Remote Ultrasonic Detector
Using
He-Ne Laser
and
Confocal Fabry-Perot Interferometer

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Physics Department
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Why to build this sensor?

sensor

Remote detection

specimen

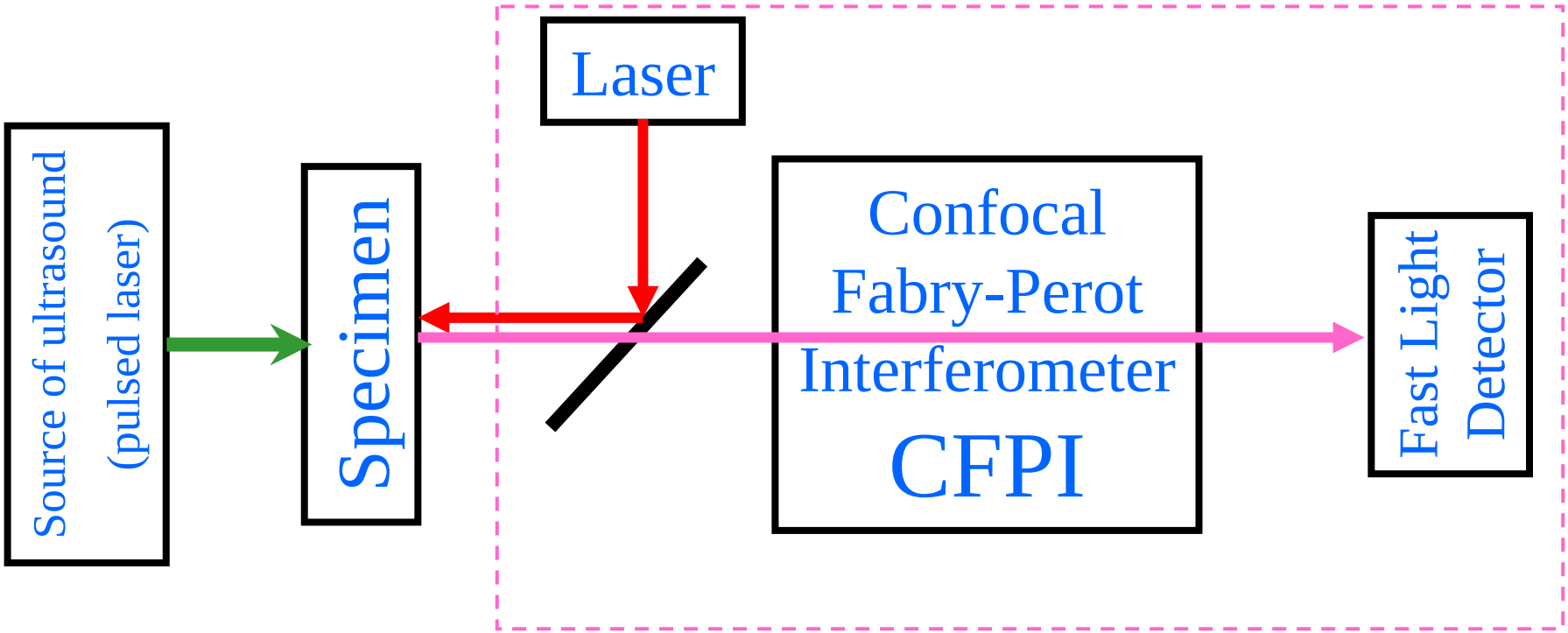
Hot

Fast inspection

Hazardous

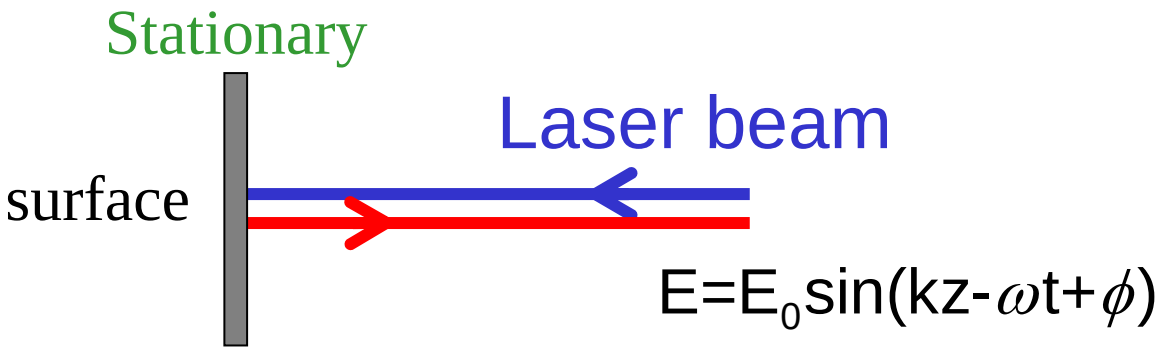
Fragile

Main Components?

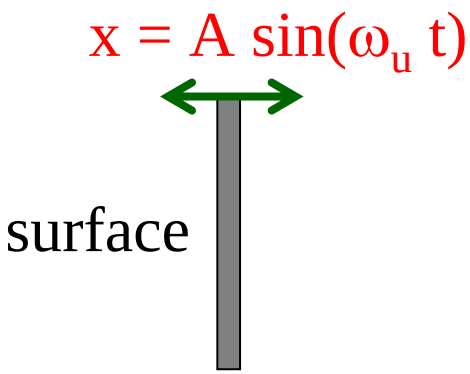


Measure motion of surfaces by analyzing the phase of the reflected light

Light modulation by moving surfaces



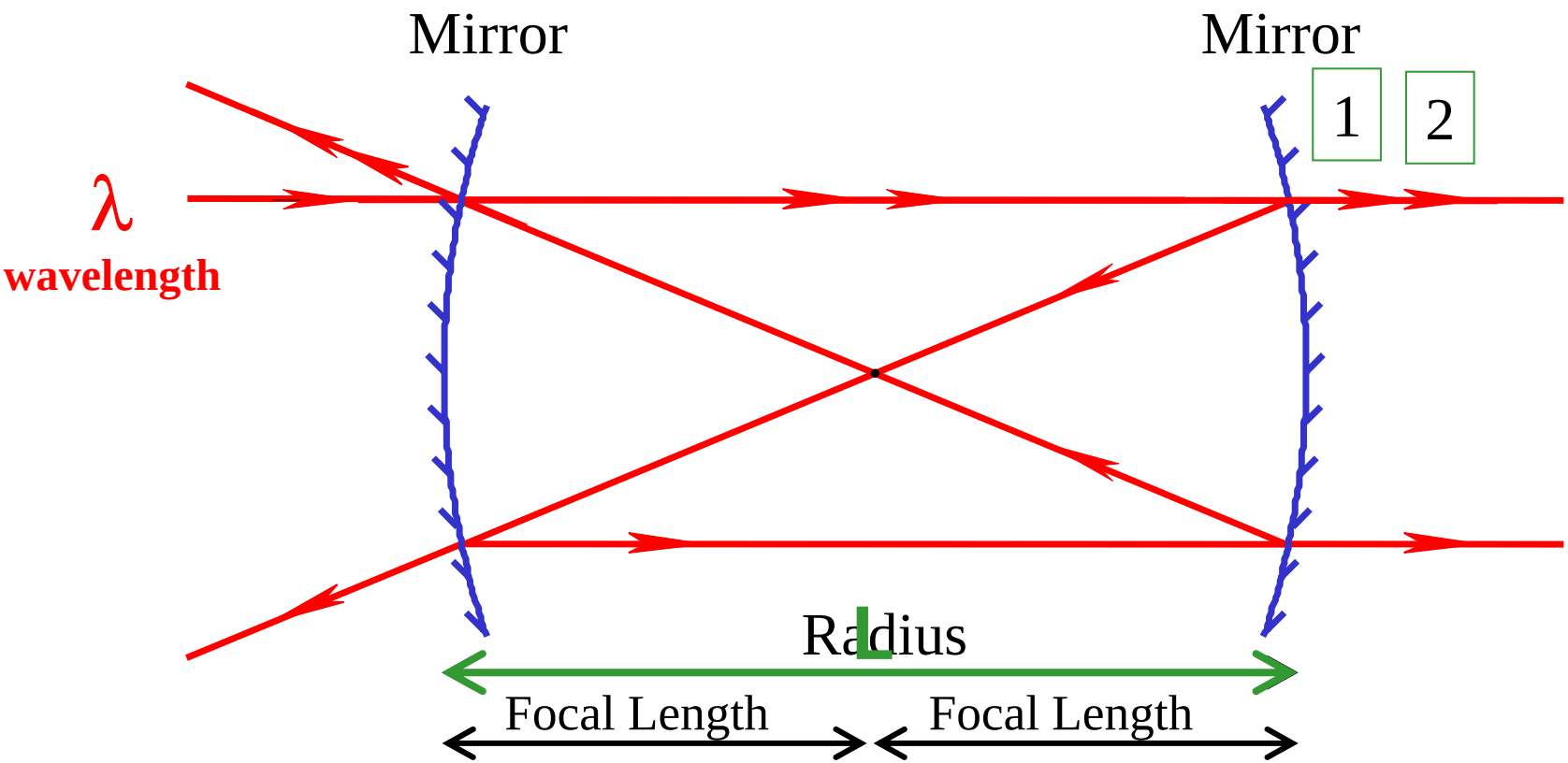
$E=E_0\sin(kz-\omega t+\phi)$



$E=E_0\sin(k(z+2\,A\sin(\omega_u t))-\omega t+\phi+)$

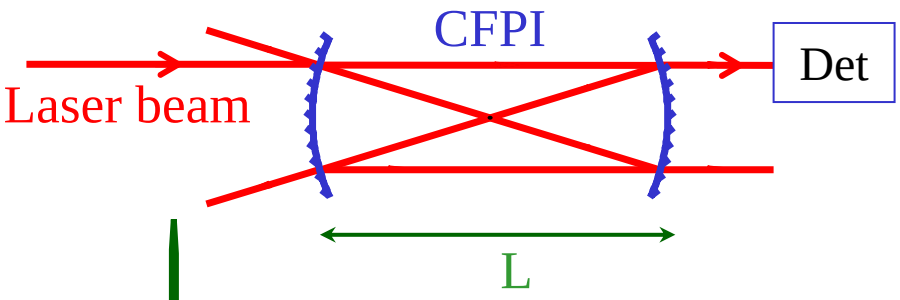
$$E=E_0\sin\left(kz-\omega t+\phi+\frac{4\pi A}{\lambda}\sin(\omega_u t)\right)$$

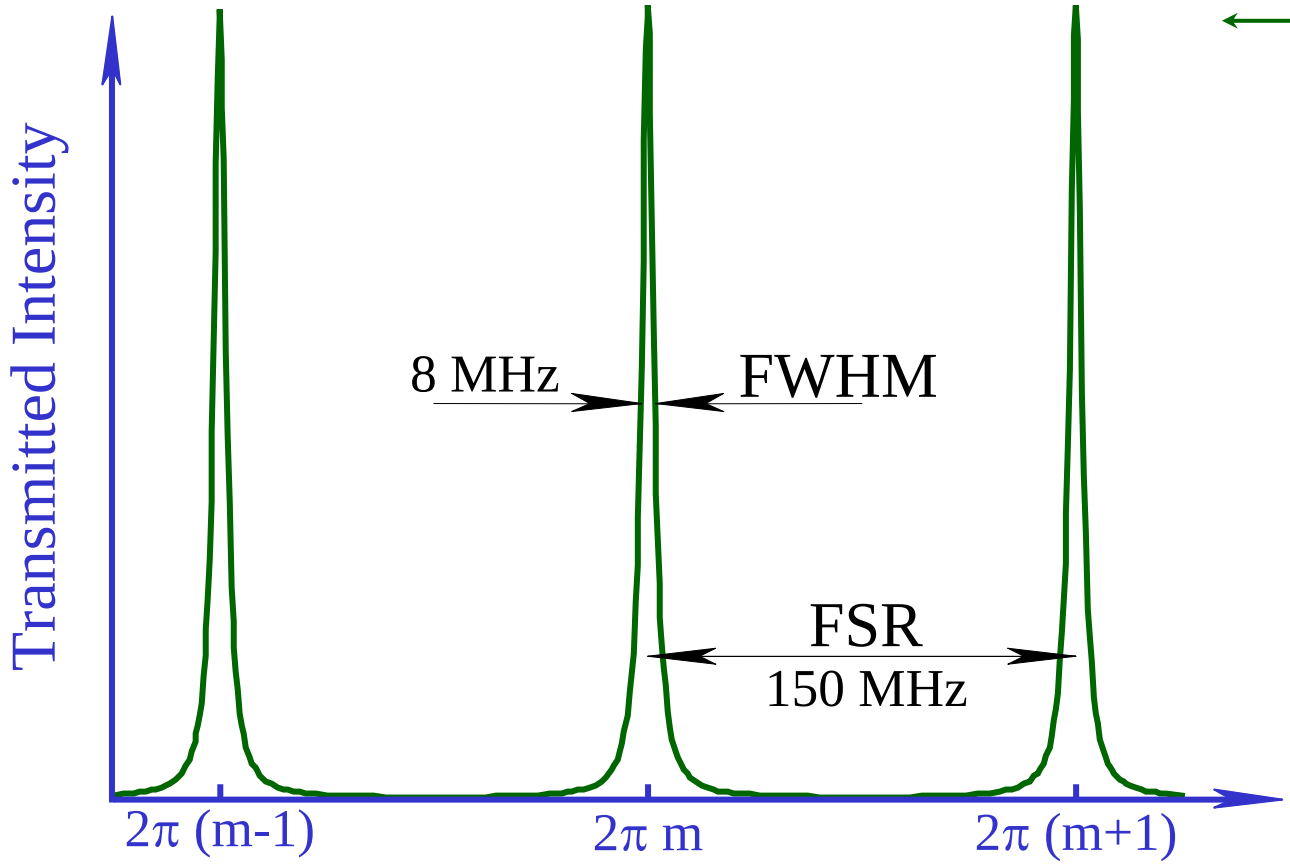
What is Confocal Fabry-Perot Interferometer?



$$\text{phase difference} = \frac{2\pi}{\lambda} 4L$$

Transmission of CFPI

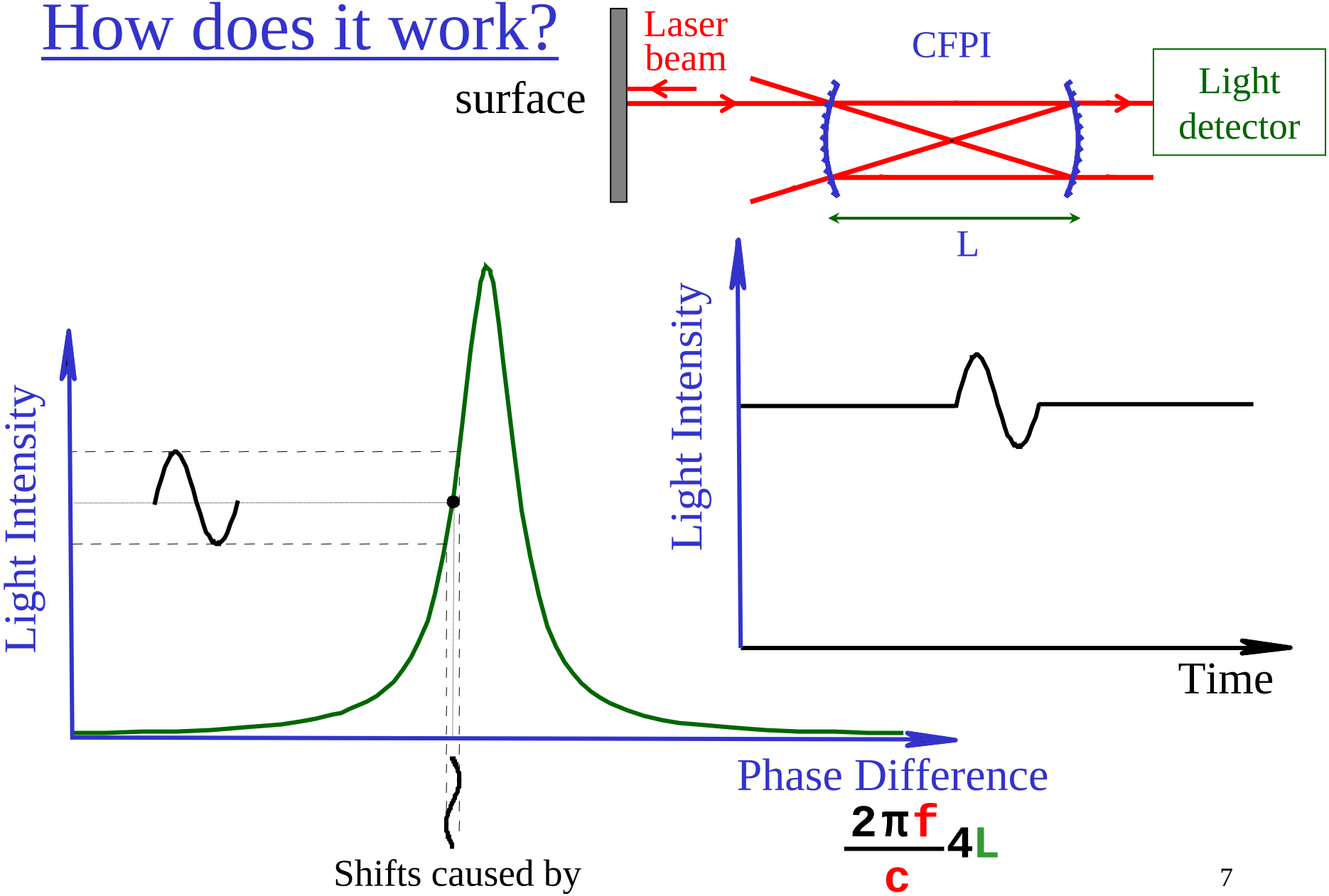




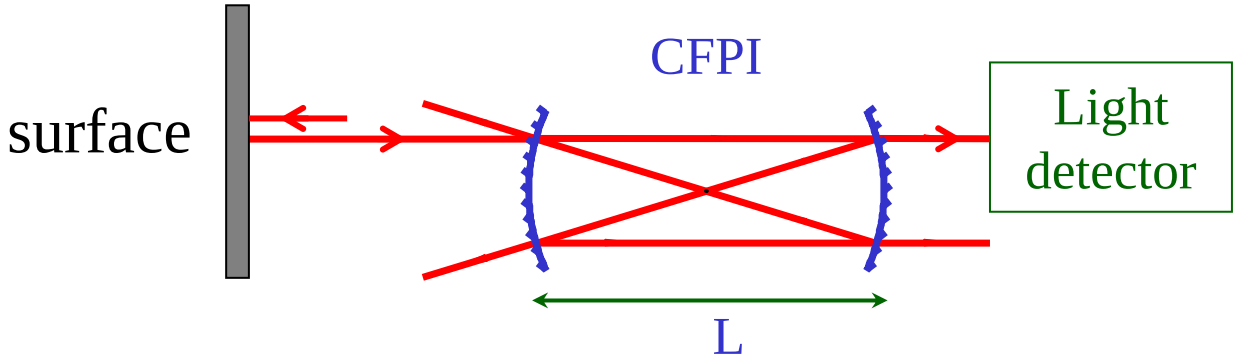
Phase Difference

$$= \frac{2\pi}{\lambda} 4L = \frac{2\pi f}{c} 4L$$

How does it work?



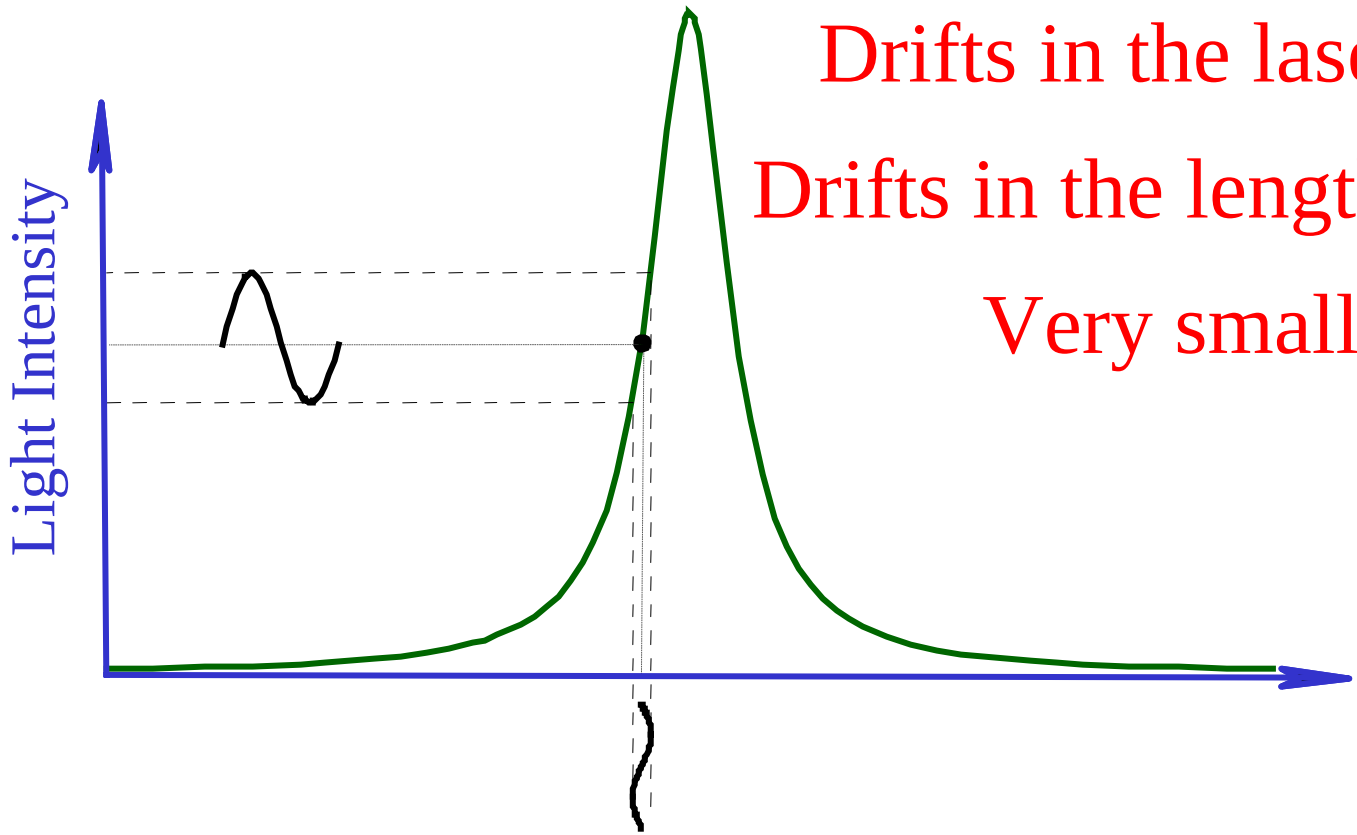
Practical Considerations



Drifts in the laser frequency

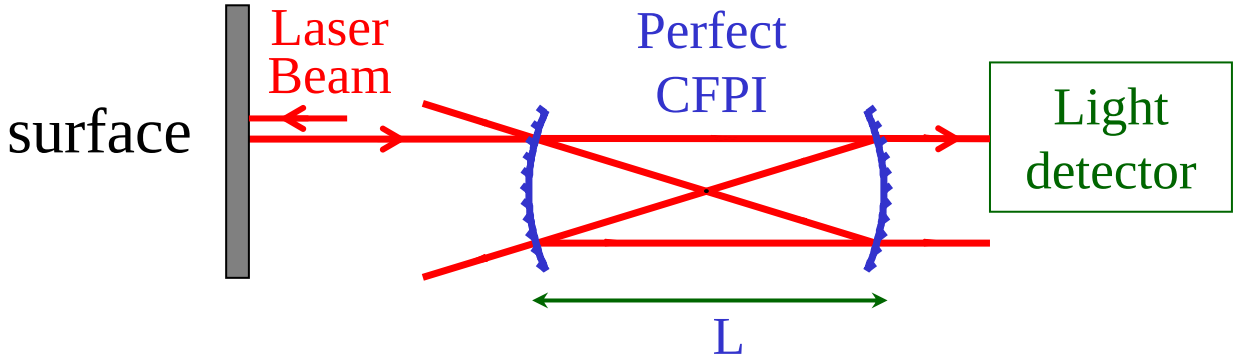
Drifts in the length of the CFPI

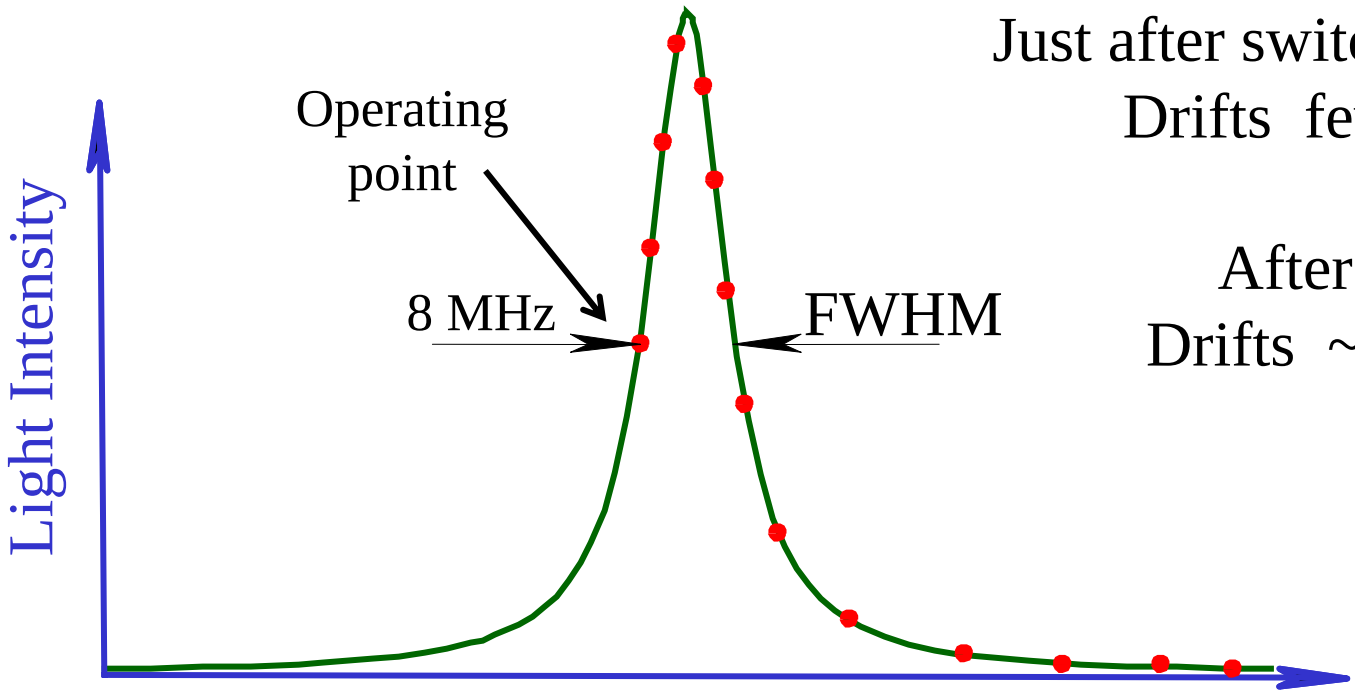
Very small signals



$$\frac{2\pi f}{c} 4L$$

Drifts in the laser frequency



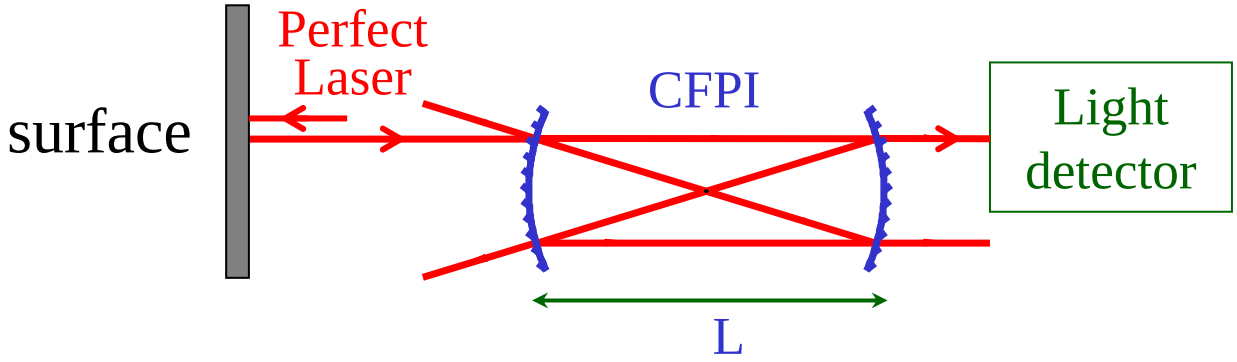


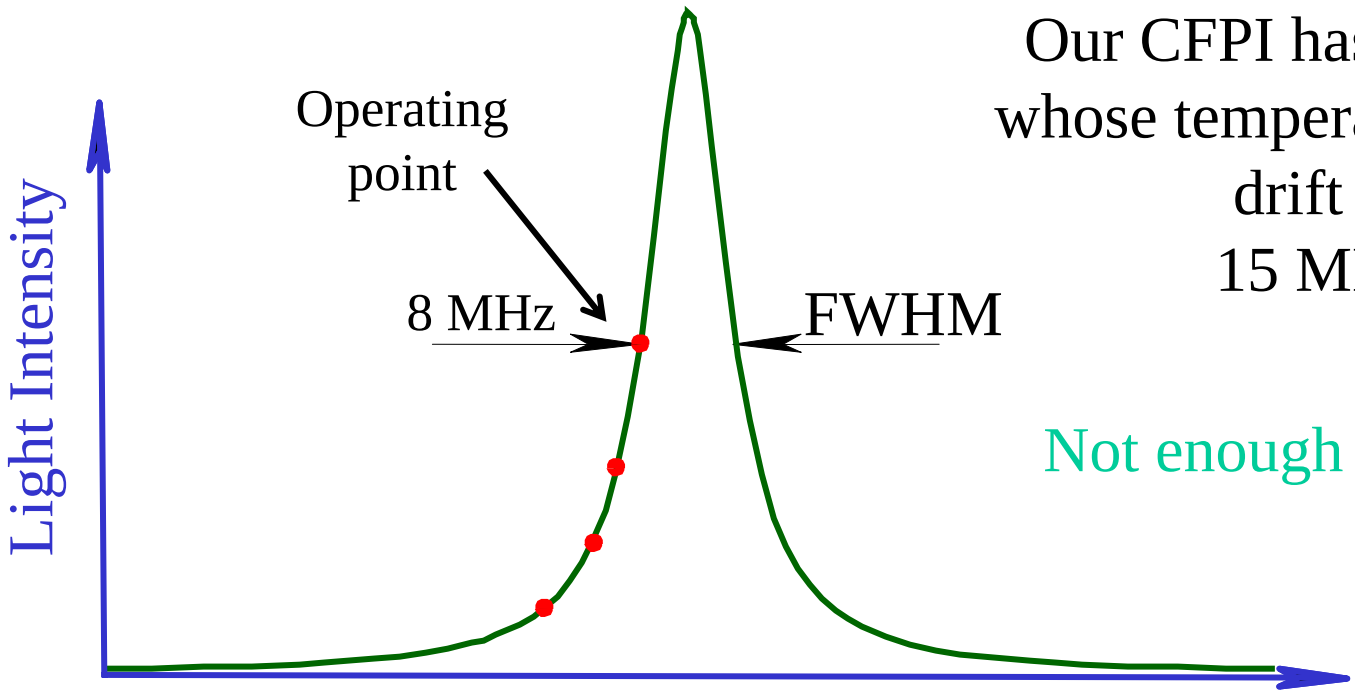
Just after switching the laser on
Drifts few GHz/ min

After 90 minutes
Drifts ~ 50 MHz/ min

$$\frac{2\pi f}{c} 4L$$

Drifts in the Length of CFPI



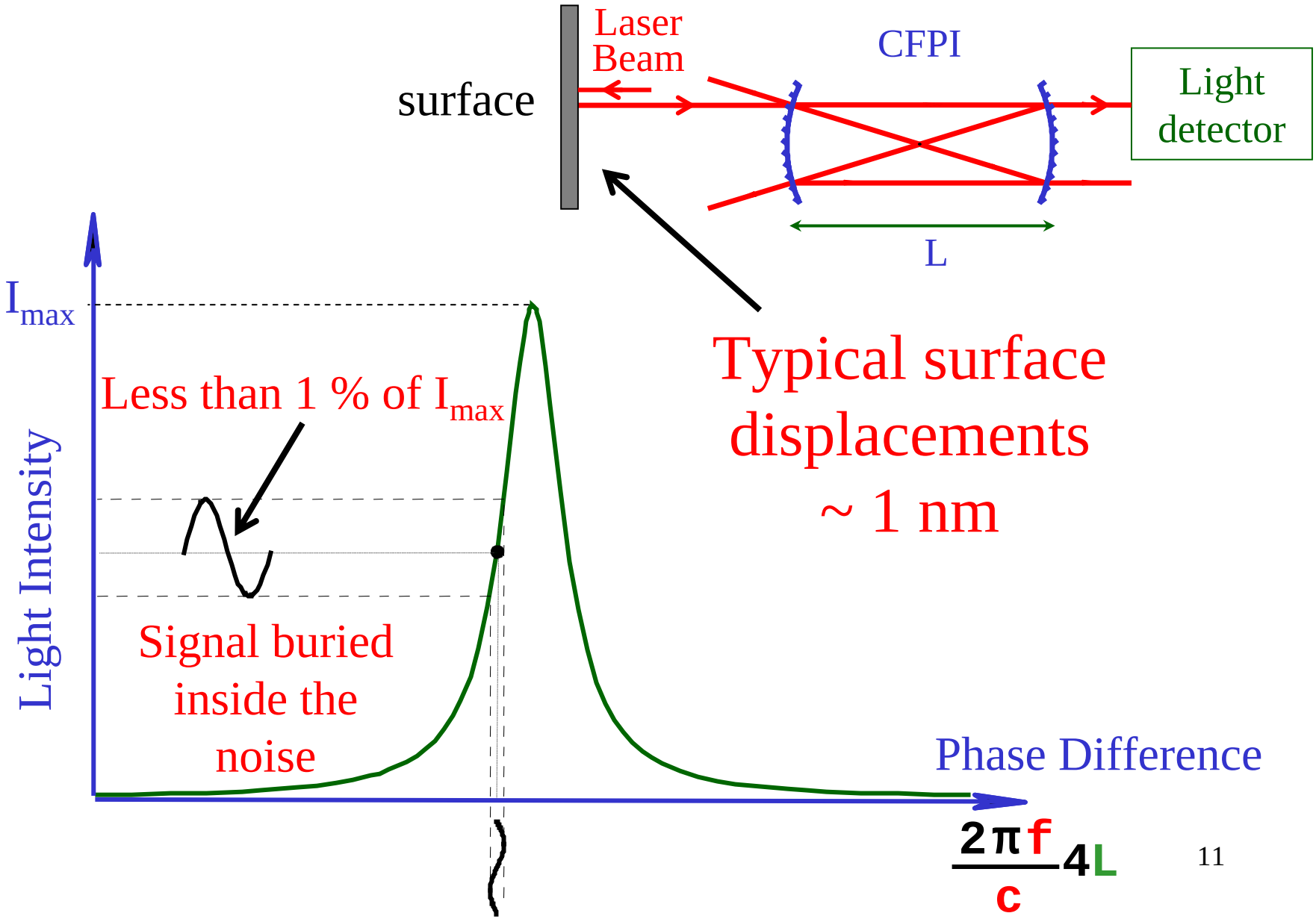


Our CFPI has a sealed cavity whose temperature is stabilized
drift is about
15 MHz/ hour

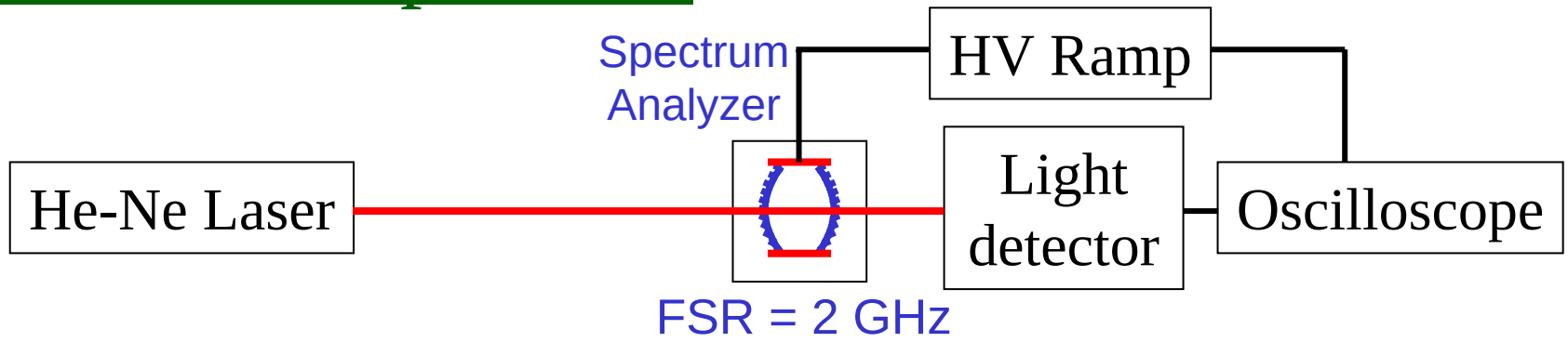
Not enough to our application

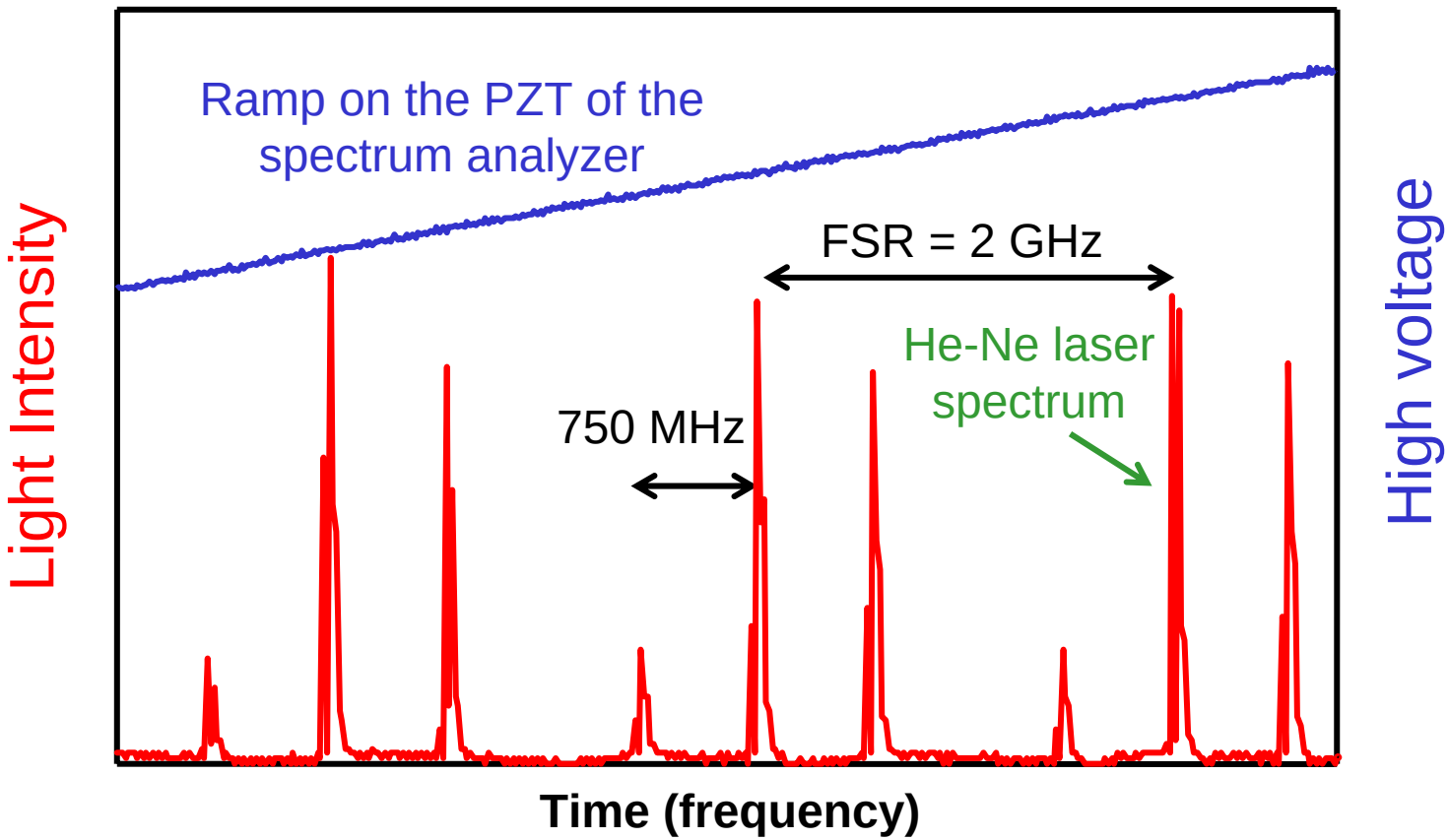
$$\frac{2\pi f}{c} 4L$$

Very small signal

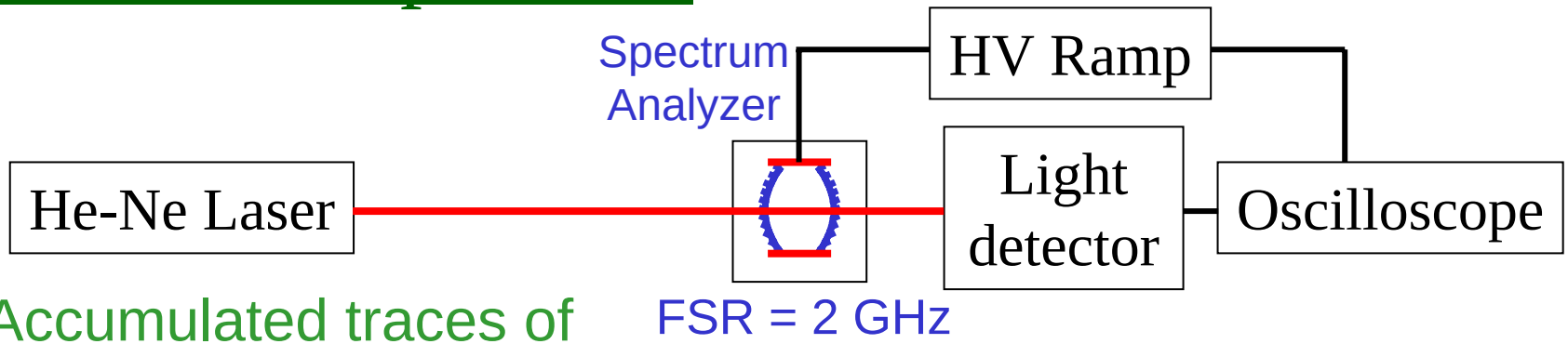


He-Ne laser spectrum

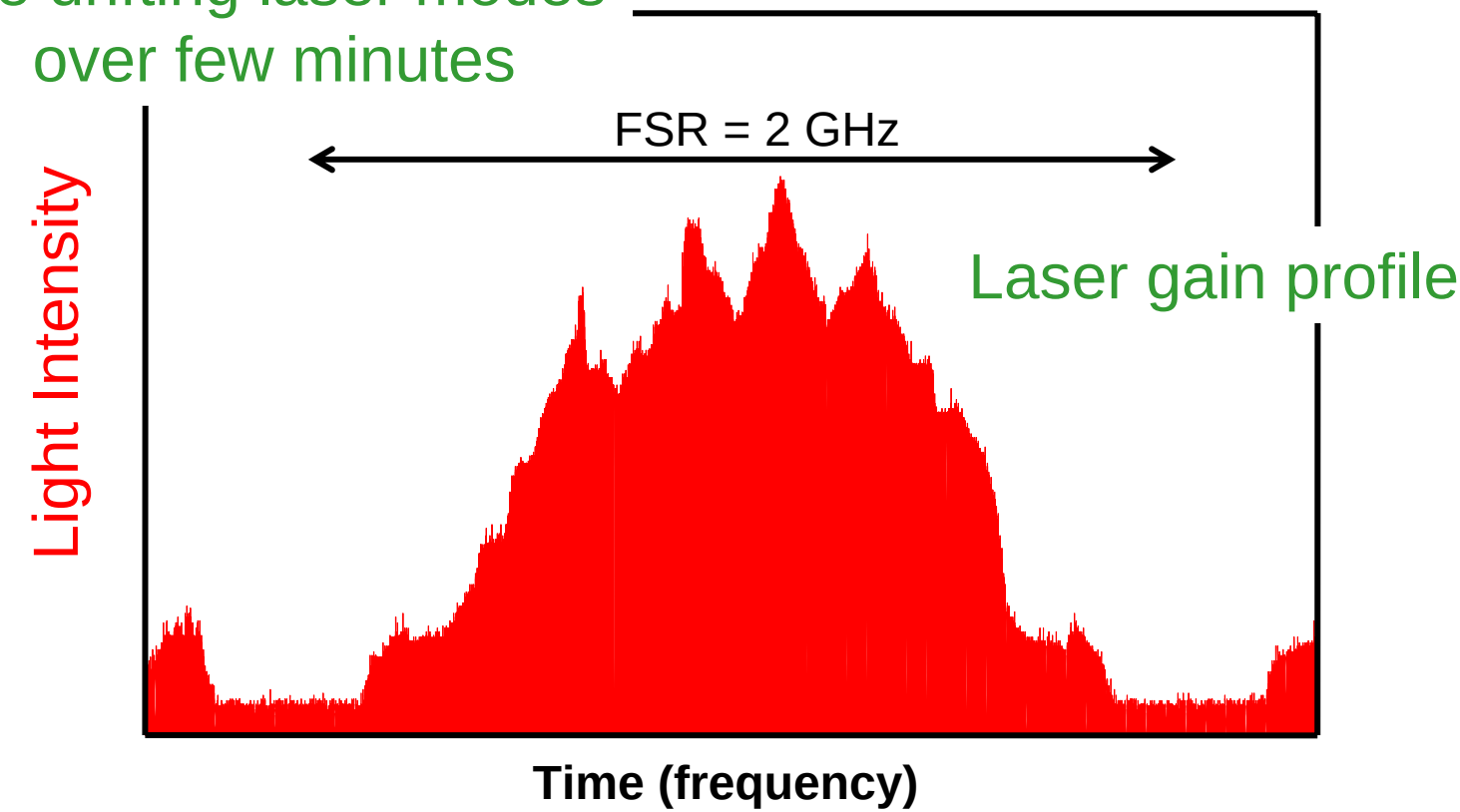




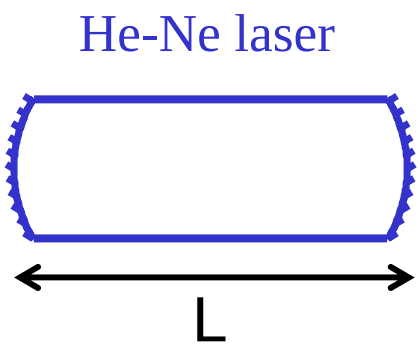
He-Ne laser spectrum



Accumulated traces of the drifting laser modes over few minutes

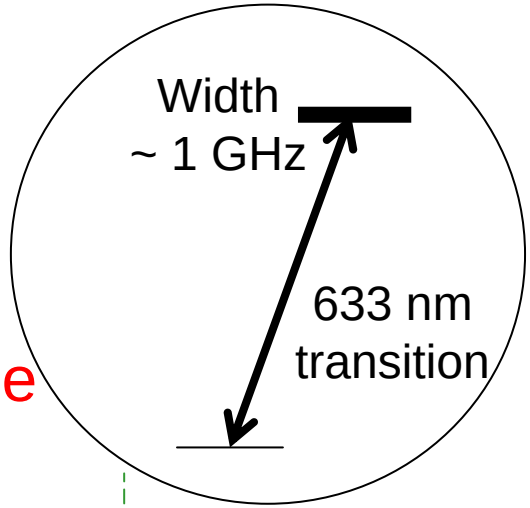


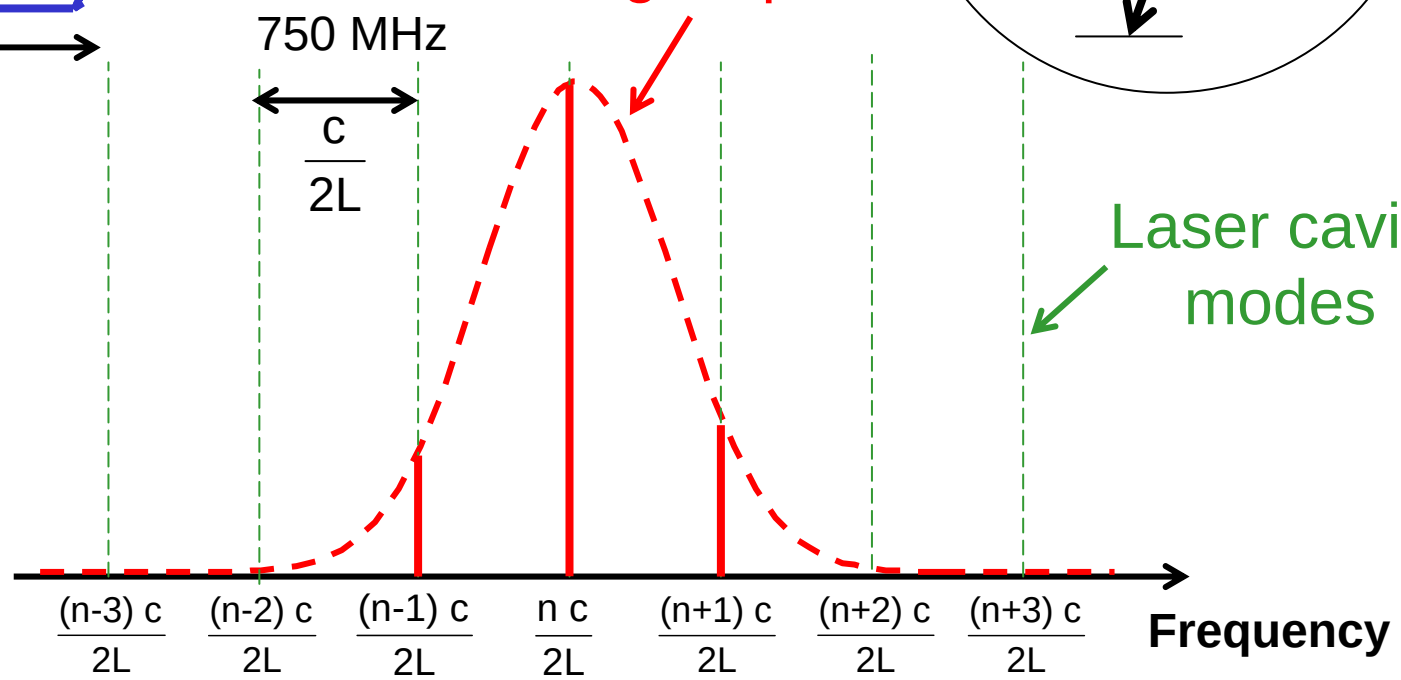
Why does the frequency drift?



$$f_n = \frac{n\,c}{2L}$$

$n \sim 10^6$





Changes in the laser cavity length cause frequency drifts

Changes in temperature and pressure

Estimate of temperature change

What ΔT that causes $\Delta f = 1$ MHz?

$$f_n = \frac{n\,c}{2L}$$

$$\frac{\Delta f_n}{f_n} = -\frac{\Delta L}{L} = \alpha\,\Delta T$$

For glass tube,
coefficient of linear expansion
9×10^{-6} /K

$$\Delta T \approx 0.25 \text{ mK}$$

$$\Delta L \approx 1 \text{ nm}$$

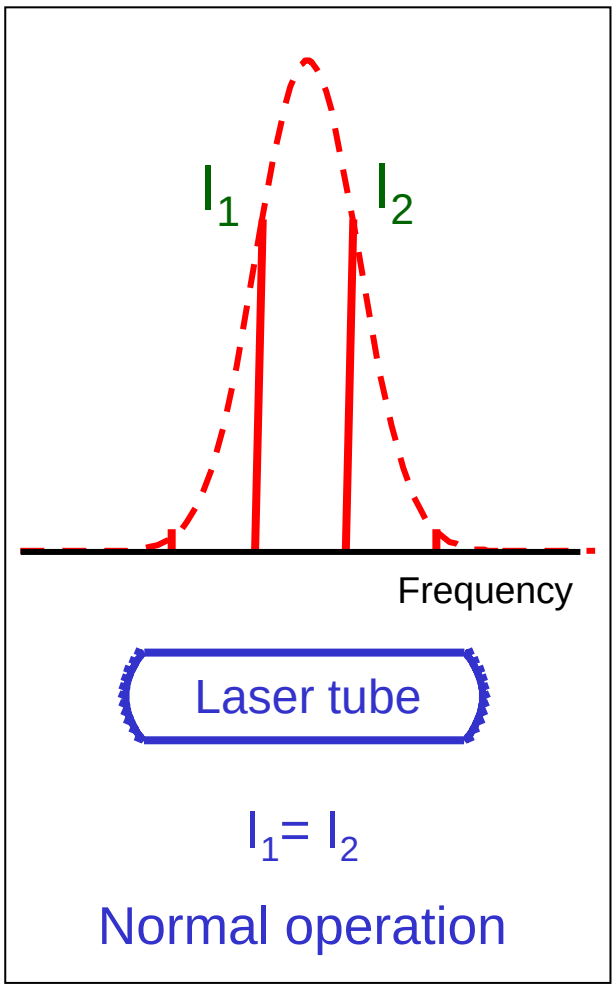
For a laser tube of 30 cm length

Control the temperature of the laser tube
to better than 0.25 mK

Fortunately, there are many ways to do this!

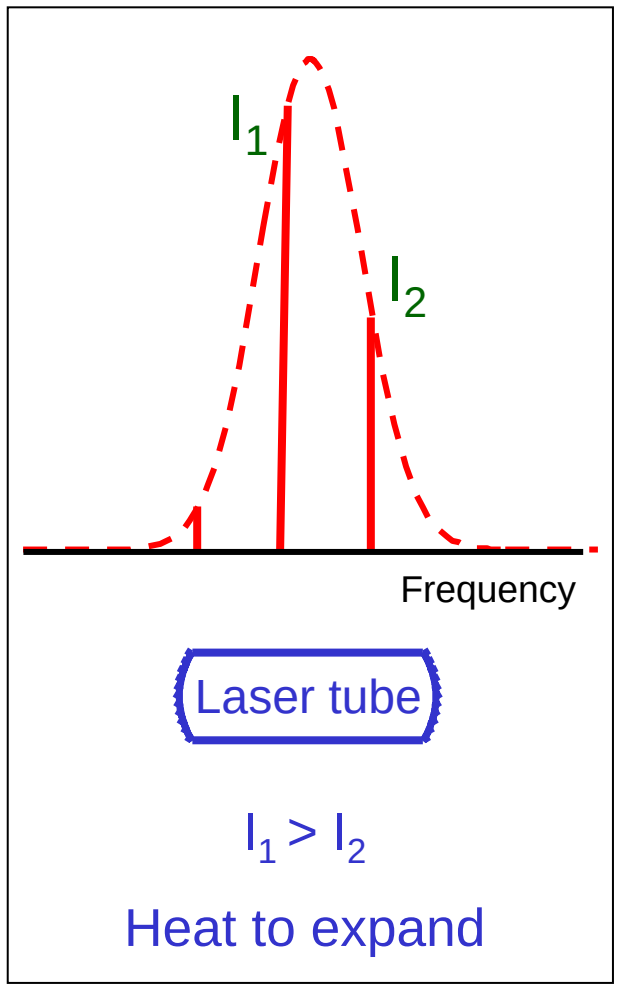
Stabilizing the laser

Compare the intensities of the two main modes



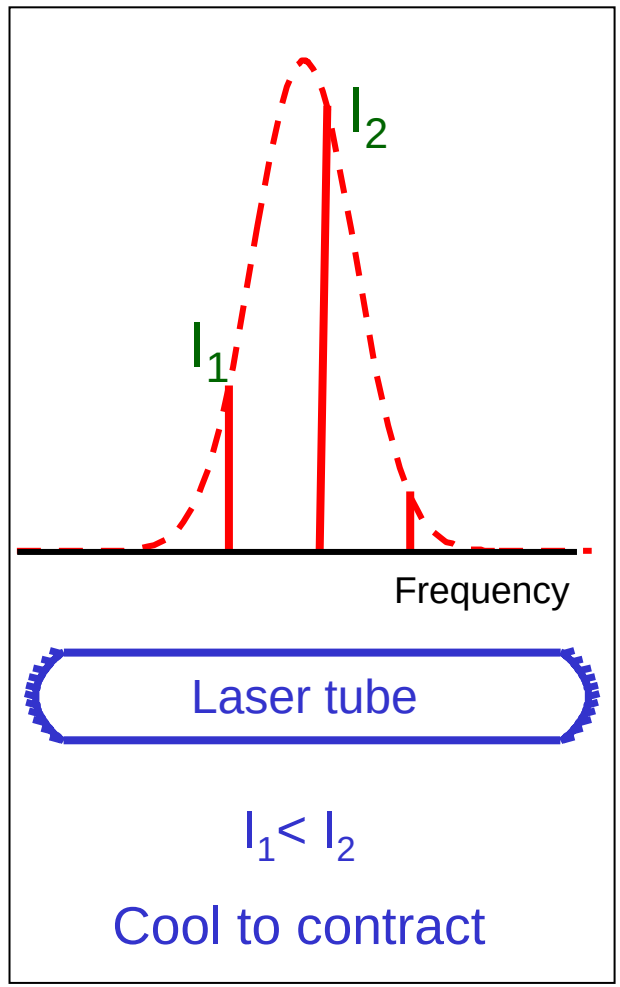
$I_1 = I_2$

Normal operation



$I_1 > I_2$

Heat to expand

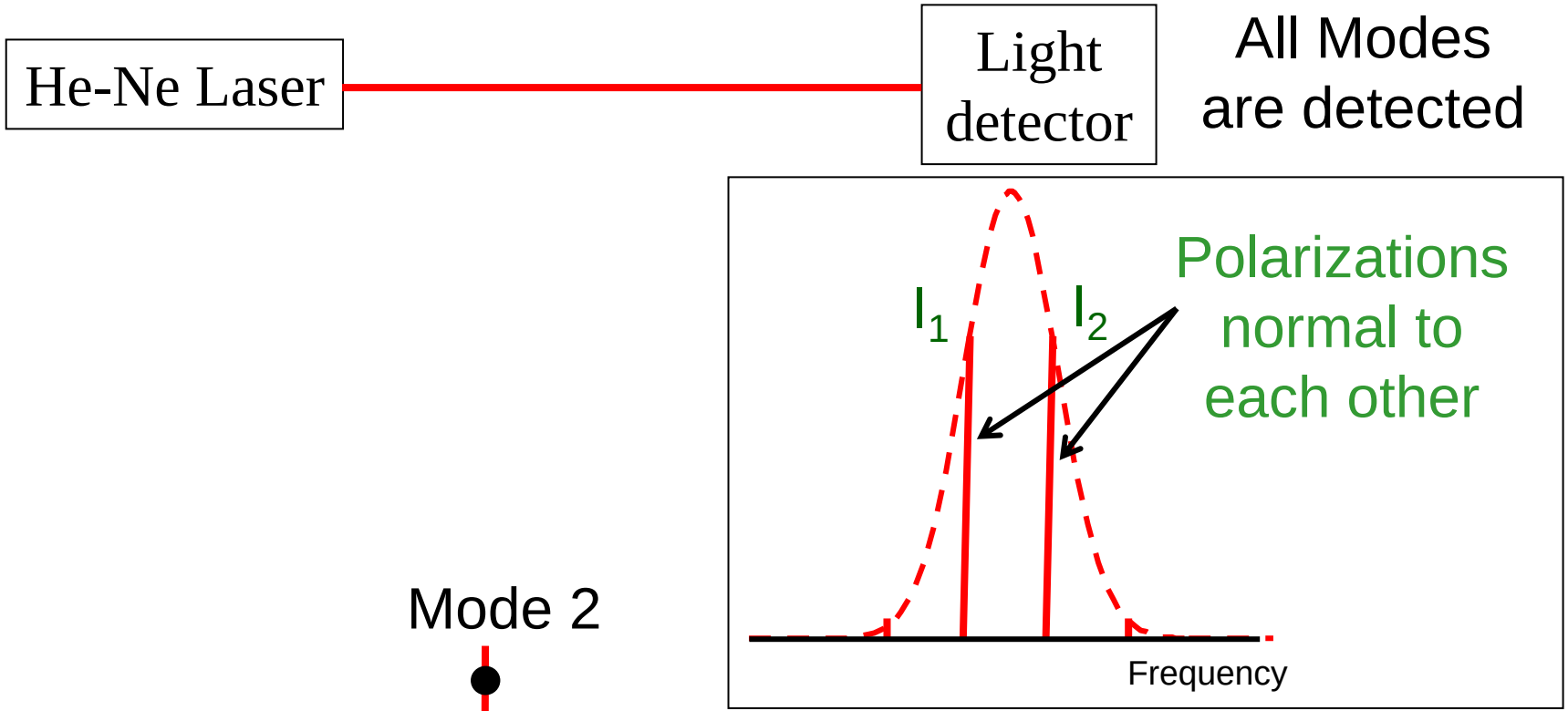


$I_1 < I_2$

Cool to contract

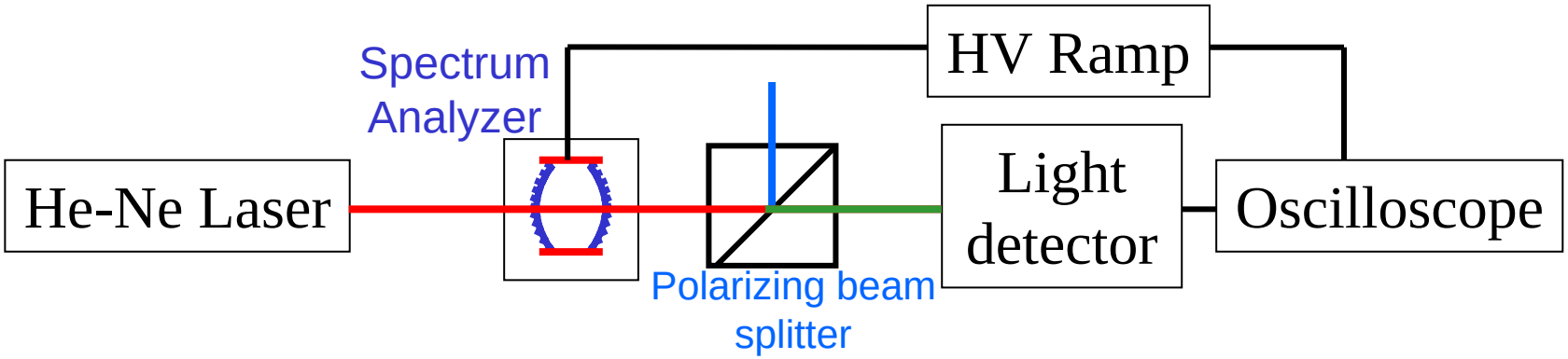
Stabilizing the laser

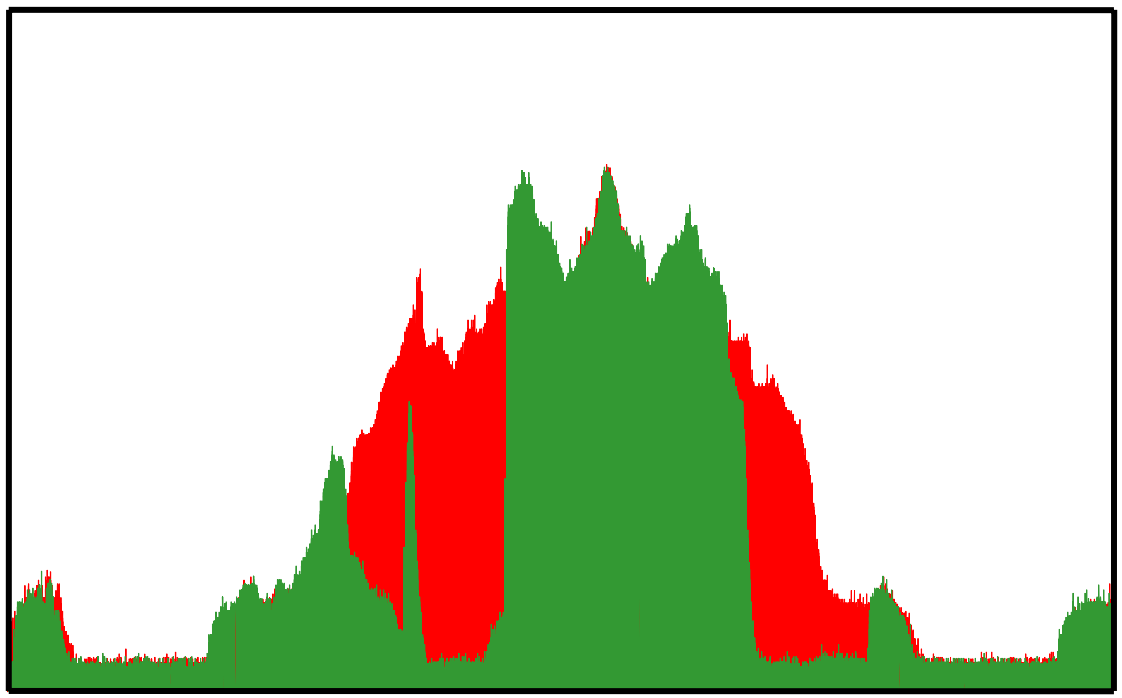
How to separate modes spatially?



Stabilizing the laser

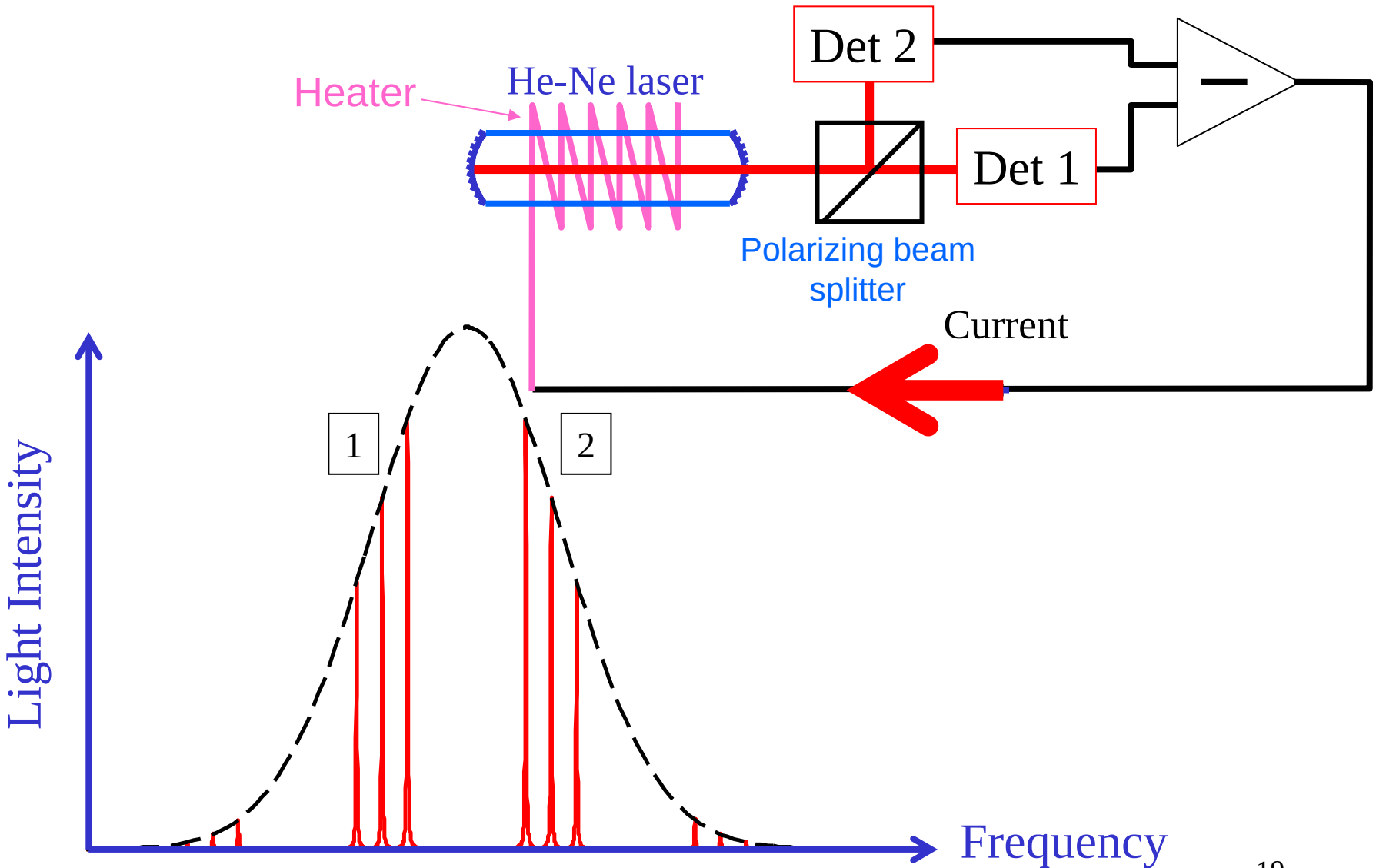
Polarization of laser modes



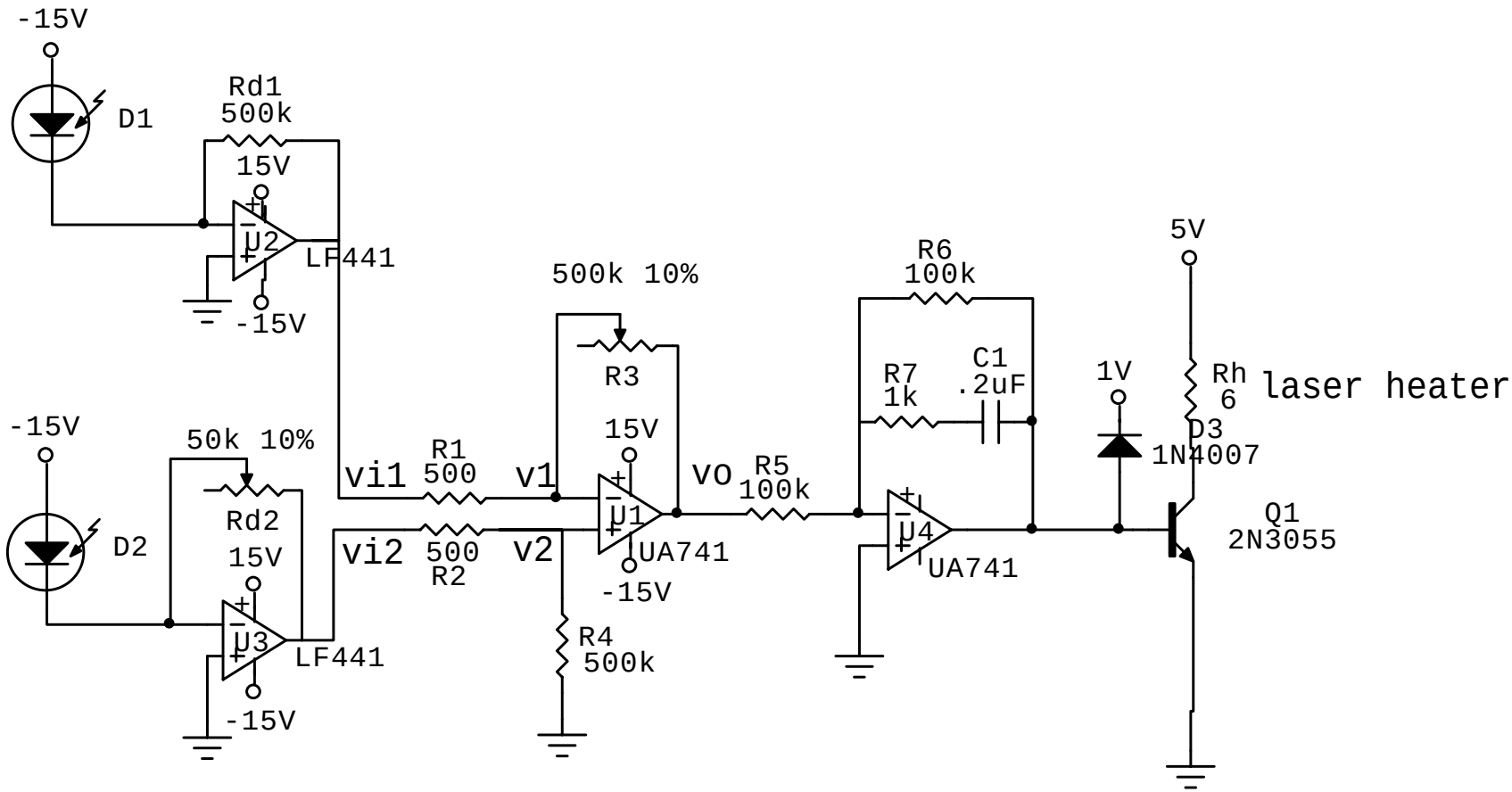


Frequency

Stabilizing the laser

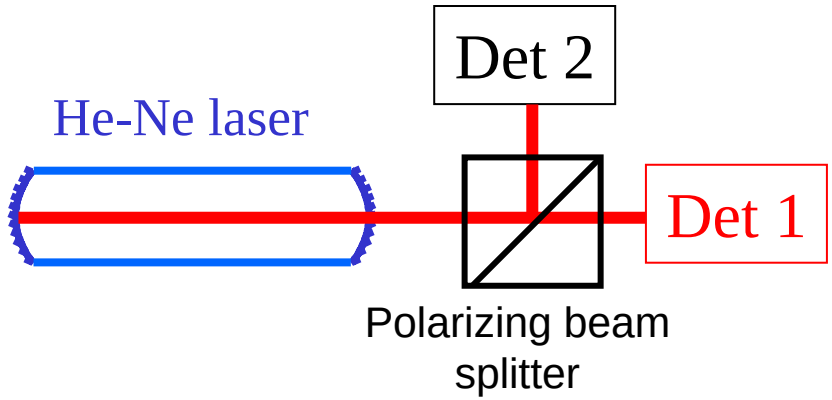


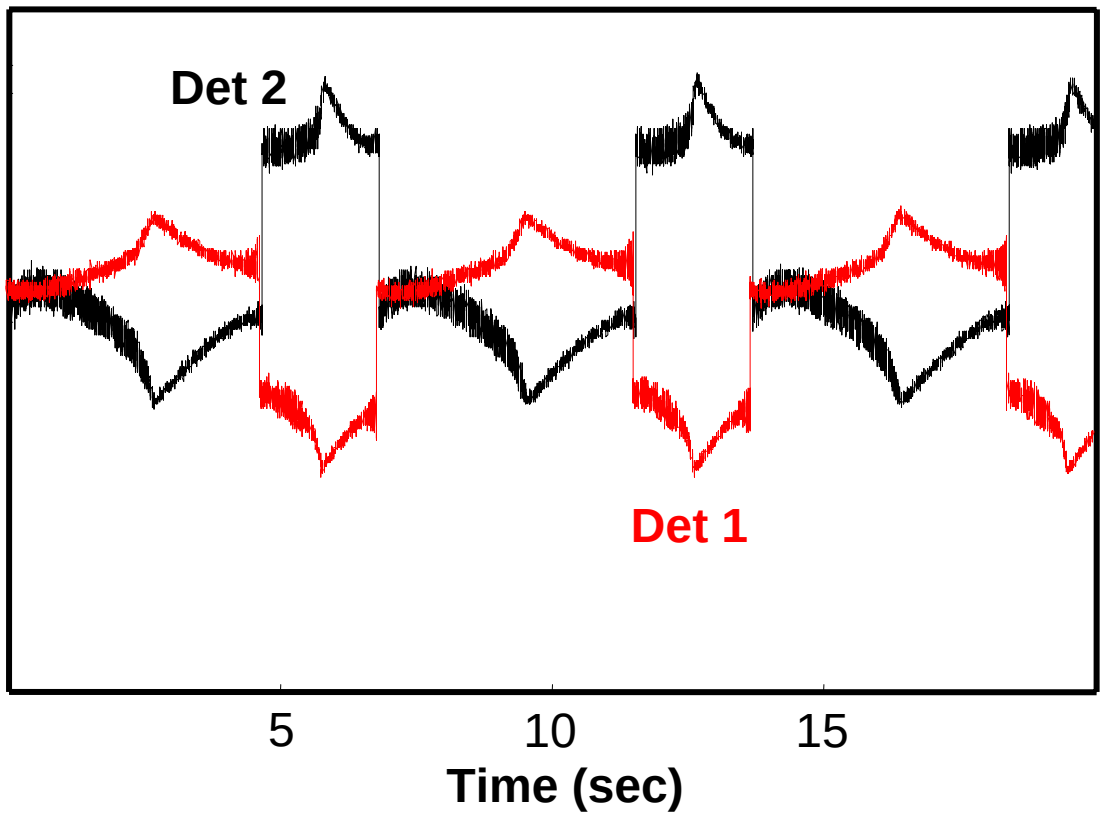
Laser stabilization Circuit



Stabilizing the laser

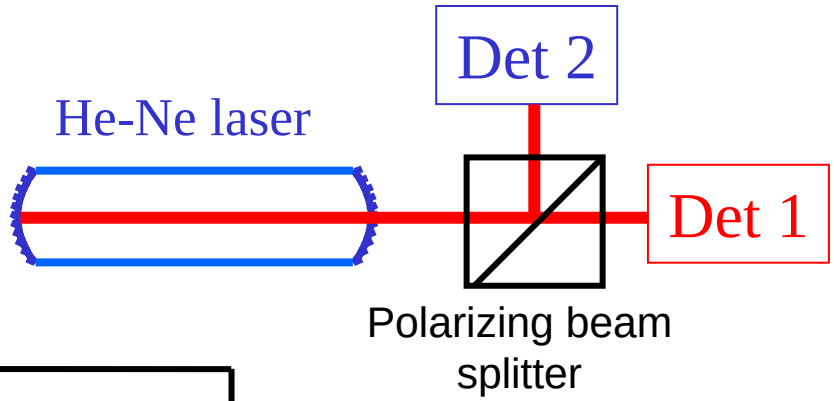
Stabilizing circuit is not engaged

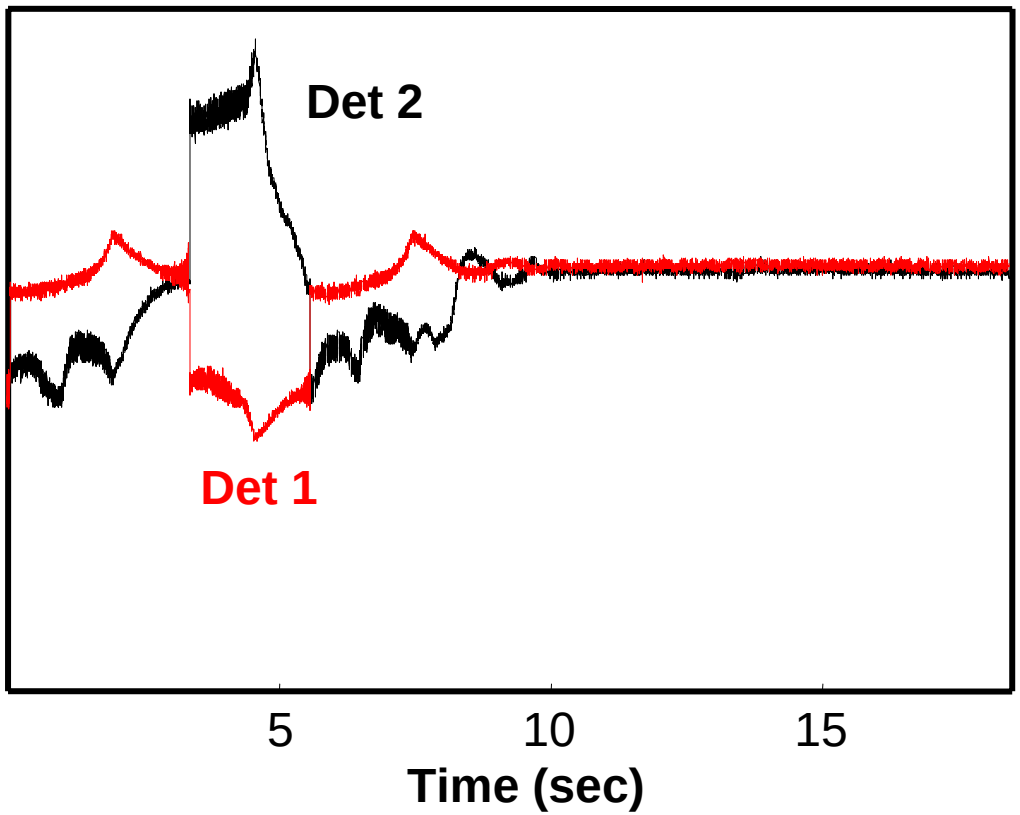




Stabilizing the laser

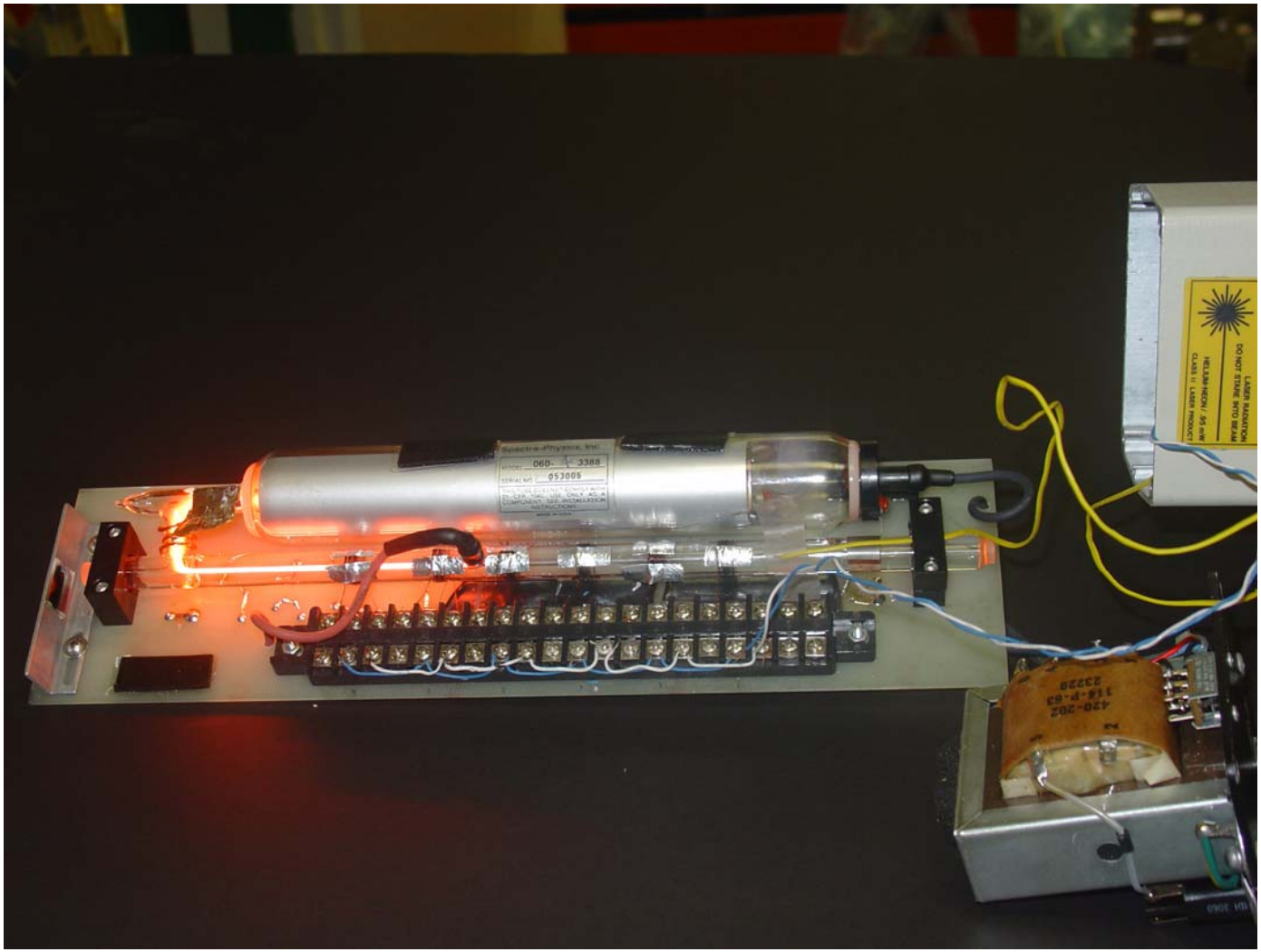
Stabilizing circuit is engaged





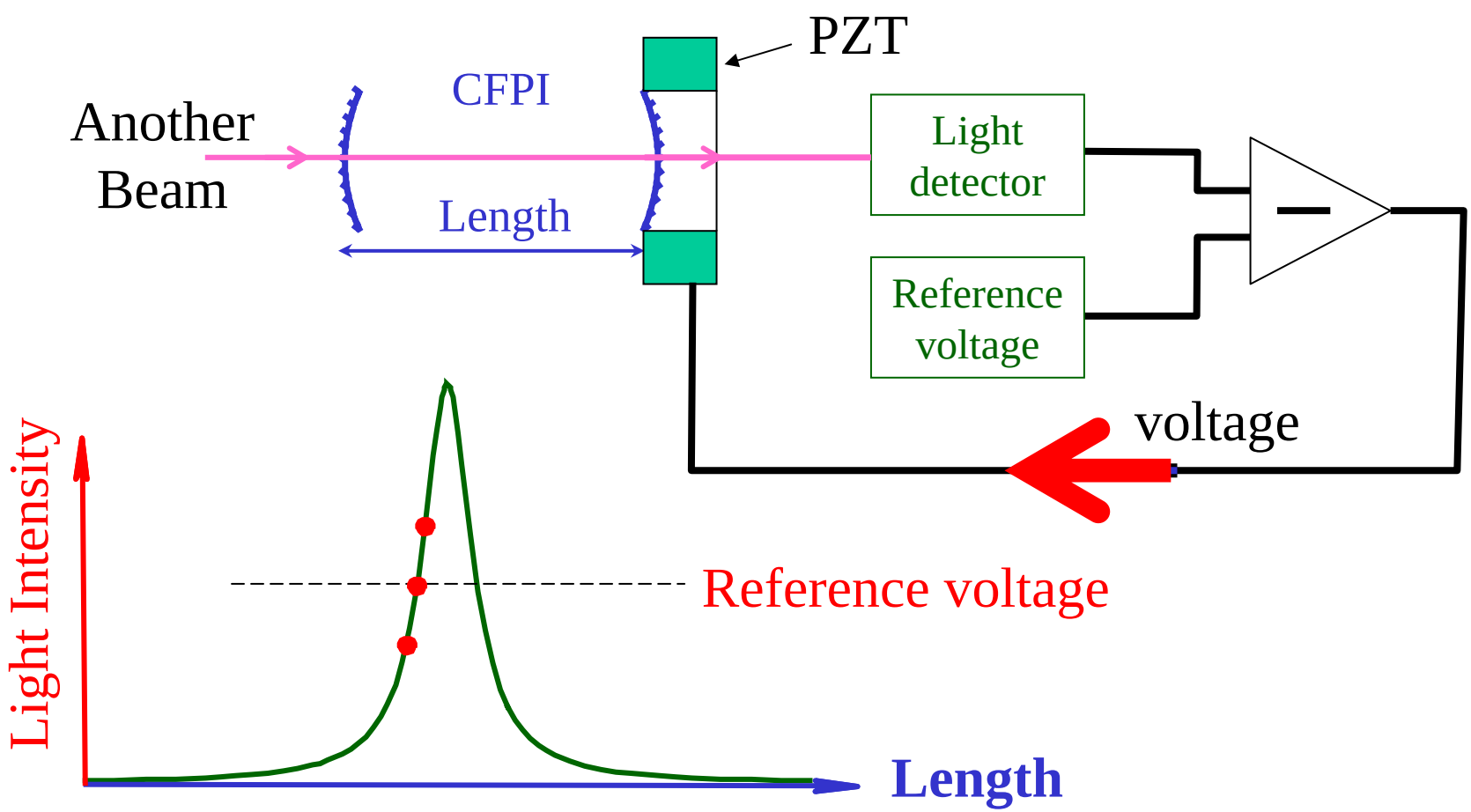
The He-Ne laser is stabilized to about 1 MHz

Stabilizing the laser

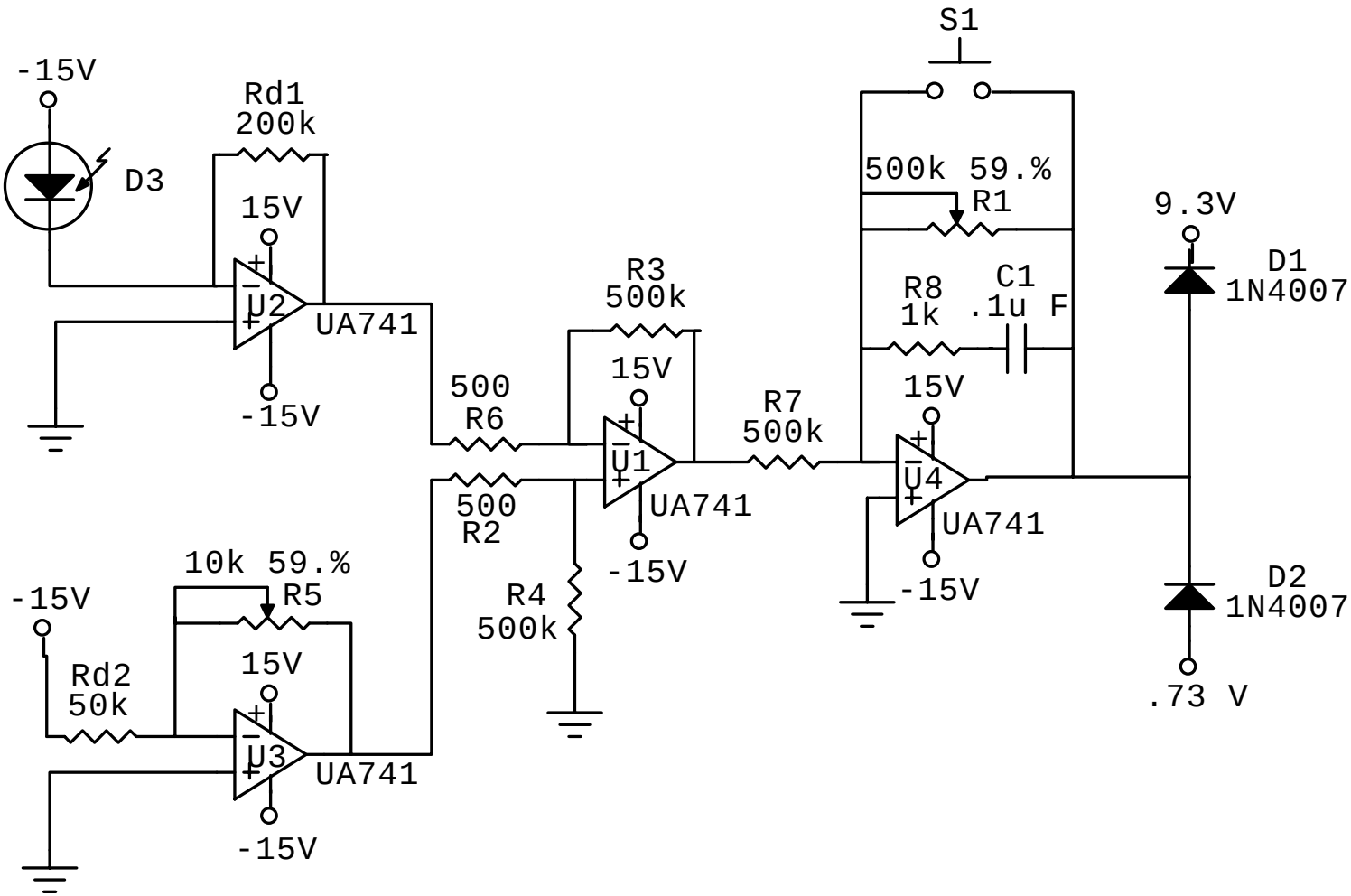


Locking CFPI to laser

Compare transmission to a reference voltage

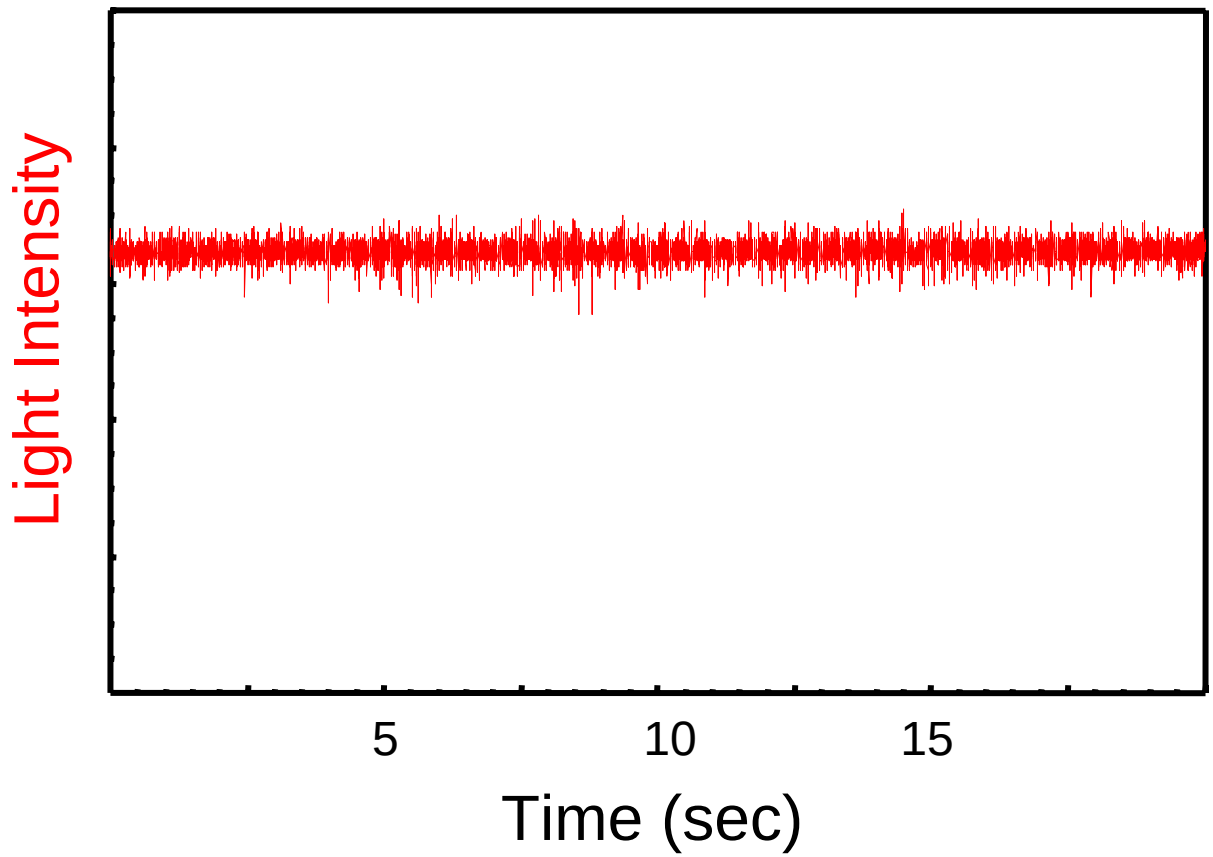


Locking CFPI to laser circuit

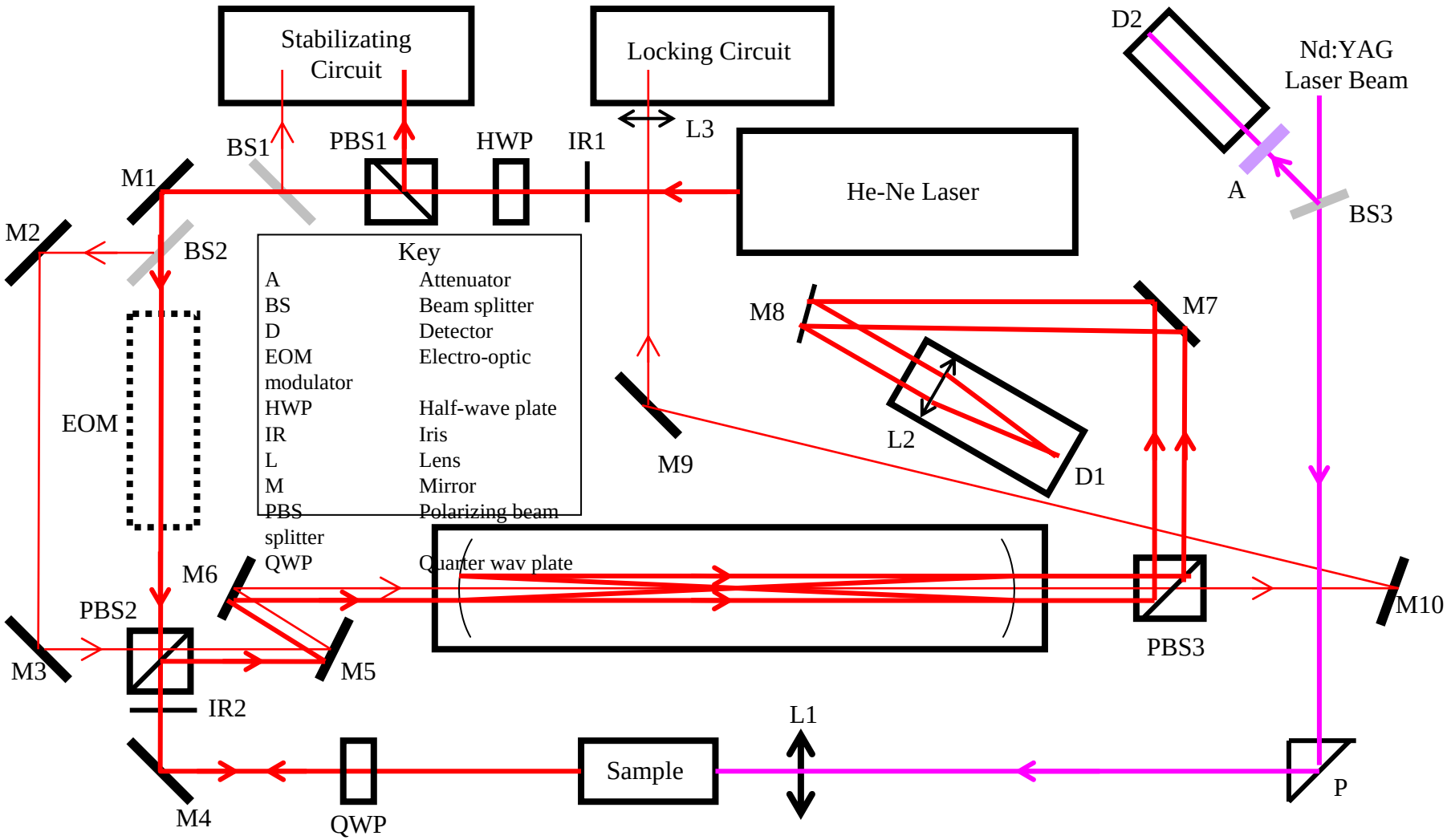


Locking CFPI to laser

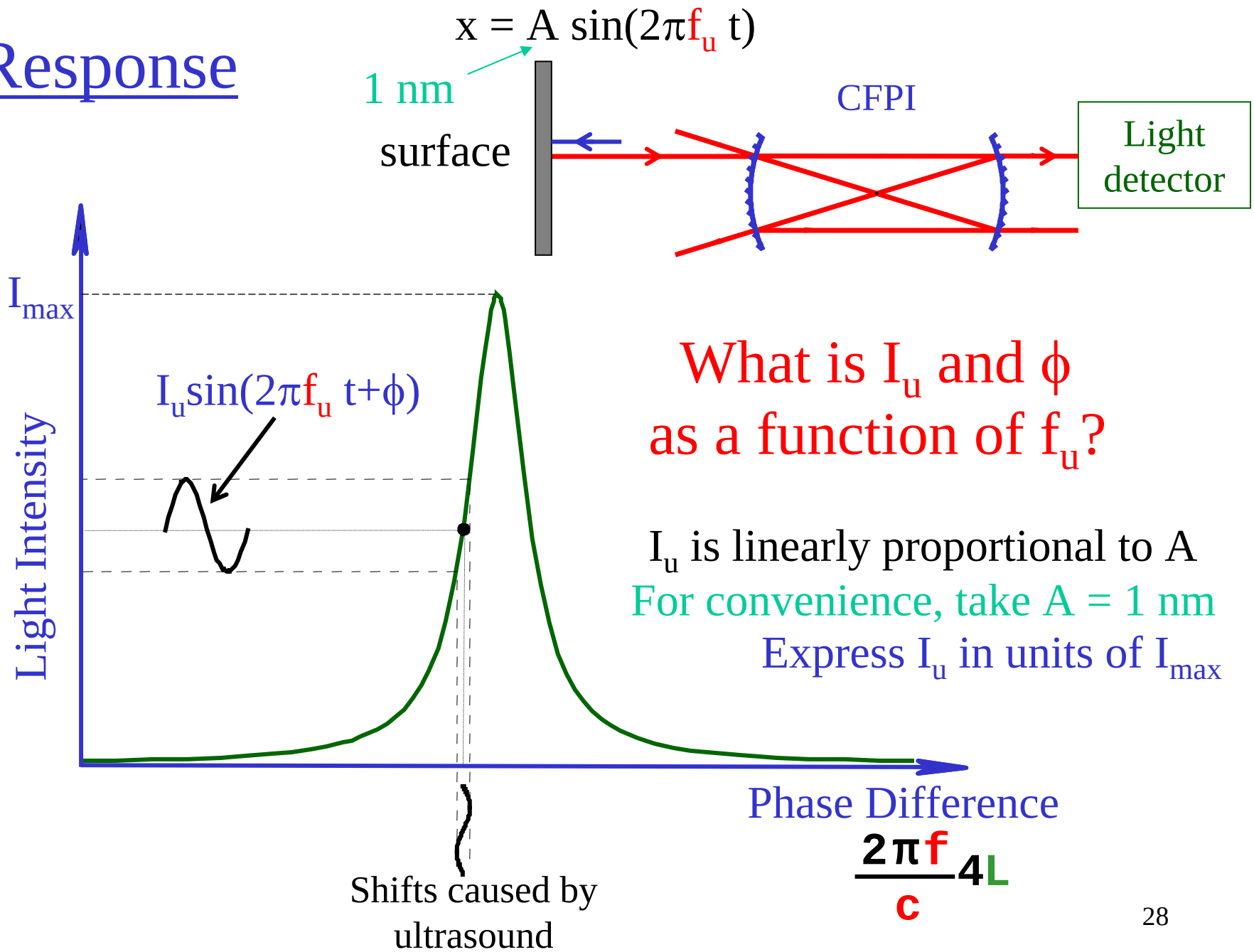
Transmission of CFPI when it is locked to the laser



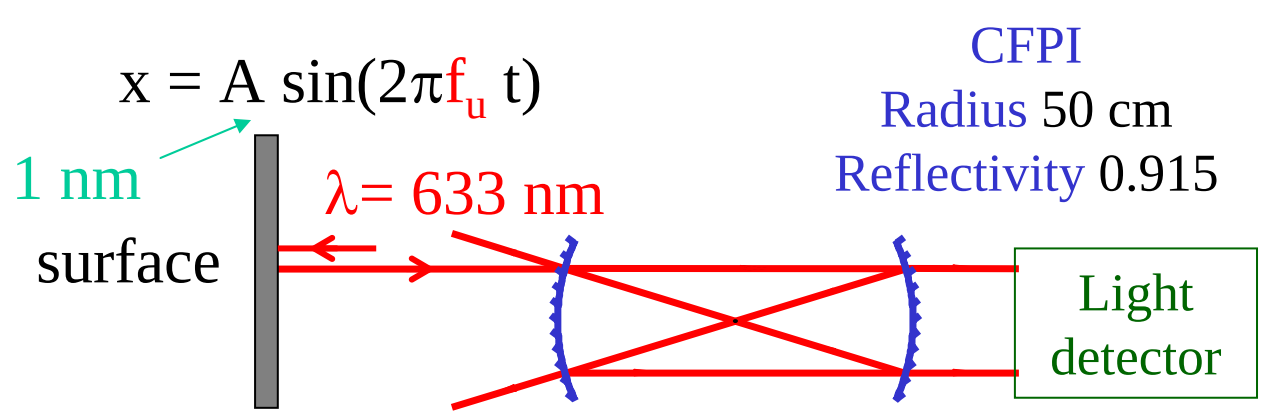
Setup


Stabilizating Circuit
Locking Circuit
D2
Nd:YAG Laser Beam
BS1
PBS1
HWP
IR1
L3
M1
He-Ne Laser
A
BS3
M2
BS2
Key
A Attenuator
BS Beam splitter
D Detector
EOM Electro-optic modulator
HWP Half-wave plate
IR Iris
L Lens
M Mirror
PBS Polarizing beam splitter
QWP Quarter wav plate
M8
M7
EOM
L2
M9
D1
M6
PBS2
M10
PBS3
M3
M5
IR2
L1
Sample
P
M4
QWP

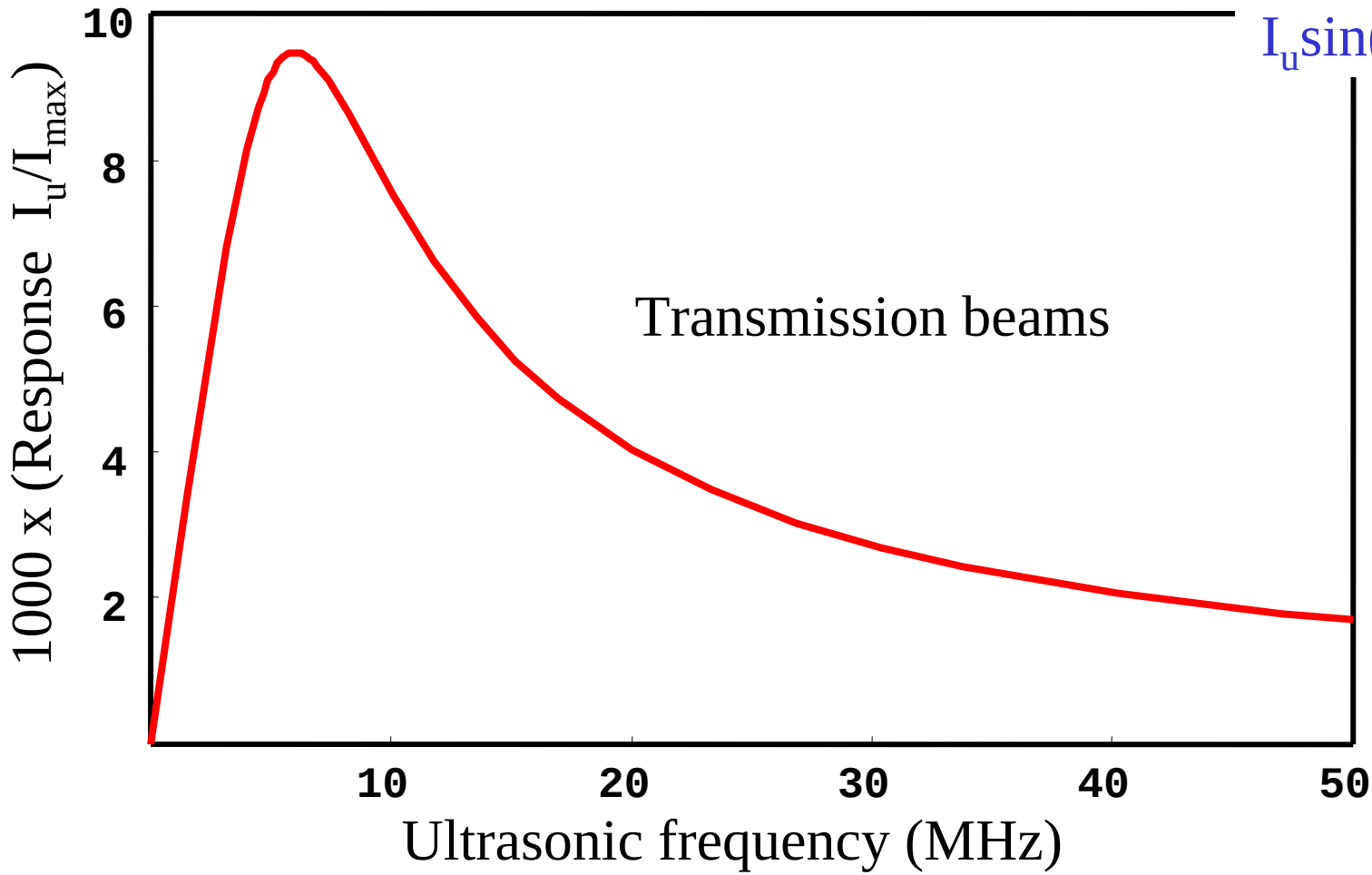
Response


x = A sin(2πf_u t)
1 nm
surface
CFPI
Light detector
I_max
I_u sin(2πf_u t+ϕ)
Light Intensity
What is I_u and ϕ as a function of f_u?
I_u is linearly proportional to A
For convenience, take A = 1 nm
Express I_u in units of I_max
Phase Difference
2πf/c 4L
Shifts caused by ultrasound

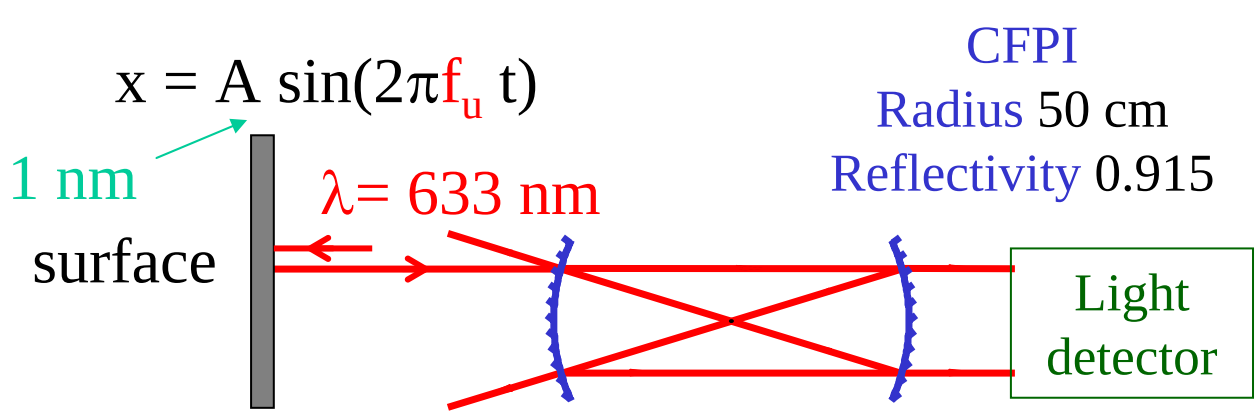
Response

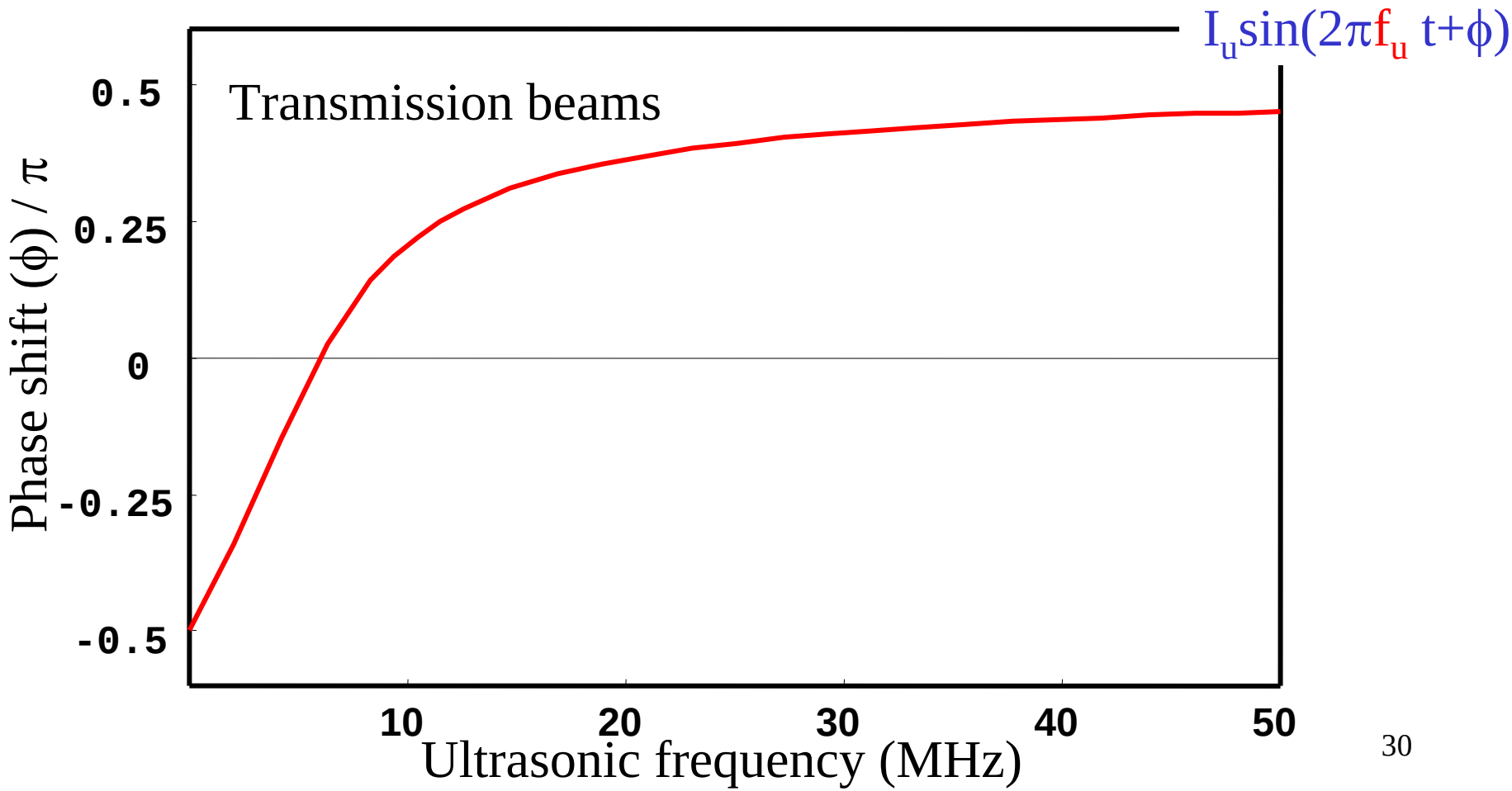


$I_u \sin(2\pi f_u t+\phi)$

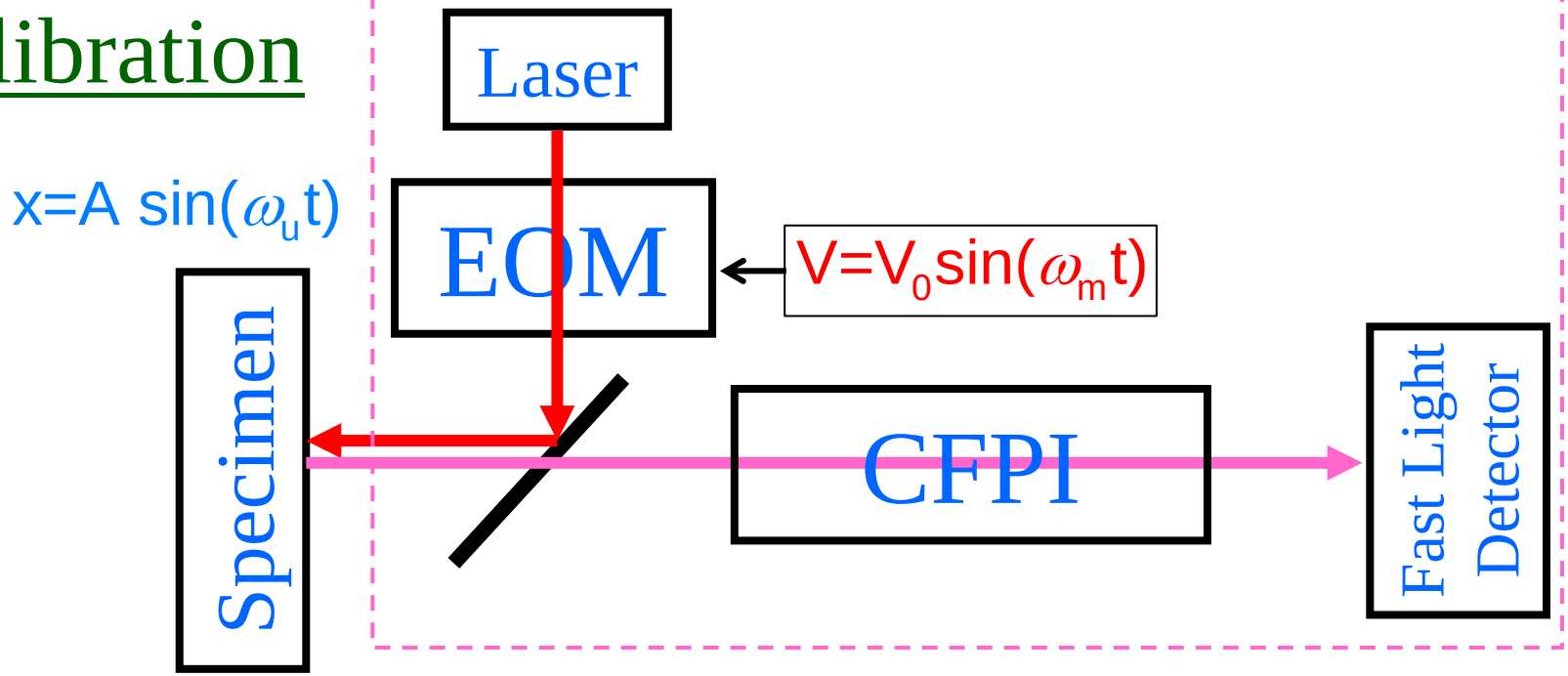


Response


x = A sin(2πf_u t)
1 nm
surface
λ= 633 nm
CFPI
Radius 50 cm
Reflectivity 0.915
Light
detector


I_u sin(2πf_u t+ϕ)
Transmission beams
Phase shift (ϕ) / π
0.5
0.25
0
-0.25
-0.5
10
20
30
40
50
Ultrasonic frequency (MHz)

Calibration



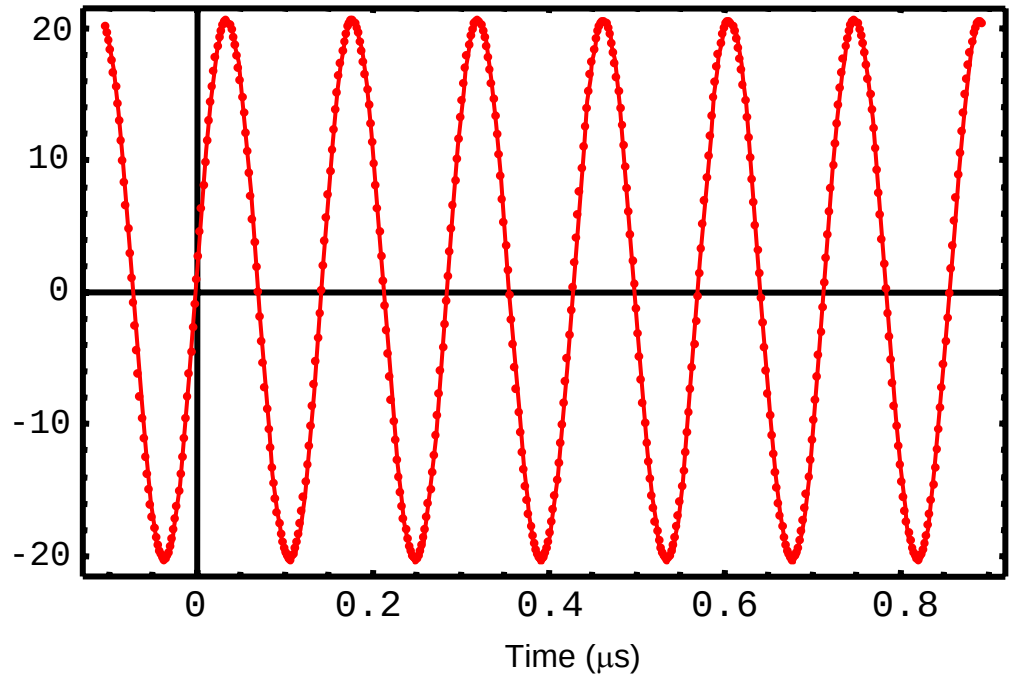
Ultrasound modulation	$E=E_0\sin(kz-\omega t+\frac{4\pi}{\lambda} A\sin(\omega_u t))$
EOM modulation	$E=E_0\sin(kx-\omega t+\frac{\pi}{2}\frac{V_0}{V_\pi}\sin(\omega_m t))$

$$A=\frac{\lambda}{8}\frac{V_0}{V_\pi}$$

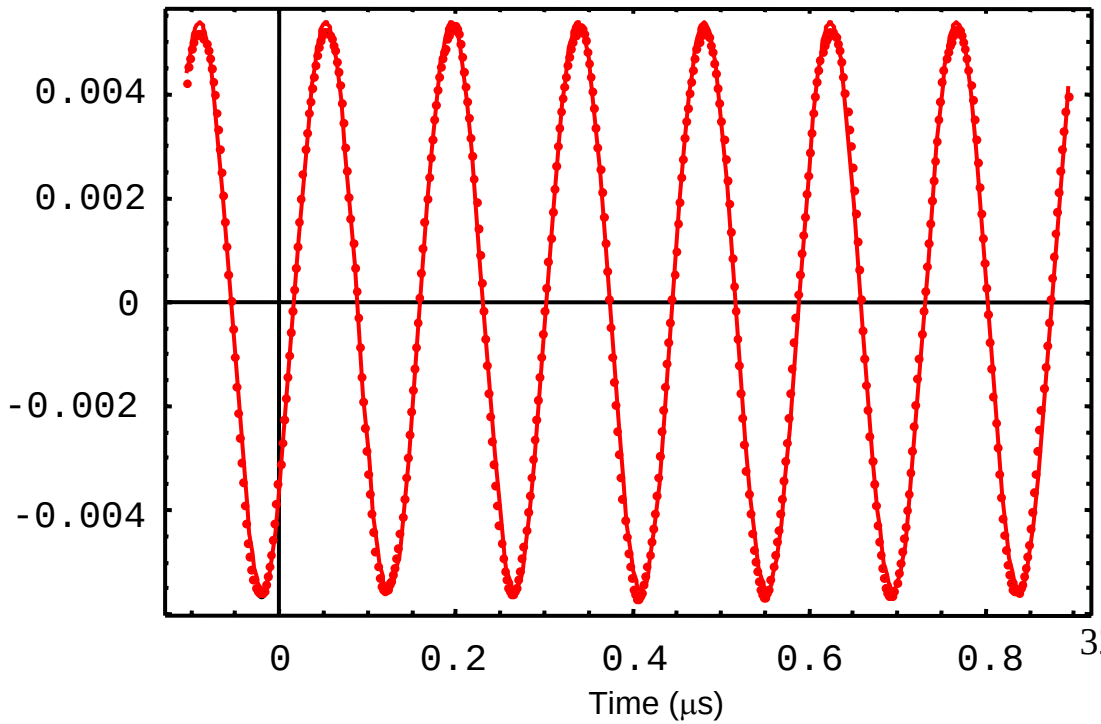
Half-wave voltage for our EOM V_π=230 V

Calibration

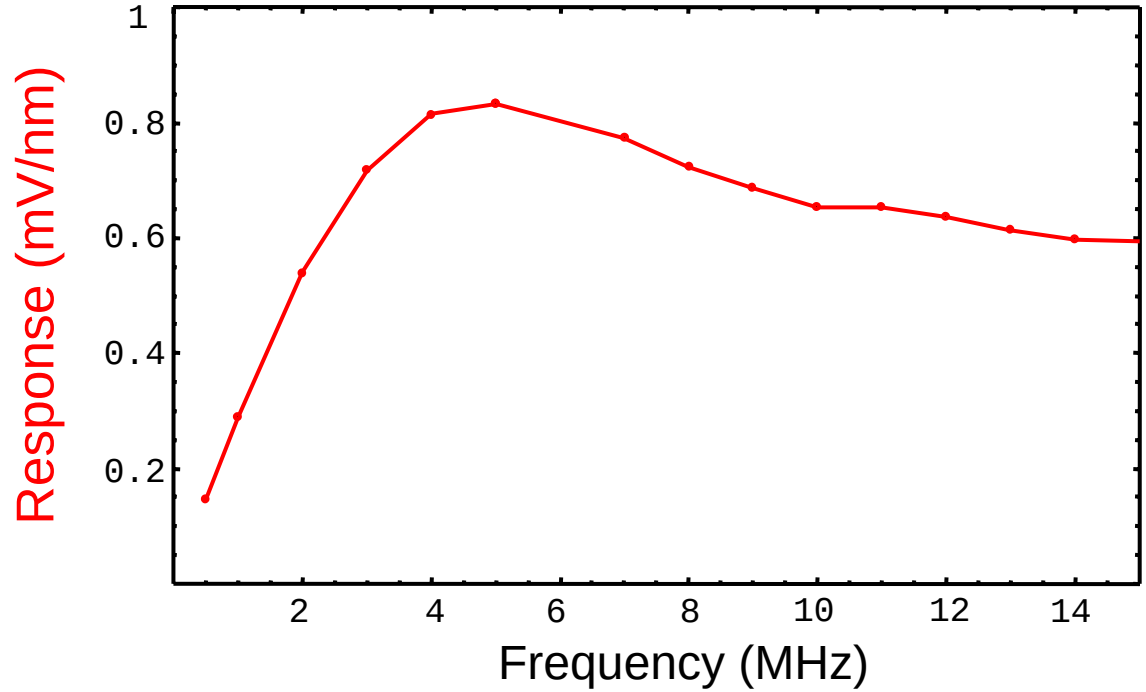
Signal fed to the EOM

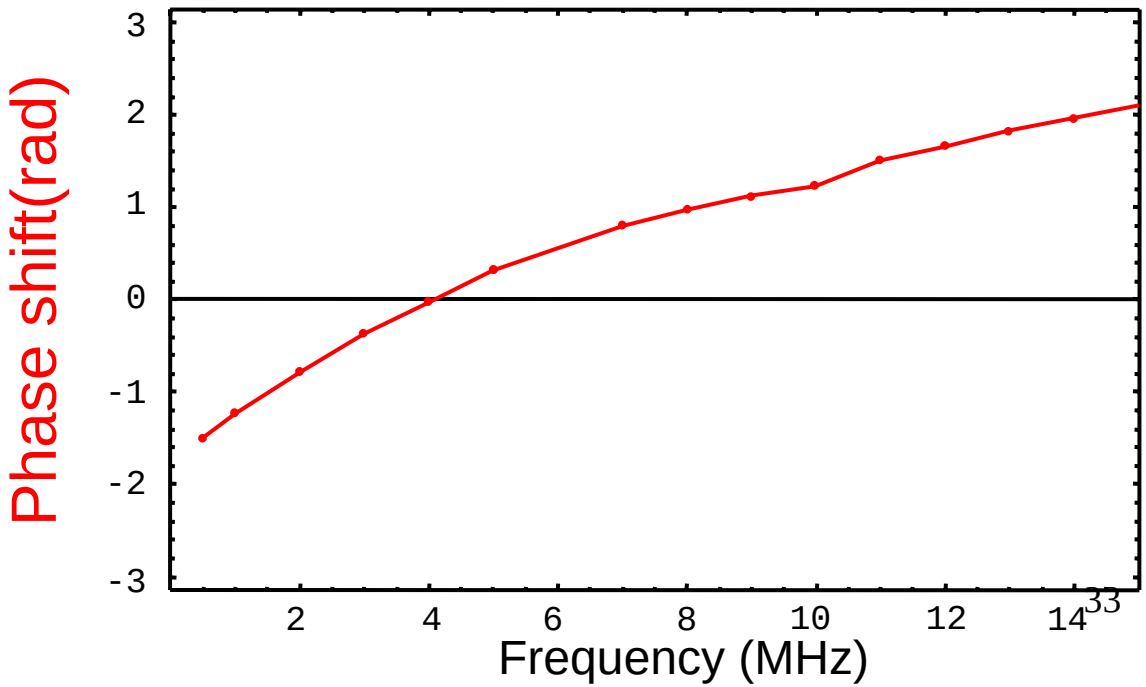


Signal detected by our detector



Calibration



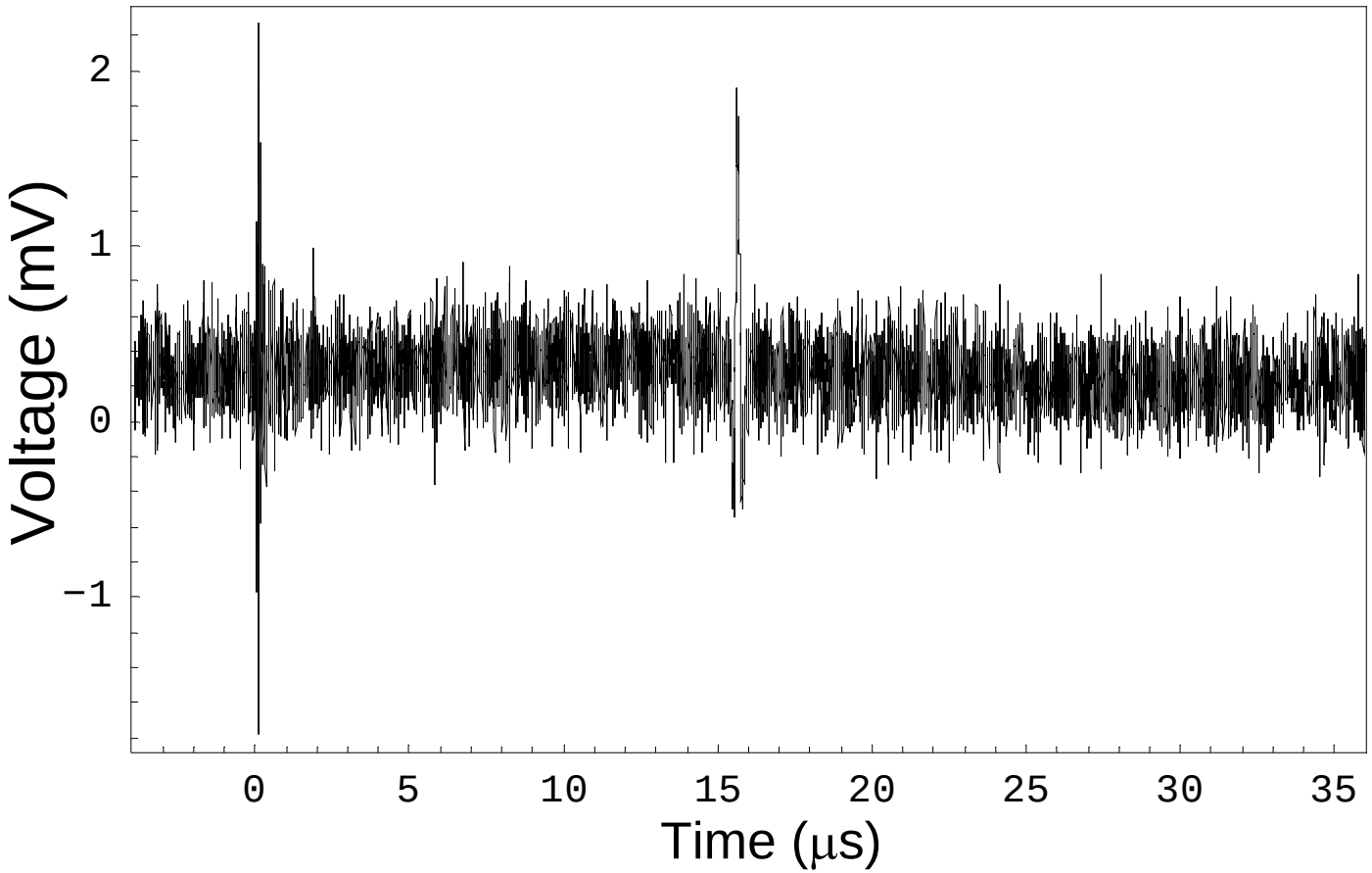


Testing

Source PZT
3.5 MHz

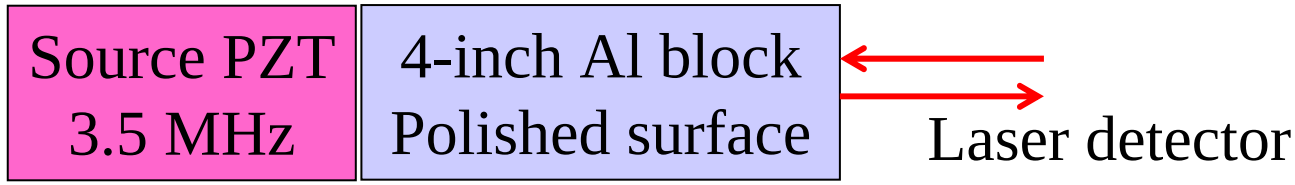
4-inch Al block
Polished surface

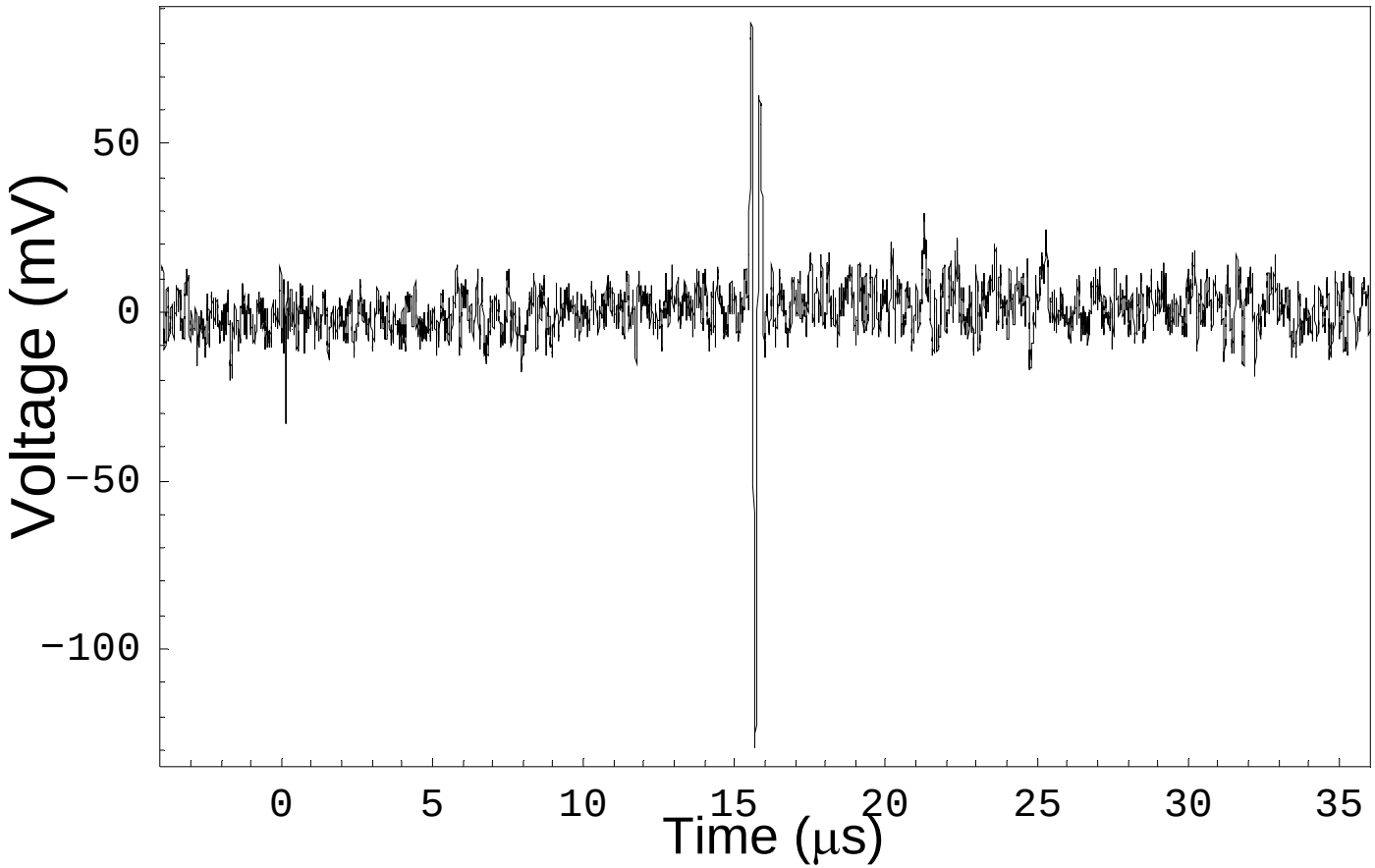
Laser detector



Averaged over 128 traces

Testing



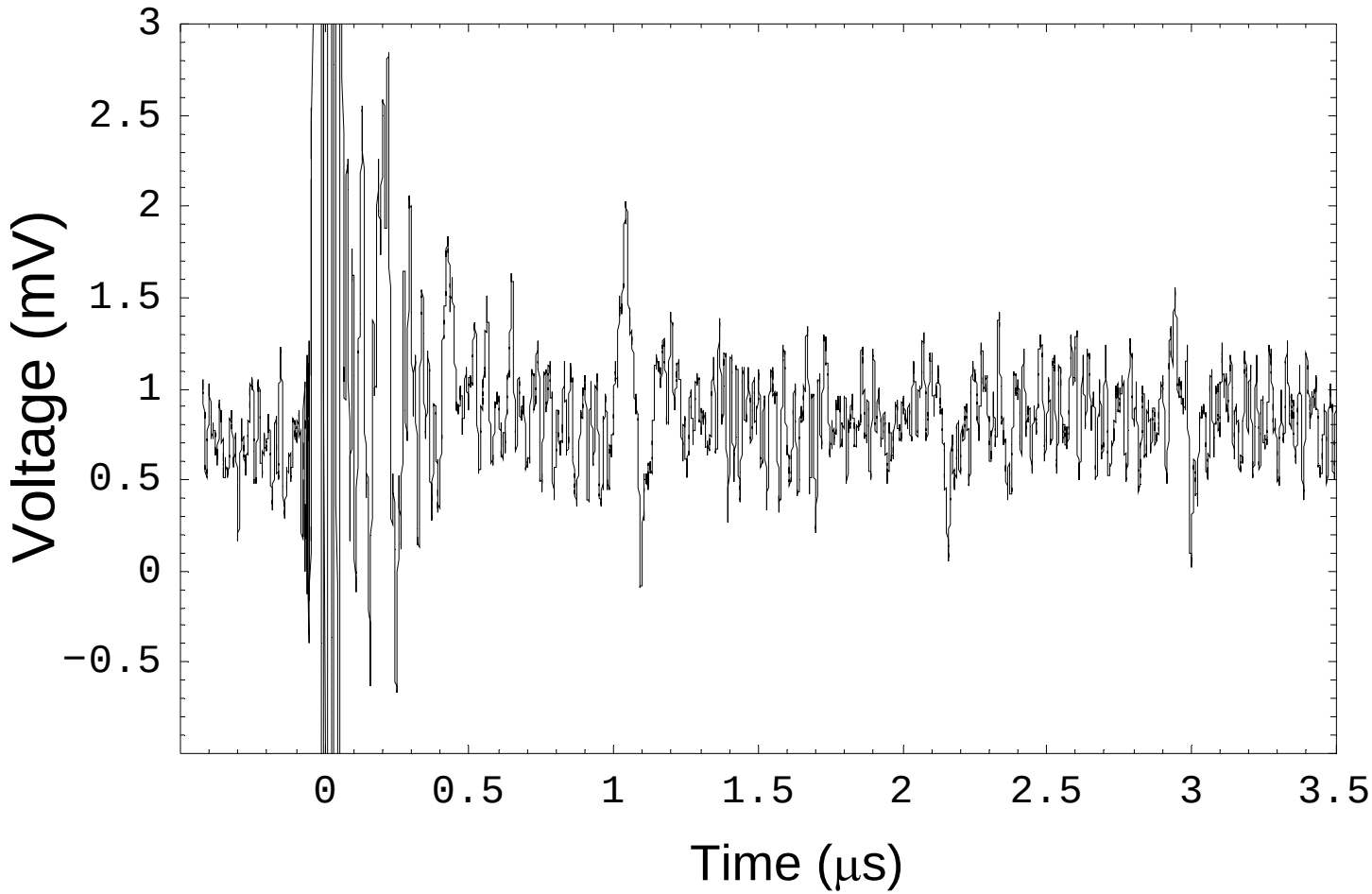


Extra amplifier gain = 50 V/V

Averaged over 128 traces

Testing

Pulsed dye Laser → 1/4-inch Al block Polished surface ↔ Laser detector

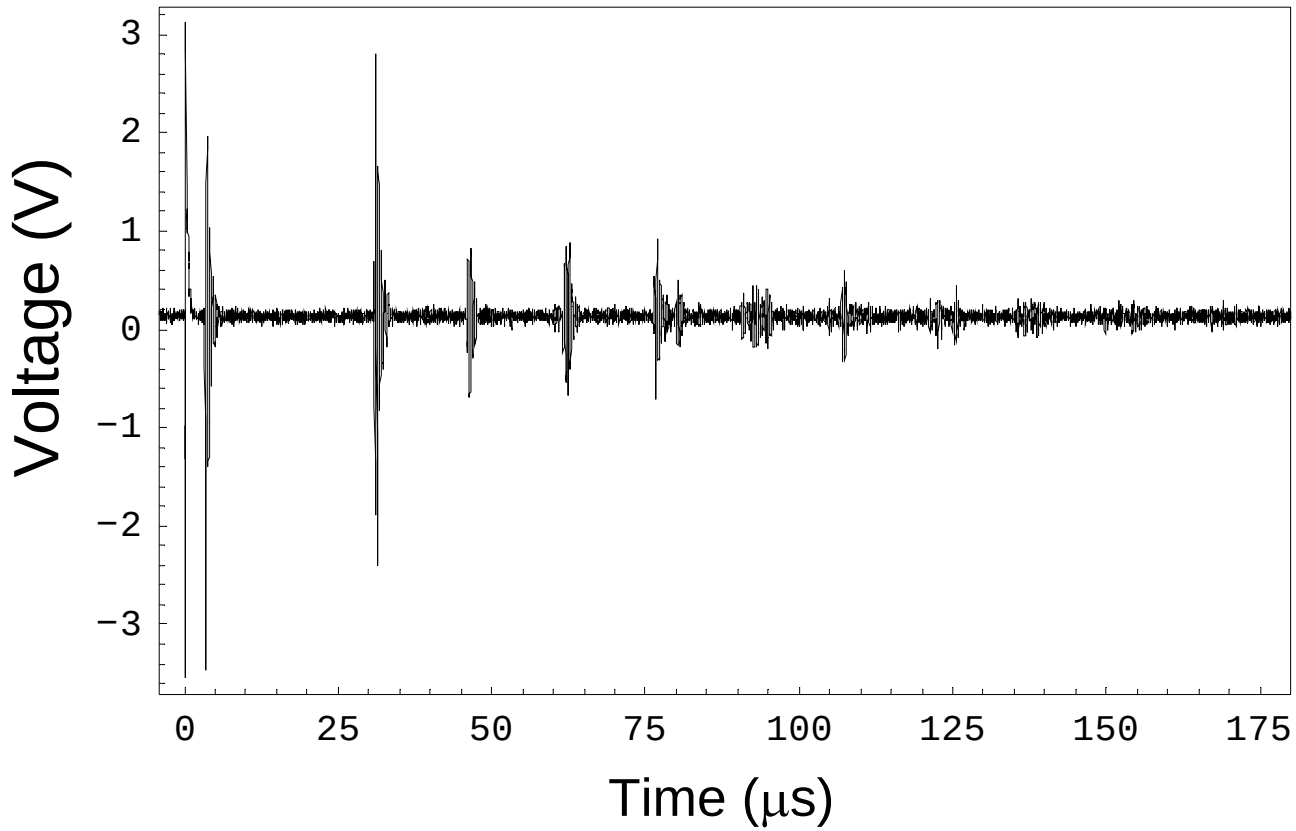


Averaged over 128 traces

Comparison with PZT transducer

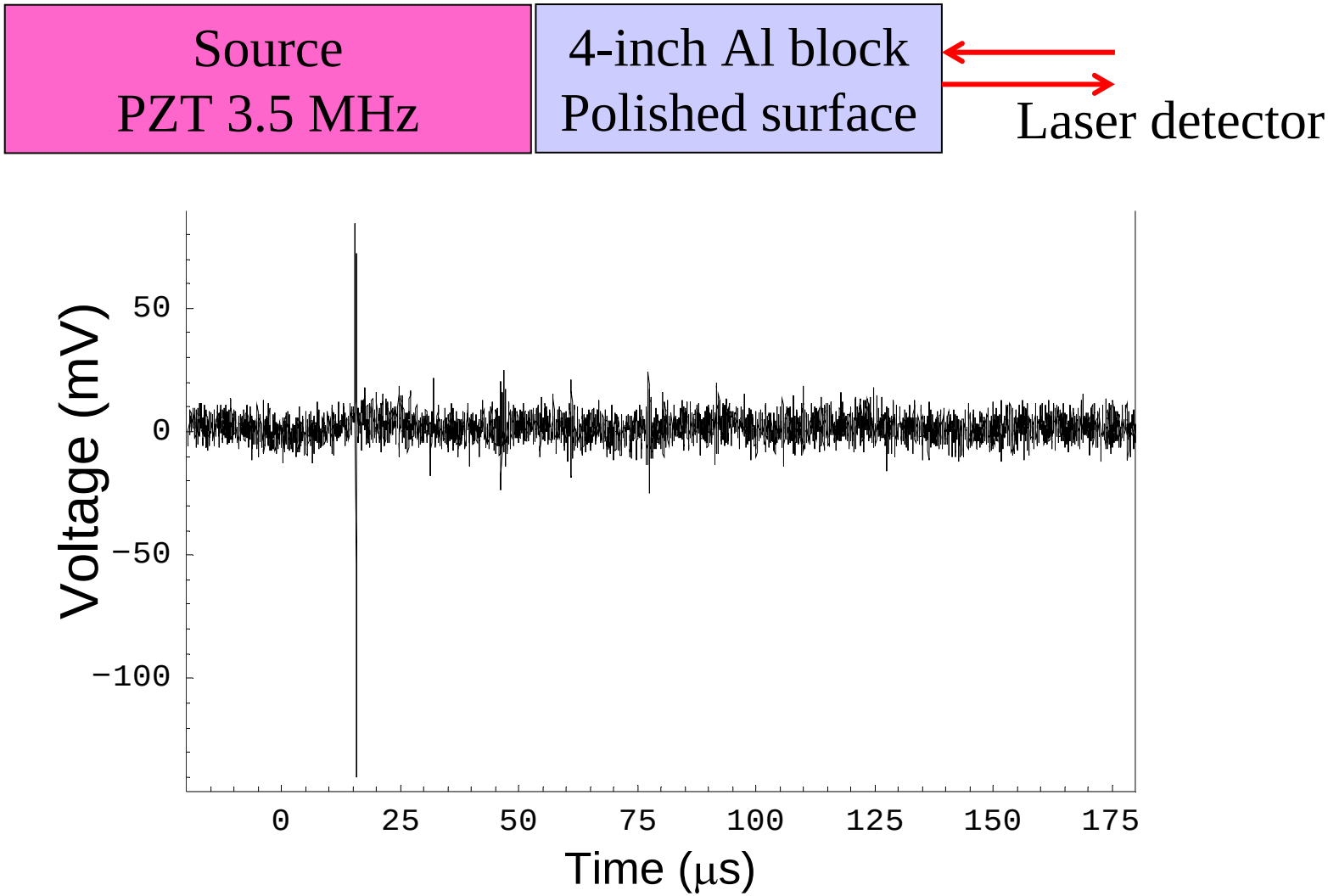
Source and receiver
PZT 3.5 MHz

4-inch Al block
Polished surface



One trace

Comparison with PZT transducer



Averaged over 128 traces

Comparison with PZT transducer

PZT transducer ~ 40 more sensitive than our laser detector

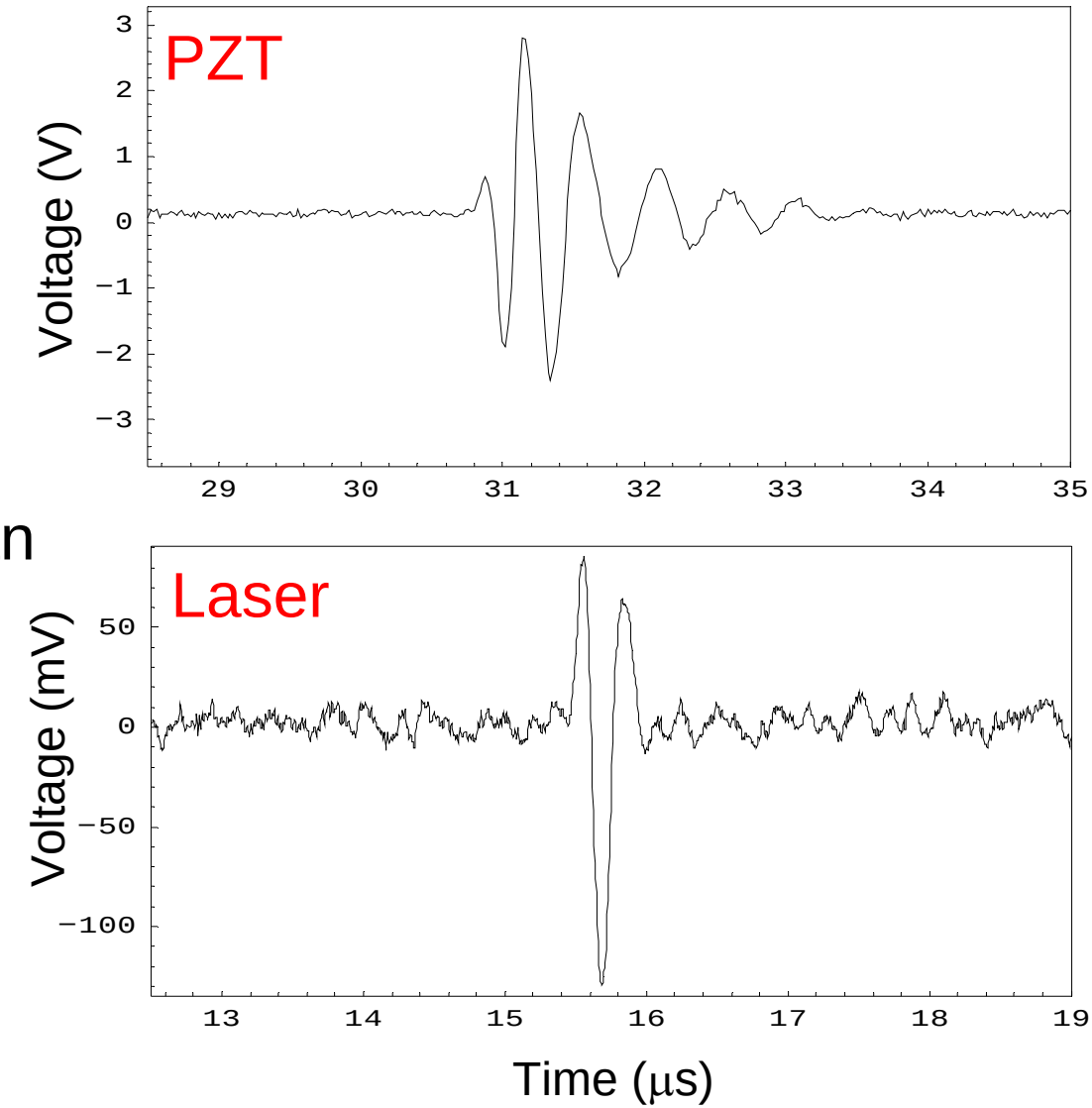
$$\text{laser detector sensitivity} \propto \sqrt{\text{laser power}}$$

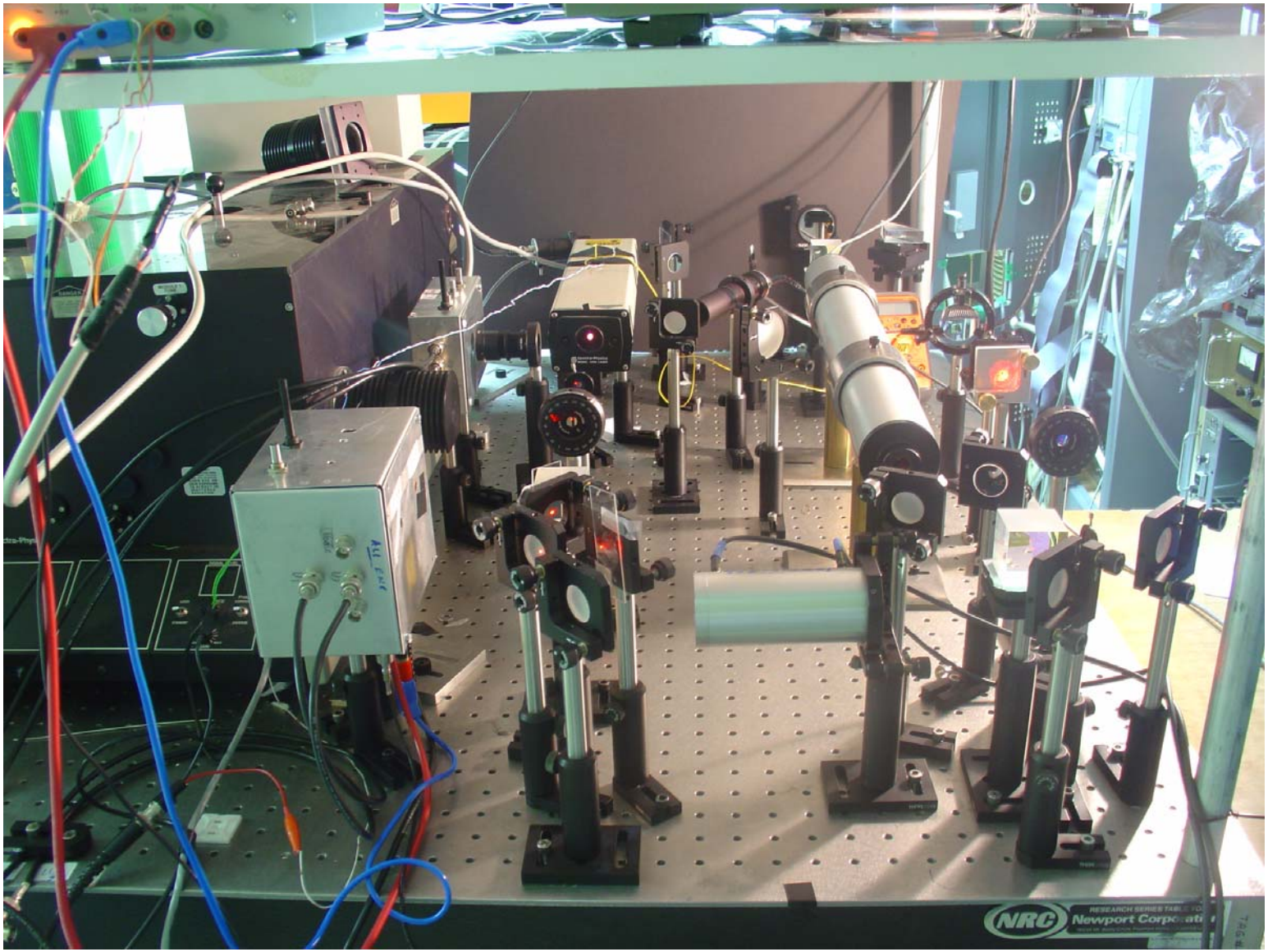
Only 30 μW of the laser power is used in our case

Comparable sensitivities of that of PZT transducers should be attained if we can channel 50 mW of the laser power though our detector

Comparison with PZT transducer

The laser detector provides much better temporal resolution than the PZT transducer



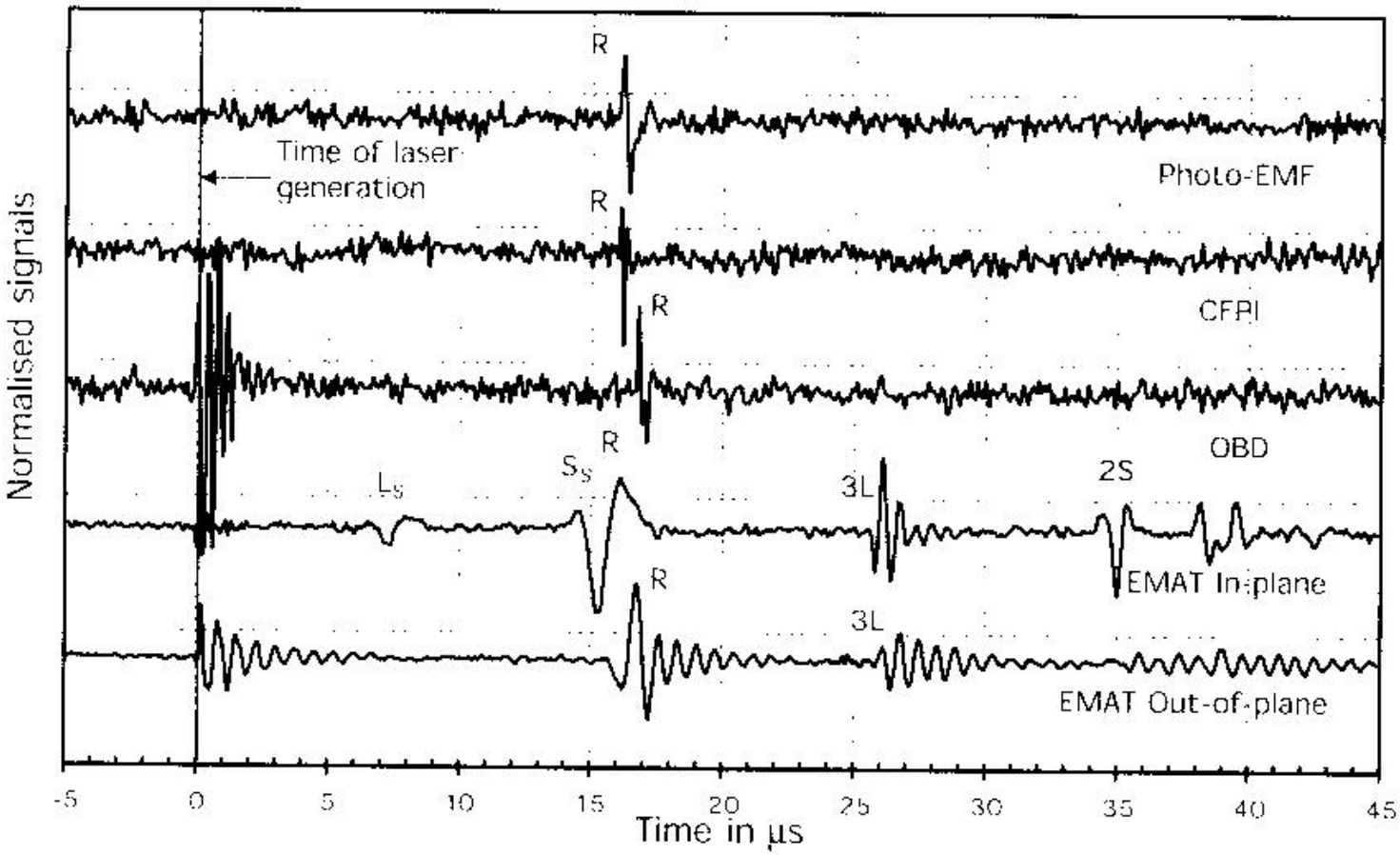

NRC
Newport

Thank You For Your Listening

- Applied Research Grant 2002 program
- Center for Applied Physical Sciences
- Physics Department

- Team
  - Abdulaziz aljalal
  - Mohammed Aslam Khan
  - Rizq Alrehan

Comparison with other noncontact transducers



Ref. A. S. Murfin, R. A. J. Soden, D. Hatrick and R. J. Dewhurst, Meas. Sci. Technol, 11, 1208 (2000).