DANCE: Searching for Axion-like particle dark matter with optical bow-tie ring cavity

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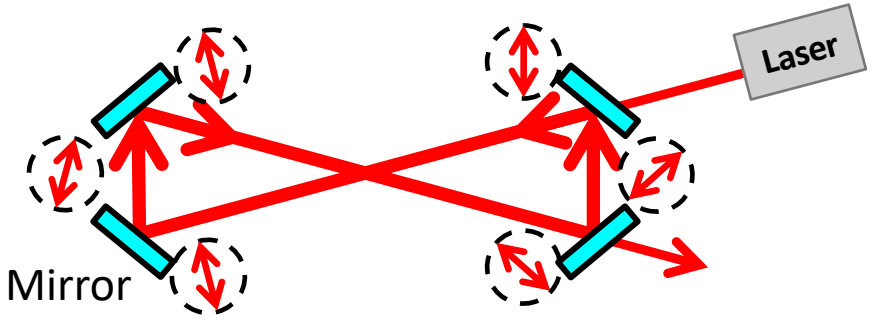
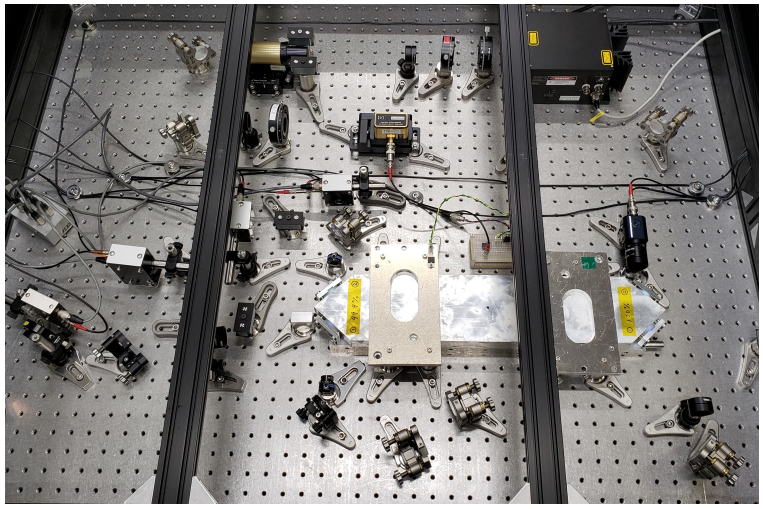
Overview

DANCE: Dark matter Axion search with riNg Cavity Experiment

- Search for axion-like particle dark matter with optical bow-tie ring cavity
- Prototype experiment: DANCE Act-1 is underway
  - Issue of resonant frequency difference between polarizations
  - Data analysis





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- Dark matter search and DANCE
- Principle and target sensitivity of DANCE
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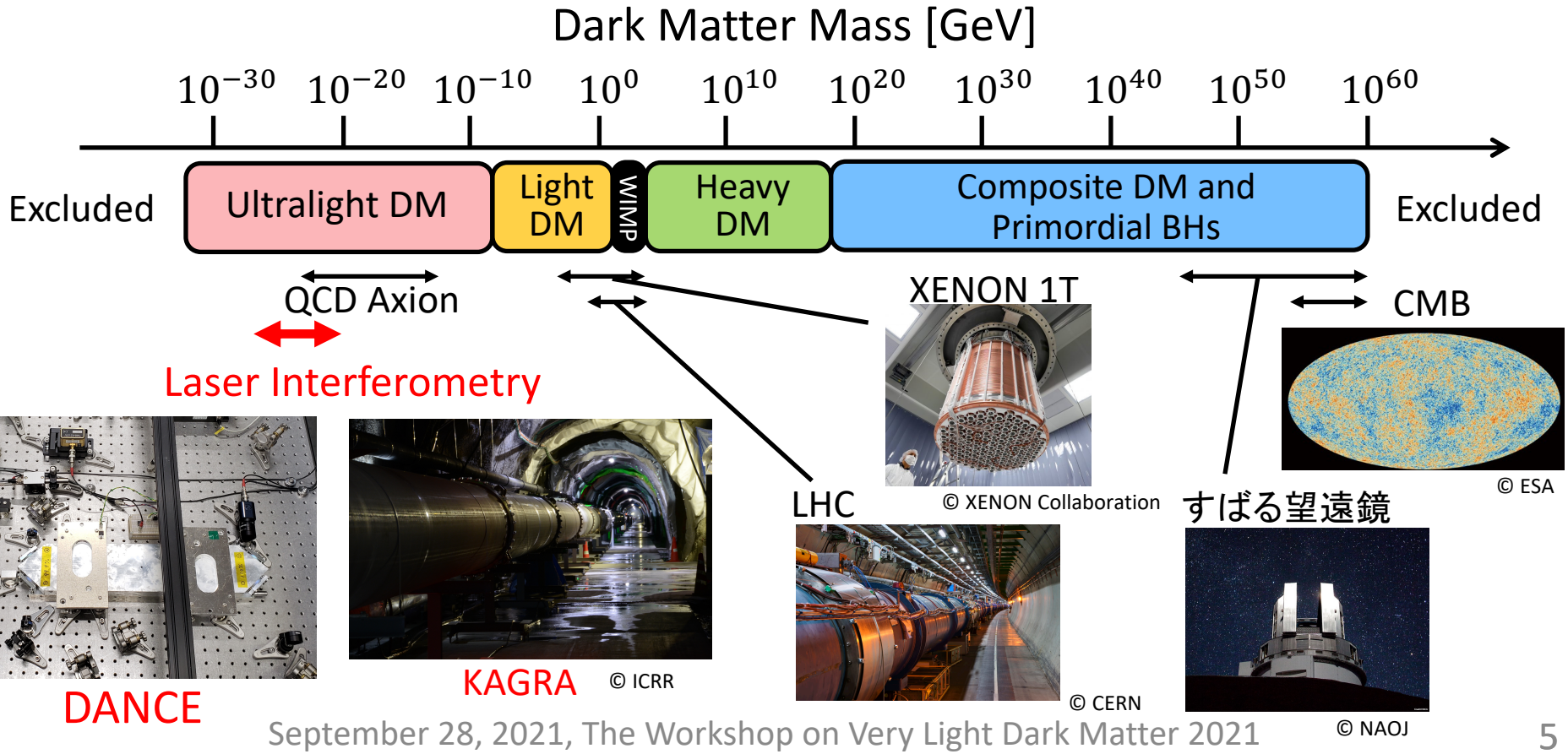
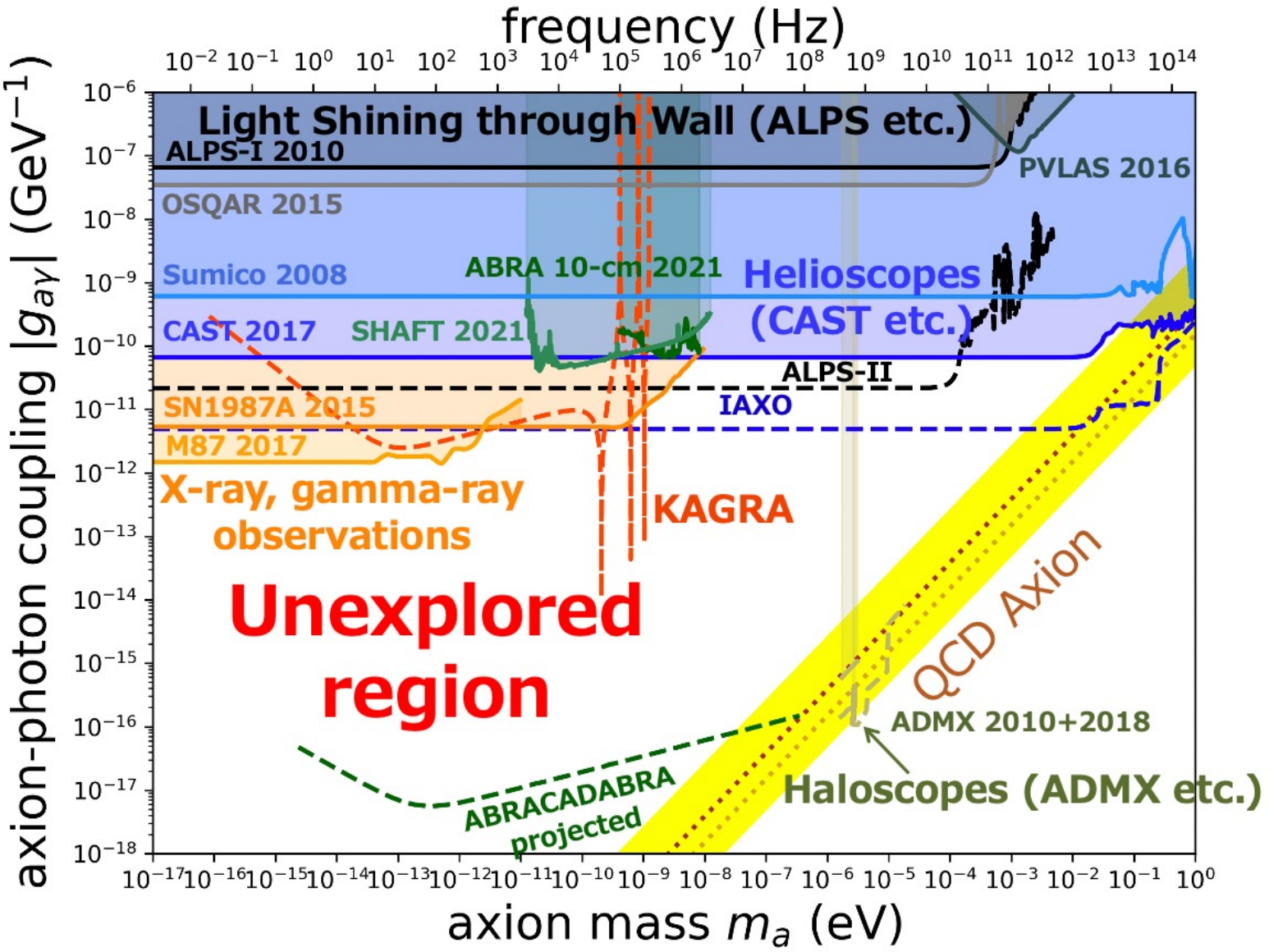
Dark matter search and DANCE

- One of dark matter search experiments by interferometer
- DANCE searches for axion-like particle (ALP) dark matter



Previous researches



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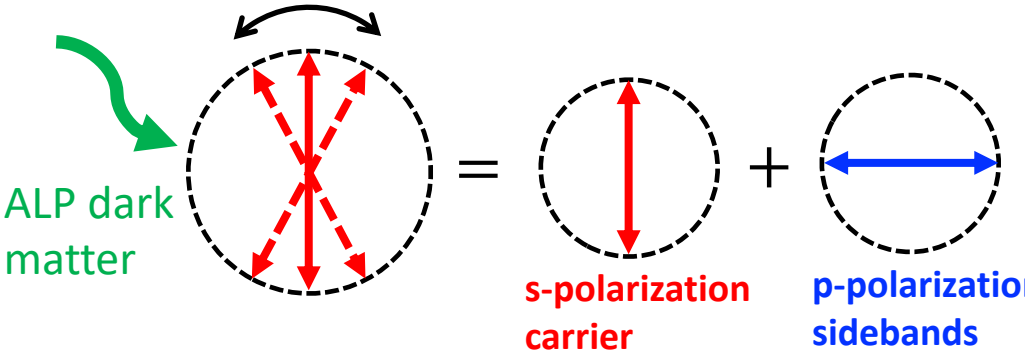
Axion-photon interaction

Axion-photon interaction causes phase velocity difference

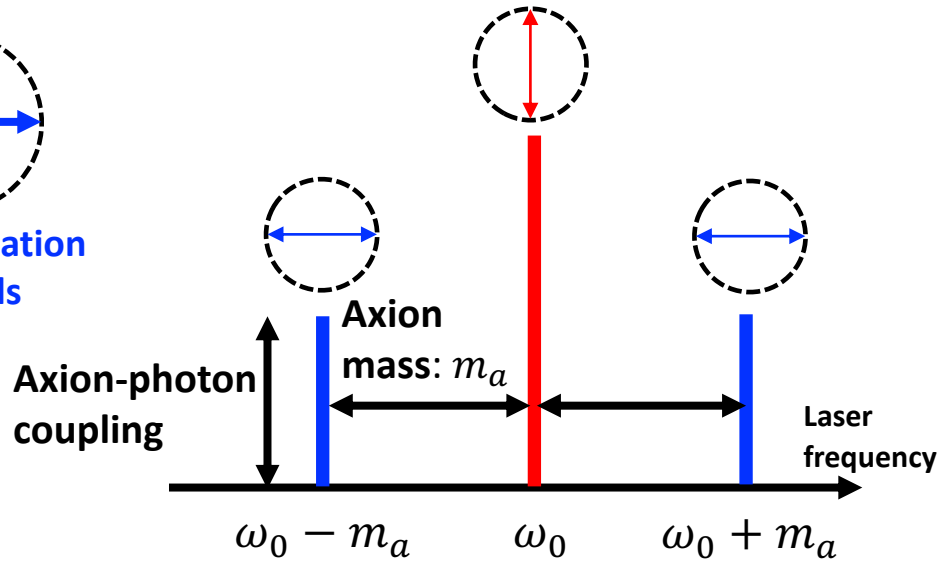
$$c_{L/R} = \sqrt{1 \pm \frac{g_{a\gamma} a_0 m_a}{k} \sin(m_a t + \delta_\tau)}$$

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

➡ Rotational oscillation of linearly polarized light

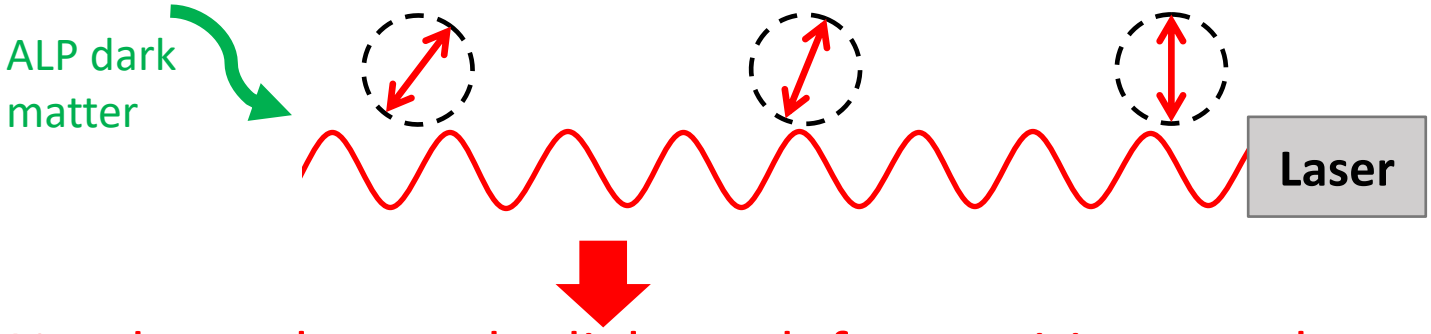


Axion signal is produced as p-polalization



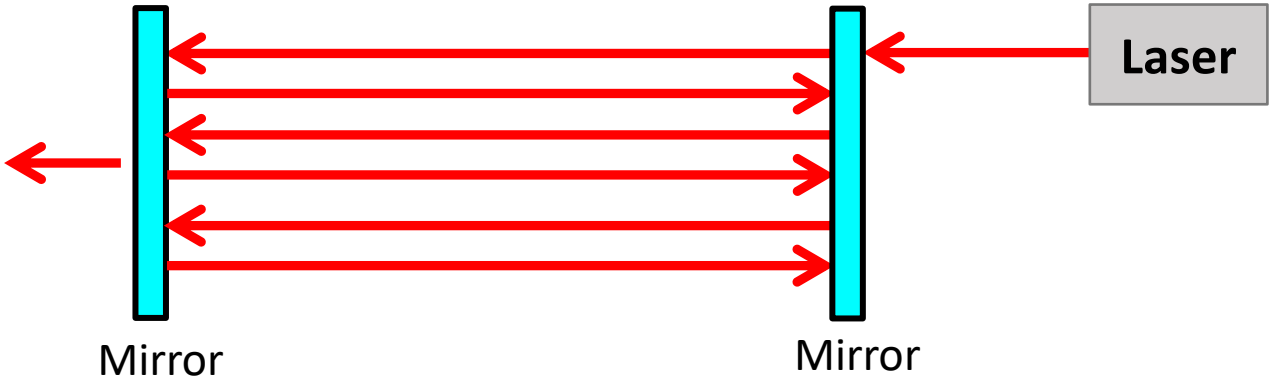
Principle of DANCE

- Rotational amplitude becomes large as light path increases



Need to enhance the light path for sensitive search

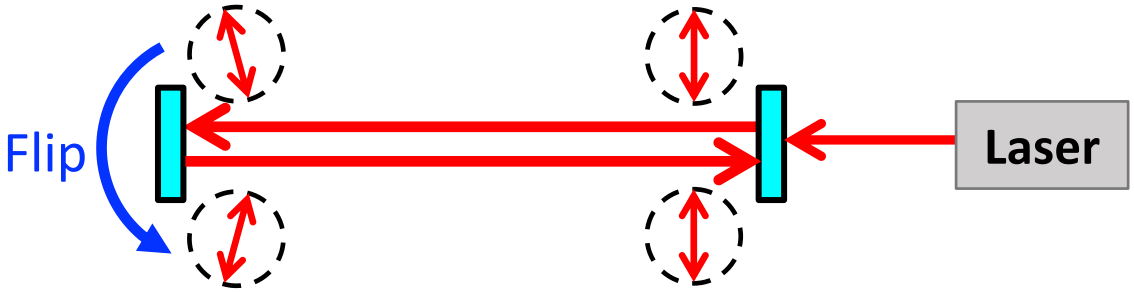
- Optical cavity can enhance the light path



Principle of DANCE

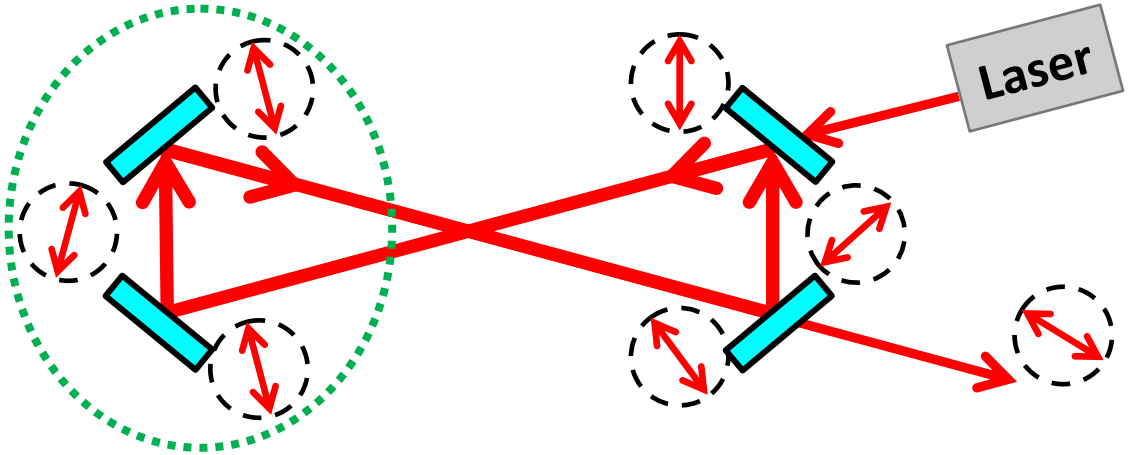
- Linear cavity

Plane of polarization flips by reflection ⇒ cancels rotation



- Bow-tie ring cavity

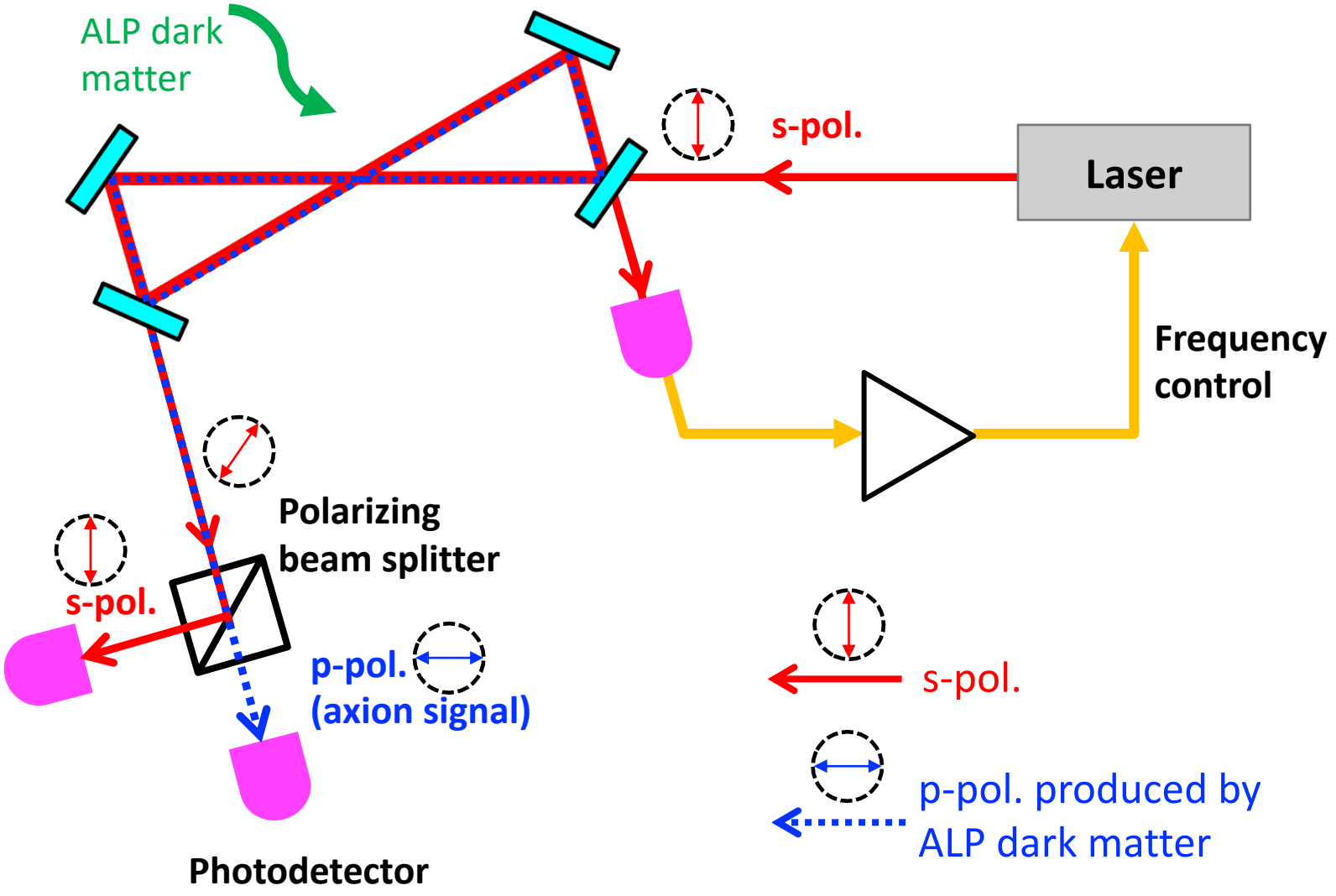
Two reflections prevent polarization flip ⇒ enhances rotational angle



Preserves polarization plane

Amplified rotational angle (axion signal)

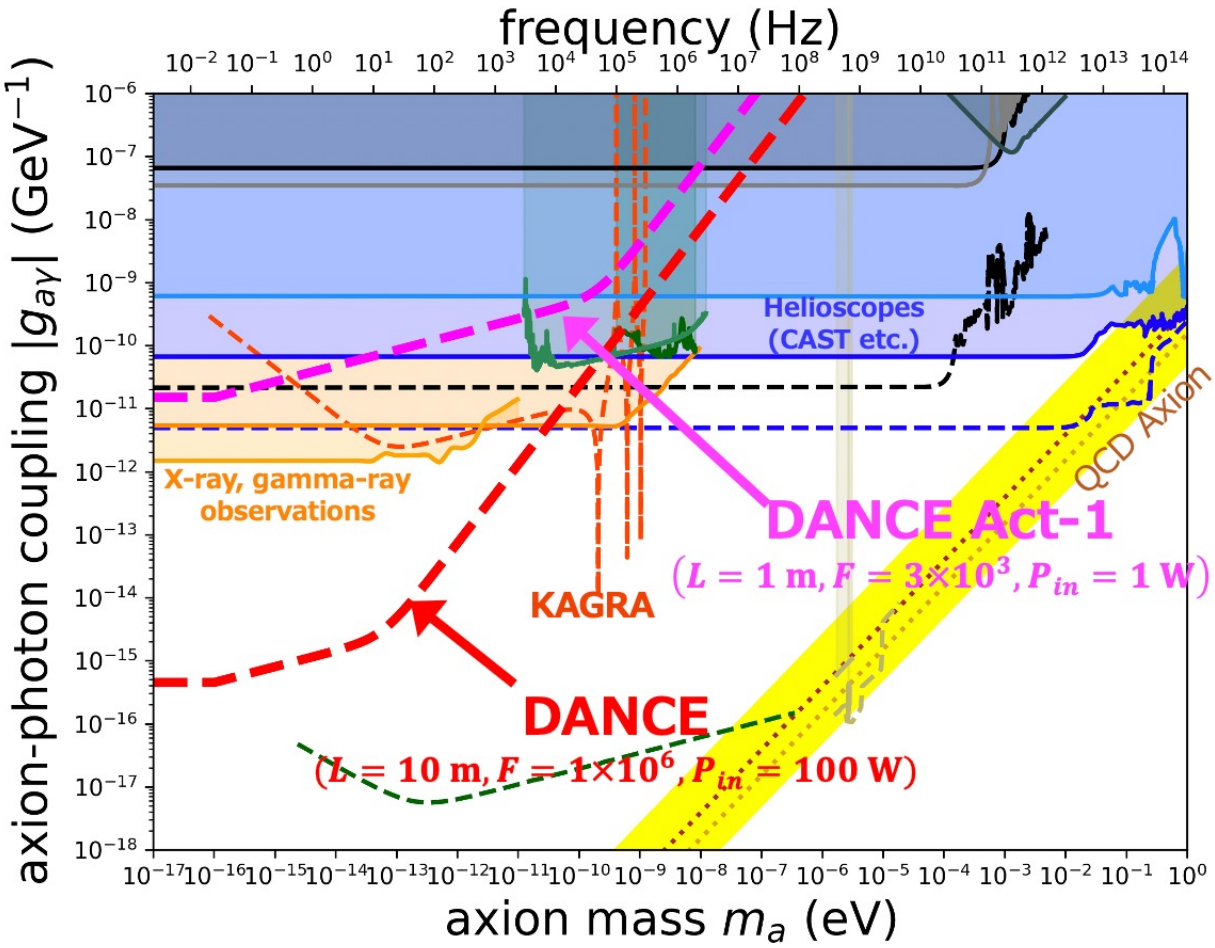
Experimental setup



Target sensitivity of DANCE

Parameters of DANCE

- L: Round-trip length
- F: Finesse (number of round trips)
- P_{in}: Input laser power



Shot noise limit in one-year observation

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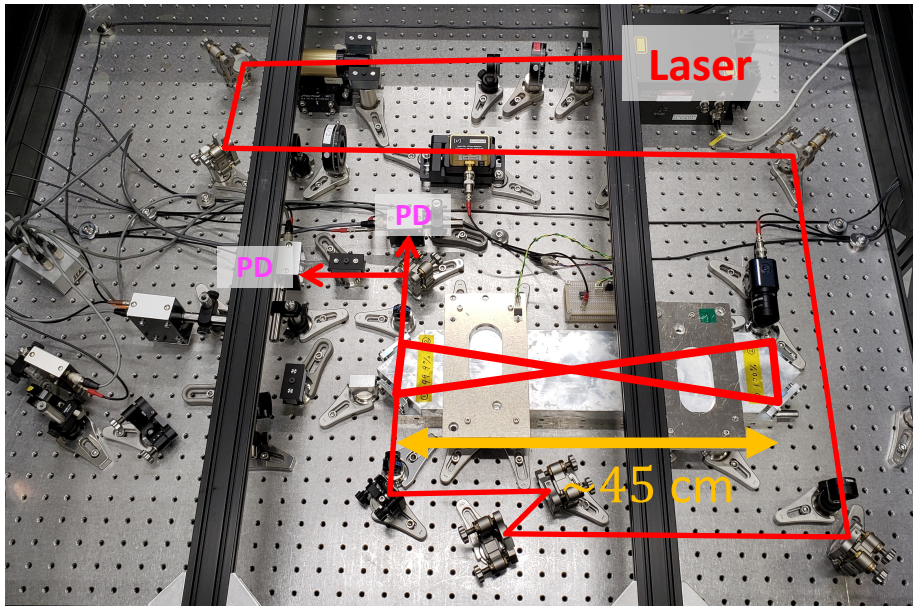
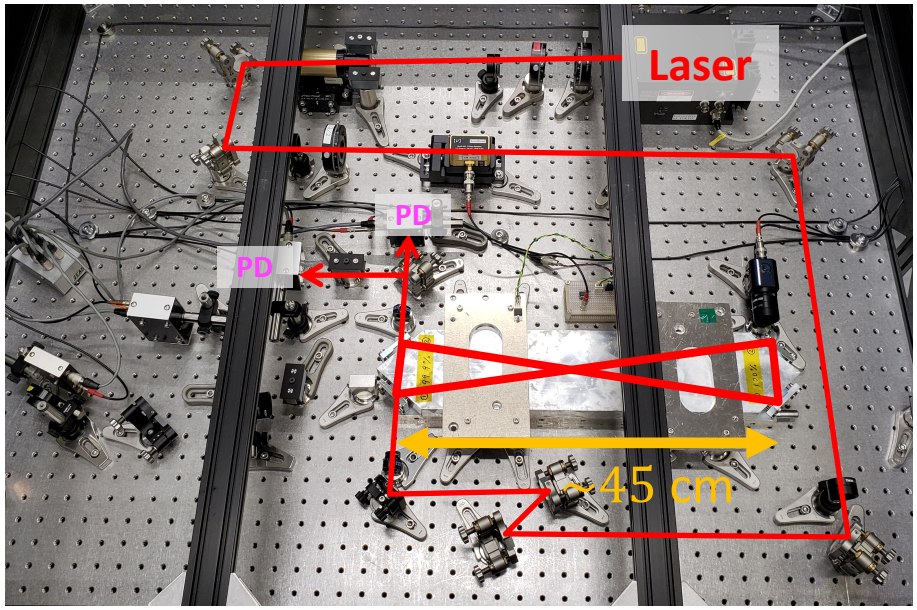
DANCE Act-1

- Prototype experiment for
  - ➢identifying technical issues
  - ➢proof of principle
- Feasible parameters (Round-trip length = 1 m, Designed finesse = 3000, Input laser power = 1 W)



DANCE Act-1

- Prototype experiment for
  - ➢identifying technical issues ➡ Resonant frequency difference between s- and p-pol.
  - ➢proof of principle ➡ Data analysis
- Feasible parameters (Round-trip length = 1 m, Designed finesse = 3000, Input laser power = 1 W)



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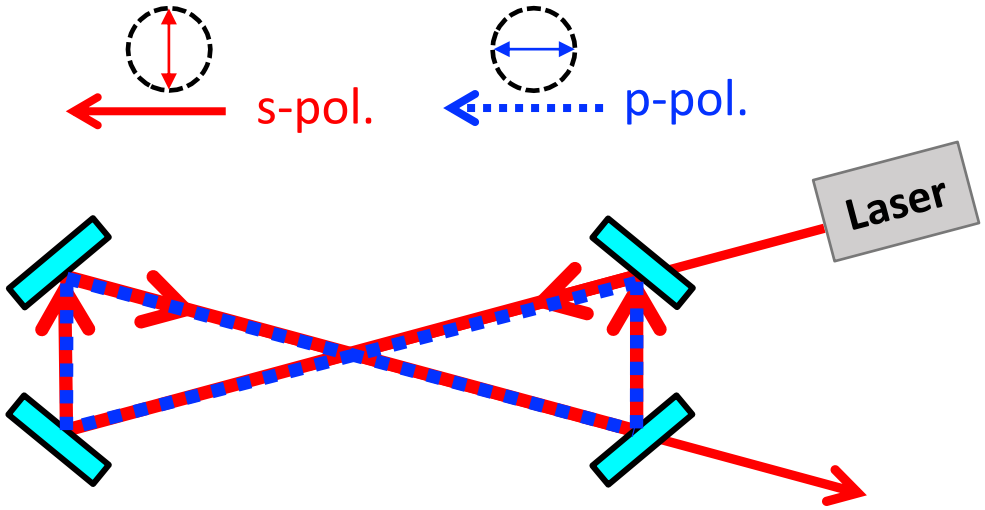
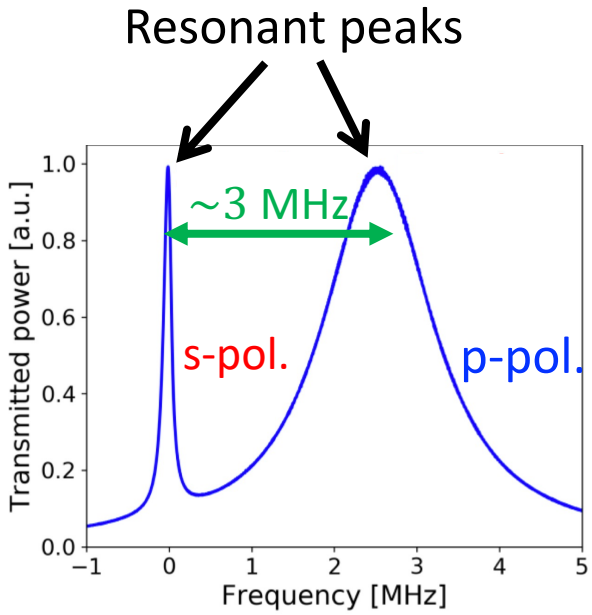
Resonant frequency difference

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

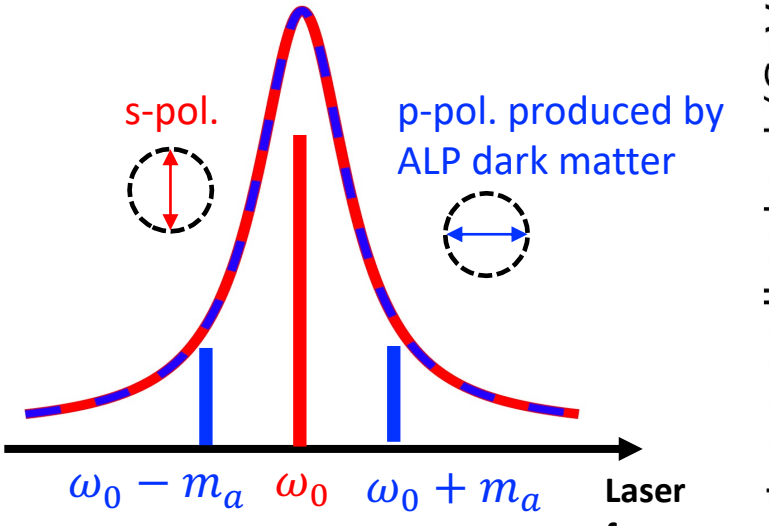
s-pol. and p-pol. can not resonate simultaneously



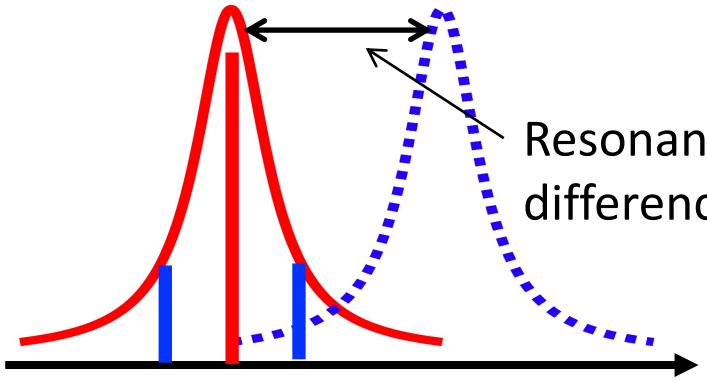


Degradation of sensitivity

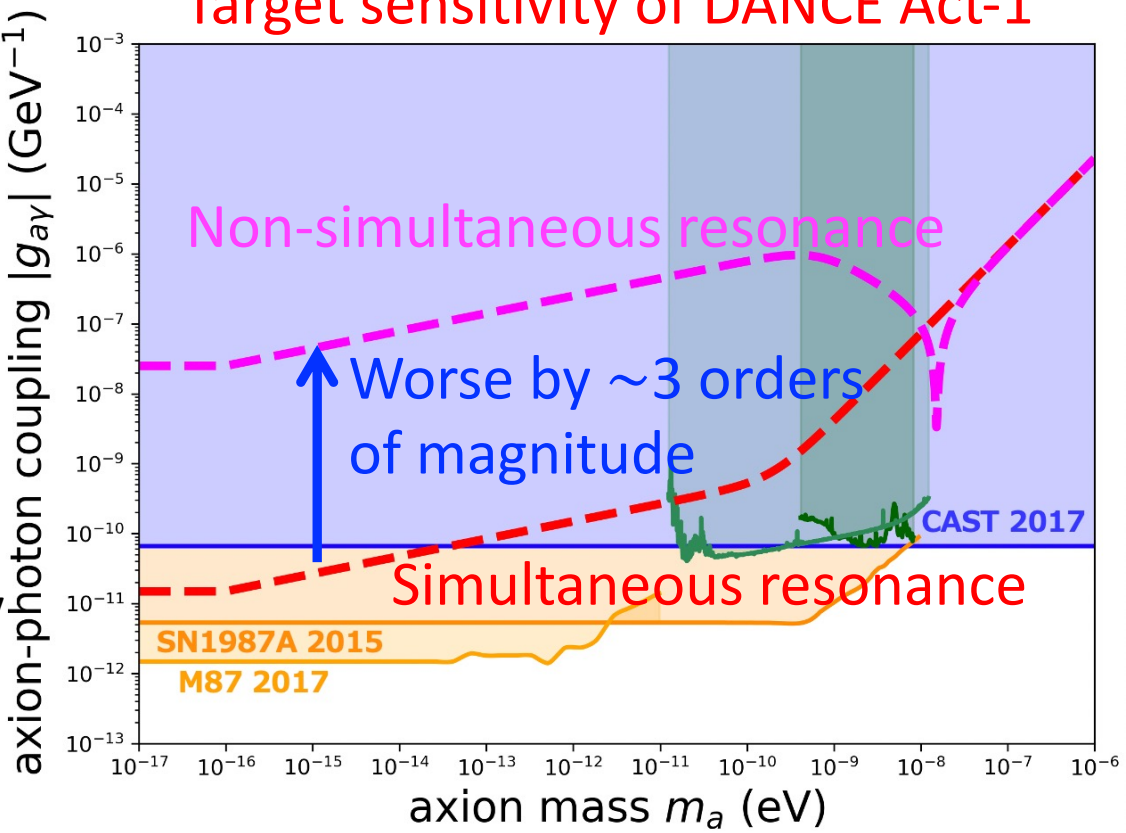
Simultaneous resonance



Non-simultaneous resonance



Target sensitivity of DANCE Act-1



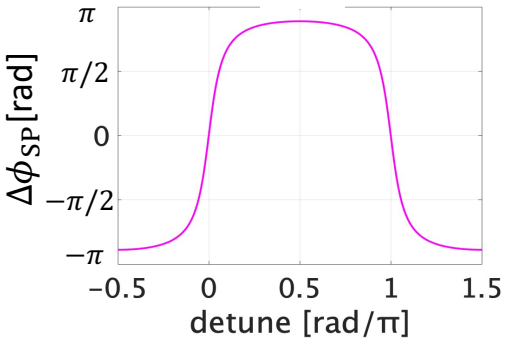
Simultaneous resonance is necessary for high sensitivity

Auxiliary cavity for simultaneous resonance

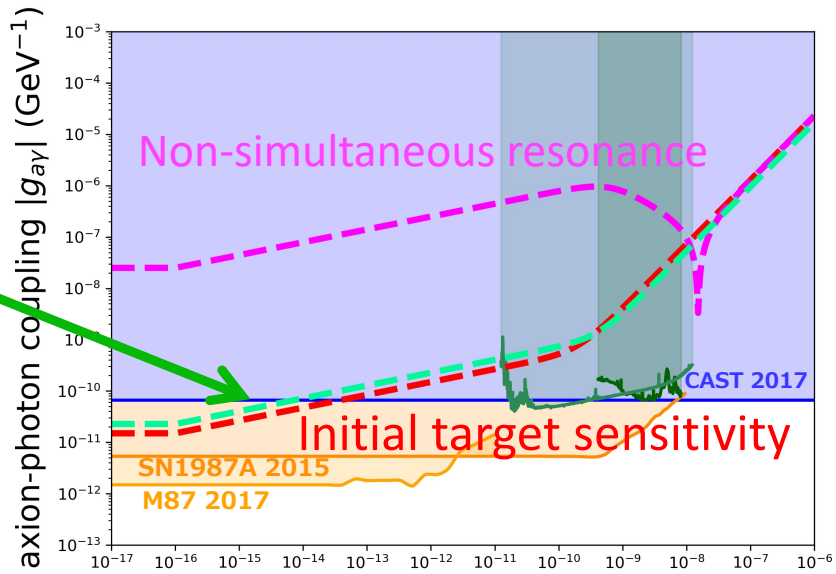
- Auxiliary cavity can control the phase difference between s- and p-pol. [1]

Resonant frequency difference can be cancelled out

Phase difference between s- and p-pol. reflected by auxiliary cavity



- Design has been completed
- Developing auxiliary cavity currently



[1] D. Martynov and H. Miao, *Phys. Rev. D* **101**, 095034 (2020)

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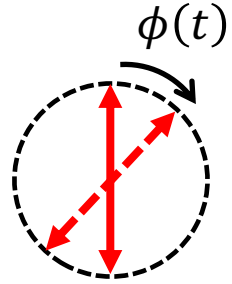
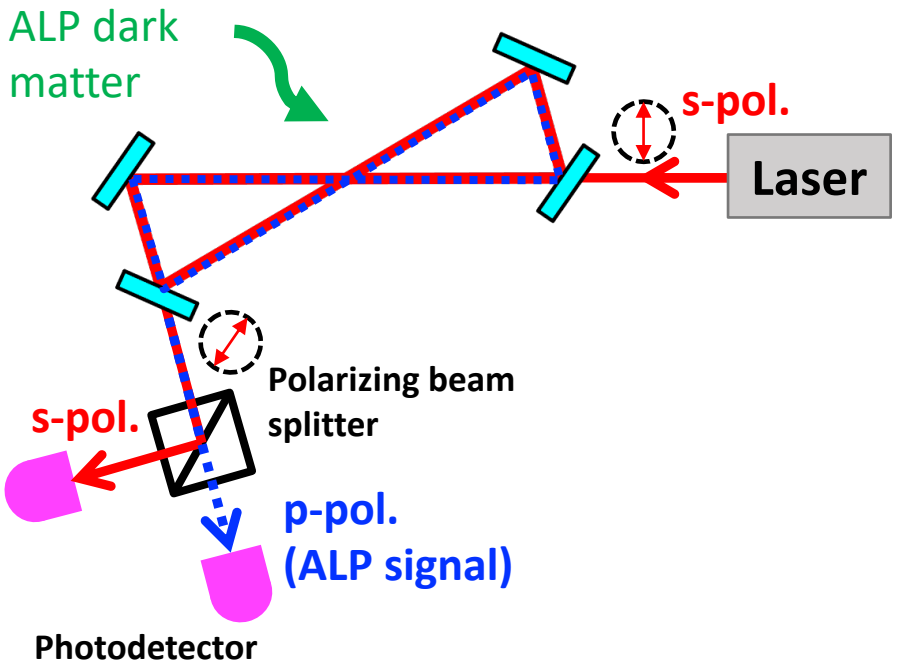
Data acquisition and calibration

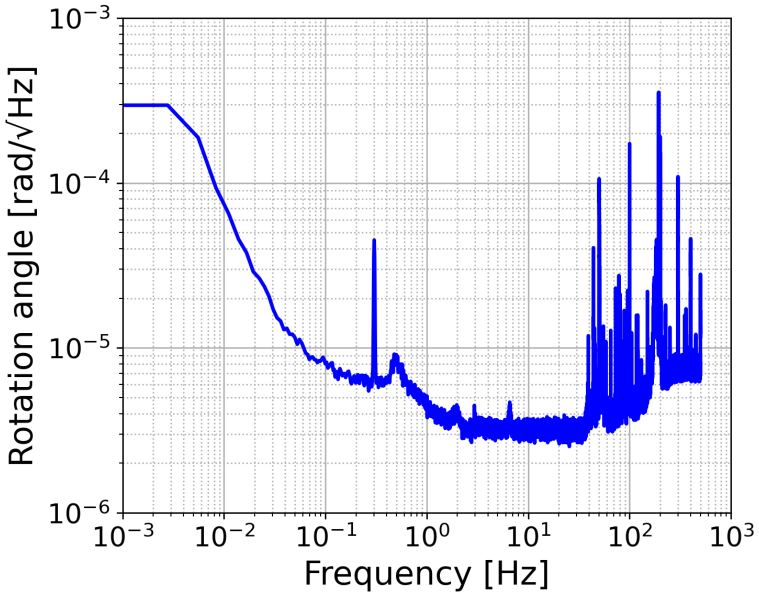
- Recorded p-pol. $P_{\mathrm{P}}(t)$ and total transmitted light $P_{\mathrm{tot}}(t)$ for 12 days (May 18-30, 2021)

- Calibrated to rotational angle of linear polarization

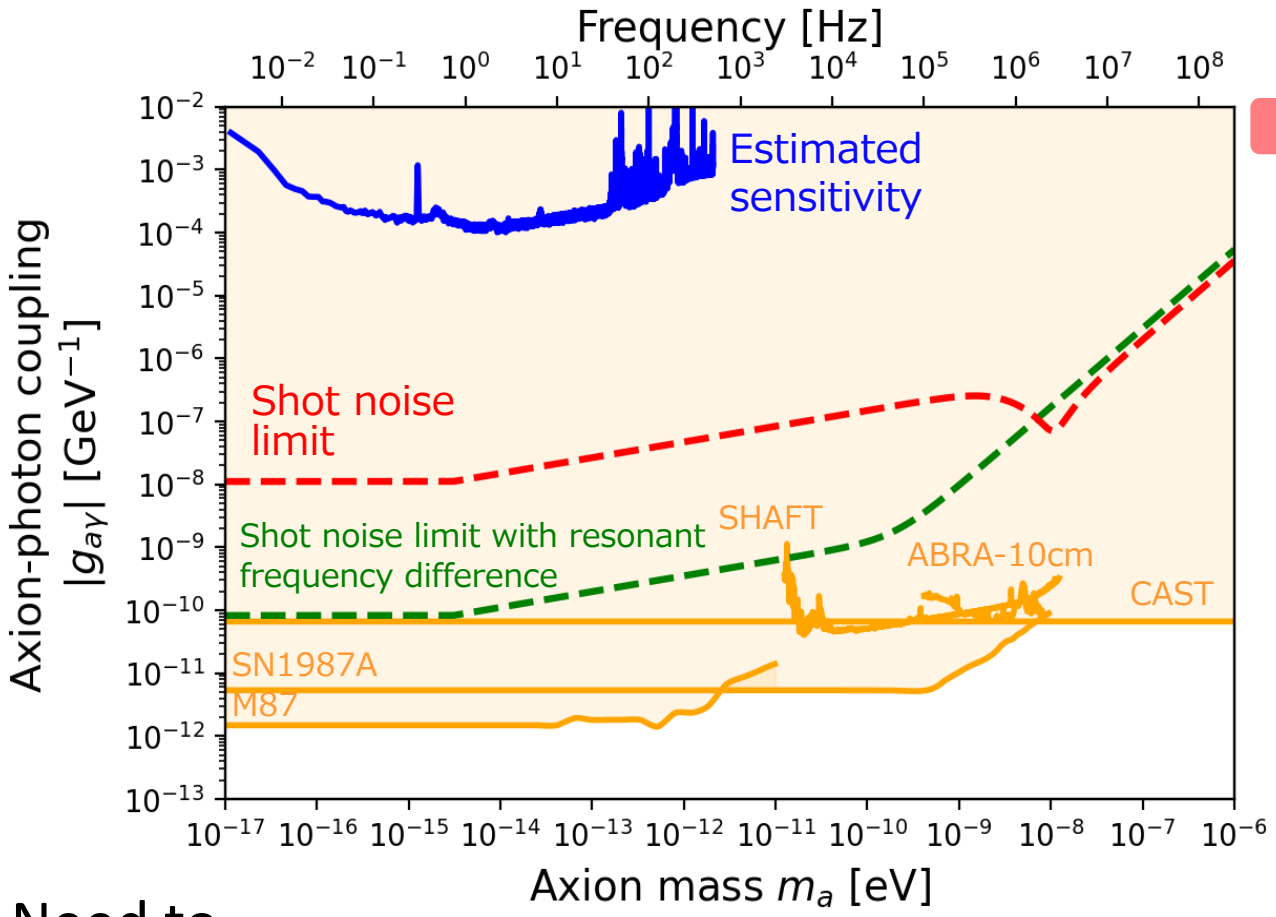
$$\phi(t) = \sqrt{P_{\mathrm{P}}(t)/P_{\mathrm{tot}}}$$







Estimated sensitivity



Preliminary

Assuming 12-day observation

Need to

- investigate the cause of noise
- reduce the noise (e.g. laser intensity noise, vibration)

to reach shot noise

Data analysis

- Started analysis with 10-hour data of rotational angle

→ Found 55 candidate peaks

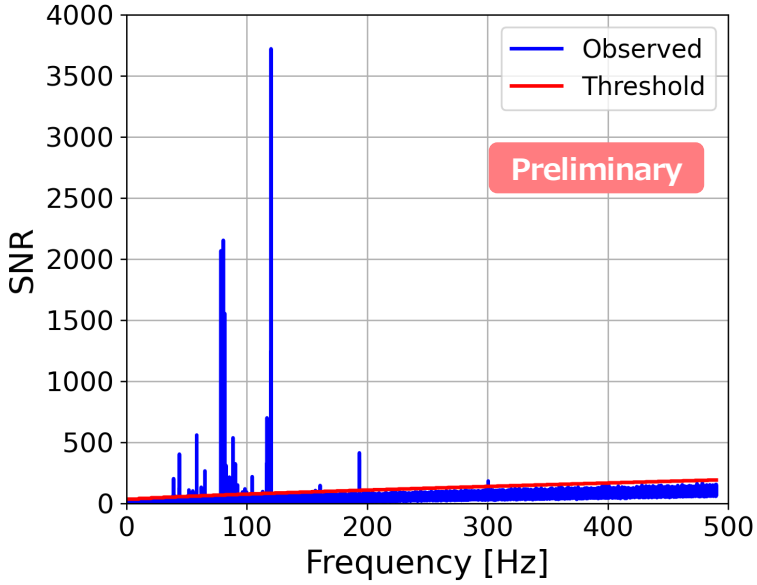
Veto candidate peaks

➢Q-factor veto:

ALP signal should have Q of ~10^6

➢Consistency with the other 10-hour data

reduced to 8 candidate peaks

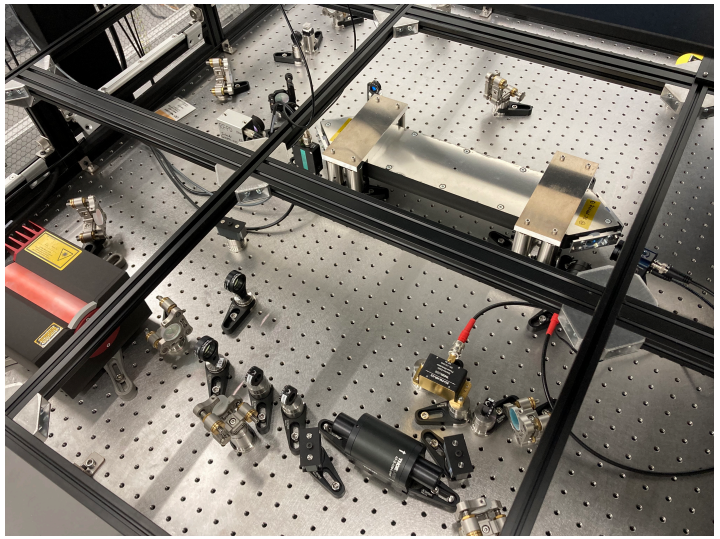


Need to investigate the cause of these peaks

Summary

- DANCE searches for ALP dark matter with ring cavity by enhancing the rotation of linear polarization.

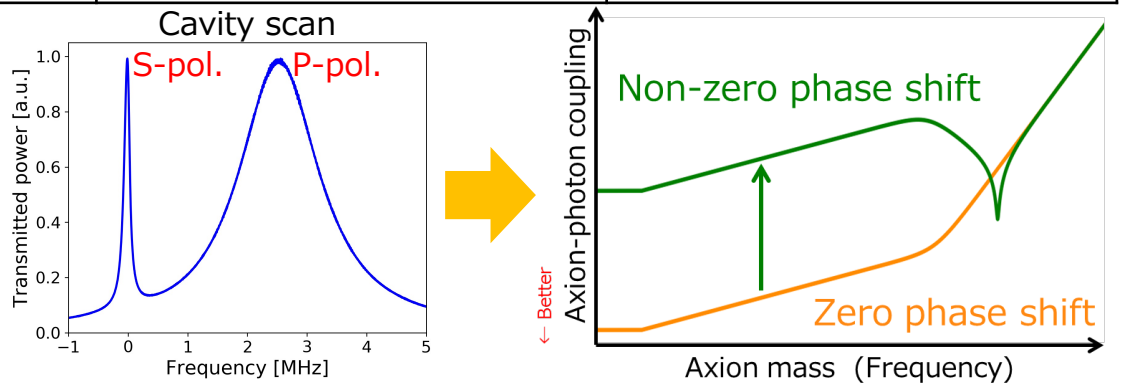
- Prototype experiment: DANCE Act-1 is underway
  - ➢ developing auxiliary cavity to realize simultaneous resonance of s- and p-pol.
  - ➢ analyzing obtained data



Appendix

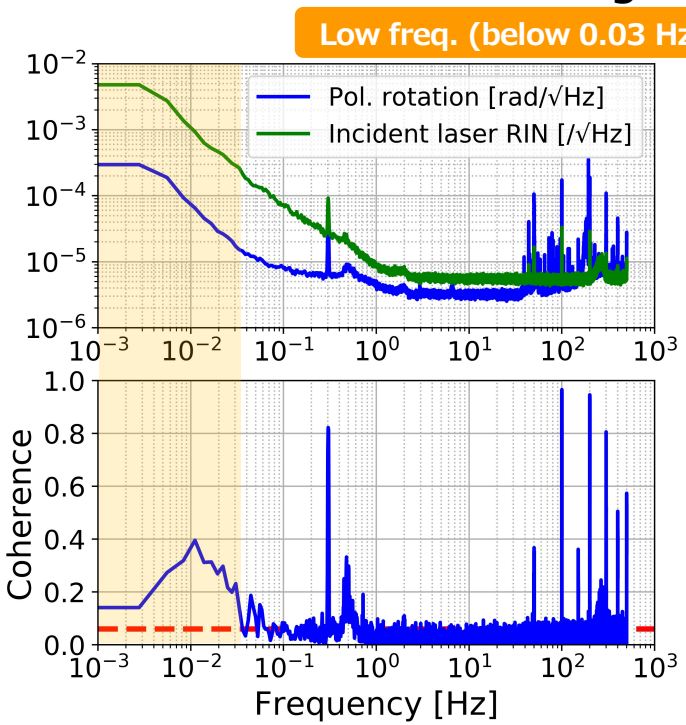
Performance evaluation of the cavity

	Designed values	Measured values
Input laser power	1 W	242(12) mW
Transmitted laser power	1 W	153(8) mW
Finesse for carrier	3×10^3	$2.85(5)\times10^3$ (S-pol.)
Finesse for sidebands	3×10^3	195(3) (P-pol.)
Resonant frequency difference between S- and P-pol.	0 Hz	2.52(2) MHz



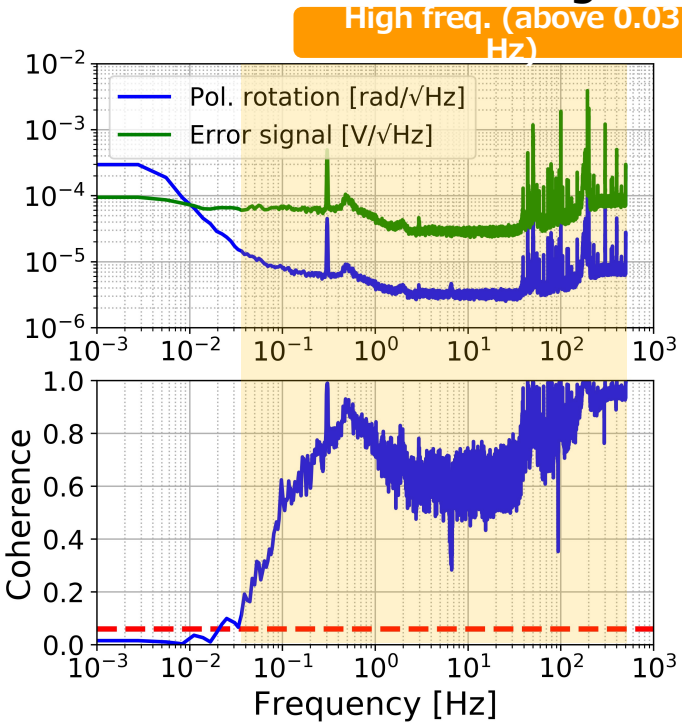
Discussion for noises

Correlation with incident light



Suggested to be limited by laser intensity noise

Correlation with error signal



Suggested to be limited by external noises such as mechanical vibration