# High Energy 2-micron Laser Developments

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2007 Solid State Diode Laser Technology Review

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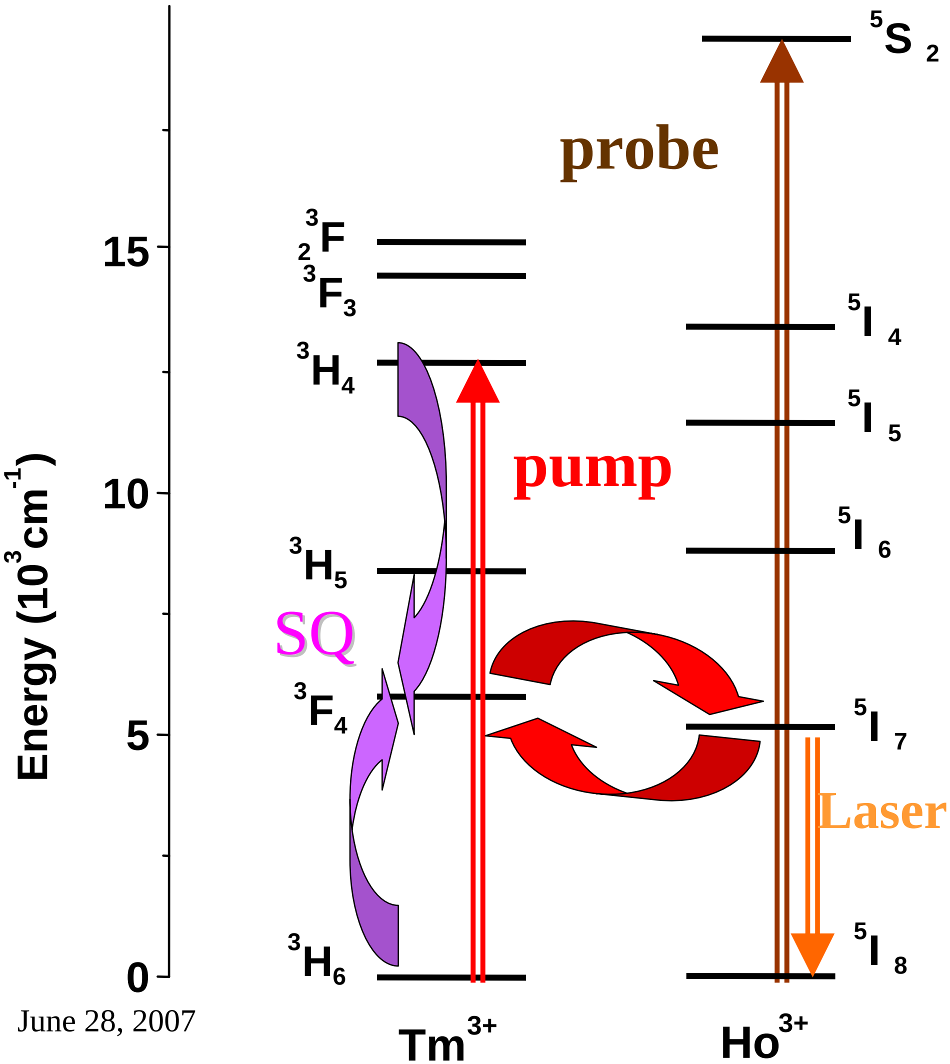
# Outline

- Overview 2-micron solid state lasers
- Modeling and population inversion measurement
- Side pump oscillator
- One Joule 2-μm Laser
- Conclusion

# Solid State 2-micron Lasers

- Tm Lasers (pump diodes 780-805nm)
  - YAG, YLF, $YAlO_3$, $YVO_4$
- **Ho:Tm Lasers** (pump diodes 780-805nm)
  - LuLF, YLF, GdLF, YAG, $YVO_4$
- Tm pumped Ho lasers (pump diodes 780nm)
  - Tm solid state laser pumped Ho Laser
  - Tm fiber laser pumped Ho Laser
- Ho Lasers (pump diodes 1900nm)
  - YAG
- Tm Fiber Lasers

# Energy transfers between $Ho^{3+}$ and $Tm^{3+}$ ions and Pump-probe experiment



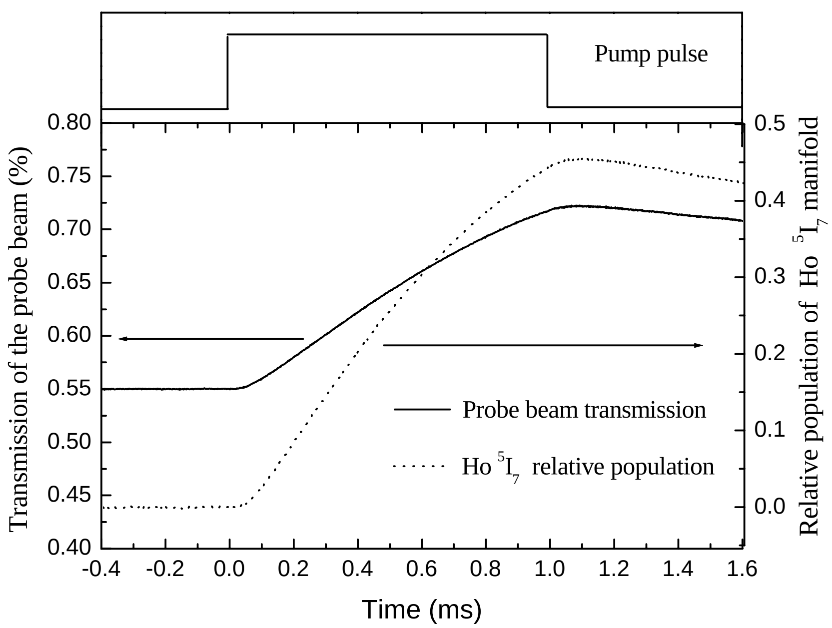

- **Pump at 792nm ( $^3H_6 \rightarrow {}^3H_4$ transition)**

- **Energy transfers :**
  - Self-quenching ($P_{SQ}$)
    two $Tm^{3+}$ ions in the $^3F_4$ manifold
  - ($^3F_4 \Rightarrow {}^5I_7$ ) energy transfer ($P(Tm \rightarrow Ho)$ )
  - ($^5I_7 \Rightarrow {}^3F_4$ ) energy transfer ($P(Ho \rightarrow Tm)$ )
  - Ho , Tm upconversion ($P_{UC}$ )

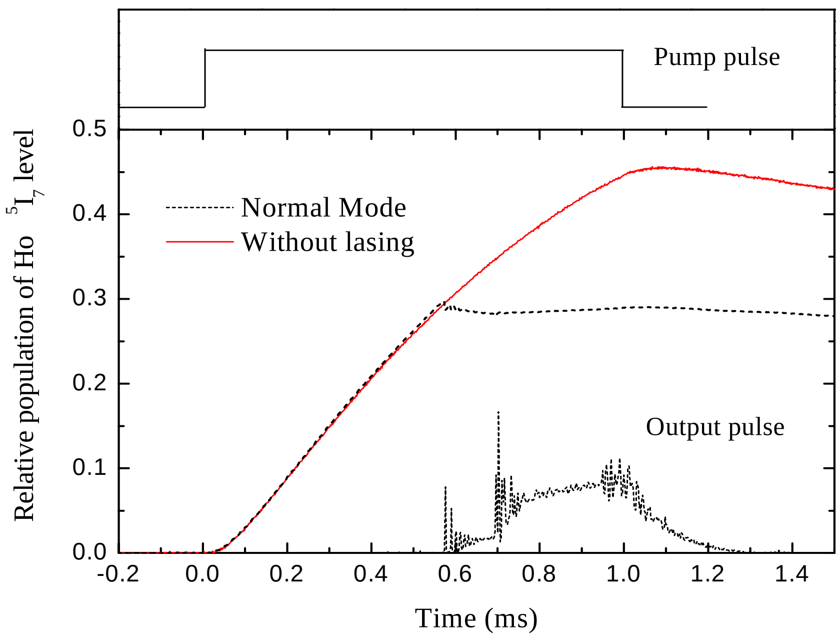
- **Probe at 543nm ($^5I_8 \rightarrow {}^5S_2$ transition)**
  - **Probe the $^5I_8$ ground-state depletion**

# Evolution of the probe beam transmission and the corresponding population of the Ho $^5I_7$ manifold

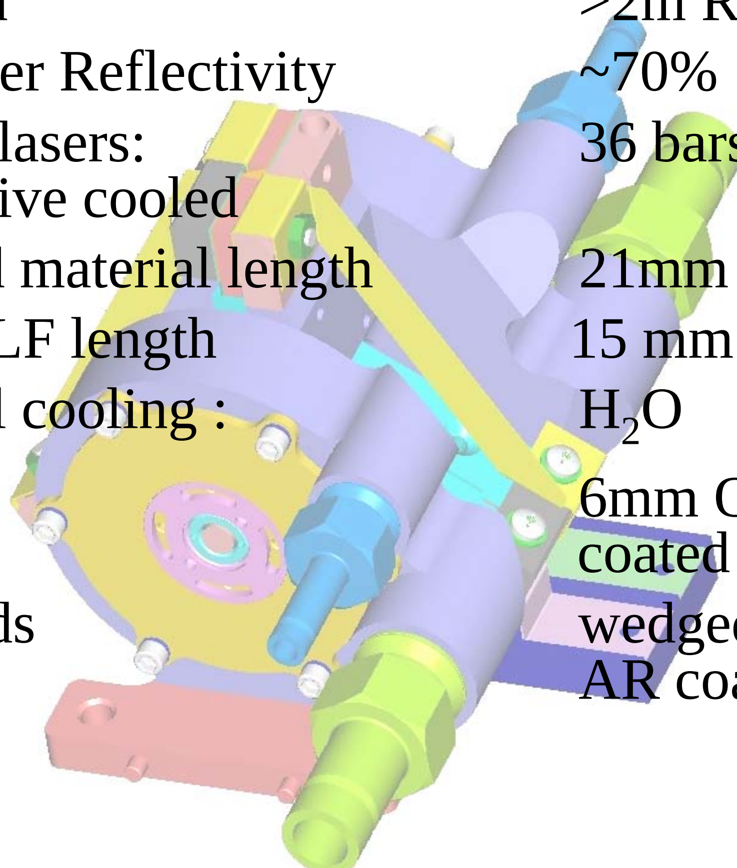
## Probe beam transmission and the population of the Ho $5I_7$ manifold




## Ho $5I_7$ population at lasing and without lasing condition

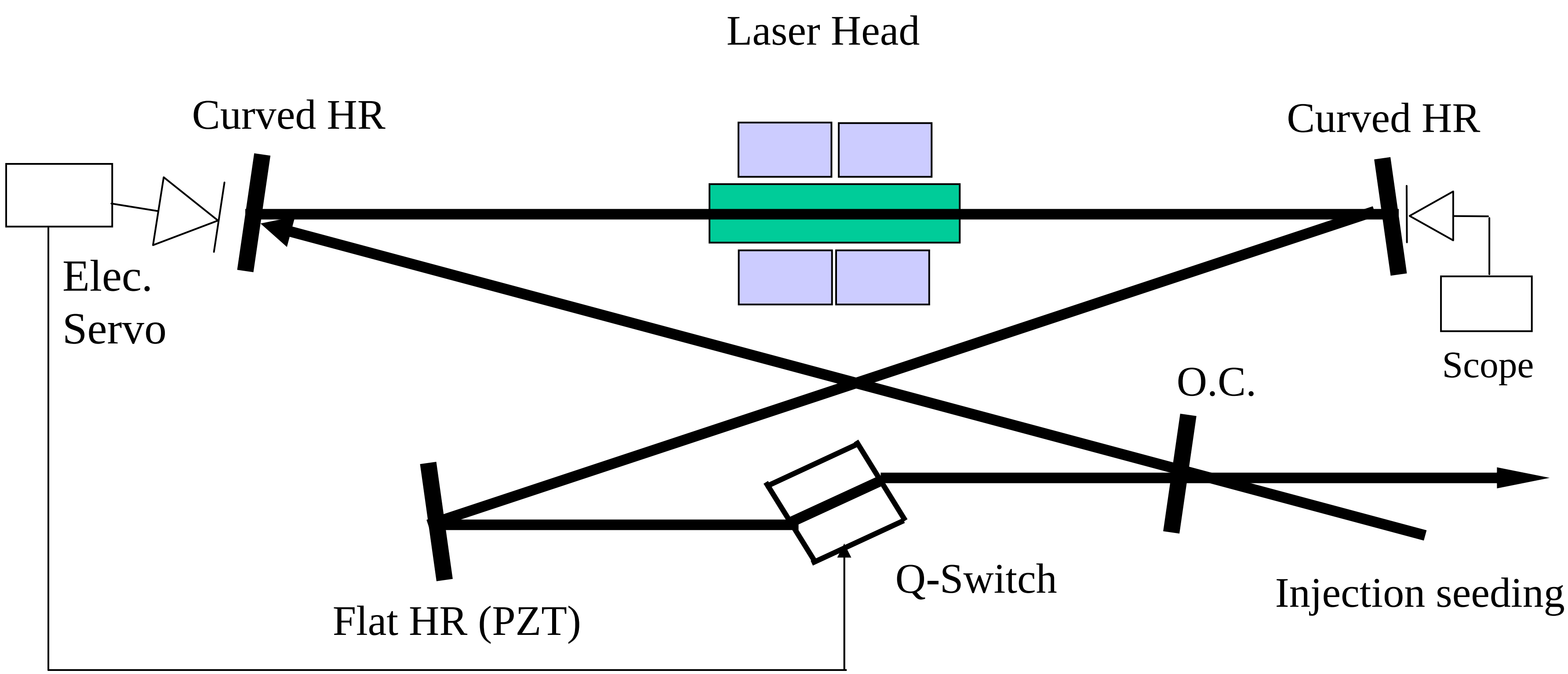


# Oscillator features



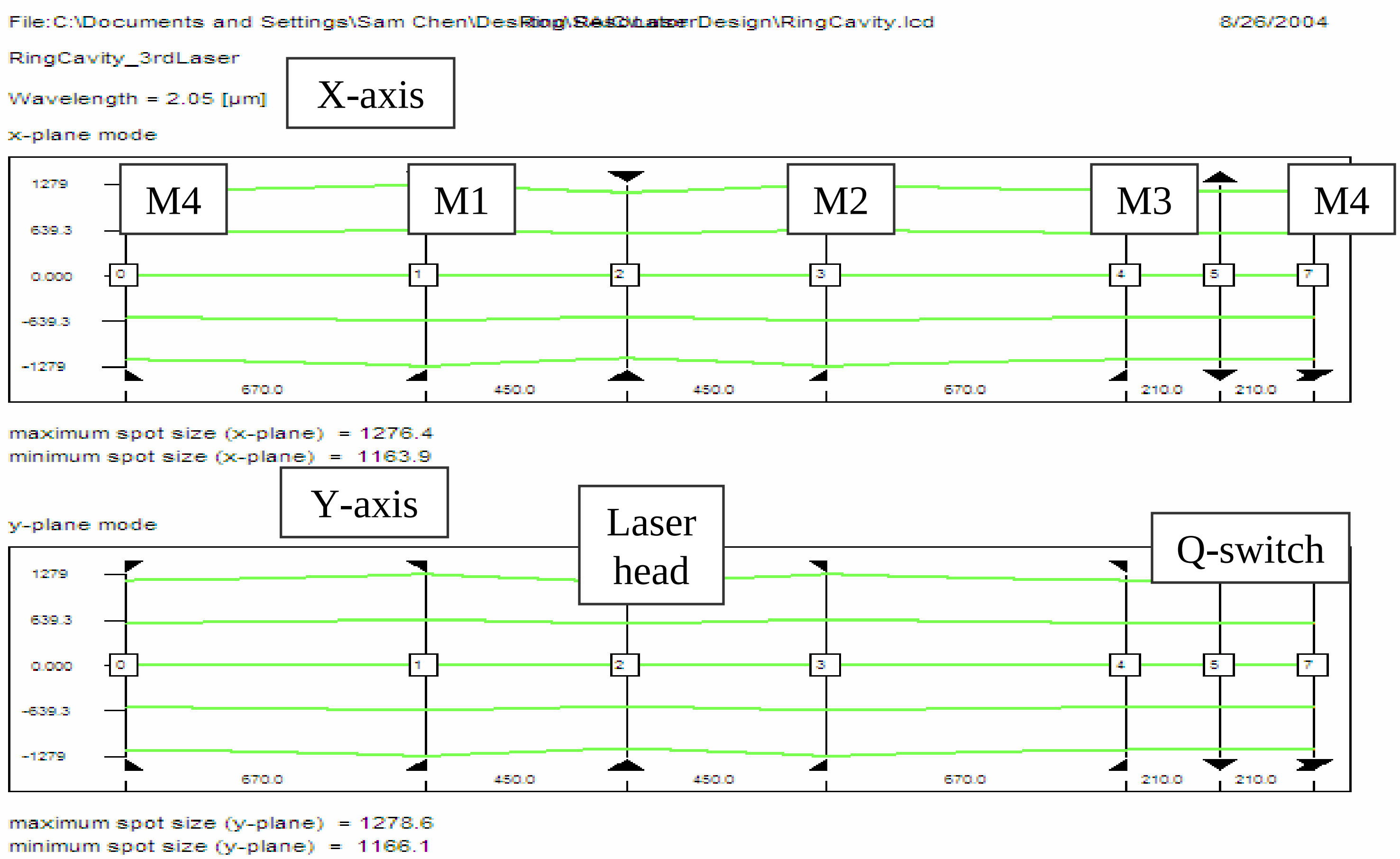
- Injection seeded
- Cavity length — >2m Ring
- Output coupler Reflectivity — ~70%
- Diode pump lasers: conductive cooled — 36 bars 100W/bar
- crystal doped material length — 21mm
- undoped LuLF length — 15 mm
- Laser crystal cooling : — $H_2O$
- Tube size: — 6mm OD 5mm ID AR coated for 792nm
- Laser rod ends — wedged 0.5° along c-axis AR coated for 2.053μm

# Laser Oscillator Ring Cavity

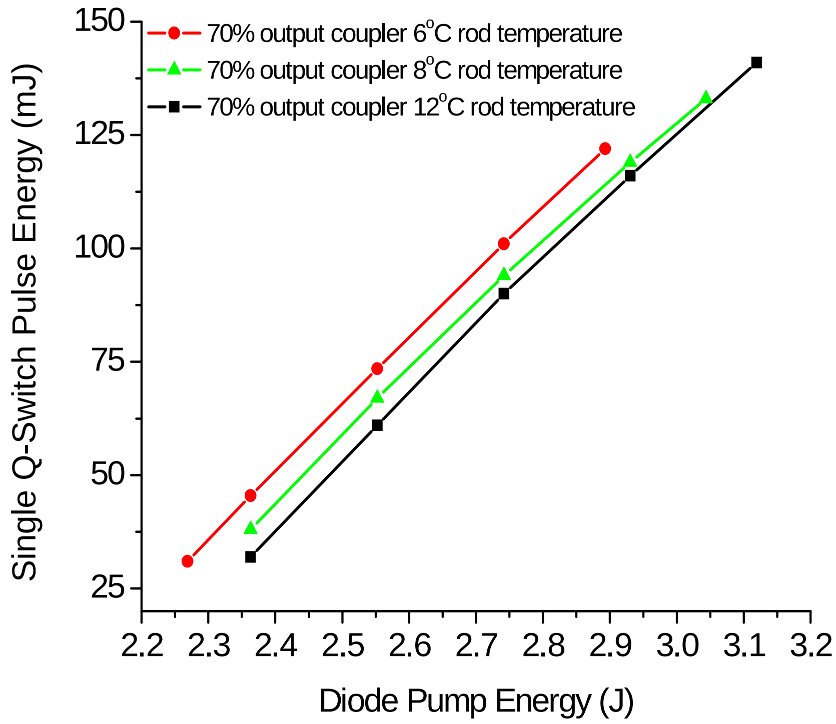


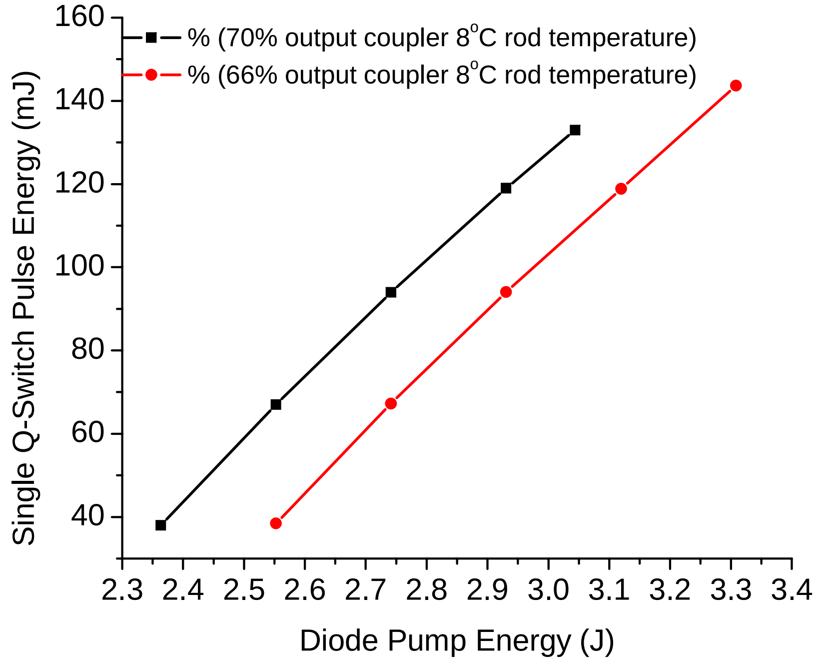
# Cavity Mode Simulation

## (Ring Cavity with two curved high reflectors)

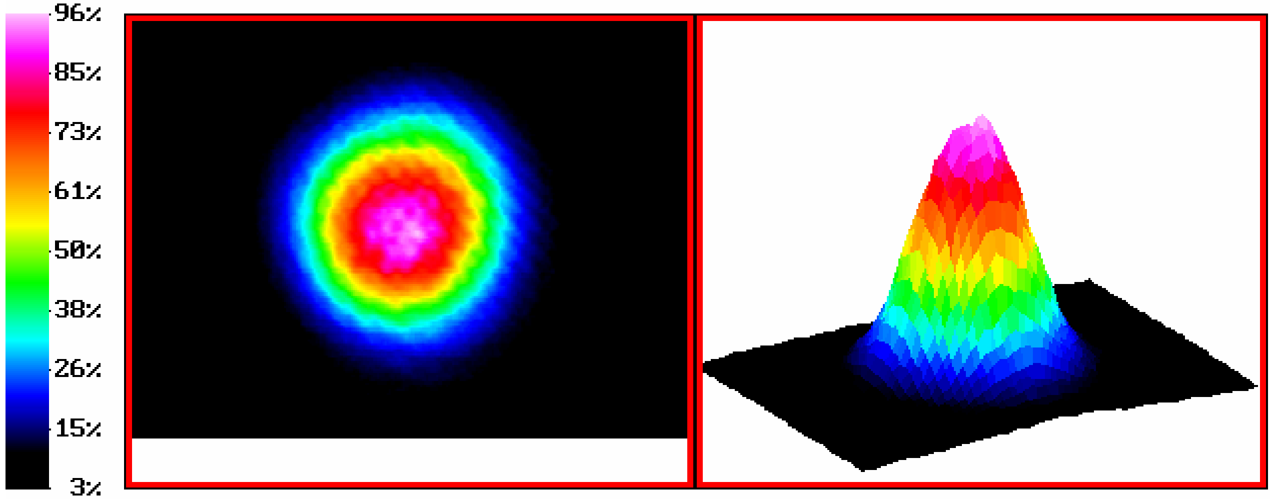


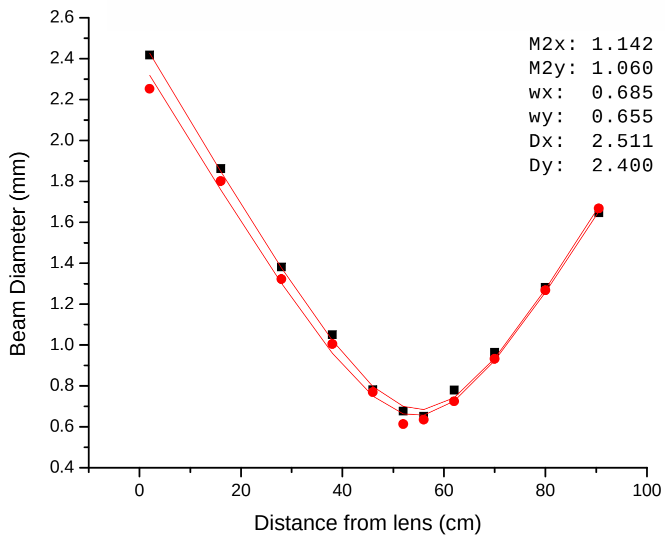
# Laser Output Energy

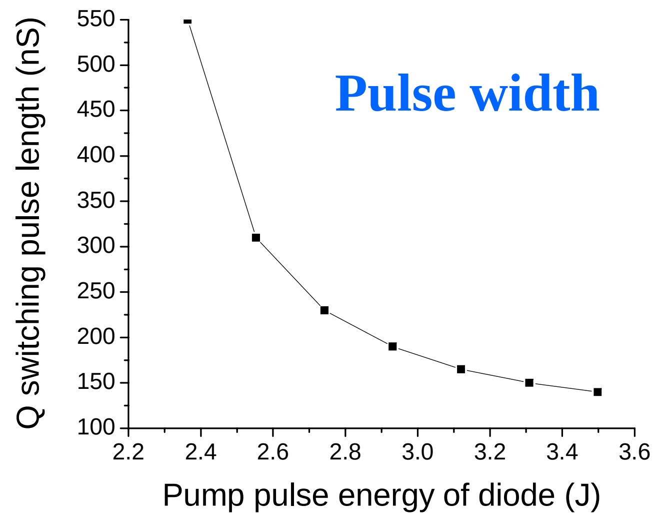


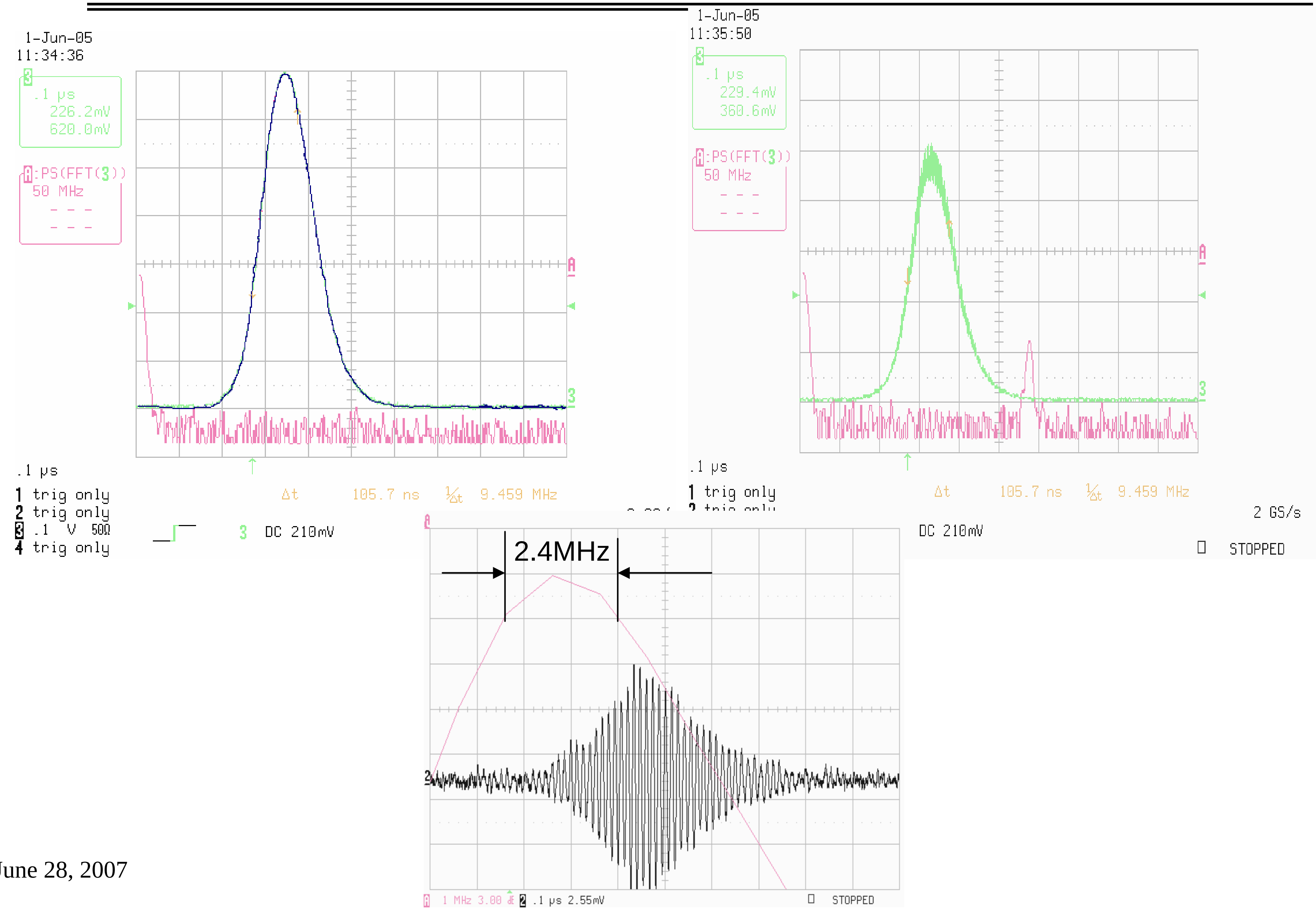
# Laser beam profile



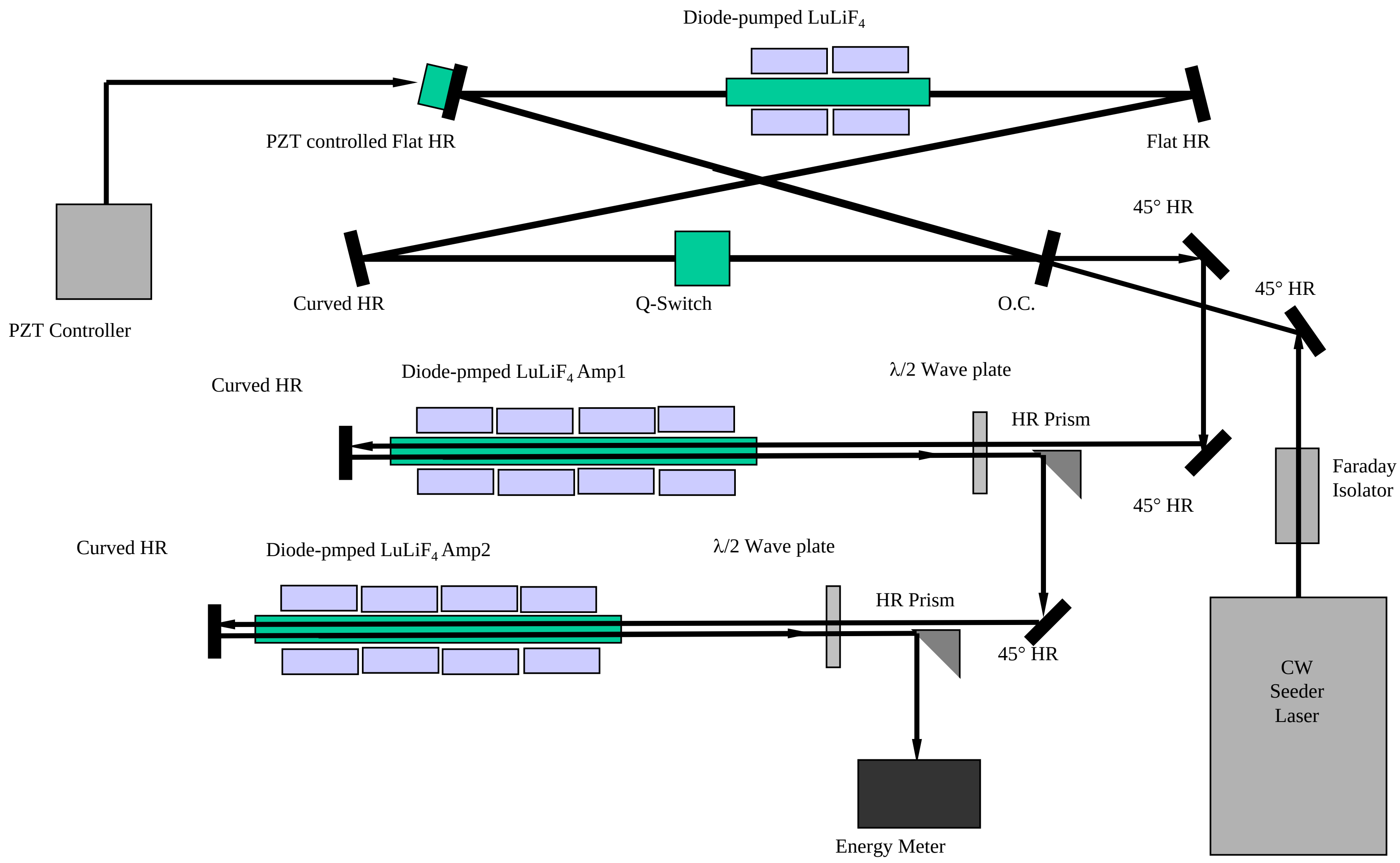



# Seeding verification

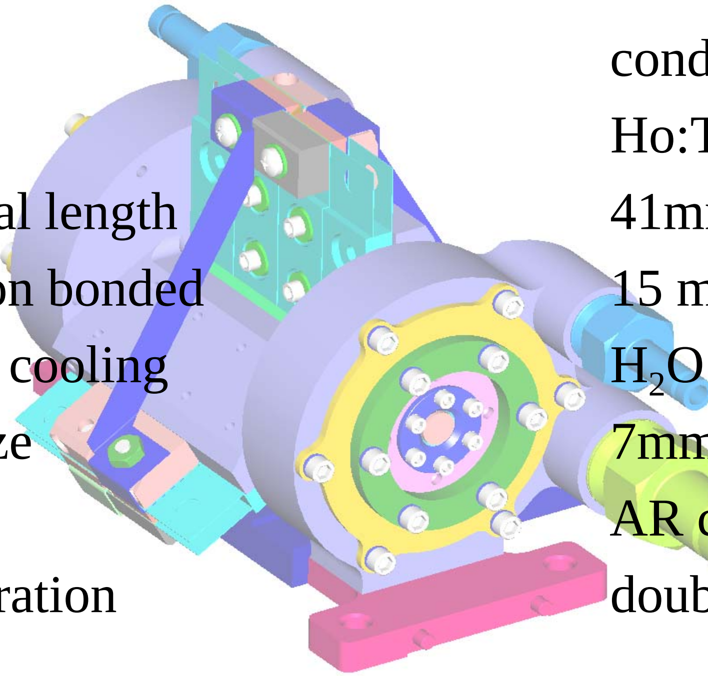


# MOPA Experimental Diagram

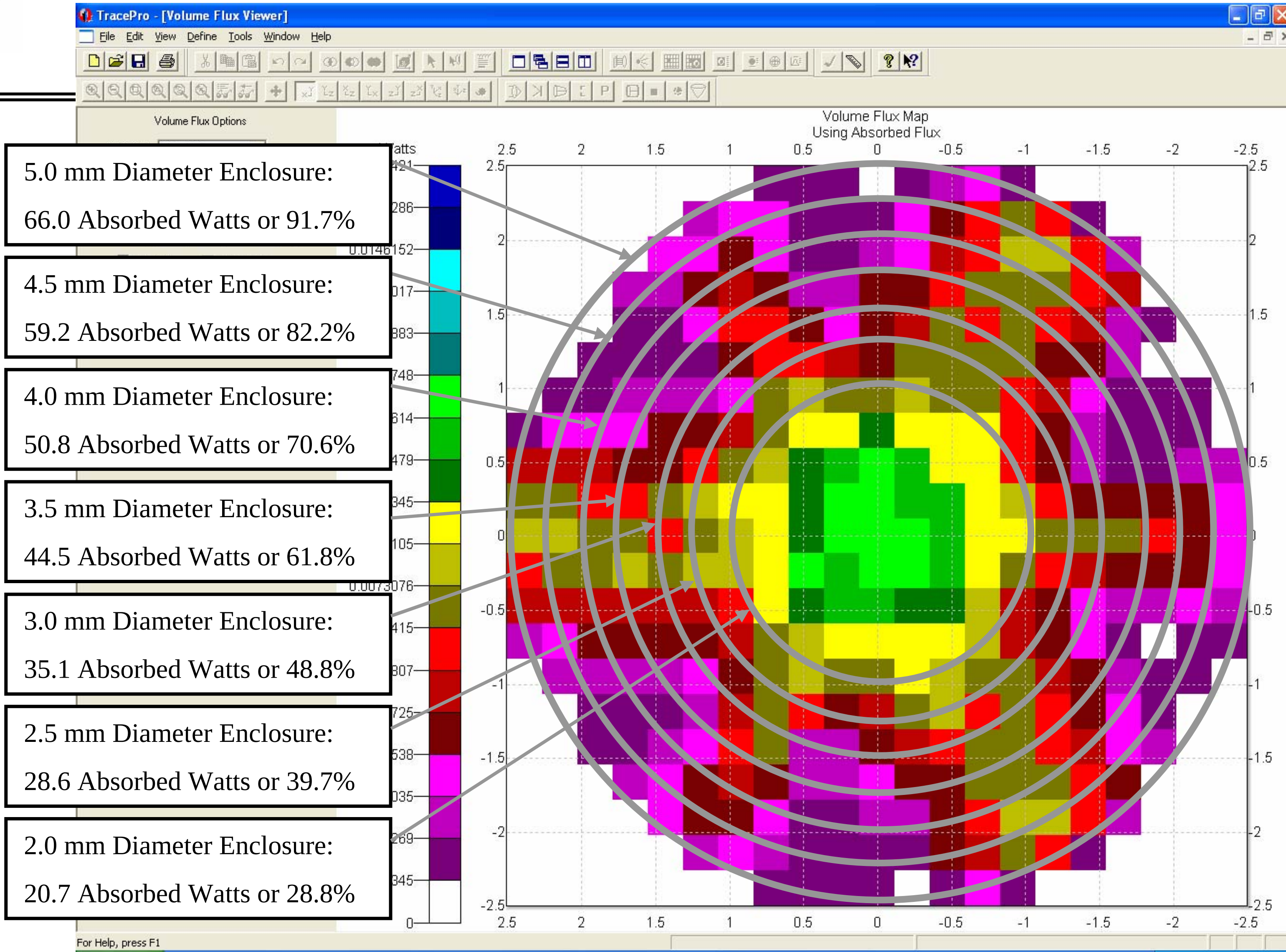


# Amplifier features

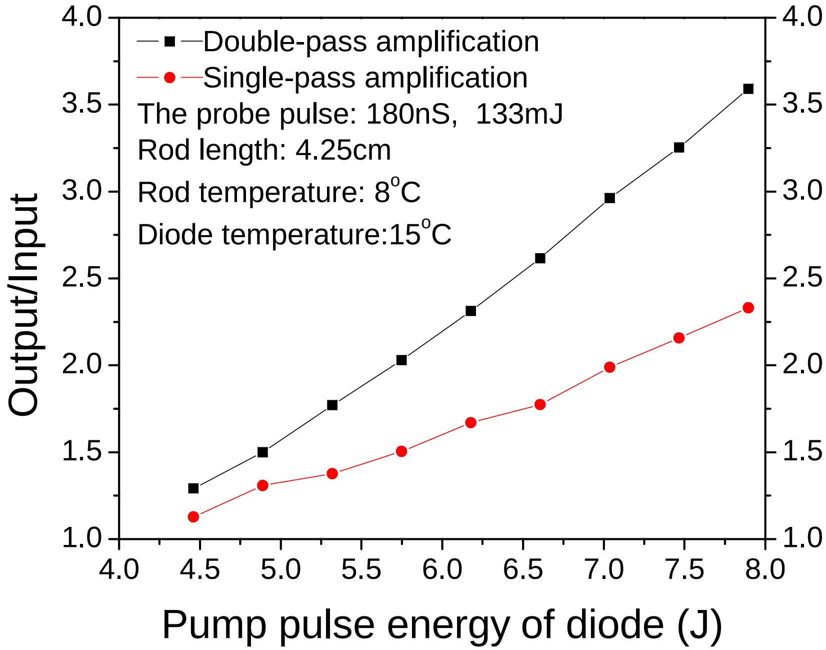
- Pump energy 7.2Joules12x6 bar arrays with 100w/bar
- Diode laser conductive cooled 'A'Pkg
- Laser crystal Ho:Tm:LuLF 0.5% Ho 6%Tm
- Doped Crystal length 41mm
- Ends diffusion bonded 15 mm undoped LuLF crystals
- Laser crystal cooling $H_2O$
- Flow tube size 7mm OD 6mm ID AR coated
- Rod ends AR coated for 2.053µm flat
- Path configuration double pass

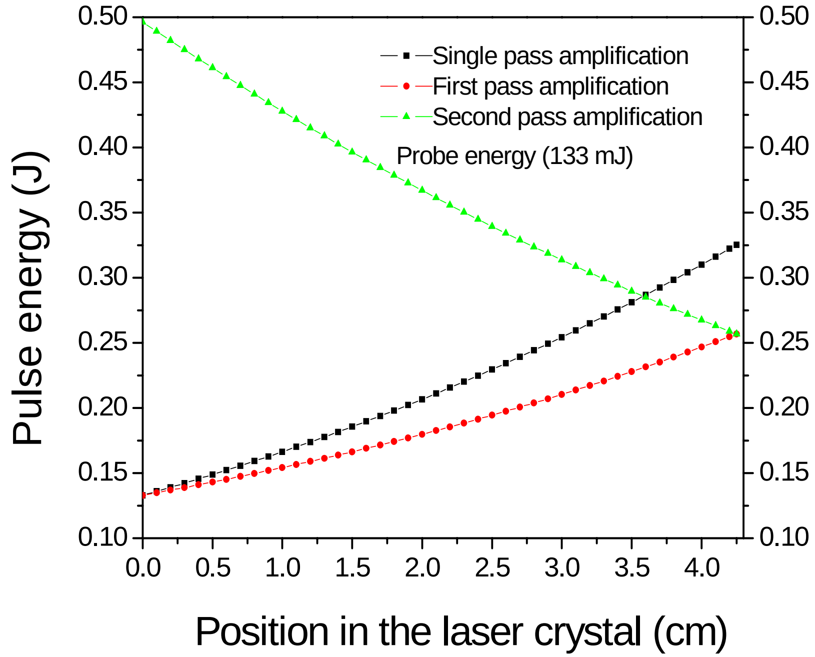


# Absorbed pump power distribution

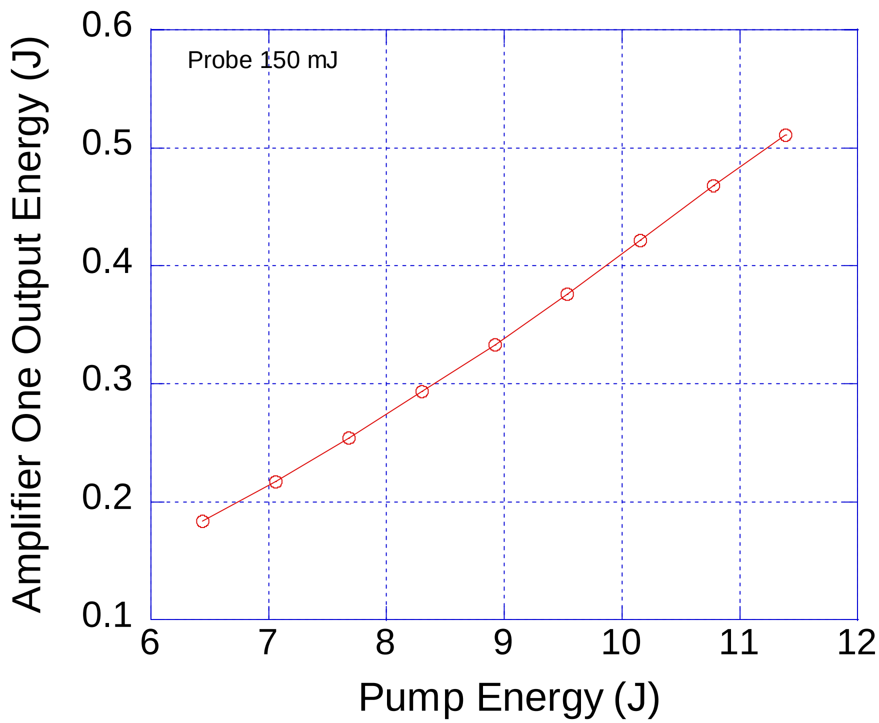


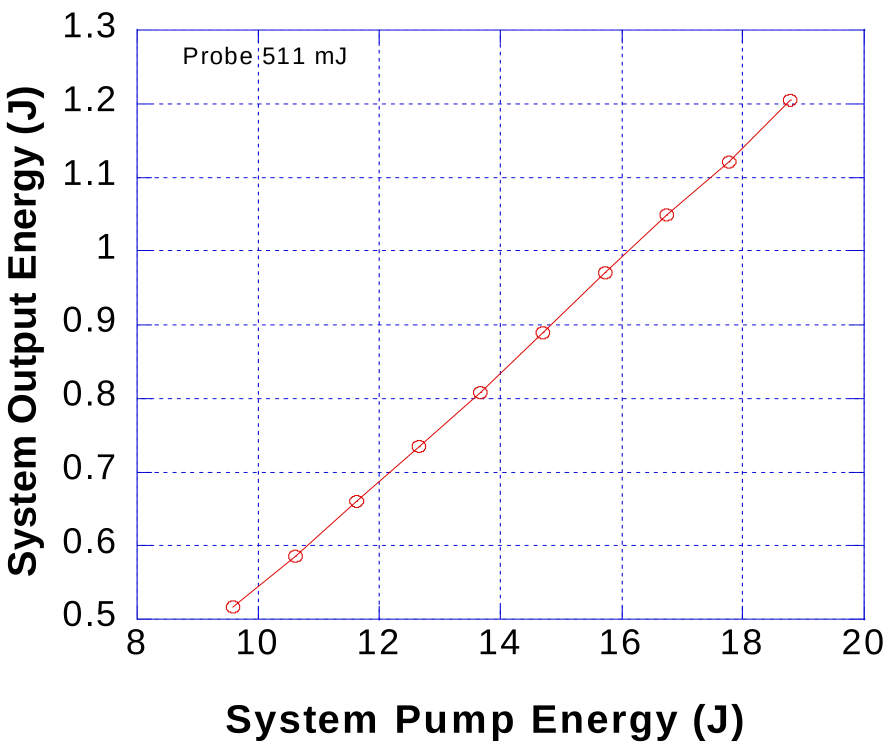
# Single and Double Pass Amplification



# Amplifier Performances



# Objective

- Develop a technology that enables the production of a high-energy and a high- efficiency 2 mm LIDAR transmitter capable of measuring global wind from various platforms.
- Enhance the understanding atmospheric phenomena and improve weather prediction accuracy.
- Reduce risks associated with Doppler Lidar transmitter.
- Identify lifetime sensitive components and initiate early testing.

# Compact Laser Design Goal

- Pulse energy: >250mJ
- Repetition rate: 10Hz
- Wavelength: 2.053 µm
- Laser material: LuLF 0.5% Ho, 6%Tm
- Pulse length: > 100ns
- Line width: < 2.5 MHz
- Heterodyne frequency offset: 105 MHz
- Beam quality: <1.3 diffraction limit
- Beam size: 6 mm at the amplifier output

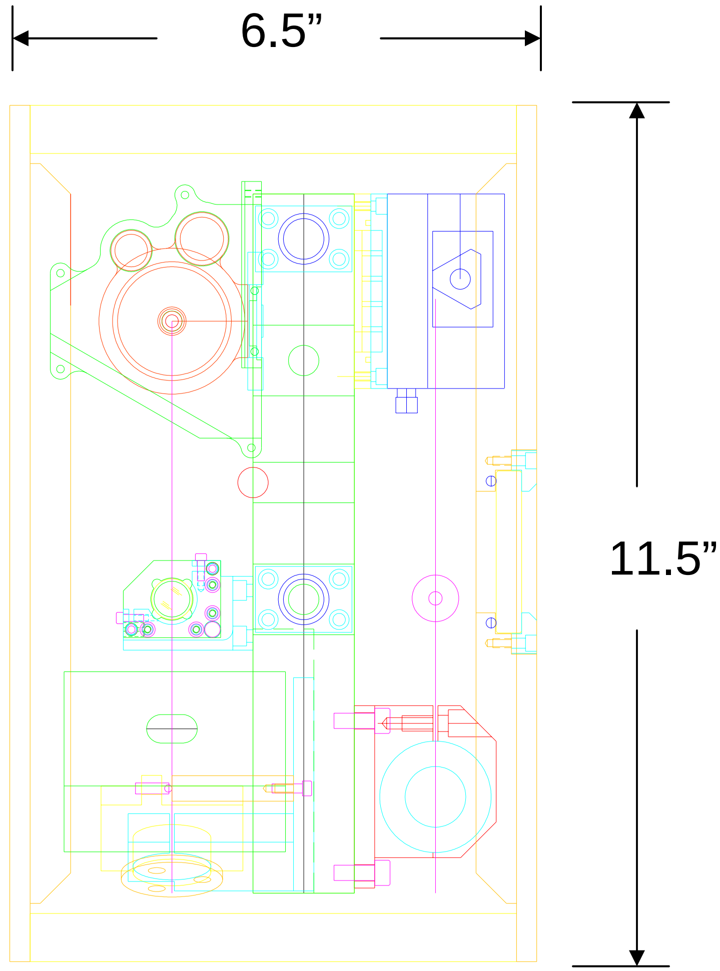
# Environment Requirements

| | |
|---|---|
| • Platform: | ground-based (Airborne qualify-able) |
| • Operational Temperature | 0°C -30°C |
| • Operating Altitude Range | Sea level to 30,000 ft |
| • Vibration | 2.0 g-rms |
| • Coolant Temperature | 5 °C and 15 °C |
| • Coolant Flow | |
| – Laser rod | .5 GPM |
| – Diode Laser | 2 GPM |
| – Bench | 2 GPM |
| • Coolant Pressure | 50 psi at 6 GPM |

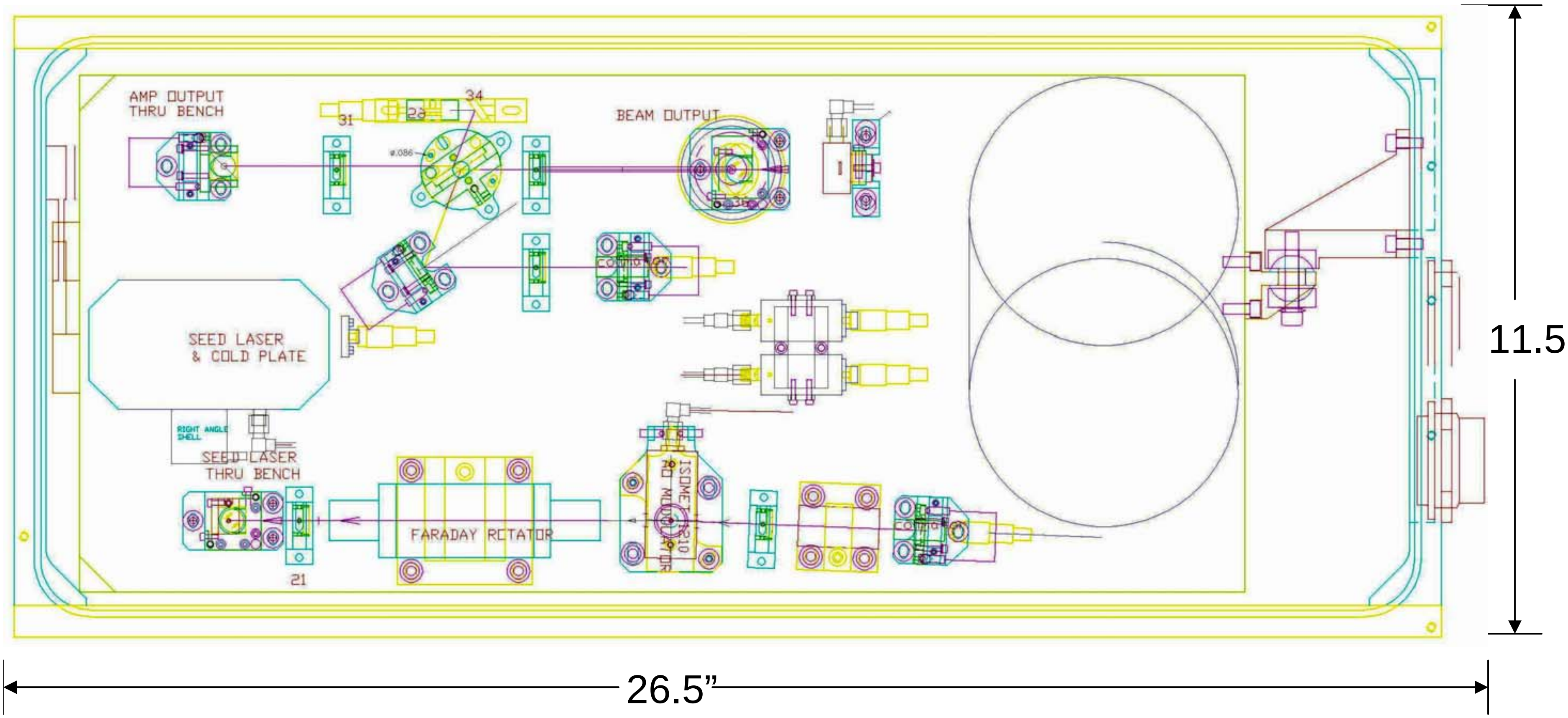
# Mechanical Design Guidelines

- Laser enclosure
  - compact, sealed, and dry air purged
- Optical bench
  - populated on both sides
  - temperature controlled
- Optical mounts
  - hardened- space laser inherited
  - Optical height 1 inch

# Enclosure & Optical Bench



# Optical Layout Side 1

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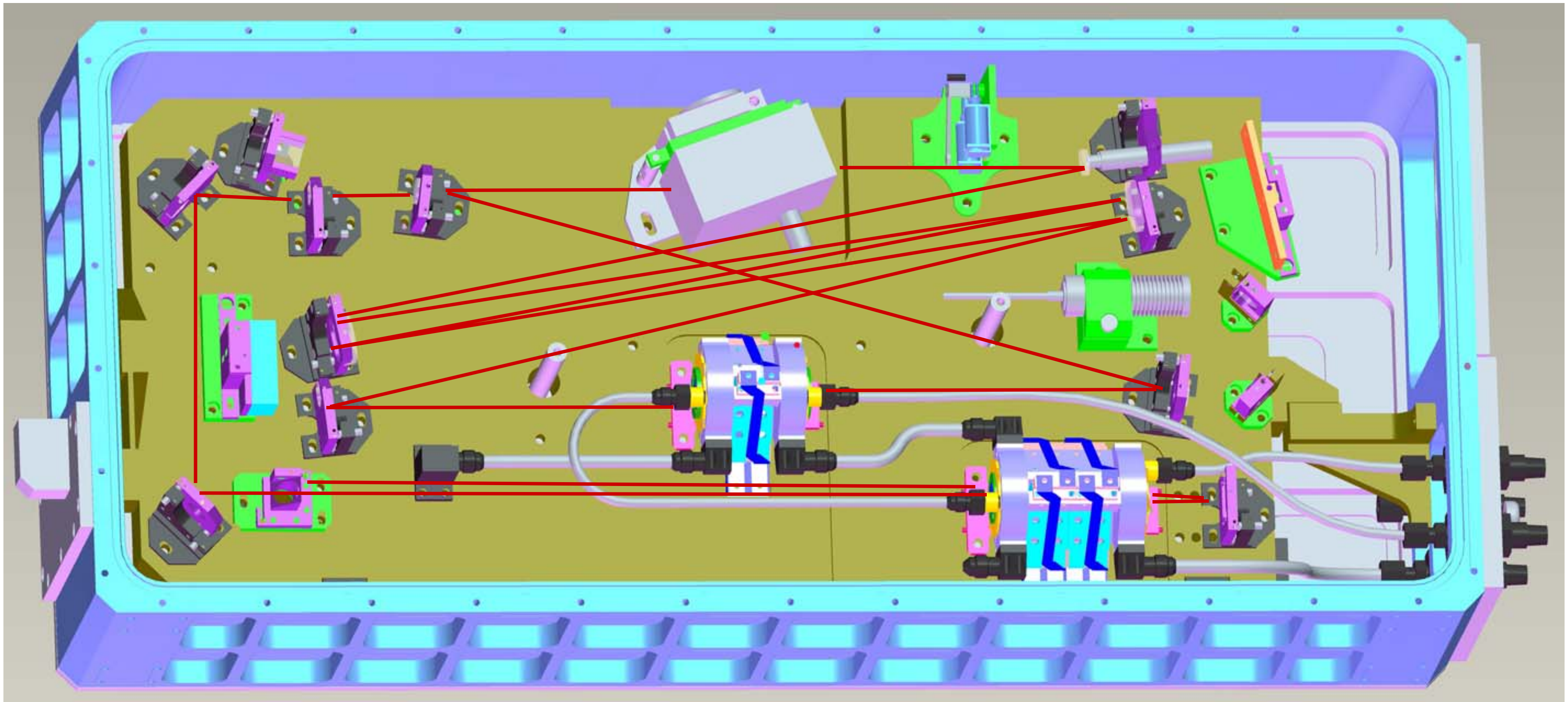
# Optical Layout Side 2



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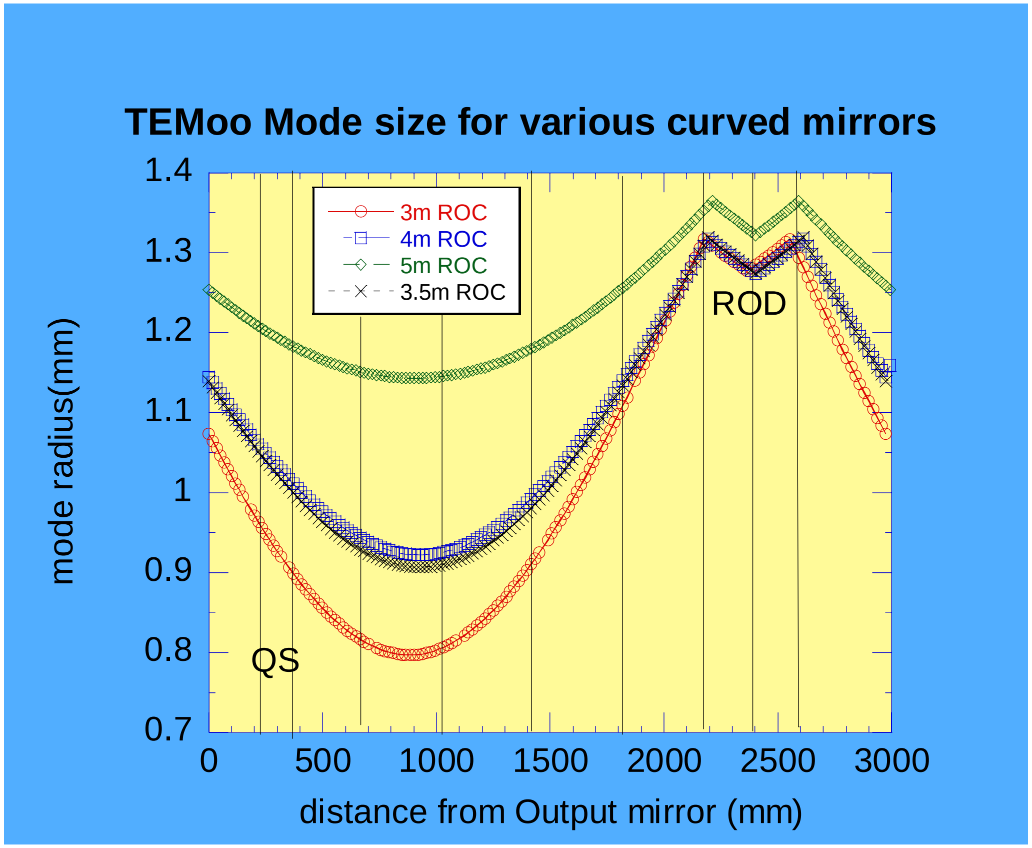
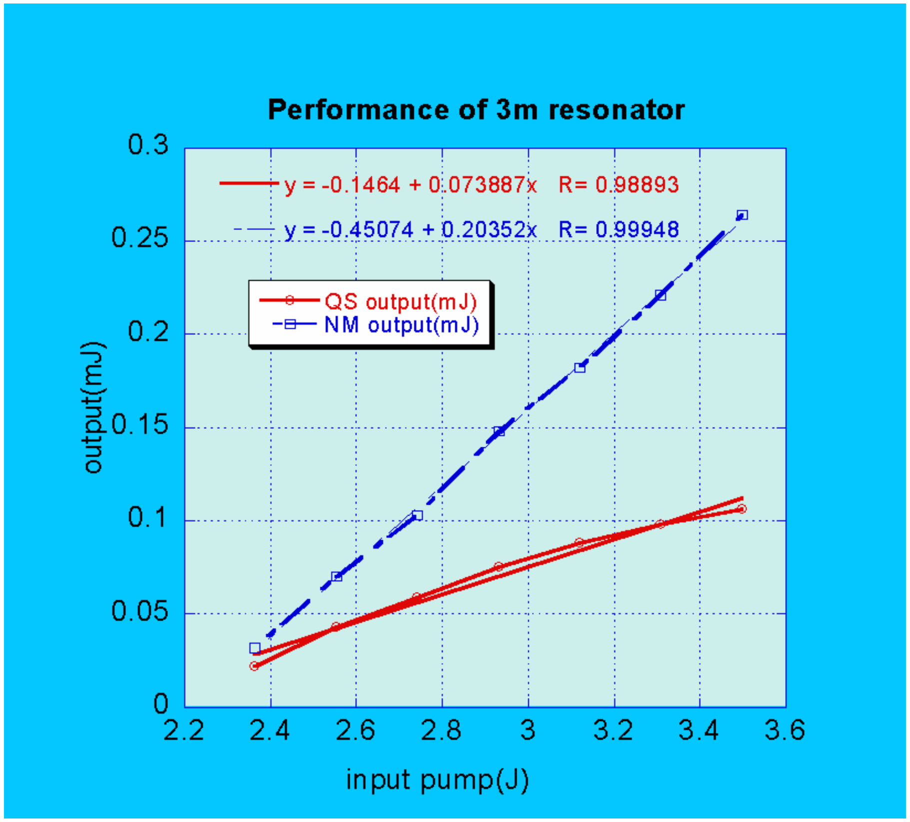
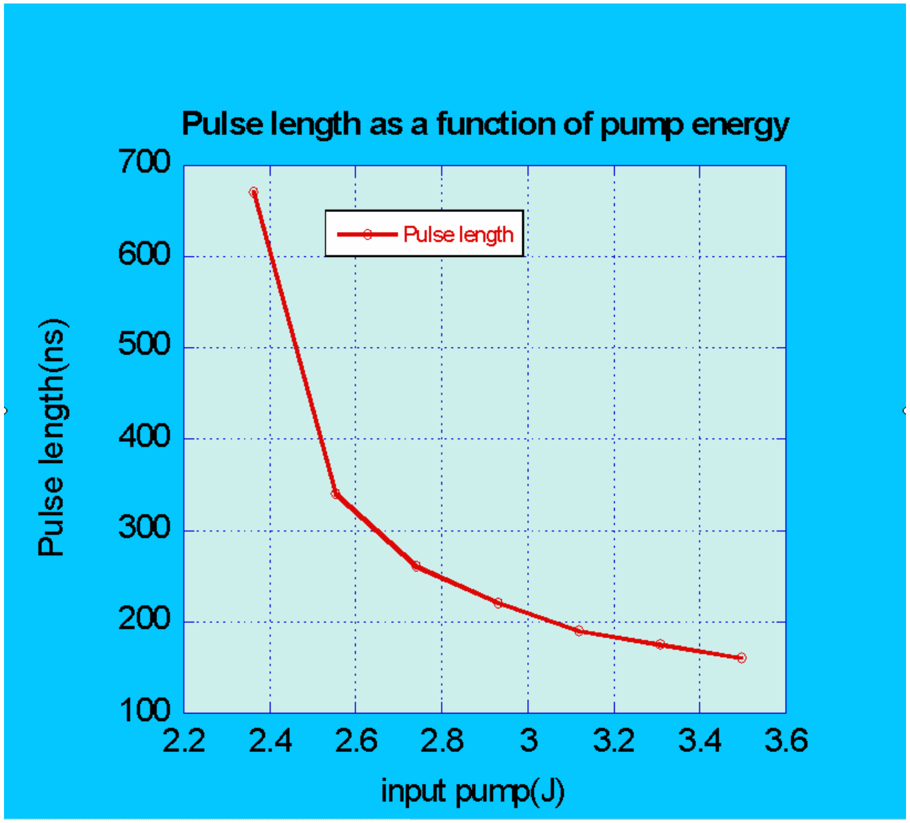
# 3m Long Ring Resonator Design



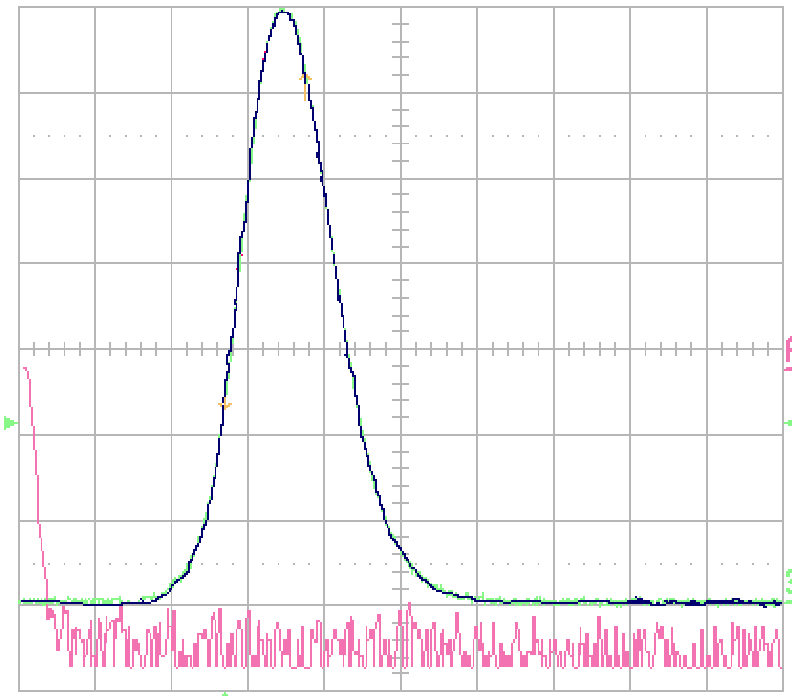

- The rod is placed between two curved mirrors.
- Angles between the folding mirrors minimized.
- In the final configuration a 4m radius of curvature mirror is selected.

# 10Hz Oscillator Performance

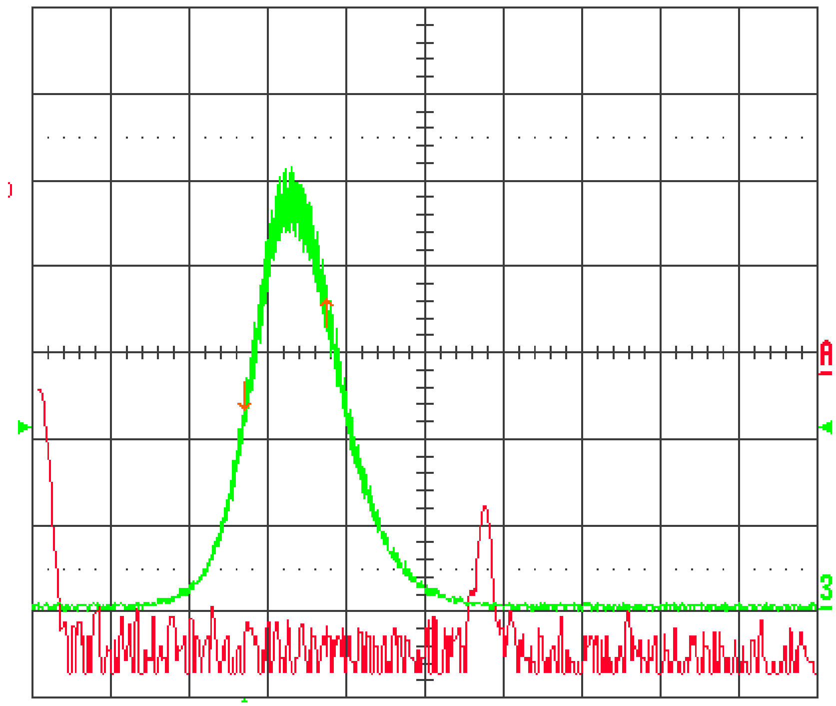


# Seeding Verification

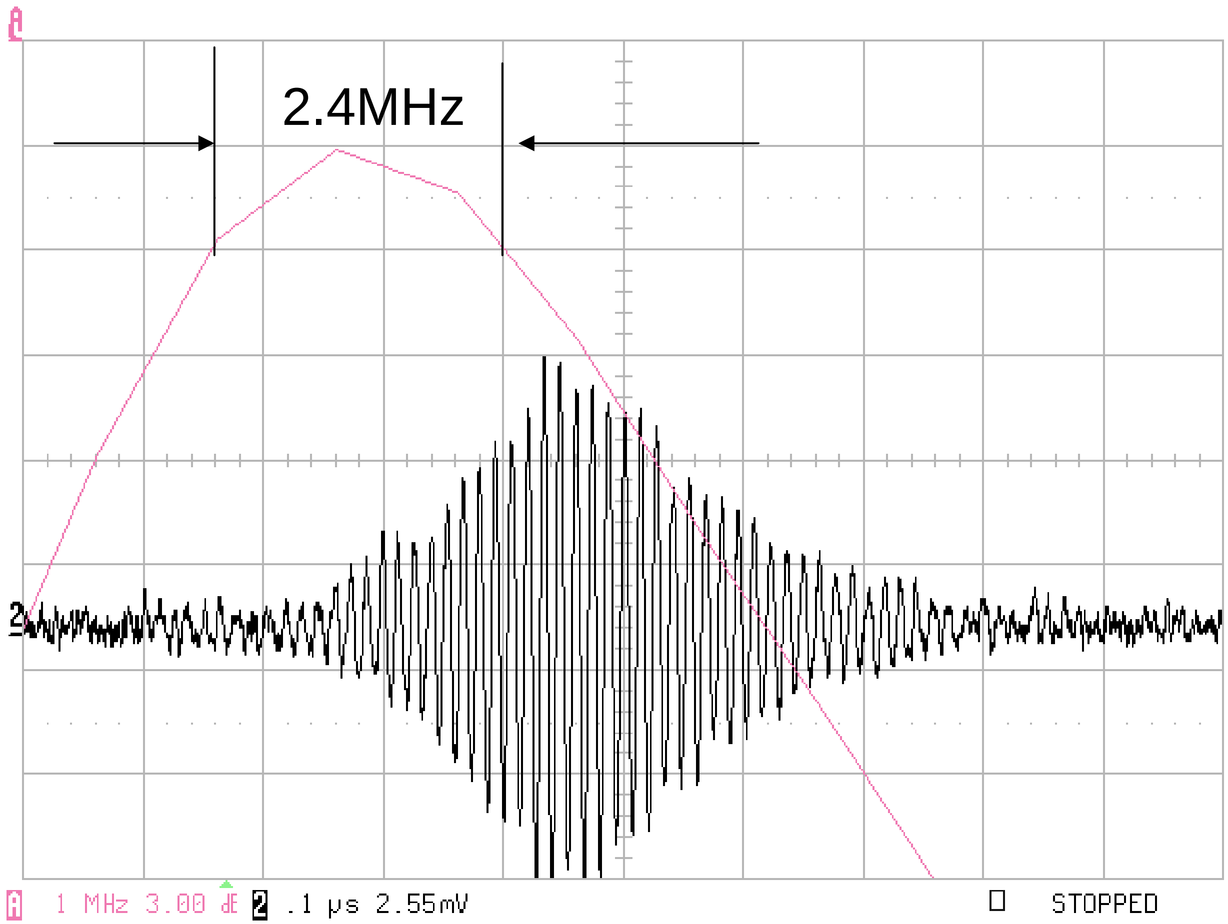


Seeded pulse has no mode-beating



Unseeded pulse

# Oscillator Line Width

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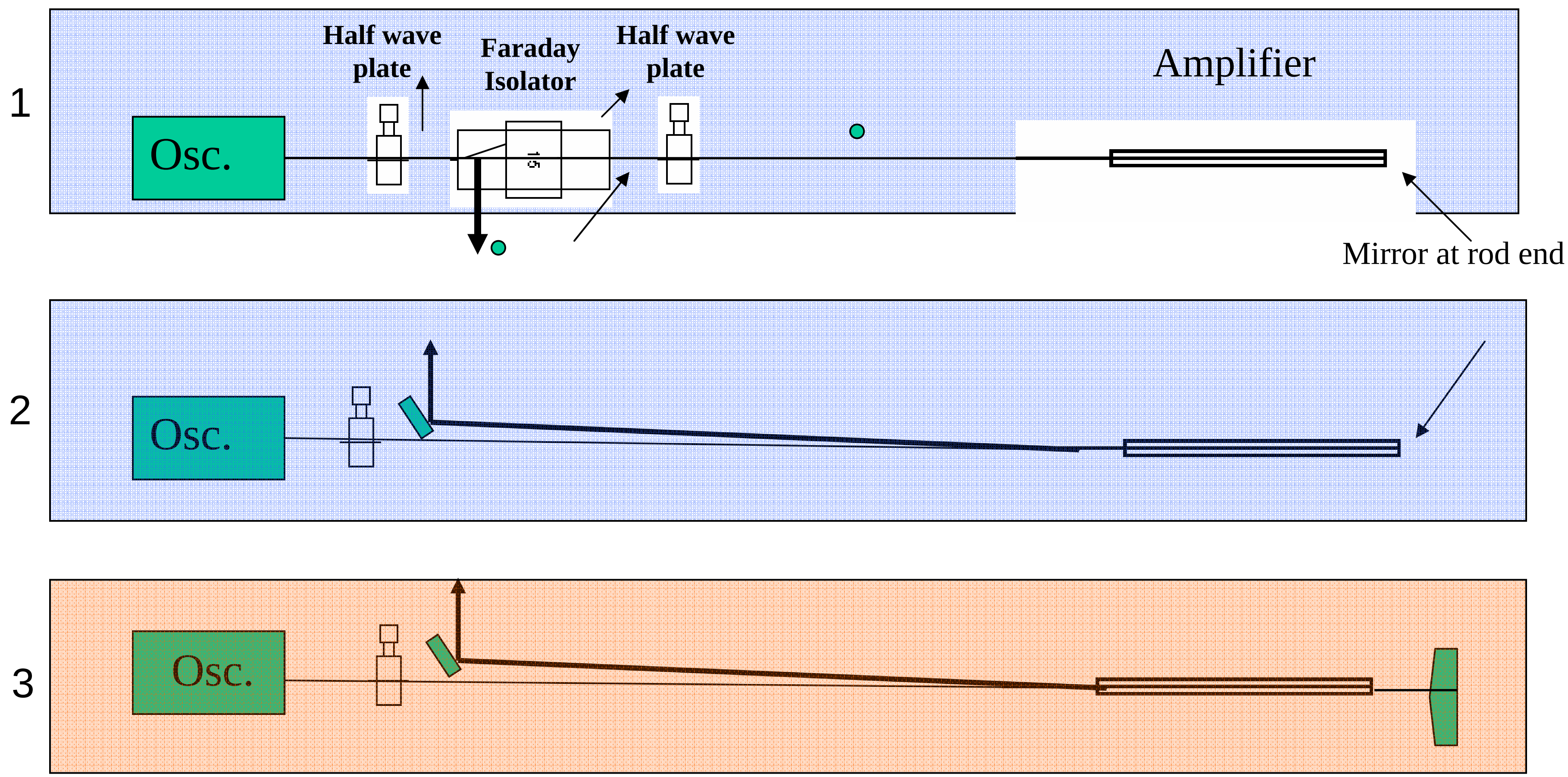
# Amplifier Architecture Considerations




Option 3 selected - Minimum loss, No optical damage, and Optical distortion corrected

# Amplifier rod size selection

- 4 and 5 mm diameter rods were compared
- Probe energy and size were varied

| Probe E (mJ) | 45 | | | 70 | | | 90 | | |
|---|---|---|---|---|---|---|---|---|---|
| Probe dia. (mm) | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 5mm rod E. (mJ) | 89 | 96 | 82 | | 136 | 134 | | 172 | 180 |
| 4mm rod E. (mJ) | 108 | 119 | | 158 | 170 | | 190 | 215 | |

Single pass gain for 4mm rod ~ 2.3
4mm rod with a 3mm probe performs better.

# 4.0 mm Diameter Laser Rod Absorption

4.0 mm Diameter Enclosure:

63.1 Absorbed Watts or 87.6%

3.5 mm Diameter Enclosure:

53.7 Absorbed Watts or 74.6%

3.0 mm Diameter Enclosure:

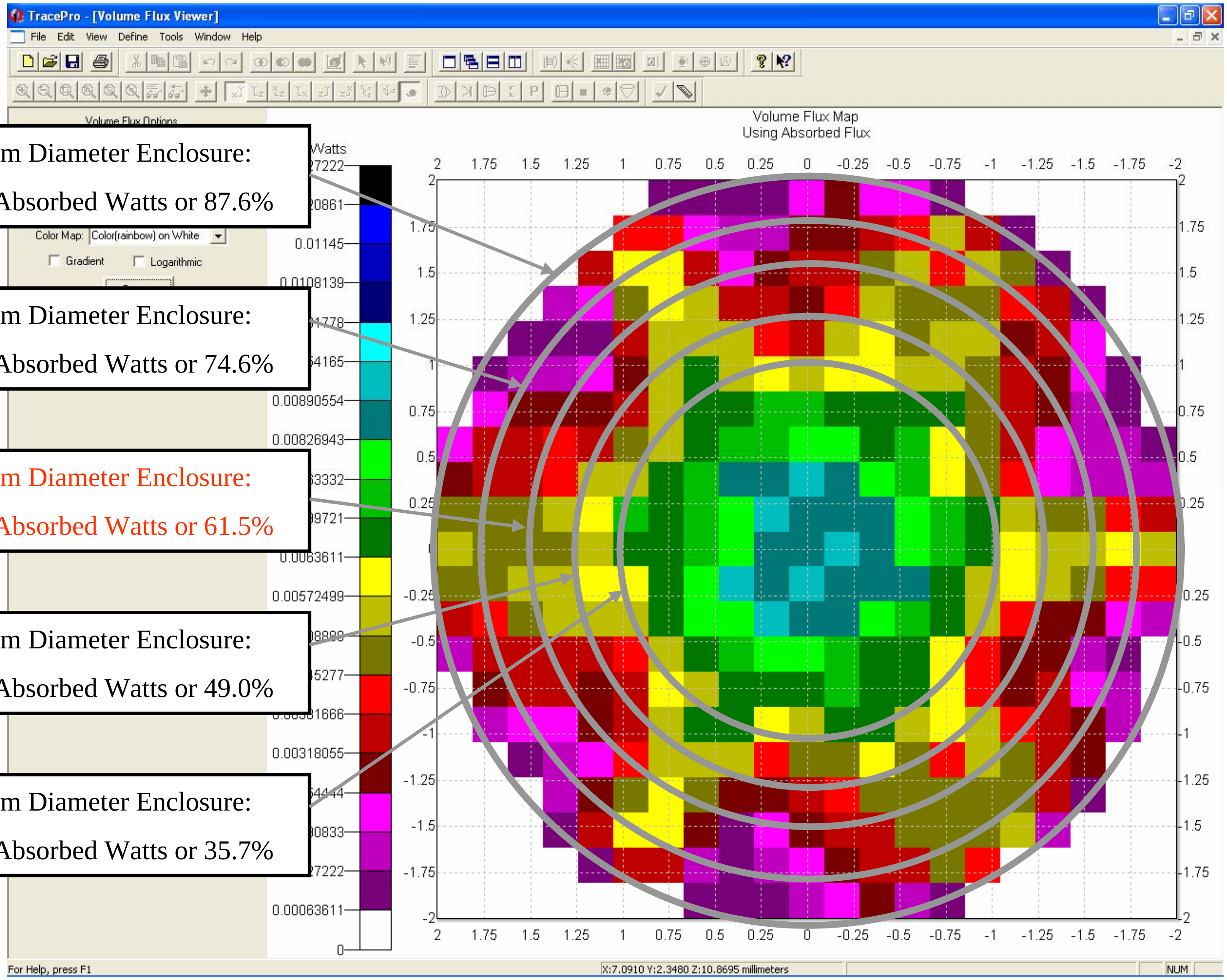
44.3 Absorbed Watts or 61.5%

2.5 mm Diameter Enclosure:

35.3 Absorbed Watts or 49.0%

2.0 mm Diameter Enclosure:

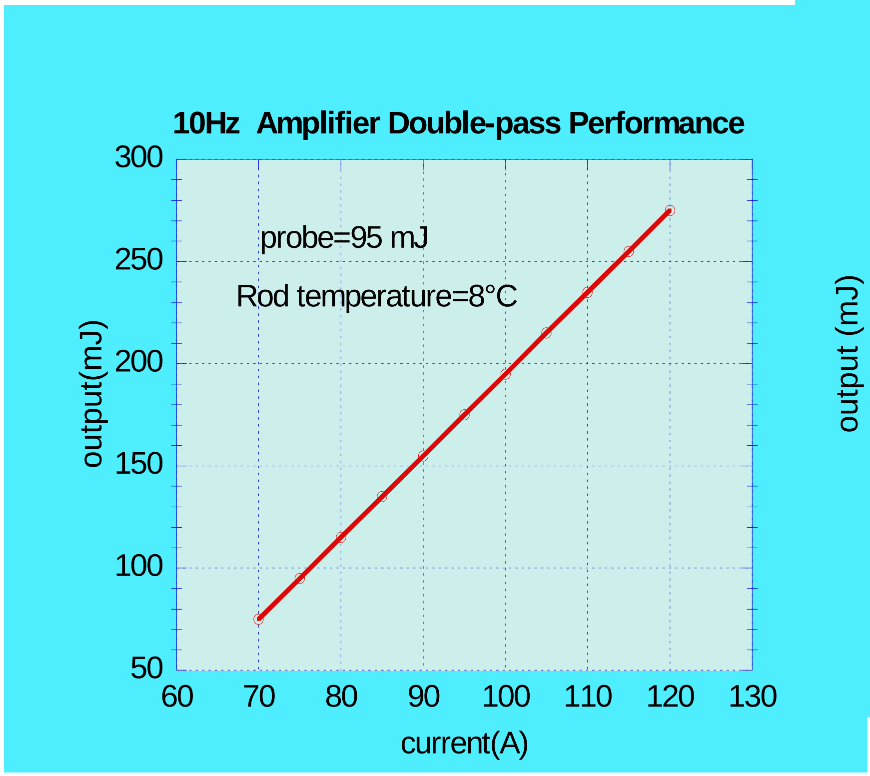
25.7 Absorbed Watts or 35.7%

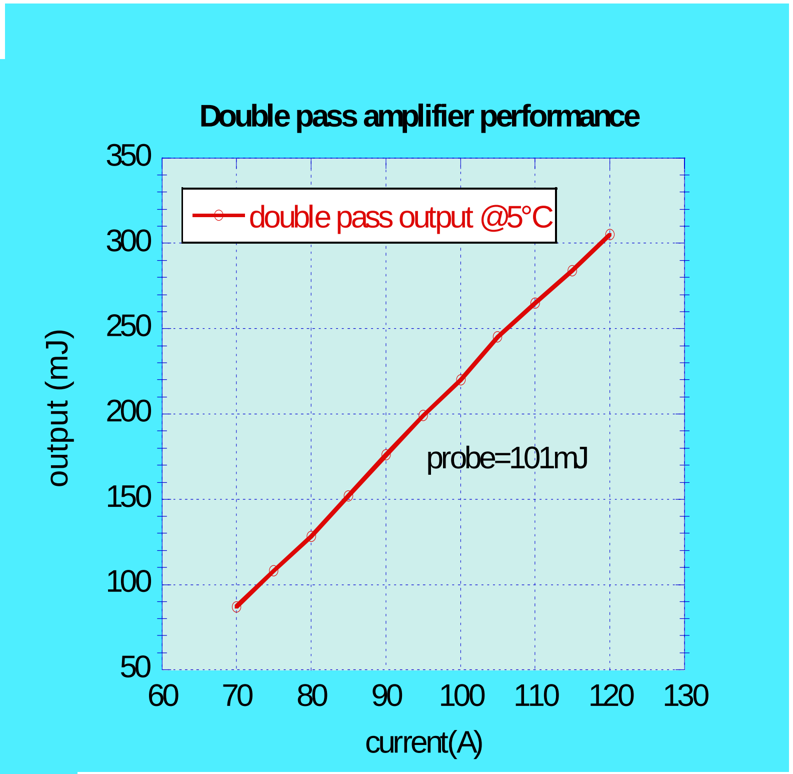


# Amplifier Thermal Lensing

- Amplifier thermal lensing is -1.1m in the x-axis and  -1.8m in y-axis.
- To reduce this effect the c-axis of the amplifier rod is oriented orthogonal to the oscillator rod.
- Once the thermal lensing was measured, the parameter is used in an optical model and a cylindrical correction lens was chosen and implemented that circularized the beam.

# Double pass amplifier performance




Amplifier gain: double pass ~3

# Conclusion

- **A diode-laser-side-pumped 2 μm Ho:Tm:LuLF laser oscillator and two amplifiers (MOPA) have been developed**

| | Master Oscillator | MOPA |
|---|---|---|
| Output energy | 142 mJ (SP) | 1.2 J(SP) |
| Optical efficiency | 4.3 % | 6.5 % |