Novel Hot-Spot–Ignition Designs for Inertial Confinement Fusion with Liquid Deuterium–Tritium Spheres

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Summary

The dynamic shell formation concept* expands the parameter space for MJ-yield and high-gain ignition designs

- A liquid DT sphere inside a wetted foam shell is used as a target in the new design; the lower-density central region and higher-density shell are created dynamically by appropriately shaping the laser pulse
- Changing the strength of outward mass flow enables the design to control density in the central region and target convergence ratio
- Accurate multidimensional modeling of the new designs are underway to assess their stability properties

The dynamic shell design evolves through three stages:

1. **Shock heating**
   - Converging shocks
   - Shock-collision region
   - Fuel flow

2. **Blast wave expansion, density relaxation, and shell formation**
   - Shell-forming shocks
   - Lower-density region

3. **Shell acceleration and hot-spot formation**
The dynamic shell design offers several advantages over a conventional layered target design:

- Target simplicity
- Fuel uniformity
- Control of density in central region
- Control of shell velocity and ablated mass with pulse shaping

The stronger blast wave leads to lower central density. The shell and hot-spot convergence ratio can be controlled by varying central density.
The dynamic shell formation designs expand the ignition parameter space

Ignition/Lawson criterion

\[ \frac{\text{Power gain}}{\text{Power loss}} > 1 \]

\[ P_{hs} R_{hs} > 1 \text{ Gbar} \times \text{cm; } T_i > 4 \text{ keV} \]

\[ E_{hs} > 16 \text{ kJ} \left( \frac{R_{hs}}{50 \mu m} \right)^2 \]
The dynamic shell formation designs expand the ignition parameter space.

High convergence, CR > 30
Low required hot-spot energy
High fuel mass, low $V_{\text{imp}}$
$Y_n \sim 100$ MJ

Low convergence, CR < 15
High required hot-spot energy
Low fuel mass, high $V_{\text{imp}}$
$Y_n \sim 1$ MJ

Including hydroefficiency

Incident $E_{\text{laser}} = 1$ MJ

Nominal hot-spot LDD designs $1 < \alpha < 7$

Smaller hot spots
Larger hot spots
Improved laser coupling is required to access low-CR design space

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Incident $E_{laser} = 1$ MJ

- $P_a = 70$ MBar
  No CBET mitigation

- $P_a = 200$ MBar
  Total CBET mitigation, with zooming

- $P_a = 250$ MBar
  Total CBET mitigation, with zooming
The high and low CR’s are achieved in the dynamic shell designs by controlling density in the central (void) region.

Shell CR is controlled by:
- Shell adiabat $\alpha$,
- Implosion velocity $V_{\text{imp}}$
- Void density $\rho_v$

$\text{CR} \sim \Phi(\rho_v) V_{\text{imp}}^{0.7} \alpha^{0.3}$

Vapor density of a layered target

End of the shell formation stage

$Y \sim 100 \text{ MJ}$
$\text{CR} \sim 40, V_{\text{imp}} = 3.3 \times 10^7 \text{ cm/s}$

$Y \sim 1 \text{ MJ}$
$\text{CR} \sim 12, V_{\text{imp}} = 5 \times 10^7 \text{ cm/s}$

Dynamic shell design

Vapor density at triple point

Mass density (g/cm$^3$)

End of the shell formation stage

Distance (µm)
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