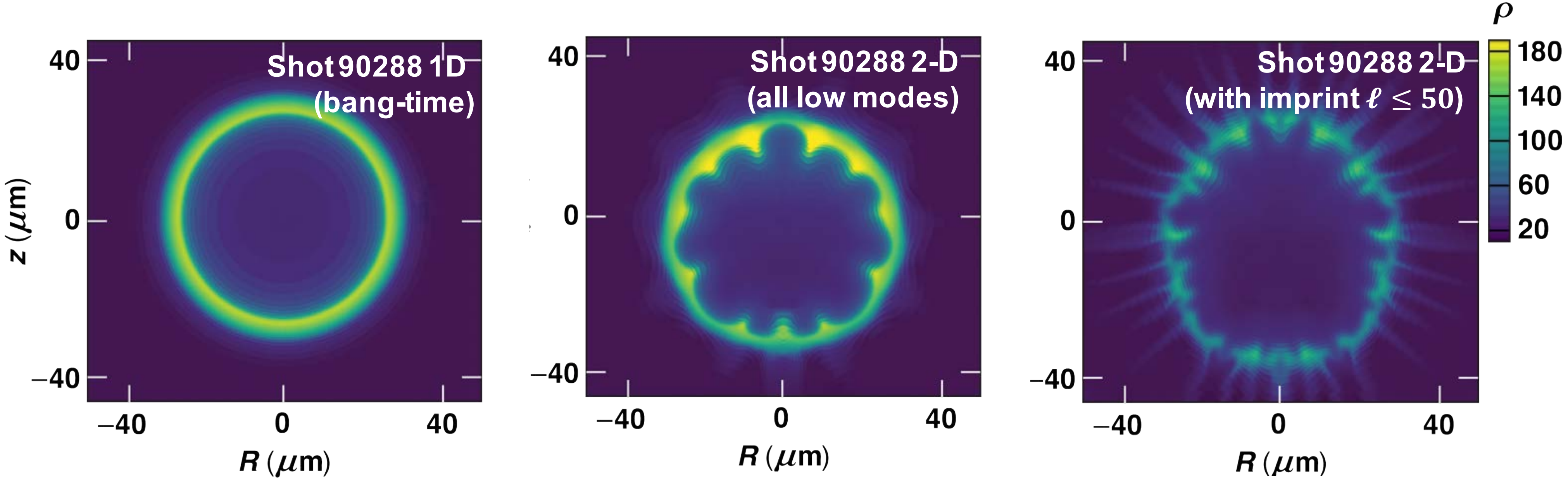
Understanding Origins of Observed Fusion-Yield Dependencies for Direct-Drive Implosions on OMEGA



$$\frac{Y_{exp}}{Y_{sim}} \sim A^{\alpha} B^{\beta} C^{\gamma} \cdots$$

$$\frac{Y_{exp}}{Y_{sim}} \sim A^{\eta} B^{\mu} C^{\nu} \cdots$$

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Summary

DRACO 2D simulations were used to decompose observed fusion yield dependencies to responses of known perturbations

- A. Lees et al previously developed scaling factors to predict yield-over-clean (YOC) from 1D code predictions*
- These scalings are further understood using correlations to 2D DRACO** simulations with known perturbations
  - Degradation from imprint found to scale with R_{beam}/R_{target} in addition to hydro-stability
  - Residual scalings quantify missing physics or perturbation sources needed in rad-hydro models

YOC: yield-over-clean
* A. Lees *et al*., Phys. Rev. Lett. 127, 105001 (2021).
** P. B. Radha et al., Physics of Plasmas 12, 056307 (2005)

Collaborators

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W. Theobald, J. P. Knauer, P. B. Radha, C. Stoeckl, S. P. Regan,
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Four factors were empirically developed to predict YOC from 1D*

$$\frac{Y_{\mathrm{measured}}}{Y_{\mathrm{1-D}}} \approx \mathrm{YOC}_{\mathrm{predicted}} = \mathrm{YOC}_{R_{\mathrm{b}}/R_t} \cdot \mathrm{YOC}_{\mathrm{hydro}} \cdot \mathrm{YOC}_{\mathrm{fuel\ age}} \cdot \mathrm{YOC}_{\mathrm{low-mode}}$$

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Determined from measured T_{ion} asymmetry

Beam Geom.

$$\sim \left(\frac{R_{\text{beam}}}{R_{\text{target}}}\right)^{3.0}$$

Hydro-instability effect

$$\sim \left(\frac{s_\alpha}{0.8}\right)^{\eta} \text{CR}^{-1.0} \left(\frac{R_{\text{target}}}{R_{\text{inner},0}}\right)^{-3.4}$$

$$s_\alpha = \frac{(\alpha/3)^{1.1}}{\text{IFAR}/20}, \qquad \eta = \begin{cases} 1.06 & s_\alpha < 0.8 \\ 0.45 & s_\alpha > 0.8 \end{cases}$$

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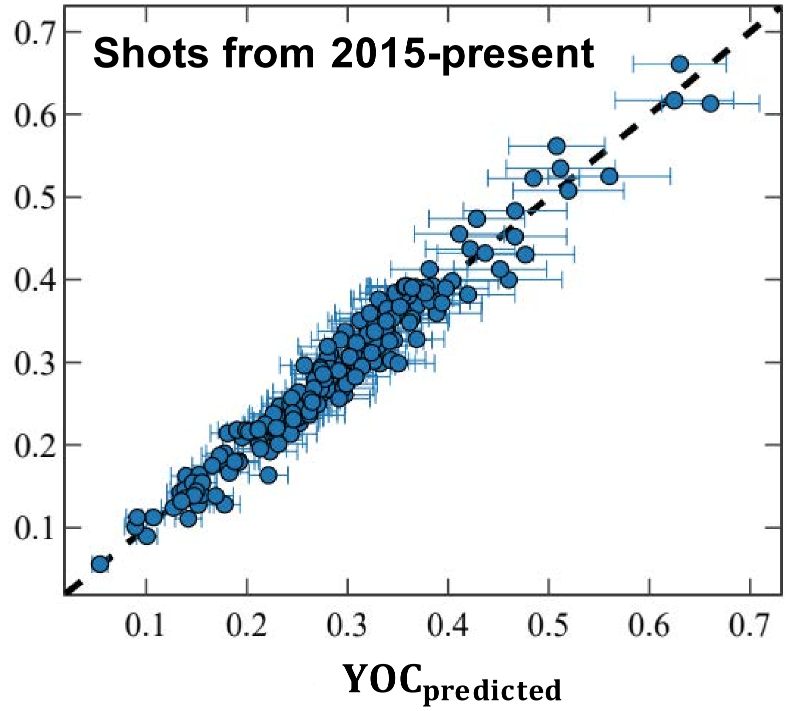

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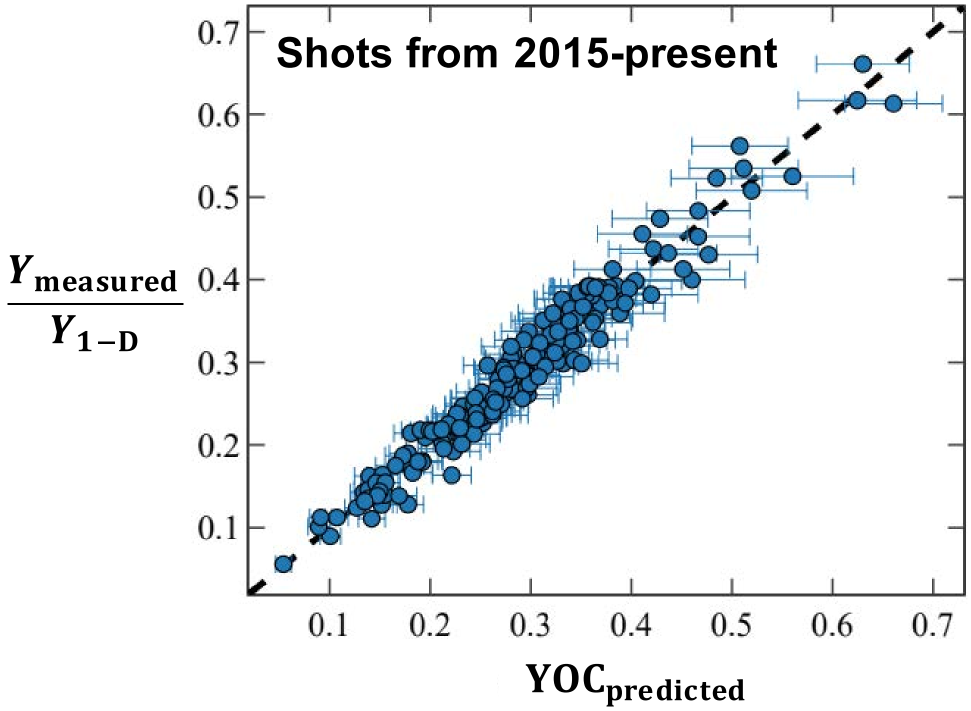
How far can existing (multi-dimensional) physics models capture and explain these effects?



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*DRACO*** 2-D database includes 38 shots (150 simulations)

$3 < \alpha < 7$

$15 < \text{IFAR} < 50$

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Y_{exp}/Y_{code} scaling should approach unity as one adds more complexity to the code

Y_{exp}/Y_{code}	Beam Geom.	Hydro-instability effect
Experiment over 1-D (*LILAC* and *DRACO*):	$\sim \left(\frac{R_b}{R_t}\right)^{3.0}$	$\cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} CR^{-1.0} \left(\frac{R_{outer}}{R_{inner}}\right)^{-3.4}\right]^{1.0} \cdot YOC_{fuel\ age} \cdot YOC_{low\ mode}$ *
Experiment over ideal prediction:	$\sim \left(\frac{R_b}{R_t}\right)^{0.0}$	$\cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} CR^{-1.0} \left(\frac{R_{outer}}{R_{inner}}\right)^{-3.4}\right]^{0.0} \cdot YOC_{fuel\ age} \cdot YOC_{low\ mode}$

Exponents should go to zero if effects perfectly captured in code

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$Y_{\text{exp}}/Y_{\text{code}}$

Beam Geom.

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Experiment over *DRACO* 2D (beam ports only):

$$\sim \left(\frac{R_b}{R_t}\right)^{1.5} \cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} \mathrm{CR}^{-1.0} \left(\frac{R_{\text{outer}}}{R_{\text{inner}}}\right)^{-3.4}\right]^{0.7} \cdot \mathrm{YOC}_{\text{fuel age}} \cdot \mathrm{YOC}_{\text{low mode}}$$

Adding ports alone does not entirely explain the R_b/R_t scaling – what about additional effects?

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Experiment over *DRACO* 2D (beam-ports + ice roughness + offset and power balance):	$\sim \left(\frac{R_b}{R_t}\right)^{1.5} \cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} CR^{-1.0} \left(\frac{R_{outer}}{R_{inner}}\right)^{-3.4}\right]^{0.7} \cdot YOC_{fuel\ age} \cdot YOC_{low-mode}^{1.1}$

Adding known sources of "low-mode" does not change scalings much.

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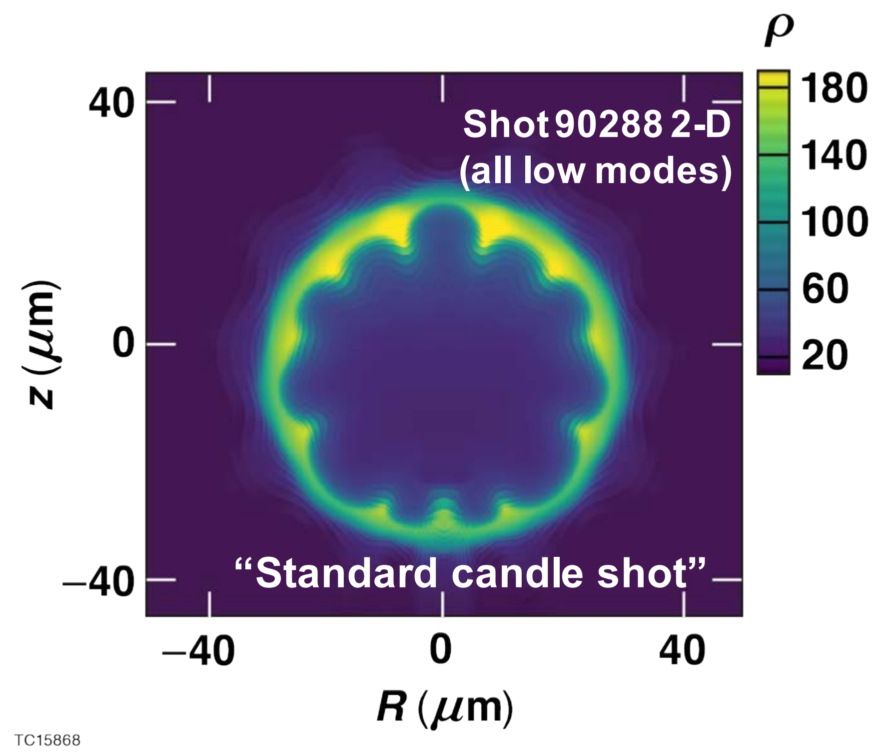

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Experiment over *DRACO* 2D (above + imprint*):	$\sim \left(\frac{R_b}{R_t}\right)^{0.7}$	$\cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} CR^{-1.0} \left(\frac{R_{outer}}{R_{inner}}\right)^{-3.4}\right]^{0.3}$	$\cdot YOC_{fuel\ age} \cdot YOC_{low-mode}^{1.0}$

Adding imprint reduces the hydro term and surprisingly affects R_b/R_t term as well.

* up to modes $\ell \leq 50$

For scaling with hydroscale factor, see Session CO04, C. Thomas et al

Y_{exp}/Y_{code} scaling should approach unity as one adds more complexity to the code

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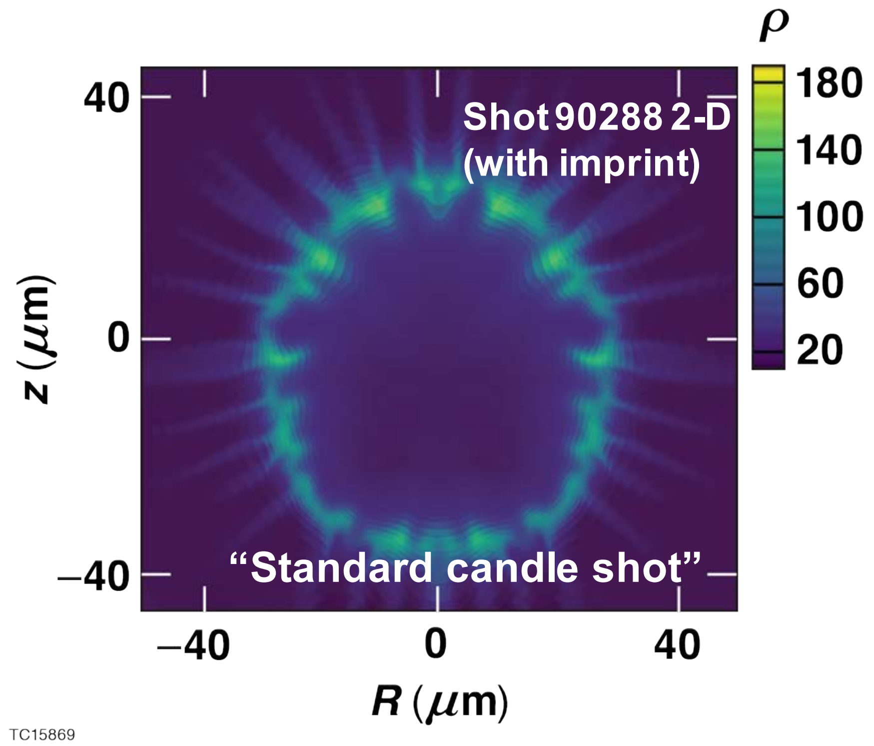

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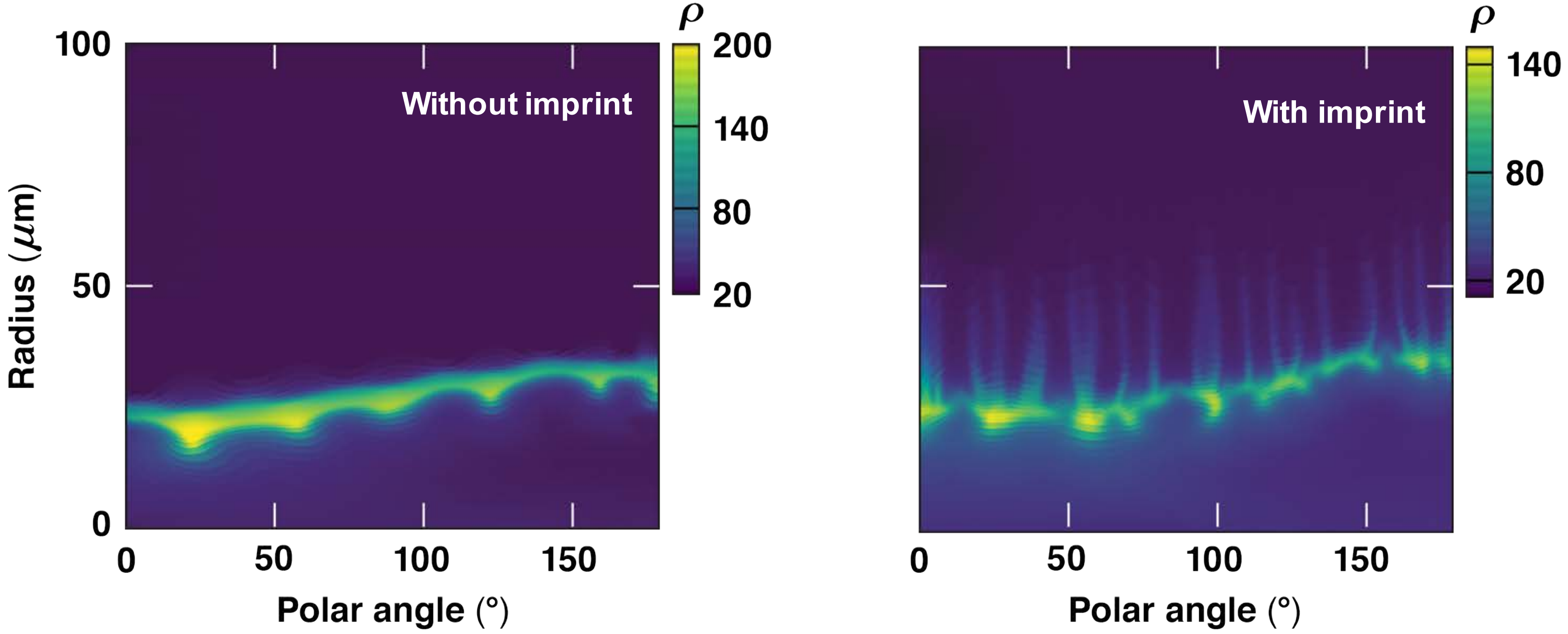
Density profiles suggest imprint enhances beam port geometry perturbation (quantification ongoing)

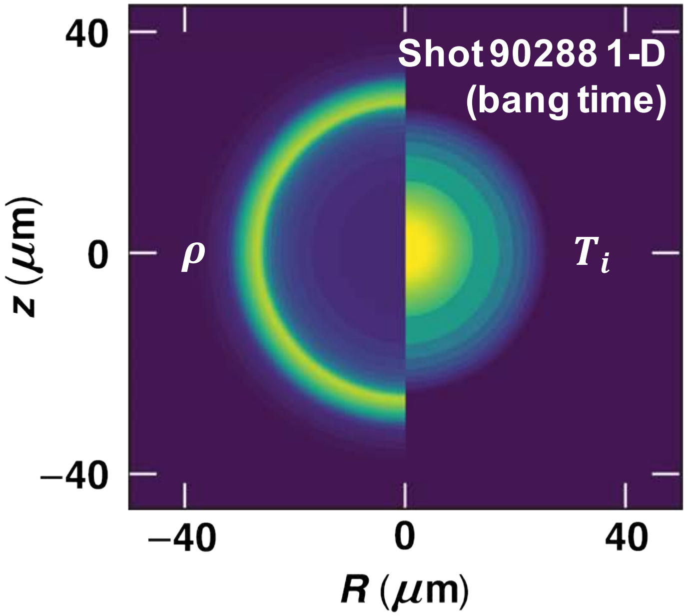
Radial unwraps at bang-time

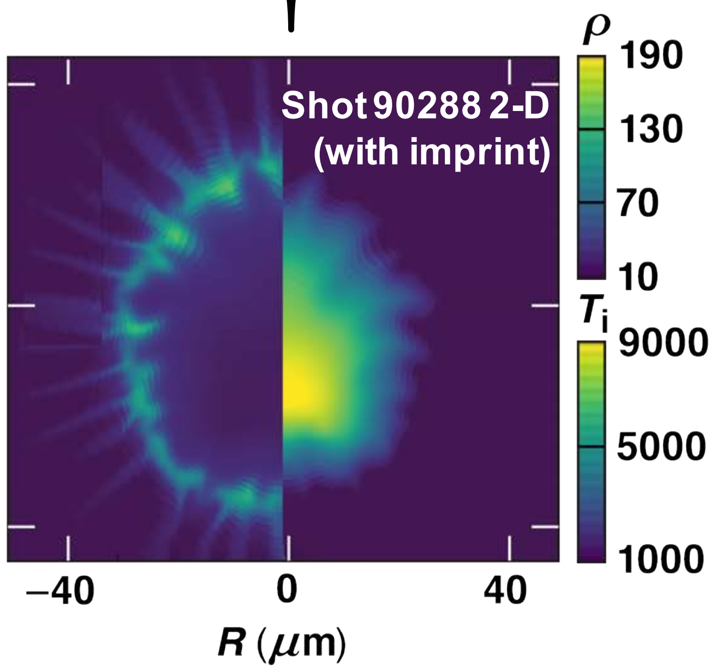


TC15870

"Leftover" scalings quantify the additional physics or perturbations that should be added to rad-hydro models

$$Y_{exp}/Y_{2-\mathrm{D}} \sim \left(\frac{R_\mathrm{b}}{R_\mathrm{t}}\right)^{0.7} \cdot \left[\left(\frac{s_\alpha}{0.8}\right)^{\eta} \mathrm{CR}^{-1.0} \left(\frac{R_\mathrm{outer}}{R_\mathrm{inner}}\right)^{-3.4}\right]^{0.3} \cdot \mathrm{YOC}_{\mathrm{fuel\ age}} \cdot \mathrm{YOC}_{\mathrm{low\ mode}}$$





Additional physics to account for:

- more imprint; some indications underestimated*
- add stalk
- 2D vs. 3D
- others?

TC15871

Even emulating what's missing will improve predictive capability, as long as it reproduces the residual scalings.

* M. M. Marinak *et al.*, Phys. Rev. Lett. **80**, 4426 (1998)

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