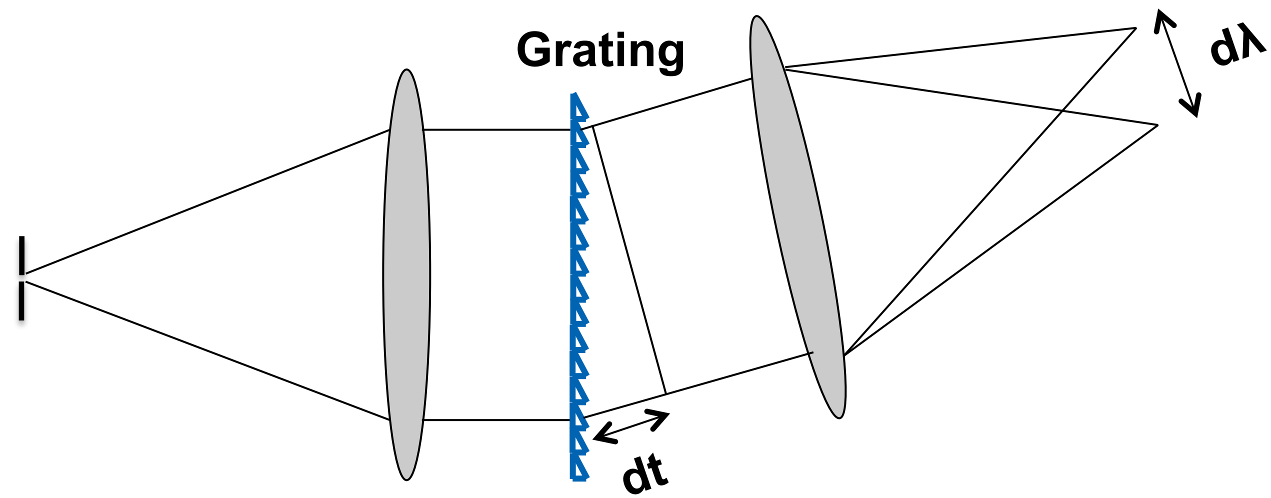
A segmented spectrometer design for high throughput, picosecond, optical spectroscopy

Typical Optical Spectrometer Layout



J. Katz
University of Rochester
Laboratory for Laser Energetics

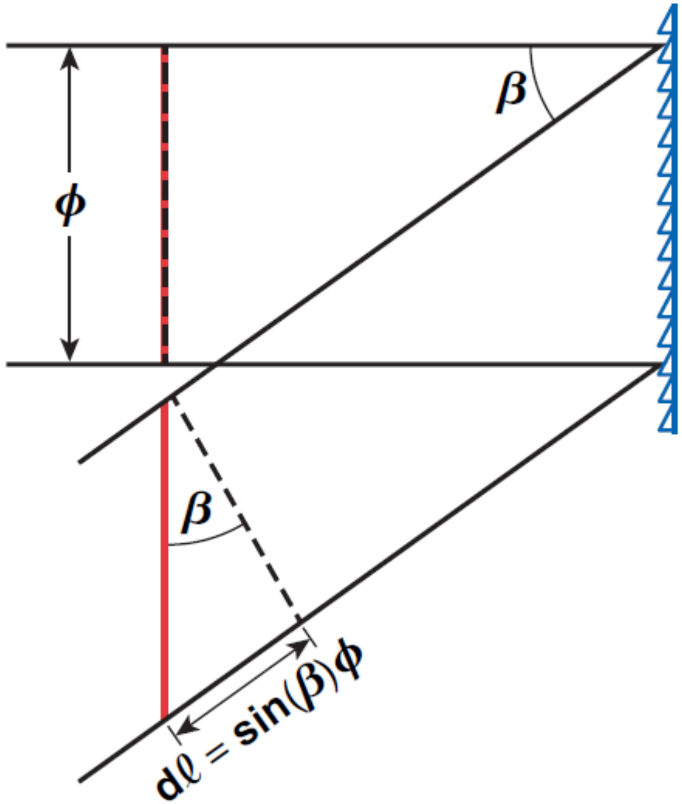
CEA-NNSA Joint Diagnostic Meeting
Rochester, NY
29-30 June 2016

Summary

A segmented spectrometer design mitigates PFT while preserving optical throughput and spectral resolution

- The path-length asymmetry introduced from the dispersive medium in a spectrometer generates pulse-front tilt (PFT)
- Spectrometers with large apertures and high spectral resolution can have PFT of the order of hundreds of picoseconds
- Temporal resolution can be recovered with no loss to throughput by segmenting the full-aperture beam into a series of sub-elements that are optically and temporally co-aligned
- A prototype segmented spectrometer has been designed to deliver 1-ps time resolution with 0.8-nm spectral resolution and *f*/2.9 throughput

Pulse-front-tilt introduced by the spectrometer grating reduces the achievable instrument temporal resolution



Grating equation

$$\sin(\alpha) + \sin(\beta) = m\lambda G$$

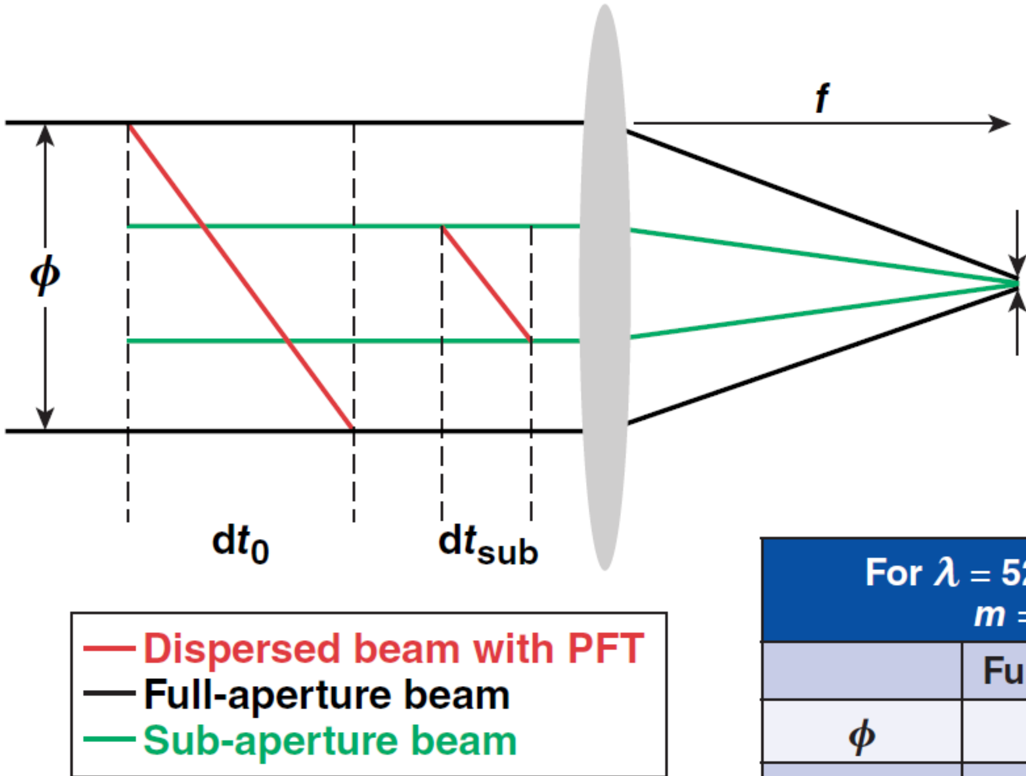
α = angle of incidence
β = angle of diffraction
$d\beta/d\lambda$ = angular dispersion
m = diffraction order
λ = wavelength
G = groove density
ϕ = input-beam diameter
$N = G\phi$ = number of grooves illuminated
PFT = $m\lambda N/c$

$$\mathrm{PFT} = \phi m \lambda \left[\frac{d\beta}{d\lambda}\right]\left[\frac{\cos(\beta)}{c}\right]$$

High angular dispersion and large beam diameters spoil temporal resolution.

E25170

Stopping down the beam aperture reduces PFT at the cost of throughput and spectral resolving power



Resolving power

$$R = \frac{\lambda}{\Delta\lambda} = mG\phi = mN$$

Diffraction-limited spot size

$$dx = \frac{\lambda f}{\phi}$$

For λ = 527 nm, G = 300 g/mm
m = 1, f = 225 mm

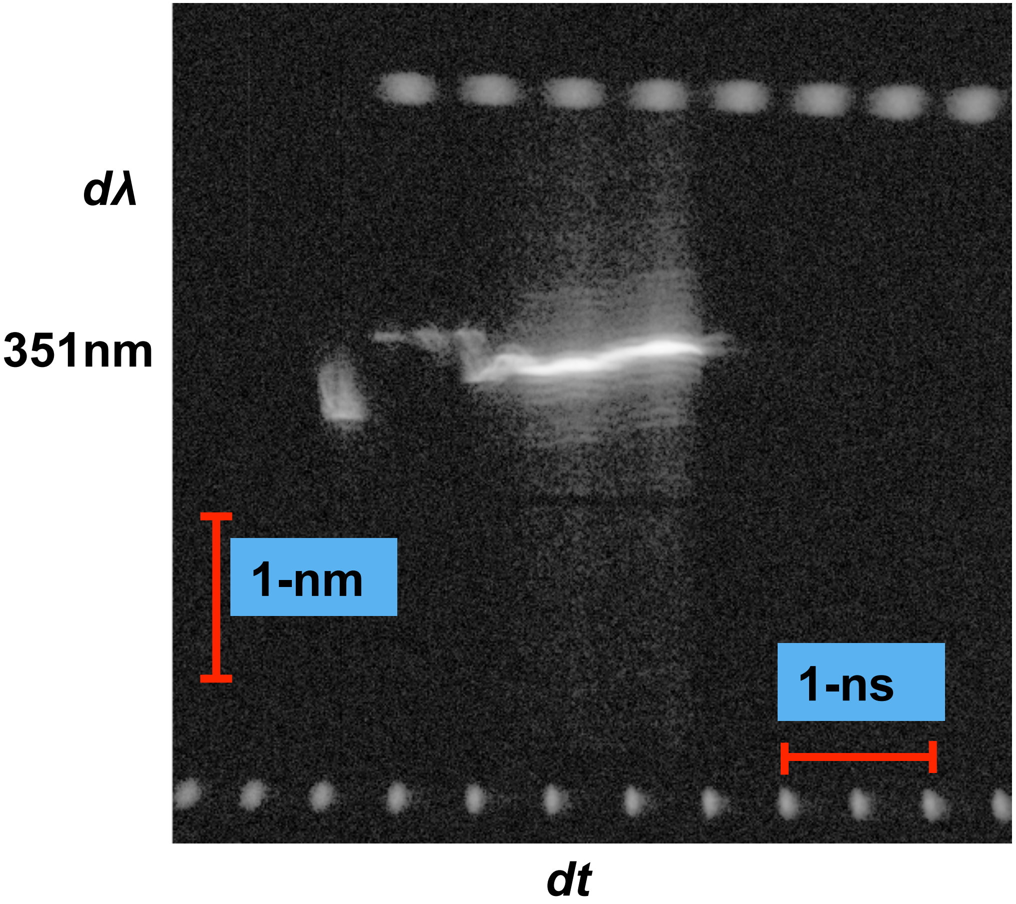
	Full aperture	Sub-aperture
ϕ	80 mm	2.25 mm
R_{max}	24,000	675
dx	1.5 μm	53 μm
PFT	42 ps	1.2 ps

E25171

Spectrometers with large apertures and high spectral resolution can have PFT of the order of hundreds of picoseconds

UR LLE

3ω Scattered Light Spectrum

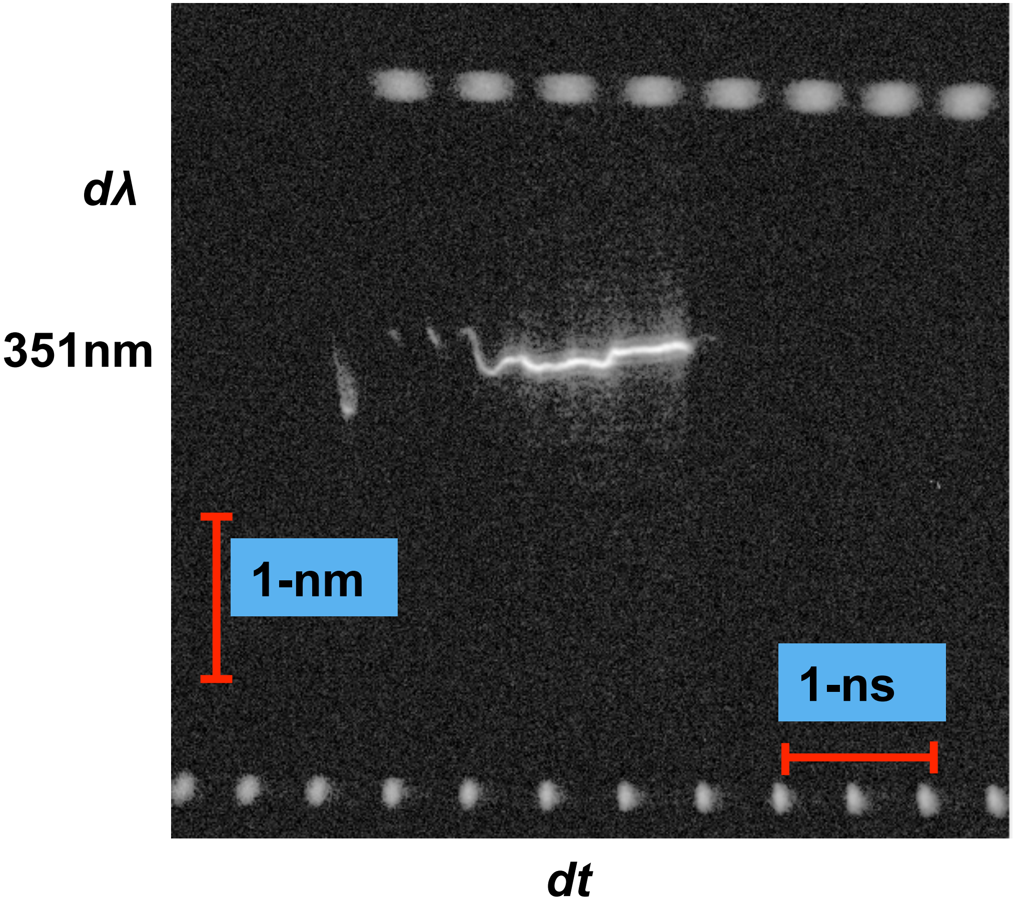


Set up Parameter	Value
Spectrometer Focal Length	1000 mm
Grating Grove Density	3600 g/mm
Acceptance Aperture	f/20
Pulse front tilt	210 ps

A stopped aperture can greatly improve data quality if there is sufficient head room in signal levels

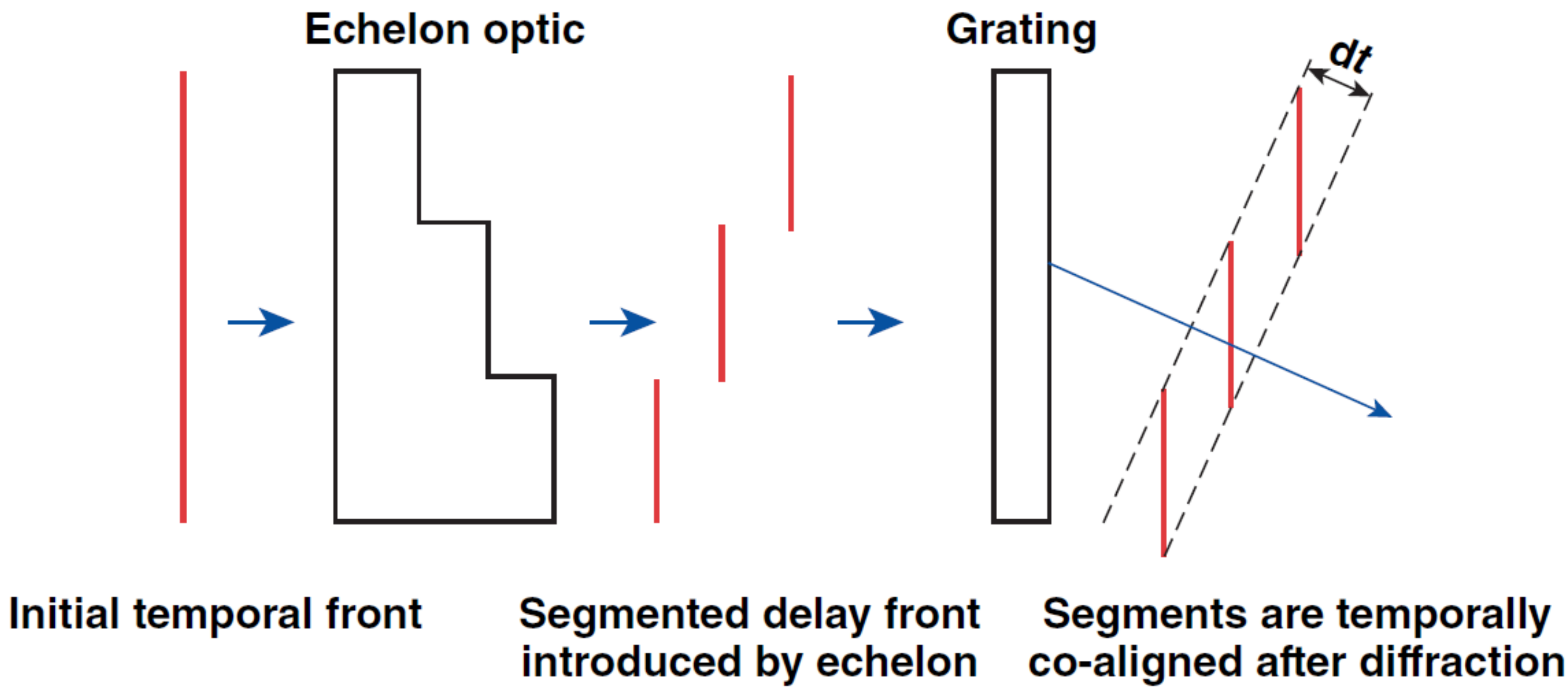
UR LLE

3ω Scattered Light Spectrum



Set up Parameter	Value
Spectrometer Focal Length	1000 mm
Grating Grove Density	3600 g/mm
Acceptance Aperture	f/100
Pulse front tilt	50 ps

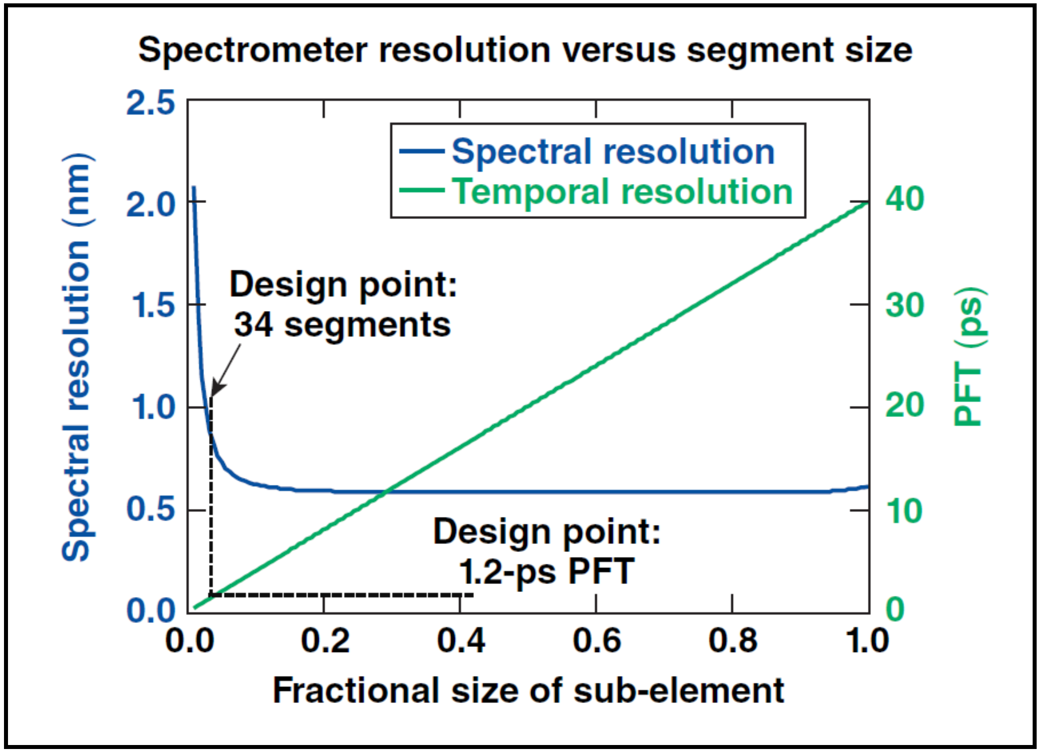
An echelon optic can be used to recover throughput by segmenting the beam into a series of temporally delayed sub-elements



Overall PFT is reduced by a factor equal to the number of sub-elements used.

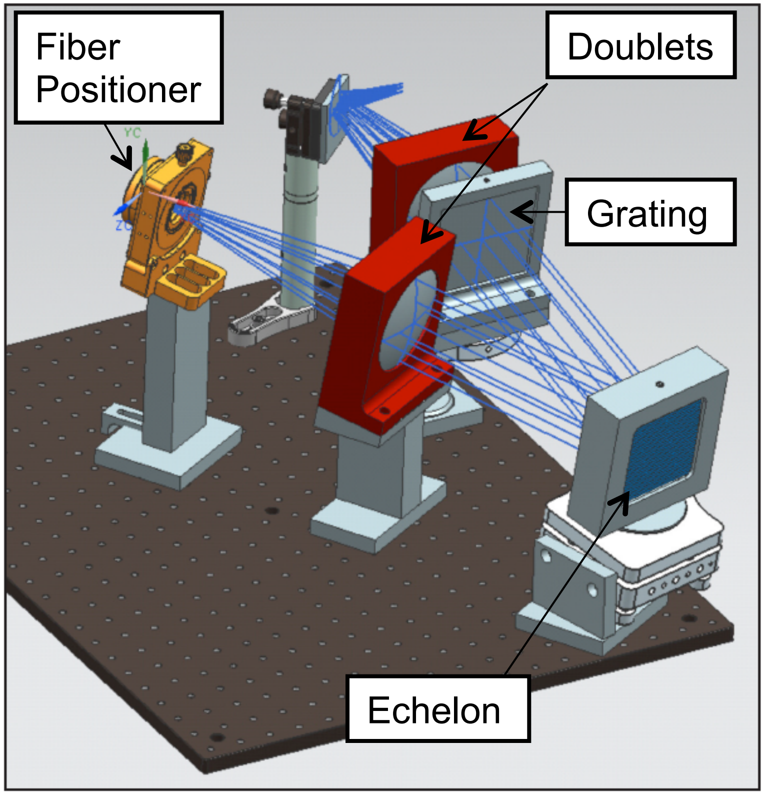
The segment aperture size is minimized until diffractive effects limit the achieved spectral resolution

$$\delta\lambda = \frac{d\beta}{d\lambda} FL \sqrt{OBJ^2 + GEO^2 + DIF^2 + SC^2}$$



Spot Size Parameter	Typical Size (µm)
Object Size	50
Geometric Aberrations	10
Diffraction Limit	1.5
Streak Camera	40

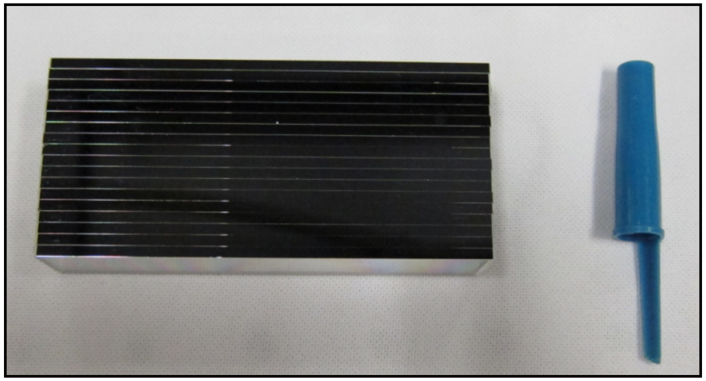
A prototype segmented spectrometer has been designed to provide measurements with 1-ps time resolution



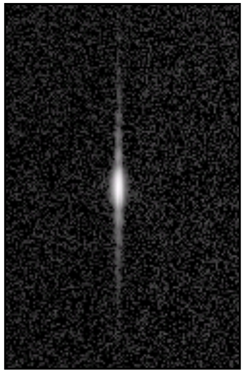
Design parameter	Specification
Spectral field of view	480 to 580 nm
Spectral resolution	0.8 nm
Resolving power	650
Aperture	*f*/2.9
Full-aperture PFT	40 ps
# of echelon elements	34
Residual PFT	1.1 ps

Construction of a reflective echelon optic is currently underway at the LLE

44x90mm 20-Element Reflective Echelon

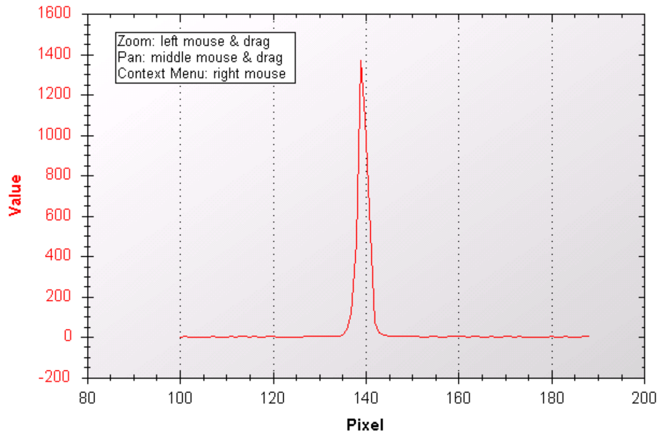


Output Image

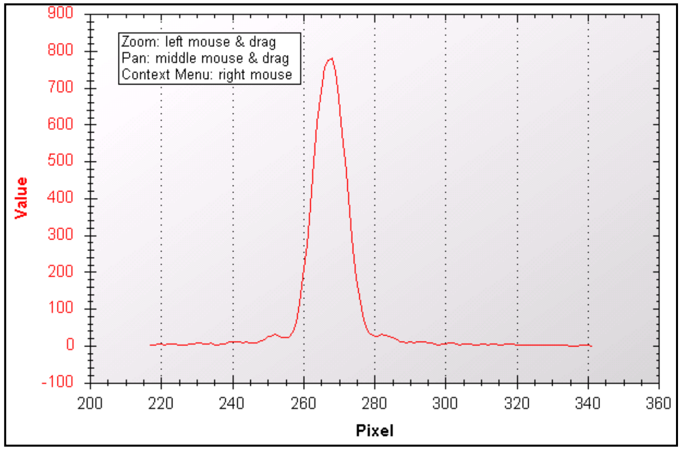


20 elements are aligned to within a fraction of the airy disk diameter

Horizontal lineout



Vertical lineout



Demonstration of the prototype spectrometer is on track for August 2016

- The path-length asymmetry introduced from the dispersive medium in a spectrometer generates pulse-front tilt (PFT)
- Spectrometer with large apertures and high spectral resolution can have PFT of the order of hundreds of picoseconds
- Temporal resolution can be recovered with no loss to throughput by segmenting the full-aperture beam into a series of sub-elements that are optically and temporally co-aligned
- A prototype segmented spectrometer has been designed to deliver 1-ps time resolution with 0.8-nm spectral resolution and *f*/2.9 throughput