

Recent progress and future plans for my Ph.D. thesis

Hinata Takidera (D3)

Department of Physics, The University of Tokyo

Ando-Michimura Group Seminar, August 7th, 2026

- Review of previous DANCE
- Recent progress
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - Others
- Future plans

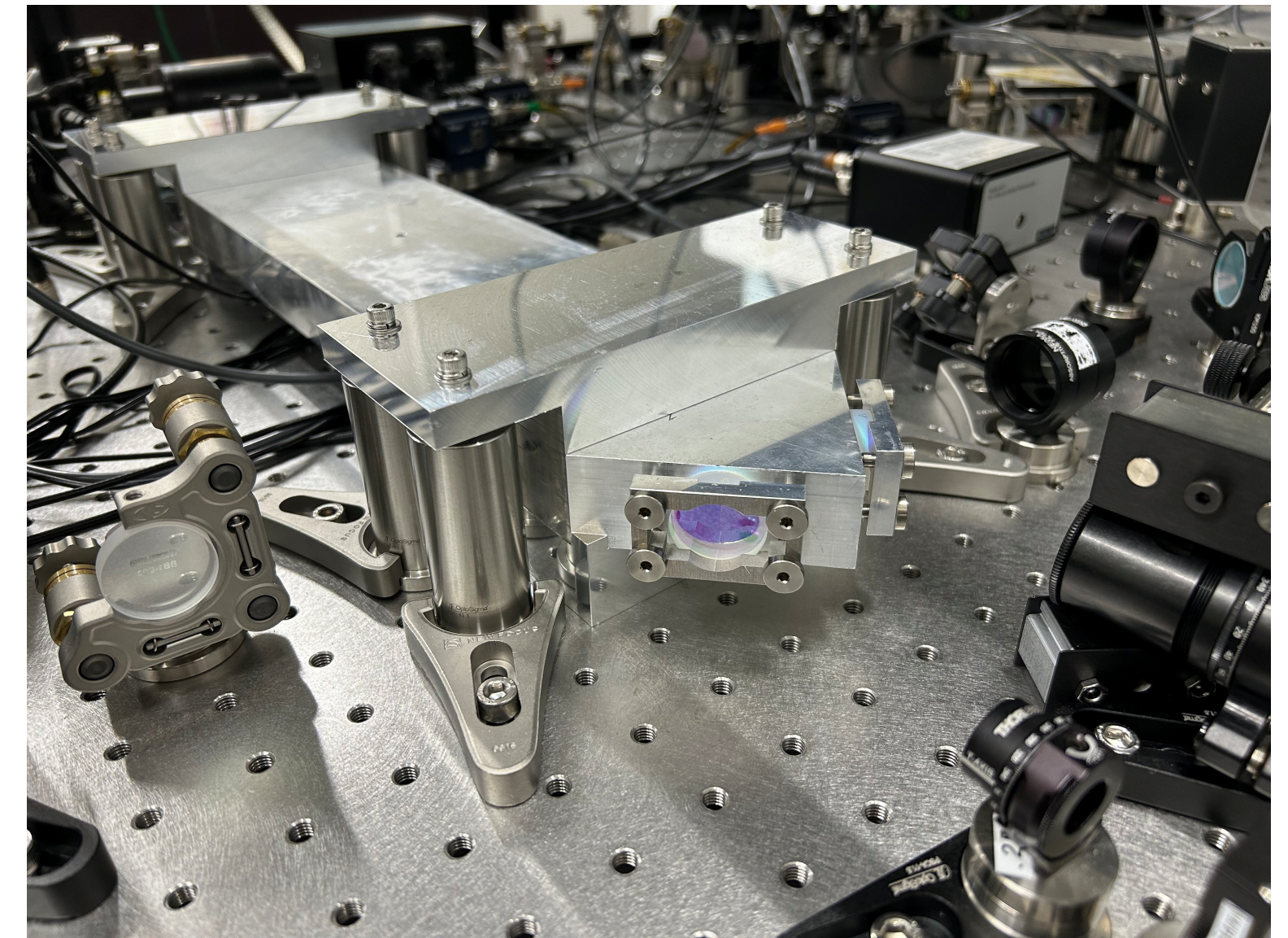
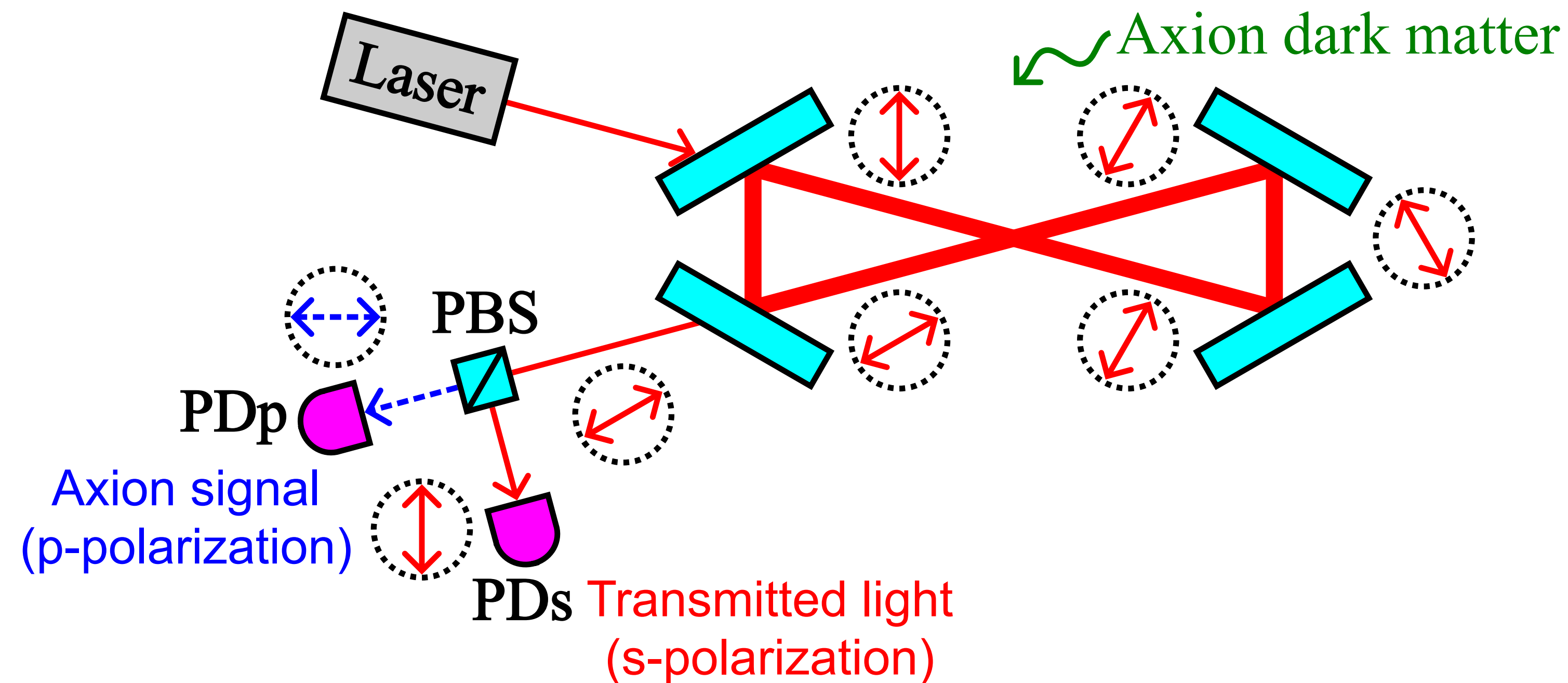
- Review of previous DANCE
- Recent progress
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - Others
- Future plans

Principle of DANCE

4

DANCE: Dark matter Axion search with ring Cavity Experiment

- Amplify polarization rotation with a bow-tie ring cavity
- Measure polarization rotation using a PBS and two PDs
- DANCE Act-1 (prototype experiment), which has round-trip of 1 m, is ongoing

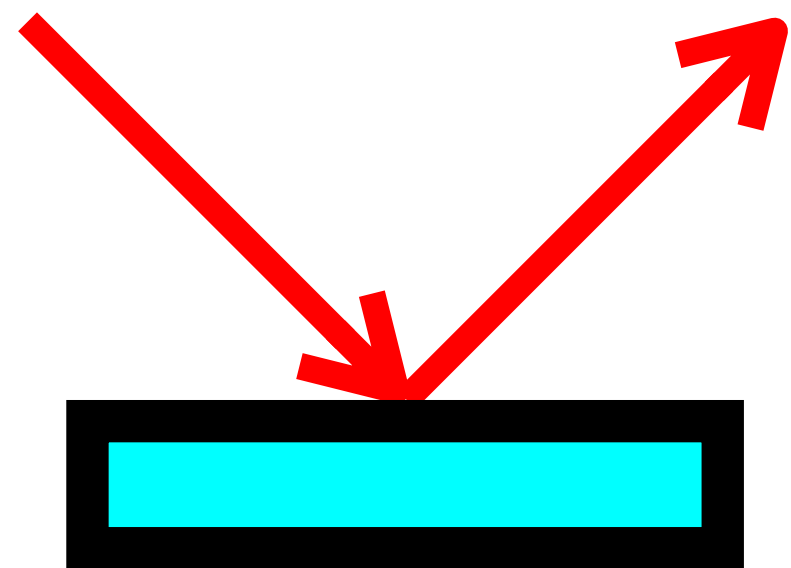


Issue: Non-simultaneous resonance

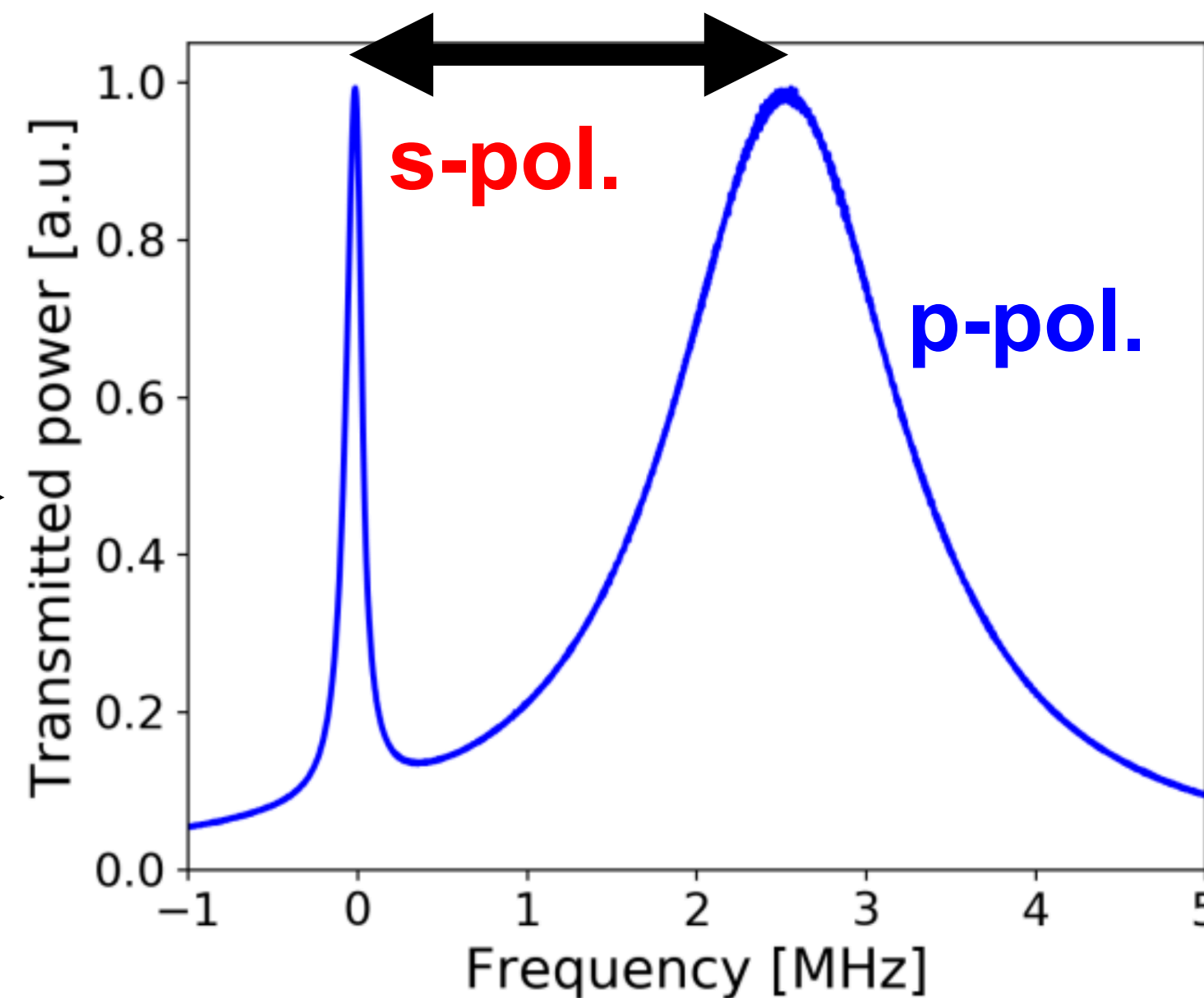
5

Reflection phase difference
between s- and p-pol.

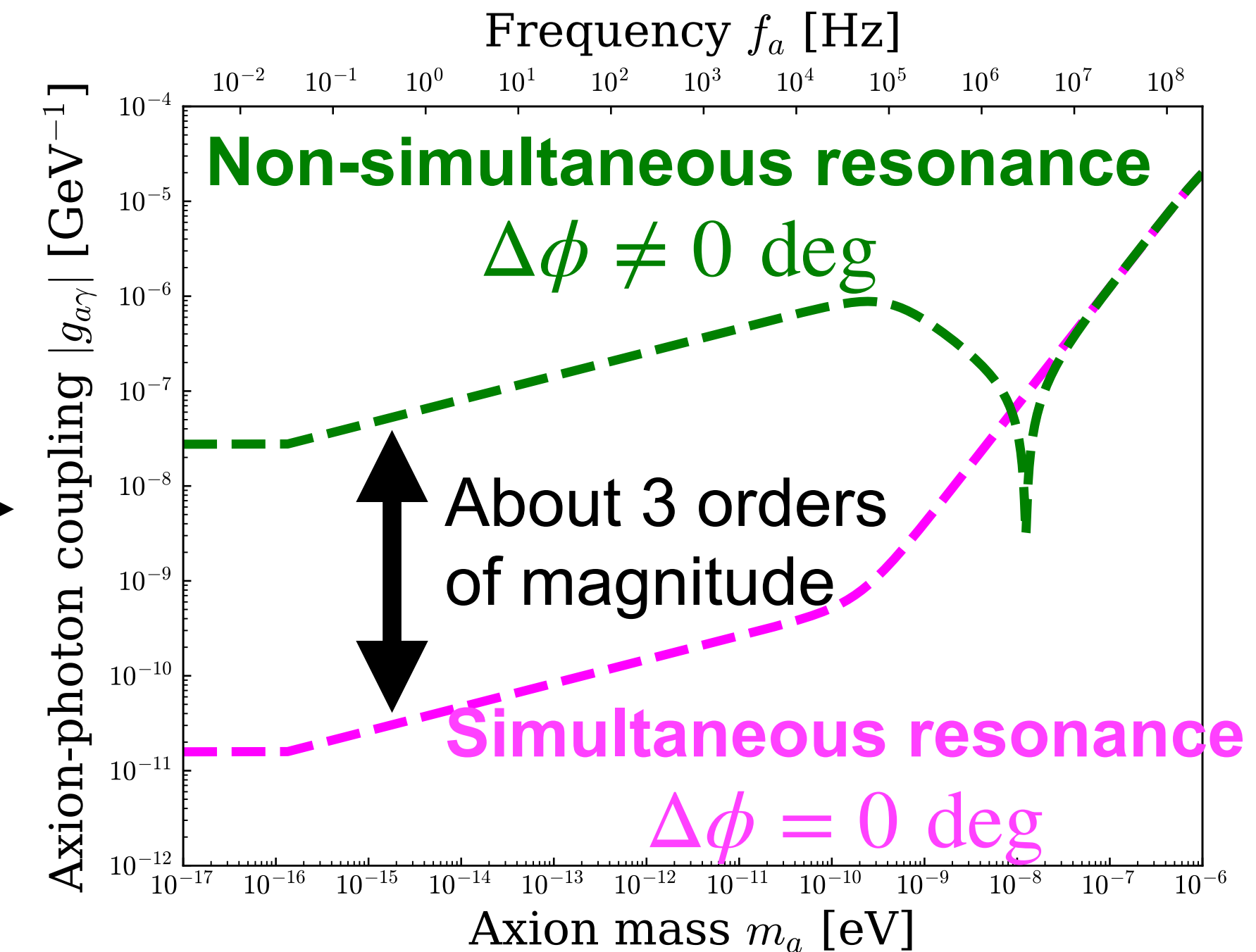
$$\Delta\phi = \phi_s - \phi_p \neq 0 \text{ deg}$$



Resonant frequency difference
between s- and p-pol.



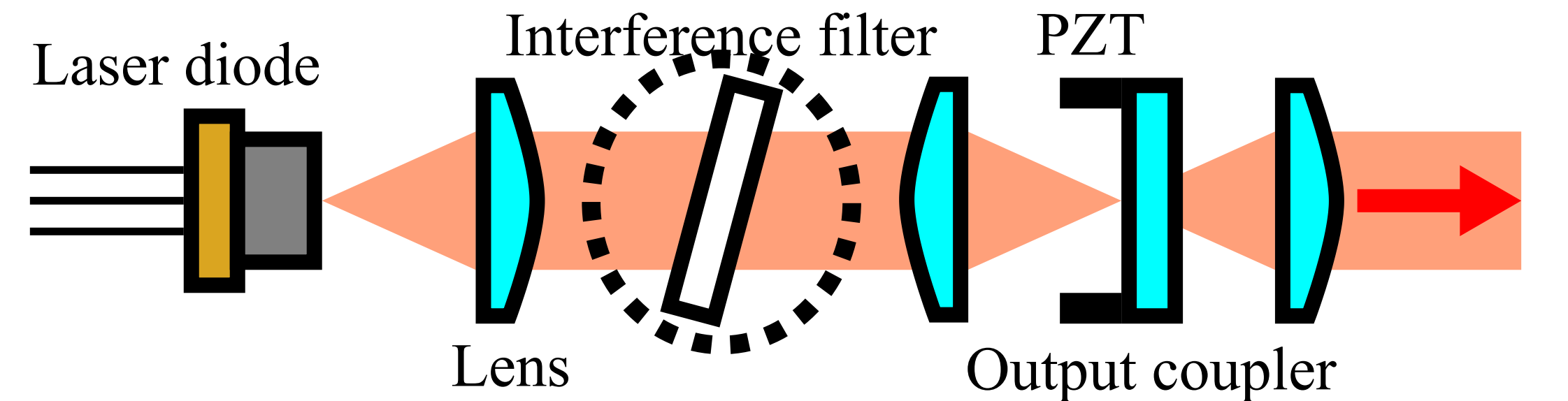
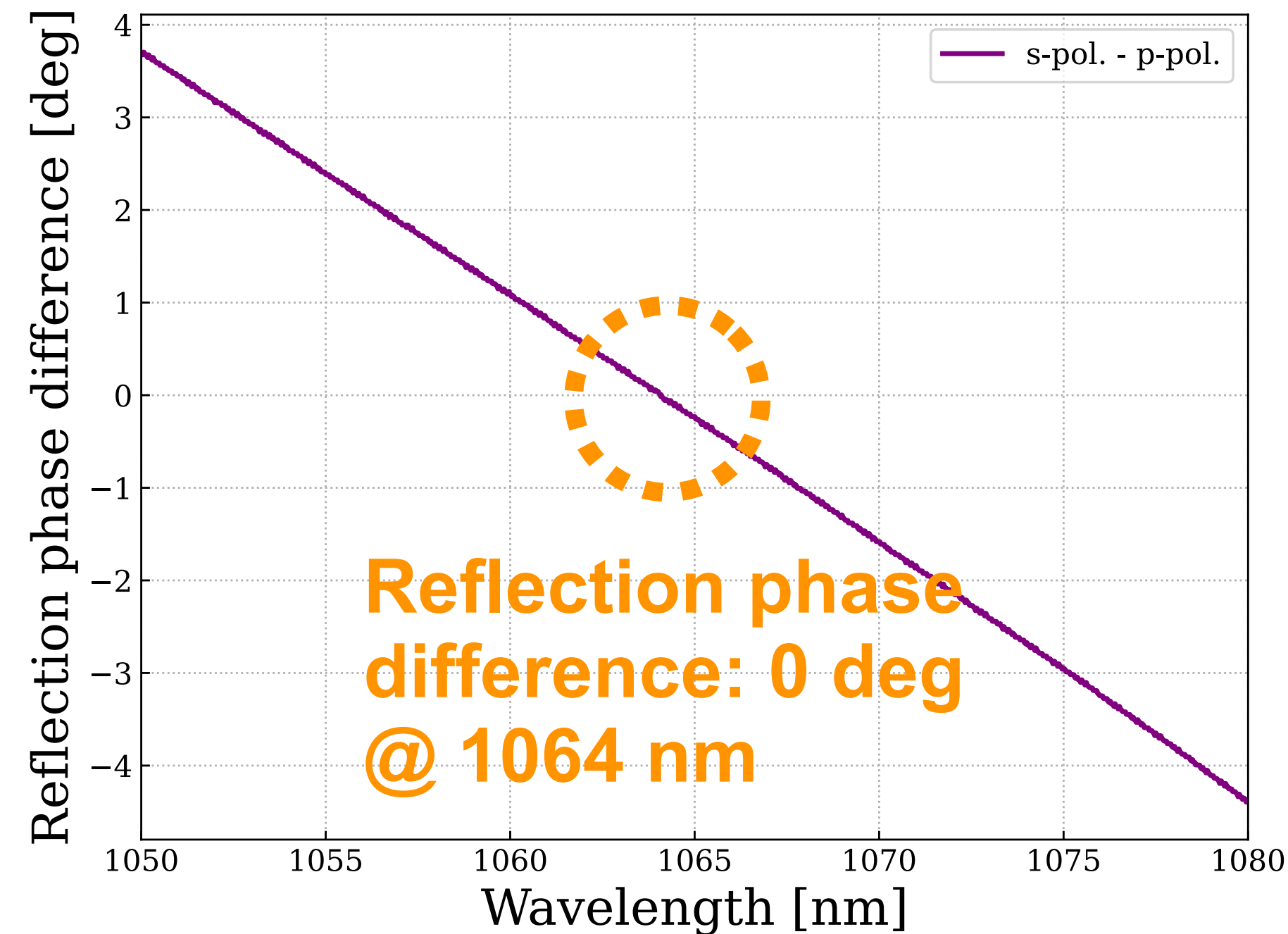
Assume resonant frequency
difference is 3 MHz



Y. Oshima *et al.*, Phys. Rev. D **108**, 072005 (2023).

Non-simultaneous resonance (**s-pol.** is resonant in the cavity, while **p-pol.** is not)

➡ **p-pol.** generated by the axion-photon interaction is not amplified, degrading the sensitivity



Select wavelength by rotating interference filter

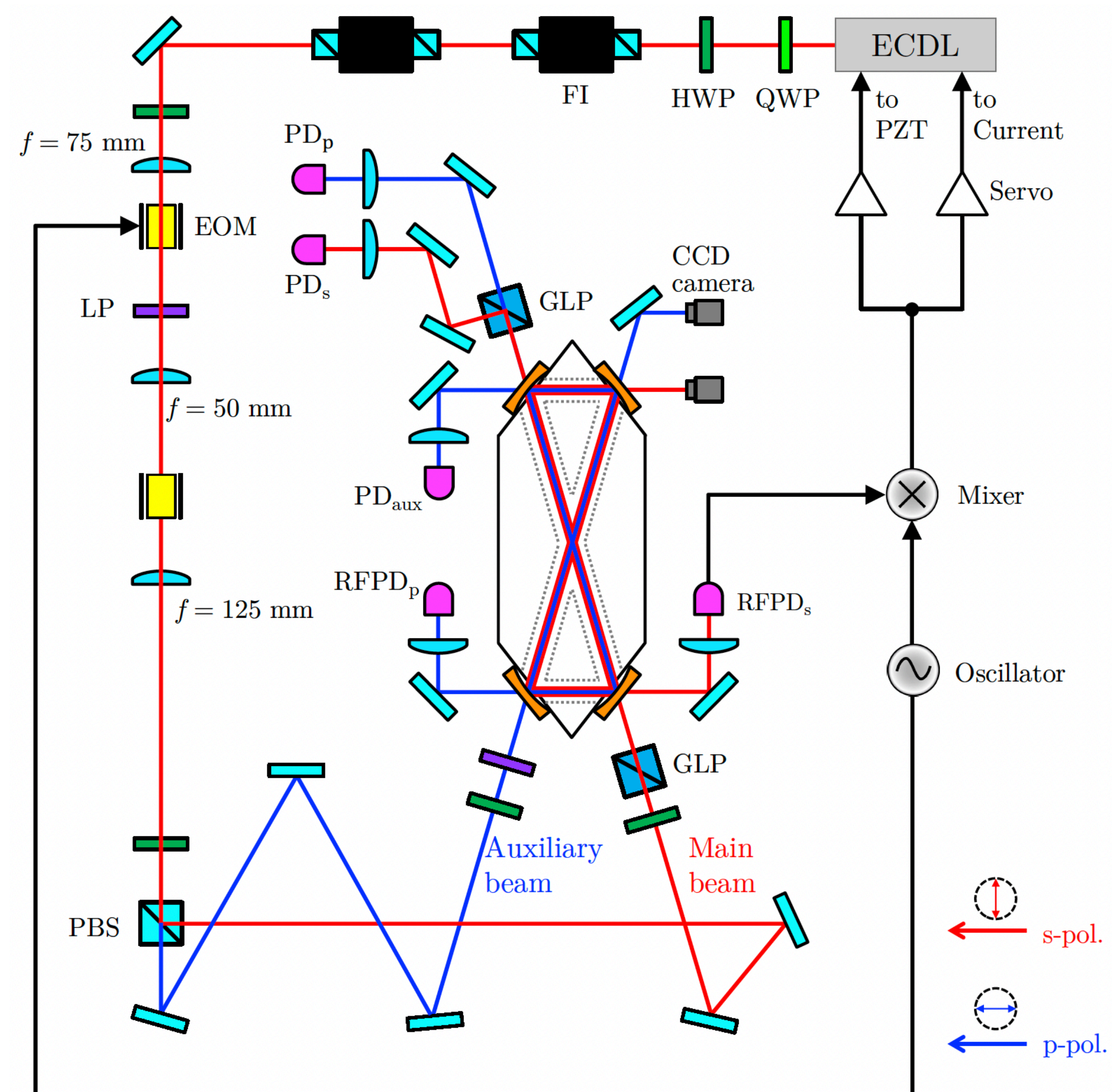
Wavelength tunable laser (ECDL)

- Wavelength tuning range: 1034 - 1067 nm
- Laser linewidth: 200 kHz
- Output: < 36.5 mW

- Zero phase shift mirror
 - Reflection phase difference is 0 deg at a wavelength and an angle of incidence
 - Coating thickness error: ± 2 deg $\gg$ Requirement: 0.015 deg
 - Wavelength tunable laser (ECDL)
 - Coating thickness error can be compensated by tuning laser wavelength
- ➡ Achieve **simultaneous resonance** (s-pol. and p-pol. are resonant in the cavity)

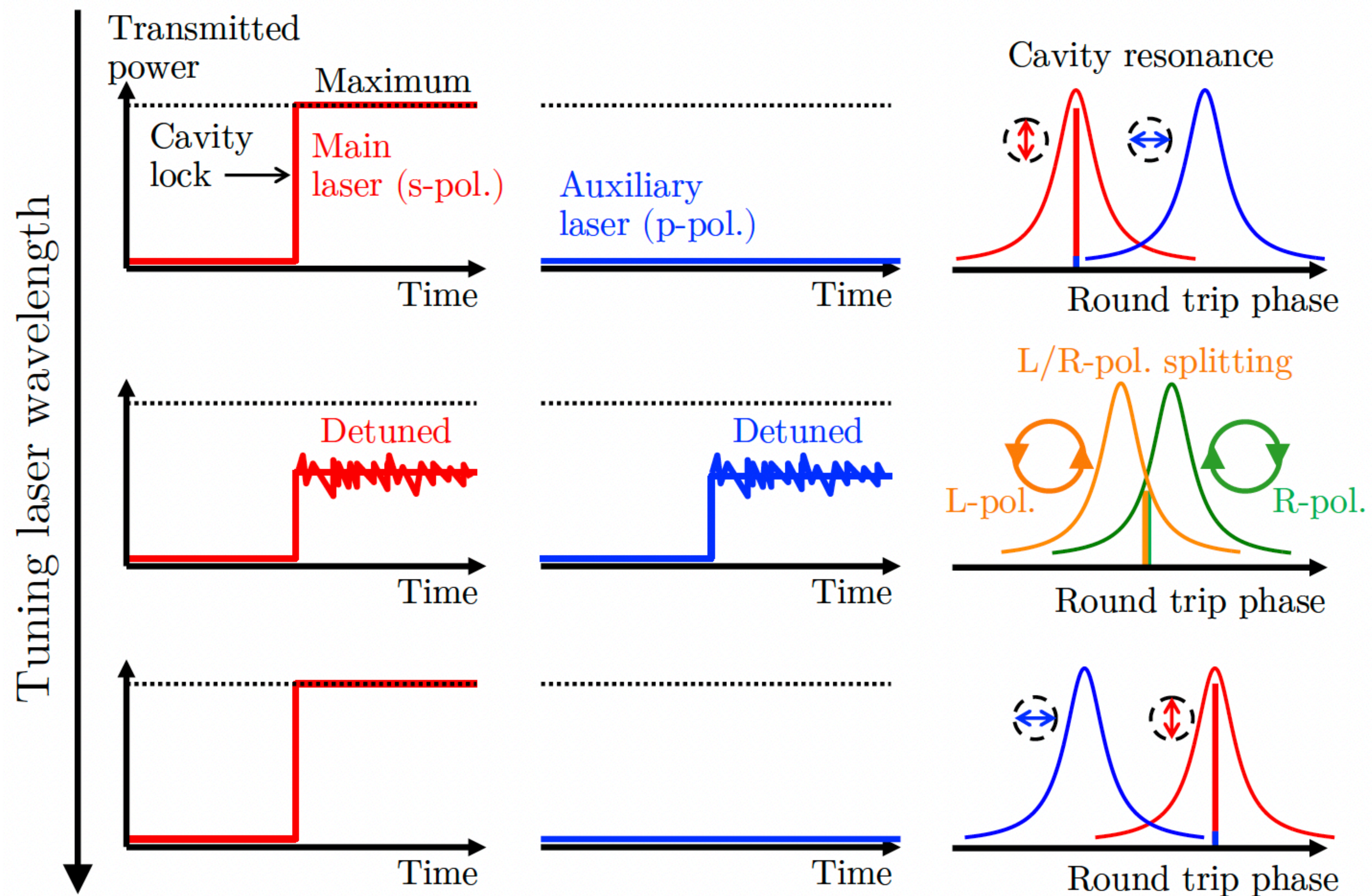
Experimental setup

7



Issue: L/R-polarization splitting

8



L/R-pol. splitting by cavity non-planarity

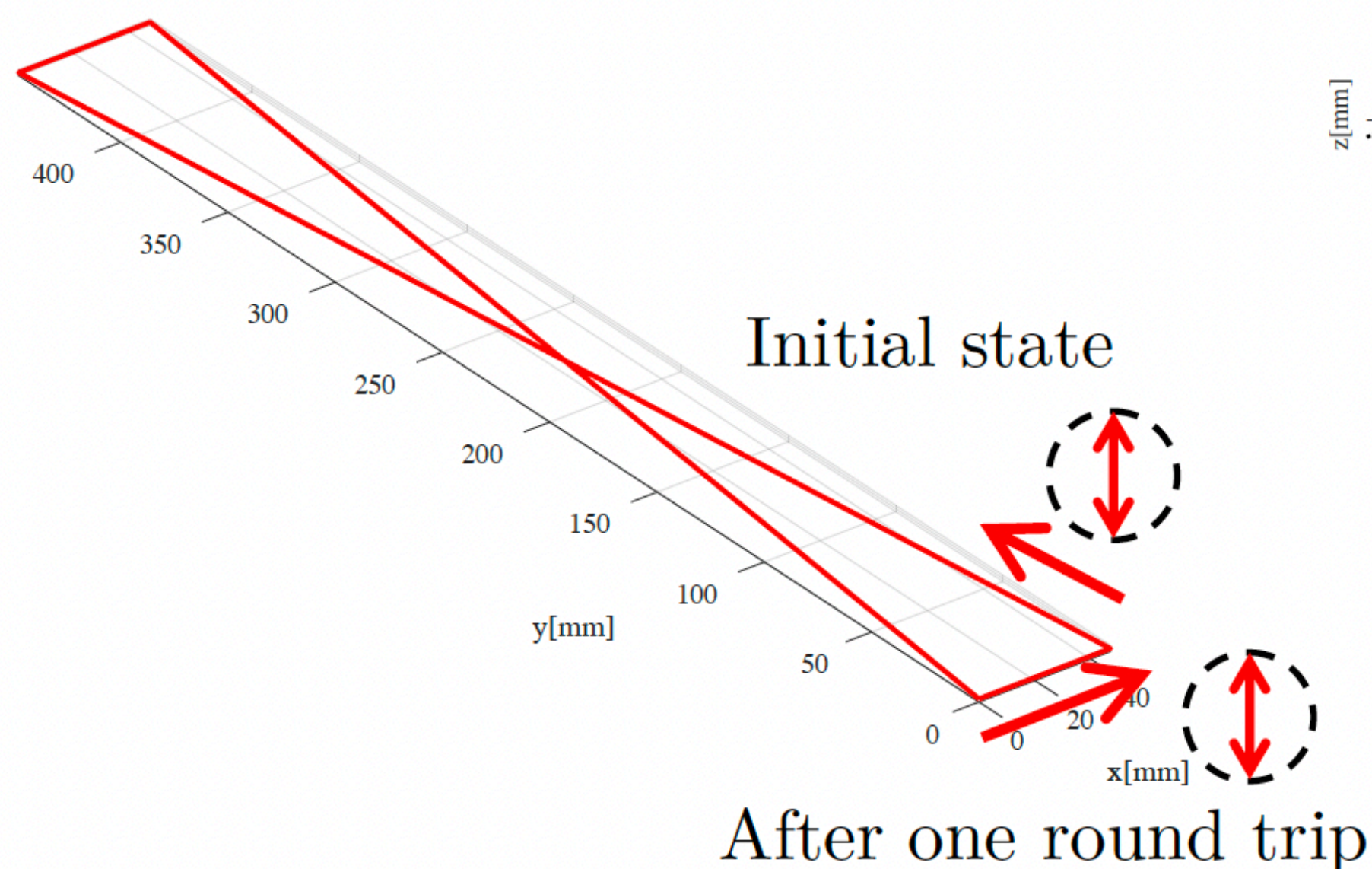
9

In general, when 4 or more mirrors are used, the optical path can be non-planar

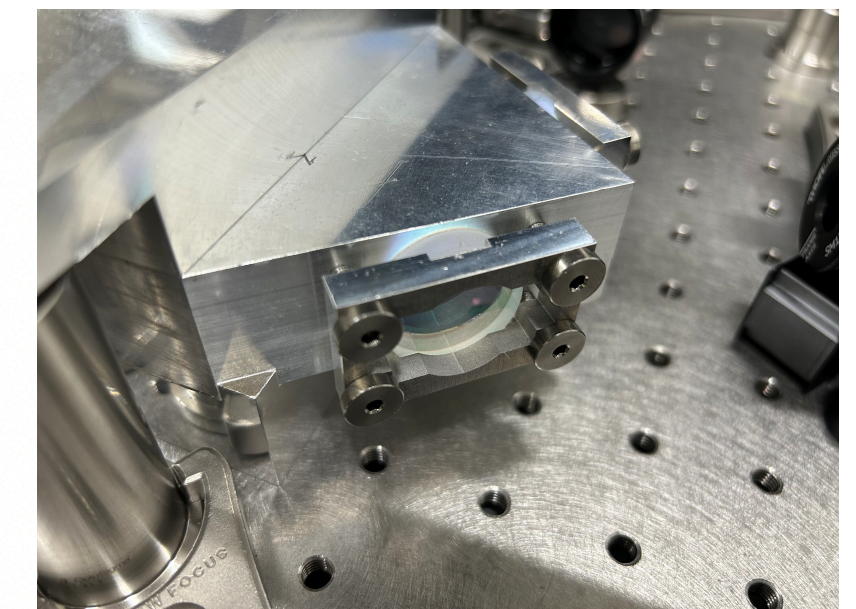
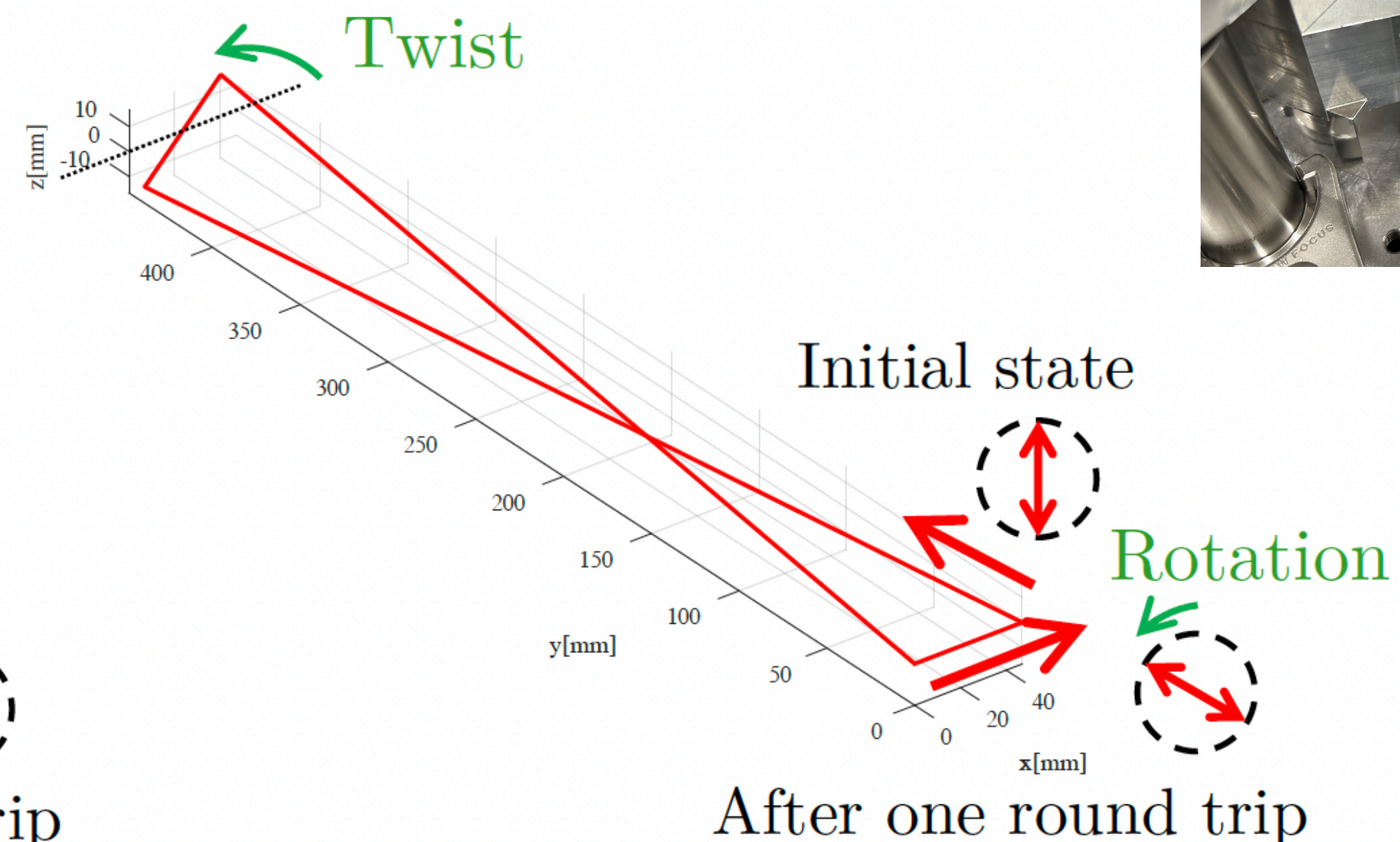
➡ DC rotation of linear polarization occurs within the cavity (non-simultaneous resonance of L/R-polarization)

➡ Solution: Adjustment of the fastening tightness of the jig that fixes the mirror

➤ Planar cavity

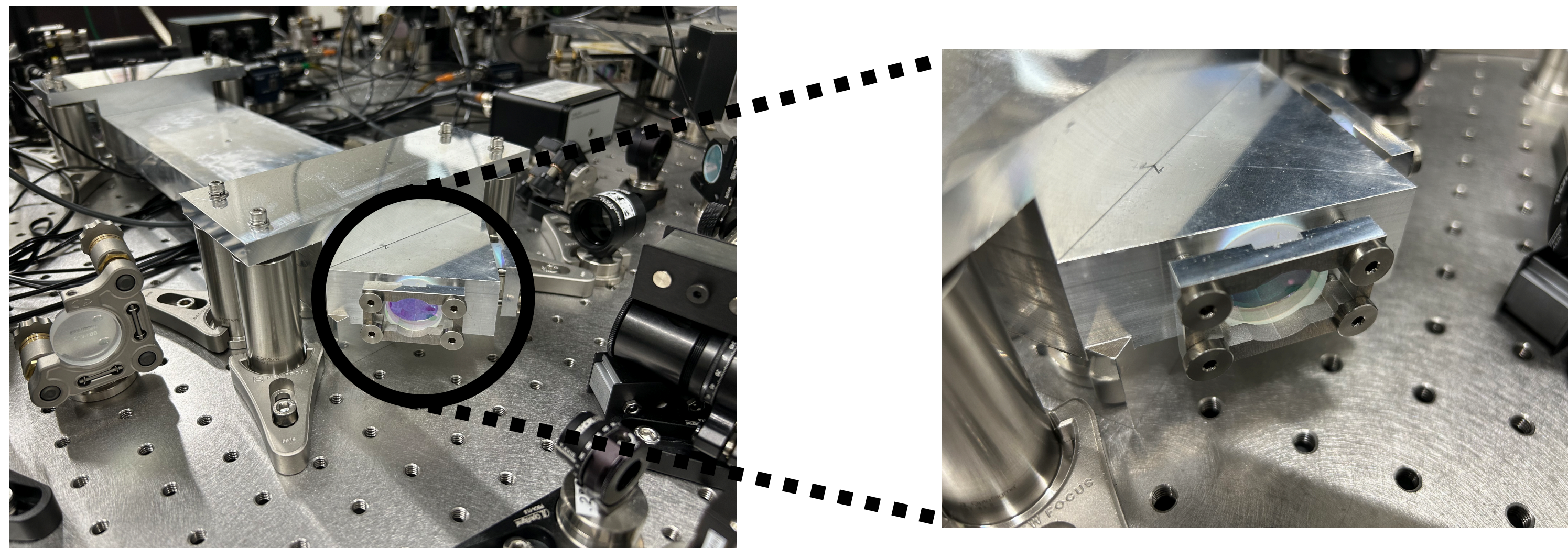


➤ Non-planar cavity



Adjustment method for cavity non-planarity 10

- ① Minimize mixture of p-polarization under non-simultaneous resonance
 - ▶ Adjust the angle of GLP so that the incident light is s-polarization and the transmitted polarization is p-polarization
 - ▶ Tune the tightness of the jig
- ② Change the laser wavelength to a wavelength that achieves simultaneous resonance
- ③ Readjust the jig fastening to eliminate the residual cavity non-planarity



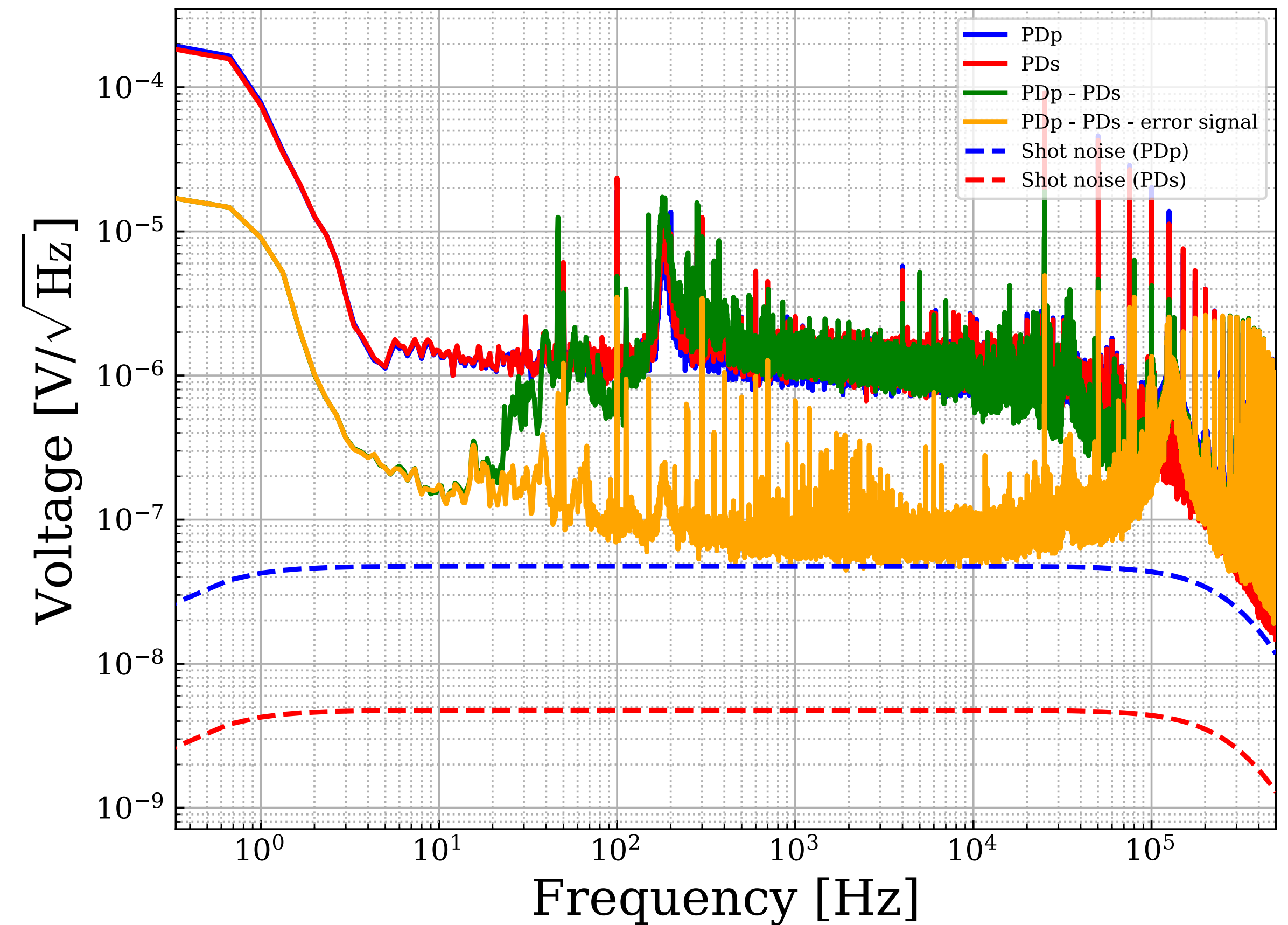
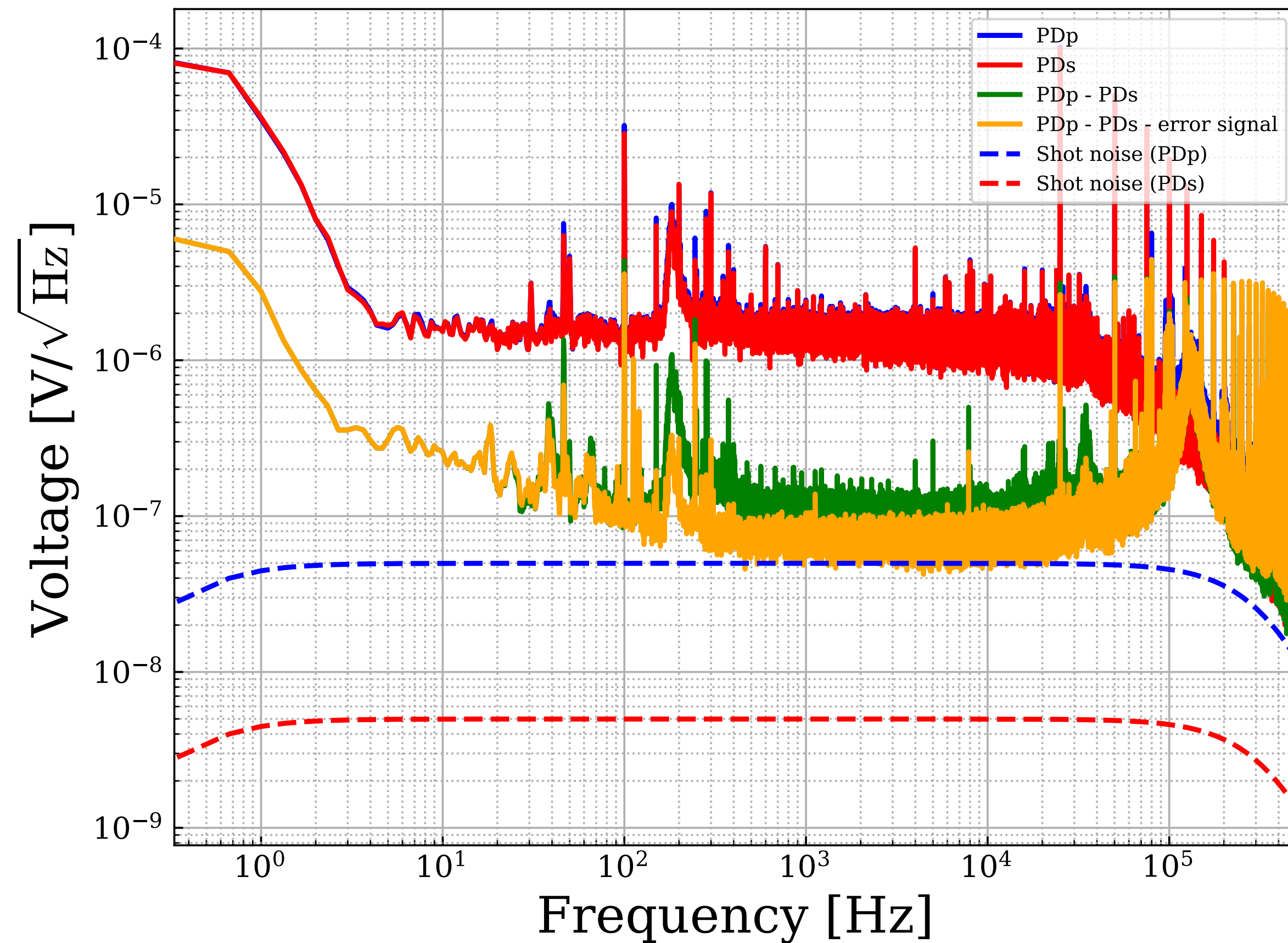
- Review of previous DANCE
- Recent progress
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - Others
- Future plans

Trade-off in cavity non-planarity adjustment 12

- Trade-off between canceling the cavity non-planarity and the amount of p-polarization generated by misalignment of the input GLP
 - When cavity non-planarity was minimized, the amount of the p-polarization injected from main laser fluctuated during auxiliary laser locking, leading to frequency noise coupling
 - When cavity non-planarity was suppressed to minimize the time fluctuation of p-polarization injected from main laser during auxiliary laser locking, frequency noise coupling became small
- ➡ Minimizing misalignment of the input GLP is important for achieving the shot noise limit over a wide frequency range

Comparison of spectrum

13



- Results on 2026/01/21 (left) and 2026/03/12 (right)
- The more intensity noise (s-pol.) we can subtract, the fewer peaks tend to appear in the spectrum

- Review of previous DANCE
- **Recent progress**
 - Trade-off in cavity non-planarity adjustment
 - **Simultaneous resonance with a critical couple cavity**
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - Others
- Future plans

DANCE Act-1

- Simultaneous resonance
- Identify noise
- Noise reduction
- Improve shot noise limit

- Long cavity: 10x
- High finesse: $\sim 3000x$
- High power: 100x



Final DANCE

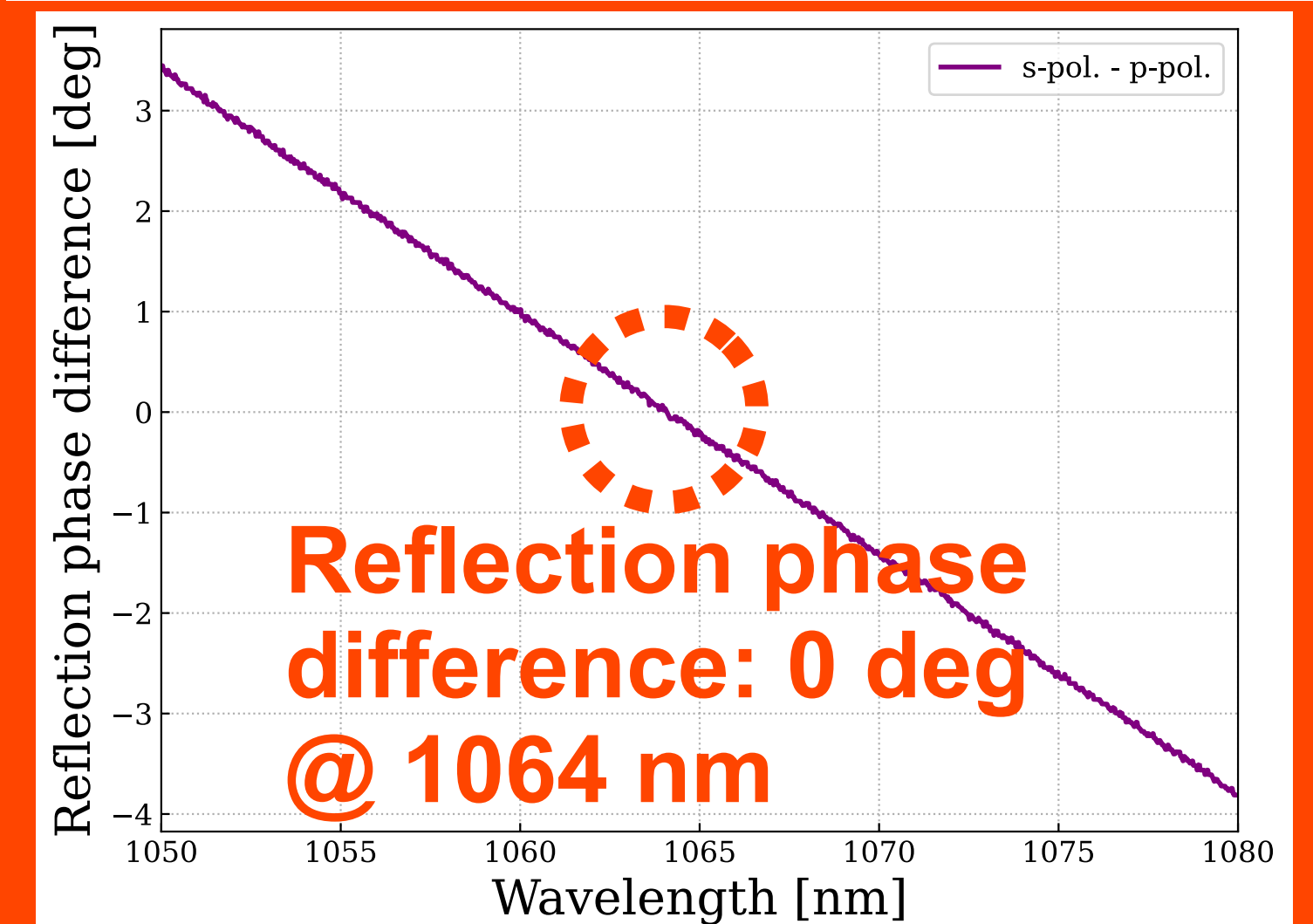
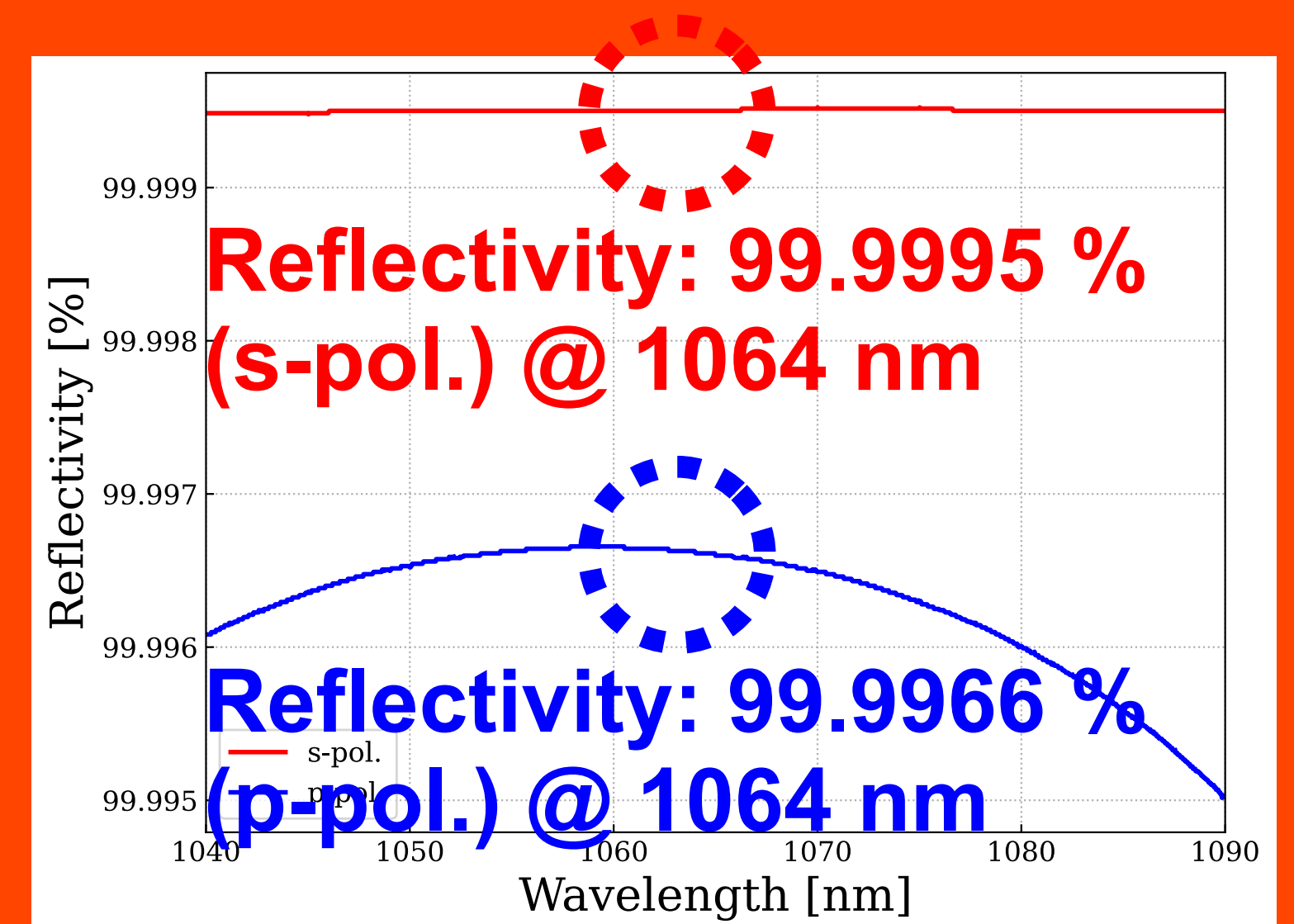
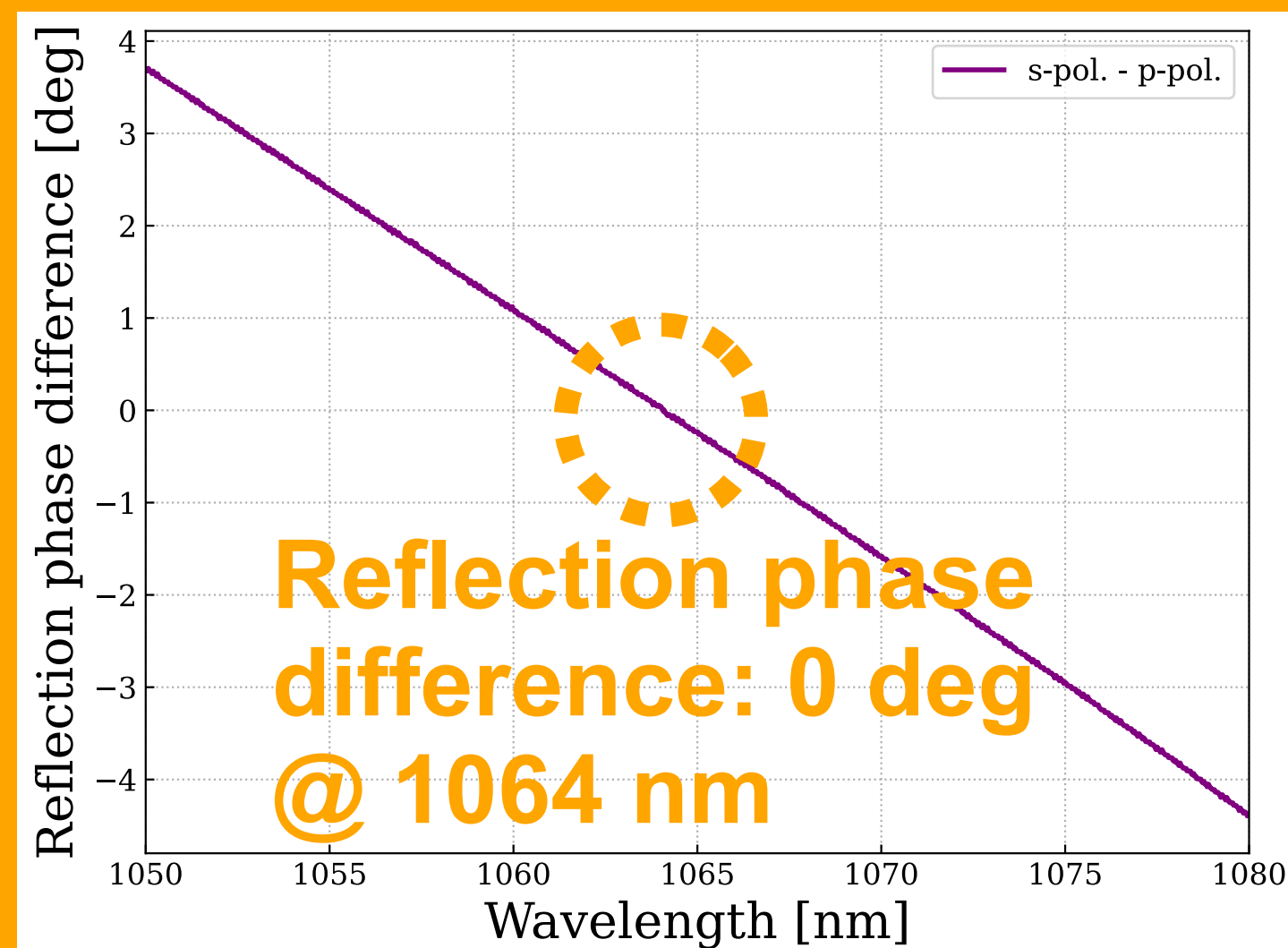
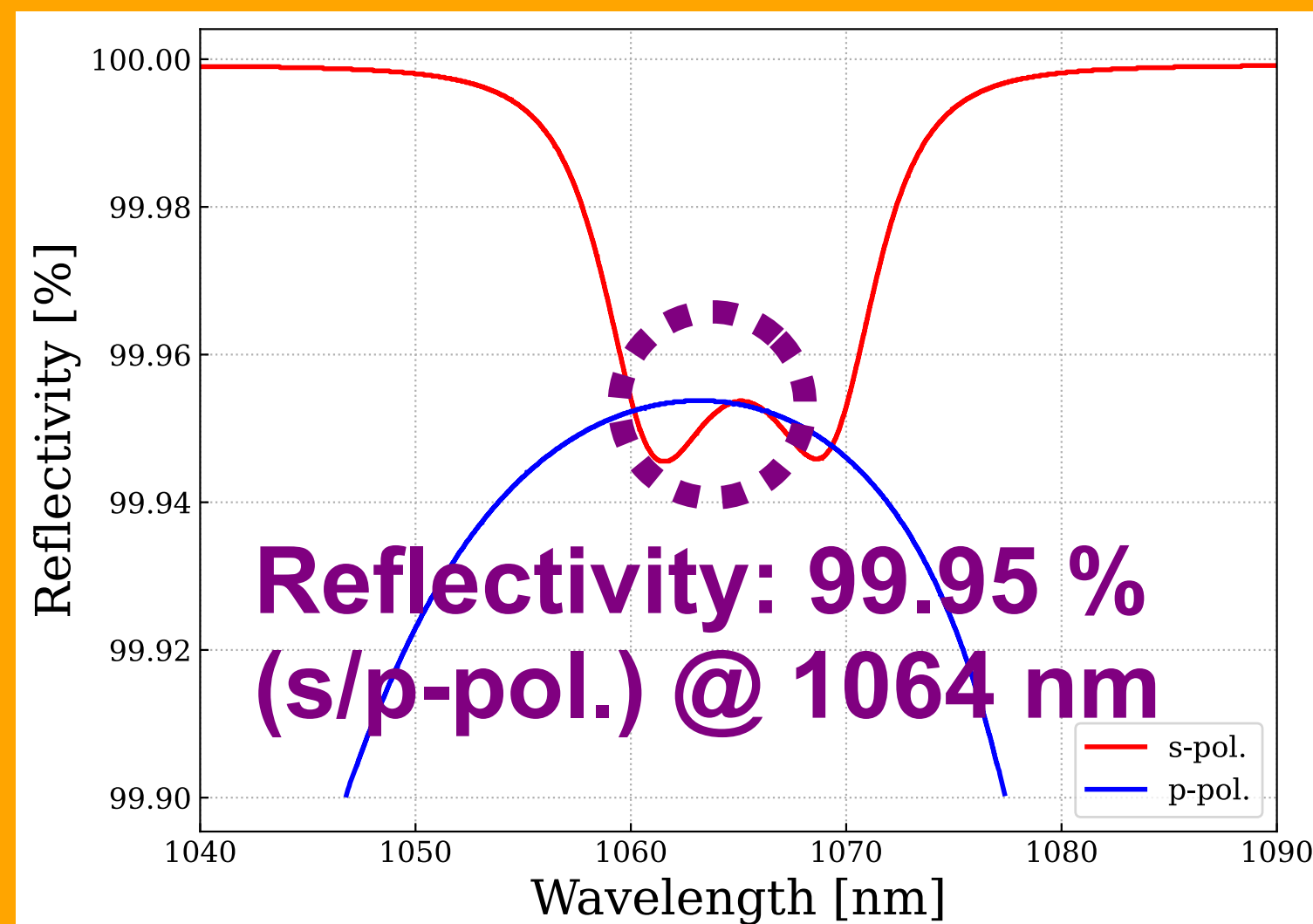
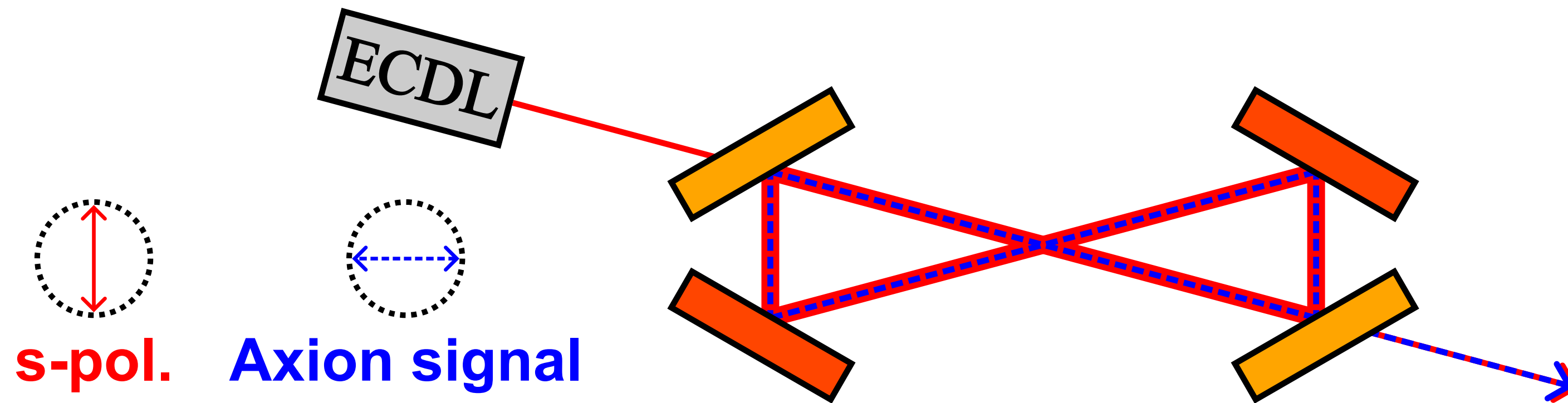
Necessary to achieve target sensitivity of DANCE Act-1

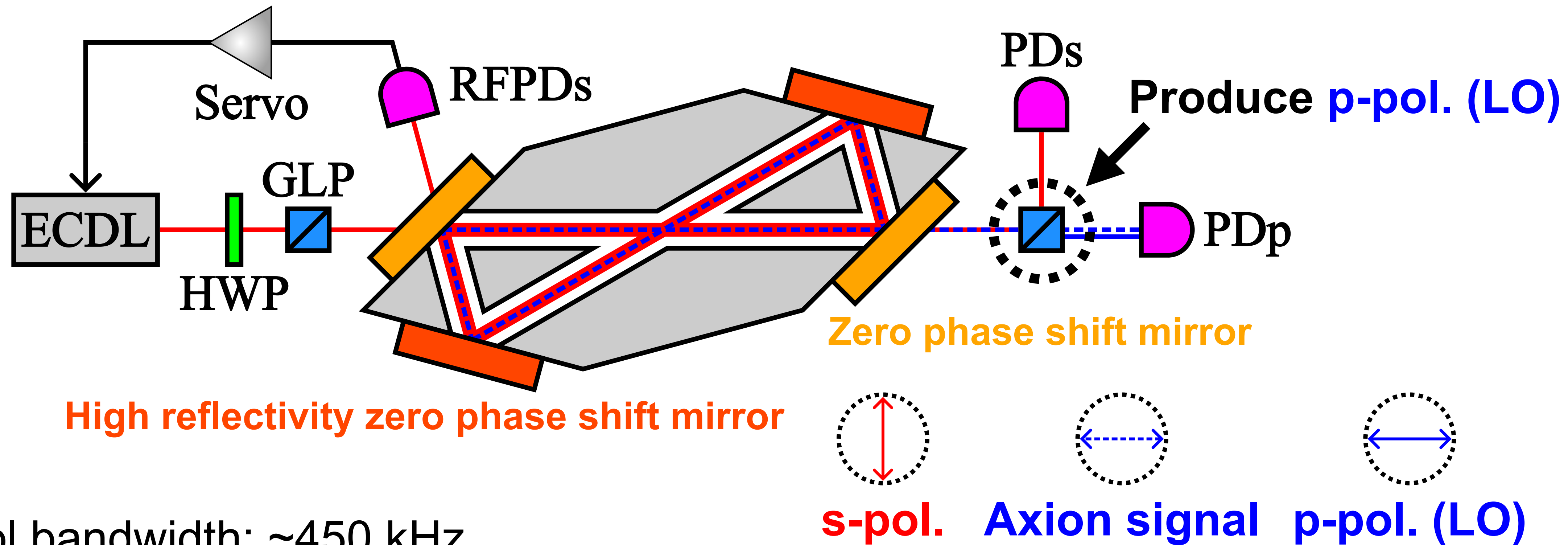
- ① Critical couple cavity
 - Cavity transmission: $\sim 2.4x$ better (17% $\rightarrow$ 99%)
 - Finesse: $\sim 2.2x$ better (s-pol.: 2600 $\rightarrow$ 6219, p-pol.: 2860 $\rightarrow$ 5882)
- ② Input power increase via power amplifier: ~ 1 order better (6 mW $\rightarrow$ 1 W)
- ③ Long-term observation: $\sim 2 - 3$ orders better (30 s $\rightarrow$ 1 month)

Critical couple cavity

16

Replaced 2 out of 4 mirrors with high reflectivity zero phase shift mirrors

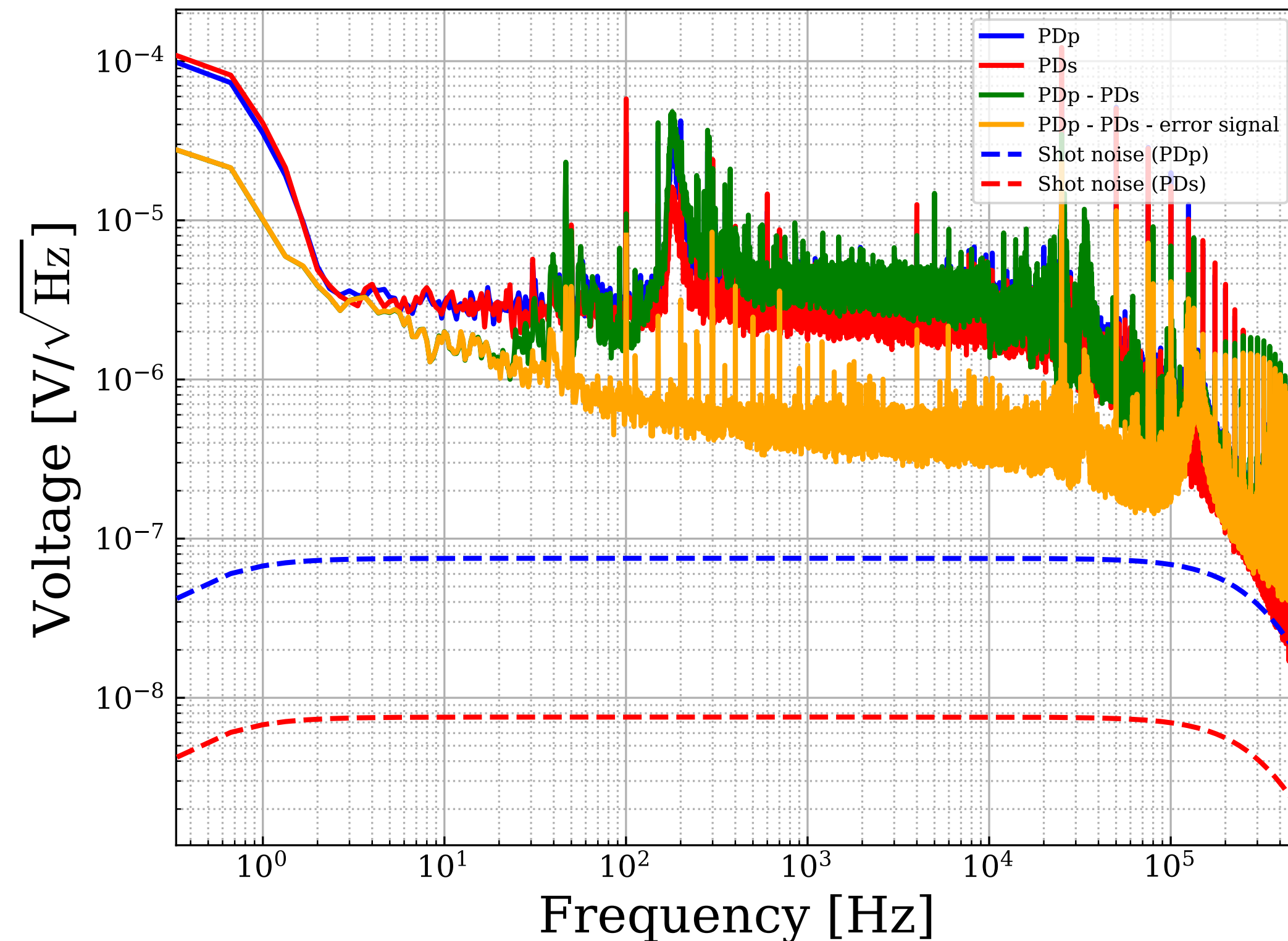




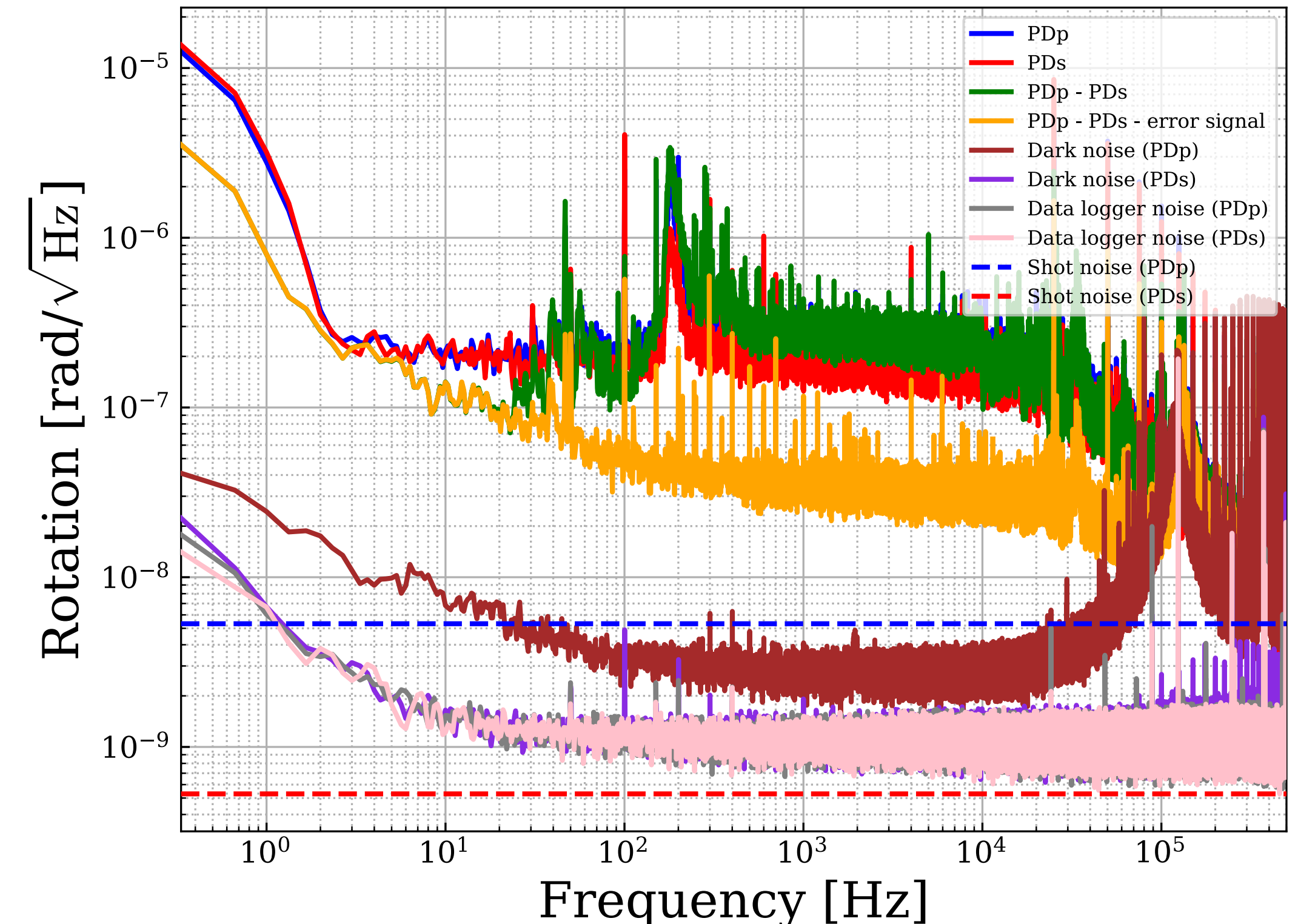
- Control bandwidth: ~ 450 kHz
- Finesse: s-pol.: $4.8(6) \times 10^3$, p-pol.: $4.8(5) \times 10^3$
- Reflectivity
 - Low: s-pol.: $99.9428(8) \%$, p-pol.: $99.9421(9) \%$
 - High: s-pol.: $99.9922(1) \%$, p-pol.: $99.99218(9) \%$

Polarization rotation spectrum

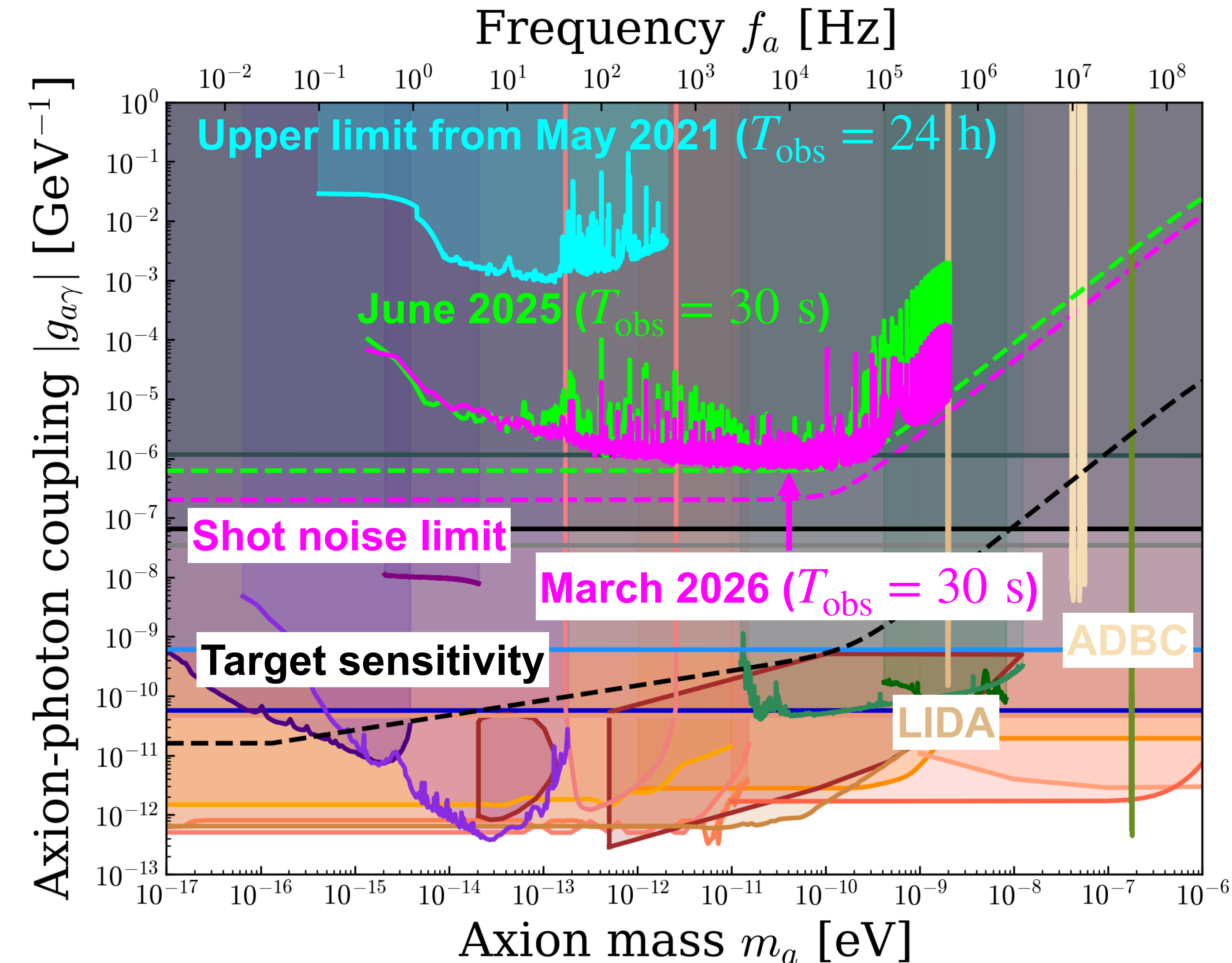
18



Calibration
→



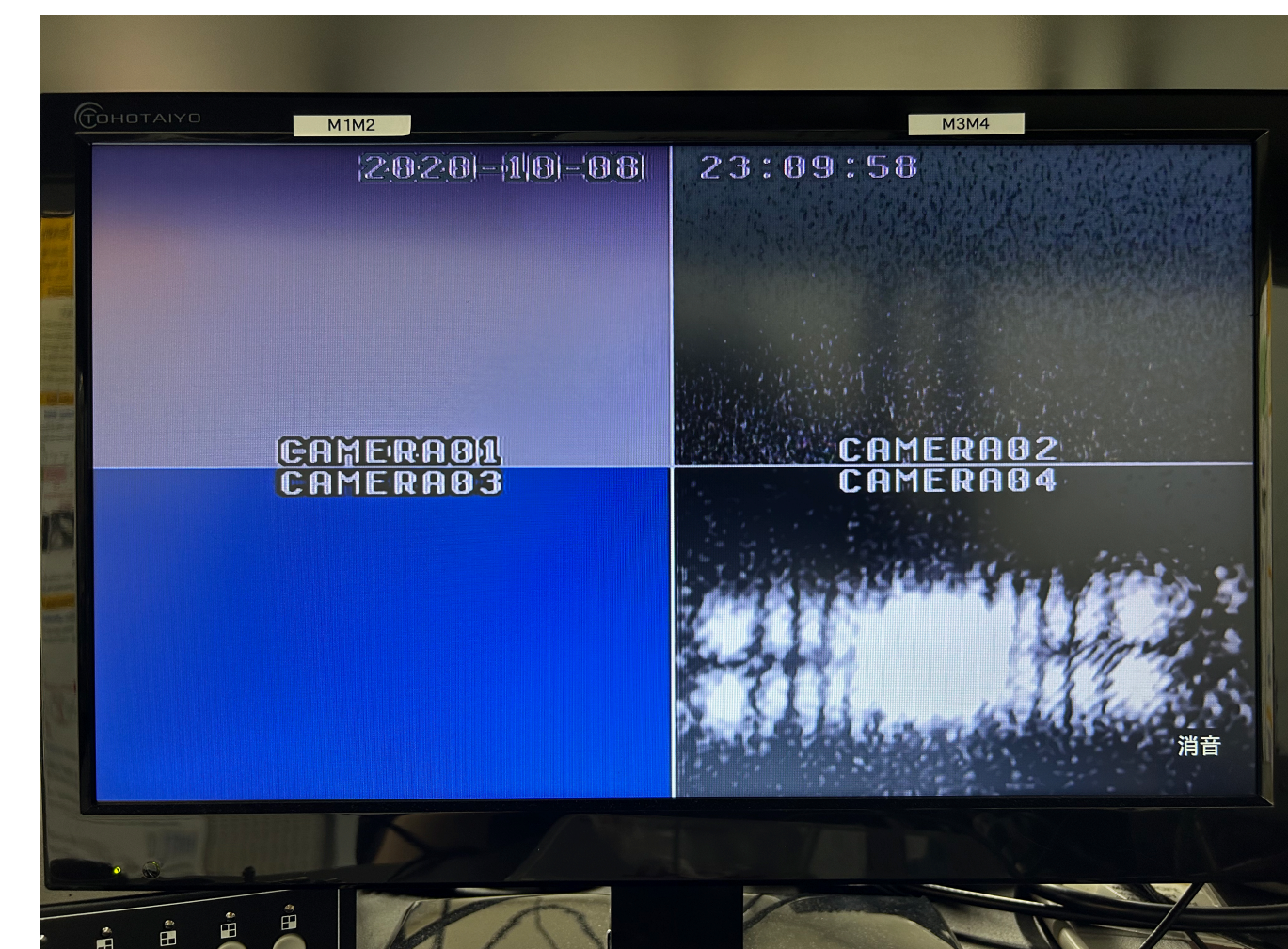
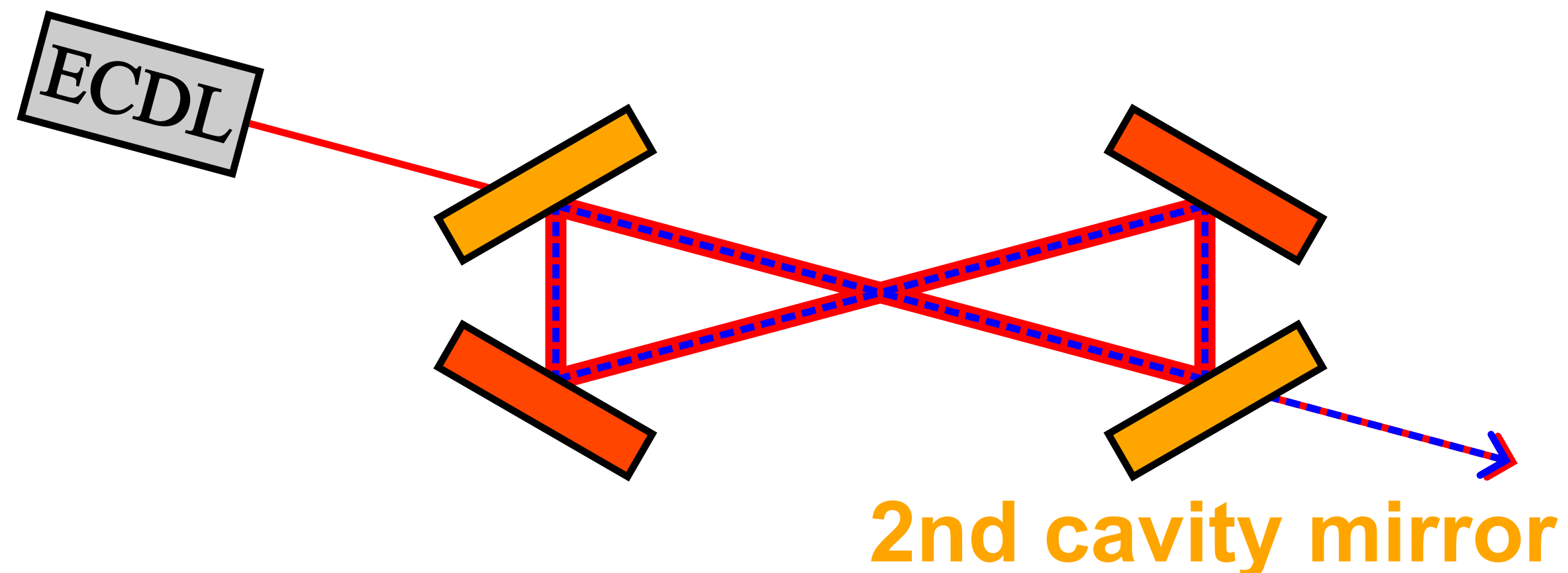
- Residual resonant frequency difference: **5.3(5) kHz**
- ➡ Satisfy requirement (within HWHM of p-polarization): **25.6 kHz**
- Simultaneous resonance wavelength shifted from 1065.99(2) nm to **1064.83(2) nm** by using high reflectivity zero phase shift mirrors
- Misalignment angle of input GLP: **~1.8 deg**



- Critical couple cavity
 - Cavity transmission: ~ 1.63 x better
 - Finesse: ~ 1.76 x better
- ➡ Shot noise limit improved by ~ 2.86 x
- Sensitivity is enhanced by up to ~ 1 order of magnitude

- Review of previous DANCE
- **Recent progress**
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - **Loss of zero phase shift mirrors**
 - Installation of new shield at B111
 - Others
- Future plans

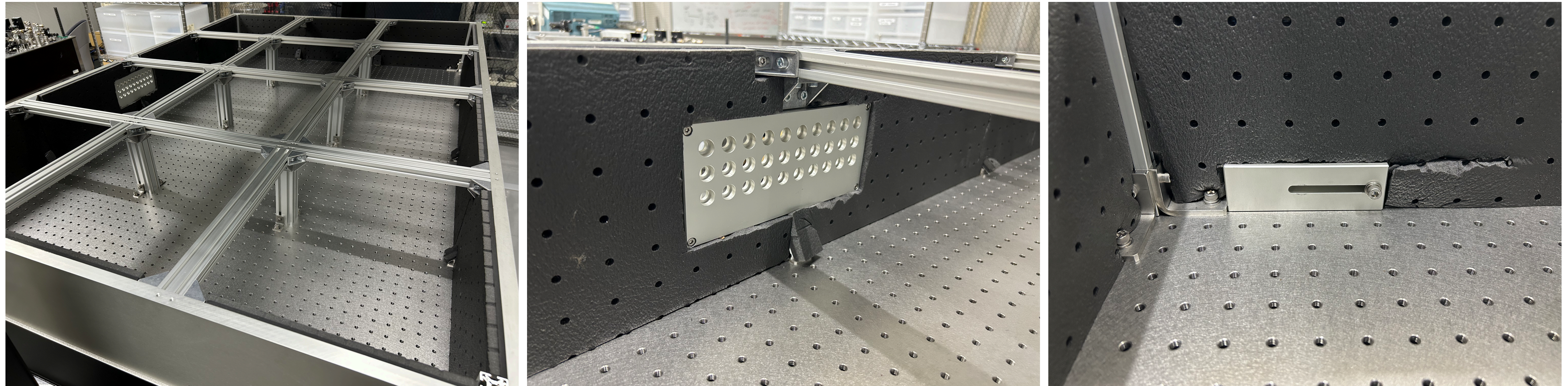
- The loss of the 2nd cavity mirror suddenly increased twice while adjusting the cavity non-planarity (The first one has already been cleaned with First Contact, while the second one has not yet been cleaned with it)
 - Finesse
 - First one: s-pol.: $2.49(8) \times 10^3$, p-pol.: $2.43(6) \times 10^3$
 - Second one: s-pol.: $1.77(6) \times 10^3$, p-pol.: $1.59(5) \times 10^3$
- ➡ Finesse was recovered after cleaning with First Contact
- ➡ Caused by dust on the mirror?



- Review of previous DANCE
- **Recent progress**
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - **Installation of new shield at B111**
 - Others
- Future plans

Installation of new shield at B111

23



- Preventing acoustic noise and wind from air conditioner
- LEMO connector plate is used for 15 V power supply and signal acquisition
(Note that sharing these GNDs introduces 50 Hz line noise)
- Other cables (RF input for EOM, power supply of CCD camera, etc.) are routed through small feedthrough holes

- Review of previous DANCE
- **Recent progress**
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - **Others**
- Future plans

- Constructed experimental setup
- Confirmed that the output power from Ytterbium-doped fiber amplifier was ~1.8 W
- PZT inside the ECDL was damaged due to applying 150 V (Data sheet allows up to 500 V, but the laser construction manual describes a maximum of 100 V)
- Made 4 PDs for polarization rotation measurement, monitor for transmission from auxiliary laser, intensity stabilization system (ISS), and monitor for cavity scan with a folded cavity
 - PD calibration
 - Frequency response of PD
- Recently working on ISS test

- Review of previous DANCE
- Recent progress
 - Trade-off in cavity non-planarity adjustment
 - Simultaneous resonance with a critical couple cavity
 - Loss of zero phase shift mirrors
 - Installation of new shield at B111
 - Others
- Future plans

- Evaluation of intensity noise using Ytterbium-doped fiber amplifier and construction of ISS
- Measure reflection phase difference between s- and p-polarizations per mirror using folded cavity
- Lock a bow-tie cavity with power amplified ECDL
 - Gradually increasing power and monitoring the amount of detune from simultaneous resonance
 - Investigation of the wavelength that achieves simultaneous resonance
 - Measure reflection phase difference using folded cavity again after injecting high power laser
 - Polarization rotation measurement under simultaneous resonance (30 s, 1 day, and 1 month)
- Time fluctuations of reflection phase difference between s- and p-polarizations
 - Beat note between the two ECDLs (main: s-polarization, reference: p-polarization)
 - Conduct separately from the polarization rotation measurement on a different day
- Data analysis

- Electronic circuit
 - Filter for PZT control loop
 - Filter for current control loop
 - Laser current modulation
 - Filter for ISS
 - Offset circuit?

- Consideration of input beam diameters for EOPM and EOAM

For a input power of 2 W, the beam diameter threshold is > 1.13 mm, while the clear aperture of EOPM and EOAM is 2 mm

➡ > 3.39 mm clear aperture is required to prevent damage and allow 3σ beam transmission

- PlanA: Continue to use the current ones, with care taken to input larger beam size
- PlanB: Purchase custom ones with a larger aperture from Thorlabs (currently inquiring)
- PlanC: Purchase new ones from agency: [i-wave Corporation](#) (manufacturer: [Agiltron](#)) (currently inquiring)