High-Power, Diode-Pumped Nd:YLF Laser Systems

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Q-peak

APPLIED PHOTONIC SYSTEMS

What is Q-Peak???

Research Division of Schwartz Electro-Optics, Inc.

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SEO Boston (name change)

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Q-Peak, Inc. (wholly owned subsidiary)

Credits

- **Researchers**
  - **Jim Harrison, R. Martisen, Andy Finch**
  - **Peter Moulton, David Welford, John Flint, Martin Jaspan, Anton Zavriyev, Yelena Isyanova, Alex Dergachev, Jeff Manni (JGM Associates)**
- **Collaboration**
  - **Ushio, Inc. (UV generation)**
- **Government Support**
  - **NASA Langley (OPOs, Ti:sapphire UV generation)**
  - **NASA Goddard (microlasers)**
  - **Army ERDEC (OPOs, Ti:sapphire UV generation)**
  - **DARPA (intracavity OPOs)**
  - **Air Force (Ti:sapphire, OPOs)**

Outline

- **Brief discussion of Nd:YLF and diode pumping**
- **Nd:YLF gain modules**
- **Oscillators and MOPAs**
- **OPOs**

Three Nd Laser Hosts As Choices

Crystal	Wavelength (nm)	Gain cross section (10-19 cm2)	Lifetime (μs)	Peak absorption (cm-1)
YAG	1065	3.3	240	10
YLF (π) YLF (σ)	1047 1053	1.9-2.3 π / 1.5	480-520	11
YVO4 (π)	1064	9.8-15.6	97	40

Crystal	Thermal conductivity (W/m K)	Expansion coeff. (10-6)	Thermal shock (W/m)	dn/dT (10-6)	Lensing
YAG	13	6.7	1450	+7.3	moderate
YLF	5.8 (c) 7.2 (a)	8 (c) 13(a)	240	-4.3 (e) -2.0 (o)	weak
YVO4	5.2	7.3 (a) ?? (c)	?	+2.9 (e) +8.5 (o)	strong

Why Nd:YLF?

- Advantages
  - Weak thermal lensing reduces connection between beam properties and pump power
  - Natural birefringence eliminates depolarization from stress-induced birefringence
  - Long lifetime maximizes energy in Q-switched pulse
- Challenge
  - Fracture a greater concern than with YAG

Diode Pumping Genera

- **Longitudinal Pumping ("End Pumping")**

  High degree of overlap between the laser mode and pump volume; requires high brightness diode lasers

  ⇒ High efficiency

  ⇒ High thermal density ⇒ Large thermally induced lensing, birefringence, and thermal fracture

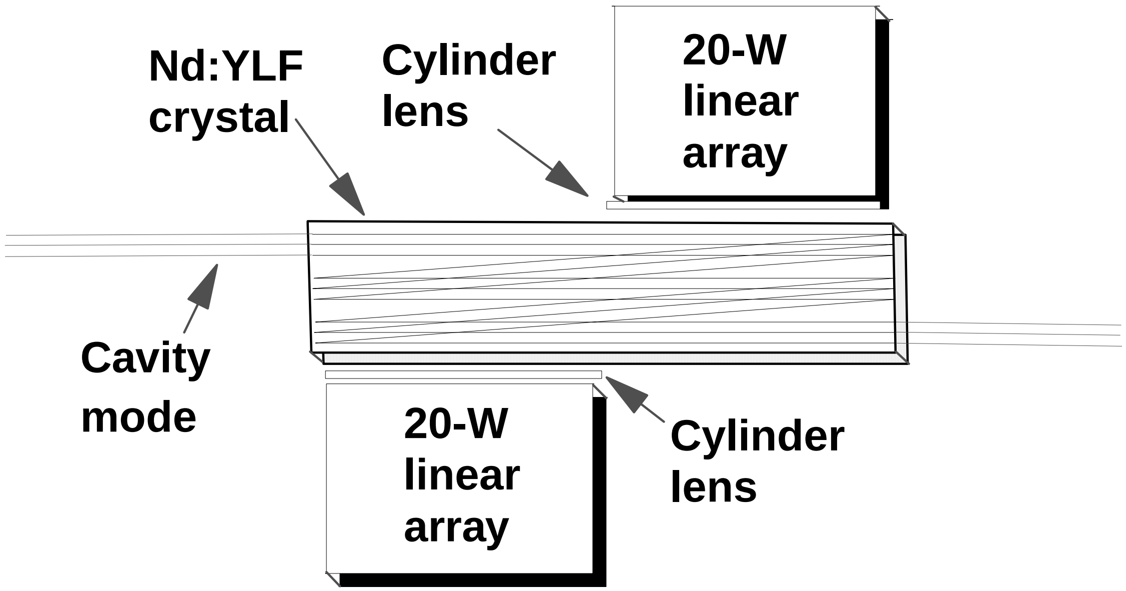
- **Transverse Pumping ("Side Pumping")**

  Challenging to get good overlap between laser mode and pump volume; can use lower brightness diode lasers

  ⇒ Lower efficiency than longitudinal pumping

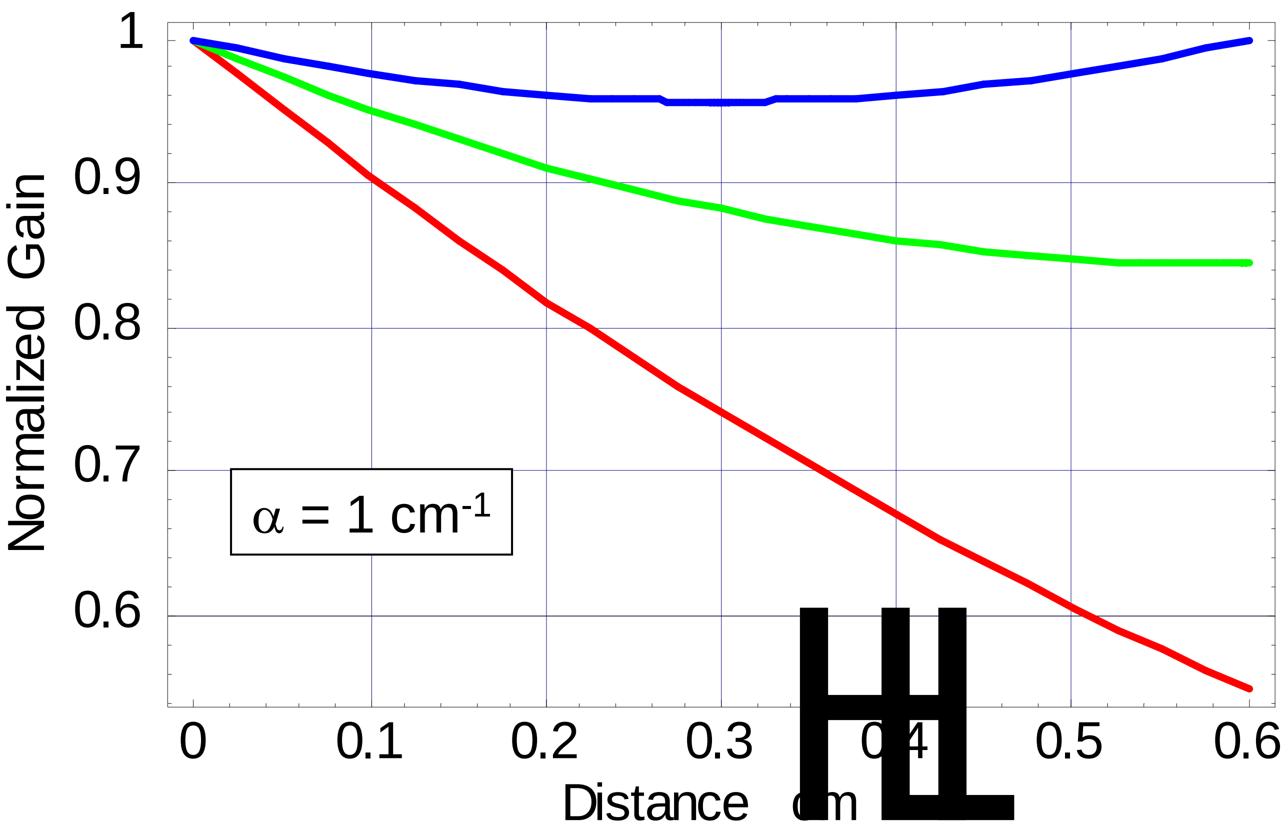
  ⇒ Lower thermal density ⇒ Lower thermally induced lensing, birefringence, and thermal fracture

Nd:YLF “Gain Module” Uses Transverse Pumping



- Multi-pass design extracts large fraction of available power in TEM_{00} mode, has high gain
- Low average excitation density minimizes stress, beam distortion
- Simple, single-element pump optics

Integrated Fluorescence Distributions

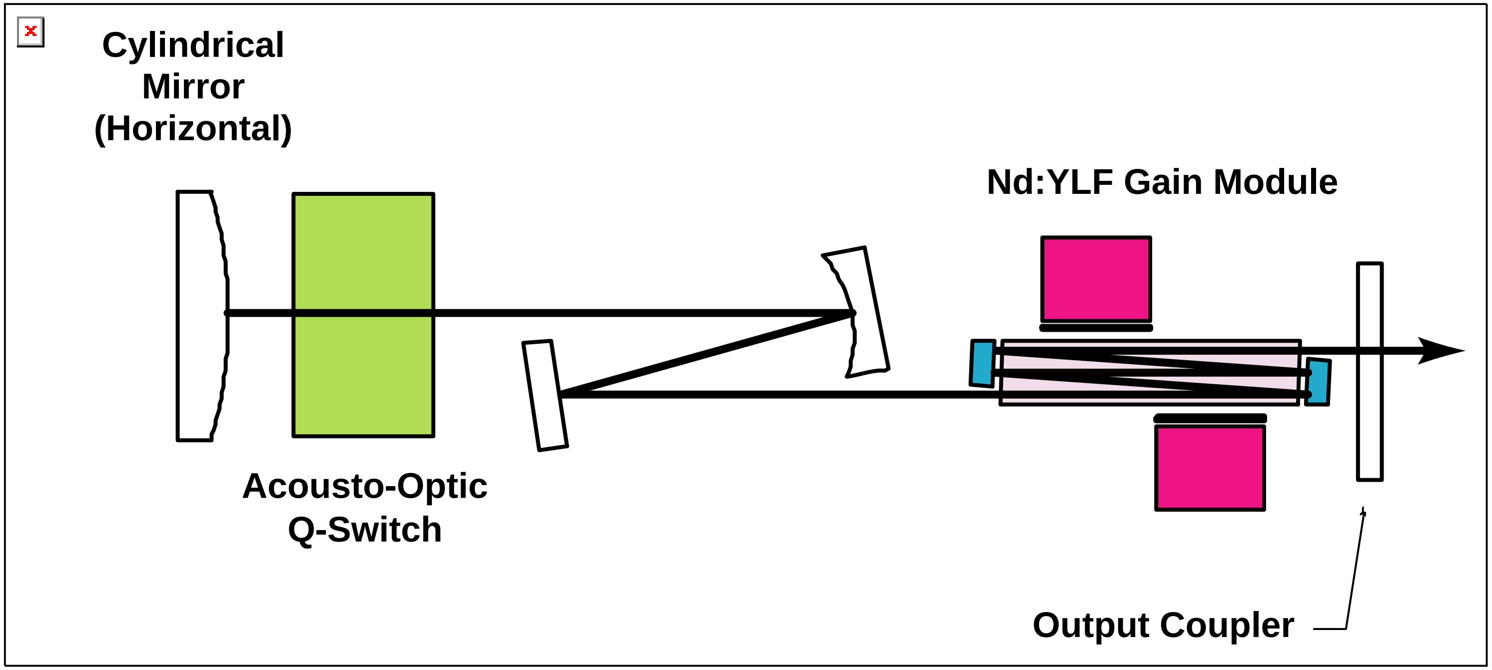


Two Diode Pumping with Reflection

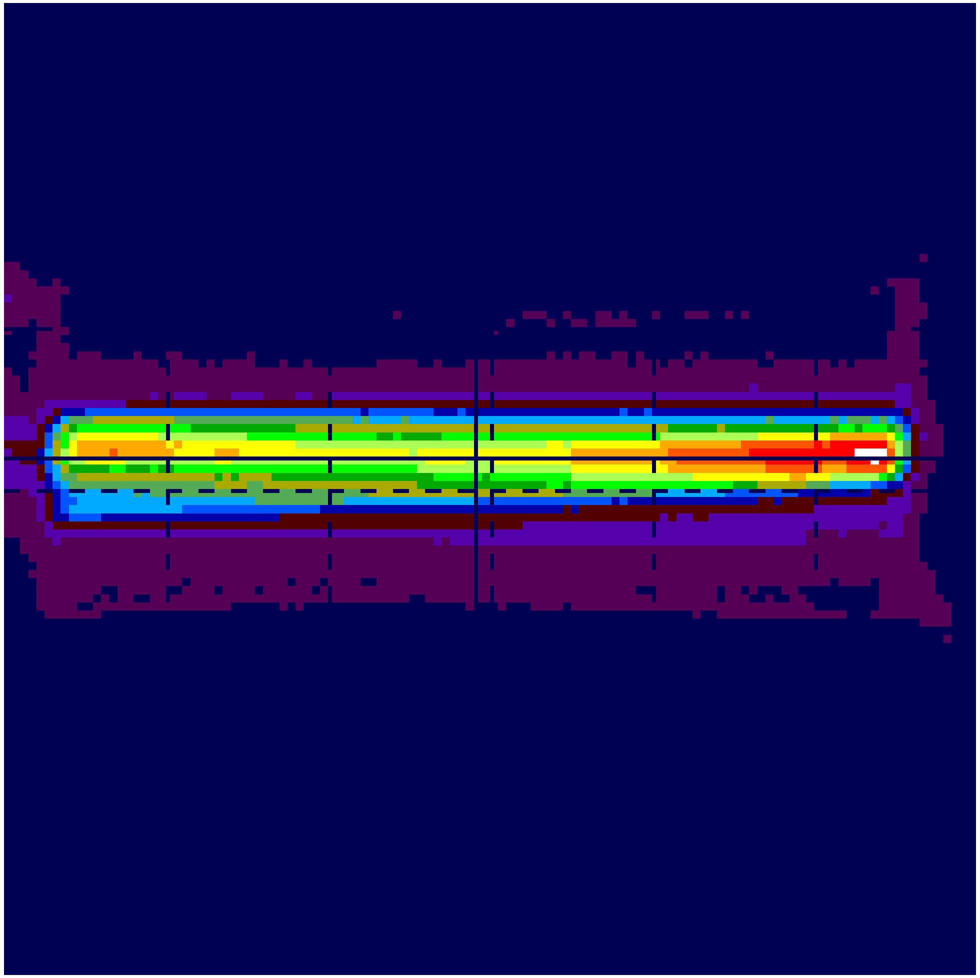
One Diode Pumping with Reflection

One Diode Pumping; no Reflection

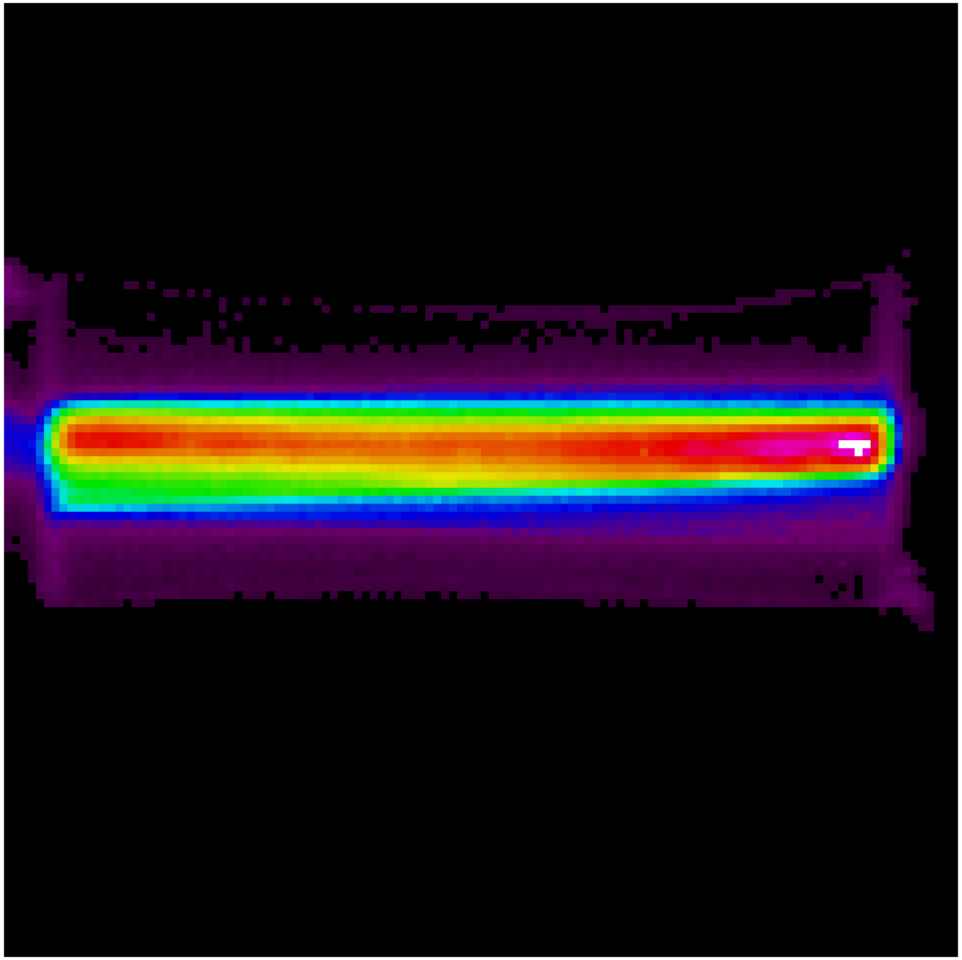
MPS Laser Schematic



Fluorescence Profile with One-Sided Pumping

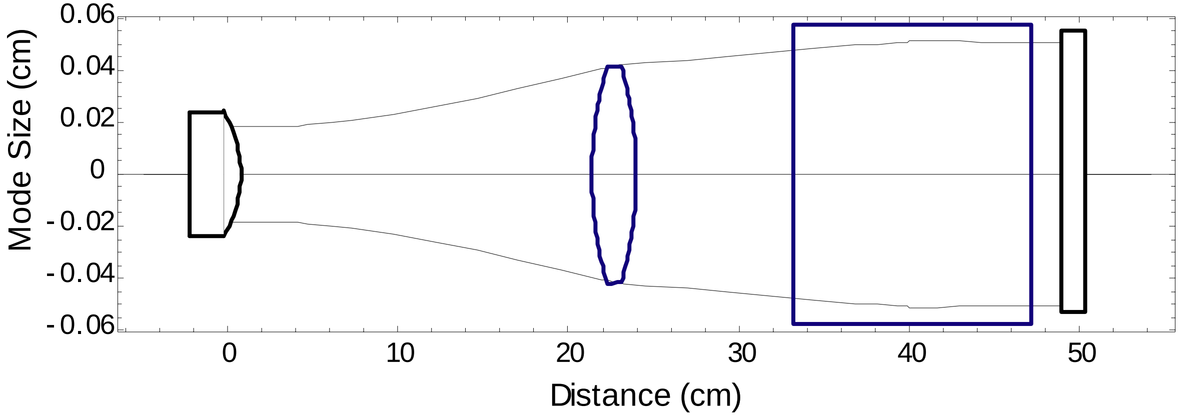


Fluorescence Profile with Double-Sided Pumping

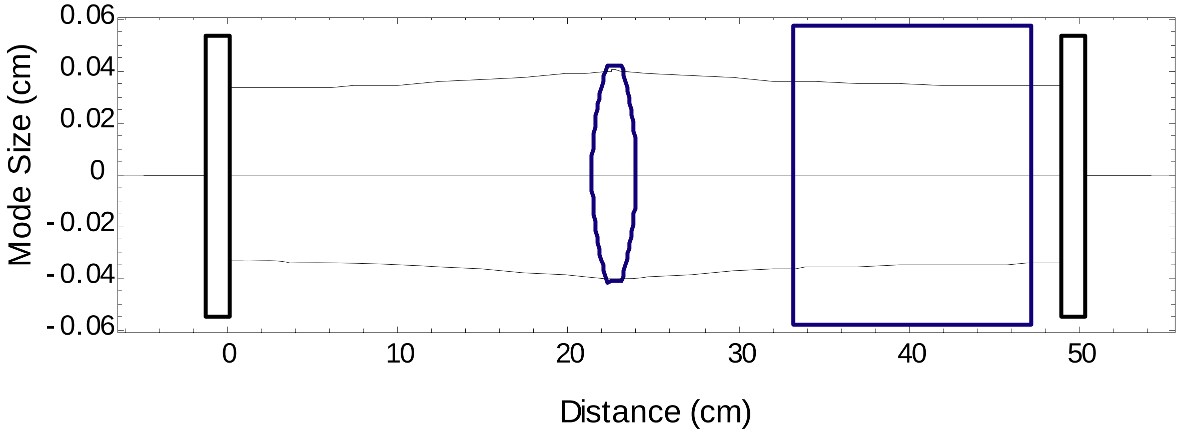


Nd:YLF Oscillator Laser Mode

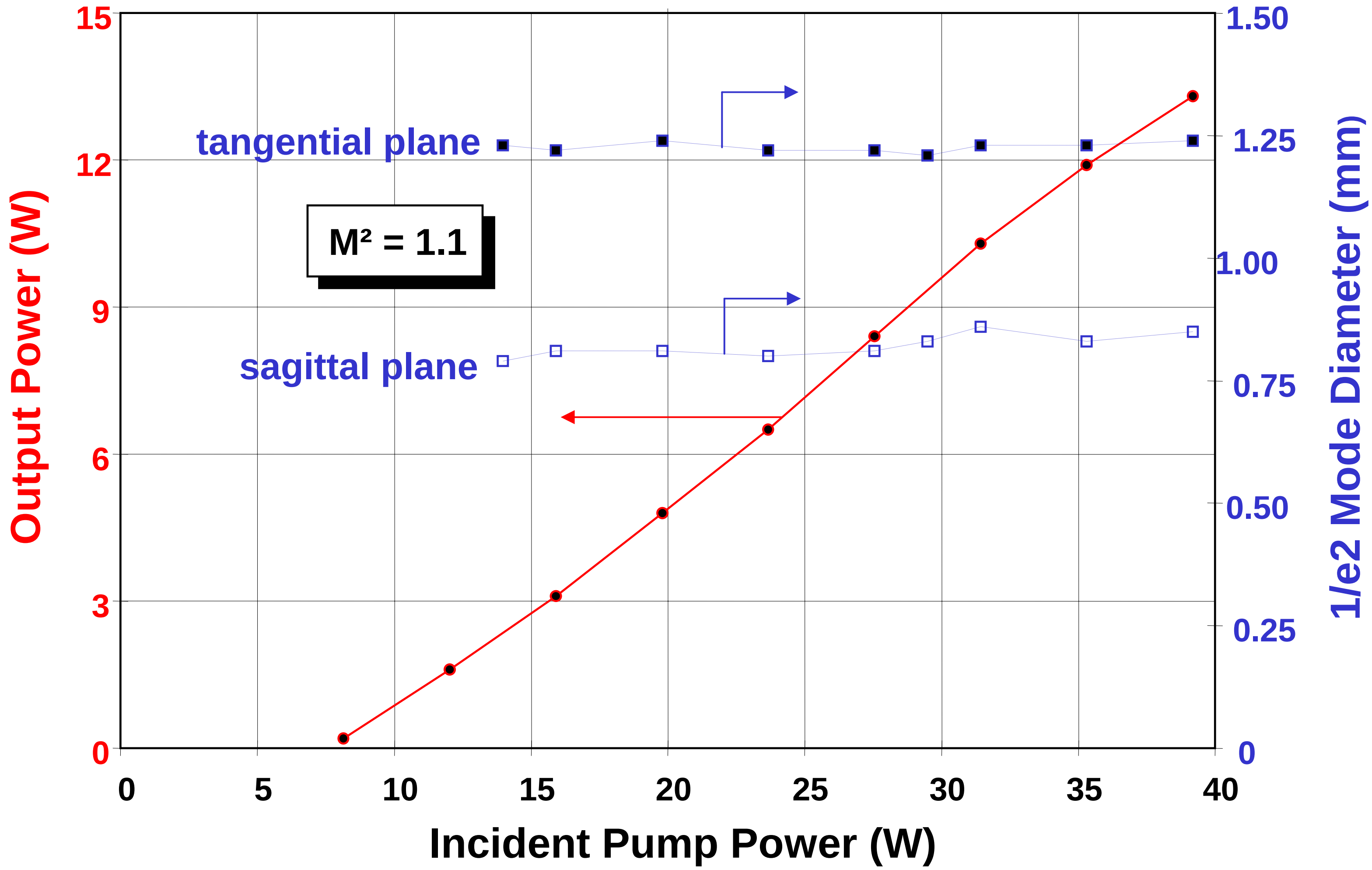
Horizontal



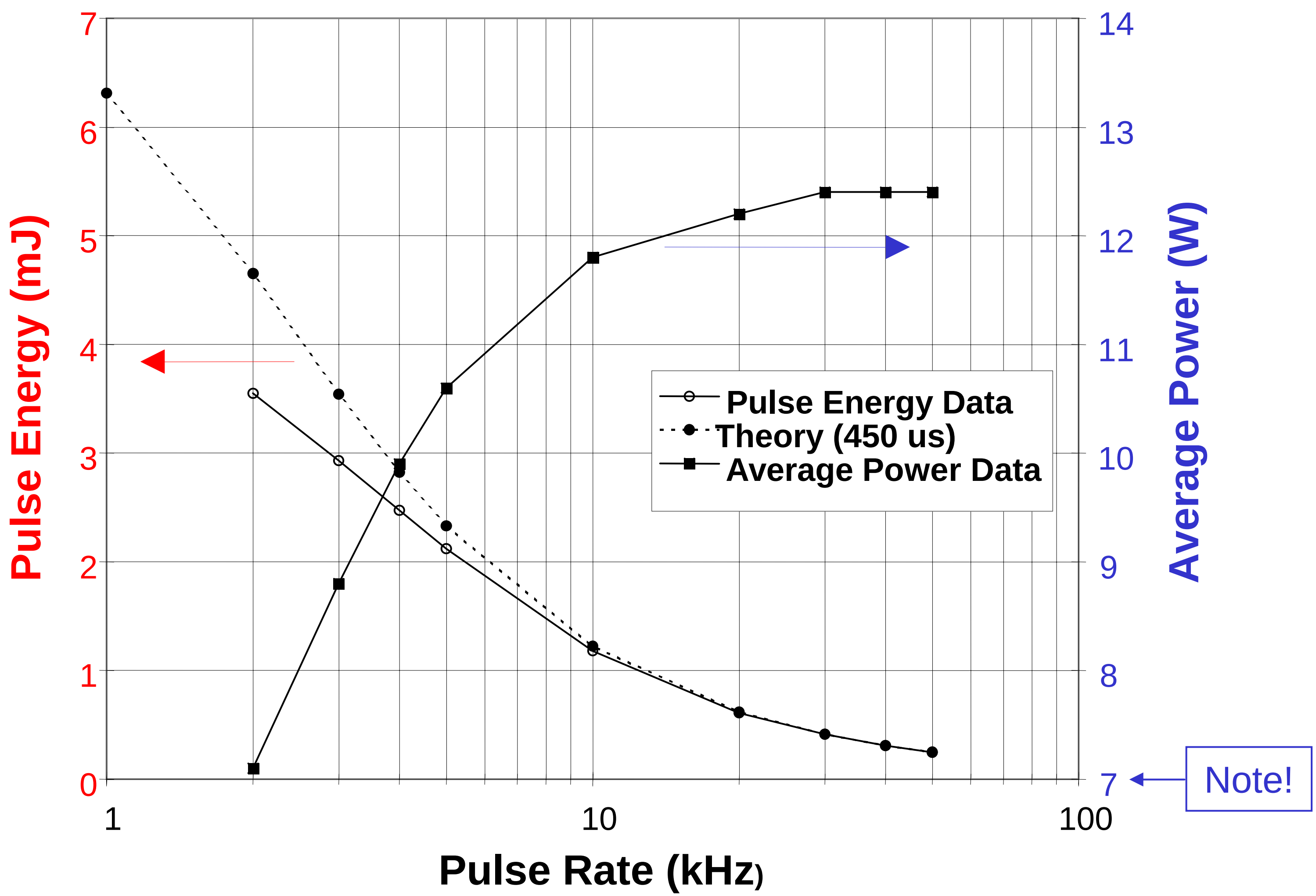
Vertical



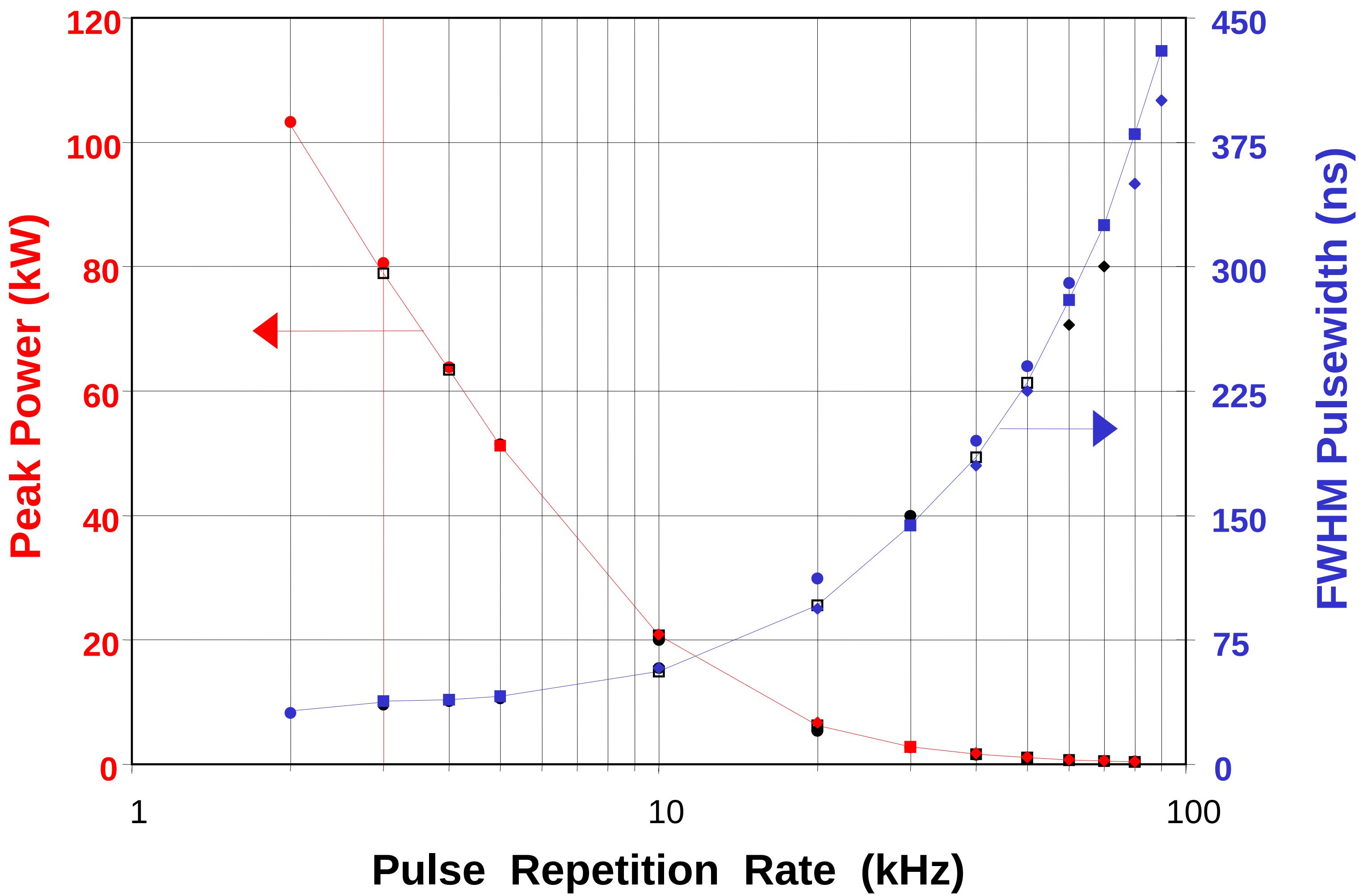
I/O and Beam Properties



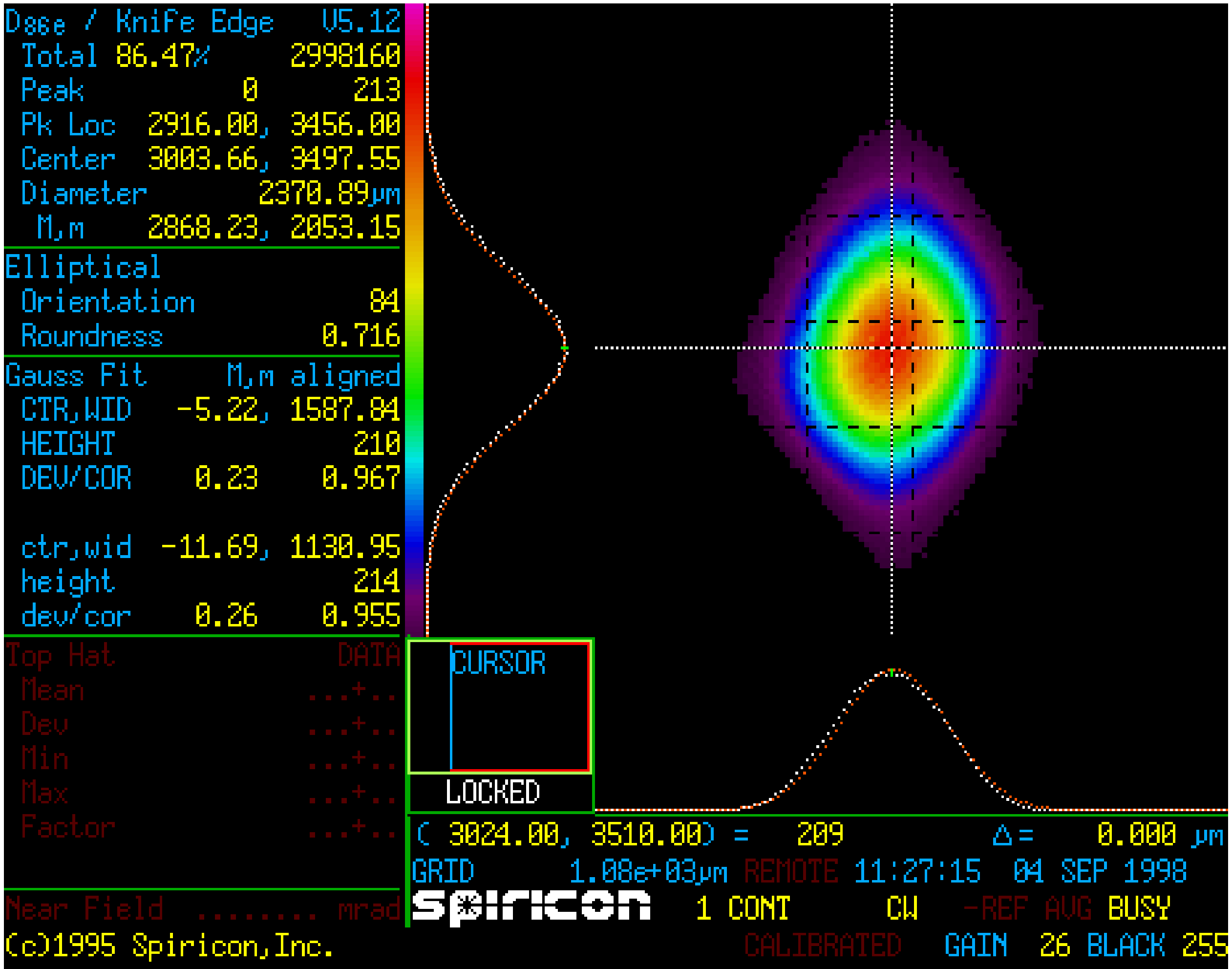
Q-Switching Results for a Single Gain Module Show >12 W above 10-kHz PRR



Q-Switching Data

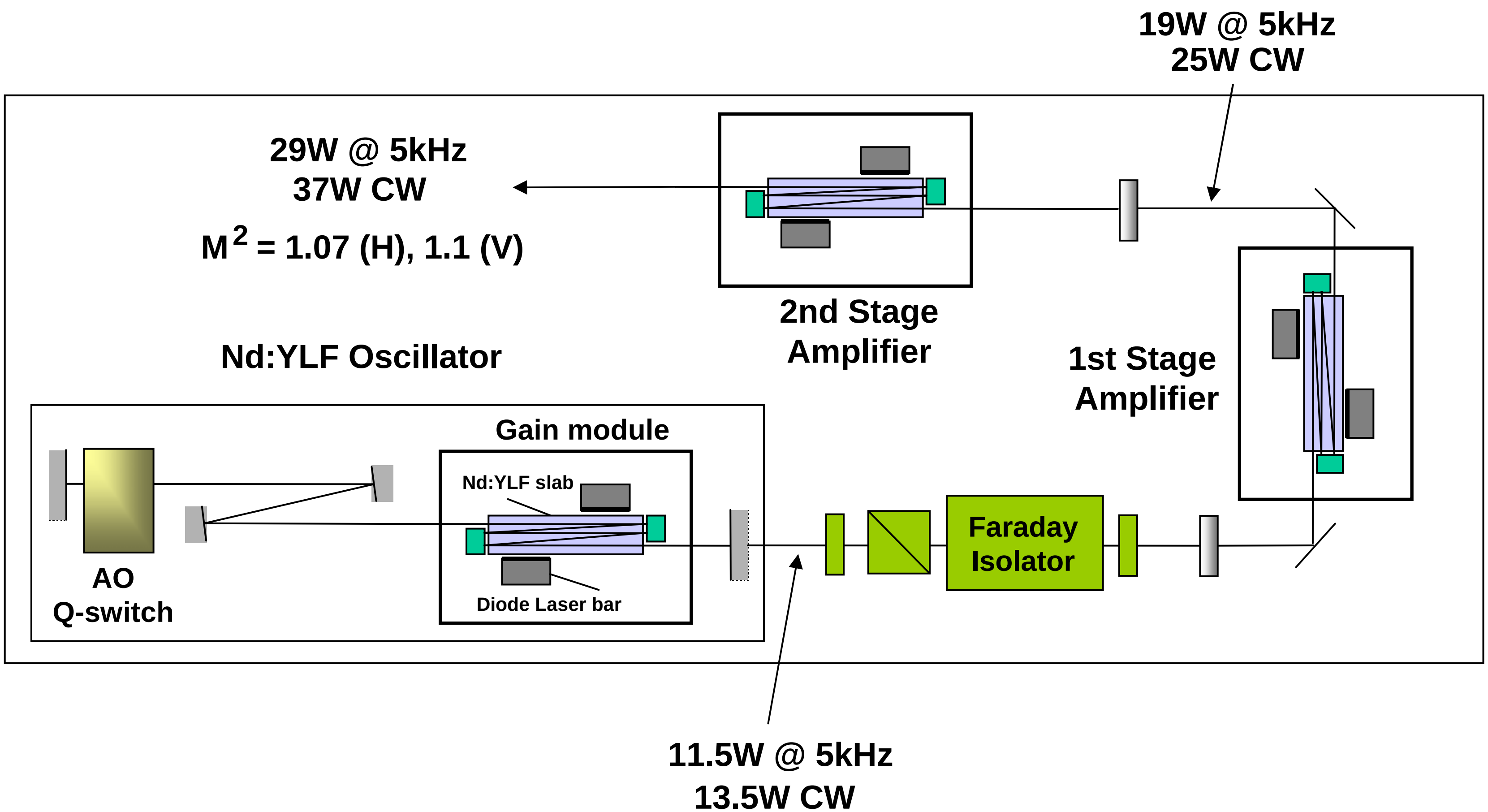


Output Beam Profile of MPS Oscillator



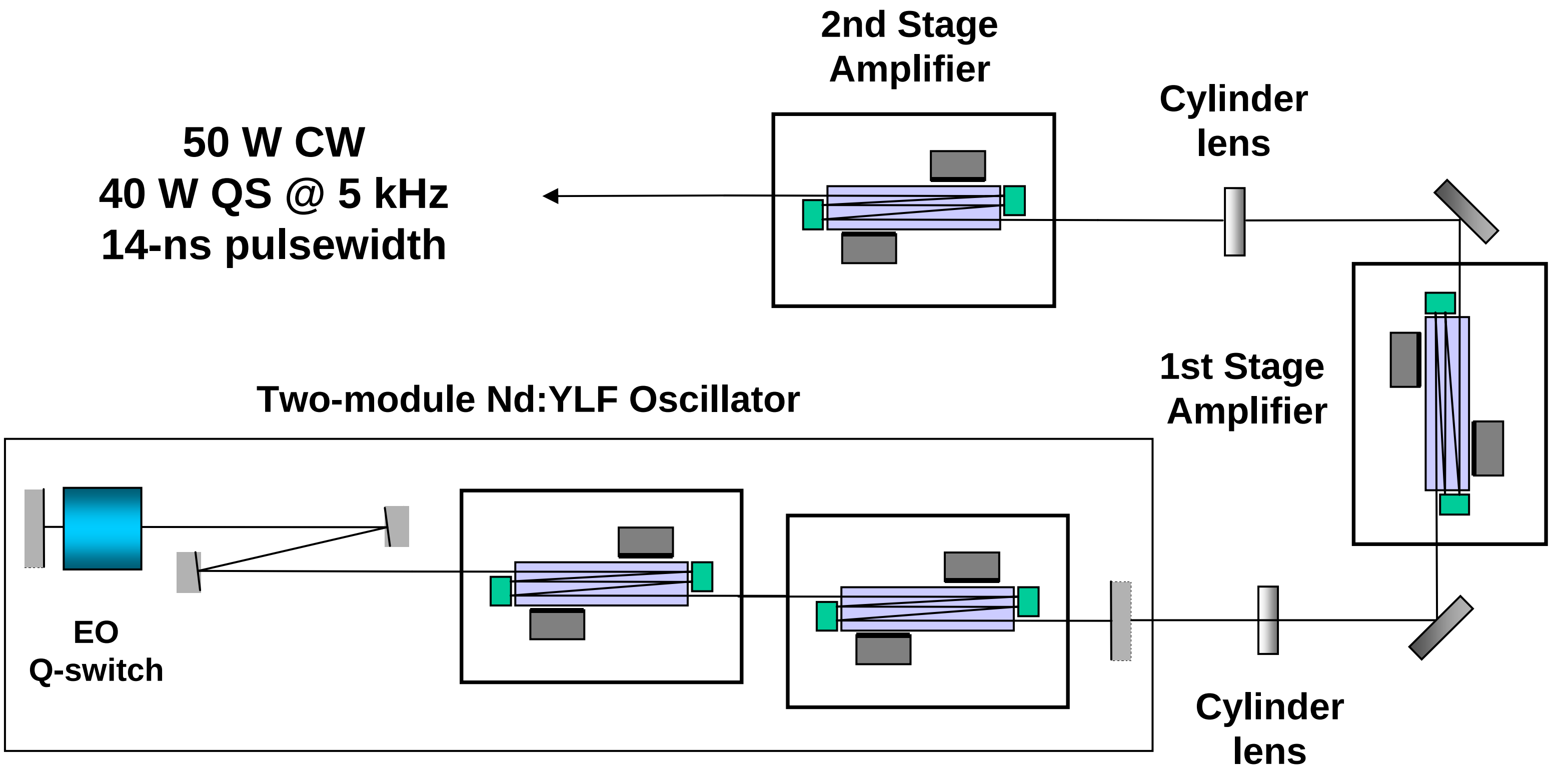
MPS Product Viewgraph

MOPA Design #1; Single-Gain-Module Oscillator, Two Amplifiers

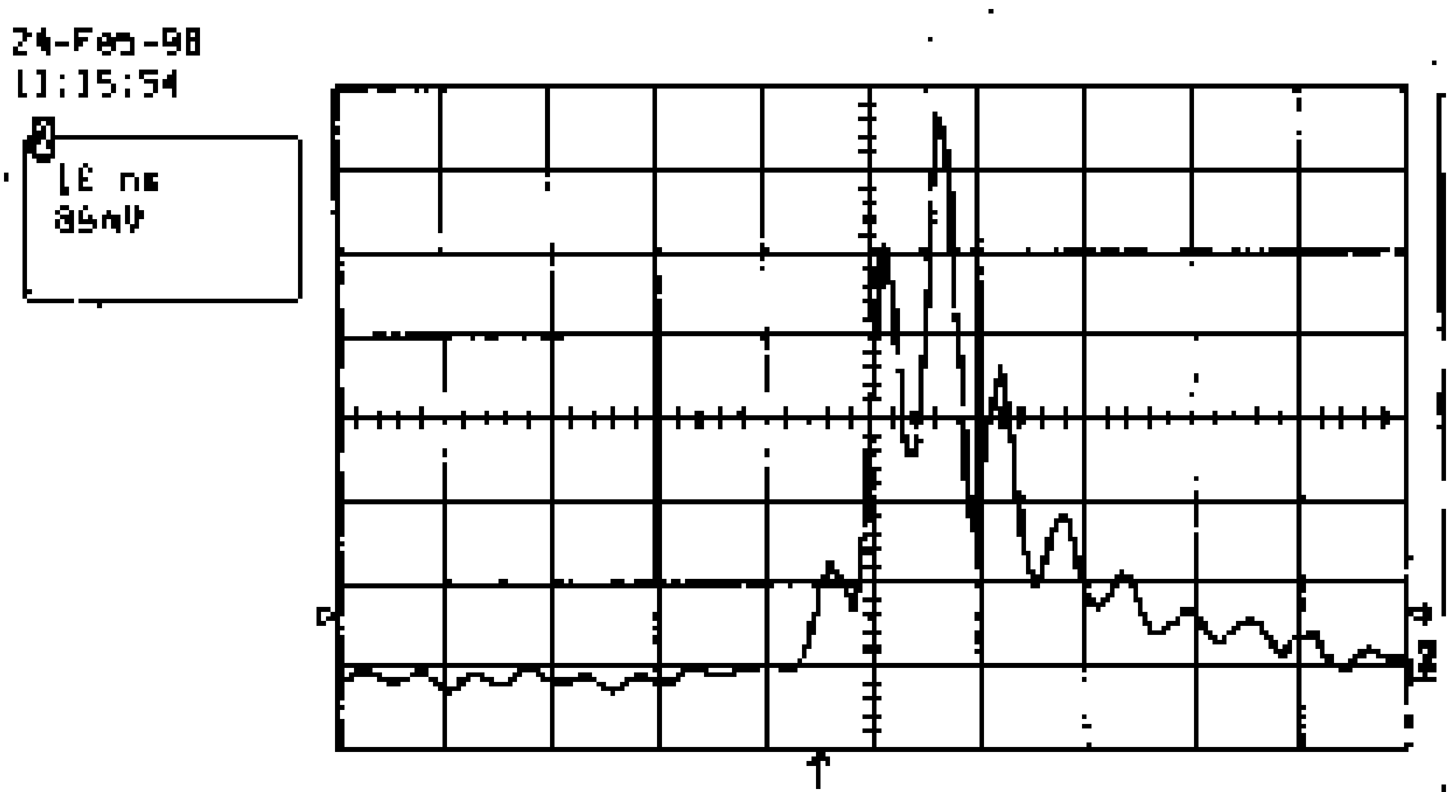


Green MOPA M^2

MOPA Design #2; Two-Gain-Module Oscillator, One Amplifier; 0.6-MW Pulses at 5 kHz



Two-Gain-Module Oscillator Generates 14-ns Pulses at a 5-kHz Pulse Rate



10 ns per division

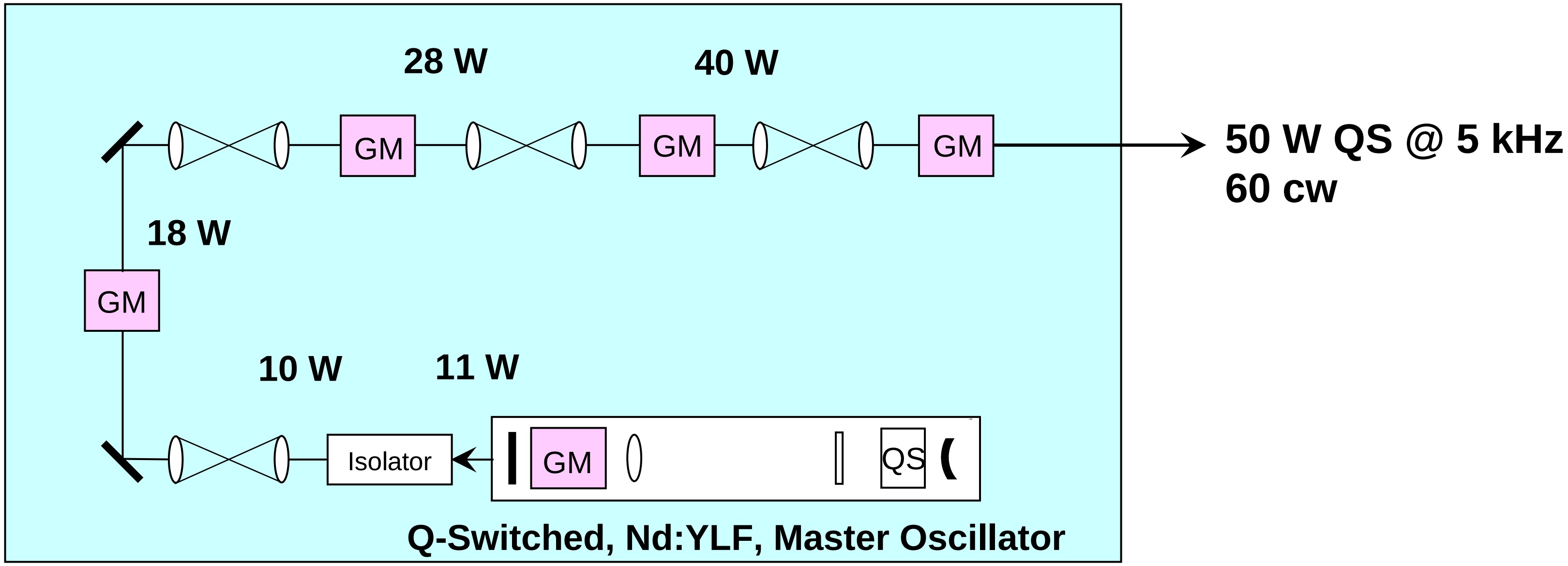
MOPA Design #2 Package

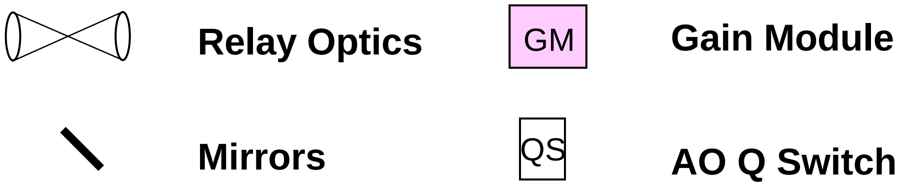
Scaling Results, Two Modules

- **Two-module oscillator**
  - 28 W CW power, TEM_{00}
  - 14-ns-duration Q-switched pulses at 5 kHz
  - EO Q-switch

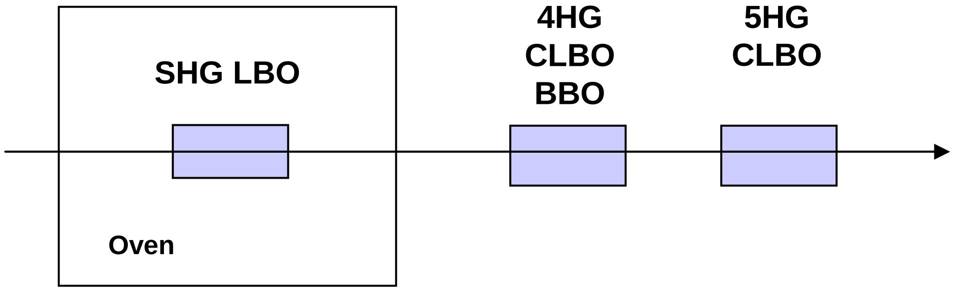
- **Oscillator-amplifier**
  - 25 W CW power (with isolator), TEM_{00}
  - 19 W Q-switched average power at 5 kHz, 20-ns pulses
  - Small signal gain of 4
  - >30% extraction of cw pump power

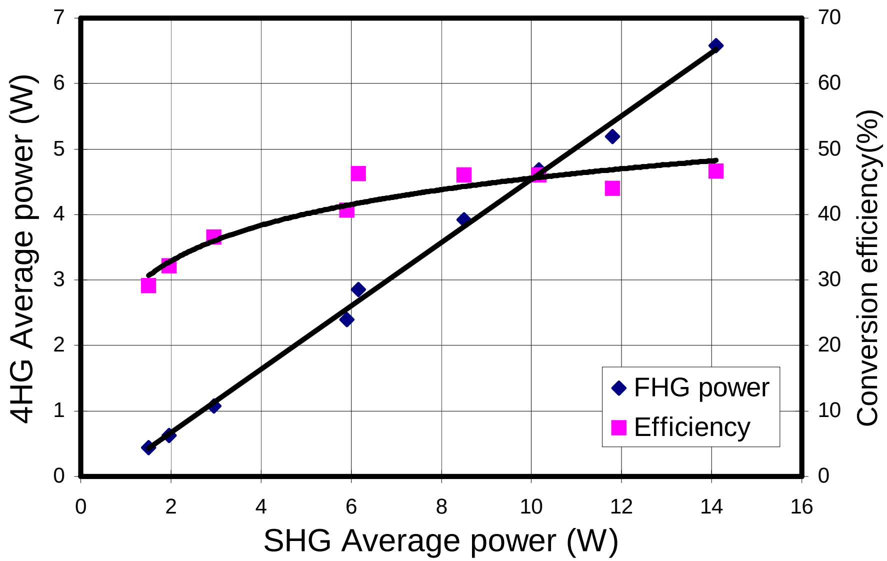
MOPA Design #3; Single Gain Module Oscillator, Four Amplifiers





Harmonic Conversion Generates Visible UV Power





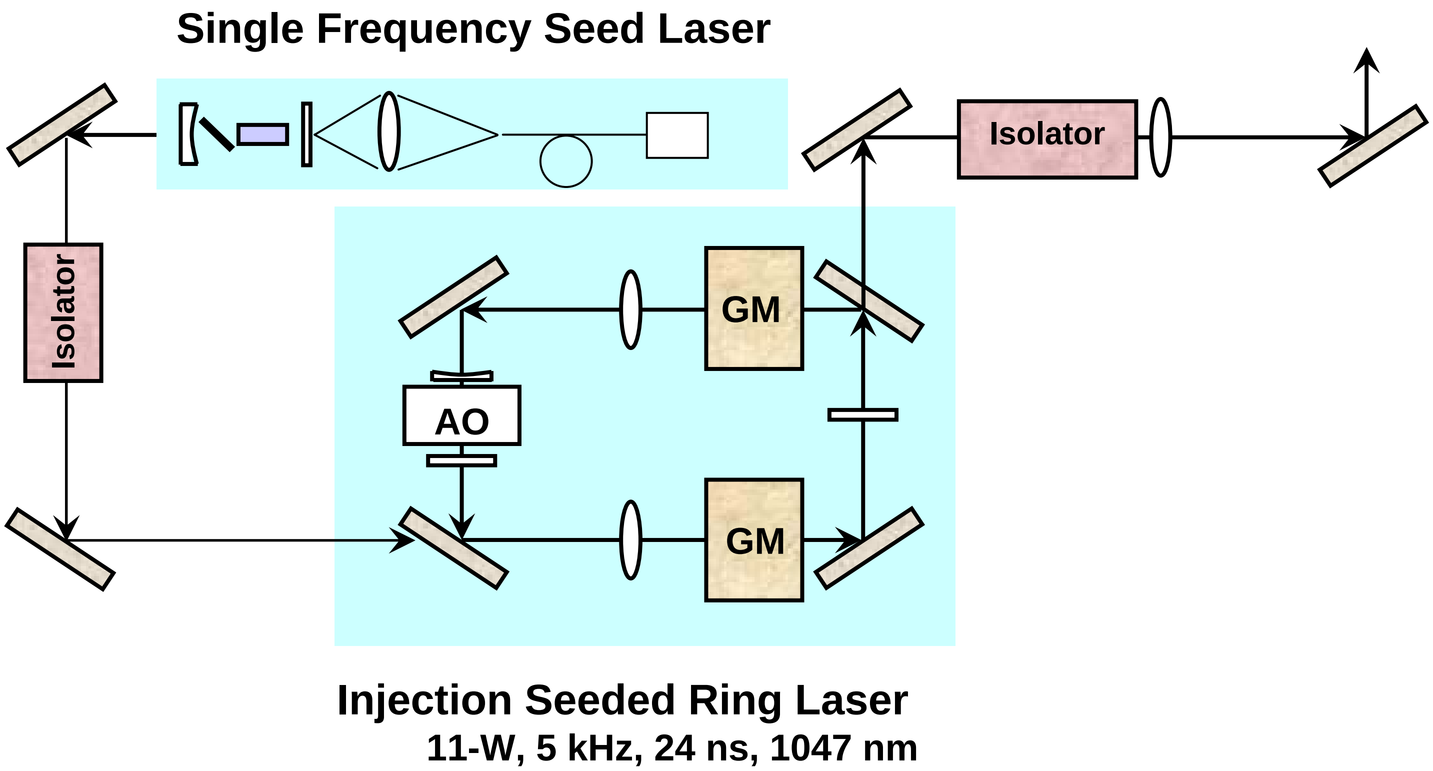
Best results:

SHG (523.5 nm):
14 W at 5 kHz
and 65% conversion
in LBO

4HG (262 nm):
6.6 W (internal)
at 5 kHz with CLBO
2.5 W at 10 kHz in BBO

5HG (207 nm):
2 W (internal)
at 5 kHz with CLBO

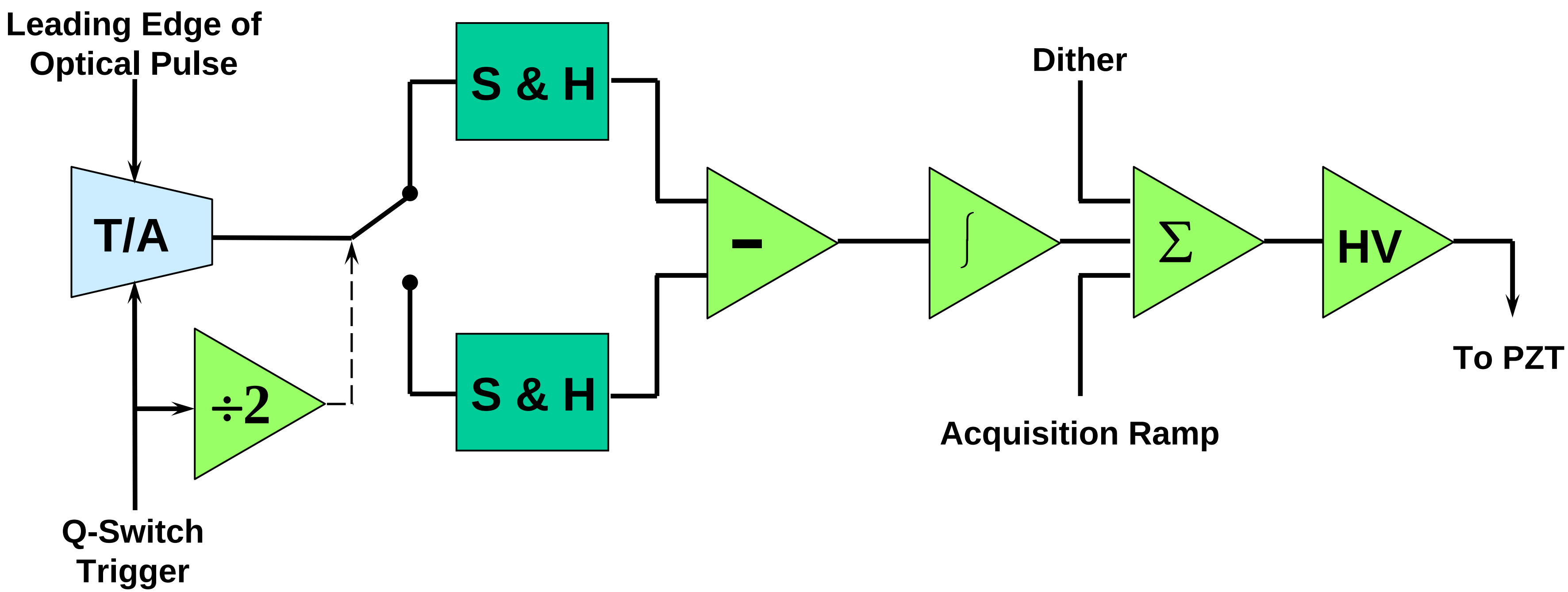
Single Frequency Oscillator Schematic



Nd:YLF Seed Laser

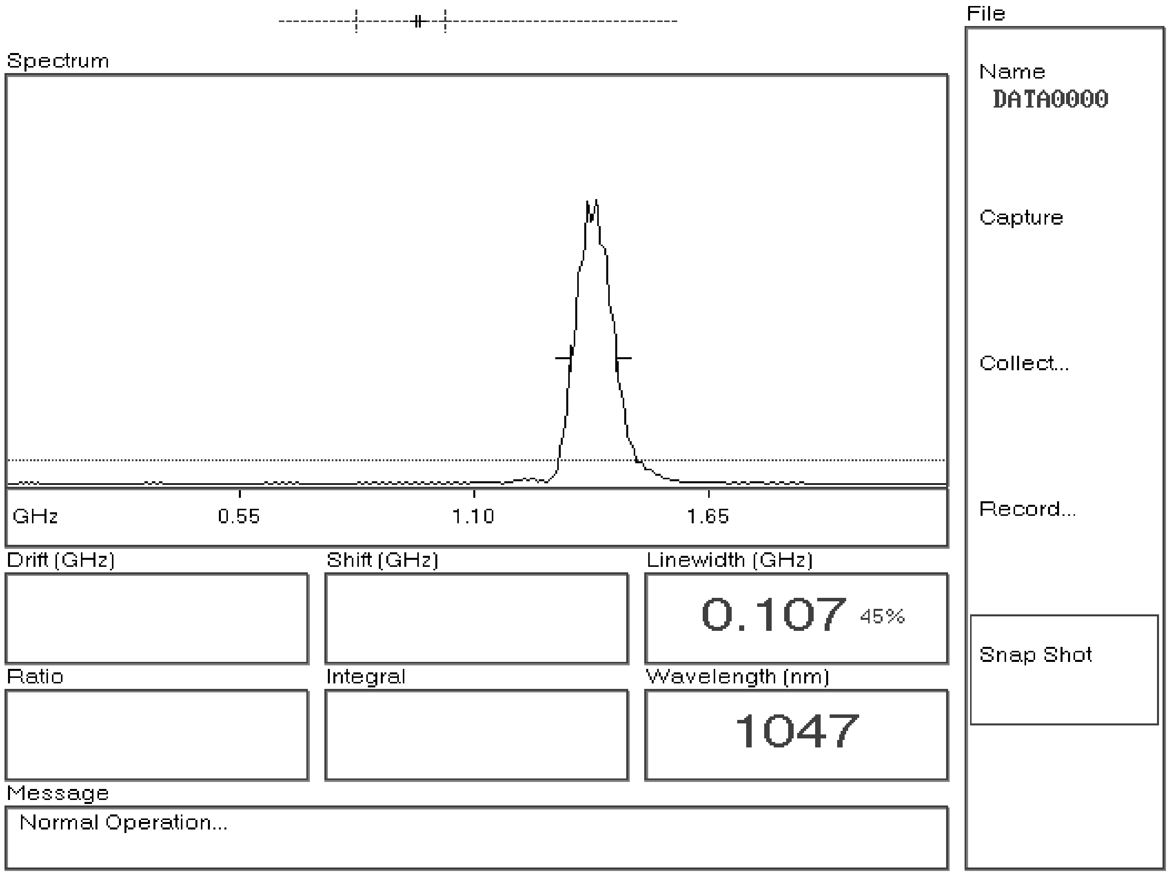
- **Uses Proprietary Technology**
- **Output**
  - 10 mW
  - single longitudinal mode
  - TEM_{00}
  - 1047 or 1053 nm
- **Can be applied to**
  - Ho:Th:YLF
  - $Nd:YVO_4$

Pulse Build-Up Time Reduction Seeding Technique

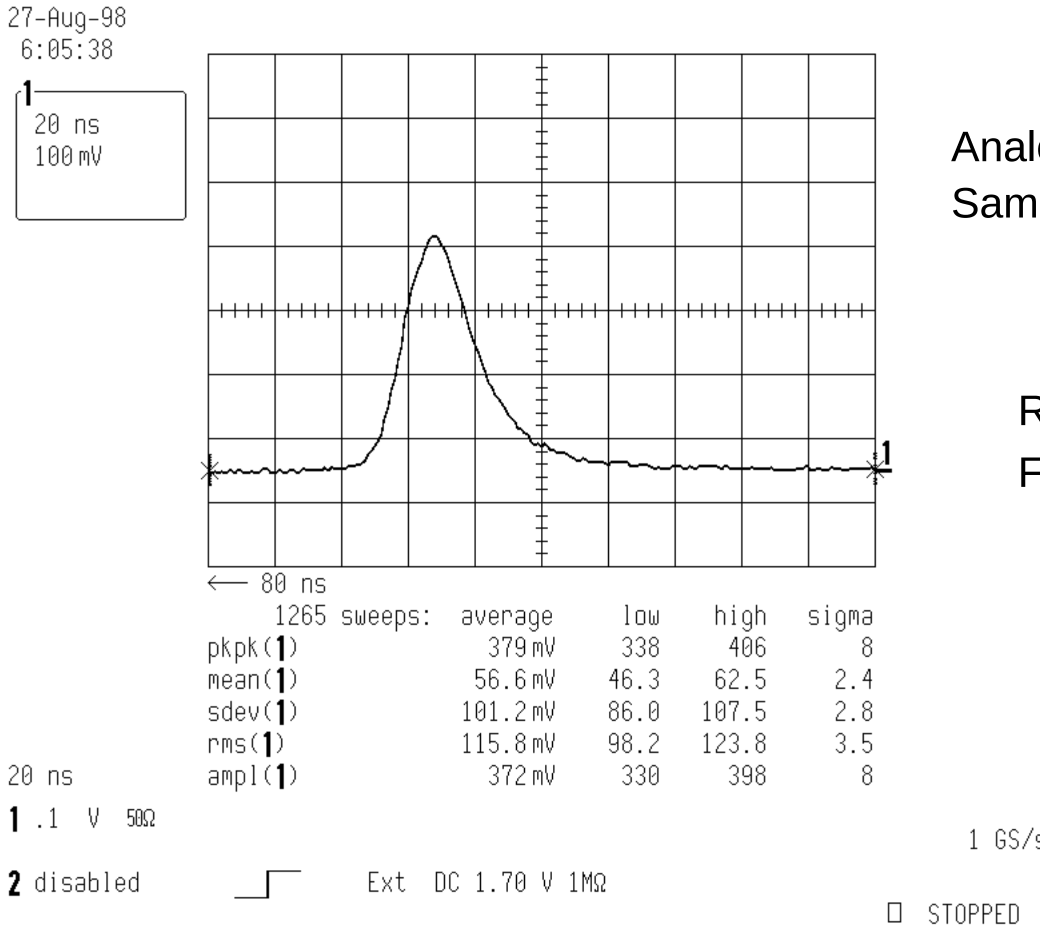


- When the seed laser frequency corresponds to a longitudinal mode of the slave laser, the build up time is the shortest.

The Linewidth of the Single Frequency Ring Laser is < 100 MHz (Resolution Limited)



Single-Frequency MOPA Pulse Profile



Oscilloscope

Analog Bandwidth: 1 GHz

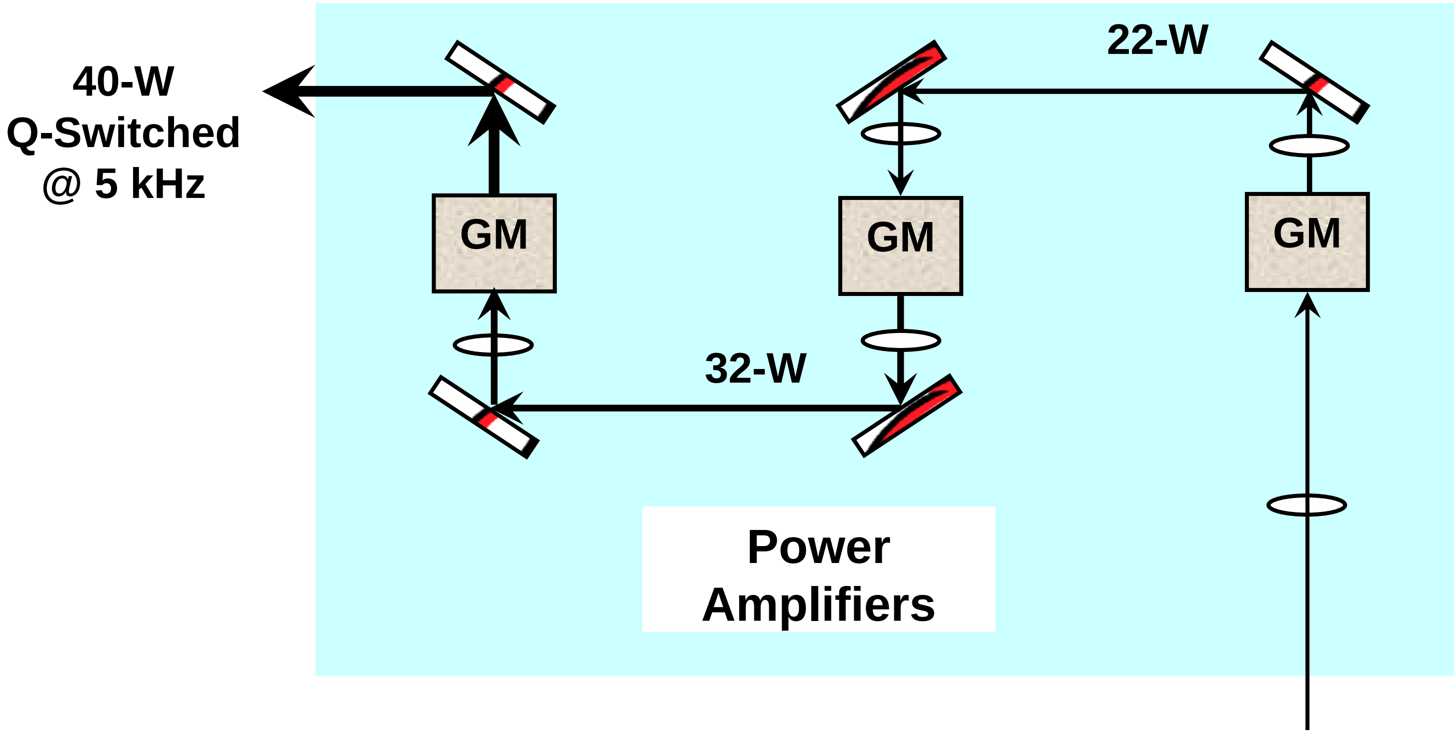
Sampling Rate: 1 GHz

Detector

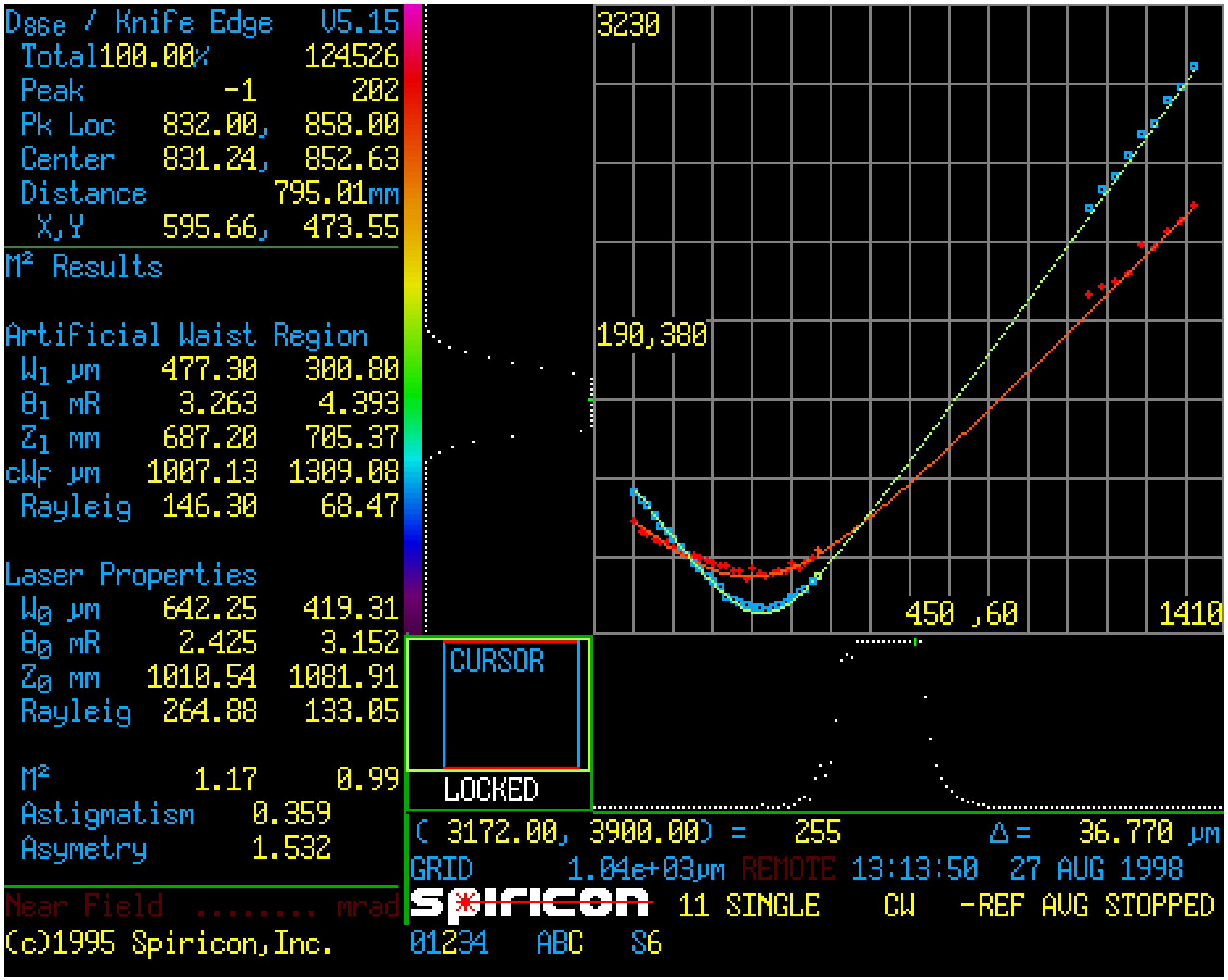
Risetime: < 200 ps

Falltime: < 350 ps

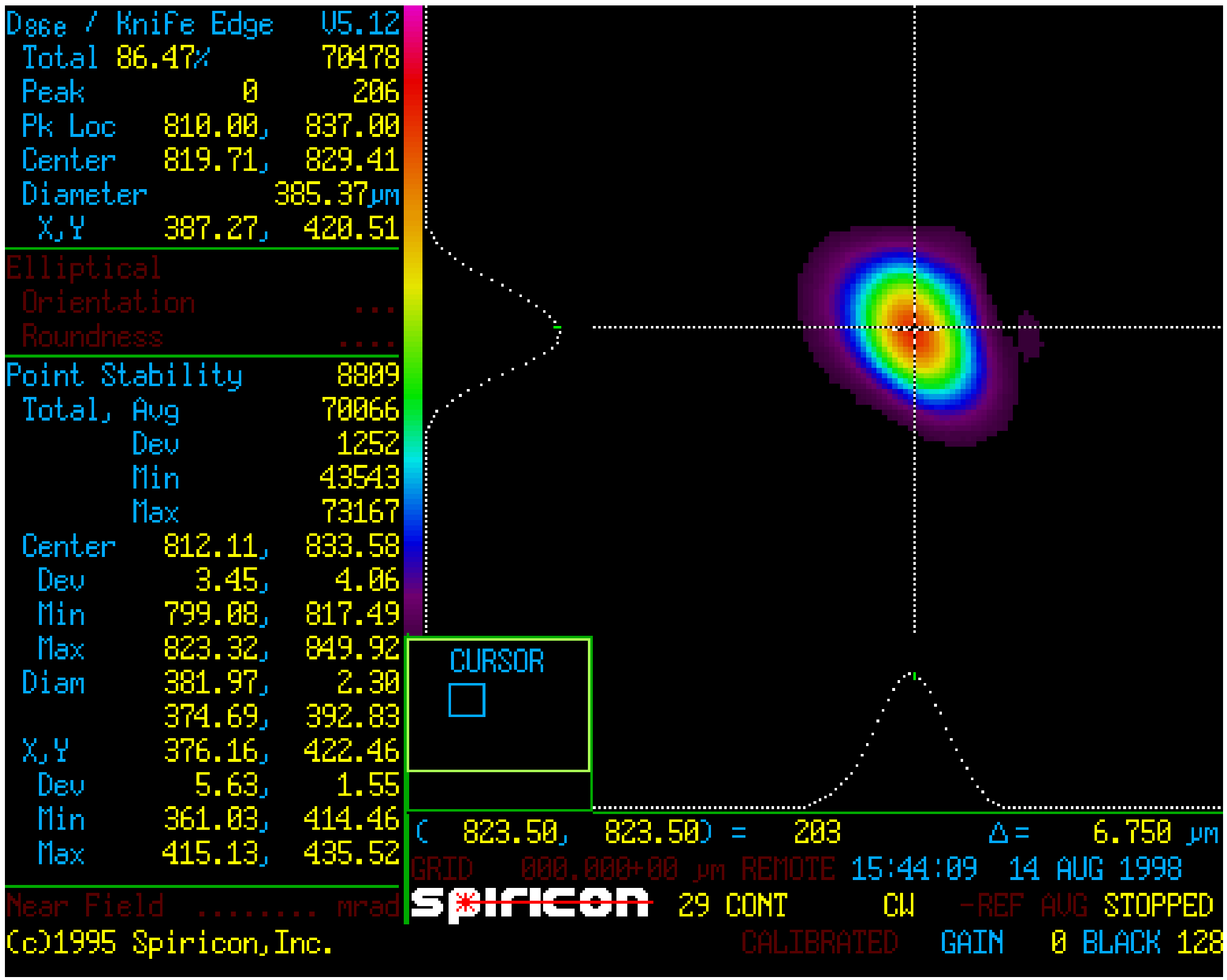
Single-Frequency MOPA Power Amplifiers



Beam Quality of Single-Frequency MOPA



Pointing Stability Over 1 hr is ± 2 μrad



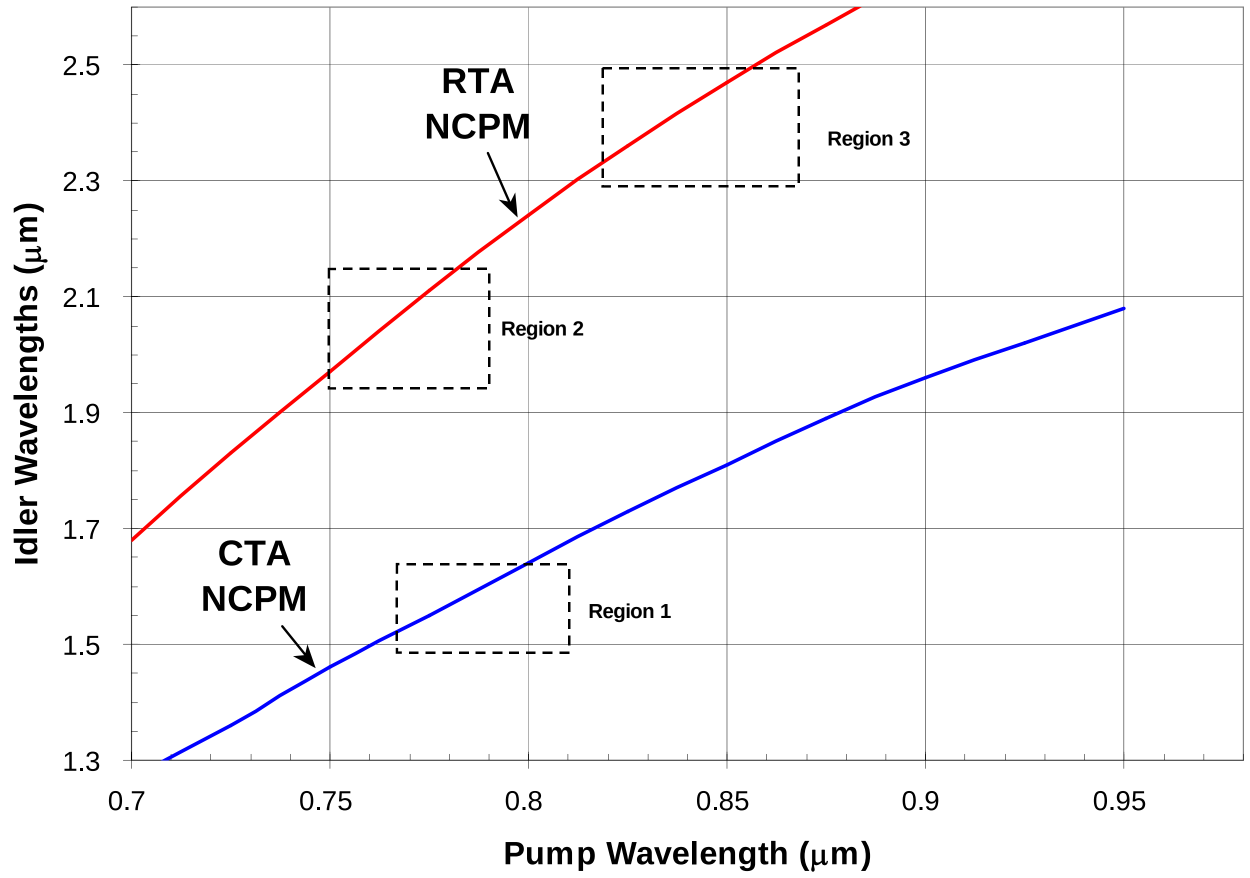
Optical Parametric Oscillators (OPOs)

- **Optical parametric oscillators are nonlinear optical devices that convert a fraction of the output of a laser (the pump) into two outputs, the signal and idler, both at longer wavelengths**
- **The frequencies of the signal and idler sum to that of the pump**
- **For a given pump, the signal and idler wavelengths are determined by the characteristics of the nonlinear crystal used in the OPO**

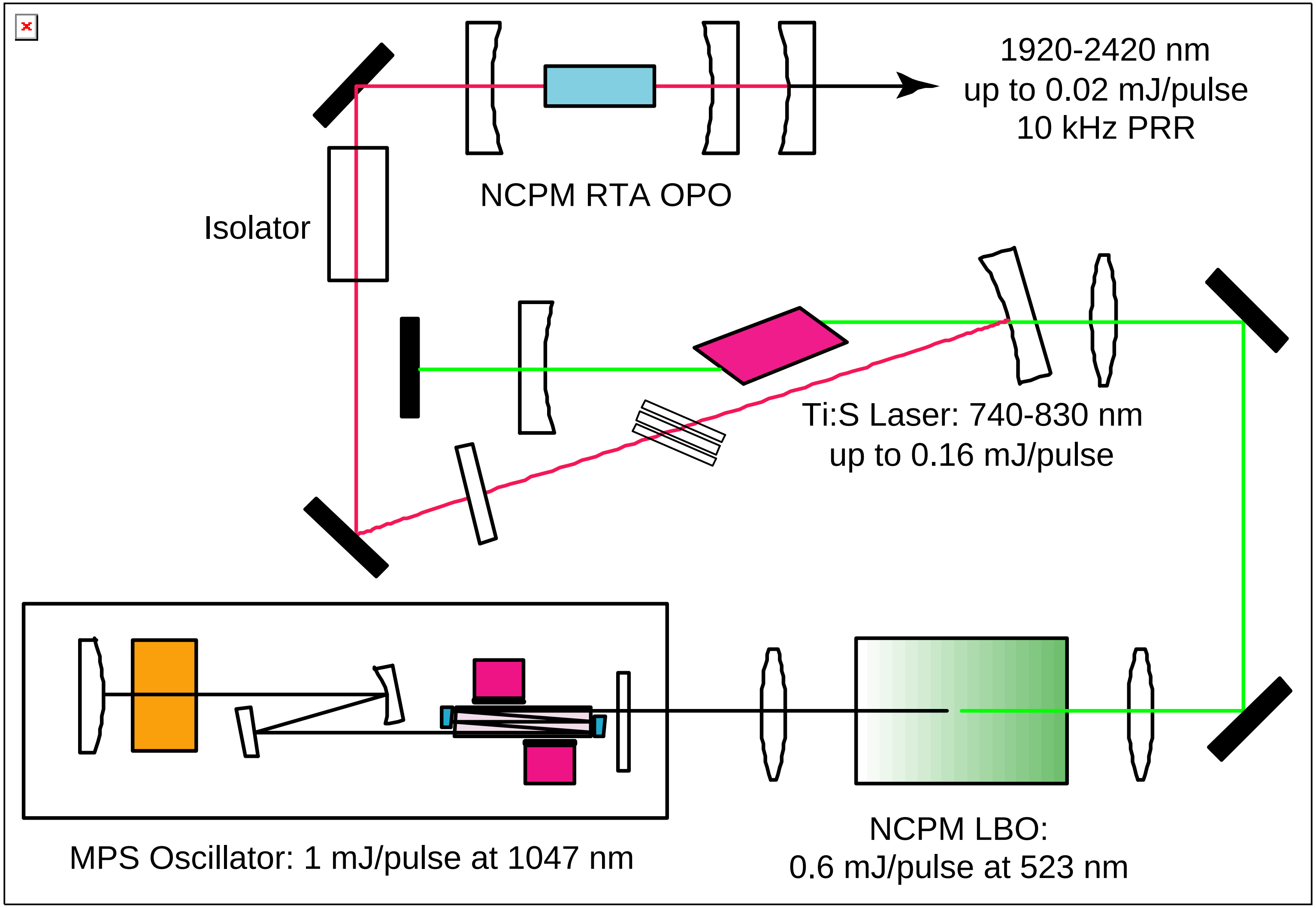
KTP-Family OPOs are Used as Eyesafe Sources

- Several crystals belonging to the KTP family, when pumped by Nd-doped laser pumps around 1050-1070 nm, generate signal wavelengths around 1550 nm, the maximally eyesafe wavelength region
- The advantages of the KTP family include:
  - non-critical phase-matching, which allows good OPO conversion efficiency even with poor-beam-quality pump lasers
  - large available crystal sizes, which allows generation of high energies

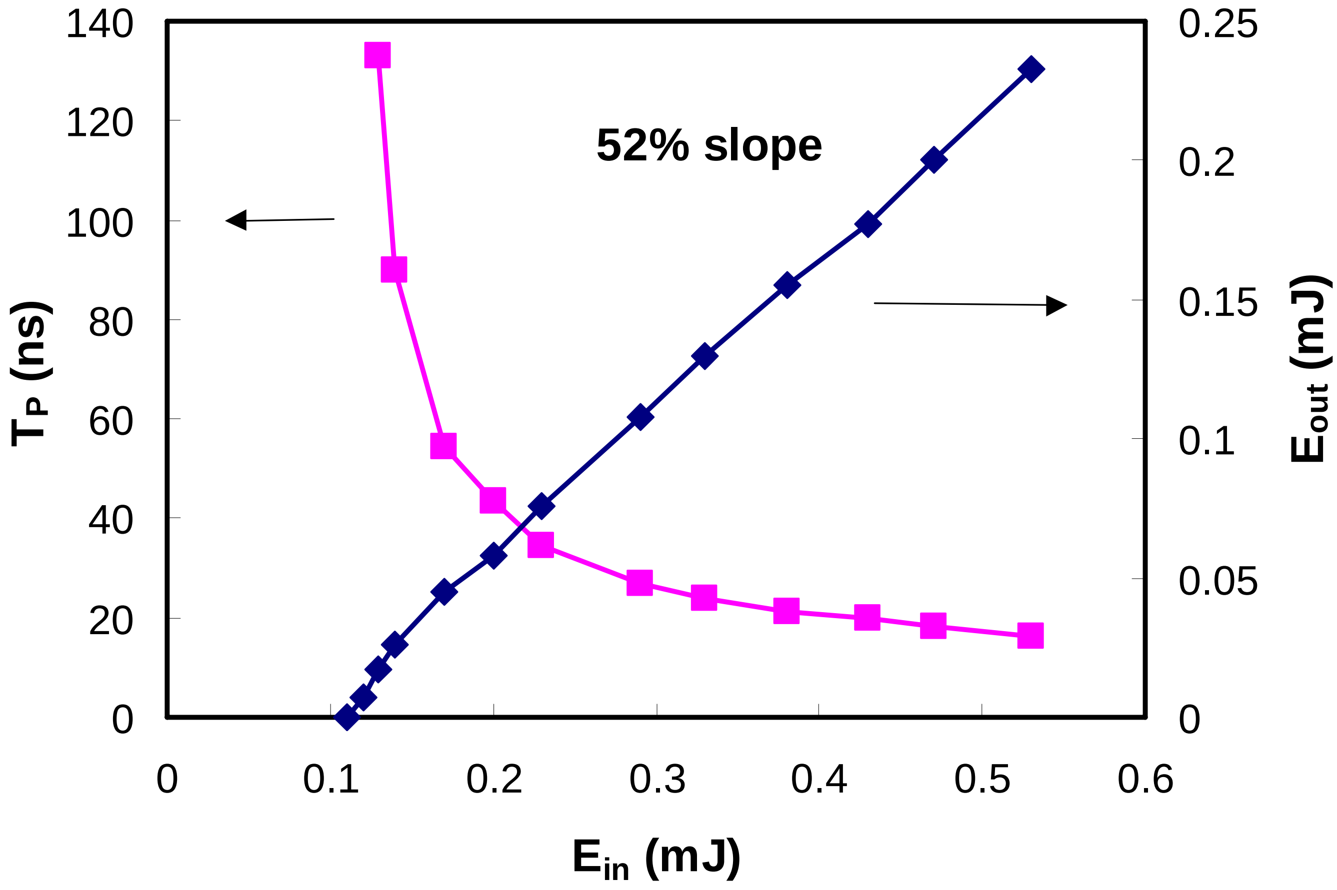
RTA and CTA OPO Non-Critically Phase Matched Idler Tuning Curves



Broadly Tunable Mid-IR Source



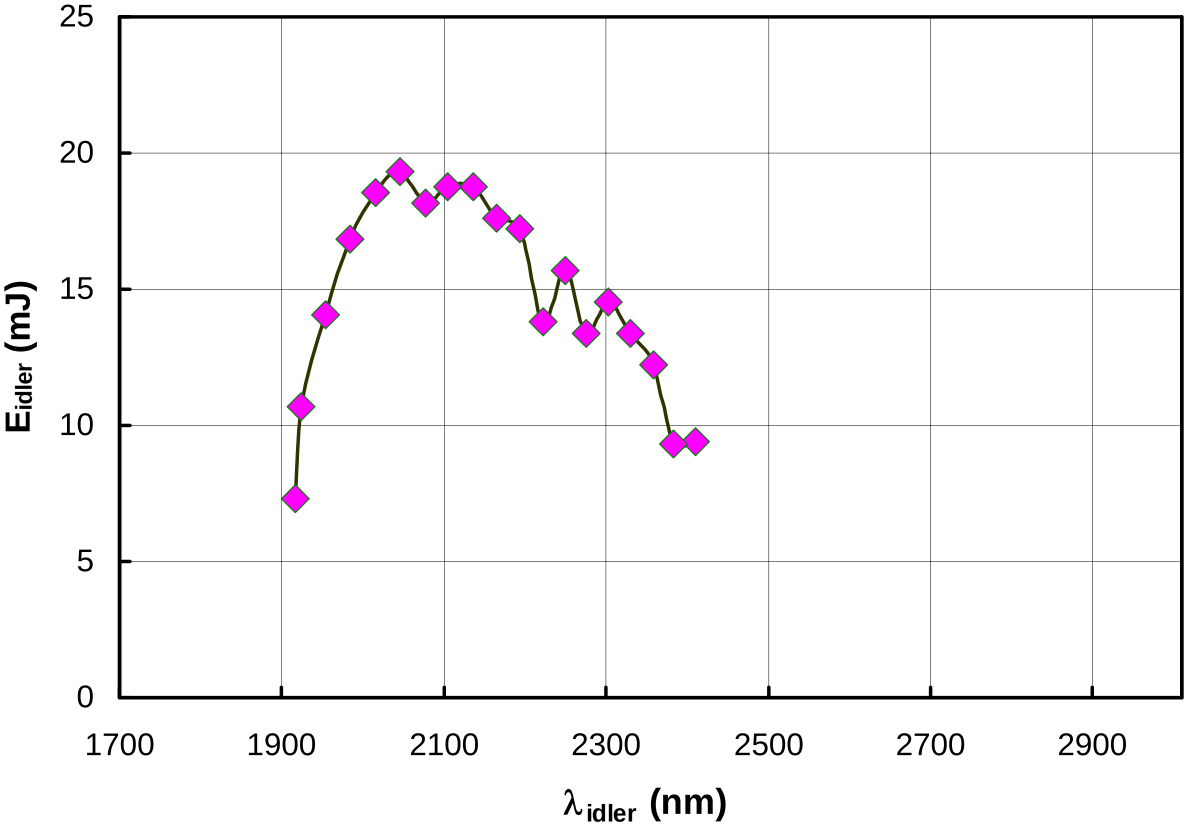
Ti:Sapphire Laser Pumped by Doubled Nd:YLF Laser has 44% Conversion Efficiency



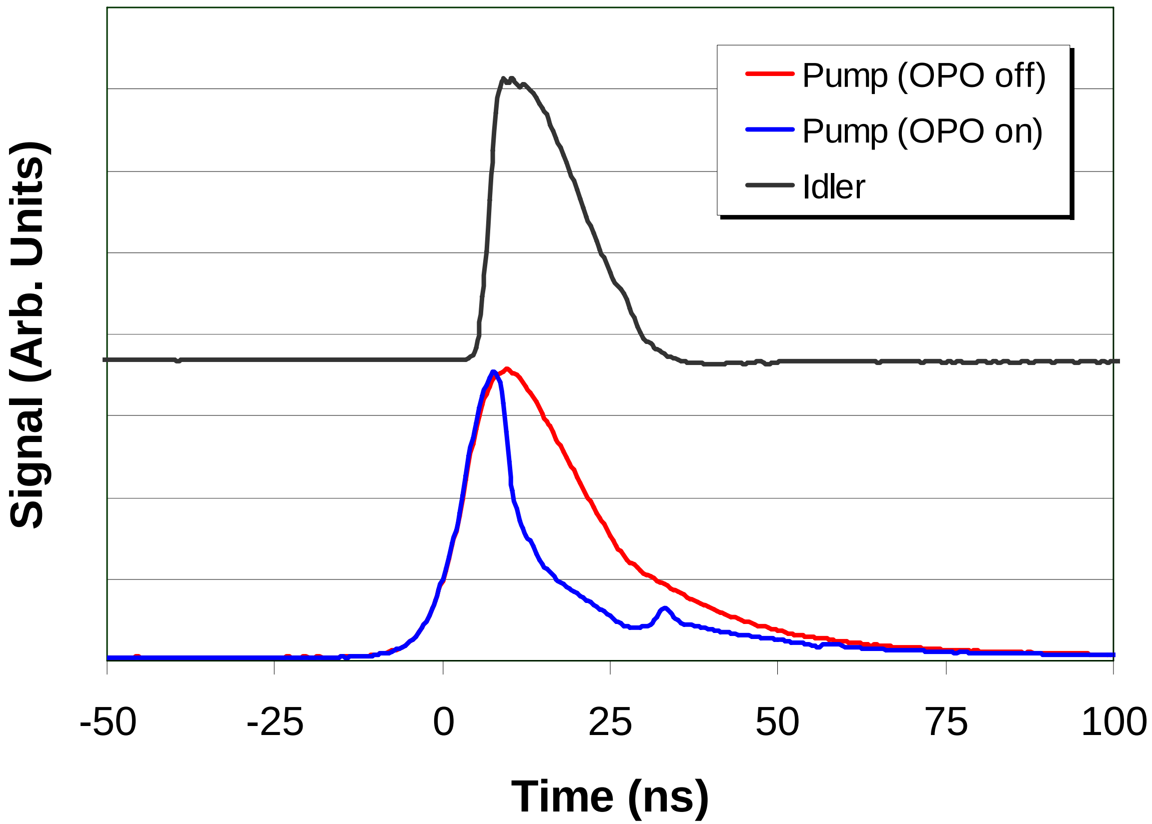
RTA OPO Tuning Curve

Ti:sapphire *theoretical* tuning range

700 nm ⟷ **1000 nm**

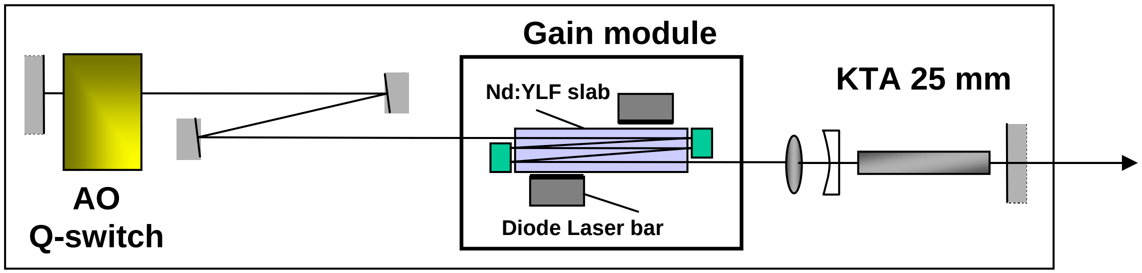


RTA OPO Temporal Characteristics



OPOs provide high power at eyesafe wavelengths

Intracavity OPO



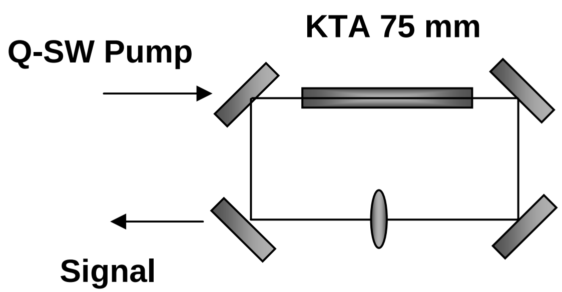
1 W output

at 1507 nm

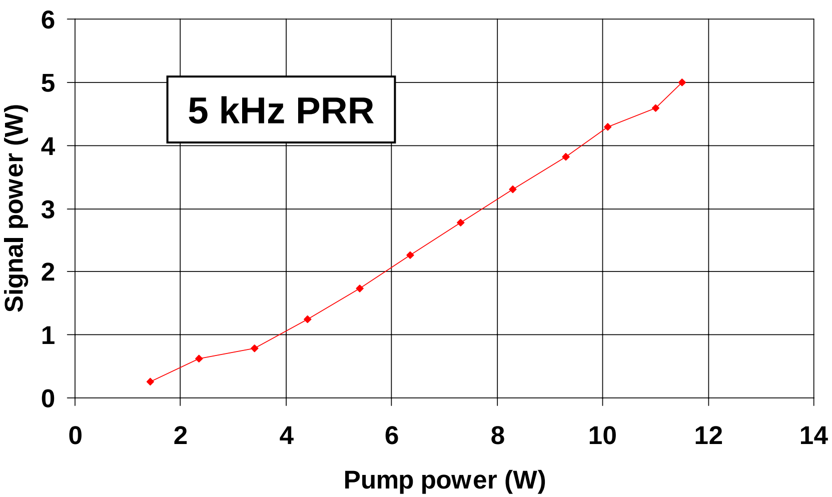
12.5 kHz PRR

6 ns pulsewidth

External OPO



43% conversion to 1507 nm



KTA and PPLN OPOs Provide Longer-Wavelength IR

- **Pump source: MOPA #2**
- **KTA OPO**
  - **60-mm crystal length, 80-degree cut**
    - 30 W pump, 5 kHz PRR
    - 10 W at 1530 nm, 3 W at 3340 nm
  - **40-mm crystal length, 60-degree cut**
    - 33 W pump, 5 kHz PRR
    - 5-6 W of idler tunable from 2300-3000 nm
- **PPLN OPO**
  - **19-mm crystal length, 30.8-um pitch**
    - 30 W pump, 5 kHz PRR
    - 5.2 W at 2610-nm idler, 3W at 1720-nm signal

Closing Comments

- **Nd:YLF can be used to generate high beam quality lasers systems with output powers of up to 50-W Q-switched and 60 W cw**

- **A full range of nonlinear optics (harmonic generators, OPOs) and tunable lasers (Ti:sapphire, etc.) are usable with the cw-pumped "engines" to provide wavelength diversity and tunability**

- **Gee. What if we pumped with 40-W diode lasers instead of 20-W?**