September 2016

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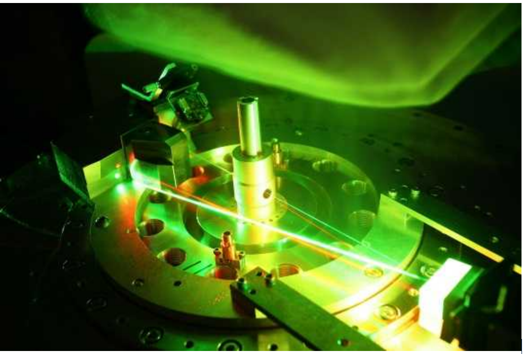

Sandia National Laboratories

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New Developments on Sandia's Z-Petawatt Laser

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NNSA National Nuclear Security Administration

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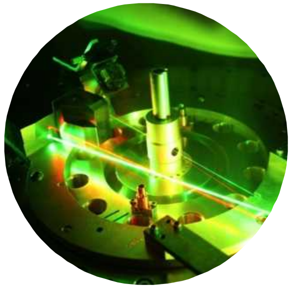
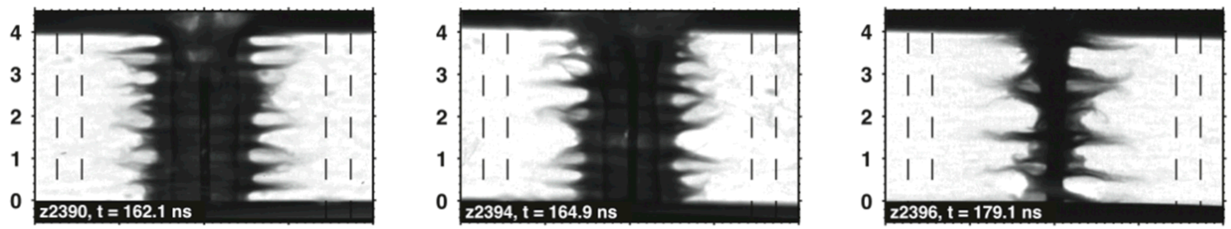
Motivation: Z-Backlighter Research Support at Z



Drive 1.8 and 6.2 keV x-ray backlighters for x-ray radiography on Z (sub-ns synchronization)

Desired:

- ***9-16keV Sources***
- ***More frames per shot***

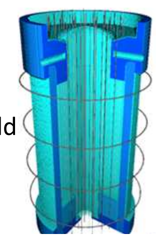


Preheat a Magnetized Liner Inertial Fusion (MagLIF) target

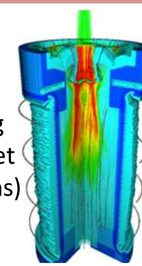
Desired:

- ***More energy***
- ***More pulse delay options***

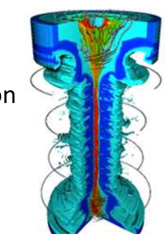
Magnetization with external B-Field (ABZ, 10-30 T)

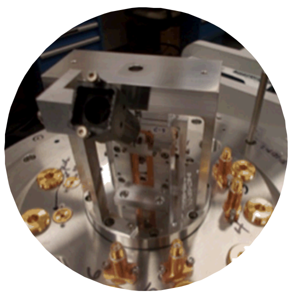


Laser heating with Z-Beamlet (2-6 kJ @ 2-6 ns)



Compression with Z

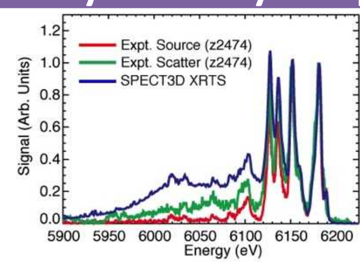


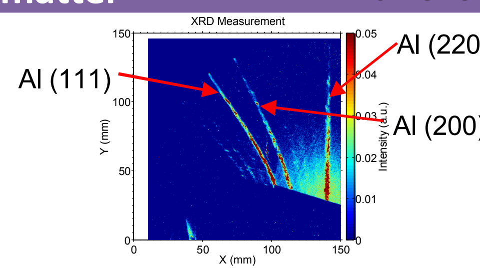


Generate x-ray sources for x-ray scattering and diffraction on dynamically compressed matter

Desired:

- ***More energy***
- ***10-25keV sub-ns sources***





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Z-Backlighter Facility

Desired:

- ***9-25keV sub-ns sources***
- ***More frames per shot***
- ***More MagLIF energy***

Z Backlighter

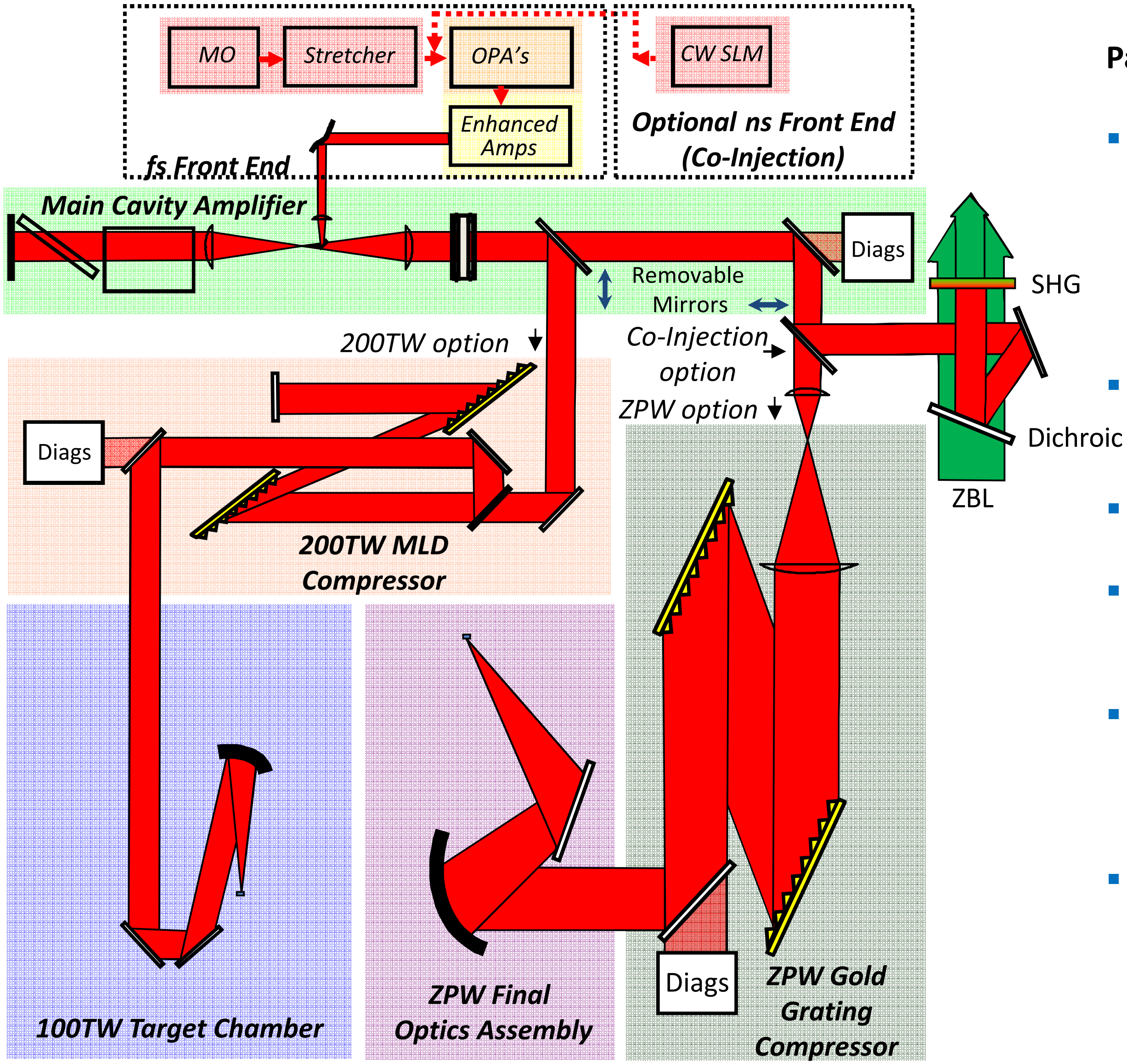
Solutions:

→ **ZBL is in high demand and can only increase energy via boosters.**

→ **ZPW could be adapted to meet all of these objectives.**

	Z Beamlet	Z Petawatt Co-Injection	Z Petawatt Full-Aperture	Chaco
λ (nm)	527	527	1054	(1064) 532
τ	0.3-8 ns, typ. 2 ns	≥ 2ns SLM	(0.5 to) 200ps	100 ps – 10 ns
typ. Spot size (μm FWHM)	75	50	50	20
E_{max} (J)	4000	<400J (sub-ap); <2000J (full-ap)	<2000	(100) 50
I (W/cm²)	~ 10^{17}	~ 10^{17}	(~ 10^{20} to) ~ 10^{18}	~ 10^{17}
Shot Intervals (minutes)	180	180	180	20
'Special feature'	2 pulse MFB (two frame/2 color)	Variable delay WRT ZBL; Variable pointing WRT ZBL	Variable delay WRT ZBL; Different from λ ZBL	Bursts; 8-10 ns option; 1ω and >100J (pending)

1st Modification to ZPW: Co-Injection



Path:

- Add narrow-band chopped CW seed.
  - OPCPA pump gates CW to ~2ns.
  - SLM seeding avoids the gain narrowing and associated B-integral issues of chirped pulses.
- Add further rod amplification to reach the design output.
- By-pass the compressors.
- Combine the beam is with ZBL at a dichroic beamsplitter.
- Point and center the preceding mirrors to co-bore the injected beam with ZBL.
- Perform SHG in the orthogonal polarization to ZBL for ns 2ω applications.

Co-Injection Changes

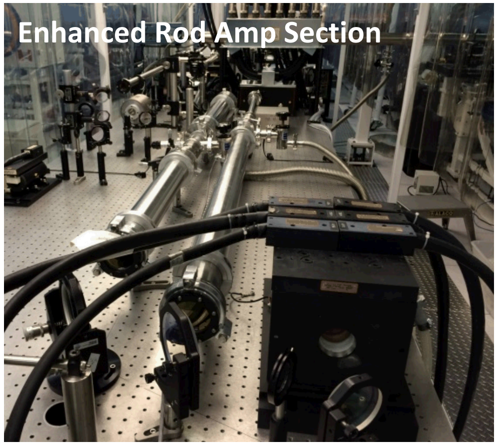
Front-end Changes:

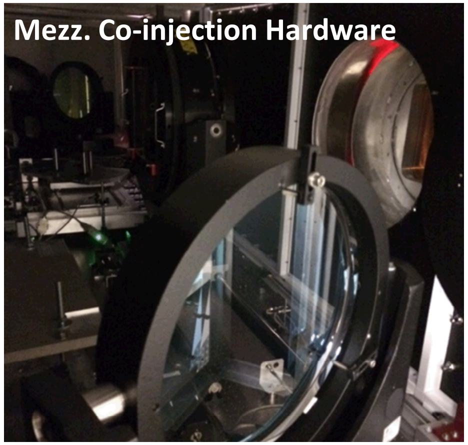
- **New CW-SLM seeder option (SLM-OPA)**
- **Modification to OPA system for improved stability and slightly longer pump pulsewidths**
  - **2.2ns FWHM super-Gaussian/40mJ/10Hz demonstrated**
- **Pulseshaping Pockels cell at OPA exit**
  - **Slow ramp for compensation of pulseshape distortion**
- **Modification to Nd:Phosphate glass rod amplifiers**
  - **Previously: 2-pass 16mm and 25mm rods**
  - **Now: Additional VSF relays, 2-pass 45 and 64mm rods**
  - **Results: 28J/2ns demonstrated (<15J needed)**
- **75mm isolation Pockels cell after rod amplifiers**
  - **Higher LIDT's (~5J/cm^2) and lower n_2 than Faraday glass**
  - **Time-gating of pre-pulse ASE as well as back-reflections**
  - **Results: 600:1 on-off contrast; ~50ns FWHM gate**

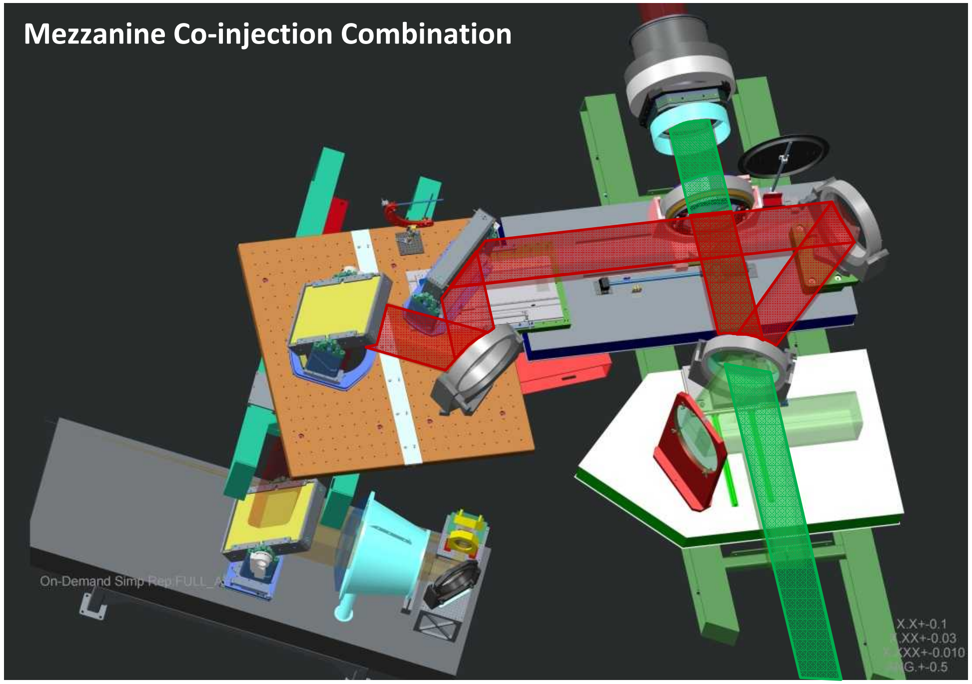
→ 306J (1ω) amplified SLM-OPA demonstrated

Mezzanine Changes:

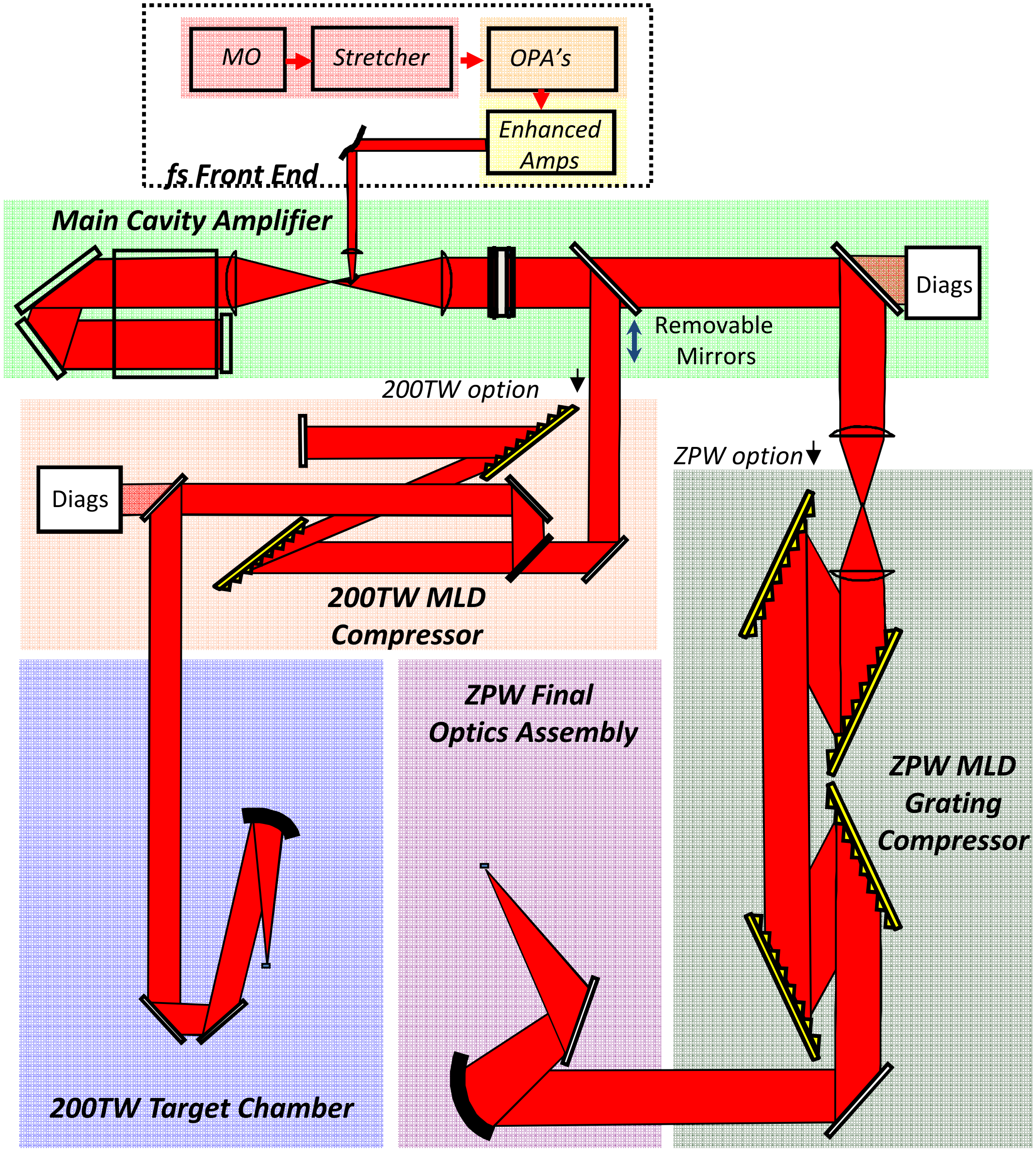
- **Mezzanine enclosures joined**
- **New optics added: 2 ZPW HR's and SHG crystal**
  - **Focused SHG of OPA seed: 10x15μm^2 FWHM (6.7μm DL)**
- **ZBL beamsampler replaced with custom SNL dichroic:**
  - **HR at 1054nm/HT at 527nm at 22.5° AOI (Strips ZBL 1ω)**







2nd Modification to ZPW: Full-Aperture



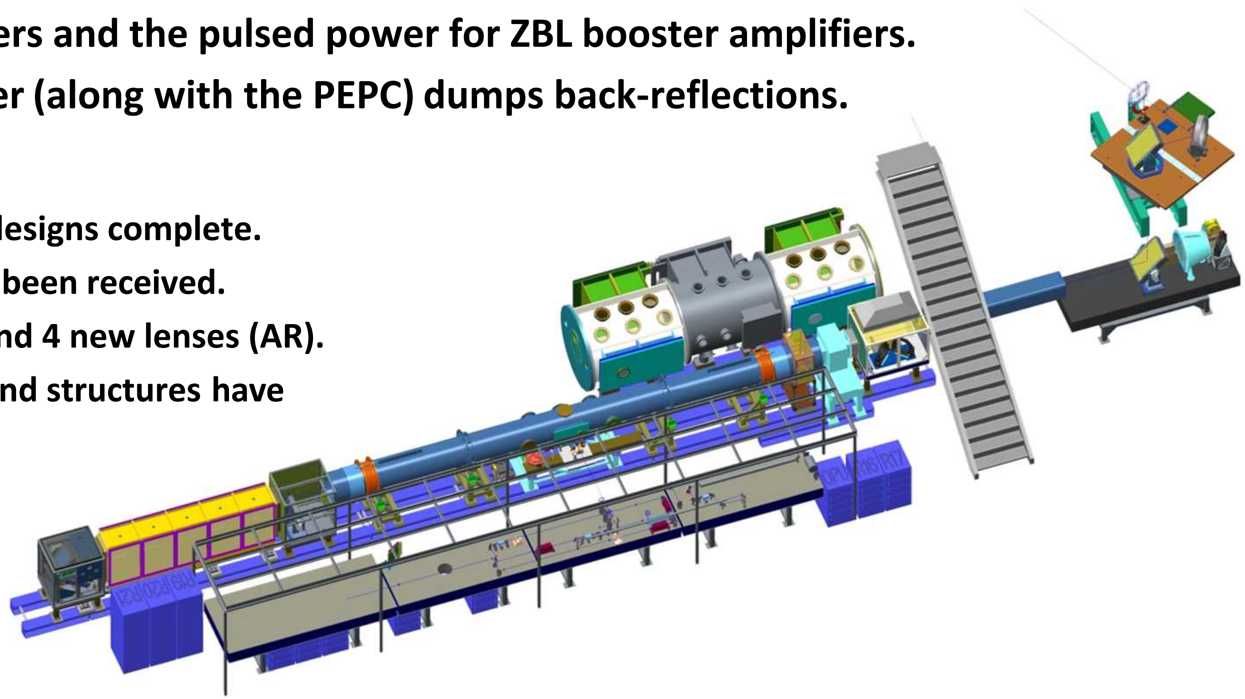
Note: Amplifiers already have 40cm X 40cm CA.

Path:

- **Use a new apodizer and magnification on the injection telescope (after the rod amplifiers) to set the larger beamsize.**
  - **Current: sub-apertured 15cm round beam**
  - **New: 28cm x 32cm beam**
    - **Size is adjustable down using a smaller front end apodizer**
- **Fold the amplifier design to save space.**
- **Replace the subsequent optics with appropriately sized ones.**
- **Modify compressor interior to utilization of full-aperture MLD gratings.**

Full-Aperture ZPW

- The front-end and injection area stay the same as the enhanced system built for co-injection.
  - The increased rod amplifier output allows a two-pass main amplifier design to fulfill design objectives.
  - This higher input energy increases the system B-integral slightly but by-passes the need for a double-pulse PEPC or two PEPC's, although a single PEPC at the output serves for back-reflection protection.
- The main cavity spatial filter length increases from 5 to 9m, vignetting beamsize to 28cm x 32cm.
- The longer VSF in a fixed building drives us to better use the 2X1 basic amplifier structure.
  - Current: Linear 10x1 design (bottom aperture unused)
  - New: Folded 5x2 design
- This design frees 5 amplifiers and the pulsed power for ZBL booster amplifiers.
- The fold periscope polarizer (along with the PEPC) dumps back-reflections.
- Status:
  - Optical and mechanical designs complete.
  - All uncoated optics have been received.
  - SNL to coat 7 new HR's and 4 new lenses (AR).
  - All mounting hardware and structures have been procured.

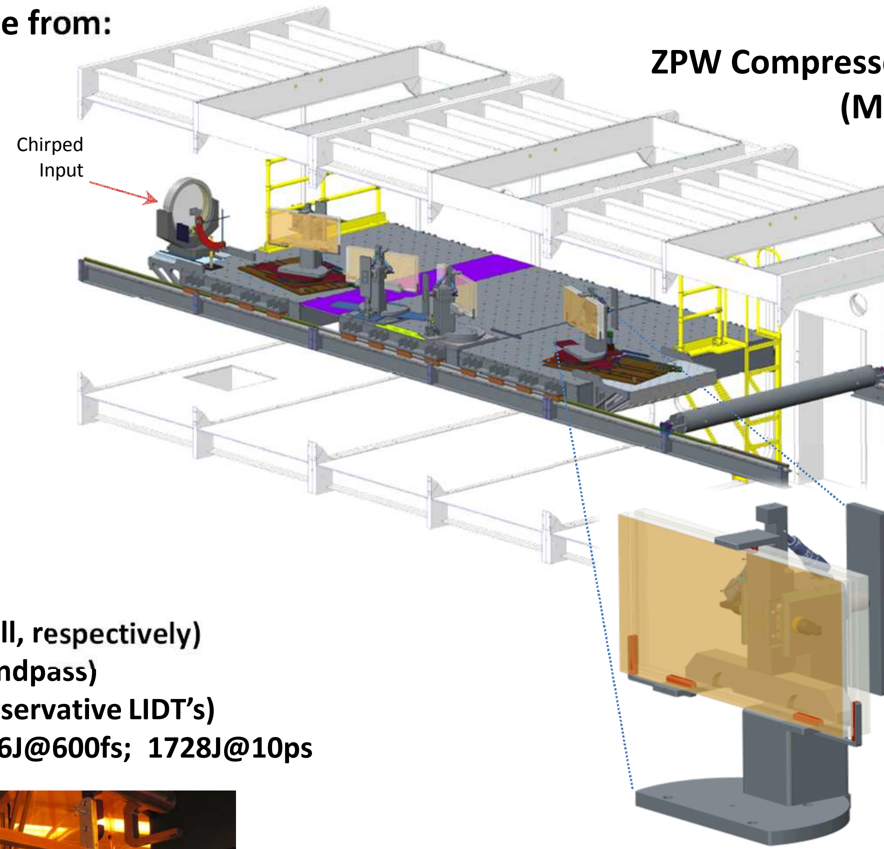


MLD Grating Upgrade

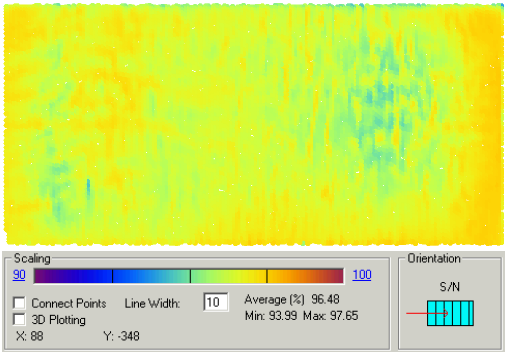
- The compressor vessel interior design will change from:
  - 2 single-pass Gold gratings (1480 l/mm) …to…
  - 4 single-pass MLD's (1740 l/mm)
- The optical design:
  - Eliminates the previous spatially chirped near-field
  - Avoids tiling complexities
- The mechanical design:
  - Utilizes new bezel-free mounts (optimal clearance)
  - Avoids fall protection and confined space concerns
- System Design Specs:
  - Expected 72° AOI damage threshold of:

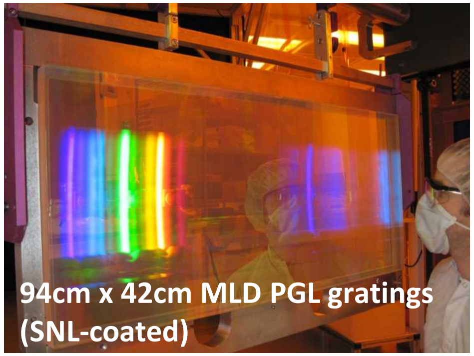
    → >1 J/cm² in the RHσ at 0.5ps; >3 J/cm² at 10ps
  - Input RHσ: 32cm x 24cm rectangle (A= 768cm²)
  - 1st Grating Projection: 32cm X 78cm (76% and 83% fill, respectively)
  - 2nd Grating Projection: 32cm X 94cm (for 8nm full bandpass)
  - Max Energy: 768J@600fs; 2304J@10ps (based on conservative LIDT's)
  - Safety De-rated Energy (1.3:1 beam modulation) : 576J@600fs; 1728J@10ps

ZPW Compressor Interior (MLD layout)



ZPW MLD mount





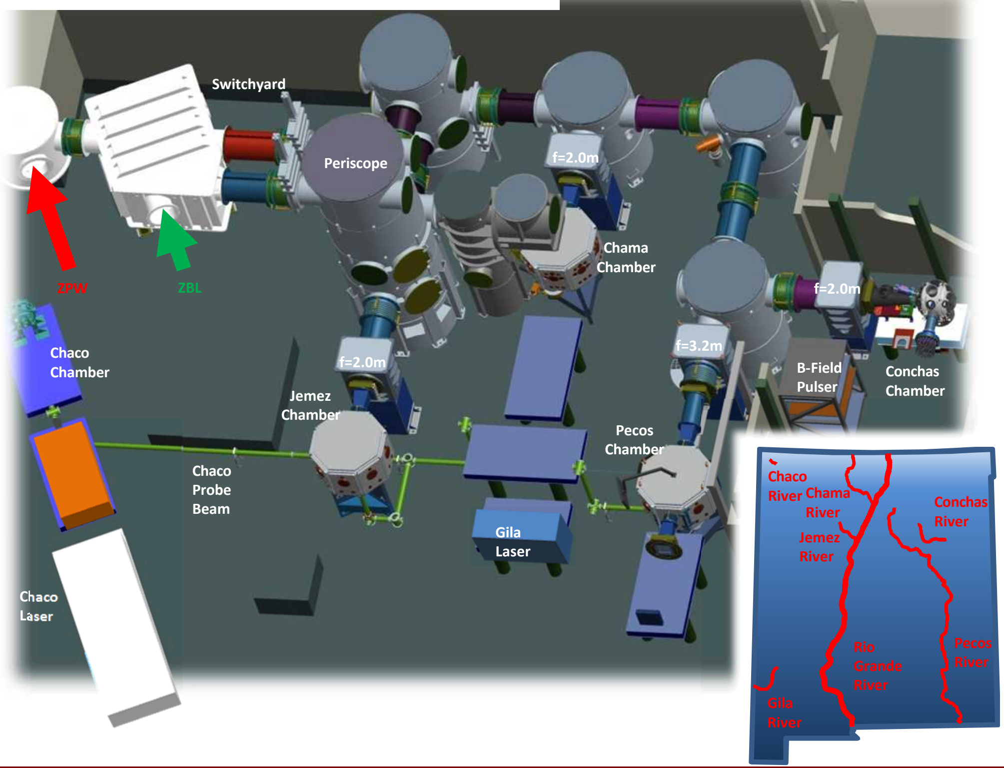
94cm x 42cm MLD PGL gratings (SNL-coated)

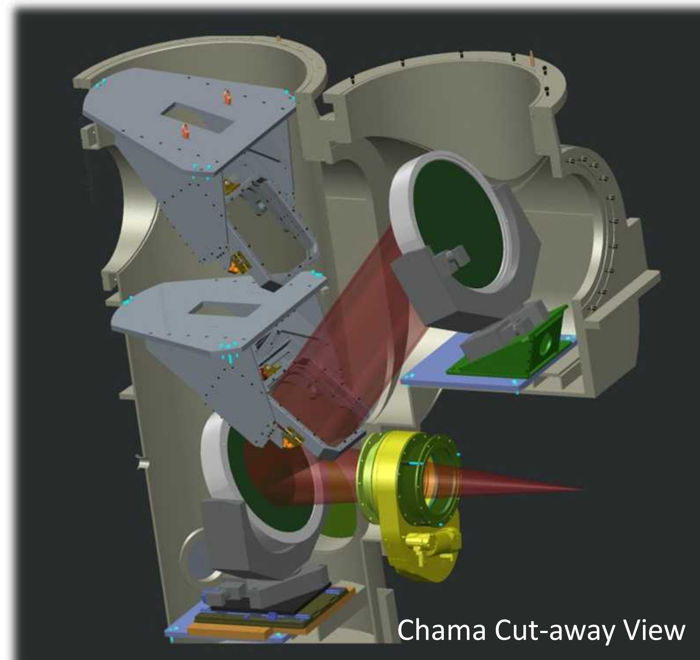
Status:

- All optics procured
  - MLD'S are currently under re-evaluation and cleaning after long storage.
- Mechanical design is complete
- Hardware orders pending

The Target Bay

- For ZPW, the last of 5 target chambers (Chama, in center) in our Target Bay is being brought on-line.
- The intended final OAP will be exchanged for a lens and fold mirror with the same final focus position.
  - More cost effective, easier alignments than OAP
  - Allows standard vacuum window/debris shields
- Highly chirped beams (1kJ/0.1ns or 2kJ/0.2ns) focused by lens satisfy system B-integral limitations.
  - Estimated peak intensity of 8×10^{18} W/cm^2





Conclusions

- The Z-Backlighter Facility will benefit from two key modifications to the ZPW system:
  - Co-injection, which generates a ns scale 527nm pulse that co-propagates with the ZBL system; and
  - A full-aperture upgrade, which increases the available laser energy to the multi-kilojoule range as applied to:
    - Co-injection, and
    - MLD grating pulse compression

- The Target Bay build-out is nearing completion with the implementation of the final chamber (Chama) for ZPW use.
  - Chirped pulse lens-based focusing for x-ray generation will be tested in Chama.

Backups

Chirped ZPW Lens-Based Focusing

- **Traditional CPA beam focusing by an OAP (needed for B-integral) can be tricky or cumbersome.**
- **For *our* backlighting needs, longer pulsewidths still generate sufficient k_α x-rays while mitigating the bremsstrahlung.**
- **Highly chirped beams reduce the B-integral enough to standard lens-based focusing, which has several advantages:**
  - **Cost effective at large aperture**
  - **More alignment tolerant**
  - **Allows common Z vacuum windows/ debris shields**
- **A B-integral analysis shows that B limits can be maintained through the final lens.**
- **Targeting 10TW (1kJ/0.1ns or 2kJ/0.2ns), modeling indicates:**
  - **An ideal focal spot size of 11µmX10µm (FWHM)**
  - **A best focus intensity of 8x10^{18} W/cm^2 (not projected on a target)**
- **The approach allows:**
  - **A *practical* path to higher x-ray photon energies on Z; and**
  - **The option for tandem backlighting (Additional frames to ZBL or backlighting of ZBL/Z target interactions (like MagLIF))**