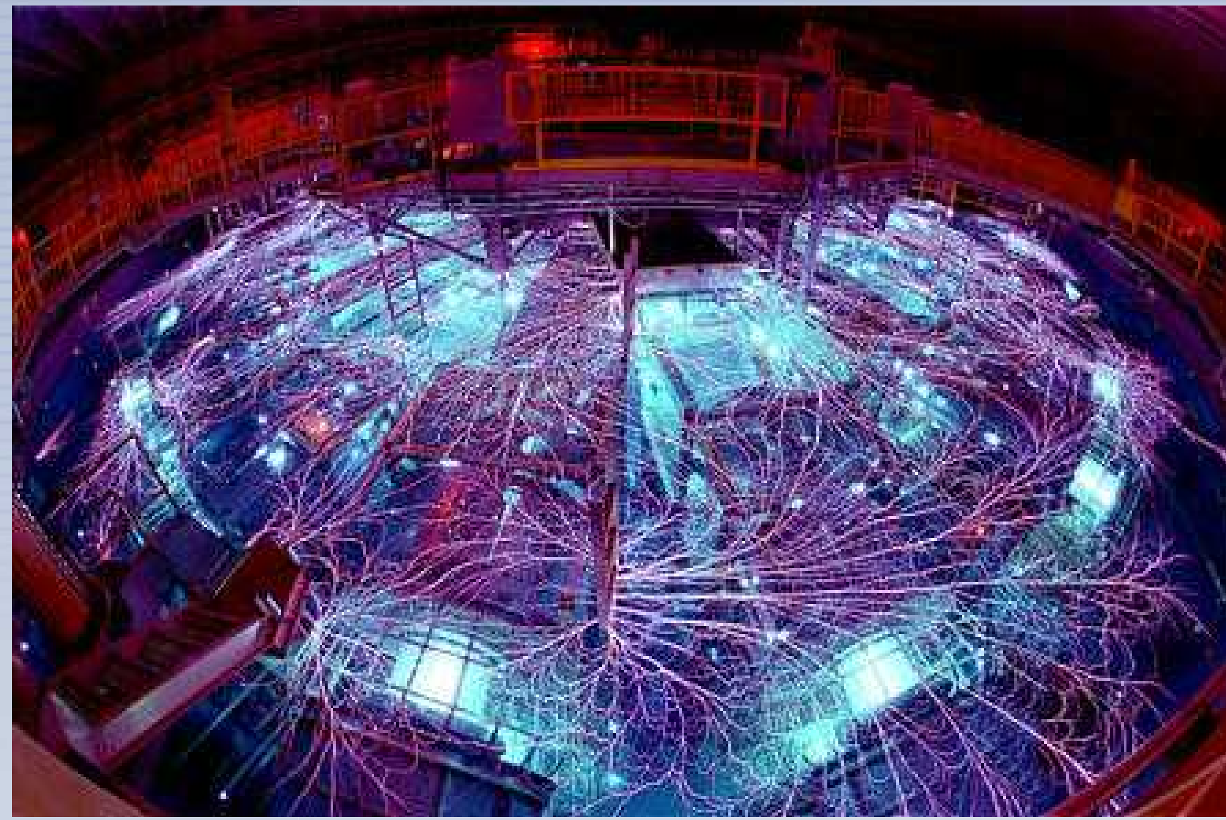
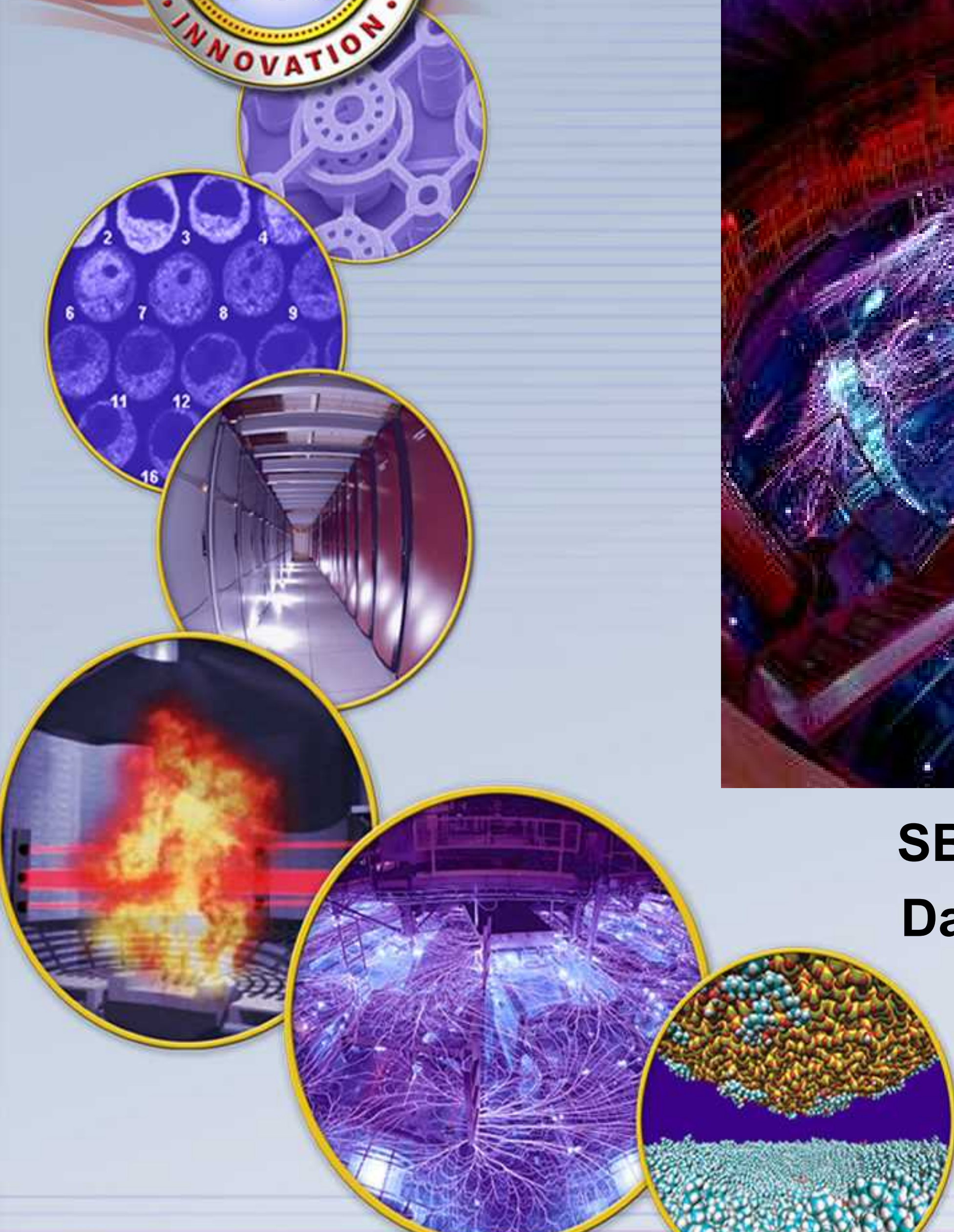
Z-Backlighter Laser Facility

SAND2009-5337C

Z-Beamlet and Z-Petawatt Laser Systems





SBS Workshop Prague, CZ, August 2009

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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.

Sandia National Laboratories

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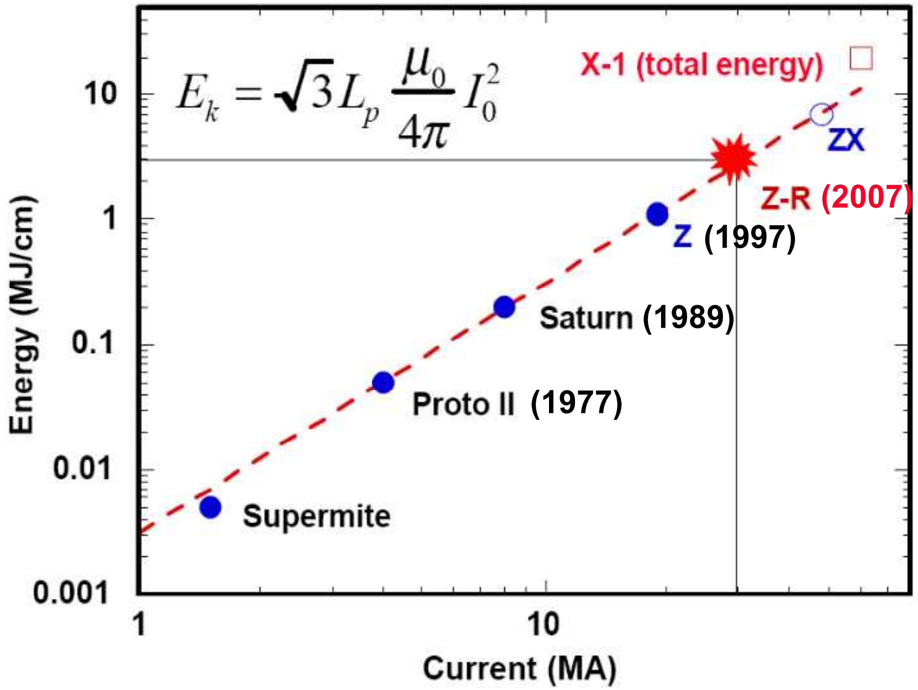
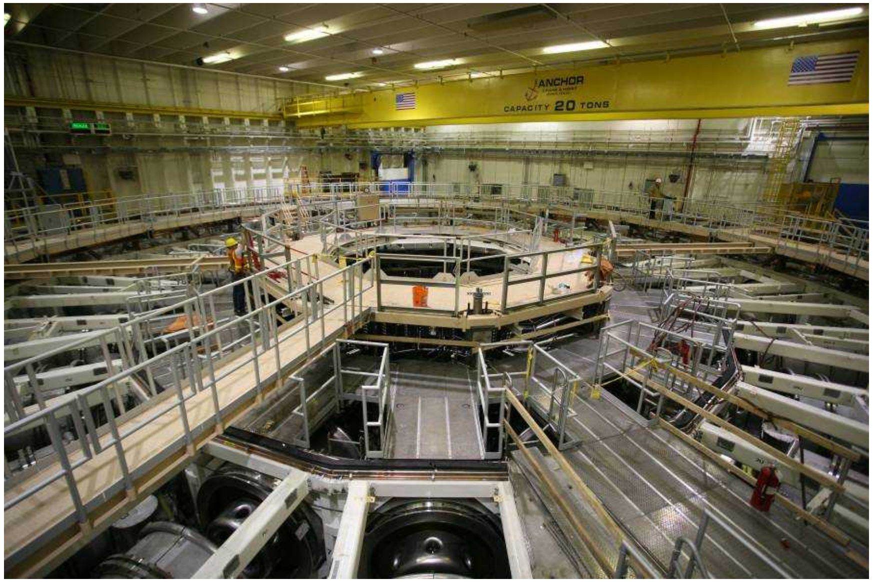
Outline

- ZR facility
- Backlighting mission
  - Point projection imaging
  - Curved crystal imaging
- Optical coating facility
- Lasers
  - NLS
  - Z-Beamlet
    - » Laser
    - » Target area
  - Z-Petawatt
    - » Laser
    - » Commissioning
    - » FOA/Debris
    - » 100TW target area
    - » New target area
      - Resent results
- How to get experimental time at Z-Backlighter laser facility

The new ZR facility in operations



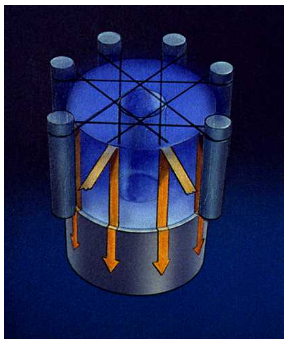


Capability	Z	ZR
Peak load current reproducibility	5%	2%
Pulse shaping flexibility	Minimal	Significant Variability
Peak Current	18 MA	26 MA
Full current operation	100 ns	130ns, 300ns
Diagnostic Lines of Sights	9	18

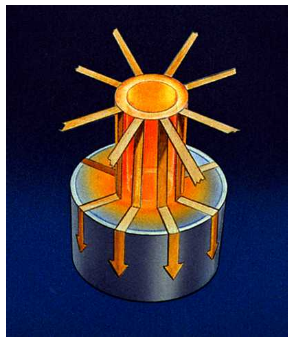
Sandia's ZR Z-pinch facility

Phases of a z-pinch implosion

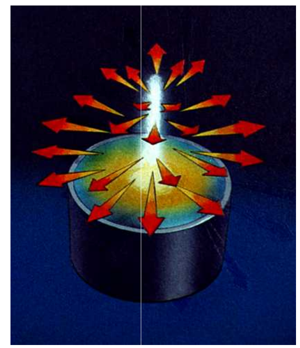
initiation



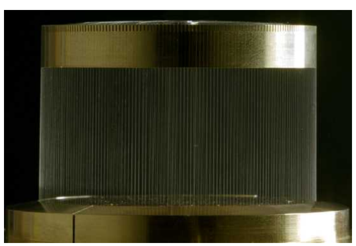
implosion

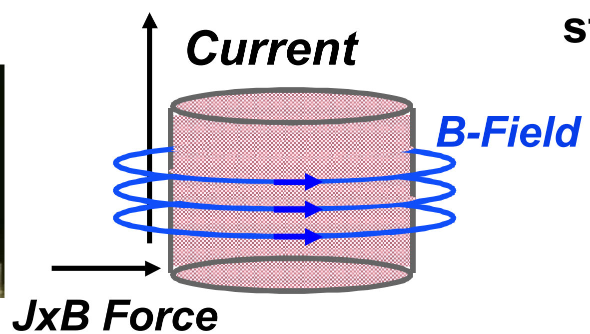


stagnation

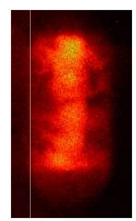


wire array

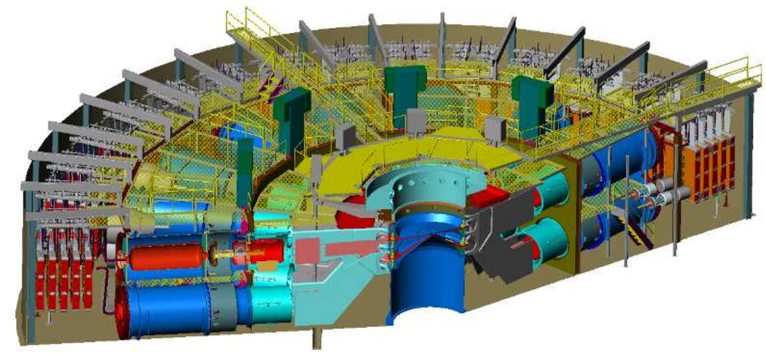




stagnation



ZR z-pinch facility



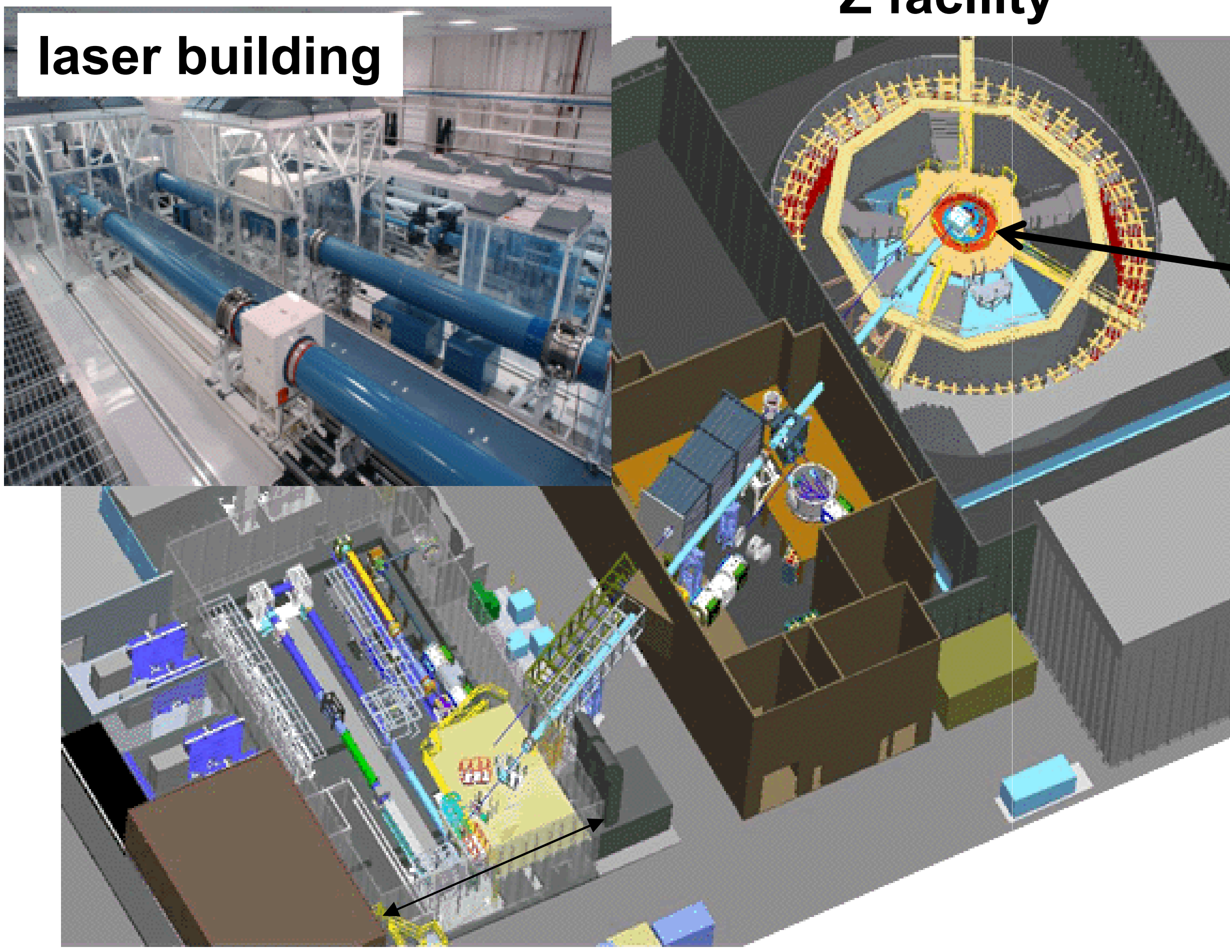
ZR parameters

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-Backlighter Laser facility

- The terawatt-class Z-Beamlet laser creates backlighting x-ray sources in the 1-9 keV range.
- The Z-Petawatt laser creates backlighting > 8keV range

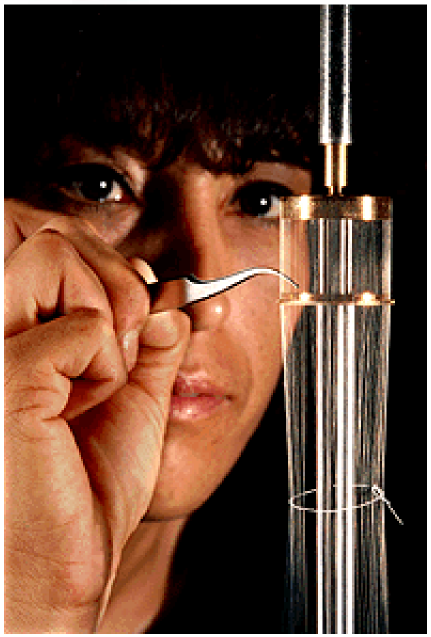
Z facility

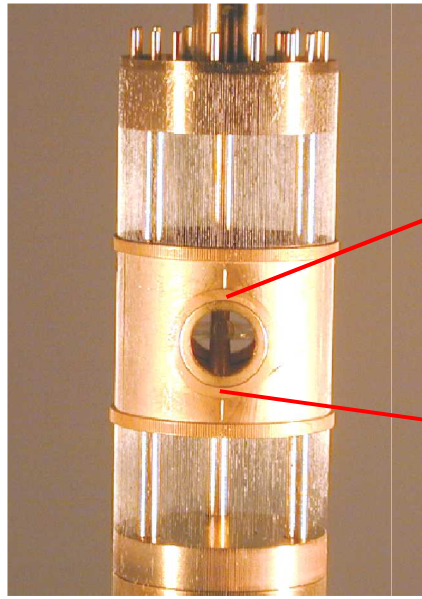


Z-Backlighter laser facility

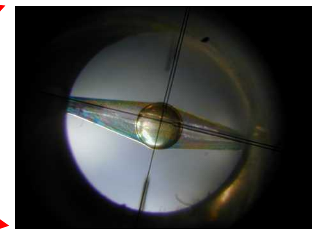
Final Optics Assembly Installed on Z

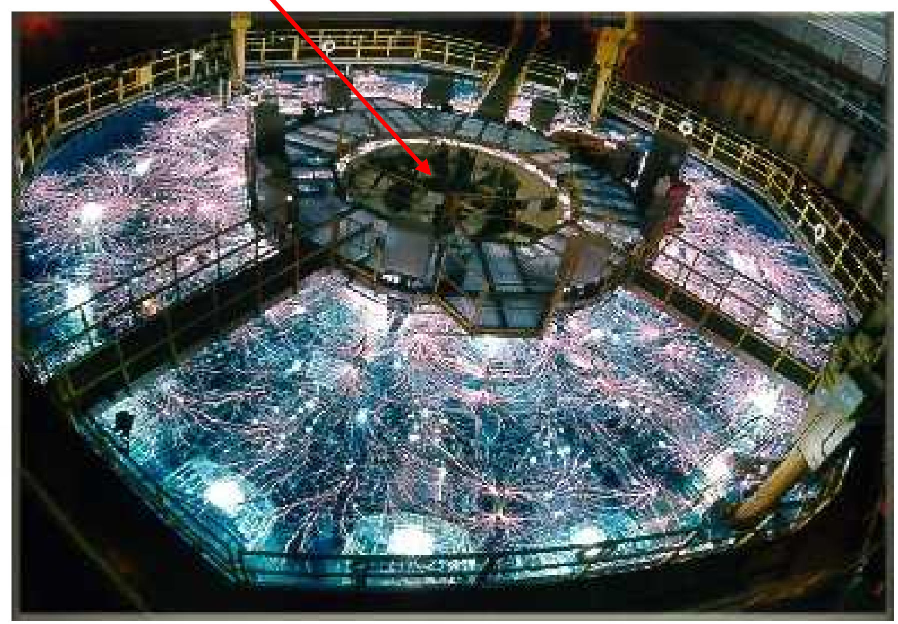
Inertial Confinement Fusion (ICF) Research on Z



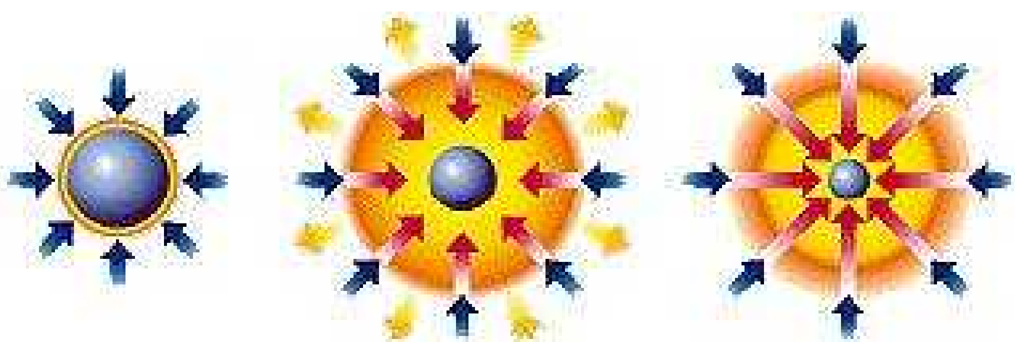


ICF capsule

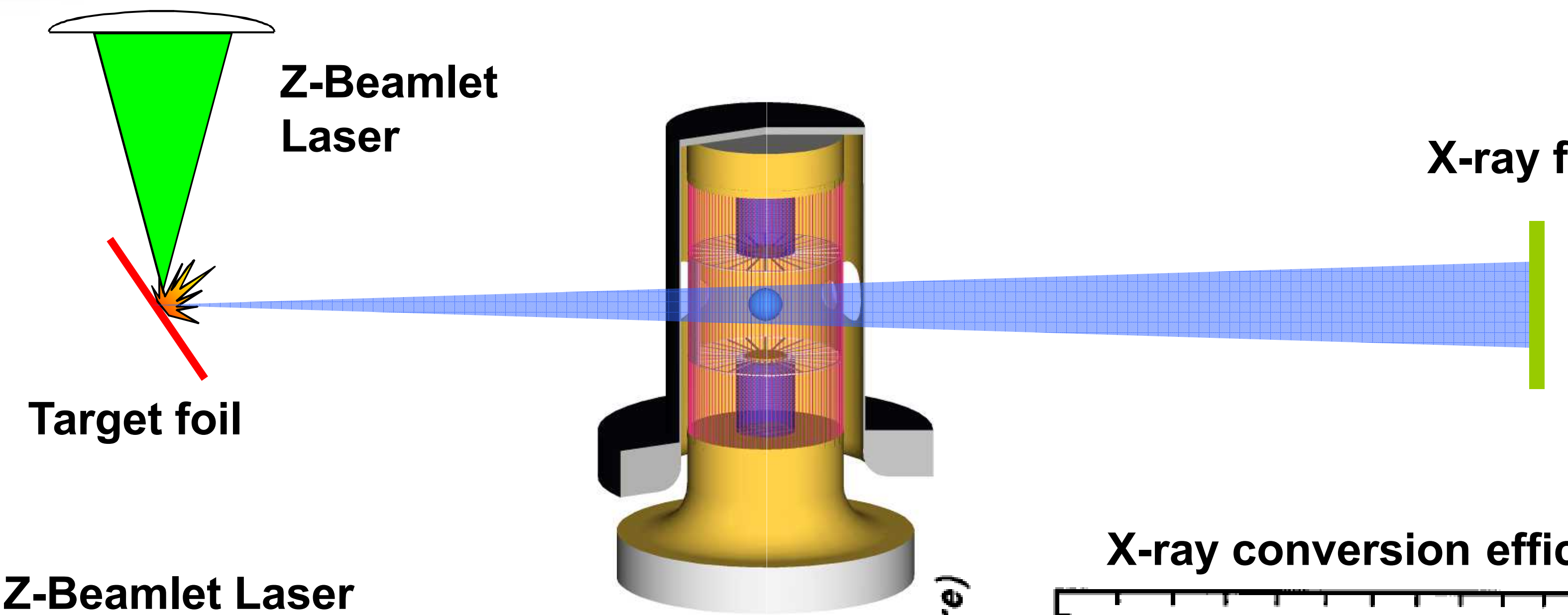




Hot Spot Ignition Concept

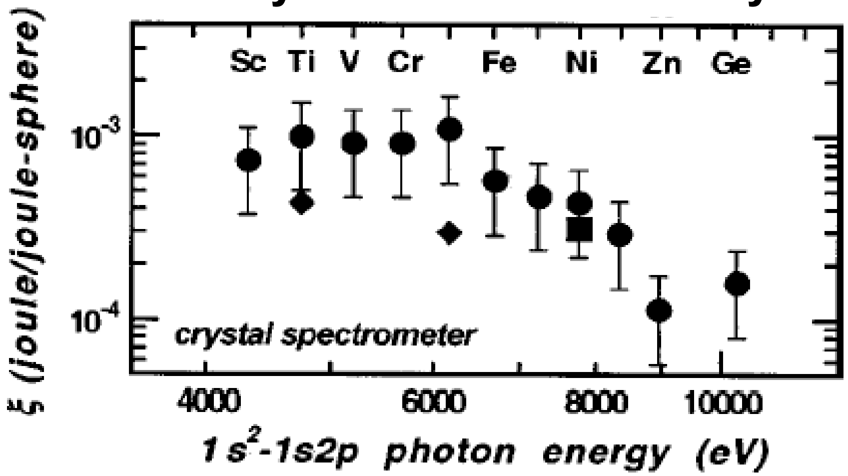


Point projection x-ray backlighting using the Z-Beamlet Laser



Z-Beamlet Laser

X-ray conversion efficiency



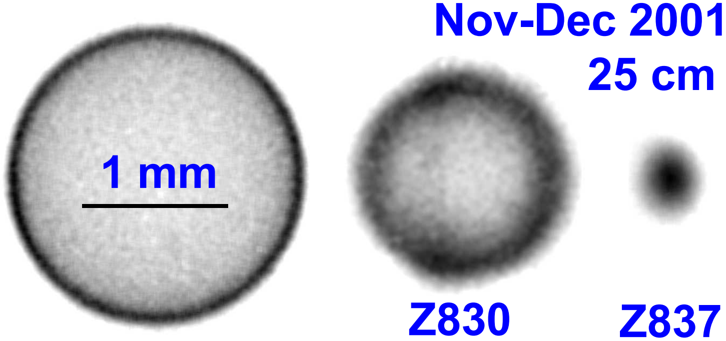
L. E. Ruggles,a) et. al.
REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 74, NUMBER 3 MARCH 2003

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

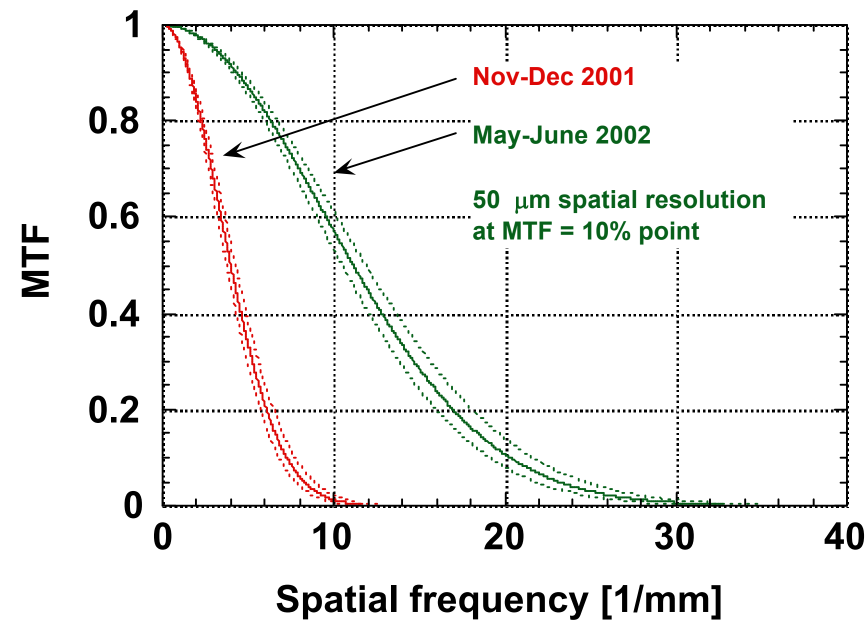
Nov-Dec 2001 [4.8x, 3.2 m lens, 25 cm x 25 cm aperture]

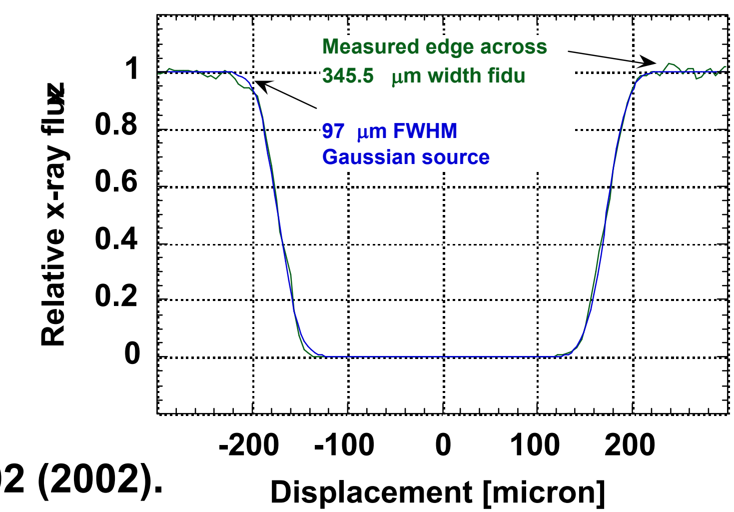


Z830 **Z837**

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

Z918 **Z919** **Z917**





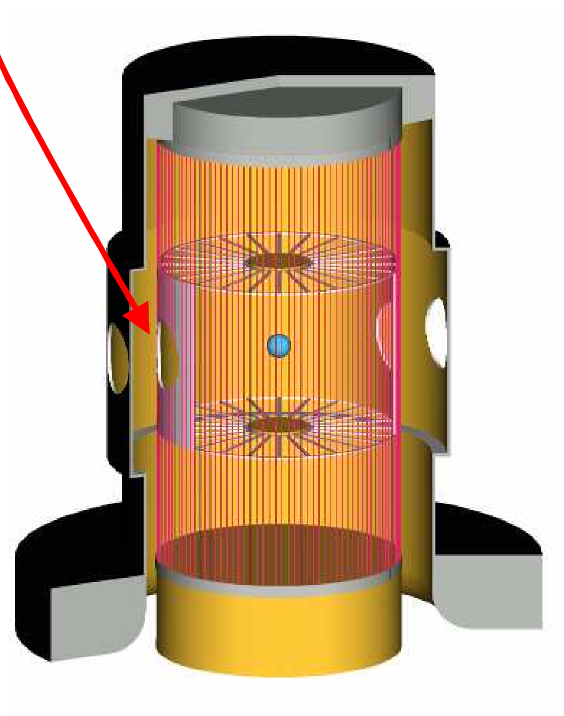
Z Backlighter

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

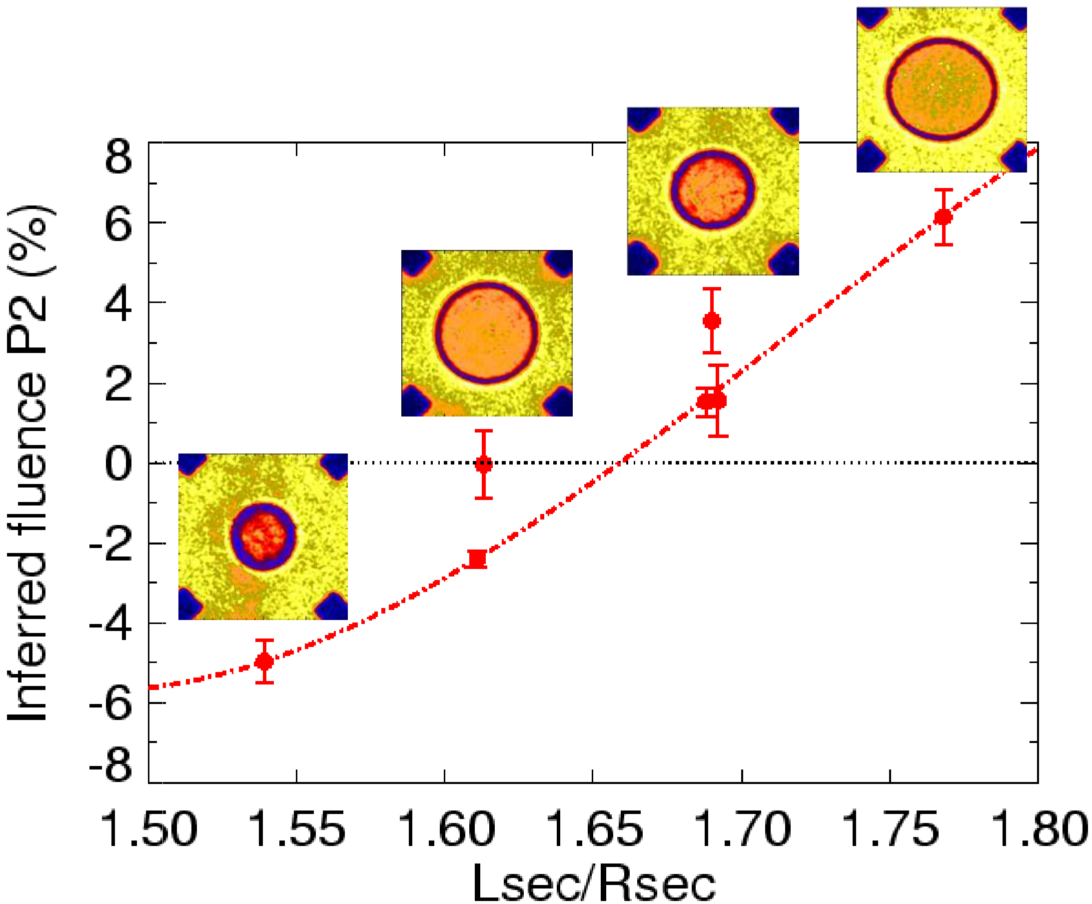
X-ray backlighting enabled us to optimize the symmetry of capsule implosions on Z.

Secondary hohlraum dimensions

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

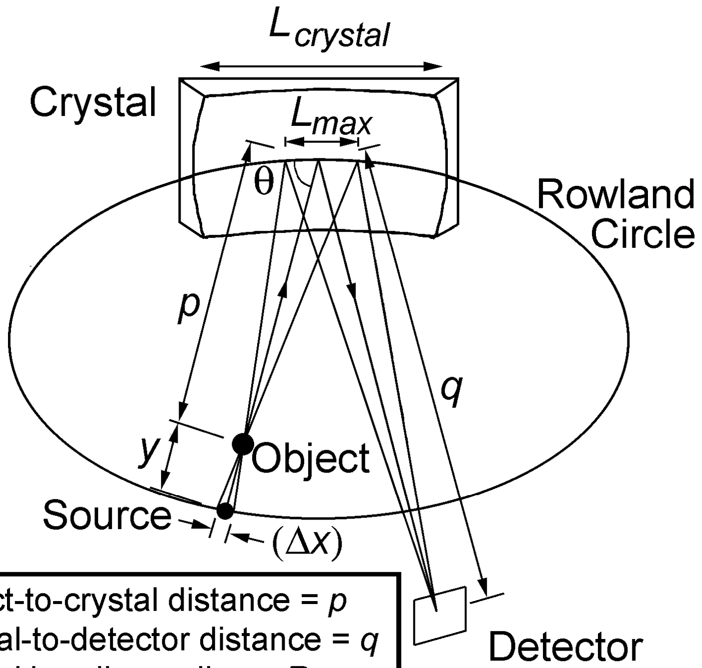


Time-integrated P_2 radiation symmetry



Backlighting Using Bent Crystal Imaging

X-ray Imaging with a Spherically Bent Crystal



Object-to-crystal distance = *p*
Crystal-to-detector distance = *q*
Crystal bending radius = *R*
Rowland Circle radius = *R/2*

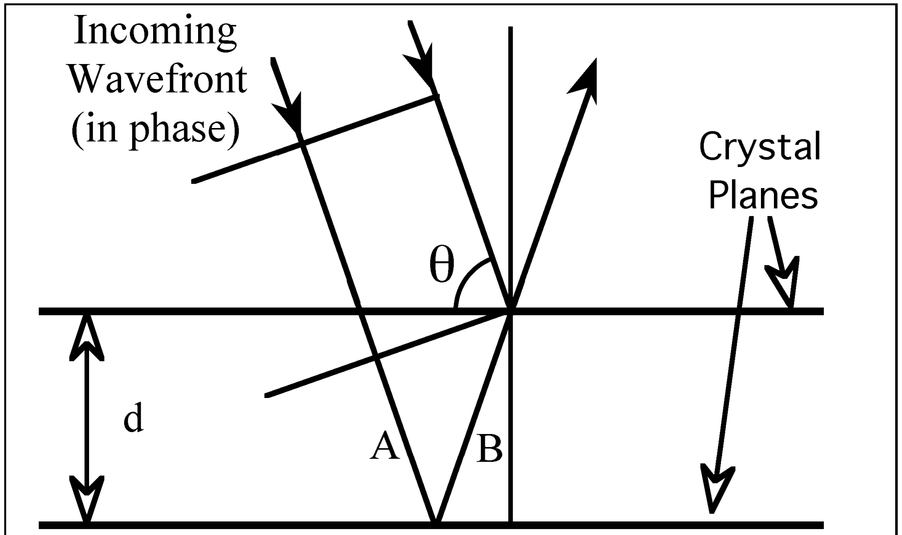
<u>Detector position determined by:</u>

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

<u>Field of view:</u>

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

Bragg Condition



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

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

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

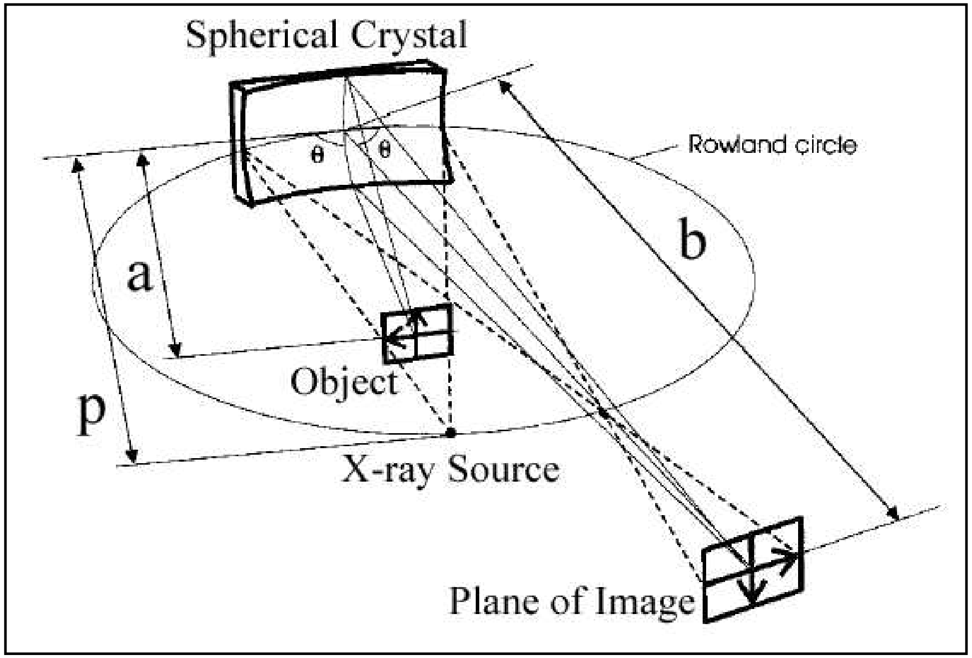
<u>Spectral bandpass:</u>

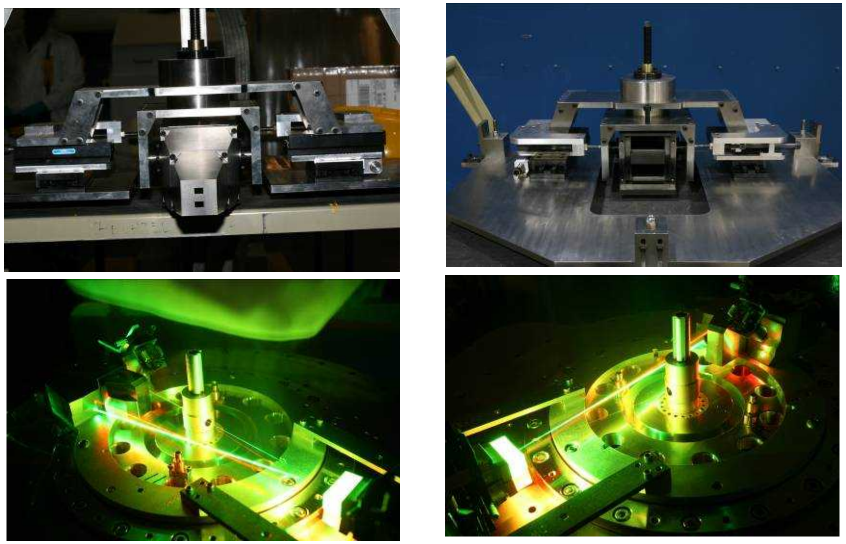
$$\Delta\lambda/\lambda = (\Delta x/R) \cot(\theta)$$

<u>Magnification:</u>

$$M = q / p$$

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



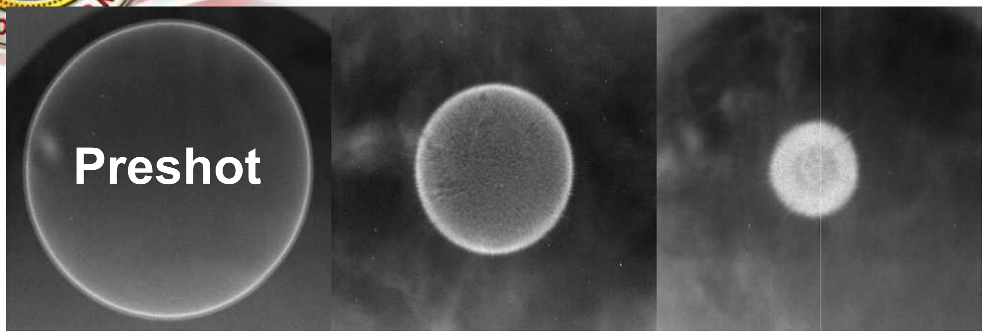


Bent-crystal Imaging

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

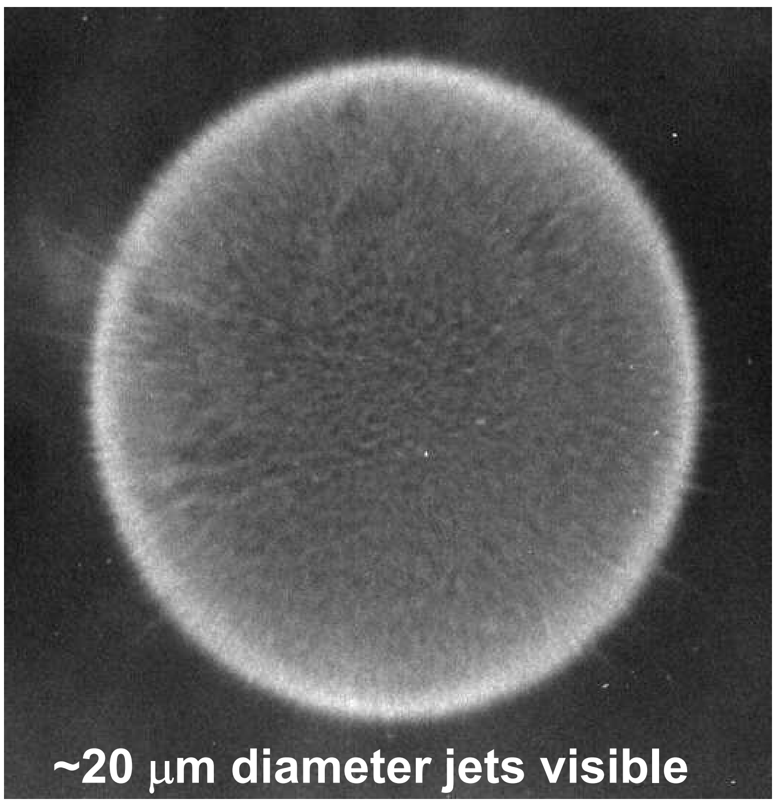
- **Concept proposed in mid-1990s.**
  - S.A. Pikuz *et al.,* Rev. Sci. Instrum. **68**, 740 (1997).
- **A 1.865 keV backlighter built at NRL**
  - Y. Aglitskiy et al., Rev. Sci. Instrum. 70, 530 (1999).
- **Crystal imaging techniques proposed for microscopy/backlighting on NIF**
  - J.A. Koch et al., 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).

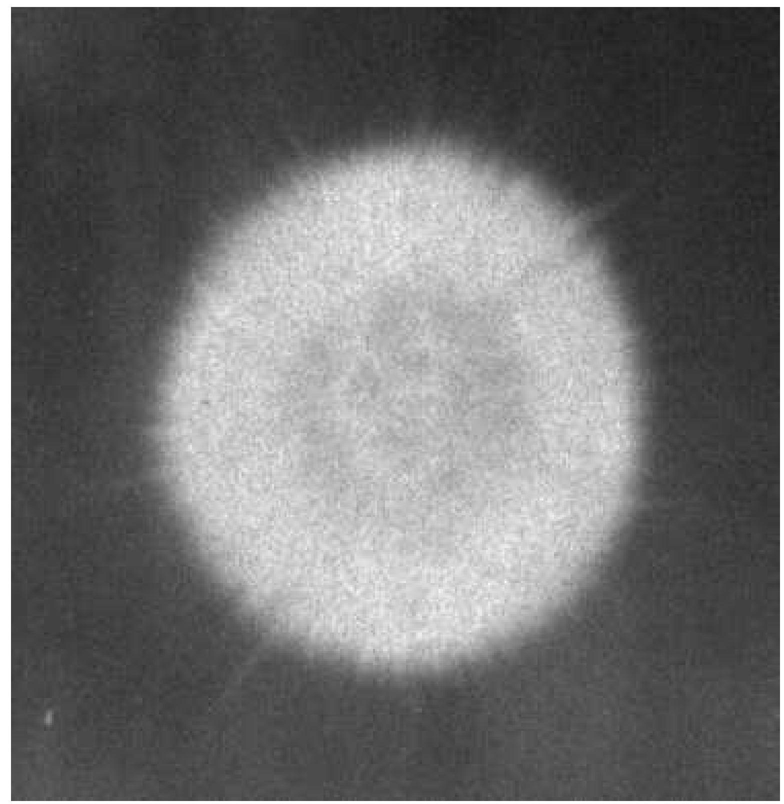
The higher spatial resolution bent-crystal imaging system revealed new features in imploding capsules



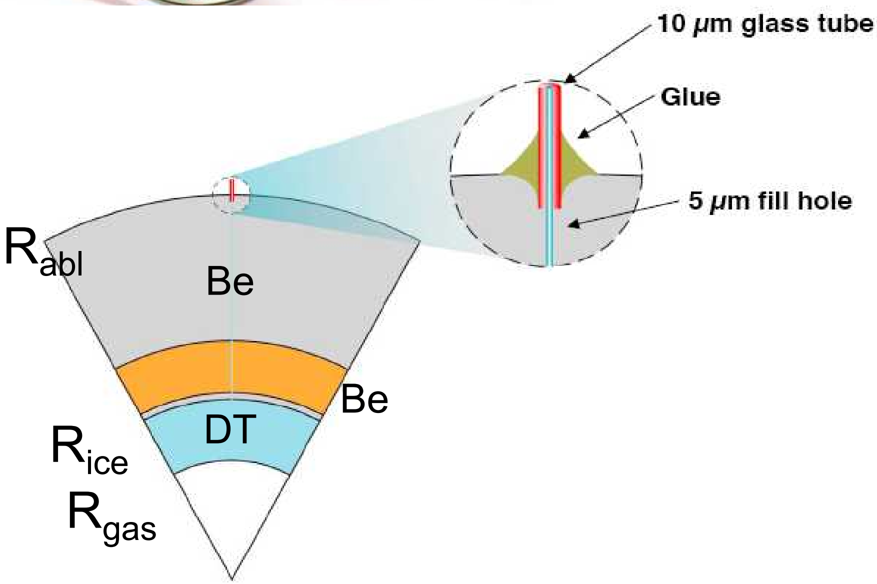
3.4 mm diameter plastic ICF capsule

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





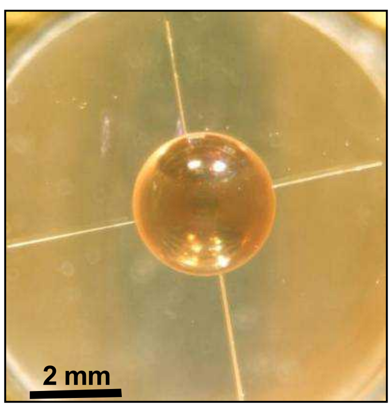
X-ray backlighting enabled us to measure the effects of DT fuel fill-tubes on capsule implosions



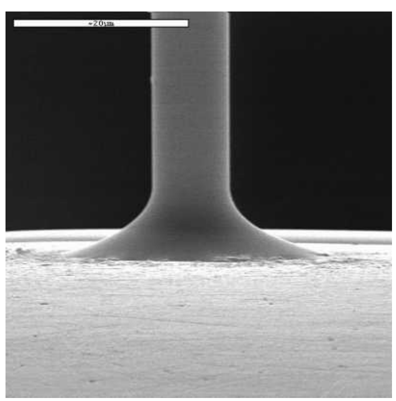
Using fill tubes significantly reduces complexity and expense of cryogenics system compared with diffusion fill and cryo transport

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

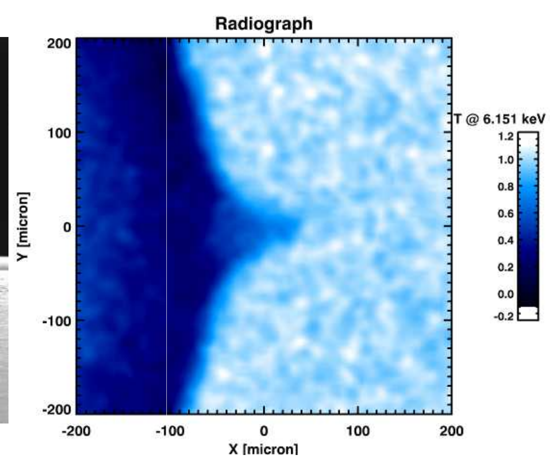
Calculating the perturbations arising from fill tubes is a computational challenge



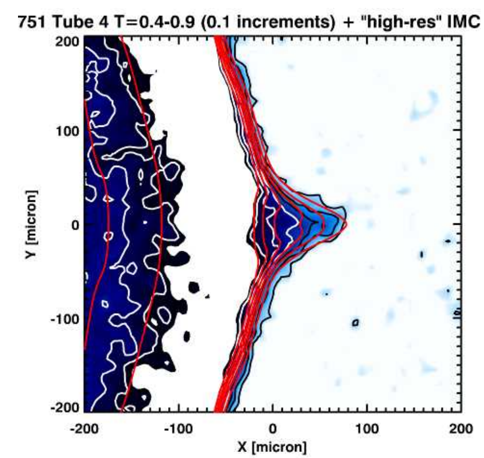
CH capsule with 4 fill tubes (12-45 micron OD)



SEM image of tube and glue fillet



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).

Z Backlighter

GENERAL ATOMICS

Sandia National Laboratories

Available Laser Systems

Z Backlighter

Z Beamlet

- λ=527nm
- τ=0.3-2ns (8ns with modulation) (2ns common)
- ϕ~75μm spotsize
- E<2kJ
- I<10^{17} W/cm^2
- ~3 hr/shot
- 2 pulse MFB

Z Petawatt

- λ=1054nm
- τ=500fs min
- ϕ~30μm spotsize
- E<60J (<500J pending)
- I>10^{19} W/cm^2
- ~3 hr/shot
- Sub-ps probe @ 527nm, <20mJ

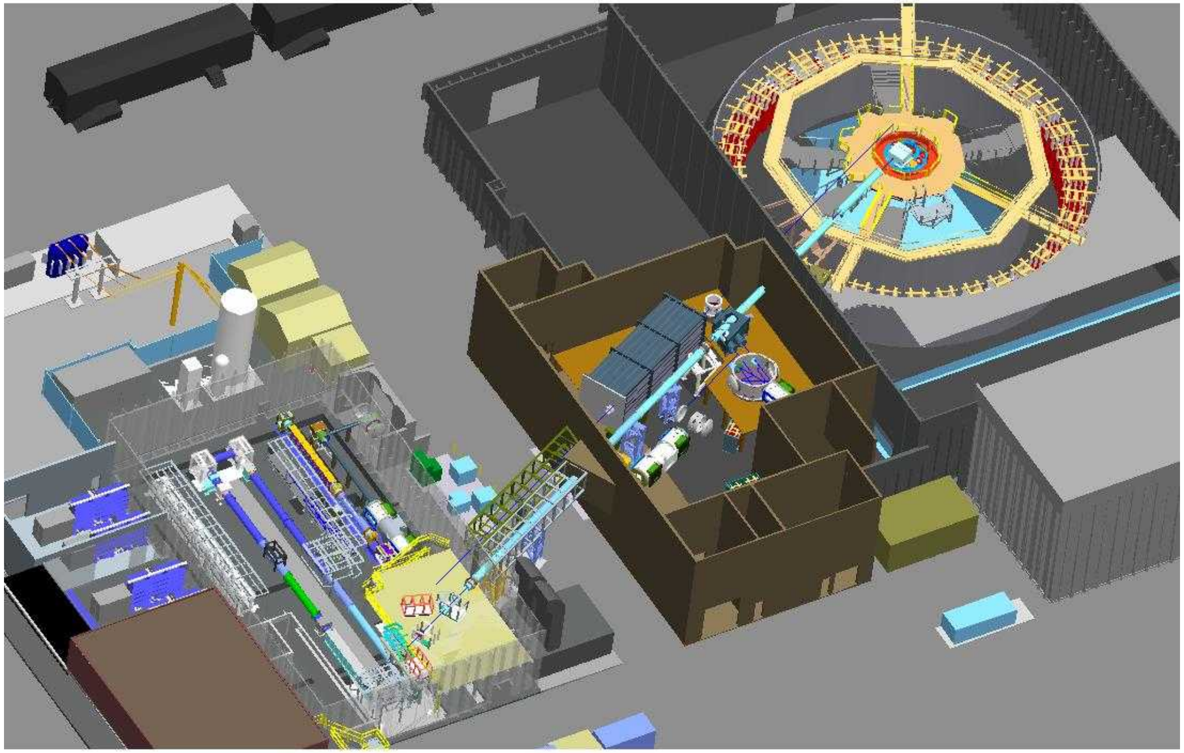
NLS

- λ=1064nm (532nm option)
- τ=150ps
- ϕ~5μm spotsize
- E<10J
- I<10^{17} W/cm^2
- ~20 min/shot
- Pending: 8-10ns operations at >100J @1ω

Facility Overview
(“Buildings 983/986”)

Z

ZBeamlet



NLS

OSF

ZPetawatt

ZBacklighter

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.

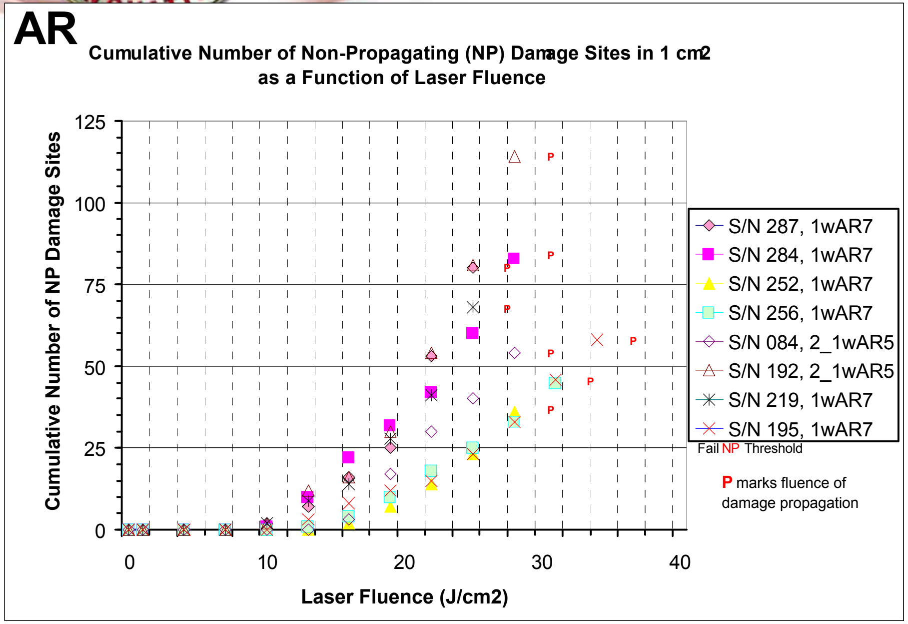
• Single-run capability: 3 at 94 cm optics
1 at 1.5 m option

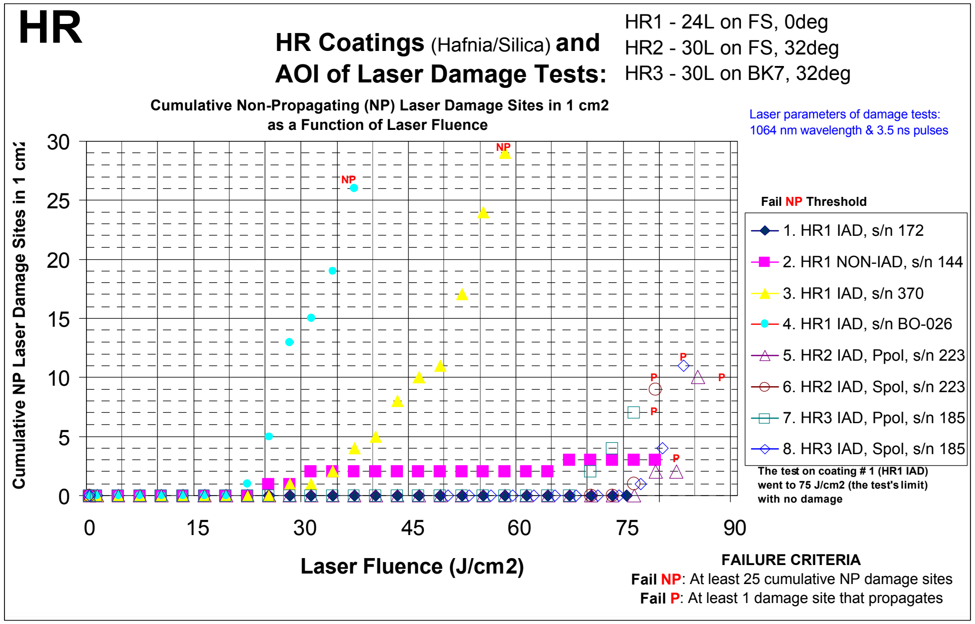
• Ion-assisted deposition (IAD) optional

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

FY07 Optics	*30 cm*	*60 cm*	*94 cm*
Z-Beamlet	**42 AR**	**4AR**	
Z-Petawatt	**6AR & 4HR**	**3AR**	**3HR**

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

Z Backlighter
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Neodymium Laser System (NLS)

- λ=1064nm (532nm option)
- τ=150ps
- ϕ~5μm spotsize
- E<10J
- I>10^{17} W/cm^2
- ~20 min/shot
- New front end
  - Pending: 8-10ns operations at >100J @1ω

The Z-Beamlet Laser system

<5 kJ every 4 hours

Cavity Spatial Filter

Booster Amplifiers

Transport Spatial Filter

Polarizer

1 ω Beam Diagnostics

Frequency Converter

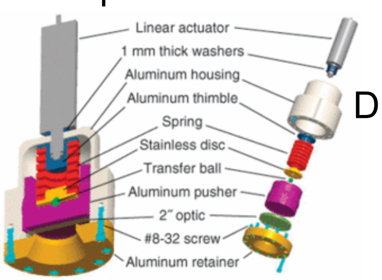
2 ω Beam Diagnostics

<1nJ @250 Hz @ 1053.14 nm

Cavity Amplifiers

PEPC

2ω Relay Telescope



DFM

4-Pass Rod Amp

Master Oscillator

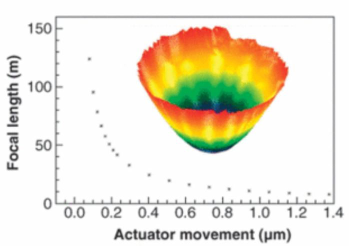
Beam Shaping

Regenerative Amplifier

Focus Lens

Debris Shield

Target on Z



Fiber link

Front End

< 10^{16} W/cm² per shot

<10 J every 15 minutes

<10 mJ @ 0.2Hz

Z Backlighter

Sandia National Laboratories

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

Injection Box with 10’ trombone addition

Optional Booster Amplifiers

“Leaky” Mirror

1 ω Beam Diagnostics

<5 kJ every 4 hours

Frequency Converter

Two beams Angled/Time multiplexed

2 ω Beam Diagnostics

Polarizer

Cavity Amplifiers

PEPC

2ω Relay Telescope

<10 J every 15 minutes

4-Pass Rod Amp

Master Oscillator

Two beams Angled/Time multiplexed

DFM

Beam Shaping

Regenerative Amplifier

To injection lens

mirror

Existing front end

Fiber link

Dump

Front End

Focus Lens

Debris Shield

Targets

half-wave plate

s

de-collimating lenses

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

Polarizer split into two beams

p

Variable delay (2 – 20 ns)

- 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)

Z Backlighter

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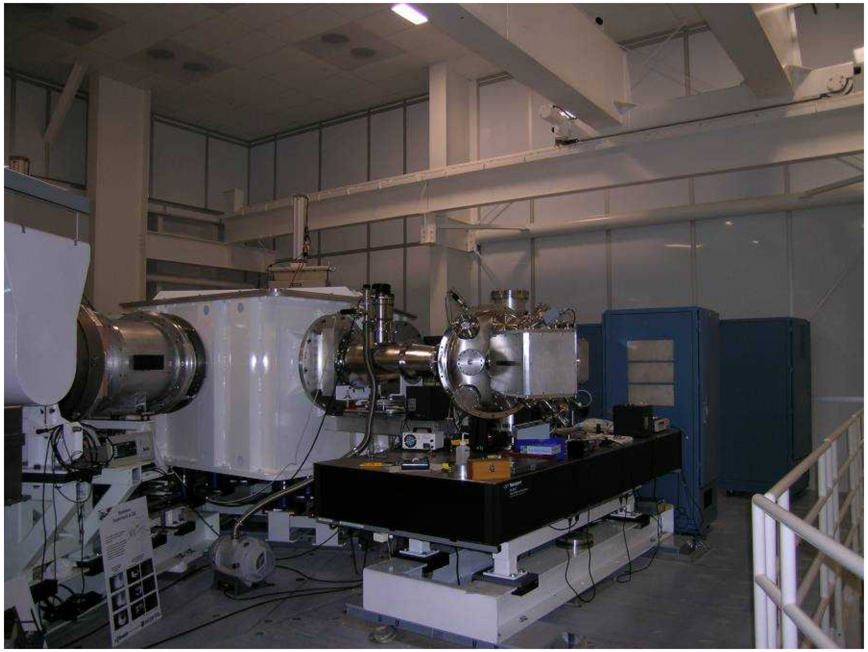
Z-Beamlet Calibration Chamber



Lasers:

- Typical: 527 nm, 1200 J each, ~1 ns, ~ 10^{16} W/cm^2 laser intensity, two beams 1.3mrad
- Optical probe beam at 1054 nm, 30/10 mJ, □τ < 500 fs, ps to multi ns delay possible
- NLS laser 1064/532 nm, 10/5 J, 180ps
- VISAR laser 532nm, 10mJ, 10ns

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

Conclusion/Future Upgrades

- Z- Beamlet laser will upgrade to a new front end
  - Master Oscillator to more commercial products and add bandwidth and pulse shaping to allow >2ns operation
  - Regen was upgraded to provide more stable operation and easier maintenance.
  - New off-the-shelf rod amplifier

- Adaptive optics
  - Single actuator "active optic" in place, pre-compensates thermal power of amplifier slabs during shot
  - Bi-morph DFM from Cilas
    - several wavefront sensors
    - control loop
    - custom control loop to allow tight integration with the laser control system for enhanced functionality

The 100TW/Petawatt System

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited
<50J in 500fs
(sub-aperture)

<10nJ in 150 fs
@ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

~ 10^{19} W/cm^2
per shot

CW

OPA's

Temporal Stretcher

Off-Axis Parabola

50 mJ in 3 ns stretched
pulse @ 10Hz

Front End

The 100TW/Petawatt System

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited
<50J in 500fs
(sub-aperture)

<10nJ in 150 fs
@ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

DFM

CW

~ 10^{19} W/cm^2
per shot

OPA's

Temporal Stretcher

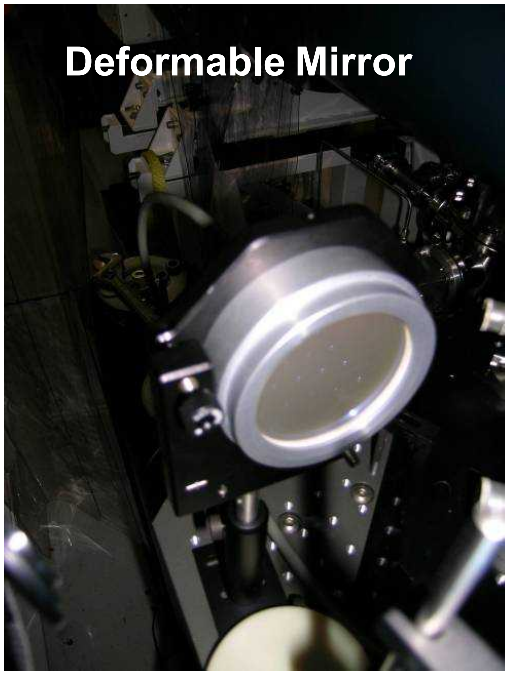
Off-Axis Parabola

50 mJ in 3 ns stretched
pulse @ 10Hz

Front End

Adaptive Optics

- **For higher order corrections, a commercial Phasics adaptive optics system has been installed in August 2007.**



From
Front End

To
Targe
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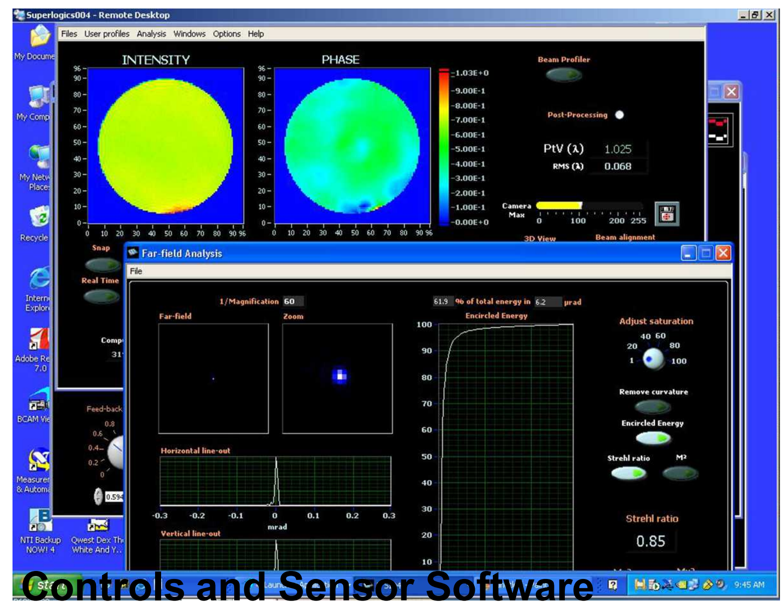
DFM



- This screen shot shows a compensated full system shot:
  PV: 1.03 waves
  RMS: 0.07 waves
  Strehl ratio: 0.85.

The 100TW/Petawatt System

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

PEPC

Cavity Amplifiers

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited <50J in 500fs (sub-aperture)

<10nJ in 150 fs @ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

DFM

CW

~ 10^{19} W/cm^2 per shot

OPA's

Temporal Stretcher

Off-Axis Parabola

50 mJ in 3 ns stretched pulse @ 10Hz

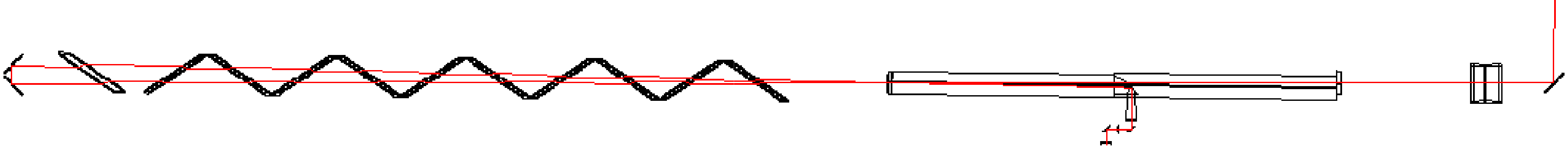
Front End

PEPC for Backreflection Isolation

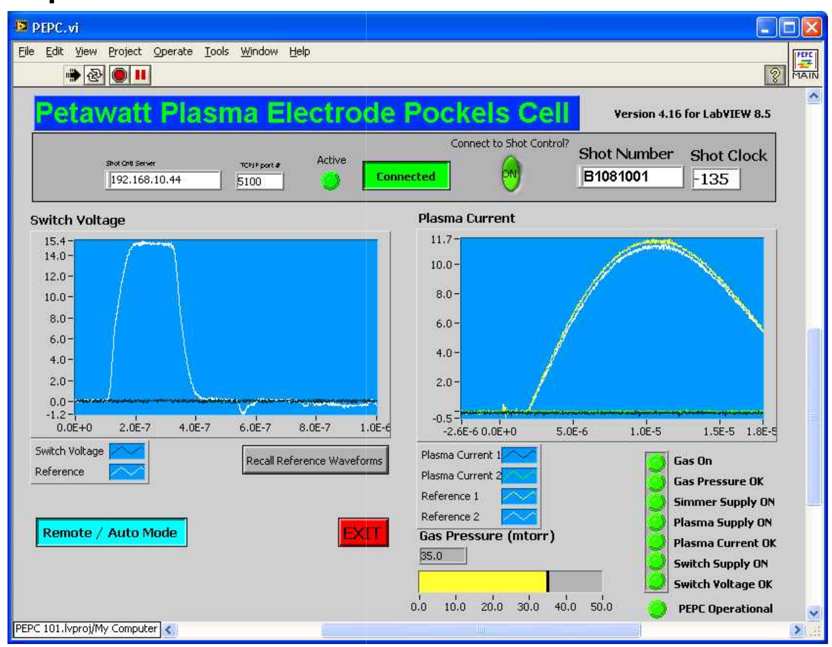
• **Initial tests on 100 TW system showed that target back reflection would cause laser damage at 1 PW level.**
=> Installation of plasma electrode Pockels cell for isolation

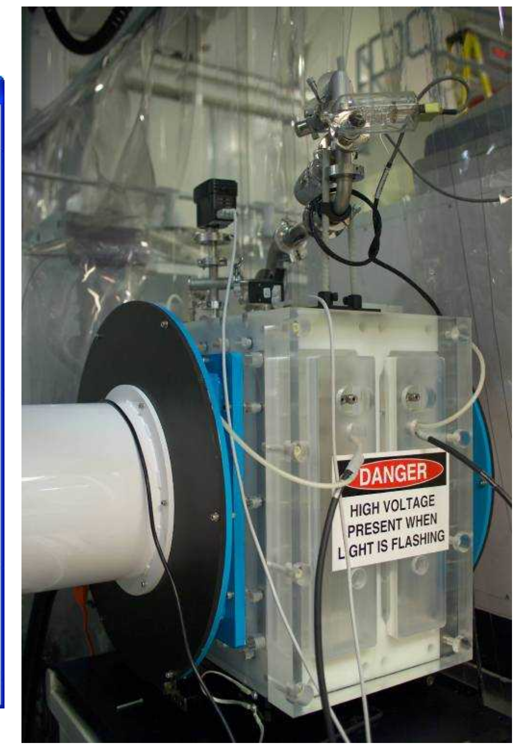
Polarizer

PEPC



pepc





The 100TW/Petawatt System

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

PEPC

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited <50J in 500fs (sub-aperture)

<10nJ in 150 fs @ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

DFM

CW

~ 10^{19} W/cm^2 per shot

OPA's

Temporal Stretcher

Off-Axis Parabola

50 mJ in 3 ns stretched pulse @ 10Hz

Front End

Diverter and Periscope

• Optics and hardware installed and aligned.

The 100TW/Petawatt System

Transport Telescope

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

PEPC

Cavity Amplifiers

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited
<50J in 500fs
(sub-aperture)

<10nJ in 150 fs
@ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

~ 10^{19} W/cm^2
per shot

DFM

CW

OPA's

Temporal Stretcher

Off-Axis Parabola

50 mJ in 3 ns stretched
pulse @ 10Hz

Front End

Transport Telescope

The 100TW/Petawatt System

Transport Telescope

Grating Compressor

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

PEPC

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited
<50J in 500fs
(sub-aperture)

<10nJ in 150 fs
@ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

~ 10^{19} W/cm^2
per shot

DFM

CW

OPA's

Temporal Stretcher

Off-Axis Parabola

50 mJ in 3 ns stretched
pulse @ 10Hz

Front End

Z Backlighter

Sandia National Laboratories

Petawatt Compressor Vessel

Three sections form vessel:
each 4.4 x 4.4 x 4.4 m^3
• 2 Tier design
• weight: 43 tons
• 4600m^3/h roughing + 3 ISO 500
Cryos allow:
$1x10^{-5}$ Torr in 3 hours or
$2x10^{-7}$ Torr in 15 hours

Uncompressed energy: 420 J

Initial temporal compression: < 2ps
Compressed energy: 125 J

The 100TW/Petawatt System

Transport Telescope

Grating Compressor

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

PEPC

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

<10nJ in 150 fs @ 1053 nm

Grating-limited <50J in 500fs (sub-aperture)

<5 J every 15 minutes

Target

Double-Pass Rod Amps

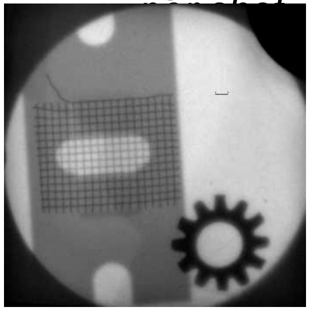
Ti:Sapphire Master Oscillator

first PW contact radiograph

~10^{19} W/cm^2

DFM

CW



OPA's

Temporal Stretcher

Off-Axis Parabola

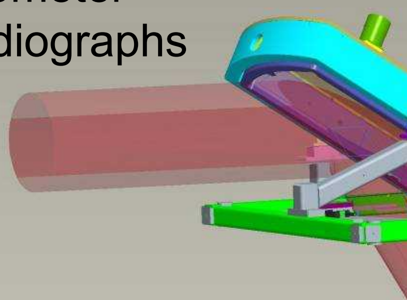
50 mJ in 3 ns stretched pulse @ 10Hz

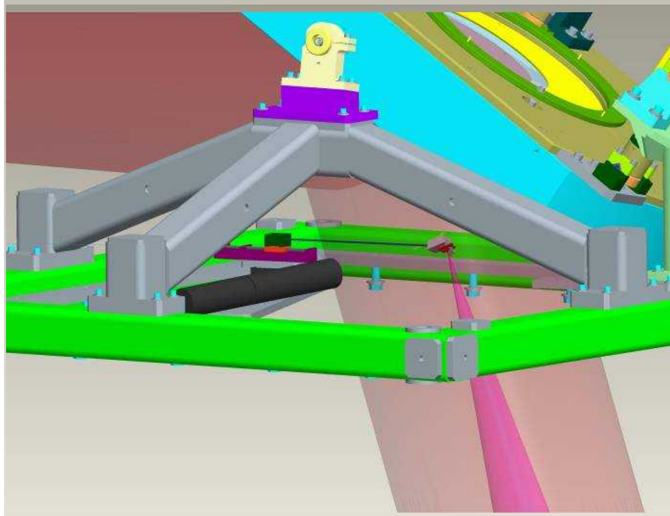
Front End

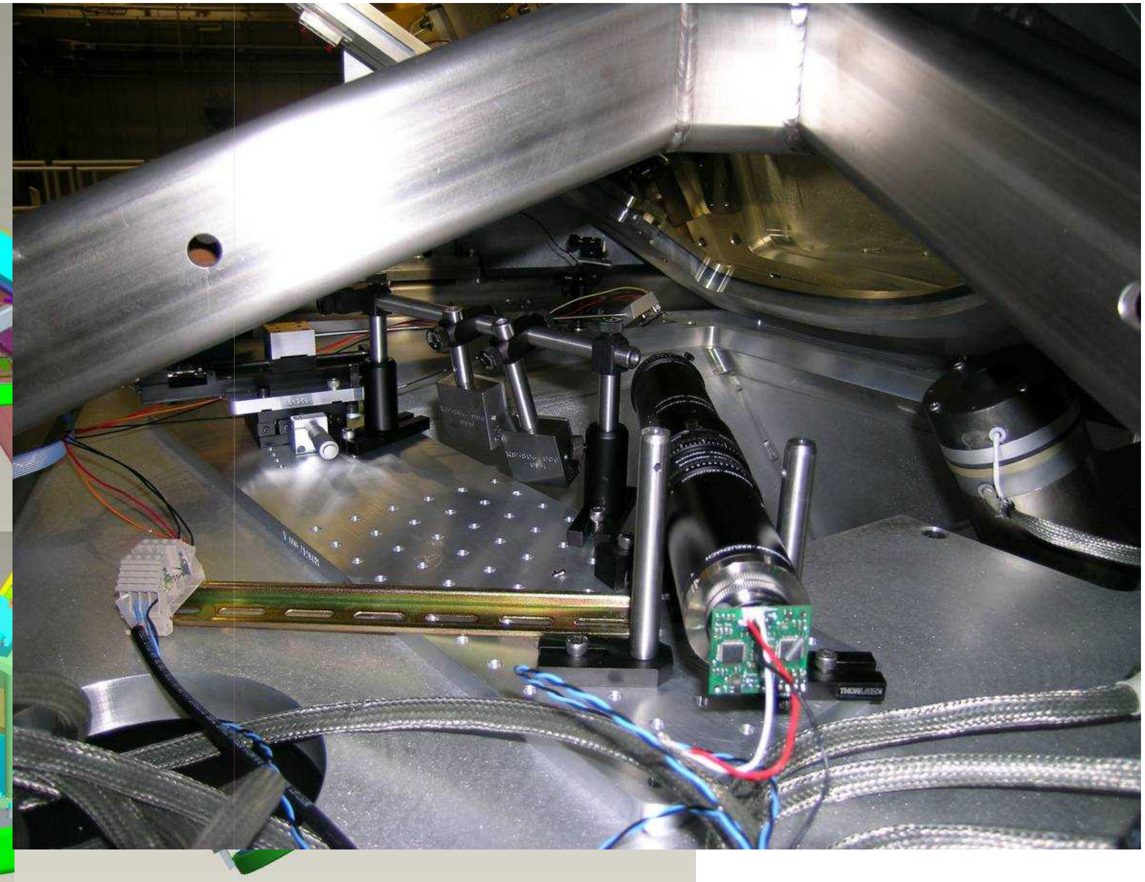
Commissioning Shot Setup

Measurements:

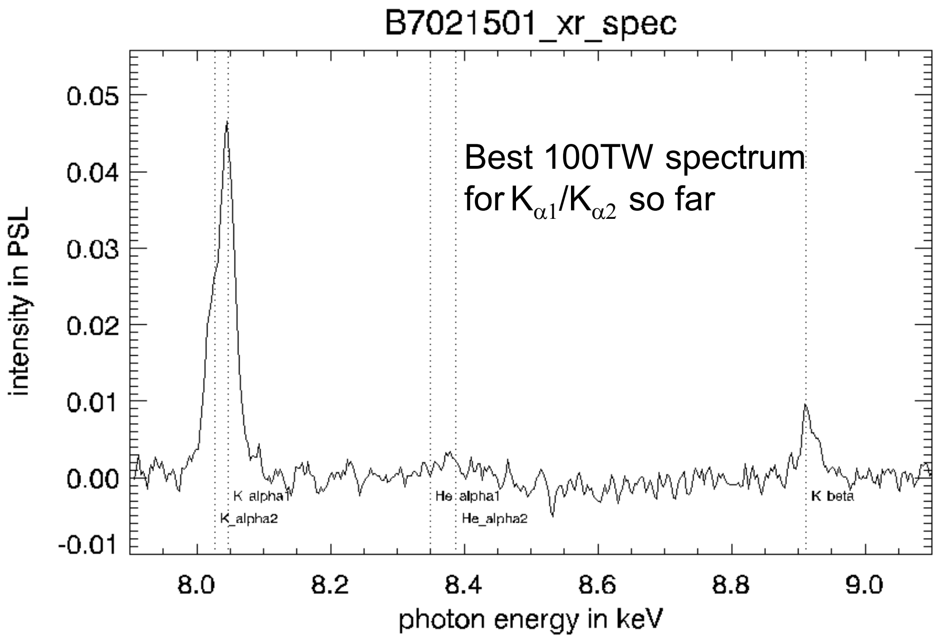
- Kα spectrometer
- contact radiographs

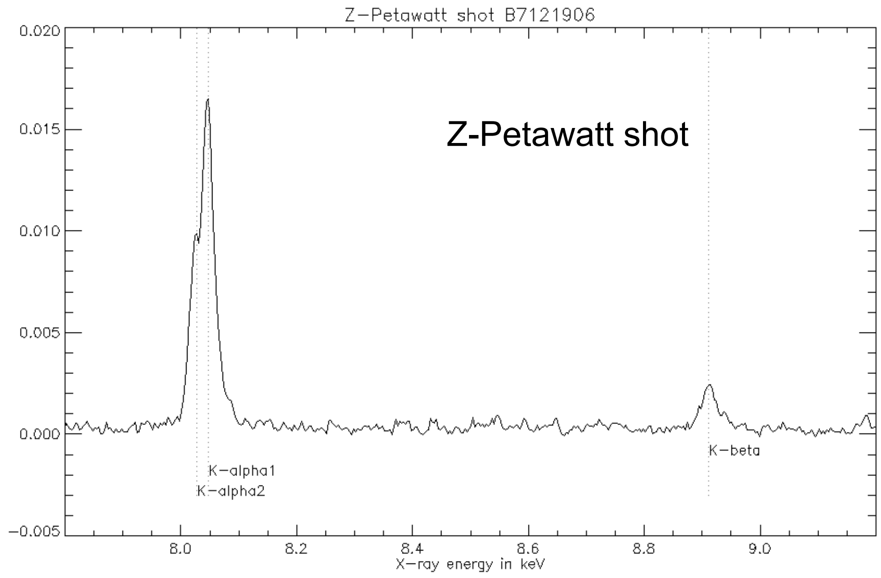






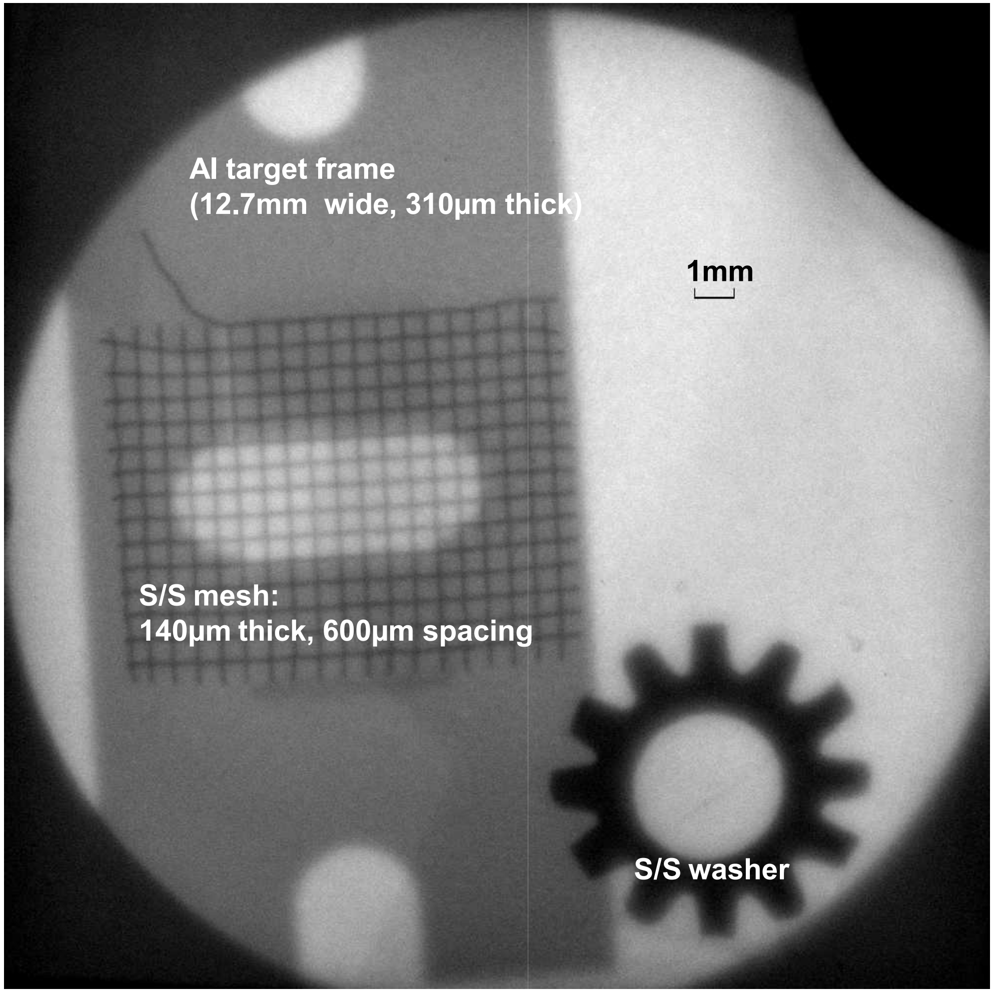
1st Z-Petawatt Shot (Spectrum)





- Intensities don't scale (different scanning parameters).
- Signal-to-noise ratio for the Z-Petawatt shot is the best we have ever achieved for K_α measurements.
- Very nice resolution/separation of $K_{\alpha1}/K_{\alpha2}$ doublet.

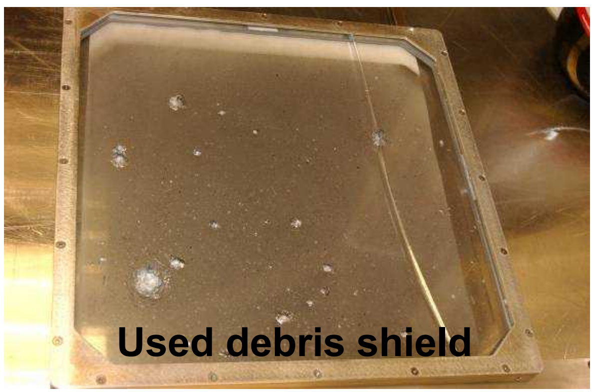
1st Z-Petawatt Shot (Radiograph)



PW FOA Debris

- Debris is generated from laser target interactions (minor) and z-pinch (major) sources.
  - Vapor debris <25km/s
  - Particulate debris <1km/s

- Terawatt/nanosecond scale backlighting deals with debris via debris shields (30X30X1cm^3)



Target s
• Forces c
optics to r
• Possibly
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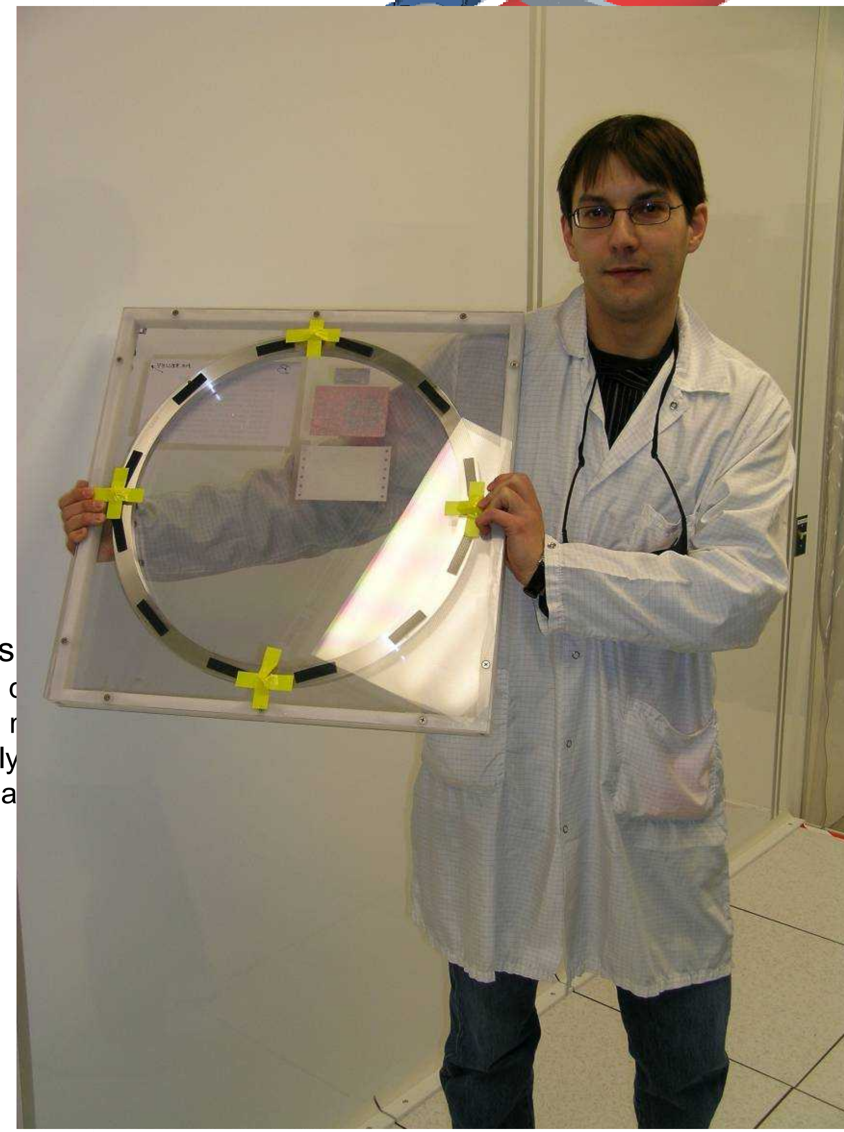
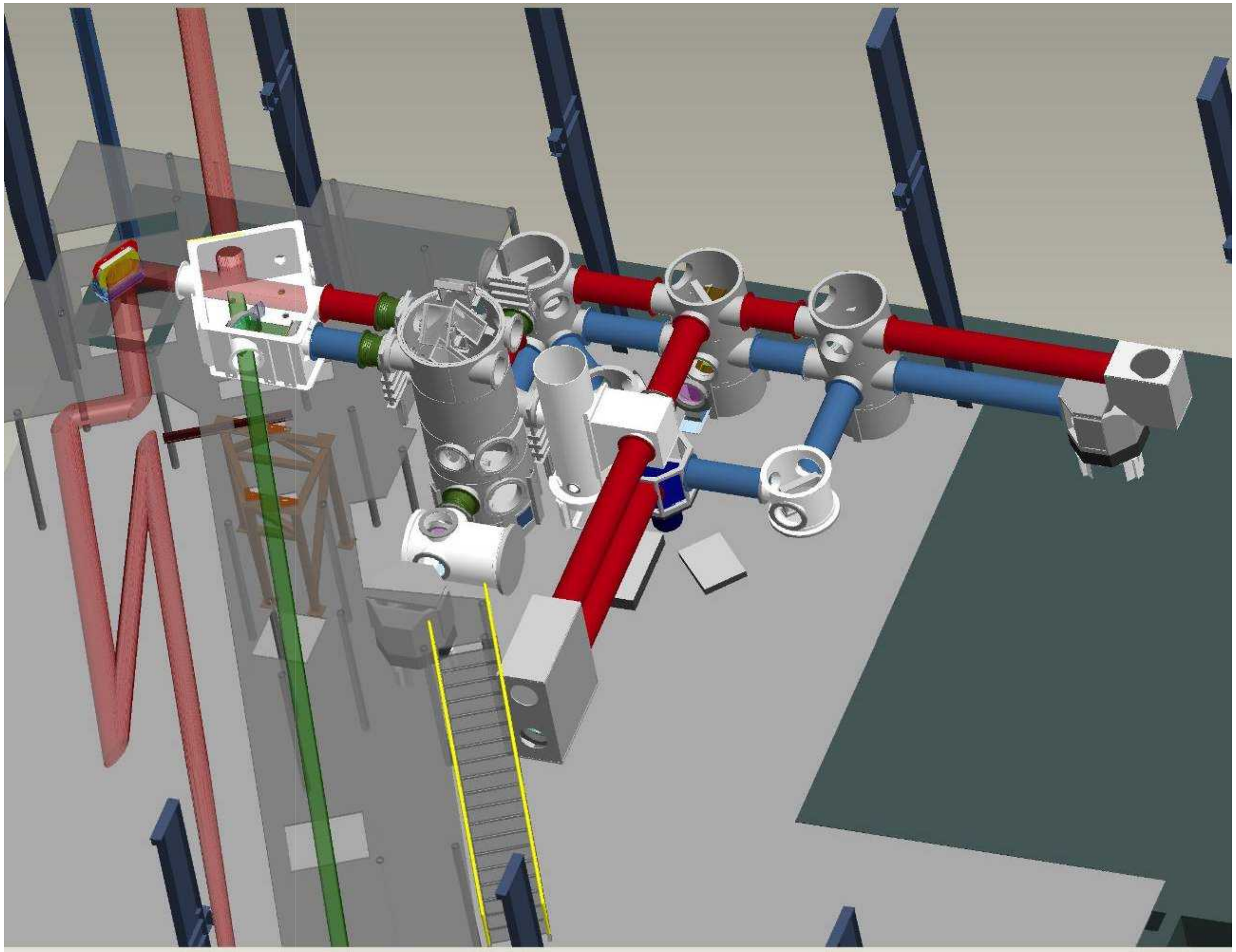


- Petawatt/picosecond scale backlighting must deal with debris differently due to B-integral effects:
  - Thin (2.7 μm) polymer film shields (passive)
  - Intelligent optics enclosure design
  - Fast debris shutters (active)

PW Target Area

•Experimental Capabilities:

- ZBL only
- Z-PW only
- ZBL and Z-PW
- Small pulsed power supply
- High grade radiation shielding



The 100TW/Petawatt System

Transport Telescope

Grating Compressor

<500 J every 3 hours (if full-aperture)
<50J every 3 hours (if sub-aperture)

Cavity Amplifiers

PEPC

1 ω Beam Diagnostics (Final)

1 ω Beam Diagnostics (Midchain)

Grating-limited <50J in 500fs (sub-aperture)

<10nJ in 150 fs @ 1053 nm

<5 J every 15 minutes

Target

Double-Pass Rod Amps

Ti:Sapphire Master Oscillator

~ 10^{19} W/cm^2 per shot

DFM

CW

OPA's

Temporal Stretcher

Off-Axis Parabola

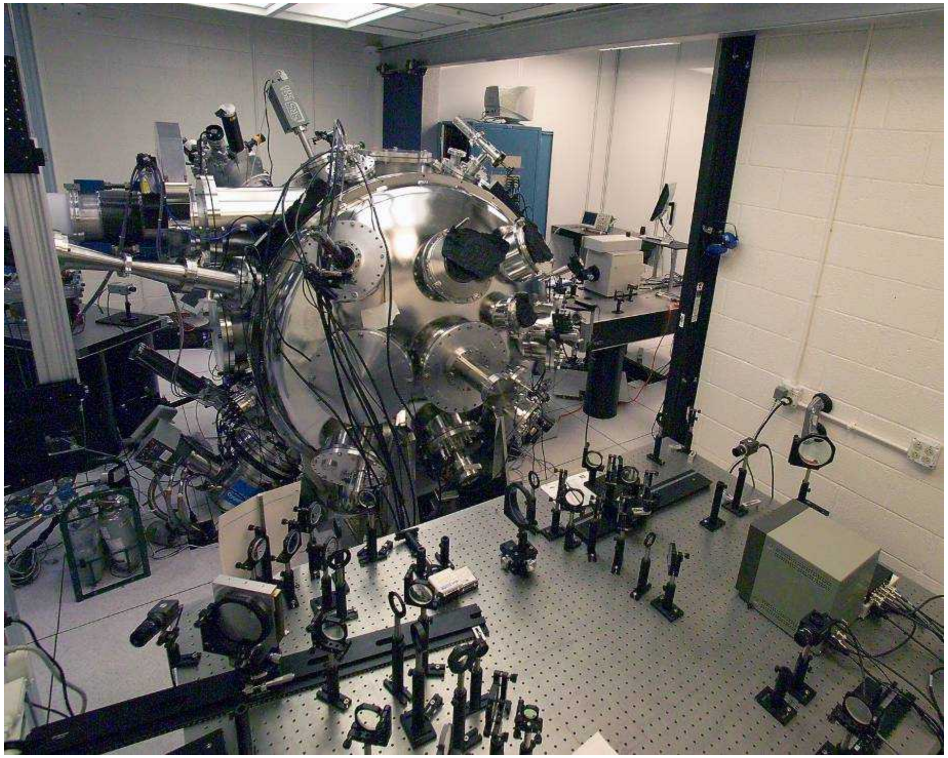
50 mJ in 3 ns stretched pulse @ 10Hz

Front End

100TW Target Area

Lasers:

•Typical: 1054 nm, 50 J, < 1 ps, ~ 10^{19} W/cm^2
laser intensity pointing stability < 50 μm
• Optical probe beam at 1054/527 nm, 30/10 mJ,
τ < 500 fs, ps to multi ns delay possible



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 GHz digital scopes
• Thompson parabola
• HV supplies up to 20 kV
• IP and CR39 detectors
• EMI shielded instrumentation cabinets up to 120 dB

Proton Focusing

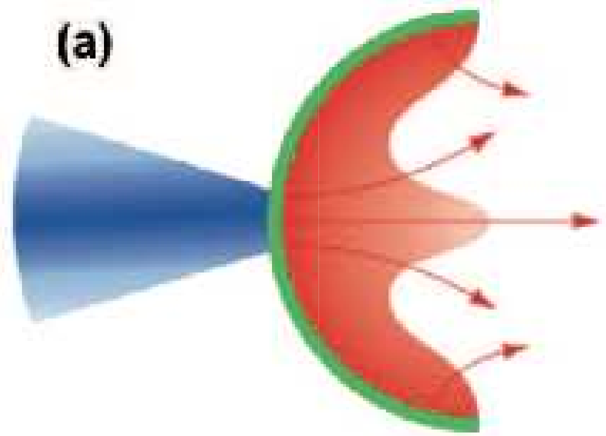
Applications:

- Use proton beam on secondary target to increase x-ray yields for backlighting
- Possible candidate for FI applications
- Focused proton beam as an initial stage for particle acceleration

Experiments:

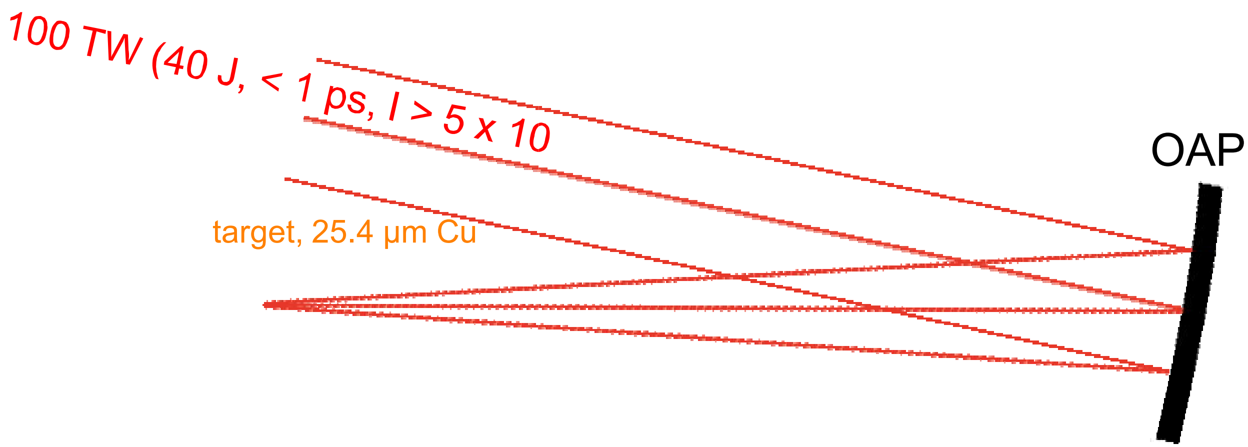
- Ballistic focusing in which focusing is achieved through target geometry (e.g. Gaussian)
- External magnetic fields in which protons are focused through quadrupoles

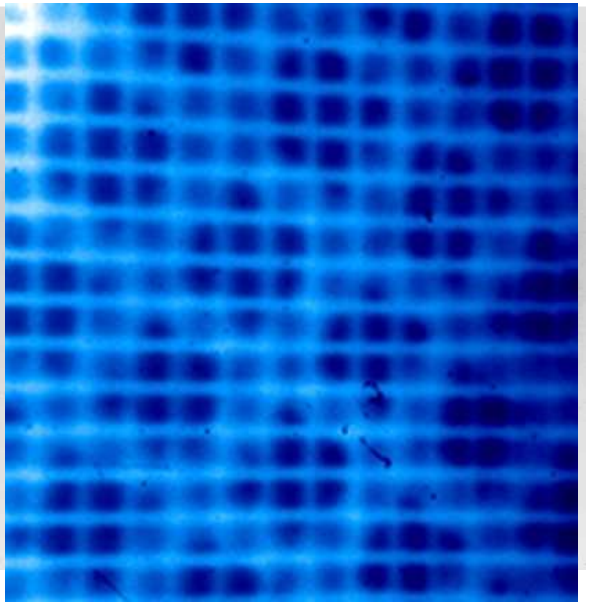
(a)



Collaboration with: Marius Schollmeier, Jörg Schütrumpf, Markus Roth (TUD), Kirk Flippo, Manual Hegelich, Sandrine Gaillard (LANL), Stefan Becker, Florian Grüner, Dieter Habs (MPQ/LM

Ballistic Proton Focusing Diagnostic





Magnification:

12x for small pattern
45x for large pattern

750 lpi superfine mesh:

wire distance: 33.9 μm
wire thickness: 8.6 μm

Quadrupole Focusing Experiments

Z-100 TW; E = 40 J, I > 5 x 10^{19} W/cm^2

target, 25.4 µm Cu

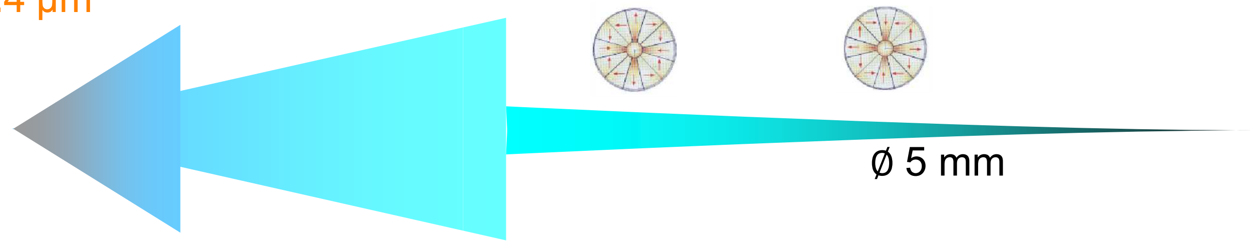
RCF

Al, 12.7 mm

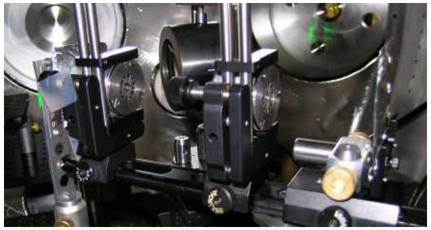
stainless steel, 6.35 mm

RCF

1st QP, 17 mm



ø 5 mm



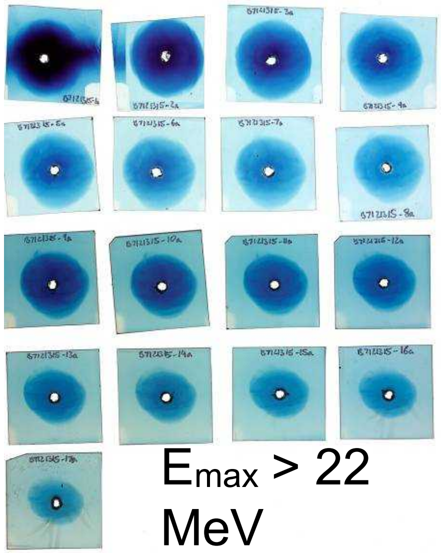
40 mm

170 mm

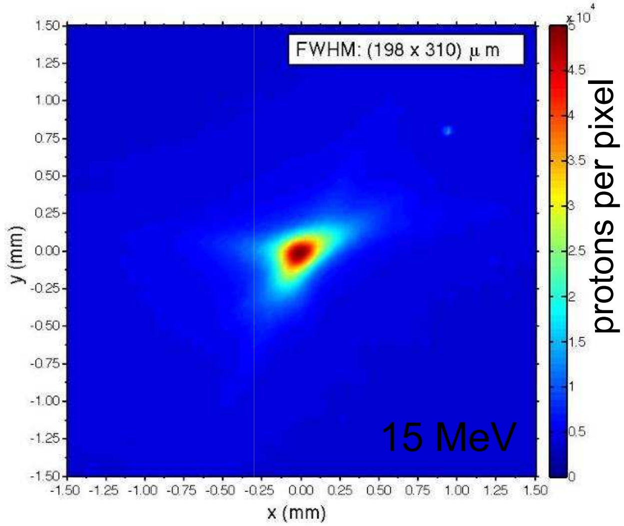
43 mm

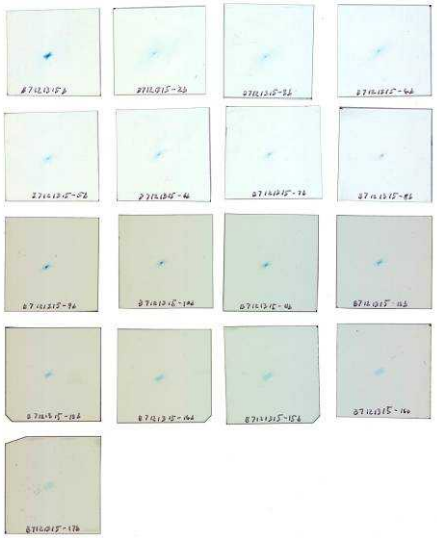
255 mm

500mm

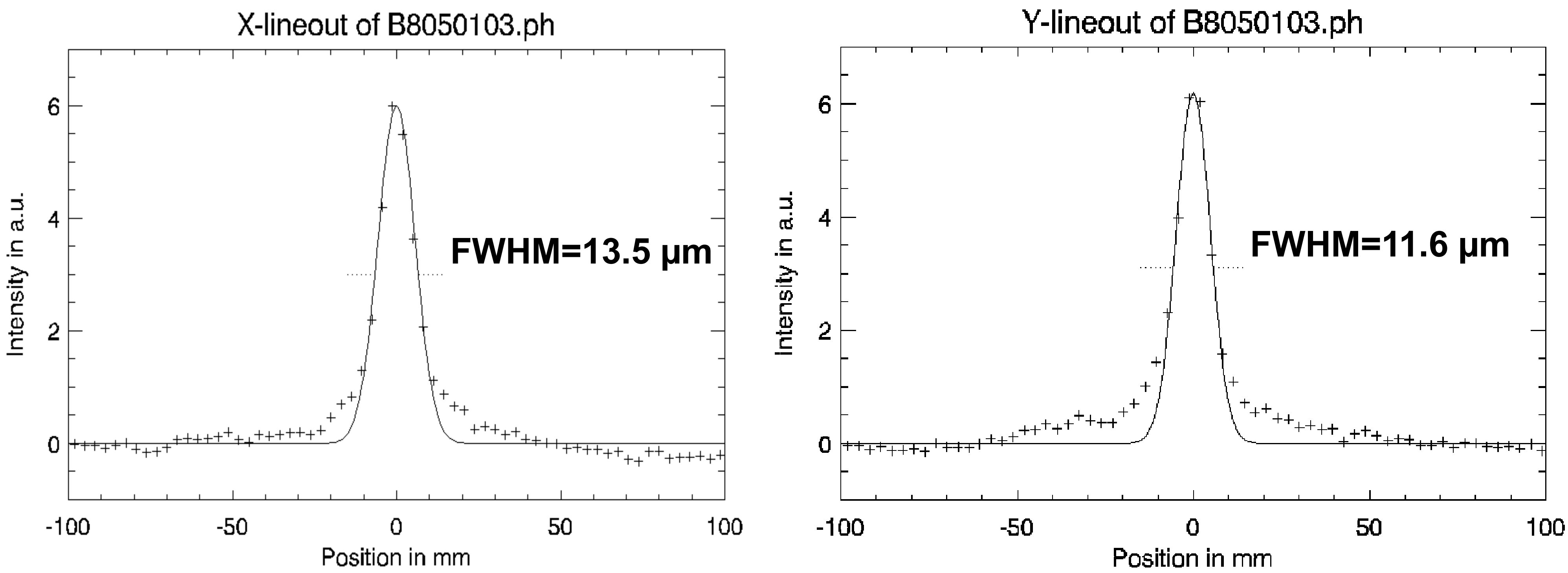


E_{max} > 22 MeV





X-Ray Spot Size Zirconium



Z-Petawatt
Conclusion/Future Upgrades

- Every component of the PW system has been exercised and the commissioning shot last year demonstrated integrated system functionality.

- New PW FOA needs to be assembled and installed for ZPW on Z.

- Several subsystems need to be optimized, e.g.: PEPC, DFM, laser diagnostics

- Dichroic mirror will enable ZBL/ZPW on same shot; focusing needs to be addressed

- PW target chamber in Target Bay will allow ZBL/ZPW experiments (planned FY08/09)

- Upgrade to MLD gratings (80cm X 20cm) will allow 240J@600fs operation in the 100TW target chamber

- Upgrade to MLD gratings (1.2 m x 0.4 m) will safely allow: 4.2 kJ @ 10 ps
  94 cm x 40 cm gratings already demonstrated at Osaka, 60 cm x 20 cm for testing in house 1.4 kJ @ 600 fs

- Main cavity redesign to full aperture 4-pass configuration will allow to extract up to 5 kJ long pulse; cavity lenses and transport telescope lenses are on order

Experimental Proposals For Use Of ZBL Facilities

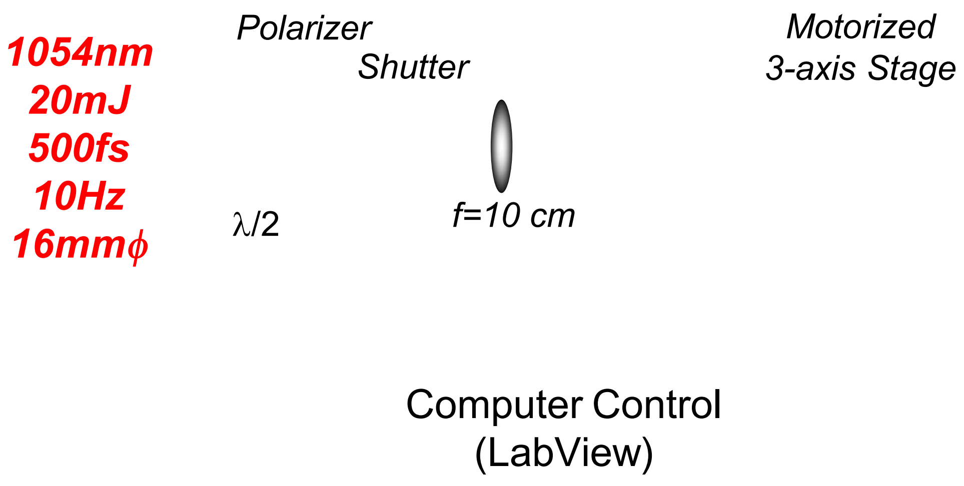
- Written Proposal (Three months before experiment)
  - Section I: Background
  - Section II : Team Members
  - Section III : Scientific/Program Objective
  - Section IV : Hypotheses Investigated
  - Section V : Experimental Approach
  - Section VI : Scientific Critical Performance Parameters
  - Section VII : Mechanical System(s) Critical Performance Parameters
  - Section VIII : Diagnostics Necessary to Measure the Critical Performance Parameters
  - Section IX : Laboratory Hazard Analysis
  - Section X : Experimental Description/Layout/Program Plan
  - Exhibit 1 : Other Material
- Presentation 30-min (8-weeks before experiment)
  - Summarizing written proposal
  - Detailing experimental setup and working with ZBL staff for a successful experiment
- Presentation 30-min (8-to-10 weeks after experiment)
  - Achievements
  - Lessons learned

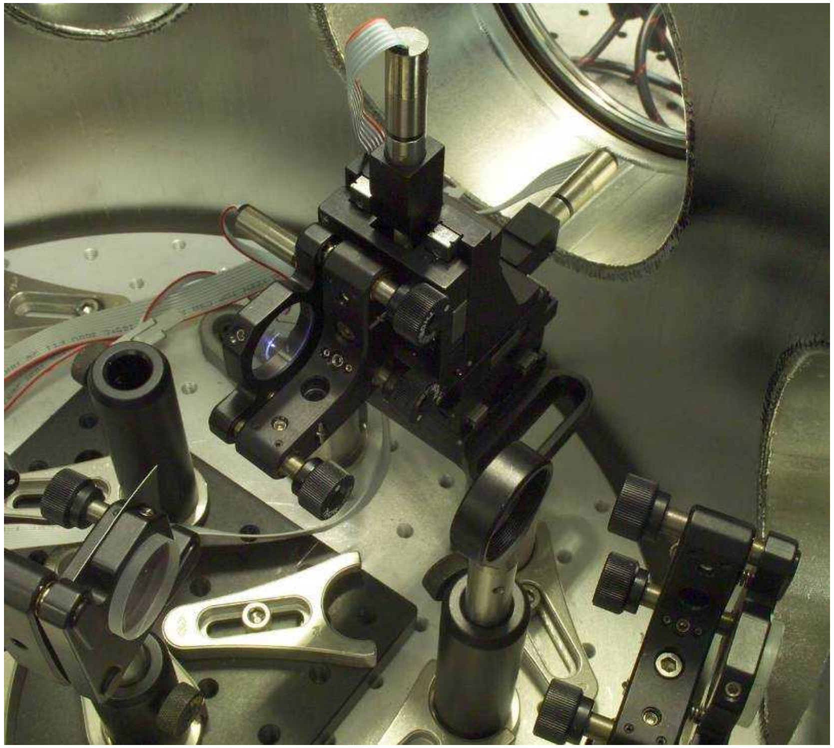
Backup slides

Fabrication Method:
Ultrashort Pulse Laser Machining Setup

- Part production time is limited by effective scan rate, as dictated by:
  → Laser repetition rate (10Hz); Number of shots/site, Stage velocity, and Laser spotsize

- Feature size/Exposure is controlled in 3 ways:
  → Energy (J); Fluence (J/cm^2), and Net exposure (x*J/cm^2)



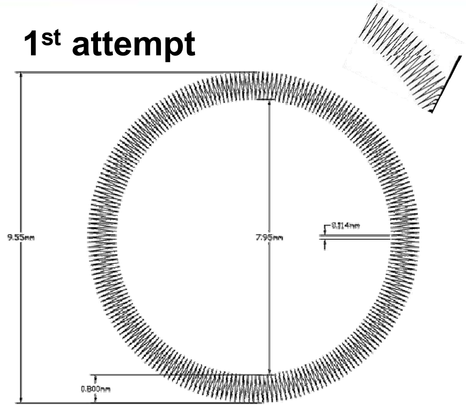


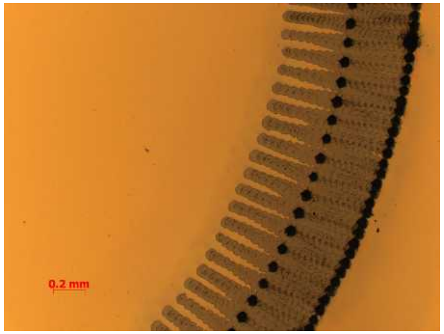
Dielectric Apodizer

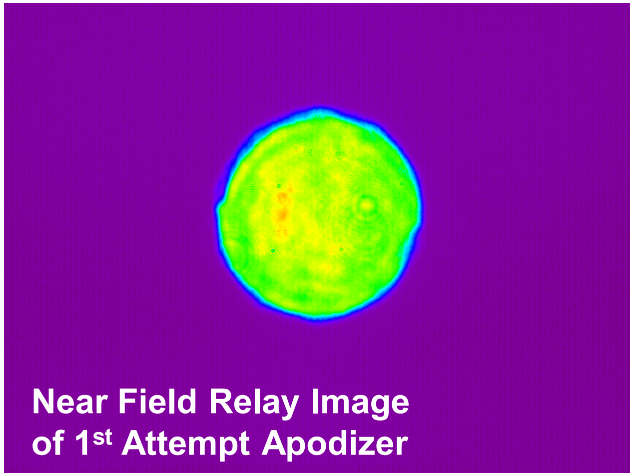
- **Approach: Use a vector-based drawing for the teeth in a multilayer manner**
  - **1st write fine teeth features then backfill behind teeth with coarser damage**
  - **Shield outermost perimeter with opaque mask**

- **Use slow speeds for spot overlay and multiple passes for precise damage which scatters more (requires accurately encoded stage)**

1st attempt







Near Field Relay Image of 1st Attempt Apodizer

- **Comparison of the apodized spatially filtered beam agrees reasonably well with design parameters**

Measured FWHM:	**8.3mm(X), 8.4mm(Y)**
Design FWHM:	**8.35mm**
Measured 90%-10% roll-off:	**470µm and 690µm(X)**
	835µm and 610µm(Y)
Gaussian tooth depth:	**800µm**

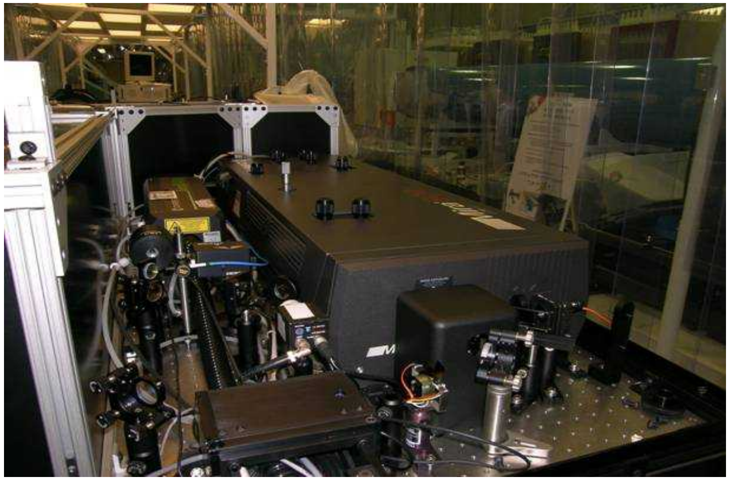
Z-Petawatt System Block Diagram

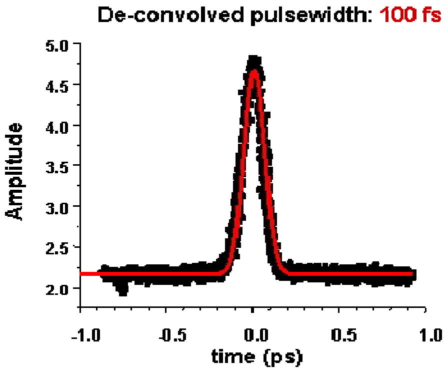
Oscillator and Stretcher

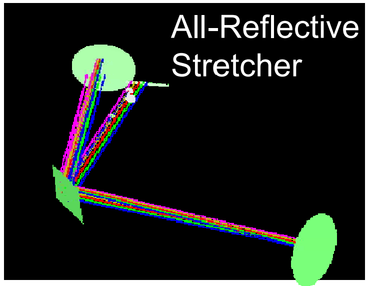
- A broadband oscillator is temporally stretched to mitigate non-linear effects and damage in the subsequent amplifiers, with larger stretching for our case to keep these same effects minimized at the larger kilojoule scale energies planned.

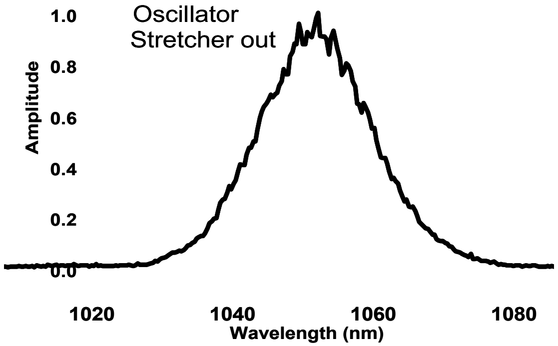
- Seeder: Coherent ***Mira*** Ti:Sapphire (pumped by a Coherent ***Verdi***).
  - **λ=1053nm, $\Delta\lambda$>16nm,**
  - **τ_p=100fs, 80MHz, 250mW**

- Compact all-reflective stretcher (Banks/Perry design)
  - **τ_{out}=3ns, $\Delta\lambda_{out}$=12nm (4nm/ns)**
  - **T=12%**





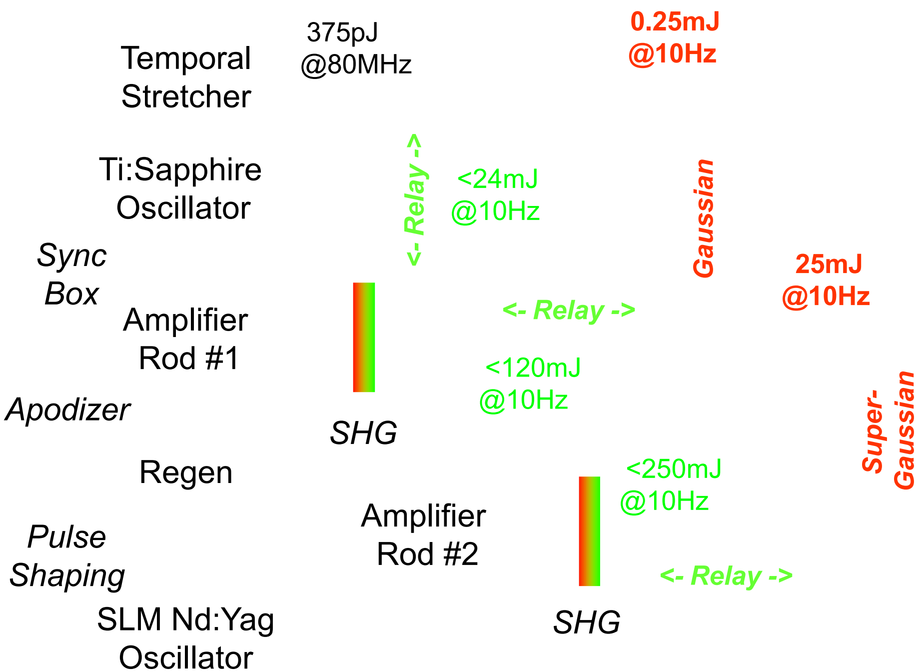


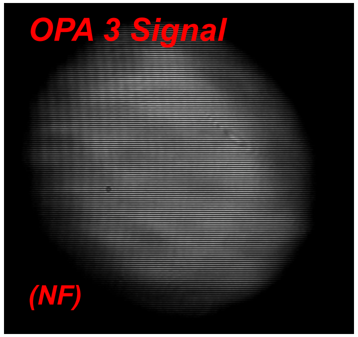


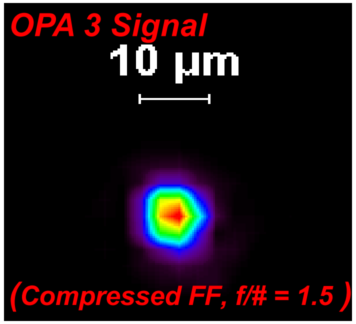
OPCPA

Optical parametric chirped pulse amplification (OPCPA) offers certain benefits:

- The OPA process can be efficient and high gain such that only single passes are needed, thus reducing material dispersion.
- The lack of thermal loading in the material helps maintain wavefront quality.
- Near degeneracy, the amplified spectrum can exceed that of a similar regenerative amplifier system .
- Since gain only exists during pumping, pre- and post-pulses are gated out.



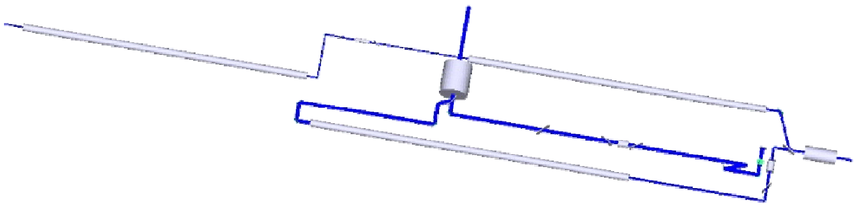


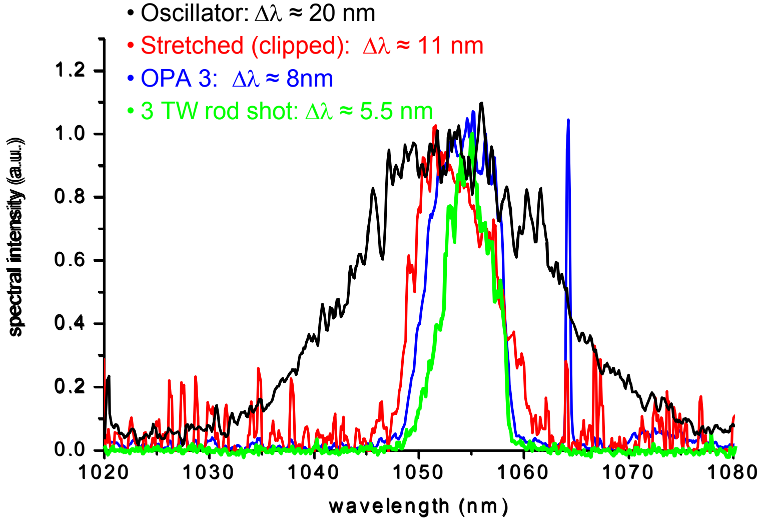


<80mJ output
λ=1054nm
$\delta\lambda$=8nm, δt=2ns
Rep rate=10Hz

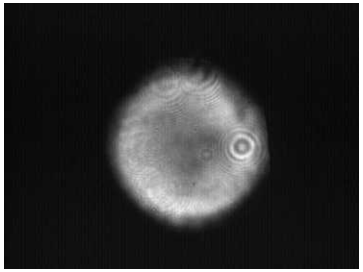
Rod Amplifiers

- After the OPCPA section, the output is relay imaged and magnified through a rod amplifier chain.
- The design utilizes double-pass 16 mm and 25 mm diameter rods, both of Nd:Phosphate glass. Double-pass configuration improves energy extraction and mitigates thermal birefringence.





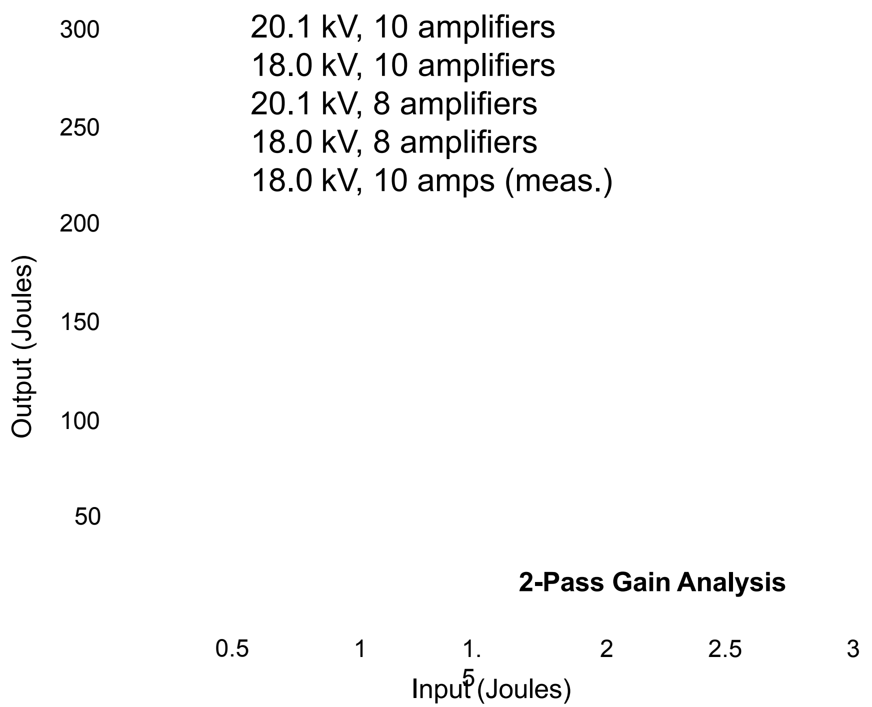
- Amplification to 5 J while maintaining >5 nm of spectral bandwidth has been demonstrated.
- Minor radial gain differences can be dealt with in the future via a custom amplitude filter.



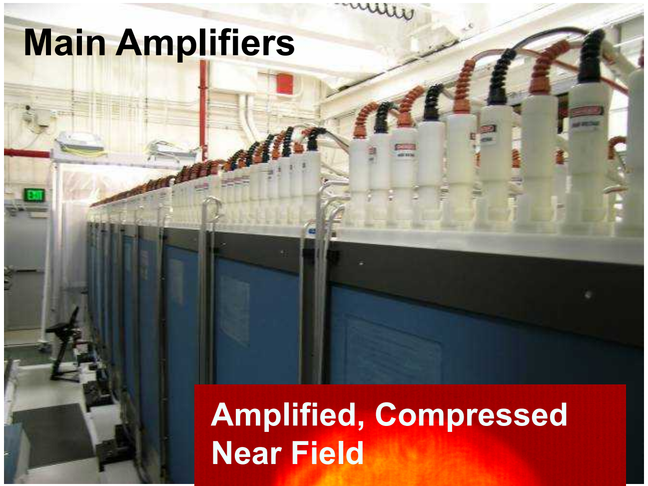
Main Amplifiers

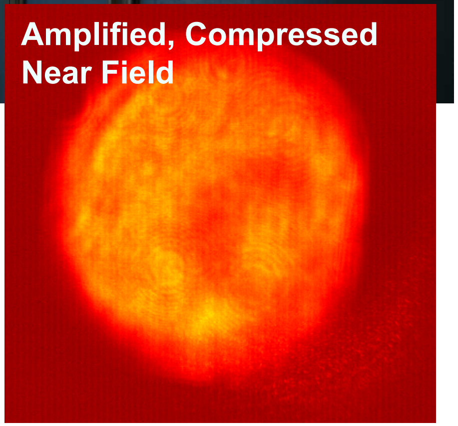
- The rod amplified output is injected into a double-pass amplifier of 10 Nd:Phosphate slabs (clear aperture: 40 cm X 40 cm).

- Initial beamsize is sub-apertured to 15 cm to mitigate costs and delays. Future beam scale-up and 4-pass design will enable multi-kiloJoule operation. Currently >400J has been demonstrated.

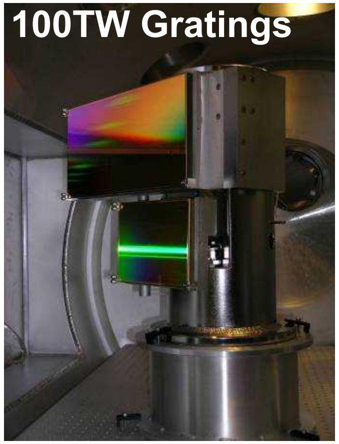


2-Pass Gain Analysis





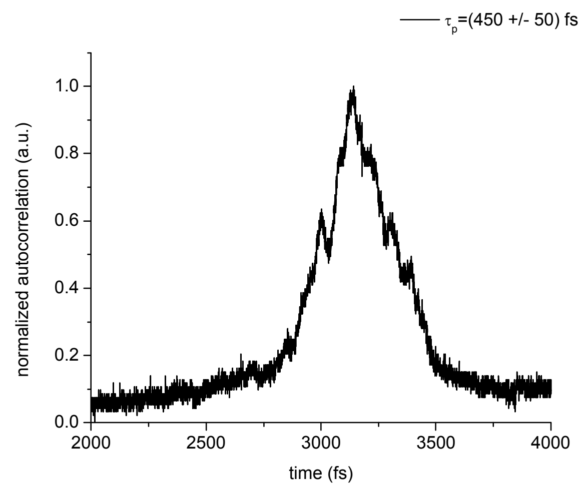
100TW Compression



- Via an insertable mirror, the beam is re-routed at ϕ=15 cm and used at 100 TW (50J/500 fs) levels, as limited by grating damage thresholds.

- Gratings: 42cm x 21cm 1480 l/mm, Au
- Vacuum Vessel: 6.35m(L) x 1.83 m(ϕ), 7.5 Tons, Al

- At modest energies of a few Joules, compression has been demonstrated to 450fs.



- A future upgrade to MLD gratings will enhance energy capability.

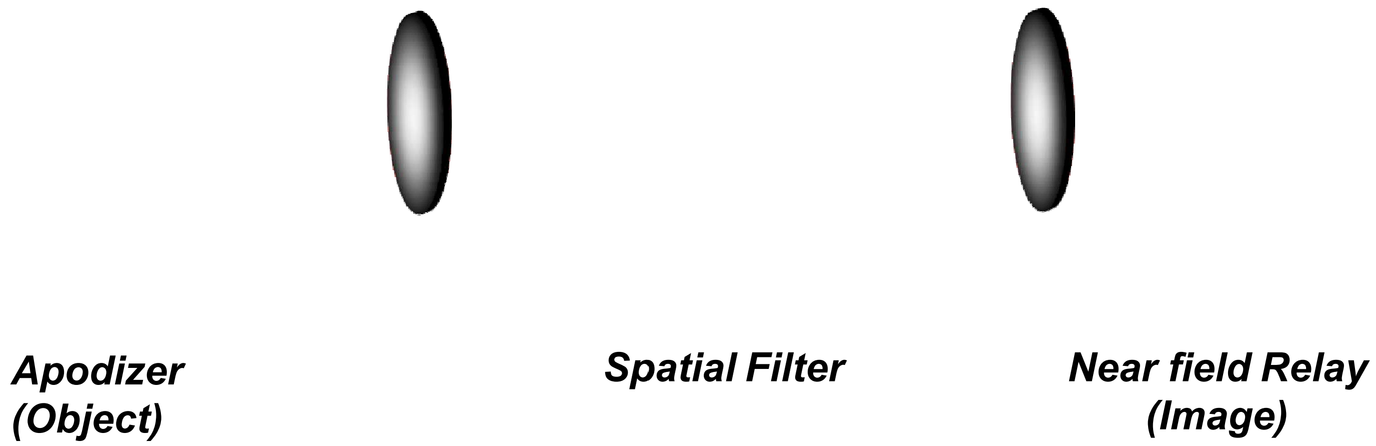
Methodology

• For efficient energy extraction in our high energy laser, a flattop beam profile is created with modest to fast edge roll-offs such that the wings of the beam profile do not clip in the amplifiers.

• The flattop is generated by clipping the beam with an apodizer followed by a spatial filter.

• The apodizer serves as an object plane for relay imaging throughout the system.

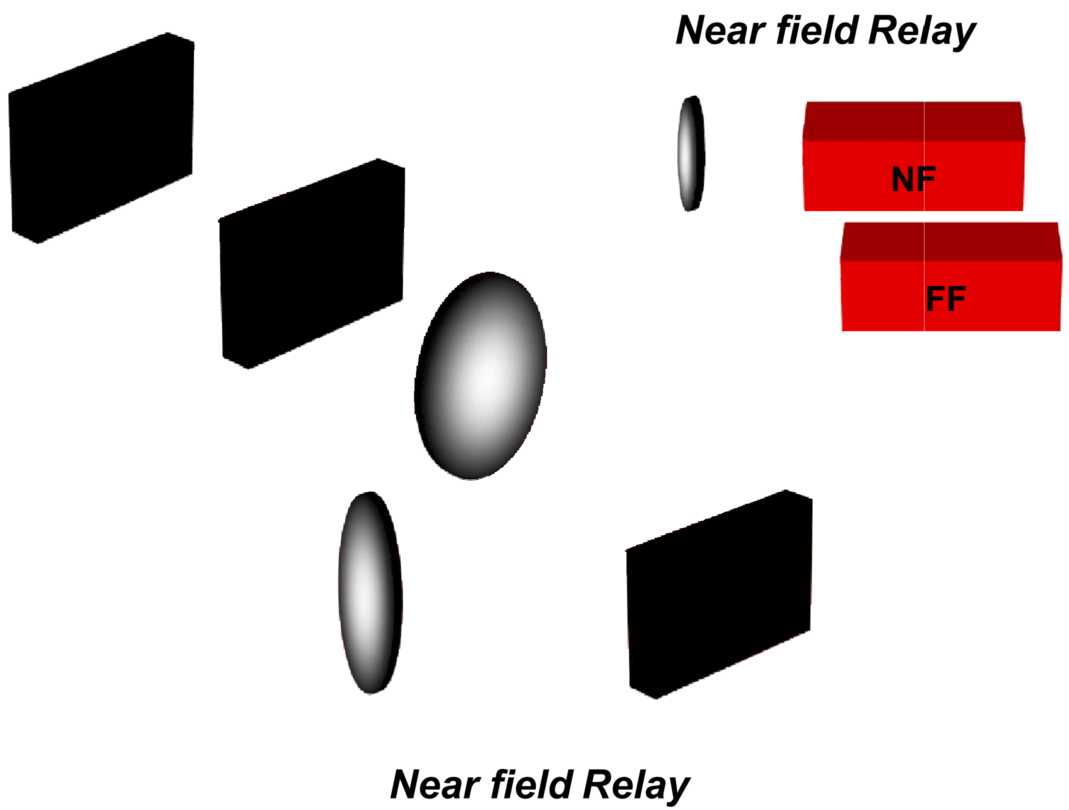
• Beam diagnostics refer back to this apodizer object plane
  - Near field sensors and wavefront sensors are images if this plane (or occasionally an object of interest nearby such as a deformable mirror).
  - Far field sensors are set to the best beam focus which should also be a relay plane to spatial filter pinhole planes.



Diagnostics Packages

• Of the two main laser systems in the Z-Backlighter Facility (the ~kJ/ns Z-Beamlet and the ~500J/500fs Z-Petawatt), beam diagnostics occur:

- After the seeder, after each stage of amplification, and after compression



• After pick-offs, beams are reduced with a collection lens

• NF's are images of preceding relays and are in collimated-space

• FF's are placed at the focus of the collection lens

- FF's are not used in transmission at any of the diagnostic beamsplitters
- FF magnification may be increased with a negative lens by increasing the effective focal length of the collection lens

Near Field Diagnostics

- NF's are typically recorded with Pulnix TM-9701 cameras:
  - Triggerable
  - Progressive scan

    → Stores frame internally for easier frame grabber DAQ
  - 2/3" Format
  - 768 (H) x 484 (V) pixels
  - 11.6μm x 13.6μm Pixel Size
  - Windowless chip option
  - 8-bit
  - Multi-pin connector interface or camera link
  - Additional video out option for monitors

    → Facilitates alignments
  - Dimensions:

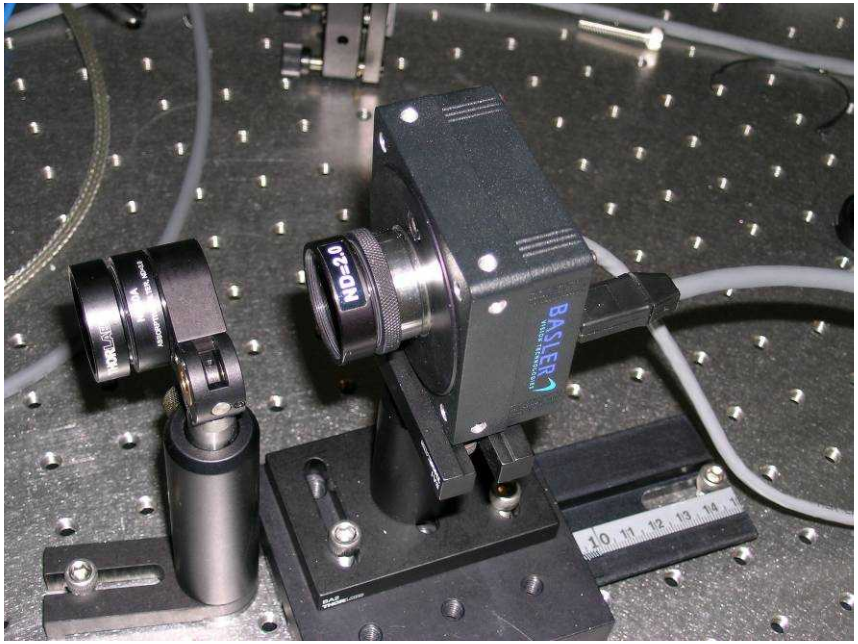
    48mm x 44mm x 136mm

    →Sometimes bulky

Far Field Diagnostics

• FF's are recorded with either Pulnix TM-9701 (mainly for pointing) or Basler A102f

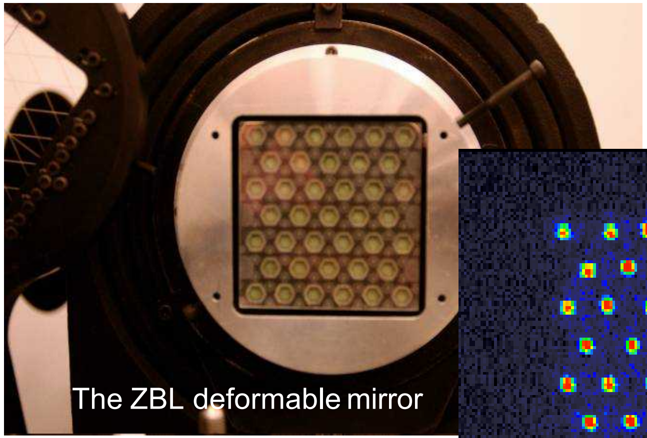
- Triggerable
- Progressive scan
- Fire wire
- 12 bit
- 2/3" Format
- 1392 (H) x 1040 (V) pixels
- 6.45µm x 6.45µm Pixel Size
- No additional video out option
  →Only computer interface
- Dimensions:
  32mm x 62mm x 62mm
  →Compact

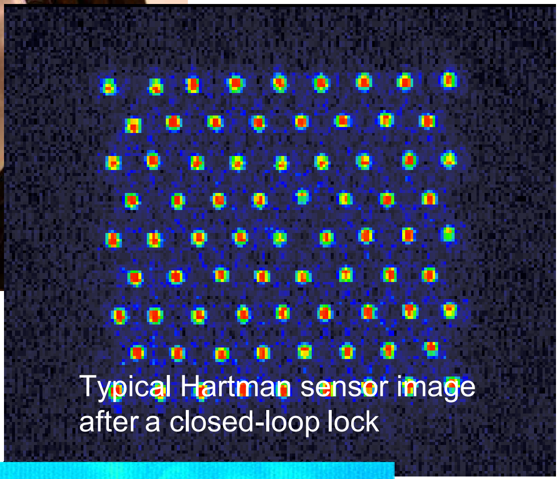


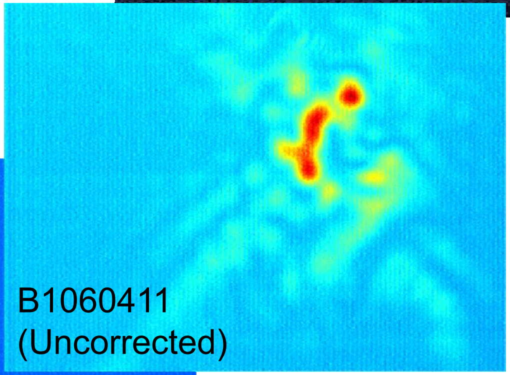
Adaptive Optic Approaches

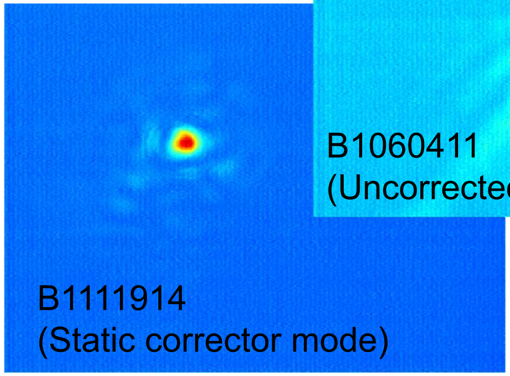
• Over the course of the facility, several AO approaches have been tried or investigated:

- **Custom LLNL legacy solution**
  →Worked to some degree, problems with legacy codes and hardware
- OKO system solution
  → Small sizes and delamination issues with mirrors, code not a smooth fit
- AOA sensors with custom mirrors (OKO,CILAS, in-house)
  → AOA hardware works but can be tricky, Software interface issues
  → Used effectively open-loop with in-house developed deformable mirrors
- Phasics system solution
  → Nice flexible sensor with working AO loop
  → Minor mirror communications issues being worked out


The ZBL deformable mirror


Typical Hartman sensor image after a closed-loop lock


B1060411 (Uncorrected)


B1111914 (Static corrector mode)

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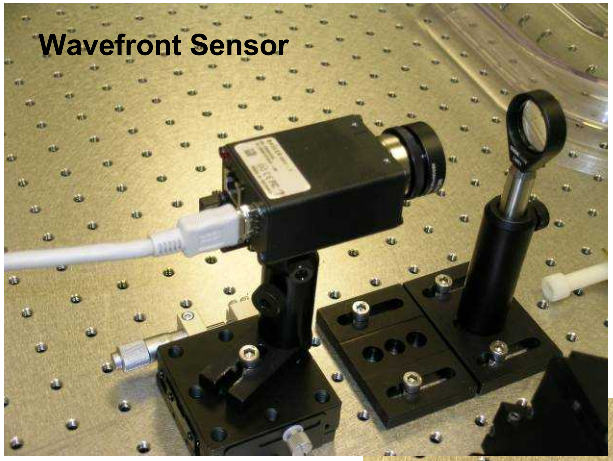

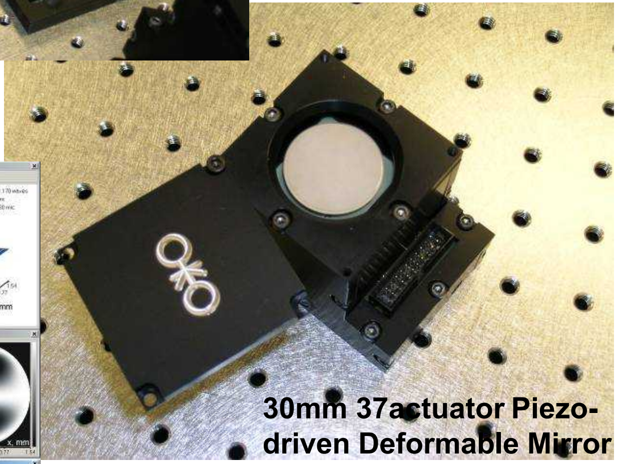

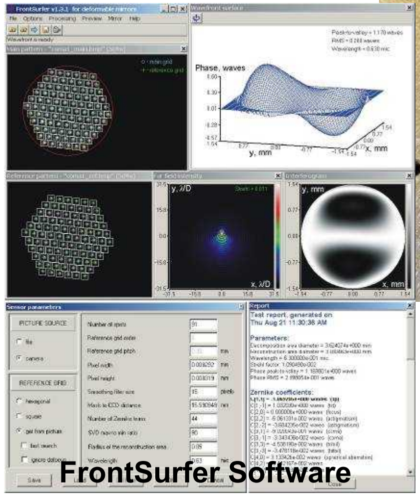

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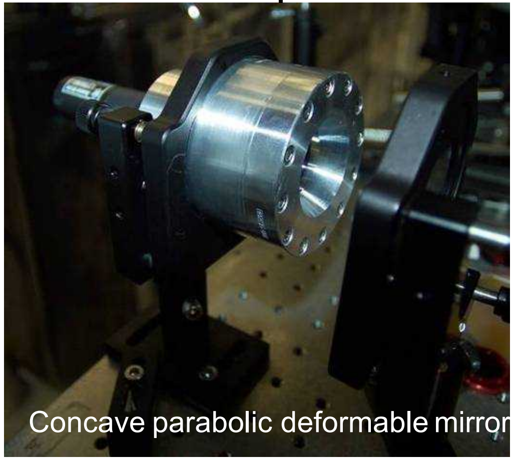
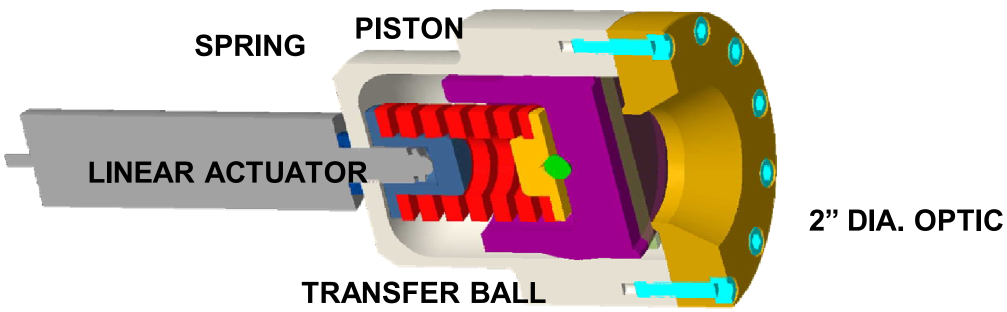
- Custom single-actuator mirrors can be:
  → Convex parabolic [Schwarz, AppPhysB v82 (2006)]
  → Concave parabolic [Schwarz, OptExp v14 (2006)]
  → Cylindrical concave [Schwarz, OptComm v264 (2006)]
  → Off-axis parabolic


Concave parabolic deformable mirror



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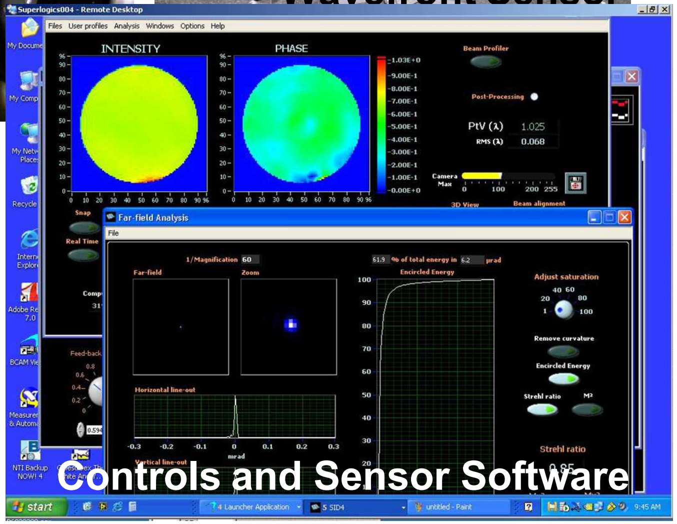

- **Compensated full system shot:**
  PV: 1.03 waves
  RMS: 0.07 waves
  Strehl ratio: 0.85.