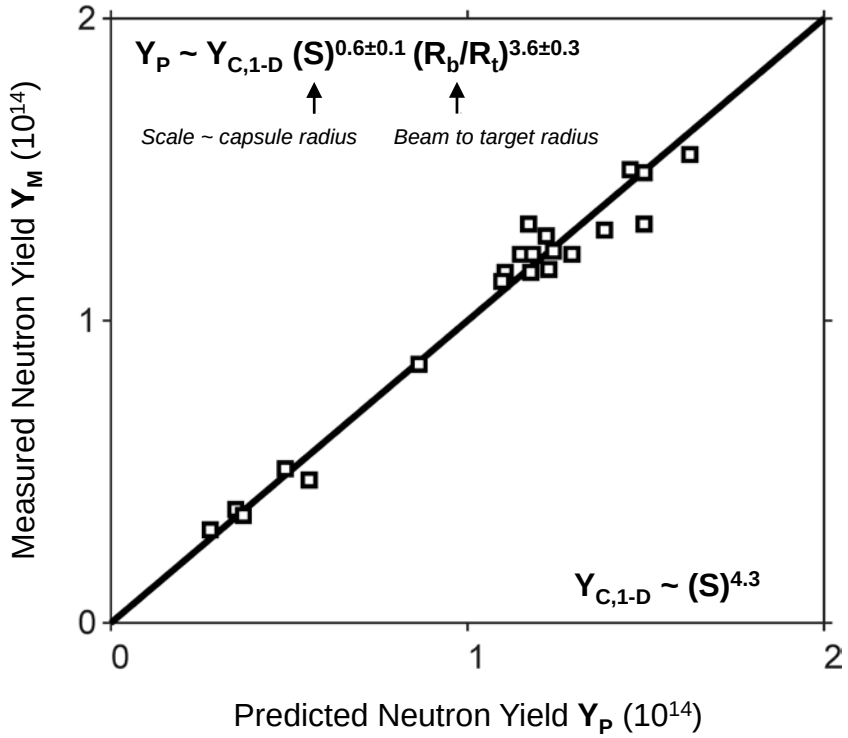
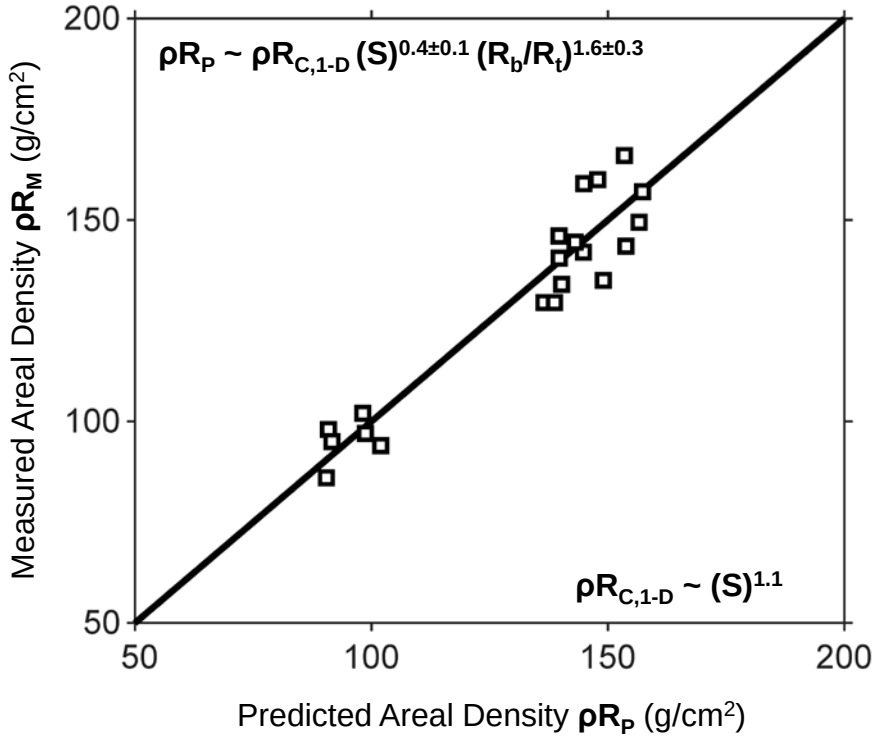
The analysis below is limited to experiments with the same laser pulse and ablator as shot 90288.

Quantifying the effects of scale and illumination geometry in Laser Direct Drive





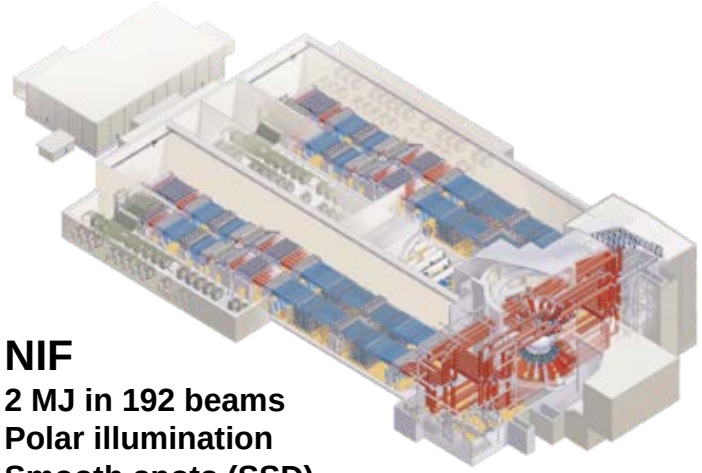
Cliff A. Thomas
University of Rochester
Laboratory for Laser Energetics

62nd APS Division of Plasma Physics
Virtual Meeting
November 9-13, 2020

Summary

Dedicated OMEGA shots have tested scale (S) and beam to target radius (R_b/R_t)

- Yield and areal density improve with capsule size and laser uniformity
- Results validate and refine previous analyses of the full database[1-3]
- Upcoming shots will test other factors, such as polar illumination[4,5]
- Experiments at NIF-scale could exceed simple hydro extrapolation



NIF
2 MJ in 192 beams
Polar illumination
Smooth spots (SSD)

1 V. Gopalaswamy *et al.*, Nature 565, 581 (2019).
2 A. Lees *et al.* TI01.00005.
3 R. Betti *et al.* BO09.00009.
4 P. B. Radha *et al.* BO09.00014.
5 W. Theobald *et al.* BO09.00010.
6 I. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).
7 I. Igumenshchev *et al.*, Phys. Plasmas 24, 056307 (2017).

Scale and beam-to-target radius can partly mitigate 3-D sources of degradation[6-7]

Collaborators

C.A. Thomas, D. Cao, W. Theobald, R. Betti, K.S. Anderson, K.A. Bauer, E.M. Campbell, A.R. Christopherson, T.J.B. Collins, R.S. Craxton, D.H. Edgell, R. Epstein, C.J. Forrest, V.Yu. Glebov, V. Gopalaswamy, I.V. Igumenshchev, S.T. Ivancic, D.W. Jacobs-Perkins, R.T. Janezic, T. Joshi, J.P. Knauer, J. Kwiatkowski, A. Lees, O.M. Mannion, F.J. Marshall, M. Michalko, Z.L. Mohamed, D. Patel, J.L. Peebles, P.B. Radha, S.P. Regan, H.G. Rinderknecht, M.J. Rosenberg, S. Sampat, T.C. Sangster, R.C. Shah, C. Stoeckl, V.N. Goncharov

Sensitivity studies at LLE benefit from experiments that are well-controlled and diagnosed that are widely separated in parameter space

Assume a power law? *Sources of error and uncertainty.*

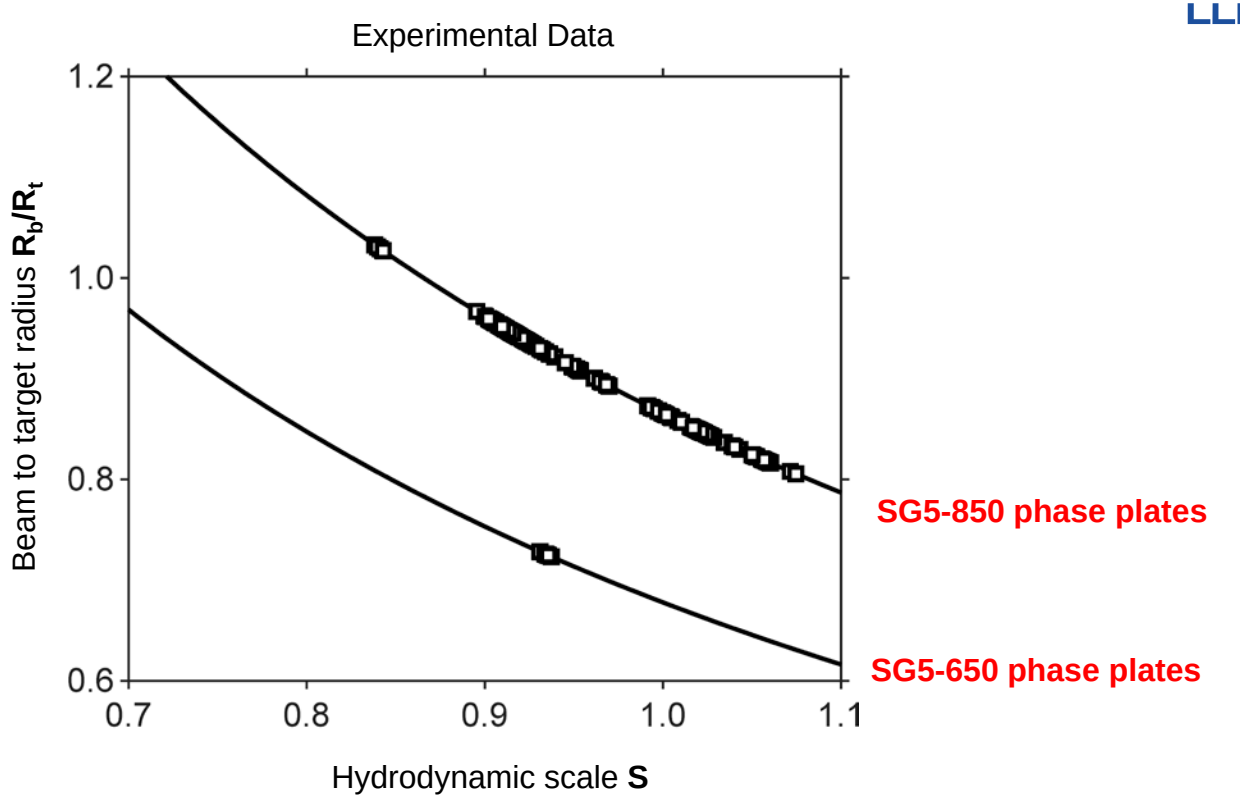
$$Y_{M,1} = C\, S_1^{X}\, Y_{C,1}\, (1+E_1)$$
$$Y_{M,2} = C\, S_2^{X}\, Y_{C,2}\, (1+E_2)$$
$$\vdots$$

$$Y_{M,1}/Y_{C,1} = C\, S_1^{X}\, (1+E_1)$$
$$Y_{M,2}/Y_{C,2} = C\, S_2^{X}\, (1+E_2)$$
$$\vdots$$

$$X \sim (\Delta Y/Y) / (\Delta S/S)$$

$$\Delta X \sim E\, N^{-1/2} / (\Delta Y/Y)$$

Number of measurements being averaged.



Statistical analyses let us correct for large asymmetries (e.g., L = 1), fuel age, and other factors, while testing aspects of physics[1-3]

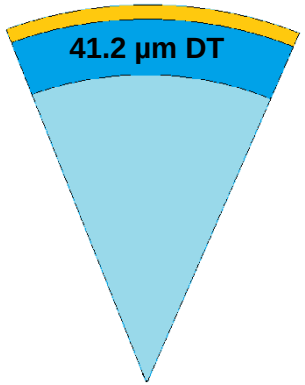
1 V. Gopalaswamy *et al.*, Nature 565, 581 (2019).
2 A. Lees *et al.* TI01.00005.
3 R. Betti *et al.* BO09.00009.

Scaling experiments use capsules and phase plates with all dimensions smaller by the same ratio (S = 0.8) to change yield > 2x

S = 1.0

R_b = 415 um
R_t = 479.4 um

7.6 μm CD



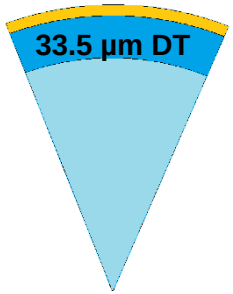
Y_{1D} = 4.3e14
ρR_{1D} = 180 mg/cm^2

E_L = 28 kJ

S = 0.8

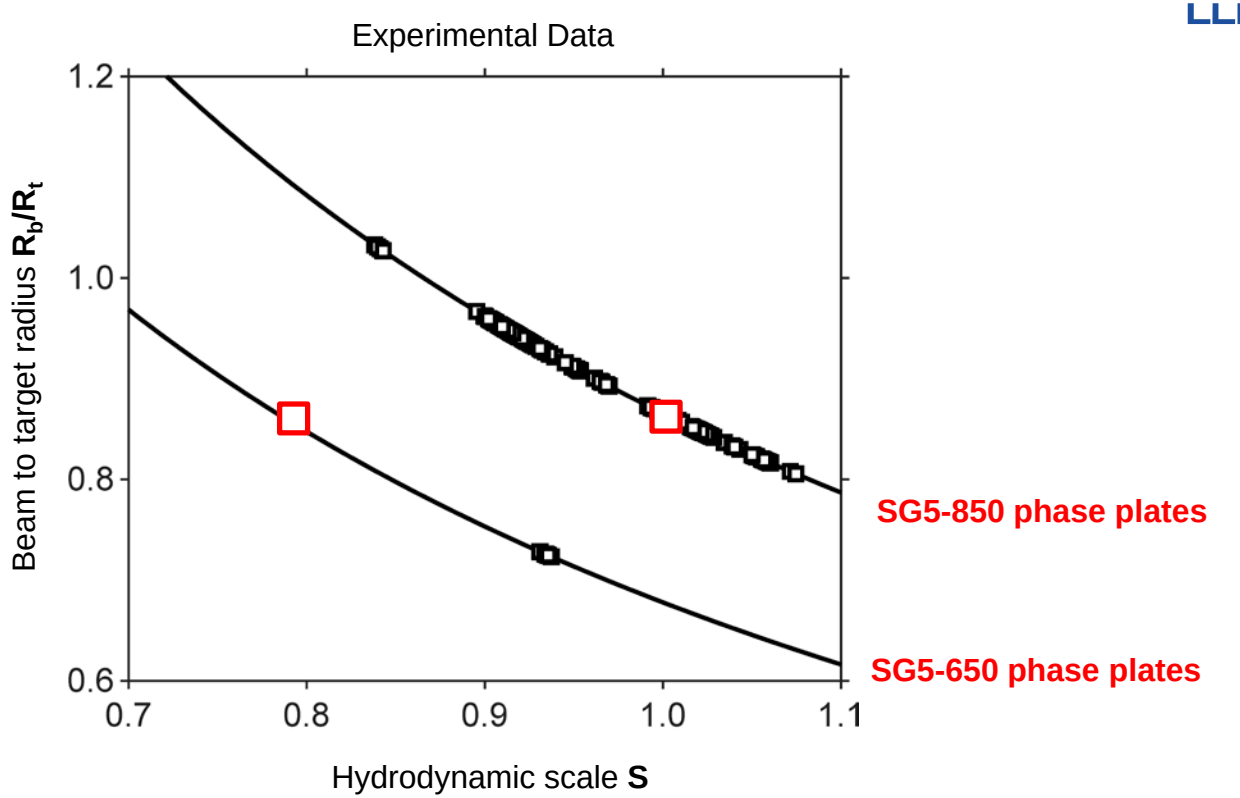
R_b = 325 um
R_t = 383.5 um

6.2 μm CD



Y_{1D} = 1.6e14
ρR_{1D} = 140 mg/cm^2

E_L = 14 kJ



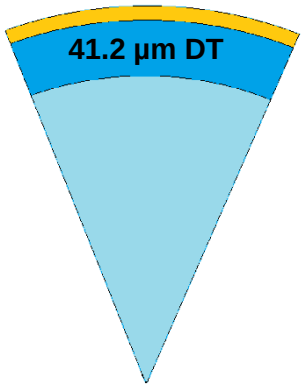
$Y \sim (S)^{X1} \sim (R_t)^{X1}$

Tests of R_b/R_t modify the laser spots independent of the capsule, and could change yield > 4x relative to 1-D LILAC

R_b/R_t = 0.87

R_b = 415 um
R_t = 479.4 um

7.6 μm CD



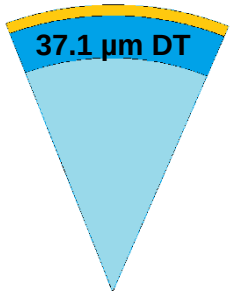
Y_{1D} = 4.3e14
ρR_{1D} = 180 mg/cm^2

E_L = 28 kJ

R_b/R_t = 0.97

R_b = 415 um
R_t = 431.5 um

6.8 μm CD



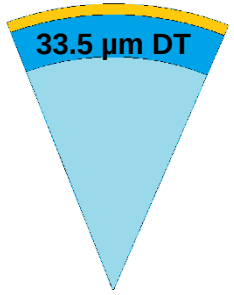
Y_{1D} = 2.7e14
ρR_{1D} = 160 mg/cm^2

E_L = 23.1 kJ

R_b/R_t = 1.07

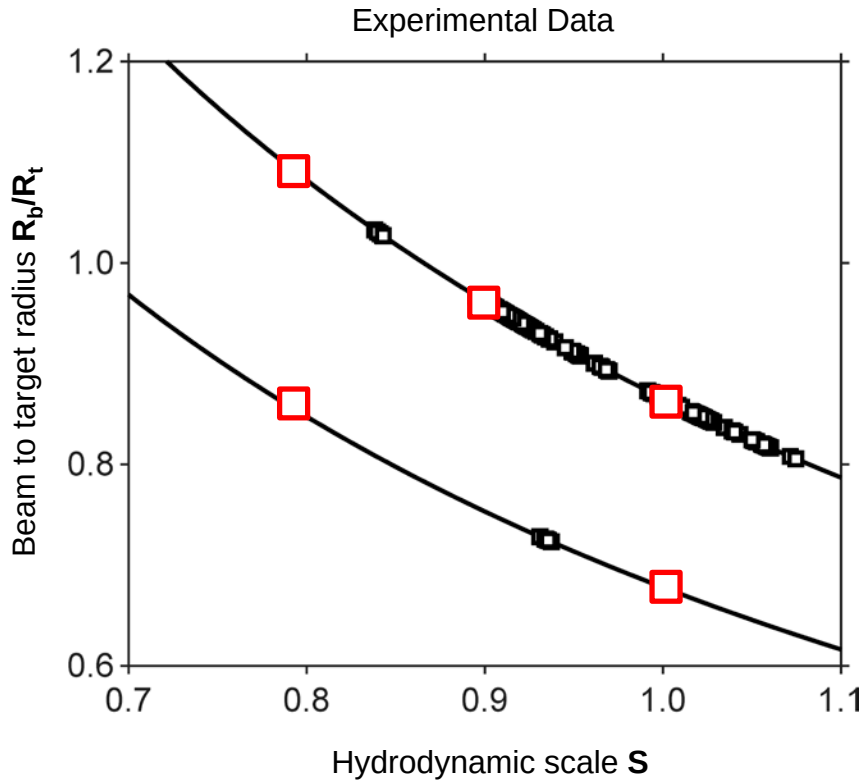
R_b = 415 um
R_t = 383.5 um

6.2 μm CD



Y_{1D} = 1.6e14
ρR_{1D} = 140 mg/cm^2

E_L = 18.9 kJ



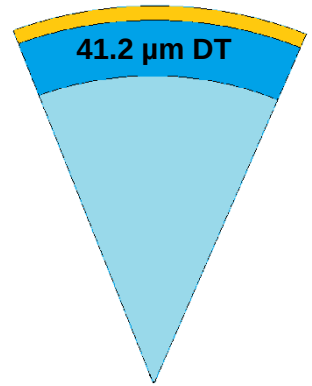
$$Y \sim (S)^{X1} (R_b/R_t)^{X2} \sim (R_t)^{X1-X2} (R_b)^{X2}$$

Accuracy is improved by varying both radii individually

R_b/R_t = 0.67

R_b = 325 um
R_t = 479.4 um

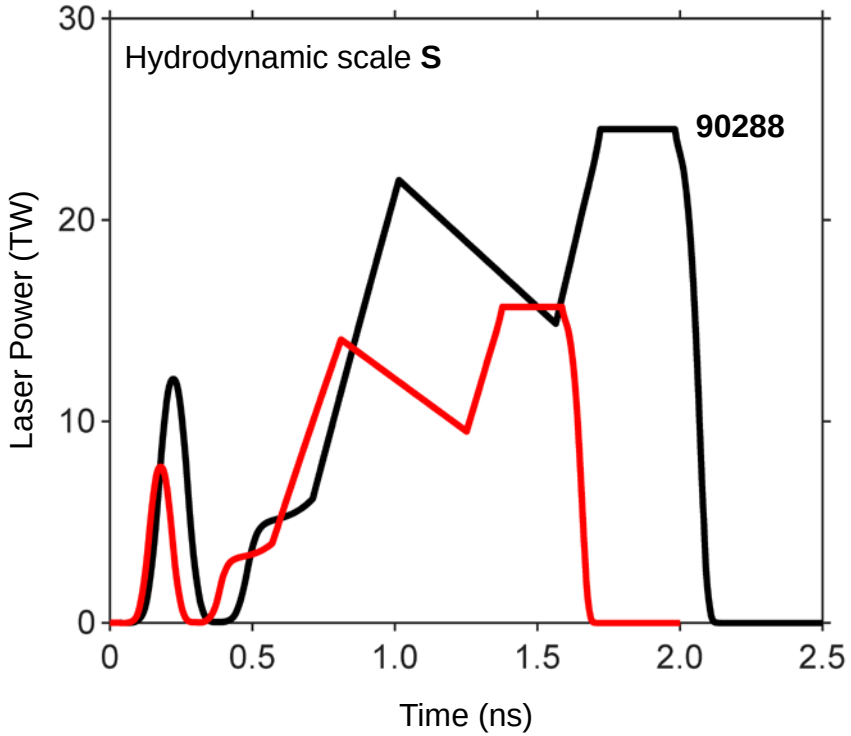
7.6 μm CD

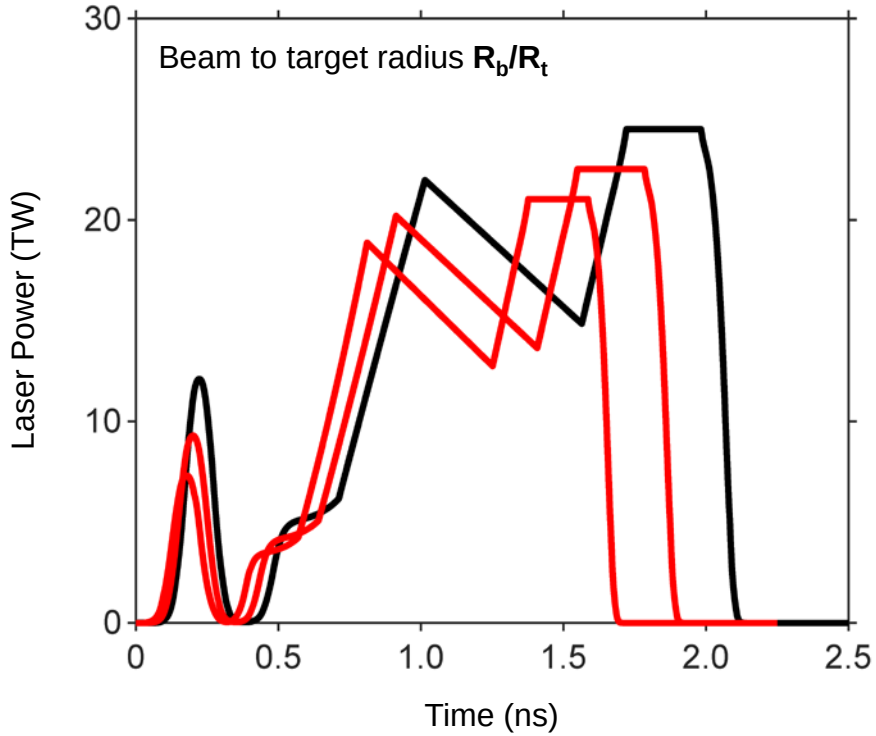


Y_{1D} = 6.6e14
ρR_{1D} = 180 mg/cm^2

E_L = 28 kJ

Uncertainty is reduced by using pulses that minimize changes in velocity, adiabat, IFAR, etc., to isolate scale and beam to target radius

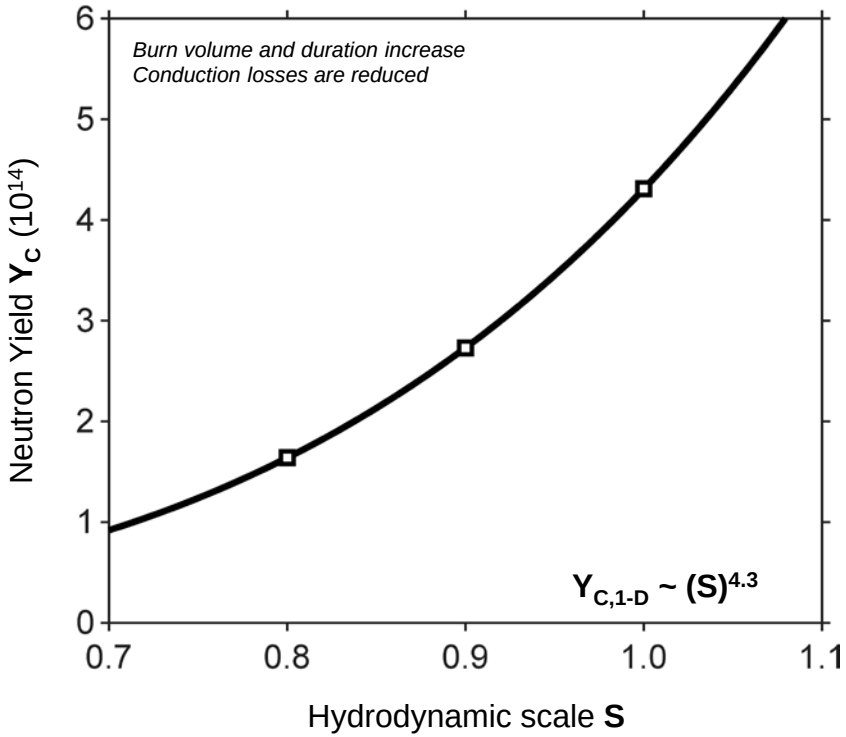


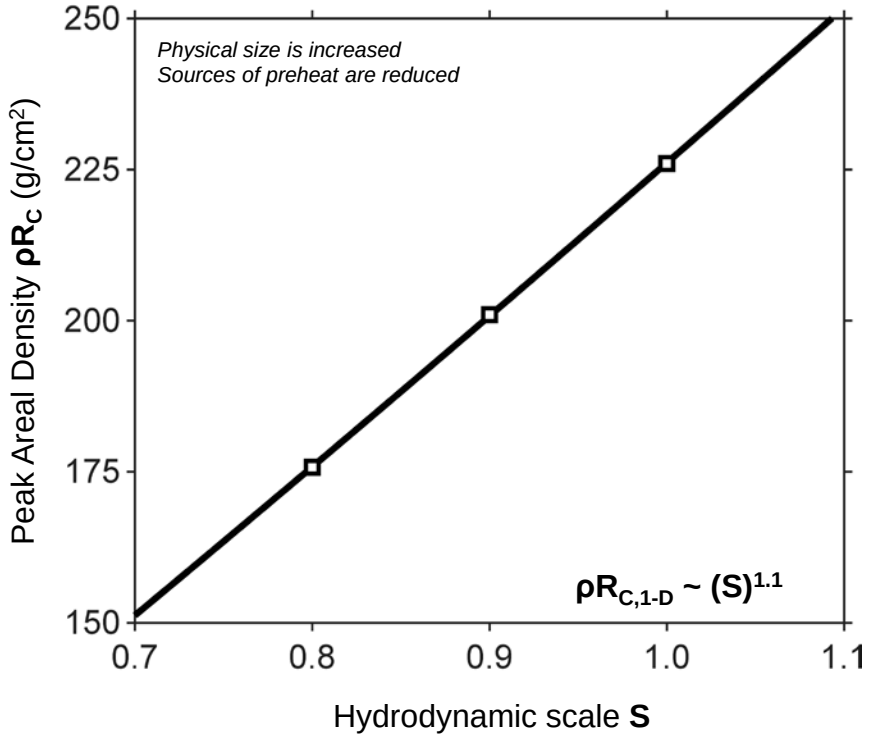


S	v (km/s)	adiabat	IFAR	BT/S (ns)
1.0	471	4.8	29	2.19
0.8	477	4.8	30	2.19

R_b/R_t	v (km/s)	adiabat	IFAR	BT/S (ns)
0.87	471	4.8	29	2.19
0.97	474	4.8	29	2.19
1.07	477	4.8	30	2.19

Calculations in 1-D LILAC serve as our reference[1-3] and account for small variations in the delivered laser pulse and target





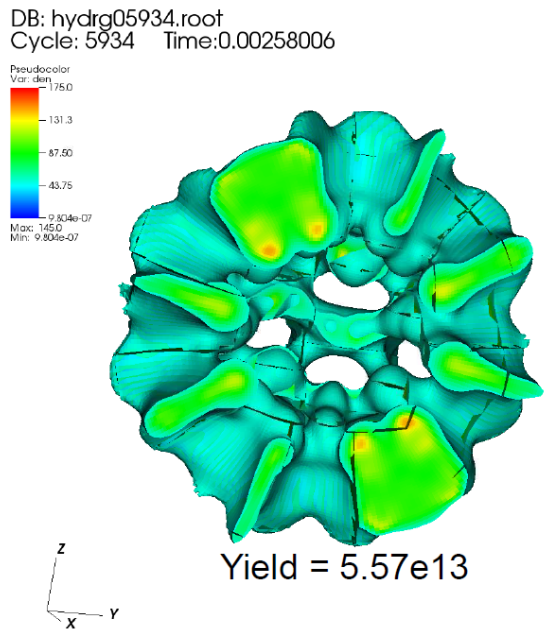
Deviation(s) from these trends suggest whether 2-D and 3-D physics impact performance[4,5]

1 V. Gopalaswamy *et al.,* Nature 565, 581 (2019).
2 A. Lees *et al.* TI01.00005.
3 R. Betti *et al.* BO09.00009.

4 I. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).
5 I. Igumenshchev *et al.*, Phys. Plasmas 24, 056307 (2017).

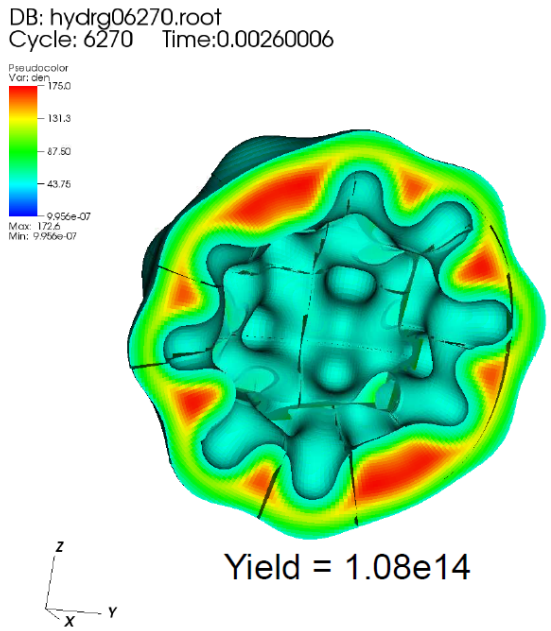
The OMEGA port geometry should imprint 3-D perturbations[1]

$R_b/R_t = 0.65$



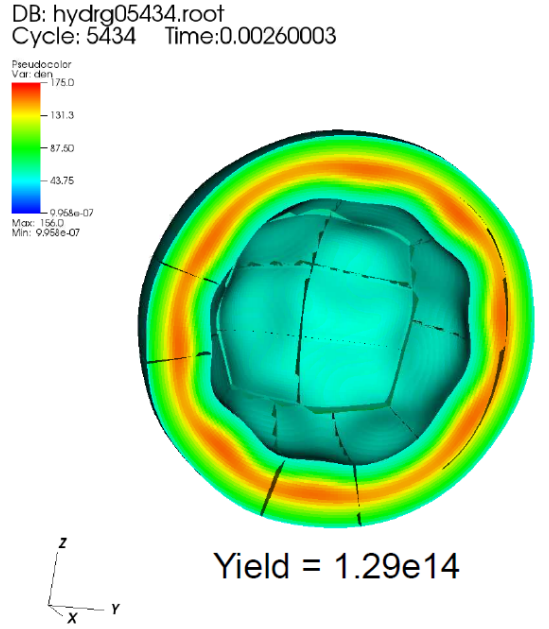
Yield = 5.57e13

$R_b/R_t = 0.75$



Yield = 1.08e14

$R_b/R_t = 0.85$



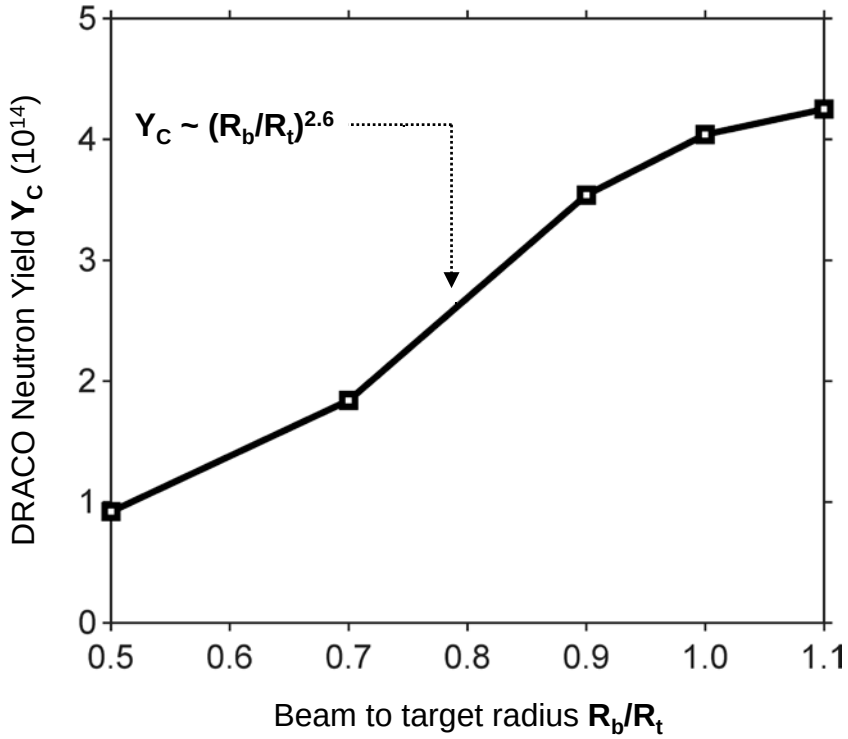
Yield = 1.29e14

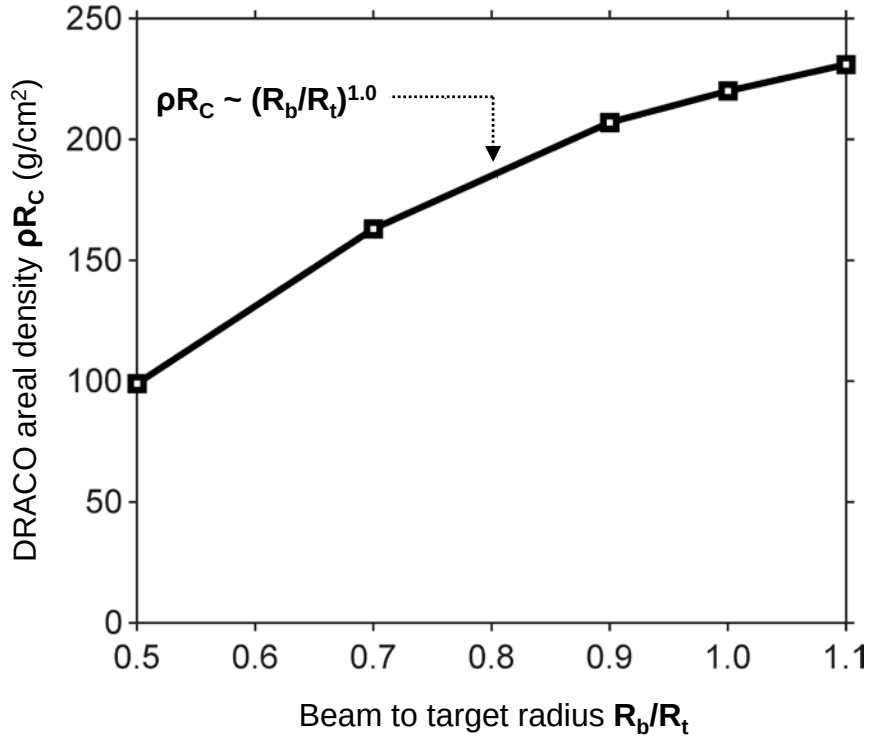
Existing experimental diagnostics are unable to resolve L = 10; it has to be inferred

1 Calculations in 3-D HYDRA courtesy of K. Anderson.

The calculations shown below are designed to keep the implosion velocity, adiabat, IFAR, etc. constant.

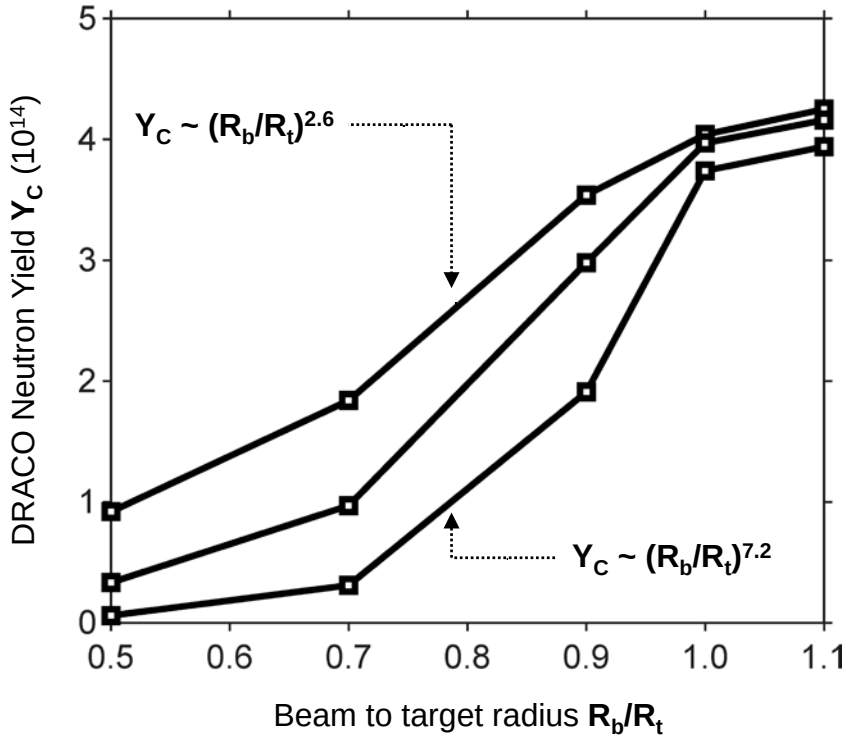
Calculations in DRACO predict a significant impact from L = 10 even in 2-D





Data should be 3-D and subject to laser imprint, as well as small imperfections in target fielding

R_b/R_t is predicted to be more important when failure modes couple; uncertainties in CBET, preheat, etc. could also play a role

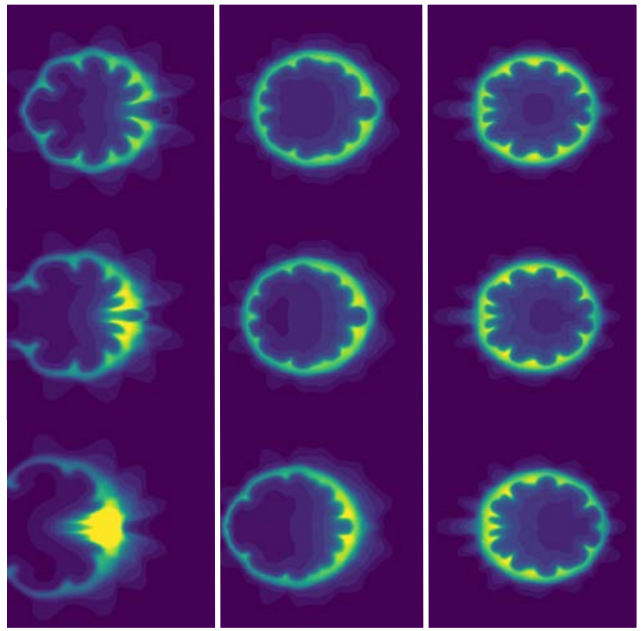


Target offsets

10 um

20 um

40 um



10 um

20 um

40 um

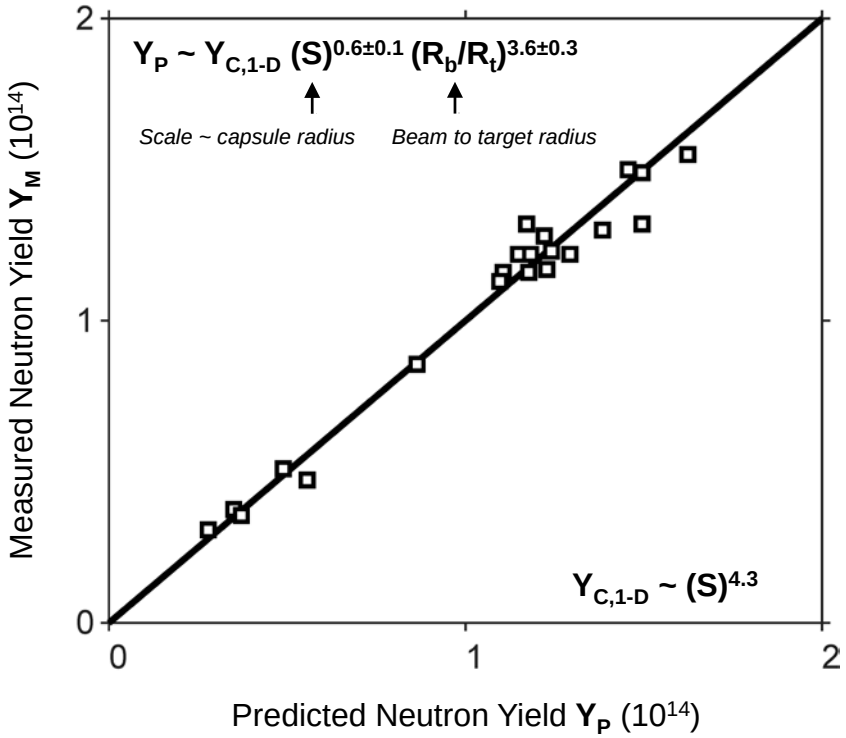
R_b/R_t = 0.7 **R_b/R_t = 0.9** **R_b/R_t = 1.1**

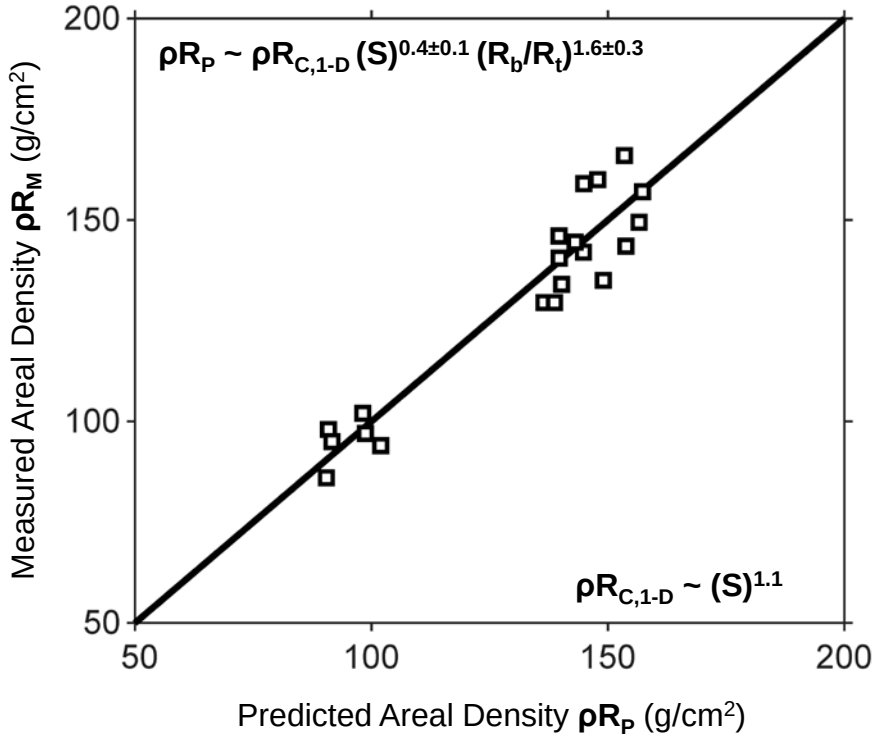
Can flaws in the target and facility be mitigated by operating at $R_b/R_t > 1$?

Are impacts a function of design? Laser intensity? Or the DT adiabat?

The analysis below is limited to experiments with the same laser pulse and ablator as shot 90288.

Initial results confirm benefits to scale and beam to target radius that are qualitatively consistent with calculations and prior findings





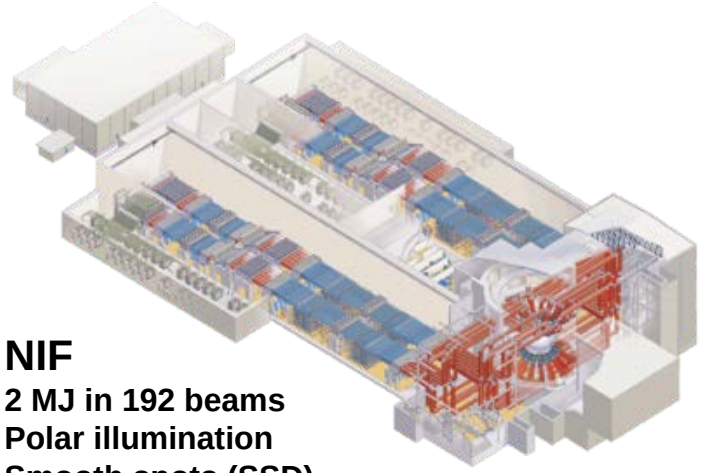
Results suggest performance can improve at $R_b/R_t > 1$ (experiments planned for November)

Experiments at NIF-scale could exceed simple theory – R. Betti *et al.* BO09.00009.

Summary/Conclusions

Dedicated OMEGA shots have tested scale (S) and beam to target radius (R_b/R_t)

- Yield and areal density improve with capsule size and laser uniformity
- Results validate and refine previous analyses of the full database[1-3]
- Upcoming shots will test other factors, such as polar illumination[4,5]
- Experiments at NIF-scale could exceed simple hydro extrapolation



NIF
2 MJ in 192 beams
Polar illumination
Smooth spots (SSD)

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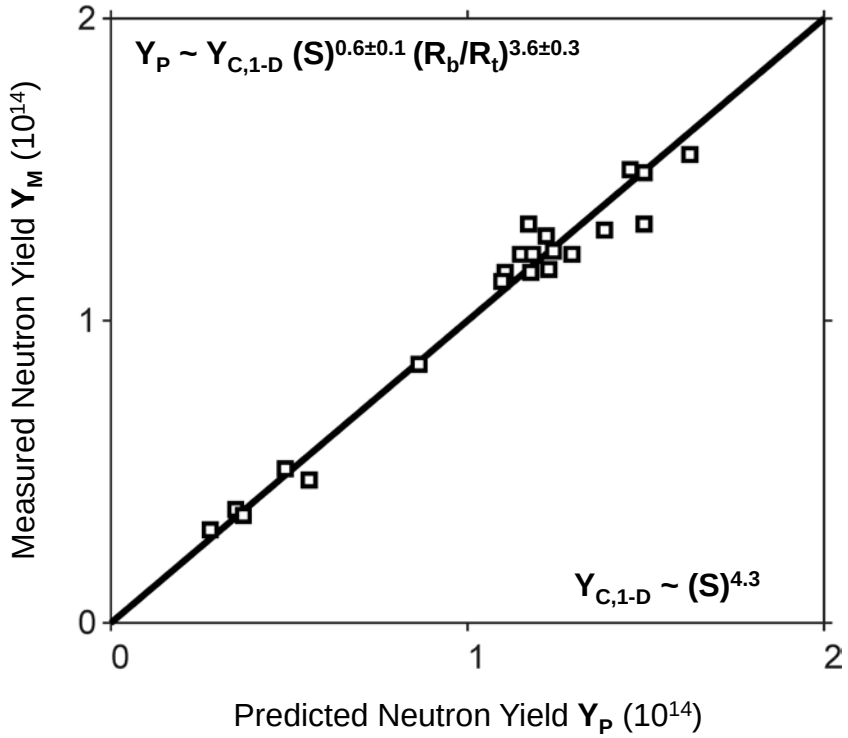
6 I. Igumenshchev *et al.*, Phys. Plasmas 23, 052702 (2016).
7 I. Igumenshchev *et al.*, Phys. Plasmas 24, 056307 (2017).

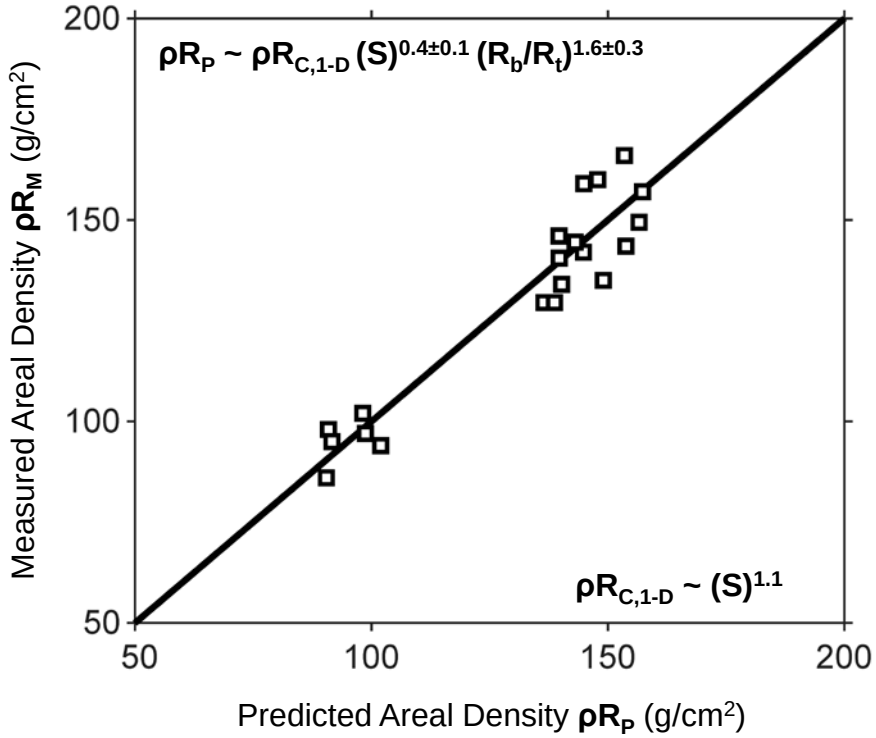
Planned experiments will improve statistics, check if findings are a function of adiabat or laser intensity, and test $R_b/R_t > 1$ (do results saturate, or continue to improve?)

Backups

The analysis below is limited to experiments with the same laser pulse and ablator as shot 90288.

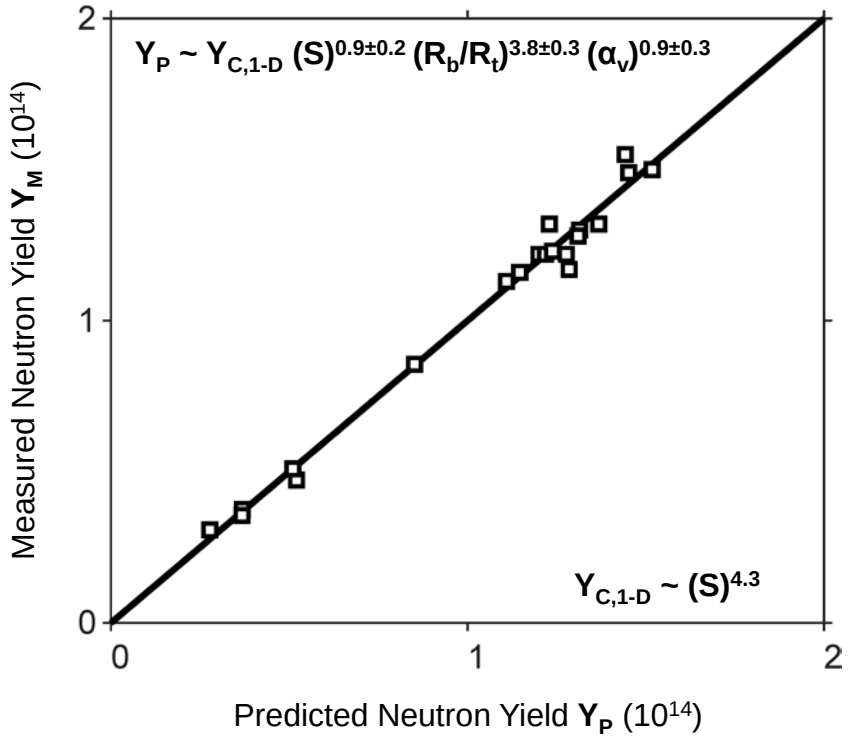
Analysis based on scale and beam to target radius

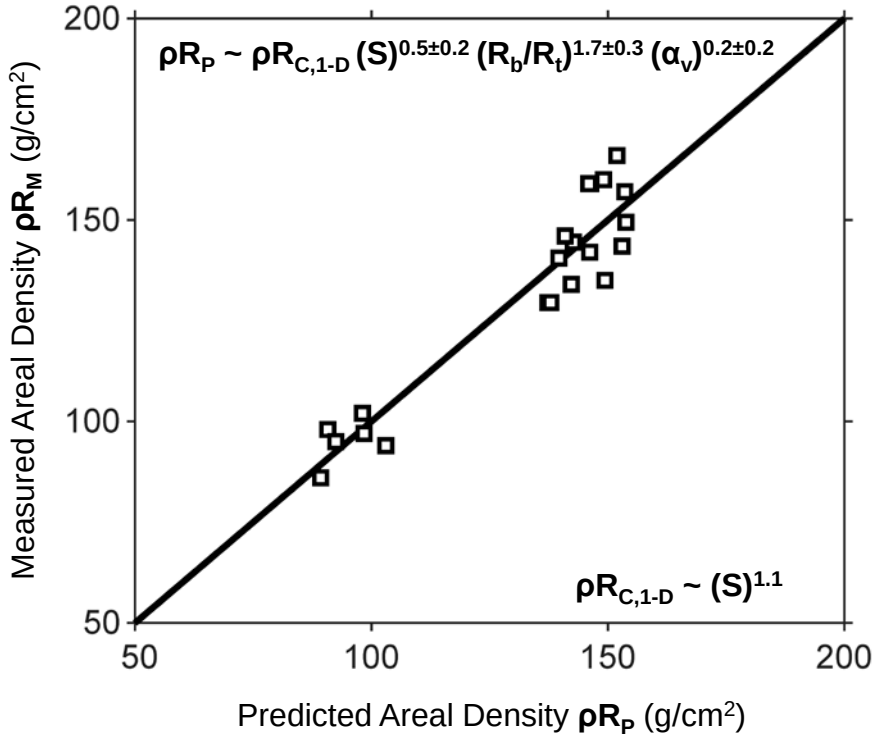




The analysis below is limited to experiments with the same laser pulse and ablator as shot 90288.

Analysis based on scale, beam to target radius, and calculated adiabat





Experiments suggest a tradeoff in 1-D energetics (scale) and symmetry (R_b/R_t) with implications to Laser Direct Drive at NIF[1-3]

$\rho R_{C,1\text{-}D} \sim (S)^{1.1} \sim (R_t)^{1.1}$ → $\rho R_P \sim \rho R_{C,1\text{-}D}\,(S)^{0.4\pm0.1}\,(R_b/R_t)^{1.6\pm0.3}$

$\rho R_P \sim (R_t)^{1.1+0.4-1.6}\,(R_b)^{1.6}$

$\rho R_P \sim (R_t)^{-0.1}\,(R_b)^{1.6}$

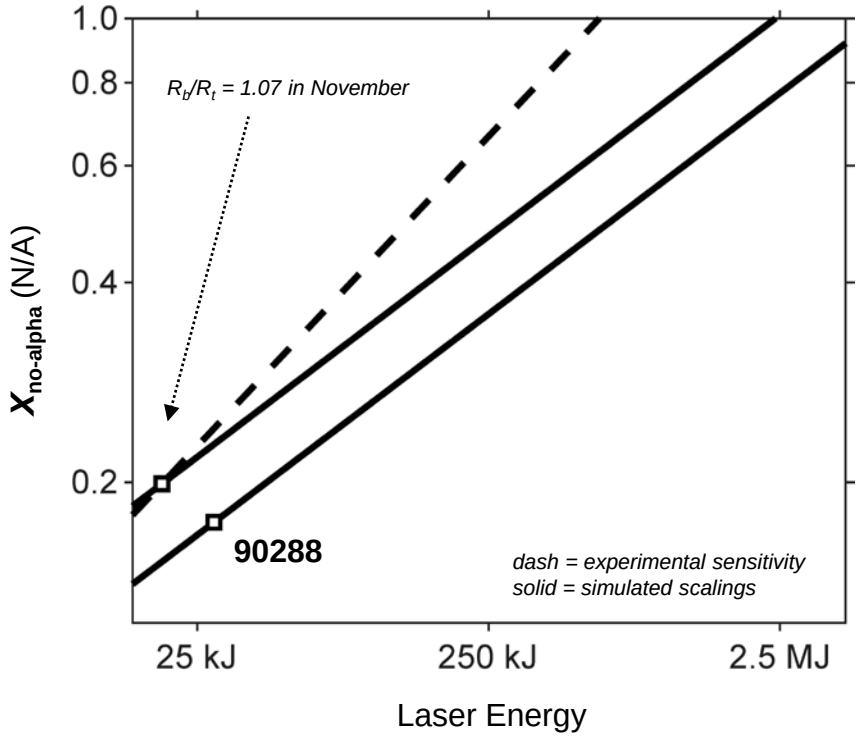
$Y_{C,1\text{-}D} \sim (S)^{4.3} \sim (R_t)^{4.3}$ → $Y_P \sim Y_{C,1\text{-}D}\,(S)^{0.6\pm0.1}\,(R_b/R_t)^{3.6\pm0.3}$

$Y_P \sim (R_t)^{4.3+0.6-3.6}\,(R_b)^{3.6} \sim (R_t)^{1.3}\,(R_b)^{3.6}$

$Y_P/M \sim (R_t)^{-1.7}\,(R_b)^{3.6}$

Potential 14% improvement for capsules that are smaller by 20%

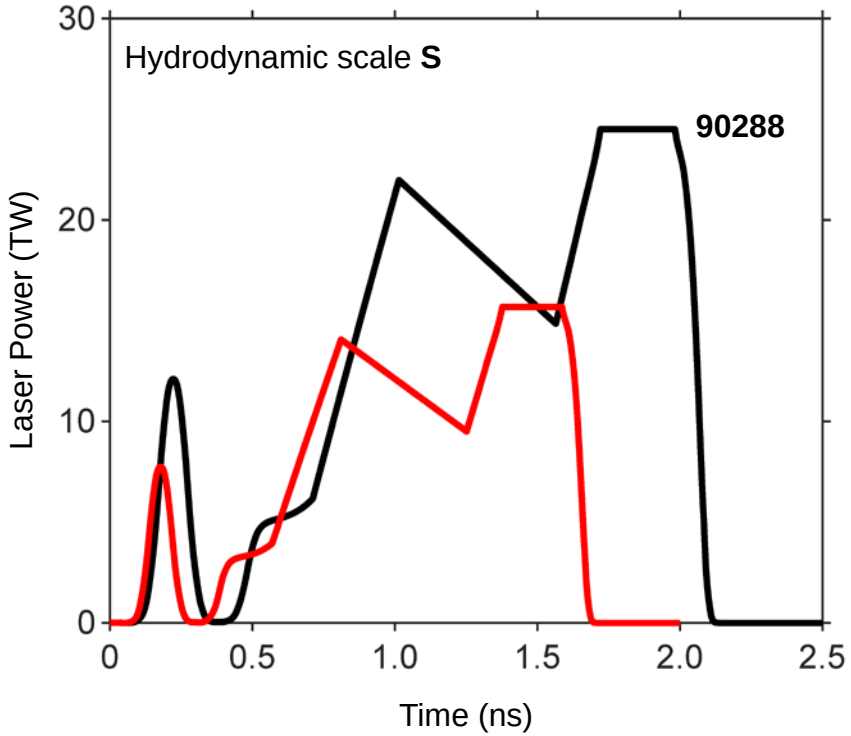
$X_{OMEGA} \sim (\rho R_P)^{0.6}\,(Y_P/M)^{0.3} \sim (R_t)^{-0.6}\,(R_b)^{2.0}$

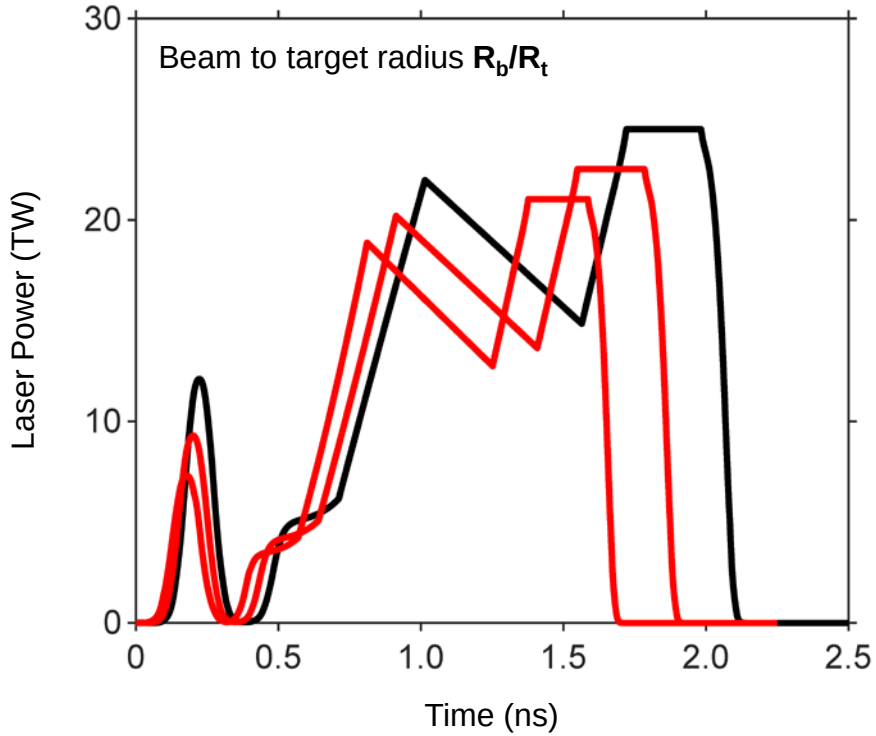


Any advantage from $R_b/R_t > 1$ will depend on the precise form of $Y(R_b/R_t)$ and how it saturates

1 V. Gopalaswamy *et al.*, Nature 565, 581 (2019).
2 A. Lees *et al.* TI01.00005.
3 R. Betti *et al.* BO09.00009.

Multipliers on the picket, foot and peak are designed using LILAC



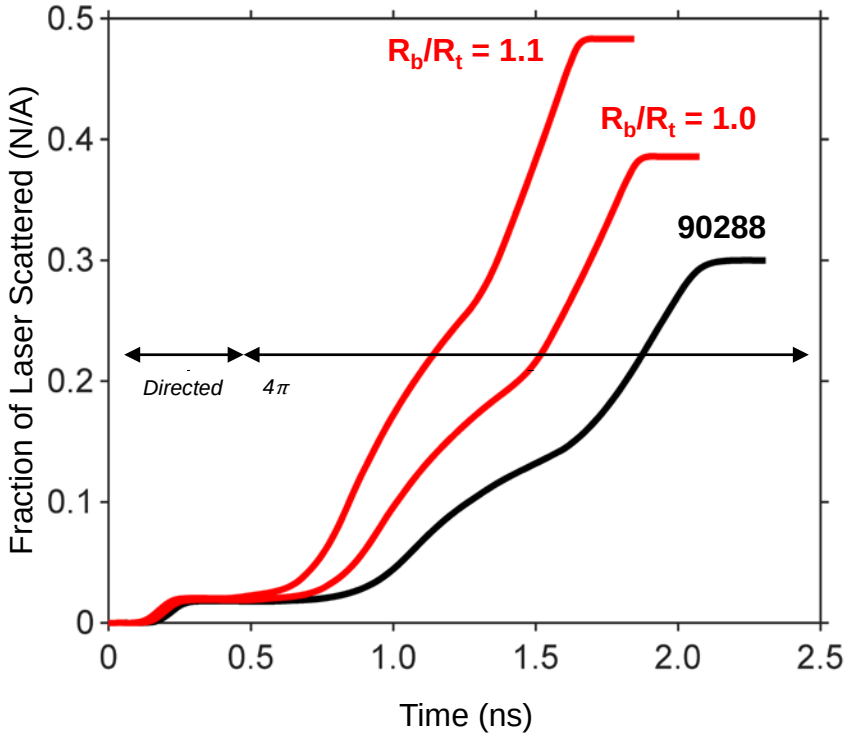


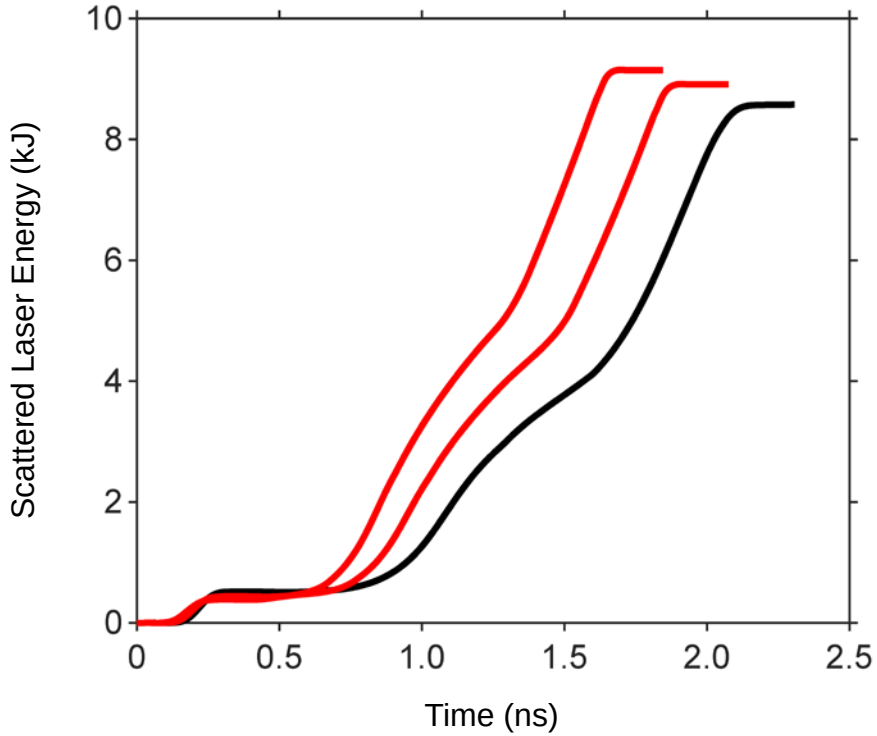
S	picket	foot	peak
1.0	1.00	1.00	1.00
0.8	0.64	0.64	0.64

R_b/R_t	picket	foot	peak
0.87	1.00	1.00	1.00
0.97	0.87	0.84	0.91
1.07	0.77	0.70	0.85

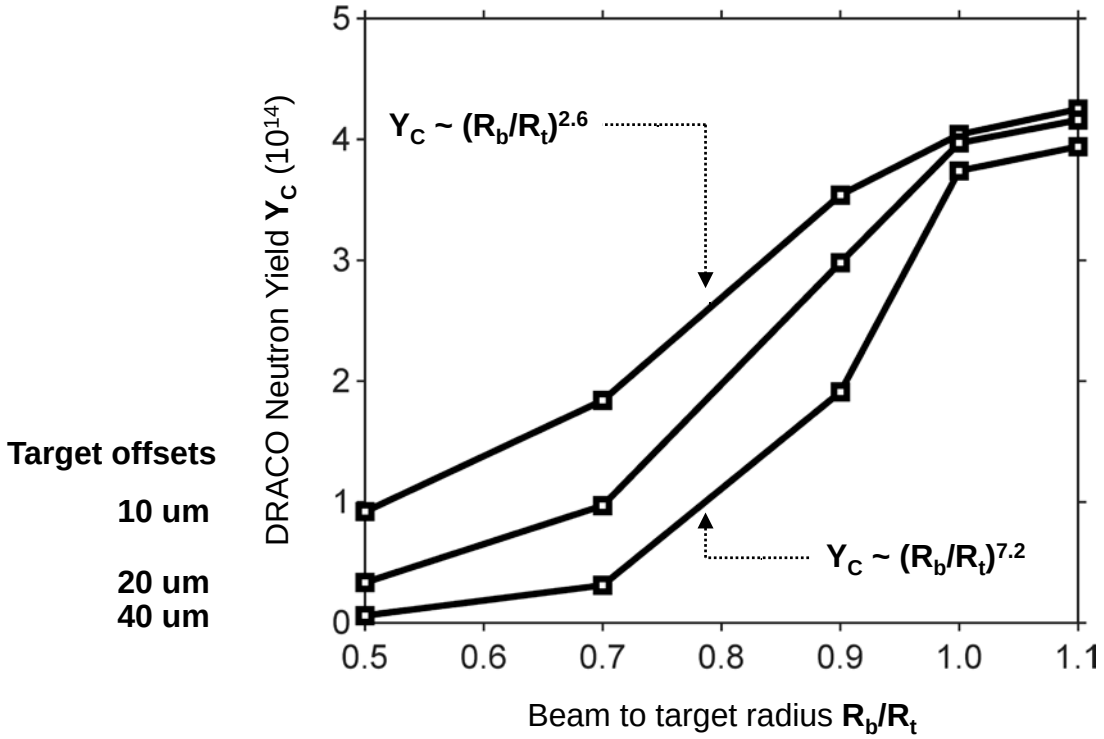
Headroom to increase TW or kJ

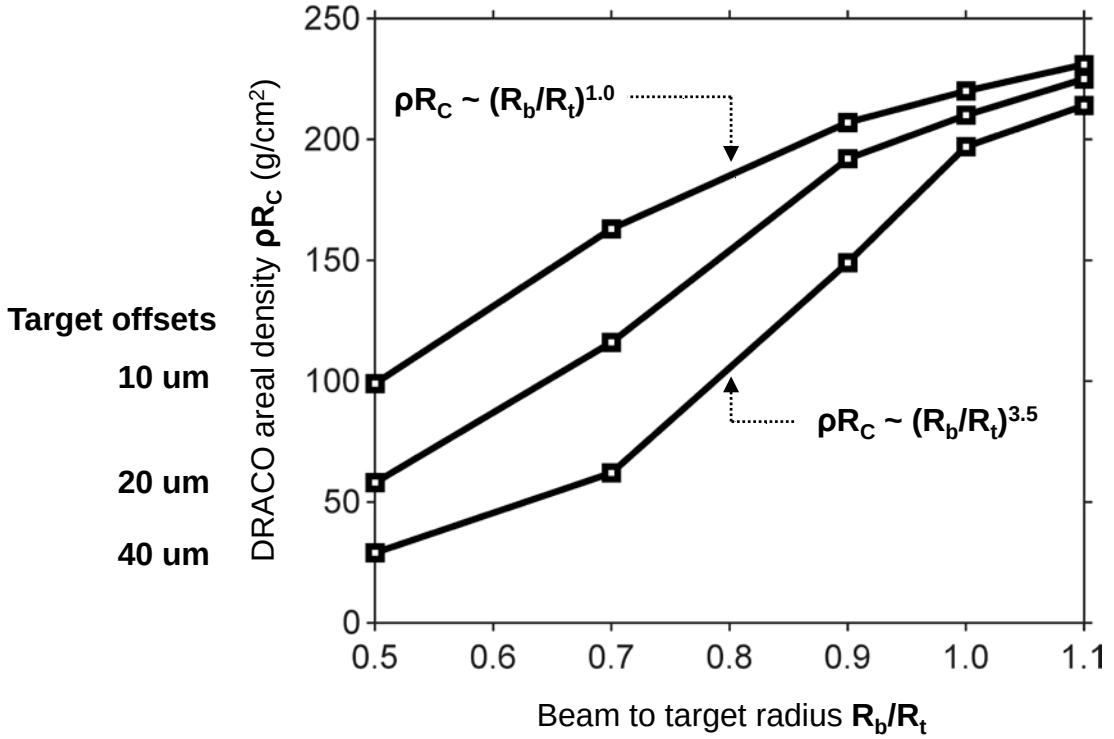
Targets with $R_b/R_t > 1$ absorb less energy





R_b/R_t is predicted to be more important when failure modes couple; uncertainties in CBET (spot profile vs time?), preheat, etc. could also play a role

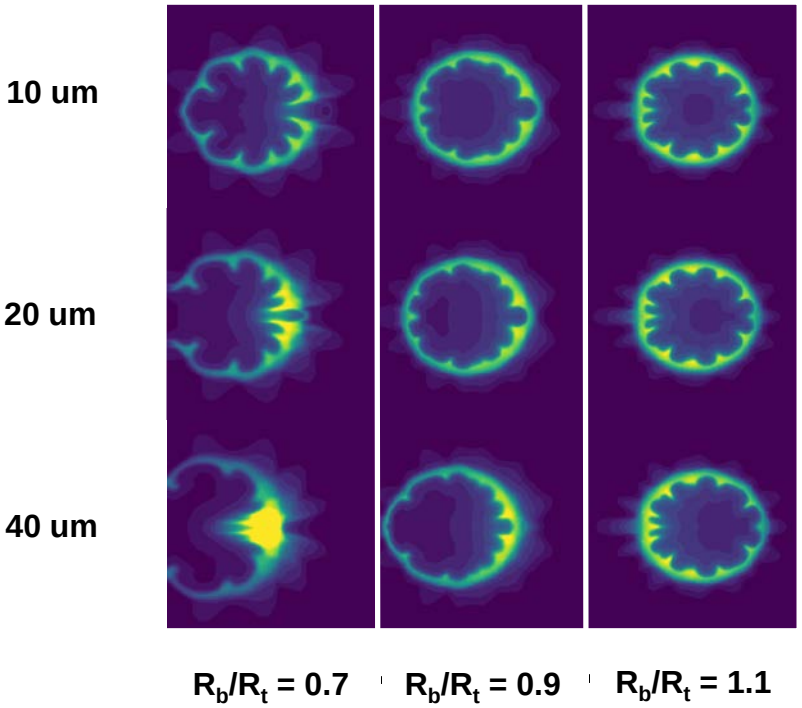


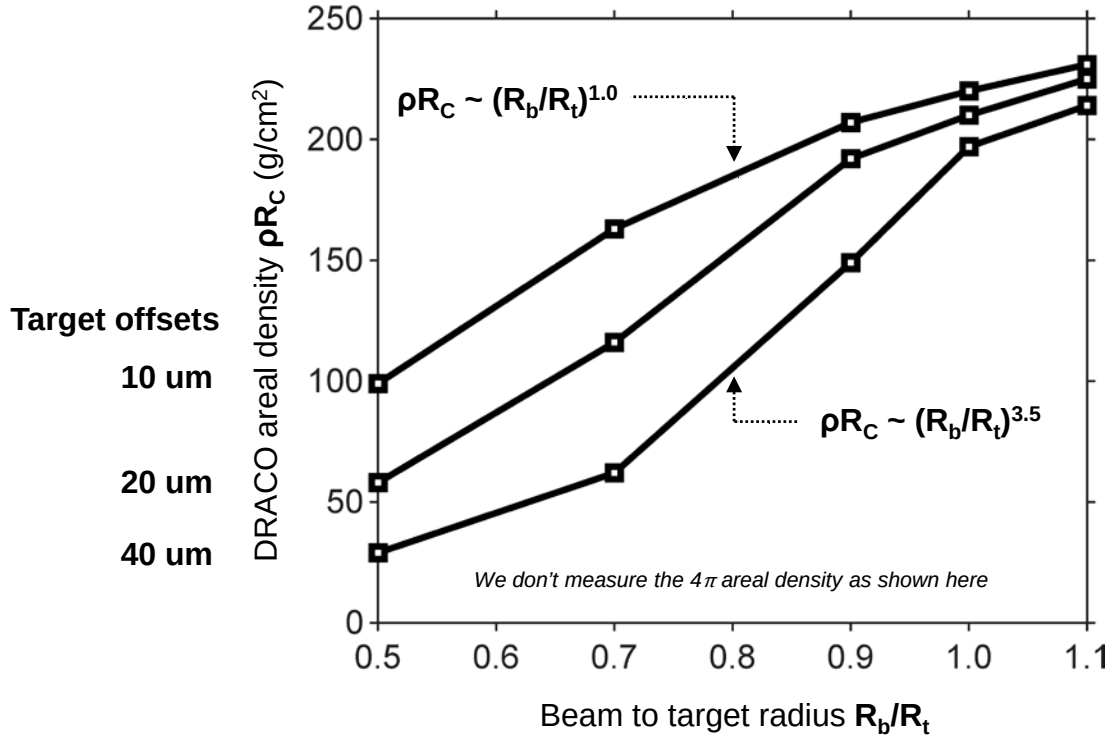


Can flaws in the target and facility be mitigated by operating at $R_b/R_t > 1$?

Are impacts a function of design? Laser intensity? Or the DT adiabat?

It is difficult to uniquely interpret the cold shell with existing diagnostics





Target offsets are common, and it is unlikely that we can see/sample the max or min ρR

MRS and KODI are important to constrain, uncertainty ~ 1/sqrt(number of measurements)

Important to fitting data?

1. 1-D energetics, velocity and adiabat
2. Modes 1 and 2
3. Port geometry (to help explain sensitivity to R_b/R_t)
4. Surrogate for imprint and instability (to further reduce areal density)
5. Hot-spot mass/mix