PAUL SCHERRER INSTITUT

Searching for New Physics at the Quantum Technology Frontier

21st Jan. 2022

Duarte Pais
UCN group at PSI

On the path to improve the nuclear g-factor of ^{133}Cs

Outline

1. **Improve the measurement of the nuclear Landé g-factor of the ^{133}Cs ground state**

2. **The measurement exploiting Bell-Bloom magnetometry**

3. **Preliminary analysis (and potential relevance for axion-wind effects)**

1. Precession frequency and Landé g-factors

The spin of a particle precesses around the magnetic field.

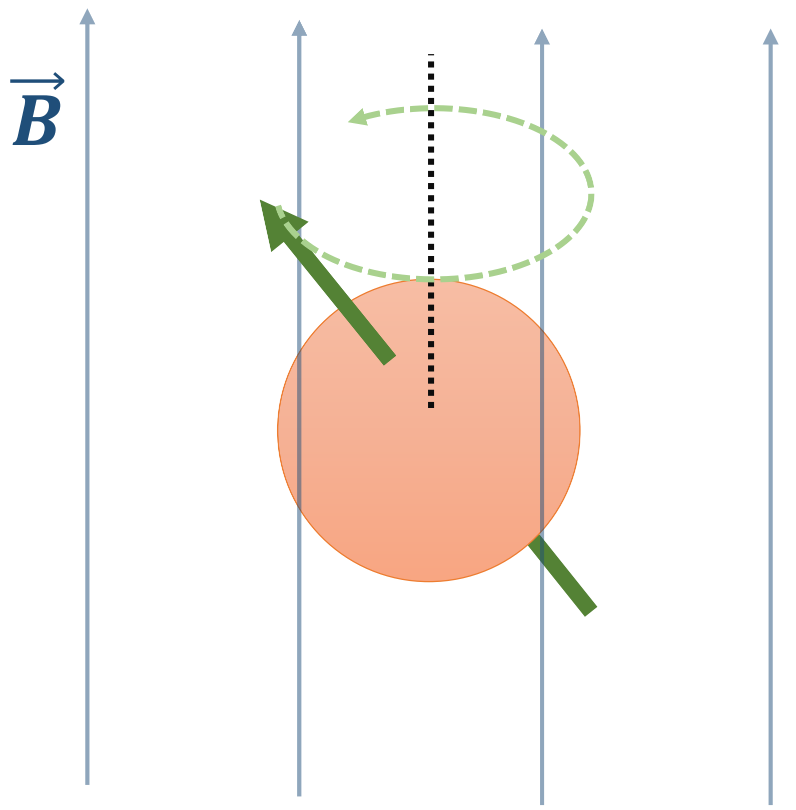
This frequency is given by

$$\omega = \gamma \left| \vec{B} \right|$$

Where γ is the gyromagnetic ratio of the spin state.

This γ itself is a function of

$$\gamma = \frac{g\ \mu_B}{\hbar}$$



1. Precession frequency and Landé g-factors

When the spin is associated with a hyperfine level, the corresponding Landé g-factor is

$$g_F = g_J \frac{F(F+1) - I(I+1) + J(J+1)}{2F(F+1)} + g_I \frac{F(F+1) + I(I+1) - J(J+1)}{2F(F+1)}$$

where F, I and J are the hyperfine, nuclear and electronic angular momenta quantum numbers.

The ground state of ^{133}Cs is $6\ ^2S_{1/2}$. Given that $I = \frac{7}{2}$ and $J = \frac{1}{2}$ there are two possibilities for $F = 3, 4$.

$F = 3$

$$g_{F=3} = \frac{-g_J + 9g_I}{8}$$

$F = 4$

$$g_{F=3} = \frac{g_J + 7g_I}{8}$$

1. Precession frequency and Landé g-factors

If two precession frequencies associated with each hyperfine level are measured **at the same time**, then

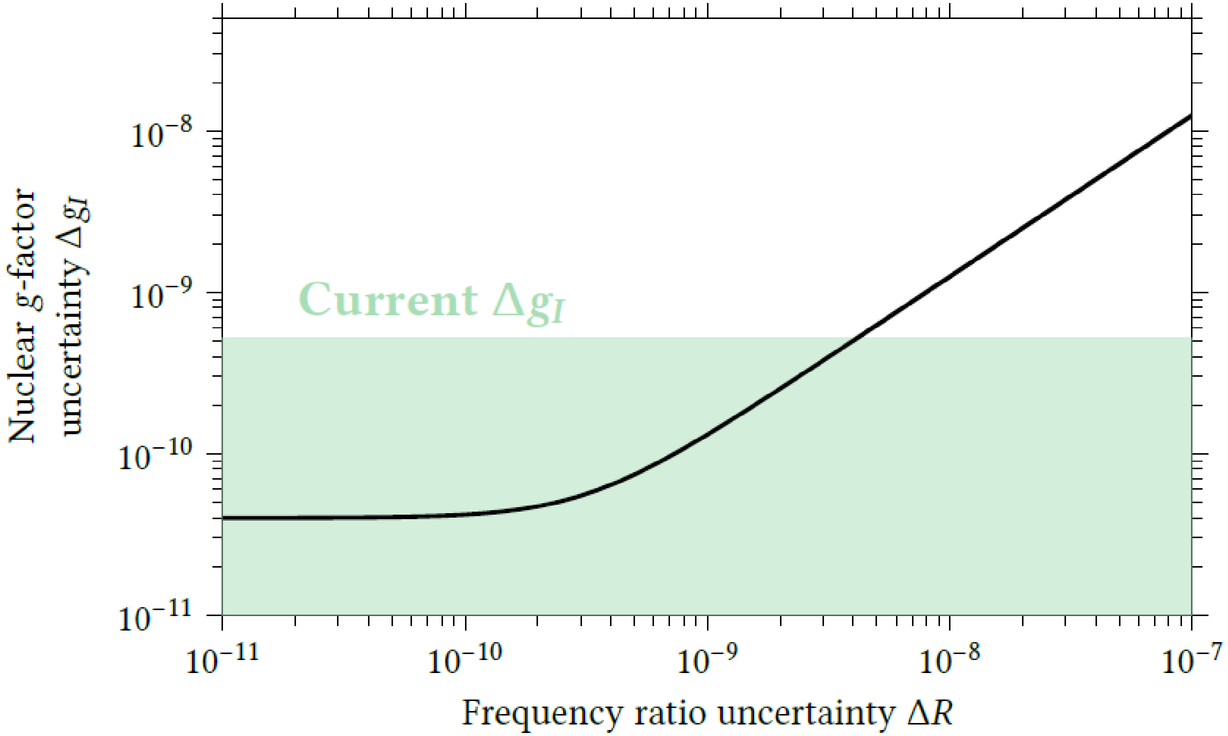
$$R = \frac{\omega_{F=3}}{\omega_{F=4}} = \frac{|\gamma_{F=3}||\vec{B}|}{|\gamma_{F=4}||\vec{B}|} = \frac{\frac{g_{F=3}\mu_B}{\hbar}}{\frac{g_{F=4}\mu_B}{\hbar}} = \frac{|-g_J + 9g_I|}{|g_J + 7g_I|}$$

Given that $g_J = 2.002\,540\,32(20)$

and $g_I = -0.000\,398\,853\,95(52)$,

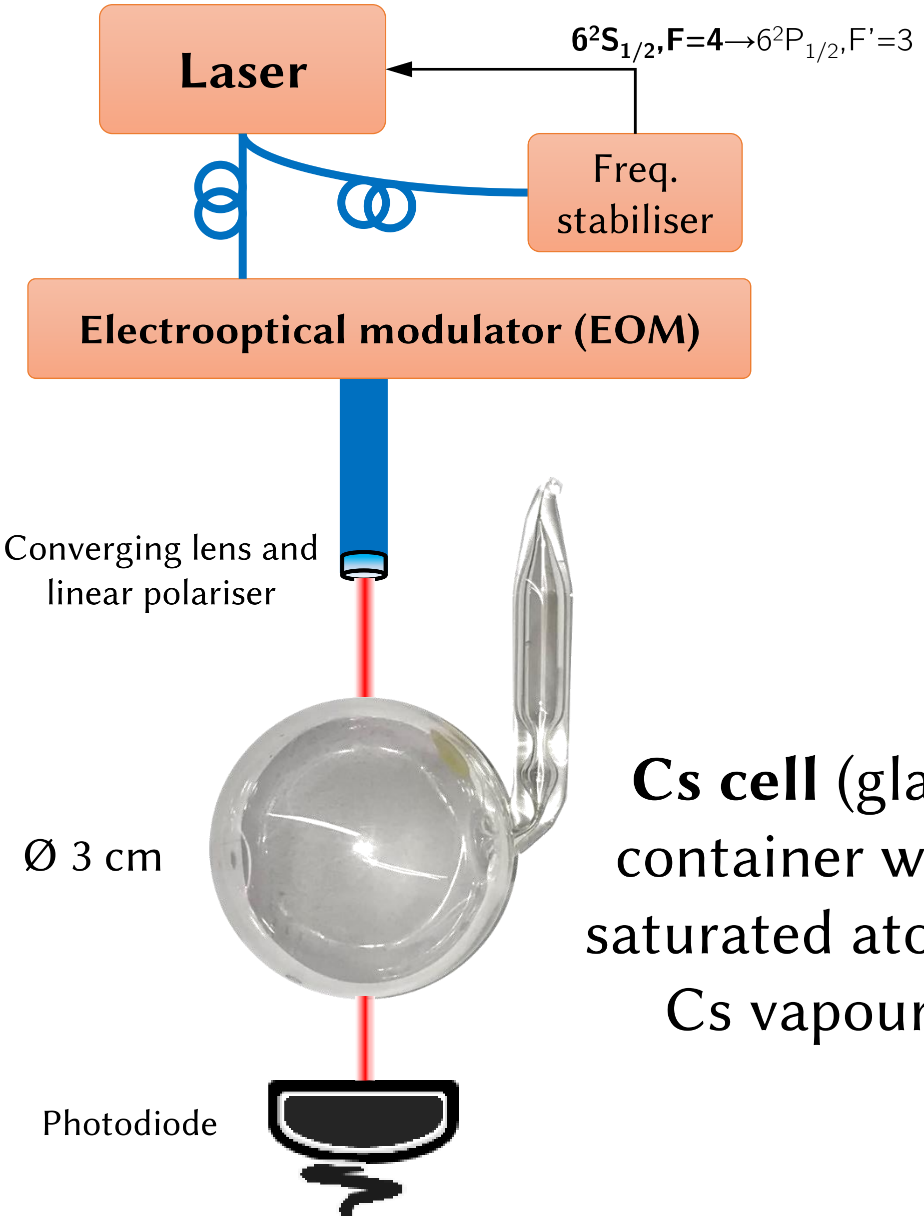
(White et al. PR A 7(3) 1973 and Arimondo et al. Rev. Mod. Phys. 49(1) 1977)

my idea was to improve Δg_I



More on Chapter 8 of "Development of the caesium magnetometer array for the n2EDM experiment", Pais 2021

2.1 The measurement: Bell-Bloom magnetometry



Cs cell (glass container with saturated atomic Cs vapour)

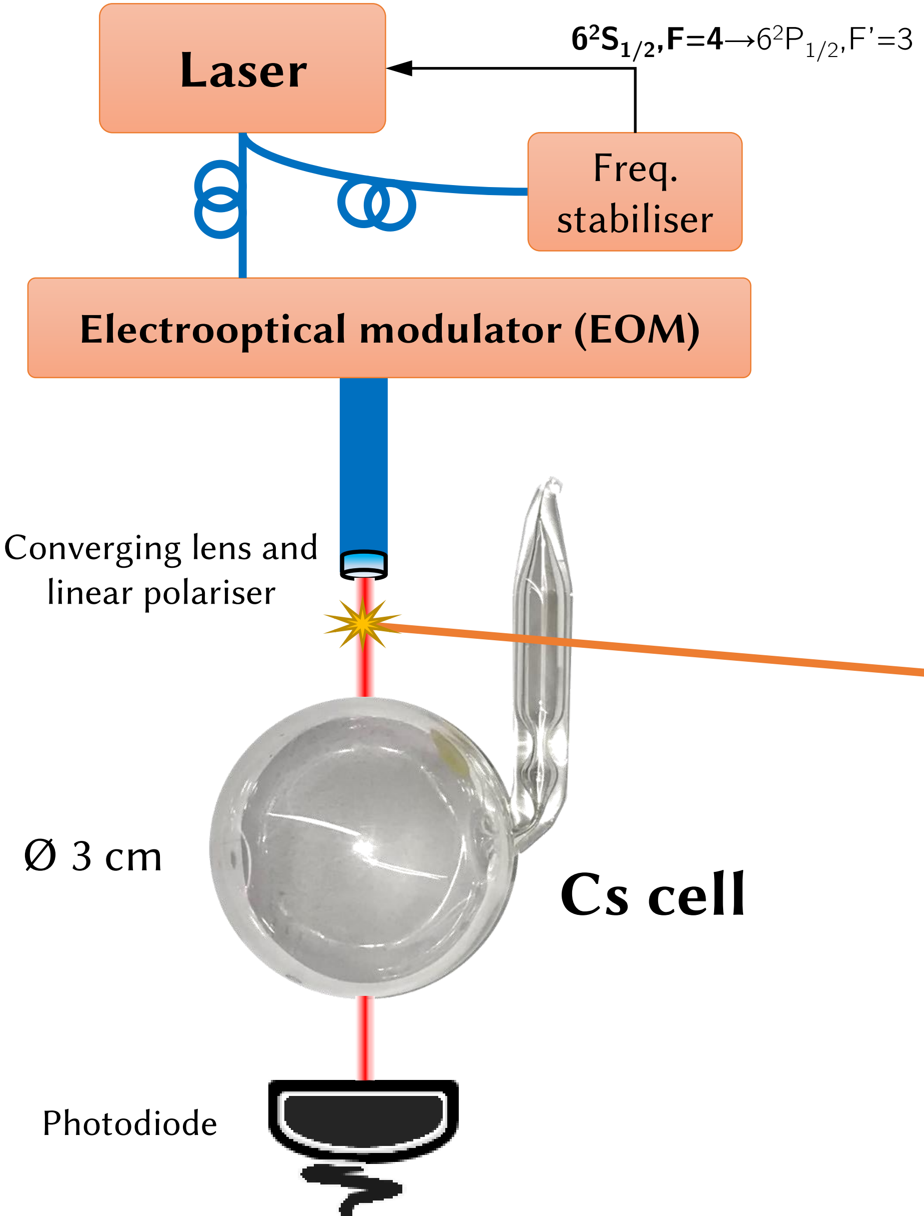
The CsM is based on the Bell-Bloom technique, with linear polarisation, and **it measures** $|\vec{B}|$.

This is achieved by pumping and probing a coherent precession of an **aligned** spin ensemble of Cs atoms.

In order to do so, the light power must be appropriately modulated.

More on Chapter 3 of "Development of the caesium magnetometer array for the n2EDM experiment", Pais 2021

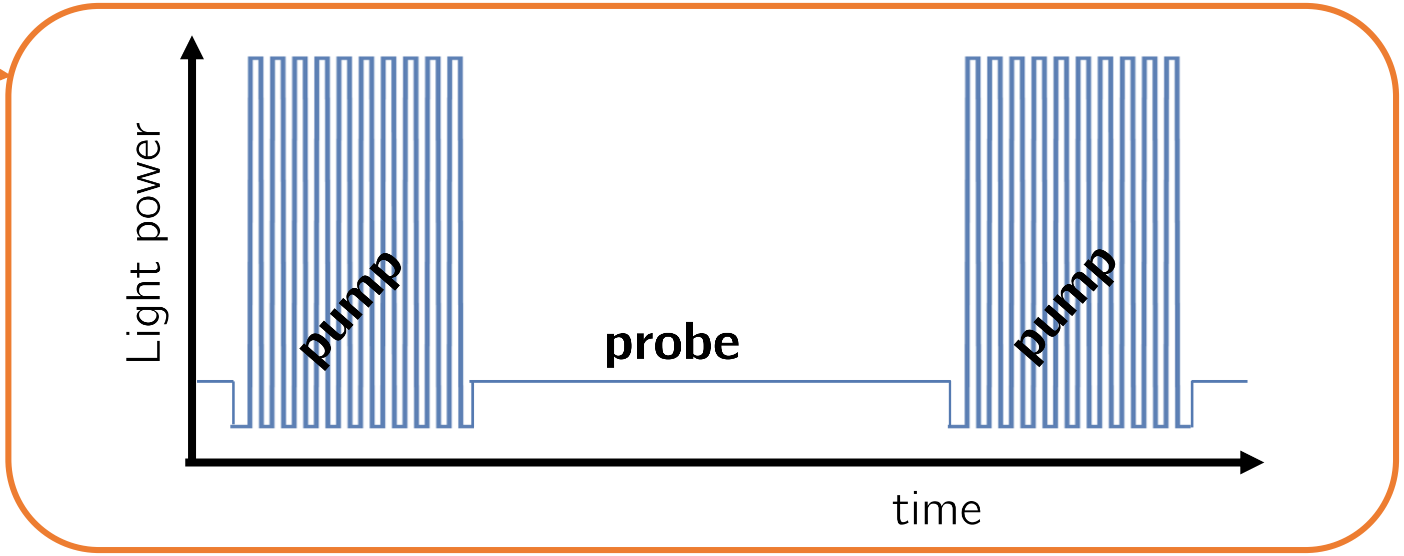
2.1 The measurement: Bell-Bloom magnetometry



The CsM is based on the Bell-Bloom technique, with linear polarisation, and **it measures** $|\vec{B}|$.

This is achieved by pumping and probing a coherent precession of an **aligned** spin ensemble of Cs atoms.

In order to do so, the light power must be appropriately modulated.

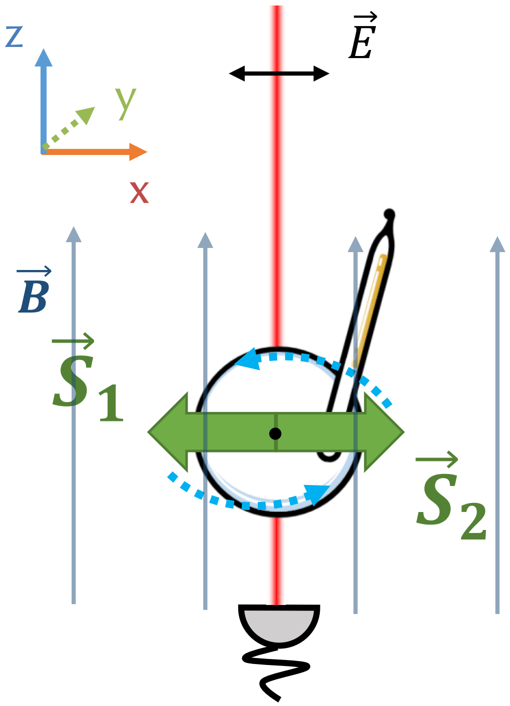


2.1 The measurement: Bell-Bloom magnetometry - probing

Both $\vec{S}_1$ and $\vec{S}_2$ precess with the Larmor frequency $\omega_L = \gamma|\vec{B}|$.

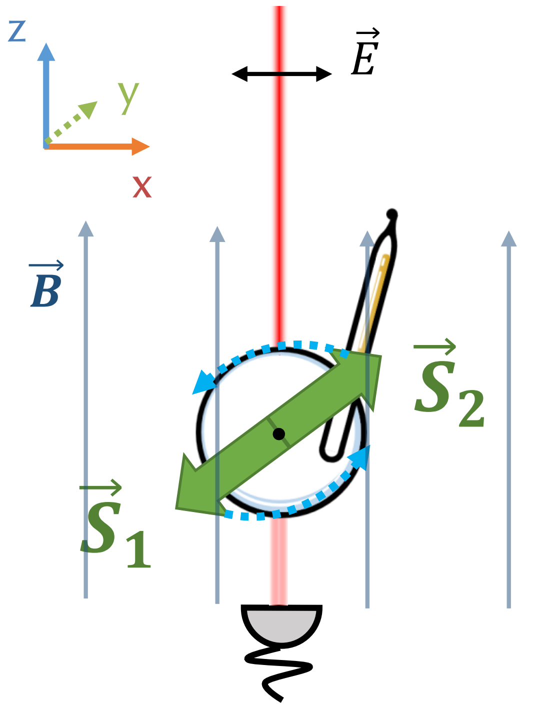
Since the 'head' and 'tail' are indistinguishable, this spin alignment precesses at $2\omega_L$.

Probing precession



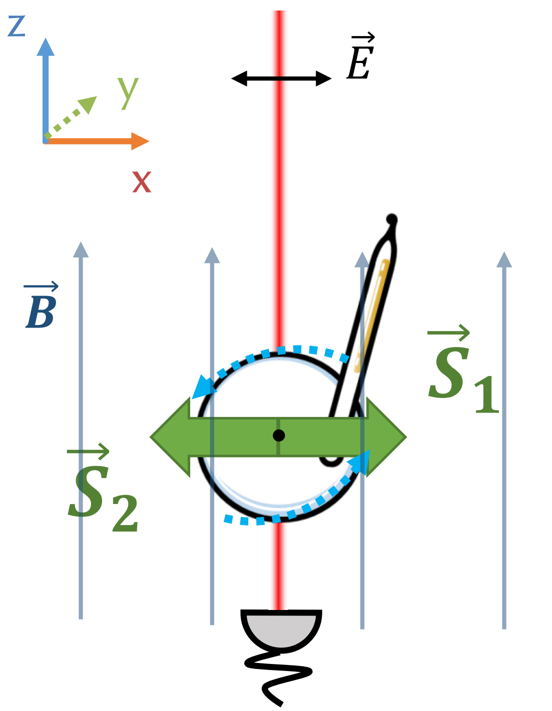
The aligned spins precess freely around $\vec{z}$

Probing precession



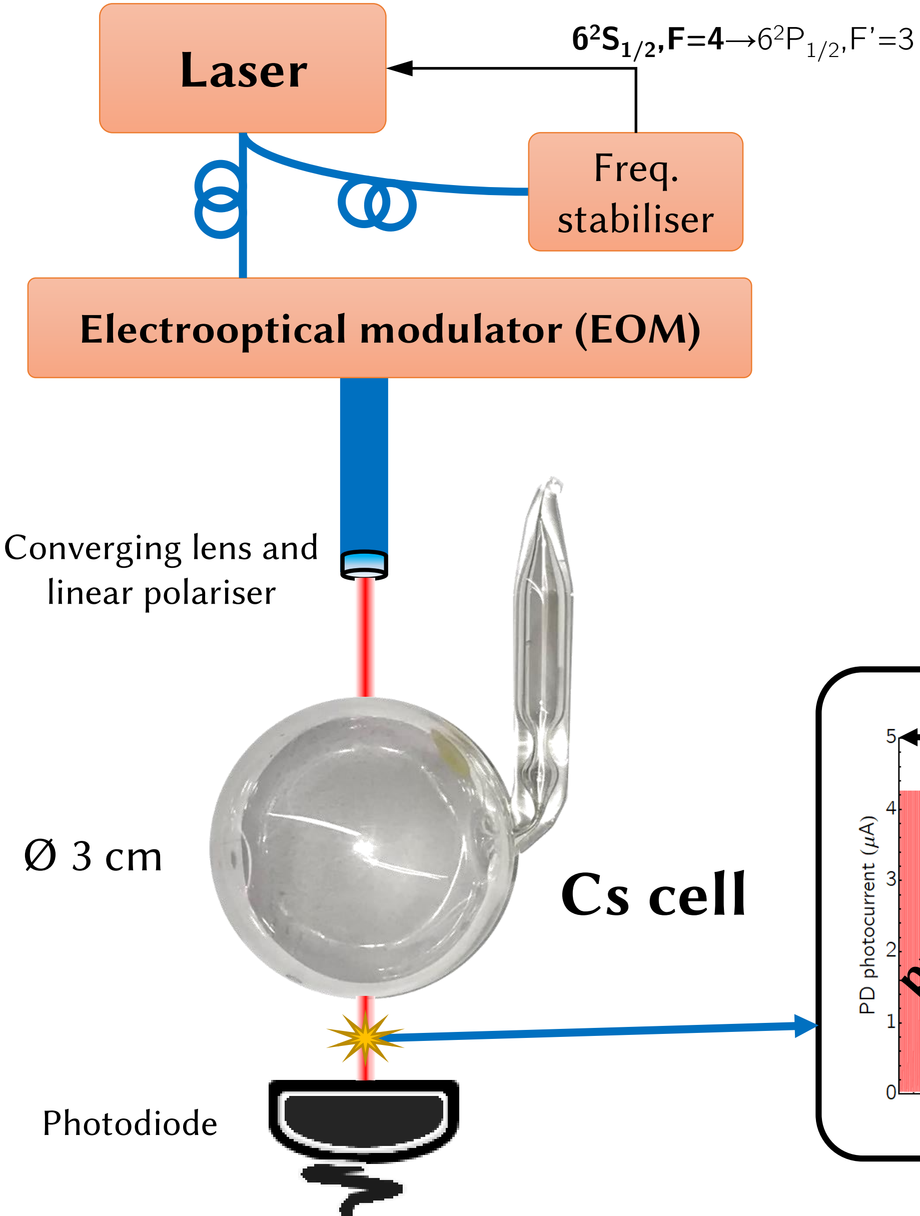
Whenever $\vec{S} \perp \vec{E}$, absorption is at its **maximum**

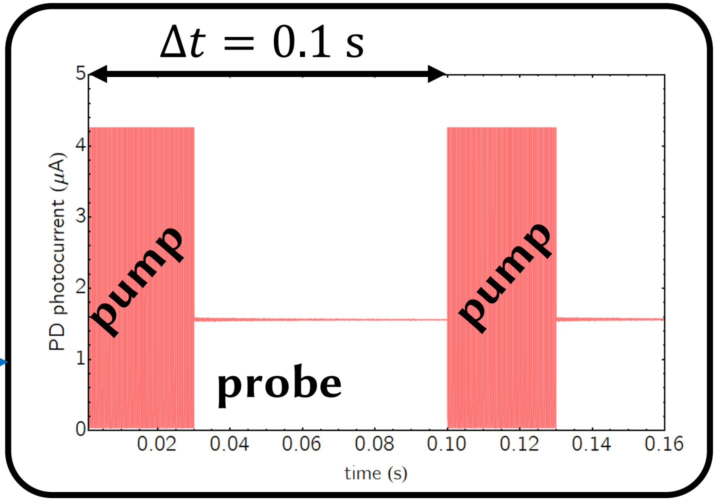
Probing precession



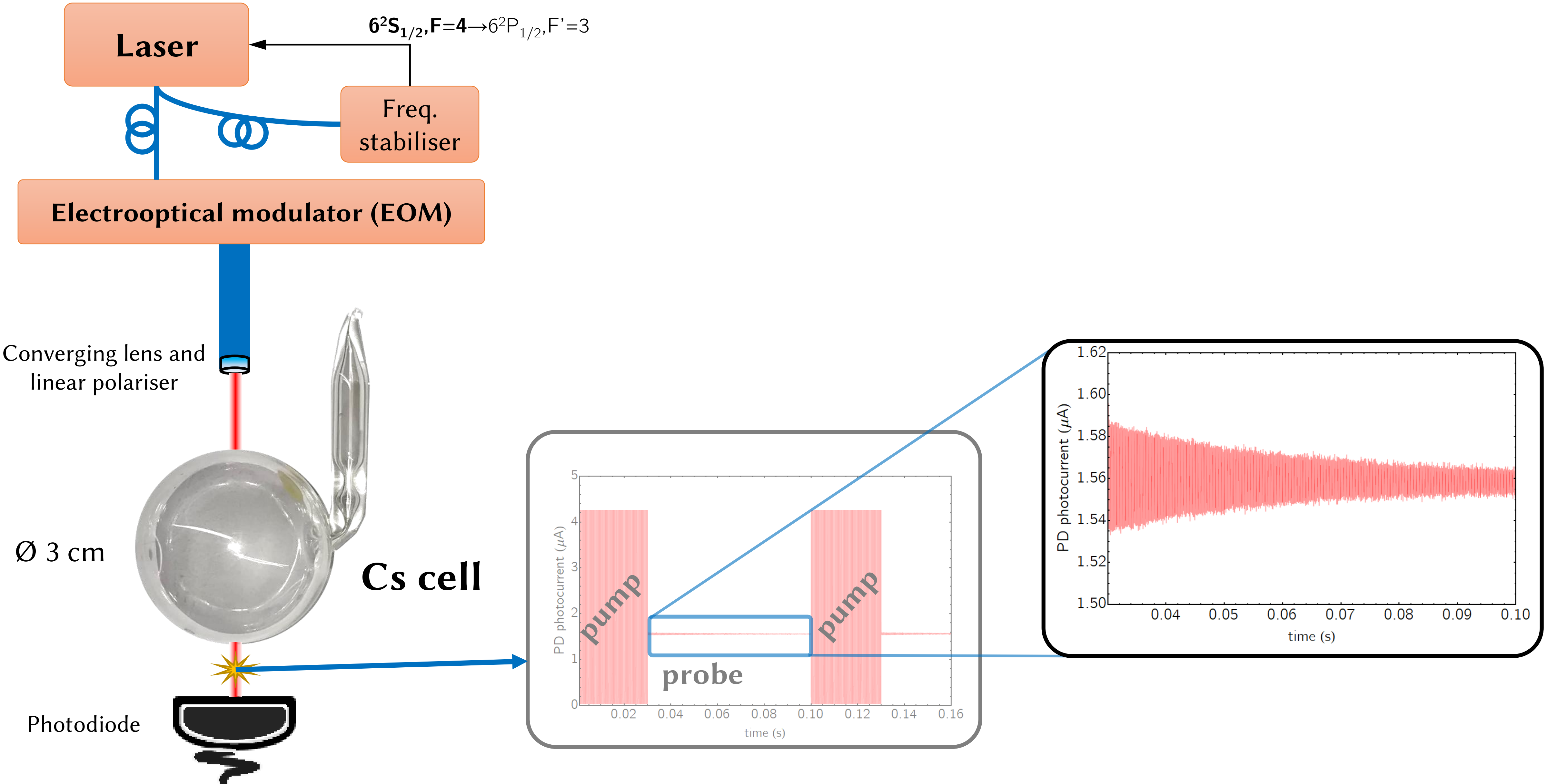
Whenever $\vec{S} \parallel \vec{E}$, absorption is at its **minimum**

2.1 The measurement: Bell-Bloom magnetometry – the signal

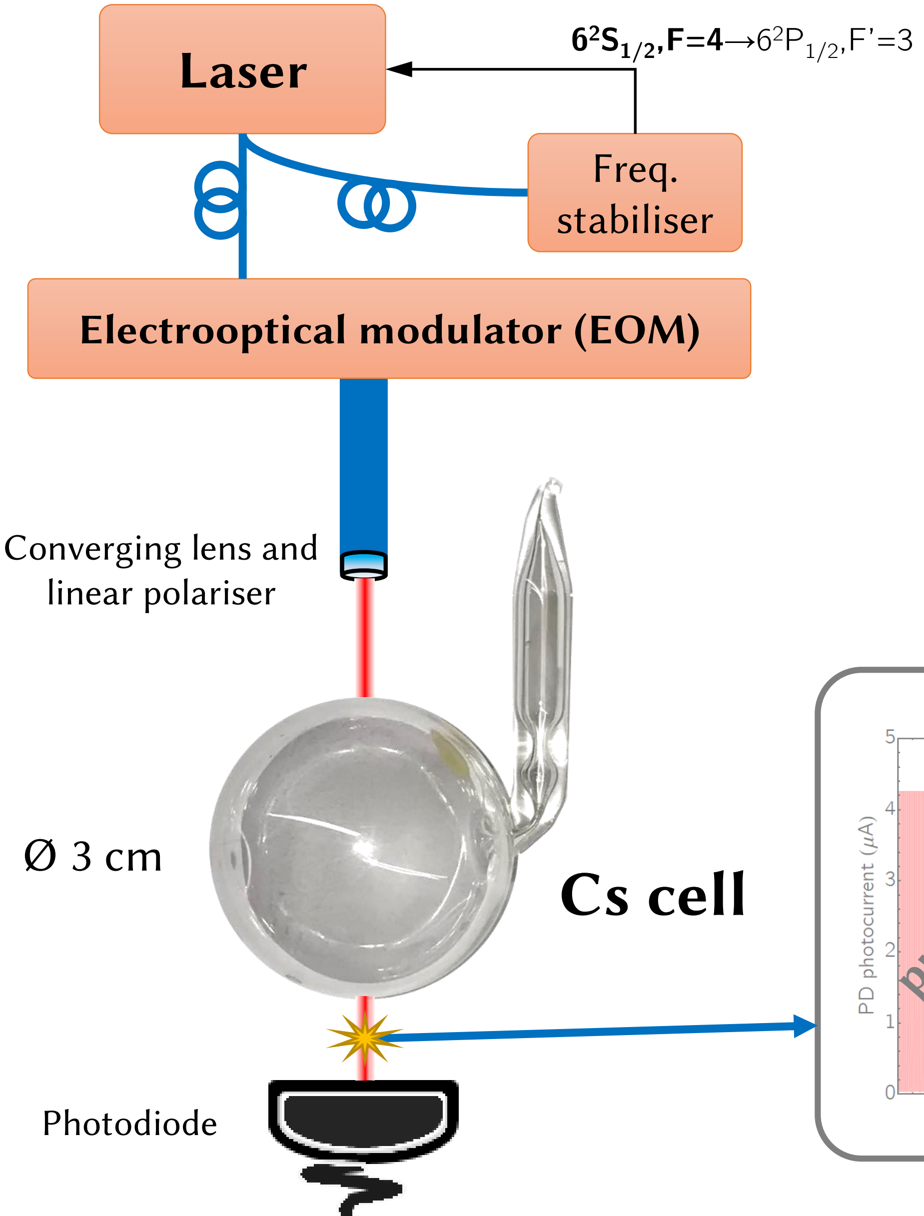


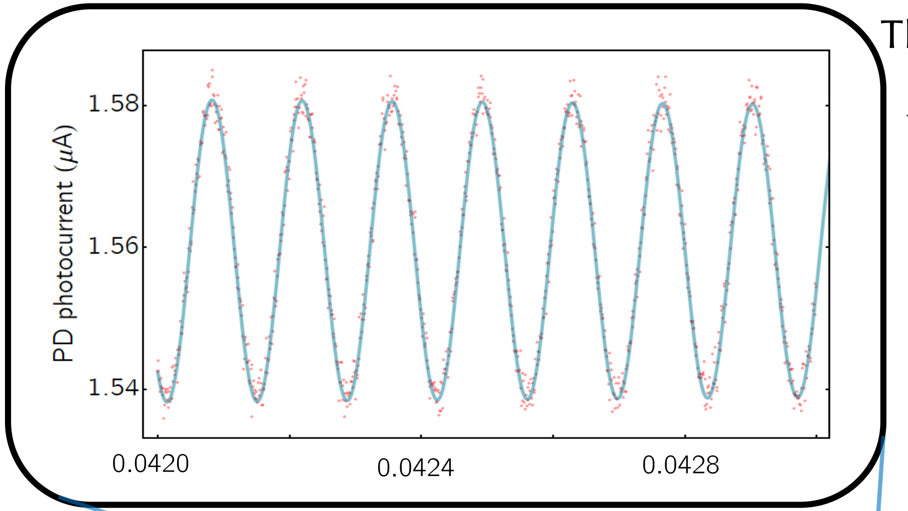


2.1 The measurement: Bell-Bloom magnetometry – the signal



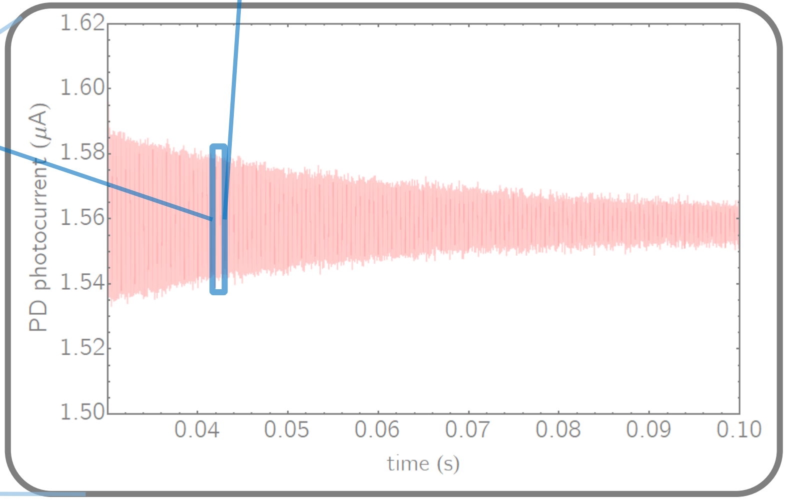
2.1 The measurement: Bell-Bloom magnetometry – the signal

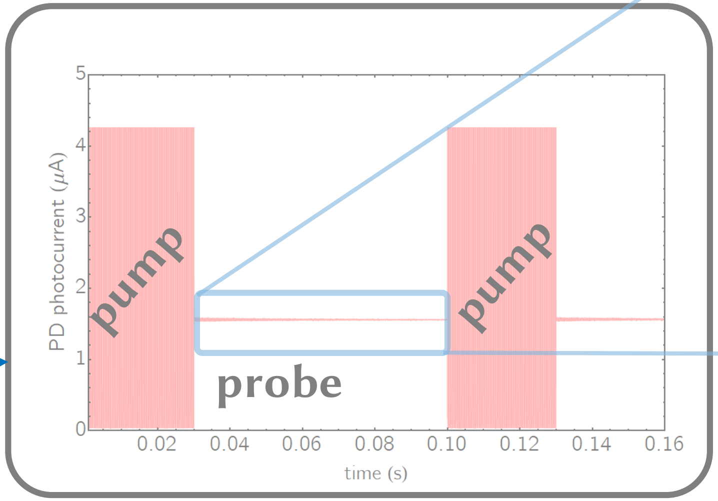




The signal is of the form

$$I(t) = e^{-t/T_2}\sin(2\boldsymbol{\omega_{F=4}}t + \phi) + C$$





2.2 The dual Bell-Bloom measurement

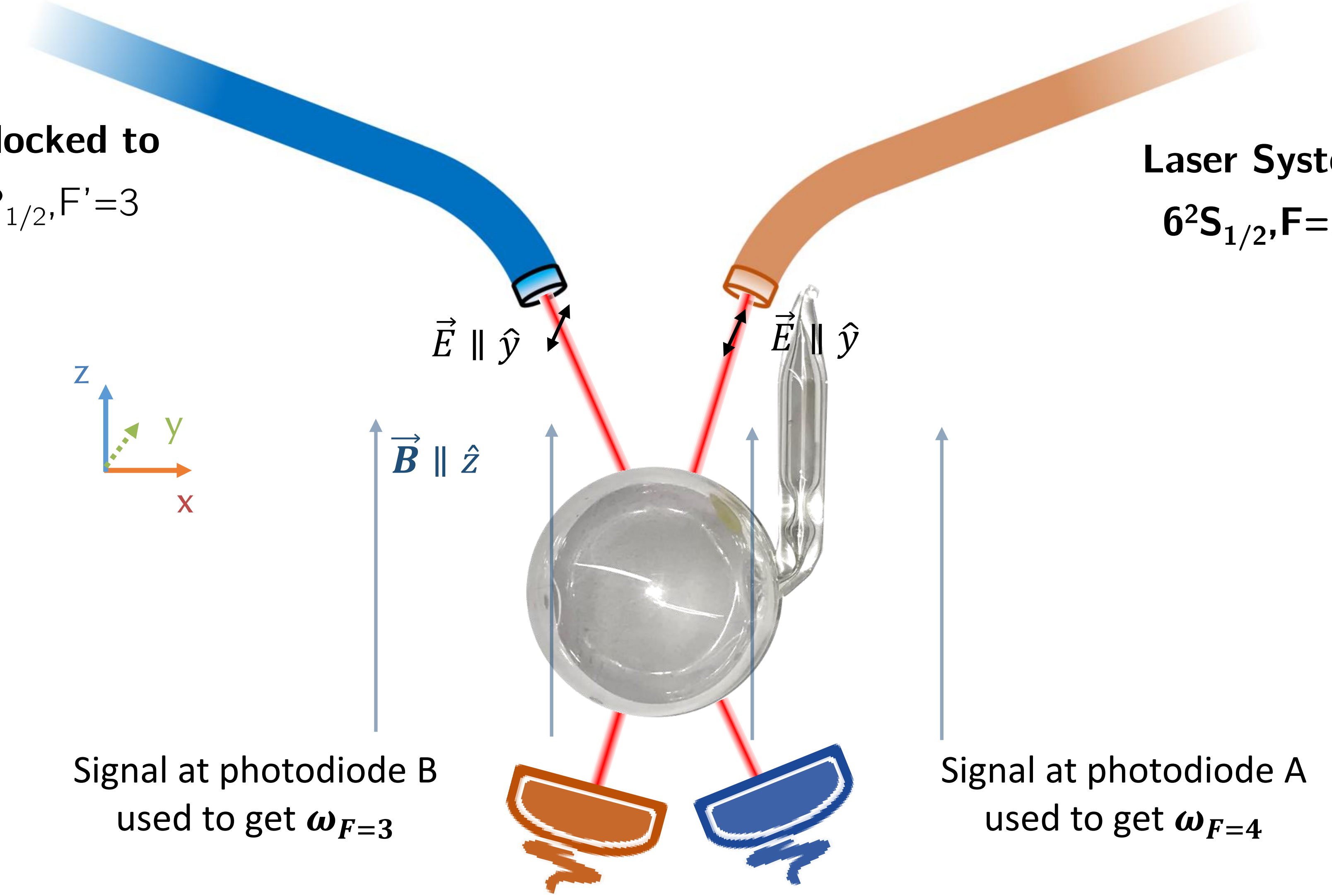
Both $\boldsymbol{\omega_{F=4}}$ and $\boldsymbol{\omega_{F=3}}$ can be **alternatingly** obtained with the following setup

Laser System A locked to

$6^2S_{1/2}$,F=4→$6^2P_{1/2}$,F'=3

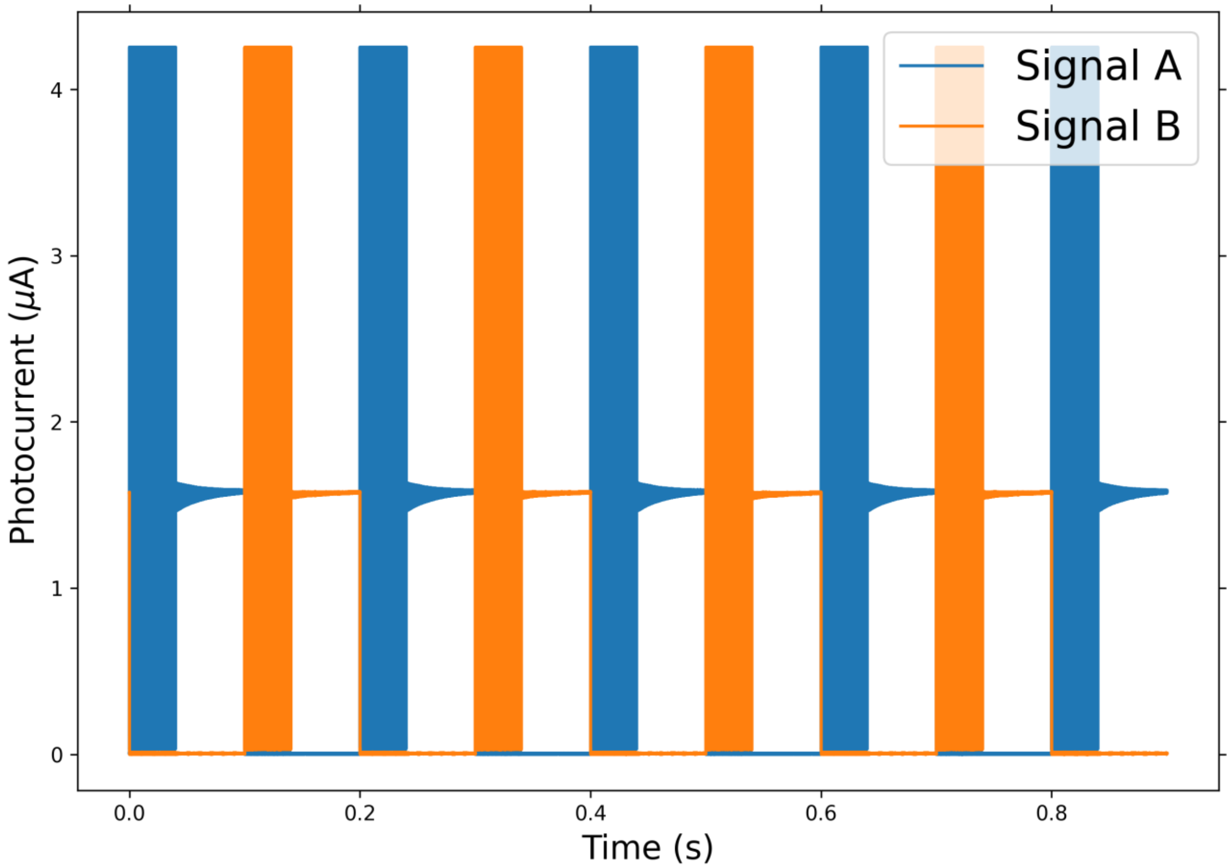
Laser System B locked to

$6^2S_{1/2}$,F=3→$6^2P_{1/2}$,F'=3



2.2 The dual Bell-Bloom measurement

id est...

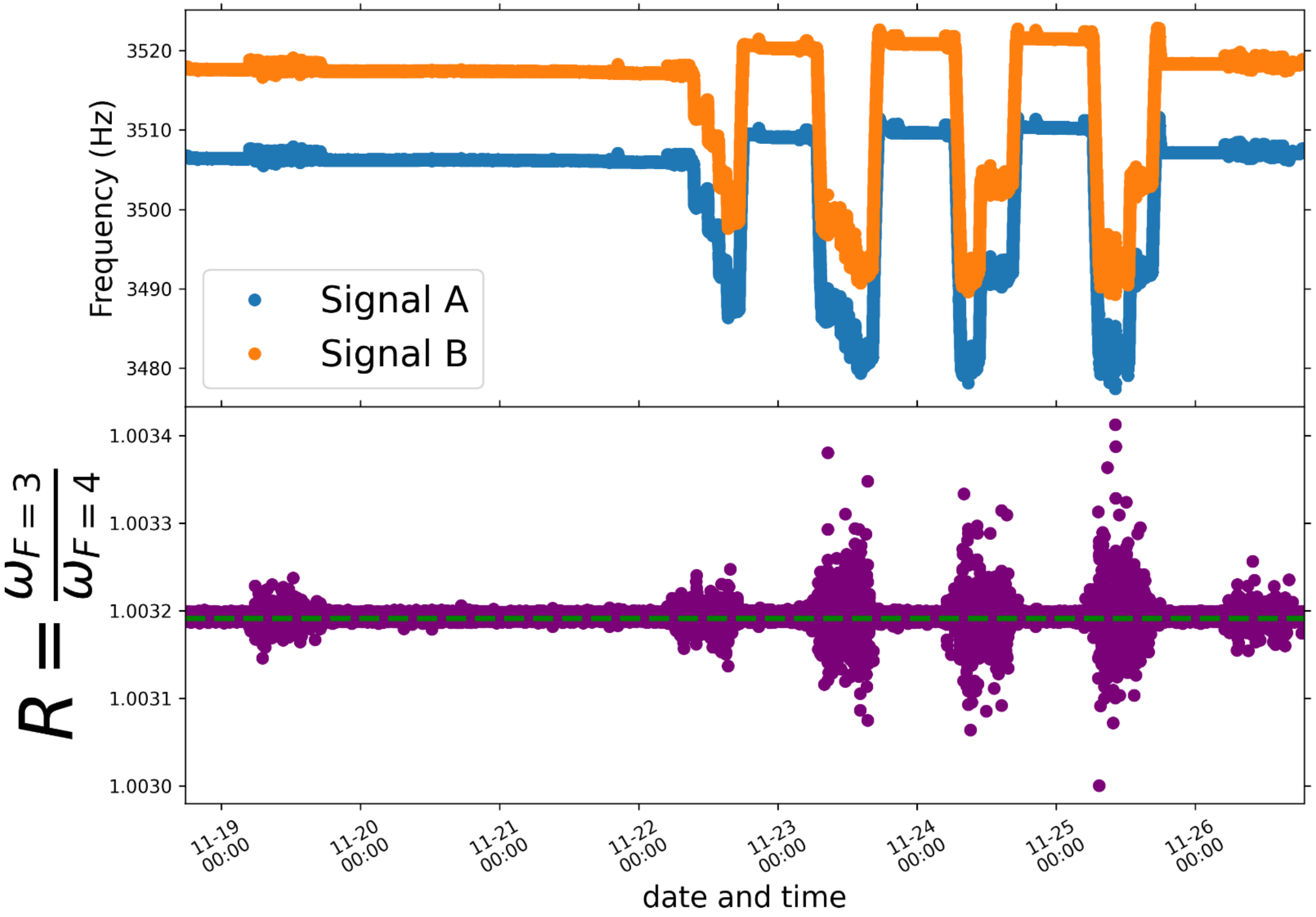


3 Preliminary Analysis

In order to cancel for unknowns drifts, a 3rd order ABBABABBA... was followed.

Initially, a fixed probe light power was chosen, allowing the best ω_F estimation.

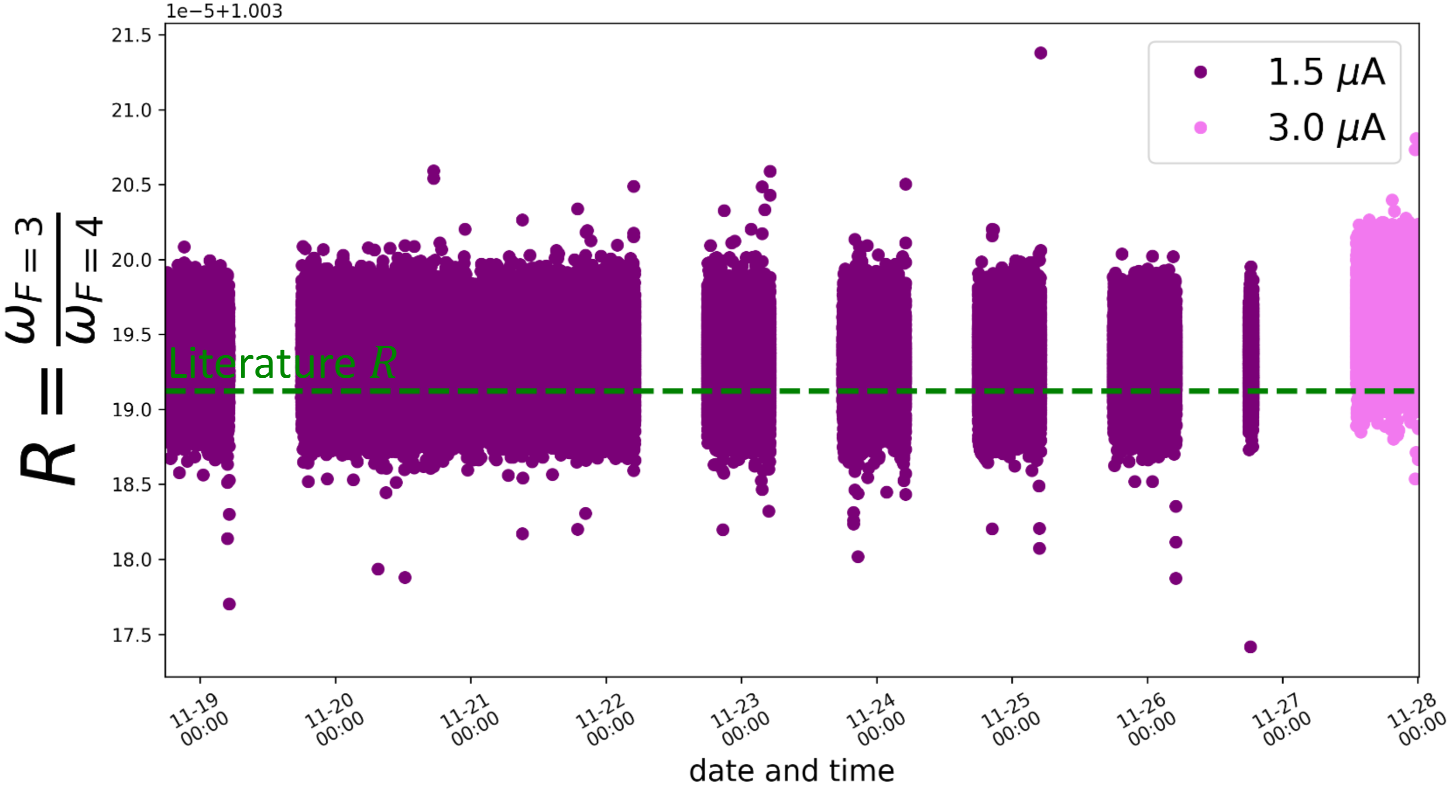
This measurement has been running continuously, whenever possible.



3 Preliminary Analysis

When daytime data is neglected, a clear offset from the literature value of R is visible.

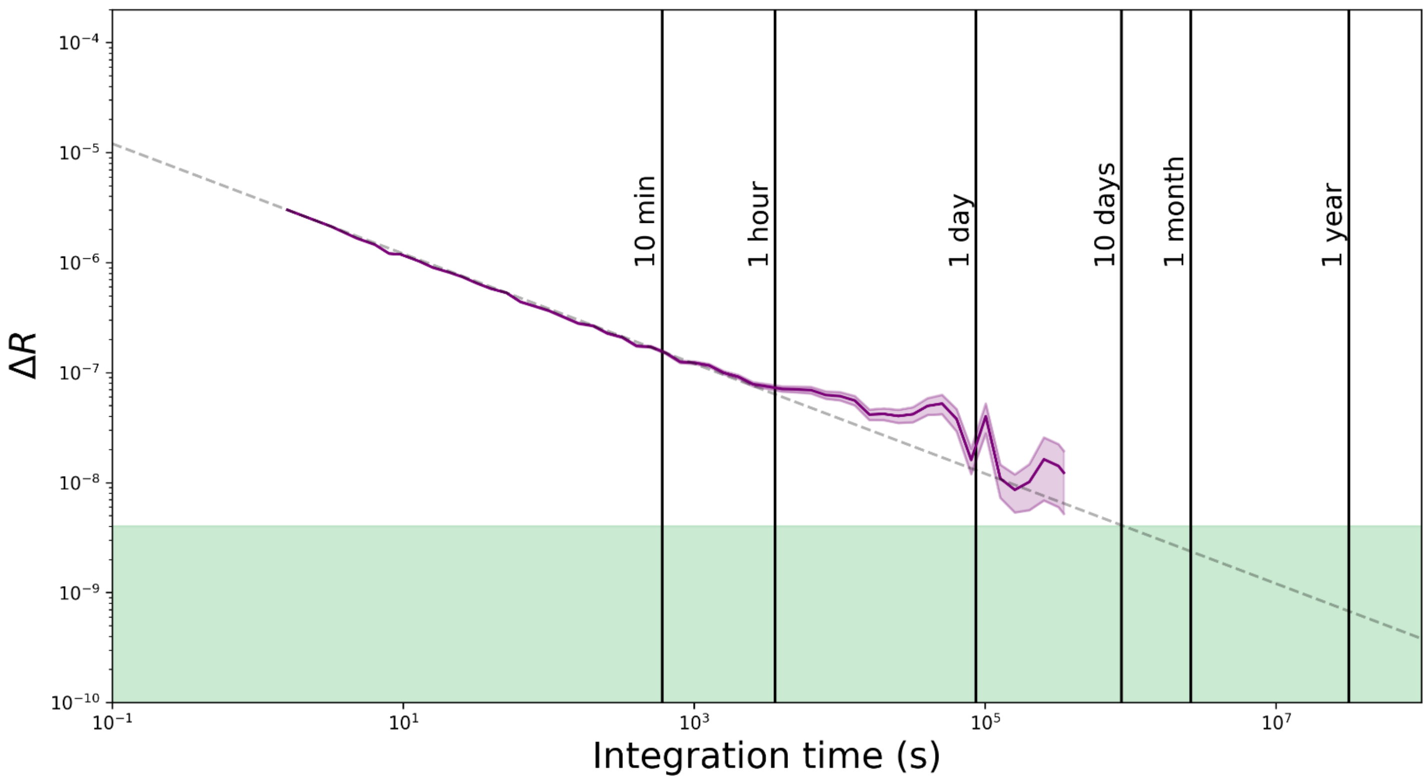
This offset seems to be light intensity dependent.



3 Preliminary Analysis

Doing an Allan standard deviation vs. integration time plot for the first batch of data indicates that the ΔR limit to improve Δg_I can be achieved between 10 days and 1 month.

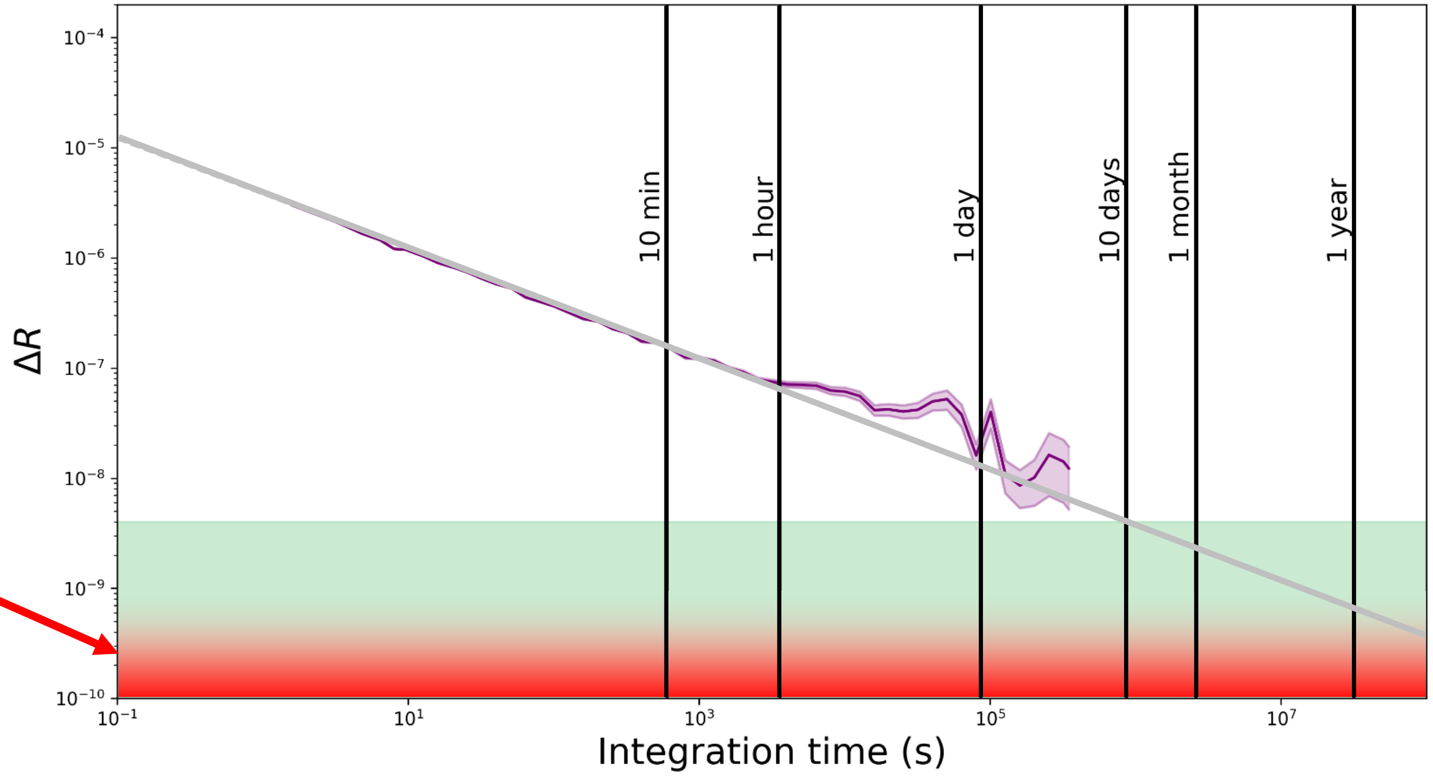
However, light intensity corrections need to be taken into account.



3 Preliminary Analysis

According to Bevington et al. PR A 032804 (2020), such a measurement of ΔR can be used to probe axion-wind effects (for both axion-nucleon and axion-electron interactions).

Much more stringent limits are required though, of the order of $\Delta R{\sim}10^{-10}$.



Conclusion

1. The measurement of the larmour precession frequency of both hyperfine ground states of ^{133}Cs could potentially be used to improve Δg_I

2. A measurement type is suggested: the dual Bell-Bloom magnetometer.

3. The analysis is ongoing. The current plan is to take care of the probe light power dependency of $R = \frac{\omega_{F=3}}{\omega_{F=4}}$

Merci Vielmals!