Section 2
PROGRESS IN LASER FUSION

2.A Irradiation Uniformity Experiments on OMEGA

Initial experiments on the 24-beam OMEGA laser system were conducted in 1981 with high intensities ($>10^{15}$ W/cm^2) on target, resulting in exploding pusher target implosions driven by long mean-free-path hot electrons. The increase in pulse length from 100 psec to 1 nsec in 1982 and the use of larger targets produced lower intensities ($4\text{x}10^{14}$ W/cm^2) which enable targets to be driven ablatively, i.e. a small fraction of the pellet mass is ablated outwards, driving the rest inwards like a rocket.

It is currently thought that spherical convergence of ablatively driven targets requires drive pressure uniformities (dP/P) on the order of a few percent. This in turn demands an irradiation uniformity (dI/I) of the same order, across the target surface. The OMEGA system permits this issue of uniformity to be addressed, since the on-target intensity distribution can be carefully diagnosed and controlled.

Perhaps the most surprising result of this series of experiments was that high aspect ratio targets (ratio of initial target radius to wall thickness = 200) could be compressed several hundredfold without breaking up. This is due to the high degree of irradiation uniformity provided by OMEGA.

Intensity Distribution on Target

It is difficult to directly measure the distribution of intensity across the target surface under full power conditions. Instead, a sample of each laser beam is photographed as it is focused onto a plane equivalent to the target surface. A single representative distribution is chosen from the set of 24 such photographs, and is digitized and azimuthally averaged to yield a single radial beam profile. This profile is then analytically added over the surface of the target to give the intensity at any point on the target (see LLE Review, Volume 4).

The intensity distribution may also be expressed as a series of spherical harmonic functions. The coefficients of this expansion contain information about the spatial frequency of intensity nonuniformities. Modes with low spatial frequency will affect the gross shape of the core and are difficult to smooth, whereas high frequency modes may be smoothed but may drive hydrodynamic instabilities.

Such modelling of the intensity distribution permits the effects of laser parameters such as beam profile and focusing conditions to be determined, and to quantify the degree of nonuniformity.

Uniformity Experiments

A number of target shots were taken under carefully controlled conditions to assess the effects of irradiation uniformity on target performance. The targets were a homogeneous group of 400 μm diameter glass microballoons with 1 μm walls filled with 20 atmospheres of DT gas. The laser produced over 2 kJ on target in a 1 nsec pulse, and the standard deviation of the 24-beam energies was below 9%. Principal diagnostics were x-ray imaging through a pair of x-ray microscopes, and neutron yield measurements.

The program was divided into three main sets of experiments. The first two considered the effect of varying focus conditions and number of beams. The third set involved imposing intentional nonuniformities on the target.

Effects of Beam Focus

The point at which the beams are focused is described in terms of distance behind the center of the target, in multiples of the target radius, R. At approximately 3R focus, the beams begin to overlap their neighbors. At 8R, each beam illuminates an entire hemisphere.

A series of shots was taken with the focus varied from 5R to 10R. Figure 8 shows the time-averaged x-ray emission from the targets. At any instant of time, most of the emission will come from near the ablation surface. As the target implodes, this annular emission will progress inwards to the radius at which the ablation surface stagnates. At about this time, an expanding shock wave in the DT fuel strikes the inside of the shell, causing an emission there. In between these two points, corresponding to the cold compressed shell, there should be no emission. Indeed, in the lower photograph in Fig. 8, such a nonemitting ring is evident, indicating that the shell remains intact during the implosion. However the upper photograph, corresponding to 6R focus, shows no such feature, indicating that the shell is probably breaking up.

Figure 9 shows the amplitudes of the spherical harmonic components of the illumination nonuniformity for the two cases shown in Fig. 8.

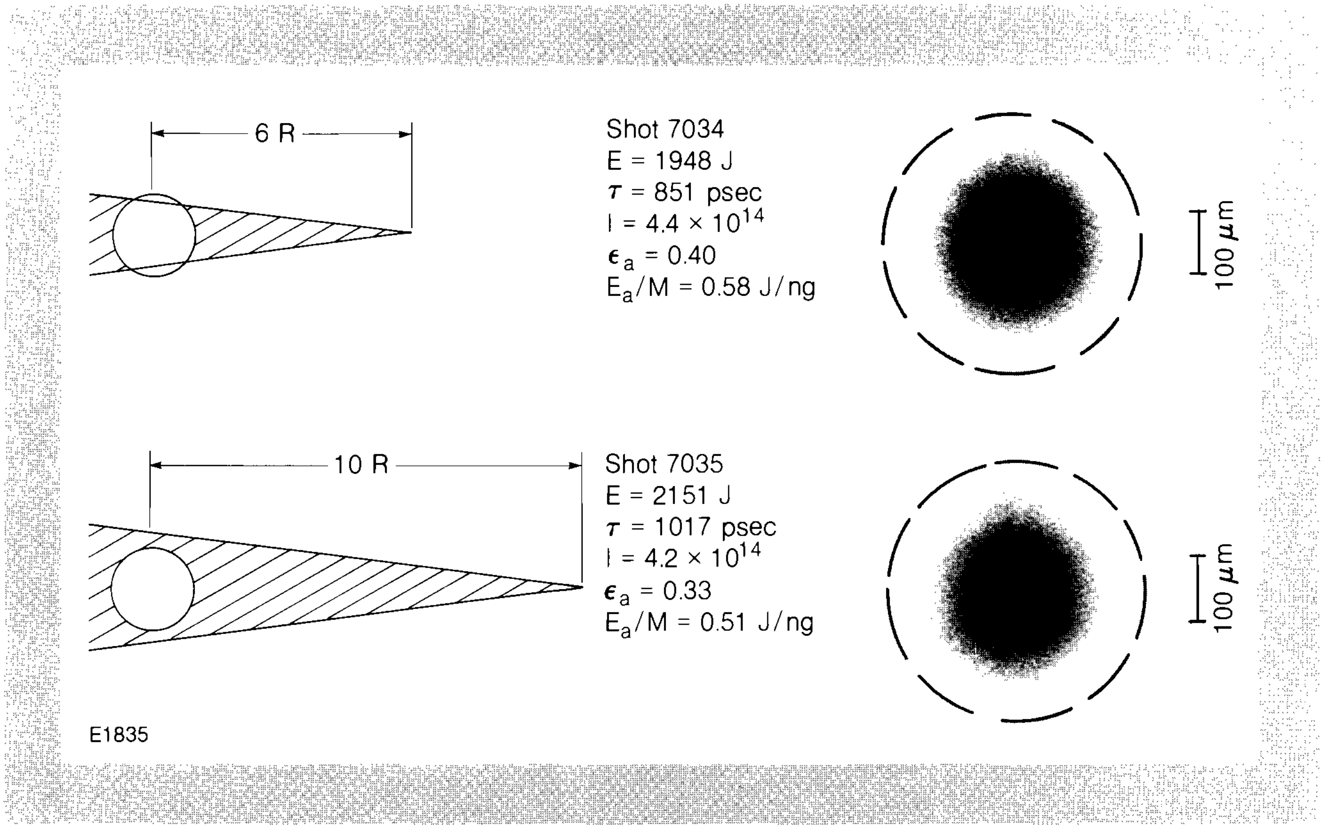

Fig. 8
Photographs of the x-ray self-emission of 400 μm diameter targets taken with x-ray microscopes show the integrity of the shell when the irradiation is sufficiently uniform. The two micrographs show targets irradiated under different focus conditions. Only the 10R shot shows a well-defined stagnated shell. The symbols used in this and subsequent figures are: E (energy on target), τ (laser FWHM pulse width), I (average intensity on target), ε_a (fraction of incident energy absorbed by the target), E_a/M (specific absorbed energy, i.e. absorbed energy divided by target mass).

The dominant mode at $\ell = 8$ is a consequence of the 24-beam OMEGA geometry. All modes have greater amplitudes for the 6R focus than for 10R, suggesting that 10R should provide more uniform illumination. This is borne out by the results in Fig. 8.

Number of Beams

The second set of experiments was designed to determine how the number of beams on target affected target performance. Targets were irradiated at 10^{14} W/cm^2 with 6, 12, and 24 beams. As the number of beams was increased, individual beam energy was reduced to maintain the same power on target.

Figure 10 shows the x-ray emission from targets irradiated with 6, 12, and 24 beams. The 6-beam shot shows the imprint of the beams outside the core, and the nonemitting ring around the core is poorly defined. On the other hand, the core is better defined in the 24-beam case, indicative of better uniformity. The 12-beam shot is intermediate.

Figure 11 shows the ℓ-mode amplitudes corresponding to these three shots. Clearly the 24-beam case is best. The biggest contribution to nonuniformity for the 6-beam set is the $\ell = 2$ and $\ell = 4$ modes, which should produce visible structure on the target, as is seen.

It should be noted that these results, indicating that $\geqslant 12$ beams are required for uniform compression, are dependent on the OMEGA beam geometry and f/3 lenses. The 24-beam geometry, in which neighboring beams are not equidistant, is different from a regular polyhedron with,

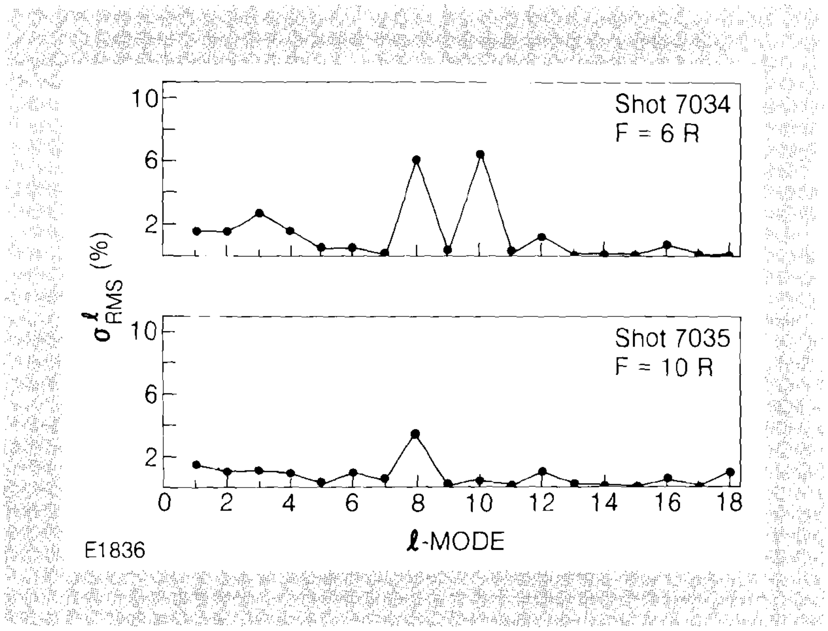

Fig. 9
The standard deviation of the intensity distribution is decomposed into spherical harmonic components for the two shots shown in Fig. 8. Higher ℓ-modes correspond to nonuniformities with higher spatial frequencies.

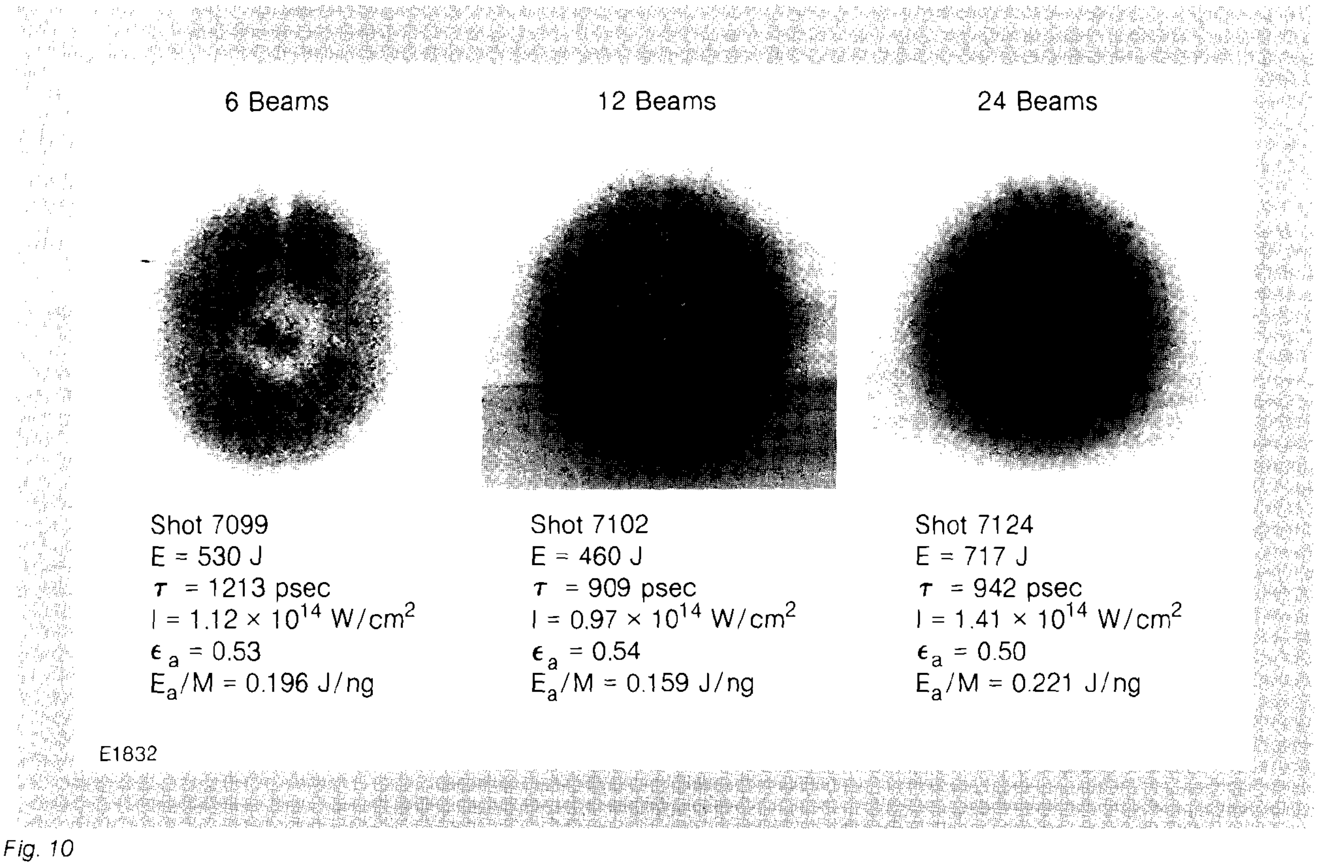

Fig. 10
X-ray micrographs of targets irradiated with the same average intensity but differing numbers of beams show improved target performance with larger numbers of beams.

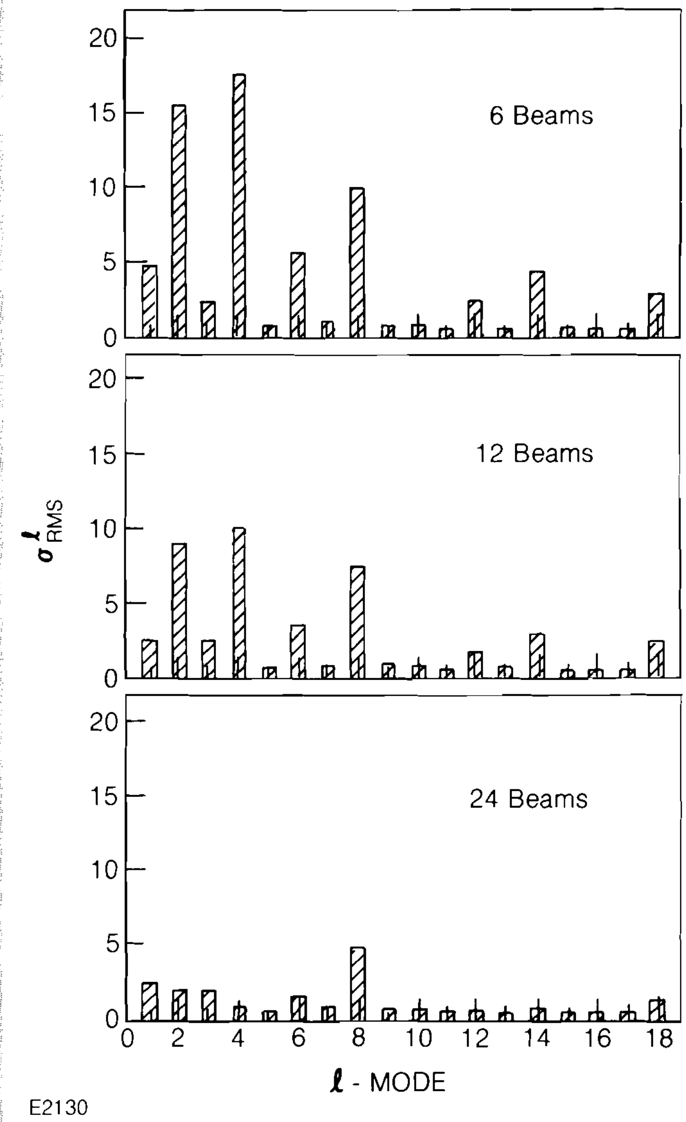

Fig. 11
Spherical harmonic contributions to the intensity uniformity confirm that irradiation uniformity is improved with larger numbers of beams.

say, 20 faces. There may be conditions in which such a regular geometry may produce even better irradition uniformity. However, the 24-beam geometry was chosen because it is less sensitive to focus conditions than the 20-beam set.

Figure 12 shows the neutron yield for shots with intensities near 10^{14} W/cm^2, versus number of beams. There is a significant increase from N = 6 to N = 12, and a small one from N = 12 to N = 24. However, neutron yield is a rather poor indicator of irradiation uniformity, since with these targets, most of the yield is produced by a shock wave before peak compression of the fuel, and the shock shape is relatively insensitive to drive nonuniformity.

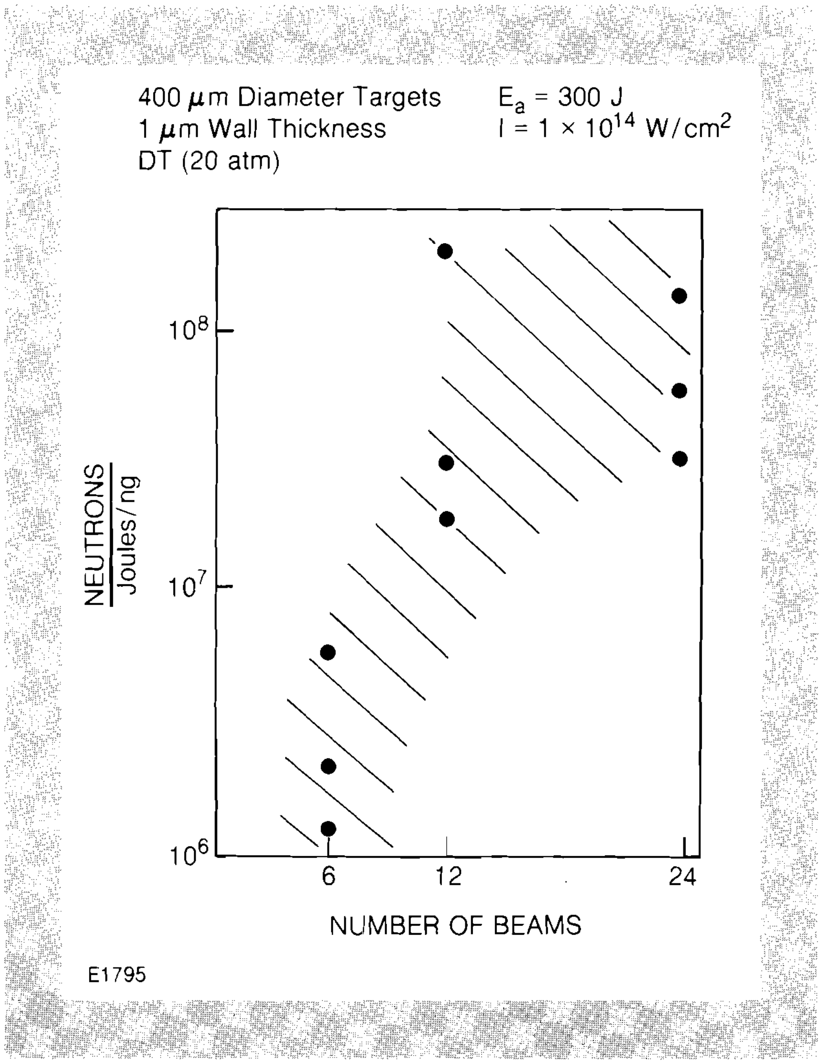

Fig. 12
Neutron yield, normalized to specific absorbed energy, is plotted versus number of beams for shots taken with intensities near 10^{14}W/cm^2.

Intentional Nonuniformities

It is possible to excite low order nonuniformities by adjusting individual beam energies. Such modes should produce visible deformities in the core. $\ell = 1$ modes are driven by imbalancing opposing beams. For the shot shown in the right-hand x-ray micrograph in Fig. 13, the intensity on the left-hand side of the target was reduced by a factor of two. Because the absorption is somewhat higher with lower intensity, the actual drive difference is less than a factor of two, giving an $\ell = 1$ amplitude of 22%. Compared with the balanced shot also shown in Fig. 13, it can be seen that the core is shifted to the left, and the cool region descending from the mounting stalk describes a curved trajectory.

The brightest x-ray emission comes from the inside of the stagnated shell on the low-intensity side. This is most likely due to a shock launched from the high-intensity side colliding with the opposing wall. In spite of the severe asymmetry, neutron yield was only reduced by a factor of two for this shot.

$\ell = 2$ modes were driven by irradiating targets with two opposing clusters of 4 beams each, as shown in Fig. 14. The two views indicate that

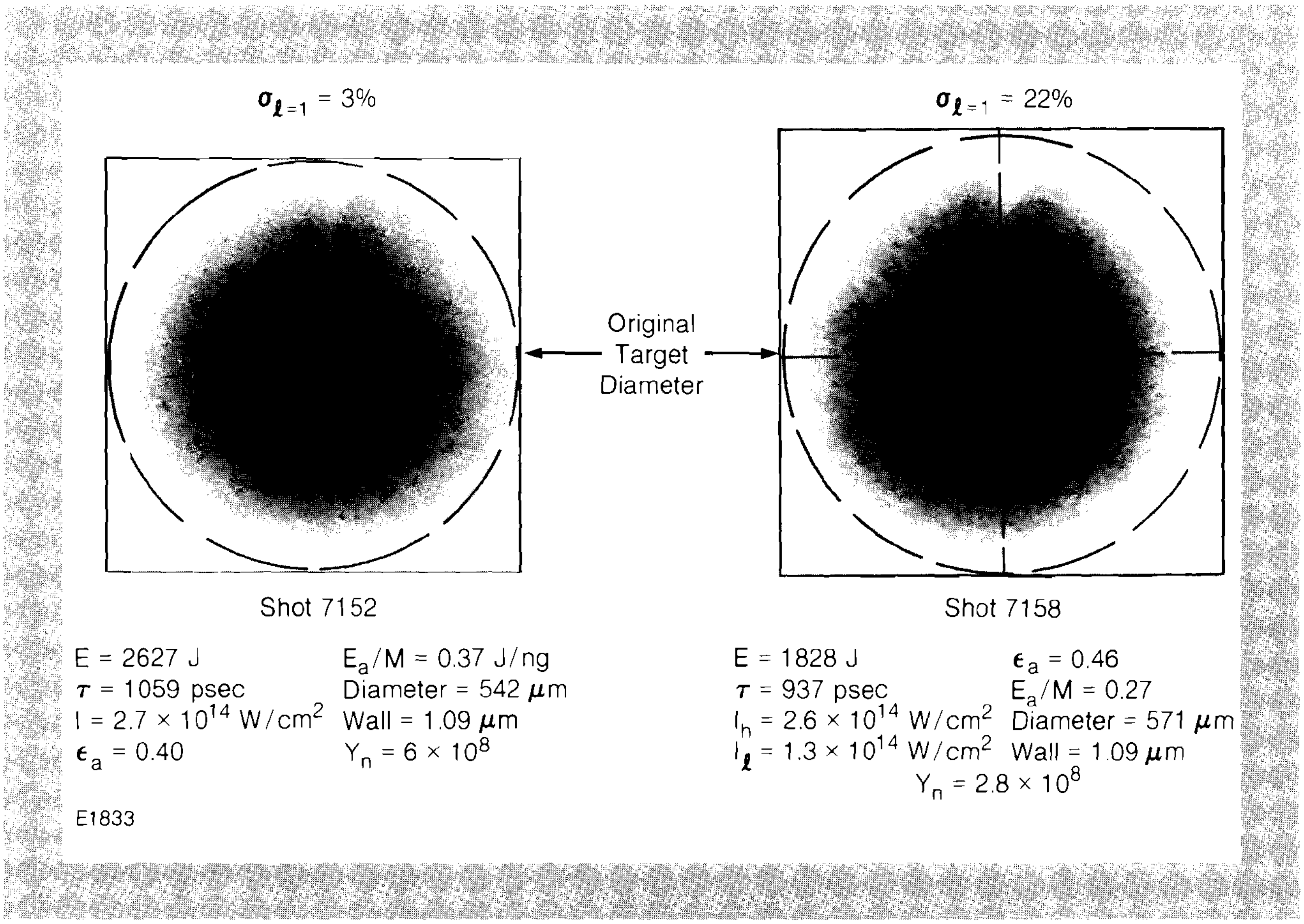

Fig. 13
The intensity on the left side of the target (I_ℓ) was intentionally reduced from that on the right (I_h) in order to observe the effects of an $\ell = 1$ mode. The left-hand target is under normal irradiation conditions, while the right-hand target has a 22% $\ell = 1$ mode. The core is clearly decentered due to this imbalance.

the core is pancake-shaped. Clearly this 8-beam set is much worse than the symmetric 6-beam set shown in Fig. 10. Again, the neutron yield was not seriously degraded, showing that even a severely perturbed core does not affect the shock-produced yield.

Summary

The symmetric compression of high-aspect ratio shells has been demonstrated on OMEGA. The shell integrity is affected by focus conditions, and at least 12 beams are required to produce symmetric implosions. Intentional illumination asymmetries were used to study their effects on gross core shape.