

Implosion Symmetry of Laser-Irradiated Cylindrical Targets

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Experiments with laser-irradiated cylindrical targets allow to study the basic physics of the implosion process of inertial fusion capsules. We consider a target composed of a cylindrical $(\text{CH}_2)_n$ shell with 0.06 cm internal radius and 0.004 cm thickness, filled with deuterium at 30 bars (5.35 mg cm^{-3}). This target will be irradiated with the eight blue beams of the OCTALIL laser system [1] in an octahedral configuration, with a total laser energy of 50 kJ delivered in 5 ns.

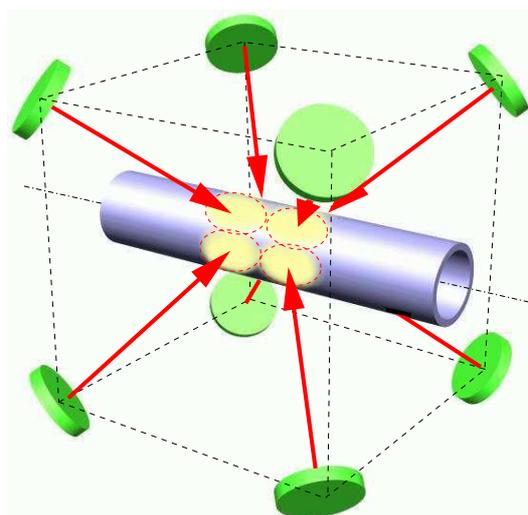


Figure 1: OCTALIL cylindrical target

Due to the finite number of beams, the irradiation asymmetries will constrain the achievable final compressed configuration. Although, in principle, the process is three-dimensional, we can extract useful information from currently available two-dimensional simulations.

We have used the MULTI [2, 3, 4, 5] code to study both, the transversal and longitudinal 2D sections of the cylindrical target (as well as the 1D averaged problem). This code solves the hydrodynamic equations in a Lagrangian 1D or 2D grid together with sev-

eral energy transport mechanisms: electronic heat conduction, radiation, laser and ion beam deposition¹. Equations of state and opacities are interpolated from tables (SESAME, SNOP, MPQEOS, etc). Laser beam transport is computed by the ray-tracing approach; the beam is considered to be composed of certain number of rays randomly generated in each time step; each ray is followed in 3D space, and deposits its energy into the 2D computational grid (azimuthally averaged).

The first issue to be analyzed is in which extent cylindrical symmetry is preserved in the implosion. For this purpose we consider the longitudinal section of the target containing the

¹Other code features: nuclear reactions, alpha particle transport, Eulerian hydrodynamics, etc, are described in more detail in [2] and [5].

symmetry axis. We use a rectangular grid with 264 divisions in radial direction (R) and 48 in longitudinal direction (Z). The laser illumination is described by beams (400 rays in each timestep) which central line intersects the axis of symmetry at point of coordinate $Z = Z_{focus}$ at an angle of 54.7365° from the axis. The intensity profile has a super-Gaussian distribution:

$$I(r) \propto e^{-(r/\alpha)^{2\beta}} \quad (\alpha = 0.093 \text{ cm}, \quad \beta = 2.2)$$

The laser beams (10 TW, 5 ns) are divided in 2 rings coming from left and right hand sides.

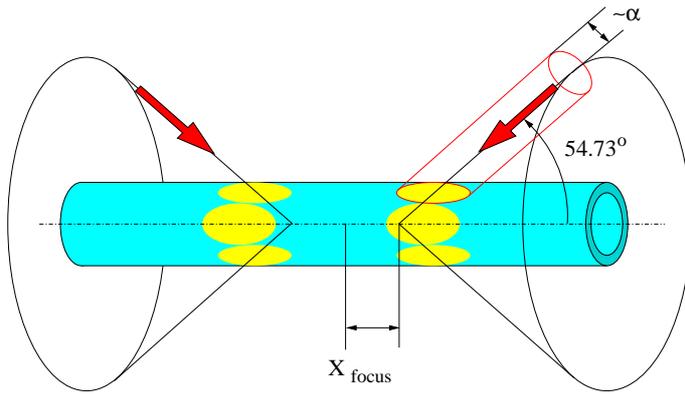


Figure 2: Irradiation scheme

We have simulated different focusing configurations, with Z_{focus} ranging from -0.14 cm to 0.1 cm (Figure 2). With $Z_{focus} \simeq -0.045$ the initial focal spots of left and right sides coincide, producing a strong and concentrated implosion. At the moment of maximum compression (see figure 3), a central region of 0.1 cm length is compressed up to 0.001815 cm radius. The average density is about 4 g cm^{-3} , below the 1D

value ($\rho_0(r_0/r_1)^2 = 5.8 \text{ g cm}^{-3}$) due to some lateral expansion. By using $Z_{focus} \simeq -0.13$, the

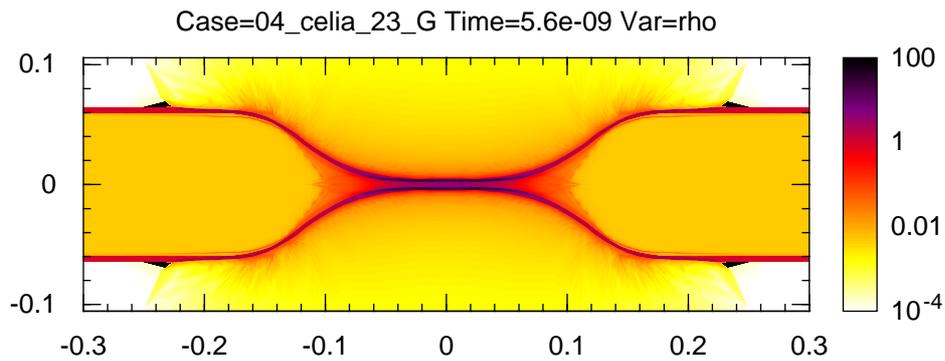


Figure 3: Case $Z_{focus} \simeq -0.045$ at maximum compression

laser beams cross each other and the focal spots of both sides overlap in such a manner that the longitudinal uniformity is maximized. A filamentary compressed region of 0.25 cm length is produced. The compression is up to 0.0025 cm radius (see figure 4), with an average density of 2.2 g cm^{-3} , below the 1D value $\rho_0(r_0/r_1)^2 = 3.2 \text{ g cm}^{-3}$, and below the one attained pre-

viously. Alternatively, equivalent longitudinal uniformity is also obtained with $Z_{focus} \simeq 0.6$ (in

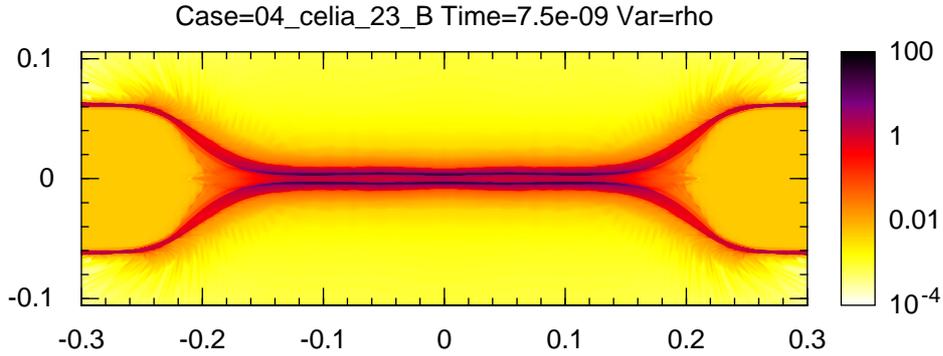


Figure 4: Case $Z_{focus} \simeq -0.13$ at maximum compression

that case the laser beams do not cross). Figure 5 shows the density profiles in both cases. As we can see, one can choose between a high density configuration, or a pretty uniform and long compressed region with a little smaller density.

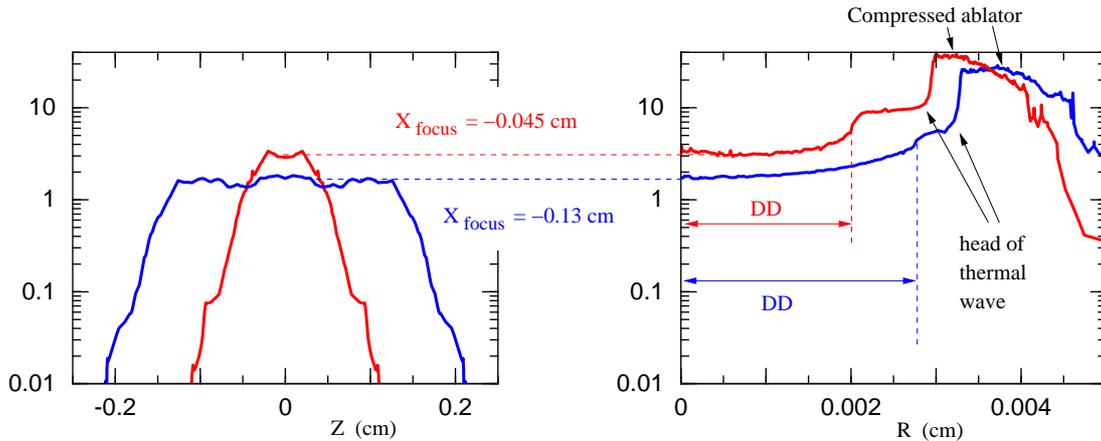


Figure 5: Longitudinal and radial density profiles

We have also analyzed the asymmetries in the transversal cross section. We use a regular grid with 66 cells in radial direction and 64 in azimuthal direction. The laser is described by four beams propagating at 45° , 135° , 225° , and 315° with a Gaussian profile of width σ . Figure 6 shows the time evolution for three representative cases. Case A corresponds to concentrated beams with $\sigma = 0.03$ cm (approximately 1/2 of the cylinder radius); the implosion is too strong near the diagonal directions of each quadrant, producing a cross-shaped final configuration. Case B with $\sigma = 0.06$ cm shows a good symmetry; the average final radius of deuterium gas is \simeq

$18\mu\text{m}$; this value is a little above the $15\mu\text{m}$ obtained in 1D simulations with radially converging irradiation. For larger values of σ (0.12 cm in case C), the symmetry pattern approaches to the one of 4 uniform beams. On a cylindrical surface $I(\theta) \propto |\cos(\theta - 45^\circ)| + |\cos(\theta + 45^\circ)|$, with a RMS non uniformity of 9.77 %. This non uniformity is smoothed by the transport from the absorption region to the ablation surface, giving place to a final configuration similar to the one in case B. By the other hand, larger values of σ imply that some part of the laser energy miss the target, producing a slower implosion.

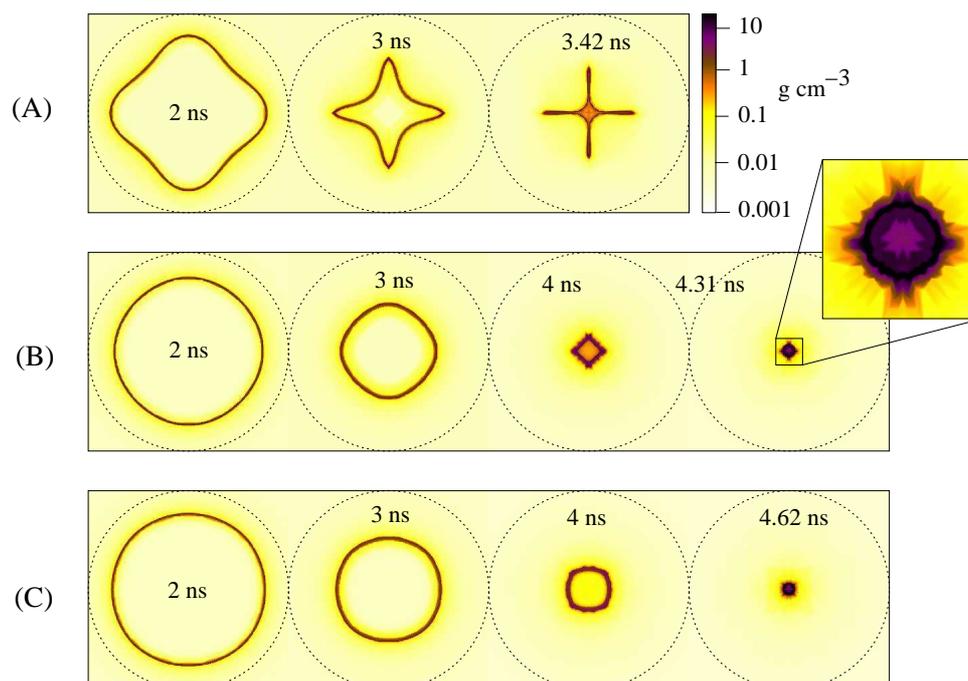


Figure 6: Cross section cuts at different times for cases A, B and C

Acknowledgments

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