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Z-Backlighter Facility upgrades: A path to short/long pulse, multi-frame, multi color backlighting at the Z-Accelerator

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Sandia National Laboratories

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Outline

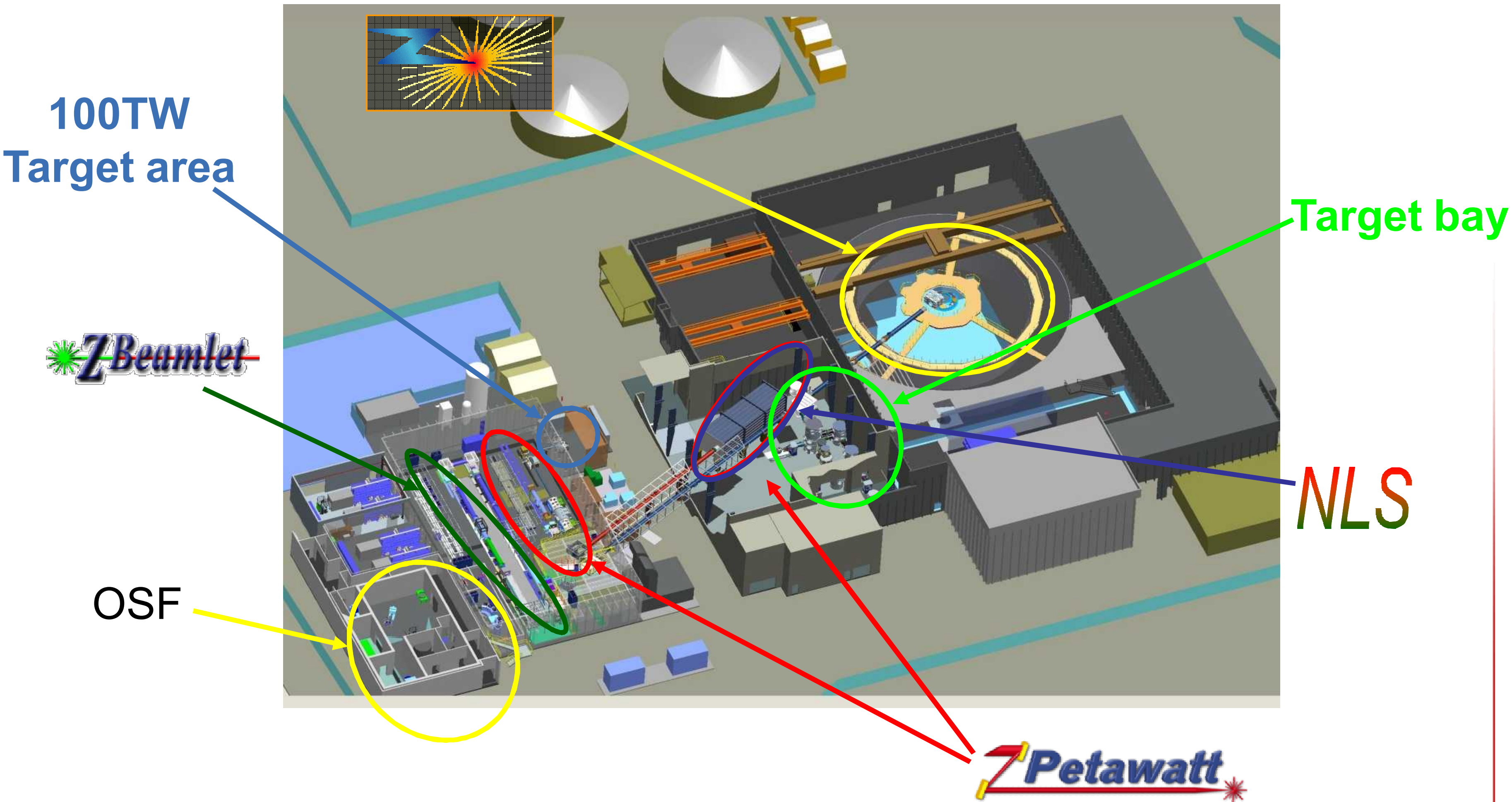
- Z-Backlighter facility overview
- X-ray backlighting
  - point projection vs. crystal imaging
- Multi-frame backlighting on Z-Beamlet
- Upgrades on Z-Petawatt
  - New OPCPA front end
  - Large MLD gratings upgrade
- Enabling technology for short/long pulse combination
  - Debris mitigation techniques for Z-Accelerator
  - Coating/damage testing of dichroic beam combiners and dichroic mirrors
- Target area for testing of new capabilities

Z Backlighter

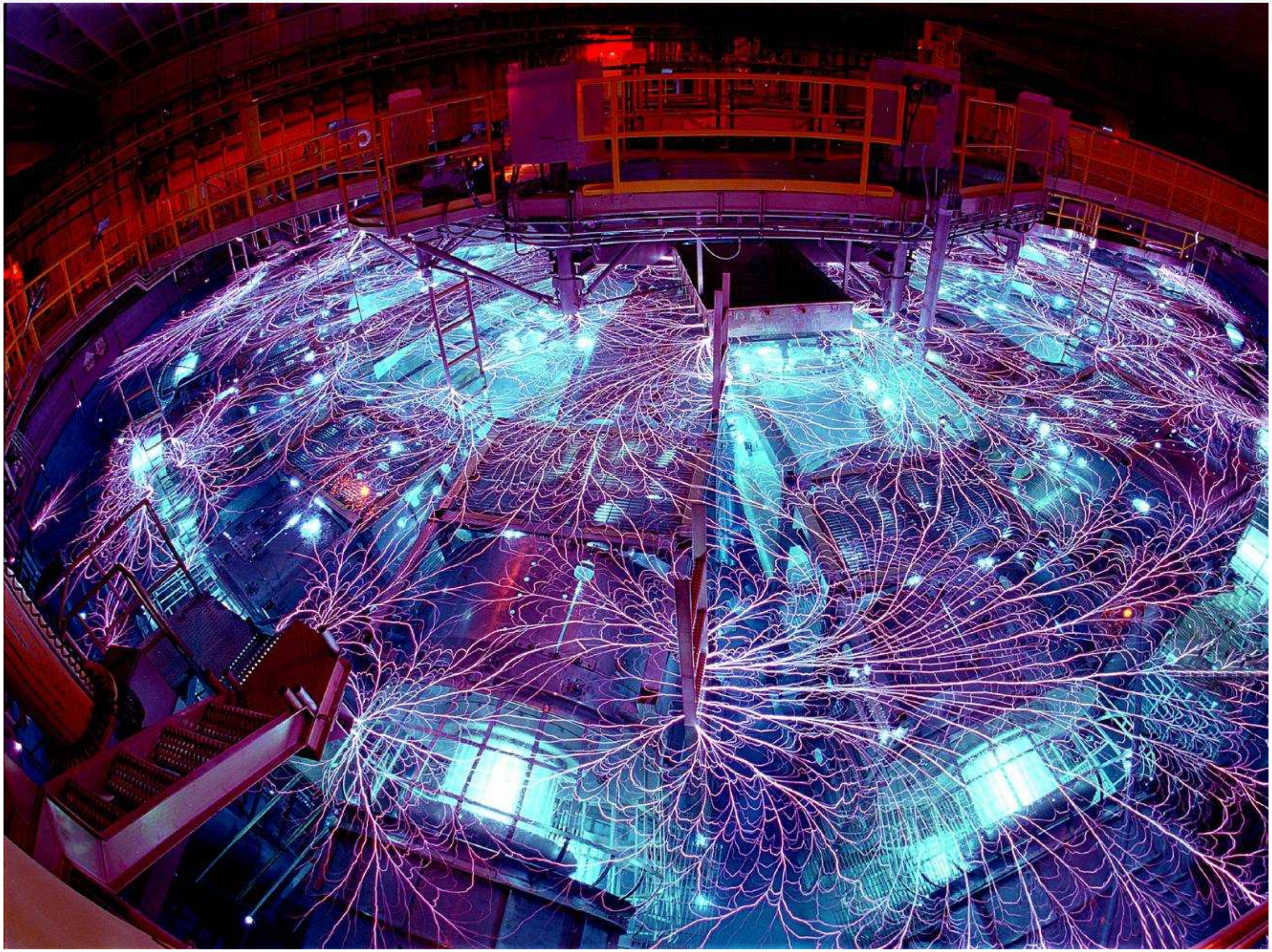
λ (nm)	105	
τ	fs (mi	
typ. Spot s (µm FWH		
E_{max} (J)	00 (PW)	15 (10)
I (W/cm	~ 10^{20}	< 10^{16}
Shot Interv (minutes	180	20
'Special feature'	20 mJ)	8-10 ns option: 1ω and >100J (pending)

Facility Overview

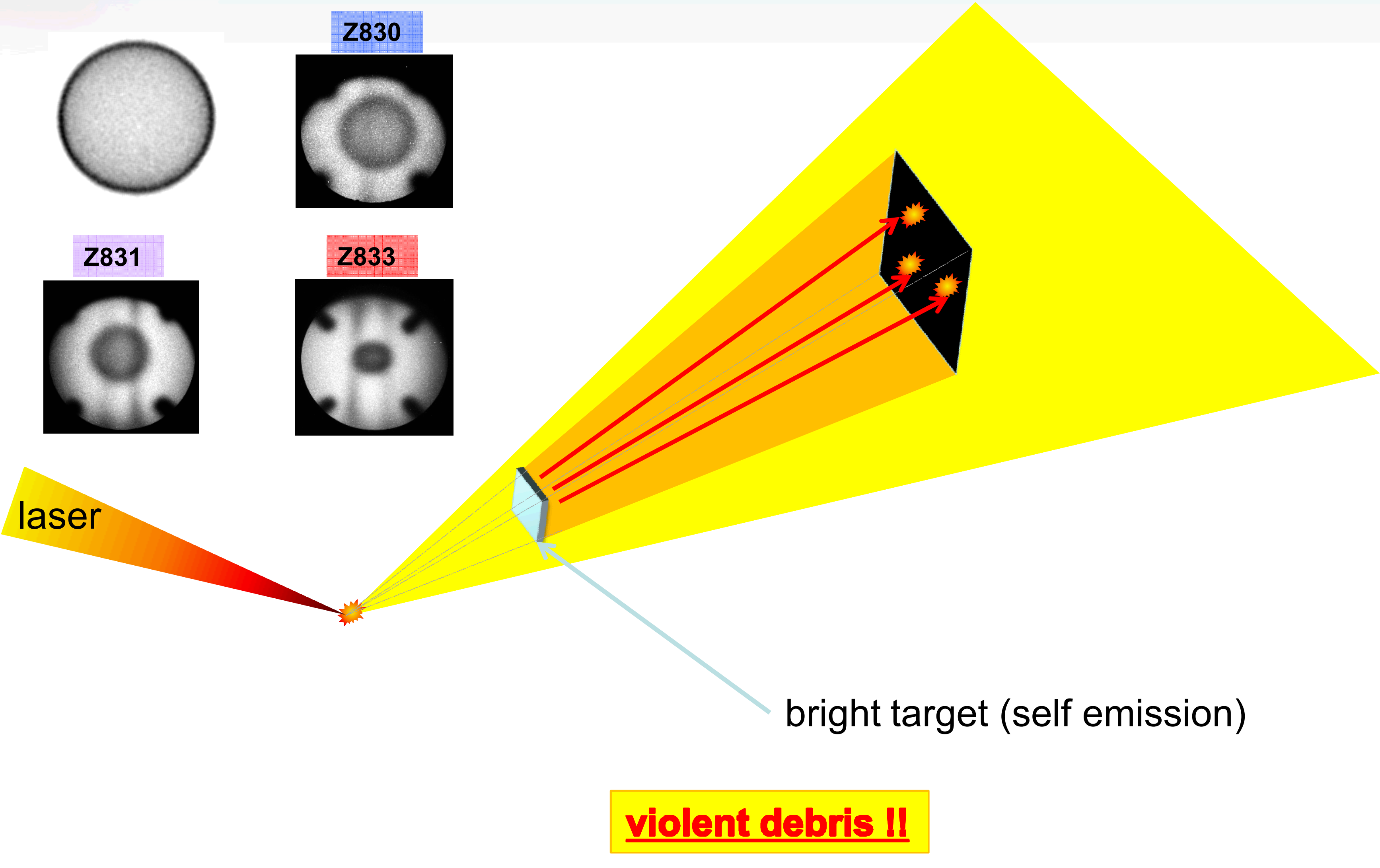
("Buildings 983/986")



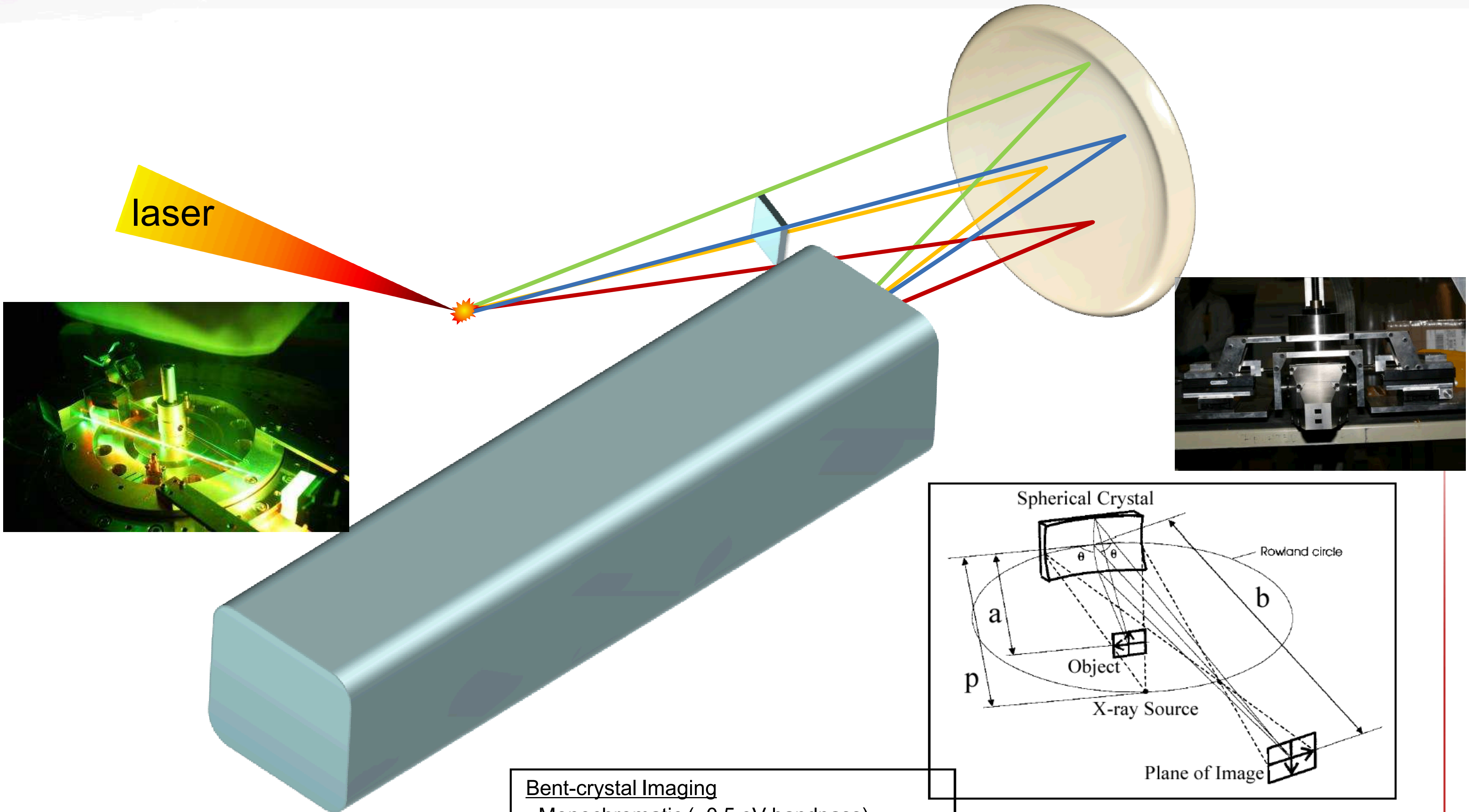
Z-Accelerator: 300TW, 2MJ X-rays



Point Projection Backlighting



Curved Crystal Imaging

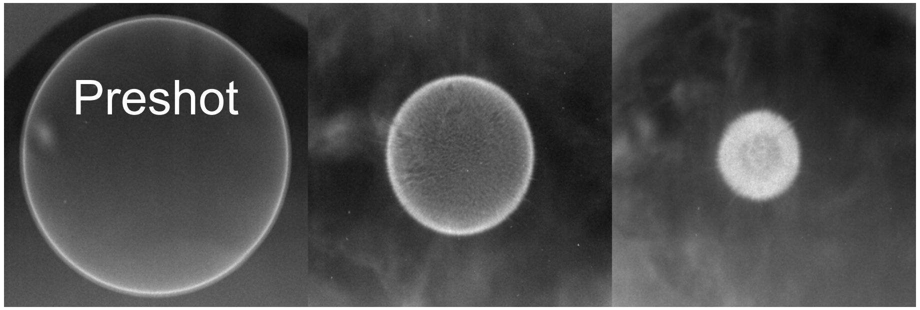


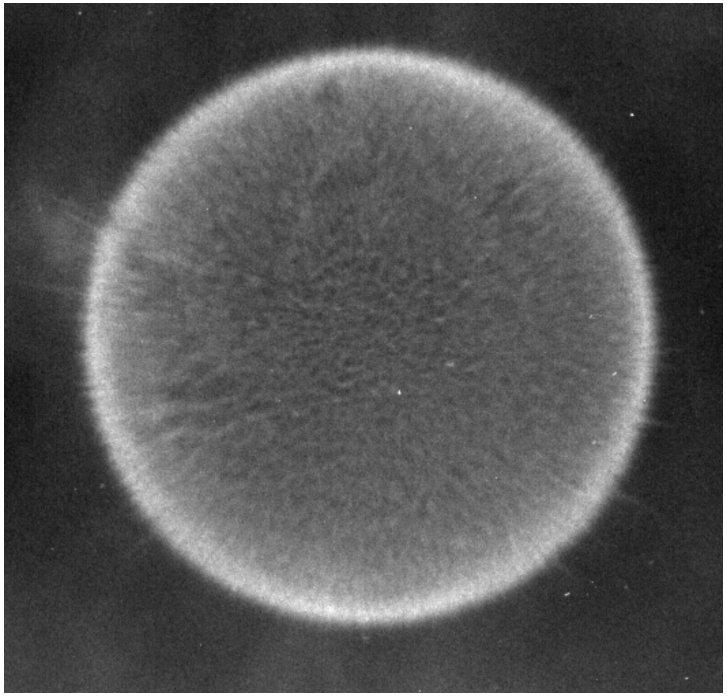
Bent-crystal Imaging
- Monochromatic (~0.5 eV bandpass)
- 10 micron resolution
- Large field of view (e.g. 20 mm x 4 mm)
- Debris mitigation

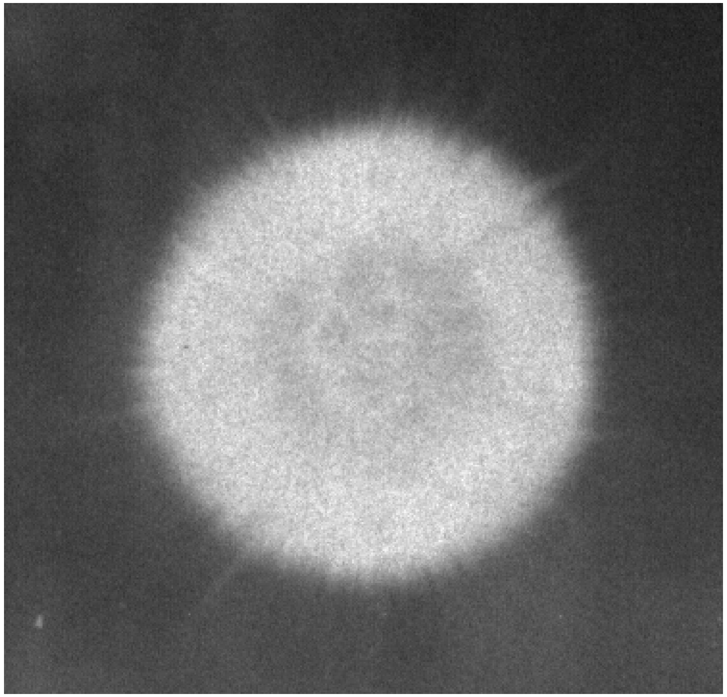
High Resolution Imaging

3.4-mm diameter plastic ICF capsule

Capsules had 100s of known defects on surface that apparently produced a myriad of small jets





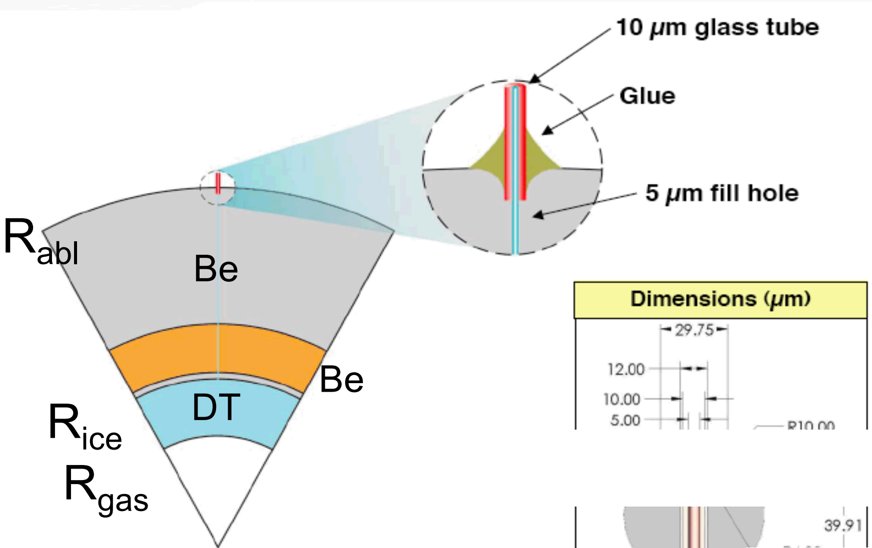


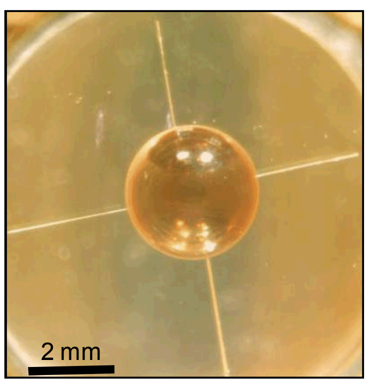
X-ray backlighting enabled us to measure the effects of DT fuel fill-tubes on capsule implosions

Using fill tubes significantly reduces complexity and expense of cryogenics system compared with diffusion fill and cryo transport

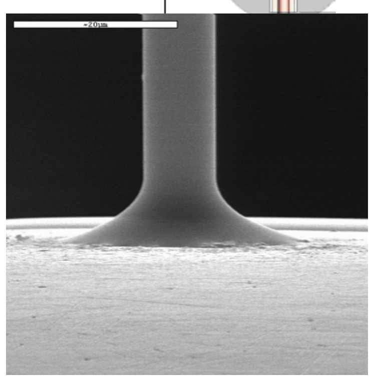
Target fabrication has demonstrated that fill tubes and holes can be made at the NIF specifications

Calculating the perturbations arising from fill tubes is a computational challenge

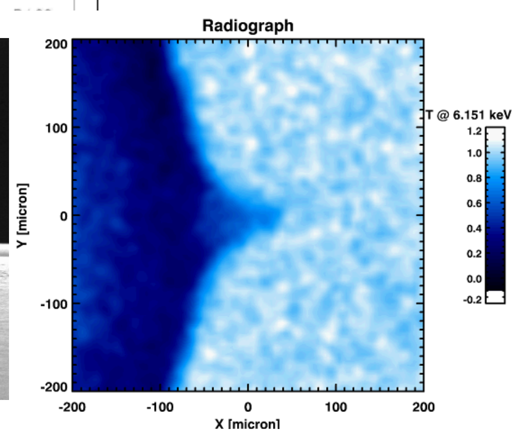




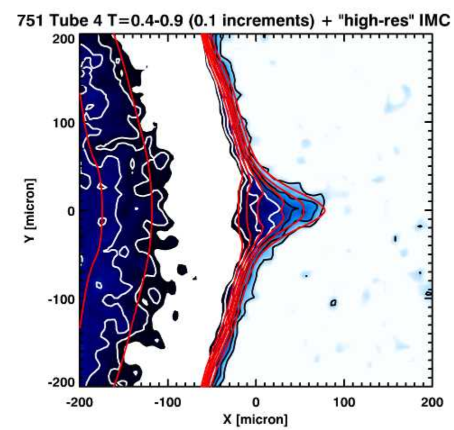
CH capsule with 4 fill tubes (12-45 micron OD)



SEM image of tube and glue fillet



Radiograph at 6.151 keV at convergence ratio 1.5



Comparison of experimental radiograph and simulated radiograph

G.R. Bennett, M.C. Herrmann, *et al.*, Phys. Rev. Lett. 99, 205003 (2007).

GENERAL ATOMICS

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Proposed New OPCPA Design

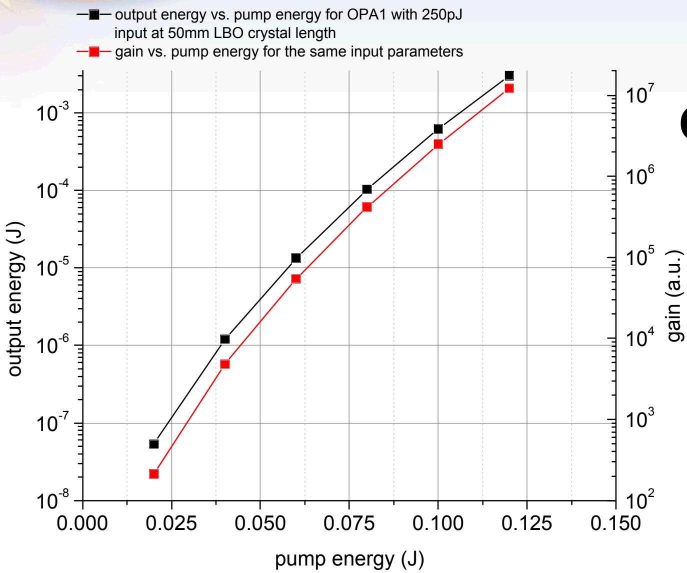
- The new OPCPA system consists of four OPA stages:
  - Two 4x4x25mm walk-off corrected LBO crystals
  - Two 4x4x13mm walk-off corrected LBO crystals
  - One 8x8x6mm BBO crystal
  - One 20x20x9mm BBO crystal

- The OPCPA pump laser has the following parameters:
  Wavelength: 532 nm (SLM)
  - Energy: 5J @ 532nm
  - Pulsewidth: 4.3ns FWHM with temporal flat top and 300ps rise time,
  - flat over 3.7ns.
  - Spatial Profile: round top hat with < 1.15:1 modulation at central 80% and < 1.2:1 over the rest

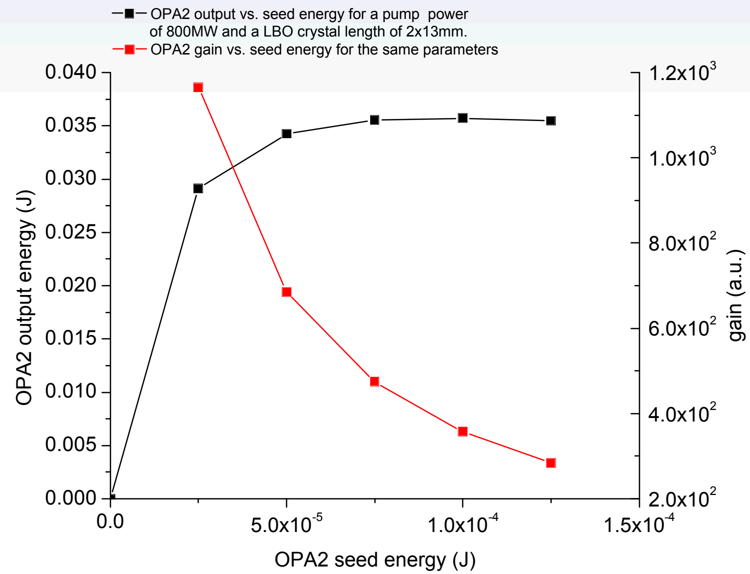
- The stretched seed/signal beam has the following characteristics:
  - Wavelength: centered at 1054nm with a Gaussian hard clipped bandwidth of 16nm
  - Chirp: 4nm/ns (1.08E-3 THz/ps)

Proposed New OPCPA Modeling

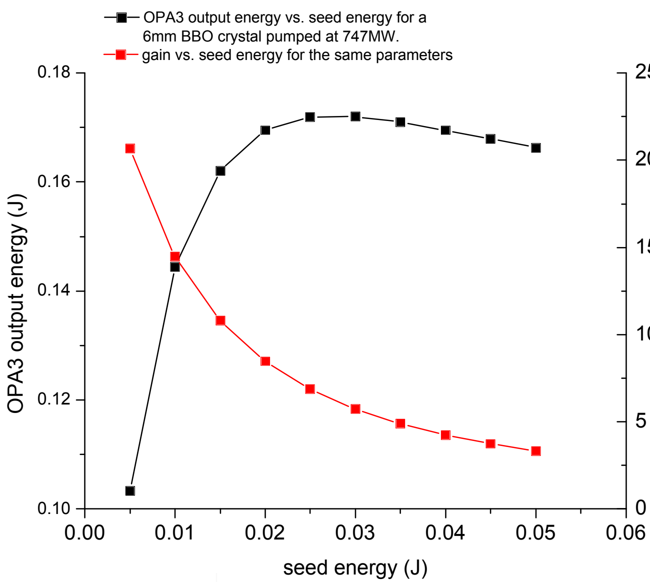
OPA1



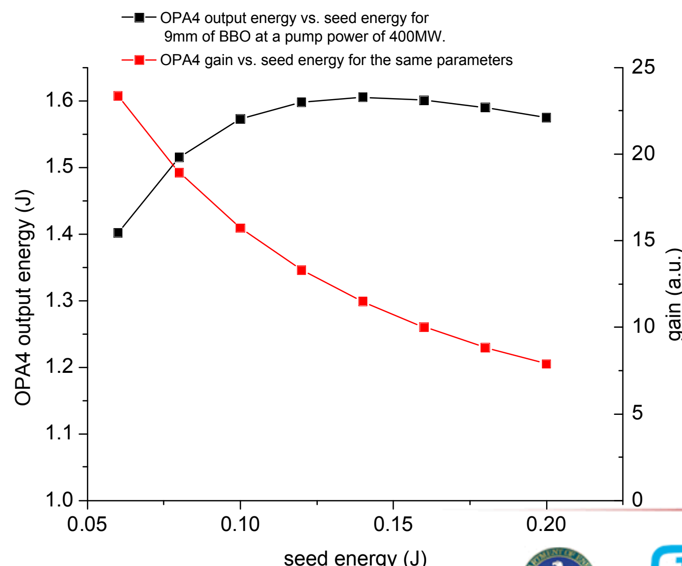
OPA2



OPA3



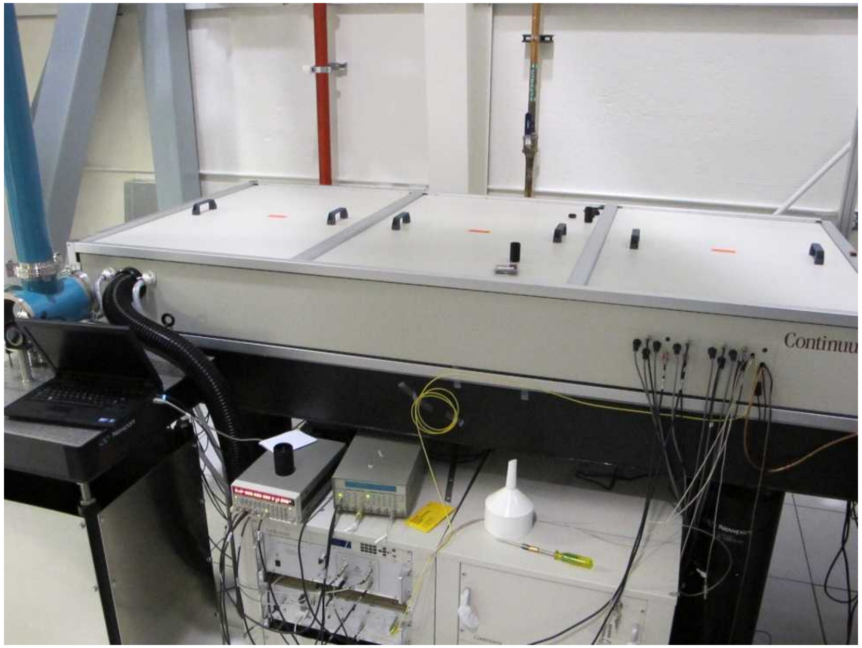
OPA4



Modeled using modified SNLO code by Arlee Smith (www.as-photonics.com)

Proposed New OPCPA Implementation

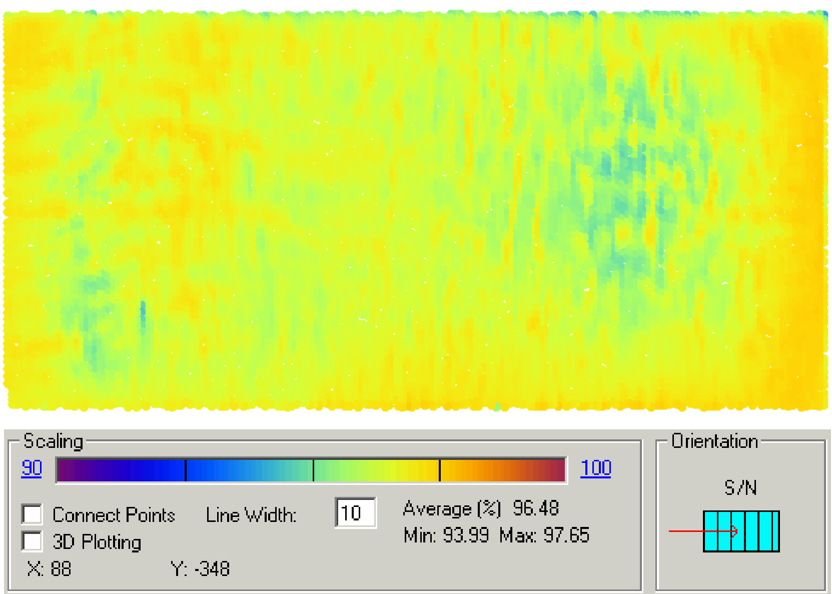
•Every stage in the system has been designed to be insensitive to the input energy (except for stage one).
• All simulations represent an idealized case and one should expect less performance than is modeled. This has been taken into account when choosing the input energies for each stage.
•Pump intensities have been kept under 800 MW/cm^2 (3.5 J/cm^2) to avoid laser damage.
•The output spectrum from each stage has been modeled and shows no unusual behavior.



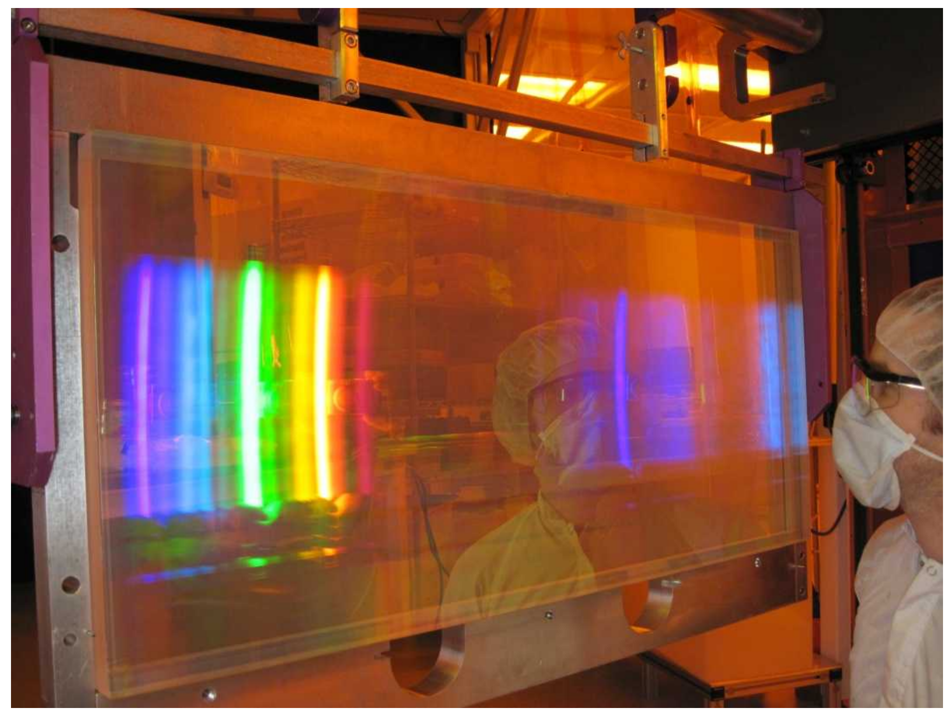
wavelength (m)

Large MLD Grating Upgrade

- Our short pulse laser energy is currently limited by the damage threshold of the old NOVA gold gratings from LLNL.
- Acquired 4ea. 94cm x 42cm, 1740l/mm multi layer dielectric (MLD) gratings from PGL with required damage threshold of:
    - >1 J/cm^2 in the RHσ at 500fs
    - >3 J/cm^2 in the RHσ at 10ps



Diffraction efficiency in 1st order >96%



Expected Output Energy

Grating Operating Parameters:

λ=1054nm; d^{-1}=1740l/mm (groove density);
θ_i=72.0° (incidence angle); θ_d=62.0° (1st order diffracted angle);
l_g=2.24m (pair separation for 4 grating/1pass operation)

Chirp:	$\psi'' = -1.276 \times 10^8\ fs^2$; $\psi''' = +1.787 \times 10^9\ fs^3$
Grating sizes:	42cm X 94cm
LIDT:	1.0 J/cm^2 for 500fs at 72°
	3.2 J/cm^2 for 10ps at 72°

General Case (modest contrast and energy): 8nm bandpass

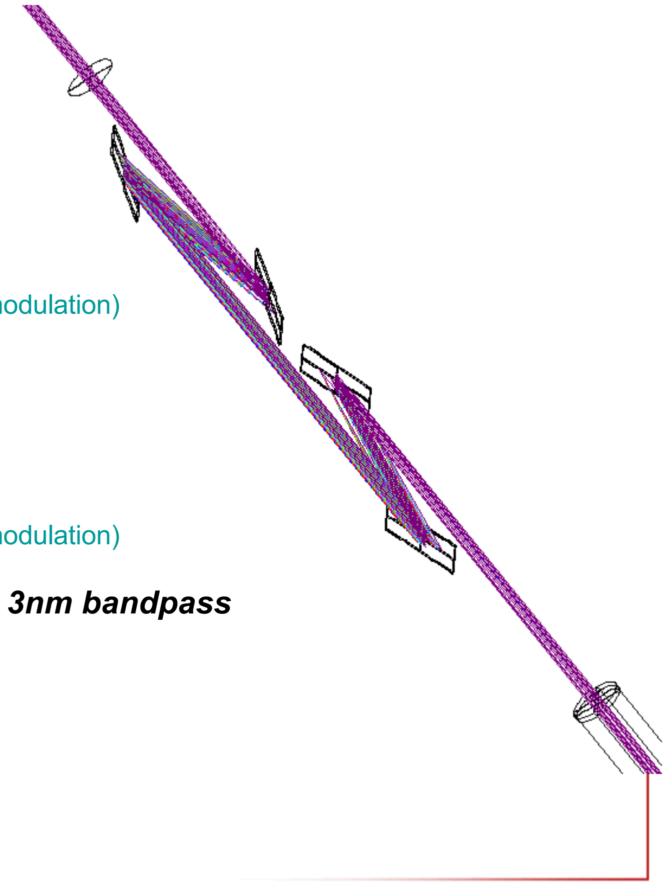
Beam sizes:	(Input RHσ) 32cm x 24cm= 768cm^2
	(1st Grating Projection) 32cm X 78cm
	(2nd Grating Projection) 32cm X 94cm
Max Energy:	768J at 500fs; 2458J at 10ps
75% Max Energy:	590J at 500fs; 1890J at 10ps (safety derated for 1.3:1 beam modulation)

High-contrast Case (more modest energy): 12nm bandpass

Beam sizes:	(Input RHσ) 32cm x 22cm= 704cm^2
	(1st Grating Projection) 32cm X 72cm
	(2nd Grating Projection) 32cm X 94cm
Max Energy:	704J at 500fs; 2253J at 10ps
75% Max Energy:	542J at 500fs; 1733J at 10ps (safety derated for 1.3:1 beam modulation)

Highest-energy Case (10ps, <1nm FWHM –Spectral filtered, not Chirped) : 3nm bandpass

Beam sizes:	(Input RHσ) 32cm x 27cm= 864cm^2
	(1st Grating Projection) 32cm X 88cm [Very tight]
	(2nd Grating Projection) 32cm X 94cm
Max Energy:	2765J at 10ps
75% Max Energy:	2127J at 10ps (safety derated for 1.3:1 beam modulation)



Debris mitigation at the FOA

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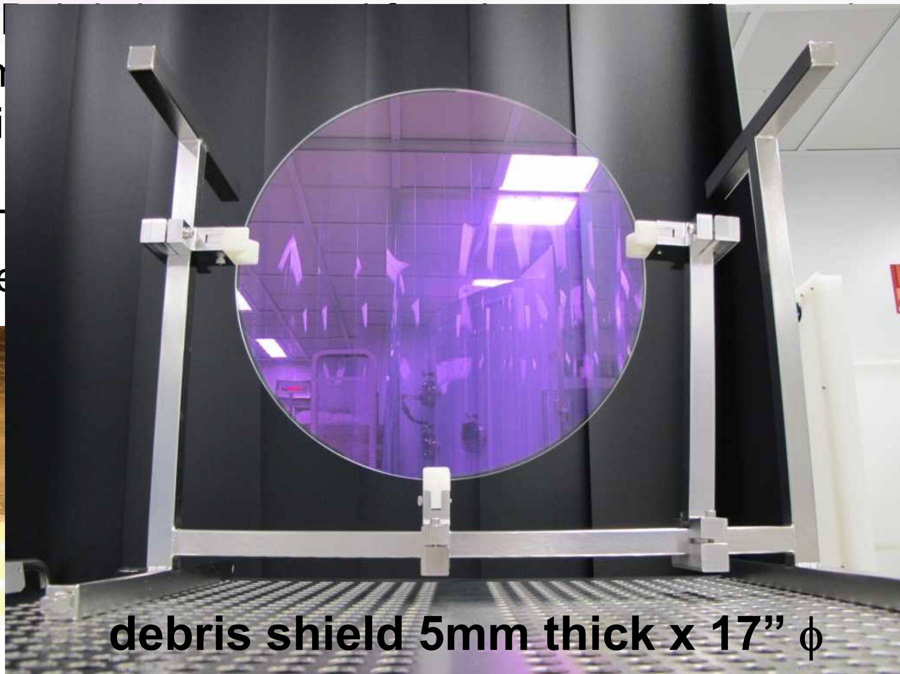
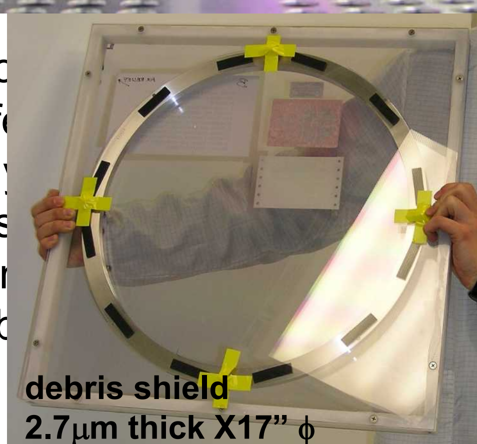
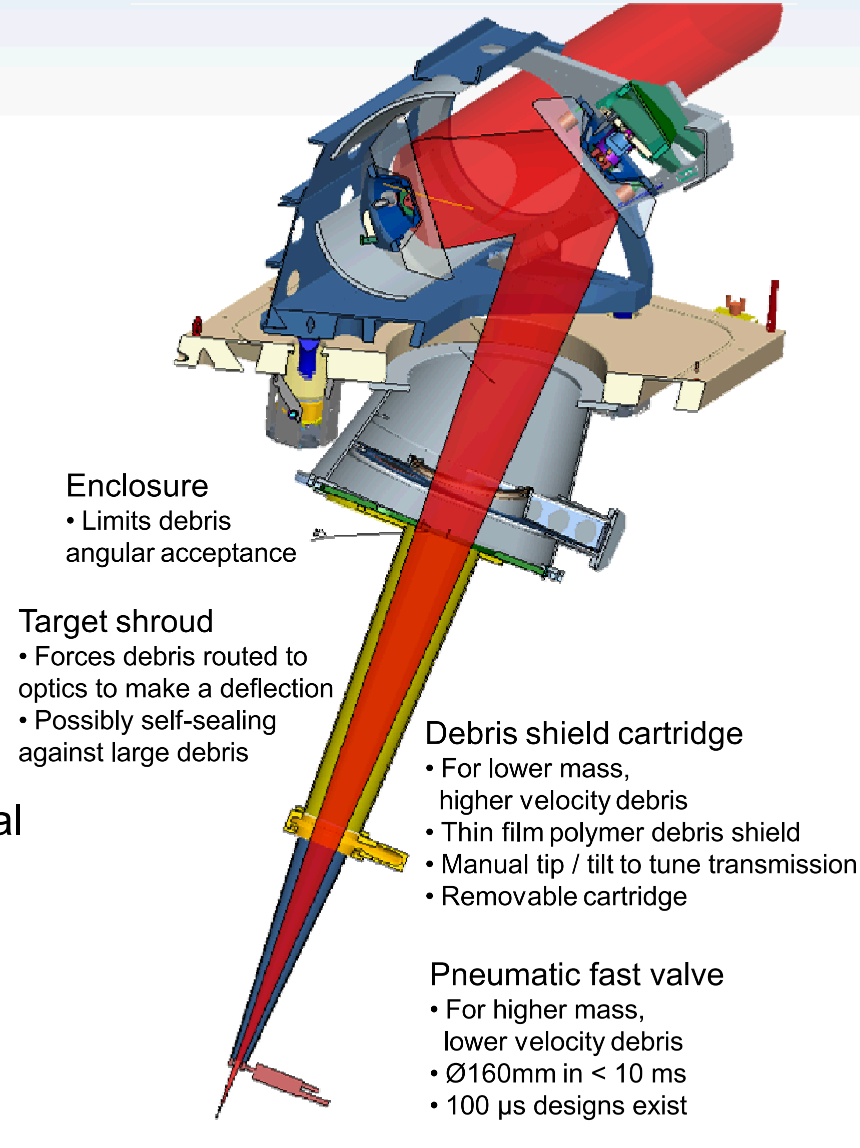
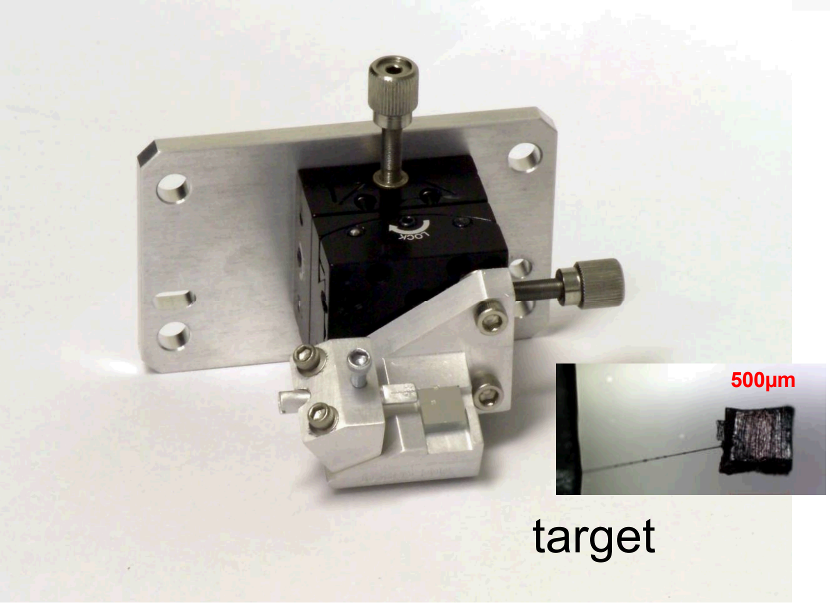

debris shield 5mm thick x 17” ϕ

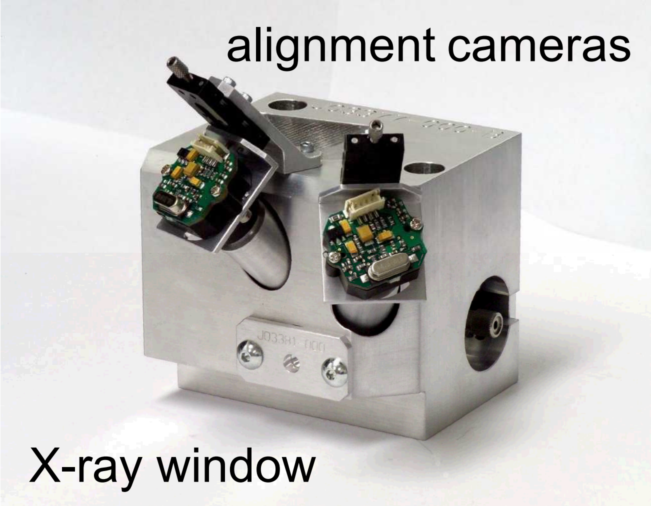

debris shield
2.7μm thick X17” ϕ

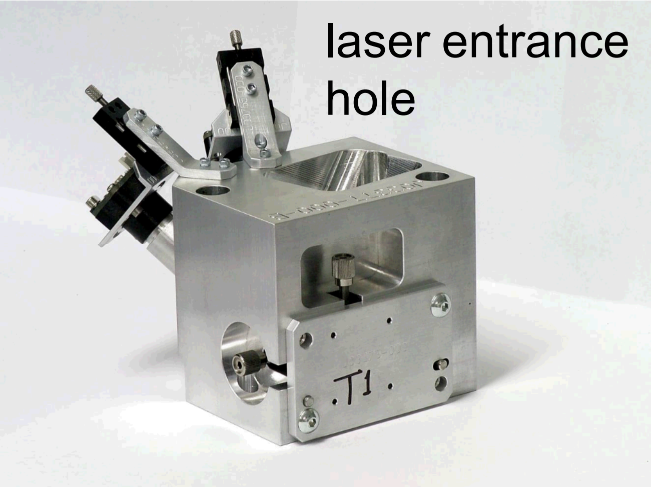
• Petawatt/pico … g must deal with debris diff…
  • Thin poly … 0fs
  • 5mm fus … >10ps
  • Intelliger … n
  • Fast deb…



25 keV Laser Target for Z







A box with two microscope-CCD cameras was developed to hold the target while allowing precision alignment and debris protection.

The X-ray window was chosen to be a combination of mostly Be and Kapton.

Large Scale Coating Chamber

• Backlighting operations require a continuous supply of AR coated debris shields.

• To this end, we installed a 90” e-beam deposition coating chamber.

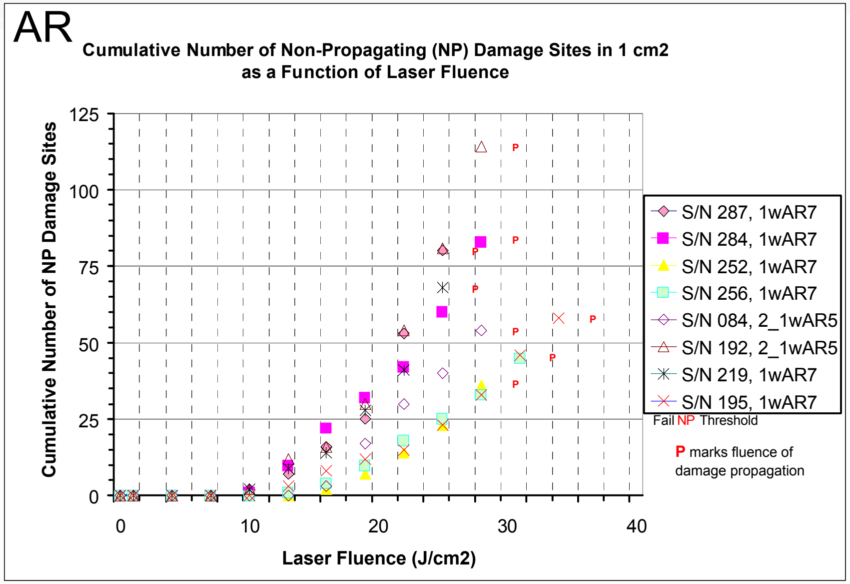
• Single-run capability: 3 at 94 cm optics
1 at 1.5 m option

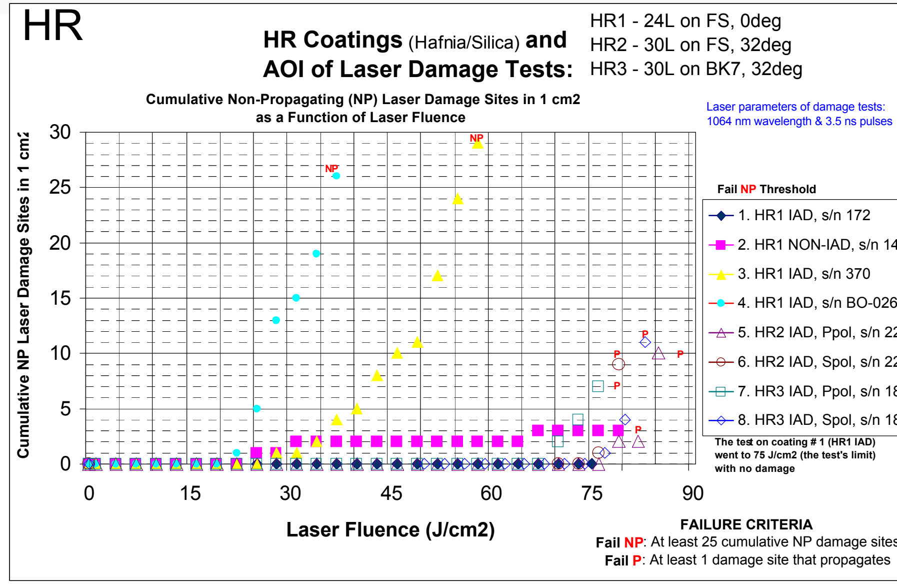
• Ion-assisted deposition (IAD) optional

• Recent coating efforts have focused on Z-Petawatt needs, including 94 cm truncated HR mirrors, OAP.

Fy09 Optics	*30 cm*	*94 cm*
Z-Beamlet	**91 AR**	**2 HR**
Z-Petawatt	**6AR & 4HR**	**8HR**

Large Scale Coating Chamber





- Independent damage testing (SPICA) has shown good test results. Using a definition of 25 cumulated damage sites (non-propagating) gives thresholds:
  - In the range of 17-25 J/cm^2 for AR coatings
  - In the range of 75-85 J/cm^2 for HR coatings
- Successful application to both air and vacuum use environments.

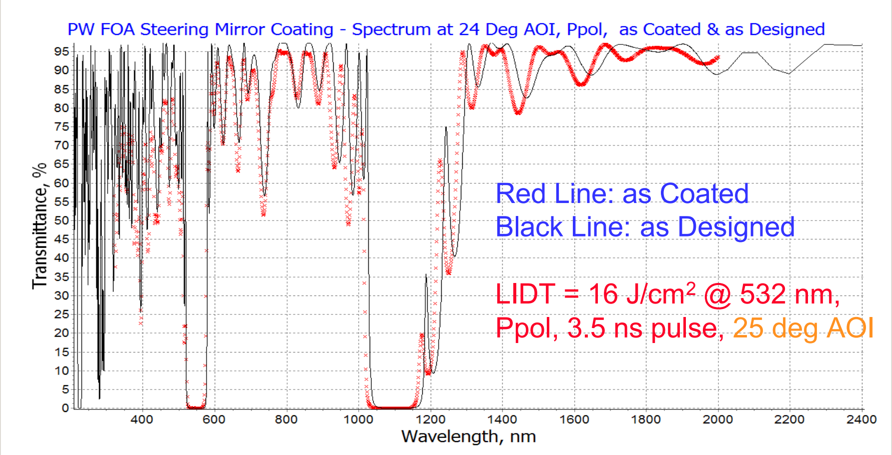
* 1064nm, 3.5ns pulse, 1.06mm spot scanned to fill 1cm^2 with 2300 shots for each of 13 levels from 1-37 J/cm^2, NP sites are of size 15μm

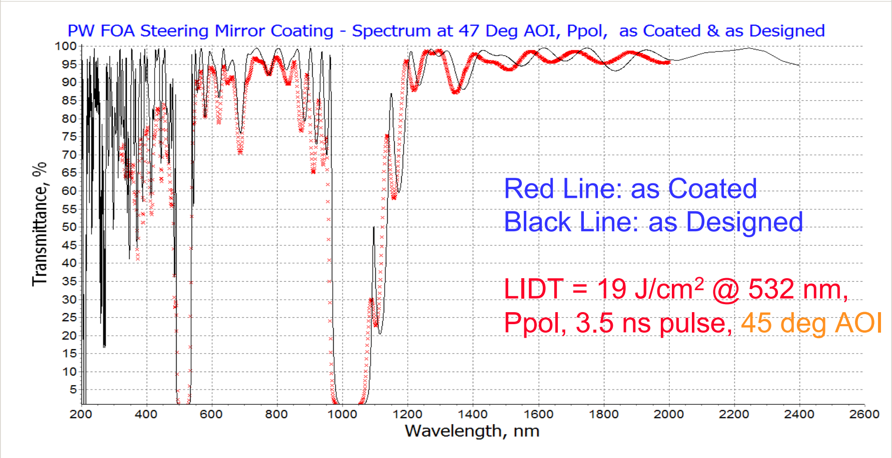
Challenge Coating:
ZPW FOA Fold Mirror

- Requirements:

→Dual Wavelength
→Large Range of AOIs
→Both S & P Polarizations:
RSpol & RPpol > 99.6%
@ 1054nm +/- 6nm (1w)
& @ 527nm +/- 3nm (2w)
& AOIs from 24 to 47°
→High LIDT's:
Goal: LIDT > 2 J/cm^2 for
sub-ps pulses/1ω
& > 10 J/cm^2 for ns pulses/2ω
Reality: LIDT ~ 1.4 J/cm^2 for
sub-ps pulses/1ω
& > 15 J/cm^2 for ns pulses/2ω

- Success Achieved with a 50 Layer Coating Design





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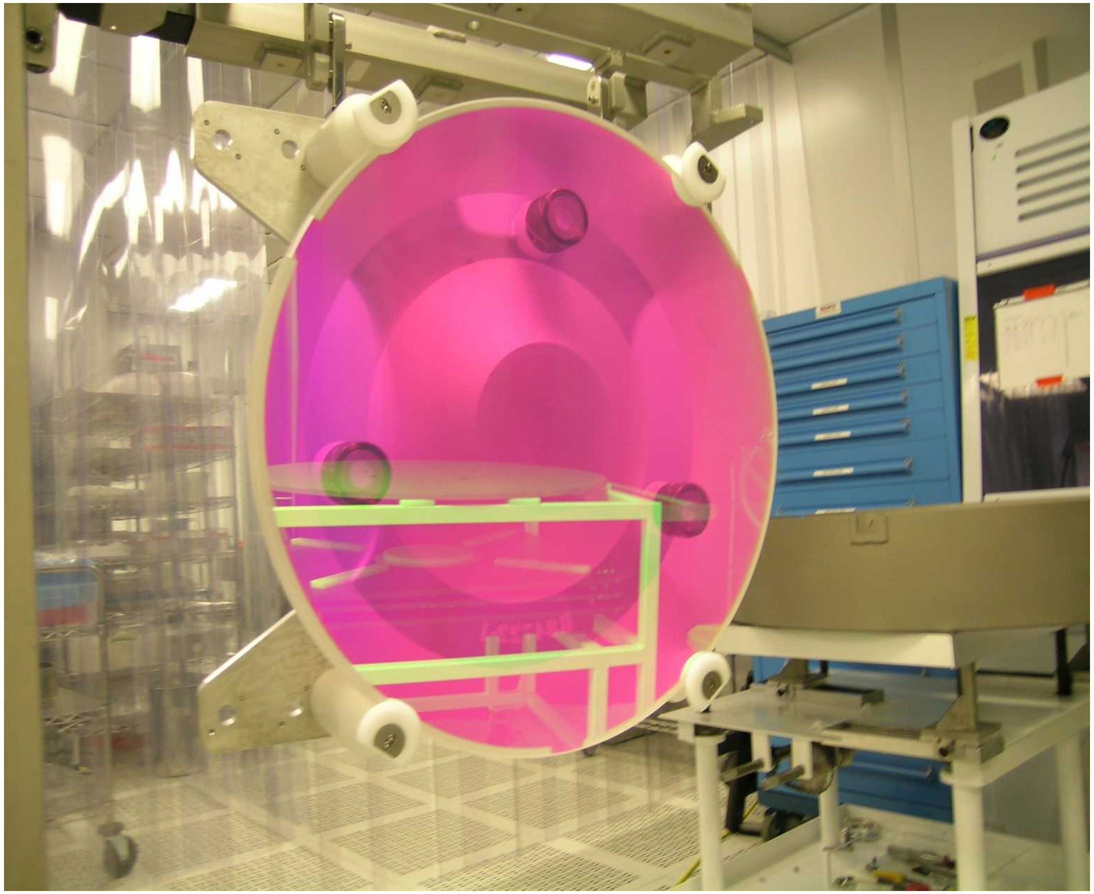
PW FOA Fold Mirror: Coated Product

- High dollar
- 75 cm diameter Fused Silica substrate
- Sculpted back surface
- Optic weight ~ 200 lb
- 50 layer IAD coating



Z Backlighter

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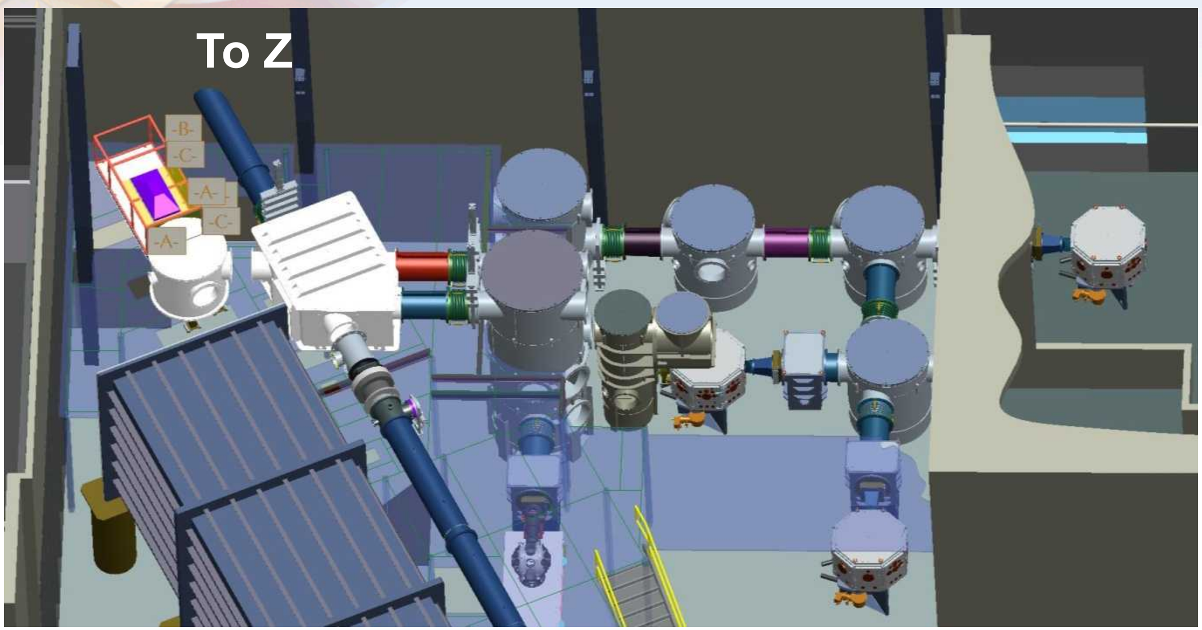
Z Petawatt

Dual Wavelength HR optics: LIDT

- Short/long pulse laser damage testing was performed in house on Sandia custom dichroic coatings that will allow beam combination of Z-Beamlet and Z-Petawatt.
- Petawatt fluence is limited to ~1J/cm^2 at 1054nm and 500fs
- Z-Beamlet fluences do not exceed 8J/cm^2.

Laser 1 (350 fs) only	1.32 J/cm^2
Laser 2 (7 ns) only	70.1 J/cm^2
Laser 1 20ns before Laser 2	1.32 J/cm^2
Laser 1 and Laser 2 co-temporal	1.05 J/cm^2
Laser 1 20ns after Laser 2	1.32J/cm^2
Laser 1 20ns before Laser 2	1.32 J/cm^2
Laser 1 and Laser 2 co-temporal	0.75 J/cm^2
Laser 1 20ns after Laser 2	1.32J/cm^2

The Target Bay



Diagnostics:

- Kα imager, X-ray pin-hole cameras
- multiple X-ray and optical streak cameras, 200 fs resolution at 1:40 dynamic range, 5 ps at 1:1000
- various X-ray and optical spectrometers
- single photon counting CCD's
- 12/8 GHz digital scopes
- Micro Channel Plate
- HV supplies up to 20 kV
- IP and CR39 detectors
- NLS laser 1064/532 nm, 10/5 J, 180ps
- VISAR laser 532nm, 10mJ, 10ns

Z-Beamlet (small)	5/2010	5/2010	6.25	50	80 cm
Diagnostic Calibration	1/2011	4/2011	6.25	50	1.5 m
Z-Beamlet (Large)	3/2011	6/2011	10	80	1.5 m
Z-Petawatt	6/2011	9/2011	4.5	6	1.5 m
			6.25	50	1.5 m

1.5 m Target chamber

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Conclusion

- Multi-frame backlighting has been successfully demonstrated with Z-Beamlet.
- Z-Petawatt upgrades will provide stable, high energy short pulses.
- Dual wavelength beam transport into Z-Accelerator in place and tested.
    - Dichroic beam combination is pending.
- Debris mitigation techniques for Z-shots have been established and tested.
- Target area for testing of new capabilities and advanced experiments are being built.