Analysis of the FID signal of the Hg comagnetometer of the nEDM experiment at PSI

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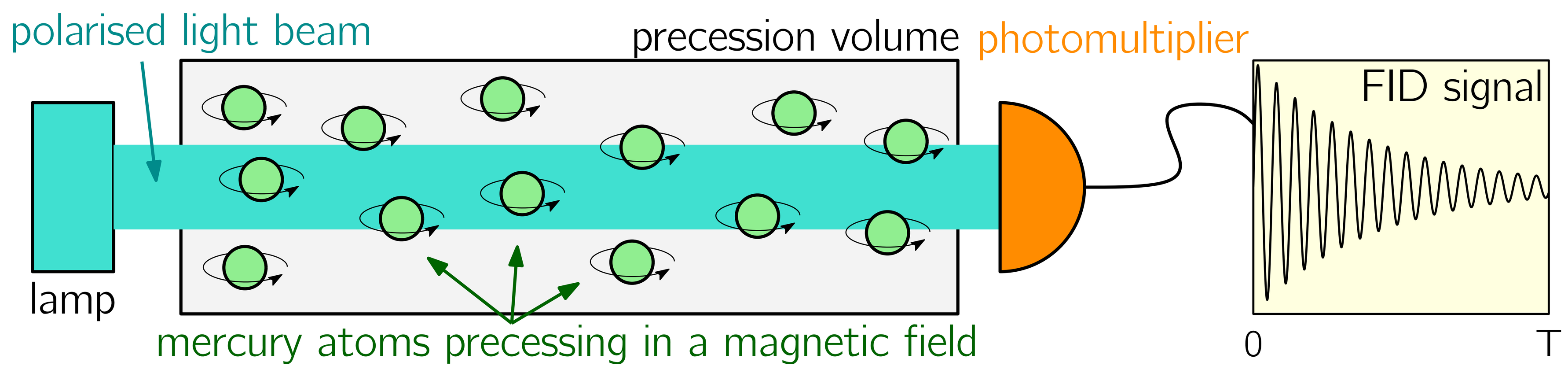
Introduction

The purpose of the ^{199}Hg comagnetometer is to measure the average magnetic field in the precession volume during the free precession period [1]. The comagnetometer generates a damped oscillation signal called a *Free Induction Decay* (FID). As the magnetic field in the precession volume is known to drift, the FID's frequency drifts, too. These changes often exceed the precision of the comagnetometer. Therefore, the frequency of the FID signal cannot be assumed to be constant. Having that in mind, one needs to find a good estimator of the average frequency of the FID signal.



The estimation method

The average magnetic field can be estimated with phases found at the boundaries of the FID signal [2]:

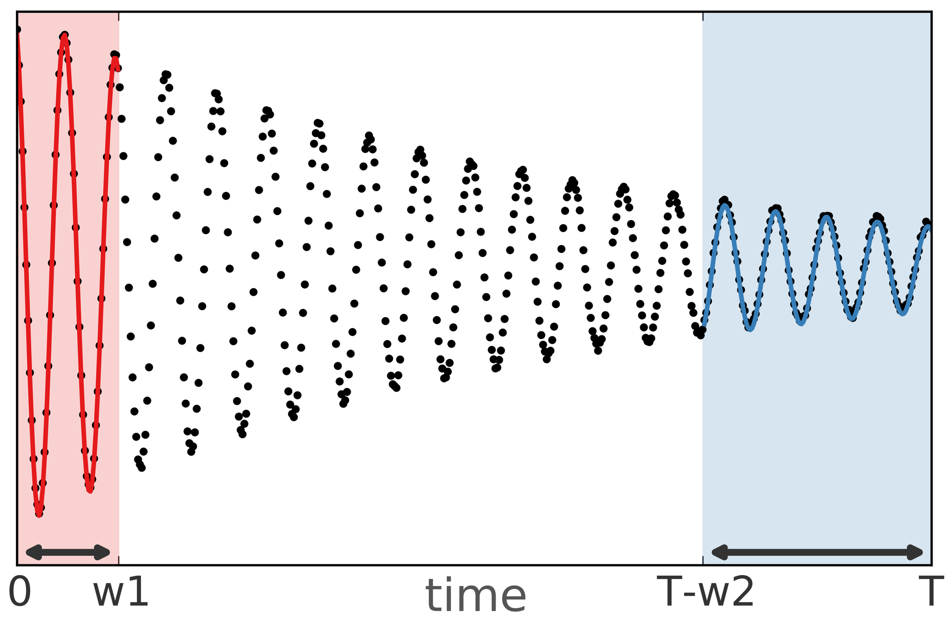
$$\langle B \rangle \propto \langle f \rangle = \frac{1}{T}\int_0^T f(t)\,\mathrm{d}t = \frac{\phi(T)-\phi(0)}{2\pi T}$$

Both $\phi(0)$ and $\phi(T)$ are estimated with a least squares fit to data in a *window* of a chosen length. The frequency is assumed to be constant in each of the two *windows*.

There are two major questions regarding this $\langle f \rangle$ estimator:

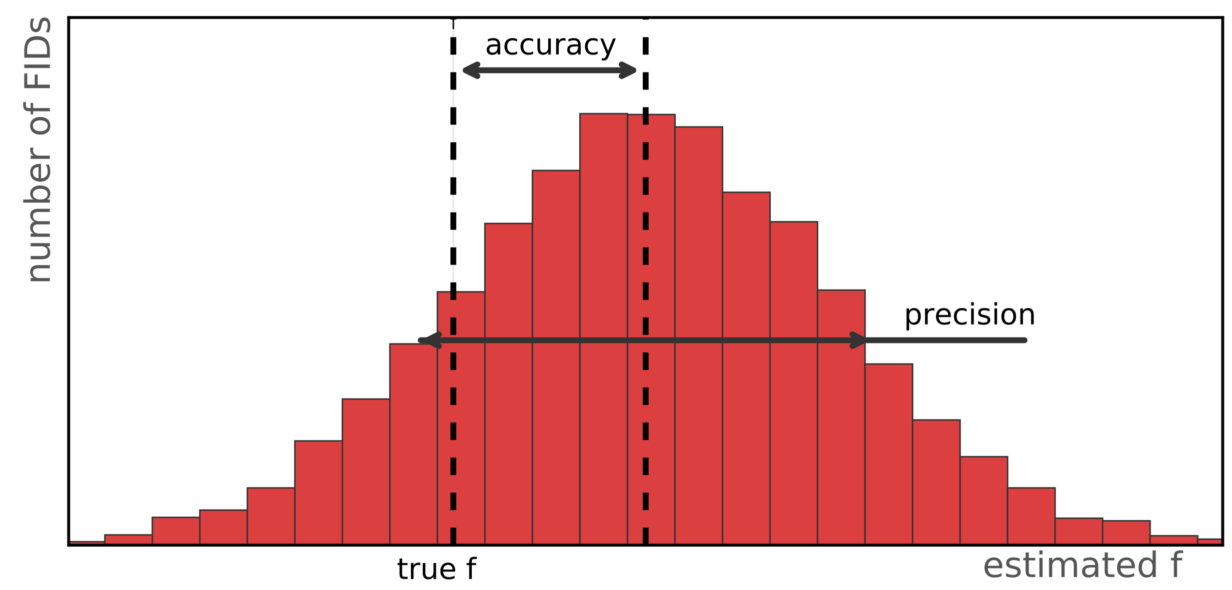
How large should the windows be?

How big is the systematic effect due to the constant frequency assumption?



Accuracy and precision of the estimator

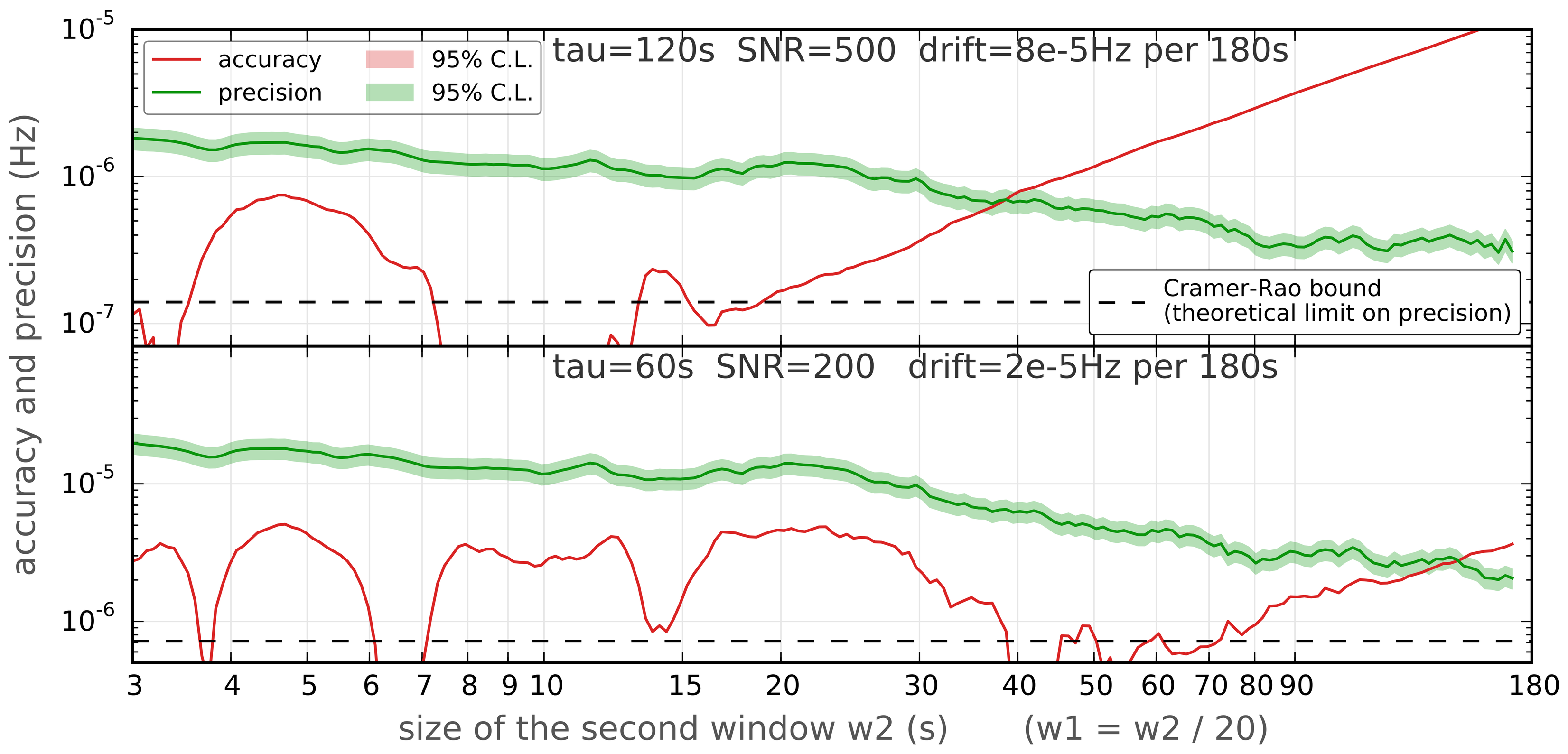
Accuracy is defined as an **average shift** with respect to the real value. *Precision* is a **spread of results**. Analyzing a set of simulated FIDs with an assumed $f(t)$ (and thus known $\langle f \rangle$) allows one to directly calculate both accuracy and precision of the estimation.



As such an approach is external to the estimation method itself it also serves as a test of the precision estimator $s(\langle f \rangle)$.

Optimization of the estimator

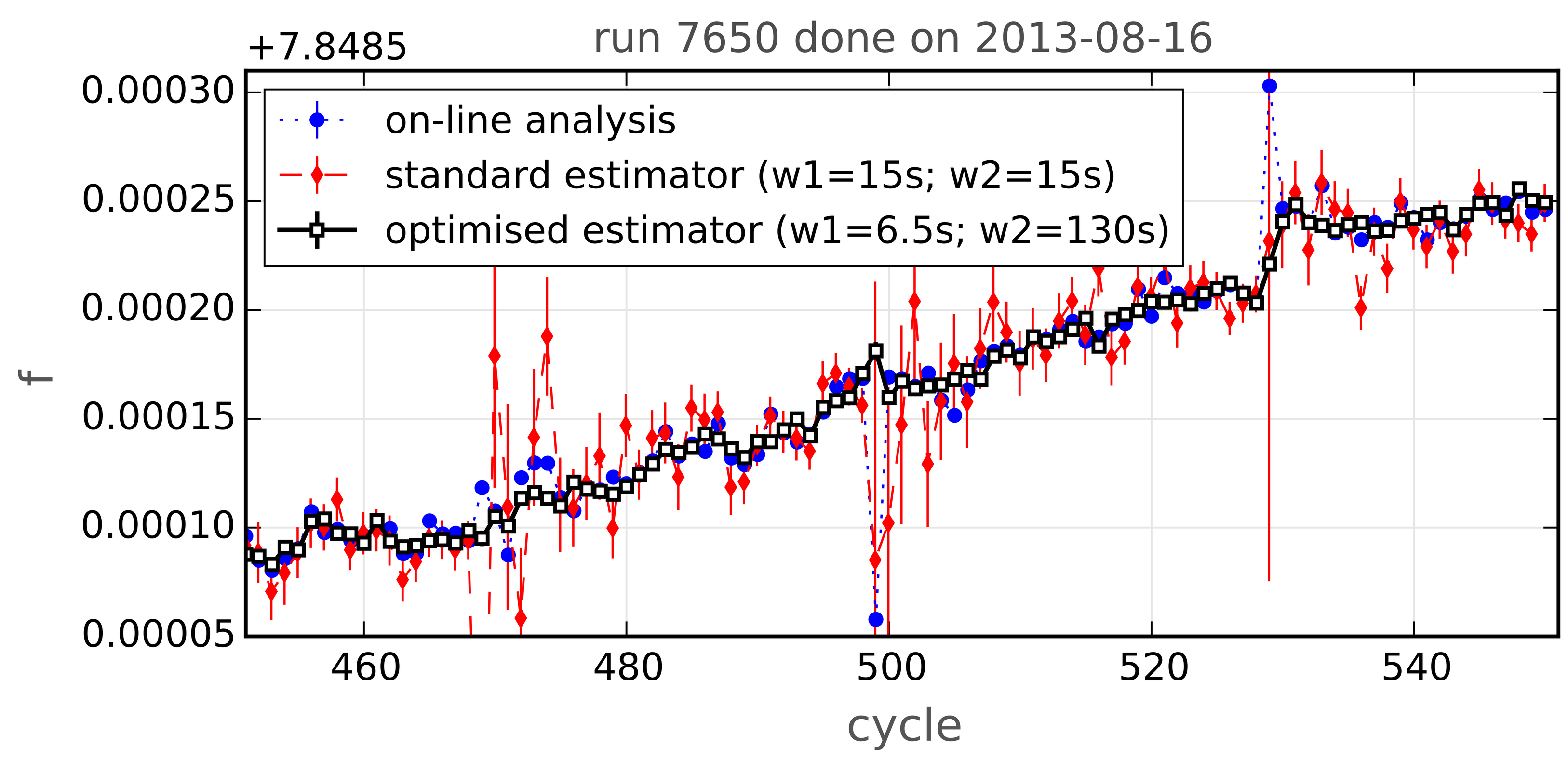
The $\langle f \rangle$ estimator can be optimized by calculating accuracy and precision as the function of the sizes of the windows. The plot shows that enlarging the windows improves the precision, but worsens the accuracy. The reason is the frequency drift which makes the constant frequency assumption invalid for large windows.



The second window should be larger to have $\sigma(\phi(0)) \approx \sigma(\phi(T))$.

The proposed analysis scheme

1. FIDs are analysed with initial sizes of the windows, e.g. $w_1 = 1\,\mathrm{s}$, $w_2 = 10\,\mathrm{s}$.
2. The results are used to assess the properties of the FIDs: signal-to-noise ratio and relaxation time.
3. Analysis of the $\langle f \rangle$ evolution across subsequent FIDs is used to assess drifts in $f(t)$.
4. A set of FIDs with properties close to the ones to be analysed is simulated.
5. The simulated FIDs are used to optimize w_1 and w_2, as well as to assess the systematic errors.
6. The FIDs are analysed with the optimized estimation method.



References

[1] C. A. Baker et al. Apparatus for measurement of the electric dipole moment of the neutron using a cohabiting atomic-mercury magnetometer. 2013.

[2] Y Chibane et al. Minimum variance of frequency estimations for a sinusoidal signal with low noise. Measurement Science and Technology, 6(12):1671, 1995.

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