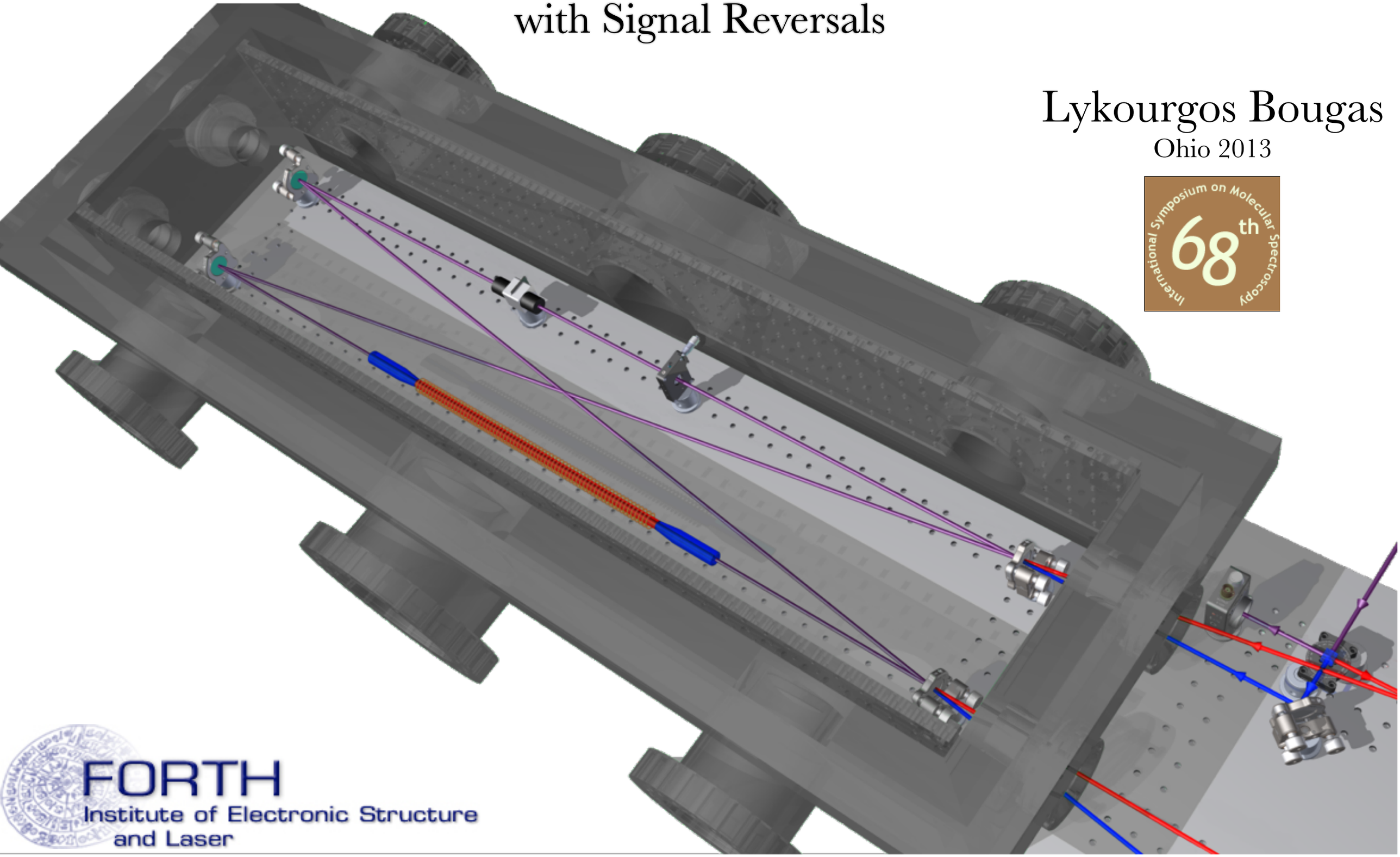
Chiral Cavity Ring-Down

Absolute Measurements of Optical Rotation in Gases and Liquids with Signal Reversals

Lykourgos Bougas

Ohio 2013



FORTH
Institute of Electronic Structure and Laser

How to enhance circular birefringence?

PNC optical rotation & natural optical activity

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density or path length

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(R=99.99% $\rightarrow$N~10^4)

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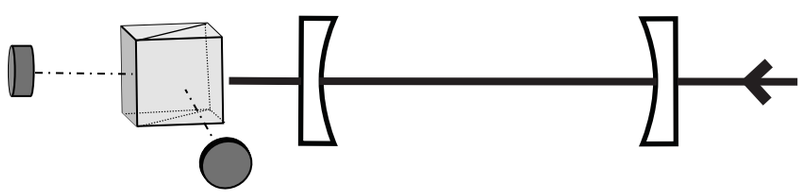

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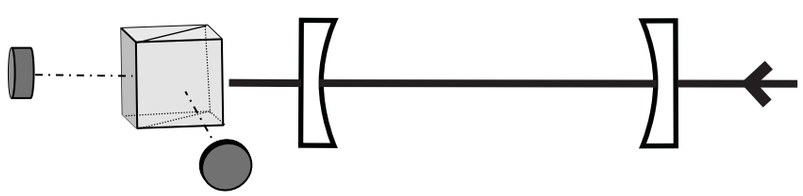

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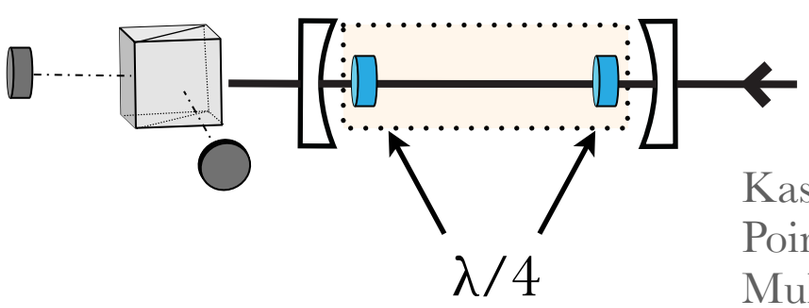

YES

Kastler (1970)
Poirson et. al. (1998)
Muller et. al. (2002)

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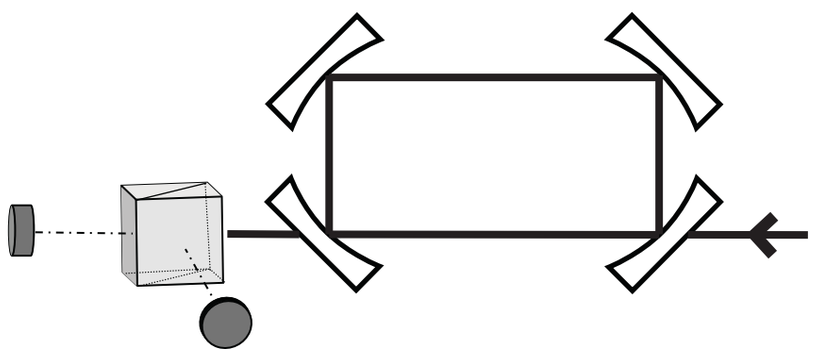

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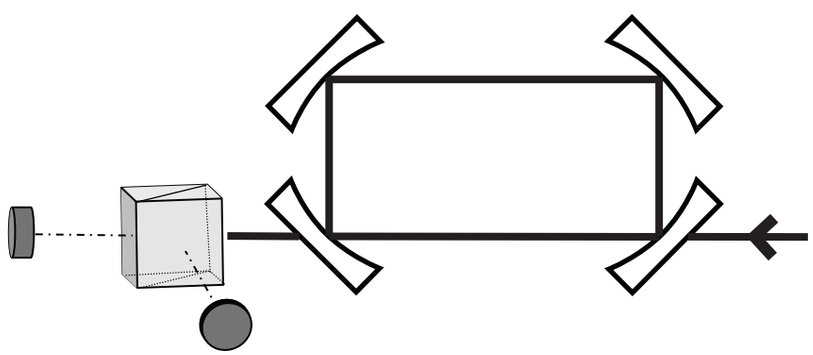


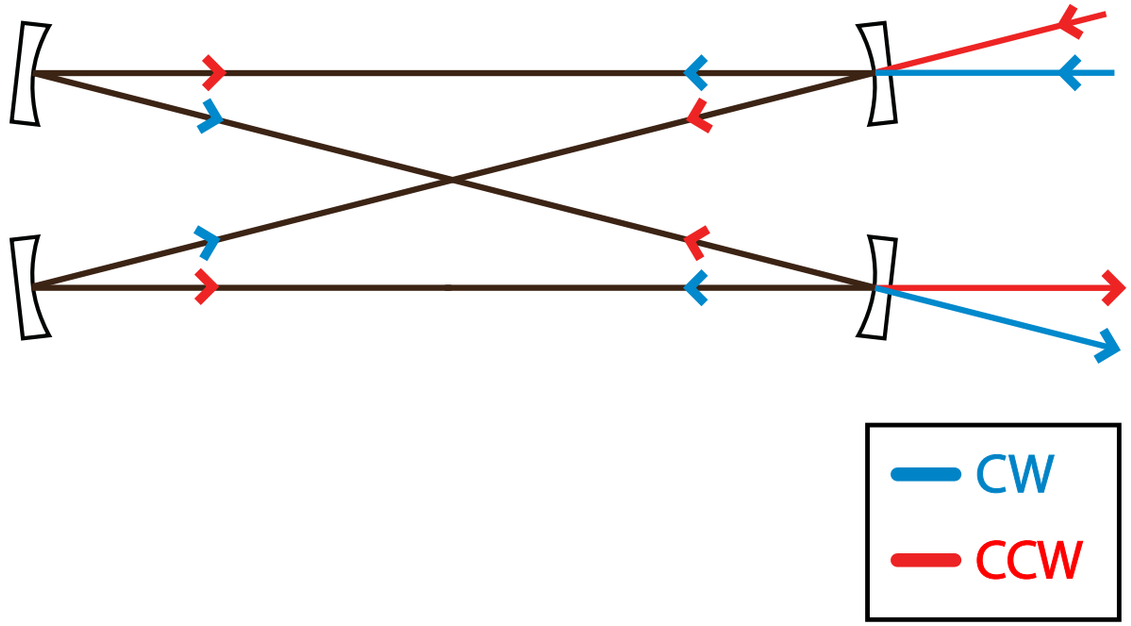
Disadvantages:

- mechanical adjustments
- measurements of CB only
- large linear birefringence
- intracavity optics

A new technique

4-mirror bowtie cavity

- supports counter-propagating beams
- simultaneous measure effects of different symmetry under P & T
- δ/reflection < 1mrad
- signal reversals



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linear birefringence presents an adversity to high precision optical rotation measurements using high-finesse cavities

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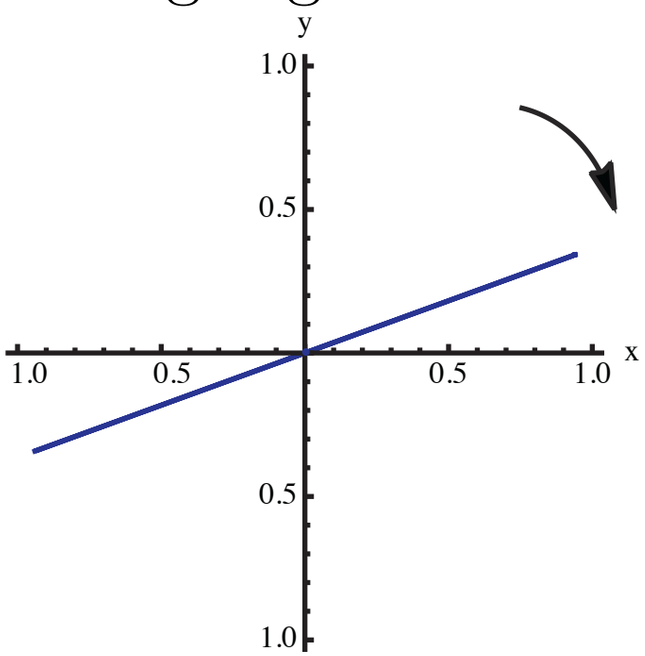

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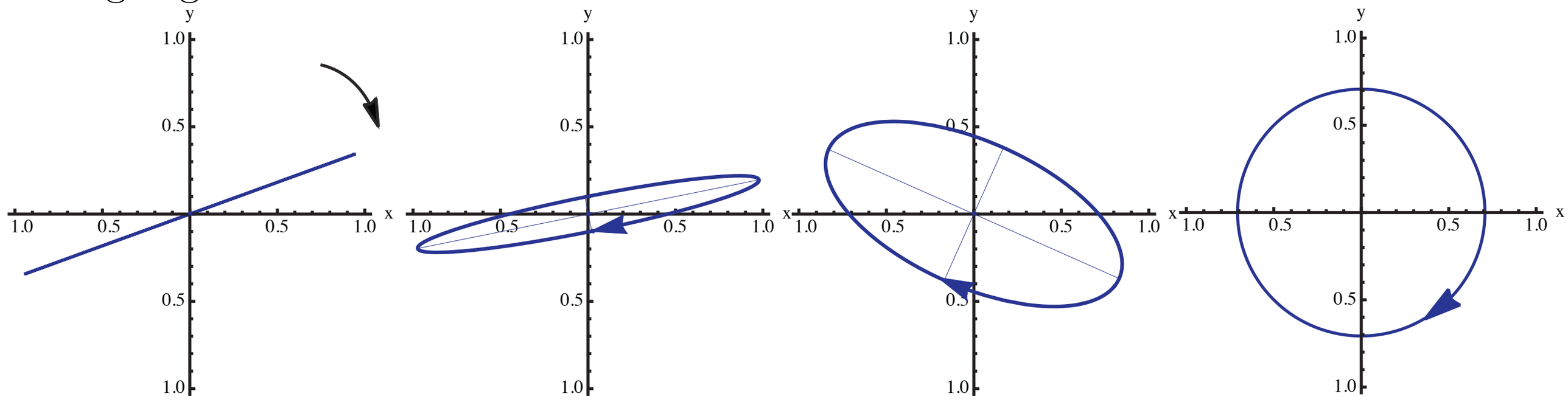

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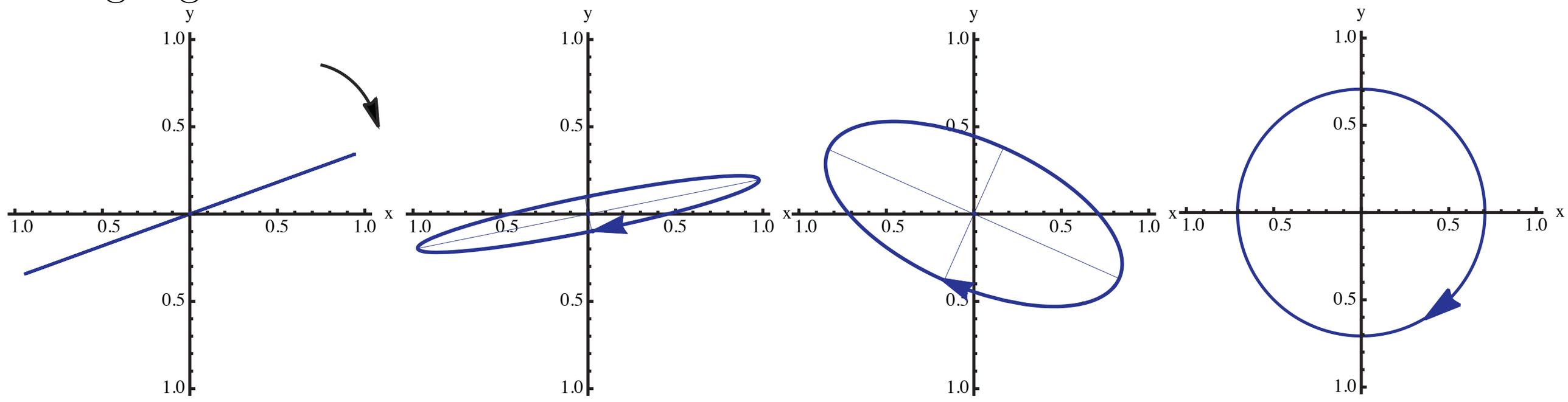

How? **inducing a larger circular birefringence α≫δ keeps intracavity light linearly polarized**

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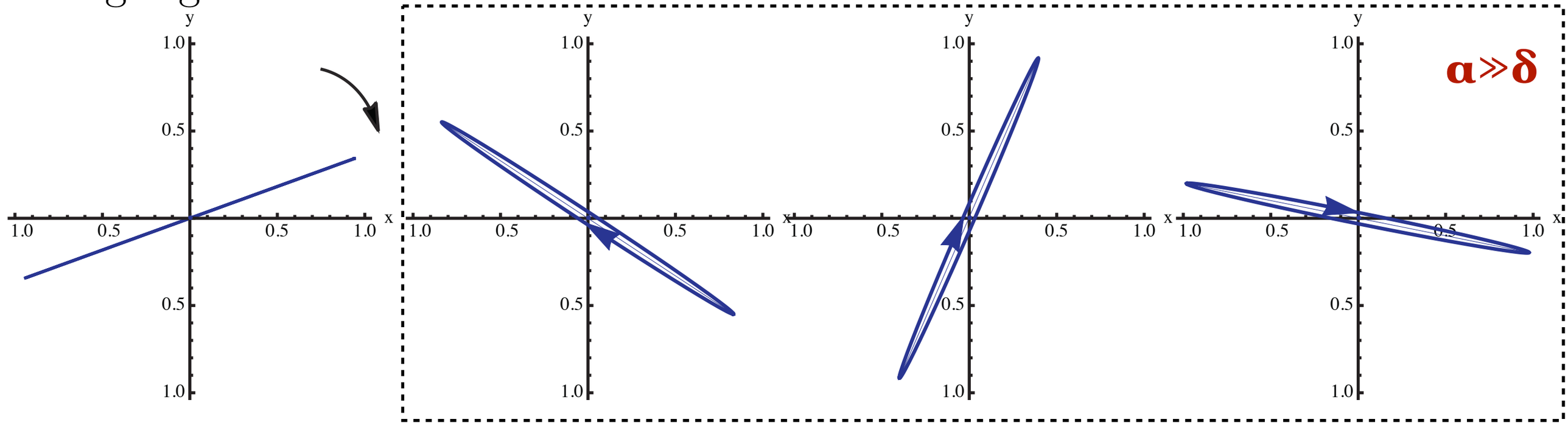

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α≫δ ensures the enhancement of the circular birefringence

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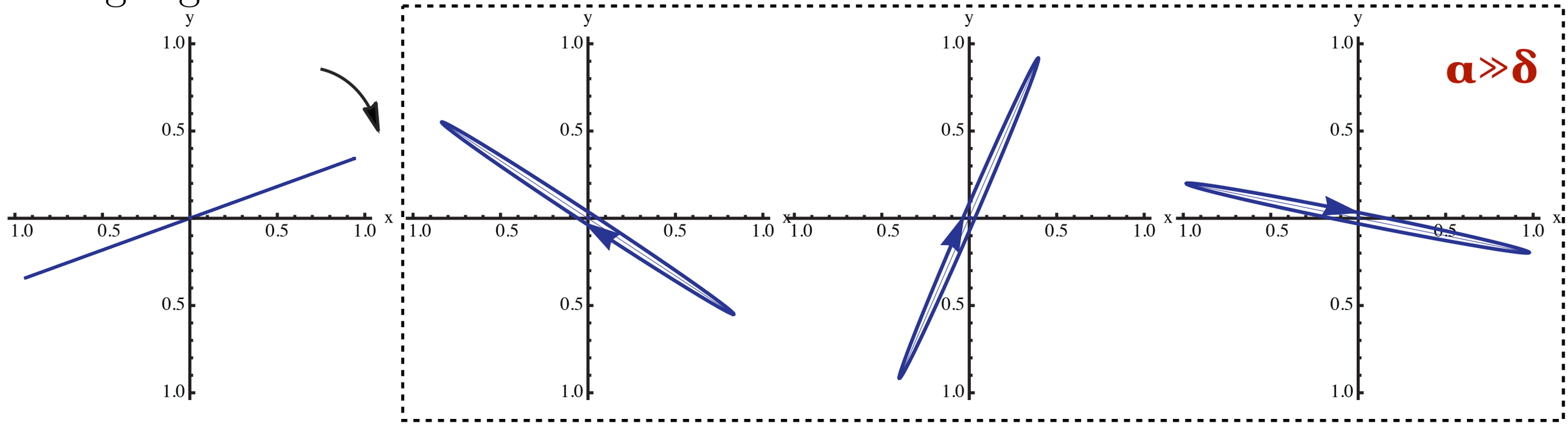

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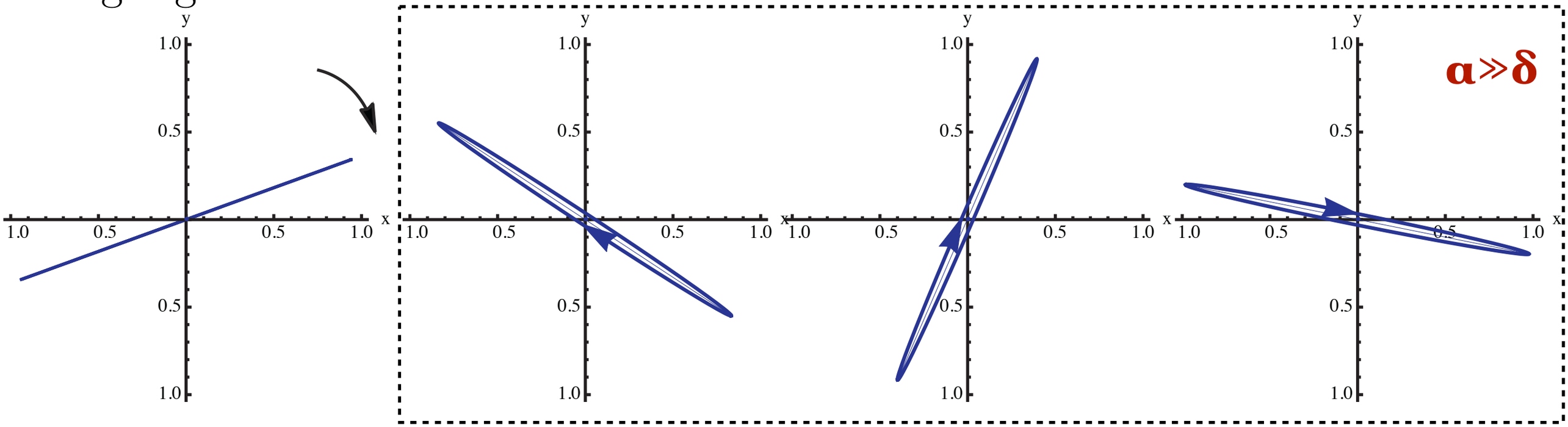

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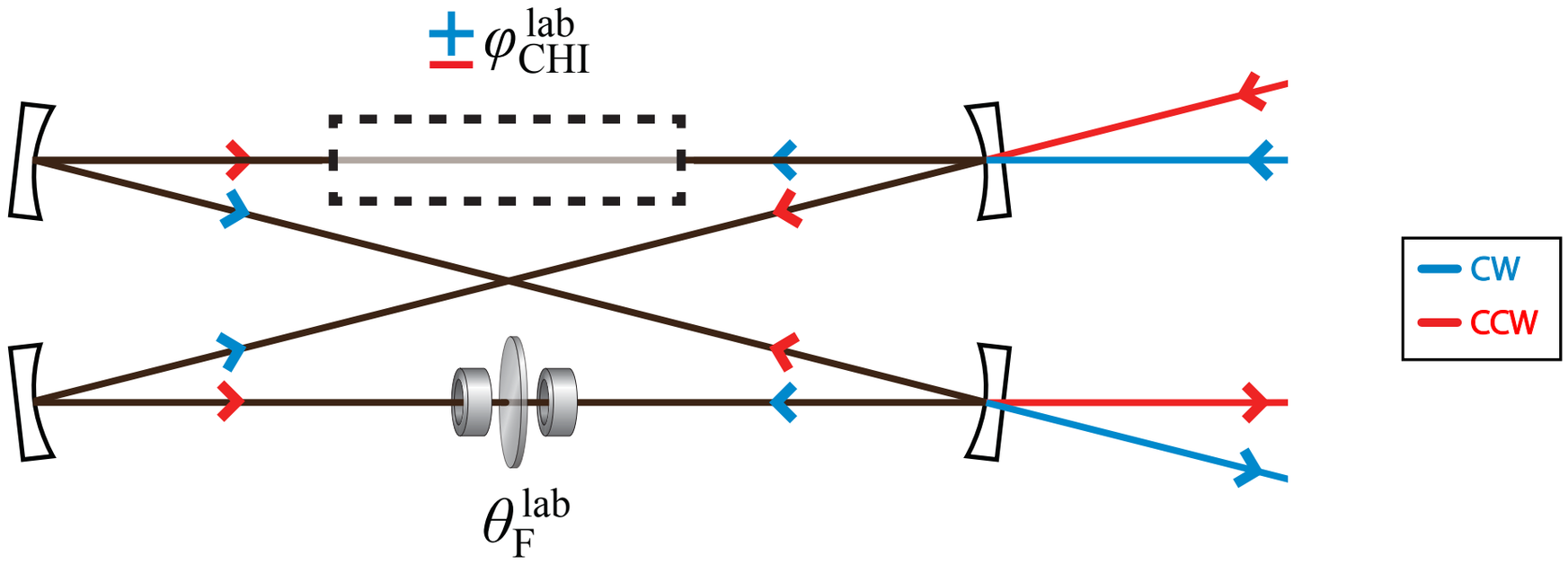

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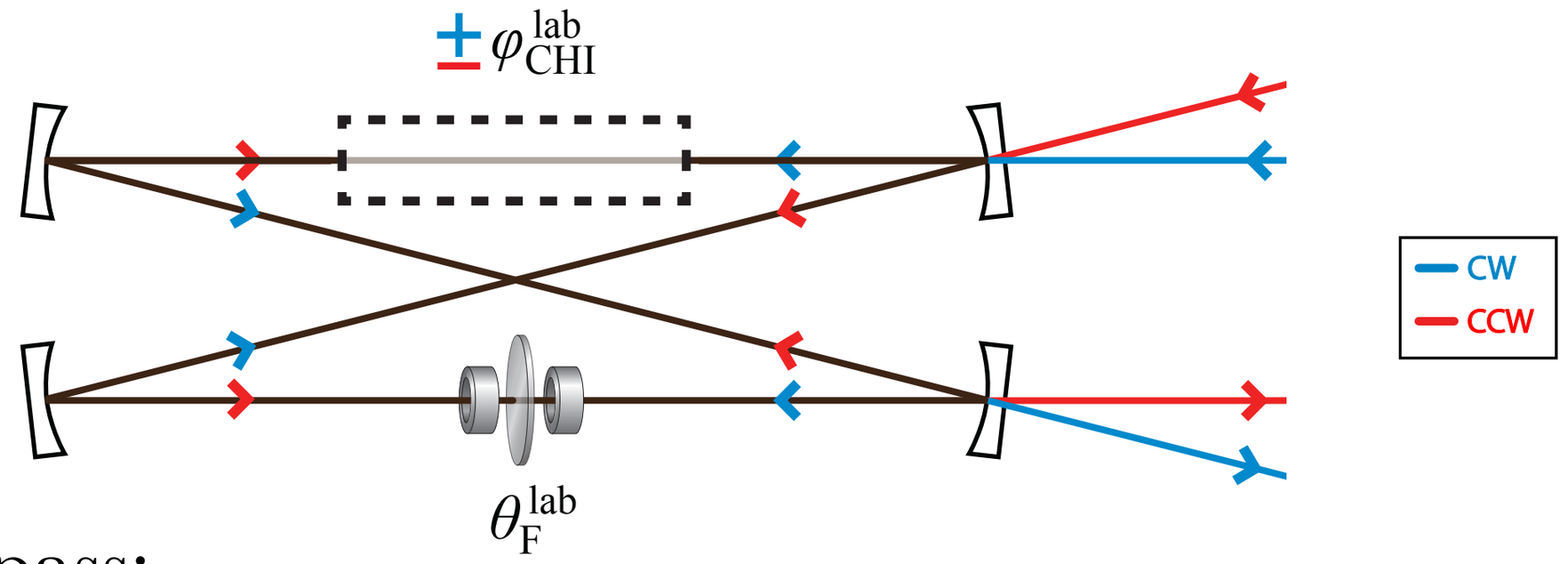

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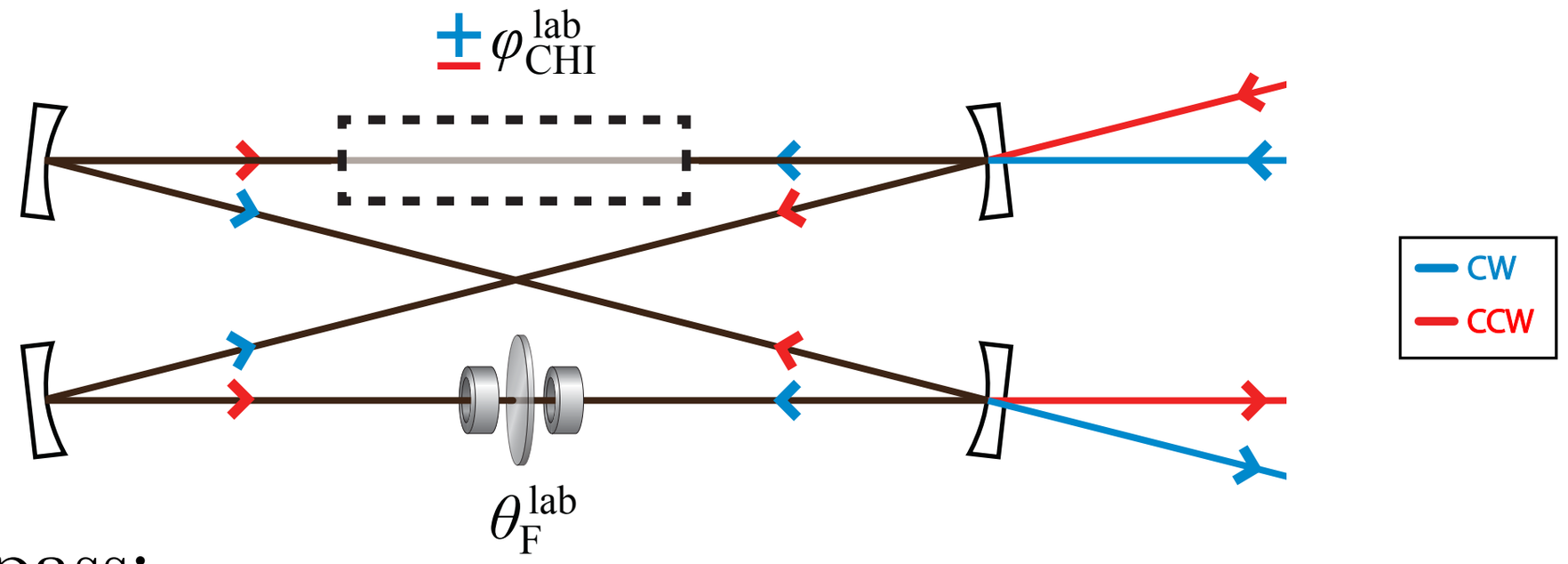

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$$\alpha_{CW} - \alpha_{CCW} = 2\phi_{CHI}$$

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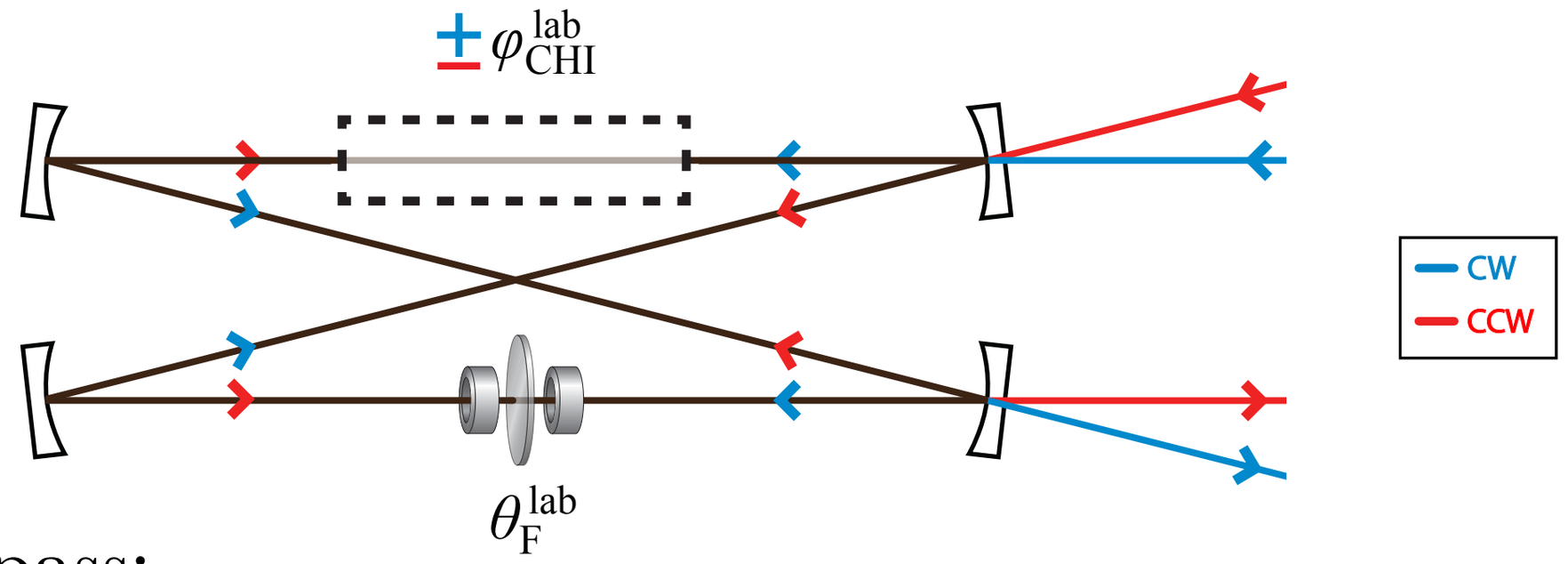

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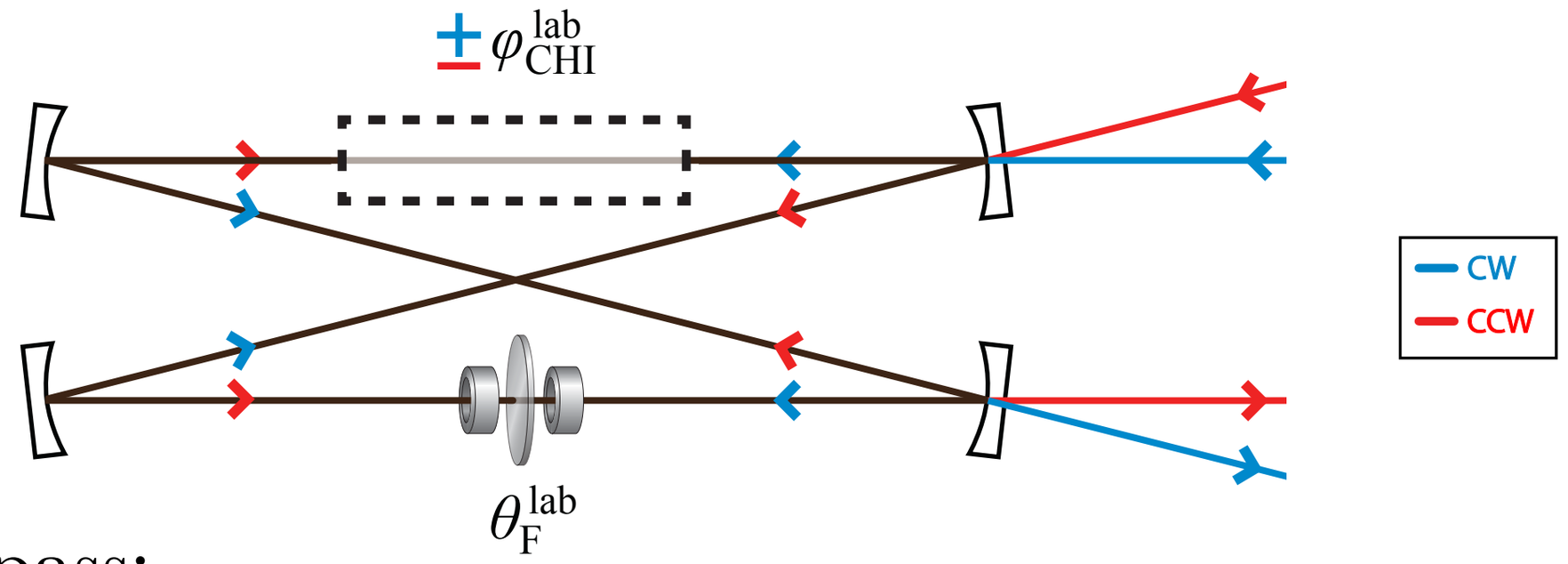

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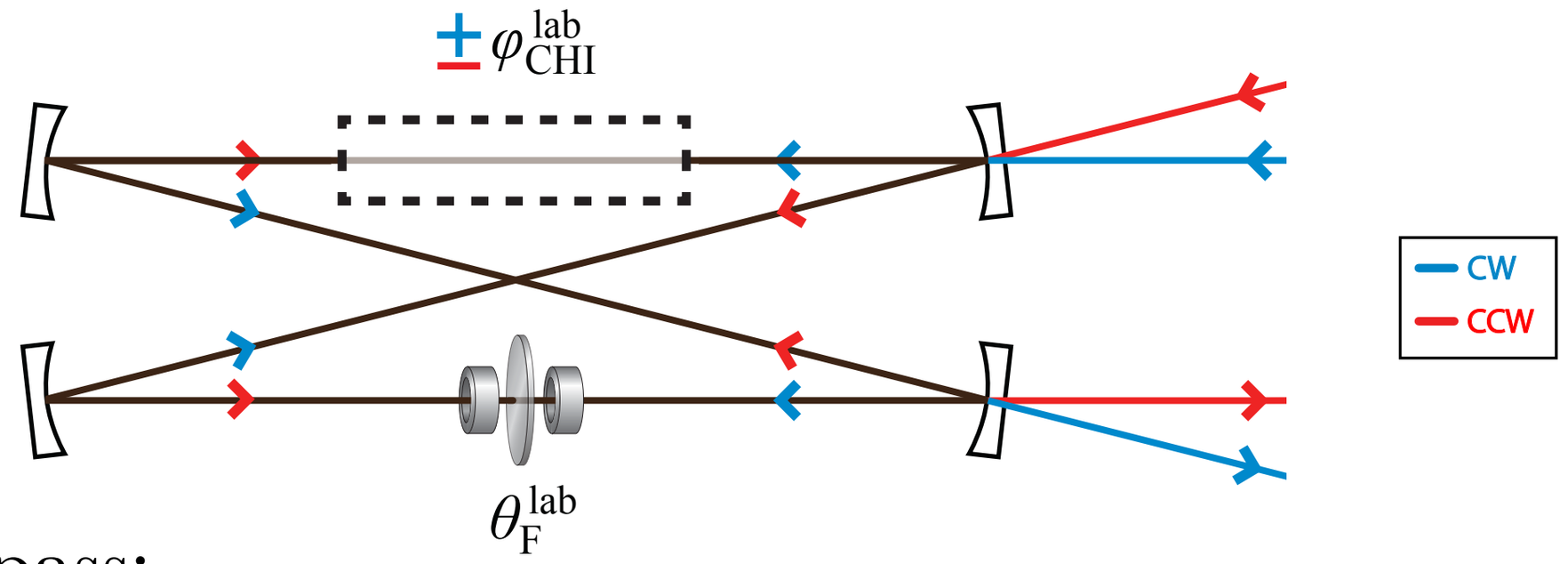

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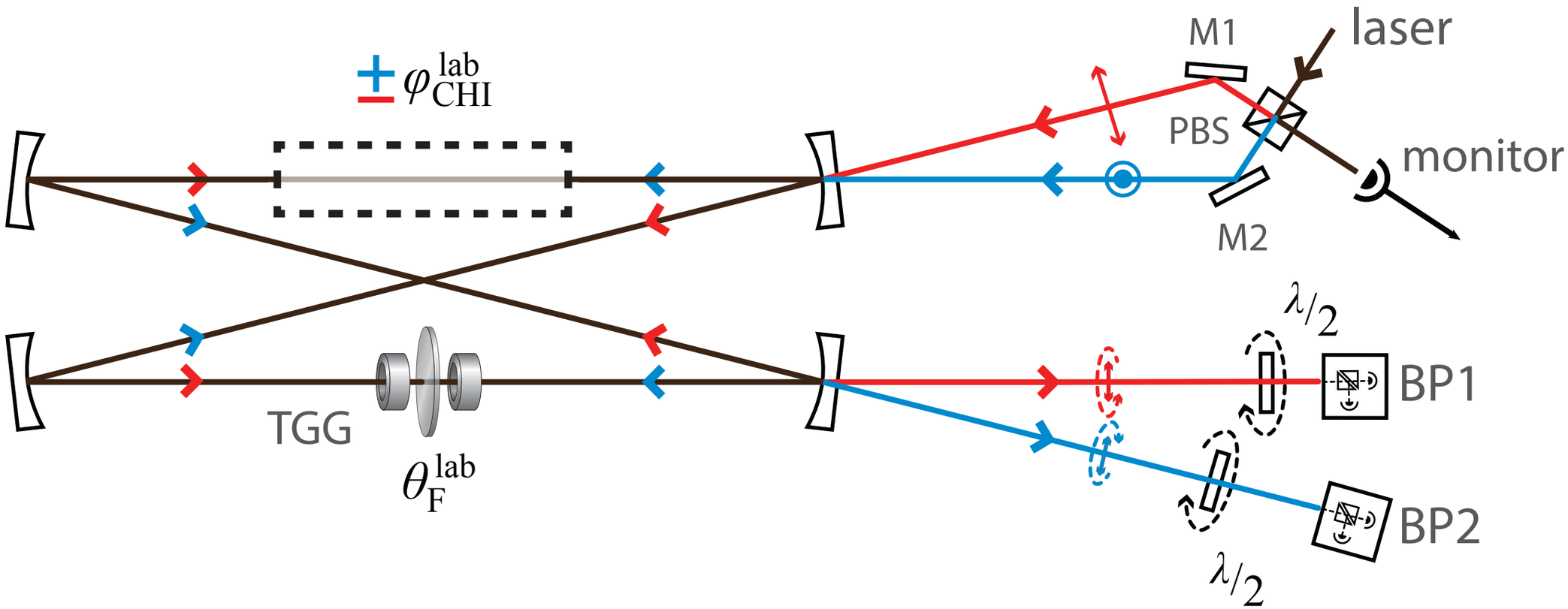
$$\Delta\alpha(+B) - \Delta\alpha(-B) = 4\phi_{CHI}$$

Chiral Cavity Ring Down



A pulsed proof-of-principle experiment

Chiral Cavity Ring Down

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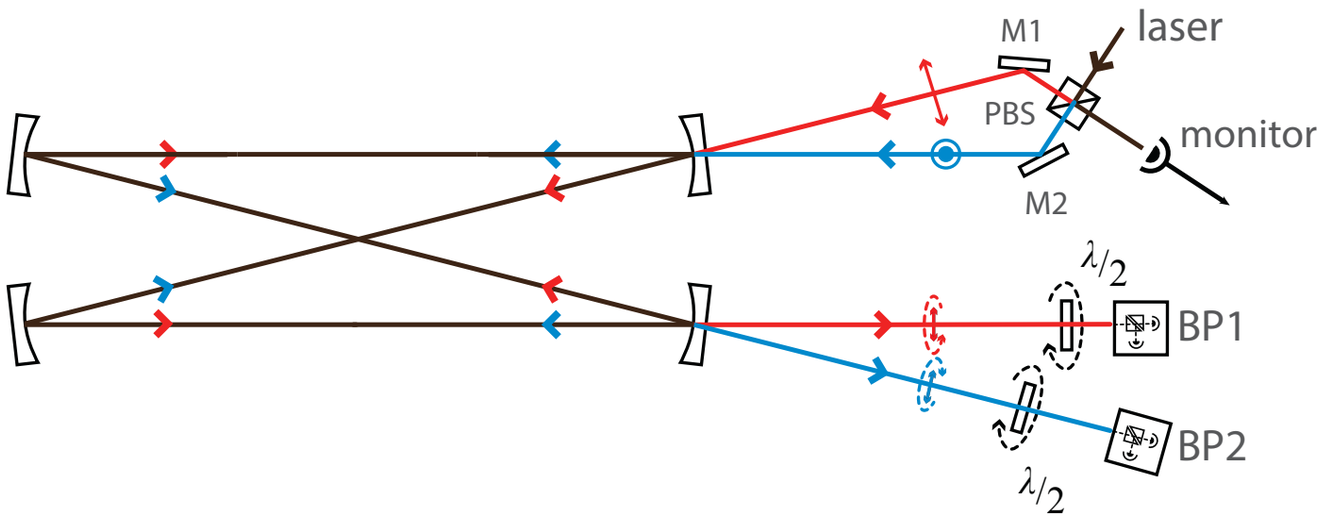

Cavity Ring Down: one measures the temporal evolution of a light pulse injected in the cavity

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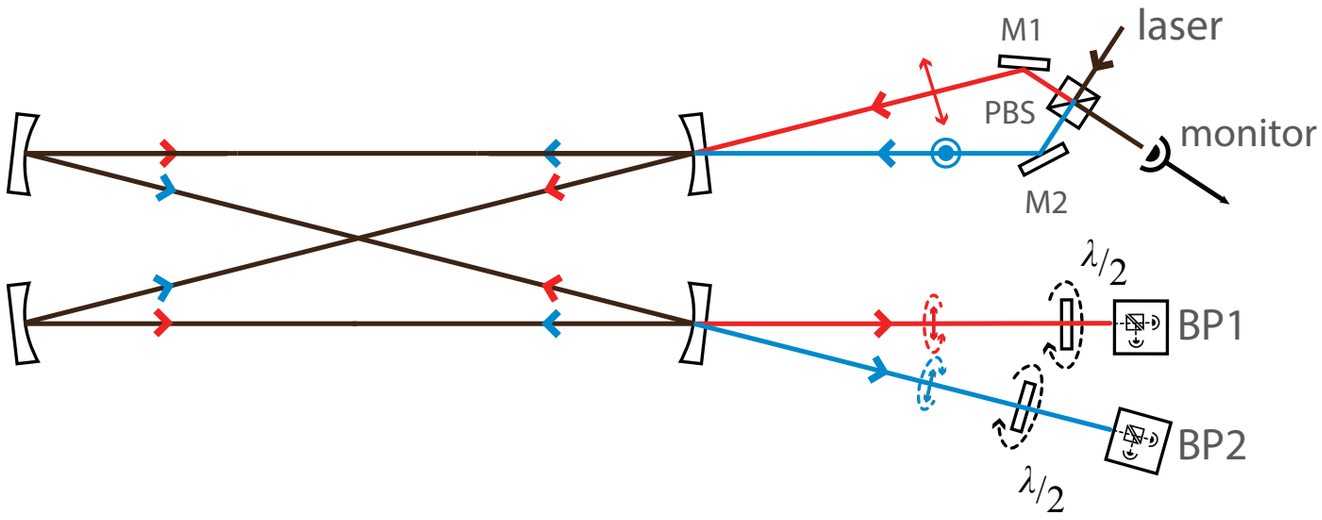

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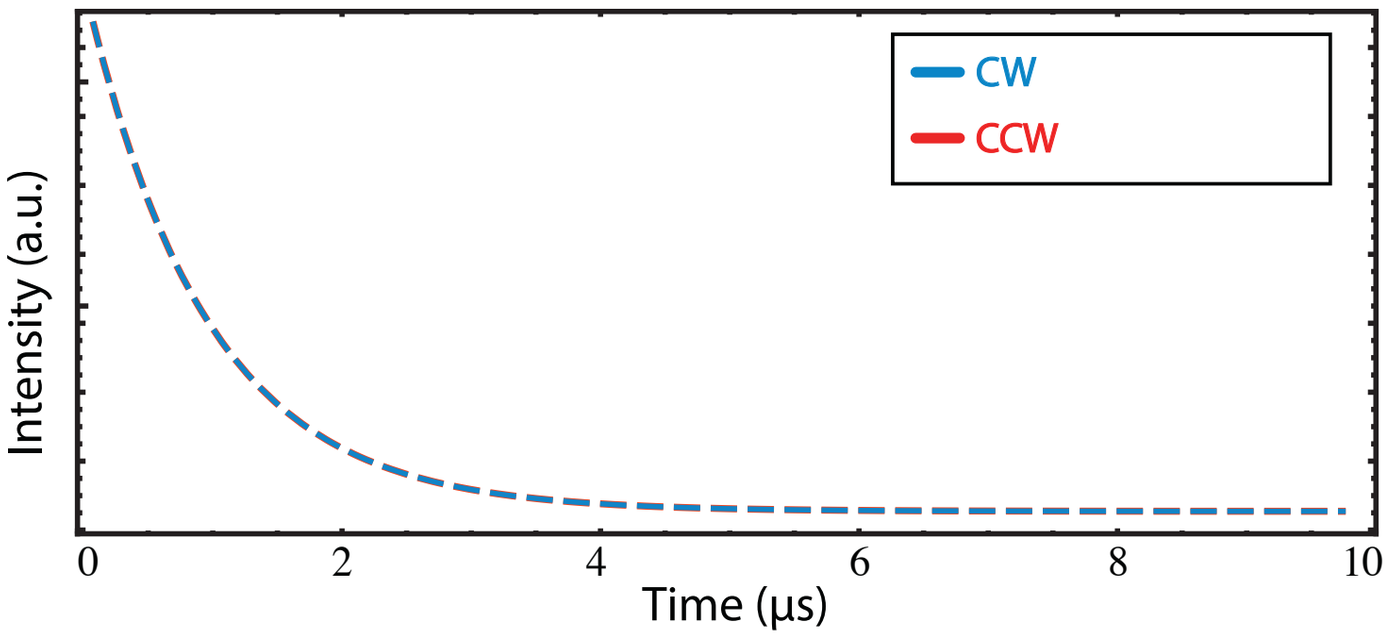

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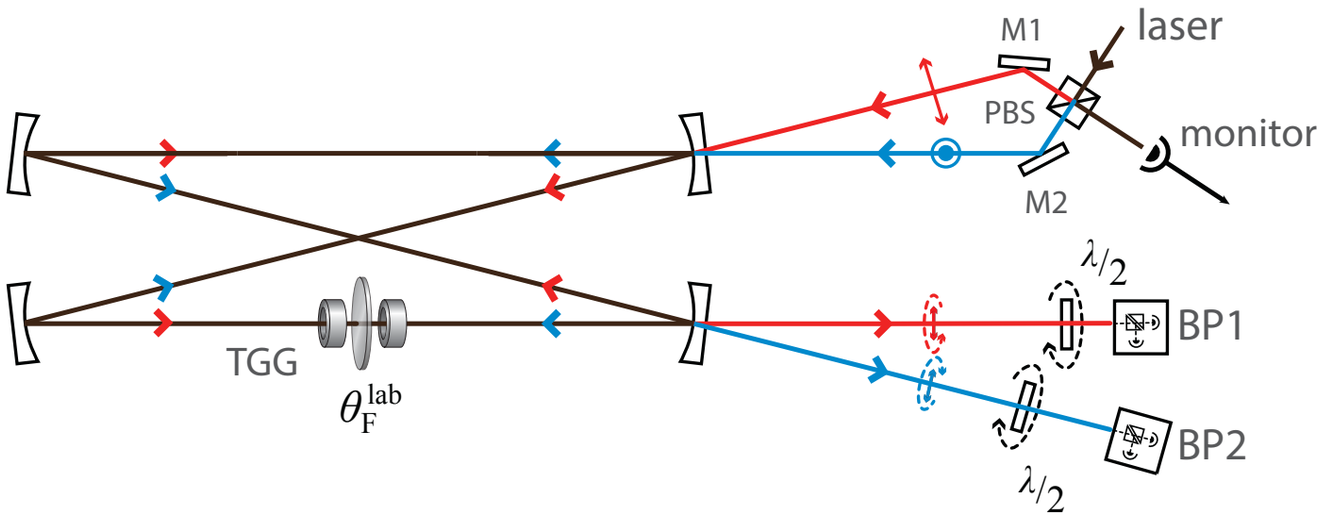

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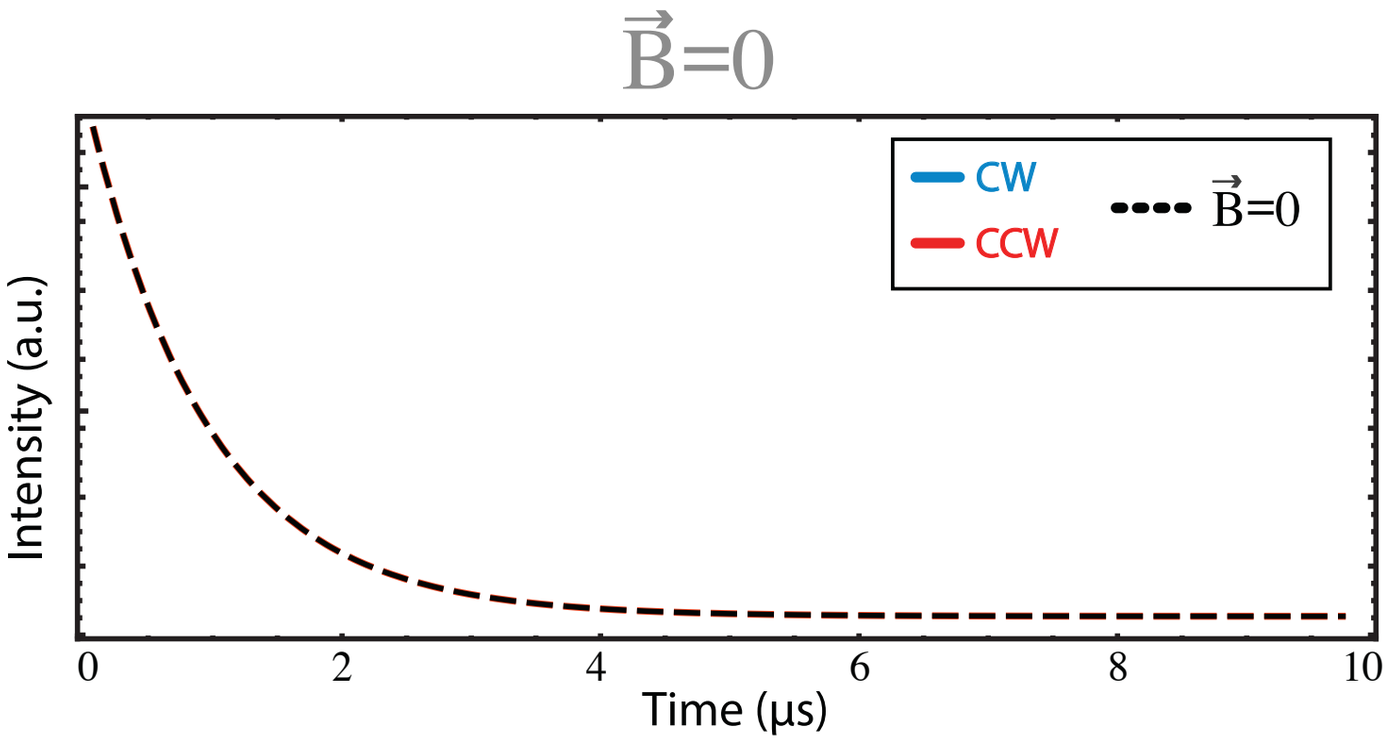

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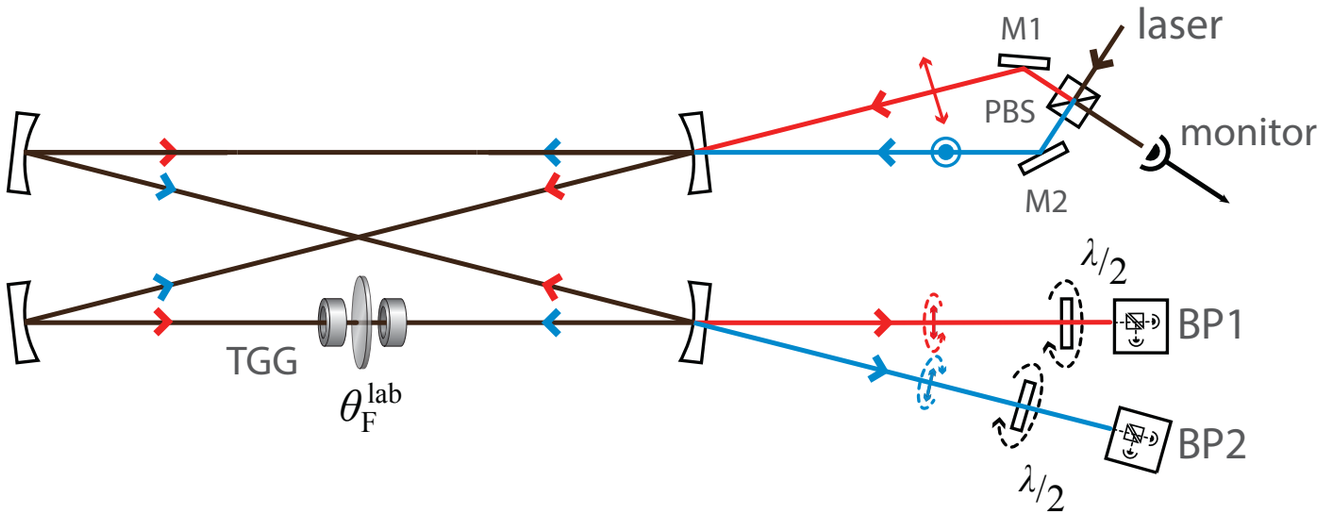
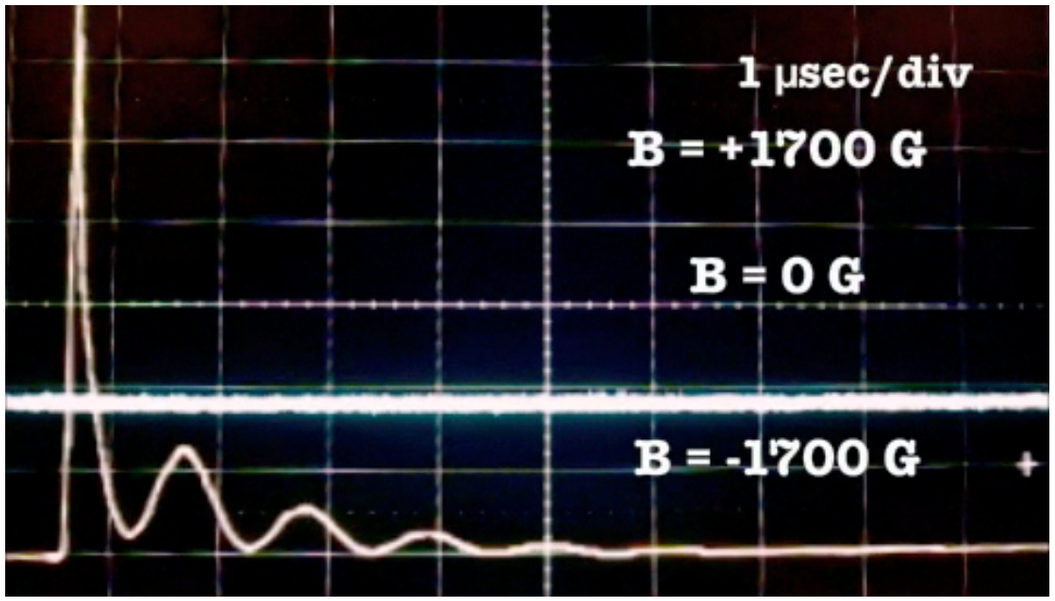
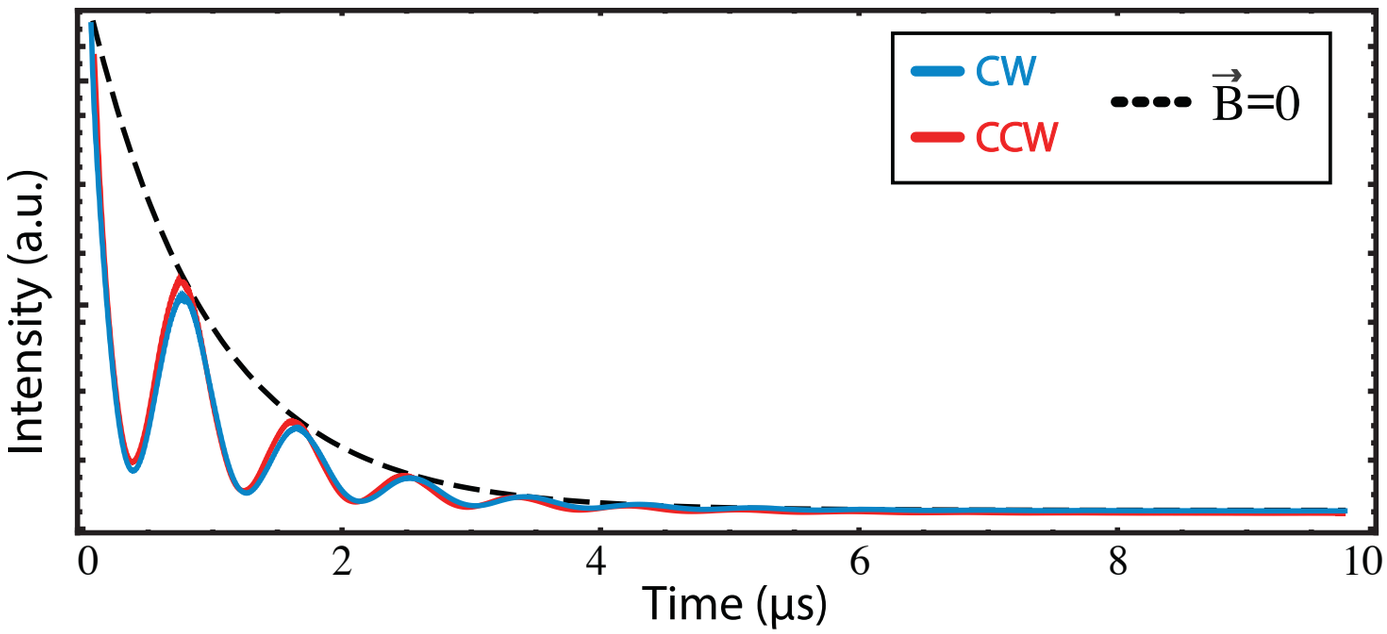




$\vec{B}\neq 0$



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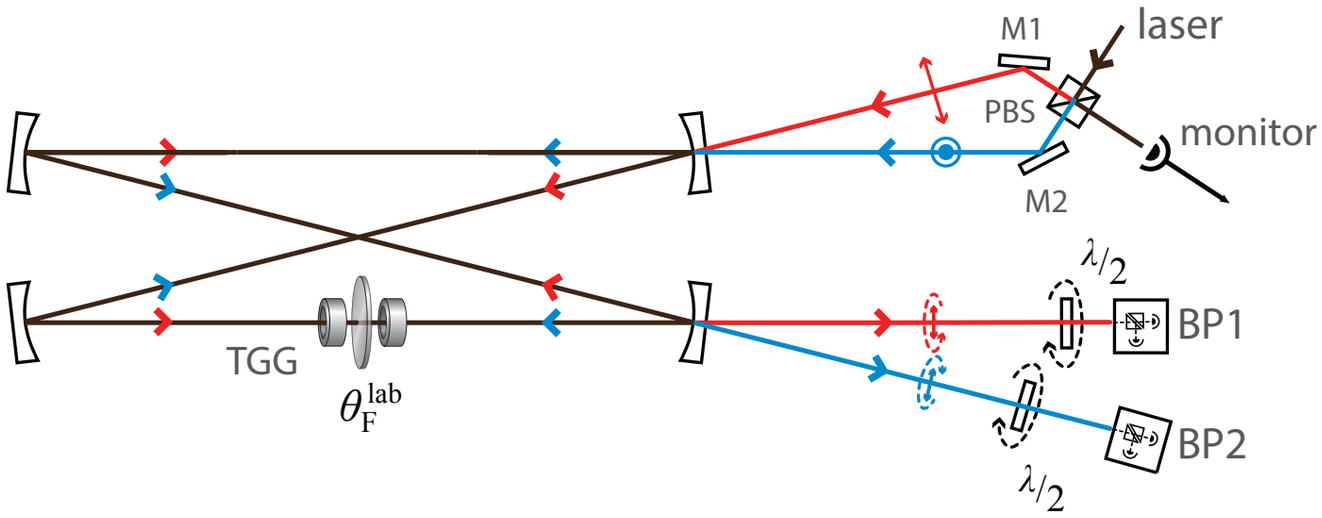

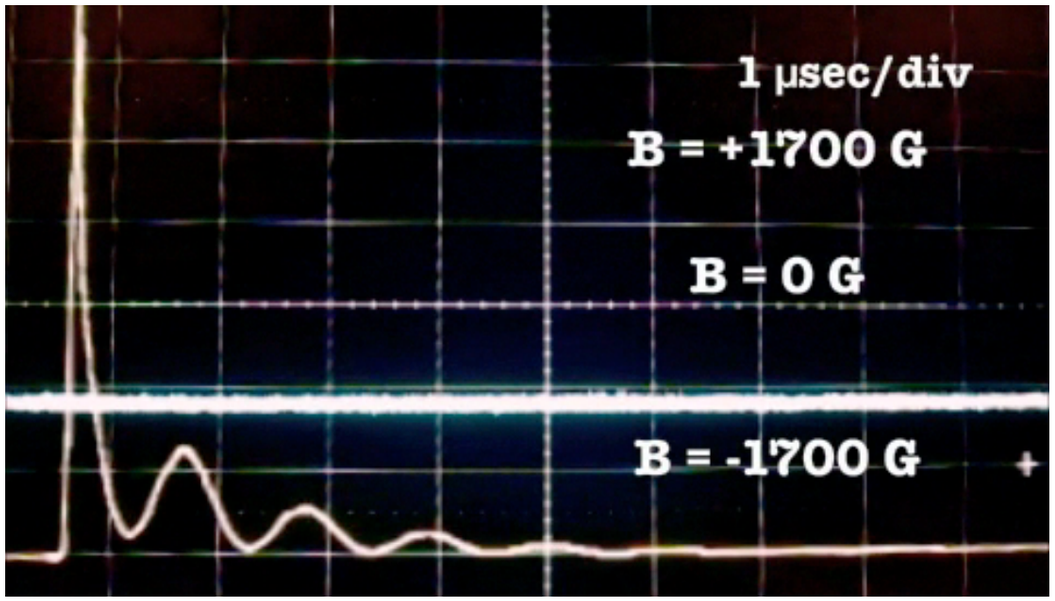

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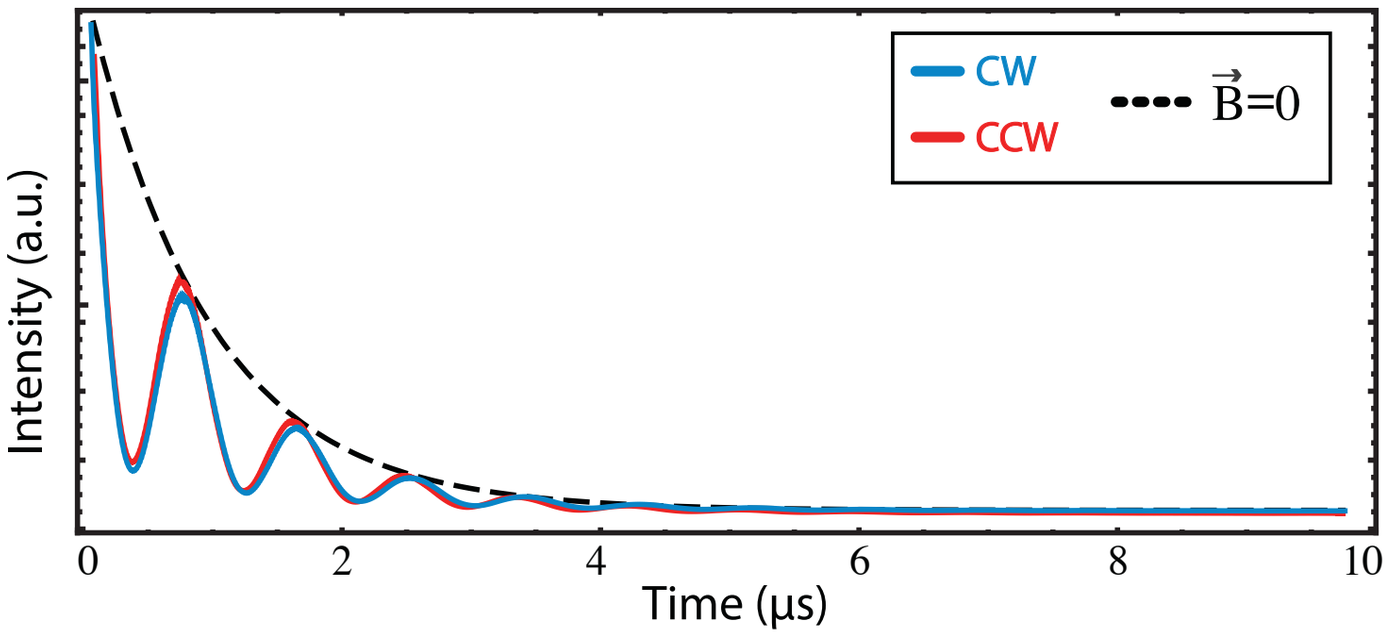

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CRD Polarimetry: one measures the rate of the polarization rotation of light injected in the cavity

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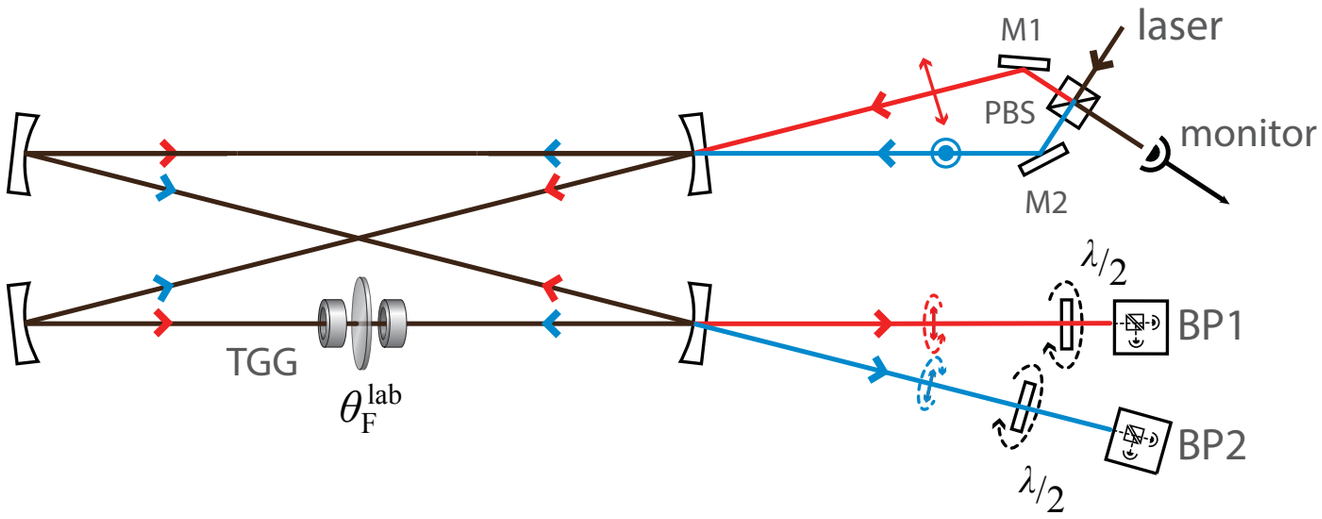

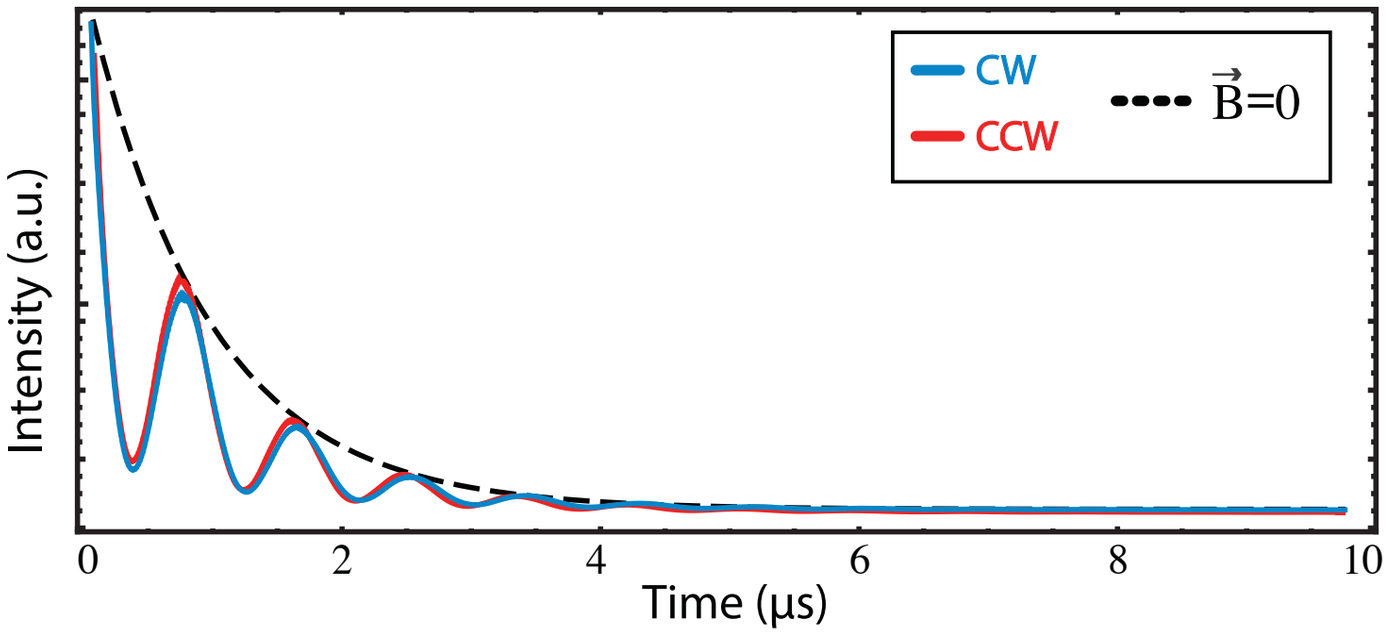

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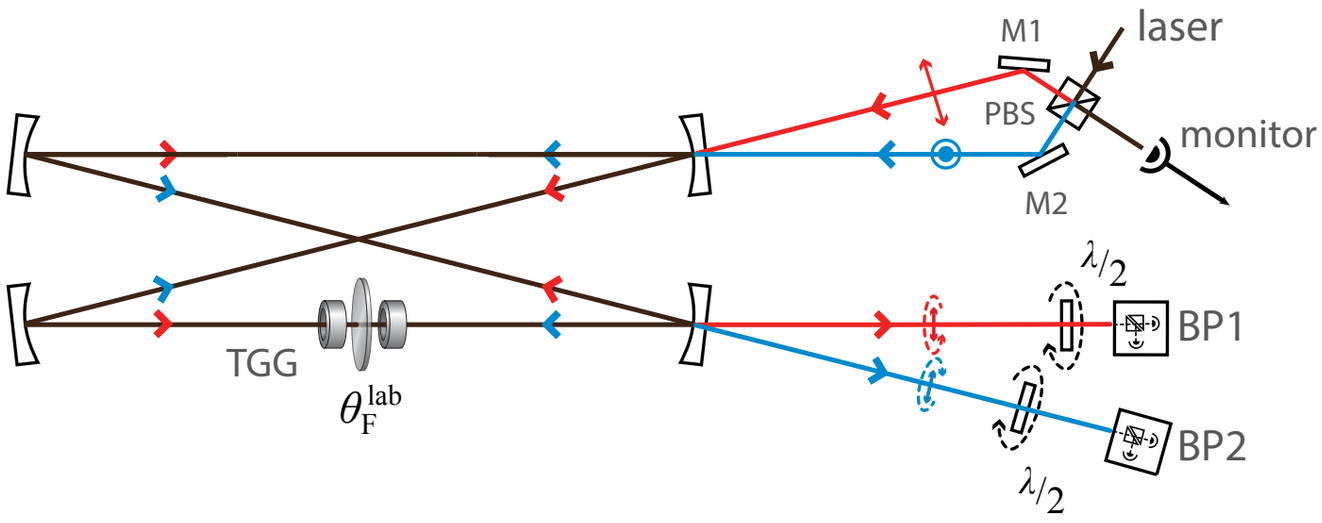
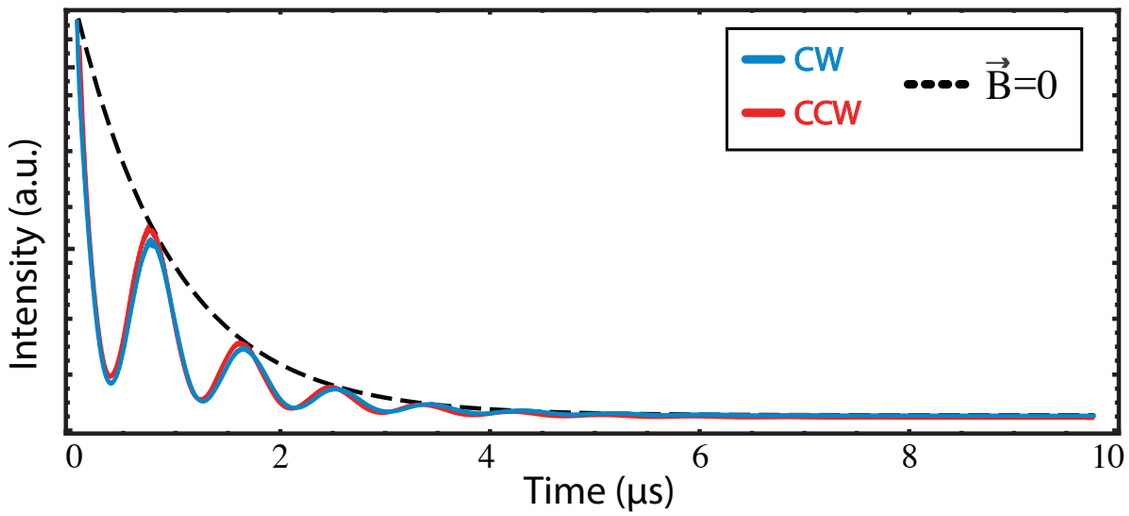
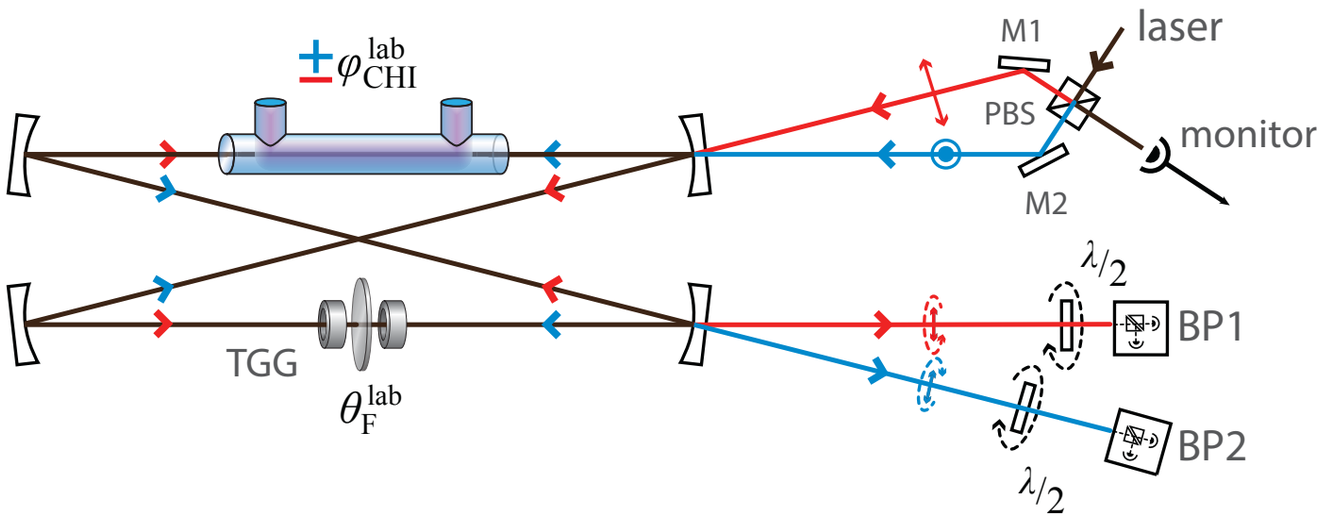


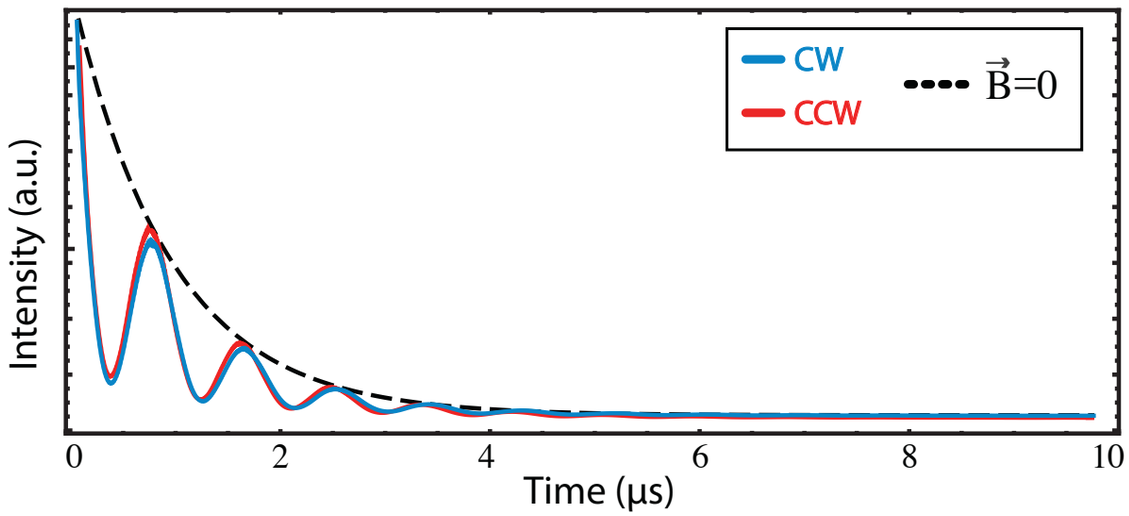


Chiral Cavity Ring Down

Experiment

Gas Cell





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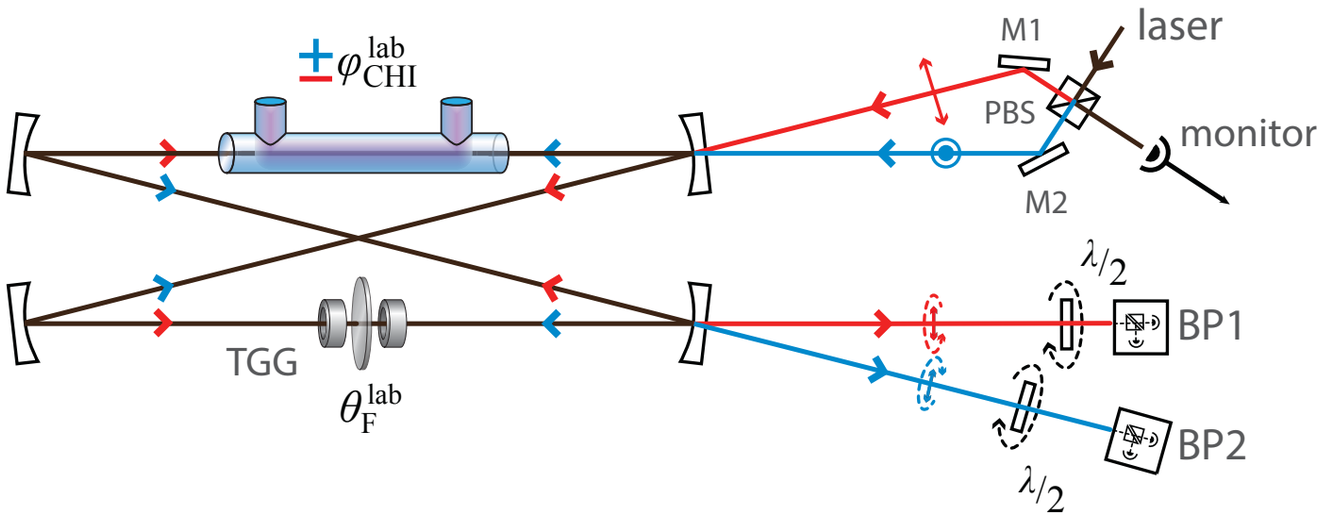

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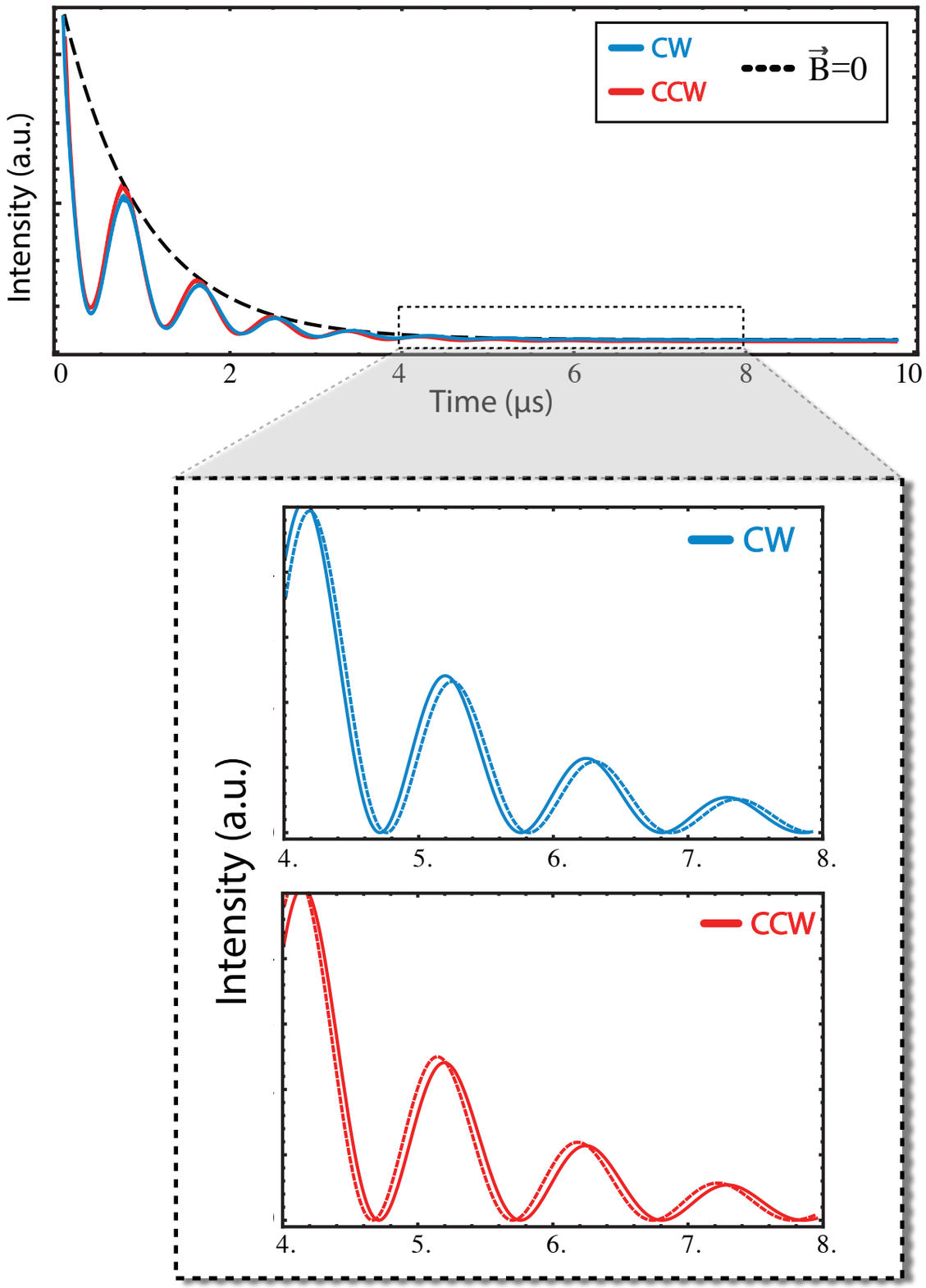

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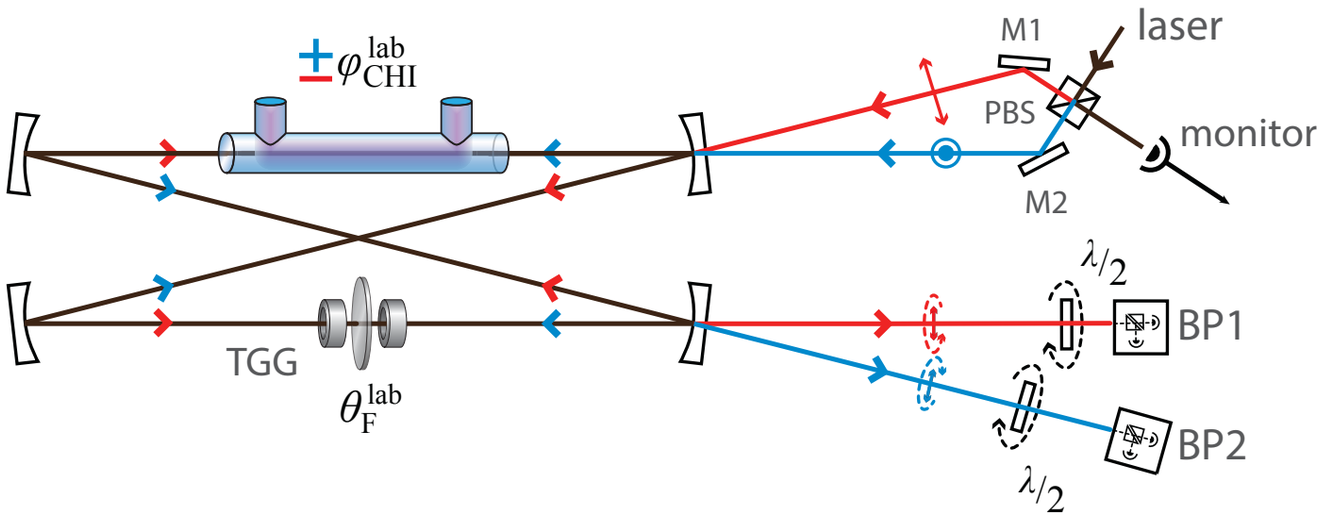
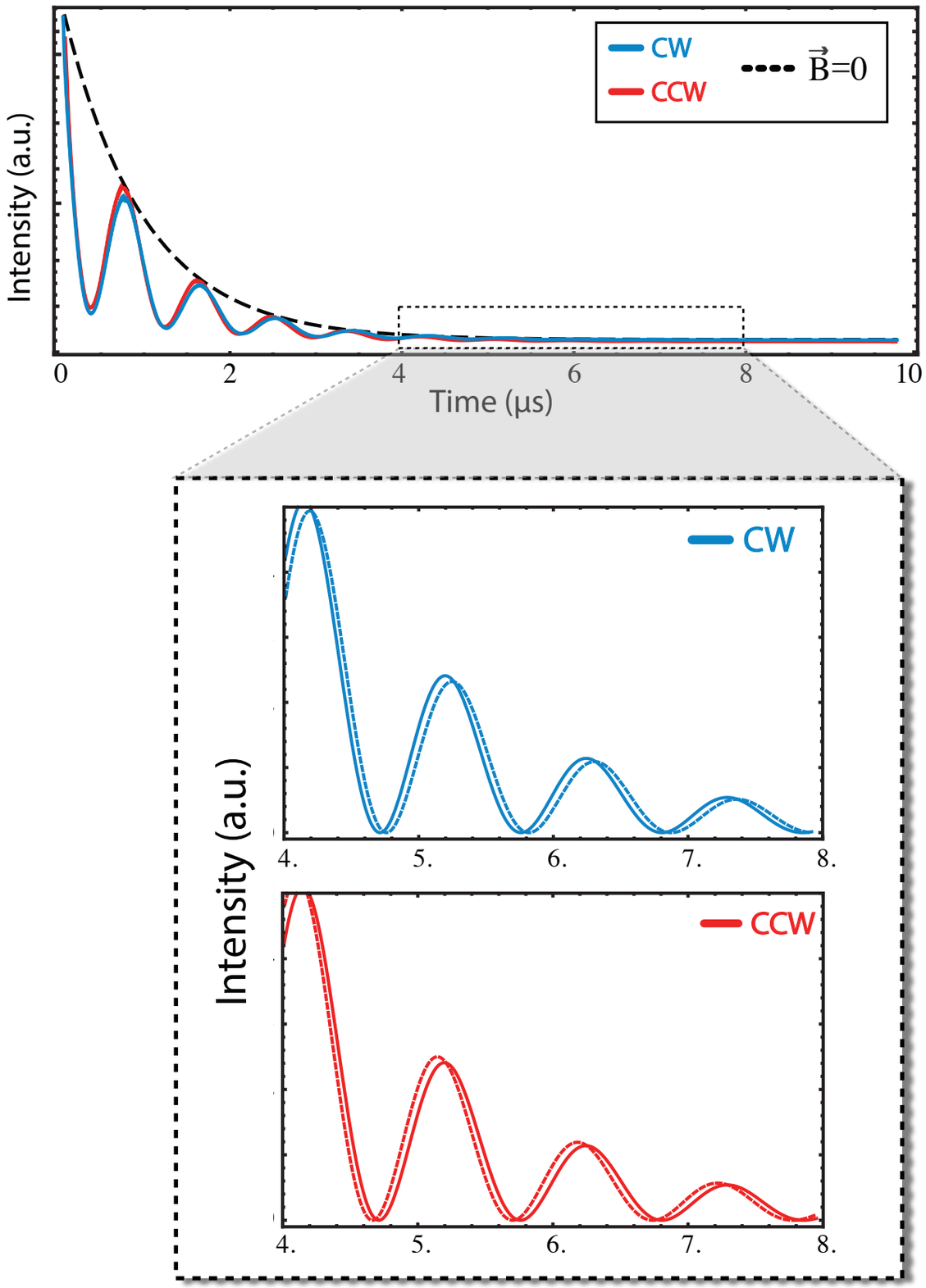


$$I(t)=I_0 e^{-t/\tau}[\cos^2(\omega t+\phi)+\beta]$$

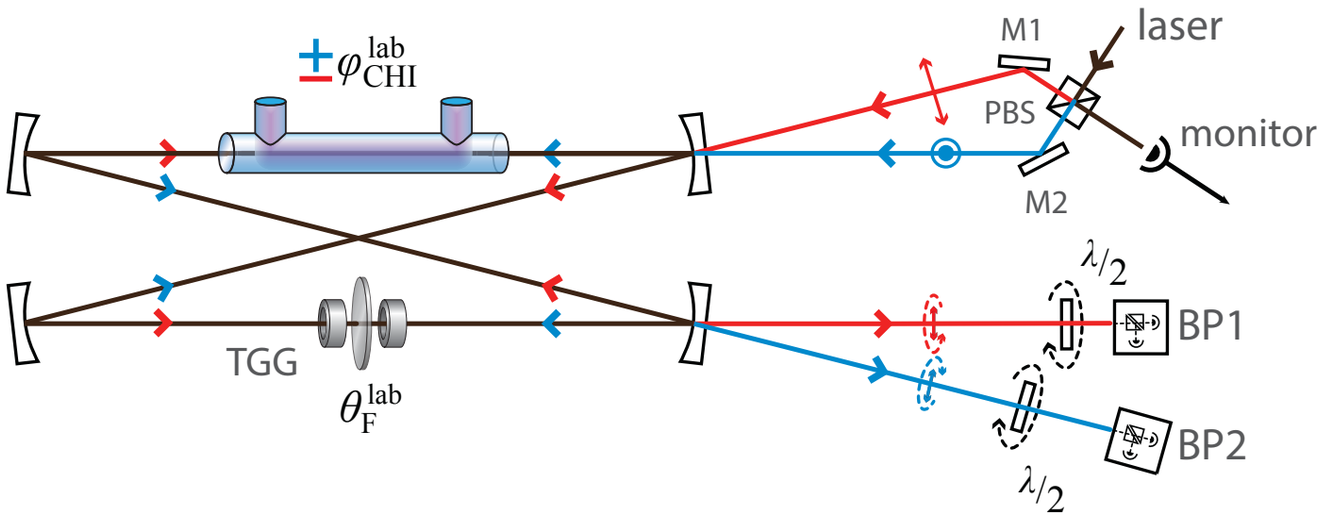
$$\Rightarrow \quad \omega=\alpha_{CW,CCW}\,(c/L)$$

Experiment

Gas Cell



Chiral Cavity Ring Down



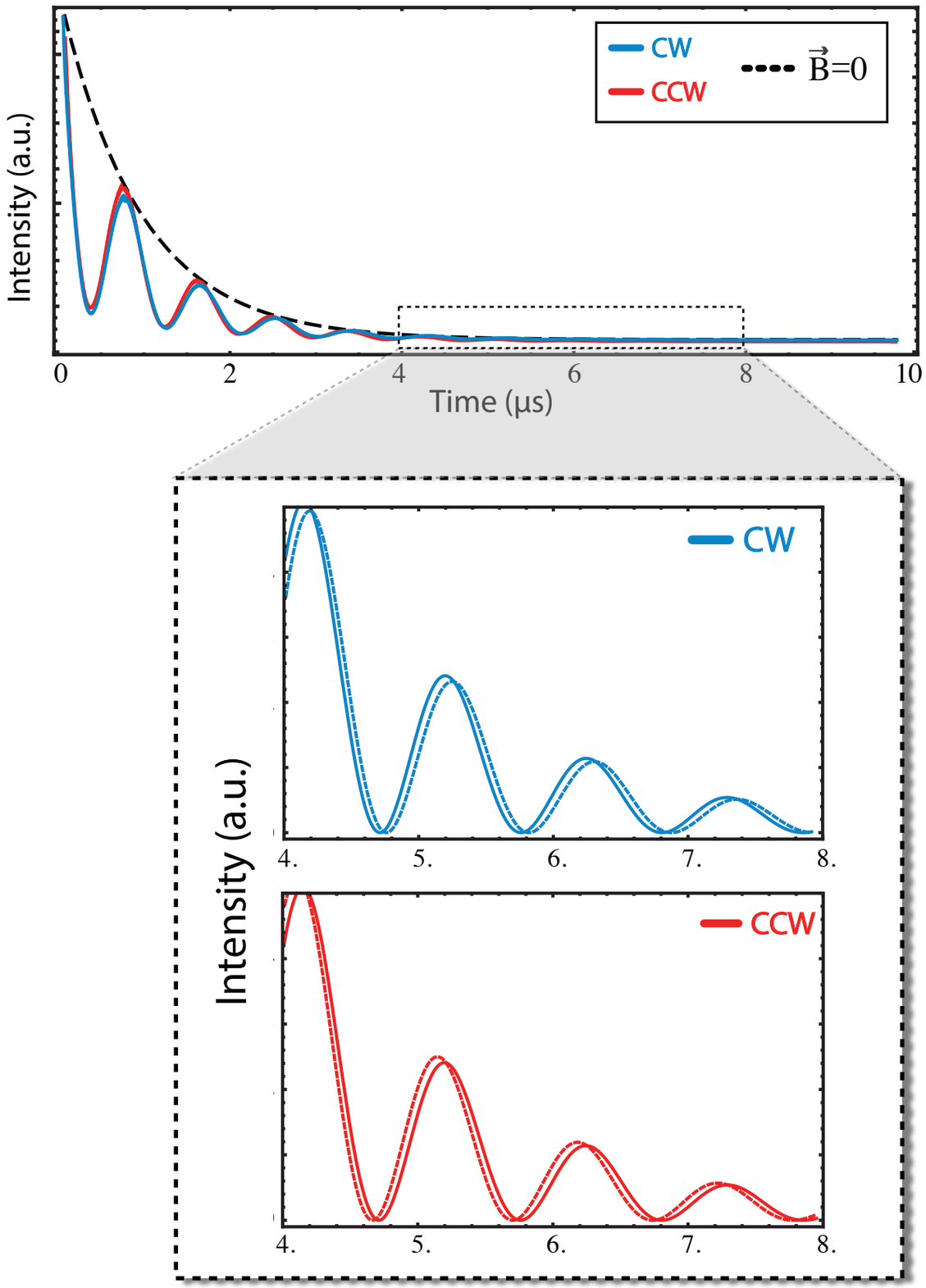
$$I(t)=I_0 e^{-t/\tau}[\cos^2(\omega t+\phi)+\beta]$$

$$\Rightarrow \omega=\alpha_{CW,CCW}\,(c/L)$$

$$\Rightarrow \Delta\alpha_{CW,CCW}=\pm\phi_{CHI}$$

Experiment

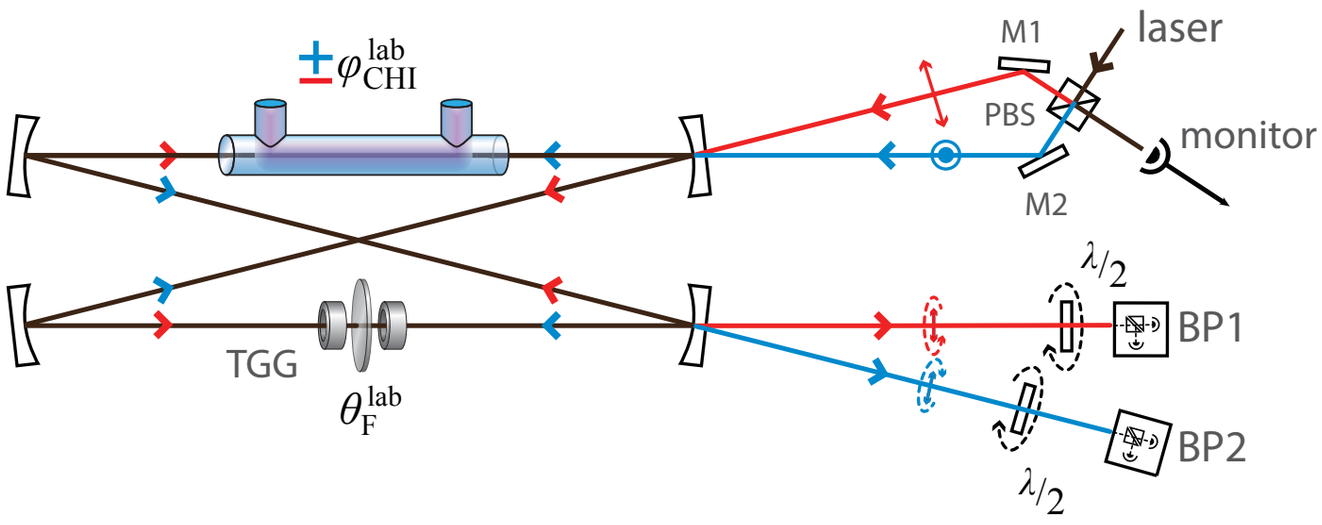
Gas Cell

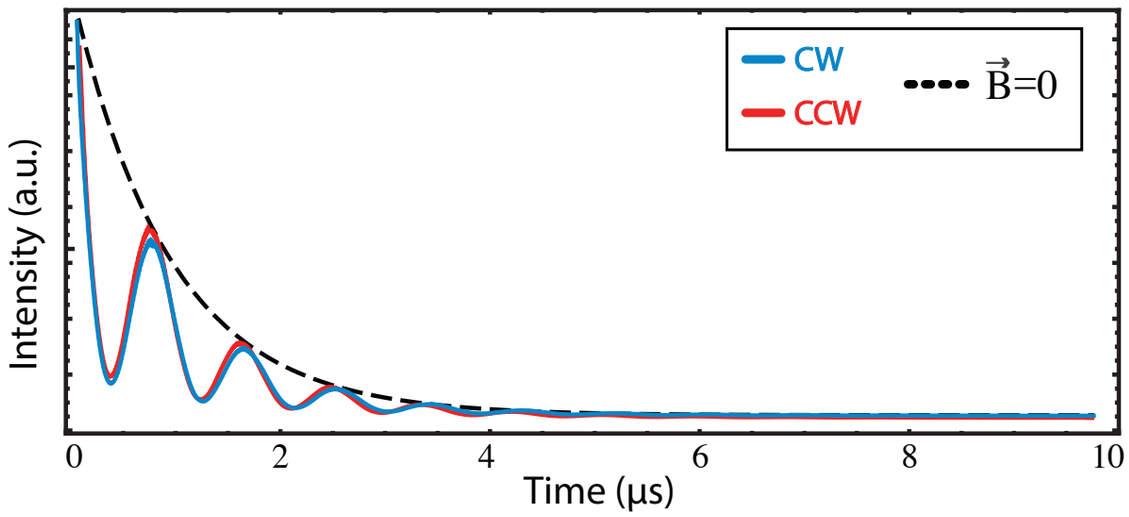


Chiral Cavity Ring Down

Experiment

Gas Cell





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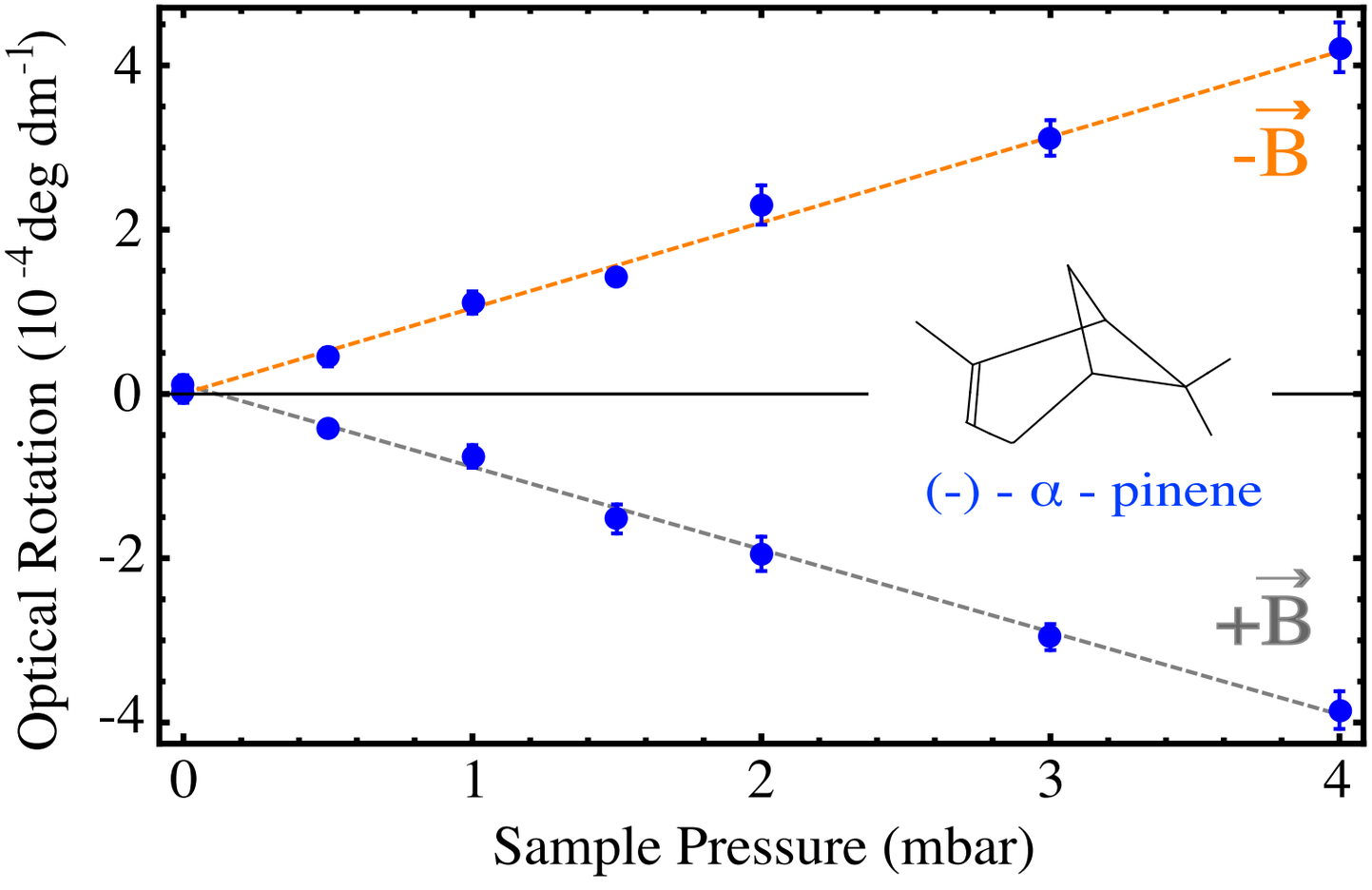
$$\Rightarrow \Delta\alpha_{CW,CCW}=\pm\phi_{CHI}$$



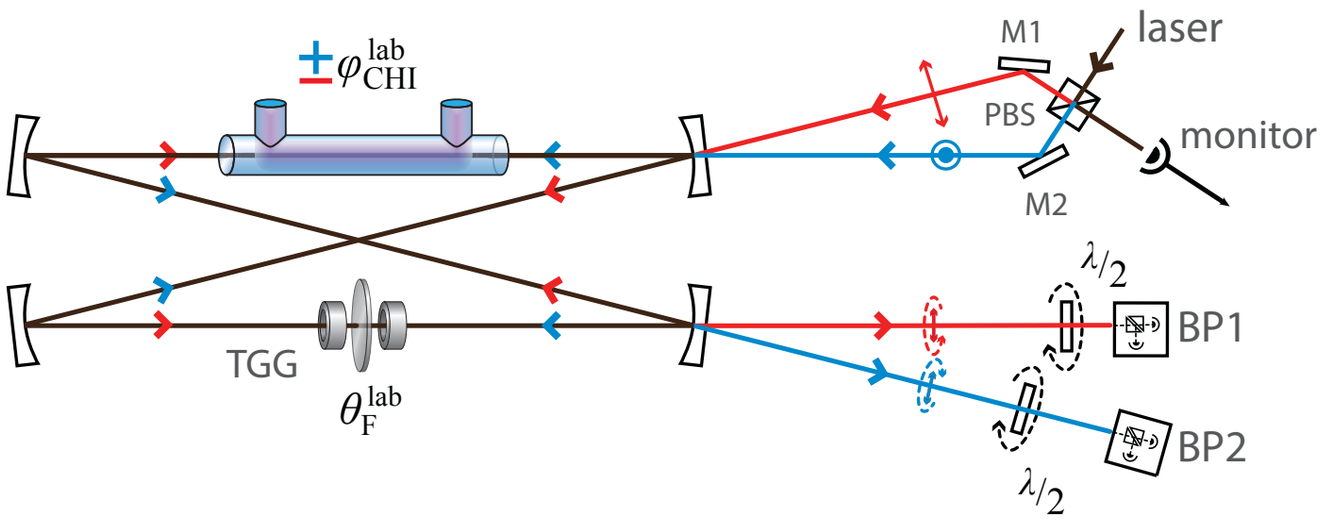
$f_{reversal}$: 0.04 Hz

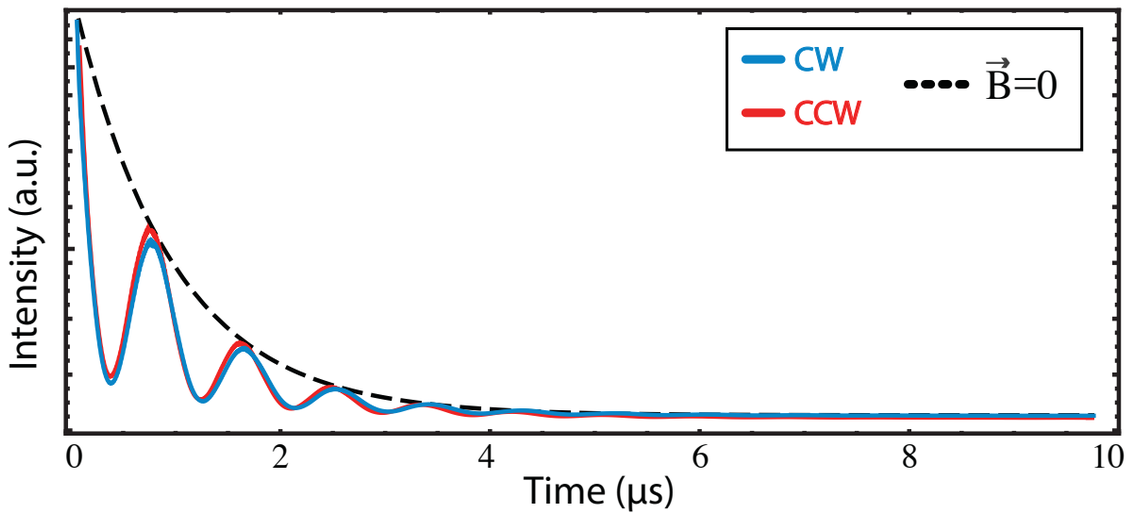
l_{sample}=7.5 dm

Chiral Cavity Ring Down

Experiment

Gas Cell

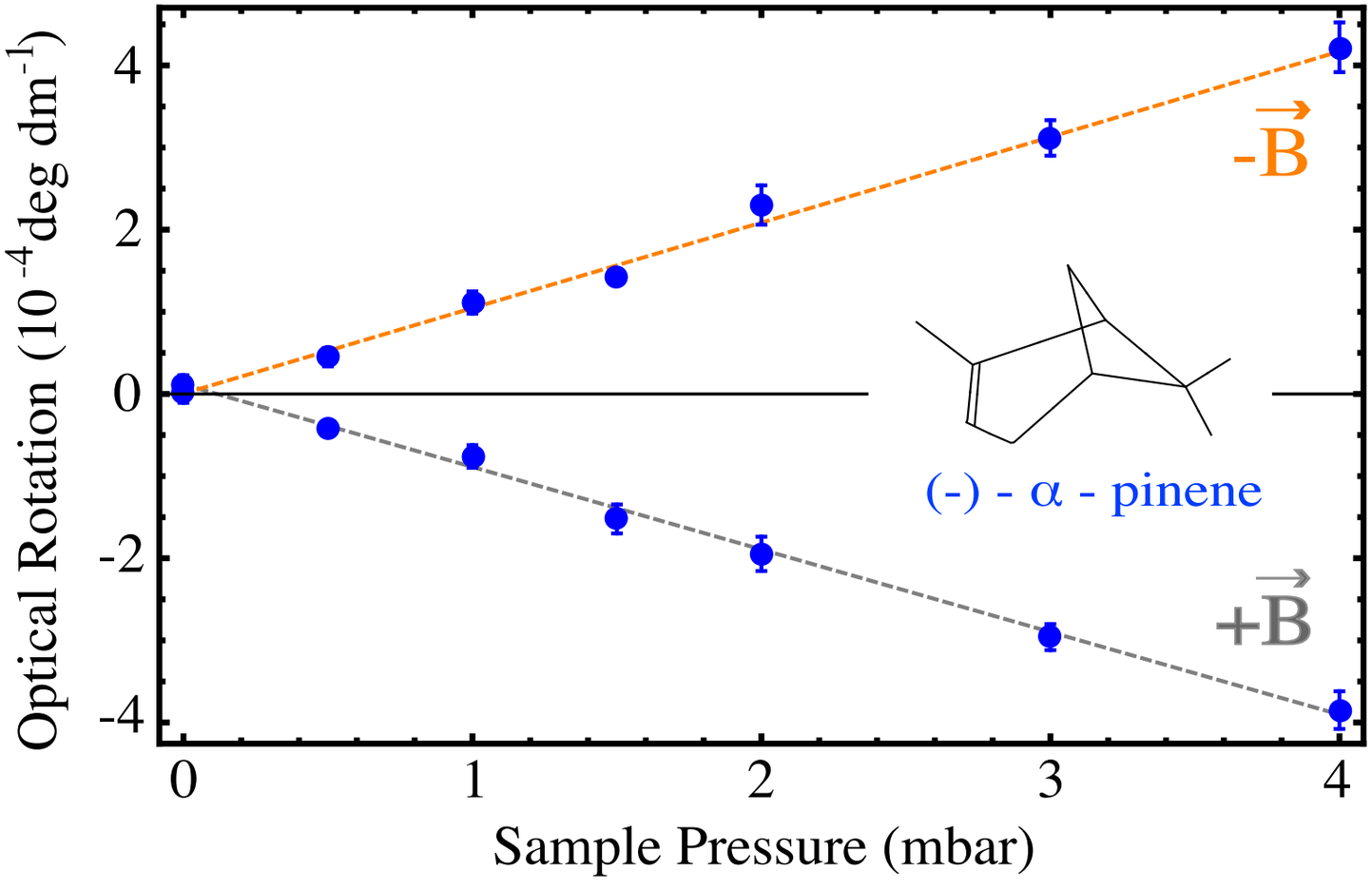




$$I(t)=I_0 e^{-t/\tau}[\cos^2(\omega t+\phi)+\beta]$$

$$\Rightarrow \omega=\alpha_{CW,CCW}\,(c/L)$$

$$\Rightarrow \Delta\omega(\pm B)$$



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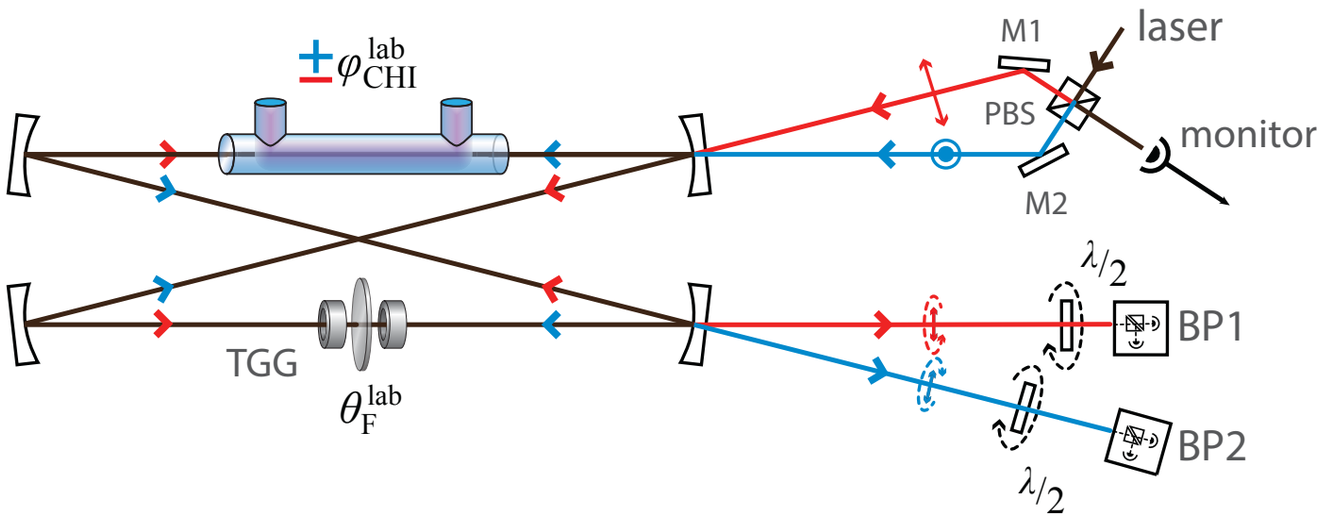
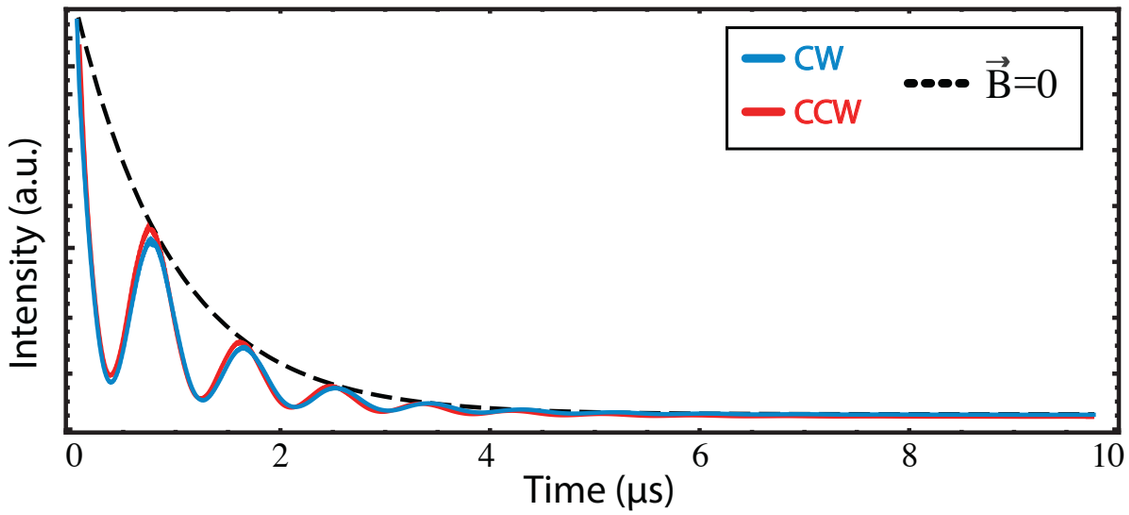
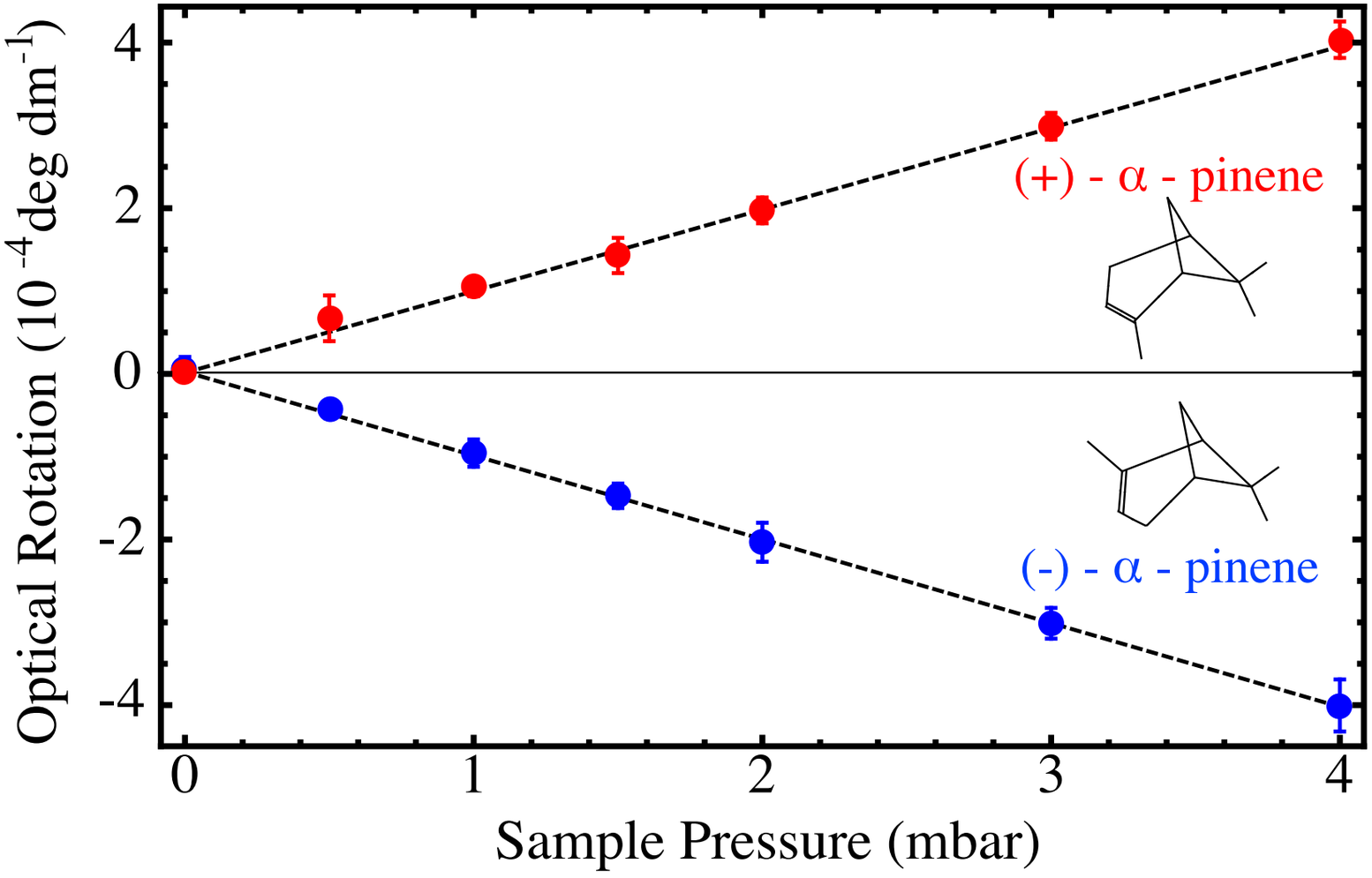
Chiral Cavity Ring Down



Experiment

Gas Cell



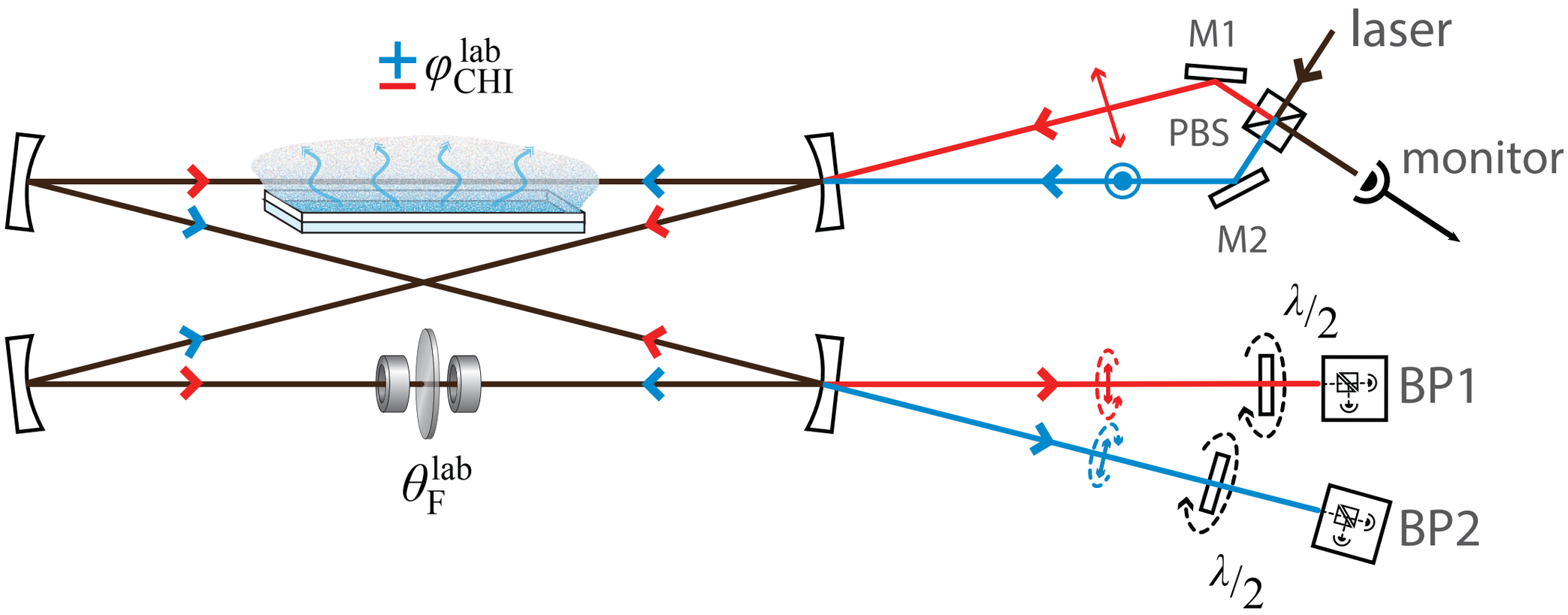


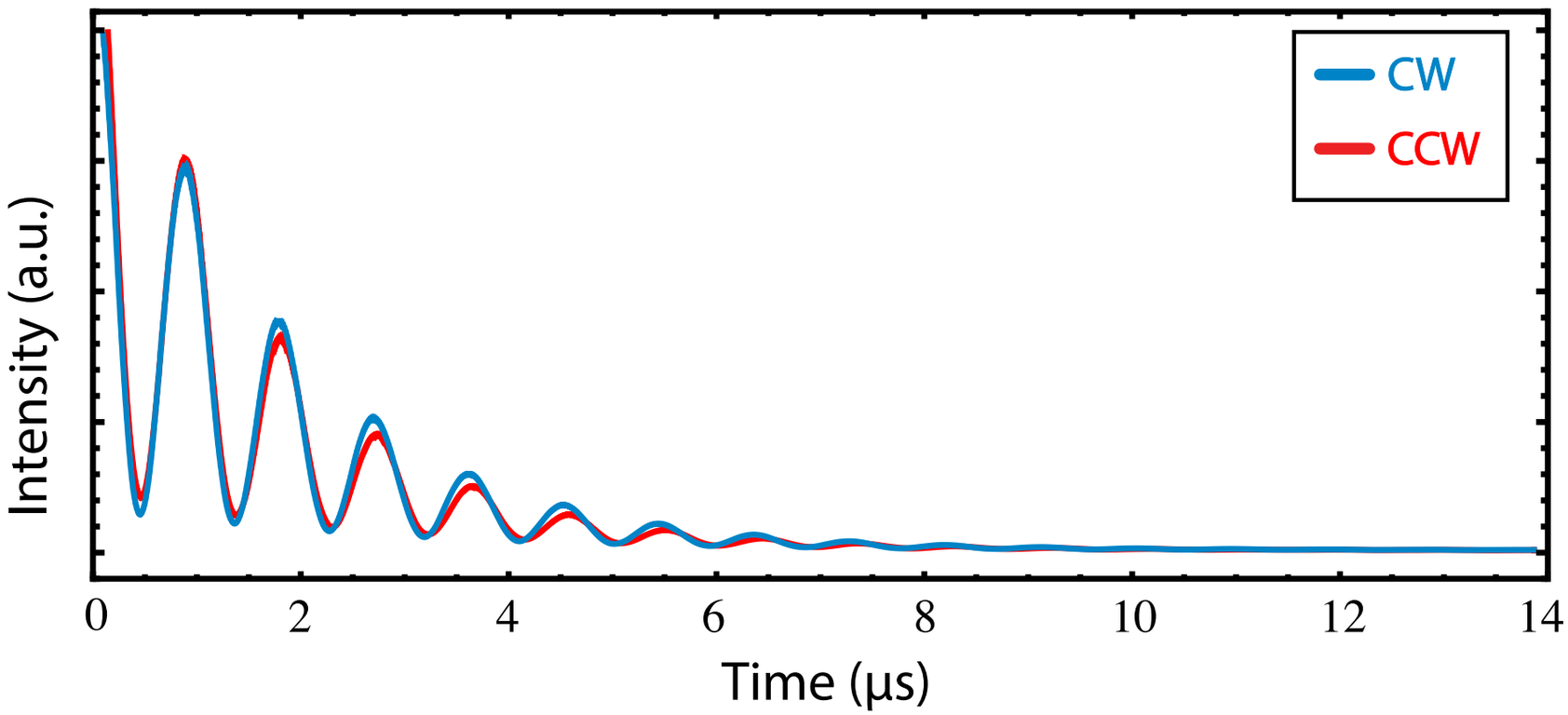
different enantiomers of α-pinene

Chiral Cavity Ring Down

Experiment

Open air



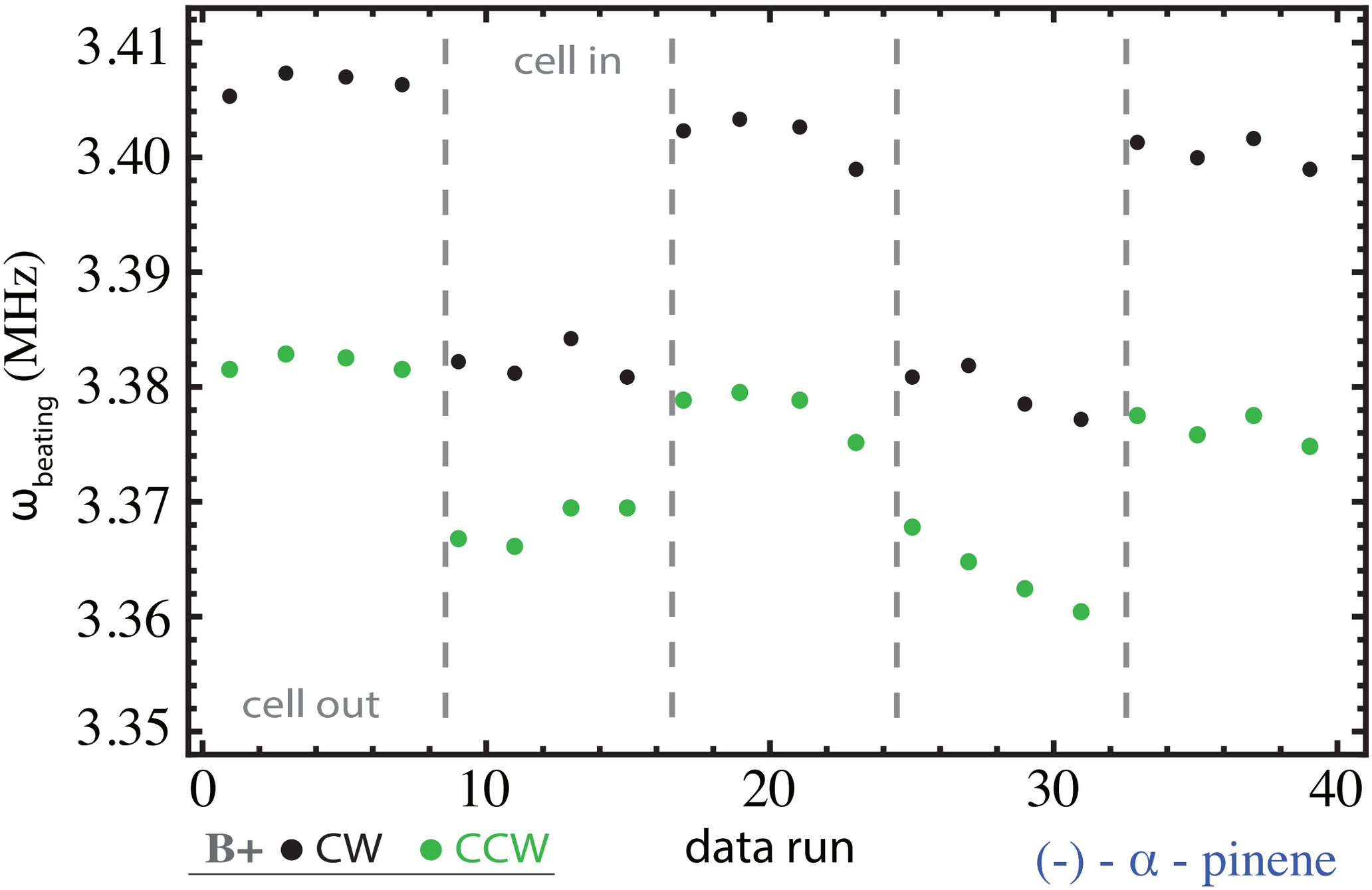


Chiral Cavity Ring Down

Experiment

Open air

Raw Data:

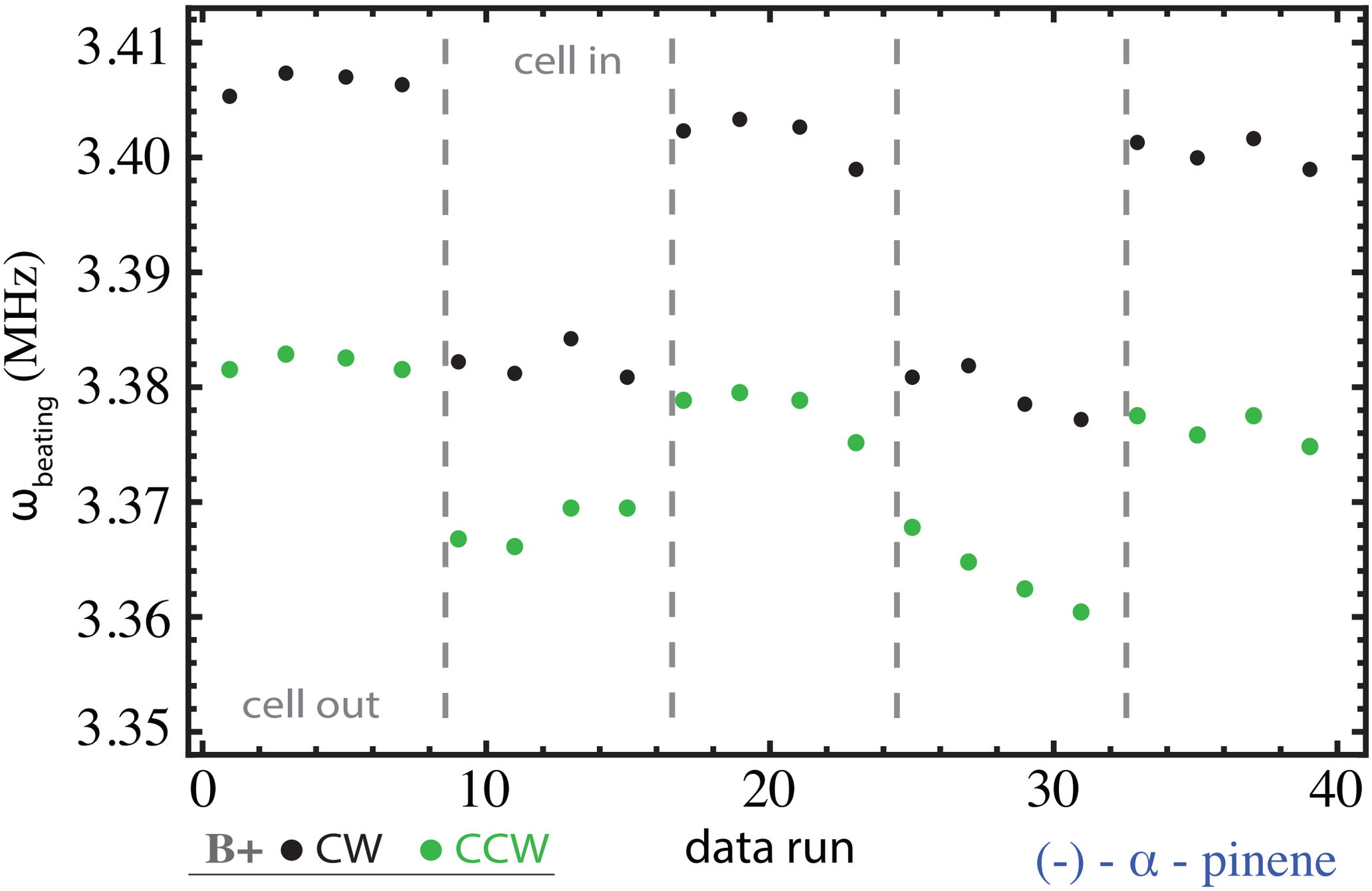


Chiral Cavity Ring Down

Experiment

Open air

Raw Data: Single-channel signal gives the wrong answer !

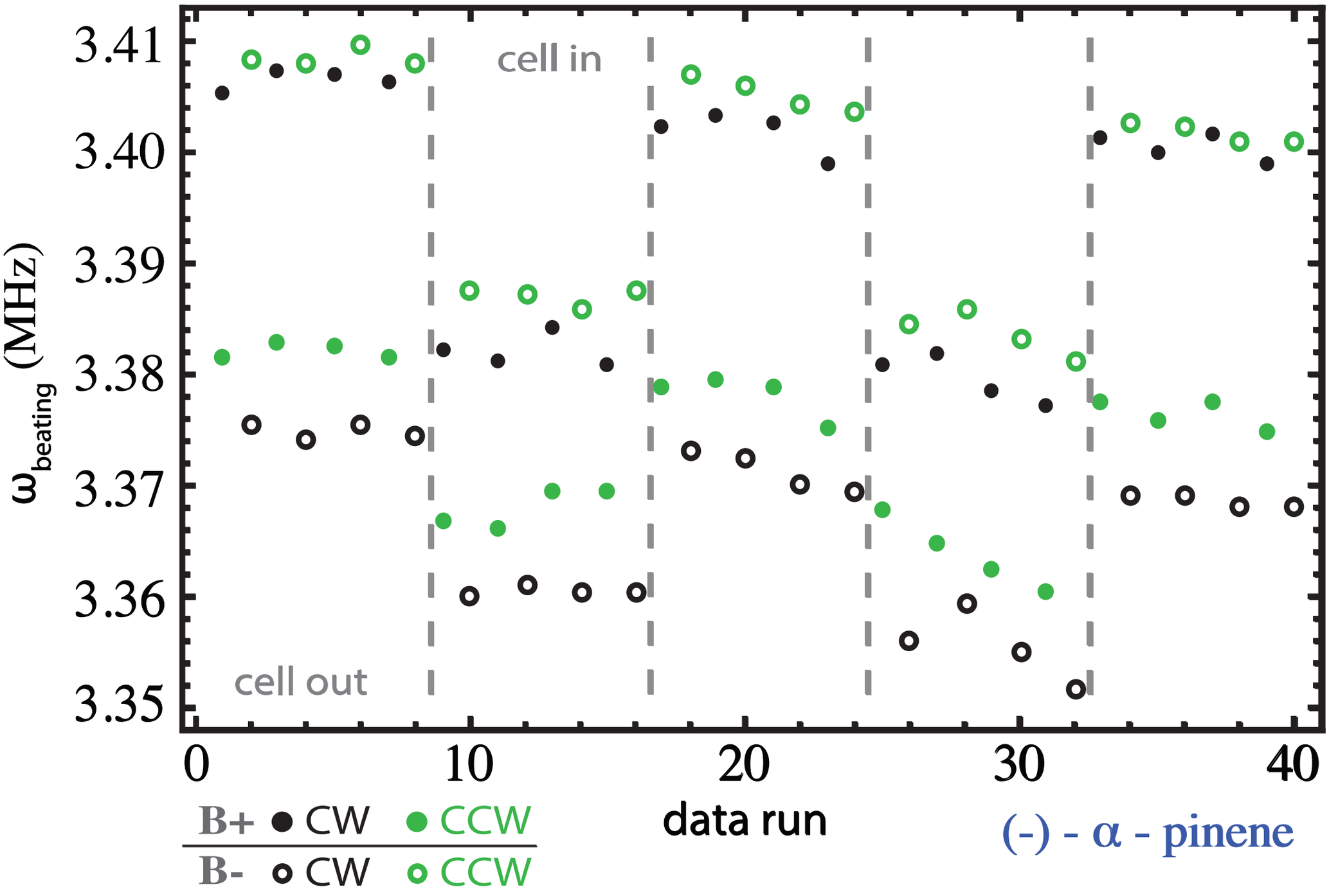


Chiral Cavity Ring Down

Experiment

Open air

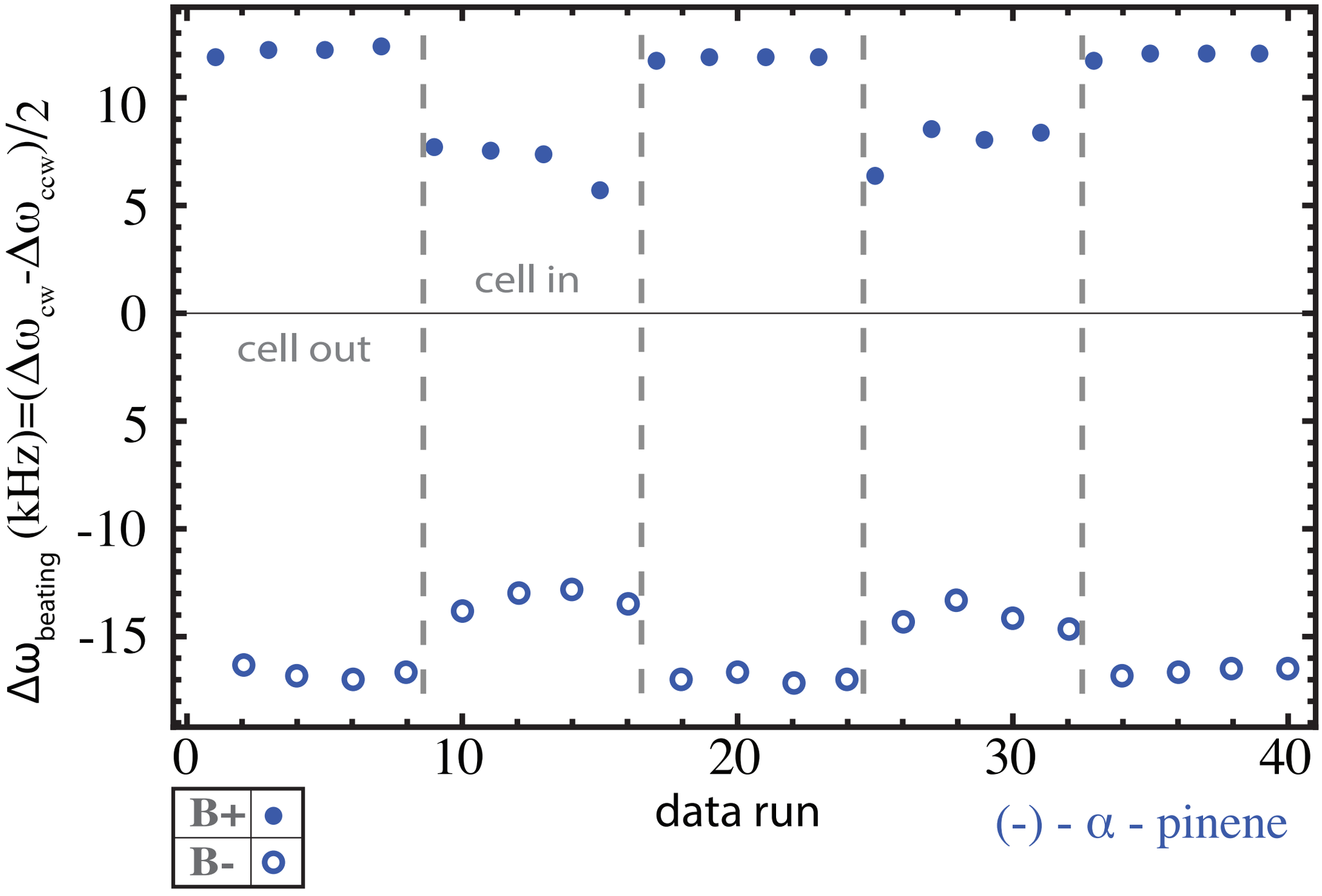
Raw Data: Single-channel signal gives the wrong answer !



Chiral Cavity Ring Down

Experiment

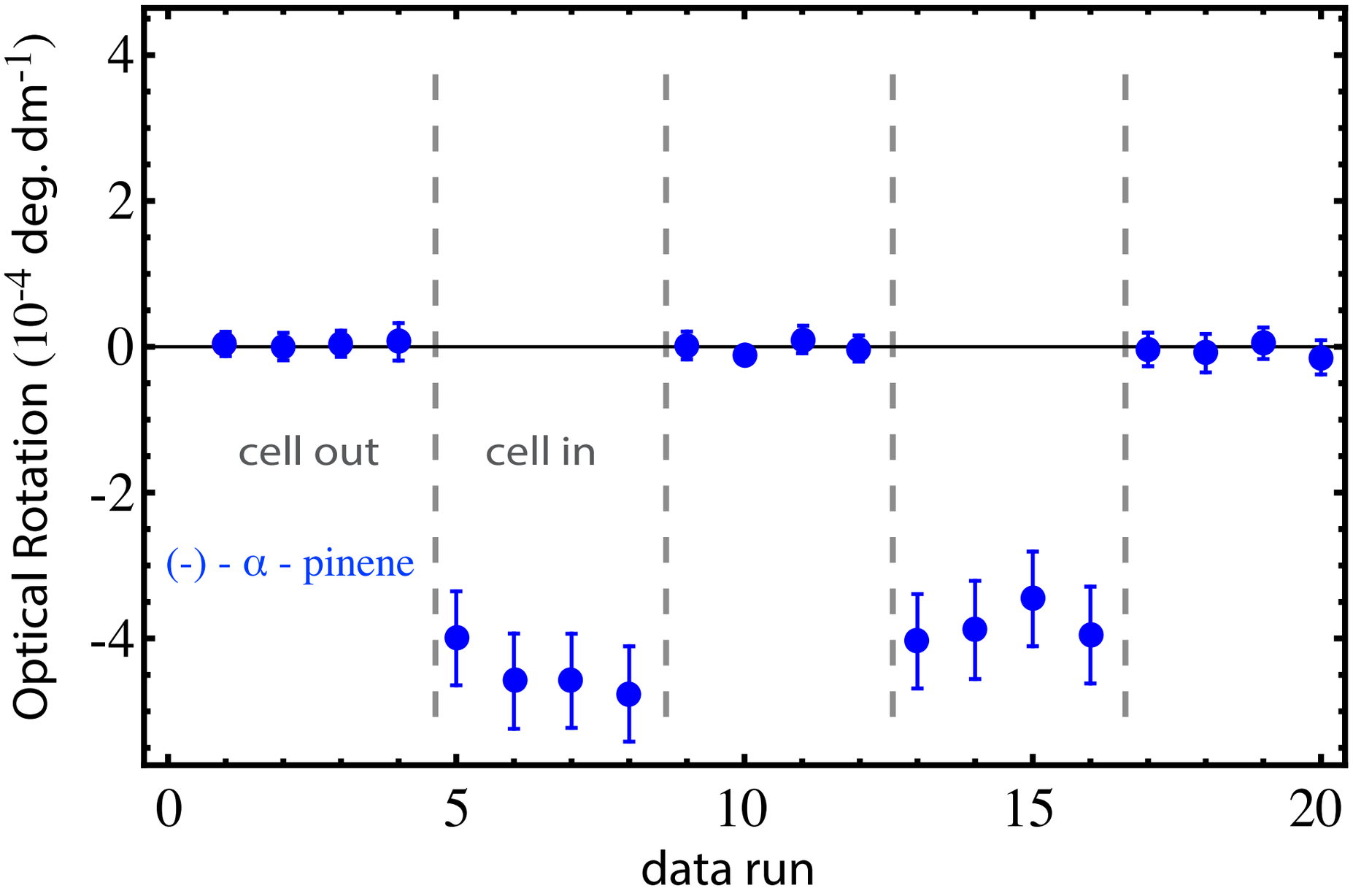
Open air



Chiral Cavity Ring Down

Experiment

Open air



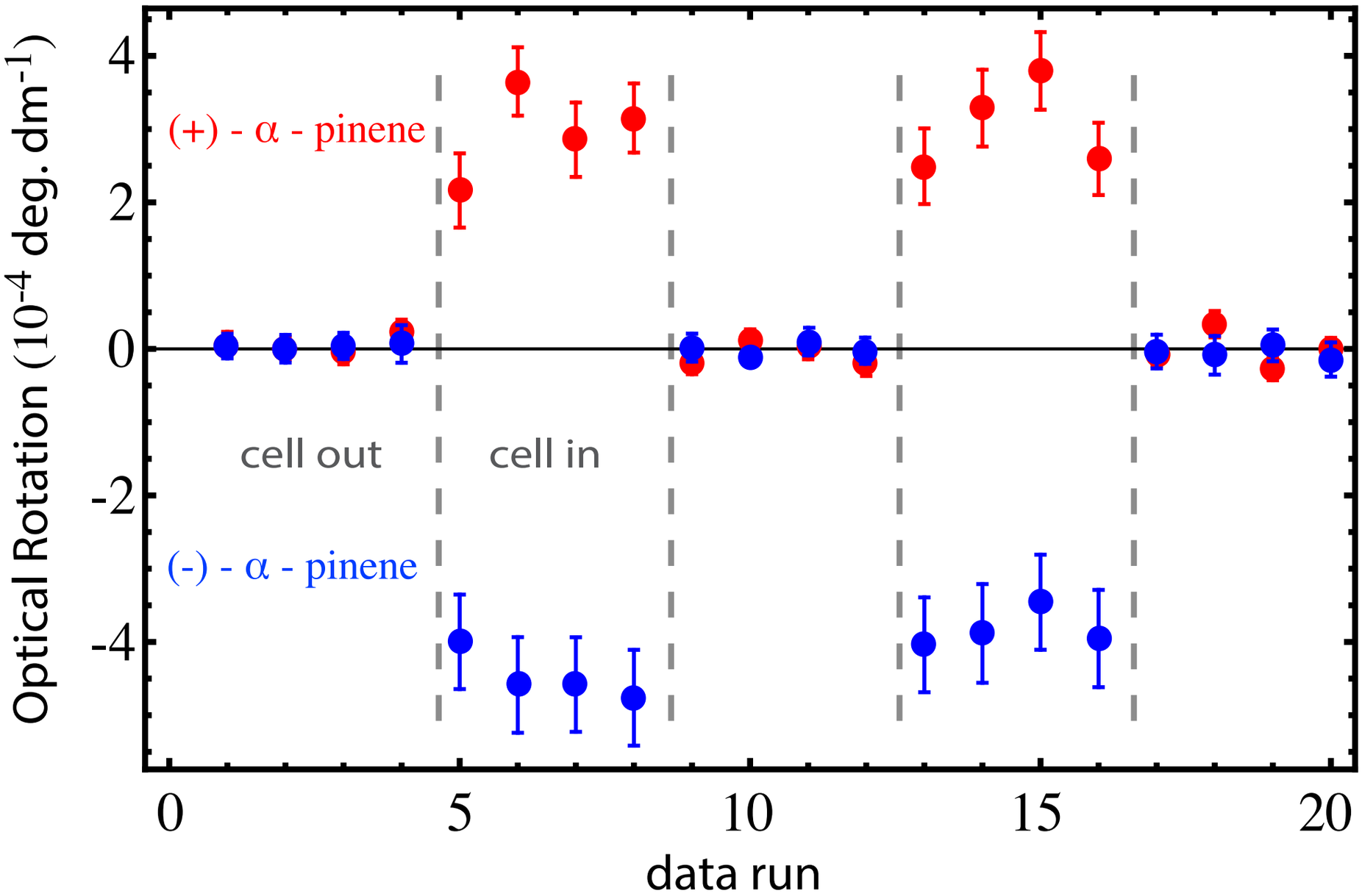
$V_{sample} \sim 4mL$

$$\Delta\alpha(+B) - \Delta\alpha(-B) = 4\phi_{CHI}$$

Chiral Cavity Ring Down

Experiment

Open air



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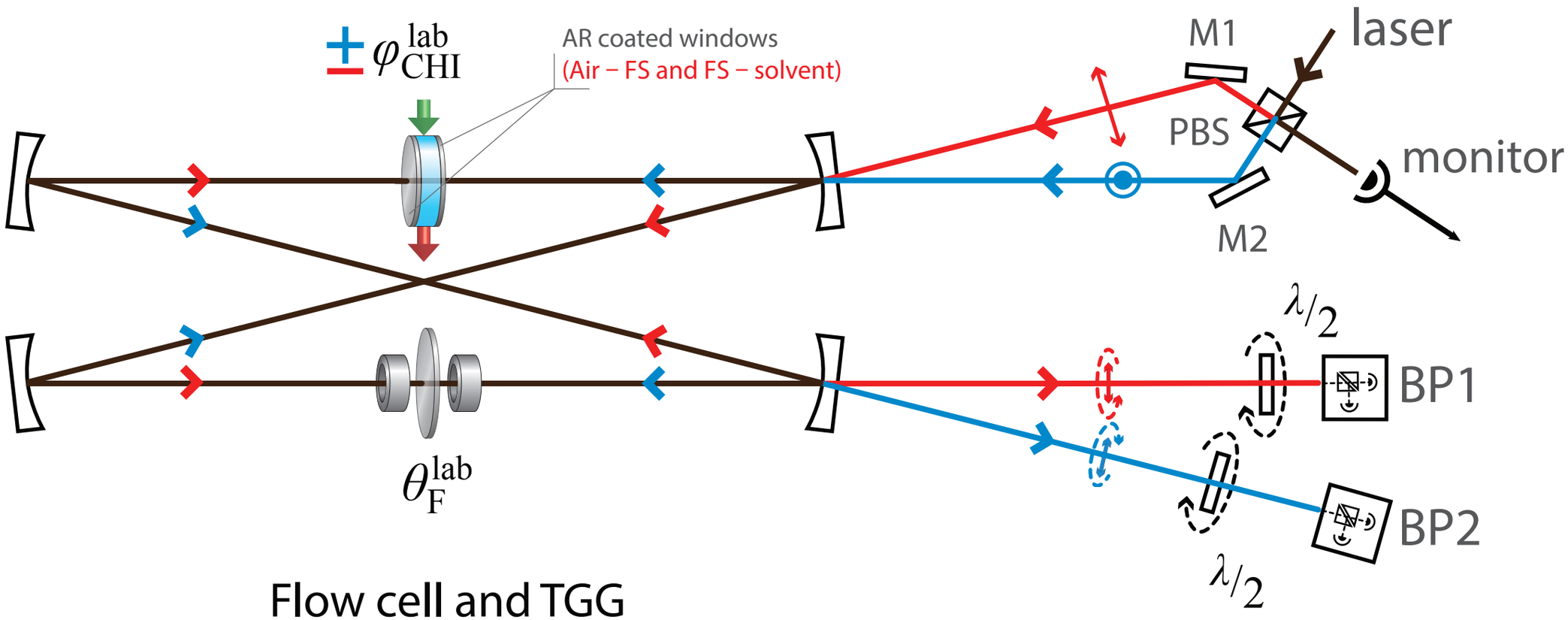
Chiral Cavity Ring Down

Experiment

Liquid

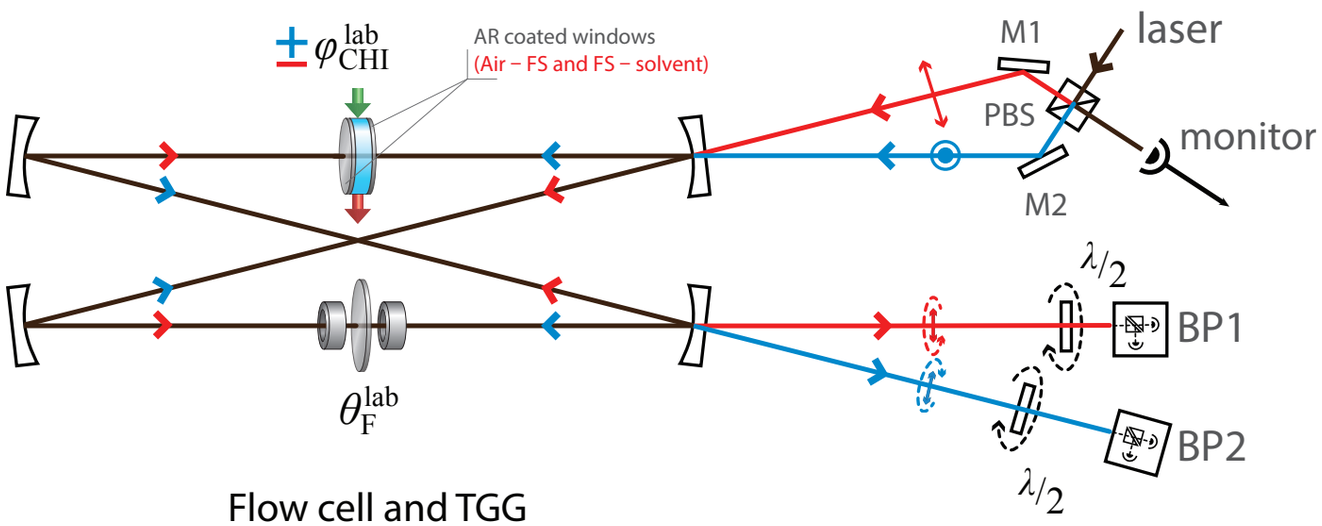


Chirality Measurements in Liquids

Chiral Cavity Ring Down

Experiment

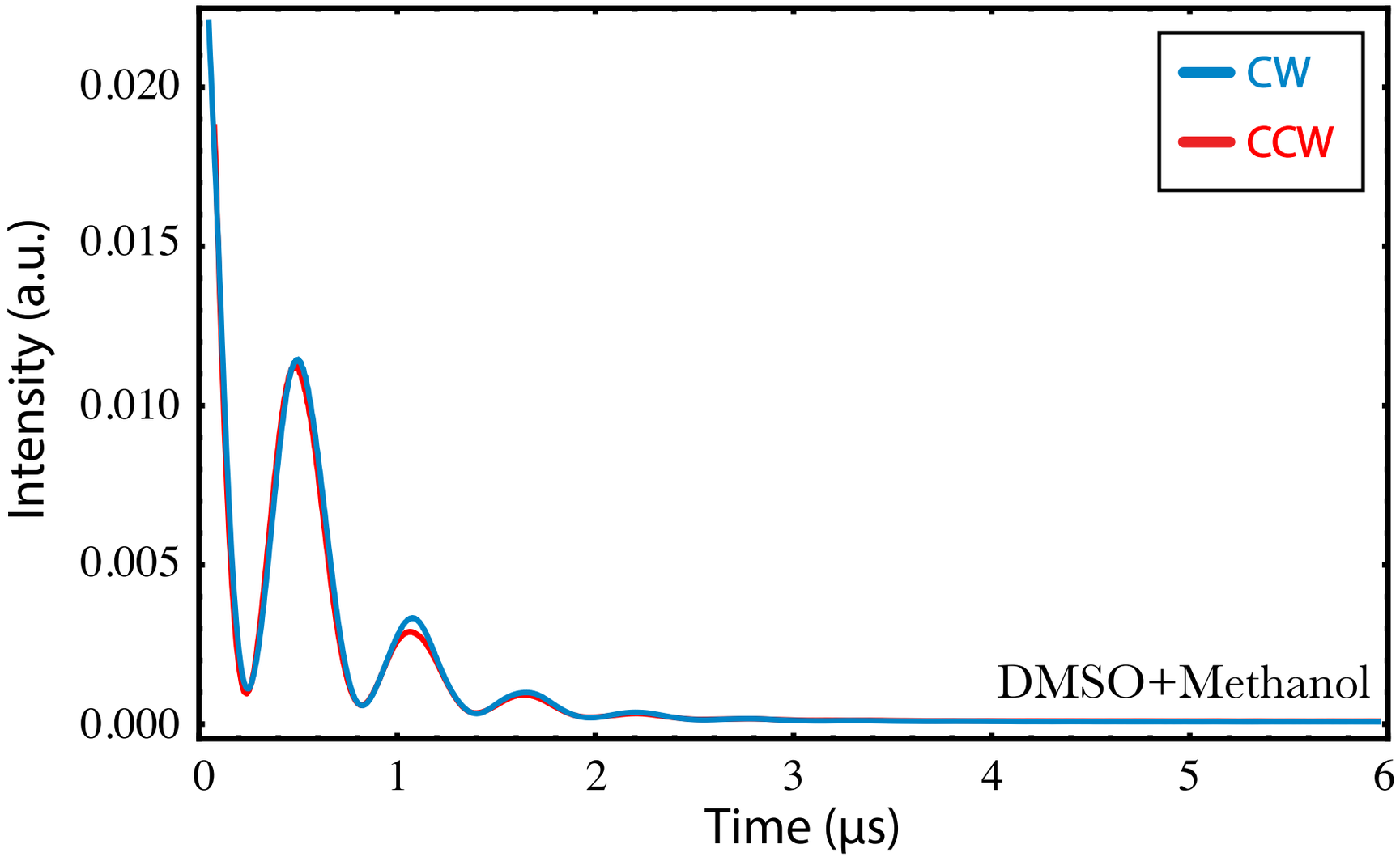
Liquid



Flow cell and TGG

d_{cell}=2.6mm

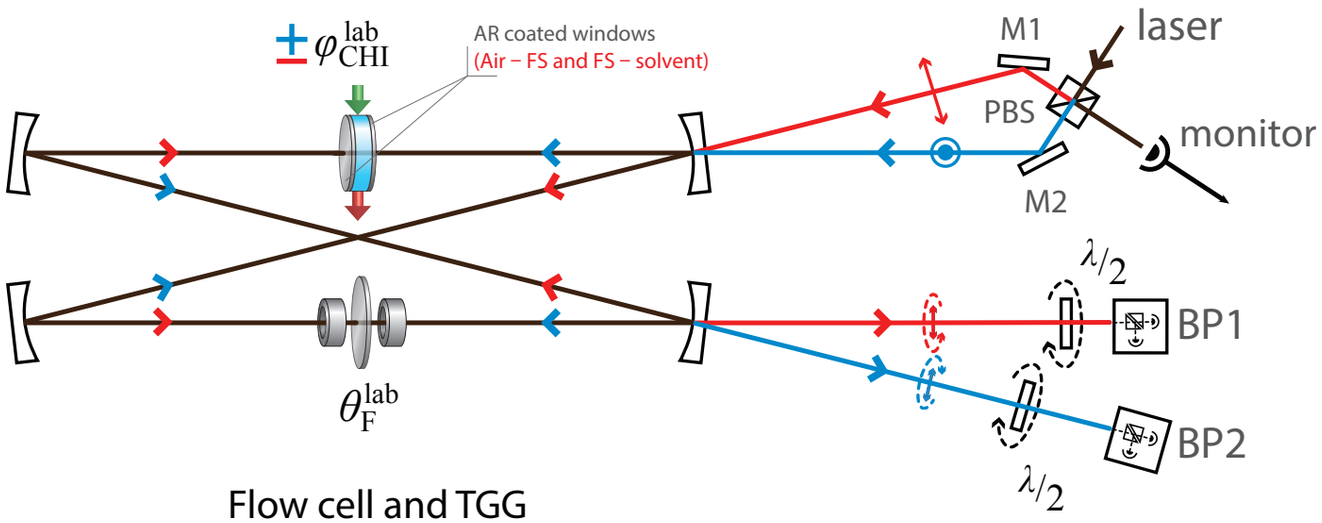
V_{cell}~200μL



Chiral Cavity Ring Down

Experiment

Liquid



Flow cell and TGG

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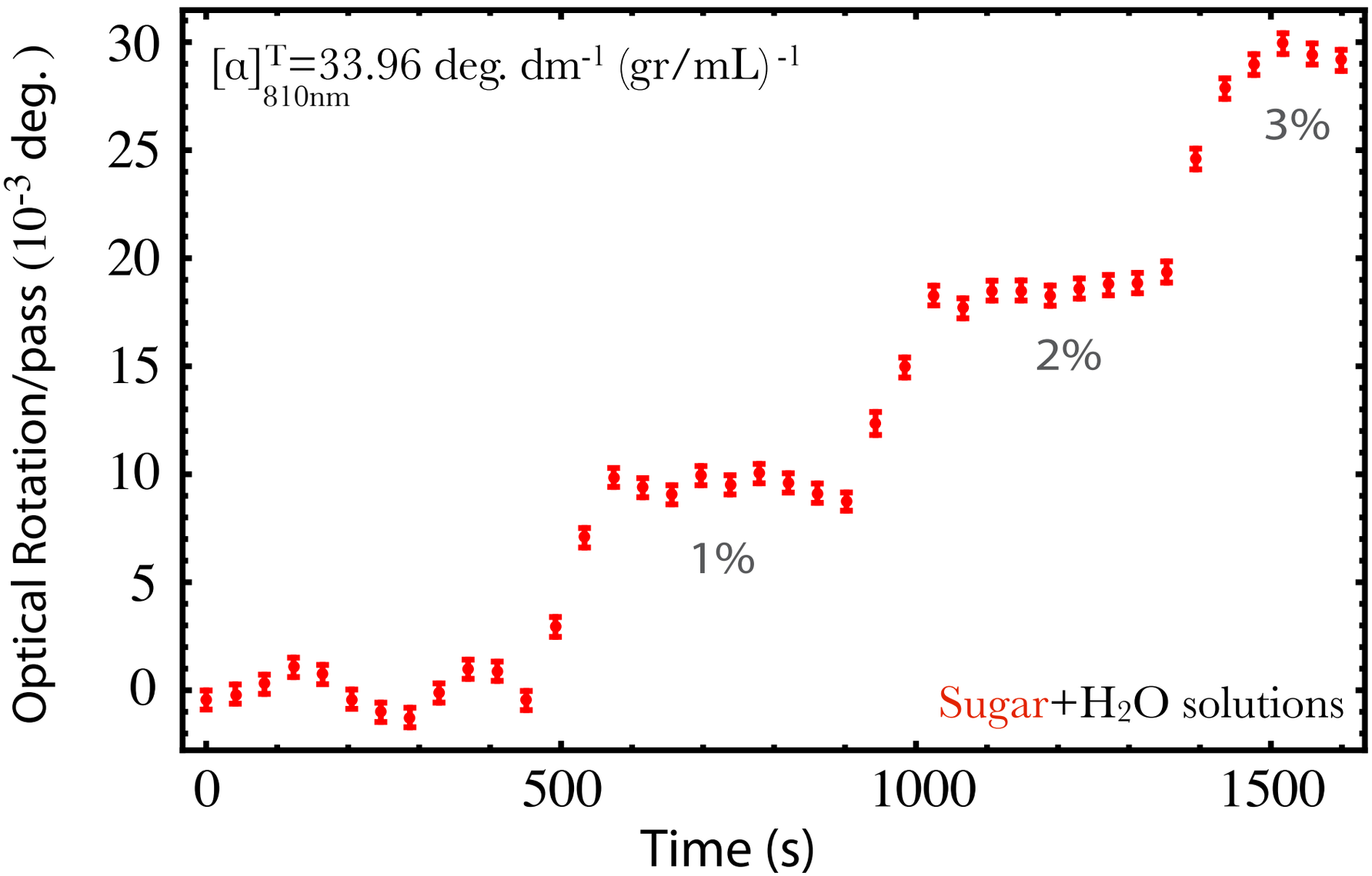
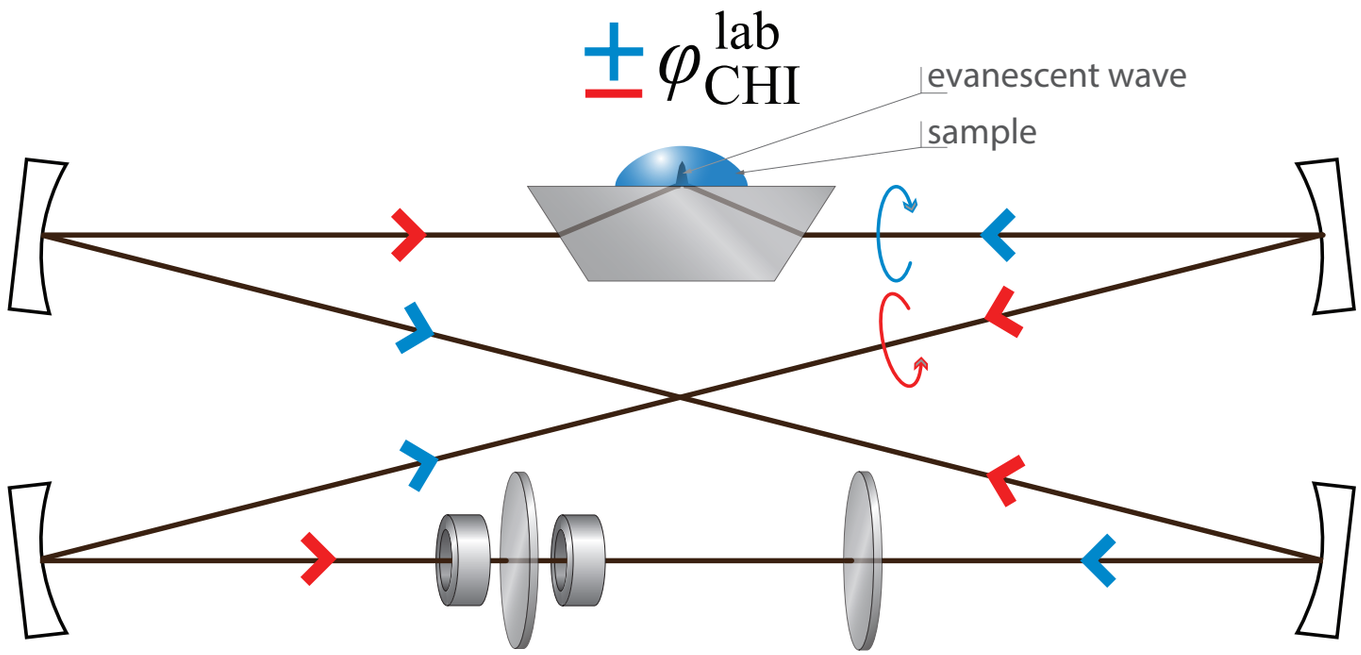


Chiral Cavity Ring Down

Experiment

Surface



future work

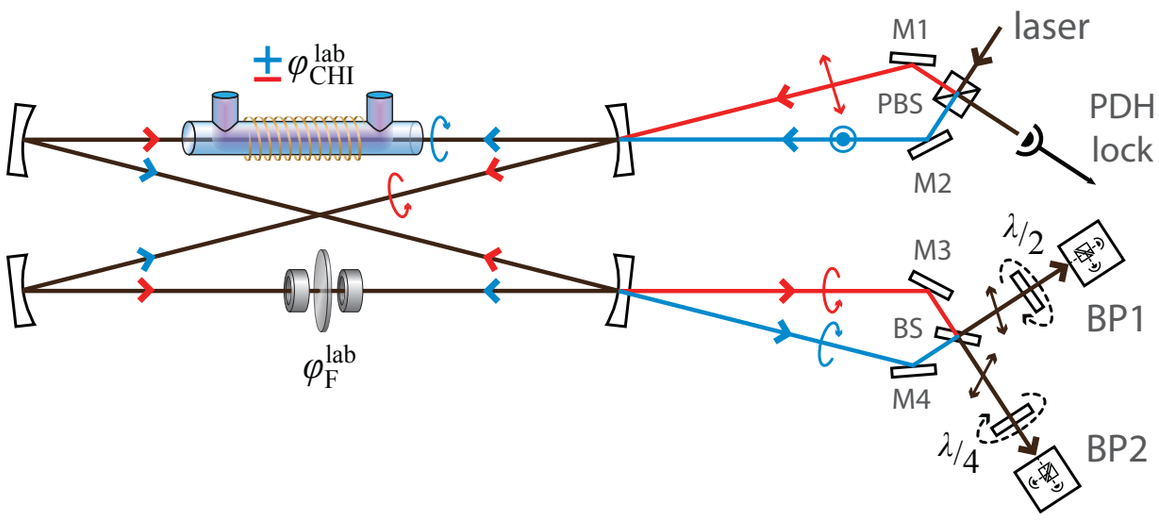
$\varphi_{\mathrm{F}}^{\mathrm{lab}}$ compensator

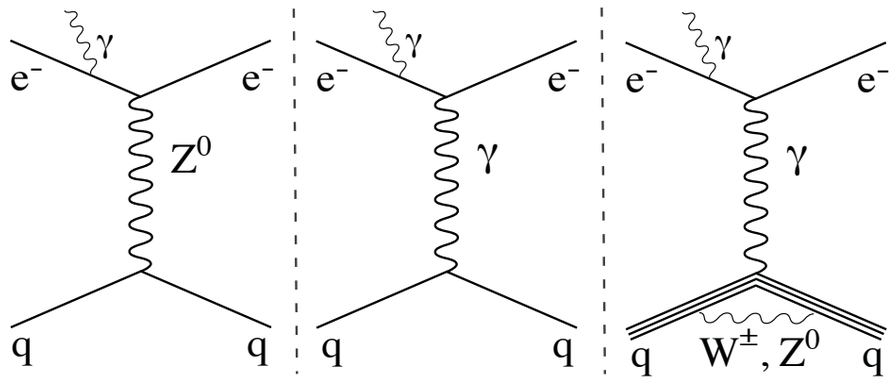
TIR prism, TGG and compensator

Evanescent-wave chirality measurements

Summary

Parity Violation in Hg, Xe, I & Cs

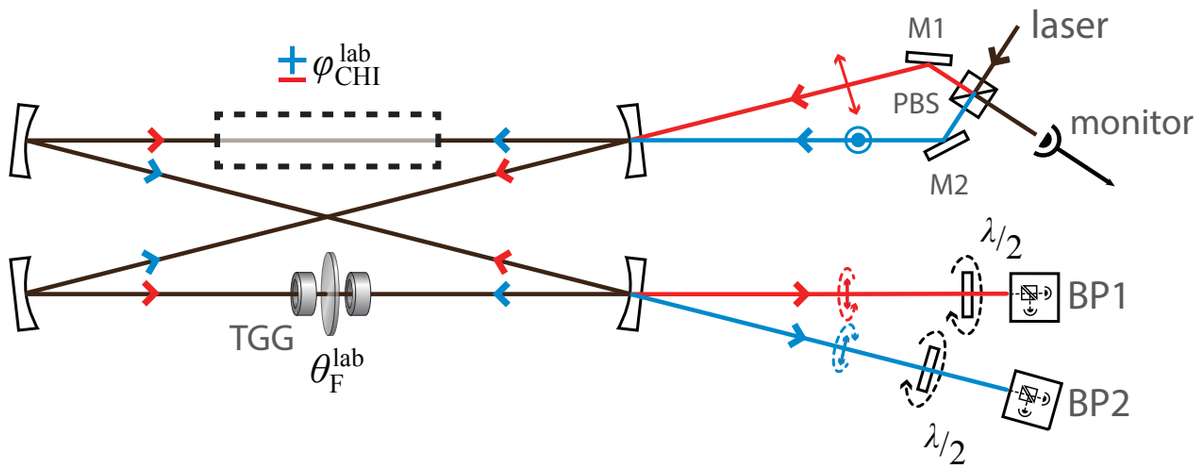


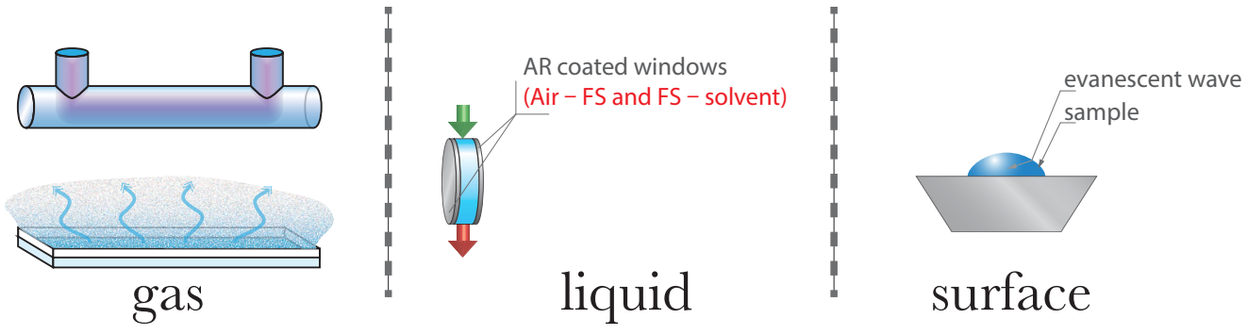


Future goal:
- cw laser source / locked cavity
- fast reversals (100-1kHz)
- sensitivity ~ shot noise (<1 nrad)

Chiral Cavity Ring Down

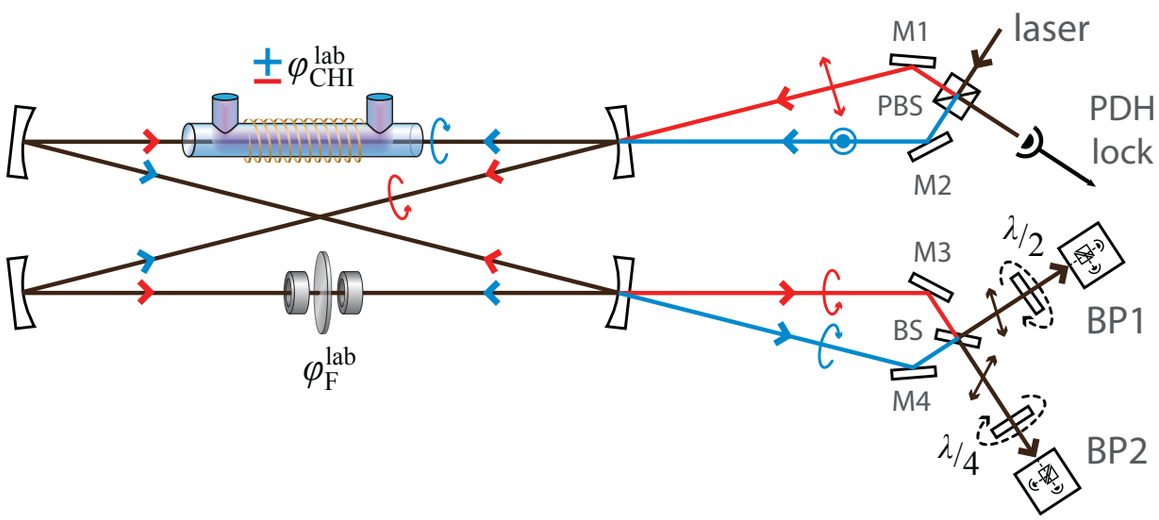
measurements of chirality in gases and liquids

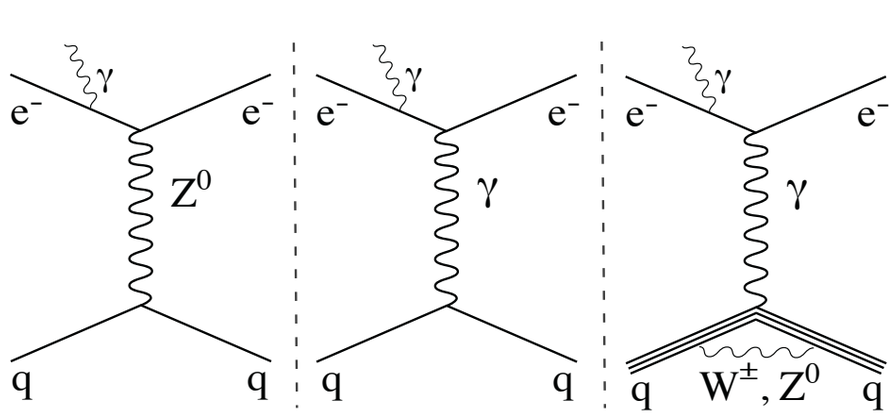




Present Status:
- pulsed laser source
- long acquisition times / slow reversals
- sensitivity ~ 1μrad

Parity Violation in Hg, Xe, I & Cs





Future goal:

- cw laser source / locked cavity
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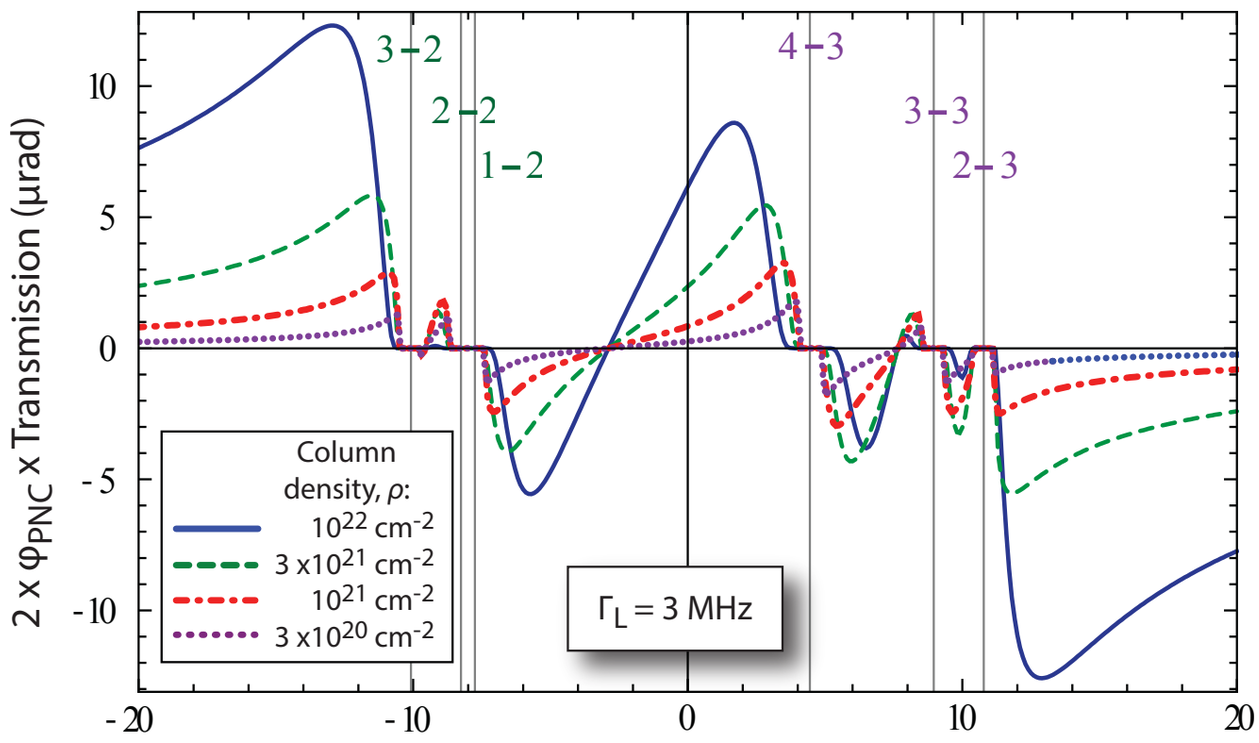
- sensitivity ~ shot noise (<1 nrad)

Iodine PNC optical rotation signal



FORTH
Institute of Electronic Structure and Laser

European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS, CULTURE & SPORTS
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Group/Co-workers:

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T.P. Rakitzis.
& B. Loppinet
W. von Klitzing

what does the future hold?

TABLE I. Review of recent experimental results concerning small birefringence measurements in gases. The reported γ_n is the noise equivalent birefringence at the detection frequency, while δn corresponds to the smallest measured birefringence value inferred from the published data.

Year	Group	Effect	Technique	γ_n $(1/\sqrt{\text{Hz}})$	δn
2000	Tel-Aviv[a]	Kerr	Resonant cavity ellipsometer	3×10^{-15}	1×10^{-13}
2005	BMV[b]	Kerr	Resonant cavity ellipsometer	2×10^{-15}	1×10^{-15}
2009	PVLAS[c]	Cotton–Mouton	Resonant cavity ellipsometer	5×10^{-17}	1×10^{-17}
2009	Q & A[d]	Cotton–Mouton	Resonant cavity ellipsometer	1×10^{-15}	1×10^{-15}
2009	BMV[e]	Cotton–Mouton	Resonant cavity ellipsometer	2×10^{-18}	2×10^{-15}
2009	LASIM/LSP[f]	Kerr	Resonant cavity ellipsometer	8×10^{-19}	4×10^{-19}
2003	Tokyo[g]	Cotton–Mouton	Single pass ellipsometer	3×10^{-13}	2×10^{-15}
2000	JILA[h]	Sensitivity test	Frequency measurement	2×10^{-15}	1×10^{-17}
2009	This work	Sensitivity test	Frequency measurement	1×10^{-16}	2×10^{-18}

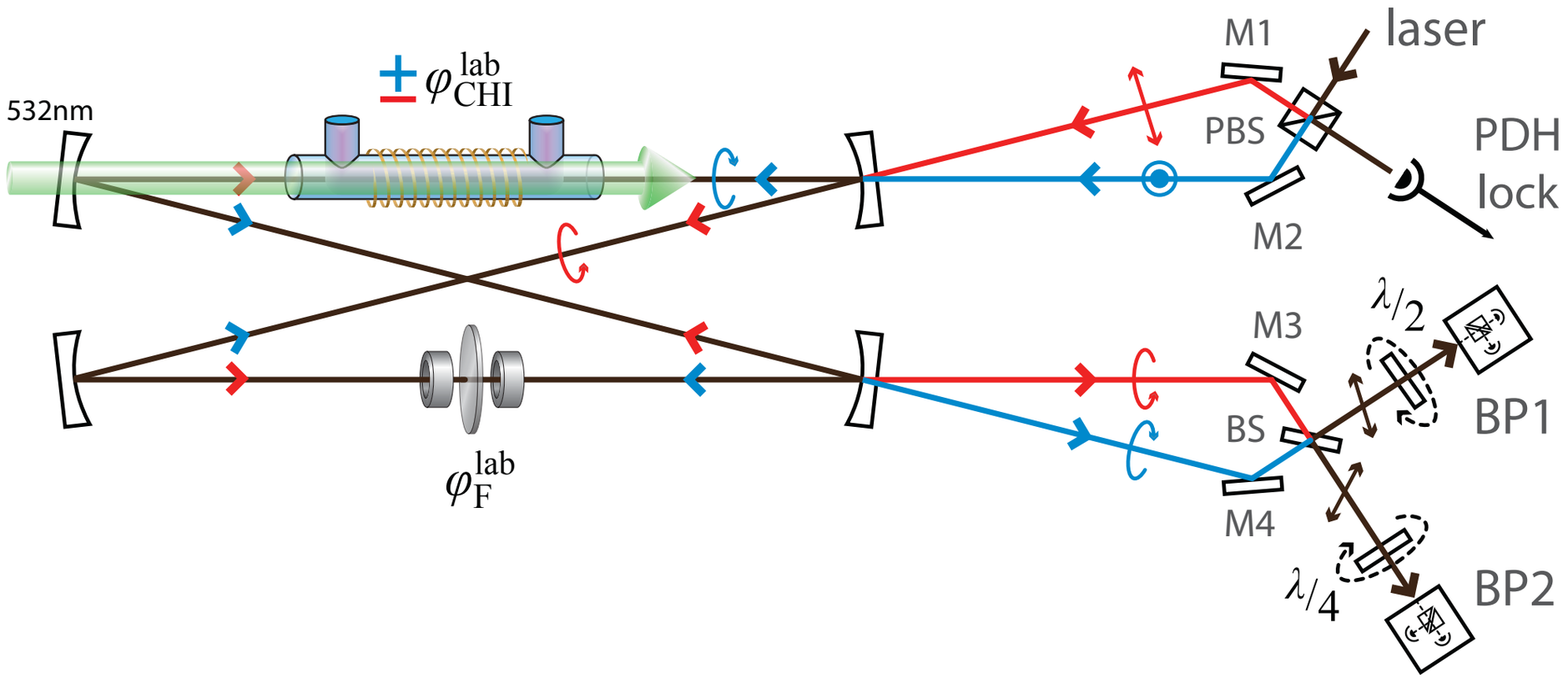
Bailly et. al. RevSciInstrum 81, 033105 (2010)

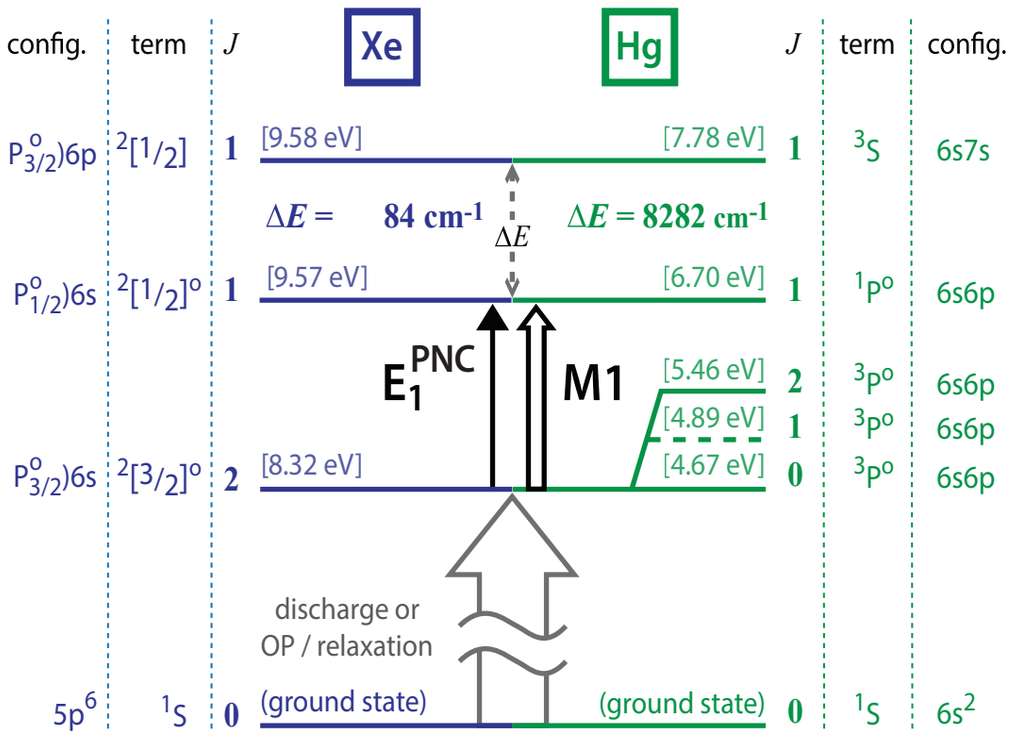
4 mirror ring cavity with counter-propagating beams

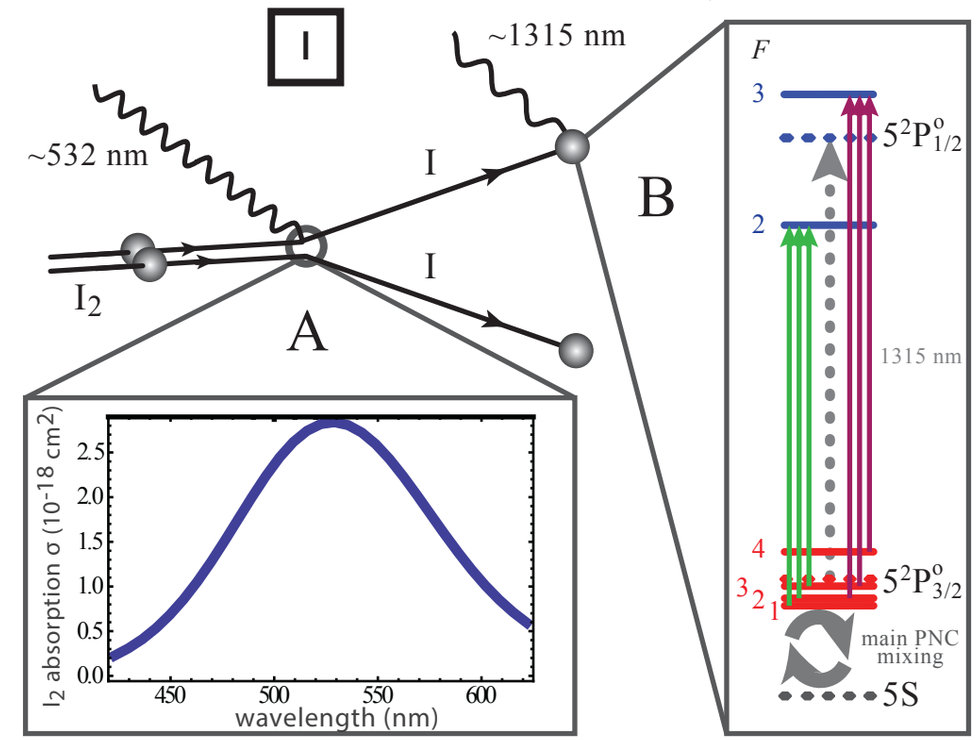
state-of-art 3×10^{-13} rad

(QED vacuum birefringence)

Durand et. al. PRA 82 (2010)







Metastable densities ~10^{12} cm^{-3}

(for discharge lamp pathlengths of 100cm
column densities of ~10^{14} cm^{-2})

Steady state densities ~10^{15}-10^{16} cm^{-3}

(for pathlengths of 100cm
column densities of ~10^{17}-10^{18} cm^{-2})

	Z	ΔE (cm^{-1})	Transition	λ (nm)	$M1$ (μ_B)	Isotopes with $I \neq 0$	$\mathrm{Im}(E_1^{\mathrm{PNC}})$ $\times 10^{-10}\, e\alpha_B$	$\mathcal{R}$ $\times 10^{-8}$
I	53	53293.3	$^2\mathrm{P}_{3/2} \rightarrow {}^2\mathrm{P}_{1/2}$	1315	1.15	^{127}I	0.335(67)	0.80(16)
Hg	80	8281.64	$^3\mathrm{P}_0^\circ \rightarrow {}^1\mathrm{P}_1^\circ$	609	0.229	$\{^{199}\mathrm{Hg}, {}^{201}\mathrm{Hg}\}$	$3.4(2), 3.5(2)$	$41(2), 42(2)$
			$^3\mathrm{P}_1^\circ \rightarrow {}^1\mathrm{P}_1^\circ$	682	0.199		$5.3(3), 5.4(3)$	$73(4), 74(4)$
			$^3\mathrm{P}_2^\circ \rightarrow {}^1\mathrm{P}_1^\circ$	997	0.272		$3.7(2), 3.8(2)$	$37(2), 38(2)$
Xe	54	84.1	$6s^2[3/2]_2^\circ \rightarrow 6\mathrm{s}'^2[1/2]_1^\circ$	988	1.22	$\{^{129}\mathrm{Xe}, {}^{131}\mathrm{Xe}\}$	$3.16, 3.25$	$7.1(7), 7.3(7)$

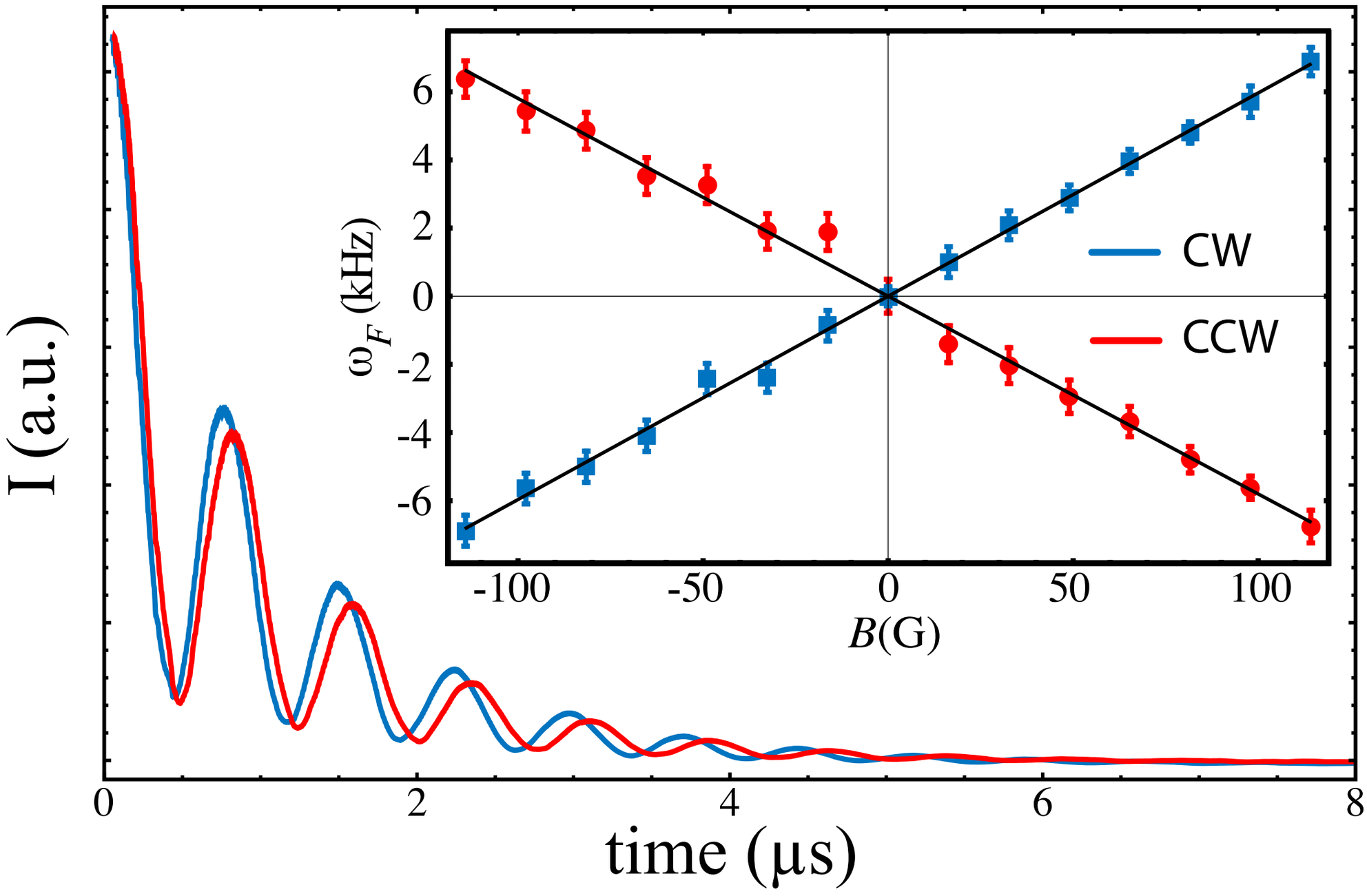
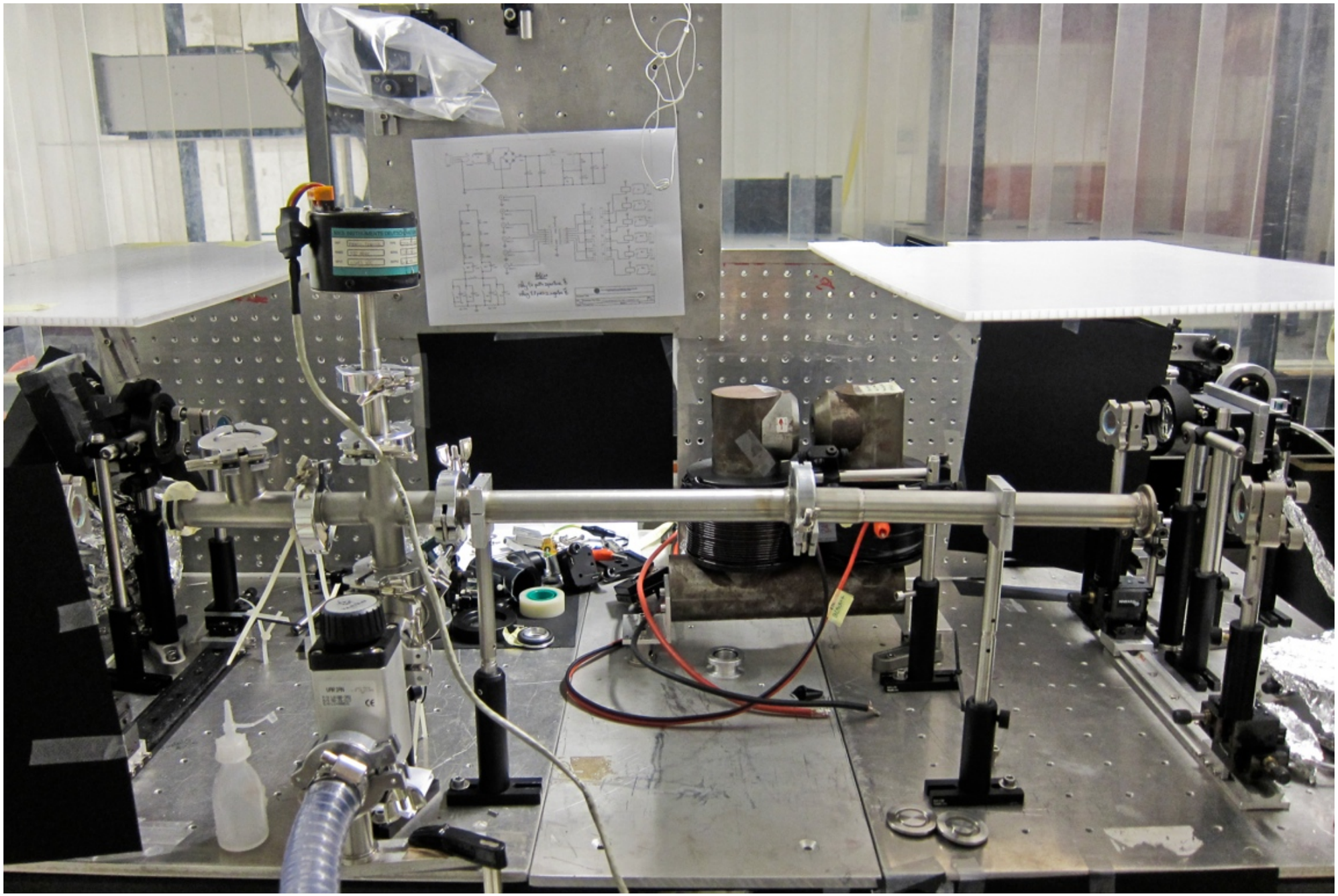


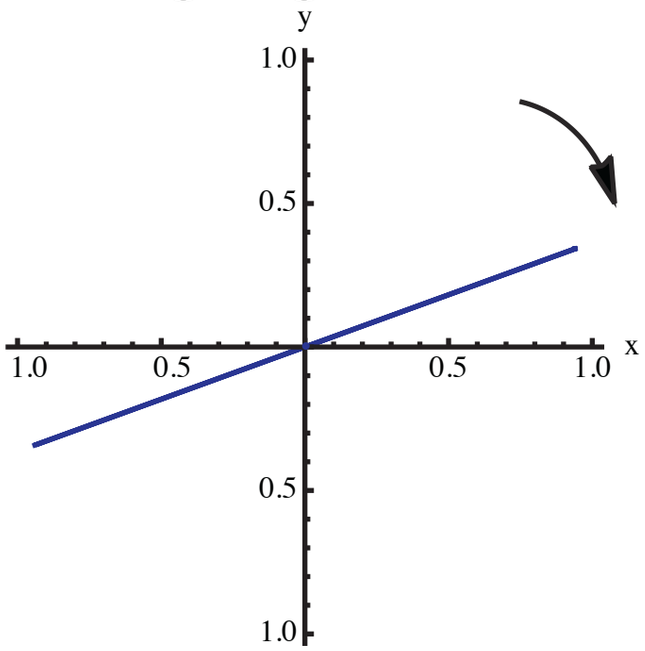
FIG. 4: Non-resonant Faraday effect of an intracavity SiO_2 window at 800 nm. The cavity ring-down polarization beating frequencies for counterpropagating beams are visibly different (magnetic field of 1000 G). The inset shows the linear and antisymmetric magnetic-field dependence of $\omega_{\mathrm{CW}} - \omega_{\mathrm{CCW}}$.

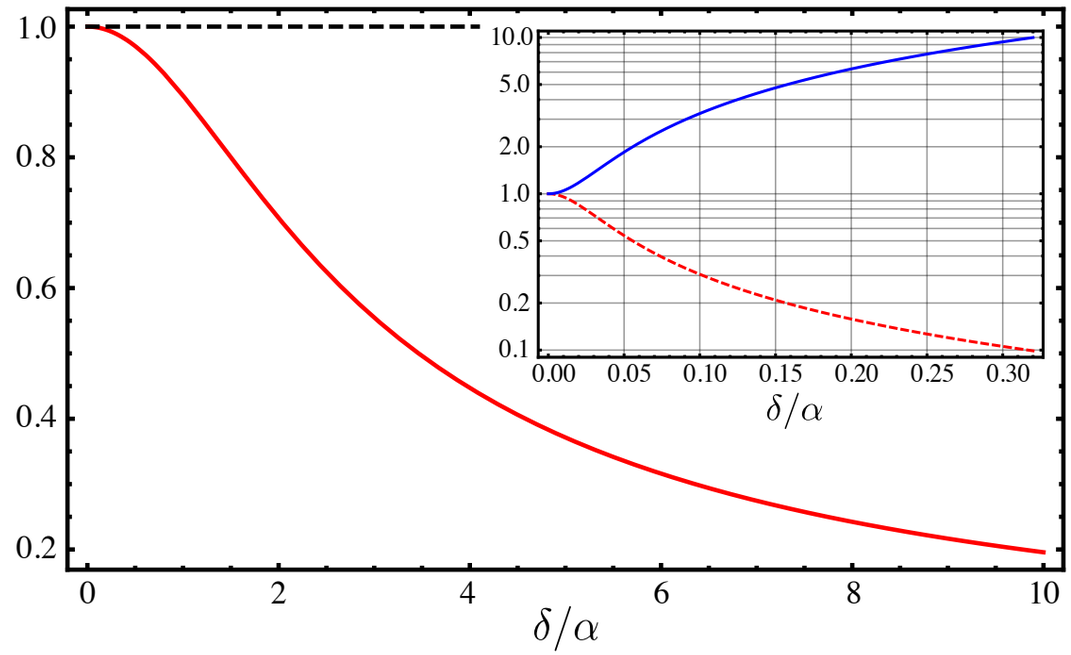


Linear birefringence δ:

linear birefringence presents an adversity to high precision optical rotation measurements using high-finesse cavities

$\delta=\pi/(2N)$ ➪ after N passes light becomes circular





α≫δ

How?

inducing a larger circular birefringence α≫δ keeps intracavity light linearly polarized

magneto-optical rotation: Faraday effect $\theta_F=VBl$ (V=Verdet constant)

P even & T odd