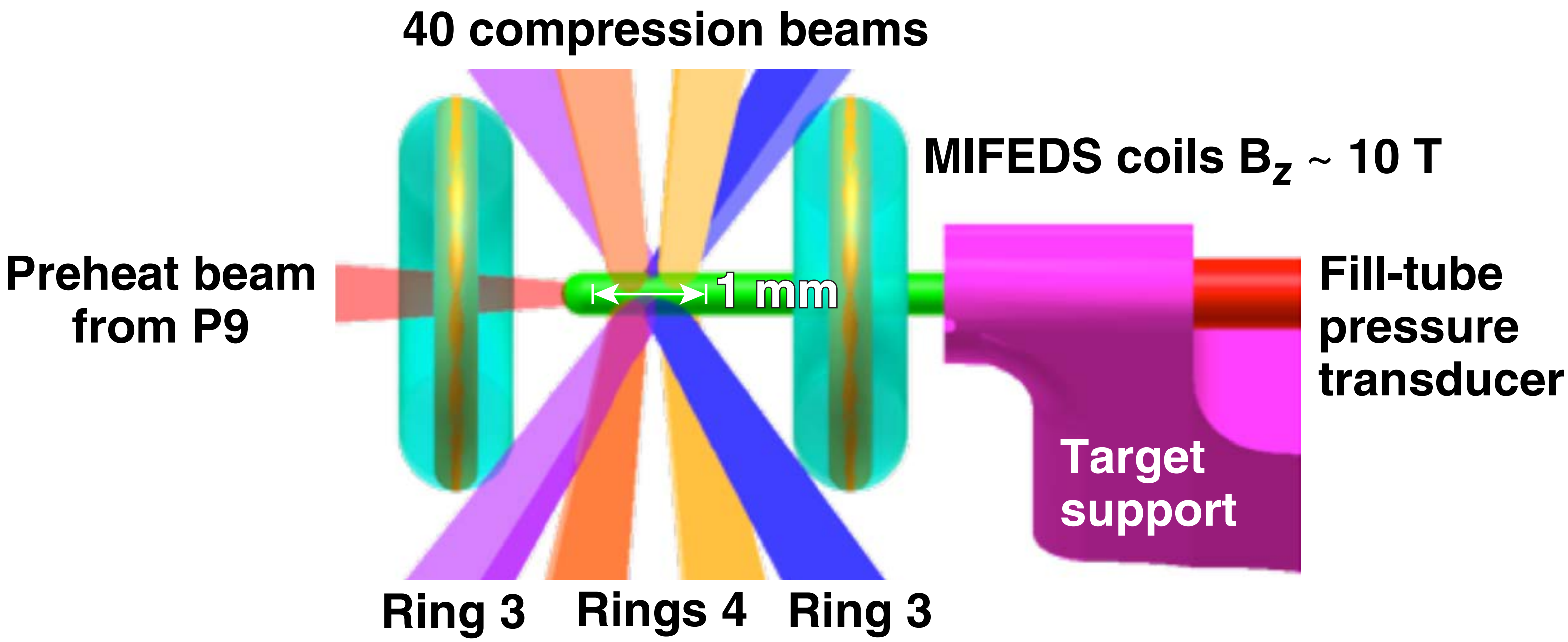
An Overview of Laser-Driven Magnetized Liner Inertial Fusion on OMEGA



J. R. Davies
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Omega Laser Facility
Users Group Workshop
Rochester, NY
27–29 April 2016

Summary

Laser-driven magnetized liner inertial fusion (MagLIF) is being developed on OMEGA to study MagLIF scaling

- **An energy-scaled point design for laser-driven MagLIF on OMEGA has been developed that is 10× smaller in linear dimensions than Z targets***
- **The key elements of preheating to >100 eV and uniform cylindrical compression at ~100 km/s have been demonstrated in experiments**
- **A 3ω beam from P9 using Beam 35 is being implemented for preheating**
- **The first integrated laser-driven MagLIF experiment is scheduled for 19 July 2016**

*S. A. Slutz *et al*., Phys. Plasmas 17, 056303 (2010);
M. R. Gomez *et al*., Phys. Rev. Lett. 113, 155003 (2014);
P. F. Schmit *et al*., Phys. Rev. Lett. 113, 155004 (2014).

Collaborators

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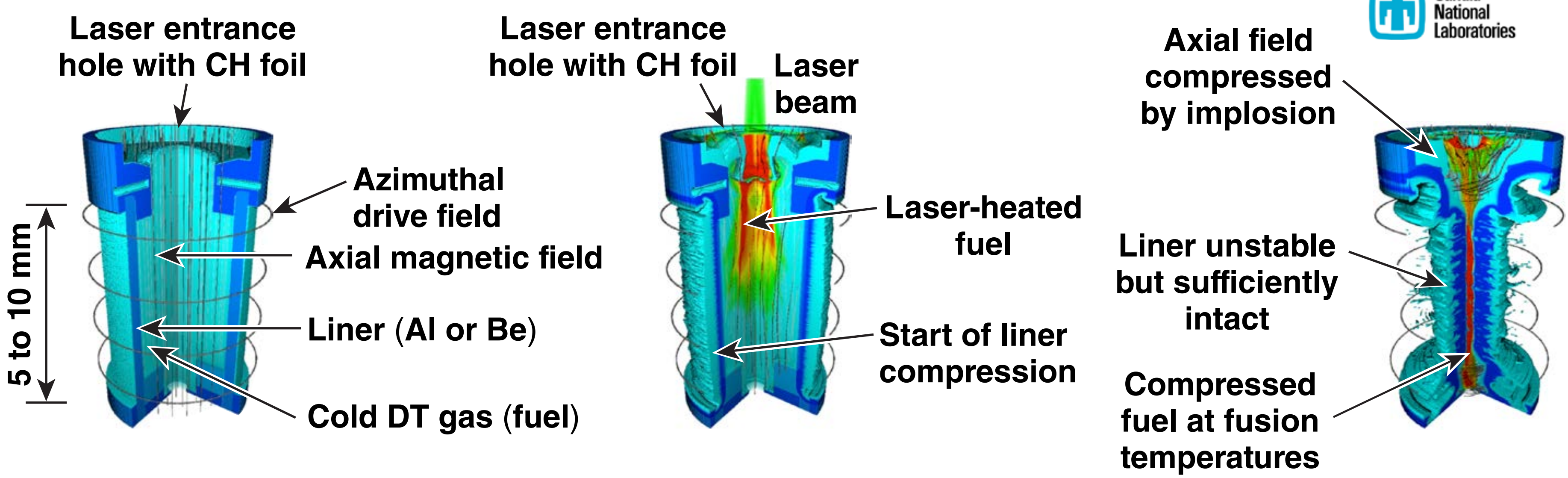
MagLIF is an inertial confinement fusion (ICF) scheme using magnetized preheated fuel to allow for cylindrical implosions with lower velocities and lower convergence ratios than conventional ICF*

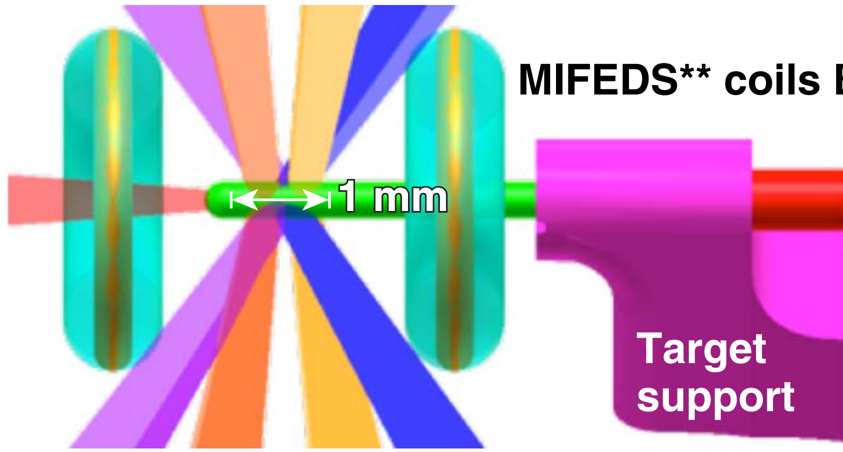


- An axial magnetic field lowers electron thermal conductivity, allowing for a near-adiabatic compression at lower implosion velocities and confines alpha particles, allowing for a lower areal density
- Laser preheating to ~100 eV makes it possible for >1 keV to be reached at a convergence ratio <30

I2185c

*S. A. Slutz *et al*., Phys. Plasmas 17, 056303 (2010).

A point design for laser-driven MagLIF on OMEGA has been developed by scaling down the Z point design* by a factor of 1000 in drive energy



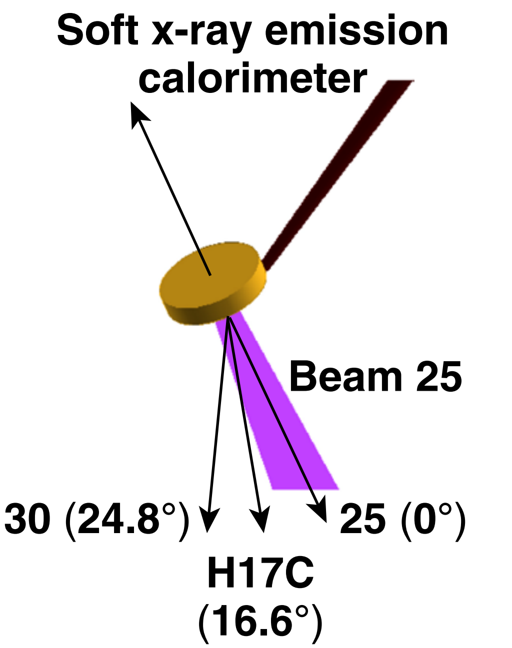
	r (mm)	Δr (mm)	$r/\Delta r$	ρ_{fuel} (mg/cm^3)	B_0 (T)	T_0 (eV)	V_{imp} (km/s)	Convergence ratio	T_{max} (keV)
Z	3.48	0.58	6	3 (DT)	30	250	70	25	8.0
OMEGA	0.30	0.03	10	2.4 (D_2)	10	200	154	26	2.9

*S. A. Slutz *et al.*, Phys. Plasmas 17, 056303 (2010).
**MIFEDS: magneto-inertial fusion electrical discharge system

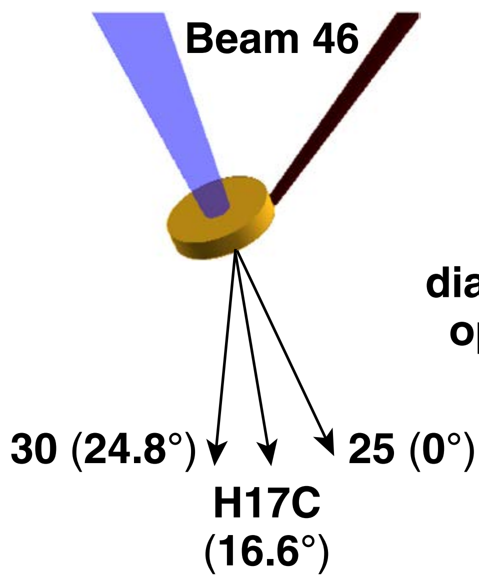
TC12449a

The first two shot days were supported by the Laboratory Basic Science (LBS) Program and Sandia National Laboratories (SNL)

Laser entrance foil-only targets (1.84-μm polyimide)

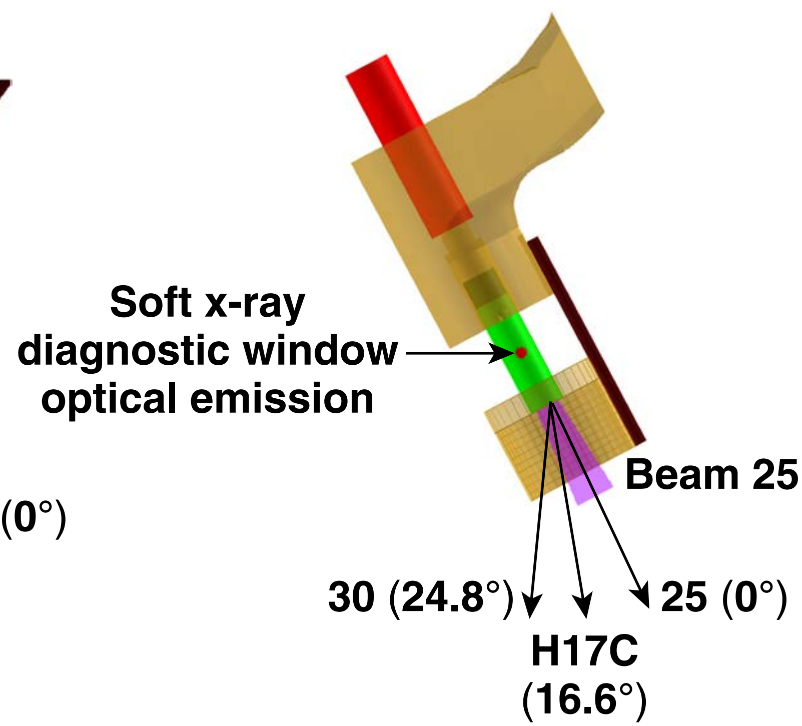


Time-resolved spectra



Time-resolved spectra
Soft x-ray emission

Full targets



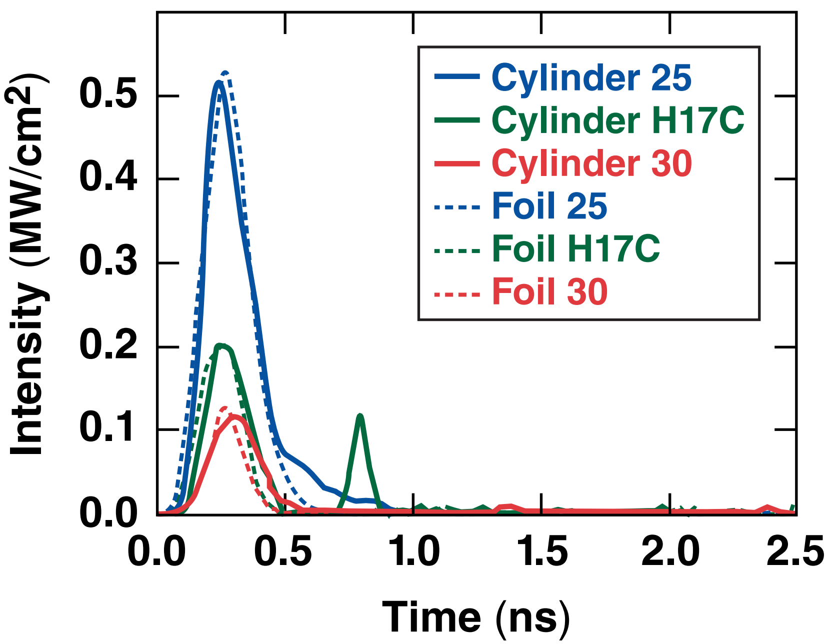
Time-resolved spectra
Soft x-ray emission

Empty cylinders were used for compression-only shots

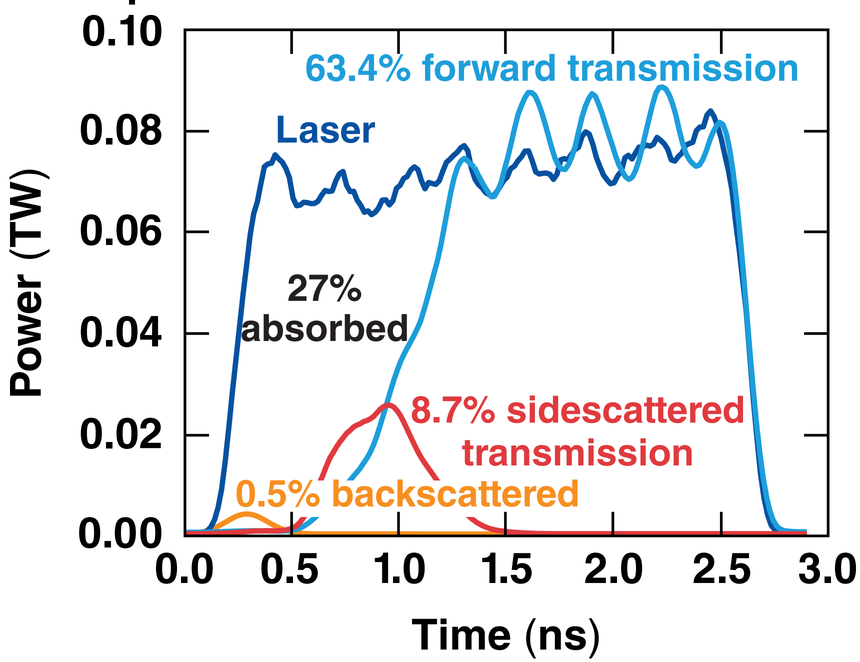
TC12451a

Foil transmission exceeds 50% with no backscatter from the gas and less than 10% sidescatter of transmitted light

Backscattered intensities measured for a full target and a foil



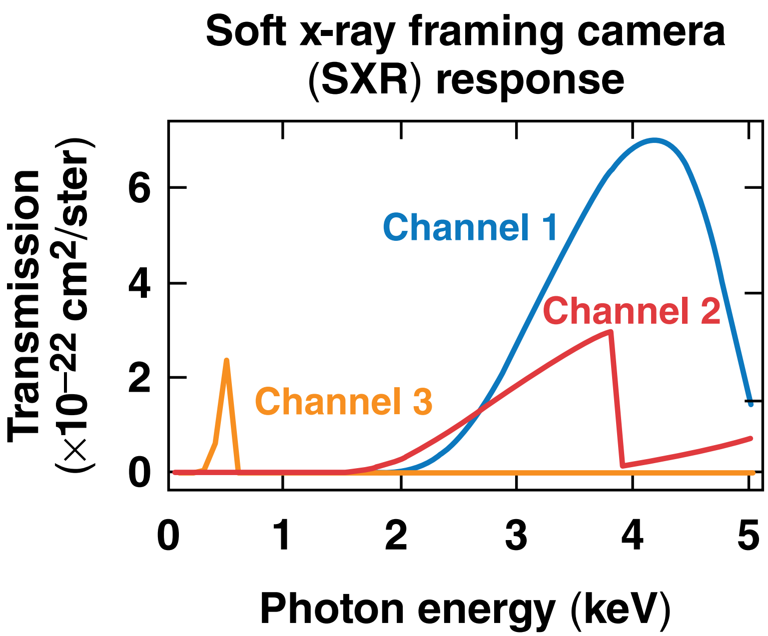
Total transmitted and backscattered powers calculated from two foil shots

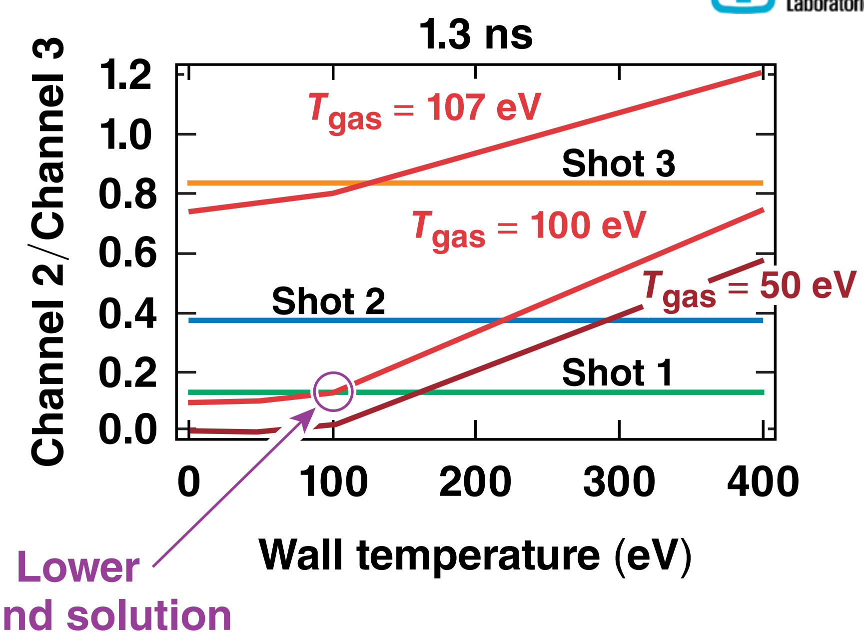


Backscatter from foils and from full targets are very similar and contain a negligible amount of the laser energy.

TC12456a

Three-channel soft x-ray imaging of the side window shows a gas temperature of >100 eV



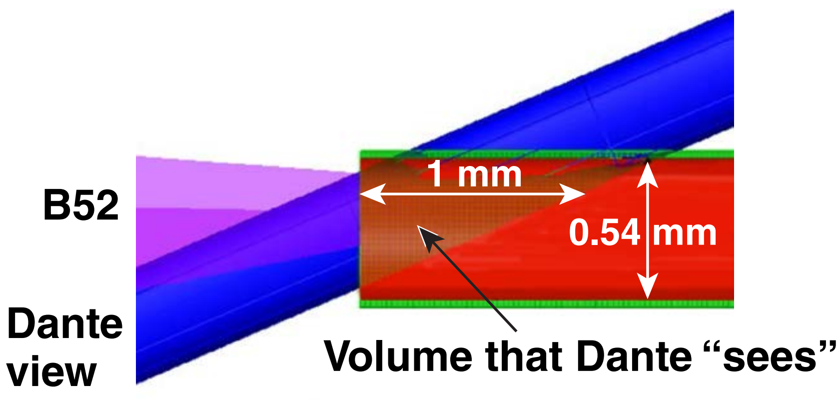


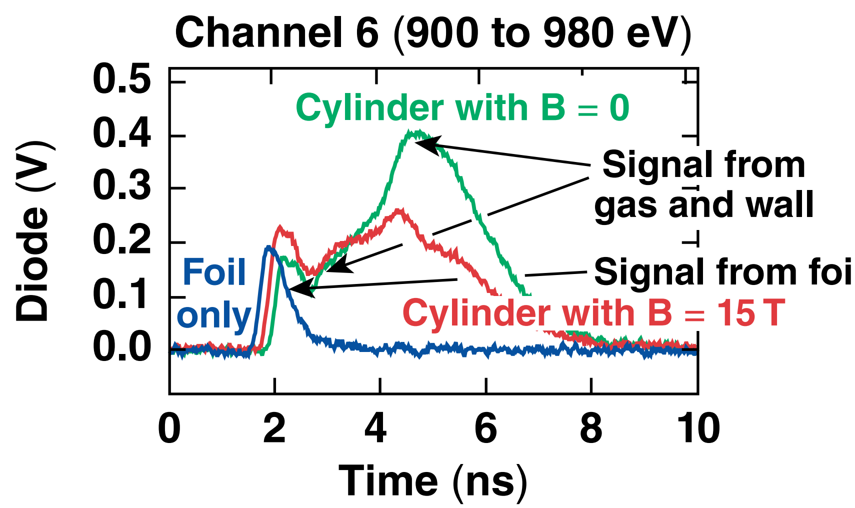
- SXR is not absolutely calibrated so it gives two channel ratios
- Used *Spect3D* to generate channel ratios for a range of gas and wall temperatures and densities (assumed uniform): four free parameters to fit the 2 channel ratios
- With the constraint $T_{gas} > T_{wall}$, one can determine $T_{gas} > 100$ eV

According to 1-D models there is a preheat threshold of 100 eV.

TC12574a

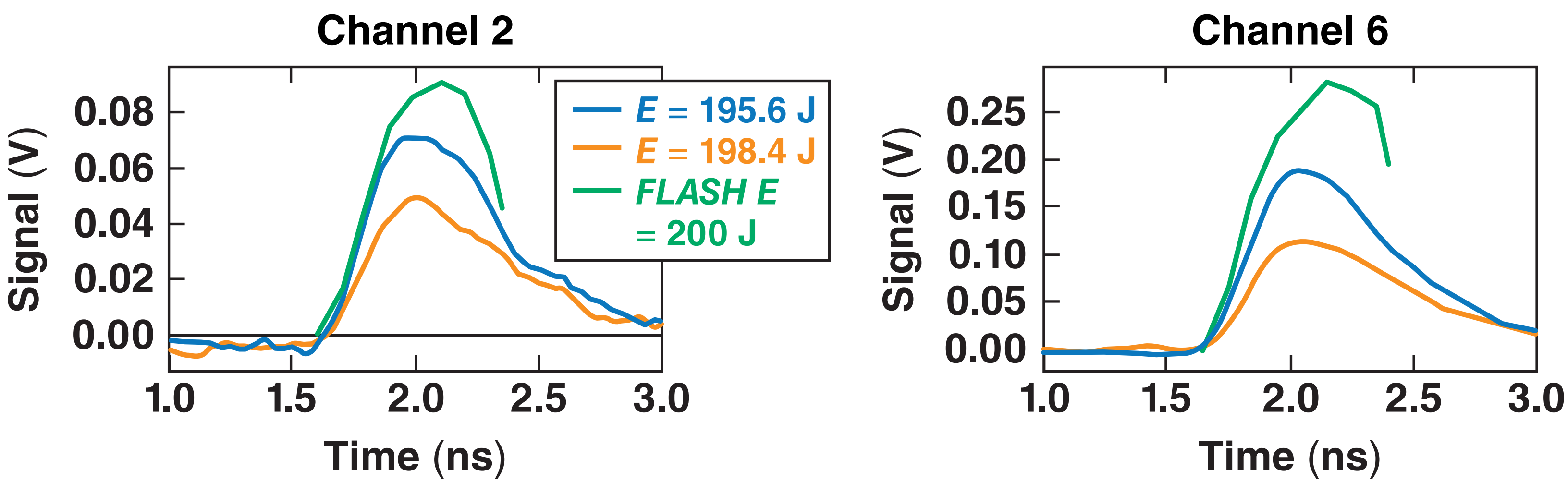
X-ray emission recorded by Dante shows window, gas, and wall heating





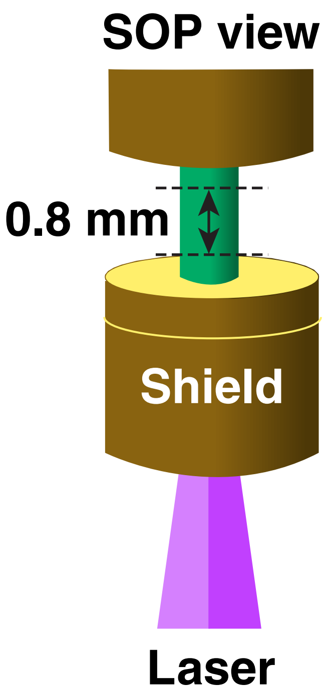
TC12575a

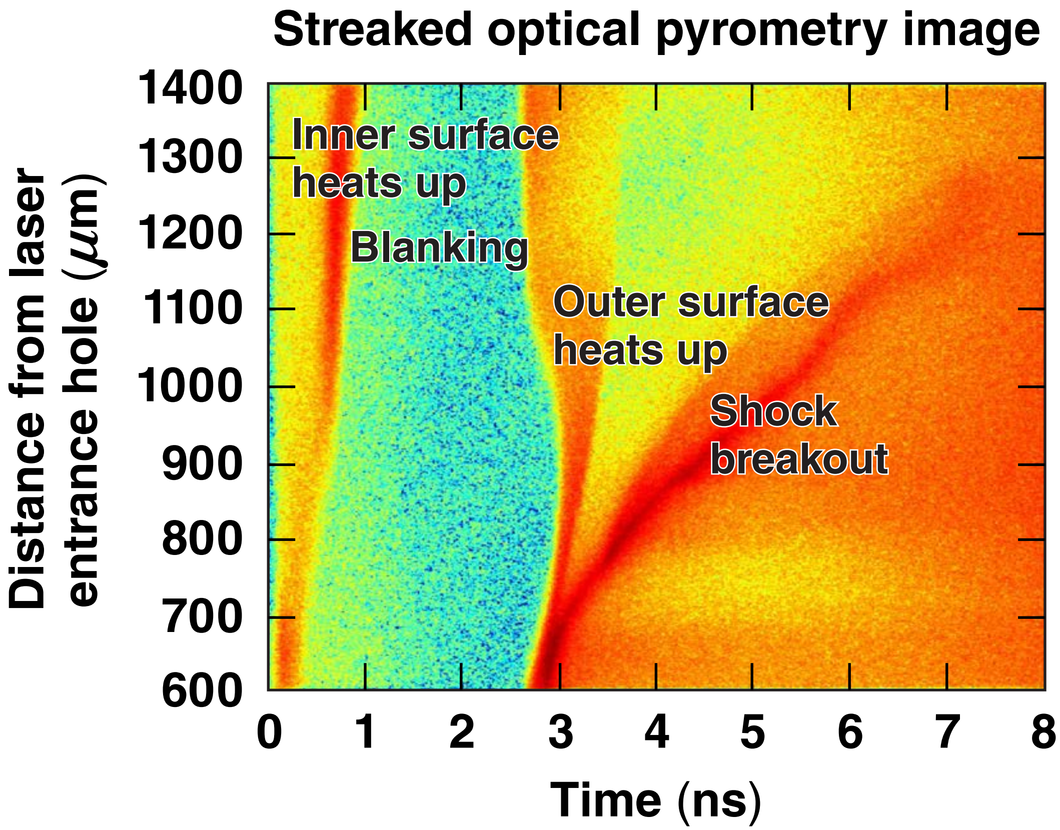
Two-dimensional hydrocode predictions are in reasonable agreement with Dante measurements



TC12575b

Streaked optical pyrometry (SOP) of the cylinder surface demonstrates energy coupling to the central 0.8 mm





E24973

The implosion of empty cylinders with rings 3 and 4 was measured separately using x-ray framing cameras

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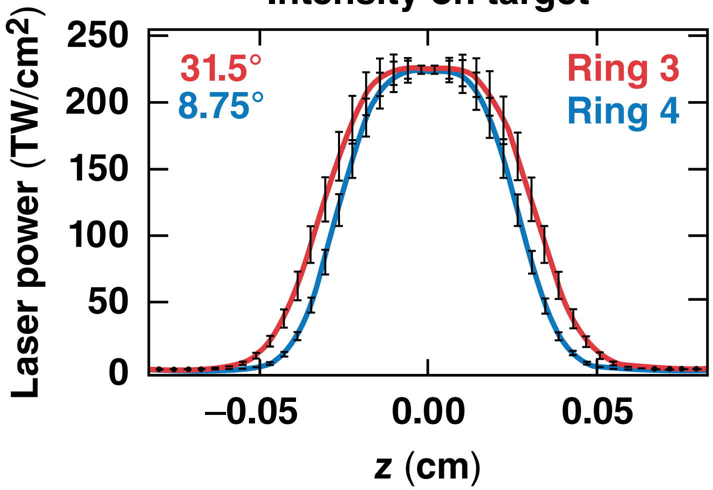
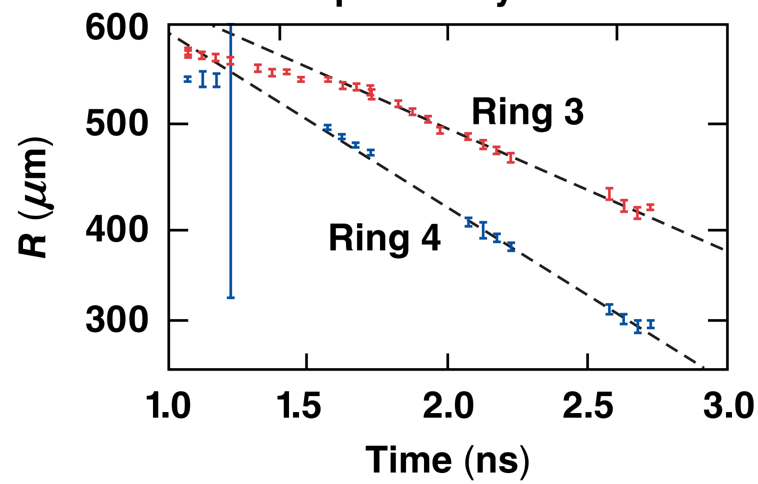
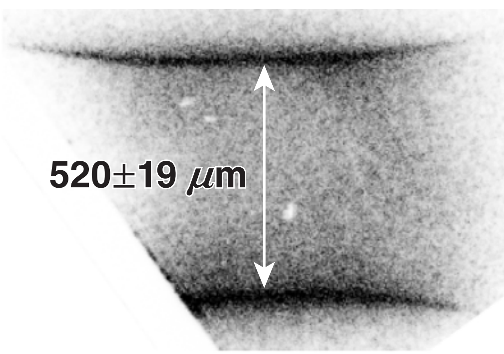
Intensity on target



Position of peak x-ray self-emission



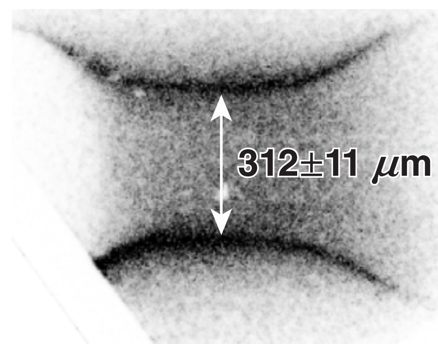
Ring 3 only



t = 2.55 ns
(end of laser pulse)

V_{ring3} = 124.3±4.0 km/s
V_{ring3} = 178.1±1.2 km/s

Ring 4 only



Overlap rings 3 at center and drive the ends with rings 4

E24974

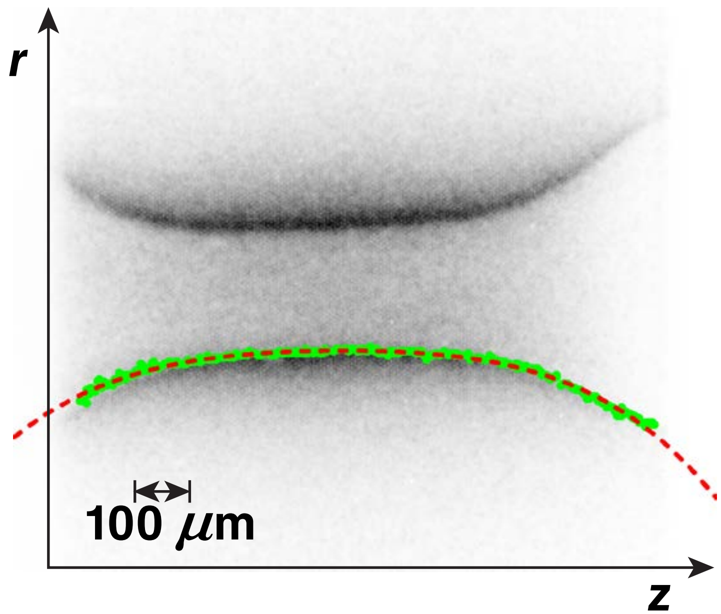
A nine-shot day program is now being suported by the Advanced Research Projects Agency-Energy (ARPA-E)

1. Optimize ring-3 and ring-4 energy balance without preheat (1 Sept 15)
2. Complete optimization of ring-3 and ring-4 drive and reduce shell thickness without preheat (24 Nov 15)
3. Optimize preheat timing and vary preheat energy (19 July 16)
4. Complete B/no-B and preheat level dataset (22 Sept 16)
5. Measure axial B-field evolution 1: proton probing with D^3He backlighter using H_2 fill to avoid proton production from target
6. Axial B-field evolution 2: use OMEGA EP if D^3He is unsuccessful or extend dataset
7. Complete initial B-field scan including a higher value, if possible, with two MIFEDS and/or transformer coils (under development) with preheat
8. Fill-density and shell-thickness scans with B and preheat
9. Contingency: fill in missing data, address unforeseen issues, or extend dataset

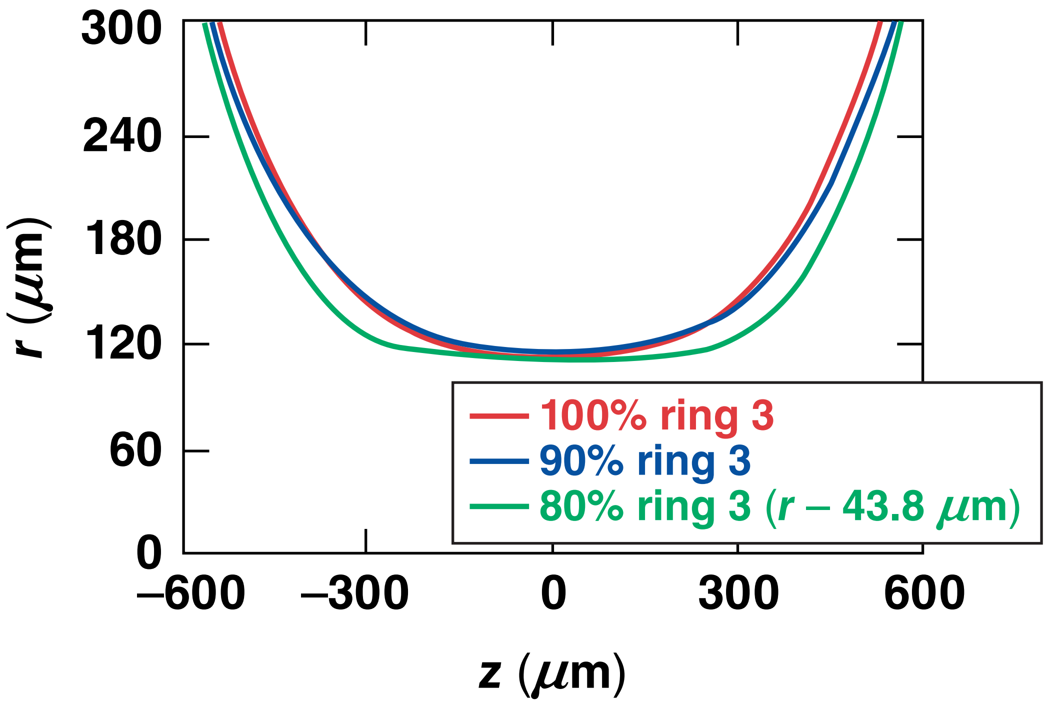
E24975

Compression-only shots have shown that axial uniformity can be controlled by beam balance and a 0.7-mm-long region can be compressed at >100 km/s

Sample x-ray framing camera (XRFC)



Radius (μm) of peak x-ray self-emission at 2.55 ns (end of laser pulse)

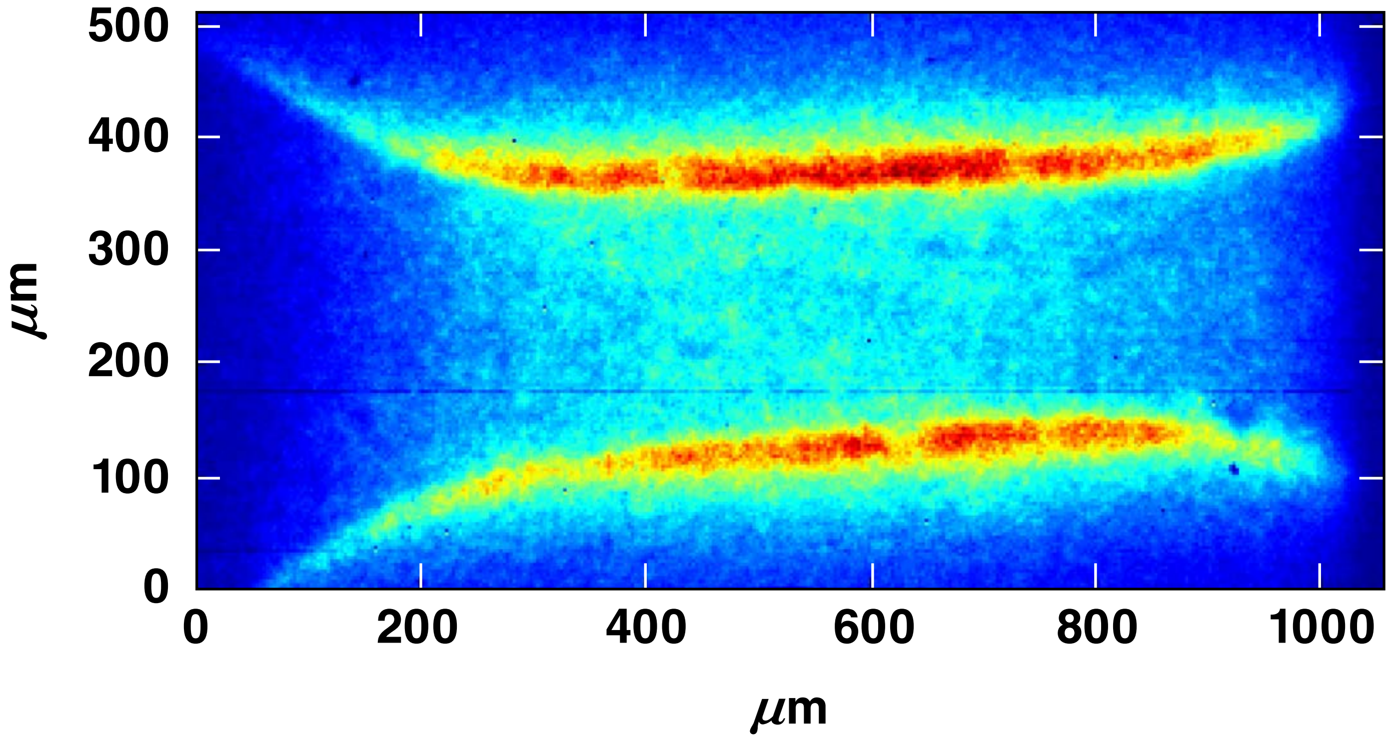


40-μm-thick shells with 12 kJ in 2.5 ns

TC12532a

Hot-core formation and expansion have been observed with side-on x-ray framing cameras

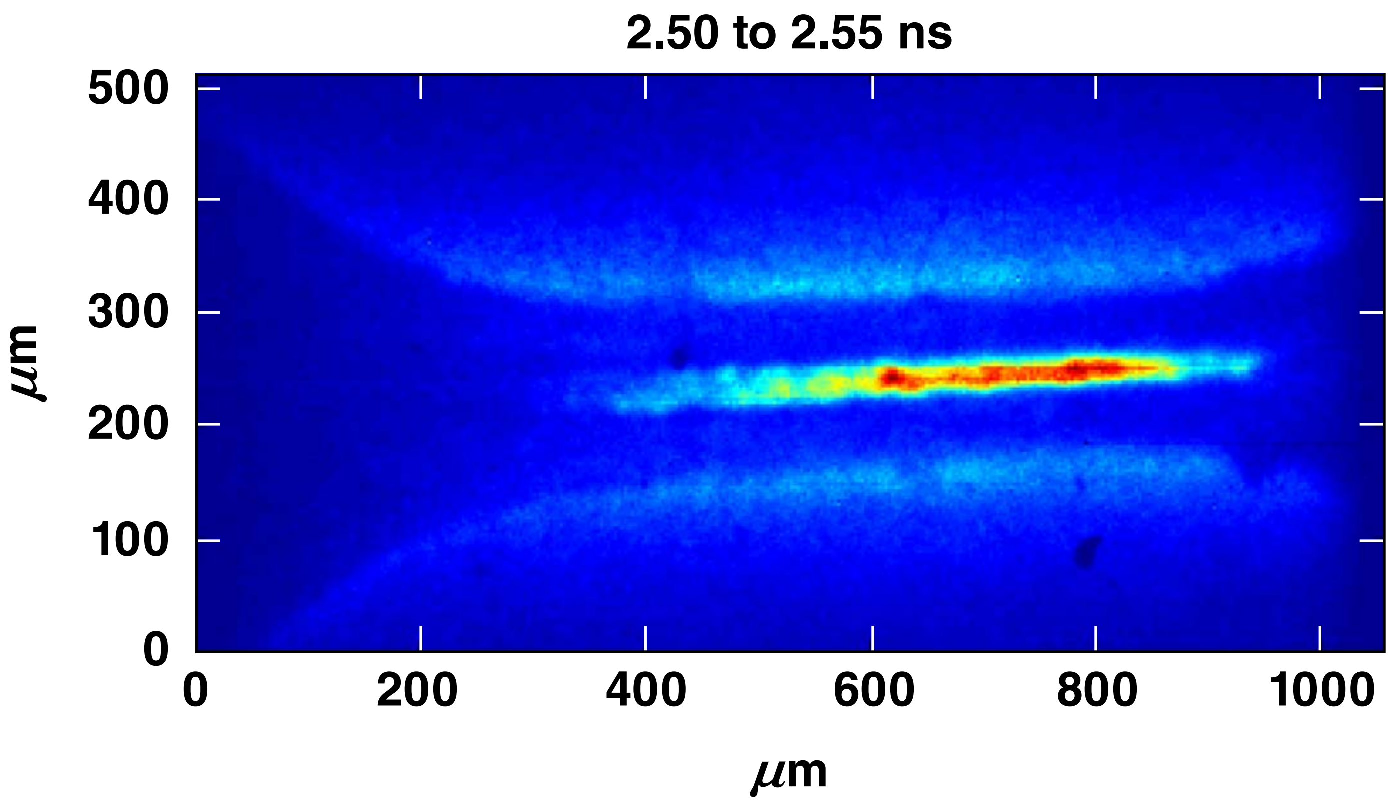
2.20 to 2.25 ns



30-μm-thick shell with 13.2 kJ in 2 ns

E24976

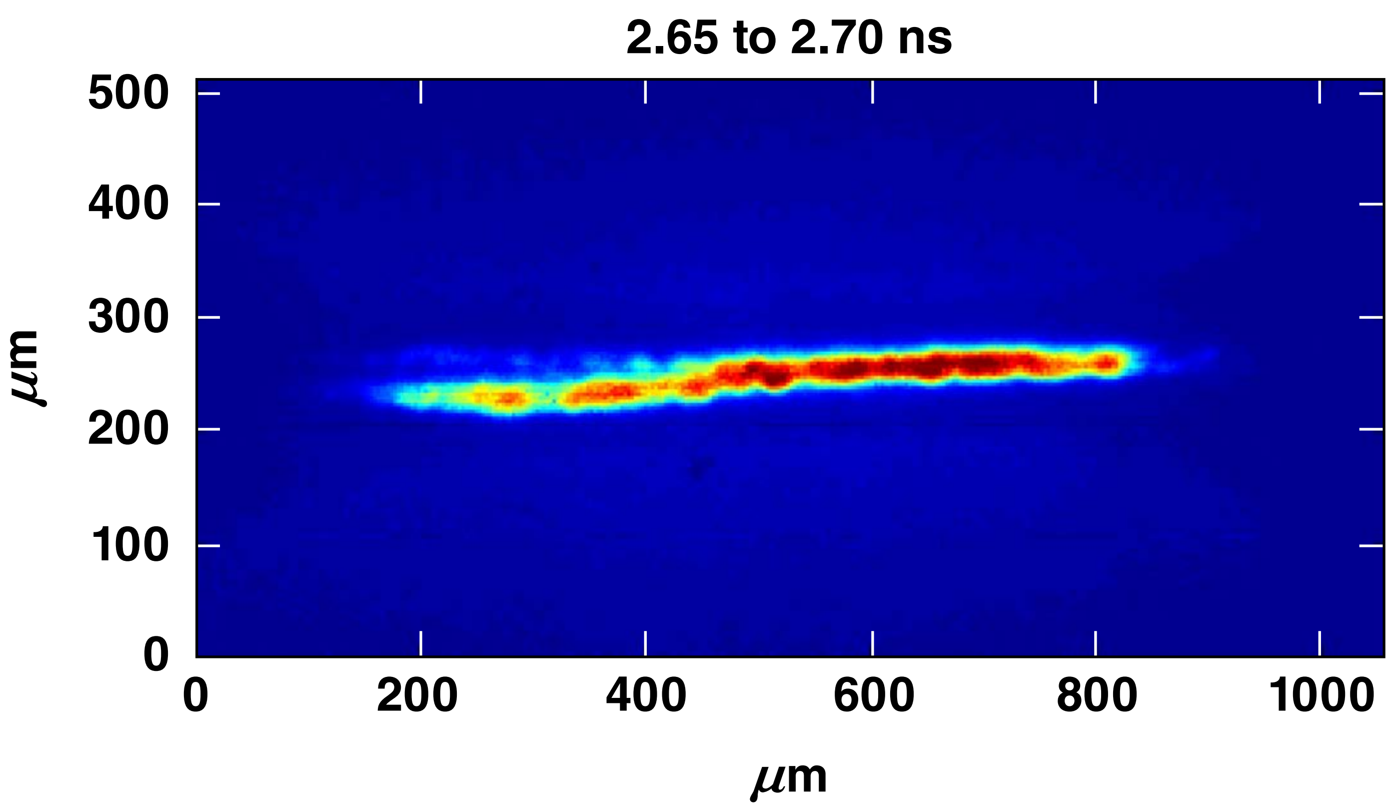
Hot-core formation and expansion have been observed with side-on x-ray framing cameras



30-μm-thick shell with 13.2 kJ in 2 ns

E24977

Hot-core formation and expansion have been observed with side-on x-ray framing cameras

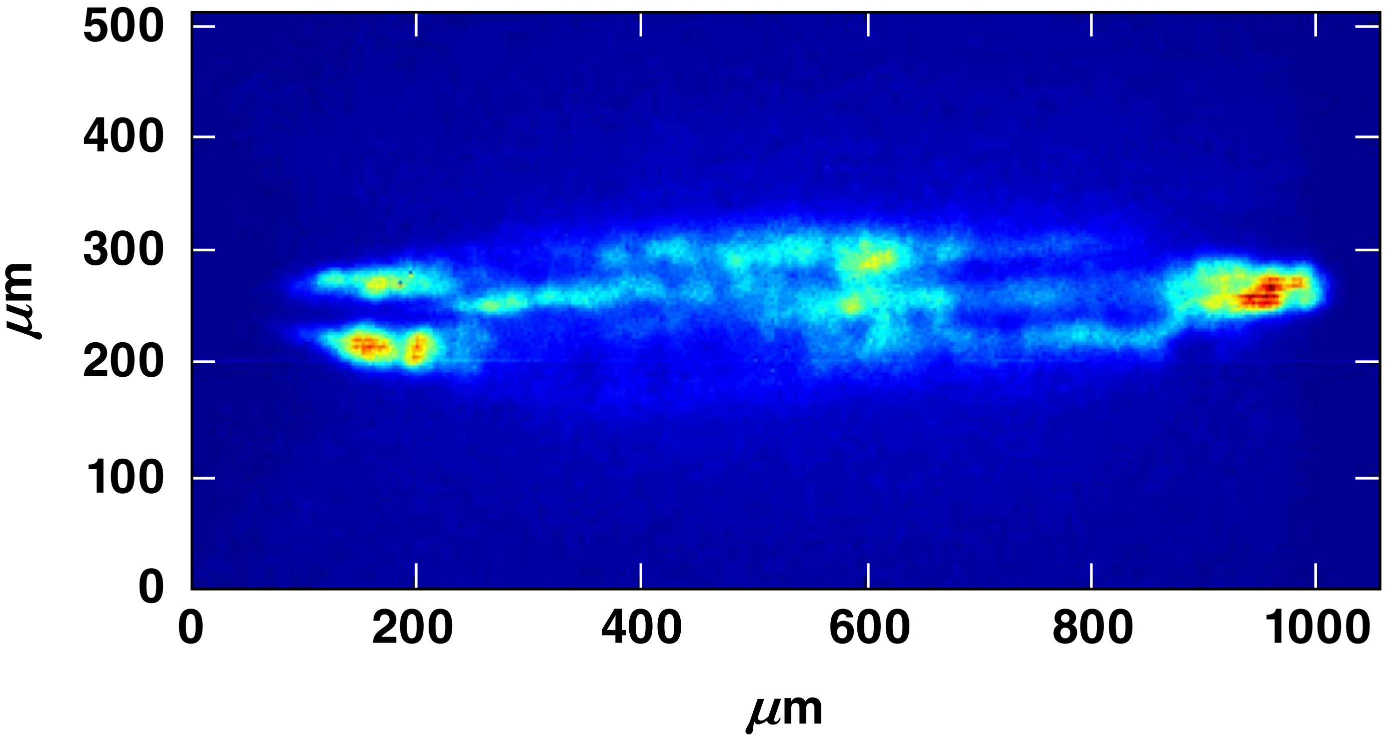


30-μm-thick shell with 13.2 kJ in 2 ns

E24977a

Hot-core formation and expansion have been observed with side-on x-ray framing cameras

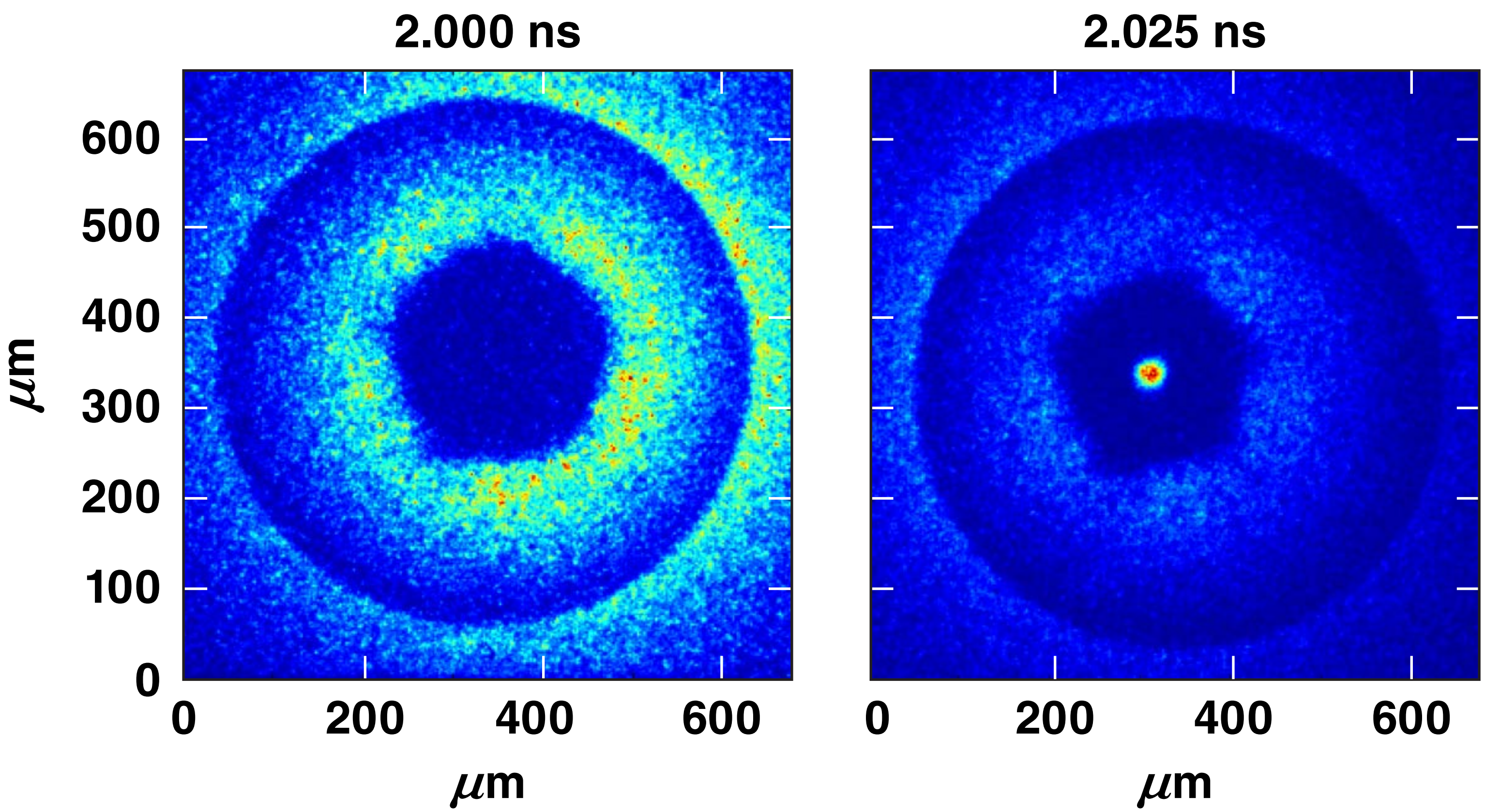
2.90 to 2.95 ns



30-μm-thick shell with 13.2 kJ in 2 ns

E24977b

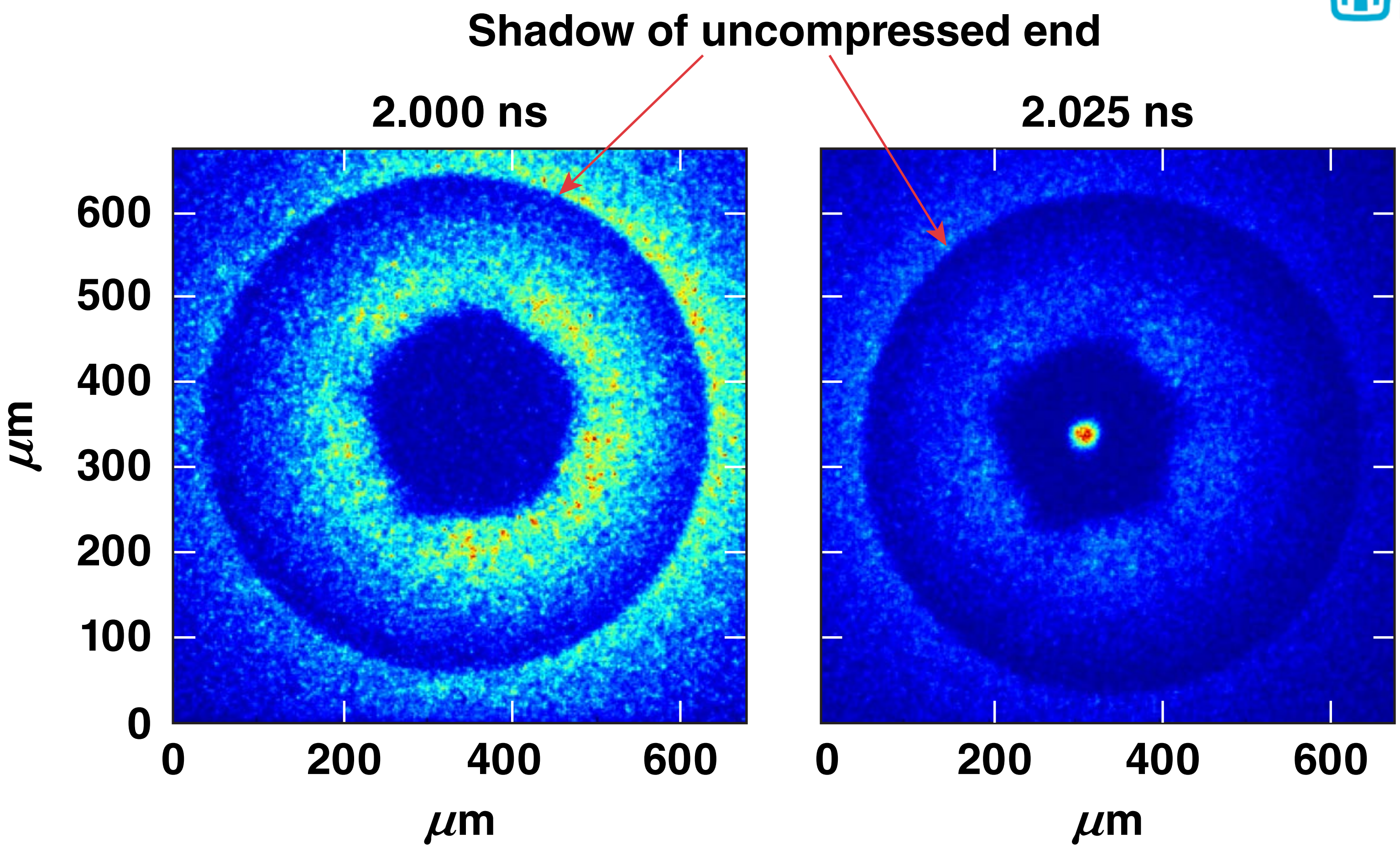
End-on x-ray framing-camera images show core emission earlier and a pentagonal structure to the shell



30-μm-thick shell with 13.2 kJ in 2 ns

E24978

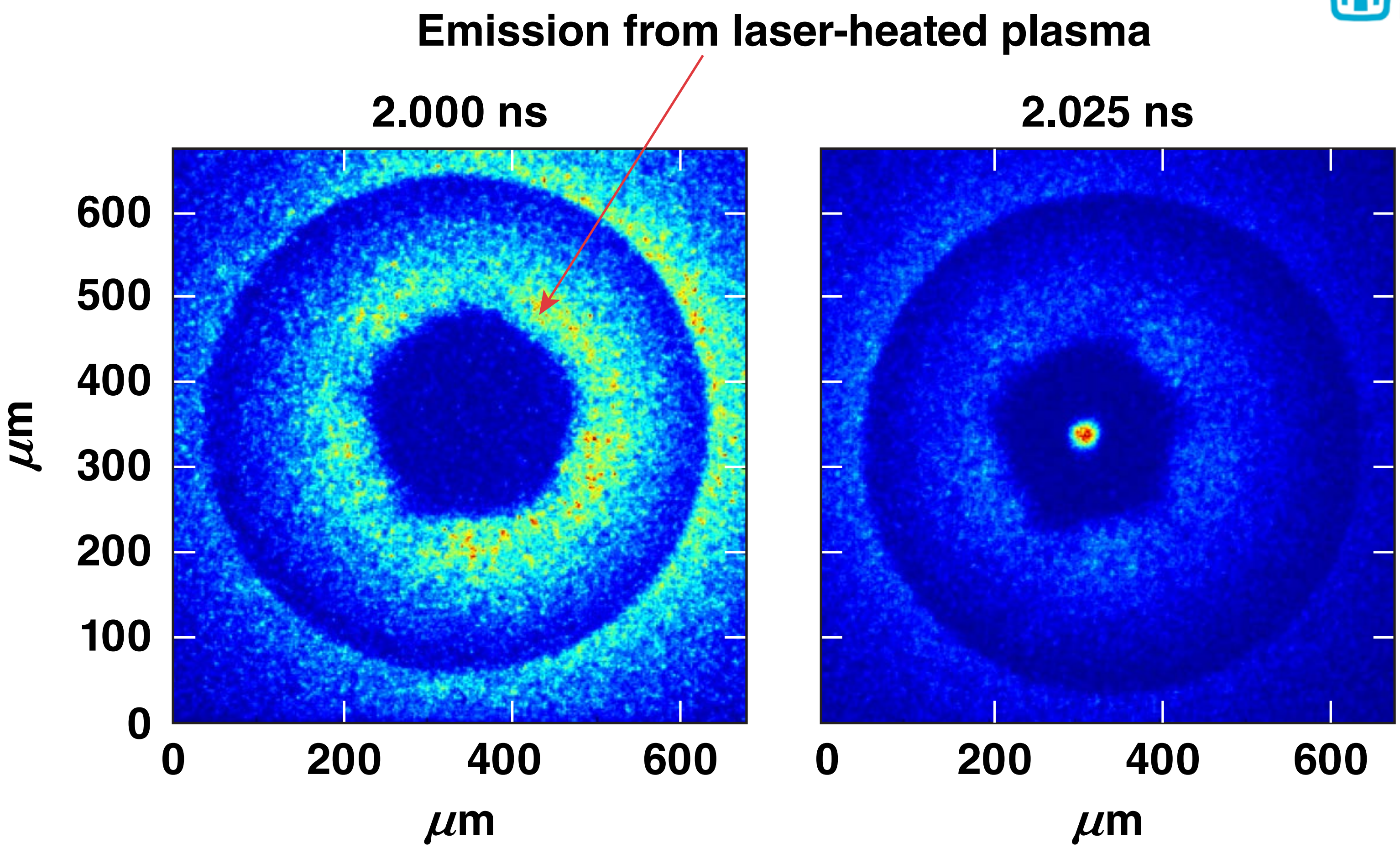
End-on x-ray framing-camera images show core emission earlier and a pentagonal structure to the shell



30-μm-thick shell with 13.2 kJ in 2 ns

E24978a

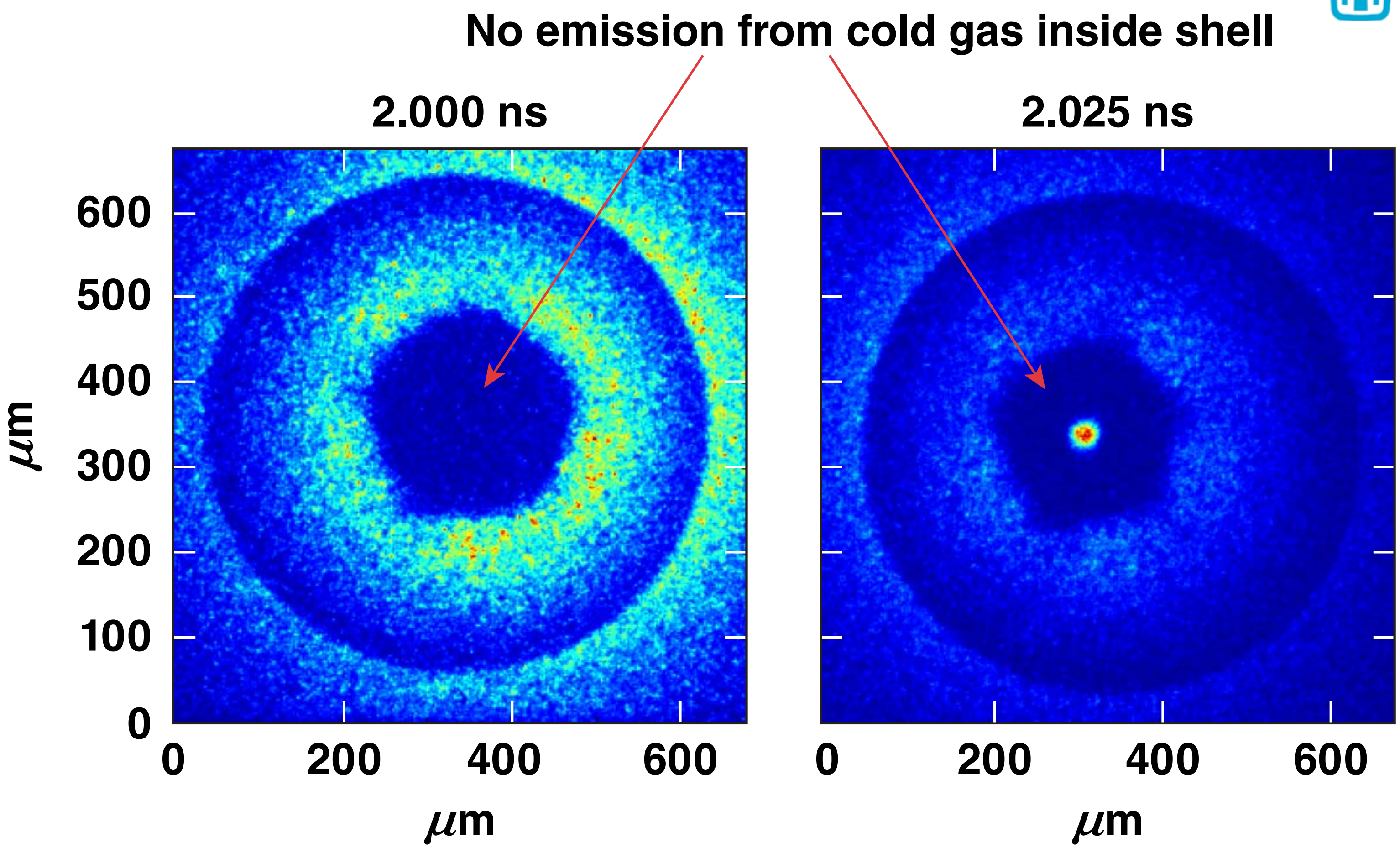
End-on x-ray framing-camera images show core emission earlier and a pentagonal structure to the shell



30-μm-thick shell with 13.2 kJ in 2 ns

E24978b

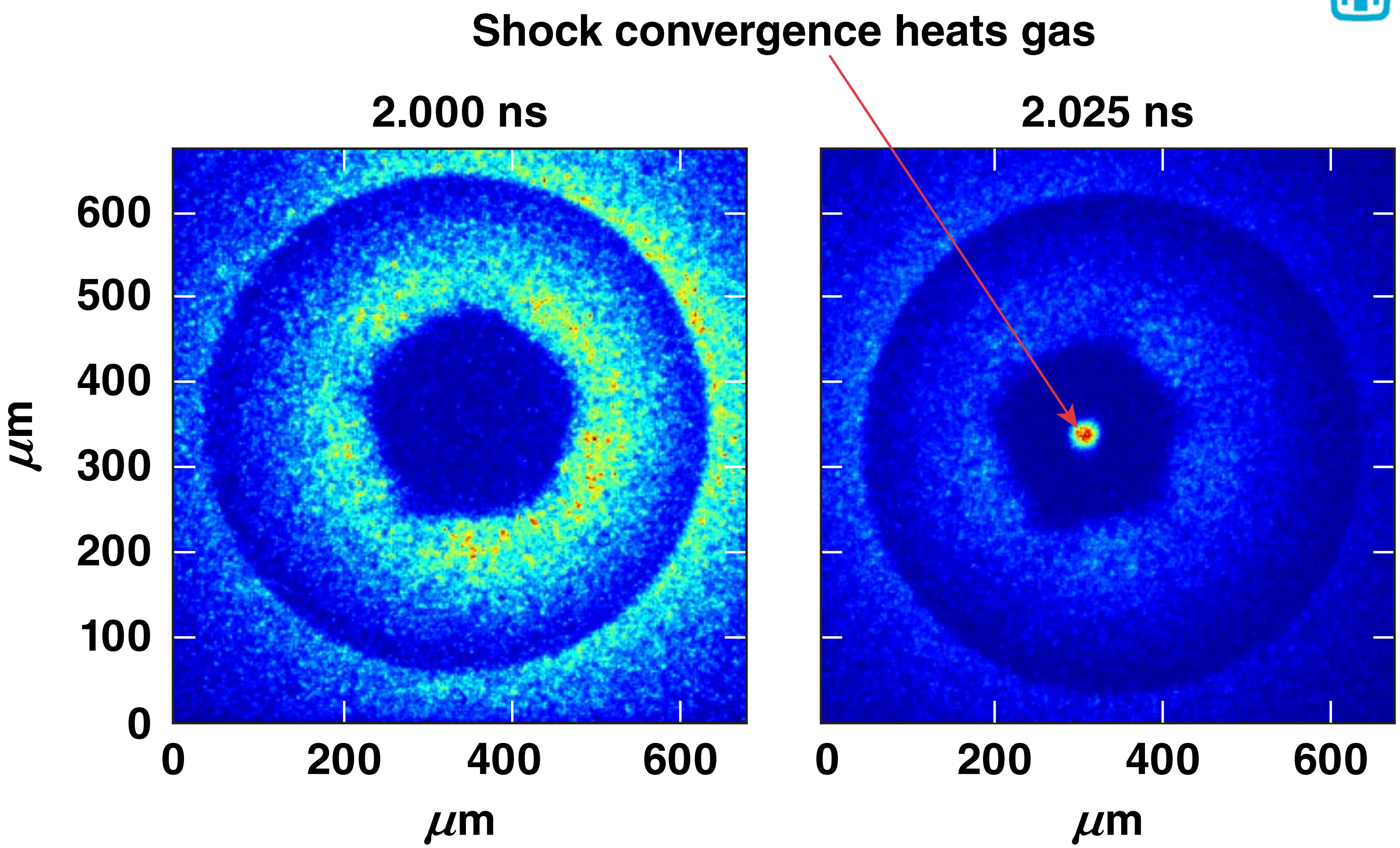
End-on x-ray framing camera images show core emission earlier and a pentagonal structure to the shell



30-μm-thick shell with 13.2 kJ in 2 ns

E24978c

End-on x-ray framing-camera images show core emission earlier and a pentagonal structure to the shell

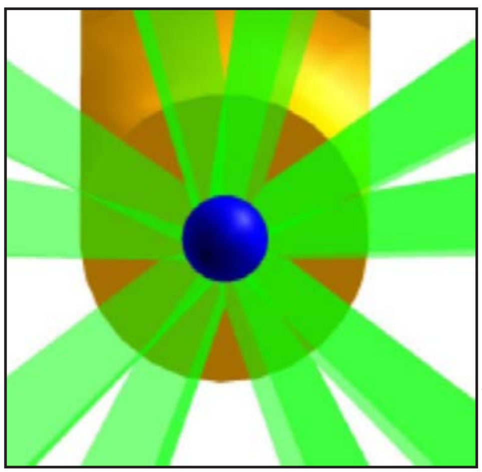


30-μm-thick shell with 13.2 kJ in 2 ns

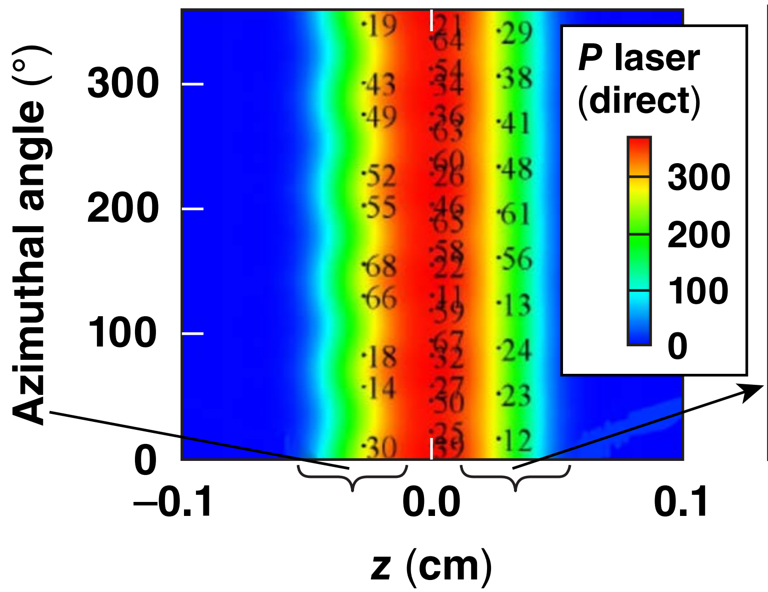
E24978d

The pentagon corresponds to the azimuthal beam distribution in ring 4 and can be removed by repointing

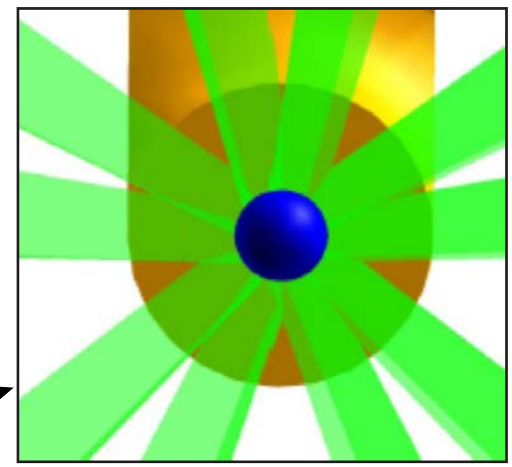
Standard beam distribution



Direct laser power deposited (TW/cm²)



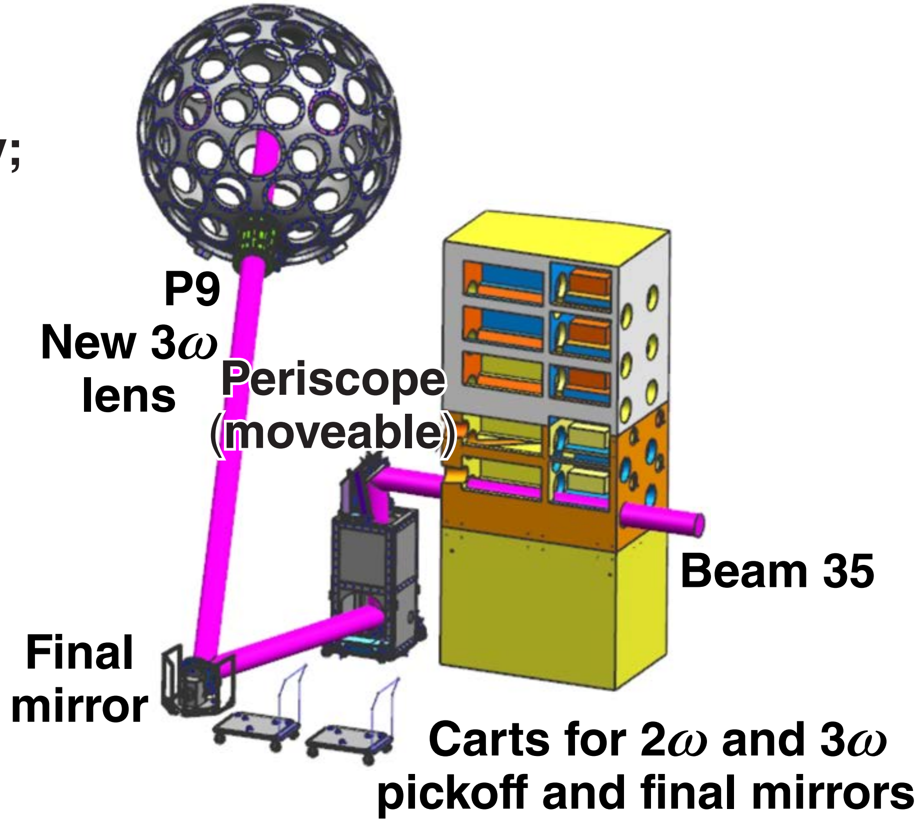
Uniform beam distribution



E24979

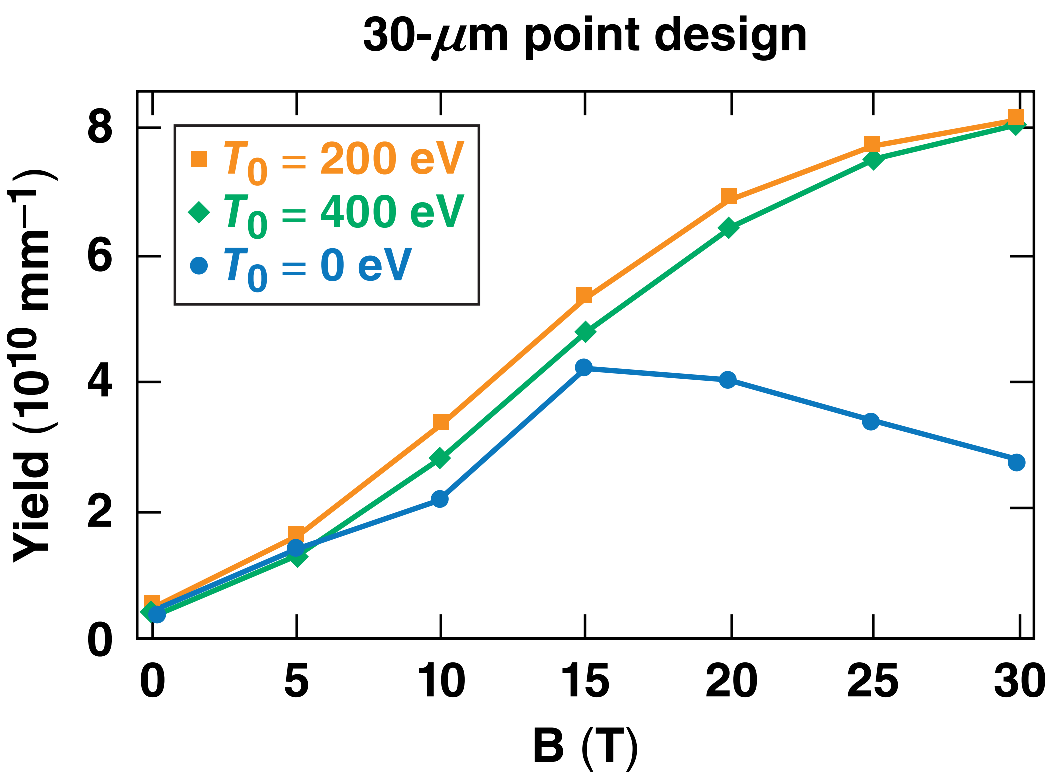
A 3ω beam from P9 using Beam 35 is being implemented for preheating

- Current P9 system provides 2ω or 4ω using Beam 25
- 2ω has too low a critical density; 4ω has no diagnostics and no phase plate
- Beam 25 is required for compression
- A project to move Beam 35 at 3ω into P9 is underway
- First use date is 19 July 2016
- Current capabilities will be maintained



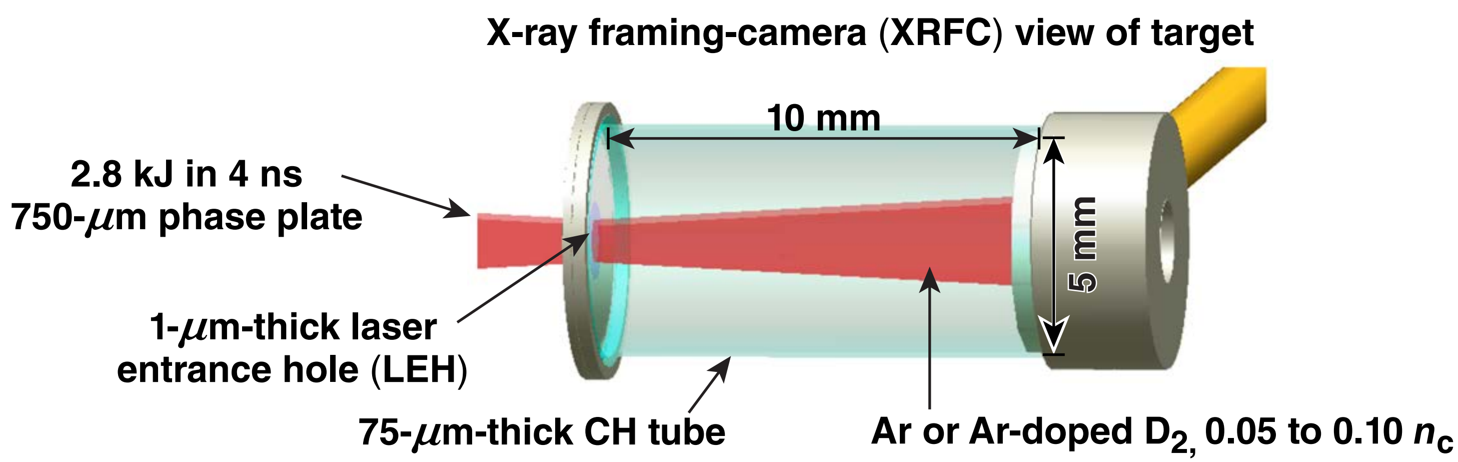
E25033

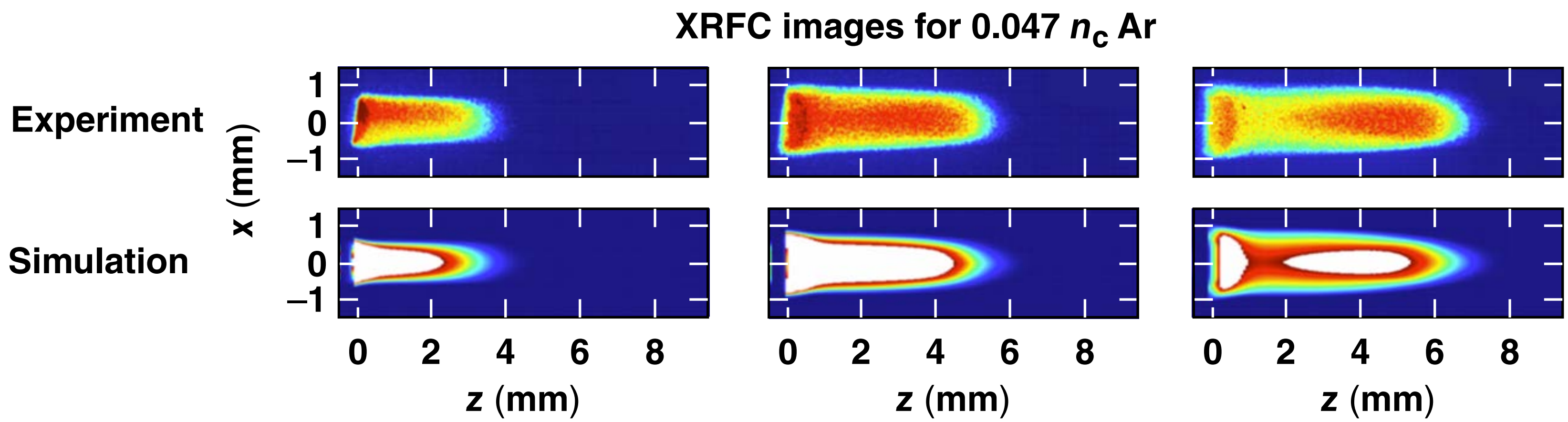
Laser-driven MagLIF would benefit considerably from an increase in the field-generation capability on OMEGA



E25125

OMEGA EP experiments investigate laser preheating at Z scale

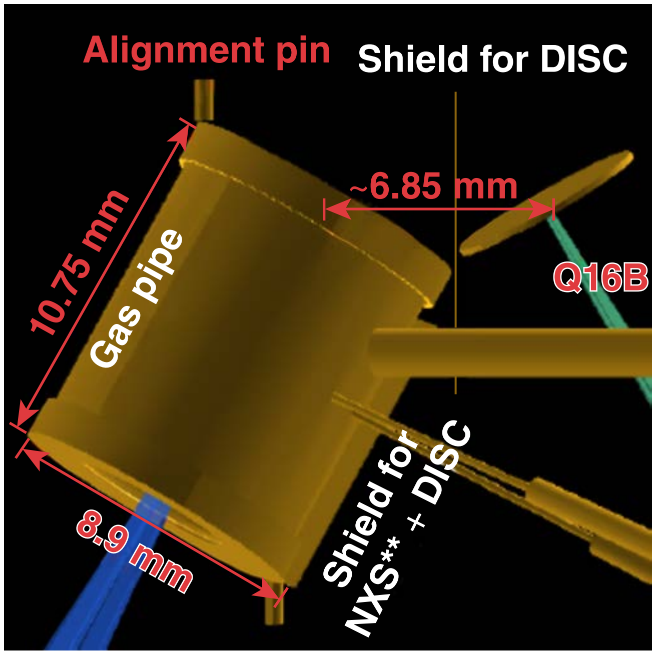




*A. J. Harvey-Thompson *et al*., Phys. Plasmas 22, 122708 (2015).

E25126

NIF* experiments investigate laser preheating at ignition scale



Calibration plate

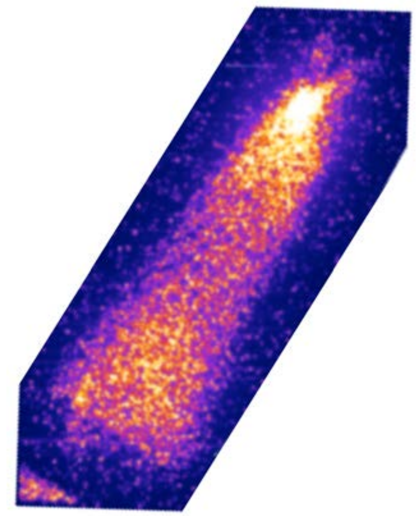
Target positioner

Gas-fill lines

Q31B
focused at the center of the pipe

30 kJ in 10 ns

Framing-camera image at 9 ns

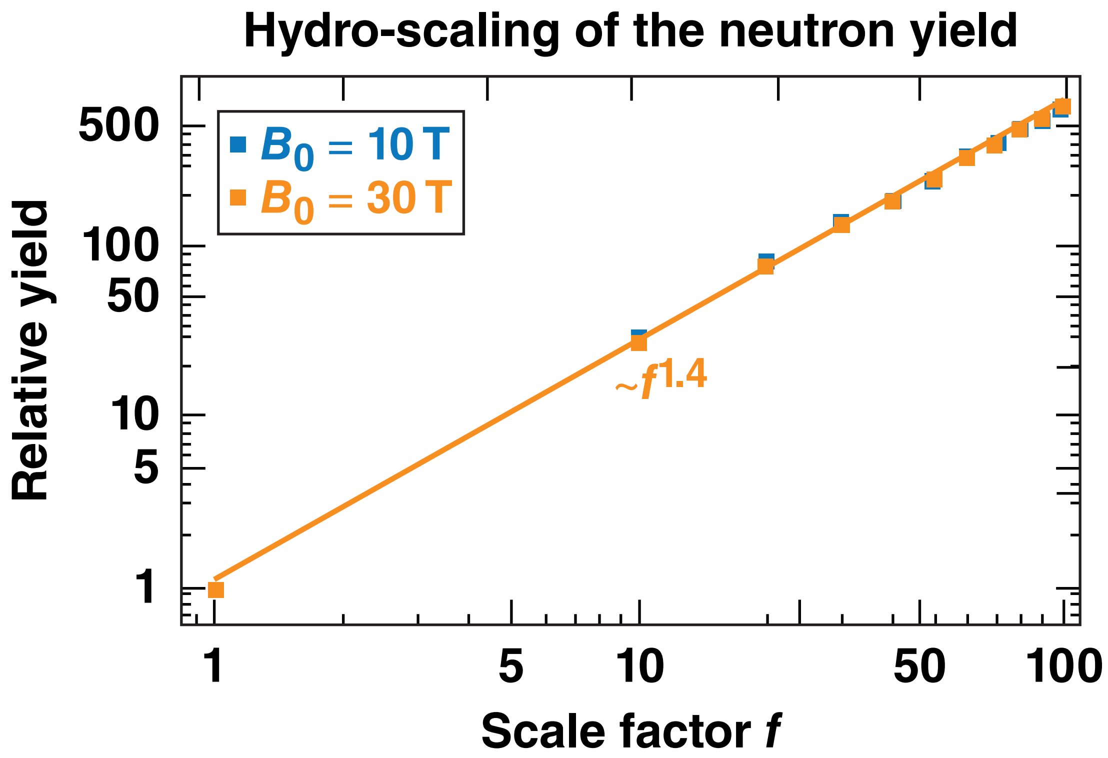


- C_5H_{12} (warm), $B_z = 0$
- D_2 (cryo), $B_z = 0$
- D_2 (cryo), $B_z = 20$ to 30 T

*NIF: National Ignition Facility
**NXS: NIF x-ray spectrometer

E25127

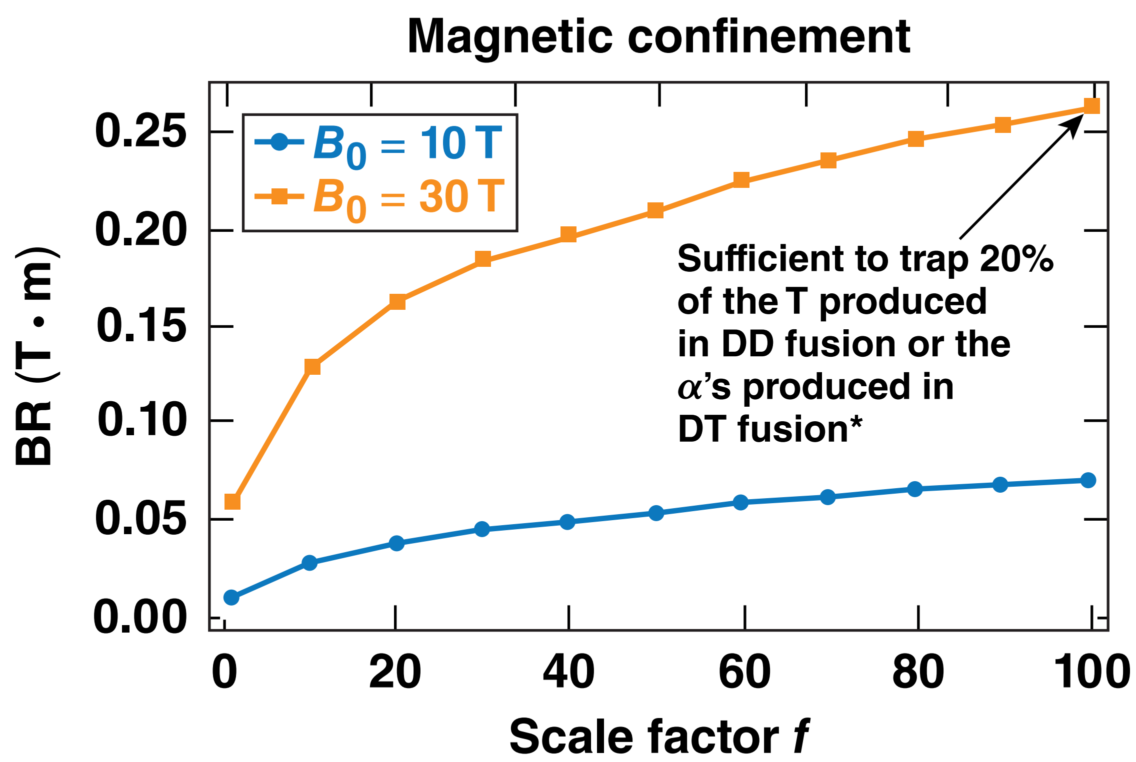
Scaling up the OMEGA laser-driven MagLIF point design to NIF energies has been considered



- NIF has 10× less drive energy than Z so would still give a smaller scale MagLIF target that could not achieve ignition
- $E_L = fE_\Omega$, $r = f^{1/3} r_\Omega$, $L = f^{1/3} r_\Omega$, $t = f^{1/3} r_\Omega$, I_L constant
- Consider f up to 100; approximately 1.6 MJ

E25128

Laser-driven MagLIF on the NIF having a 30-T initial field could achieve measurable magnetic confinement of fusion products



E25129

*P. F. Schmit *et al*., Phys. Rev. Lett. 113, 155004 (2014).

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