

# **Development and Application of the Diagnostic Improvement and Verification Apparatus (DIVA) at the Z-Backlighter Laser Facility at Sandia National Laboratories**

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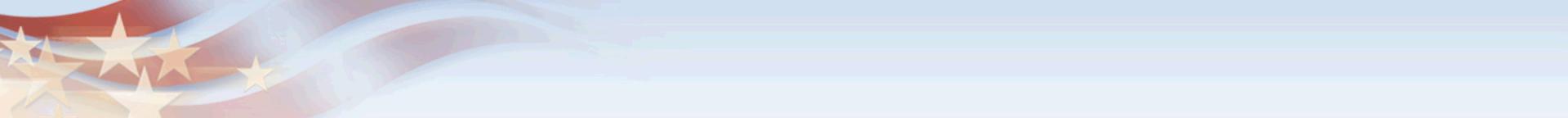
Sandia National Labs, USA

**SPIE**

***Optics and Optoelectronics***

Prague, Czech Republic, April 15-18, 2013

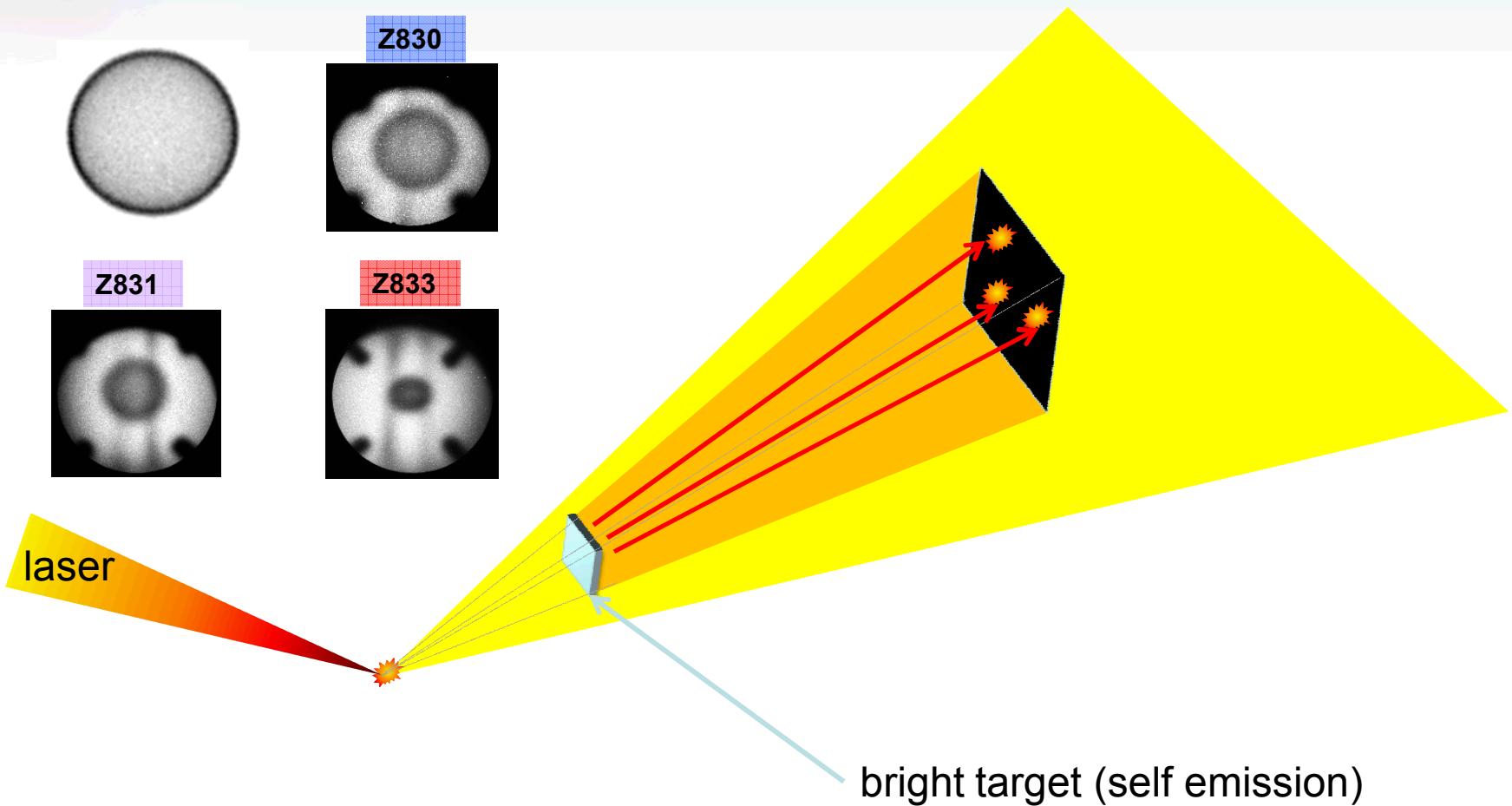
Paper 8780-3



# Outline

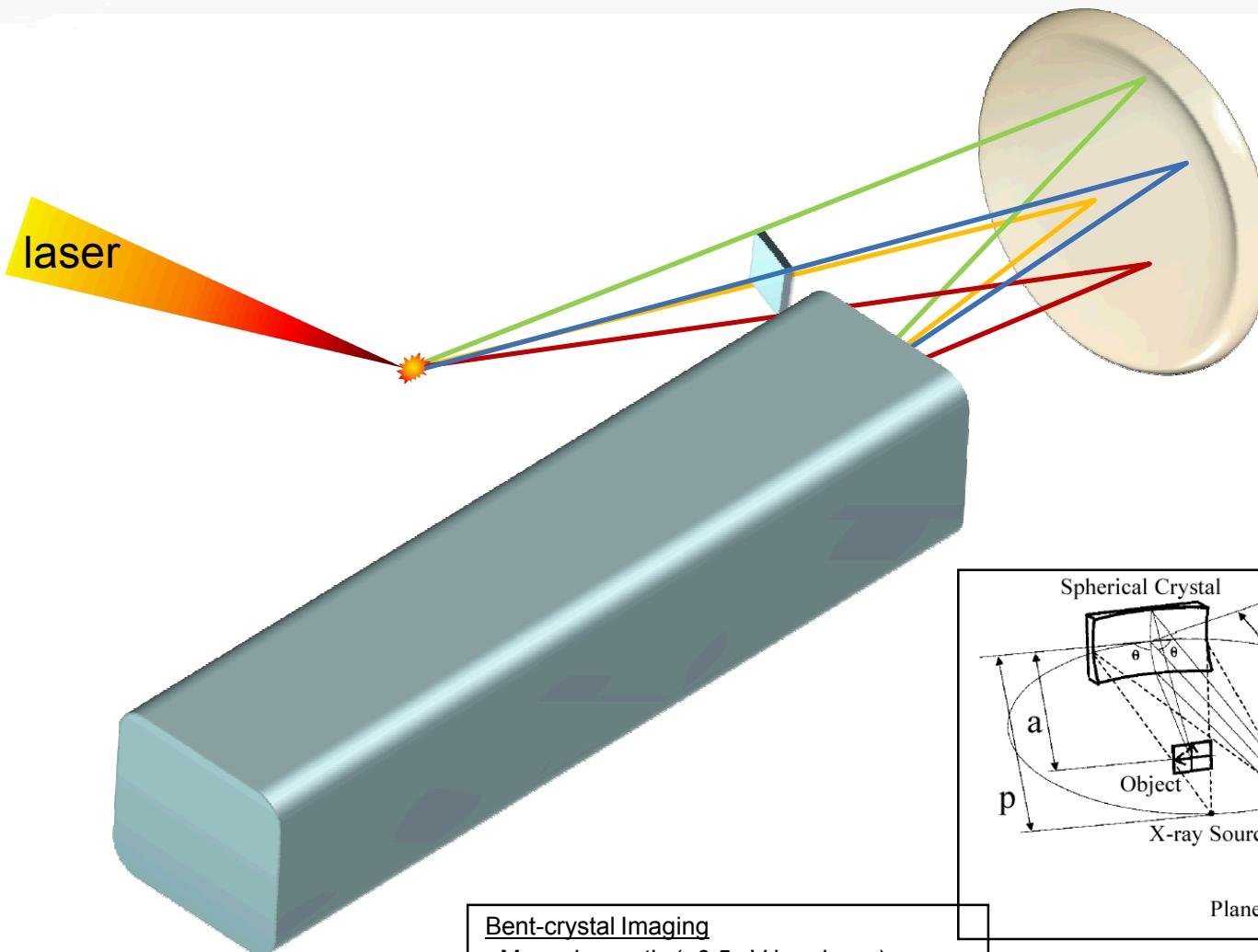
1. Introduction to Z-Backlighter Facility
2. DIVA description
3. Application of the DIVA system
4. Future improvements and applications

# Point Projection Backlighting



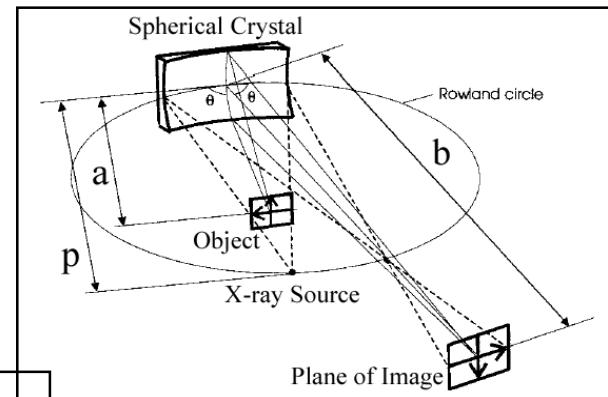
**violent debris !!**

# Curved Crystal Imaging



## Bent-crystal Imaging

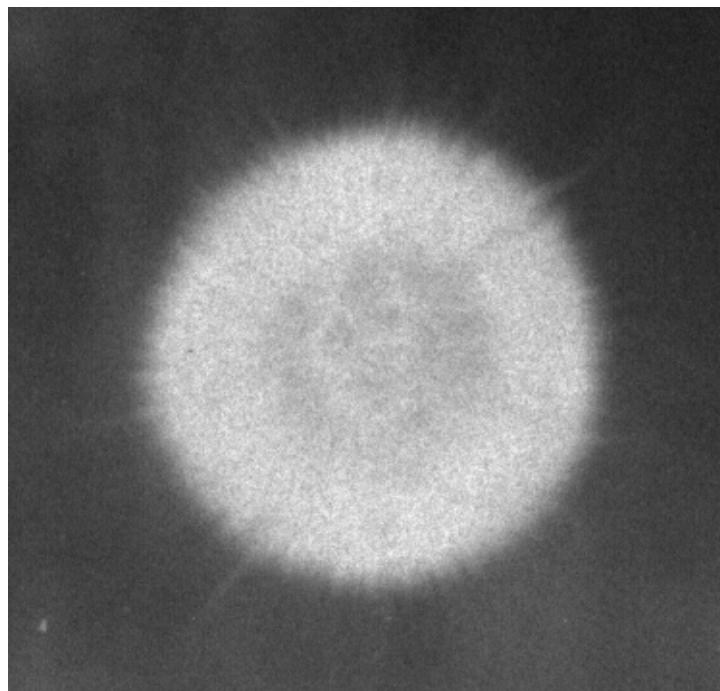
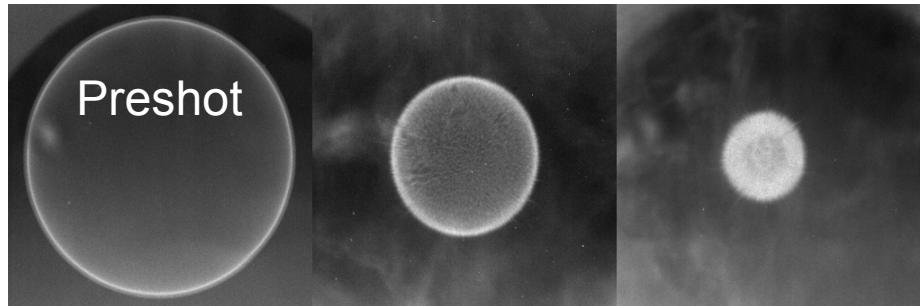
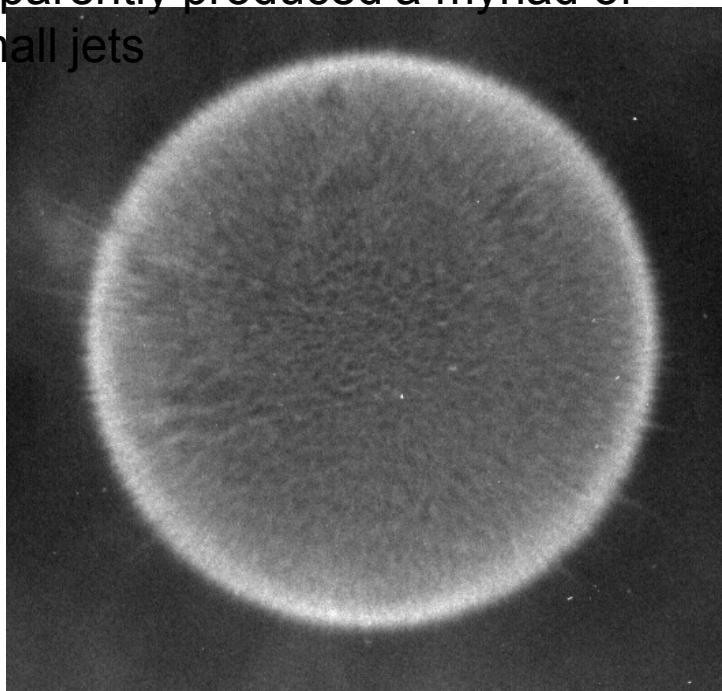
- Monochromatic (~0.5 eV bandpass)
- 10 micron resolution
- Large field of view (e.g. 20 mm x 4 mm)
- Debris mitigation



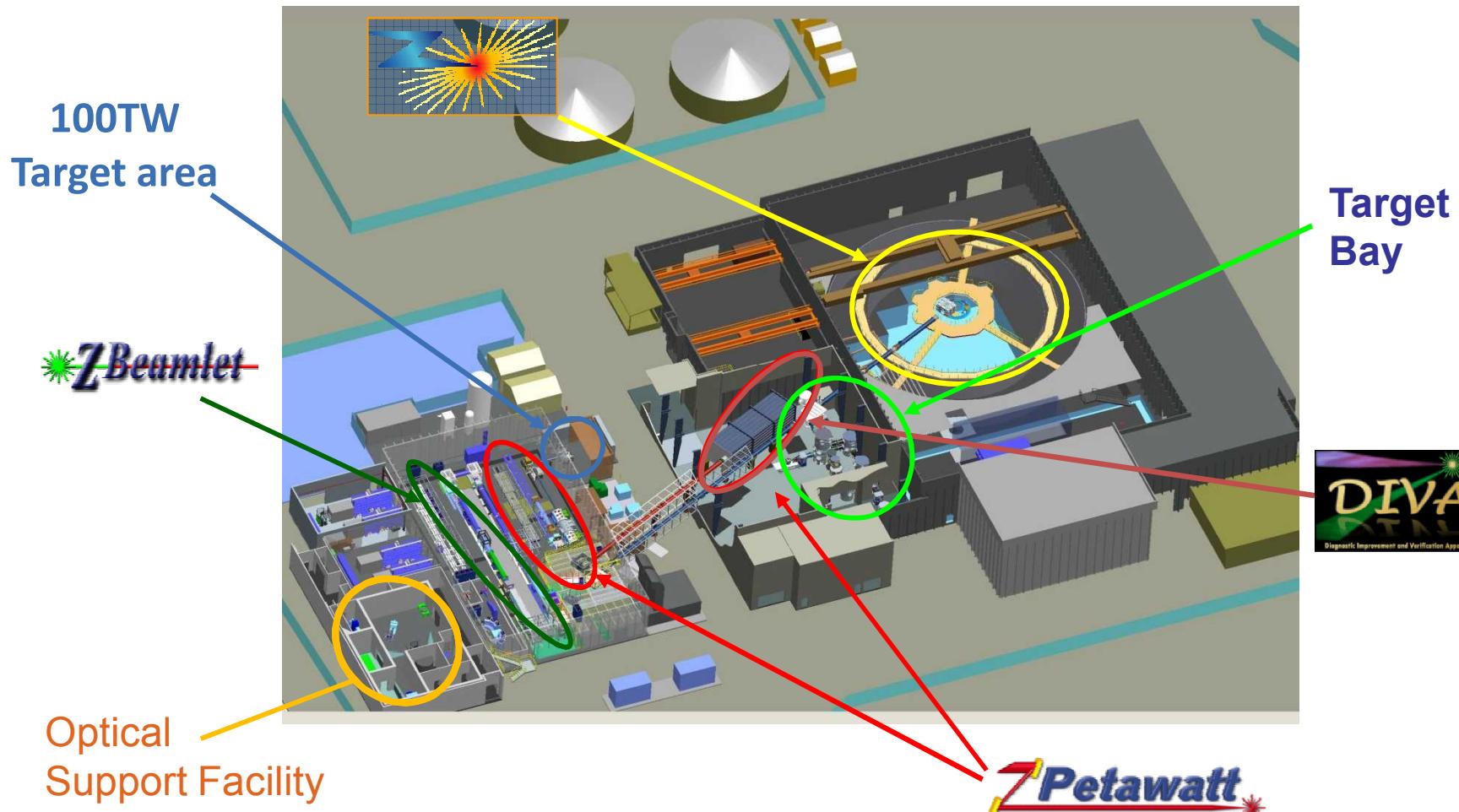
# High Resolution Imaging

3.4-mm diameter plastic ICF capsule

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



# Facility Overview

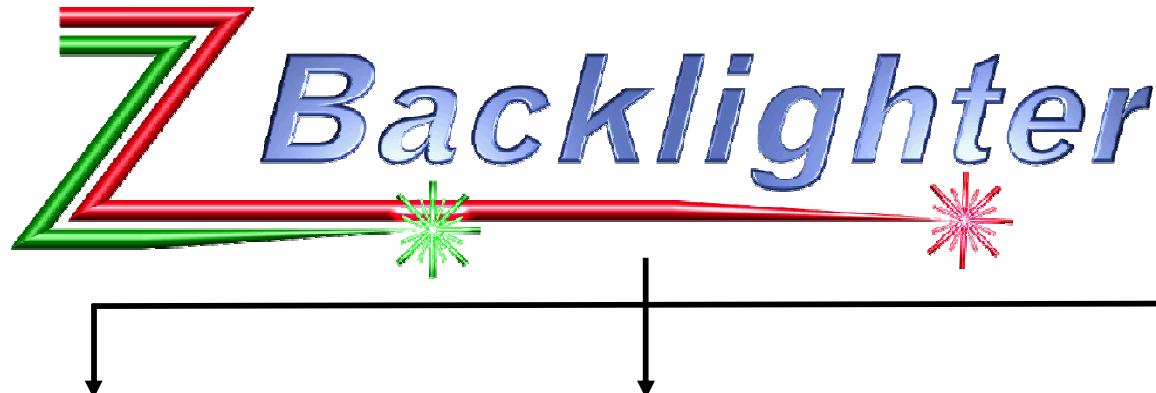




# Large Optic Coating Operation



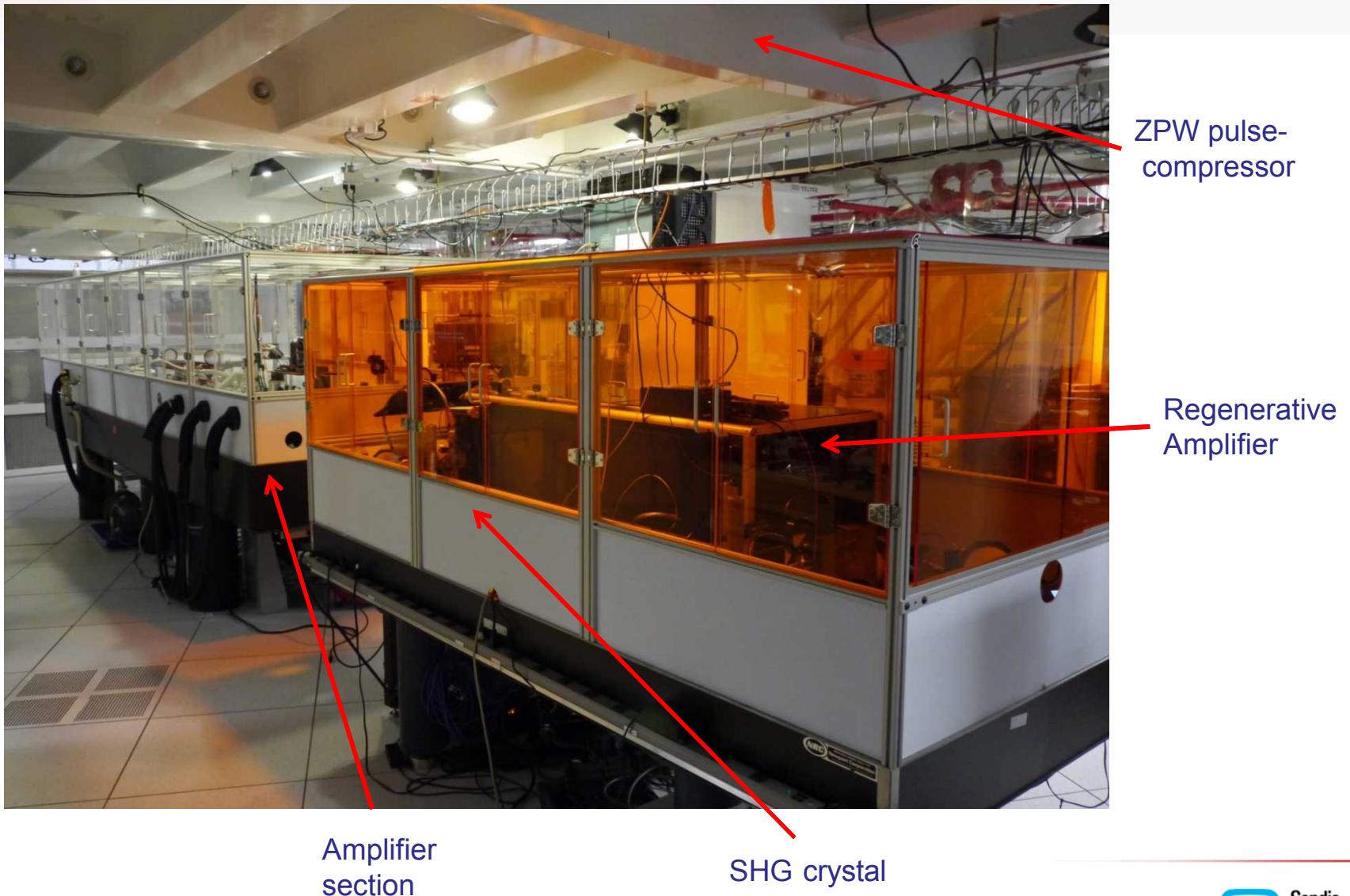
- Backlighting operations need a continuous supply of AR coated debris shields.
- To this end, we installed a 90" coating chamber into a Class 100 cleanroom area with optical metrology capabilities, an endeavor that we call the Sandia Large Optic Coating Operation.
- Coatings:
  - Materials: Typically  $\text{HfO}_2/\text{SiO}_2$
  - 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
- Coating Examples (both air and vacuum use environment designs):
  - AR's at 1054nm/1064nm and 527nm/532nm (1045-1064nm option)
  - HR's at 1054nm/1064nm and 527nm/532nm (1045-1064nm option)
  - MLD grating's
  - Thin Film Polarizers for 1045nm-1064nm
- Independent ns-laser damage testing (SPICA) shows good damage thresholds:
  - In the range of 17-25  $\text{J}/\text{cm}^2$  for AR coatings
  - In the range of 75-85  $\text{J}/\text{cm}^2$  for HR coatings
- In-house small-area testing at Sandia with ns sources corroborates this performance (fs source testing optional).



			
$\lambda$ (nm)	527	1054	1064 (532)
$\tau$	0.3-8 ns, typ. 2 ns	500 fs (min.)	0.3-4ns
typ. Spot size ( $\mu\text{m}$ FWHM)	75	6	10
$E_{\text{max}}$ (J)	2000	120 (100TW) / 500 (PW)	13J@1064nm/10J@532nm (0.3ns) to 50J@1064nm/30J@532nm (2ns)
$I$ (W/cm <sup>2</sup> )	$< 10^{17}$	$\sim 10^{19}$	$< 10^{16}$
Shot Intervals (minutes)	180	180	12
'Special feature'	2 pulse MFB (two frame/2 color)	CPA probe beam (< 20 mJ)	8-10 ns option: 1064nm and >100J Multiple pulse capability



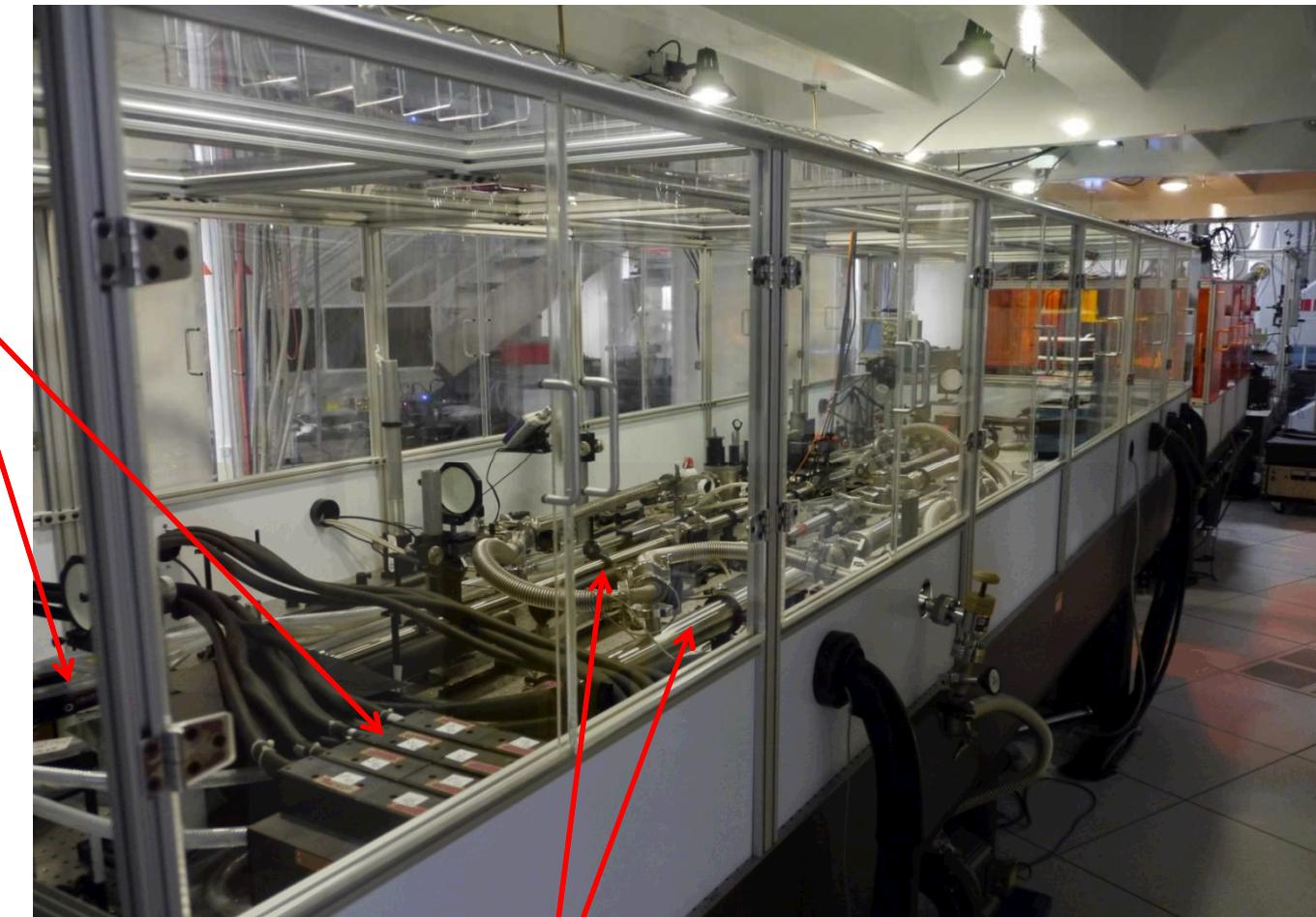
# DIVA laser system





# Amplifier Section

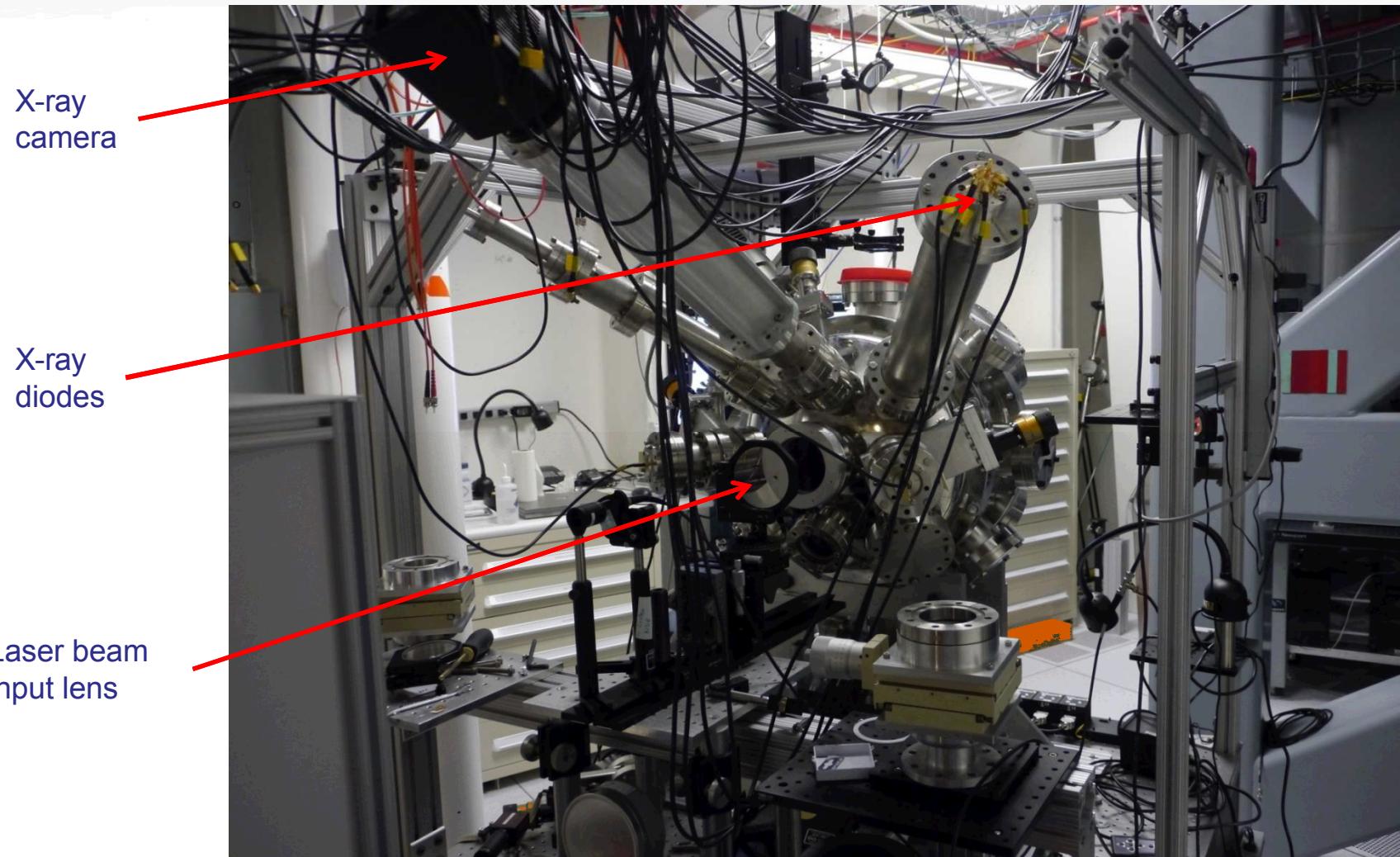
Rod amp heads



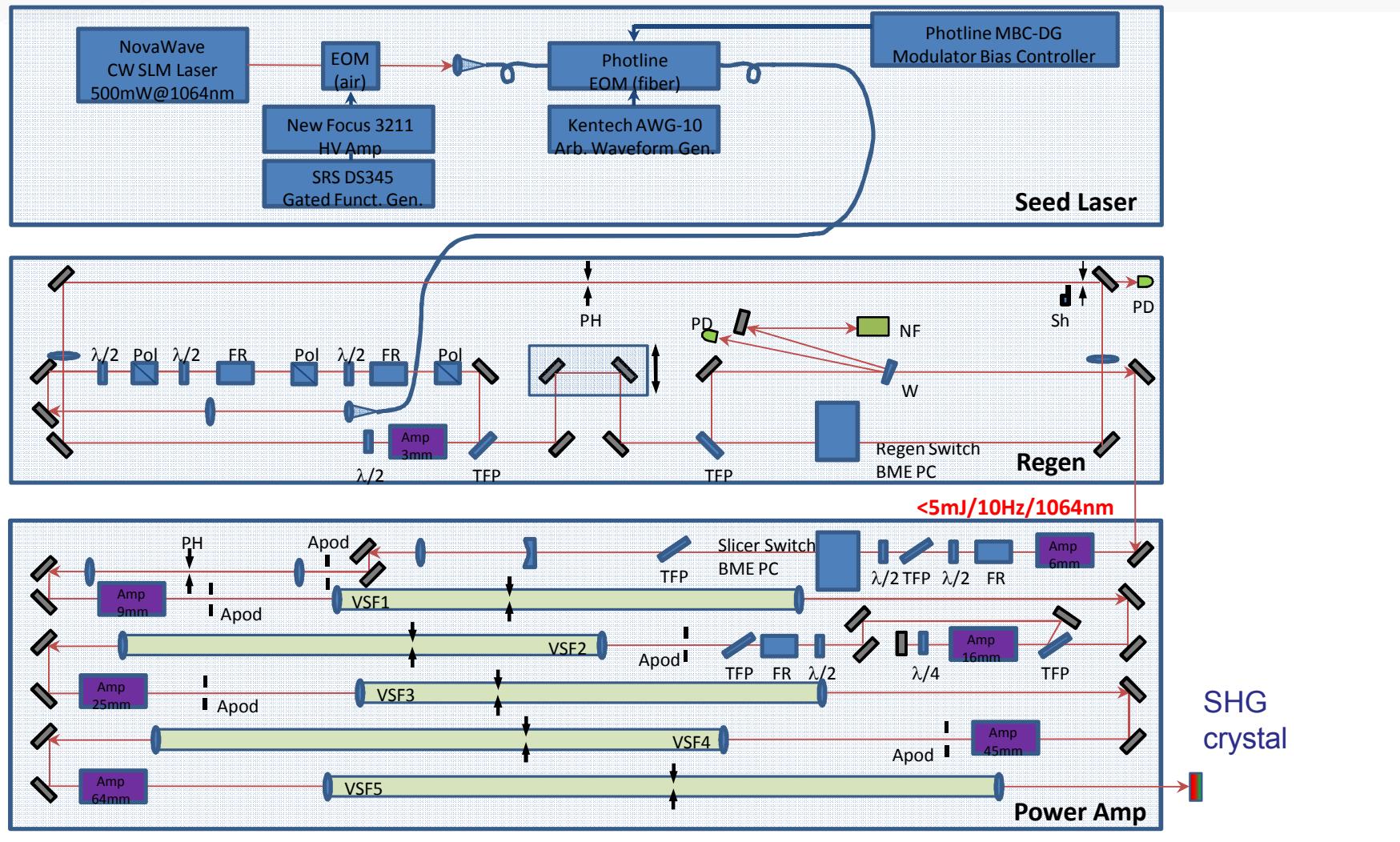
Vacuum spatial filters



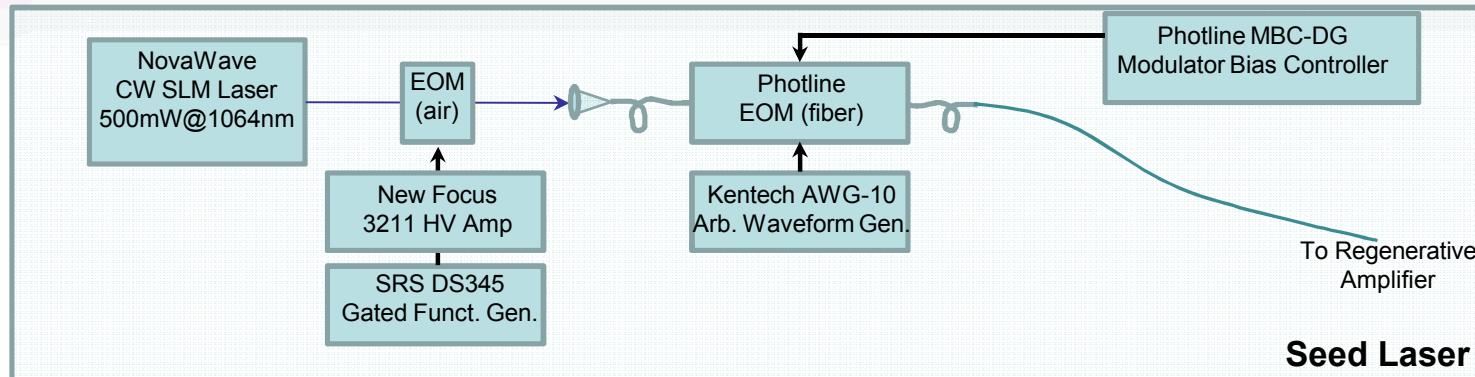
# DIVA target chamber



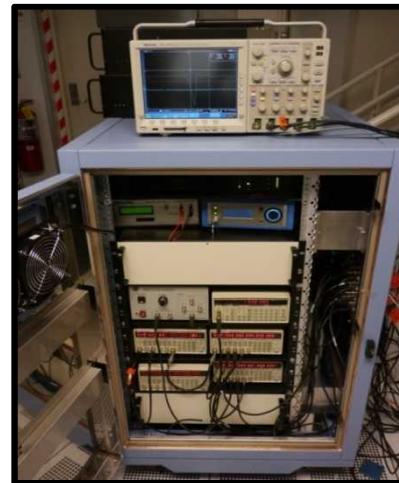
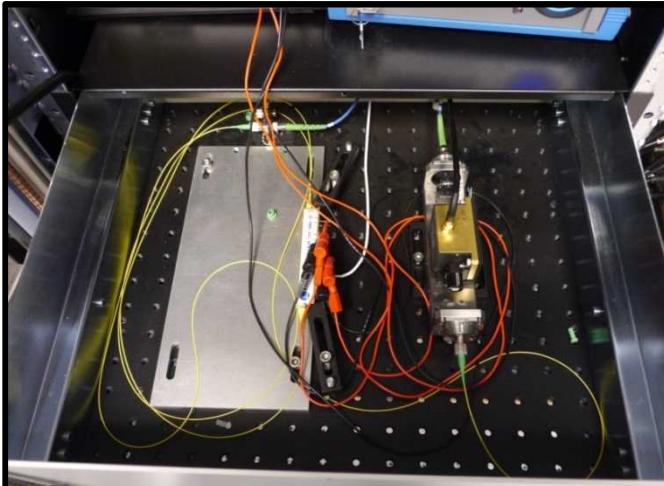
# Laser System Diagram



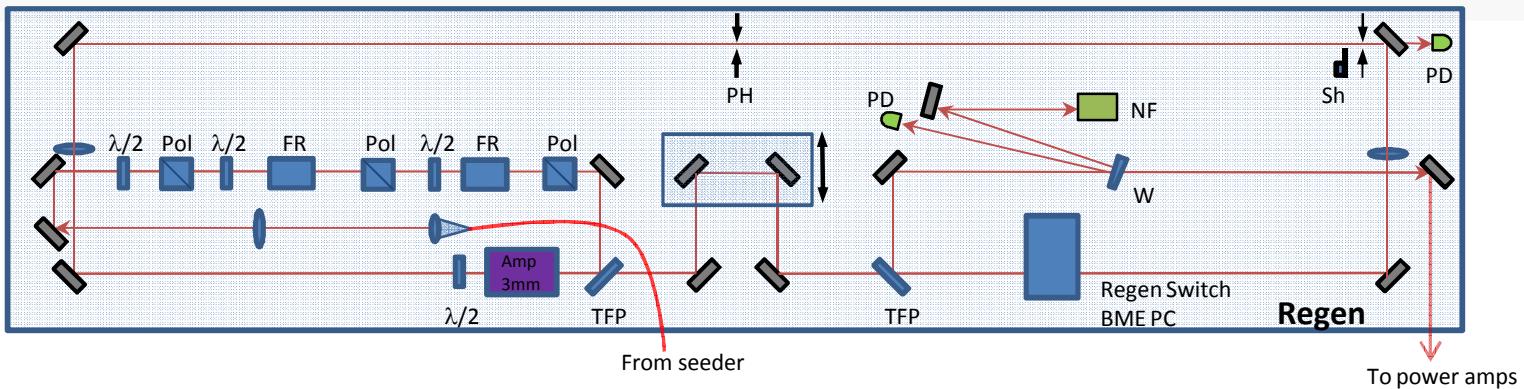
# Seed Laser



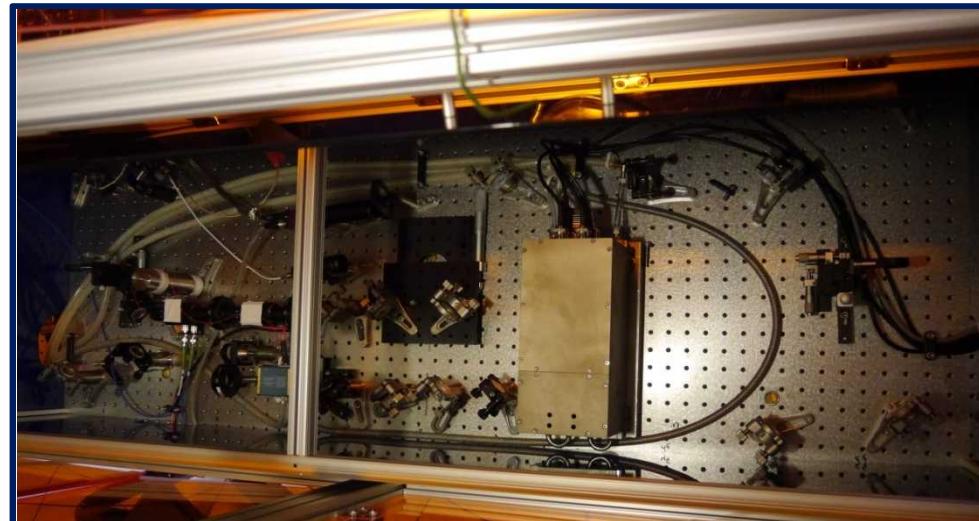
- Commercial off-the-shelf technology (COTS)
- Bias controller prevents EOM baseline drift and maintains high temporal contrast
- 300ps to 8ns pulsewidths
- EMP resistant, thermally stable shielded housing contributes to stable operation
- Fiber coupled to regenerative amplifier



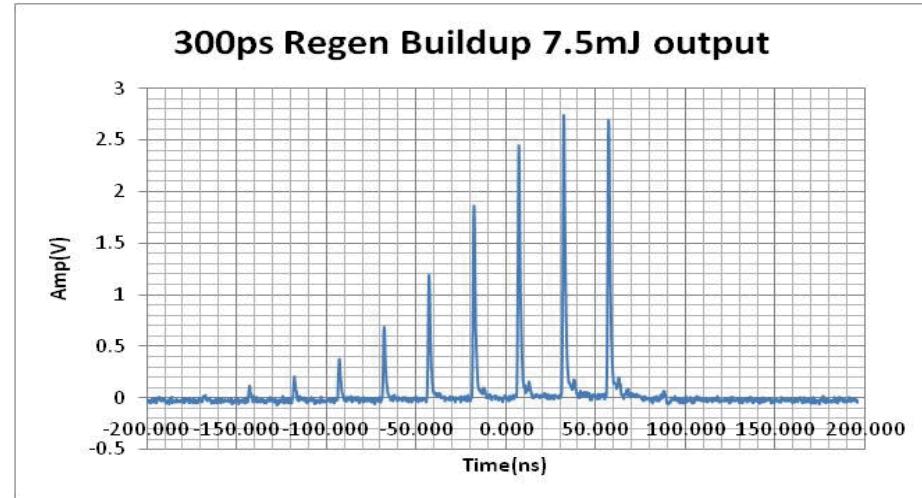
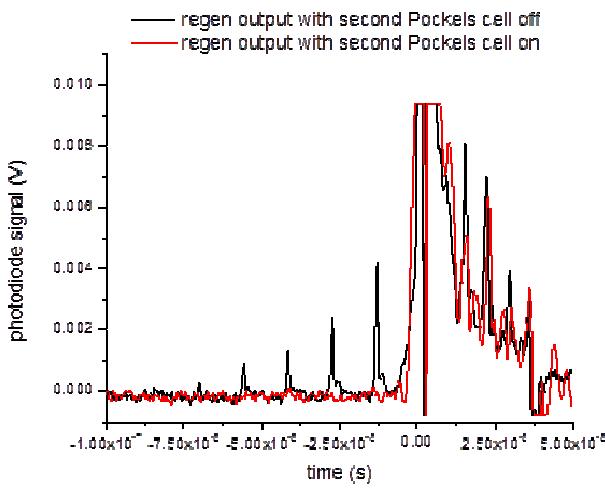
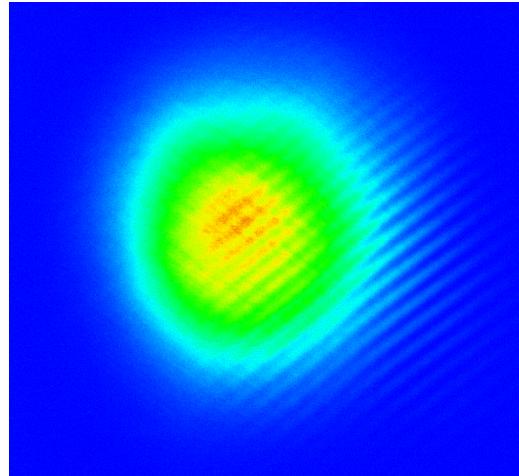
# Regenerative Amplifier



- Relay-imaged ring design
- COTS key components
- DPSS Nd:YAG
- Adjustable cavity length
- Thermally isolated DPSS head and Pockels cell and robust enclosure contribute to good day to day system stability
- 1.2% rms amplitude jitter
- 35psec rms timing jitter

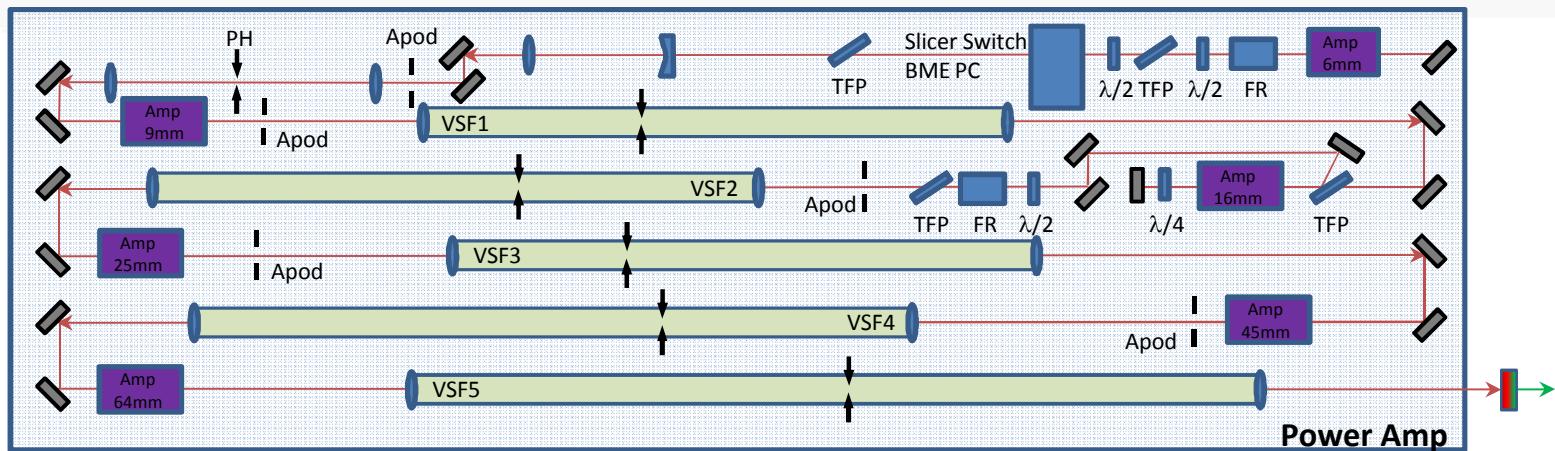


# Regen output parameters



- Gaussian spatial mode output
- 350 nsec build-up time
- Chopping Pockels cell on output for contrast improvement

# Power Amplifier

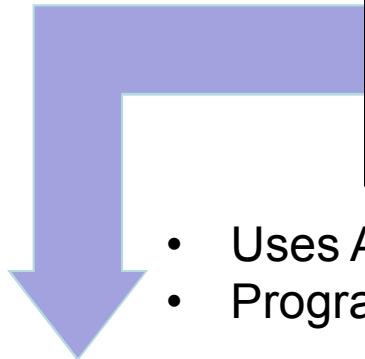
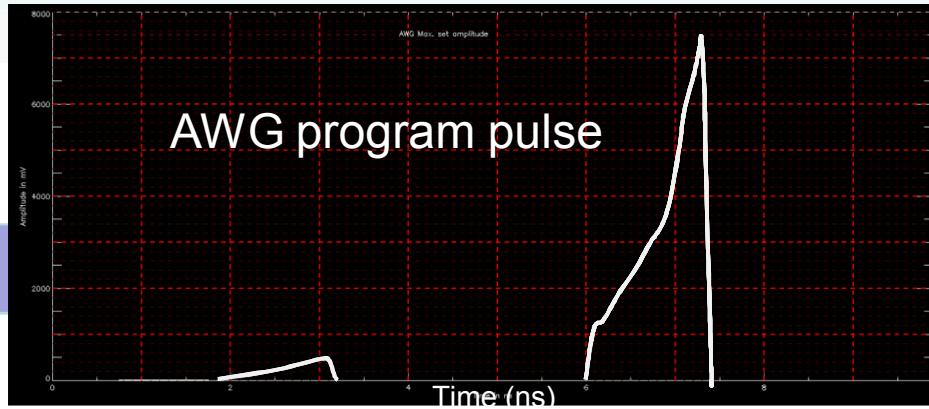


- Builds on existing “legacy” equipment already in-house
- Amplified pulse is relay-imaged through vacuum spatial filters (VSF) between amplifier stages

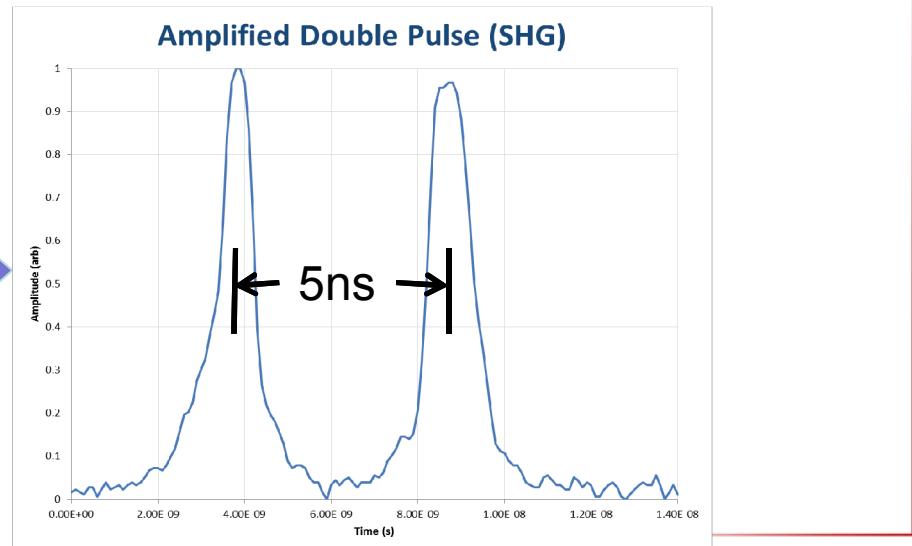
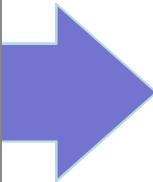
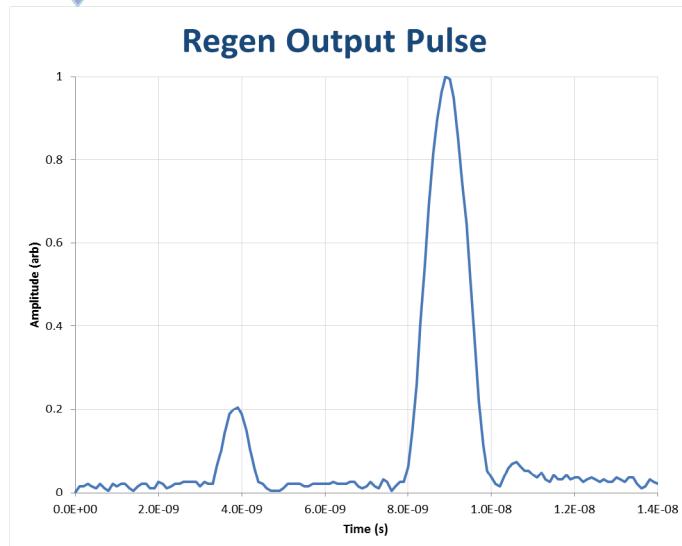
Rod Amplifier Parameters for 300ps seed pulse

Diameter (mm)	Length (mm)	Glass Type	Max Rep Rate (ppm)	Output Energy (J)	Fluence (J/cm <sup>2</sup> )	Gain/pass
9	115	Nd:Silicate	1	0.1	0.096042	6.666667
16	235	Nd:Silicate	0.5	0.768	0.284557	7.68
25	235	Nd:Silicate	0.25	1.79	0.187649	2.330729
45	235	Nd:Silicate	0.125	5	0.279268	2.793296
64	235	Nd:Silicate	0.05	14	0.781951	2.8

# Multi Pulse Capability 1

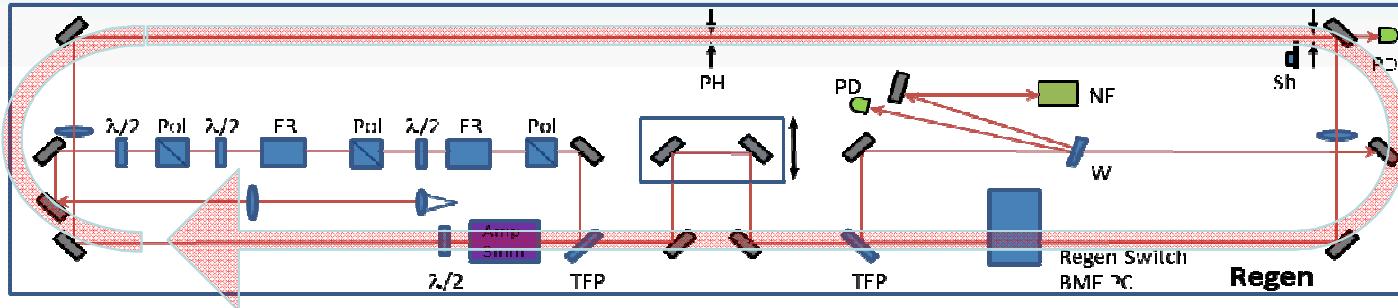


- Uses AWG to produce double pulses within the Regen round trip time
- Programmed pulse can be changed in minutes

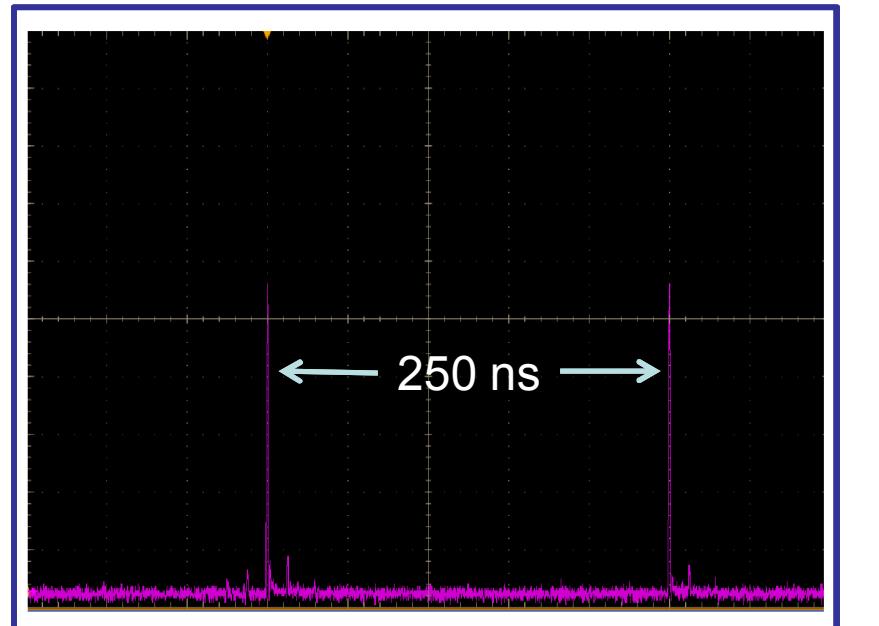
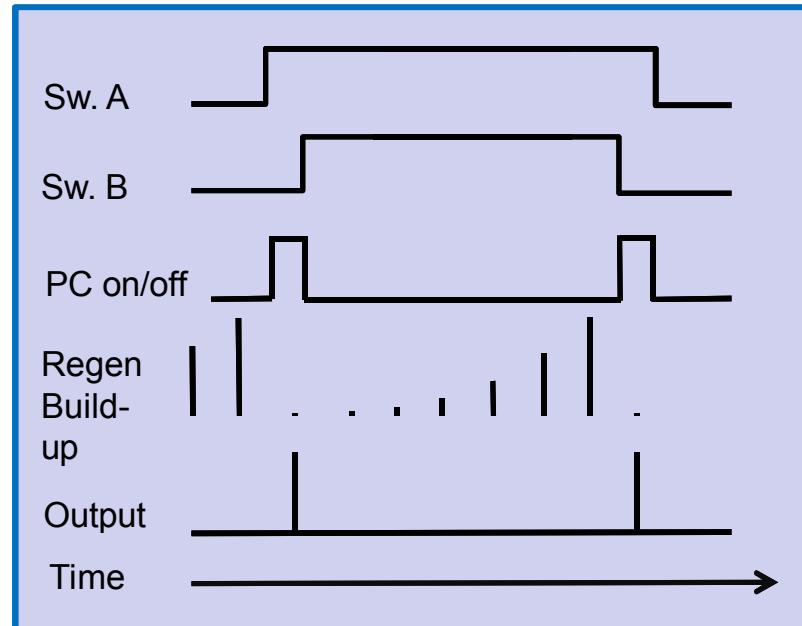


# Multi Pulse Capability 2

12.5ns  
round  
trip

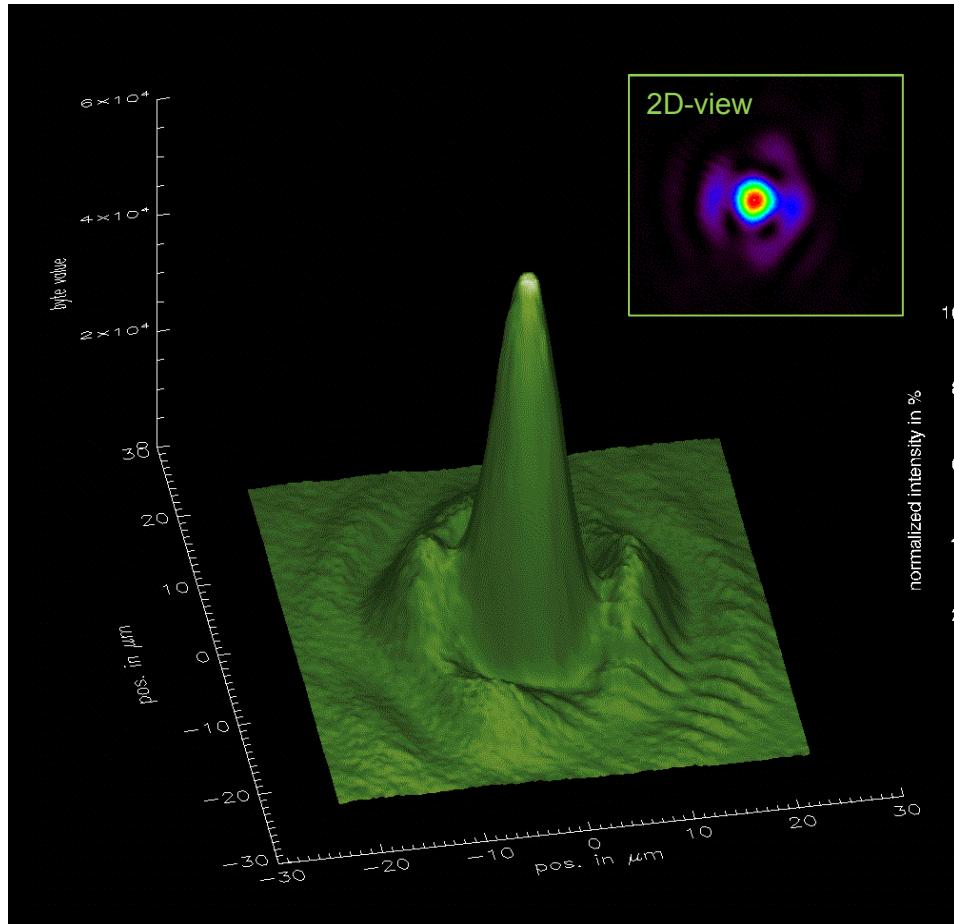


- Utilizes unique burst-mode capability of Pockels cell
- Variable pulse separation time is a multiple of cavity round trip time (12.5 ns)

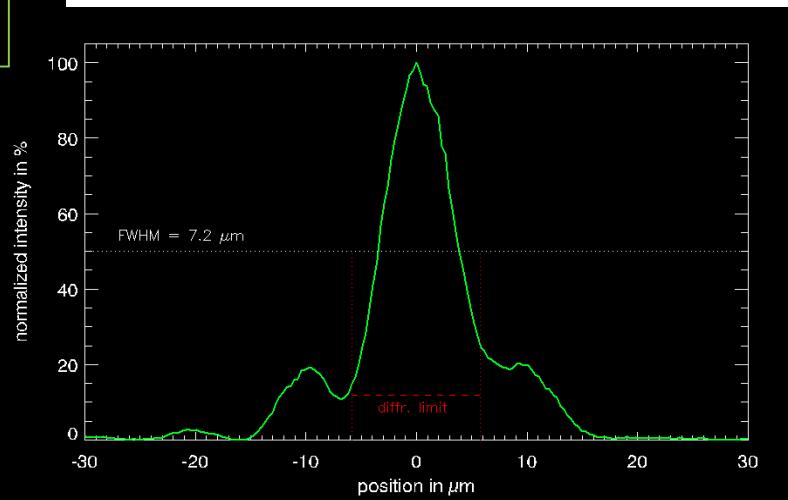


# Focus measurement

DIVA amplified pulse in vacuum



- $<10\mu\text{m}$  focus in vacuum
- Focal intensities of  $10^{16} \text{ W/cm}^2$
- Multi-element DM planned for improvement of Strehl Ratio

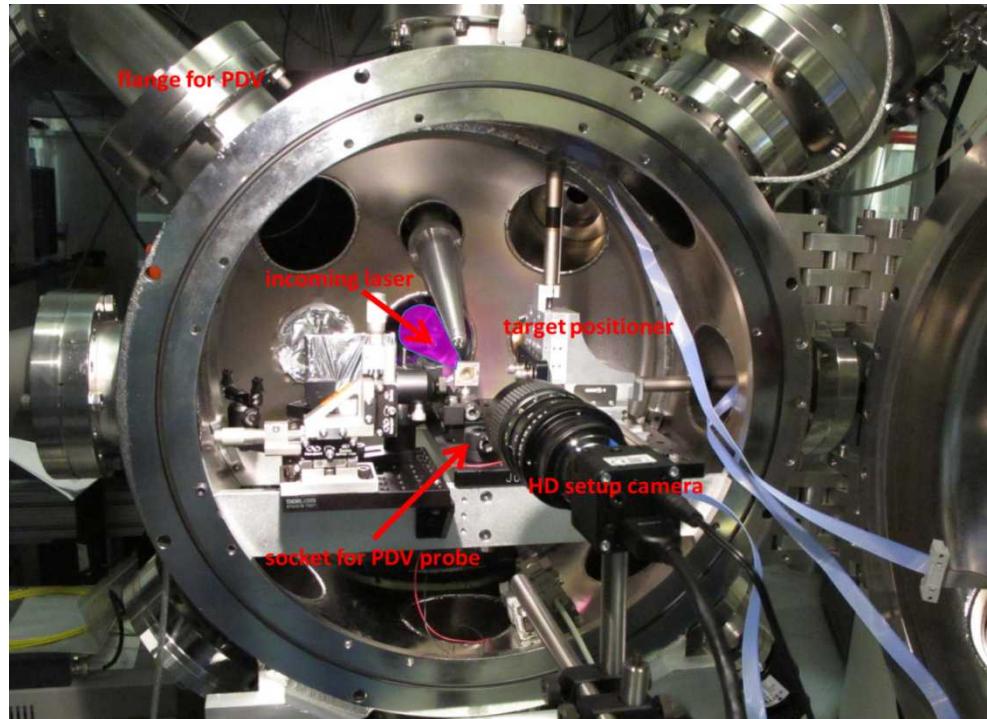




# Application to Meteoritic Shock Measurements

- Goal

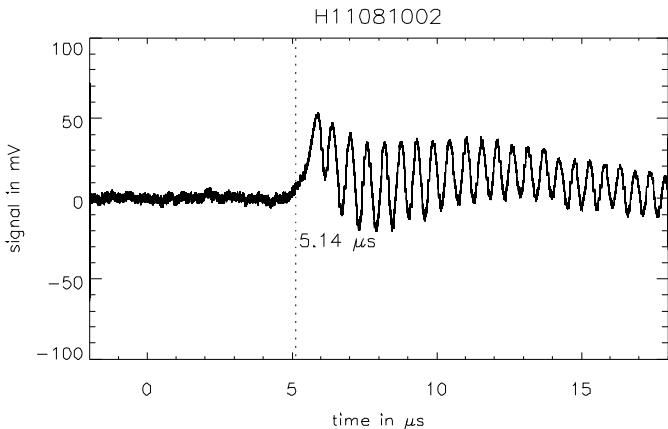
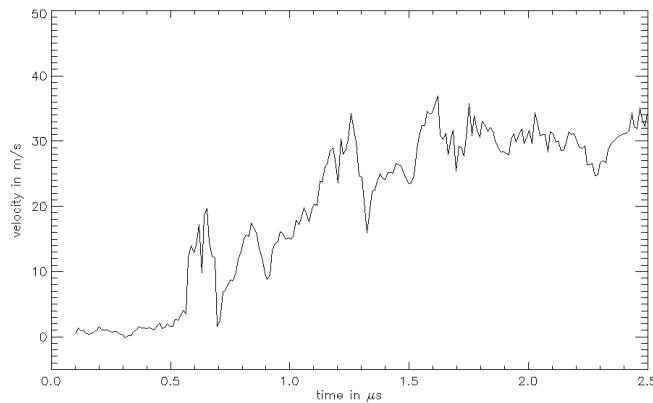
Measure the chemistry of meteoric material (Dunite) under laser induced extreme temperatures and pressures



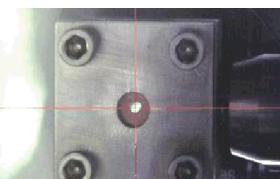
Laser was tuned to provide 25J/pulse at 532nm in a 1.3ns Pulsewidth  $1.5\text{mm}^2$

Photonic Doppler Velocimetry (PDV) used to measure laser-Induced shock velocities

# Application to Meteoritic Shock Measurements



before shot



alignment



after shot

- PDV tested

Plot showing the laser induced pressure wave velocity in 100um thick Al foil measured on the rear surface, derived from change in PDV carrier frequency.

- Dunite tested

Plot showing the reflectivity changes at 5.14 $\mu$ s after laser impact ( $t=0$ ), when the pressure wave reaches the rear surface of the Dunite target. (transit time)

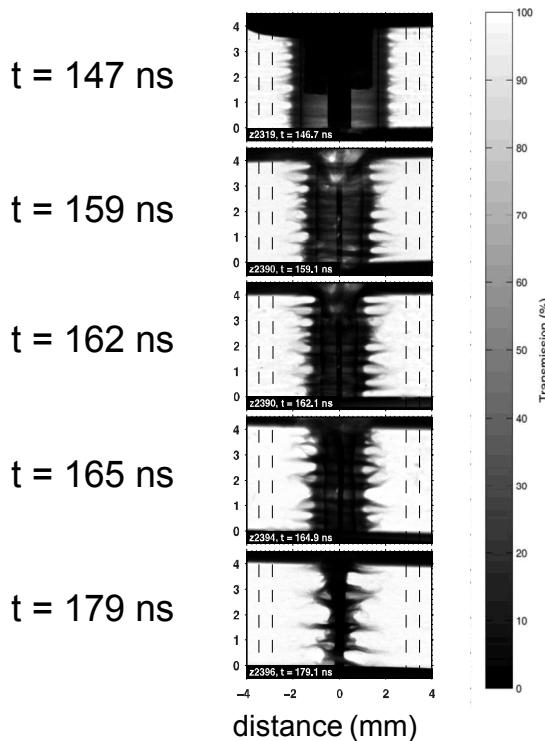
- We learned that sintered Dunite would not propagate a measurable shock wave without destroying

- Intention was to not destroy target, but to be able to analyze the crater for phase changes after the shot

# Application to Ultrafast X-ray Imager (UXI) development

- Goal

Develop a multi-frame time-gated x-ray detector to replace image plate in the crystal-imaging x-ray backlighter diagnostic used on Z (monochromatic backlighting at 6.151 keV, 1 ns exposure time)

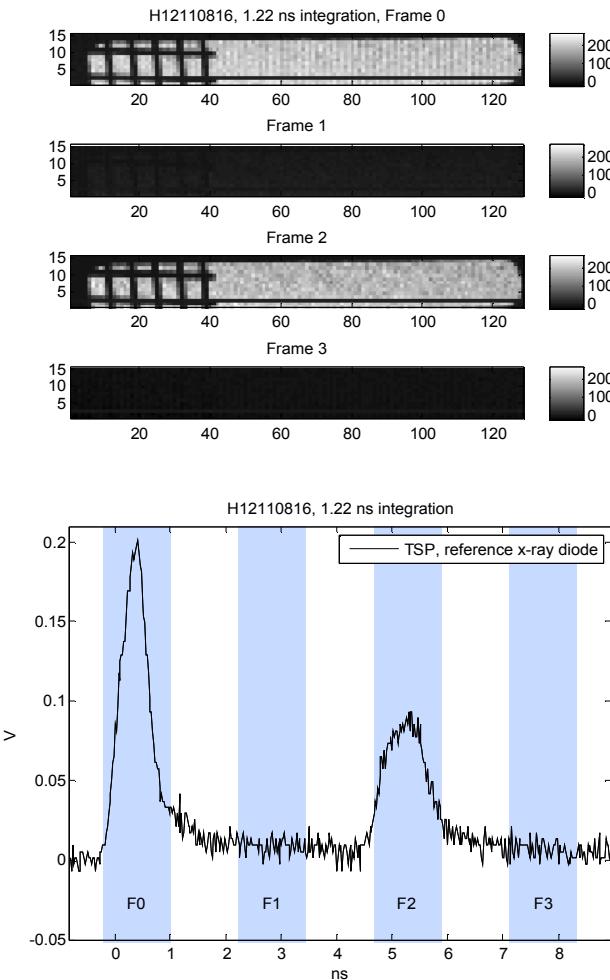


Example of backlighting images of z-pinch implosion acquired over multiple shots on Z (Ryan McBride, et. al., to be published in Physics of Plasmas, May 2013)

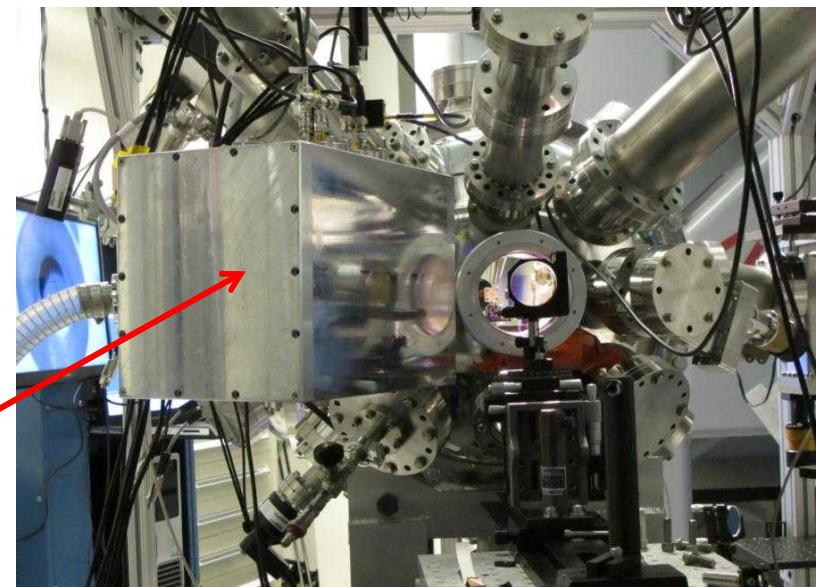
## UXI development team

- Liam Claus, Rex Kay, James MacArthur, John Porter, Gideon Robertson, Marcos Sanchez, John Stahoviak, Doug Trotter

# UXI prototype tested with DIVA system



- A 4 frame UXI prototype camera has been tested
  - The laser was tuned to provide a double pulse with 4.9ns separation
  - A Ti target was used to generate a 4.7 keV x-ray source
  - The camera was set to 1.22 ns integration time
  - The fast-gating capability of the UXI camera was demonstrated



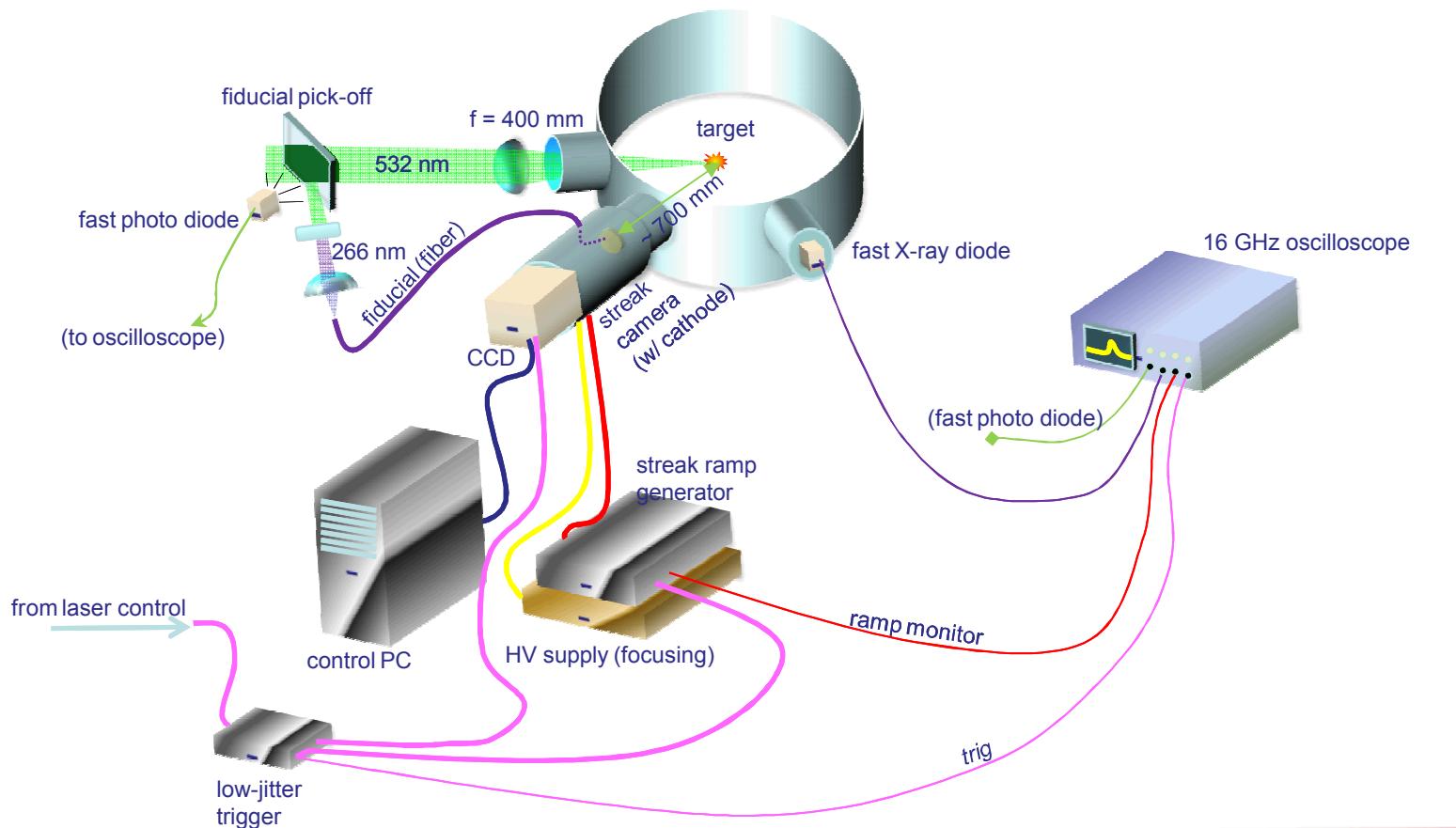
DIVA target chamber

# Characterization of the “Streak Polar Instrument for the Detection of Energetic Radiation (SPIDER)” for the National Ignition Campaign

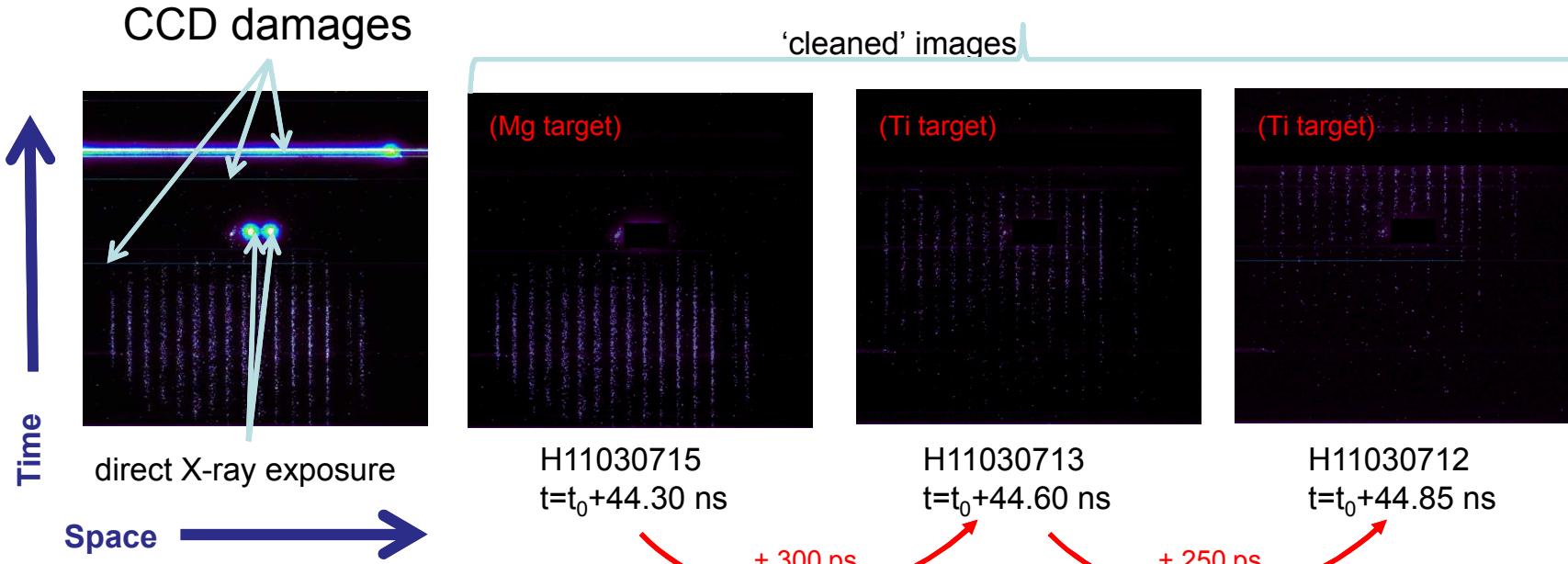
- Goal

Temporal calibration of streak images

$$\tau_{\text{exp}} = \tau_0 + \text{pixel channel} \times \text{constant}$$



# SPIDER Characterization



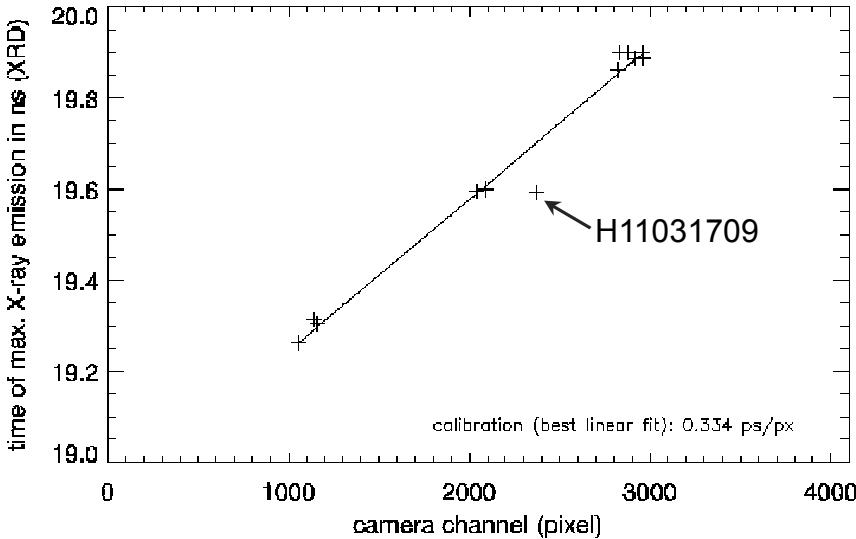
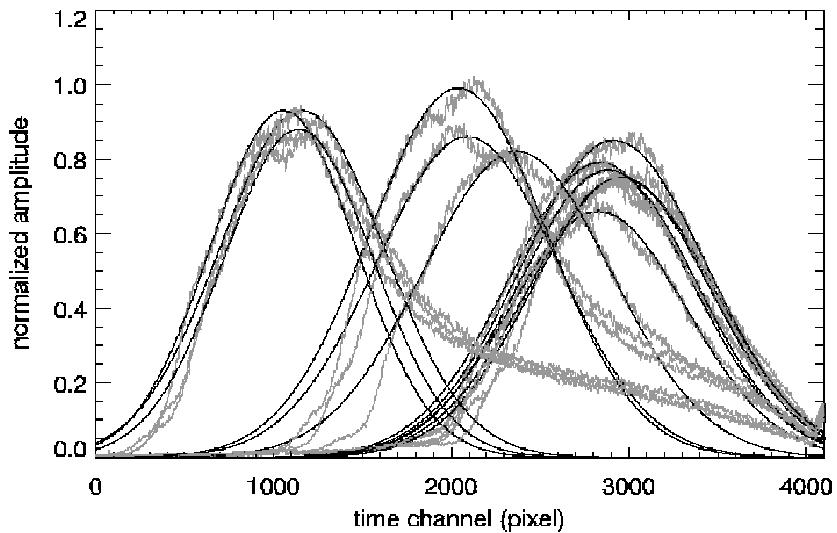
$t_0 \sim$  (laser pulse on target) – 75.5 ns (inherent device delay)

X-ray travel time from target to photocathode  $\sim 2.3 \text{ ns}$

Electron transit time from photocathode to deflectors typically 2-3 ns (?)

# Precision Correlation Measurements: Electronics vs. X-Rays

## Exact timing correlation with streak-images



The traces of the streak camera image don't match a Gaussian shape as well as the XRD and photodiode measurements. However, a Gaussian approximation is still appropriate to determine the center of the main emission (ignoring the 'tail').

It is apparent that the rising edge of the signal is faster than Gaussian, which indicates that the XRD and photodiode are not fast enough to resolve the edge.

### Linear fit:

Is shot H11031709 an anomaly?! The experiments did not indicate a problem.

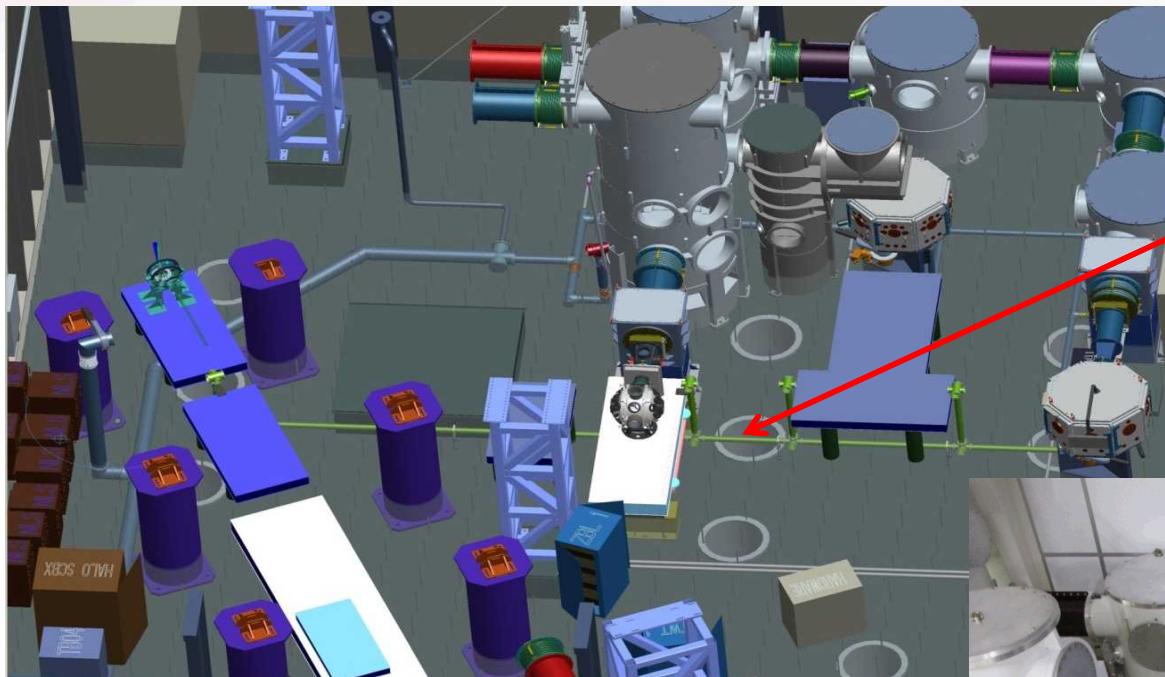
Including H11031709, a linear fit indicates **3 pixels per picosecond**. The jitter would be  **$\pm 35.5$  ps**. Without H11031709 the numbers would be **2.98 pixels/picosecond** and a jitter of  **$\pm 14.7$  ps**. Justifiable?!

FWHM:  **$385$  ps  $\pm 29$  ps**



# Future Applications

## Probe Beams



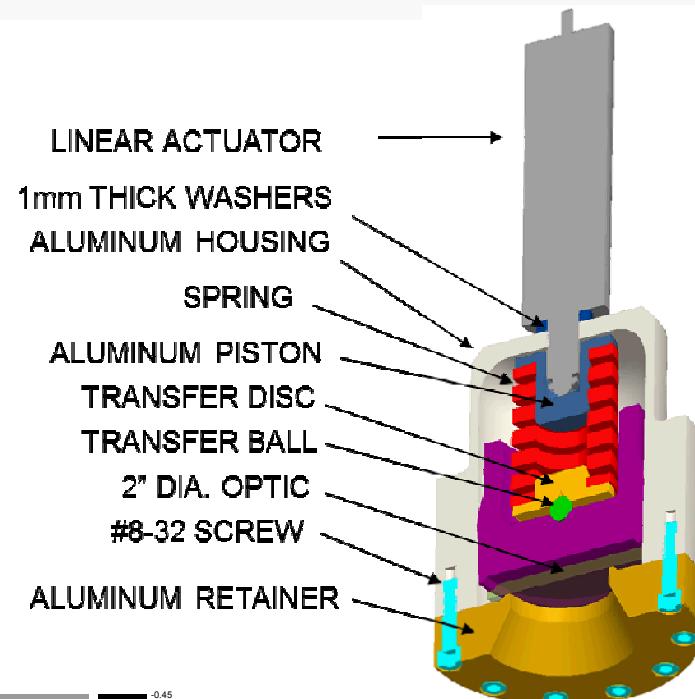
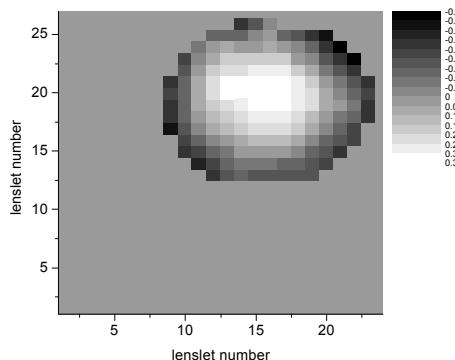
Beam tubes  
from DIVA to other  
target chambers



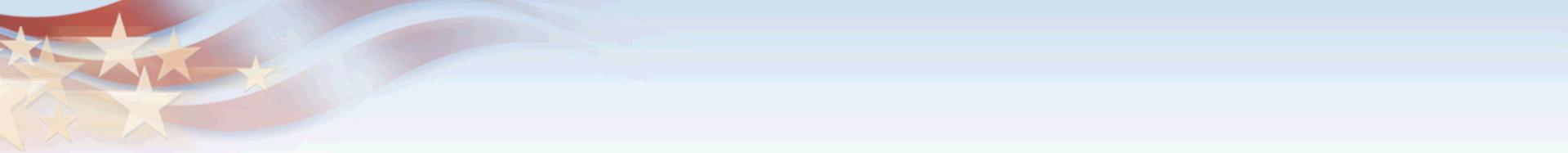
- New tubes provide access to larger target chambers  
Allows DIVA to provide probe beam support  
at 1064/532nm to HEDP studies in conjunction with  
ZBL and ZPW which operate at 527nm and 1054nm
- Vacuum Relay Imaging is possible
- Large Area Optical Damage Testing will be possible

# Future Improvements

- A negative on-shot thermal lens has been detected on the DIVA system
- The negative on-shot thermal lens is due to the fact that the instantaneous absorption of the flashlamp output preferably heats the edge of the rod
- This diverging effect is currently pre-compensated for manually using increased lens separation in the final relay telescope
- An improved system to pre-compensate utilizes a single actuator adaptive optic technique, developed at Sandia



U.S. Patent Application No. 11/017,897 "Variable Focal Length Deformable Mirror"  
D. Headley, M. Ramey, J. Schwarz



# Conclusion

- An X-ray diagnostic test bed has been developed  
A stable seed laser and regenerative amplifier provide low amplitude and temporal jitter  
Pulsewidths of 300ps to 8ns are possible and pulse energies of >100J are available  
Two methods have been developed to provide multiple pulse operation of the amplified system
- X-ray diagnostic development missions are on-going  
Ultrafast X-ray Imager diagnostic is currently being tested  
HEDP tests of Meteoric materials have been achieved  
Temporal calibration of SPIDER diagnostic has been accomplished
- Future improvements to and applications of the system are planned  
Deformable mirrors will allow access to Intensities of  $10^{17}$  W/cm<sup>2</sup>  
Vacuum beam tubes are currently being installed which will direct the DIVA laser beam to other target chambers for probe beam support  
A Large Area Optical Damage Test apparatus is planned