35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, D-5.001 (2008)

Inertial Fusion Energy with Fast Ignition: Progress in Integrated Hohlraum Designs

P. Amendt, D. Clark, D. Ho, M. Key, J. Lindl, E. Storm, M. Tabak and R.P.J. Town
Lawrence Livermore National Laboratory, Livermore, CA 94550

With the exciting prospects for a successful demonstration of hot-spot ignition on the National Ignition Facility (NIF) after 2010 [1], planning for inertial-fusion-energy (IFE) designs is proceeding in earnest. Fast Ignition (FI) figures prominently in a growing IFE target design effort at LLNL due to its efficiency and relaxed compression and symmetry requirements [2]. The emphasis is on indirect-drive schemes that employ a high-*Z* hohlraum enclosure for absorbing laser light and reradiating the energy as soft x rays, driving a low-*Z* inertial-confinement-fusion (ICF) capsule. The methodology for attaining the status of a "point design" has been well developed over the course of preparing for the upcoming hot-spot ignition campaign on the NIF. The requirements of a point design entail an integrated hohlraum calculation which includes all of the known, relevant physics for achieving thermonuclear ignition: laser propagation and x-ray conversion efficiency, including the potential for plasma-mediated laser backscatter; accurate radiation transport; capsule and hohlraum-wall hydrodynamics; NLTE equations-of-state and opacities; and charged particle transport and thermonuclear burn physics. In addition, sensitivity analyses to deviations from ideal conditions and performance margin calculations are a key element of point designs in general. In the case of FI, extra complications arise. The presence of a high-*Z* cone penetrating the target and perturbing the spherical symmetry of the imploding capsule must be reliably accounted for. The conversion of ignitor beam energy to relativistic electrons that must propagate to the assembled fuel and (appreciably) deposit their energy is a daunting challenge from a design and calculational standpoint. Currently, the compressional phase of a FI-driven target is computationally separated from the ignitor phase. The compressional phase of the implosion is amenable to current integrated-hohlraum techniques [3] that this article describes. Some of the inherent challenges in pursuing integrated hohlraum calculations of FI designs are gauging the amount and energy of x-ray preheat penetrating the capsule and becoming absorbed in the high-*Z* cone tip. Is enough high-*Z* material ablated and entrained in the imploding, compressed fuel to lower the performance margins and significantly augment the energy requirements of the ignitor beam? What mitigation strategies could be used to keep the cone intact during the implosion and subsequent stagnation of fuel in front of the cone tip? What minimal hohlraum symmetry and drive conditions are conducive to acceptable implosion symmetry and compression? What are satisfactory hohlraum plasma conditions from the standpoint of laser backscatter, particularly if driven by 0.5 μm wavelength lasers as currently envisioned in IFE schemes? These questions can be directly answered with integrated hohlraum simulations that assess the interplay of key physical phenomena and arrive at a comprehensive picture of target performance.

A variety of conceptual IFE designs using FI are under consideration for planned integrated hohlraum simulation studies. Figure 1(a-f) shows sketches of these preliminary

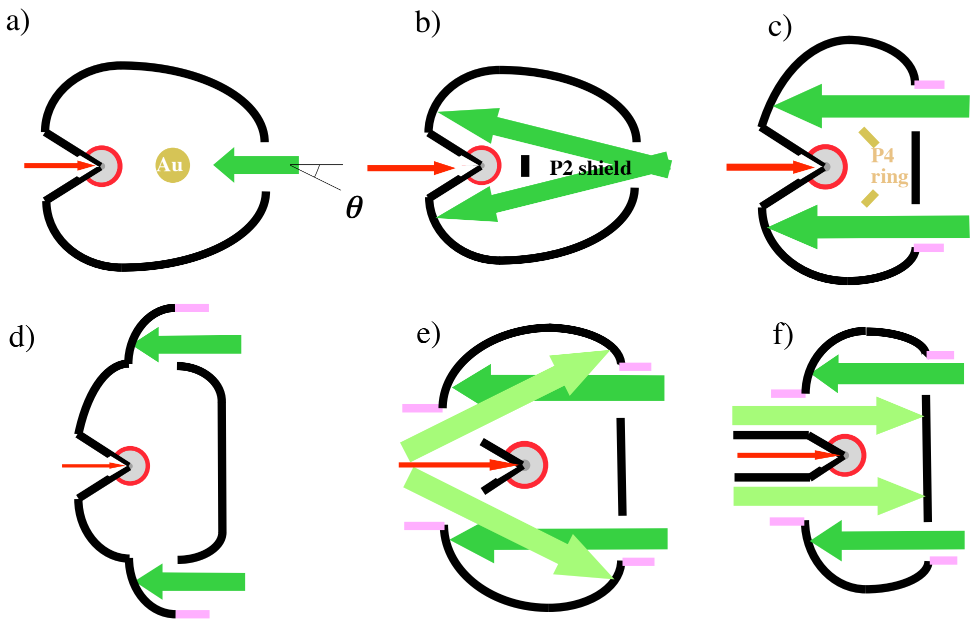

Fig. 1a-f: Schematic diagrams of conceptual designs for IFE driven by FI.

(axisymmetric) designs. Figure 1(a) presents a target geometry using zero-angle laser beams incident on a gold sphere for conversion into drive x rays. The advantage of this geometry is the short laser pathlength L through the hohlraum gas fill, reducing the potential for laser backscatter. However, the strongly overlapping laser beams from such a low angle of incidence promote a high total intensity I and the likely occurrence of significant laser backscatter. An added challenge is ensuring a satisfactorily symmetric x-ray drive onto the capsule in such a configuration; integrated hohlraum simulations confirm that the radiation flow to the cone-side of the capsule is too slow for this design to be of interest. Figure 1(b) is a low-angle design (<20°) that preferentially drives the cone-side of the capsule with a judicious placement of the laser beam. The gold "P2" shield is meant to provide late-time drive on the drive-starved symmetry axis and to block the chamber wall from the high dose of x rays and charged particles at ignition. The main challenge with this design is the long laser pathlength and the resulting large small-signal backscatter gain lengths ($\propto I\lambda^2 L$), particularly for 0.5 μm wavelength (λ) laser light. Another feature is the relatively long hohlraum required to accommodate low-angle laser beams and accompanying large x-ray energy losses in the wall. Figure 1(c) shows a one-sided, low-angle incidence, off-axis laser-drive configuration that is meant to mitigate laser backscatter risk by avoiding overlapped laser intensities on the symmetry axis. The optional, single "P4-ring" is chosen to help offset the deficit of drive at the laser-entrance-hole (LEH) near 40-50° relative to the hohlraum axis. The shortened hohlraum ensures a reduced laser pathlength and less wall energy loss, but the necessarily larger radius adds significant hohlraum surface area and more wall losses overall. Figure 1(d) exploits a heavy-ion converter design concept by ensuring laser absorption outside of the hohlraum and minimal risk of laser backscatter. The remaining challenge with this design is preventing LEH closure at late time, ensuring adequate symmetry tunability and tolerating relatively large LEH x-ray losses. Figure 1(e) depicts a double-sided illumination design that affords enhanced symmetry tunability by a propitious phasing in time of the two sets of drive beams. The challenge with this design is the relatively large laser pathlengths and the potential for large laser backscatter. A variant of this two-sided design is shown in Fig. 1(f) with low-incidence angle laser beams. Again, the main concern is the potential for backscatter, principally due to the proximity of capsule blowoff to the zero-angle beams entering from the cone side of the hohlraum.

The next step before tackling an integrated hohlraum simulation of any of the above designs is to perform a viewfactor simulation for optimizing the energetics and symmetry. Adjustments are made to the hohlraum geometry, laser placement or pointing, and laser power history to reasonably match well a tailored drive temperature history for the capsule. Although such a simulation does not ordinarily consider hydrodynamic motion - including laser spot motion - the technique is useful for quickly steering the integrated hohlraum design toward the desired region of parameter space. Figure 2 shows the material regions of an integrated hohlraum simulation after a few nanoseconds into the 80 eV "foot" radiation

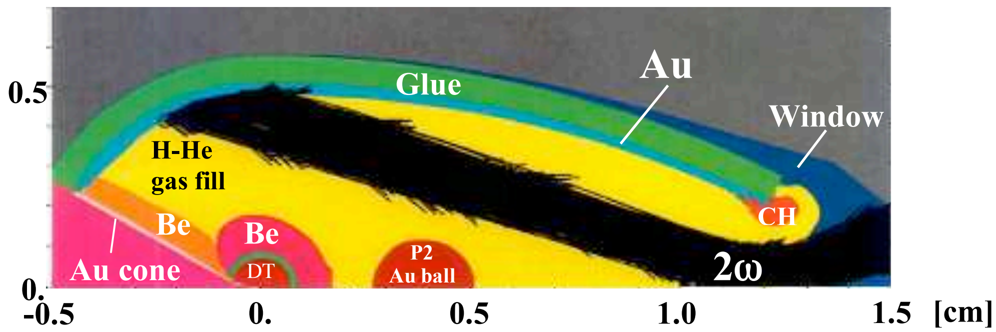

Fig. 2: Radiation-hydrodynamics simulation of target-type 1(b). Shown are various regions and laser beam geometry after several nanoseconds into the foot portion of the drive.

temperature drive history for the design shown in Fig. 1(b). Several iterations are typically required to approach the desired drive and symmetry conditions. For minimizing ablation of the gold cone and potential high-*Z* contamination of the fuel, 6 μm of Be are used to overcoat the cone and tamp the expansion from x-ray preheat originating from the laser spots. Buried dopants in the ablator, such as Cu or a mixture of Br and K, are also used to further suppress transmission of hard (gold L-shell) hohlraum x rays through the shell. Capsule design studies are in progress to achieve a quasi-isochoric implosion with minimum hot spot, sufficient robustness to drive errors, minimized spatial separations between the cone tip and assembled fuel for efficient hot-electron deposition, and cone-tip survival up to the instant of short-pulse laser deposition. Work continues in exploring grid-motion schemes for ensuring hydrodynamic integrity of the cone-and-capsule two-fluid interaction and elucidating the potential for jet formation.

In summary, efforts are now underway to generate a suite of FI IFE target point designs based on two-dimensional, integrated hohlraum simulations. Capsule optimization, viewfactor studies and laser backscatter assessments are key elements in guiding the final form of the integrated designs through the compression phase of the implosion up to the final ignitor stage.

This work performed under the auspices of the Lawrence Livermore National Security, LLC, (LLNS) under Contract DE-AC52-07NA27344.

[1] J.D. Lindl *et al.*, Phys. Plasmas **11**, 339 (2003).
[2] M. Tabak *et al.*, Phys. Plasmas **1**, 1626 (1994).
[3] D.A. Callahan *et al.*, Phys. Plasmas **13**, 056307 (2006).