Cryogenic Monolithic Interferometer

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Ando Lab Mid-term Seminar 2023

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Overview

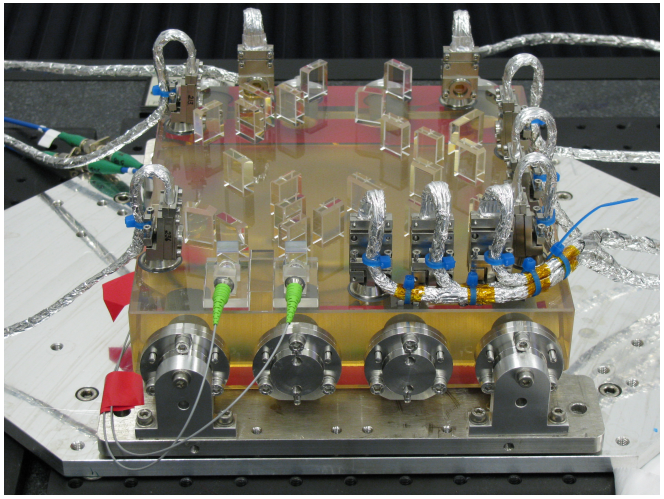
- There years I have developed a cryogenic monolithic interferometer
- Now it's close to an end (I should have finished earlier…)
- Looking back to the current achievement and issues

Contents

- Cryogenic Monolithic Interferometer
  - Design
  - Alignment
  - Bonding
  - Evaluation
- Future Plan

Cryogenic Monolithic Interferometer

Cryogenic Monolithic Interferometer



Monolithic Interferometer

- Optics are glued on a base plate directly
  - Large common mode rejection ratio
  - Small drift in long time duration
  - No way to tune alignment after gluing

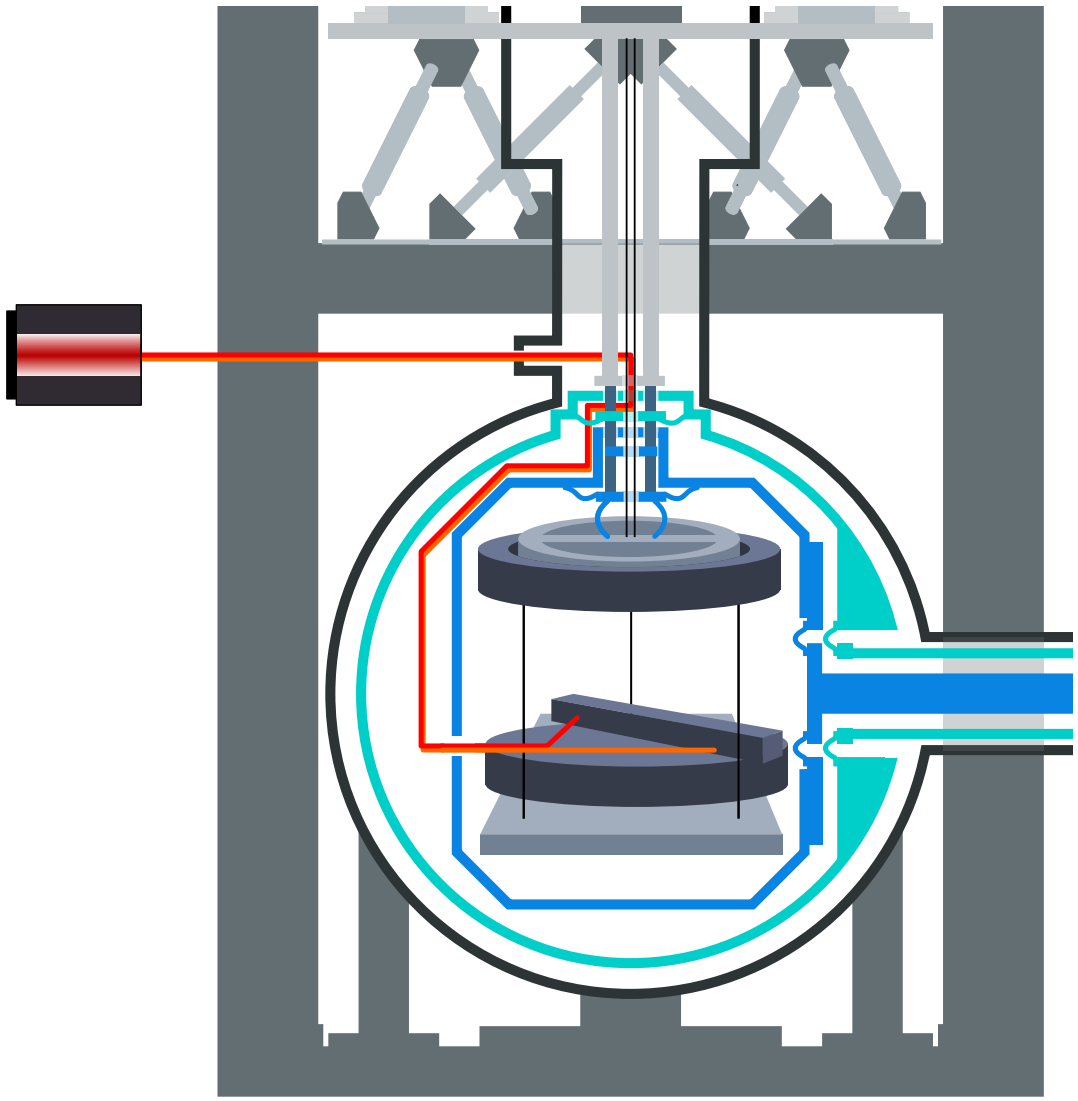
LISA Pathfinder reached displacement sensitivity to **3.5 x10^{-14} m/√Hz @ 0.1 Hz**

- Limited by noise of Phase Meter

In my research: Cryogenic Monolithic Interferometer

- Fused silica is not suitable for cryo. temp.
  - Construct (almost) all-silicon monolithic interferometer
- Target sensitivity: **10^{-15} /√Hz** (**3 x10^{-16} m/√Hz**)
  - Limited by shot noise

Setup for My Research



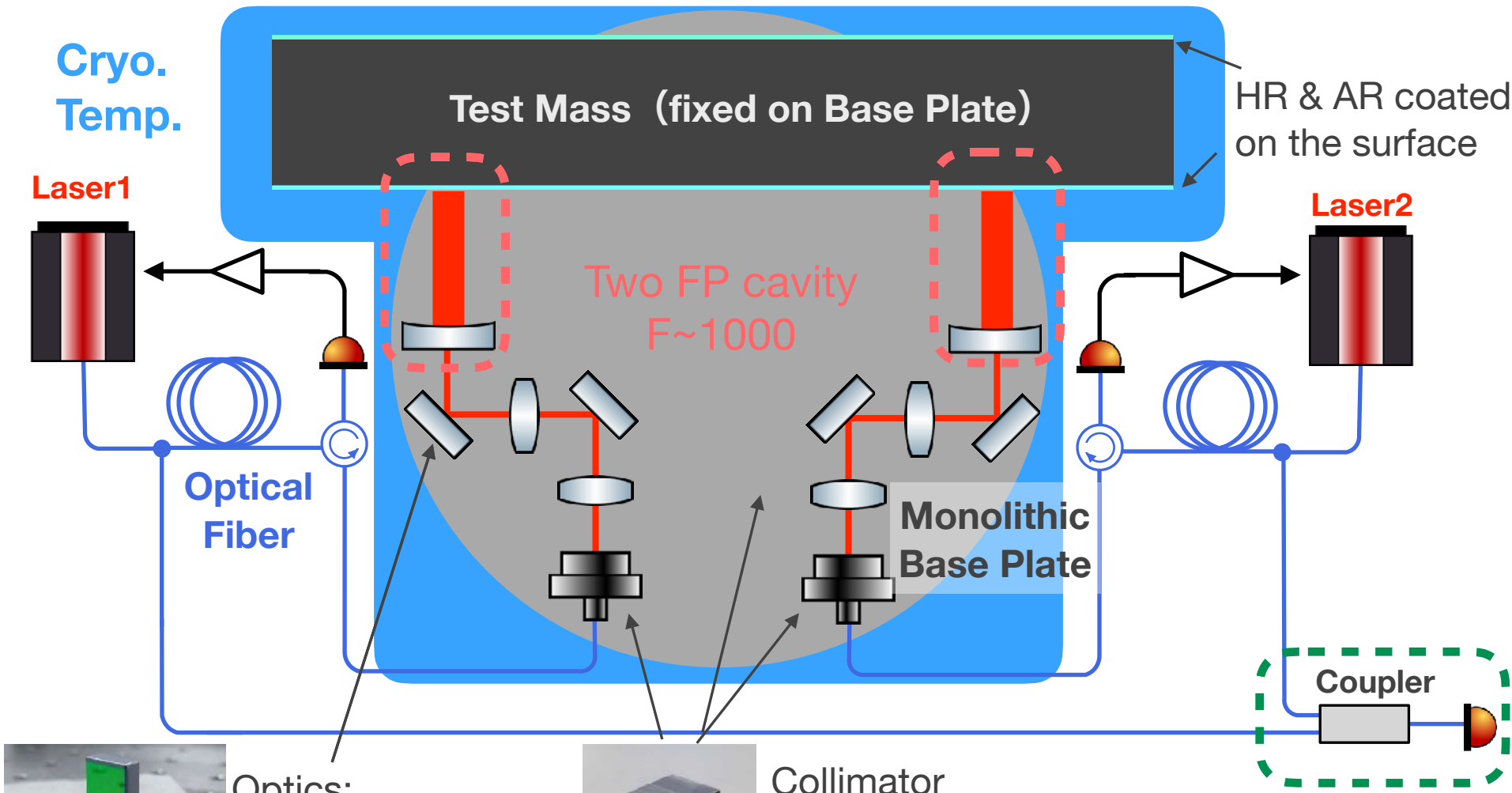
Simplification of the setup

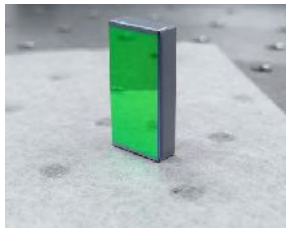
- No susoended TM, fixed on OB
- OB suspension is 2-stage
- Laser light is introduced by optical fibers

Purpose

- Operation of monolithic interferometer at cryo. temp.
- Evaluation of displacement noise
- Evaluation of CMRR by using AVIT
- Limited by shot noise at 0.1 Hz

Optical Design



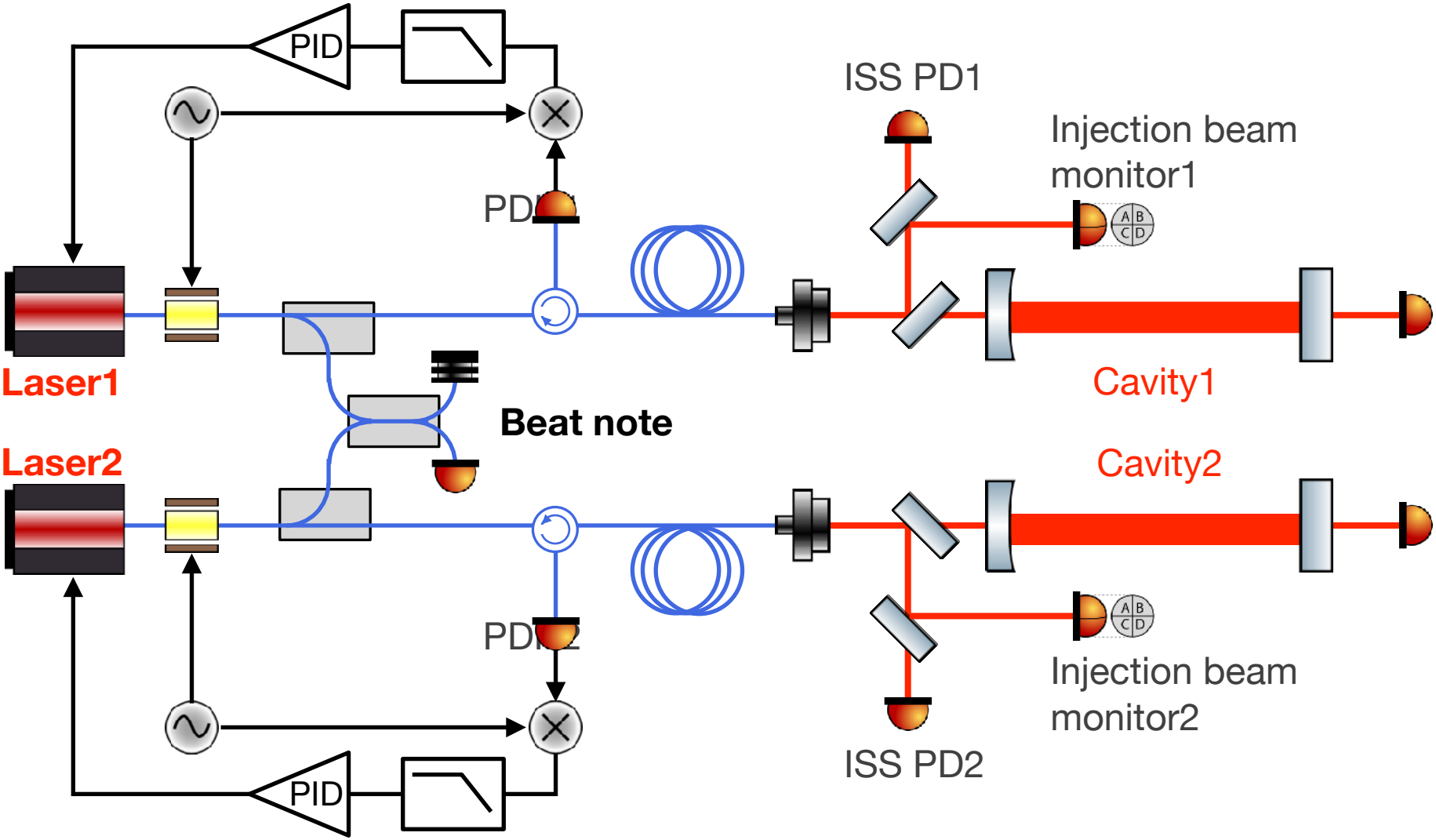


Optics:
made of silicon
TM, mirror, BS, lens

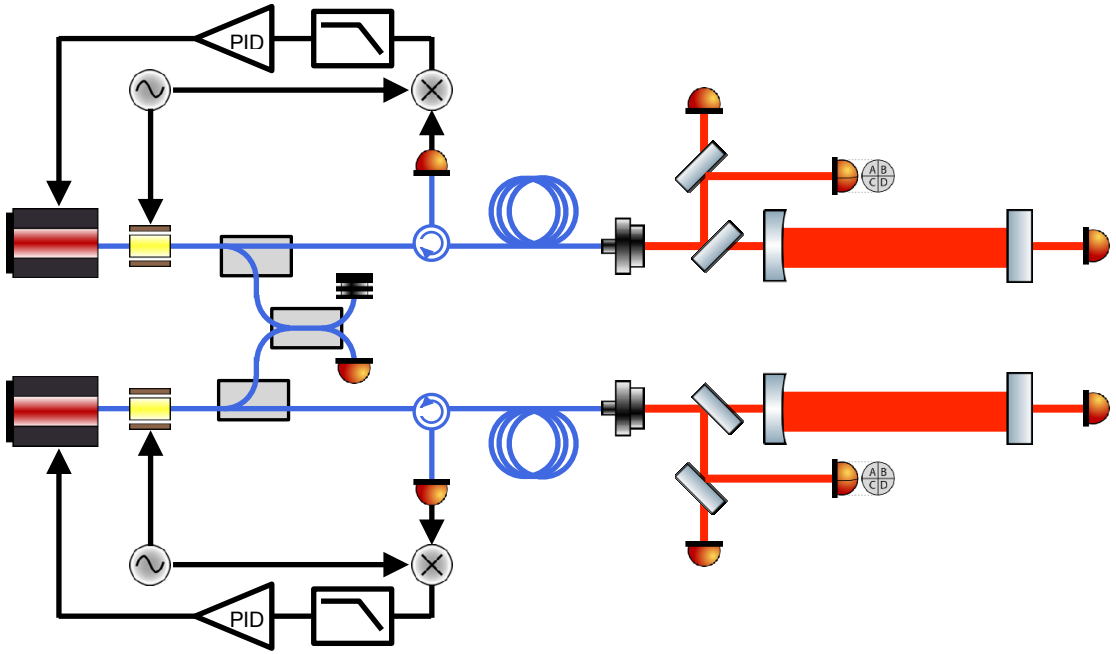
Collimator
with holder
made of invar

Differential displacement
signal from beat frequency

Optical Layout



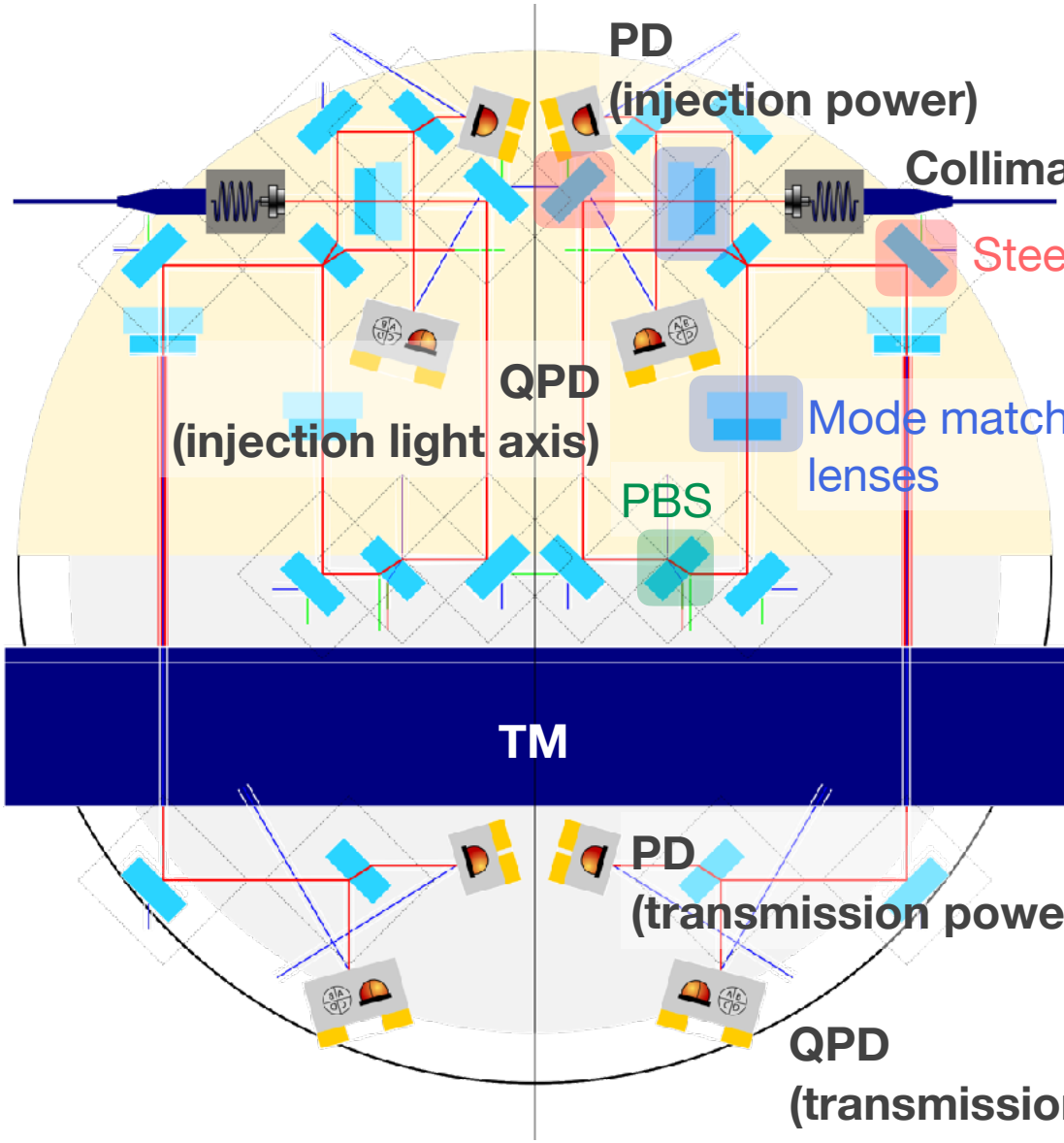
Parameters

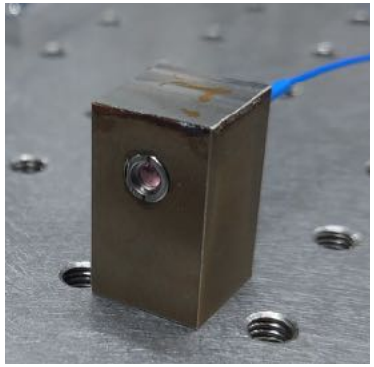


- Target: 10^{-16} m/√Hz @ 0.1Hz (differential)
- Would be limited by shot noise

Power	20 mW
Length	55 mm
Front Mirror Curvature	200 mm
End Mirror Curvature	∞
Front Mirror Reflectivity	99.5%
End Mirror Reflectivity	99.8%
Finesse	1045
FSR	2.7 GHz
FWHM	3 MHz

Optical Design



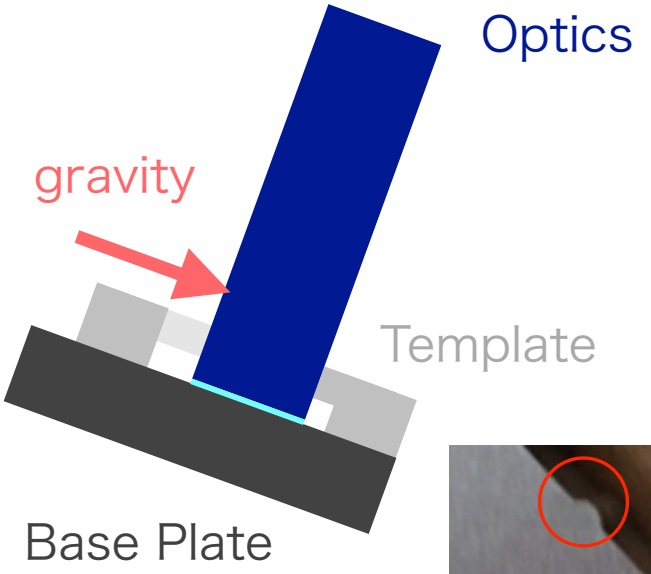


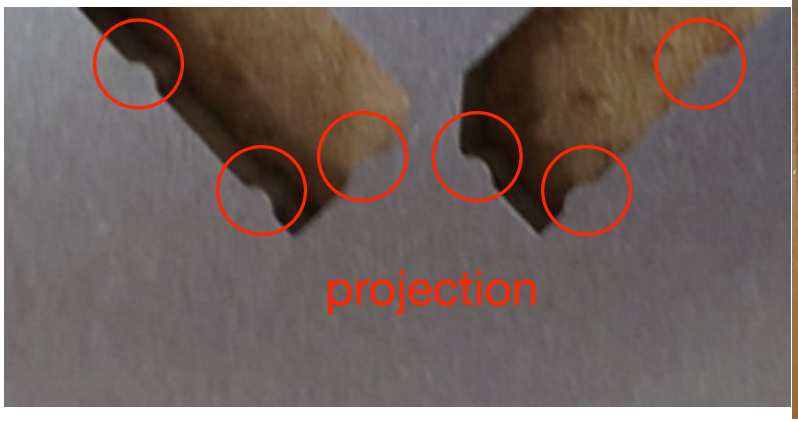
The optical path was designed by gtrace

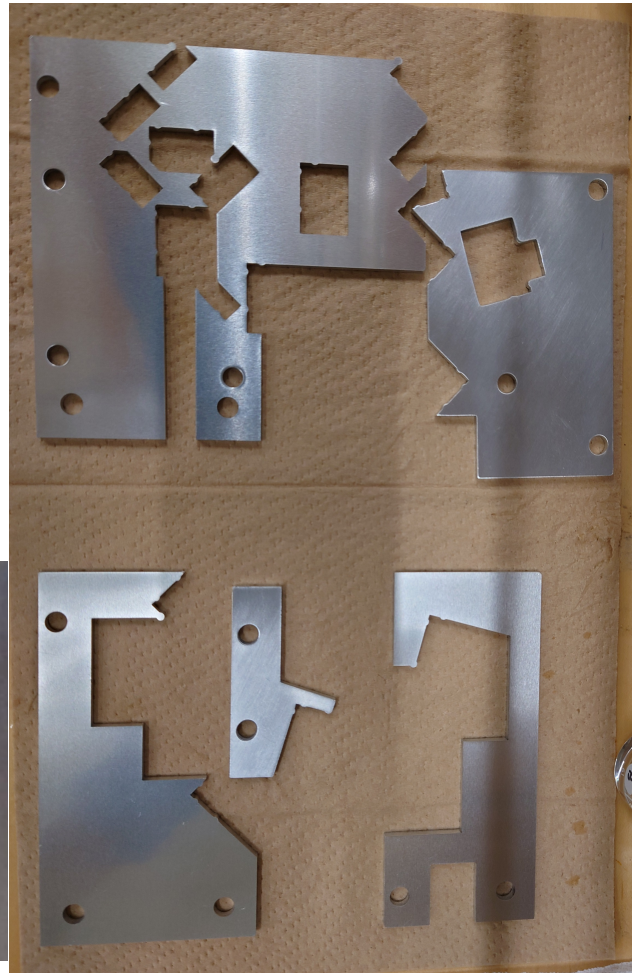
Template Bonding

Position of optics are defined by a template

- Due to gravity optics glide on the bonding glue
- Stopped by projections on the template

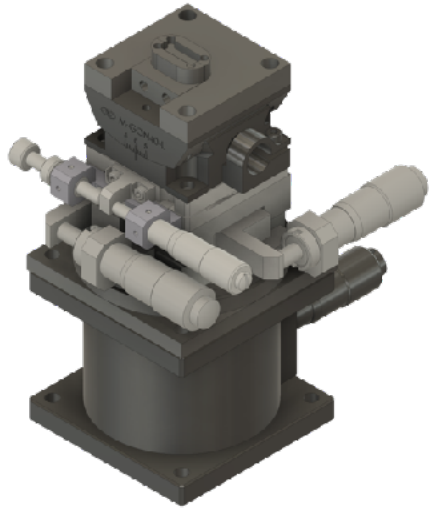


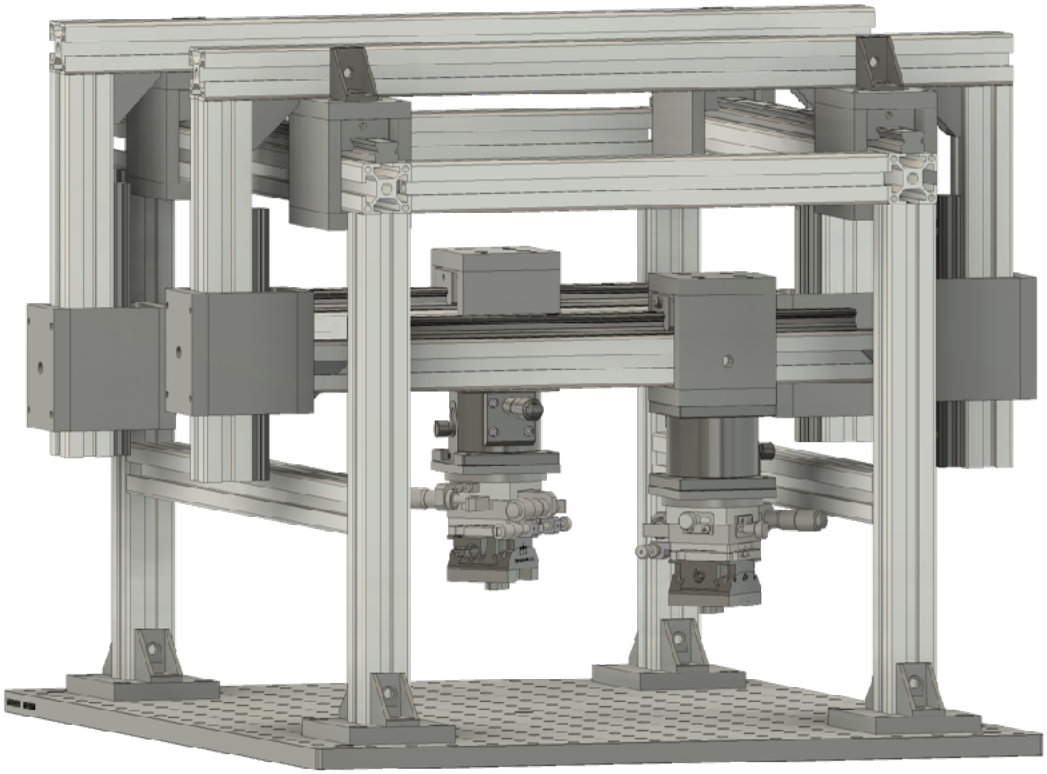


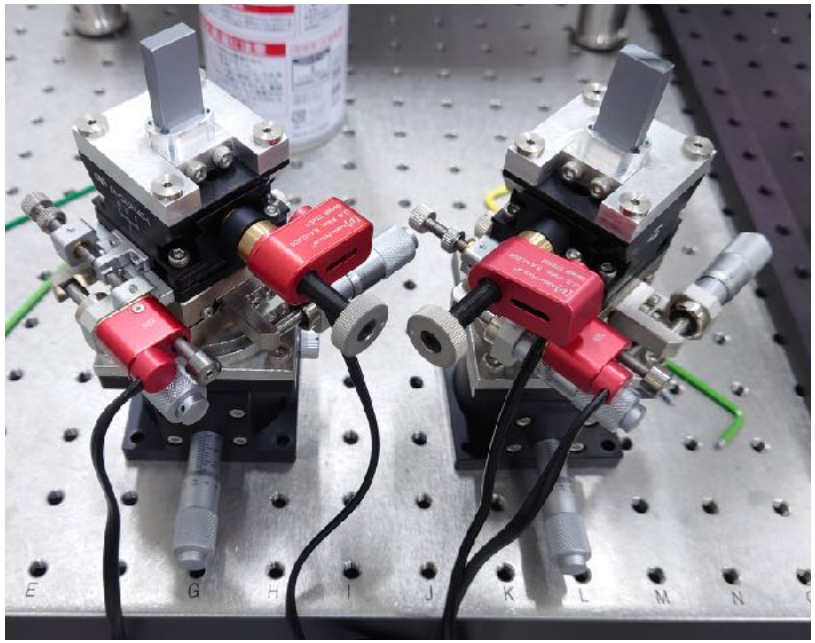


Fine Stage Alignment

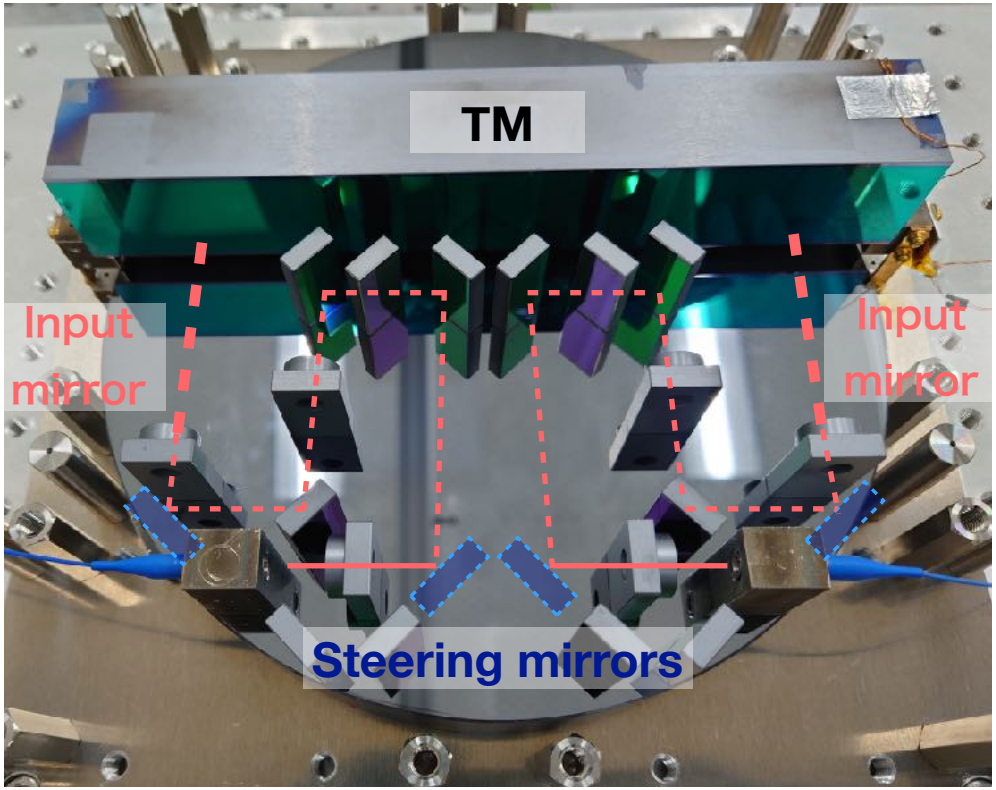
- Adjustable stages
  in 5 DoF (x, y, z, pitch, yaw)
- 3 manual (x, y, z),
  2 picomotors (pitch, yaw)



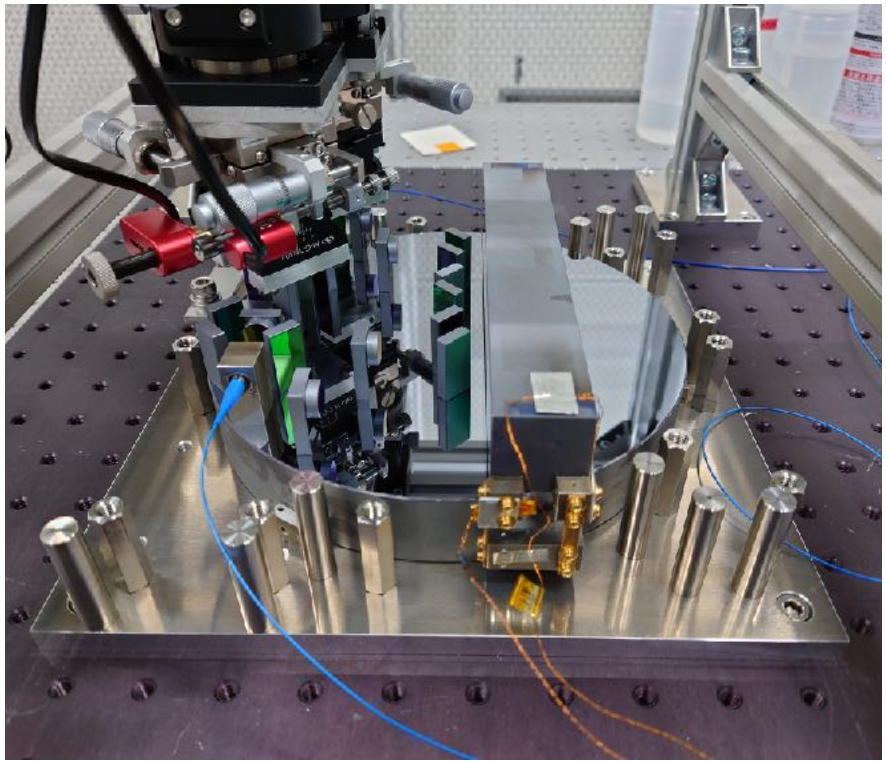




Alignment

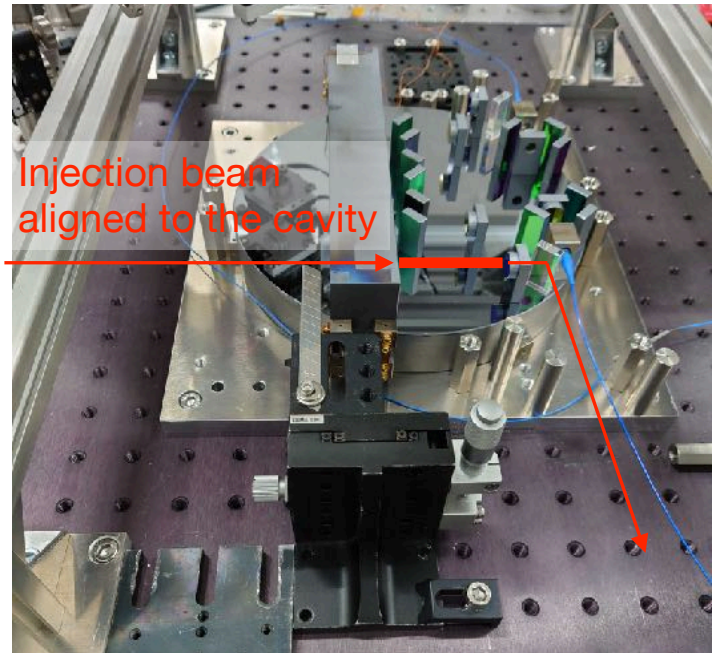


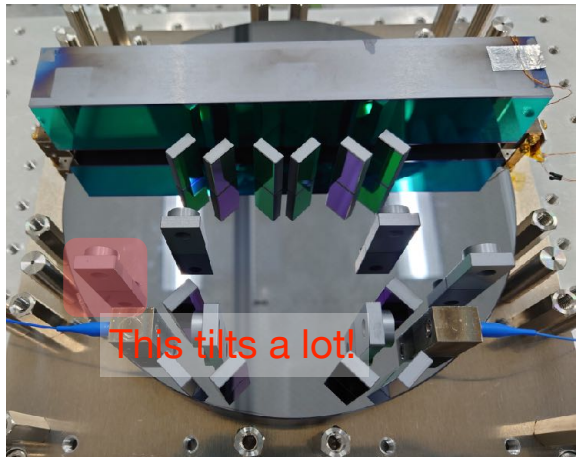
Temporary Gluing
→ Used LOCTITE 401,
not Stycast1260

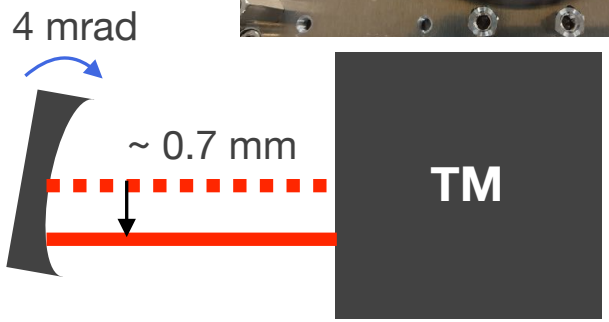


Problems with Alignment

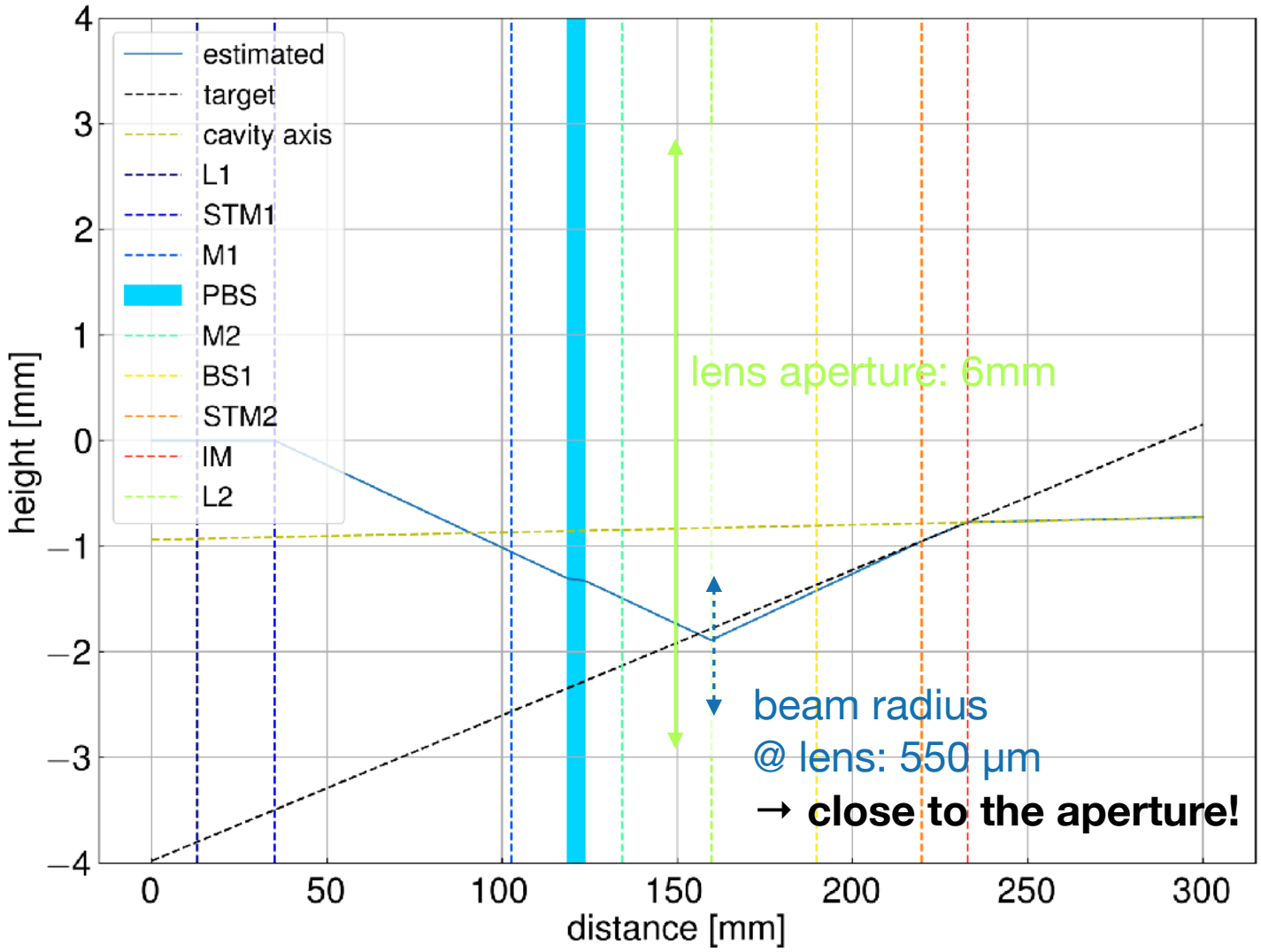
- In November 2022, tried the alignment first time
  - Maximum mode matching ratio is ~ 52%
  - Input beam seemed clipped at a mode matching lens
- Measured beam axis tilt & height by injecting laser backwards
  - One of input mirror (IM) tilts ~ **4 mrad**
  - TM & the other IM tilt < 1mrad





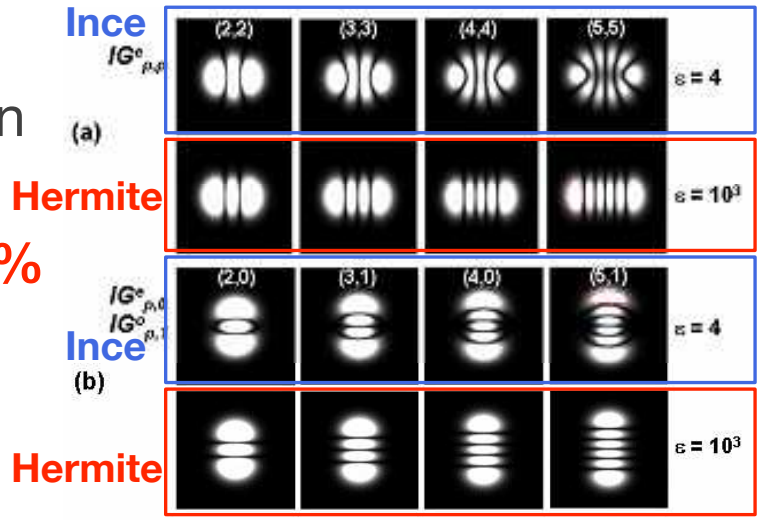


Beam Spot Simulation



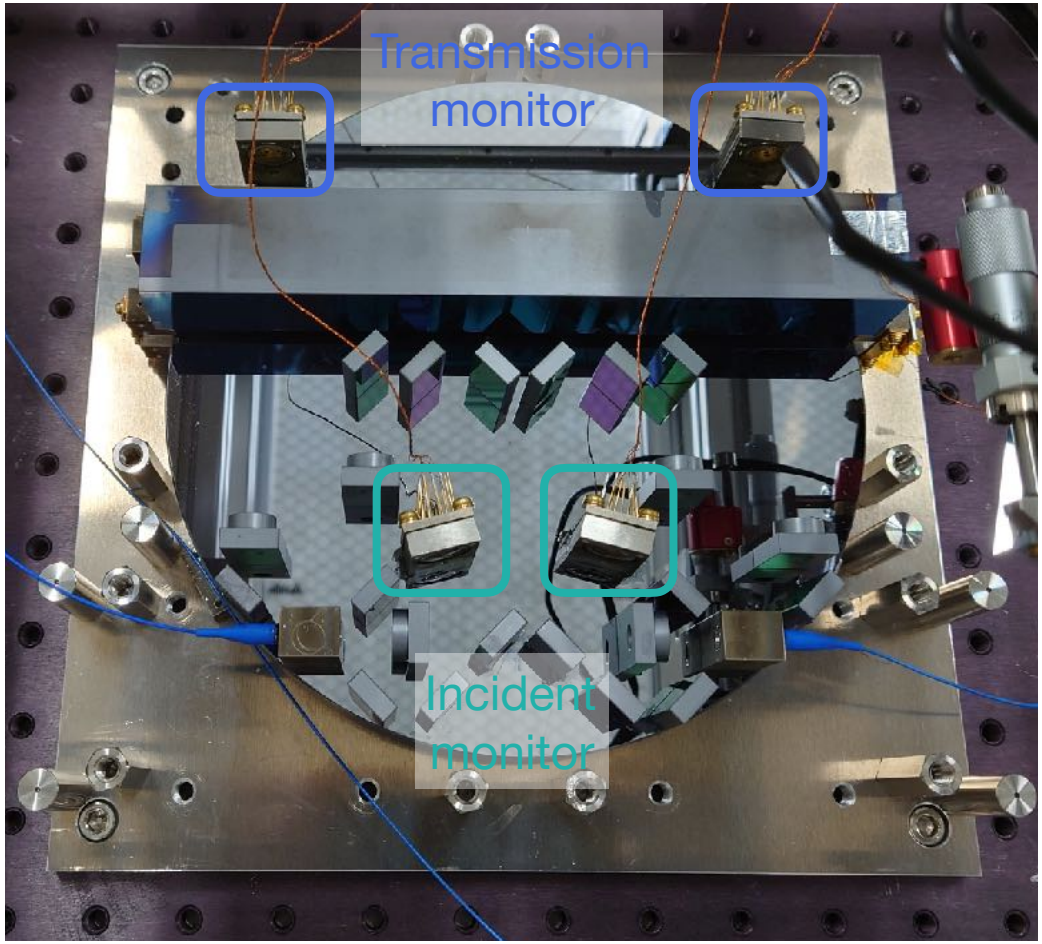
Current Status

- Aligned both cavity again
  - Better cavity: mode matching raito > **99 %**
    - When bonding I made a mistake and now ~ **95 %**
  - Worse cavity: mode matching ratio < **90 %**
    - Improved from the previous trial
      (found that there are some pit-yaw coupling in the fine tuning stage)
    - Limited by clipping at the lens
    - When clipping transmitted light changes from pure Hermite-gaussian to Ince-Gaussian
    - Finally mode matching ratio is ~ **85 %**
      (drifted during the bonding)

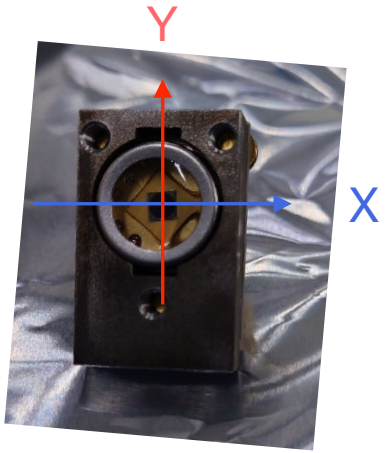


QPD Bonding

- Temporary I glued on QPDs to monitor incident and transmission beam

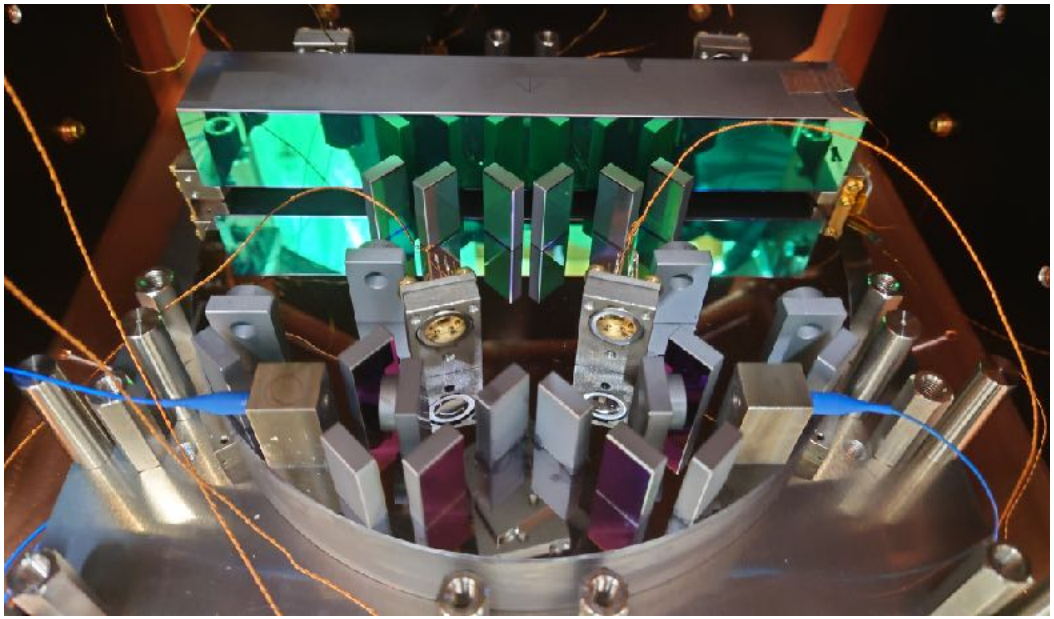


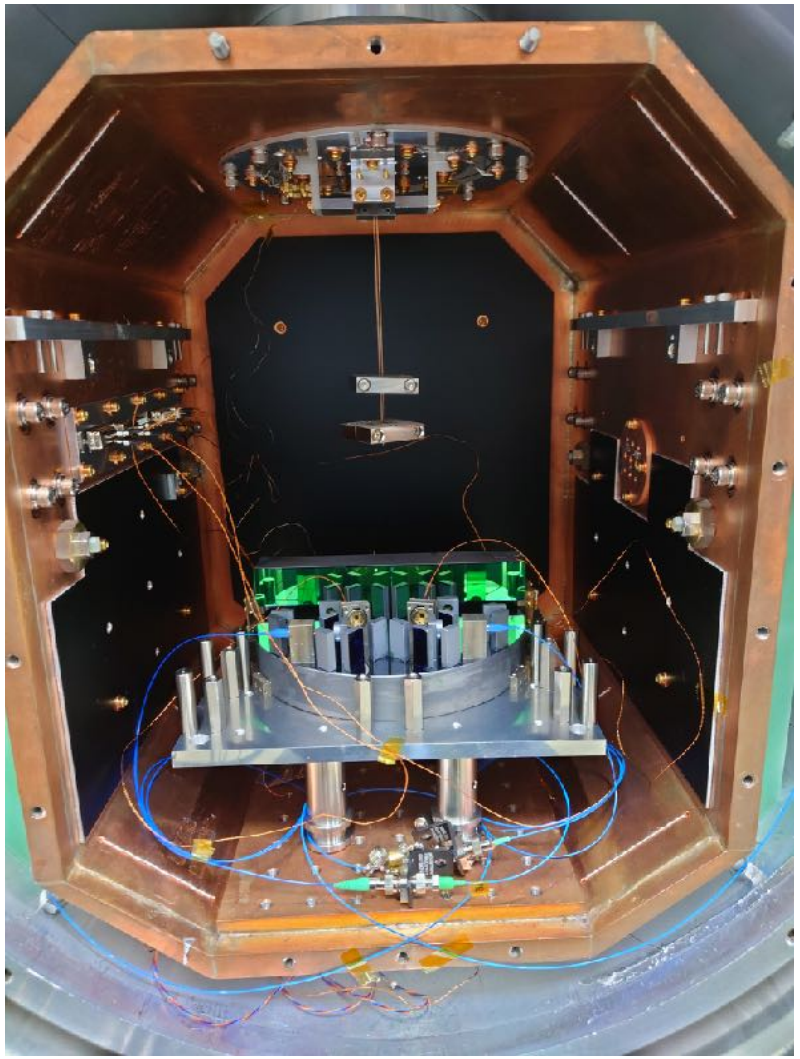
- Noticed that there is no way to align beams on QPD in Y
- Need to consider how to do it



Cavity Transmission

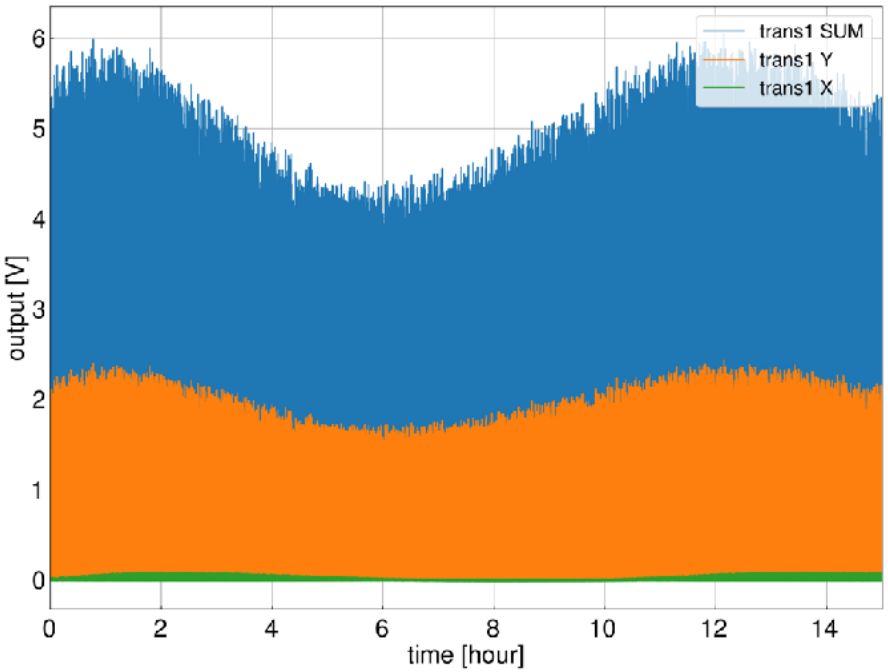
- Installed in the vacuum chamber

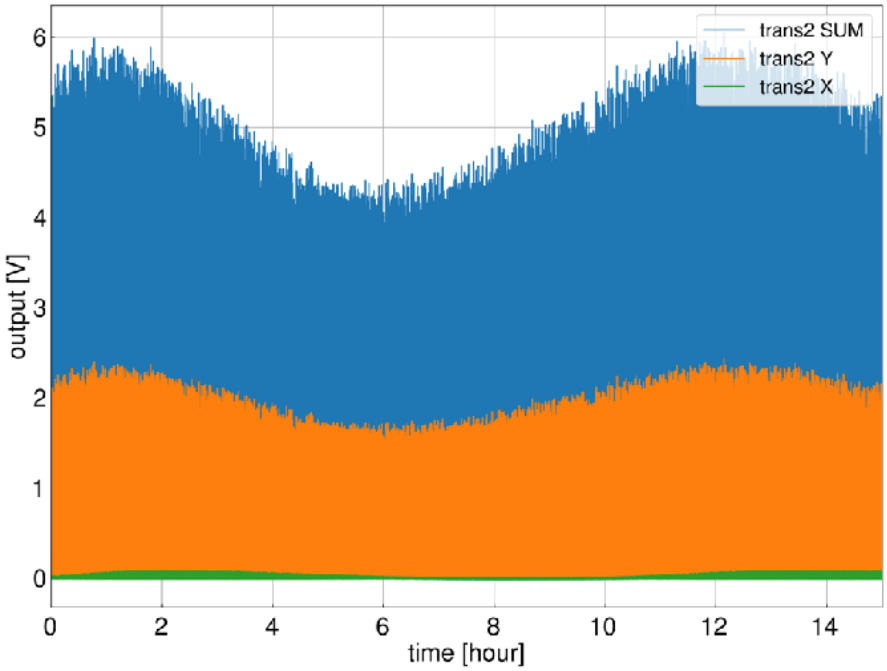




Cavity Transmission

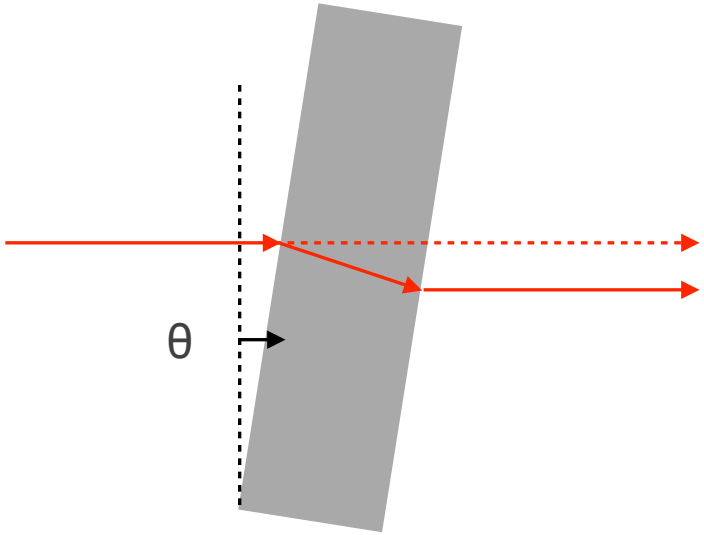
- Scanning in laser frequency
- Found slow oscillation in ~ 12 h
- What causes this?



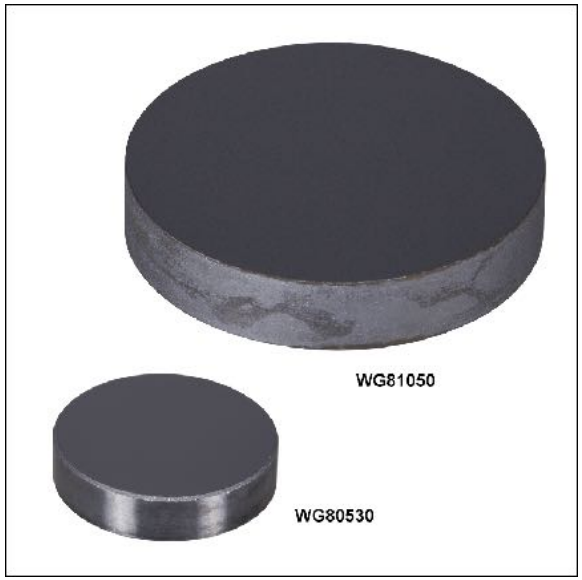


Future Plan: Beam Shfting

- Beam clipping plobrem
- Shifting plate to modify the incident beam

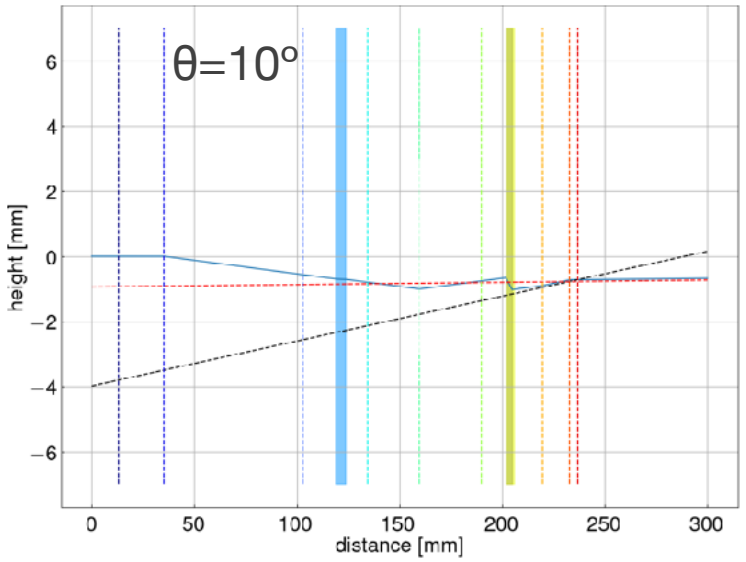


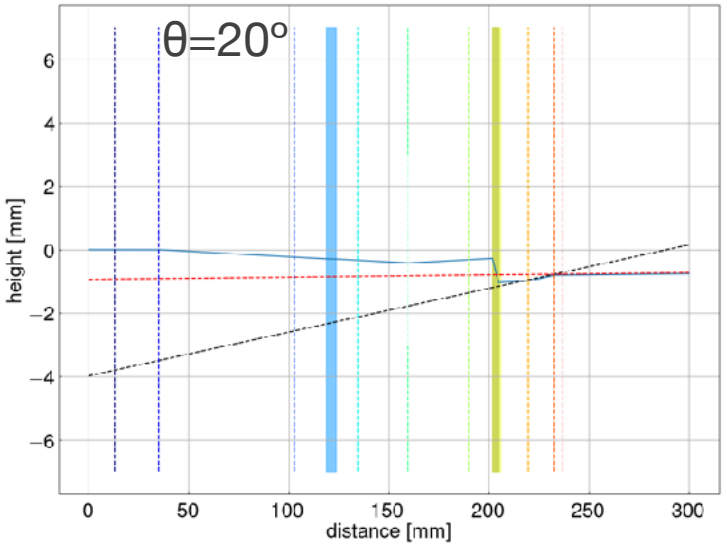
- Already bought silicon plates
  - Thorlabs WG80530, Φ12.7mm x t 3mm

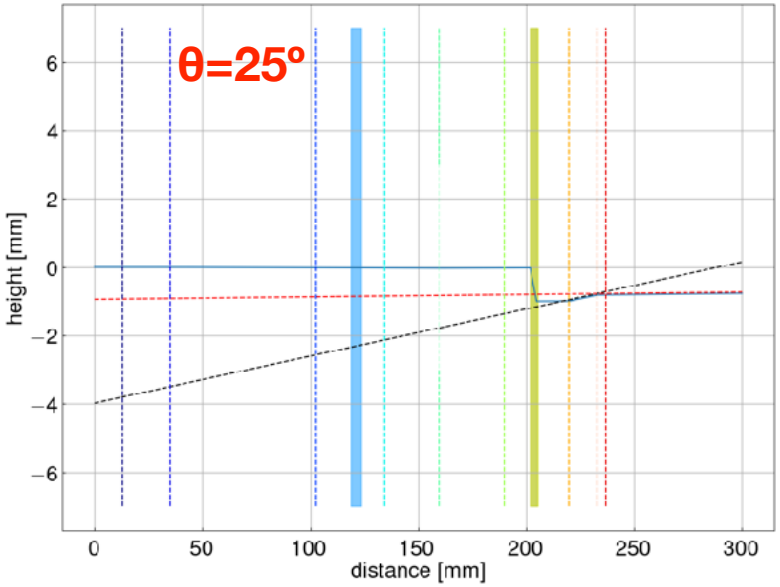


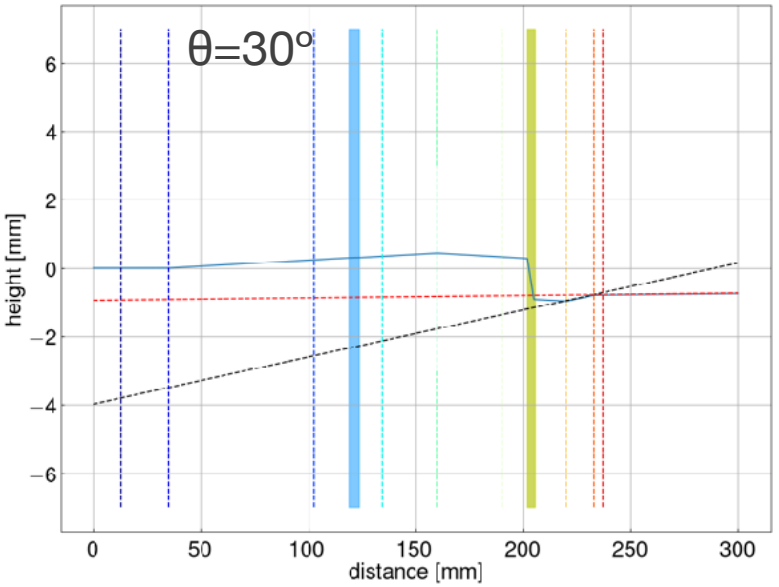
- Considering to put AR coating on both sides by Sigma-koki

Beam Shift Simulation

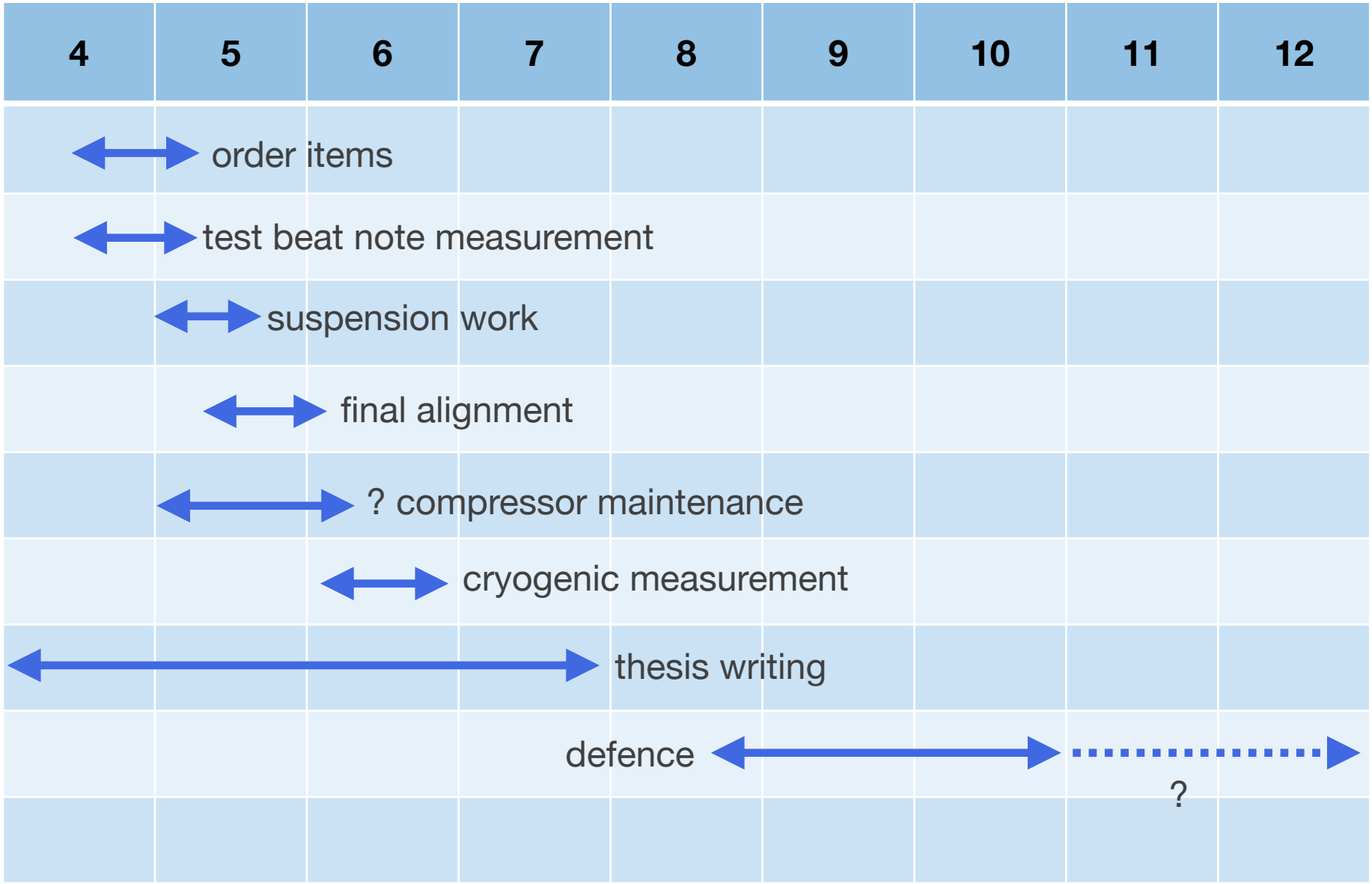








Time Line


4
5
6
7
8
9
10
11
12
order items
test beat note measurement
suspension work
final alignment
? compressor maintenance
cryogenic measurement
thesis writing
defence
?

Summary

Development of Cryogenic monolithic interferometer

- Construction scheme established
  - How to align mirrors?
  - How to bond them?
- Faced some problems
  - How to compensate mirror tilts?
  - How to align beam spot on QPDs?
  - What causes transmission fluctuation?

Goal is close.

End

Research Items

Research items:

- Investigation of components
  - Can survive under cryo. temp. or not
  - Good physical property (CTE, Q value, …) under cryo. temp.

- Alignment procedure
  - How to solve previous issues
  - How to bond

- Noise evaluation
  - Measurement electronics
  - Environmental coupling
  - Laser source related

Bonding

- Bonding candidates

	Hydro Catalytic Bonding	Optical Contact	Epoxy	UV curing
Toughness	○	○	○	△
Stability	○	○	○	△
Handling	few weeks for full cure	Difficult to Detachable	○	○
Cryo. temp.	○	○	case by case	unknown

- Tested epoxy and UV-curing glues

Cooling Test

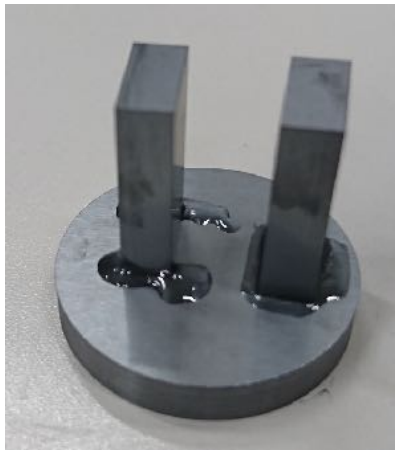
Silicon blocks are glued by:

- Stycast 1266
- DP190

Epoxy

- NOA63
- NOA81

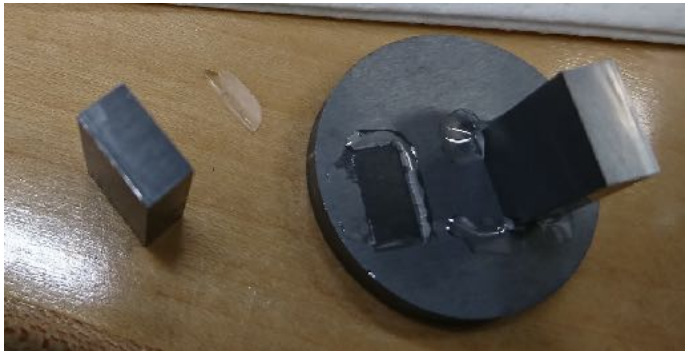
UV curing



And cooled to 4 K

- UV curing glues were broken after heating up to room temp.
- DP190 was also broken after a few cooling & heating cycles

I chose Stycast 1266



Bonding Material

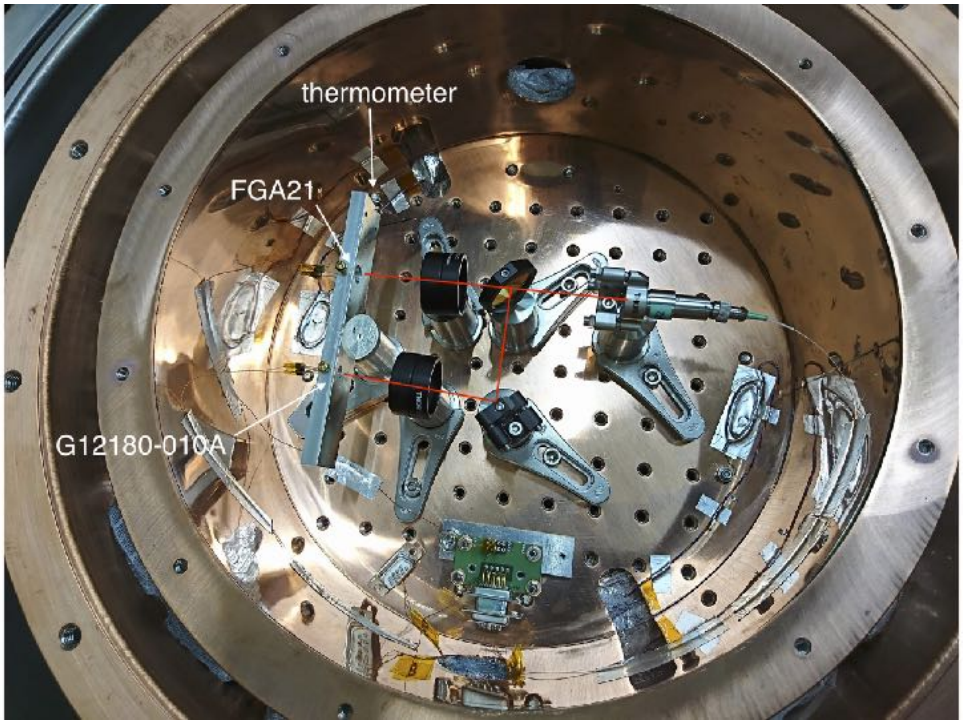
- Bonding test with materials
- Silicon, aluminum, IC-DX(invar, specialized in low temp.

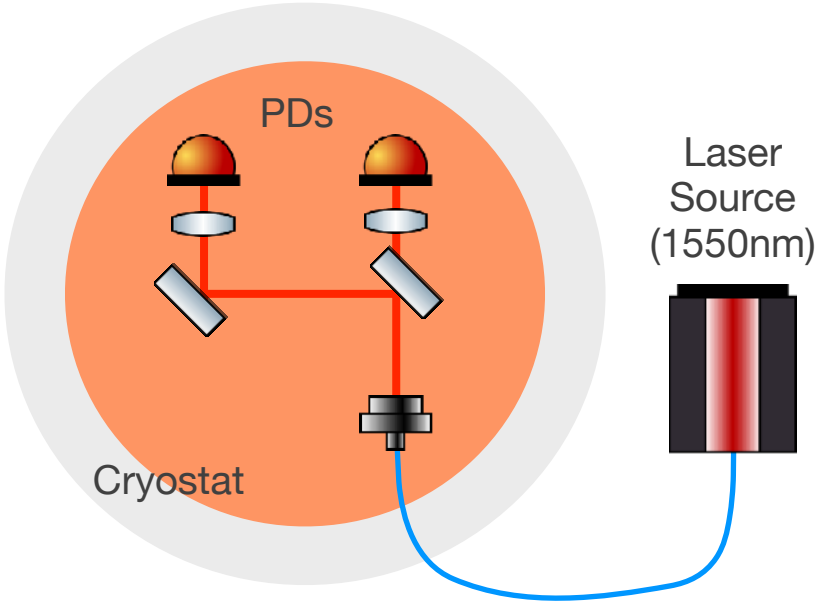
	SIlicon	Aluminum	IC-DX
Silicon	○	✕	○
Aluminum	-	○	not tested
IC-DX	-	-	not tested

- Aluminum - silicon: silicon cracked
  - Thermal contraction difference is large?
  - Silicon is more fragile than aluminum
- IC-DX - silicon: silicon survived
  - Thermal contraction difference is small?

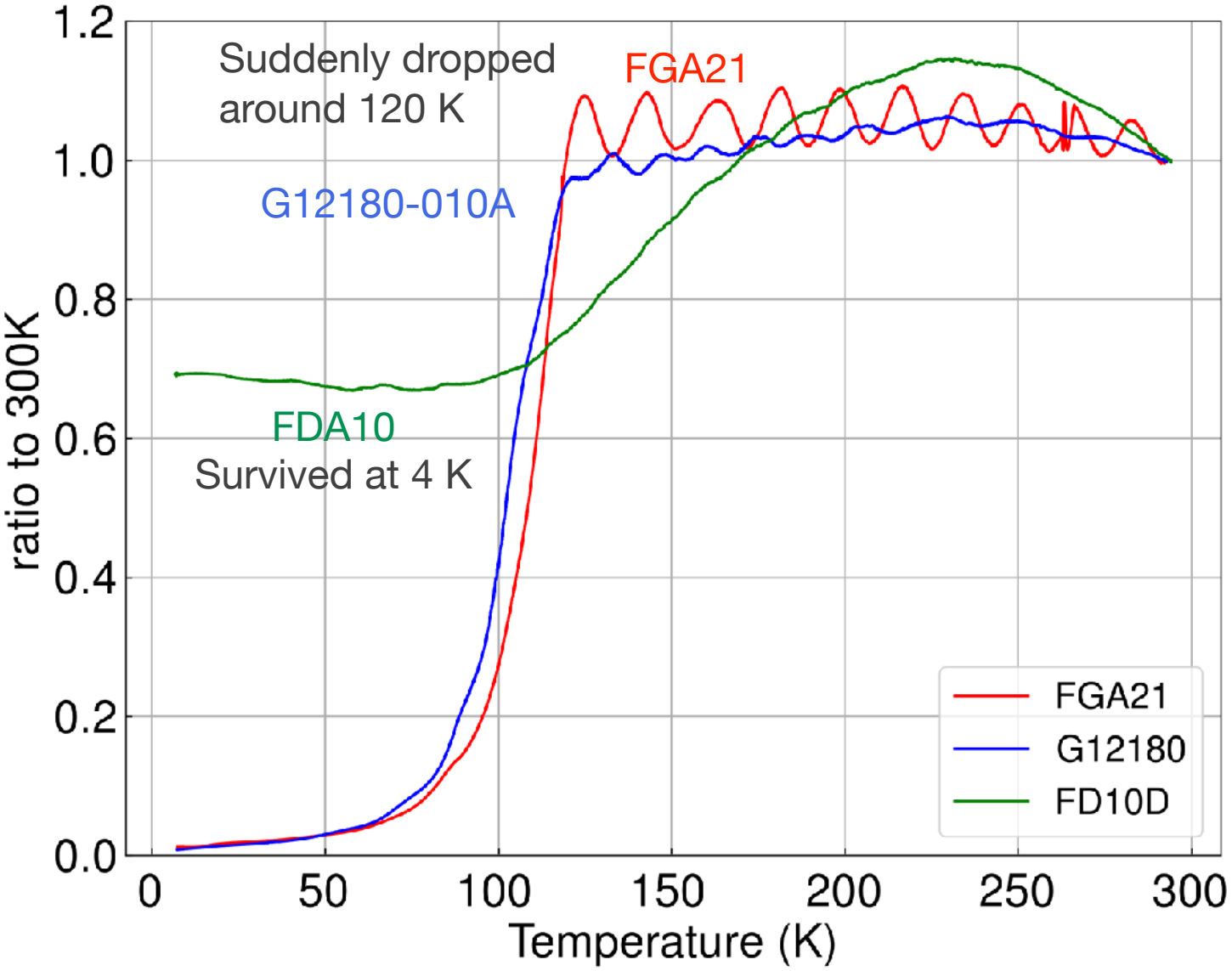
PD Selection

- Some types of PD were put in the cryostat and cooled to 4 K
- Laser light was introduced by a optical fiber
- Measured the output voltage
- PDs: FGA21, FD10D (Thorlabs), G12180-010A (Hamamatsu)



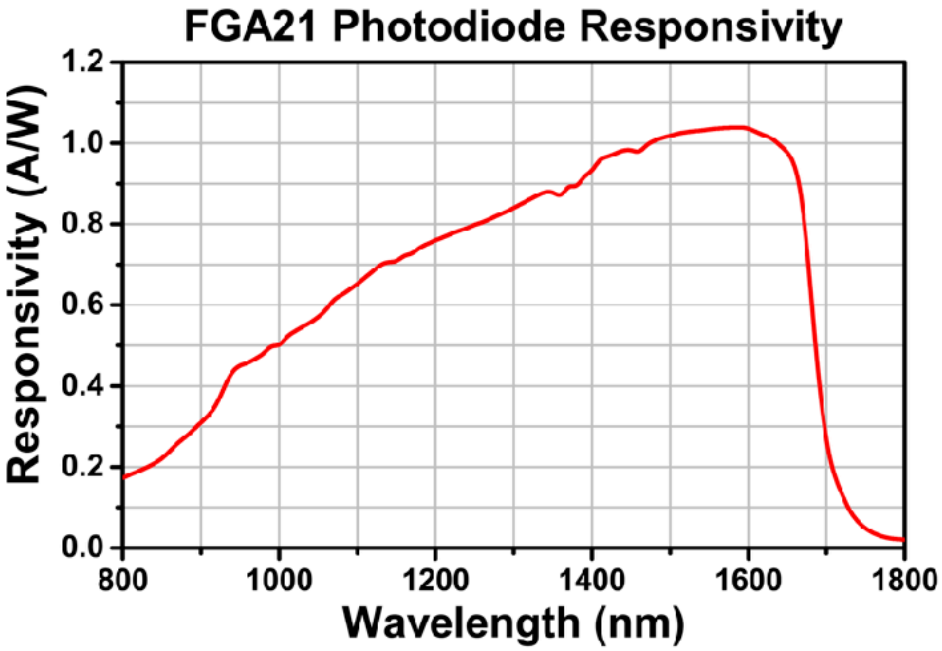


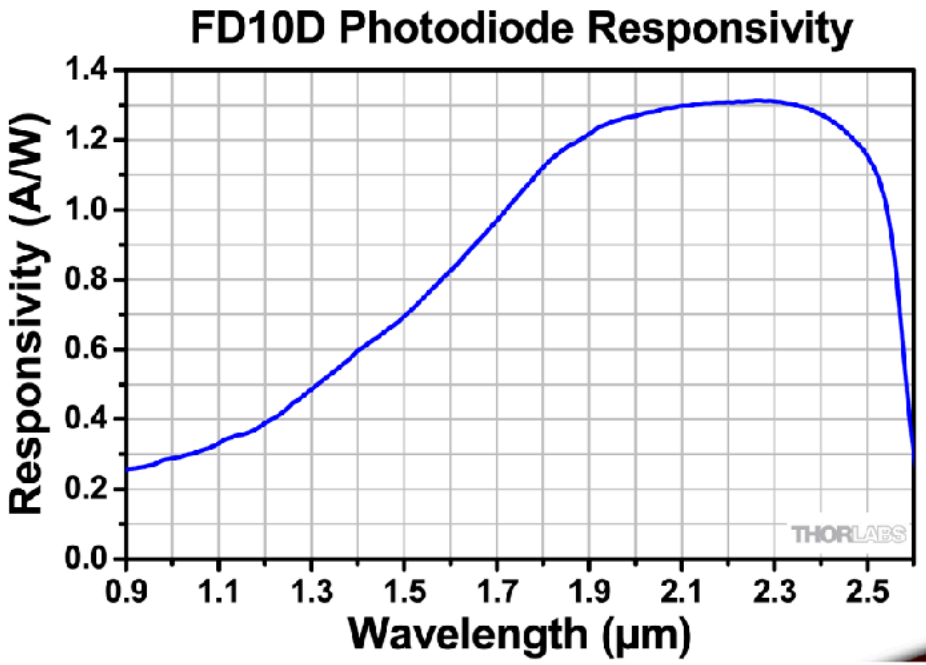
Results


Suddenly dropped
around 120 K
FGA21
G12180-010A
FDA10
Survived at 4 K
ratio to 300K
Temperature (K)
FGA21
G12180
FD10D
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
50
100
150
200
250
300

Results

- Cutoff wavelength of the PD response
- FGA21, G12180-010A: ~ 1650 nm
- FD10D: 2500 nm
- Cutoff frequency is shifted to the shorter wavelength during the cooling?





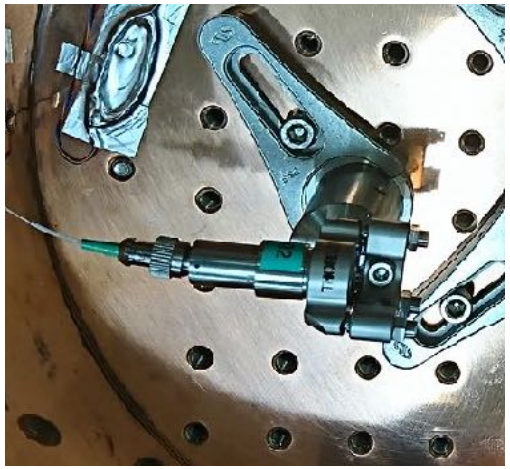
QPD

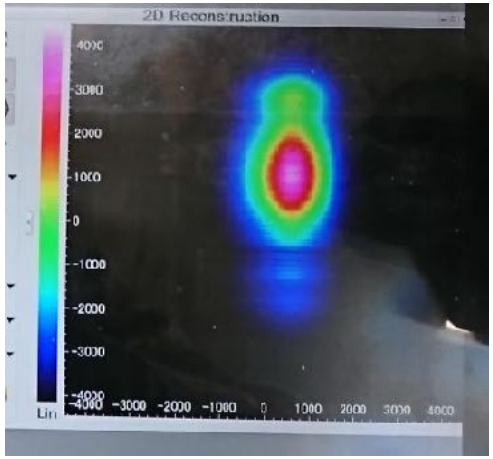
- For normal PDs I adopted FD10D
- How about QPDs?
  - Couldn’t find out QPDs with cutoff wavelength similar to FD10D
  - Ordered such QPDs to Hamamatsu Photonics

- I tested its response at some temperatures (down to 4 K)
  - Confirmed that the response is similar to that of FD10D

Fiber Collimator

- During the PD response measurement I used a fixed focus collimator F260APC-1550 (Thorlabs)
- After some cooling-heating cycles, I noticed that the shape of the output beam got ugly

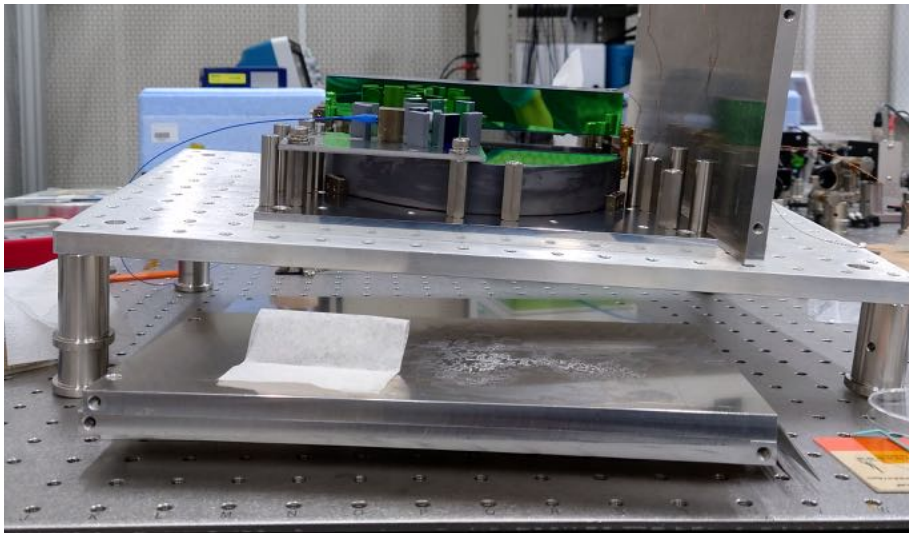


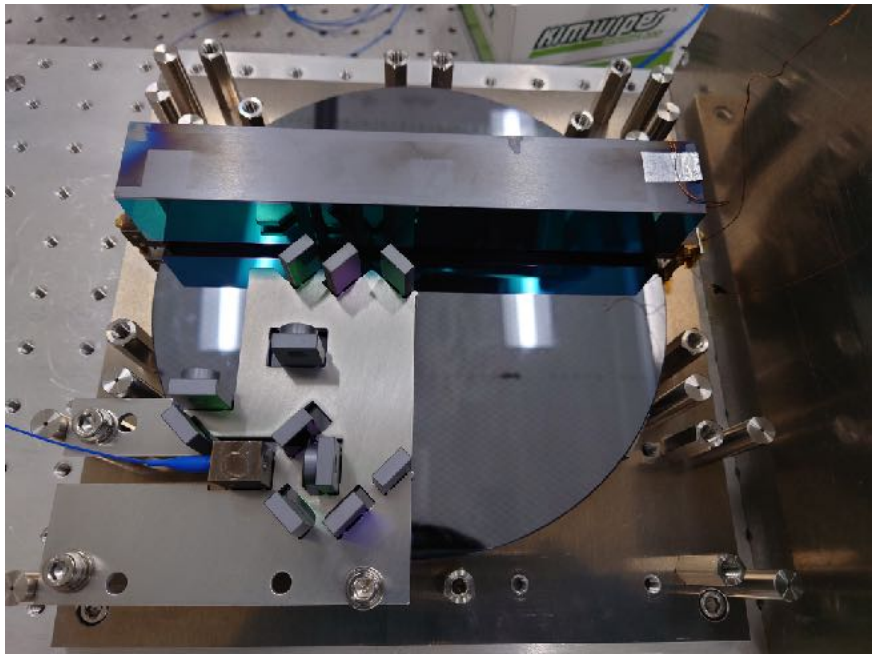


- I changed the collimator to other fixed focus collimators, and similarly the output shape changed
  - Changed the collimator type to pigtail ones
  - Tested them by cooling, and so far they looks good

The Current Status

- A half of template bonding was done
- The remained part will be done in a couple of days

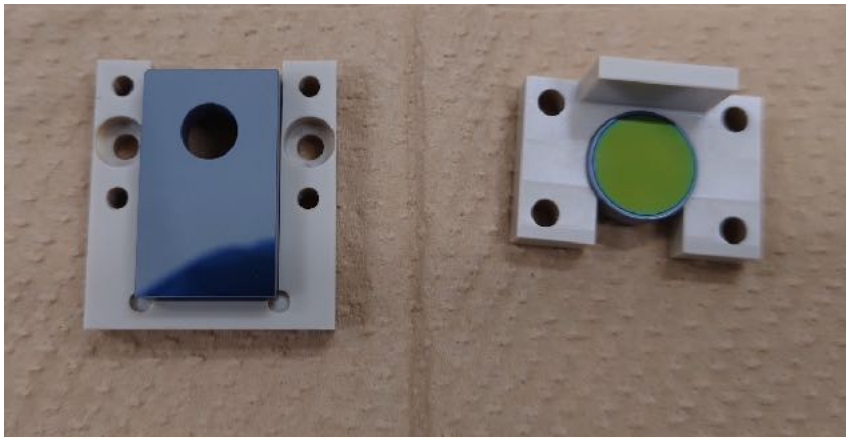


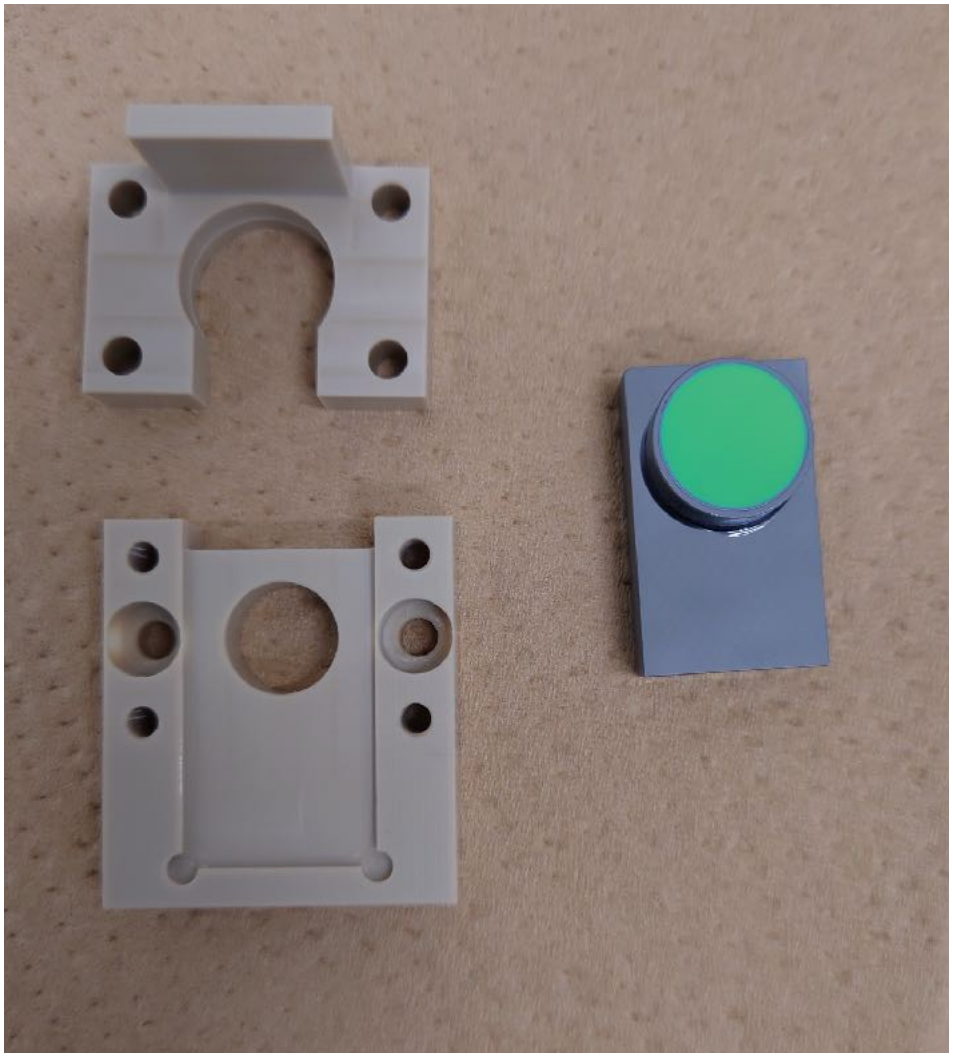


- Suspension will be installed during next week
  - Cooling start

Extra Photos

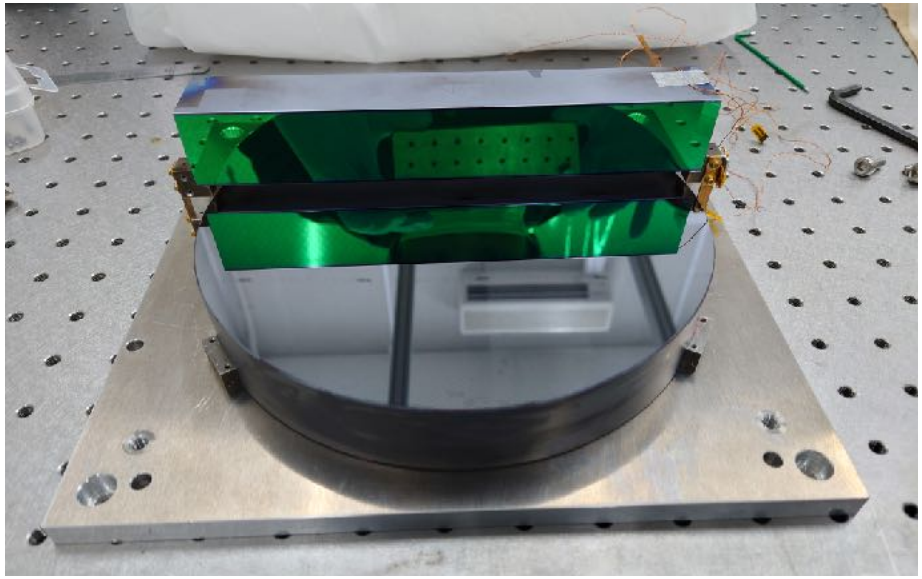
- Lens & cavity mirror bonding



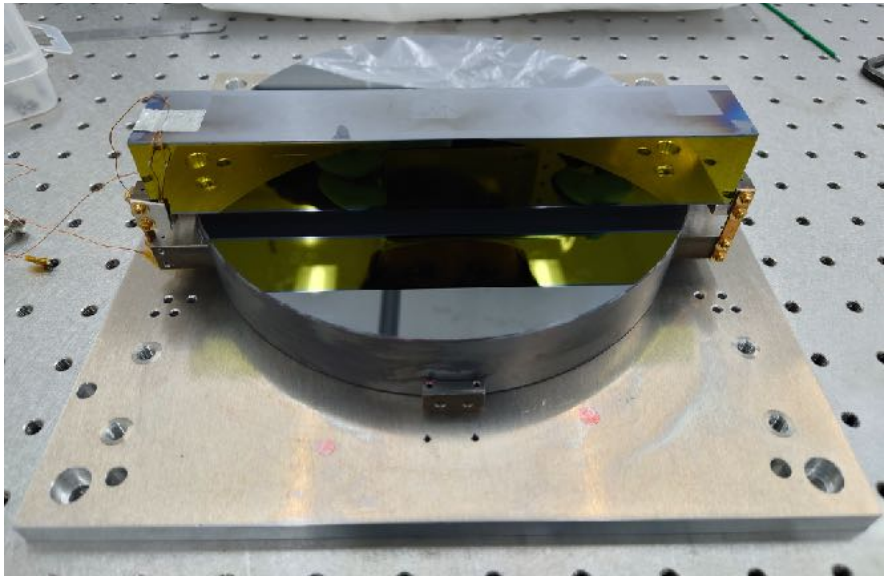


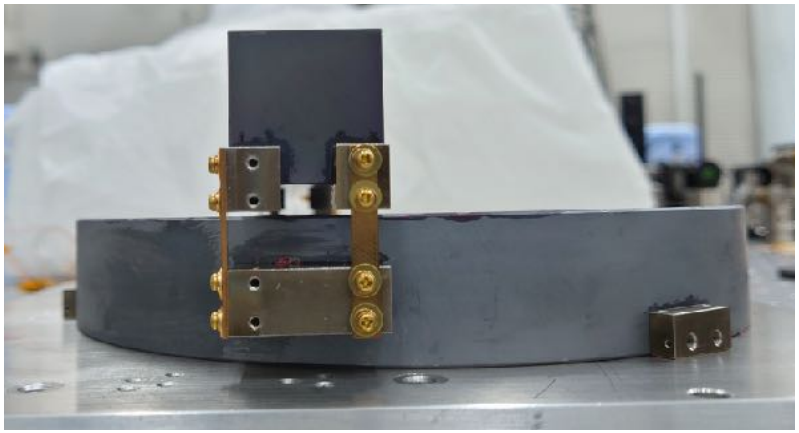
TM Support

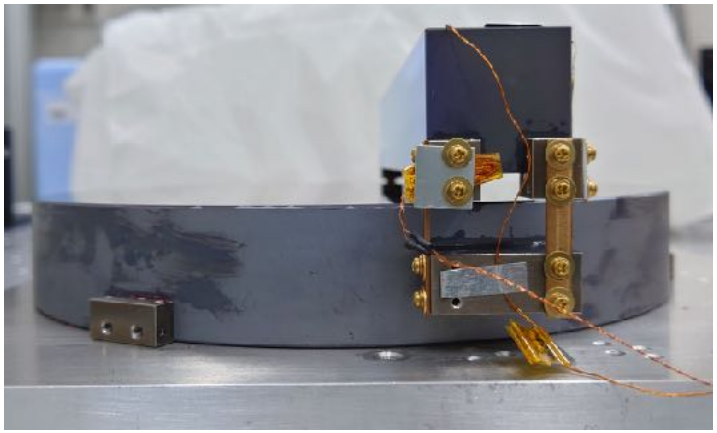
HR side



AR side







Collimator Bonding