Progress on AE85
A Multiatmosphere CO_2 Amplifier Optically Pumped by a 4.3 μm Fe:ZnSe Laser

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Jeremy Pigeon*, Sergei Tochitsky, Dana Tovey, Chan Joshi
Department of Electrical Engineering, UCLA
*Department of Physics and Astronomy, Stony Brook University
Igor Pogorelsky, Mikhail Polyanskiy
Brookhaven National Laboratory, USA
SERGEI MIROV - PI *et. al.*, University of Alabama at Birmingham

Motivation

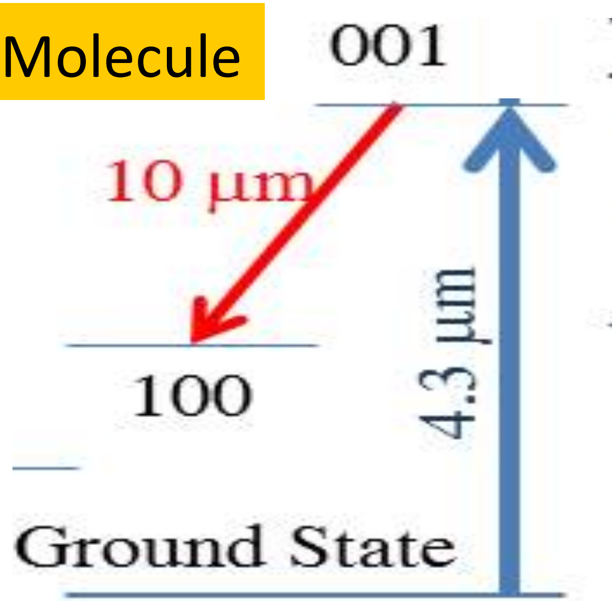
- **Long-wavelength Infrared range is attractive for particle acceleration and radiation generation. At present we experience a Renaissance of mid-IR ultrafast lasers mainly based on OPA and OPCPA in nonlinear crystals pumped at 1-2 μm.**

- **CO_2 laser is efficient and is able to store a great deal of energy within the active medium. The shortest pulse demonstrated so far is ~3 ps and all high-power picosecond systems operate in a single-shot mode limited by electrical discharge stability in a high pressure molecular gas.**

- **In AE85 experiment funded by DoE grant, we study potential of Optically Pumped CO_2 laser technology for production of ≤1 ps pulses at a high-repetition rate. A collaborative effort of BNL/UCLA/SBU (gas lasers) built around the state-of the art mid-IR solid-state lasers developed at UAB.**

Optically Pumped CO_2 Laser

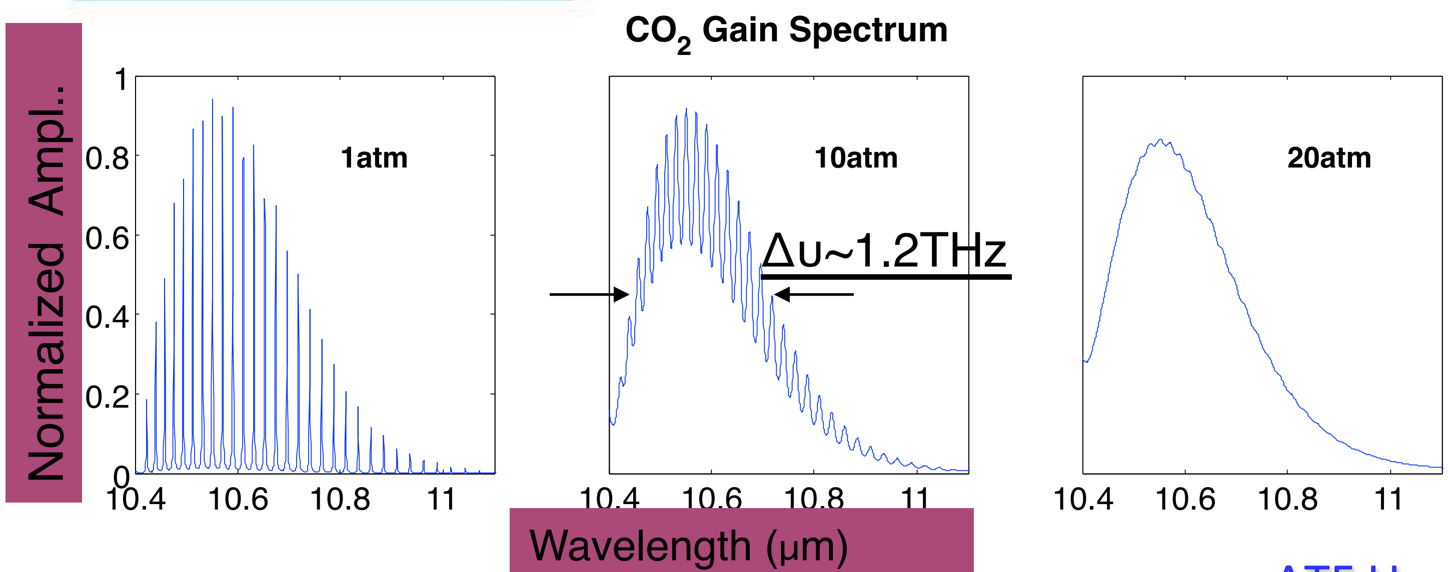
CO_2 Molecule



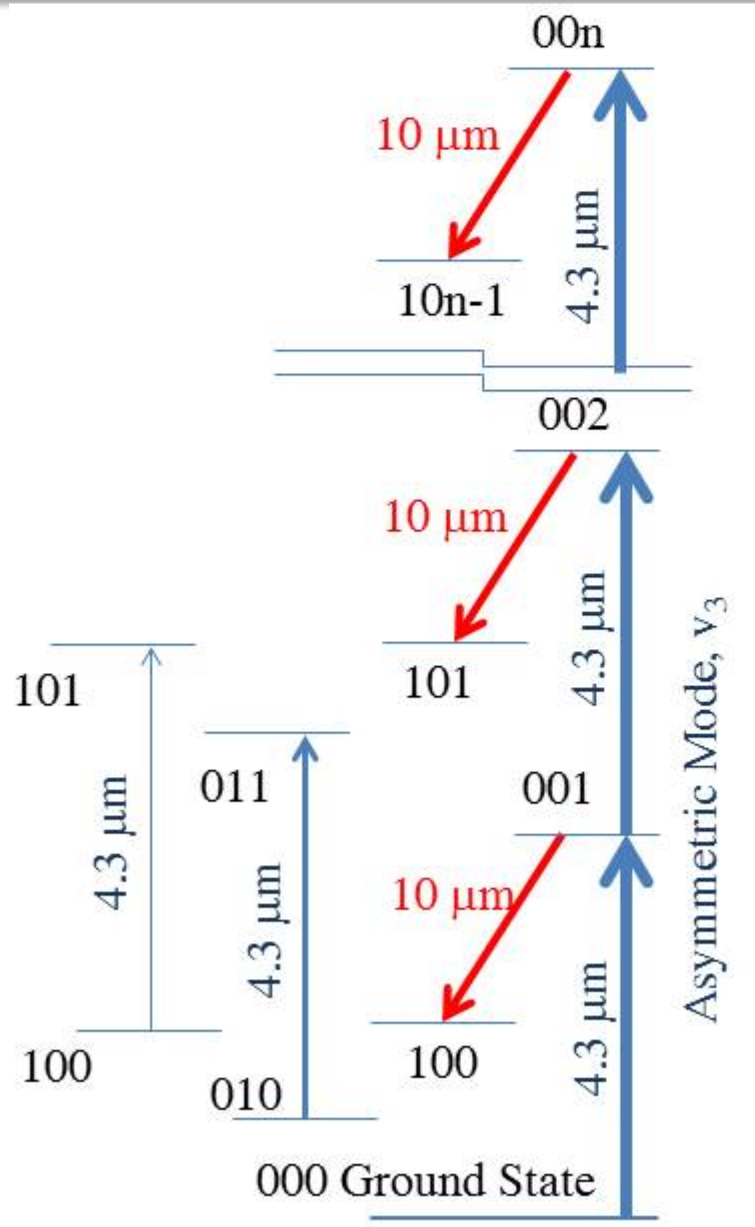
Recipe for success: High-gain CO_2 laser

Population of 001 level Maximized

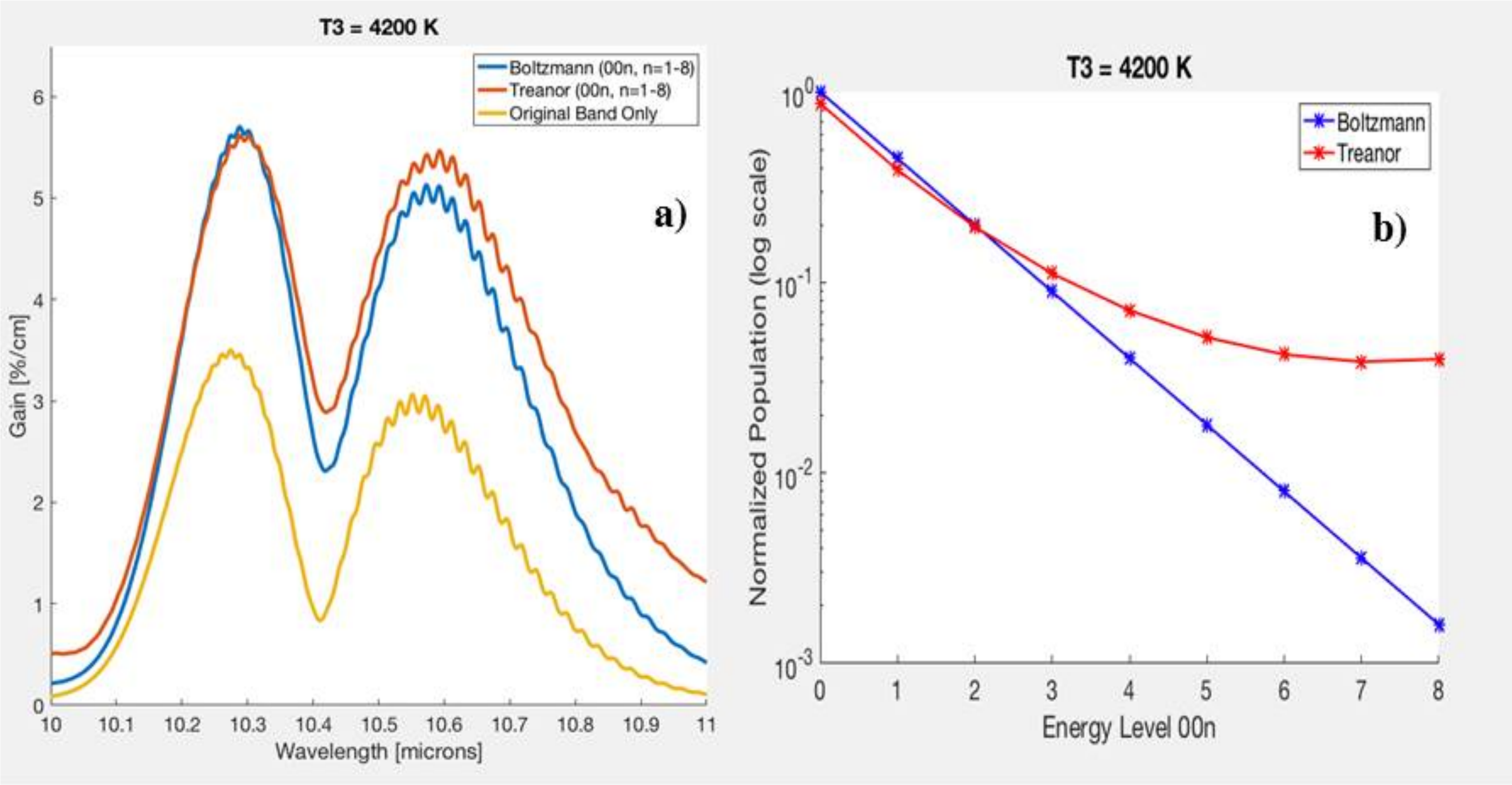
Population of 100 level Minimized



Gain Dynamics Modeling

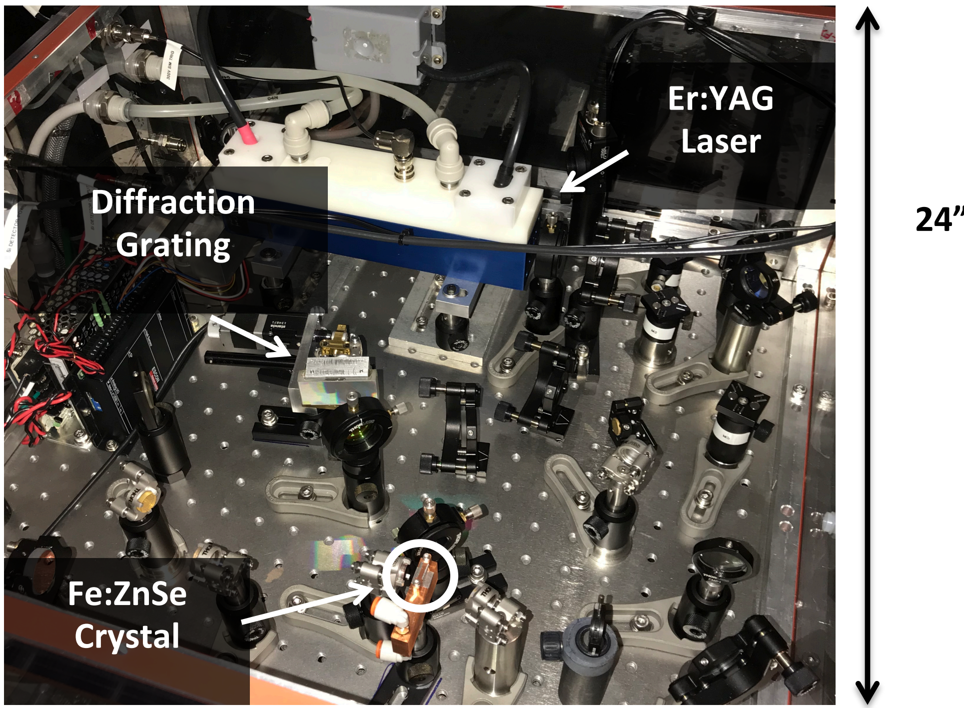


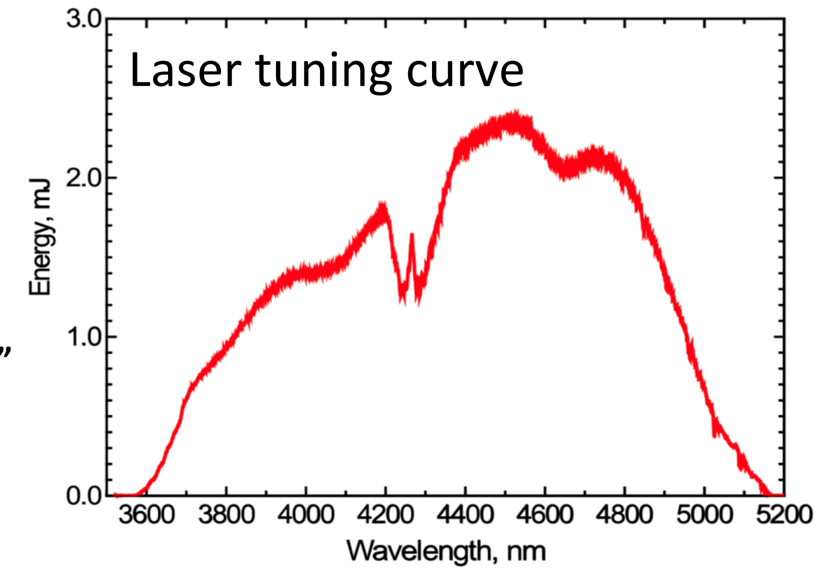
Gain Dynamics Modeling

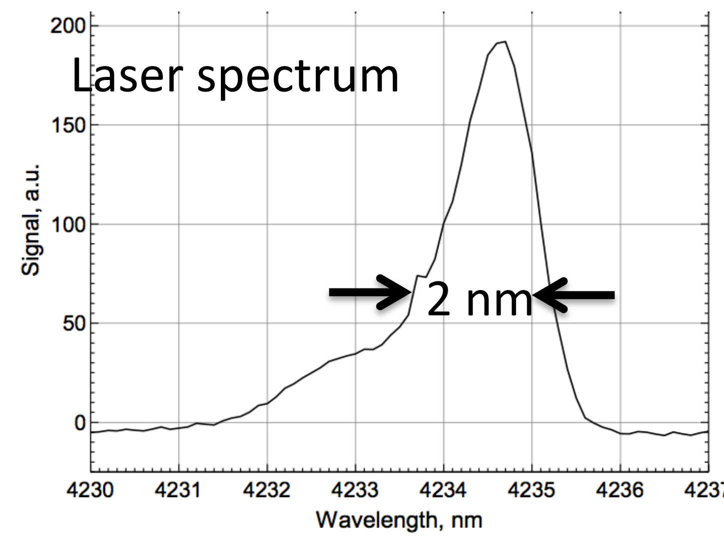


Tunable 3.9-5 μm, 2 mJ, Fe:ZnSe source for Optical Pumping of the CO_2 laser

Tunable Fe:ZnSe Laser Setup



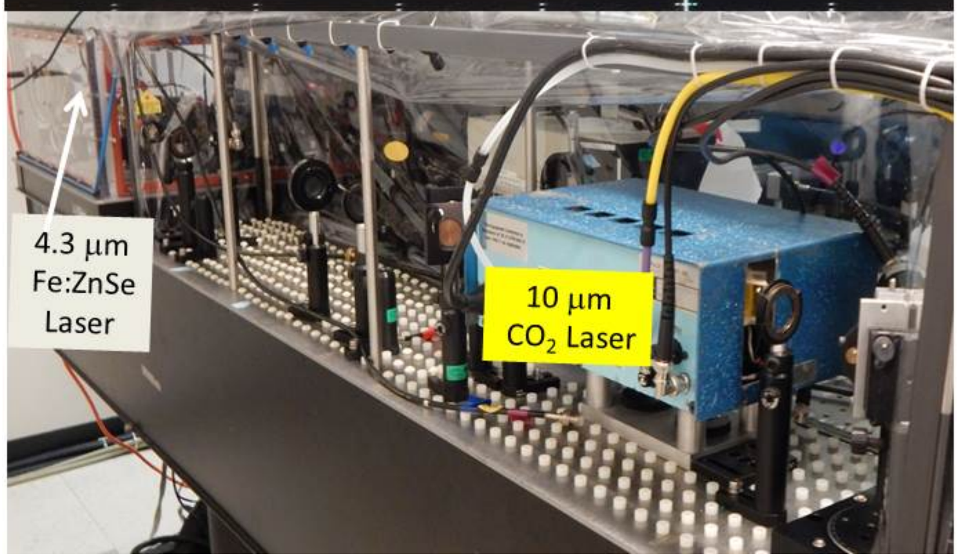




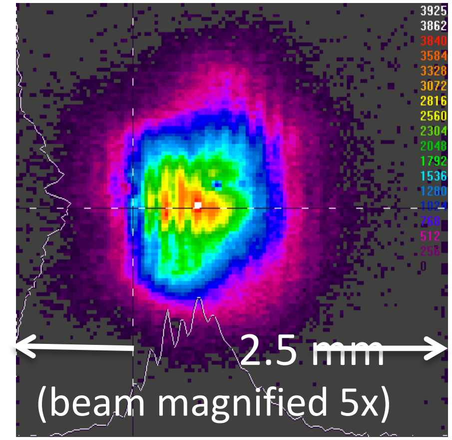
Group of Prof. S. Mirov

ATF User’s 2019

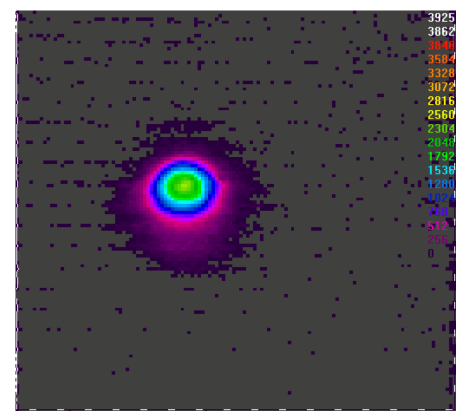
Last year: Low pressure lasing in optically pumped CO_2 active medium



4.3µm Pump Pulse Beam

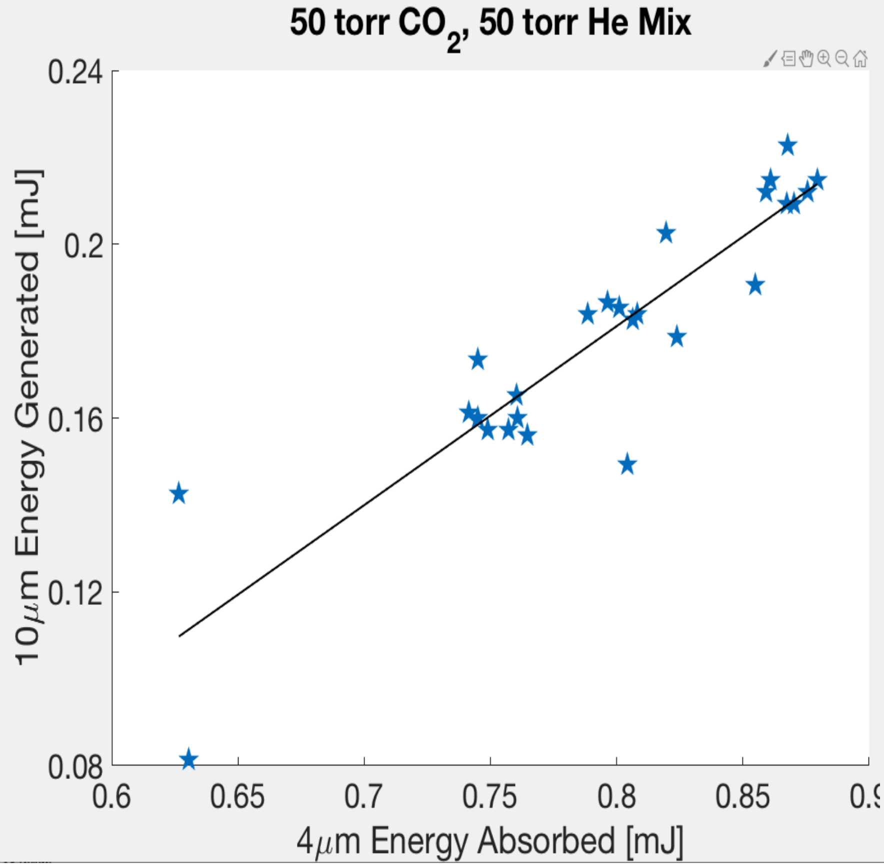


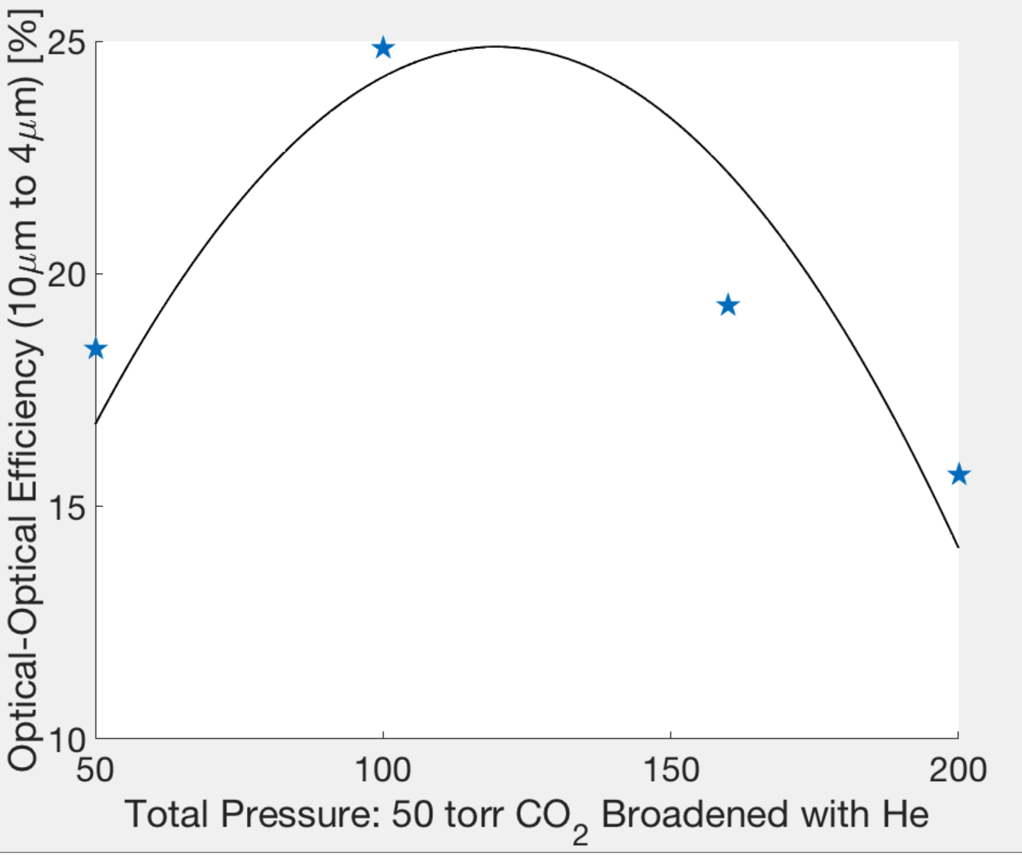
10µm Laser Pulse Beam



- Lasing at total pressures <200 torr with optical-optical conversion efficiencies up to 30%

Optical-to-optical conversion efficiency



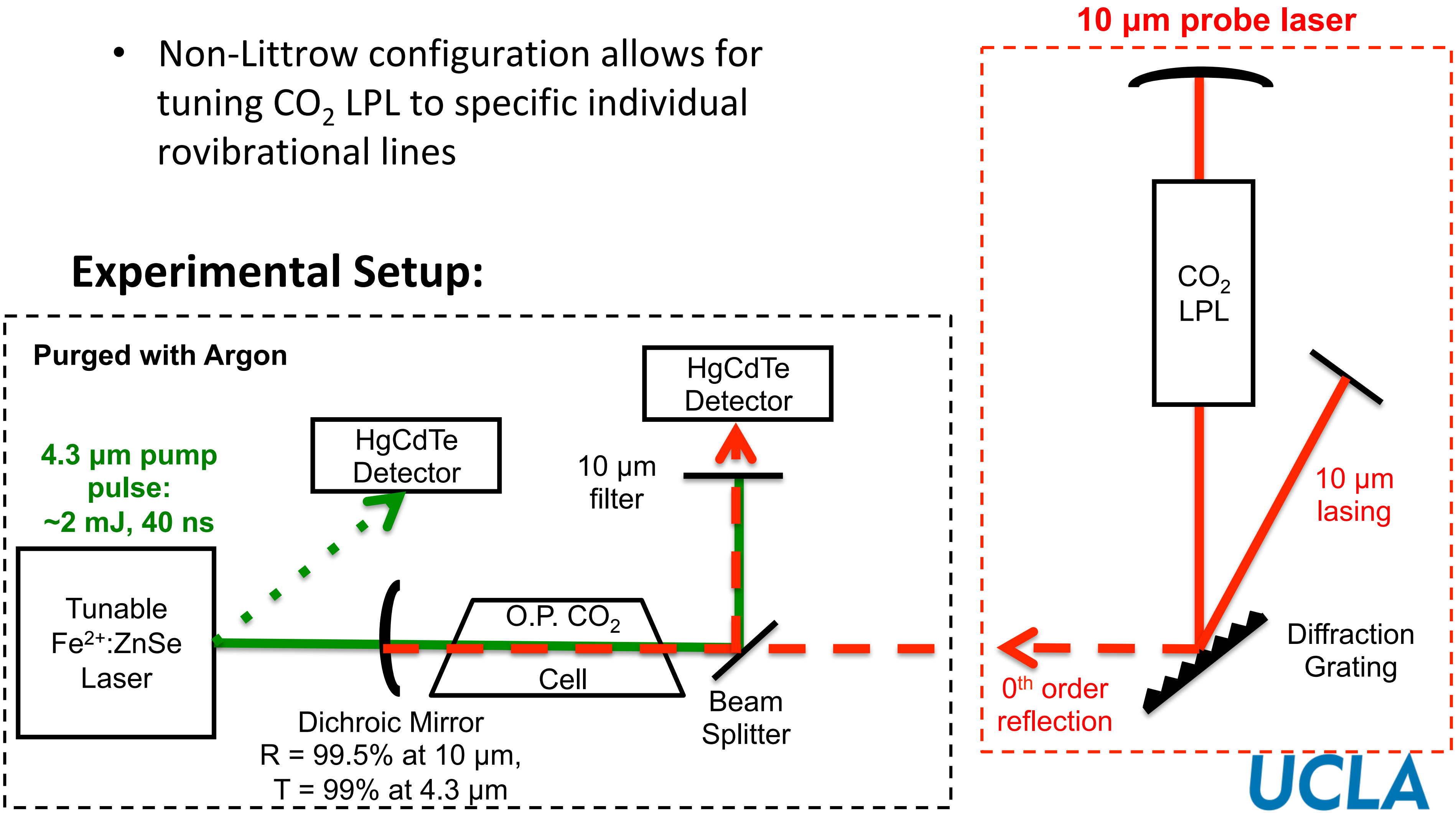


With 1.8 mJ coupled in the cavity we are limited to < 3 atm.

Small-signal gain measurements in optically pumped CO_2

- Non-Littrow configuration allows for tuning CO_2 LPL to specific individual rovibrational lines

Experimental Setup:



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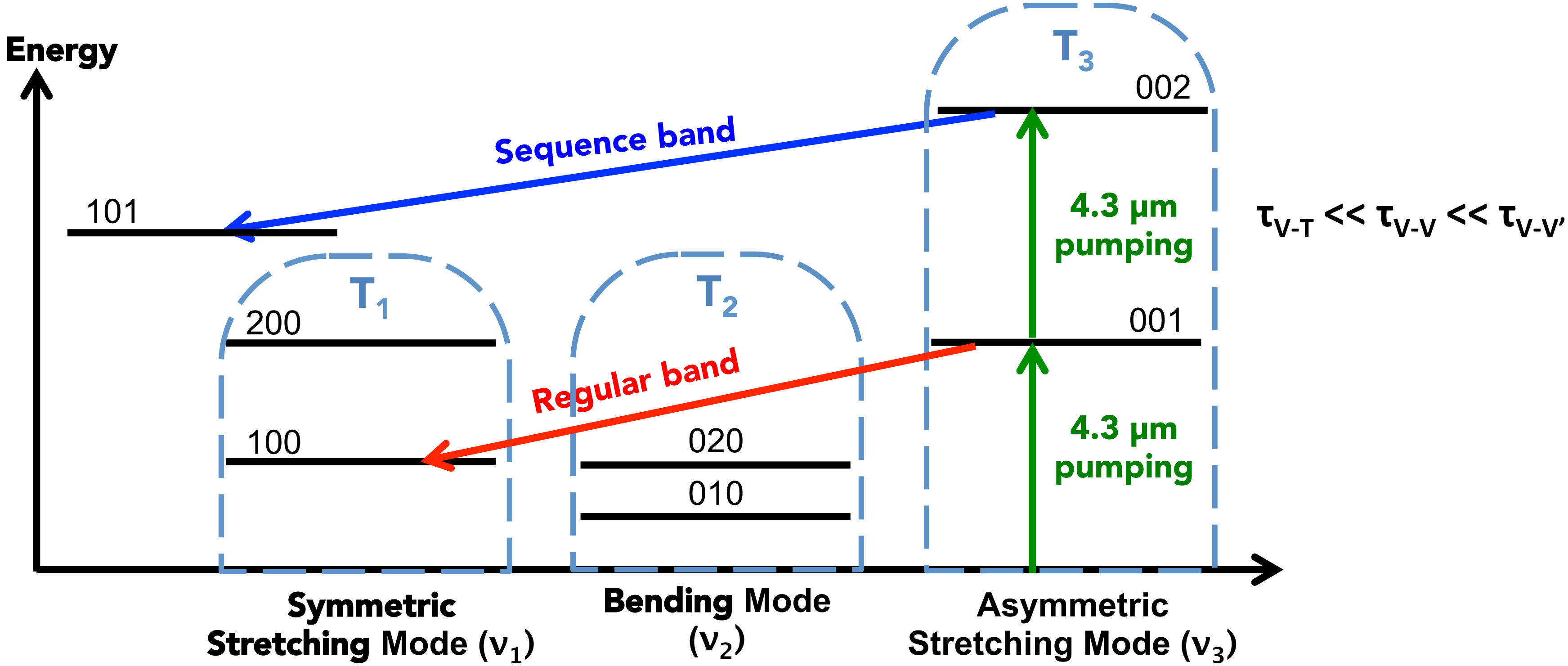
CO_2 Mode Temperature Model



- Equilibrium is established in the following order:
  1. Among rotational levels within a single vibrational level (τ_{V-T} < ns)
  2. Among vibrational levels within a single mode (τ_{V-V} ~ 10 ns)
  3. Among the gas mixture as a whole ($\tau_{V-V'}$ ~ 10 µs)

- Populations in each level are described by "mode temperatures" (T_1,T_2,T_3):

$$N(00n) = N_0 * \exp(-nh\nu_3/kT_3)$$

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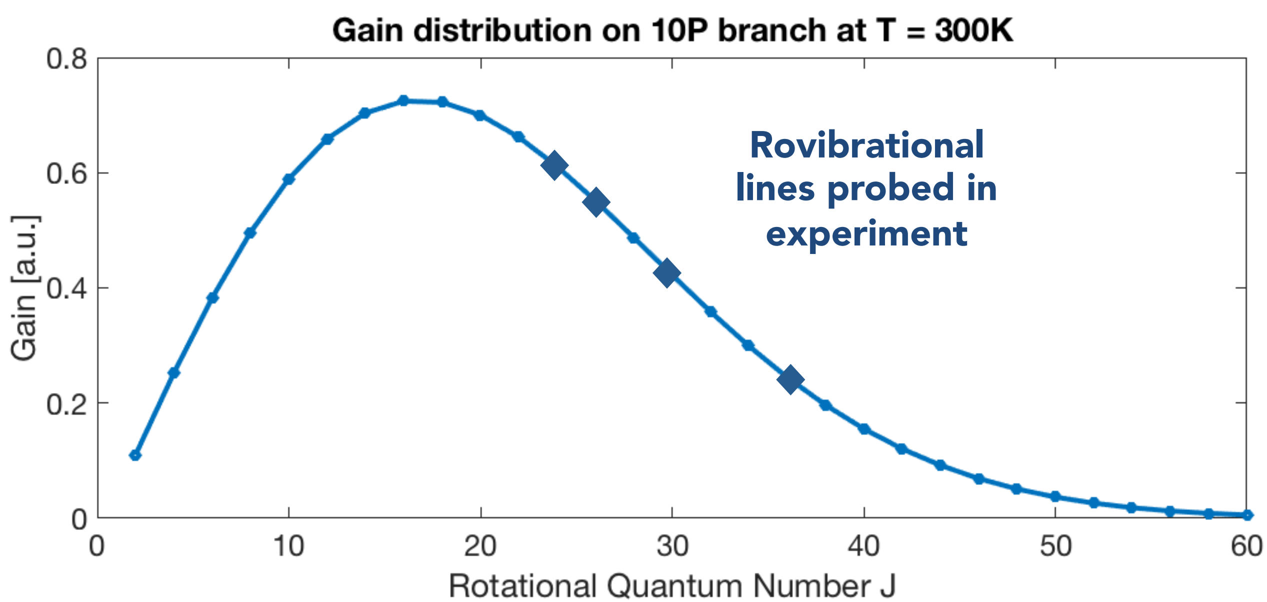
Calculating T and T_3 using small-signal gain measurements

- T_3 can be found by measuring gain ratio between regular and sequence bands: $g_{seq} / g_{reg} = 2 \exp(-h\nu_3/kT_3)$

- Translational temperature T_{trans} can be found by fitting gain measurements on different rovibrational lines to a gain distribution: $g_{reg}(J) = \text{function}(J, T_{trans})$



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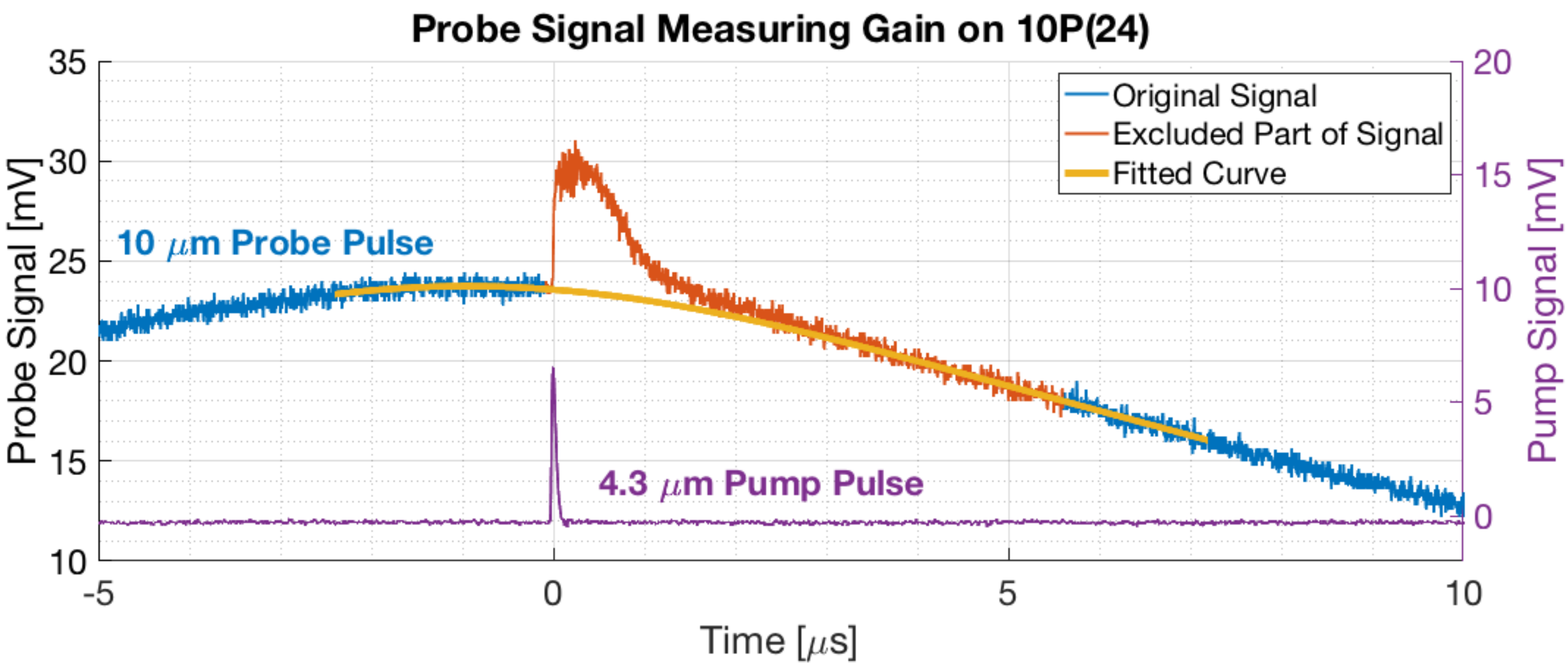
Example: small-signal gain measurement



- Ex: 50 torr pure CO_2 probed on 10P(24) rovibrational line
  → Lifetime ~1 us
- Estimated that for 10 atm, gain lifetime ~10s ns

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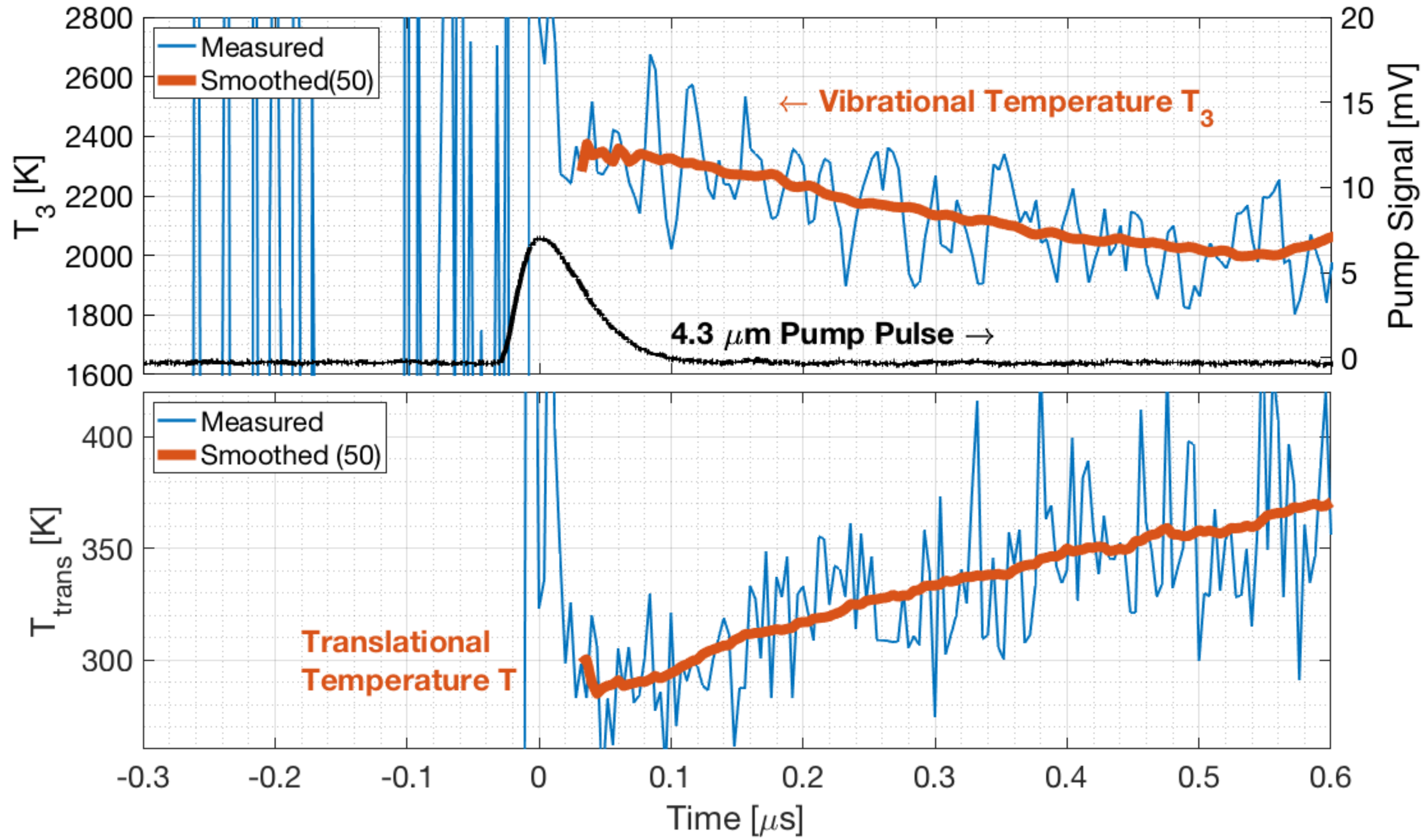
Time dynamics: 50 torr pure CO_2



- Just after pump pulse: $T_3 \approx 2400$ K, $T_{trans} \approx 300$ K
- Over time, asymmetric mode relaxes and energy goes to heat → T_3 decreases and T increases

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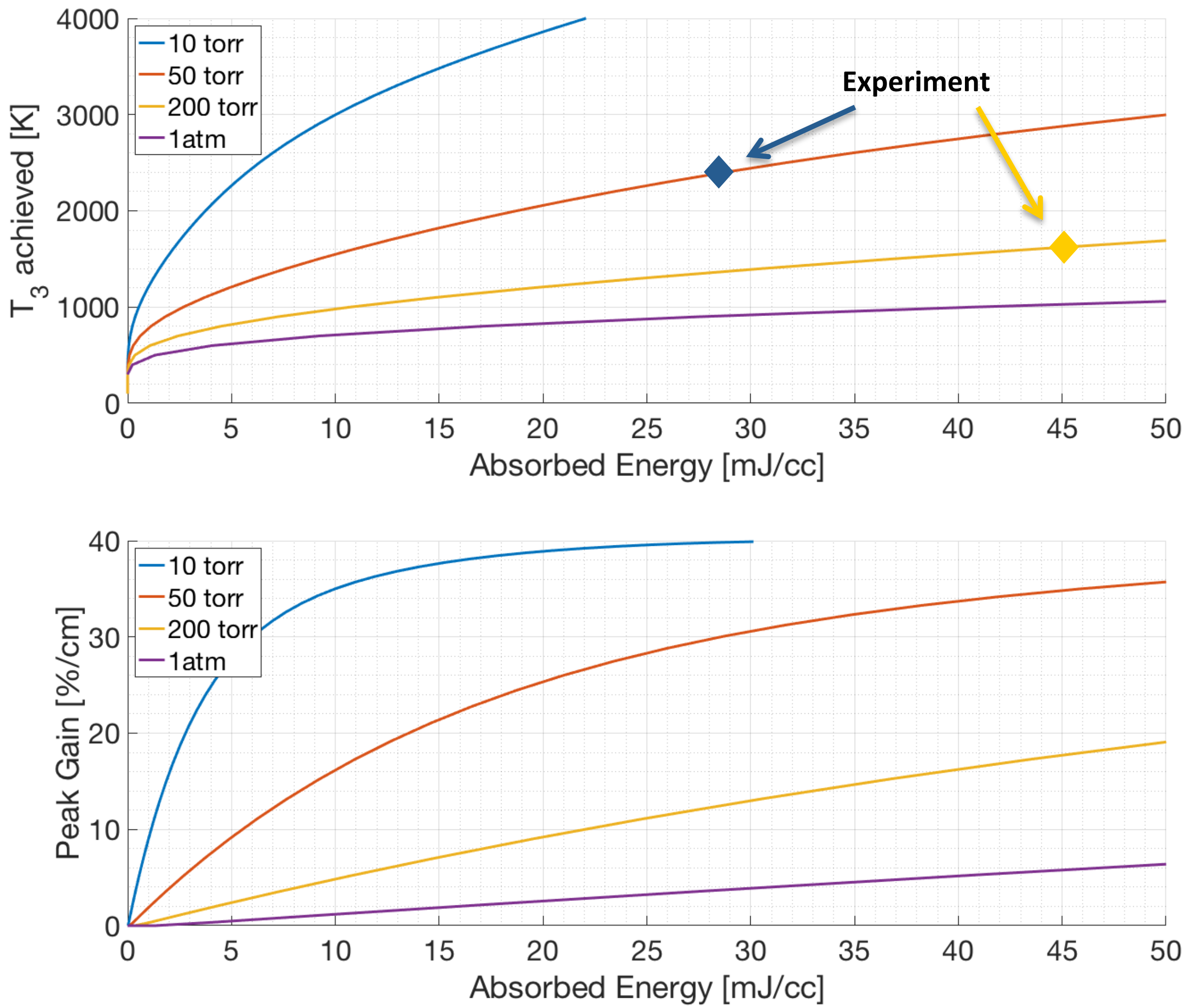
T_3 and Gain vs. Absorbed Energy



- Currently absorb ~30-40 mJ/cc with 2 mJ pump
- 200 mJ pump could allow us to reach T_3 >2000 K in 1 atm CO_2 mixes

← Showing peak gain in **pure CO_2**

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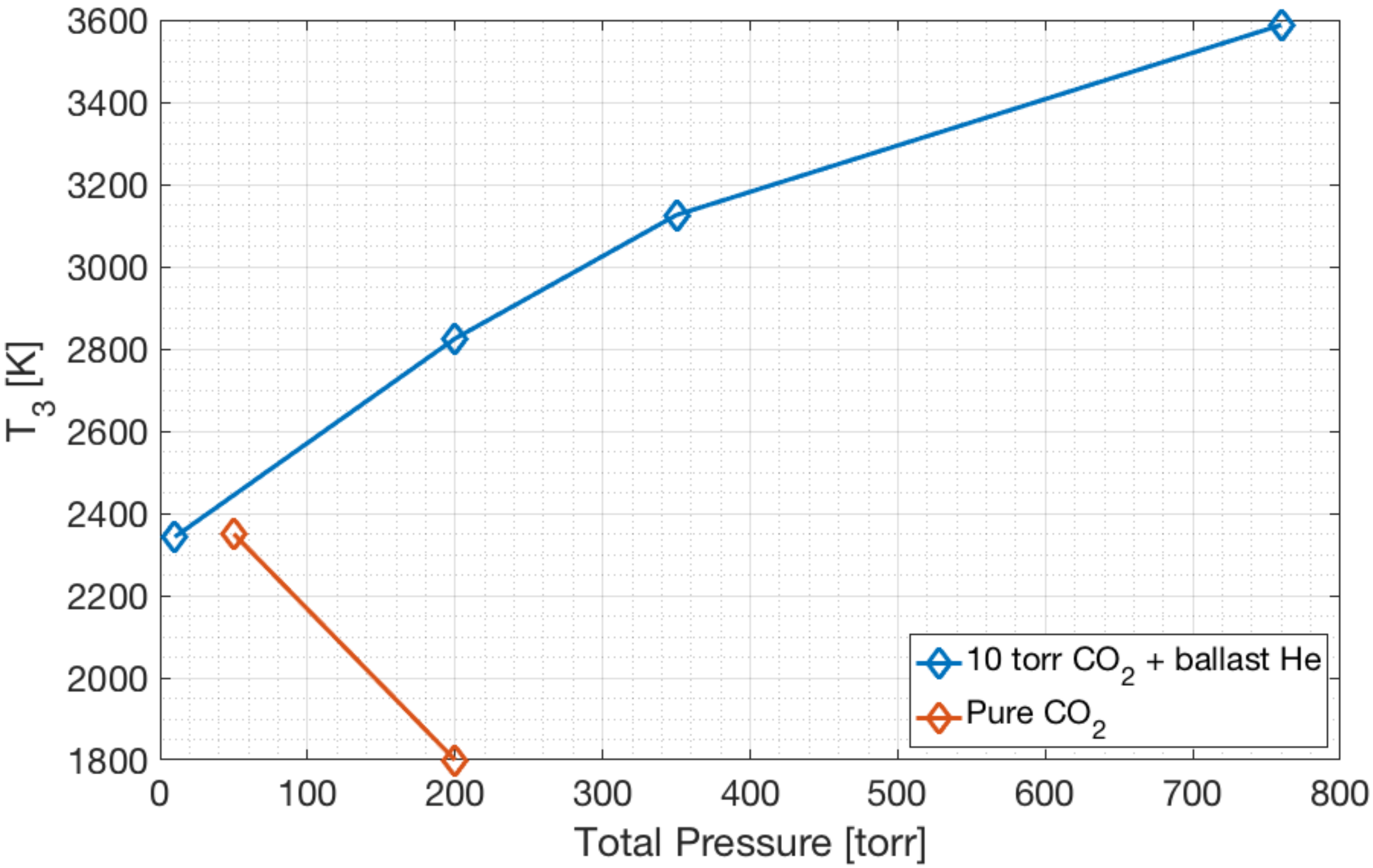
Experimental data: T_3 vs. Pressure



- Achieved T_3 > 3000 K in dilute mixes with 10 torr CO_2 with 2 mJ pump
- Corresponds to > 20 %/cm SSG − 10x larger than discharge pumped!

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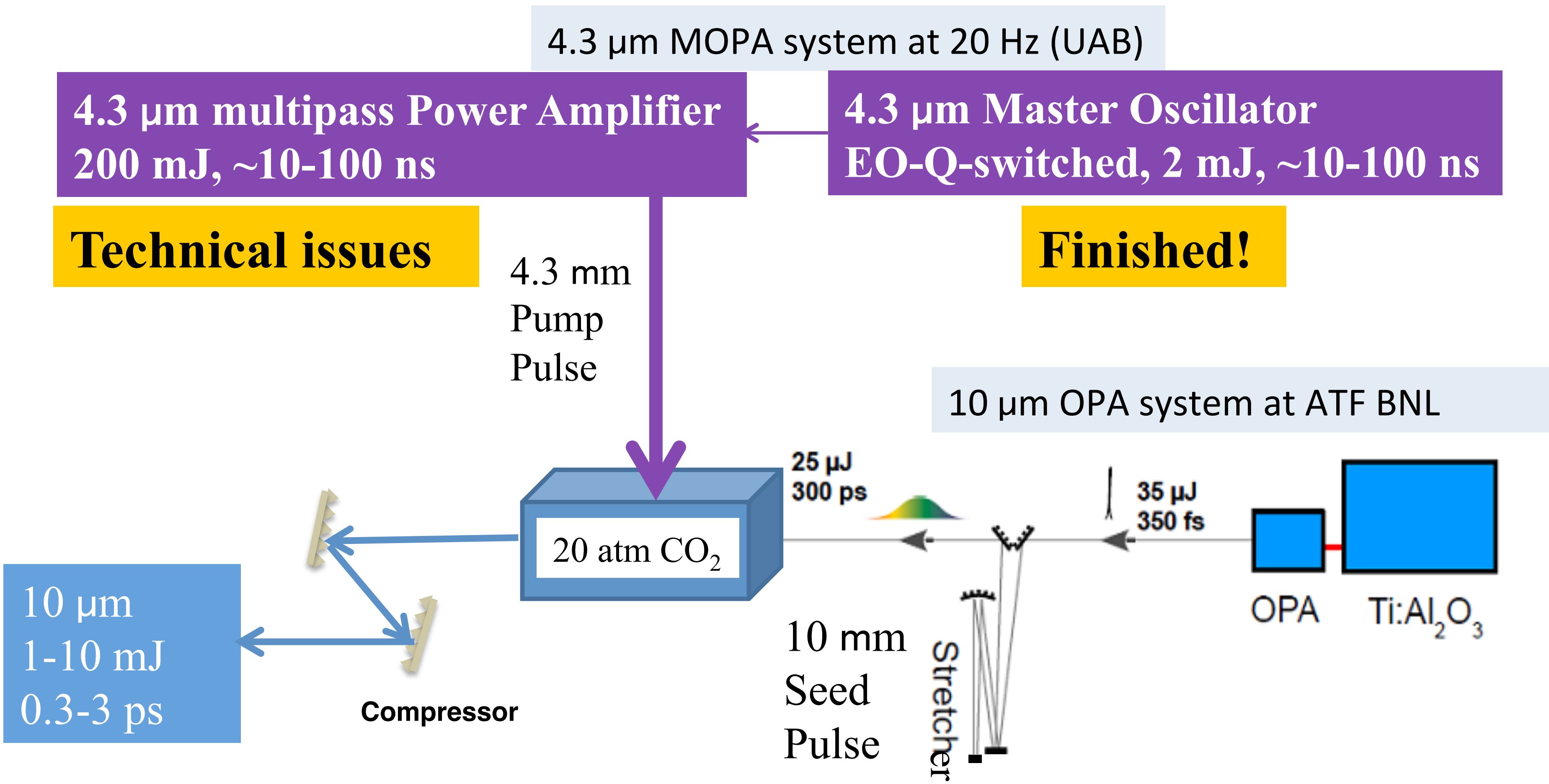
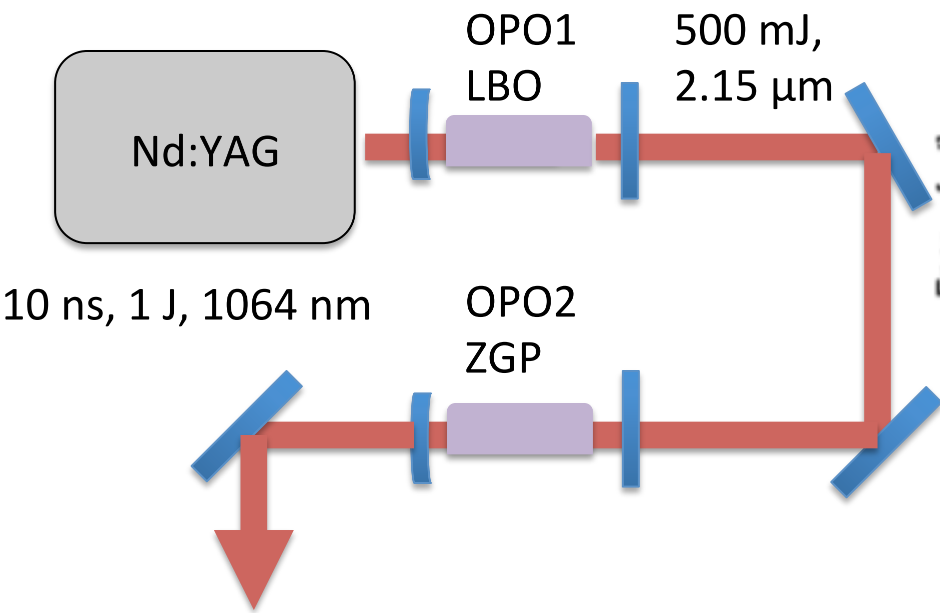
Multiatmosphere CO_2 laser at BNL Year 3



Proof-of-principle demonstration of a picosecond CO_2 OPML.

Pump laser plan B – Down conversion of Nd:YAG

1.064 µm X 4 = 4.26 µm



100 – 200 mJ, 4.26 µm

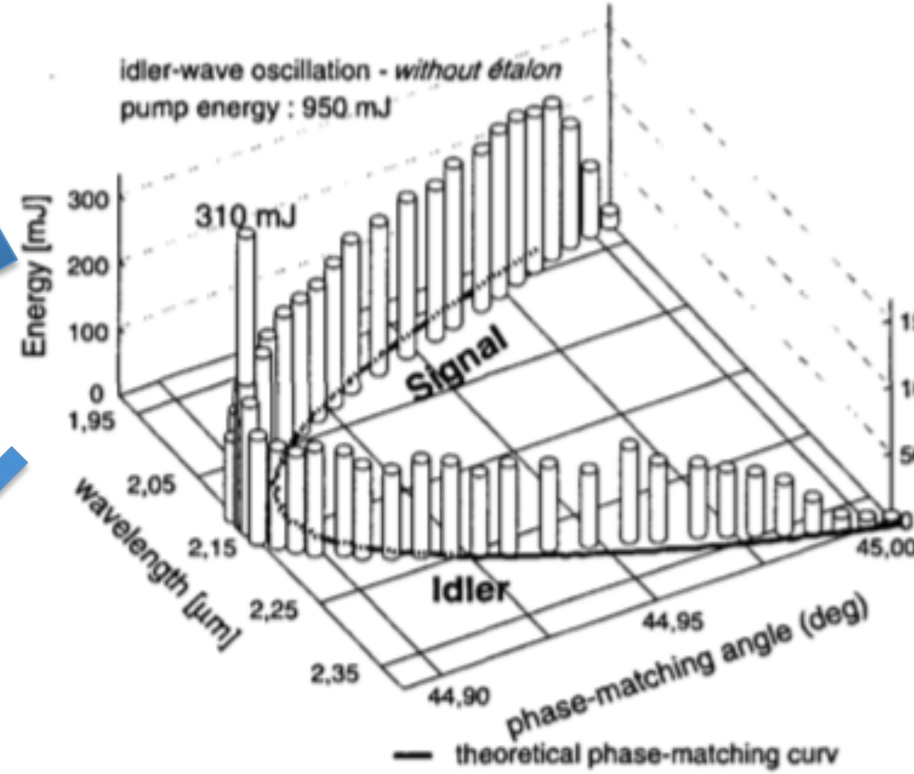


Fig. 2: OPO tunability

30% conversion efficiency has been demonstrated from 1.064 µm – 2.15 µm using J-class pulses

G. Mennerat and P. Kupecek, "High-energy narrow-linewidth tunable source in the mid infrared" OSA TOPS Vol. 19, *Advanced Solid State Lasers*, 269 - 272

2020 Experiment Time Estimates

Run Hours (include setup time in hours estimate):160 hours max 4 weeks
Number of electron beam only hours:None
Number of CO_2 laser hours delivered to laser experiment hall (”FEL room”):
Number of CO_2 laser hours, + ebeam, delivered to electron beam experiment hall:

Overall % setup time: 50-70%

Hazards & installation requirements:
Large installation (chamber, insertion device etc…): 4.3 µm Fe:ZnSe laser system
Laser use (other than CO_2): 4.3 µm Fe:ZnSe
Cryogens: LN
Introducing new magnetic elements: N
Introducing new materials into the beam path: N
Any other foreseeable beam line modifications: N

Please describe further where necessary

It is likely we will need an extension to perform experiments in 2021 due to delays with Fe:ZnSe power amplifier

Summary

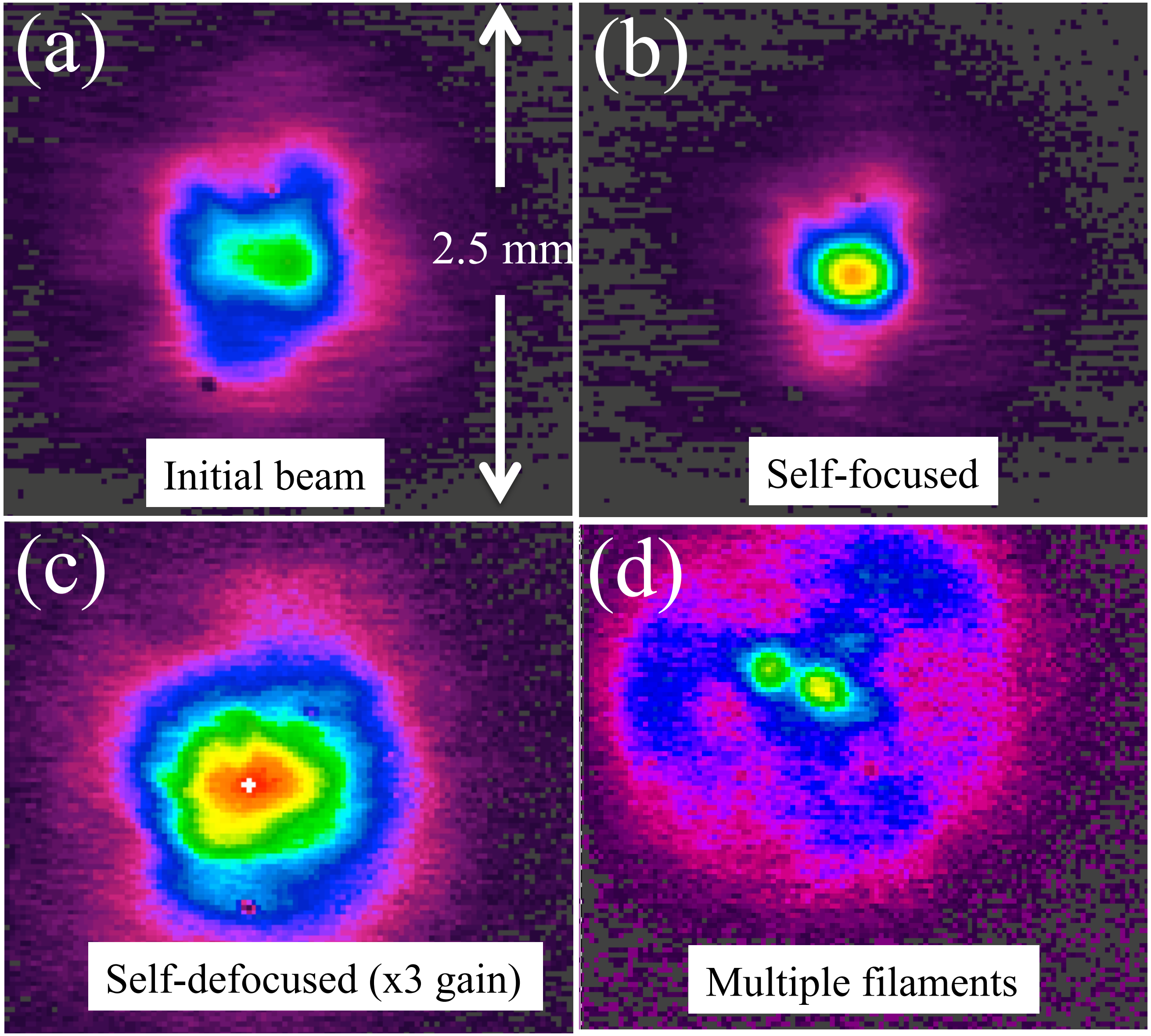
We have made important and necessary steps in AE85 experiment, a CO_2 Laser only, funded by DOE Accelerator Stewardship Program

- **Gain dynamics study in optically pumped CO_2 active medium pumped by a 2 mJ Fe:ZnSe laser indicates that a) a short 1-10 cm long cell is optimal (regenerative amplifier) to mitigate short lifetime with b) transverse pumping (line focus) to minimize self-focusing of pump c) T_3 > 4000 K with gain >20%/cm possible but requires ~ 200 mJ for high-pressure**

- **Next step in 2020 will be installation of a 100-300 mJ Fe:ZnSe laser system at BNL. Characterization of the system and study propagation of high-power 4.3 μm radiation in gases including air. Design and building a 1 cm long cell and start with lasing in the 10-20 atm CO_2-He medium.**

- **We request 3-4 weeks in 2020 (second half) using front end and maybe the 10 μm CO_2 regen.**

Nonlinear optics of CO_2 gas is an issue



Large n_2 ~10^{-12} cm^2/W for 100 torr CO_2 → **10 MW P_c in air**