LLNL-PRES-408199

# Precision Diagnostics for the Advanced Radiographic Capability on the National Ignition Facility

**3rd International Conference on Ultrahigh Intensity Lasers (ICUIL)**
**Development, Science and Emerging Applications,**
**Shanghai-Tongli, China**

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**Photon Science and Applications Program**
**NIF and Photon Science Principle Directorate**

**October 31, 2008**

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# Outline

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1. Introduction to ARC and its split-beam architecture

2. Requirements and limitations for laser diagnostics

3. ARC diagnostic development and performance

4. Dispersion Management in the ARC laser beamlines:
   - Overview and need for precision dispersion balancing
   - Group delay diagnostics
   - First results

# ARC-Diagnostics Team (present and past)

The National Ignition Facility

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- N. Wong
- I. Jovanovic*
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- N. Troy**
- K. Williams

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** UC Davis

# The split-beam architecture of enables multi-shot radiographic imaging

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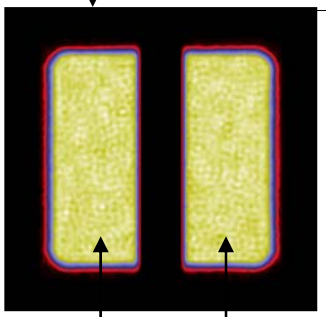
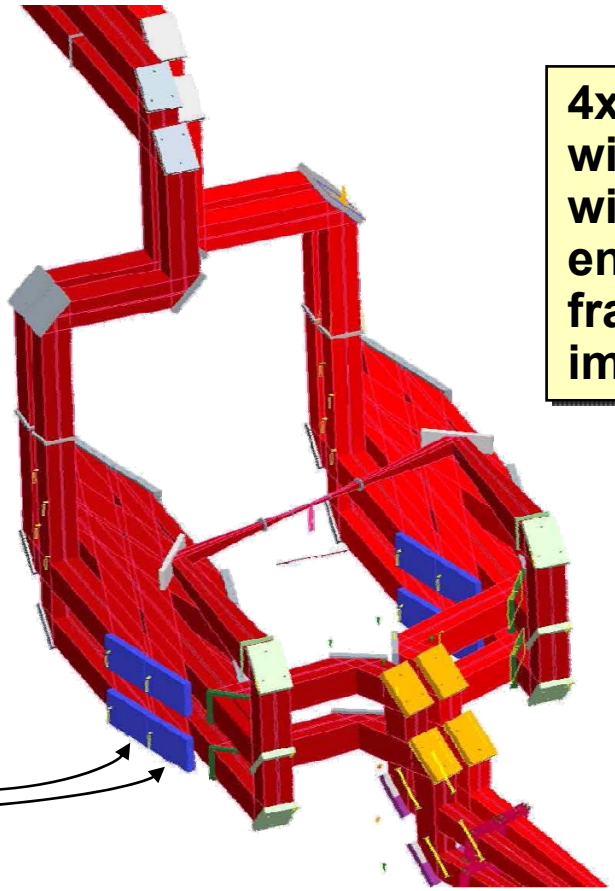
Full NIF beam aperture is square



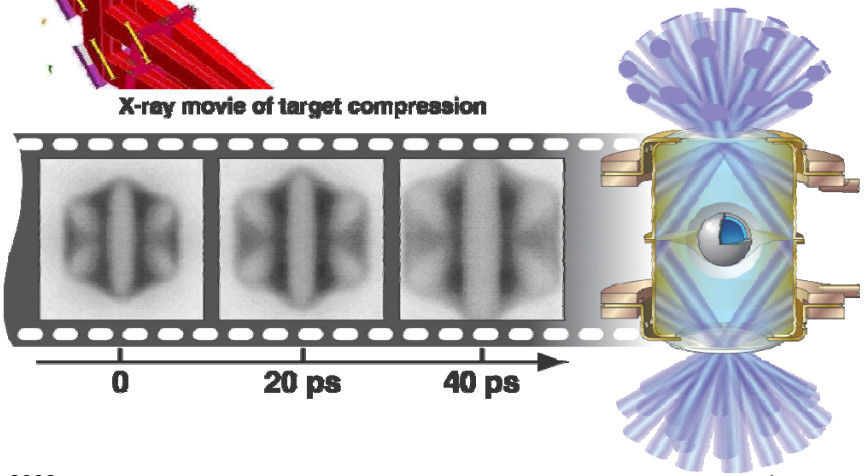
Second aperture (uses one grating)

First aperture (uses one grating)



4x 2 ARC sub-apertures will be focused on target with variable time delay, enabling hard x-ray, multi-frame radiography of imploding NIF capsules

Gives 8 Petawatt beams with adjustable delay control




J. Crane, ICUIL session 1

# Single-Shot characterization is required for a kJ-class split-beam short pulse laser system

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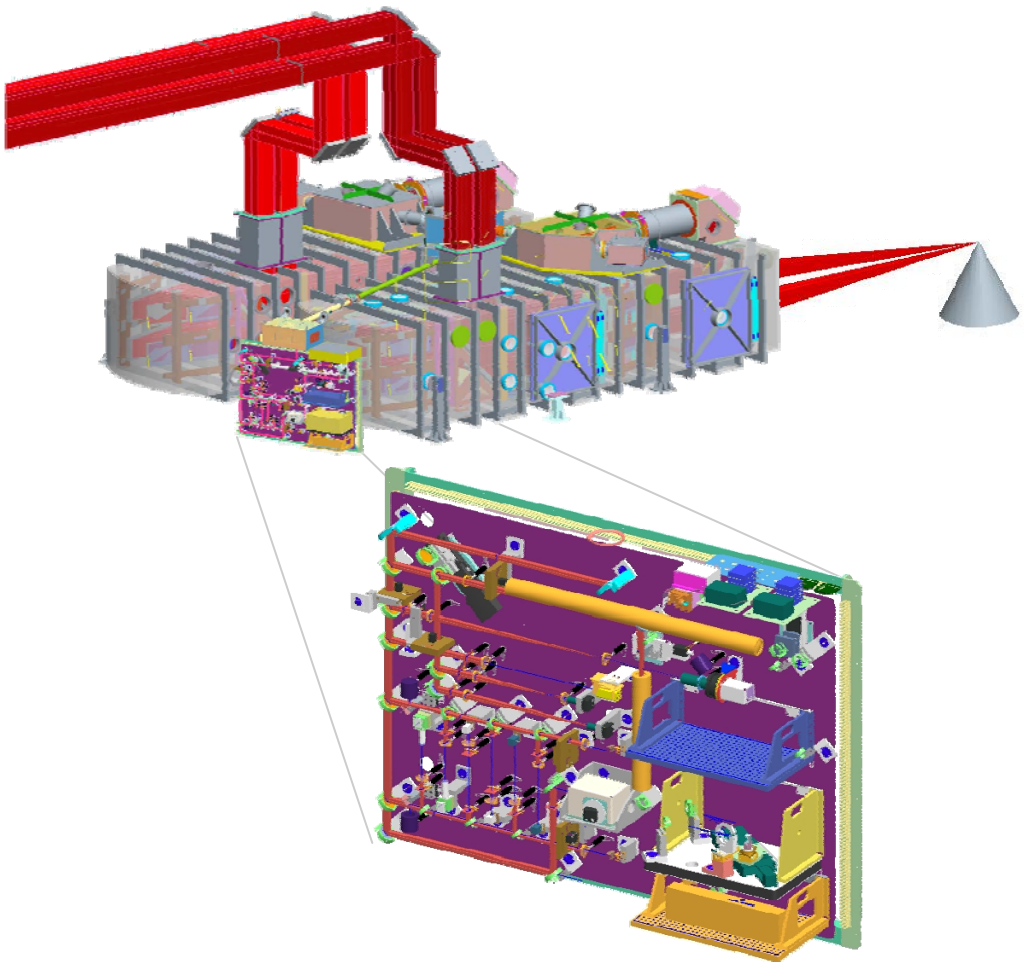

- Pulse width
- Pulse shape
- Pulse contrast
- Pulse energy
- Pulse spectrum

- Wavefront
- Inter beam coherence
- Relative pulse delay
- Near field
- Far field

# Diagnostics system is placed behind target bay wall to shield against neutrons and EMP

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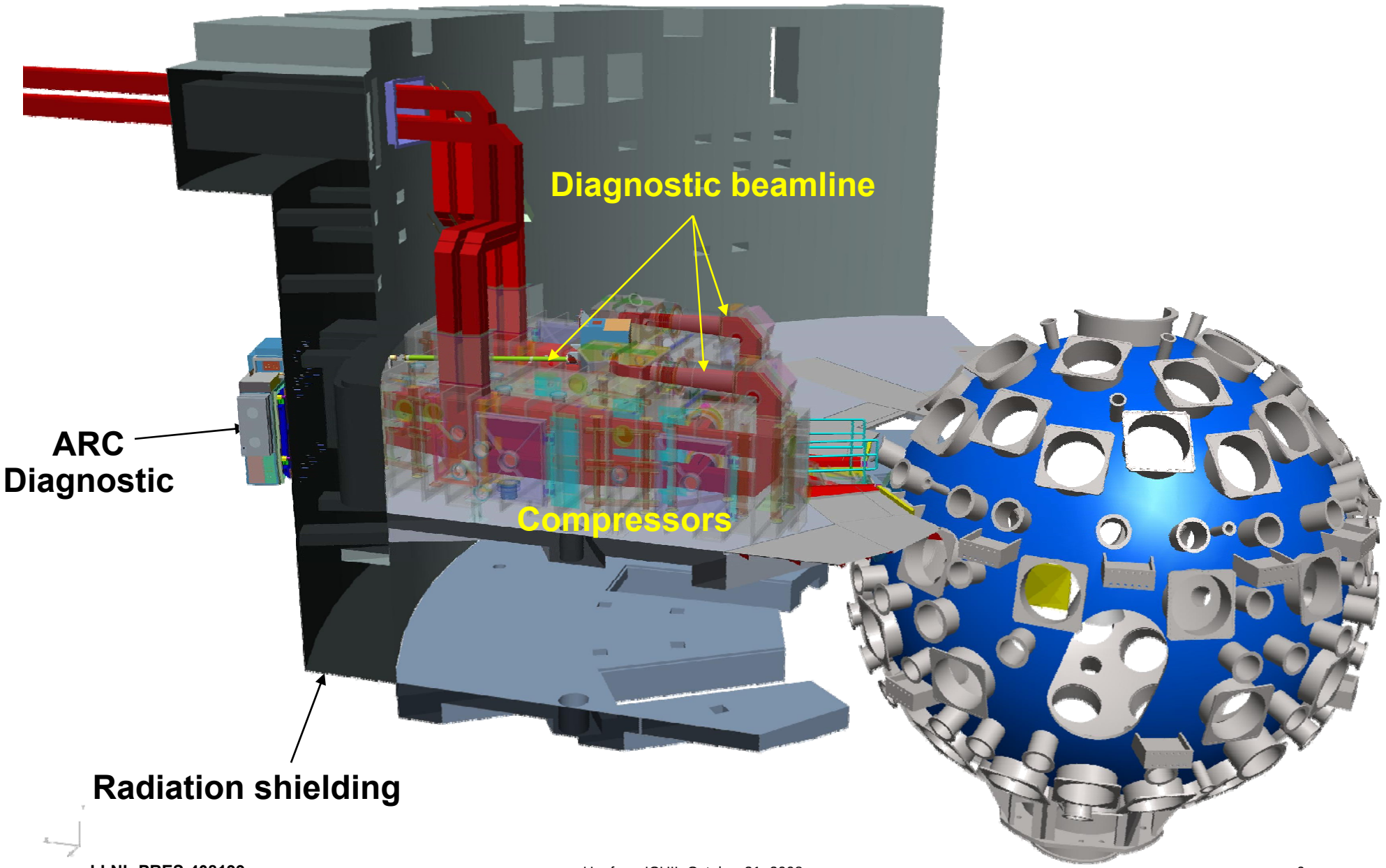

# To avoid pulse distortions in the diagnostic beamline, we keep ΣB-Integral below ~ 1 rad

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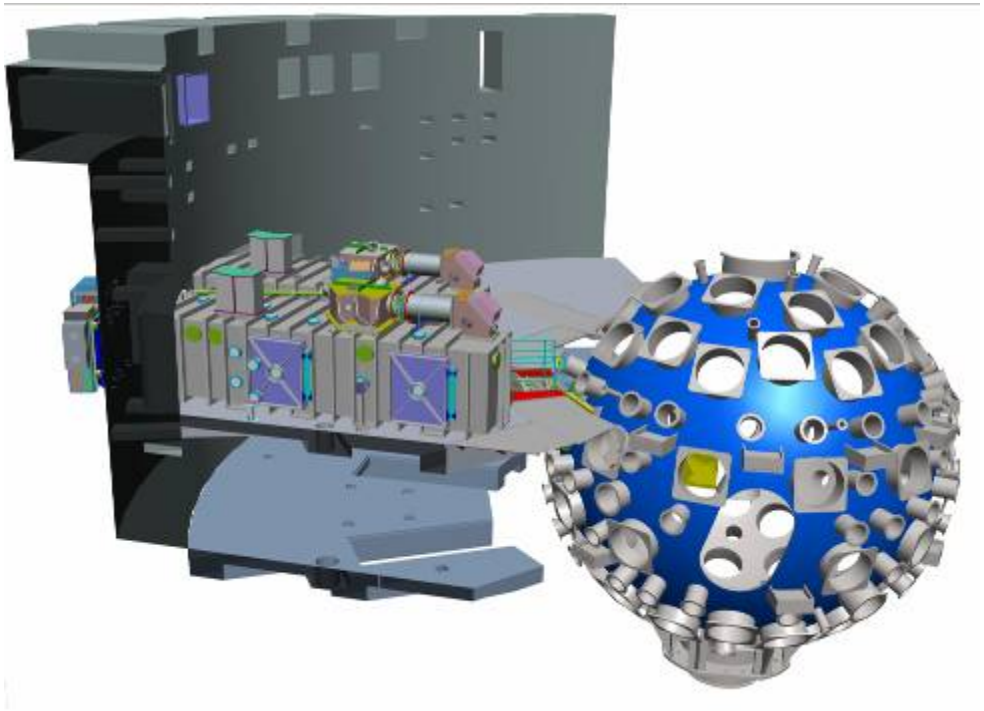

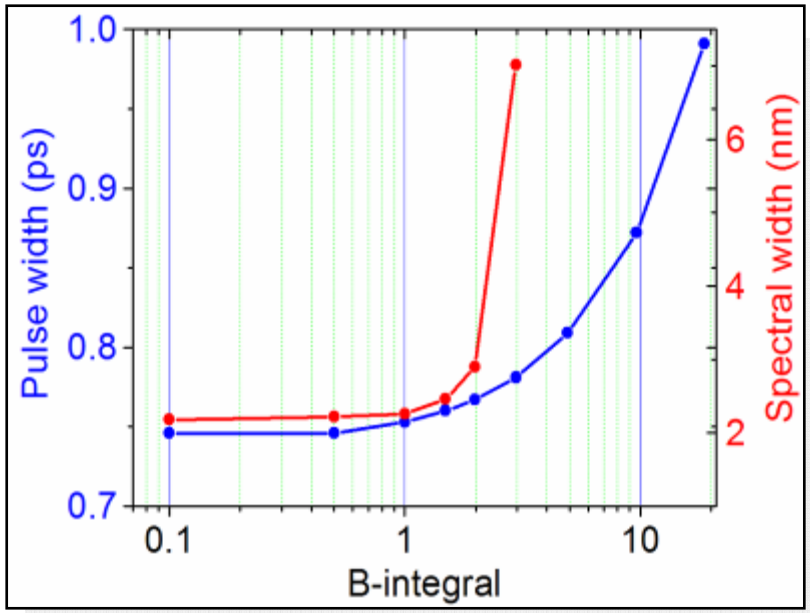


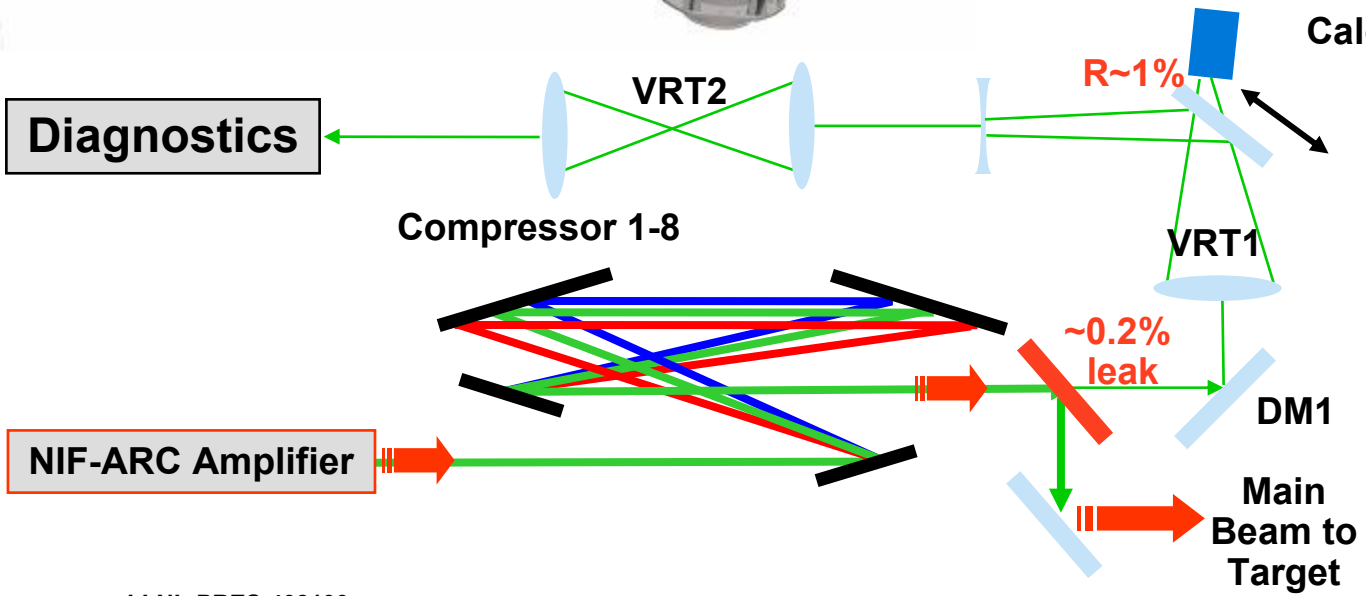

# B-Integral limits maximum energy available for laser diagnostics

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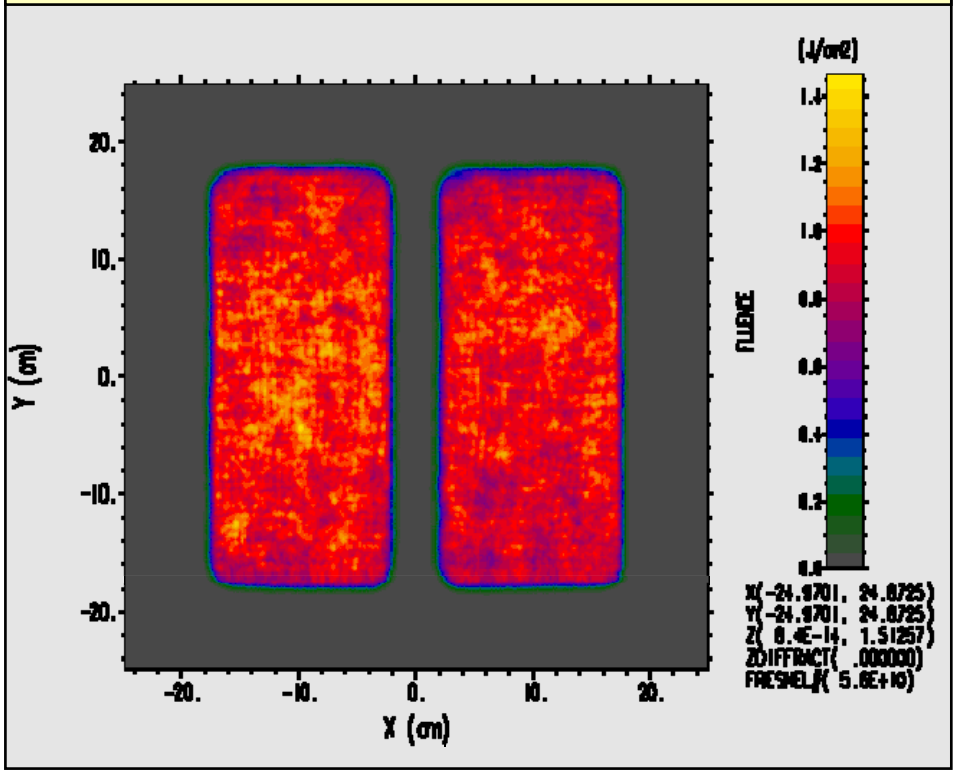
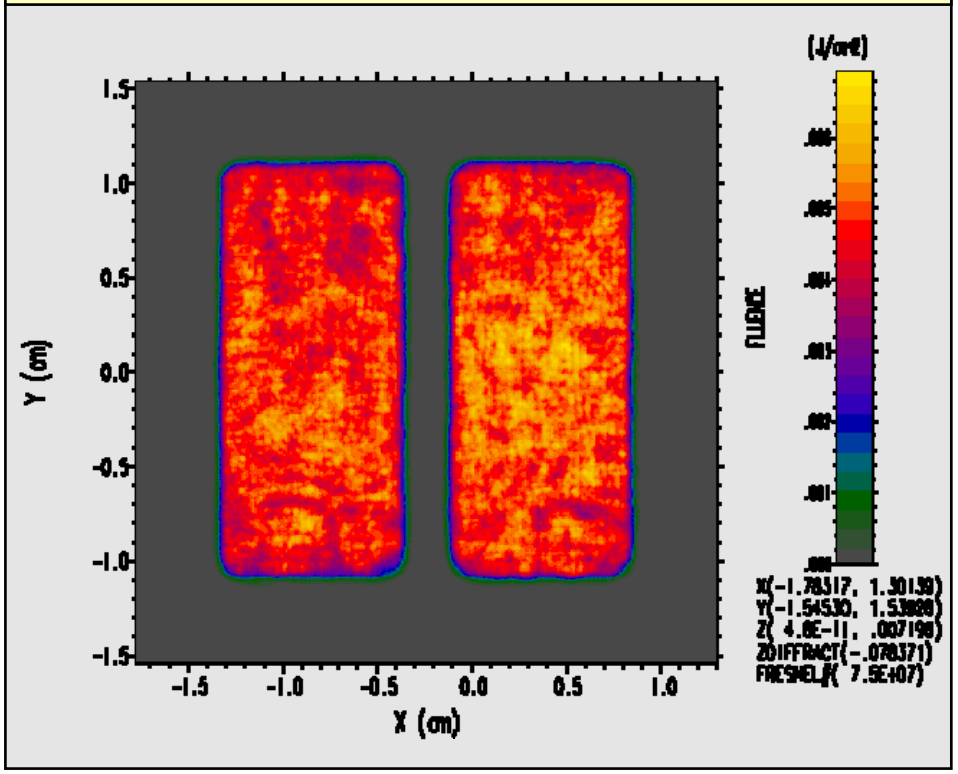
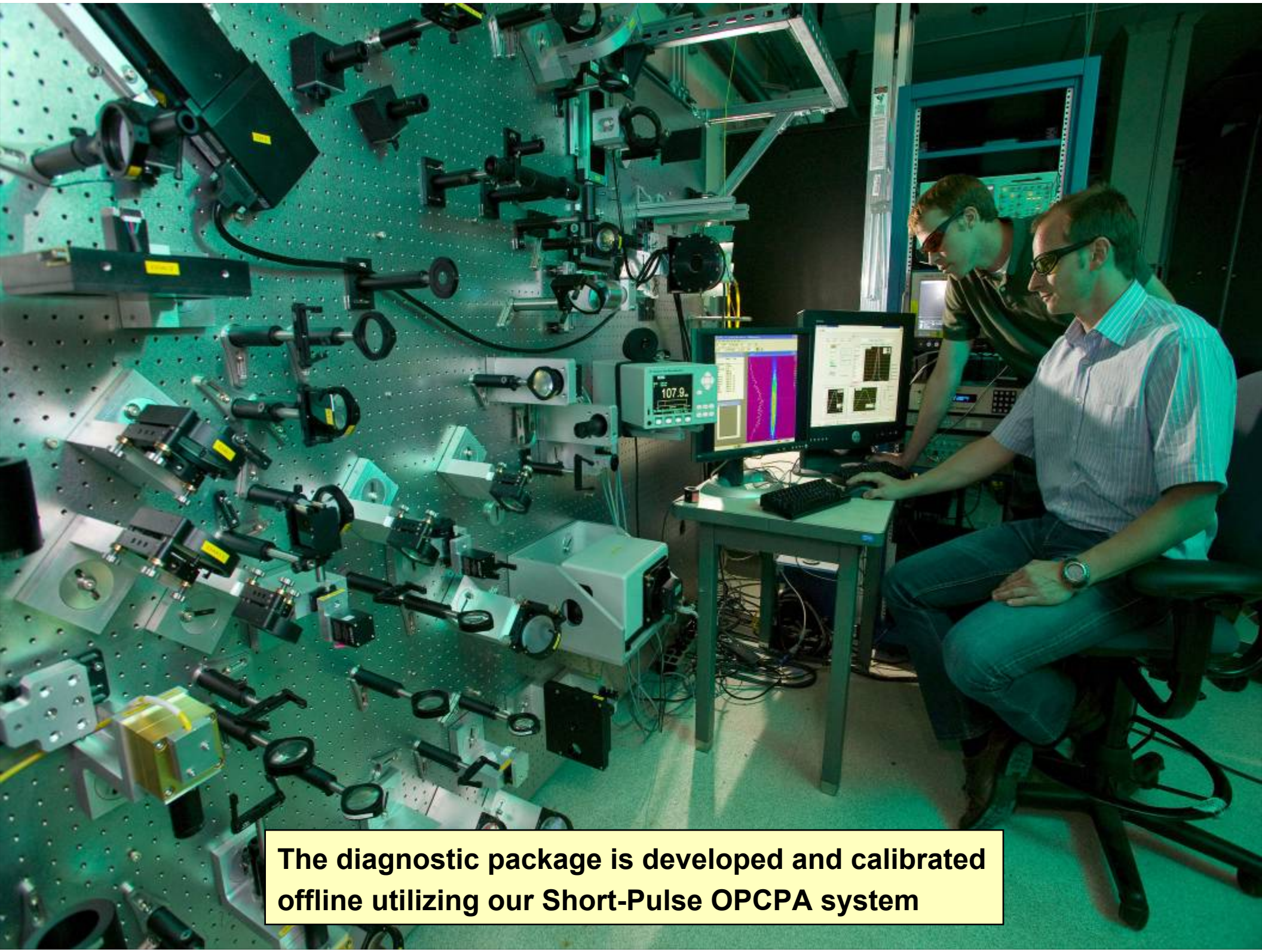
**Spatial beam profile at ARC compressor output for 1 kJ, 3 ps pulse**




**Spatial beam profile at ARC diagnostic relay plane, B=0.4 rad, E=20 mJ**




**Energy to employ all diagnostic instruments is limited to ~20 mJ for 3 ps pulses and ~55 mJ for 10 ps pulses to not exceed B>1 rad in diagnostic beamline**



**The diagnostic package is developed and calibrated offline utilizing our Short-Pulse OPCPA system**

# Spatial diagnostics have been installed and calibrated and meet specifications

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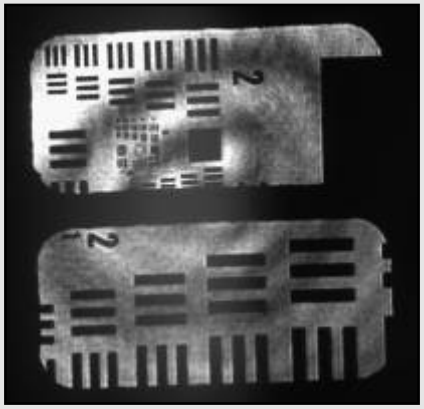
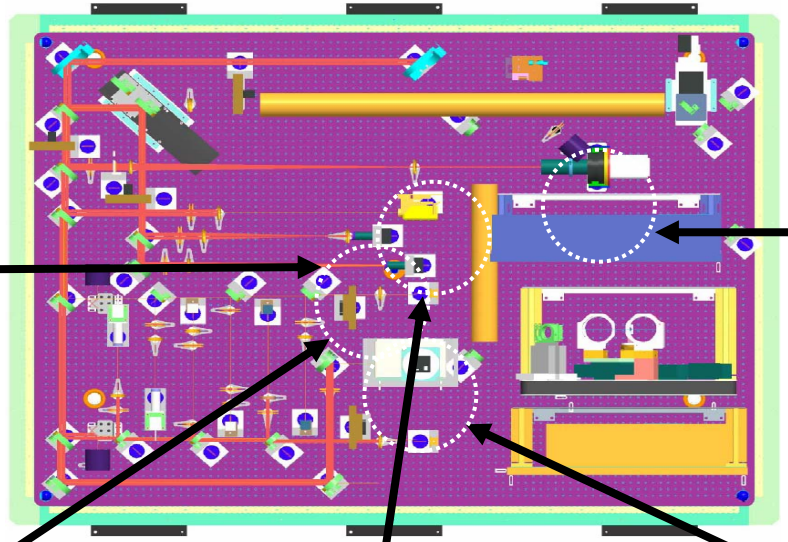
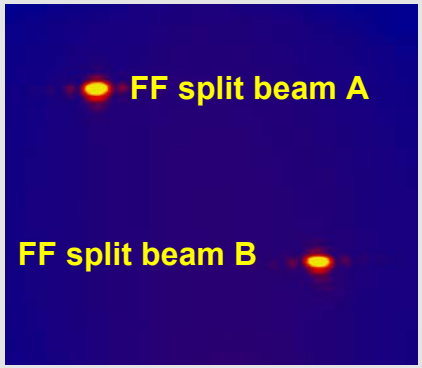
**Near-Field Camera: intensity profile, alignment, clipping: Res. < 0.5 mm/px**

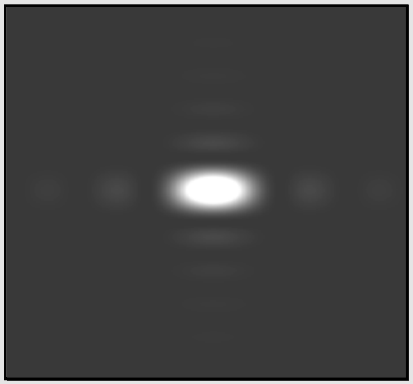




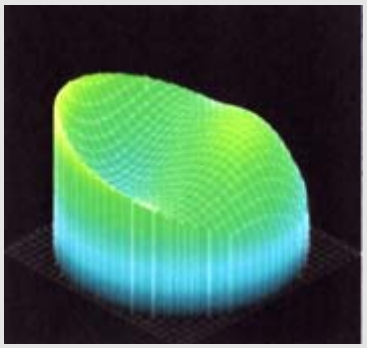
**16 bit Far Field camera in TCC conjugated plane. Res.<0.01μrad/px**




**Pointing-Camera: beam parallelism, alignment : Res. <0.54 μrad/px**

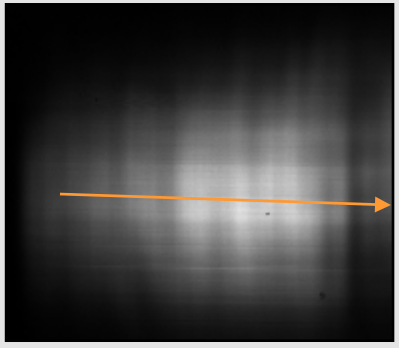


**Phasix Shearing Interferometer: FF-redundancy, adaptive mirror**



Testing in progress

**Spectrometer measuring gain narrowing and spatial chirp. Resolution <0.08 nm.**



# Temporal diagnostics cover a window of 40 ns seamlessly with high dynamic range

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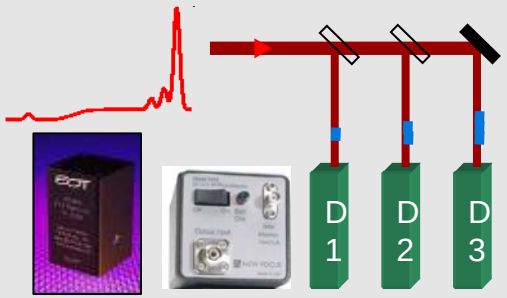
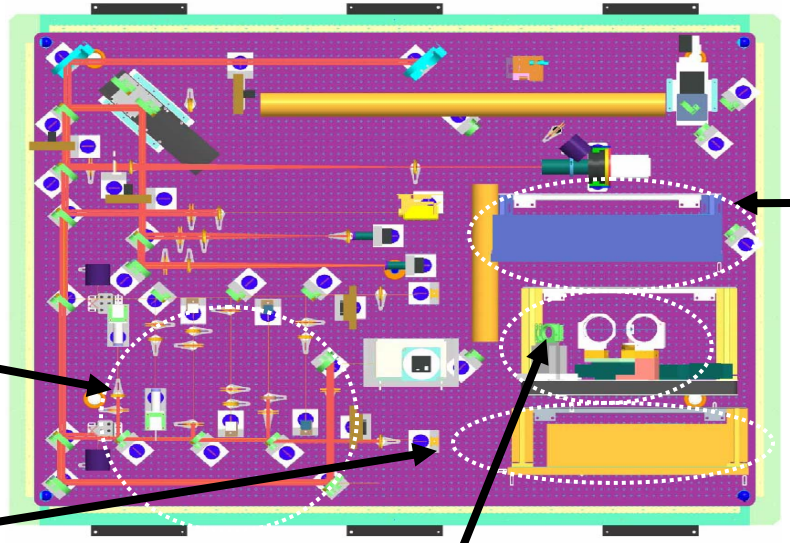
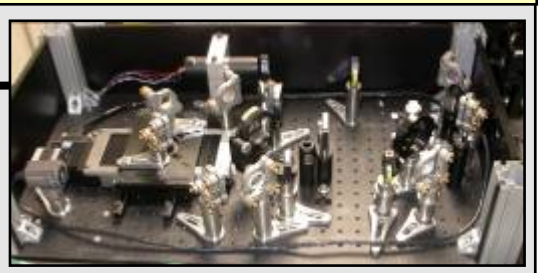
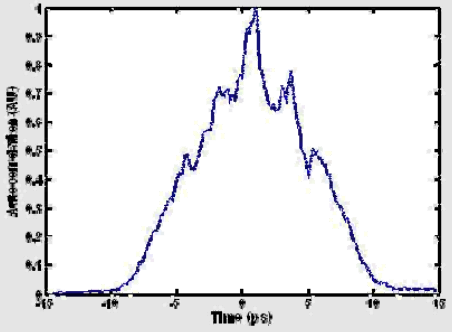
**Cascaded Photodetectors: detect temporal pulse shape from 40 ns – 35 ps with 90 dB**

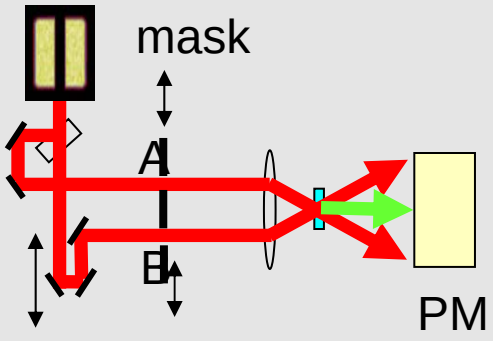


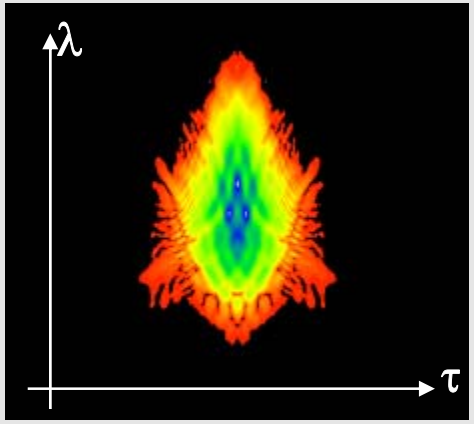
**Scanning pJ-Cross-Correlator: Intra-beam timing and pulse duration**



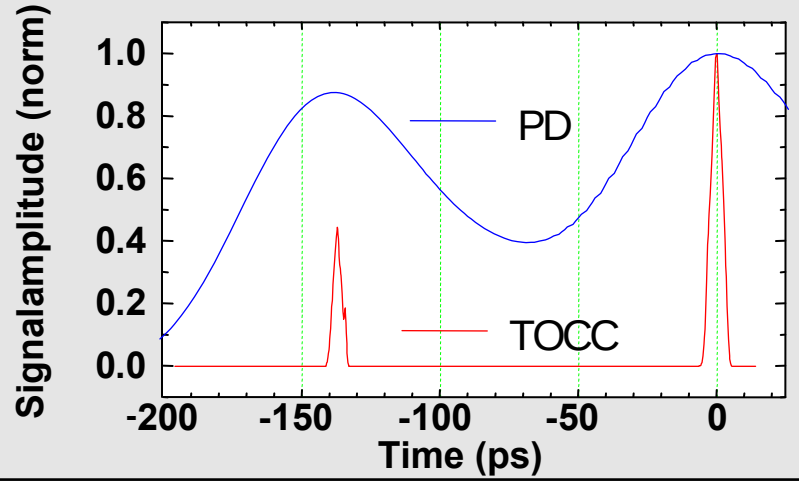





**20 ps – Single Shot FROG detects pulsefront-tilt and spatial chirp**




**Large temporal window third order Cross-Correlator with Tweaker**



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1. Introduction to ARC and its split-beam architecture

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4. **Dispersion Management in the ARC laser beamlines:**
   - **Overview and need for precision dispersion balancing**
   - **Group delay diagnostics**
   - **First results**

# To produce high intensity, short-pulses dispersion must be carefully balanced

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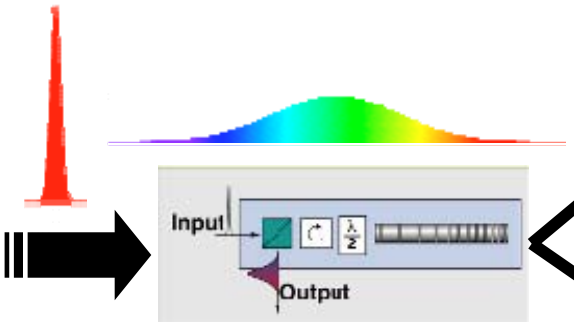
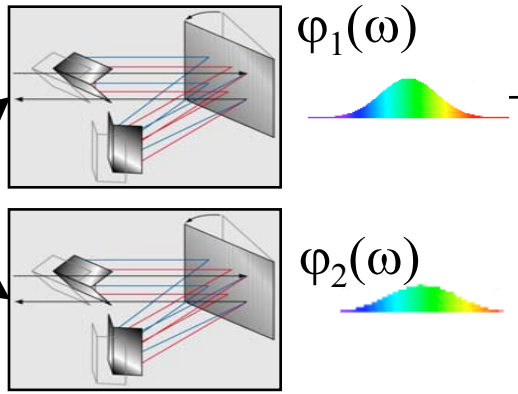
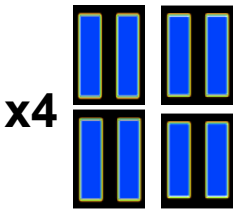
Mode-locked Fiber oscillator



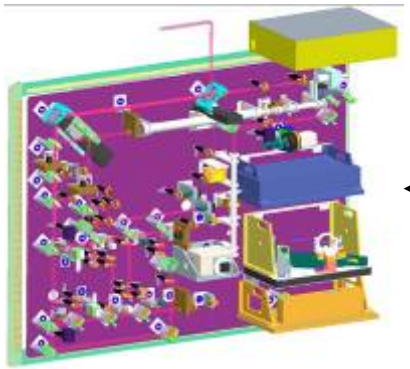

Chirped Fiber Bragg Grating Stretcher



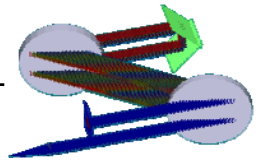

Dispersion Tweakers




Multiplexing

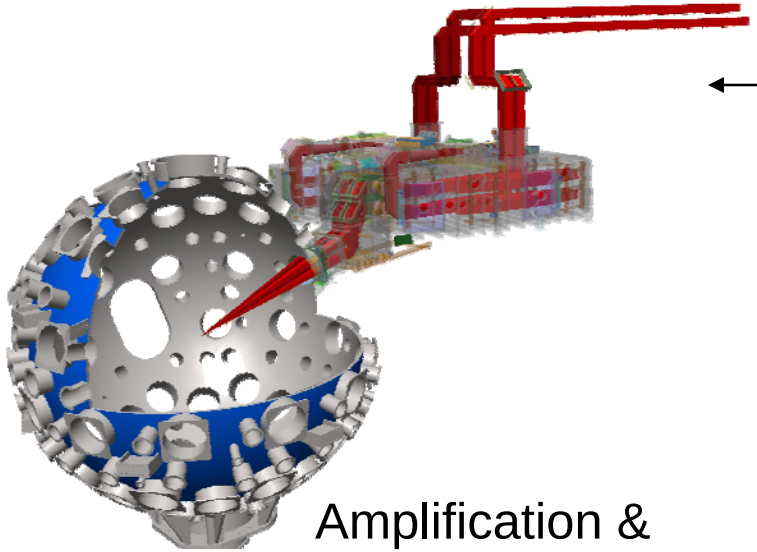


Diagnostics



Dispersion Tweaker



Amplification & partial compression

# We are using the phase-shift technique* to measure group delay better than +/- 0.6 ps

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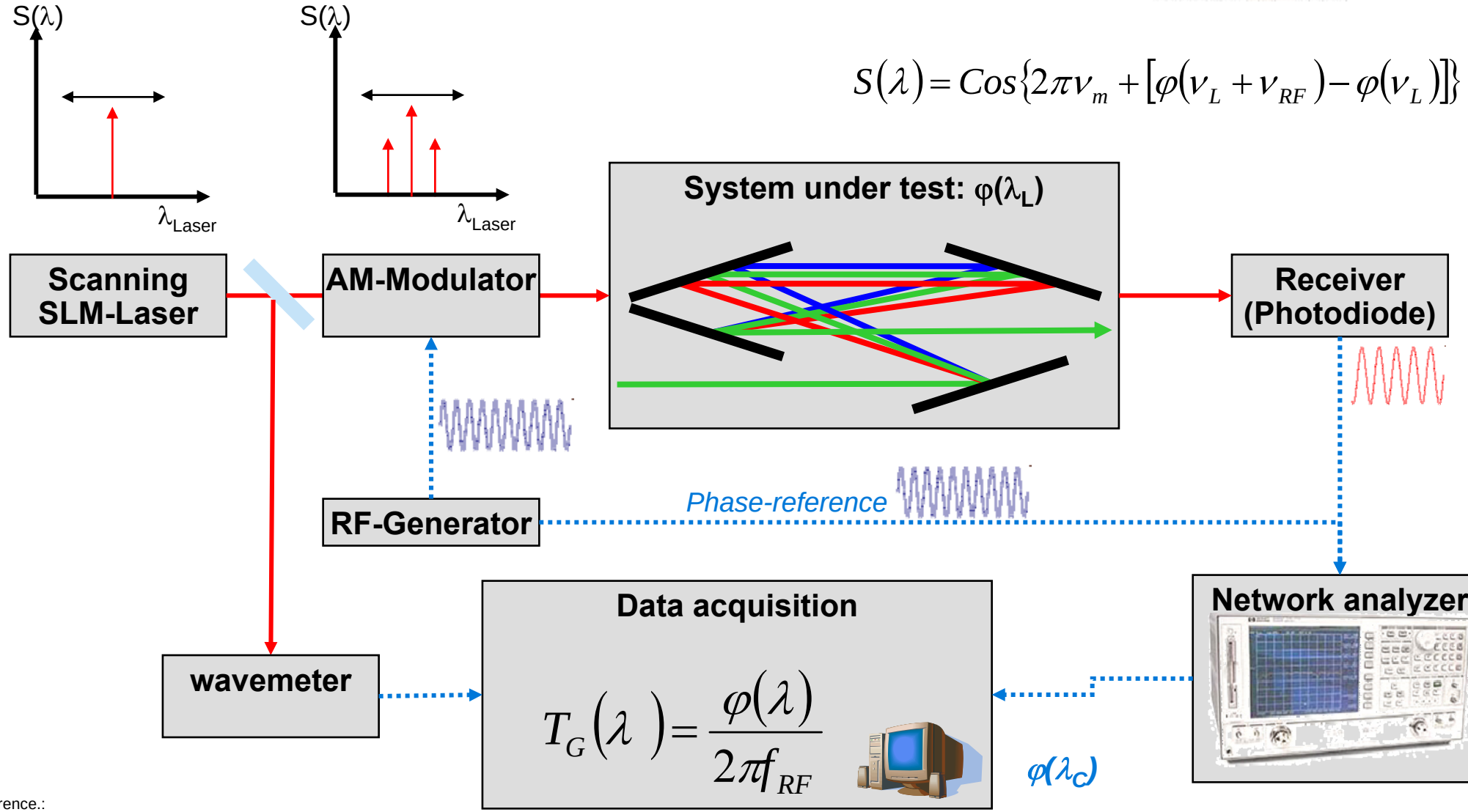



Reference.:

1. S. Ryu, Y. Horiuchi, K. Mochizuki, "Novel Chromatic Dispersion Measurement Method Over Continuous Gigahertz Tuning Range", IEEE J. Lightwave Tech. 7, 1177 (1989)

2. J. K. Crane, R. H. Page, M. Y. Shverdin, M. J. Messerly, J. D. Nissen, V. K. Kanz, J. W. Dawson, B. H. Shaw, C. Haefner, G. Shih, C. W. Siders and C.P.J. Barty: "Group Delay Measurement for Balancing Dispersion in Complex Stretcher-Compressor Systems", Conference on Lasers and Electrooptics, San Jose, 2008

# We measure group delay as a function of wavelength or radial frequency

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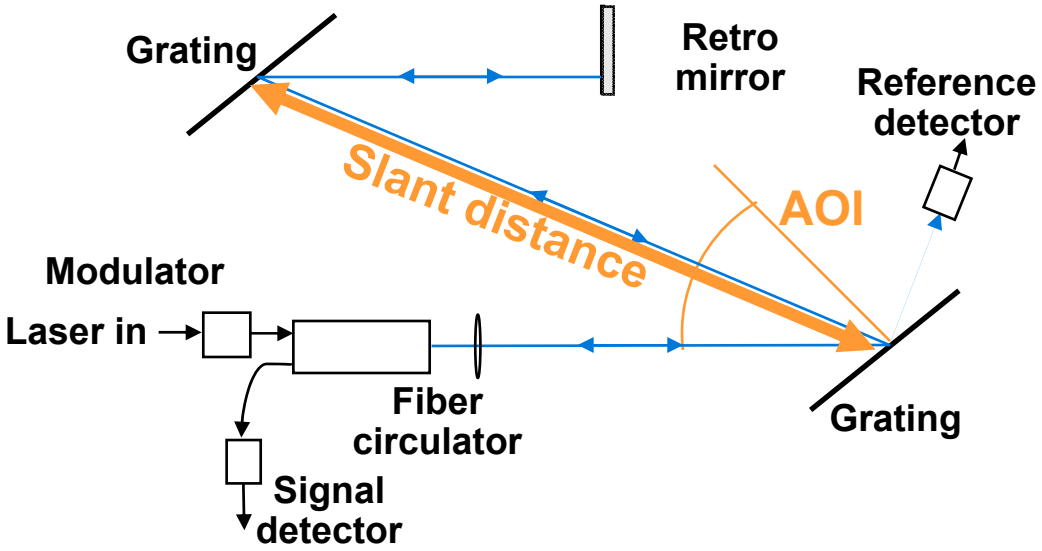
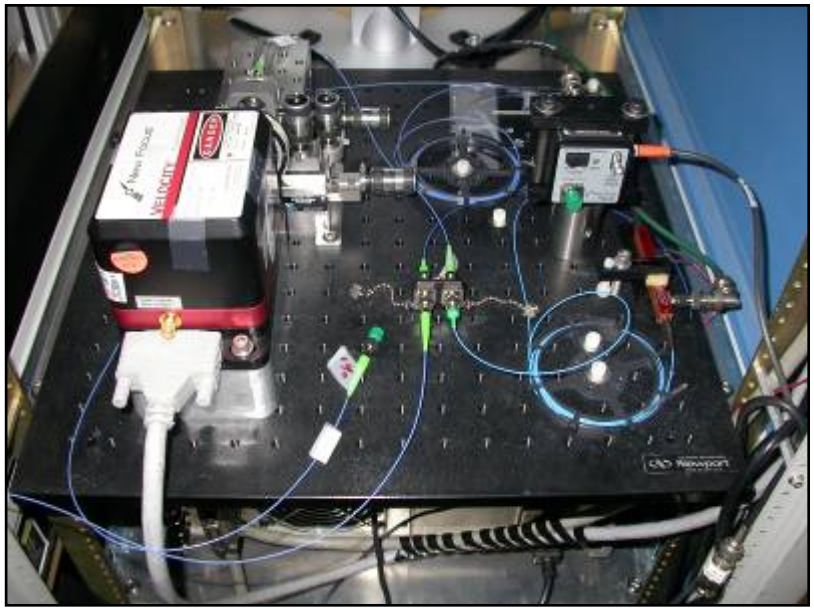
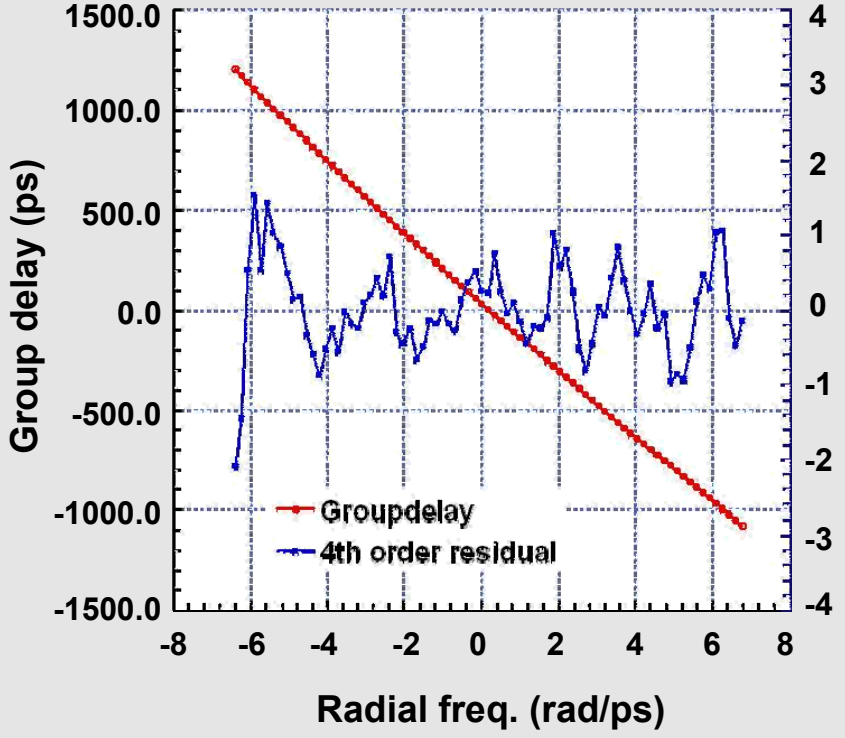


**Group delay measurement of a double-passed Treacy Compressor**




σ for this data is ±0.6 ps. Systematic error in the residuals is attributed to distortion in the modulation sine wave.

# Polynomial and Treacy fits to the group delay data agree with the compressor layout

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- **GDD repeatability: >99.9 %**
- **TOD repeatability: >99.3 %**
- **Treacy fit repeatability: >99.6 %**

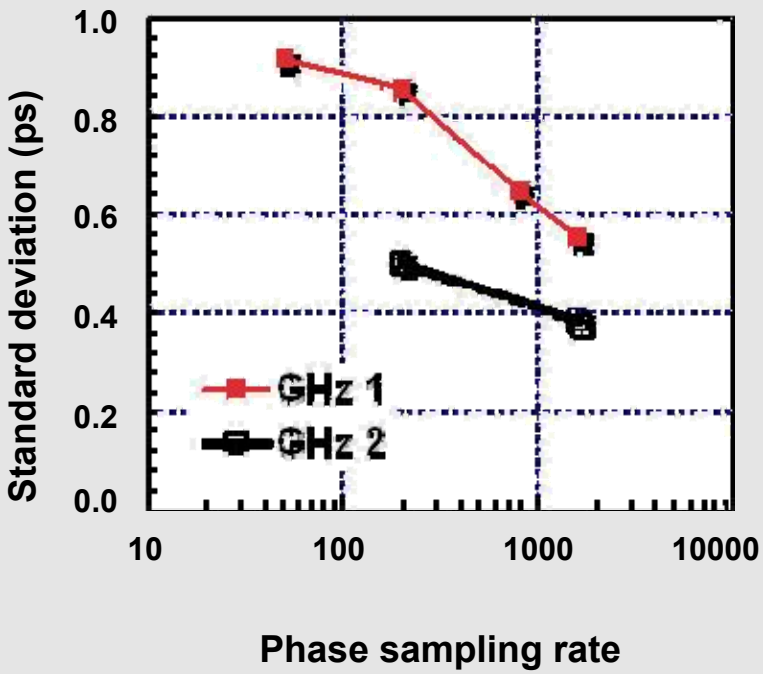
## Comparison of physically measured parameters

| | Measured values | GD Diagnostics Treacy fit |
|---|---|---|
| Included angle [deg] | 76.60 ± 0.05 | 76.57 |
| Slant distance [mm] | 2497±3 | 2499.5 |

## Comparison of resultant GDD and TOD values

| | 3rd order polynomial fit | Error from polynomial fit | Treacy model fit for GD |
|---|---|---|---|
| GDD [ps$^2$] | -172.821 | ±0.050 | -172.793 |
| TOD [ps$^3$] | 2.874 | ±0.012 | 2.871 |
| TOD/GDD [fs] | -16.630 | ±0.074 | -16.615 |

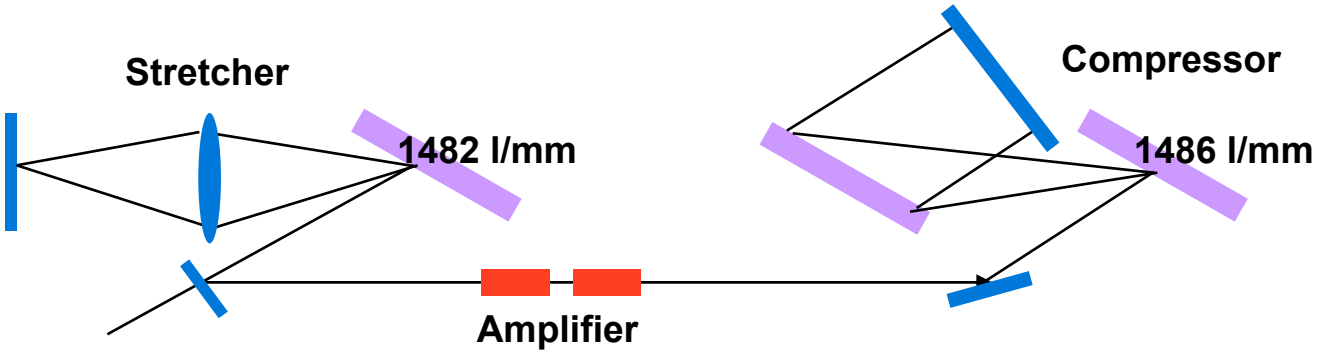
## Residual Errors




**Residual error decreases with modulation frequency and sample size**

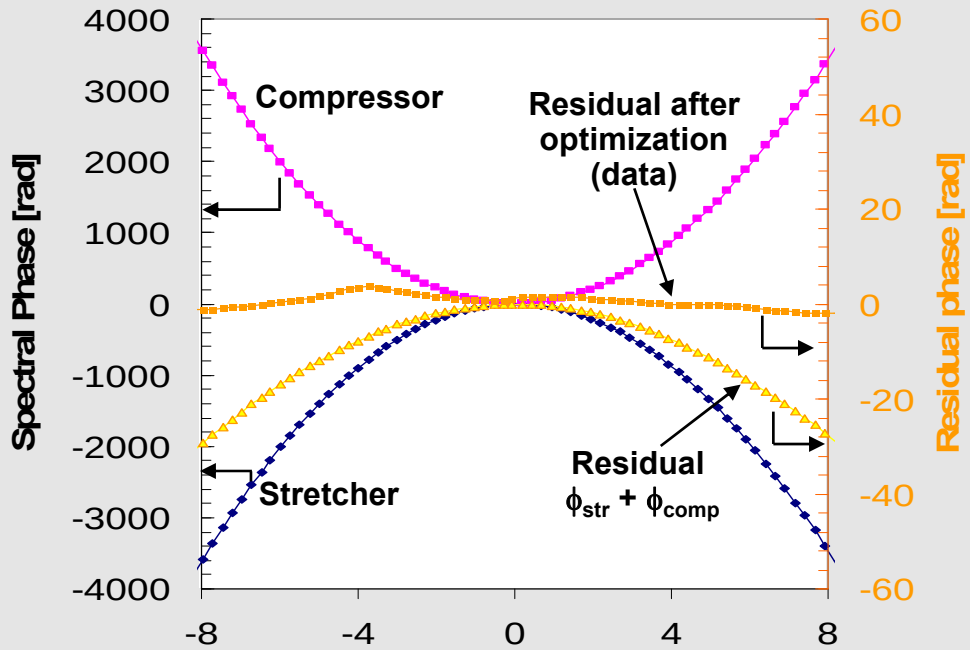
This data taken with 2 GHz modulation

# We recently applied the GD diagnostic to a full system for dispersion balance




We measured stretcher and compressor separately, and as a combined system

## Dispersion balancing




- Using the dispersion diagnostics we optimized angle of incidence and slant distance of the compressor to flatten the spectral phase.
- We discovered the residual group delay was caused by a bad coating on one optic.

# We will measure each dispersive element separately to balance net total dispersion

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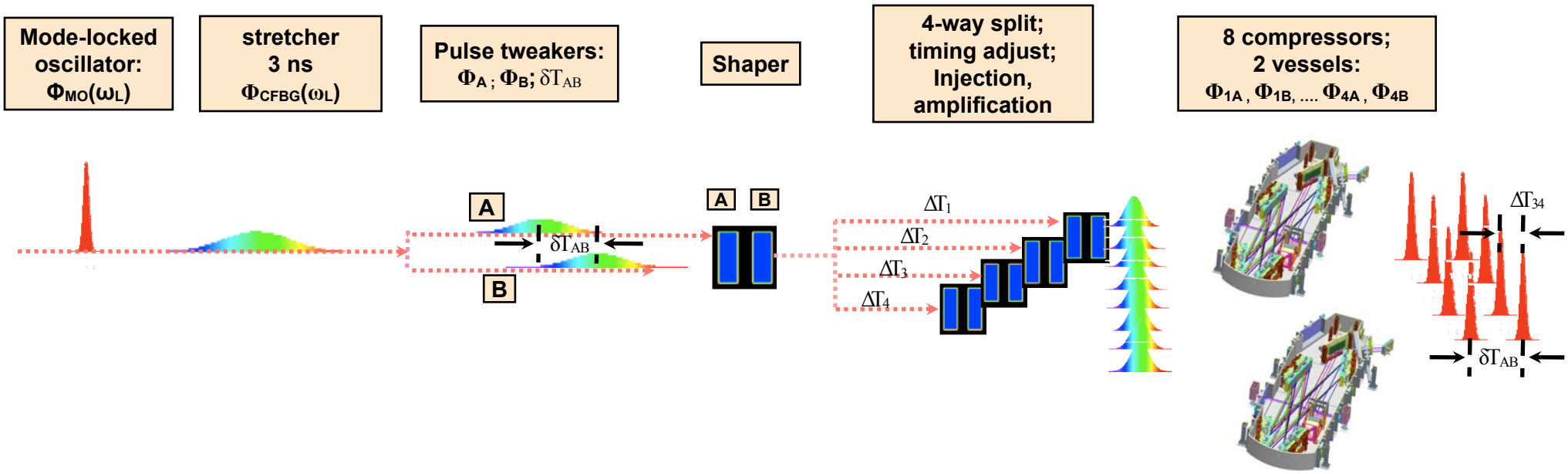
- Measure the group delay of the chirped-fiber Bragg grating in a separate measurement
- Use model for compressors and measured group delay from front end to design two tweakers (A & B) that give 1-50 ps pulse width adjustment
- Use group delay diagnostic to set up each of the 8 ARC compressors. Match the group delay in all A compressors and all B compressors.



# Summary

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- The split beam geometry of ARC provides a versatile short pulse laser system for multi-frame X-ray radiography supporting fusion ignition and high-energy density experiments
- The radiation environment around the target chamber is challenging for the development of short pulse laser diagnostics
- High-dynamic range diagnostics have been developed to meet requirements for measuring the temporal pulse shape and pulse contrast
- Aligning 4 compressors with a total of 32- large gratings will be a challenge
- We have demonstrated a specialized technique for balancing the dispersion in the ARC Quad
- The Group-Delay diagnostic is capable of measuring GD down to +/- 0.6 ps