EPJ Web of Conferences **59**, 02001 (2013)
DOI: 10.1051/epjconf/20135902001

Progress of LMJ-relevant implosions experiments on OMEGA

A. Casner[1], F. Philippe[1], V. Tassin[1], P. Seytor[1], M.-C. Monteil[1], P. Gauthier[1], H.S. Park[2], H. Robey[2], J. Ross[2], P. Amendt[2], F. Girard[1], B. Villette[1], C. Reverdin[1], P. Loiseau[1], T. Caillaud[1], O. Landoas[1], C.K. Li[3], R. Petrasso[3], F. Seguin[3], M. Rosenberg[3] and P. Renaudin[1]

[1] *CEA, DAM, DIF, 91297 Arpajon, France*
[2] *Lawrence Livermore National Laboratory, CA 94550, USA*
[3] *Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

Abstract. In preparation of the first ignition attempts on the Laser Mégajoule (LMJ), an experimental program is being pursued on OMEGA to investigate LMJ-relevant hohlraums. First, radiation temperature levels close to 300 eV were recently achieved in reduced-scale hohlraums with modest backscatter losses. Regarding the baseline target design for fusion experiments on LMJ, an extensive experimental database has also been collected for scaled implosions experiments in both empty and gas-filled rugby-shaped hohlraums. We acquired a full picture of hohlraum energetics and implosion dynamics. Not only did the rugby hohlraums show significantly higher x-ray drive energy over the cylindrical hohlraums, but symmetry control by power balance was demonstrated, as well as high-performance D_2 implosions enabling the use of a complete suite of neutrons diagnostics. Charged particle diagnostics provide complementary insights into the physics of these x-ray driven implosions. An overview of these results demonstrates our ability to control the key parameters driving the implosion, lending more confidence in extrapolations to ignition-scale targets.

1. INTRODUCTION

The first implosion experiments and ignition attempts on LMJ [1] will be performed in a two-cone irradiation scheme resulting in a 1/2-1/2 ring balance configuration in the hohlraum [2]. CEA is pursuing an experimental program at the OMEGA Laser Facility [3] to validate the conditions relevant to LMJ point design [4]. These campaigns include the demonstration of ignition radiation temperatures in reduced scale hohlraums with minimized backscattering losses. It has been shown that rugby-shaped hohlraums [5] present significant advantages in terms of coupling efficiency and symmetry control with a 1/2-1/2 energy balance [6] and several tuning campaigns have been performed for capsule implosions in empty and gas-filled hohlraums. The energetics benefit of rugby over cylinder has been demonstrated [7] in both cases, leading to the highest D_2 yields to date on OMEGA in indirect-drive [8]. These high-performance implosions enable the use of a complete suite of nuclear diagnostics, as for example the neutron temporal diagnostic for determination of the burn history [9]. We present in the following a brief overview of these LMJ-relevant implosions experiments.

2. DEMONSTRATION OF IGNITION RADIATION TEMPERATURES IN REDUCED SCALE HOHLRAUMS

Point designs for ignition requires radiation temperature at 300 eV level [4, 10]. A way to achieve such high radiation temperatures on OMEGA is to work with reduced scale empty hohlraums. However

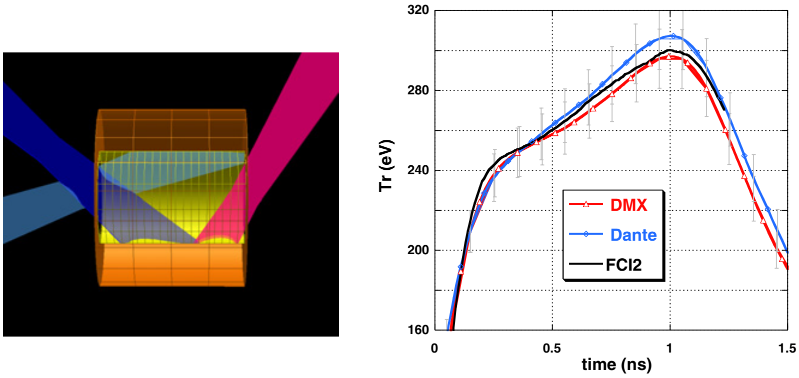

Figure 1. (a) Schematic of beam pointing inside the hohlraum. (b) Measured radiation temperature law in reduced scale hohlraums and corresponding FCI2 simulations.

previous experiments exhibited high levels of laser parametric instabilities (LPI) [11]. Working with indirect-drive phase plates and defocusing 21° and 42° cones outside the hohlraum we were able to minimize backscattering losses, with negligible Raman backscattered light and Brillouin backscattered light at less than 2%. The radiation temperature was measured with the absolutely calibrated time-resolved soft x-ray spectrometers Dante and DMX. The simulations performed with the radiation hydrodynamics code FCI2 fall within diagnostics error bars (see Fig. 1(b)), providing a benchmark of FCI2 atomic physics in this temperature range.

3. HIGH PERFORMANCE CAPSULE IMPLOSIONS WITH EMPTY RUGBY HOHLRAUMS

3.1 Enhanced x-ray drive

Regarding the results from the vacuum rugby and cylinder comparison an increase in x-ray drive (+18% in x-ray flux) has been demonstrated in empty rugby-shaped hohlraum for the same incident laser energy [6]. The reduction of the wall area with the rugby geometry was equal to 30%, for a fixed laser entrance hole size and case-to-capsule ratio [6]. Typical radiation temperatures measured by Dante are displayed on Fig. 2(a) for both cases. Moreover this increased x-ray drive leads to capsule implosion performances with record neutron yield in indirect-drive on OMEGA reaching $Y_n = 1.5\ 10^{10}$ neutrons (D_2 fuel) for a laser energy of only 19.5 kJ. The increased drive on capsule is also confirmed by a smaller energy downshift of secondary proton spectra in rugby due to greater mass ablation [7, 8, 12].

3.2 Symmetry control with a predicted cone power balance

These experiments demonstrated nevertheless a pancake (oblate) symmetry with normalized Legendre polynomial coefficient $P_2/P_0 = -20\%$ to -28% [8]. This was found to be consistent with a 10–20% backscatter on the inner cones [8]. We performed therefore a symmetry tuning with a predicted cone power balance between outer and inner cones: a 0.8x factor was applied on outer cone power (59° beams). The convergence ratio (C_R = Initial capsule radius / Final core radius) of the implosions is $C_R \sim 6$ and nearly round implosions were observed with $P_2/P_0 < 4\%$ (see Fig. 2(b)). This calculated symmetry tuning confirms that our understanding of empty rugby hohlraum energetics is sound.

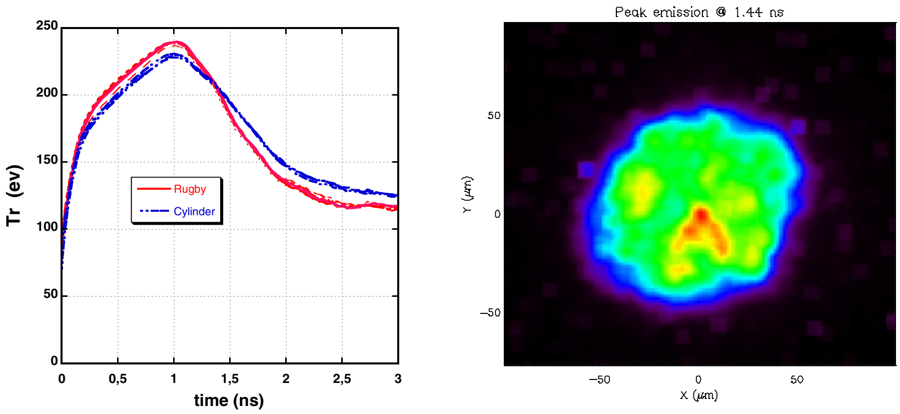

Figure 2. (a) Comparison of drive temperature history in cylindrical and rugby-shaped hohlraums. (b) Time gated x-ray emission core image at bang time obtained with a predicted 0.8 $\times$ cone power balance between inner and outer beams (hohlraum axis is horizontal).

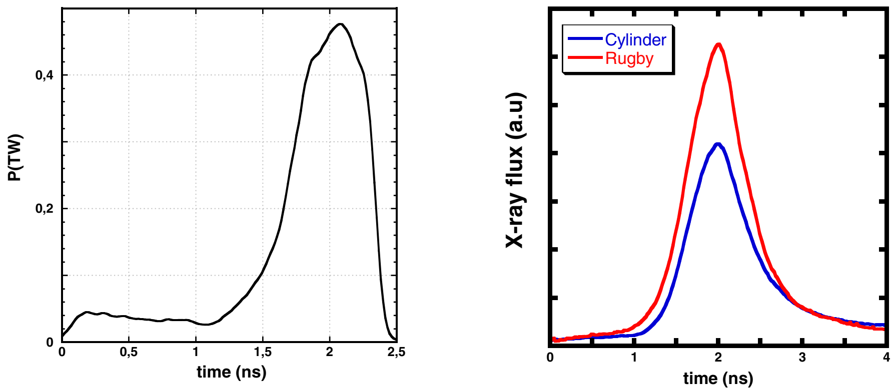

Figure 3. (a) Typical pulse-shape used for gas-filled rugby implosions experiments. (b) Emitted x-ray power (arbitrary units) for gas-filled rugby and cylindrical hohlraums.

4. ENERGETICS ADVANTAGES IN GAS-FILLED RUGBY HOHLRAUMS

We pursue the cylinder versus rugby comparison with gas-filled hohlraums. The hohlraum length, LEH size and central diameter were kept constant, leading again to a reduction of the wall area with the rugby geometry equal to 30%. A new high contrast pulse leading to a higher convergence ratio and a dominant component of compressional neutrons burn has been designed (see Fig. 3(a)). The full smoothing techniques available on OMEGA are employed: Smoothing per Spectral Dispersion (SSD), polarization rotators (DPR) and indirect drive phase plates E-IDI-300. As a consequence negligible SBS light has been measured on all cones. SRS is also negligible on cone 59° whereas SRS in the Full Aperture Backscatter Station (FABS) is only about 2% of the incoming energy. The radiant x-ray flux has been measured with Dante and the gas-filled rugby-shaped hohlraums demonstrated in average on 6 shots +40% (±10%) increase in flux in comparison with cylinders (see Fig. 3(b)). The measured increase in drive is in accordance with FCI2 simulations which take into account backscattering losses.

The symmetry is also controlled for these implosions with a $C_R \sim 13$. Temporally gated x-ray core images show a normalized Legendre polynomial coefficient P_2/P_0 equal to 8% (±2%). The nuclear diagnostics confirm the enhanced x-ray drive. Earlier bang times (by up to 300 ps in advance) as well as consistently higher yields are systematically observed for implosions performed with rugby hohlraums. The average improvement in yield over 6 shots in gas-filled rugby hohlraum is equal to a factor of 3.9 ($\pm$1.2).

5. CONCLUSION AND PERSPECTIVES

A comprehensive experimental program including hohlraum energetics and implosion experiments is being pursued by CEA to validate at OMEGA scale some aspects of the physics of LMJ rugby-shaped hohlraum point design. A significant x-ray drive enhancement (+18%) in empty rugby-shaped hohlraum has been demonstrated and confirmed by nuclear capsule performances. The drive enhancement is even larger in the case of gas-filled rugby hohlraums. We have demonstrated that symmetry can be controlled and that backscatter is acceptable for rugby-shaped hohlraums. At OMEGA scale backscattering losses are not very different in cylinders and rugby hohlraum. At MJ scale LPI in rugby hohlraum is an open question but various mitigation options are available including hohlraum wall shape [2, 4]. The energetics benefit of rugby-shaped hohlraum could be useful either to increase the x-ray drive (and so favor higher capsule implosion velocity) for the same laser power, to achieve the same drive at reduced laser power or for high-gain target designs [13].

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