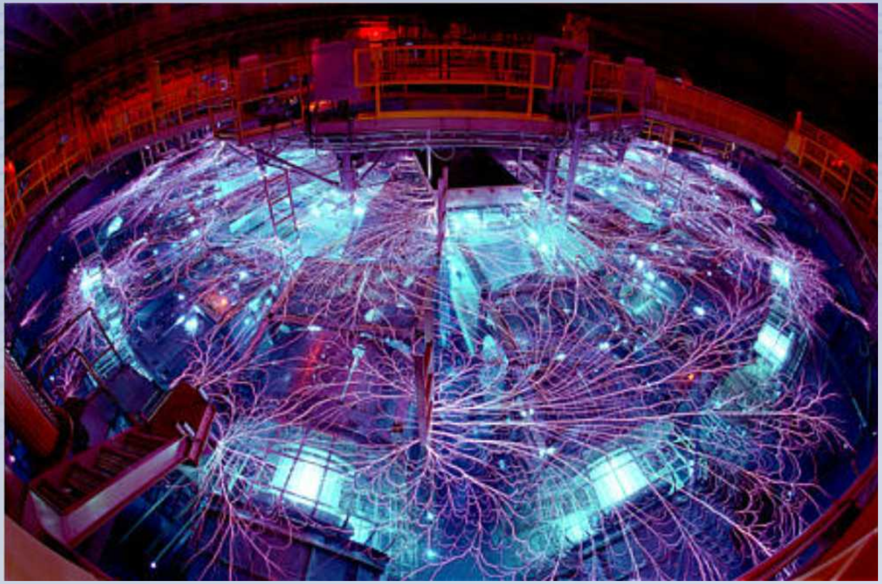
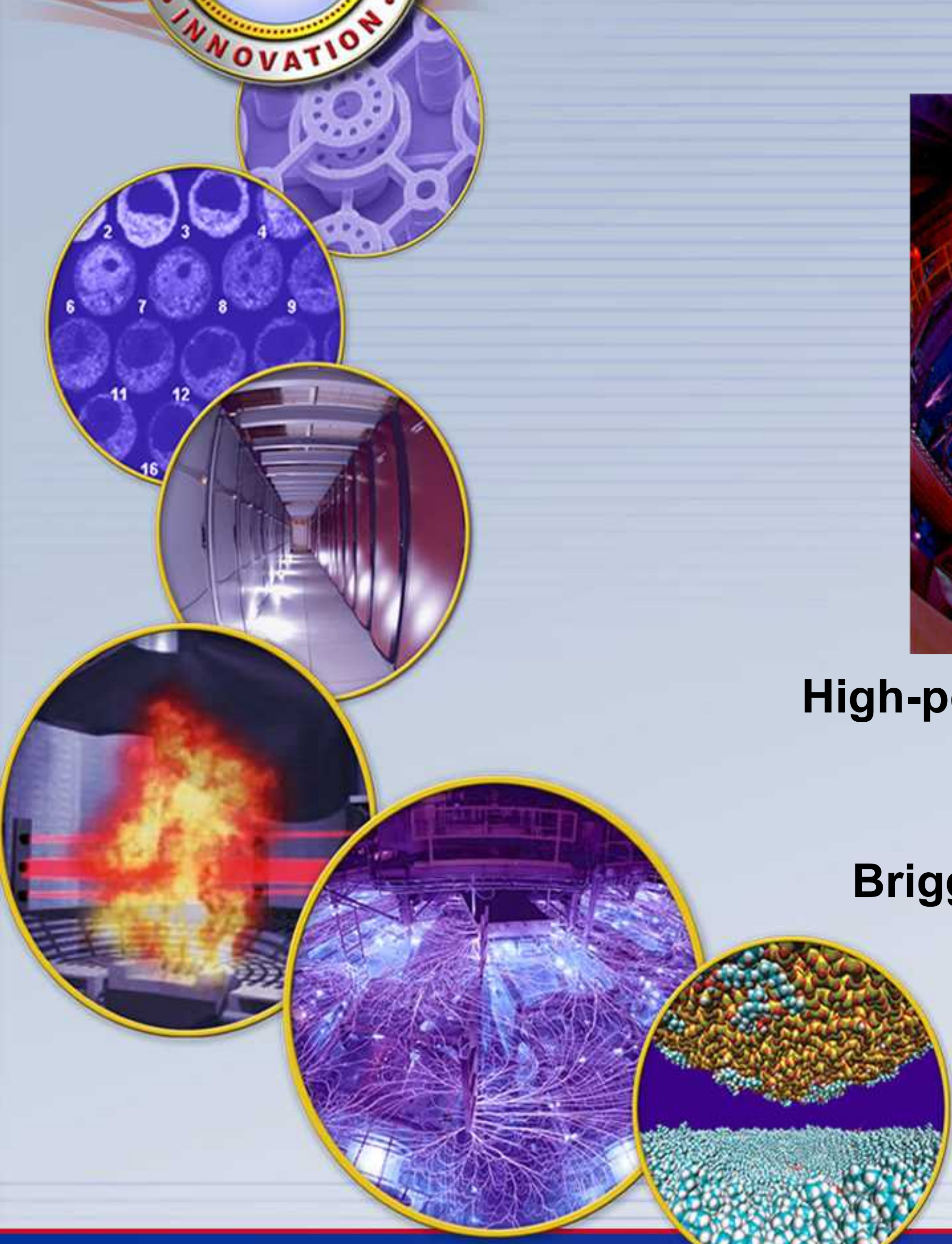
X-ray Backlighting Using the Multi-kilojoule Z-Beamlet Laser System

SAND2008-1007P

A shot on the Z Machine





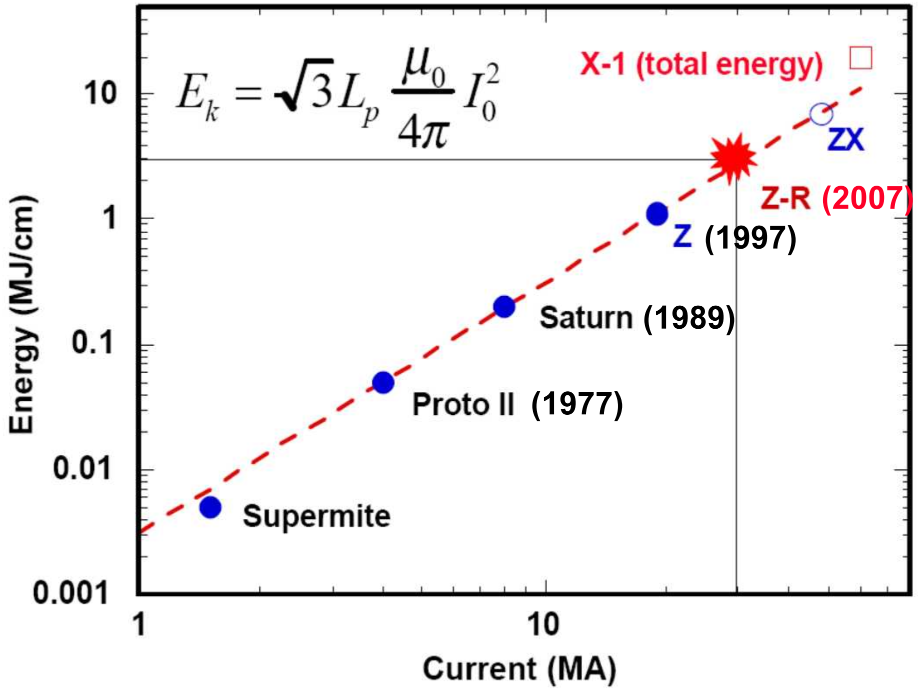
High-power lasers and investigations of physics of high energy densities

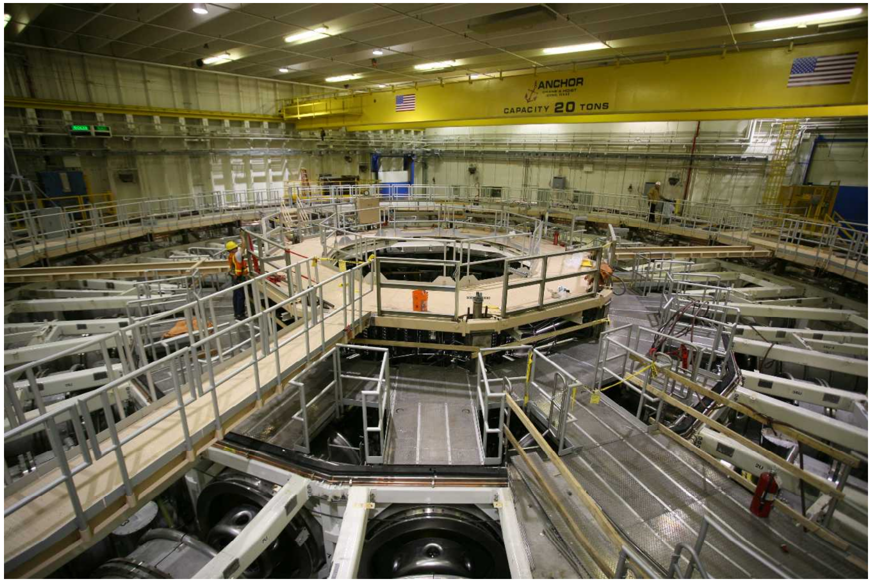
Sarov Russia, March, 11-14 2008

Briggs Atherton, Sandia National Laboratories
(505) 284-9505; bwather@sandia.gov

Sandia National Laboratories

The new ZR facility will begin operation later this month





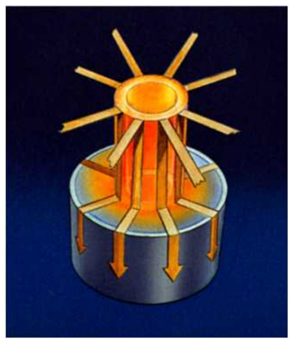
Capability	Z	ZR
Peak load current reproducibility	5%	2%
Pulse shaping flexibility	Minimal	Significant Variability
Peak Current	18 MA	26 MA
Full current operation	100 ns	130ns, 300ns
Diagnostic Lines of Sights	9	18

Sandia's ZR z-pinch facility

Phases of a z-pinch implosion

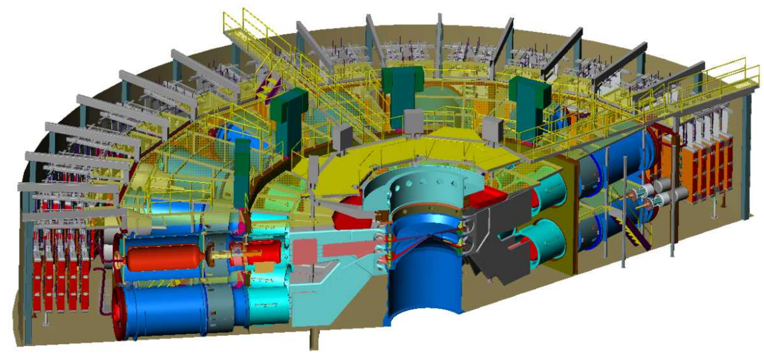
initiation

implosion

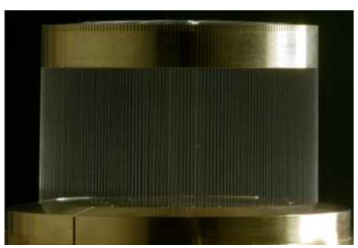


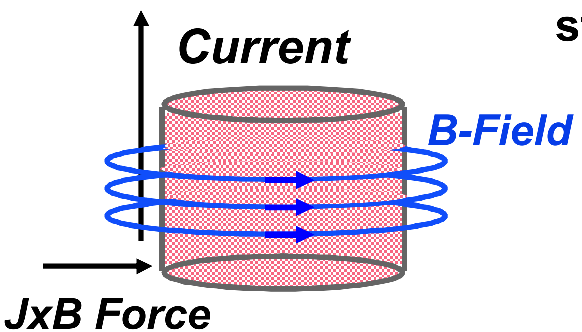
stagnation

ZR z-pinch facility

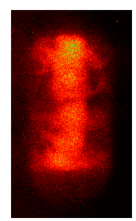


wire array





stagnation



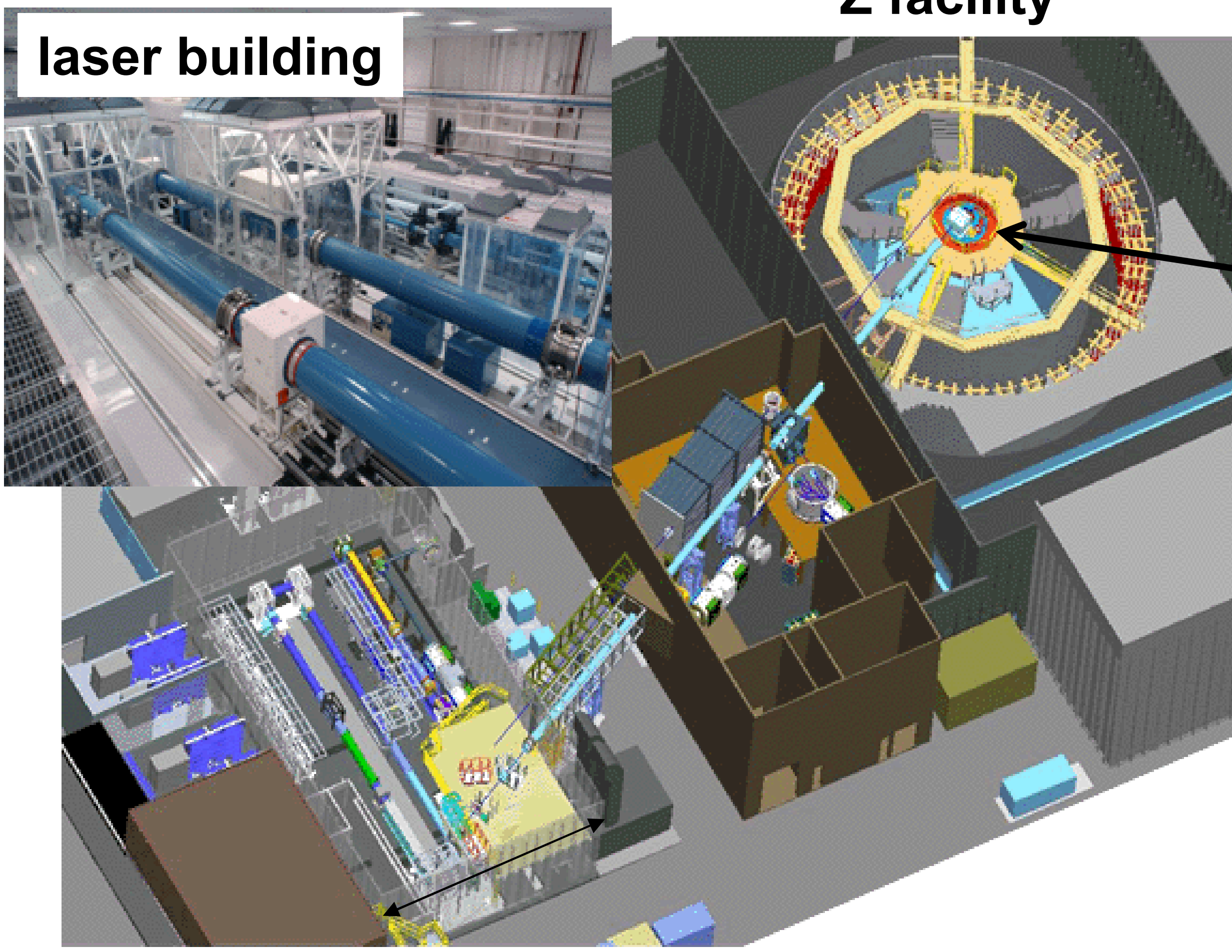
ZR parameters

20 MJ stored energy
26 MA peak current
100 TW electrical power pulse
≥ 300 TW x-ray power
≥ 2 MJ x-ray energy
≥ 200eV Blackbody radiation

The Z-Beamlet Laser facility

- **The terawatt-class Z-Beamlet laser creates backlighting x-ray sources in the 1-9 keV range**

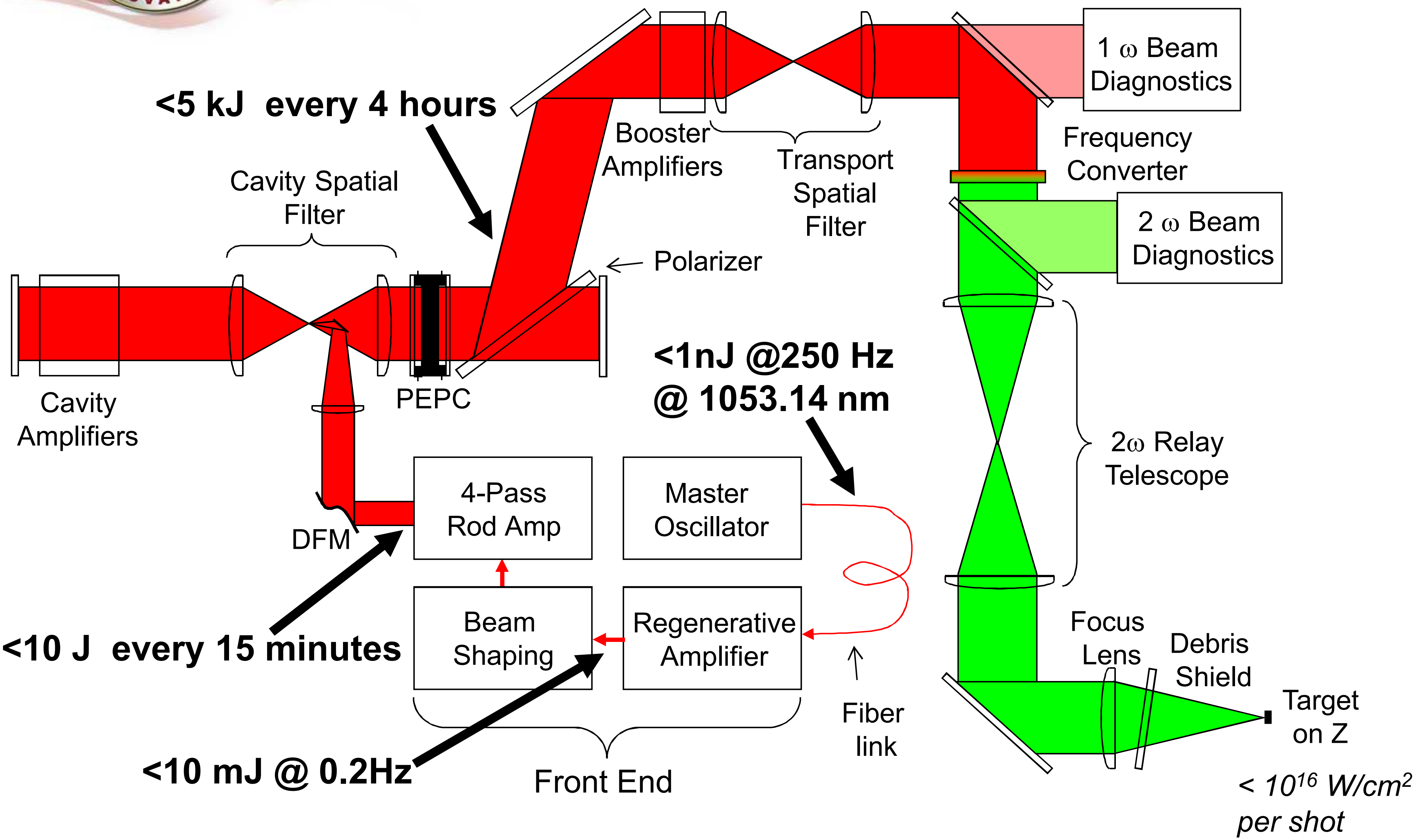
Z facility



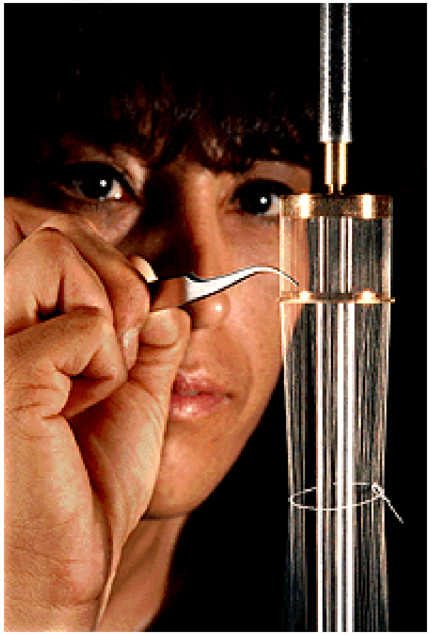
Z-Beamlet laser facility

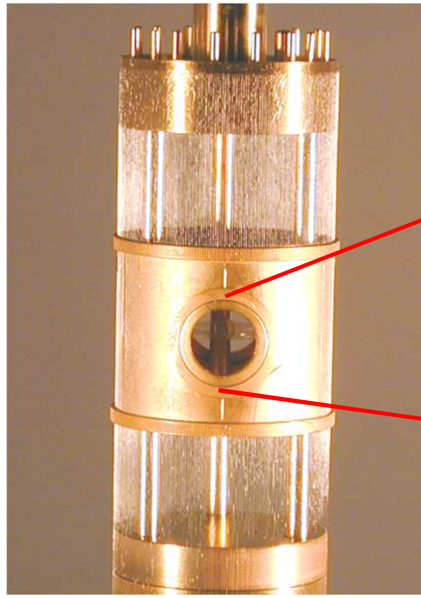
Final Optics Assembly Installed on Z

The Z-Beamlet Laser system

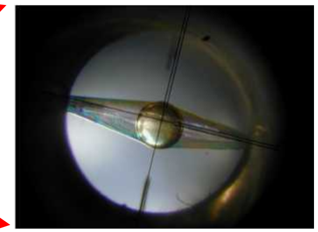


Inertial Confinement Fusion (ICF) Research on Z

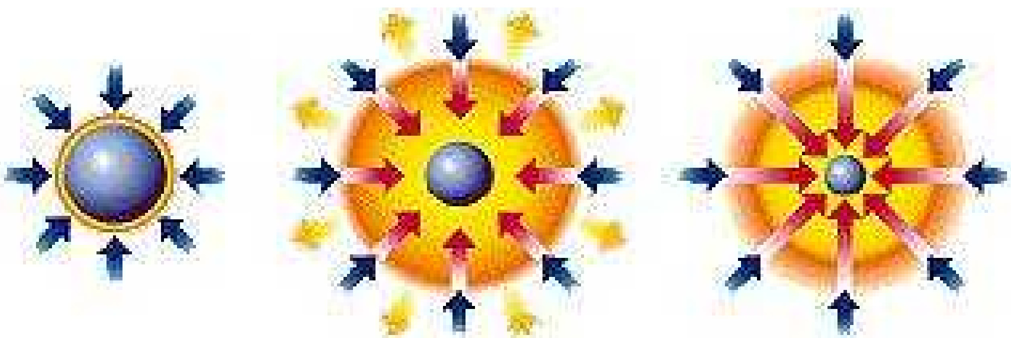




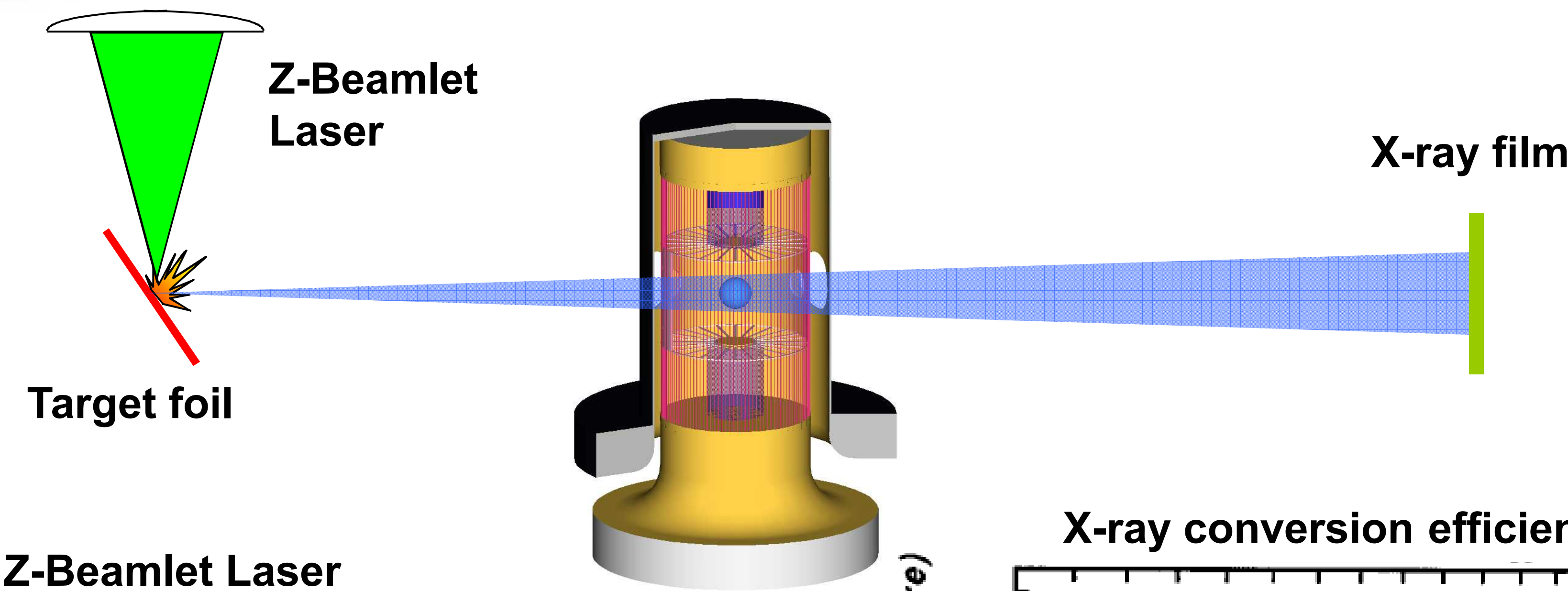
ICF capsule



Hot Spot Ignition Concept

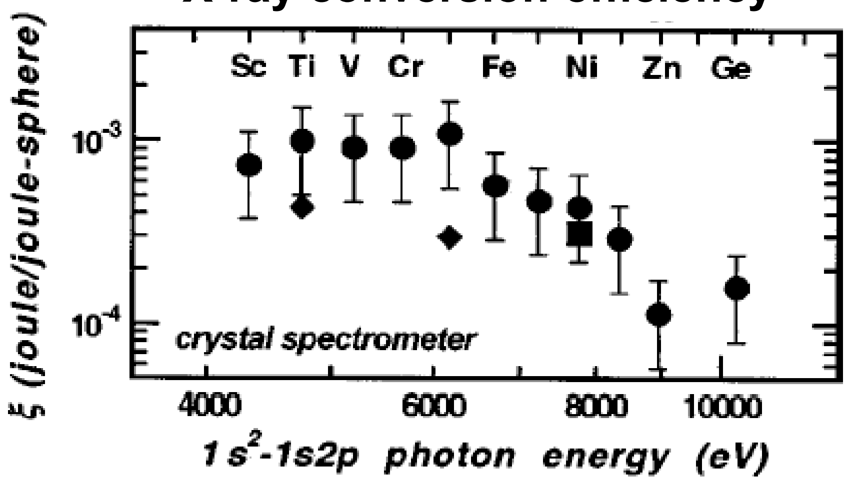


Point projection x-ray backlighting using the Z-Beamlet Laser



Z-Beamlet Laser

X-ray conversion efficiency

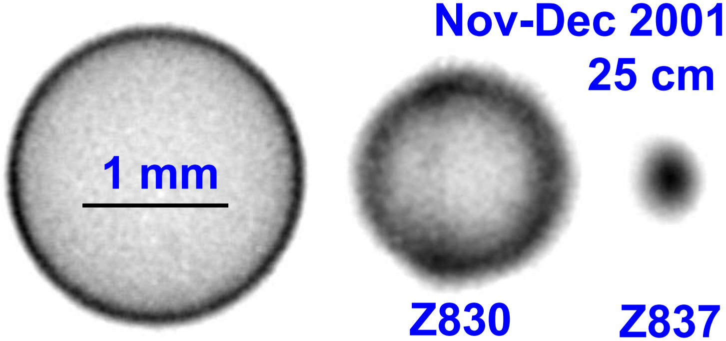


Point-projection x-ray backlighting has been used extensively to study ICF capsule implosions

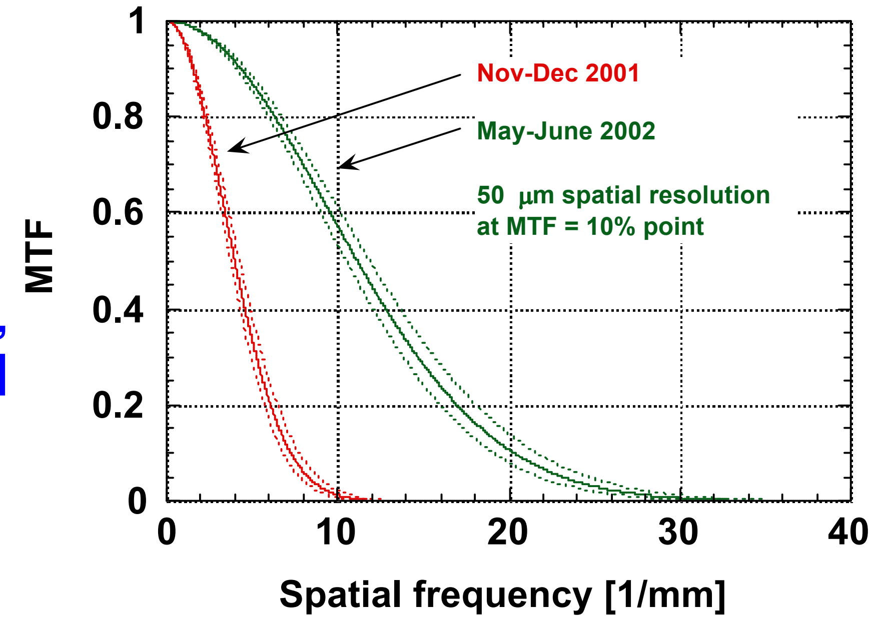
Initial 6.7 keV imaging used a 4.8x imaging geometry with a large laser focal spot size

Improved 6.7 keV system used 1.7x imaging with 100 μm spot sizes to yield 50 μm spatial resolution

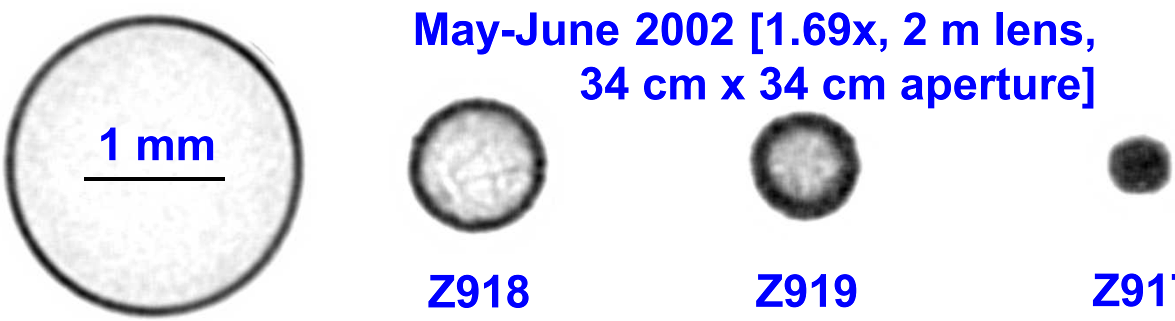
Nov-Dec 2001 [4.8x, 3.2 m lens, 25 cm x 25 cm aperture]



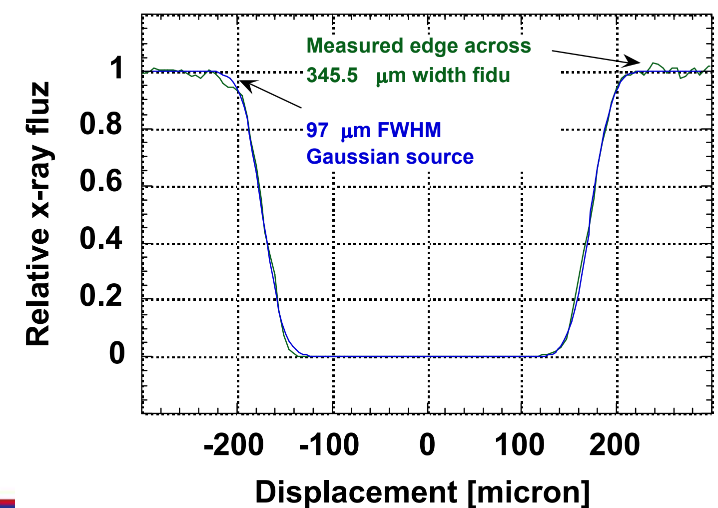
Z830 **Z837**



May-June 2002 [1.69x, 2 m lens, 34 cm x 34 cm aperture]



Z918 **Z919** **Z917**

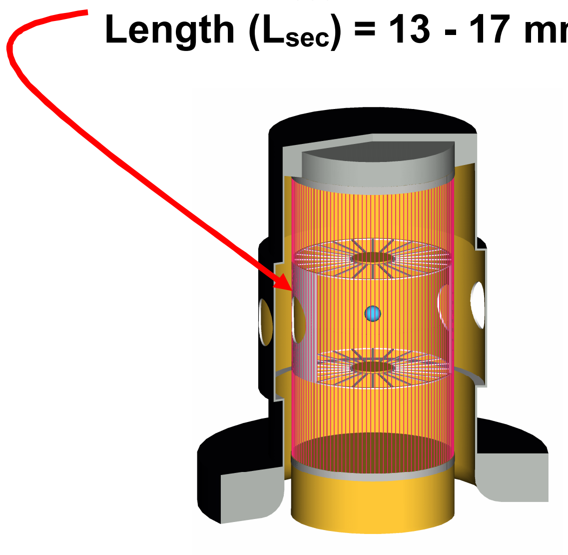


* G.R. Bennett *et al.*, Phys. Rev. Lett. 89, 245002 (2002).

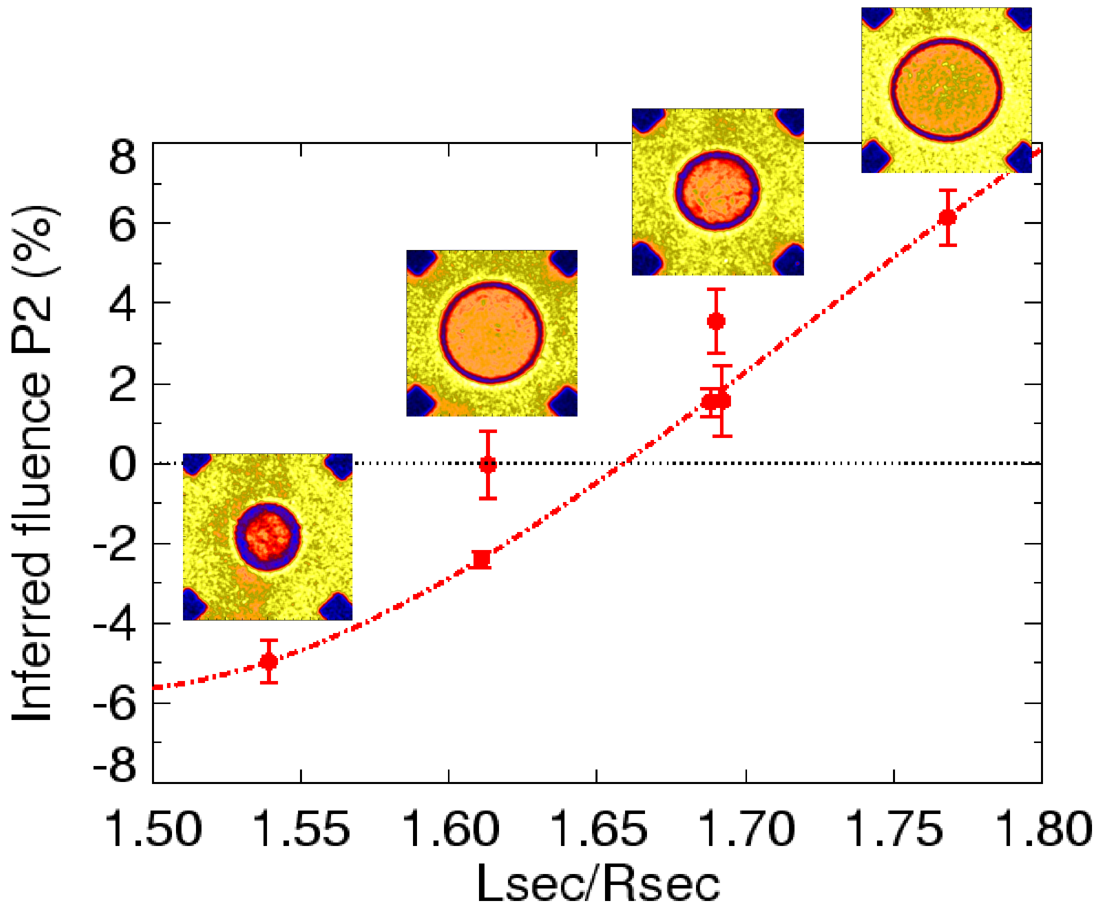
X-ray backlighting enabled us to optimize the symmetry of capsule implosions on Z

Secondary hohlraum dimensions

Radius (R_{sec}) = 9.6 mm
Length (L_{sec}) = 13 - 17 mm

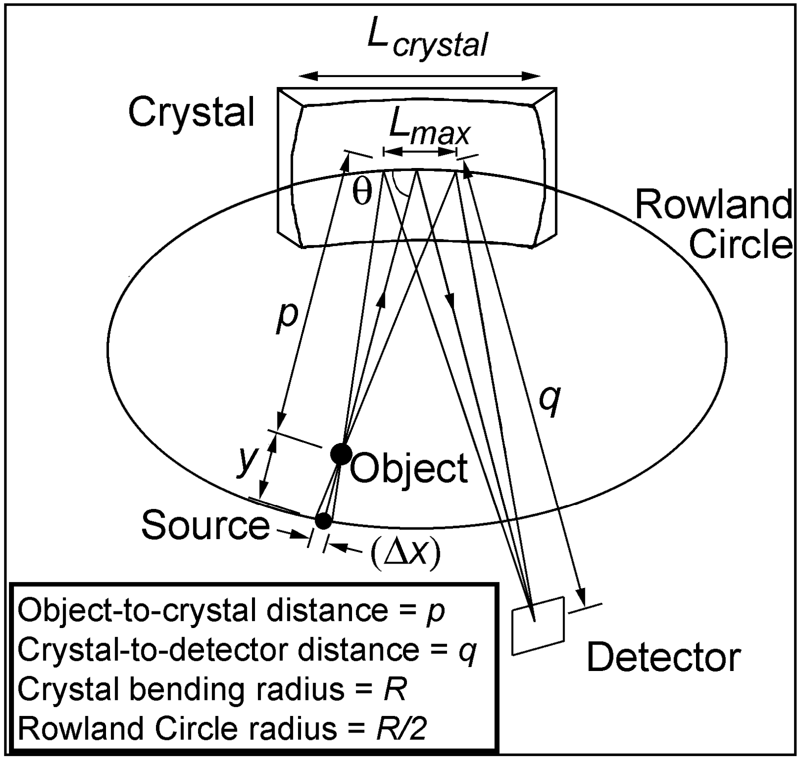


Time-integrated P_2 radiation symmetry



Backlighting Using Bent Crystal Imaging

X-ray Imaging with a Spherically Bent Crystal



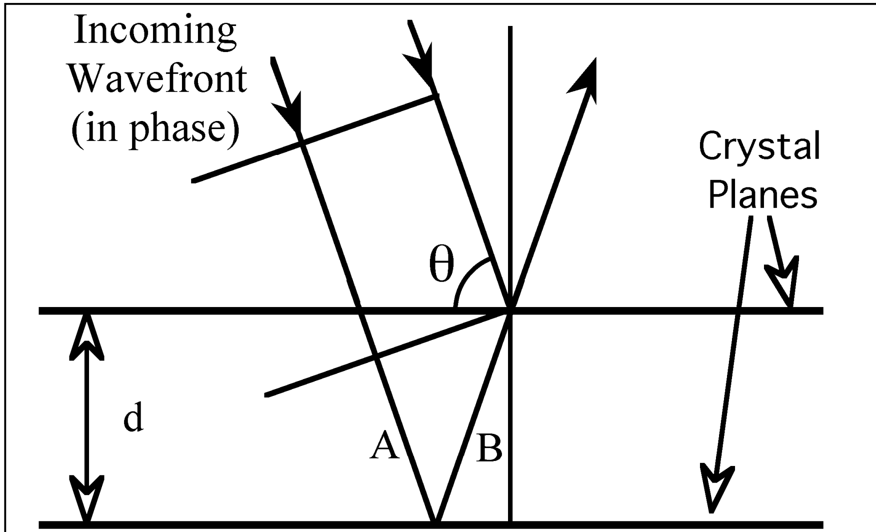
Detector position determined by:

$1/p + 1/q = 2 / (R \sin\theta)$

Field of view:

$FOV = L_{crystal}\{y/(p+y)\}$

Bragg Condition



$A = d / \sin(\theta) - 2 d \cos(\theta) / \tan(\theta)$

$B = d / \sin(\theta)$

Total path length difference = $A + B = 2 d \sin(\theta)$

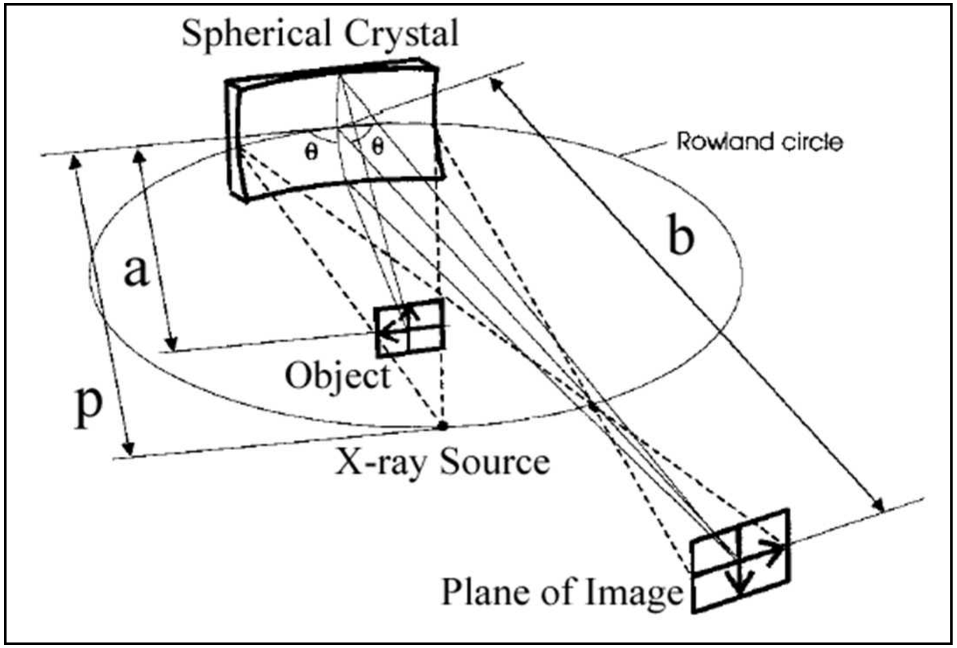
Spectral bandpass:

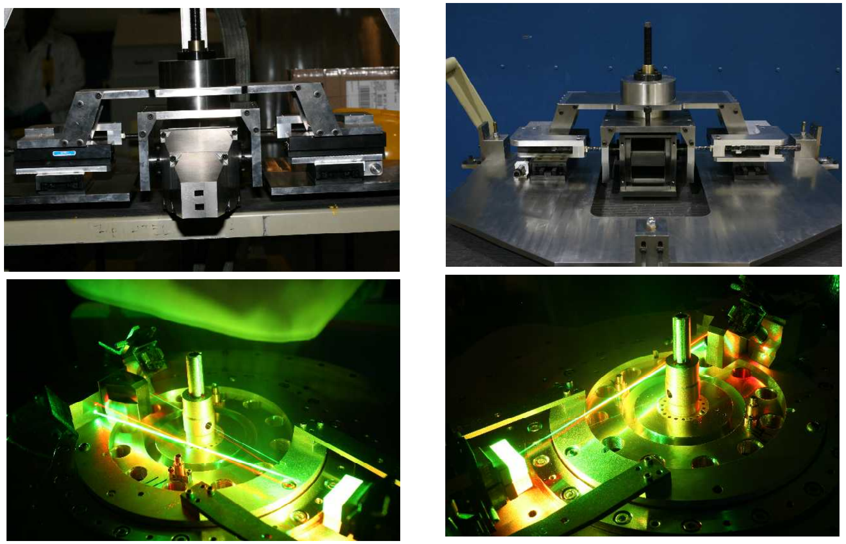
$\Delta\lambda/\lambda = (\Delta x/R) \cot(\theta)$

Magnification:

$M = q / p$

Curved-crystal imaging offers an elegant solution for backlighting in hostile environments





<u>Bent-crystal Imaging</u>

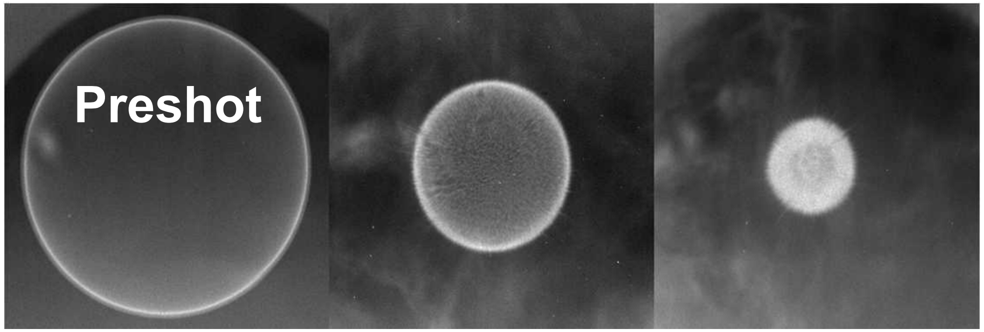
- **Monochromatic (~0.5 eV bandpass)**
- **10 micron resolution**
- **Large field of view (e.g. 20 mm x 4 mm)**
- **Debris mitigation**

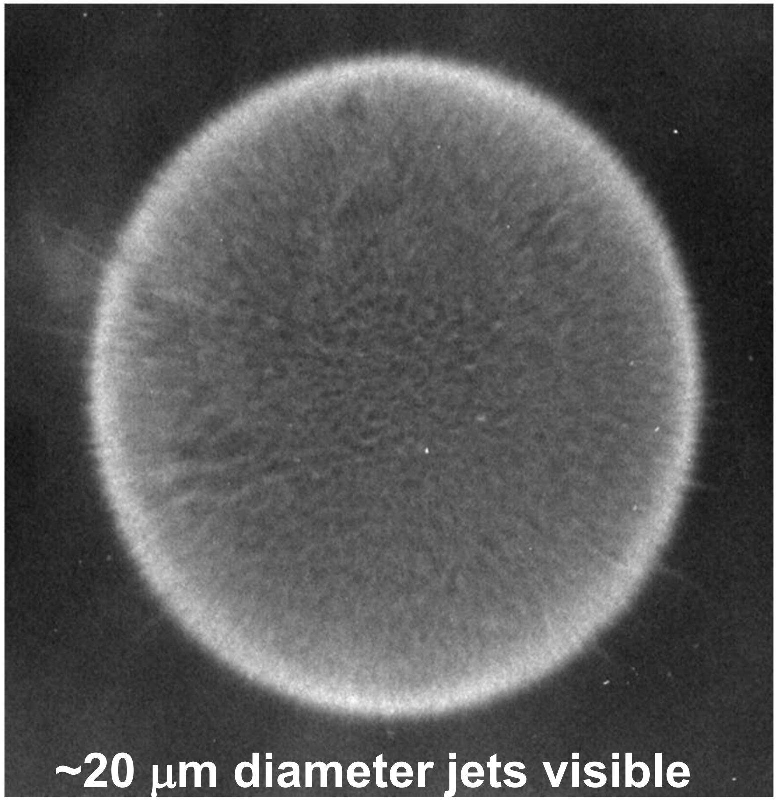
- **Concept proposed in mid-1990s.**
  - S.A. Pikuz *et al.,* Rev. Sci. Instrum. **68**, 740 (1997).
- **A 1.865 keV backlighter built at NRL**
  - Y. Aglitskiy *et al*., Rev. Sci. Instrum. **70**, 530 (1999).
- **Crystal imaging techniques proposed for microscopy/backlighting on NIF**
  - J.A. Koch *et al*., Rev. Sci. Instrum. **70**, 525 (1999).
- **1.865 and 6.151 keV diagnostics successfully implemented on Z facility**
  - D.B. Sinars *et al*., Rev. Sci. Instrum. **75**, 3672 (2004).

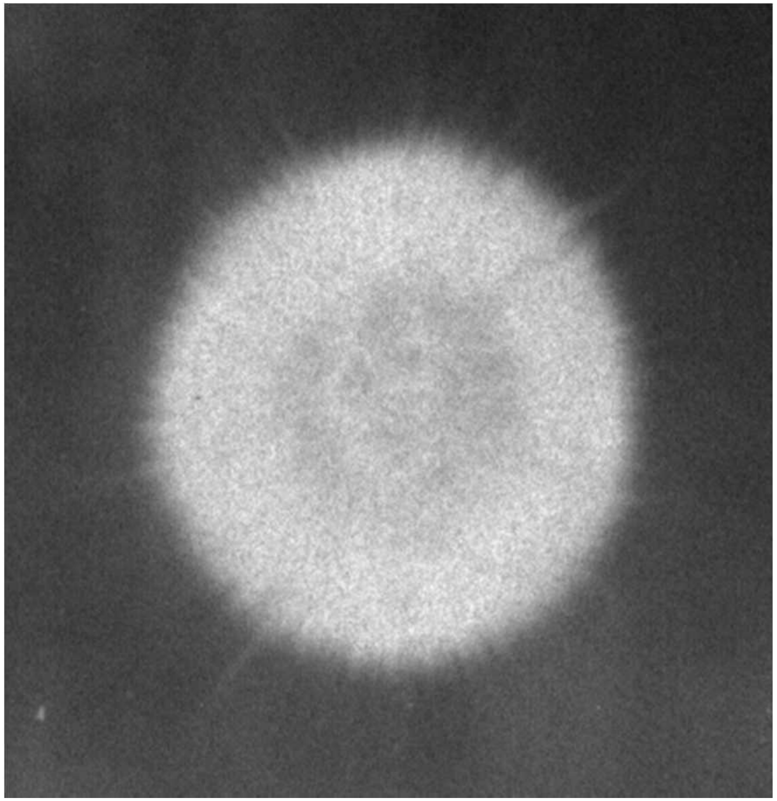
The higher spatial resolution bent-crystal imaging system revealed new features in imploding capsules

3.4-mm diameter plastic ICF capsule

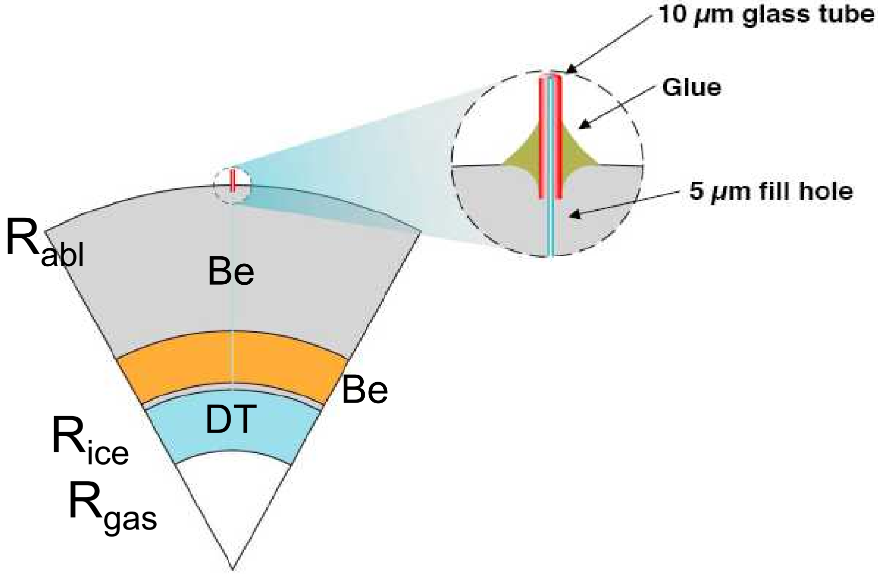
Capsules had 100s of known defects on surface that apparently produced a myriad of small jets







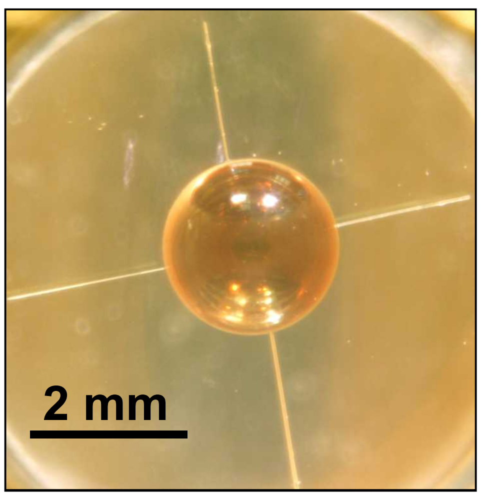
X-ray backlighting enabled us to measure the effects of DT fuel fill-tubes on capsule implosions



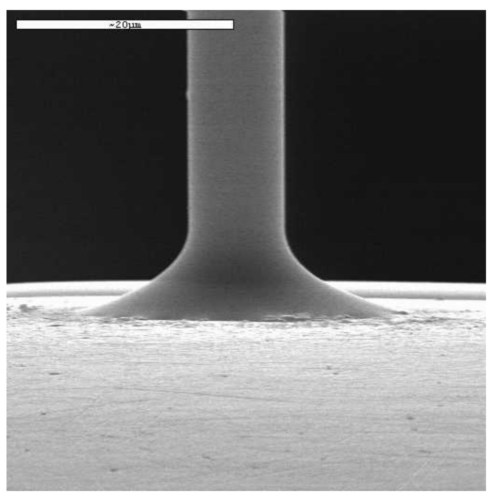
Using fill tubes significantly reduces complexity and expense of cryogenics system compared with diffusion fill and cryo transport

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



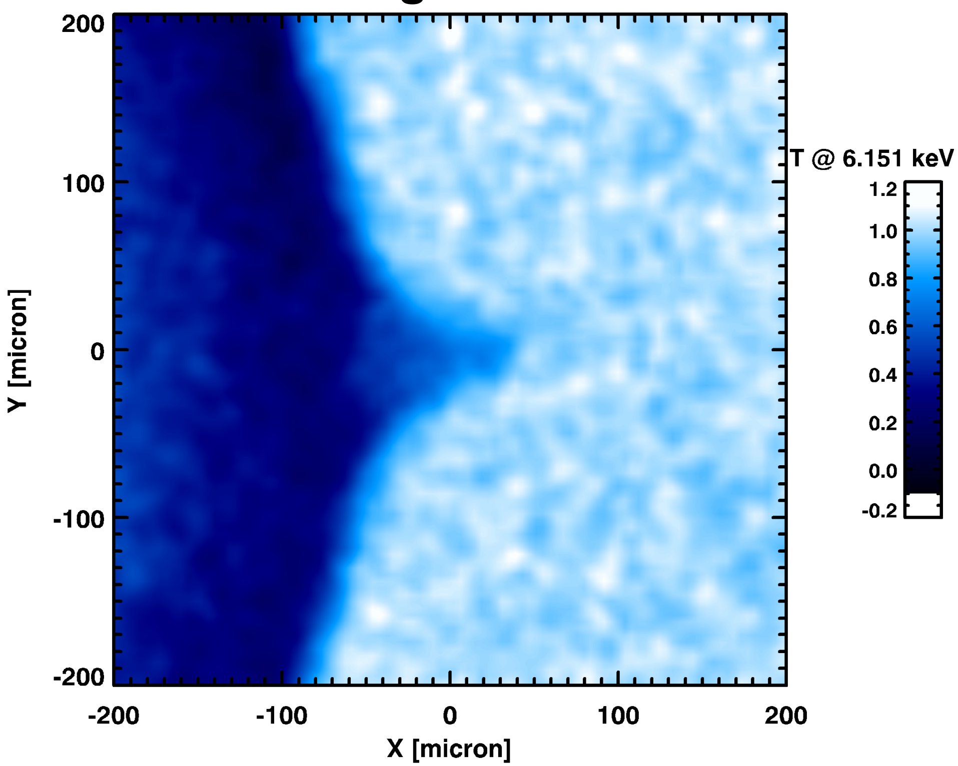
CH capsule with 4 fill tubes (12-45 micron OD)



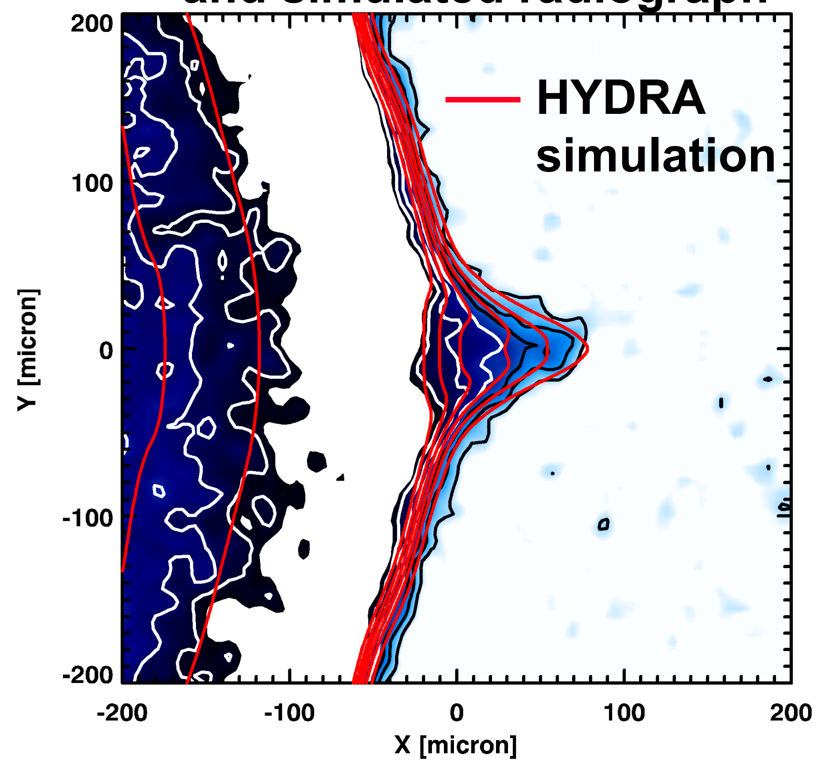
SEM image of tube and glue fillet

High quality data enables quantitative comparisons with simulations of ignition-relevant fill tubes

Radiograph at 6.151 keV at convergence ratio 1.5

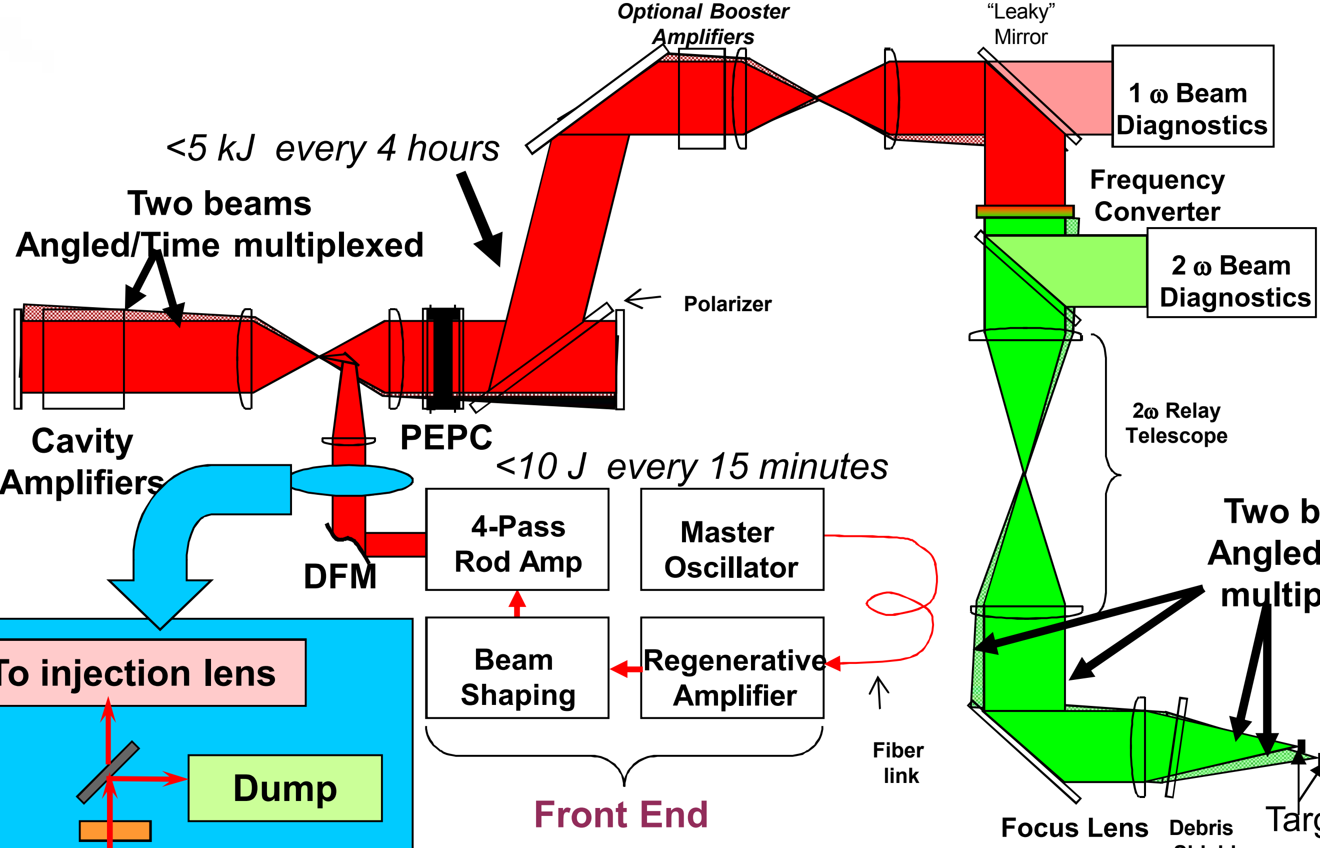


Comparison of experimental radiograph and simulated radiograph

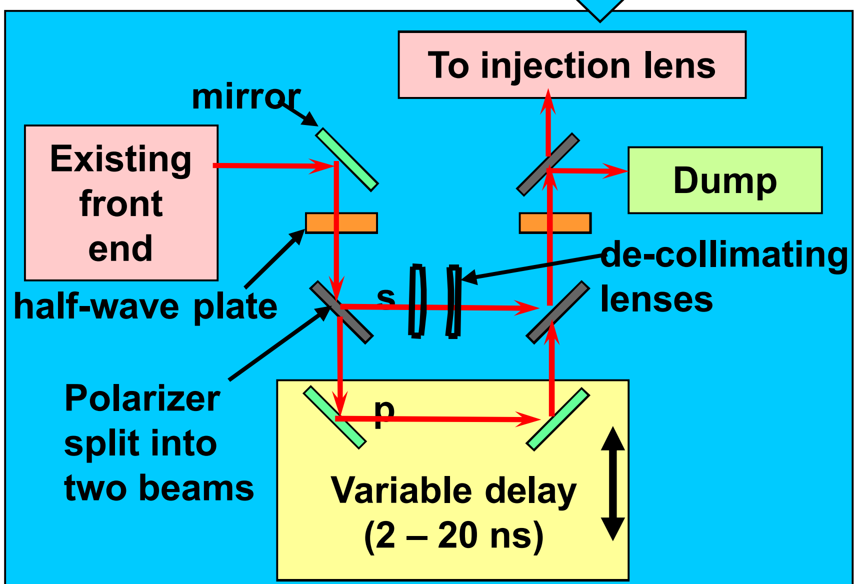


The Z-Beamlet Laser has recently being modified to provide a "2-frame" backlighting capability

Injection Box with 10' trombone addition



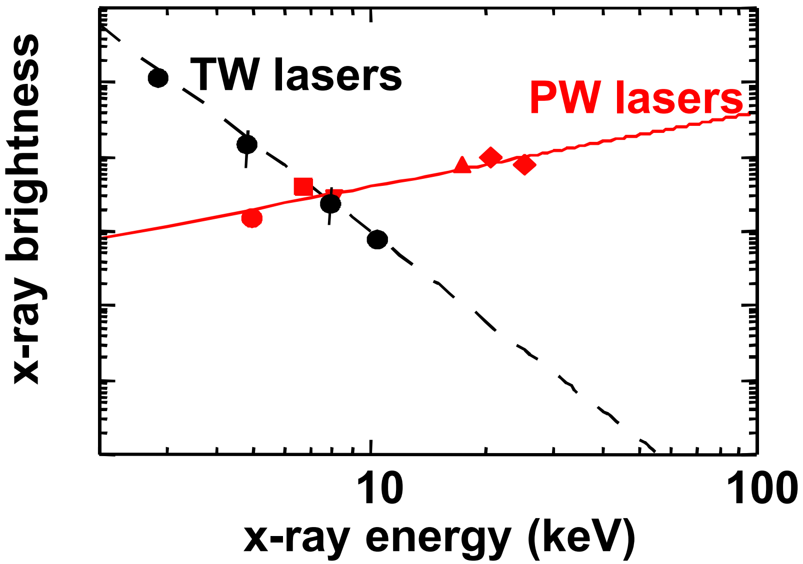
< 10^{16} W/cm^2 per shot



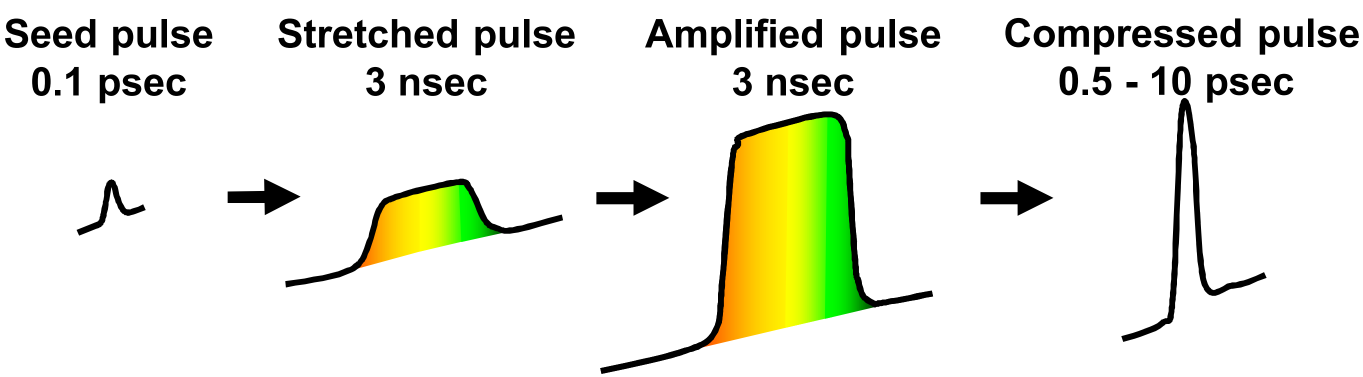
- The front end beam is split into two variable energy ratios beams
  - 1st beam
    - The focus is changed
  - 2nd beam
    - delayed 2-20 ns
    - Small change in angle (1.3 mrad)

A new Z-Petawatt laser system will provide a new capability for diagnosing Z experiments

- Z-Beamlet can produce x-ray sources at ≤ 9 keV for radiography on Z.
- A short pulse upgrade to Z-Beamlet will enable x-ray radiography on ZR at > 9 keV.



Chirped Pulse Amplification Concept



Conclusion

- X-ray backlighting using the Z-Beamlet Laser is a critical diagnostic for experiments on the Z facility.

- New multi-frame and high-energy x-ray backlighting capabilities will soon become available on Z.

- We continue to search for new approaches to x-ray backlighting using high-power lasers.