Status of the input optics for the O3

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University of Toyama

KAGRA

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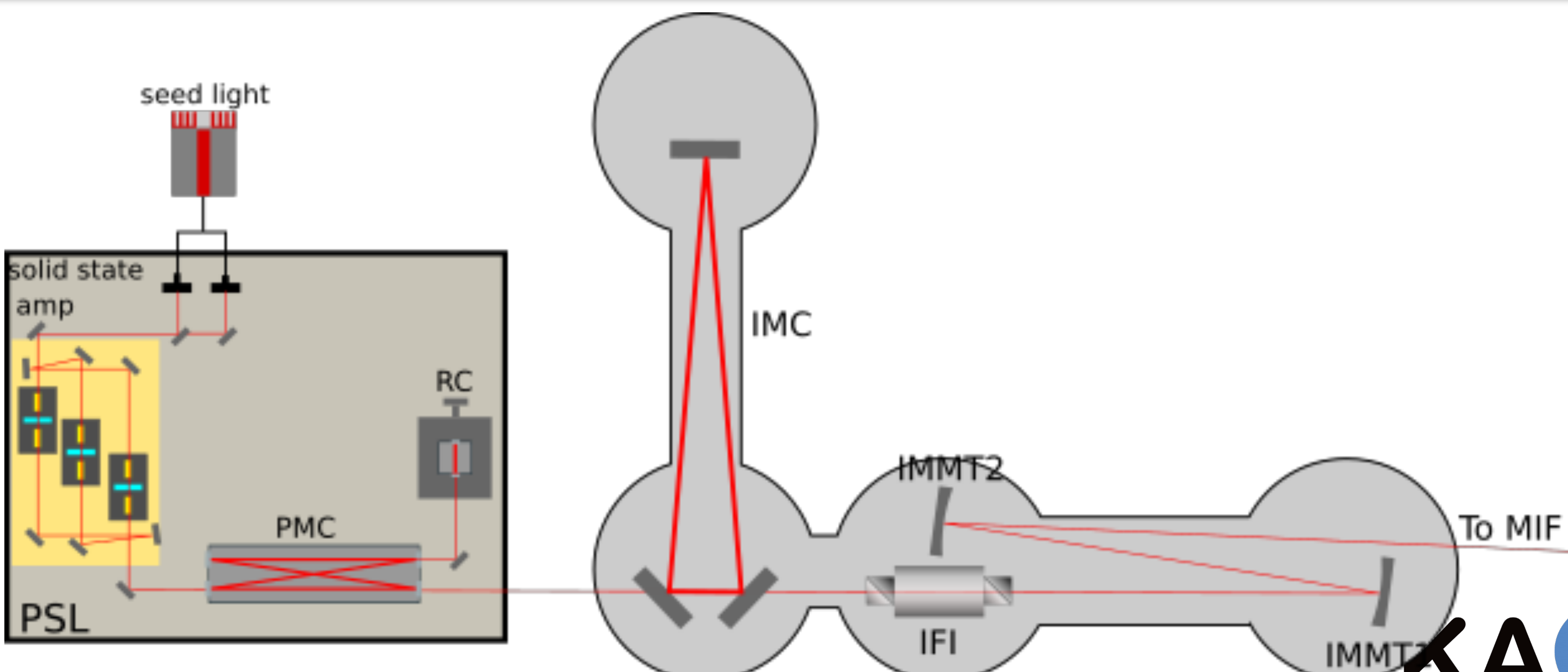
Objectives of the input optics

Objectives of the input optics

Provide the stable laser to the main interferometer.

- ✓ The frequency stabilization
- ✓ The intensity stabilization
- ✓ The reduction of the beam jitter
- ✓ The cleaning of the spacial mode of the laser



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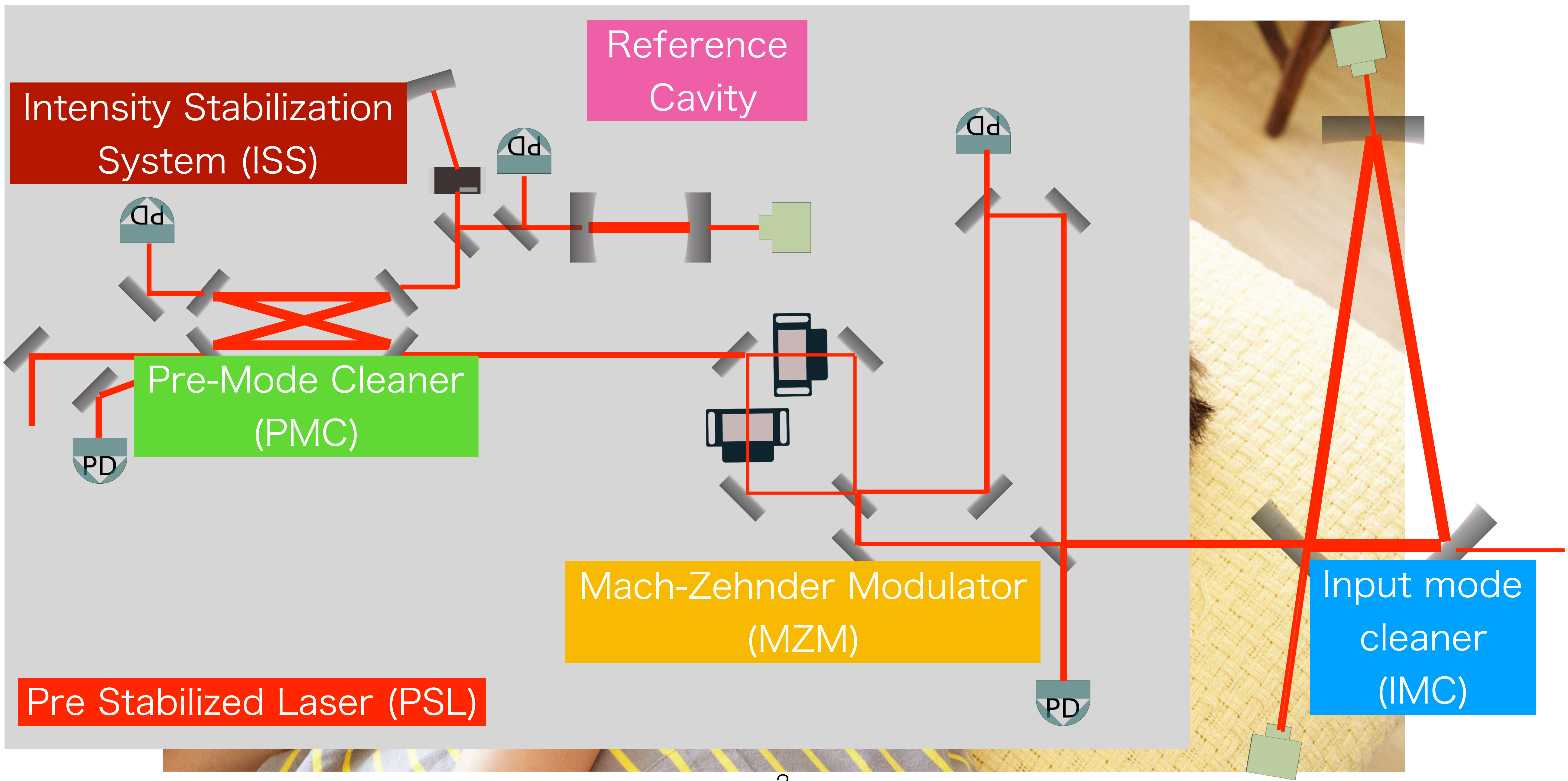
Overview of the input optics



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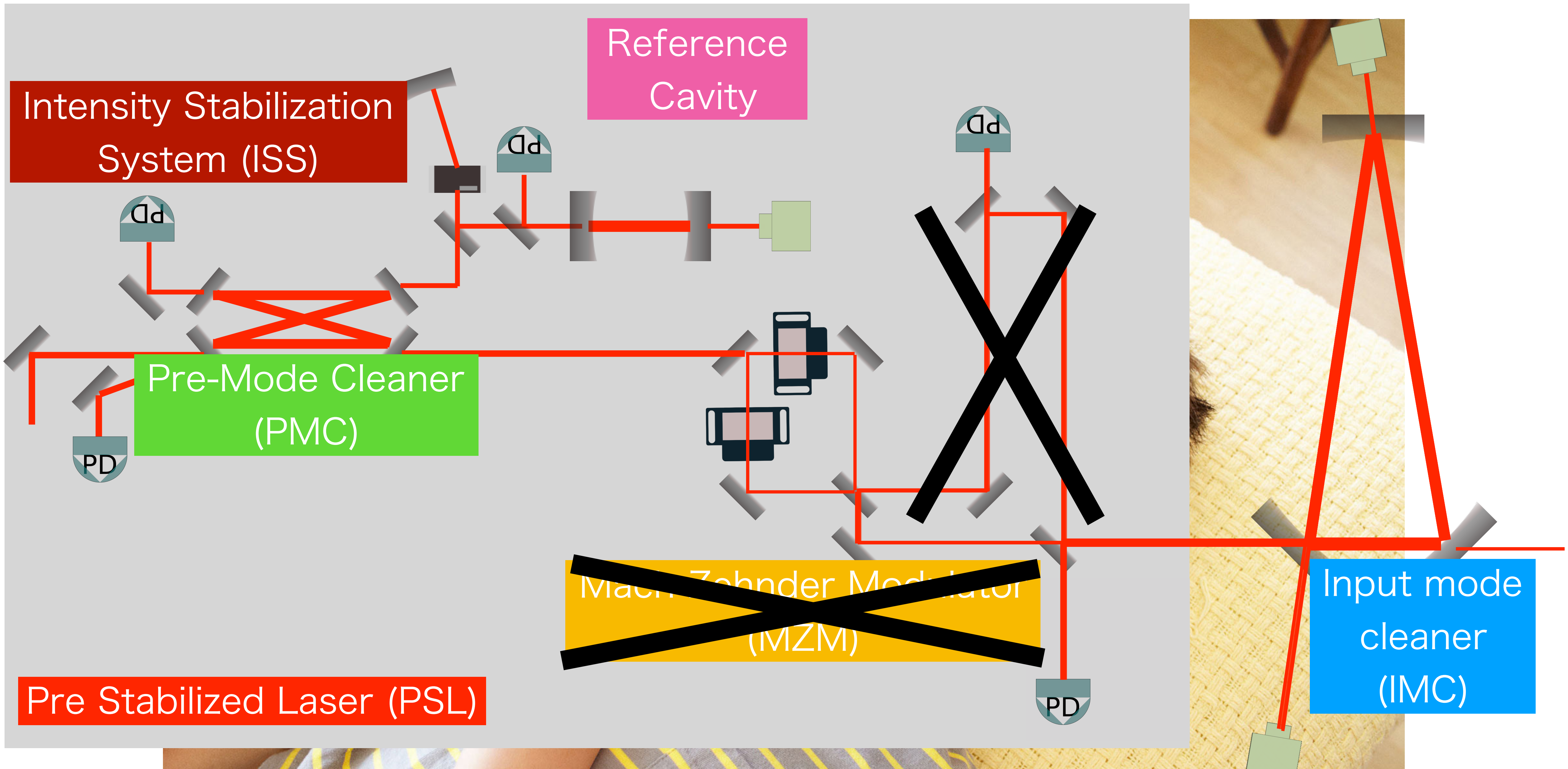
Overview of the input optics



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MZM
PMC
FSS

IOO Status

	Status
PMC	Installed and operated very stably. Noise budget (NB) has been done
RefCav	Installed and operated very stably. NB is on going
ISS	Installation is on going
MZM	Installed once, but removed and not used for O3
IMC	Installed and operated very stably
HP test	Have done, and ready
Safety	On going

IMC alignment sensing and control

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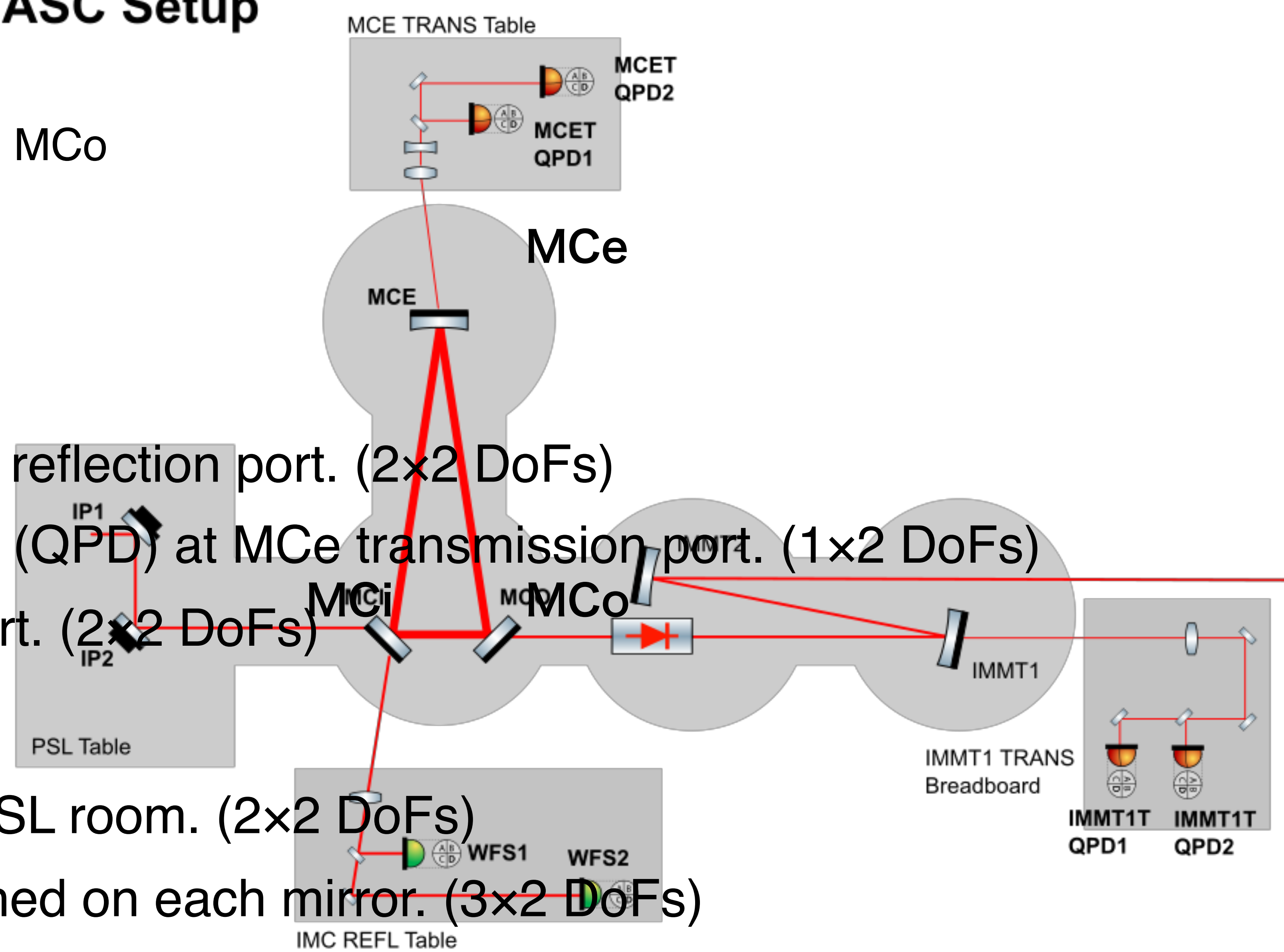
IMC alignment sensing & control (ASC)

- IMC ASC DoFs
  - ✓ Cavity axis (3×2 DoFs)
    ➡Bases:
    Diff./Comm. motion of MCi and MCo
    Beam position on Mice
  - ✓ Input axis (2×2 DoFs)
- Sensors
  - ✓ Wave Front Sensors at IMC reflection port. (2×2 DoFs)
  - ✓ DC quadrant photo detector (QPD) at MCe transmission port. (1×2 DoFs)
  - ✓ DC QPDs at MCo output port. (2×2 DoFs)
- Actuators
  - ✓ Input pointing PZTs in the PSL room. (2×2 DoFs)
  - ✓ Magnet-coil actuators attached on each mirror. (3×2 DoFs)

ASC Setup



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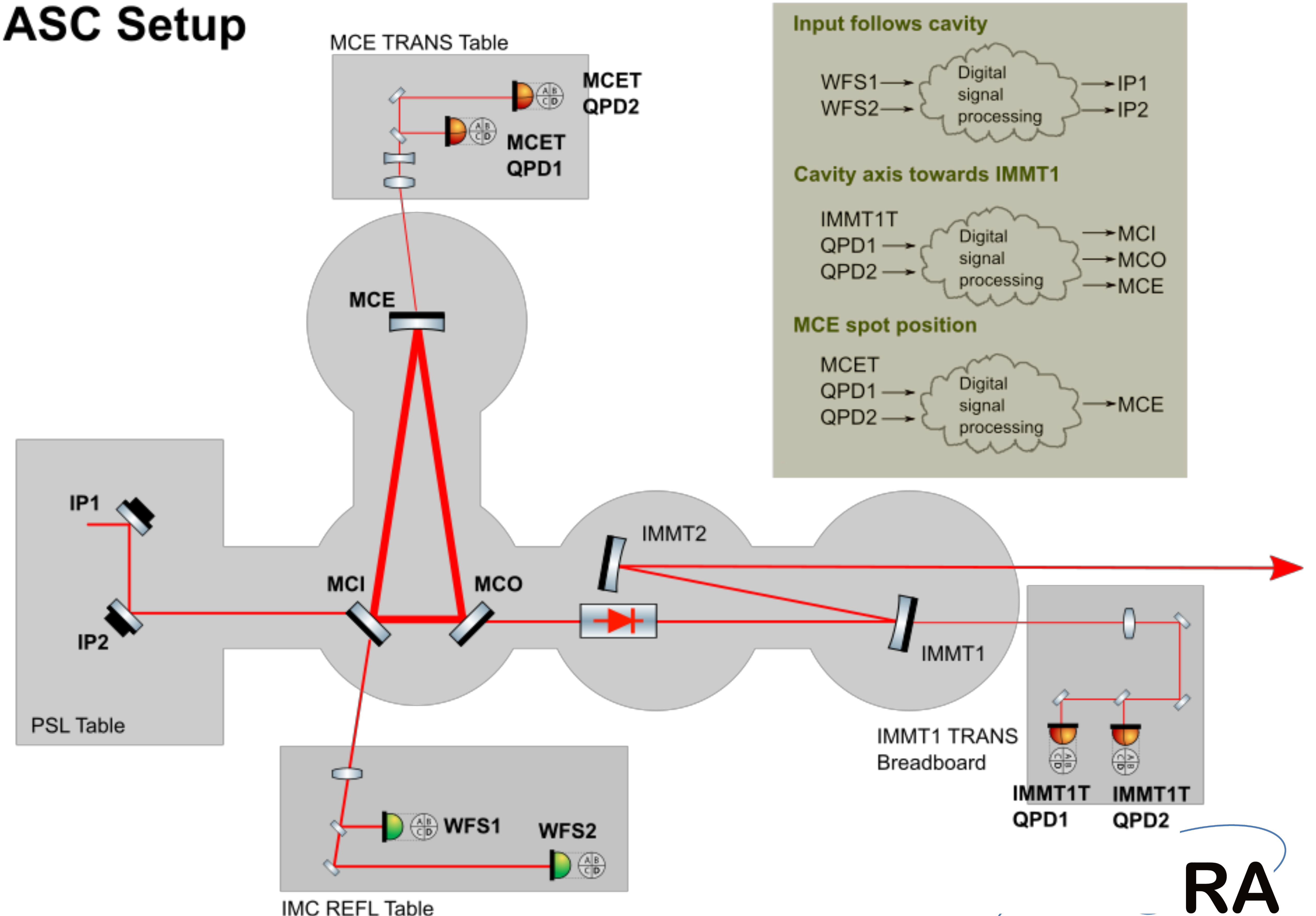
ASC Setup

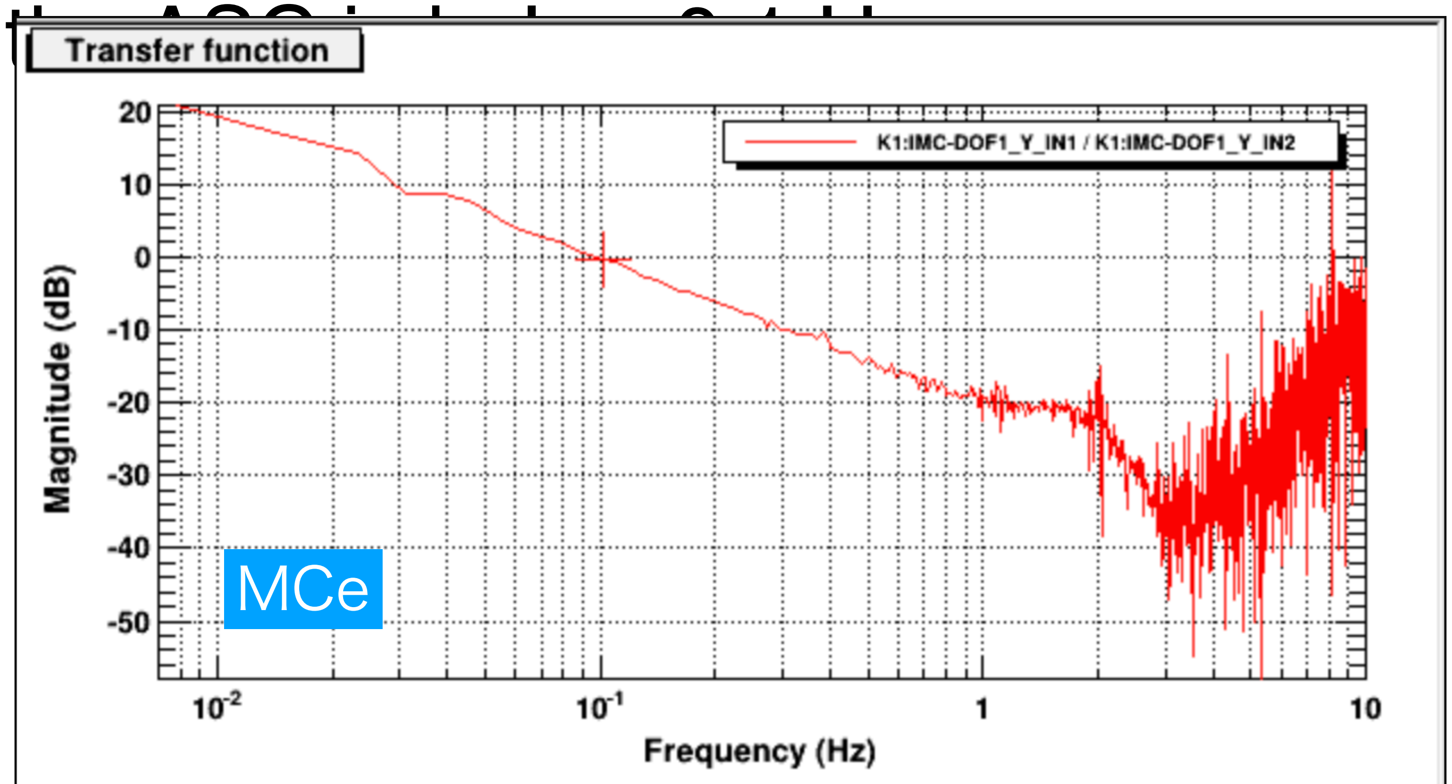
Planned feedback configuration

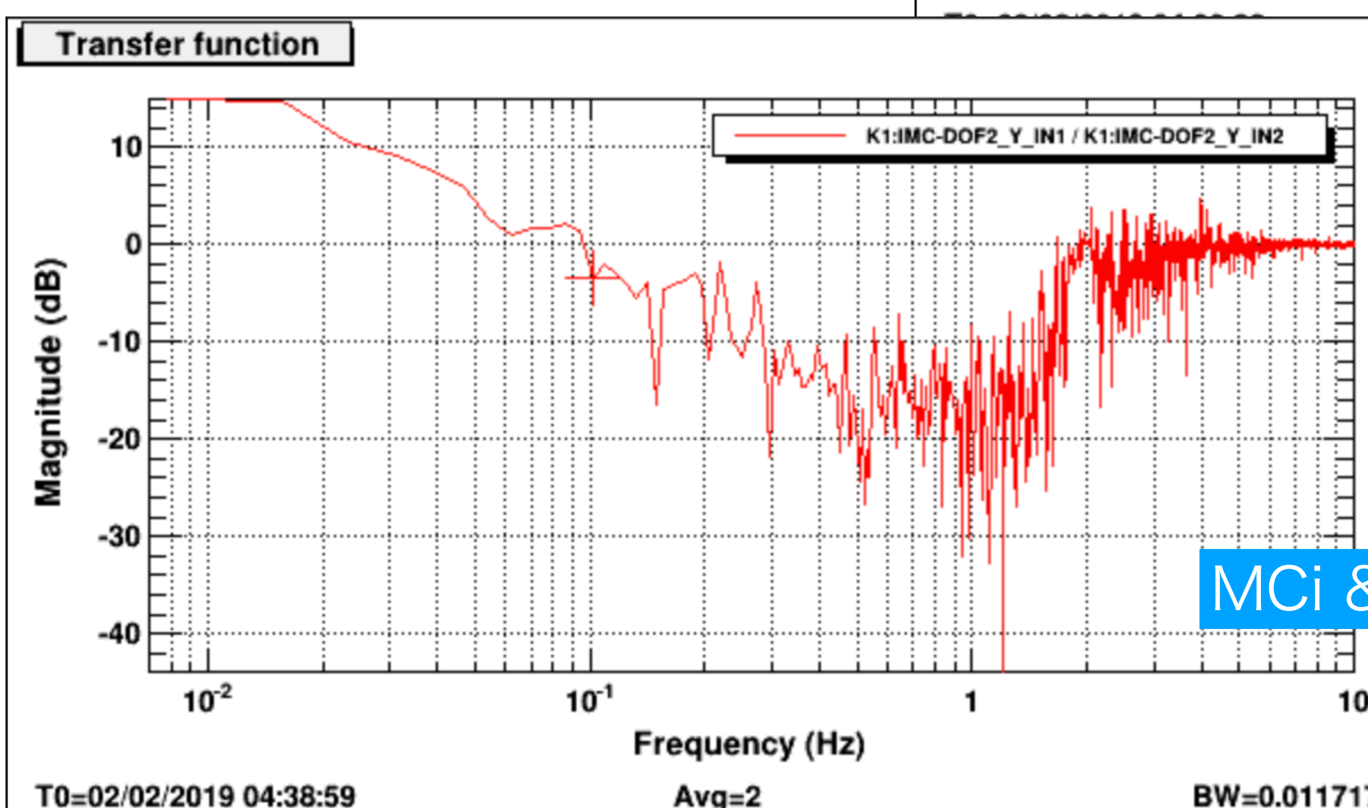


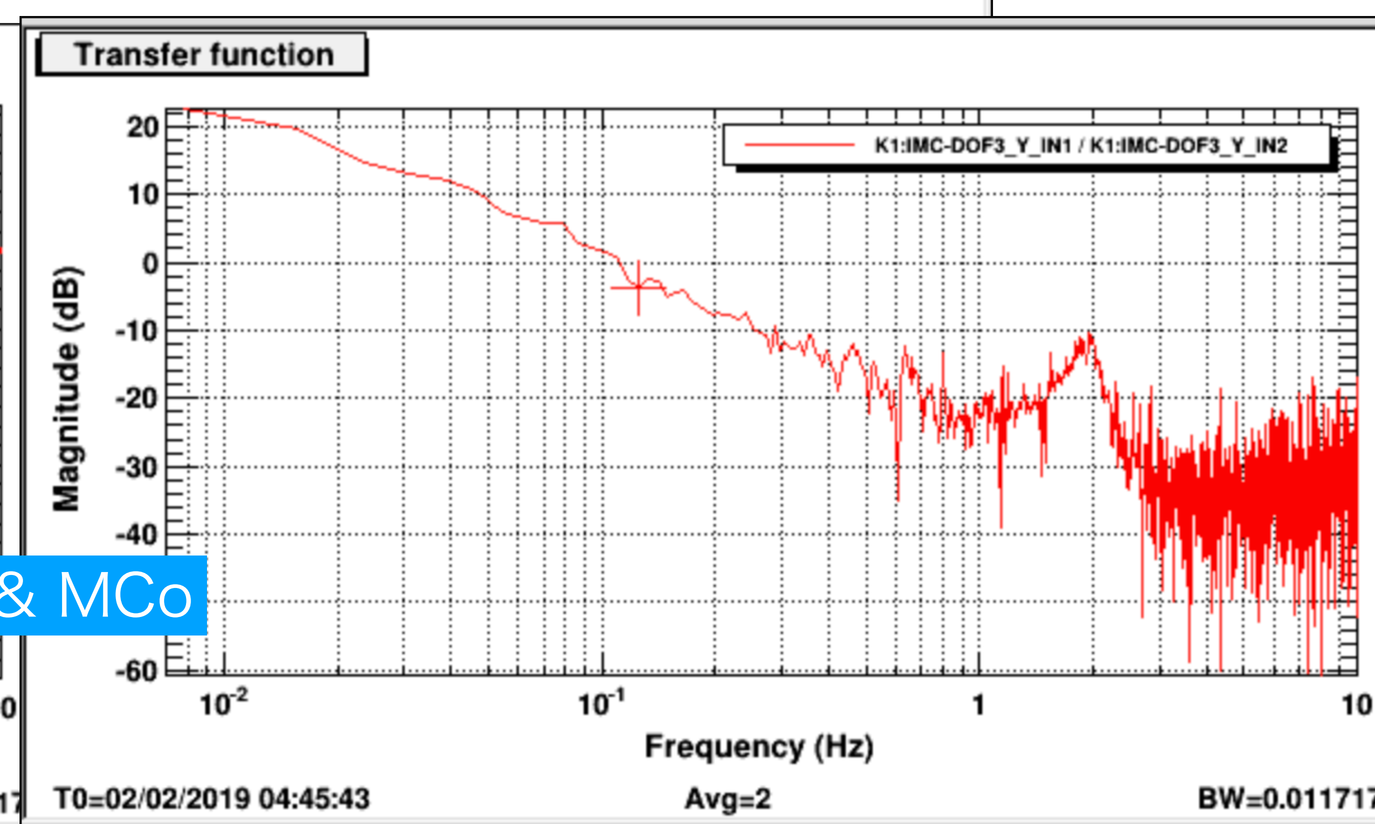
Control bandwidth

- The bandwidth of t

Open loop transfer functions for 3 DOFs







MCi & MCo

To Dos beyond O3

- Two IP PZTs are degenerated due to the PSL beam propagation design, and we could not control all of the DoFs.
  - ✓ We can only control 4×2 DoFs in 5×2.
  - ✓ We need to re-design and re-align the PSL optics.
- Noise budget and hunting
  - ✓ No noise budget so far.
  - ✓ Ex.) IMC REFL table has wind-shield, but is not good enough.

High power test

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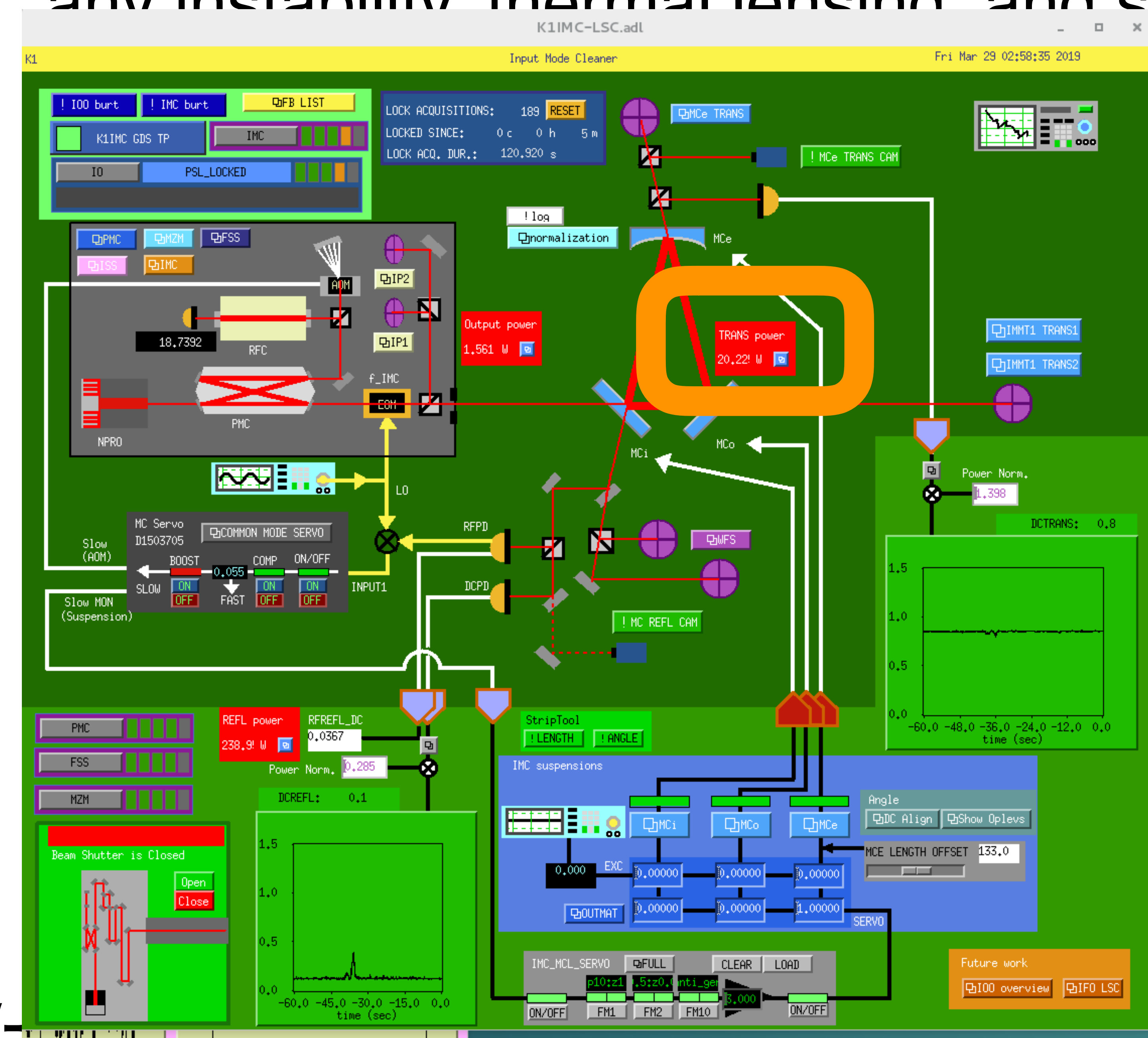
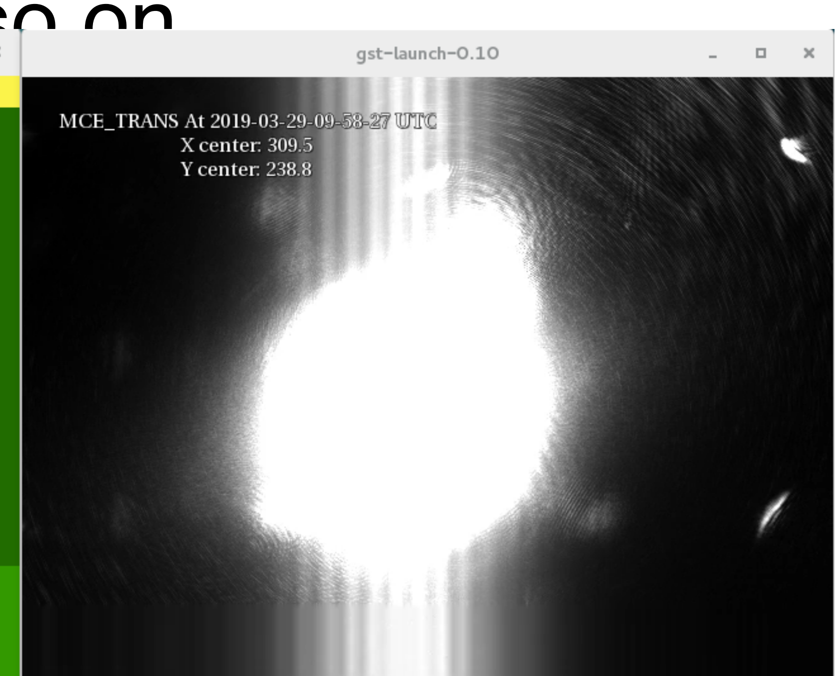
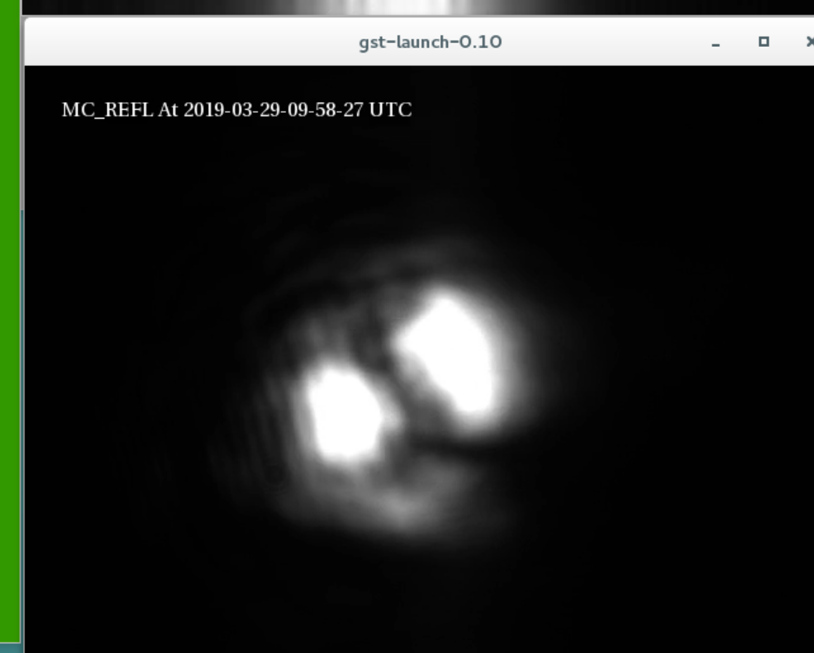
High power test

- The laser power reached up to 20 W at the IMC output.
- We operated the IMC with HP for ~1h, but we did not observe any instability, thermal lensing, and so on.

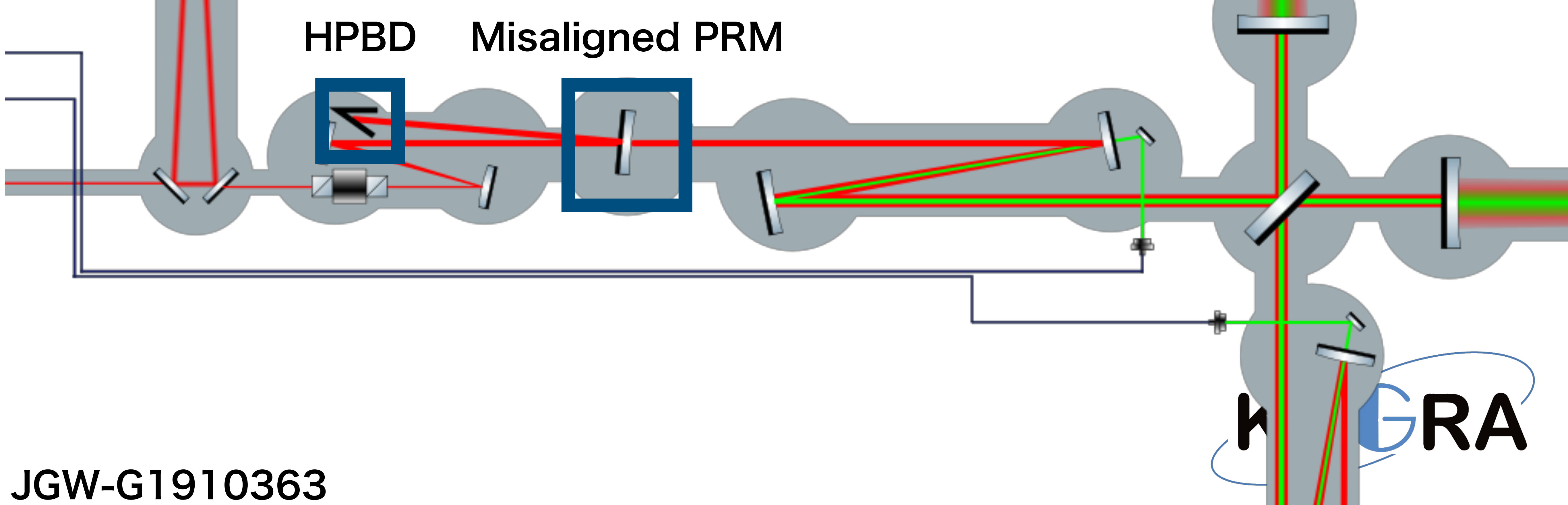






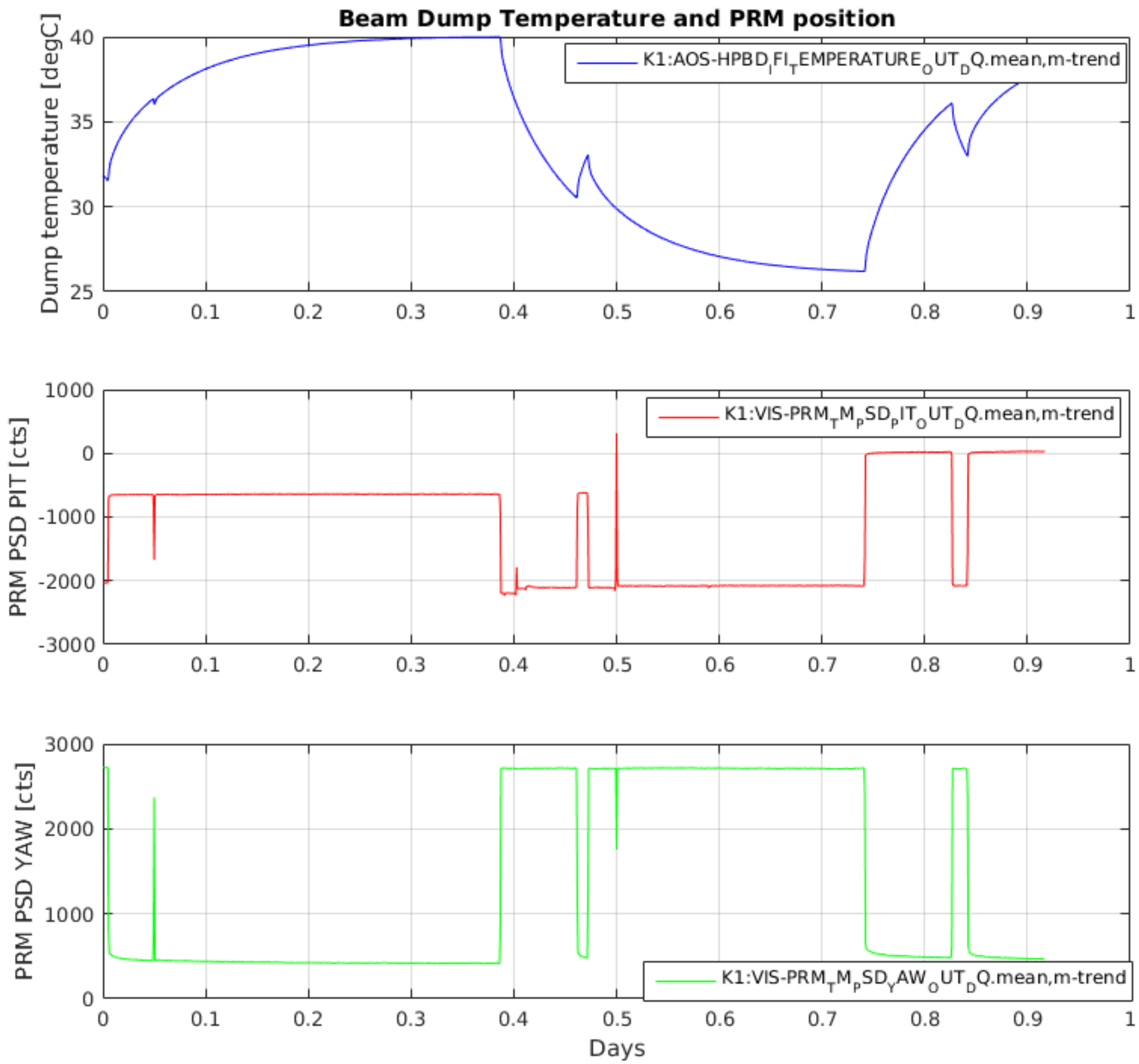
High power beam damp

- During the commissioning, the power-recycling mirror is often misaligned intentionally.
- Since reflectivity of the PRM is 90 %, the reflected beam need to be damped.



High power beam damp

- Thermometer is attached on the beam damp.
- When the beam hits the beam damp, the temperature gets higher.



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Laser Safety

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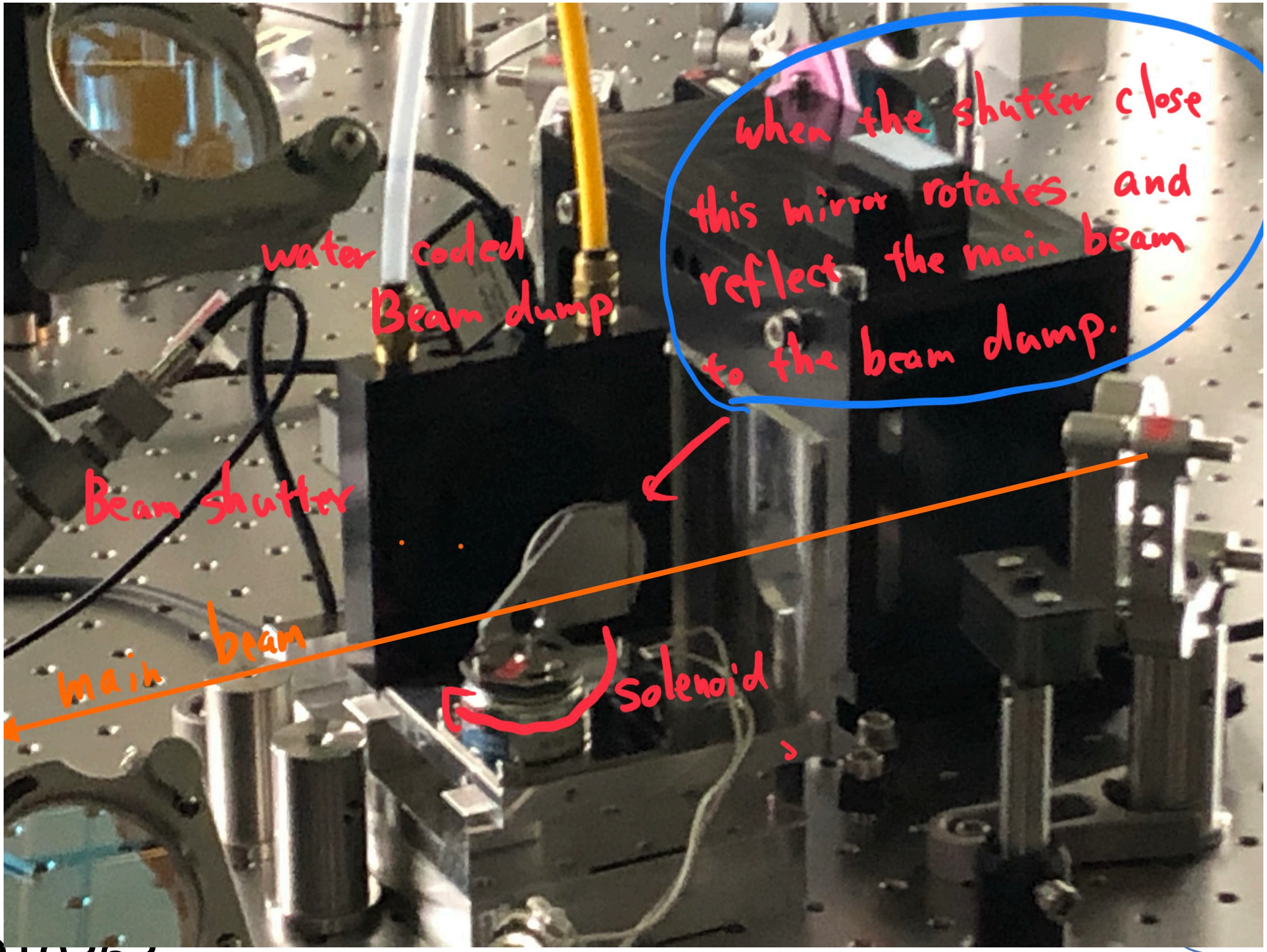
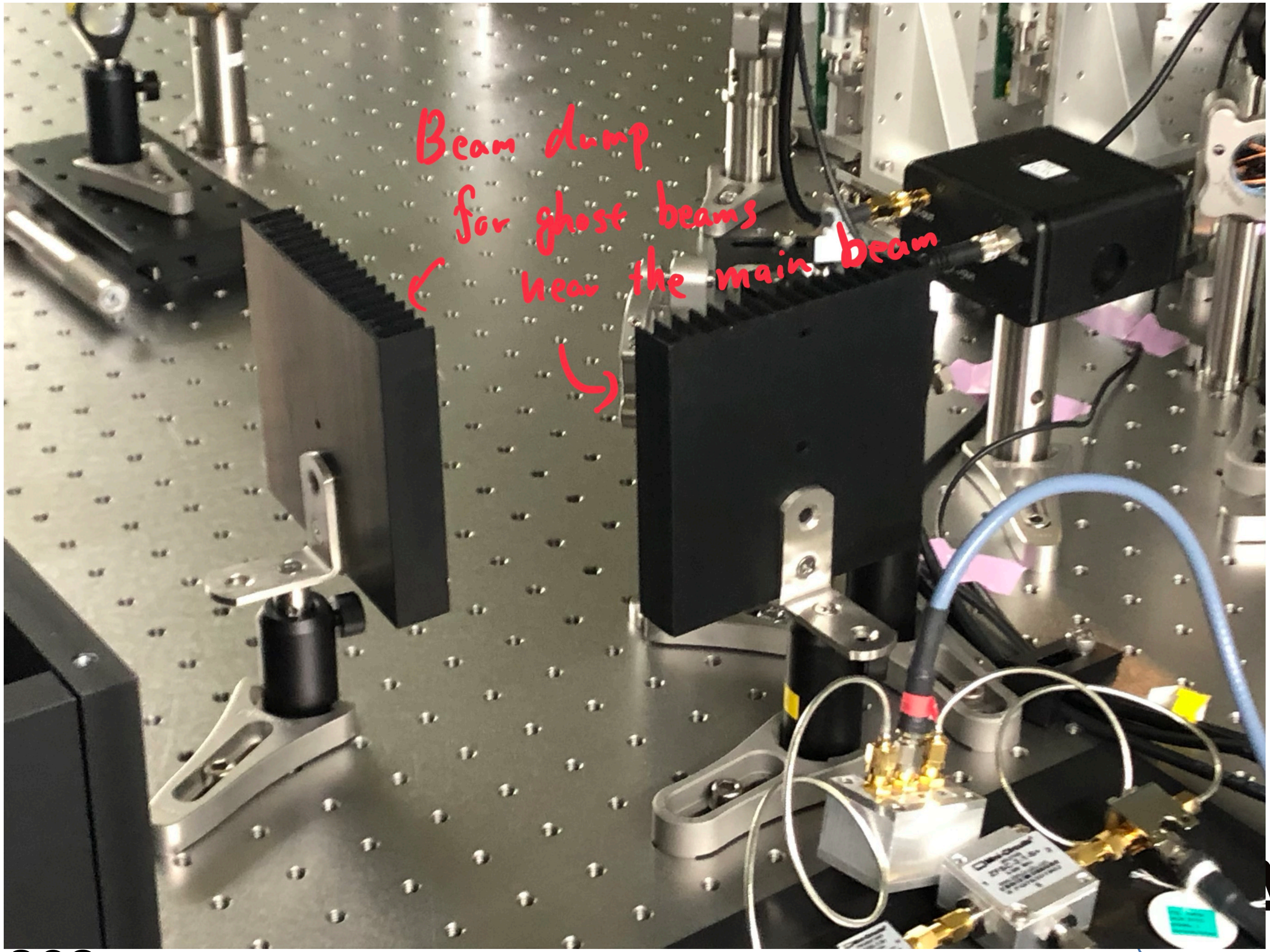
Laser safety

- High power beam shutter



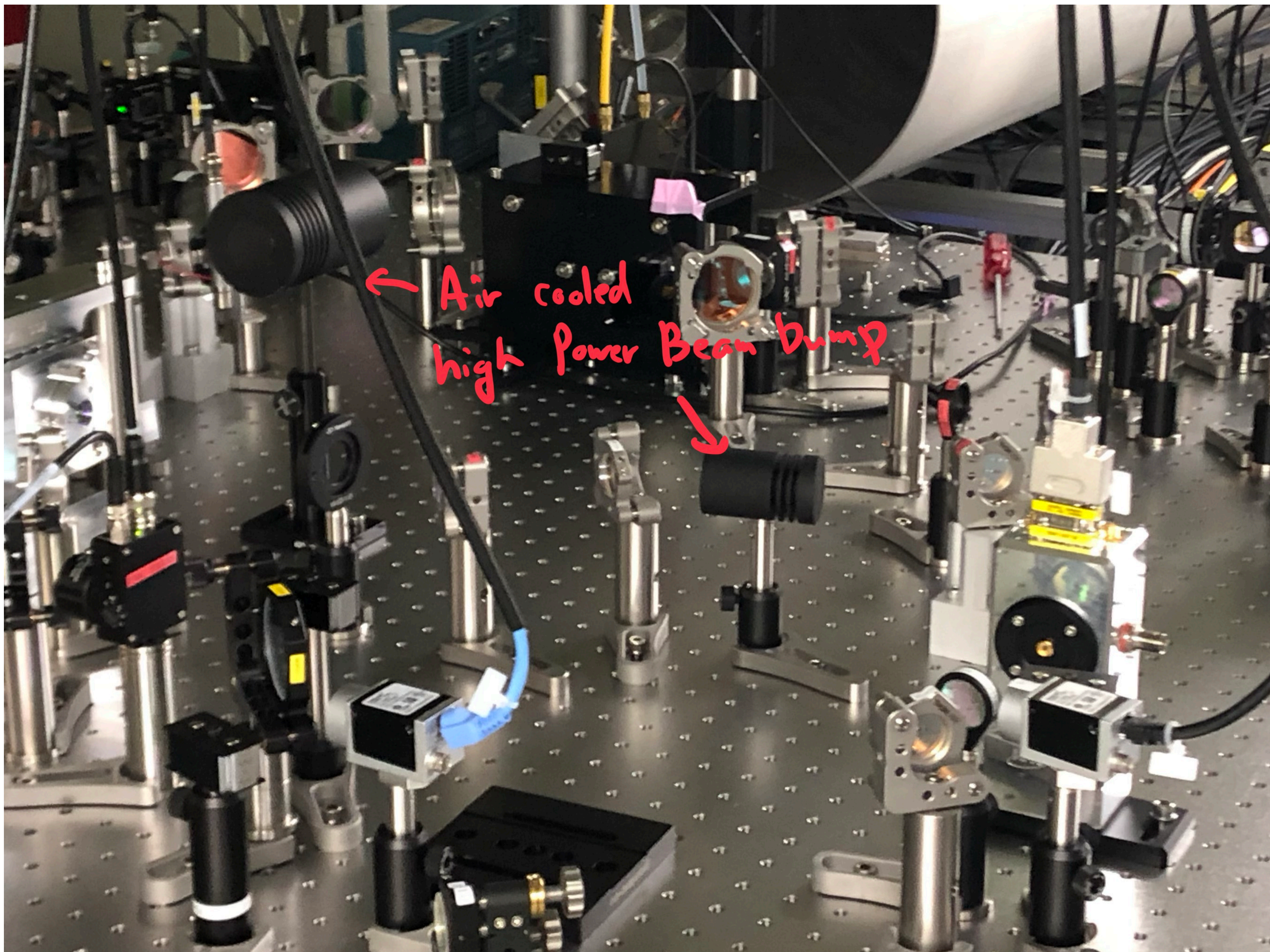
Laser safety

- Beam damp for the ghost beam nearby the main beam



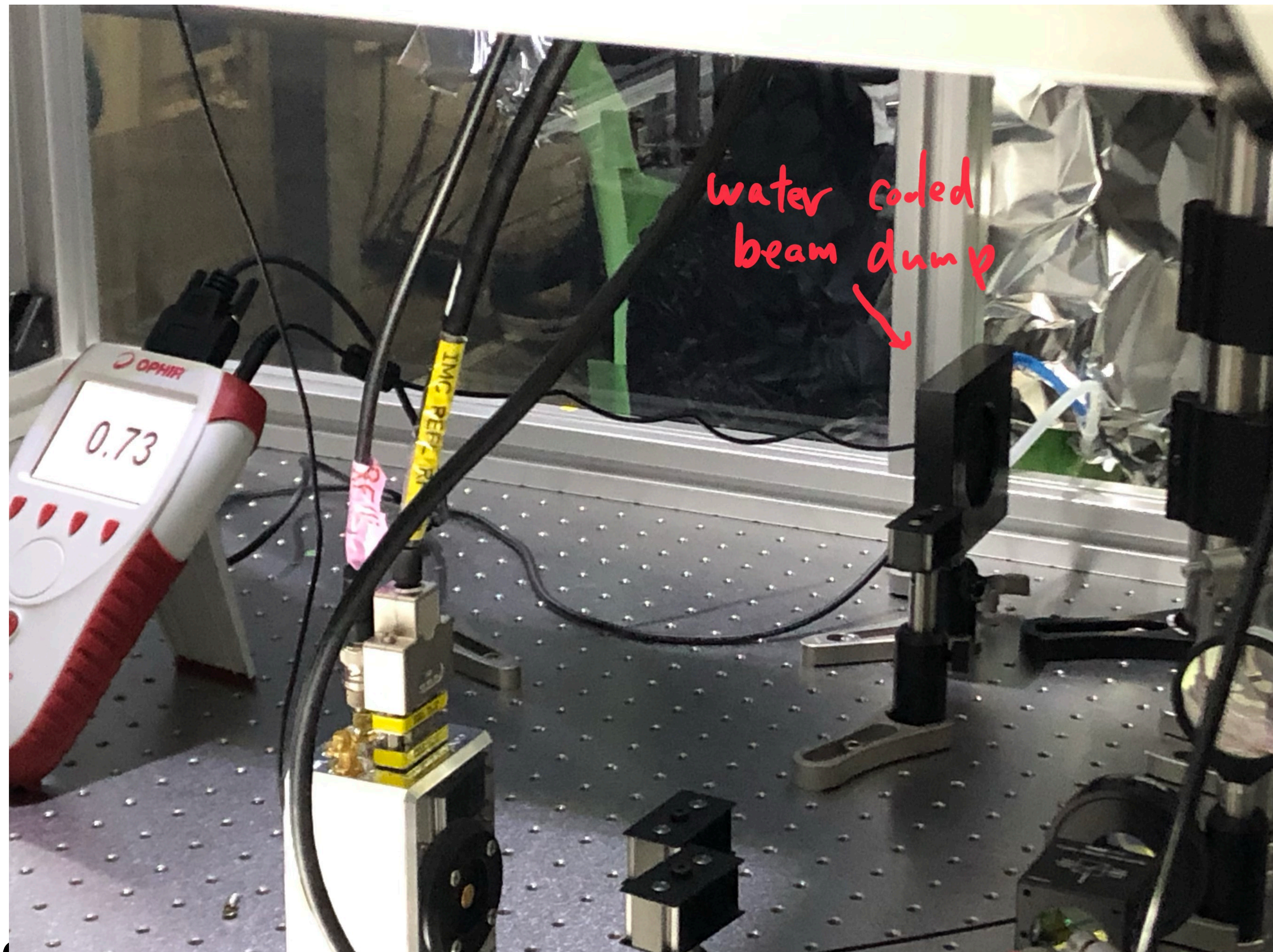
Laser safegy

- Beam damp in the PSL



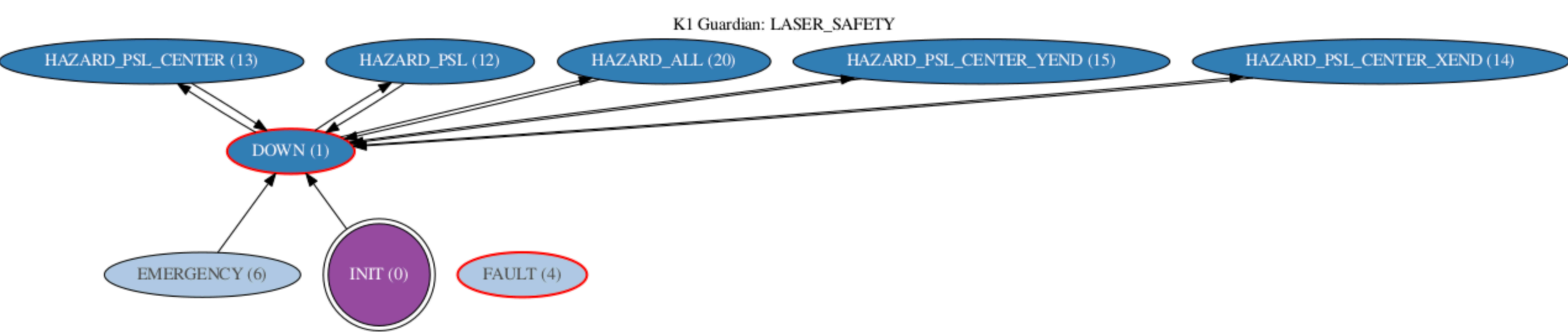
Laser safety

- Water cooled beam damp on the IMC REFL



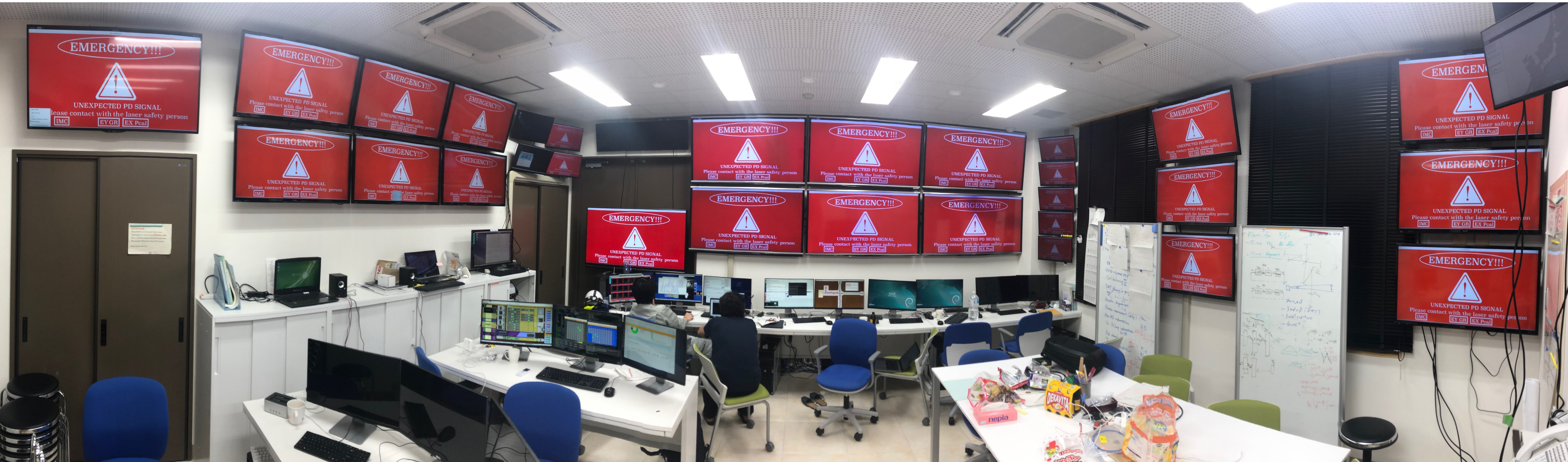
Laser safety guardian

- Guardian is the script to automate the control of IFO, suspension, etc.
- We implemented 'Laser Safety Guardian'
  - ✓ Ex.) If we don't want laser output outside of the PSL room, we just need to request state of 'HAZARD_PSL' to the guardian.
  - ✓ In this state, this guardian shut down all of the laser shutter, and monitor nobody can open it.



Laser Safety Guardian

- ✓ When the guardian had a request to change the state, it send e-mail to the safety manager.
- ✓ Furthermore, it monitor the PD signals outside of the PSL, and if there is any unexpected PD signal, the control room goes to ‘emergency state’ shown in the picture.



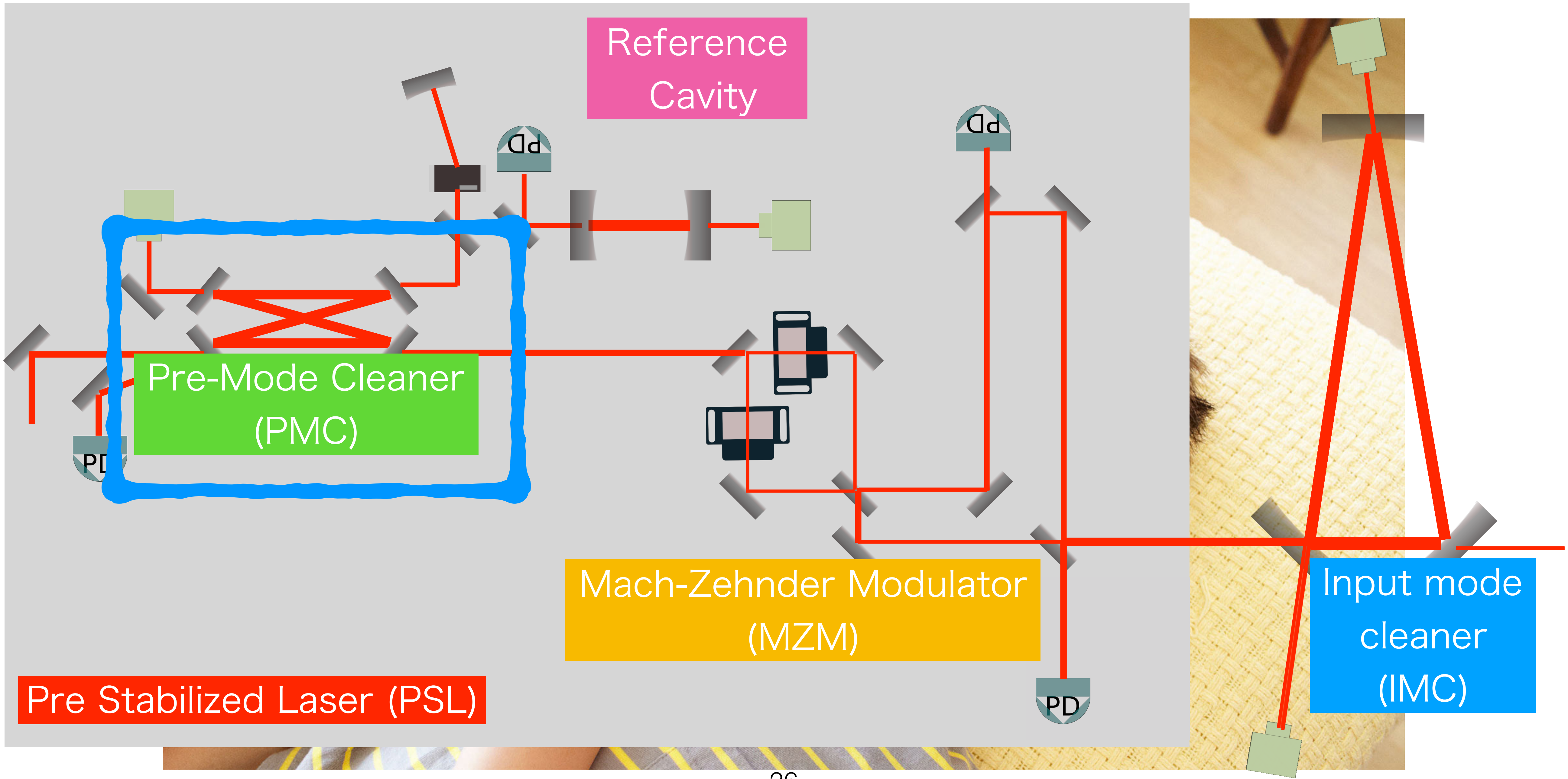
Summary

- All systems are installed and being operated.
- IMC ASC has been implemented, but we need to modify the system after O3.
- High power test has been done, and we are ready to provide 20 W laser into the main interferometer.
- Laser safety control is being improved.

Appendix

Pre-Mode Cleaner (PMC)

Pre-Mode Cleaner



Pre-Mode Cleaner (PMC)

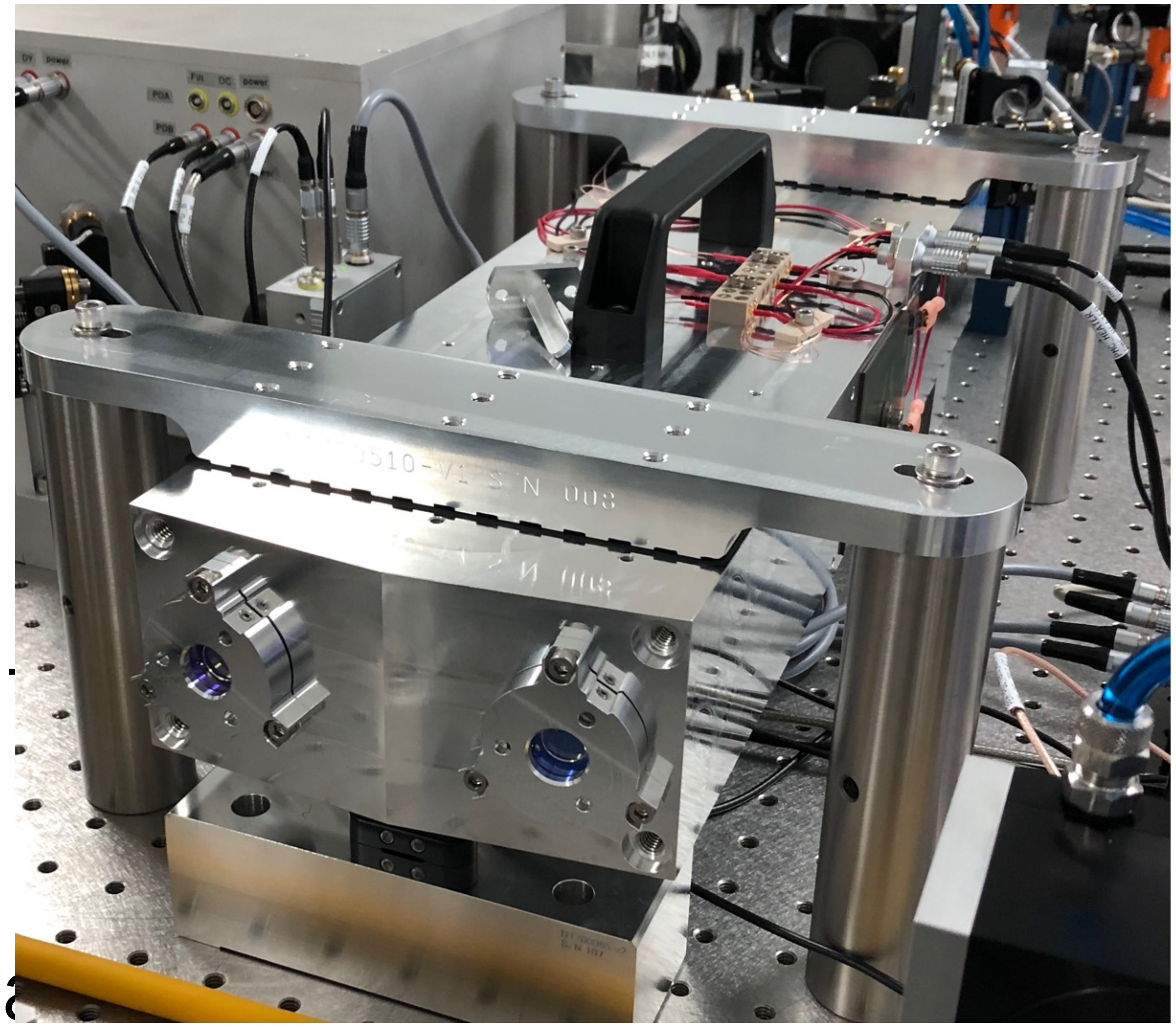
The PMC is a bow-tie shaped cavity which is the most upstream cavity in the KAGRA.

✓ Objectives
- Cleaning up the spacial higher-order modes
- Filtering the RF amplitude noise
- Reduction of the beam jitter

✓ Cavity parameters:
- FSR: 147.4 MHz
- Finesse: 120
- Cavity pole: 610 kHz

✓ Length control:
- Using PDH method
- Two actuators:
    1. Heater (below 100 mHz)
    2. PZT (below 5 kHz)

✓ Noise budget
- The residual length motion was estimated by the in-loop error signal
- Acoustic vibration dominates the residual motion



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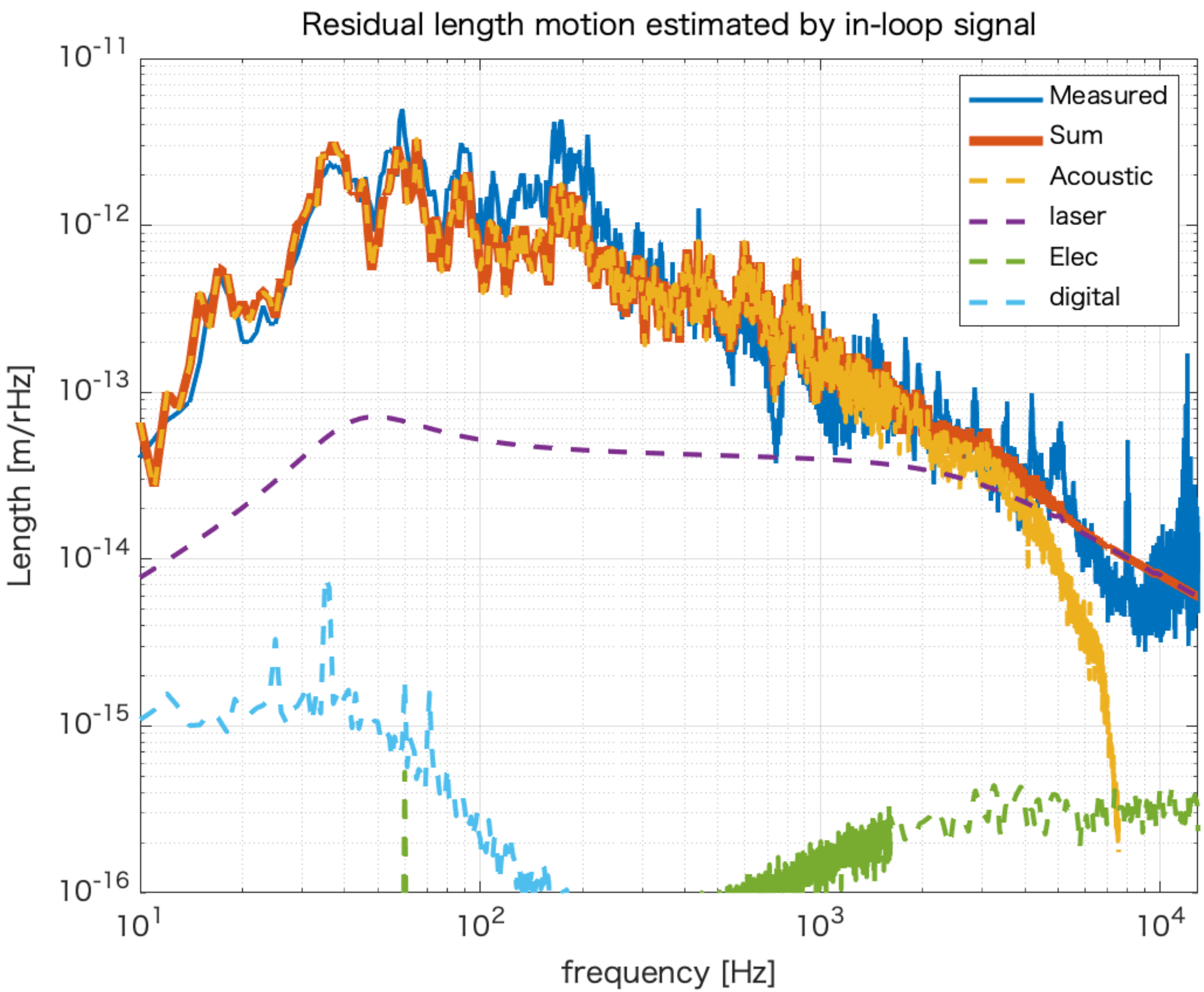
PMC NB


Residual length motion estimated by in-loop signal
Length [m/rHz]
frequency [Hz]
Measured
Sum
Acoustic
laser
Elec
digital
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{1}
10^{2}
10^{3}
10^{4}

Input Mode Cleaner (IMC)
And
Reference Cavity(RefCav)

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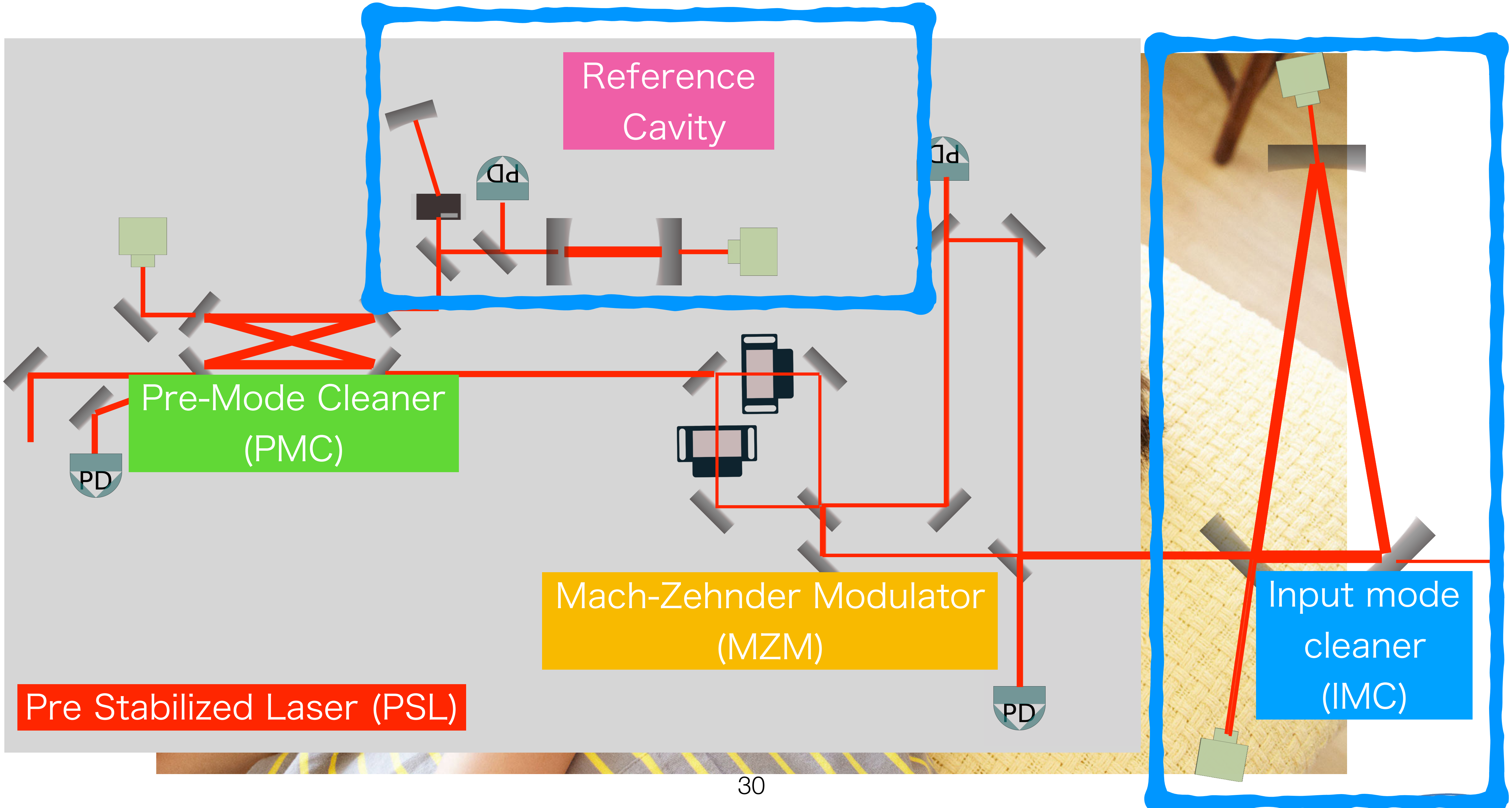
IMC and RefCav



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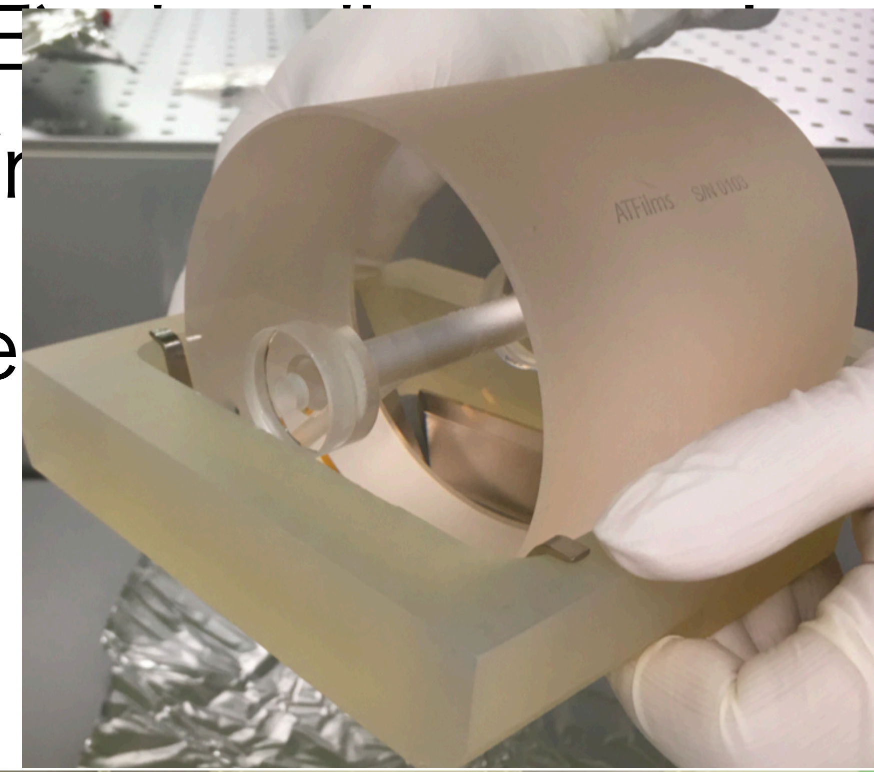
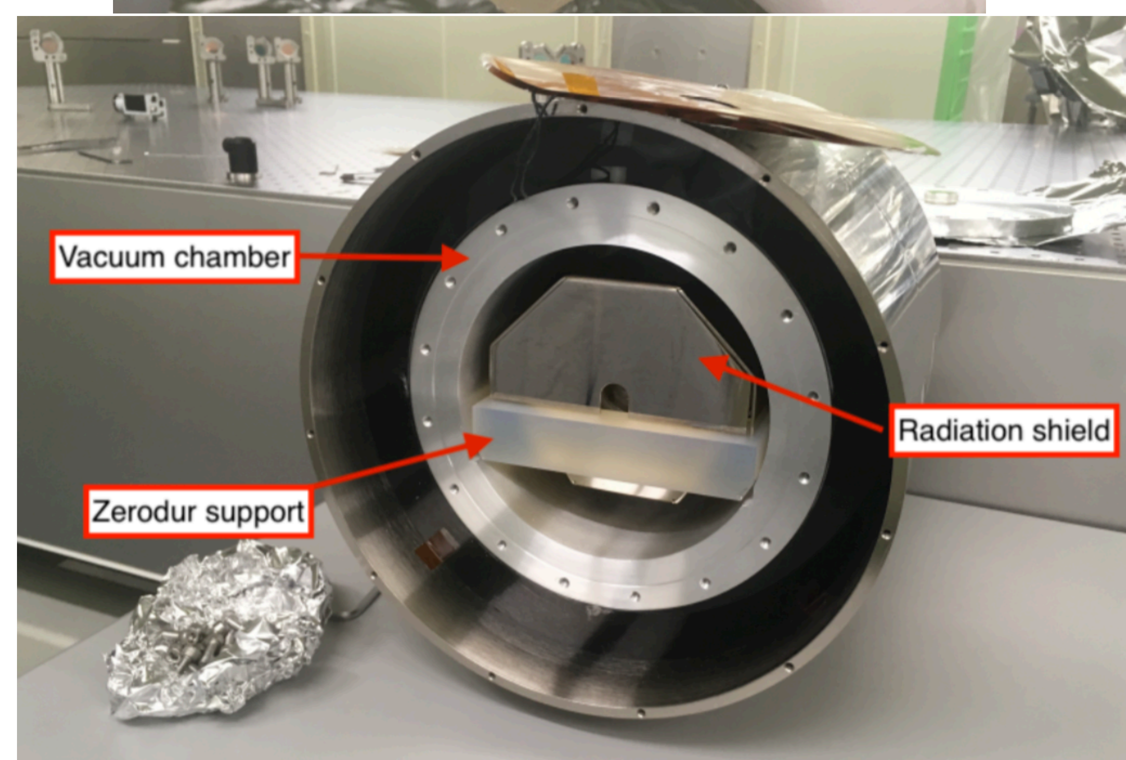
Reference Cavity

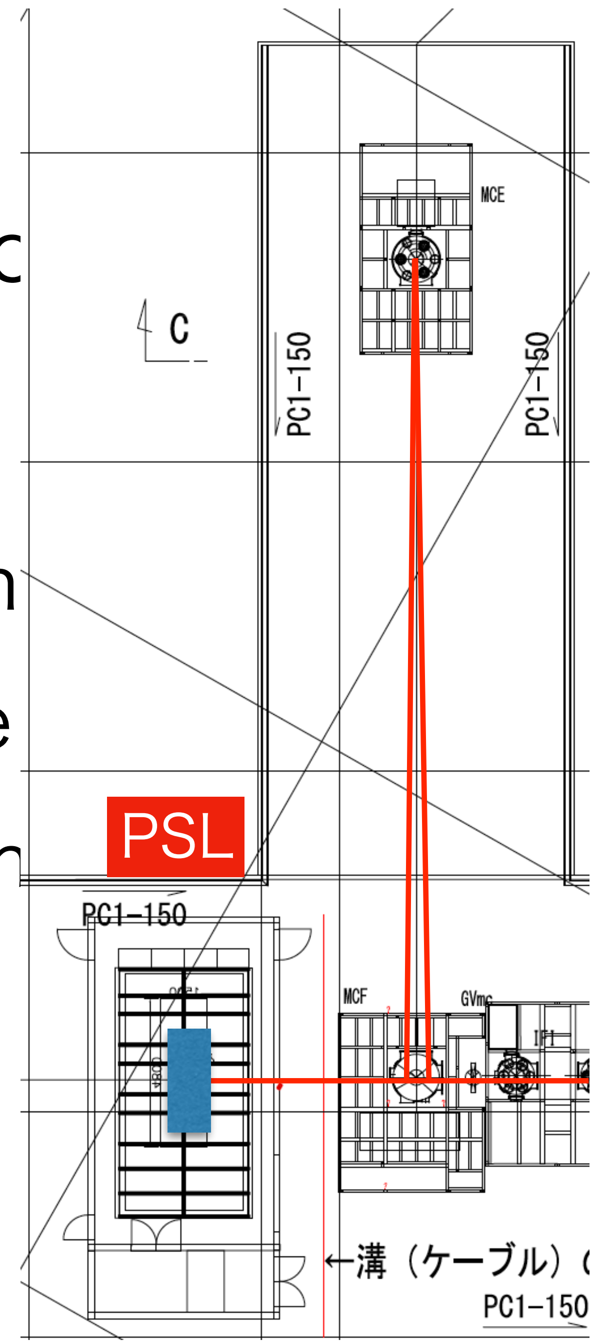
- Use the Ultra-Low Expansion (ULE as the frequency reference for the fr n.
- The Cavity is located inside of the
  - ✓ Evacuated down to ~1Pa.

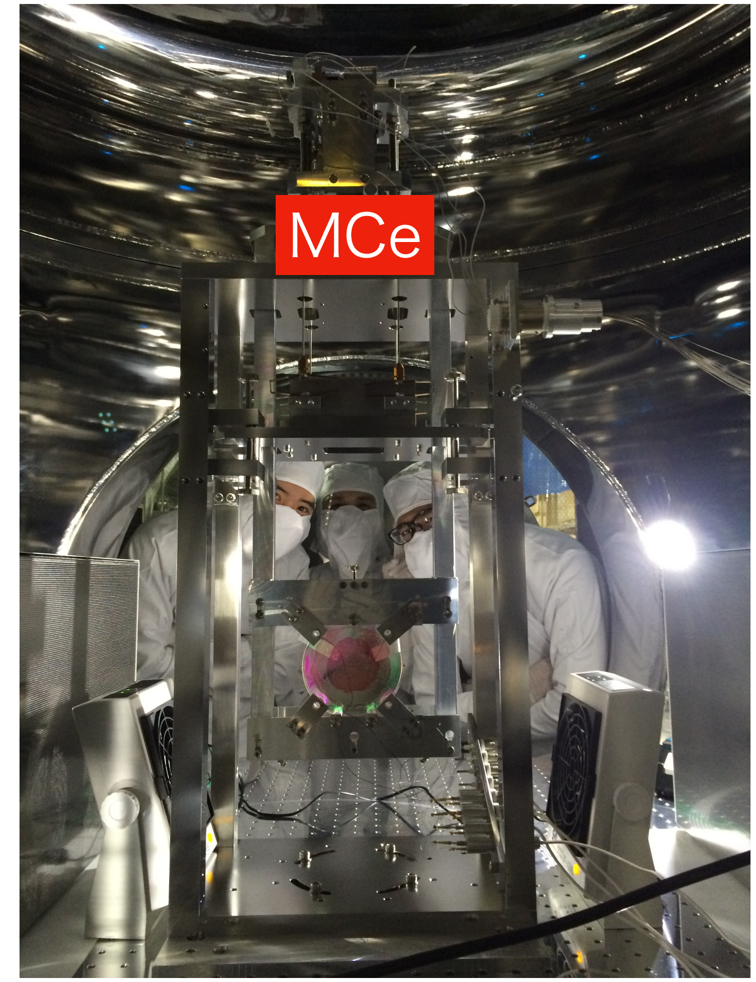


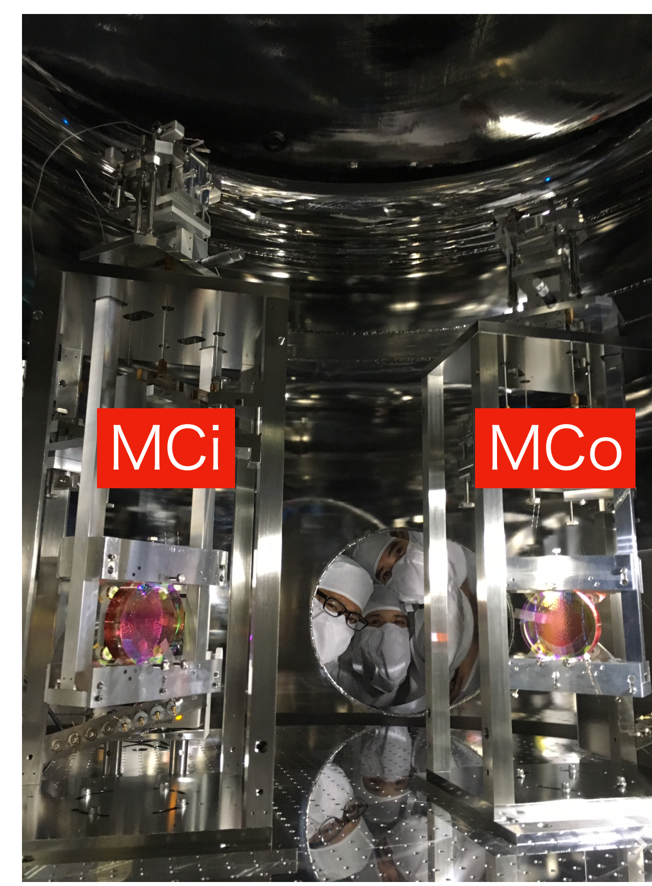


Input Mode Cleaner (IMC)

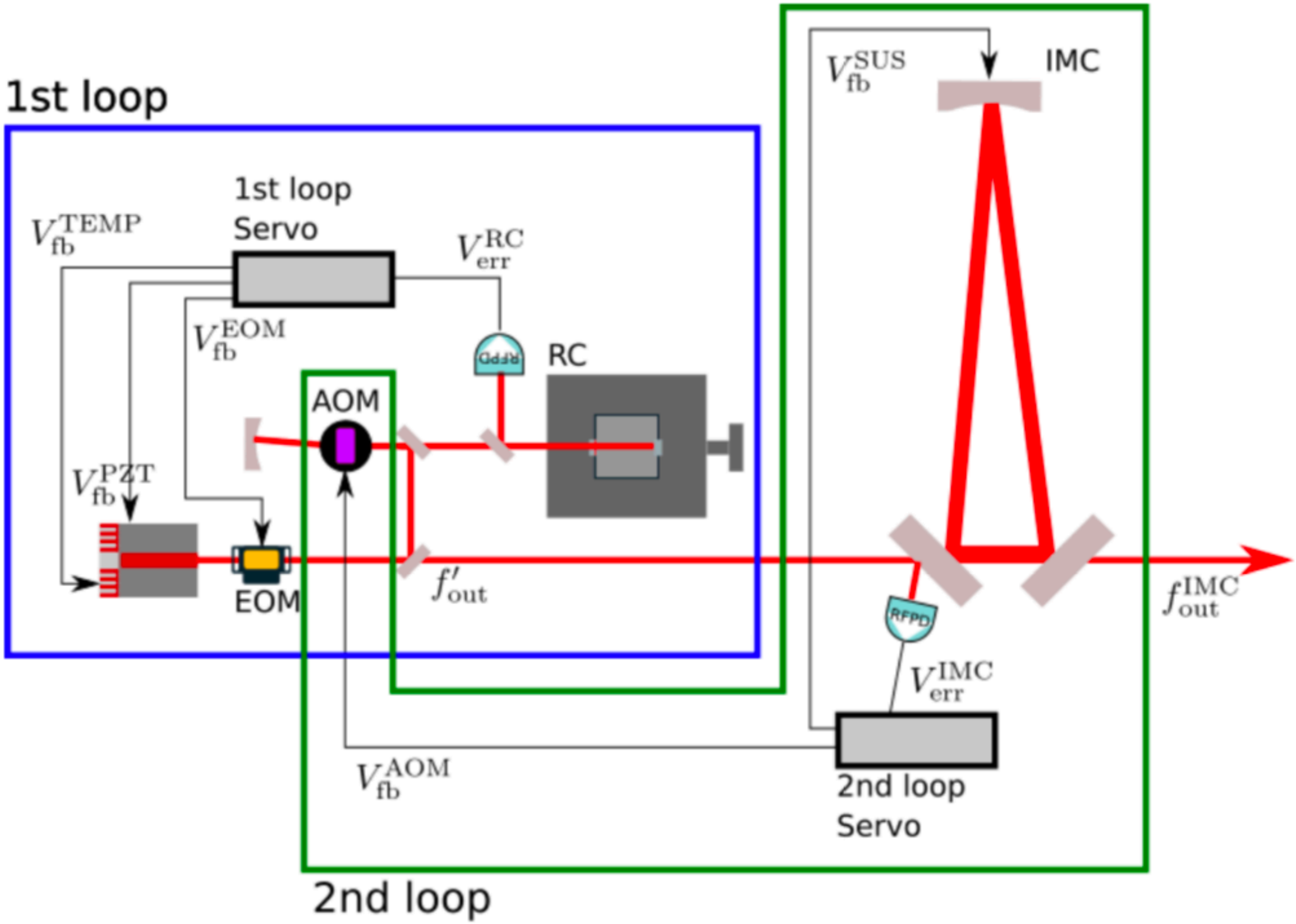
- Suspended triangular cavity
  - ✓ Cavity length: 25 m
- Located in the vacuum c
- Objectives
  - ✓ The spacial mode cleanin
  - ✓ The frequency reference
  - ✓ The beam jitter reduction





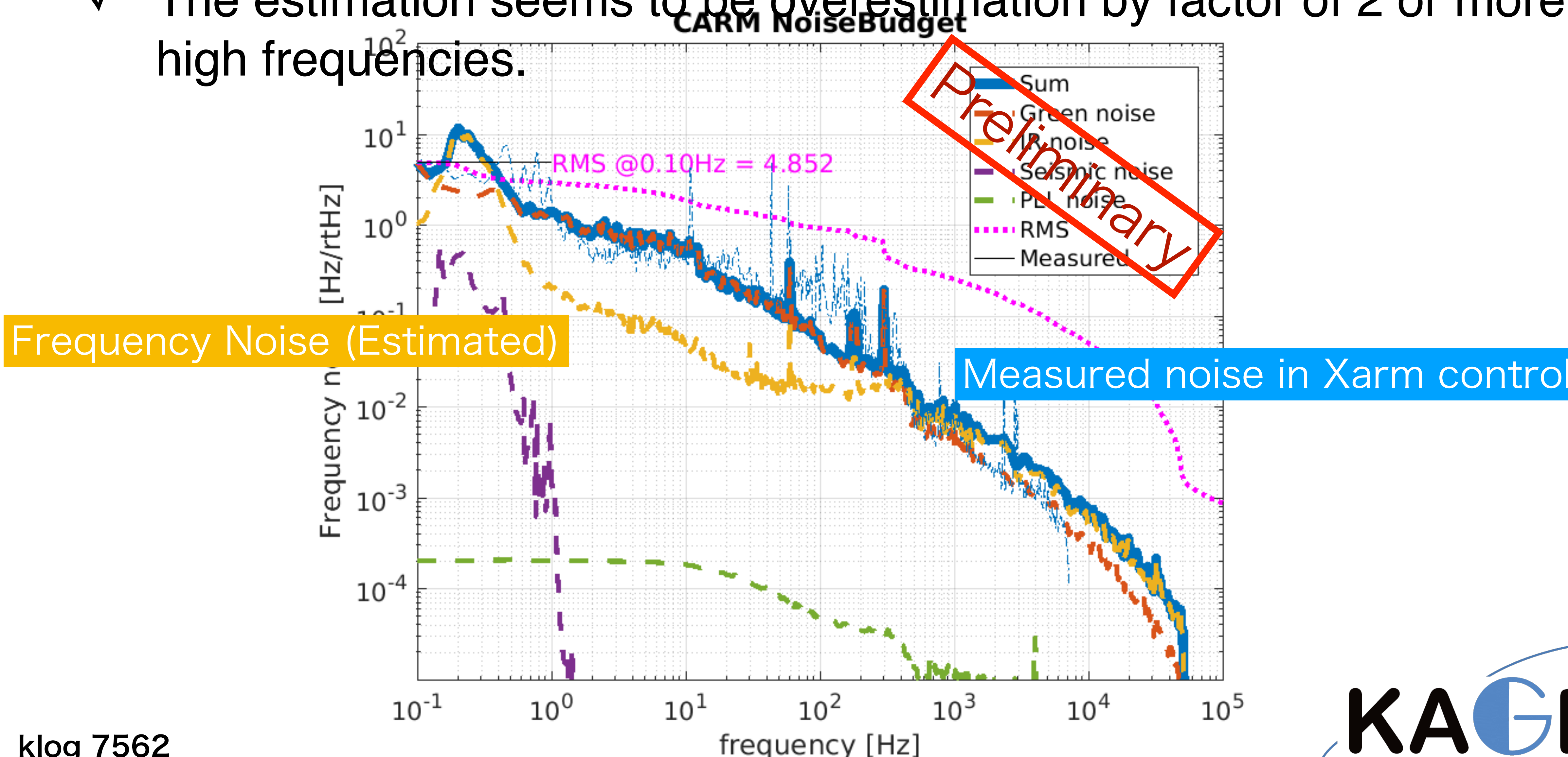


Frequency Stabilization



Frequency Noise

- The frequency noise was measured by using the Xarm
  - ✓ Orange: Estimated frequency noise by using the in-loop signal in the FSS loop.
  - ✓ The estimation seems to be overestimation by factor of 2 or more in high frequencies.



klog 7562

Calculated by Y. Enomoto, K. Yokogawa

IMC Alignment Sensing and Control (ASC)

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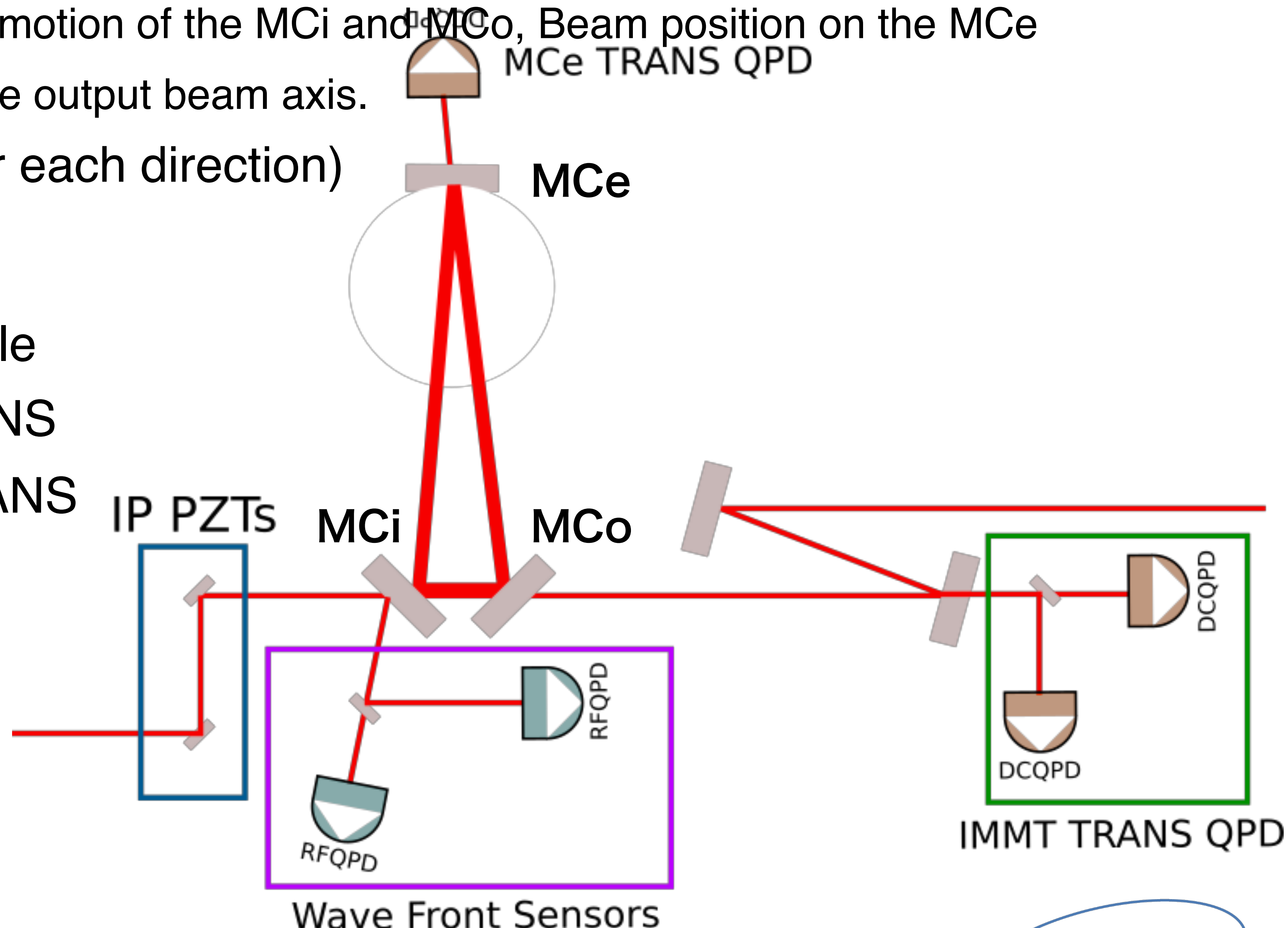
IMC alignment sensing & control (ASC)

- 5 DOFs for each direction (pitch and yaw) to be controlled
  - ✓ Cavity axis (3 DOFs for each direction)
    - ➡Bases: Common/Differencial motion of the MCi and MCo, Beam position on the MCe
    - ➡The cavity axis determines the output beam axis.
  - ✓ Injection beam (2 DOFs for each direction)
- 5 sensors
  - ✓ WFS on the IMC REFL table
  - ✓ DC QPD for the MCe TRANS
  - ✓ DC QPD for the IMMT TRANS
- 5 actuators
  - ✓ Input pointing PZTs.
    - ➡In the PSL room.
  - ✓ IMC suspended mirrors.



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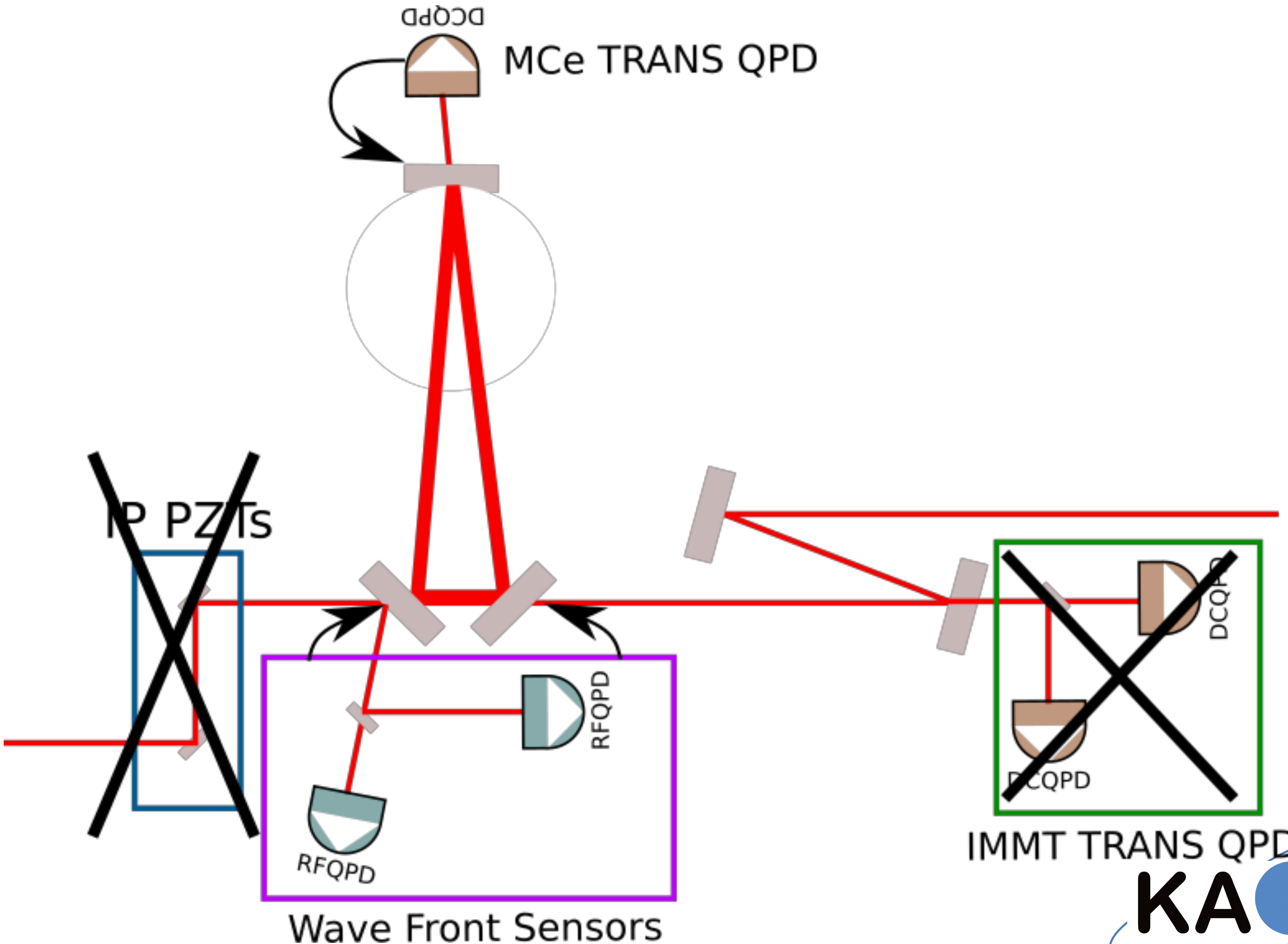
IMC ASC (current configuration)



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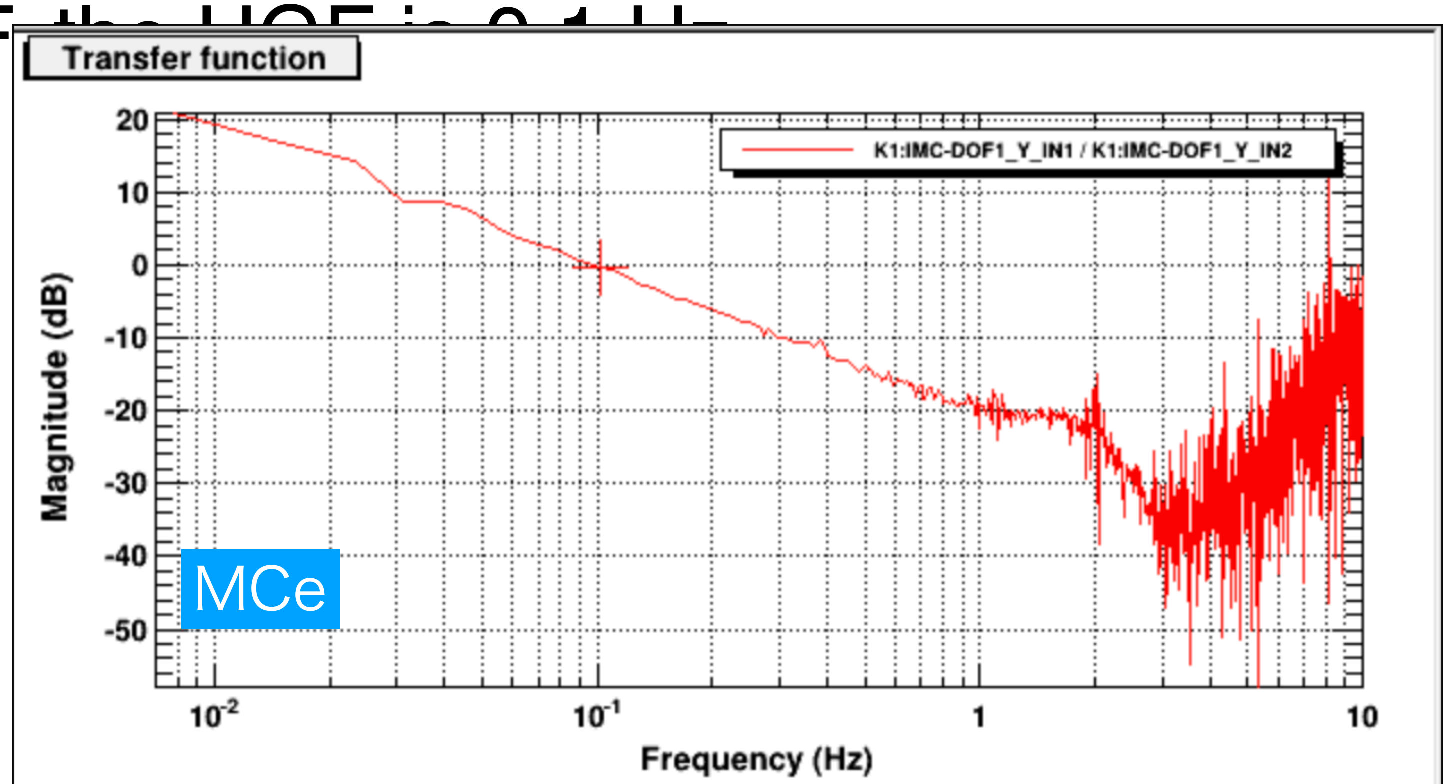
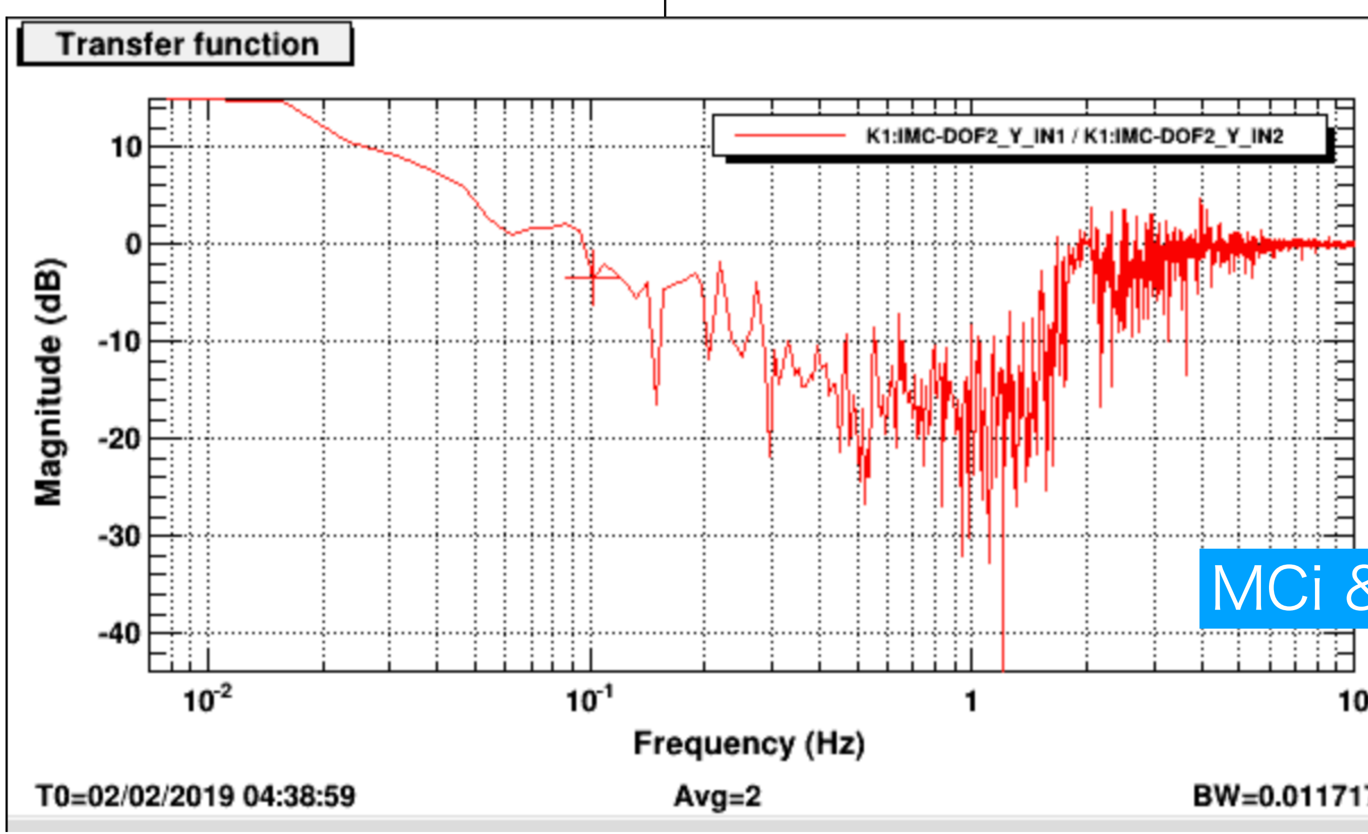
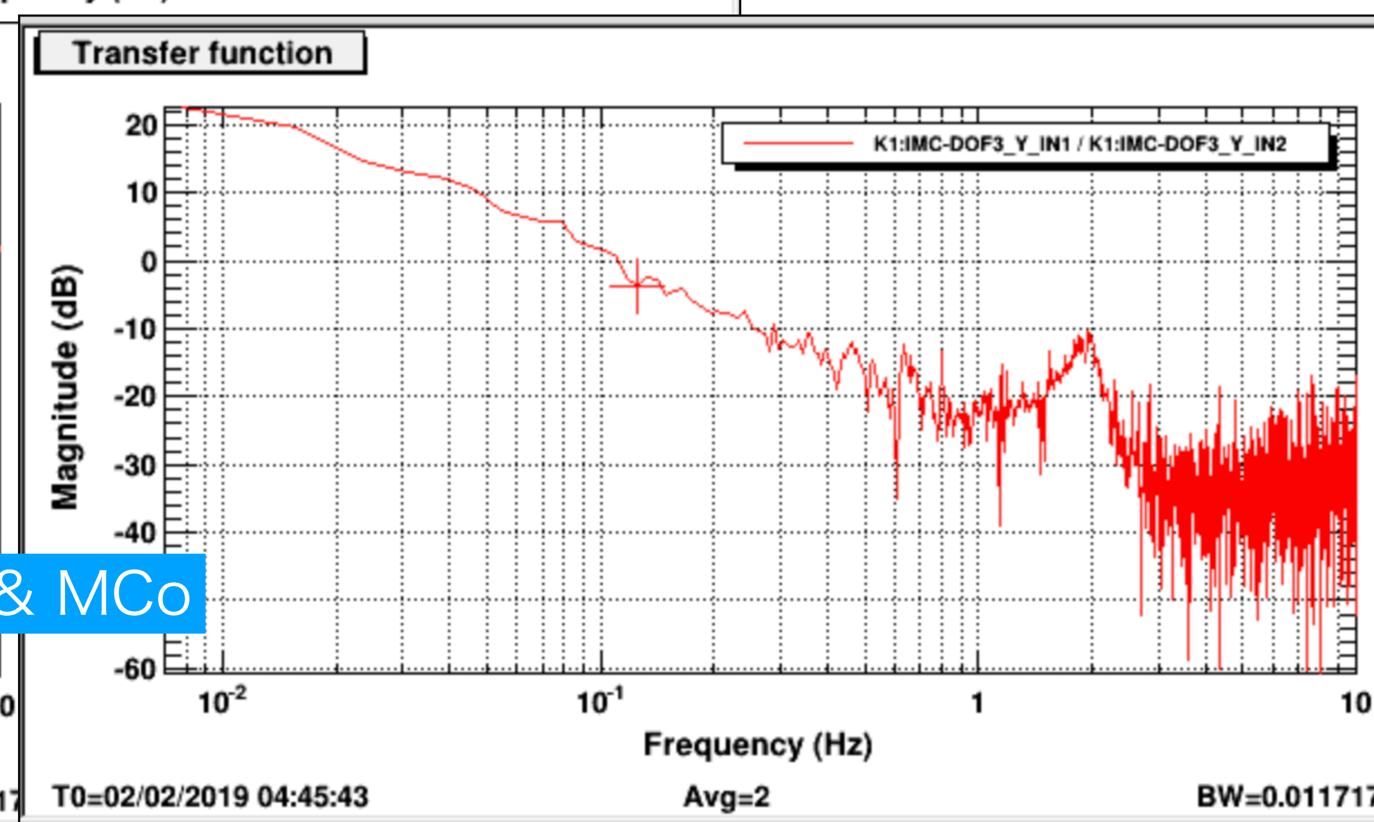
Control bandwidth

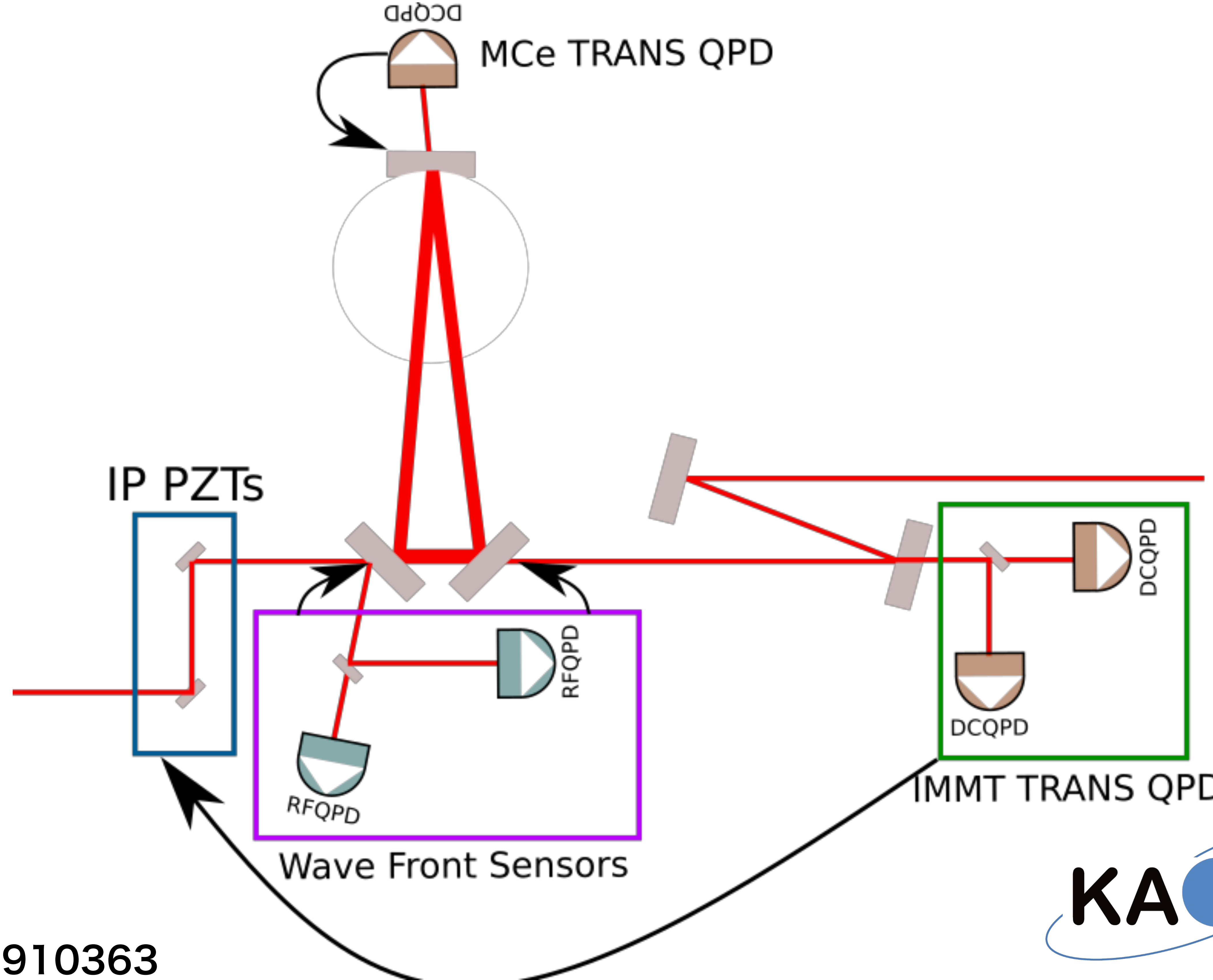
- For all DOF







IMC ASC (final configuraion 1)



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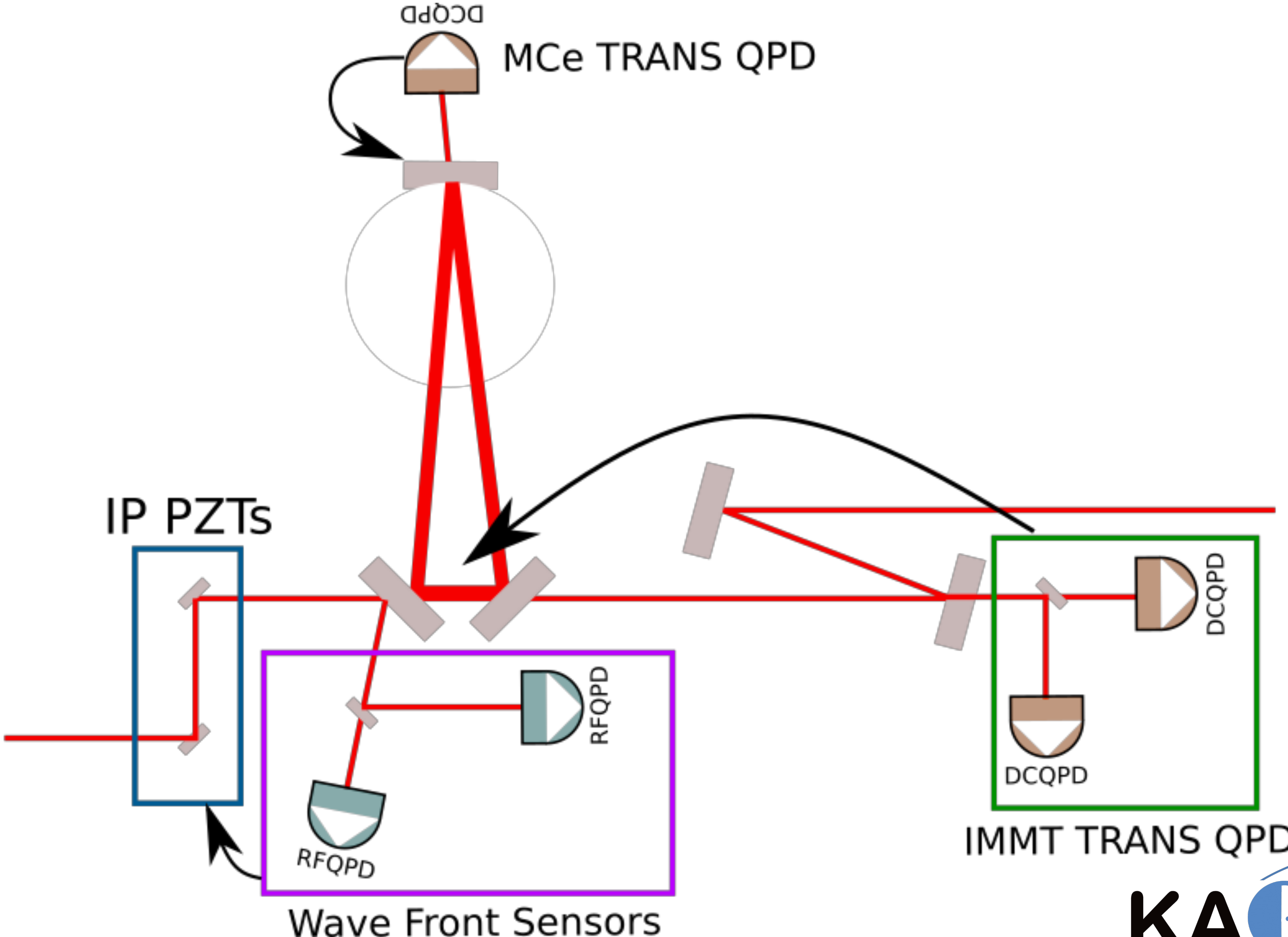
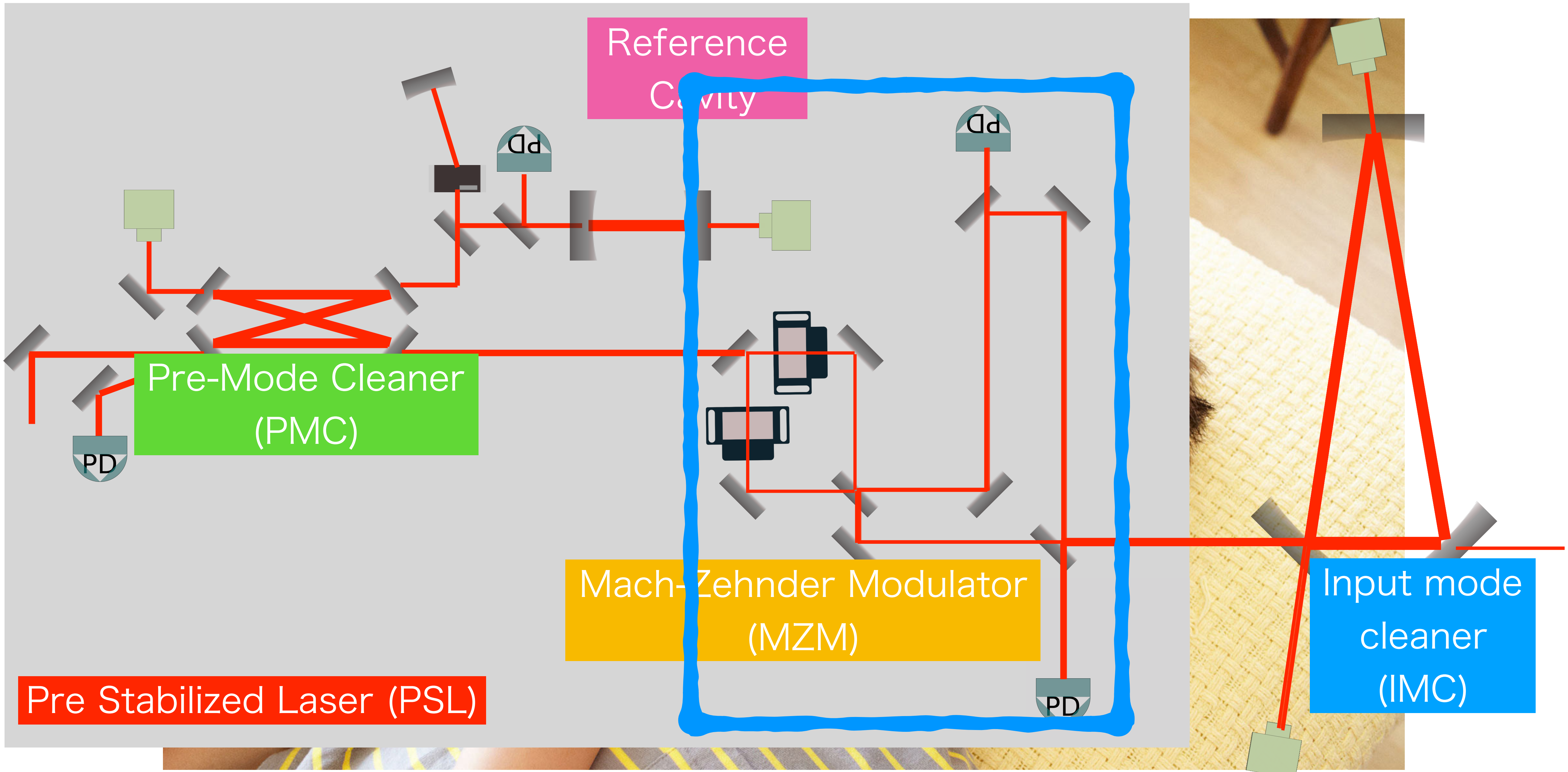
IMC ASC (final configuration 2)



Mach-Zehnder Modulator (MZM)

Overview of the input optics



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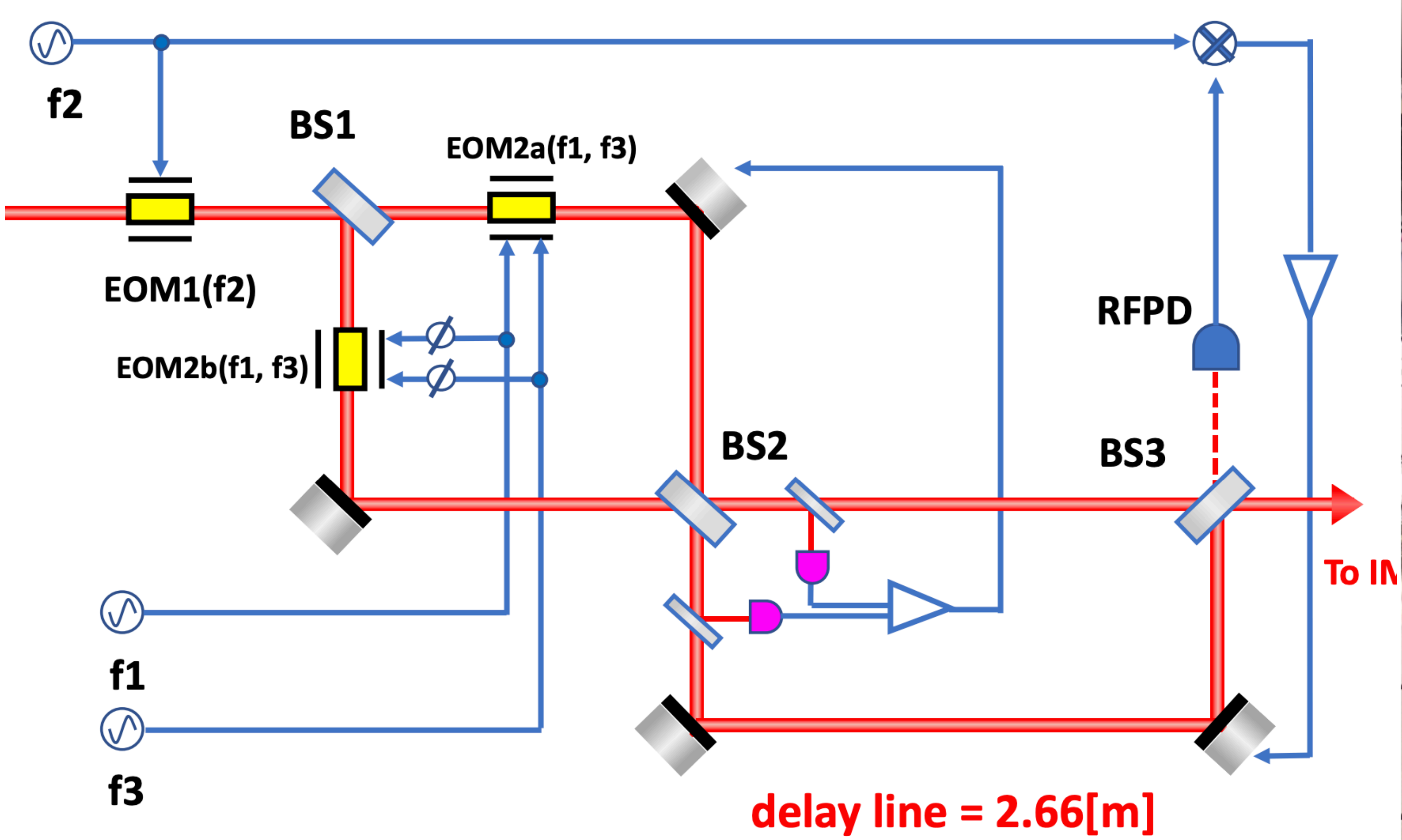
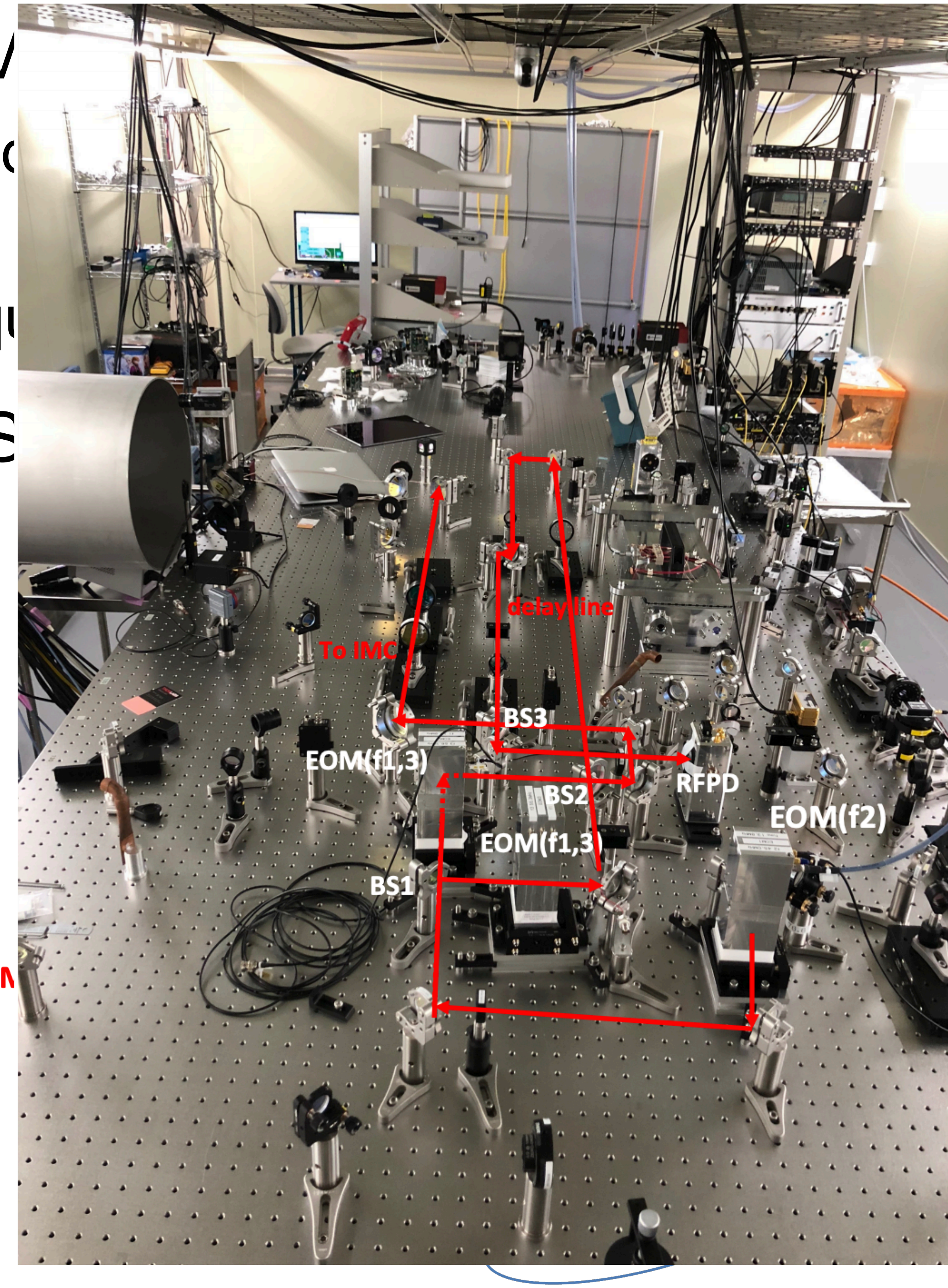
Mach-Zehnder Modulator (MZM)

Kohei Yamamoto, JGW-G1909583

- MZM can generate the tunable AM
  - ✓ To cancel the AM generated by the c interferometer
  - ✓ To generate the AM for the lock acq
- MZM has been installed on the PS





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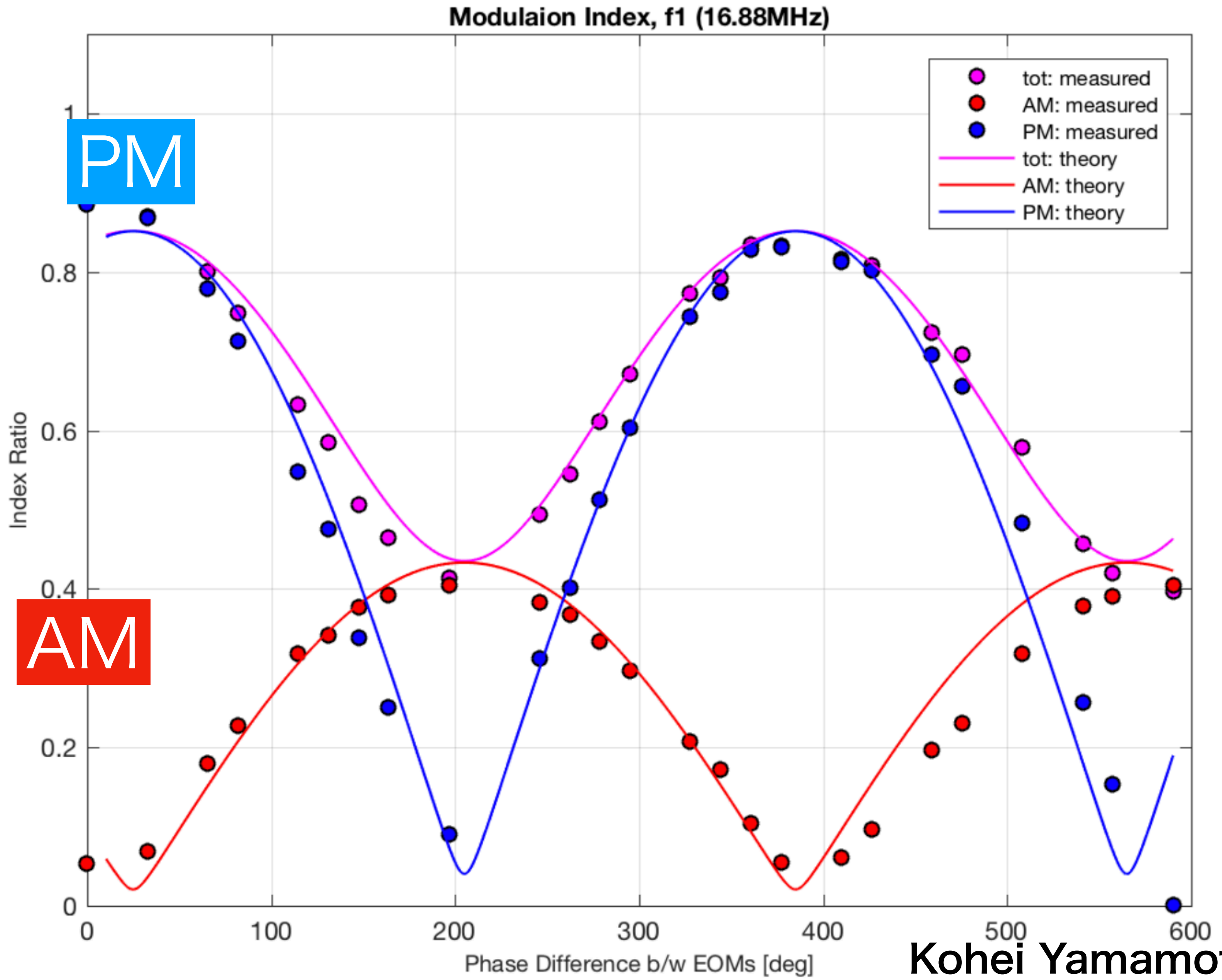
Mach-Zehnder Modulator (MZM)

- The AM can be tuned by tuning the phase difference between the EOMs
  - ✓ Demonstrated by the experiment

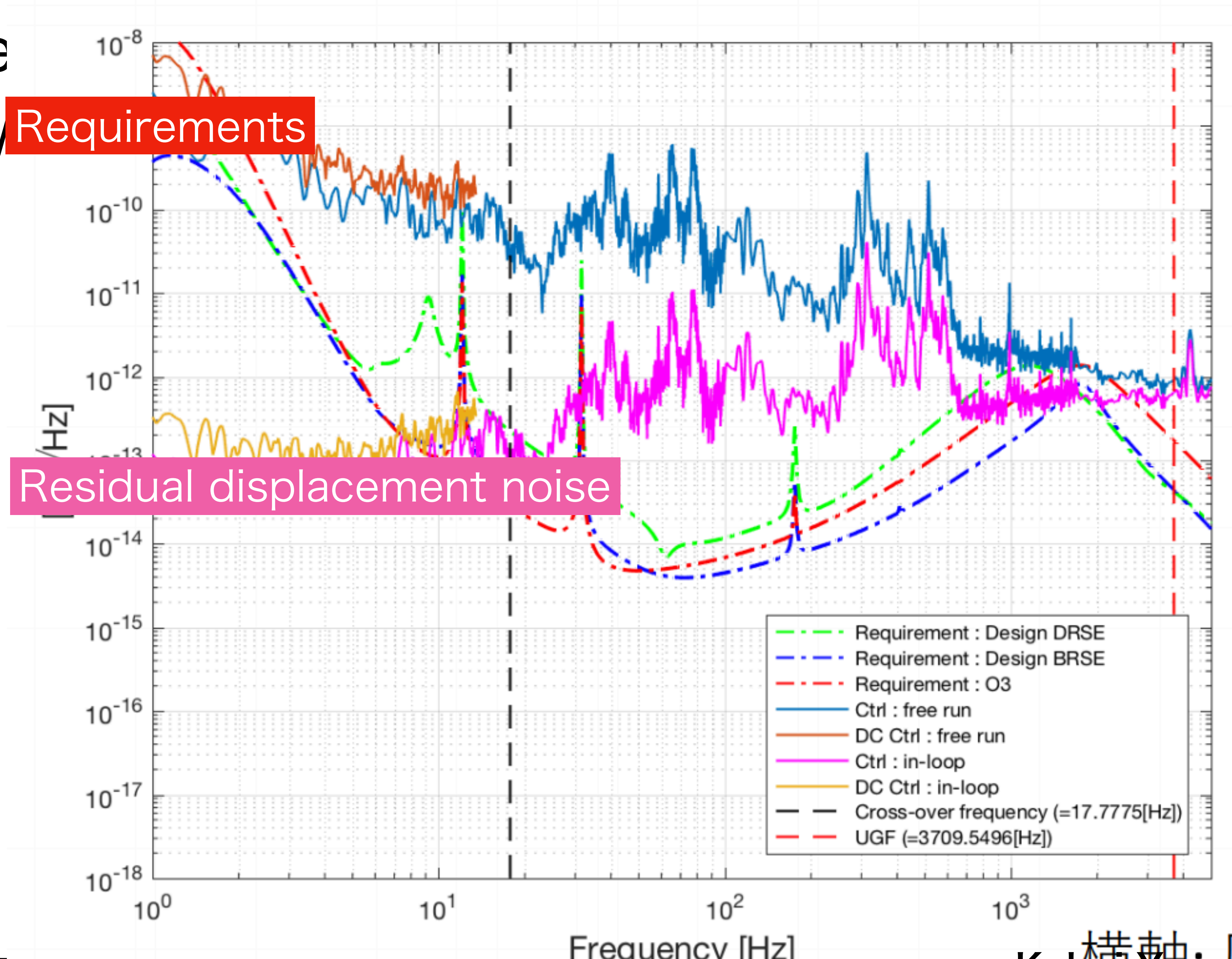


Kohei Yamamoto, JGW-G1909583

Displacement noise of the MZM

- The displacement noise couples with the GW signals via the modulations.

- The ... ment
  - ✓ W



Summary

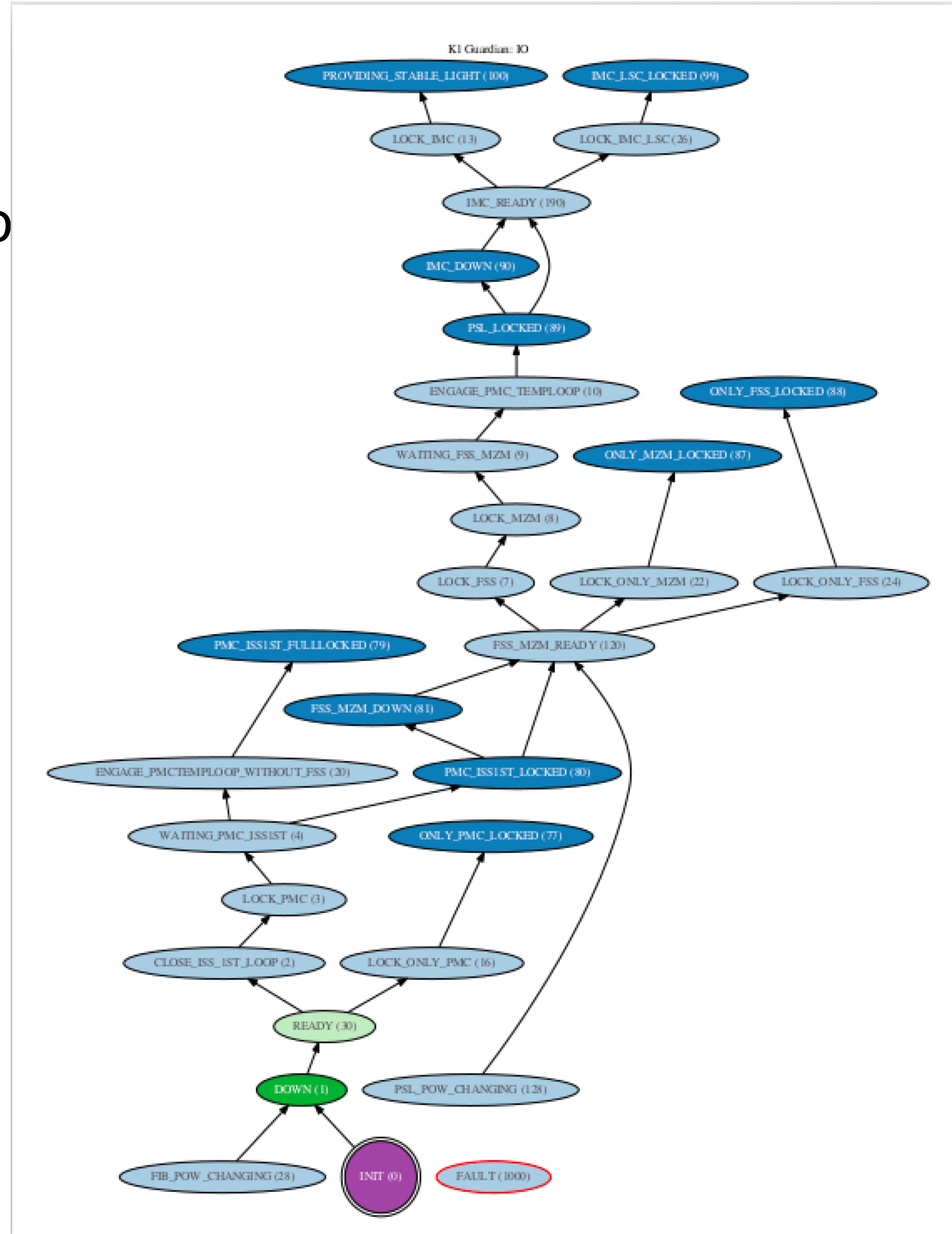
Summary

- Almost all system has been installed.
- All system are operated automatically with the guardian.
- The frequency noise has been estimated by using the Xarm control signal
- IMC ASC is using limited sensors so far.
  - ✓ It will be finalized in a couple of weeks.
- MZM has been installed and demonstrated to generate the tunable AM.
  - ✓ The displacement noise has not met the requirement.
    - Use the monolithic MZI?
    - Use the rigid mirror mounts?
- High power test is on going.
  - ✓ Up to now, the maximum power from the IMC is 4 W

Appendix

Guardian

- All system has been o
  guardian.



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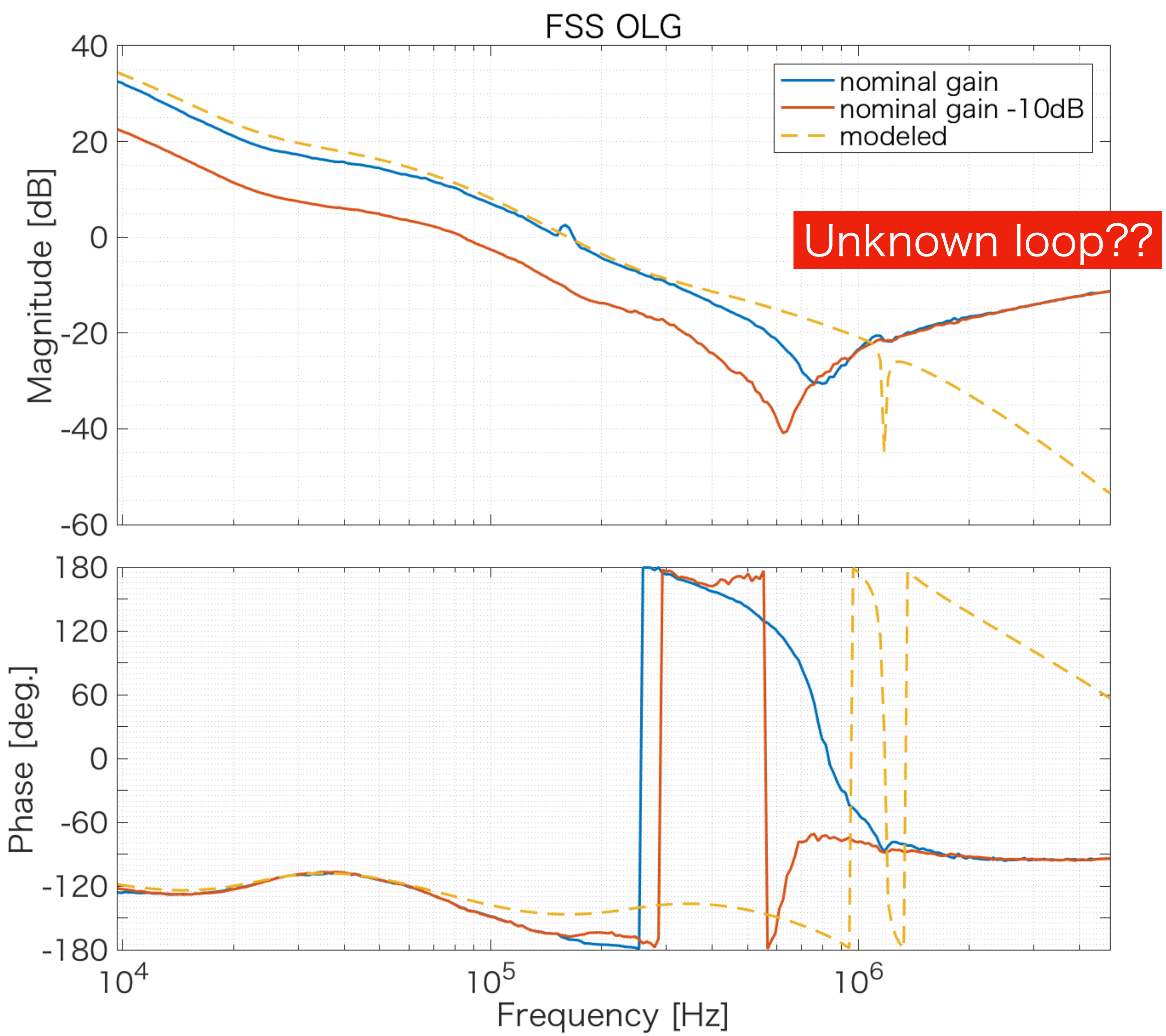
Status of the input optics

- Almost all system has installed.
- The maximum power from the IMC is 4 W so far.
- The alignment control for the input mode cleaner is not finalized yet.
- Although the modulation system using the Mach-Zehnder interferometer has been installed, the displacement noise does not meet the requirement for the O3.
  - ✓ We decided not to use the MZM in the O3.

Unknown loop in the FSS

- The plot shows the OLGs with two different servo gain.
  - gain is different
  - dent from the FSS loop



Klog5892

Control Bandwidth of the PMC

- UGF: ~6 kHz -> Is enough?

Beyond O3

- IMC ASC improvement
- ~200-W high power laser
-