Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

25th Annual

Accelerator Test Facility (ATF) Users' Meeting

Progress on Laser Upgrades

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Accelerator Facilities Division

2023-02-28

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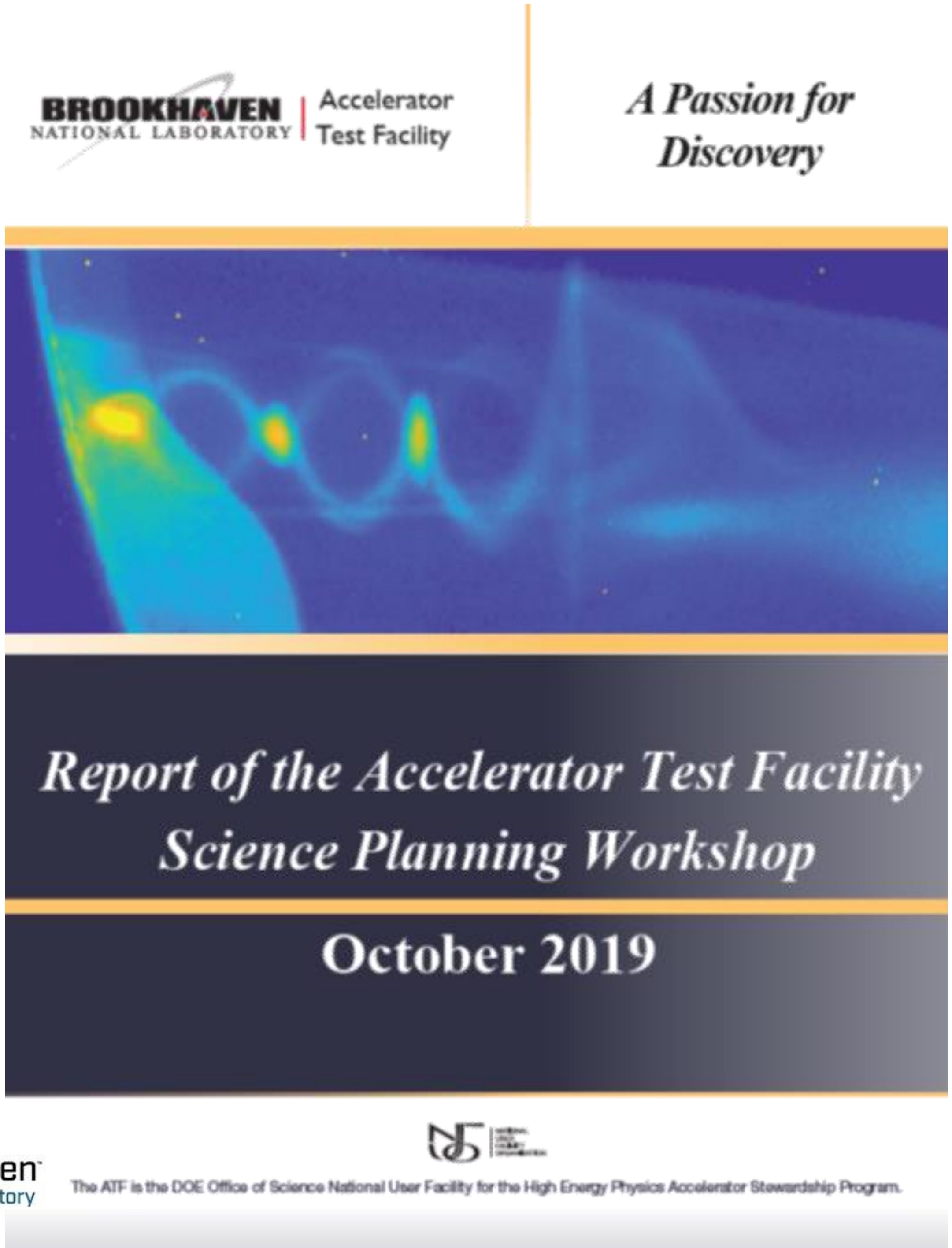
Outline

- LWIR status and present capabilities
- CO_2 system upgrades
- Ti:Sapphire system performance
- NIR upgrades
- Vacuum laser transport overview
- Laser scientific productivity

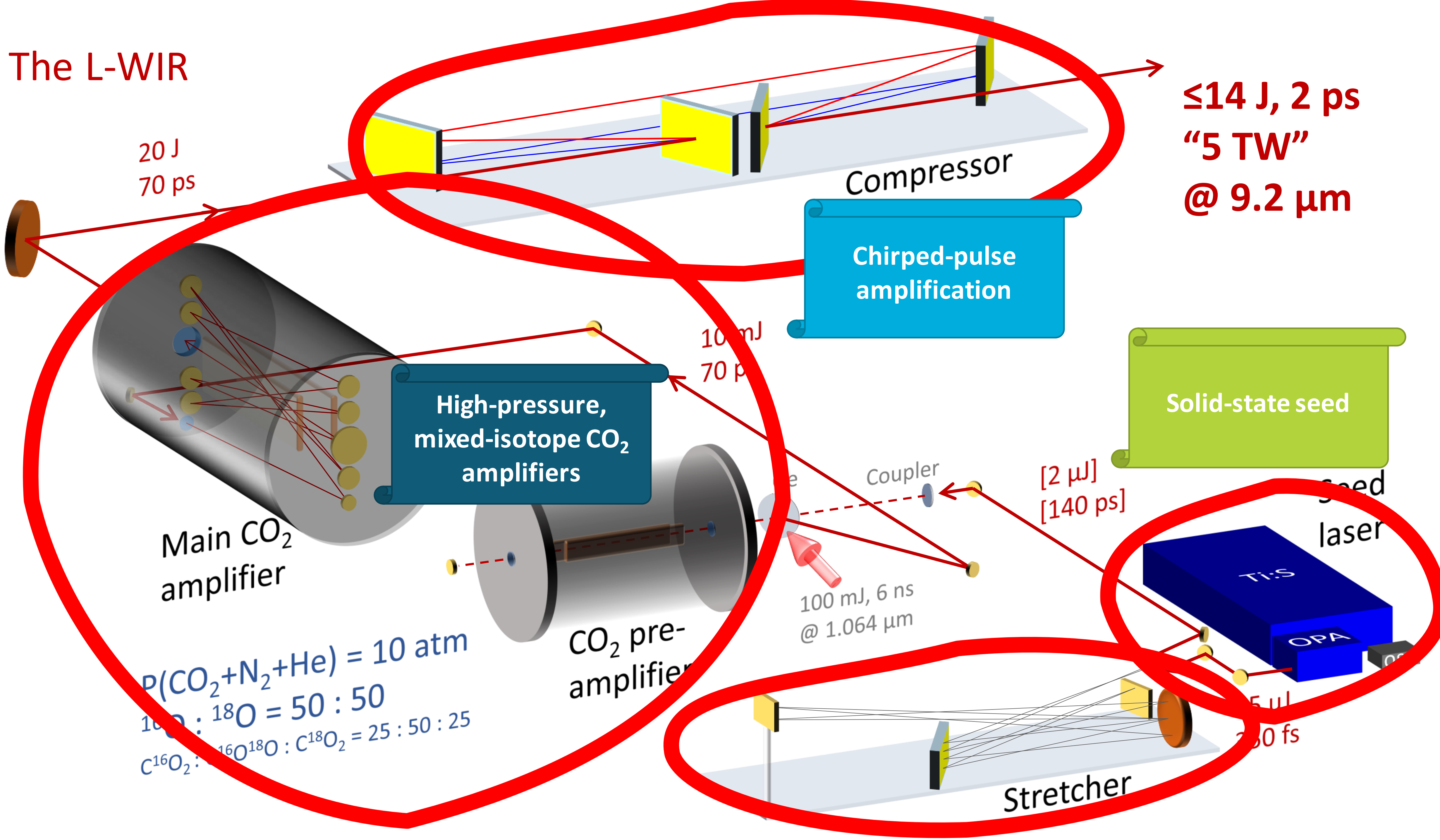


Experiment	LWIR Laser
PRD A.1: Ion Acceleration	10 TW: ~ 10 MeV ions 25 TW: ~ 100 MeV ions Circ. Pol. For advanced methods (RPA, etc)
PRD A.2 e- Acceleration	10 TW, 1ps: Blowout regime 20 TW, 0.5 ps: Bubble regime Integrated intense NIR: two color injection
PRD A.3 Weibel	1 TW, ~3 ps, circ. Pol.
PRD C.1 e- injection into LWFA in blowout	20 TW, 0.5 ps: Bubble regime
PRD C.1 e+ beam generation	0.5-5 TW, ~2 ps, spot size w_0~50-100 µm
PRD C.2 Dielectric Laser Acceleration	20 mJ, 2 ps, 10 Hz rep rate
PRD C.2 Direct Laser Acceleration	20 TW, 0.5 ps: Bubble regime
PRD C.3 Inverse Compton Scattering	$a_0 = 1.5$, Circular polarization: nonlinear ICS $a_0 = 2$, linear polarization: harmonic radiation $a_0 = 10$, any polarization: higher order multiphoton Thomson scattering

L-WIR Highlights 2022—23

- Getting ready to deliver 5 TW to IP in 2023
  - Vacuum compressor and photon delivery
  - Polarization rotator
- Reliability improvements
  - Implemented shot counter
  - Increased # of shots between spark-gap replacement by enforcing 1 min delay between shots
- Clear roadmap from 2ps/5TW to 0.5ps/15TW and 100fs/25TW

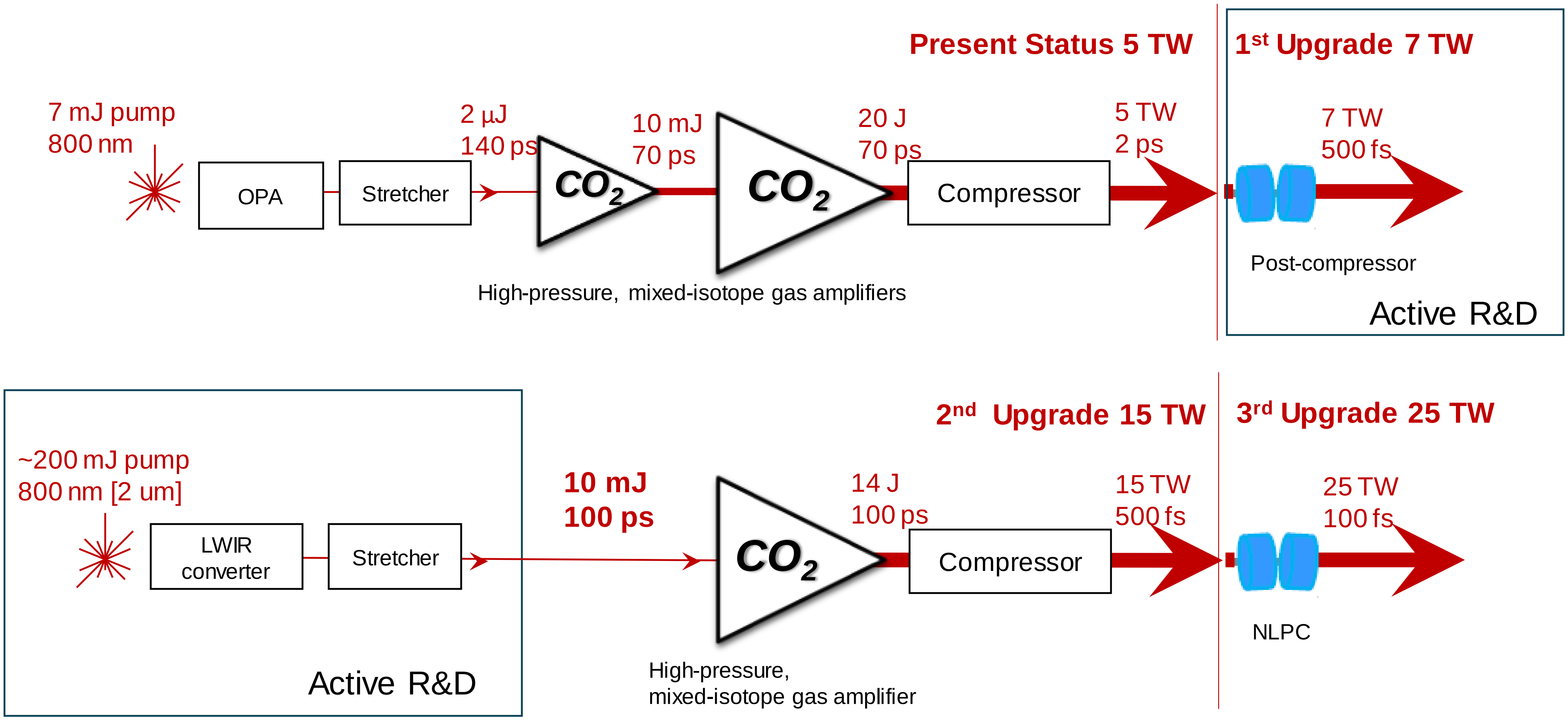
The L-WIR



20 J
70 ps
Compressor
≤14 J, 2 ps
"5 TW"
@ 9.2 µm
Chirped-pulse amplification
High-pressure, mixed-isotope CO2 amplifiers
Solid-state seed
Coupler
[2 µJ]
[140 ps]
laser
Ti:S
OPA
Main CO2 amplifier
CO2 pre-
100 mJ, 6 ns
@ 1.064 µm
P(CO2+N2+He) = 10 atm
18O = 50 : 50
C18O2 = 25 : 50 : 25
Stretcher

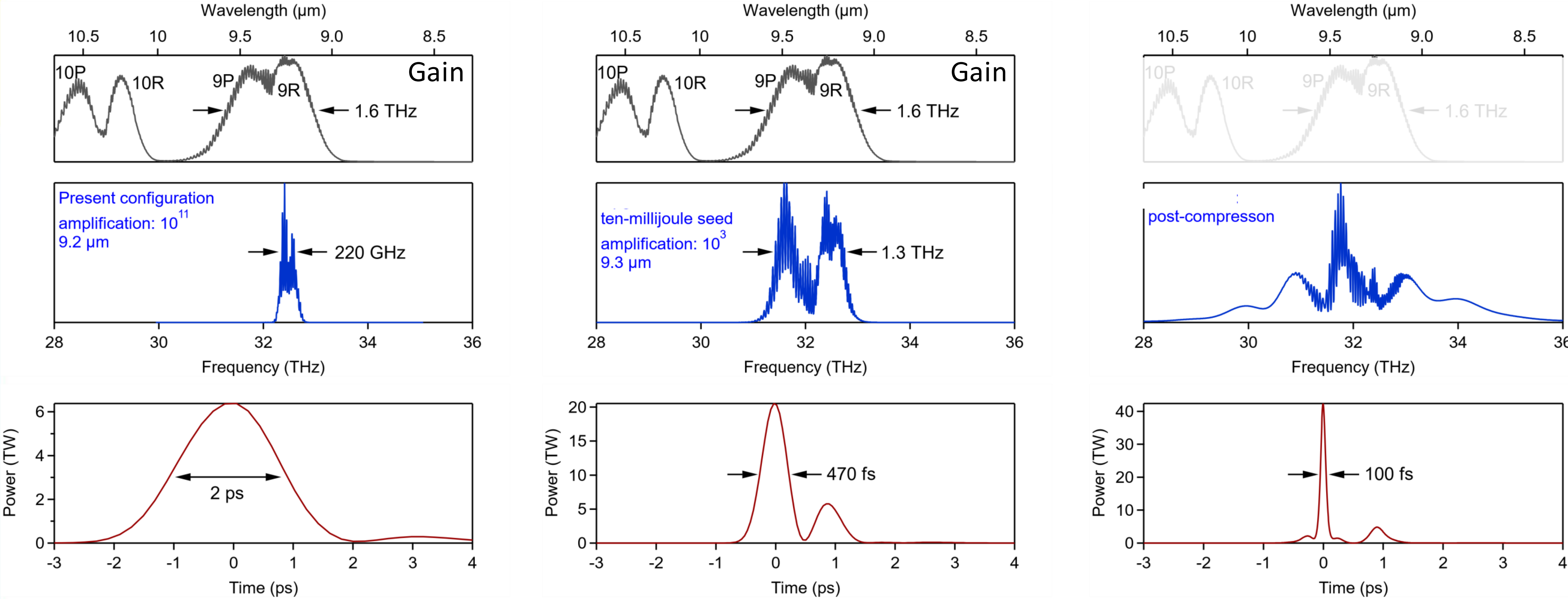
L-WIR Spec Sheet v.2023

	High-power regime (two amplifiers)	High-repetition regime (pre-amplifier only)
Central wavelength	9.22 µm	9.22 µm
Peak power	**5 TW**	1 GW
Pulse energy	12 J	2.5 mJ
Pulse duration	2 ps (FWHM)	2 ps (FWHM)
Repetition rate	1 shot/min	**1.5 or 3 Hz** (e-beam rep-rate)


Present Status 5 TW
1st Upgrade 7 TW
7 mJ pump
800 nm
OPA
Stretcher
2 µJ
140 ps
CO2
10 mJ
70 ps
CO2
20 J
70 ps
Compressor
5 TW
2 ps
7 TW
500 fs
Post-compressor
High-pressure, mixed-isotope gas amplifiers
Active R&D
2nd Upgrade 15 TW
3rd Upgrade 25 TW
~200 mJ pump
800 nm [2 um]
LWIR
converter
Stretcher
10 mJ
100 ps
CO2
14 J
100 ps
Compressor
15 TW
500 fs
25 TW
100 fs
NLPC
High-pressure,
mixed-isotope gas amplifier
Active R&D

L-WIR Upgrade Roadmap

Polyanskiy et al., AAC '22

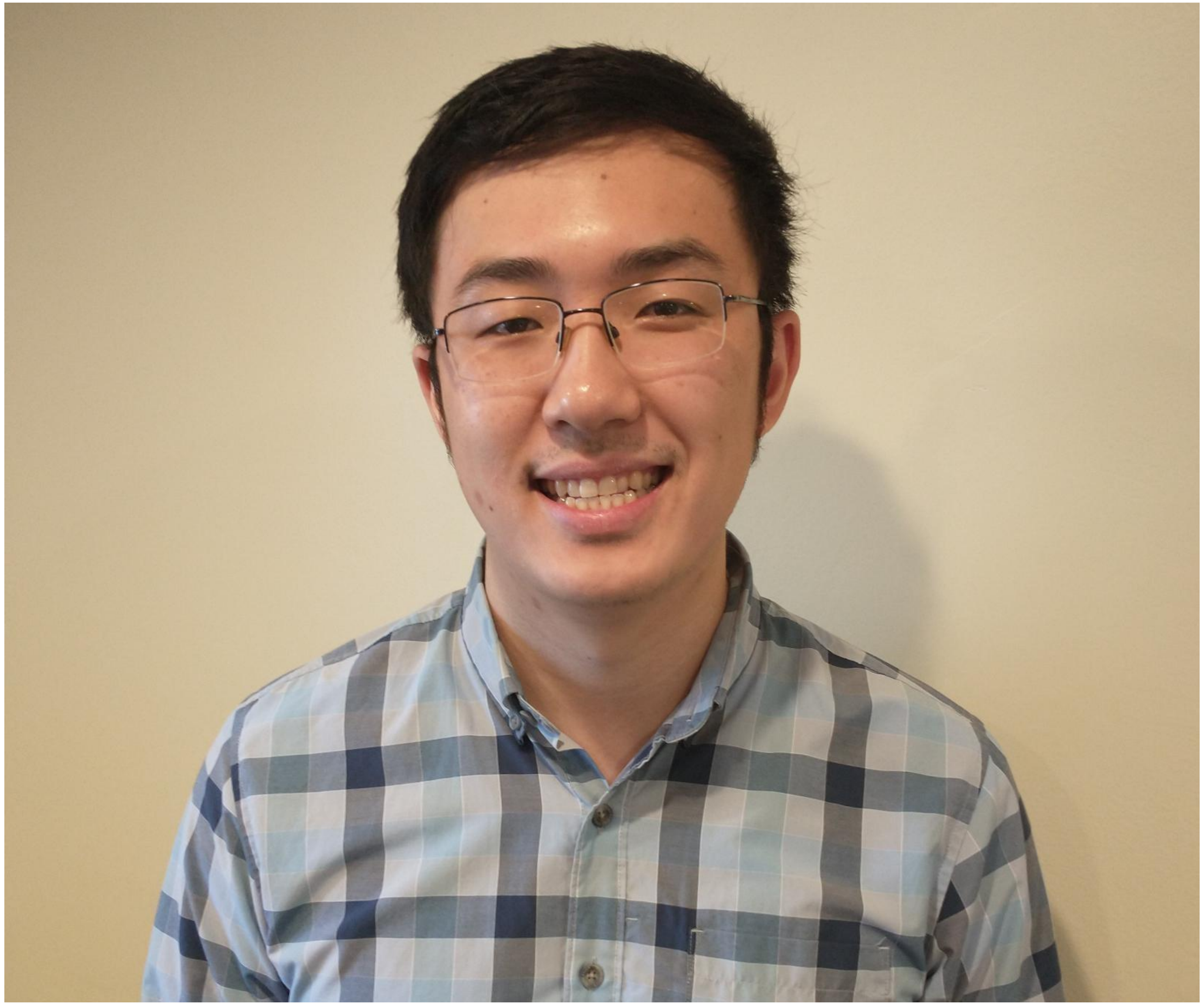


2023: **5 TW**
isotopes, CPA, μJ seed
vacuum beam delivery

Upgrade #2: **15 TW**
10 mJ seed

Upgrade #3: **25 TW**
post-compression

Welcome to ATF Laser Team! --- William Li



Experience

Postdoctoral Research Associate
Brookhaven National Laboratory · Full-time
Aug 2022 - Present · 7 mos

Graduate Research Assistant
Cornell University
Aug 2016 - Aug 2022 · 6 yrs 1 mo

Chess Coach
Chess4Life
Dec 2013 - Jan 2016 · 2 yrs 2 mos

Education

Cornell University
Doctor of Philosophy - PhD, Physics
Aug 2016 - Aug 2022

University of Washington
Bachelor of Science (B.S.), Computer Science
Sep 2012 - Jun 2016
Grade: 3.9

NIR Performance Transitioning Phase I → II

Parameter	Units	Stage I Values	Current Values	Stage II Values
Central Wavelength	nm	800	811	800
FWHM Bandwidth	nm	20	20	13
Compressed FWHM Pulsewidth	fs	<55	<70	<75
Chirped FWHM Pulsewidth	ps	>50	>50	>50
Chirped Energy	mJ	>30	50	200
Compressed Energy	mJ	>14	32	100
Energy to Experiments	mJ	>10	>30	>80
Power to Experiments	GW	>250	>400	>1067

Ongoing NIR Work

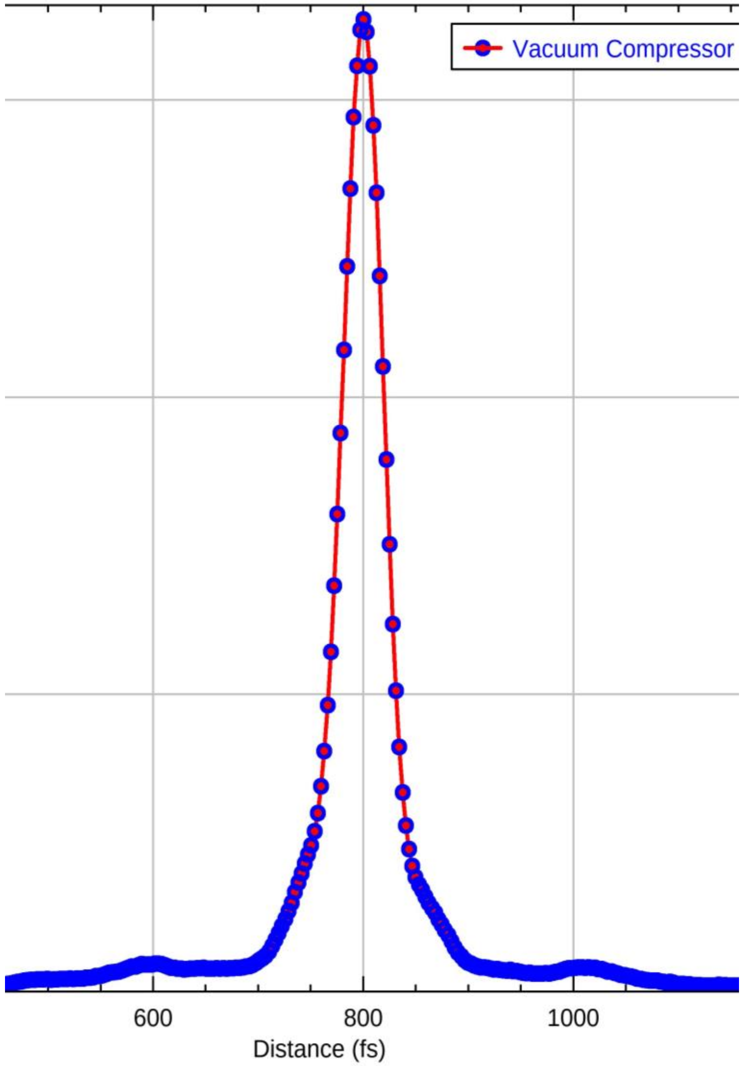
- Diagnose and eliminate ~15% amplitude pre-pulse in Ti:Sapphire discovered during last run period
- Enlarge front end vacuum aperture to enable delivery of full Phase II Ti:Sapphire energy to experiments (100 mJ) – (Spring 2023)
- Integrate previously utilized optical trombone and Nd:YAG amplifier with vacuum transport to re-establish delivery of 1064 nm to BL1 for Compton scattering experiments
- Continue to automate system startup/shutdown as experience is gained to enable autonomous user operation

Future NIR Upgrades

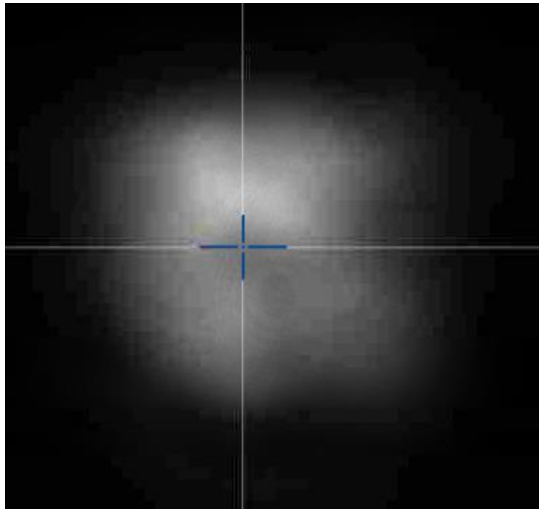
Improve Ti:Sapphire diagnostics to more efficiently use run time

- Make existing instruments accessible to users online/realtime, e.g. synchronization monitoring oscilloscope

- Add diagnostics for more complete characterization and possible normalization of shot-to-shot variations in spot size, position, energy, pulsewidth, and timing

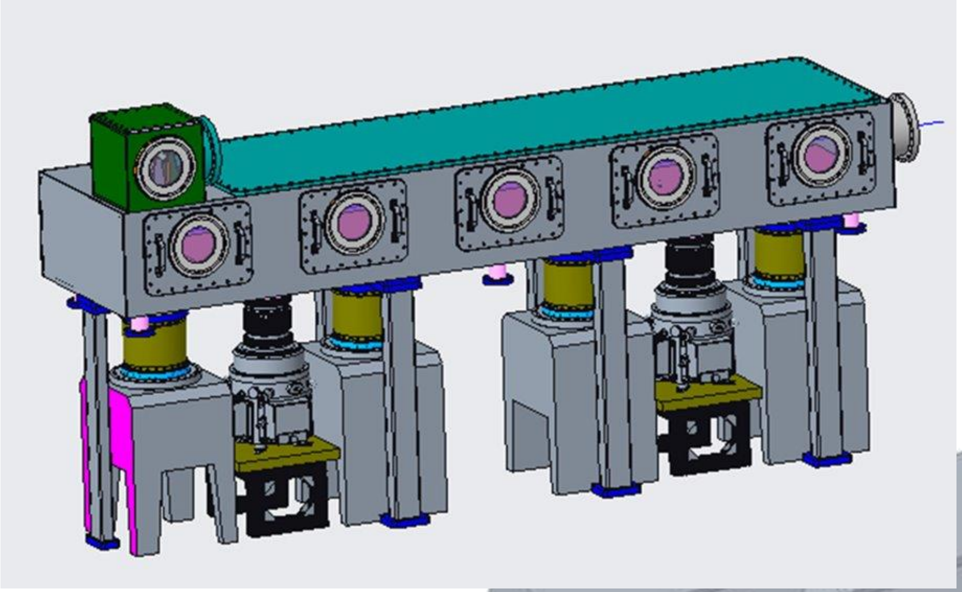


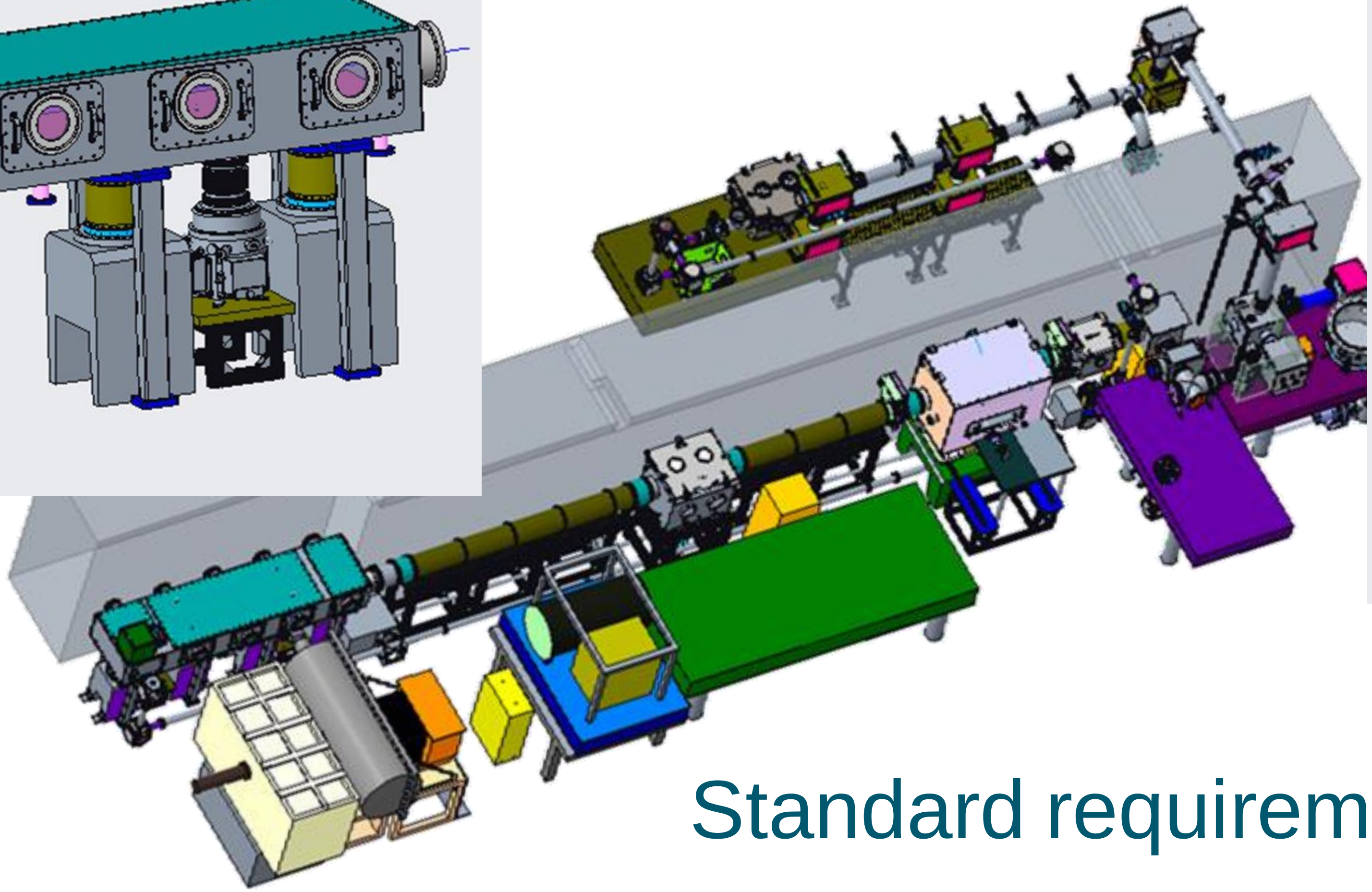
- Investigate reduction of beam profile distortion from amplifier non-uniform pumping to improve M^2/Strehl ratio

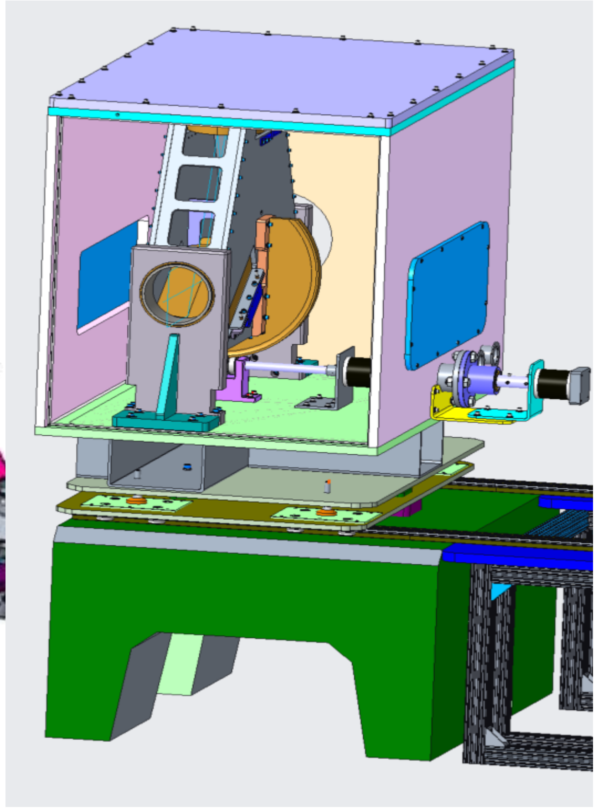


- Finish optical delay line for user control of CO_2 synchronization when RF engineer becomes available

LWIR Vacuum Transport



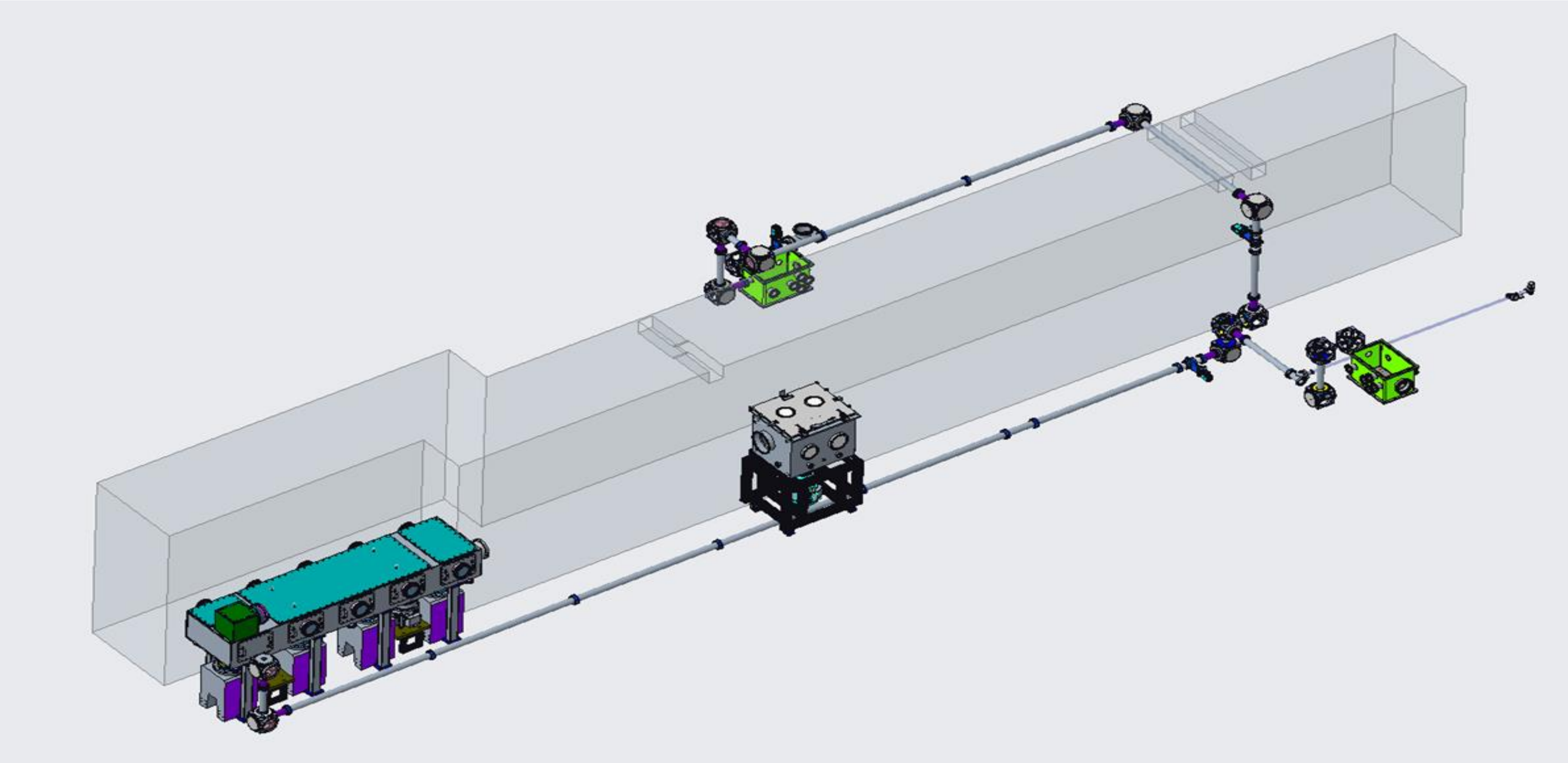




Standard requirement: **B < 1**

	Air (12 m)	NaCl (40 mm)	Air + NaCl
n2	3.0e-19 cm^2/W	3.0e-16 cm^2/W	
B-integral @ 5 TW	1.0	3.3	4.3

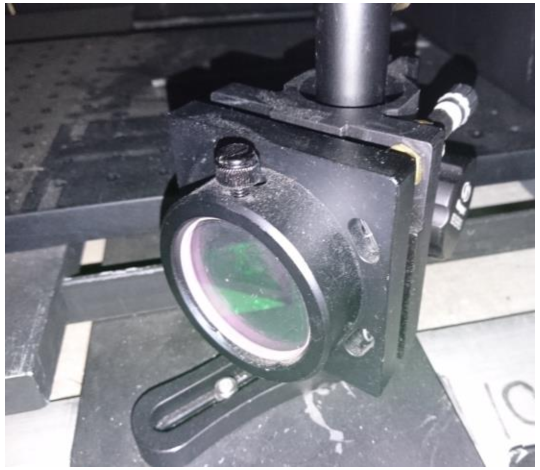
NIR vacuum transport



NIR Vacuum Transport Upgrade

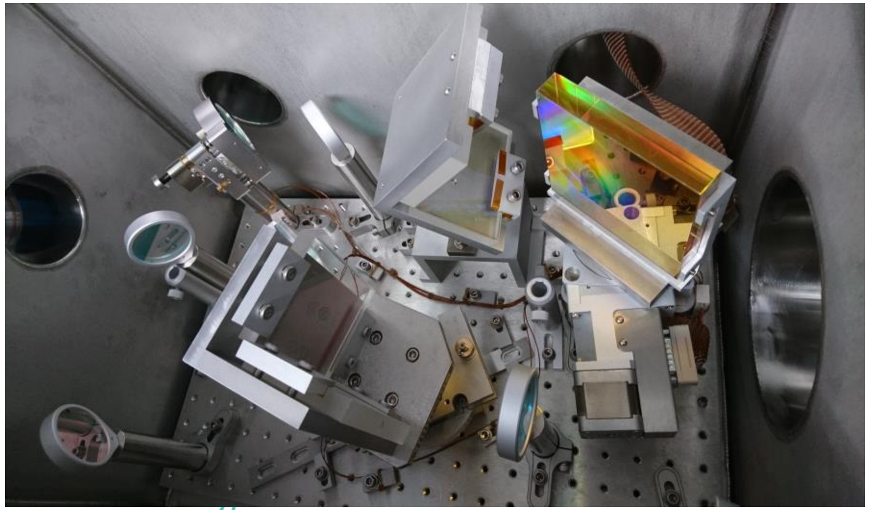
Motivated by need to deliver higher energy & power with greater stability and reliable long-term performance

- Vacuum envelope extended from front end through to IP’s
- Full remote actuation of mounts
- Diagnostic cameras at bends
- Dedicated chamber for in-vacuum compressor can be isolated from user chamber
- Compressor design is modular for use at other IP’s as needs arise
- First user runs validated stable day-to-day alignment
- Some pumpdown flexure observed and now being mitigated



Turning Mirrors

Grating Compressor



Active laser experiments and hours delivered at ATF in FY2022

Expt	Title	LWIR	NIR	e-
AE087	Hard X-ray ICS			
AE089	Plasma compression for terawatt long wavelength lasers	12	51	NA
AE093	Direct measurement of fields and radiation in the self-modulated plasma wakefield regime	220		[illegible]
AE095	Optical diagnosis of self-modulated CO_2-laser driven plasma wake			
AE098	Probing electron Weibel instability in optical field-ionized plasmas using ultrashort electron bunches	130	188	[illegible]
AE099	Directional X-ray radiation produced by an ultra-short period plasma magneto-static undulator			
AE100	The study of high-intensity laser pulse interactions with near-critical density plasmas	94	92	NA
AE101*	Optical materials for ultrahigh-power long-wave infrared lasers	122		NA
AE108*	Development of wavelength conversion techniques for generation of coherent radiation at the mid- to long-wave infrared		40	NA
AE119*	Broadband microwave emission from LWIR picosecond laser ablation	94		NA
AE122*	Remote detection of radioactivity using long-wave infrared laser-driven avalanche breakdown	73		NA

Laser + e-beam Laser only *In-air transport

Publications

Laser + e-beam
Laser

JOURNALS

1. R. Kupfer et al., "Raman wavelength conversion in ionic liquids", Phys. Rev. Appl. 19, 014052, 2023
2. C. Zhang et al., "Electron Weibel instability induced magnetic fields in optical-field ionized plasmas", Phys. Plasmas 29, 062102, 2022
3. Z. Chang et al., "Intense infrared lasers for strong-field science", Adv. Opt. Photonics 14, 652–782, 2022

CONFERENCES

Advanced Accelerator Concepts Workshop (AAC), Long Island, NY (USA), November 6–11, 2022

1. W. Li et al., "Raman-based Wavelength Conversion for Seeding and Optical Pumping of CO_2 Laser Amplifiers"
2. I. Petrushina, et al, "Characterization of the fields inside the CO2-laser-driven wakefield accelerators using relativistic electron beams"
3. N. Vafaei-Najafabadi , et al, "Experimental Evidence for Suitability of Krypton as a Plasma Source for Two-Color Ionization Injection"
4. M. Polyanskiy et al., "9.3 microns: Toward next-generation CO_2 laser for particle accelerators"
5. I. Pogorelsky, et al, "Fulfilling the mission of Brookhaven ATF as a DOE's flagship user facility in Accelerator Stewardship"

64th Annual Meeting of the APS Division of Plasma Physics, Spokane, WA (USA), October 17–21, 2022

1. Y.-H. Chen et al., " Proton acceleration in an overdense hydrogen plasma by intense CO_2 laser pulses with nonlinear focusing effects in the underdense preplasma"

Other conferences

1. M. Polyanskiy, "Multi-terawatt long wave infrared lasers: Status and perspectives", 23rd International Symposium on High-Power Laser Systems and Applications, Prague (Czech Republic) June 13–16, 2022
2. M. N. Polyanskiy et al., "The choice of materials for post-compression of high-peak-power long-wave infrared pulses", Conference on Lasers and Electro-Optics (CLEO), San Jose, CA (USA), May 15–20 2022

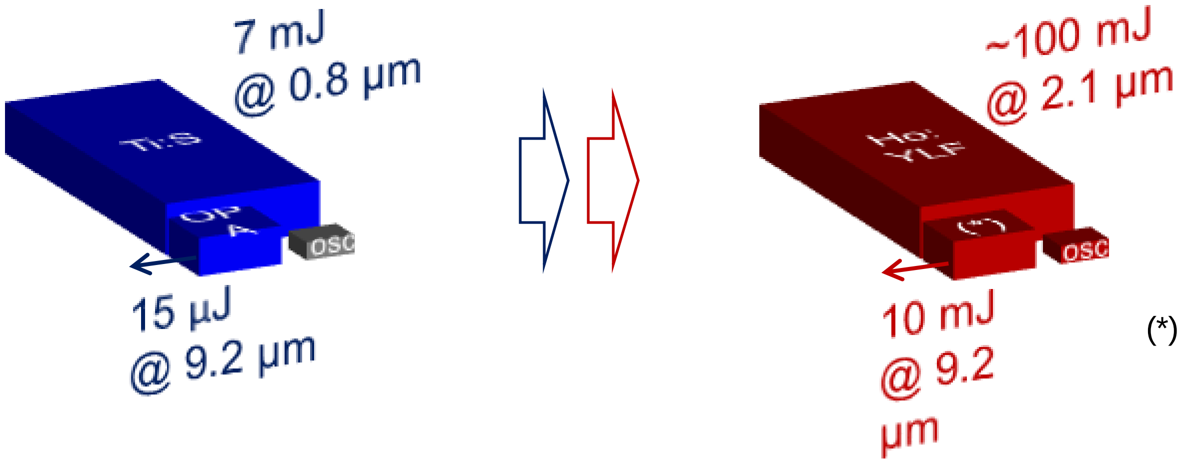
Questions?

Backup slides

Enabling technologies

1) Efficient 2 μm laser

Ho:YLF & Ho:YAG = "mid-IR Ti:Sapphire"



(*) OPCPA or Raman+DFG (see AE-108 report)

2) Reliable post-compressor

Two-element bulk-material LWIR post-compressor with spatial filter
- see AE-101 report-