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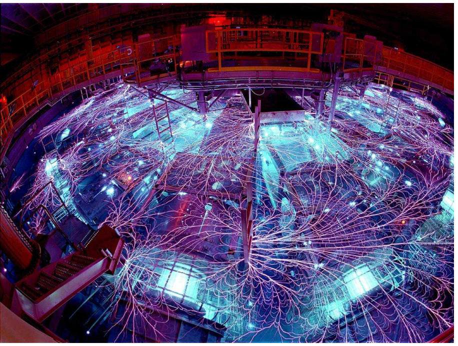

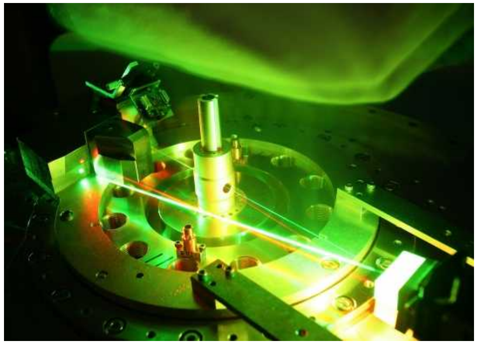

Z-Backlighter: Past - Present - Future

Jens Schwarz

Patrick Rambo, Ian Smith, Jonathan Shores, Shane Speas, Mark, Kimmel, Darrell Armstrong, Matthias Geissel, Marius Schollmeier, Ella Field, Damon Kletecka, and John Porter

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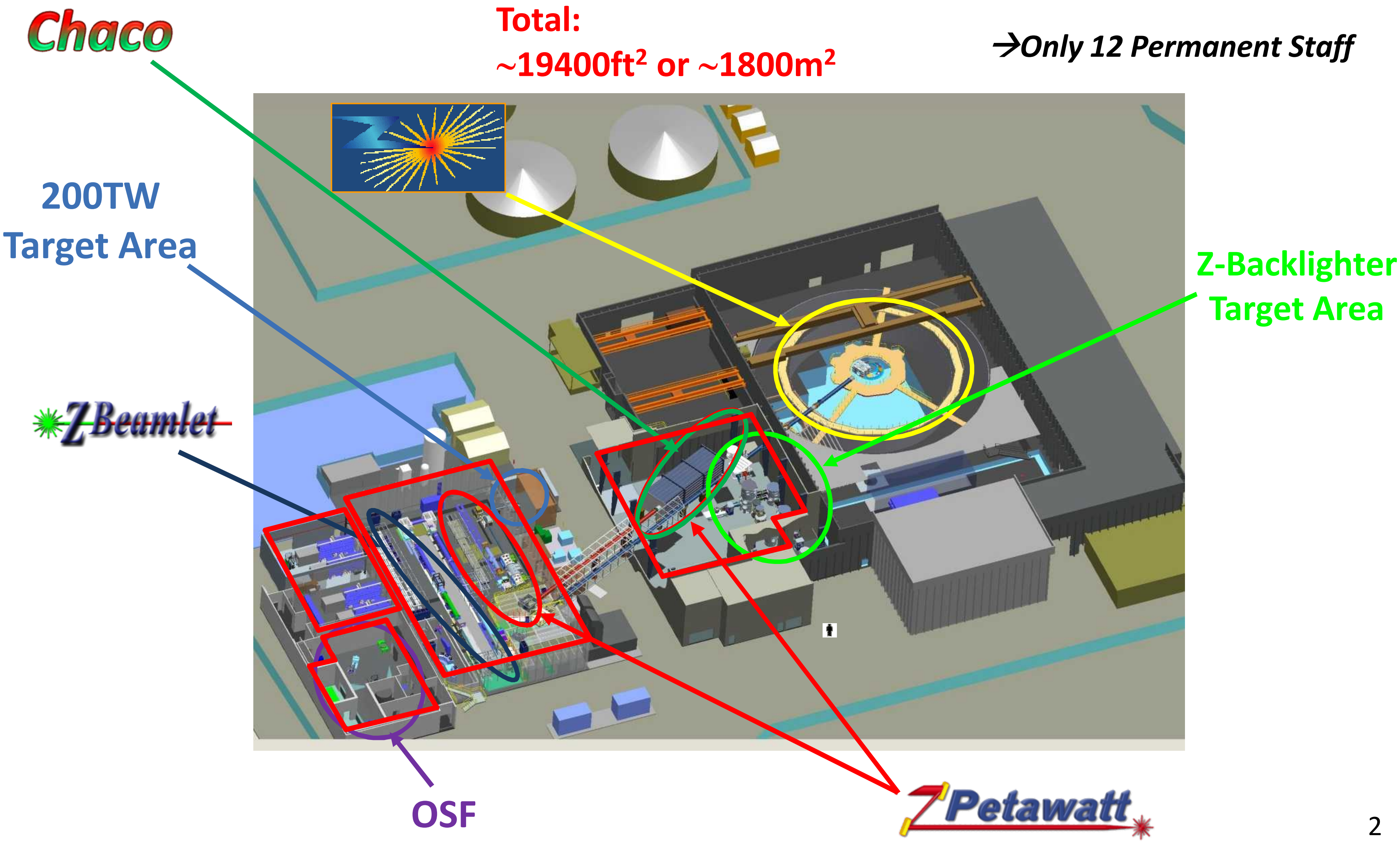
Z-Backlighter Facility



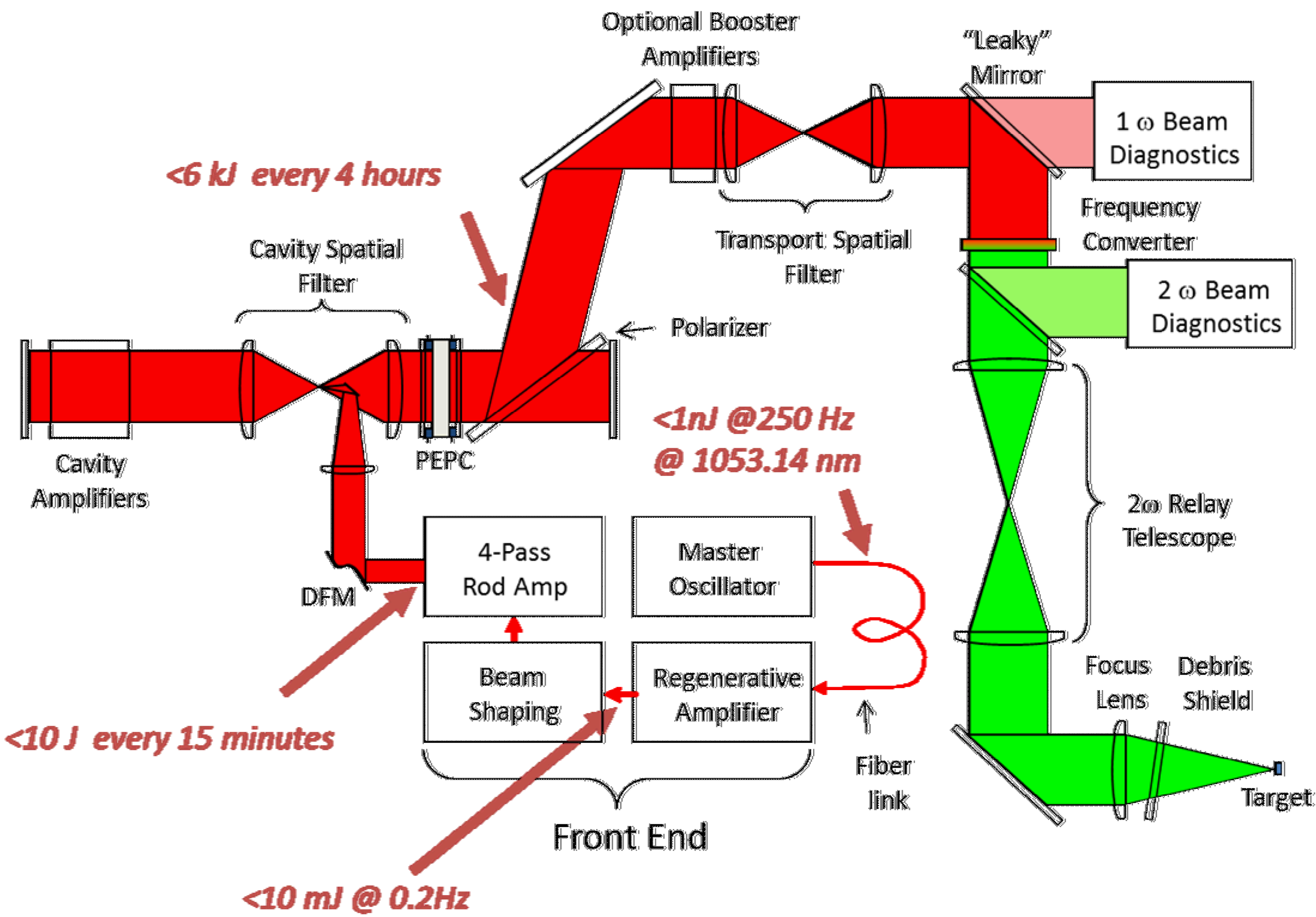
From Beamlet to Z-Beamlet

- The Beamlet Laser was conceived by LLNL in the 1990s as the prototype laser for the National Ignition Facility (NIF).
- It was operated from 1994-1997 and later shipped to Sandia National Laboratories where is was rebuilt and started it's life as Z-Beamlet in 2001.

Beamlet Laser at LLNL

Z-Beamlet Laser at SNL

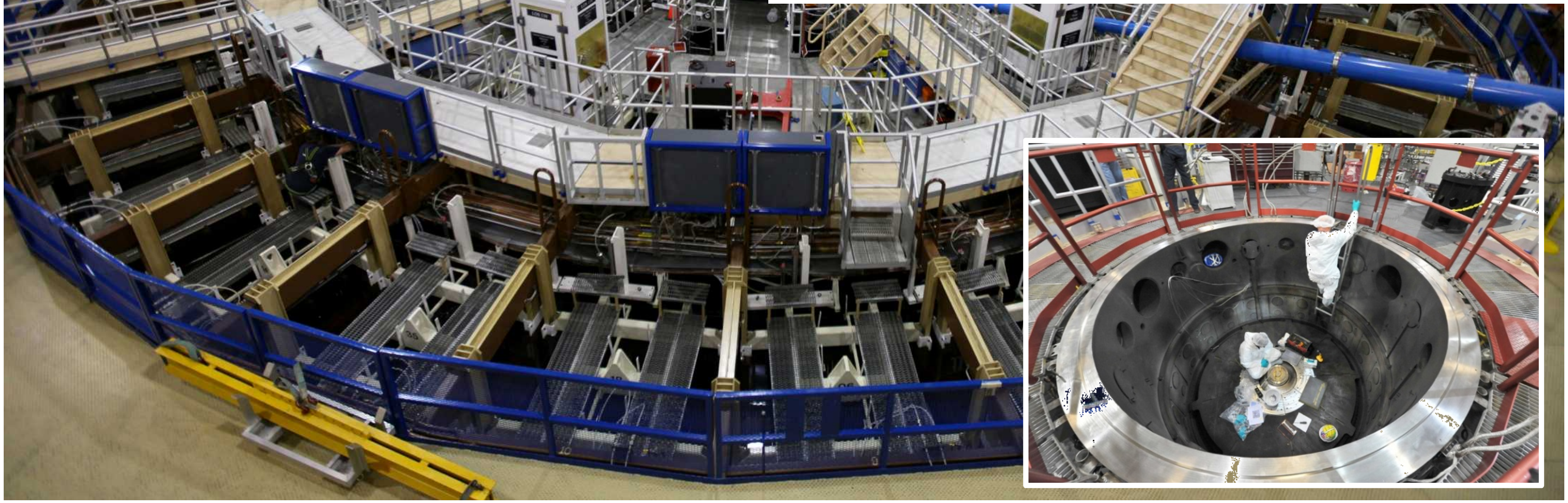
Basic Z-Beamlet Architecture



Backlighting of various HED events

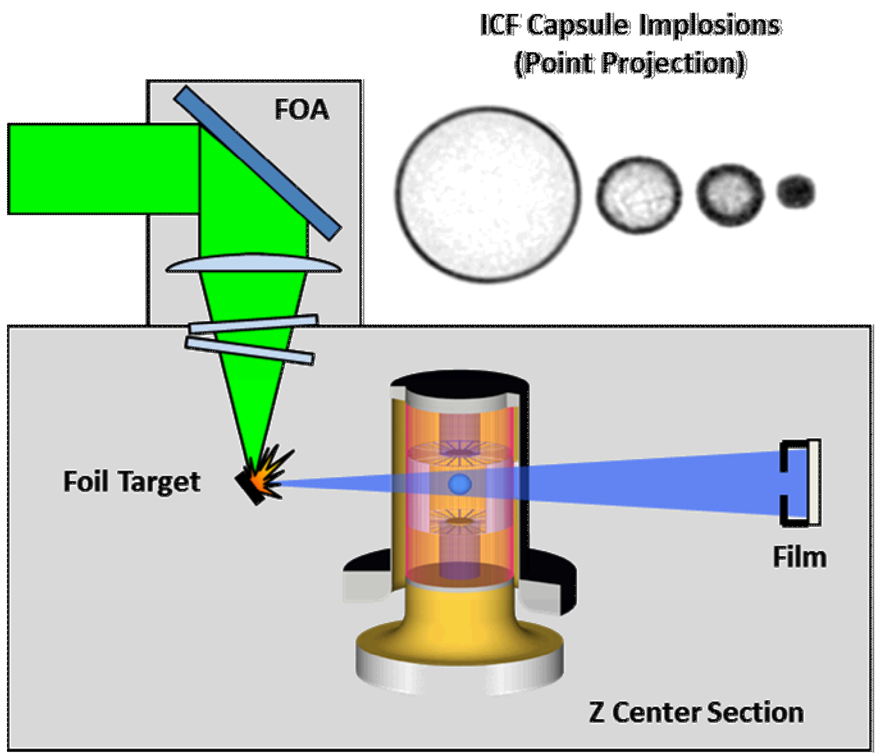
Sandia National Laboratories

- 36 modules
- 11-27 MA, 22 MJ electrical energy
- 100-300 ns pulse lengths
- Staff: ≈250
- ≈150 shots per year
- Large array of diagnostics for power & energy, spectroscopy, imaging, shock, neutrons + high-energy laser



Backlighting of various HED events

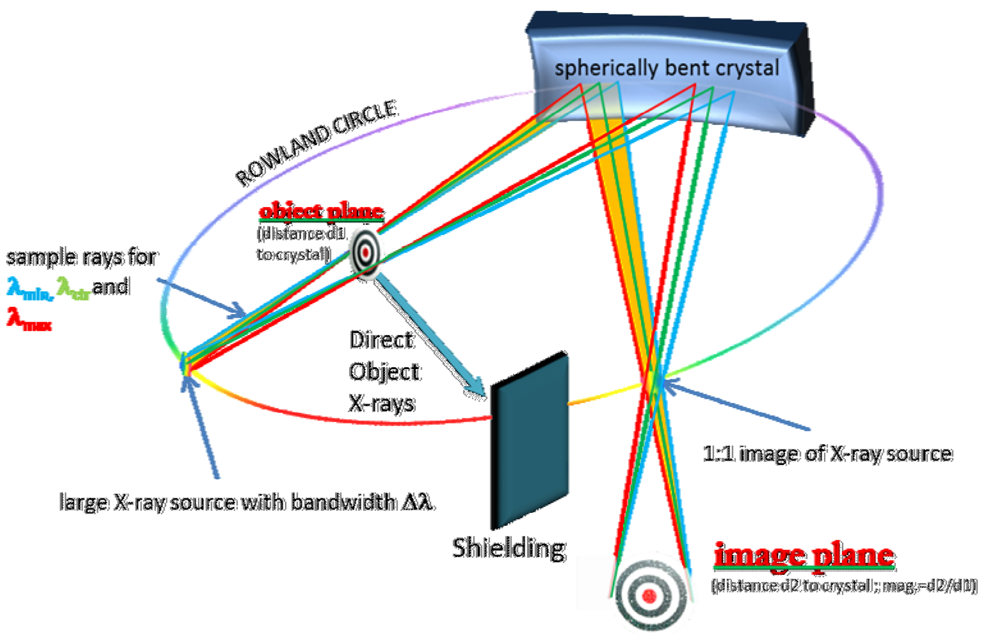
- Point-projection was first used to image HED events
  - Advantage: Most simple to implement
  - Disadvantage: Low resolution, small FOV, detector damage

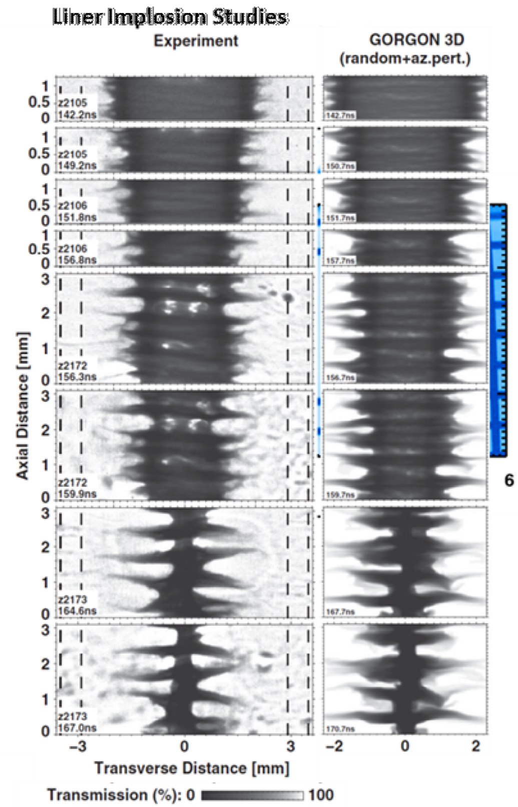


Point-Projection to Crystal Imaging

Sandia National Laboratories

- Early point-projection images lagged resolution and SNR
- As a result, crystal backlighting was developed in 2003.

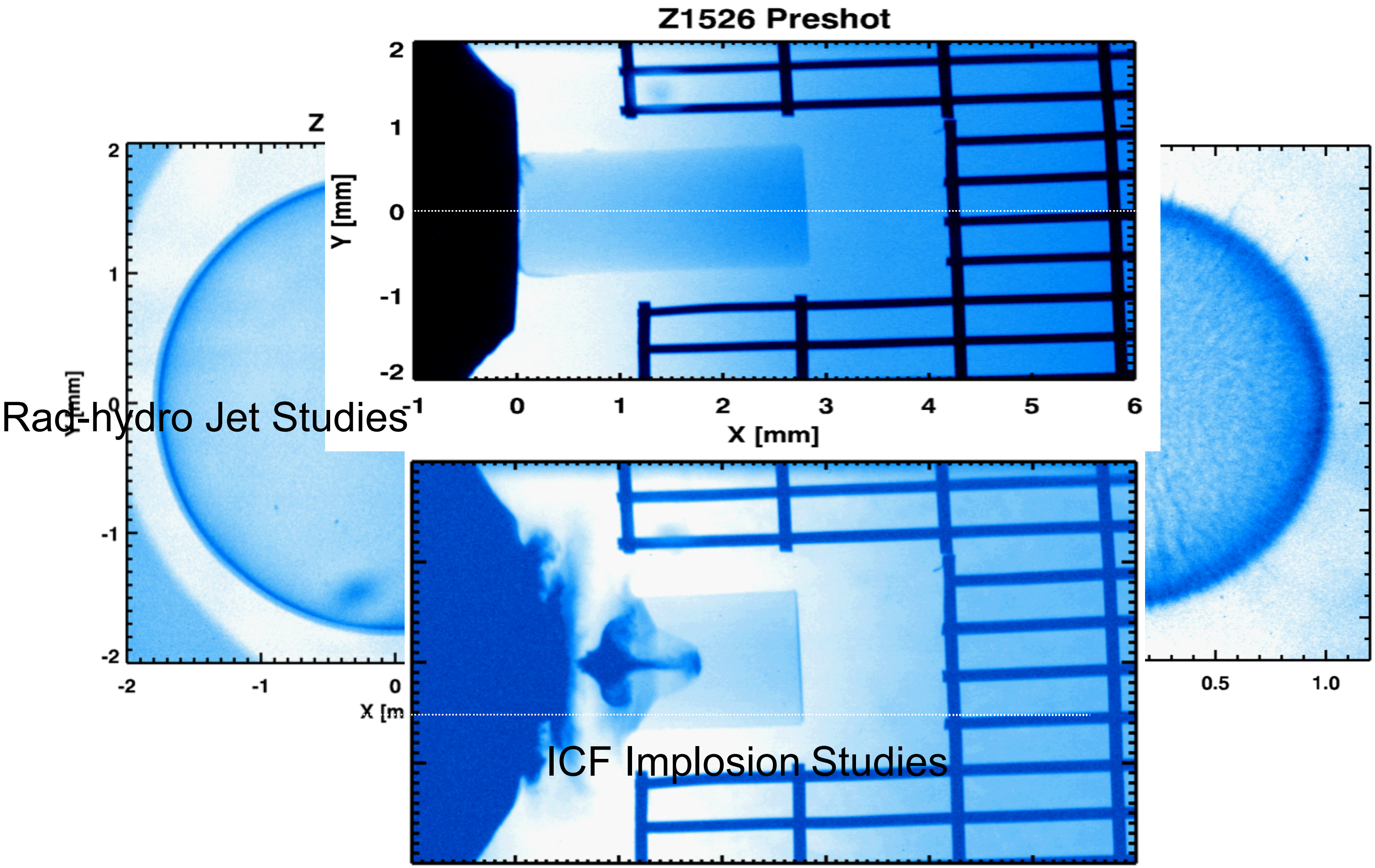




*R.McBride *et al.*, PRL 109, 135004 (2012)

Bent crystal x-ray imaging improves monochromaticity, resolution, and field of view

Single Frame Backlighting



Taming the unique Z environment

Pre-shot photo of target hardware

spherical crystals

laser target + camera

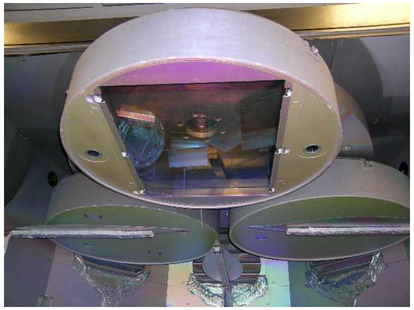
return aperture towards image plate detector

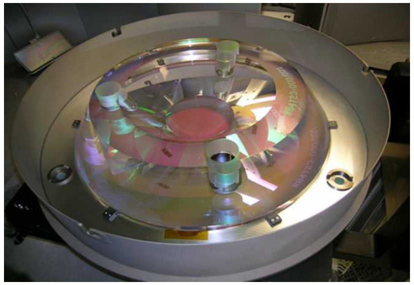
Post-shot photo

Optics Support Facility

- A steady supply of AR-coated debris shields and vacuum windows is needed: 50/year of each
- To this end, the Z-Backlighter facility installed a 90" coating chamber into a Class 100 cleanroom area with optical metrology capabilities.





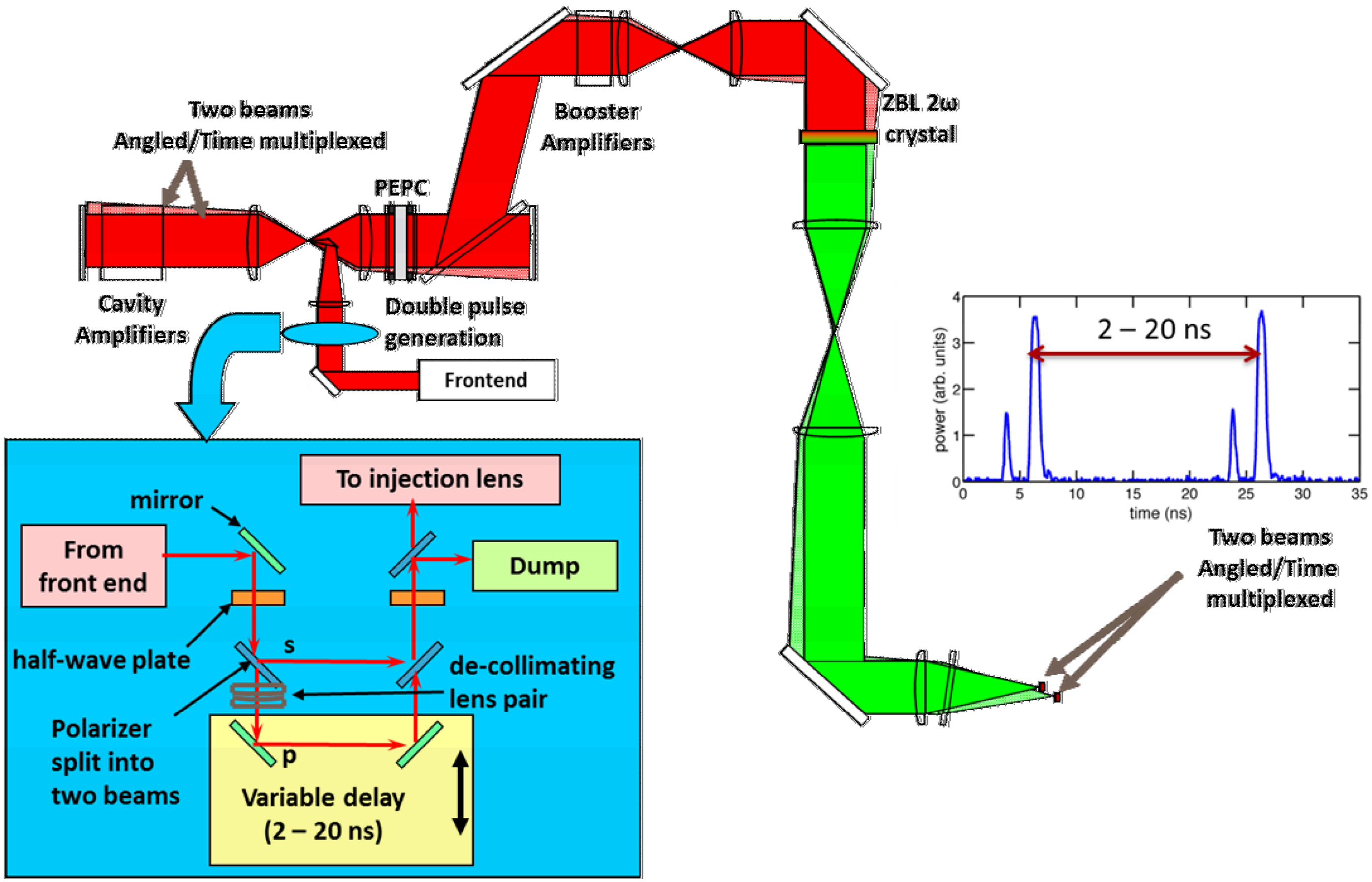



Optics Support Facility

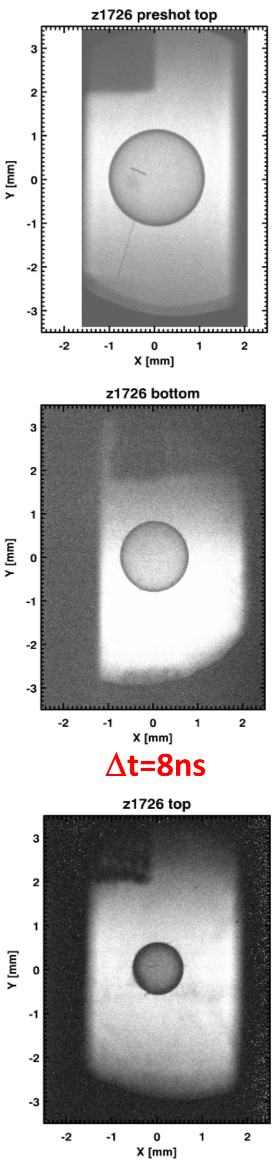
- Coatings:
  - Materials: HfO_2/SiO_2, (Al_2O_3, TiO_2, Nb_2O_5, Ta_2O_5) also used
  - Deposition methods: e-beam, ion-assisted deposition e-beam
  - Single-run size capability: 3 optics at 94 cm, 1 at 1.5 m option
- Metrology: Spectrophotometer, Large-area reflectometer, Interferometer
- Independent ns-laser damage testing (SPICA) shows good damage thresholds:
  - 17-25 J/cm2 for AR coatings
  - 75-85 J/cm2 for HR coatings
- Newest coating developments:
  - Broad bandwidth mirrors for fs-class PW laser pulses (RAL)
  - Dual wavelength beam splitter coatings for 527 and 1054 nm

Two-frame Backlighting

- Pretty soon, experimenters asked for multi-frame backlighting



Two-frame Backlighting

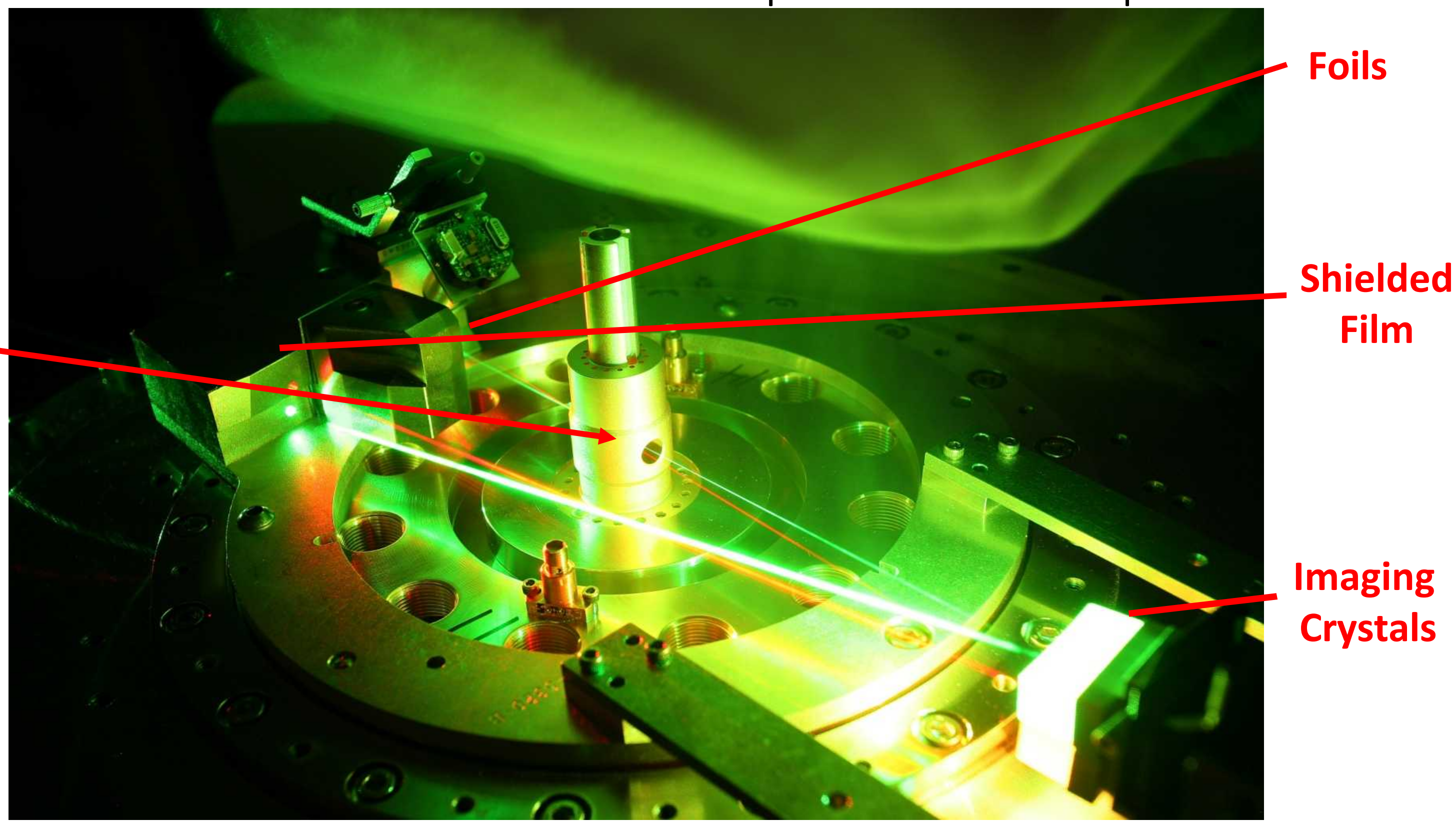


X-ray sources:

- Si He_{α} (1.865 keV) and/or
- Mn He_{α} (6.151 keV)

Imaging parameters:

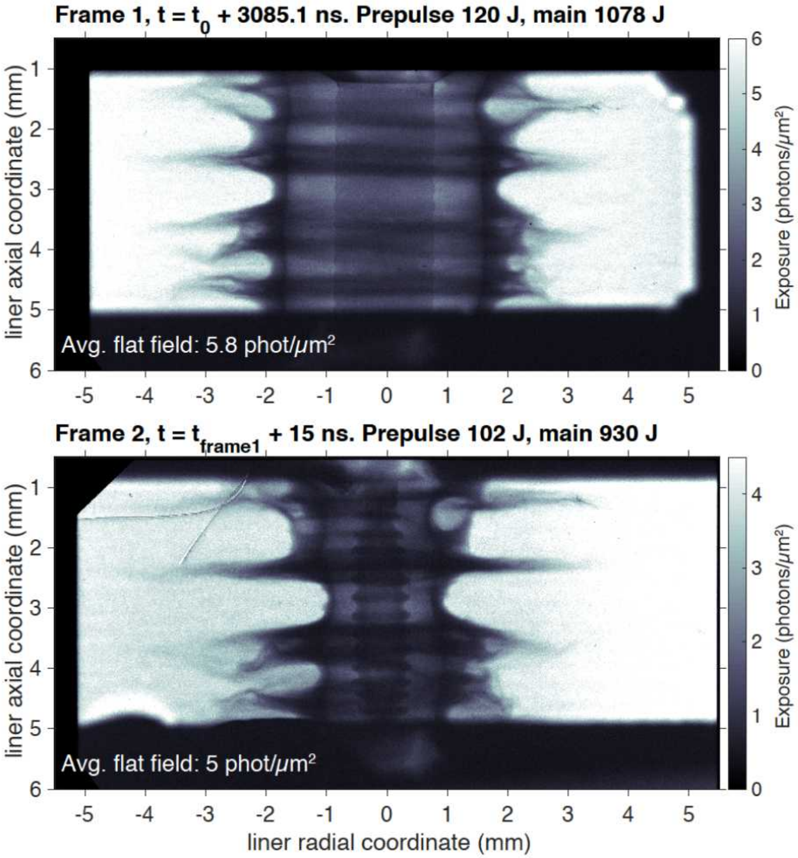
- FOV: 11.7 x 4 mm
- Magnification: 5.8
- Spatial resolution: 12 μm



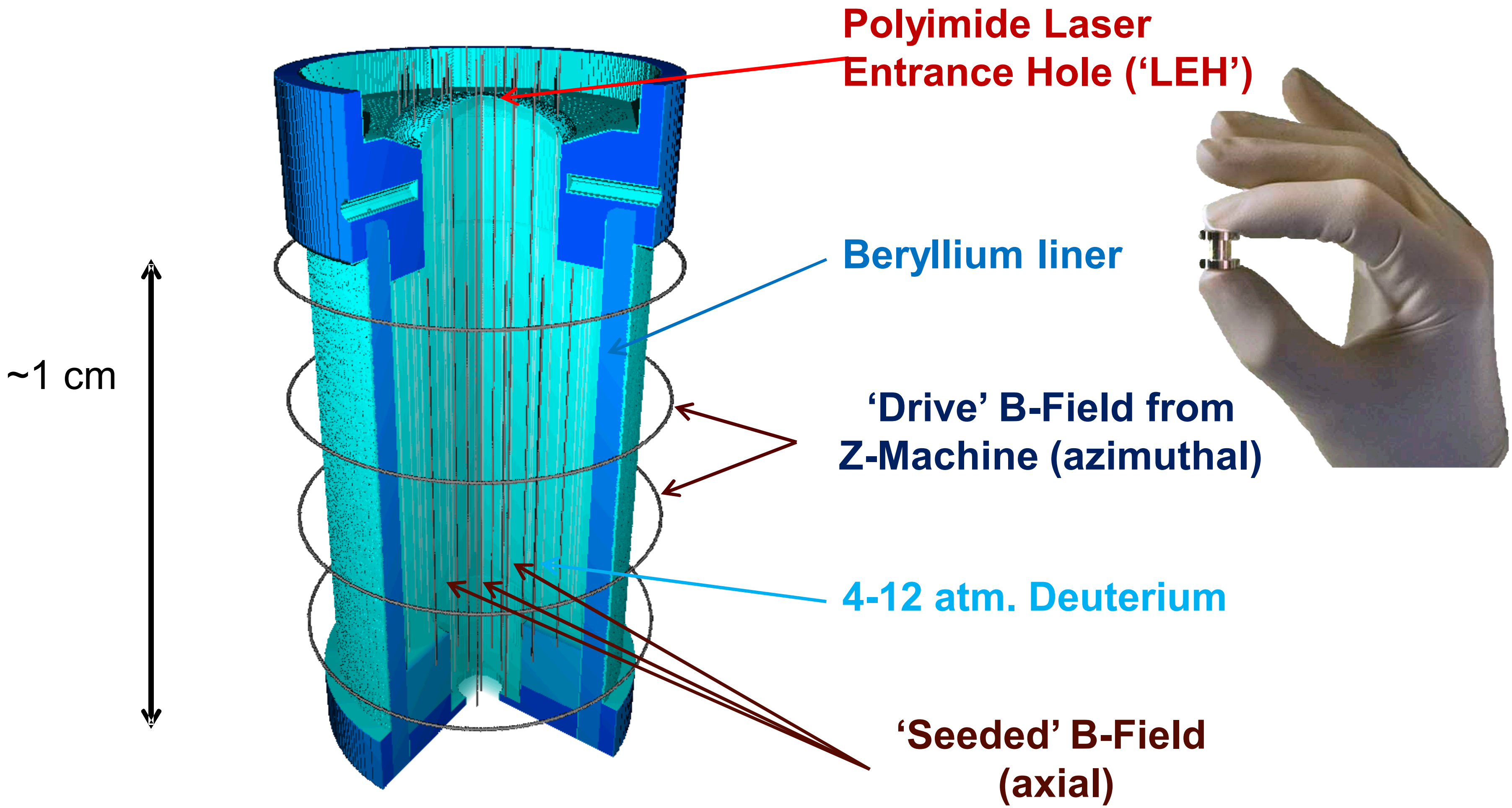
Higher Energy Backlighting (7.2keV)

- Now that we have two frames, how about higher energy?
- Development of 7.2 keV backlighting followed.

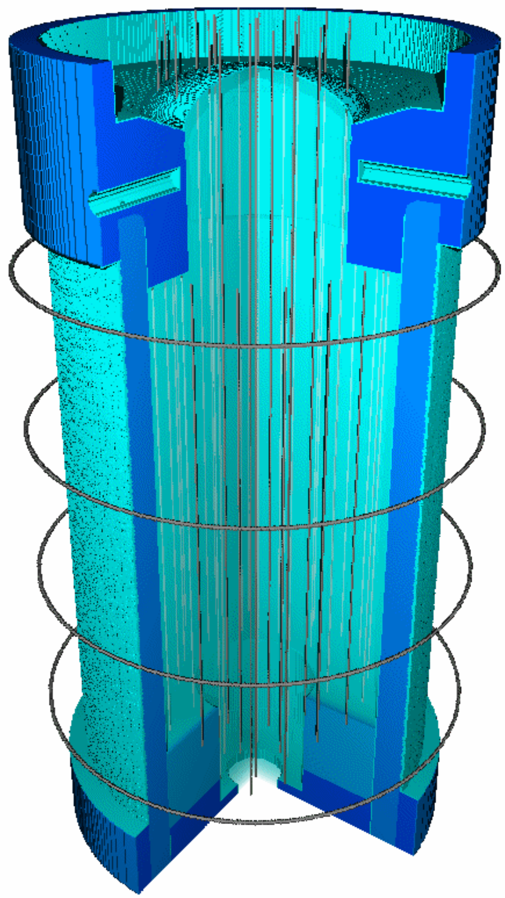
- Specifications:
  - 7.242 keV Co He-α resonance
  - Ge (335) crystal imager
  - Bragg angle close to 1.87 keV and 6.15 keV systems, facilitating two-color radiography



From Diagnostic to Fusion: MagLIF

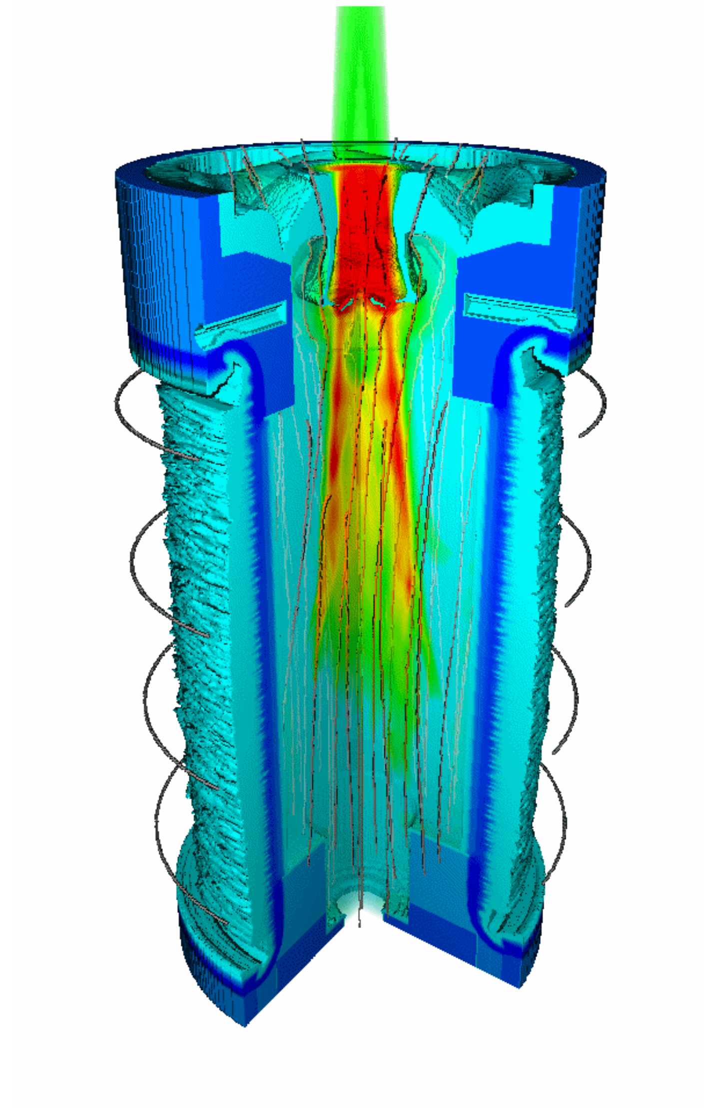


Magnetized Liner Inertial Fusion

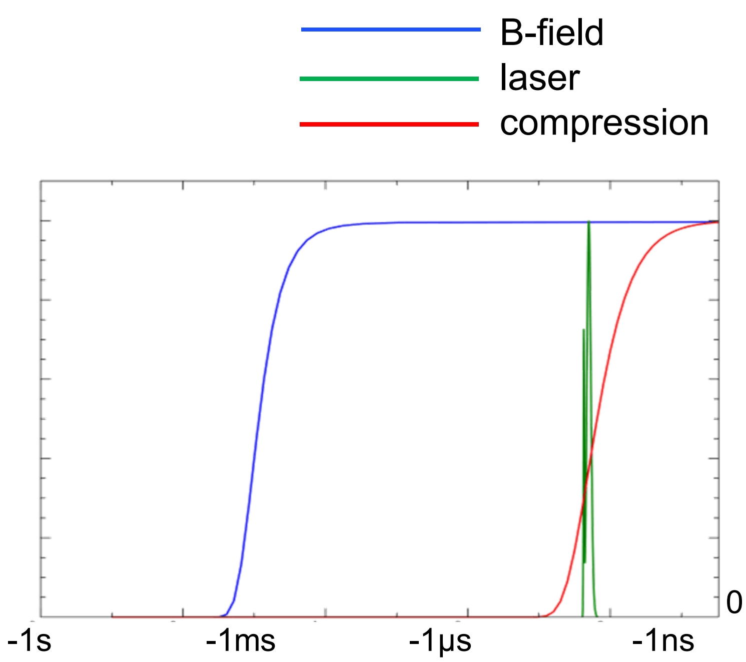


- B-Field from Z machine drive current starts to compress the Be lines and fuel
- Z-Beamlet injects several kJ of energy at 527nm into fuel
  - Magnetization of fuel
  - Minimizes heat conduction losses
  - B-Field compression
  - Stagnation temperature is proportional to initial temperature

Magnetized Liner Inertial Fusion

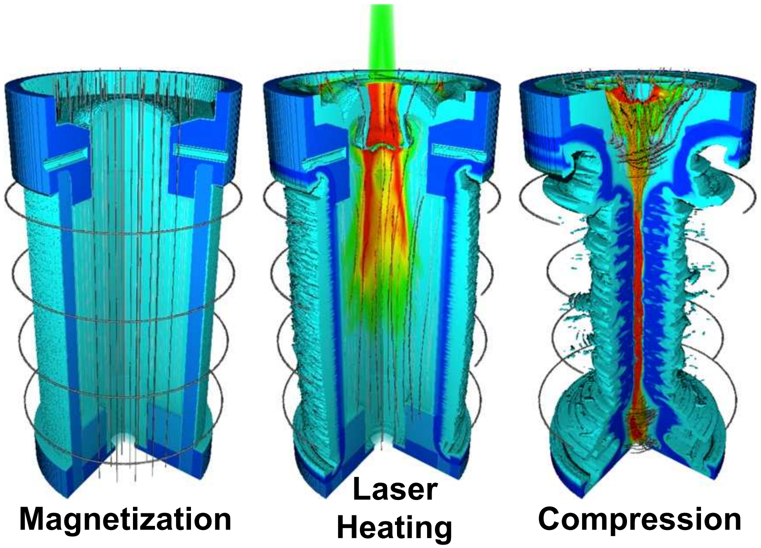


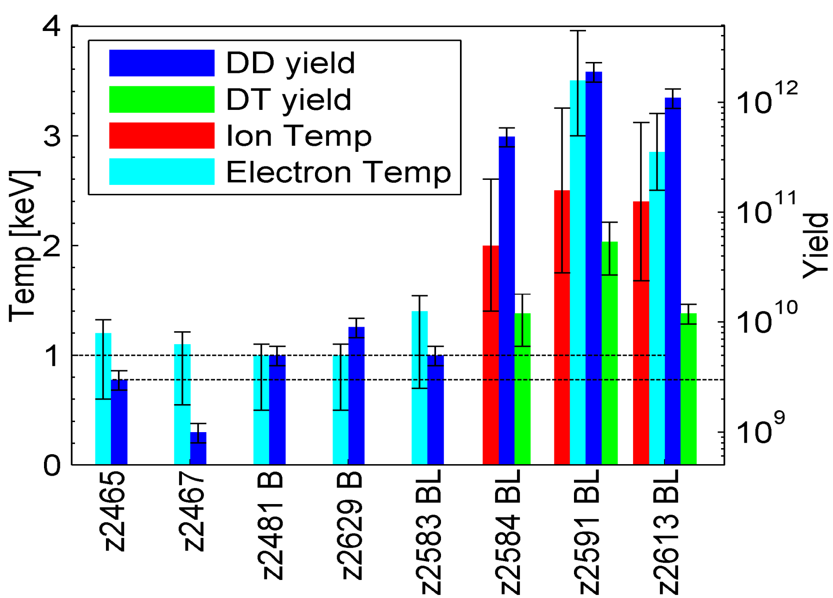
- Fuel compresses to densities and temperatures enabling thermonuclear fusion



Magnetized Liner Inertial Fusion

Sandia National Laboratories



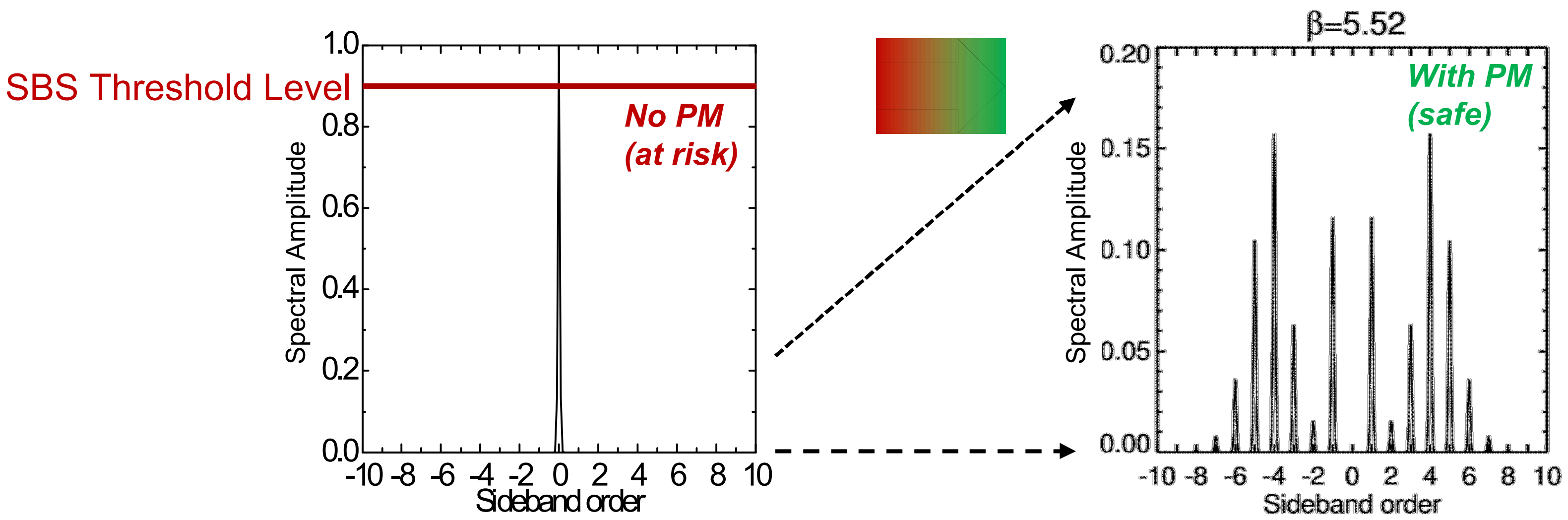


- Point Design:
  - 30 Tesla initial magnetic field
  - Laser heating of ~3 mg/cm^3 D_2 fuel produces ~250 eV plasma
  - Thick (AR=6) Be liner with R_0=2.7 mm, peak velocity ~100 km/s for a 27 MA peak current drive
  - At stagnation the fuel absorbs 120 kJ, reaches 8 keV and ~0.5 g/cm^3, and is highly magnetized at 13500 Tesla
  - Yields >100 kJ predicted in 2D

S. Slutz et al.: Physics of Plasmas **17**, 056303 (2010)

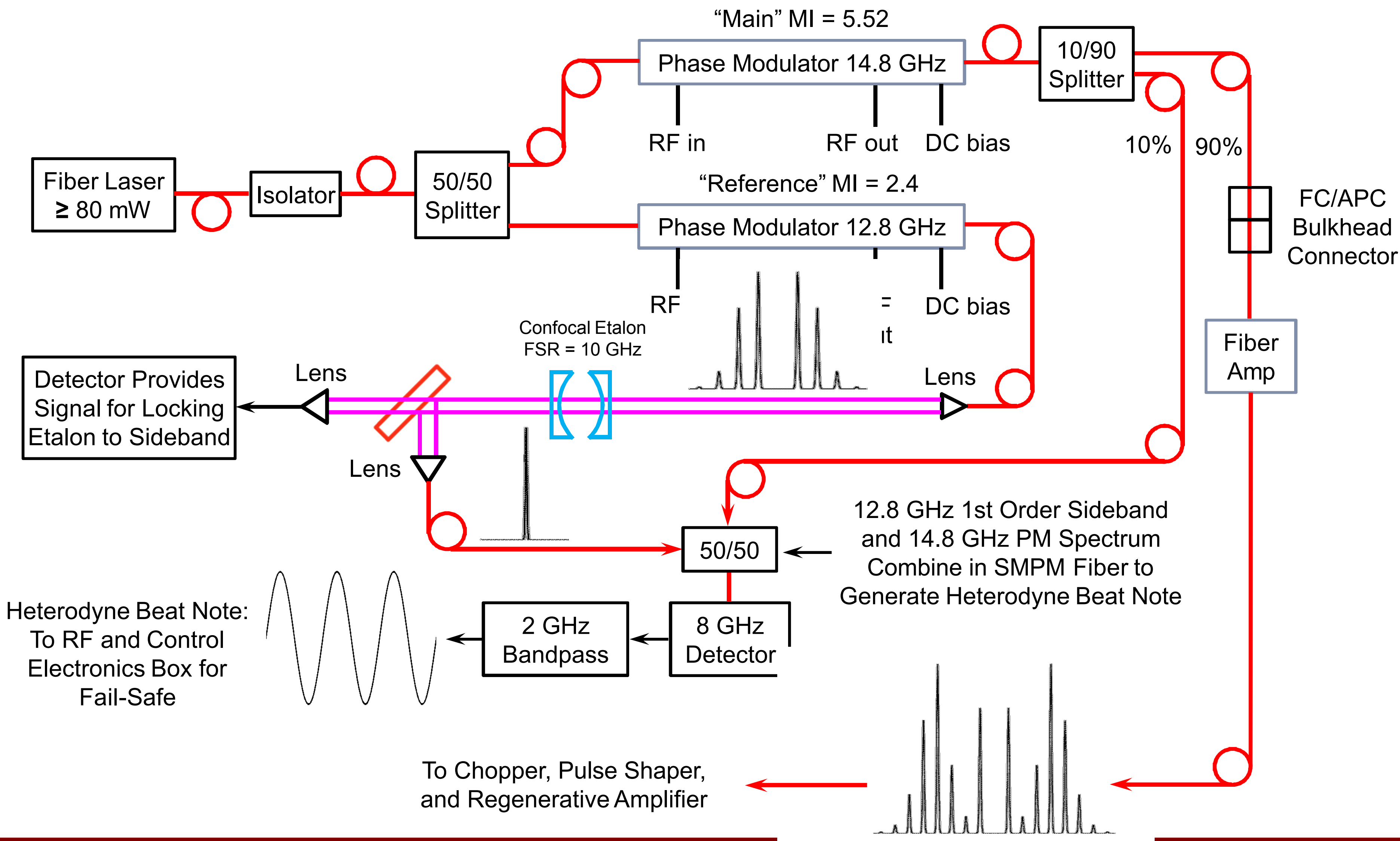
Backlighter Driver: SBS suppression

- High intensity laser beams generate acoustic waves in a large aperture medium so that the waves can amplify, leading to optical scattering, energy instability, and optical damage.
  - Estimated SBS threshold for a desired 4ns FWHM pulse: 5.2kJ
- Adding spectral sidebands is needed for SBS suppression



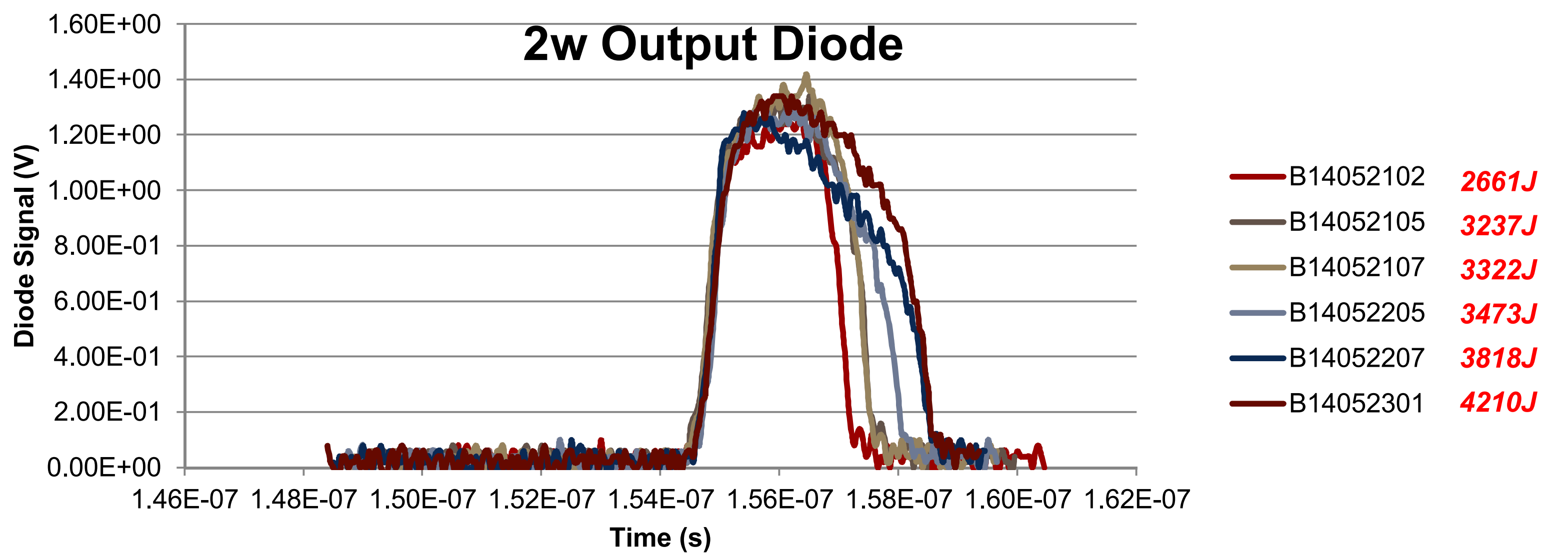
J. Murray *et.al*, J. Opt. Soc. Am. B **6**, 2402-2411 (1989)

Design for PM and Heterodyne



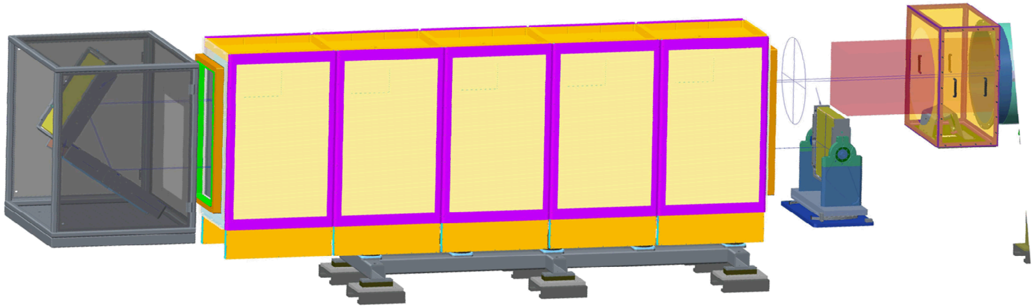
SBS suppression: Results

- Achieved FM->AM compensation in fiber transport and regen by installing a grating compressor and a BRF
- Tested PM failsafe system
- Demonstrated 5.6/4.2kJ at 1ω/2ω with 3.6ns pulsewidth



Adding Boosters for Z-Beamlet

- SBS suppression allows up to 5 booster amplifiers, each adding about 500J of stored energy (11+5)*500J=8kJ at 1054nm
  - Maximum extractable energy: 6 kJ at 527nm
- One booster was activated this last year using spare circuits
- Further booster activation would require a modification of the PW amplifiers in order to free up pulsed power circuits.

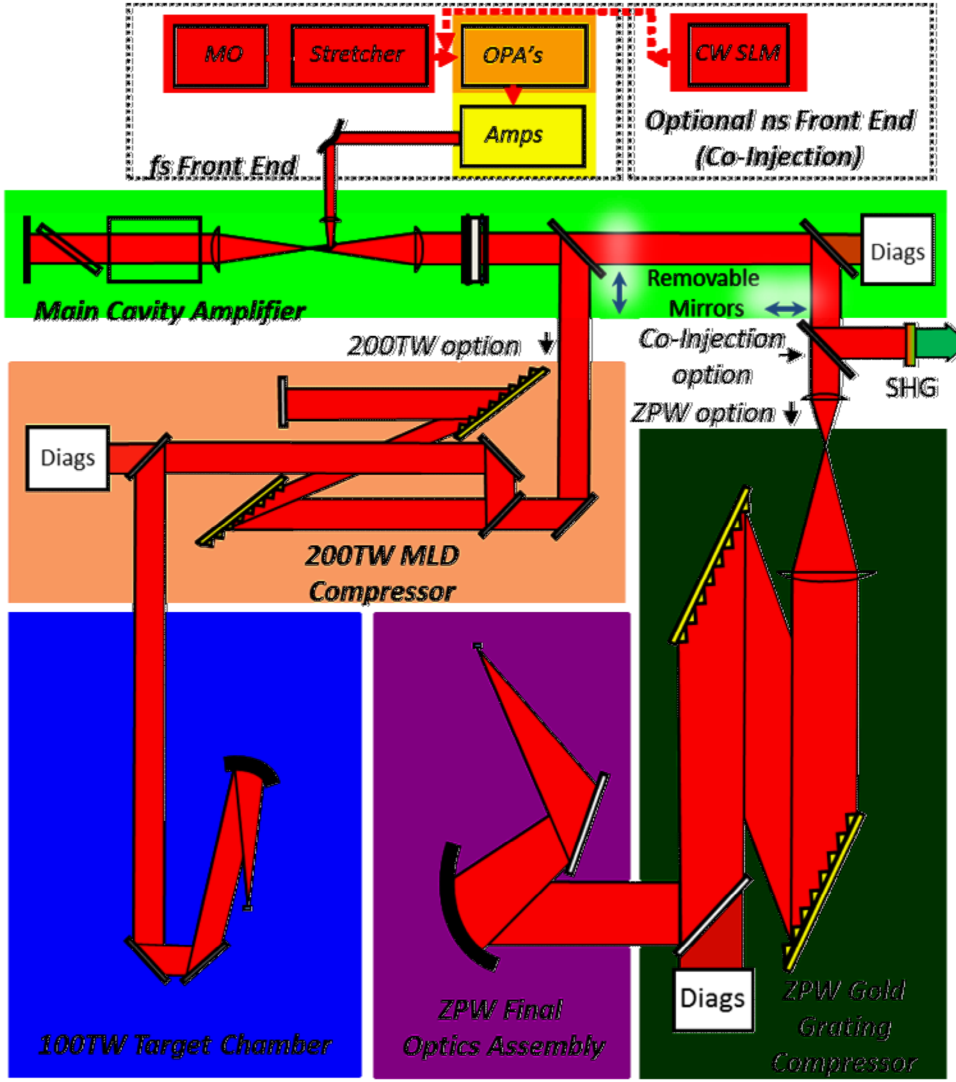


Long Pulse to Short Pulse

- Based on the early success with ZBL, it was decided to build a short pulse, PW class system.
  - Higher temporal resolution
  - Less motion blurring
  - Higher x-ray energies possible
- Approach:
  - Use the existing Beamlet main amplifiers and put a short pulse front end on.

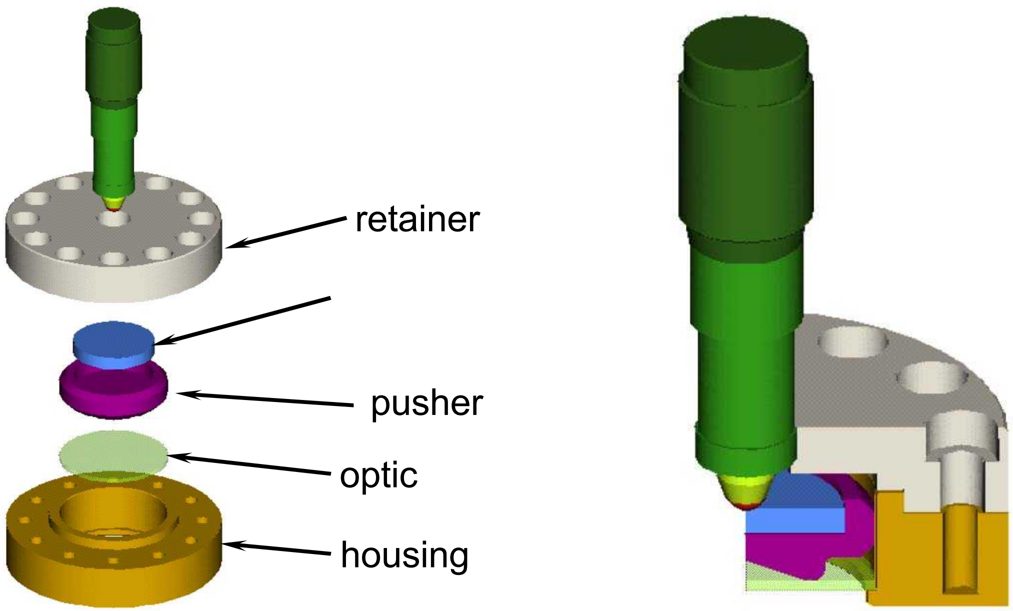
Petawatt Basic Architecture

- Laser Parameters:
  - ZPW: <500 J @ 1053nm, 0.5-200ps, 41 x 41 cm^2
  - 200TW: <150 J @ 1053nm, 0.5ps, 15 cm round
  - Co-injection: <500 J 527nm, 2ns , 15cm round
- I ≈ 10^{20} W/cm2 @ 1ω
- Application:
  - >8keV Backlighting
  - High field physics (TNSA)
  - Dynamic Diffraction



OPCPA front end

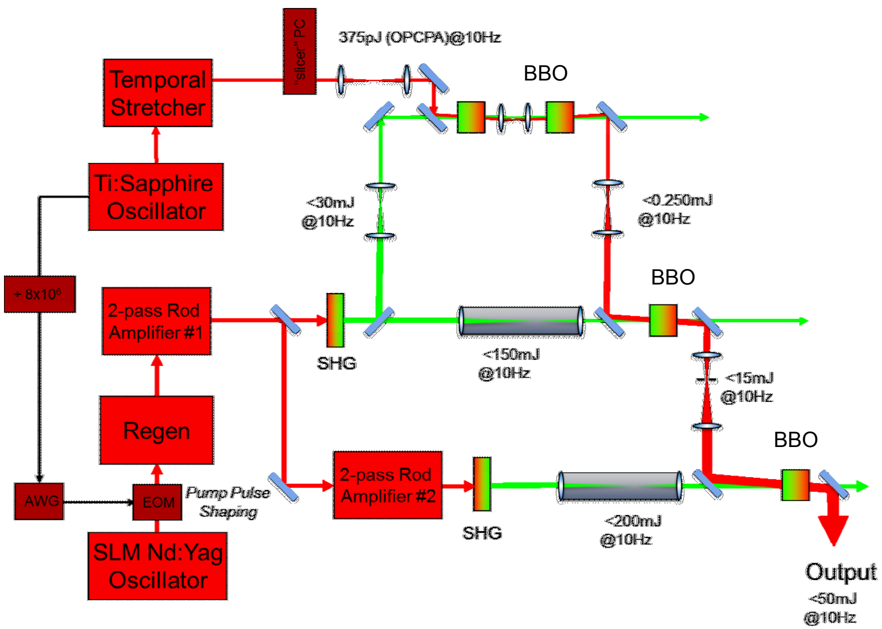
- What so see is “not always” what you get…
- OPCPA was delivered running at 11.5 Hz, because repetition rate was used in order to control thermal lensing in amps.
- Hence, we had to “invent” a simple variable deformable mirror



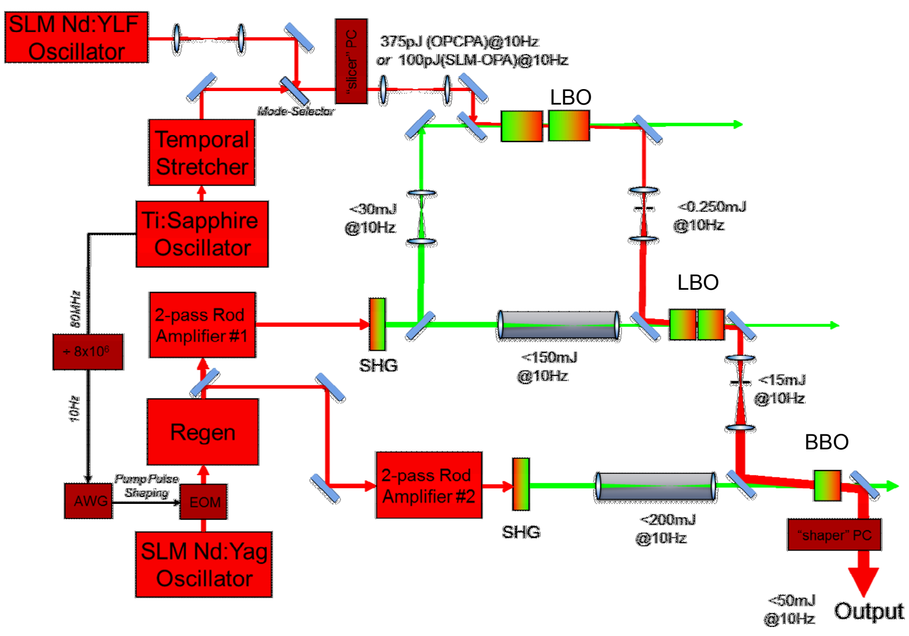
OPCPA front end: re-design

- Old/New schematic for CPA operation
  - Improved spectral bandwidth, energy and pointing stability
  - Less laser damage, higher temporal/spectral control

Old

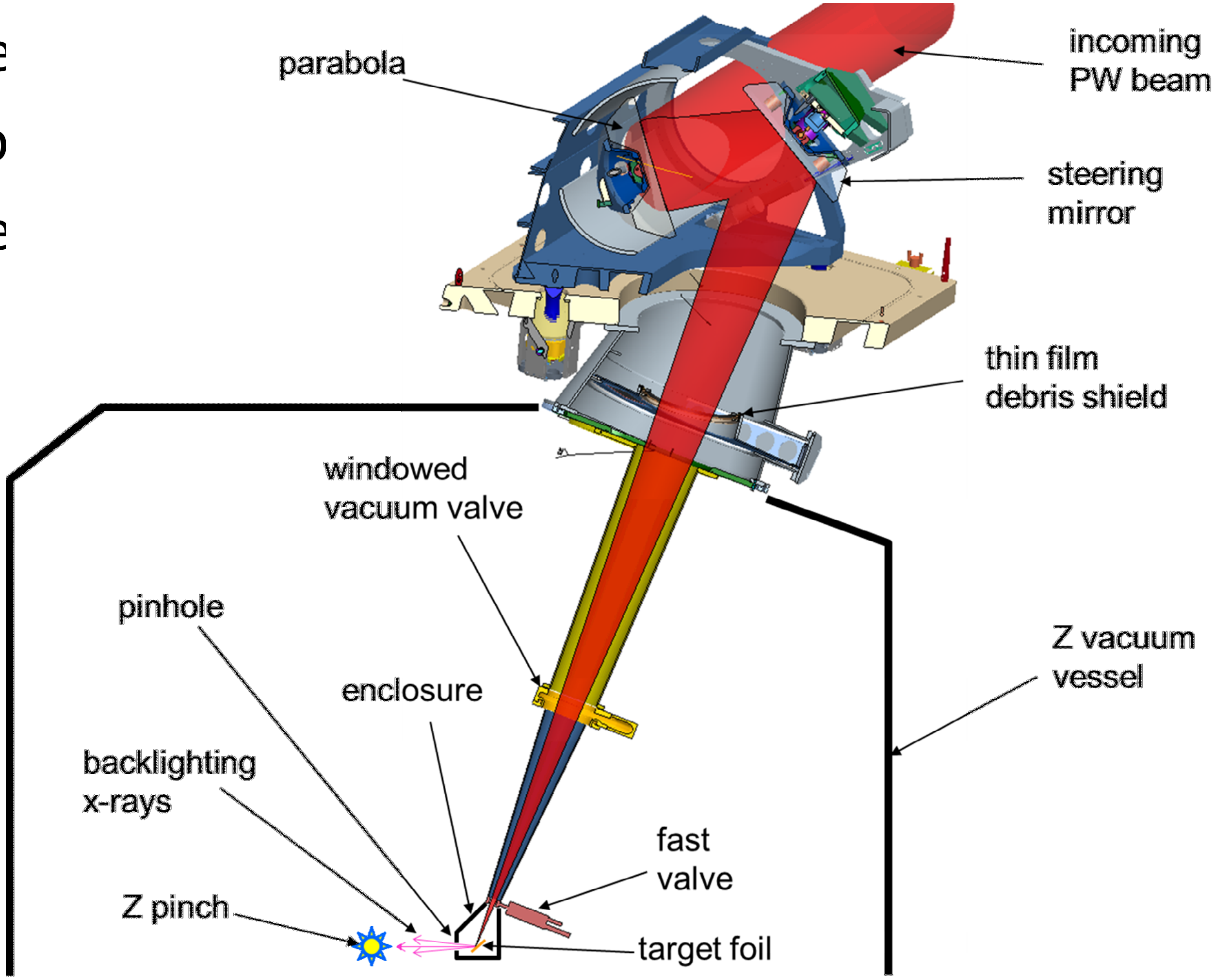


New



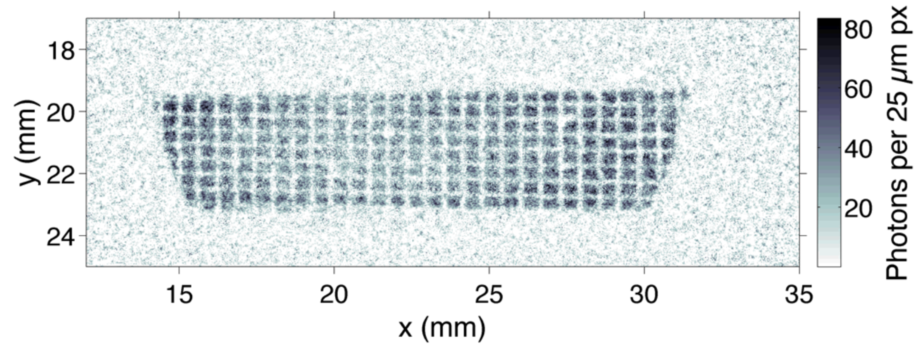
Debris mitigation in Z environment

- Short pulse re
  ultra-thin deb
- Nitrocellulose

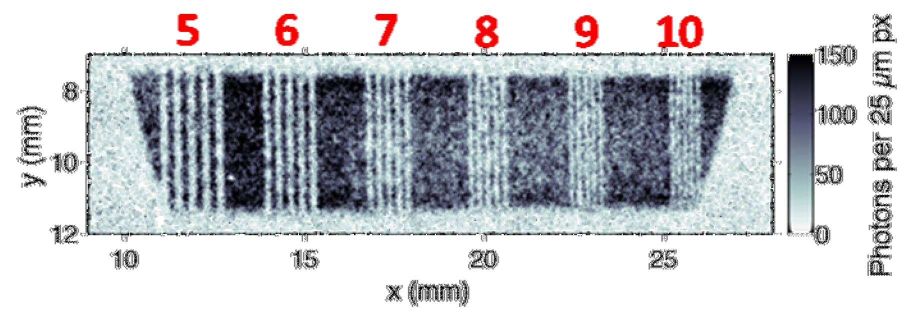


15.7keV Backlighting demonstrated

- Laser parameters:
  - 70-200 J, 500 fs or 15 ps
  - I ≈ 10^{20} W/cm2
- X-ray spectrometers:
  - flat HOPG: ZYA grade, 2nd order
  - CRITR: cylindr. α-Quartz 1011
  - Single Photon Counter (SPC)
- X-ray imagers:
  - 15.7 keV Ge 220 backlighter
  - 15.7 keV Quartz 3140 imager
  - 8 keV Quartz 2131 imager
- Total number of Kα photons: $(1.1 \pm 0.3) \times 10^{13}$
- Laser-to-photon conversion efficiency: $(2.8 \pm 0.8) \times 10^{-4}$

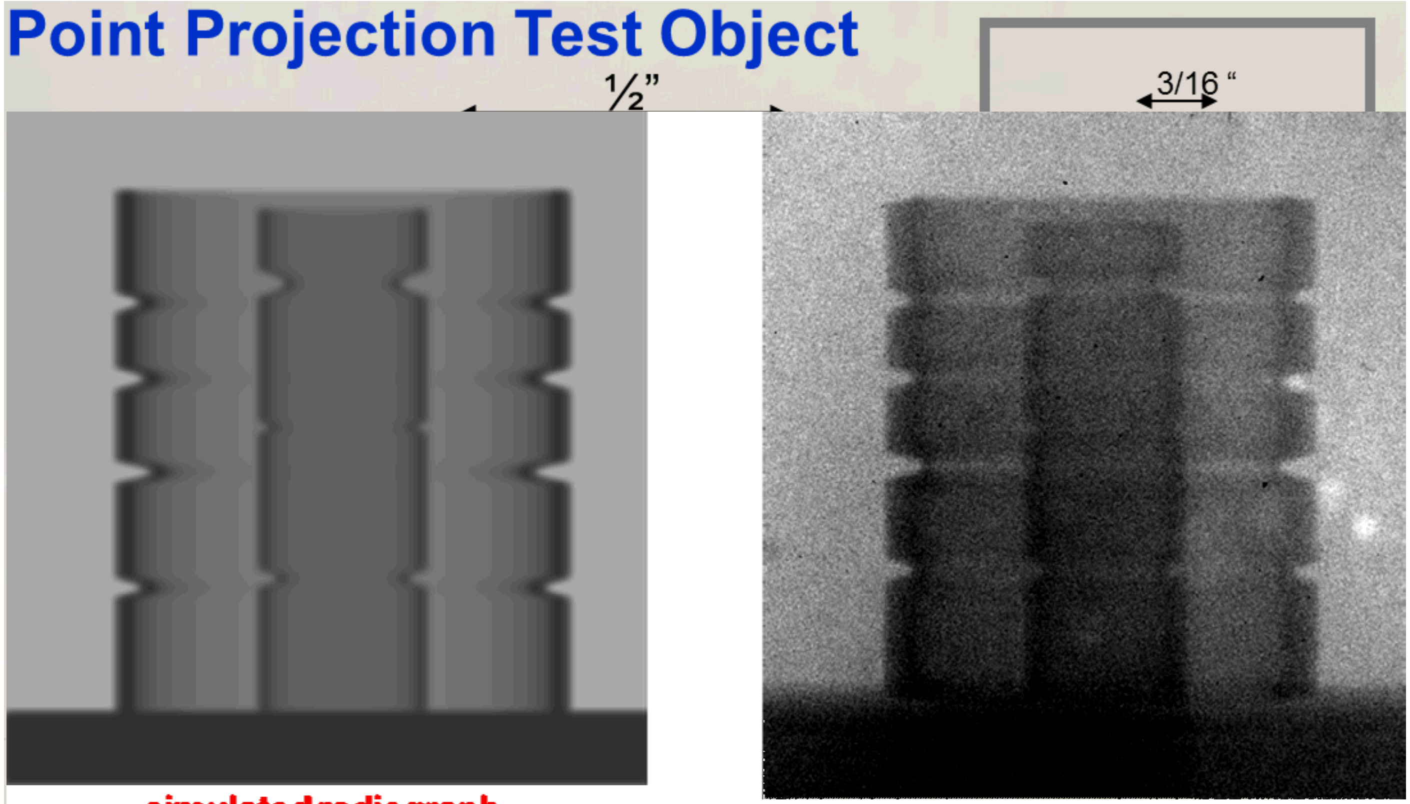


Resolution: 80 um



25keV point-projection

- 100TW laser focused on a 500x500x100μm^3 Tin target



simulated radiograph
(500 µm X-ray source)

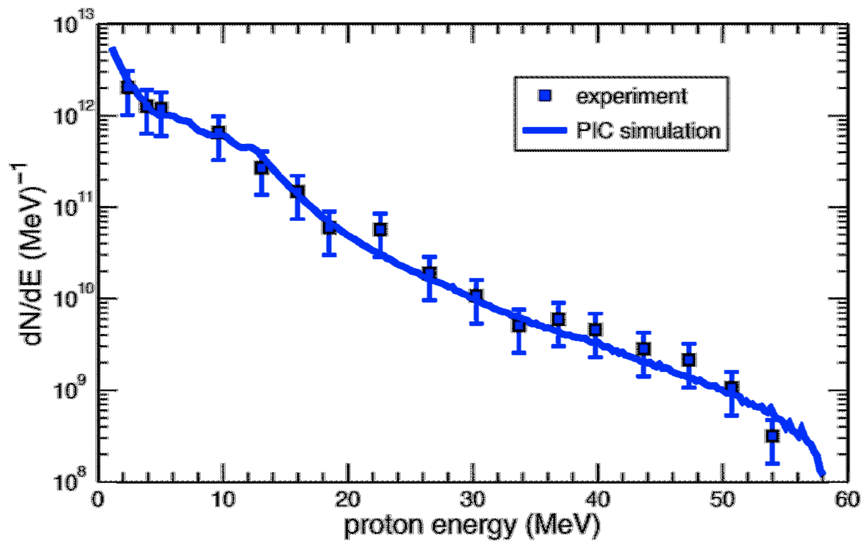
measured radiograph

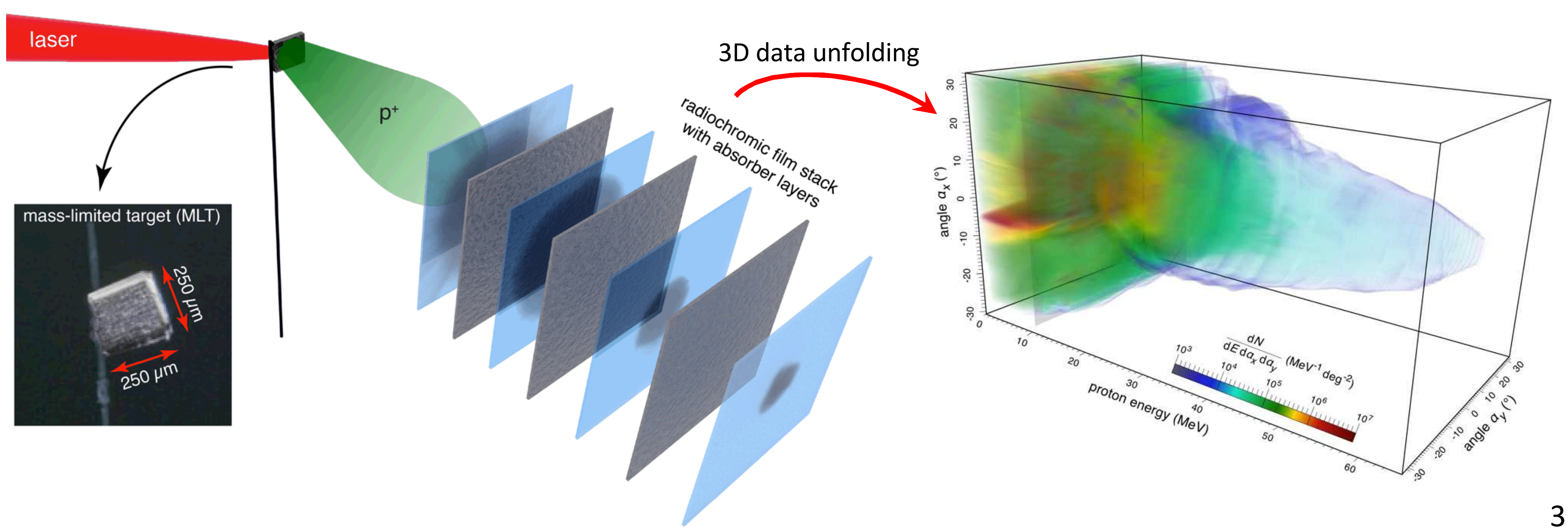
Victims of our own success

- Even though ZPW was able to demonstrate adequate debris mitigation and high energy x-ray radiography, it was never used as an experimental diagnostic in Z.
- The reasons for that were:
  - Complex focusing parabola alignment adds to the tight Z-timeline
  - Simulated image contrast was too low because x-ray energy was TOO high for many applications
  - ZBL worked very reliable and produced consistent great results
    - No experimenter wants to “give up” shots to fully develop the new capability

Proton Acceleration via TNSA

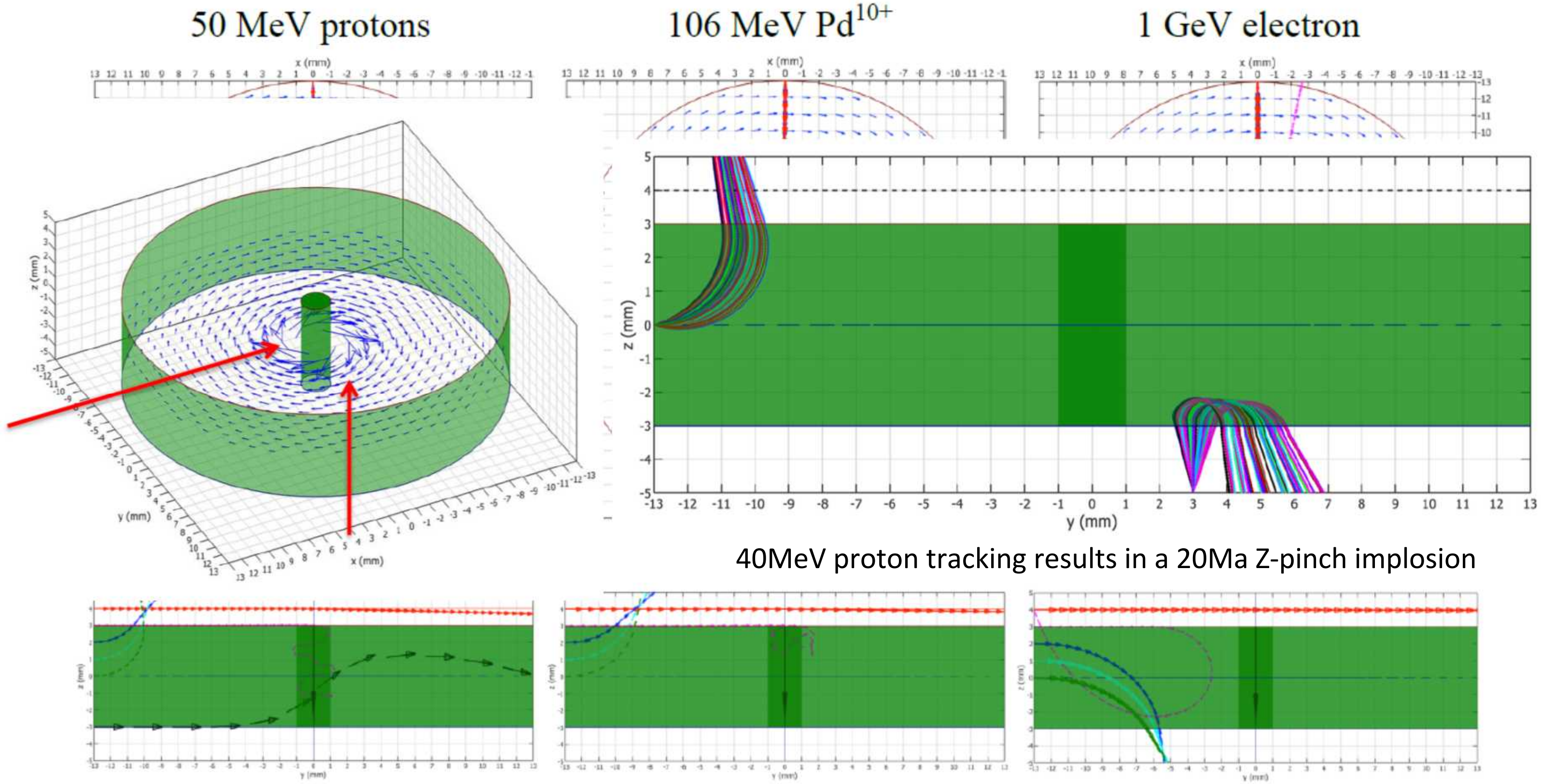
- 200 TW @ 10^{20} W/cm^2
- Thermal spectrum up 65MeV
- ≈ 10^{13} protons total
- Beam divergence $\pm 30^o$





Proton Deflectometry on Z

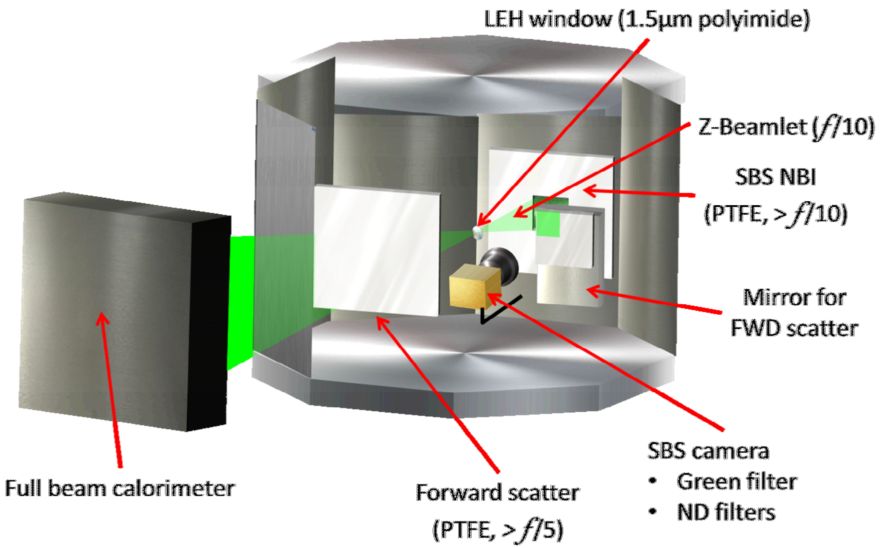
- Modeling of protons, ions and electrons in Z B-field

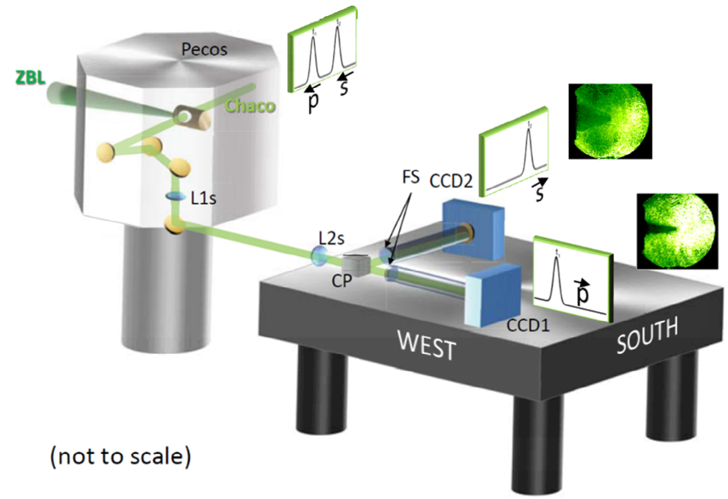


40MeV proton tracking results in a 20Ma Z-pinch implosion

MagLIF saves the day…

- The "standard" MagLIF concept relies on the fact that a 200J pre-pulse, 3.5 ns prior to the main pulse (limited by pinhole closure in main amps) can disassemble the laser entry window.
- Detailed studies show that this concept has strong limitations.

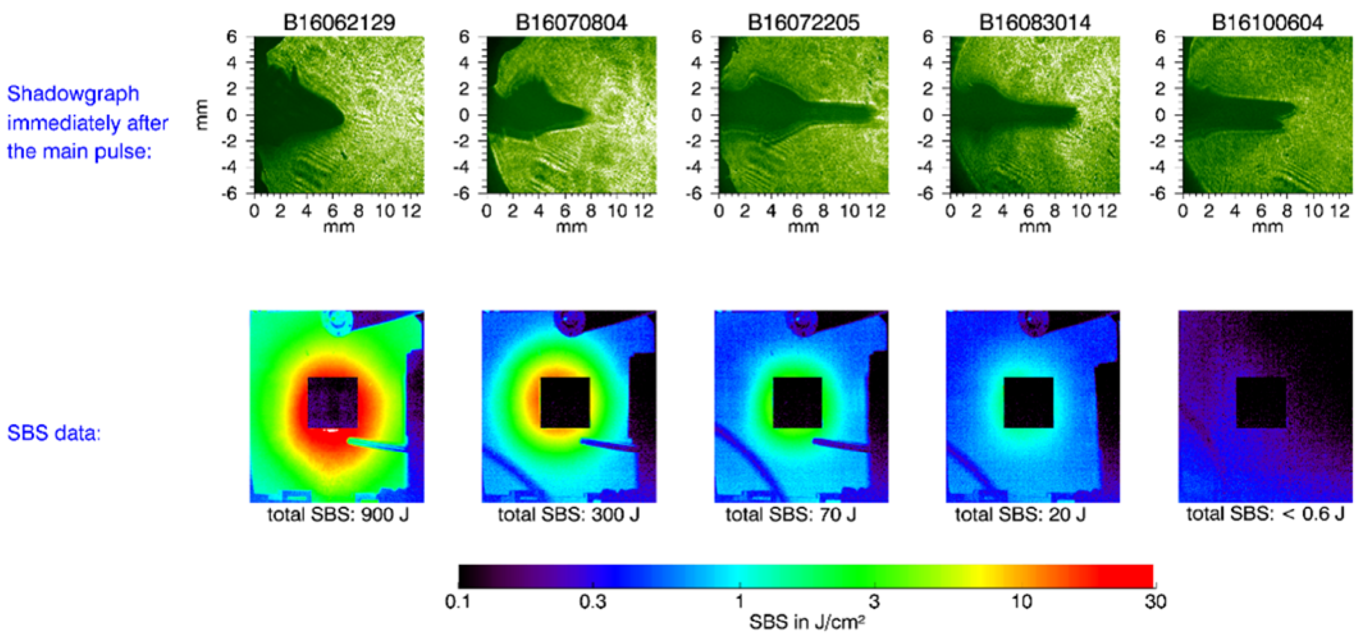




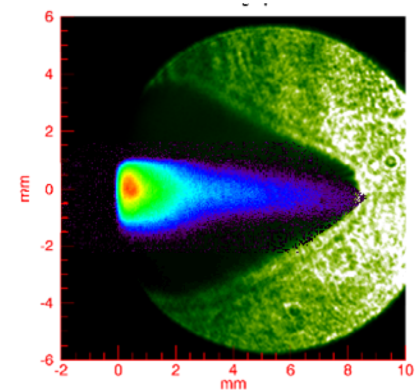
Laser Plasma Interactions @ window

- One can see how LPI reduces with decreasing laser intensity

	"Full Intensity"	"Full Intensity"	"Half-Intensity"	"Quarter-Intensity"	"1/8-Intensity"
Av. focal intensity:	(poorly defined)	190 TW/cm²	100 TW/cm²	50 TW/cm²	35 TW/cm²
Pre-pulse:	310 J	230 J	220 J	240 J	60 J
Main pulse:	1800 J	1300 J	1200 J	1300 J	850 J
Phase plate:	no DPP	750 μm DPP	750 μm DPP	1100 μm DPP	1100 μm DPP

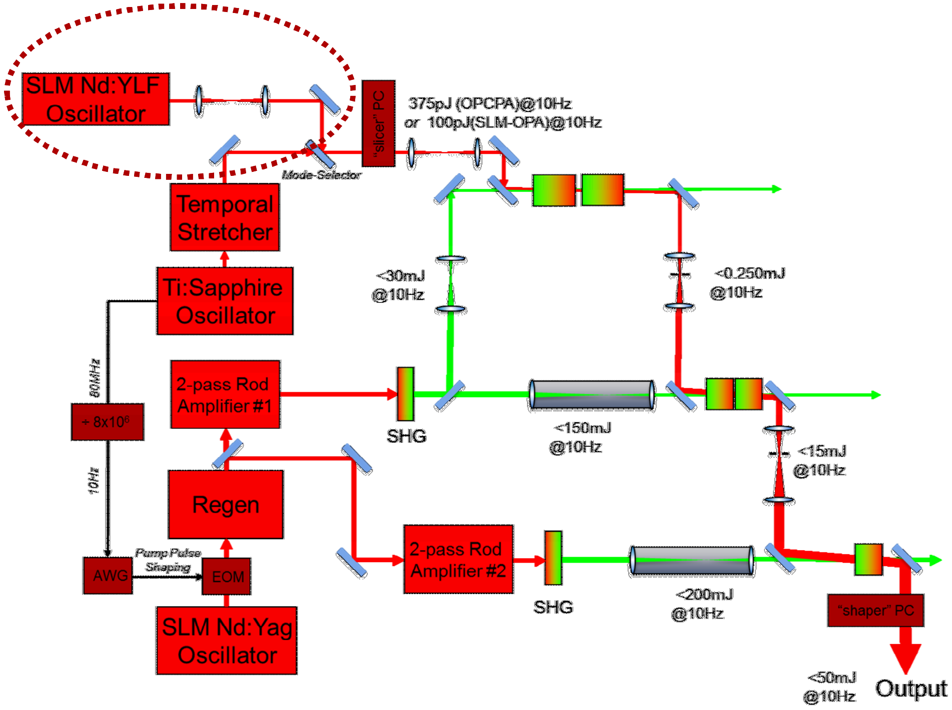


NEW!
Shadowgraphy
+ X-ray pinhole



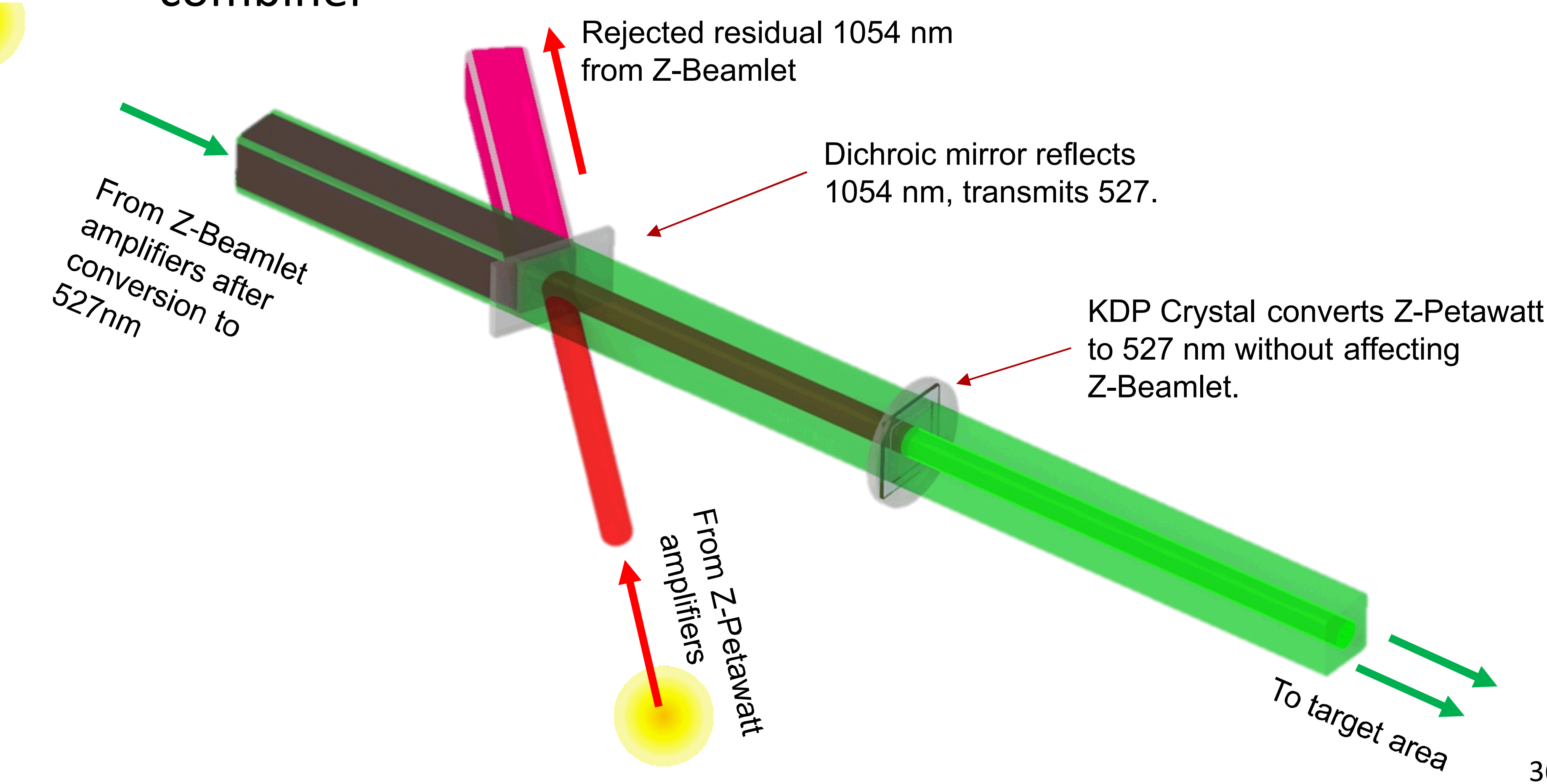
Long Pulse PW for MagLIF

- The temporal pre-pulse limit (3.5ns) could be lifted, if we had a second, independent long pulse laser.
- Idea: Modify ZPW to operate in long pulse mode and co-inject into the ZBL beamline.
- Modified OPCPA to work as SLM seeded OPA.



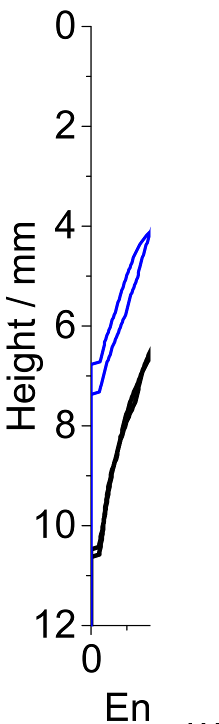
ZBL – ZPW co-injection

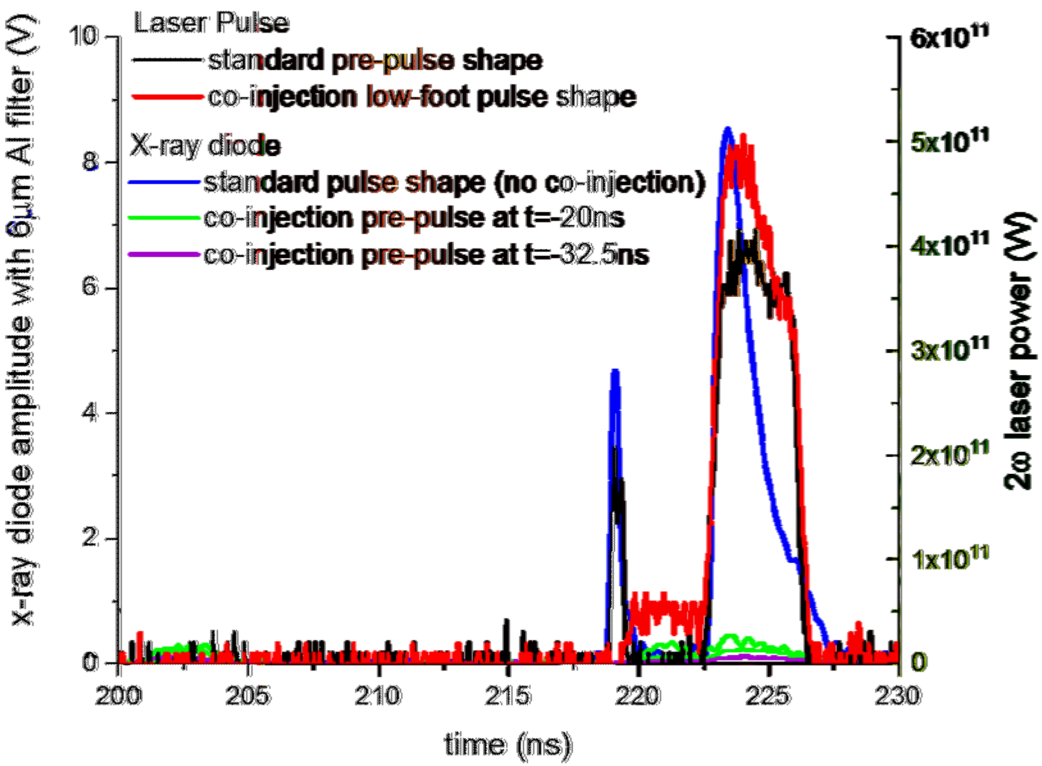
- We co-inject (co-bore) ZPW with ZBL by means of a dichroic combiner

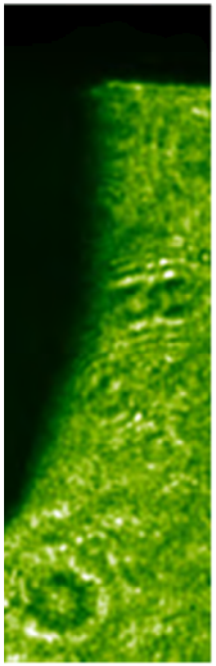


ZBL – ZPW co-injection: Success

- The ability to inject a pre-pulse at around -20ns and -32.5ns showed a dramatic improvement in plasma shape and plasma penetration depth.





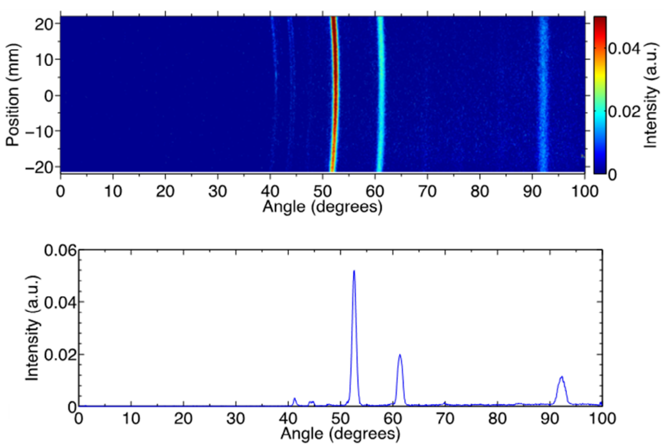


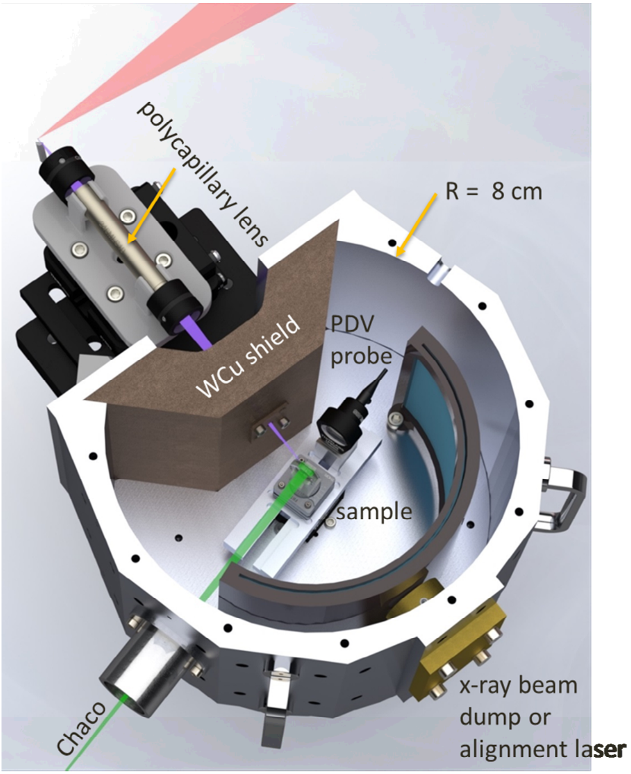
Dynamic x-ray diffraction

- Dynamic x-ray diffraction for high Z materials is currently being developed
  - To achieve the needed x-ray penetration depth, one has to use a PW class laser system

ZBL: Ag (fcc) sample with 6.2 keV Mn source

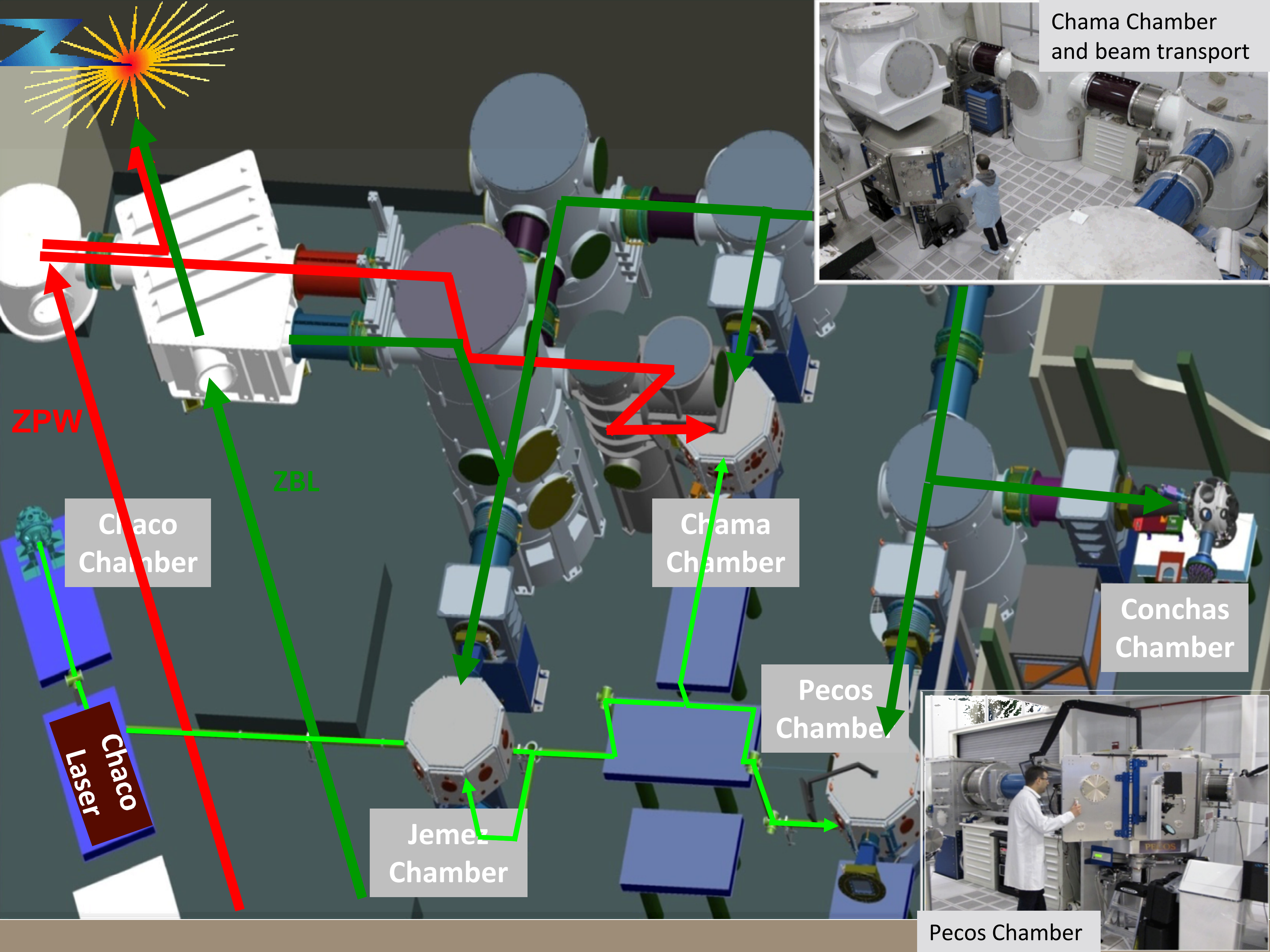
- Laser energy: 1476 J
- ≈5" distance (source/sample & sample/detector)
- Expected signal: 5 mPSL
- Measured signal: ≈20 mPSL





Everyone wants PW…

- As a result, the ZPW is now a vital part of ICF and dynamic material research.



Chama Chamber and beam transport
ZPW
ZBL
Chaco Chamber
Chama Chamber
Conchas Chamber
Chaco Laser
Pecos Chamber
Jemez Chamber
Pecos Chamber

Conclusion

- Your facility will be constantly evolving: Plan for that!
- Your experimenters may want something different from what you thought they did when you did the initial planning
  - Every “crazy” new request is an opportunity to build “know how” and infrastructure capability
  - Be adaptable and flexible
- You have an amazing facility: Go, have fun with it!