# Contactless Resistivity Measurement for Quantum Phenomenon Studies

Christophe Coillot, Sébastien Nanot, Benoit Jouault, Perine Landois, Sylvie Contreras

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C. Coillot[1], S. Nanot[1], B. Jouault[1], P. Landois[1] and S. Contreras[1]
[1]Laboratoire Charles Coulomb (L2C), University of Montpellier (FRANCE), CNRS

**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.

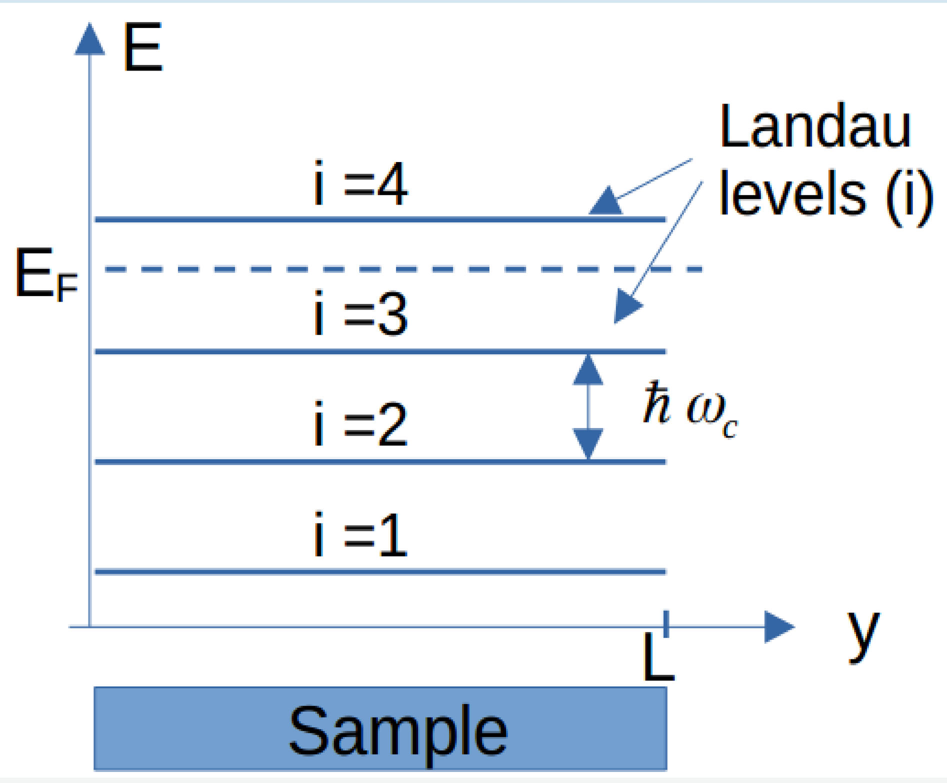
**Context :** The resistivity measurement is a trivial way to characterize and study electronic properties of materials.
The experimental methods based on electrical contacts (needle probe and/or wire bonding) are :
- Van der Pauw method [1]
- Hall effect

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

**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].

## Resistivity oscillations phenomenon @ low T and high B

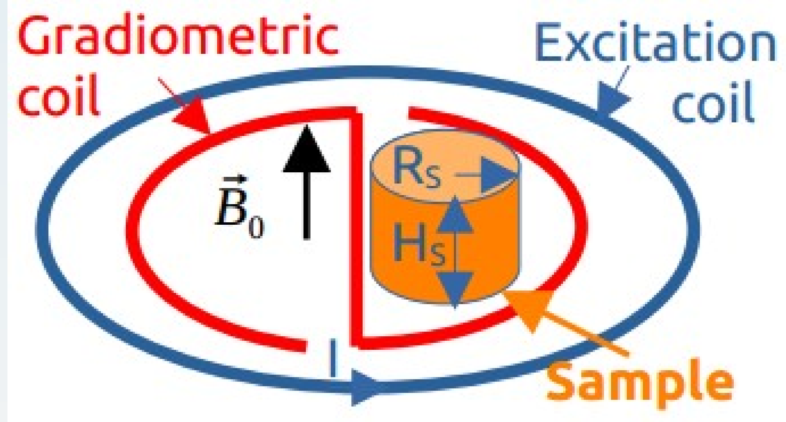
Low temperature reveals the quantization of energy levels.
Magnetic field (B) accentuates the separation of the energy levels [4,5].
When an energy level (i) crosses the Fermi level ($E_F$), it tecomes depleted and the result is a release of charge carriers modifying the resistivity.
Thus, when B increases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



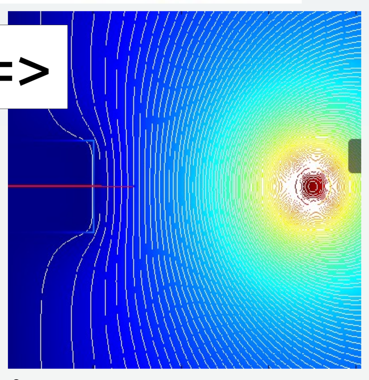

$$\Delta\left(\frac{1}{B}\right)=\frac{2q}{nh}$$

## 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=>

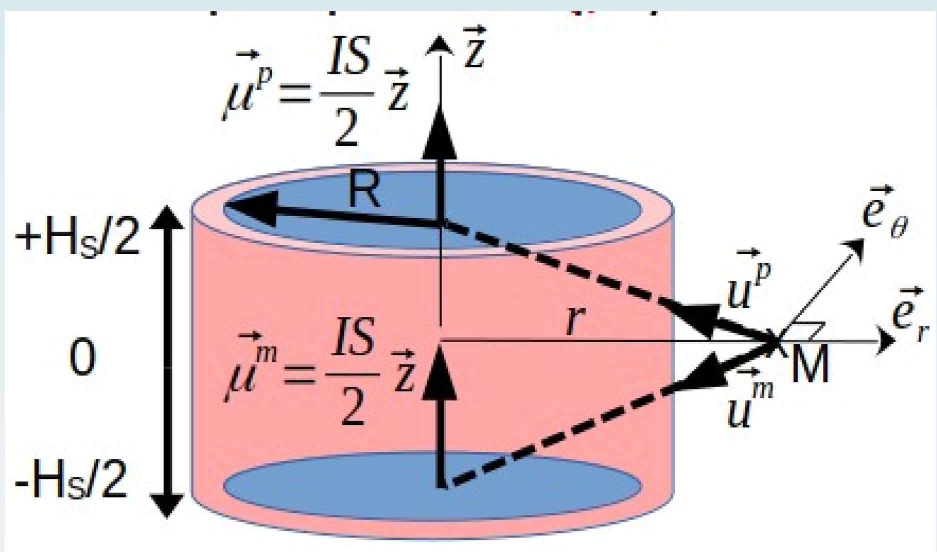


Gradiometric coil measures the unbalanced induced voltage :

$$\delta e \propto \omega\,\delta\phi(\rho,\omega,R_S,H_S)$$

## Overview of the analytic modelling

Resolution of the Maxwell-equations
=> Bz distribution inside the sample
+ dipolar magnetic moment ($B_\mu(r)$) :




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

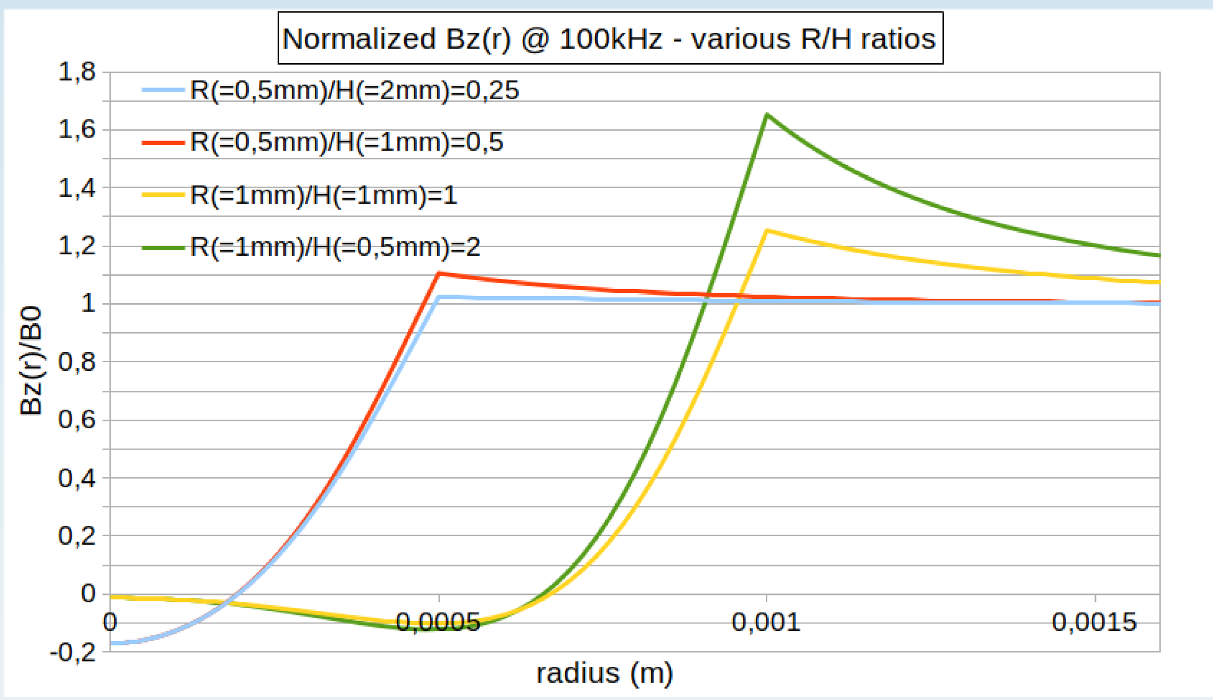
Inside the sample ($r<R_S$):

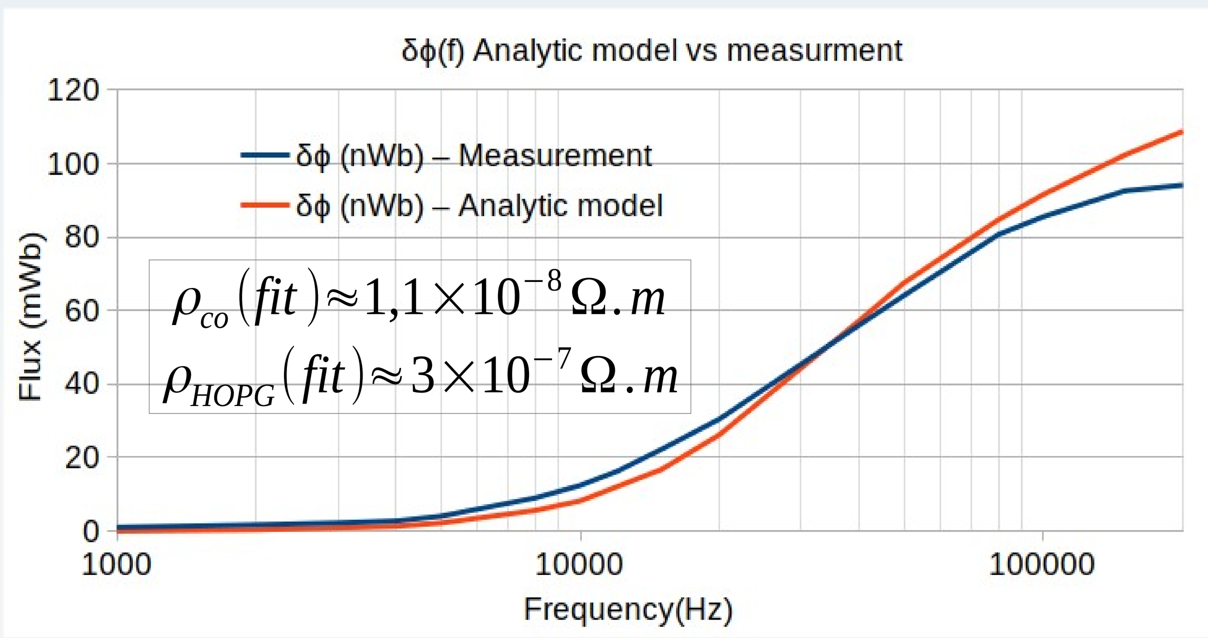
$$B_{sample}=B_0\frac{J_0(r/k)}{J_0(R_S/k)} \quad \& \quad I(r)=\int_0^r j_\theta(r')\,2\pi r'\,H_S\,dr'$$

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

Outside the sample ($R_S>r>R_{gradio}$)

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

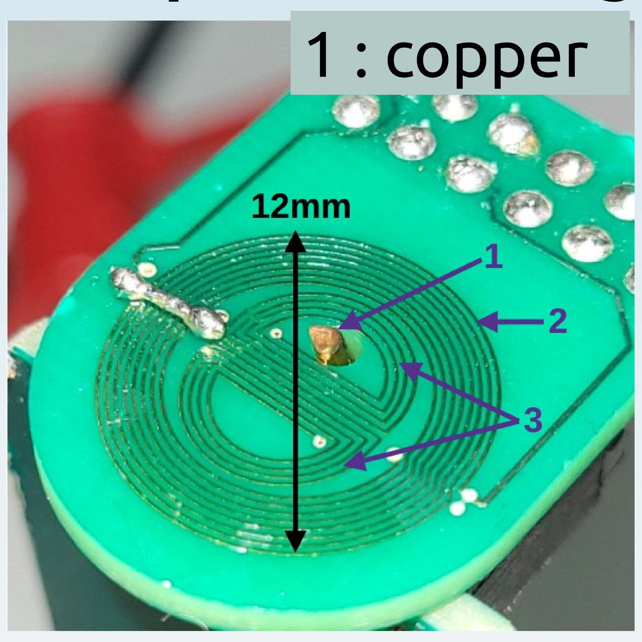


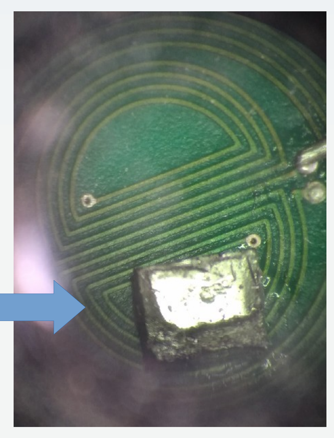

$$\rightarrow \delta\phi(\rho,\omega,R_S,H_S)=\int_0^{R_{gradio}} B_z(r)\,2\pi r\,dr$$

## Experimental Setup

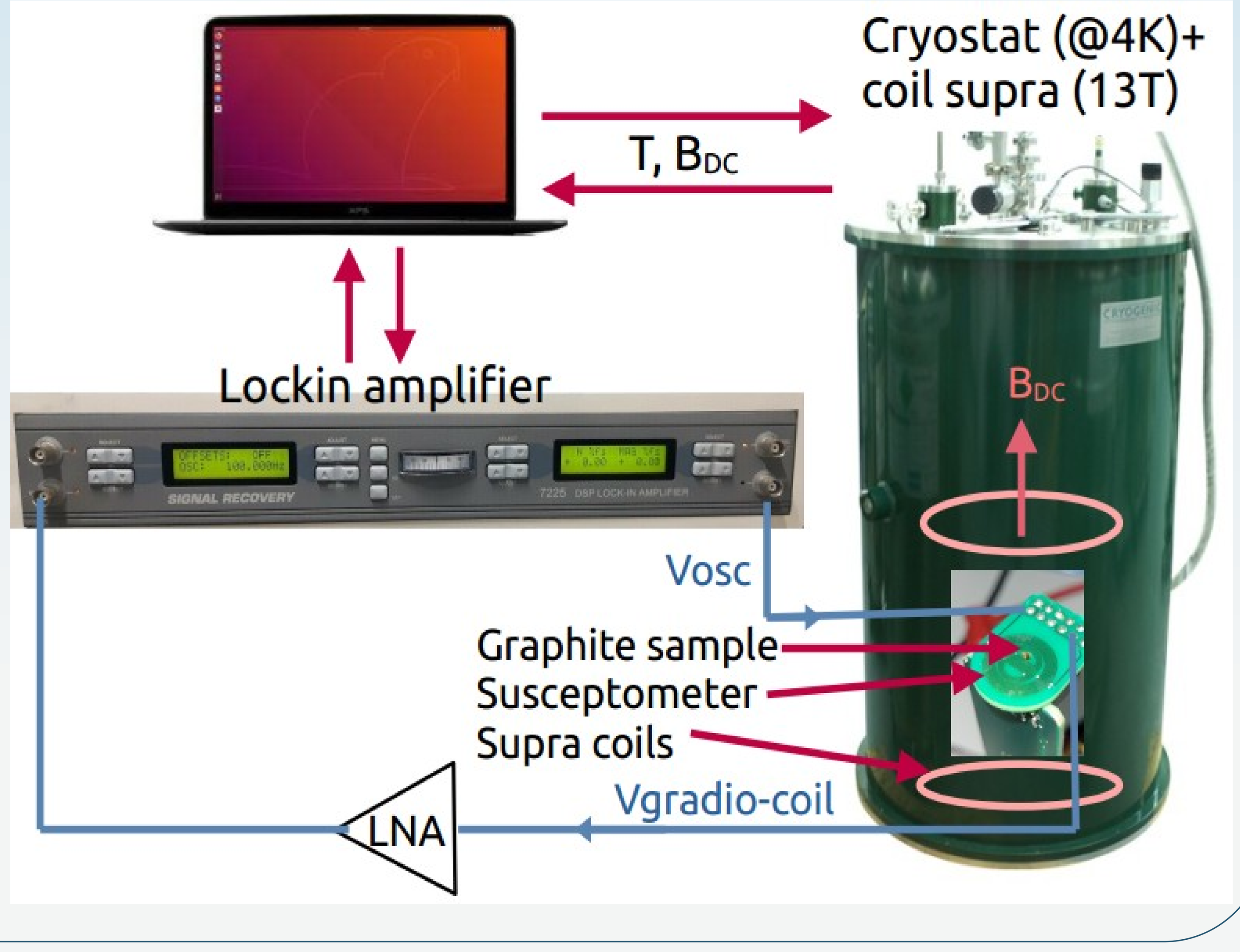
### Susceptometer design




2 : HOPG (Highly Oriented Pyrolytic Graphite)

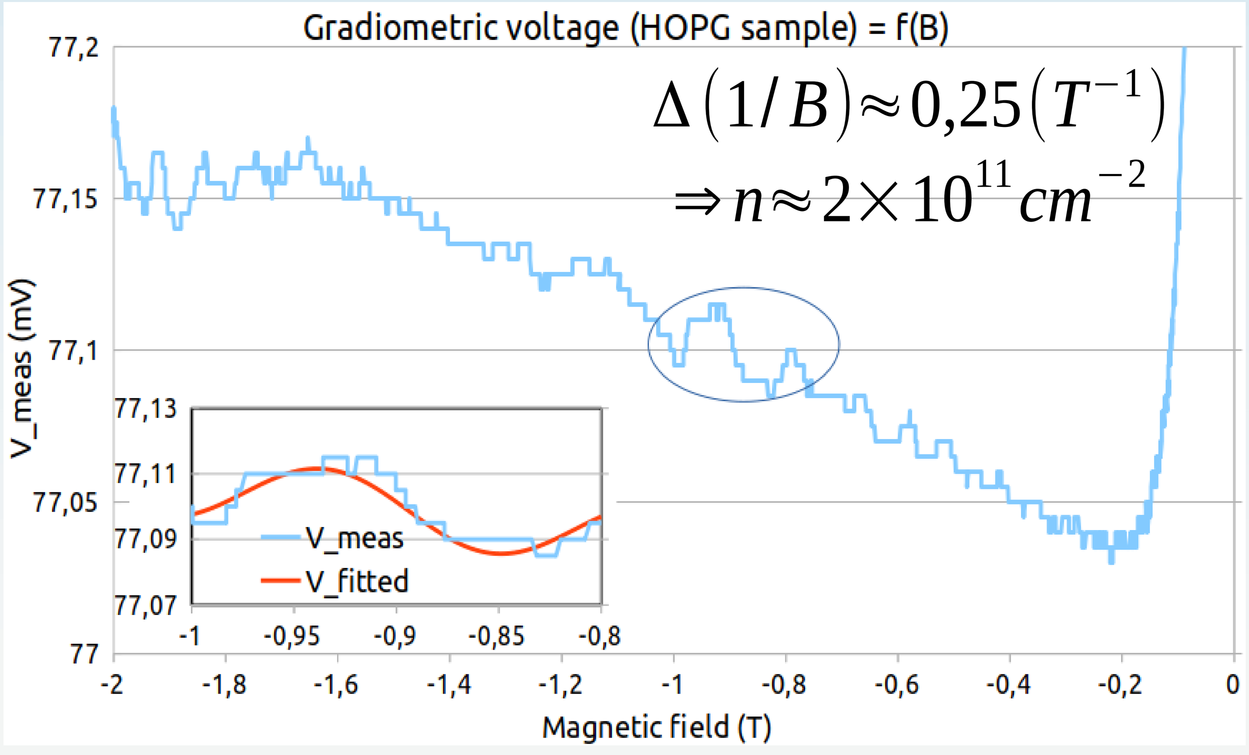


### Liquid-Helium Cryostat




## 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 litterature [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.

**Acknowledgments :** We thank Benjamin Benhamou--Bui for the cryogenic measurements.

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