AE93: Direct Measurements of Fields and Radiation in the Self-Modulated Plasma Wakefield Regime

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TEXAS The University of Texas at Austin: R. Zgadzaj, M. Downer

Fundamental LWFA research at ATF

Mid-IR Laser

- P_L >1 TW
- $\lambda \sim 10.6\ \mu m$
- $\tau_L \sim 2$ ps

Powerful wakefield driver in the long pulse regime $c\tau \gg \lambda_p$

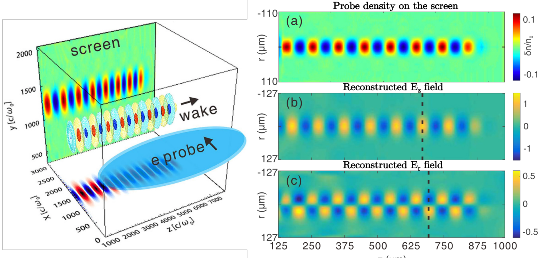
Electron Beam

- $E_e \sim$ 50-70 MeV
- $Q_e \sim 0.5$ nC
- $\varepsilon_n \sim$ 1-3 mm-mrad

Transverse probe for plasma wake

Research Capabilities:

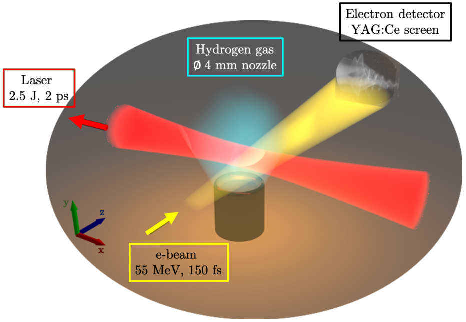
- Study of long-pulse laser plasma interaction in nonlinear regime
- High resolution density and **field probing of LWFA**
- **External injection in LWFA in the blowout regime**

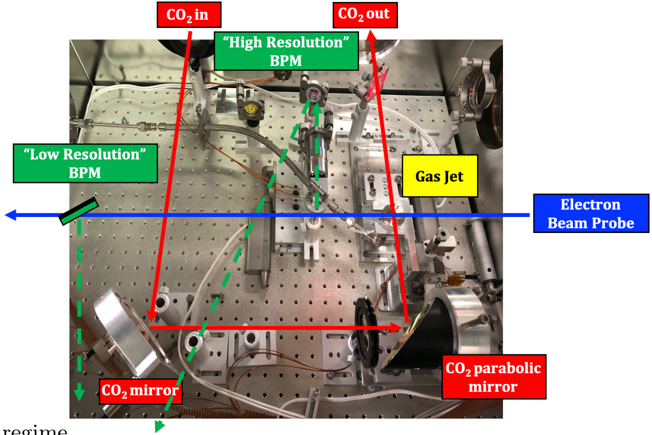


C.J. Zhang et al., Scientific Reports 6:29485 | DOI: 10.1038/srep29485

Timeline proposed in 2018

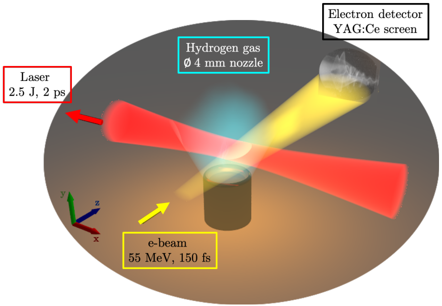
2019	✓	Direct measurement of the fields in a self-modulated (SM) laser wakefield accelerator (LWFA) using linac electron beam as a transverse probe.
2019/2020	✓	Parametric study of laser evolution in the SM regime and study of novel physics predicted by simulations in this interaction.
2020	1/2 ✓	Coordinate electron characterization, wake visualization and simulations to achieve comprehensive understanding of CO_2-laser-driven wakefield acceleration in nonlinear regime.
2021		Characterization of radiation-generation capability of the channel region in SM-LWFA using longitudinal probe. In particular, the role of direct laser acceleration (DLA) in enhancing the gamma radiation will be investigated.

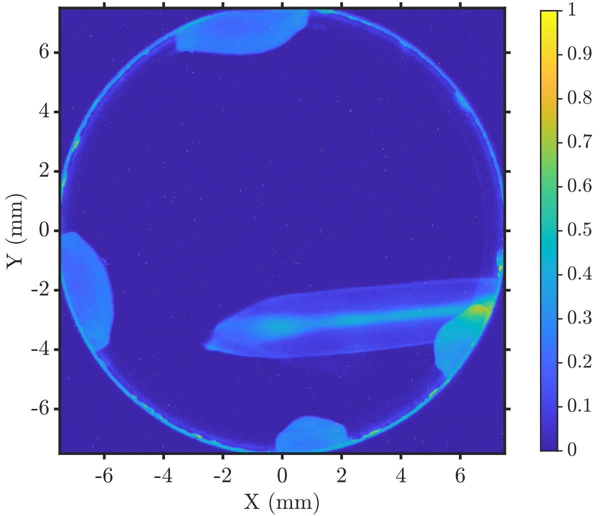




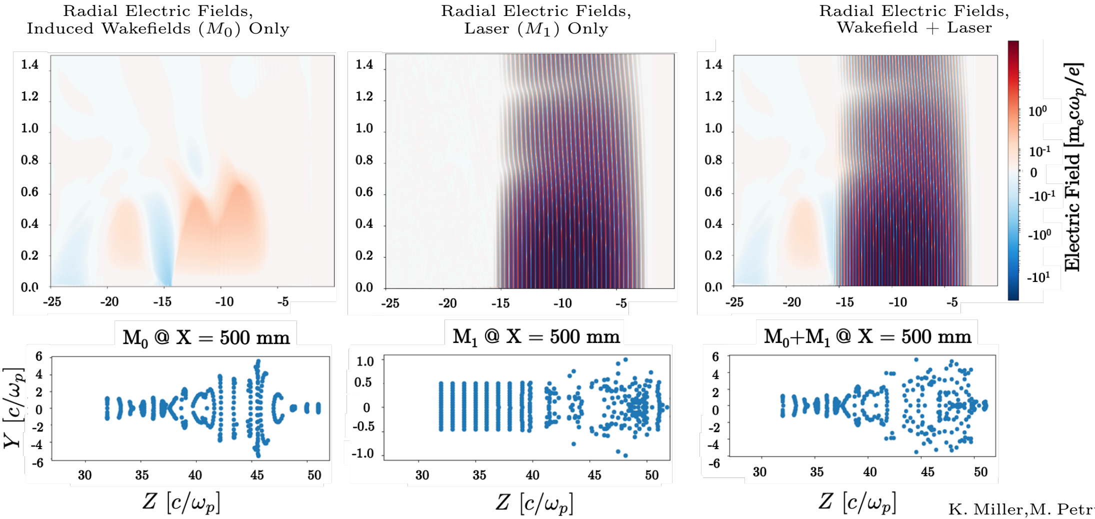
- **Goal:** visualize wakefield in self-modulation regime
- **Result:**
  - obtained two data sets for "low-density" ($\sim 10^{15}\text{cm}^{-3}$) and "high-density" ($\sim 10^{17}\text{cm}^{-3}$) regimes.
  - obtained time-evolution of the wake by varying the delay between the laser beam and e-beam
  - Note: imaging plane was fixed and located 50 cm downstream of the interaction point.

First glance at the low density data





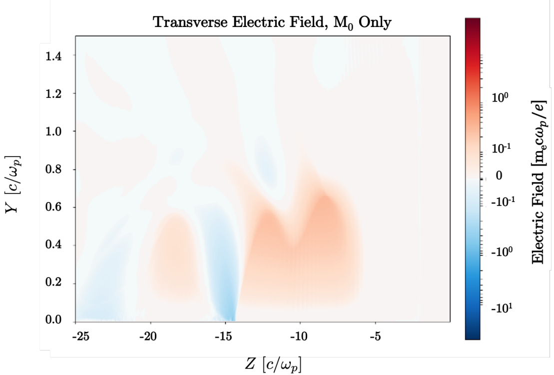
Separating Wakefield and Laser Effects:

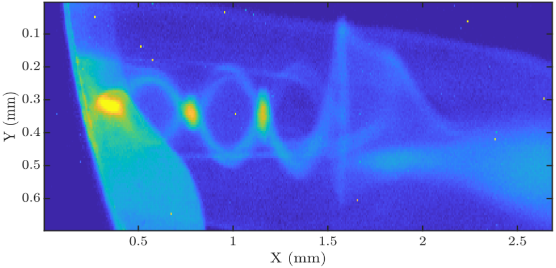


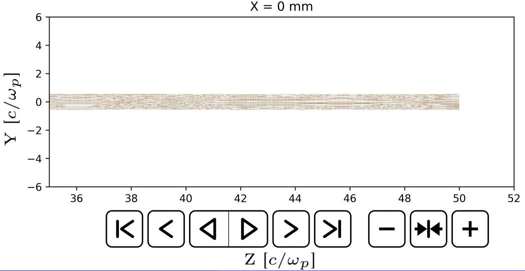
K. Miller, M. Petrusky

Evolution of narrow probe:

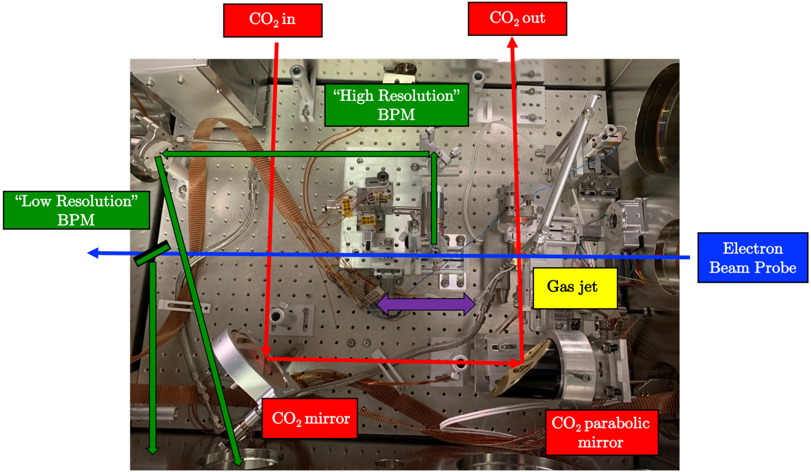
- $\Delta y = 1.6c/\omega_p$
- $\Delta z = 15c/\omega_p$
- Centered at $\xi = -10c/\omega_p$ ($z = 42c/\omega_p$).





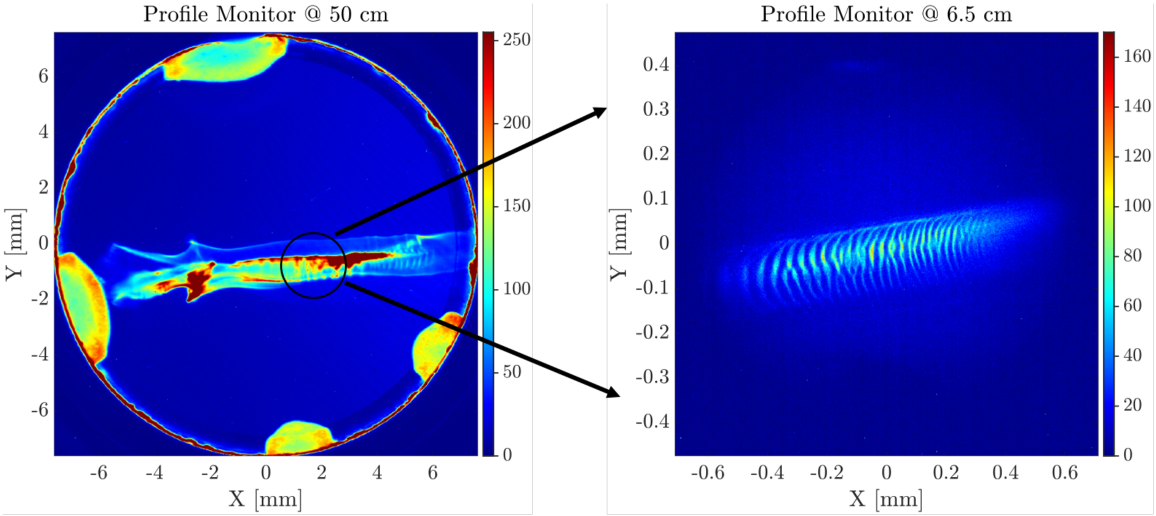


Electron beam probing experiment at ATF in 2020



- movable YAG screen (allows to find the best imaging plane)
- remote control of the objective motion
- remote control of the ZnSe lens and Ge crystal

Electron beam probing experiment at ATF in 2020 - PRELIMINARY



Future plans

- Implement high resolution BPM measurement for detailed study of fields in SM-LWFA with spatial resolution on the scale of the laser wavelength.
- Improve gas targets and diagnostics to enable simultaneous observation of e-beam probe diagnostic, YAG laser diagnostic, and forward electron spectrum.
- Obtain required data for a complete analysis of density and laser power scaling in SM-LWFA.

2020 Activities & Impacts Associated with this Experiment

- Manuscripts:
  - I. Petrushina, et. al *"Evolution of a Self-modulated Laser Wake and Relativistic Self-focusing Induced Plasma Channel Produced by a TW-class CO_2 Laser Pulse in an Underdense Plasma"* (in preparation for publication *PRAB*)
  - P. Kumar, et. al *"Evolution of the self-injection process in long wavelength infrared laser driven LWFA"* (*Physics of Plasmas*)
- Talks:
  - I. Petrushina, *"Direct visualization of the interplay between a self-modulated wake and a hydrodynamic channel formation using a relativistic electron beam as a probe"*, UCLA Summer Seminar, August 2020.
  - I. Petrushina, *"Experimental investigation of interactions of long CO_2 laser pulse with plasma at ATF"*, APS DPP, November 2020.

COVID-19 Pandemic Impacts

- The beam time initially scheduled in March 2020 was postponed until November 2020
- The experiment was performed with the reduced team.

Electron Beam Requirements

Parameter	Units	Typical Values	Comments	Requested Values
Beam Energy	MeV	50-65	*Full range is ~15-75 MeV with highest beam quality at nominal values*	*Nominal (50-65 MeV)*
Bunch Charge	nC	0.1-2.0	*Bunch length & emittance vary with charge*	*~1*
Compression	fs	Down to 100 fs (up to 1 kA peak current)	*A magnetic bunch compressor available to compress bunch down to ~100 fs. Beam quality is variable depending on charge and amount of compression required.* *NOTE: Further compression options are being developed to provide bunch lengths down to the ~10 fs level*	*100 fs*
Transverse size at IP (σ)	μm	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*	*100 um (longitudinal probe)* *1 mm (transverse probe)*
Normalized Emittance	μm	1 (at 0.3 nC)	*Variable with bunch charge*	*1*
Rep. Rate (Hz)	Hz	1.5	*3 Hz also available if needed*	*Up to 1.5*
Trains mode	---	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*	*Single bunch*

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 CPA Beam	Wavelength	µm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	2	*~5 TW operation is planned for FY21 (requires further in-vacuum transport upgrade). A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	*2*
	Pulse Mode	---	Single		*Single*
	Pulse Length	ps	2		*2*
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available in FY20*	*5*
	M^2	---	~2		*~2*
	Repetition Rate	Hz	0.05		*0.05*
	Polarization		Linear	*Adjustable linear polarization along with circular polarization will become available in FY20*	*Linear*

Special Equipment Requirements and Hazards

- Electron Beam
  - Please indicate any special equipment that you expect to need, including (but not limited to) the transverse deflecting cavity, shaped bunch using mask technique, plasma capillary discharge system, bolometer/interferometer setup etc.:
- CO_2 Laser
  - Please note any specialty laser configurations required here:
- Ti:Sapphire and Nd:YAG Lasers
  - Please note any specialty non-CO_2 laser configurations required here: **N/A**
- Hazards & Special Installation Requirements
  - Large installation (chamber, insertion device, etc.): **N**
  - Cryogens: **N**
  - Introducing new magnetic elements: **Magnetic Spectrometer**
  - Introducing new materials into the beam path: **Y** (Yag BPM & Mirror)
  - Any other foreseeable beam line modifications: **Y** (Permanent magnet chicane for beam compression)

Experimental Time Request

CY2021 Time Request

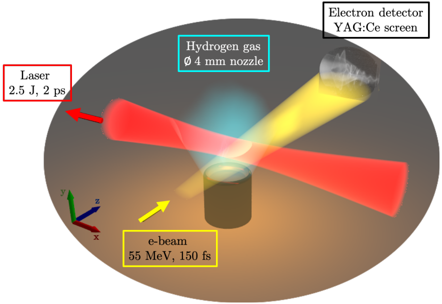
Capability	Setup Hours	Running Hours
Electron Beam Only	0	0
Laser* Only (in FEL Room)	0	0
Laser* + Electron Beam	80	240

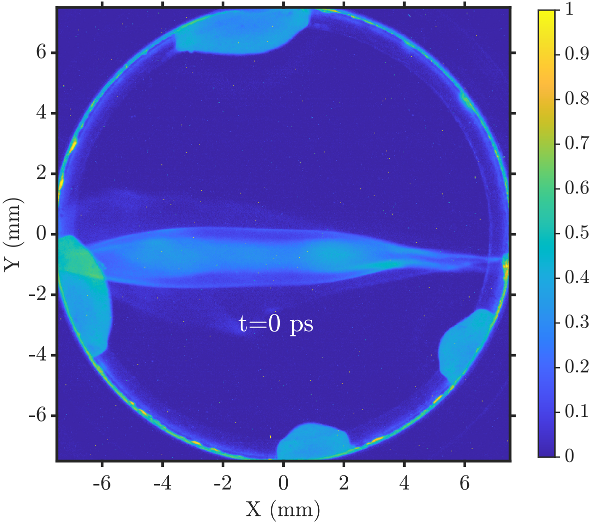
Time Estimate for Remaining Years of Experiment (including CY2021)

Capability	Setup Hours	Running Hours
Electron Beam Only		
Laser* Only (in FEL Room)		
Laser* + Electron Beam	240	720

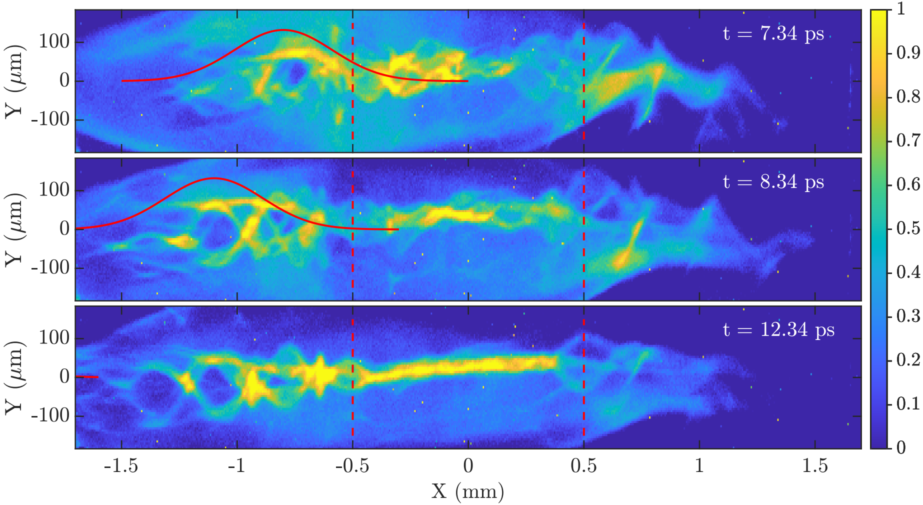
* Laser = Near-IR or LWIR (CO_2) Laser

Back-Up Slides

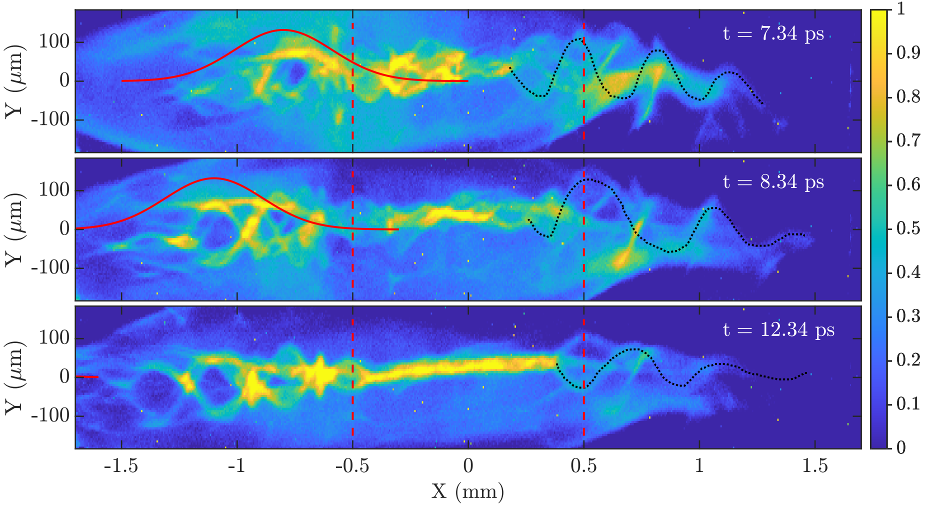

Electron detector
YAG:Ce screen
Hydrogen gas
Ø 4 mm nozzle
Laser
2.5 J, 2 ps
e-beam
55 MeV, 150 fs
y
z
x


t=0 ps
Y (mm)
X (mm)
6
4
2
0
-2
-4
-6
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

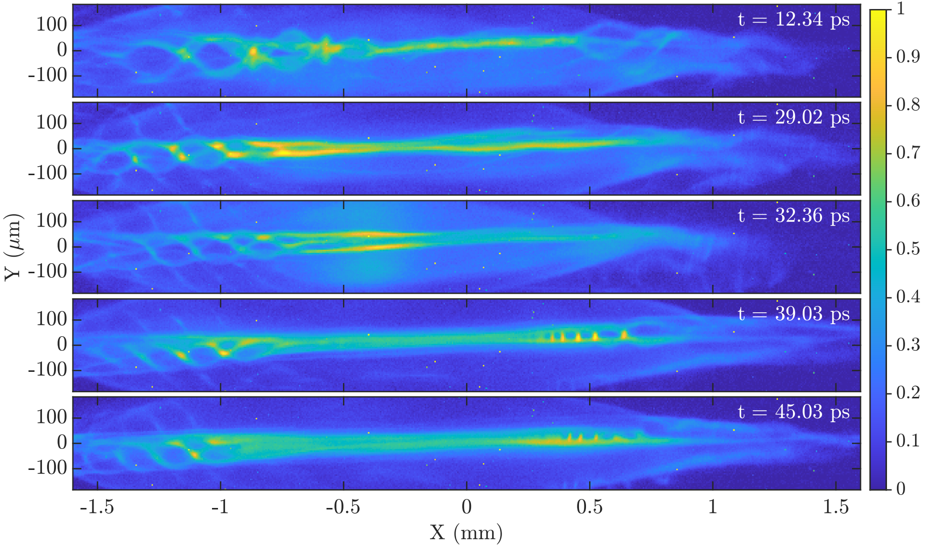
Wake time-evolution. Part 1.



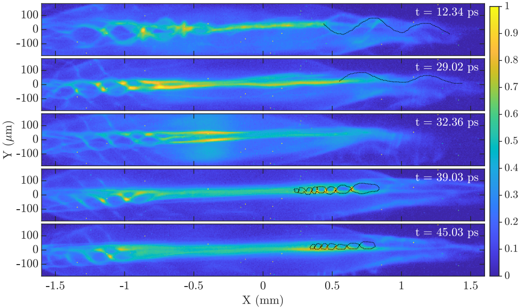
Wake time-evolution. Part 1.

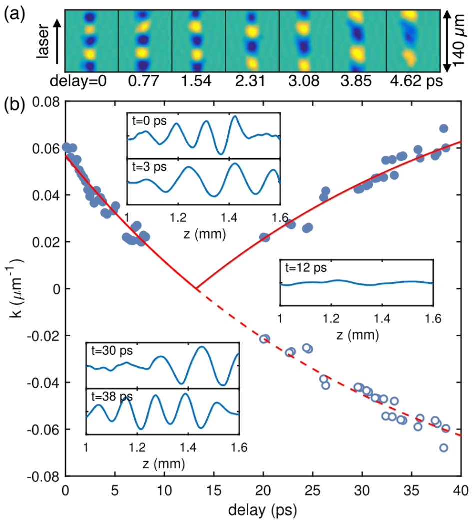


Wake time-evolution. Part 2.



Up-ramp: wake reversal is observed





C. Zhang et al., Phys. Rev. Lett. 119, 064801

Channel formation