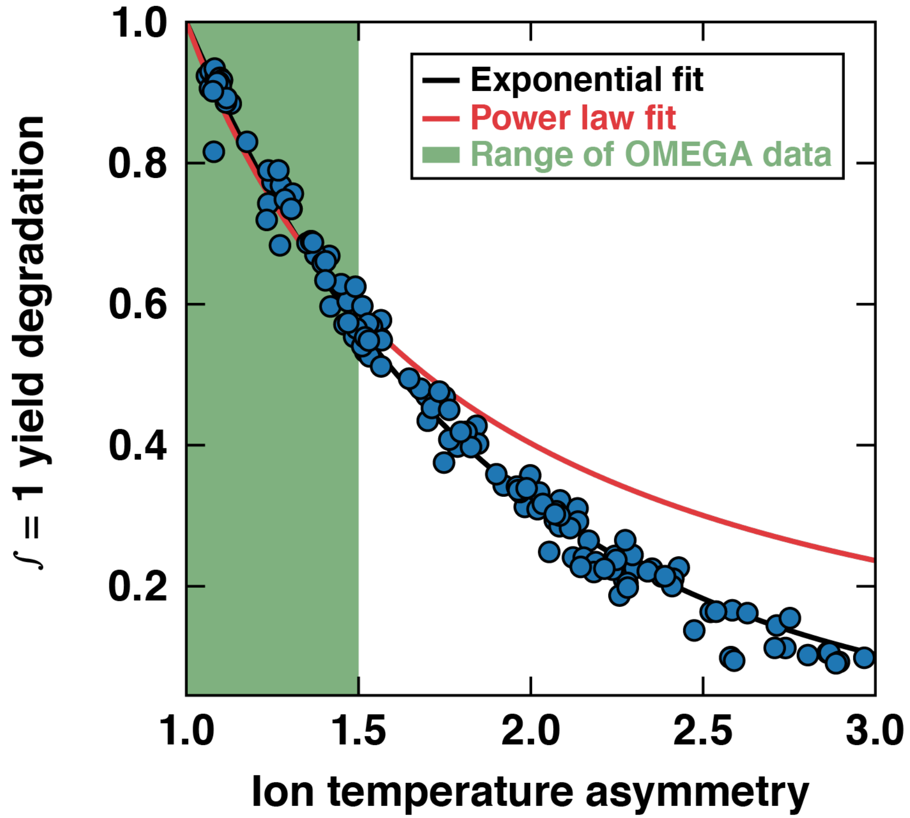
Inferring Degradation Mechanisms in OMEGA Cryogenic Implosions Through Statistical Modeling



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Meeting
Location
Date

A plausible physical mechanism has been inferred for some yield degradation sources for OMEGA cryogenic implosions

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- The statistical model for OMEGA implosions can be formulated to isolate degradation terms
- Synthetic experiments with 3D radiation-hydrodynamic simulations can be used to test hypothesis linking these degradation terms with physical mechanism
- The degradation of yield due to inferred ion temperature variation can be linked to the effect of $l = 1$ asymmetries during the drive phase
- The degradation of yield due to the ratio of beam-to-target radius can be linked to the illumination non-uniformity

Collaborators

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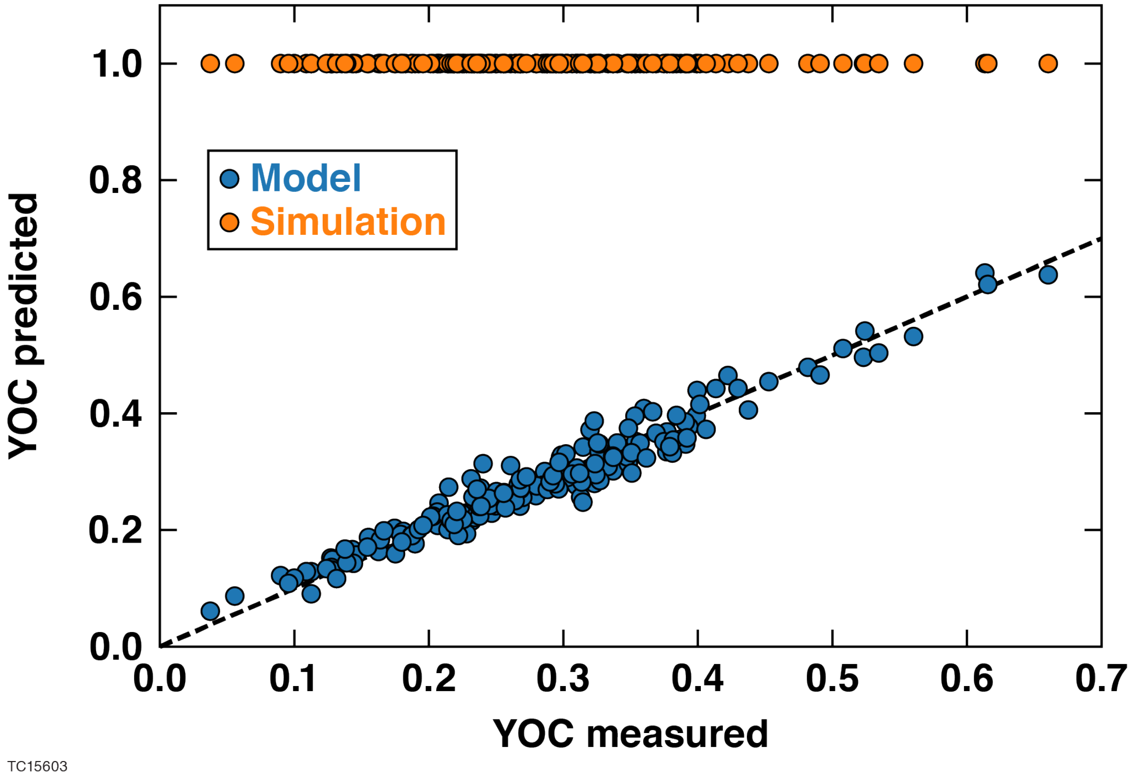
Predictive statistical models for OMEGA cryogenic implosion yields can be formulated to explicitly expose degradation factors

- **Assumptions*:**
  - Simulations and experiments take the same initial conditions
  - Experiments are systematically degraded with respect to simulations
  - Random perturbations are rare/Experiments are repeatable
  - Output from simulations uniquely specify initial conditions
- **Prediction target can be YOC instead of yield**



$$Y_{degradation} = \frac{Y_{exp}}{Y_{LILAC}} = \left(\frac{R_{beam}}{R_{target}}\right)^{3.4} \Delta \mathrm{T_i}^{-1.4} f_{He3}^{1.3} \alpha^{0.7} t_{rel}^{3} R_{beam}$$

* V. Gopalaswamy et al, Nature 565, 581–586 (2019)

Physical mechanisms that give rise to these degradation factors can be hypothesized

- Beam geometry mode
- CBET

Scaling in excess of hydrodynamic scaling*

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Low Modes
- Laser mispointing
- Target offset
- CBET

Helium-3 Buildup**

High modes/Stability
- Surface Roughness
- Laser Imprint

* R. Betti, this conference
** A. Lees, this conference

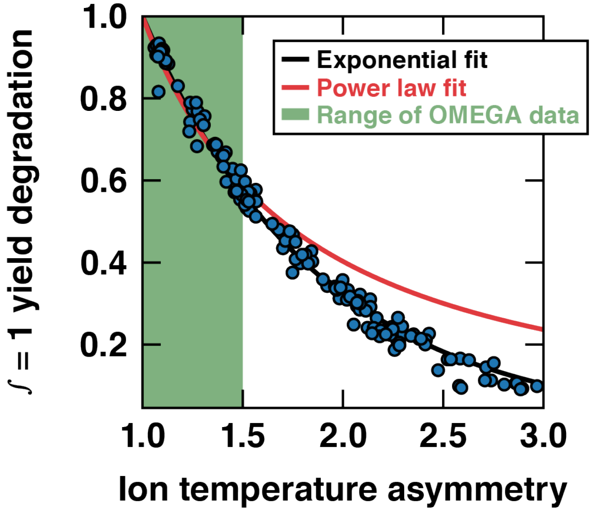
Synthetic experiments are used to test hypotheses in a controlled environment

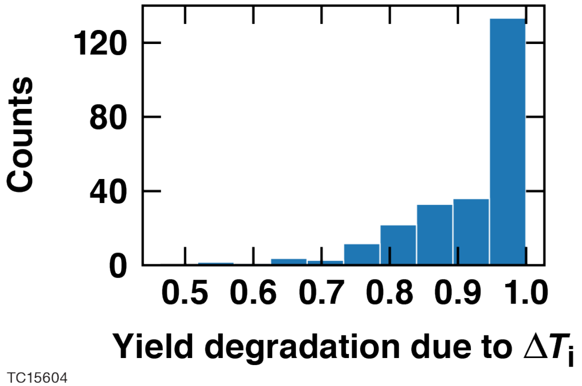
- Predetermined degradations are applied to 3D ASTER* simulations
  - CBET, nonlocal thermal transport and radiation transport are disabled
- Initial conditions are chosen to span the range of conditions of OMEGA experiments
- Results from degraded simulations are compared to corresponding 1D ASTER simulations with identical physics packages
- Since we only consider the trends in differences between the 1D and 3D simulations, choice of physics packages only matter if they alter the trend

* I. Igumenshchev et al, Physics of Plasmas 24, 056307 (2017)

Synthetic experiments with low mode drive asymmetry show good agreement with experimentally inferred degradation factor

- **Neutron spectrum is broadened by reactant velocities along the detector LOS**
- **Random low mode perturbations → bulk flows → ↑inferred T_i along flow direction**
- **$\Delta T_i = \frac{T_{max}}{T_{min}}$ acts as a proxy for this effect**
- **3D ASTER simulations with systematically imposed $l = 1$ drive asymmetry**
- **Yield degradation is well modeled by $\Delta T_i^{-1.4}$ for typical OMEGA experiments**
- **ASTER simulations indicate that an exponential fall off is more physical for large ΔT_i**

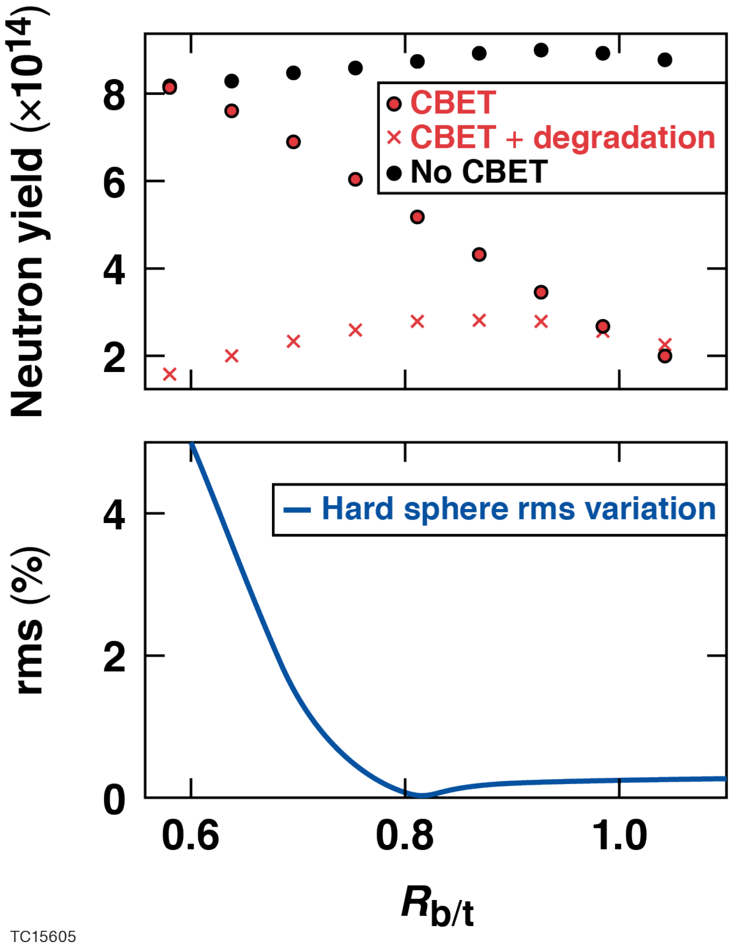




TC15604

Altering the beam-radius ratio increases drive coupling and drive asymmetry

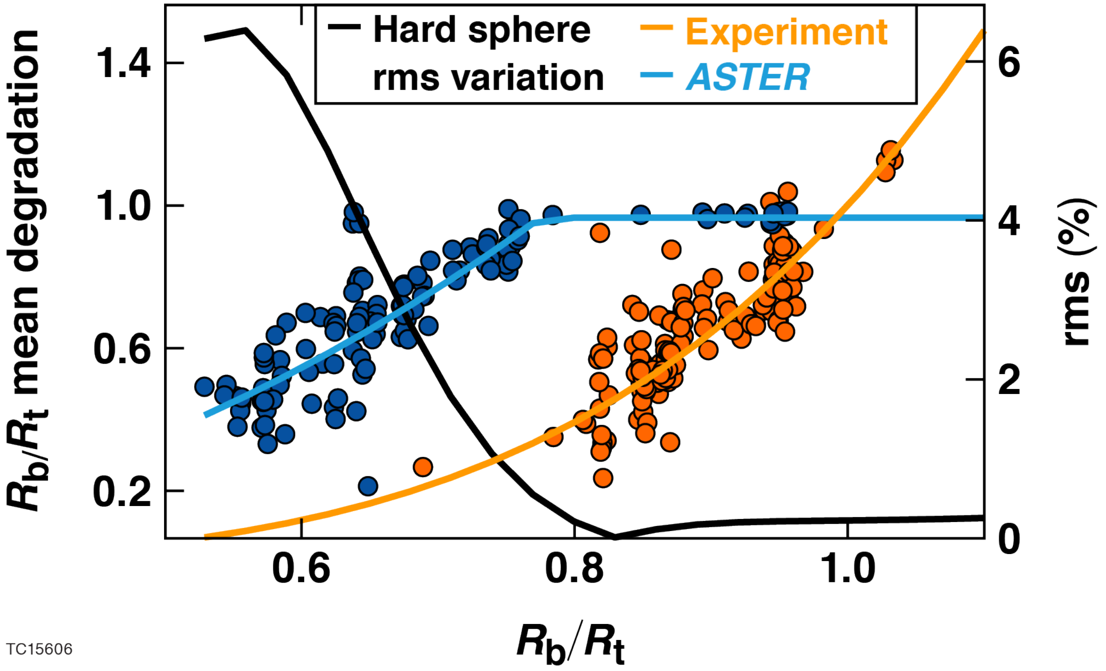
- As the beam-radius ratio $R_{b/t}$ is decreased, cross-beam overlap decreases, mitigating CBET
- This increases the yield as the coupling efficiency of the implosion increases
- The decrease in overlap also increases the hard sphere illumination non-uniformity
- CBET is likely to increase the illumination nonuniformity with respect to the hard sphere prediction, but the trend should remain similar



TC15605

Synthetic experiments show yield degradation increasing with the hard sphere drive asymmetry, unlike experiments

- Three different beam radii (280 , 330, 415) μm were used
- Synthetic experiments show yield degradation only after a critical value of $R^*_{b/t} = 0.77$ is exceeded
- A modified functional form was chosen to model the onset
  - $YOC_{ASTER\ Rb/t} \sim \Theta(\mathrm{R_{b/t}}, 0.77)^{2.2+0.8\,CR\,-0.1\alpha}$
- This $R^*_{b/t}$ is consistent with the hard sphere nonuniformity
- Experiments do not appear to have a critical value for degradation onset
  - CBET?
  - Need to test $\mathrm{R_{b/t}} > 1$*



TC15606

* C. Thomas, this conference

A plausible physical mechanism has been inferred for some yield degradation sources for OMEGA cryogenic implosions

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  - Physics not accounted for in ASTER may be responsible for qualitative differences in trends