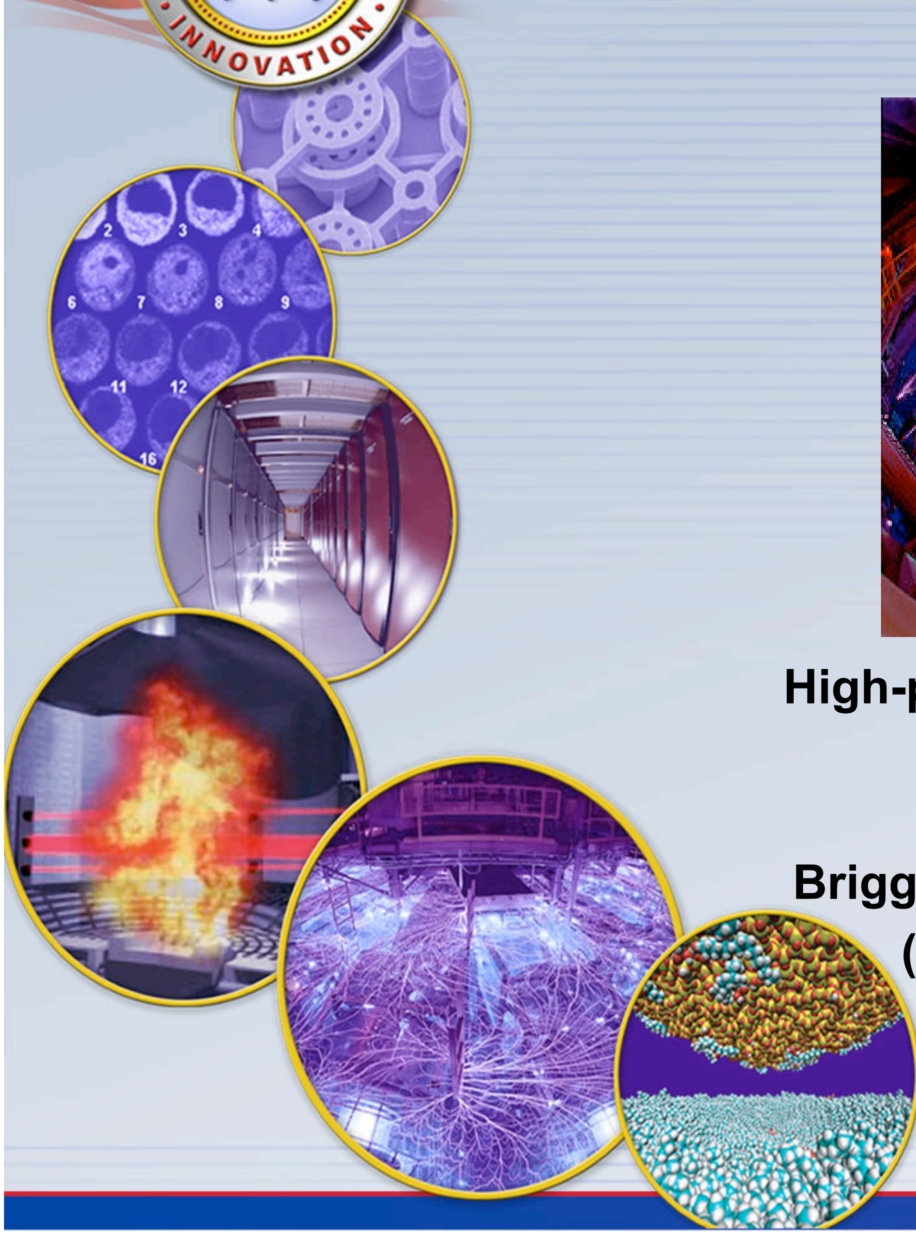
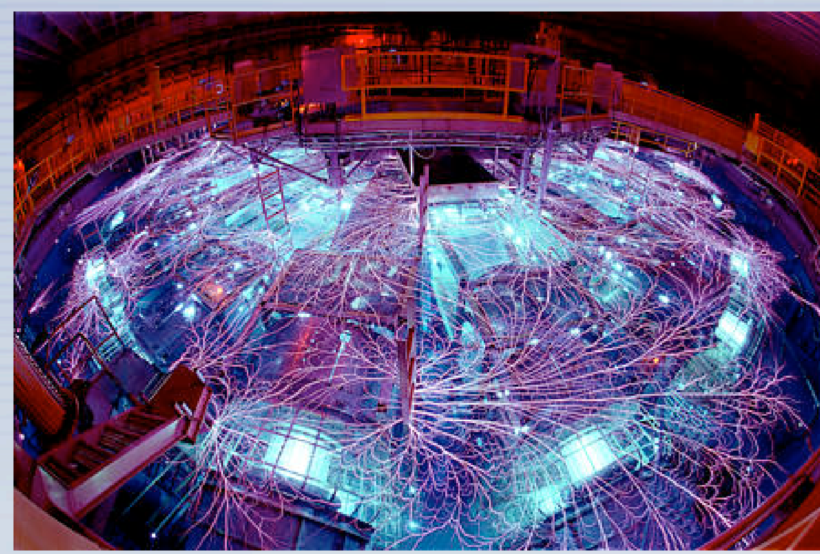
# Z-Backlighter Laser Facility
# Z-Beamlet and Z-Petawatt Laser Systems



A shot on the Z Machine



**High-power lasers to investigate the physics of high energy densities**

**Santa Fe, NM, August, 5 2010**

**Briggs Atherton, Sandia National Laboratories**

**(505) 284-9505; bwather@sandia.gov**

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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# Z-Backlighter-Team Members

Manager

Briggs Atherton

## Laser Science and Operations

Dave Bliss
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Mark Kimmel
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## Electronics, Controls and Pulsed Power

*Michael Jones*
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## Target Science and Experiments

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## Optics and Clean-room Support

John Bellum
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Joanne Wistor

## Engineering

*Carlos Cox*
*Daniel Headley*
*Jeff Kellogg*
*Grafton Robertson*

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# Outline

- System overview
- Optical support facility
- Z-Petawatt laser
  - 100TW laser
  - 100TW target chamber
  - Z-Petawatt transport
  - Z-Petawatt laser
- Z-Beamlet laser
- Target area
- NLS laser
- Experimental proposals submission process

# Z-Backlighter Facility

## Z Backlighter

### ZBeamlet

- $\lambda$=527nm
- $\tau$=0.3-8ns
  (2ns common)
- $\phi$~75$\mu$m spotsize
- E<2kJ
- $I<10^{17}$ W/cm$^2$
- ~3 hr/shot
- 2 pulse MFB

### ZPetawatt

- $\lambda$=1054nm
- $\tau$=500fs min
- $\phi$~6$\mu$m spotsize
- E<120J (100TW); <500J (PW)
- $I>10^{20}$ W/cm$^2$
- ~3 hr/shot
- Sub-ps probe
  @ 527nm, <20mJ

### NLS

- $\lambda$=1064nm (532nm option)
- $\tau$=150ps
- $\phi$~50$\mu$m spotsize
- E<10J
- $I<10^{16}$ W/cm$^2$
- ~20 min/shot
- Pending: 8-10ns operations
  at >100J @1$\omega$

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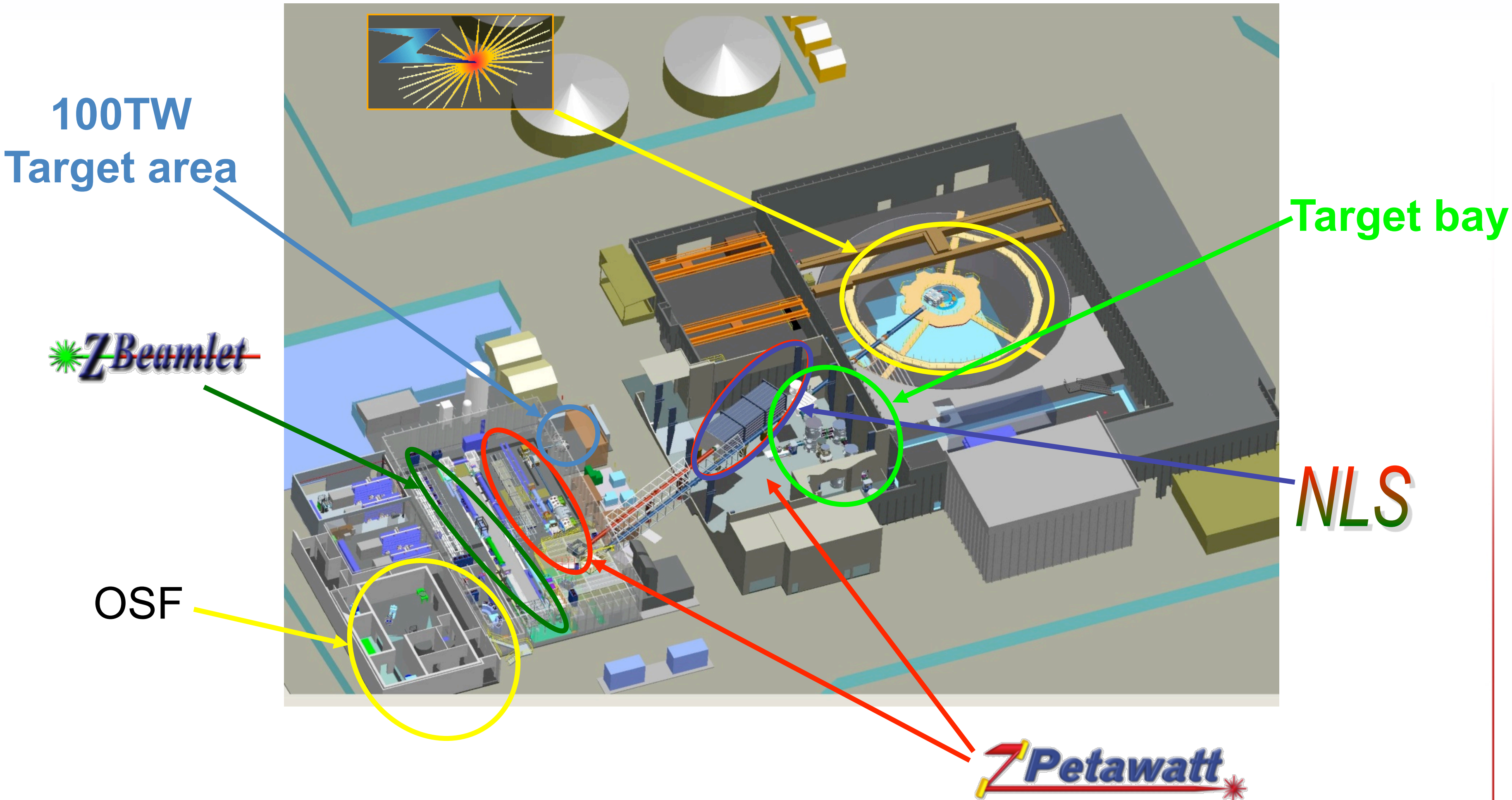
# Facility Overview
("Buildings 983/986")



# Large Scale Coating Chamber


• 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 |

• 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

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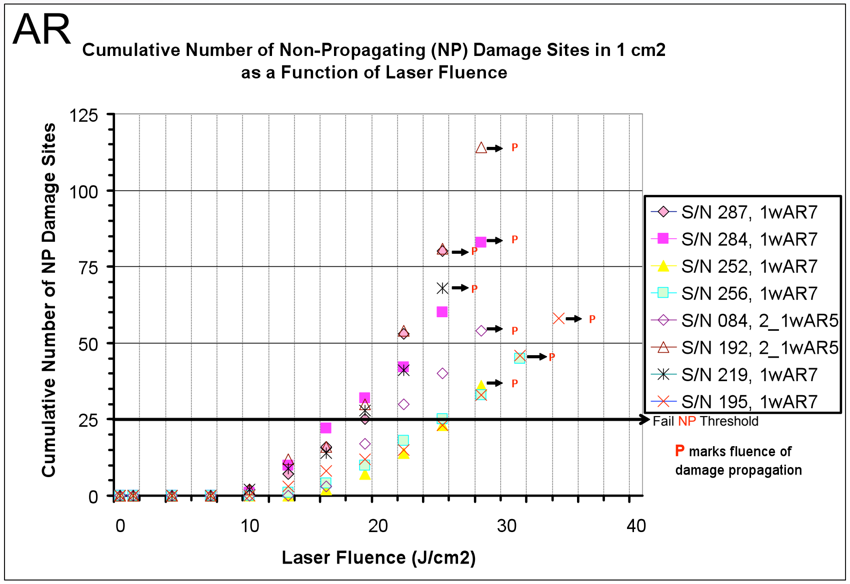
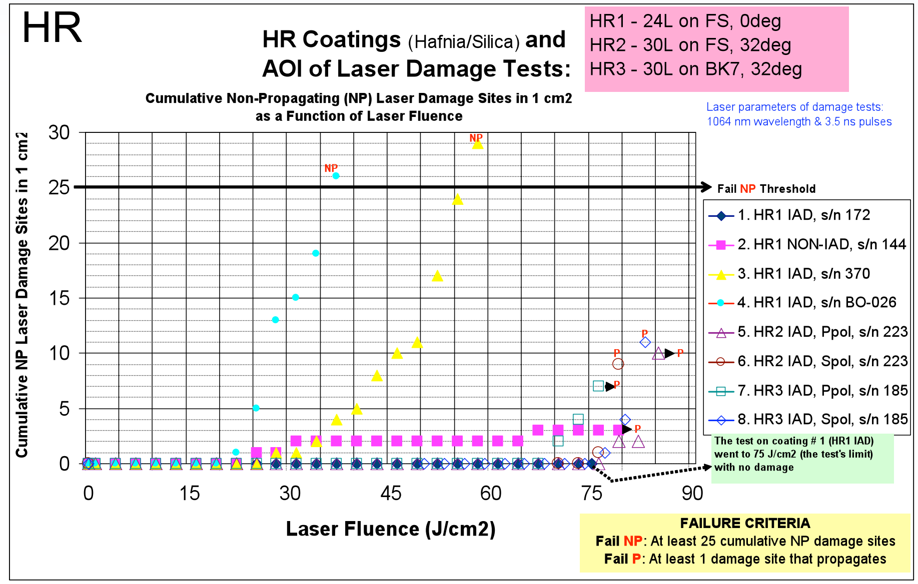
# Large Scale Coating Chamber

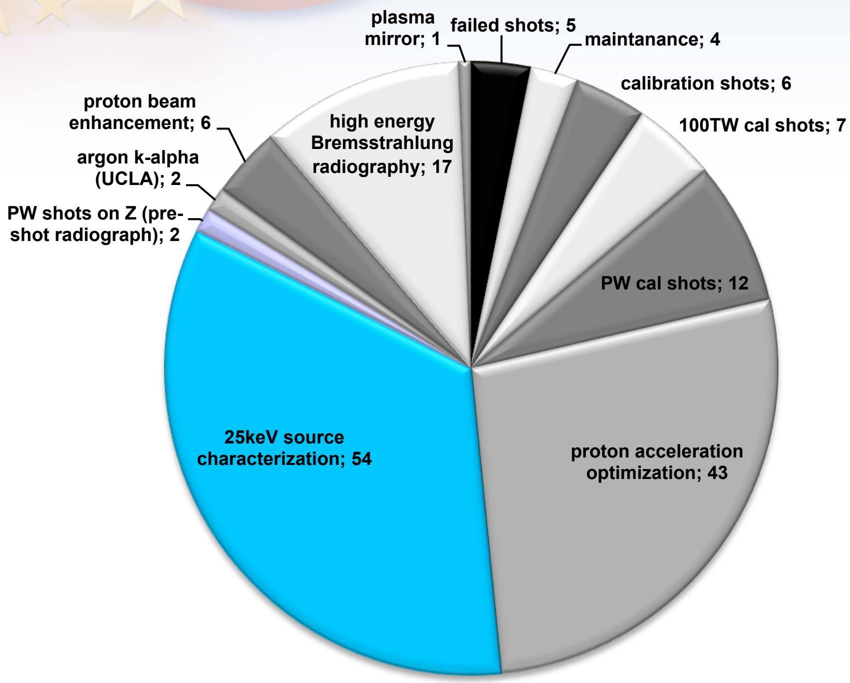


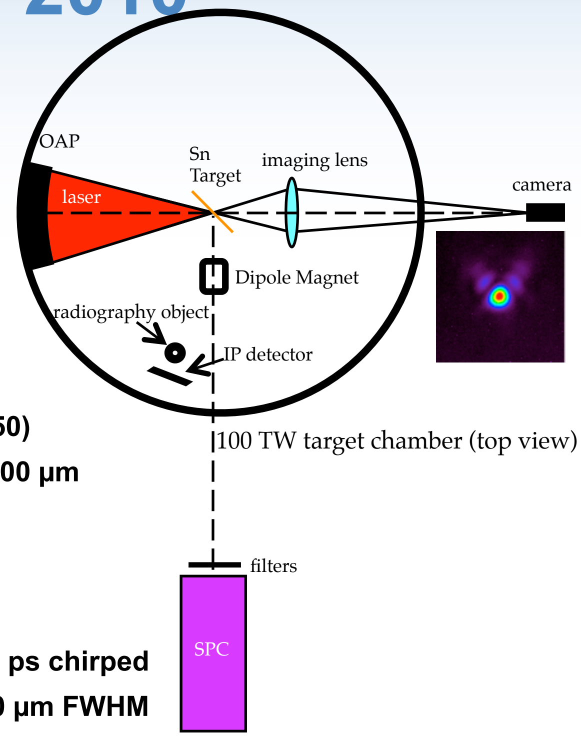

- Independent damage testing (SPICA) has shown good test results. Using a definition of 25 cumulated damage sites (non-propagating) gives thresholds:
  - In the range of 17-25 J/cm$^2$ for AR coatings
  - In the range of 75-85 J/cm$^2$ for HR coatings
- Successful application to both air and vacuum use 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-Petawatt Shot Status 2010




**Total 159 shots from Oct. 2009 – June 2010**



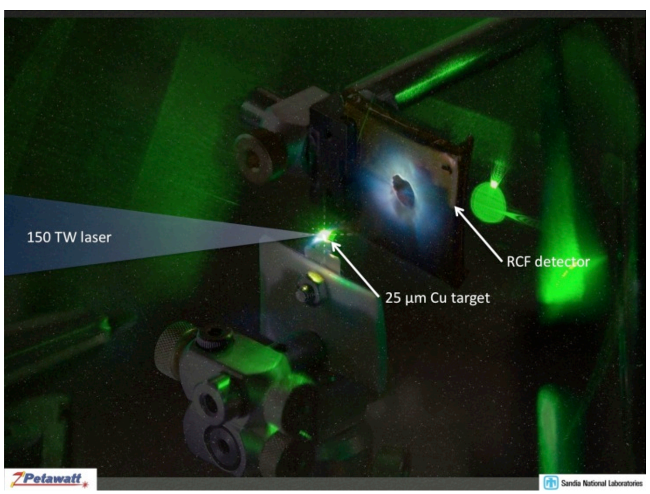

**Backlighter target**

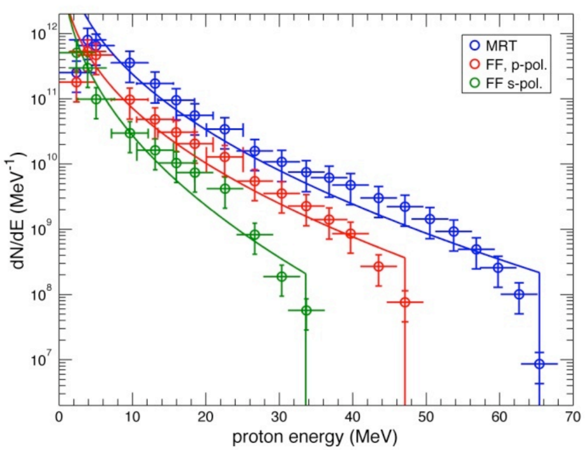
- Tin (atomic number 50)
- 500 µm x 500 µm x 100 µm
- 25keV $K_\alpha$ X-ray line

**Laser Parameter**

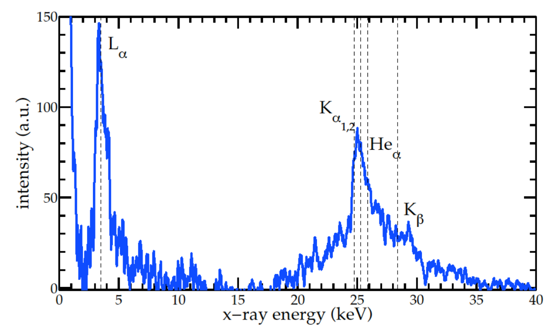
- Laser Energy: 100 J
- Laser pulse width: 7 ps chirped
- Laser spot size: ~ 10 µm FWHM

Schematic of 100TW target area




**Proton acceleration**




**25keV Source Spectrum**

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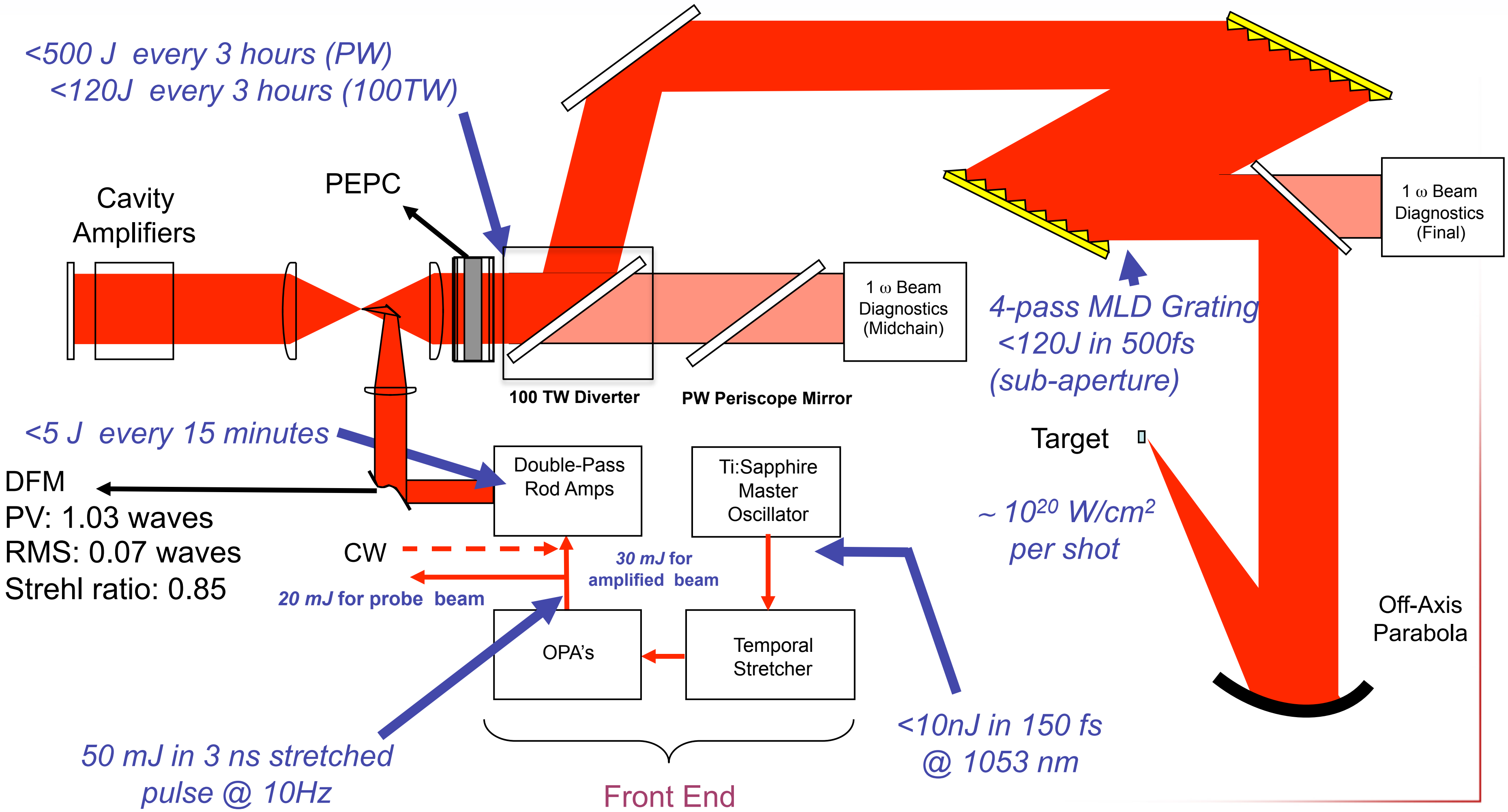
# The 100TW/Petawatt System

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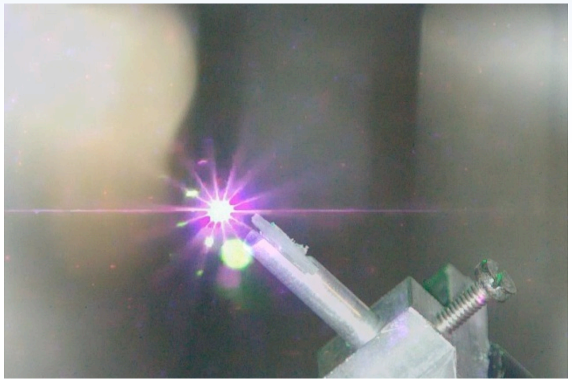
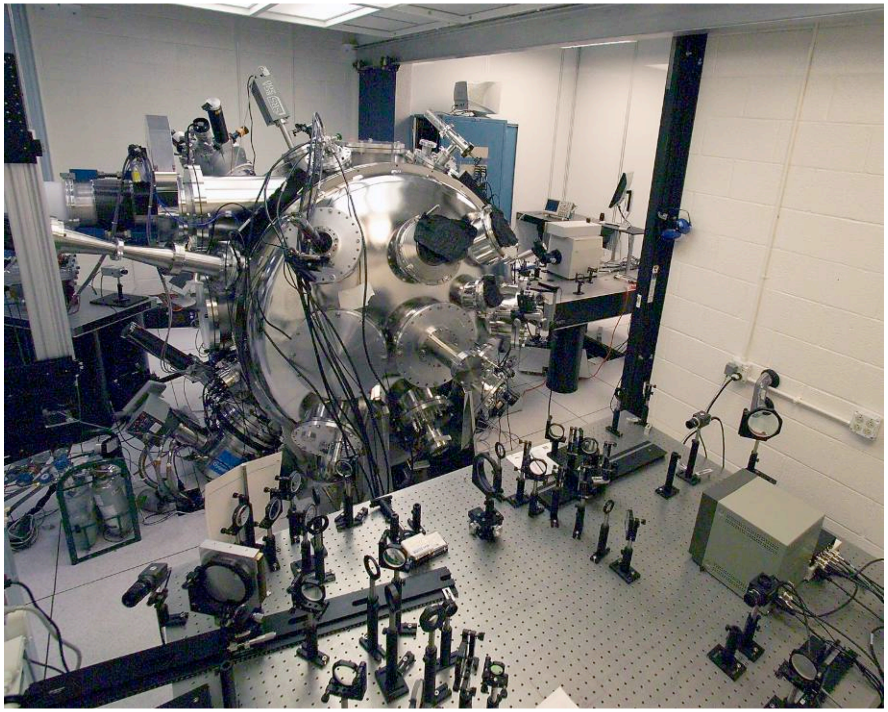
# 100TW Target Area

**Lasers:**

- Typical: 1054 nm, 120 J, < 1 ps, ~ $10^{20}$ W/cm$^2$ laser intensity pointing stability < 20 $\mu$m
- Optical probe beam at 1054/527 nm, 30/10 mJ, $\tau$ < 500 fs, ps to multi ns delay possible





**Diagnostics:**

- K$\alpha$ 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 scope
- 8 GHz digital scopes
- Thomson parabola
- HV supplies up to 20 kV
- RCF, IP (calibrated scanner) and CR39 detectors
- EMI shielded instrumentation cabinets up to 120 dB

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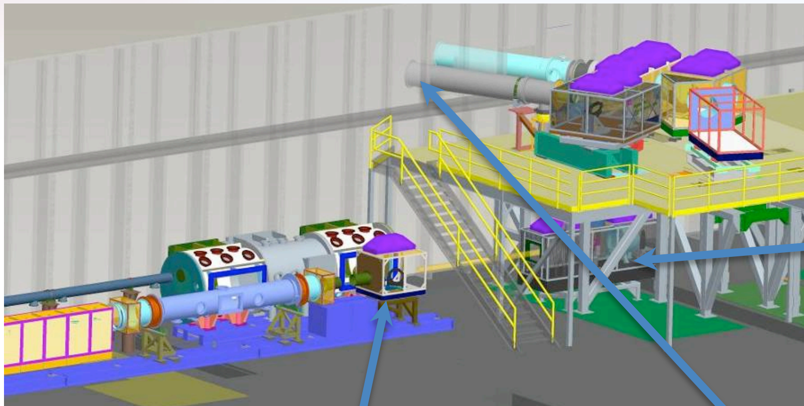
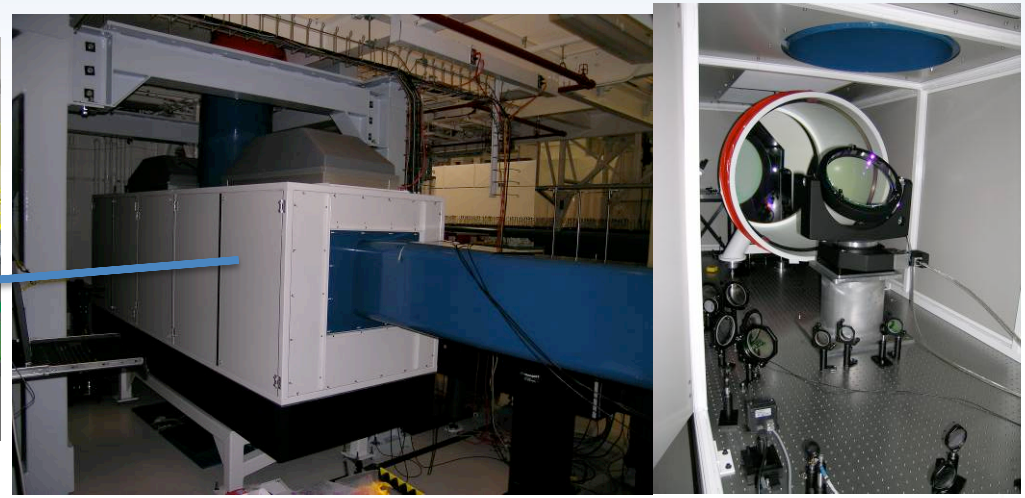
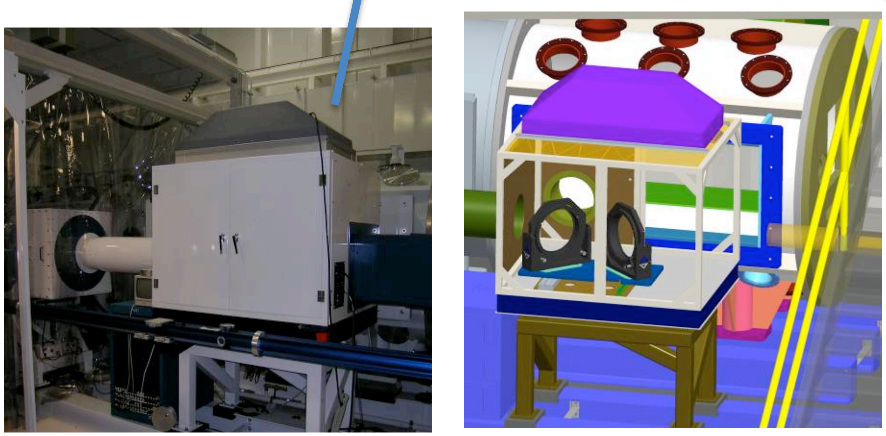
# Z-Petawatt Transport



Schematic of main amps and transport of the Z-Petawatt laser



Z-Petawatt lower periscope housing & diagnostics



100TW Turning mirror box


Transport tubes from laser-bay into target-bay

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# Petawatt Compressor Vessel

Three sections form vessel:
each 4.4 x 4.4 x 14.4 $m^3$
• 2 Tier design
• weight: 43 tons
• 4600$m^3$/h roughing + 3 ISO 500 Cryos
allow:
$1 \times 10^{-5}$ Torr in 3 hours or
$2 \times 10^{-7}$ Torr in 15 hours

Uncompressed energy: 420 J

Initial temporal compression: < 2ps
Compressed energy: 250 J


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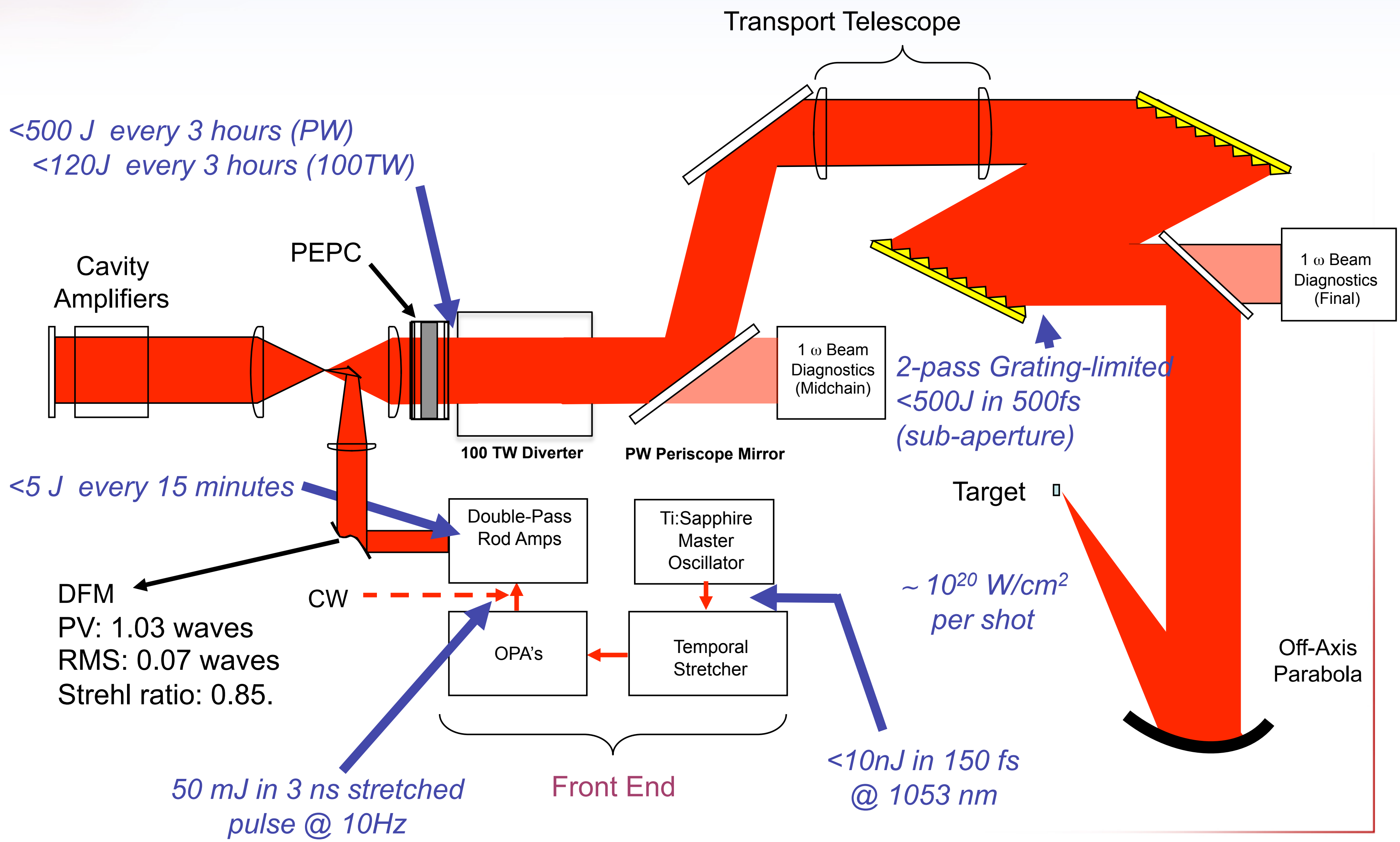
# The 100TW/Petawatt System



# Z-Petawatt/100TW Conclusion/Future Upgrades

- Z-Petawatt operates routinely:
  - >100J ≥500fs into 100TW chamber
  - >400J ~1ps into Z

- Z- Petawatt laser will upgrade to a new front end
  - Pump laser is a commercial product
    - This allows higher reliability

- Laser Diagnostics
  - 4-order magnitude single shot pulse-width measurement

- Higher Petawatt energies
  - Multilayer Dielectric Gratings
    - 4-pass configuration
    - Higher energy (2kJ @ 1ps)
  - 4-pass amplifier configuration
    - Currently limited to 500J due to sub aperture saturation
    - Allow up to 2kJ @ 1ps and have higher energies at longer pulse lengths.

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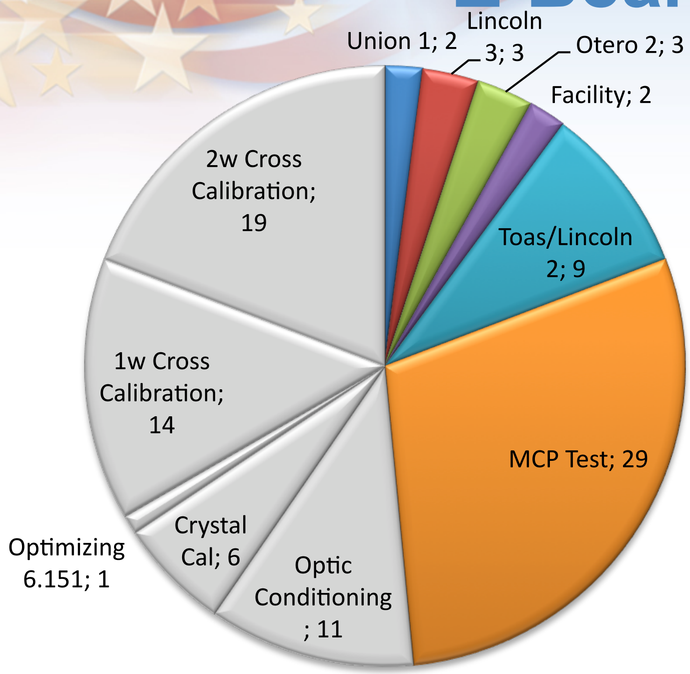
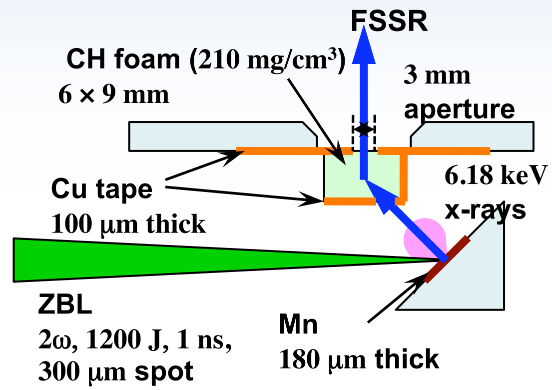
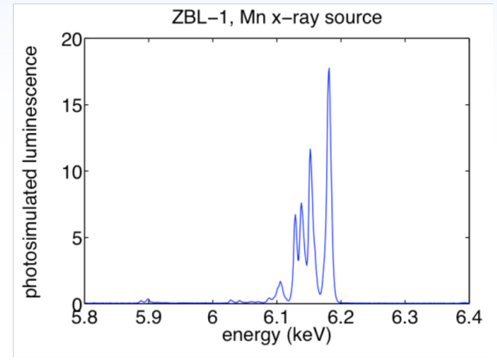
# Z-Beamlet Shot Status 2010

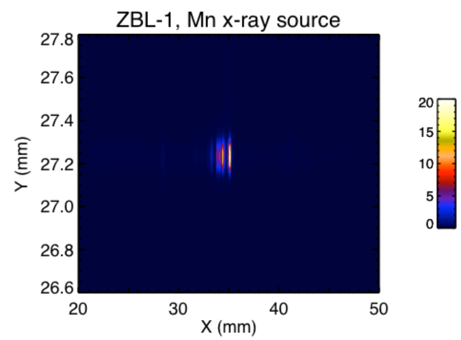


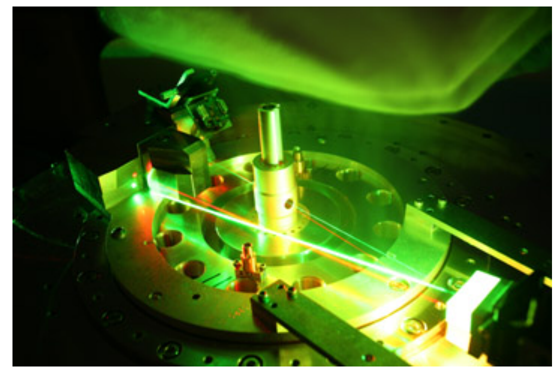

**Total 99 shots from Oct. 2009 – June 2010**




**Experimental setup Thomson scattering**



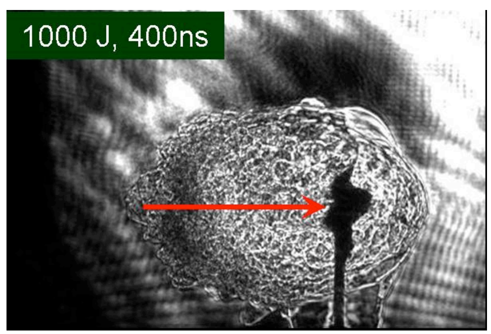



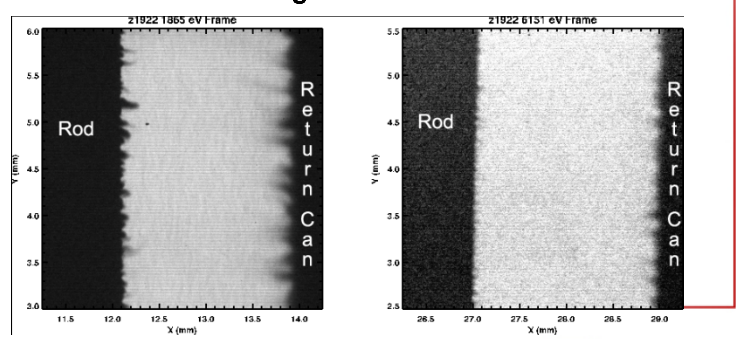
**Z-Backlighter 2-"frame/color" hardware**

## Laboratory astrophysics

**Astrophysical blast wave: the Vela supernova remnant.**




**A laboratory blast wave produced by the Beamlet laser.**




**2-color (1.818keV & 6.151keV) images**

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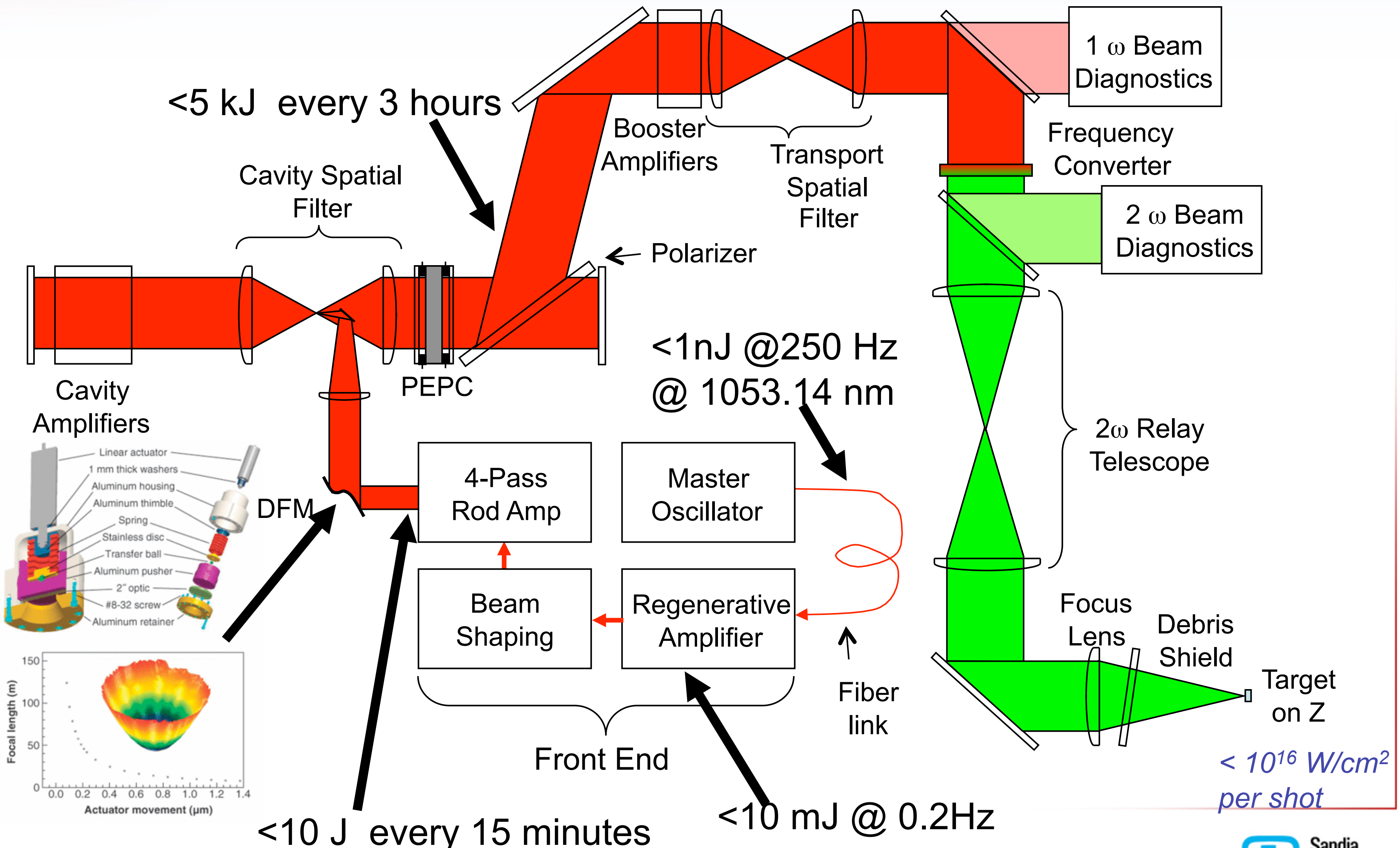
# The Z-Beamlet Laser system

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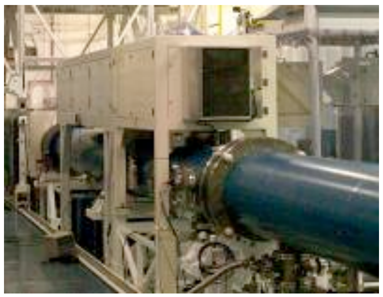
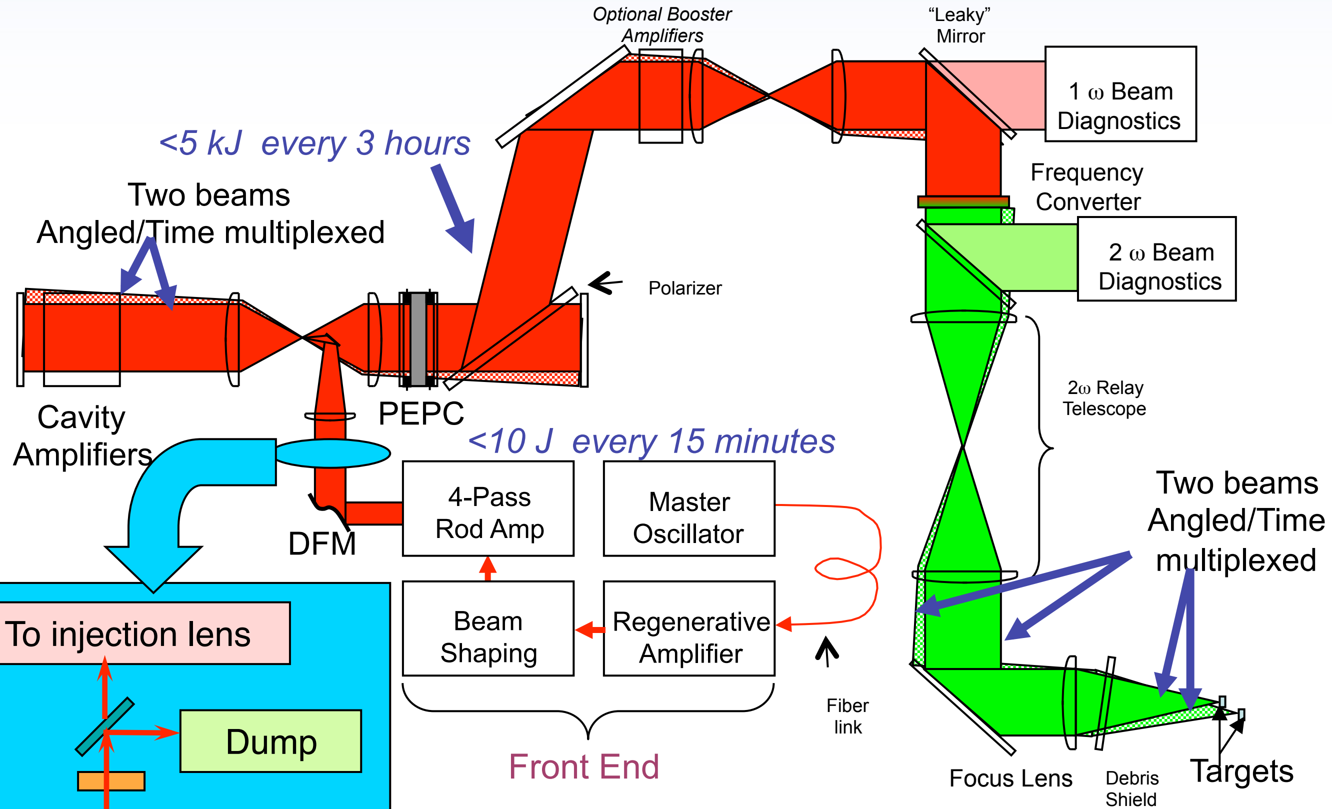
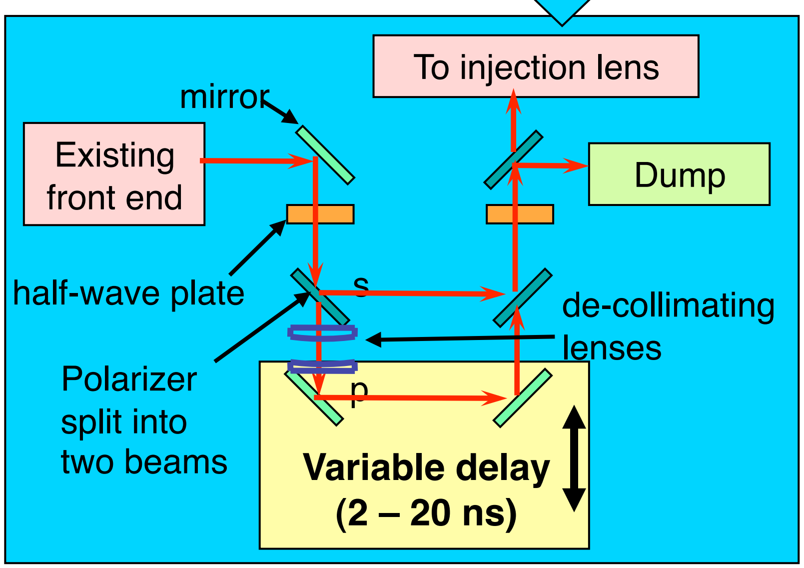
# The Z-Beamlet Laser has a "2-frame" option

Injection Box with 10' trombone addition






- 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)

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# Z-Beamlet Conclusion/Future Upgrades

- Z-Beamlet operates routinely:
  - ≤1200J @ 1ns into Z or target area
  - Phase-plate to give 1mm spot-size

- Z- Beamlet laser will upgrade to a new front end
  - Master Oscillator uses 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

- Half-wave plate for polarization control

- Higher shot rate (1-shot every 2-hours)
  - 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
  - Burst cooling of laser slabs

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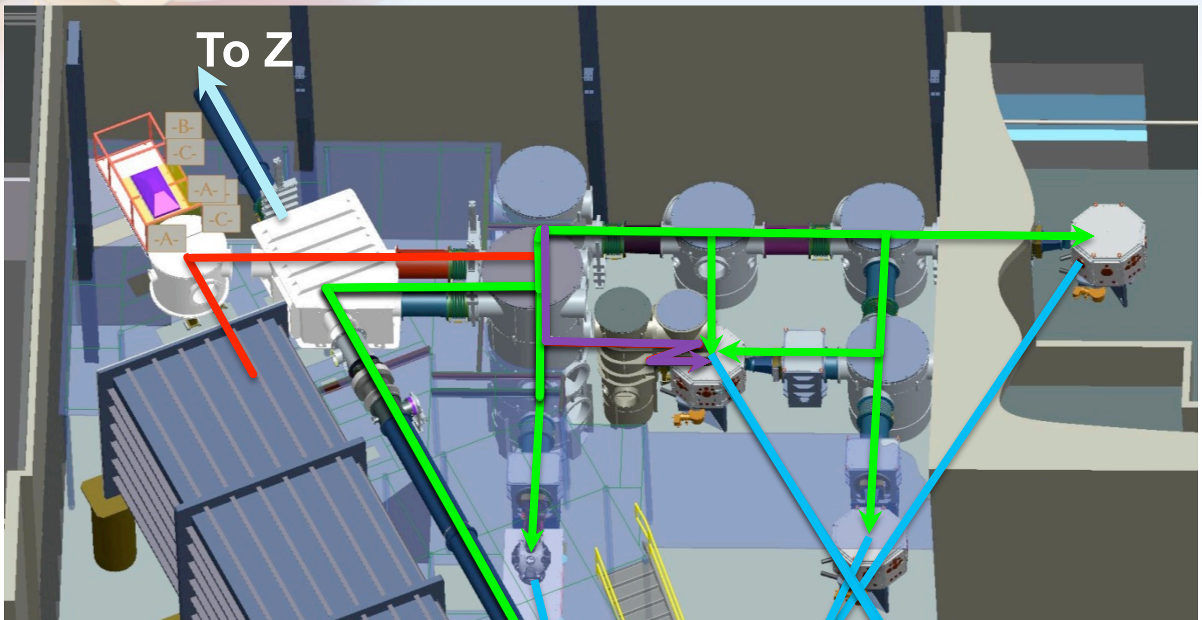
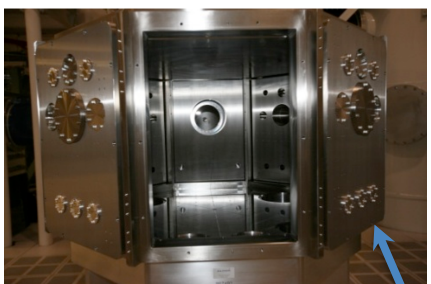
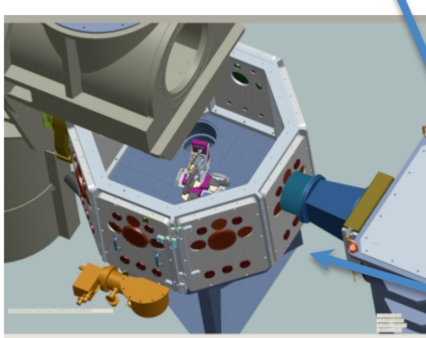
# The Target Bay




**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





| Target Chamber | On-Line | Fully Useful | F# | Spot Size (um) | Chamber size |
|---|---|---|---|---|---|
| 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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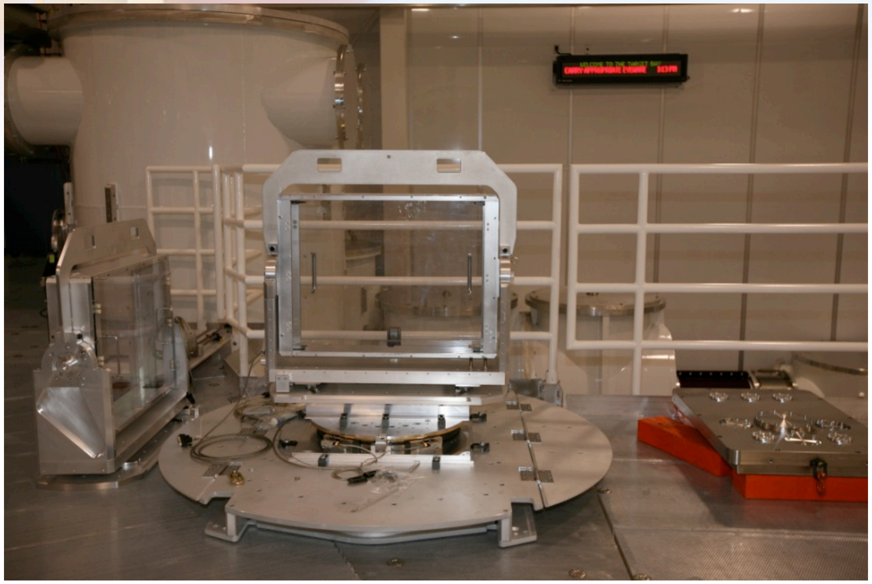
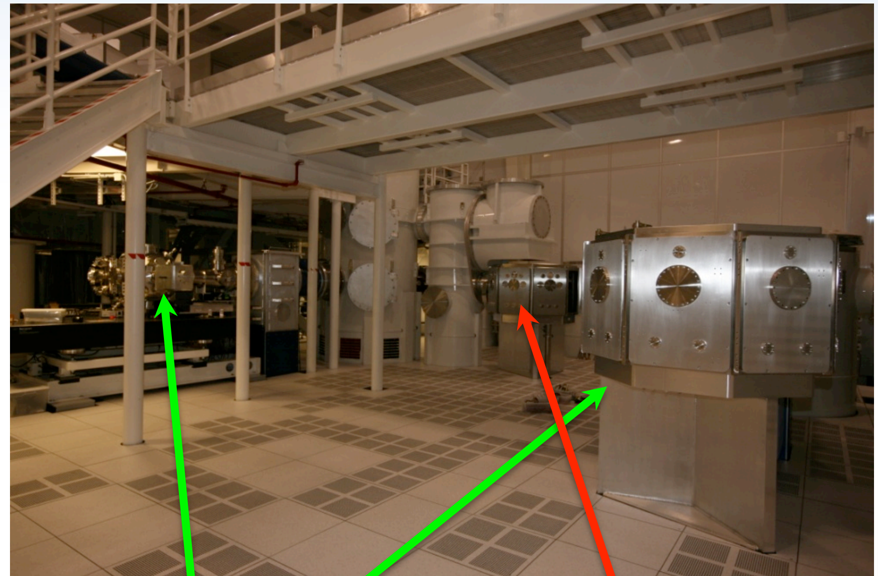
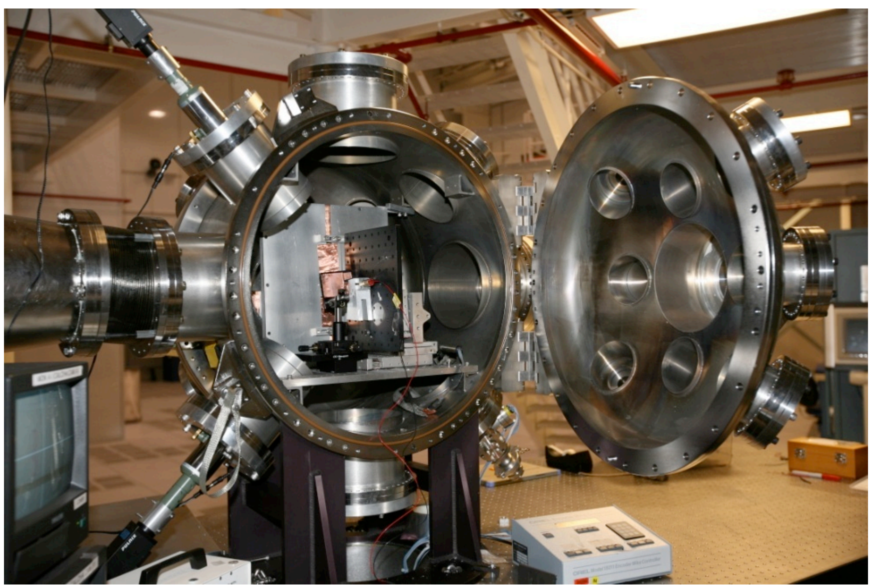
# Images of The Target Bay

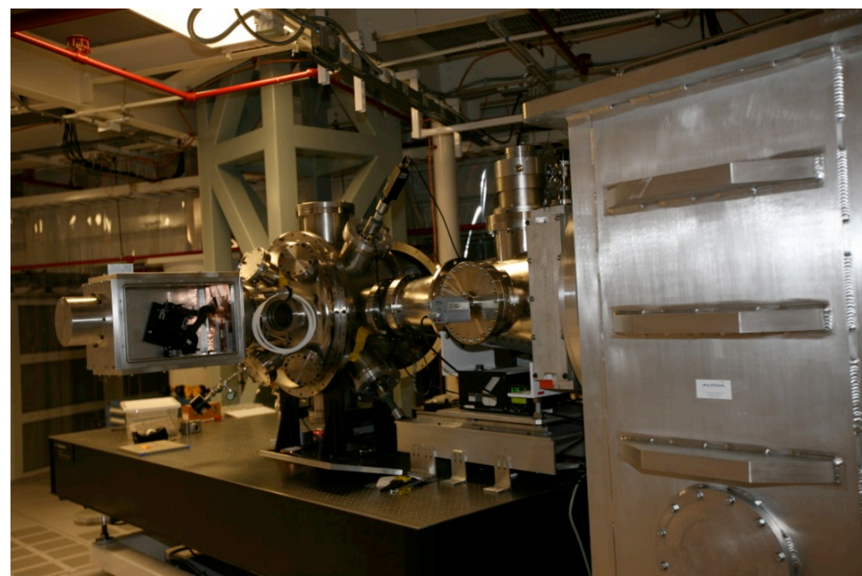


Mirror mount



Z-Beamlet (a) small, (b) large and (C) Z-Petawatt target cambers





Z-Beamlet small target camber for the Thomson scattering experiment.

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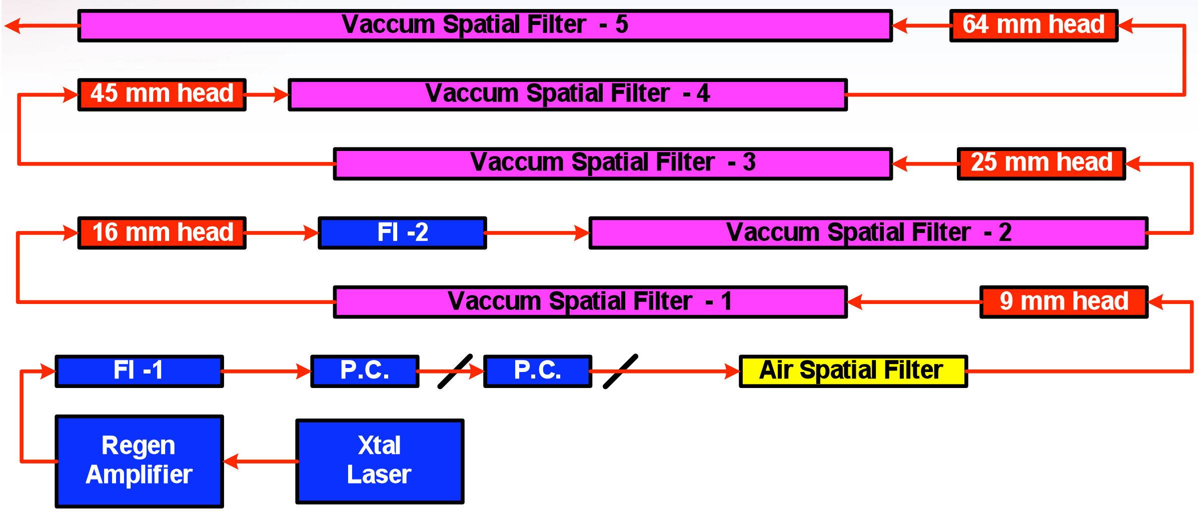
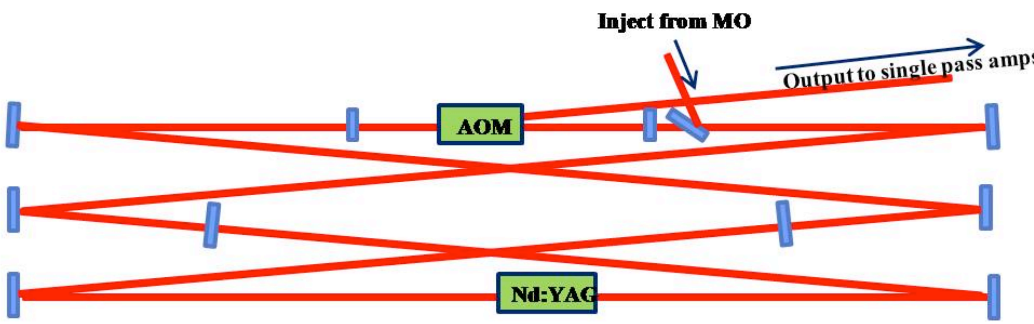
# Neodymium Laser System (NLS)




- λ=1064nm (532nm option)
- E<10J @ τ=150ps
- ϕ~5μm spotsize
- I>$10^{17}$ W/cm$^2$
- ~20 min/shot
- New front end
  - •Pending: 8-10ns operations at >100J @1ω
- New front end
  - Pending: 4-1ns pulses @ 250usec separation




4MHz (25ns round-trip) Regenerative Amplifier

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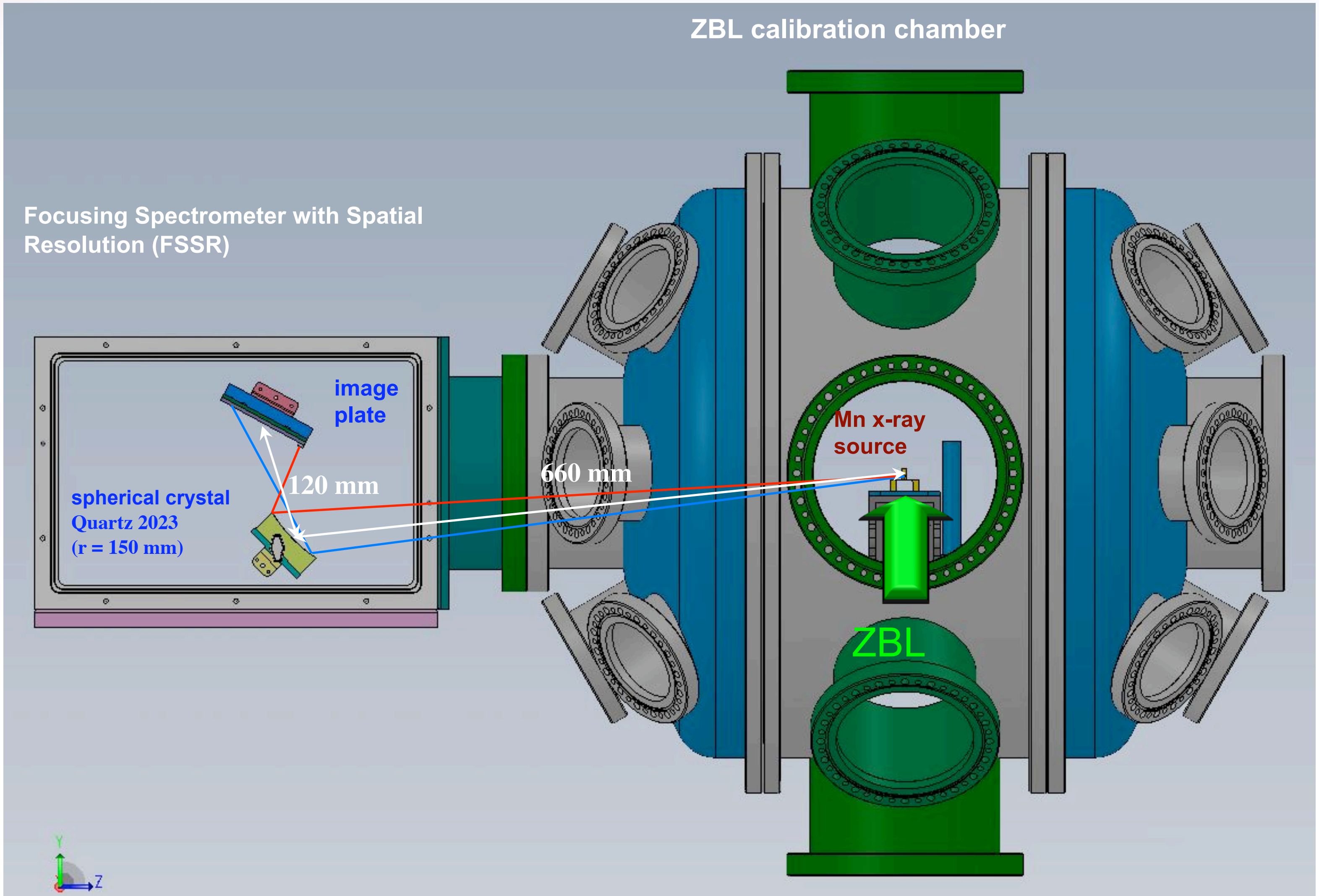
# Experimental Proposals For Use Of Facilities

- 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 (including diagrams)
  - 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 (any electronics/vacuum equipment, targets, ..etc)
  - 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
- Training
  - Laser eye exam
  - Laser training
  - Experimental area training
- Presentation 30-min (8-to-10 weeks after experiment)
  - Achievements
  - Lessons learned

# Backup Slides

# X-ray Thomson scattering in ZBL calibration chamber

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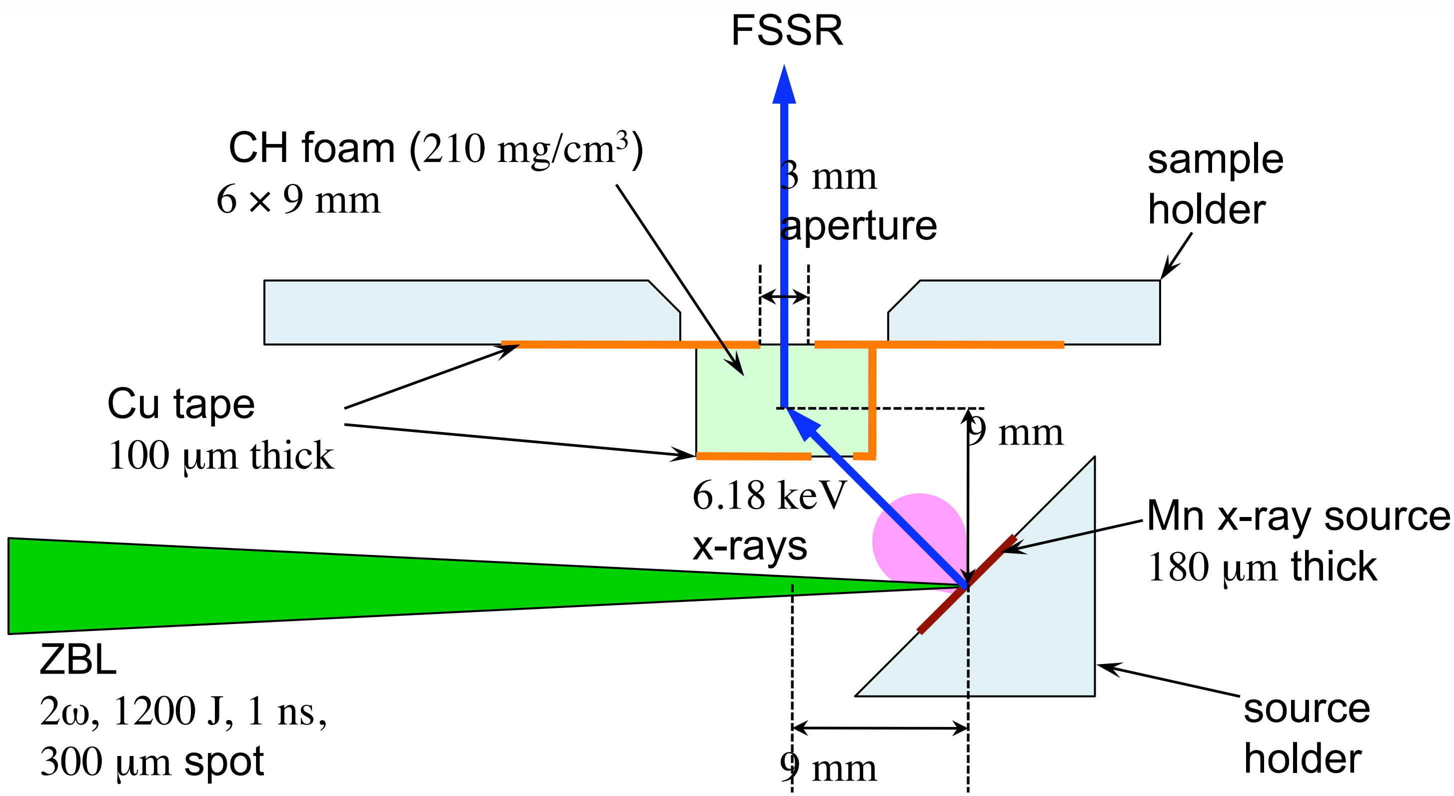
# Experimental setup

- **Forward scattering (45°) of Mn-He-α 6.18 keV x-rays**

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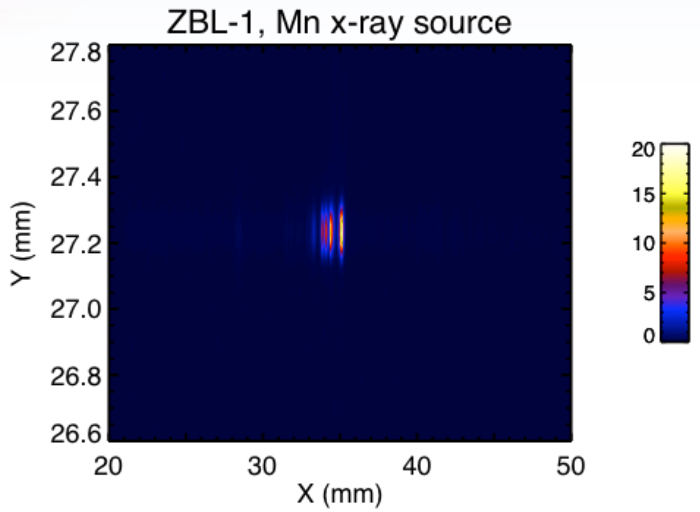
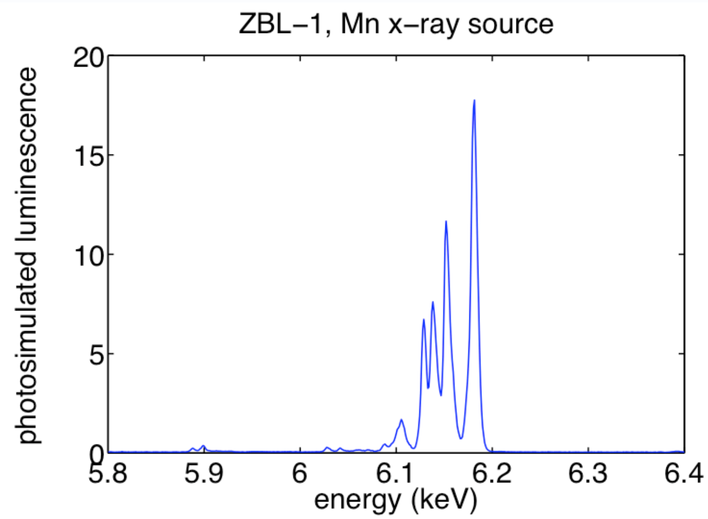
# Measured x-rays

Preliminary data

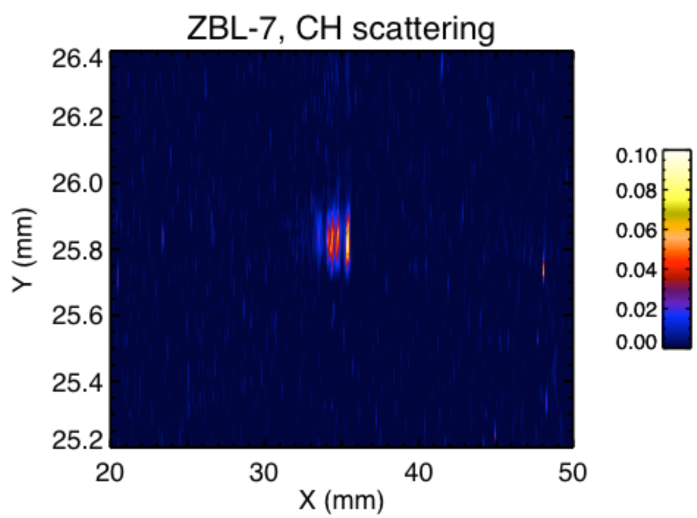
- **Mn-He-α x-rays generated by ZBL**

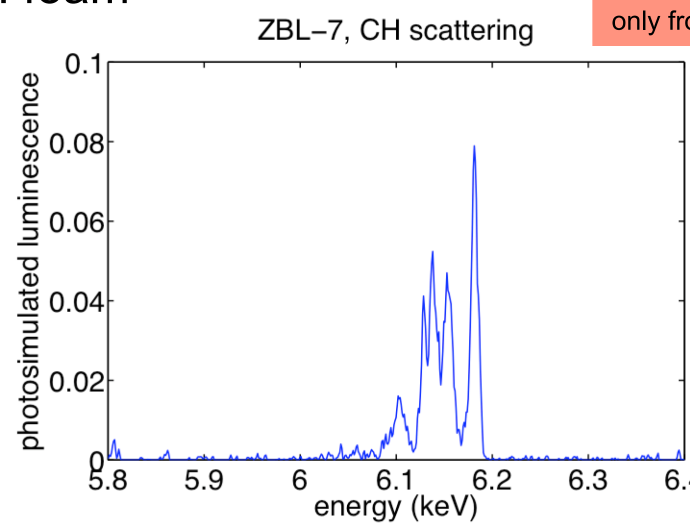



- **Mn-He-α x-rays scattered** from CH foam

Null test show x-rays only from scattering

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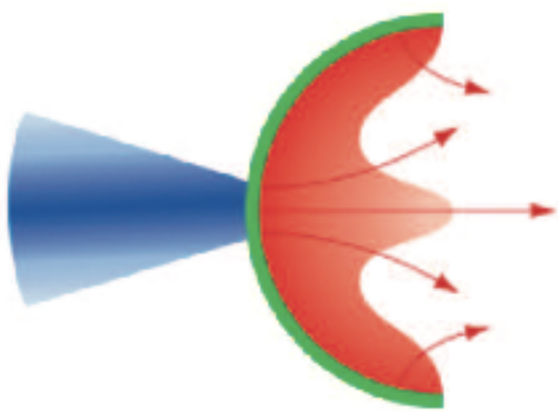
# Proton Focusing

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



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

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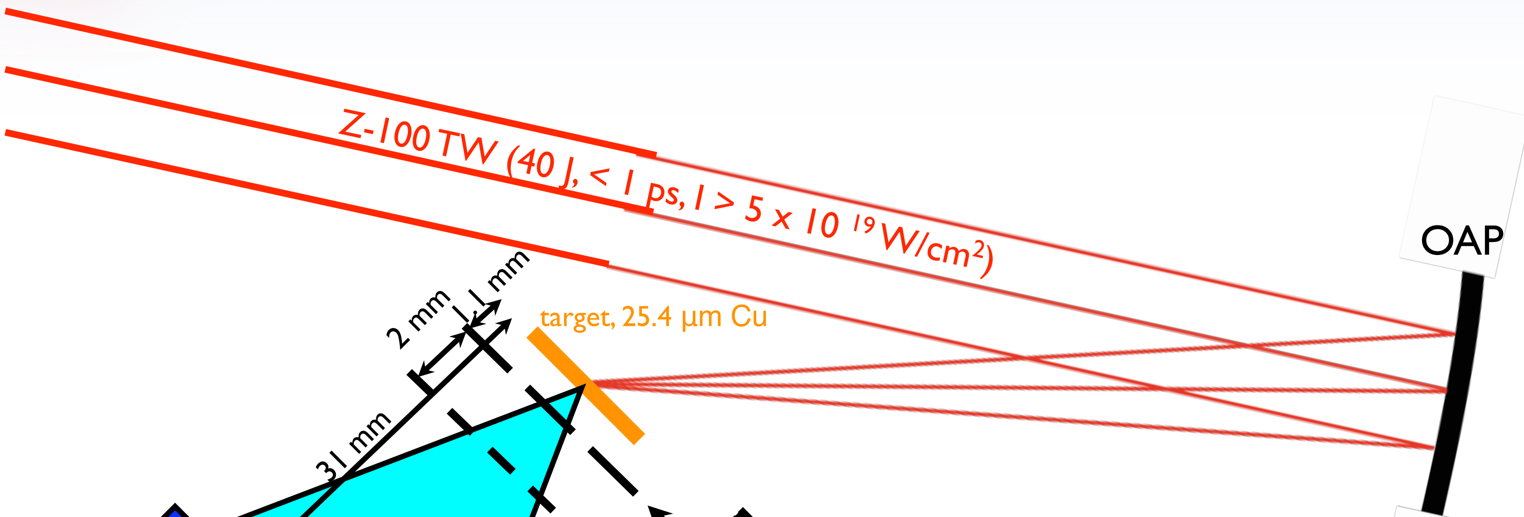
# Ballistic Proton Focusing Diagnostic

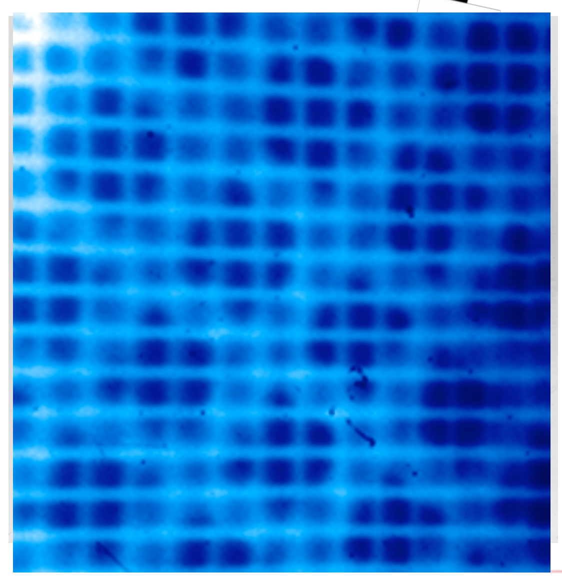



Magnification:

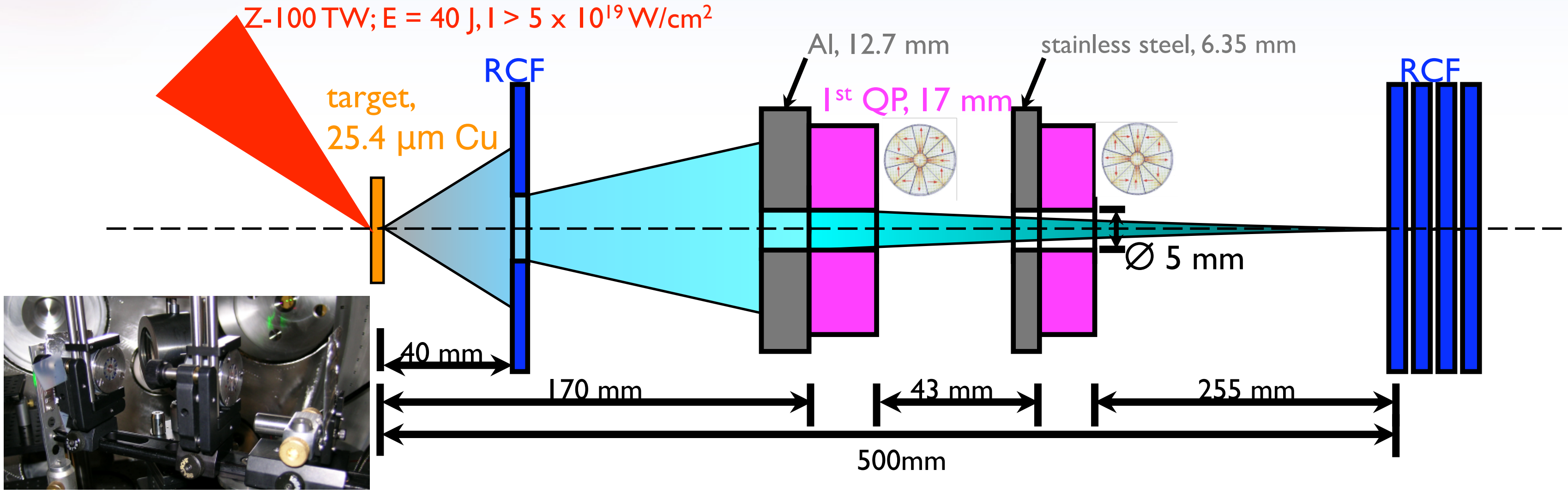
12x for small pattern
45x for large pattern

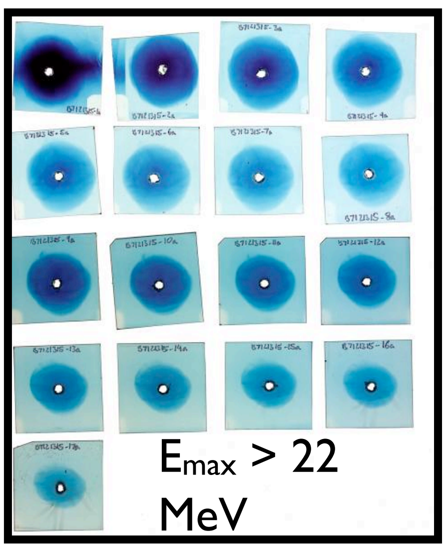
750 lpi superfine mesh:

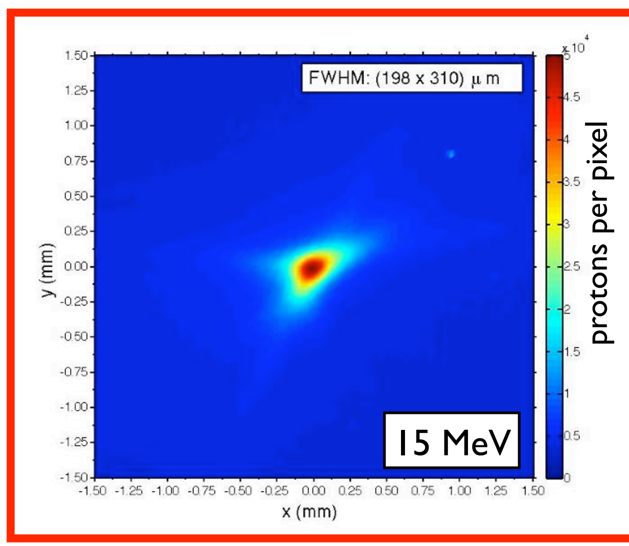
wire distance: 33.9 µm
wire thickness: 8.6 µm



# Quadrupole Focusing Experiments



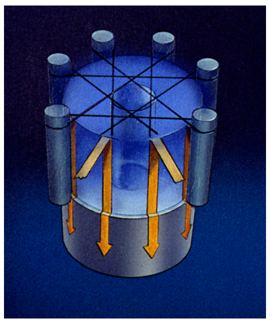



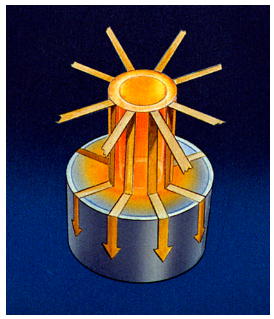

# Sandia's ZR z-pinch facility

Phases of a z-pinch implosion

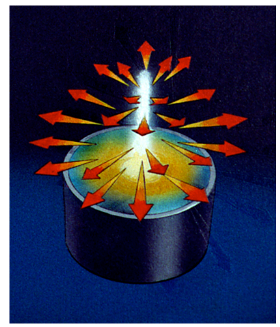
initiation



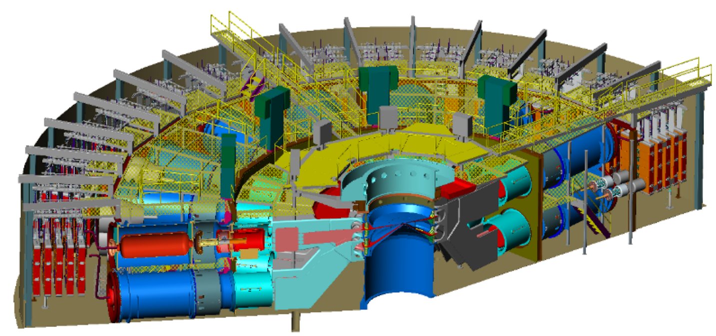
implosion



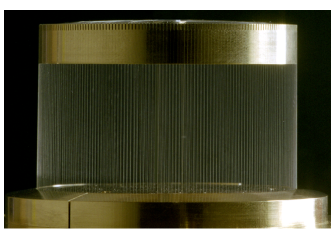
stagnation

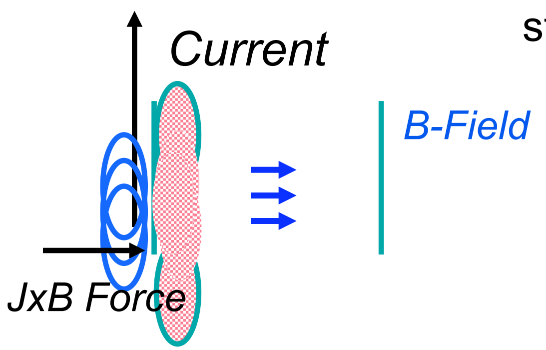


ZR z-pinch facility

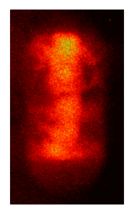


wire array






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

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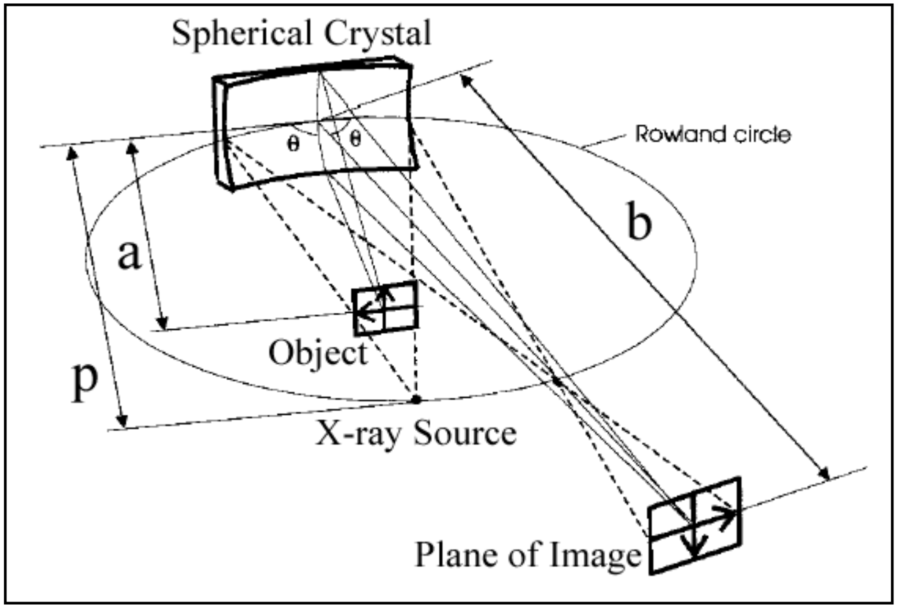
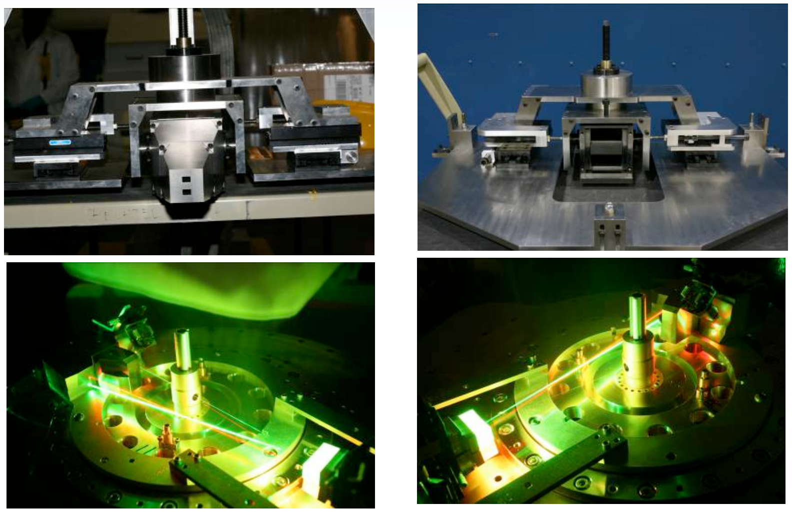
# Curved-crystal imaging offers an elegant solution for backlighting in hostile environments



<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).

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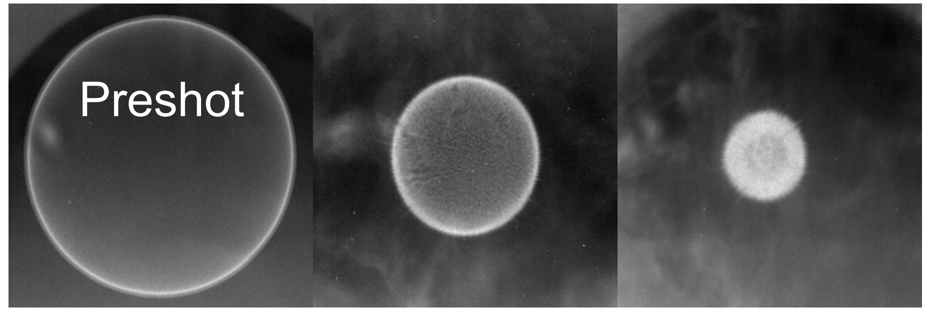
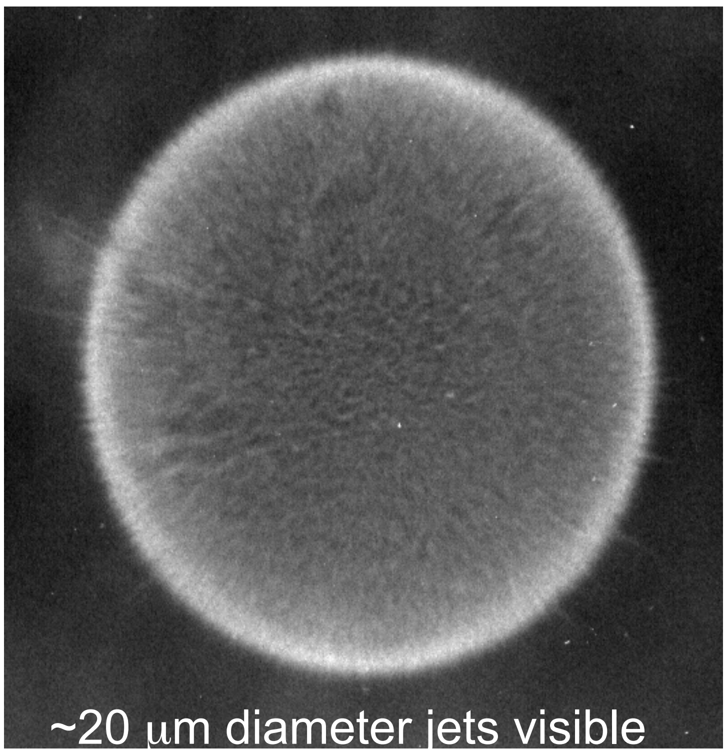
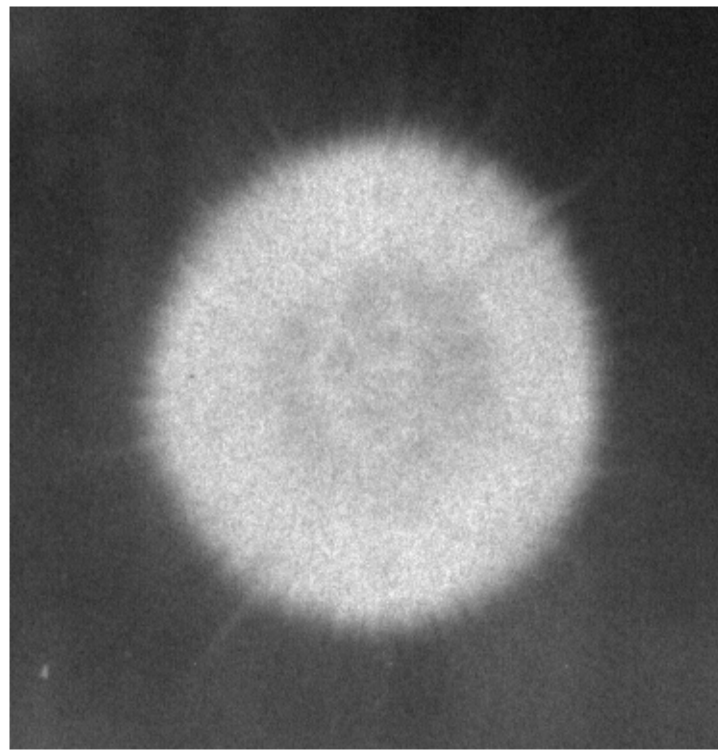
# The higher spatial resolution bent-crystal imaging system revealed new features in imploding capsules

3.4-mm diameter plastic ICF capsule

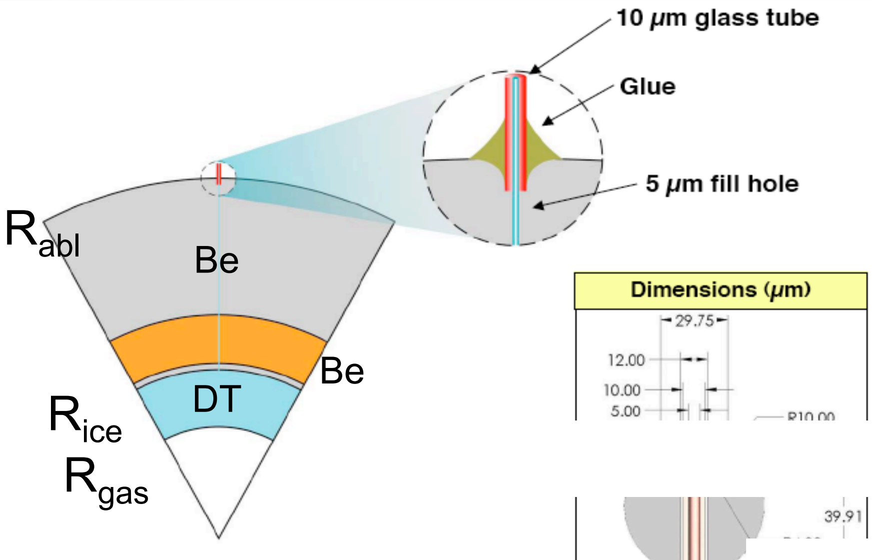
Capsules had 100s of known defects on surface that apparently produced a myriad of small jets



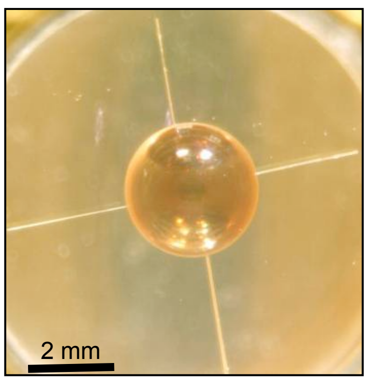
# X-ray backlighting enabled us to measure the effects of DT fuel fill-tubes on capsule implosions



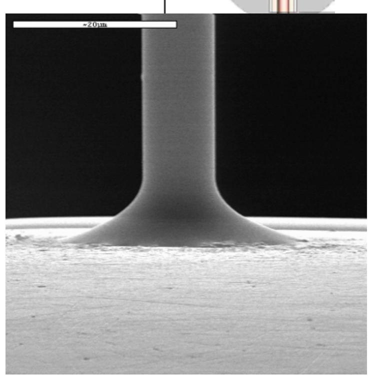

Using fill tubes significantly reduces complexity and expense of cryogenics system compared with diffusion fill and cryo transport

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

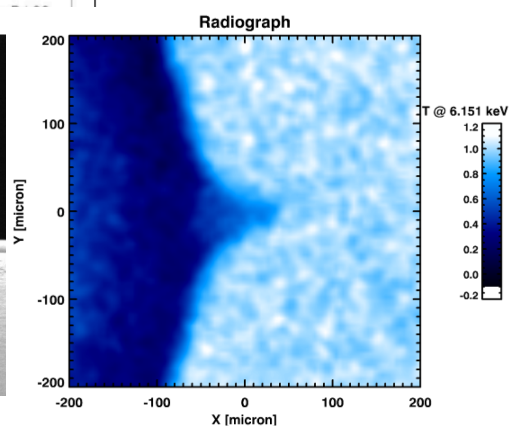
Calculating the perturbations arising from fill tubes is a computational challenge



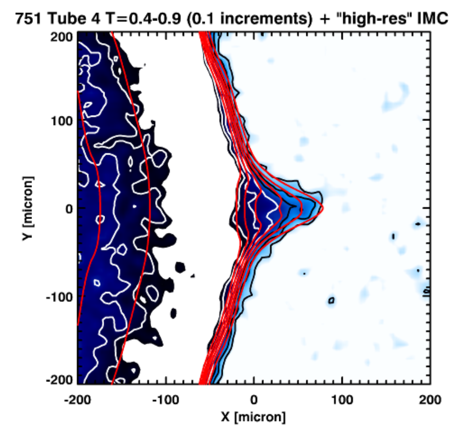

CH capsule with 4 fill tubes (12-45 micron OD)



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).

GENERAL ATOMICS

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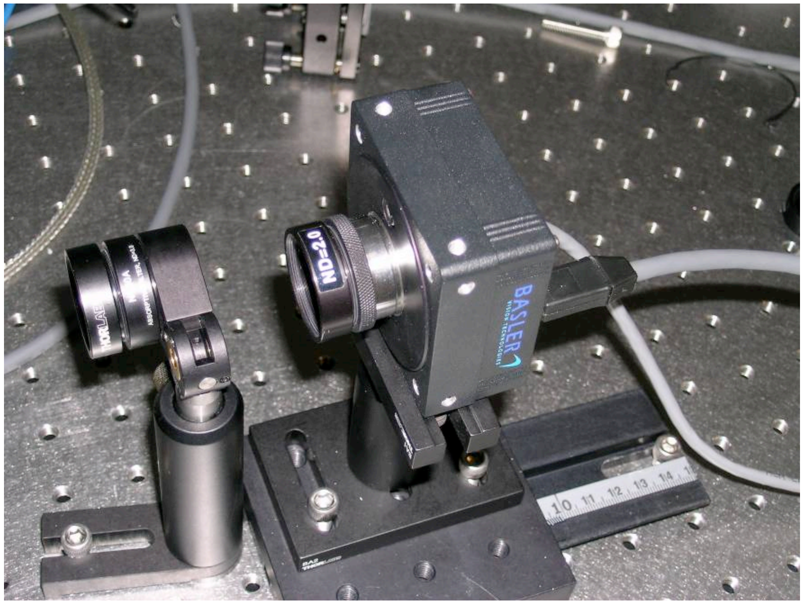
# Near Field Diagnostics

- 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 wi legacy codes and hardware
  - OKO system solution

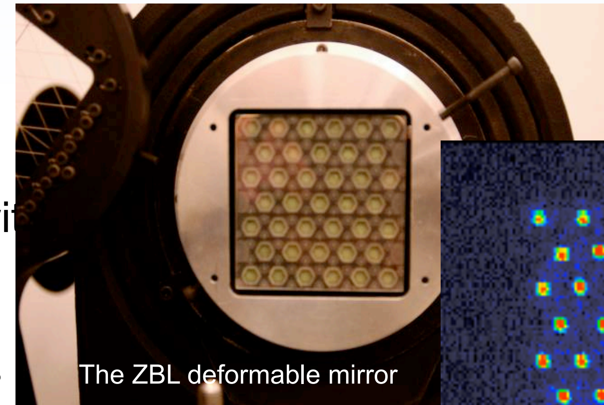
    → Small sizes and delamination issues with mirrors, code not a smooth fit
  - AOA sensors with custom mirrors (OKO,CILAS, in-house)

    → AOA hardware works but can be tricky, Software interface issues

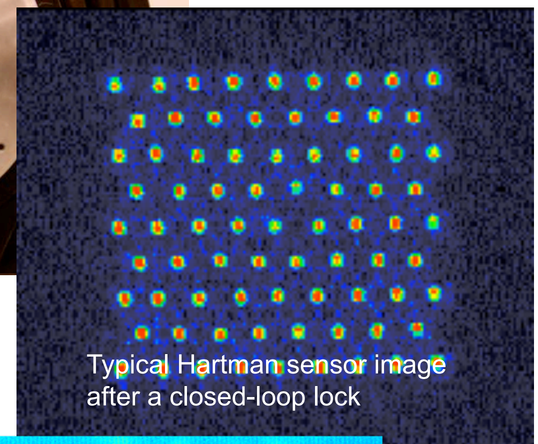
    → Used effectively open-loop with in-house developed deformable mirrors
  - Phasics system solution

    → Nice flexible sensor with working AO loop

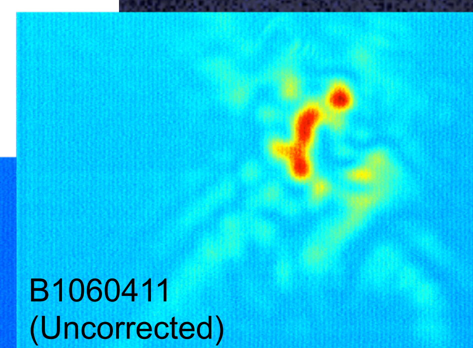
    → Minor mirror communications issues being worked out



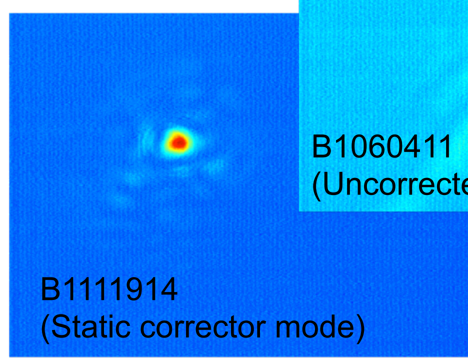
The ZBL deformable mirror



Typical Hartman sensor image after a closed-loop lock



B1060411 (Uncorrected)



B1111914 (Static corrector mode)

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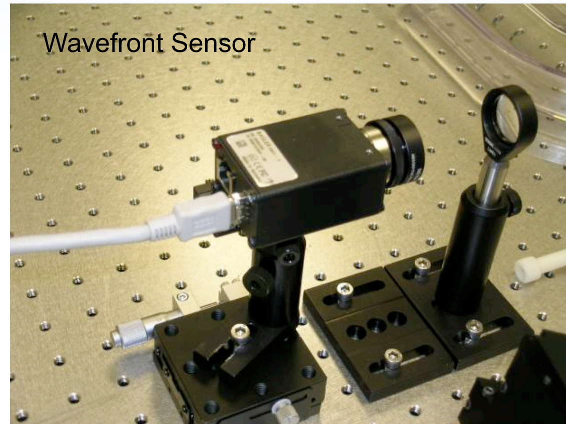


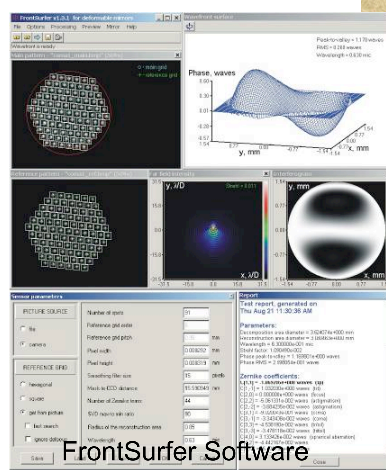


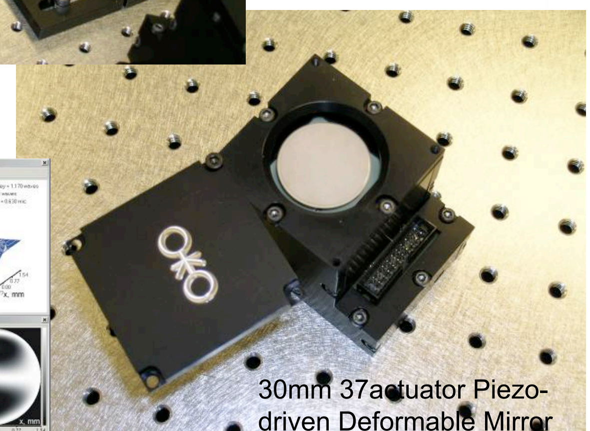

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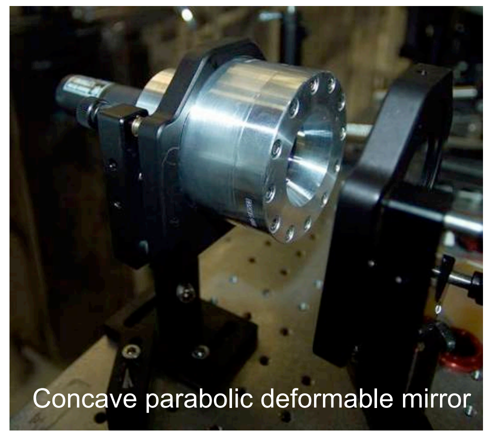
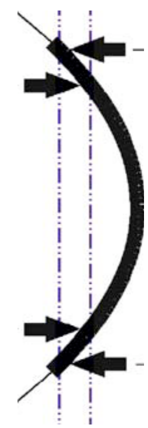
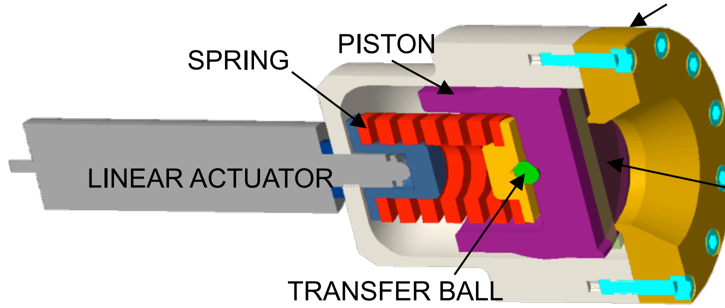
- Custom single-actuator mirrors can be:
  - → Convex parabolic [Schwarz, AppPhysB v82 (2006)]
  - → Concave parabolic [Schwarz, OptExp v14 (2006)]
  - → Cylindrical concave [Schwarz, OptComm v264 (2006)]
  - → Off-axis parabolic


Concave parabolic deformable mirror



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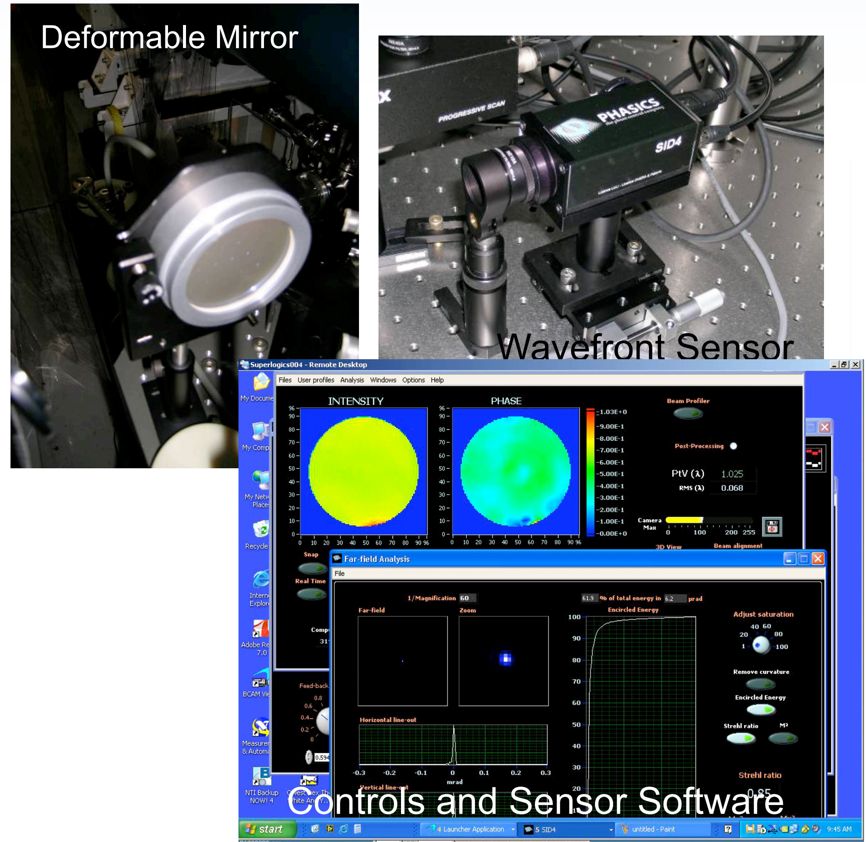


- Compensated full system shot:

  PV: 1.03 waves

  RMS: 0.07 waves

  Strehl ratio: 0.85.

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