Status of High Power Laser Development at Stanford

Shally Saraf
Stanford University

LSC meeting

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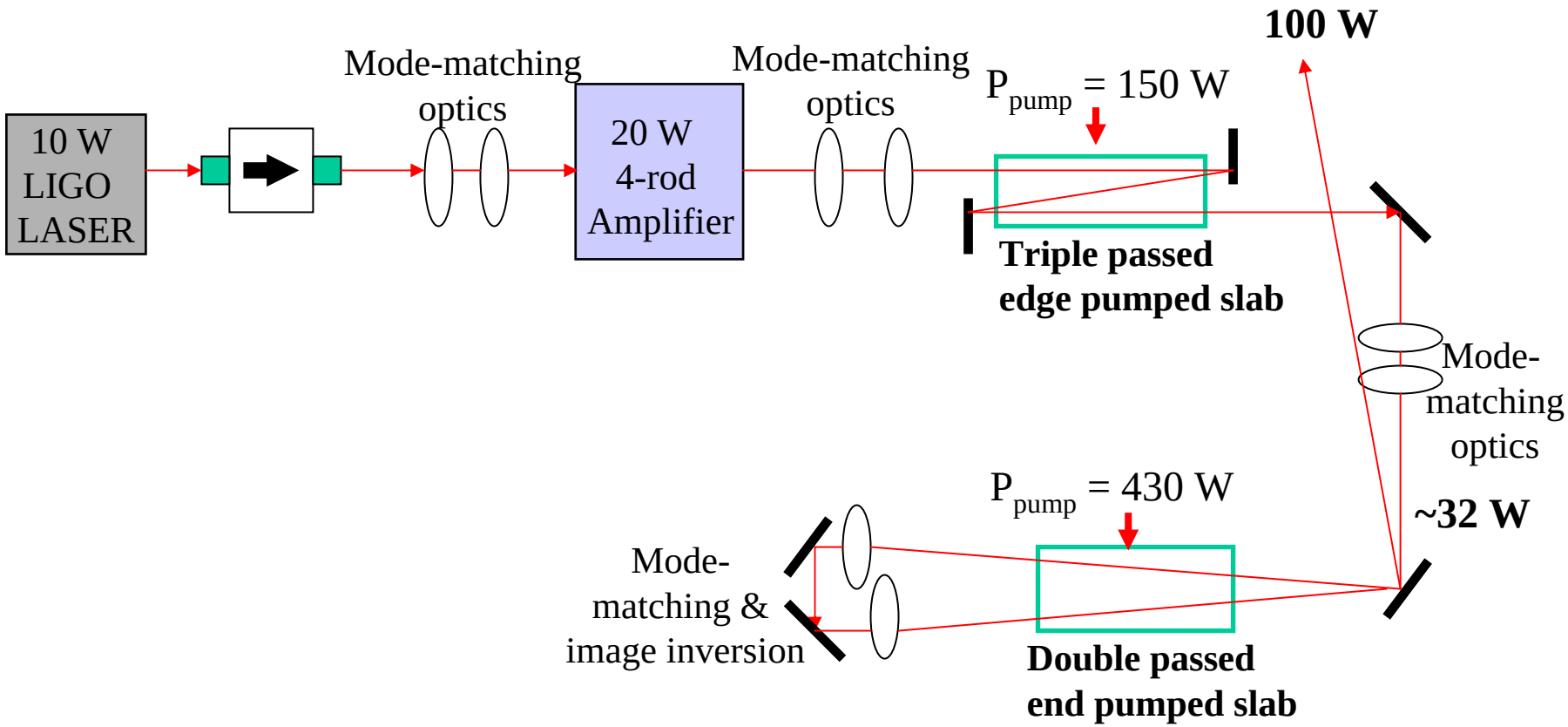
*saraf@stanford.edu

Outline

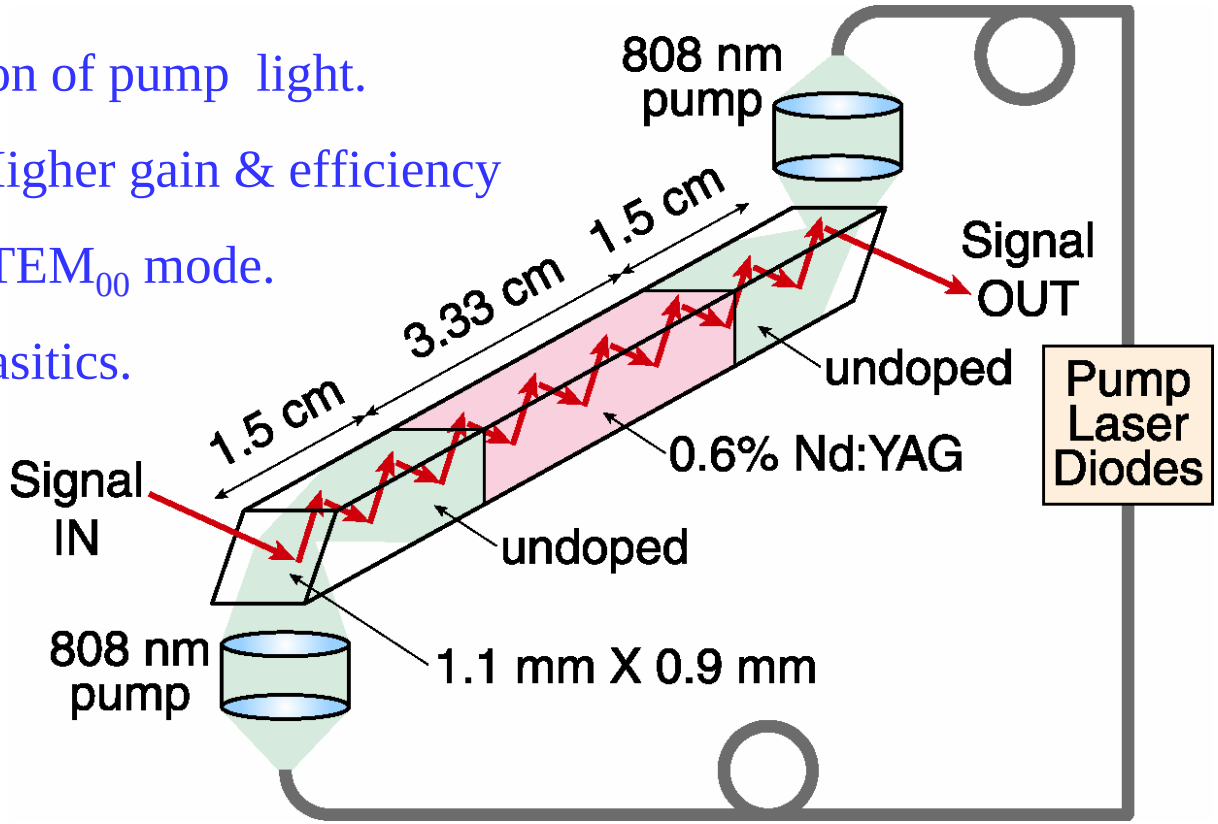
- **Slab Laser Amplifiers**
  - **100 W MOPA experiment using end-pumped slabs**
- **Quantum noise measurements in amplifiers**
  - **Saturated amplifier quantum noise experiment**
- **One-step power scaling**
  - **30 W amplifier module**
- **200 W MOPA**
  - **2 end-pumped power amplifier stages**
- **Future work**

Experimental setup for MOPA experiment

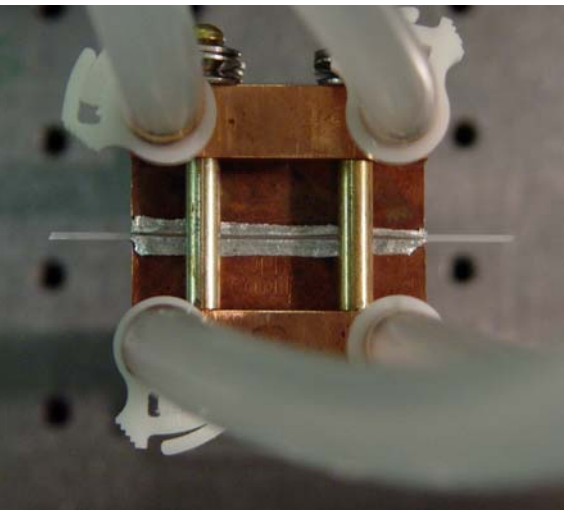


End-pumped Amplifier Slab Geometry

- Nearly complete absorption of pump light.
- Better mode overlap => Higher gain & efficiency
- Square geometry prefers TEM_{00} mode.
- Rough sides suppress parasitics.

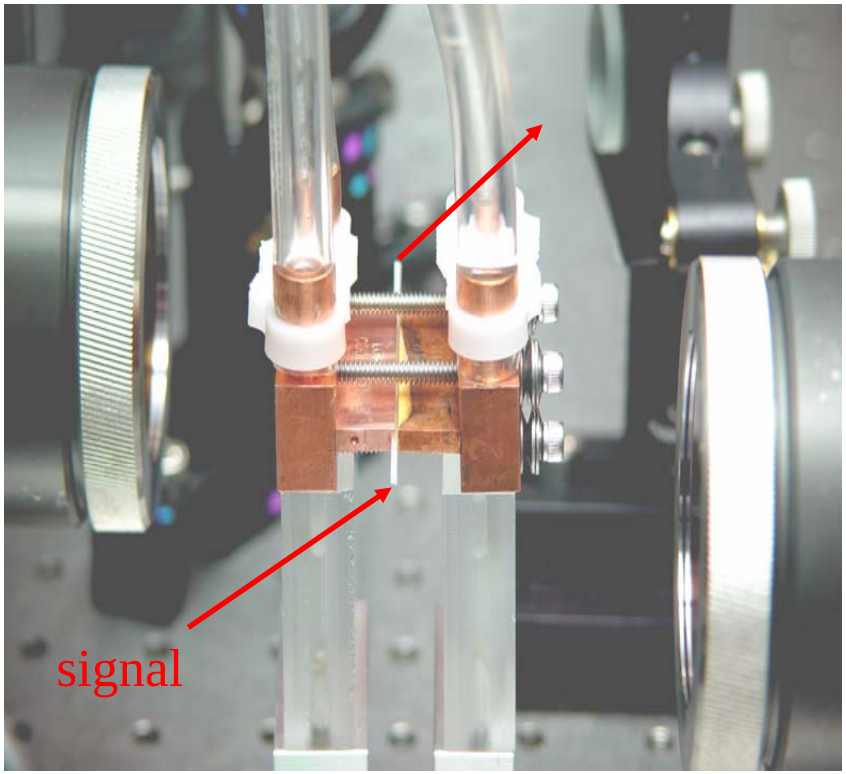


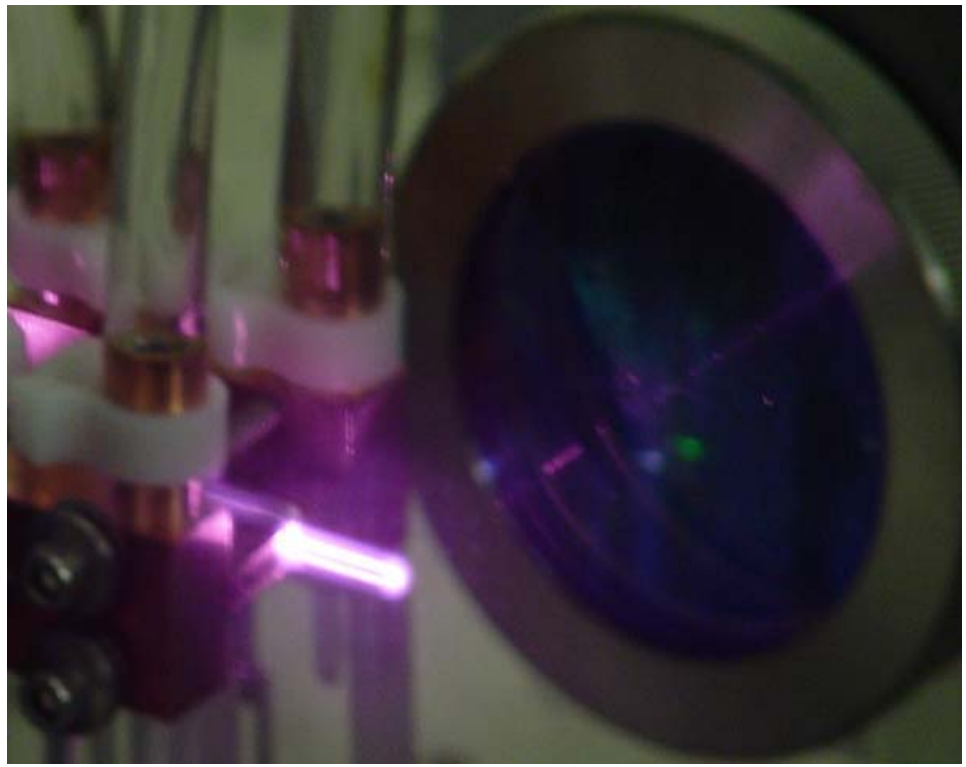
Goodno et. al., ASSL 2001



Saraf et. al., ASSP 2004

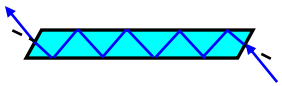
End-pumped slab laser head



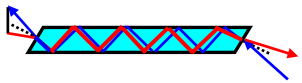


✓1 mm^2 slab ends pumped with up to 300 W on a 400 μm spot size!

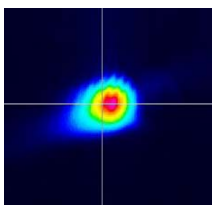
Results of MOPA experiment



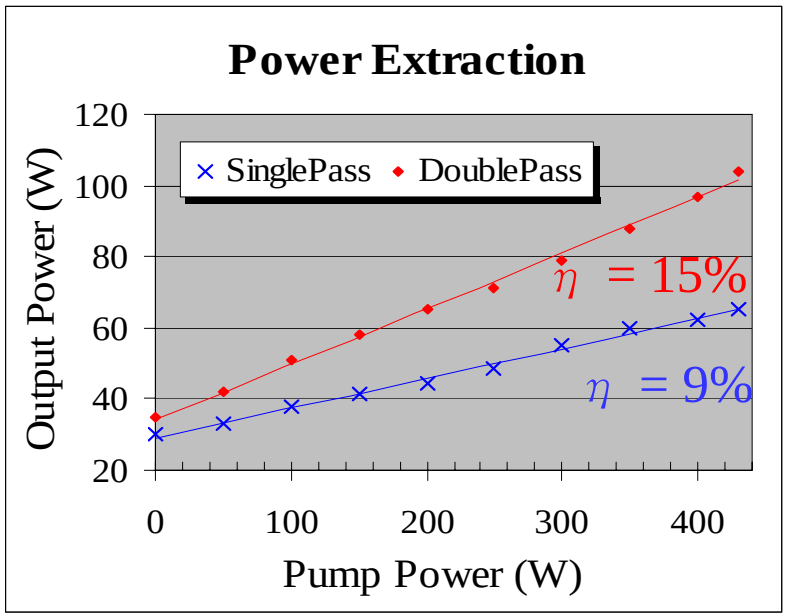
- Single Pass Power Output ~ 65 W
  - –Depolarization ~ 1.5%.
  - –P-P intensity fluctuations < 2%
  - –M^2 < 1.08, TEM_{00} content 74 %.

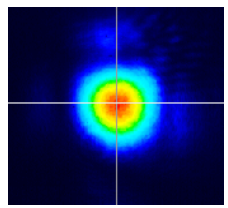


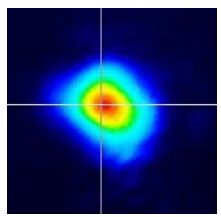
- ✓ Double Pass Power Output ~ 104 W
  - –Angular multiplexing avoids Faraday rotator.
  - –Depolarization < 3%.
  - –P-P intensity fluctuations < 2%
  - –M^2 < 1.09, TEM_{00} content 89 %.



COLD SLAB



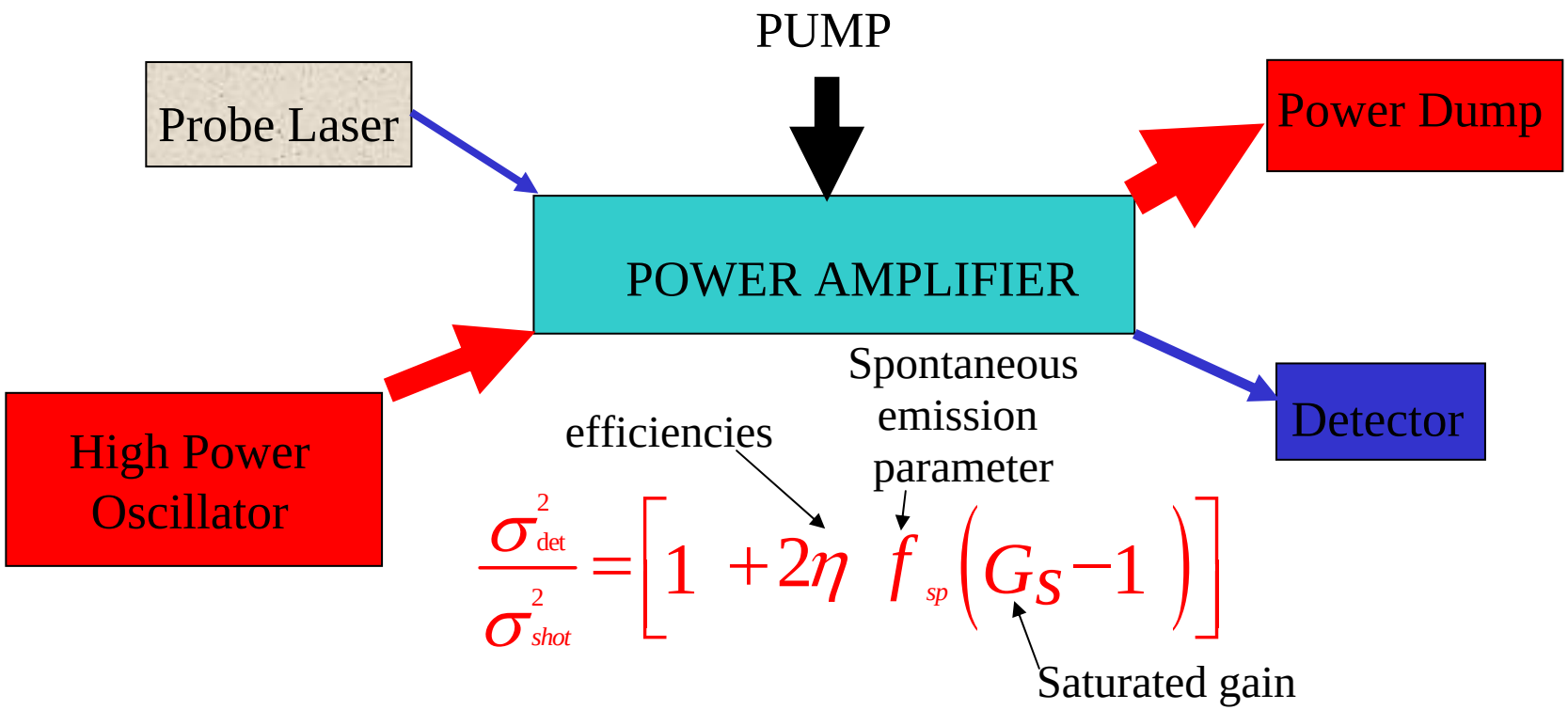




Saraf, et.al.,

Submitted Opt. Lett., (2004)

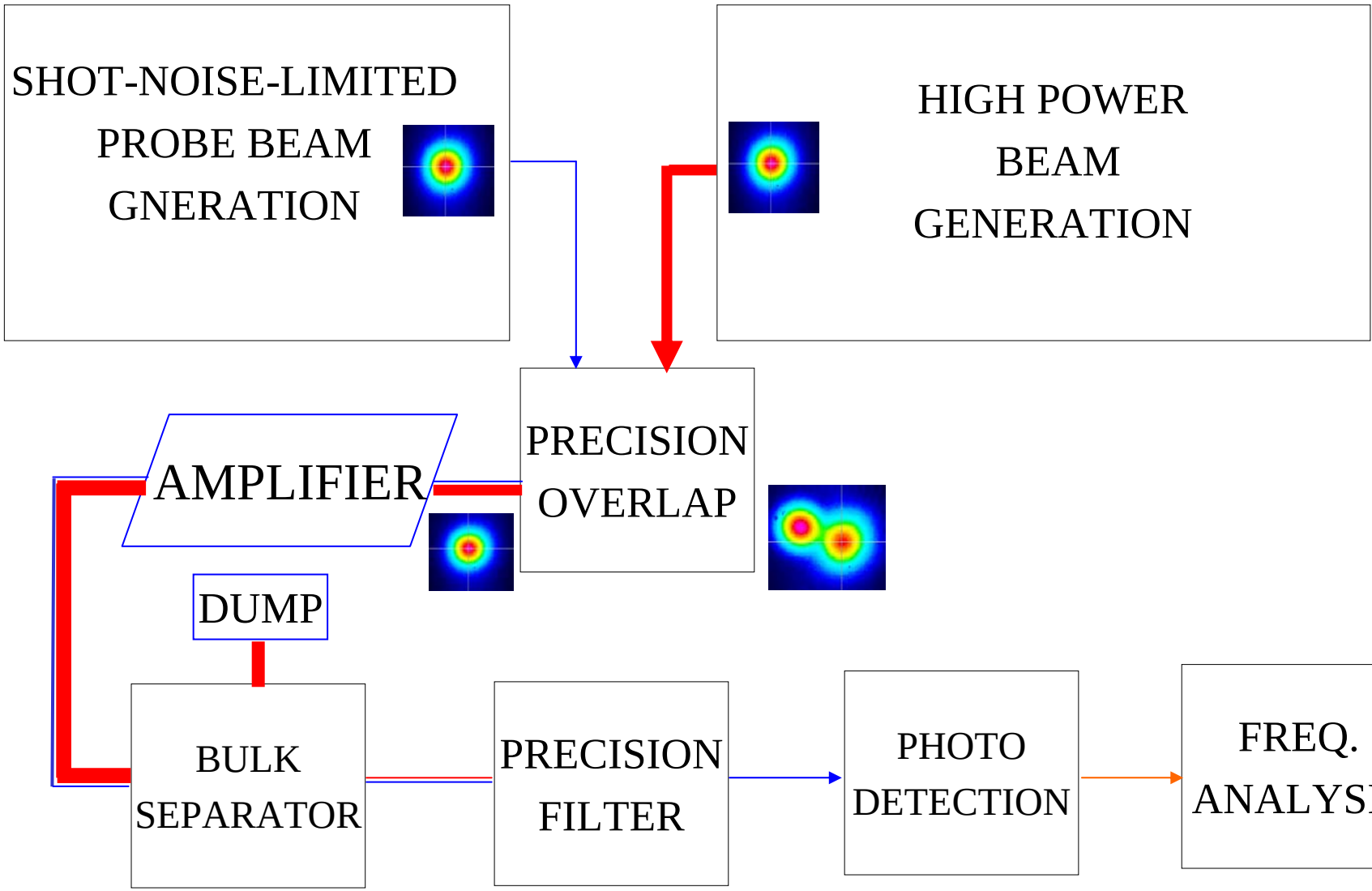
Saturated Amplifier Noise Measurement



- Direct noise measurement on a high power beam is difficult.
- Attenuating a high power beam for photodetection makes it SNL.

✓Piggy-back a low-power probe beam and measure quantum noise of the probe.

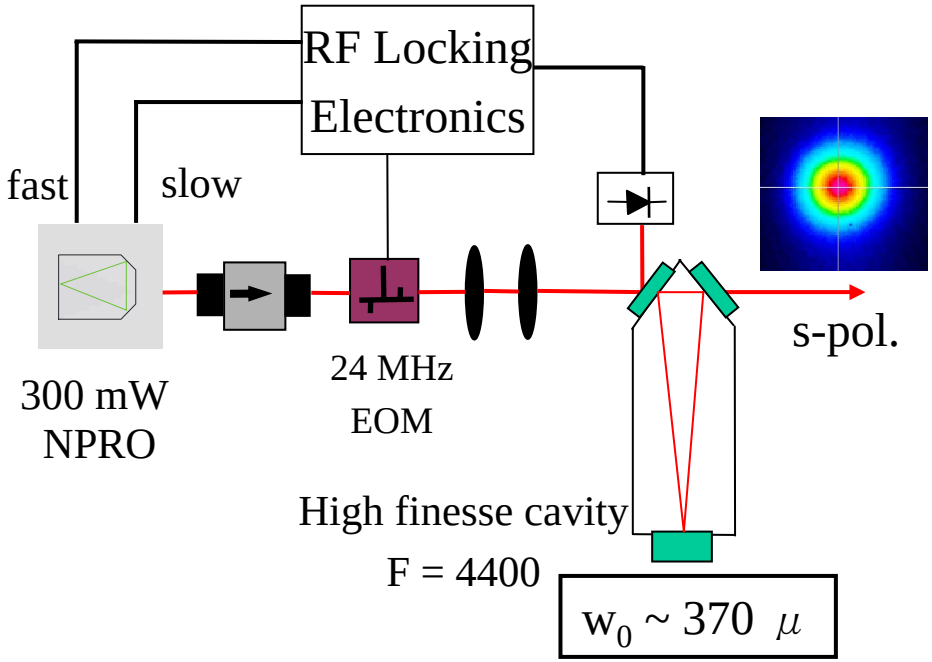
Experiment Block Diagram



Probe Beam Generation

Laser : Non-Planar Ring Oscillator (NPRO)

Locking Technique: Pound-Drever-Hall



- Laser frequency follows stable cavity.
- Temporal filtering by high finesse cavity reduces power noise of the master oscillator. (~34 dB at 4 MHz)
- Spatial filtering results in < 0.1% higher-order transverse mode content.

Willke, et.al, *Opt. Lett.*, 23, 1704(1998)

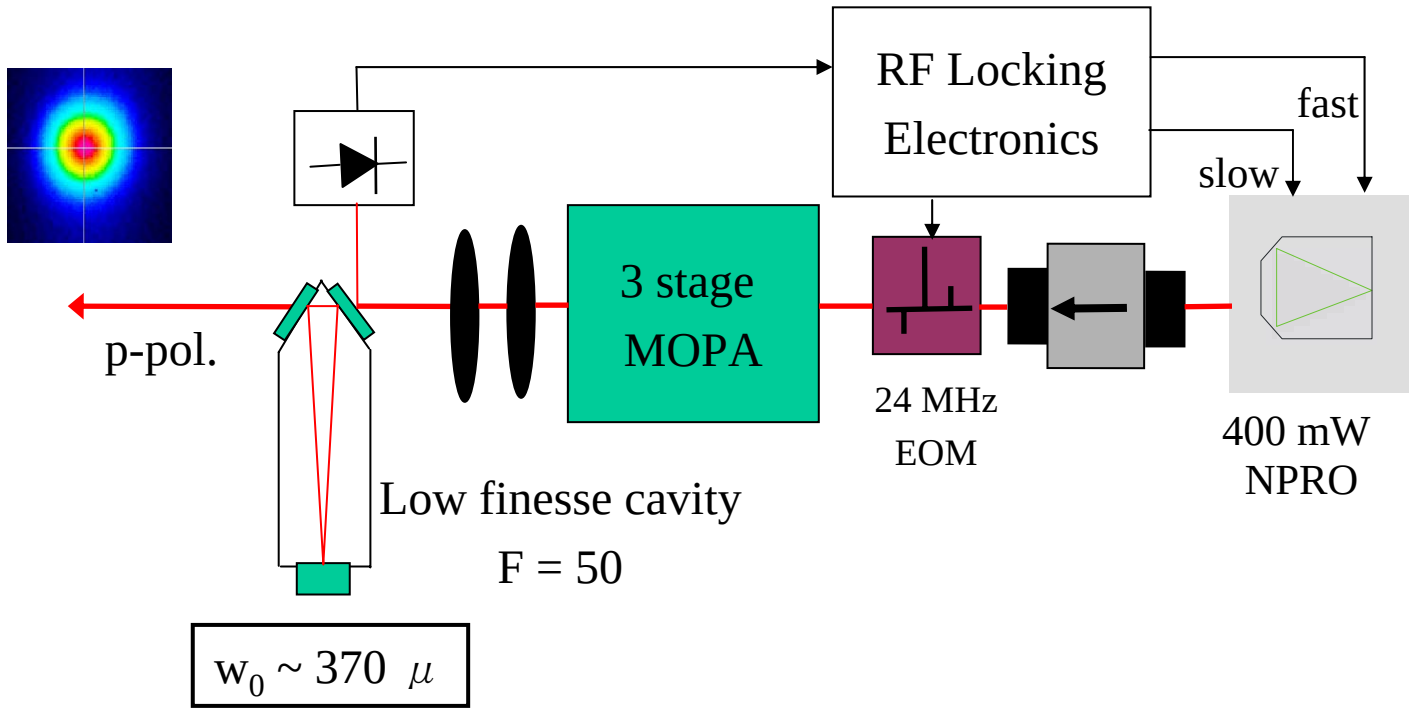
Fast Servo: Drives piezo on YAG crystal

Slow Servo: Drives TEC controller on YAG crystal

Length + refractive index control => Frequency Control!

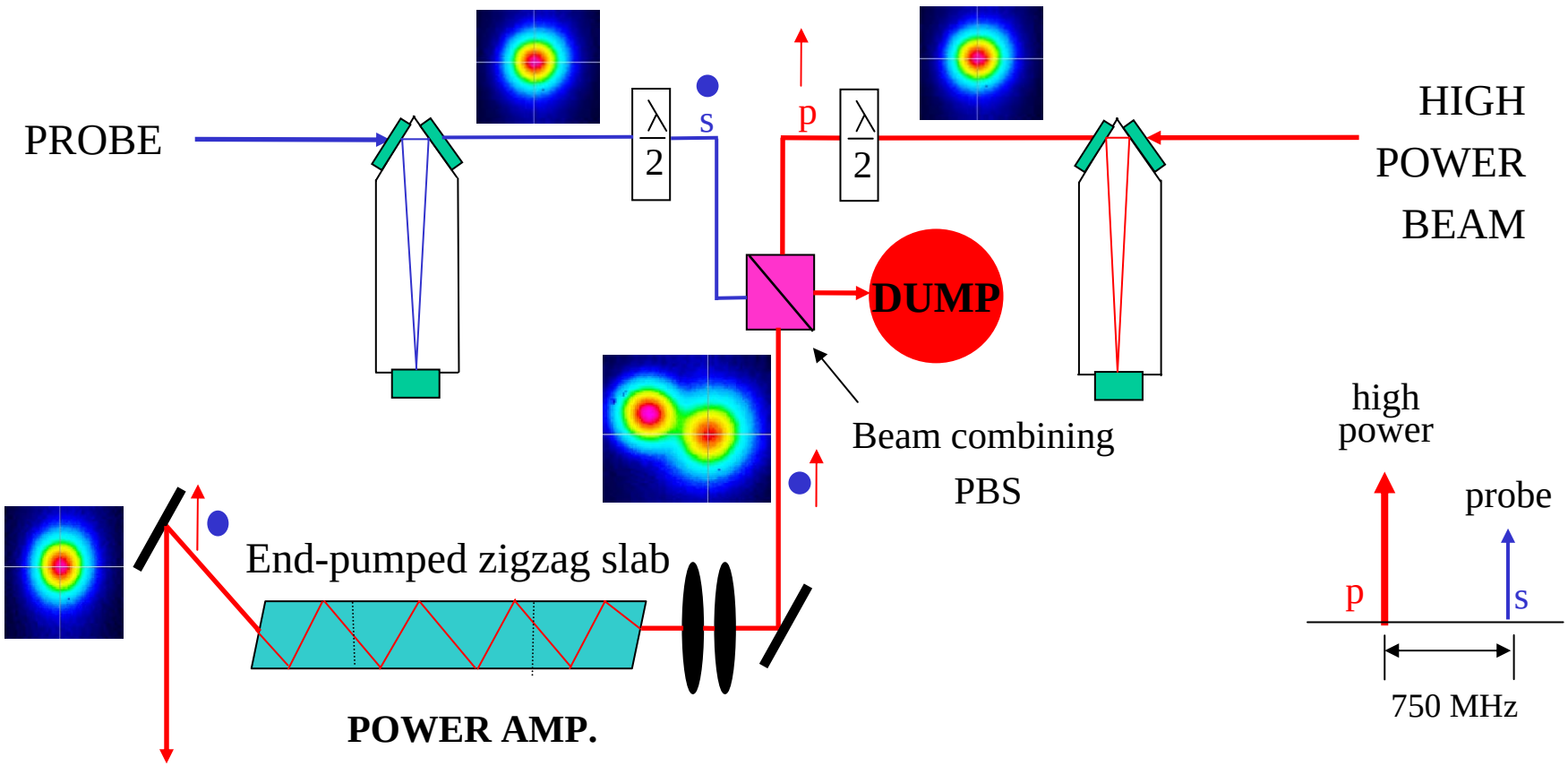
✓Output of mode cleaner is a single spatial mode shot-noise-limited at 4 MHz!

High Power Beam Generation



✓Maximum TEM_{00} power output of cavity = 30 W with fixed pointing and a defined waist size and location.

Beam Combination and Amplification



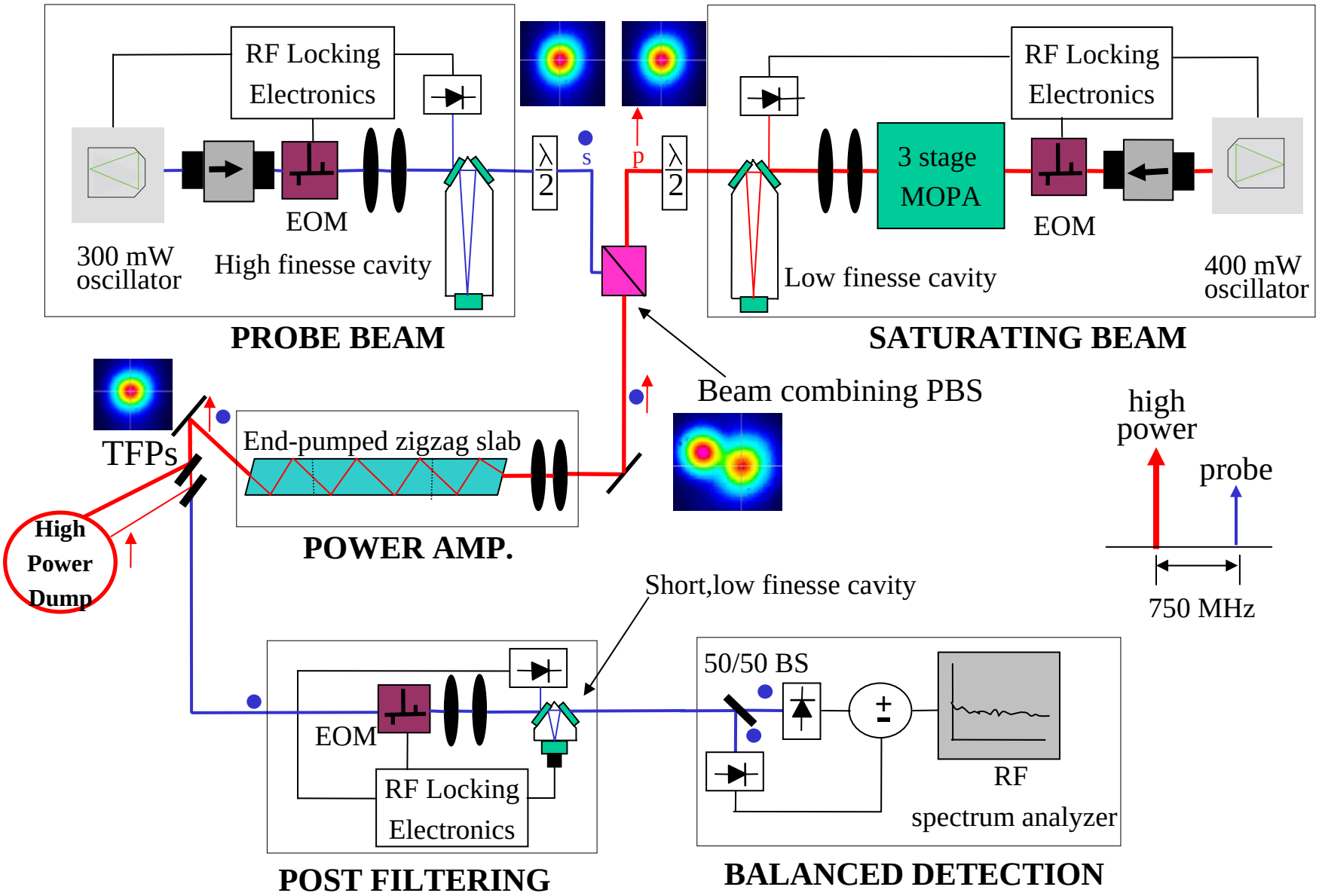
- Beam spot sizes are the same for the two mode cleaners.
- Beams are perfectly overlapped.

✓Power Gain is the same for both beams!

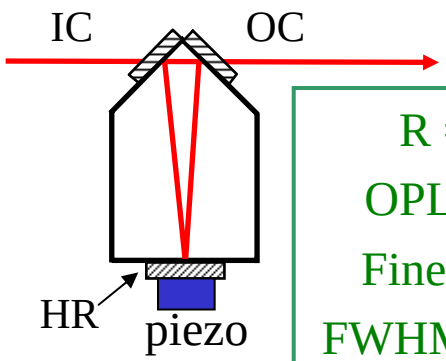
✓Challenge: Separate beams with 25dB power contrast!

- HP beam = 45 W
- Probe = 150 mW

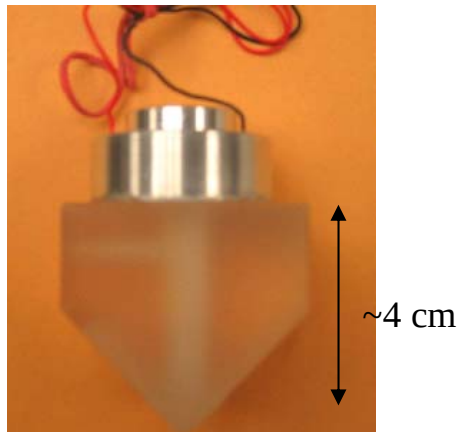
Saturated Amplifier Noise Experiment Setup

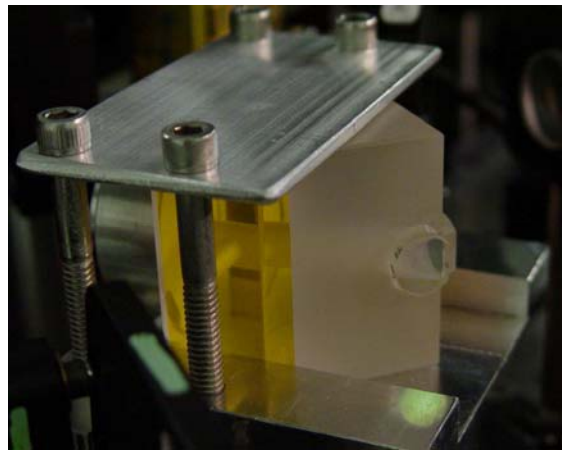


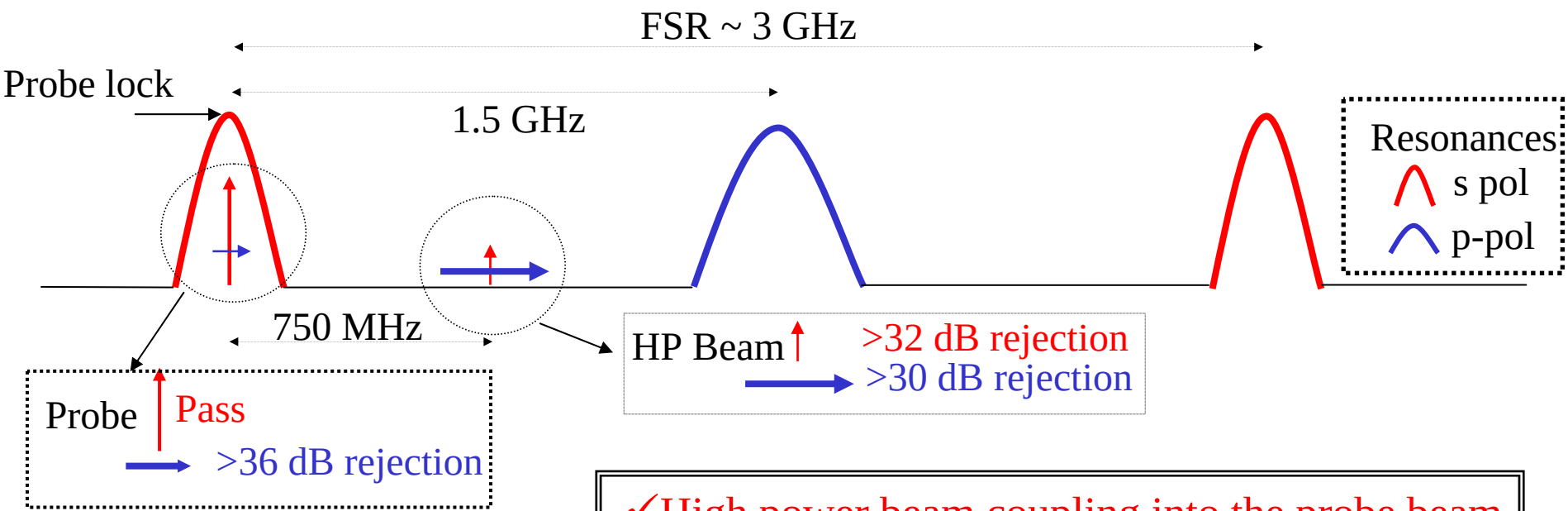
Post Filtering



R = 0.975
OPL = 10 cm
Finesse = 125
FWHM ~ 25MHz

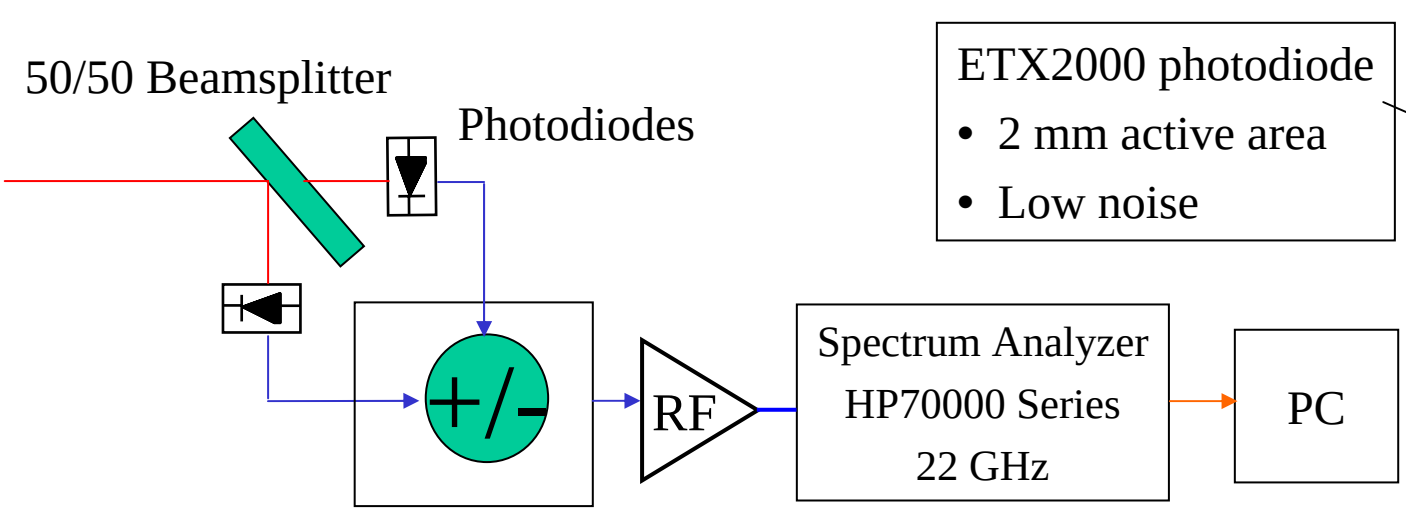




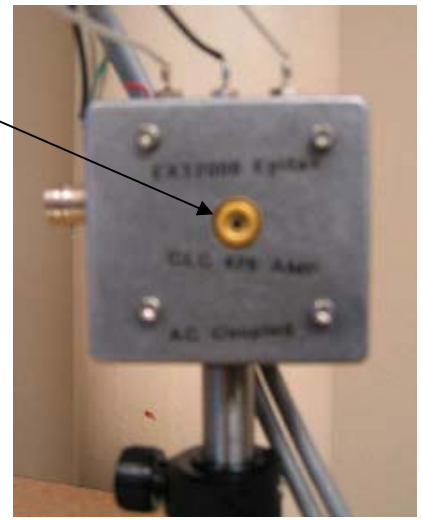


✓High power beam coupling into the probe beam is completely rejected with mode cleaner action.

Balanced Detection



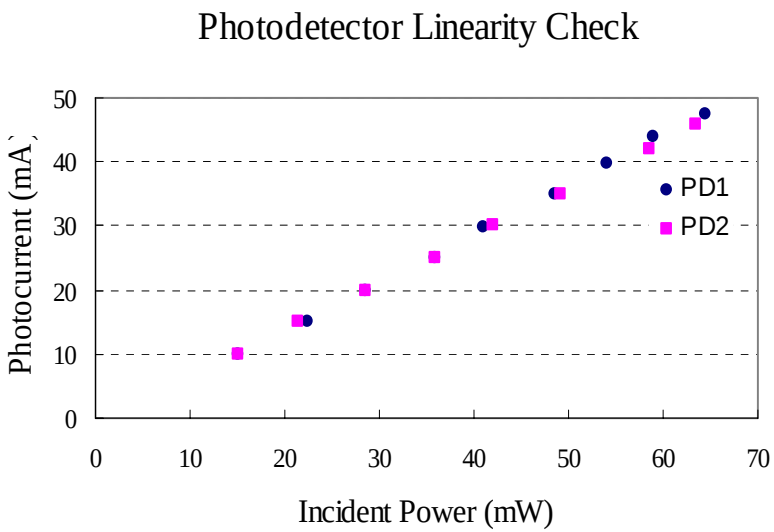
ETX2000 photodiode
- 2 mm active area
- Low noise

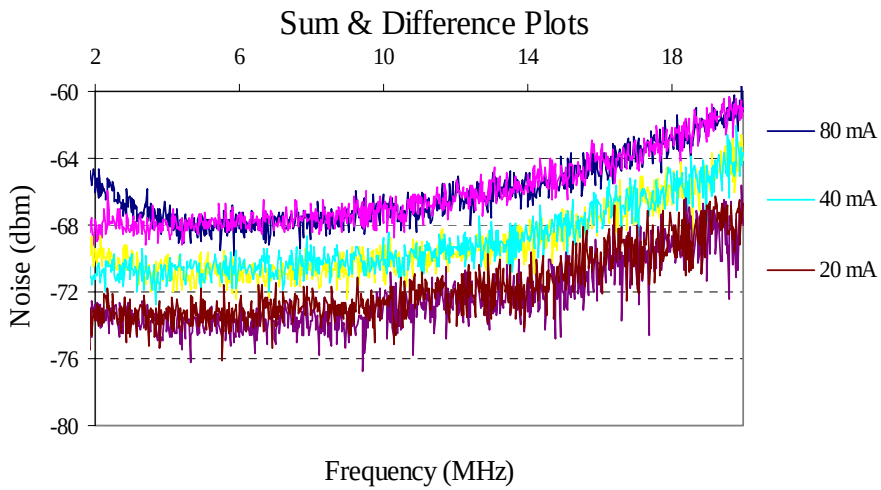


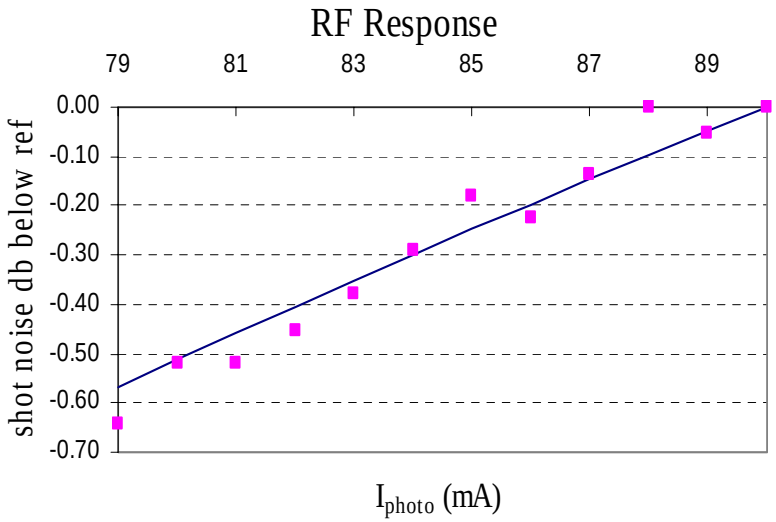
- Matched InGaAs photodiodes and transimpedance amplifiers.
- 45 mA photocurrent per photodiode for all measurements
- Linear power and RF response.
- Measurement frequency range 6.25 MHz – 15.625 MHz

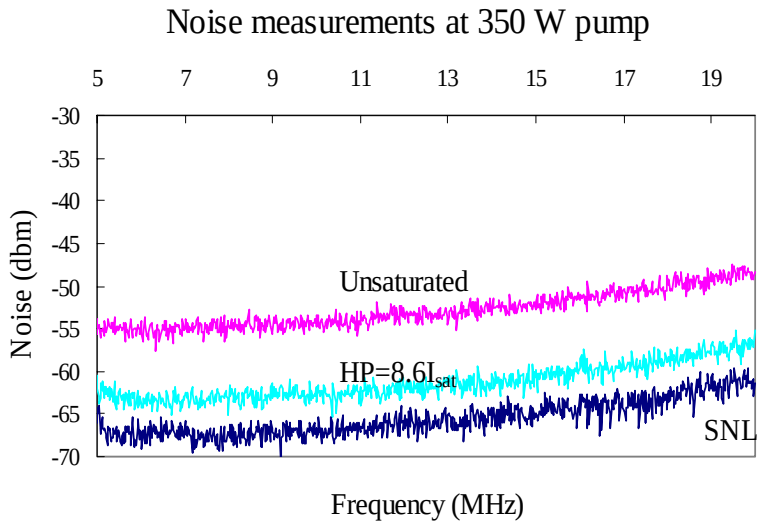
✓Sum signal → Total noise power, Difference signal → Shot noise reference

Linearity Check and Noise Traces

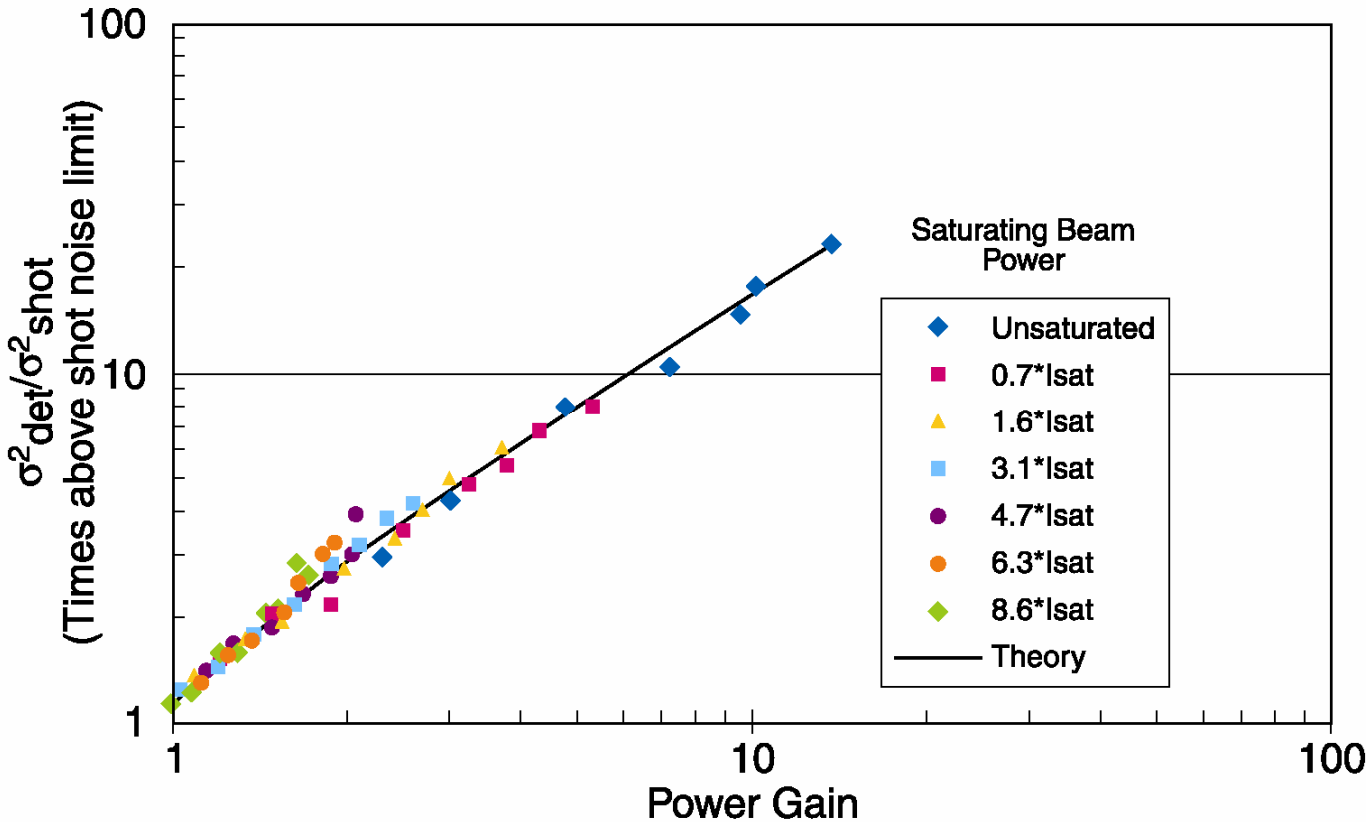








Quantum Noise versus Power Gain

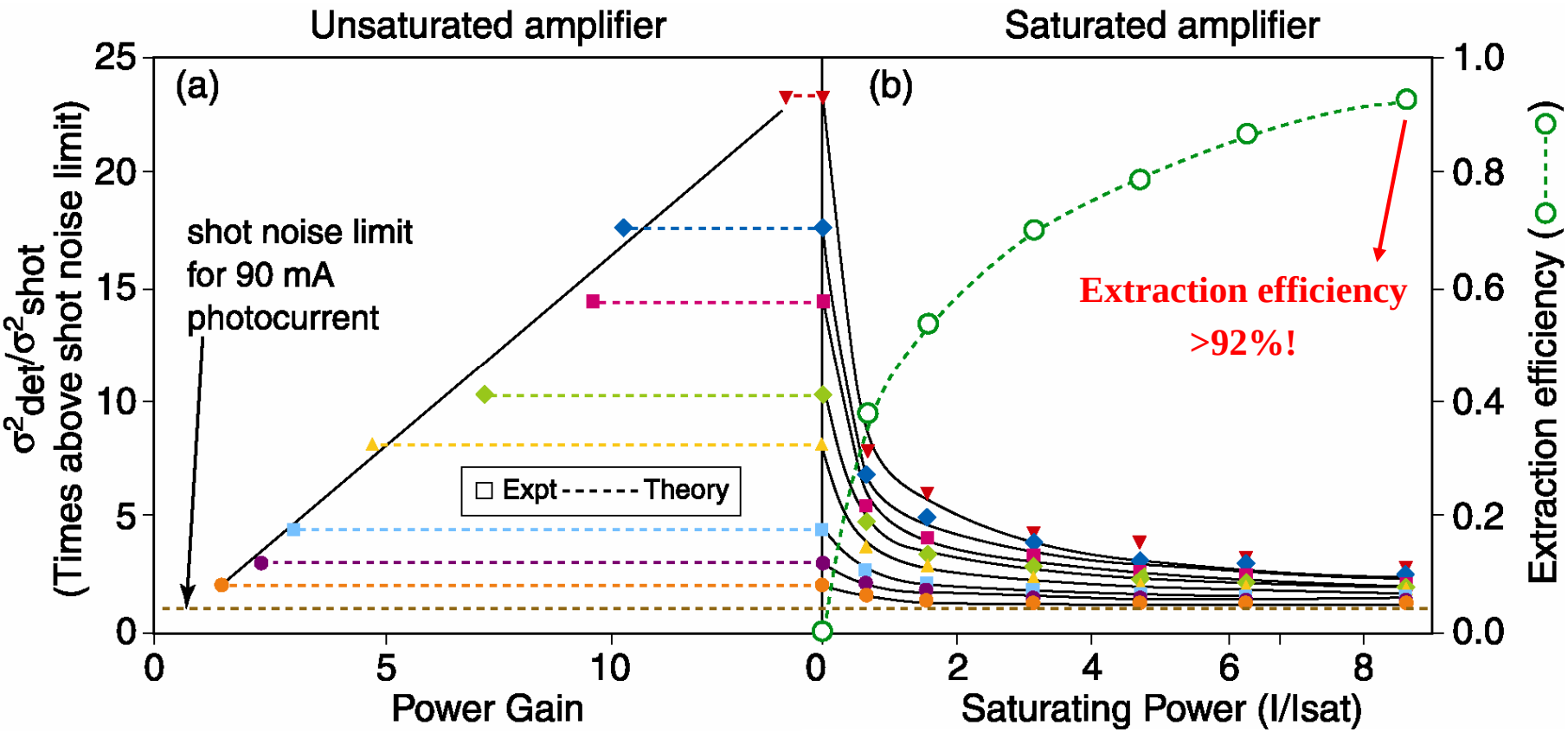


✓**THEORY** $\frac{\sigma^2_{det}}{\sigma^2_{shot}} = \left[1 + 2\eta\ f_{sp}\left(G - 1\right)\right]$

Saraf, et.al.,

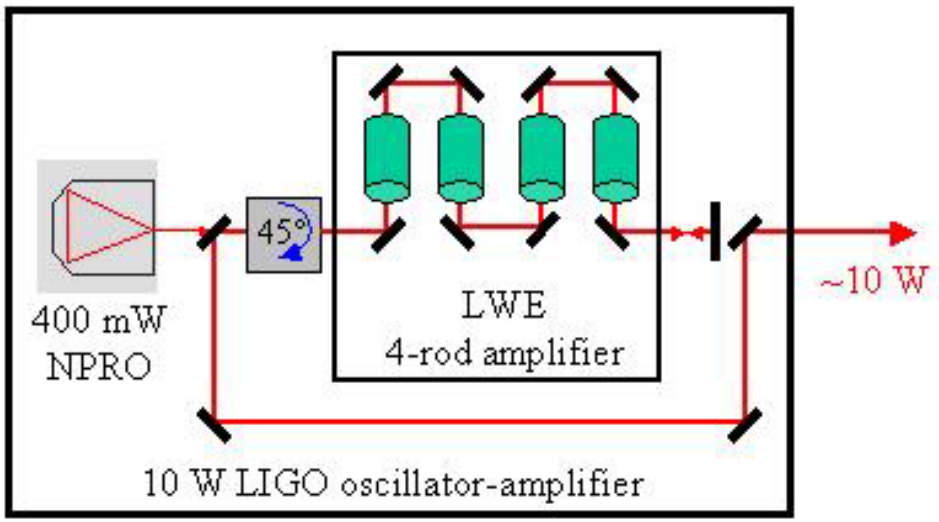
To be published, Opt. Lett. (2005)

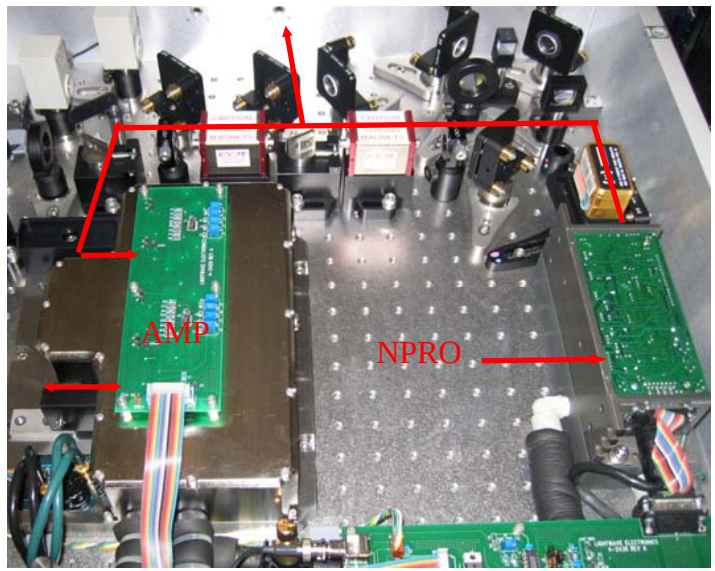
Quantum Noise and Power Extraction



✓Extraction efficiency increases and quantum noise decreases as the amplifier is saturated.

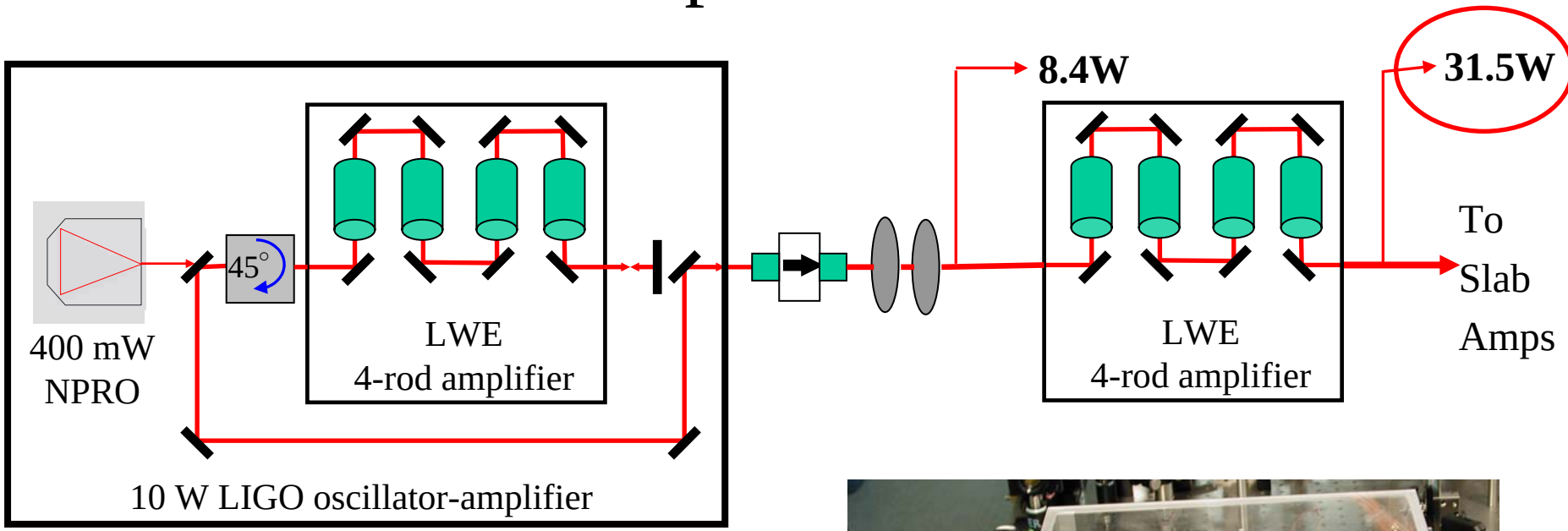
10 W → 30 W in One Step

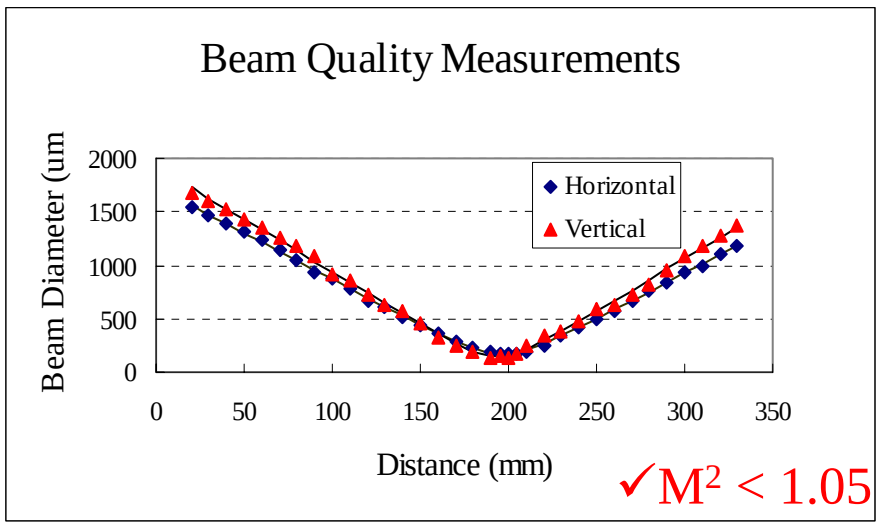


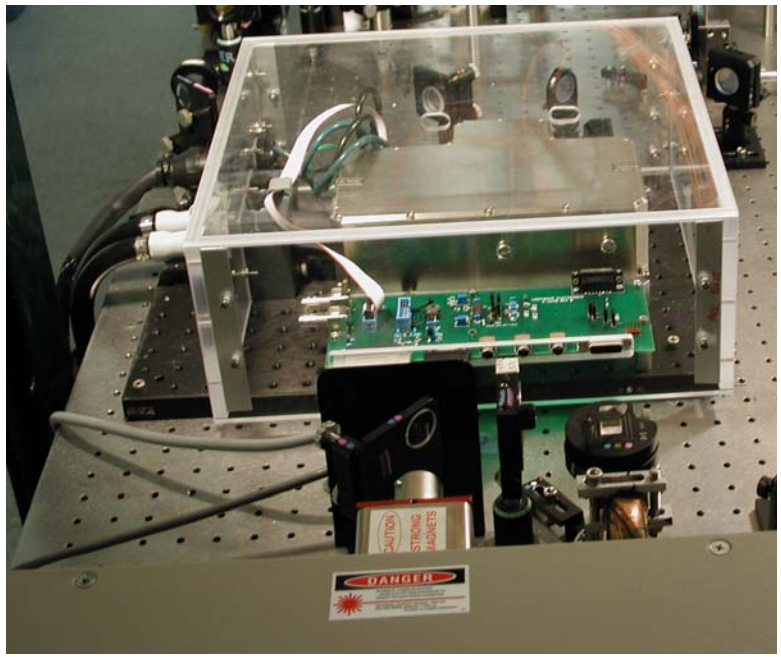


10 W LIGO Laser

30 W Amplifier Module



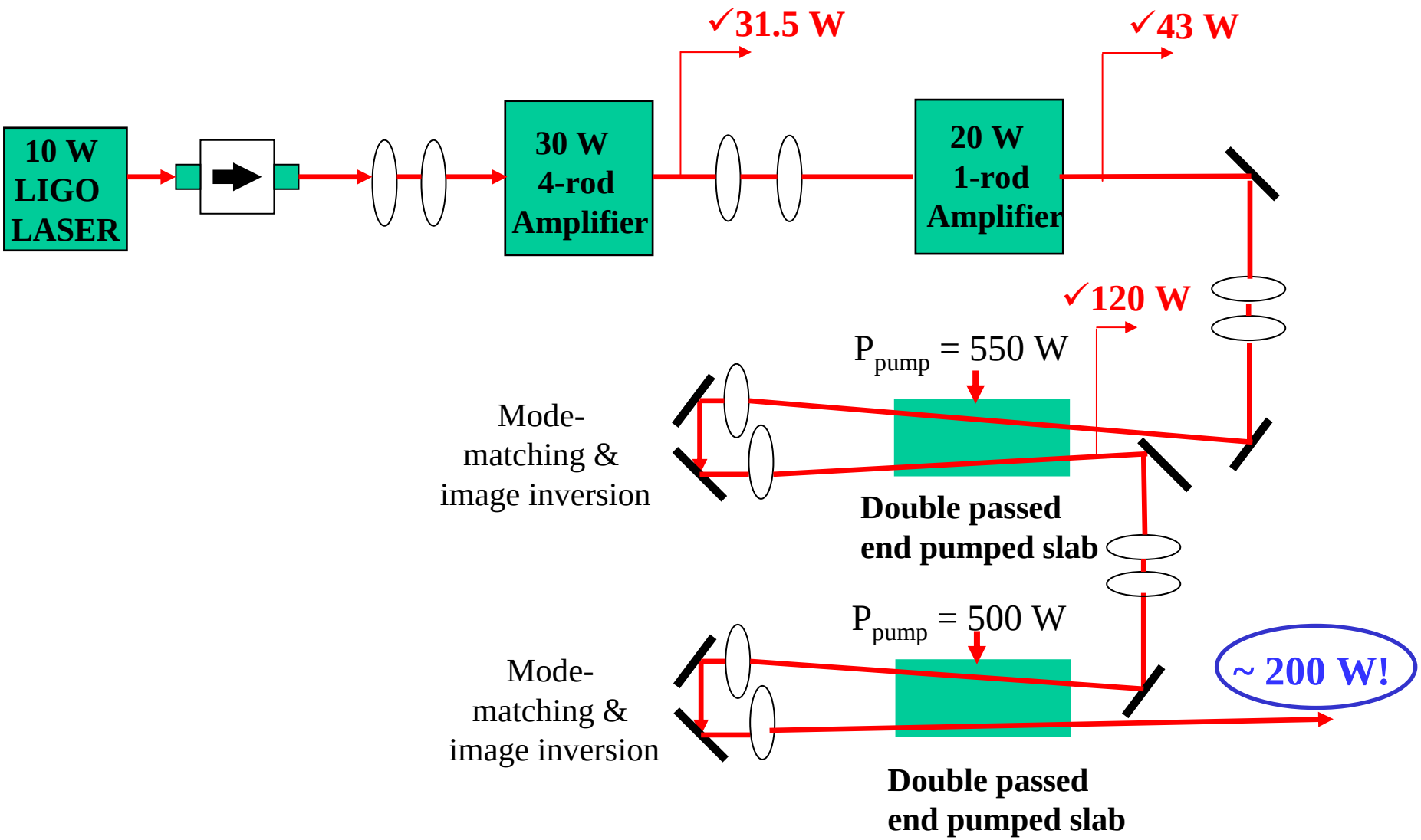




30 W Amplifier Key Points

- Pin = 8.4 W, Pout = 31.5 W. Extracted power is 23.1 W.
- First two rods in the amplifier are not fully saturated.
  - Careful modematching and double pass could pull out another 6-8 W.
    => Output could get close to 40 W!
- Beam Quality is excellent.
- Module has been reliable and worked in the lab for three years.
- TEM_{00} content needs to be measured with a mode cleaner?

Scaling to 200 W

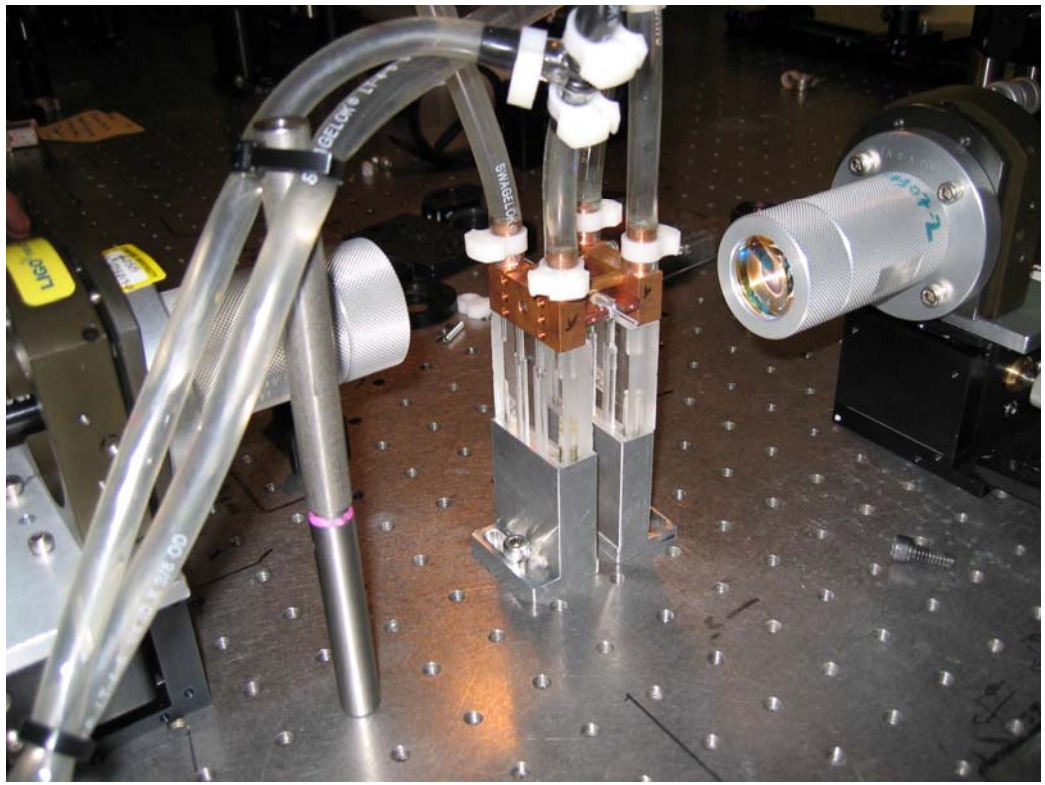


Problems with Pump Diodes

- Received pump modules from LIMO with smashed optics.

- Pump spot size after refocussing module is 700 μ instead of 400 μ
  - Procuring new lenses from vendor. (unnecessary delay!)

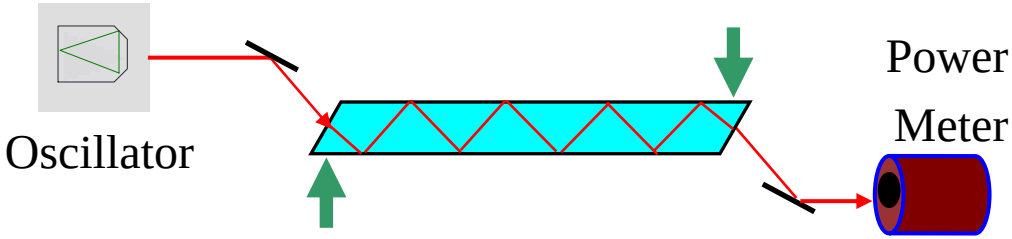
End-pumped Slab #2



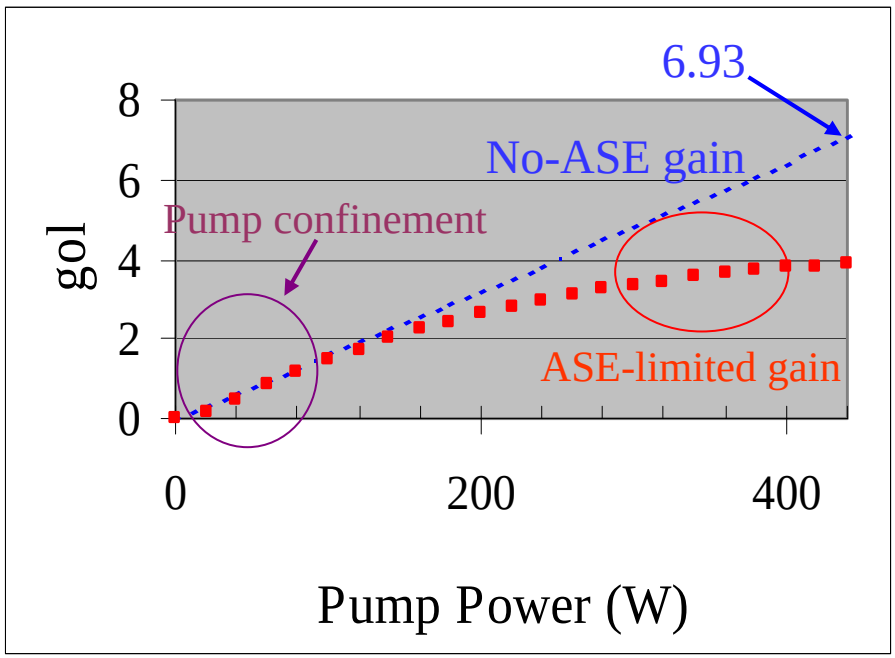
- ✓ Wavelength tuned to 808 nm with chiller temperature and flow rate.
- ✓ Pump power ~ 250 W/module.

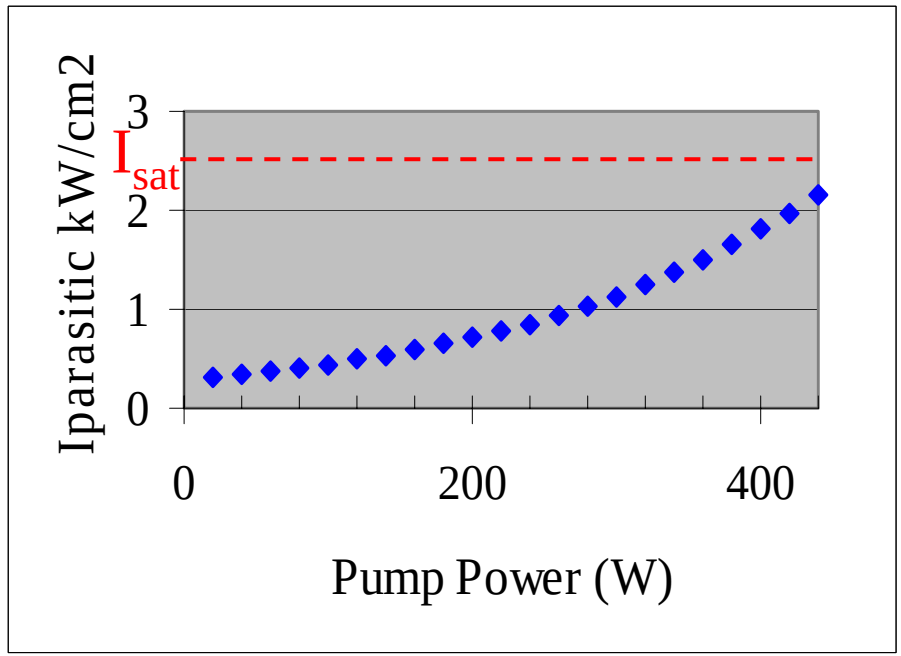
Work in Progress!

Gain Measurements



• "Equivalent" ASE intensity can be modeled.

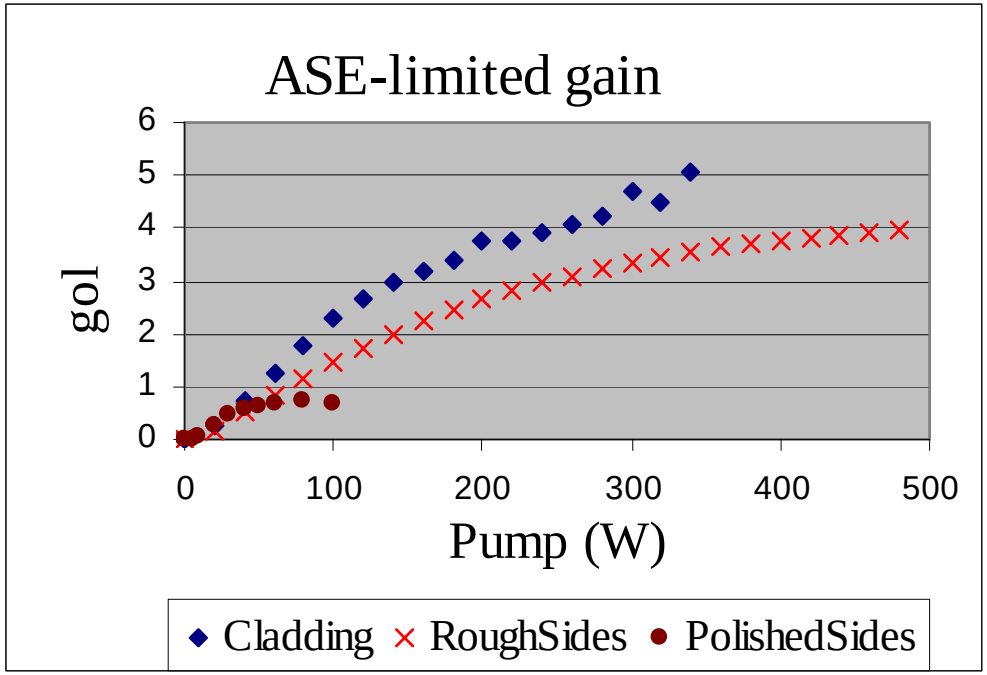


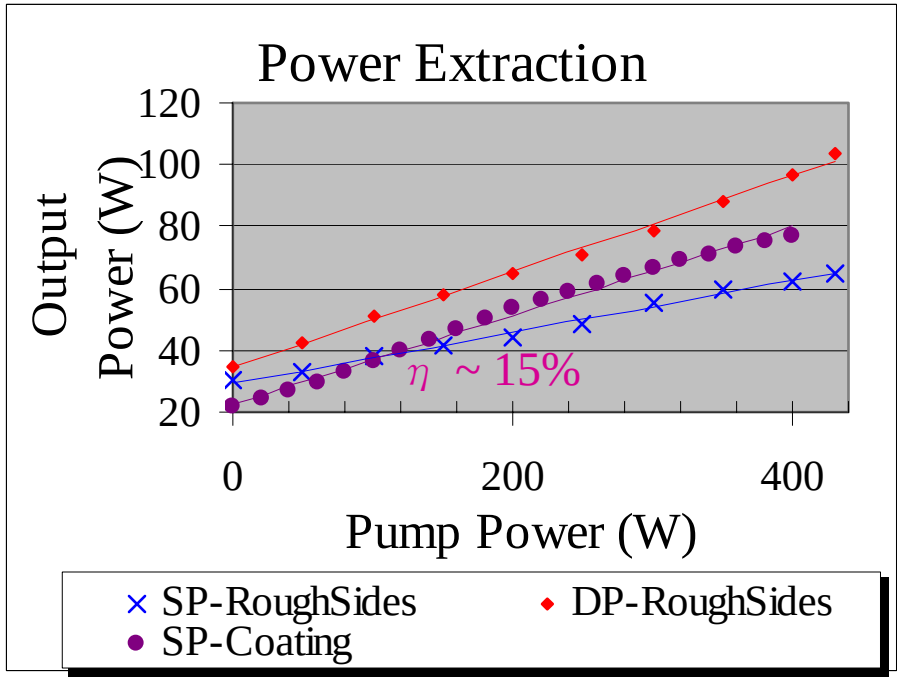


•Input signal intensity ~ 6.6 * I_{sat}

✓Saturated amplifier sees the no-ASE gain!!

Parasitic Suppression and Power Extraction





- Estimated double pass extraction from slab with cladding > 110 W!

✓Claddings significantly improve gain and extraction from slabs with parasitic suppression.

✓Heavily saturated end-pumped slab # 2 could use a slab with polished sides => $P_{extracted}$ can potentially be >150 W!

Future Work

- Complete power scaling experiment to 200 W.
  - Use end-pumped slab with polished sides to scale to the 250 W level?
- Quantify TEM_{00} content with a locked mode cleaner
- Pointing and polarization stability measurements
- RIN measurements
- Measure frequency noise?
- Reliability test for 1000 hrs?