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Target studies for the HiPER project

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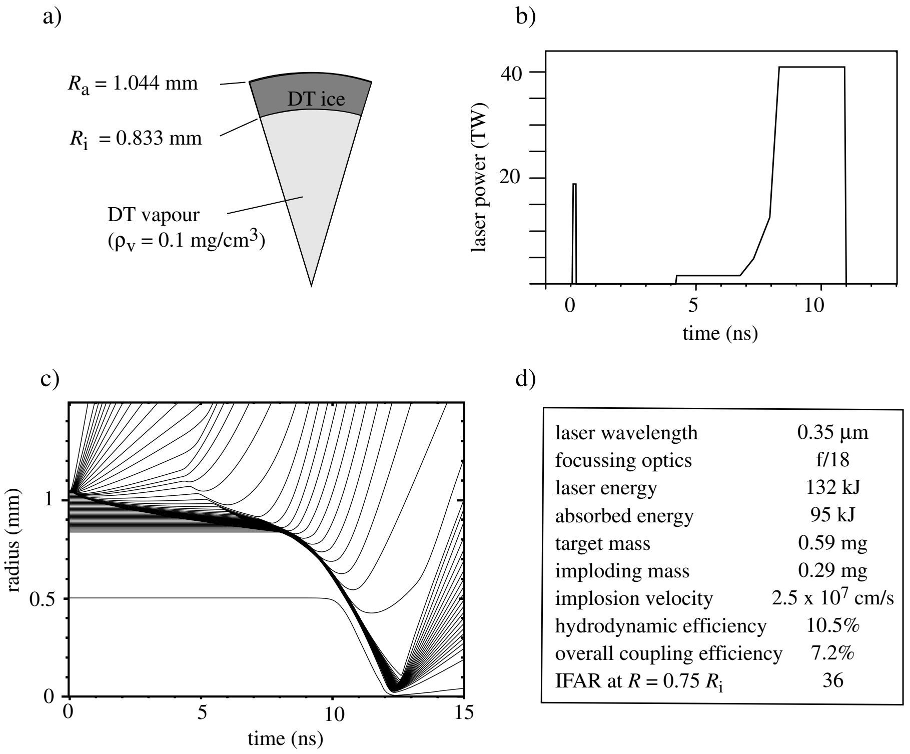
Recently, a European collaboration has proposed the HiPER facility [1], aiming at the demonstration of laser driven inertial fusion fast ignition [2, 3]. According to the present design [4], HiPER will have a multi-beam, multi-ns pulse of about 250 kJ at the wavelength of 0.35 μm, and an ignition beam delivering about 70 kJ in about 15 ps at wavelength $\lambda_{\rm ig}$ of 0.53 μm or 0.35 μm. In the past two years we have addressed several issues concerning the design of targets for HiPER. We have first developed an integrated gain model, and then performed 1D simulations of laser driven compression, stability analyses by models using the time-dependent 1D flow as an input, and 2D simulations of ignition and burn. These studies have led to a reference conceptual design [4, 5], which is now under detailed investigation. Here, we summarize some of the main results, while a full discussion can be found in Ref. [5].

A crucial issue for fast ignition is the choice of ignition beam frequency. However, while both compression and burn have been studied in detail with reliable codes, coupling of the ultra-intense ignition beam with the plasma cannot yet be studied self-consistently [3]. In our study, it has been parametrized in a simple, rough way. We have assumed that the intense beam energy generates fast particles with penetration depth $\mathscr{R}$, with given effeciency $\eta_{\rm ig}$ (for which we have taken a reference value of 25%). We have used $\mathscr{R}({\rm g/cm^2}) = 0.6 f_{\rm R} T({\rm MeV})$, where T is the hot electron tempereratura. This is related to igniting laser intensity $I_{\rm ig}$ and wavelength $\lambda_{\rm ig}$ by a ponderomotive scaling, $T({\rm MeV}) = [I_{\rm ig}\hat{\lambda}^2/(1.2\times 10^{19}{\rm W/cm^2})]^{1/2}$. Here $\hat{\lambda}_{\rm ig} = \lambda_{\rm ig}/(1\mu{\rm m})$ and $f_{\rm R}$ is a free parameter. Both our analytical model (using an upgraded version [6] of a standard ignition criterion [7]) and simulations indicate that keeping the igniting beam energy below 100 kJ requires [8, 5] $f_R\hat{\lambda} < 0.5$, i.e. either second harmonic Nd:glass ignition laser and/or electron range shortening. This is confirmed by recent work by the LLE group [9].

We have considered simple all-DT capsules, driven by a shaped pulse, preceeded by an intense picket to shape the ablator adiabat [10], thus reducing the growth rate of the Rayleigh-Taylor instability (RTI). In this way, we achieve low average fuel isentrope, $\alpha \simeq 1$, and integrated RTI exponential growth factor below 5 for all perturbation modes. The reference capsule, pulse, implosion diagram, and a few main results are shown in Fig. 1 (2T IMPLO simulation). At stagnation the density of most of the fuel exceeds 300 g/cm^3, with a peak of about 500 g/cm^3 (see also Fig. 2). The confinement parameter $<\rho R>$ peaks at 1.3–1.6 g/cm^2 (depending on the



laser wavelength	0.35 μm
focussing optics	f/18
laser energy	132 kJ
absorbed energy	95 kJ
target mass	0.59 mg
imploding mass	0.29 mg
implosion velocity	2.5 x 10^7 cm/s
hydrodynamic efficiency	10.5%
overall coupling efficiency	7.2%
IFAR at $R = 0.75\ R_i$	36

Figure 1: Reference target: target sketch, laser pulse, implosion flowchart, main drive parameters and implosion results.

simulation model). These results have been confirmed by independent calculations performed by GIFI-UPM [11] and CELIA [12].

Target and pulse have been scaled in size and energy, by keeping fixed the laser intensity and the shell initial aspect ratio, and scaling mass and energy as R^3, and times as R. Taking the previous target (with mass M_0) as reference, we designed a *small* target with mass $(2/3)M_0$ and a *large* target with mass $2M_0$. After scaling, the pulse has been optimized by small changes to the initial picket, and all targets achieve nearly the same density, while $<\rho R> \propto M^{1/3}$ [13].

Ignition and burn have been studied by a large set of 2D simulations, assuming as initial conditions those computed by the 1D run around peak $<\rho R>$, and varying pulse intensity, duration, spot size, and particle penetration depth. An example of a 2D simulation of the ignition of the reference target is shown in Fig. 2. A 16-ps long, 20 μm in radius, pulse of particles with assigned penetration depth $\mathscr{R}$ impinges on the fuel. In this case, $\mathscr{R} = 1.2$ g/cm^2, the beam intensity is 10^{20} W/cm^2, and the total particle beam energy is 20 kJ. Assuming coupling efficiency $\eta_{\rm ig} = 0.25$, the laser intensity is 4×10^{20} W/cm^2 and the assumed range is consistent with $f_R \lambda_{\rm ig} \simeq 0.4\ \mu$m. The corresponding ignition laser energy is 80 kJ. According to the 2D simulation, the target releases 13 MJ of fusion energy, which, assuming again $\eta_{\rm ig} = 0.25$, cor-

eters, we find [see Fig. 4a)] a sharp ignition threshold for each value of the penetration depth, with optimal $\mathscr{R} \simeq 1.2$ g/cm^2 for the reference target. This is clearly seen in Fig. 4b), where the ignition energy is plotted as a function of $\mathscr{R}$ for the three considered targets. Finally, concerning the synchronization of the laser pulses, we find that the ignition pulse must be fired within a 75-100 ps window, centered about 30–50 ps before the time of peak $<\rho R>$.

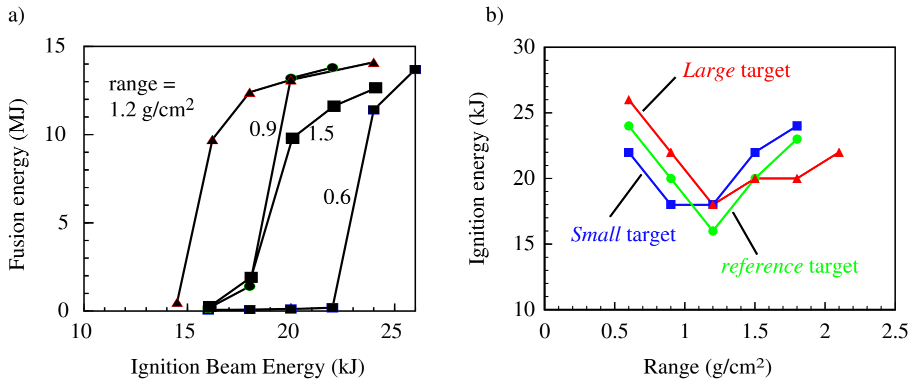


Figure 4: a) Fusion energy vs energy delivered by the igniting beam, for the reference target and different values of the penetration depth of the igniting particles; b) Ignition energy vs range for the three targets considered in the present study.

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