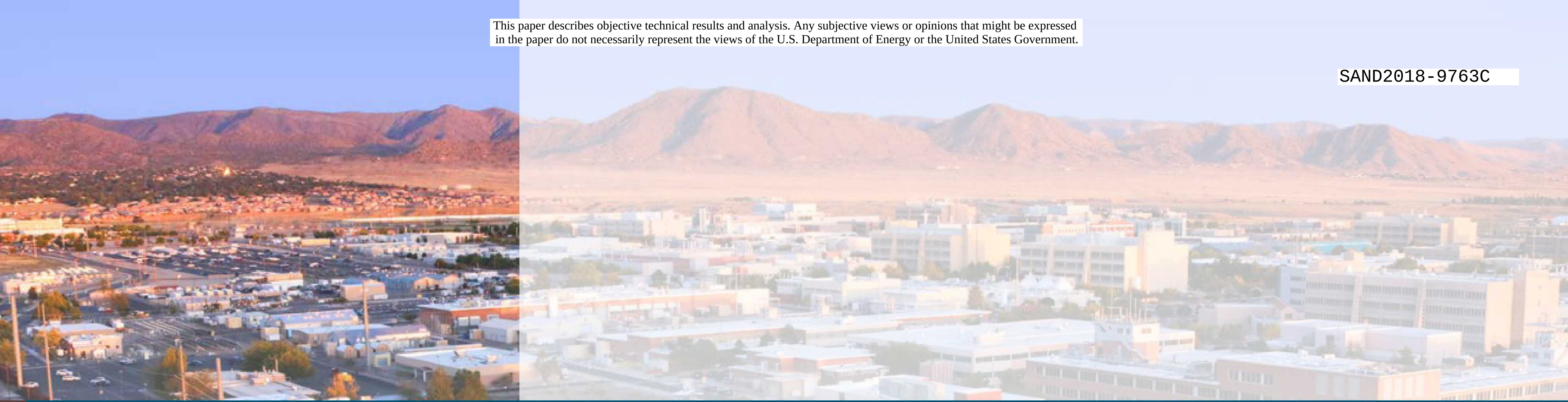
SAND2018-9763C



Upgrades to the Z-Petawatt Laser at Sandia National Laboratories

P. Rambo, J. Schwarz, M. Schollmeier, M. Geissel, I. Smith, C. Speas, J. Shores, B. Galloway, E. Field, D. Kletecka, and J.L. Porter

8TH CONFERENCE OF THE INTERNATIONAL COMMITTEE ON ULTRAHIGH INTENSITY LASERS

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

- Current State: Dual-mode operation
  - Narrow-band SLM-OPA seed
    - Co-injection mode
    - Application: MagLIF
  - Broad-band OPCPA seed
    - Chama Target Chamber Activation
    - Lens-Based Focusing
    - Application: Diffraction
- Future State
  - Full-aperture Upgrade
    - Broad-band Impact
    - Narrow-band Impact
- Conclusions

Z-Backlighter Facility: Recent ZPW Motivations

Desired:

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

Z Backlighter

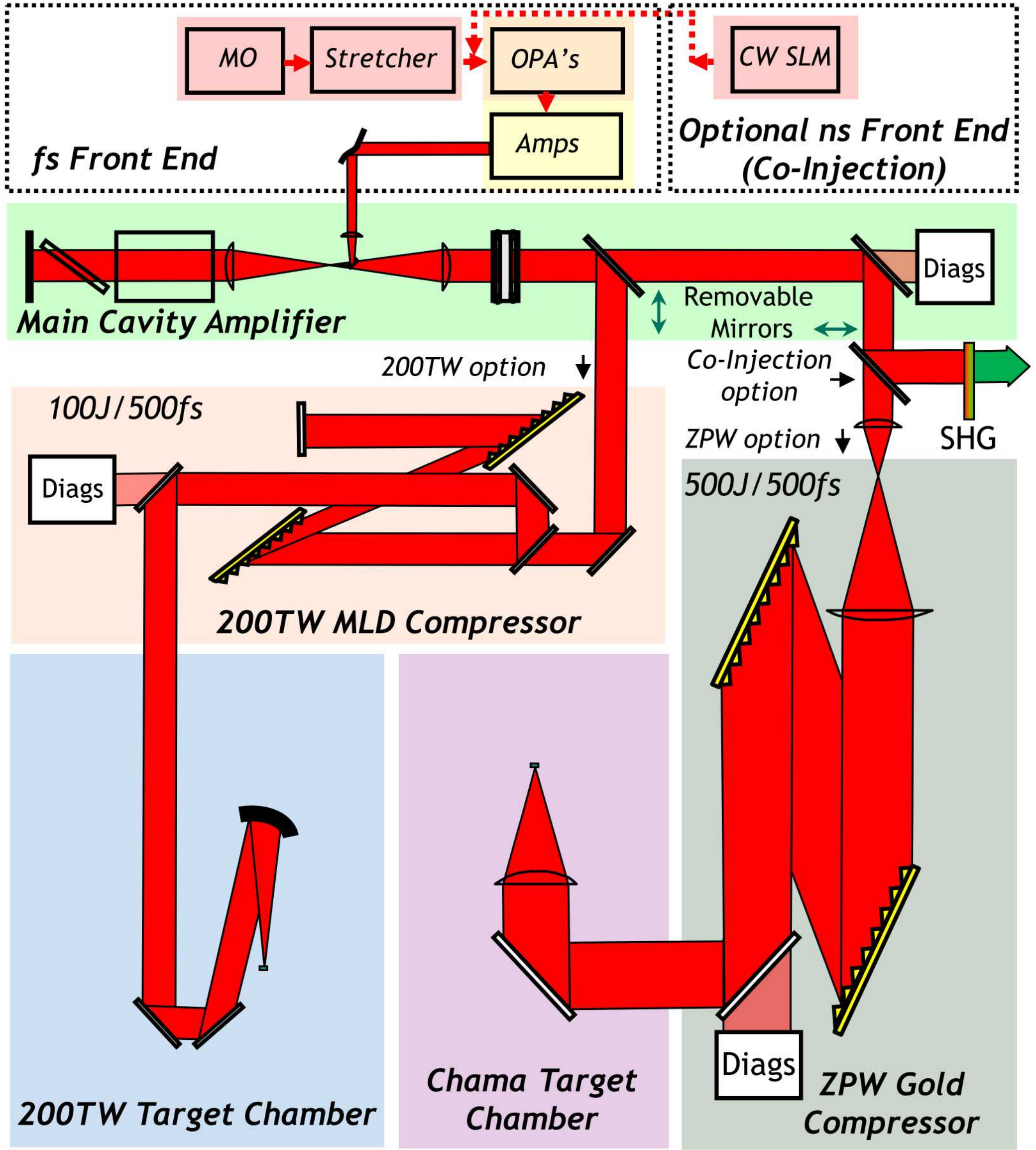
Solutions:

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

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

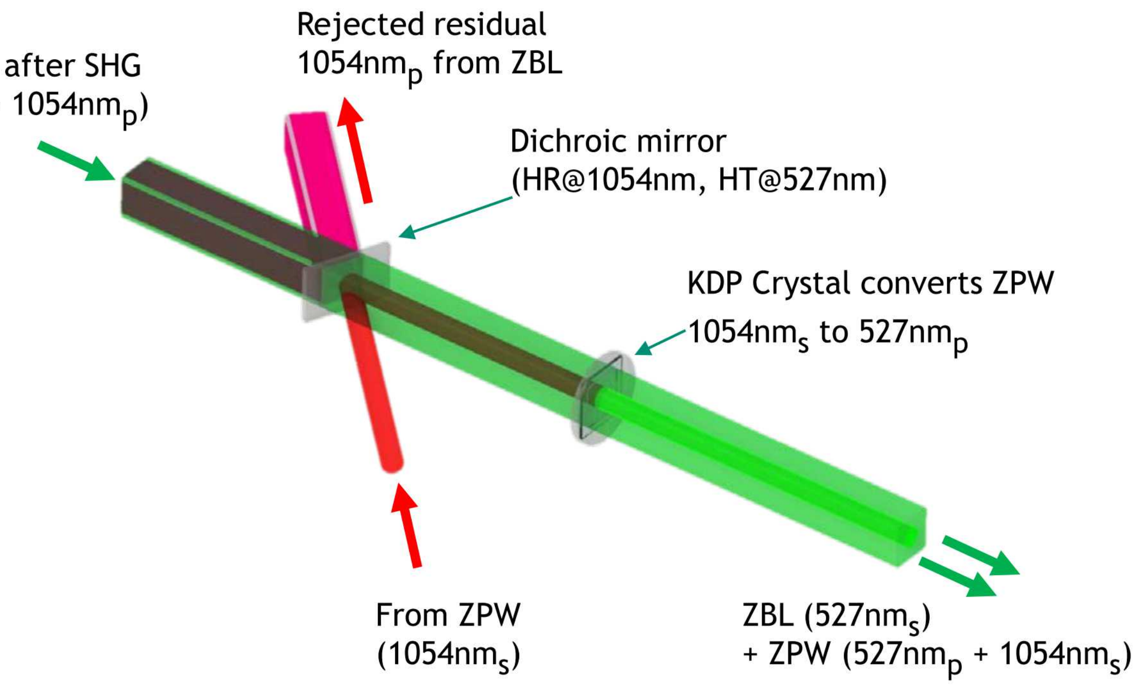
	Z Beamlet	Z Petawatt Co-Injection	Z Petawatt Full-Aperture	Chaco
λ (nm)	527	527	1054	(1064) 532
τ	0.3-8 ns, typ. 2 ns	≥ 2ns SLM	(0.5 to) 200ps	100 ps – 10 ns
typ. Spot size (μm FWHM)	75	50	50	20
E_{max} (J)	4000	<400J (sub-ap) <2000J (full-ap)	<2000	(100) 50
I (W/cm^2)	~ 10^{17}	~ 10^{17}	(~ 10^{20} 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)

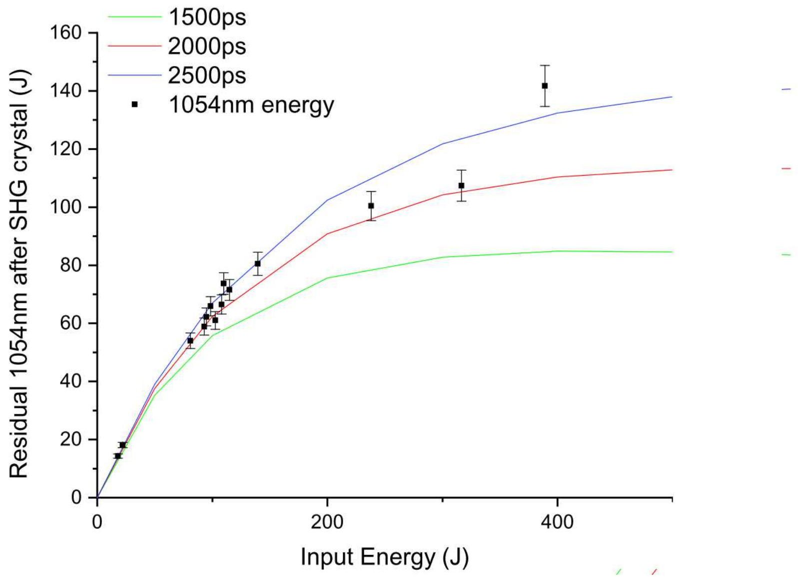
Recent Z-Petawatt Laser Changes: Dual-Mode Operation Overview

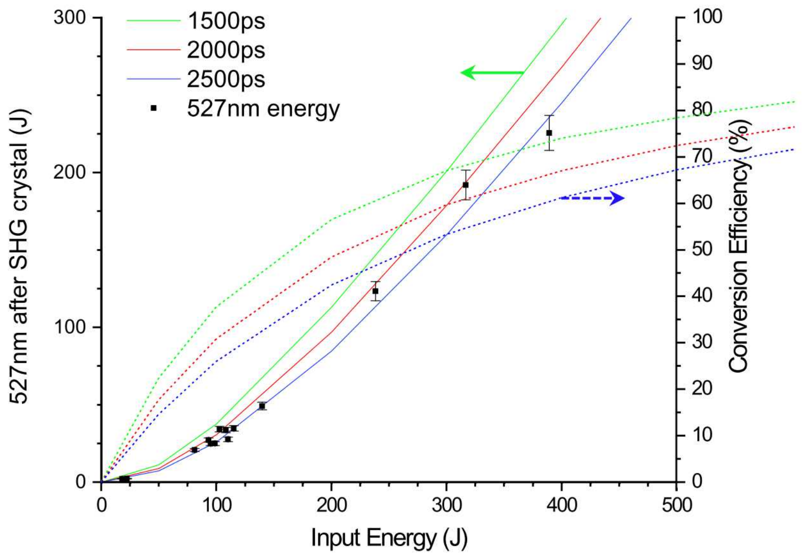


- The ZPW system has historically amplified via
  - an OPCPA front-end (50mJ/10nm/10Hz) to seed
  - an Nd:Phosphate Glass rod chain (<10J @ 1/15min) and
  - the main slab amplifiers (<500J output in ~15cmϕ @ 1/3hr).
- For compression and application, we use either:
  - reduced energy at ~15cmϕ in the 200TW (100J/500fs) MLD compressor in associated target area, or
  - near maximum energy at 42cmϕ with 94cm gold gratings **in a recently commissioned stand-alone target chamber.**
- Recently, a narrow-band long-pulse (~2.5ns) mode referred to as co-injection was added to yield a variable delay 527nm pulse co-bored and co-pointed with Z-Beamlet (ZBL).
  - Operation through initial amplified main system shots were discussed in ICUIL 2016.
  - **Frequency doubling, relative timing, co-alignment features with respect to ZBL, and experimental application have been implemented since then.**

Z-Petawatt Long-Pulse Mode: Co-injection







- To have robust co-injection operation, we:
  - Co-bored and co-pointed with ZBL into one of our target chambers
  - Optimized the SHG for co-injection
  - Established an ex-situ reflective (achromatic) far-field diagnostic to qualify the co-pointing of 1054nm ZPW and 527nm ZBL (from alignment beams at the SHG crystal)
  - Established an in situ far-field diagnostic comparing the SHG crystal back-reflection with a fixed fiducial so as to verify the optimal crystal phase matching

Z-Petawatt Long-Pulse Mode: Co-injection Application

- MagLIF experiments at Sandia use the ZBL laser to pre-heat magnetized gas that is then compressed by Z, with the intent of increased fusion yields.

- Delivery of the ZBL laser pulse through the polyimide window on the laser entrance hole of the LEH can generate significant nonlinear effects that in turn reduce the desired laser heating.

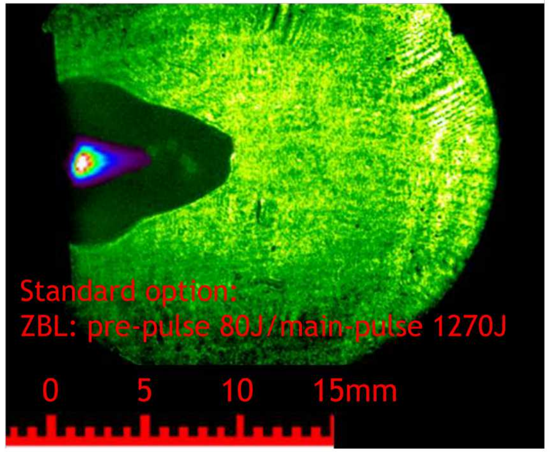
- Using ZPW in the co-injection mode to provide a pulse 25J/20ns before ZBL, the LEH window can be effectively dissembled before the main ZBL pulse arrival. ZBL can currently only generate pre-pulses within a 7ns temporal window.

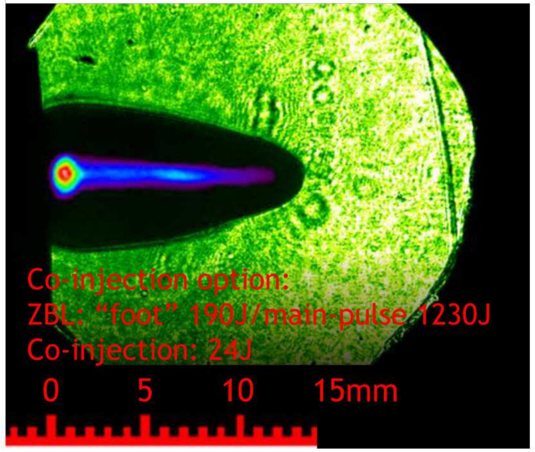
- This yields more effective heating over longer depths in the gas cell while also reducing the presence of “mix” from the window material into the gas volume.

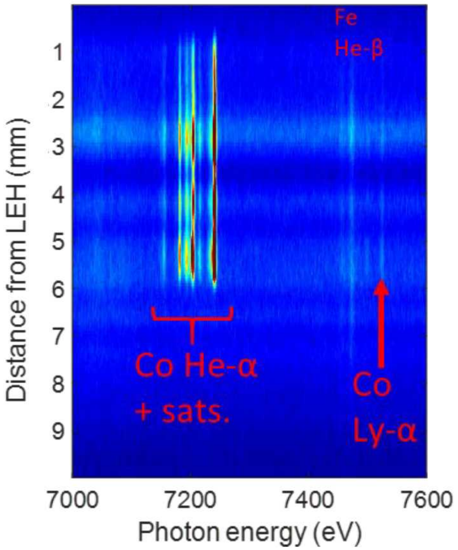
Impact of Co-injection on Mix in Co-doped LEH Windows

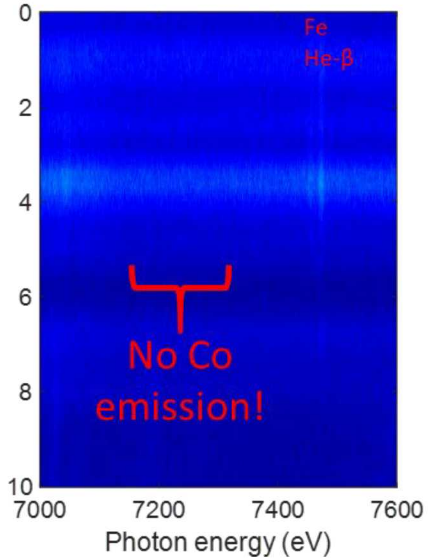
	z3057 ZBL only	z3143 Co-injection (13J)
Energy	111 + 1380 J	24 + 183 + 1626 J
Gas fill	0.7 mg/cc (5% n_{crit})	1.05 mg/cc (7.5% n_{crit})
LEH window	3 mm diam.; 1.77 μm thick	2 mm diam.; 1.77 μm thick
DD *(HYDRA)*	2.0e12 ± 20%	2.2e12 ± 20% *(2.4e12)*
T_{ion} (Ntof)	2.4 keV ± 20%	2.1 keV ± 20%

Gas cell experiments showing Shadowgraphy with X-ray Pinhole Camera Overlay
Both with 1100μm Phase Plate, 90PSI D_2 (7.5% n_{crit})

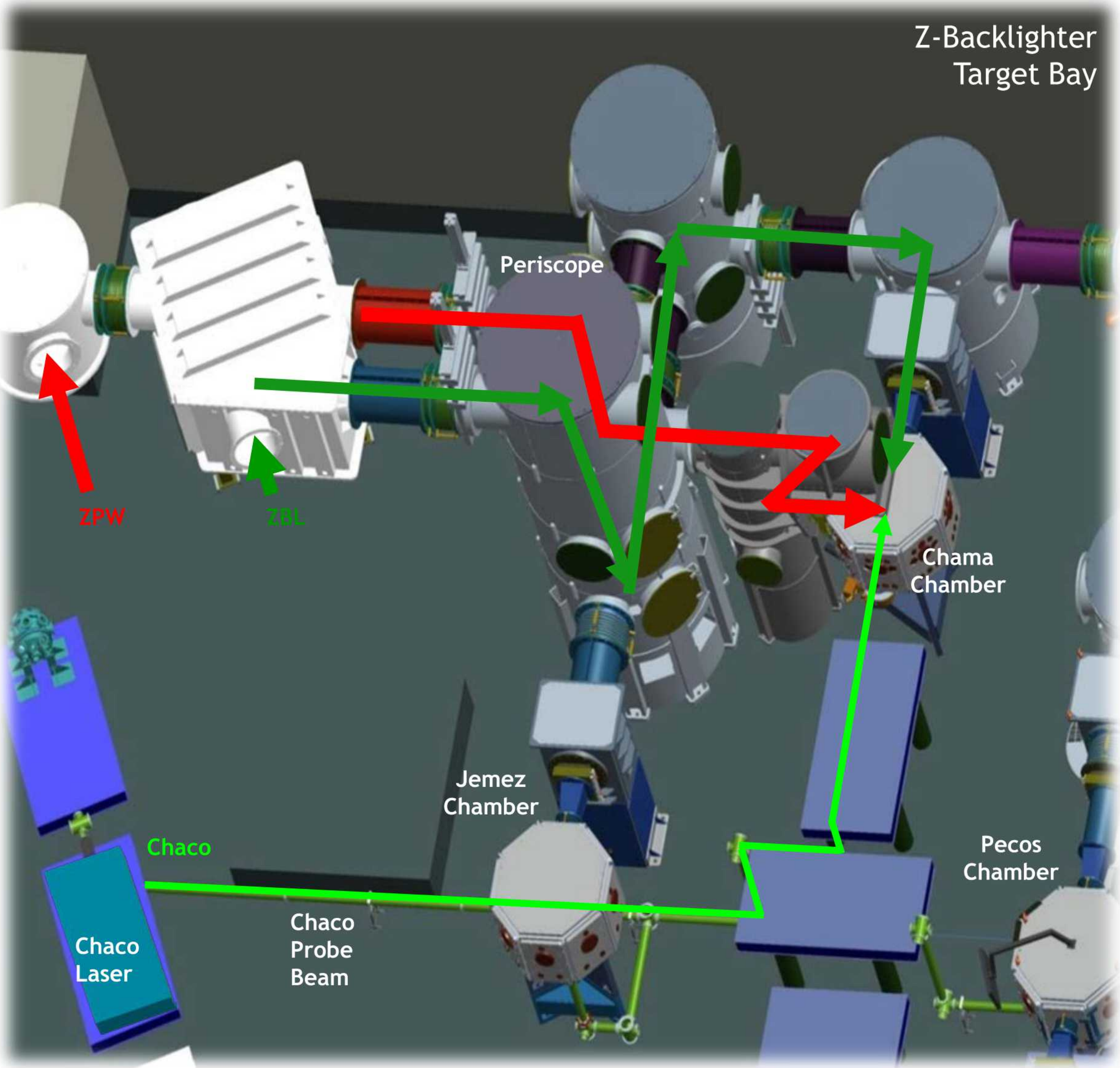


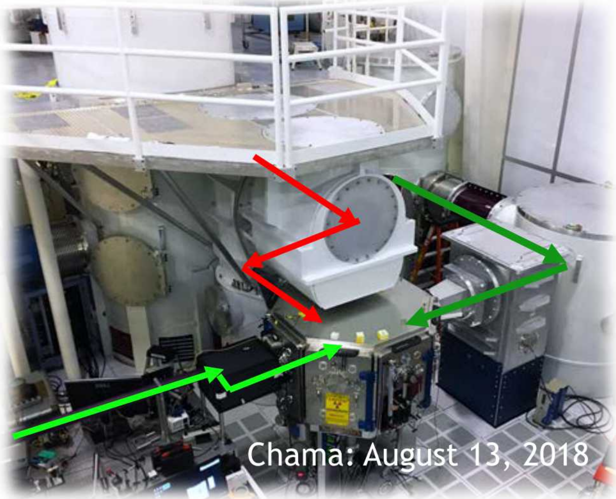


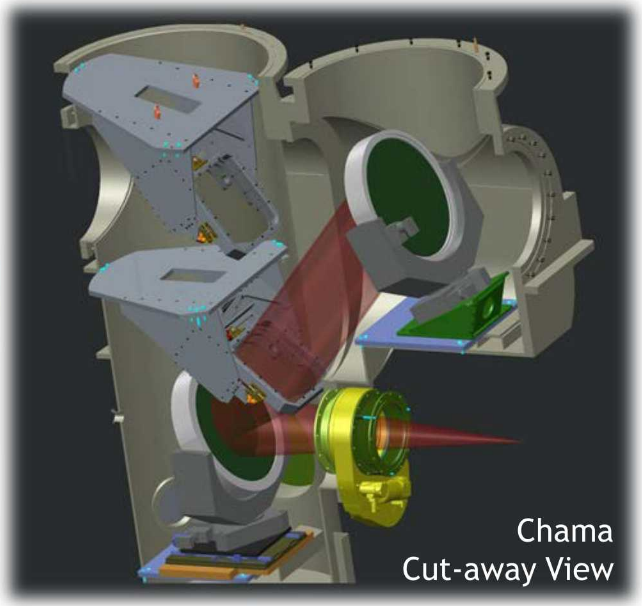




Z-Petawatt Short-Pulse Mode: Chama Chamber Activation





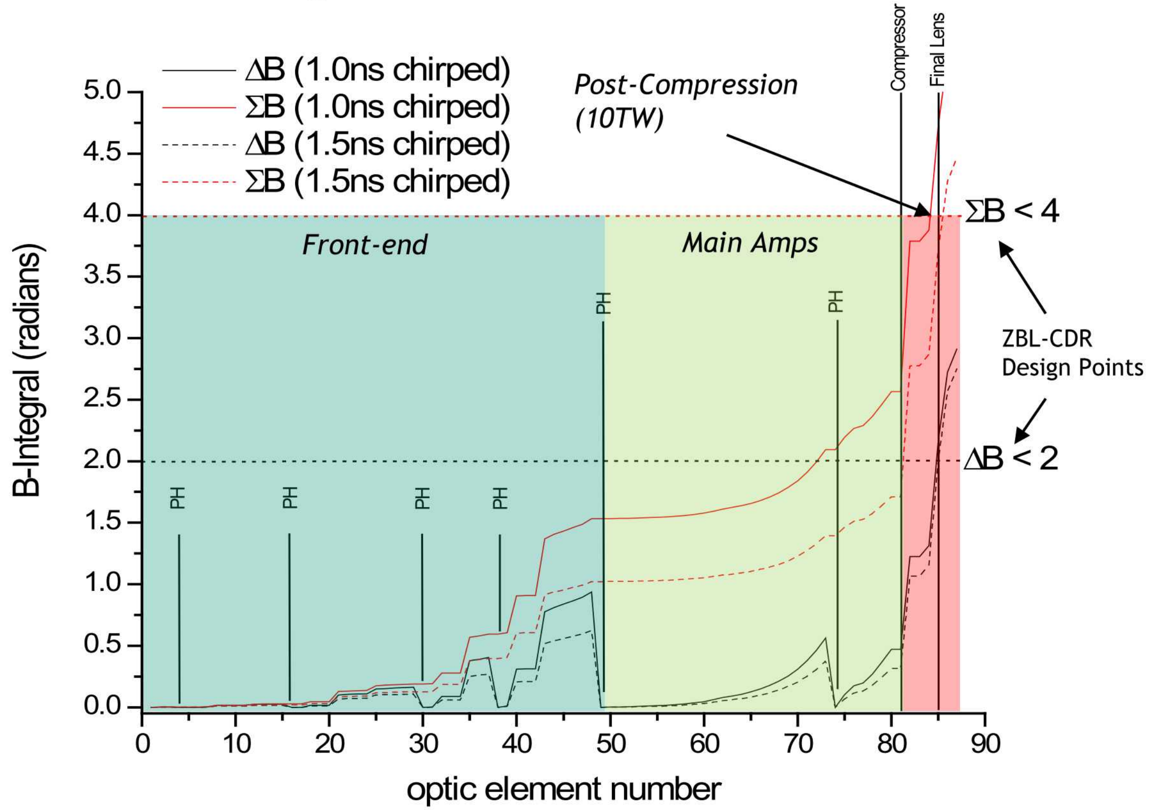


- **The last of 5 target chambers (Chama, in center) in our Target Bay was activated in mid-2017.**
- **The intended final OAP was exchanged for a lens and fold mirror with the same final focus position.**
- **The chamber is the only one in the facility that allows all three beams to interact at high energy.**
- **This capability is relevant for:**
  - **Pump-probe experiments (i.e. dynamic radiography, etc.)**
  - **Equivalent experiments between ZBL and ZPW**
  - **Dynamic diffraction efforts**

Z-Petawatt Short-Pulse Mode: Lens-Based Focusing

- Traditional CPA beam focusing by an OAP can be challenging while lens-based focusing has several advantages:
  - More cost effective at large aperture
  - More alignment tolerant
  - Allows common Z vacuum windows/ debris shields

- Highly chirped beams reduce the B-integral enough for this to work
  - Requires >1ns chirped duration in the amplifiers for targeted 10TW (1kJ/0.1ns or 2kJ/0.2ns) operation.
    - → Can be achieved with gain narrowing compensation methods (see Schwarz ICUIL 2018)

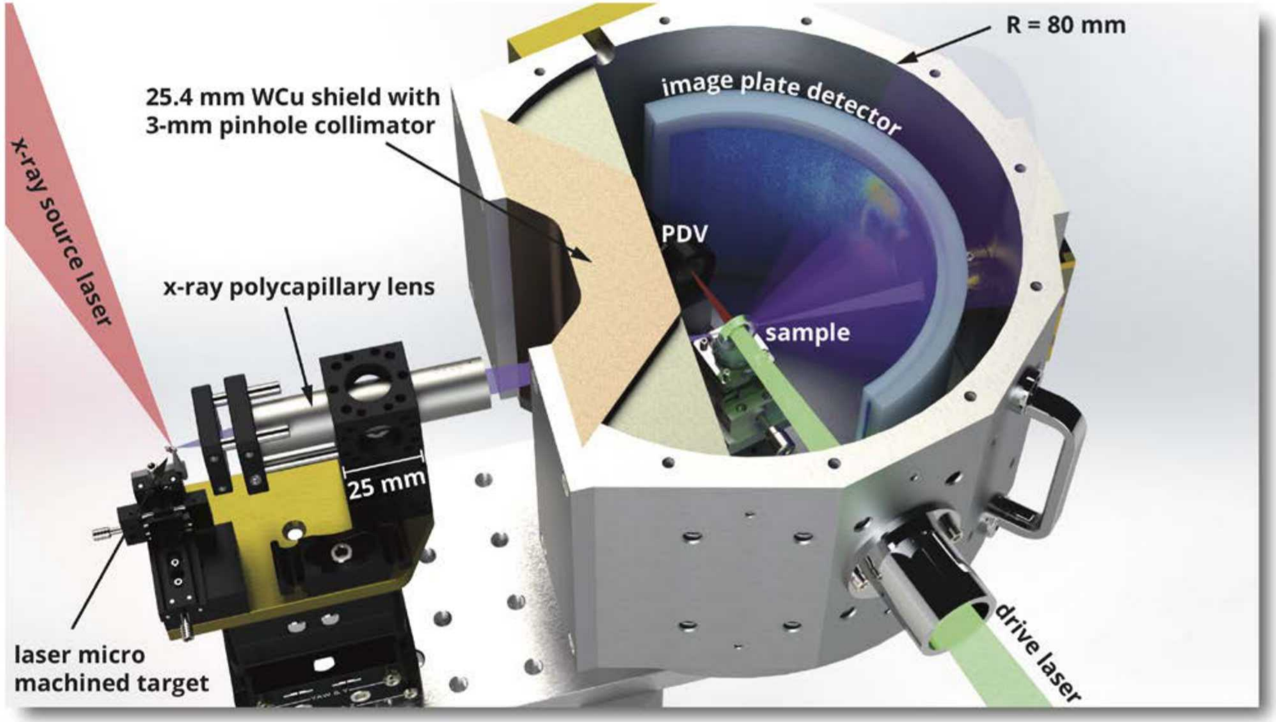


Parameters	Peak Strehl Ratio (SR)	$\Delta\lambda$ for SR>0.8	$\Delta\lambda$ for SR>0.5
f=2.0m; 39x39cm^2	0.772	0.0nm	2.3nm
f=2.0m; 32x28cm^2	0.831	2.2nm	4.4nm
f=3.2m; 32x28cm^2	0.997	4.1nm	7.3nm

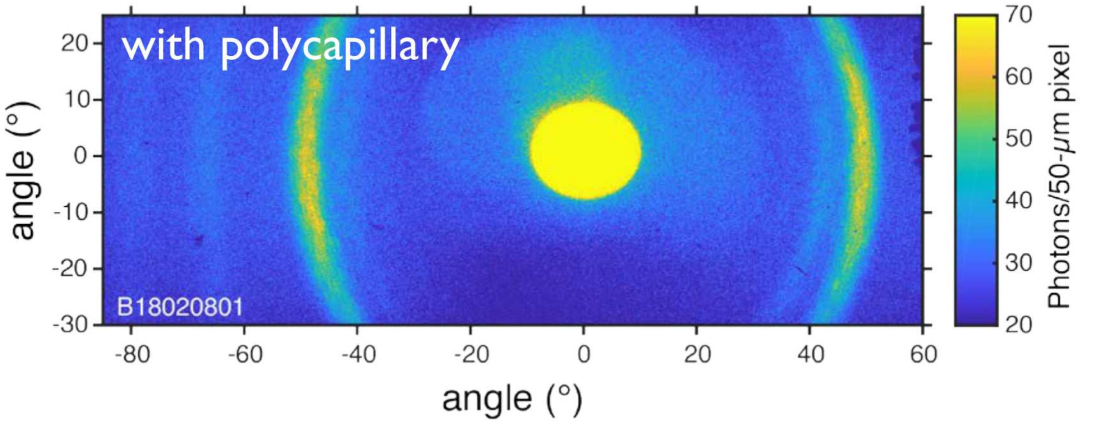
- Chromatic aberration does come into play even for the small bandwidths.
- The Strehl Ratio shows poor performance when one fills the full clear aperture of an aplanatic f=2.0m standard ZBL (as is current on Chama).
- This improves as one shifts to consider an f=3.2m ZBL aplanat with the designed beamsize for the full aperture upgrade.

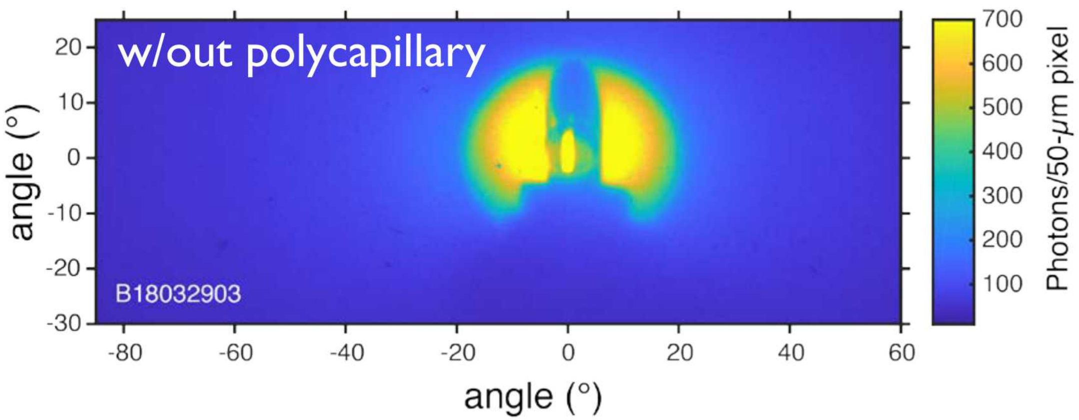
Z-Petawatt Short-Pulse Mode: Diffraction Application in Chama

- Time-resolved x-ray diffraction on shocked samples offers insight in material physics.
- Generally, ZBL is favorable for samples below requiring X-ray probes of <15keV while ZPW is favorable for >15keV.
- Testing at longer ZPW pulse durations (~100ps) is desired to yield strong K_α x-rays while mitigating bremsstrahlung x-ray contributions.
- Lens-based focusing works adequately in this range but background due to bremsstrahlung both directly from the laser target and indirectly from subsequent hot electrons is a challenge.

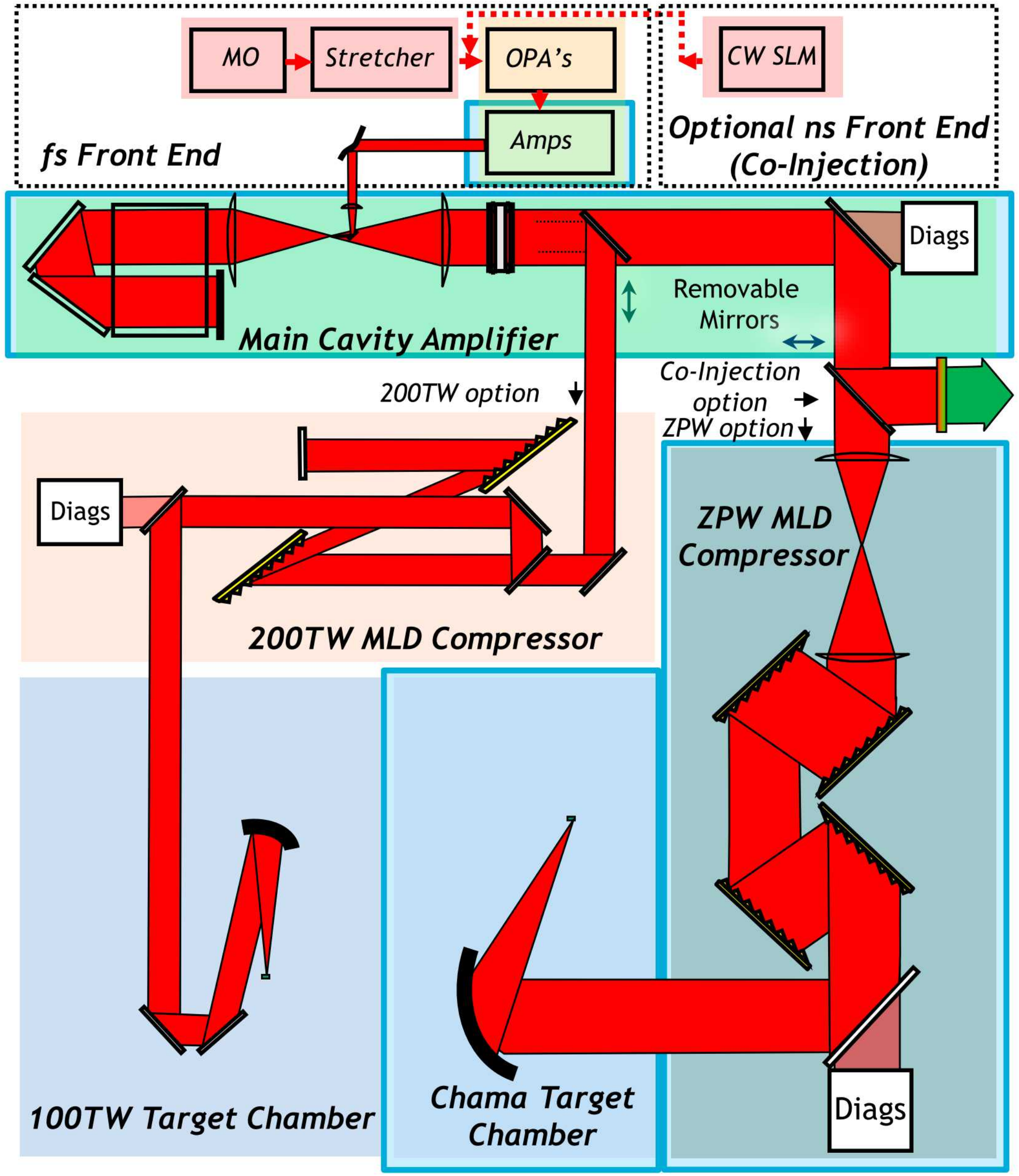


Cu K_α (8.05 keV.) incident on unshocked Be diffraction sample (1.3 mm.): ZPW@250 J/100 PS, I ≈ 10^{18} W/cm^2 → $N_{phot,sample}$ ~ 2×10^8



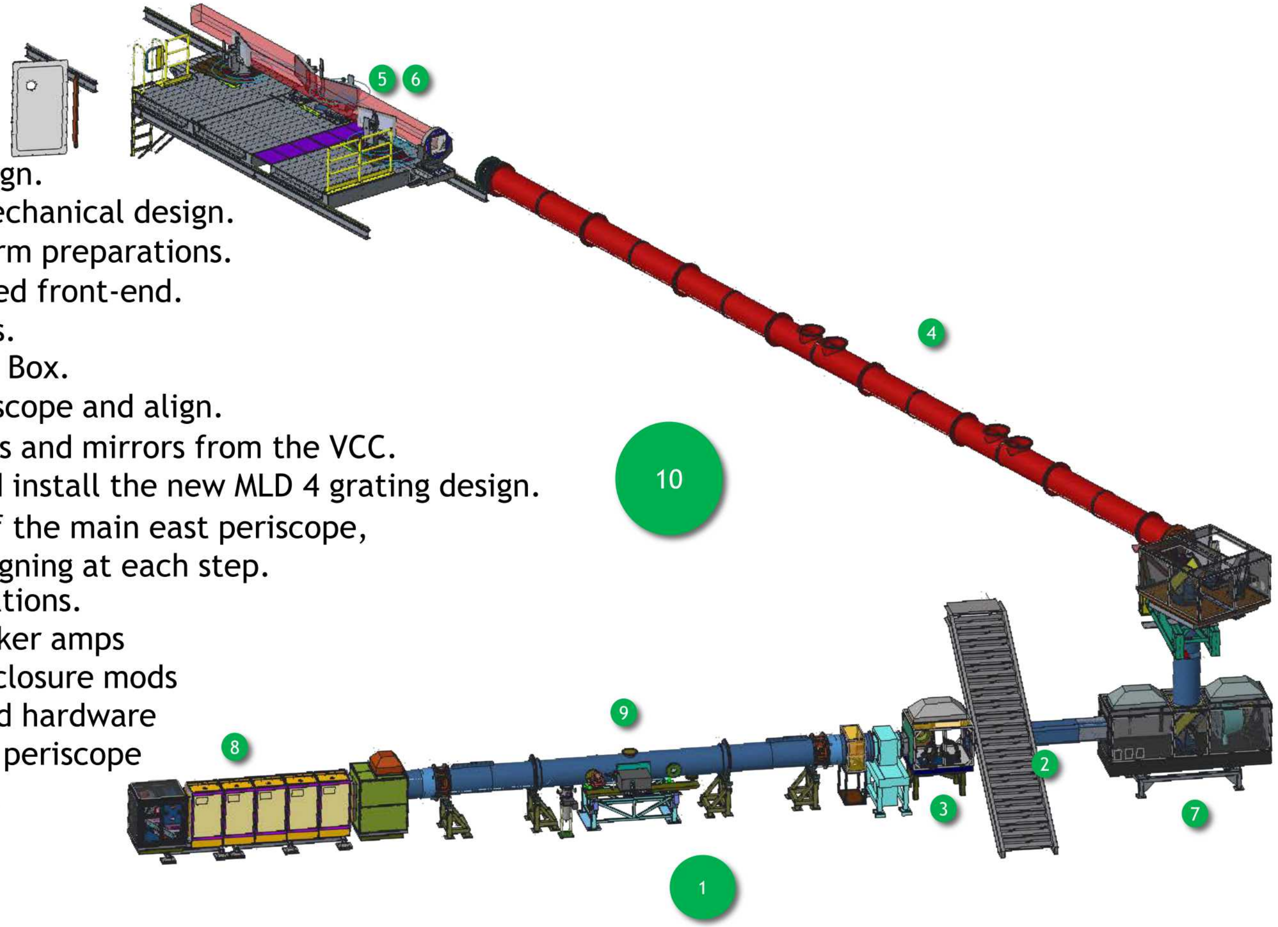


Z-Petawatt Future: The Full-Aperture Upgrade Motivations



- Full-aperture HEPW (1-2kJ/1054nm/500fs to 200ps)
  - High x-ray energies (>15keV) for backlighting and diffraction
- Full-aperture co-injection (1.5-2.5kJ/527nm/2ns)
  - Lower x-ray energies (<15keV) for
    - Backlighting w/ ZBL (flexible, tandem, tomography, etc.)
    - Diffraction w/ ZBL (flexible)
  - Additional energy for
    - Extra heating with ZBL on MagLIF
    - Improved ZBL x-ray yields
  - More ZPW energy is achievable by:
    - Increasing the seed energy into the main amps,
    - Switching to high LIDT MLD gratings, and
    - Switching to full-aperture amplification.

Z-Petawatt Future: The Full-Aperture Upgrade Planning



Backlighting Runs (Spring 2018)

- ✓ A. Perform the optical design.
- ✓ B. Perform the detailed mechanical design.
- ✓ C. Procure parts and perform preparations.

1. ✓ Commission the enhanced front-end.
2. ✓ Make stair modifications.
3. Move PEPC and Diverter Box.

After LDRD (Aug.-Sept. 2018 & Jan. 2019)

4. Replace the bridge telescope and align.
5. Remove existing gratings and mirrors from the VCC.

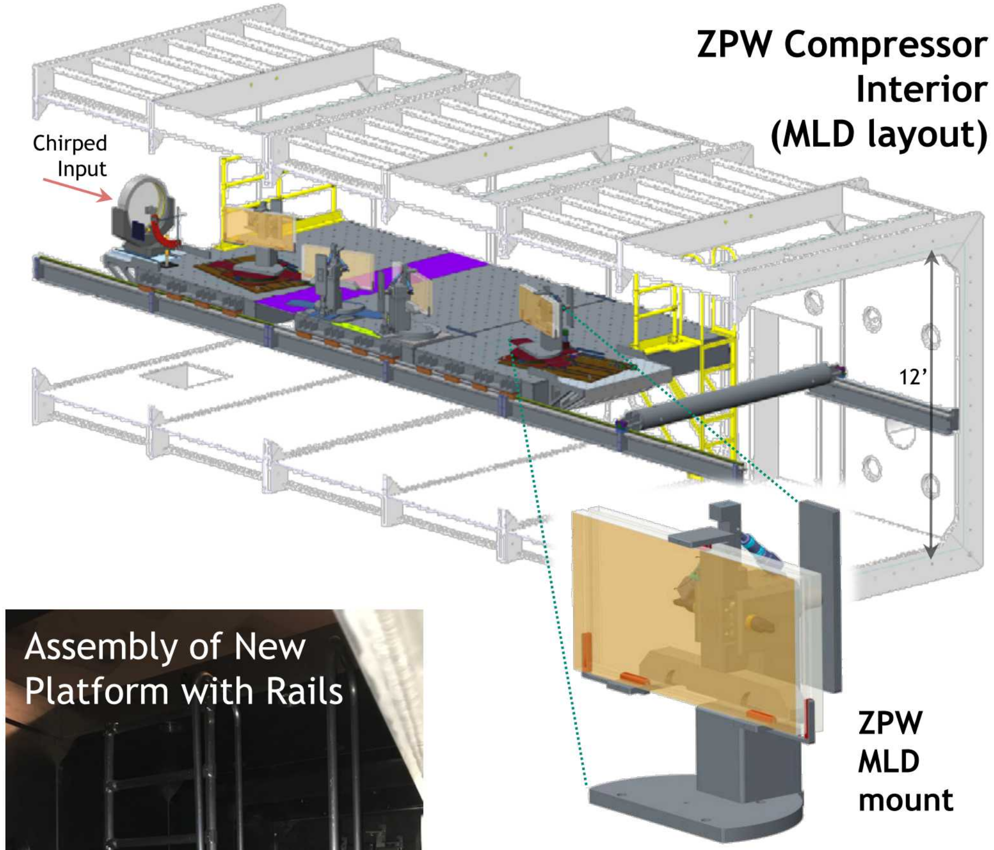
MagLIF Gap (Oct-Dec. 2018)

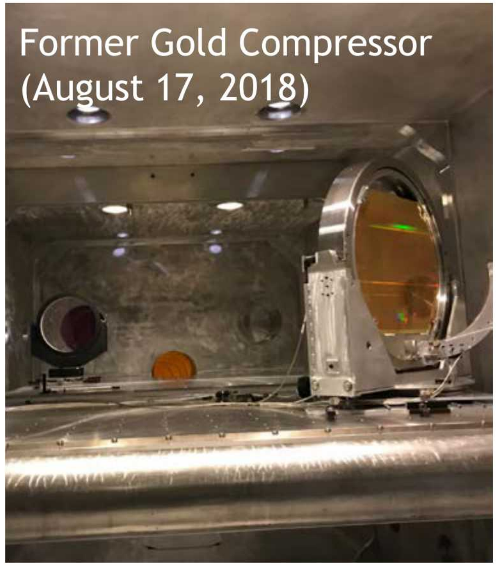
6. Modify the platform and install the new MLD 4 grating design.
7. Replace the 3 mirrors of the main east periscope, one at a time and re-aligning at each step.
8. Make west end modifications.
   - Remove 5 single decker amps
   - Make end mirror/enclosure mods
   - Remove the west end hardware
   - Install the new west periscope
9. Make VSF modifications.
   - Remove the lenses
   - Add the outriggers.
   - Add the new lenses.
   - Modify the pinhole area and injection point.
10. Align.

- ***Design involves 4-6 months of intermittent downtime for the entire switch.***
- ***About 3 months are needed for the VSF and amplifier area alone (co-injection downtime).***

Z-Petawatt Future: The Full-Aperture Compression and Focal Changes

- The vessel interior single-pass design will change from:
  - 2 single Gold gratings (1480 l/mm) to 4 single MLD's (1740 l/mm)
- The mechanical design:
  - Utilizes new bezel-free mounts with optimal clearance
  - Avoids fall protection and confined space concerns
- System Design Specs:
  - De-rated Energy Maximum (1.8:1 beam modulation) at 72° AOI :
    - 476J@500fs; 1.43kJ@10ps; 3.10kJ@200ps*.
- Progress:
  - Grating mounts are assembled and pending installation all gratings.
  - Disassembly of gold grating compressor is underway.





* See pulsewidth dependent LIDT testing of MLD gratings in Kong et al, *Optics and Laser Technology* and Alessi et al, *Proc.SPIE*, both 2015. Associated $\tau^{0.26}$ scaling* indicates LIDT@6.5J/cm^2 @ 200ps

Conclusions

- The Z-Backlighter Facility has recently made two key modifications to the ZPW system:
  - Co-injection (ns-scale 527nm aligned with ZBL) and
  - ZPW Chama target chamber activation.

- Both of these have had immediate experimental impact in the last 2 years for:
  - MagLIF applications and
  - Dynamic diffraction (respectively).

- The full-aperture upgrade, which increases the available laser energy to the multi-kilojoule range, is underway and promises to create new opportunities at our facility.