Division of Plasma Physics DPP

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Until 8 a.m. EDT, Monday, November 17, 2025
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Lighting a Star on Earth—Again and Again

LLNL researchers advance understanding of fusion ignition through new high-energy experiments.

LONG BEACH, Calif. — At Lawrence Livermore National Laboratory's (LLNL) National Ignition Facility (NIF), scientists are learning what it takes to keep a fusion reaction burning. Their latest experiments, presented this week at the American Physical Society's Division of Plasma Physics annual meeting, build on a series of successful ignition shots to reveal how capsule design and laser precision can sustain record-setting performance.

At NIF, researchers are consistently producing plasmas dominated by self-heating from fusion reactions, achieving target gain greater than two — meaning the fusion output energy exceeds twice the energy used to initiate the reaction. Using the world's most energetic laser to create these conditions, LLNL scientists can explore the detailed physics of ignition and burn that underpin the Laboratory's stockpile modernization mission.

"It's a bit like lighting a campfire with a match and a single breath," said LLNL physicist David Schlossberg, who is co-leading the work. "If you have too little fuel, it burns out quickly; too much, and it won't light at all. We've found the balance between capsule mass and drive strength that starts the burn and keeps it going efficiently."

NIF is the only laboratory in the world to have achieved fusion ignition, a historic breakthrough first realized in December 2022. Since then, the facility has repeated ignition ten times, most recently in October 2025, demonstrating the robustness of the experimental platform and the reproducibility of ignition physics.

Optimizing implosions for high fusion energy gain

Since 2022, LLNL teams have been studying how to trade off implosion velocity for capsule mass, a design approach that affects how well the plasma confines energy after ignition begins. Each fusion capsule, a hollow diamond sphere smaller than a peppercorn, contains frozen hydrogen fuel that's rapidly compressed by NIF's lasers. By increasing capsule mass to improve confinement while ensuring velocity is just high enough to trigger ignition, researchers have maintained high performance and gained new insight into how these variables interact (Figure 1).

The ongoing "Hybrid-E High Energy" campaign uses 2.2 megajoules of laser energy to examine these mass-to-velocity tradeoffs through experiments, modeling, and theory. The work explores how factors like residual kinetic energy, symmetry and material mix influence burn efficiency and energy yield.

"These experiments help us refine our understanding of the physical processes that drive ignition and burn," Schlossberg said. "They also validate the predictive models that are essential to high-energy-density science and our national security mission."

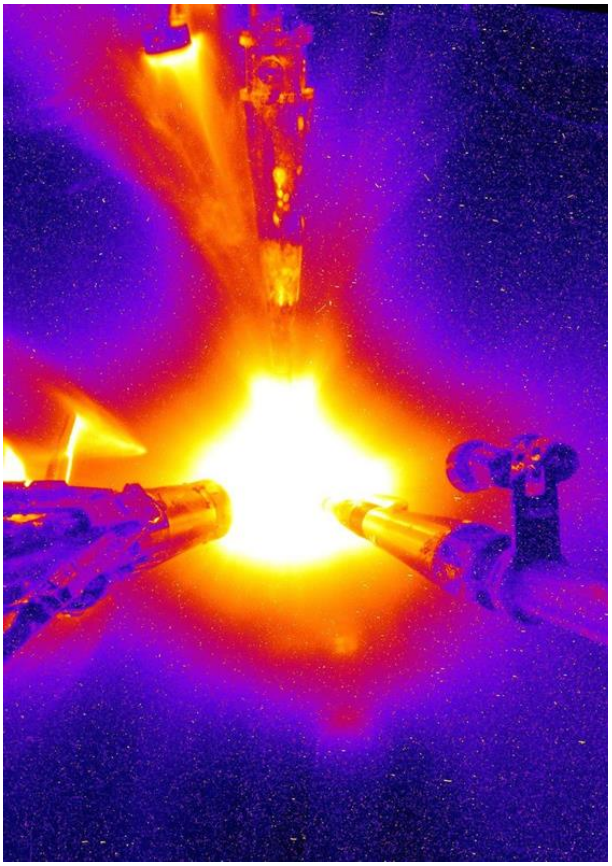

Figure 1: A rendering shows laser beams converging on a target inside Lawrence Livermore National Laboratory's National Ignition Facility. Researchers are studying how adjusting capsule mass and implosion speed affects confinement, fuel burn, and ignition performance. Credit: Lawrence Livermore National Laboratory

Toward higher gains and greater stability

The team is developing next-generation capsule designs that reduce unwanted motion and mixing during compression. One approach adds a small amount of another element to the capsule—a "dopant"—to make the implosion more stable and prevent material from mixing into the fusion fuel. In related experiments at 2.05 megajoules, a ramped-dopant profile was shown to further stabilize the implosion and increase yield. Upcoming NIF shots will incorporate these techniques at higher energy to continue exploring the limits of confinement and performance.

"We plan to push this design even further, driving more massive implosions to study larger burn fractions and higher gains in future experiments," said Annie Kritcher, LLNL's capsule science modeling lead. "Our findings prove that finding the right balance between capsule mass and implosion speed is a key to unlocking better performance."

This research reflects years of collaboration among many scientists and engineers across NIF. Multiple LLNL contributors are sharing related work at the APS Division of Plasma Physics annual meeting. A complete list of LLNL presentations is provided in the appendix. These efforts are conducted under the direction of the U.S. Department of Energy's National Nuclear Security Administration (NNSA). LLNL-TR-2012943

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Abstracts
APS Div. of Plasma Physics Annual Meeting
Lawrence Livermore National Laboratory Abstracts

David Schlossberg

BI02.1	Optimizing Implosions for High Fusion Energy Gain
Session	BI02: ICF Approaches to High Gain Fusion 9:30 AM – 12:30 PM, Monday, November 17, 2025 Room: Grand Ballroom I

Chris Weber

BI02.6	High yield design options for a next-generation ICF facility
Session	BI02: ICF Approaches to High Gain Fusion 9:30 AM – 12:30 PM, Monday, November 17, 2025 Room: Grand Ballroom I

Daniel Clark

CO08.3	Mix mitigation by continuous capsule doping in high-performance implosions on the National Ignition Facility
Session	CO08: ICF Ignition Physics 2:00 PM – 5:00 PM Monday, November 17, 2025 Room: 202

Matthias Hohenberger

CO08.4	Demonstration of mix mitigation and record performance using continuous dopant targets in ICF implosions on the NIF
Session	CO08: ICF Ignition Physics 2:00 PM – 5:00 PM Monday, November 17, 2025 Room: 202

Annie Kritcher

CO08.6	High yield diamond ablator designs for a 2.6-10 MJ laser driver
Session	CO08: ICF Ignition Physics 2:00 PM – 5:00 PM Monday, November 17, 2025 Room: 202

Heather Johns

GO08.1	First Successful Thor DT Ignition Shot
Session	GO08: ICF Hohlraum Physics

9:30 AM – 12:06 PM Tuesday, November 18, 2025
Room: 202

Luis Leal

GO08.10	Simulated impact of increased hohlraum radius on symmetry control in igniting and burning fusion platforms on the NIF
Session	GO08: ICF Hohlraum Physics 9:30 AM – 12:06 PM Tuesday, November 18, 2025 Room: 202

Christopher Young

PO08.12	Tailored Drive Asymmetry in ICF Implosions for Reduced In-flight Shell Swing and Improved ρR Uniformity
Session	PO08: ICF Compression & Burn 2:00 PM – 5:00 PM Wednesday, November 19, 2025 Room: 202

Brian Haines

PO08.14	Relating Metrology to Performance in Recent High Yield Implosions on the National Ignition Facility
Session	PO08: ICF Compression & Burn 2:00 PM – 5:00 PM Wednesday, November 19, 2025 Room: 202

Sidney Ricketts

PT04.4	Three-Dimensional Reconstructions of Cold Fuel Shells Using Fluence-Compensated Down-Scattered Neutron Imaging at the National Ignition Facility
Session	PT04: Plasma Diagnostics 2:00 PM – 5:00 PM Wednesday, November 19, 2025 Room: 104 A/B

Joseph Ralph

ZI02.1	Optimizing Hohlraum Efficiency for Ignition and High Gain in Inertial Confinement Fusion
Session	ZI02: ICF Hohlraums & LPI 9:30 AM – 12:30 PM Friday, November 21, 2025 Room: Grand Ballroom I