LITTLE PRE-MODE CLEANER
&
TILT-FREE SEISMOMETER

Veronica Leccese, Dr. Dooley Research Group

LIGO NSF INFN

Outline

Little Pre-Mode Cleaner (PMC)

- Laser beam and its instability
- Solution: PMC
- Little PMC building
- Future work

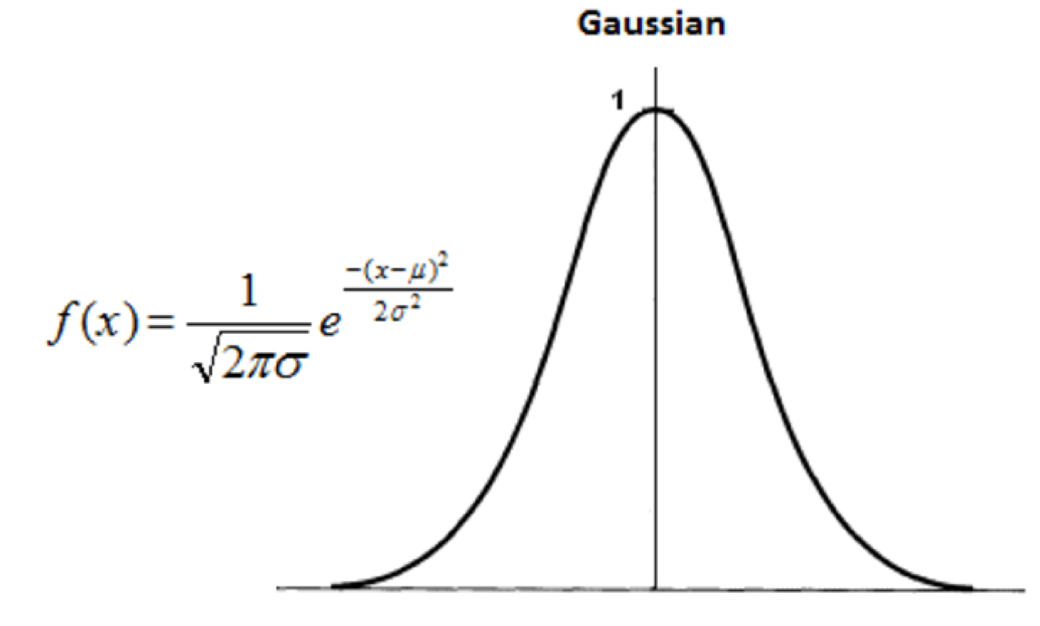
Tilt-free seismometer

- Seismic noise in LIGO: solutions
- Tilt-to-translation coupling and tilt-free sismometer
- Tilt injection: current driver
- Future work

LITTLE PRE-MODE CLEANER

Laser emission: Gaussian beam

- Gaussian beam is a beam of monochromatic electromagnetic radiation whose transverse magnetic and electric field amplitude profiles are given by the Gaussian function; this also implies a Gaussian intensity profile.



- Gaussian beams and the higher-order Gaussian modes are solutions to the wave equation for an electromagnetic field in free space or in a homogeneous dielectric medium:

$$(\nabla^2+k^2)\tilde{E}(x,y,z)=0$$

- The electric field of the fundamental transverse Gaussian mode (TEM_{00}) is:

$$E(r,z) = E_0 \frac{w_0}{w(z)} \exp(-\frac{r^2}{w(z)^2} - jkz - jk\frac{r^2}{2R(z)} + j\psi(z))$$

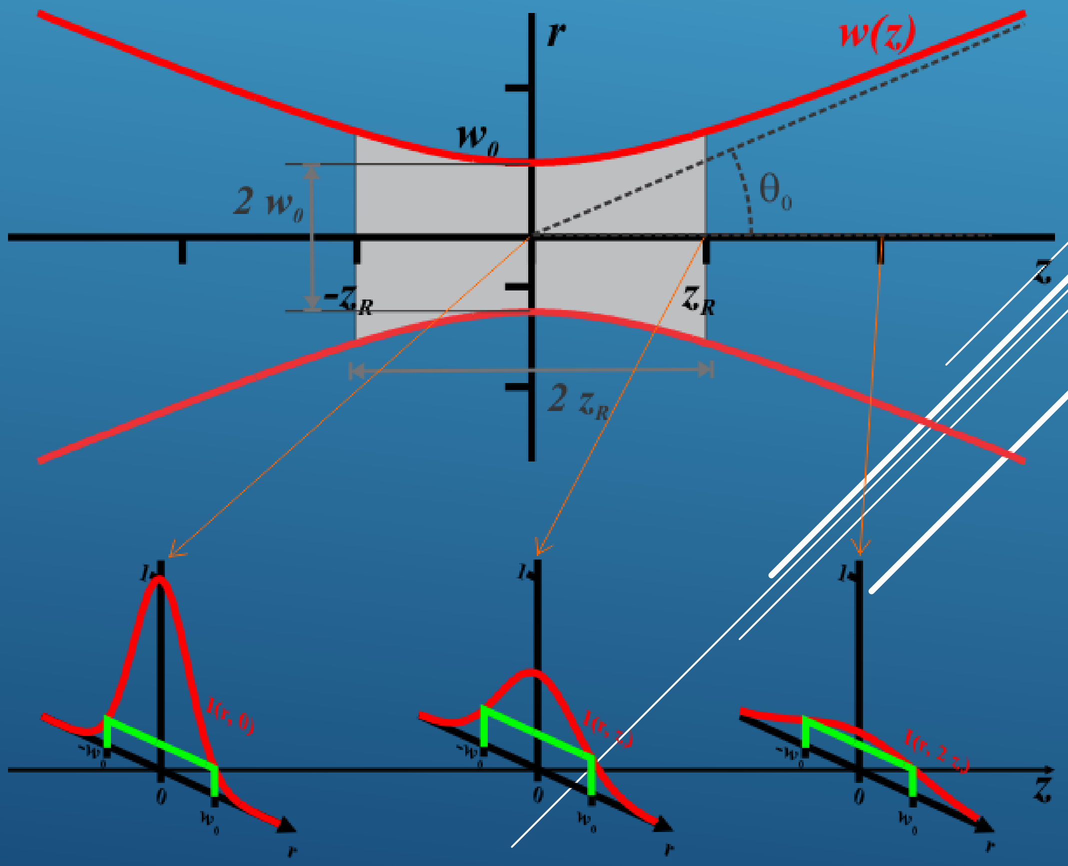
where

$w(z) = w_0\sqrt{1+\left(\frac{z}{z_R}\right)^2}$ is the radius at the plane z

$z_R = \frac{\pi}{w_0^2\lambda}$ is the Rayleigh length

$R(z) = z[1+\left(\frac{z}{z_R}\right)^2]$ is the radius of curvature of the beam's wavefront

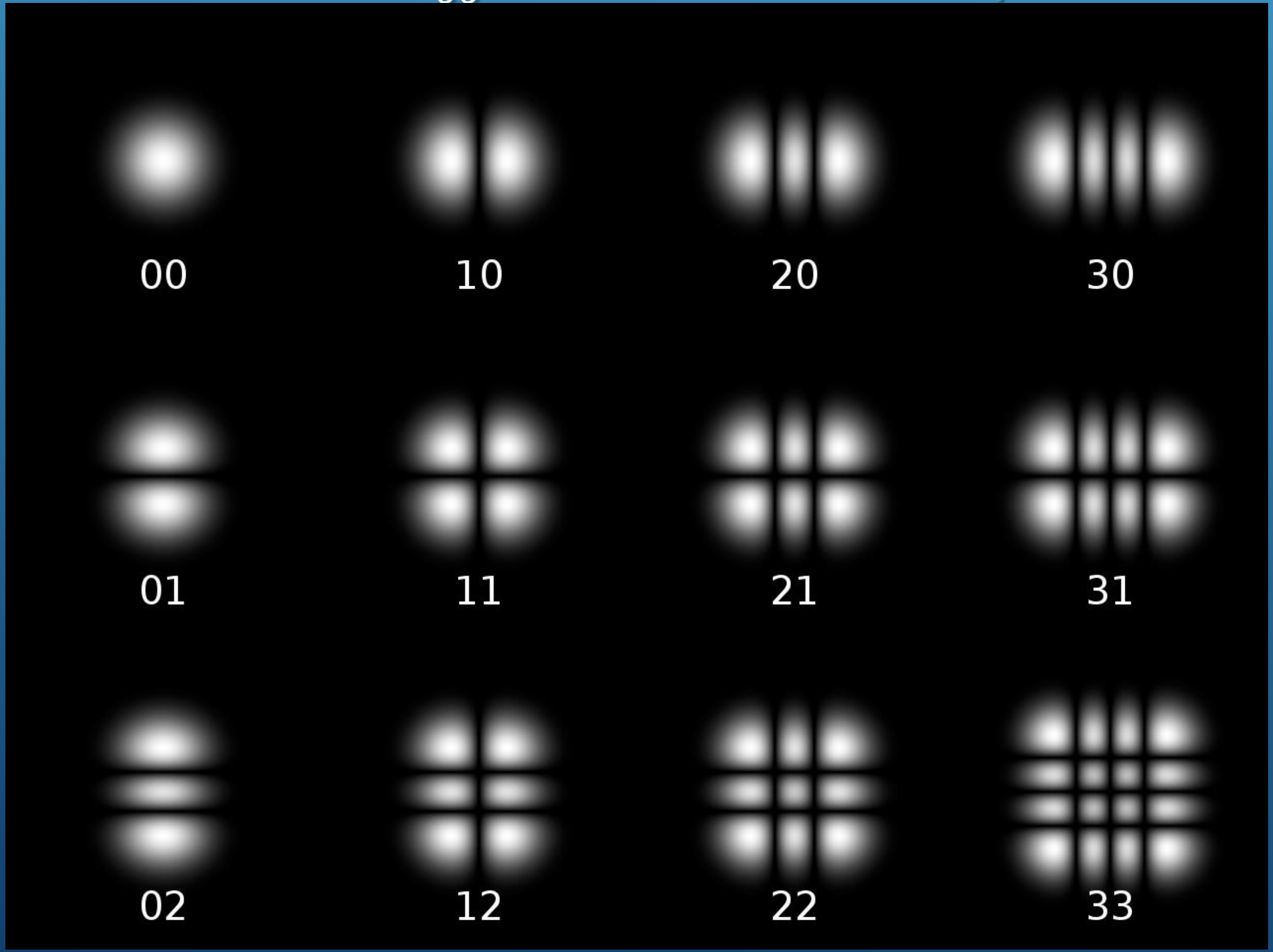
$\psi(z) = tan^{-1}(\frac{z}{z_R})$ is Gouy phase shift



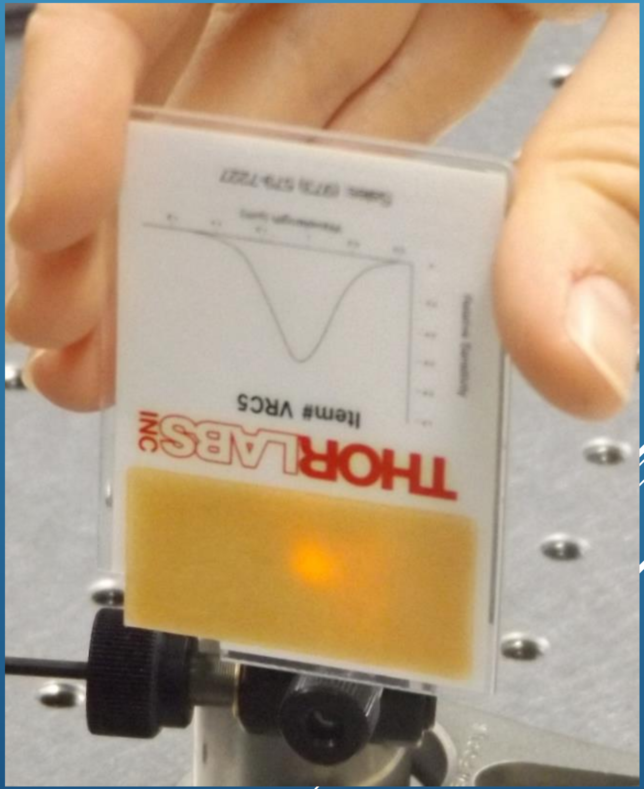
- *TEM_{00}* describes the intended output of most lasers, as such a beam can be focused into the most concentrated spot

Problem: the electric field of the laser beam cannot be described only by the one of *TEM_{00}* because of the presence of higher-trasversal modes.

T_{mn}



Wikipedia



Instability of the laser beam

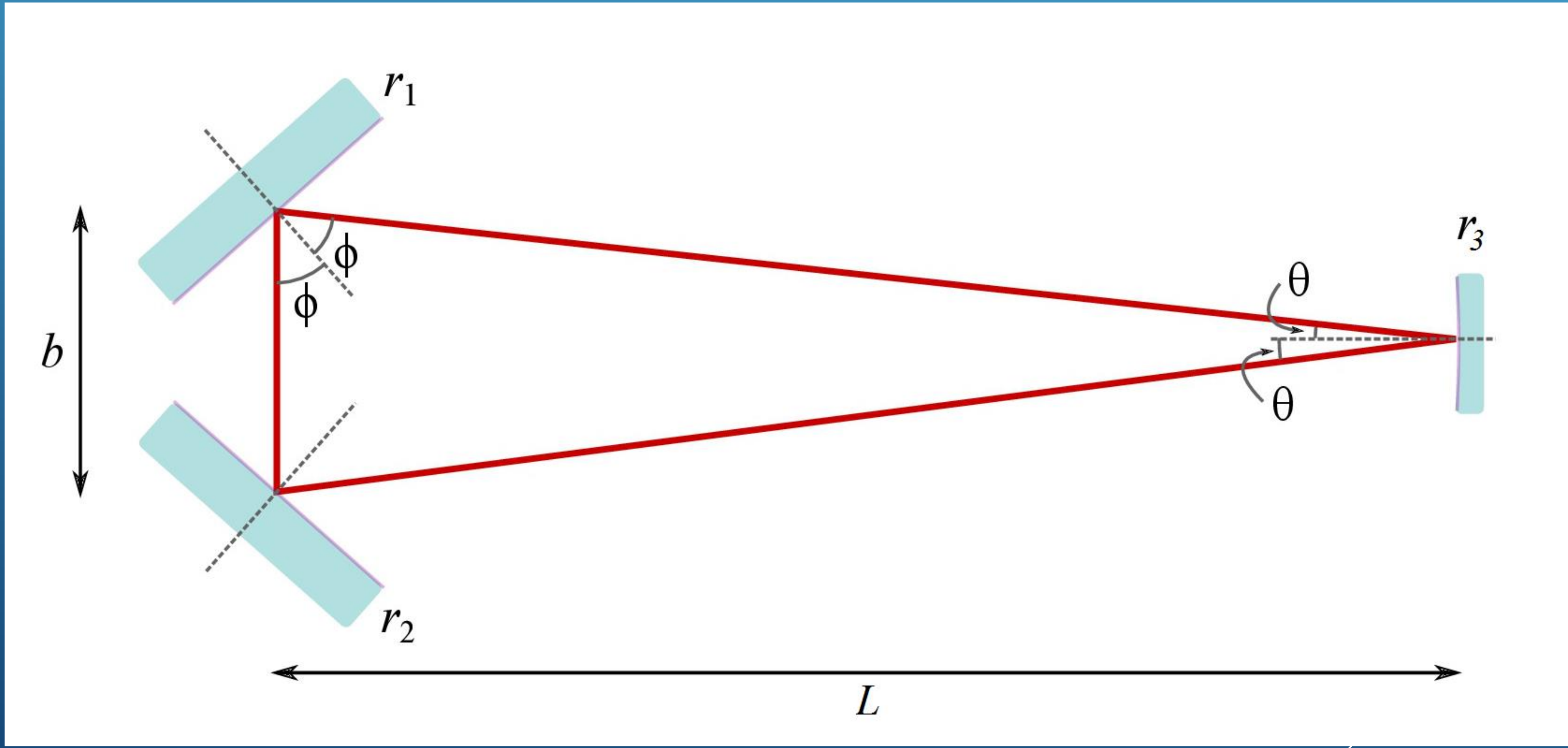
- **Spatial instability**, known as beam jitter, is due to the mixing of higher order modes with the fundamental mode *(TEM00)*.
- **Amplitude and phase fluctuations** are created by beam jitter whenever the beam interacts with a spatially sensitive element such as an optical cavity
- **Frequency instability**

↓

NOISE SOURCES

Solution: Pre-Mode Cleaner (PMC)

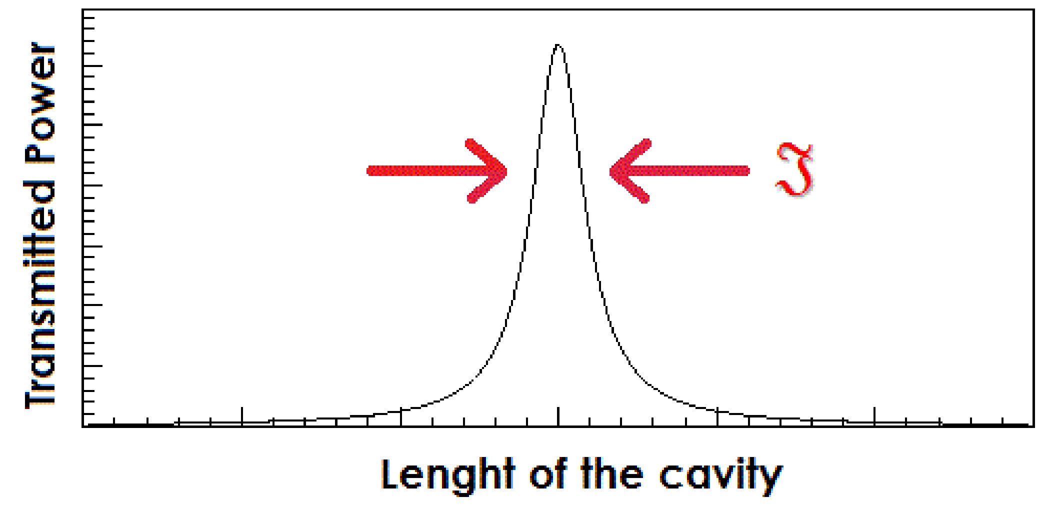
- It's a triangular ring cavity



- Only the fundamental mode is resonant – hence ‘Mode cleaner’ - and the higher order modes, having different cavity eigen frequencies, are attenuated or suppressed.

$$\text{Transmission} = T_{mn} = T_{00} \frac{1}{\left[1+\left(\frac{2}{\pi}\mathfrak{F} sin\left(\frac{2\pi L}{c}\Delta\nu_{mn}\right)\right)^2\right]^{1/2}}$$

where



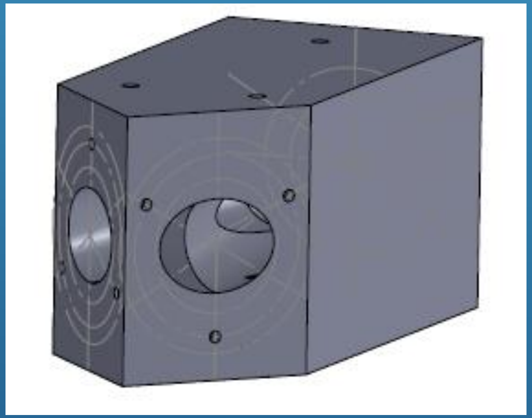
- $\mathfrak{F}$ is the finesse of the cavity

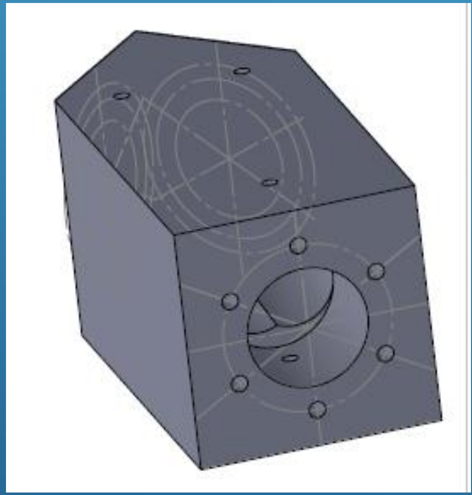
- $\Delta\nu_{mn} = \frac{c}{2L}(\mathrm{m}+\mathrm{n})\frac{1}{\pi}\arccos(\sqrt{1-\frac{L}{R}})$ is the difference in frequency between any higher order mode TEM_{mn} and the fundamental mode TEM_{00}

Building a Little PMC

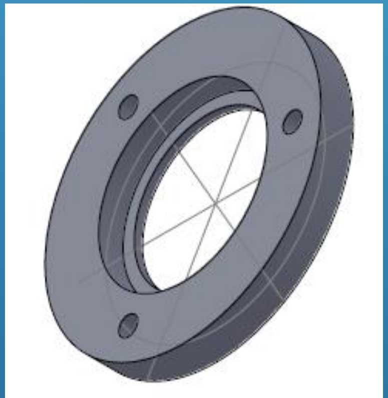
What do we need?

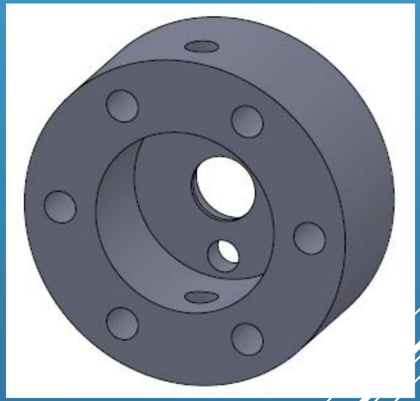
- A spacer



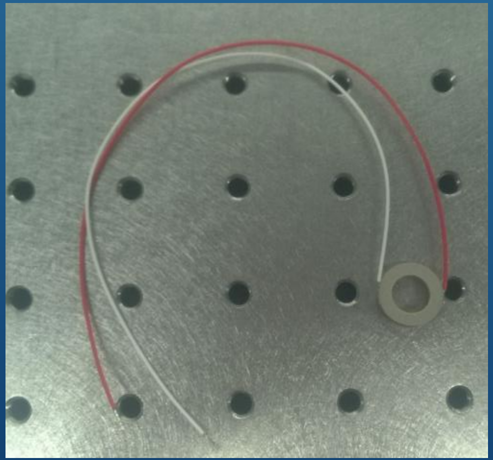


- Two clamps and an endcup

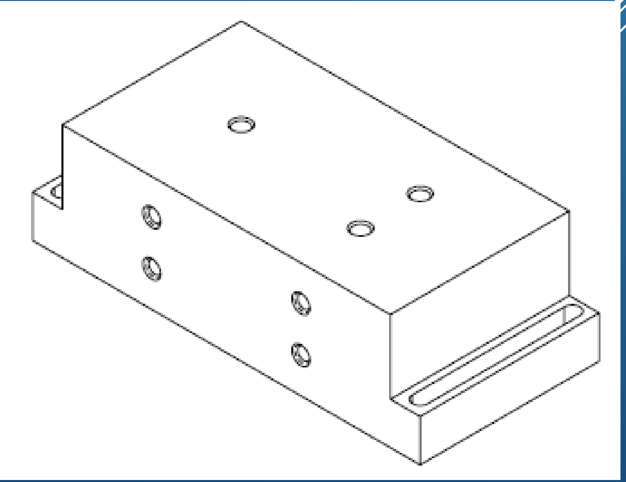




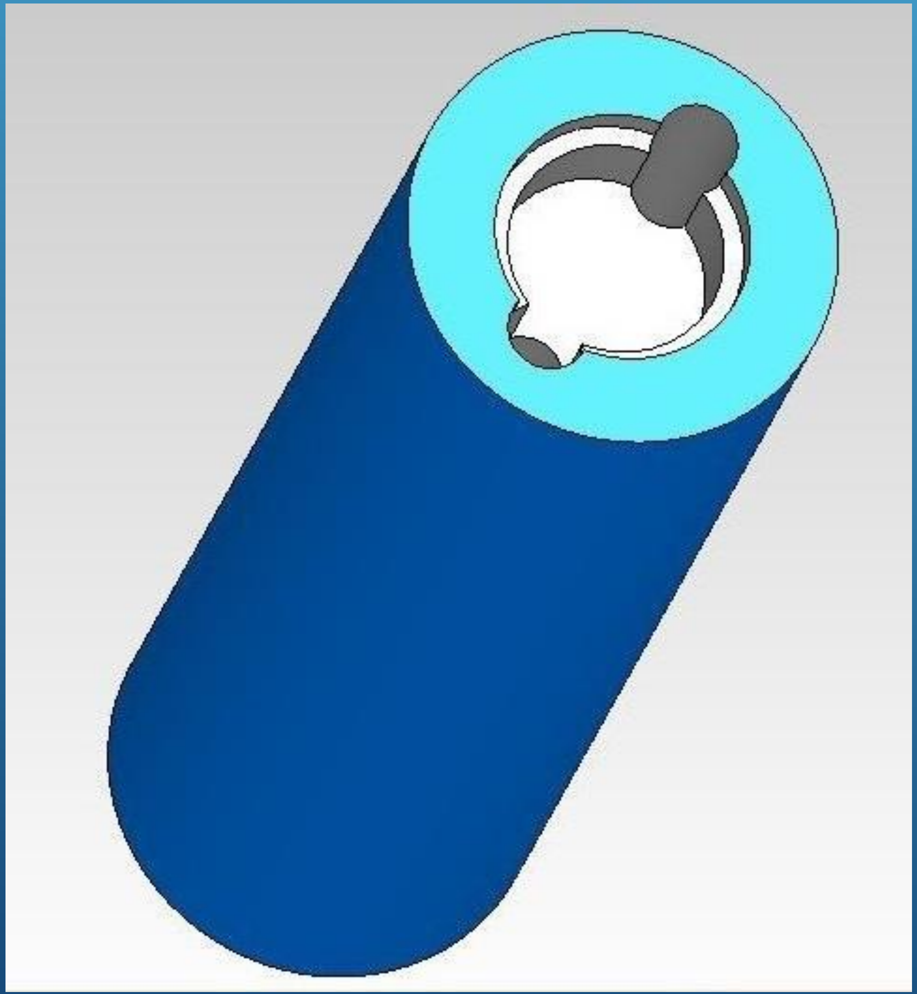
- Two flat mirrors and a curved mirror
- Piezoelectric transducer (PZT)



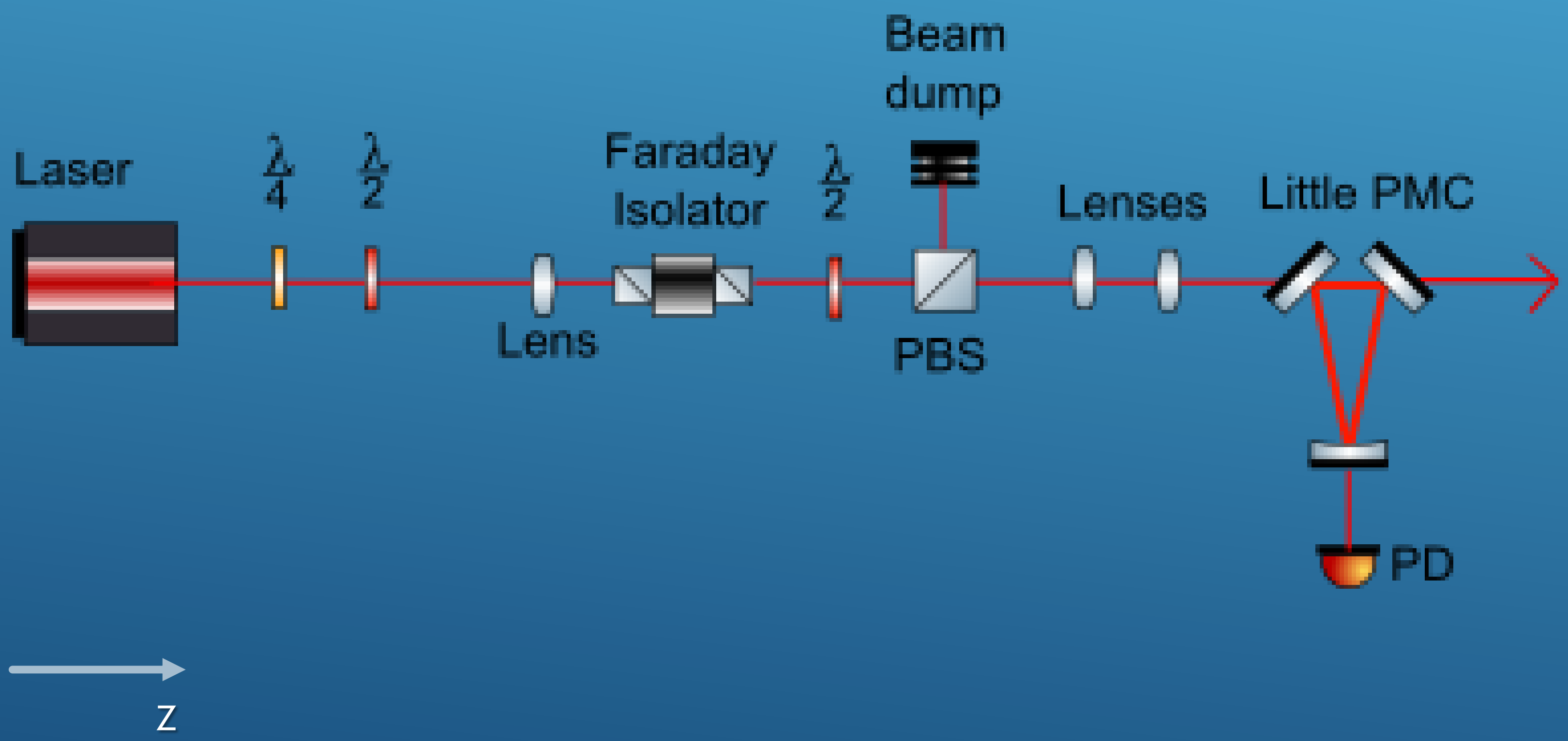
- A base



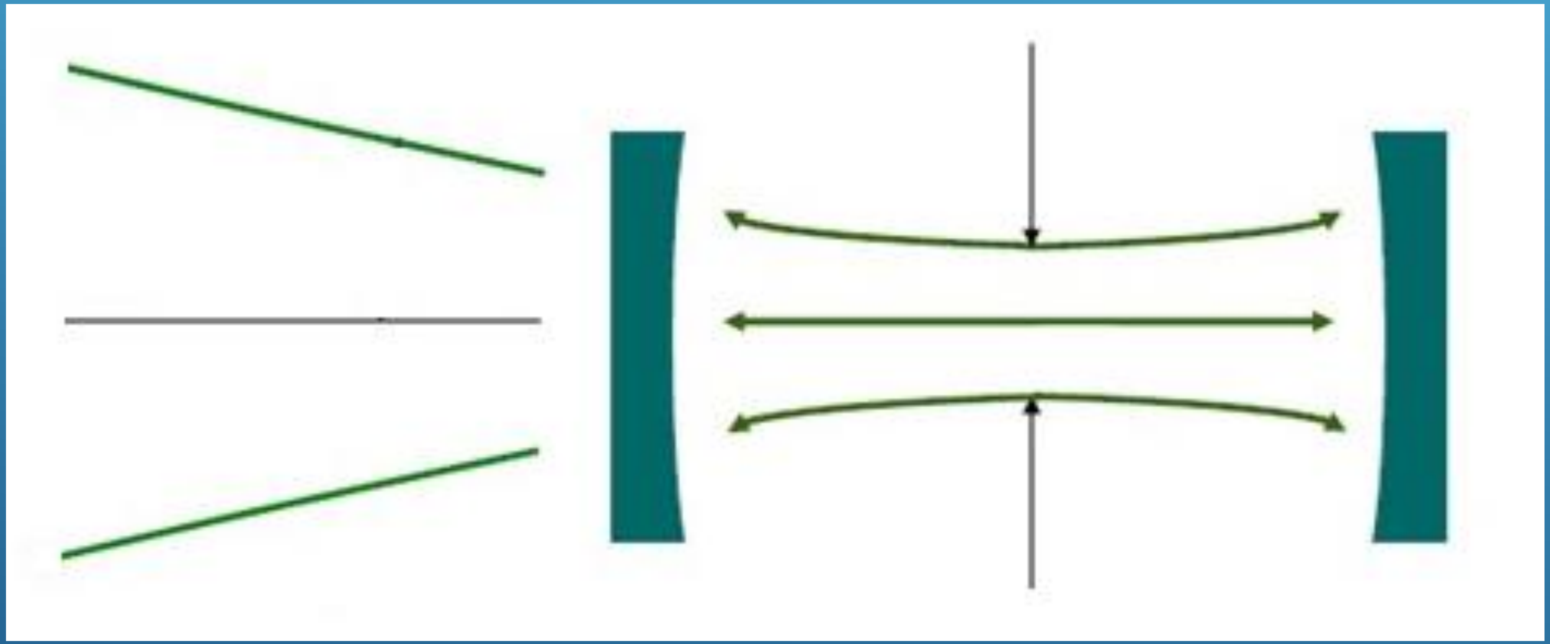
Jig



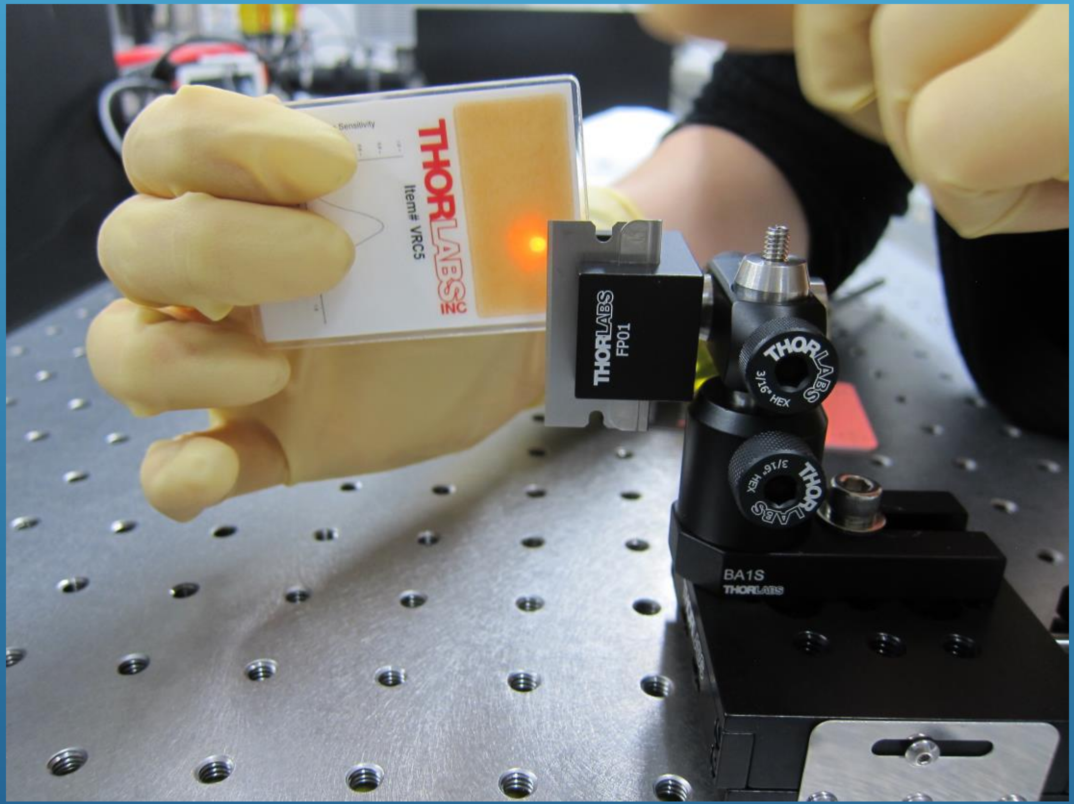
Set up for testing the Little PMC



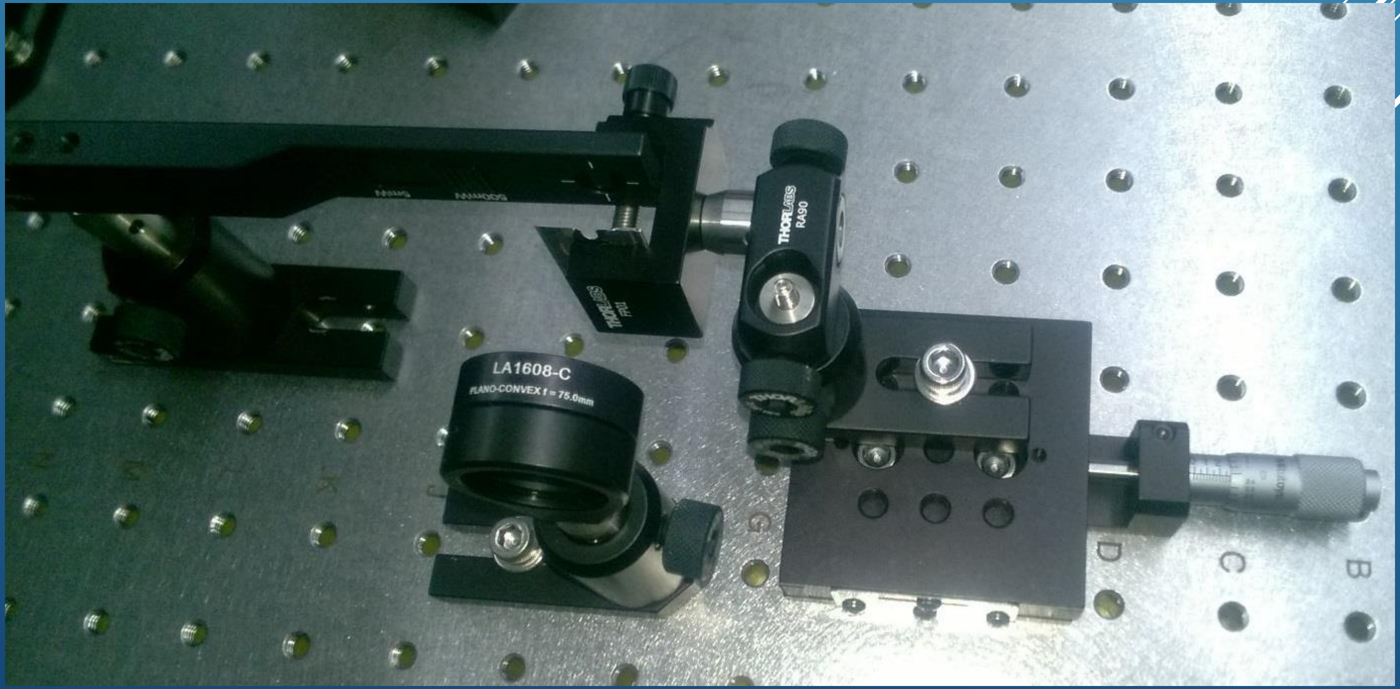
Mode matching



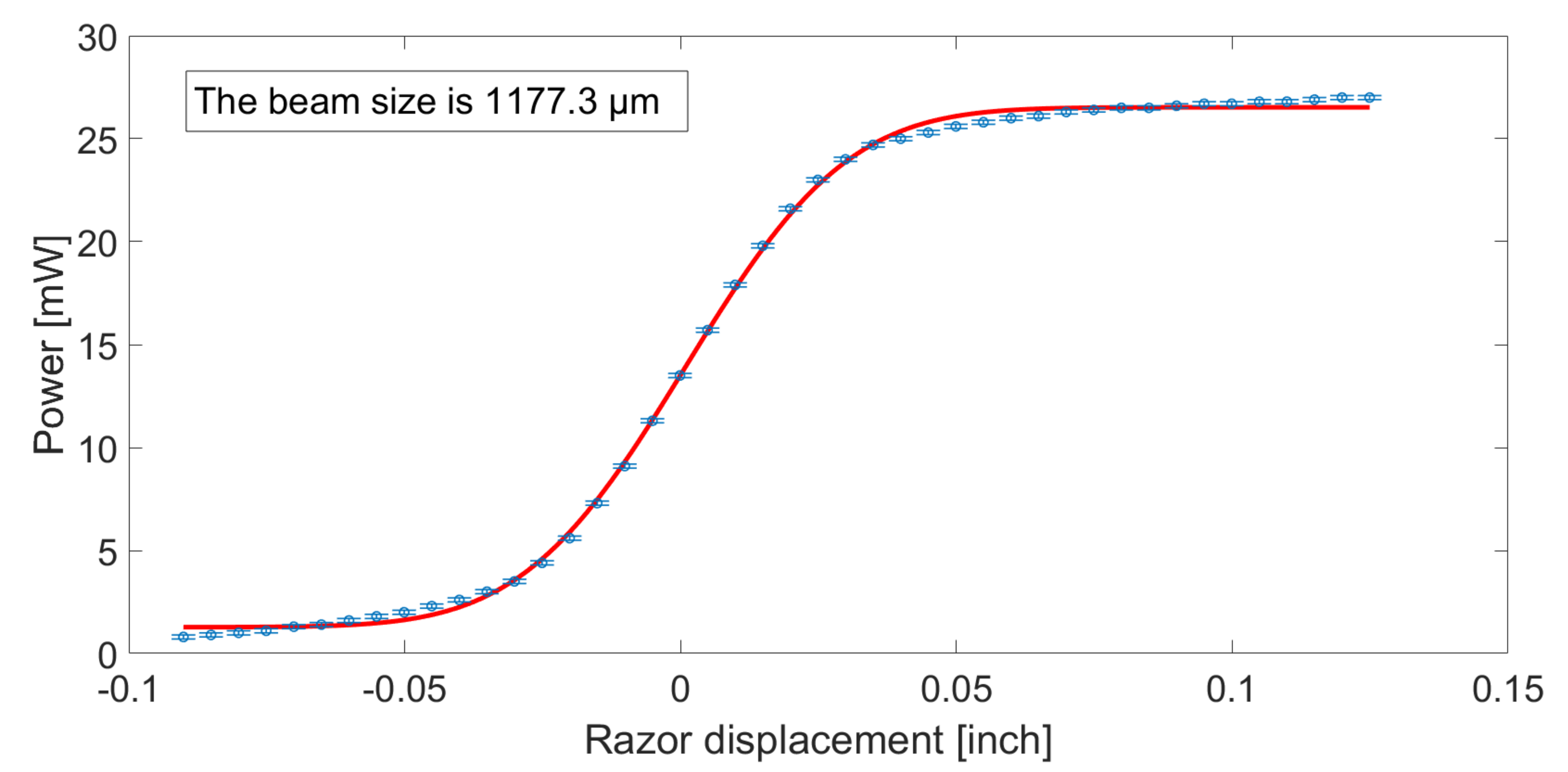
How much is the waist of the beam?

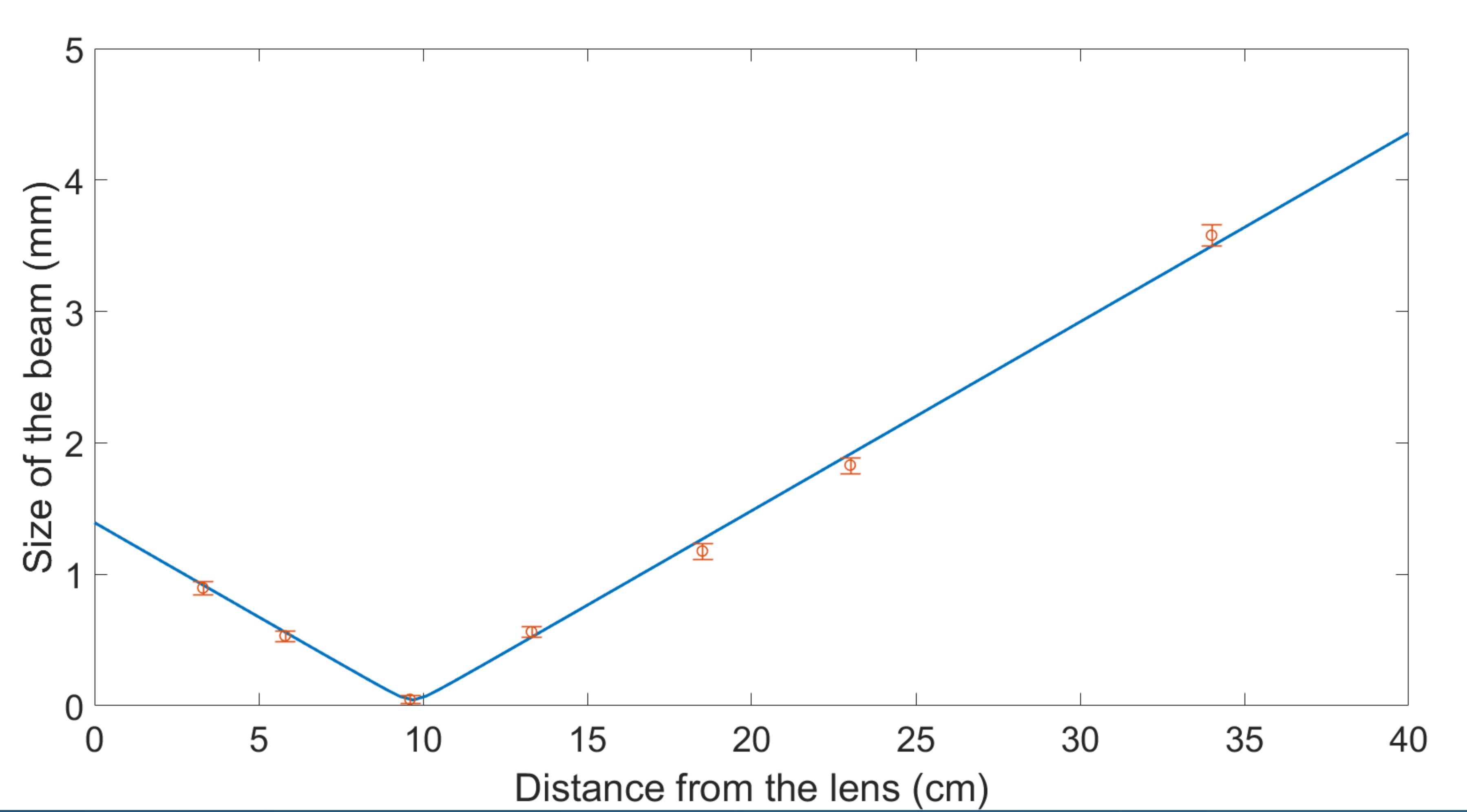


Measuring the beam size



$$P(x,y) = \int_{-\infty}^{+\infty} \int_{-\infty}^{x} \frac{2P_0}{\pi w(z)^2} \exp\left(\frac{-(2x'^2 + 2y^2)}{w(z)^2}\right) dx'dy$$





z (cm)	w(z) (mm)
3.3±0.5	0.90±0.05
5.8±0.5	0.53±0.04
9.6±0.5	0.049±0.003
13.3±0.5	0.56±0.04
18.5±0.5	1.18±0.06
23±0.5	1.83±0.06
34±0.5	3.58±0.08

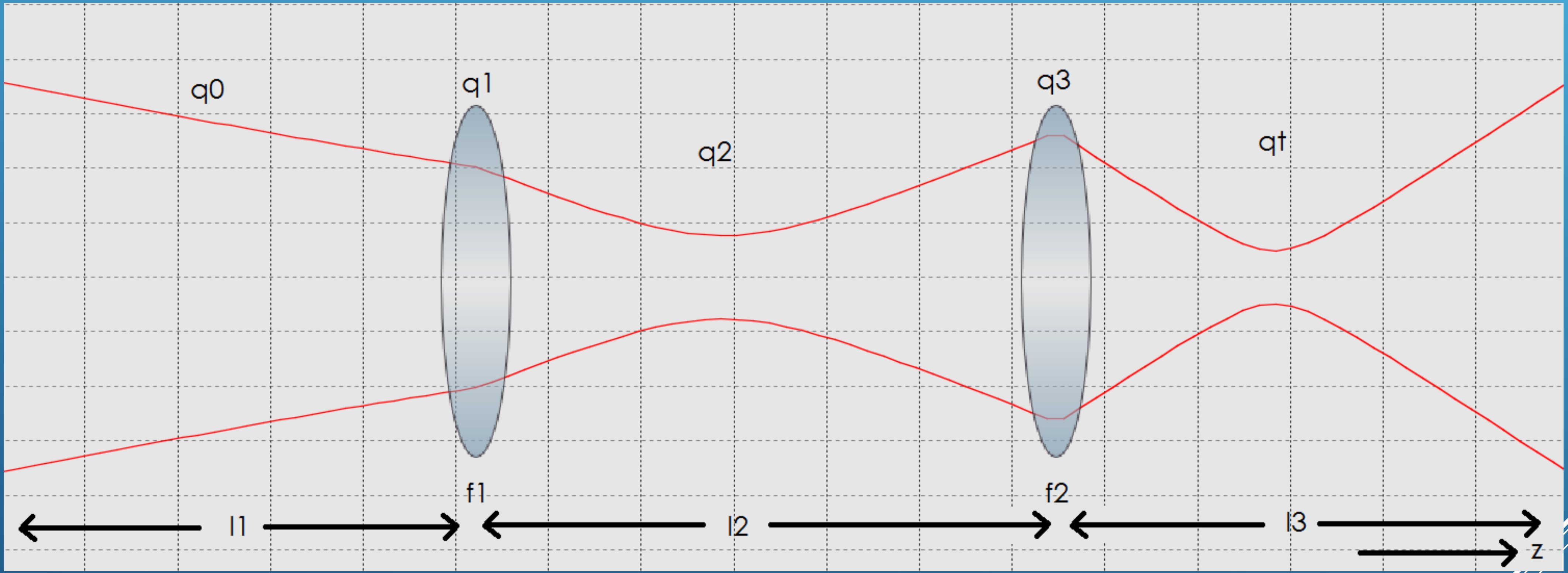
$$w(z) = w_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2}$$

$$w_0 = 0.043 \pm 0.003 \text{ mm}$$

$$w_0^{th} = 0.044 \pm 0.001 \text{mm}$$

$z_0 = 9.4 \pm 0.5$ mm from the lens

Choise of lenses



$$\begin{pmatrix} 1 & z_t \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -{}^{1}/_{f_2} & 1 \end{pmatrix} \begin{pmatrix} 1 & l_2 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -{}^{1}/_{f_1} & 1 \end{pmatrix} \begin{pmatrix} 1 & l_1 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 \\ {}^{1}/_{q_0} \end{pmatrix} = \begin{pmatrix} 1 \\ {}^{1}/_{q_t} \end{pmatrix}$$

where $\frac{1}{q} = \frac{1}{R} - j\frac{\lambda}{\pi w(z)^2}$ and $q = (z - z_0) + q_0$

Future work

- Gluing the PZT to the mirror and the mirror on the endcup
- Driver for the PZT
- Lock the PMC
- Characterize the PMC (i.e. measure the mode matching and the transmission)
- Use the cavity in optic experiments (e.g. squeezed light)

TILT-FREE SEISMOMETER

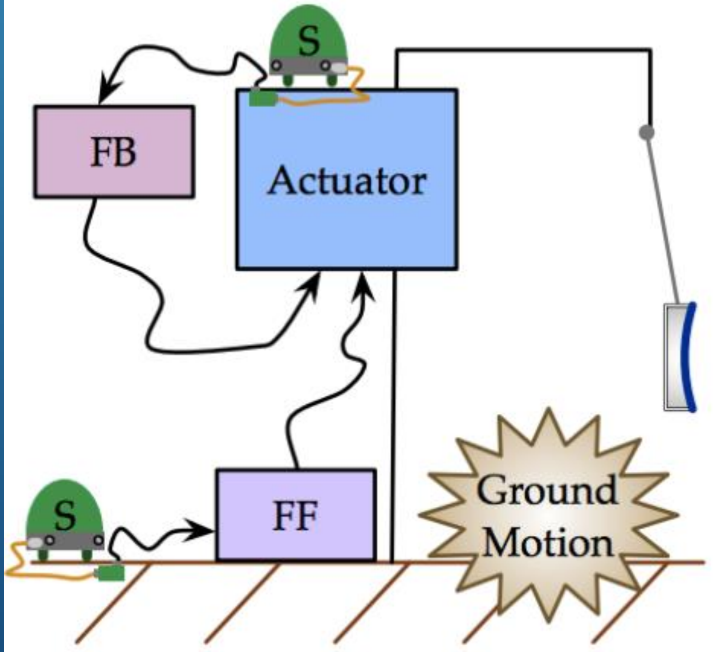
Seismic noise in LIGO: solutions

Seismic noise due to vibration of the laboratory is a low frequency limit for the interferometer in LIGO

Passive isolation

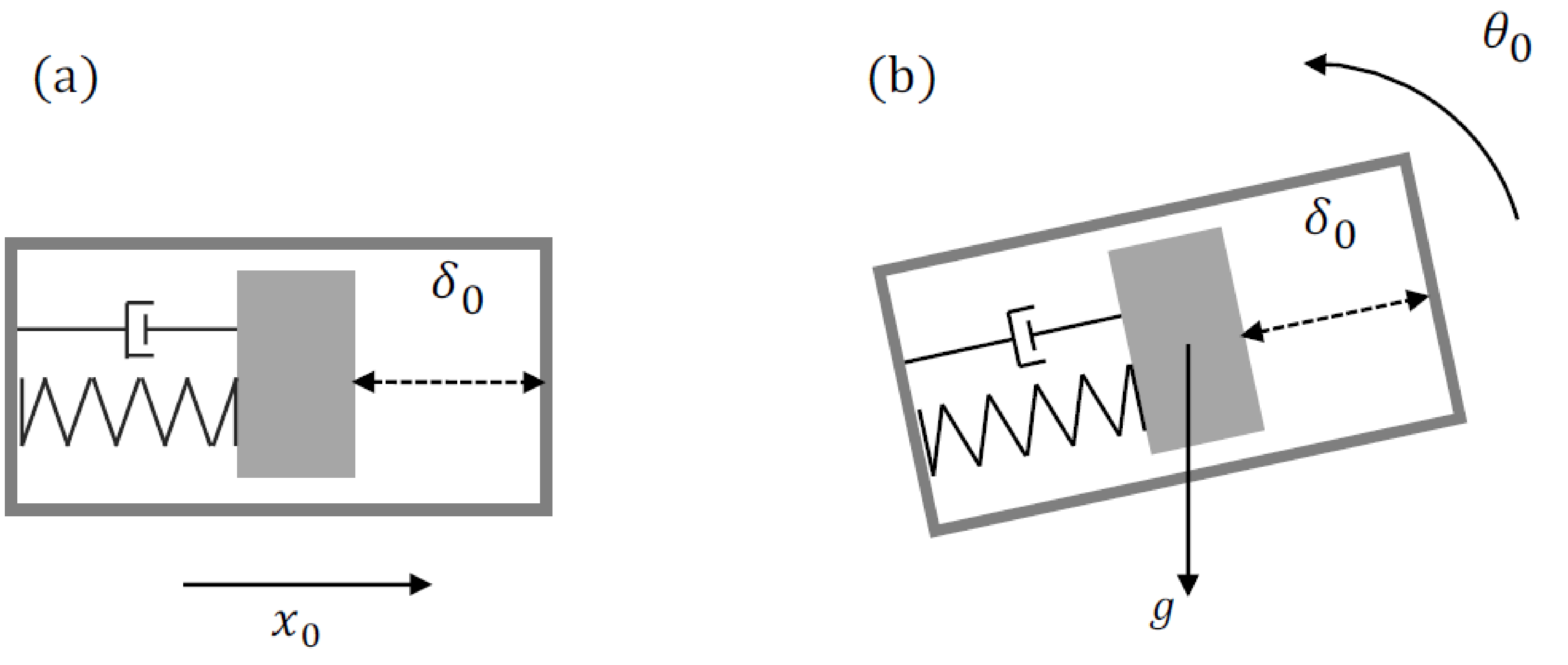
Multiple stages platforms separated by spring assembly for the optics and suspension of the optics themselves

Active isolation



J. Driggers, G1500001

Active isolation problem: tilt-to-translation coupling



F. Matichard et al, P1400061

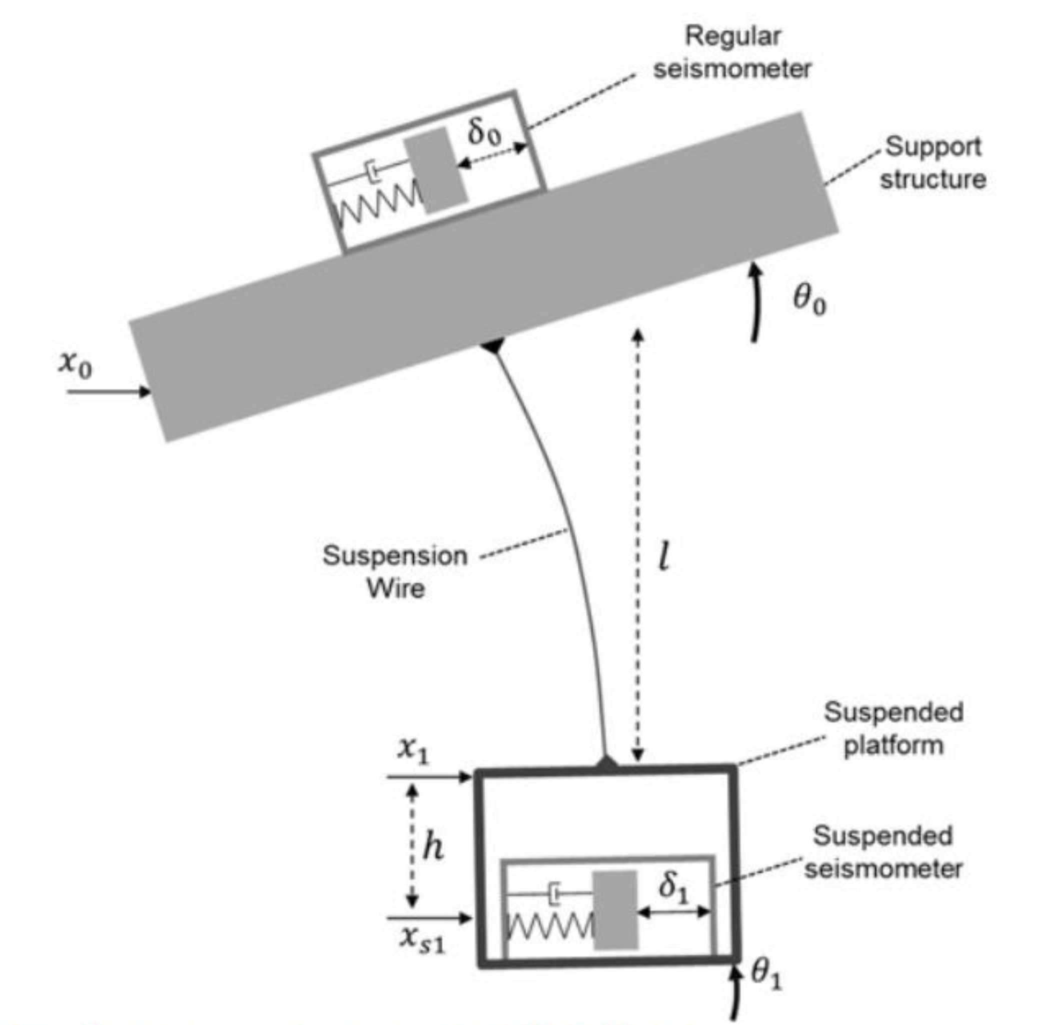
- At low frequency (< 40 mHz) the seismometer signals are too contaminated by ground tilt to be used for active control

Two different approches

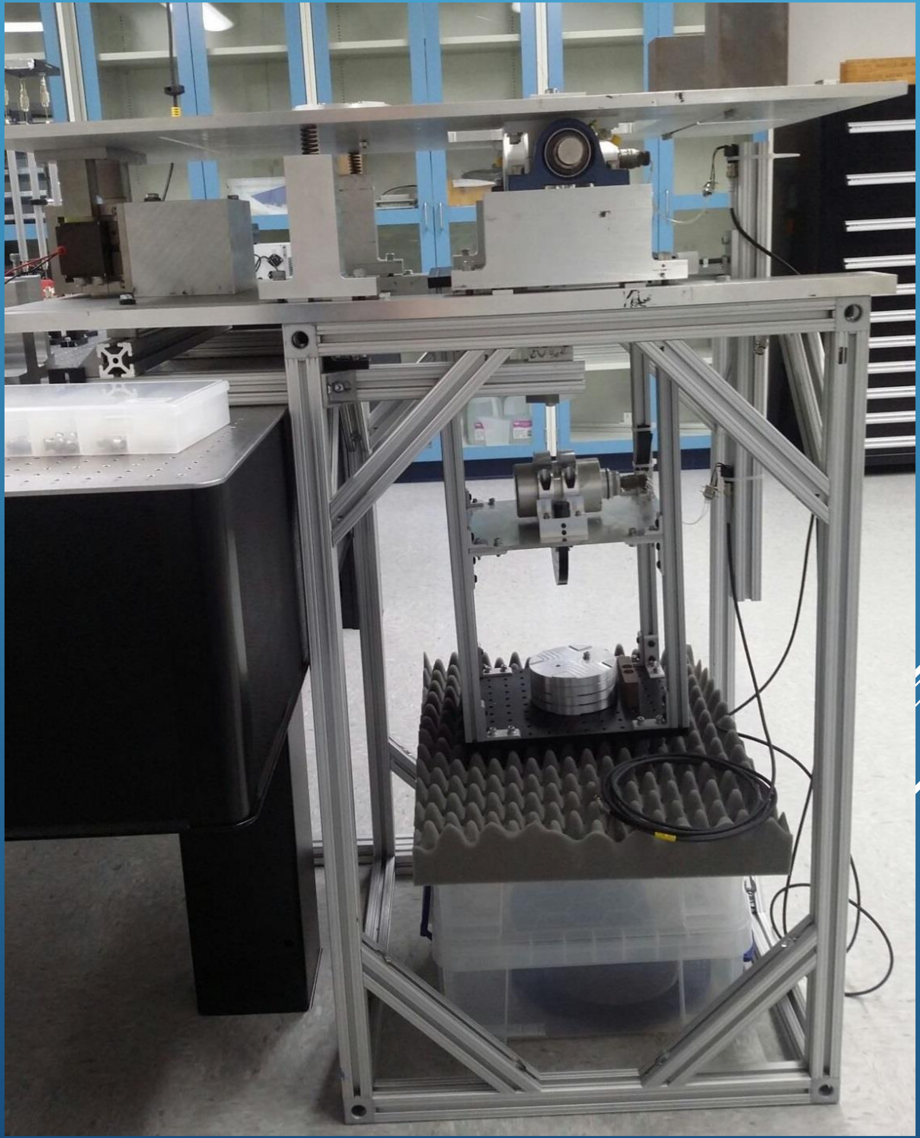
- Measuring tilt
  - Independently measure ground tilt and subtract it

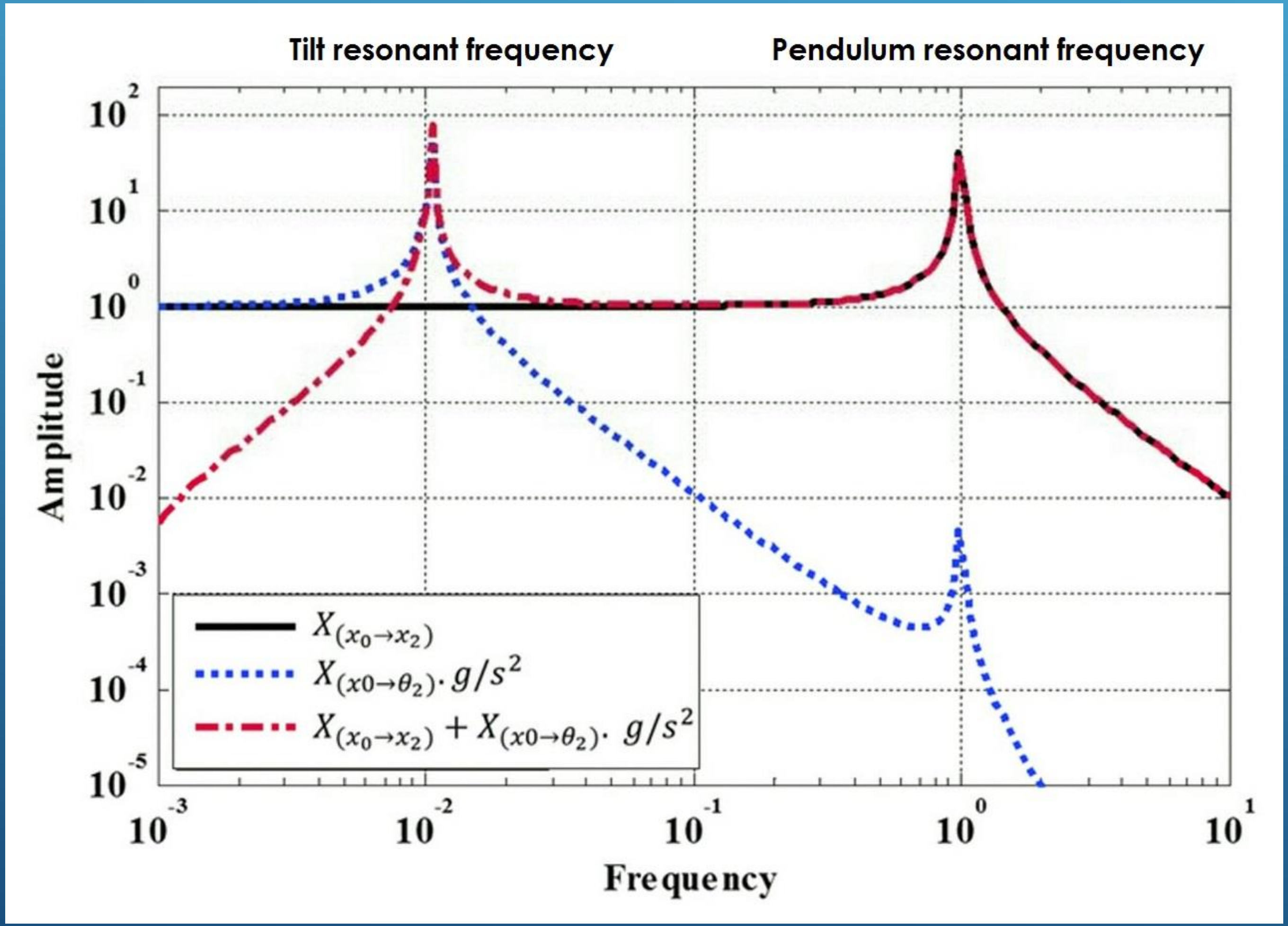
- Filtering tilt
  - Mechanically filter tilt
    - Suspended structure

Tilt-free seismometer



F. Matichard et al, P1400061

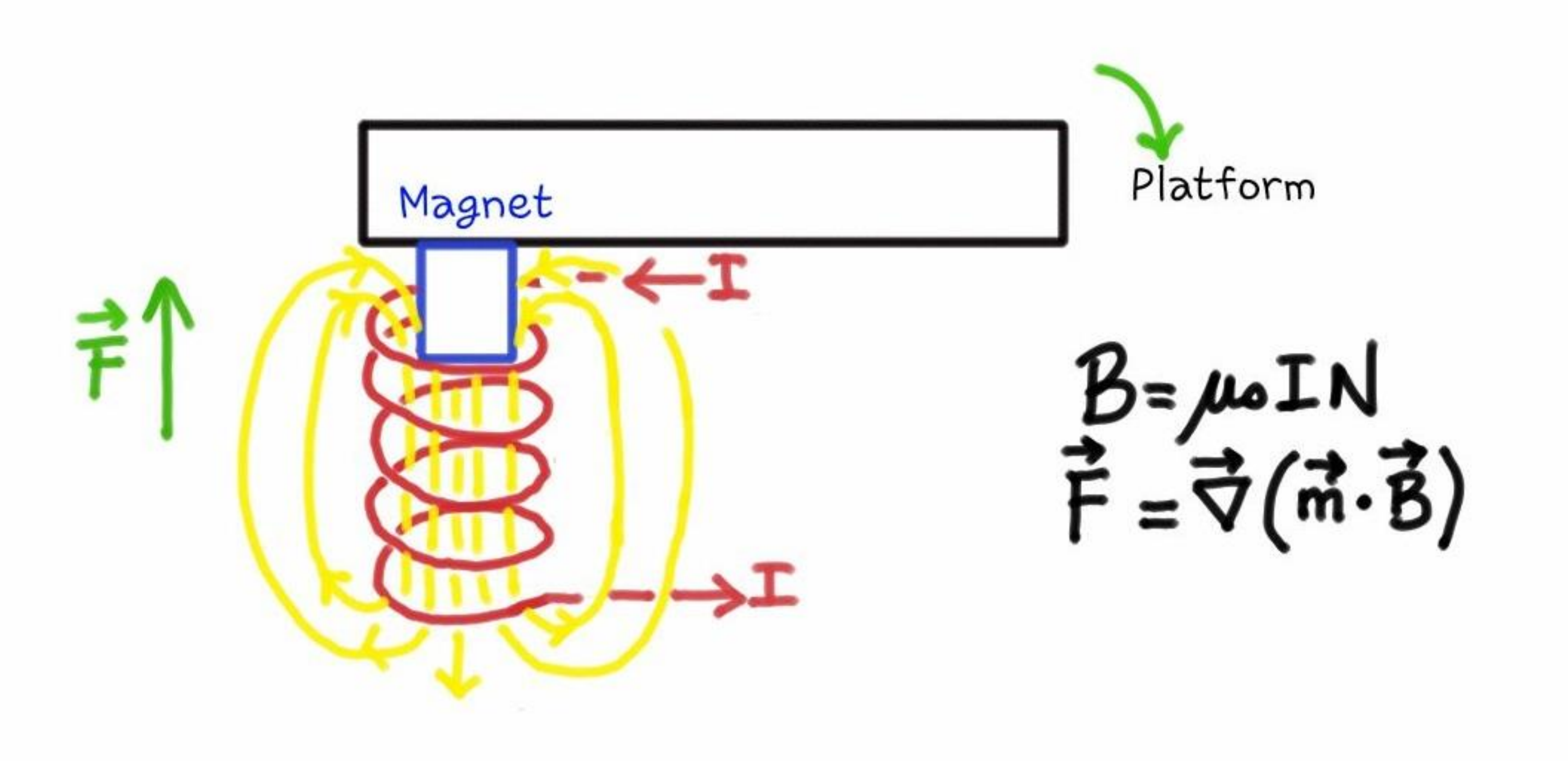




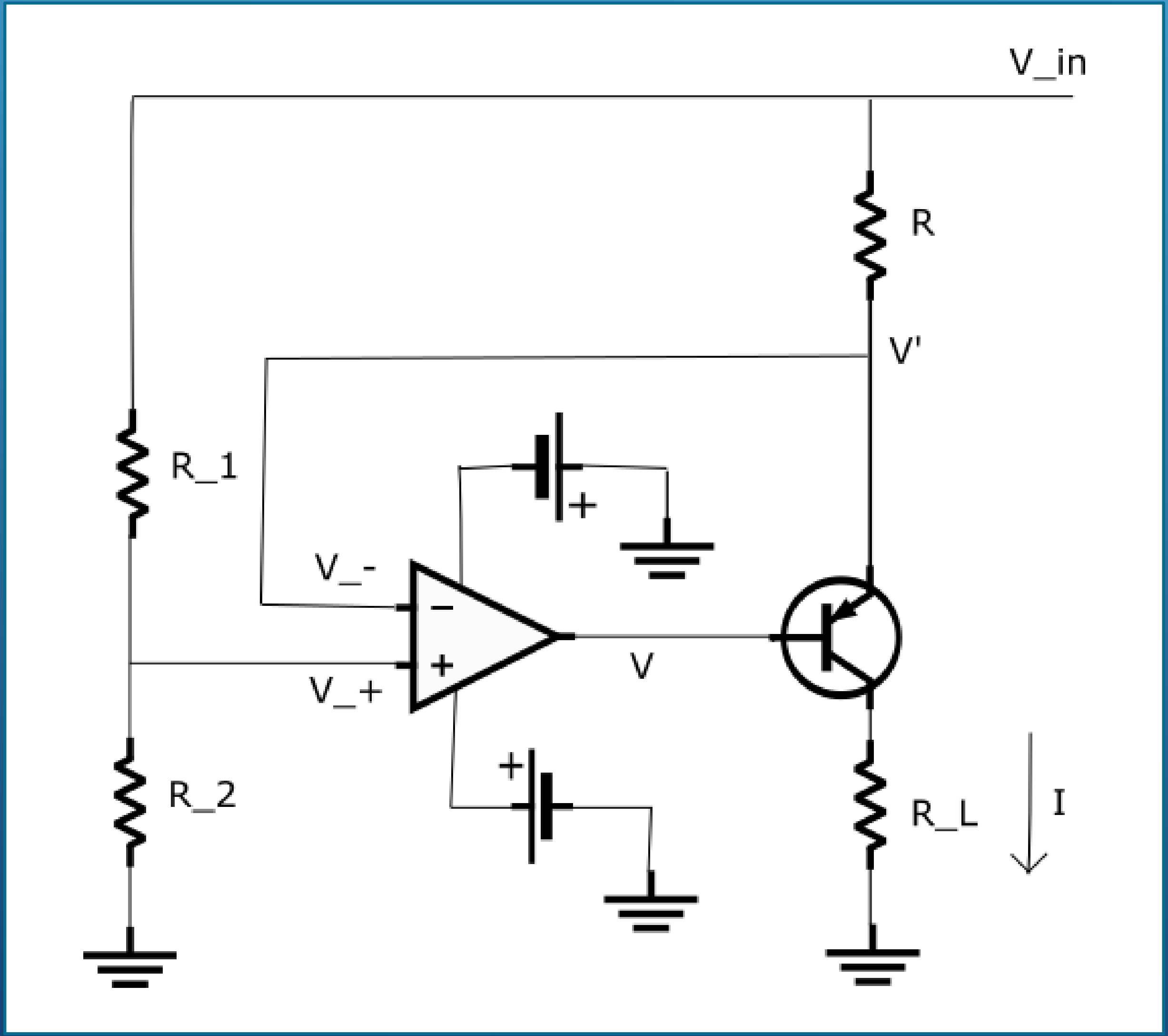
F. Matichard, DCC P1400060

- Below the pendulum resonant frequency: the suspended platform motion follows ground translation
- Above the tilt resonant frequency: 'tilt-free'

Between the tilt and pendulum frequencies: good translation sensitivity of the suspended seismometer


Platform
Magnet
I
$\vec{F}$
I
$B = \mu_0 I N$
$\vec{F} = \vec{\nabla}(\vec{m} \cdot \vec{B})$

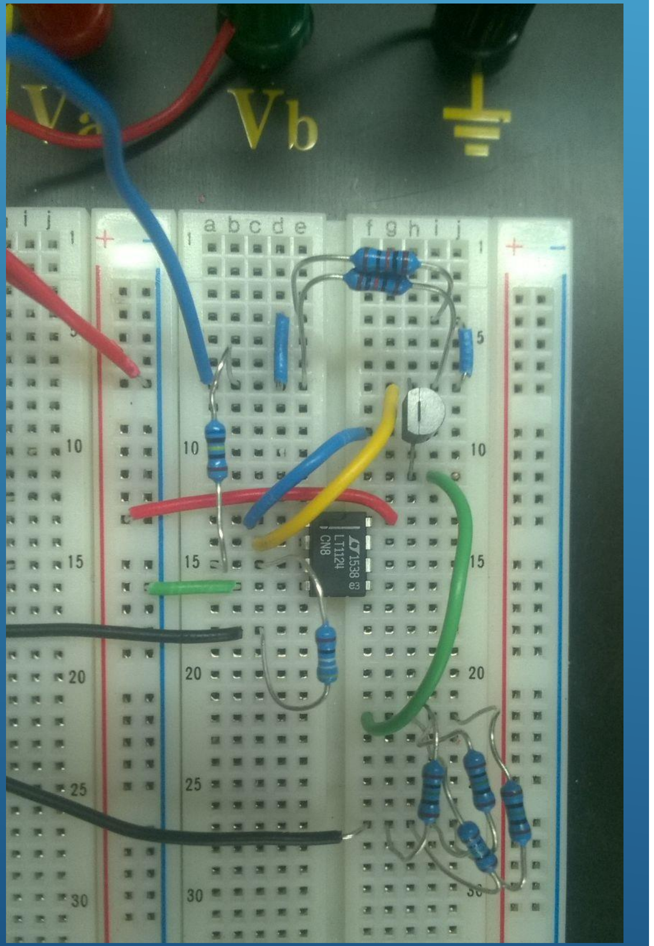
Tilt injection: current driver for the coil

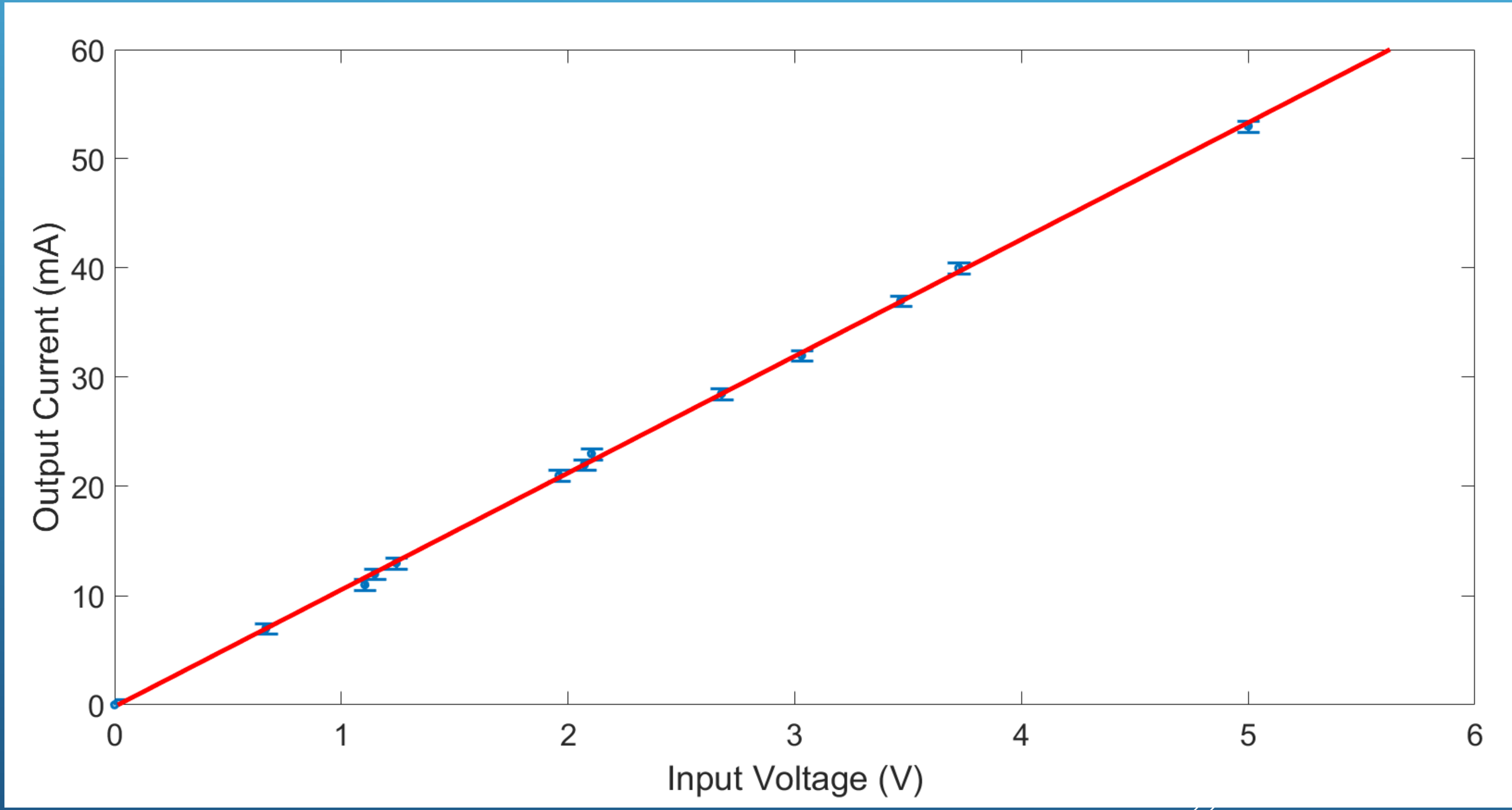


$$V_+ = V_- = V' = V_{in}\frac{R_2}{(R_1+R_2)}$$

$$V_{in} - V' = RI$$

$$I = \frac{V_{in}\left(1 - \frac{R_2}{(R_1+R_2)}\right)}{R}$$


Va
Vb


Output Current (mA)
Input Voltage (V)
0
10
20
30
40
50
60
0
1
2
3
4
5
6

Future work

- Test the circuit with the coil
- Solder components to breadboard
- Measurement of the tilt to displacement transfer function

Acknowledgments

- Dr. Kate Dooley
- Dr. Marco Cavaglià
- Dr. Antonio Perreca
- Dr. Lucien Cremaldi
- Dr. Giancarlo Cella
- Mohammad Afrough
- Camillo Cocchieri
- INFN, NSF and LIGO

Thank you for your attention!