Characterization of resistive foils as a function of humidity, temperature and integrated charge

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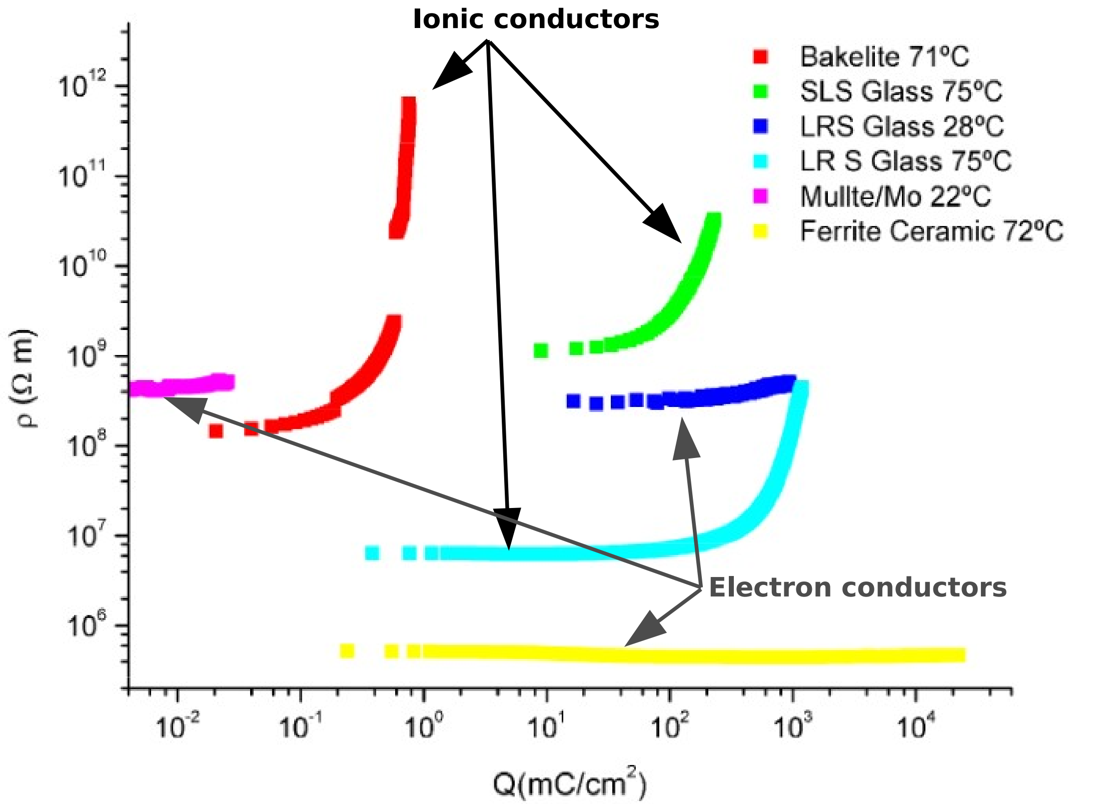
Introduction

- For ATLAS NSW Micromegas resistive layers, polymer thick film resistor paste will be screen-printed on Kapton foils. This paste consists of graphite particles dispersed in an epoxy resin.

- Two different types of Kapton foils (EN & HN) with the same screen-printed resistive paste (ESL D-RS-12115) were studied as a function of humidity, temperature and integrated charge.

Many thanks to A. Ochi for providing the foils

- Graphite is an electron conductor, thus no time dependent resistivity degradation is expected



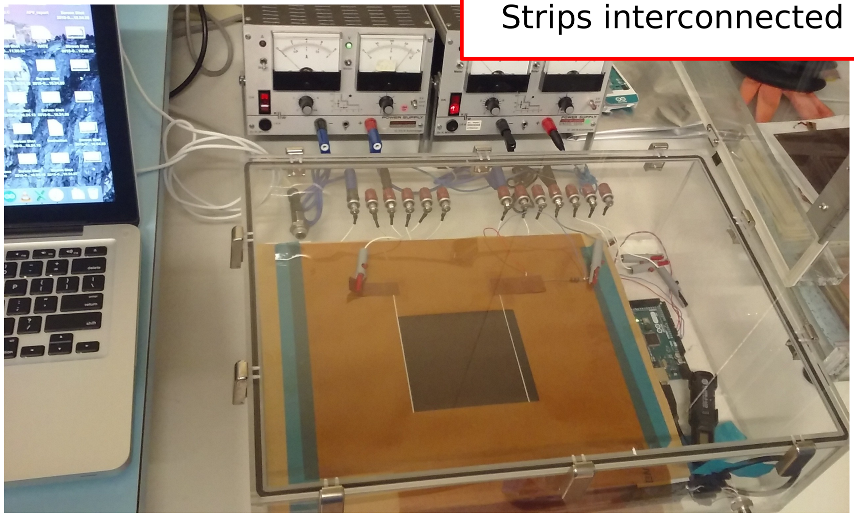
Several materials (ionic and electric conductors) studied by the RPC community for use in the resistive plates. Ionic conductors show a charge depletion behavior resulting in an increased resistivity over time, while electron conductors seem not to suffer from resistivity aging

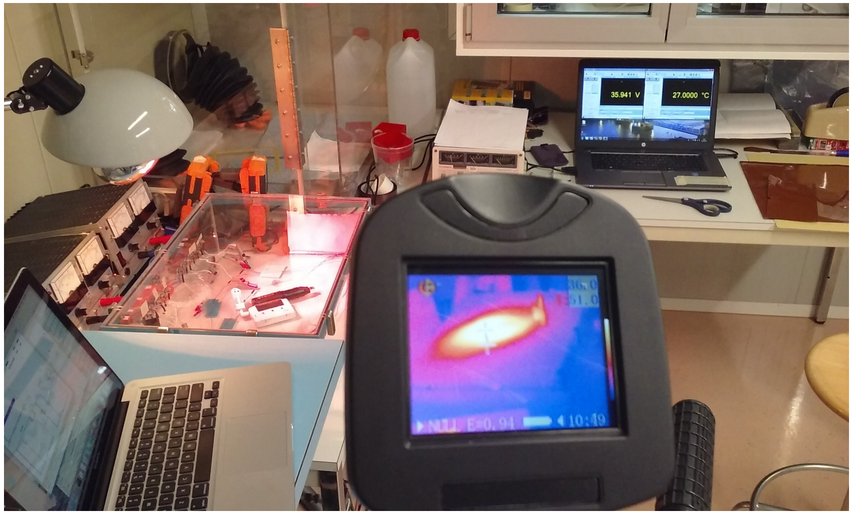
M.Morales at al, 2013 JINST 8 P010122

Experimental Setup

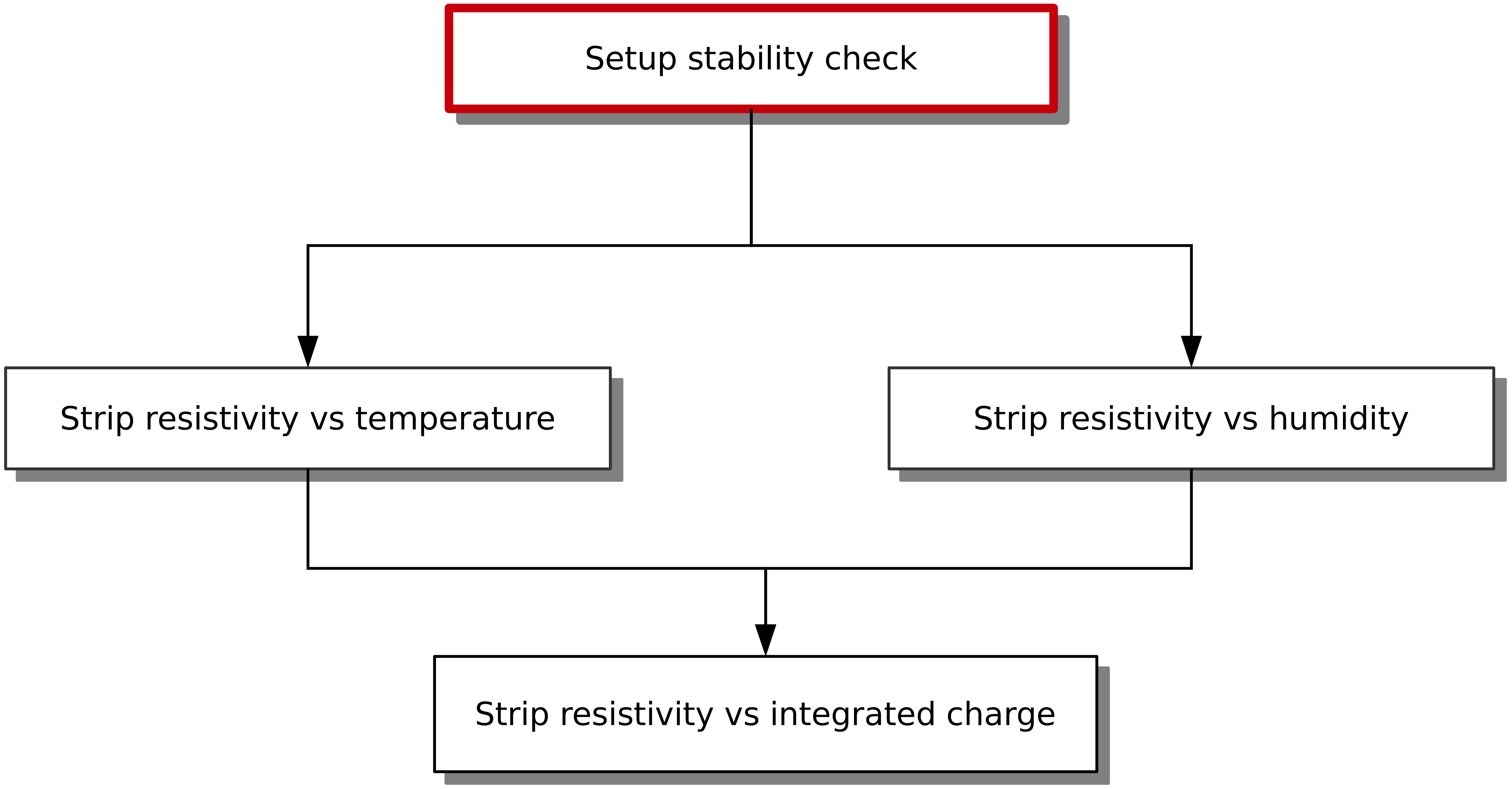
Active area: $10 \times 10 cm^2$
Num. of strips : 256
Strip width: 300 μm
Strip pitch: 400 μm
Strips interconnected

- Silver conductive paste is used as voltage supplier in the resistive strips
- The resistive strips of each foil are connected in series with small resistors ($R_{foil} \approx 100*R_{control}$) and the $\Delta V_{control}$ is recorded with an Arduino
- Relative humidity and temperature are recorded with a data-logger (*Lascar EL-USB-2-LCD*)
  - Temperature accuracy: $\pm 0.5^0$C
  - Typical r.h. accuracy: ±3% (for 20 and 80%RH)
- Everything was placed inside a plexi-glass box with N_2 flashing to dry the environment
- For the temperature measurements an IR lamp and IR camera were used
- Measurements were taken independently for the two foils



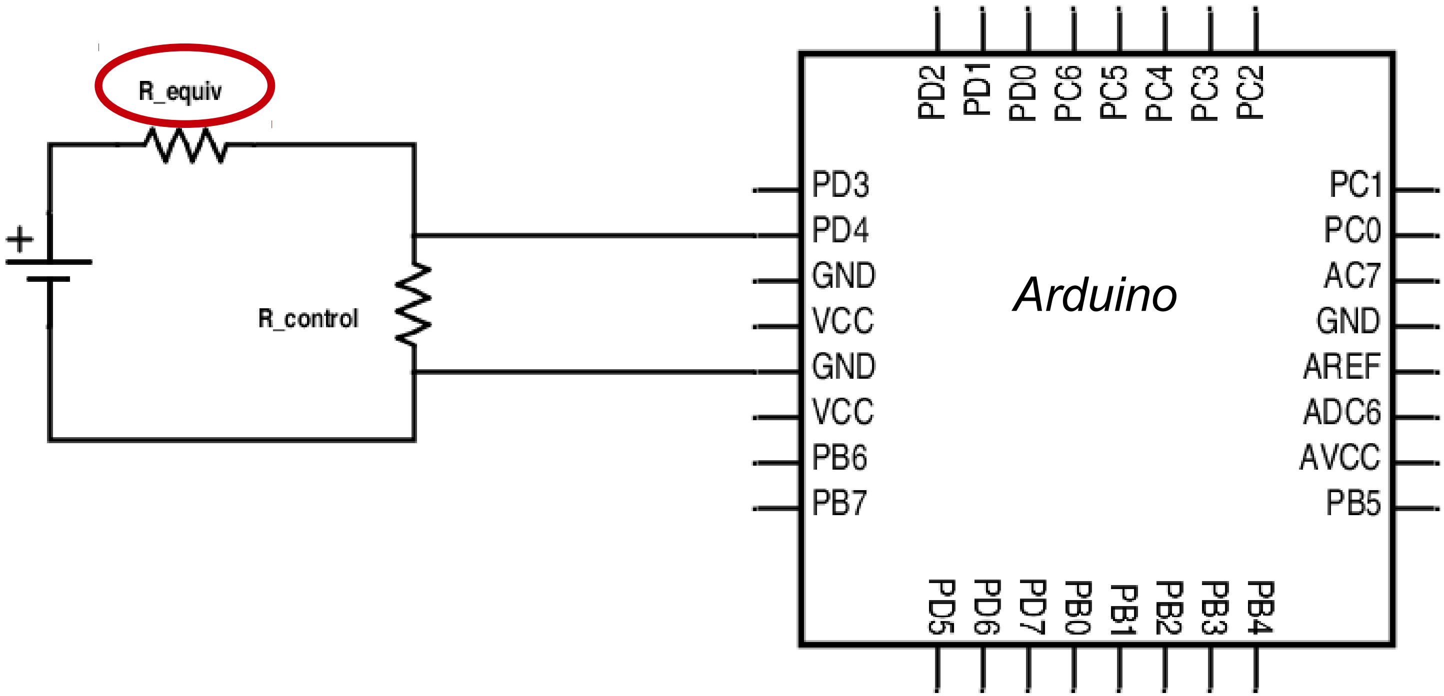


Many thanks to E. Oliveri and F. Manolescu (PH-DT) for the IR camera


Setup stability check
Strip resistivity vs temperature
Strip resistivity vs humidity
Strip resistivity vs integrated charge

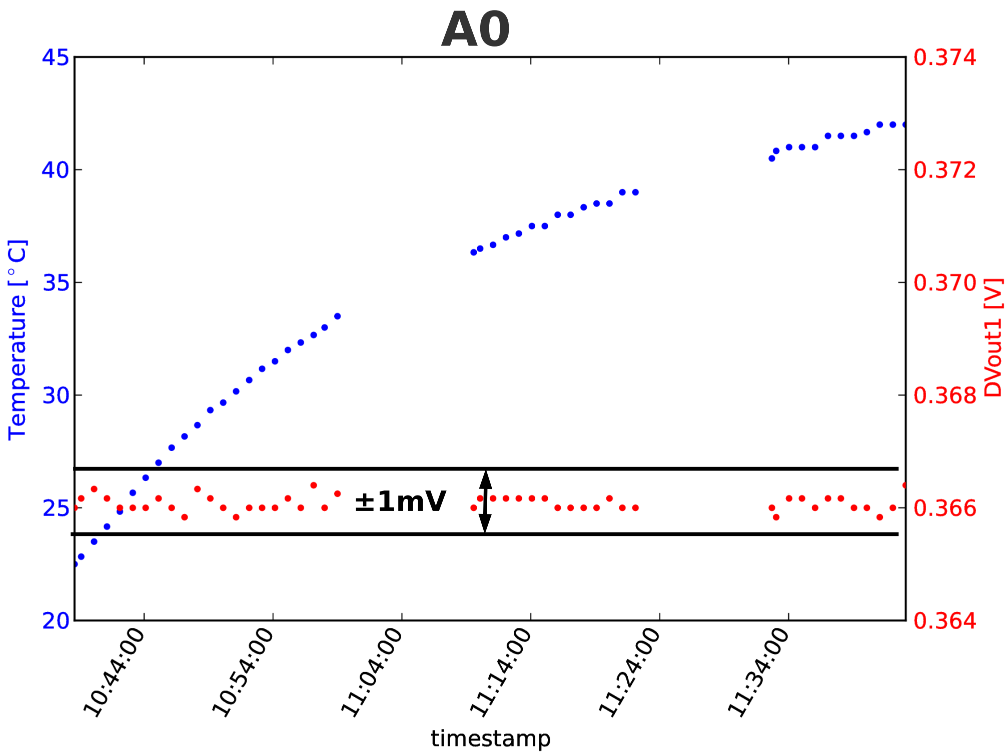
Setup stability check

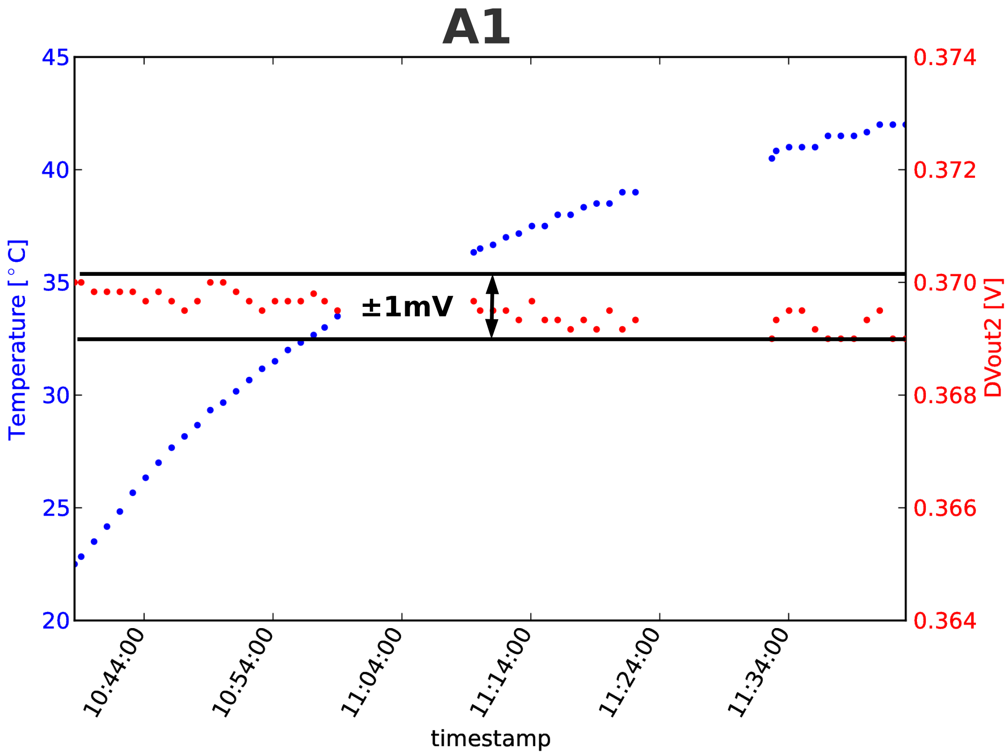
- Foils were replaced by equivalent resistors in order to check the stability of the system with respect to the temperature and relative humidity



Circuit	R_equiv [kΩ]	R_control [kΩ]
1 (A0)	544	5.62
2 (A1)	547	5.82

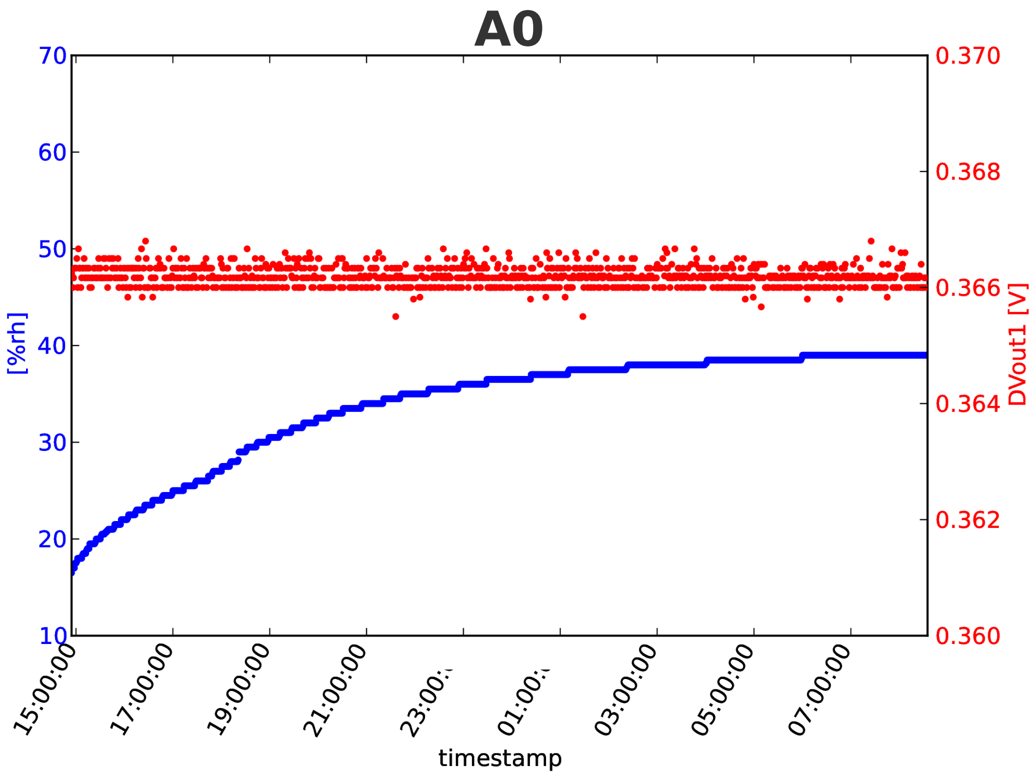
Resistors vs temperature

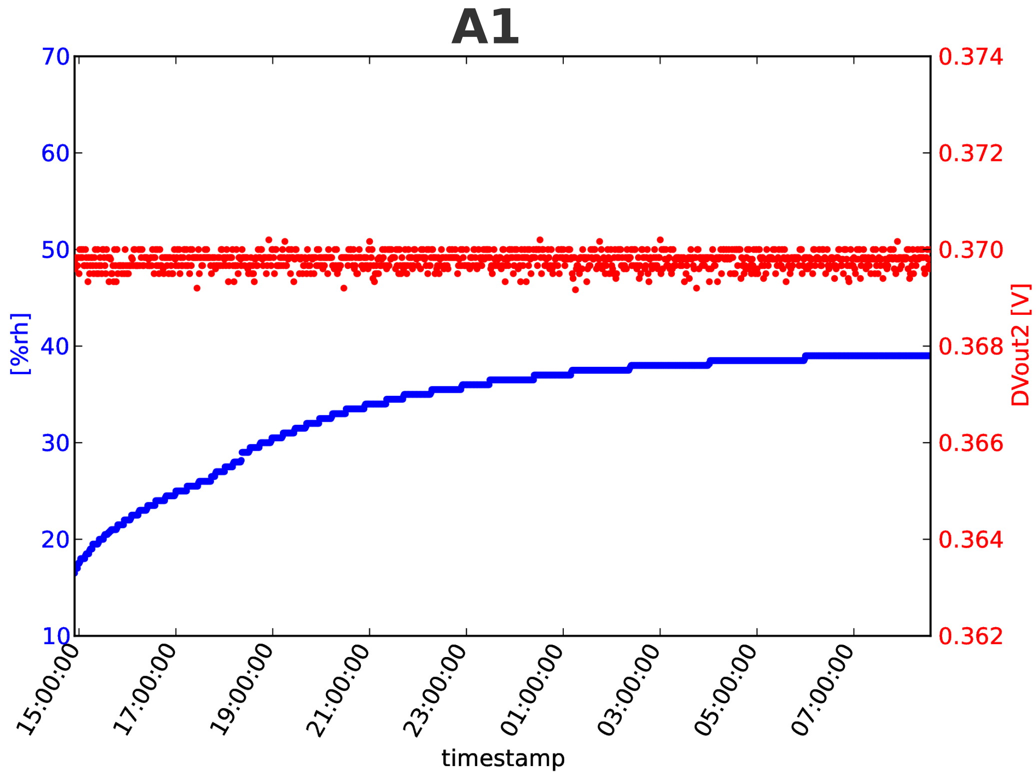




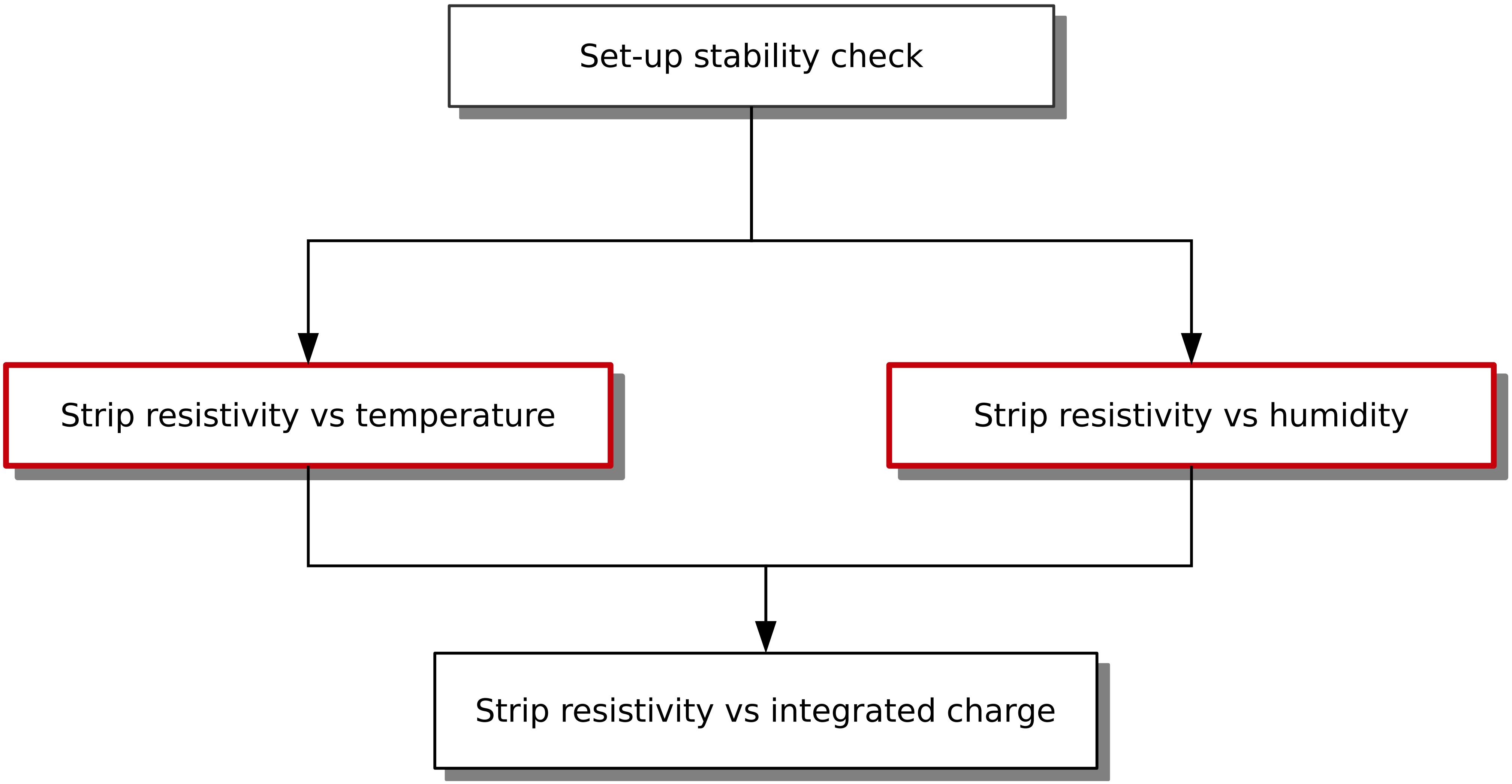
- Fluctuations of ±1mV (±0.8 kΩ) are expected due to the ADC resolution of the Arduino *(back-up slides)*
- Ohmic behavior of resistors verified up to 43°C

Resistors vs relative humidity





- Resistors are stable up to R.H ~40%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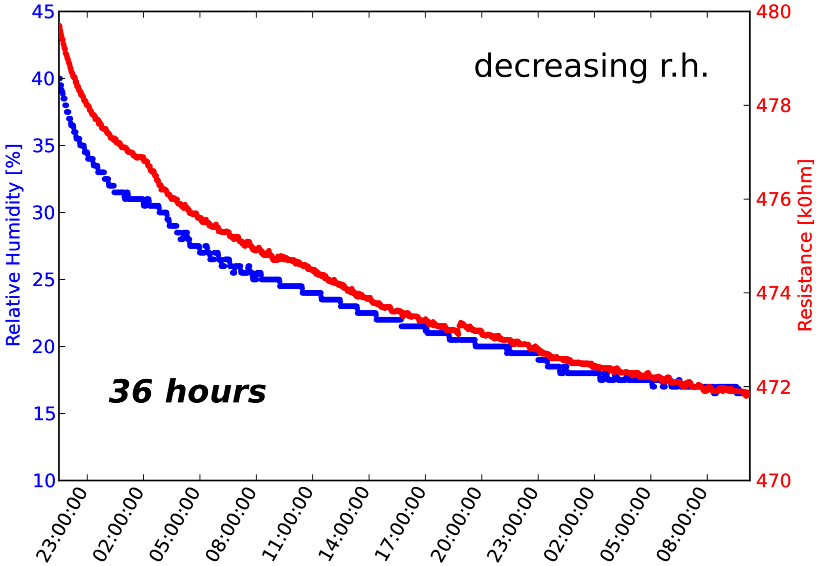
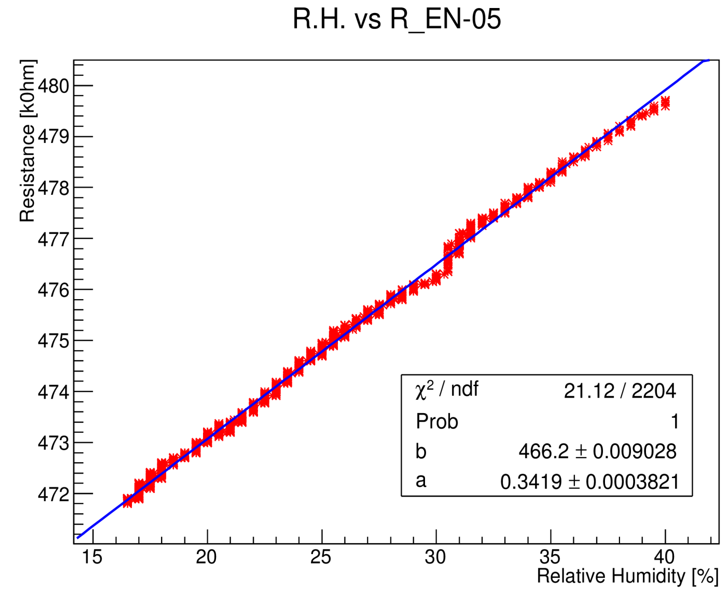
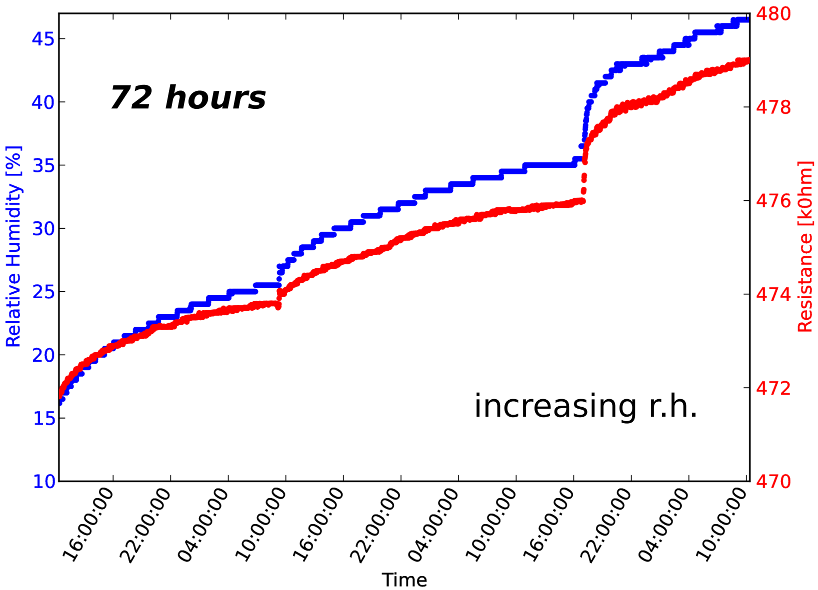
EN-05 : 1 cycle humidity test

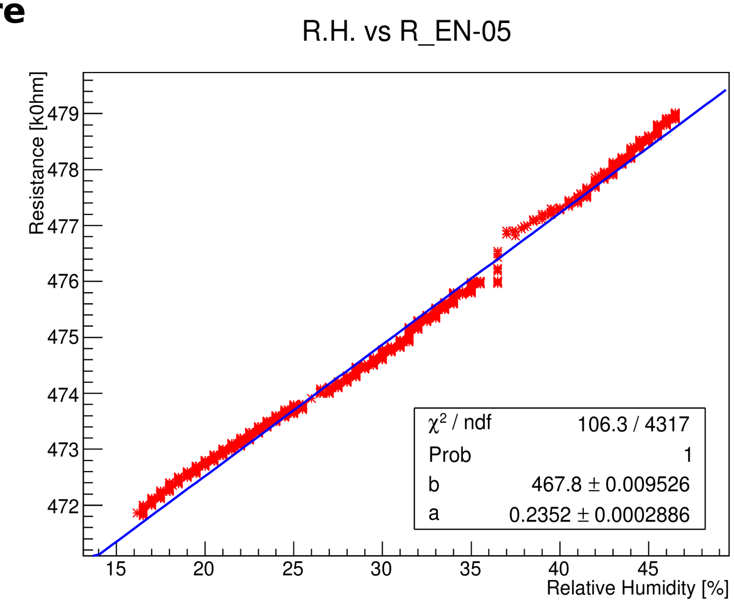
Measurement performed with a multimeter





Stable temperature at ~21 ^{0}C

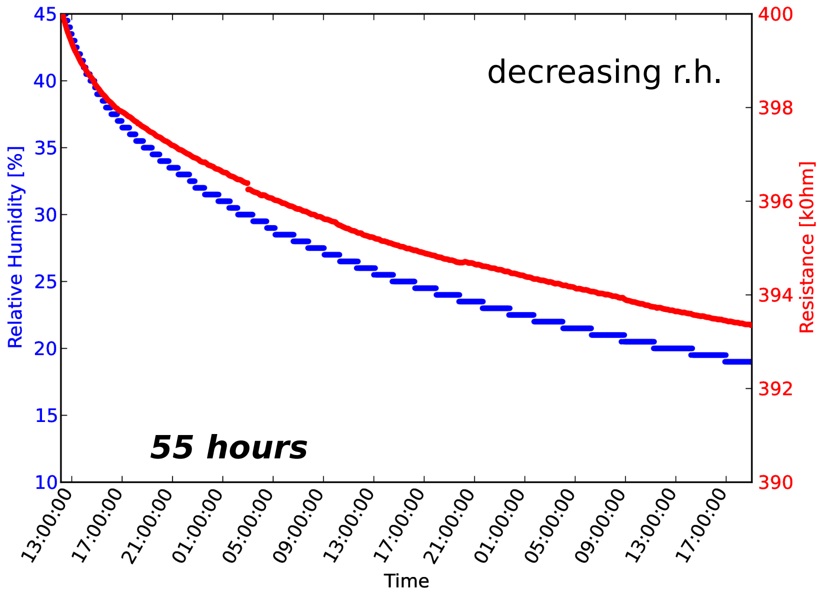


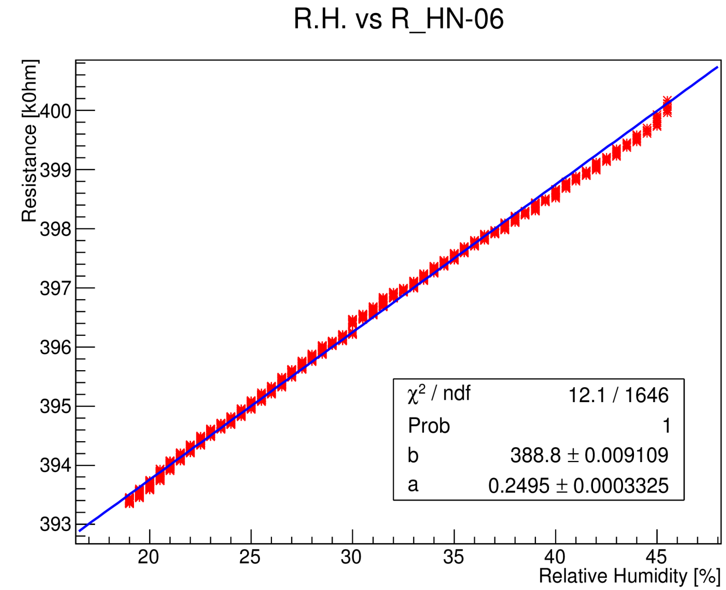


- ~59% change in r.h → ~1.5% change in resistance
- The difference in the slopes is due to the different rate variation of the humidity

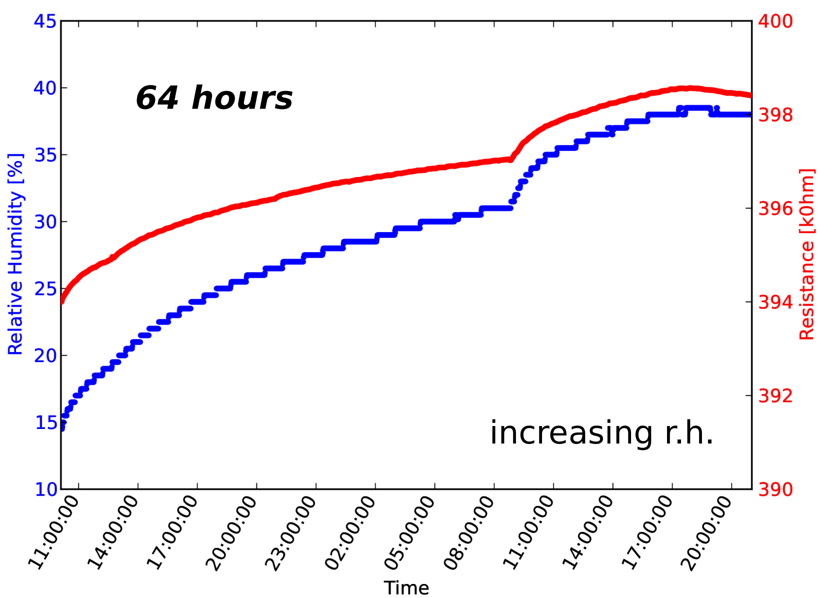
HN-06 : 1 cycle humidity test

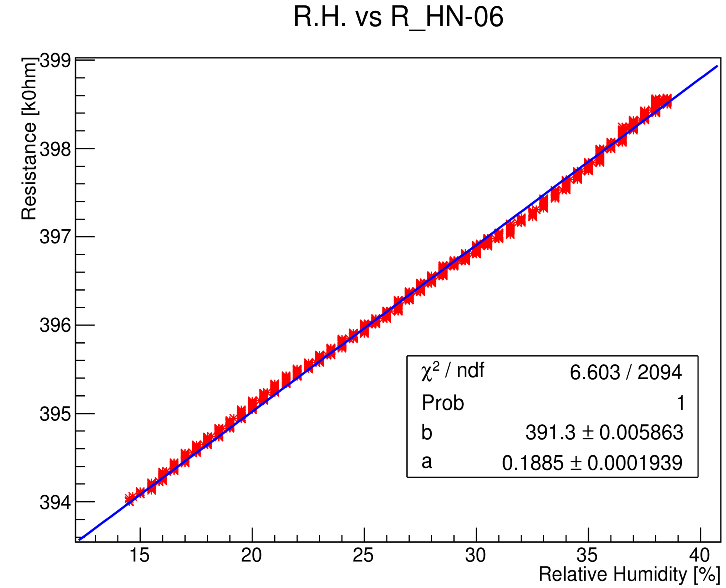
Measurement performed with a multimeter





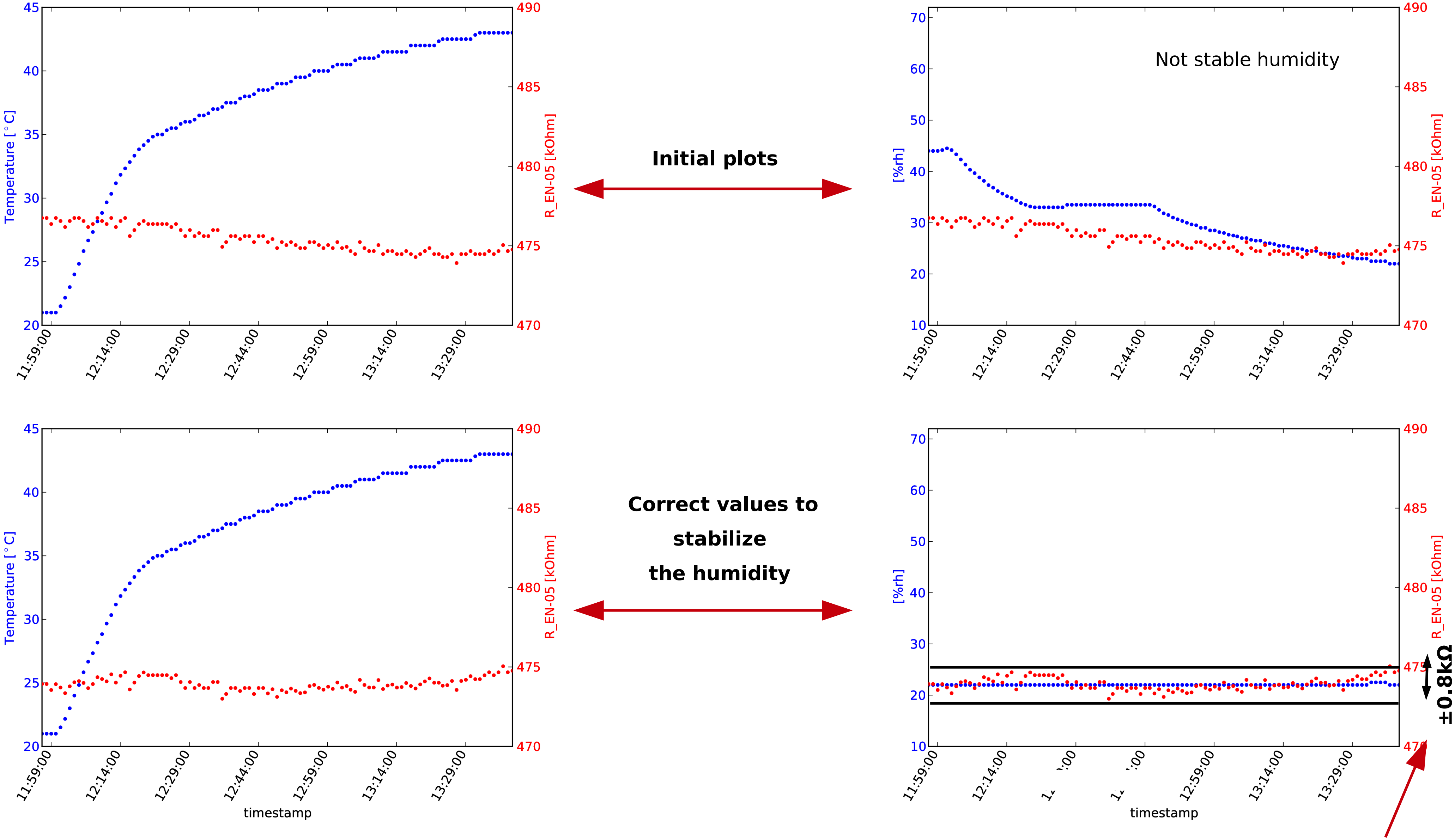
Stable temperature at ~21 ^{0}C





- The same dependence is observed as for the EN-05 foil
- ~58% change in r.h → ~1.7% change in resistance

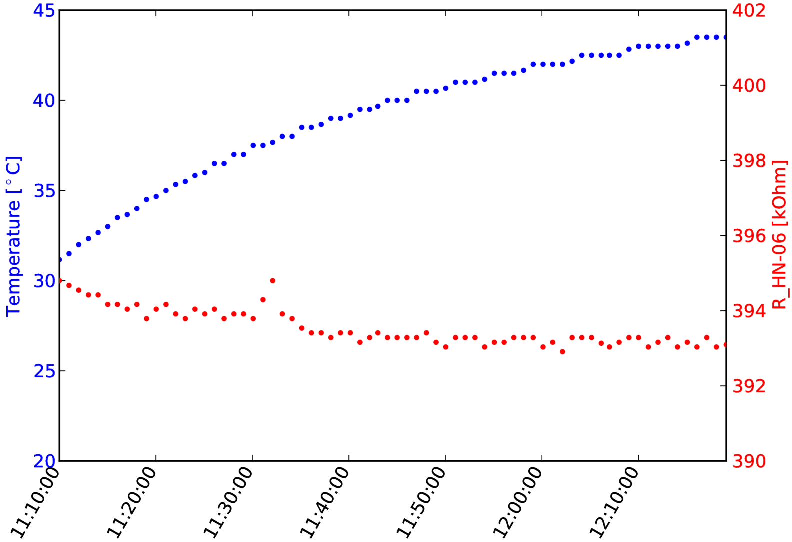
EN-05 : Temperature test



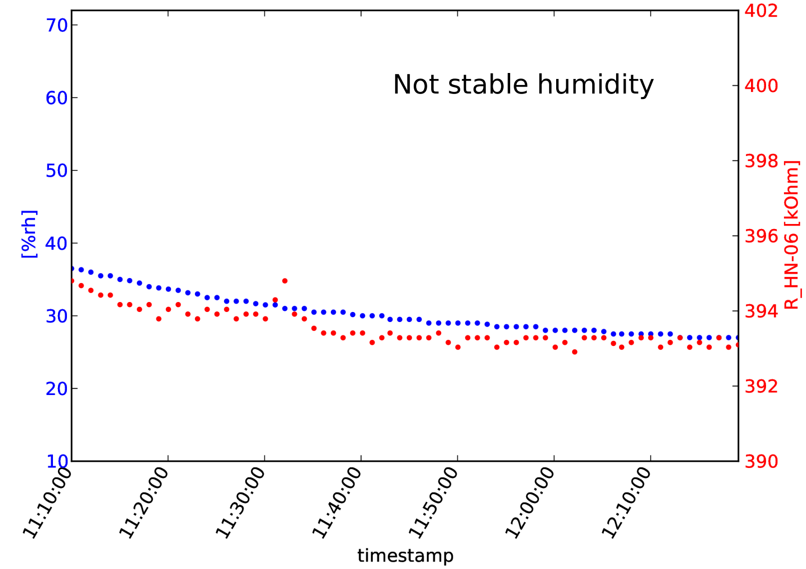
Arduino ADC fluctuations

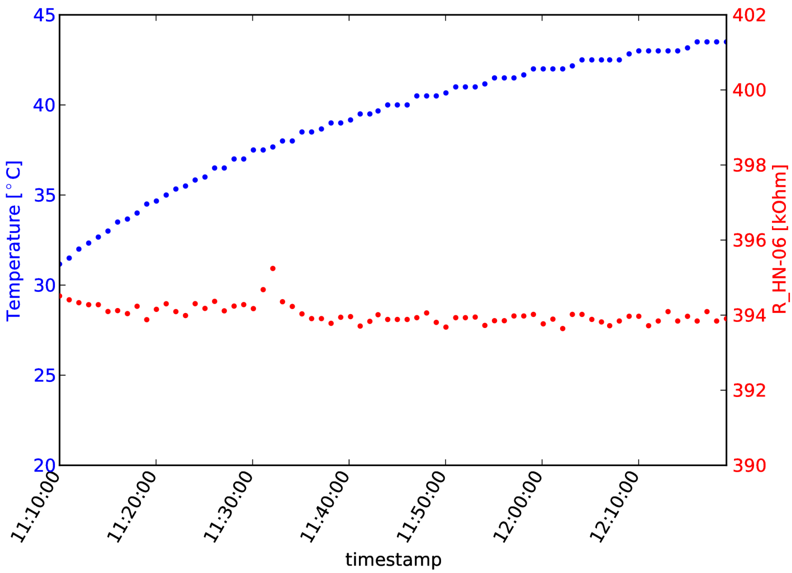
- Data corrected according to humidity measurements
- After correction the resistance of EN-05 seems to be stable up to 43°C

HN-06 : Temperature test

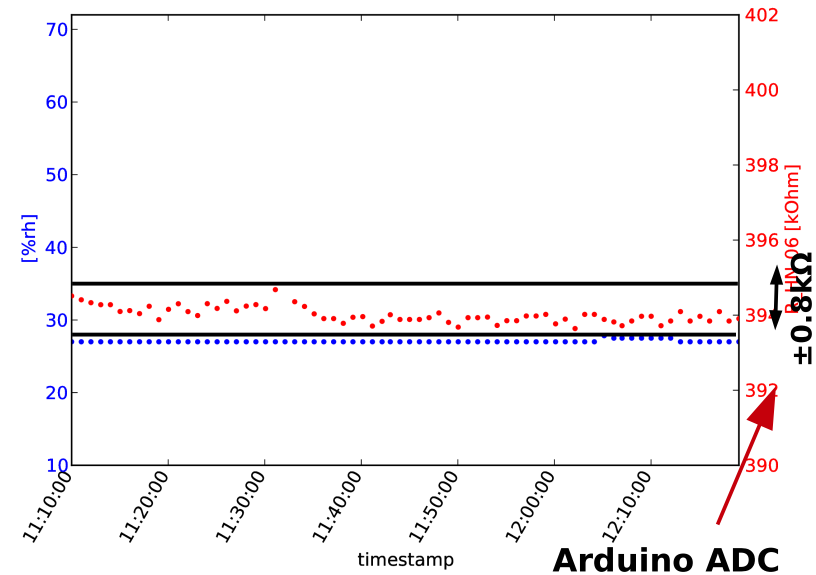


Initial plots



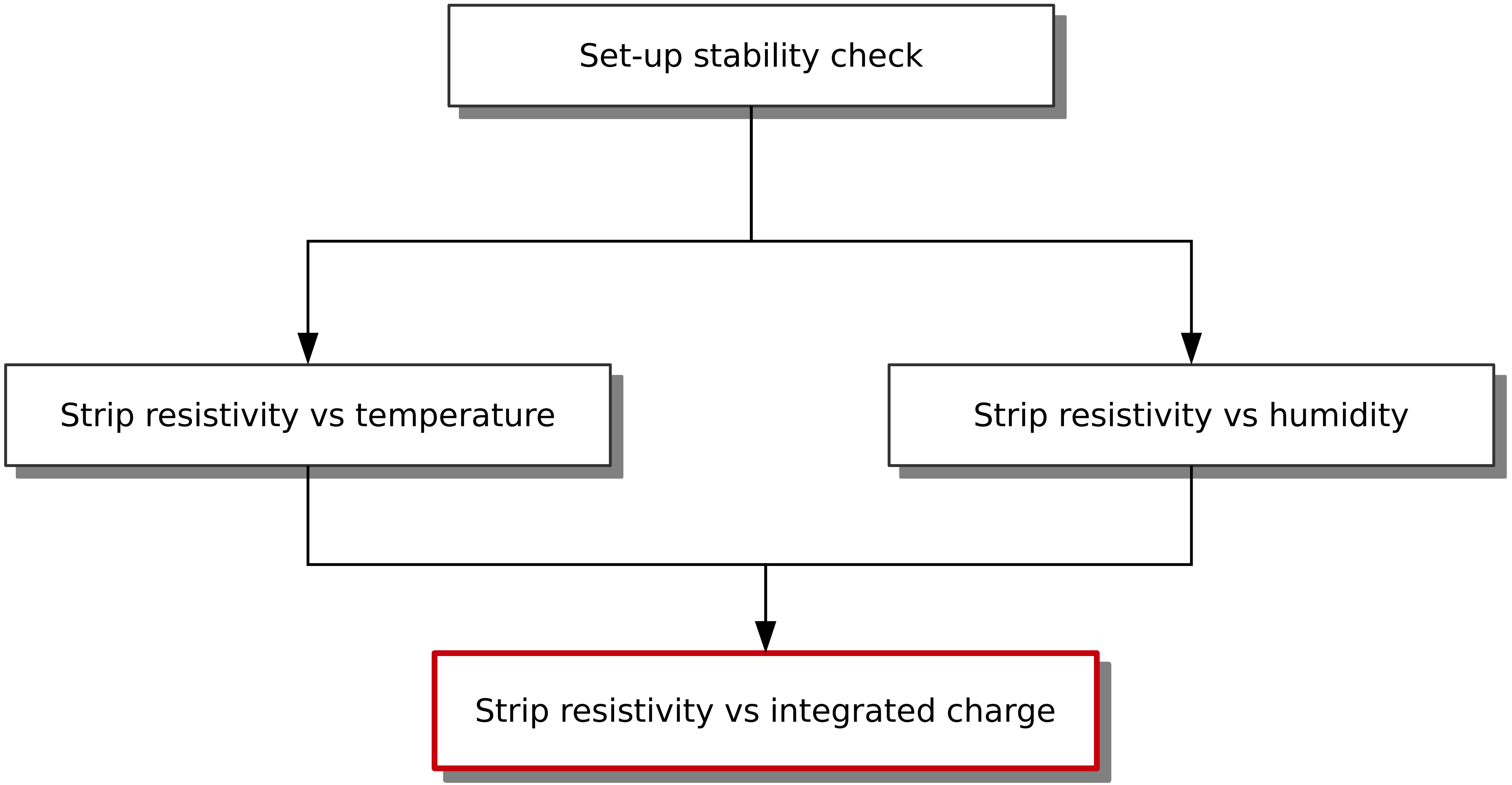


Correct values to stabilize the humidity



Arduino ADC fluctuations

- After correction the resistance of HN-06 seems to be stable up to 43°C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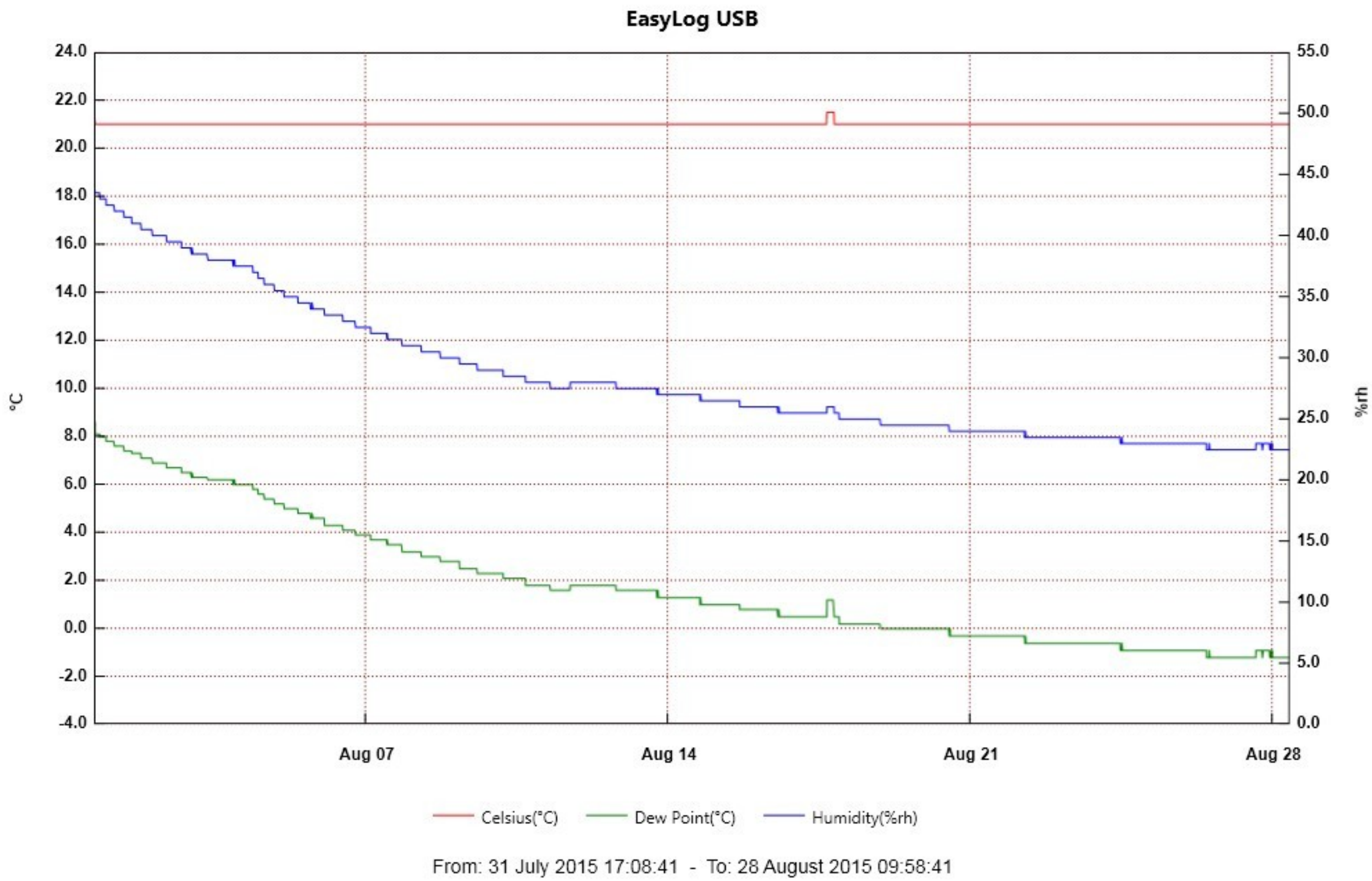
Measurement Conditions

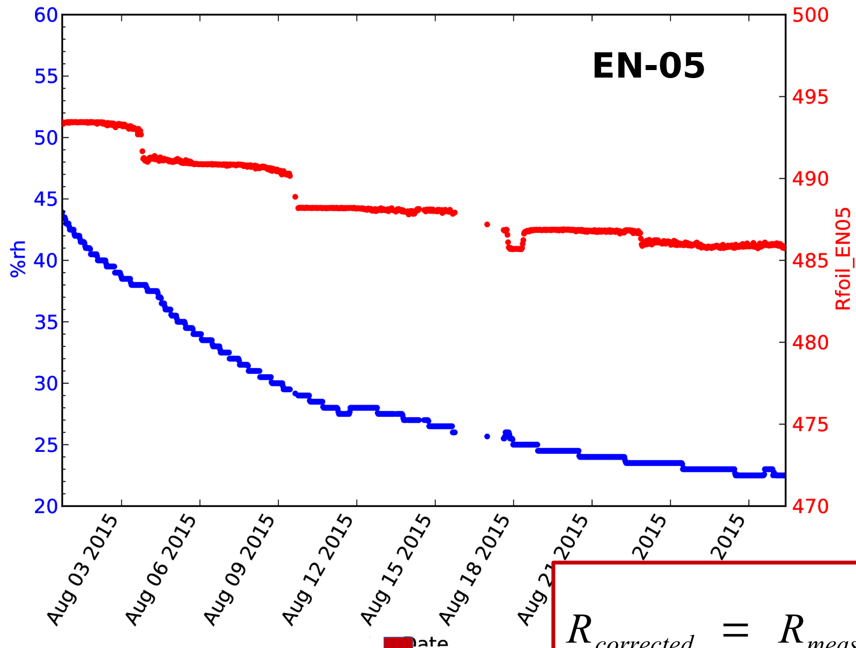


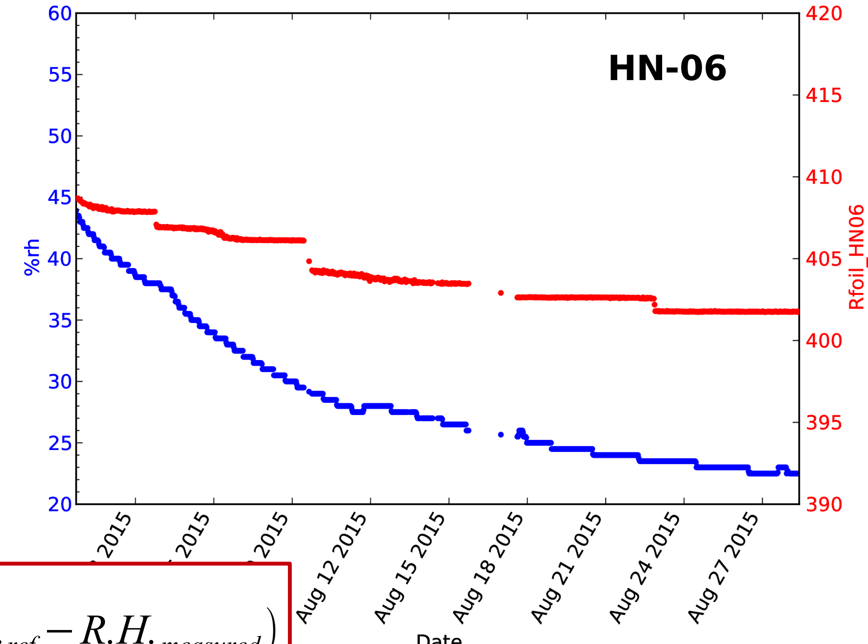
- Current was flowing in each foil for ~24.5 days
- Stable temperature at 20.5°C
- Humidity was decreasing due to not perfect sealing of the box

Expected values for stable resistors

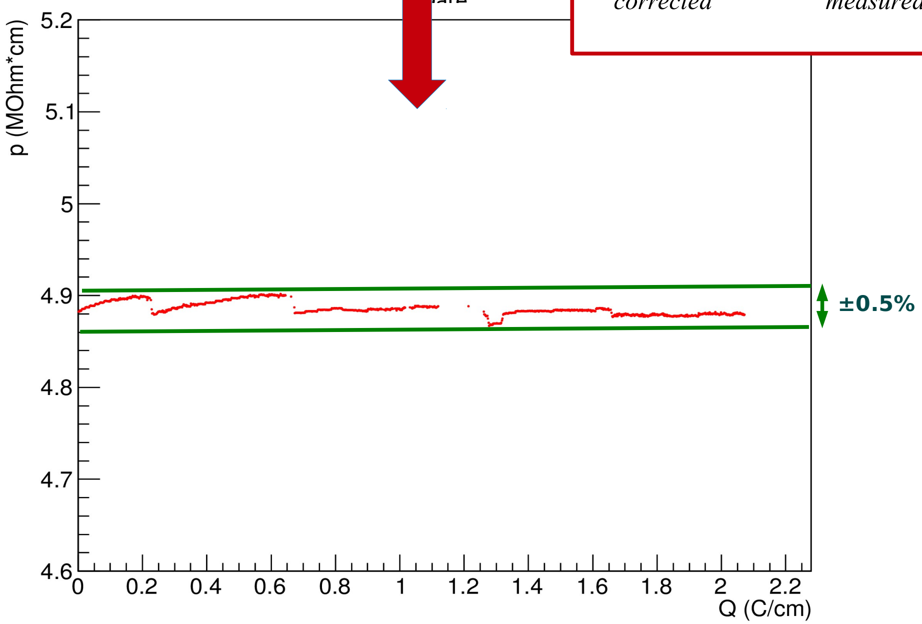
Foil	$\mathbf{I}\,(\mu\mathbf{A})$	$\int \mathbf{Idt}\,(\mathbf{C/cm})$
EN-05	71.6	1.49
HN-06	86.5	1.79

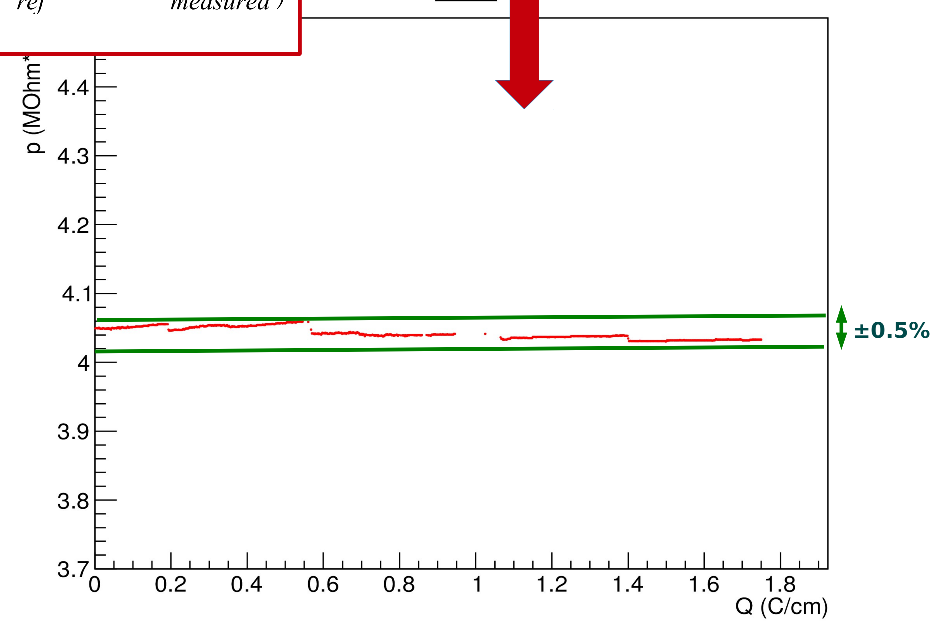
Strip resistance vs flowing charge





$$R_{corrected} = R_{measured} + a \cdot \left(R.H._{ref} - R.H._{measured} \right)$$

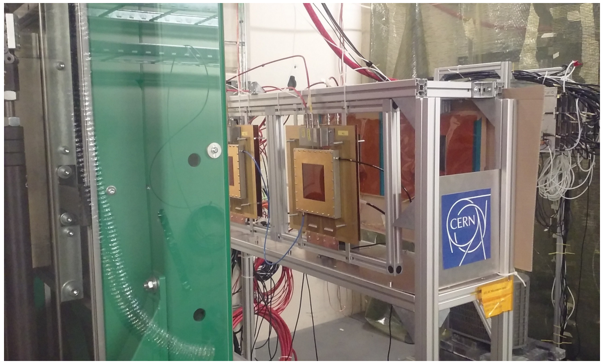




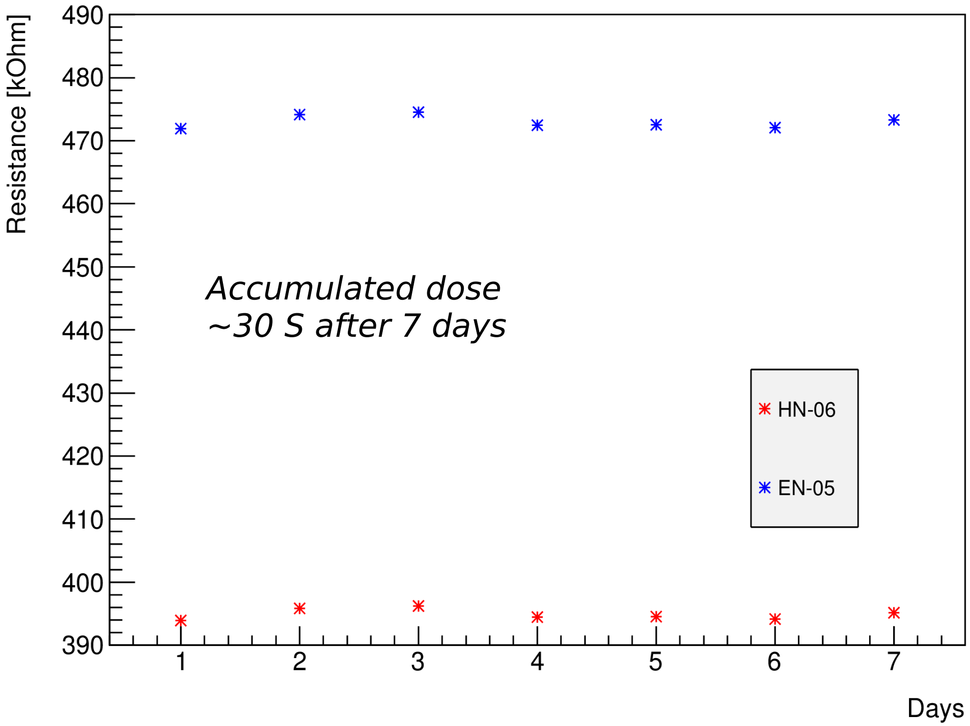
- After normalization to 20% of reference humidity according to the known dependence a residual variation of 0.5% in resistivity is observed for both foils

Radiation hardness test

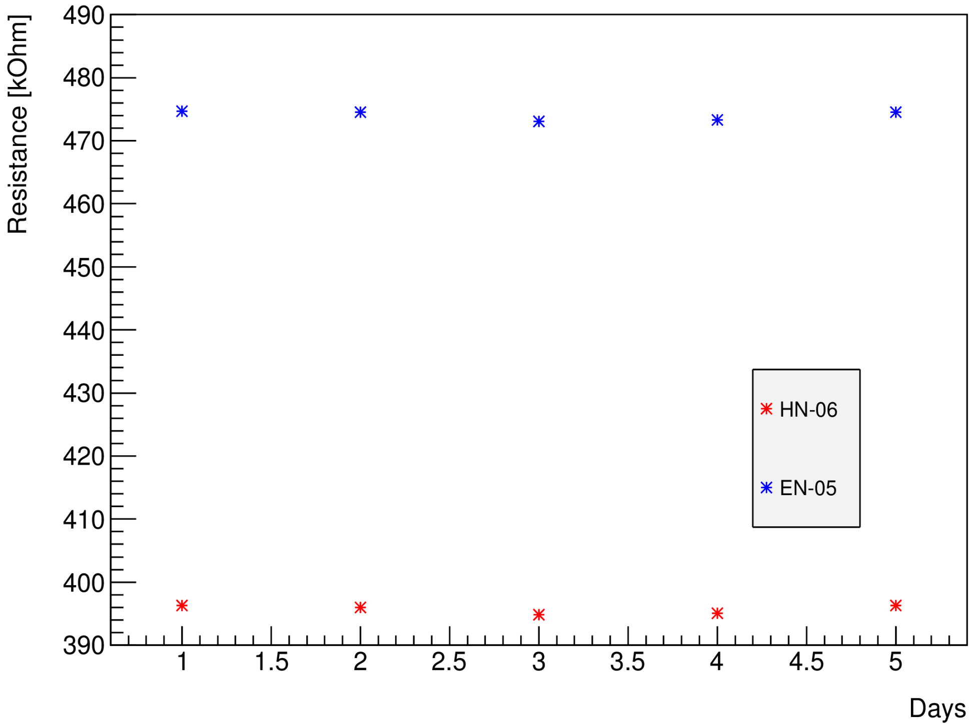
- The foils are exposed in gamma irradiation at GIF++ for radiation hardness test
  - The resistance of the foils, temperature and humidity (inside the banker) are recorded
  - Measurements are still on going since two weeks now



Preliminary results with source on



Preliminary results with source off



Conclusions

- Both foils show the same behavior with respect to temperature, humidity and flowing charge
- The strip resistivity has a clear linear dependence with respect to humidity.
  ~0.2kΩ / %r.h. depending how fast the humidity is absorbed by the resistive paste
- No change in the resistivity was observed up to 43°C
- Current was flowing in the strips for almost ~25 days accumulating 2 C/cm^2 and 1.8 C/cm^2 for EN-05 and HN-06 respectively. We did not observe any significant change in the resistivity afterwards and we can conclude that these resistive foils are not suffering from resistivity aging
- Radiation hardness test on both foils is on-going at GIF++

Many thanks especially to Eraldo and Diego for
the long discussions and suggestions about these measurements !!!

Thank you!!!!

BACK-UP

Arduino (MEGA 2560)

- The output of the Arduino are ADC counts which are converted to voltage by using the formula:

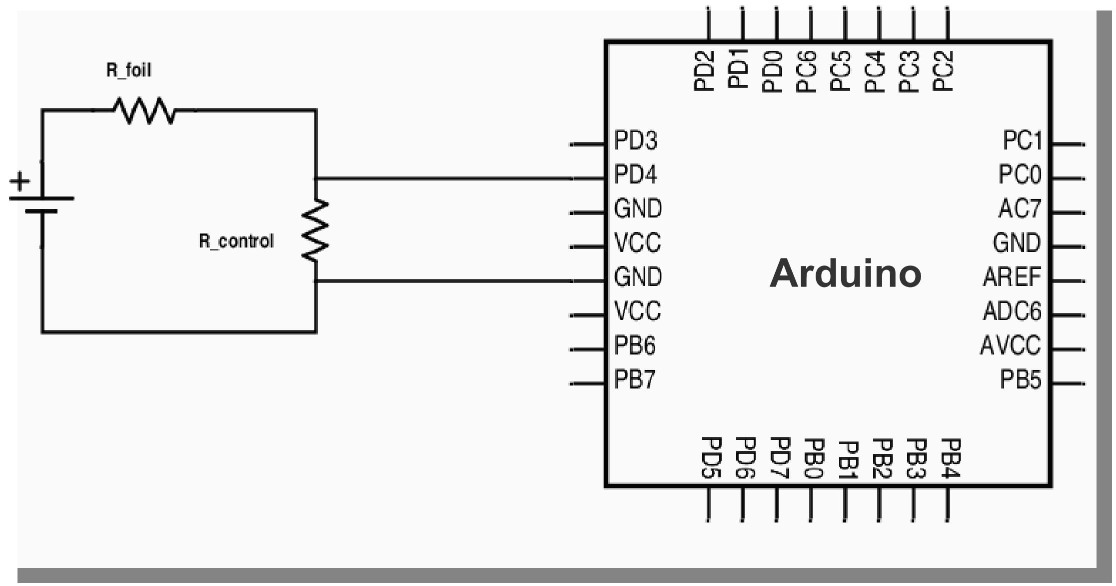
$$\Delta Vout = \frac{ADC_{count} \cdot V_{max}}{ADC_{max}}$$

where:

$$ADC_{count} = AnalogRead(port)$$
$$V_{max} = 1.1\,V\,(real\ value = 1.089\mathrm{V})$$
$$ADC_{max} = 1023$$

- 10 bits resolution (1024 different values)
- With the built-in 1.1V reference, the resolution of ΔVout has an accuracy of : 1/1024 = **1 mV**

The equivalent circuit of the foils



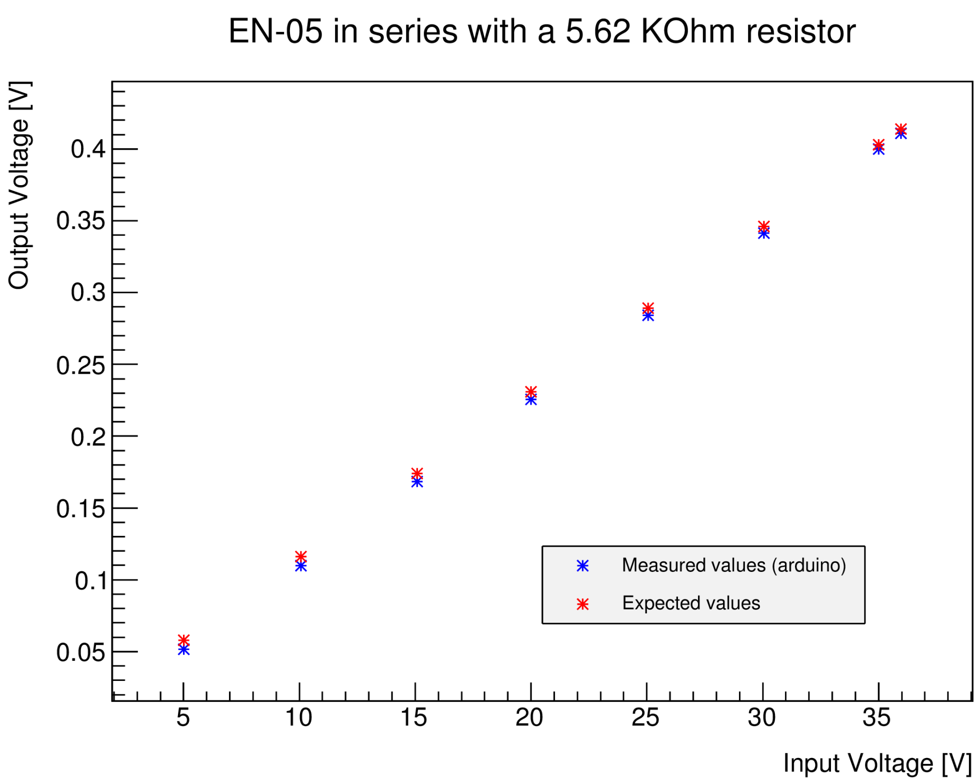
- The current flowing through the circuit :

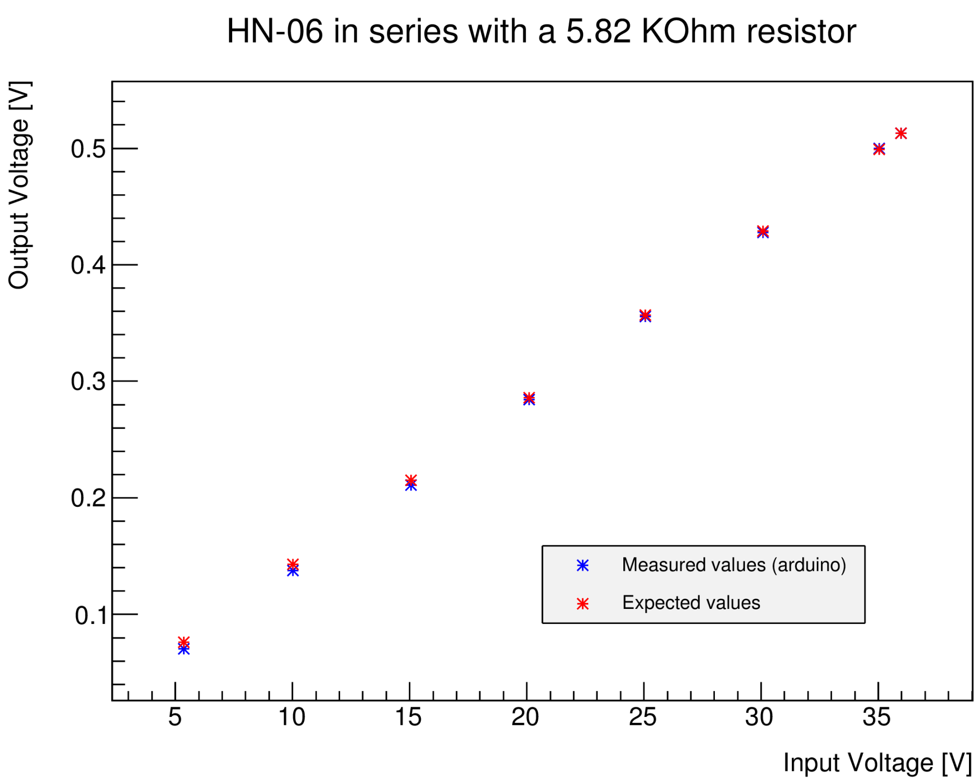
$$I = \frac{Vin}{R_{foil} + R_{control}}$$

- The output voltage measured by the Arduino

$$\Delta V_{control} = I \cdot R_{control} = \frac{Vin}{R_{foil} + R_{control}} \cdot R_{control}$$

Vin vs Vout





Temperature : 22°C

Relative Humidity: 40%

Thermal stability in 2 examples of epoxy/graphite paste without substrate

doi:10.5075/epfl-thesis-5346
http://infoscience.epfl.ch/record/175154

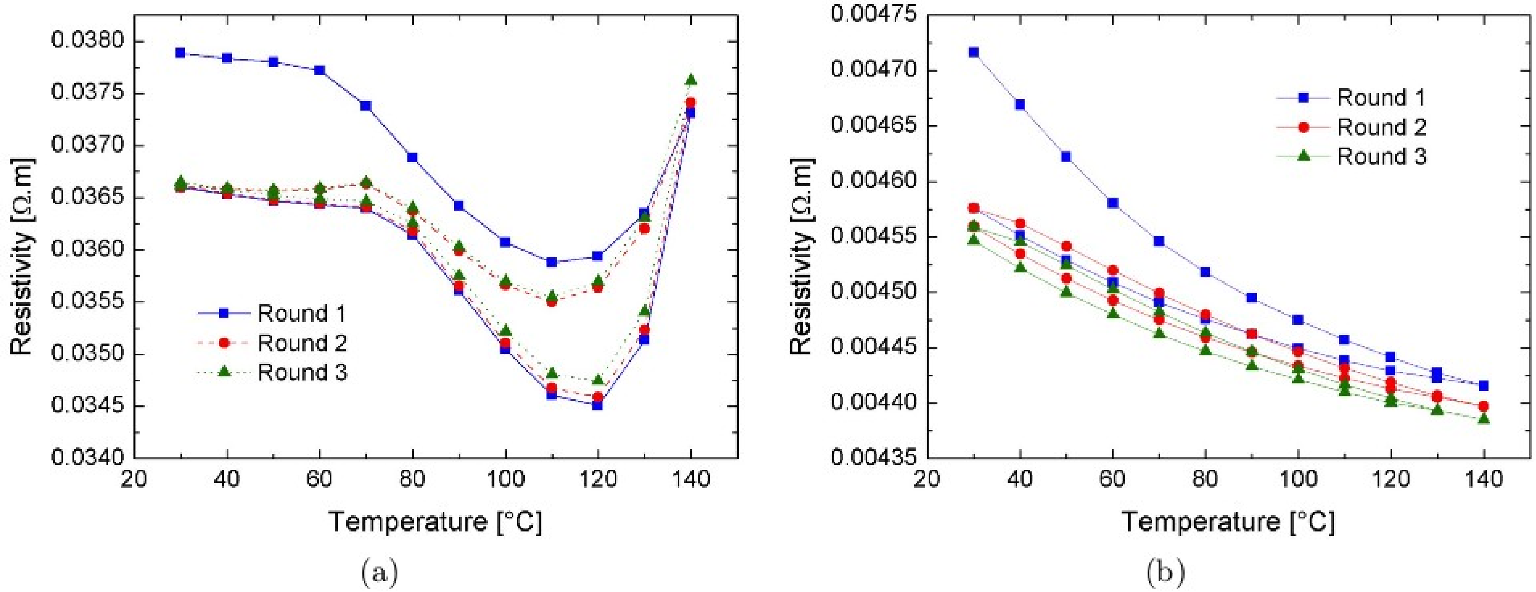


Figure 4.8: Three thermal cycles for 20% KS15 in EpoTEK 377 (a) and Martens Plus (b)

Table 3.1: Main properties of the epoxy resins (suppliers' data)

Commercial name	T_g [°C]	Viscosity at RT [mPa.s]	Curing schedule	Pot life [hour]	Hardener type
EpoTEK 377	≈ 95	150-300	2h@150°C	24	amine
R&G Martens Plus	≈ 200	2'300	24h@100°C + 15h@230°C	12	acid anhydride

Table 3.2: Main properties of graphite powders (supplier data)

Commercial name	Shape	Density [g/cm^3]	Particle size [μm]	Specific surface [m^2/g]
KS4	ellipse	≈ 2.2	< 4	26
KS15	ellipse	≈ 2.2	< 15	12