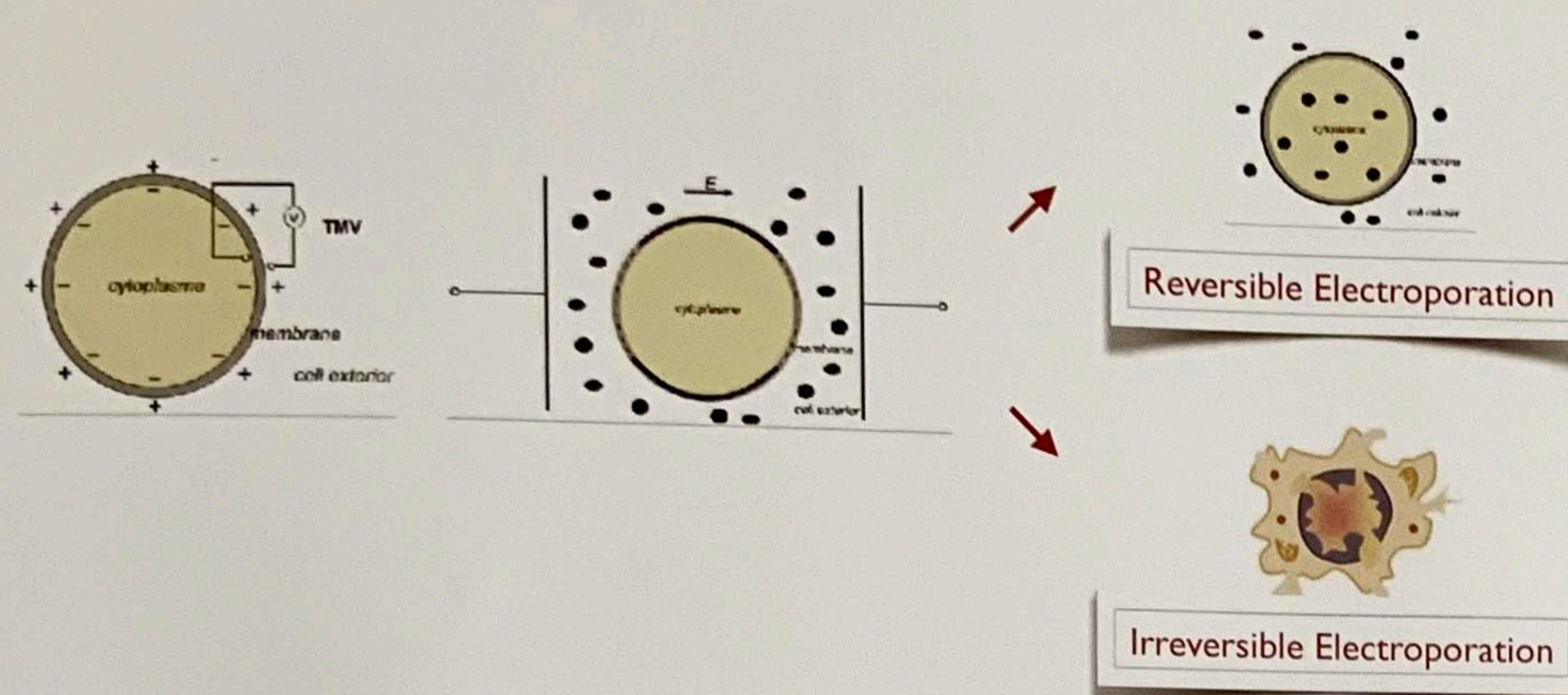


Base of Electroporation

Technique that consists of applying an electric field on a cell in order to perturb the cell transmembrane voltage and to increase the cell permeability.



Several application, in particular in cancer treatment: **ELECTROCHEMOTHERAPY**.
Today the electroporation dynamics are not totally clear!

Impedance Spectroscopy and Experience Data

Impedance spectroscopy measures the resistance and the capacitance properties of a material via the application of a sinusoidal AC excitation.

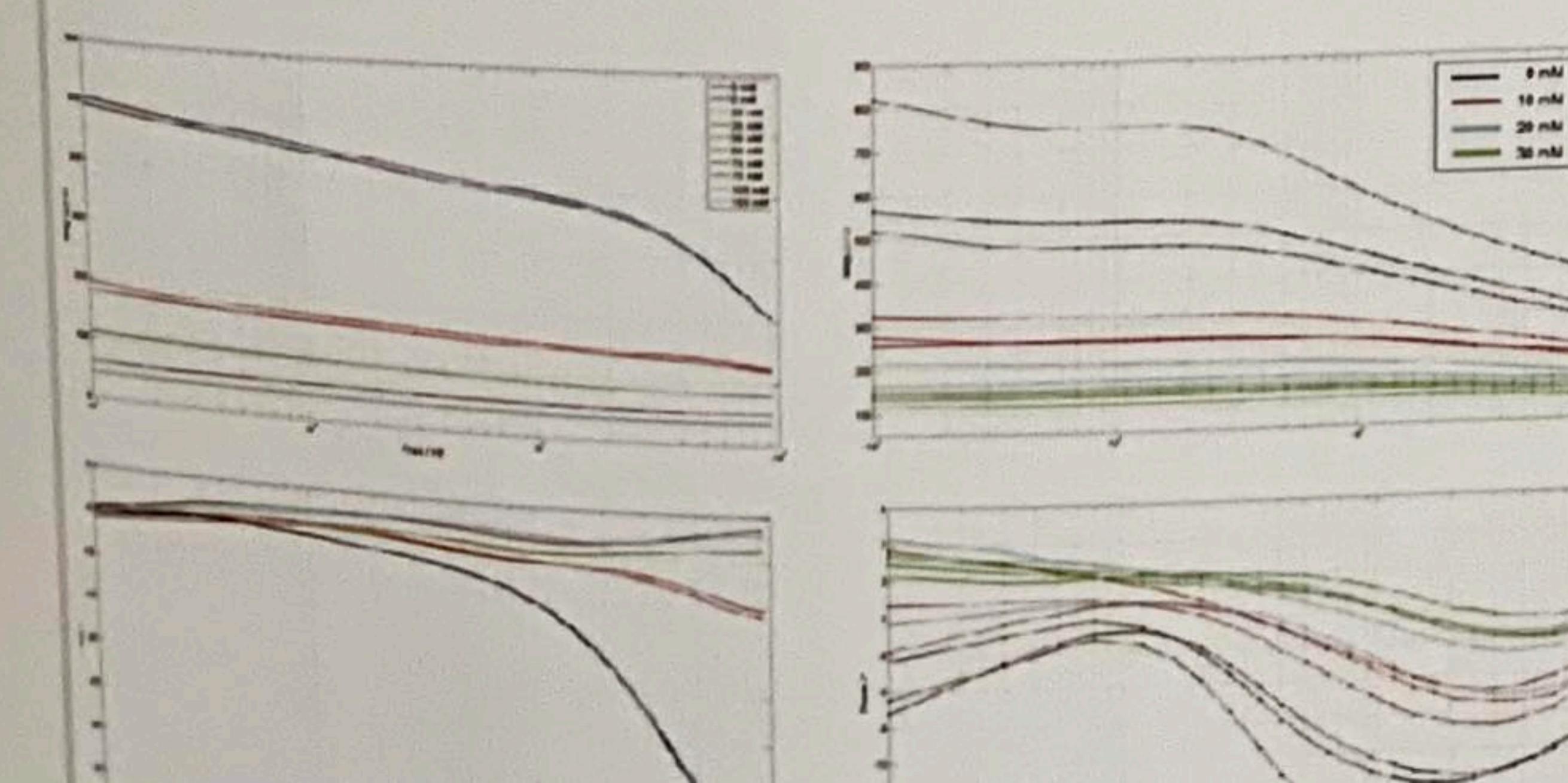
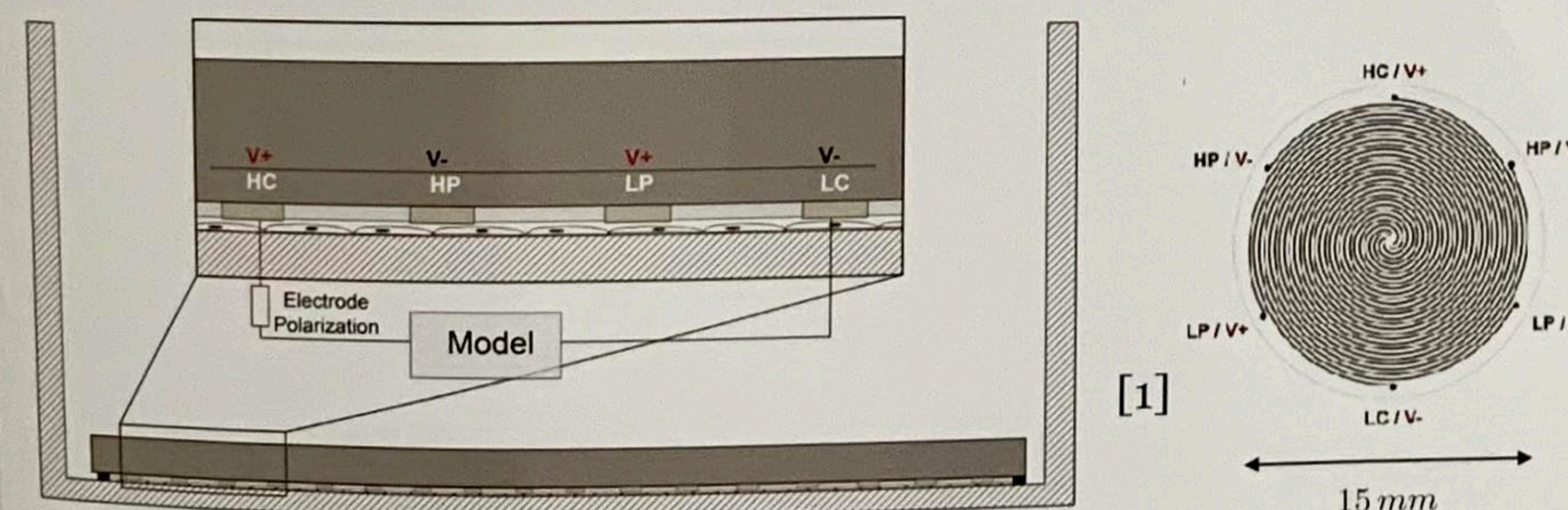
$$\text{Impedance} \quad Z = \frac{V}{I} \in \mathbb{C}$$

$\Re(Z)$: ability of a material to **resist** the flow of electrical current

$\Im(Z)$: ability of a material to **store** electrical energy

An impedance spectrum is obtained by varying frequency over a defined range.

Tomás García-Sánchez Experience, Institut de Cancérologie Gustave Roussy (Paris), Inria-Paris.
The *in vitro* experience consists in measuring the Electrochemical Impedance (EI) of a mono-layer of myotubes in a low-conductivity electroporation buffer using a six-electrode measuring configuration.

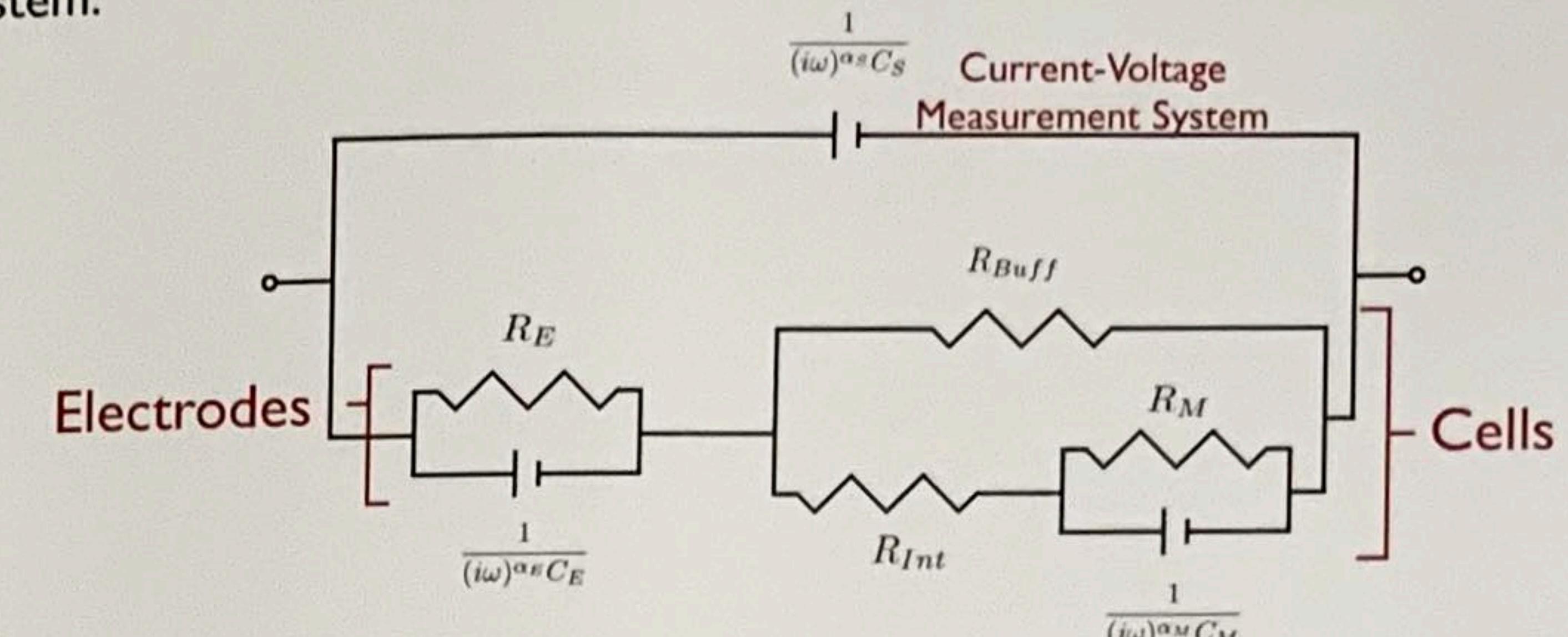


The data got from the experience, shown in Bode plots, are useful to point out the frequency dependence of EI. Two kind of measurements are performed:

- Free-cell Impedance in order to compute the measurement noises due to the electrode polarization and the voltage current measurement system,

Equivalent Circuit

Equivalent Circuit (EC) are considered in order to describe the whole system only by pure electrical terms. The goal is to find an explicit formula of EI, for a comparison with experience data, and a better understanding of the behaviour of singular part composing studied system.



$$Z_{Tot} = \frac{x_1 x_2 + y_1 y_2}{x_2^2 + y_2^2} + i \frac{x_2 y_1 - x_1 y_2}{x_2^2 + y_2^2}$$

$$x_1 = R_E + R_{Buff} + C_E R_E R_{Buff} \omega^{\alpha_E} \cos(\alpha_E \frac{\pi}{2})$$

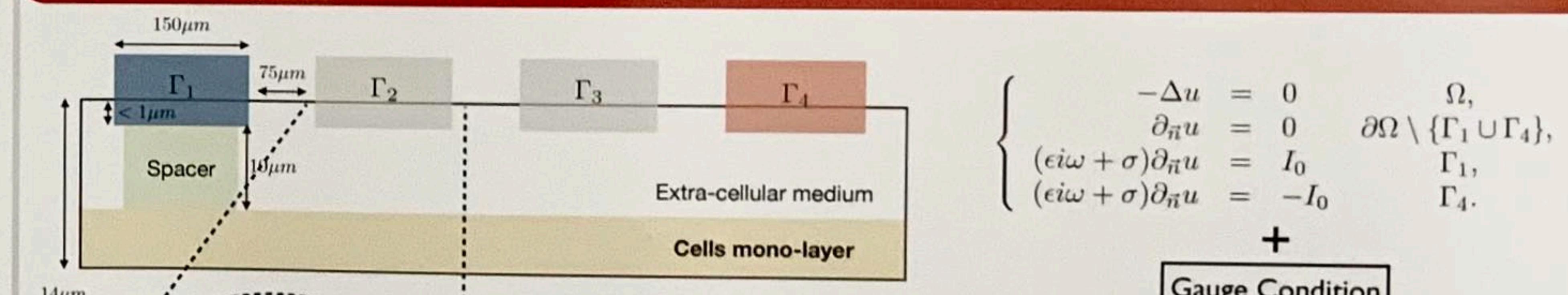
$$y_1 = C_E R_E R_{Buff} \omega^{\alpha_E} \sin(\alpha_E \frac{\pi}{2})$$

$$x_2 = 1 + C_E R_E \omega^{\alpha_E} \cos(\alpha_E \frac{\pi}{2}) + (R_E + R_{Buff}) C_S \omega^{\alpha_S} \cos(\alpha_S \frac{\pi}{2}) + C_E R_E R_{Buff} C_S \omega^{\alpha_E+\alpha_S} \cos((\alpha_E + \alpha_S) \frac{\pi}{2})$$

$$y_2 = C_E R_E \omega^{\alpha_E} \sin(\alpha_E \frac{\pi}{2}) + (R_E + R_{Buff}) C_S \omega^{\alpha_S} \sin(\alpha_S \frac{\pi}{2}) + C_E R_E R_{Buff} C_S \omega^{\alpha_E+\alpha_S} \sin((\alpha_E + \alpha_S) \frac{\pi}{2})$$

Calibration: the values of parameters are identified using the data experience. The calibration is performed in two steps: free-cell parameters evaluation and cell parameters evaluation. The physical plausibility of values found proves that the EC considered is a good approximation of the original physical system. The information got from the EC study are used to implement a Laplacian model.

From Electric Potential Model to Floating Potential Problem



$$\begin{aligned} -\Delta u_\varepsilon &= f && \text{in } \Omega_0 \cup \Gamma, \\ u_\varepsilon|_{y=Y_{max}^+} &= u_\varepsilon|_{y=Y_{max}^-}, \\ \partial_y u_\varepsilon|_{y=Y_{max}^+} &= \frac{1}{\varepsilon^k} \partial_y u_\varepsilon|_{y=Y_{max}^-}, \\ \partial_y u_\varepsilon|_{y=Y_{max}+\varepsilon} &= 0, \\ u_\varepsilon|_{y=Y_{min}} &= \gamma, \\ u_\varepsilon|_{x=0} &= u_\varepsilon|_{x=X_{max}} \quad k \geq 2 \end{aligned}$$

$\varepsilon \rightarrow 0$

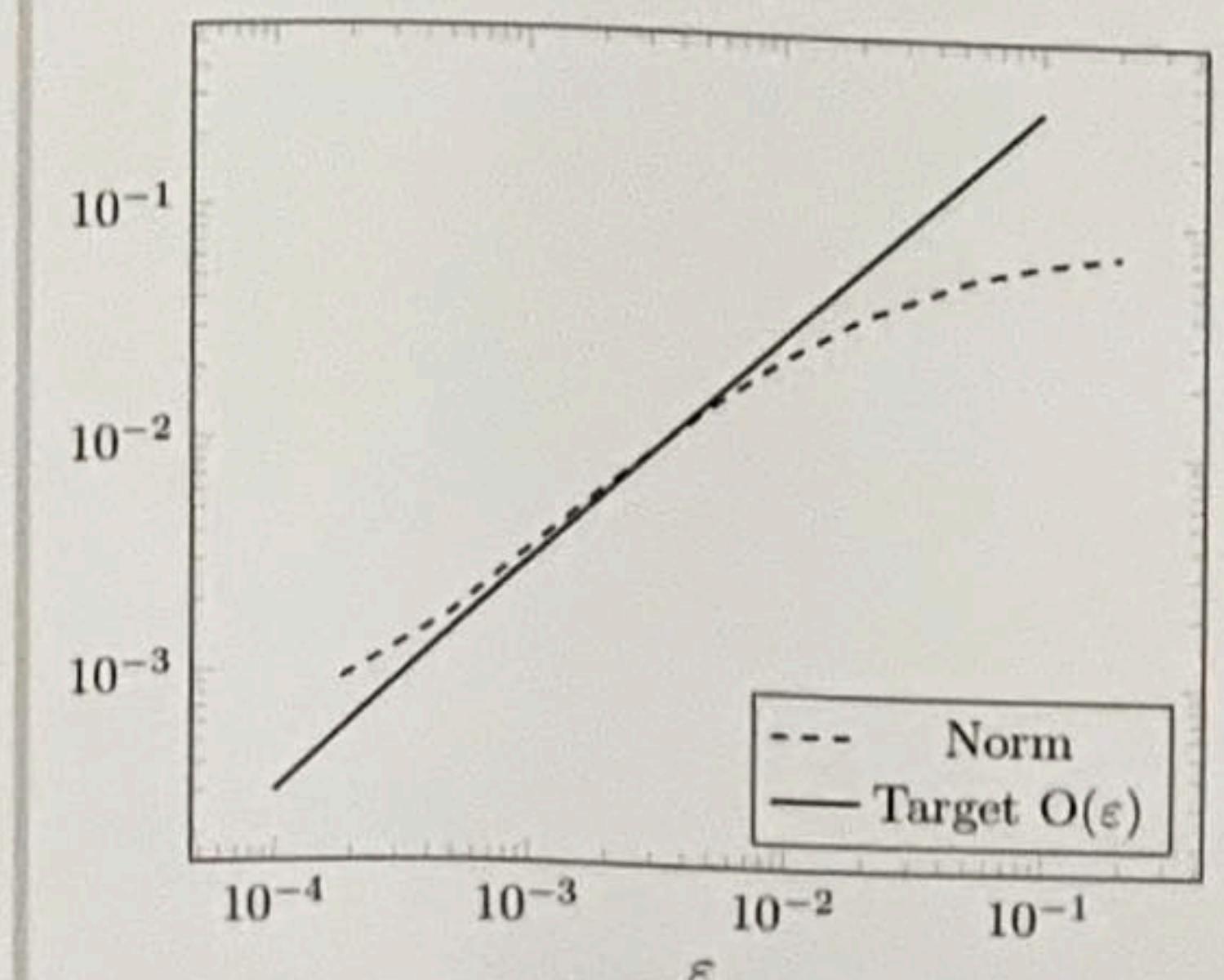
$$\begin{aligned} -\Delta u_0 &= f && \text{in } \Omega_0, \\ u_0|_{y=Y_{max}} &= \alpha, \\ \int_{Y_{max}} \partial_y u_0 dx &= 0, \\ u_0|_{y=Y_{min}} &= \gamma, \\ u_0|_{x=0} &= u_0|_{x=X_{max}} \end{aligned}$$

Laplacian Problem + Transmission Conditions

Floating Potential Problem

Considering a solution of original problem in the form of

$$u_\varepsilon = u_0 + u_1 \varepsilon + u_2 \varepsilon^2 \dots$$



and making an asymptotic analysis, the limit problem found consists in a Floating Potential Problem, which asks a high computational cost but it is possible to split it in easier resolution problems.

The original problem solution converges to the FP problem solution with a first order, as expected.