Studies on ALICE MID RPC characteristics after prolonged operation and/or storage

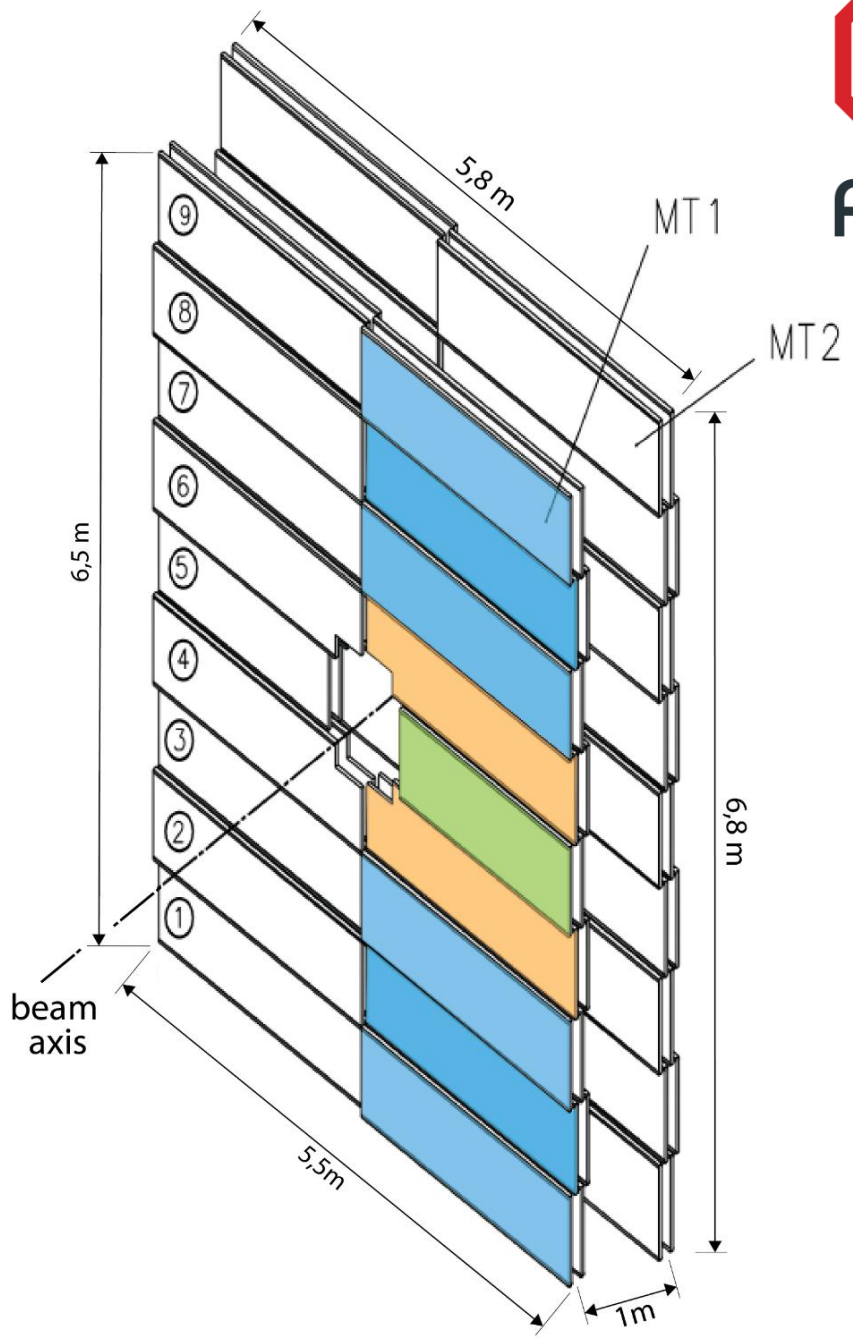
Alessandro Ferretti
(Torino University and INFN)
on behalf of the ALICE Collaboration

XVIII Conference on Resistive Plate Chambers and Related Detectors

Rio de Janeiro – Sept. 15th, 2026

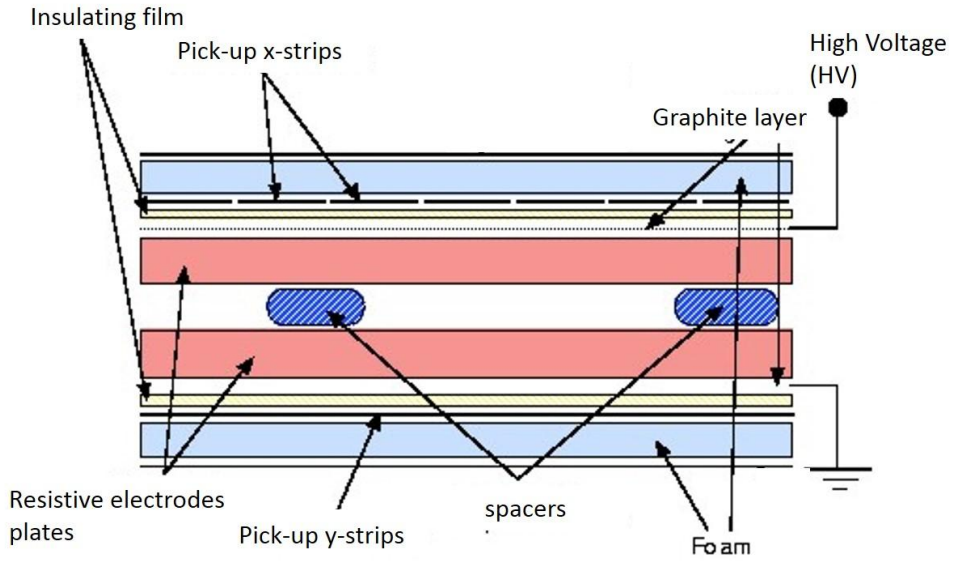
ALICE Muon IDentifier

- 72 RPC detectors about 270 x 70 cm^2
- 3 different shapes in 2 different dimensions -> 6 different geometries.
- Gas gaps manufactured in 2004-2005



ALICE RPCs

ALICE RPCs are single-gap bakelite detectors: electrodes and gas gaps are 2 mm thick, electrode resistivity between $3 \cdot 10^9$ and $1 \cdot 10^{10}$ $\Omega \cdot$cm, <u>two linseed oil layers</u>



Gas gaps manufactured at General Tecnica s.r.l. in 2004-2005 and operating in ALICE since 2010

Tested in Torino lab prior to ALICE installation in streamer mode (gas mixture 50.5% Ar, 41.3% R134a, 7.2% i-C_4H_{10}, 1% SF_6, discriminating threshold 80 mV)

Operated in ALICE in maxi-avalanche mode until Long Shutdown 2 (7 mV threshold), then in avalanche mode with FEERIC (~150 fC threshold), mixture 89.7% $C_2H_2F_4$, 10% i-C_4H_{10}, 0.3% SF_6

The effective HV applied before LS2 was about 10.4-10.5 kV at 970 mbar and 20 °C, then 9.8-10.1 kV

Tests performed in Torino Test Lab

Two series of tests were carried out

- Test on RPC spares from the original production batch (2005)
- Test of one MID RPC replaced in 2023 because of relatively high dark and working current.

MID Cosmic Test Station – INFN Torino Lab

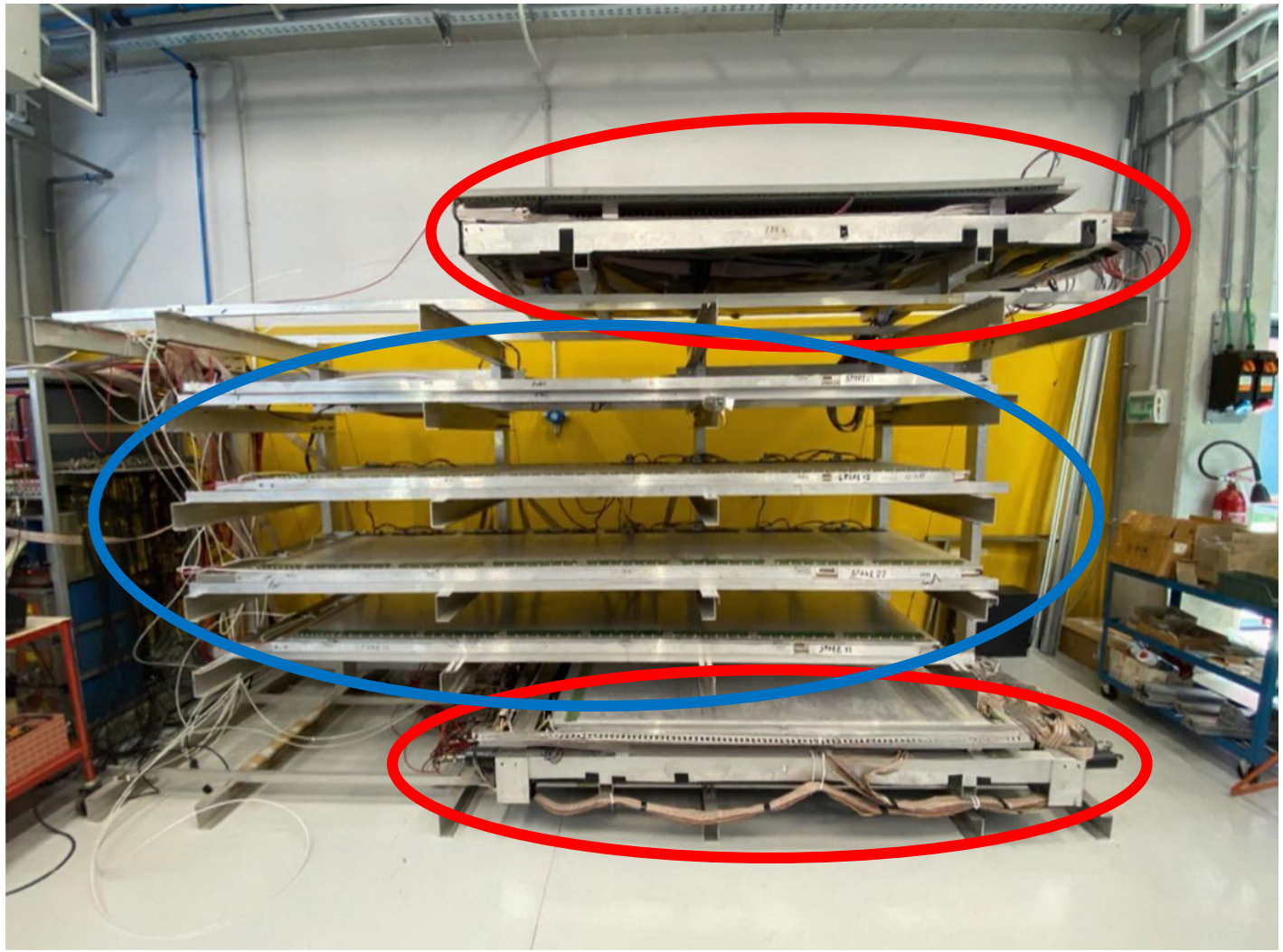


Cosmic Ray telescope

Red: cosmic rays detection and tracking

Blue: RPCs under test

RPC are tested in streamer mode



Efficiency test

- Test station with cosmic rays composed of:
  - 3 planes of 9 scintillators each in a moving support;
  - 2 tracking RPCs in a moving support;
  - 4 test slots where the RPCs to be tested are placed.
- Cosmic rays tracking allows to measure efficiency locally (1x1 cm^2 resolution)
- Streamer mixture:

Argon 50.5 %, $C_2H_2F_4$ 41.3 %, i-C_4H_{10} 7.2 %, SF_6 1 %

- ADULT front-end electronics with internal threshold of 80 mV
- 2 half-RPCs at a time can be tested.

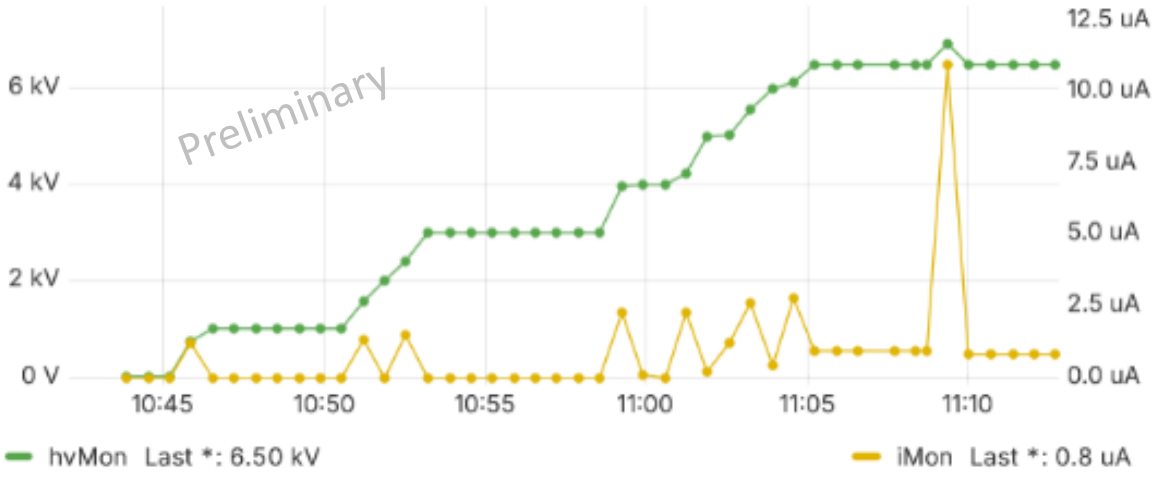
Motivation of the tests on old RPC spares

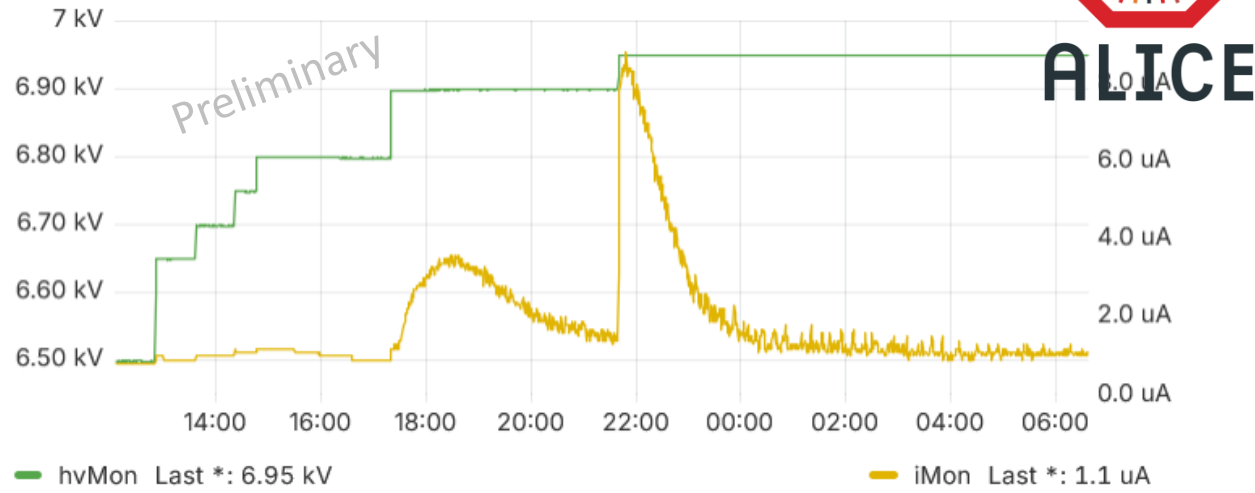
- ALICE MID RPCs designed and tested for 10 years of LHC data-taking.
- Most of them still fully operational after more than 15 years' work: less than 10% of the gas gaps replaced.
- Main challenge: ensure stable and efficient operation until the end of Run 4.
- Switch from maxi-avalanche mode to pure avalanche mode since Run 3 (thanks to FEERIC) -> lower integrated charge -> lower ageing.
- However, more than twenty years passed since manufacturing: we are on uncharted territory.
- Main goal: extend lifetime and increase resilience of the MID system until the end of Run 4.

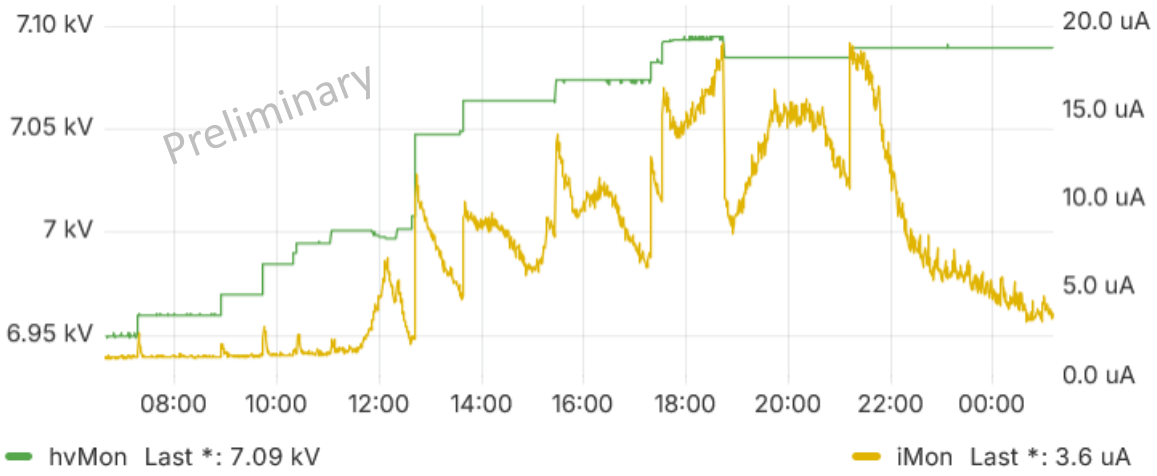
2005 RPC spares from original production

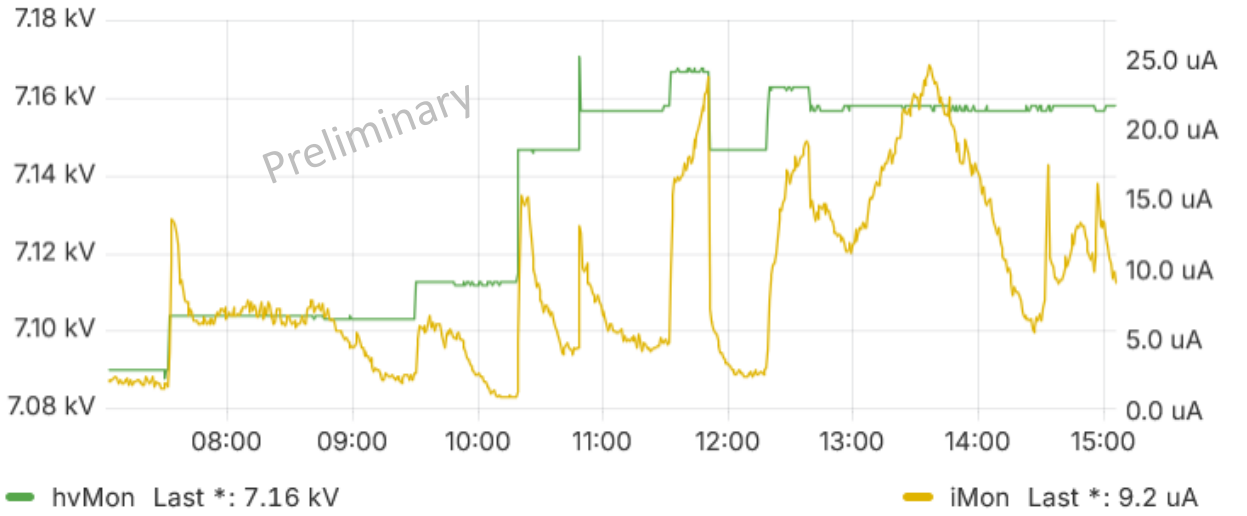
- We still have tens of spares from the original RPC production (2004-2005)
- Tests performed ten years ago showed very high dark currents - new spare production was launched
- Question: maybe old spares could be reconditioned and used as (at least) a stopgap measure in case of emergency?
- Efficiency and noise rate were tested for two such spares (gap 90 and 95), with currents measured and monitored

Anomalous currents during HV ramp up - 1





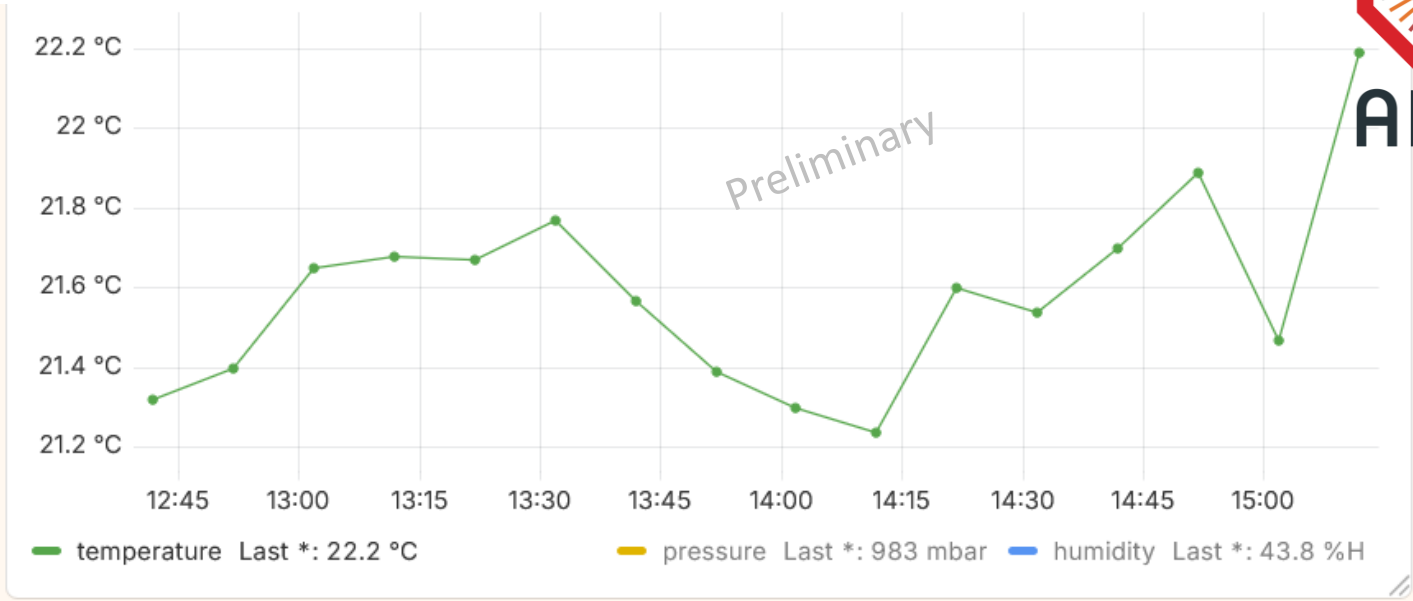


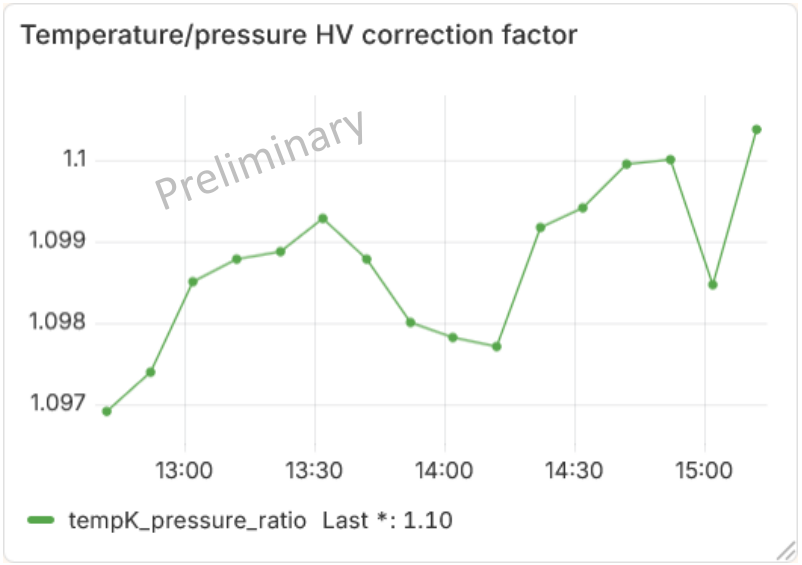


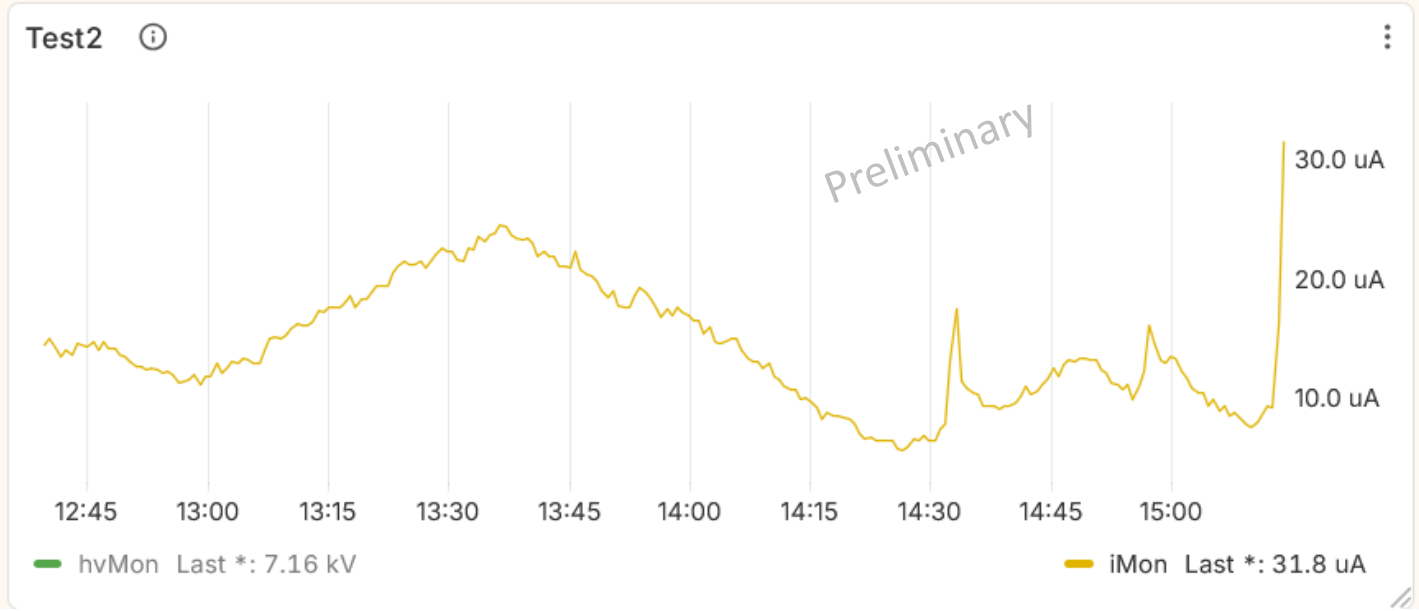
Gap 95 shows a sudden increase of current when HV > 7000 V

Anomalous currents during HV ramp up - 2

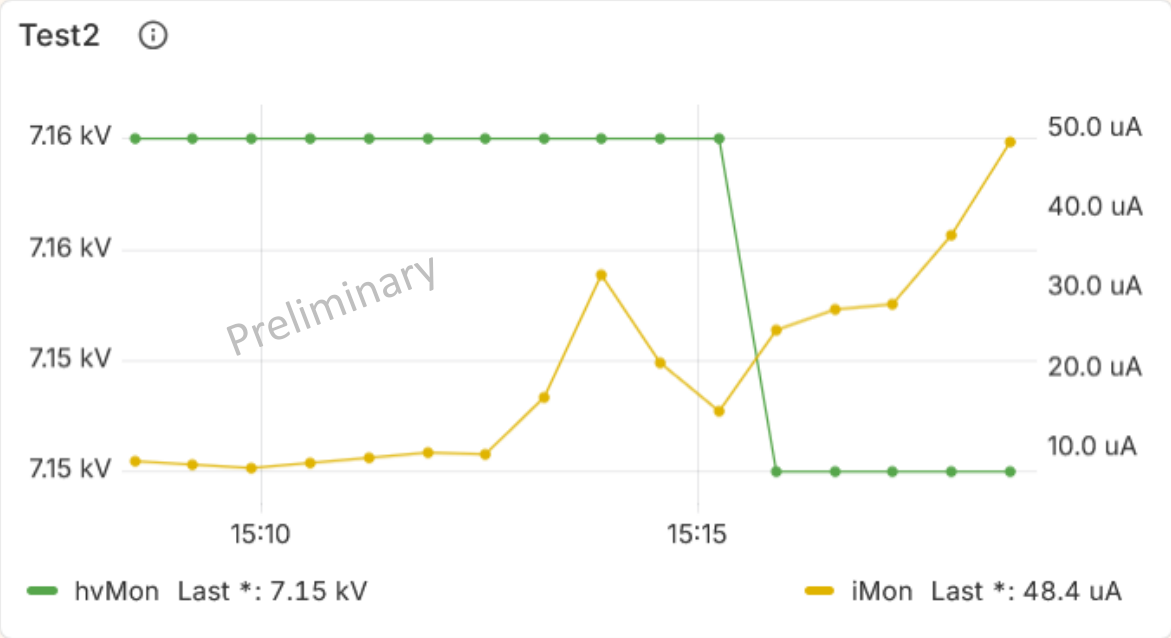
When HV is kept constant, the current follows the T/p ratio (dominated by T)

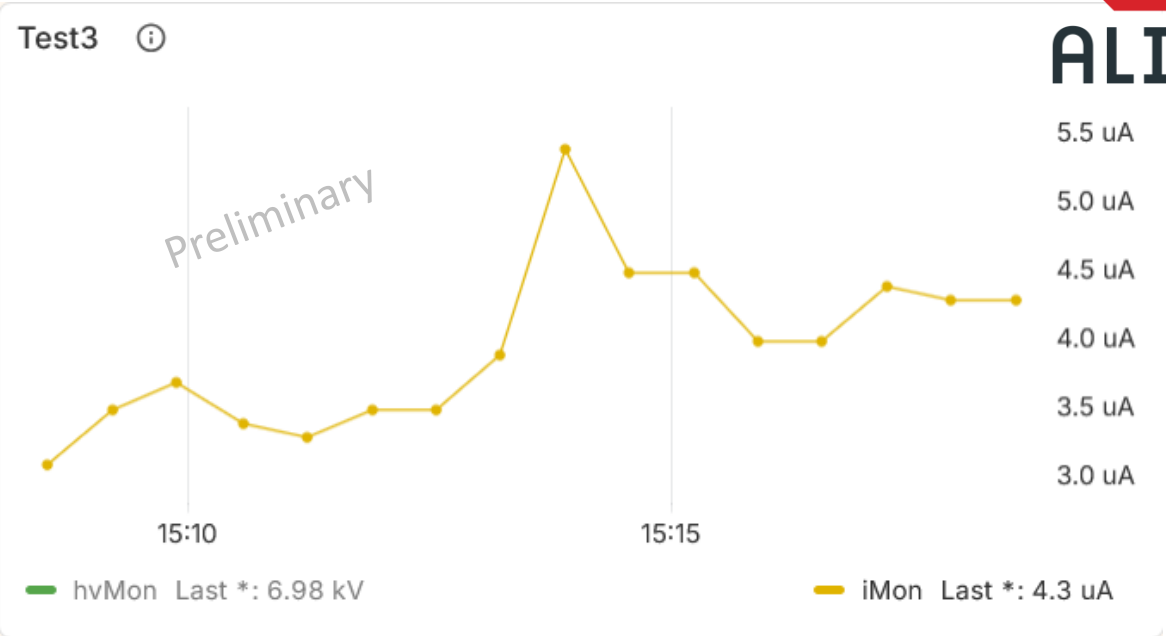






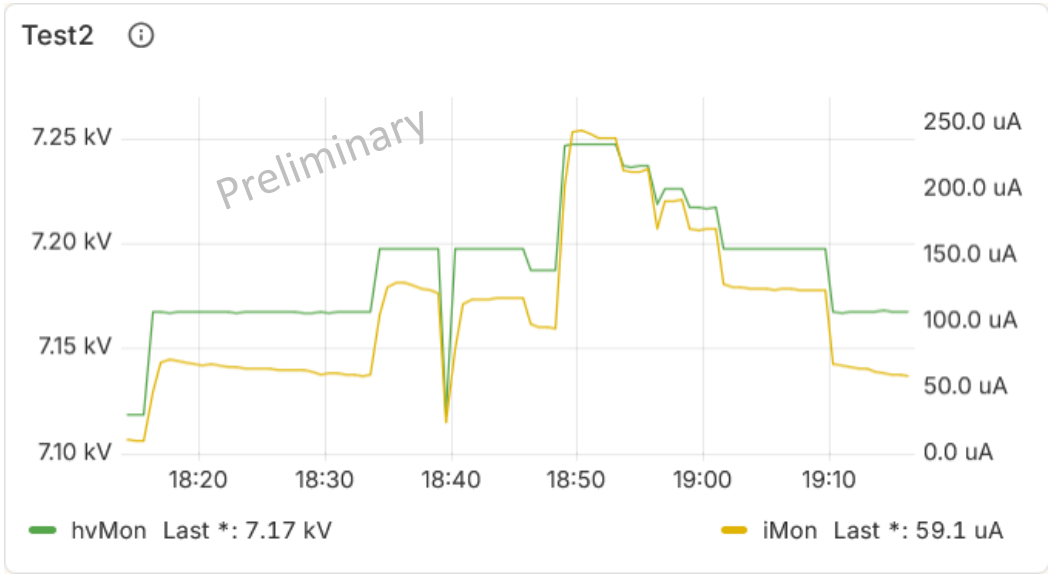
Anomalous currents during HV ramp up - 3

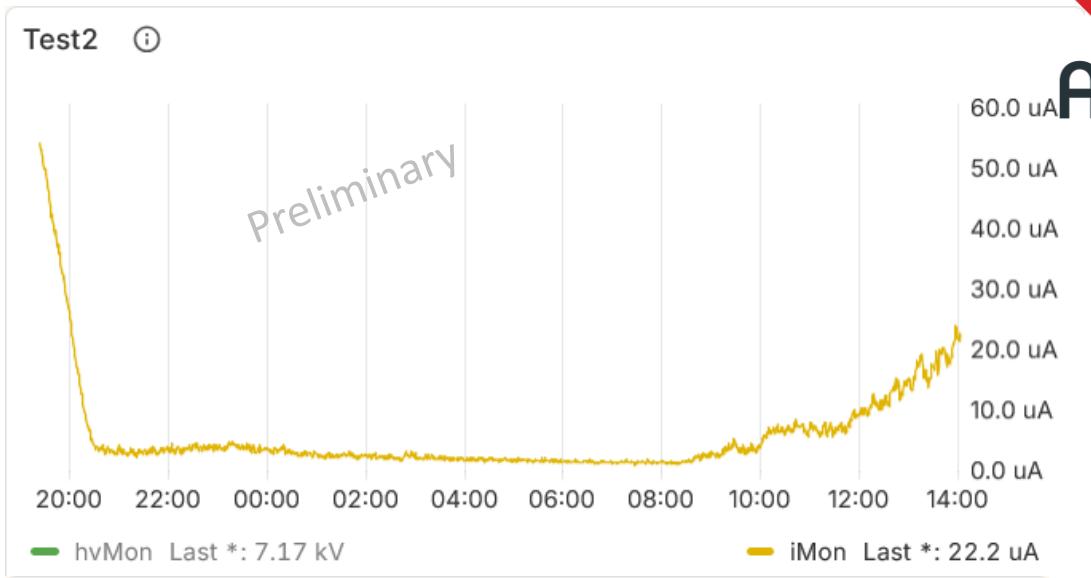


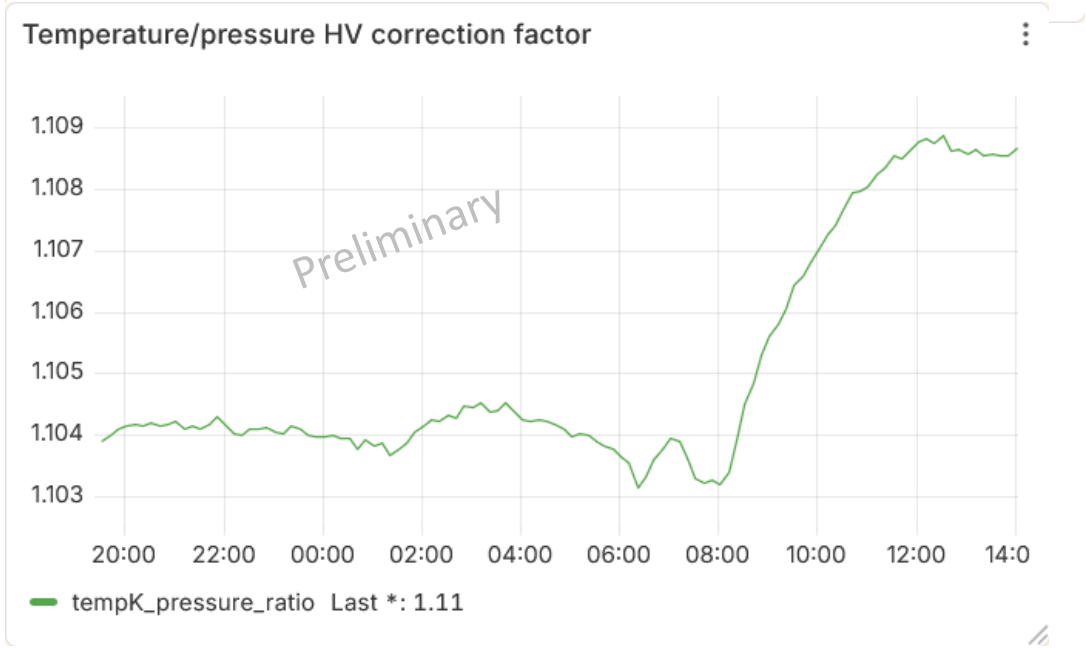


In both detectors, currents follow T/p ratio, but in some cases with different outcomes: gap 95 (left) goes up to TRIP (50 µA) at 7150 V, even after lowering HV by 10 V, while gap 90 (right) stabilizes by itself without any HV lowering

Anomalous currents during HV ramp up - 4



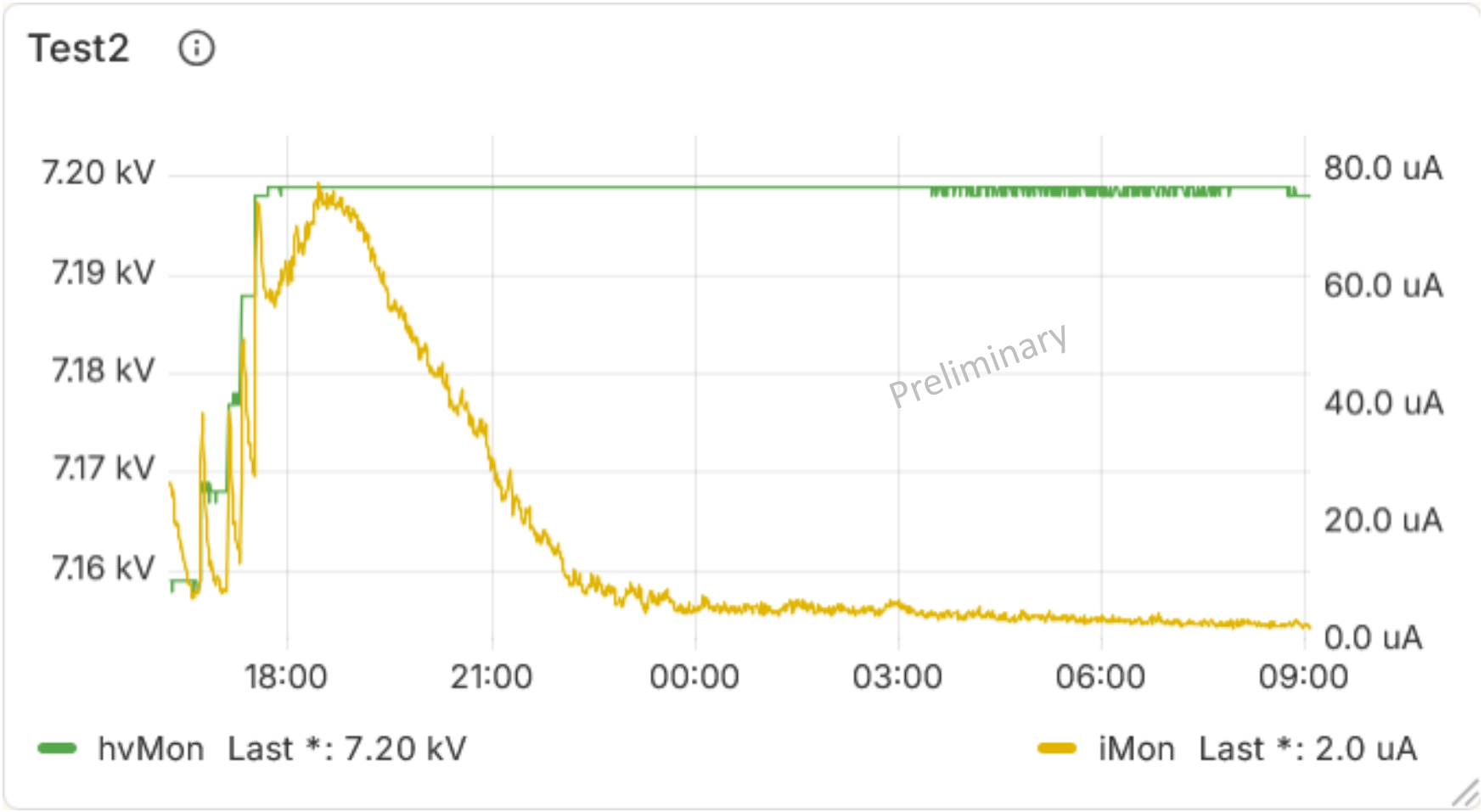




After HV trip we try to increase HV up to large currents, but HV is back to 7170 V the current is the same as before. During the night, current goes down to < 2 µA but increases again when T rises.

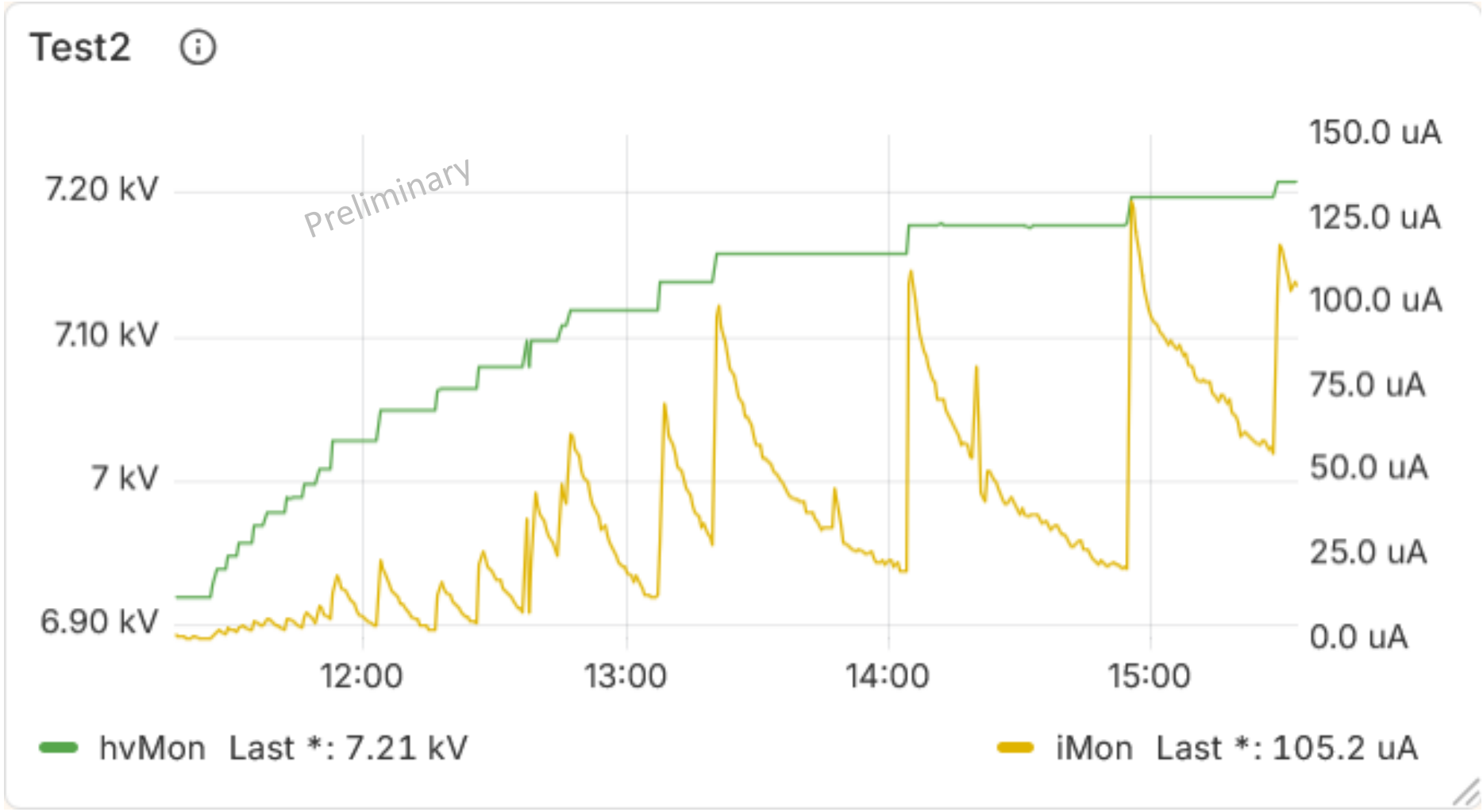
Gap 90 behaves similarly, but T-driven increase is only up to 7 µA.

Anomalous currents during HV ramp up - 5



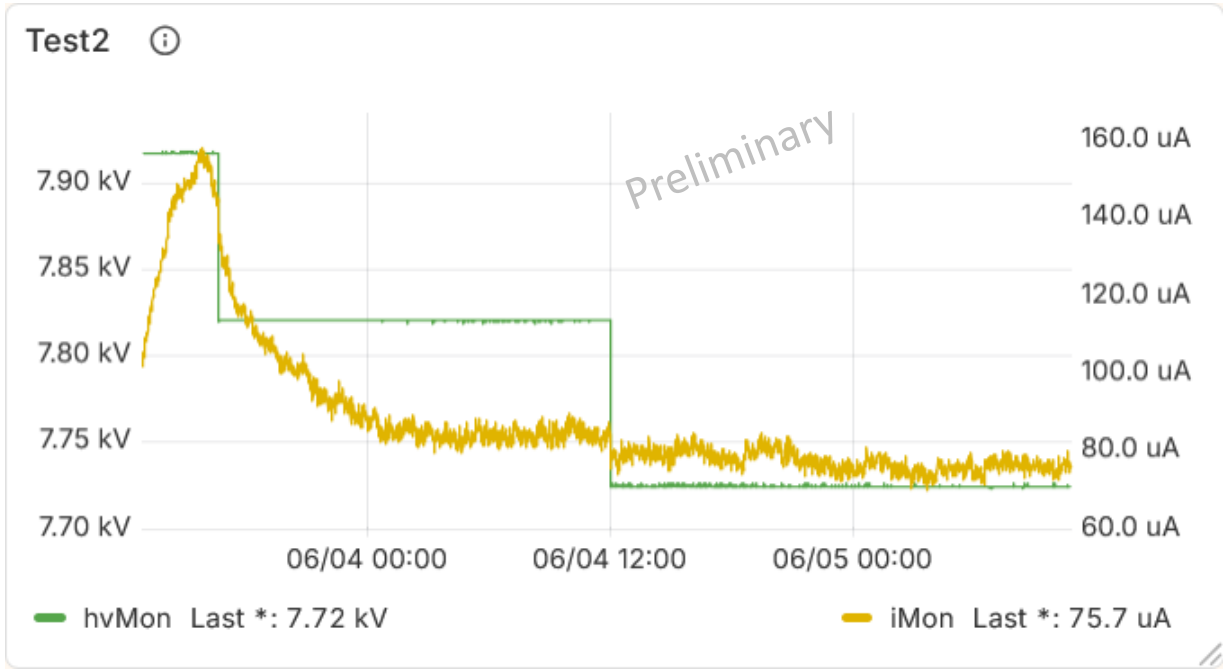
A strategy is devised: increase HV by 10-20 V steps up to large currents.. and wait! In this way, we are able to slowly reduce currents…

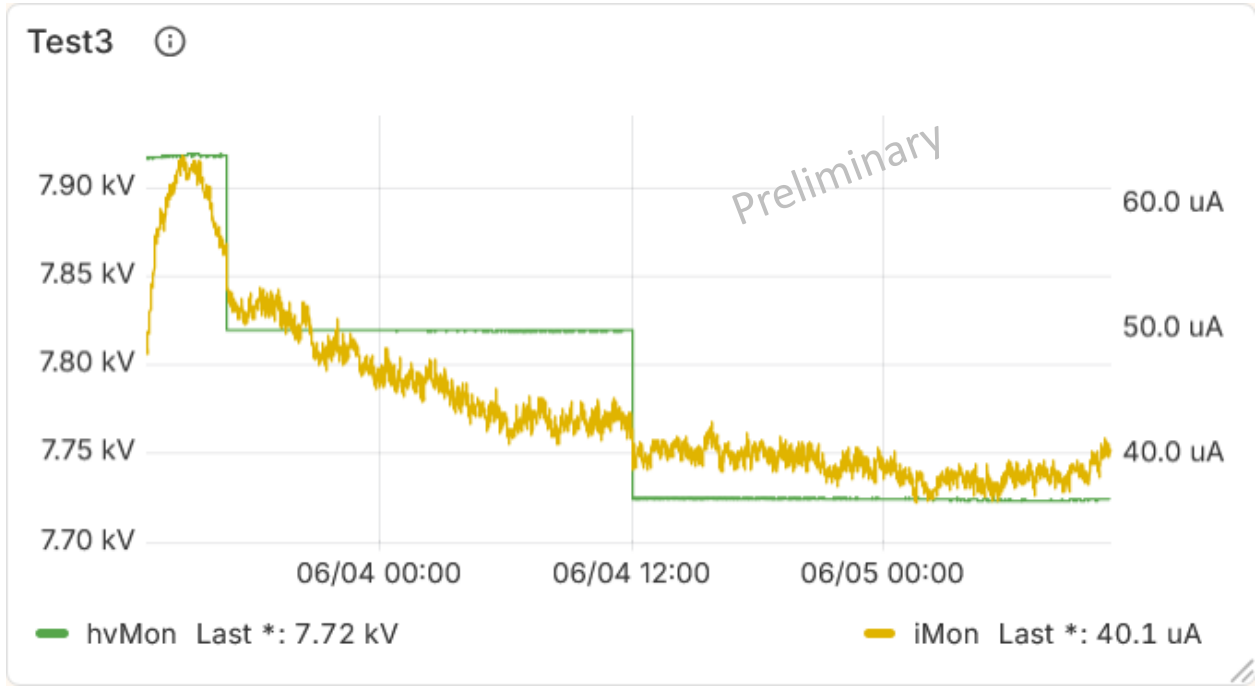
Anomalous currents during HV ramp up - 6



…but progress is not linear: we reached ~30 µA at 7270 V, but after 70 hours with HV and gas OFF, some progress is lost!

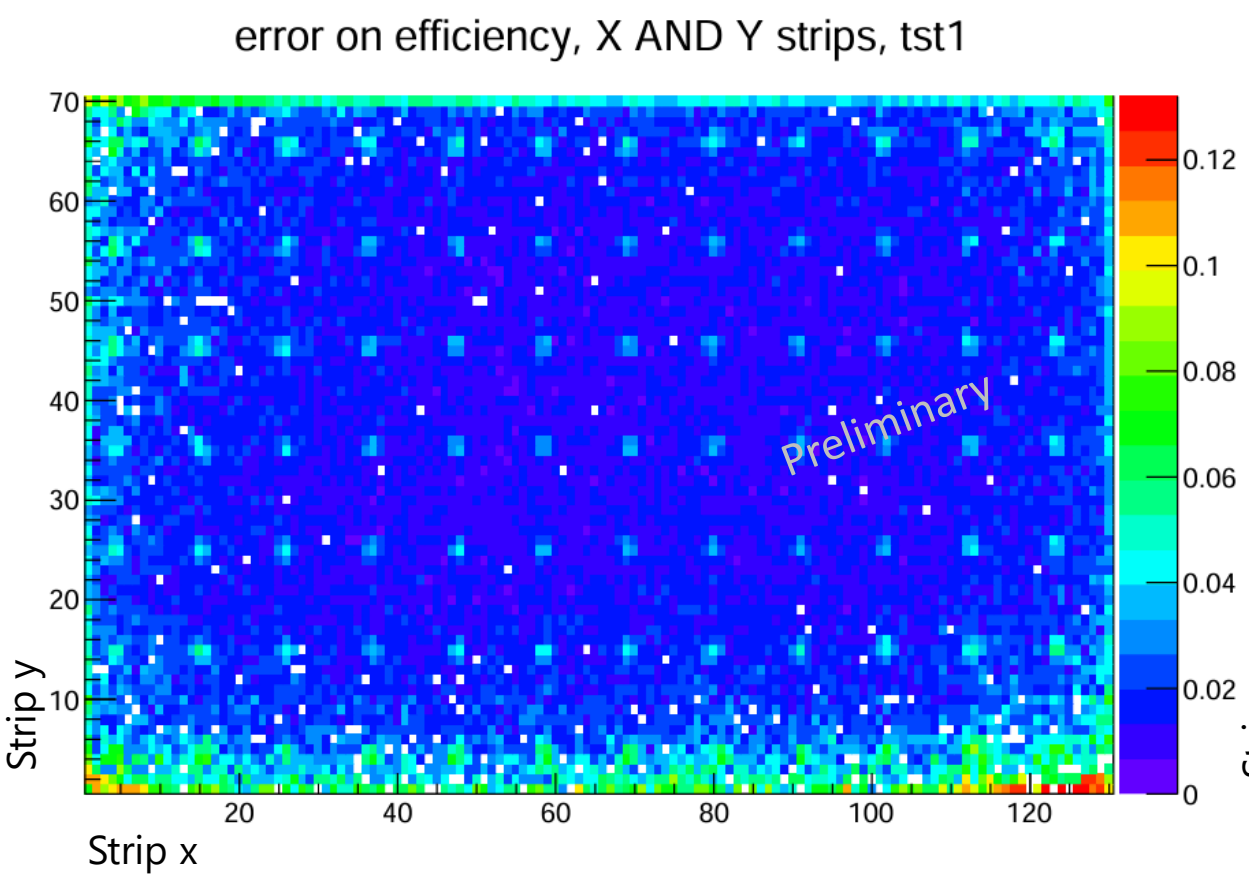
Final working currents, June 2025

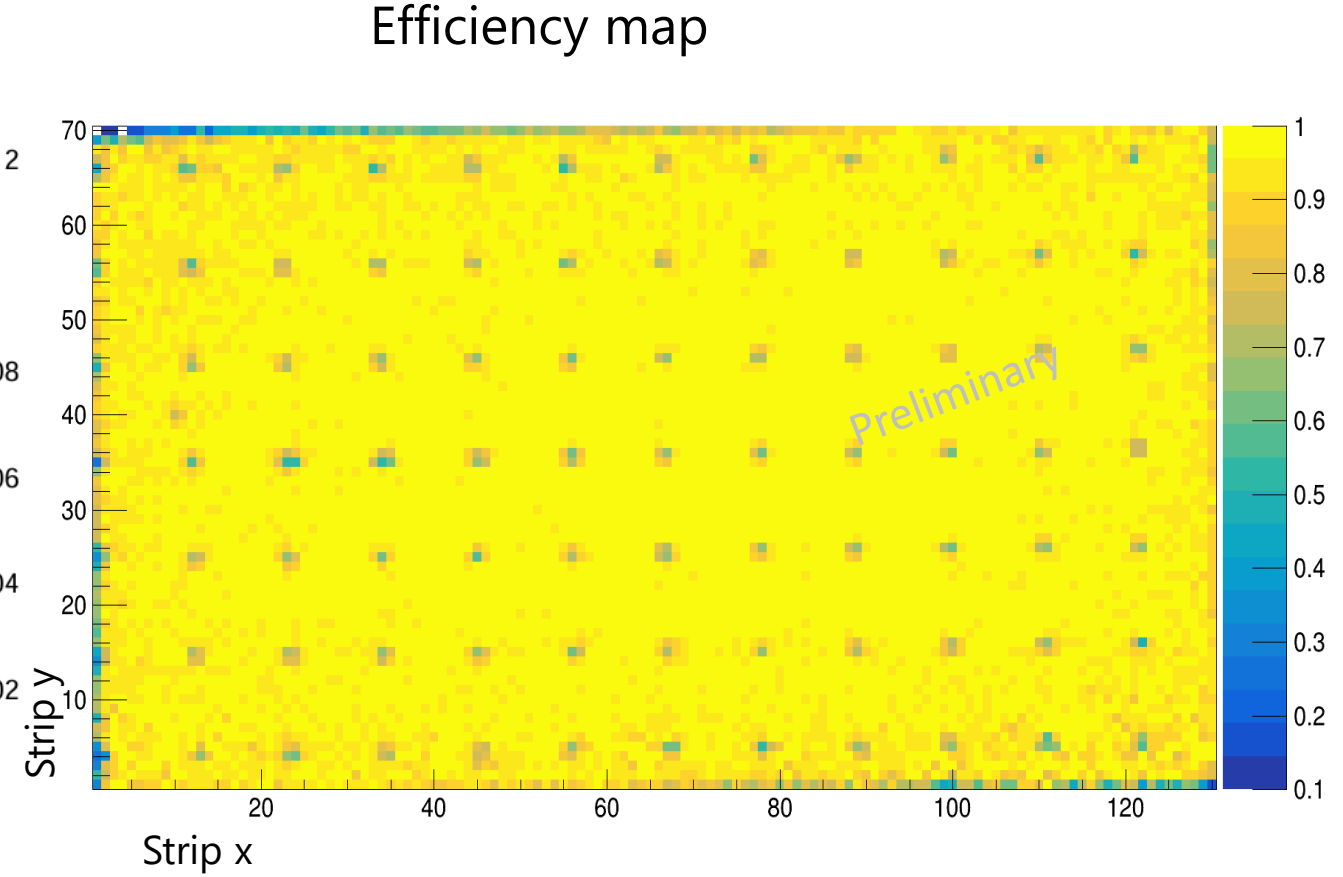




The process took two weeks, but finally we were able to reduce currents to a point which allowed to measure the chambers' efficiency at operating voltages.
Operating current was always strongly dependent on the lab temperature: for the final tests, with temperatures around 26 °C chamber 95 stabilized around 80 µA while chamber 90 reached 40 µA.

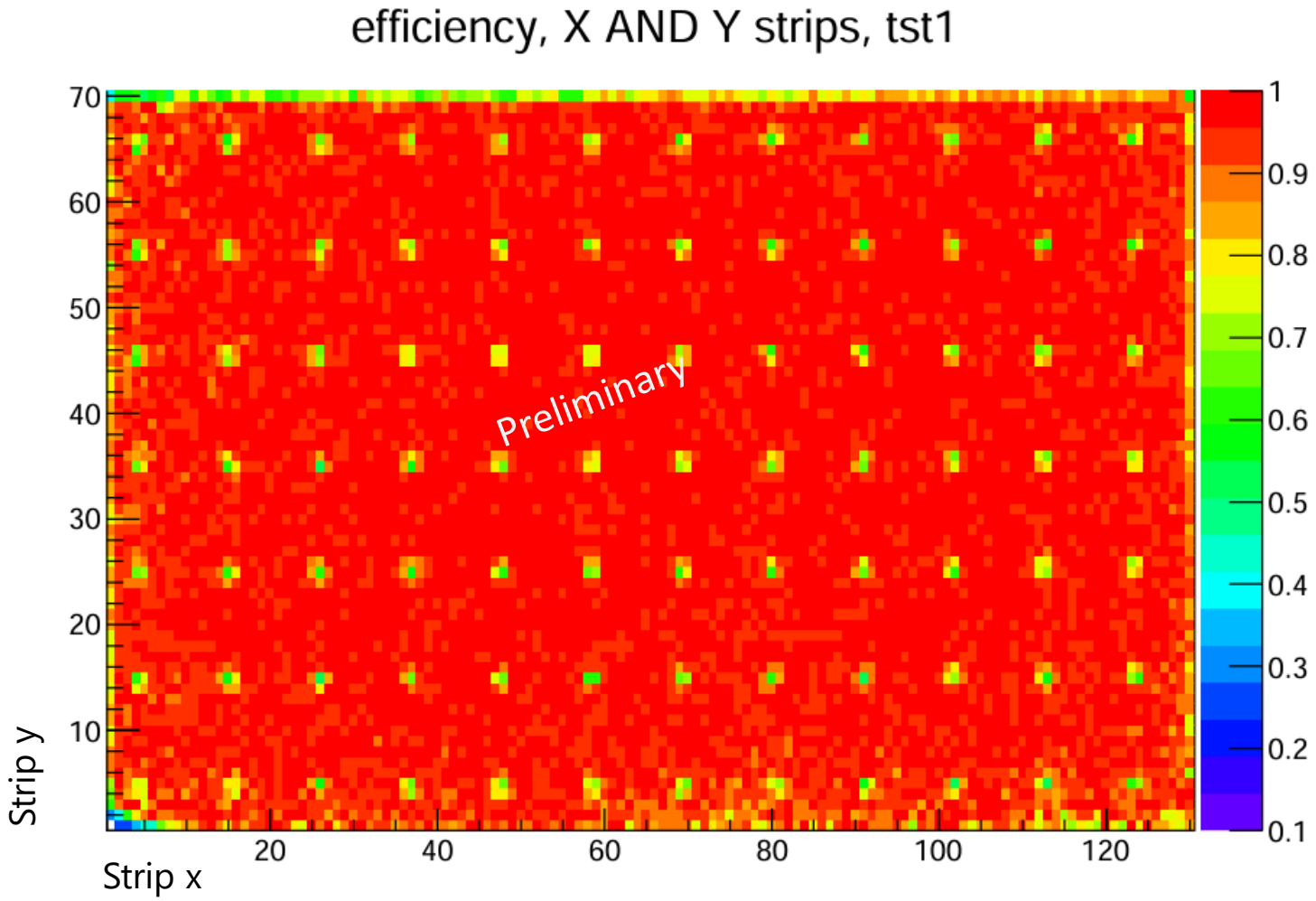
Efficiency map – gap 95





In spite of large currents, efficiency is good! Maps relative to the first half of the gap, at 8300 V operating voltage(T/p corrected) , current during test was ~95 µA. Second half is similar

Efficiency map – gap 90

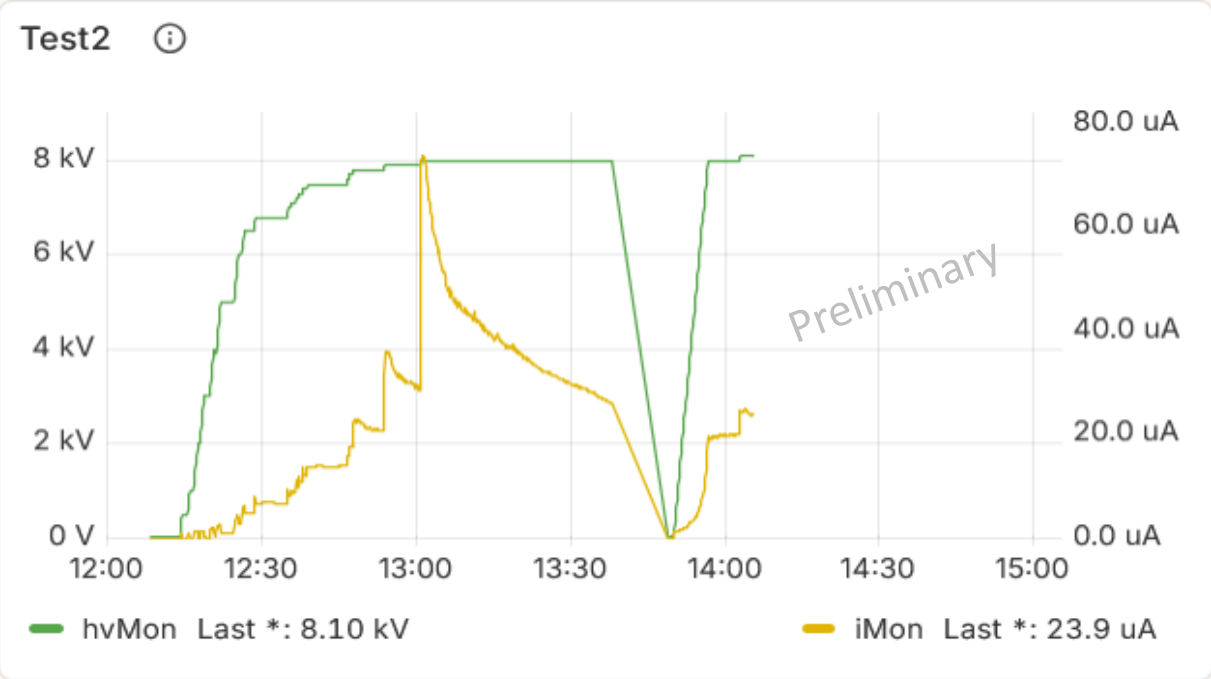


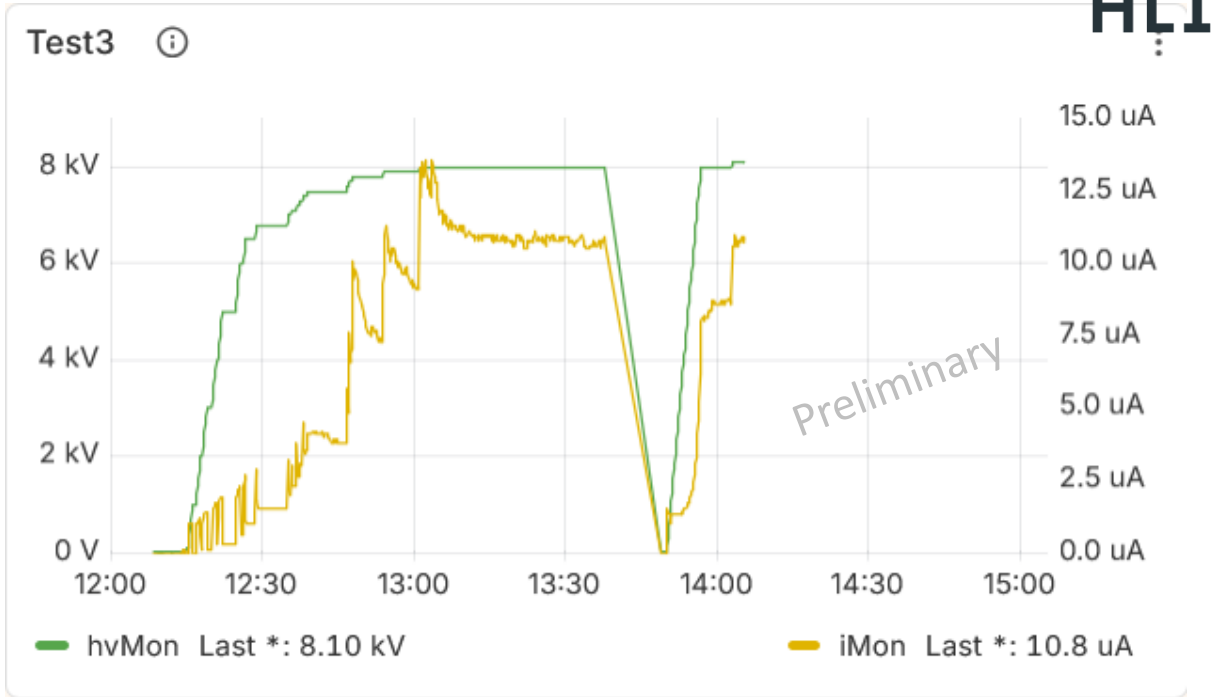
In spite of large currents, efficiency is good! Maps relative to the first half of the gap, at 8300 V operating voltage, current during test around 55 µA. Second half is similar

Dark rate measurement

- Dark rate is measured by counting the hits from the strips with scalers, to avoid problems with DAQ dead time.
- Gap 95 showed an average hit rate of 4.4 Hz/cm^2
- Considering a charge per hit of 500 pC, the corresponding current should be 40 µA. However, actual current was around 100 µA
- Gap 90 showed an average hit rate of 0.9 Hz/cm^2, corresponding to ~9 µA, However, actual current was ~40 µA

After nine months with HV off and gas off





In March, 2026 the gaps were switched on again, and the current was strongly reduced! At 8.1 kV, gap 95 drew 24 µA, while gap 90 drew 10.6 µA (temperature: 23.3 °C)

Old spares test outcome and outlook

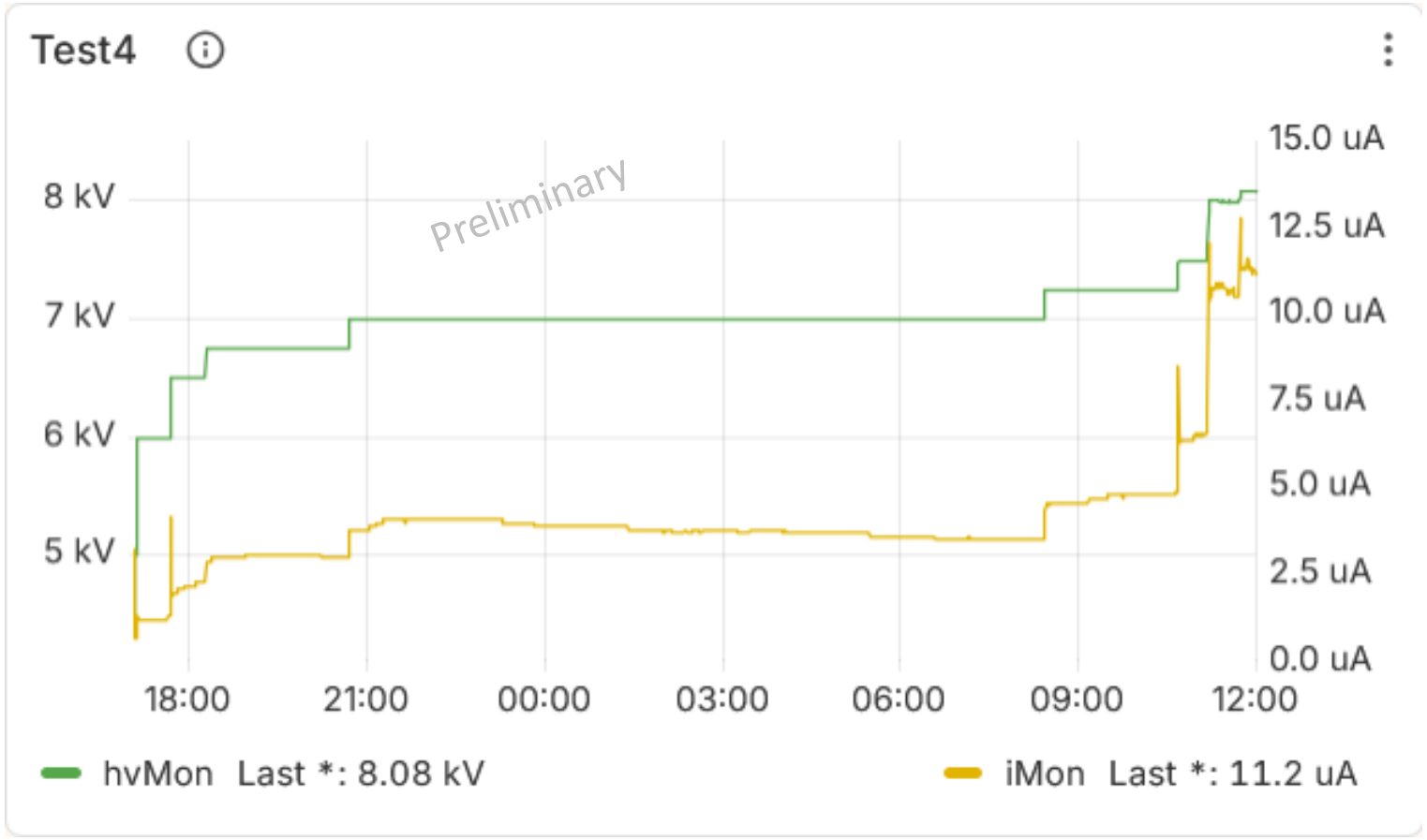
Although the current values are much higher than normal, the detectors are fully efficient and with an acceptable noise rate.

- These observations may be the starting point for further research, aimed at understanding whether it is possible to further lower and stabilize the current in with longer conditioning
- Do the efficiency and current remain stable over a relatively long data collection period?
- Most of all, which is the underlying cause for the behavior of the dark current? It is related to the higher athmospheric relative humidity w.r.t. RPC mixture? To the oxygen? Others?

Test on a chamber removed from MID

- During Long Shutdown 2 (LS2), some chambers were replaced due to increased current.
- One of these chambers was chamber 59 (L2), which was brought back to Torino
- We decided to test this chamber in Torino in order to measure its current, its efficiency (with high granularity) and the noise rate.

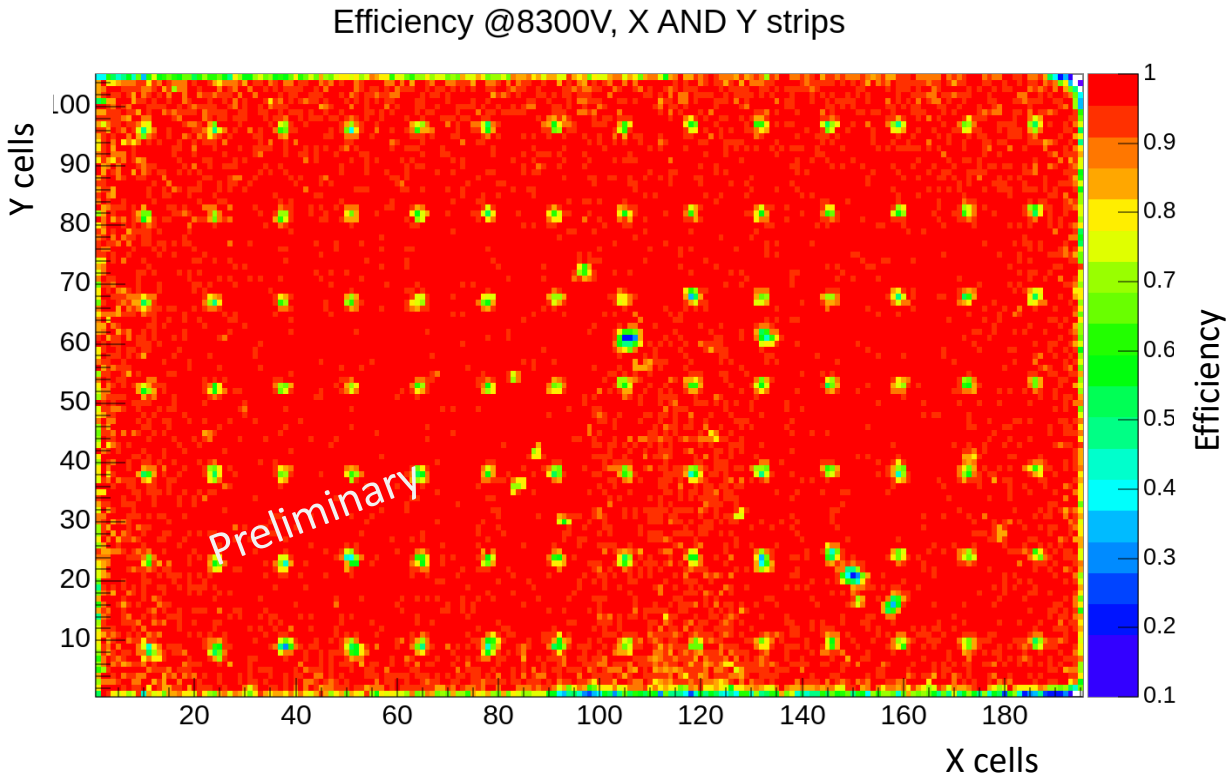
Ramp-up of gap 59



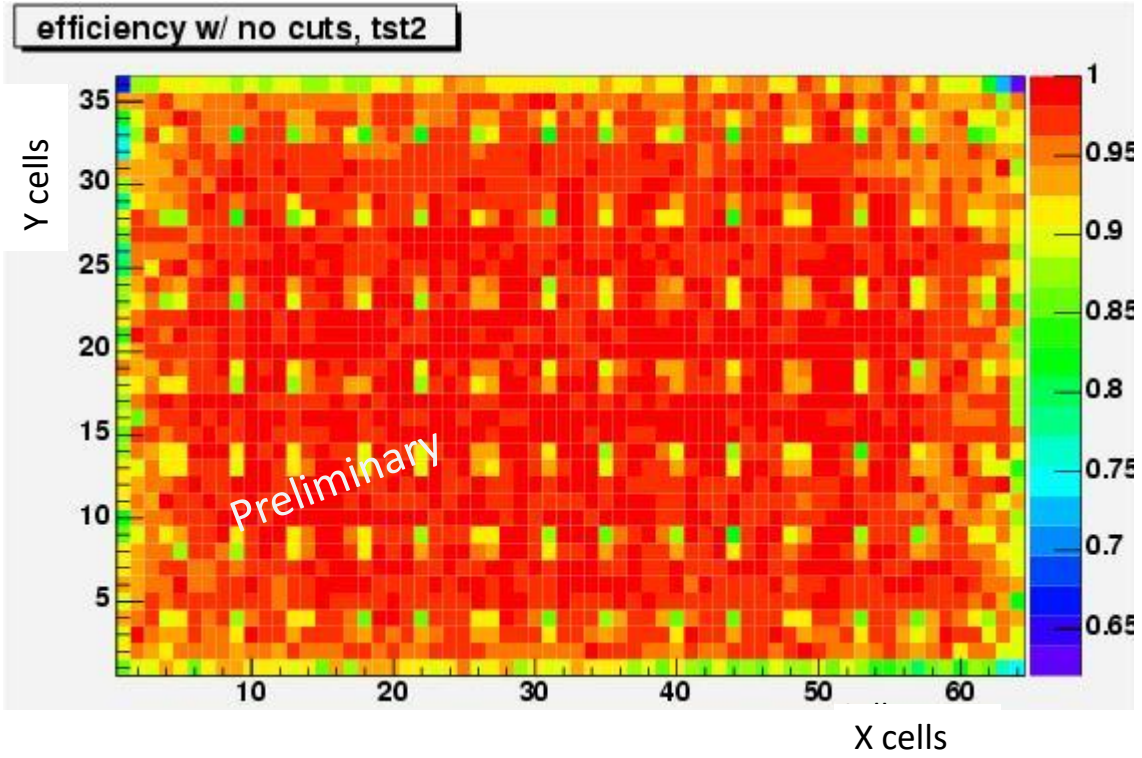
Current absorbed during Torino tests was approximately 11 µA, higher than a good new chamber (2-3 µA) but lower than when it was in the MID (about 30 µA).

Efficiency - right half – 8300 V

- In 2025:

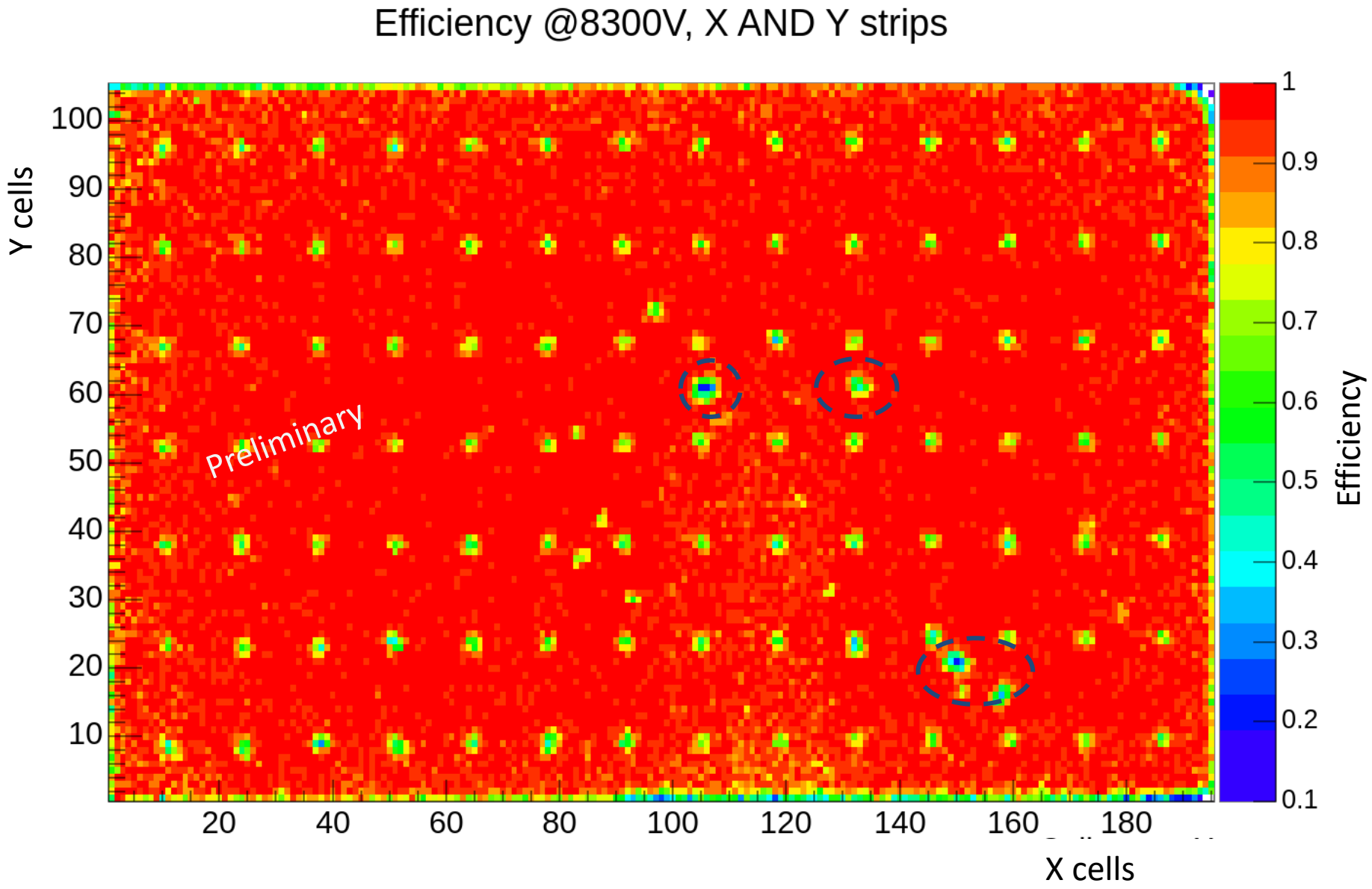


- In 2005:

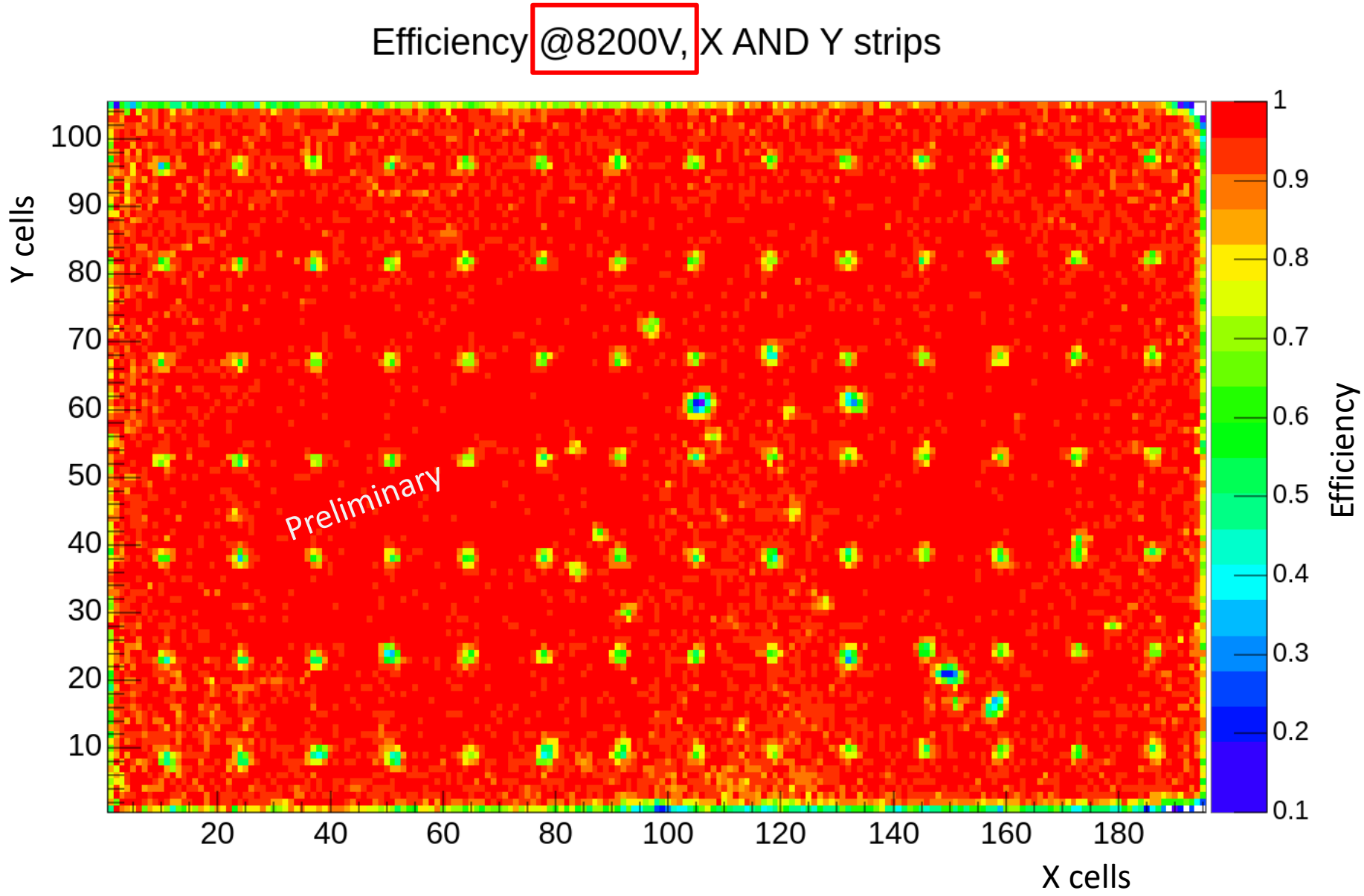


Some small inefficient spots were detected

Efficiency - right half – 8300 V

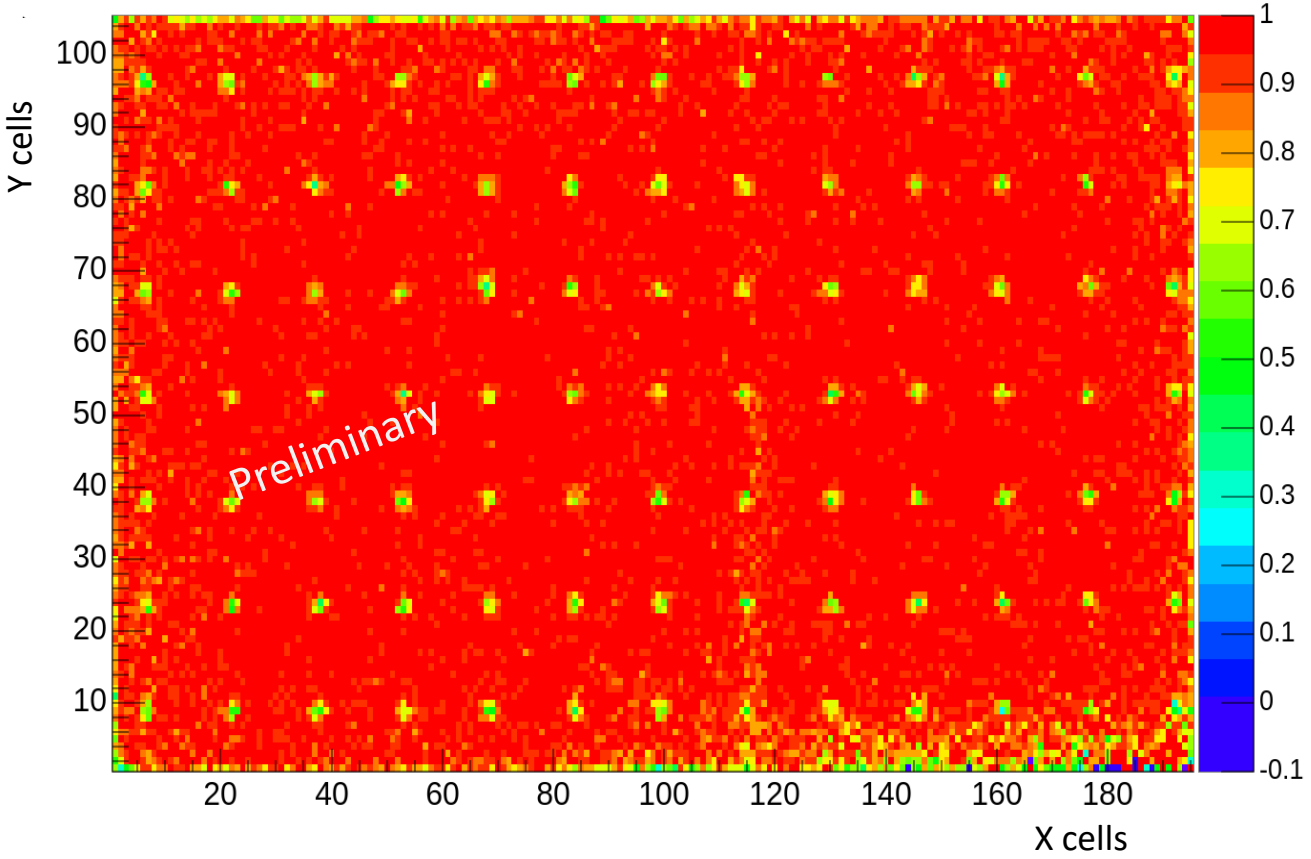


Efficiency - right half – 8200 V

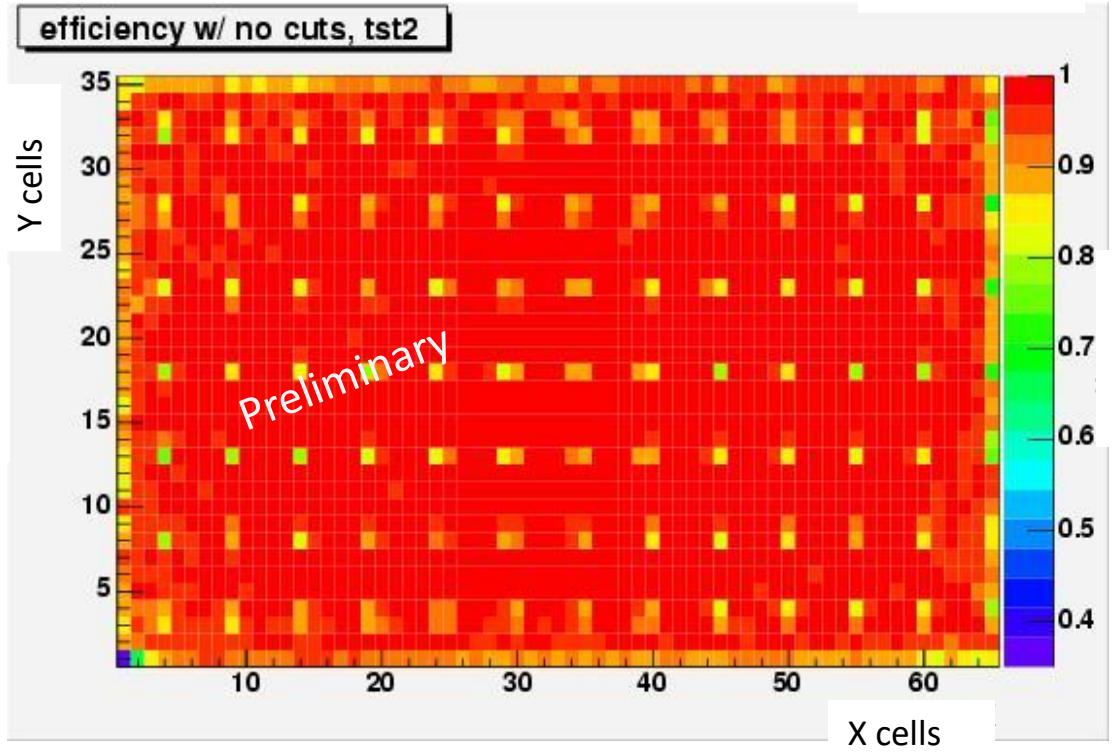


Efficiency - left half – 8300 V

- In 2025:



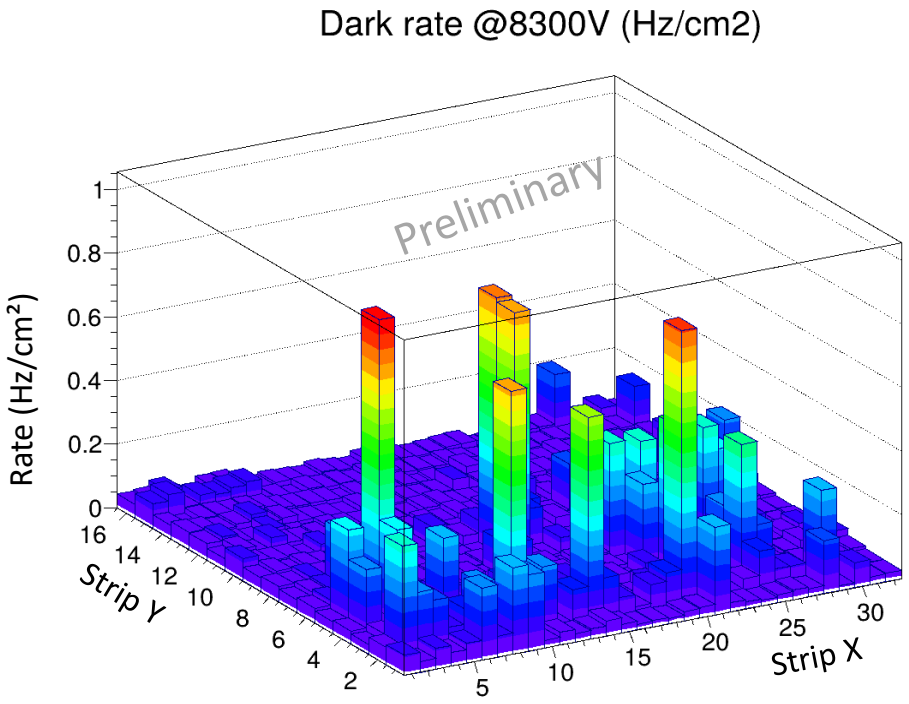
- In 2005:



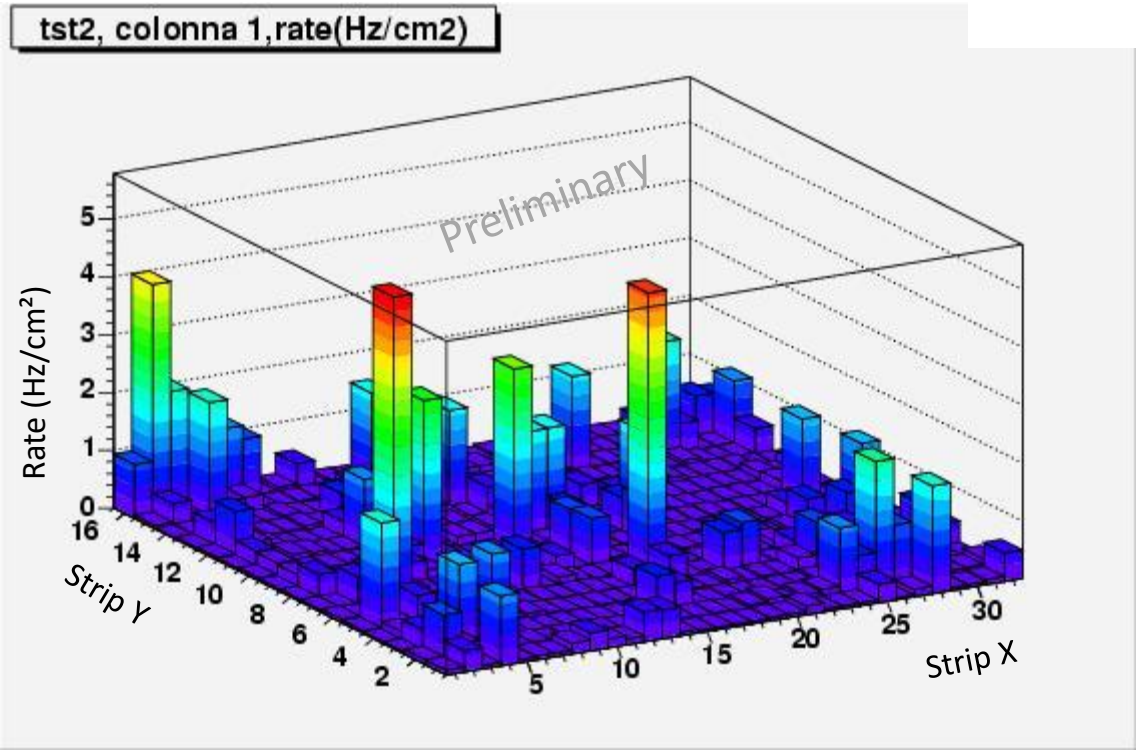
No inefficient spots

Noise rate: chamber 59, right half

2025



2005

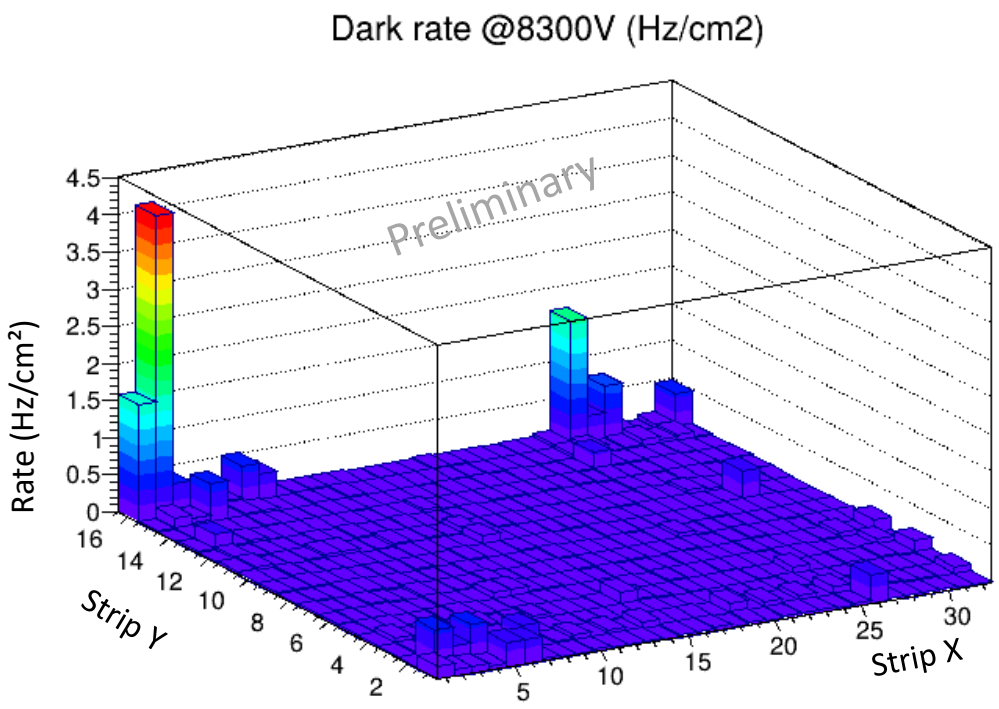


With respect to the initial tests in 2005, the noise rate is strongly reduced!

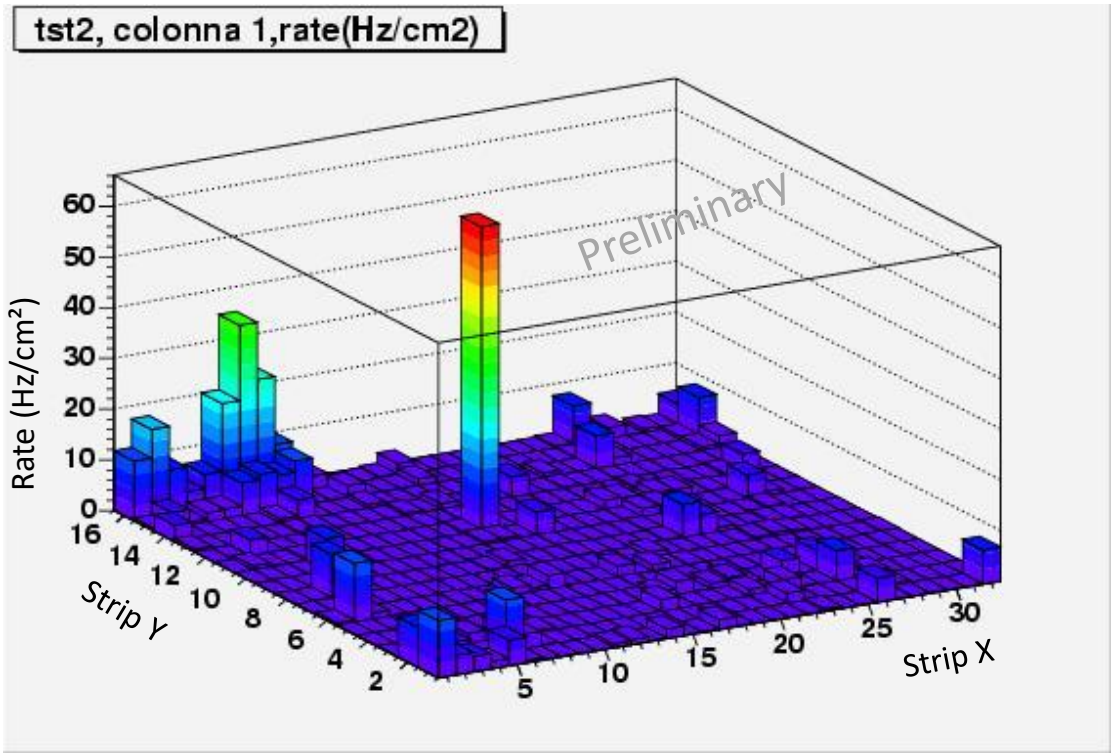
Noise rate: chamber 59, left half

Noise reduced on the left half too

2025



2005:



Average noise rate in 2025: 0.07 Hz/cm^2

Conclusions on the ex-MID RPC

Small spots of inefficiency: to be further investigated

Dark current increased w.r.t. first tests in 2005, but decreased w.r.t MID operation.

Noise rate strongly decreased

Two more chambers ready to be tested