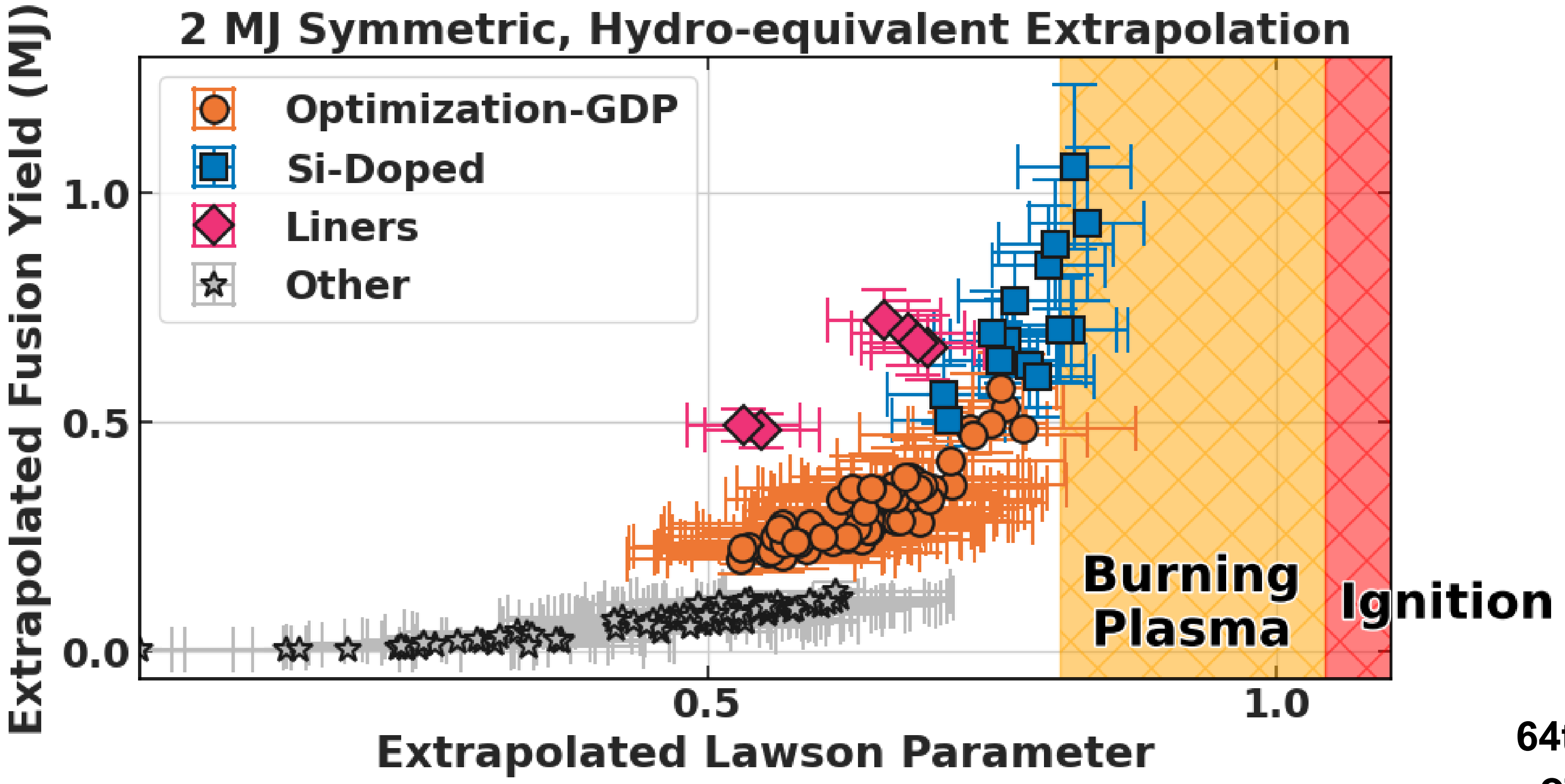
Increasing Performance of Direct-Drive Inertial Confinement Fusion Implosions on OMEGA via Enhanced Energy Coupling



University of Rochester
Laboratory for Laser Energetics

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Washington
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General Atomics

Summary

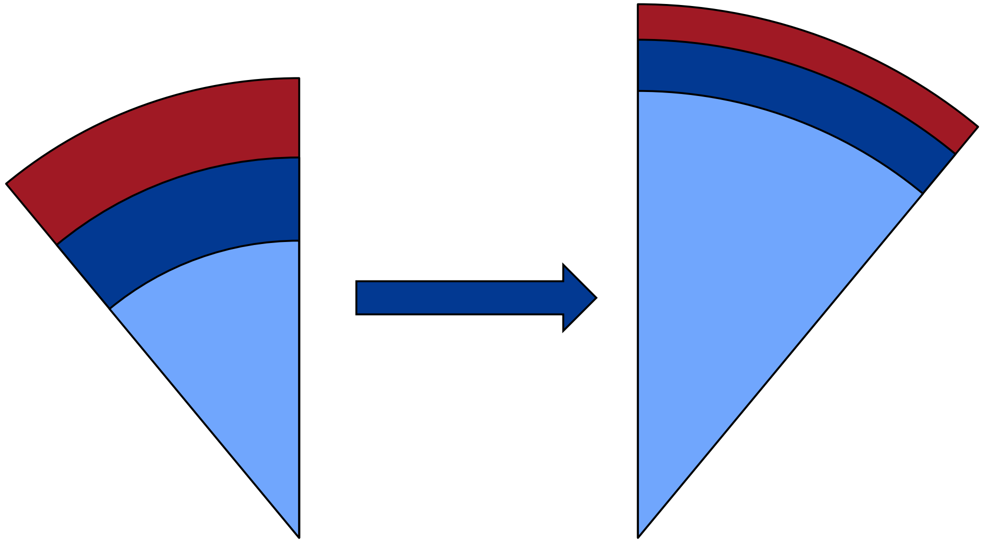
Adding Si dopant to the ablators of OMEGA DT-layered targets has resulted in record performance

- Direct-drive experiments on OMEGA have increased performance by increasing the coupled energy
- Adding mid Z dopants to the ablator increases energy coupled and mitigate LPIs
- Si-doped ablator implosions are now the best performers on OMEGA, increasing pressures and hotspot energy compared to GDP CD and have a fuel gain > 1 at OMEGA scale.*
- When hydro-equivalently scaled to a 2 MJ symmetric driver, the best performing implosions produce about 1 MJ of fusion yield and are in the burning plasma regime.

* C. A. Williams, invited talk on Wednesday

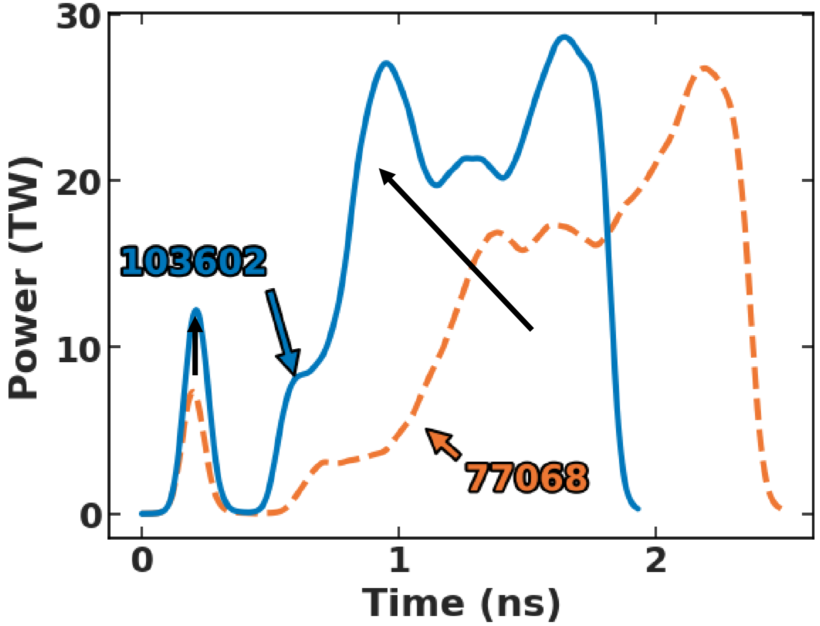
Direct-drive implosions reach high performance by increasing adiabat and coupled energy

Targets have become
- larger (CBET mitigation)
- thinner ice (faster)



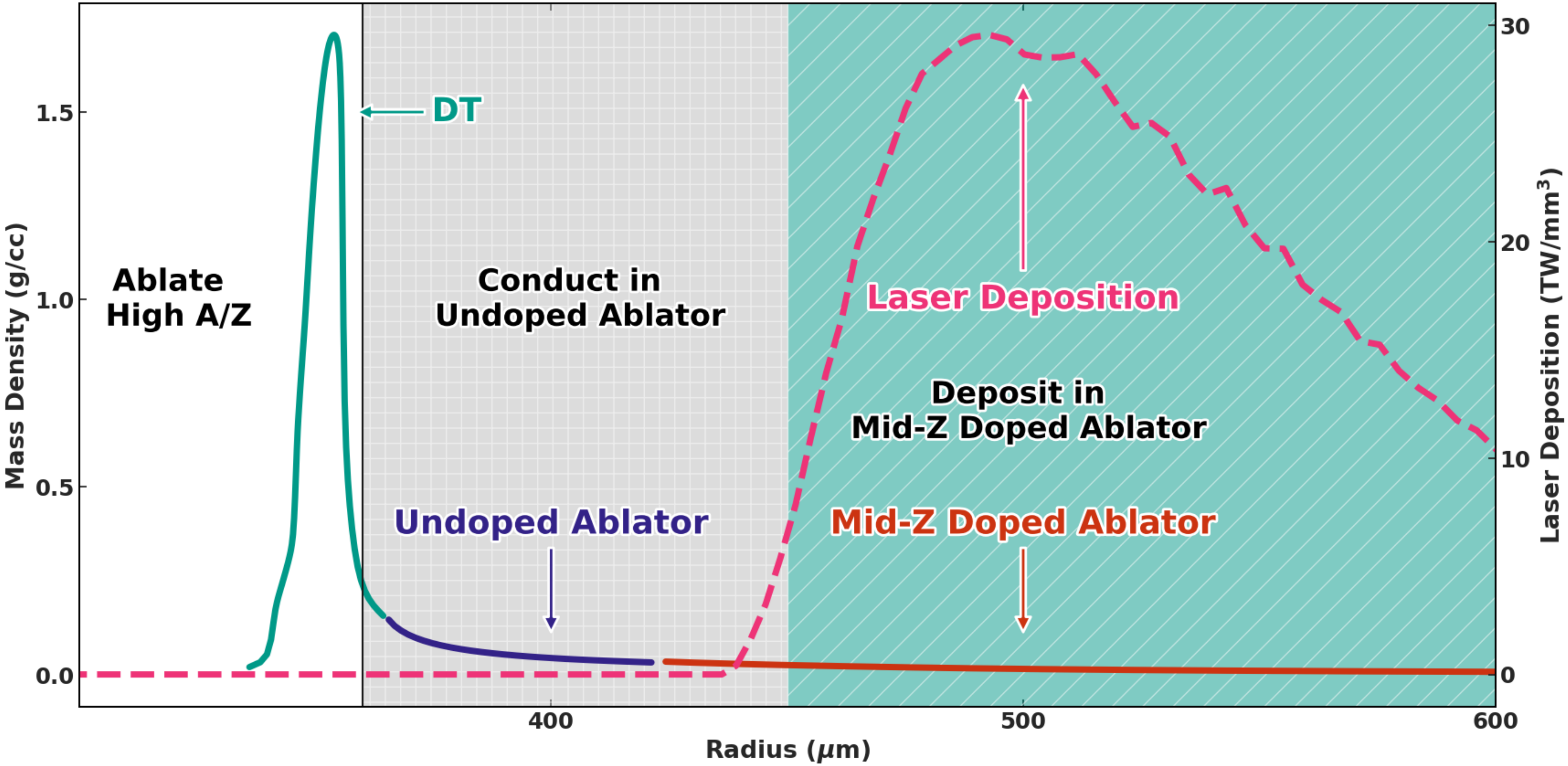
This increases velocity, but also IFAR

Pulse shapes compensate by
- Increasing picket (increases adiabat)
- Shorter pulse
- Adding double-spike (decreases IFAR)
- Increasing power

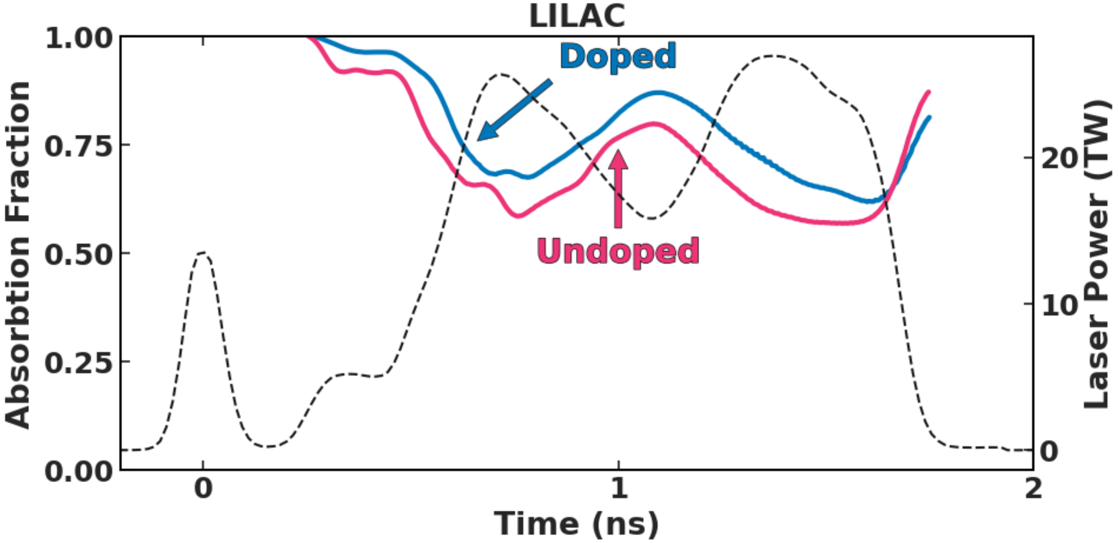


The end result is a implosion with ~ 10% more absorbed energy and higher yield, but lower ρR

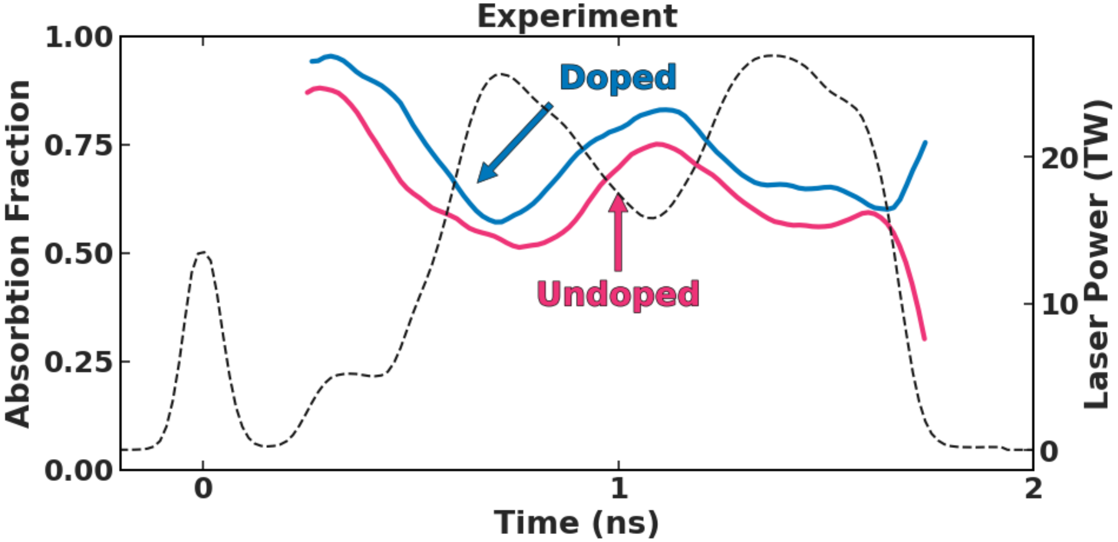
Doped-ablator designs need to be carefully optimized to trade-off CBET mitigation, hydrodynamic efficiency and radiative pre-heat

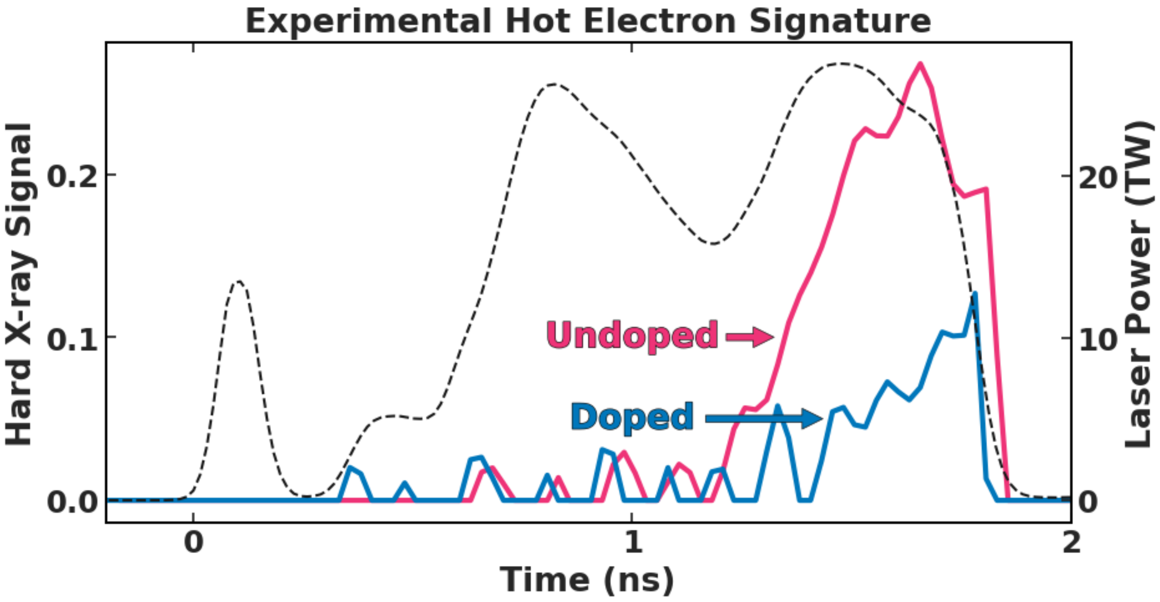


Adding mid-Z dopants into the ablator increases coupled energy and mitigates preheat in experiments

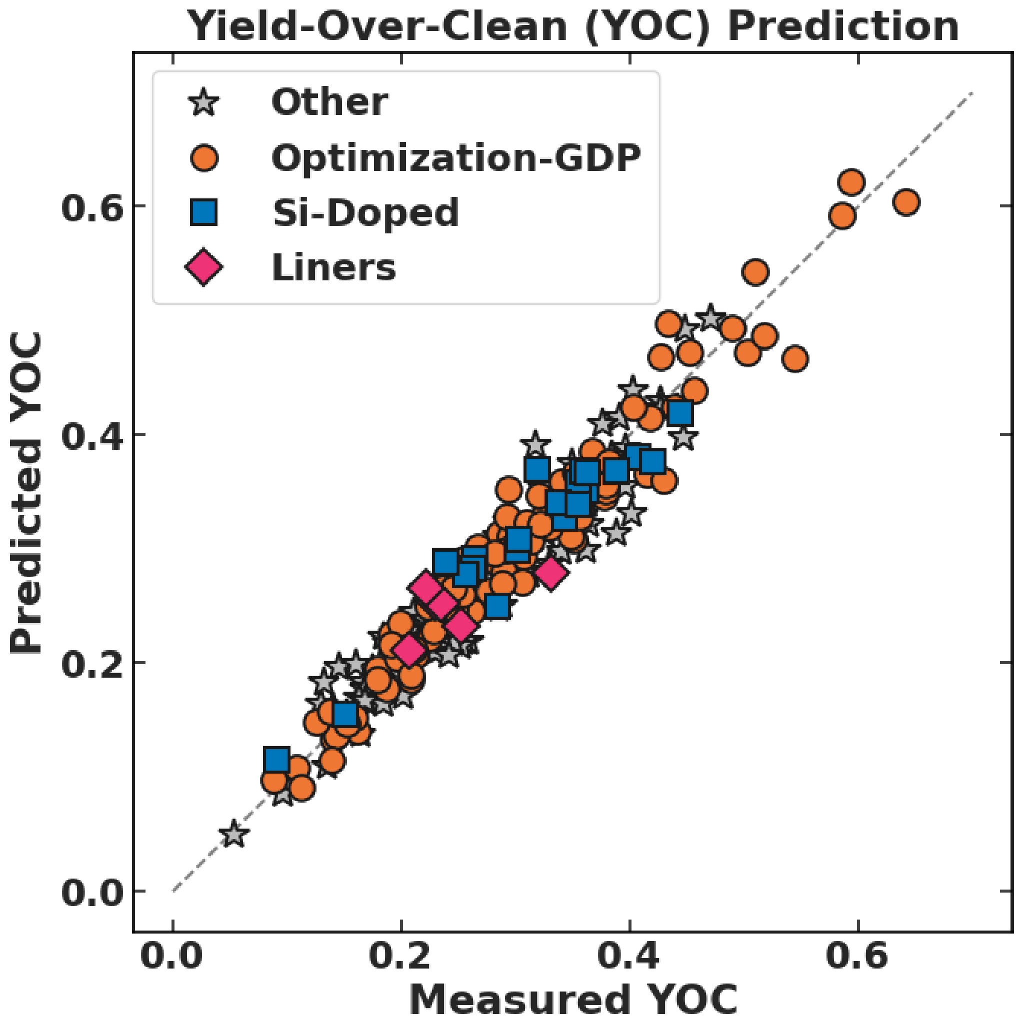


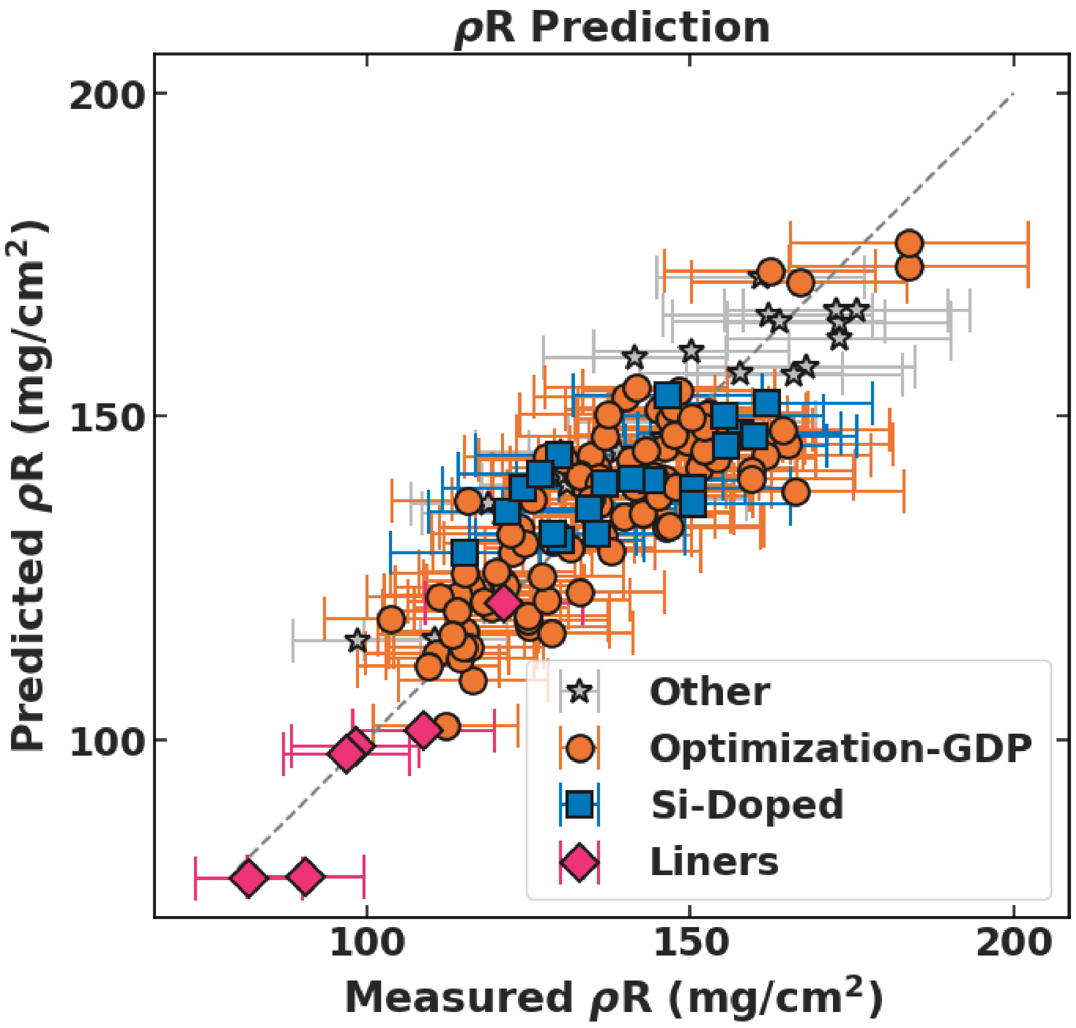
	CD (99922)	CHSi (101777)
HXRD (pC)	195±24	53±16
LILAC Absorption	66%	73%
Experiment Absorption	59±5%	69±5%





Predictive statistical models are used to find optimal designs for OMEGA

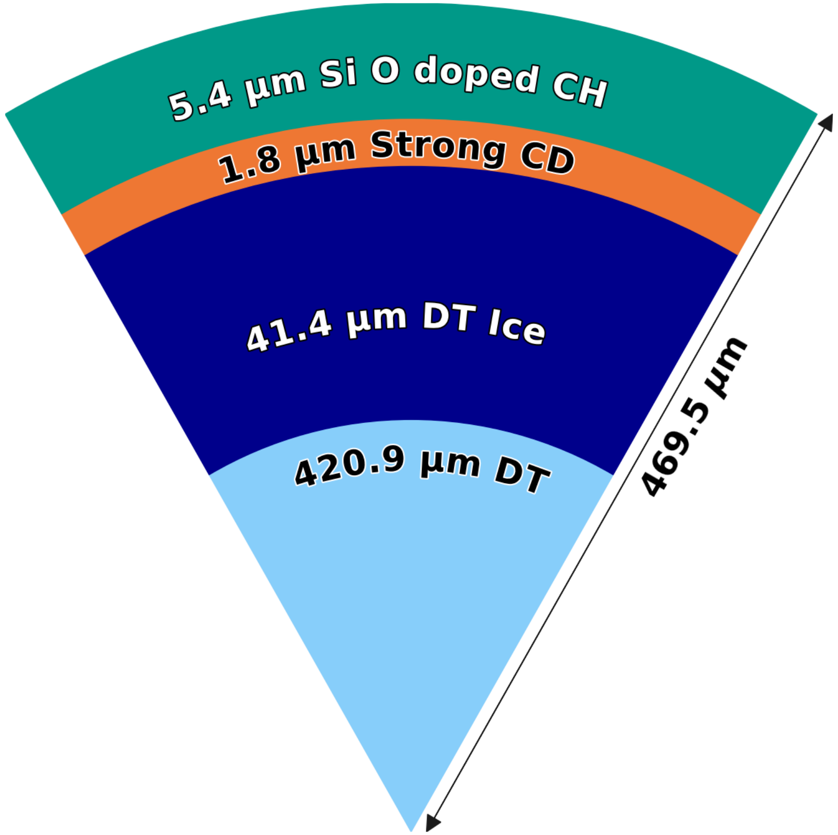


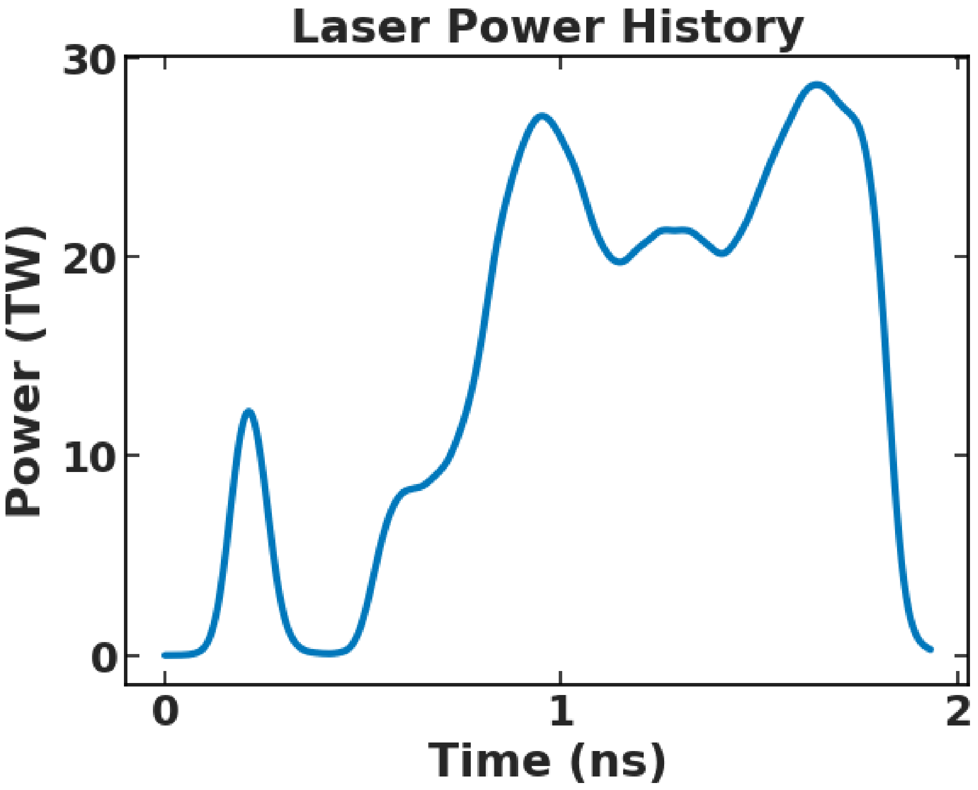


* V. Gopalaswamy et. Al, Nature 565, 581–586 (2019)
** A. Lees et al, Phys. Rev. Lett. 127, 105001 (2021)
*** C. A. Williams et al, Physics of Plasmas 28 (12), 122708 (2022)

Silicon-doped targets are now the best performers on OMEGA

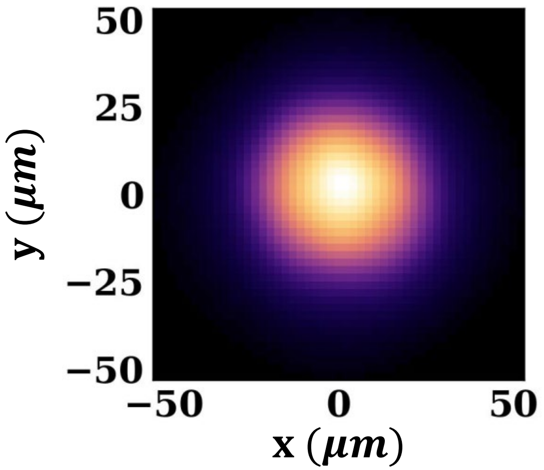
	Yield	ρR (mg/cm^2)	T_{ion} (keV)	Burn Width (ps)	X-ray R_{HS} (um)	χ scaled to 2 MJ
103602	2.44e14 ± 2e12	135.0 ± 10	5.2 ± 0.1	69 ± 5	23.5	0.82 ± 0.05



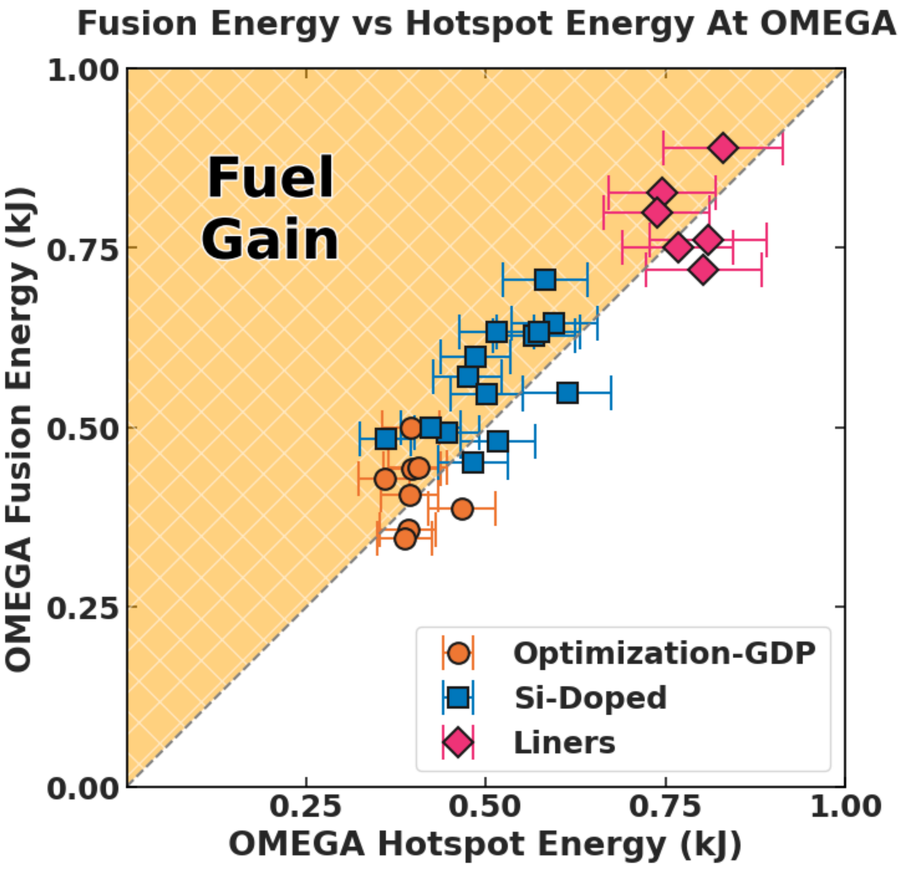


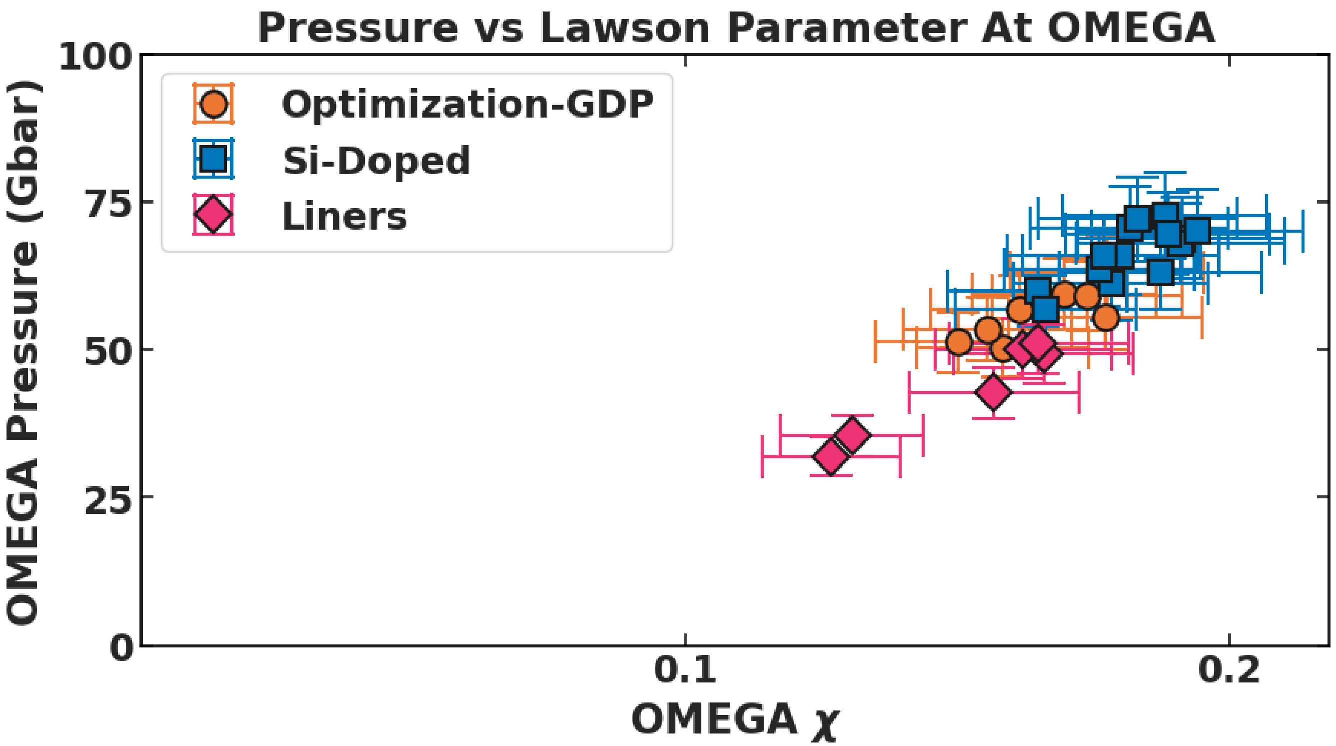
Self-emission image

103602



The increased hotspot energy and pressure of Si-doped implosions result in a fuel gain > 1 without alpha heating* and increased χ at the OMEGA scale



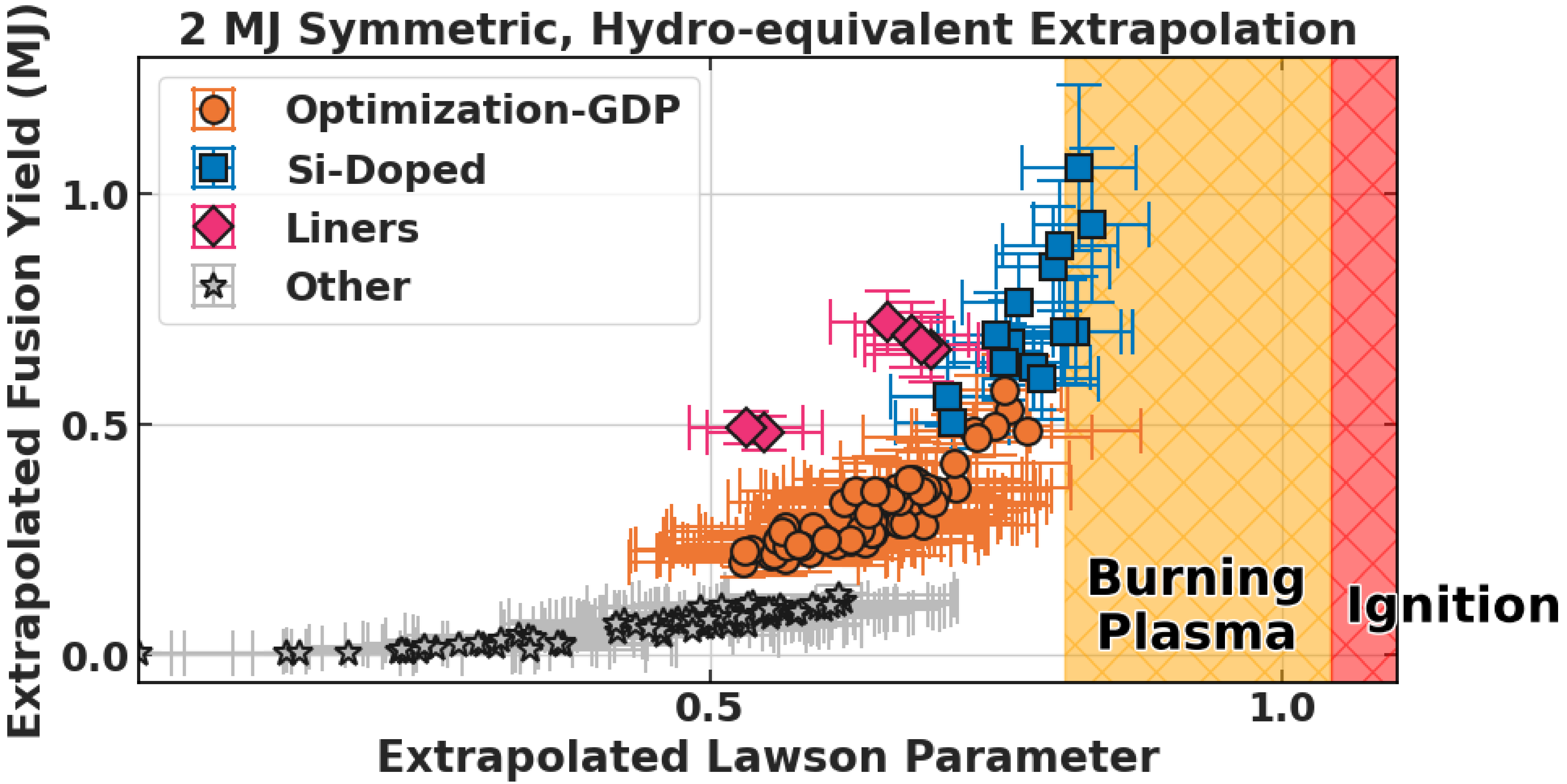


$$\text{Fuel Gain} = E_{fusion}/E_{hs}$$

$$\chi = (\rho R)^{0.61}\left(1.2 \times 10^{-17}\,\frac{Y_{DT}}{M_{DT}}\right)^{0.34}$$

* C. A. Williams et. al, in preparation

The best performing Si-doped implosions produce over a megajoule of fusion energy when hydro-equivalently extrapolated to 2 MJ of symmetric drive



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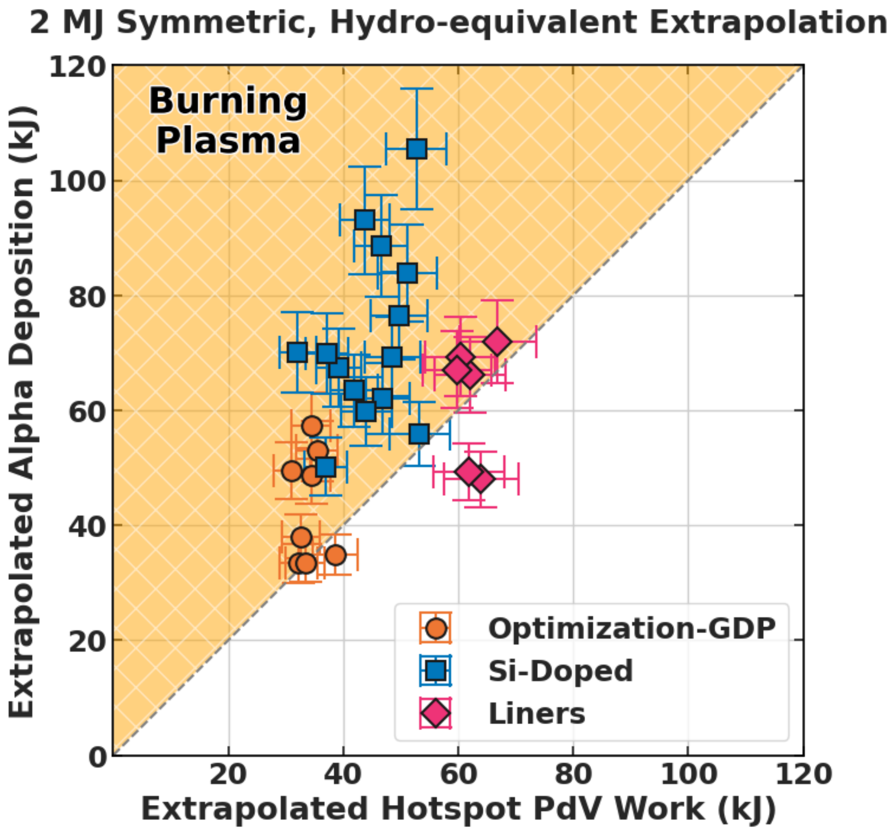
Hotspot reconstruction and hydro-equivalent extrapolation of the Si-doped implosions place them in the burning plasma regime

	χ scaled to 2 MJ	No-Alpha Hotspot Gain	PdV Work at 2 MJ (kJ)	Bang-Time Alpha Deposition At 2 MJ (kJ)	Yield Amplification at 2 MJ	Q_α at 2 MJ
103602	0.82 ± 0.05	1.2 ± 0.2	52 ± 6	105 ± 11	3.6 ± 0.3	2.0 ± 0.3

Christopherson 2018*: $Q_\alpha^{hs} > 1$ passes the burning plasma threshold

Next step – verify in 2/3D scaled simulations*

***D. Patel et al, UO04.00012**



* A. Christopherson et. al, Physics of Plasmas 25, 012703 (2018)

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