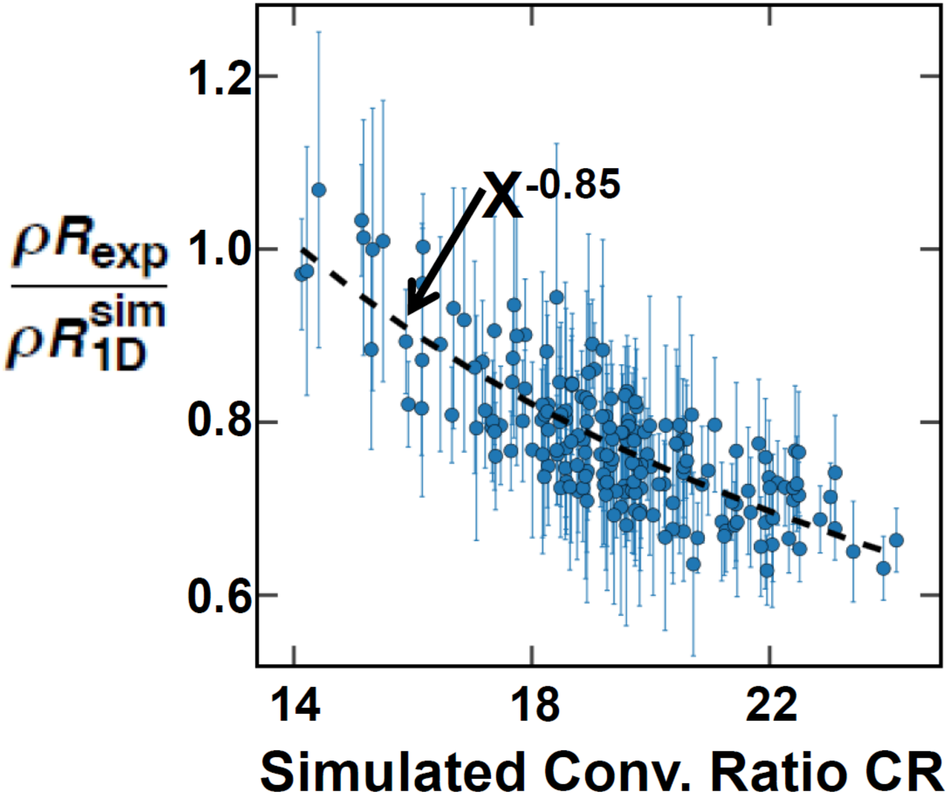
Experimentally Inferred Dependencies of the Ion Temperature, Areal Density, and Fusion Yield of OMEGA Direct-Drive Implosions



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Summary

Individual parametric dependencies of the fusion yield, areal density and ion temperature are quantified for OMEGA DT-layered implosions

- **Statistical modeling is used to extract individual dependencies of implosion performance**
- **Yields are degraded by short wavelength RT from laser imprinting, mid-modes from OMEGA illumination geometry, L=1 mode from offset and mispointing, and He^3 contamination from tritium decay**
- **Areal densities are degraded by convergence, short wavelength RT and L=1 mode**
- **Ion temperatures are degraded by short wavelength RT and He_3 contamination**

Collaborators

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R. T. Janezic, C. Fella and the Cryo Group
D. R. Harding, M. J. Bonino, and the Target Fabrication Group
S. Sampat, K. A. Bauer, and the System Science Group
S. F. B. Morse and the OMEGA Operations Group

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Plasma Science and Fusion Center
Massachusetts Institute of Technology

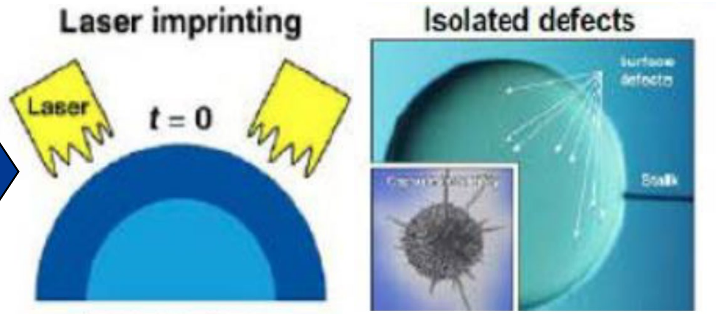
M. Farrell and C. Shuldberg
General Atomics

Relevant dimensionless parameters are identified[1-3] that determine performance degradation in OMEGA implosions

Short wavelength Rayleigh-Taylor (RT)

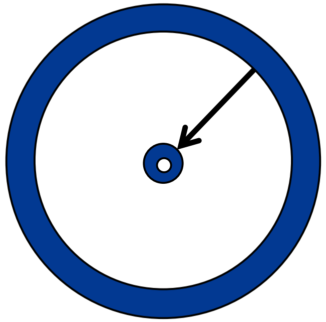
[4,5,6]

$$\frac{\alpha_F^{1.1}}{IFAR}$$



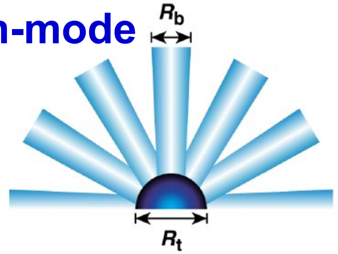
Convergence Ratio

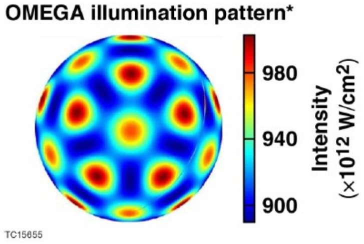
$$\frac{R_0}{R_{HS}}$$



Beam-mode

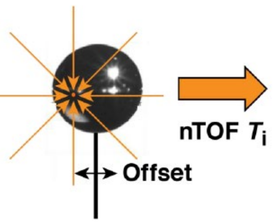
$$\frac{R_{beam}}{R_{target}}$$

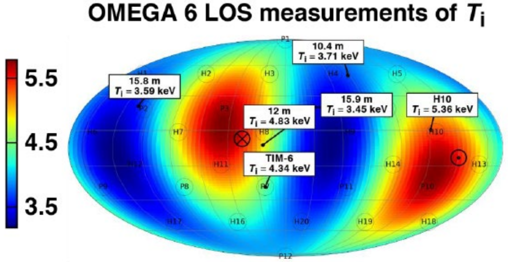




Mode L=1

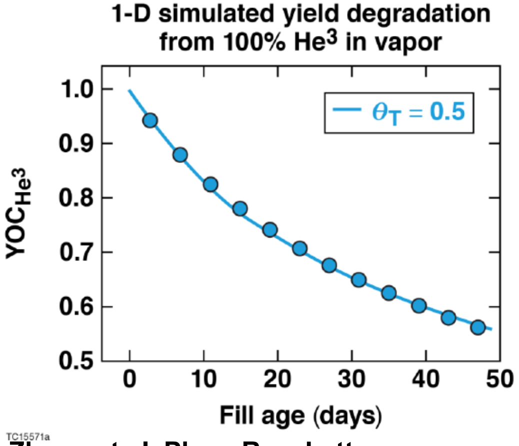
$$\frac{T_{max}}{T_{min}}$$





He^3 contamination from tritium decay

$$YOC_{He3}^{sim(1D)}$$



[1] A. Lees et al, submitted to PoP (2022)
[2] A. Lees et al, Phys. Rev. Lett. 127, 105001 (2021
[3] V. Gopalaswamy et al, Phys. Plasmas 28, 122705 (2021)
[4] V. Goncharov et al, Phys. Plasmas 21, 056315 (2014)
[5] H. Zhang et al, Phys. Rev. Lett.
[6] H. Zhang et al, Phis. Plasmas 27, 122701 (2020)

Statistical modeling[1] is used to extract individual parametric dependencies

$$YOC^{exp} \equiv \frac{Yield^{exp}}{Yield^{sim}_{1D}}$$

From 1D simulations — Post-shot

$$YOC^{exp} \approx YOC_{beam}\left(\frac{R_b}{R_t}, CR\right) YOC_{sw}(\alpha, IFAR) YOC_{L=1}\left(\frac{T^{max}_{exp}}{T^{min}_{exp}}\right) YOC_{He3}$$

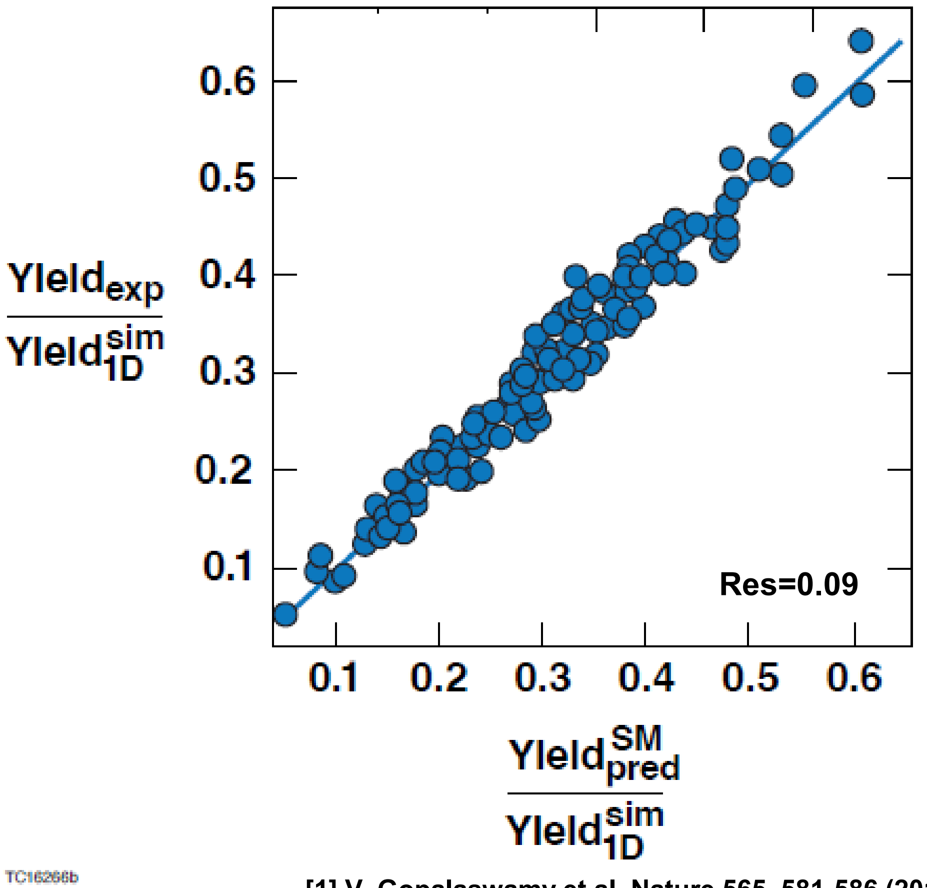
$$YOC^{exp} \approx \prod_{j=1,N} YOC_j$$

Individual parametric dependencies[2]

$$YOC_i^{exp} \approx \frac{YOC^{exp}}{\prod_{j\neq i} YOC_j}$$

For Stat Model mapped on 2D simulations see D. Cao CO05.00001
For DNN model see R. Ejaz TP11.00091

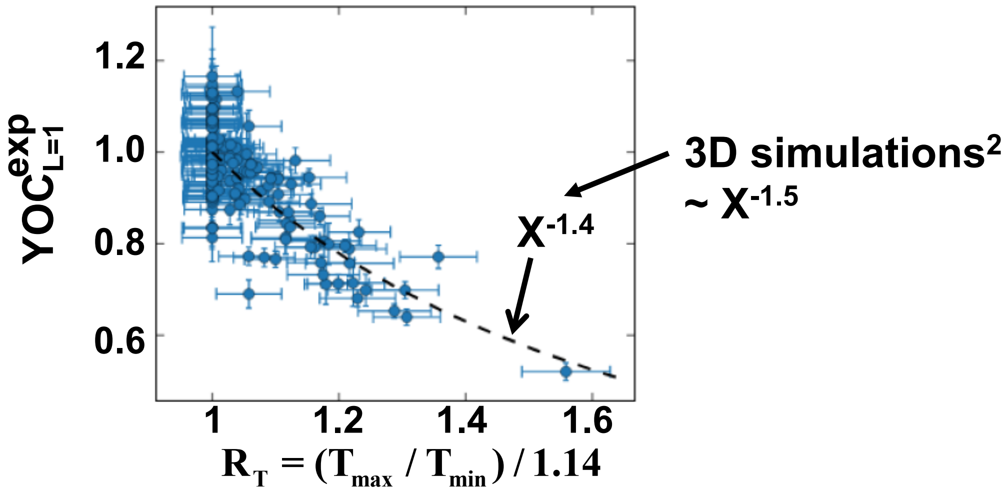
YOC measured vs YOC predicted



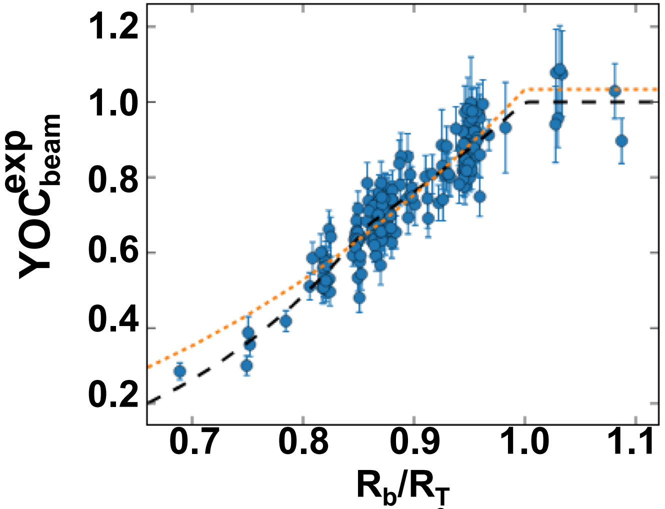
[1] V. Gopalaswamy et al, Nature 565, 581-586 (2019)
[2] A. Lees et al, Phys. Rev. Lett. 127, 105001 (2021)

Fusion-yield individual degradations are quantified[1]

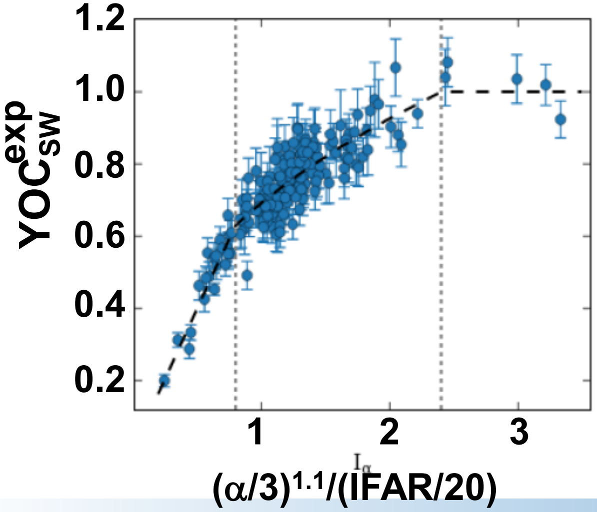
Degradation from mode L=1



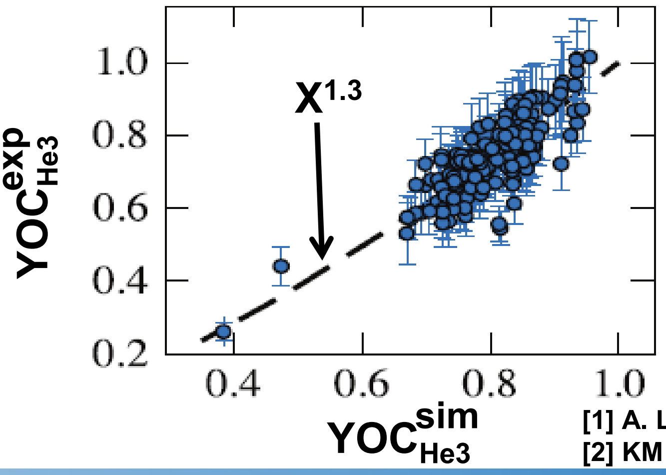
Degradation from beam mode



Degradation from short wavelength RT



Degradation from He3 accumulation



[1] A. Lees et al, Phys. Rev. Lett. 127, 105001 (2021)
[2] KM Woo et al, Phys. Plasmas 25, 052704 (2018)

The areal density is often anisotropic and can only be predicted if averaged over the entire solid angle

4π-average ρR degradation

$$\rho \mathrm{ROC}^{\mathrm{exp}} \equiv \frac{\langle \rho \mathrm{R} \rangle_{4\pi}^{\mathrm{exp}}}{\rho \mathrm{R}_{1\mathrm{D}}^{\mathrm{sim}}}$$

ρR degradation in the statistical model

$$\rho \mathrm{ROC}^{\mathrm{exp}} \approx \rho \mathrm{ROC}(\mathrm{CR})\, \rho \mathrm{ROC}(\alpha, \mathrm{IFAR})\, \rho \mathrm{ROC}_{\mathrm{L}=1}\left(\frac{\mathrm{T}_{\mathrm{exp}}^{\mathrm{max}}}{\mathrm{T}_{\mathrm{exp}}^{\mathrm{min}}}\right)$$

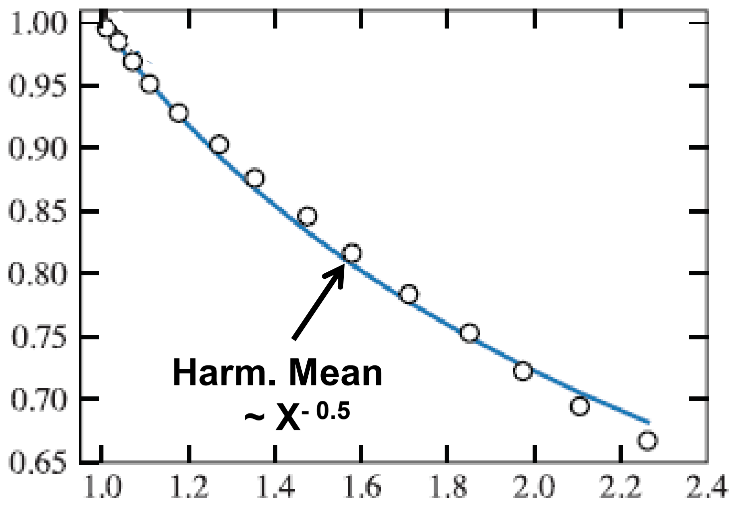
beam mode? short wav RT

- Currently, the SM model uses the average ρR from two LOS. Uses DSR from Magnetic Recoil Spectrometer (MRS)[2] and nT backscatter edge from 13.4m NTOF[3]

$$\rho \mathrm{ROC}_{3D}^{sim} \equiv \frac{\langle \rho \mathrm{R} \rangle_{4\pi}}{\rho \mathrm{R}_{1D}}$$

DEC3D Simulations[3]

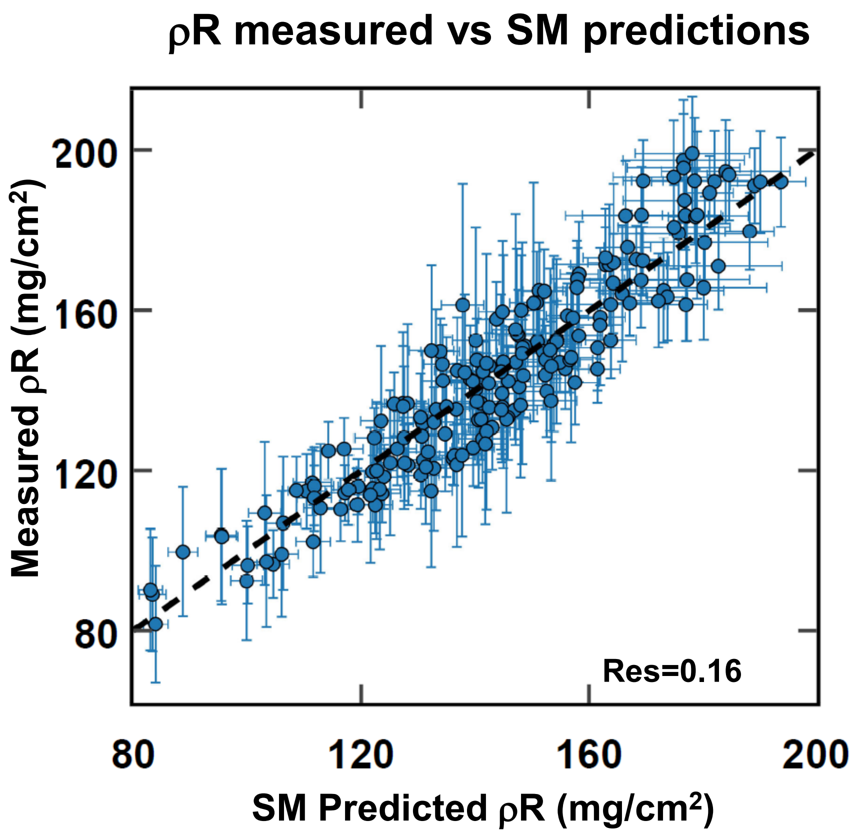
Degradation of 4π-average ρR from mode L=1

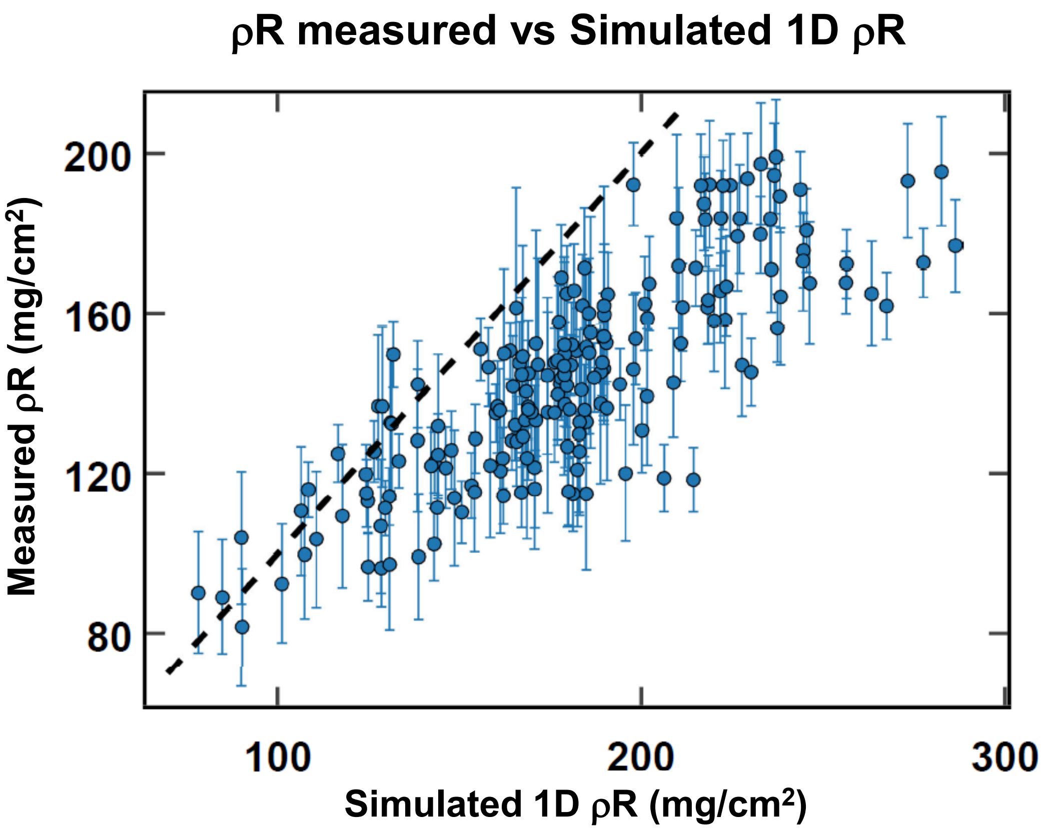


T_{max}/T_{min}

[1] J. Frenje et al, Rev. Sci. Instrum. 79, 10E502 (2008) [2] C.J. Forrest et al, Rev. Sci. Instrum. 83, 10D919 (2012) [3] K.M. Woo, Phys. Plasmas 28, 054503 (2021)

Areal density predictions are less accurate than yield predictions and measured ρR deviates from simulated ρR at high ρR

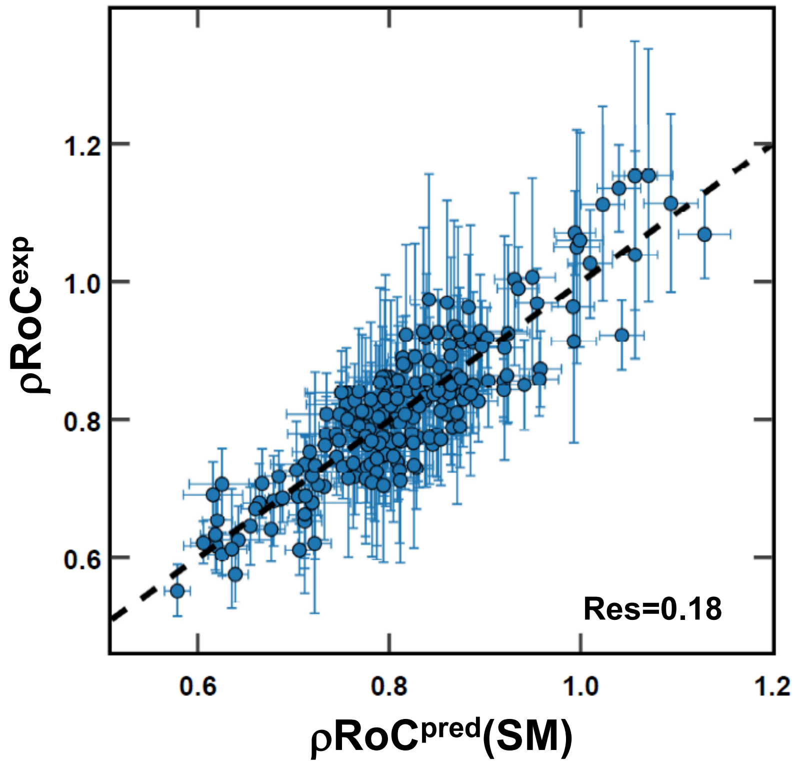




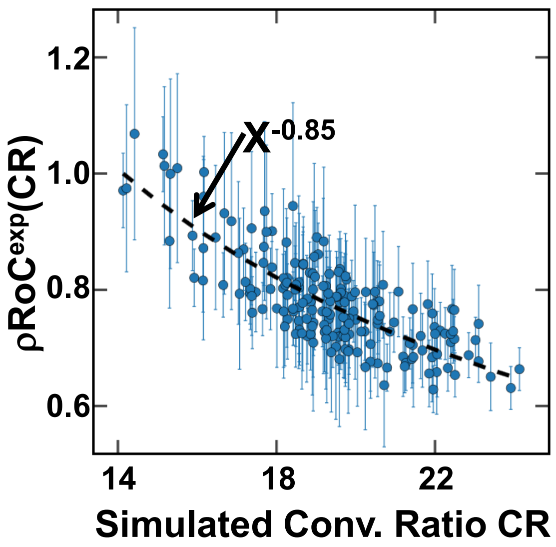
ρR degradation with respect to simulated 1D comes from convergence, short wavelength RT and L=1 mode

ρR degradation ➔ $$\rho\text{RoC} = \frac{\langle \rho R \rangle^{\exp}_{2LOS}}{\rho R^{\text{sim}}_{1D}}$$

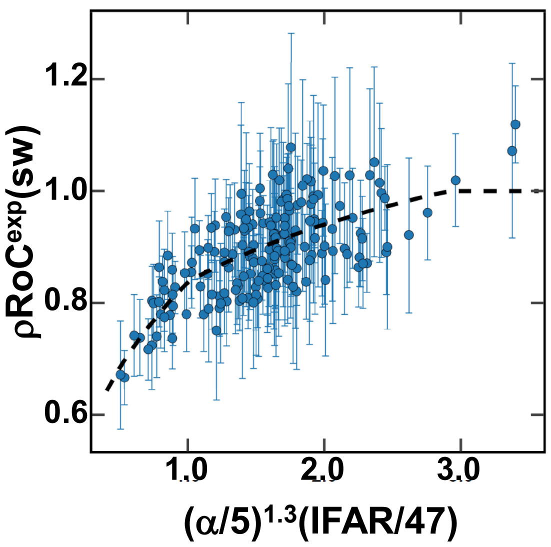
ρRoC measured vs SM predictions



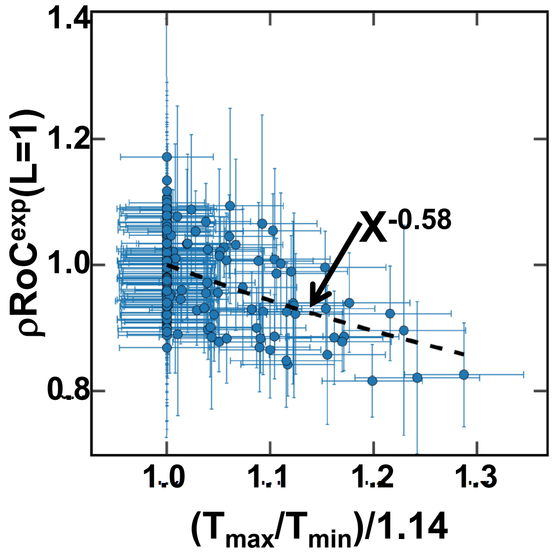
Degradation from convergence



Degradation from short wav. RT

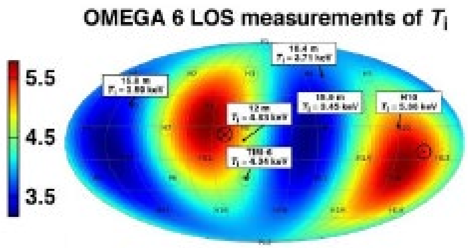


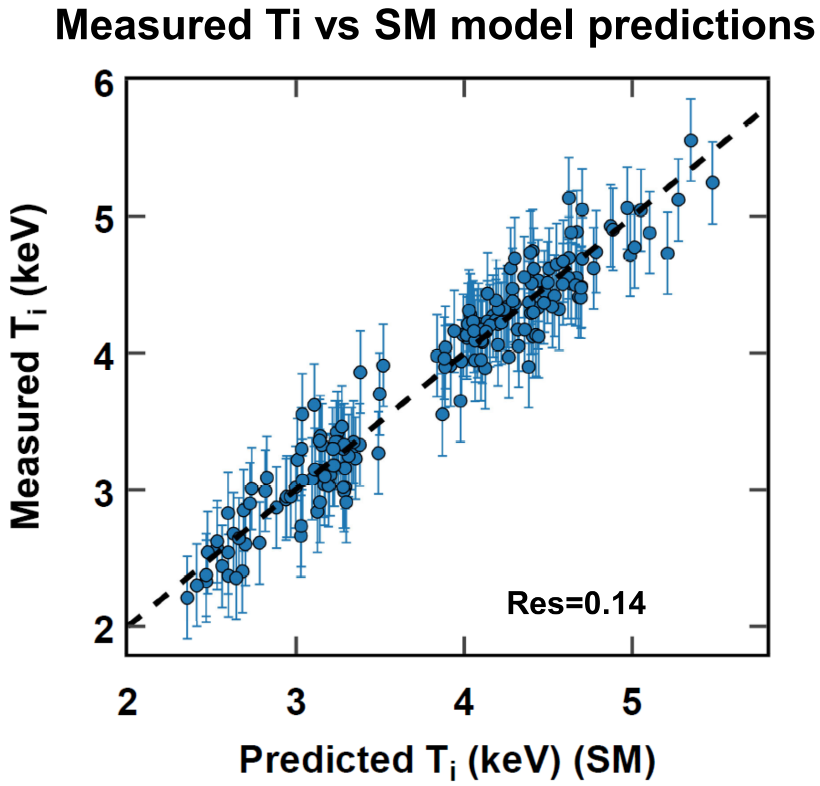
Degradation from mode L=1

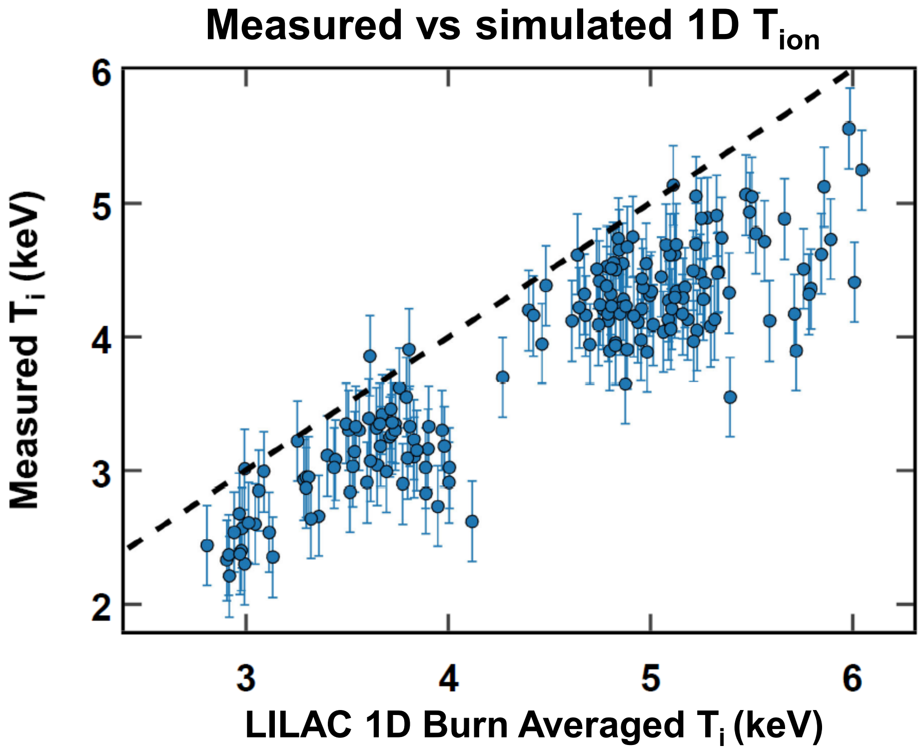


T_{ion} predictions are less accurate than yield predictions and measured T_{ion} deviates from simulated T_{ion} over entire database

- Measured T_i is the minimum DT ion temperature among 6 LOS →



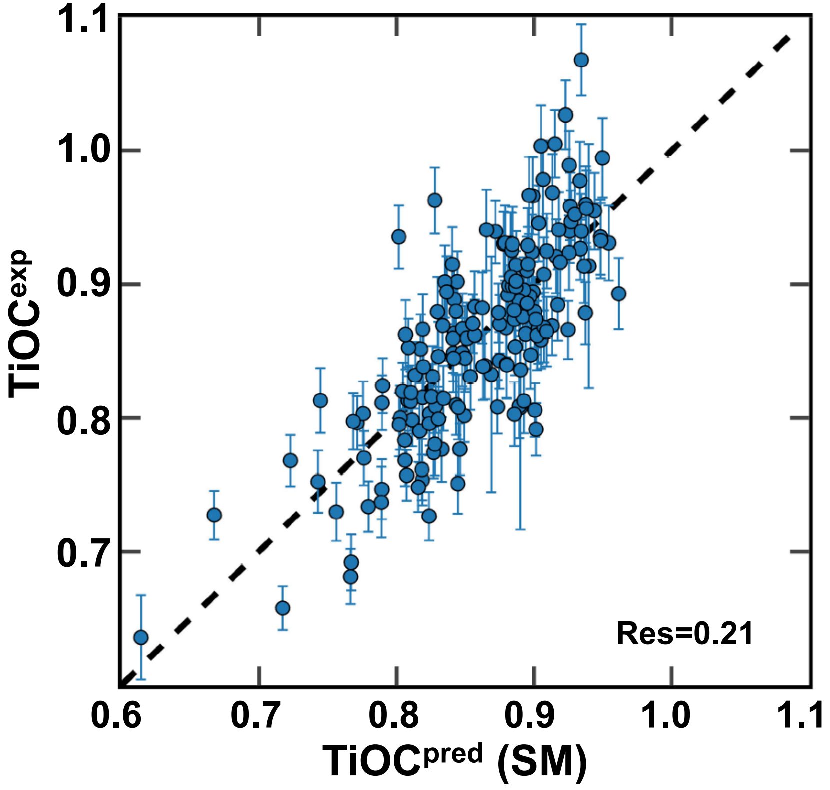




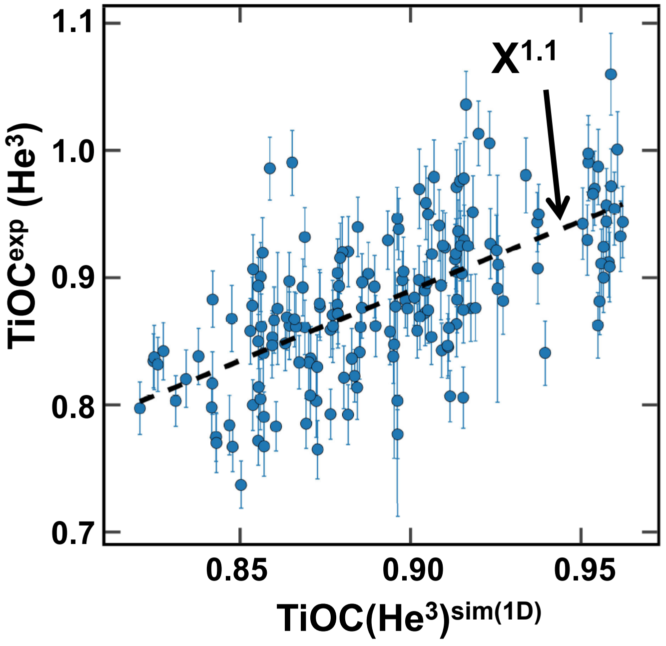
Extracting individual dependencies shows ion temperature degraded from He^3 contamination and hydrodynamic stability

T_{ion} degradation ➡ $TiOC = T^{exp} / T^{1D}$

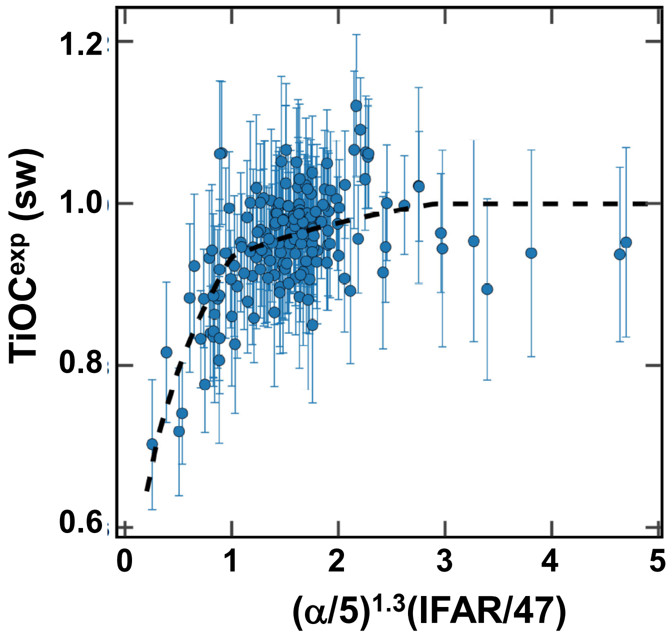
Measured TiOC vs SM model predictions



Degradation from He³



Degradation from short wav. RT



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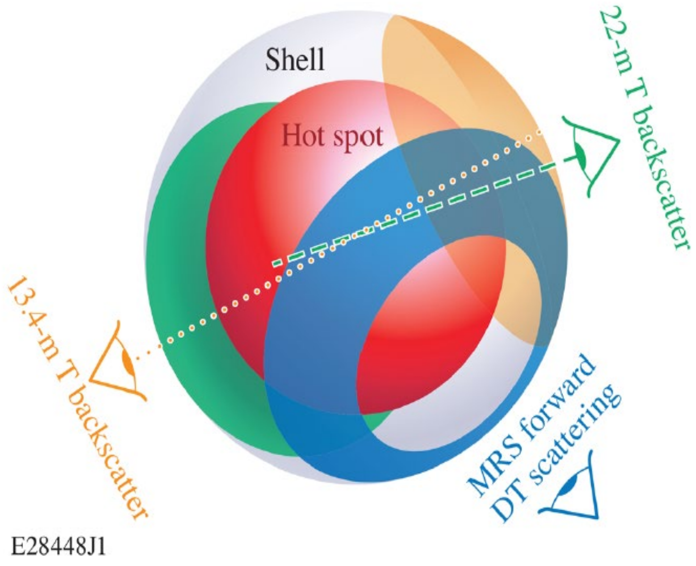
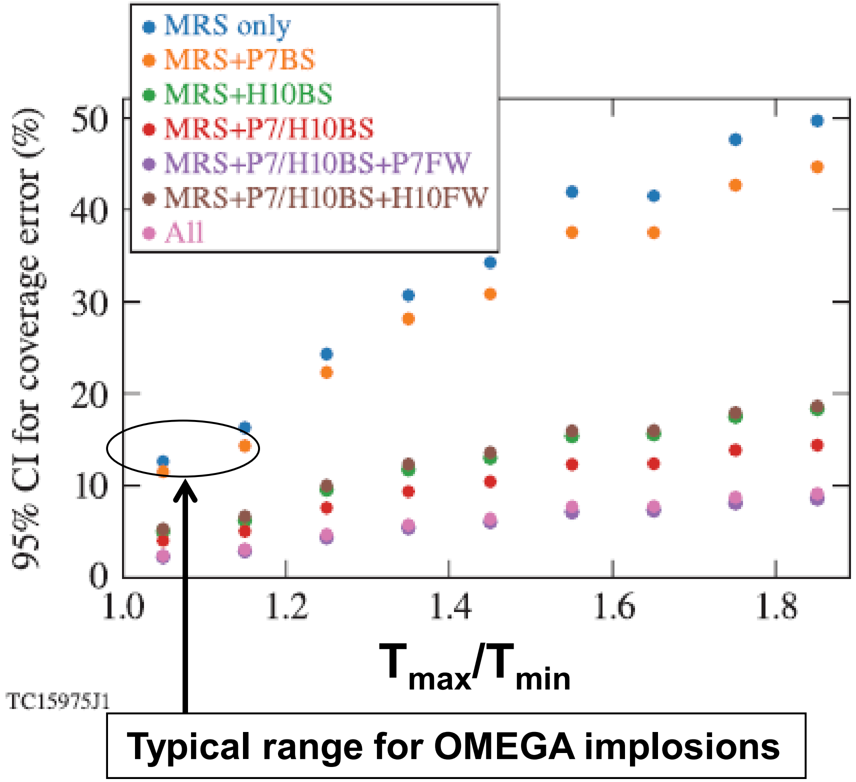
OMEGA implosion results, invited talks on Wednesday

C. Williams, NI0200004 "Achieving highest fusion yields in direct-drive ICF"

J. Knauer, NI02.0000 "A Systematic Study of Laser Imprint for Direct Drive"

The average areal density defined in the statistical analysis uses measurements along two LOS and the coverage error* from L=1 asymmetry is expected ≤ 15%





$$\rho R^{ave} \equiv \rho R^{\beta}_{MRS} \rho R^{1-\beta}_{P7BS}$$

SM finds β=0.48

*V. Gopalaswamy et al, PoP (2022)