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Unconverted light management on the NIF – Wedged lens configuration

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This document provides information on the distribution of unconverted light in the NIF target chamber with the wedged final focus lens that has been adopted by the NIF project. It includes a comparison of the wedged lens configuration with the CSG. There are significant benefits to the wedged lens design as it greatly simplifies experiment design.

Background:
The NIF target chamber is subject to large fluences of unconverted 1ω and 2ω laser light. It is important that this light be deflected away from the 3ω best focus in order to prevent 1ω prepulse from impacting an ignition capsule before the shot. It is also important that this light not impact target physics packages or diagnostics.

Previously, the baseline plan was to use a symmetric final focus lens and a color separation grating (CSG) to control the distribution of unconverted light. The CSG disperses the light into many different orders that may impact not only the target, but also diagnostics, the inner wall of the target chamber, and nearly opposing final optics assemblies (FOAs).[1]

The CSG introduces risk for 3ω damage due to modulation it adds to the NIF beam. As a result of this and also the issue of beam rotation in the mapping to the FOA assembly, it has been recommended that the NIF final optics assembly configuration incorporate a wedged focus lens.[2] This eliminates the need for a CSG. This change alters the distribution of unconverted light in the target chamber.

Wedged lens design:
The purpose of a wedged final focus lens is to redirect and focus the 3ω light from adjacent beams in each quad that enter the FOA parallel such that their 3ω focal spots overlap at TCC. This configuration both eliminates the relative

angular offset of adjacent beams within a quad and provides separation of the unconverted light at TCC without a CSG. A sketch of the wedged lens is shown in Figure 1. This shows two adjacent beams entering the FOA along parallel paths. They are redirected focussed to target chamber center with the wedged lens.

Unconverted light distribution:
The wedged lens configuration disperses the light so that the unconverted 1ω and 2ω footprints are offset from chamber center in a compact distribution. The distribution of 1ω and 2ω light from a single FOA (quad of 4 beams) is shown in Figure 2.

The degree of the wedge is fixed to deflect adjacent 3ω beams that are transported in parallel pairs (top two beams in each quad and bottom two beams in each quad independently) to point them at target chamber center with a ~4.14° angle between them (center-center full angle). The 1ω and 2ω are deflected less due to the dispersion of the wedge. This results in an offset of the unconverted light relative to the 3ω best focus position.

The wedge is implemented in the FOA to disperse the light only in the horizontal direction. The overlap of the unconverted light for beams entering from the top half of the chamber is shown in Figure 3.

Impact on target chamber and experiments:
The wedged lens design affects experiment design differently than the color separation grating. Highlights of the differences are presented below in Table 1. These are discussed in more detail below:

1. Unconverted light incident on LEH

With the wedged lens, the full footprint of unconverted light is offset relative to the 3ω focus. There is no residual light overlapping the 3ω focus.

With a centered lens, however, the footprint of unconverted light is centered on the 3ω focus. The sub-aperture color separation grating disperses the central portion of this footprint away from the 3ω focus, leaving a residual intensity of unconverted light of about 1% (design goal).

2. Minimum clearance for unconverted light

The wedge required to offset two parallel beams such that the 3ω focal spots overlap at TCC provides a separation between 2ω unconverted light footprints of 5.8 mm (with a fused silica wedge/lens). The separation of the 1ω unconverted light footprints is approximately 9.9 mm.

With the centered lens and CSG, the region that is kept clear of high intensity zero order unconverted light is 5 mm for 2ω and 6 mm for 1ω. This diameter may be increased by changing the size of the CSG aperture. At the limit of a full aperture CSG, there are severe impacts to the target chamber and beam pointing due to increased dispersion, and overall 3ω propagated to target due to the poor transmission efficiency of a CSG that has been demonstrated.

3. Orders of dispersed light

The wedged lens design introduces dispersion of the zero-order beams. There is no diffractive element with descrete phase steps to produce diffraction into multiple orders.

The CSG design uses a diffractive element which produces diffraction into multiple orders that must be documented and accounted for in all target experiment designs.

4. Envelope of unconverted light at TCC

The full pattern of unconverted 1ω and 2ω light is confined within a radius of 31 mm of TCC with the wedged final focus lens.

With the CSG, the zero order light is confined within a radius of 15 mm of TCC, but there are also multiple orders that are displaced by up tens of cm from TCC.

5. Overlapped intensity on the outside of the hohlraum

With the wedged lens, the unconverted light is offset horizontally from TCC. This leaves a 9.9 mm diameter cylindrical region that is clear from 1ω light, and a 5.8 mm diameter cylindrical region that is clear from 2ω light. For a standard ignition hohlraum, there is no 1ω light incident on the outside of the hohlraum, as illustrated in Figure 4. However, for targets that are larger or include external physics packages, they may extend into the unconverted light pattern. Since the zero order unconverted light footprints are offset from chamber center, their overlap occupies a larger region (31 mm radius at TCC for 1ω), and the overall intensity is lower. For 96 beams pointed such that the 3ω focal spots overlap, the overlapped 1ω intensity does not exceed 27 times that of a single beam at normal incidence.

For the case of the centered lens, the zero-order unconverted light footprints overlap at target chamber center. Therefore maximum intensity is the sum of all 96 beams. This is equivalent to 74 times that of a single beam at normal incidence.

Note that in both cases, there may be additional impact of unconverted light due to backlighter beam alignment. A backlighter structure may experience high fluences of unconverted light. In addition, the unconverted light from the backlighter beams may affect the main target. This impact needs to be assessed for each target during the experiment design process.

6. Impact on target chamber
With the wedged lens, there will be restrictions on beam pointing in order to minimize the impact of unconverted light on nearly opposing FOAs. Specifically, for offset pointing in specific directions, a reduced aperture will be required.

The impact on pointing due to the zero-order light is similar with a color separation grating. However, there is the additional issue of high order dispersed light. Light dispersed into the 7-10th orders may still ablate material from the inside of nearly opposing FOAs without additional pointing restrictions.

7. Target design and shielding
With the wedged lens, the distribution of unconverted light is symmetric about TCC, which simplifies target design. However, it also may force some targets to have larger shields.

With the color separation grating, the distribution of unconverted light is asymmetric. Smaller shields may be used for some target designs, but the overall design may be more complicated.

8. Impact on diagnostic access
With the wedge lens, diagnostics are not impacted by unconverted light as close as 31 mm of TCC from all directions around the midplane of the chamber.

With the color separation grating, there is diagnostic access close to the target only along specific lines of sight due to the asymmetric distribution of high order dispersed unconverted light.

As described in (5) above, the extent of the unconverted light will increase when beams are pointed offset from TCC.

DIM and x-ray diagnostic locations:

The plan proposed for DIM and x-ray diagnostic locations (NIF 0035359) was developed based on experimental requirements during the start-up sequence from first cluster through full NIF. These recommended port allocations do not change as a result of the introduction of the wedged lens. However, the change to a wedged lens does free up more ports for diagnostics since the impact of unconverted light is reduced to only the zero order. Additional DIMs may be added at other port locations as experiments are fielded on the NIF.

The baseline plan for DIM and x-ray diagnostic locations for full NIF is summarized below in Table 2.

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[1] D. Kalantar, S. Dixit, R. Lyons, *"Impact of zero order unconverted light on beam pointing"*, NIF-0033352.

[2] P. Wegner *et al, "Recommendations to reintroduce a wedged lens in the FOA"*, NIF-0039912.

Table 1: Target and diagnostic issues with a wedged final focus lens design.

	Wedged lens	**Color separation grating**
Unconverted light incident on LEH	Zero residual unconverted light overlaps 3ω focal spot	1% residual unconverted light overlaps 3ω focal spot
Minimum clearance for unconverted light	9.9 mm diameter clearance for high intensity 1 (all 1ω) 5.8 mm diameter clearance for high intensity 2ω (all 2ω)	6 mm diameter clearance for high intensity 1ω (0-order) 5 mm diameter clearance for high intensity 2ω (0-order)
Orders of dispersed light	Offset zero-order footprint only, no other orders	No offset of zero-order footprint Offset of CSG aperture by dispersion into many orders
Envelope of unconverted light at TCC	1w footprint confined to within 31 mm of TCC	Undispersed 1ω light is within 15 mm of TCC, High orders up to 10s of cm from TCC
Overlapped intensity on the outside of the hohlraum	High intensity 1ω equivalent to 27 beams overlapped at normal incidence	High intensity 1ω equivalent to >74 beams overlapped at normal incidence
Impact on target chamber	Require reduced aperture for offset pointing in specific directions	Require reduced aperture for offset pointing in specific directions Some high dispersed orders impact nearly opposing FOAs
Target design and shielding	Symmetry of unconverted light distribution Potentially larger shields	Asymmetric 3-D unconverted light distribution CSG orientations isolate specific regions away form TCC free of unconverted light
Impact on diagnostic access	Diagnostic access from all directions without impact up to 3 cm from TCC	Diagnostic access close to chamber center only along specific lines of sight

Table 2: Baseline plan for DIM and x-ray diagnostic placement on NIF (full NIF operation).

NIF port	Diagnostic	Comments
0-0	DIM	Top view, face-on for vert'l halfraum, axial for hohlraum
90-213	DIM	Waist view, orthogonal to 90-123
90-315	DIM	Waist view, side-on, orthogonal to 90-45
90-348	DIM	Waist view, preferred for symmetry expts
90-45	DIM	Waist view, side-on, orthogonal to 90-315
90-123	DIM	Waist view, aligned with inner cone beams in hohlraum
116-129	DIM	Below waist, near to Cluster 4 beams
18-123	SXI	Within 20° of vertical axis, near top
161-236	SXI	Within 20° of vertical axis, near bottom
90-174	Drive	LEH view for horiz'l halfraum, waist view for hohlraum
143-94	Drive	View in LEH for vertical hohlraums

NOTE: DIM locations that are shaded are not configured with separate DIMs. To use these ports, the DIM must be moved from a nearby location.

Figure 1: Use of a wedged lens to focus two adjacent beams that are parallel entering the FOA to TCC. We show only 1ω and 3ω for simplicity.

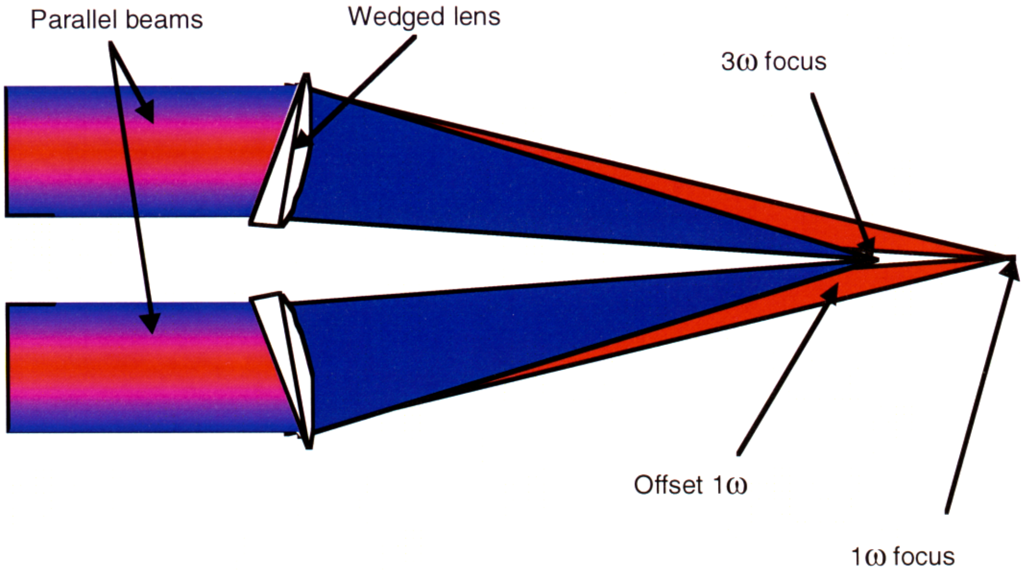


Figure 2: Distribution of unconverted light from the 4 beams in a single FOA (viewed along the beam direction). An ignition scale hohlraum is shown for reference.

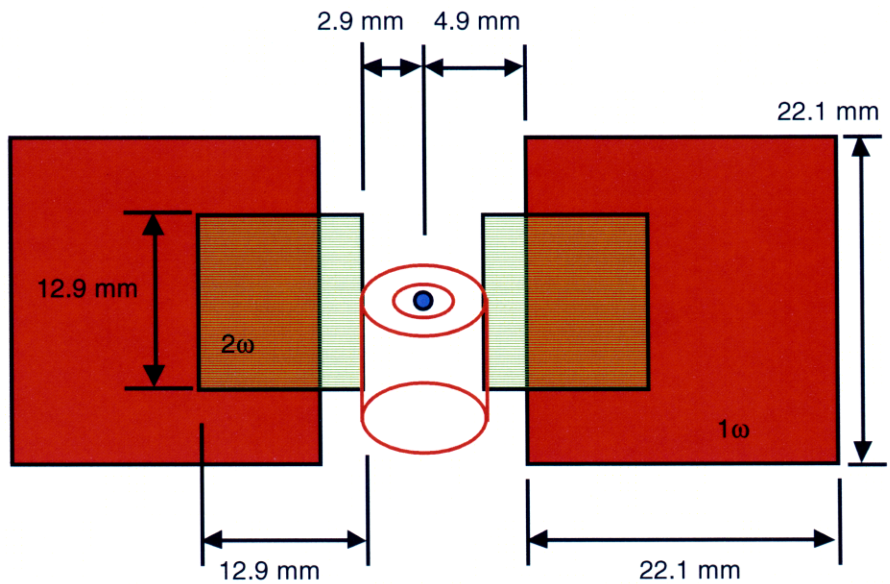
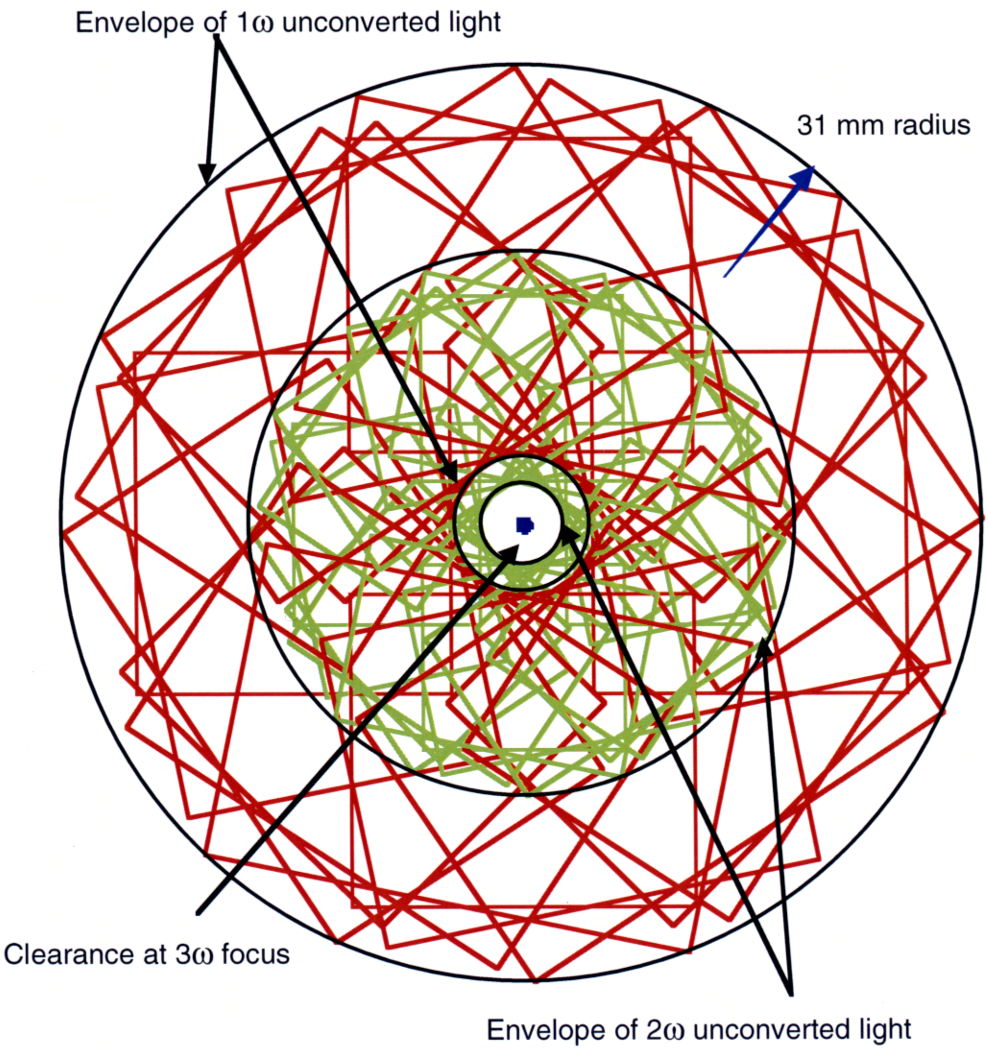


Figure 3: Distribution of unconverted light near target chamber center:
a) Overlap distribution of 96 beams from the top half of the target chamber. The distribution is taken at the plane of the LEH for a vertical hohlraum target.



b) View of unconverted light distribution near target chamber center. This is shown as a vertical slice to illustrate the clear region about the target.

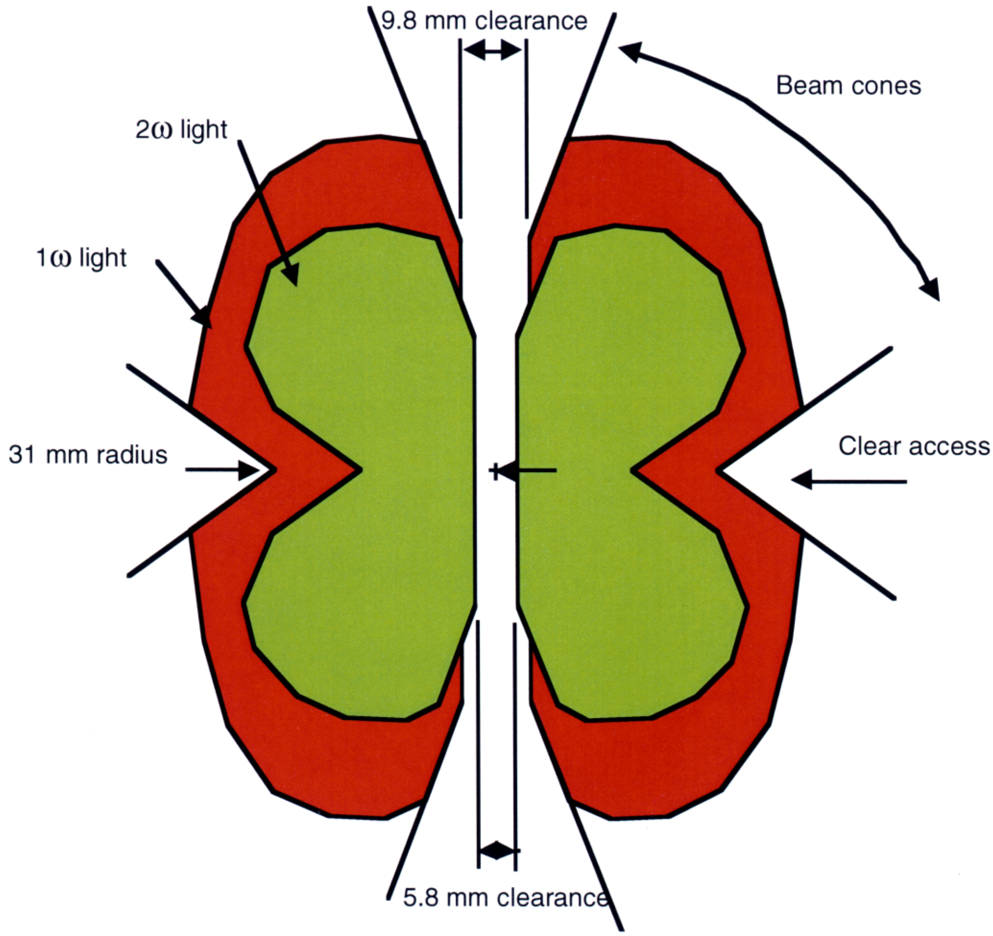


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Figure 4: Impact of unconverted light from a single beam on the outside of an ignition scale hohlraum with the wedged lens vs. centered lens.