

Recent Upgrades and Future Prospects of DANCE

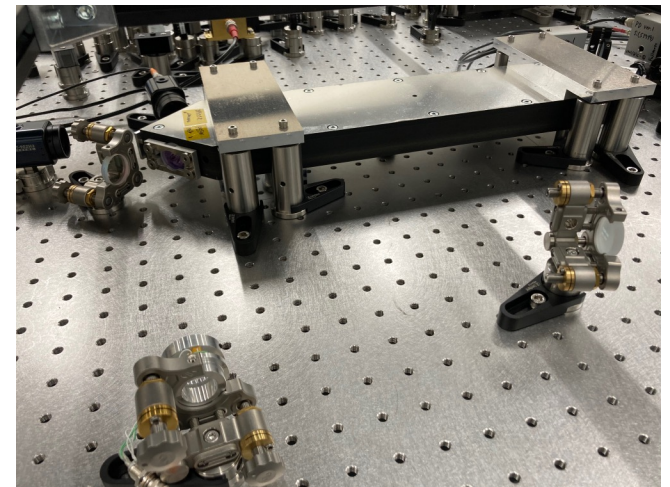
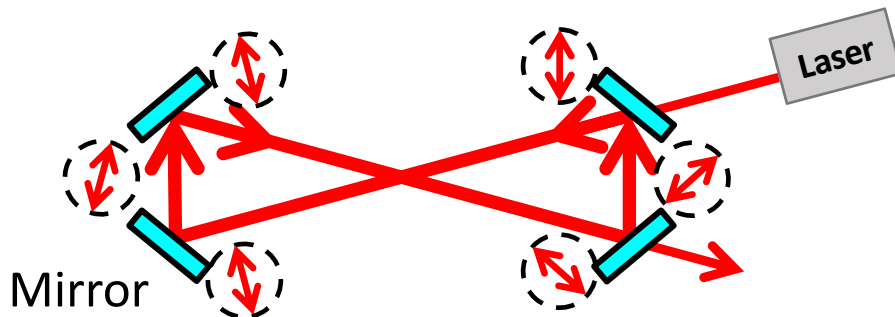
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Overview

- **DANCE: Dark matter Axion search with ring Cavity Experiment**
 - Search for axion dark matter with optical bow-tie ring cavity
 - Prototype experiment: DANCE Act-1 is underway
- Recent upgrades of DANCE Act-1:
 - Development of auxiliary cavity for simultaneous resonance
 - Noise hunting and offline noise reduction
- Latest sensitivity and Future plans



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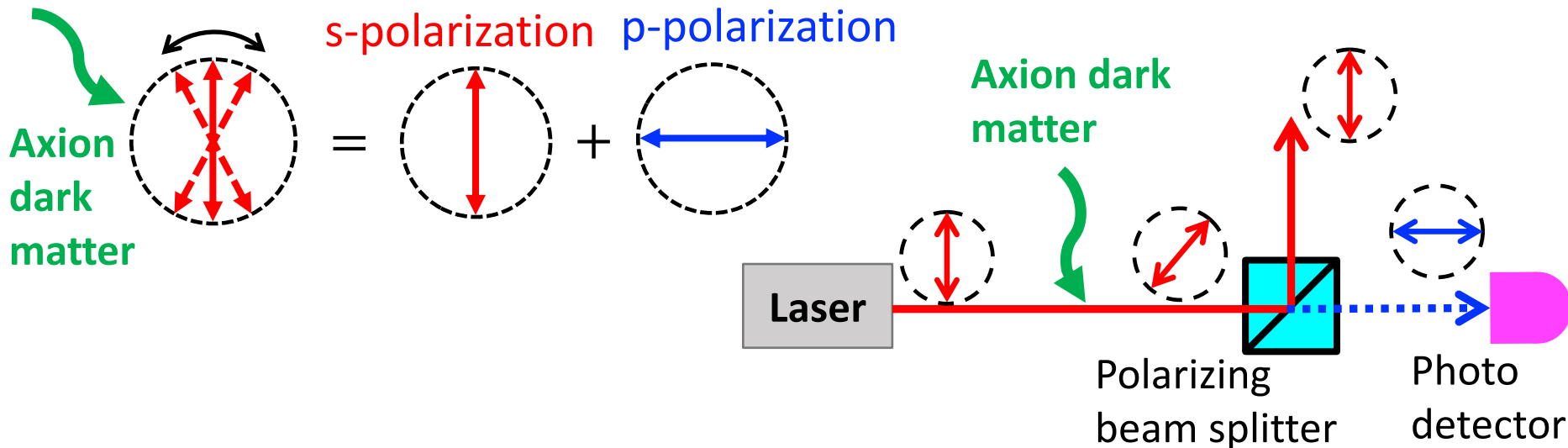
Axion-photon interaction

Axion-photon interaction causes phase velocity difference

$$c_{L/R} = \sqrt{1 \pm \frac{g_{a\gamma} a_0 m_a}{k} \sin(m_a t + \delta_\tau)}$$

Left-/Right-handed polarization Axion-photon coupling constant Axion field Axion mass

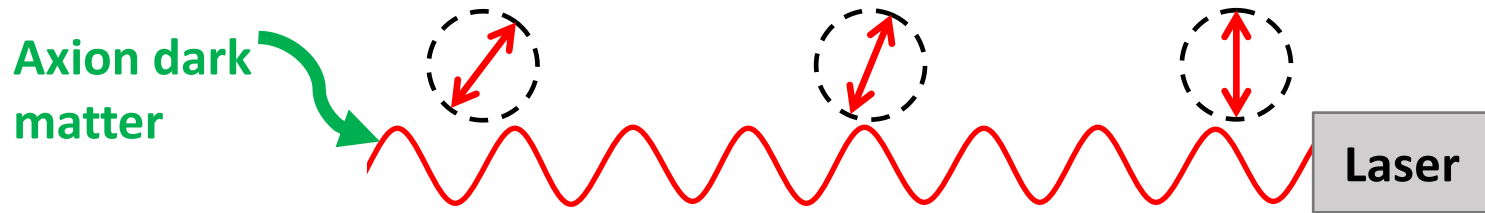
➡ Rotational oscillation of linearly polarized light



- Axion signal is produced as p-polarization

Principle of DANCE

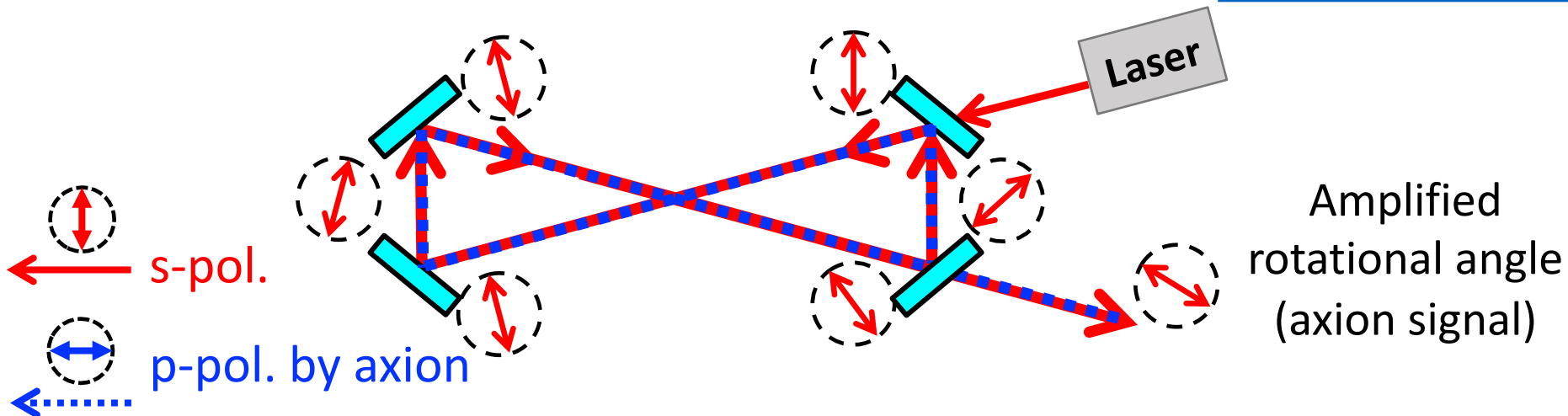
- Rotational amplitude becomes larger as light path increases



➔ Enhance light path and rotation with **bow-tie ring cavity**

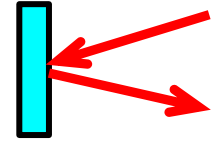
- Resonant condition: **Roundtrip length = $n\lambda$**
⇒ **Light circulates between 4 mirrors**
- Both **s-pol.** and **p-pol.** need to be resonant

I. Obata, T. Fujita,
and Y. Michimura:
[PRL 121, 161301 \(2018\).](#)
H. Liu *et al.*:
[PRD 100, 023548 \(2019\).](#)



Issue – Resonant frequency difference–

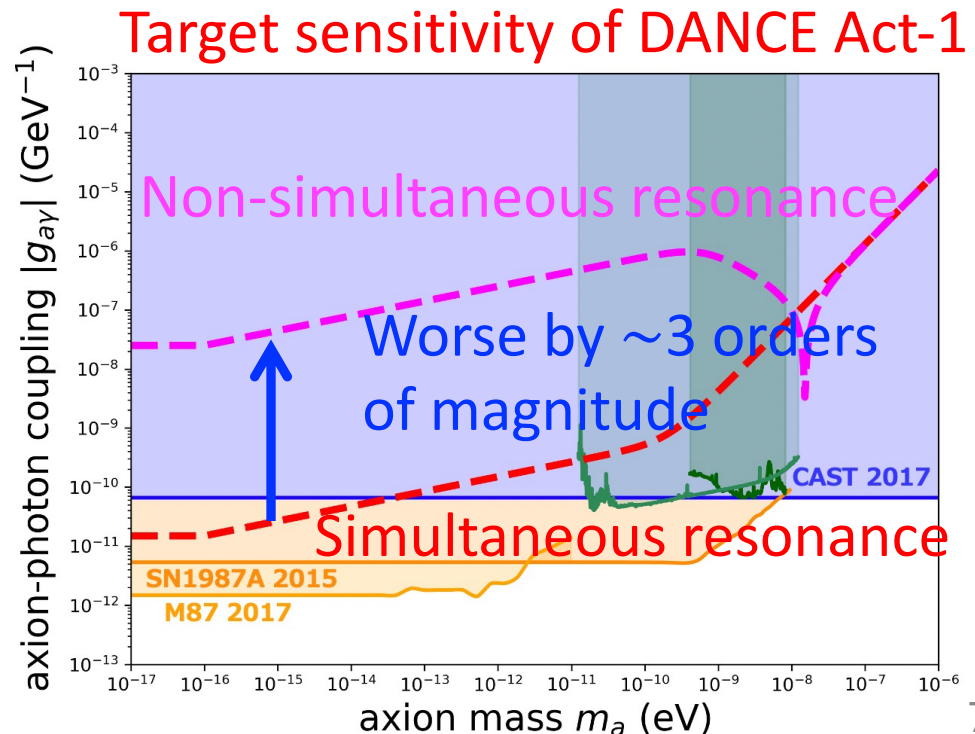
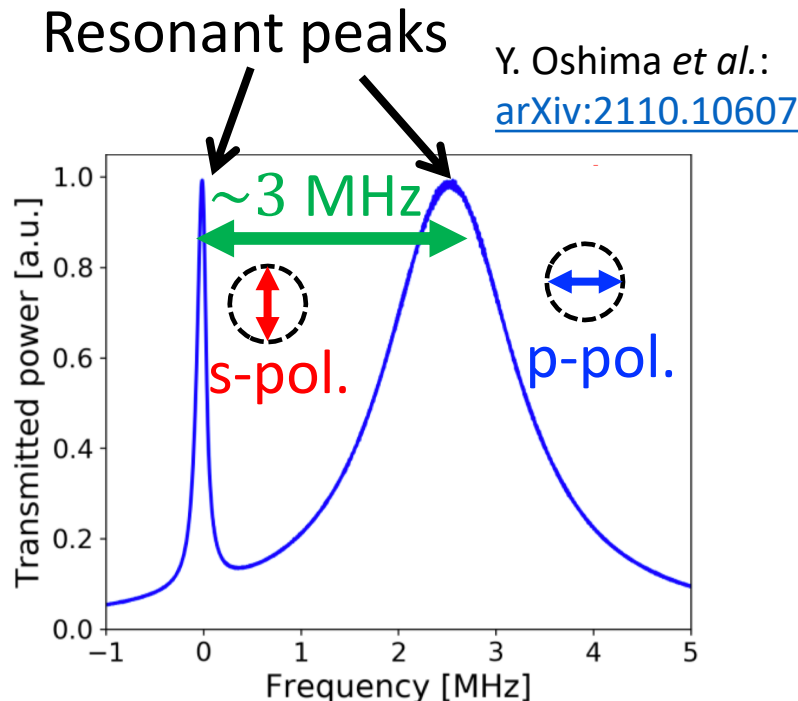
- There is resonant frequency difference between s-pol. and p-pol. (~ 3 MHz in DANCE Act-1)



by phase shift $\Delta\phi$
on cavity mirrors



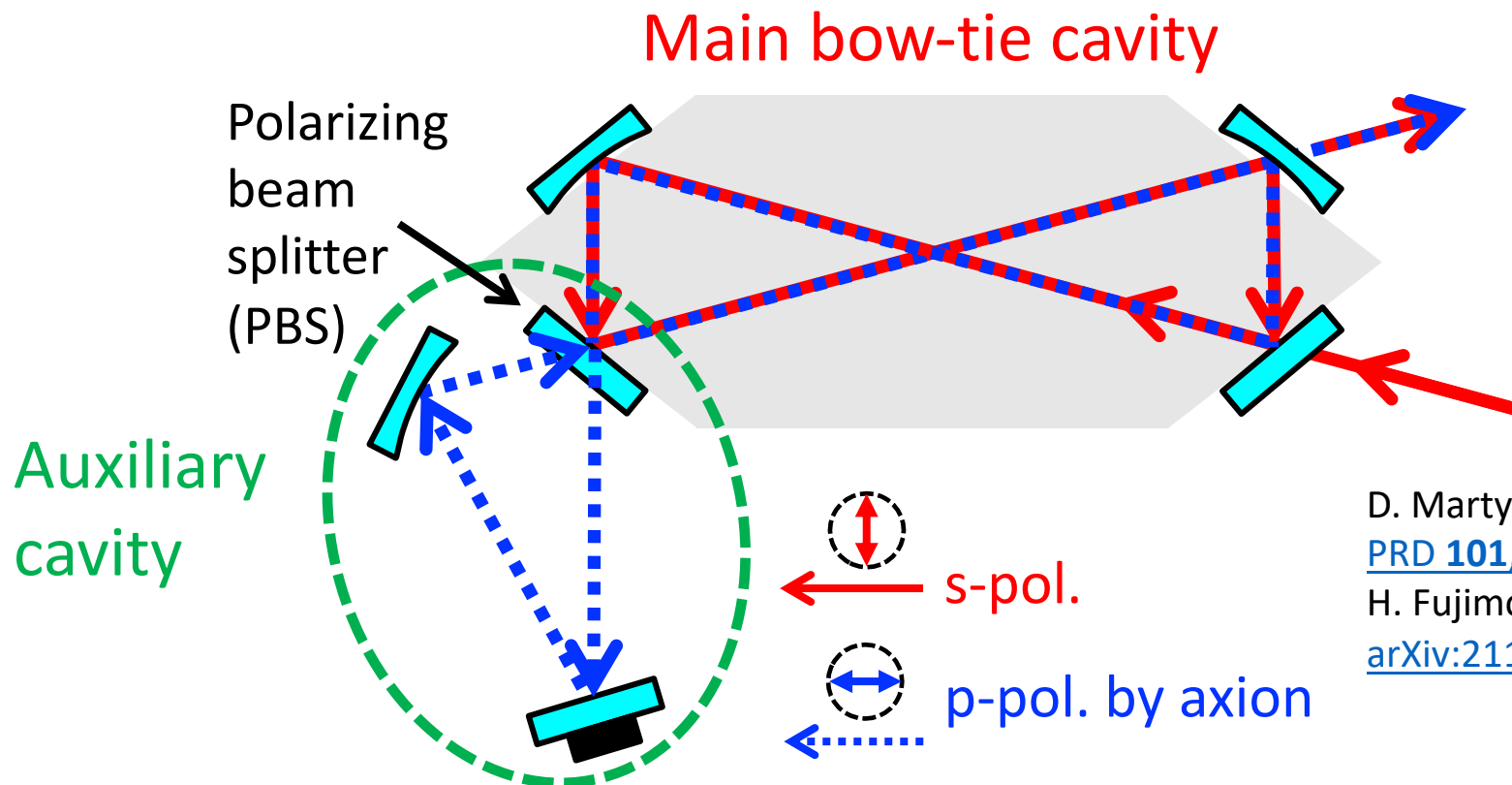
- s-pol. and p-pol. **can not resonate simultaneously**
- **Sensitivity is degraded**



Auxiliary cavity for simultaneous resonance

- Auxiliary cavity can control the length of light path for p-pol.

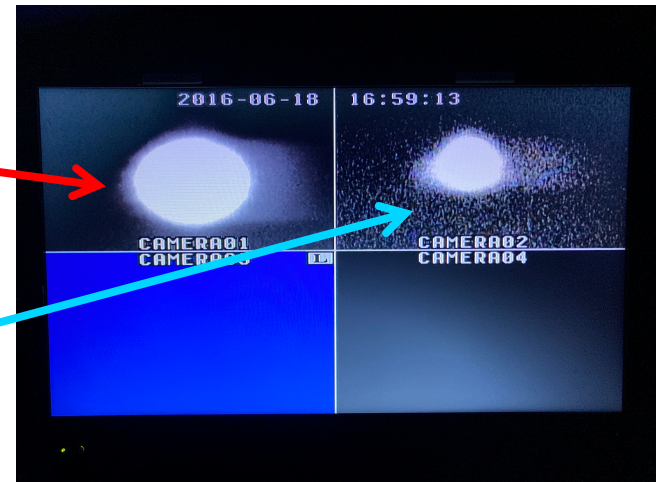
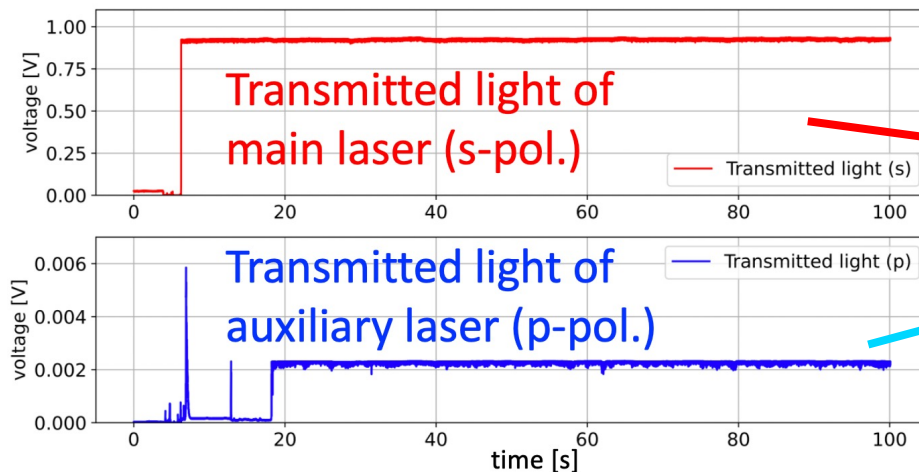
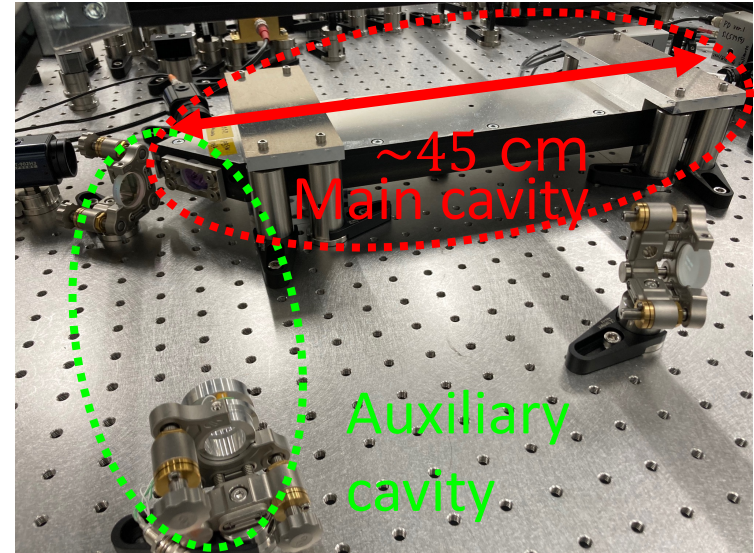
➔ able to compensate resonant frequency difference and realize simultaneous resonance



D. Martynov and H. Miao:
[PRD **101**, 095034 \(2020\).](#)
H. Fujimoto *et al.*:
[arXiv:2110.12023.](#)

Development of auxiliary cavity

- Auxiliary cavity is now installed
- Succeeded in simultaneous resonance
- Performance of the cavities:
 - Finesse for s-pol. : 549 ± 3
 - Finesse for p-pol. : 36.8 ± 0.2



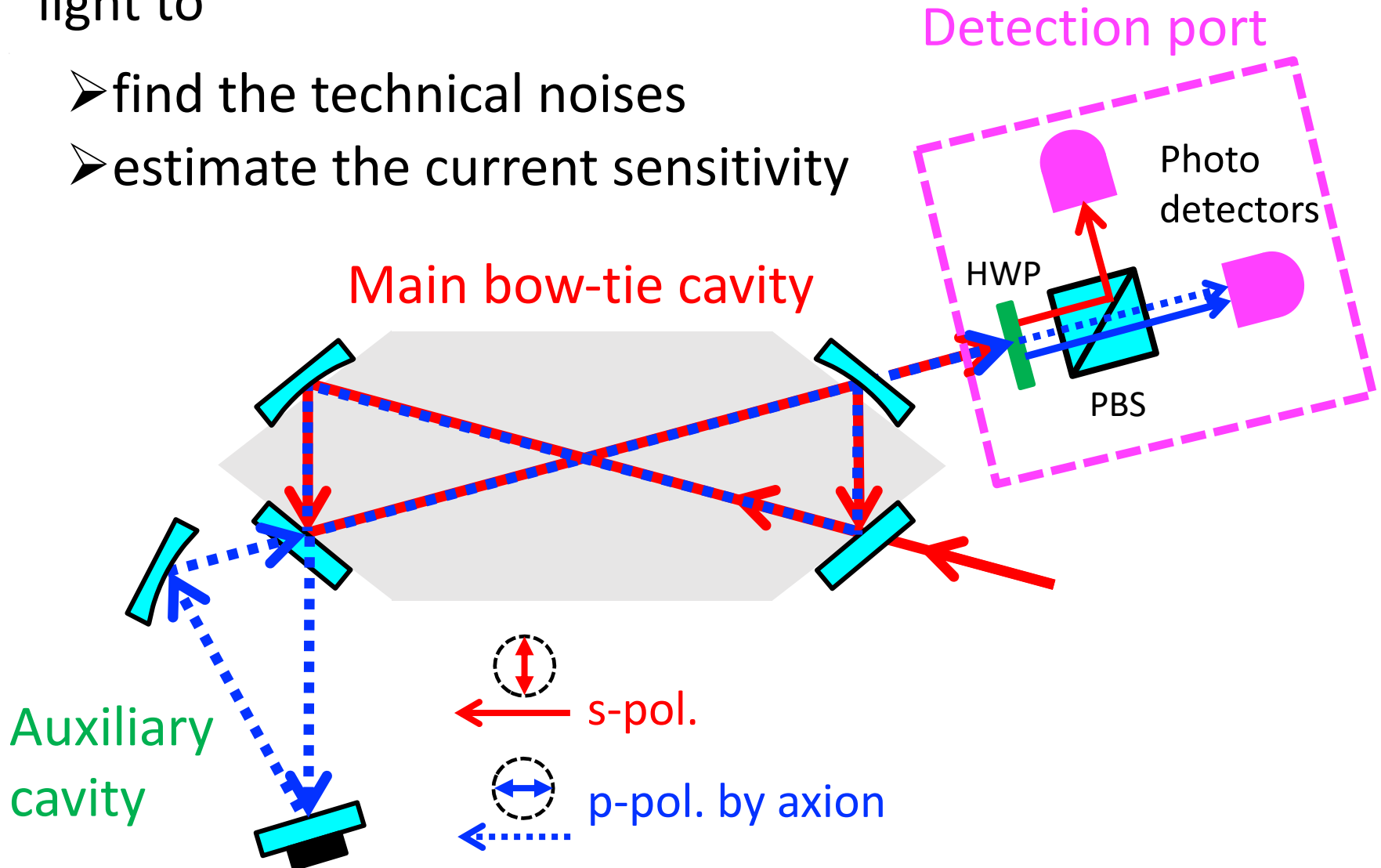
Contents

- Development of auxiliary cavity for simultaneous resonance
- **Noise hunting and offline noise reduction**
- Latest sensitivity and Future plans

Measurement of polarization rotation

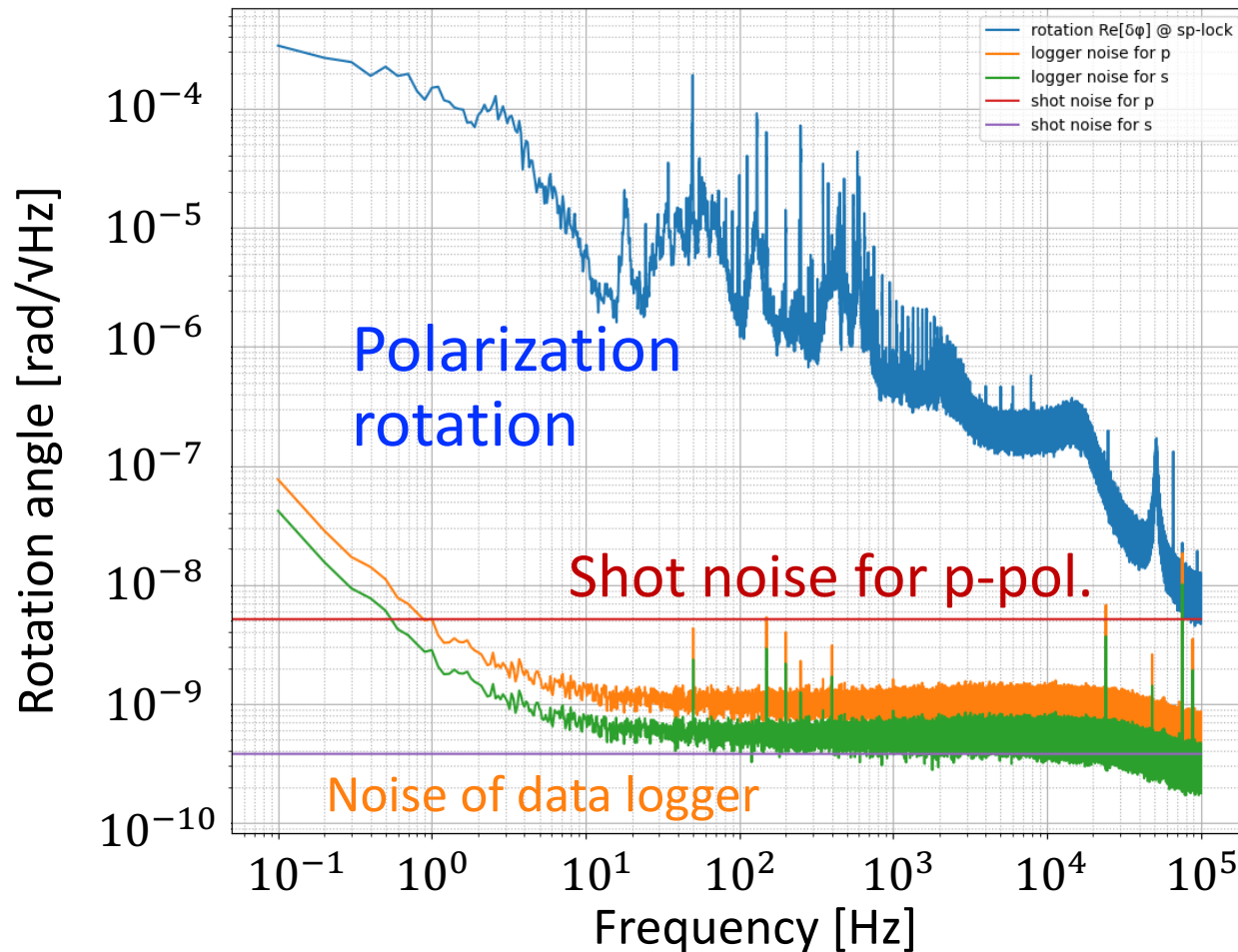
- Measured the polarization rotation of transmitted light to

- find the technical noises
- estimate the current sensitivity



Power spectrum of polarization rotation

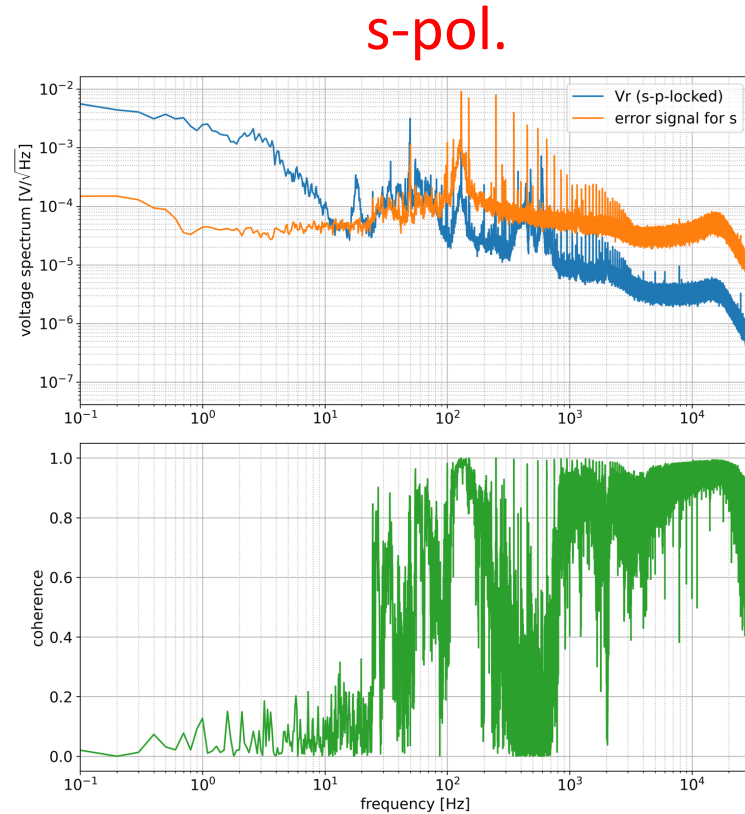
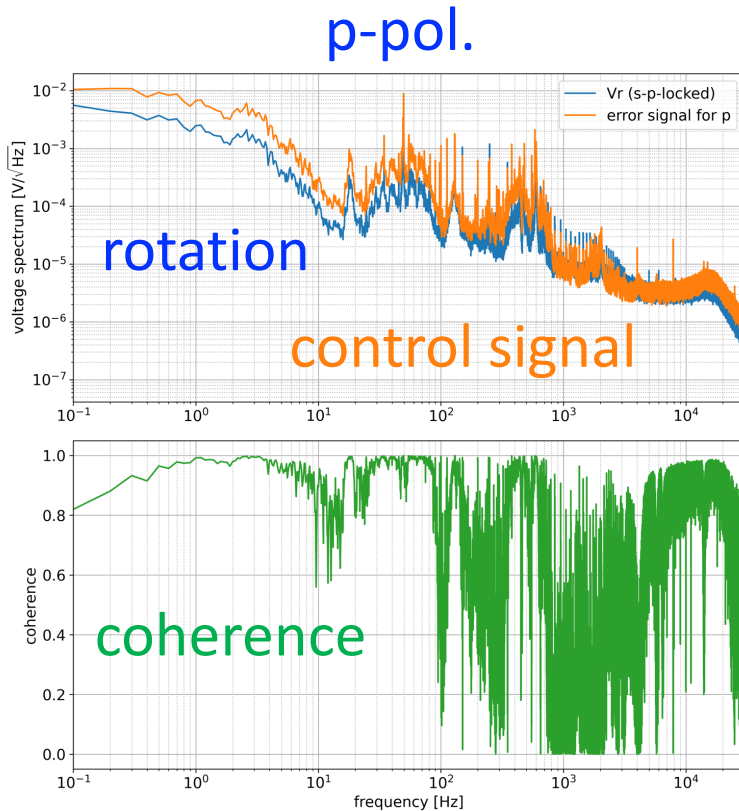
- Measured the rotational angle of the transmitted light



- Measured noise is larger than shot noise by 1~4 orders of magnitude

Noise hunting

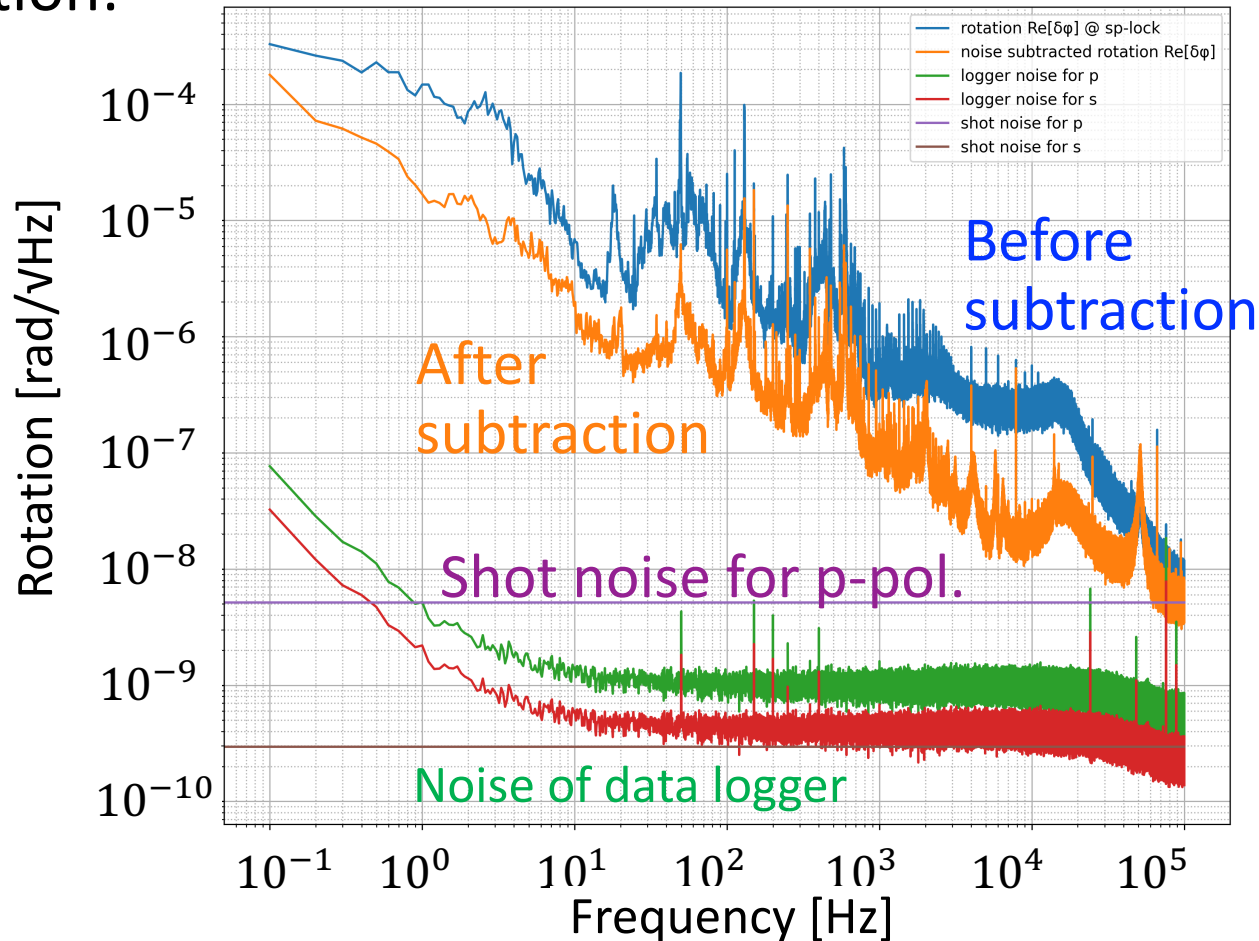
- High coherence between polarization rotation and feedback control signals for the simultaneous resonance



- Phase noise (cavity vibration and laser frequency noise) is limiting the current sensitivity

Offline subtraction of phase noise

- Subtracted the control signals from the data of polarization rotation:

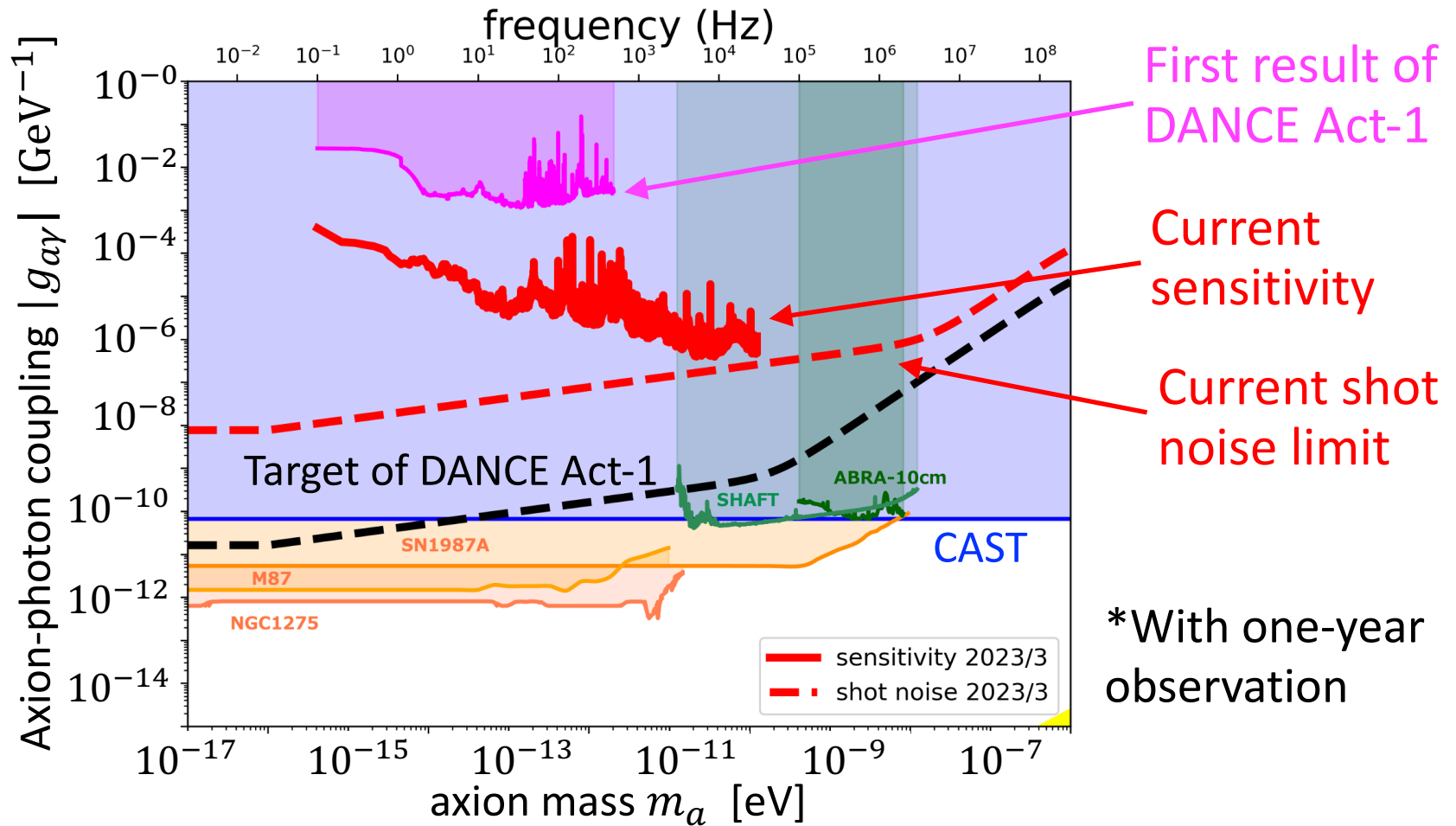


- Succeeded in reducing noise by ~ 1 order of magnitude in broad range

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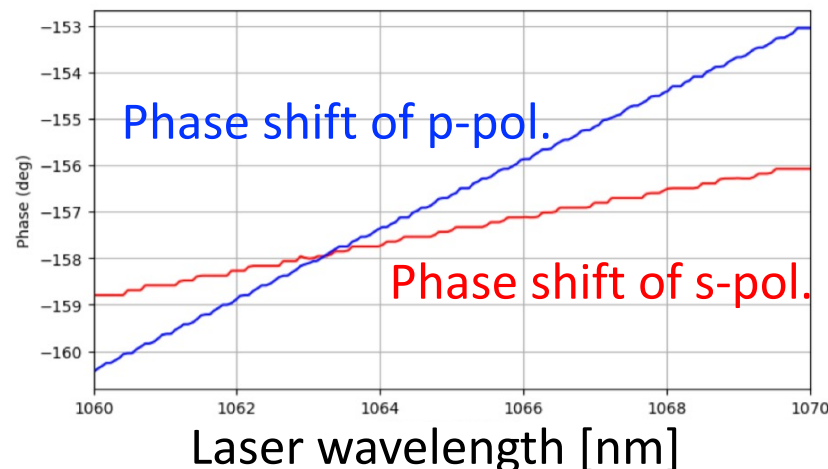
Estimated sensitivity



- Current sensitivity: $|g_{a\gamma}| \gtrsim 10^{-6}$ GeV⁻¹ at $m_a = 10^{-15} \sim 10^{-10}$ eV
- > 2 orders of magnitude better than the first result of DANCE Act-1
- ~ 4 orders of magnitude worse than CAST limit

Future plans of DANCE Act-1

- Reduction of various noises
 - **Optimize cavity resonance control** to reduce phase noise
 - Replace cavity mirrors for higher finesse
 - High power laser for better shot noise
- Simultaneous resonance **without using auxiliary cavity**
 - Auxiliary cavity introduces optical losses (lowers finesse)
 - **Frequency-tunable laser** may change the reflective phase shift and realize simultaneous resonance



Summary

- DANCE searches for axion dark matter with ring cavity by enhancing the rotation of linear polarization.
- Prototype experiment: DANCE Act-1 is underway:
 - Development of auxiliary cavity for simultaneous resonance between s- and p-pol.
 - Noise hunting and offline noise reduction
- Further commissioning and development of advanced simultaneous resonance are needed for better sensitivity

