Time-resolved implosion asymmetry in indirect-drive inertial confinement fusion on the Shenguang III prototype laser facility

H. Li[1, 2*], Y.D. Pu[1], L.F. Jing[1], Z.W. Lin[1], B.L. Chen[1], W. Jiang[1, 2], J.Y. Zhou[1], T.X. Huang[1], H.Y. Zhang[1], R.Z. Yu[1], J.Y. Zhang[1], W.Y. Miao[1], Z.J. Zheng[1], Z.R. Cao[1], J.M. Yang[1], S.Y. Liu[1], S.E. Jiang[1, 2†], Y.K. Ding[1, 2], L.Y. Kuang[1, 2], G.Y. Hu[2], J. Zheng[2], C.S. Wu[3], Y.Q. Zhao[3], J.F. Gu[3], D.G. Kang[3], K. Lan[3]

[1] *Research Center of Laser Fusion, China Academy of Engineering Physics, Mianyang, China*

[2] *CAS Key Laboratory of Basic Plasma Physics and Department of Modern Physics, University of Science and Technology of China, Hefei, China*

[3] *Institute of Applied Physics and Computational Mathematics, Beijing, China*

In order to achieve high compression in laser indirect-drive inertial confinement fusion, the implosion symmetry and hohlraum radiation uniformity are strictly required.

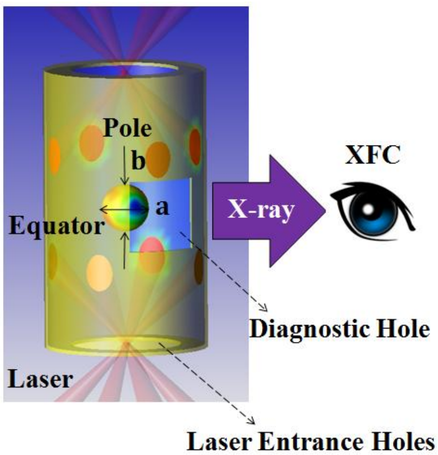

Fig.1 Experimental target & setup

The implosion symmetry experiment was carried out on the Shenguang III prototype high power laser facility. As shown in Fig.1, eight laser beams were focused into a cylindrical hohlraum simultaneously respectively through two laser entrance holes (LEHs) at each end, converted to x-ray radiation ablating a spherical capsule to implode. Each beam delivered energy of 600 J in 1 ns square pulse without beam smoothing. The gold hohlraum was 1000 μm in diameter. Different hohlraum lengths,

* E-mail: njlihang@163.com

† E-mail: jiangshn@vip.sina.com

namely 1600 μm, 1700 μm, and 1800 μm, were used to study the symmetry scaling. The capsule was 300 μm in diameter, 18 μm in shell thickness, filled with 10 atm D_2 gas, and a trace of 0.2 atm Ar gas was doped in the D_2 gas to enhace x-ray emission of the hot spot. Through 450 μm×450 μm diagnostic hole (DH), x-ray emission above 2 keV from capsule fuel was measured by an x-ray framing camera (XFC), whose spatial resolution was less than 21 μm, and time resolution was about 0.1 ns. The typical experimental results of implosion symmetry with different hohlraum lengths and time are shown in Fig.2.

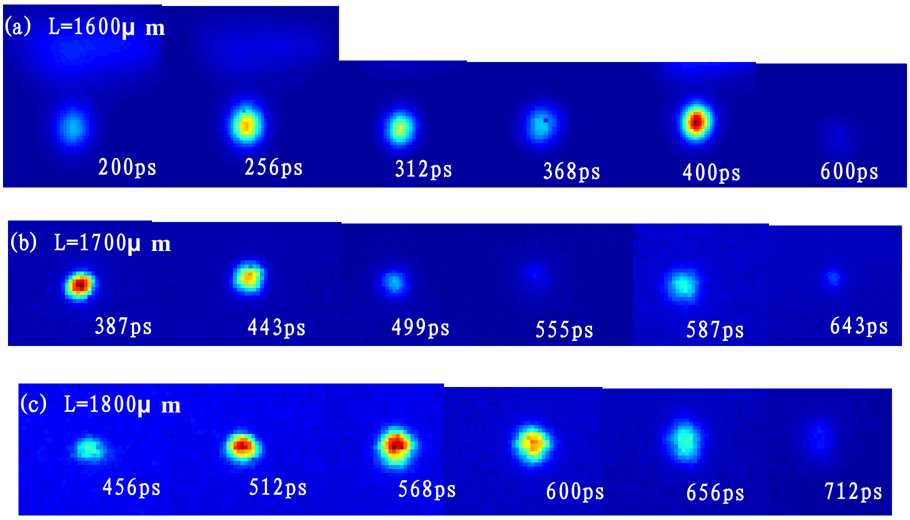

Fig.2 Experimental results of implosion symmetry measured by XFC. (a) the 1600-μm-long short hohraum ; (b) the 1700-μm-long medium hohlraum ; (c) the 1800-μm-long long hohraum

Hot spot ellipticity a/b shows a "P2 like" implosion distortion. The "a" is defined as the hot spot scale at the equator, and "b" is defined as the scale at the pole. Variation process of observed a/b with hohlraum length and time is shown in Fig.3.

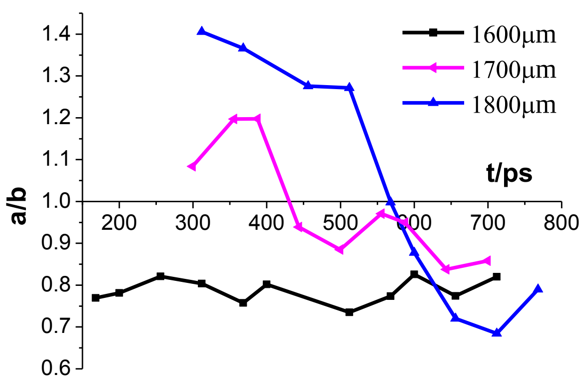

Fig.3 Variation process of a/b with hohlraum length and time.

The indirect-drive implosion asymmetry is determined by the hohlraum radiation uniformity, while the hohlraum radiation uniformity is affected by many factors: length-diameter ratio of hohlraums, hohlraum inner wall albedo, plasma and laser spots movement, hohlraum-capsule ratio (including capsule compression), laser spots positions, LEH and DH's effects, and laser plasma interactions. Most factors above can be taken into account by a view-factor code IRAD 3D, so time-resolved difference between polar and equatorial radiation flux can by calculated by IRAD 3D. Then, the time-resolved a/b evolution can be calculated by a simplified analytic model integrating the total difference between polar and equatorial radiation flux before each moment, because during the acceleration phase the capsule distortion at some time is the accumulation effect of total radiation drive before that time. As shown in Fig.4, the calculated results of the time-resolved implosion asymmetry are basically in agreement with experimental results.

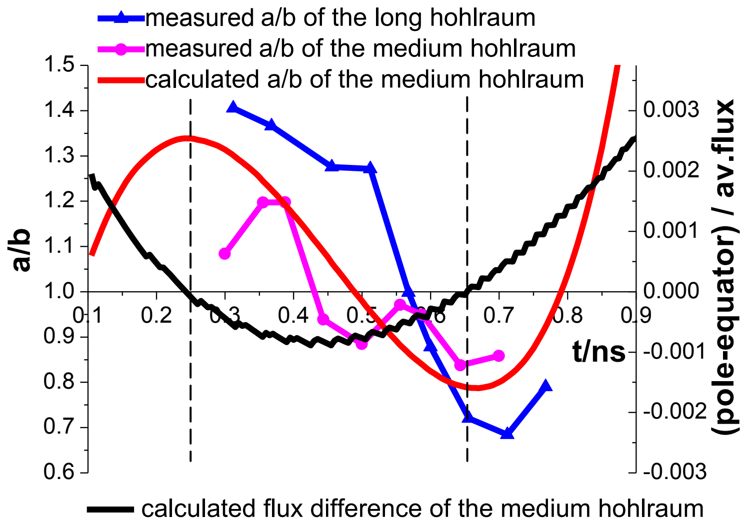

Fig.4 Difference between polar and equatorial radiation flux of the medium hohlraum, and variation process of a/b from calculation and experiment.

As shown in Fig.5, the physical mechanism for how hohlraum radiation nonuniformity evolution induces the variations of implosion asymmetry with hohlraum length and time is analyzed. For the short hohlraum, x-ray radiated from laser spots and that from other hohlraum inner wall both keep equatorial-dominant compression, so that a/b remains less than 1 in the entire evolution. For the medium and the long hohlraum, in the early stage, the regions of the hohlraum walls outside the laser spots are at a significantly lower temperature than the regions directly heated by the laser, so that x-ray radiation is mainly from laser spots and polar drive is dominant. In the mid-stage, the whole hohlraum inner wall has been heated up and albedo rises up, so that equatorial drive turns dominant. In the late stage, plasma filling reduces effective hohlraum diameter, so polar drive returns to a dominant position. Therefore the observed a/b of the medium hohraum increases to greater than 1 first, then falls to less than 1. Comparing the a/b of the medium hohraum, the a/b of the long hohraum has similar but more drastic variation trend, and has a trend back to 1 after 0.7 ns.

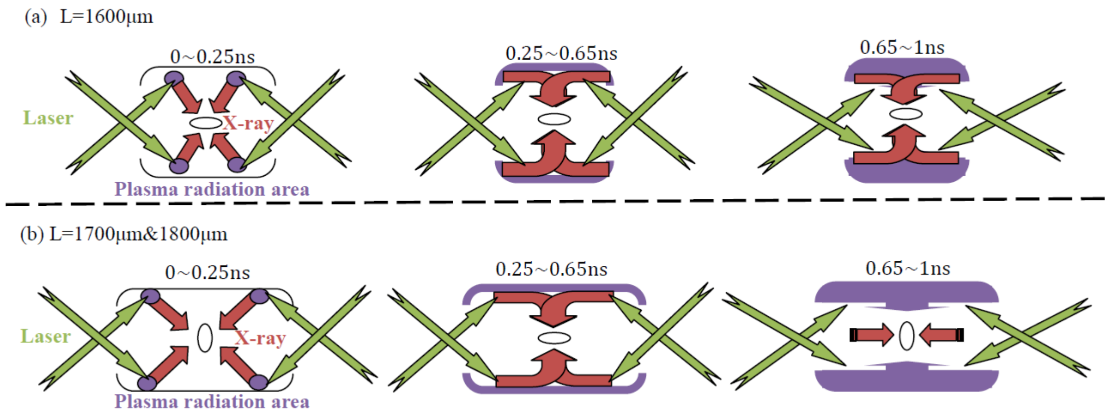

Fig.5 The physical mechanism for how hohlraum radiation nonuniformity evolution induces the variations of implosion asymmetry with hohlraum length and time is analyzed. (a) the short hohraum; (b) the medium and the long hohraum.

In order to ignite, it is required to keep the magnitude of implosion asymmetry swings at a low level in the compression process and to achieve implosion symmetry at bang time. Based on the observed capsule compression process and the calculated results of the view-factor code, it is preliminarily concluded that the medium hohlraum with 1700 μm long and 1000 μm in diameter is the optimal one satisfying implosion symmetry requirement driven by Shenguang III prototype lasers without beam smoothing.

The authors would like to thank the target fabrication, the laser operation, and the experiment diagnostics staffs for their excellent work.