Detailed study on impulse response fluctuation induced by polarization variation

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Objective

- Confirm observations of polarization induced noise made by others
  - Agilent: D. Cunningham *et al.*
  - Infineon: J.R. Kropp
  - Big Bear Networks: J. King

- Enhance resolution with impulse response measurement
  - Validate that power simply transfers from group to another

- Evaluate effect of connector misalignment to polarization induced noise
  - Determine if polarization coherence reduces

- Confirm relative effect of center and offset launch

- Build up a methodology to quantify the polarization variation impact on channel performance

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Experimental Apparatus
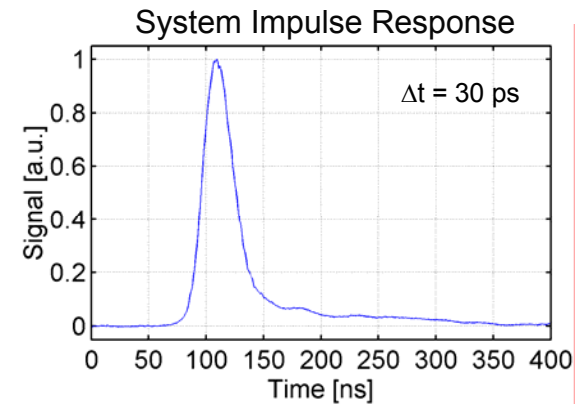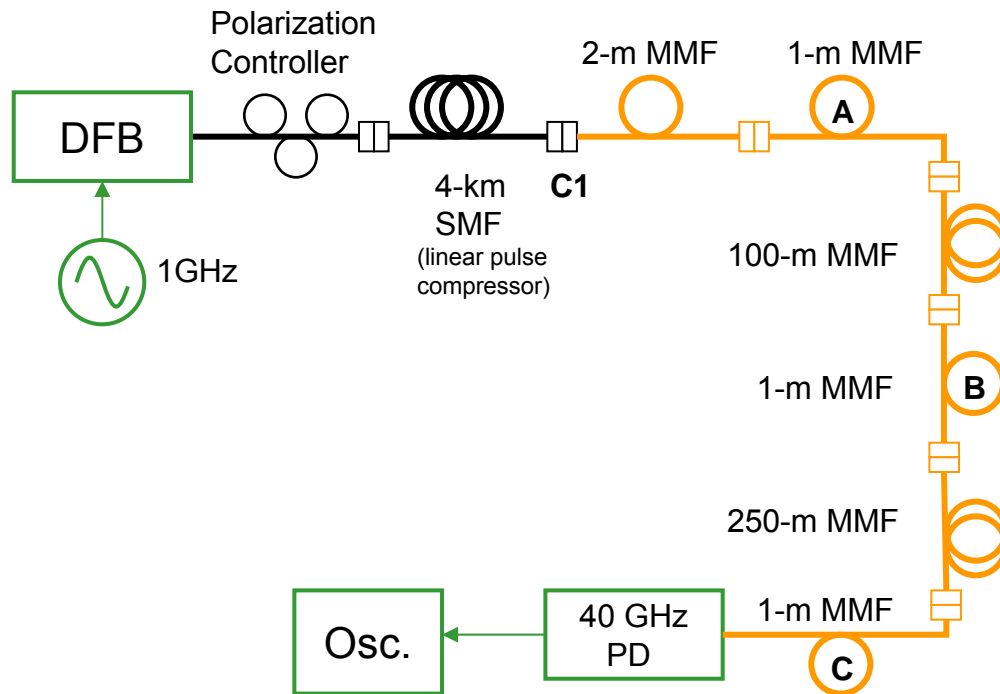
- At location C1: SMF to MMF launch site
  - ➢ Center or offset (via GbE style MCP)

- At locations A, B or C: MMF to MMF offset "stressor" patchcord is used
  - ➢ Stressor offset estimated from loss measurement by LED
    - ▪ -0.5 dB → ~ 4 μm offset
    - ▪ -1.5 dB → ~ 12 μm offset

Fiber DMD

- DMD suggests presence of profile "kink"
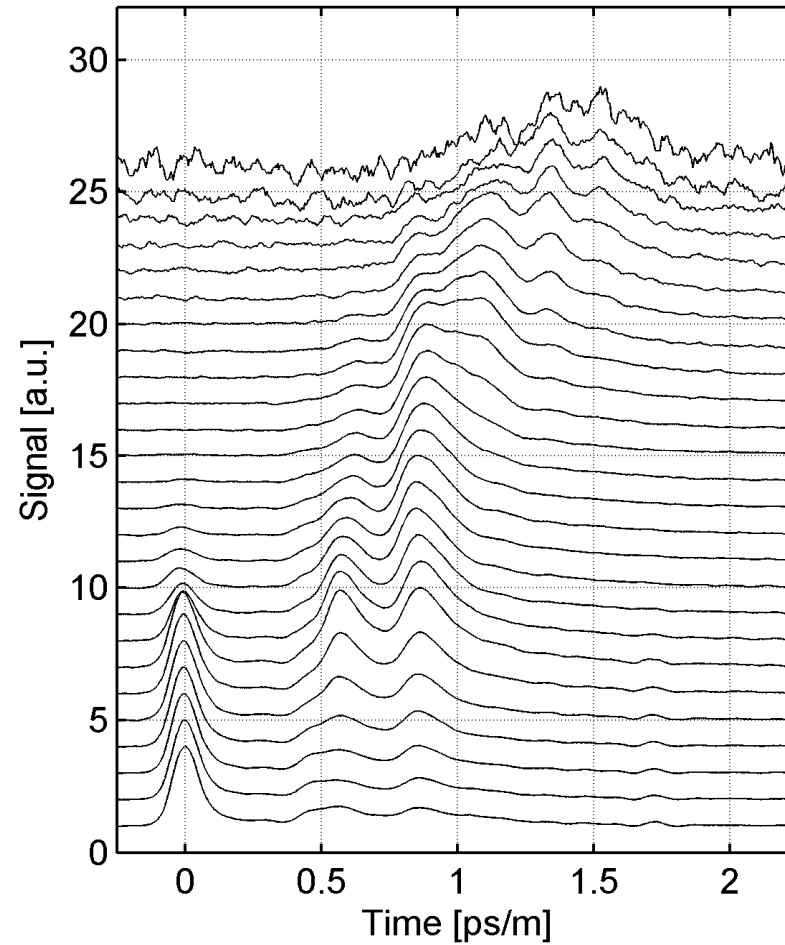
Methodology

- Comparison of induced fluctuation for various locations of offset patchcord
  - Spliced patchcord with 0, 4 and 12-μm splice offset considered
  - "Offset" placed at locations A,B, or C

- Polarization controller manipulated to induce impulse response fluctuations
  - Remain link fiber left unperturbed
  - 75 traces taken with 2 sec interval
  - NOT strictly "random"

- Various figure of merits considered
  - Pulse energy
    - optical pulse energy normalized to maximum observed pulse energy
  - Relative "peak" energy
    - energy within bit period ($1/f_{rate}$) window around impulse peak normalized by total pulse energy
  - PIE-D
    - simulated link with measured impulse response
    - 10.3125 Gb/s data rate, 30-ps Gaussian edge pulse, and 7.5 GHz BT filter

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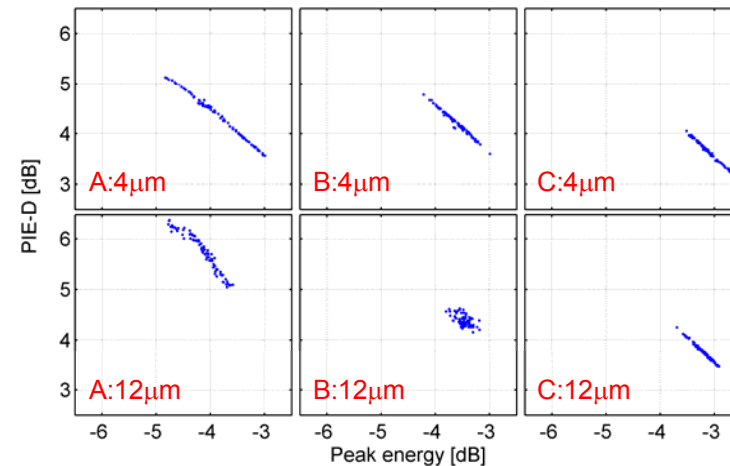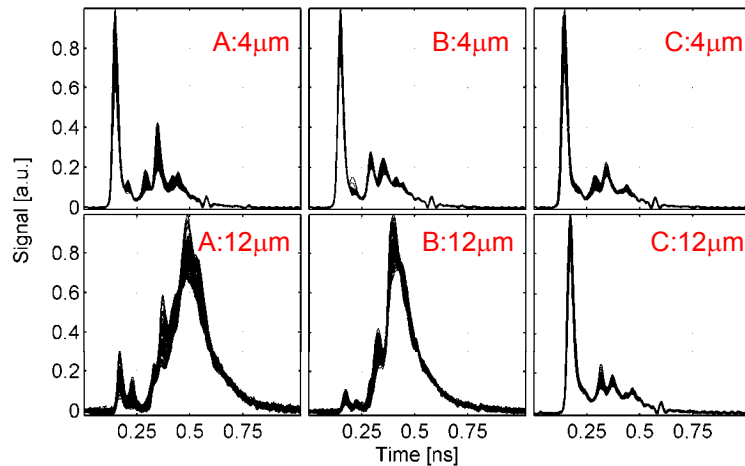*Leading Optical Innovations*

Temporal Fluctuations: Offset Launch

Stressor-free
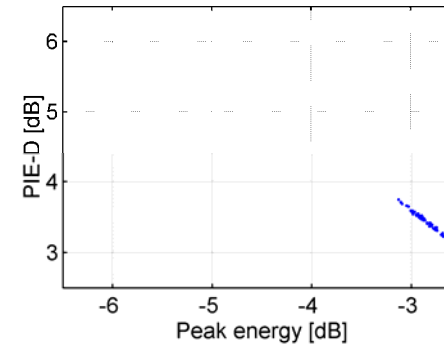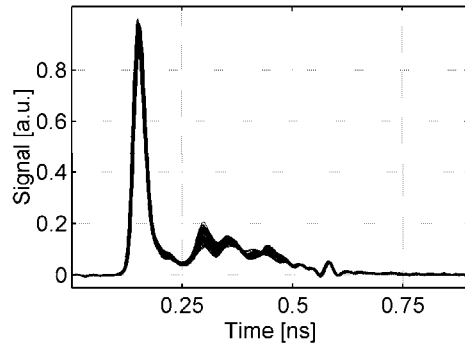
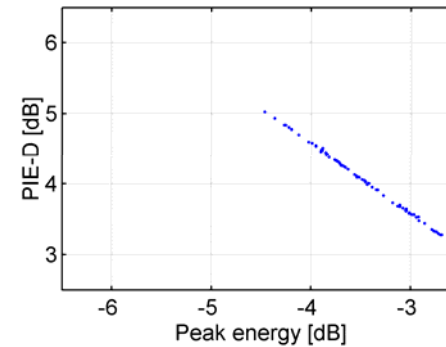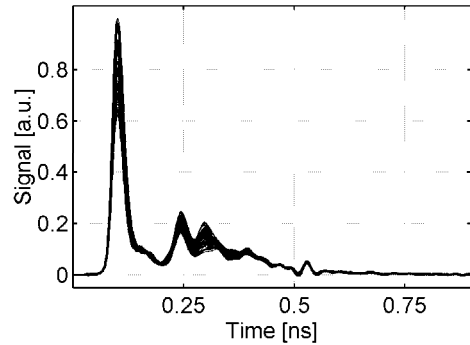System noise results in 0.2 dB pk-pk in PIE-D and relative peak energy metrics

With MMF-MMF stressor @ locations A,B, or C

- Presence of MMF-MMF offset (4 or 12 μm) results in enhance fluctuations

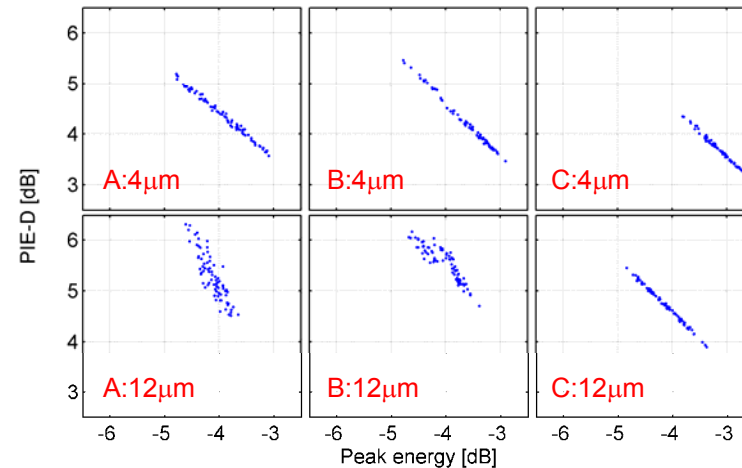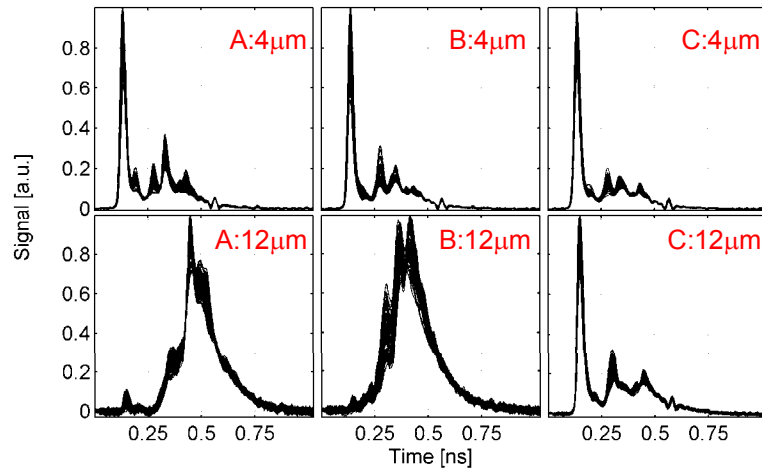- Fluctuation diminishes with MMF-MMF offset located downstream (locations B and C)

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Temporal Fluctuations: Center Launch

Stressor-free

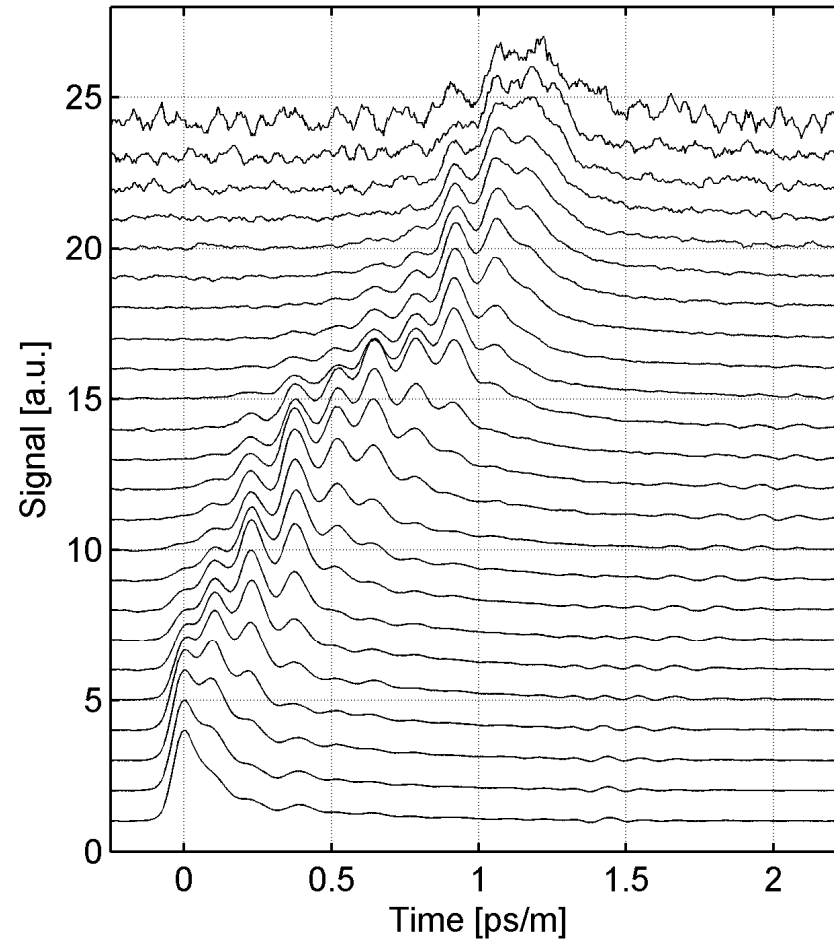System noise results in 0.2 dB pk-pk in PIE-D and relative peak energy metrics

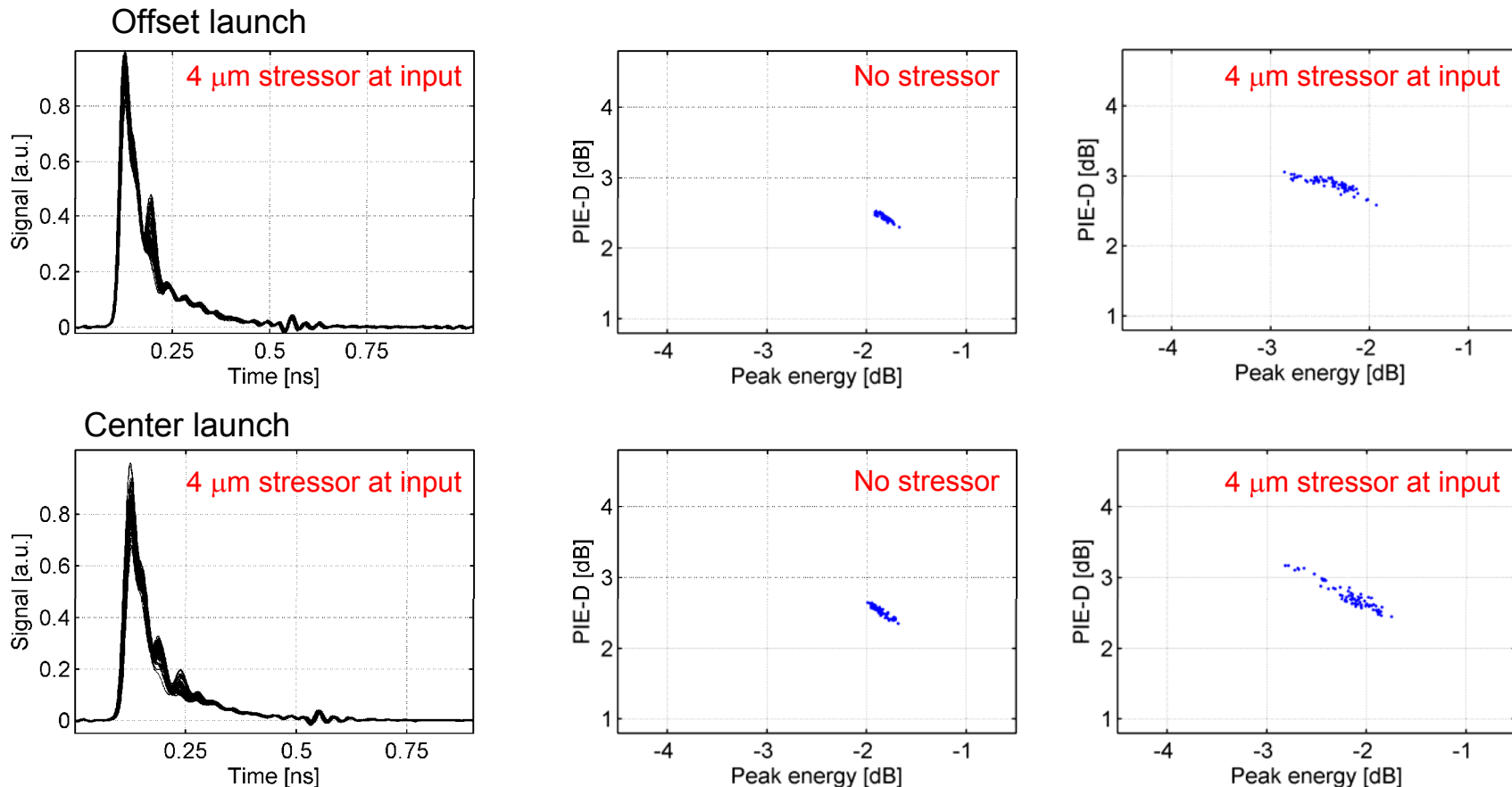With MMF-MMF stressor @ locations A,B, or C

- Stronger fluctuation observed with center launch compared to offset launch

- Fluctuation diminishes with MMF-MMF offset located downstream (locations B and C)

Low-defect OM3 Fiber

- Consider impact of polarization effect with low defect fiber core

Temporal Fluctuations: OM3 fiber

Offset launch

4 μm stressor at input

No stressor

4 μm stressor at input

Center launch

4 μm stressor at input

No stressor

4 μm stressor at input

- Polarization induced fluctuations reduces compared to high-defect core profile
  - ➢ Impulse response is strongly limited by measurement system resolution

- Stressor enhances fluctuation, demonstrating sensitivity to polarization
  - ➢ Effect is more perceivable with relative "peak" energy
  - ➢ PIE-D may not be sufficiently sensitive for link with low DMD

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Summary

- Without connector offset, impulse response fluctuation (IRF) is observed for both offset and center launch
  - ➢ Observed in impulse response, PIE-D and relative peak energy

- Center launch seems worse
  - ➢ With or without profile kink, center launch produces more fluctuation than with offset launch

- Use of offset at input of main fiber enhances fluctuations in relative "peak" energy and PIE-D metrics
  - ➢ Fluctuation is strongest with stressor at input of fiber
  - ➢ Diminished to near system noise for stressor at link output

- Polarization state appears to impact coupling at fiber-fiber interface
  - ➢ Power seems to transfer among modes groups of established group delay, i.e. peaks of impulse response DO NOT shift in time

- Sensitivity to polarization fluctuation exhibited in low-defect profile

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Backup material

Measurement System Noise
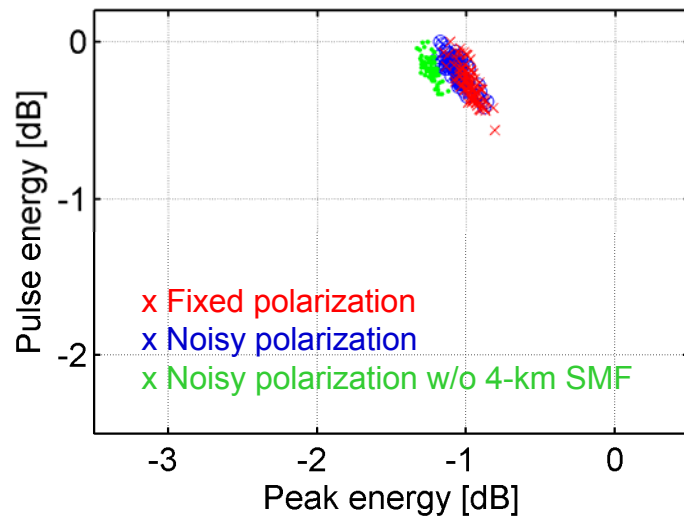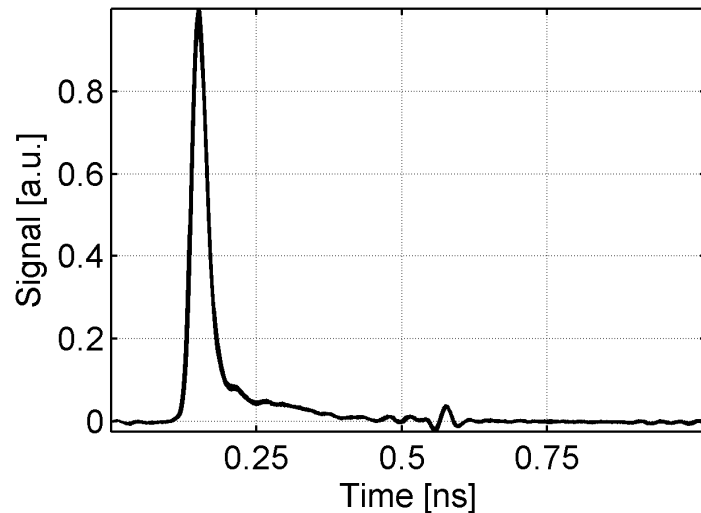
- Pulse response of all-SMF link

- Pulse energy noise in system is 0.3-0.4 dB
  - Independent of PC state
  - σ = 0.09 dB

- PIE-D fluctuation is 0.3dB
  - σ = 0.07 dB
  - PIE-D computation includes normalization of pulse

- Most likely due to thermal noise and trigger jitter of oscilloscope
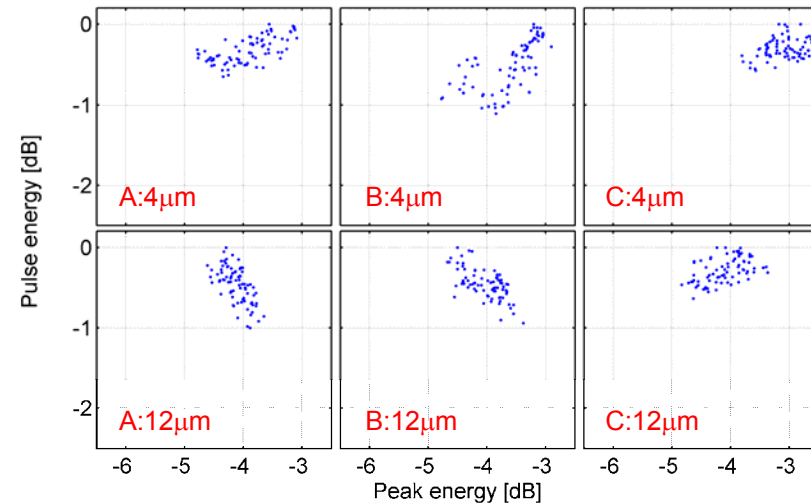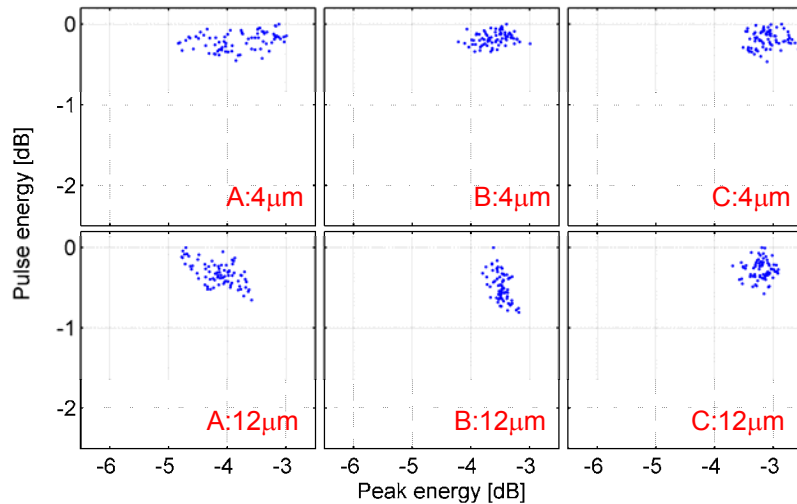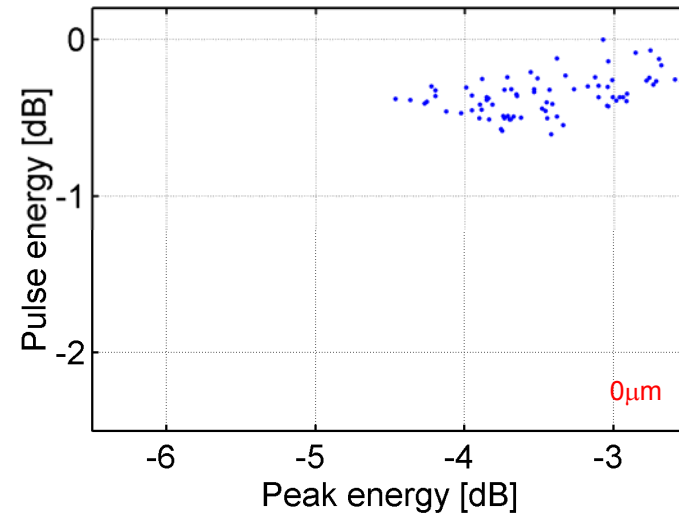 - Timing to amplitude jitter conversion through "mixing" process by digital sampling of short pulse
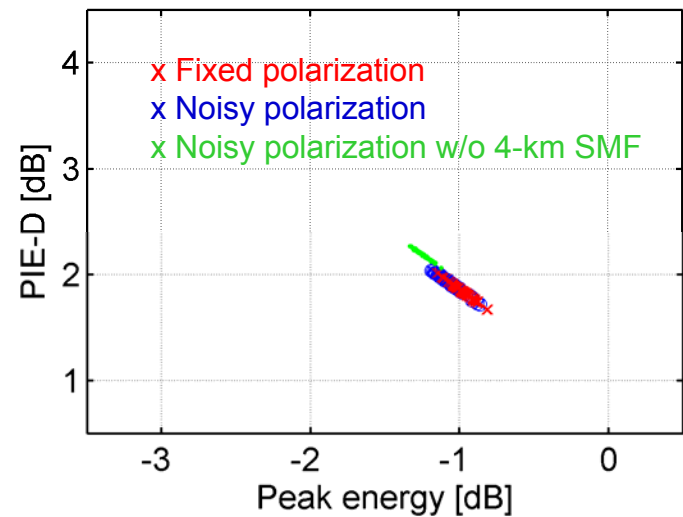
Average Power Fluctuations

System noise: 0.4dB pk-pk

Offset Launch
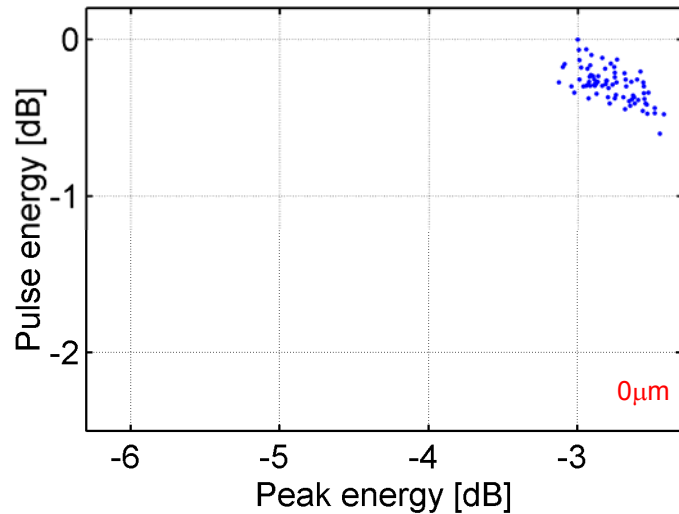
Center Launch

NOTE: A,B,C → stressor location

IEEE 802.3aq 10GBASE-LRM Task Force

Speckle Pattern Apparatus
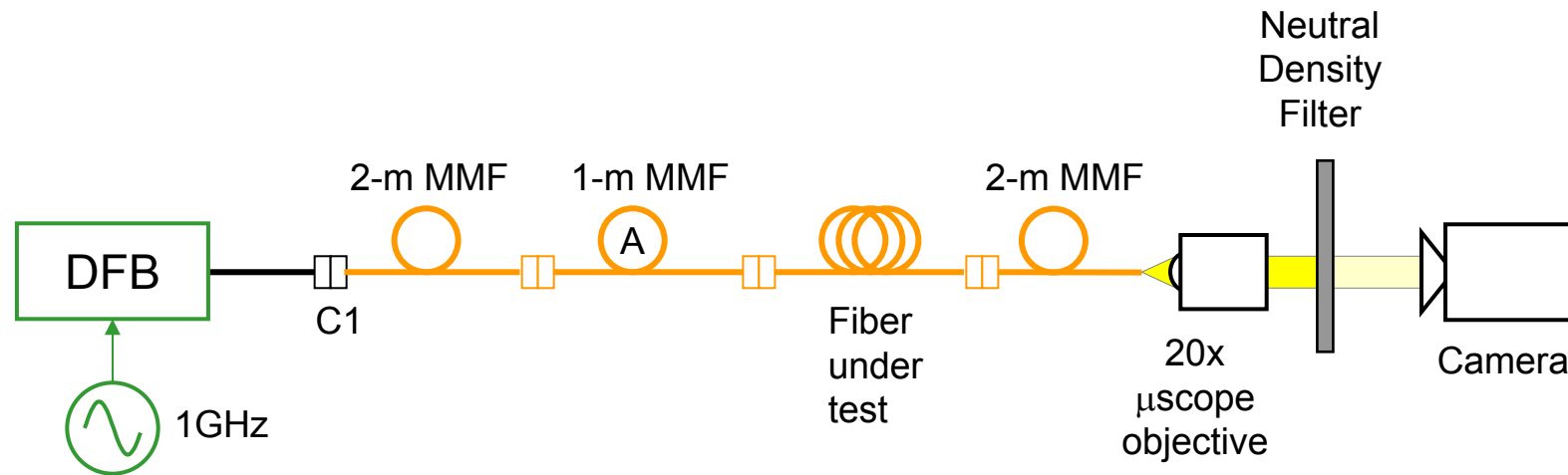
- Source coherence time: ~ 3-6 ps

- Capture speckle pattern image with various stressor patchcord location A

- Perturbed 2-m MMF (flip the fiber coils up side down) for each offset condition
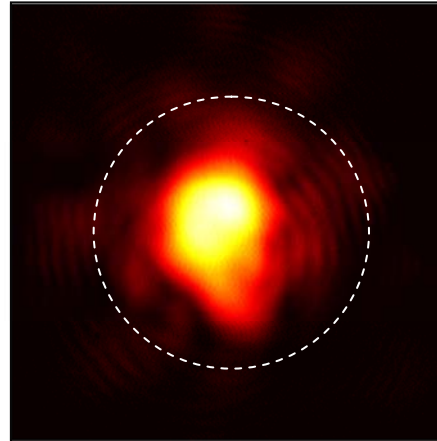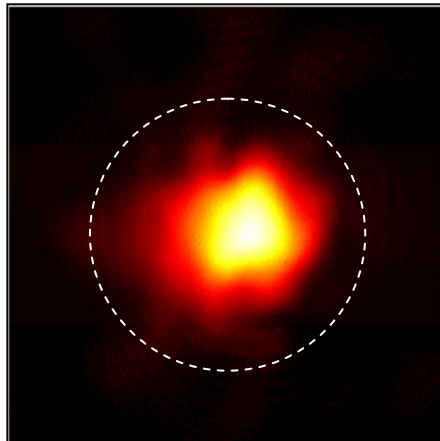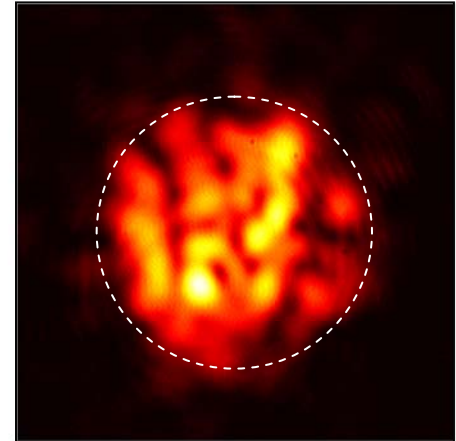
Source spectrum
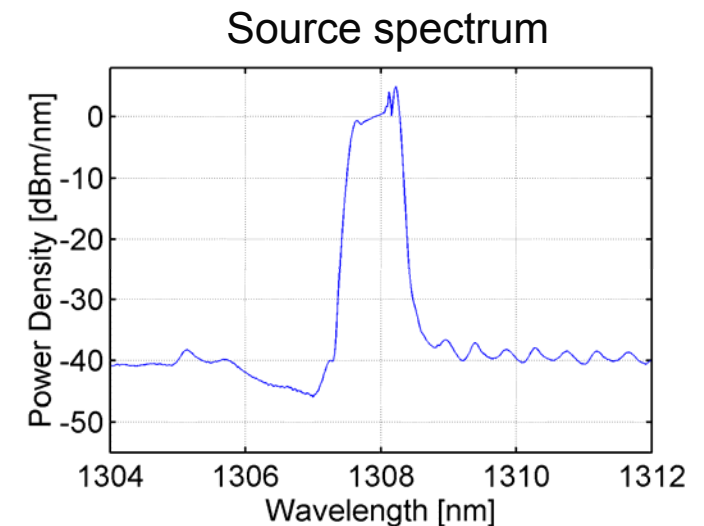
Speckle pattern: SMF center launch
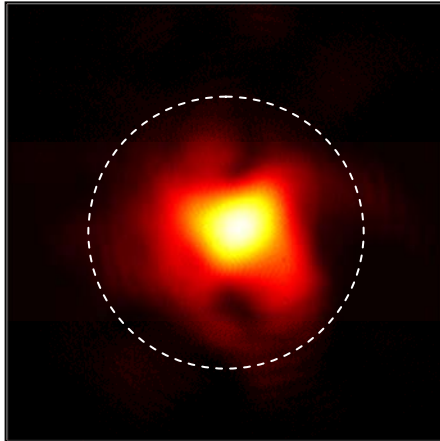
0-μm stressor	4-μm stressor	12-μm stressor

polarization 1   polarization 1

polarization 2   polarization 2
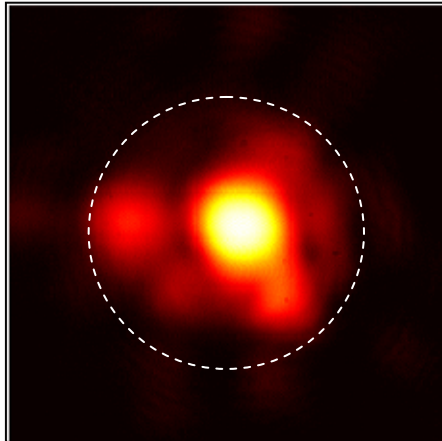
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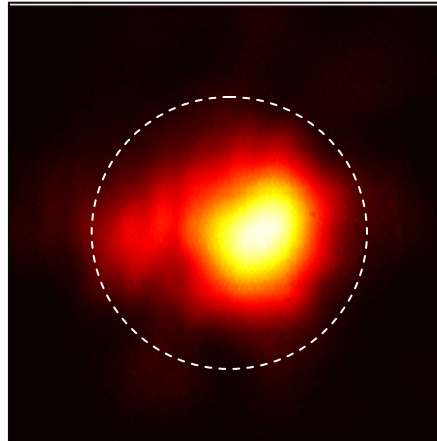*Leading Optical Innovations*
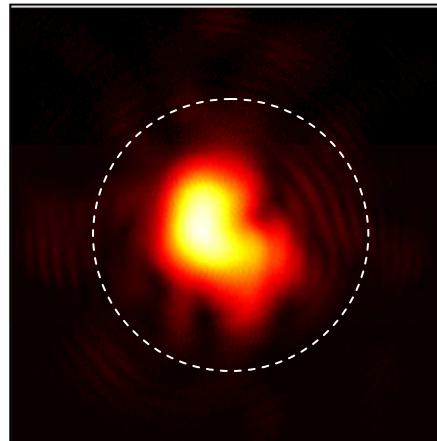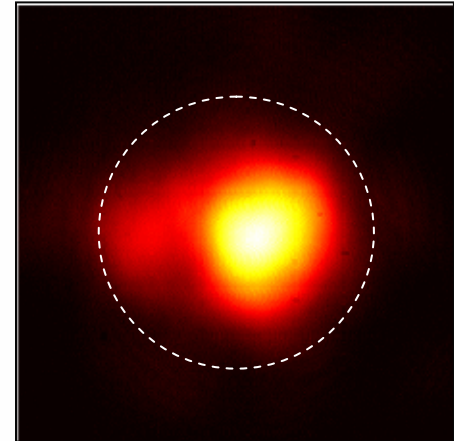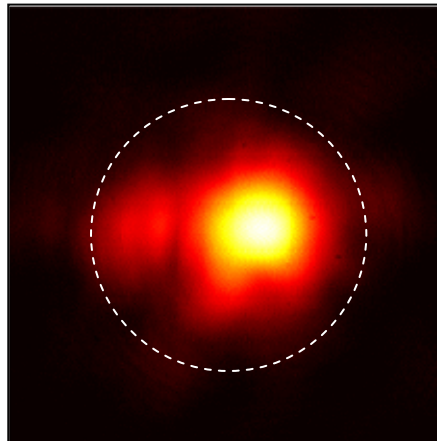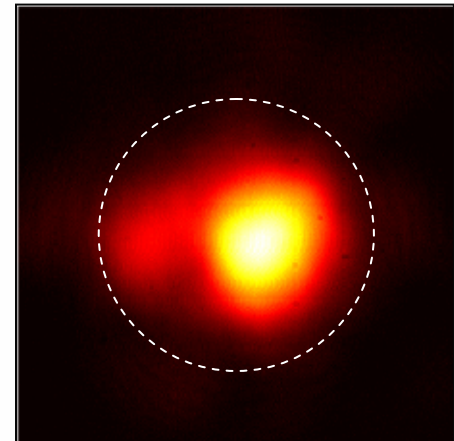
Speckle pattern: SMF offset launch

0 μm, 2m patch cord — polarization 1

0 μm, 100m MMF — polarization 1

0 μm, 350m MMF — polarization 1

0 μm, 2m patch cord — polarization 2

0 μm, 100m MMF — polarization 2

0 μm, 350m MMF — polarization 2