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# Development and Characterization of a Bidirectional Optical Multipass Cavity for Counter-propagating High Energy Pulsed Laser Applications



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# Overview



- **Multipass cavity was developed for counter-propagating high energy pulsed laser applications**
- **Cavity was designed to potentially allow for repeated temporal and spatial superposition of counter-propagating pulses**
  - Trap: One-time change in pulse polarization state
  - Maintain: Optical focusing system employed
  - Optimized: by simulation
  - Experimentally characterized

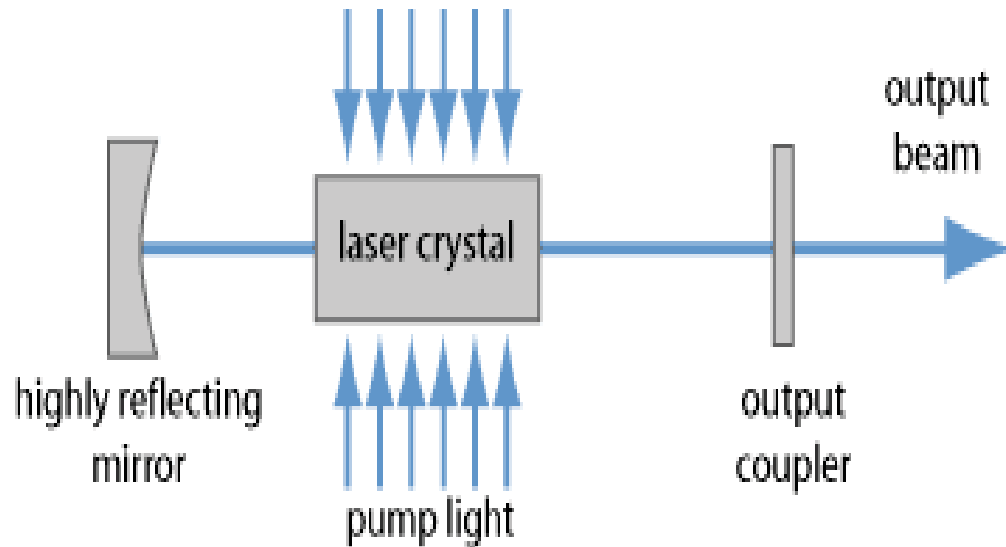


# Optical Cavities



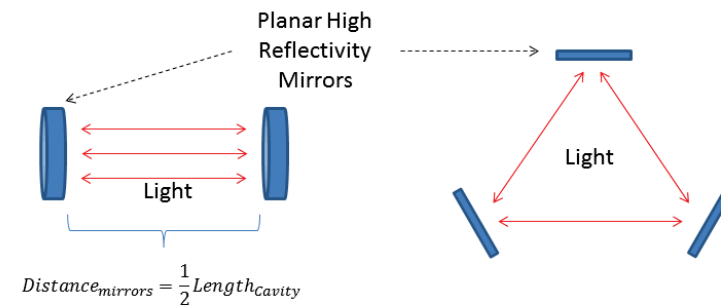
- **Cavities**

- provide a closed path for circulation of light
- Function follows form:
  - 1.) Active & resonant
  - 2.) Passive & resonant /nonresonant



- **What can they do for me?**

- Increased laser pulse repetition rates
- Increased laser-gas energy deposition efficiency
- Increased absorption path length
- Increased sensitivity in spectroscopy studies
- Variety of energy storage & amplification schemes

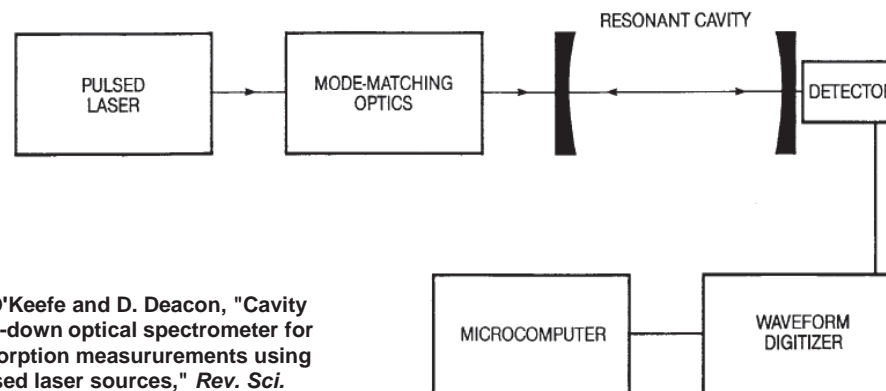
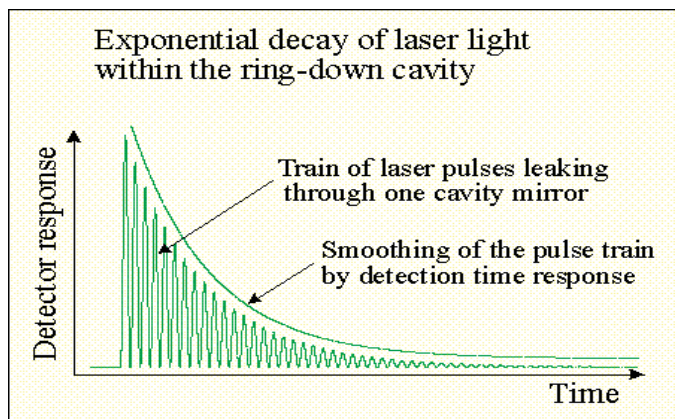




# Prior Multipass Cavity Applications



1. Potential non-resonant laser gas heating
2. X- and  $\gamma$ -ray production using Inverse Compton scattering
3. Chemical Kinetics using Infrared Multiple Photon Dissociation (IRMD)
4. Raman scattering for molecular structure studies
5. Cavity ring-down laser absorption spectroscopy (CRDS)
6. Laser absorption spectroscopy



A. O'Keefe and D. Deacon, "Cavity ring-down optical spectrometer for absorption measurements using pulsed laser sources," *Rev. Sci. Instrum.*, vol. 59, p. 2544, 1988.



# Experimental Cavity Requirements

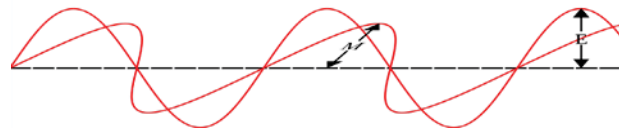


## Experimental

- For the requirement of this study, any potential cavity design must:
  - Efficiently trap/contain pulsed laser light at 532 nm
  - Simultaneous injection pulses
  - Exhibit high damage thresholds
  - Spatial/temporal superposition
  - Reduce beam diameters down to  $\sim 50 \mu\text{m}$

## Implementation

- Problem: Time reversibility
- Possible solutions
  1. Laser Resonant Cavity
  2. Long path length
  3. Modification and Trap
    - a. Color Change Cavity
    - b. One-time Polarization Change
- Selected Approach: Pockels Cell
  - Linear electro optic Pockels effect
  - Introduces net relative phase shift between orthogonal components
  - Can act as a dynamic  $\lambda/2$  or  $\lambda/4$  wave plate/dynamic phase retarder/frequency shifter



$$T_0 = T_1$$

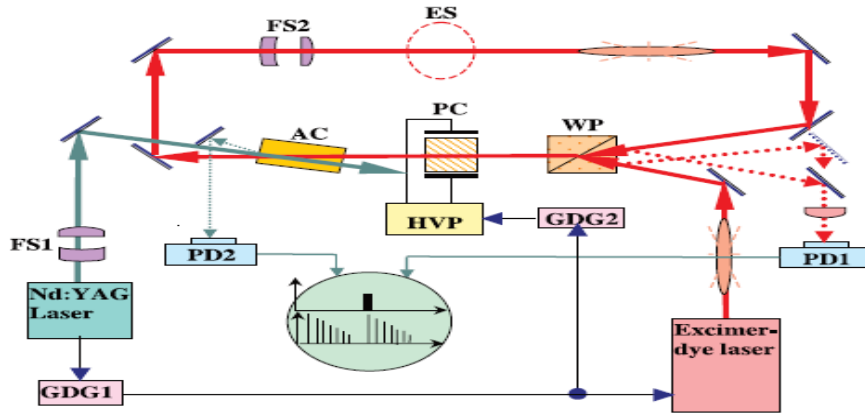




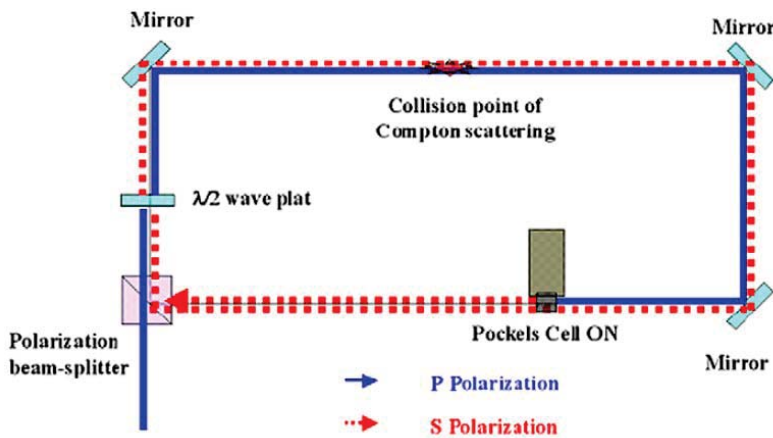
# Single Pockels Cell Cavity Design



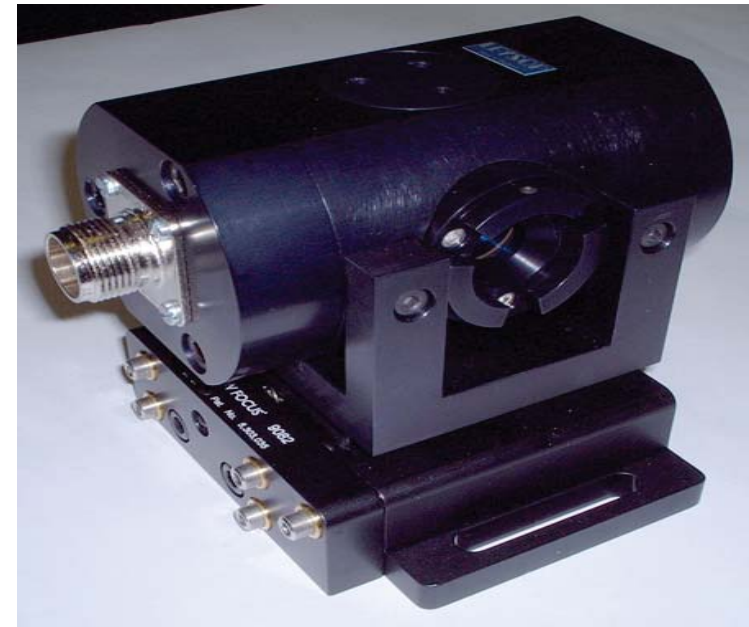
## Mohamed et al.



## Meng et al.



## Pockels Cell



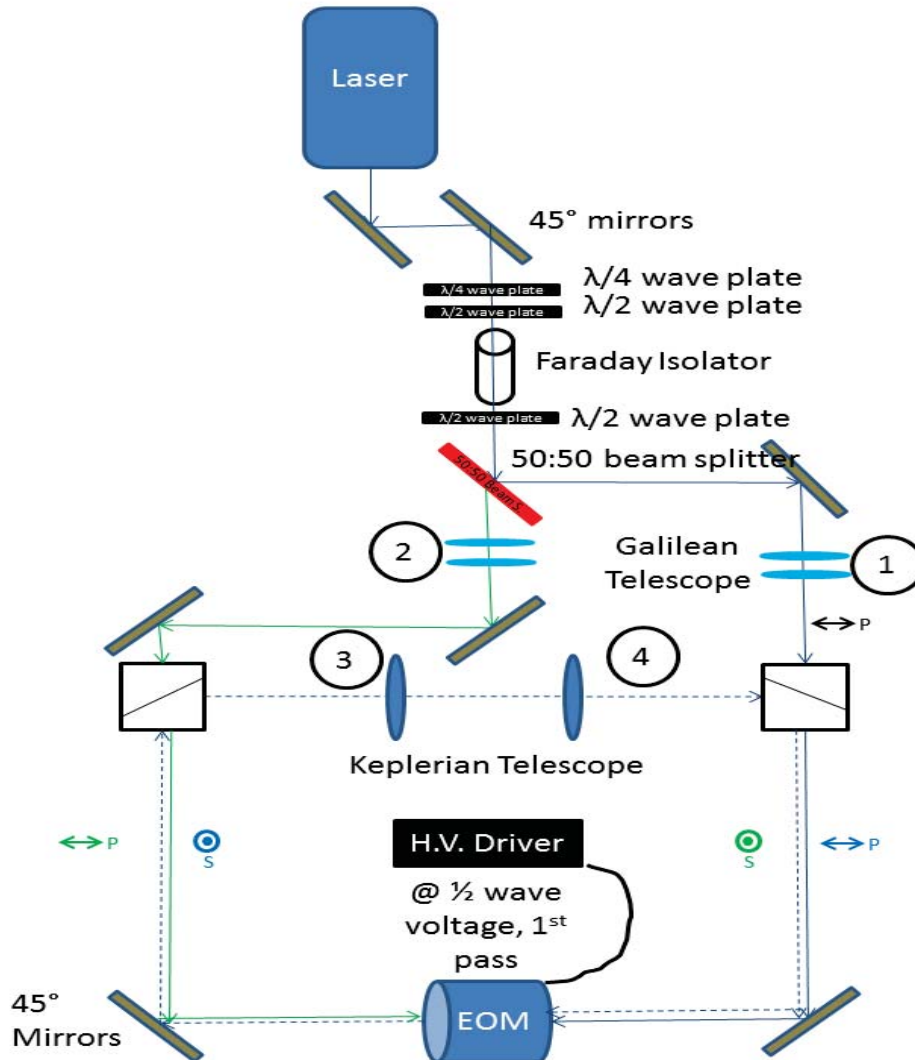
- Pockels effect is a linear electrooptic effect
- Birefringence
  - Index of refraction
- Pockels cell used for dynamic phase retardation
- 2 important voltages

$$V_{\lambda/2} = \frac{\lambda}{2n_0^3 r_{63}}$$

$V_{\lambda/2}$  for KD\*P at 532 nm  $\approx$  3.6 kV



# Single Pockels Cell Cavity Design



- Conditioning wave plates
- Faraday Isolator
  - Faraday effect
  - Faraday rotator & 2 Glan polarizers
  - Non-reciprocal rotation
  - One-way valve
- Galilean Telescopes
- PBCs
  - p/s polarization
  - Differential response
- Pockels Cell/Driver
  - @  $V_{\lambda/2}$  on 1<sup>st</sup> pass
  - $V=0$  on subsequent passes
  - One-way valve
- Keplerian

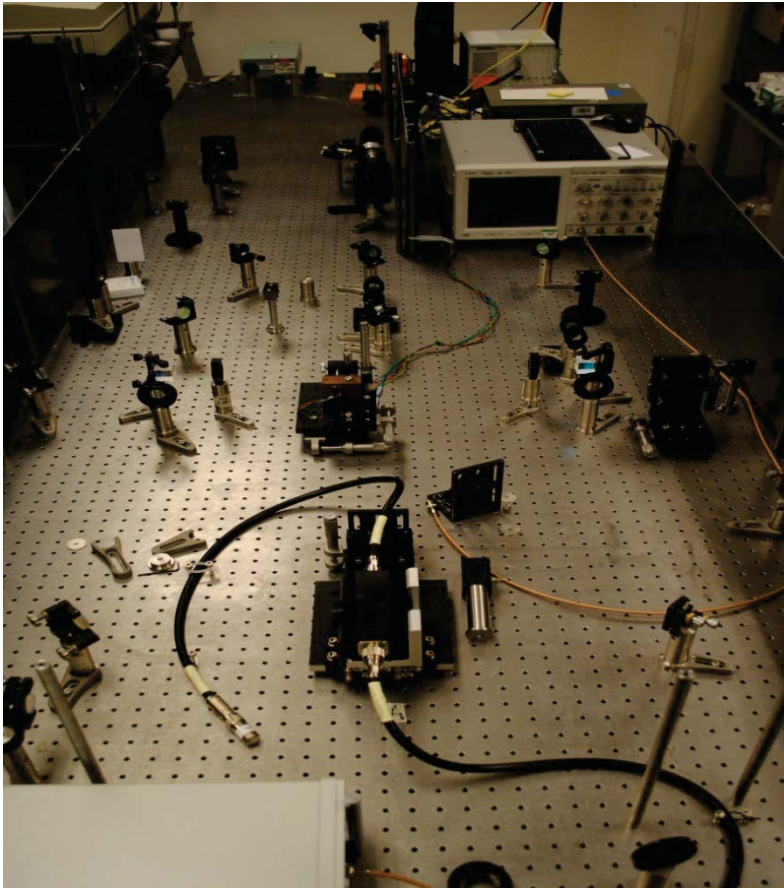




# Implementation



## Experimental Setup

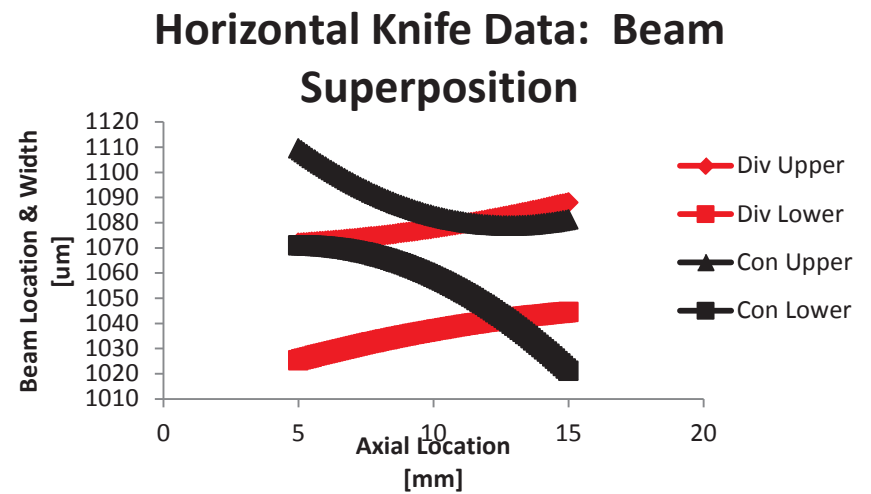
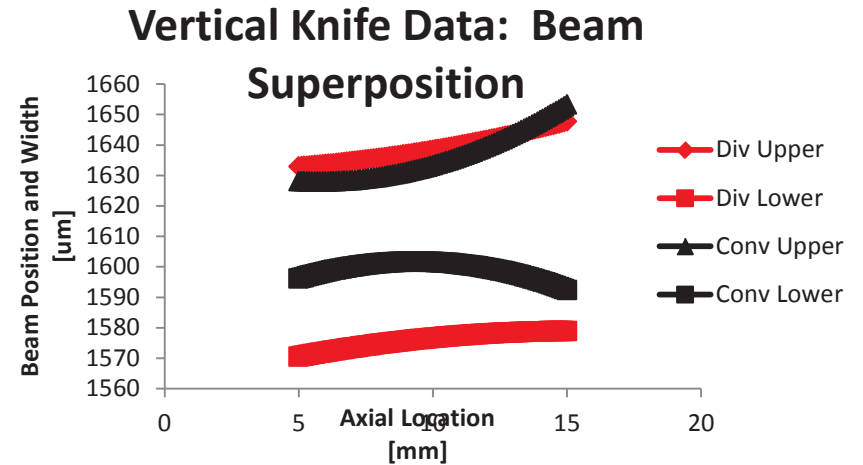
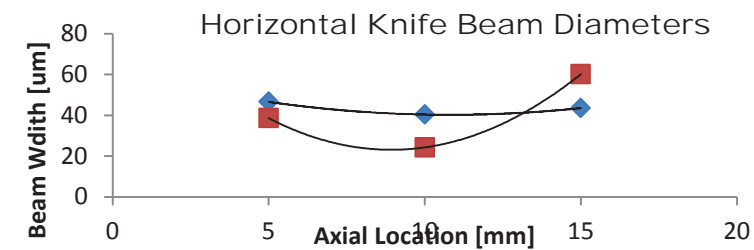
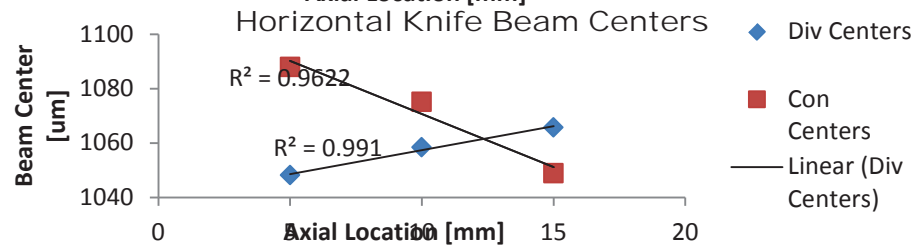
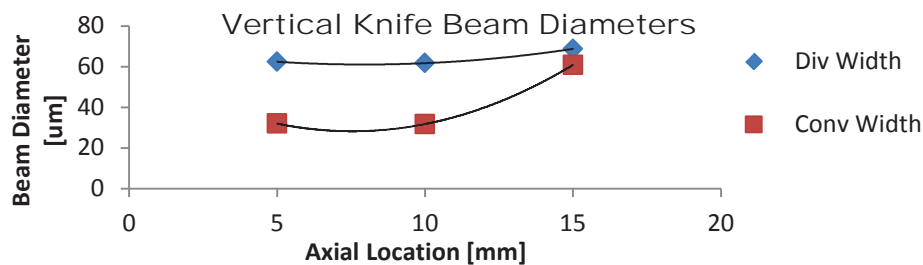
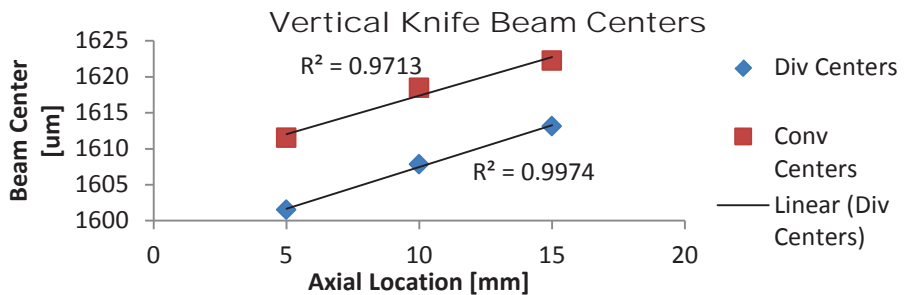


## Equipment

- **Laser(s)**
  - Nd:YAG 532 nm, 5 ns FWHM, Continuum Minilite/Powerlite
- **Cavity length 2.4284 m (96 in); rt pulse time 8.09 ns**
- **Timing Control**
  - SRS DG535 x3
- **Pockels cell/driver**
  - Leysop Ltd. UPC 6 mm aperture; 250 ps rise, 6 ns width; KD\*P 650MW/cm<sup>2</sup>
- **Intra- and extra-cavity focusing system**
- **Knife Edge System**



# Results: Spatial Superposition

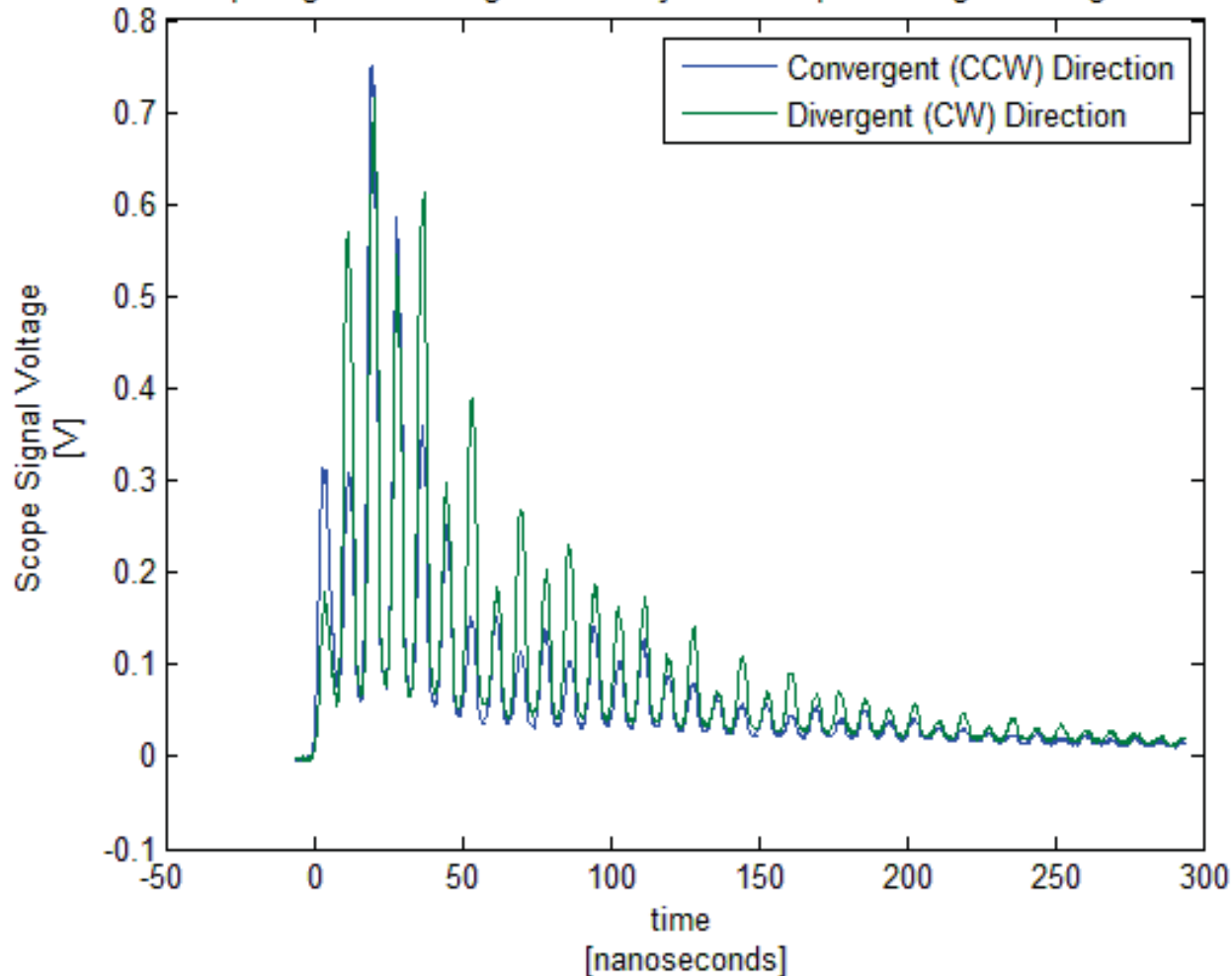




# Results: Temporal Superposition



Oscilloscope Signal Indicating Each Cavity Round Trip in Convergent/Divergent Direction



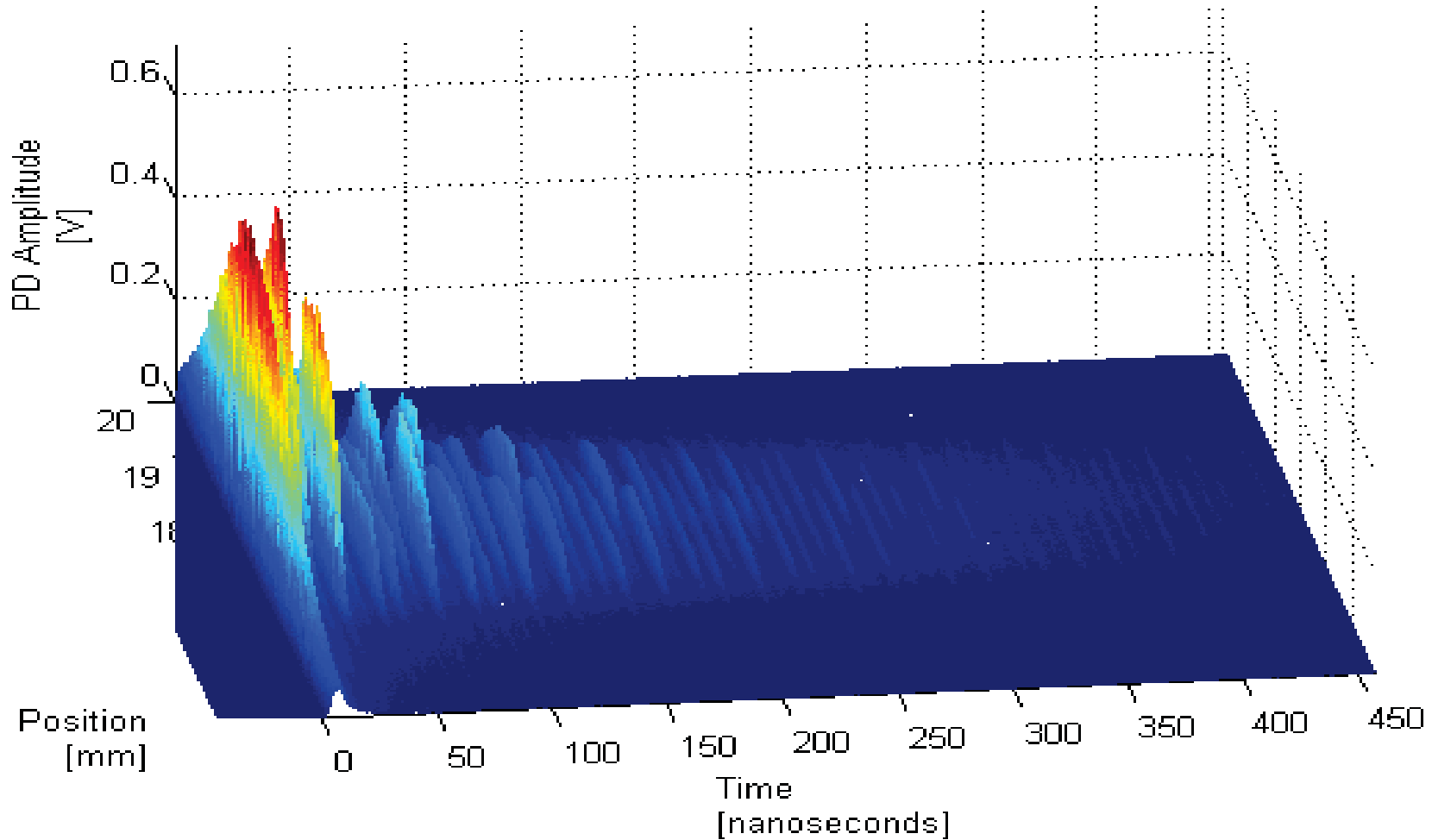
- **Temporal pulse superposition**
- Greater than 40 rt
  - 532 nm, 5 ns FWHM, Continuum Minilite, 4 mJ
- Cavity length 2.4284 m (96 in); period 8.09 ns
- Pockels cell/driver
  - Leysop Ltd. UPC 6 mm aperture; 250 ps rise, 6 ns width
- Periodicity matches cavity
- PD
  - Active area  $.006 \text{ mm}^2$



# Results (continued)



3-D Plot of Roundtrip Amplitude as a function of Horizontal Translational Position and Time

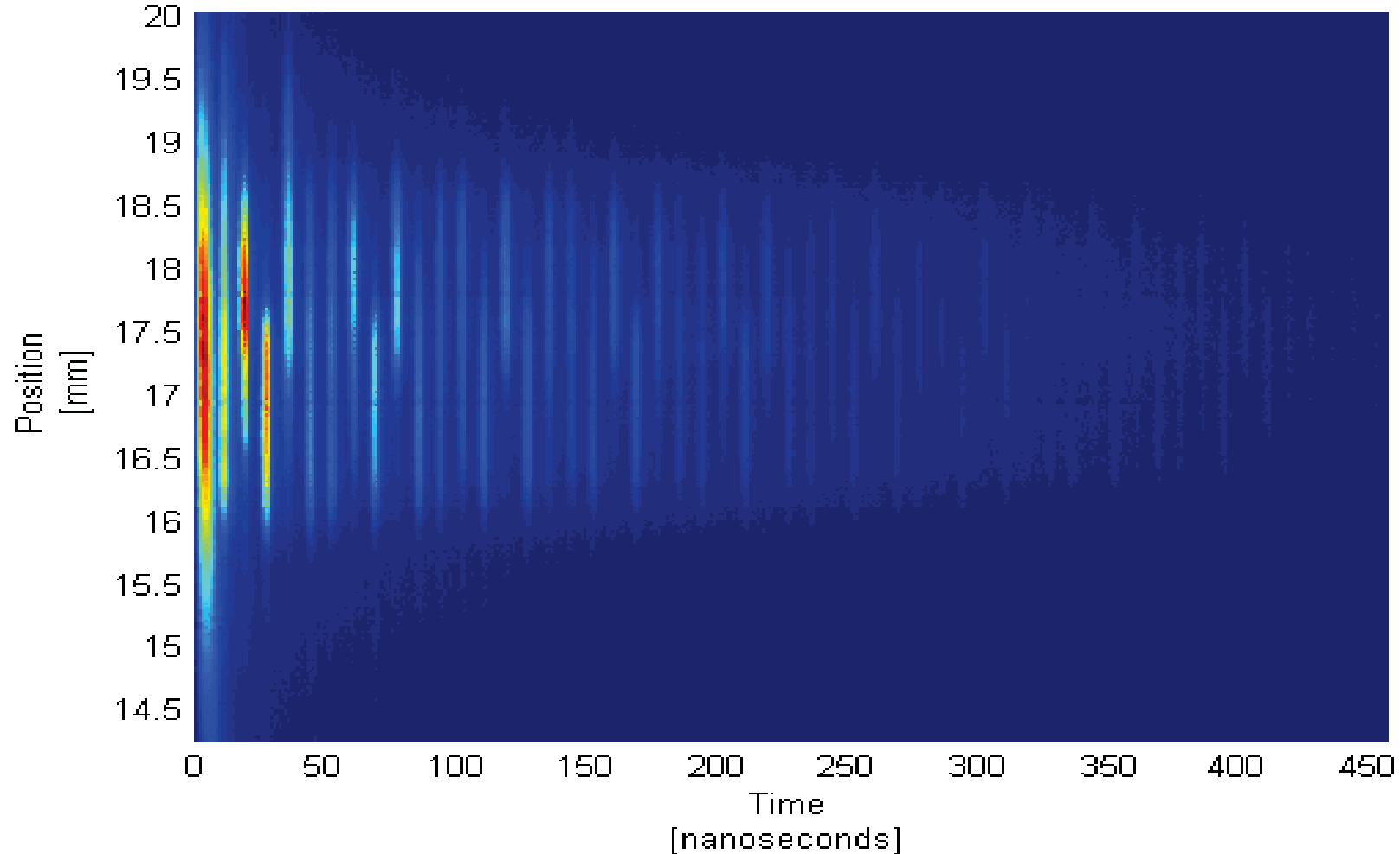




# Results (continued)



3-D Plot of Roundtrip Amplitude as a function of Horizontal Translational Position and Time





# Summary



- **First bidirectional cavity for counter-propagating high energy laser pulses**
  - Temporal superposition confirmed within cavity on every round trip
  - Spatial superposition confirmed on 1<sup>st</sup> R.T.
  - 40+ R.T. observed for 4 mJ initial pulse energy
  - Cavity indicates a dual-stability condition
  - 8.3 fold increase in energy deposition ‘opportunity’ over the single pulse/single pass case