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Contactless Resistivity Measurement for Quantum Phenomenon Studies

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Abstract: This work explores a contactless resistivity measurement method dedicated to the study of quantum phenomena. The method belongs to the category of RadioFrequency (RF) eddy currents and is based on a gradiometric inductive coil.

Context: The resistivity measurement is a trivial way to characterize and study electronic properties of materials. The experimental methods based on electrical contacts (needle probe and/or wire bonding) are :

- Van der Pauw method [1]
- Hall effect

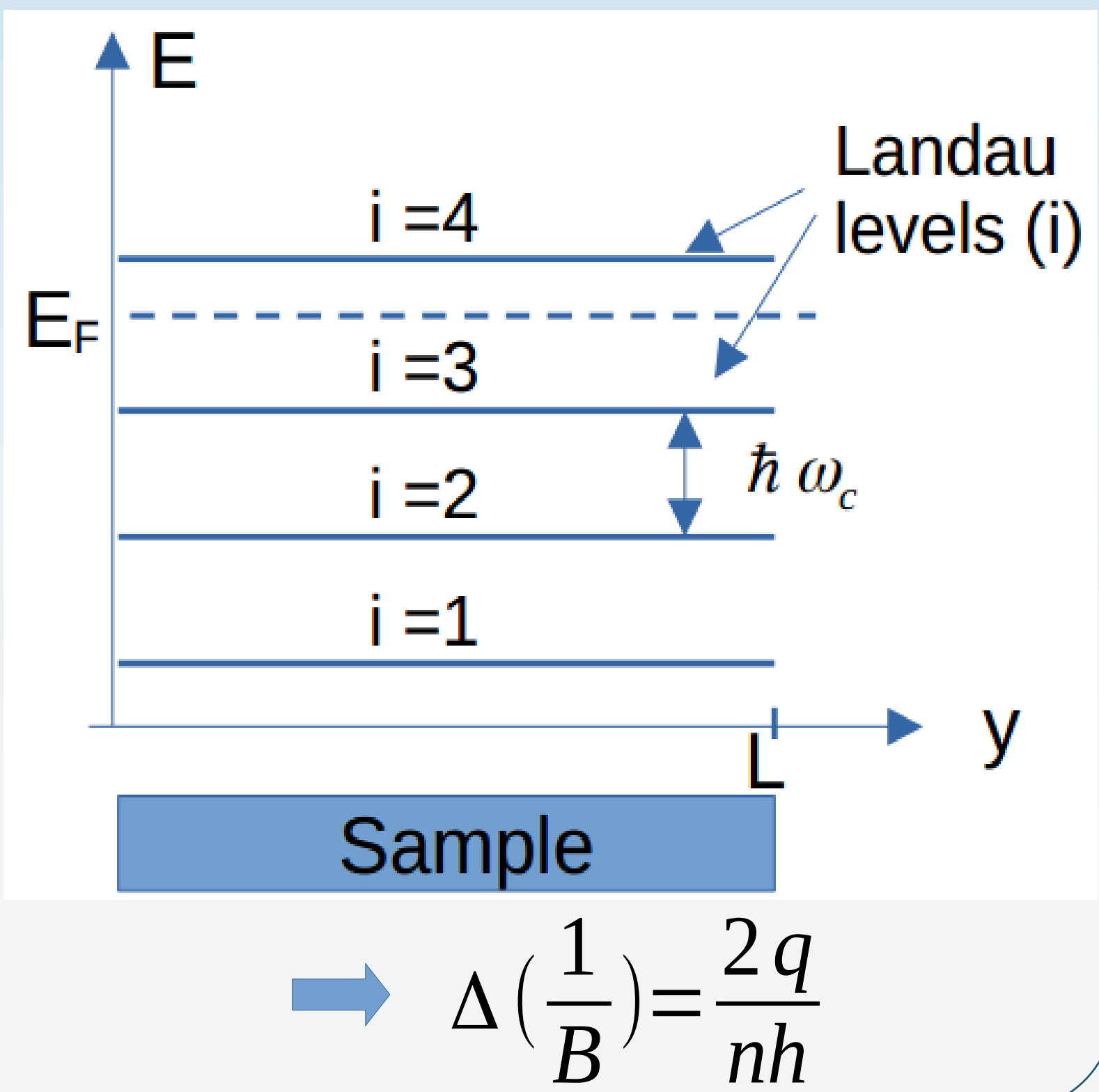
Drawbacks: parasitic contact resistance, mechanical alteration of the surface, Schottky barrier or thermoelectric effect.

Contactless resistivity measurement methods: capacitive, RF eddy current, or microwave [2,3].

$$\sigma = qn\mu$$
$$V_H = IB/nq$$

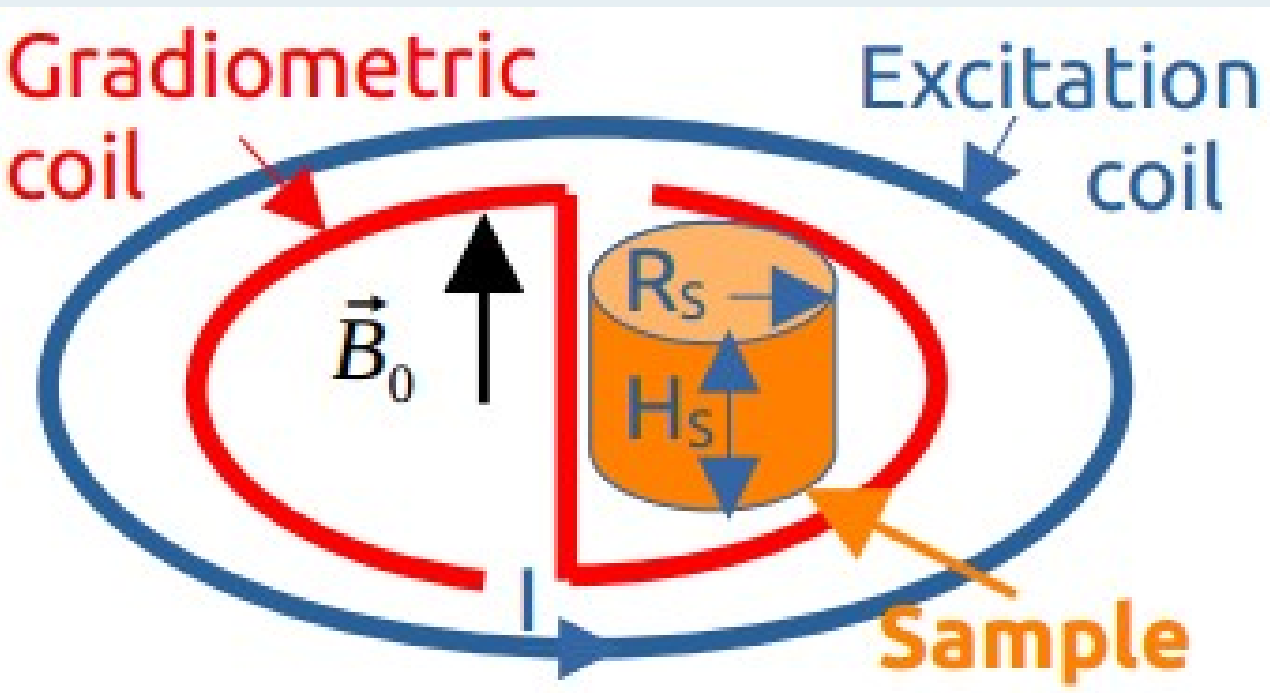
Resistivity oscillations phenomenon @ low T and high B

Low temperature reveals the quantization of energy levels. Magnetic field (B) accentuates the separation of the energy levels [4,5]. When an energy level (i) crosses the Fermi level (E_F), it becomes depleted and the result is a release of charge carriers modifying the resistivity. Thus, when B increases resistivity oscillations occur (=Shubnikov de Haas oscillations). The period of oscillations is related to the carrier concentration :



The susceptometer : a RF eddy current technique

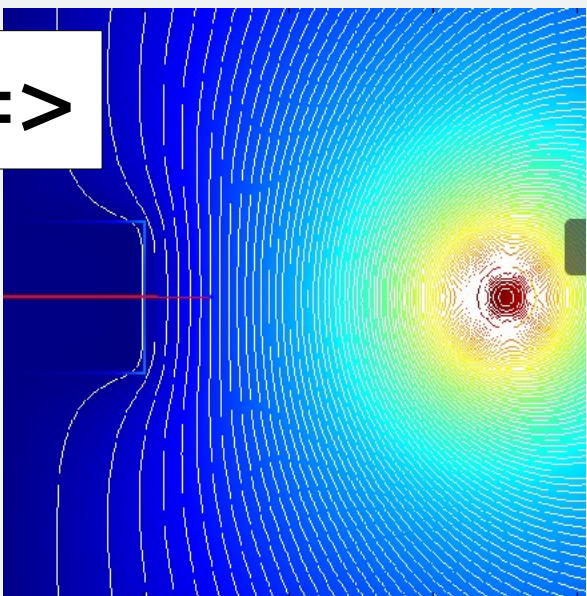
Excitation coil produces a variable magnetic field inducing eddy currents inside the sample to be characterized => the magnetic field is expelled



FEM Simulation=>

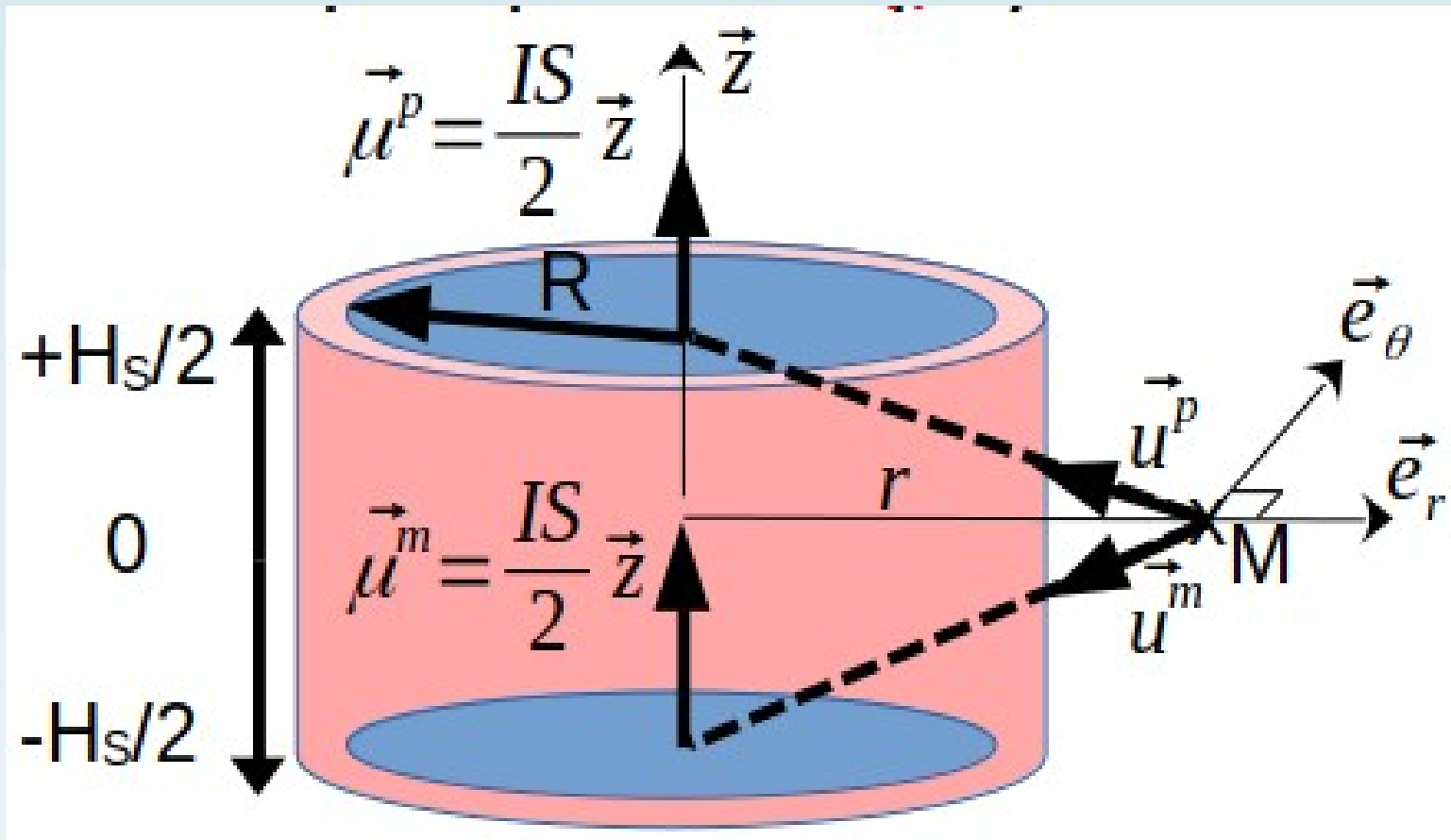
Gradiometric coil measures the unbalanced induced voltage :

$$\delta e \propto \omega \delta \phi(\rho, \omega, R_s, H_s)$$



Overview of the analytic modelling

Resolution of the Maxwell-equations => B_z distribution inside the sample + dipolar magnetic moment (B_μ(r)) :



$$B_z(r) = B_{sample} + \frac{\mu_0 I R_s^2}{4 \left(r^2 + \left(\frac{H_s}{2} \right)^2 \right)^{3/2}} \left(\frac{3 H_s^2}{4 \sqrt{r^2 + \left(\frac{H_s}{2} \right)^2}} - 1 \right)$$

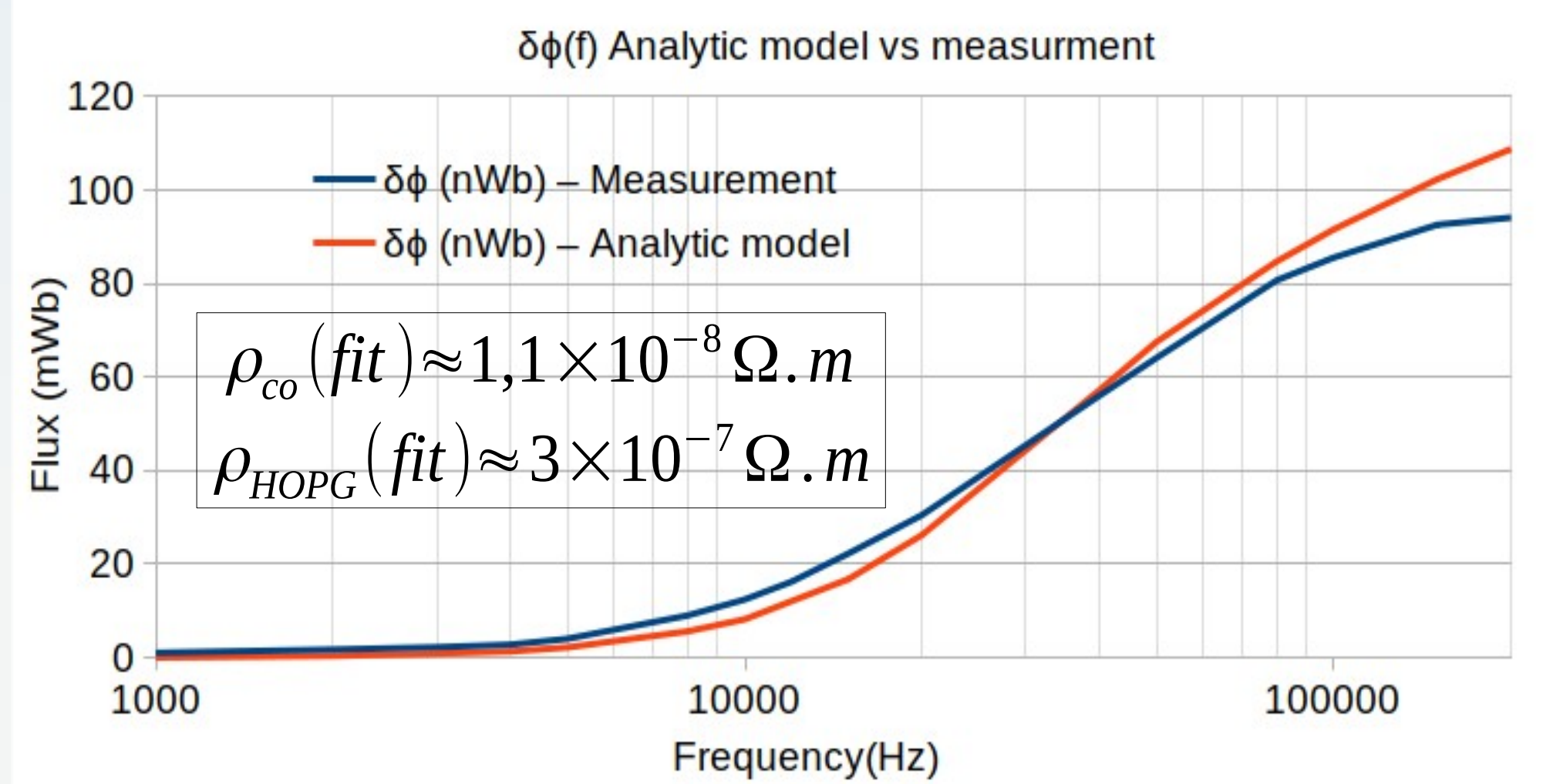
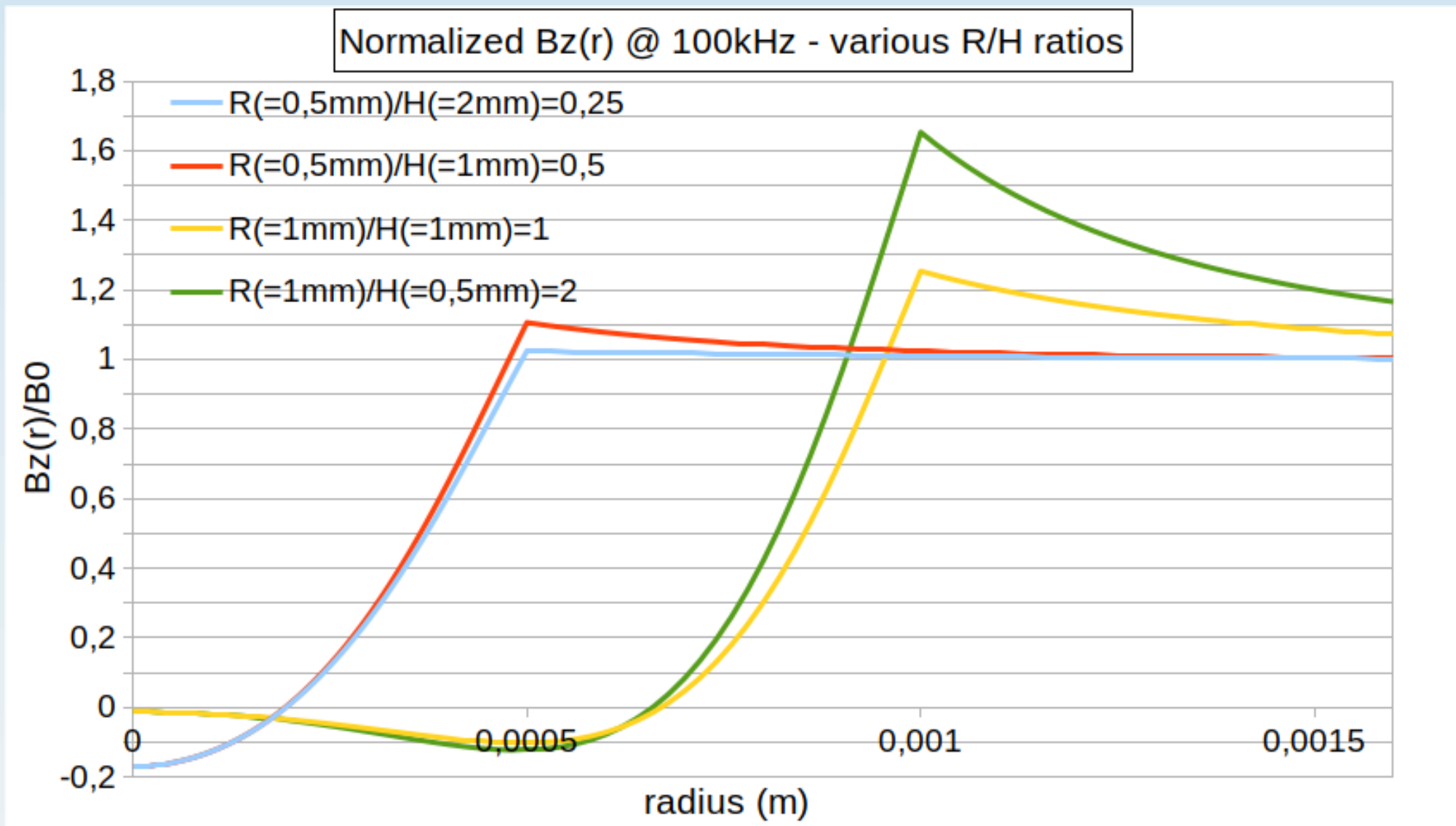
Inside the sample (r < R_s):

$$B_{sample} = B_0 \frac{J_0(r/k)}{J_0(R_s/k)} \quad \& \quad I(r) = \int_0^r j_\theta(r') 2 \pi r' H_s dr'$$

with $k^2 = -1/(j \omega \sigma \mu_0)$

Outside the sample (R_s > r > R_{gradio})

$$B_{sample} = B_0 \quad \& \quad I = \int_0^{R_s} j_\theta(r') 2 \pi r' H_s dr$$

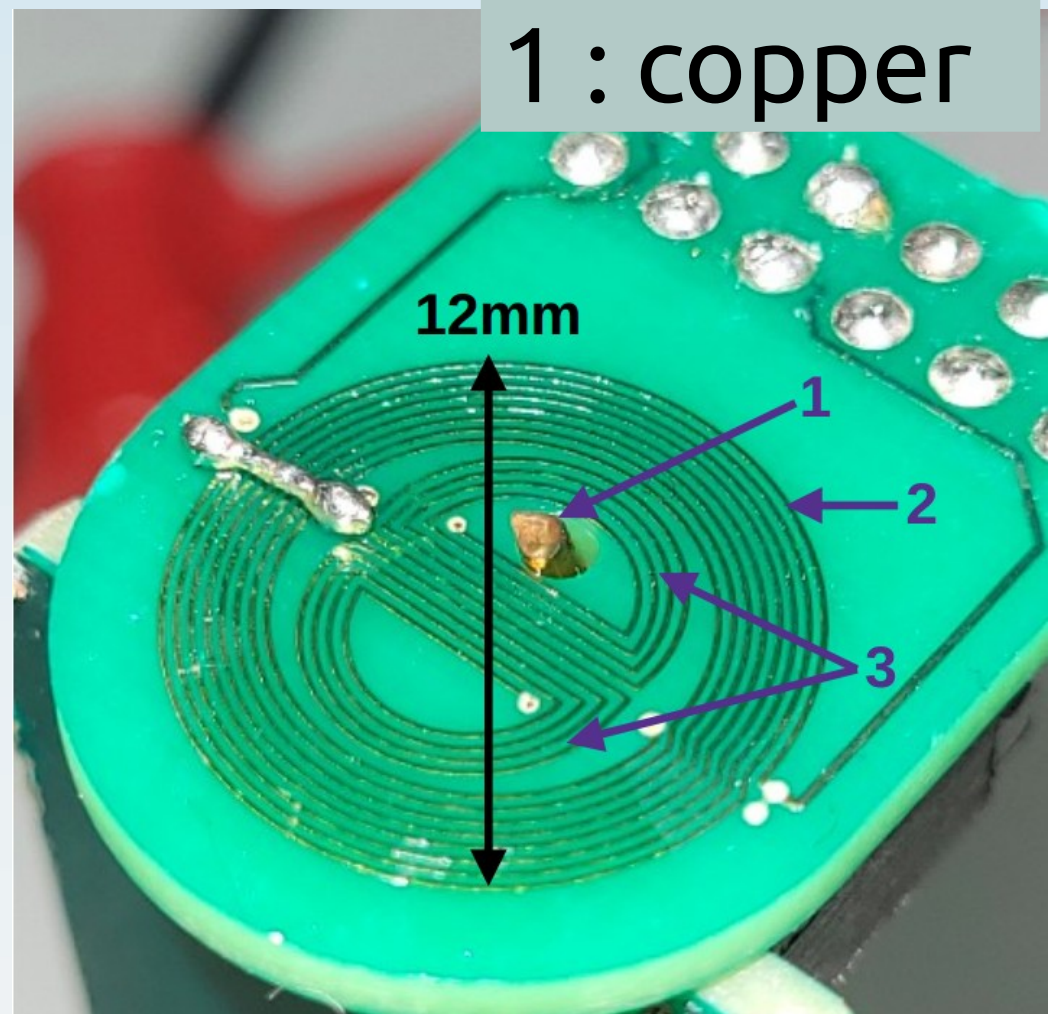


$$\rightarrow \delta \phi(\rho, \omega, R_s, H_s) = \int_0^{R_{gradio}} B_z(r) 2 \pi r dr$$

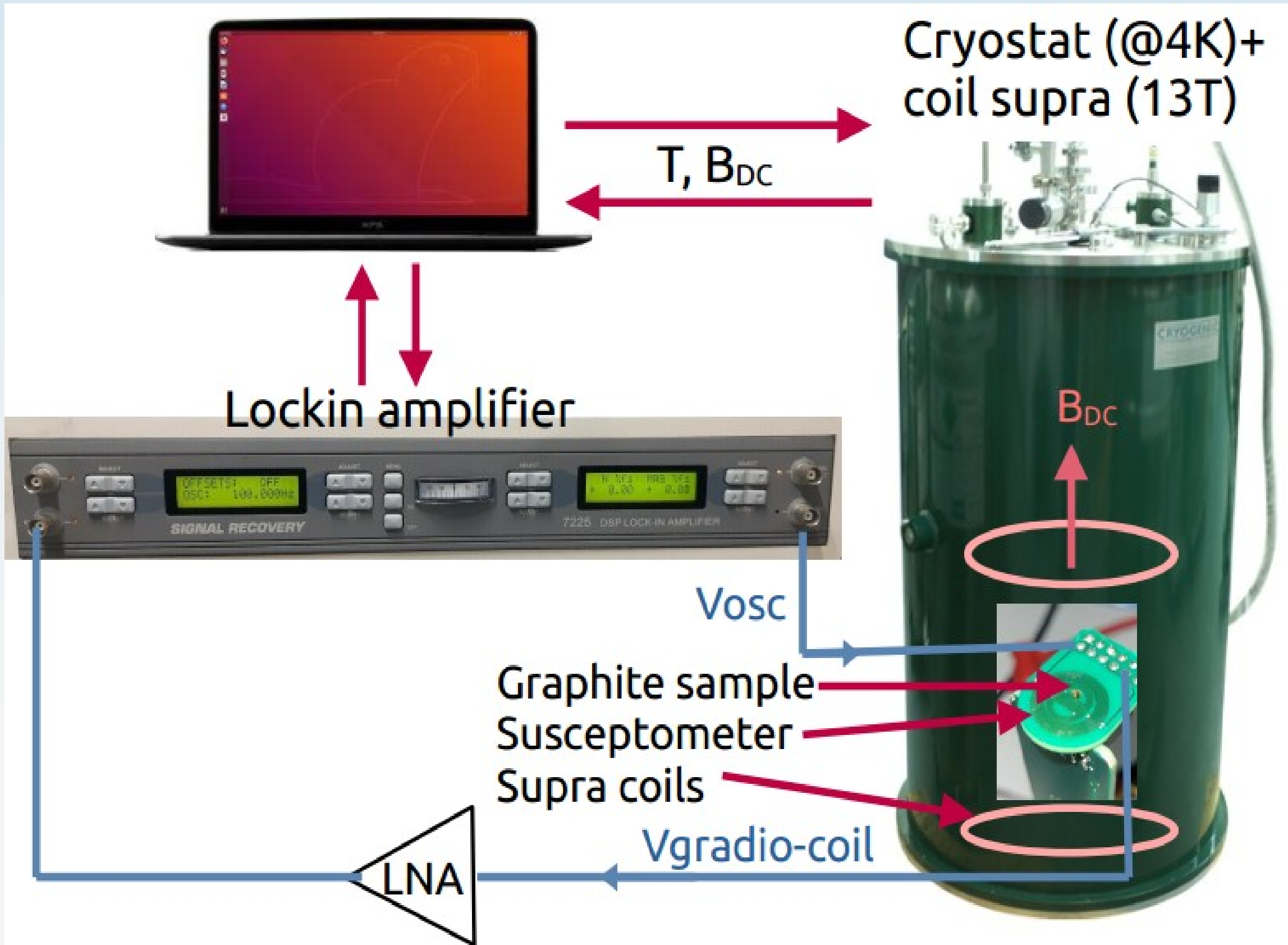
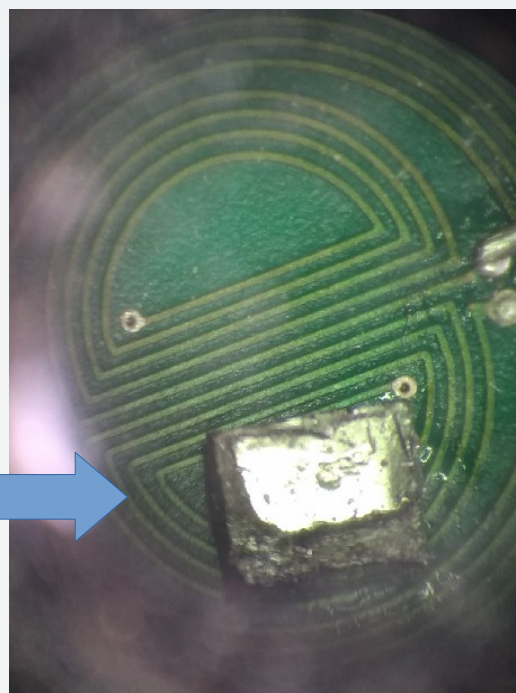
Experimental Setup

Liquid-Helium Cryostat

Susceptometer design

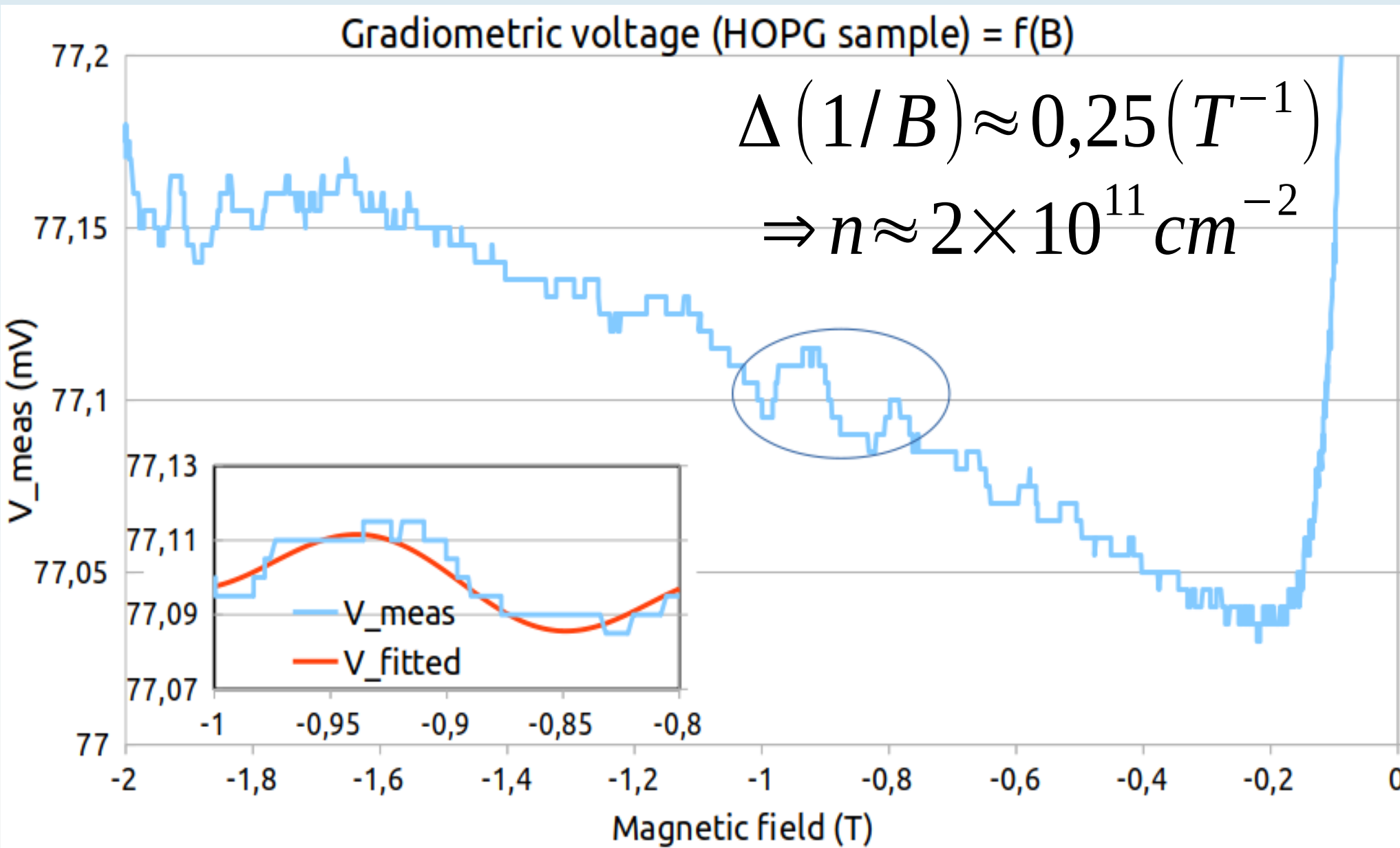


2 : HOPG (Highly Oriented Pyrolytic Graphite)



Results

A sample of cubic HOPG was measured into the cryostat @4,2K & @100kHz B_{DC} field sweep : from -6T up to 6T.



The obtained carrier concentration is consistent with literature [6]

Conclusion & Perspectives

The SdH oscillations are weak but measurable. Various possibilities will allow improving the resolution of the susceptometer, thus giving birth to a new tool for the investigation of quantum physics.

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