Plans at BNL-ATF of Interest to ALIC

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BNL Accelerator Test Facility

BROOKHAVEN NATIONAL LABORATORY

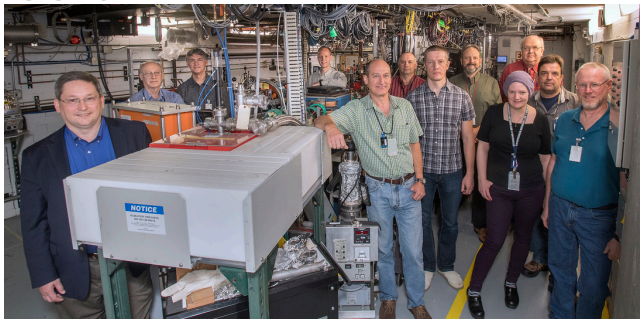
U.S. DEPARTMENT OF ENERGY

Outline

- Facility Overview
- Recent Advances in LWIR Performance
- Next Facility Steps
- Research Relevance for ALIC
- Conclusion
- An Invitation

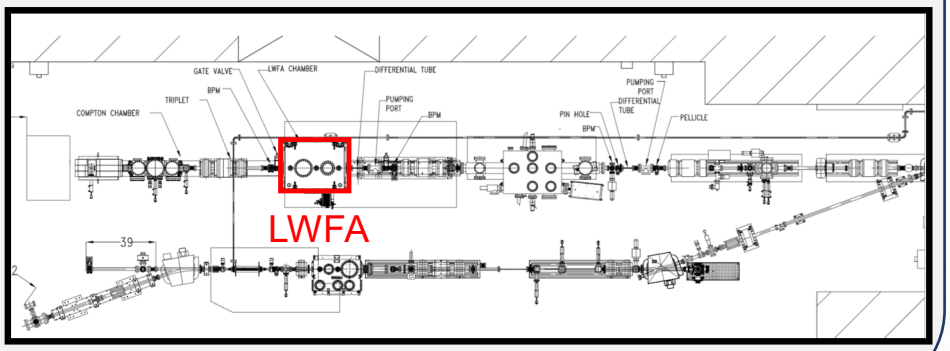
The Accelerator Test Facility

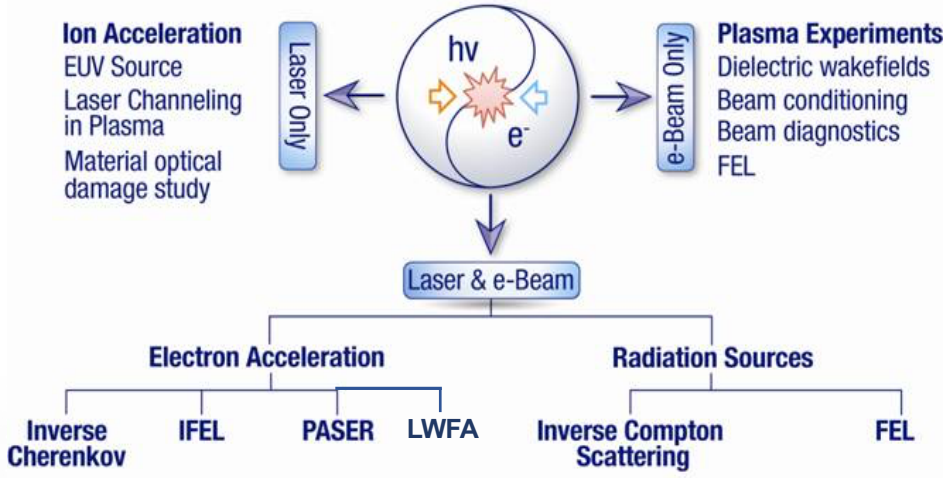
Serving the US DOE Accelerator Stewardship Mission



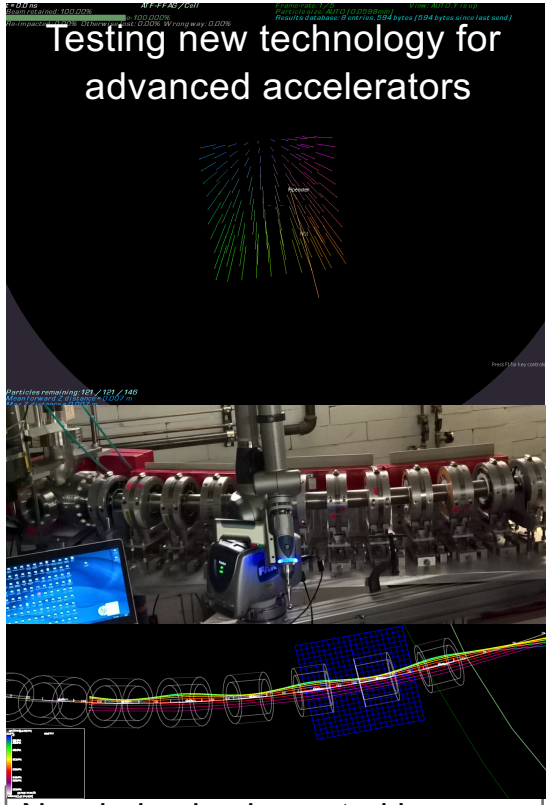
- Provides User Capabilities Spanning:
  - **Novel particle acceleration techniques**
  - **High-brightness radiation sources**
  - **Beam manipulation and beam instrumentation**
  - **Ion generation and acceleration**
  - **Ultrafast Electron Diffraction/Microscopy**
- In FY18 the facility delivered 2529 user hours as a DOE Office of Science User Facility

2 Electron Beam Lines
High power in-vacuum laser transport to LWFA chamber





Electron Beam Capability



Now being implemented in CBeta (the Cornell-Brookhaven Electron Test Accelerator), a developmental ERL (Energy Recovery Linear Accelerator)

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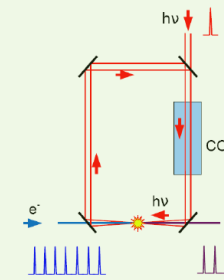
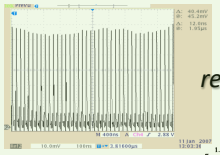
Combined Capabilities

Intra-cavity ICS

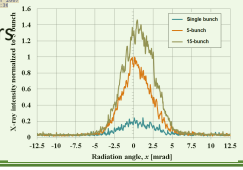


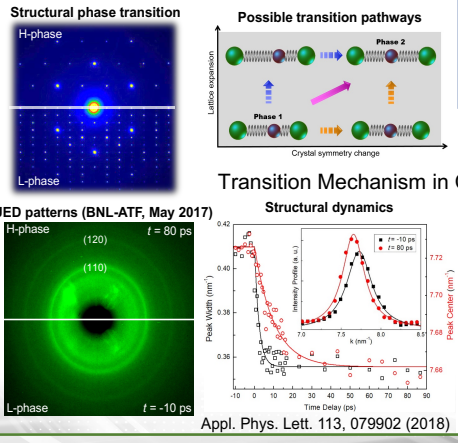
AE-59
Radiabeam
DOE SBIR



Multiplication of x-ray yield by reusing a laser pulse multiple times

Applied Physics Letters **109**, 253504 (2017)

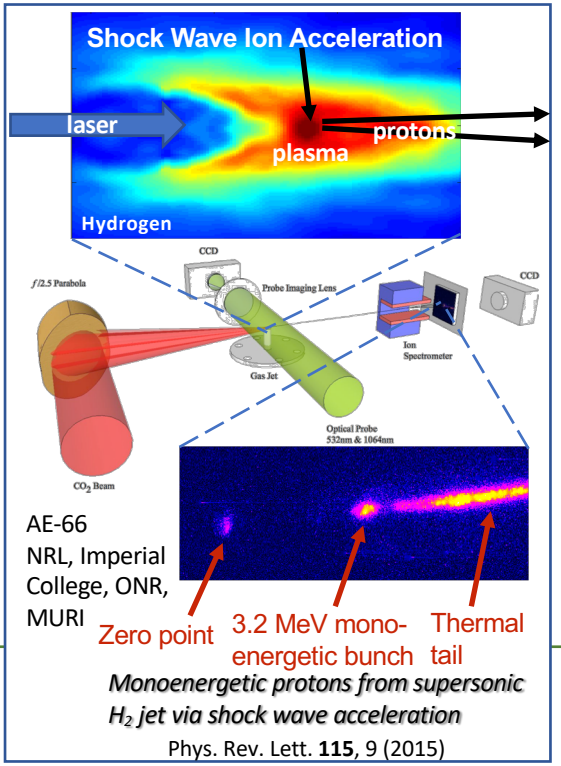




Transition Mechanism in Cu_2S

Appl. Phys. Lett. 113, 079902 (2018)

LWIR Laser Capability

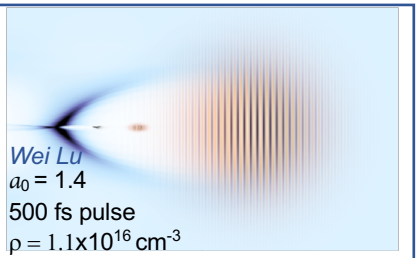


AE-66
NRL, Imperial College, ONR, MURI

Monoenergetic protons from supersonic H_2 jet via shock wave acceleration

Phys. Rev. Lett. **115**, 9 (2015)

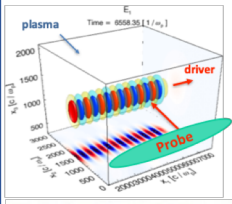
LWFA Thrusts

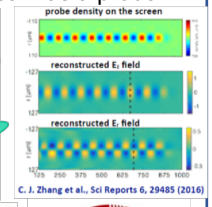


Wei Lu
$a_0 = 1.4$
500 fs pulse
$\rho = 1.1 \times 10^{16}$ cm^{-3}

AE-71 and successor experiments
Self-modulated ⇨ Bubble Regime

- Bubble:
  >300 μm transverse dimension
  >1 ps duration
- Suitable for external injection studies (with ATF e-beam)
- Suitable for 2-color ionization injection studies (AE-88)
- Utilize ATF's e-beam as a probe





C. J. Zhang et al., Sci Reports 6, 29485 (2016)

THE UNIVERSITY OF TEXAS AT AUSTIN
Stony Brook University
BROOKHAVEN NATIONAL LABORATORY
UCLA

UED is a powerful probe enabling picosecond time-resolved studies of solid-state structural dynamics

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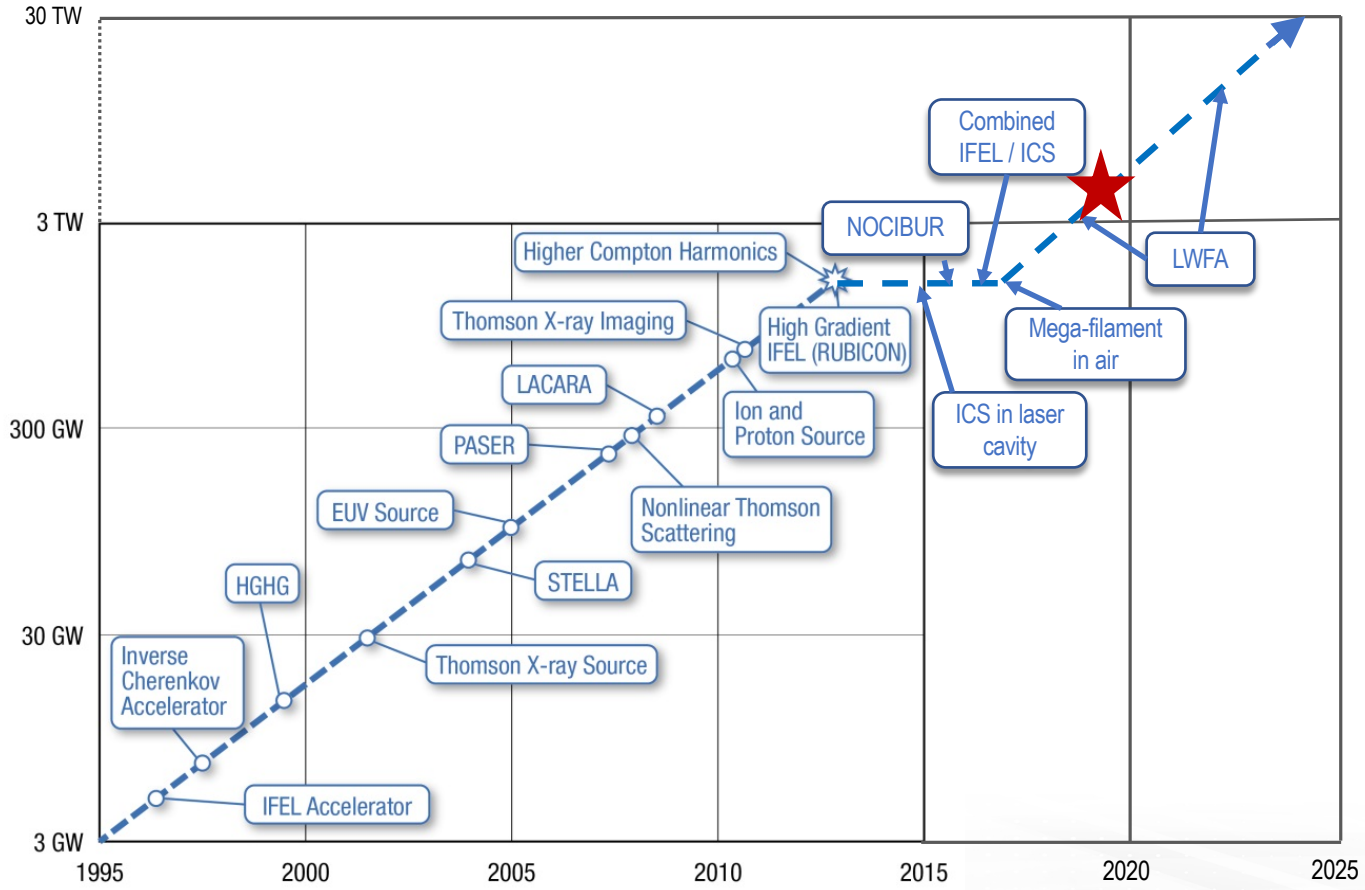
History of ATF CO_2 laser upgrades



1995-2015

- 10x power increase every 7 years
- Reached saturation at 2 TW due to nonlinear distortions with lower powers deliverable to users

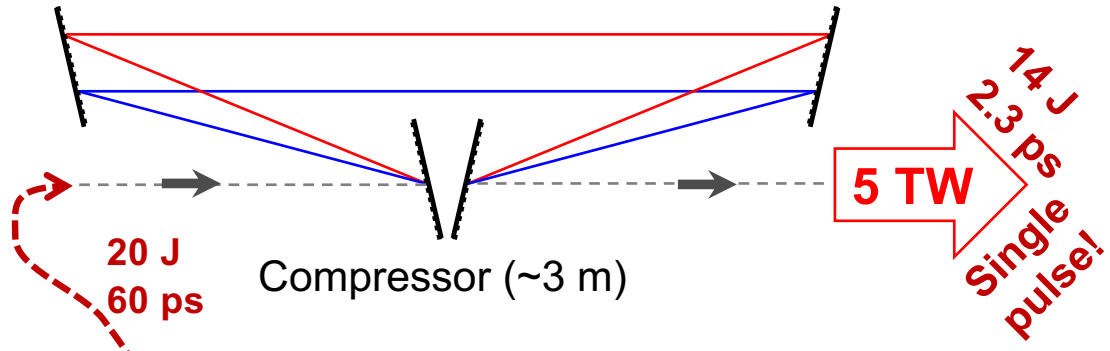
2016-2018

- Regroup to implement new concepts & improve engineering
- R&D to make new concepts productive

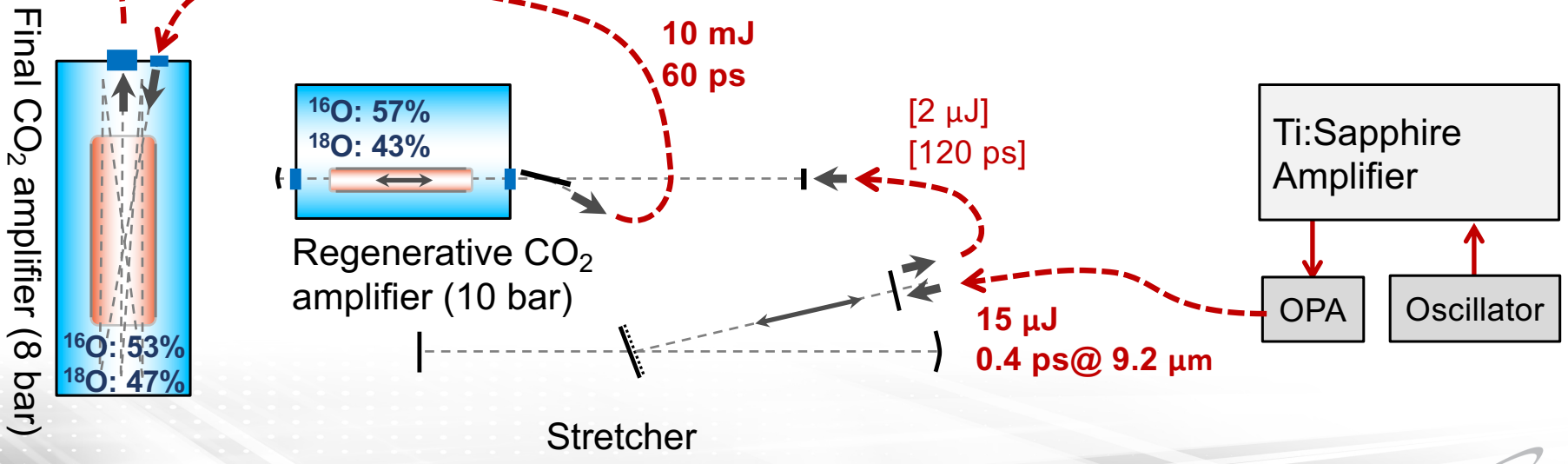
2018 and after

- Continue initial trend of power increase alongside with continuing R&D
- Reach 10s of TW @ < 1ps

The ATF **5 TW** LWIR (**9.2 µm**) Laser

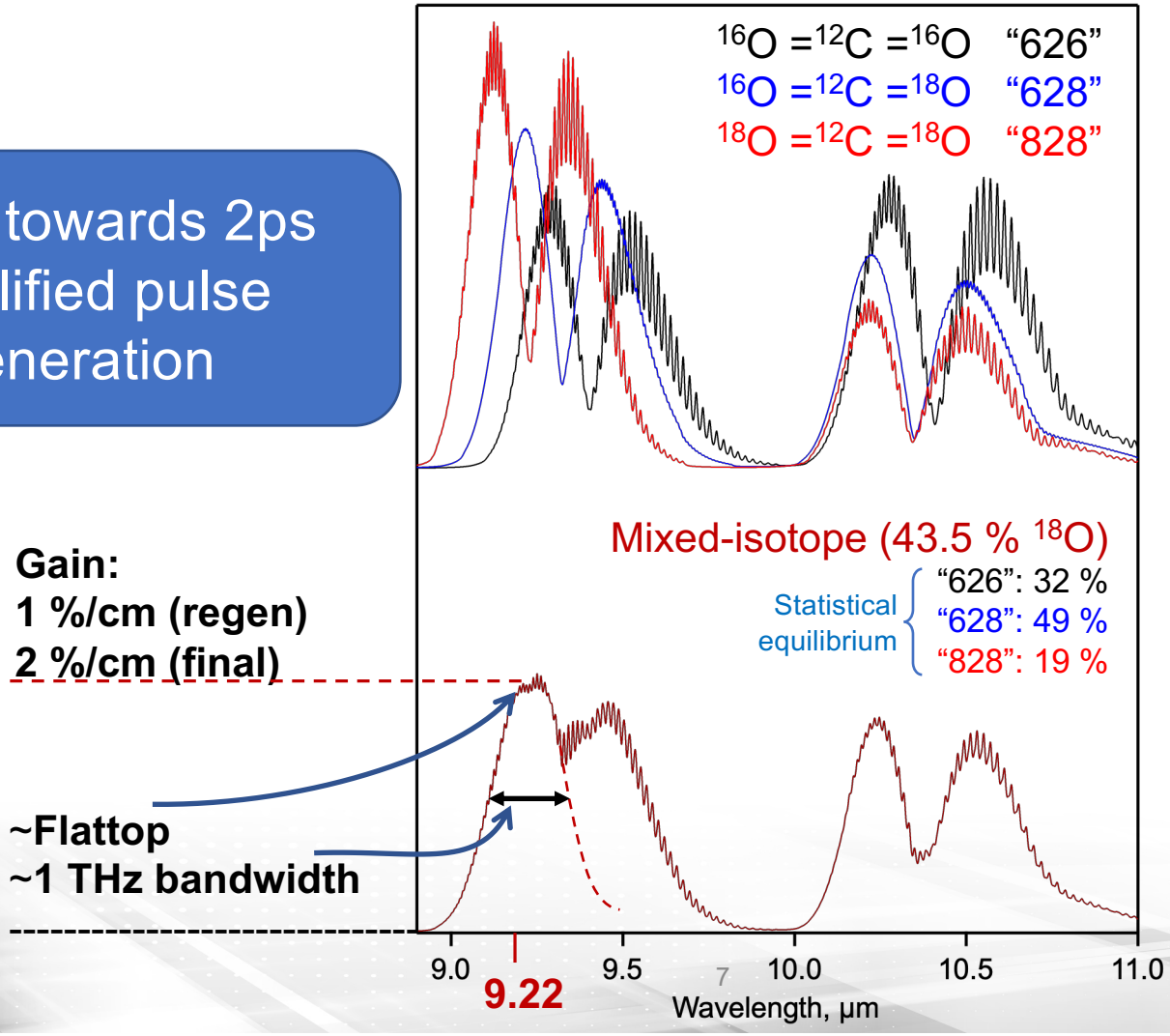


ATF Advances
- First mixed-isotope picosecond CO_2 laser
- First gas laser with CPA
- Solid-state seed laser



Mixed-isotope, High-pressure CO_2 Amplifiers

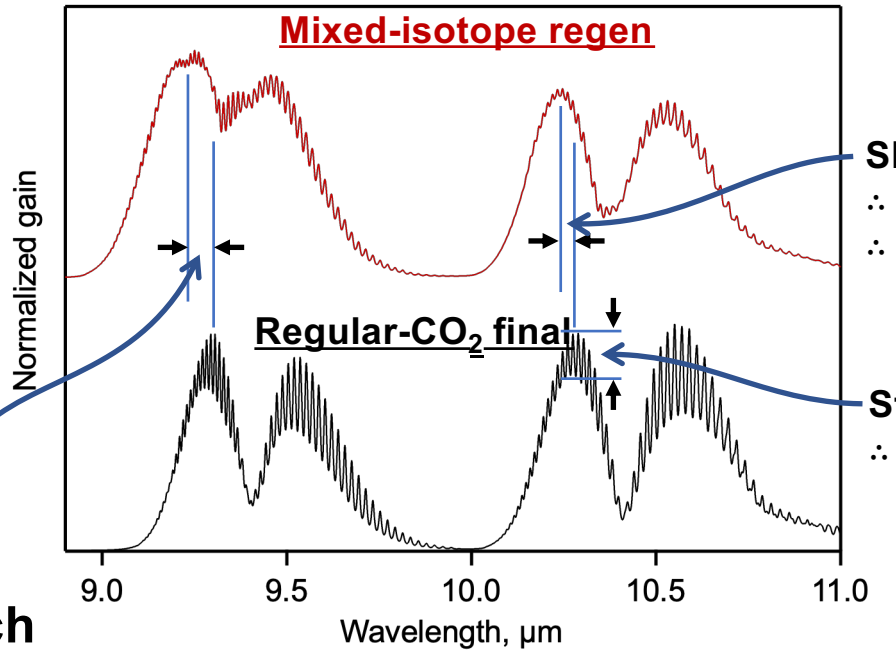
Steps towards 2ps amplified pulse generation



Regenerative Amplifier
10 bar
CO_2: 0.3
N_2: 0.1
He: 9.6
^{18}O: 43.5 %

Final Amplifier
8.25 bar
CO_2: 0.5
N_2: 0.25
He: 7.5
^{18}O: 47 %

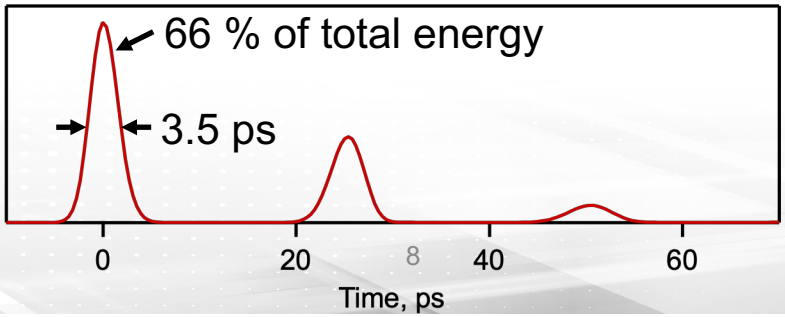
2017 Configuration



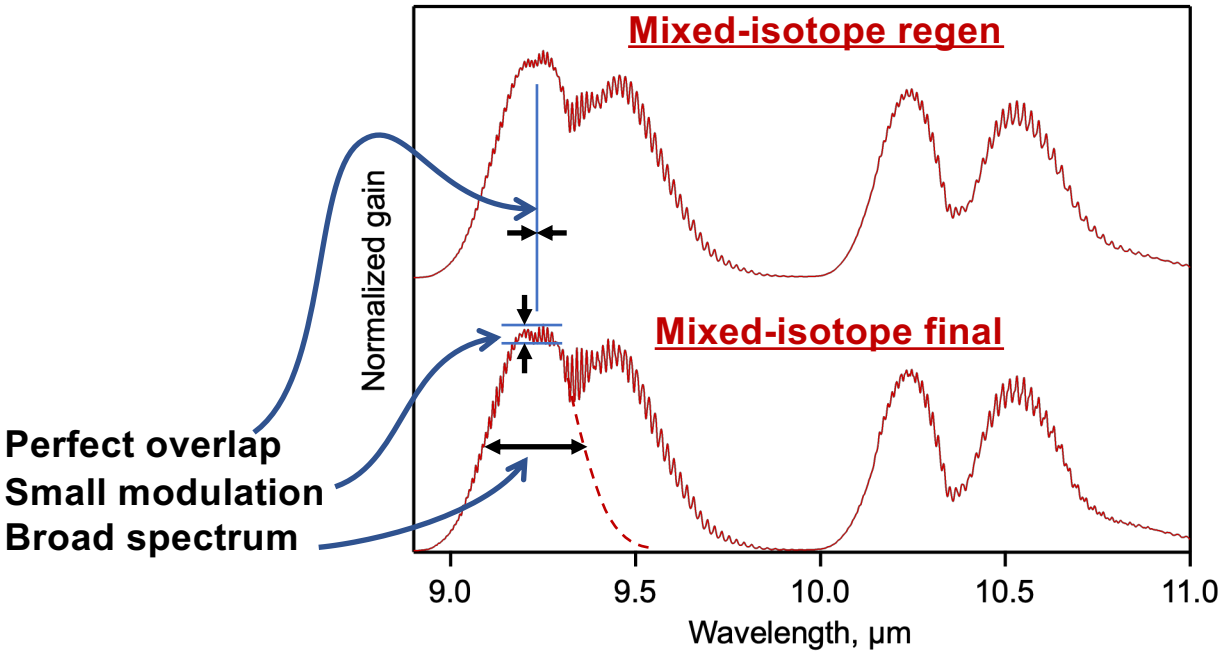
Shift
∴ spectrum narrowing
∴ pulse broadening

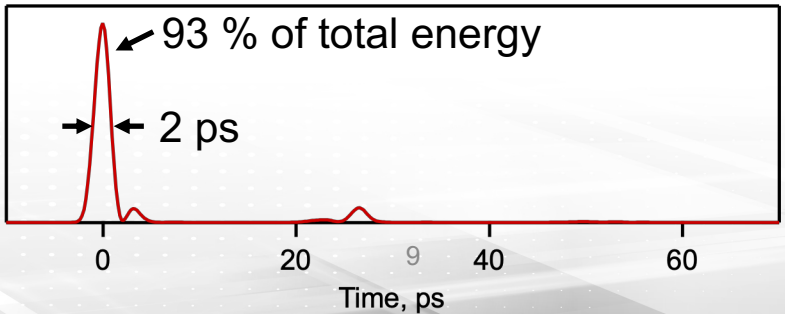
Strong modulation
∴ pulse splitting

Spectrum mismatch
∴ cannot run @ 9.2 μm

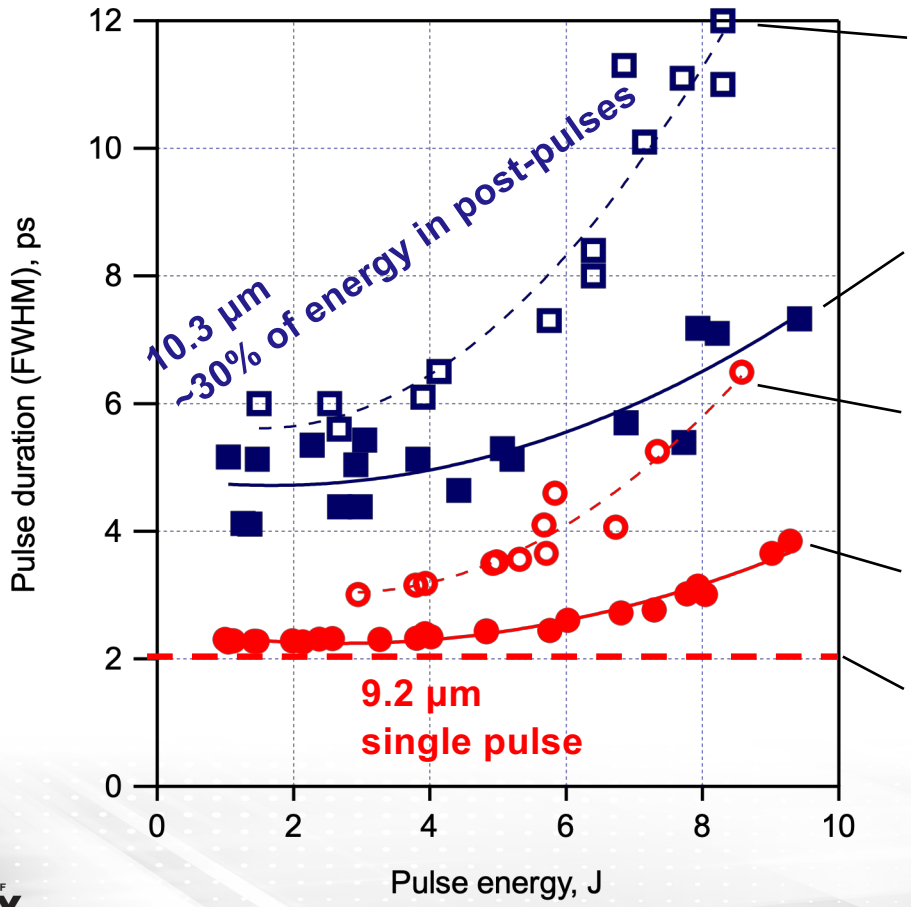


2018 Configuration





CPA Pulse Compression: 2017-2018



Nov 2017
- Initial implementation of full-scale CPA
- Natural CO_2 in final amplifier

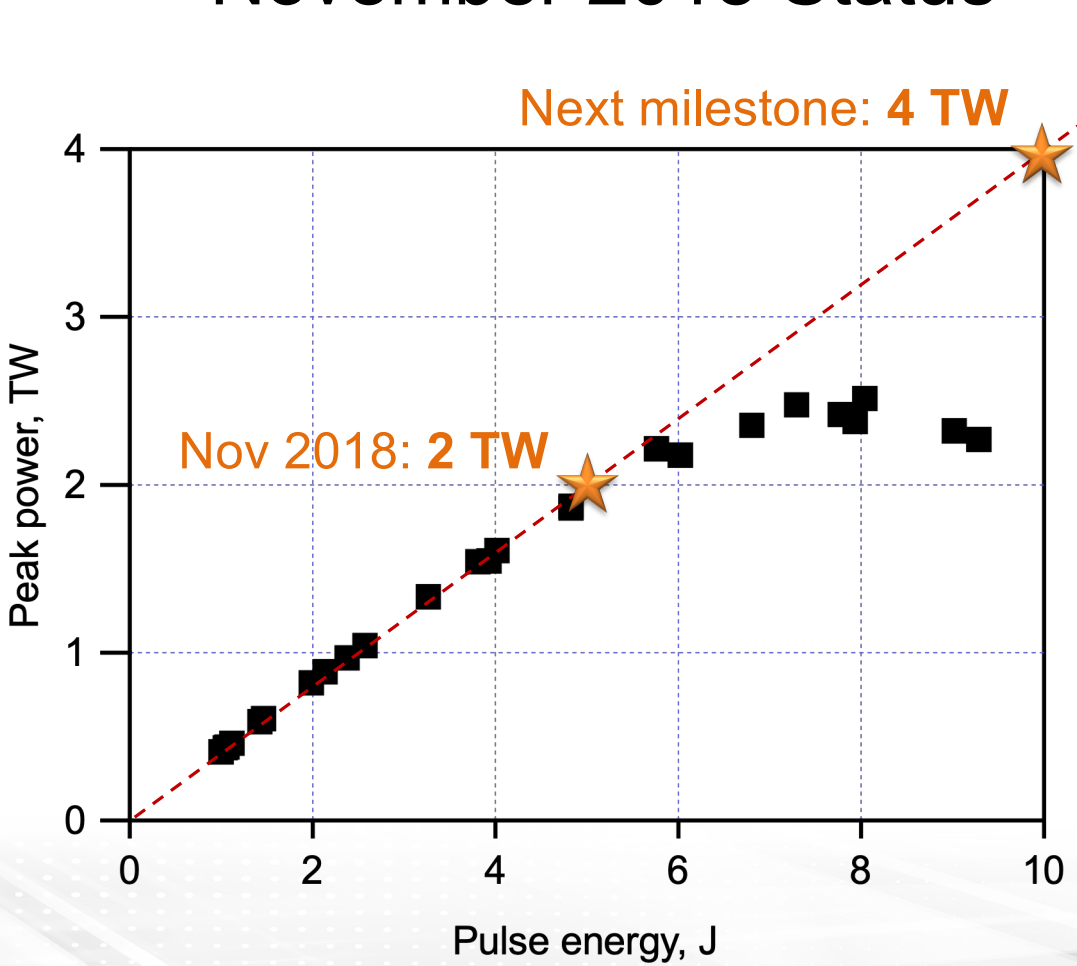
Dec 2017
- Compressor optimization

Aug 2018
- Mixed-isotope CO_2 in final amplifier

Nov 2018
- Compressor optimization

Mid-2019 goal
- New (denser) compressor gratings

November 2018 Status



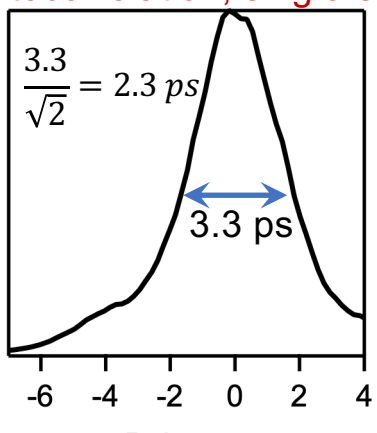
5 TW
Requires improved compressor efficiency
50% ⇨ 70%

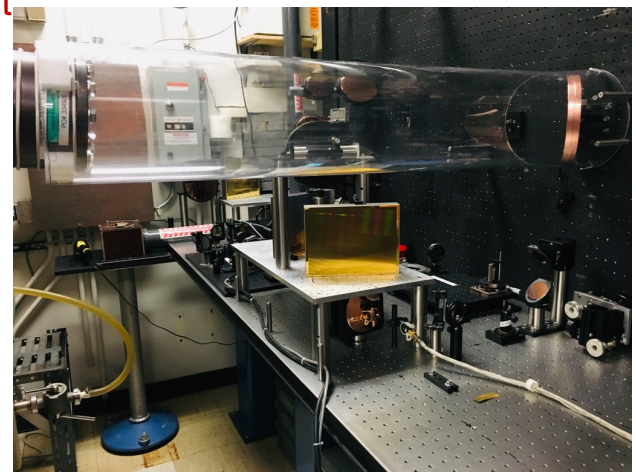
Delivery of >5 TW LWIR Laser Performance

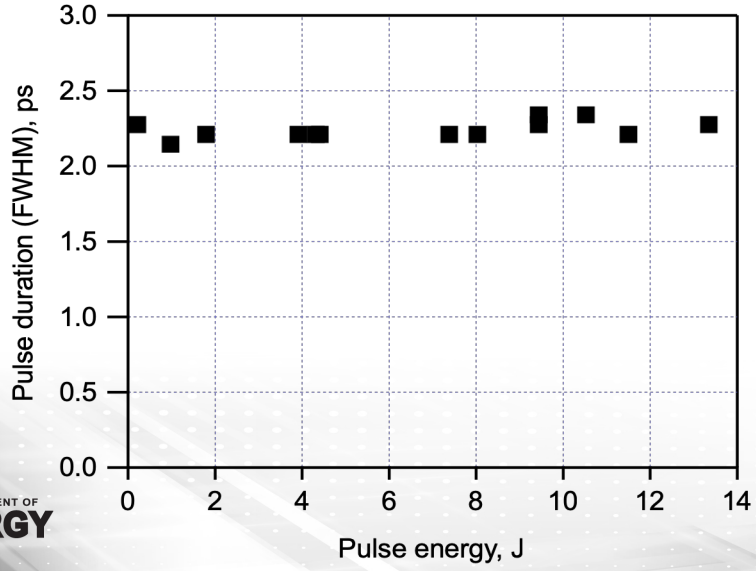
Advances in CPA Gratings

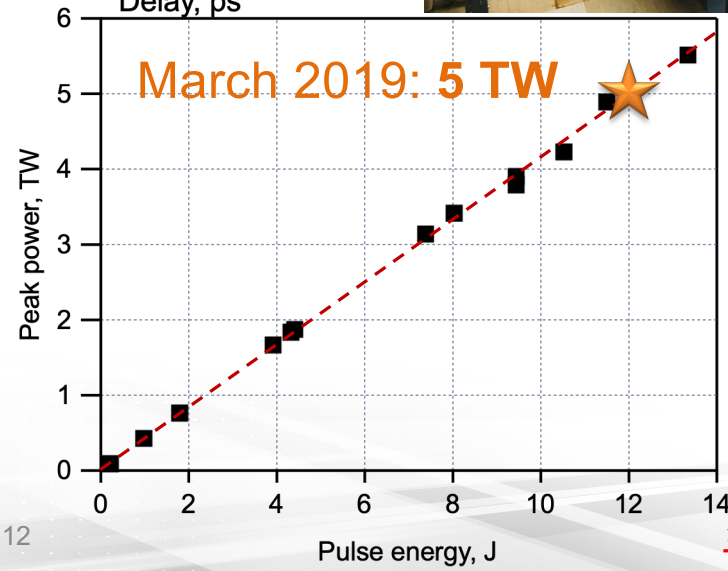
Line density:	75 → 100 lines/mm
Coating:	Al → Au
Blaze wavelength:	10.0 → 9.3 μm
Efficiency:	84 → 92 %
Efficiency (4x):	50 → 70 %
Damage threshold:	0.5 → 2 J/cm^2

Autocorrelation, single-shot









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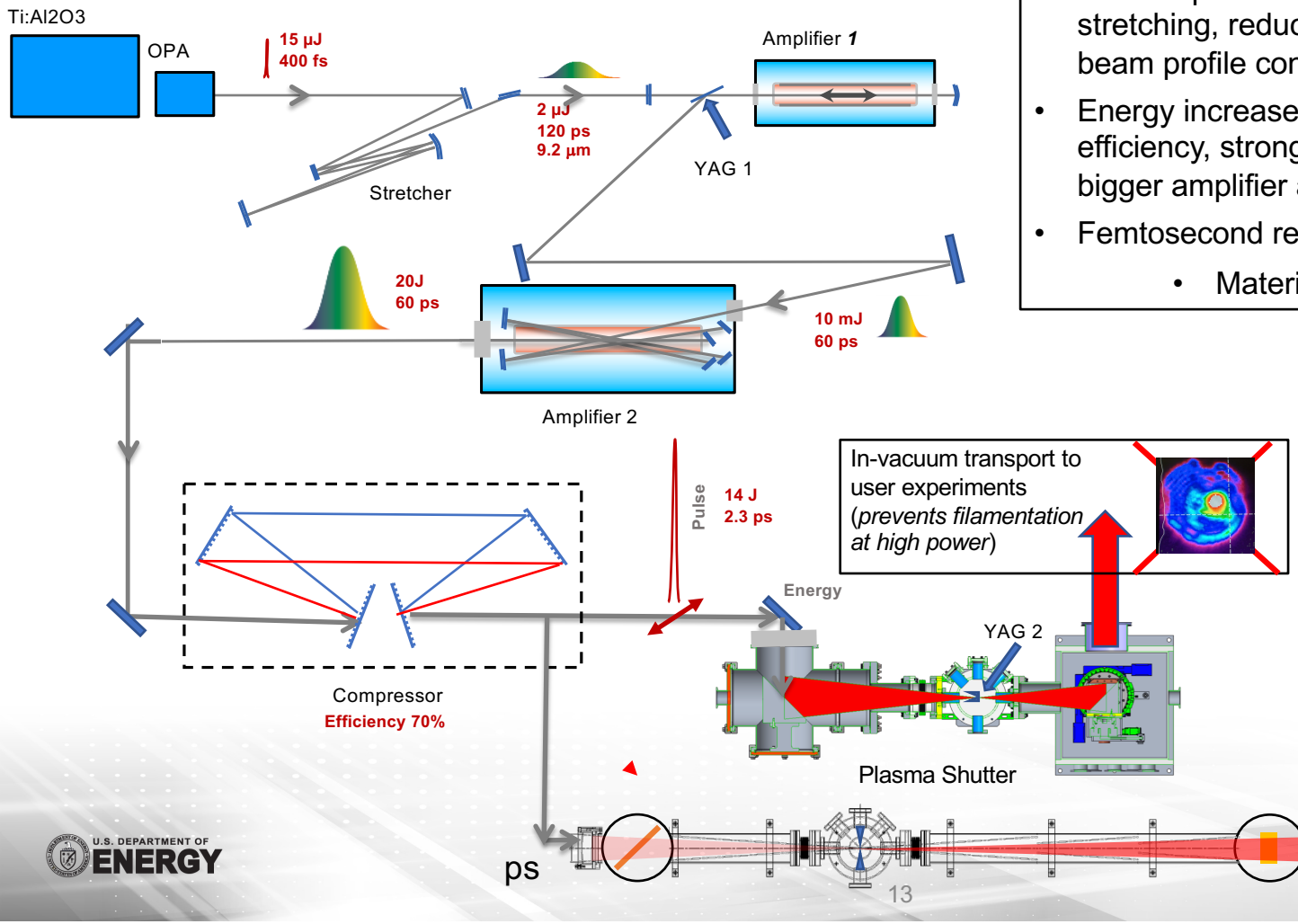
Next Facility Steps



Upgrade R&D thrusts:

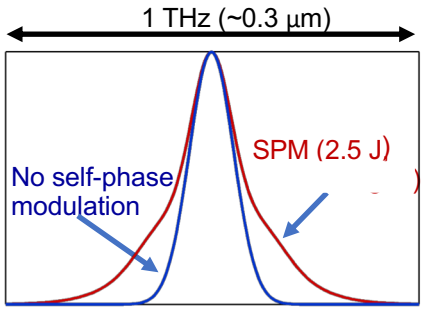
- Reduce pulse expansion via stronger pulse stretching, reducing amplifier window thickness, beam profile control (apodizing, adaptive mirror)
- Energy increase by improving compressor efficiency, stronger pulse stretching, implementing a bigger amplifier and window (long term)
- Femtosecond regime with NLPC
  - Material studies

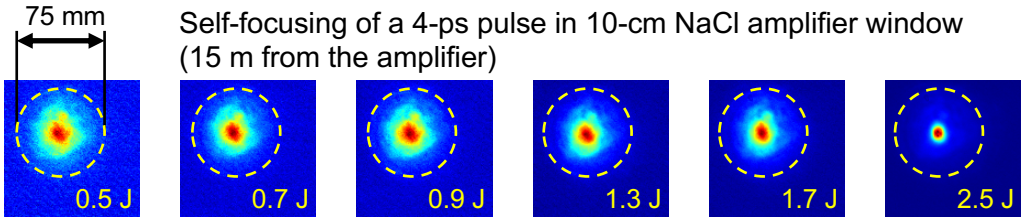
Planned Improvements:

- Higher Rep. rate (faster HV switches, **optical pumping –** *progress in 2.8 µm GaSb laser diodes, SUNY-SB*)
  - Achieve rep rates matched to ATF e-beam
- Beam quality
- Energy/power stability
- System reliability
- Variable polarization

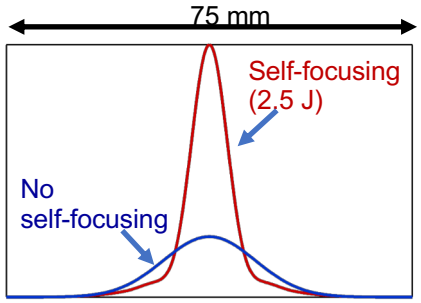
ATF Approach to NLPC

- We already observed Kerr effect $n = n_0 + n_2 I$ on the amplifier's output window that leads to the beam's spectral self-chirping and spatial self-focusing

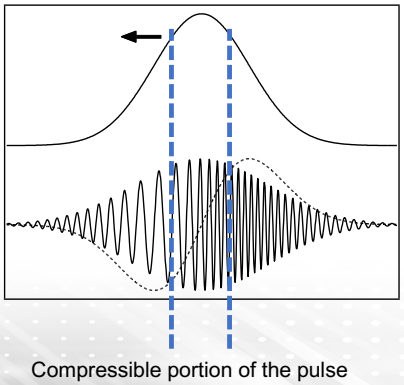


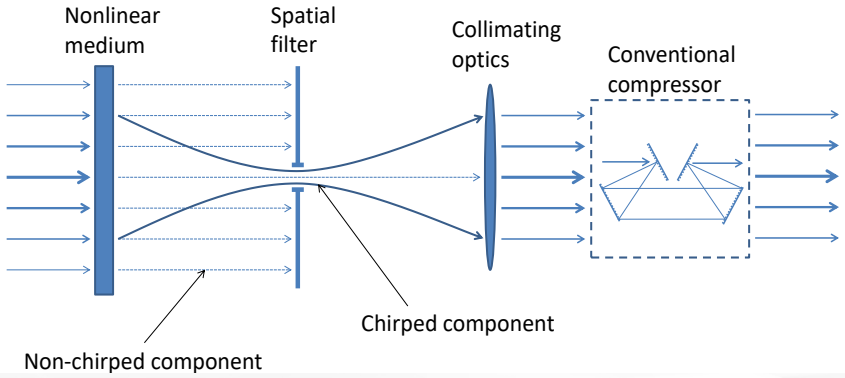


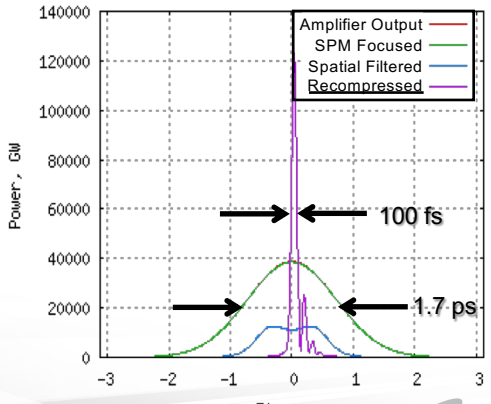
Self-focusing of a 4-ps pulse in 10-cm NaCl amplifier window (15 m from the amplifier)



- Now we are going to use this "parasitic" effect productively by compressing a self-chirped component and spatially filtering it out it via self-focusing with properly selected optical elements







Laser experimental requirements by topical area

from the report of Scientific Needs Workshop 2017

Experiment	Entry Level Requirements	ATF Laser Upgrade
Nonlinear Kerr effect	1 TW	Yes
Non-linear LWFA	~2 TW	Yes
Blow-out LWFA	5 TW, 0.5 ps	Yes, near term upgrade
Bubble LWFA	25 TW, 0.5 ps	R&D Effort Underway
Ion acceleration	25 TW, circ. polar	R&D Effort Underway
IFEL	25 TW	R&D Effort Underway
DLA	10 GW	Yes
ICS	2 TW	Yes
Phase space manipulation	~1 TW	Yes

ATF CO_2 upgrade is matched to the scientific needs identified in SNW report https://www.bnl.gov/atf/docs/atf_snw_report_final.pdf

Research Relevance for ALIC

- ATF R&D Program for: >10 TW, <500 fs @9.2 μm
  - Within the next 3-5 years
  - Along with:
    - Beam quality improvements
    - Repetition rate improvement to offer matched e-beam/laser operation
    - Flexible polarization
- Enables:
  - LWFA Experiments
    - Production of significantly larger bubbles
    - Detailed and higher resolution diagnostics of internal structure and evolution of plasma bubbles
    - Sub-% energy spread with bunches
    - Higher charge demonstration
    - Detailed studies of:
      - External injection
      - Two-color injection
  - Also other acceleration schemes (e.g. well-matched to dielectric laser acceleration needs)

Conclusion

- Significant improvements to the ATF CO_2 laser system have been implemented over the last 2 years
  - A systematic effort to provide the next steps forward is underway
    - Pulse compression for sub-picosecond operation
    - Power increases into the 10s of Terawatts regime
    - Along with multiple operational improvements
- The ATF offers a unique opportunity to conduct studies with a combination of a high brightness electron beam and an LWIR laser system
- We expect to move into the sub-picosecond operational regime over the next 3 years ⇨ ***thus opening up new opportunities to conduct research of relevance for an Advanced Linear Collider!***

An Invitation