Vibrating Sample Magnetometry

Theoretical principle

Faraday's law of induction

$$V(t) = -\frac{\mathrm{d}\phi_B}{\mathrm{d}t} \tag{1}$$

$$\phi_B = \iint_S \vec{B}\,(\vec{r}, t) \cdot \mathrm{d}\vec{A} = BS \tag{2}$$

$$\implies V(z, t) = -NS\frac{\mathrm{d}B}{\mathrm{d}z}\frac{\mathrm{d}z}{\mathrm{d}t} \tag{3}$$

Magnetization

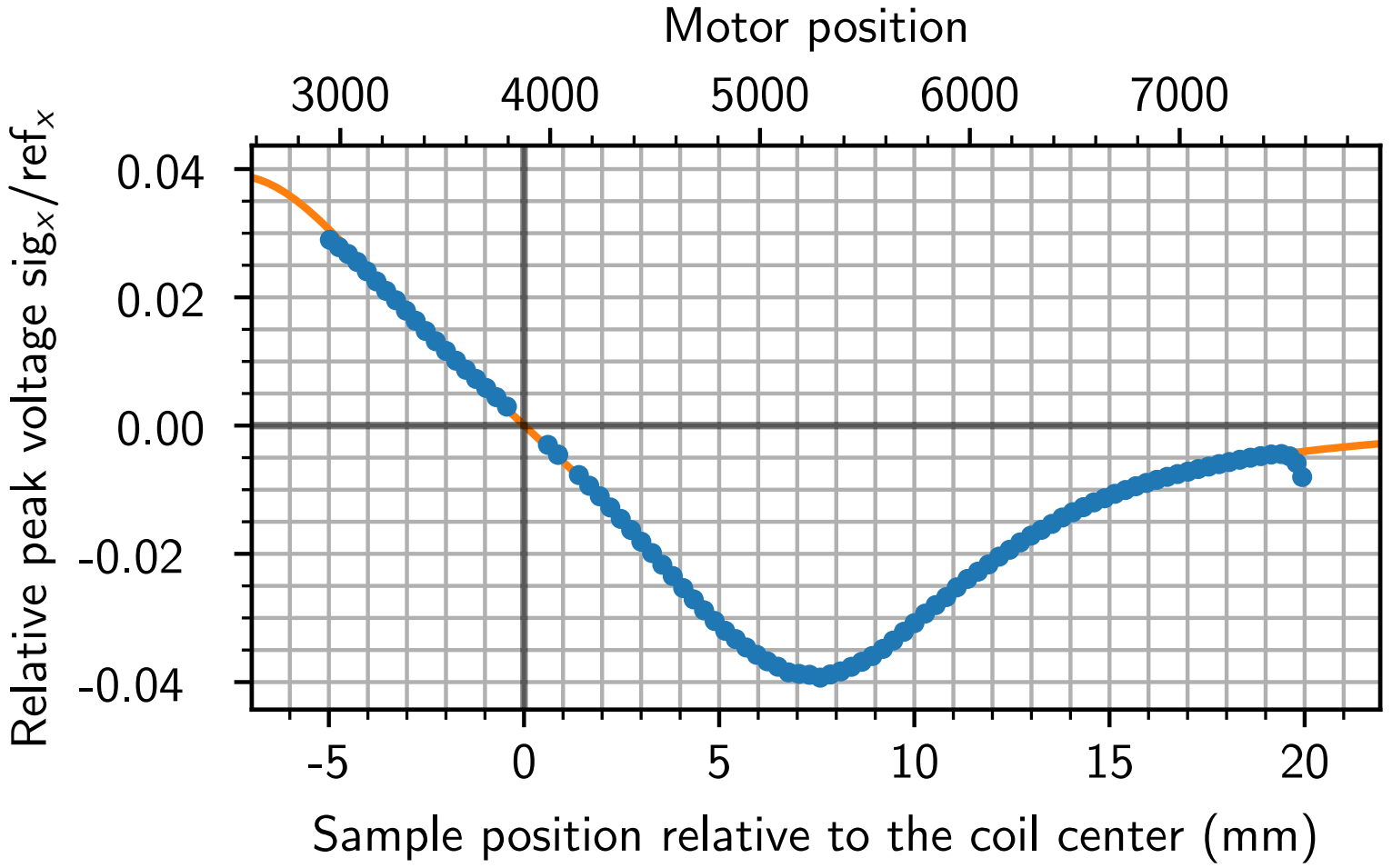
- **Paramagnetism:** Magnetic moment of unpaired electrons
- **Diamagnetism:** Lorentz force on electrons in orbitals

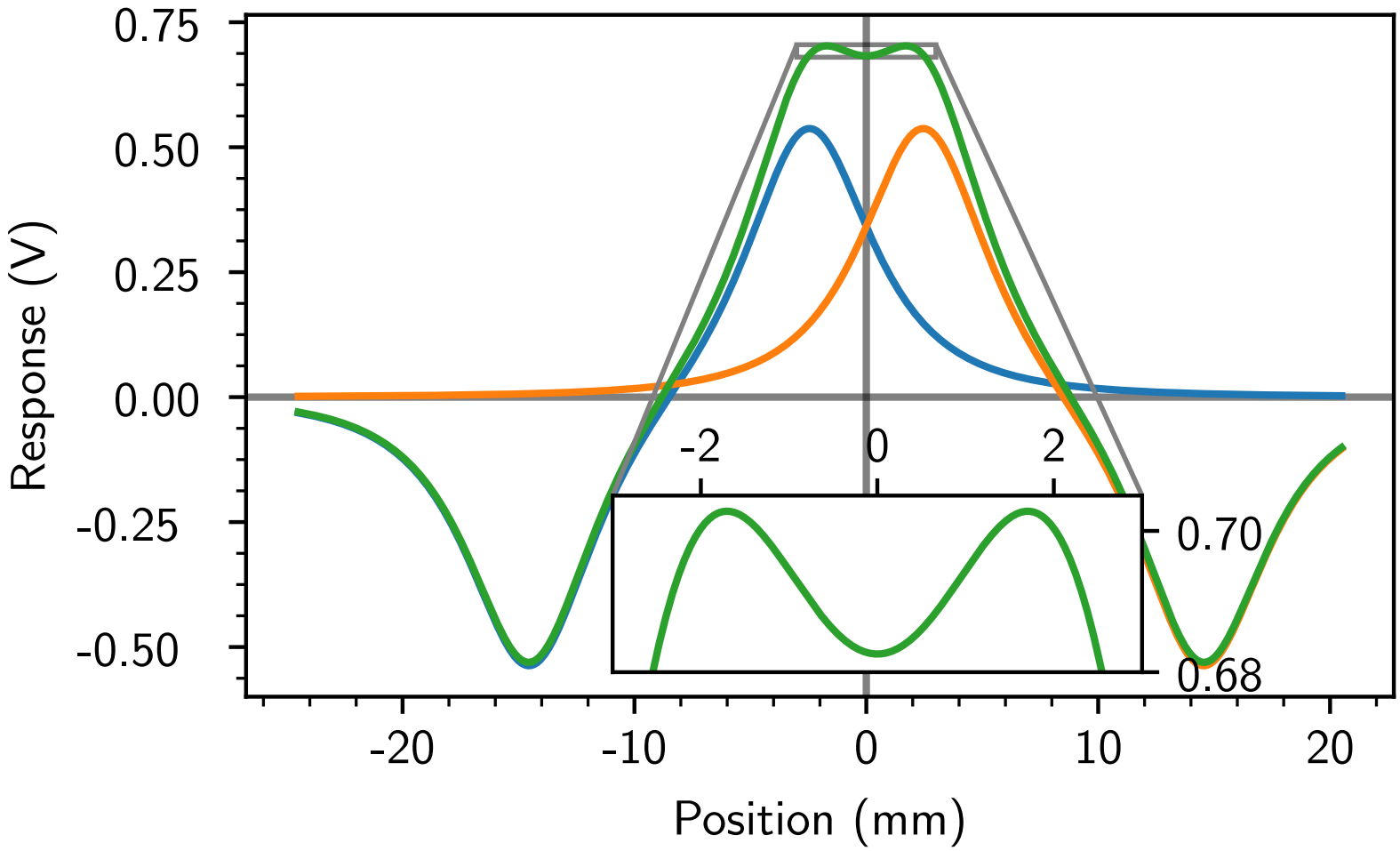
Theoretical principle

Induction on one pickup coil

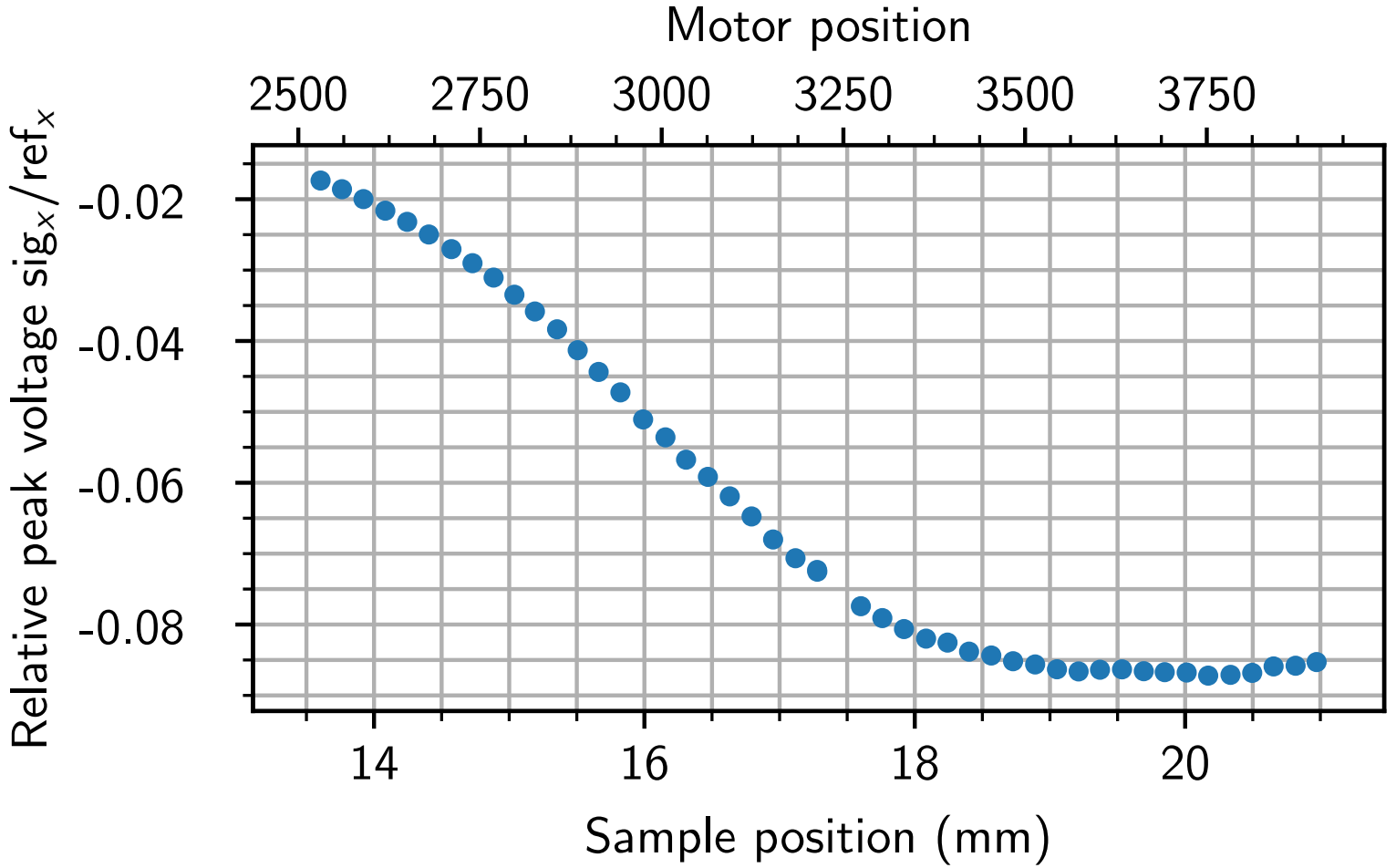
$$V(z) = -NASI\mu_0 \frac{f\pi}{\sqrt{2}} \left[\ln\left(r_2 + \sqrt{r_2^2 + (z-L)^2} \right) - \ln\left(r_1 + \sqrt{r_1^2 + (z-L)^2} \right) + \right.$$
$$(z-L)^2 \left(\frac{1}{r_2\sqrt{r_2^2 + (z-L)^2} + r_2^2 + (z-L)^2} - \frac{1}{r_1\sqrt{r_1^2 + (z-L)^2} + r_1^2 + (z-L)^2} \right) +$$
$$\ln\left(r_1 + \sqrt{r_1^2 + z^2} \right) - \ln\left(r_2 + \sqrt{r_2^2 + z^2} \right) +$$
$$\left. z^2 \left(\frac{1}{r_1\sqrt{r_1^2 + z^2} + r_1^2 + z^2} - \frac{1}{r_2\sqrt{r_2^2 + z^2} + r_2^2 + z^2} \right) \right] \tag{4}$$

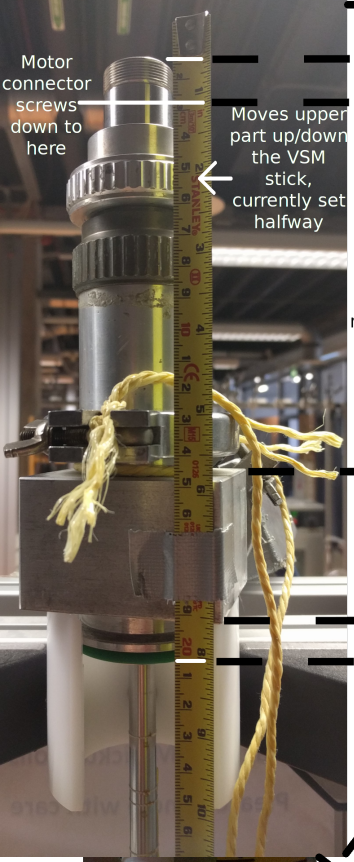
One pickup coil, permanent magnet: 30.9 mg




0.75
0.50
0.25
0.00
-0.25
-0.50
Response (V)
-20
-10
0
10
20
Position (mm)
-2
0
2
0.70
0.68

All 4 pickup coils, Nickel: 42.5 mg **at** 2 T **(Room Temperature)**





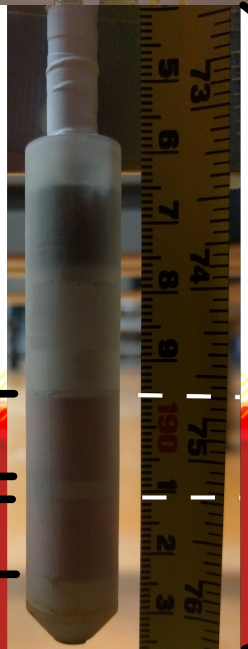
15

149±12

Note that moving the upper part will (only) change these lengths

210 ±12

44



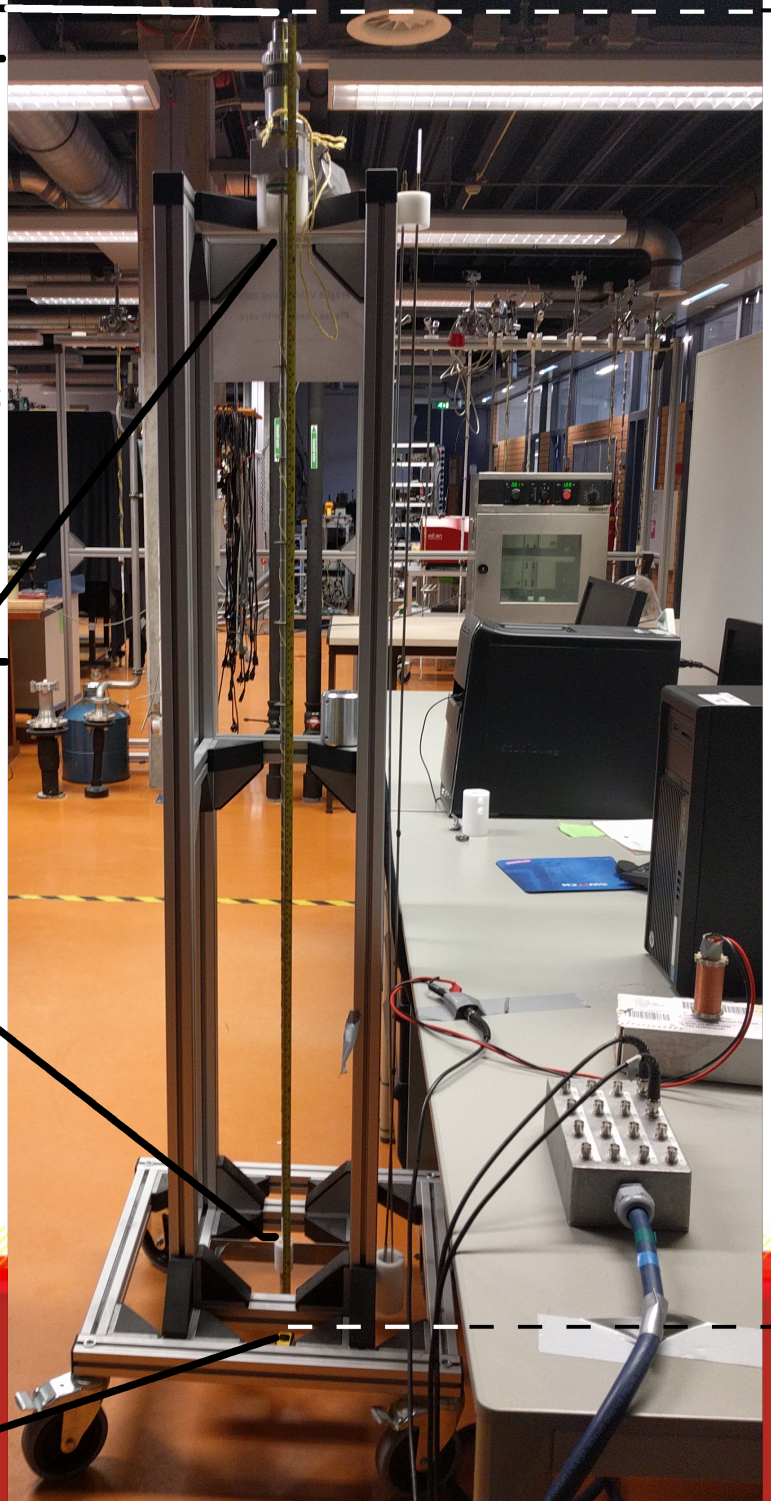
1895

1910

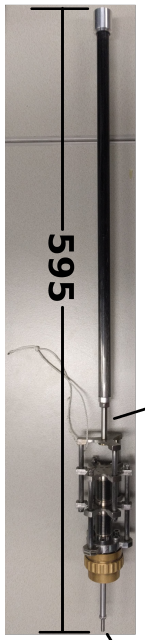
12

3

12



1935



595

372

In rest: 103
Max: 115
Min: 91

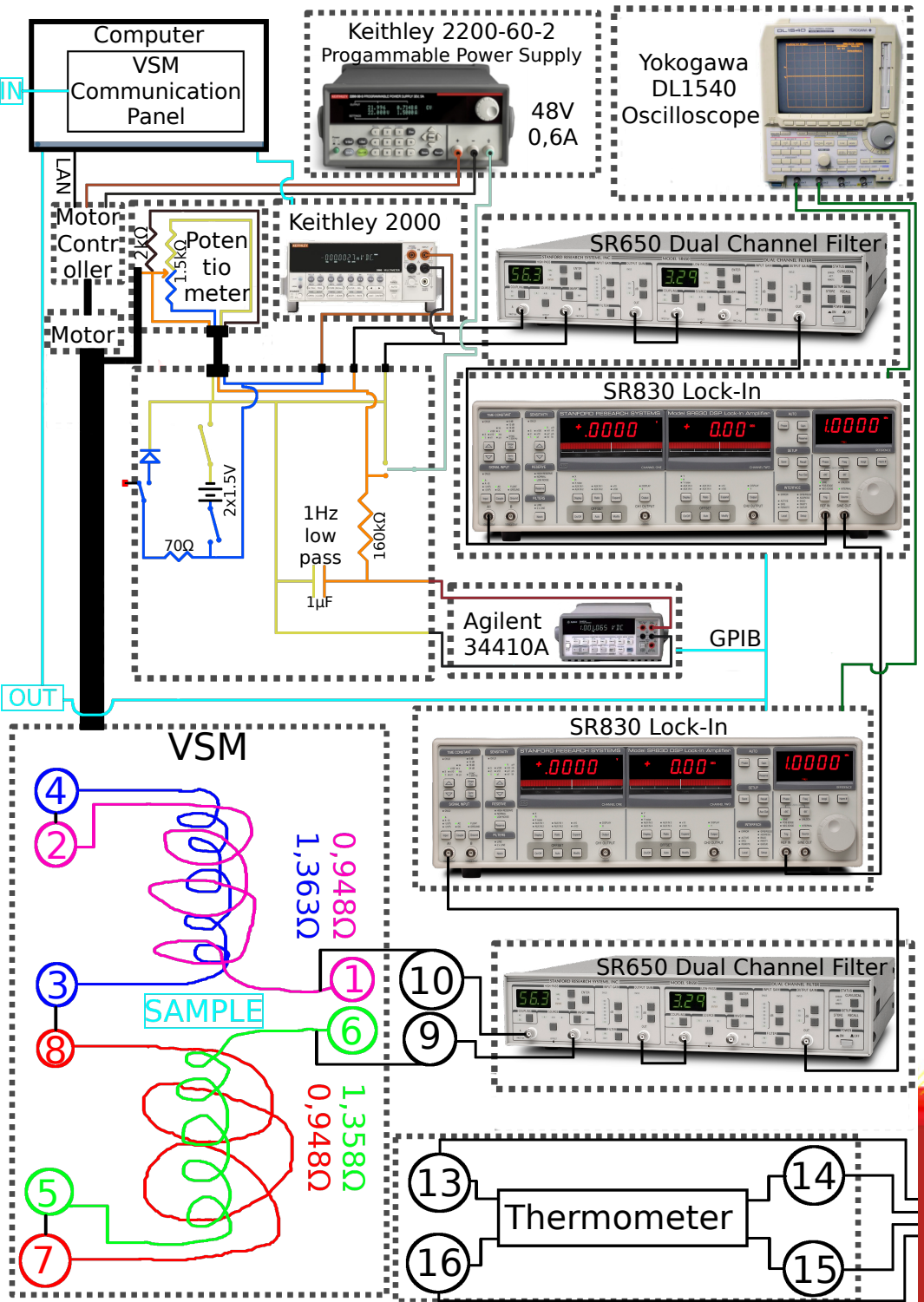
15

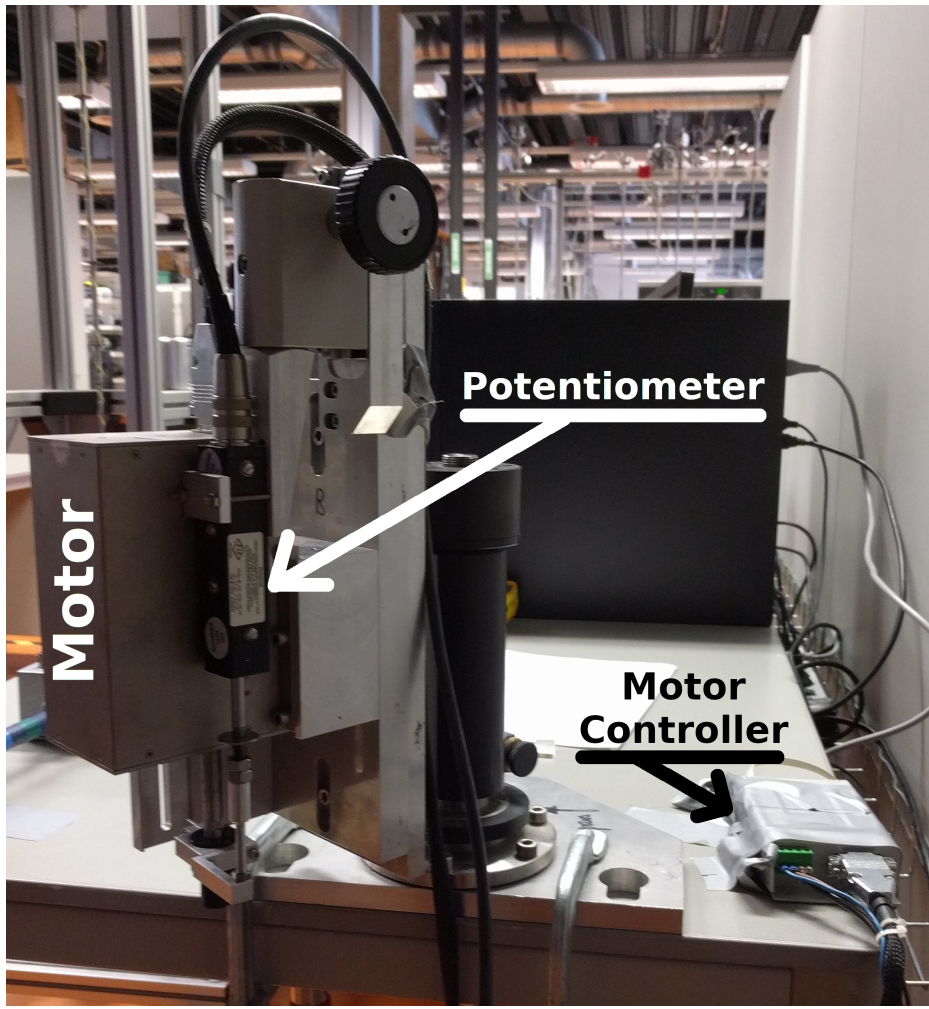
44

14

Radboud University

IN DEI NOMINE FELICITER

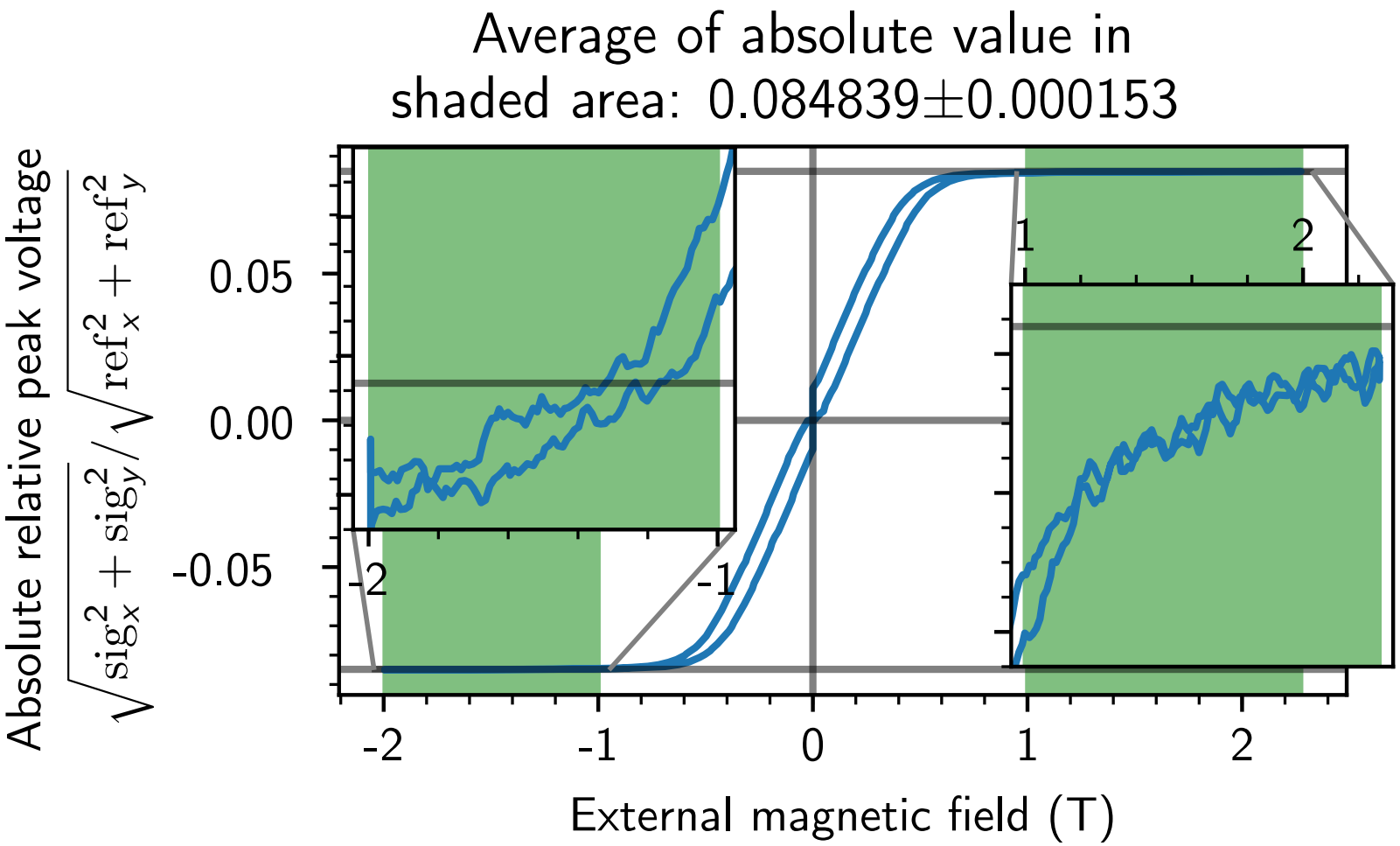




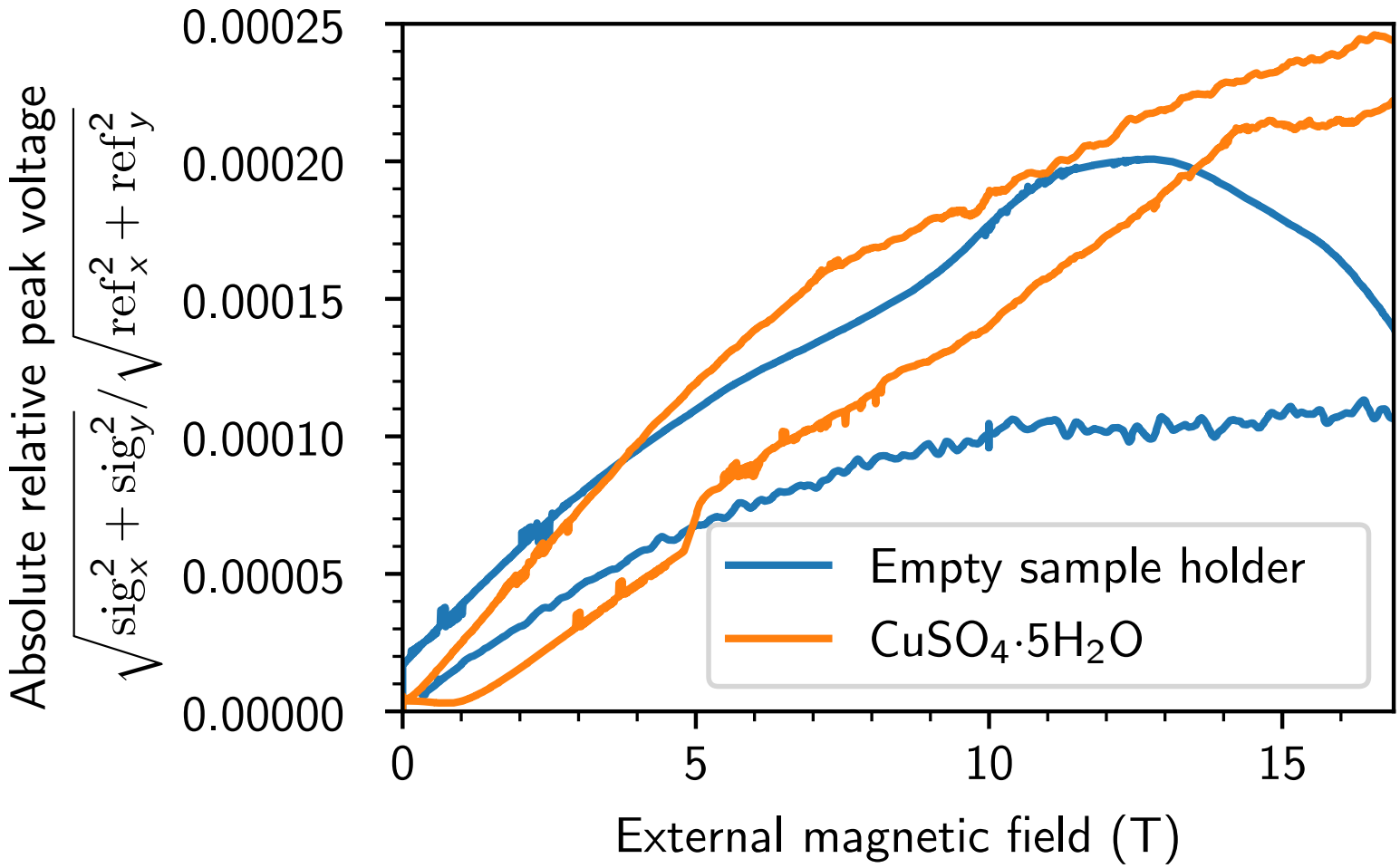
Radboud University

Nickel: 42.5 mg **(Room Temperature)**

(58.57 ± 0.03) emu/g $\Longrightarrow$ (2.489 ± 0.002) emu $\Longrightarrow$ c=(29.34 ± 0.06) emu

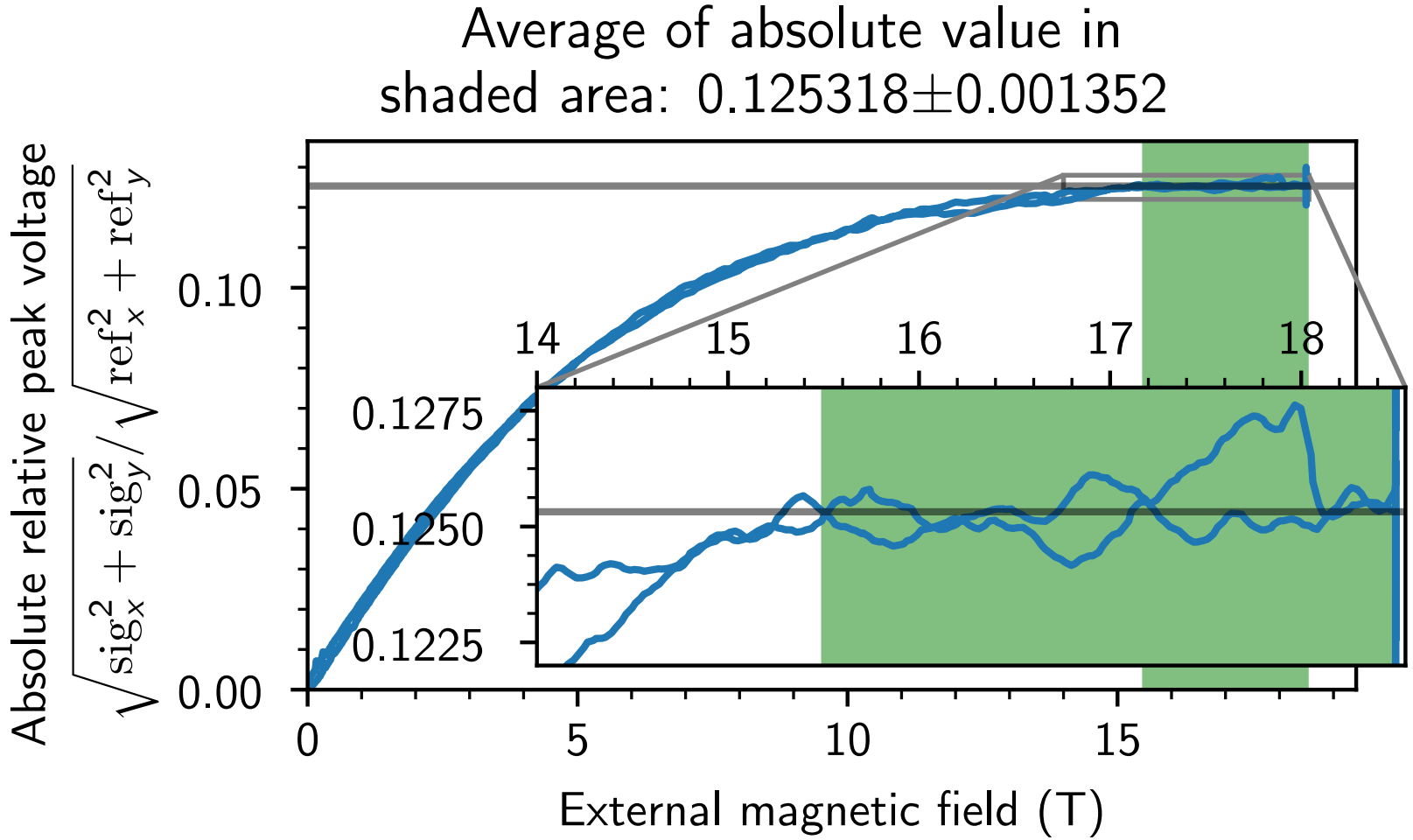


$CuSO_4 \cdot 5\,H_2O$: 143 mg (Room Temperature)



$CuSO_4 \cdot 5\,H_2O$: 143 mg **(4 K)**

c=(29.34 ± 0.06) emu $\Longrightarrow$ (3.67 ± 0.04) emu $\Longrightarrow$ (25.7 ± 0.3) emu/g



Sanity Check

- Paramagnetic Cu^{2+} ions: Spin $1/2$
- $2\sqrt{s\,(s+1)} = \sqrt{3}\ \mu_B$
- $CuSO_4 \cdot 5\,H_2O$: 249.684 u
- $\Longrightarrow$ 39 emu/g
- Diamagnetic contributions of H_2O and SO_4^{2-}

More info:
github.com/AndrewAmmerlaan/HFML-VSM_CoilProfilePlotter

Acknowledgements:
Thanks to Uli Zeitler, Hung van Luong, and all the other staff and students at HFML