

Cr⁺⁴:forsterite four-stage MOPA laser system for a high resolution MIR spectroscopy

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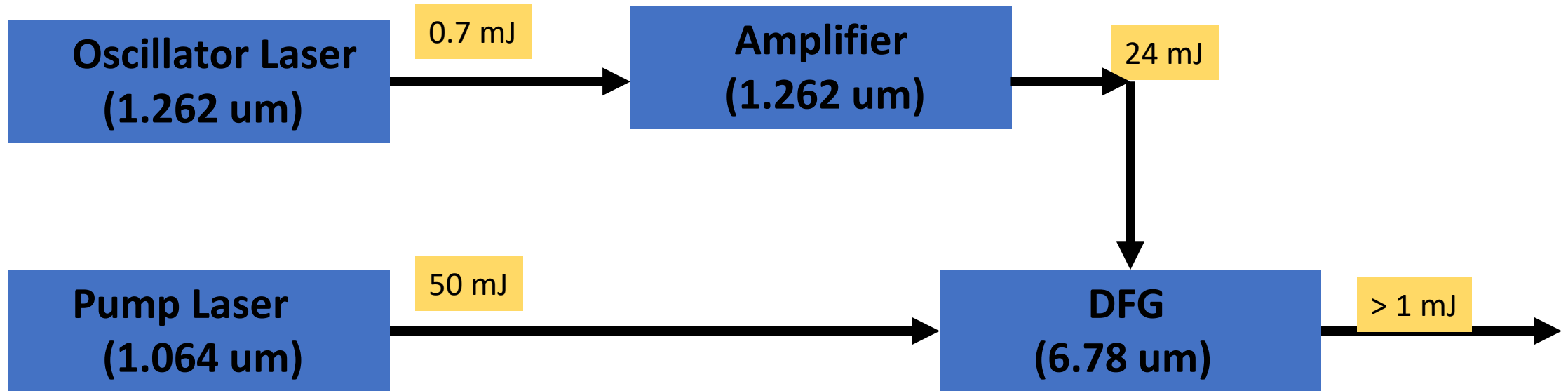
What are NIR and MIR lasers good for?

- Resonance Laser Ionization Spectroscopy
- Laser Isotope Separation
- Non- Linear Optical Processes
- **Muonic Hydrogen Atom Spectroscopy**

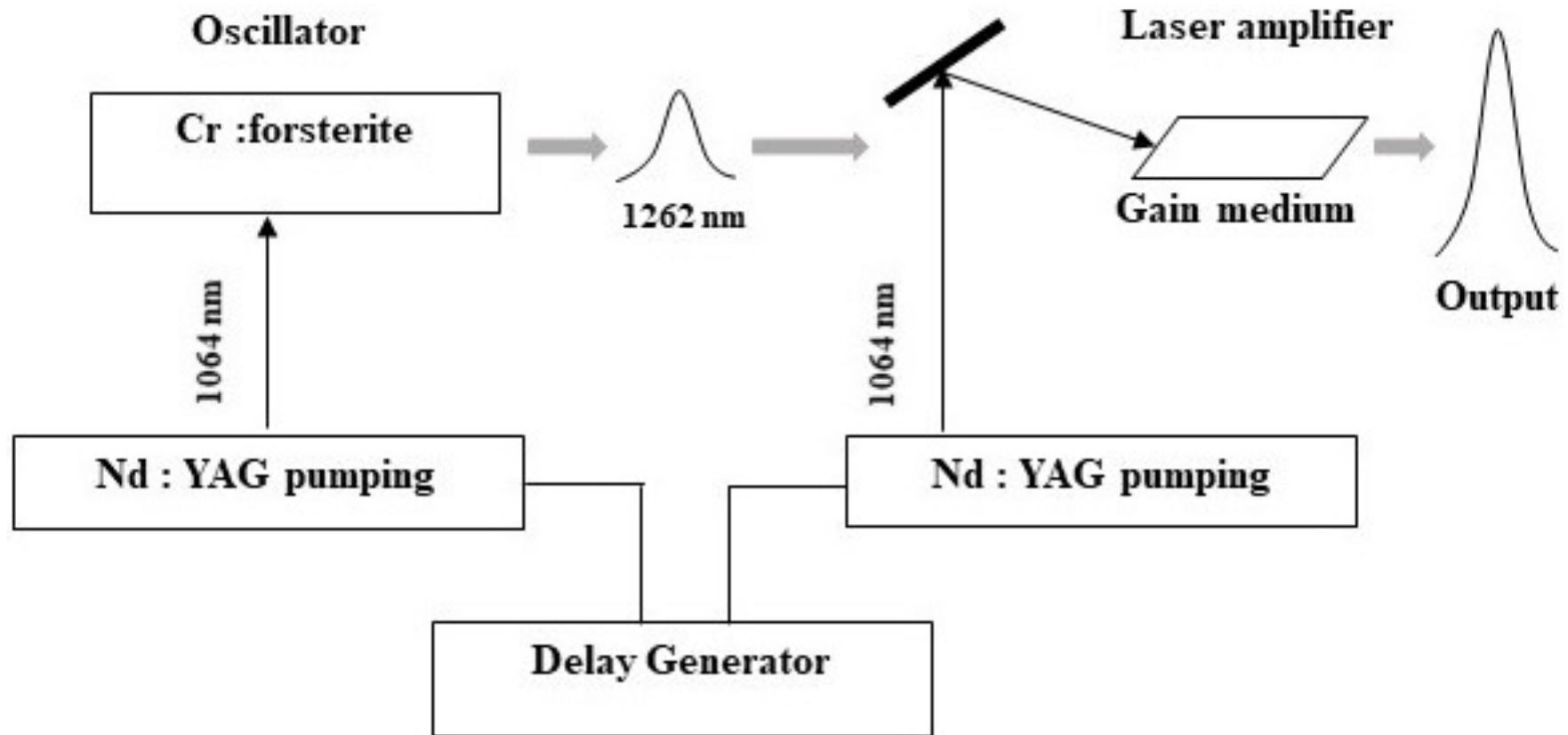
Chrome-Forsterite crystals ($\text{Mg}_2\text{SiO}_4:\text{Cr}^{4+}$)

- Narrow-band tunable emitted radiation: (NIR: 1150–1360nm)
- Continuous or pulsed mode-locking generation
- Broad absorption band wavelengths of many commercially available pump lasers.
- Suitable for nonlinear down-conversion to MIR
- FAMU needs: (>1.5 mJ) pulsed laser source, tunable around the 6785nm wavelength with a narrow linewidth output (<70 pm).

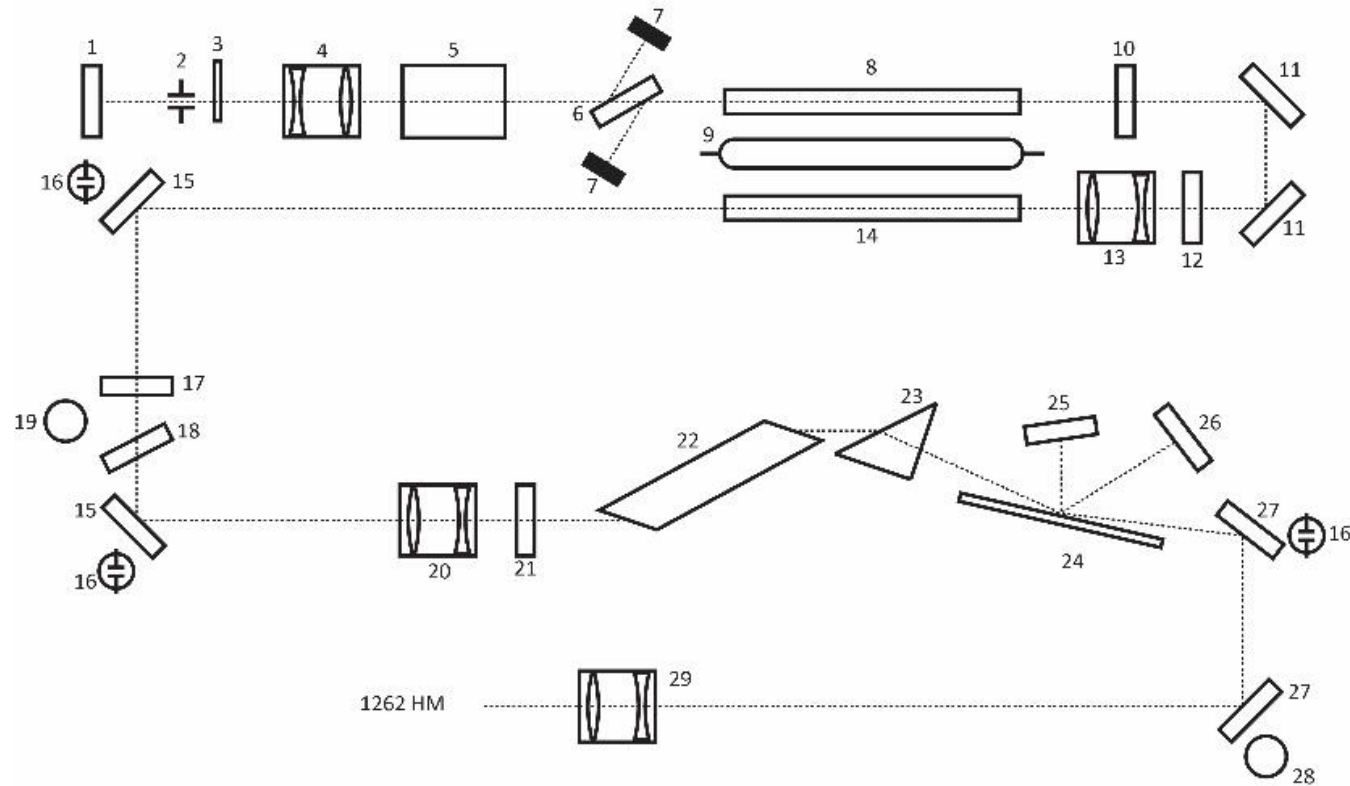
FAMU Laser System



Schematic diagram of the Cr⁴:forsterite oscillator-amplifier laser system.



Cr4:Forsterite Oscillator

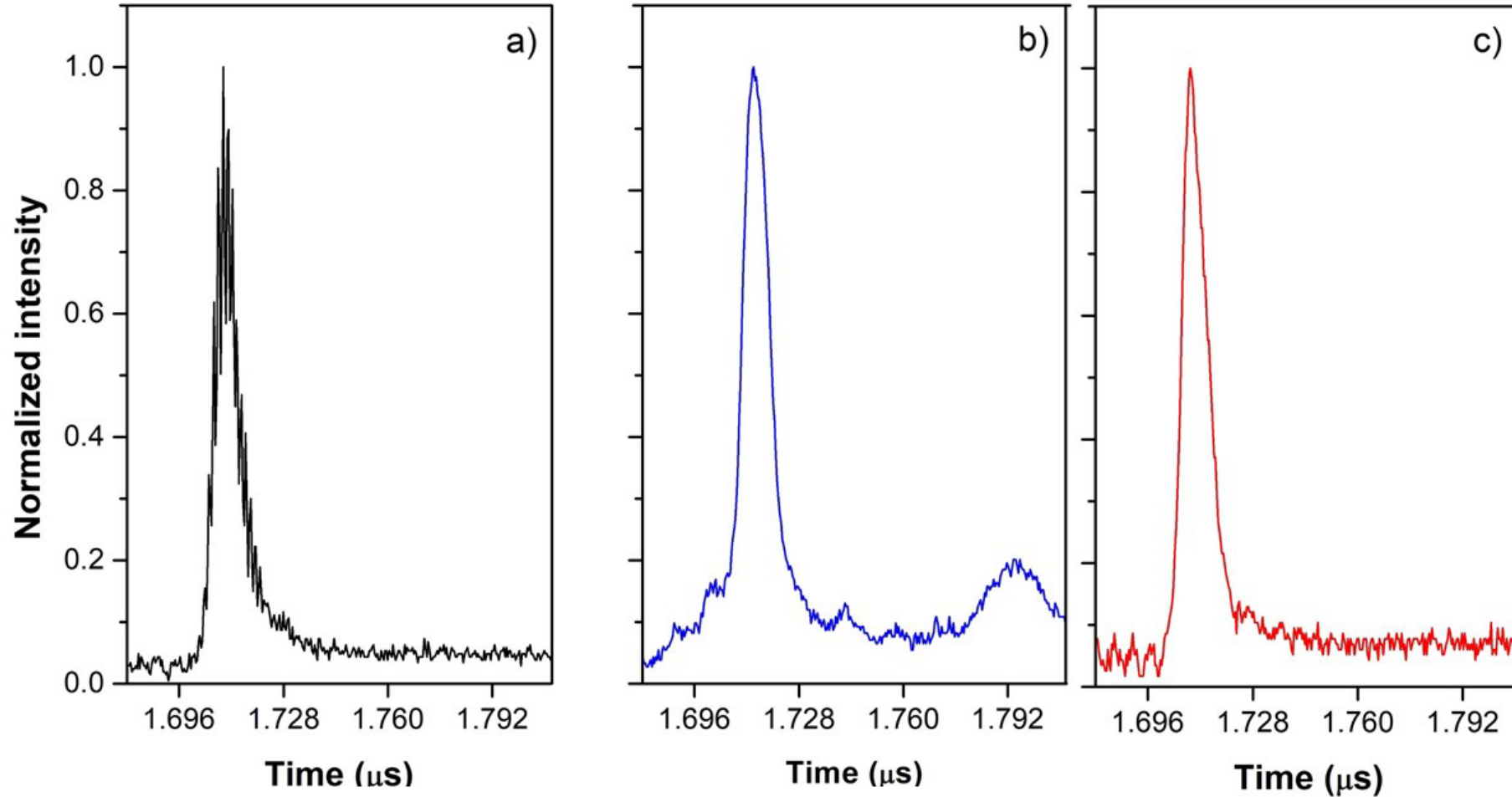


20: decreasing telescope, 21: input cavity mirror (1257-1267 nm), 22: Cr:forsterite AE, 23: right-angle prism (STK19 glass), 24: diffraction grating, 25: rear mirror (1257-1267 nm), 26: mirror (1257-1267 nm), 27: mirrors (1257-1267 nm), 28: beam stop, 29: increasing telescope.

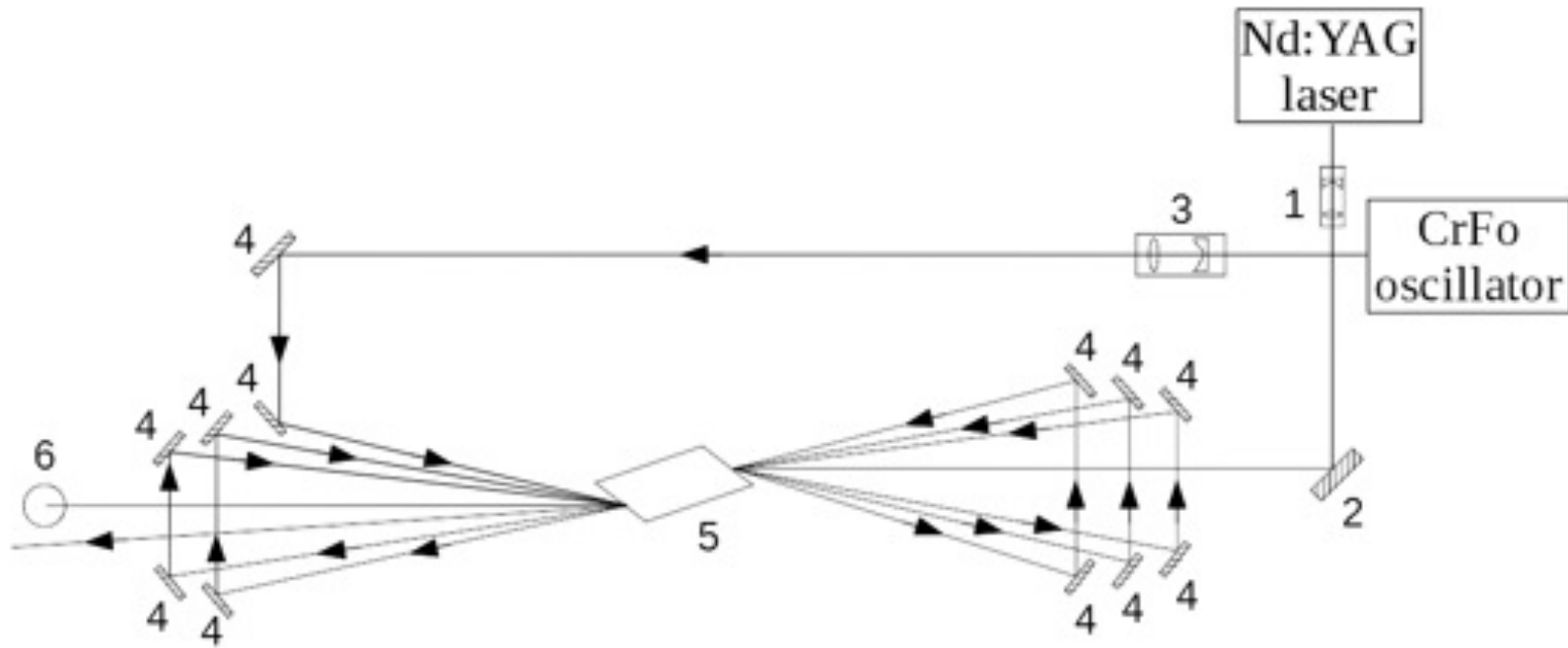
Oscillator beam

- Pulse rate: 25 Hz,
- tunable in the spectral range 1257–1267nm,
- Output Energy ~0.8–1.5 mJ
- stability of 2% RMS
- 7.5 ns pulse length
- timing jitter of ± 2.5 ns.

Oscillator beam

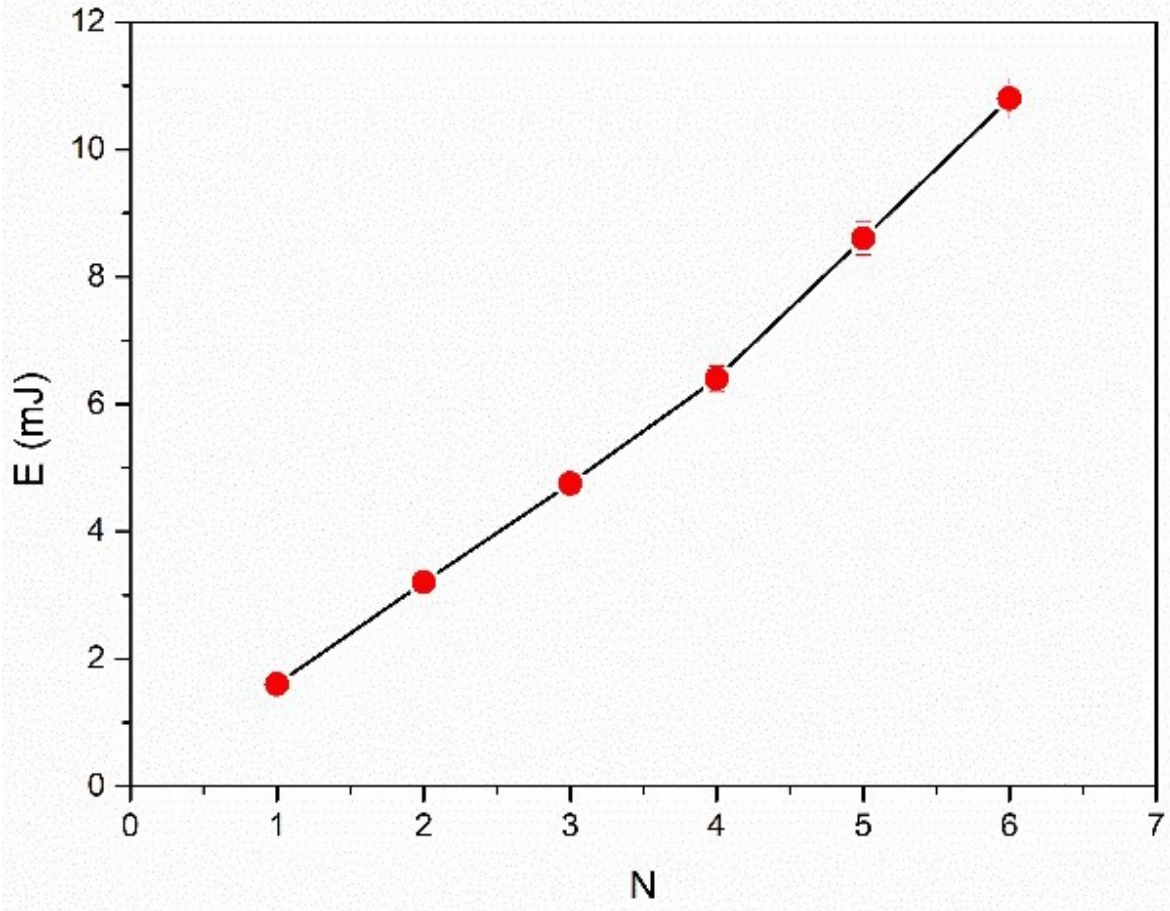


Amplifier

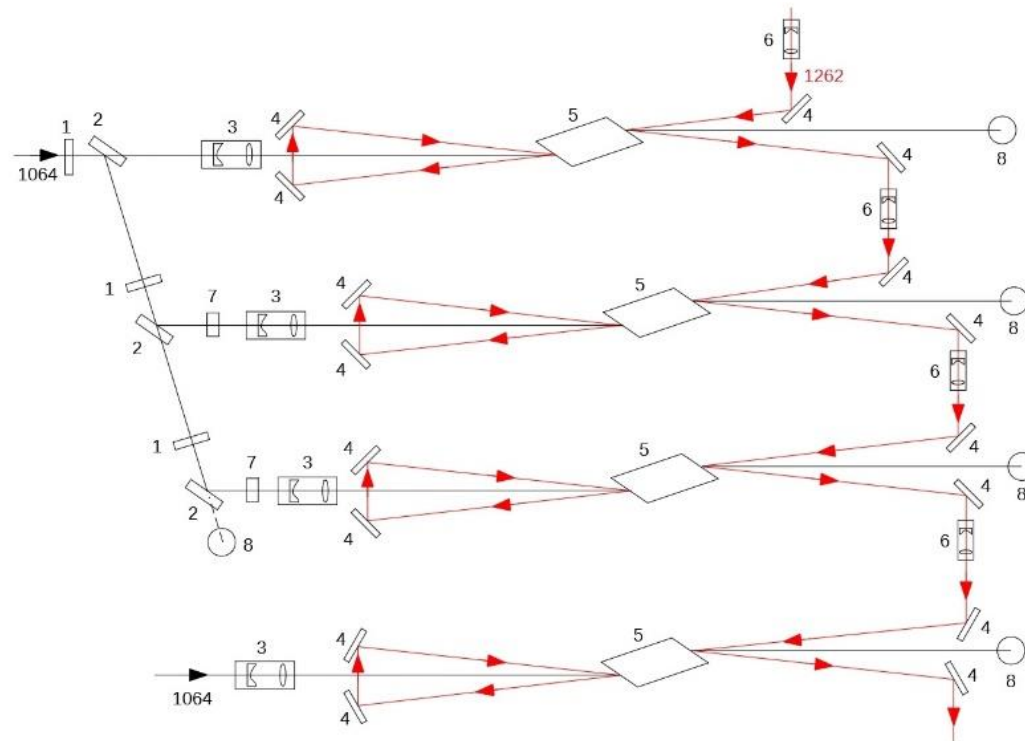


1: decreasing telescope 1064 nm, 2: turning mirror 1064 nm, 3: decreasing telescope 1262 nm. 4: turning mirrors 1257–1267 nm, 5: Cr:forsterite crystal, 6: beam stop.

Amplification curve



Multi-stage amplifier (MOPA)

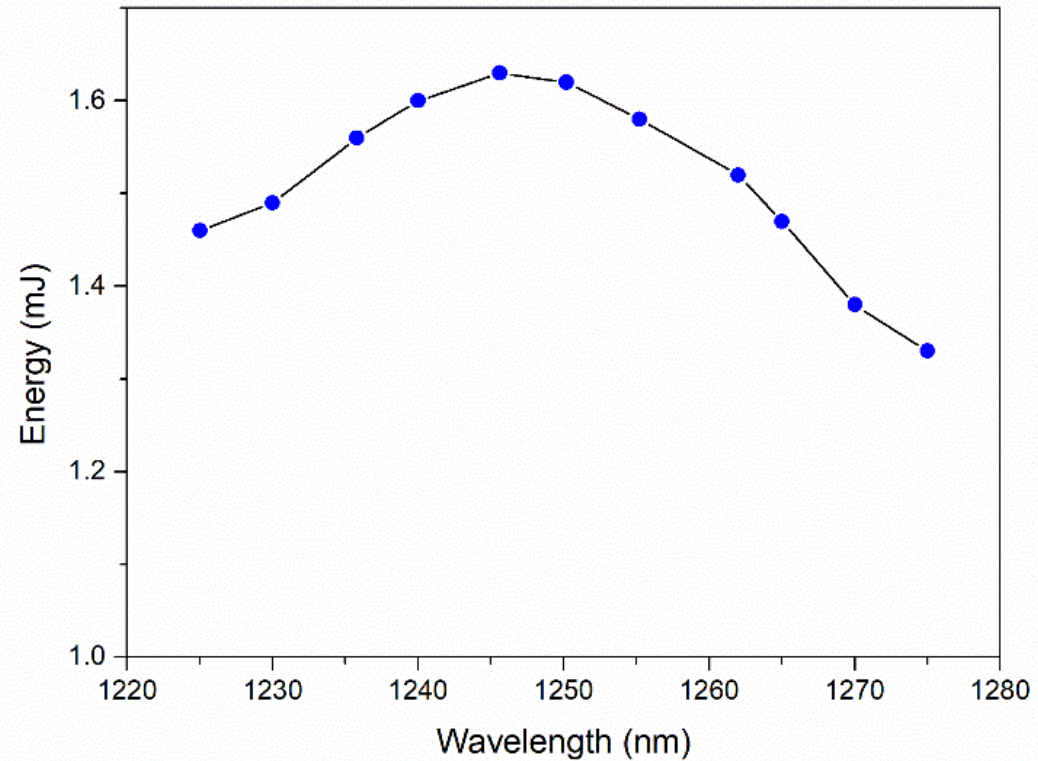


Multi-stages amplifier. 1: half-wave plate (1064 nm), 2: polarizer, 3: compressing telescope (1064 nm), 4: turning mirrors (1262 nm), 5: Cr:forsterite active element, 6: expanding telescope (1225-1275 nm), 8: beam stops.

Energy outputs of the MOPA

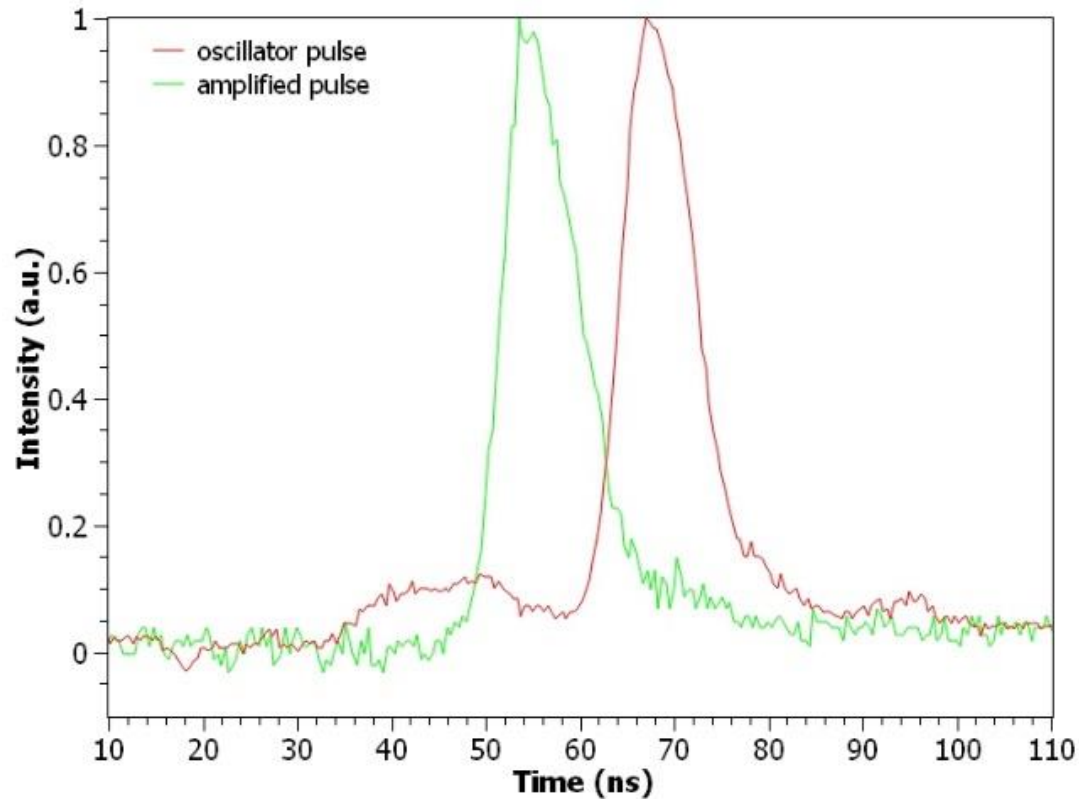
| N Stages | $E_{in}(1262 \text{ nm})$ mJ | $E_{out}(1262 \text{ nm})$ mJ | $E_d(1064 \text{ nm})$ J/cm ² |
|----------|------------------------------|-------------------------------|------------------------------------------|
| 1 | 1.50 | 2.70 | 1.2 |
| 2 | 2.70 | 5.50 | 0.94 |
| 3 | 5.50 | 13 | 0.88 |
| 4 | 13 | 24 | 0.7 |

Tunability of the MOPA



Energy output versus the wavelength of the single-mode Cr:forsterite oscillator.

Oscillator and amplified pulses



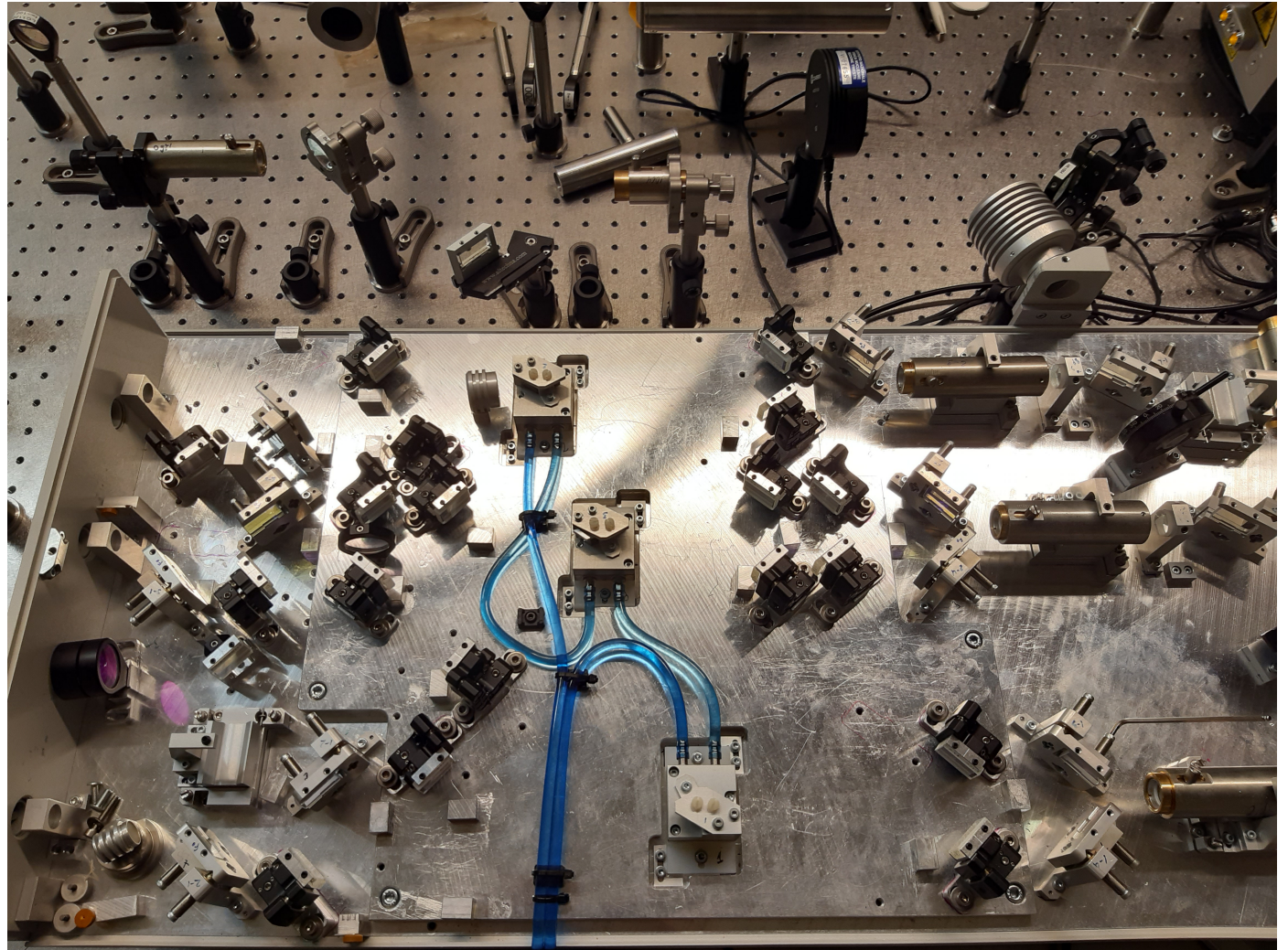
Pulse shape for oscillator and after the amplifier stages.

The oscillator pulse shape and the pulse after 8 passes in the amplifier

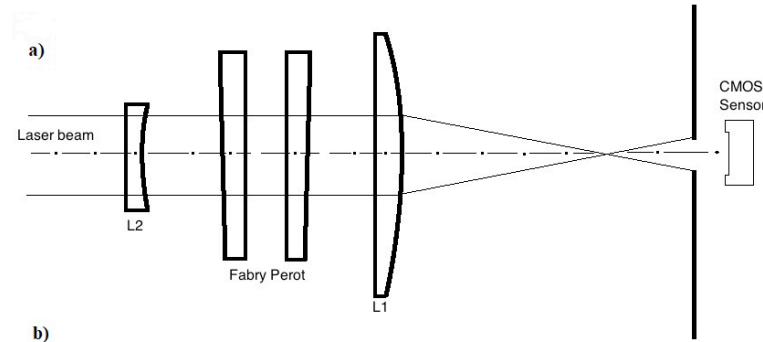
The pulse width was 9 ns (at FWHM) for the oscillator and the amplifier time jitter was ~ 2 ns.

3rd Configuration Amplifier

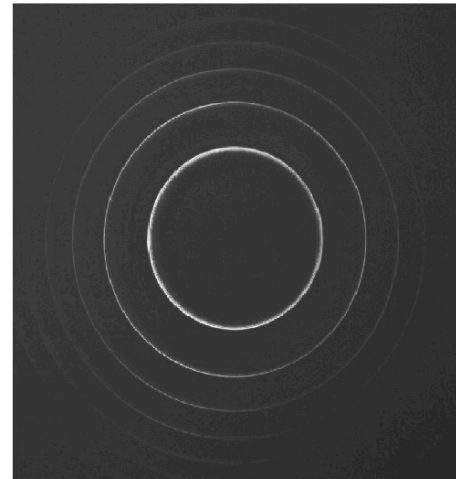
- 3 stages with 4, 6, and 4 passes respect.
- 32 mJ from 0.8mJ for a total gain of about 40.



Measuring beam parameters



$$\Delta\lambda = \lambda \frac{r\Delta r}{f_1^2}$$

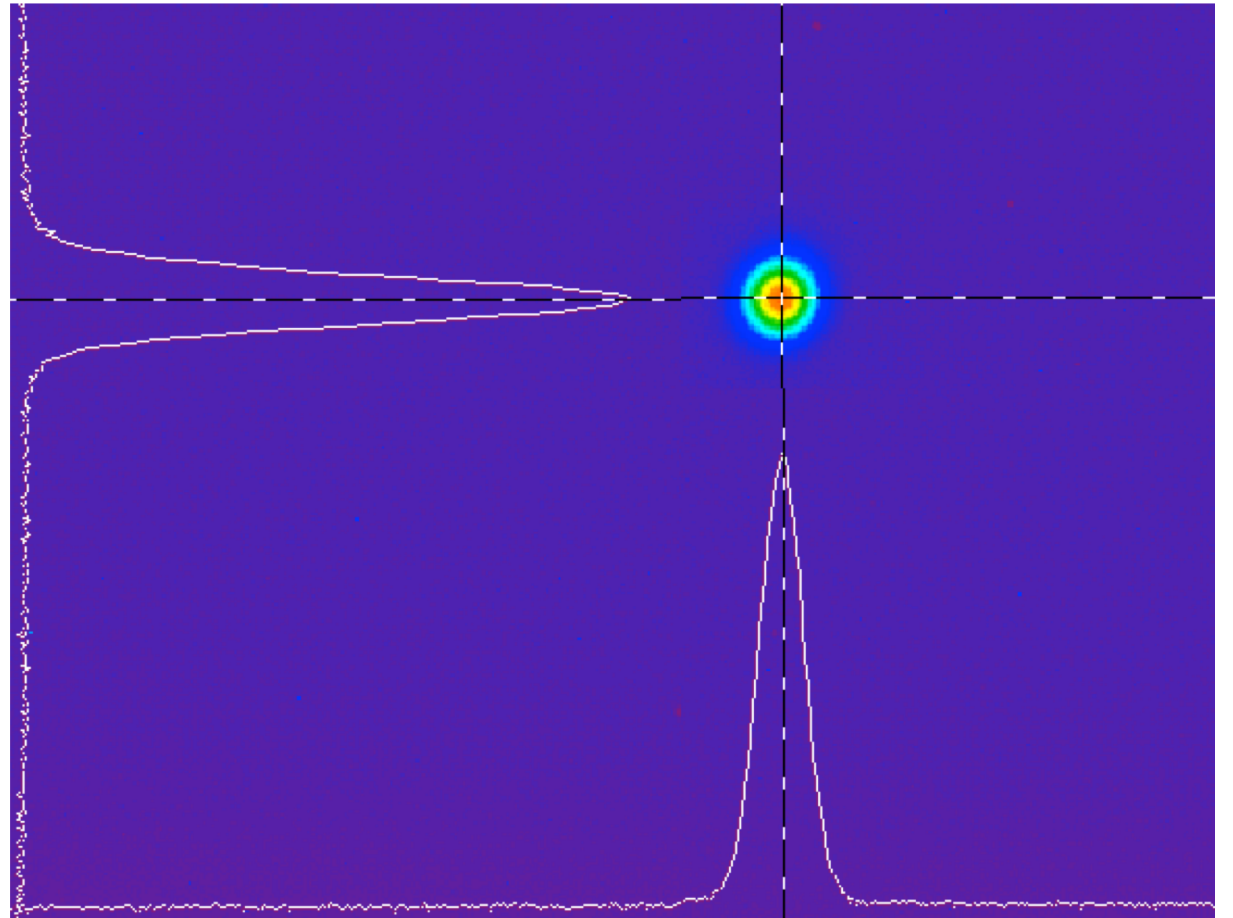


Linewidth:
 0.93 ± 0.18 and 1.10 ± 0.18 pm

L2: -30 cm diverging lens, *L1*: imaging lens. (b) FP Interference fringes for the oscillator in SLM operation.

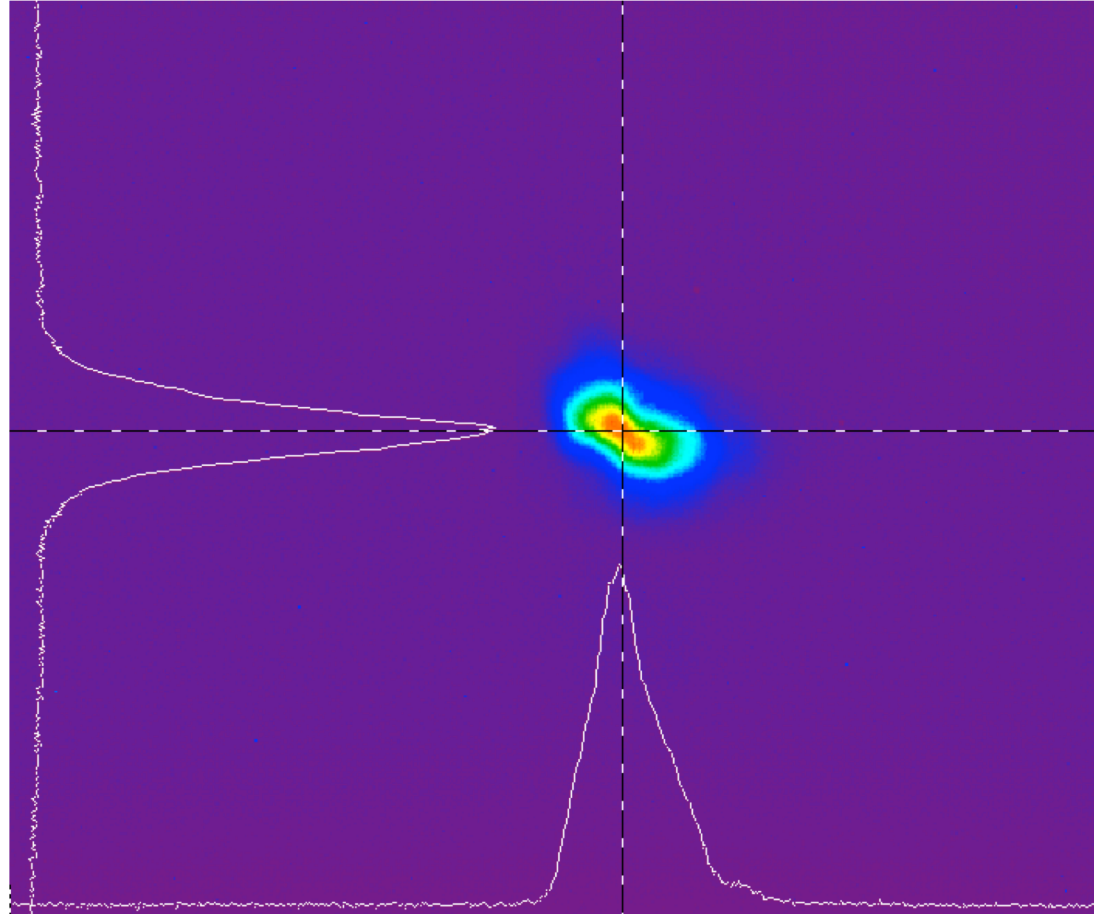
Amplifier Gaussian beam

M^2 value of 1.6 and 1.7

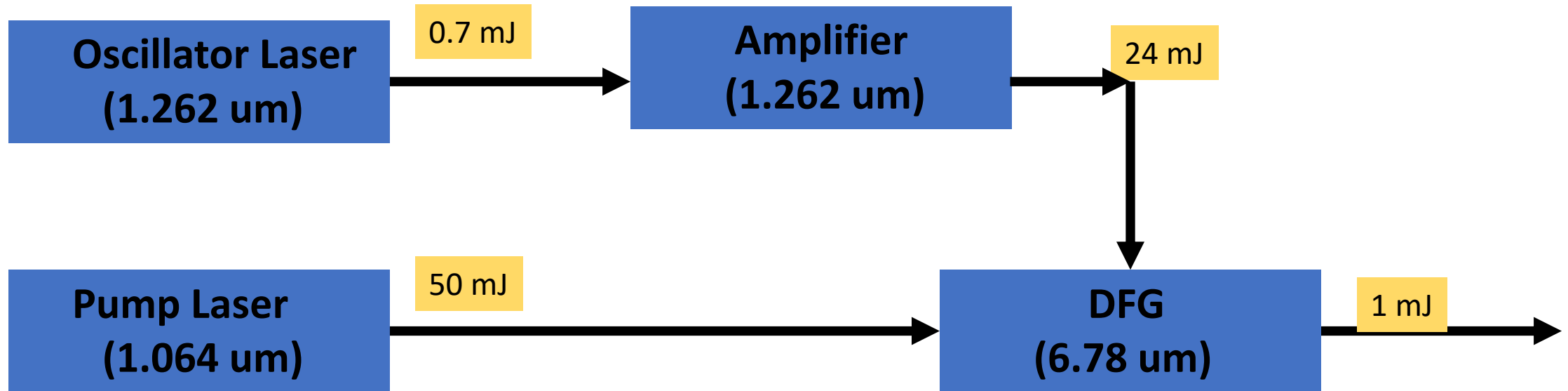


Non-gaussian deviations

M^2 value > 4

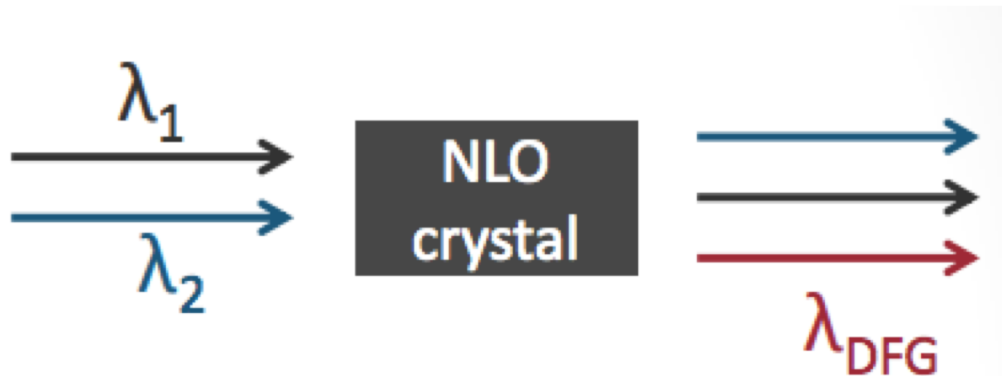


FAMU Laser System



DFG

- Required output > 1.5 mJ
- Output Wavelength: 6.758um
- Inputs: 20-40 mJ @ 1.064 nm and 25 mJ 1.262 nm

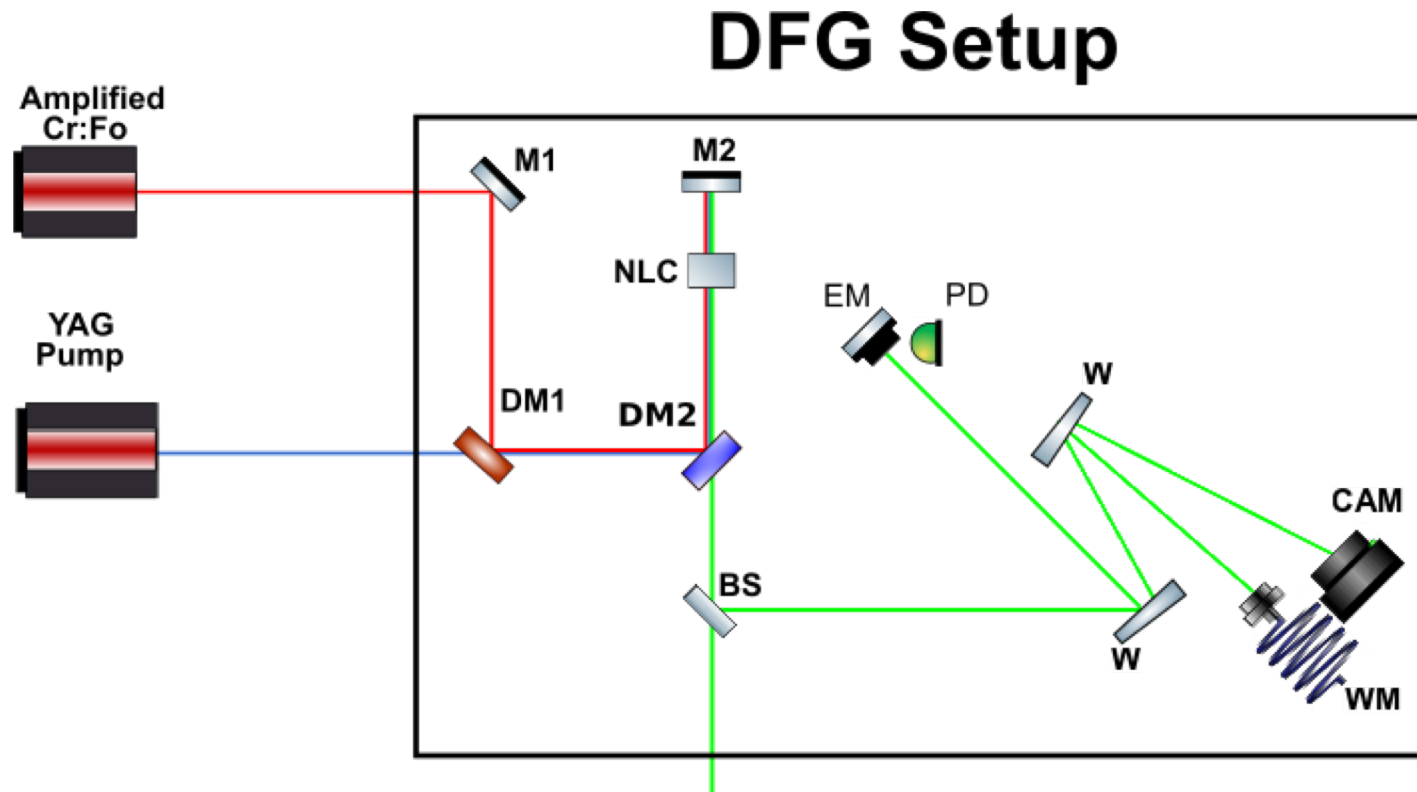


$$\lambda_{DFG}^{-1} = \lambda_1^{-1} - \lambda_2^{-1}$$

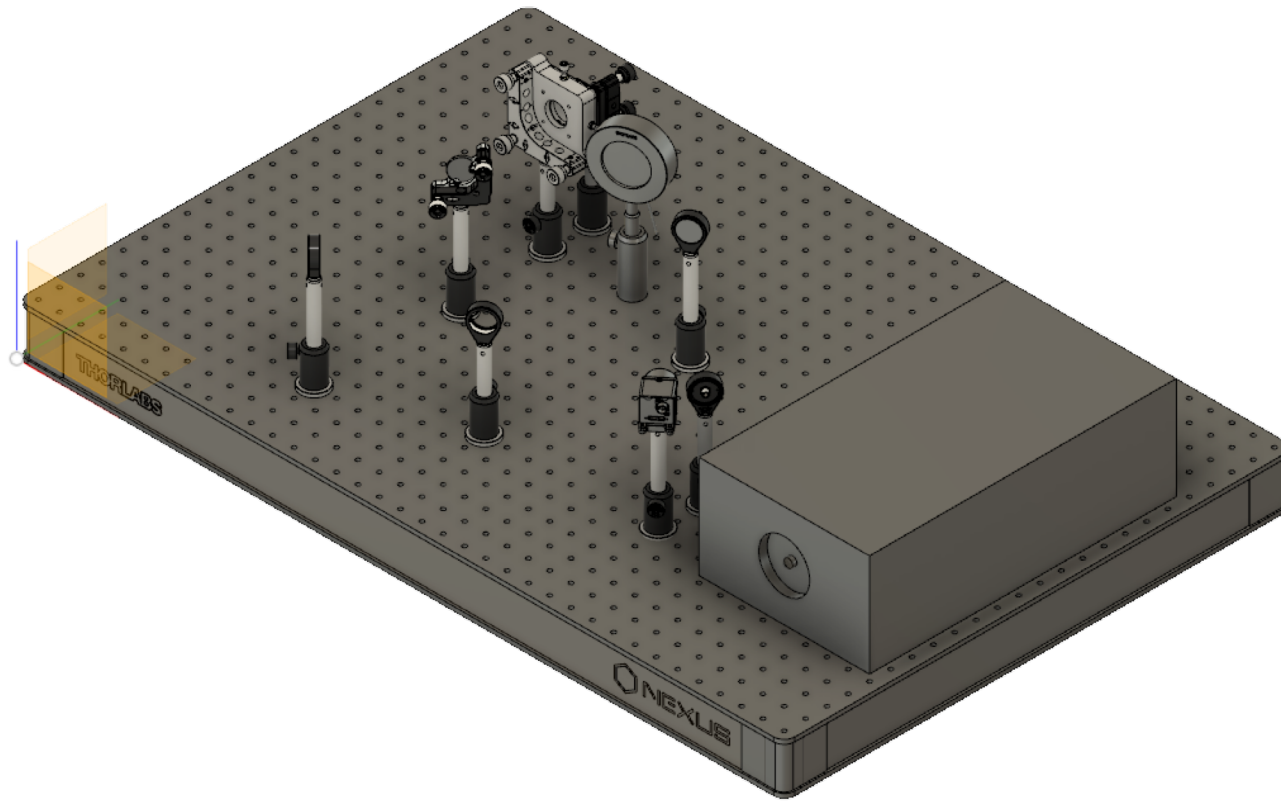
Monitoring energy budget

- WM -> 100uJ
- EM -> 300 nJ
- PD -> small reflections
- Camera -> 0.5 nJ/px (sensitivity)

Box optical diagram



CAD open box



References

- Stoychev et al. “DFG-based mid-IR laser system for muonic-hydrogen spectroscopy” *Proc. SPIE* 9135 91350J, 2014
- Stoychev et al. “Pulse amplification in a Cr⁴⁺:forsterite single longitudinal mode (SLM) multi-pass amplifier. *Laser Physics* 29, 065801, 2019.
- Stoychev et al. “24 mJ Cr⁴⁺:forsterite four-stage MOPA laser system for a high resolution MIR spectroscopy” *Rev. Sci. Instr.* (In press, Aug 2019)