Status report and future plans

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Abstract about Axion

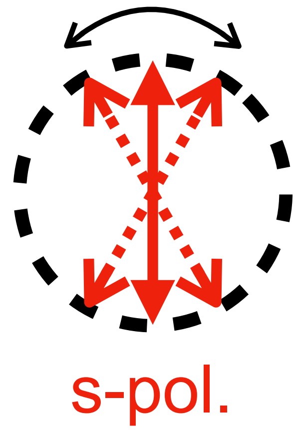
- Axion behaves as a coherent field $a(t)$ with its mass m_a and a phase factor $\delta_\tau(t)$

$$a(t) = a_0 \cos\left(m_a t + \delta_\tau(t)\right)$$

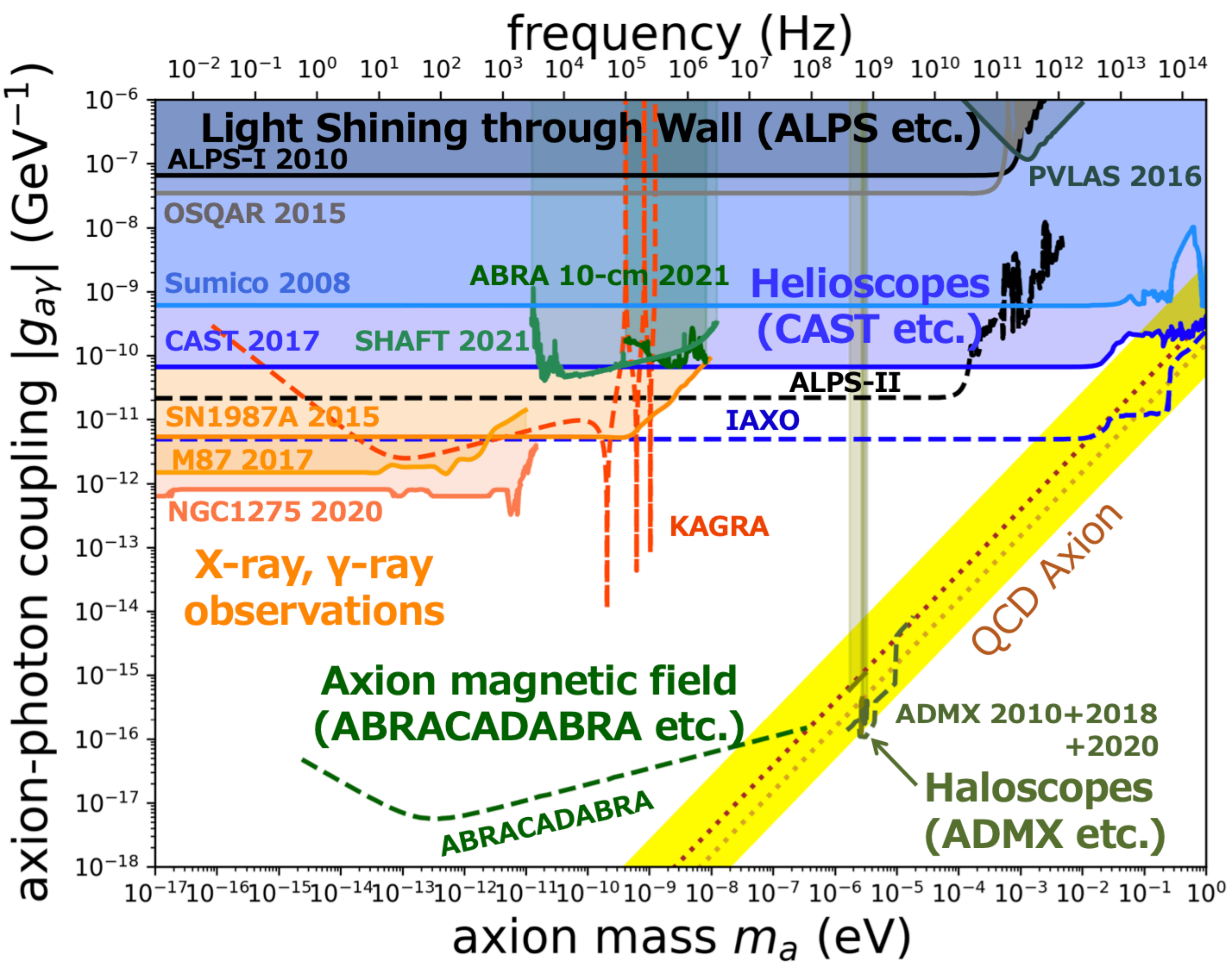
- The axion-photon interaction gives a phase velocity difference between left-handed and right-handed circularly polarized light.

$$c_{L/R}(t) \simeq 1 \mp \frac{g_{a\gamma}\dot{a}(t)}{2k}$$

- The modulated phase velocity difference gives the modulation of the polarization angle of linearly polarized light.



Abstract about Axion



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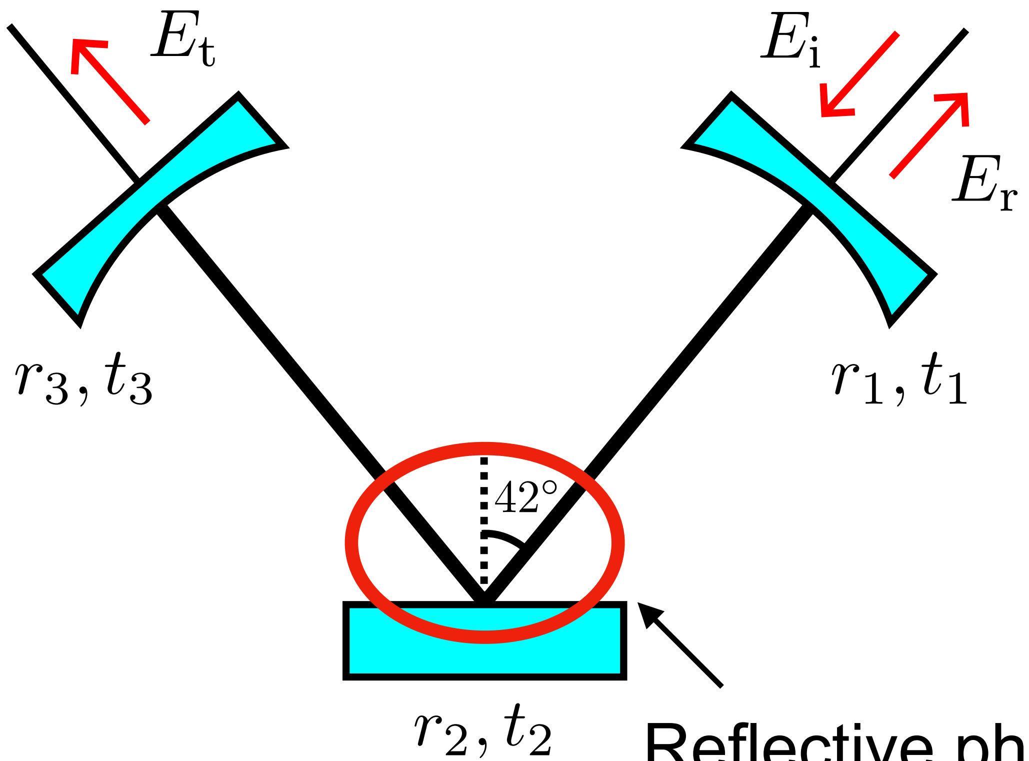
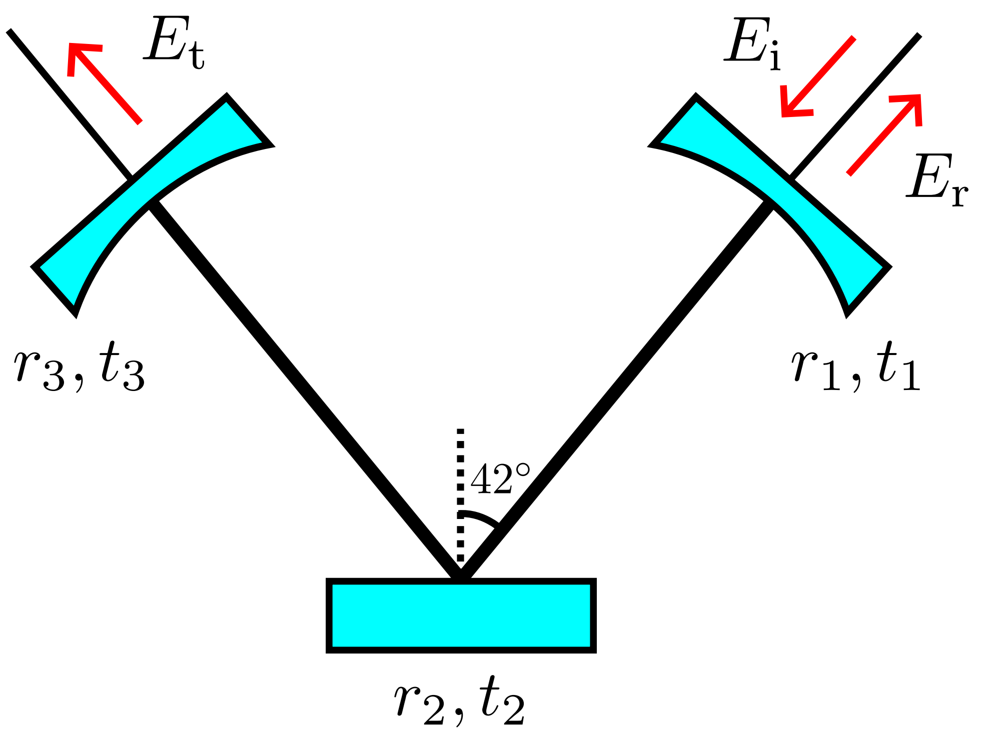
Design



Reflective phase difference occurs in oblique incidence

- Need for calibration
- Obtain time dependence data to investigate whether phase difference between s-pol. and p-pol. is drifting

Design



phase shift: $\phi = \dfrac{\omega L}{c}$

$$E_r = E_i(-r_1) + E_i t_1^2 r_2^2 r_3 e^{-i2\phi} + E_i t_1^2 r_1 r_2^4 r_3 e^{-i4\phi} + E_i t_1^2 r_1^2 r_2^6 r_3^3 e^{-i6\phi} + \cdots$$

$$= E_i \left(-r_1 + \frac{t_1^2 r_2^2 r_3 e^{-i2\phi}}{1 - r_1 r_2^2 r_3 e^{-i2\phi}} \right)$$

$$E_t = E_i t_1 r_2 t_3 e^{-i\phi} + E_i t_1 r_1 r_2^3 t_3 r_3 e^{-i3\phi} + E_i t_1 r_1^2 r_2^5 r_3^2 t_3 e^{-i5\phi} + \cdots$$

$$= E_i \frac{t_1 r_2 t_3 e^{-i\phi}}{1 - r_1 r_2^2 r_3 e^{-i2\phi}}$$

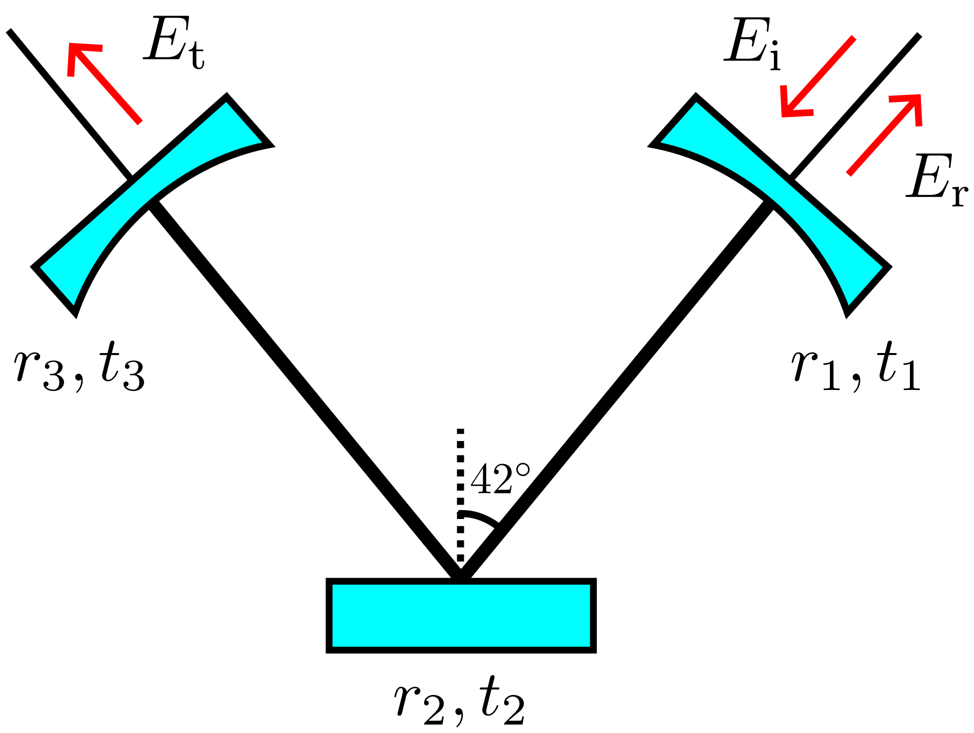
Amplitude reflectance: $r(\phi) = -r_1 + \dfrac{t_1^2 r_2^2 r_3 e^{-i2\phi}}{1 - r_1 r_2^2 r_3 e^{-i2\phi}}$

Amplitude transmittance: $t(\phi) = \dfrac{t_1 r_2 t_3 e^{-i\phi}}{1 - r_1 r_2^2 r_3 e^{-i2\phi}}$

Reflected light intensity: $P_r = |E_r|^2 = \dfrac{\left[\left(t_1^2 + r_1^2\right) r_2^2 r_3 - r_1\right]^2 + 4 r_1 r_2^2 r_3 \left(t_1^2 + r_1^2\right) \sin^2\phi}{\left(1 - r_1 r_2^2 r_3\right)^2 + 4 r_1 r_2^2 r_3 \sin^2\phi} |E_i|^2$

Transmitted light intensity: $P_t = |E_t|^2 = \dfrac{(t_1 r_2 t_3)^2}{\left(1 - r_1 r_2^2 r_3\right)^2 + 4 r_1 r_2^2 r_3 \sin^2\phi} |E_i|^2$

Design



Resonance condition

$$\phi = \pi m \rightarrow 2L = m\lambda (m \in \mathbb{N})$$

Free spectral range: $\nu_{FSR} = \dfrac{c}{2L}$

By Reflected light intensity P_r,

$$\frac{1}{1 + \frac{4r_1r_2^2r_3}{\left(1 - r_1r_2^2r_3\right)^2}\sin^2\left(\frac{\pi\nu_{FWHM}L}{c}\right)} = \frac{1}{2}$$

Assume $\dfrac{\pi\nu_{FWHM}L}{c} = \dfrac{\pi\nu_{FWHM}}{2\nu_{FSR}} \ll 1$,

Full Width at Half Maximum:

$$\nu_{FWHM} = \frac{c\left(1 - r_1r_2^2r_3\right)}{2\pi L\sqrt{r_1r_2^2r_3}}$$

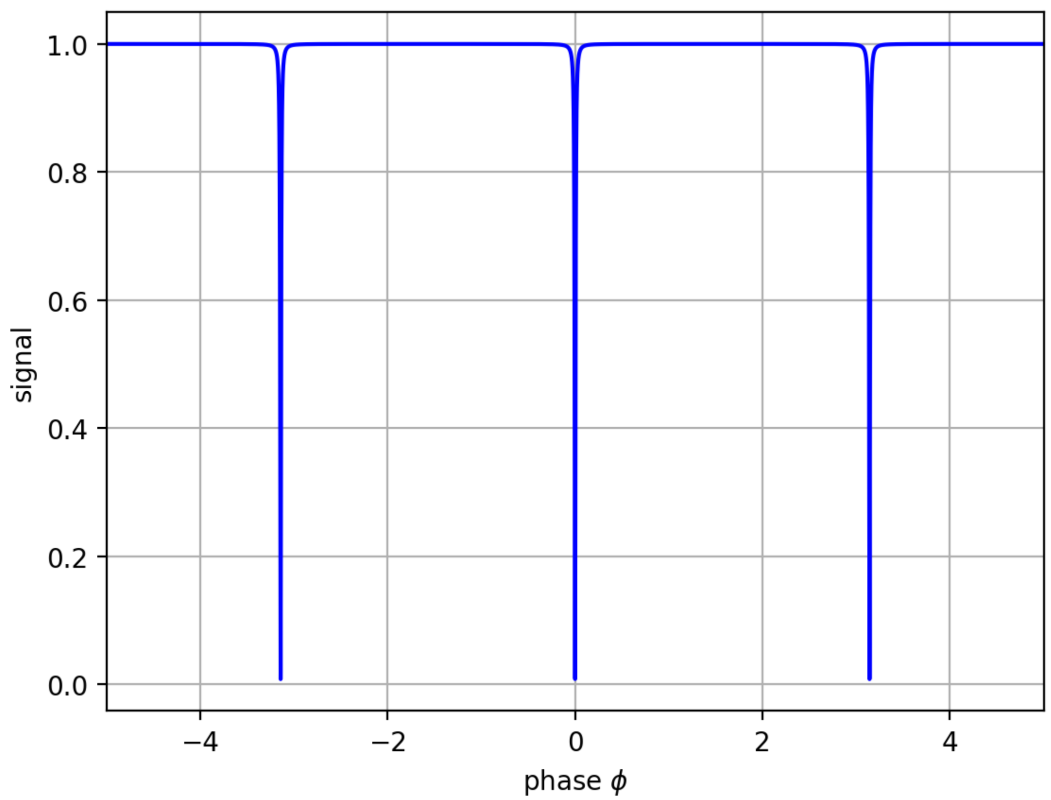
Finesse:

$$\mathscr{F} = \frac{\nu_{FSR}}{\nu_{FWHM}} = \frac{\pi\sqrt{r_1r_2^2r_3}}{1 - r_1r_2^2r_3}$$

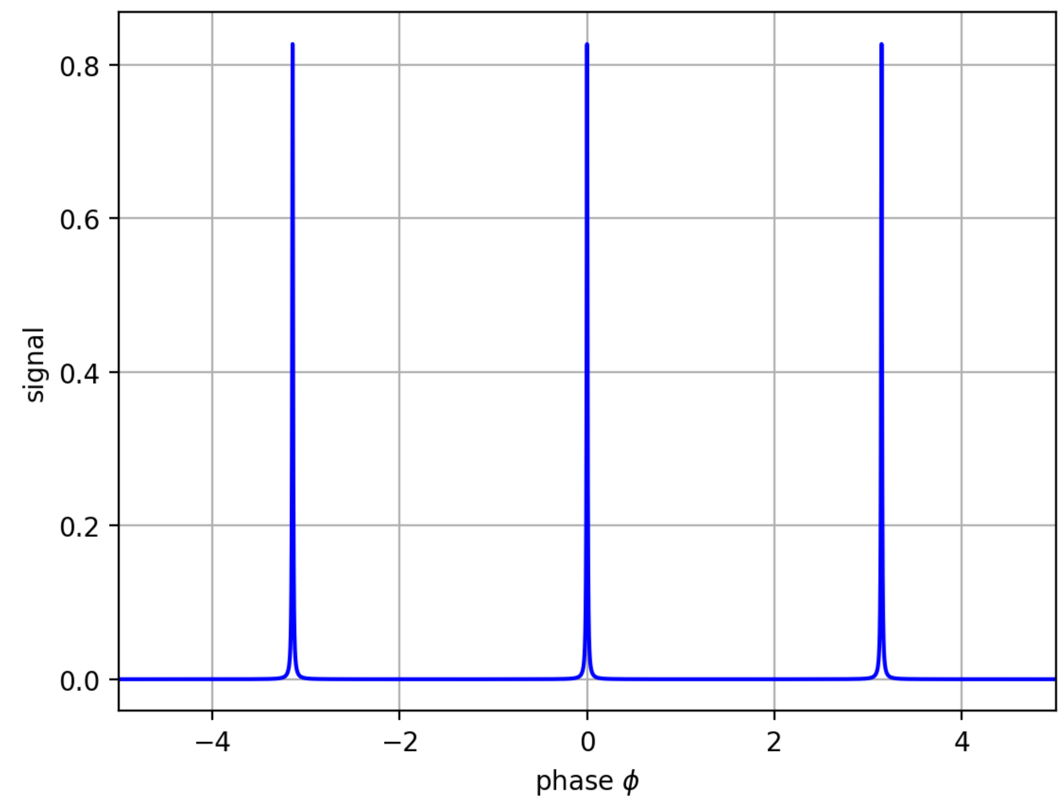
Design

$$r_1 = \sqrt{0.99}, r_2 = \sqrt{0.999}, r_3 = \sqrt{0.99}, t_1 = \sqrt{1 - r_1^2}, t_2 = \sqrt{1 - r_2^2}, t_3 = \sqrt{1 - r_3^2}, |E_i|^2 = 1, L = 60mm$$

$$P_r = \frac{\left[\left(t_1^2 + r_1^2\right) r_2^2 r_3 - r_1\right]^2 + 4 r_1 r_2^2 r_3 \left(t_1^2 + r_1^2\right) \sin^2\phi}{\left(1 - r_1 r_2^2 r_3\right)^2 + 4 r_1 r_2^2 r_3 \sin^2\phi} |E_i|^2 \qquad P_t = \frac{(t_1 r_2 t_3)^2}{\left(1 - r_1 r_2^2 r_3\right)^2 + 4 r_1 r_2^2 r_3 \sin^2\phi} |E_i|^2$$



Reflected light



Transmitted light

Calculated value:

$\nu_{FSR} = 2.5\text{GHz}, \nu_{FWHM} = 8.8\text{MHz}, \mathscr{F} = 284.2$

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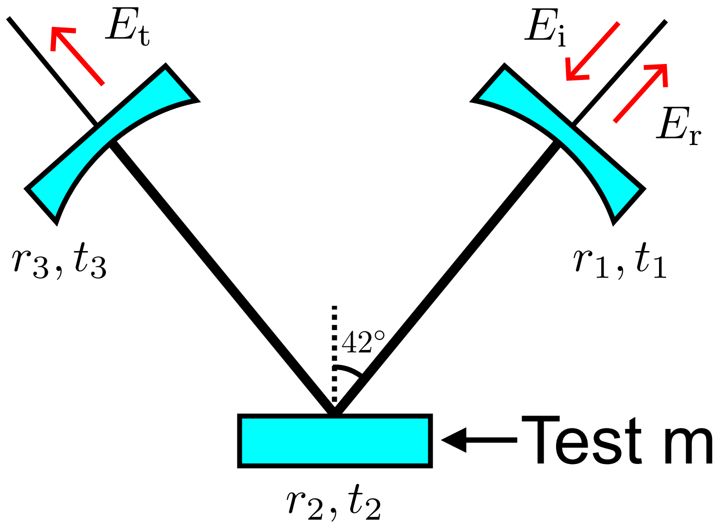
Mode matching ratio



Mode matching ratio M

$$M = 4\left[\frac{z_{R1}^2 z_{Rx} z_{Ry}}{\{(z_{R1}+z_{Rx})^2+(d_1-d_x)^2\}\{(z_{R1}+z_{Ry})^2+(d_1-d_y)^2\}}\right]^{\frac{1}{2}}$$

Raab, F.J. and S.E. Whitcomb (1992) Estimation of Special Optical Properties of a Triangular Ring Cavity. *LIGO Tech. Rep.*, No.108: 1-8.

Assume the beam is circle $z_{Rx} = z_{Rx} = z_{R2}, d_x = d_y = d_2$, M is given by

$$M = \frac{4 z_{R1} z_{R2}}{(z_{R1}+z_{R2})^2+(d_1-d_2)^2}$$

- Test mirror with flat: 100%
- Test mirror with CC(center of curvature)1000mm

  Front and end mirror with CC 50mm: 99.94%

  Front and end mirror with CC1000mm: 97.17%

  → The larger CC, mode matching ratio gets worse

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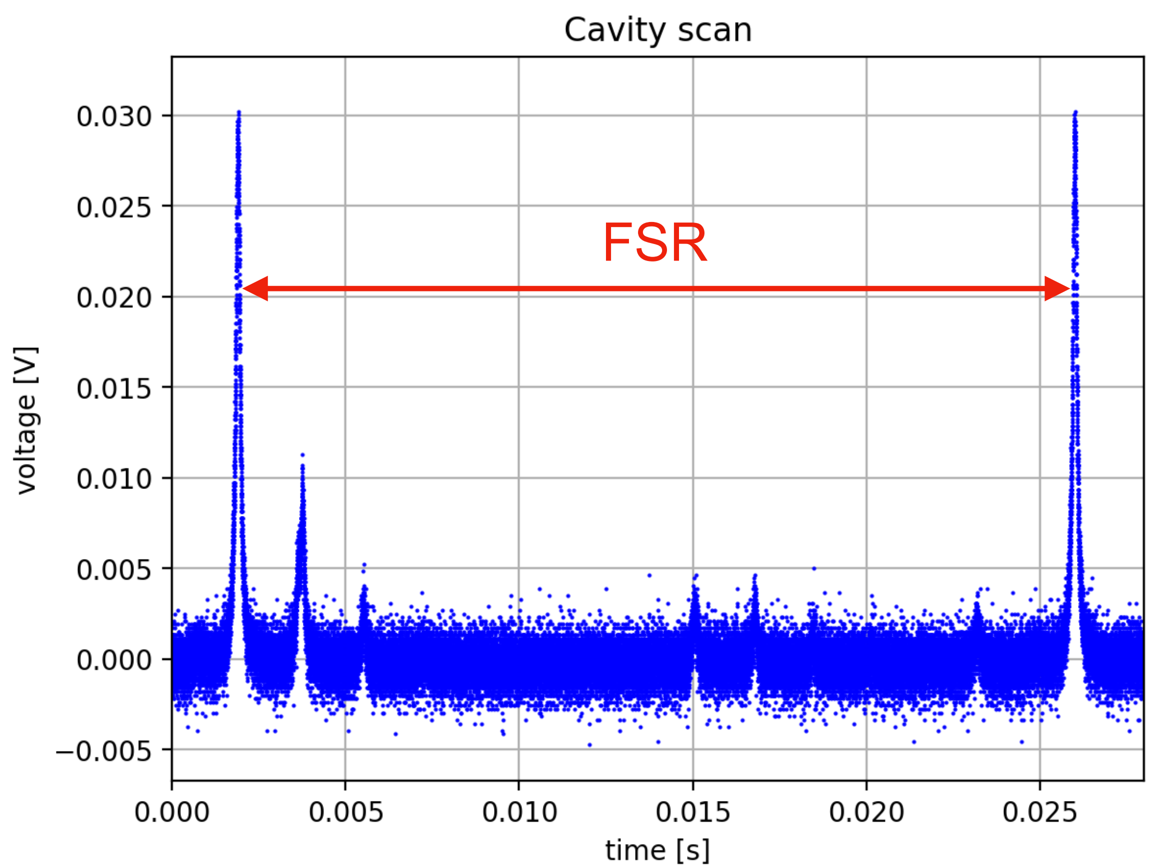
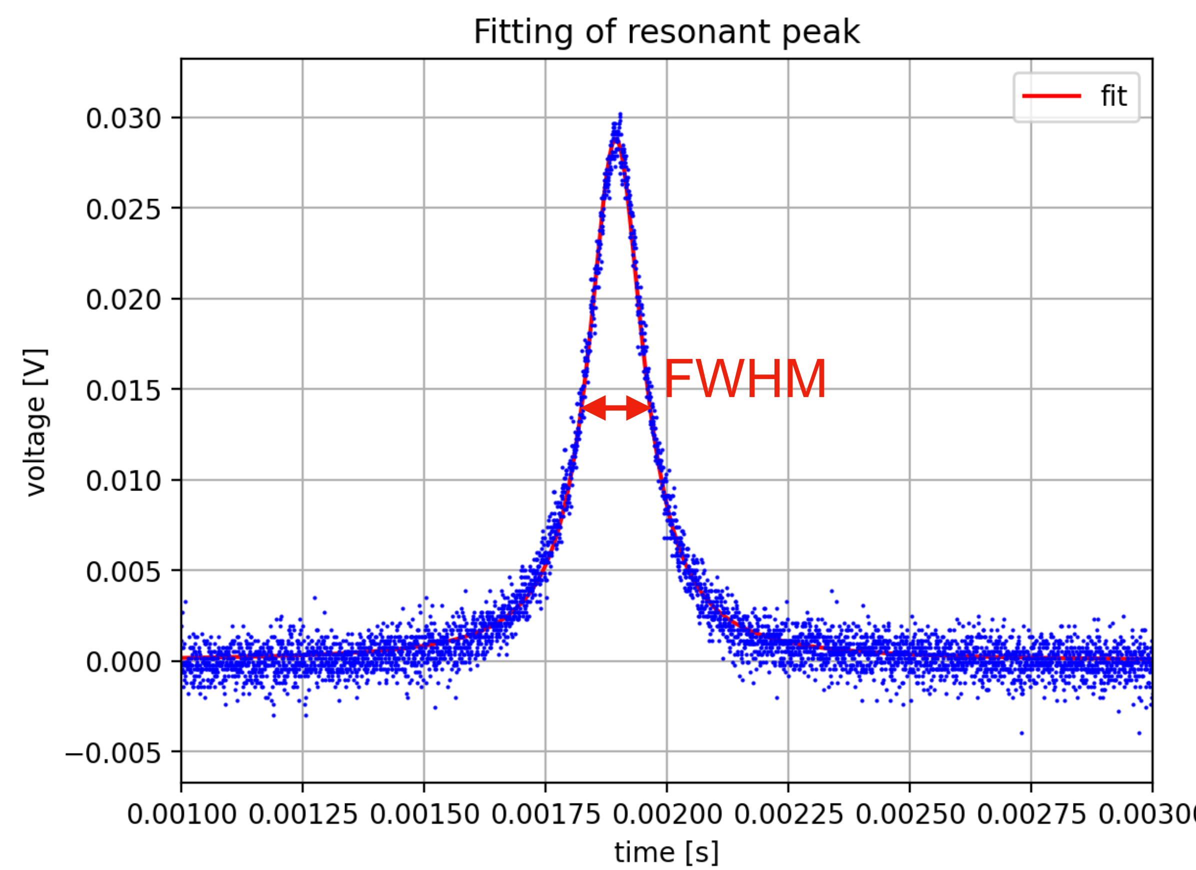
Finesse, mode matching ratio

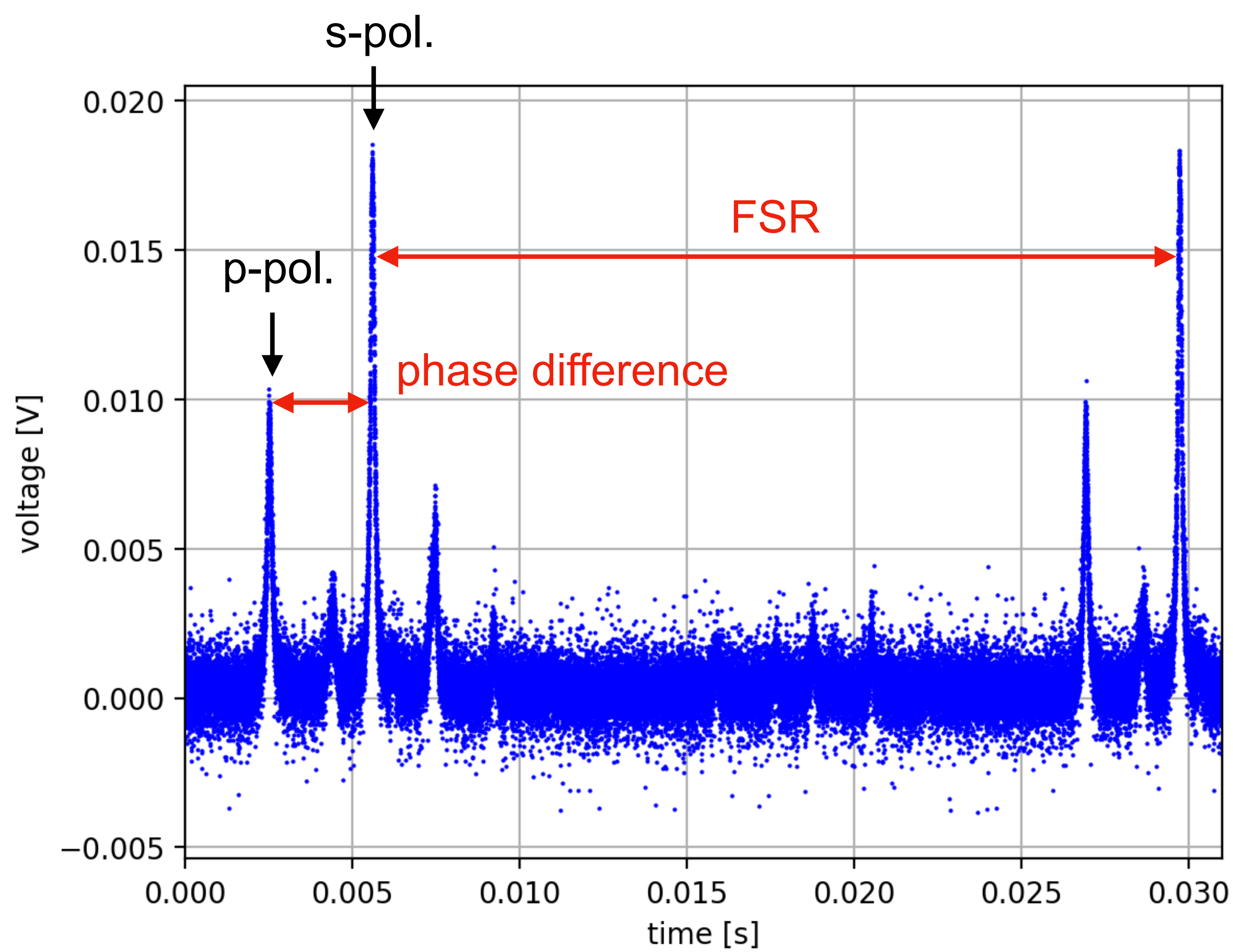




→ Finesse: $\mathscr{F} = 166.6 \pm 8.9$

Mode matching ratio: $M = 65.6\,\%$

Phase difference between s-pol. and p-pol.



Phase difference between s-pol. and p-pol.

$$\Delta\phi = 23.27 \pm 0.46[\mathrm{deg}]$$

→ Compared with previous result , this result matches!

(Fujimoto-san's)

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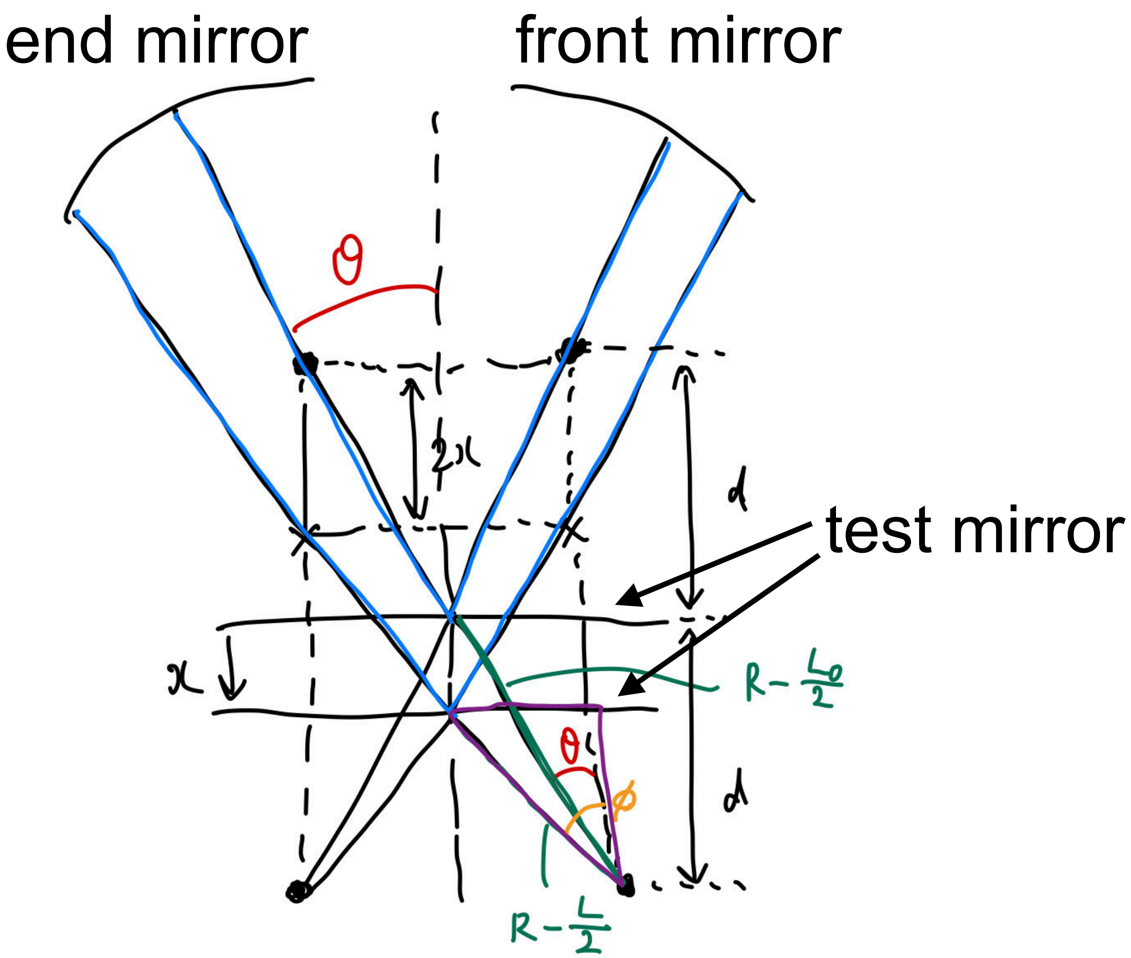
Incident angle



x: motion of test mirror

d: distance between test mirror and center of curvature

R: curvature of front and end mirror

L_0: cavity length (initial)

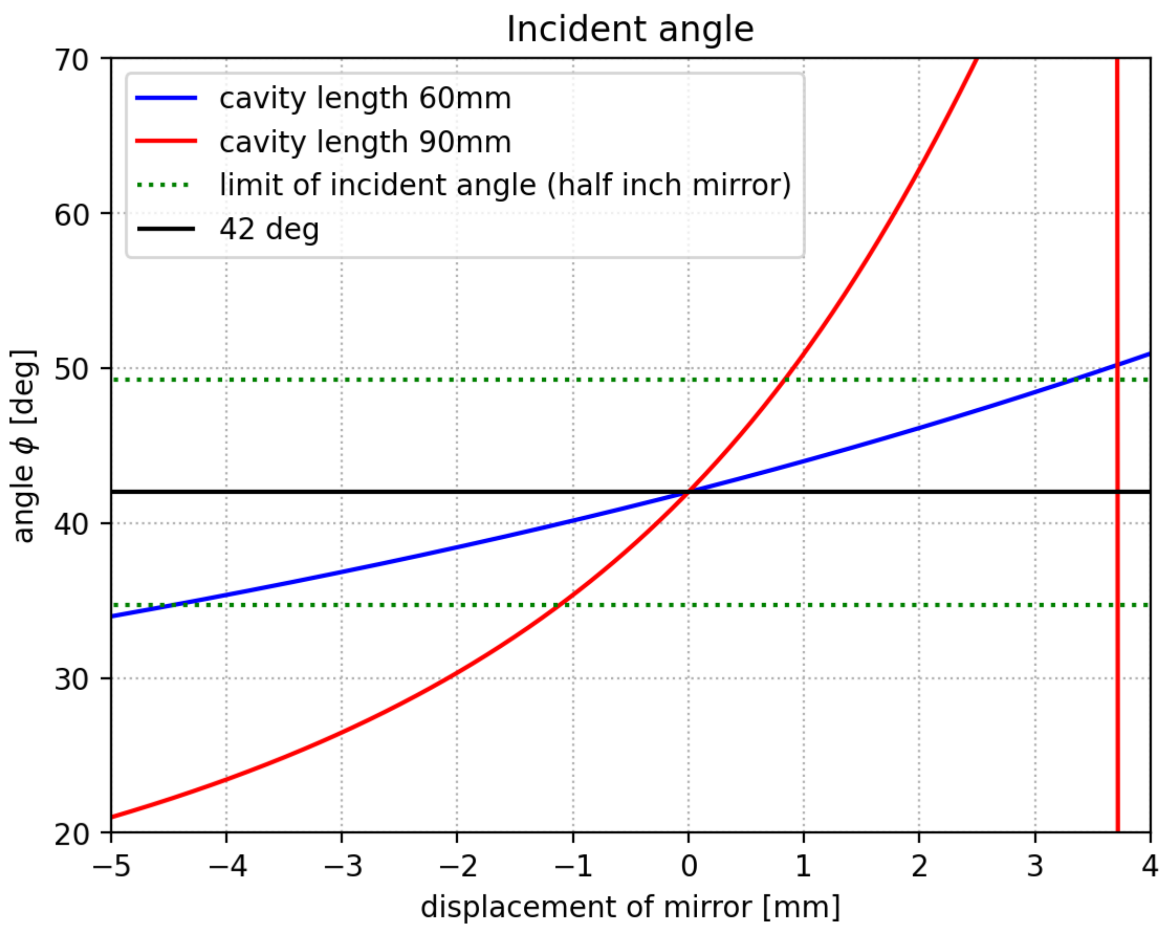
θ: incident angle (initial)

Focus on purple triangle, incident angle ϕ is given by

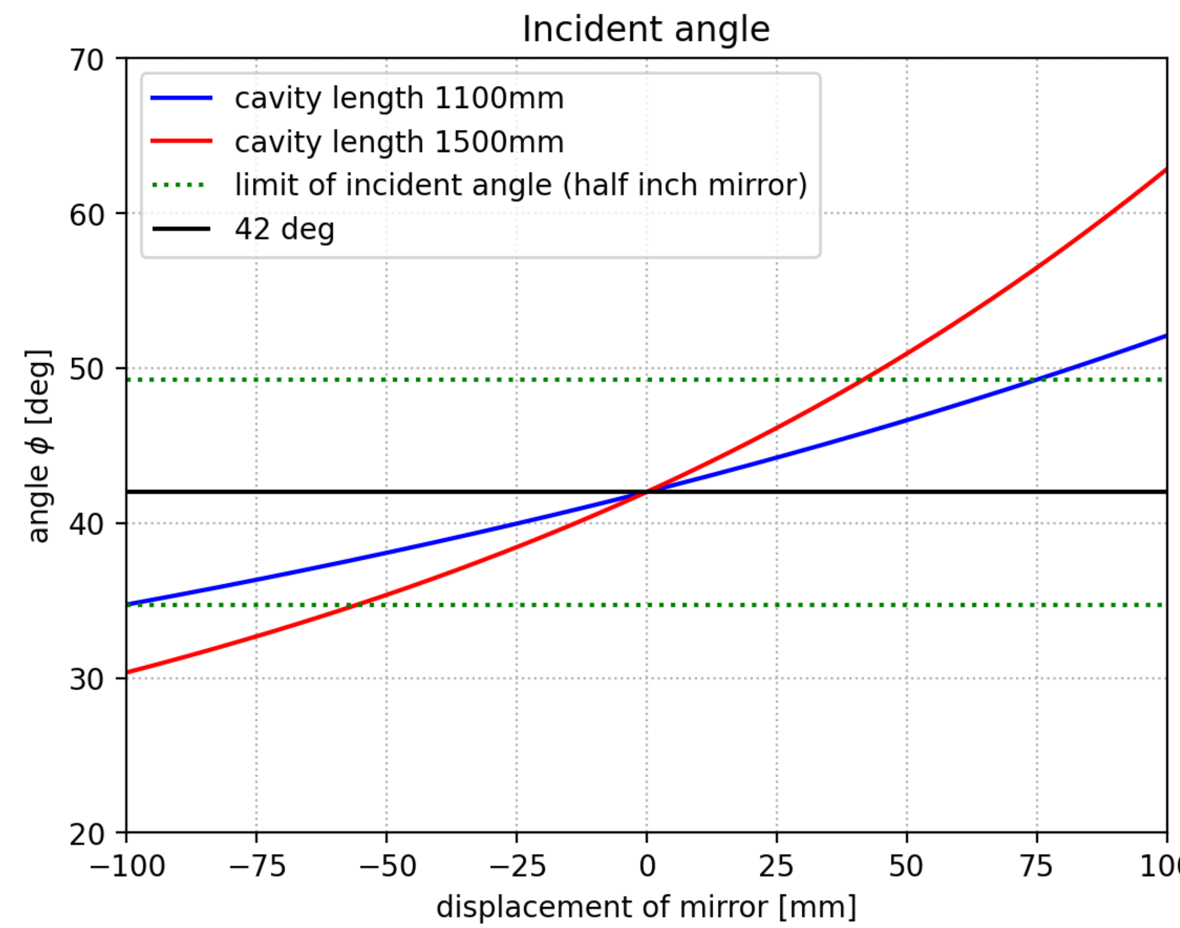
$$\phi = \tan^{-1}\left[\frac{1}{d-x}\left(R - \frac{L_0}{2}\right)\sin\theta\right] \quad \left(d = \left(R - \frac{L_0}{2}\right)\cos\theta\right)$$

Calculated result about range of angle

$$\phi = \tan^{-1}\left[\frac{1}{d-x}\left(R - \frac{L_0}{2}\right)\sin\theta\right]$$



Front and end mirror with $R = 50$mm



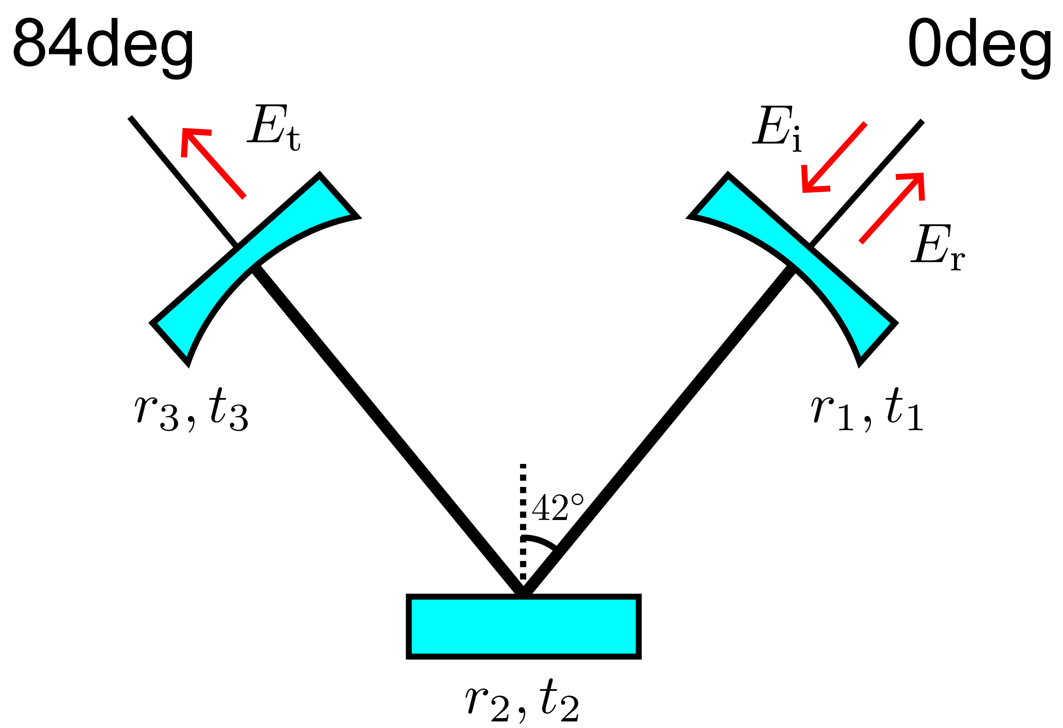
Front and end mirror with $R = 1000$mm

→ When the cavity length is long, Incident angle is sensitive to displacement of mirror

How to measure the angle accurately

1.Reflect the beam to the laser source (0deg)

2.Using the rotation mount to tune 42deg



example(rotation mount)

https://www.thorlabs.co.jp/thorproduct.cfm?partnumber=PR01/M

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Future Plans

1. Measure the time dependence of phase difference between s-pol. and p-pol.
2. Confirm whether the phase difference depends on incident angle
3. Prepare the wavelength sensitive phase-shifting mirror
4. Introduce wavelength tunable laser to realize simultaneous resonance