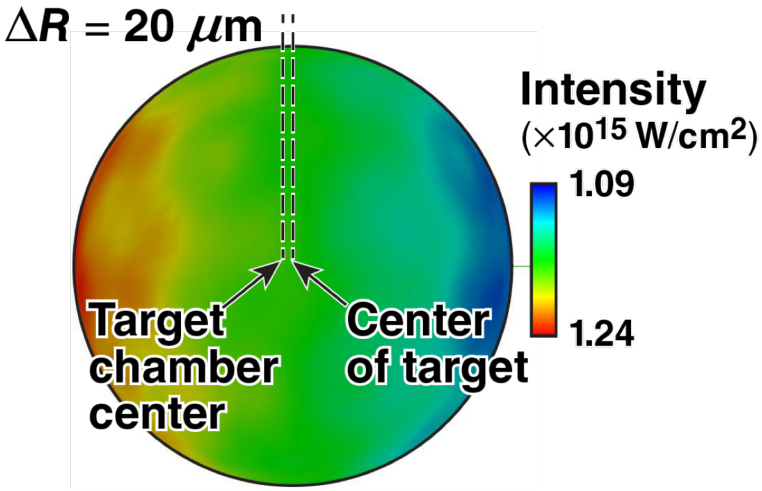
Target positioning



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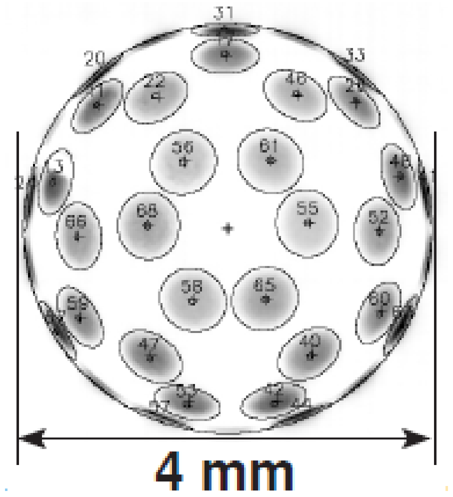
Beam pointing, geometry, timing, laser power

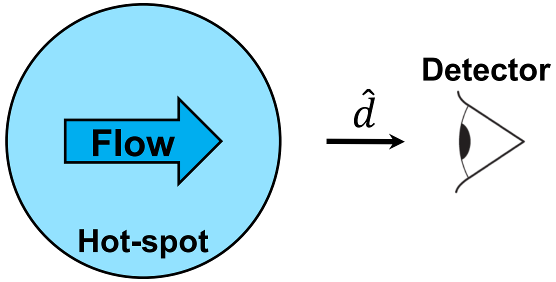


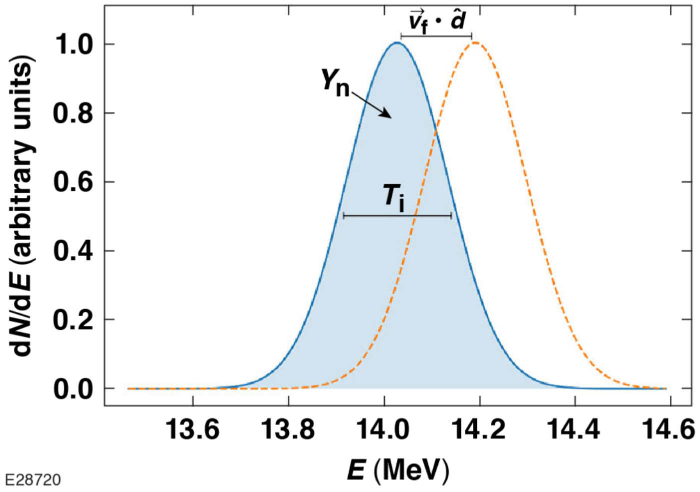
The on-target, laser drive is adjusted by changing initial target position to counteract the measured hot-spot flow velocity.

Asymmetric compression drives a hot-spot flow affecting the 1st and 2nd moments of the primary DT fusion neutrons*

1st moment

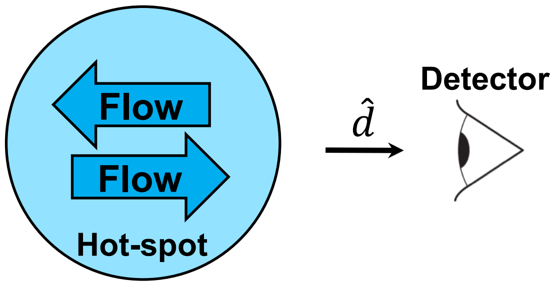
(Hot-spot flow velocity)

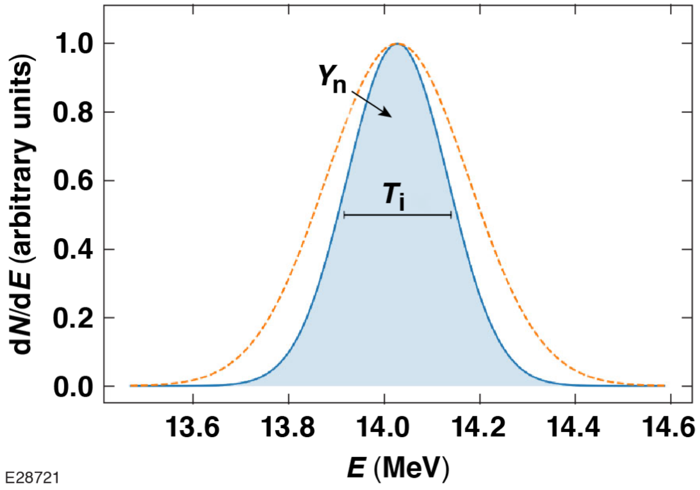




2nd moment

(Inferred T_i)

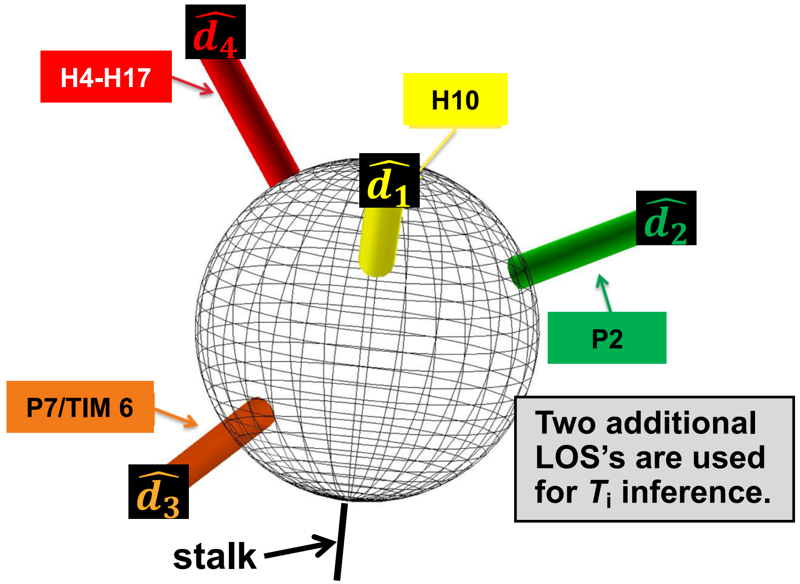




*B. Appelbe and J. Chittenden, Plasma Phys. Control. Fusion 53, 045002 (2011);
D. H. Munro, Nucl. Fusion 56, 036001 (2016).

Six neutron time-of-flight detectors are used on OMEGA to infer hot-spot flow velocity and apparent T_i asymmetry*

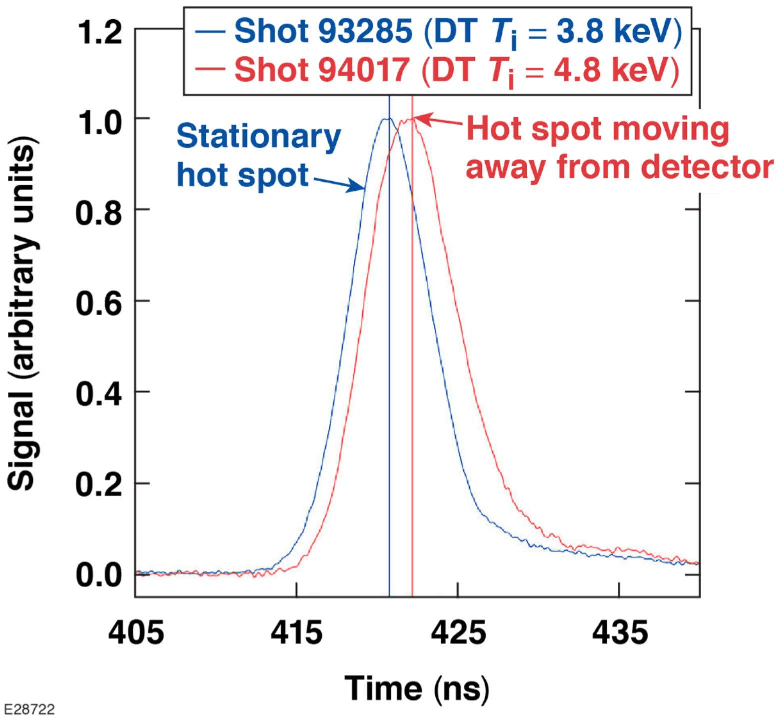
nTOF detectors positioned along four axes



$$\langle E_1 \rangle = E_0 + \Delta E_{th}(T_i) + \Delta E_f(\vec{v}_f \cdot \hat{d}_1)$$

with *i* = 1, 2, 3, 4

H10 nTOF example measurements of DT neutrons



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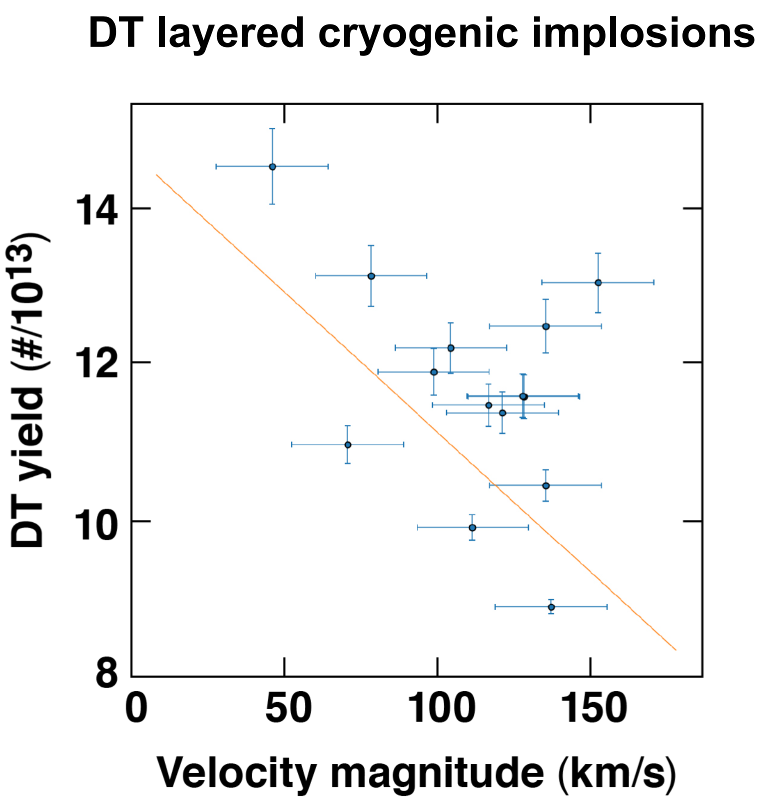
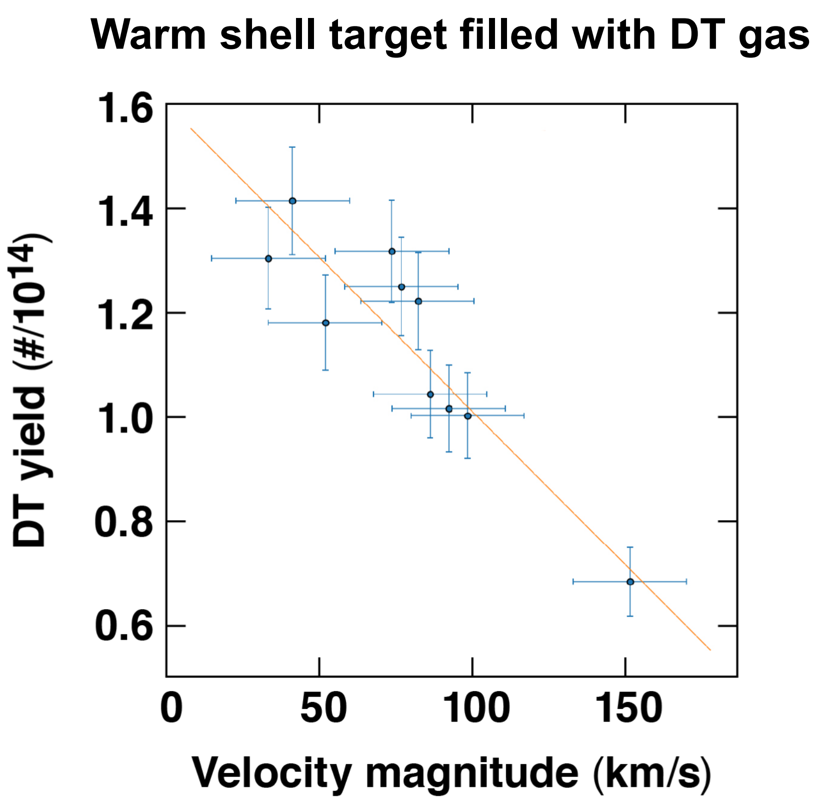
The hot-spot center of mass flow velocity is determined from the four measurements.

LOS: line of sight

*O. M. Mannion *et al.*, "A Suite of Neutron Time-of-Flight Detectors for Measurements of Hot Spot Motion in Direct Drive Inertial Confinement Fusion Experiments on OMEGA," to be submitted to Nuclear Instruments and Methods.

Neutron yield increases as the hot-spot flow decreases





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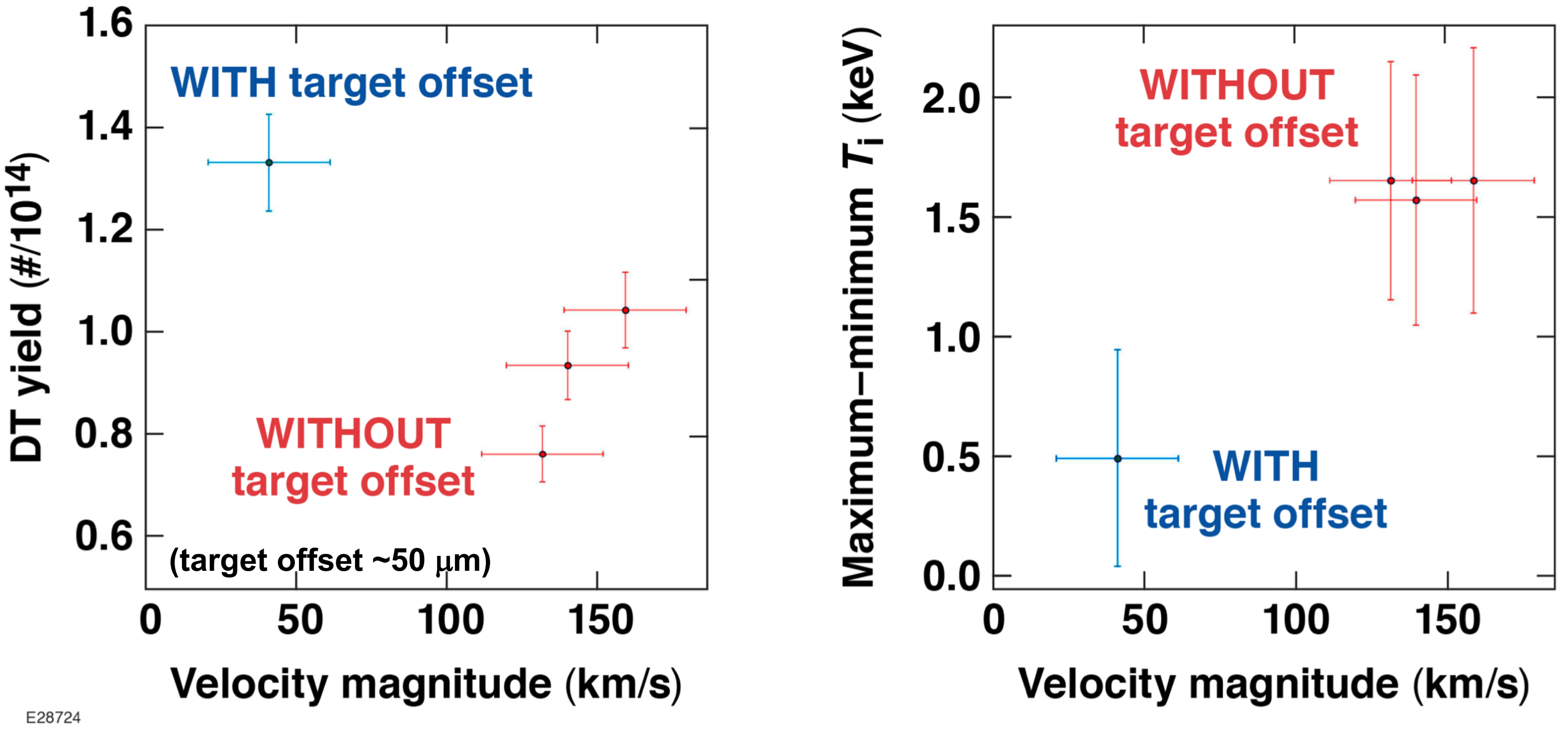
The direction of hot-spot flow is fairly constant during a shot day, but varies from one shot day to another.

Counteracting hot-spot flow velocity by imposing an $\ell = 1$ drive asymmetry with an initial target offset improves target performance at stagnation

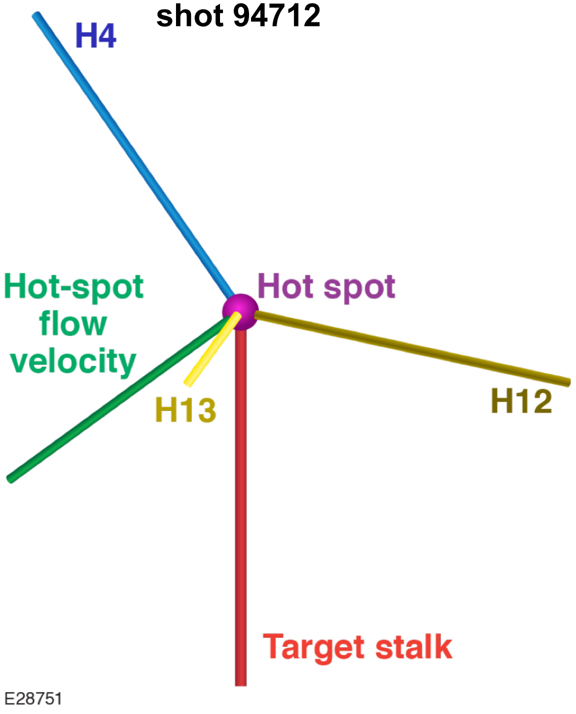
UR LLE



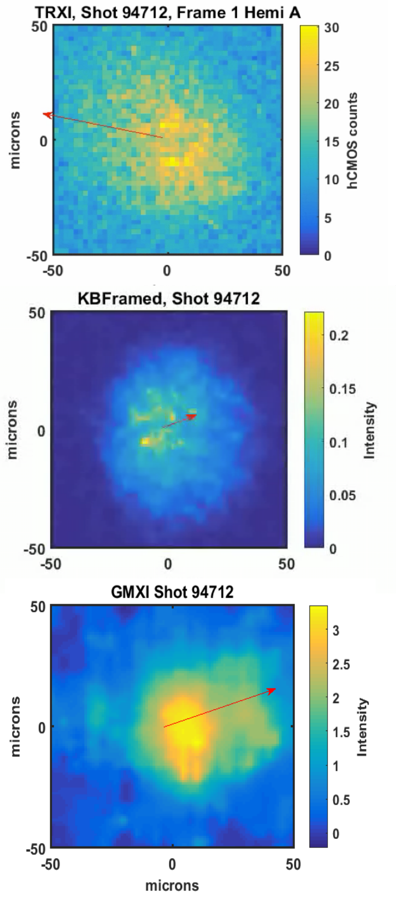
Three-dimensional measurements provide insight to improve implosion symmetry.

Comparison of 3-D hot-spot imaging with 3-D nuclear measurements of hot-spot flow reveals the hot-spot elongates along flow direction

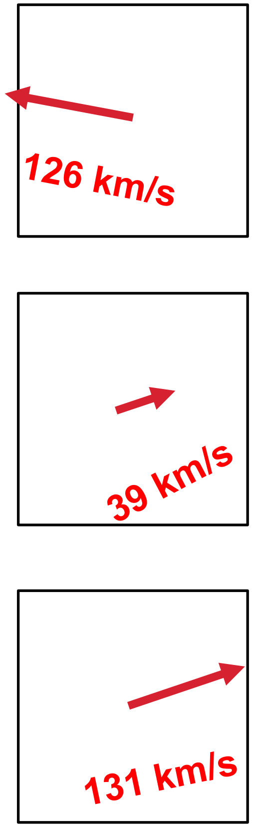
Diagnostic/target orientation
shot 94712



WITHOUT target offset
shot 94712



Flow direction in field of view



H4 view
time-resolved
pinhole imager*

H13 view
time-resolved
Kirkpatrick-Baez (KB)
microscope**

H12 view
time-integrated
KB microscope†

<u>3-D x-ray imaging of hot spot</u>
Spectral range: 4 keV ≤ $h\nu$ ≤ 8 keV
Spatial resolution: 6 to 10 μm
Temporal resolution: 20 to 40 ps

* W. Theobald *et al*., Rev. Sci. Instrum. <u>89</u> 10G117 (2018).
** F. J. Marshall *et al*., Rev. Sci. Instrum. <u>88</u>, 093702 (2017).
† F. J. Marshall and J. A. Oertel, Rev. Sci. Instrum. <u>68</u>, 735 (1997).

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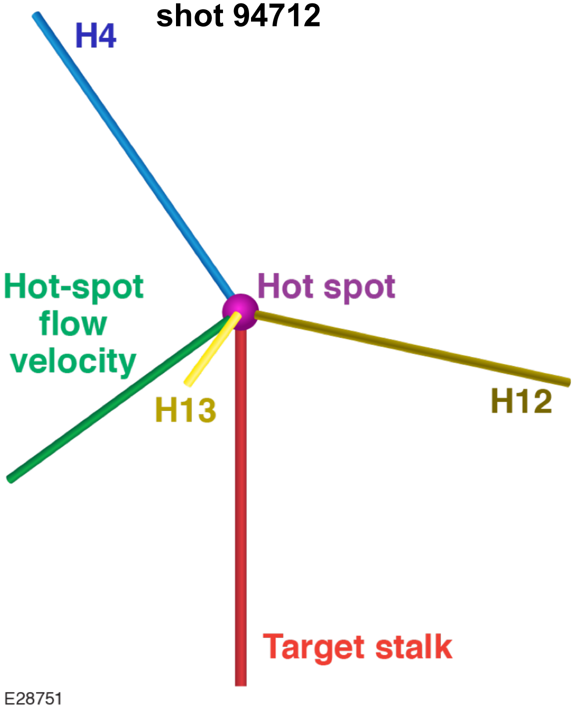
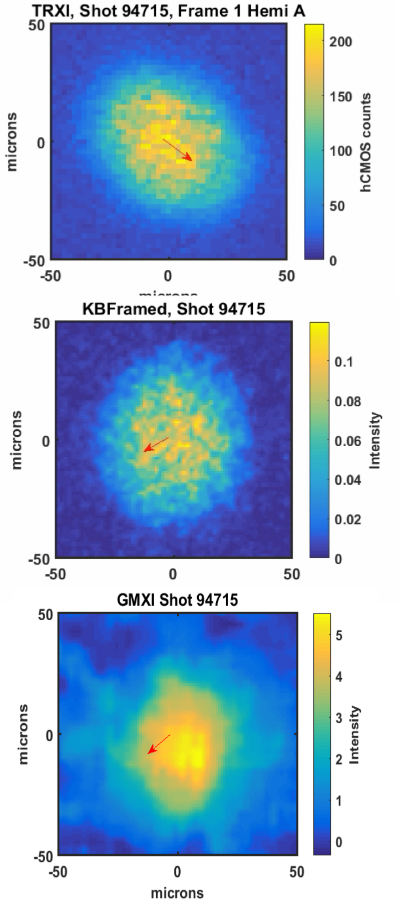
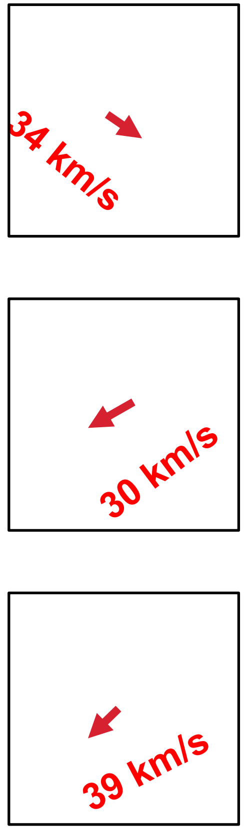
Diagnostic/target orientation
shot 94712



WITH target offset (~50 μm)
shot 94715



Flow direction in field of view



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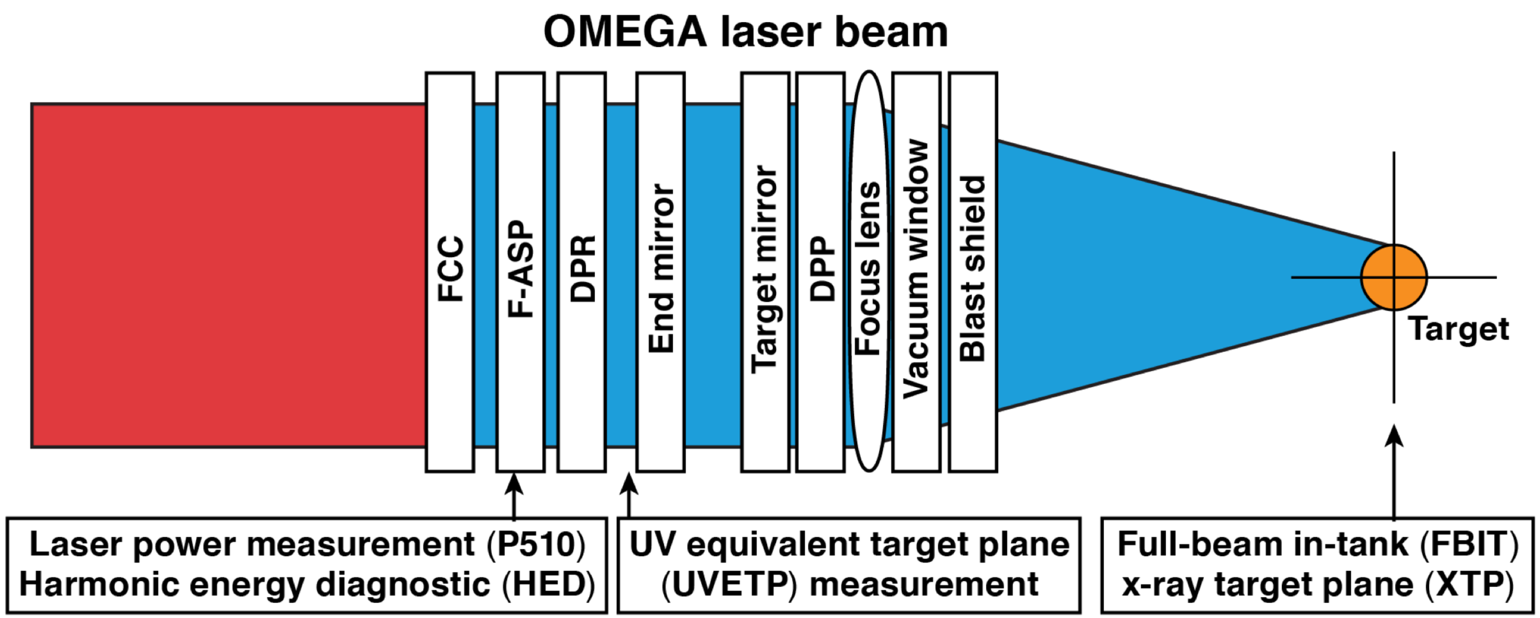
Diagnostics are being developed to measure laser drive on target

On-target, laser drive



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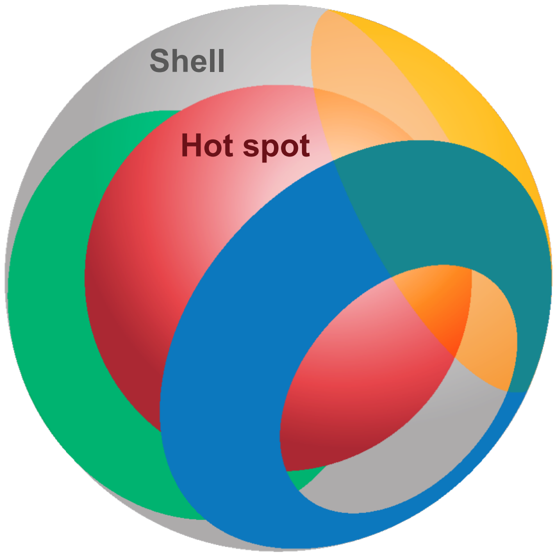
As a tool to improve the implosion symmetry, the target positioning is adjusted to compensate sources of nonuniformity.

FCC: frequency-conversion crystal
F-ASP: stage-F alignment sensor package
DPR: distributed polarization rotators
DPP: distributed phase plates

Counteracting hot-spot flow velocity by imposing an $\ell = 1$ drive asymmetry alters the spatial variation in the compressed areal density (ρR)

ρR coverage
[1st and 2nd shielded and collimated nTOF LOS's and Magnetic Recoil Spectrometer (MRS)]



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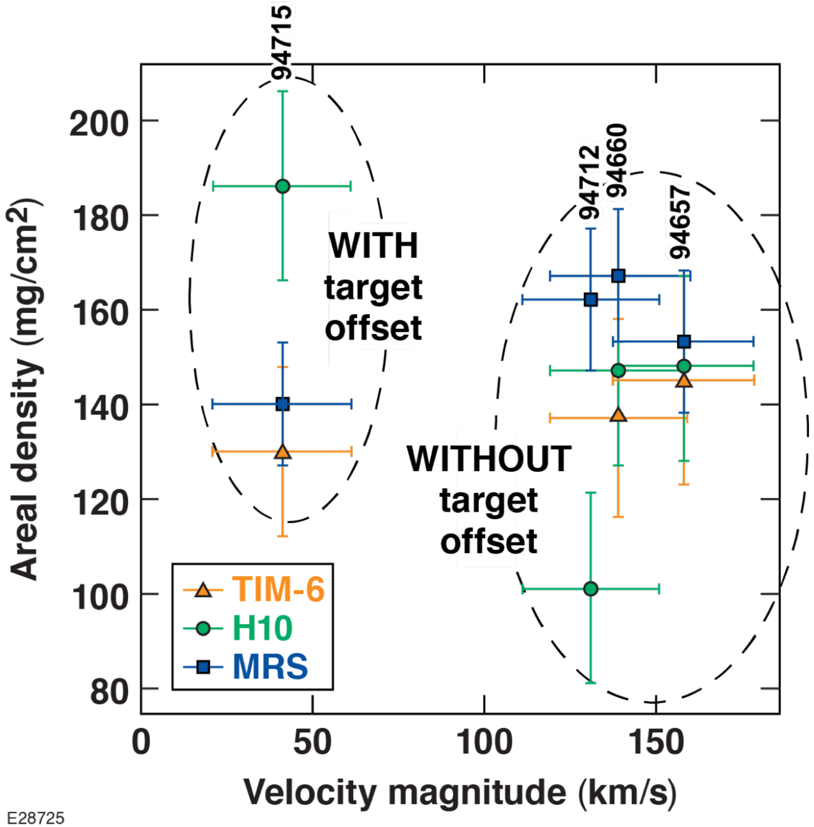

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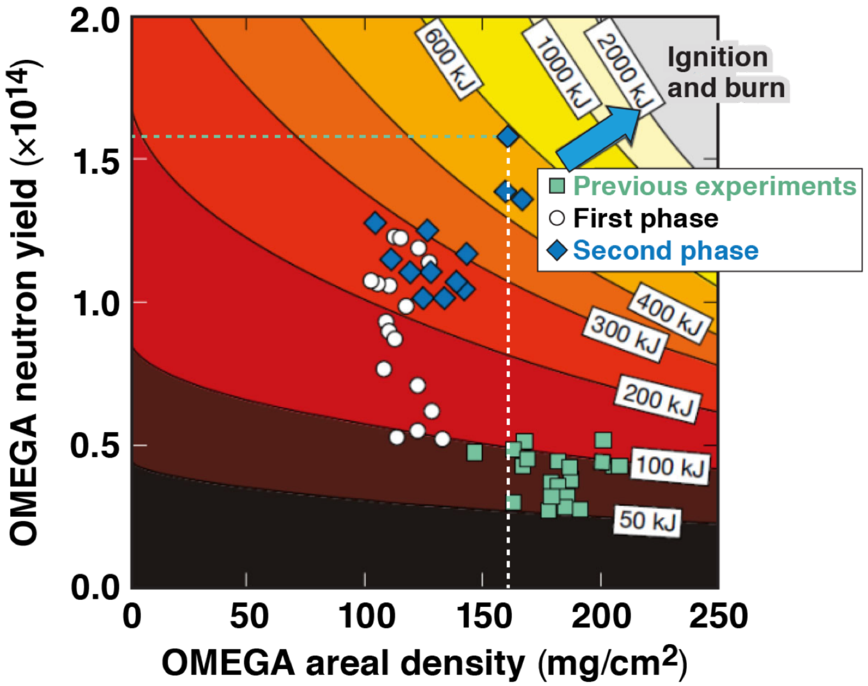
3-D diagnostics for hot spot and compressed shell are essential.

TIM: ten-inch manipulator

The best-performing implosion on OMEGA achieved an energy-scaled $(\chi_{\text{no }\alpha})_{\text{scaled}}$ = 0.74*

Metric	Shot 90288	Near-term goal
Yield	$1.6\pm0.04 \times 10^{14}$	1.5×10^{14}
$\langle T_i \rangle$ (keV)	4.55±0.3	4.5
$\langle \rho R \rangle$ (mg/cm²)	160±12	190 to 200
$\chi_\Omega = \rho R^{0.61} (0.12 Y_{16}/M_{stag})^{0.34}$	0.174 to 0.18	0.19 to 0.20
Energy scaled $(\chi_{\text{no }\alpha})_{\text{scaled}}$	0.74	0.8 to 0.85
$\langle P \rangle_{BT}$ (Gbar)	52.7±7	60 to 70

Constant fusion yield curves for 1.9 MJ of laser energy



E28712

* Scaled to E_{UV} = 1.9 MJ; V. Gopalaswamy *et al*., Nature 565, 581 (2019).