Improvement of the Laser Intensity Stabilization System for O4 in the Gravitational Wave Telescope KAGRA

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University of Toyama

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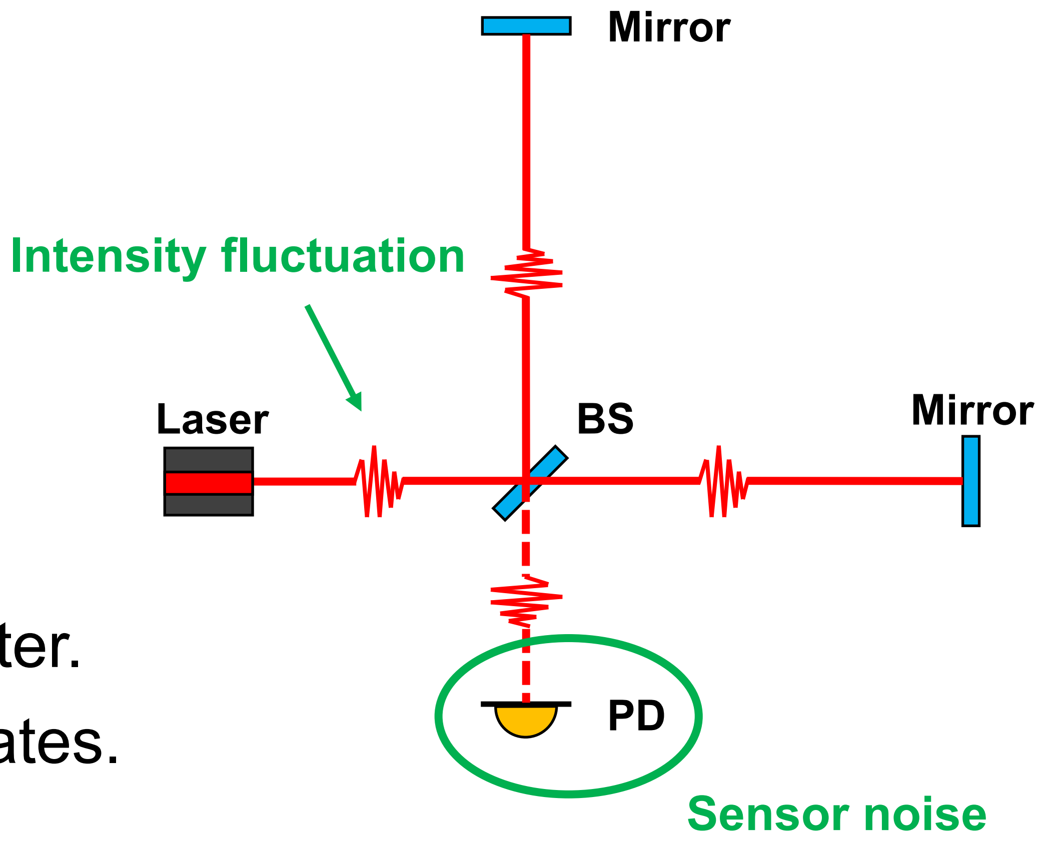
Outline

1. Introduction
2. Measurement of the Intensity noise in O3GK
3. Improvement of the ISS for O4
4. Measurement of the Beam jitter effect on the PD surface
5. Summary and Future plan

Introduction

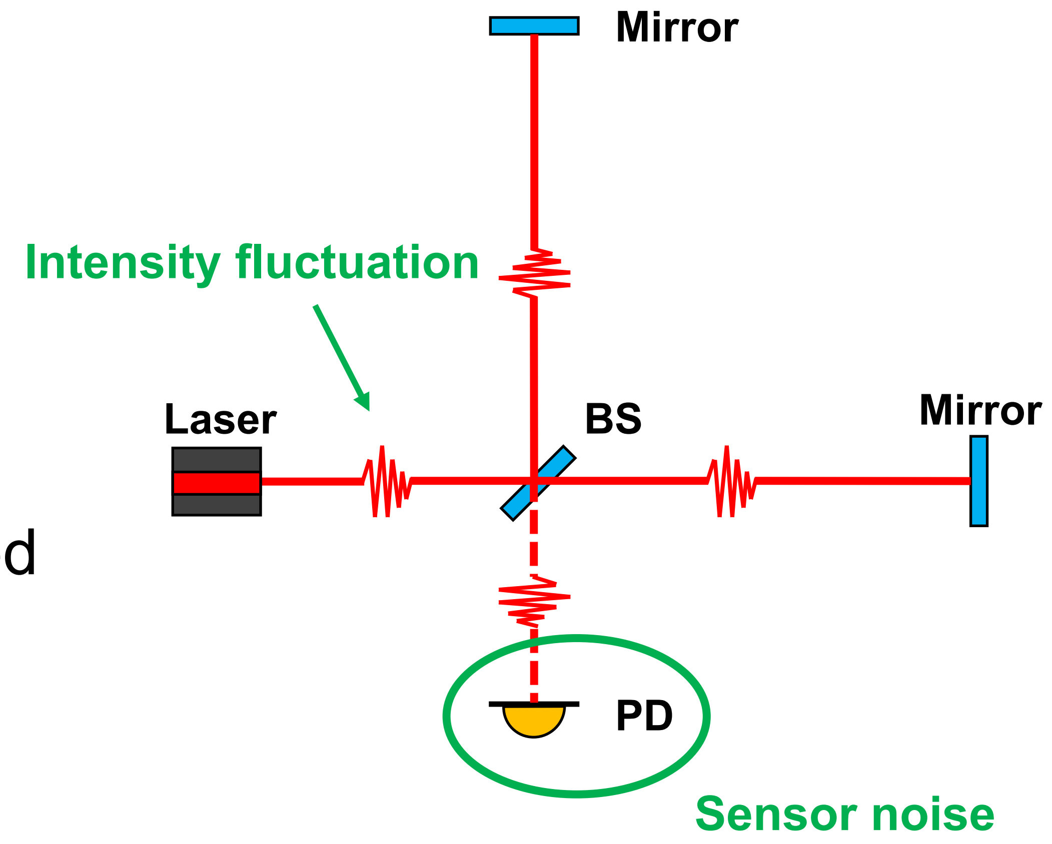
KAGRA is a gravitational wave detector based on the Michelson interferometer.

The arrival of gravitational waves fluctuates the arm length of the interferometer.
→ The signal at the interference port fluctuates.



However, Laser intensity fluctuations cause sensor noise.
→ The sensitivity of the interferometer is reduced.

Introduction



Intensity Stabilization System (ISS)
suppresses intensity fluctuations.

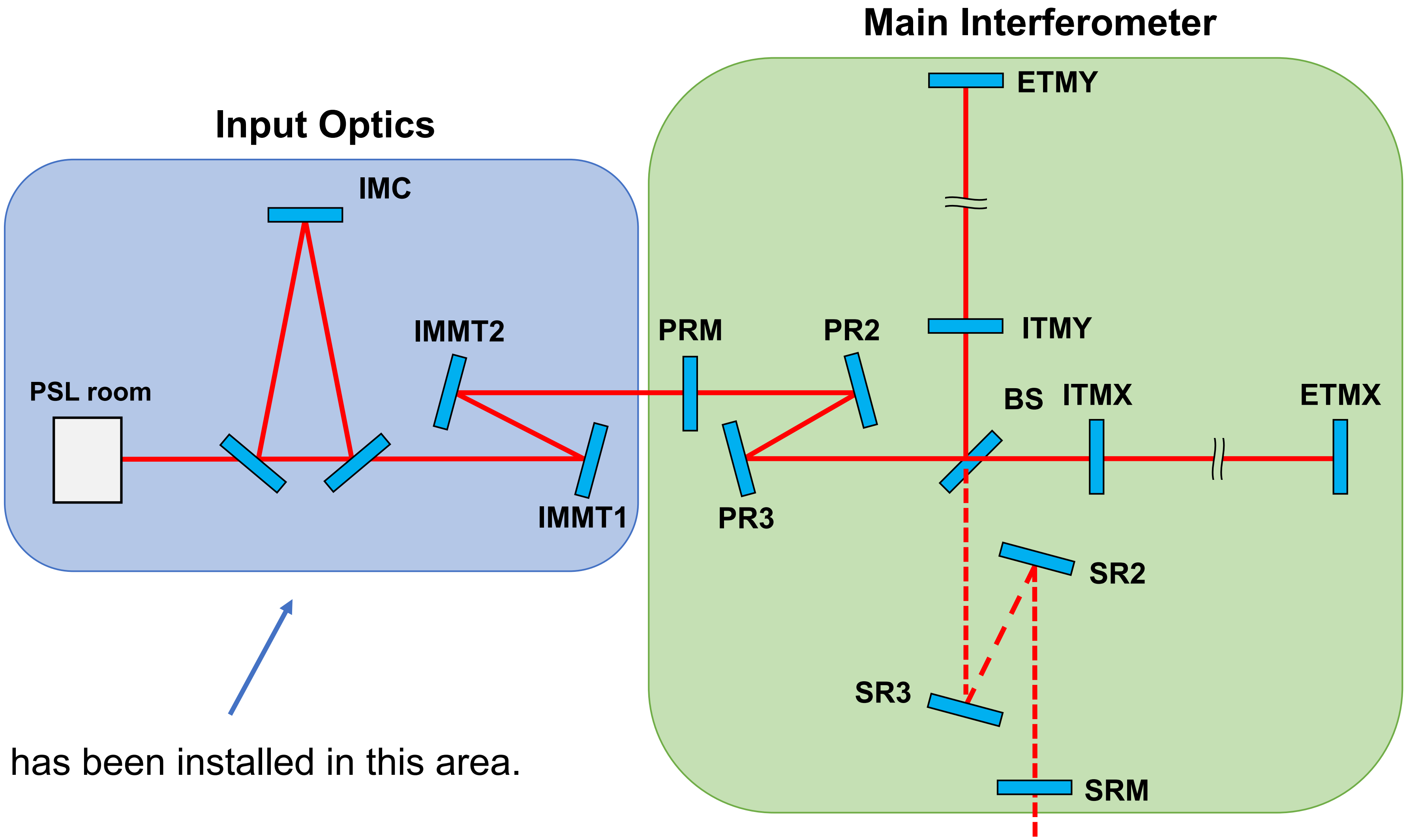
The required value for the ISS is determined by the observation sensitivity of KAGRA.

Required value in O3 = $\mathbf{1 \times 10^{-7}}$ / $\sqrt{\mathbf{Hz}}$

Required value in O4 = $\mathbf{1 \times 10^{-8}}$ / $\sqrt{\mathbf{Hz}}$

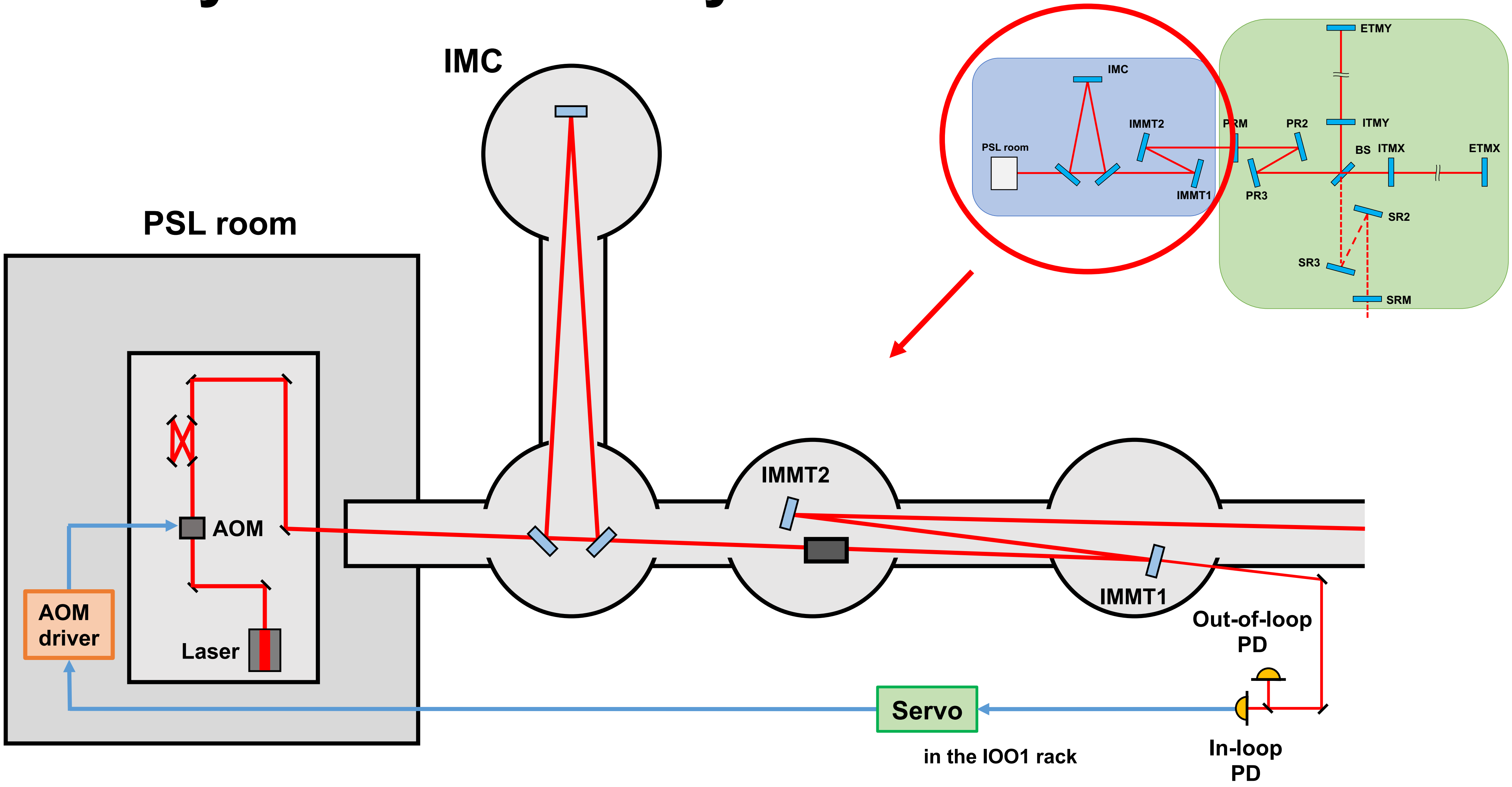
Final required value = $\mathbf{2 \times 10^{-9}}$ / $\sqrt{\mathbf{Hz}}$ @ 20 Hz

Overview of KAGRA



ISS has been installed in this area.

Intensity Stabilization System

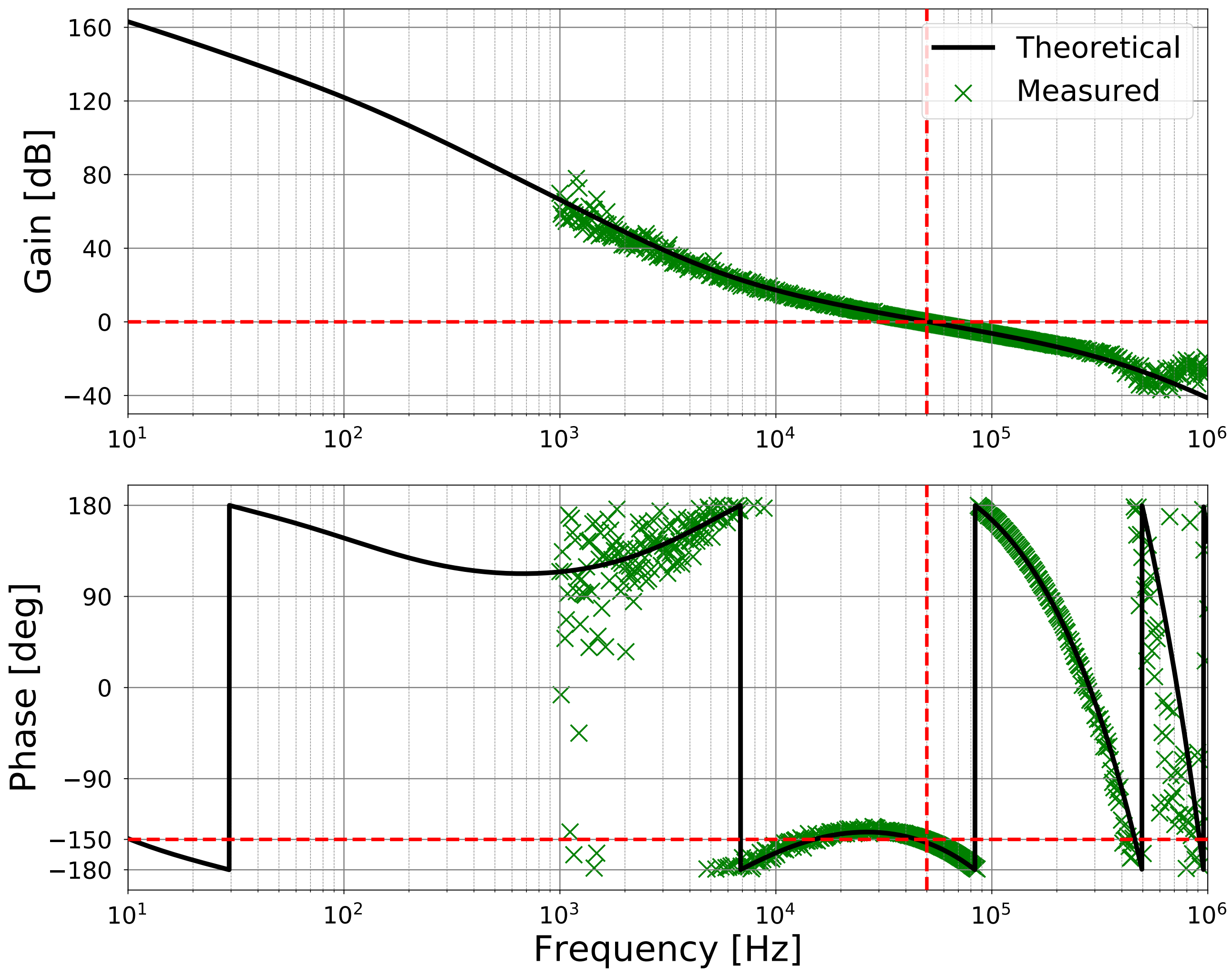


Intensity Stabilization System

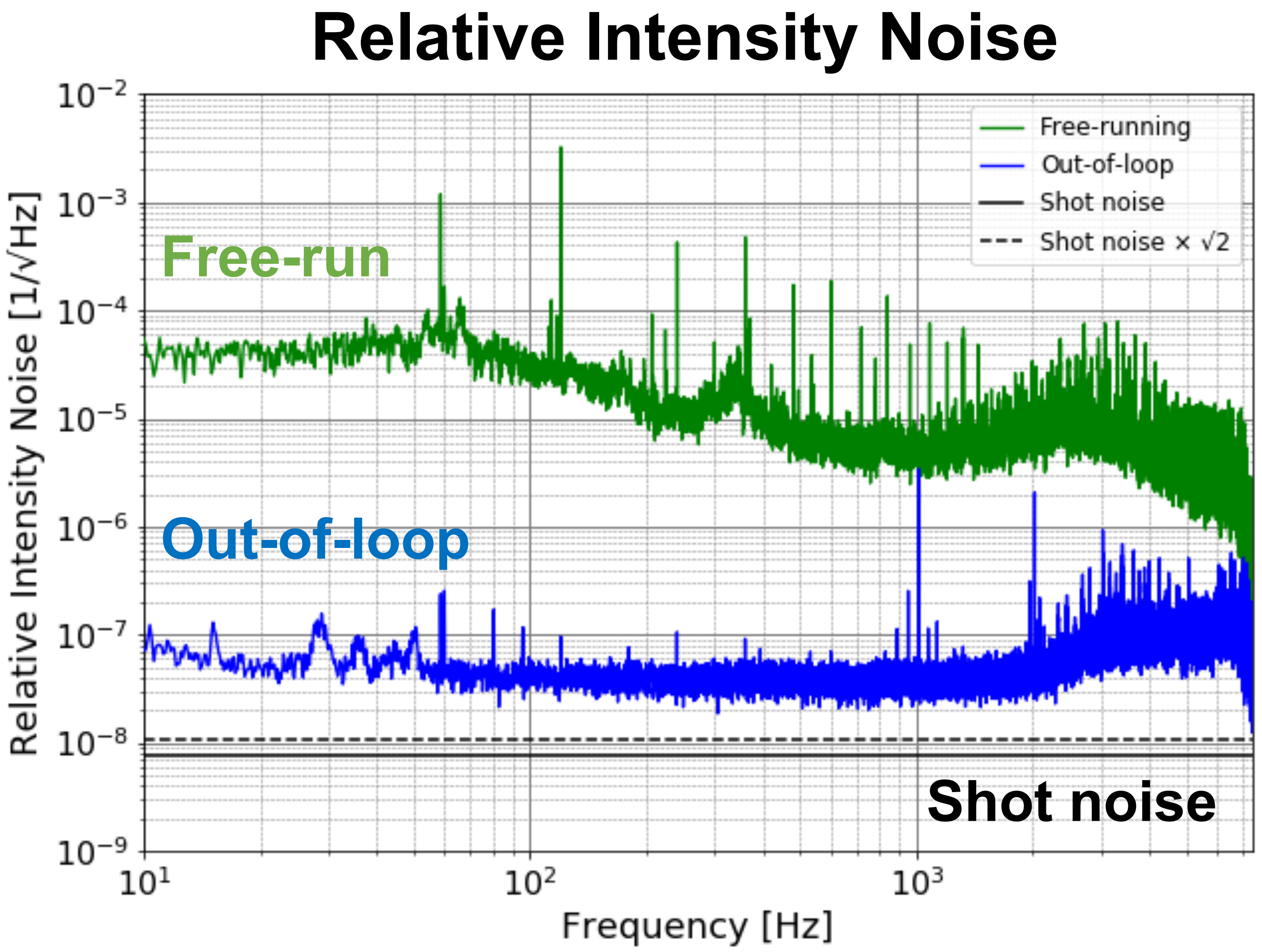
UGF = 48 kHz
Phase margin = 30 deg

We can still increase the UGF.
- Adjusting the AOM
- Using fast response operational amplifiers

Open loop transfer function



Measurement Intensity noise in O3GK



Required value

$1 \times 10^{-7}\ /\sqrt{\mathrm{Hz}}$

Laser power

Main laser

8.8 W

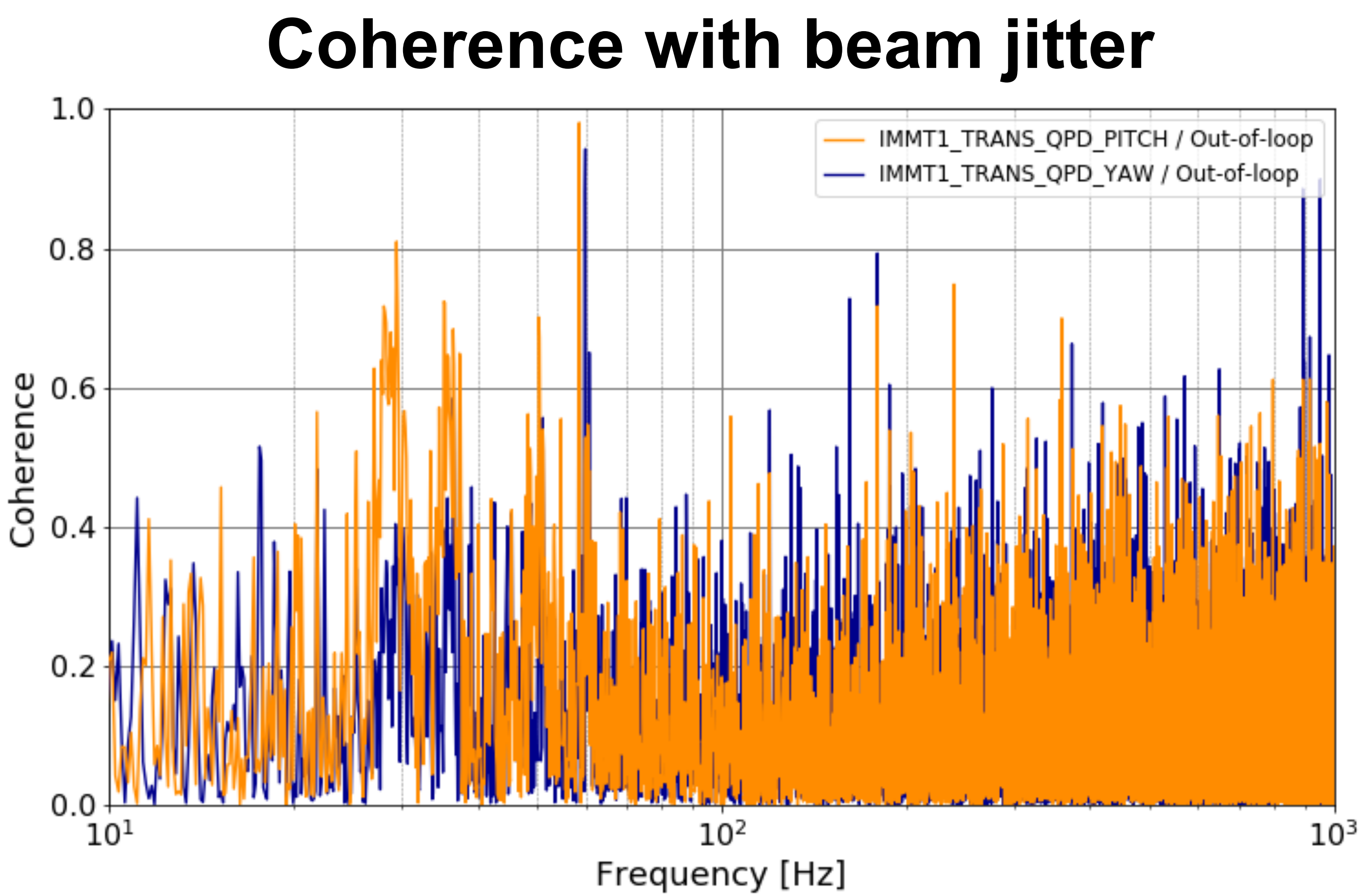
Out-of-loop

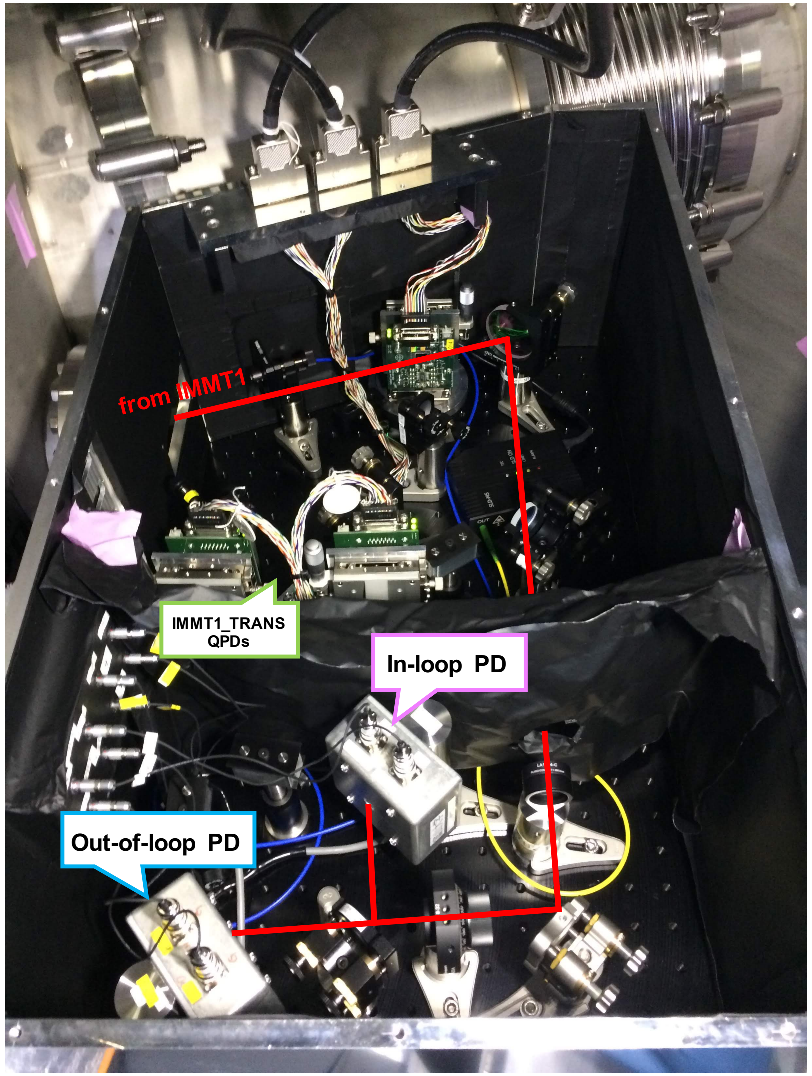
7.3 mW

Date

2020/4/10 21:00

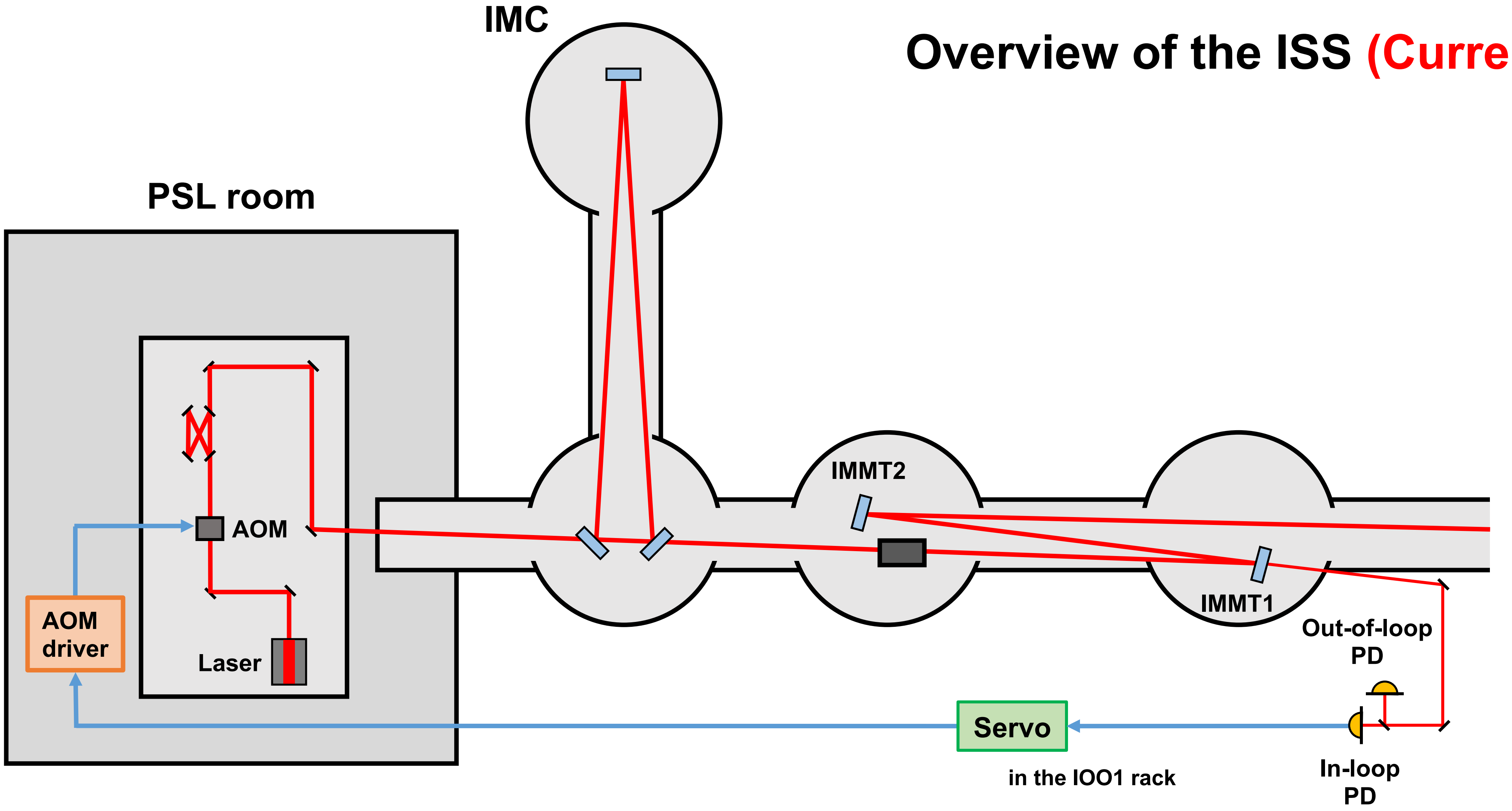
Measurement Intensity noise in O3GK



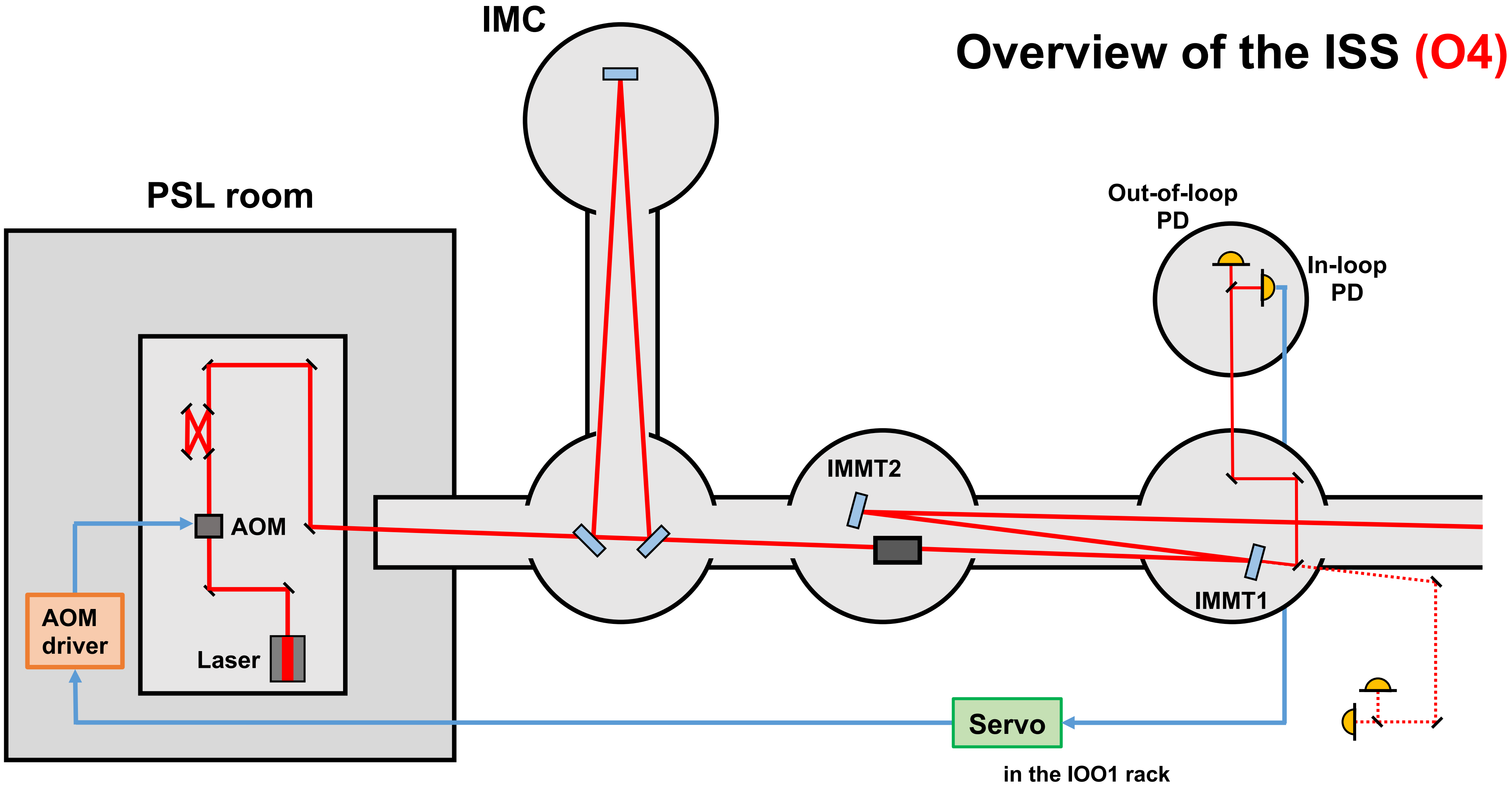


Improvement of the ISS for O4

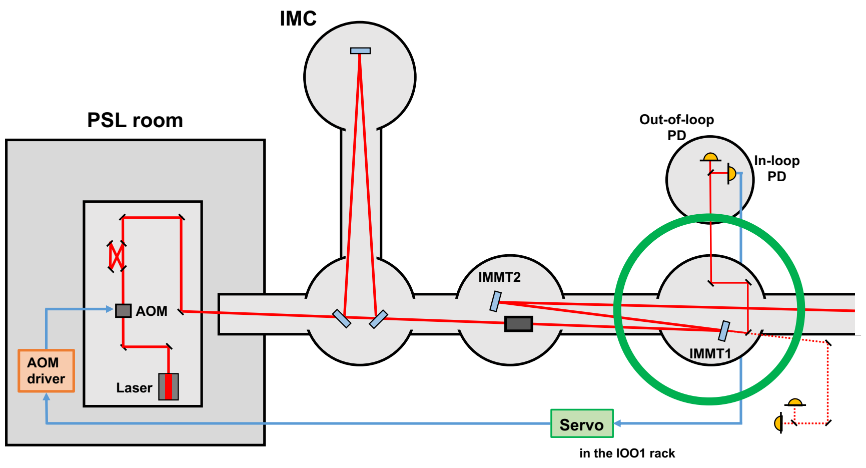
Overview of the ISS (Current)

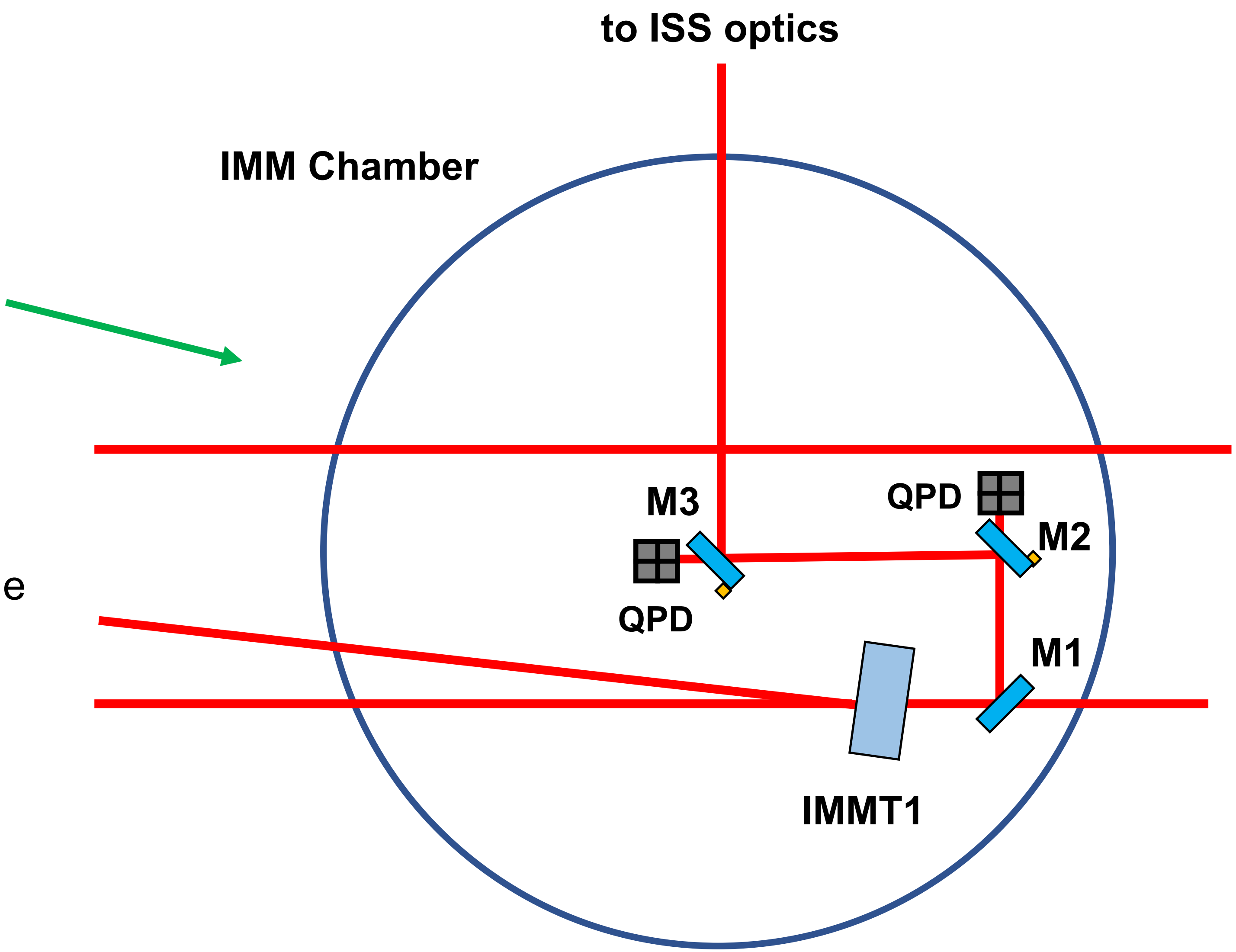


Improvement of the ISS for O4



Improvement of the ISS for O4

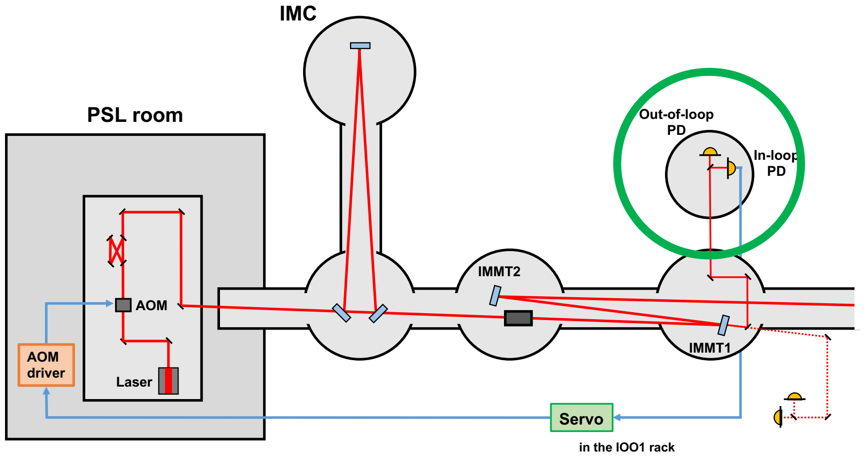


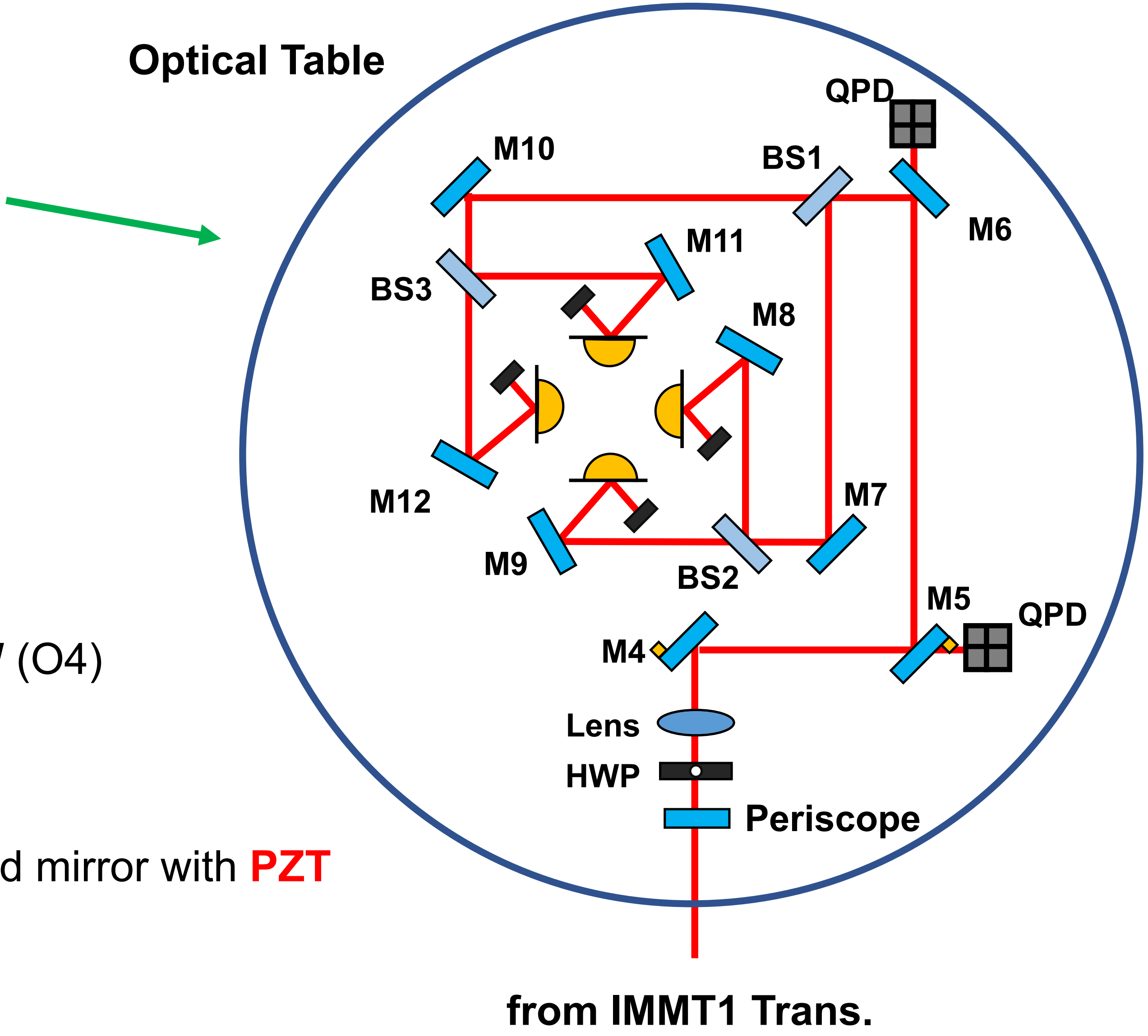


- **Stabilizing beam position**
  We monitor the beam position with the **QPD** and stabilize the beam position with two mirrors with **pico-motors**.

  But this may be changed.

Improvement of the ISS for O4

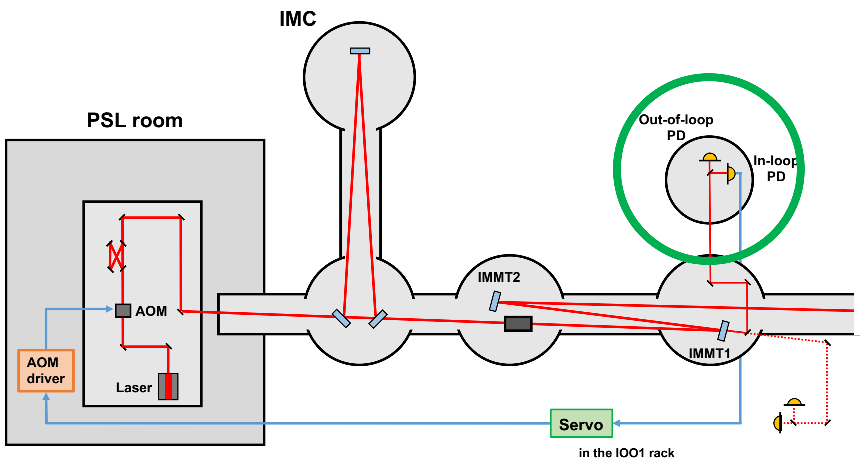




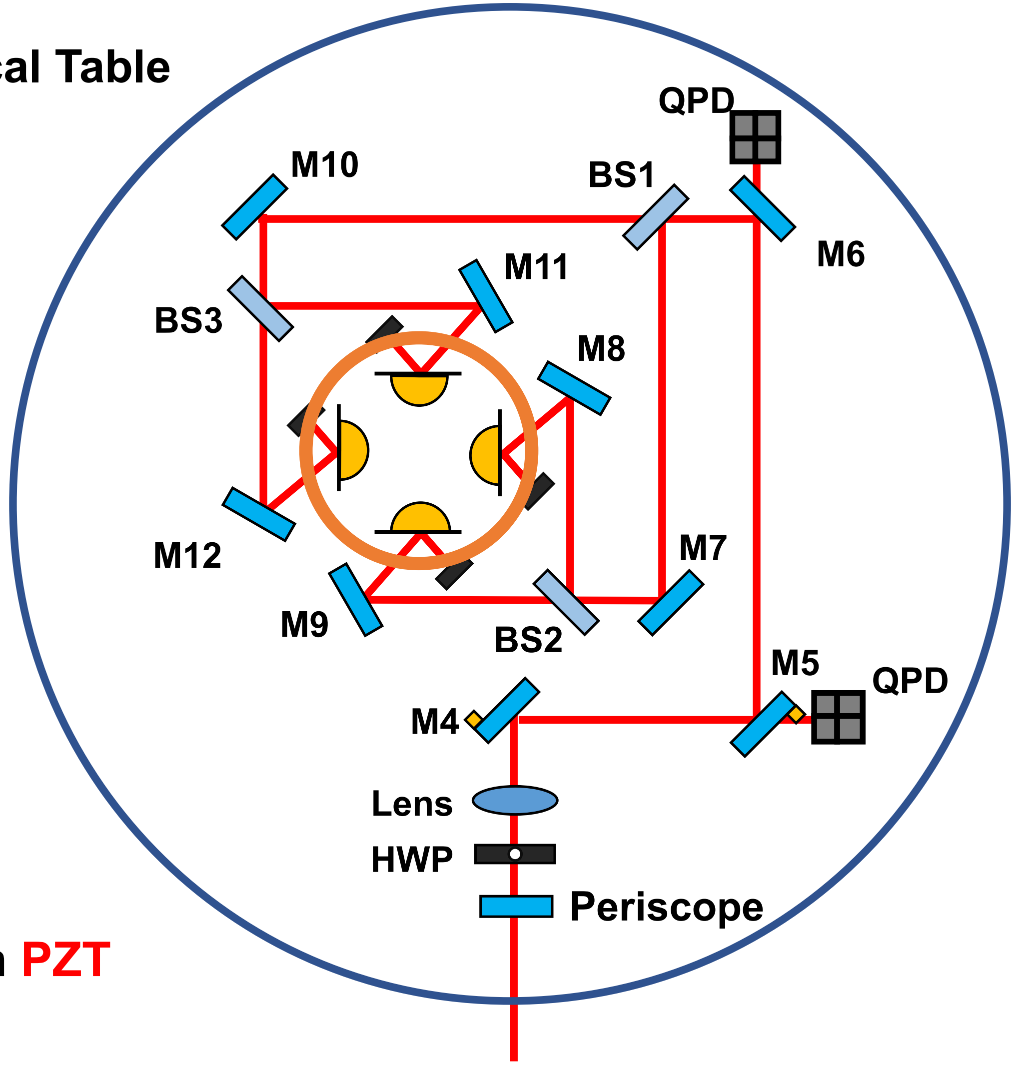
- **Support for high power laser**
  Number of PDs : **2** → **4**
  Laser power : **10 W** (O3GK) → **40 W** (O4)
  → **200 W** (Finally)

- **Suppress of beam jitter**
  Stabilize beam position with **QPD** and mirror with **PZT**

Improvement of the ISS for O4



Optical Table



from IMMT1 Trans.

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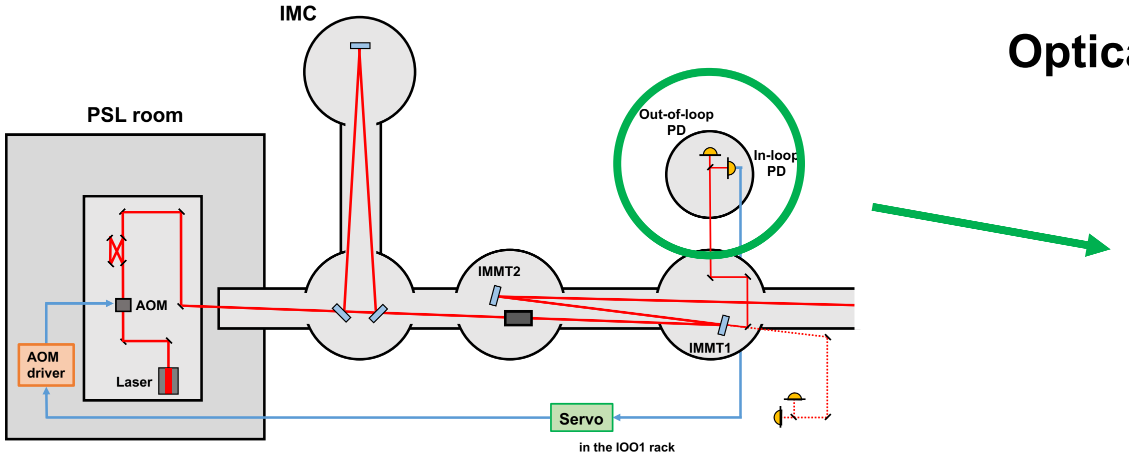

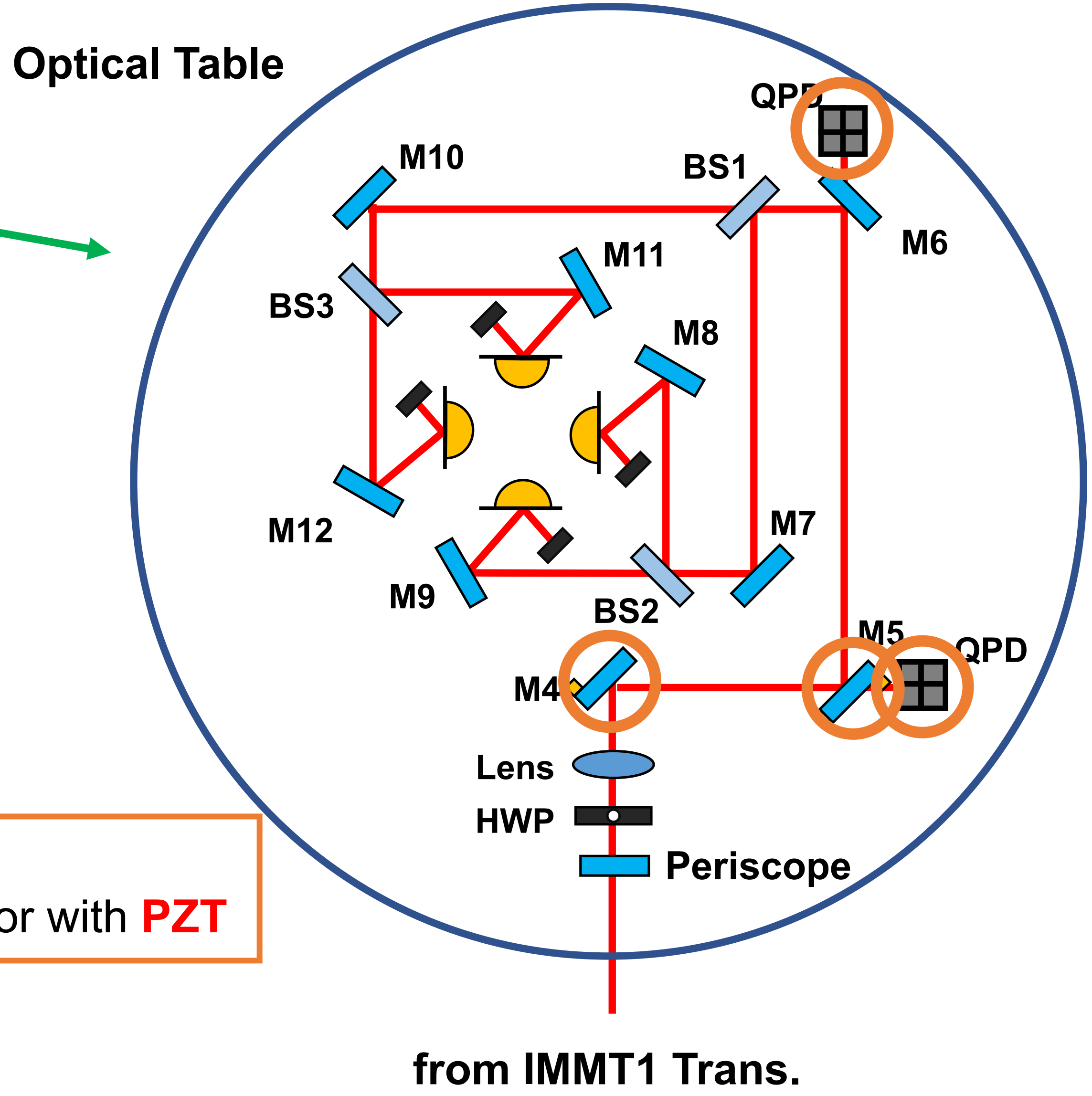

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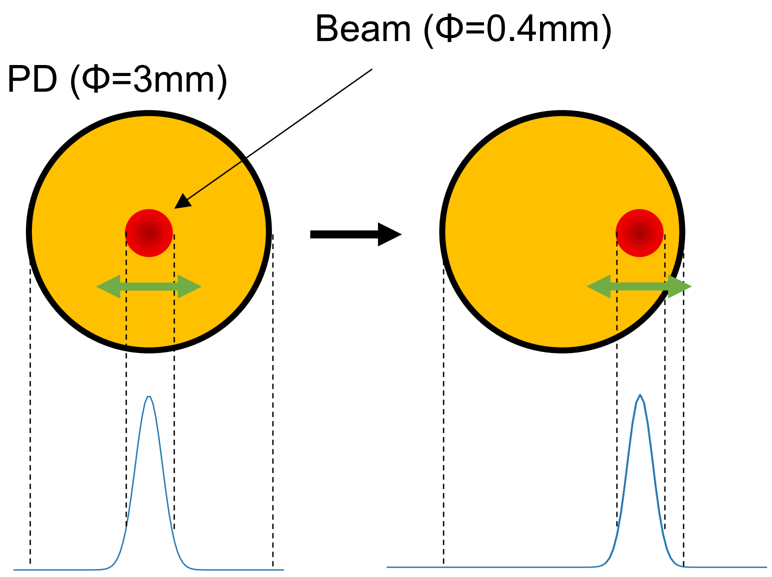
Measurement of the beam jitter effect

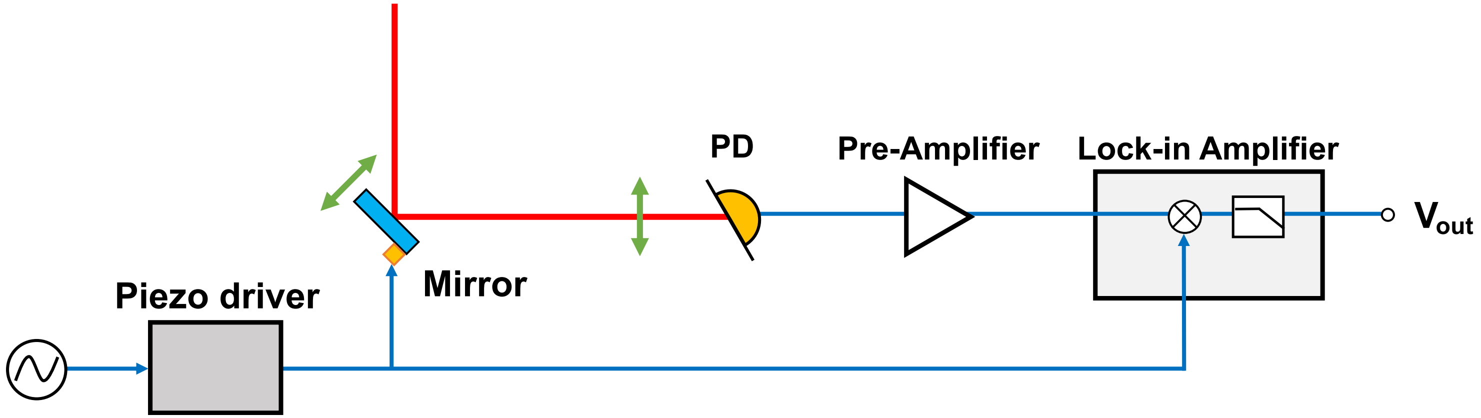
We want to determine the cause of the beam jitter in KAGRA.

We demonstrated the beam jitter effect on PD surface as follows.

- The angle of the mirror is modulated by applying sine voltage to the PZT on the mirror.
- This causes the beam position fluctuation on the PD surface.
- The beam jitter effect in the PD signal is demodulated using lock-in amplifier.

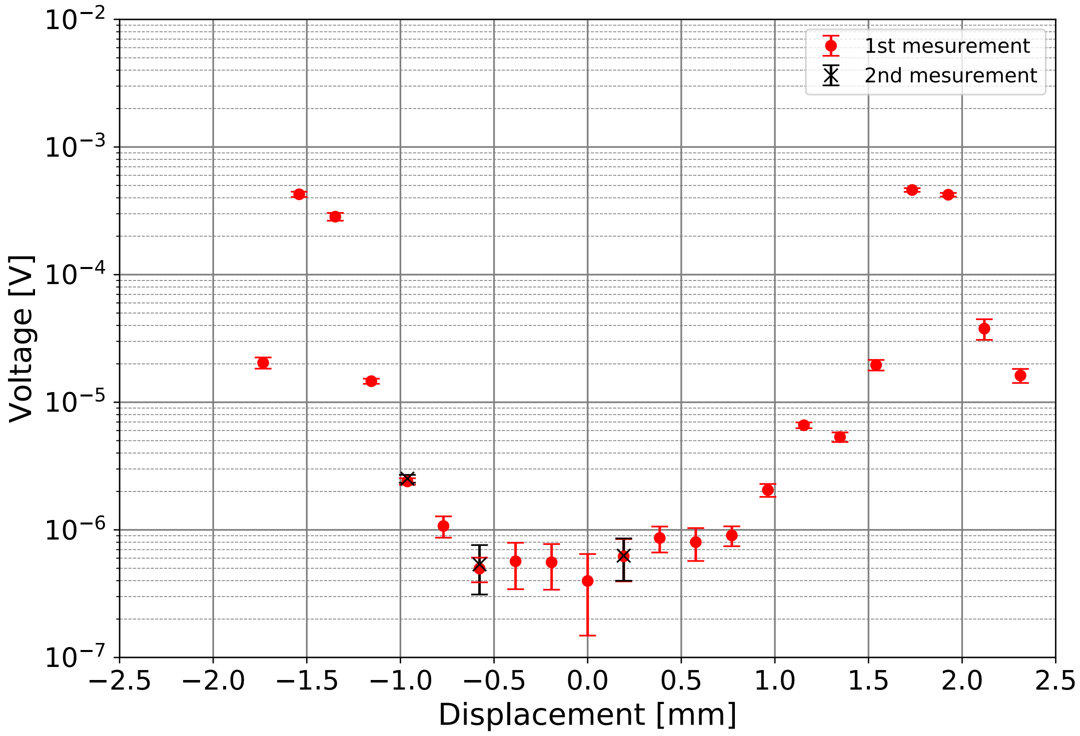
The frequencies for oscillating the mirror were **1 Hz** and **10 Hz**.

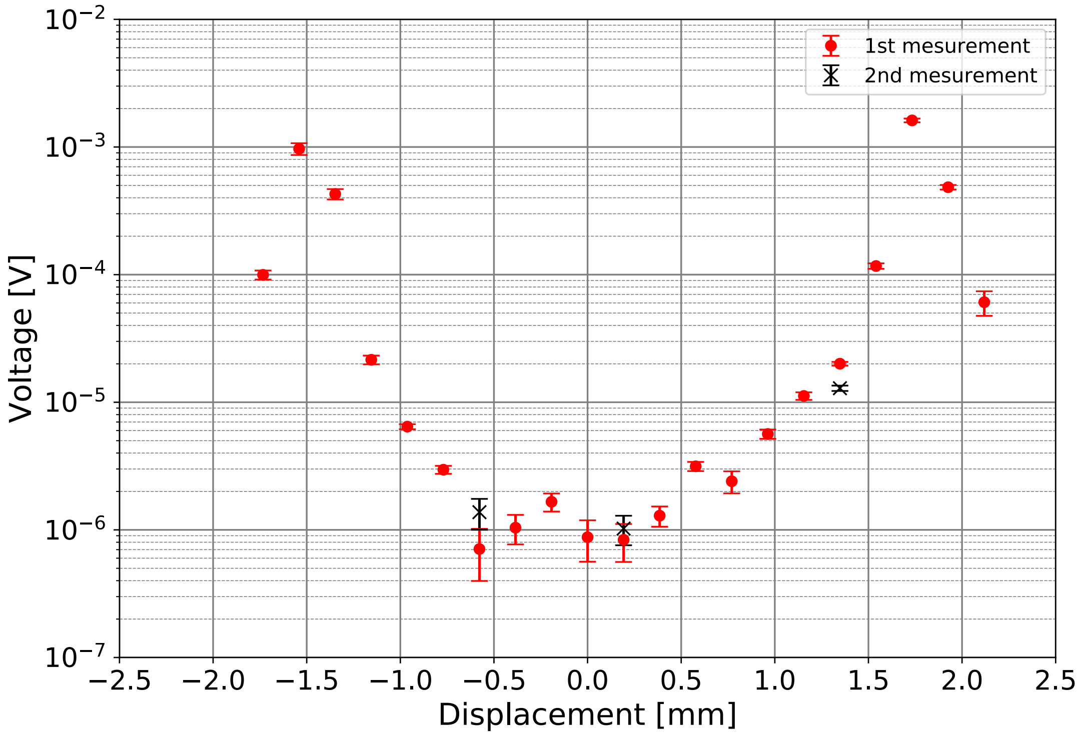




Measurement of the beam jitter effect

The magnitude of the signal for each beam position





Oscillating frequency = 1 Hz

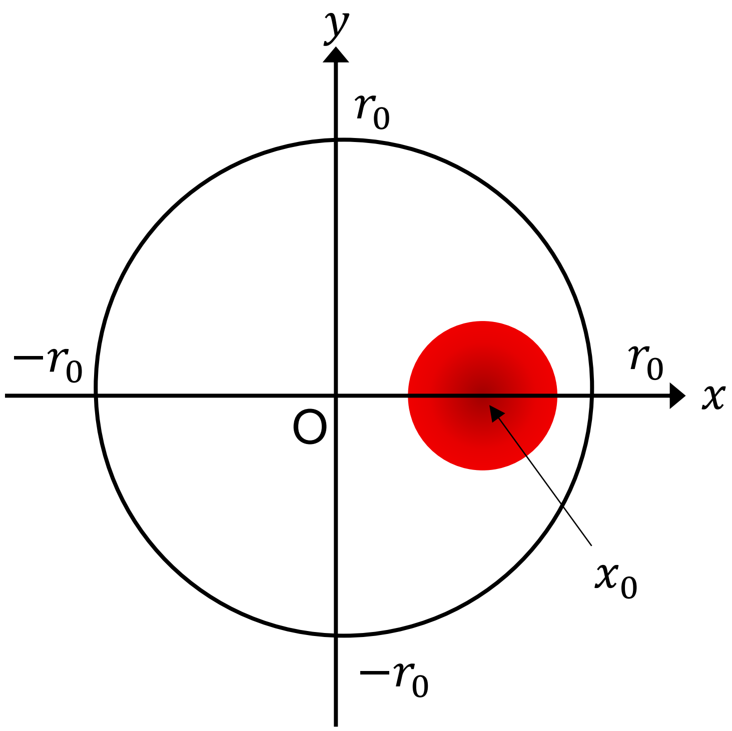
Oscillating frequency = 10 Hz

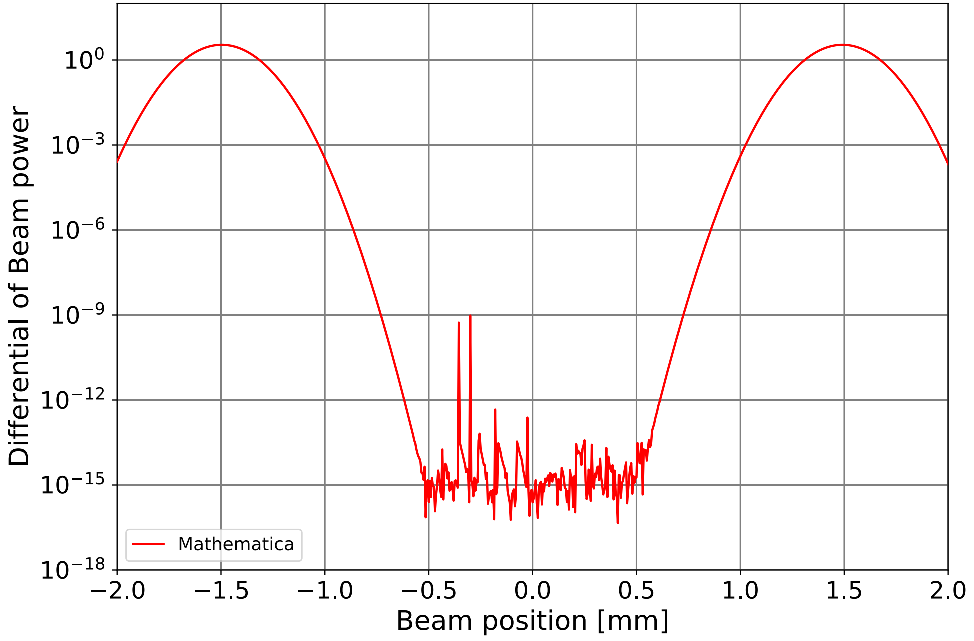
Model calculation

$$I(x,y) = I_0 \exp\left(-2\left(\frac{(x-x_0)^2}{\omega_x^2} + \frac{y^2}{\omega_y^2}\right)\right)$$

$$\frac{dP(x_0)}{dx_0} = \int_0^{r_0} rdr \int_0^{2\pi} d\theta \frac{dI(r,\theta)}{dx_0}$$

$$= \frac{4I_0}{\pi}\int_0^{r_0} rdr \int_0^{2\pi} d\theta\, (r\cos\theta - x_0)\exp\left(-2\left(\frac{(r\cos\theta - x_0)^2}{\omega_x^2} + \frac{r^2\sin\theta^2}{\omega_y^2}\right)\right)$$

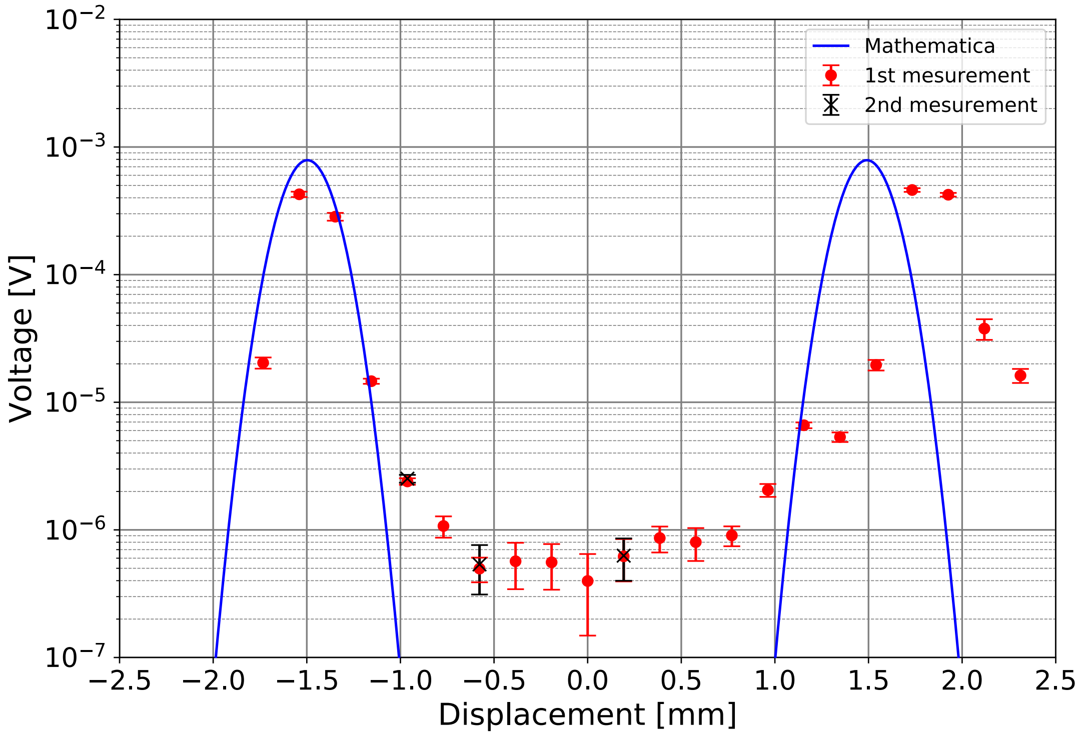




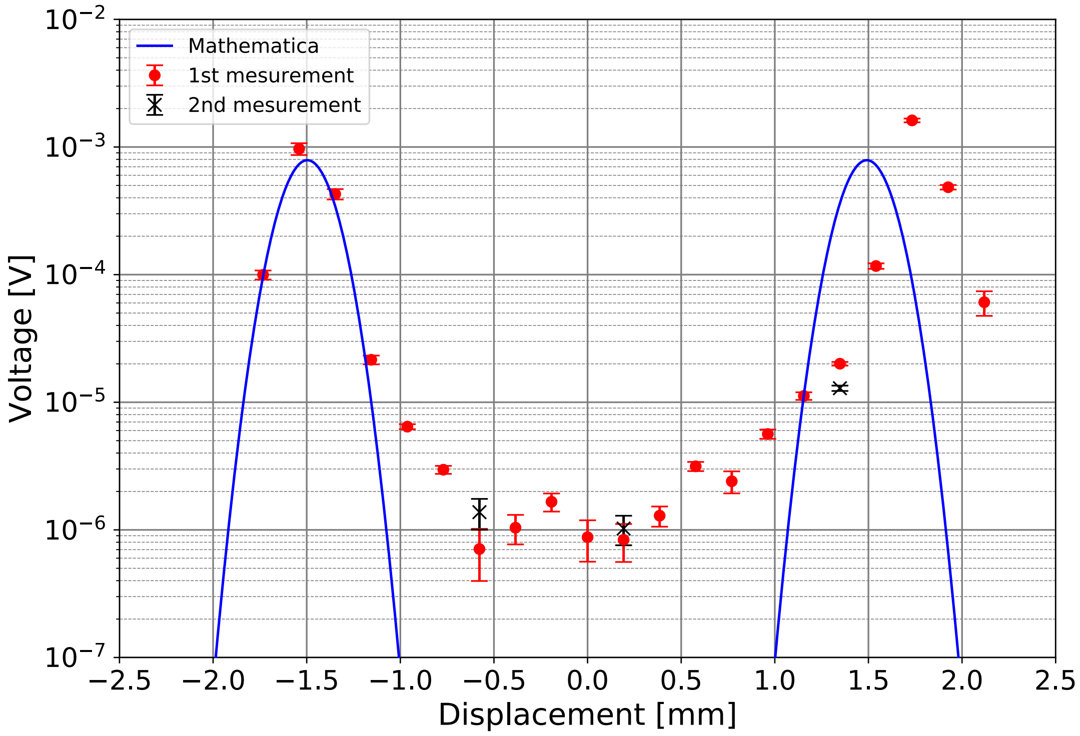
- Assume a Gaussian beam
- Differentiate the beam intensity distribution at beam position x_0 and integrate it over the area of the PD

Model calculation

Comparison of measured values and calculated values



Oscillating frequency = 1 Hz

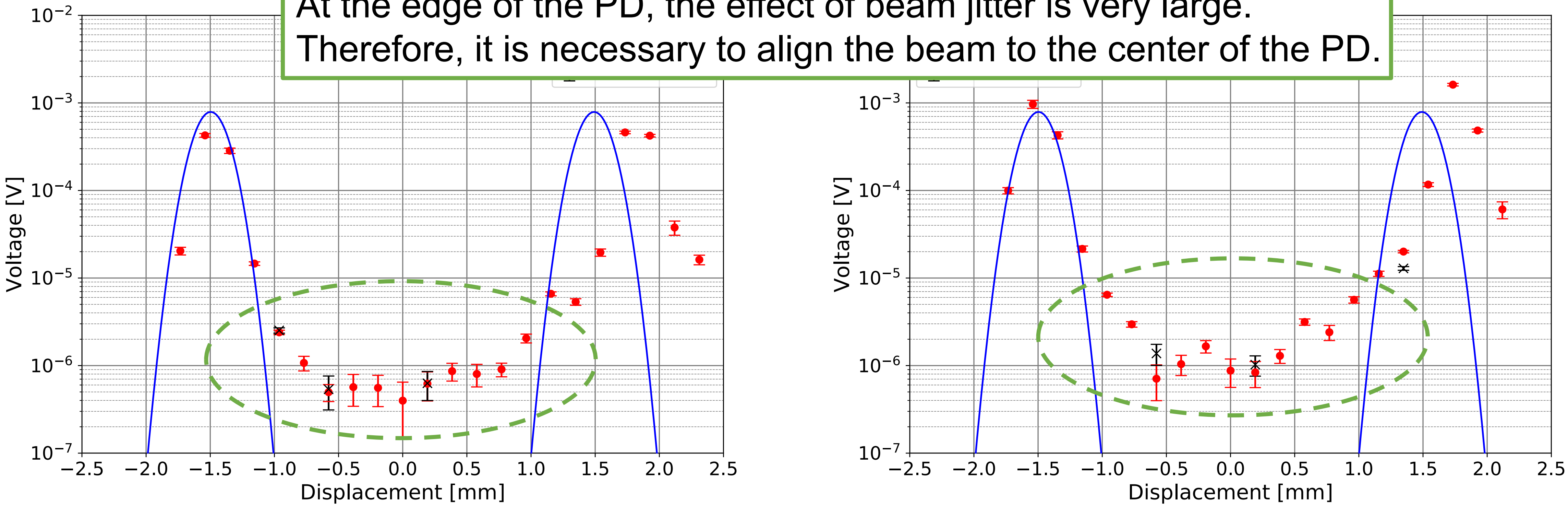


Oscillating frequency = 10 Hz

Model calculation

Comparison of measured values and calculated values

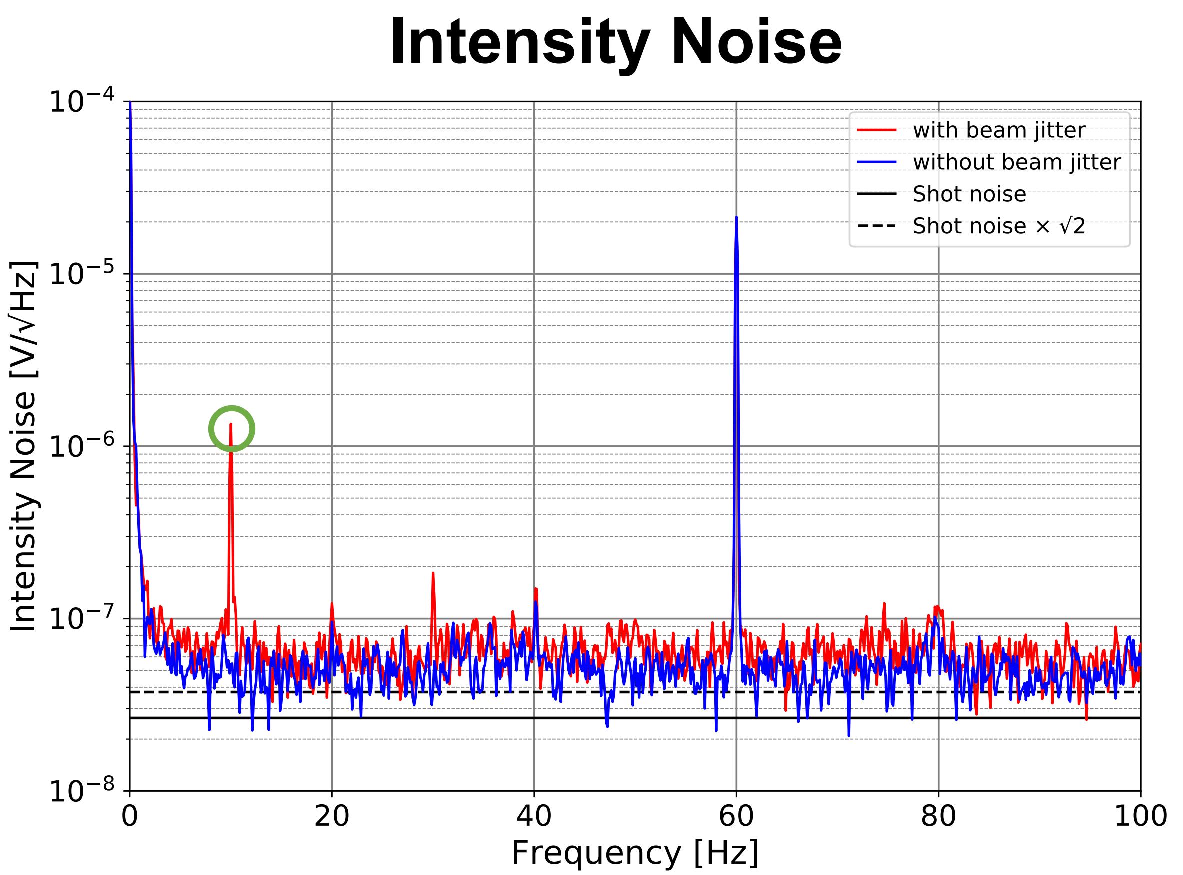
At the edge of the PD, the effect of beam jitter is very large.
Therefore, it is necessary to align the beam to the center of the PD.

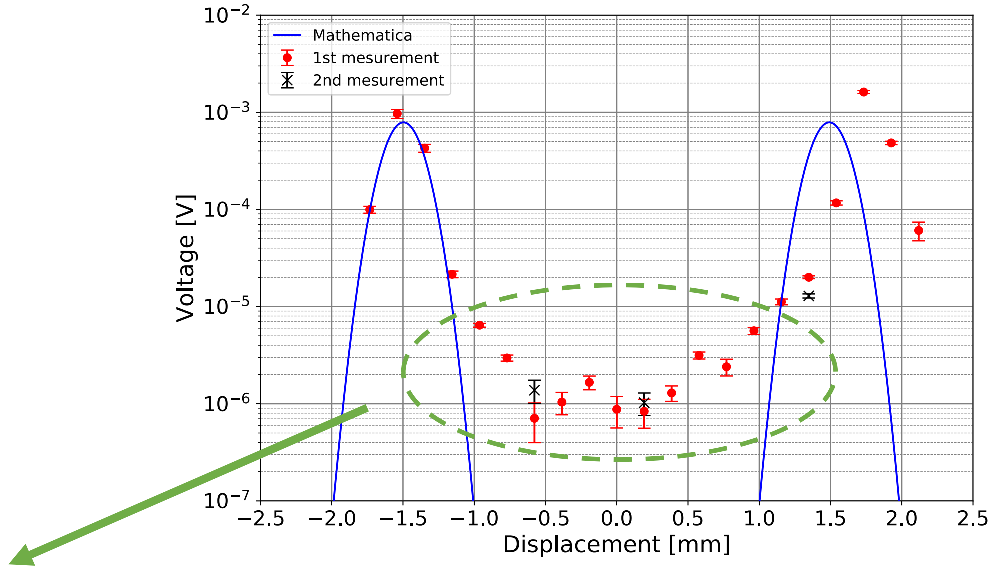


Oscillating frequency = 1 Hz

Oscillating frequency = 10 Hz

Intensity Noise and Beam jitter effect





Oscillating frequency = 10 Hz

The peak appears
at the oscillating frequency (10 Hz).

Summary

- We considered the new ISS optical system for O4.
  - Support for high power laser
  - Suppress of beam jitter
- We measured the beam jitter effect on the PD surface.
  - At the edge of the PD, beam jitter effect is due to the beam intensity distribution.
  - At the center of the PD, beam jitter effect is caused by other effects.
  - We need to align the beam to the center of the PD.

Future plan

- We will consider the detailed design of each optical element for the new optical system.
- We will proceed with the measurement of the beam jitter effect under different conditions.