Enabling R&D for Advanced M/L-WIR Laser Concepts

New proposal

Misha Polyanskiy and Dismas Choge

26th ATF Users' Meeting

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Title	Enabling R&D for Advanced M/L-WIR Laser Concepts
Status	New proposal
PI	Mikhail Polyanskiy
Team	M. Babzien, D. Choge, W. Li, I. Pogorelsky
Funding	DOE ARDAP grant Phase II (2022—2025; PI: M. Polyanskiy) ATF laser R&D funding
Funding Status	Received

Brookhaven National Laboratory

Mission

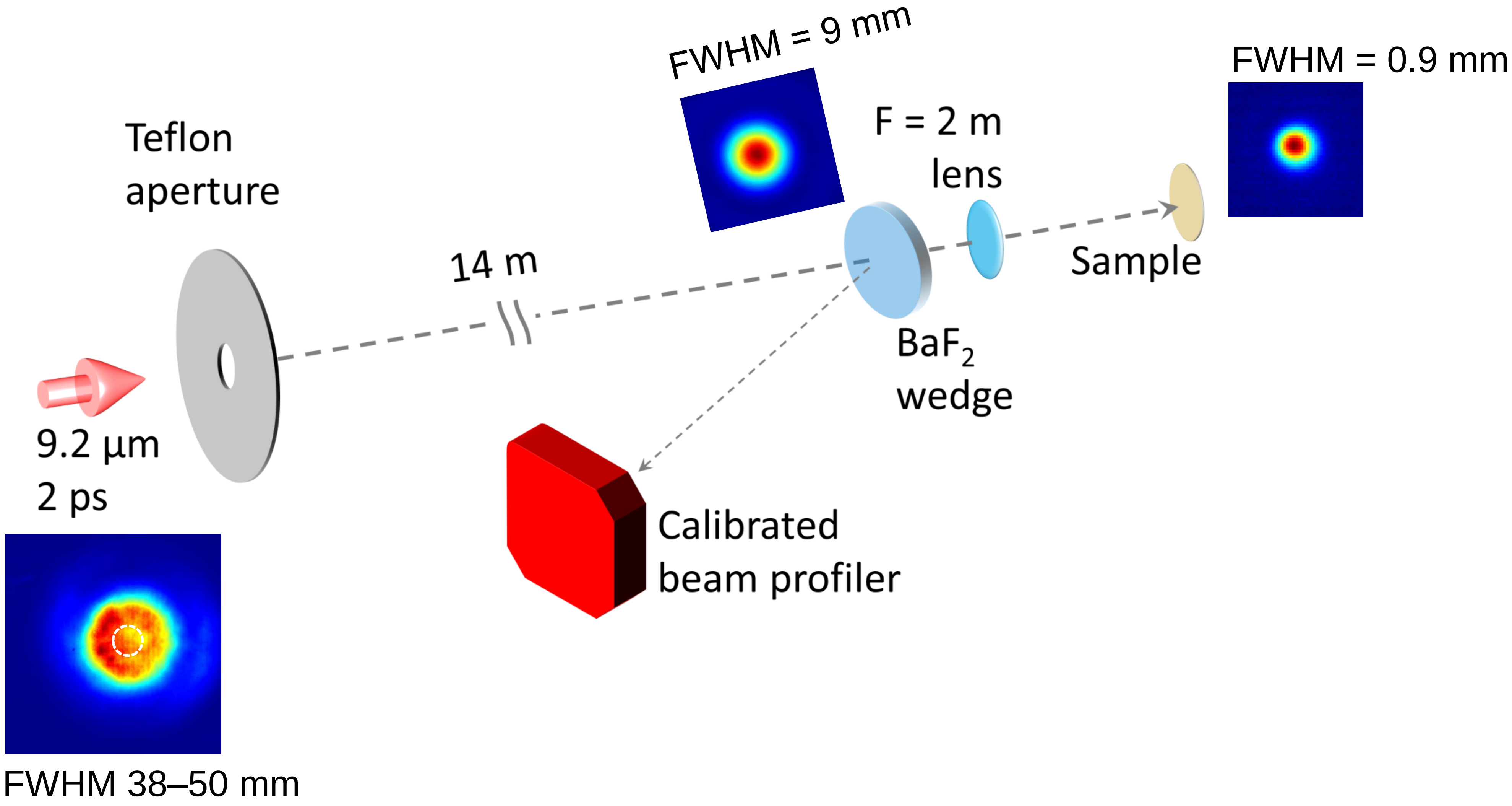
1) Systematically study laser-damage characteristics of infrared materials and laser optics under the action of intense LWIR laser irradiation

2) Deploy a full-scale working prototype of a post-compressor for a 2 ps to 500 fs compression

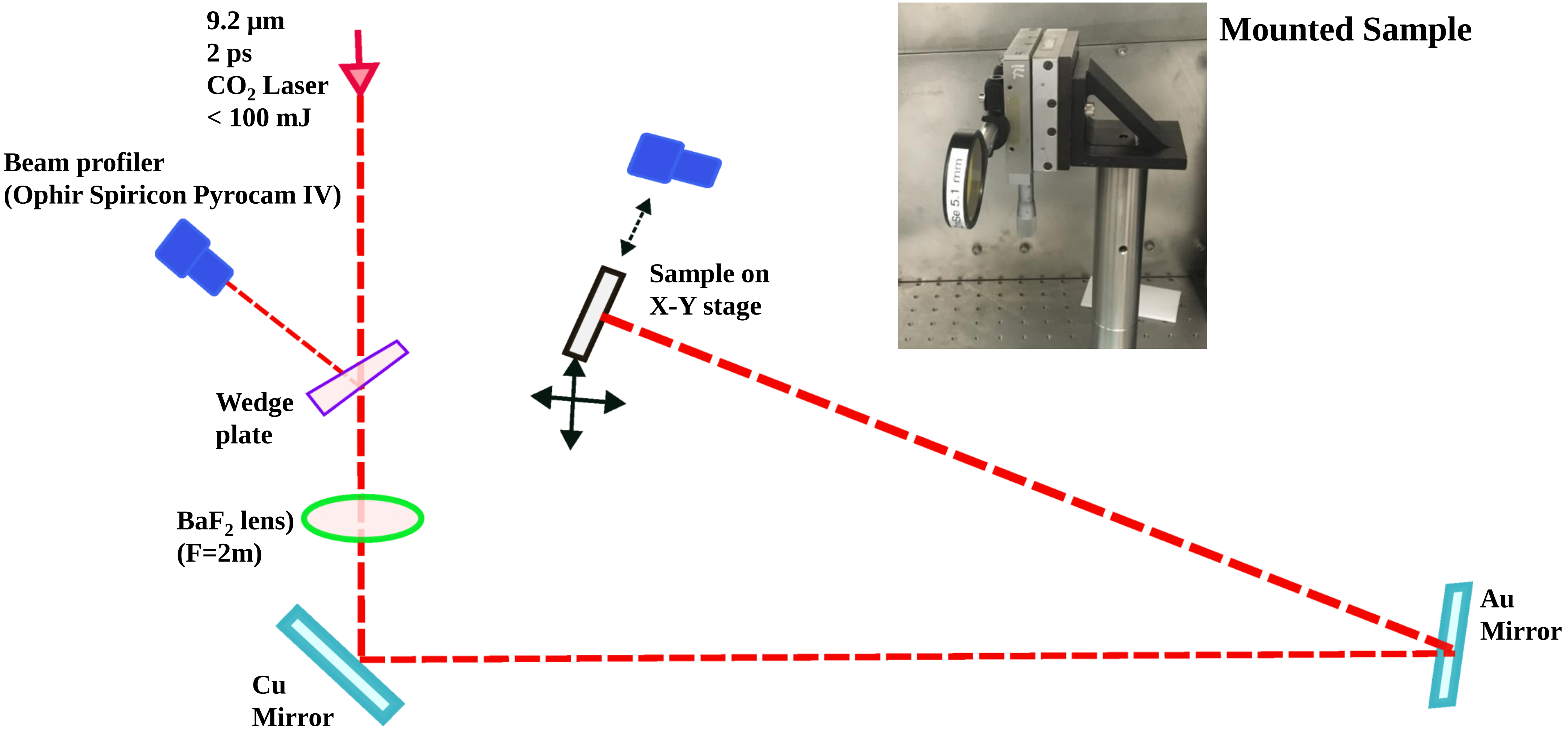
3) Initiate a pump/probe study of free carrier dynamics in semiconductor materials relevant for M/L-WIR lasers

4) Provide a framework for “small” research tasks needed for the development of M/L-WIR lasers

Laser-induced damage characterization



Single-shot laser Damage Experiment



Critical measurements

- Laser beam spot size w_0 $(1/e^2)$ criterion
- Pulse energy, E_0 -shot-shot variations originating from regen amplifier
- Damaged Area, S (measured offline with e.g optical microscope)

$$F_0 = \frac{2E_0}{\pi w_0^2}$$ Peak Fluence (J/cm^2)

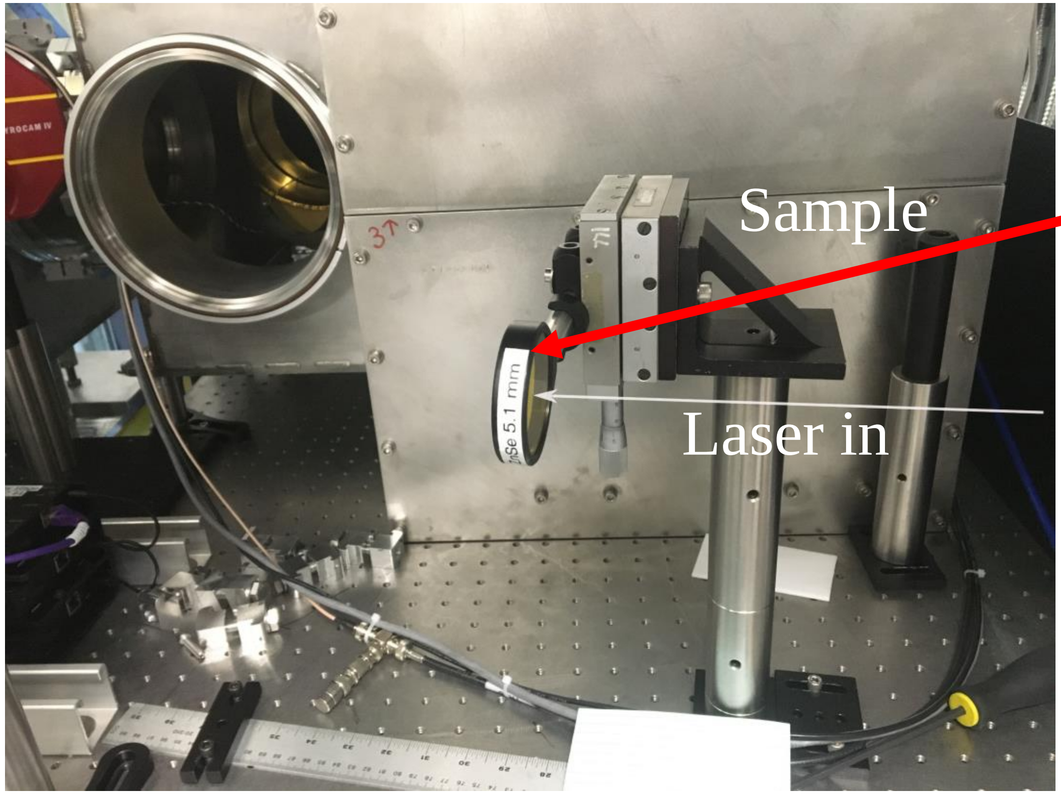
$$A = \frac{\pi w_0^2}{2} \ln\left(\frac{E_0}{E_{th}}\right)$$ Damaged Area (μm^2)

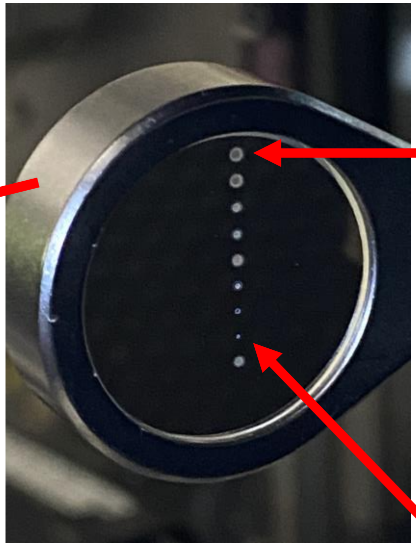
- Plot $A\ vs\ \ln(E_0)$ to obtain effective spot radius and threshold fluence

$$F_{th} = \frac{2E_{th}}{\pi w_0^2}$$

Sergey A. Lizunov et al., *Applied Physics A* (2022) 128:602

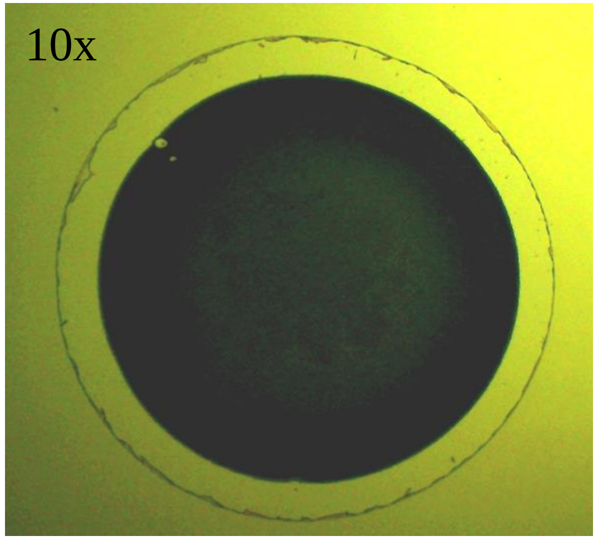
Single-shot approach





Digital image of Al mirror

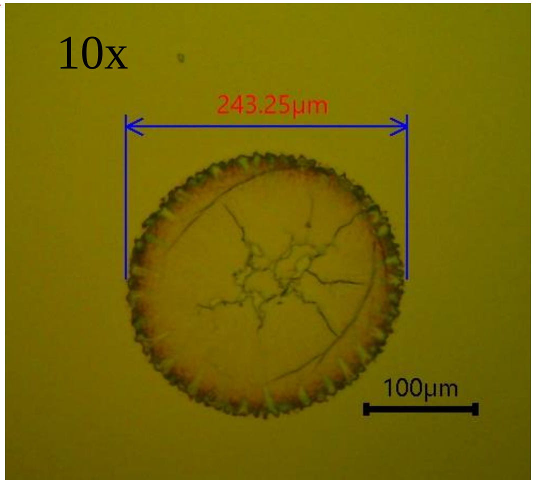
Al mirror



Optical Microscope image of damaged spot for high energy shot

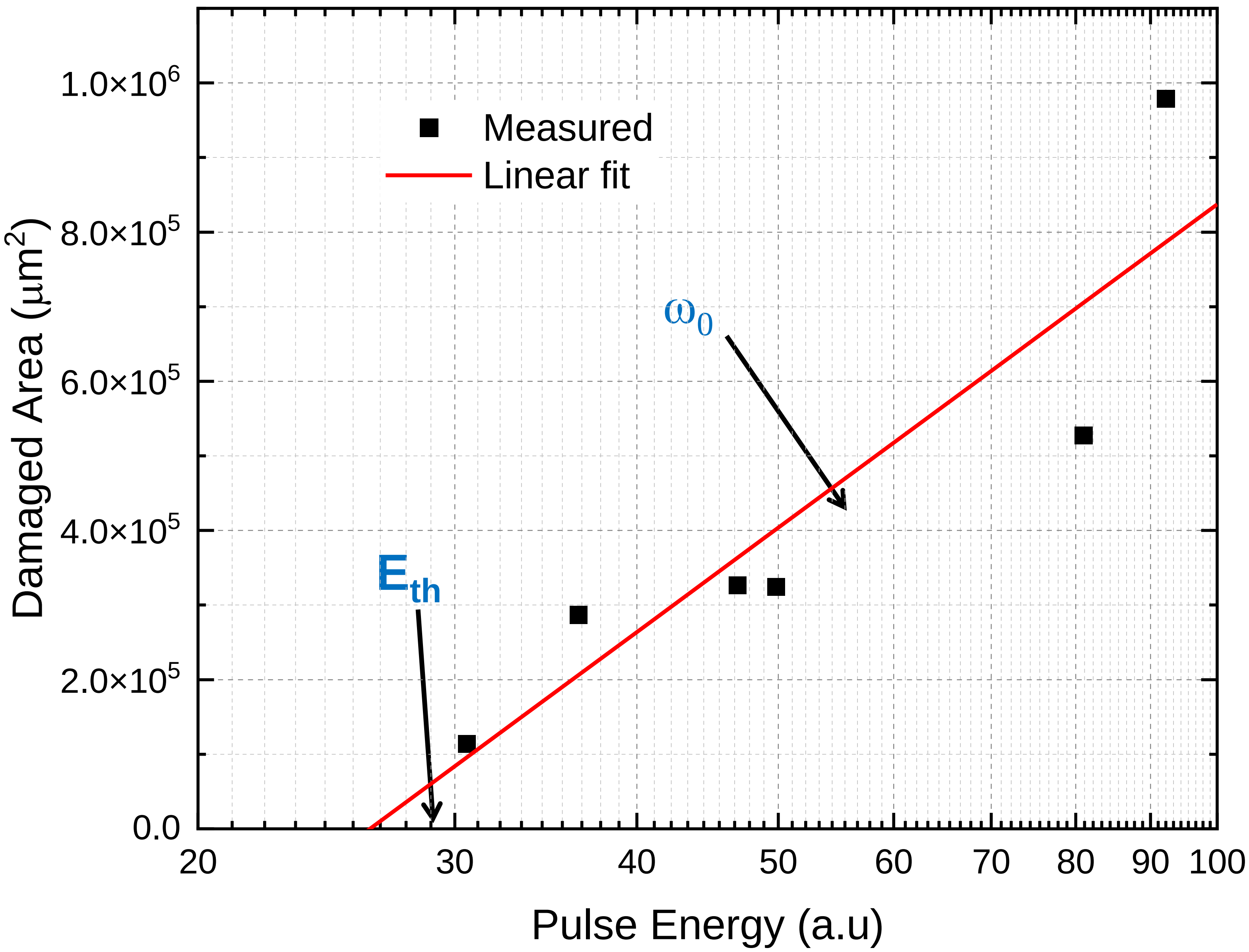
- The sample translated to a new position after every shot

Optical microscope image of damaged spot for low energy shot (but above damage threshold)



Liu's method

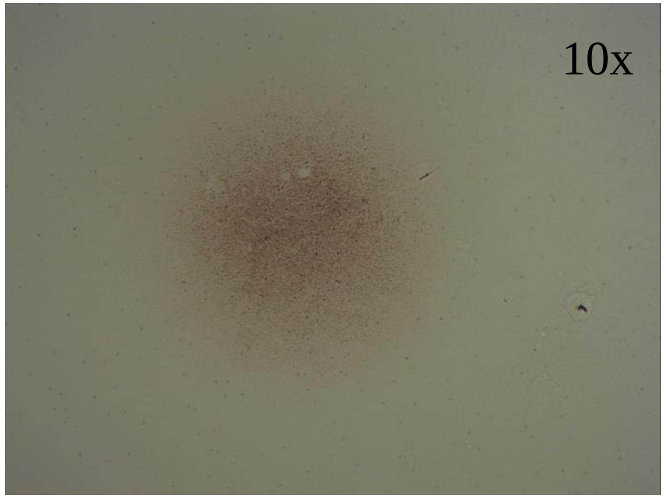
Sample:
Nacl window

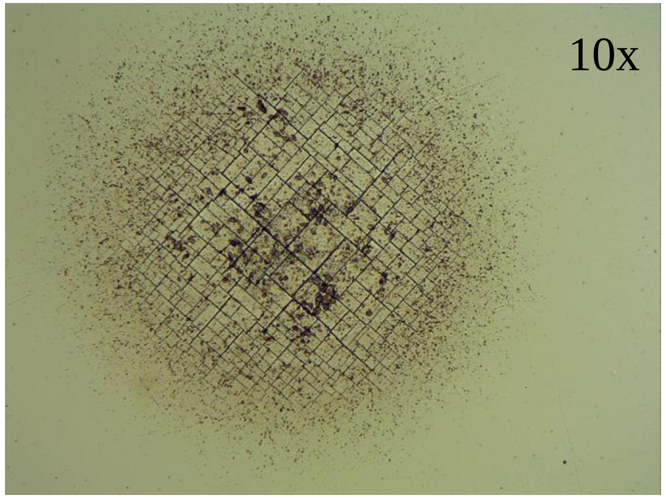


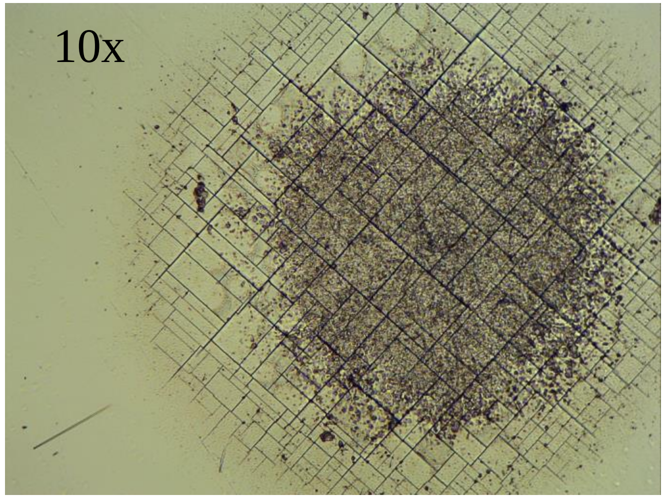
- E_{th}-Extrapolation to zero (A=0 μm^2; No damage)
- ω_0-Obtained from slope

Damage morphologies

NaCl window







Increasing pulse energy

Reported F_{th}: 0.5 J/cm^2 (*P. B. Corkum, IEEE J. Quantum Electron, 1985*)

Next-generation CO_2 laser: Post-compression

$n = n_0 + n_2 I(t)$

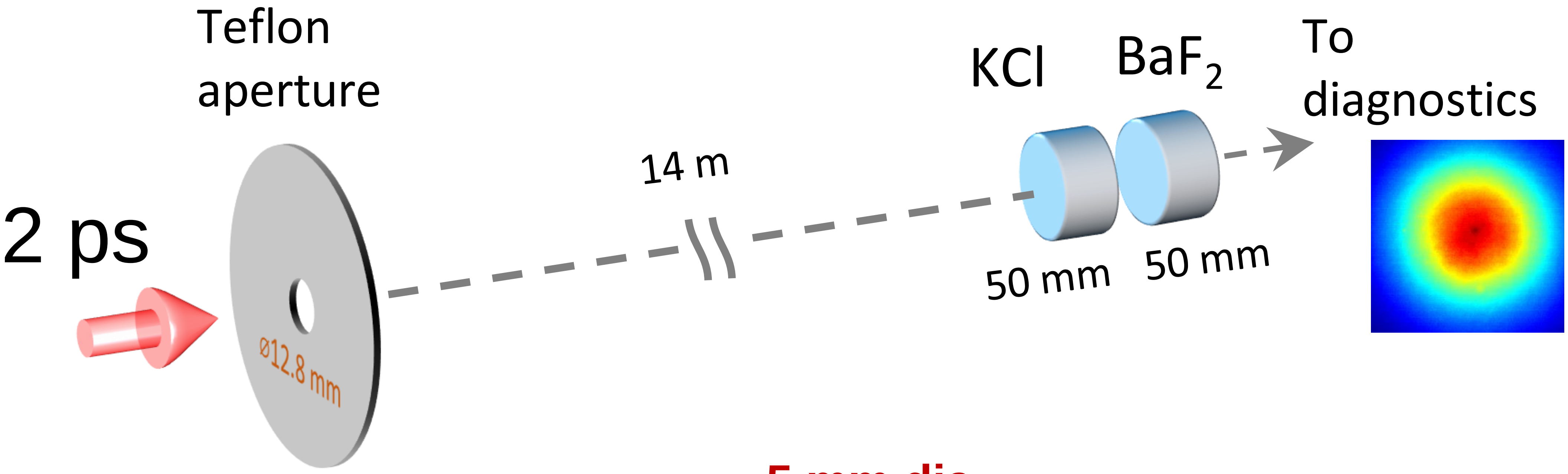
Self-phase modulation

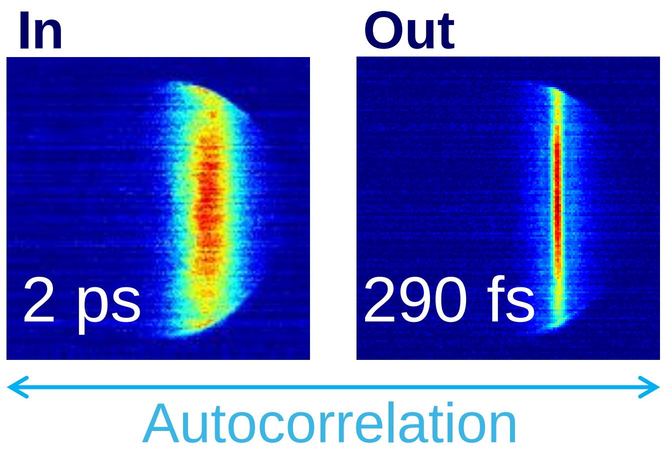
$n = n(\omega)$

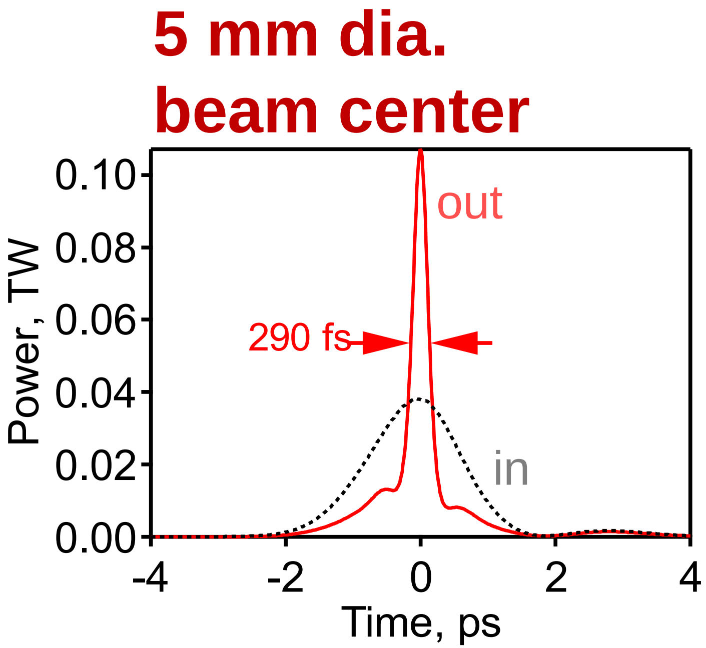
Linear dispersion

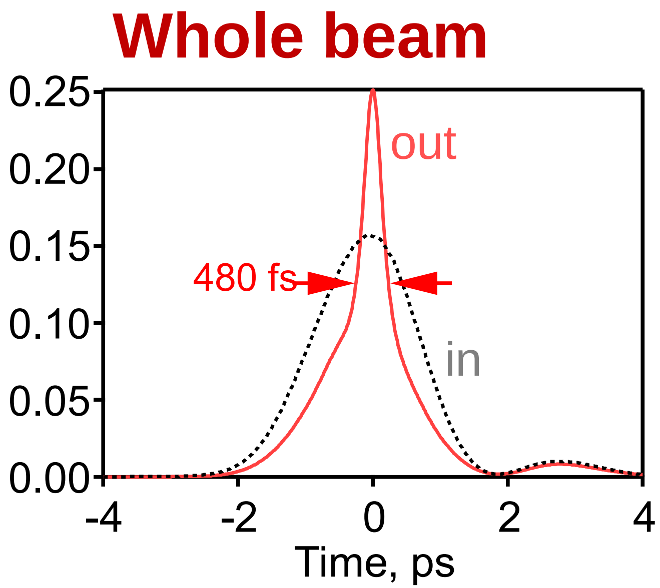
Proof of principle

- Polyanskiy et al. *Opt. Express* **29**, 31714 (2021)



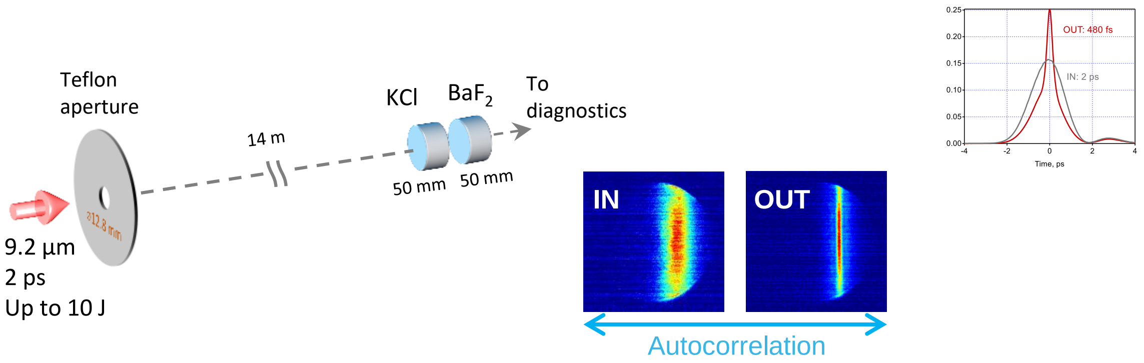




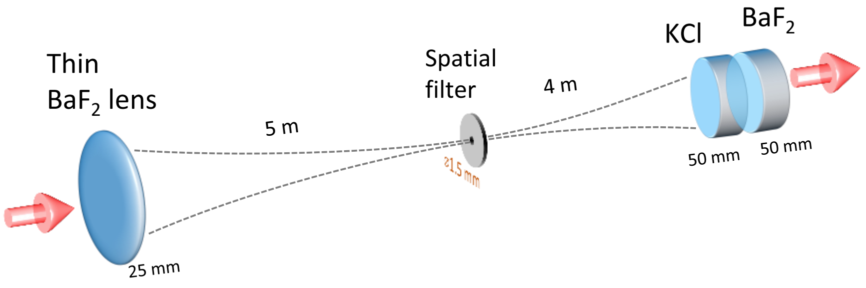


Post-compressor effort roadmap (v. 2023)

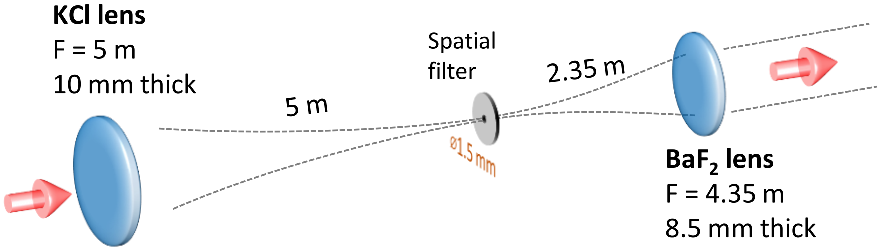
Demonstrated post-compression
Opt. Express **29**, 31714 (2021)

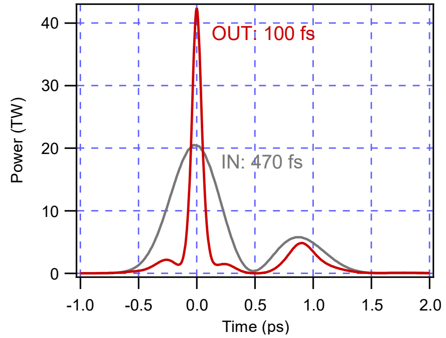


Next demonstration “3 TW”
2023 to-do



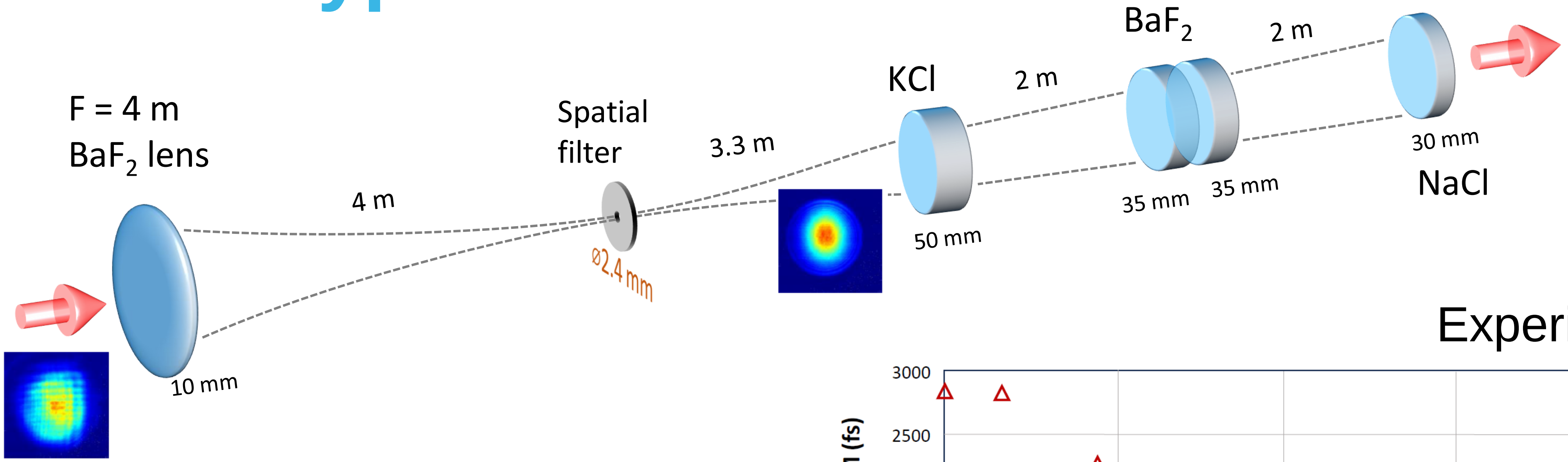
Ultimate design
Proceedings of AAC ‘22
ARDAP Phase I product



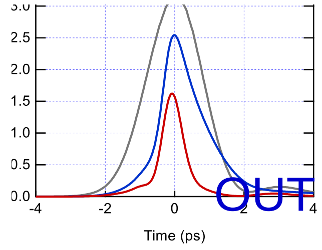


1st Prototype

- Pogorelsky et al. – *Front. Phys. (accepted)*



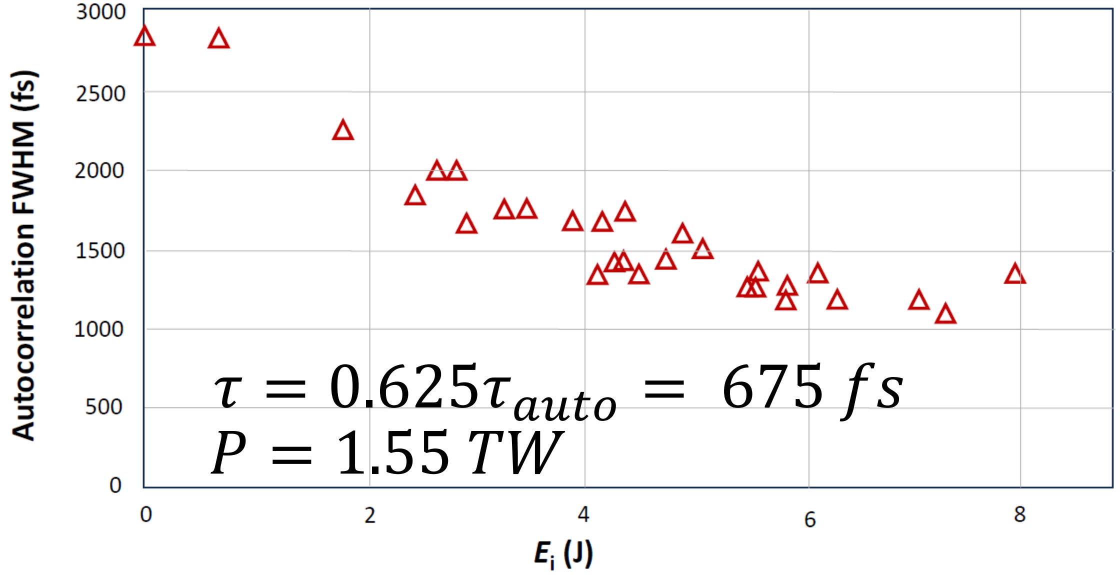
Experiment



Model

IN

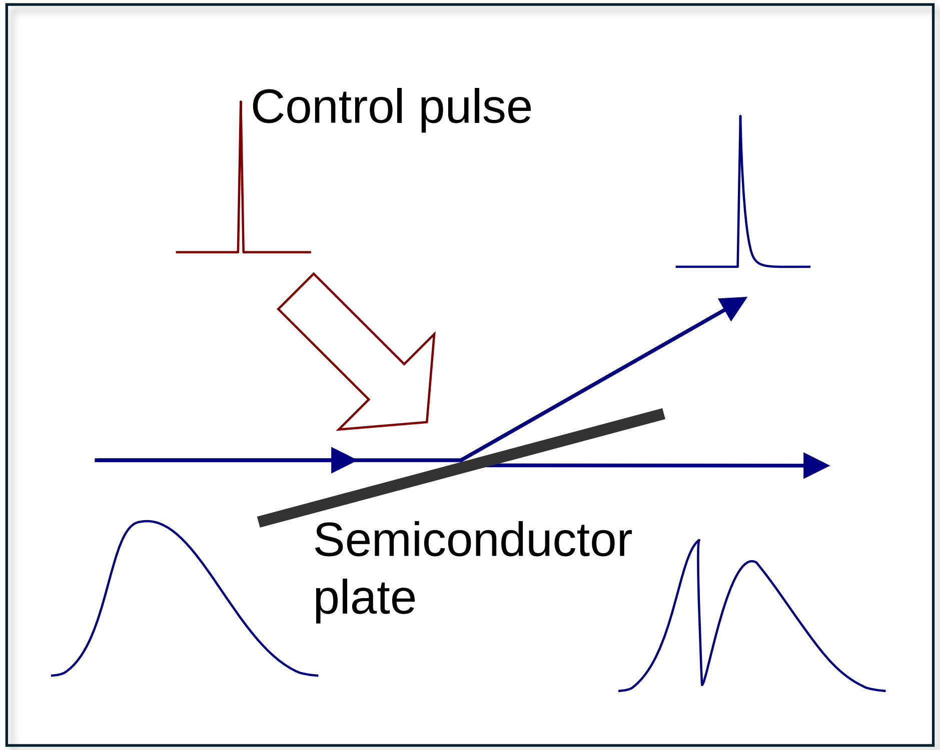
Beam
center
700 fs



measured within a central portion of the beam containing 30% of the total energy

Most powerful long-wave infrared sub-picosecond pulse ever obtained

Semiconductor switch



A fast scalable switching technique for high-power CO_2 laser radiation

A. J. Alcock, P. B. Corkum, and D. J. James*

Division of Physics, National Research Council of Canada, Ottawa, Canada
(Received 6 October 1975)

Fast switching of high-power 10-μm radiation by reflection from optically induced carriers in polycrystalline germanium has been demonstrated. Initial studies carried out with a single-mode TEA CO_2 laser and a 2-nsec ruby laser pulse have resulted in the generation of synchronized ~2-nsec pulses of 0.69- and 10-μm wavelength. Potential applications of this technique include the selection of single high-energy pulses from the mode-locked output of large-aperture CO_2 lasers.

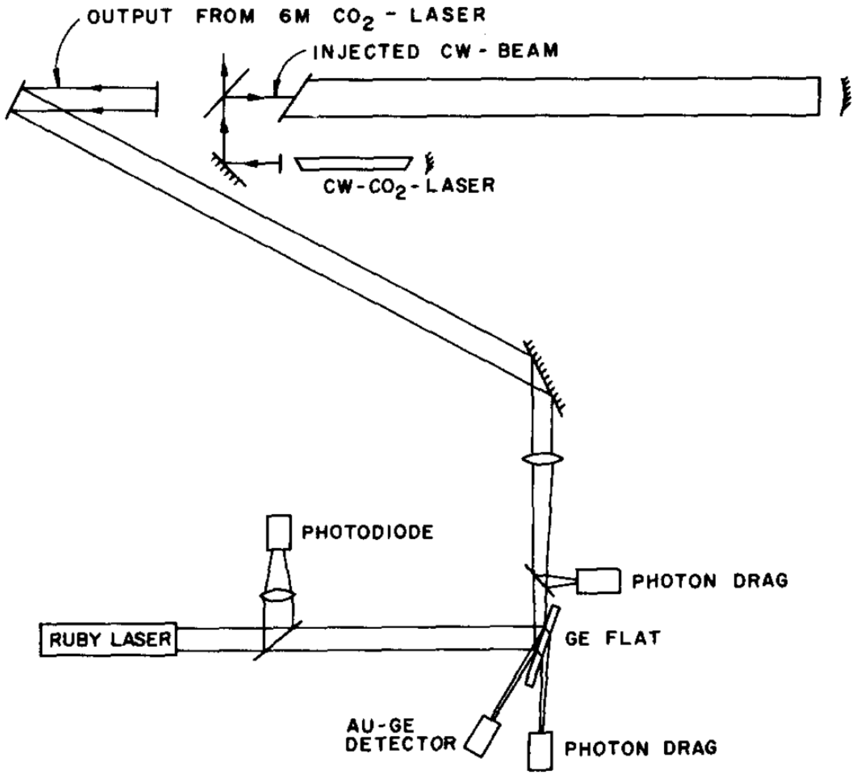
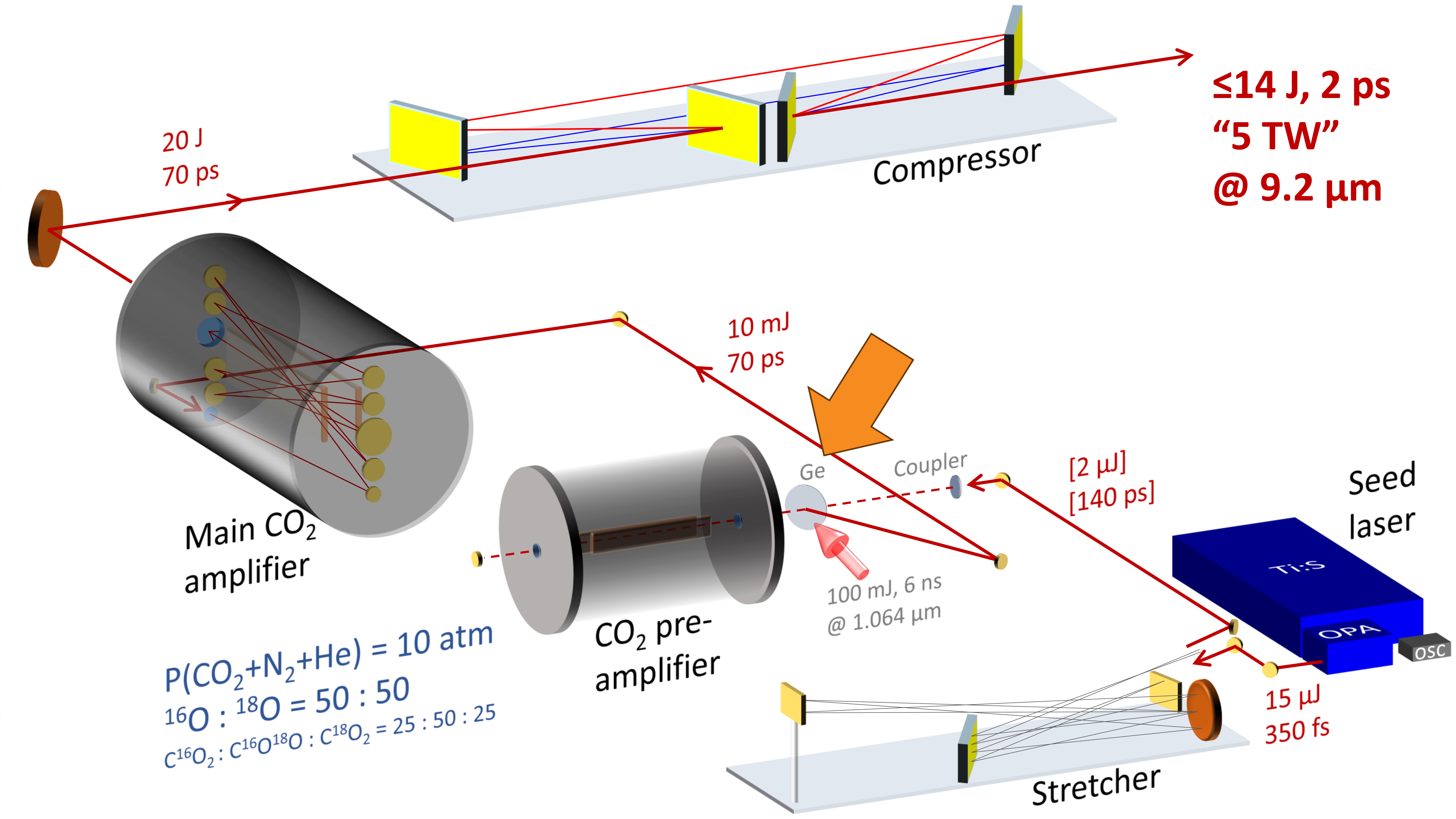


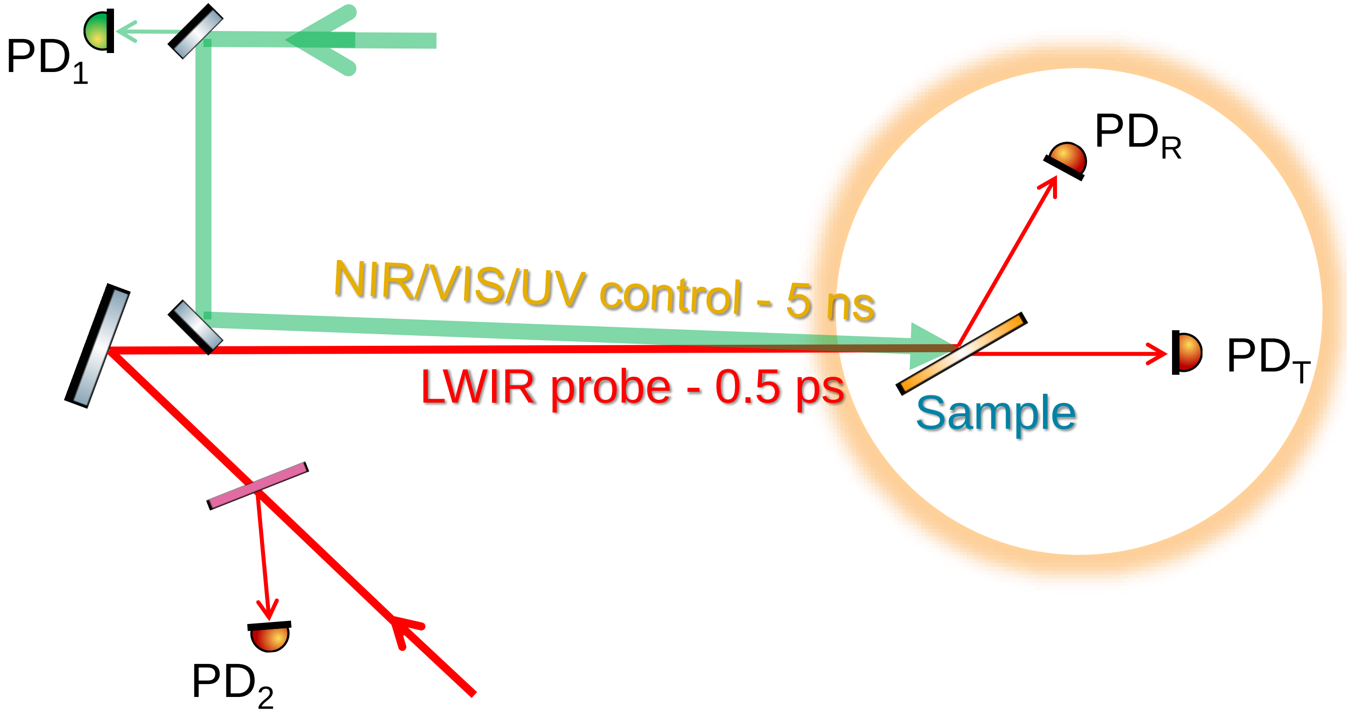
FIG. 1. Experimental configuration used to investigate semiconductor switching of 10-μm radiation.



≤14 J, 2 ps
"5 TW"
@ 9.2 µm
20 J
70 ps
Compressor
10 mJ
70 ps
Coupler
Ge
[2 µJ]
[140 ps]
Seed
laser
Ti:S
OPA
OSC
Main CO_2
amplifier
CO_2 pre-
amplifier
100 mJ, 6 ns
@ 1.064 µm
15 µJ
350 fs
Stretcher
$P(CO_2+N_2+He) = 10$ atm
$^{16}O : ^{18}O = 50 : 50$
$C^{16}O_2 : C^{16}O^{18}O : C^{18}O_2 = 25 : 50 : 25$

Pump-probe experiments

(Materials for laser-controlled LWIR optical switching elements)



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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*	-
Bunch Charge	nC	0.1-2.0	*Bunch length & emittance vary with charge*	-
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*	-
Transverse size at IP (s)	mm	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*	-
Normalized Emittance	mm	1 (at 0.3 nC)	*Variable with bunch charge*	-
Rep. Rate (Hz)	Hz	1.5	*3 Hz also available if needed*	-
Trains mode	---	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*	-

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	mm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
	Peak Power	GW	~3		*~3*
	Pulse Mode	---	Single		*Single*
	Pulse Length	ps	2		*2*
	Pulse Energy	mJ	6		*6*
	M^2	---	~1.5		*~1.5*
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	*1.5*
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	*Linear*
CO_2 CPA Beam	Wavelength	mm	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	5	*~5 TW operation will become available shortly into this year's experimental run period. 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 within the next year*	*~5*
	M^2	---	~2		*~2*
	Repetition Rate	Hz	0.05		*0.05*
	Polarization		Linear	*Adjustable linear polarization along with circular polarization can be provided upon request*	*Linear*

Other Experimental Laser Requirements

Ti:Sapphire Laser System	Units	Stage I Values	Stage II Values	Comments	Requested Values
Central Wavelength	nm	800	800	*Stage I parameters are presently available and setup to deliver Stage II parameters should be complete during FY22*	*TBD*
FWHM Bandwidth	nm	20	13		*TBD*
Compressed FWHM Pulse Width	fs	<50	<75	*Transport of compressed pulses will initially include a very limited number of experimental interaction points. Please consult with the ATF Team if you need this capability.*	*TBD*
Chirped FWHM Pulse Width	ps	≥50	≥50		*TBD*
Chirped Energy	mJ	10	200		*TBD*
Compressed Energy	mJ	7	~20	*20 mJ is presently operational with work underway this year to achieve our 100 mJ goal.*	*TBD*
Energy to Experiments	mJ	>4.9	>80		*TBD*
Power to Experiments	GW	>98	>1067		*TBD*

Nd:YAG Laser System	Units	Typical Values	Comments	Requested Values
Wavelength	nm	1064	*Single pulse*	*TBD*
Energy	mJ	5		*TBD*
Pulse Width	ps	14		*TBD*
Wavelength	nm	532	*Frequency doubled*	*TBD*
Energy	mJ	0.5		*TBD*
Pulse Width	ps	10		*TBD*

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:
  CW CO2 & ns Nd:YAG @ 355, 512 & 1024 nm

Hazards & Special Installation Requirements

- Large installation (chamber, insertion device, etc.):
- Cryogens:
- Introducing new magnetic elements:
- Introducing new materials into the beam path:
- Any other foreseeable beam line modifications:

Brookhaven National Laboratory

CY2024 Time Request

Capability	Setup Hours	Running Hours
Electron Beam		
NIR Laser		
LWIR Laser	40	2 x 40 = 80

Total Time Request for the 3-year Experiment (including CY2024-26)

Capability	Setup Hours	Running Hours
Electron Beam		
NIR Laser		
LWIR Laser	40 x 3 = 120	80 x 3 = 240