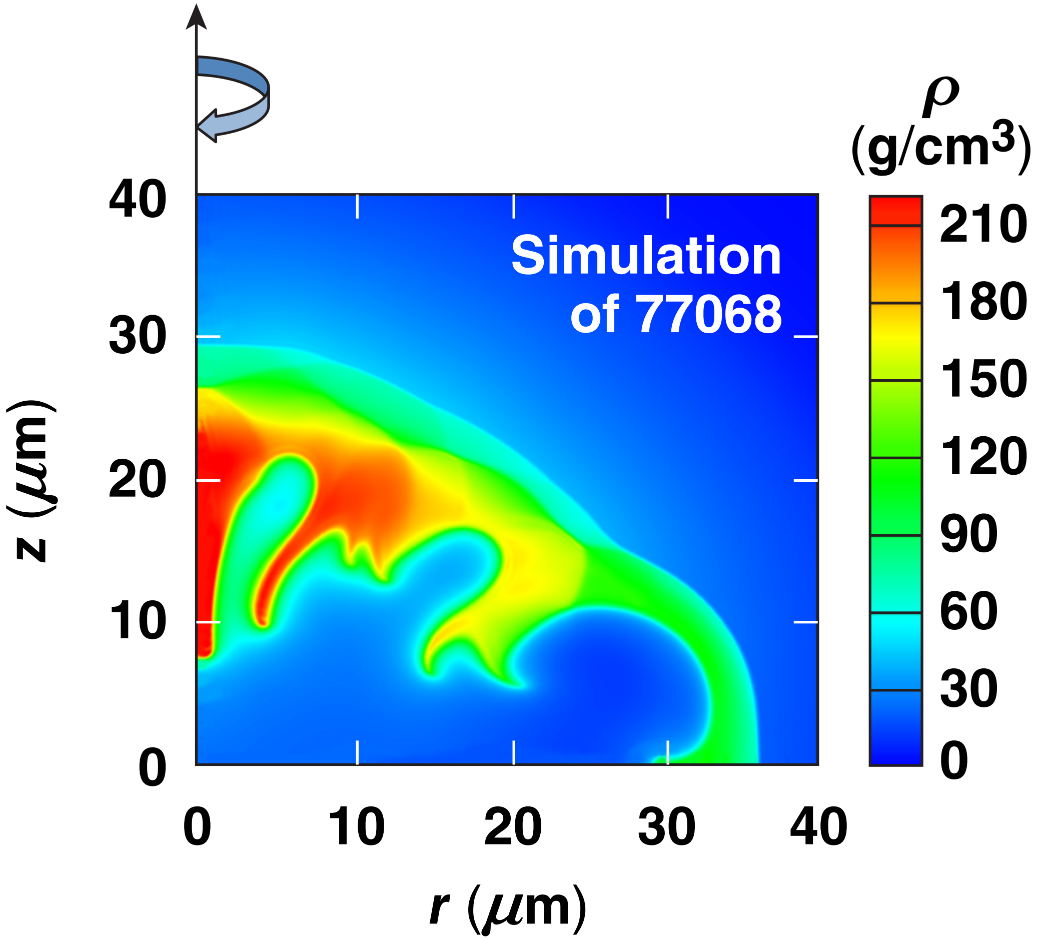
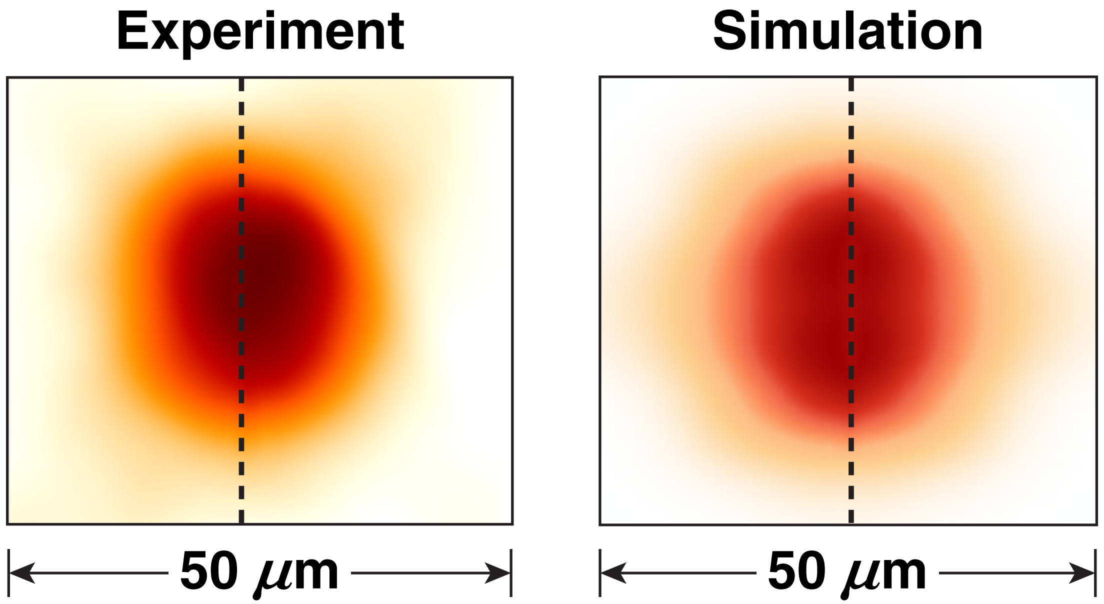
Achievement of Core Conditions for Alpha Heating in Direct-Drive Inertial Confinement Fusion



Time-integrated x-ray image of the hot spot



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Division of Plasma Physics
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Summary

OMEGA implosions hydro-scaled to the National Ignition Facility (NIF) would produce comparable alpha heating but with several times more fusion energy compared to indirect drive*

- Using hydrodynamic simulations, we reconstruct the experimentally observed conditions of the core
- Followed by a volumetric scaling of the core to a 1.9-MJ driver with the same illumination configuration and laser-target coupling; the only assumption is that the implosion hydrodynamic efficiency† is unchanged at higher energies
- We find that correcting the low-mode asymmetries can take these implosions to the burning plasma regime

TC13131

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*A. Bose *et al.*, Phys. Rev. E 94, 011201(R) (2016).

†Fraction of laser energy converted to kinetic energy of imploding shell

Collaborators

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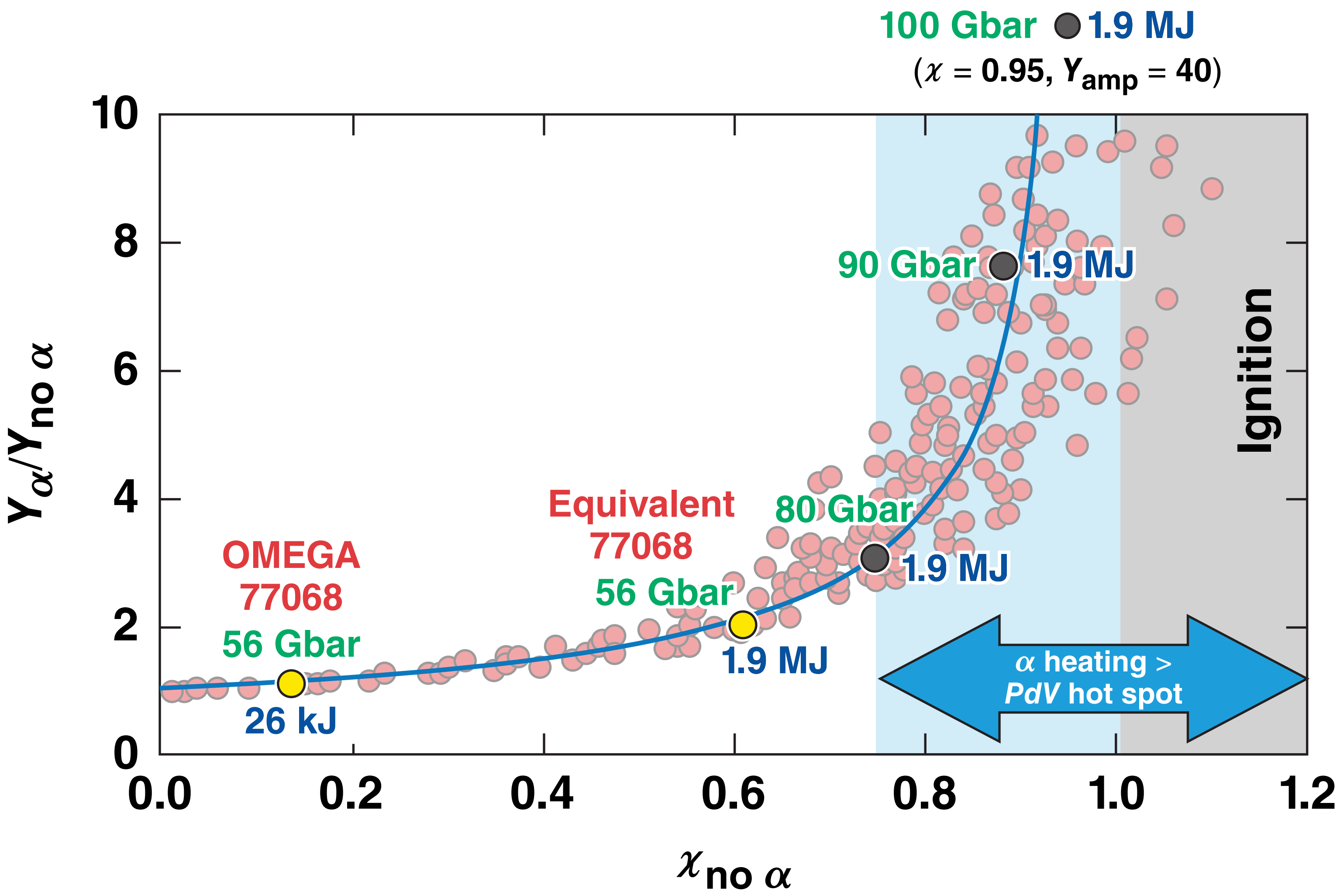
University of Michigan

Translating direct-drive hot-spot pressures to ignition and alpha-heating metrics

$$\chi_{\text{no}\,\alpha} \approx (\rho R_{\text{no}\,\alpha})^{0.61} \left(0.12 Y^{16}_{\text{no}\,\alpha} / M^{\text{stag}}_{\text{DT}}\right)^{0.34}$$

- **Measurable no-α implosion-performance metric, relevant for sub-ignition scales where alpha heating is insignificant**



Livermore ITFx ~ χ3: B. K. Spears *et al.*, Phys. Plasmas 19, 056316 (2012).
Plot based on R. Betti *et al.*, Phys. Rev. Lett. 114, 255003 (2015).
Y amplification: T. Döppner *et al.*, Phys. Rev. Lett. 115, 055001 (2015).

TC13132

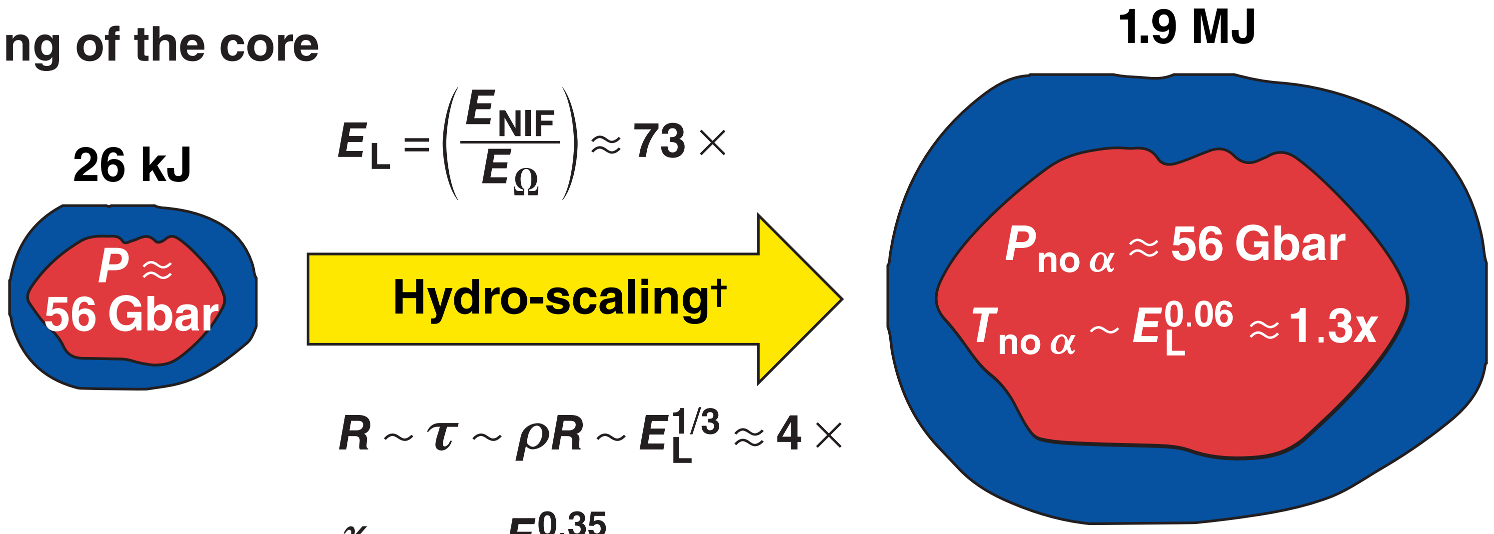
Alpha-heating yield-extrapolation technique has been developed for direct drive

- Direct-drive implosions have repeatedly demonstrated hot-spot pressures in excess of 50 Gbar*
- For the best performing shot

Yield	5.3×10^{13} (±5%)
T_i (keV)	3.6 (±0.3)
ρR (g/cm^2)	0.196 (±0.018)
Stagnating mass (μg)	11.5

OMEGA shot 77068
$\chi_{\text{no}\,\alpha} \approx 0.138$

- Hydrodynamic scaling of the core



26 kJ

$P \approx$ 56 Gbar

$$E_L = \left(\frac{E_{\text{NIF}}}{E_\Omega}\right) \approx 73\times$$

Hydro-scaling†

$$R \sim \tau \sim \rho R \sim E_L^{1/3} \approx 4\times$$

$$\chi_{\text{no}\,\alpha} \sim E_L^{0.35}$$

1.9 MJ

$P_{\text{no}\,\alpha} \approx$ 56 Gbar

$T_{\text{no}\,\alpha} \sim E_L^{0.06} \approx 1.3$x

OMEGA shot 77068 at 1.9 MJ
$\chi_{\text{no}\,\alpha} \approx 0.61$

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*S. P. Regan *et al.*, Phys. Rev. Lett. 117, 025001 (2016).
†R. Nora *et al.*, Phys. Plasmas 21, 056316 (2014).
A. Bose *et al.*, Phys. Plasmas 22, 072702 (2015).

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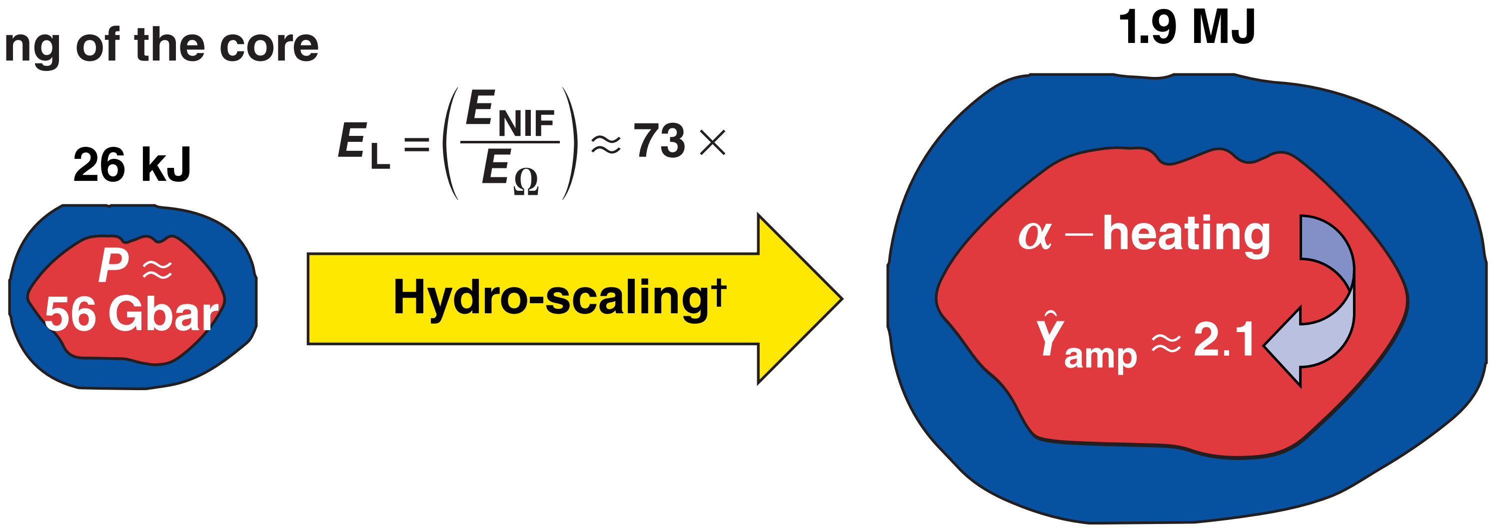

$$E_L = \left(\frac{E_{\text{NIF}}}{E_{\Omega}}\right) \approx 73 \times$$

$$\hat{Y}_{\text{amp}} = \frac{Y_{\alpha}}{Y_{\text{no }\alpha}} \simeq \left(\frac{1-\chi_{\text{no }\alpha}}{0.96}\right)^{-0.75}$$

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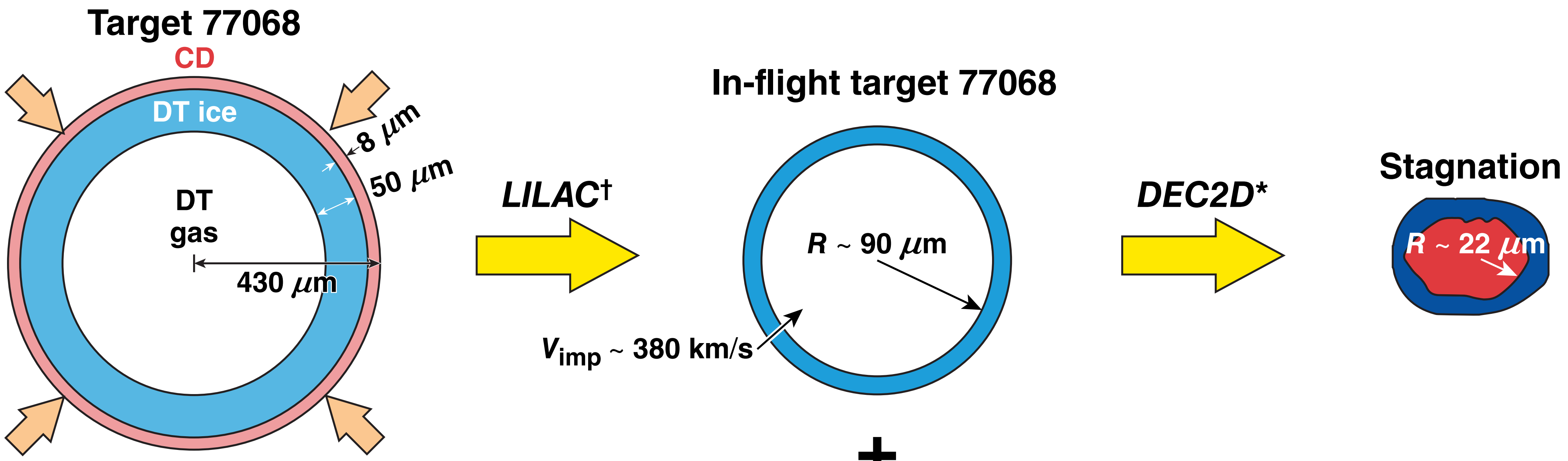
The radiation–hydrodynamic code *DEC2D** is used to simulate the deceleration phase of implosions



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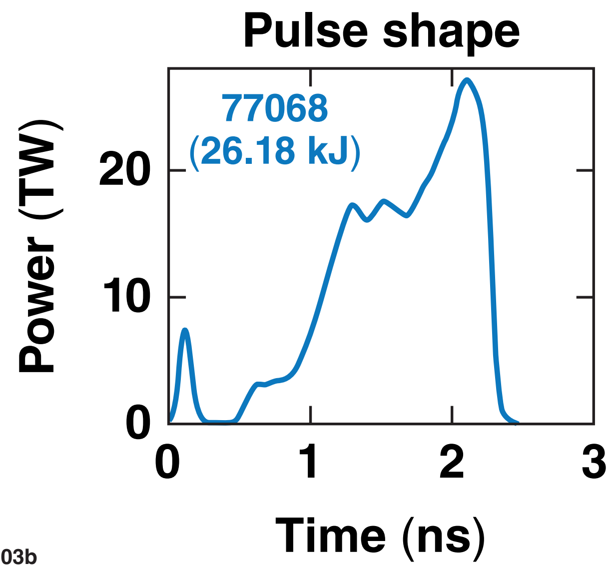

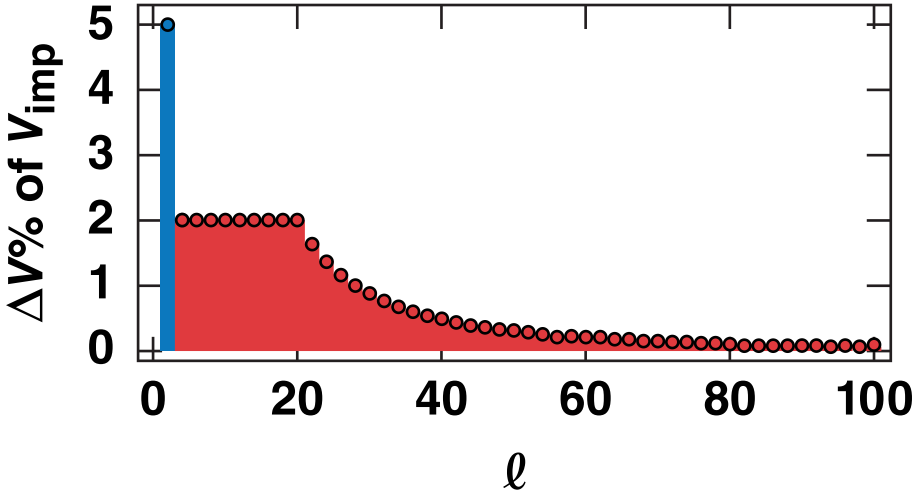

▨ Combination =

$\Delta V_1[\ell = 2]$ +

ΔV_2[intermediate modes]

TC12203b

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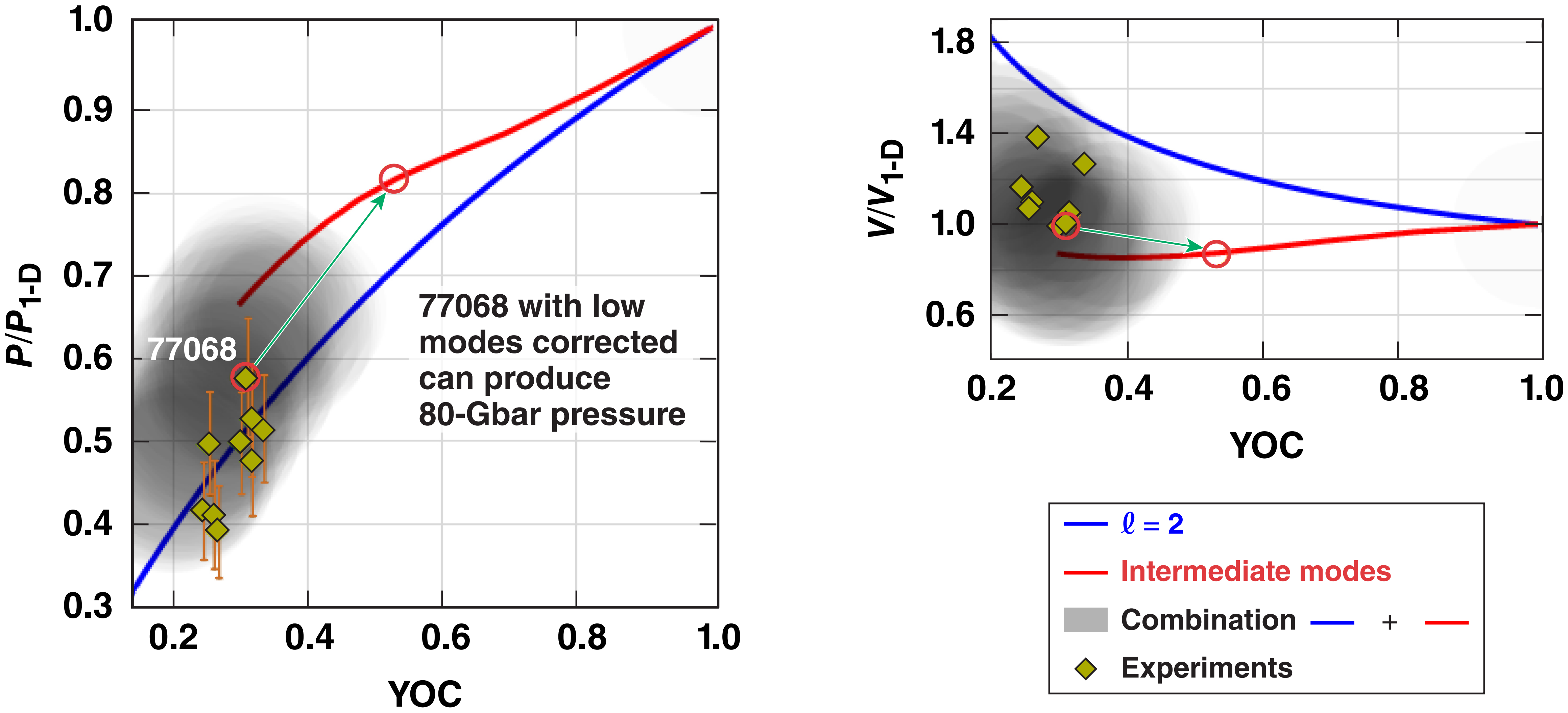
* K. M. Woo *et al.*, TO5.00015, this conference.; A. Bose *et al.*, Phys. Plasmas 22, 072702 (2015).

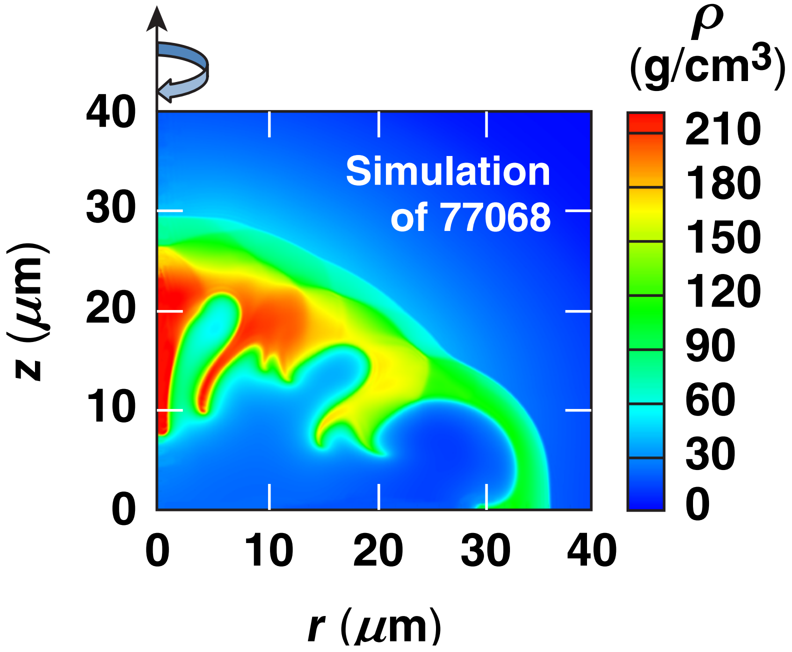
† NL+CBET model: I. V. Igumenshchev *et al.*, Phys. Plasmas 17, 122708 (2010).

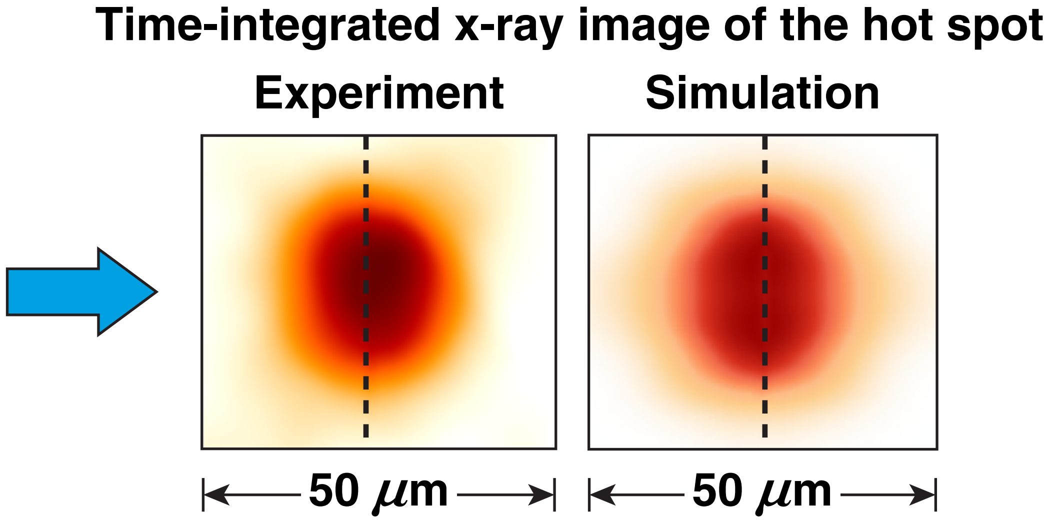
Reconstruction of the deceleration phase: using a combination of low modes ($\ell \sim 2$) to degrade the hot-spot pressure with a spectrum of intermediate modes to retain a 1-D-like hot-spot volume

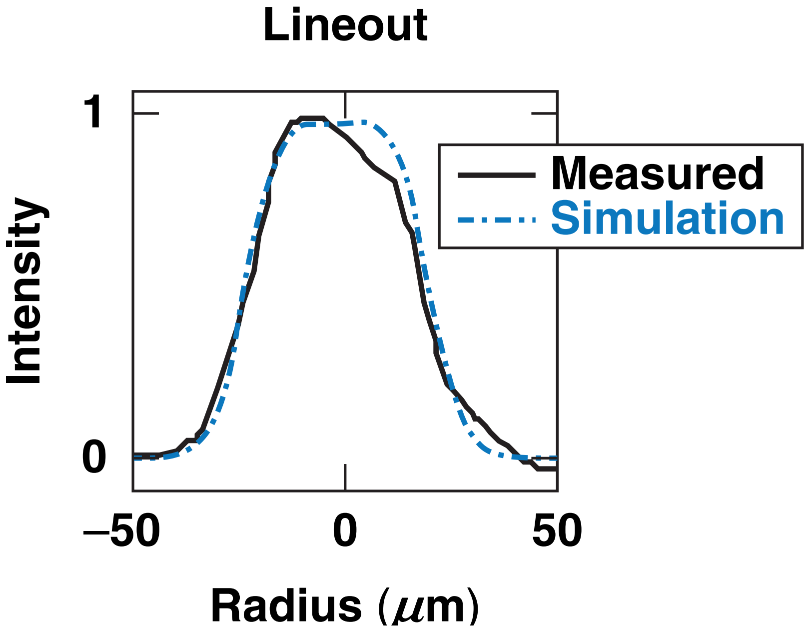


77068 with low modes corrected can produce 80-Gbar pressure

Reconstruction of the deceleration phase: to match experimental observables of the core







E_L 26.18 kJ	Experiment	1-D simulation	2-D simulation
Yield	5.3×10^{13} (±5%)	1.7×10^{14}	5.3×10^{13}
P (Gbar)	56 (±7)	97	56
T_i (keV)	3.6 (±0.3)	3.82	3.7
R_{hs} (μm)	22 (±1)	22	22
τ (ps)	66 (±10)	61	54
ρR (g/cm^2)	0.196 (±0.018)	0.211	0.194

OMEGA shot 77068
$\chi_{\text{no }\alpha} \approx 0.138$

R. Betti *et al.*, PO5.00008, this conference.

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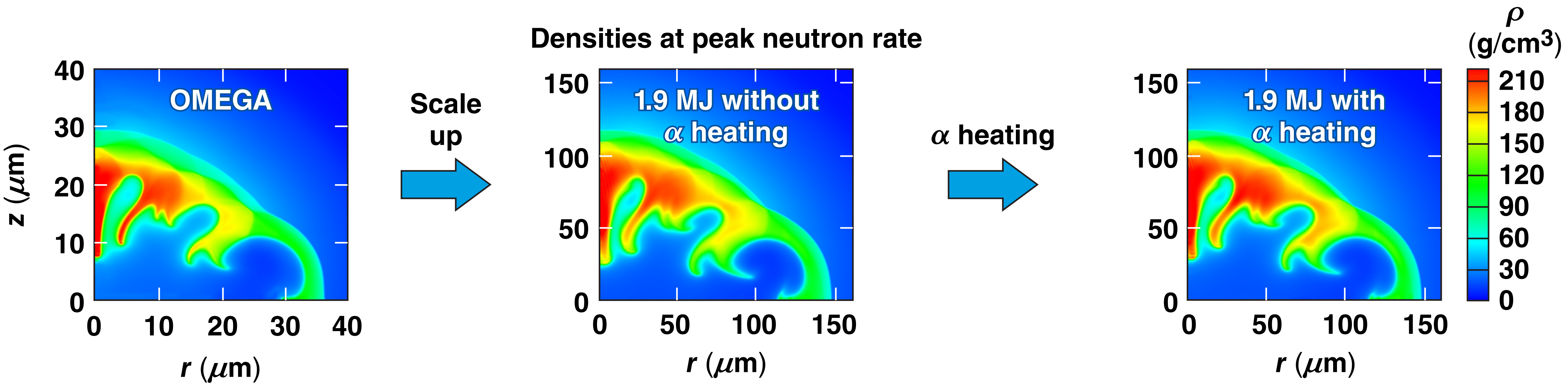
Extrapolating OMEGA results to hydro-equivalent targets driven by 1.9-MJ symmetric illumination leads to 125 kJ of fusion yield


Densities at peak neutron rate

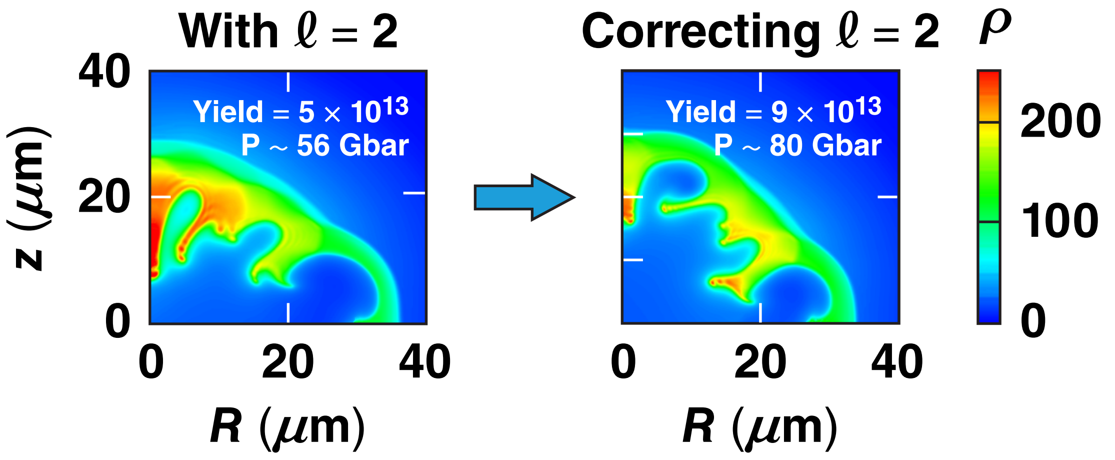
Shot 77068	OMEGA 26.18 kJ	1.9 MJ without α heating	1.9 MJ with α heating
Yield	5.3×10^{13}	2.25×10^{16}	4.45×10^{16}
P^* (Gbar)	56	56	79
T_i (keV)	3.7	4.7	5.1
R_{hs} (μm)	22	92.3	92.5
τ (ps)	54	215	193
ρR (g/cm^2)	0.194	0.83	0.81

OMEGA shot 77068 at 1.9 MJ
$\chi_{\text{no}\ \alpha} \approx 0.61$

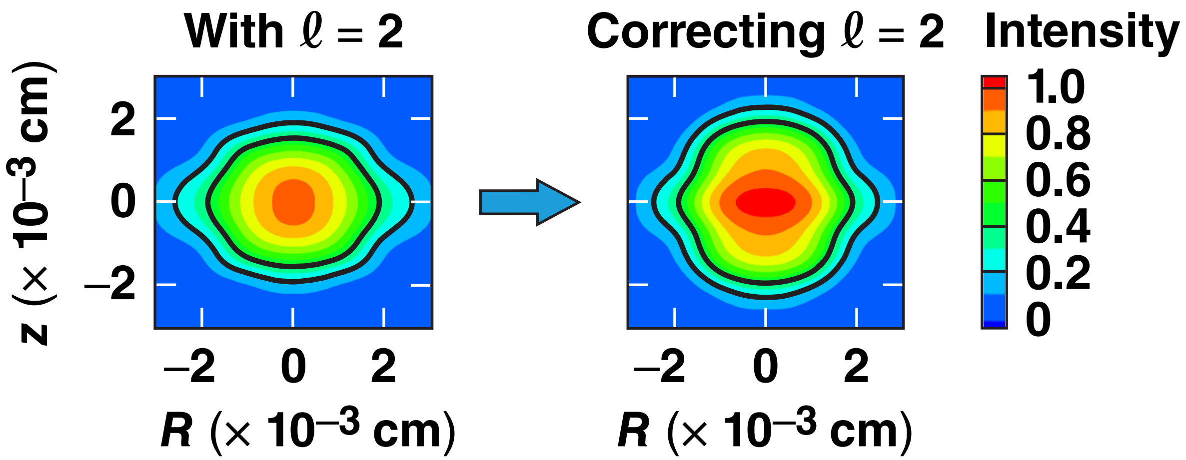
$\hat{Y}_{\text{amp}} = 2$

Correcting the low-mode asymmetries can take direct drive to the burning plasma regime

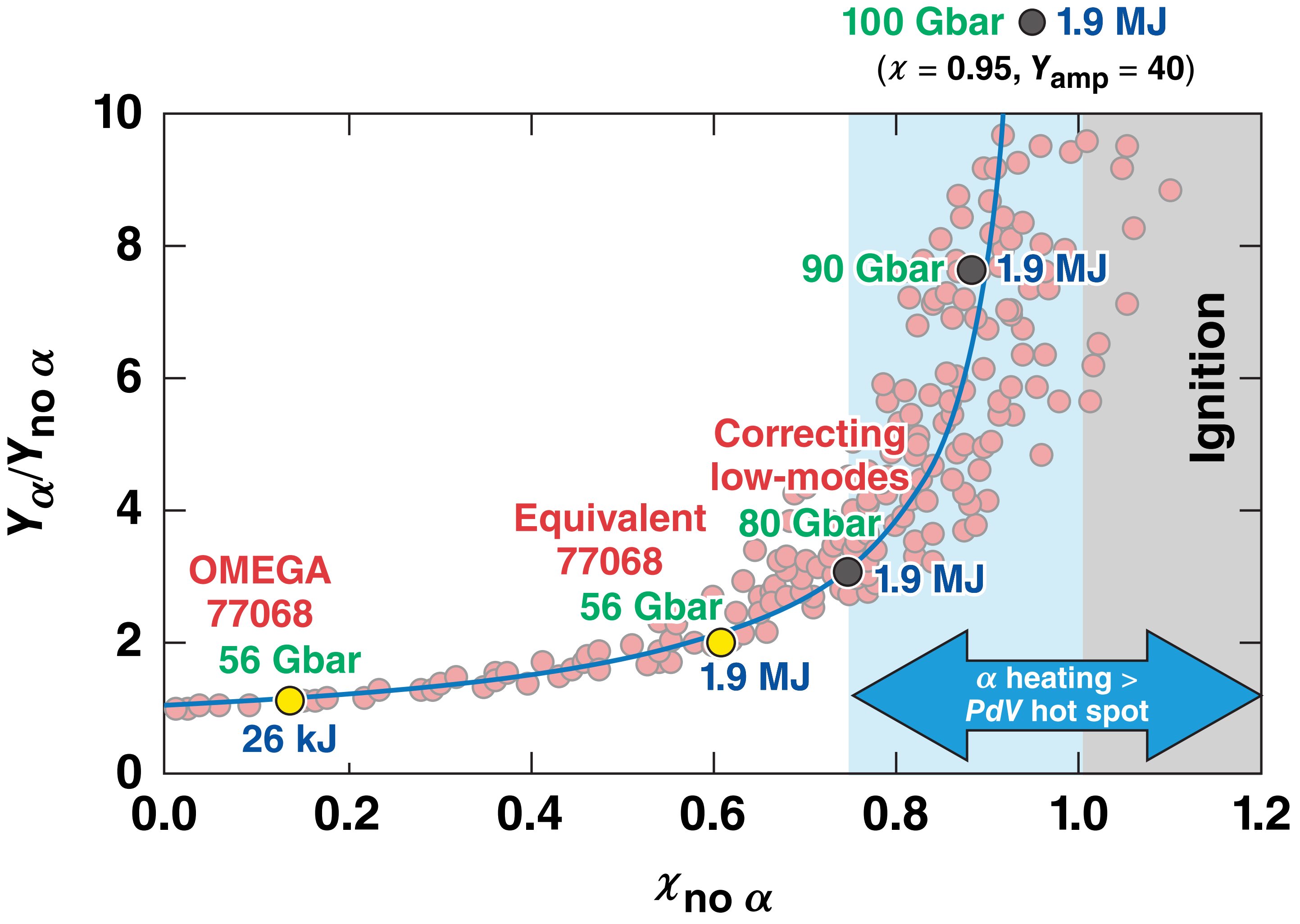
Density contour plot at peak neutron



Time-integrated x-ray image of the hot spot



Extrapolated to 1.9 MJ: Yield = 300 kJ; $\hat{Y}_{amp} \approx 3$.



Experiments for detection and correction of low modes:
Backlighting: C. Stoeckl, NI2.00004, this conference (invited).
Corona Emission: D. T. Michel, as PI

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[†] Fraction of laser energy converted to kinetic energy of imploding shell