# Alignment control of Dual-pass Fabry-Perot cavity for DECIGO

Masaya Ono

# Abstract

- Summarize what I did last year about DECIGO experiment
- Current situation of my experiment
- I will mention plans toward my master thesis

# Contents

- How to control DECIGO interferometer
  - WaveFront Senser
  - Beam Pointing Control
- Current situation of experiment
  - Setups
  - What I will do
- Plans for my master thesis
  - Instruments
    - Chamber
    - RFQPD
    - Suspension
    - Digital system
- Summary

# How to control DECIGO interferometer

# What is DECIGO, B-DECIGO ?

### Ground-Based or Space ?

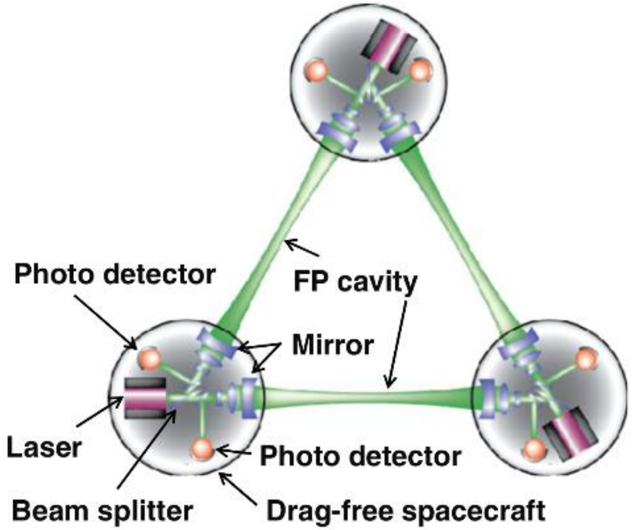
Space gravitational wave detector

### Target

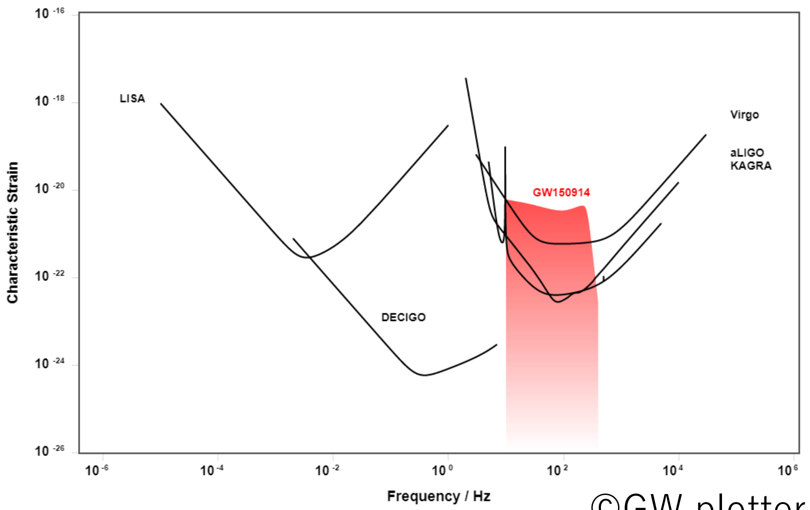
- Frequency band 0.1 Hz – 10 Hz
- The middle between Ground-Based detectors(LIGO, Virgo, KAGRA) and another space gravitational wave detector,LISA

### Expected Science

Directly detecting gravitational wave background
→ Verification of Inflation theory




(S. Kawamura et al, CQG, 2011)




©GW plotter

# Dual-Pass Fabry-Perot cavity

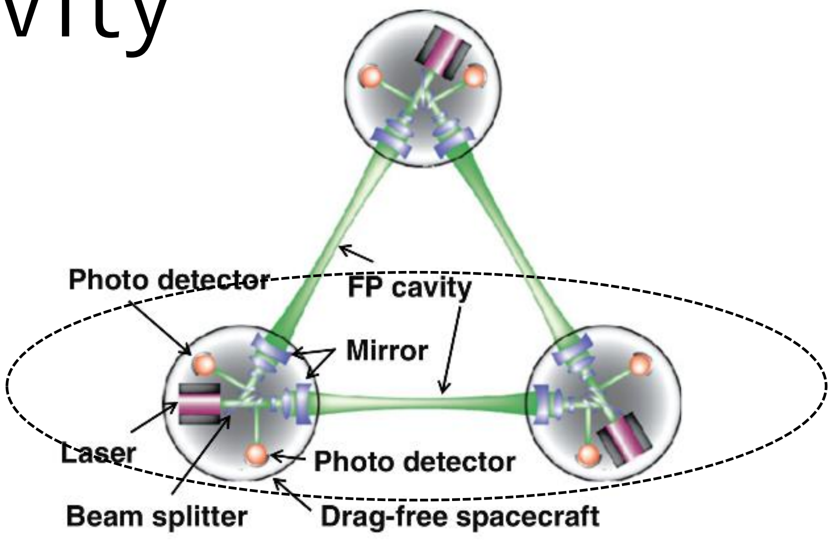
In DECIGO, two lasers are incident on
a Fabry-Perot cavity from its both sides

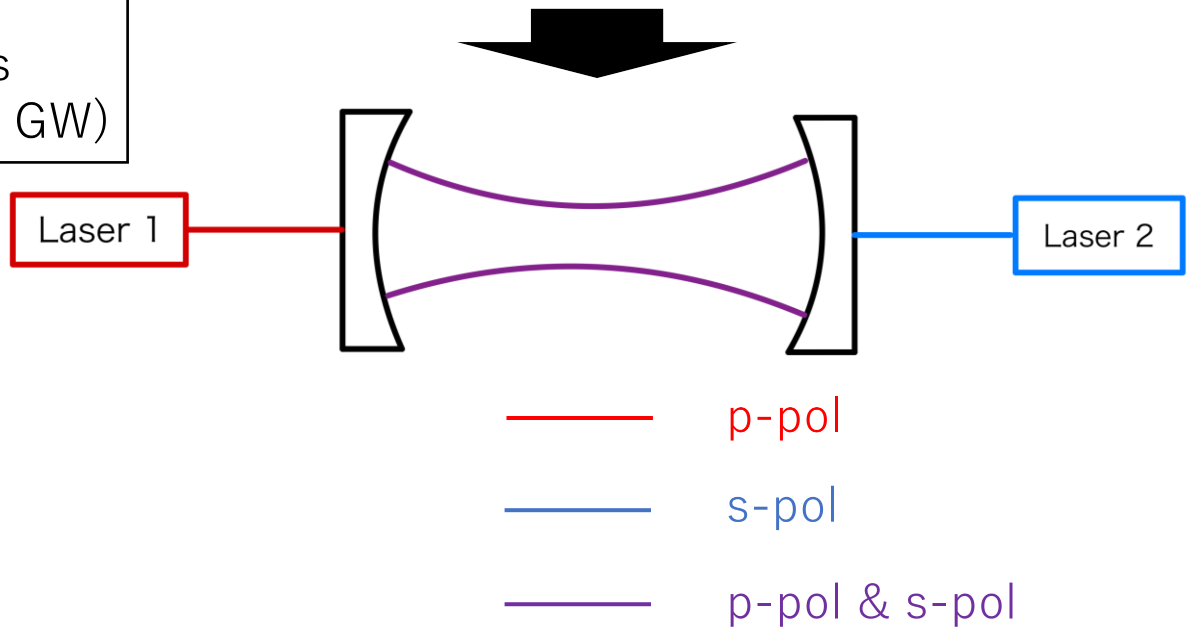
**Merits**

- Good sensitivity
- FP cavity shares two lasers

➡ It provides a margin (even if one laser is damaged, we can use another to detect GW)

**Polarization** of light is used
to distinguish which the laser it is

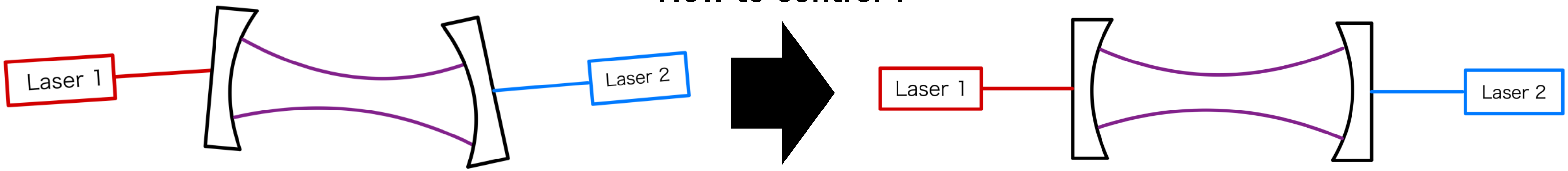


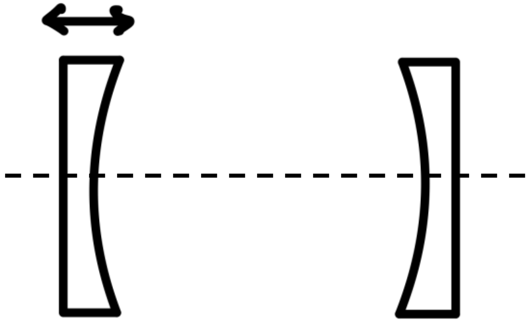
# Control of Dual-Pass Fabry-Perot cavity

the establishment and the demonstration of how to control the dual-pass Fabry-Perot cavity is needed

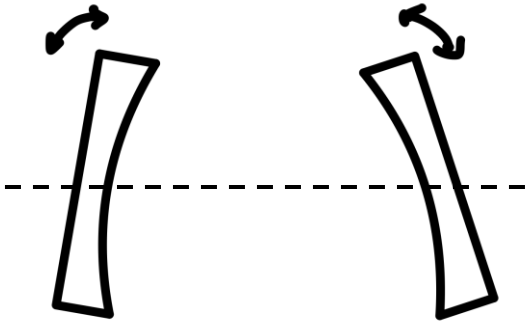
**How to control ?**




**Length control** and **alignment control** are needed

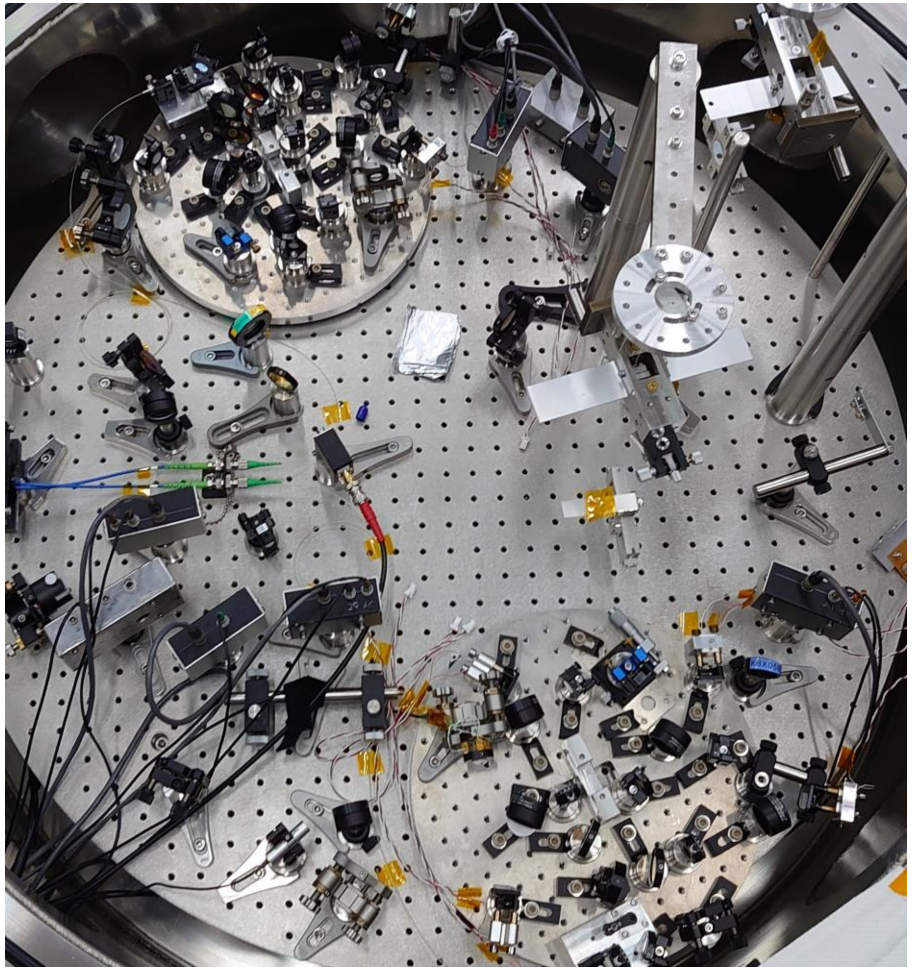


**Length control**



**Alignment control**

# Current situation of controls



- **Length control**

  Nagano-san did an experiment to lock the dual-pass Fabry-Perot cavity in the direction of length and demonstrated we can keep the resonance using PDH technique.

  Koji Nagano et al. , CQG, 2021

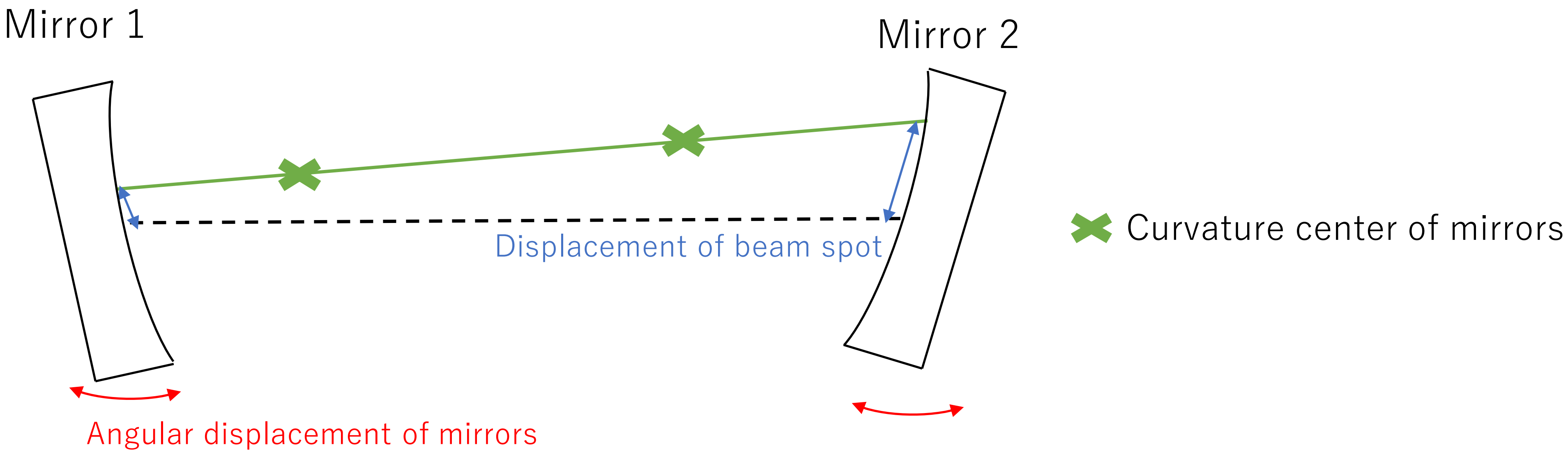
- **Alignment control**

  Proposed how to control (WaveFront Sensor and Beam Pointing Control) but it is not demonstrated yet.

# Request values of Alignment control

**Request values for Alignment control**

| | B-DECIGO | DECIGO |
|---|---|---|
| Residual angular displacement of mirrors | $1.0 \times 10^{-14}\mathrm{rad}/\sqrt{\mathrm{Hz}}@0.1\mathrm{Hz}$ | $1.0 \times 10^{-14}\mathrm{rad}/\sqrt{\mathrm{Hz}}@0.1\mathrm{Hz}$ |
| Residual angular displacement of mirrors (RMS) | $3.5 \times 10^{-10}\mathrm{rad}$ | $3.5 \times 10^{-11}\mathrm{rad}$ |
| Displacement of beam spot in a cavity | $0.1\mathrm{mm}$ | $0.1\mathrm{mm}$ |



# Requirement of Alignment control

It is necessary to align 4 axes

- Axis of laser 1
- Axis of laser 2
- Axis of a cavity (a straight line connecting two curvature centers of mirrors)
- Standard line (a straight line connecting two center of mirrors)

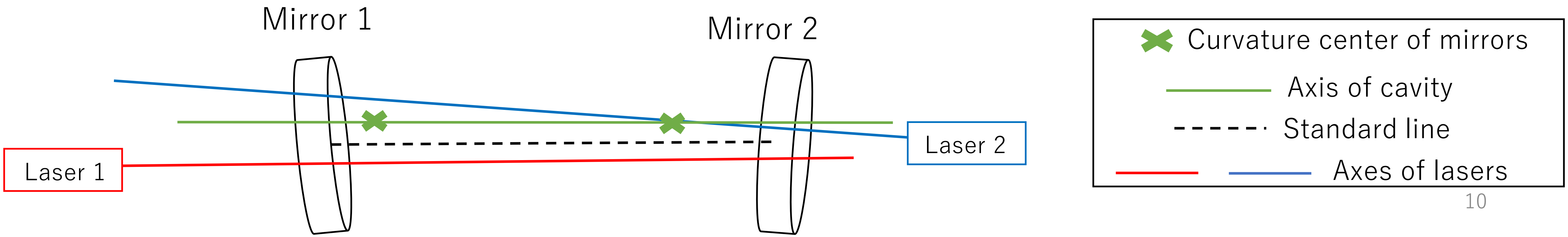
6 degrees of freedom should be controled

For the standard line,

Shifted error, Tilted error of axis of laser 1

Shifted error, Tilted error of axis of laser 2

Shifted error, Tilted error of axis of a cavity

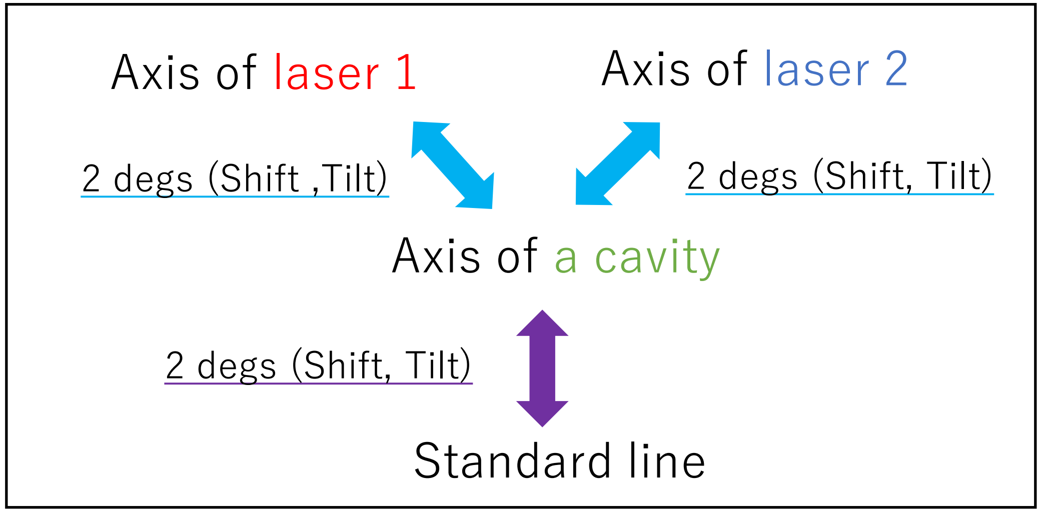


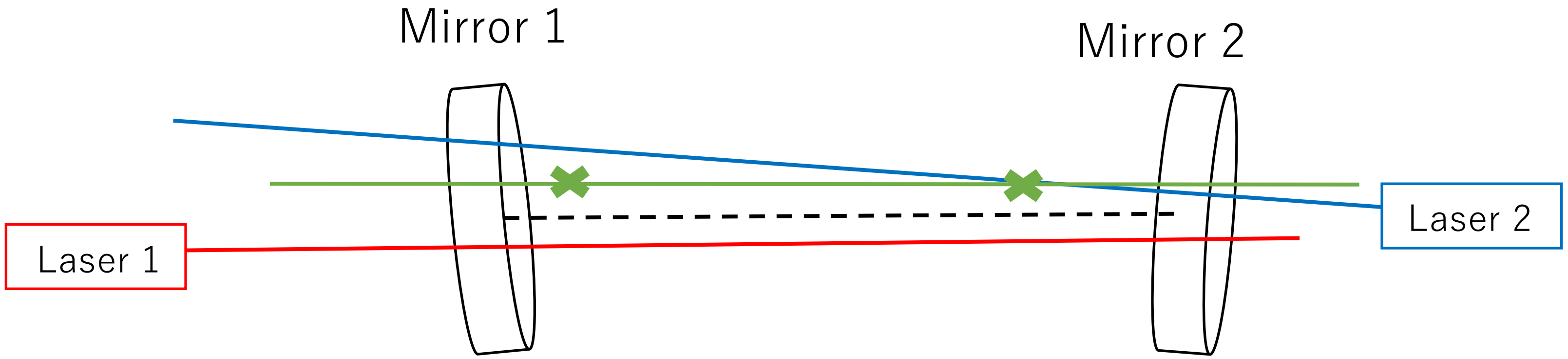
# Methods to detect angular fluctuations

Actually, we use

① WaveFront Sensor

② Beam Pointing Control



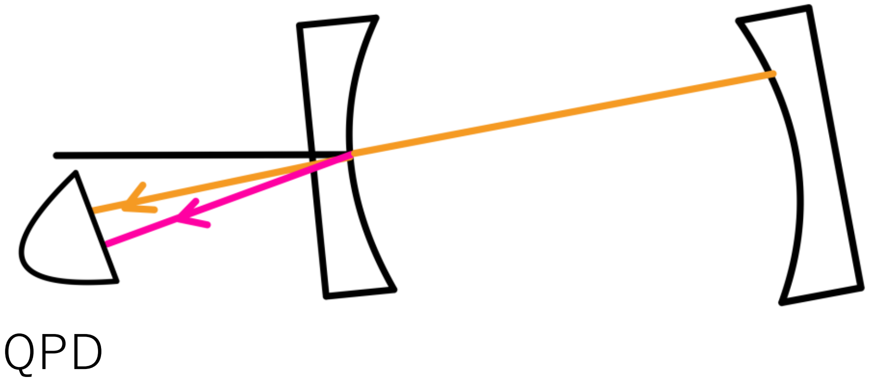
# WaveFront Sensor

- WFS detects the gap between "axis of lasers" and "axis of a cavity"

- Comparing with "Carrier" and "Sidebands"

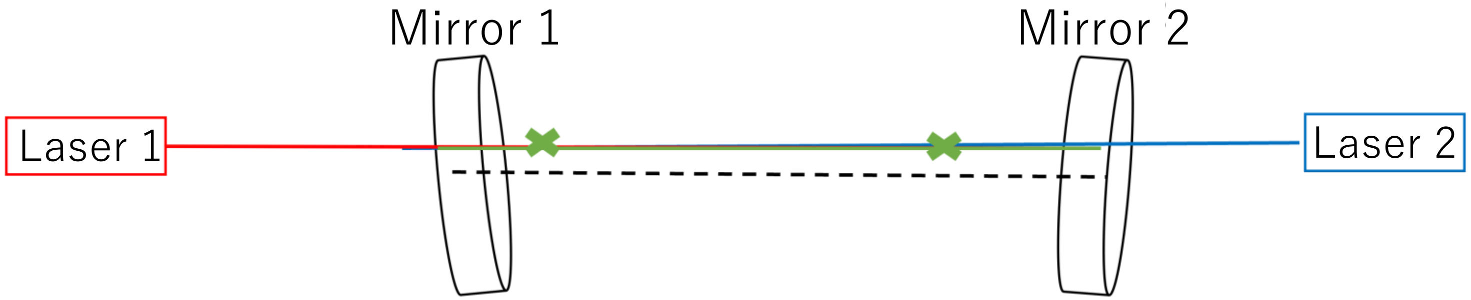
  Carrier : trips around the inside of the cavity

  Sidebands : do not get in the cavity and only reflected on FM




- We can align the axes of "laser 1", "laser 2", and "the cavity"

$$\boldsymbol{P_{WFS} \propto \frac{\delta x}{w_0} \sin \eta(z) - \frac{\delta \theta}{\alpha_0} \cos \eta(z)}$$




| | |
|---|---|
| $\delta x$ | : shifted error |
| $\delta \theta$ | : tilted error |
| $w_0$ | : radius of the beam waist |
| $\alpha_0$ | : spread angle |
| $\eta(z)$ | : Gouy phase at the position $z$ |

# Beam Pointing Control

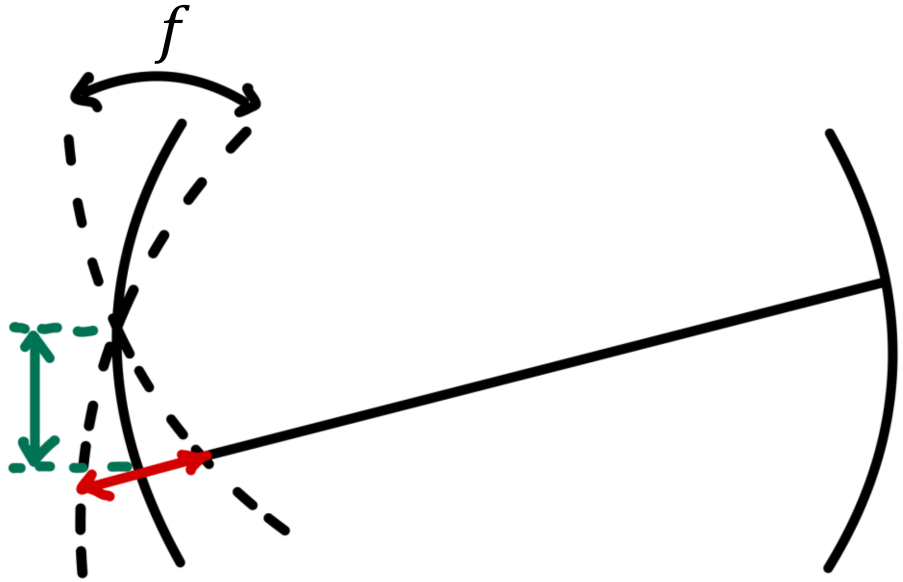
- BPC detects the gap between “Standard line” and “axis of a cavity”

- If dithering the mirror of the cavity,

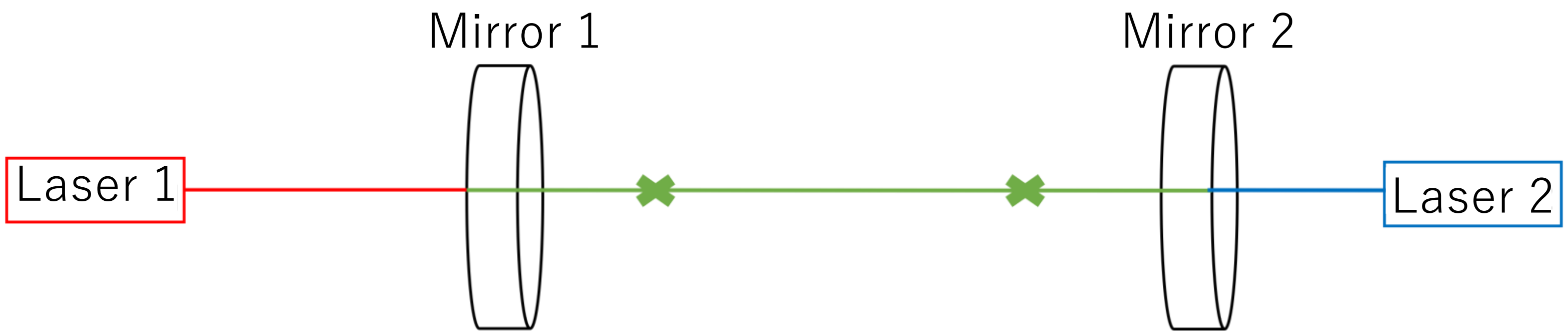
The distance between the Beam spot and the center of mirror

converts into…

Fluctuation of Length of the cavity




- We can align “the standard line” and “the axis of the cavity”



# Current Situation of the experiment

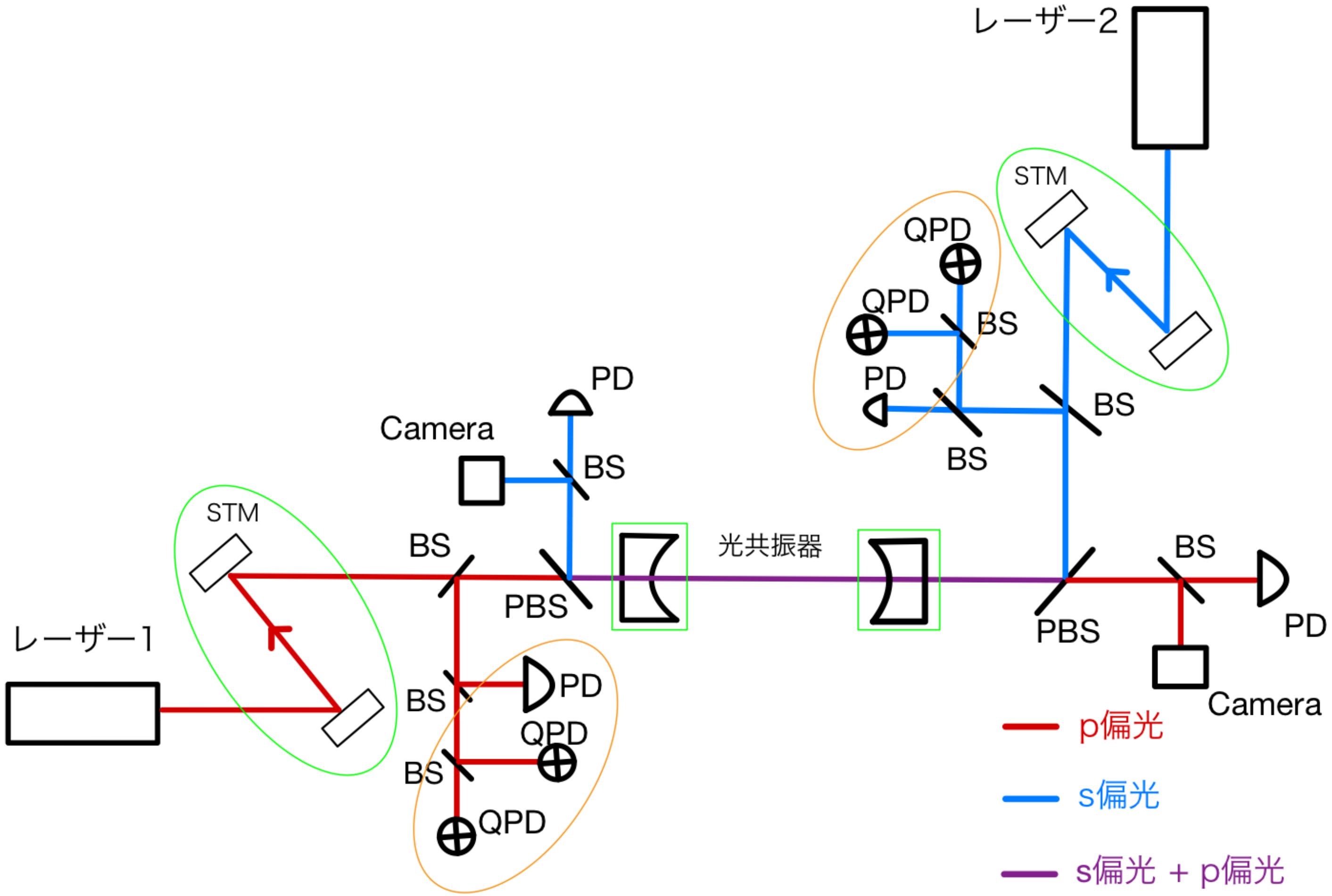
# Experiment

**Purpose**

- Get WFS signals
- Get BPC signals
- Practice simultaneous resonance using fixed mirrors

**Methods**

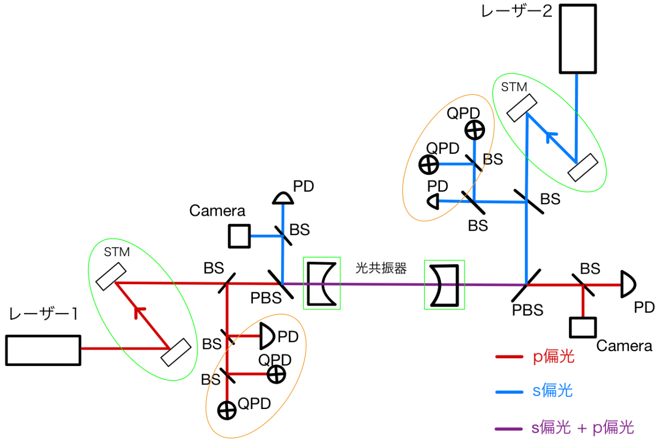
- Length control is achieved by lock each laser's frequency
- WFS signals are got by PZT of steering mirrors (STM)
- BPC signals are got by PZT of mirrors of the cavity



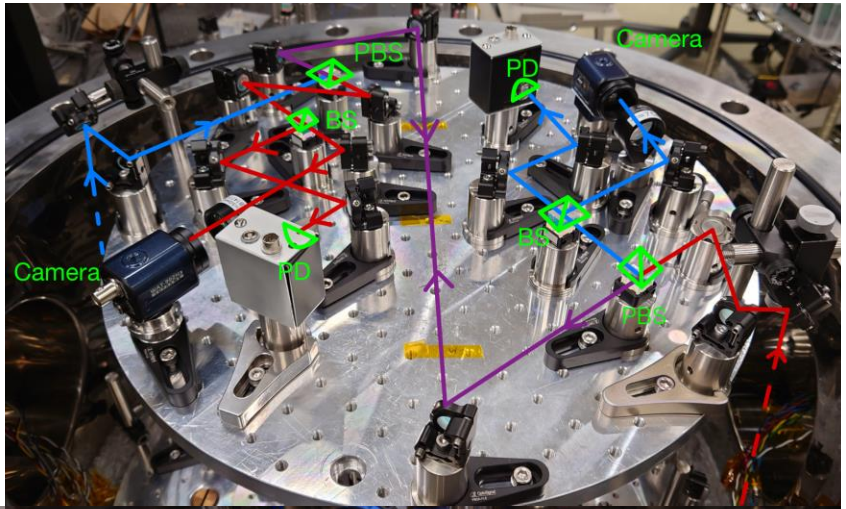
# Setup

## Updated

- Wiring
- Put mirrors of the cavity
- Put RFPD for PDH
- Alignment of one laser
- Locked the frequency

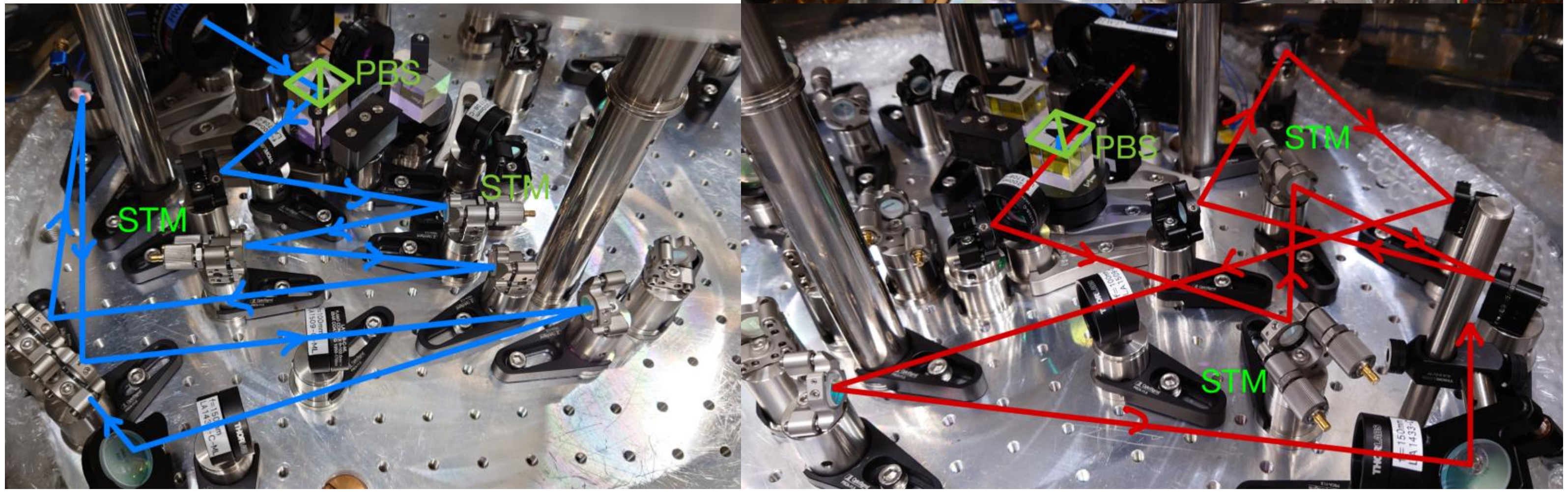



**2nd floor**




## Parameters

Wavelength : 1064 nm
Length of the cavity : 24.7 cm
FSR : 607 MHz
Curvature of the mirror : 15 cm
g-factor : -0.64
Reflectance : 99 %
Finesse : 313 (Design value)



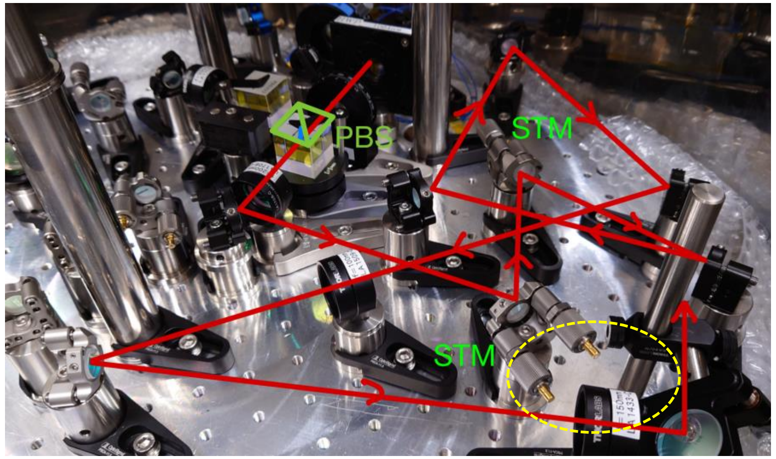

**1st floor**

in 2022 03

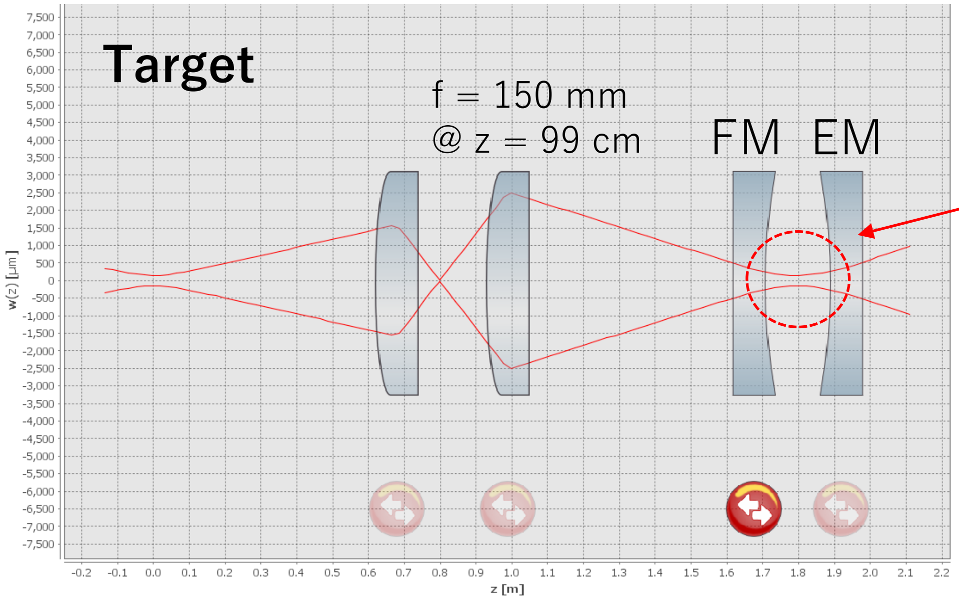
# Trivial problem and cause

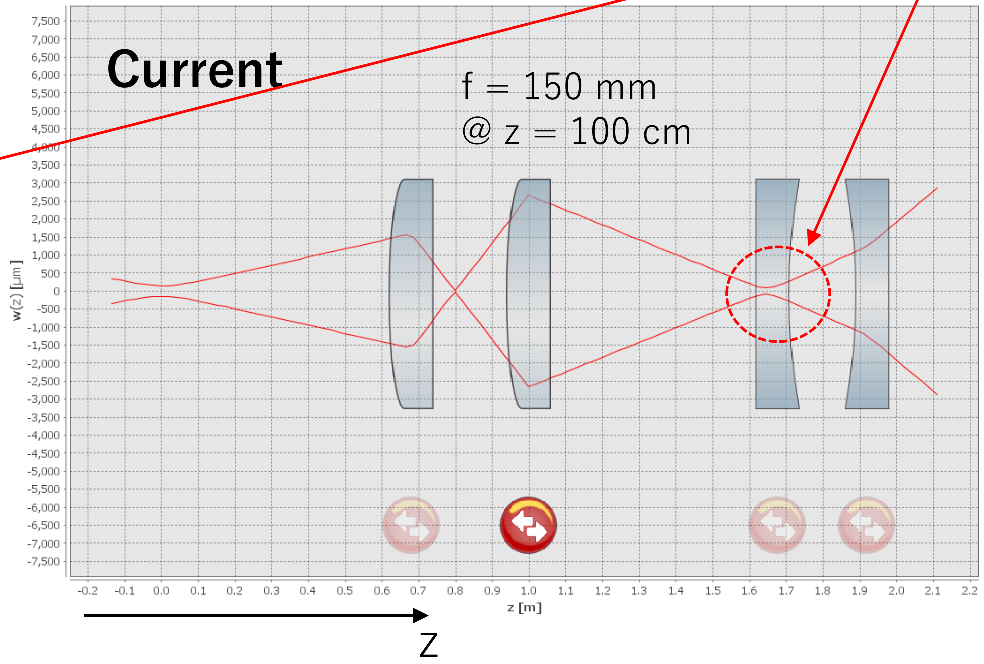
- I put mirrors of the cavity
- And Aligned
- However, the **mode match was in a bad situation** (Large LG10 mode exists)
- Looked back my simulation result (JamMt)
- Remembered I had moved a lens when wiring

LG10



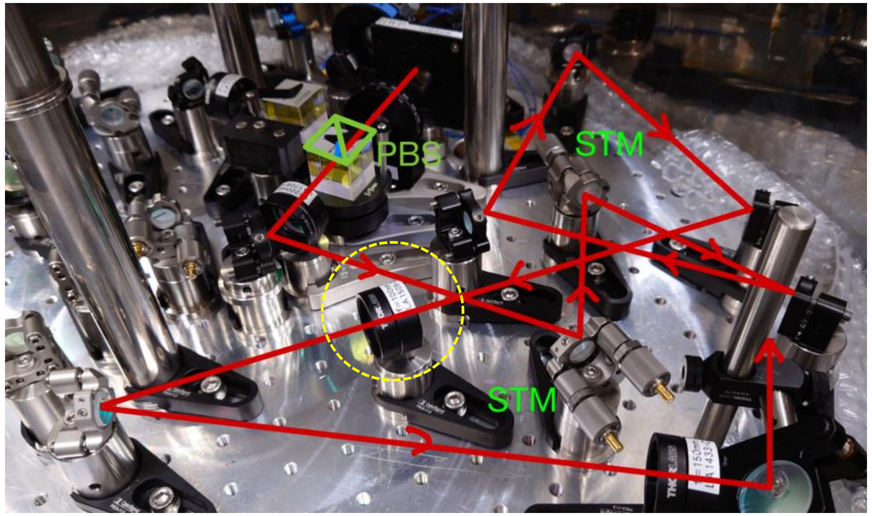

The position of the beam waist is sensitive to the position of the lens. It corresponds to the real situation.

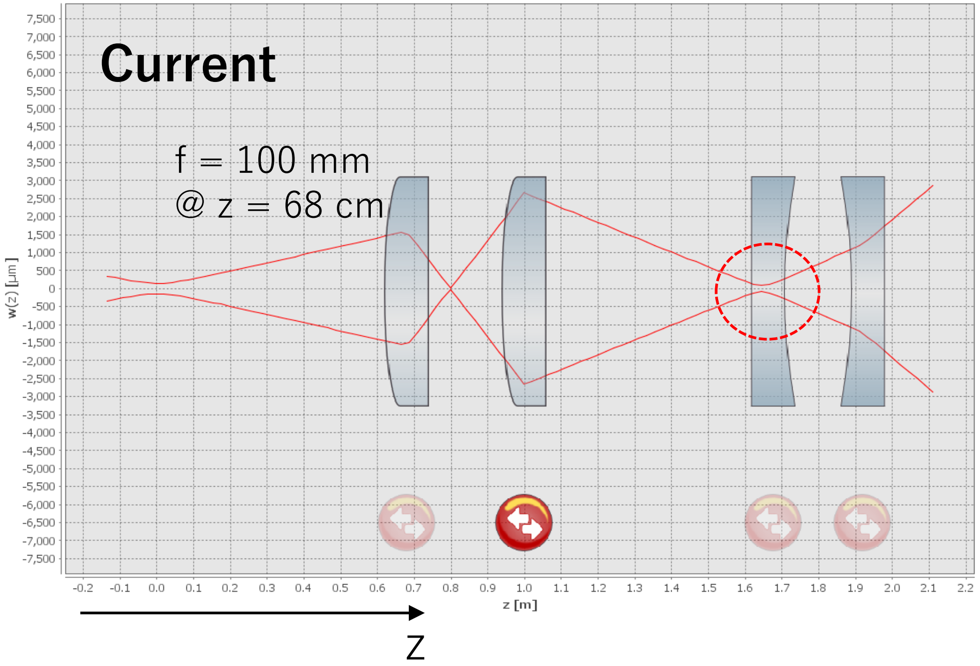


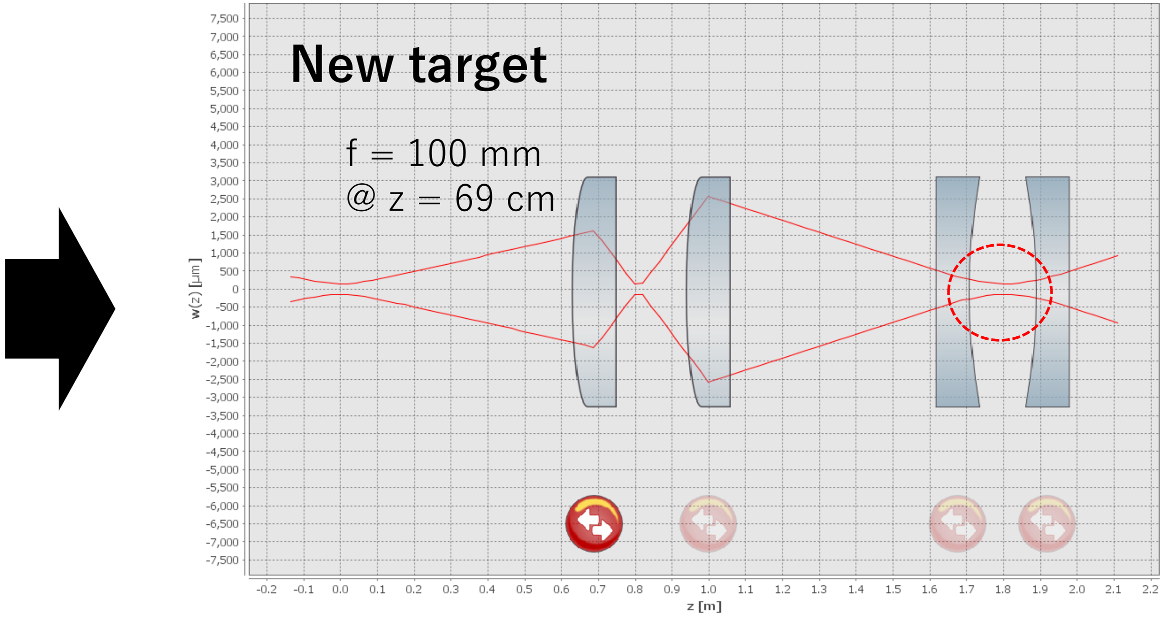



# To improve

- Will move another lens to improve this problem



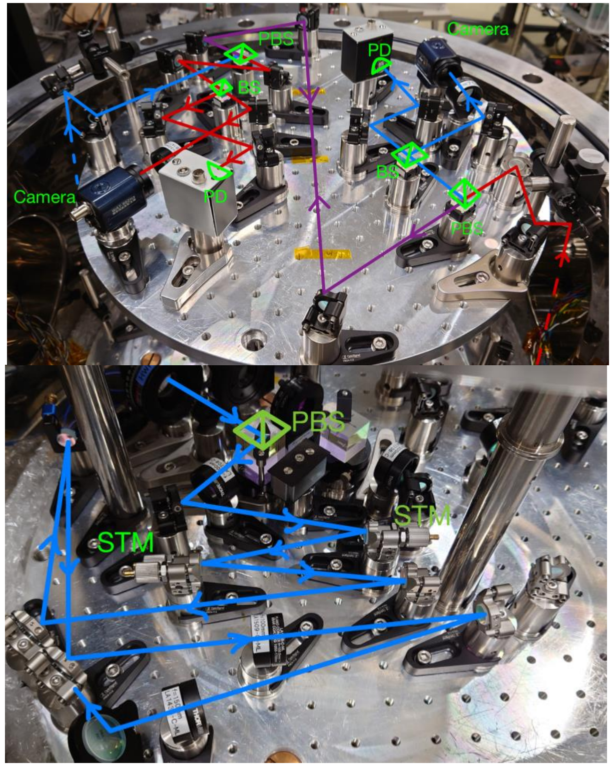
# To-do

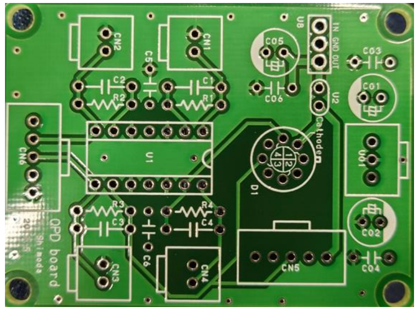
### Circuits

- make DCQPD circuits
- make pitch/yaw/sum circuits
- order RFQPD circuits
- Crimp a connector for frequency modulation

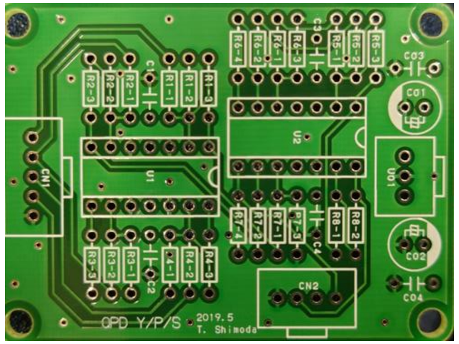
### Optics

- Alignment of another laser



DCQPD circuit board



pitch/yaw/sum circuit board

# Plans for Master thesis

# Setup

**I will update …**

Fixed mirrors → suspended mirrors

1 cavity → 2 cavities

**Purpose**

Length control of suspended cavities

Demonstration of alignment control

**Parameters and Design value**

Wavelength : 1064 nm

Length of the cavity : 70 cm

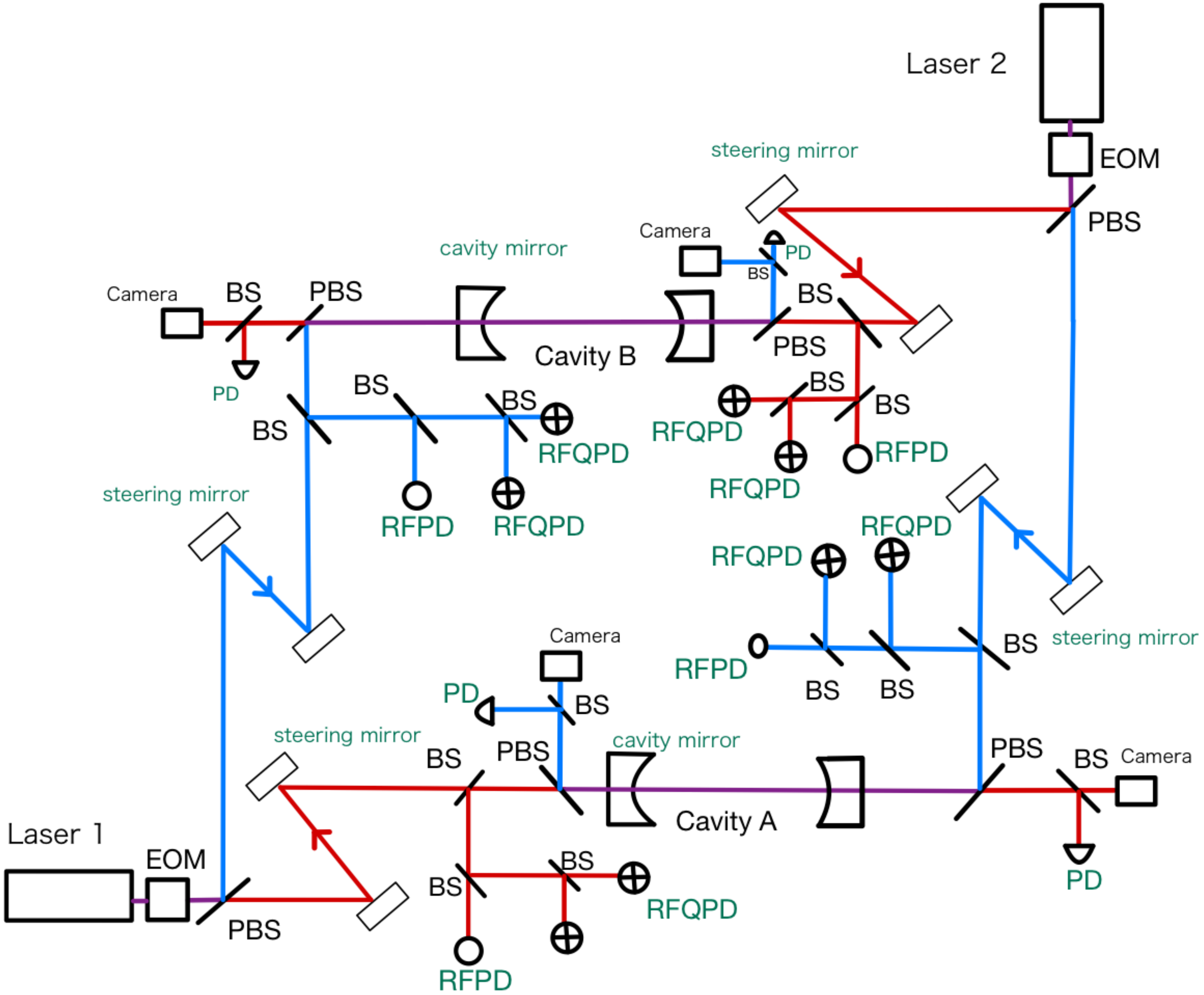
FSR : 214MHz

Curvature of the mirror : 40 cm

g-factor : -0.75

Reflectance : 99 %

Finesse : 313



# Digital system is used

I will use a digital system to lock cavities

**Motivations**

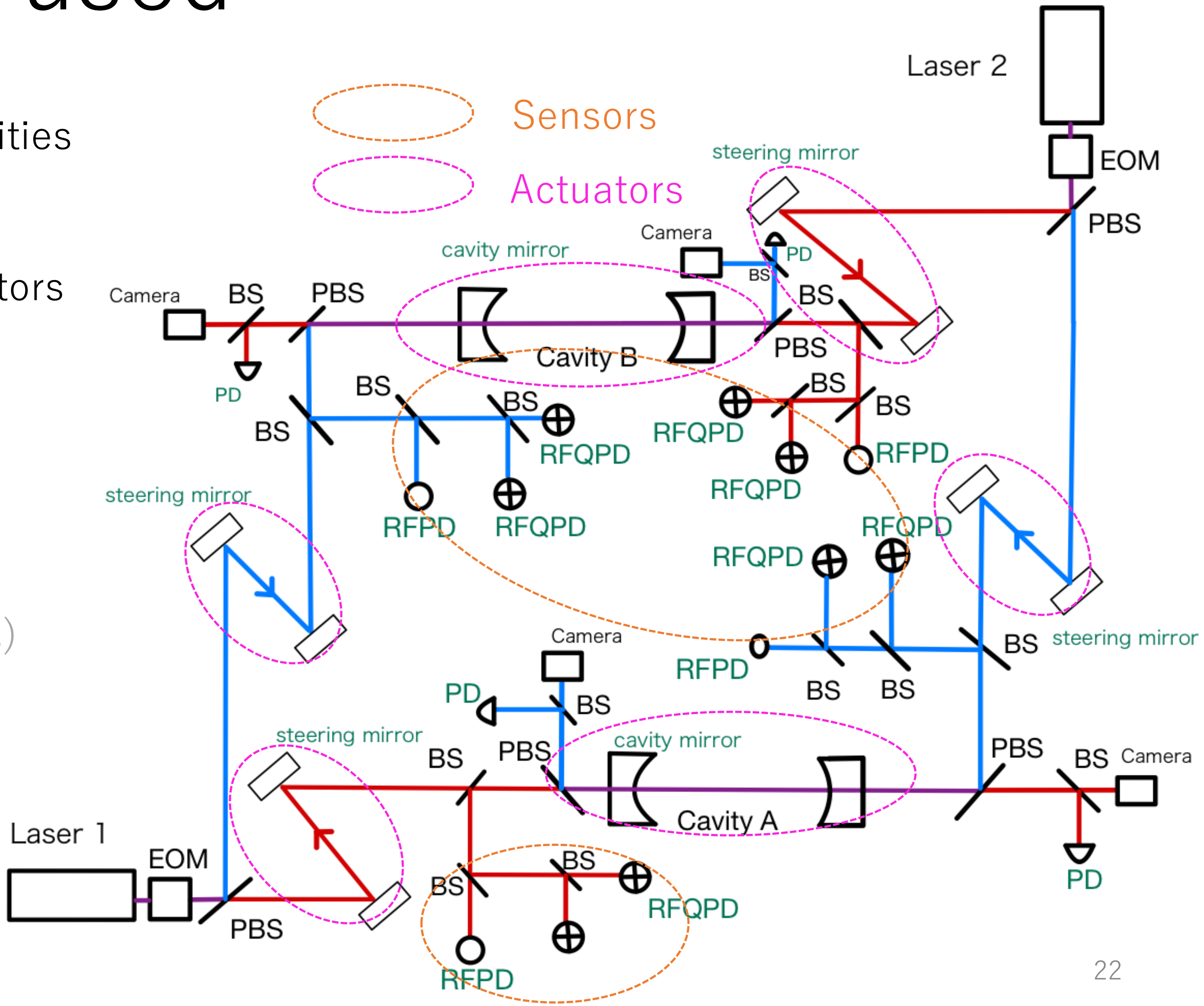
There are many sensors and actuators

**System name**

LIGO CDS

**Usage**

Filters for WFS and BPC
(Filters for PDH are analog circuits)



# Preparation for Instruments

# Instruments ～Suspension～

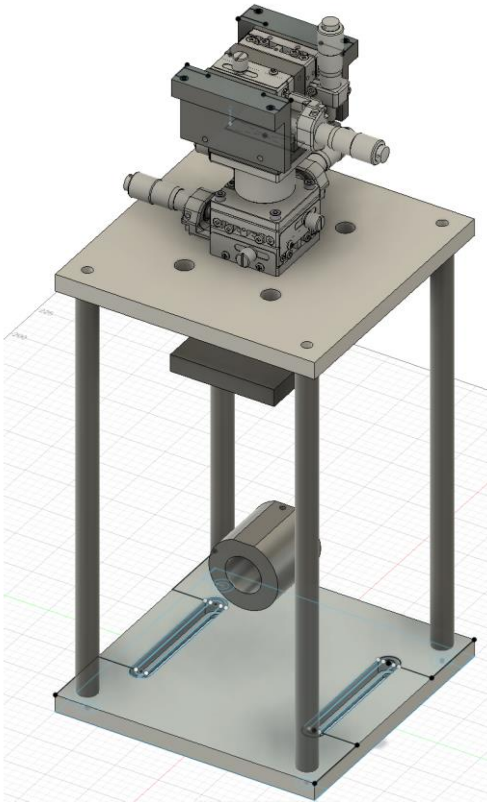
- Need to suspend mirrors of cavities
- Referred to the prototype of TAMA suspension

- 5 axes (x, y, z, pitch, yaw) can be adjusted by micrometers or picomotors

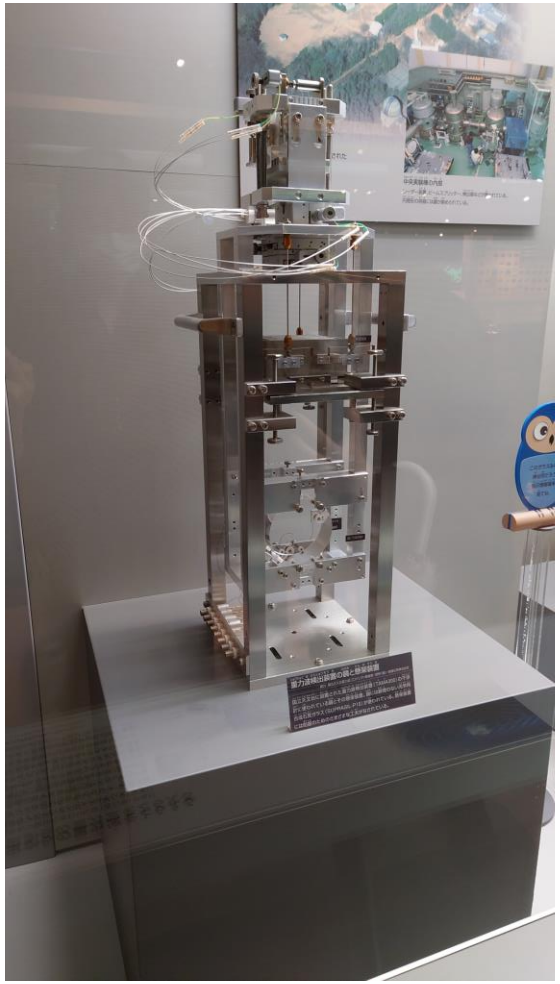
- Will update
  - Frame for damping magnet
  - Make it small

Newport picomotor 8302

Newport tiny picomotor 8353



Drawing now



Prototype of TAMA suspension

# Instruments ～Chamber～

CONFIDENTIAL

I will put suspensions on the vacuum environment (0.1 Pa)

[redacted]

Drawings are shared by 小野電機製作所 on April 22 (Fri)

**Issues**

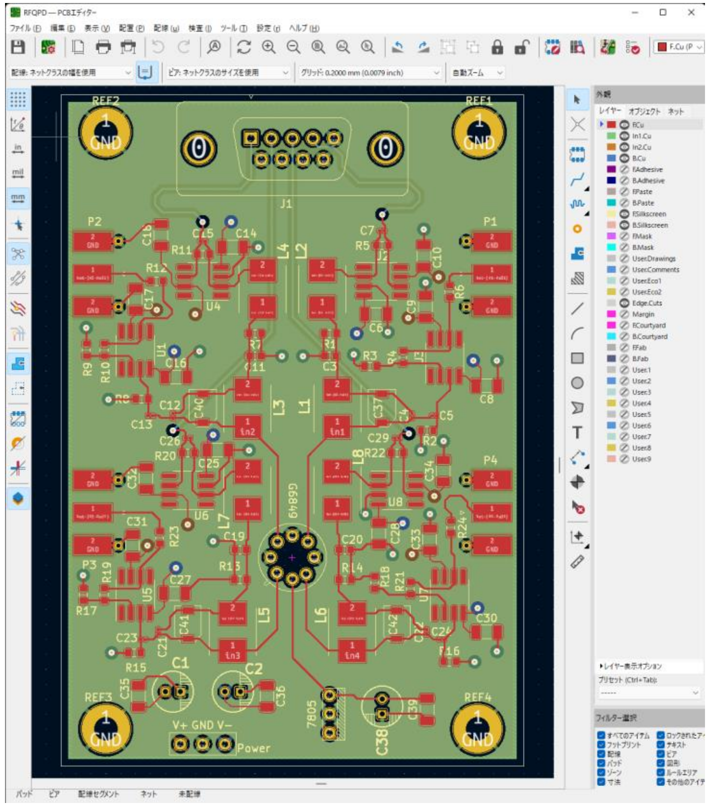
- Size
- Electropolishing or Alumite
- Position of holes

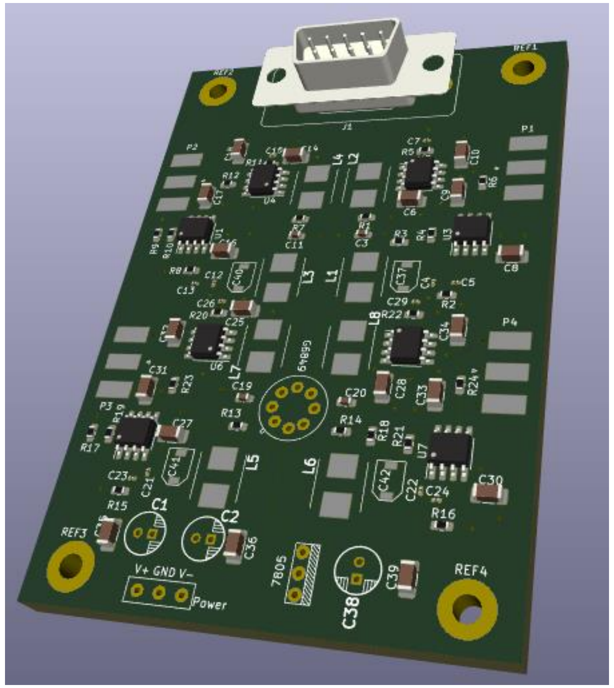
Hope to be delivered by the mid of June

EDWARDS RV12

# Instruments ～RFQPD～

- Made a drawing of RFQPD for WFS
- Referred to Enomoto-san's RFPD circuit board
- 15 MHz resonance
- Used KiCAD to design
  - 1 D-sub for DC signal
  - 4 SMA for RF signal
- Will place an order with p板.com





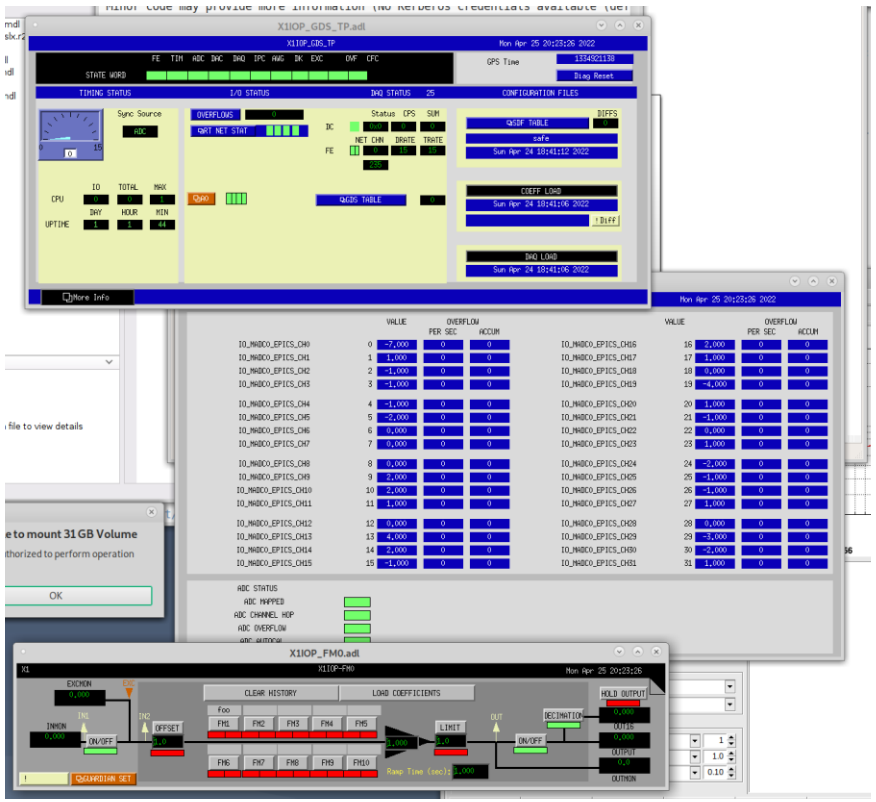
3D view

# Instruments ～Digital system～

- We installed LIGO CDS

- Reference
  - https://git.ligo.org/cds/advligorts/-/wikis/home

- Software is working well now




Standalone PC
(Supermicro)

# Troubles in LIGO CDS

- Now we have 2 ADC boards and 1 DAC board

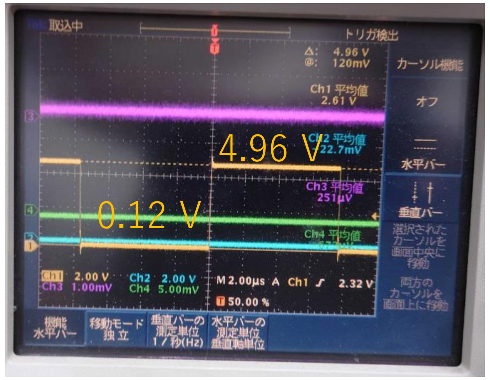
- However, these 3 boards have problems
  - ADC boards : **structure for clock signal** is damaged ?
  - DAC board : not recognized

About ADC…

- Yellow lines shown in the figures are clock signals
  - The left one is the signal only ADC board now working for TOBA digital system is slotted
  - The right one is the signal after add another ADC board which was purchased for the new LIGO CDS

Clock signal

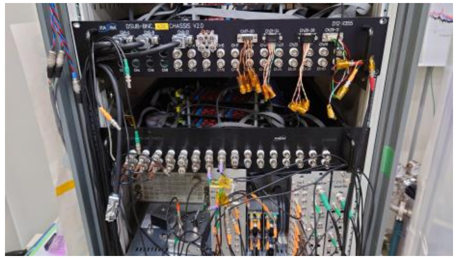
Correct



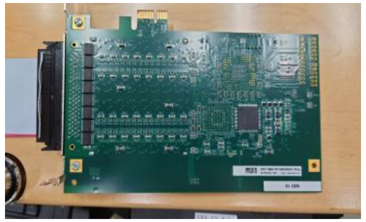

Strange


Oscilloscope

Standalone PC of TOBA digtal system



ADC board



PCIe-16AI64SSC-64-50M
(32 CH ADC board)

Adapter to input clock signal

Square wave
From 0 V
To 5V
65.536 kHz

Function generator

# Required ADC channels

- 36 channels are needed at least
- Two 32CH (64 CH) ADC boards are necessary

**Required channels for sensors**

| | Qty | Channels | Uses | Remarks |
|---|---|---|---|---|
| **PD** | 4 | 4 | Monitor transmitted power | 2 pols × 2 cavities |
| **RFPD (DC)** | 4 | 4 | Monitor reflected DC power | 2 pols × 2 cavities |
| **RFPD (RF)** | | 4 | PDH and BPC technique | 2 pols × 2 cavities |
| **QPD** | 4 | 16 | Monitor fluctuations of light axes | 2 pols × 2 cavities × 4 ports |
| **RFQPD (DC)** | 8 | 32 | Monitor reflected DC power | 2 pols × 2 cavities × 4 ports × 2 degs |
| **RFQPD (RF)** | | 32 | WFS technique | 2 pols × 2 cavities × 4 ports × 2 degs |
| **Sum (required)** | | 36 | | |
| **Sum (full)** | 20 | 92 | | |

# Required DAC channels

- 32 channels are needed at least
- Two 16CH (32 CH)DAC boards are necessary

**Required channels for sensors**

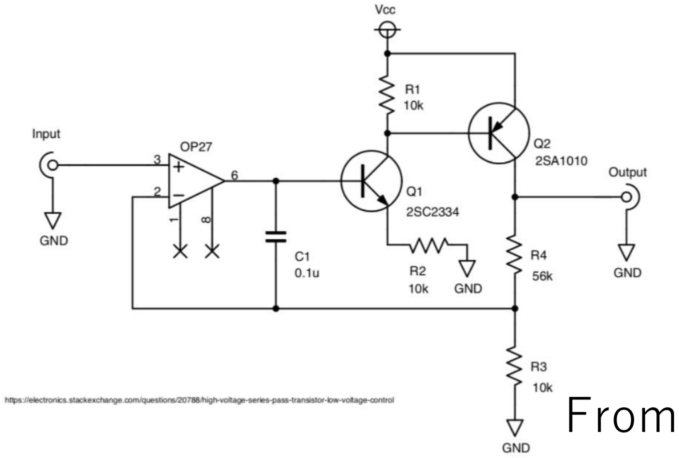
| | Qty | Channels | Uses | Remarks |
|---|---|---|---|---|
| **Steering Mirrors** | 8 | 16 | Actuate incident beam axes | 2 pols × 2 cavities × 2 directions × 2degs |
| **Coil magnet** | 16 | 16 | Actuate cavity axes | 4 coils(2 for pitch 2 for yaw) × 2 mirrors × 2 cavities |
| **Sum** | | 32 | | |

# PZT amplifier and coil driver

PI E-663

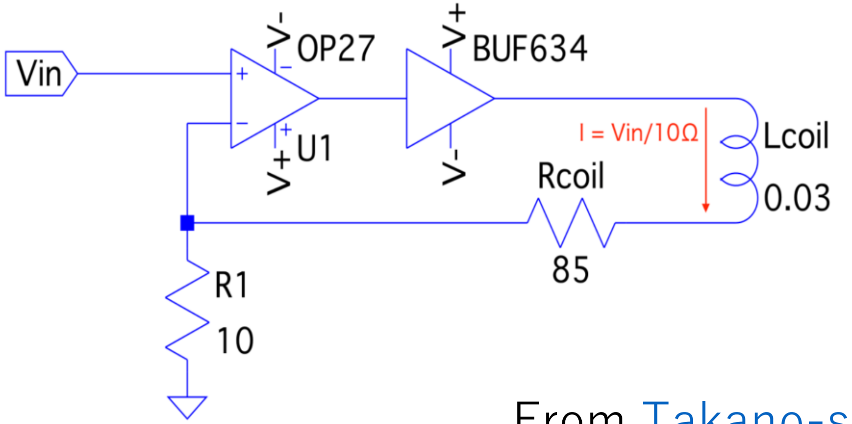
- PZT amplifier and coil driver are needed to use actuators

**PZT amplifier**




From Shimoda-san's elog

**Coil driver**




From Takano-san's elog

- Will design boards

- Other references (Shimoda-san and Miyazaki-san's elogs)

  High voltage amplifier for PZT actuator | Ando Lab ELOG (u-tokyo.ac.jp)

  Issues on the performance of PZT amplifier | Ando Lab ELOG (u-tokyo.ac.jp)

  status of a high voltage amplifier | Ando Lab ELOG (u-tokyo.ac.jp)

# Summary and Important other tasks

- **Summary**
  - Explained how to control the dual-pass Fabry-Perot cavity in the direction of angle
    - WaveFront Sensor and Beam Pointing Control
  - Current situation of the experiment for the demonstration
    - Purpose is to get error signals of WFS and BPC
  - So many things to prepare forward my master thesis experiment
    - Chamber
    - Suspension
    - Circuits (RFQPD, coil driver, PZTamp)
    - Digital system

**Experiments**

**What I do this year !!**

- **Important other tasks**

**Writings**

- DC 1 application
- Master thesis
- Defense

**Conferences**

- JPS
- GWADW
- KIW
- DECIGO-WS
- Others

Thank you for listening

# Extra slides

# Required ADC channels (Single cavity)

- 18 channels are needed at least
- one 32CH (32 CH) ADC boards are necessary

**Required channels for sensors**

| | Qty | Channels | Uses | Remarks |
|---|---|---|---|---|
| **PD** | 2 | 2 | Monitor transmitted power | 2 pols |
| **RFPD (DC)** | 2 | 2 | Monitor reflected DC power | 2 pols |
| **RFPD (RF)** | | 2 | PDH and BPC technique | 2 pols |
| **QPD** | 2 | 8 | Monitor fluctuations of light axes | 2 pols × 4 ports |
| **RFQPD (DC)** | 4 | 16 | Monitor reflected DC power | 2 pols × 4 ports × 2 degs |
| **RFQPD (RF)** | | 16 | WFS technique | 2 pols × 4 ports × 2 degs |
| **Sum (required)** | | 18 | | |
| **Sum (full)** | 20 | 46 | | |

# Required DAC channels (Single cavity)

- 16 channels are needed at least
- One 16CH (16 CH)DAC boards are necessary

**Required channels for sensors**

| | Qty | Channels | Uses | Remarks |
|---|---|---|---|---|
| **Steering Mirrors** | 4 | 8 | Actuate incident beam axes | 2 pols × 2 directions × 2degs |
| **Coil magnet** | 8 | 8 | Actuate cavity axes | 4 coils(2 for pitch 2 for yaw) × 2 mirrors |
| **Sum** | | 16 | | |

PCIe-16AO16-16-F0-DF