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[REGULAR POSTER TWIN] Improving implosion energy coupling at the NIF

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Inertial Confinement Fusion (ICF) schemes are designed to heat and compress DT fuel to conditions exceeding the Lawson criterion ($p\tau$) using implosion, which greatly amplifies the pressure of a driver (~100 MBar) to the conditions necessary for laboratory-scale ICF (~100s GBar). The National Ignition Facility (NIF) focuses on the laser indirect drive approach to ICF, in which laser energy is converted to x-ray radiation in a 'hohlraum', which drives the fuel-containing capsule[1]. This process is inefficient, with ~10% coupling efficiency from the laser energy to energy absorbed by the capsule typical. Of the energy absorbed the capsule material, only ~10% is converted into kinetic energy of the imploding fuel and internal energy of the fuel at stagnation. One focus of the program is to improve this coupling efficiency and enable larger implosions within the current capabilities of the NIF laser; this is a route towards increasing $p\tau$ on NIF and is relevant for future ignition experiments or approaches towards inertial fusion energy since the coupling efficiency feeds into requirements for driver size and target gain. In parallel, several degradation mechanisms have been identified that impact implosions on NIF, notably low-mode drive asymmetry and mix induced by target defects or engineering features. Detailed studies of these mechanisms have been conducted to identify routes towards improved performance.

In 2017-2018, record fusion yields on NIF were produced with designs that utilized high-density-carbon (HDC) capsules and low-gas-fill hohlraums[2]. These previous campaigns explored studies over several parameters, with the combination of data and theoretical scaling arguments suggesting that increasing the capsule size could be a favorable tactic for further improving performance[3], in part from the increased coupling efficiency from the driver to the fuel. With a constant available laser energy and power, a recent campaign pursued an increased capsule size in comparable hohlraums, substantially reducing the case-to-capsule ratio (CCR), from ~3 to ~2.7. A schematic of the target, compared to a previous campaign[4], is shown at the left of Fig. 1. Empirical metrics for the implosion symmetry[5] and initial data demonstrate that control over the symmetry is needed to prevent highly distorted implosions at this CCR. We use wavelength detuning ($\Delta\lambda$) between inner beams, which drive the hohlaum waist, and outer beams, which drive near the poles, to semi-empirically adjust the amount of cross-beam energy transfer (CBET) between these beams, which provides control over the implosion symmetry[6]. This wavelength detuning can be adjusted on every shot to control the shape. Example data are shown on the right of Fig. 1, demonstrating that the application of 1Å of $\Delta\lambda$ changes the implosion shape from oblate to prolate. Unlike previous campaigns that employed wavelength detuning in high-gas-fill hohlraums[7], our data demonstrate that the shape is symmetric throughout all stages of the implosion.

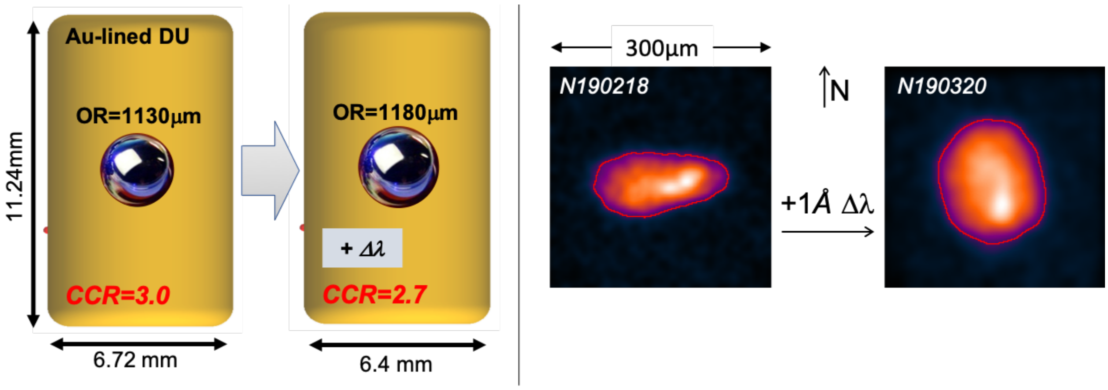

Figure 1: Left: schematic of the hohlraum and capsule for this campaign (right) compared to a previous design (left, Ref. 4). The Au-lined depleted uranium (DU) hohlraum has a reduced diameter while the capsule outer radius (OR) is increased. Right: Demonstrated control over the implosion shape, measured by x-ray emission images from the core, which varies from oblate to prolate as 1Å of $\Delta\lambda$ is applied.

With control over the shape we have conducted an initial series of three cryogenically layered DT fueled shots to assess the integrated implosion performance. The first two implosions revealed a higher than expected level of high-Z ablator material mixing into the fuel. This was successfully mitigated with two techniques: first, by increasing the fuel thickness to provide an additional buffer against mix, and second by using capsules with improved quality, or fewer seeds for deleterious hydrodynamic instabilities. These changes result in an implosion with record values for NIF for the capsule absorbed energy, fuel kinetic energy, and hot-spot internal energy, shown in Fig. 2. The highest performing shots in this campaign (N191007 and N191110) are denoted and have record values for coupled energy. Notably, these implosions have achieved record fuel energy at very modest values of other design parameters, especially the velocity. Simple scaling relations[3] expect the fusion performance to increase strongly as a function of both scale factor (S) and velocity (v) as approximately $Y \propto v^{7.7} S^{4.4}$. Increasing the velocity of these implosions is therefore a clear direction for future exploration.

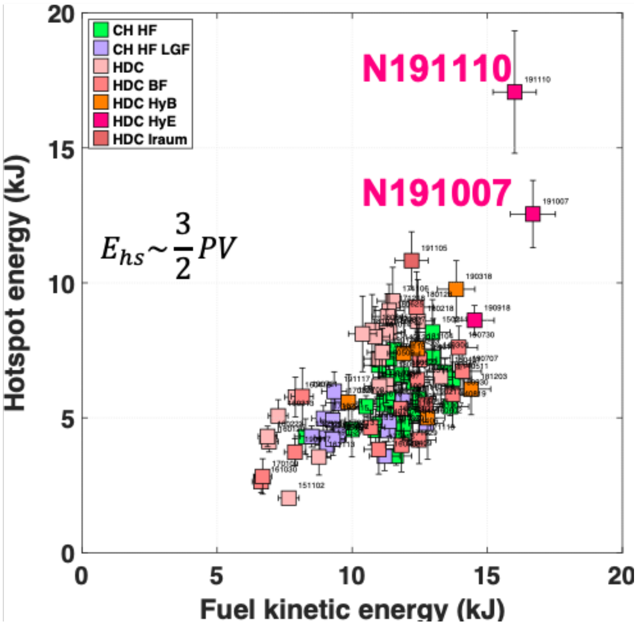

Figure 2: Inferred hot-spot energy over the fusion burn and fuel kinetic energy for NIF experiments. The shots in this campaign (N191007 and N191110) demonstrate the highest energy coupled to the fuel.

In parallel with the effort to increase energy coupling to the capsule and fuel, understanding known degradation mechanisms has been a dedicated effort of the program. Several sources of unintentional directional mode-1 drive asymmetry have been identified, including diagnostic windows in the target, random variation in the laser delivery, and anisotropic capsule thicknesses. Reducing these sources of asymmetry is expected to negate the impact of deleterious mode-1 drive asymmetry on current implosions. Similarly, several sources of high-Z material mixed into the fuel have been identified. First, engineering features such as the membrane that holds the capsule within the hohlraum and the tube used to introduce fuel into the capsule are sources of material mix into the hot spot. Second, defects introduced during the capsule manufacturing process, including 'pits' on the surface and 'voids' within the material, can cause high levels of mix into the fuel. Mitigation mechanisms for these varied sources of deleterious mix are being pursued. The degradations, when mitigated, are expected to both improve performance of current implosions and enable experiments in more aggressive parameter space.

In summary, we have conducted a campaign to improve the energy coupling efficiency for NIF implosions, by fielding a larger capsule to absorb more energy from the x-ray producing hohlraum, and have achieved record fuel kinetic energy and hot-spot internal energy with this approach. Increasing the coupling efficiency from the laser drive to the fuel is advantageous for improving performance on NIF and for projections to inertial approaches to fusion energy. In parallel, several sources of degradation mechanisms have been studied, with the causes identified and mitigation techniques in development to enable higher performing implosions.

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