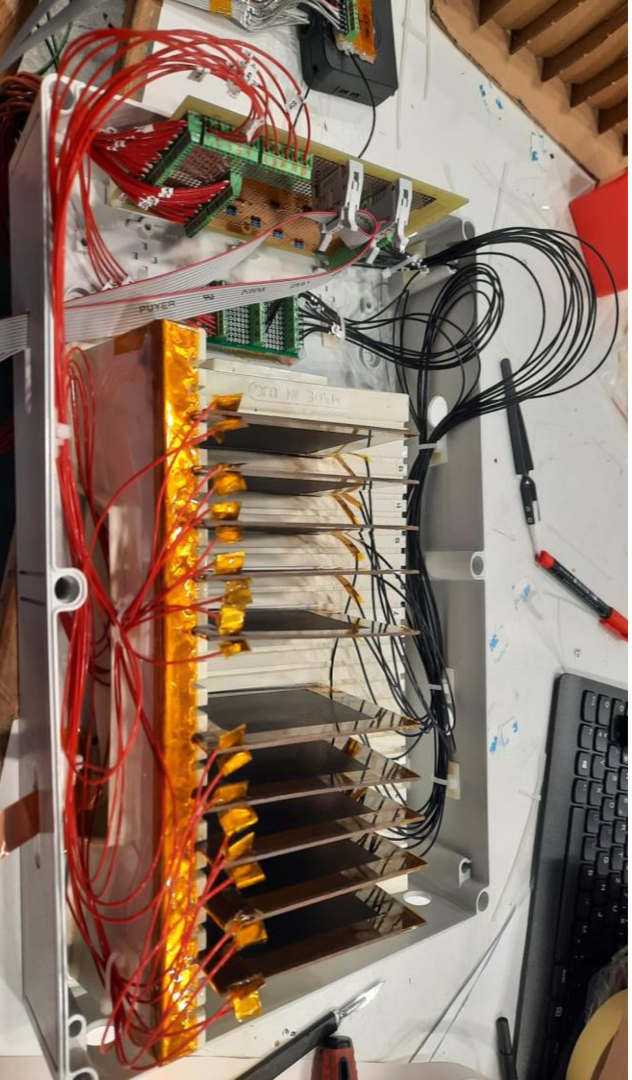


Results of an aging study for the graphite coating of thin-gap RPCs for the ATLAS phase 2 upgrade

Davide Costa
on behalf of the MPP ATLAS Muon Group

DPG-Frühjahrstagung 2025

Göttingen – 31st March - 4th April 2025

MAX-PLANCK-GESELLSCHAFT

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

FSP ATLAS
Erforschung von
Universum und Materie

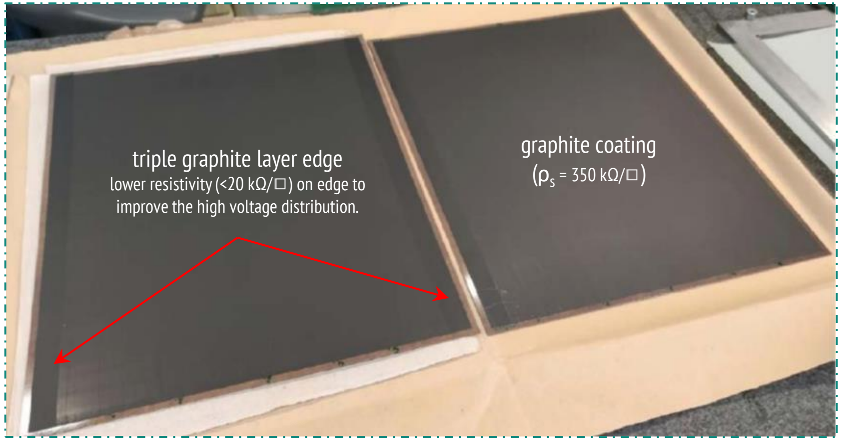
The role of graphite in RPCs

The graphite layer plays an important role in the performance of RPCs:

- Ohmic contact uniformly distributes the field.
- Transparent to prompt avalanche signal.
- Limits rate capability

  ⇒ An increase in total electrode resistance displaces the working point of the detector, worsening performance.

graphite coating of the HPL electrodes



The graphite layer must maintain a constant resistance over the whole operation of ATLAS at the rates expected for HL – LHC.

$$\Delta V = \langle Q \rangle f R$$

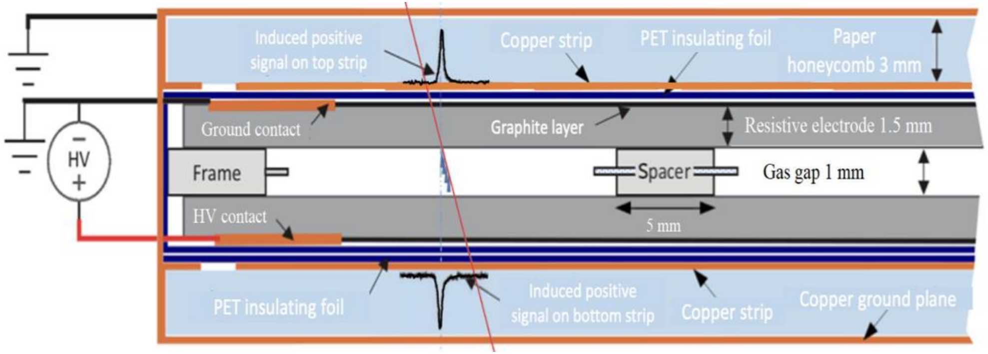
Voltage drop in RPC electrode → ΔV

Charge per event → $\langle Q \rangle$

Event rate → f

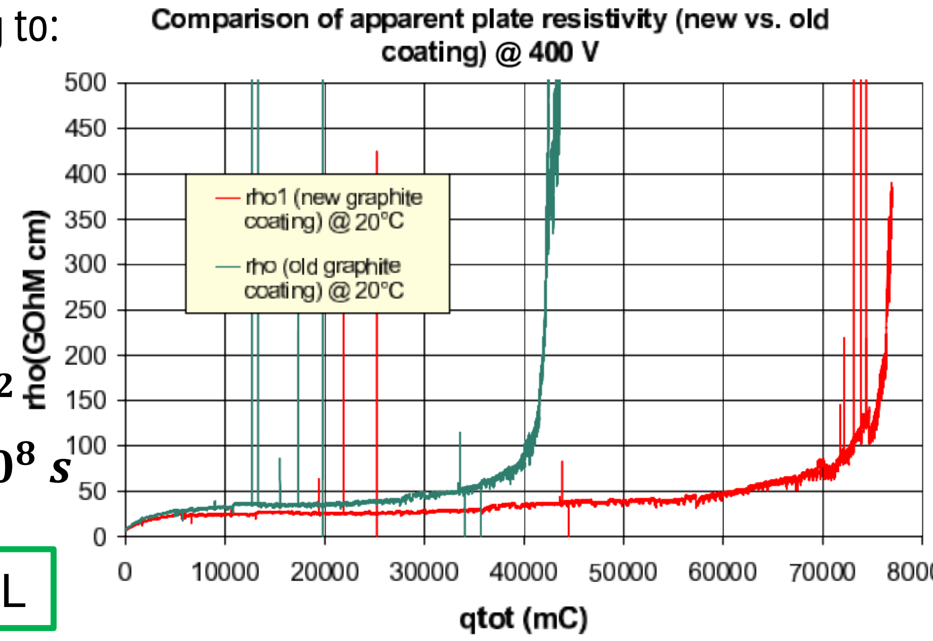
Electrode resistance → R

schematic drawing of RPC singlet



Introduction to aging

- The principal aging phenomenon in RPCs is a decrease in rate capability
  - Increase in total electrode resistance [i] leading to:
    1. Reduced V_{eff} applied to the gas
    2. Potential loss of field uniformity



- Expectations for HL – LHC
  - Charge per count $\rightarrow \boldsymbol{6\ pC}$
  - Max interaction rate in BIS $\rightarrow \boldsymbol{100\ Hz/cm^2}$
  - Effective exposure time (50%) $\rightarrow \boldsymbol{1.58 \times 10^8\ s}$

S.F. x 1

$\boldsymbol{94.8\ mC/cm^2}$ 10 yrs HL

S.F. x 3

$\boldsymbol{284.4\ mC/cm^2}$

- Tests performed at different voltages to study what impact acceleration rate has on aging.

Aging studies at MPP

- Investigating different contributions to aging under different conditions

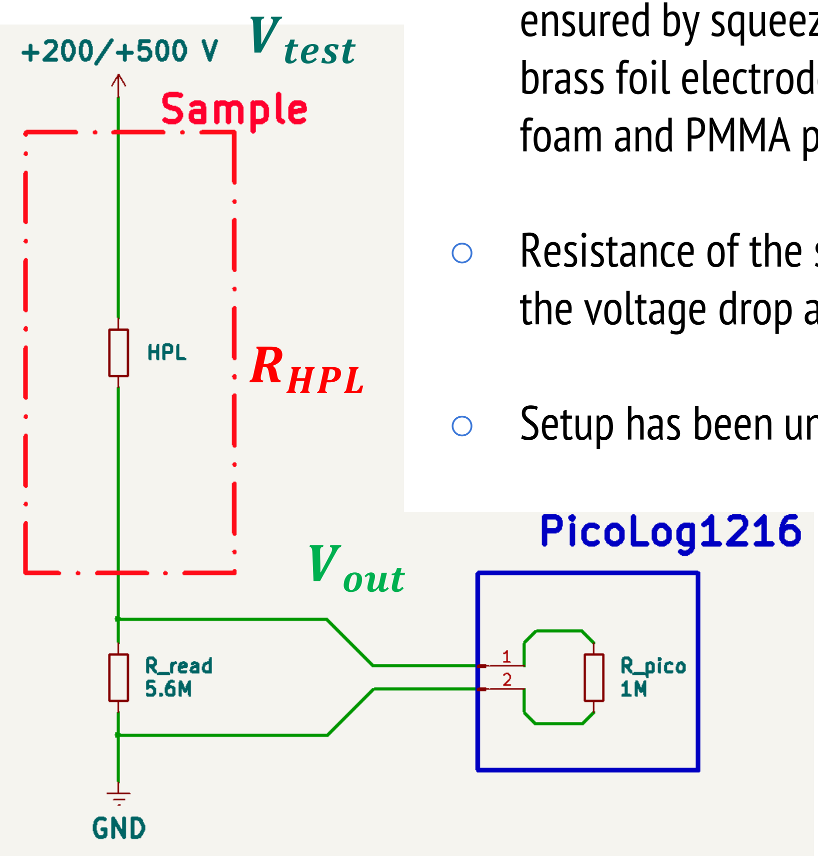
- The **Graphite** test ONGOING
  - 10x10 cm^2 Bakelite (HPL) plates
  - Graphite coating on both sides
  - Most similar to standard RPC configuration and to tests performed in the literature

- The **HPL** test ONGOING
  - 10x10 cm^2 Bakelite (HPL) plates
  - Uncoated
  - Isolate effects of aging on bulk resistivity

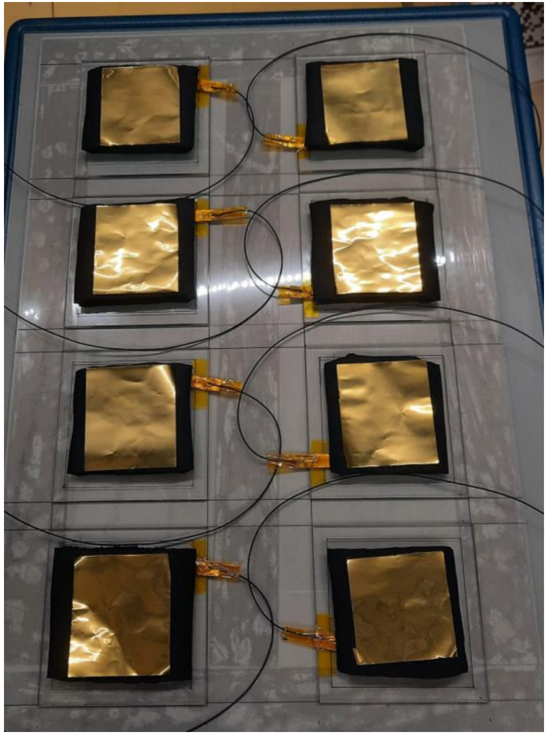
- The **Irradiation** test PLANNED
  - 10x10 cm^2 Bakelite (HPL) plates
  - Graphite coating on both sides
  - Behaviour of coating under heavy irradiation at the CHARM facility at CERN

The **Graphite** and **HPL** tests are currently being carried out in the clean room at MPP in Garching

HPL test



- No graphite coating. Electrical contact is ensured by squeezing the samples between brass foil electrodes, backed by insulating foam and PMMA plates.
- Resistance of the sample is measured through the voltage drop across a read-out resistor.
- Setup has been under test since 20/12/2024.

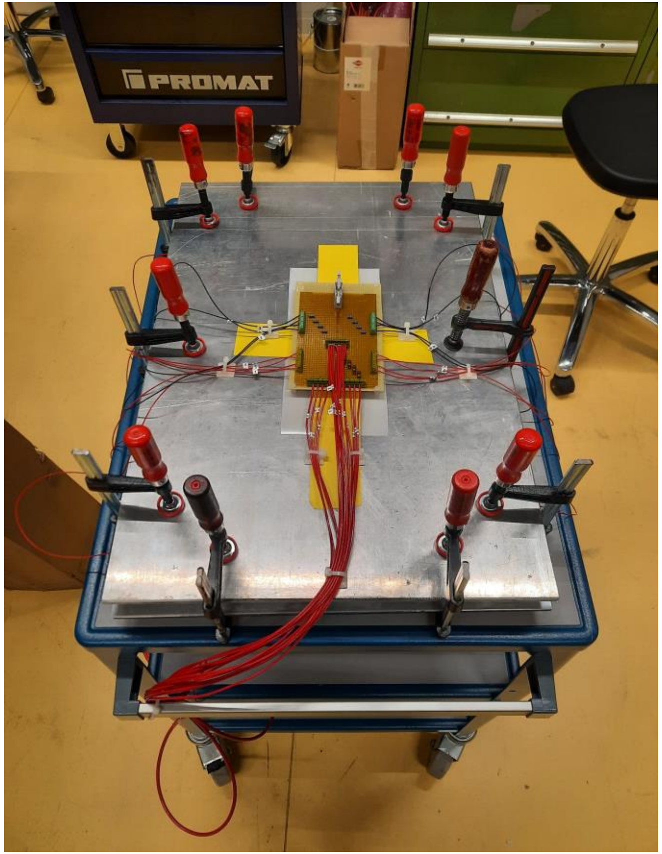


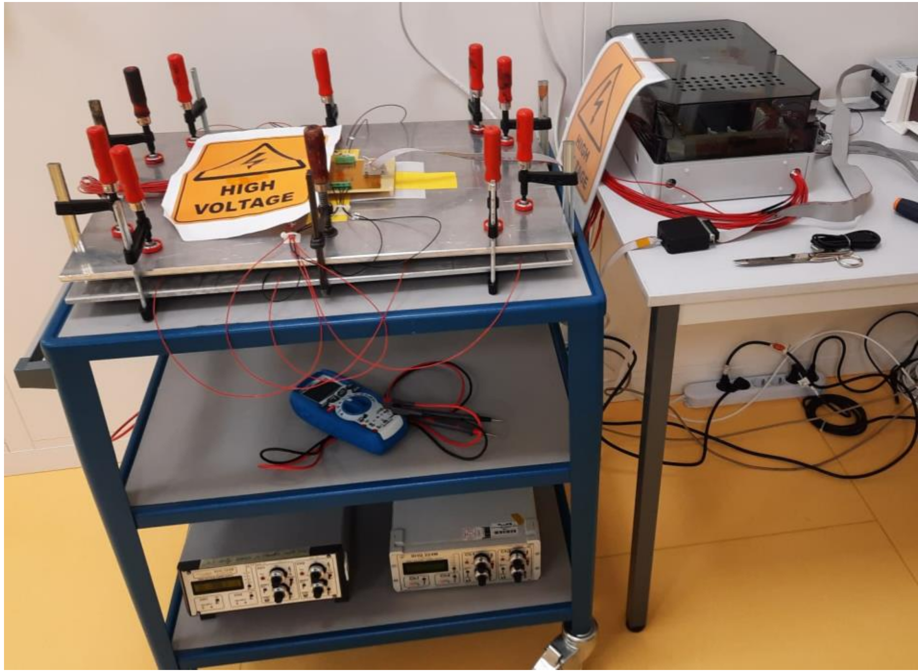
$$R_{HPL} = R_{read} \parallel R_{pico} \left({V_{test}}/{V_{out}} - 1 \right)$$

HPL test

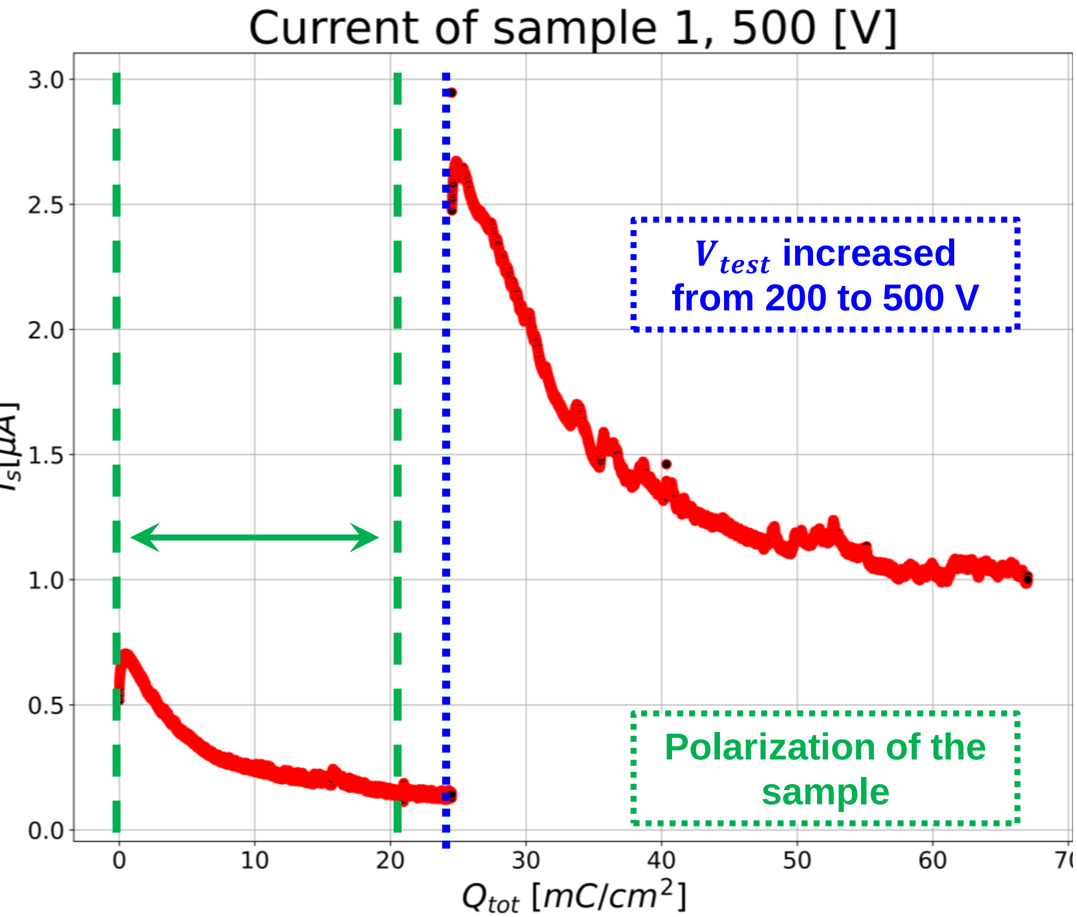
- The test serves to isolate the contribution to aging from the HPL itself.

- Carried out in the MPP clean room.





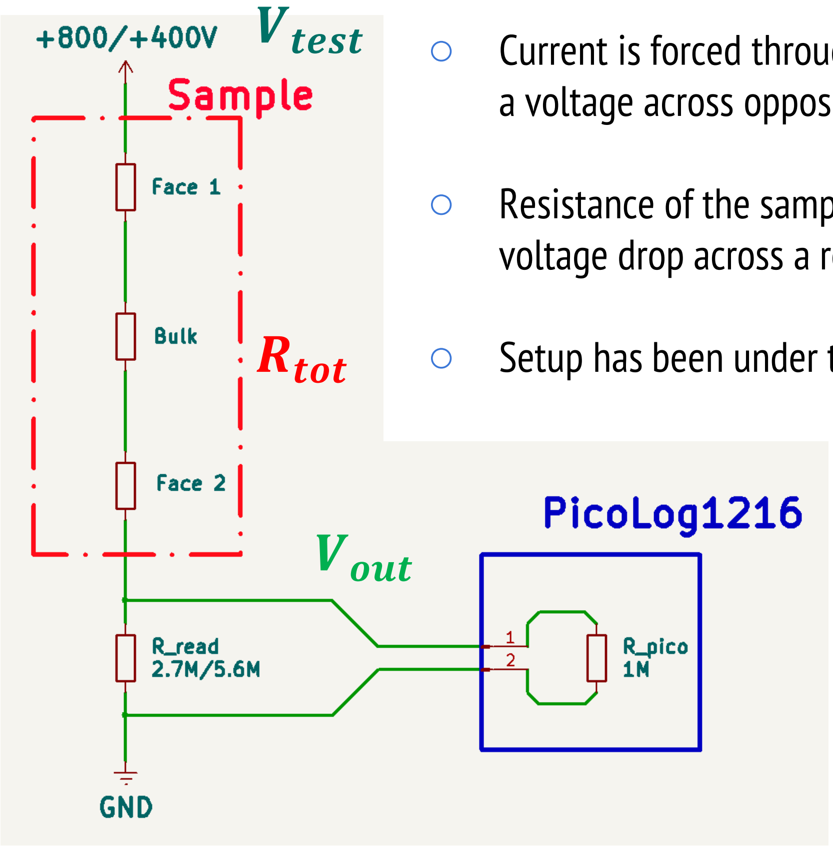
HPL test – Results*



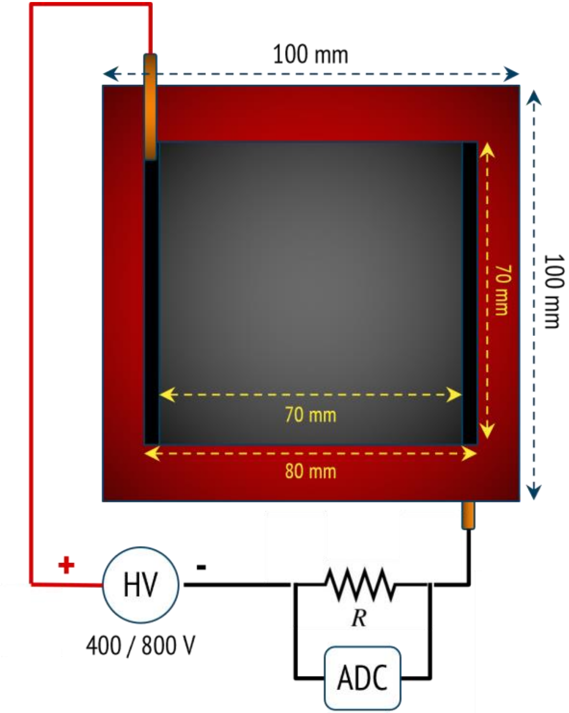
* - As of 30/03/2025

- Results are consistent across samples.
- For the moment, no significant aging effect has been observed.
- Strong polarisation effect

Graphite test



- Current is forced through the sample by applying a voltage across opposing electrodes.
- Resistance of the sample is measured through the voltage drop across a read-out resistor.
- Setup has been under test since 28/11/2024.

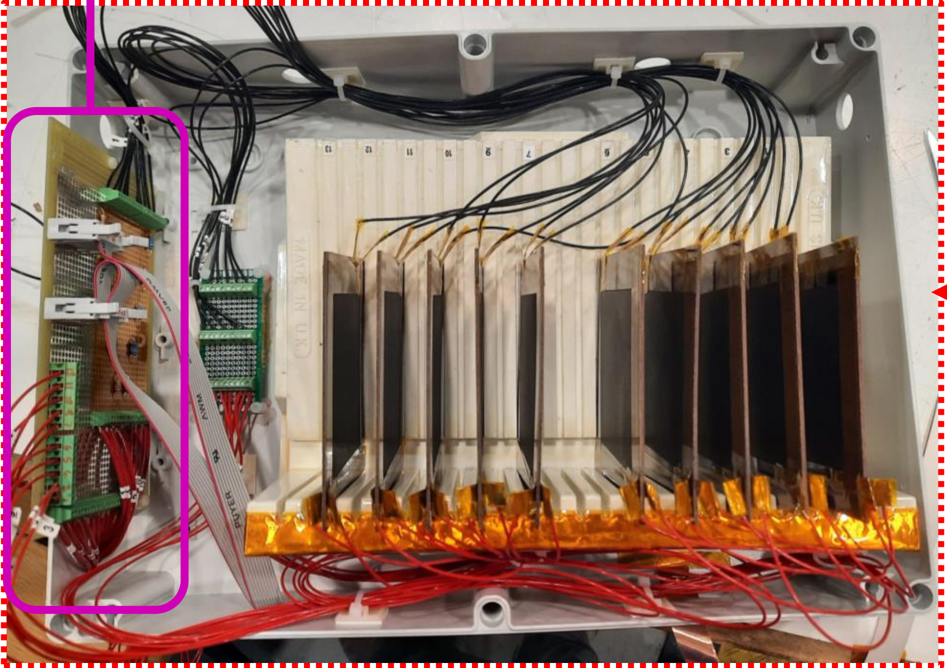


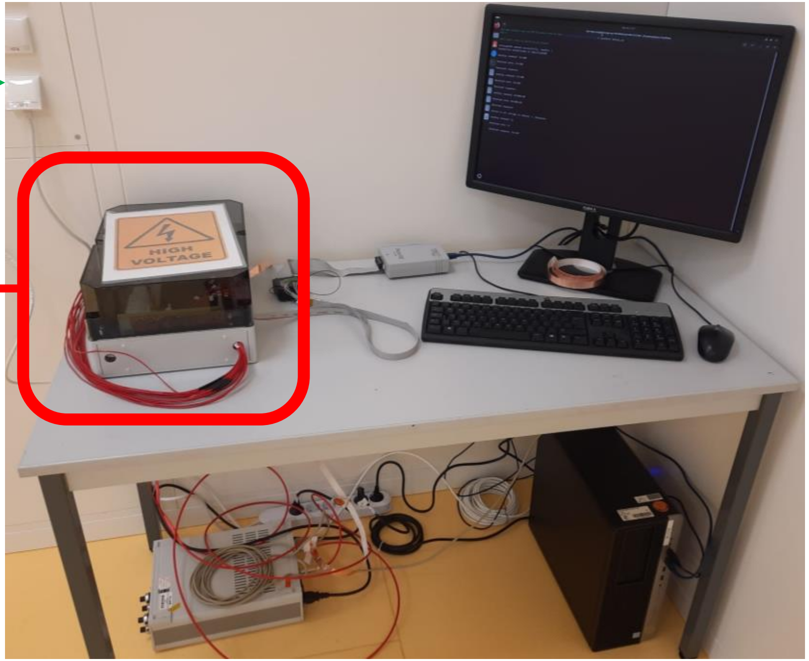
$$R_{tot} = R_{read} \parallel R_{pico} \left({V_{test}}/{V_{out}} - 1 \right)$$

Graphite test

The test is being carried out in the MPP clean room to ensure stable environmental conditions, and to allow for continuous monitoring of environmental parameters.

Readout circuit

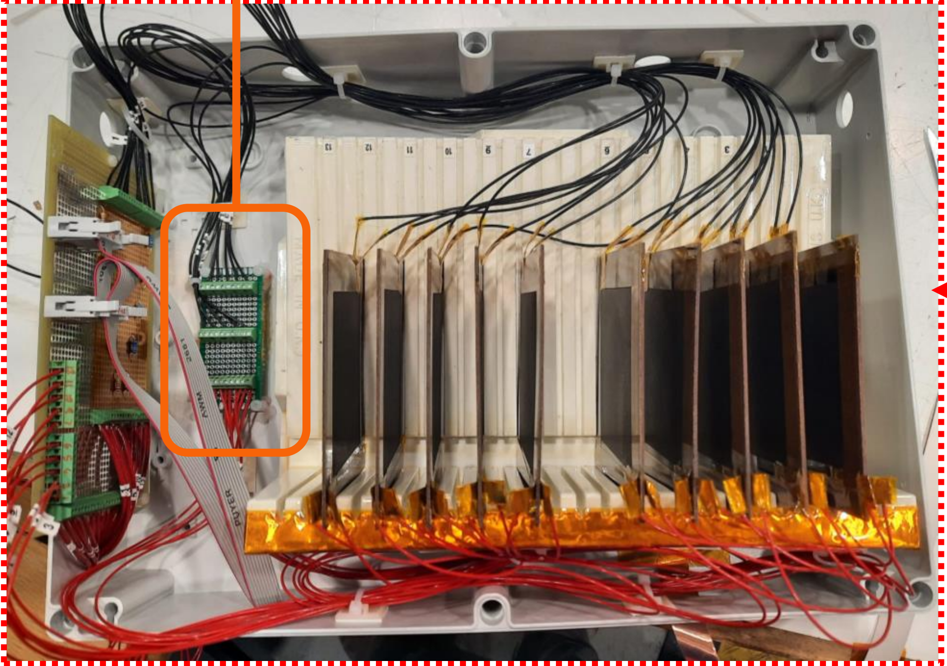


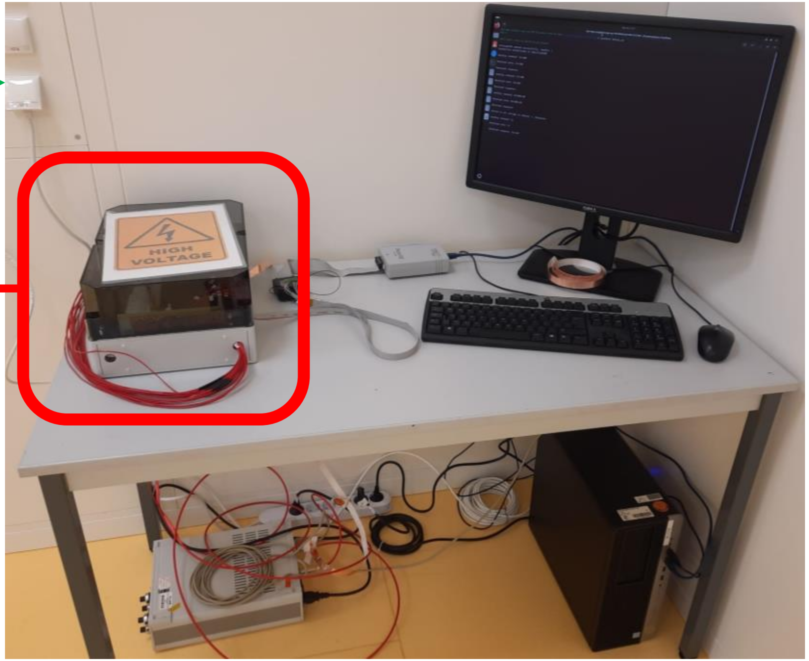


Graphite test

Additional terminals for surface resistance monitoring.

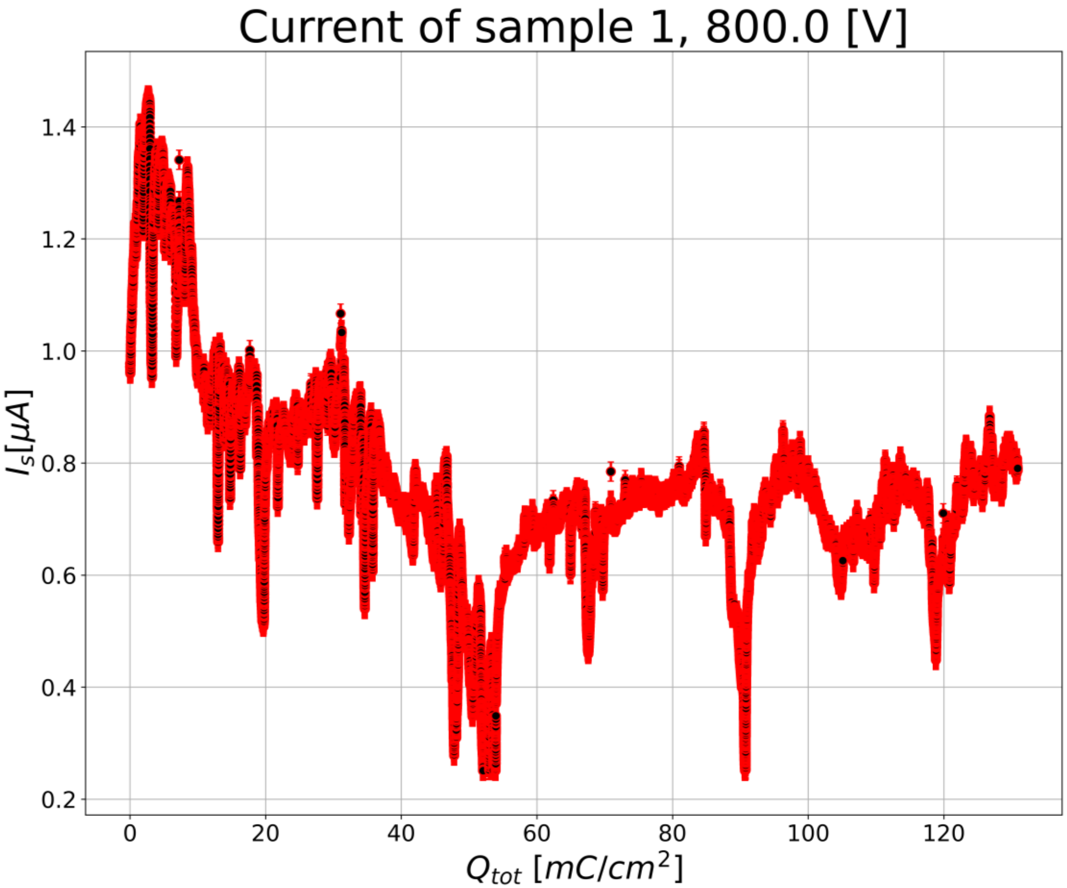
The test is being carried out in the MPP clean room to ensure stable environmental conditions, and to allow for continuous monitoring of environmental parameters.





Graphite test – Results*

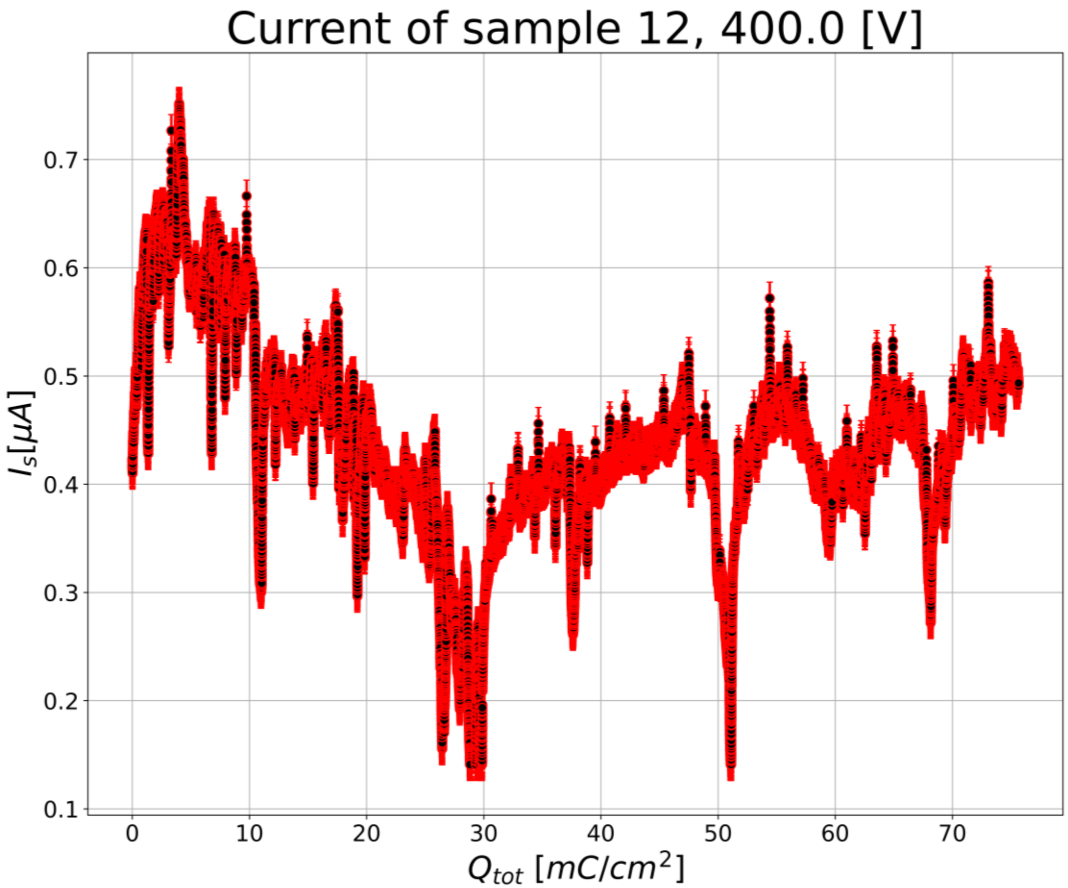
* - As of 30/03/2025



- Results are consistent across samples.
- For the moment, no significant aging effect has been observed.
- Outside of an initial polarisation period and environmental effects, the current in the sample is constant.

Graphite test – Results*

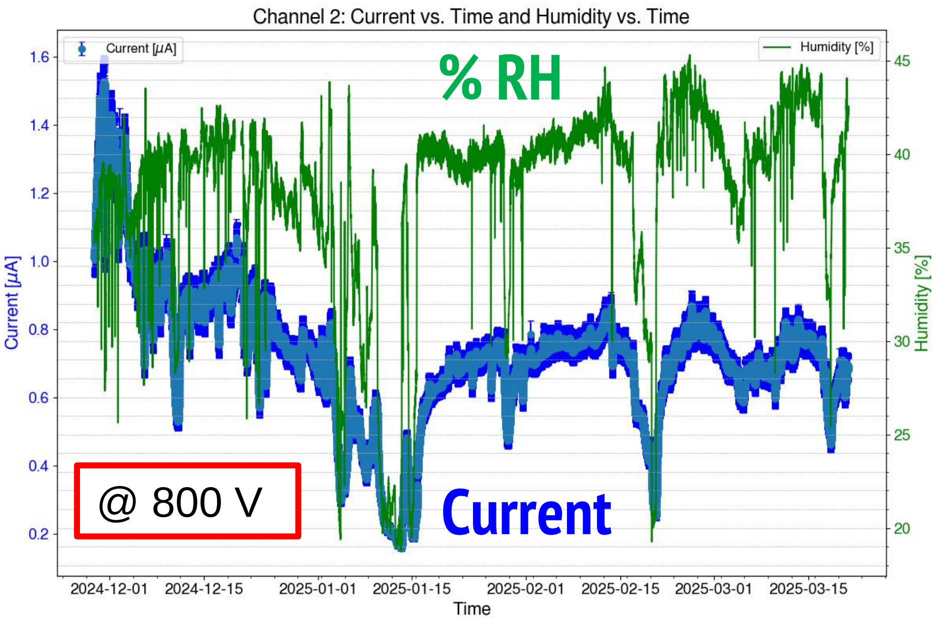
* - As of 30/03/2025

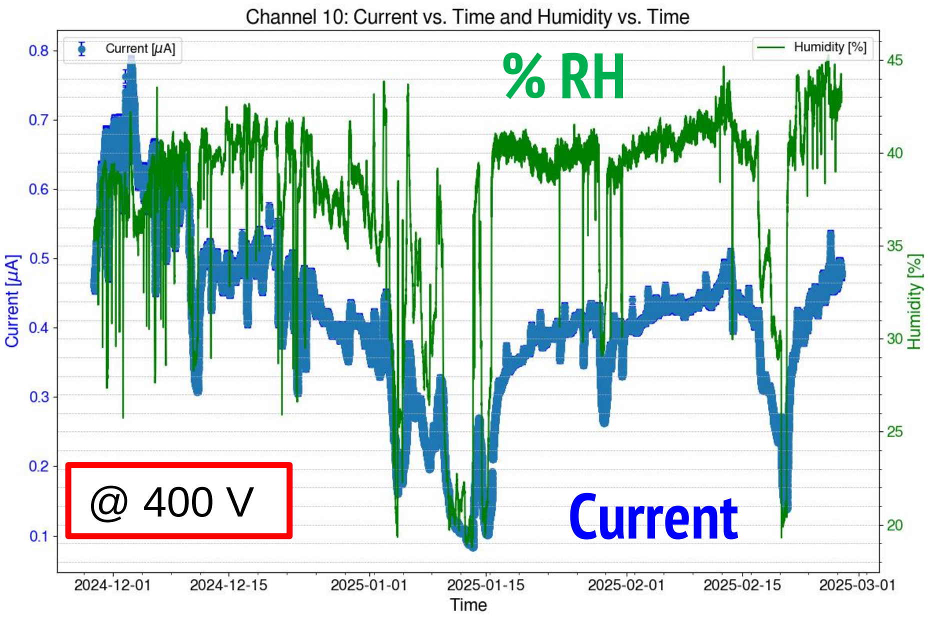


- Results are consistent across samples.
- For the moment, no significant aging effect has been observed.
- Outside of an initial polarisation period and environmental effects, the current in the sample is constant.

Graphite test – Results

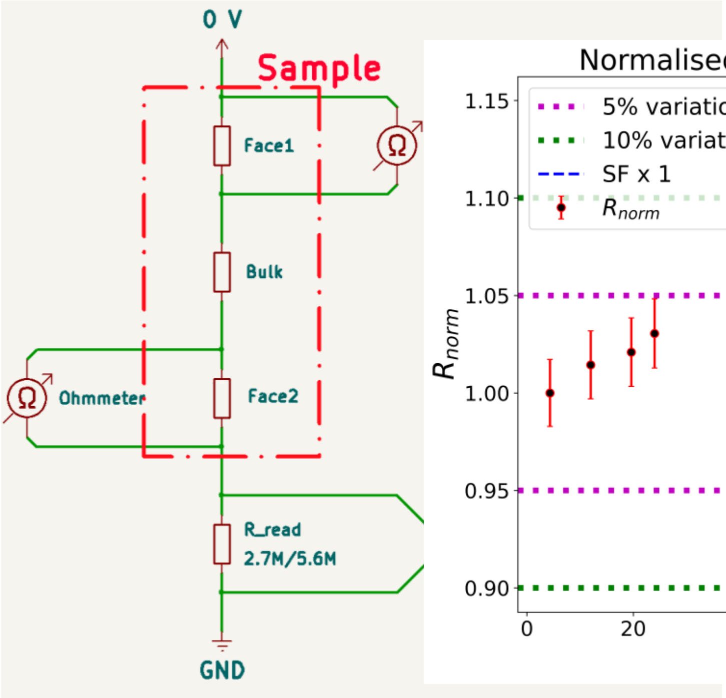
- "Spikes" are due to variations in environmental parameters (mainly RH).
- Correction is non-trivial.

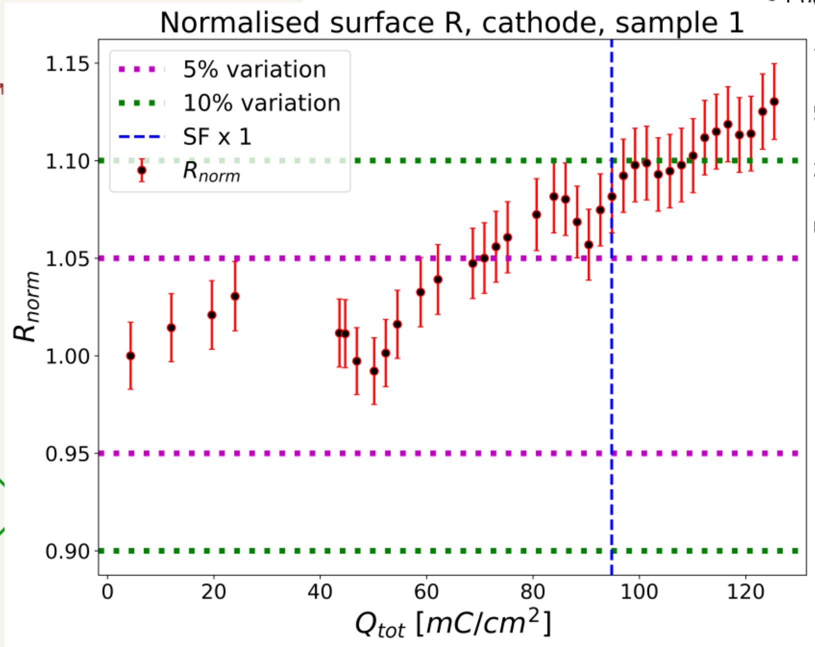


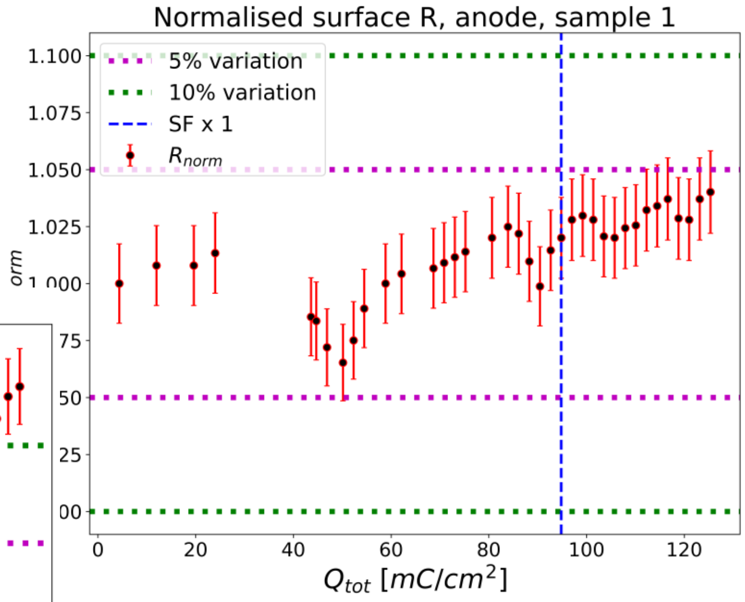


Graphite test - Surface

- Manually monitor surface resistance of the graphite electrodes at regular intervals.







Small variations observed, but within acceptable limits ($\lesssim 5\%$ for anode, $\lesssim 15\%$ for cathode @ 800 V).

Acceptance limit is 30%.

Graphite test - Surface

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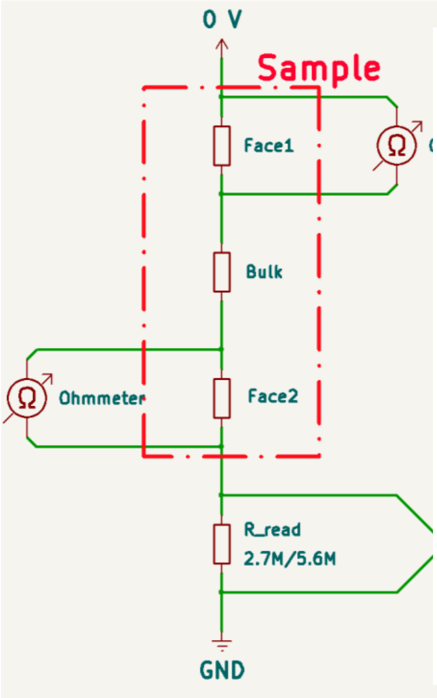
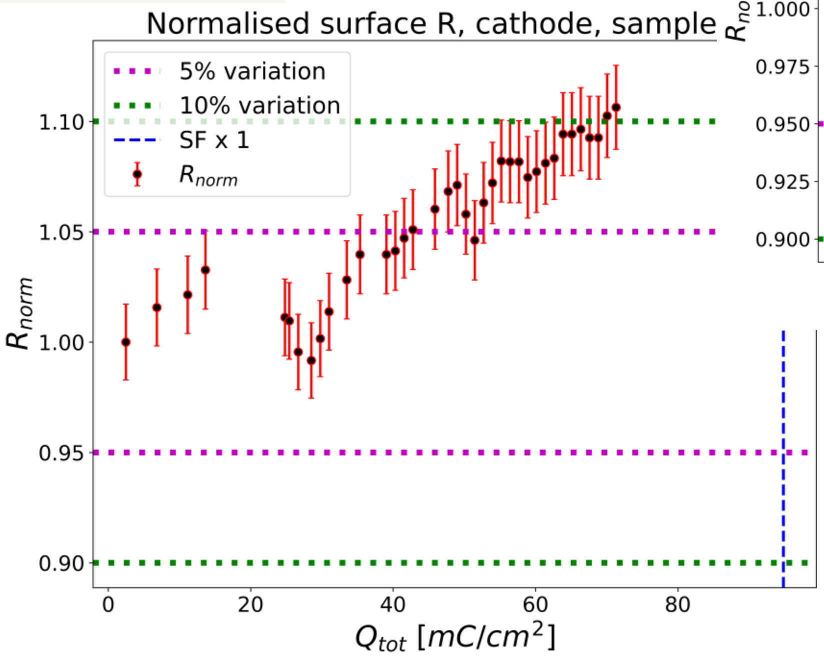
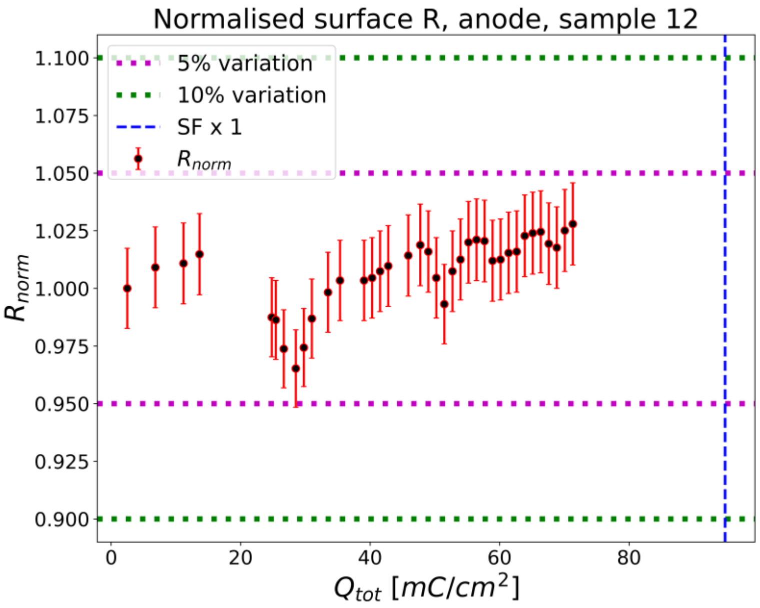






Small variations observed, but within acceptable limits ($\lesssim 5\%$ for anode, $\lesssim 15\%$ for cathode @ 400 V).

Acceptance limit is 30%.

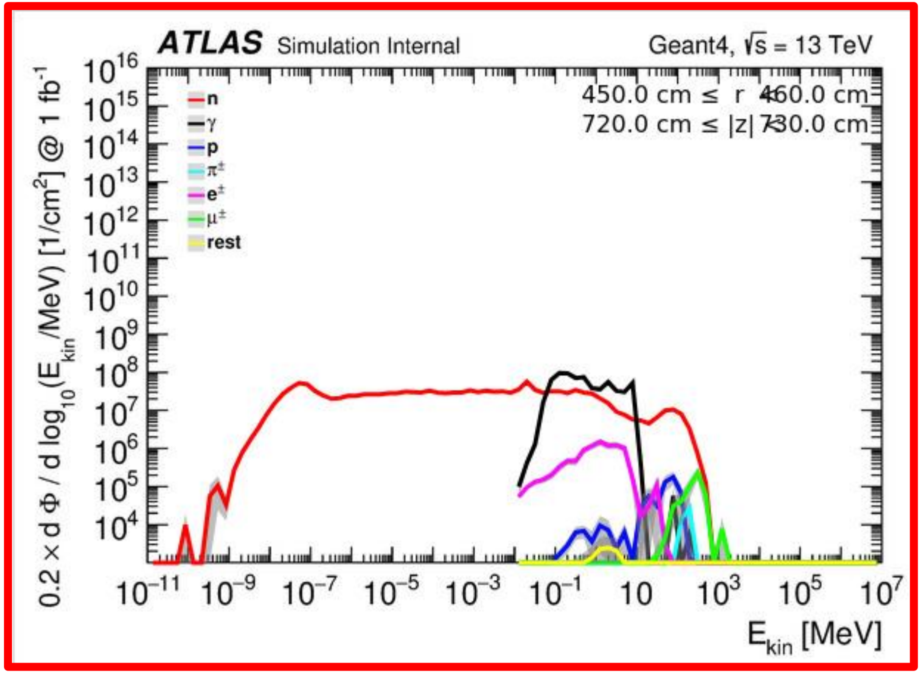
Irradiation test

- Radiation exposure could damage the graphite, further increasing electrode resistance.

- Tests on legacy RPCs have been carried out using $keV\ \gamma_s$ (^{137}Cs source at GIF++), but neutrons have greater potential to cause damage, and are a significant component of the spectrum present where the new RPCs will be installed.

- Test will take place at the CHARM facility (details incoming).

Spectrum in the hottest region of ATLAS. Y axis should be multiplied by 4000 to match expected integrated luminosity expected for HL - LHC



Irradiation test

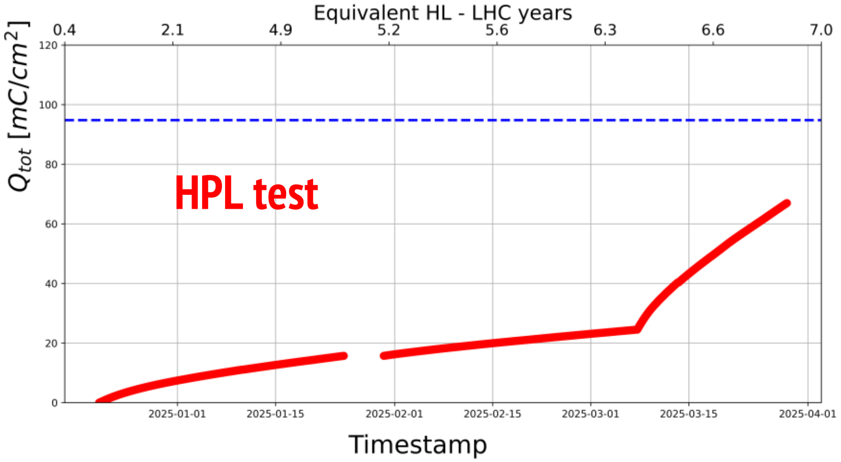
- High radiation environment imposes technical challenges and regulatory restrictions.
- Monitoring of bulk resistivity AND surface resistance must be carried out remotely, automatically, and reliably, for the whole duration of the test.
- 5 samples, prepared in the same way as the "Main" test, operated at 800 V.
- 1 week "dry run" planned at MPP.

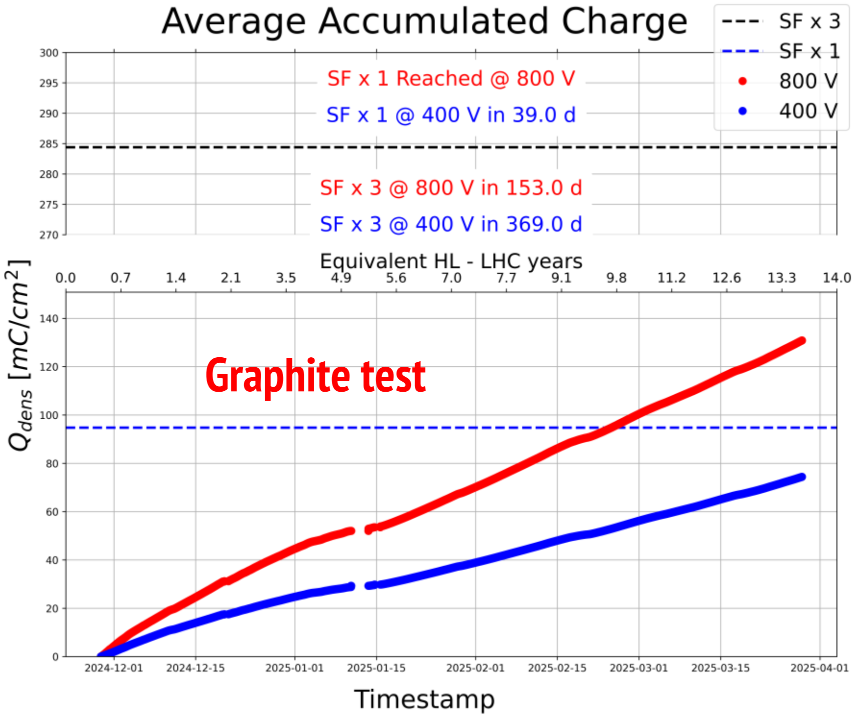
Future prospects

- Test under irradiation at CHARM (planned for May).
- Continue ongoing test until a safety factor 3 is reached.
- Compositional analysis to better elucidate the mechanisms behind aging of RPC graphite paint.

Conclusions

- A SF of 1 has already been reached, satisfying certification requirements for production.
- Ongoing tests have given us an improved understanding of the influence of environmental parameters on the behaviour of materials used in the construction of RPCs.





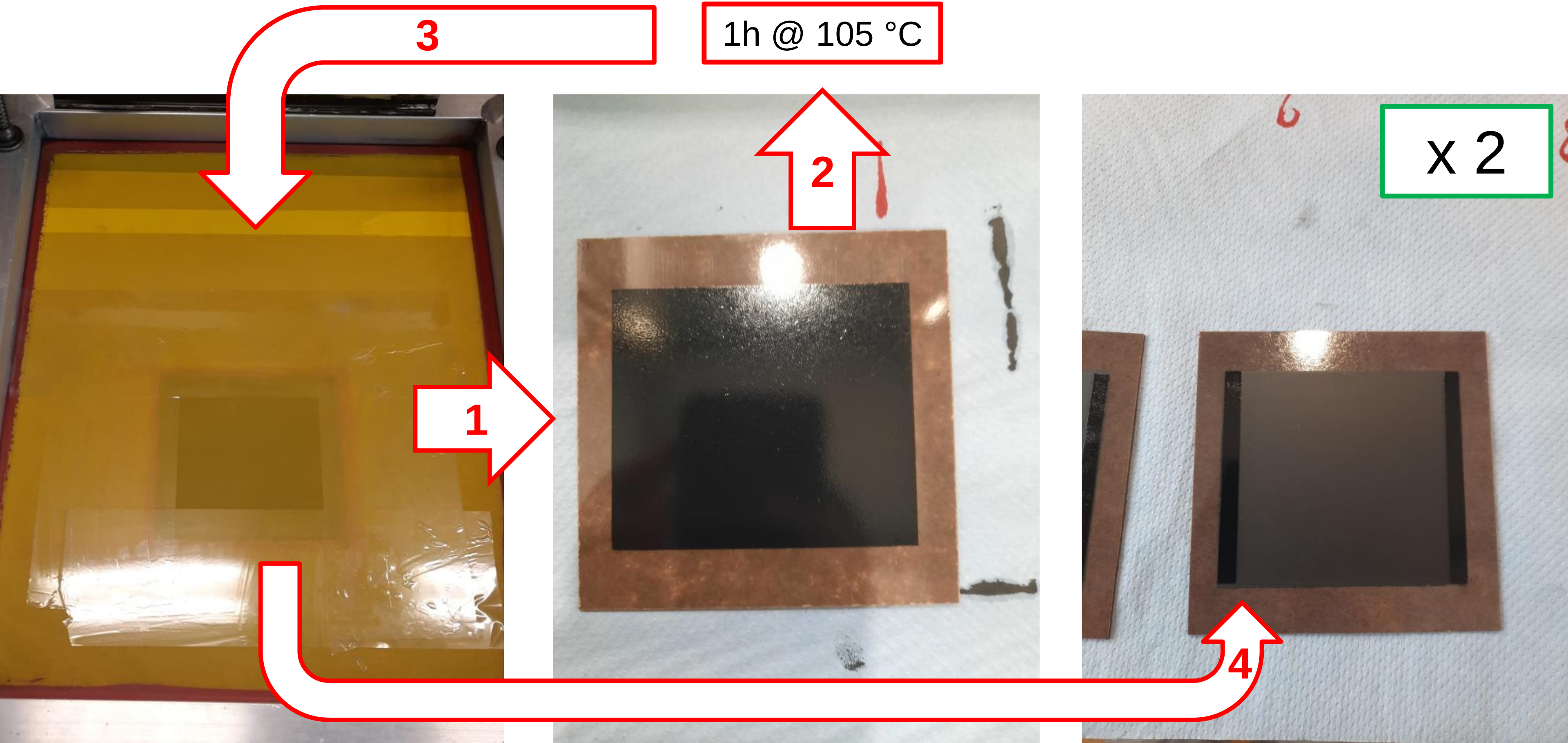
Thank you for your attention

Extras

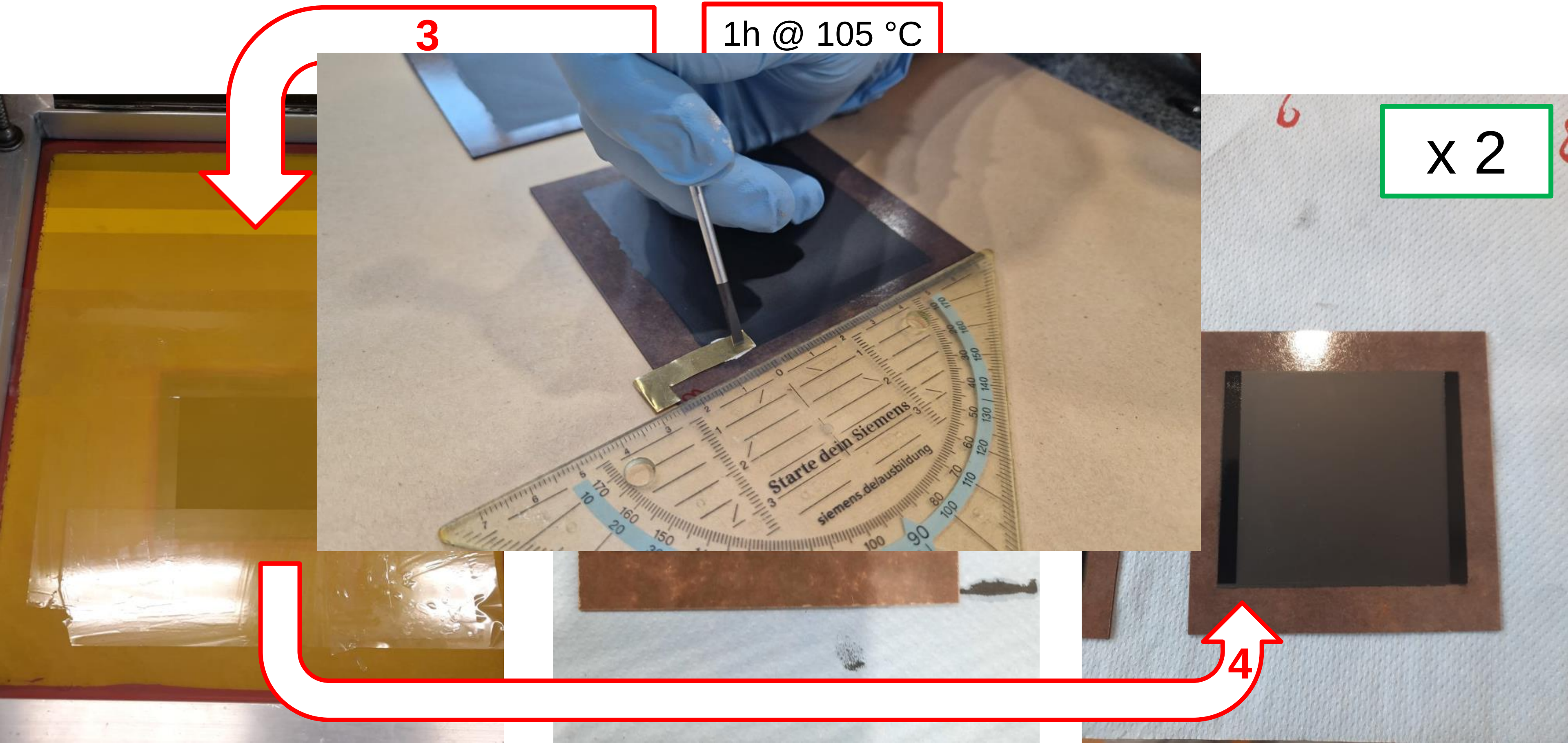
Sample preparation

- 10 cm x 10 cm HPL plates, 1.3 mm thick, bulk resistivity ~$10^{10} - 10^{11}\Omega$cm.
- Graphite paint provided by KODEL. Already used for the CMS i-RPC system.
- Higher surface resistivity square $350 \pm 30\%\ \Omega/\blacksquare$.
- Lower surface resistivity strips ensure uniform distribution of the electric field.
- 2 brass foil contacts per side, secured with conductive glue.
- Samples used both for "**Graphite**" and "**Irradiation**" tests.

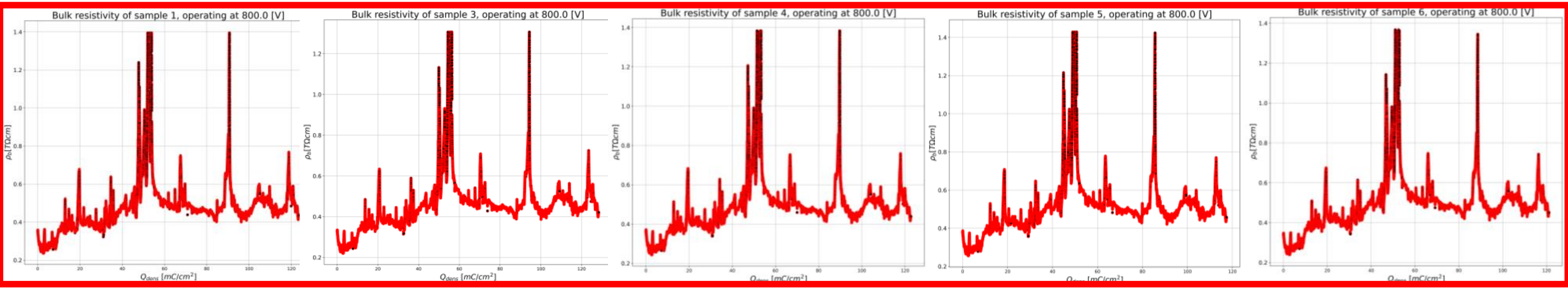
Sample preparation



Sample preparation

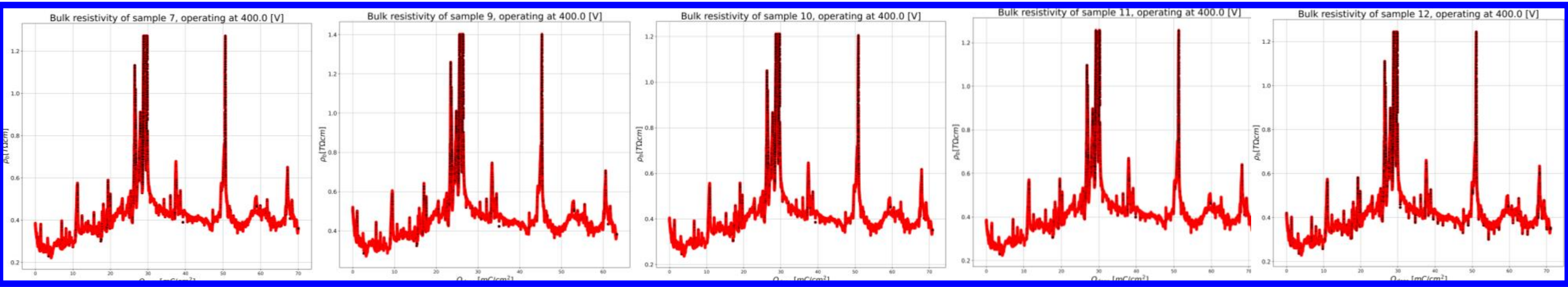


Graphite test – Results*

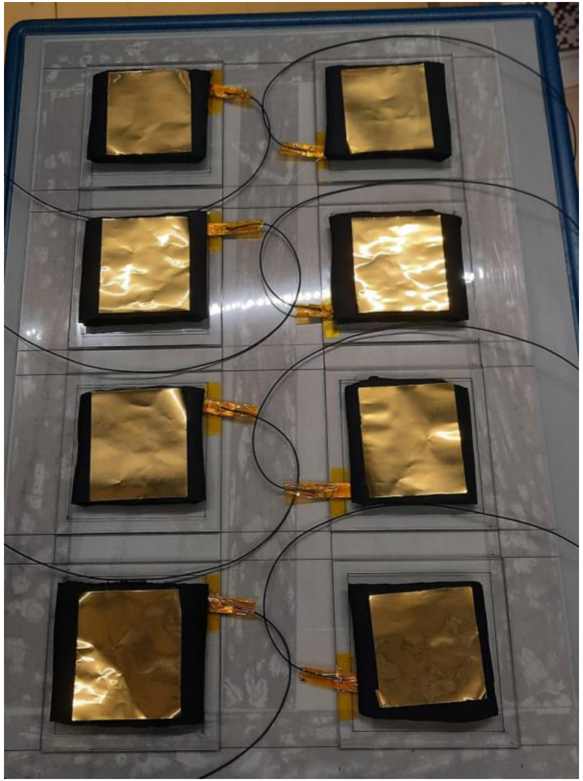


800 V

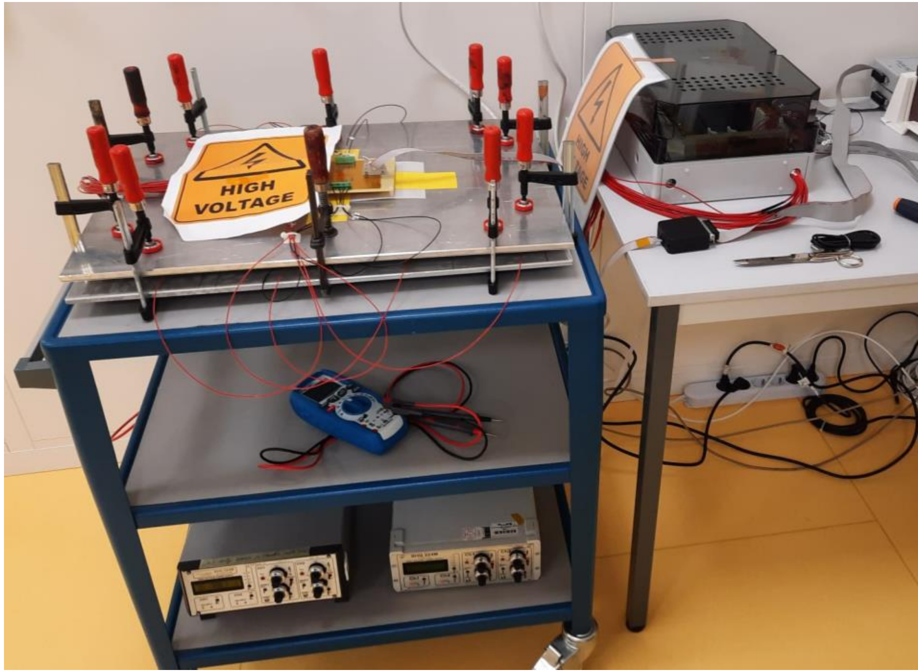
400 V



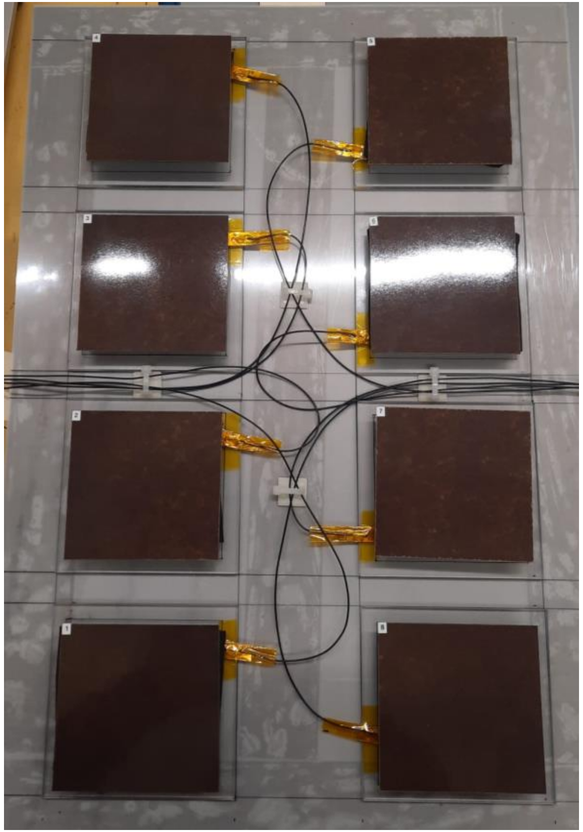
HPL test



- The test serves to isolate the contribution to aging from the HPL itself.
- Carried out in the MPP clean room.



HPL test



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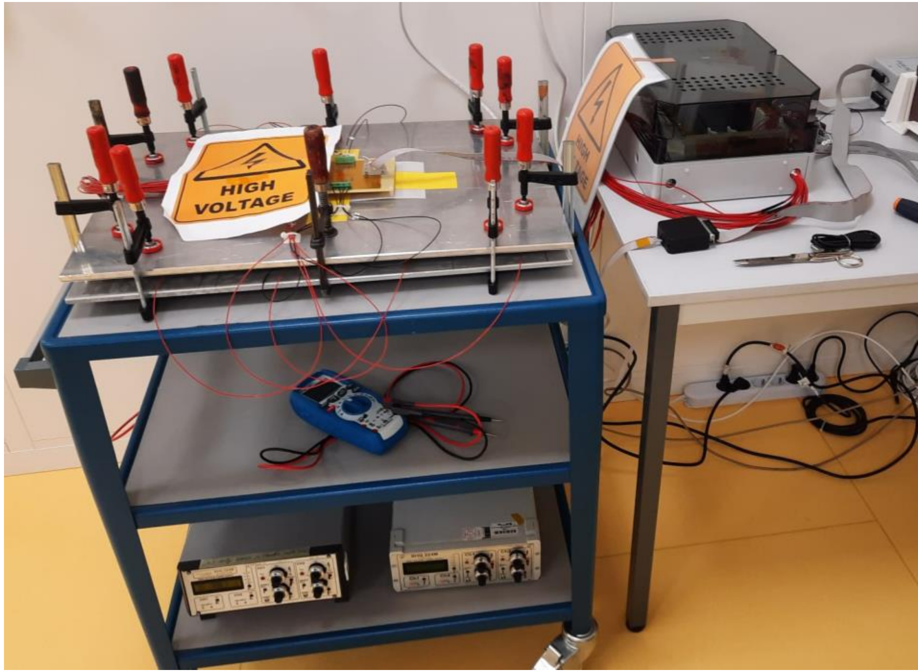

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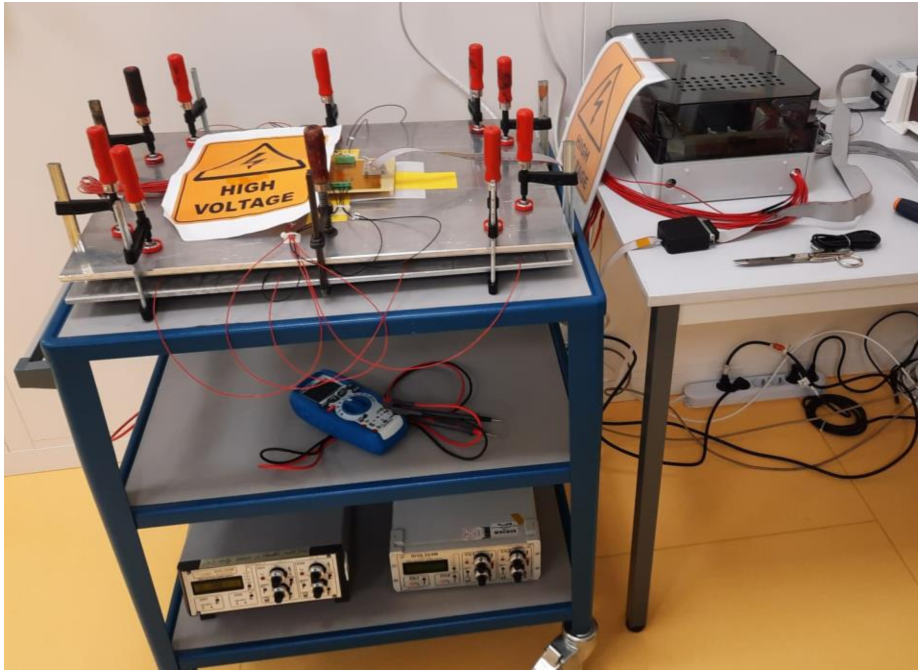

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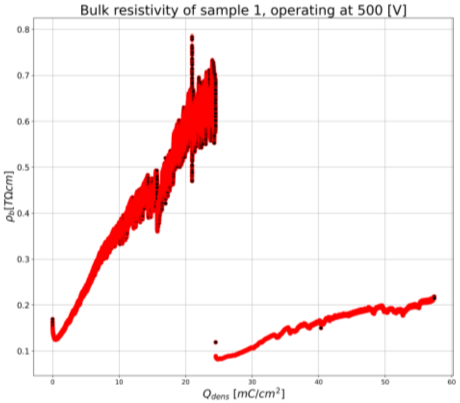
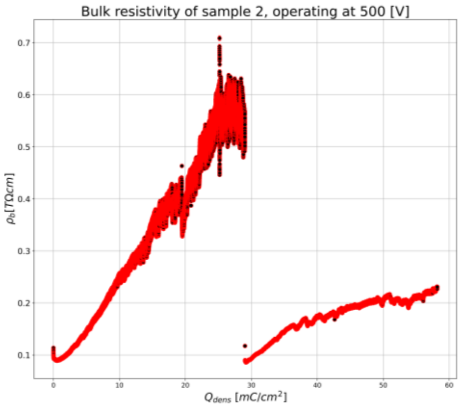
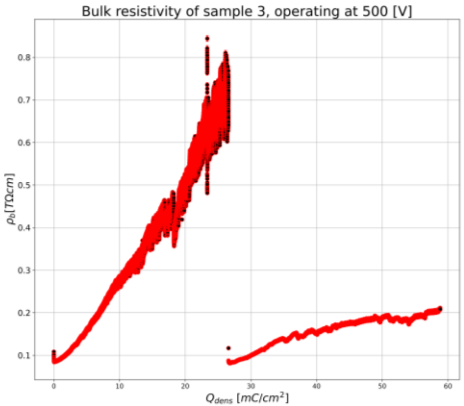
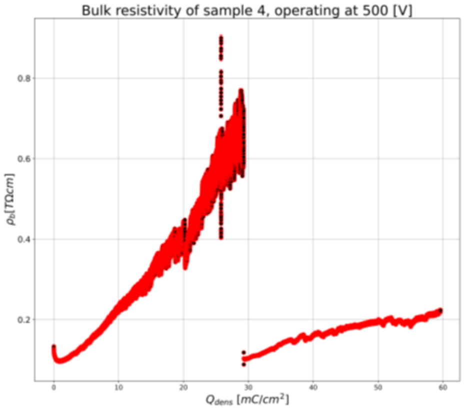
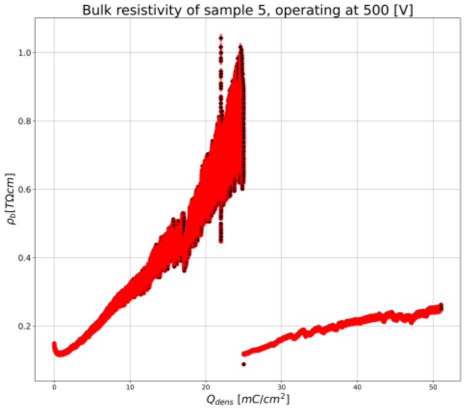
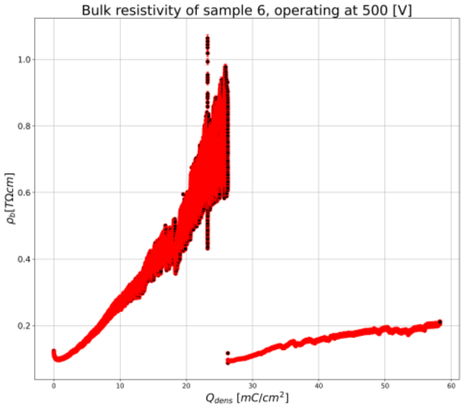


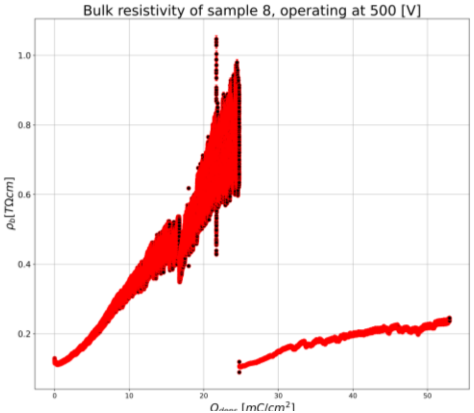






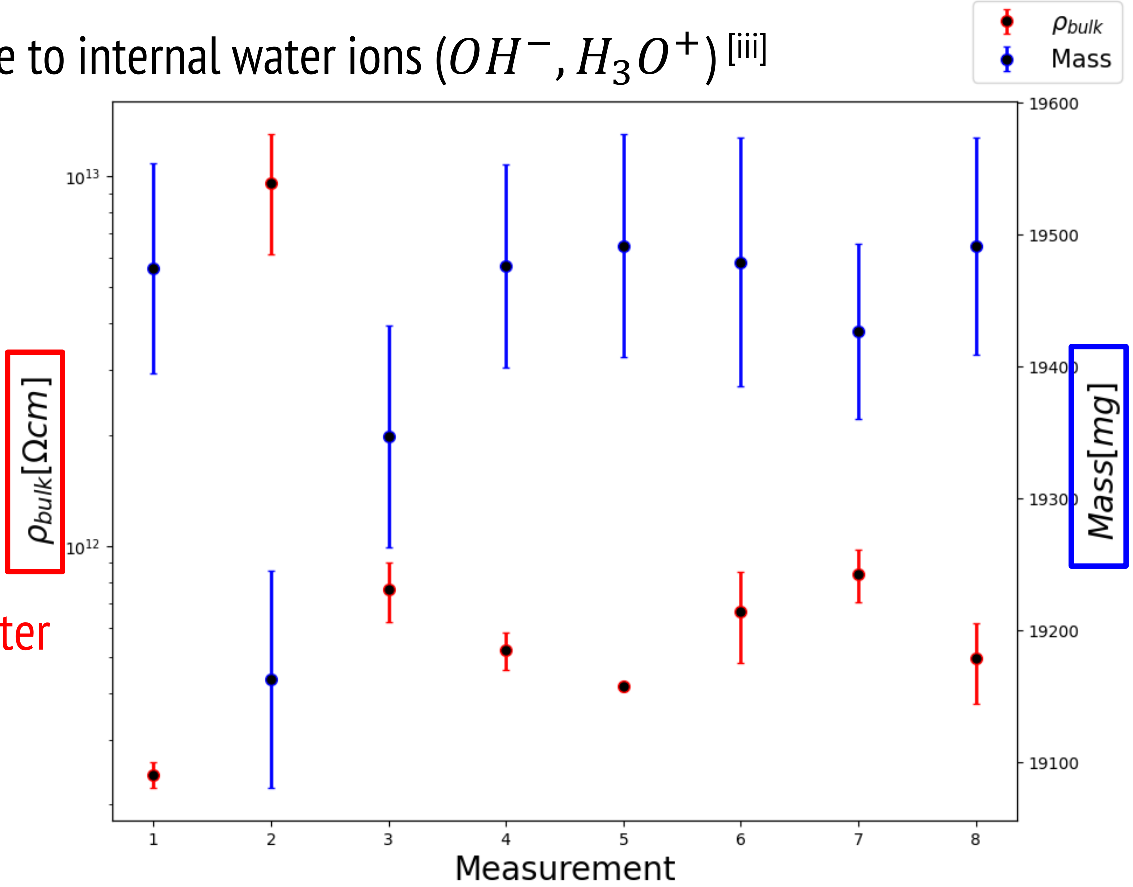




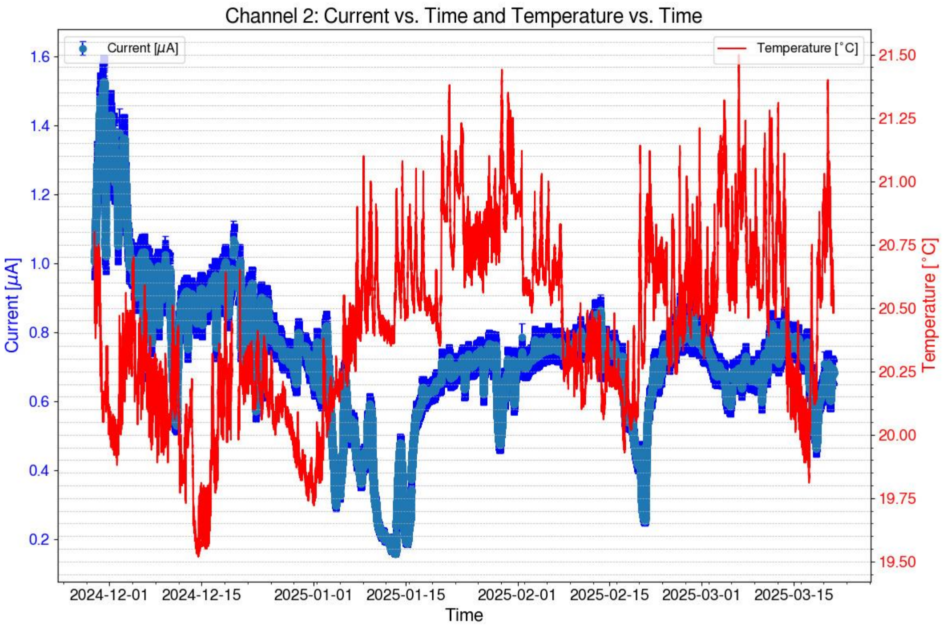


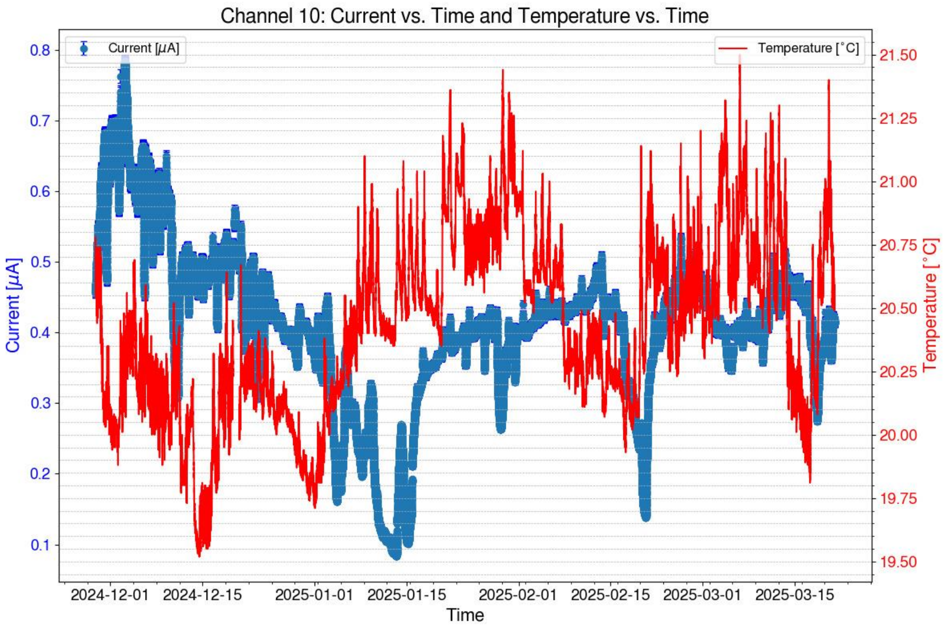
Environmental parameters

- Conductivity in the HPL is mainly due to internal water ions (OH^-, H_3O^+) [iii]
- HPL is hygroscopic.
- 5 samples, baked for 3 h at 105 °C.
- Kept at stable* T, RH and tested at regular intervals.
- Mass recovers to the initial value faster than bulk resistivity.

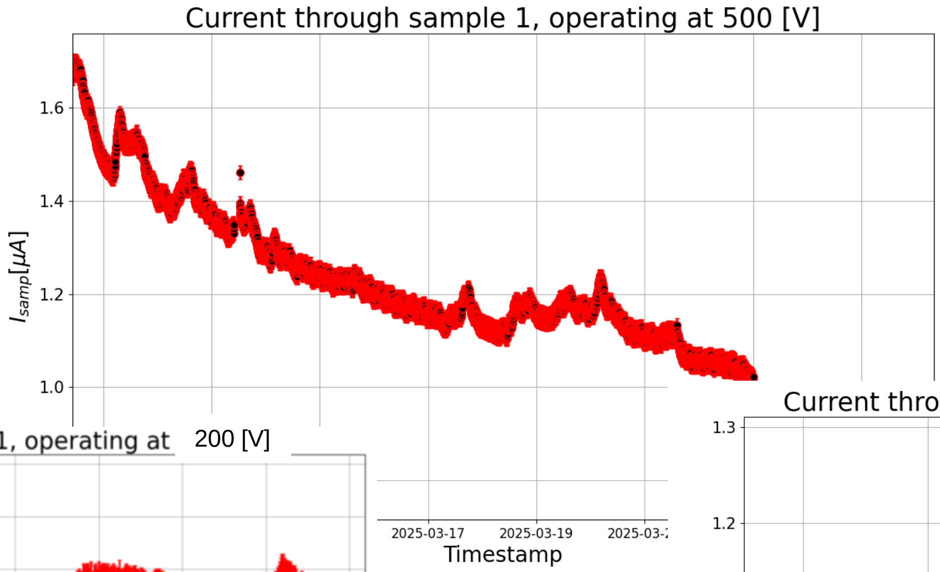


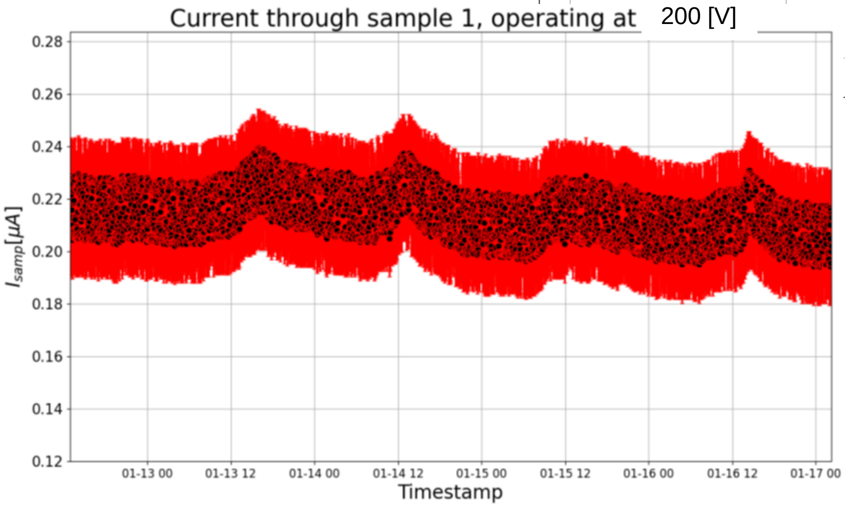
Temperature and current

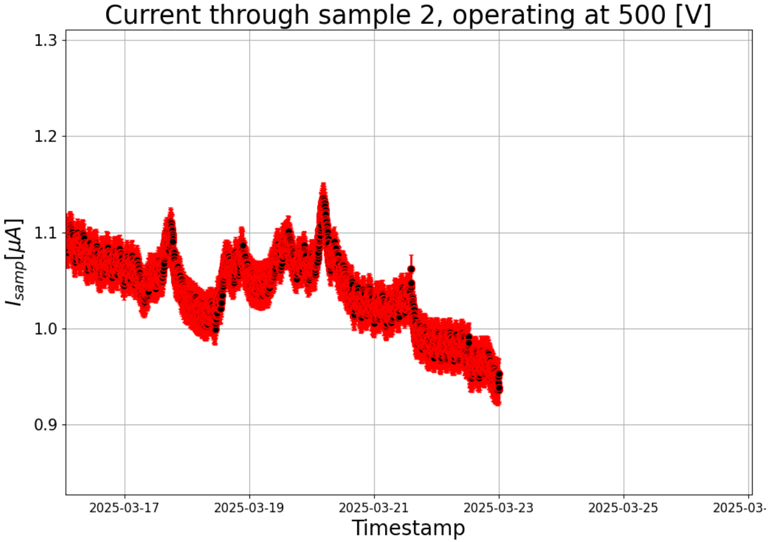




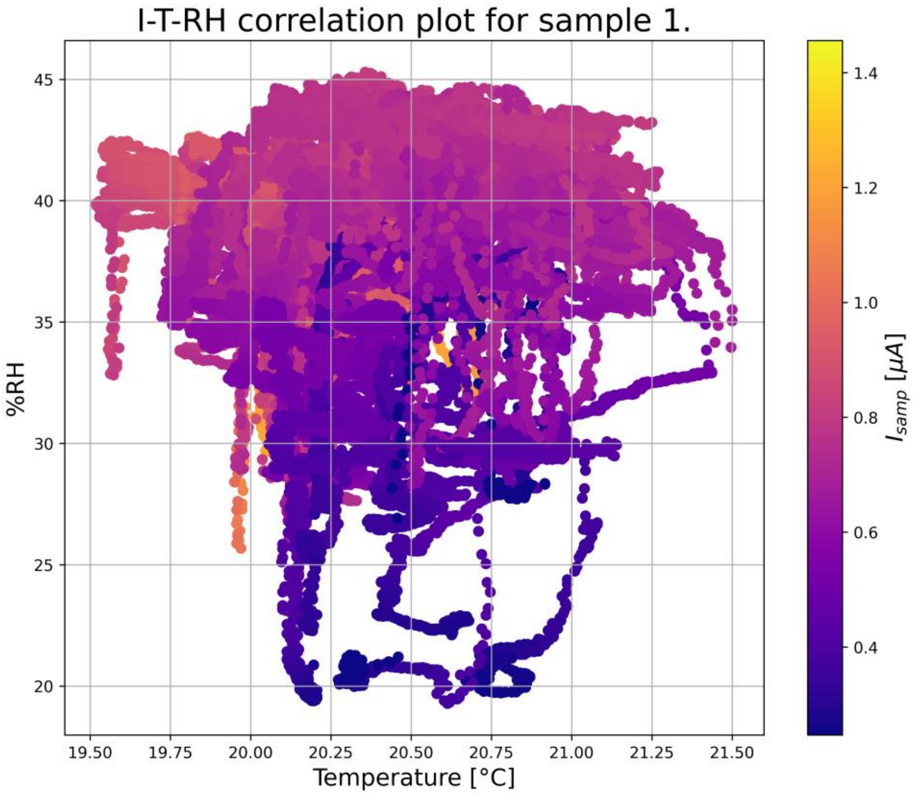
Environmental effects in “HPL”

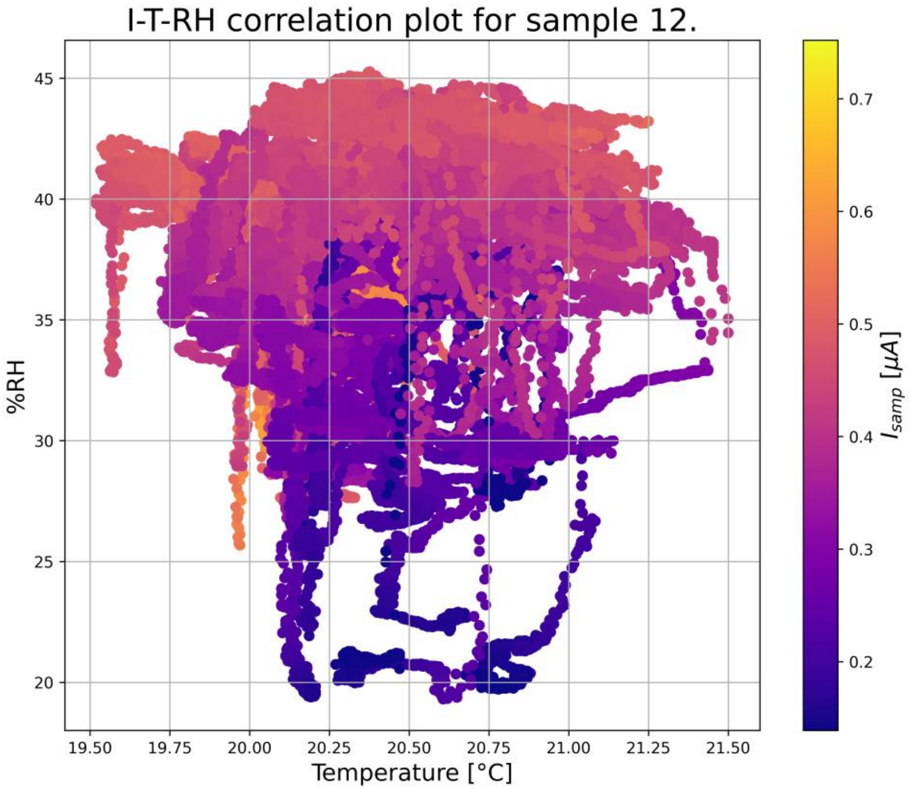






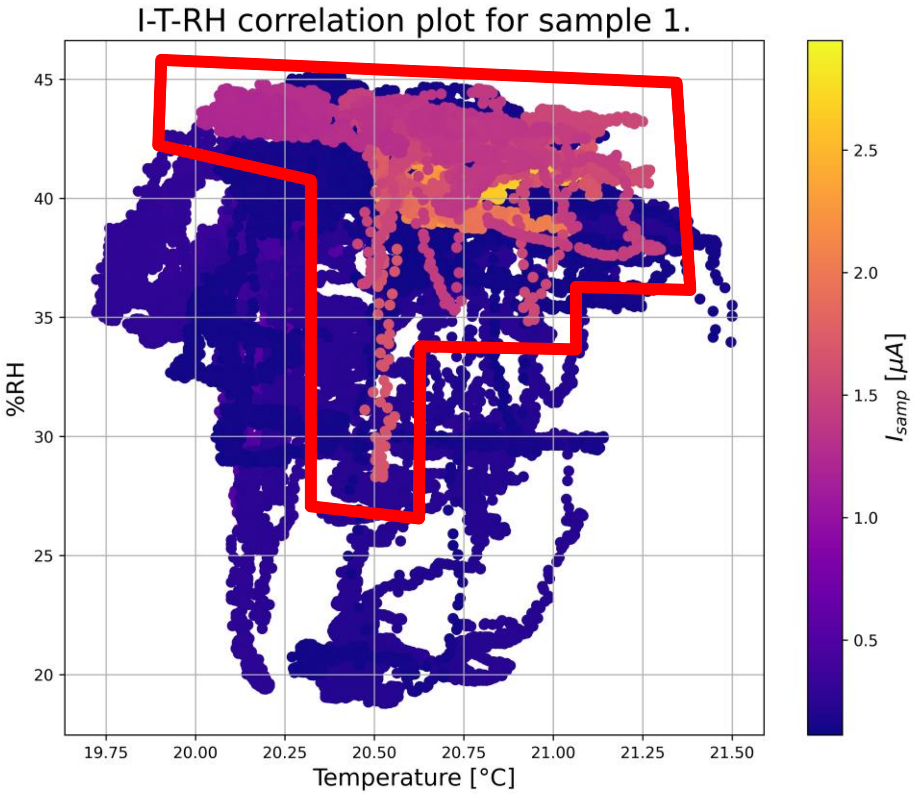
Correlation plots “Graphite”

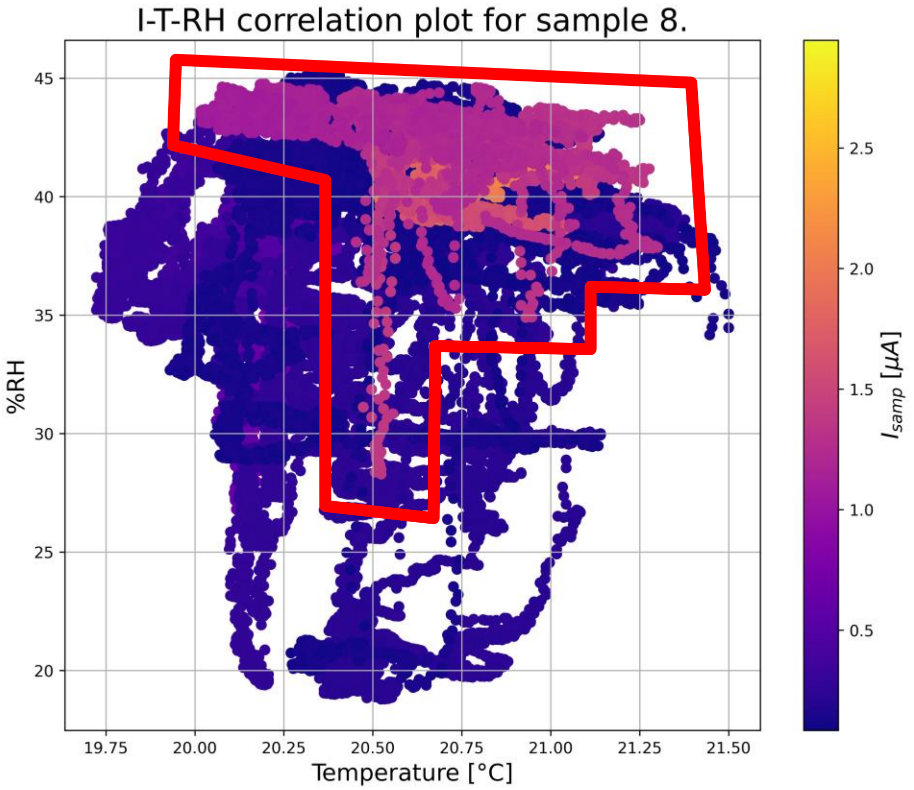




Correlation plots “HPL”

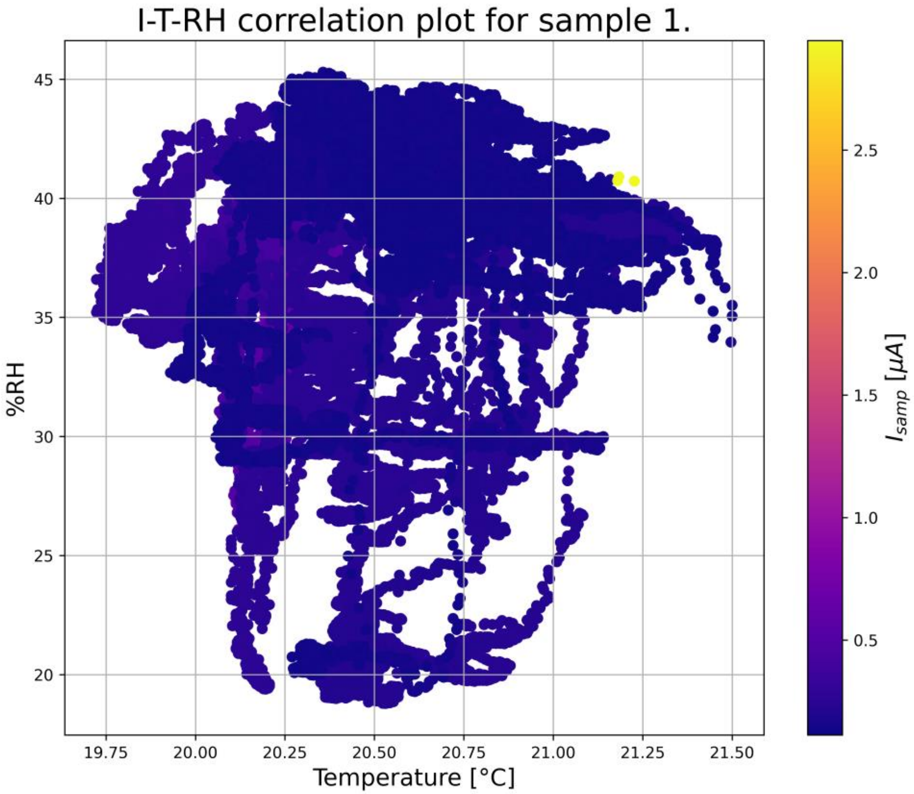
Test voltage raised 200 V ⟶ 500 V

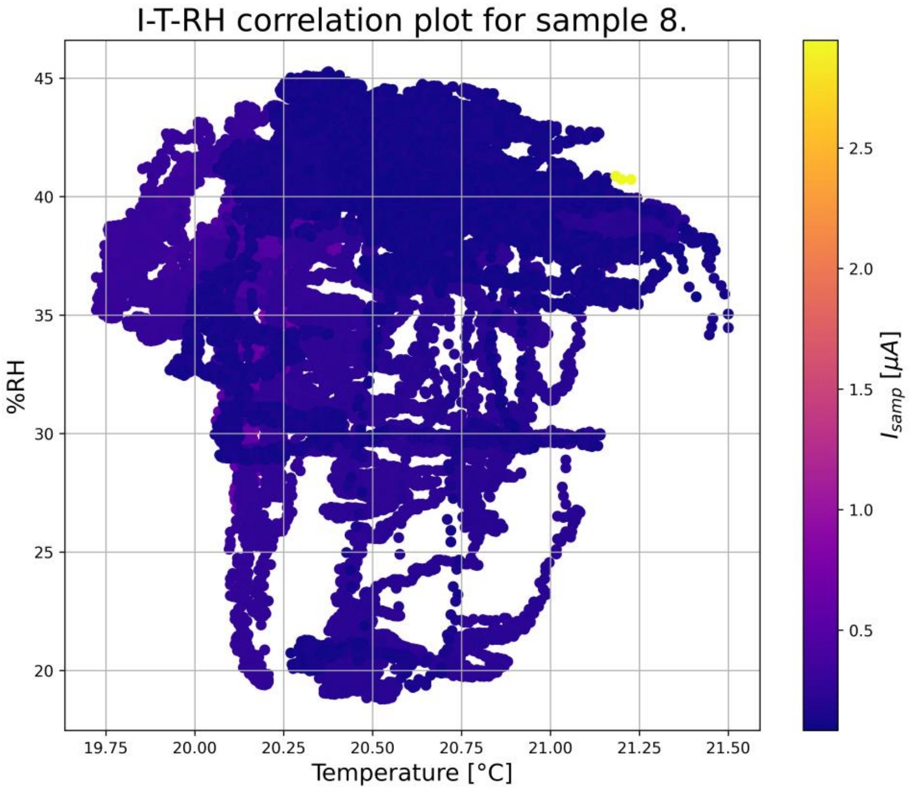




Correlation plots "HPL"

Before raising voltage to 500 V



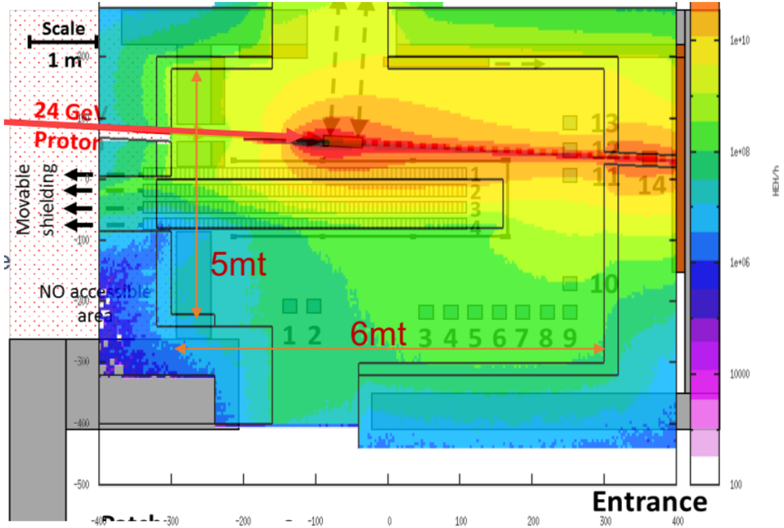


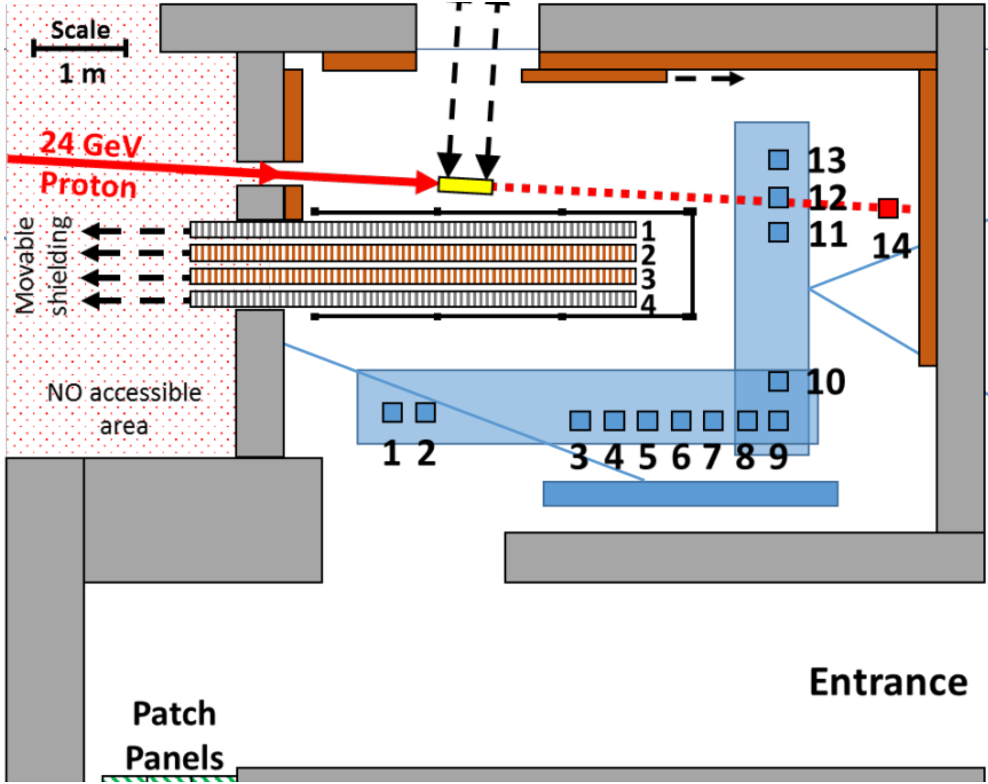
Irradiation test

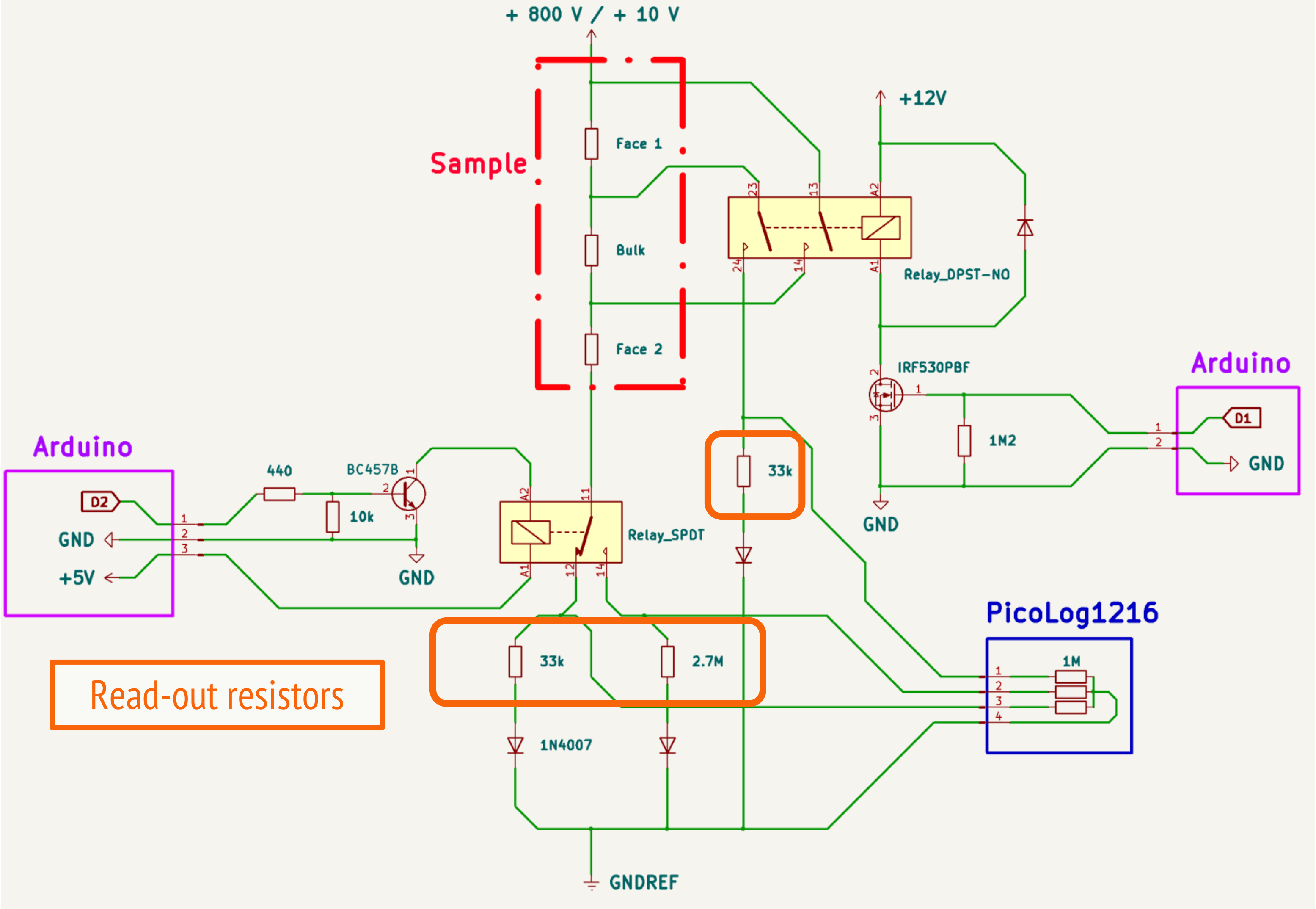
- 24 GeV protons from the PS, impinging on a copper target, provide a high intensity mixed field.

X 4 for HL - LHC

	1000 fb-1 Max(G4,FLUGG)		
	TID	NIEL	Hadrons>20
	(Gy)	10^11 n/cm2	10^11 cm-2
BIS RPC 1-7	10.2	3.06	0.591
BIS8 RPC	10.8	3.12	0.517

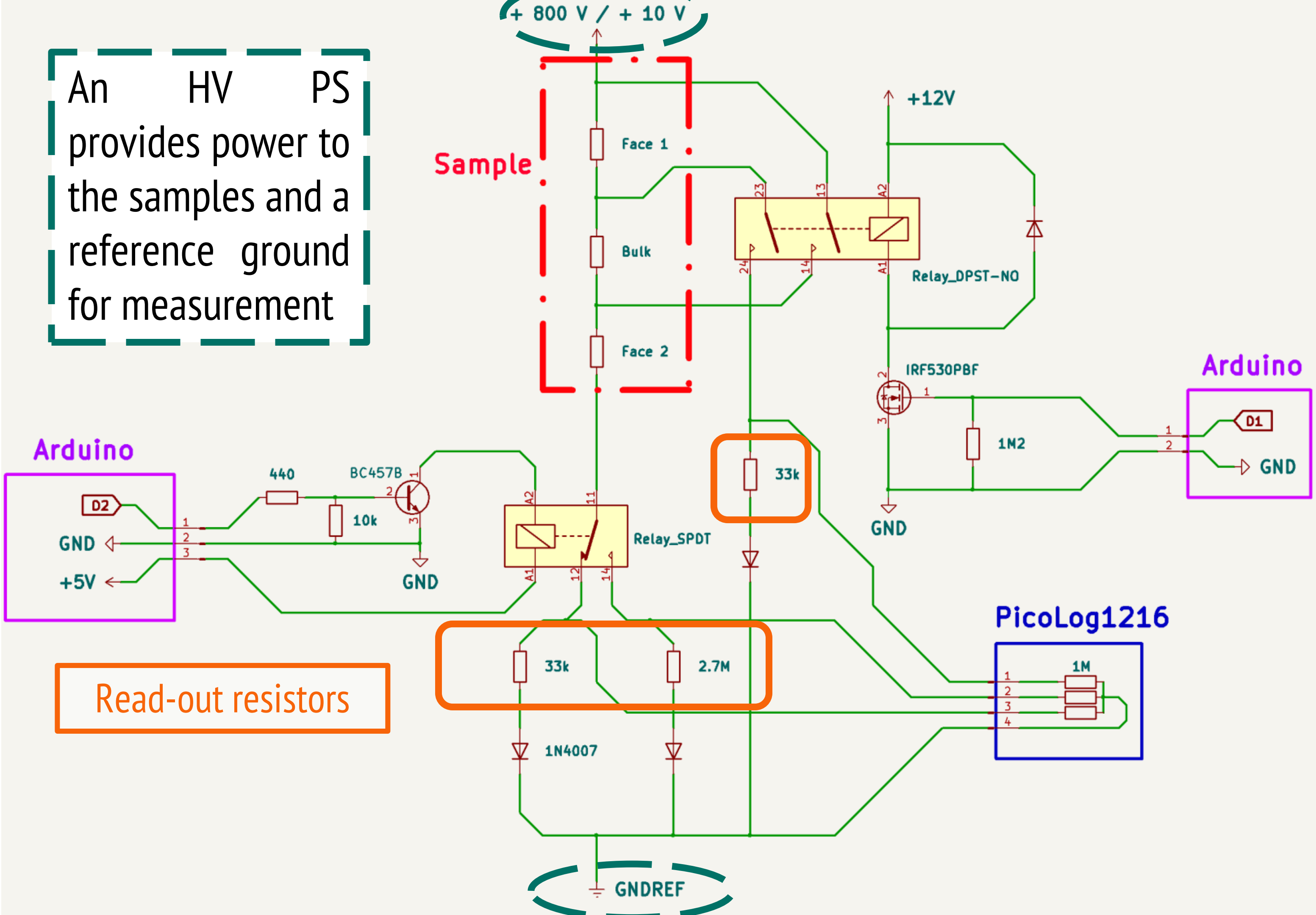






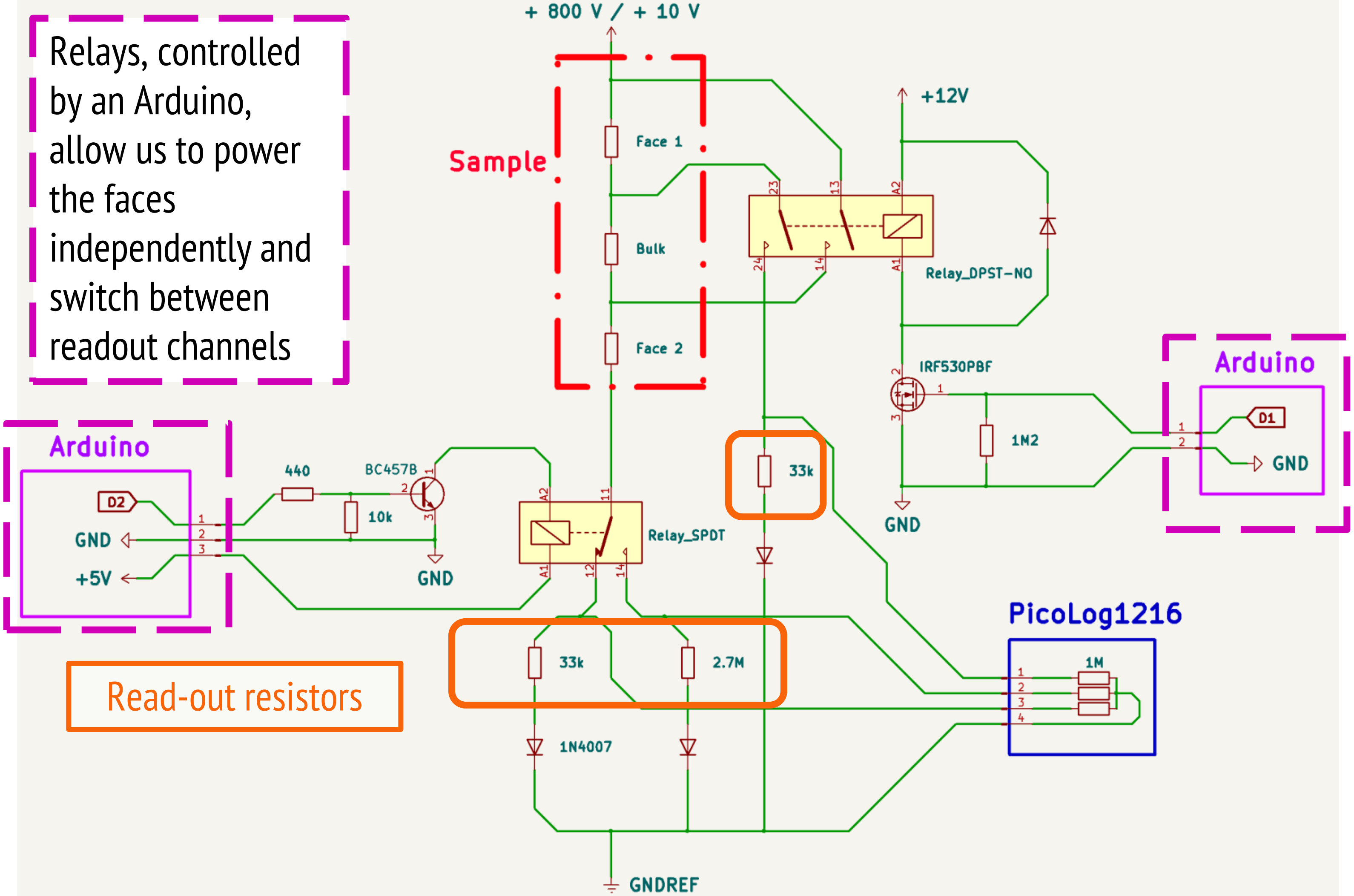
ATLAS EXPERIMENT

An HV PS provides power to the samples and a reference ground for measurement

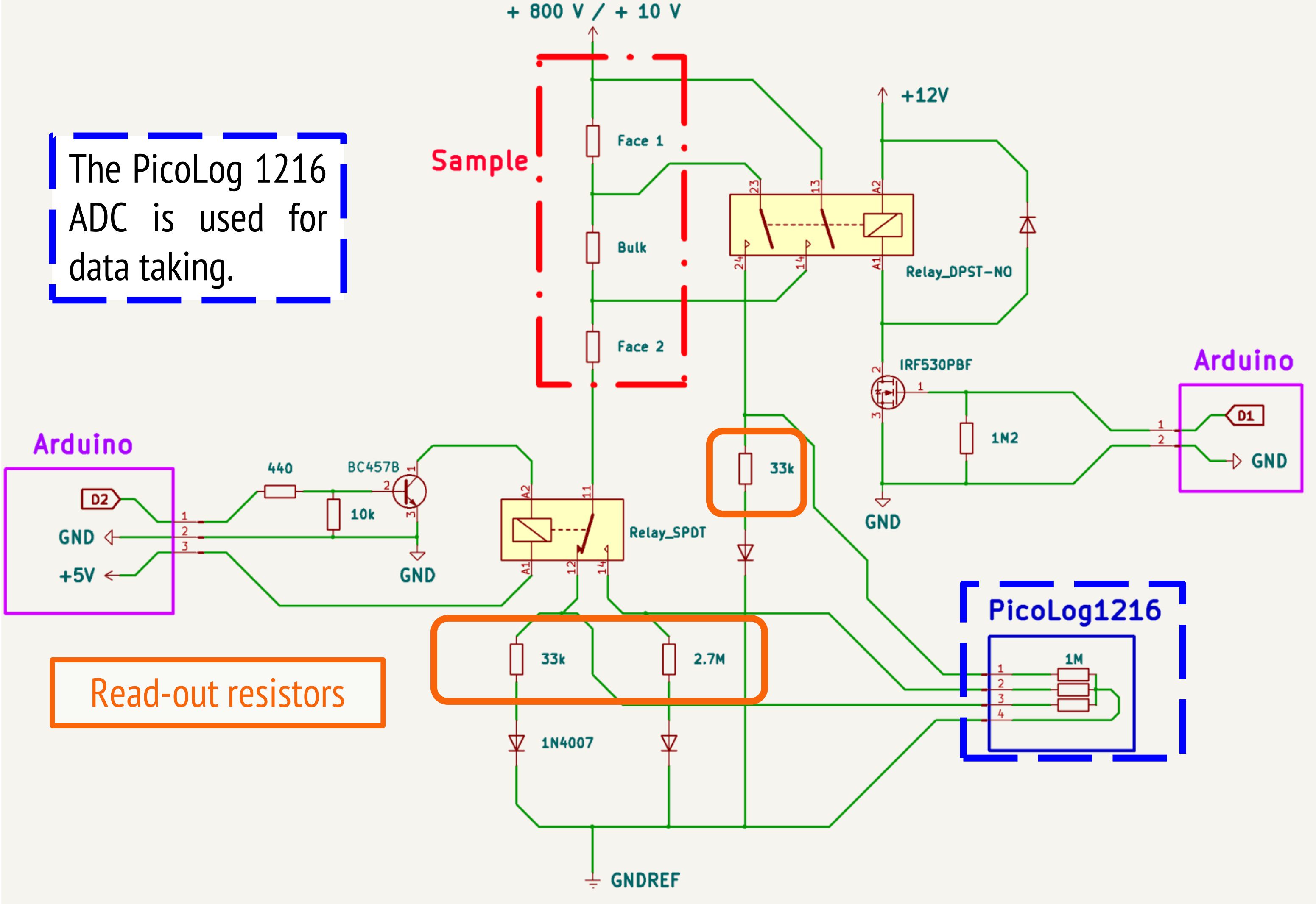


Read-out resistors

Relays, controlled by an Arduino, allow us to power the faces independently and switch between readout channels



The PicoLog 1216 ADC is used for data taking.



Read-out resistors

Location of BIS RPCs

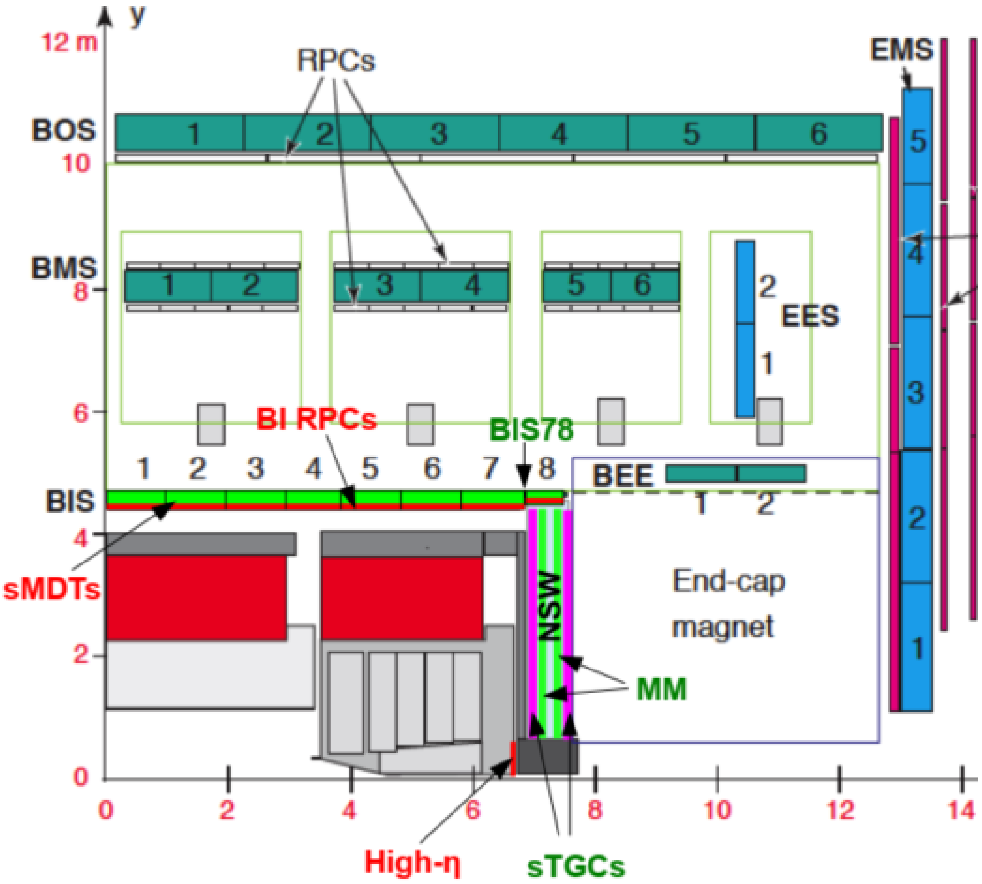


Image Credit: ATLAS Collaboration [ii]

Sources

i. Aielli, G., et. al (2003), *Further advances in aging studies for RPCs*, Nuclear Instrumentation and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 515(1-2), 335-341
ii. ATLAS collaboration (2022), *Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer.*
iii. G. Aielli (2024), *Design and construction of RPC detectors*, DRD1 gaseous detectors school, https://indico.cern.ch/event/1384298/contributions/6070891/attachments/2978847/5244587/RPC%20construction_DRD1%20school.pdf