

A PROGRAMMABLE INTRINSIC QUANTUM STANDARD OF RESISTANCE OPERATING AT ROOM TEMPERATURE AND IMPLEMENTABLE ON-CHIP BASED ON MEMRSITIVE DEVICES

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Background

• National Metrological Institutes services on chip («NMI-on-a-chip»)

The **revision of the International System of Units (SI)** in 2019 represented a historic change of paradigm for metrology, opening a new perspective on the *mise en pratique* of the SI basic units. SI units are now defined in terms of fundamental constants of nature defined by fixed numerical values.



Any experiment able to correlate measurable physical quantities to one, or a set of, fundamental constants fixed by the SI becomes a direct realization of the corresponding SI unit. Novel devices working according to the principles of quantum physics can enable the realization of reliable SI-traceable self-referenced systems.

• New horizons for electrical metrology

The quantum Hall effect, the Josephson effect and single-electron transport effects have been widely explored for the practical realization of resistance, voltage, and current electrical units, respectively. However, they require **large size and complex experiments**, operating at cryogenic temperatures, vacuum conditions, and/or in the presence of high magnetic fields, limiting their acquisition almost exclusively to universities and metrology institutions.



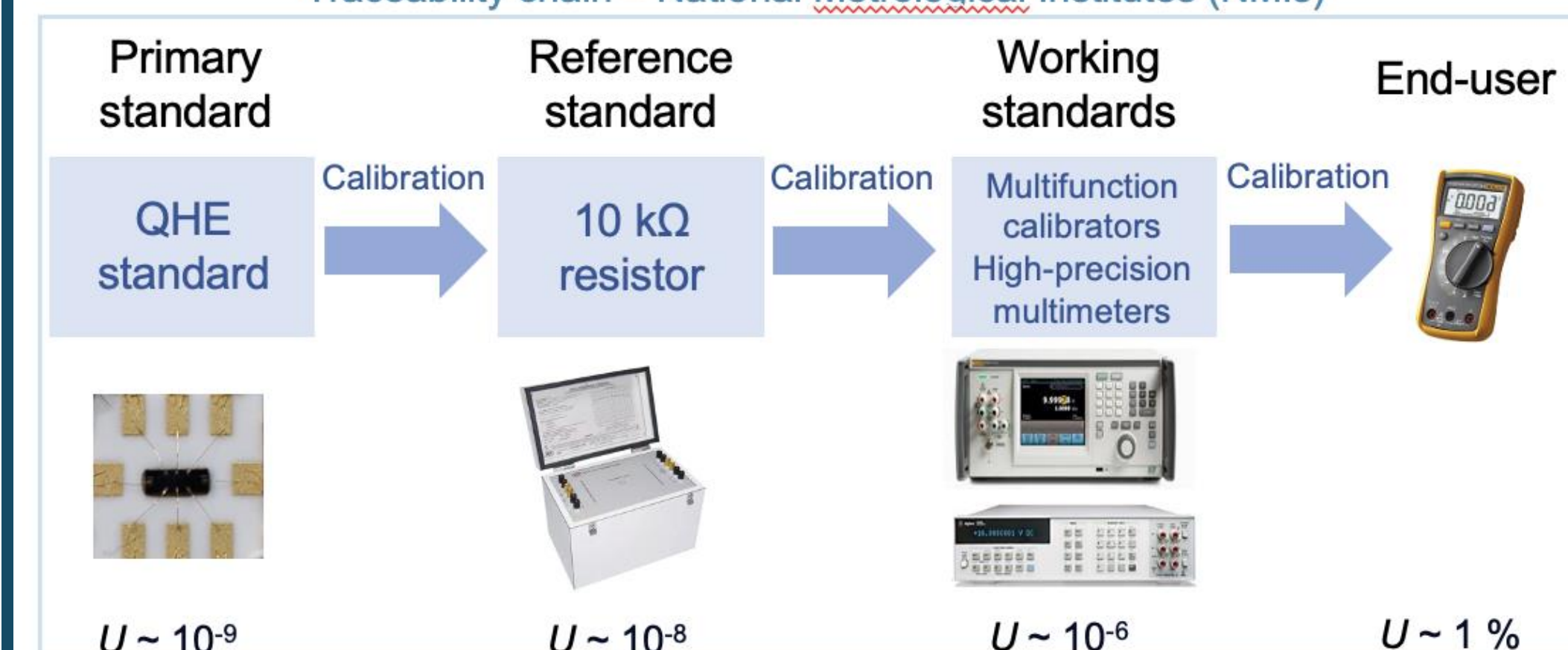
A device exhibiting a physical observable related to the fundamental quantum of conductance G_0 at room temperature, in air and without applying a magnetic field can revolutionize electrical metrology, enabling the realization of intrinsic resistance standards directly available to the end-user.



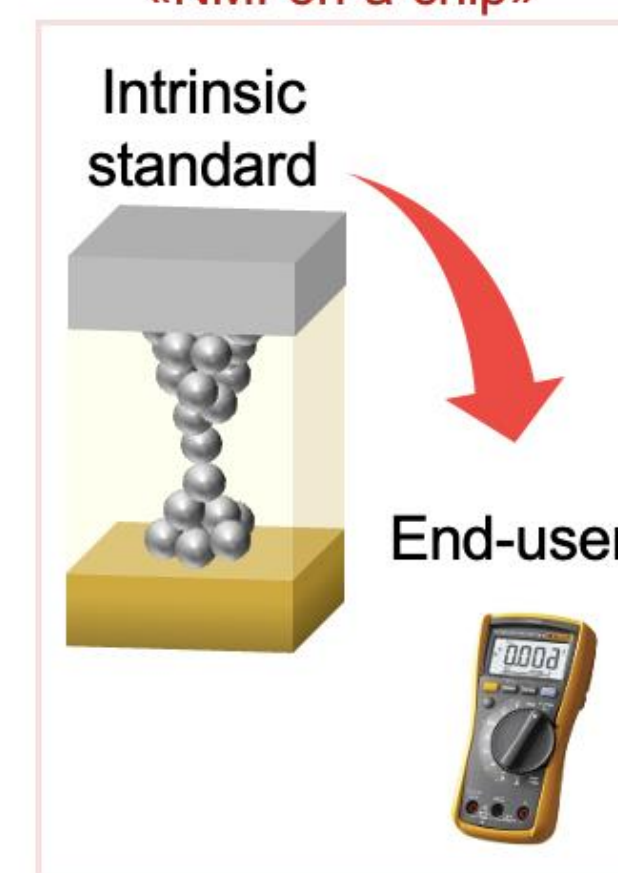
Self-calibrating electrical systems with zero-chain traceability

This avoids possible drifts of each measuring standard caused by time, environmental parameters, and/or use calibration cost, long unavailability periods of the measurement equipment and a lot of effort in the management of the calibration process.

Traceability chain – National Metrological Institutes (NMIs)



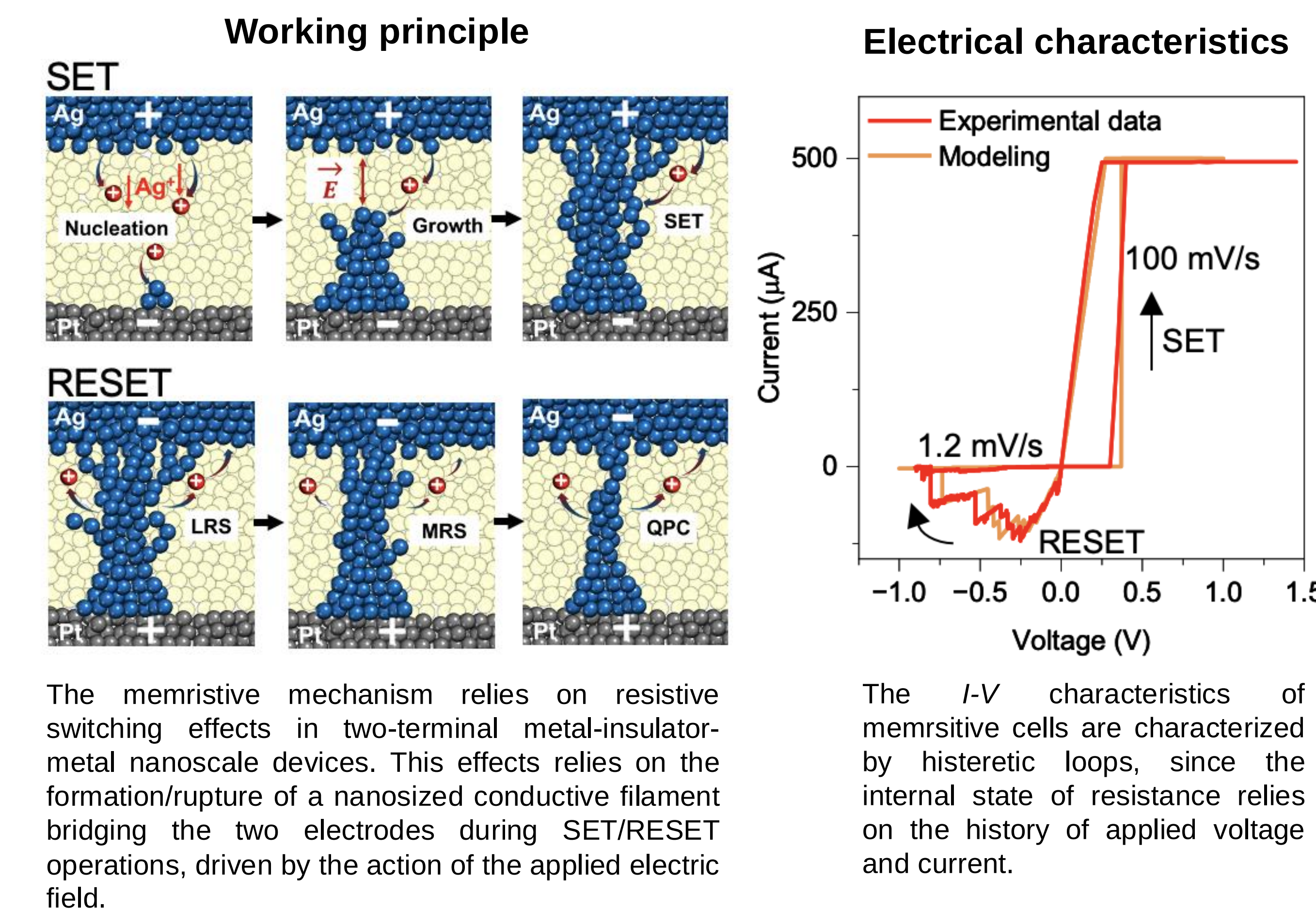
«NMI-on-a-chip»



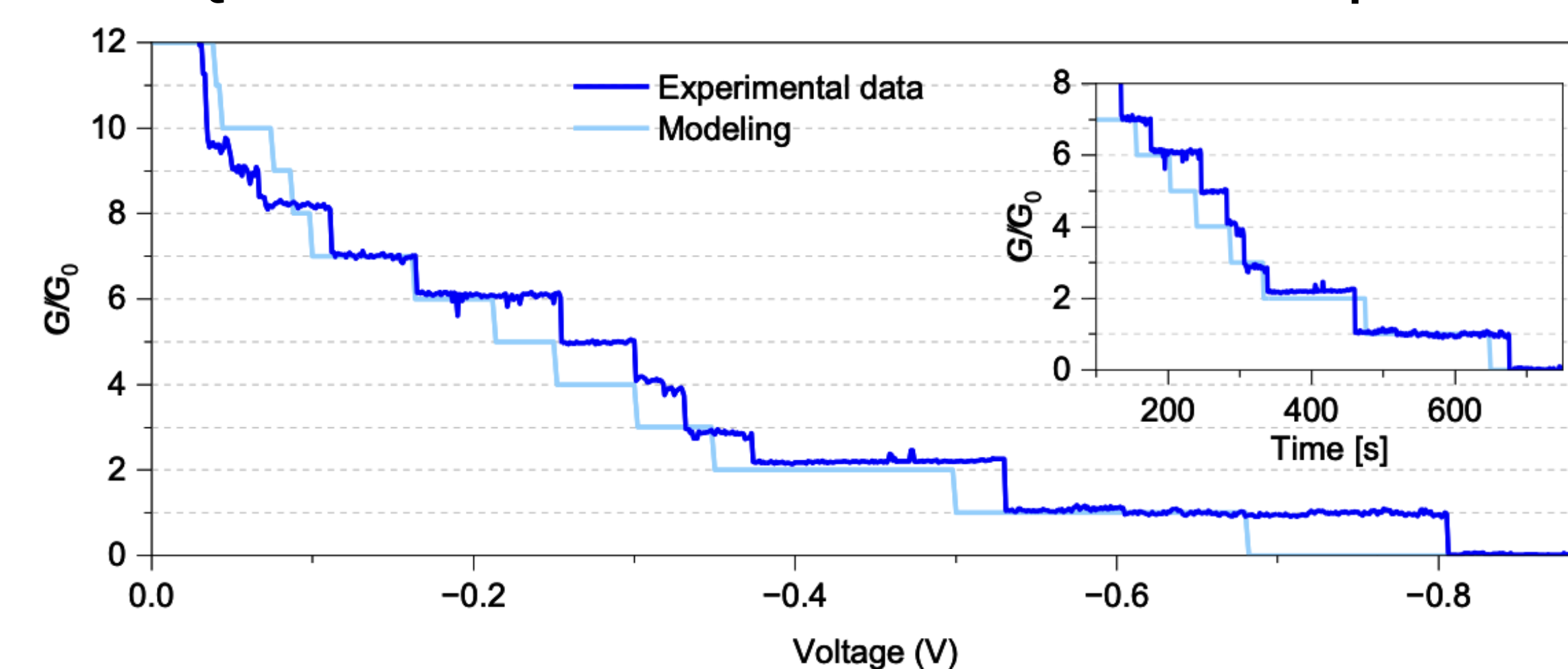
The idea

• Memristive devices for quantum metrology.

Memristive devices can exhibit conductance levels that are multiple of the fundamental quantum of conductance G_0 in air, enabling the realization of an intrinsic standard of resistance scalable to the nanometer scale and compatible with CMOS technology that can work at room temperature, in air, without applying a magnetic field [1].



Quantum conductance effects in air at room temperature



By exploiting the electropolishing effect, it is possible to control the dissolution of the filament nearly atom-by-atom, making possible the observations of quantum conductance effects with step-like behavior during the RESET process. These conductance plateaus are multiple of the fundamental quantum of conductance.

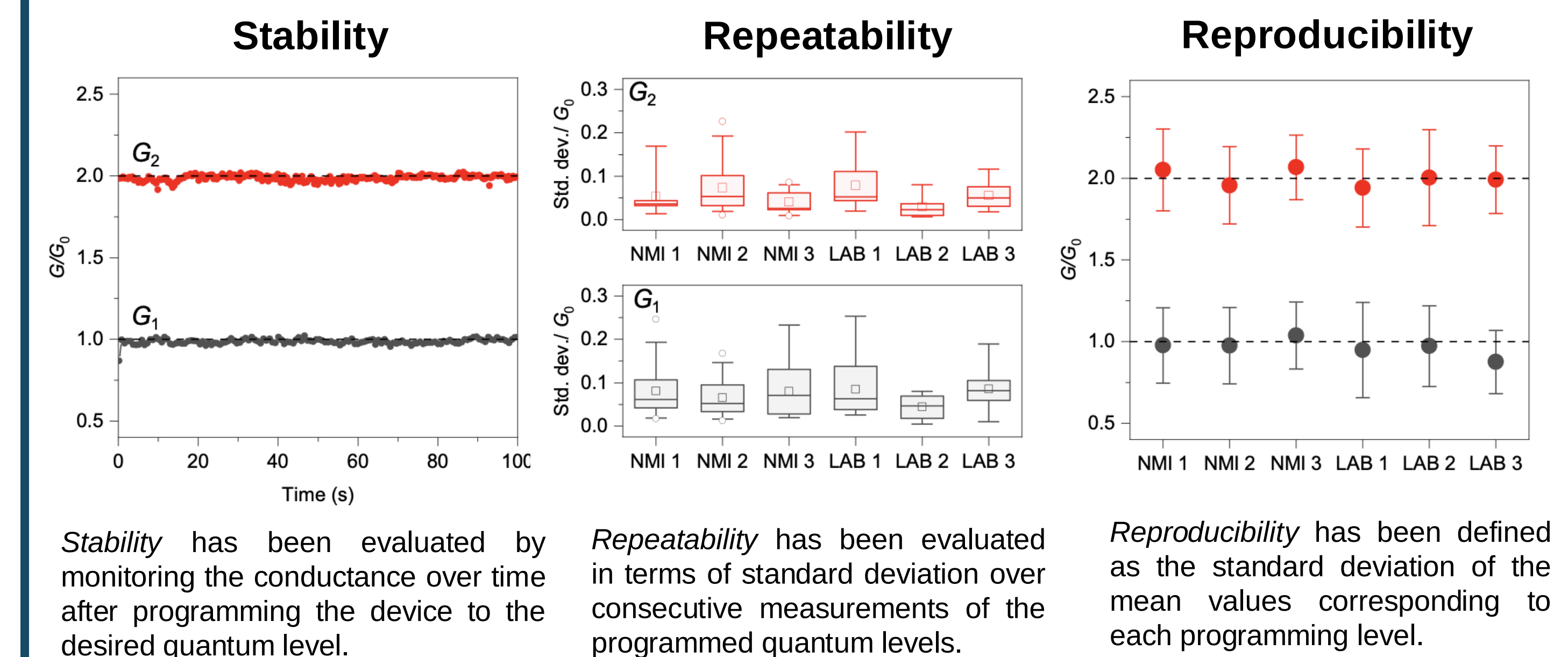
[1] Milano, Gianluca, et al. "Memristive devices for quantum metrology." *Advanced Quantum Technologies* 3.5 (2020): 2000009.

Results

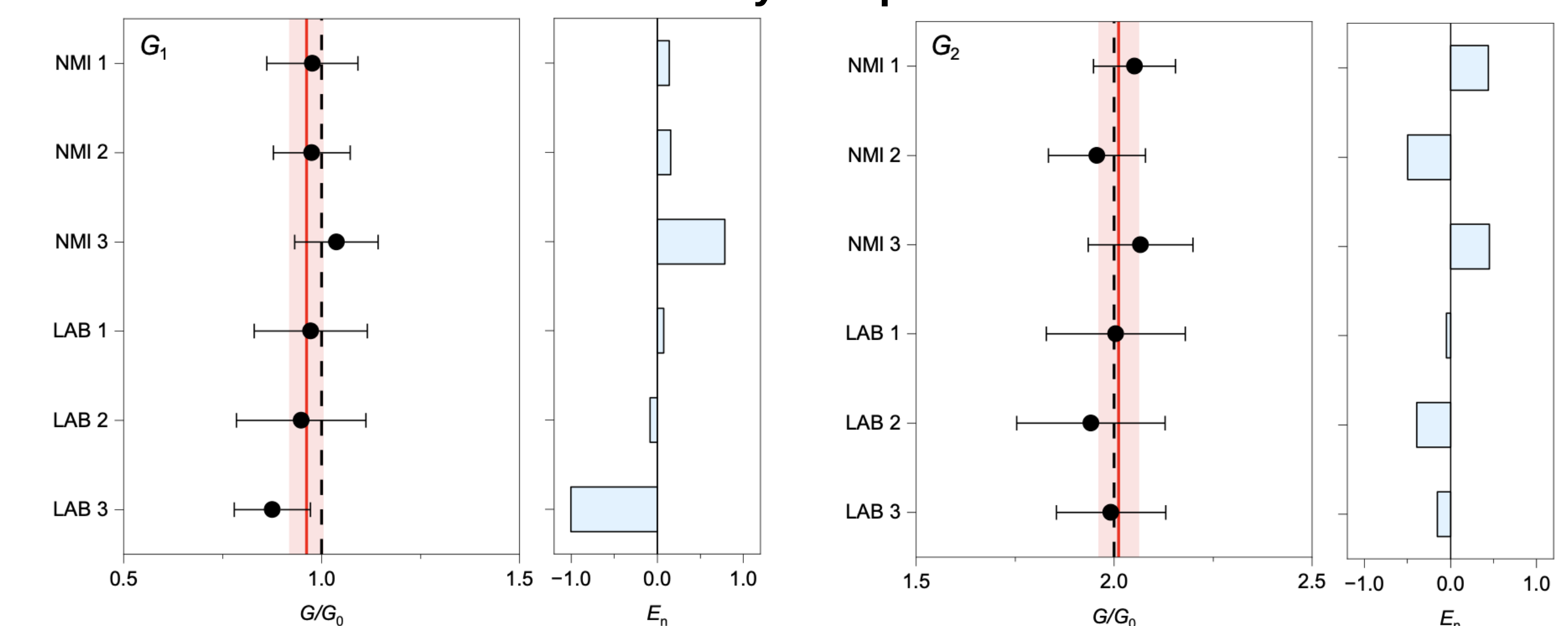
• A memristive-based resistance standard

Conductance plateaus of memristive devices operating in the quantum conductance regime have been exploited as quantum reference values for the realization of a programmable standard of resistance [2].

An interlaboratory comparison involving three NMIs and three academic/research laboratories was performed to measure the achieved quantum reference values.



Interlaboratory comparison results



A consensus value G_{cons} and expanded uncertainty $U(G_{cons})$ are $(0.962 \pm 0.043) G_0$ and $(2.012 \pm 0.051) G_0$ for G_1 and G_2 , respectively. The error of the consensus values for G_1 and G_2 is -3.8 % and 0.6 % with respect to expected G_0 and $2G_0$ theoretical values, respectively. The normalized error $E_n \leq 1.0$ for all participants shows that the measured conductance values belong to consistent sets.

Our results highlight the possibility of having a quantum resistance standard on a chip that can be incorporated into any type of electronic measurement instrumentation and device.

[2] The MEMQuD consortium, "Intrinsic, room temperature quantum resistance memristor for next generation zero-chain traceability SI standard", *arxiv preprint*, (2025).