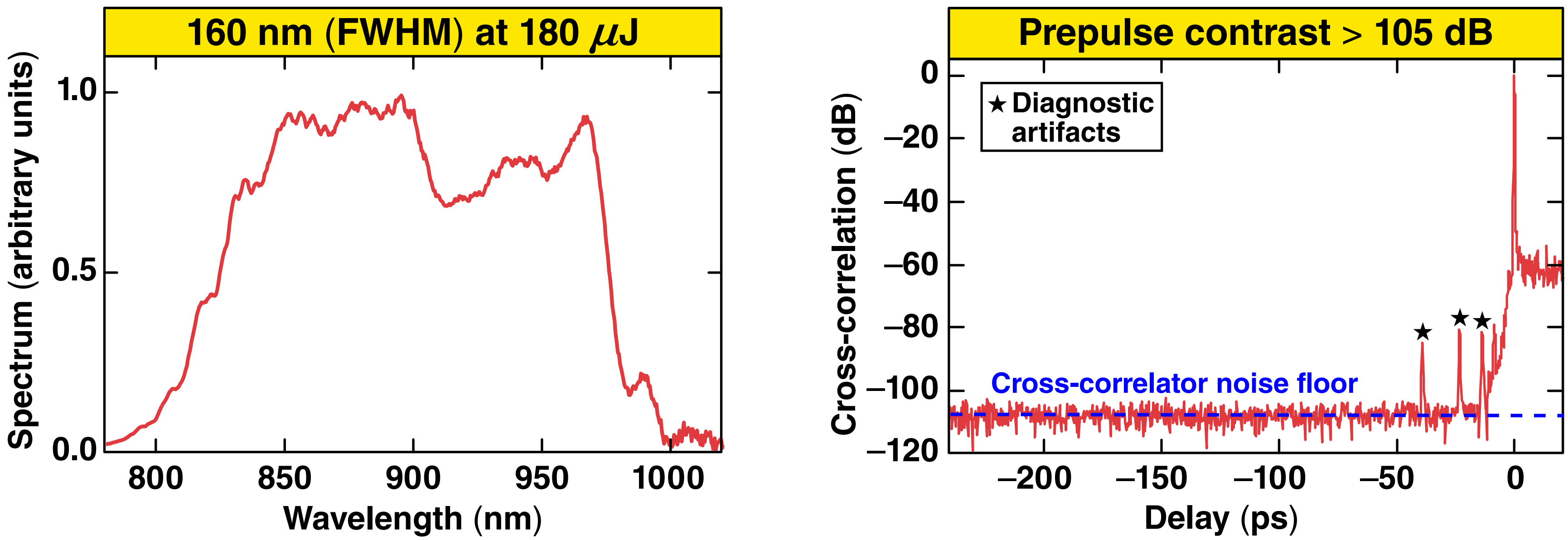
A 160-nm Bandwidth Front End for Ultra-Intense OPCPA



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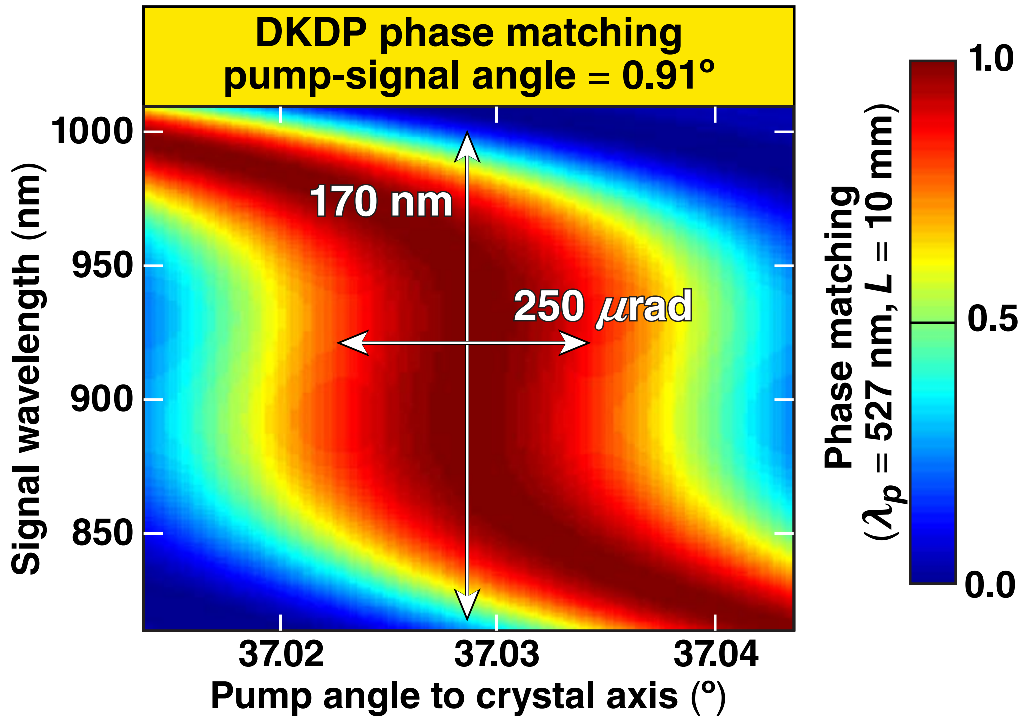
Summary

A front end based on white-light generation has been demonstrated for ultra-intense OPCPA

- LLE is developing the technologies necessary for an ultra-intense OPCPA system pumped by OMEGA EP
- A sequence of noncollinear optical parametric amplifiers (NOPA's) is seeded by white-light continuum generated in sapphire
  - 200 nm of spectral support (160-nm FWHM)
  - compressible to 13 fs (temporal Strehl ≥ 0.7)
  - low spatiotemporal coupling
- The first stage has been characterized using a NOPA-based cross-correlator
  - dynamic range = 105 dB
  - temporal resolution = 250 fs

Prepulse contrast > 105 dB up to –5 ps (detection limited, chirped pulse)

All-OPCPA systems pumped by Nd:glass lasers are an option for producing ultra-intense pulses (>10^{23} W/cm^2)



- The front end must provide
  - broadband, compressible pulses, centered at 910 nm
  - high-quality, focusable beams
  - high temporal contrast

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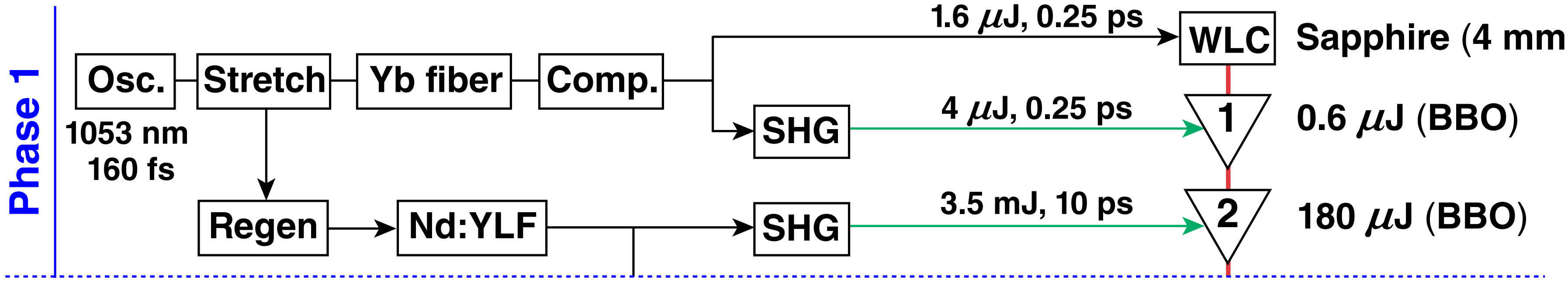
LLE's front end consists of a chain of NOPA's seeded by white-light continuum (WLC)

- Previous demonstrations used the idler from the first amplifier stage
  - chirped collinear (RAL, UK)
  - angularly dispersed (IAP, Russia)
- LLE's white-light continuum is generated in sapphire*
  - broadband (450 to 1020 nm)
  - stable (<1.3% rms)
  - focusable (spatial Strehl > 0.7)
  - compressible (temporal Strehl > 0.7)
- WLC-based approach has advantages
  - no ultra-broadband oscillator
  - no need to precisely set the chirp of the pump pulse
  - no residual angular dispersion to compensate

*Thanks to Prof. E. Riedle and Dr. C. Homann for their assistance

The first phase in demonstrating an optical parametric amplifier line (OPAL) has been completed



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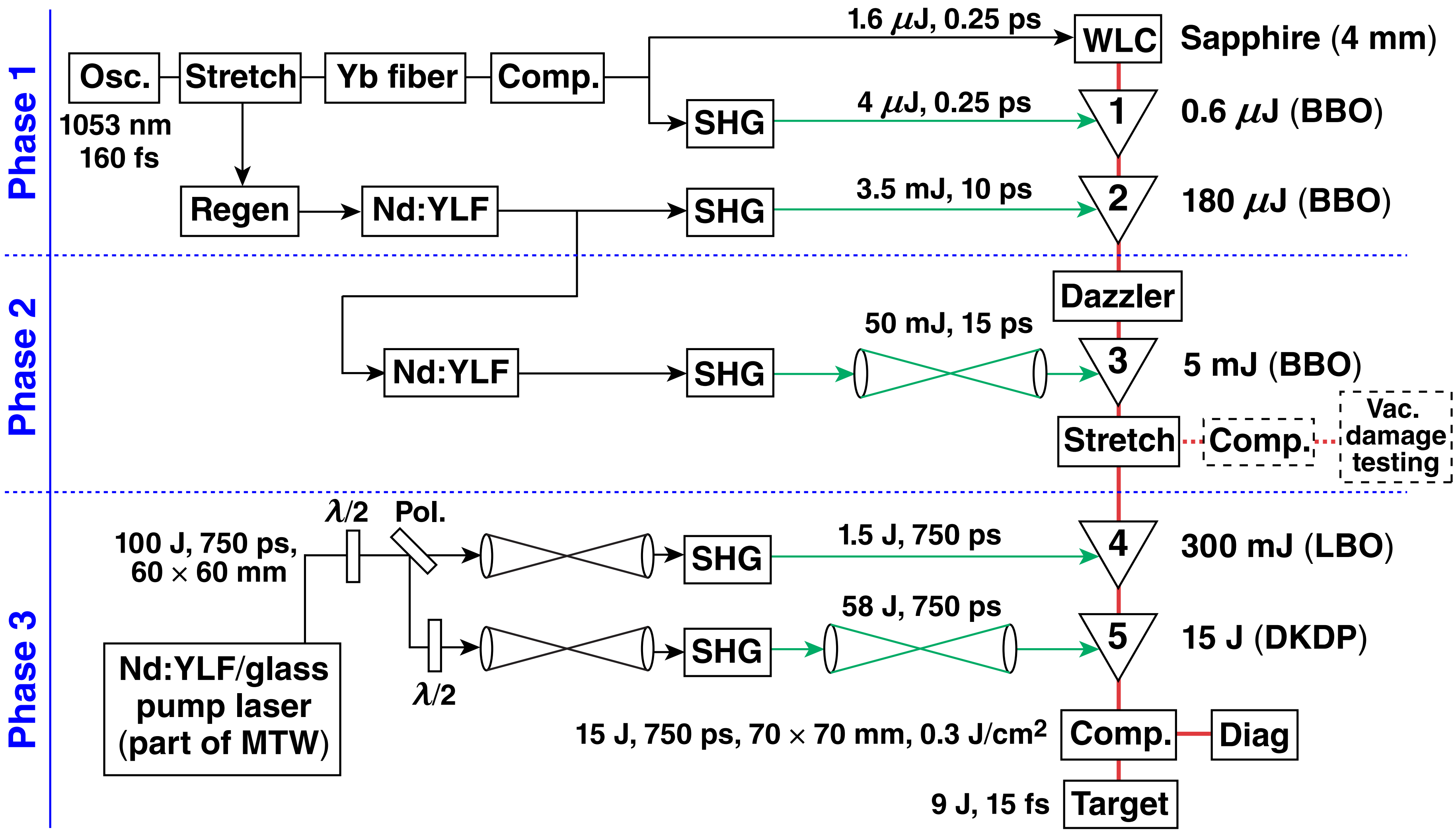
The next two phases are being designed and built



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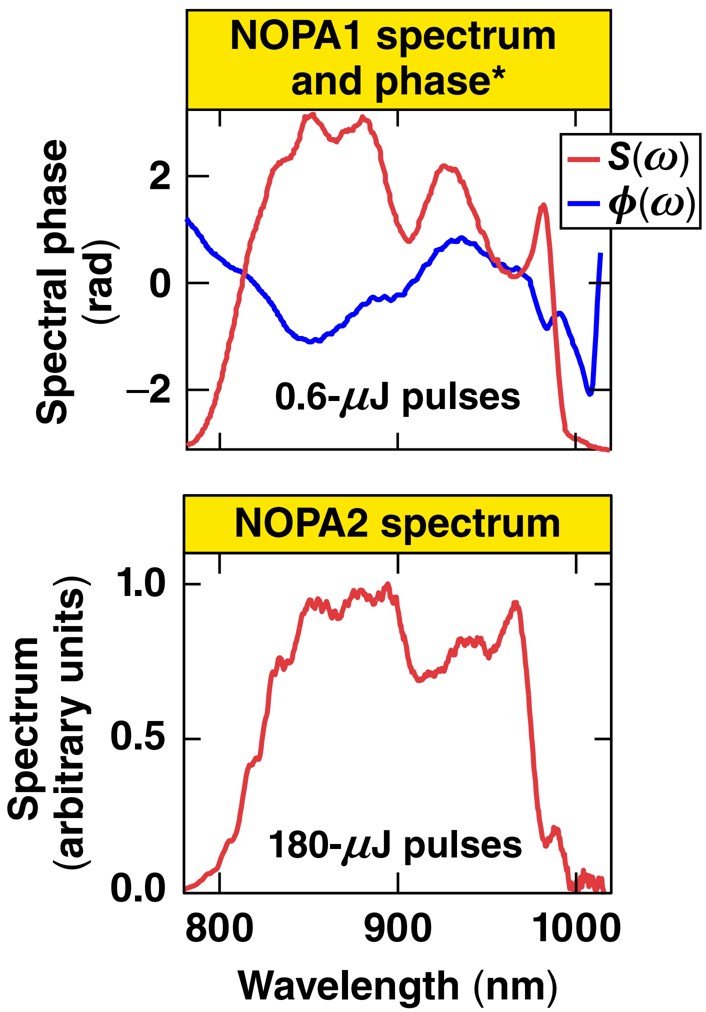
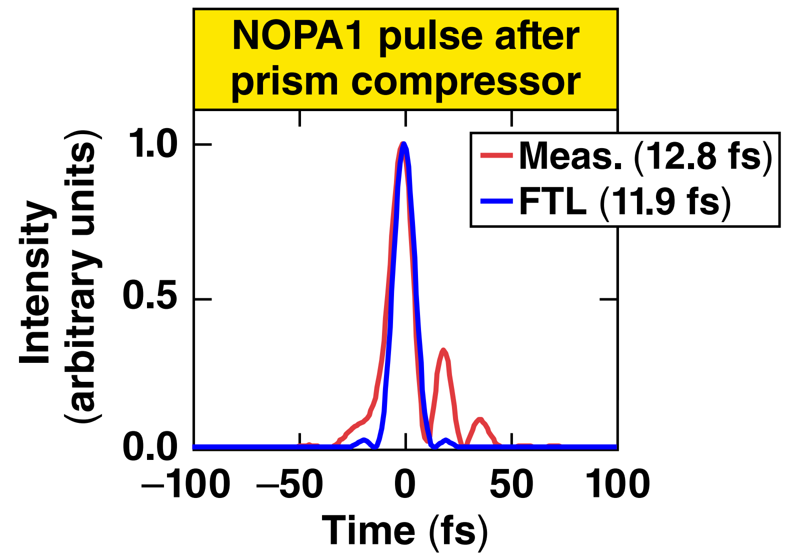
The Phase 1 results show 200 nm of spectral support (160-nm FWHM), compressible to < 13 fs

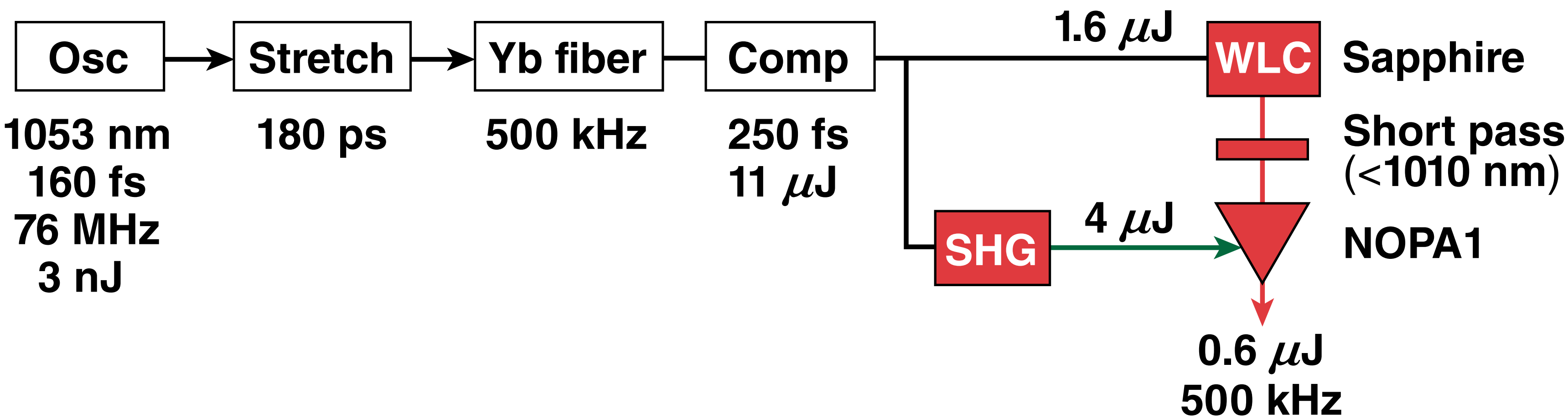




- Measured spectrum and phase of NOPA1 after a two-prism compressor
- Compressed pulses to 1.07× the Fourier transform limit
- Temporal Strehl = 0.7
- Spectral support preserved by NOPA2

*Measured using SPIDER after double-pass prism compressor

To achieve high temporal contrast, noise from the fiber-based pump laser is reduced using nonlinear processes and filters



- White-light continuum (WLC) generation
  - threshold (1.3 μJ) means no continuum from satellite pulses or ASE
- Second-harmonic generation (SHG)
  - saturated, but still reduces the impact of pump noise on the NOPA
- Noncollinear optical parametric amplification (NOPA)
  - saturated gain (19 dB) in 250-fs/200-nm window

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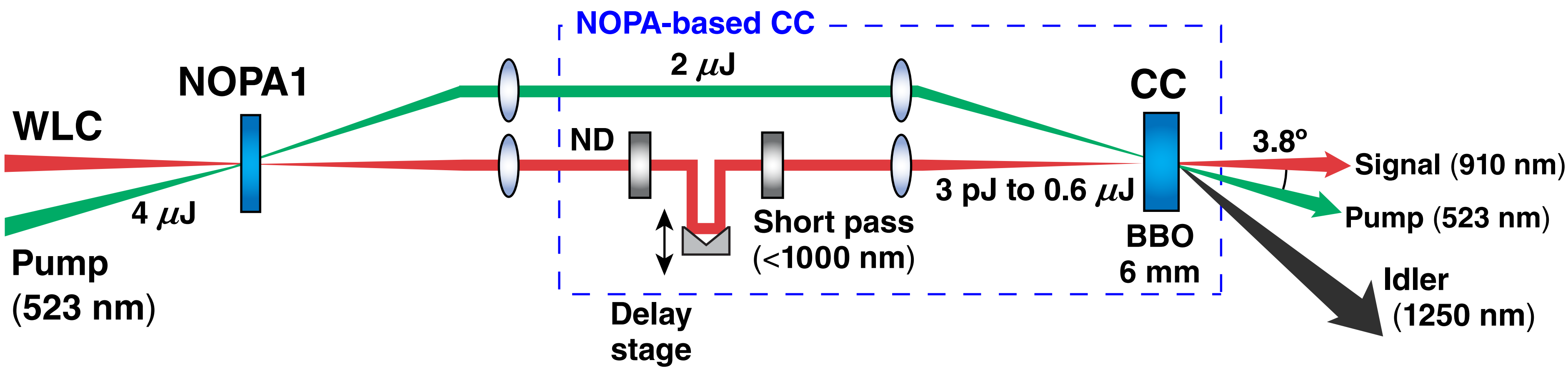
A cross-correlator (CC) with 105 dB of dynamic range has been developed to characterize NOPA1



Degenerate OPA Cross Correlator–E. J. Divall and I. N. Ross (2004).

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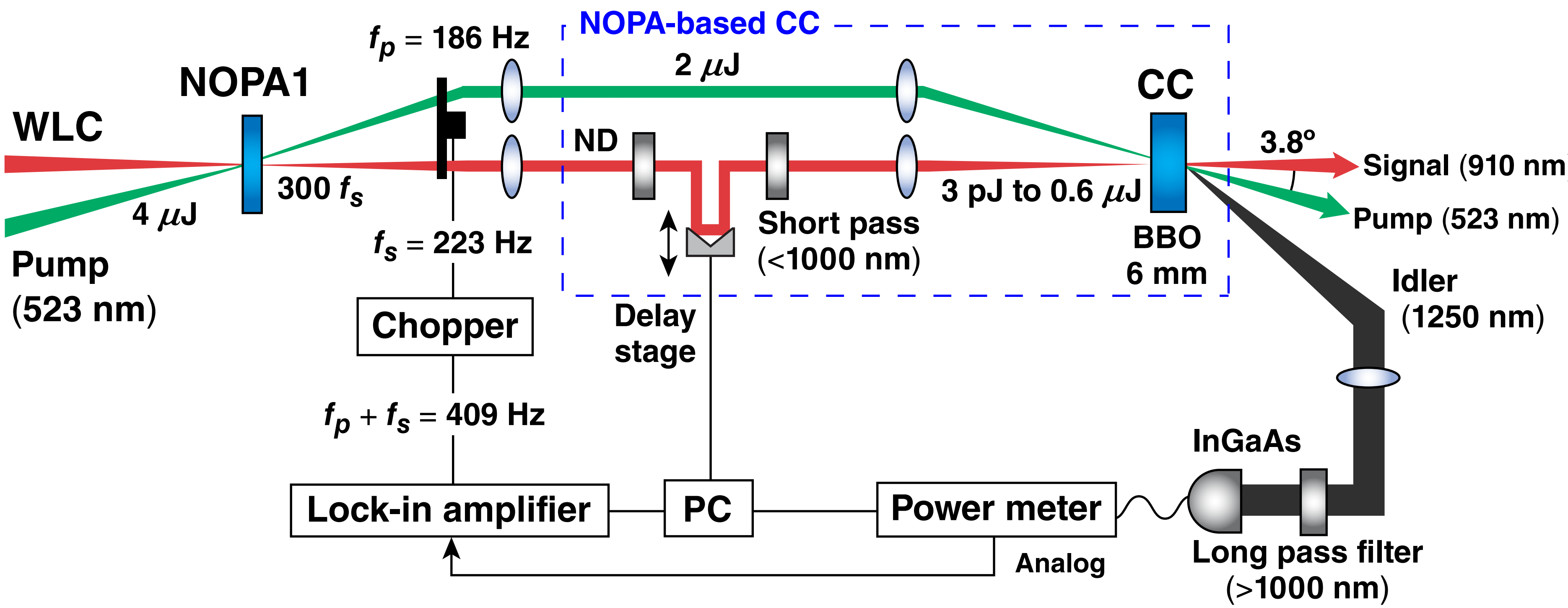
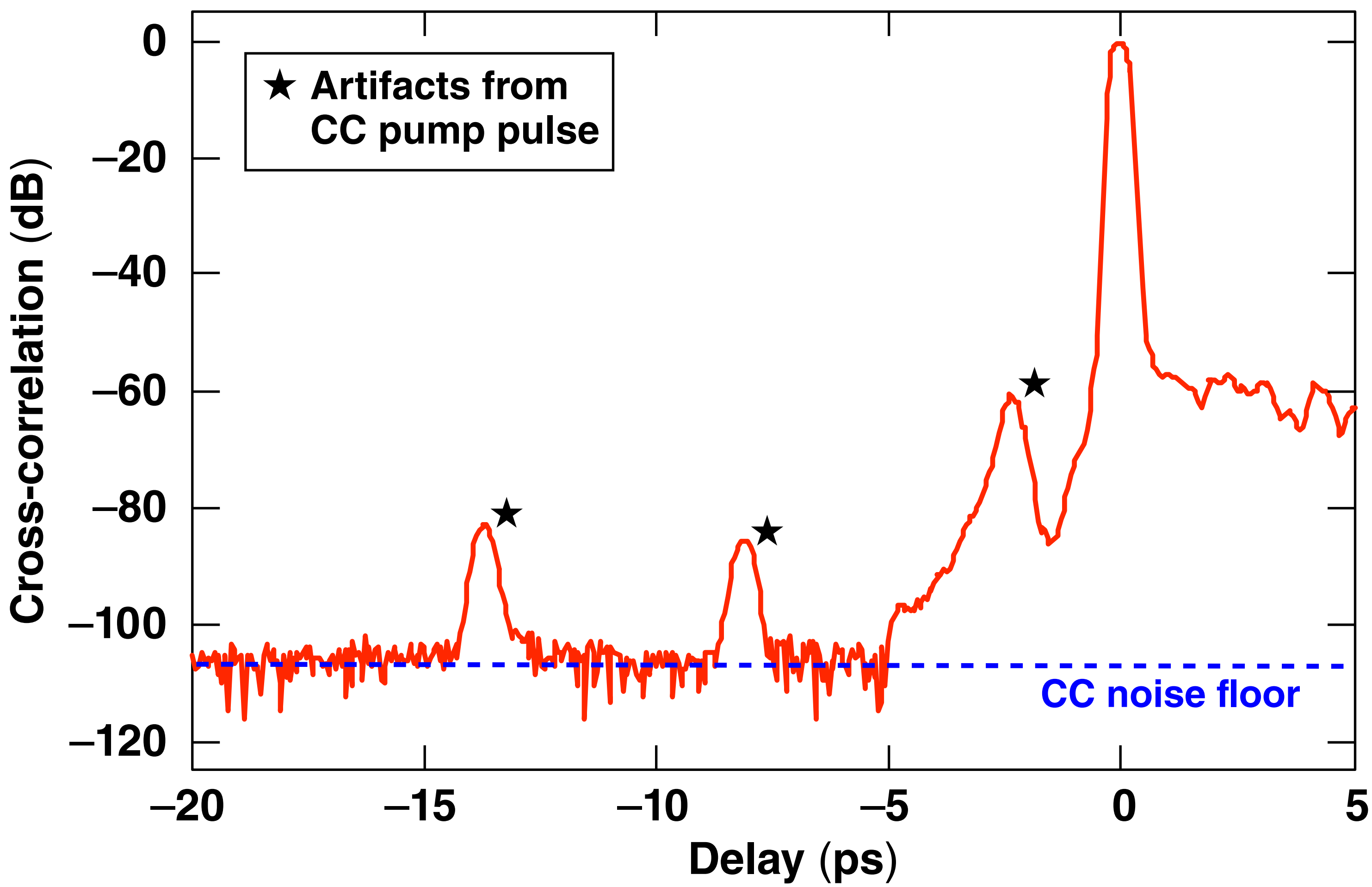


- NOPA-based CC: sensitive (39-dB gain), broadband (150 nm), high resolution (250 fs)
- Background suppression: use RG1000 filters and measure idler component at $f_p + f_s$
- Dynamic range: calibrated filters (50 dB), detector gain (40 dB), and lock in (20 dB)

Degenerate OPA Cross Correlator–E. J. Divall and I. N. Ross (2004).
Lock-in-based Autocorrelators–A. Braun *et al.* (1995), P. F. Curley *et al.* (1995).

The prepulse contrast of the uncompressed pulse up to –5 ps is better than 105 dB



Note: the width of the pulse-under-test (~300 fs) has not been deconvolved from the measurement

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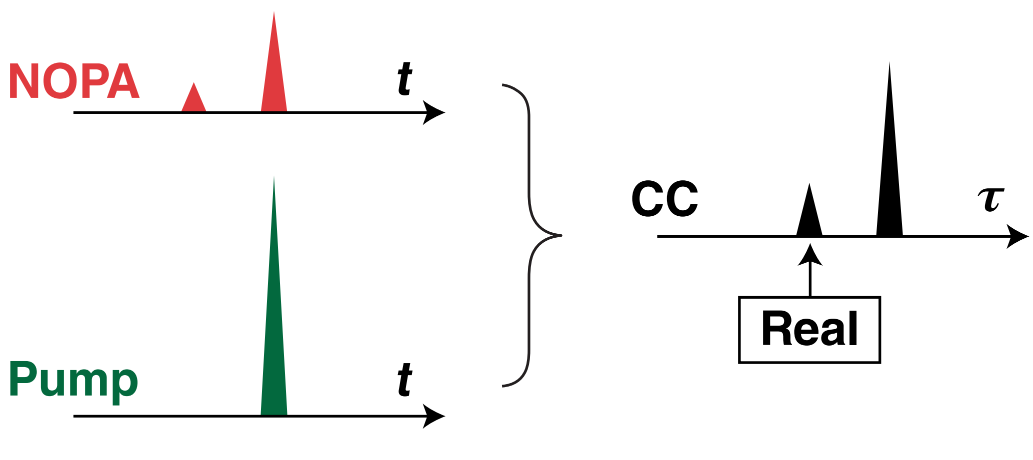
Postpulses from the CC pump produce artifacts that can be mistaken for NOPA prepulses

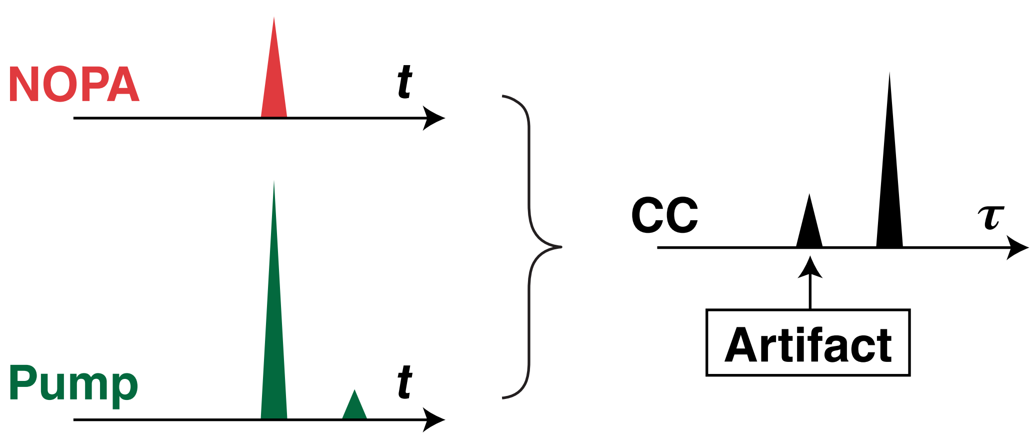


All signal pulses are weaker than pump

⇩

Small-signal regime for all CC peaks:

CC (dB) ~$\sqrt{I_{pump}}$



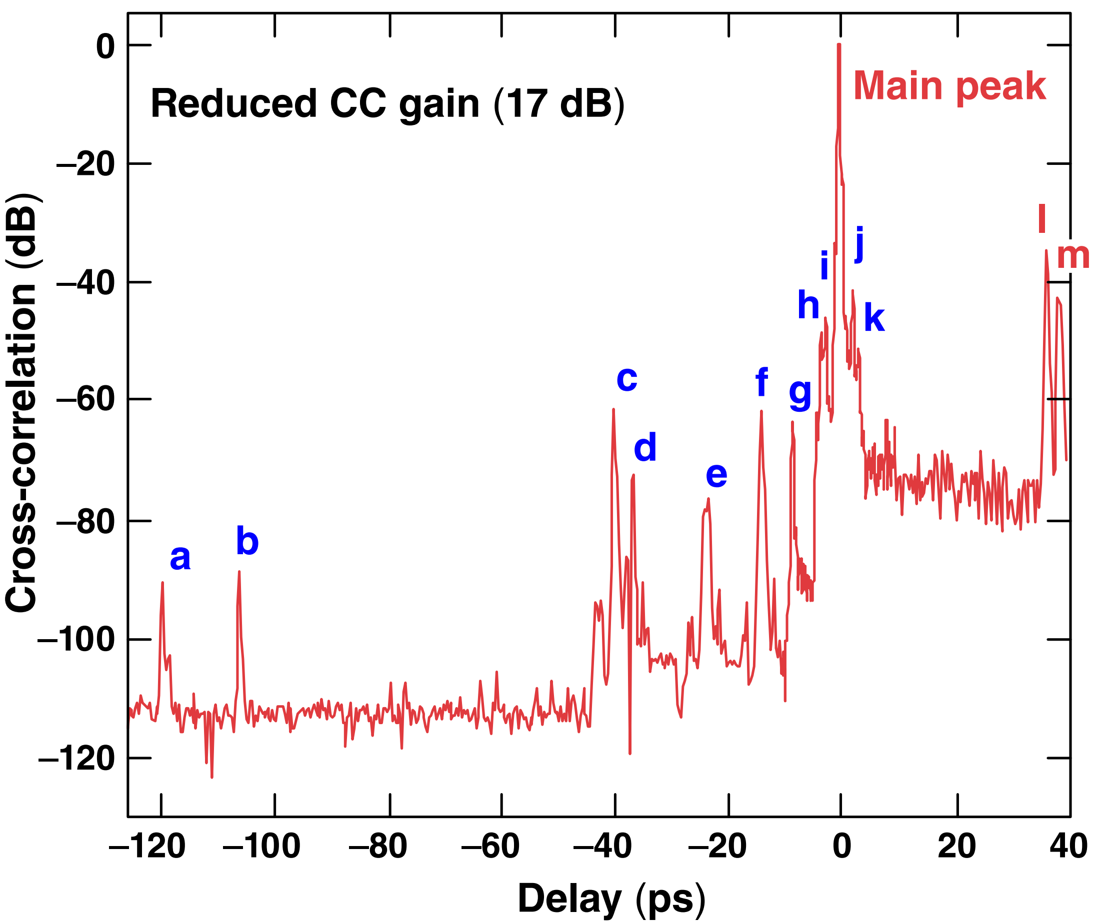
Pump postpulse is weaker than signal

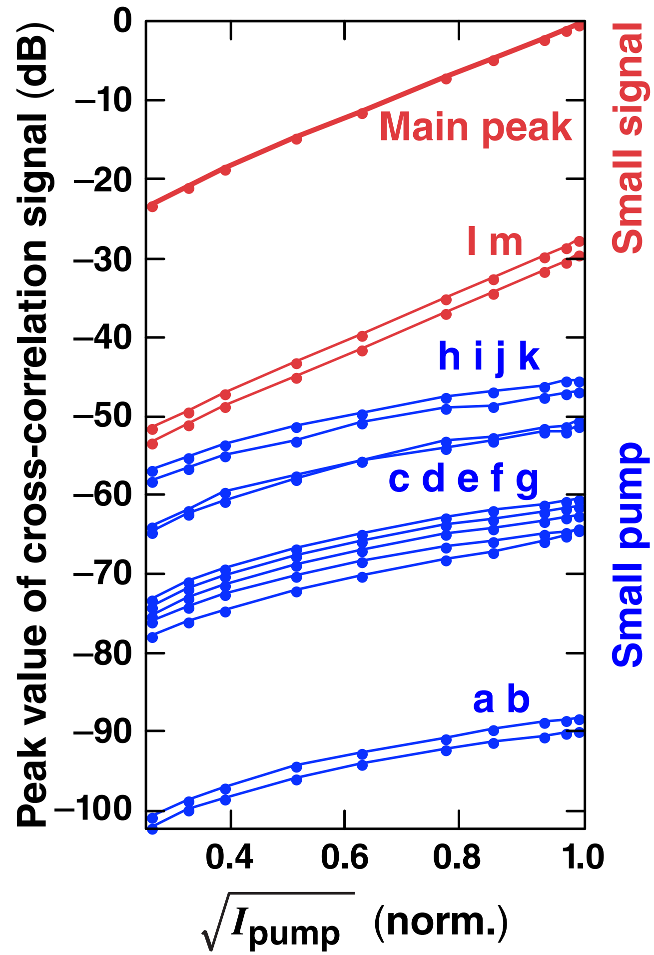
⇩

Small-pump regime for CC artifacts:

CC (linear)~ I_{pump}

All CC peaks before the main one are caused by pump postpulses and scale according to the small-pump limit





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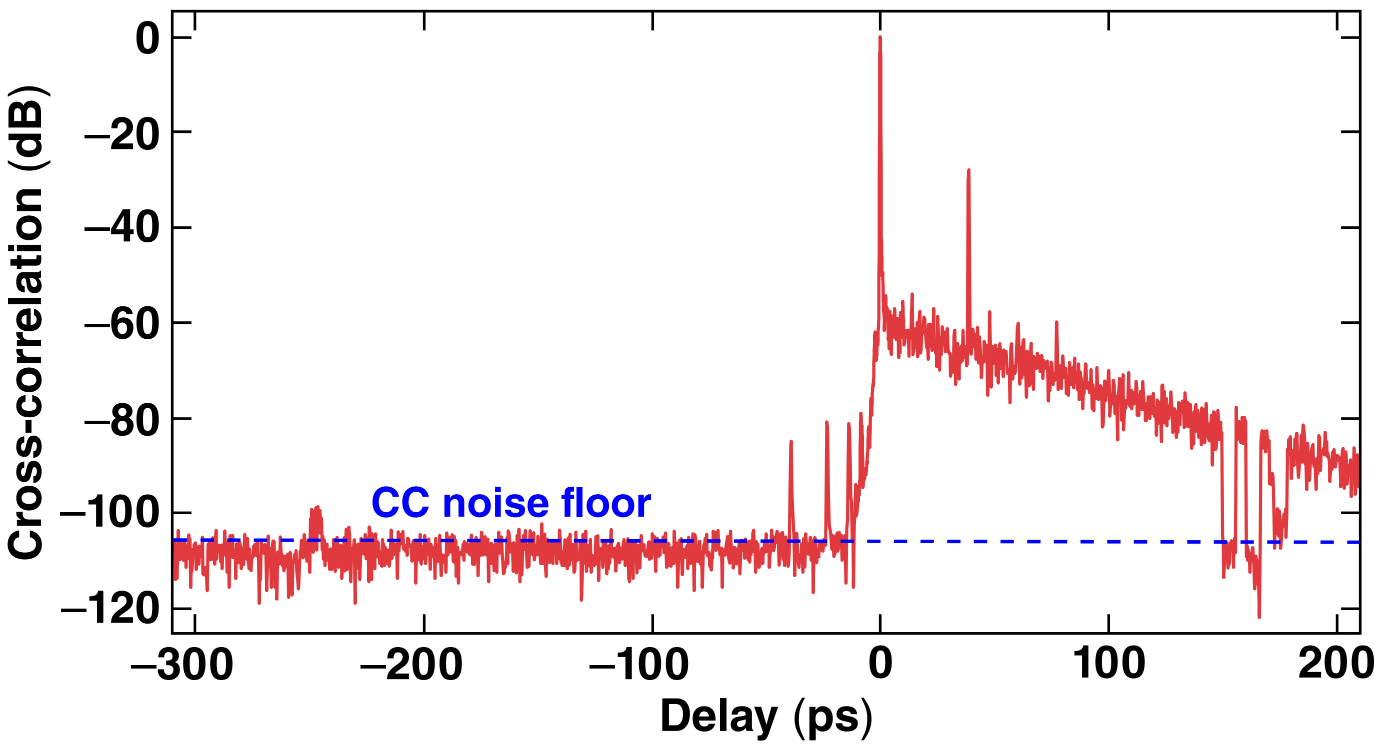
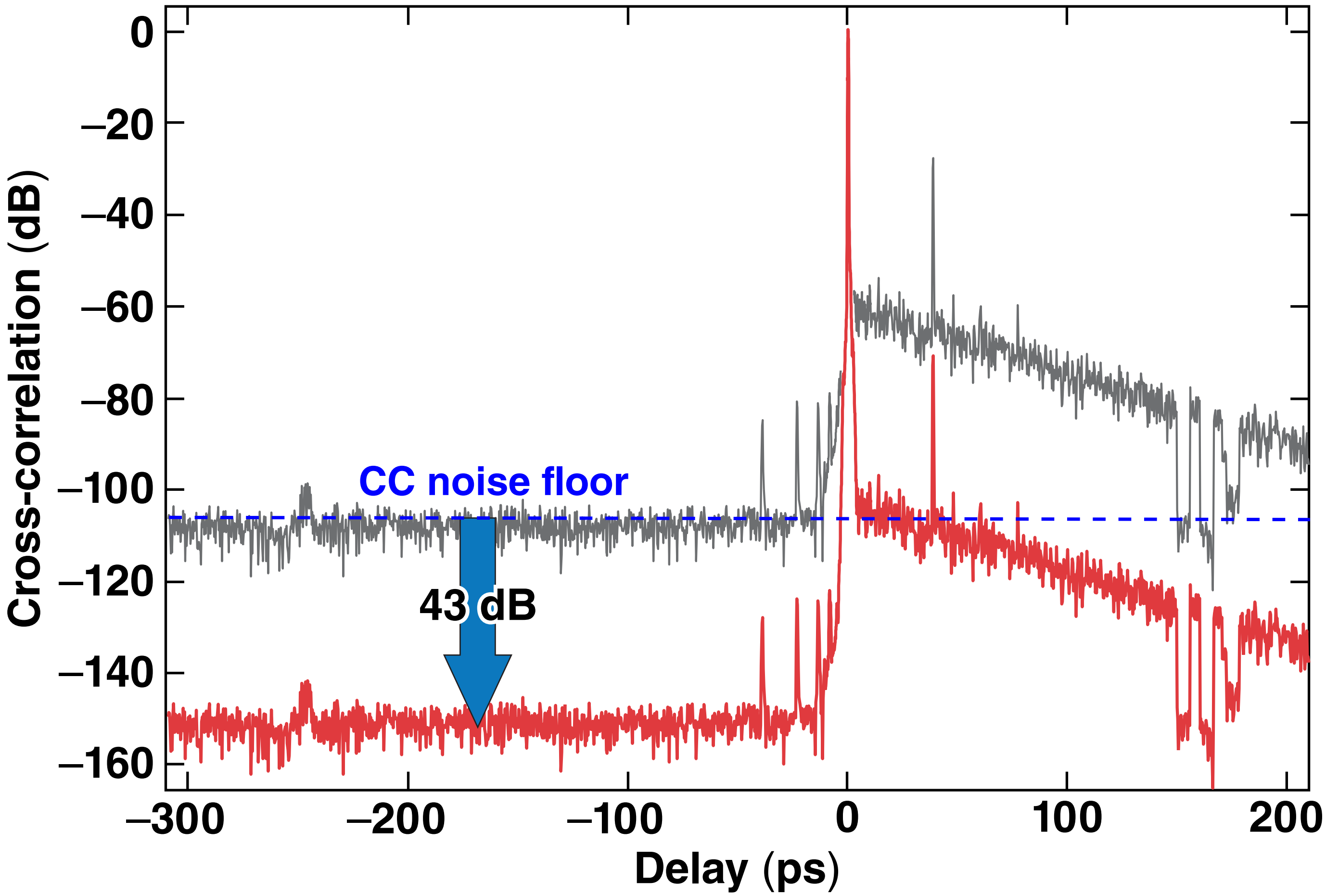
An exponential tail starts 60 dB below the main peak



- Not a CC artifact (follows $\sqrt{I_p}$ scaling)
- Time constant (1/e) = 29 ps
- Energy contrast (peak-to-tail) = 41 dB
- Property of WLC (i.e., not added by NOPA1), but its physical origin is not yet understood

43 dB gain in the next two picosecond-pumped NOPA stages will reduce the tail to a negligible level



- Estimated contrast after the next two stages produce 5-mJ pulses at 5 Hz
- Assumes 43 dB of gain in a 2-ps-wide Gaussian window

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Summary/Conclusions

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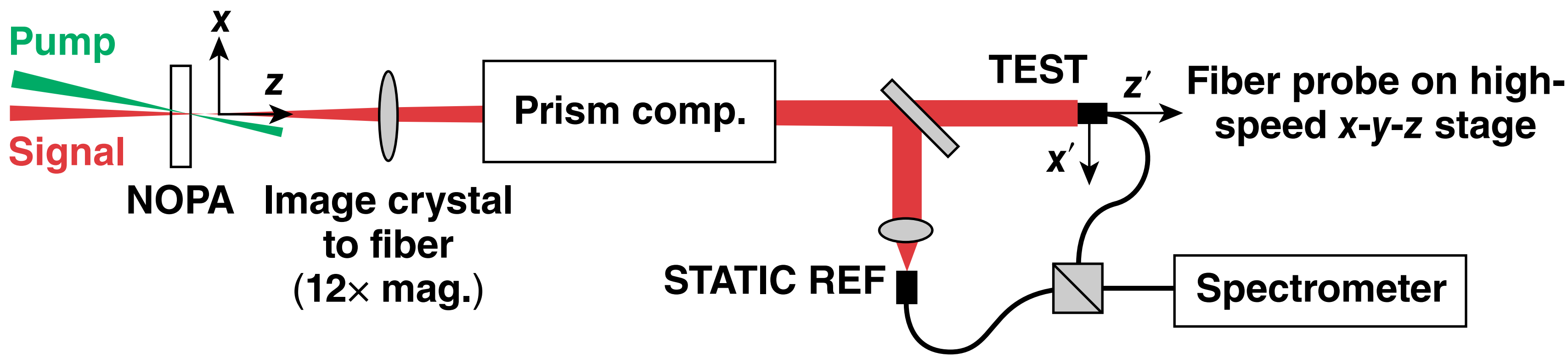
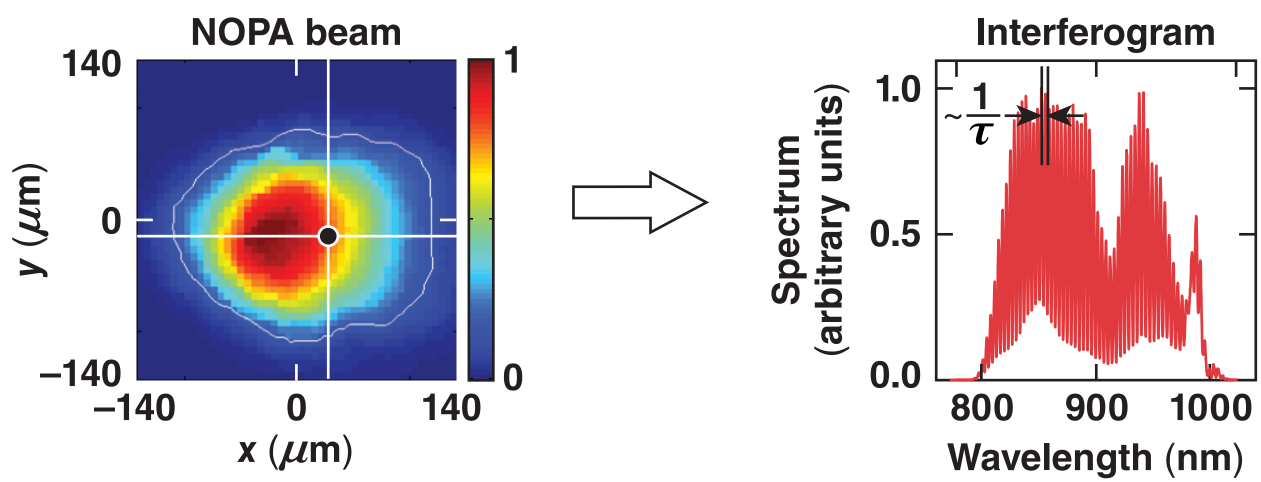
Prepulse contrast > 105 dB up to –5 ps (detection limited, chirped pulse)

Spatially resolved spectral interferometry was used to quantify the spatiotemporal properties of NOPA1





$$\Phi_{\text{MEAS}}(x,y,\omega) = \phi_{\text{NOPA}}(x,y,\omega) - \phi_{\text{REF}}(\omega) - \omega\tau$$

E18584d

*J. Jasapara and W. Rudolph, Opt. Lett. 24, 777 (1999).
P. Bowlan *et al*., Opt. Express 14, 11892 (2006).

Minimal residual higher-order spatiotemporal coupling was measured for optimum noncollinear alignment

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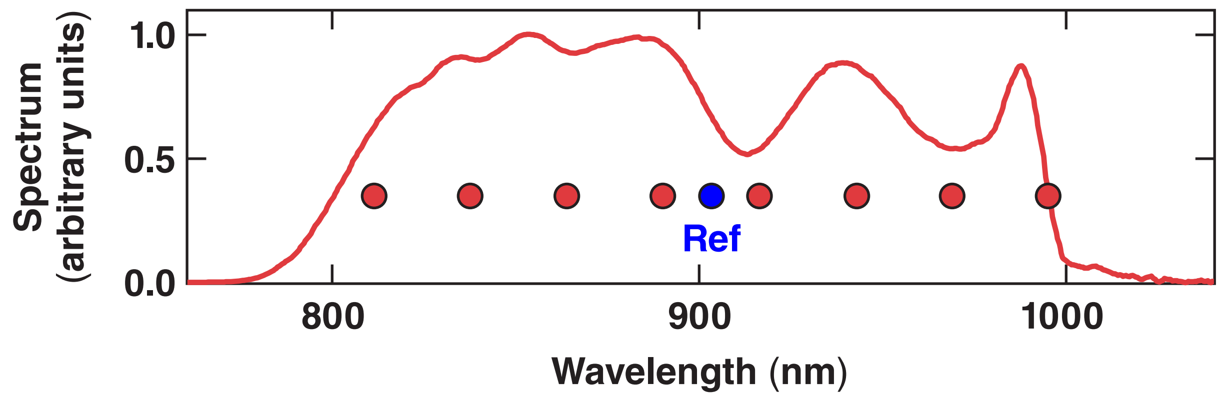

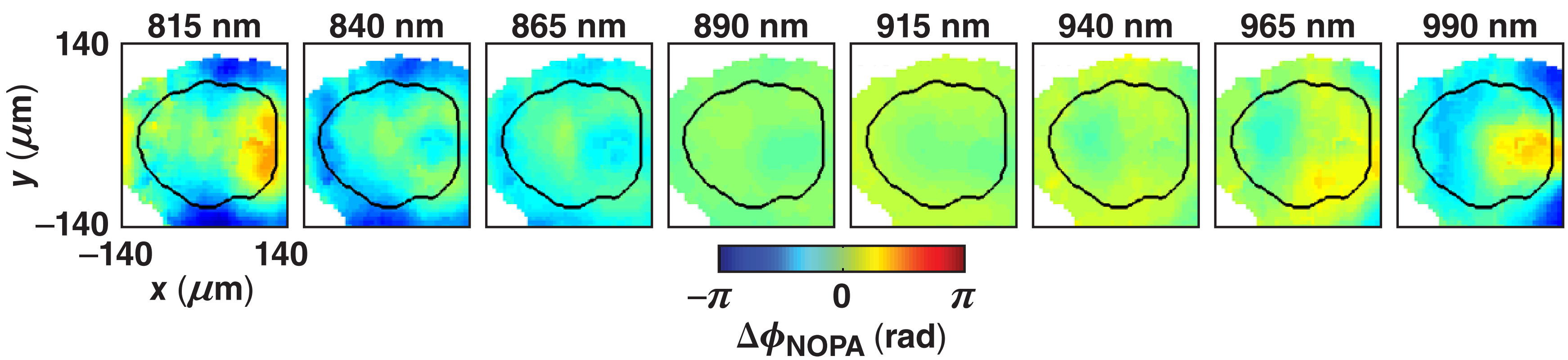

- Spatiotemporal Strehl at focus = $I_{peak}/(I_{peak}$, no coupling, flat phase)*
- Measured spatiotemporal Strehl = ~0.4 to 0.5

Spatiotemporal Strehl values as high as 0.8 could be achieved, in principle, with separate spatial and spectral compensation.

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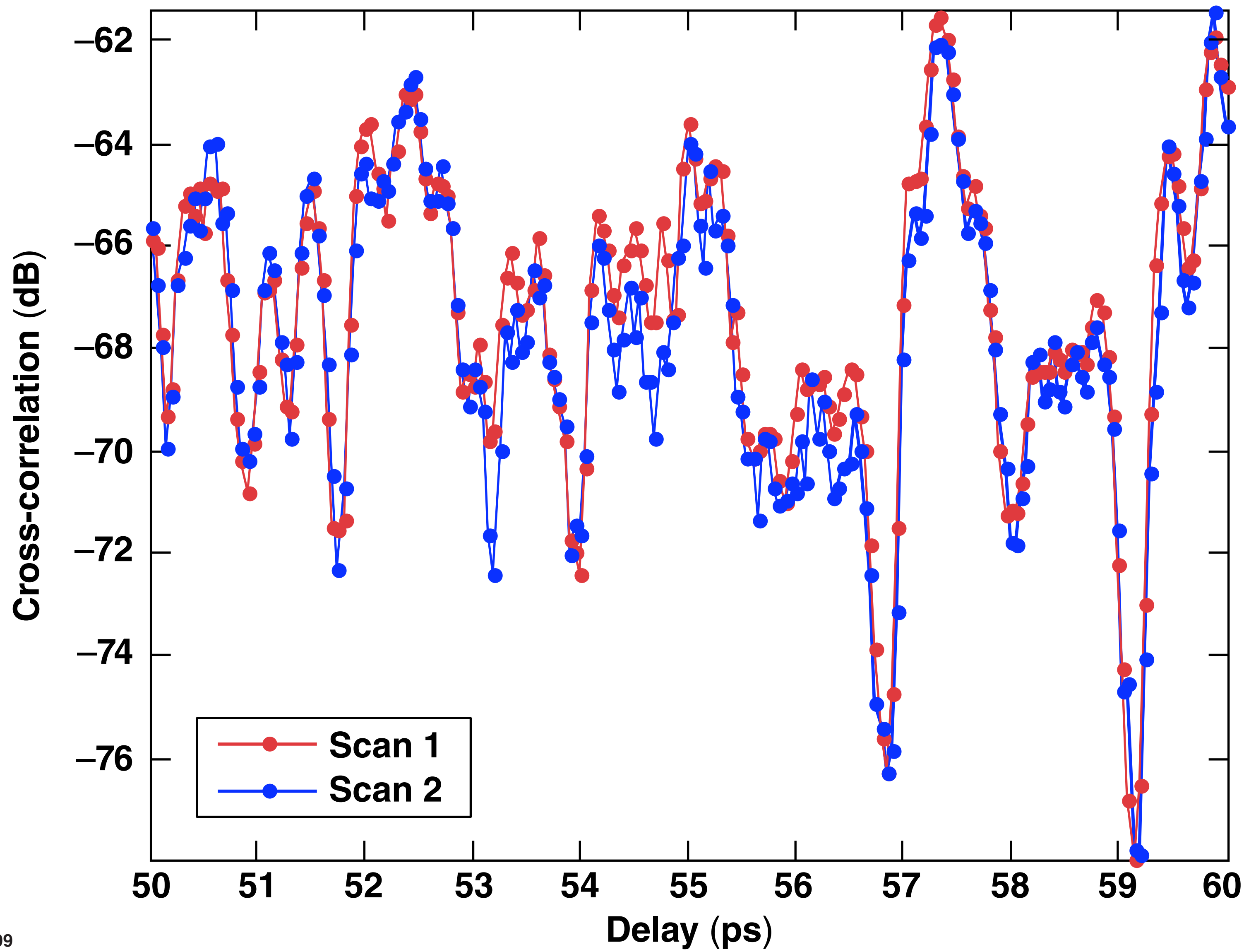
*Bromage *et al*. Opt. Lett. 35, 2251 (2010).

The structure in the tail is stable from scan to scan



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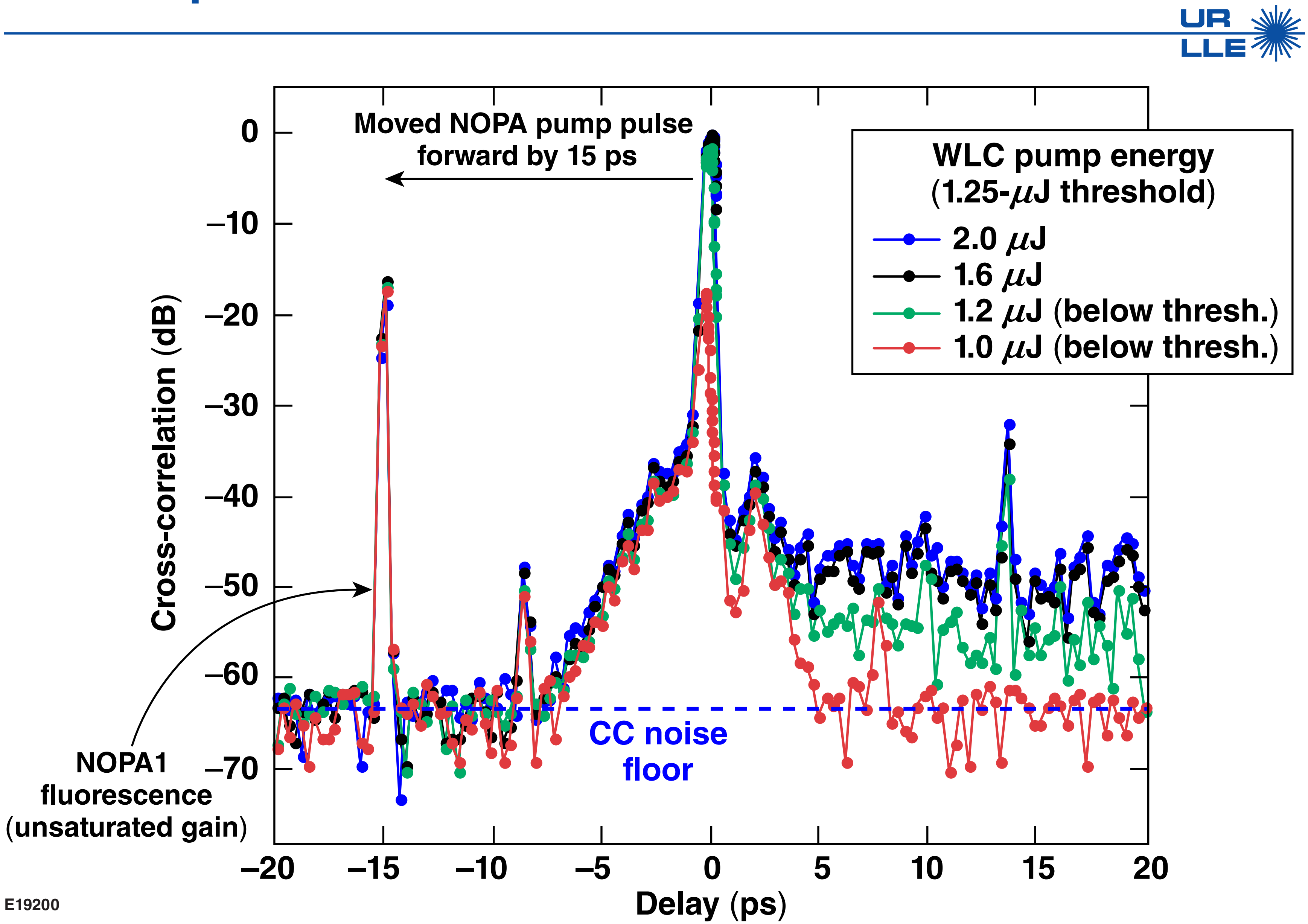
The tail depends on the energy of the pulse used to produce the WLC



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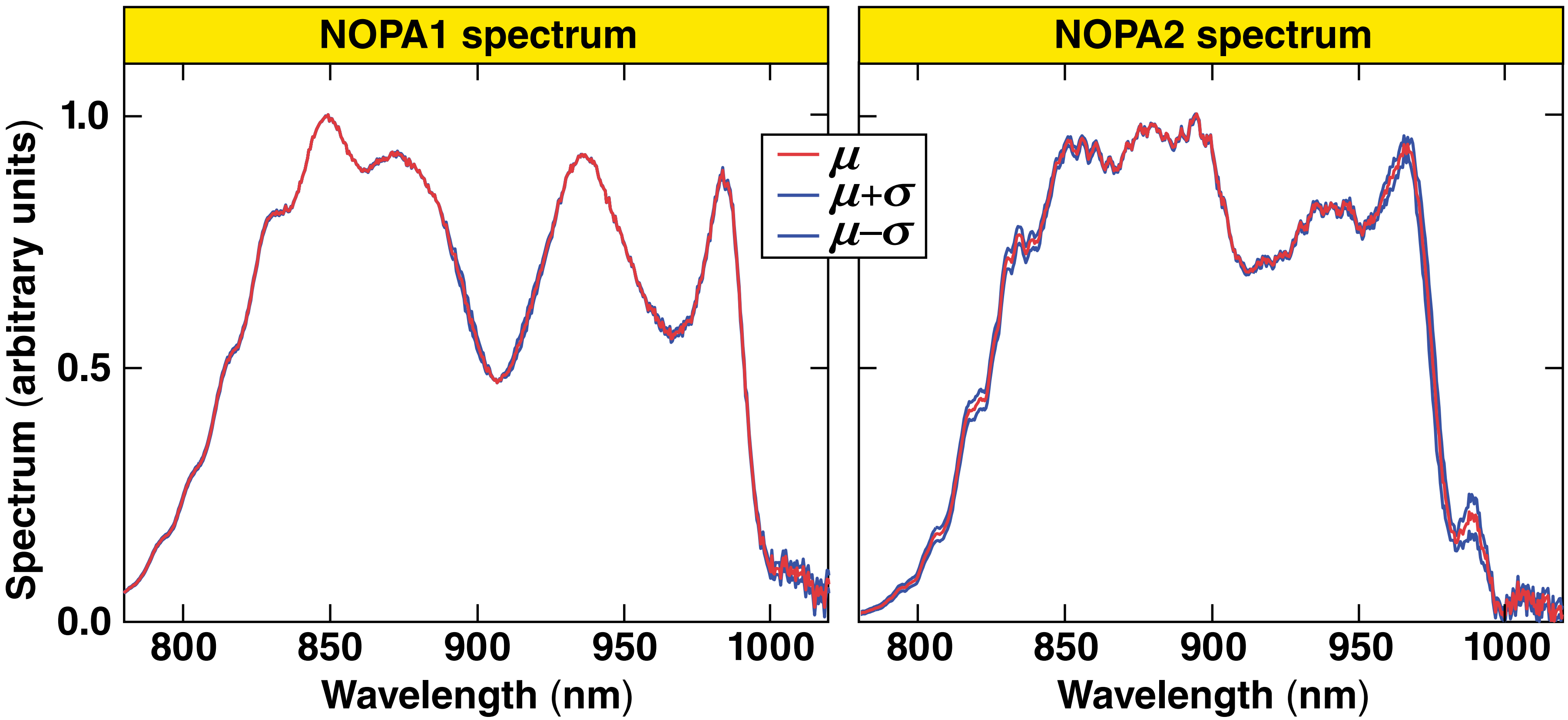
The WLC-seeded NOPA's show good spectral stability



E19201

The near-field and far-field profiles of NOPA2 satisfy the needs for Phase 2