



IRRADIATION AND GAS STUDIES OF MICROME GAS PRODUCTION CHAMBERS FOR THE ATLAS NEW SMALL WHEEL

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ON BEHALF OF THE ATLAS MUON COLLABORATION



ICHEP 2020 | PRAGUE

40th INTERNATIONAL CONFERENCE
ON HIGH ENERGY PHYSICS

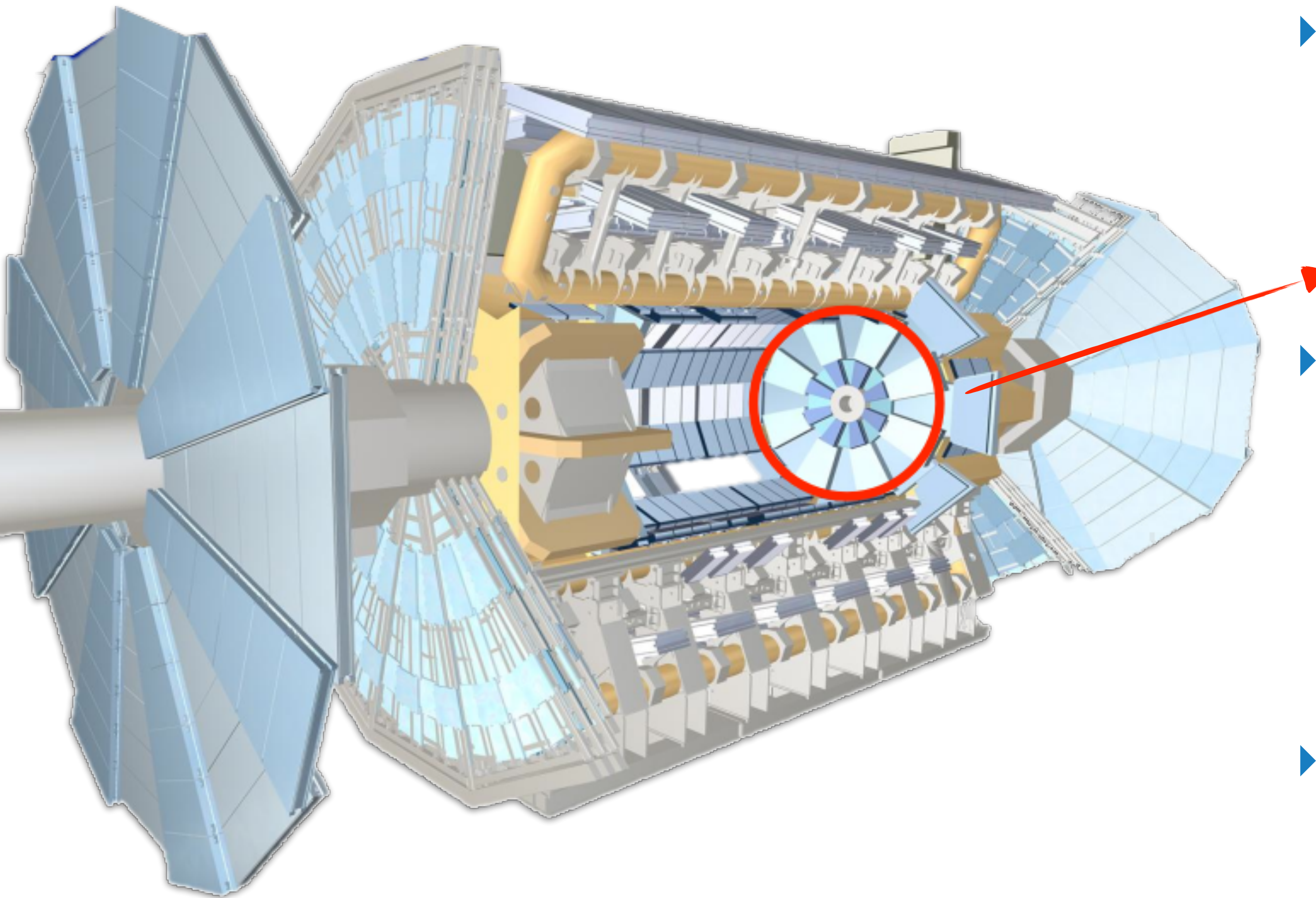
**VIRTUAL
CONFERENCE**

28 JULY - 6 AUGUST 2020

PRAGUE, CZECH REPUBLIC

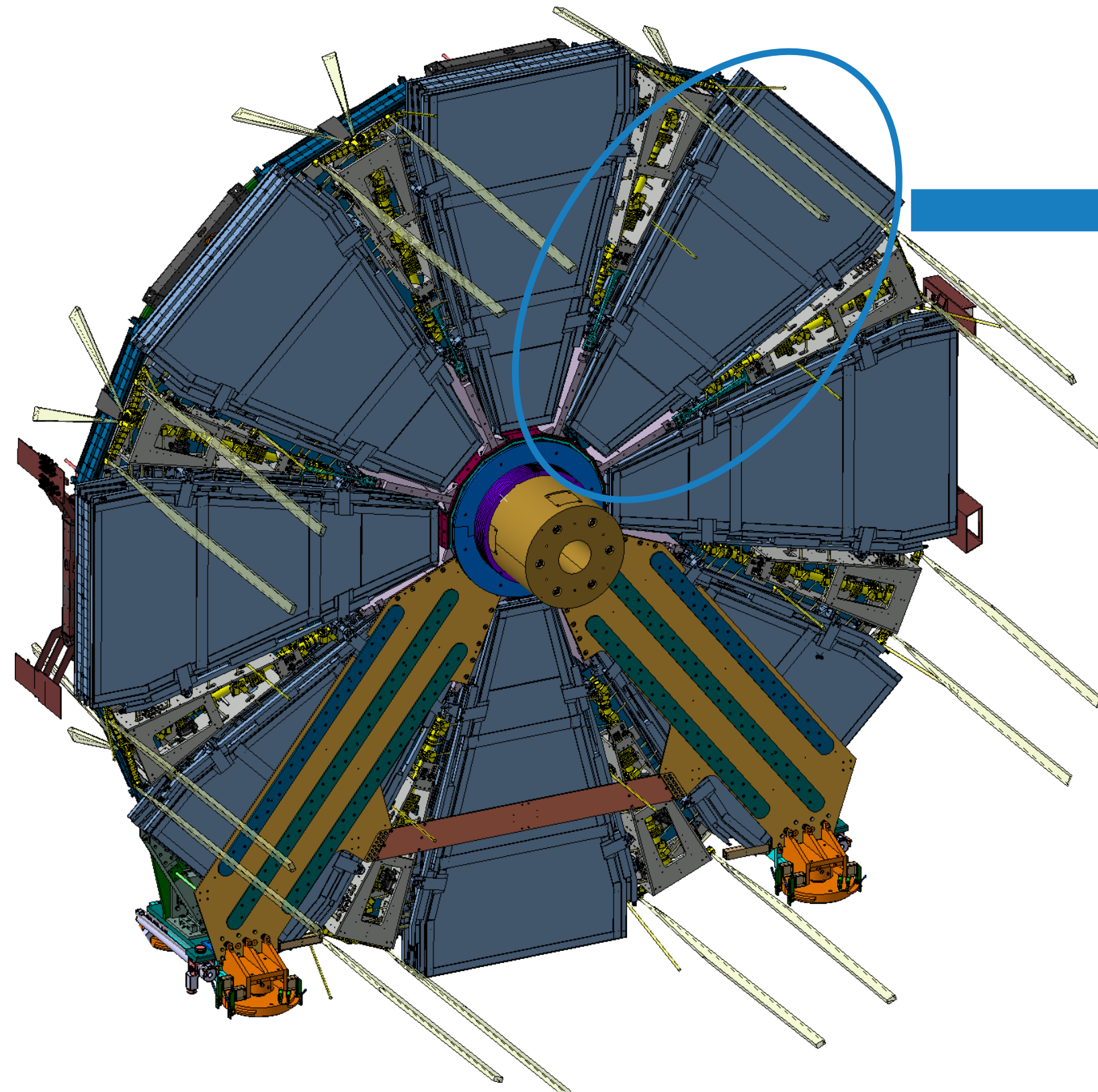


ATLAS NEW SMALL WHEEL PROJECT

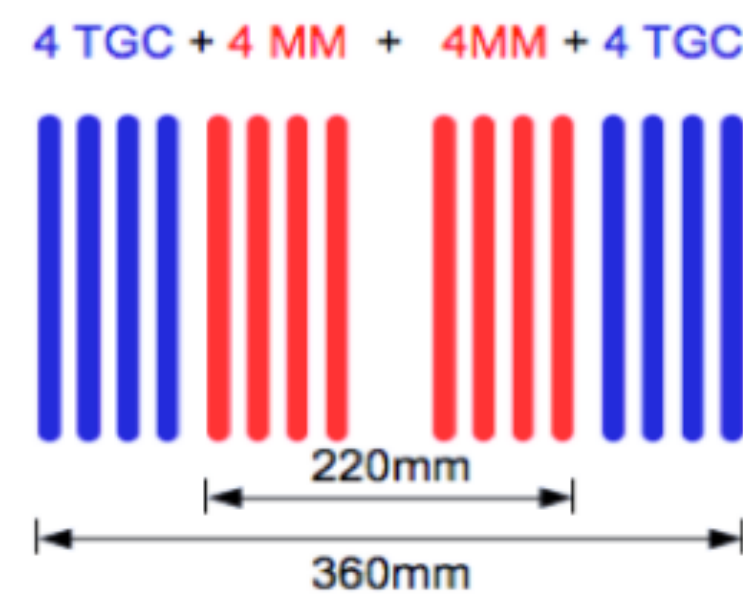
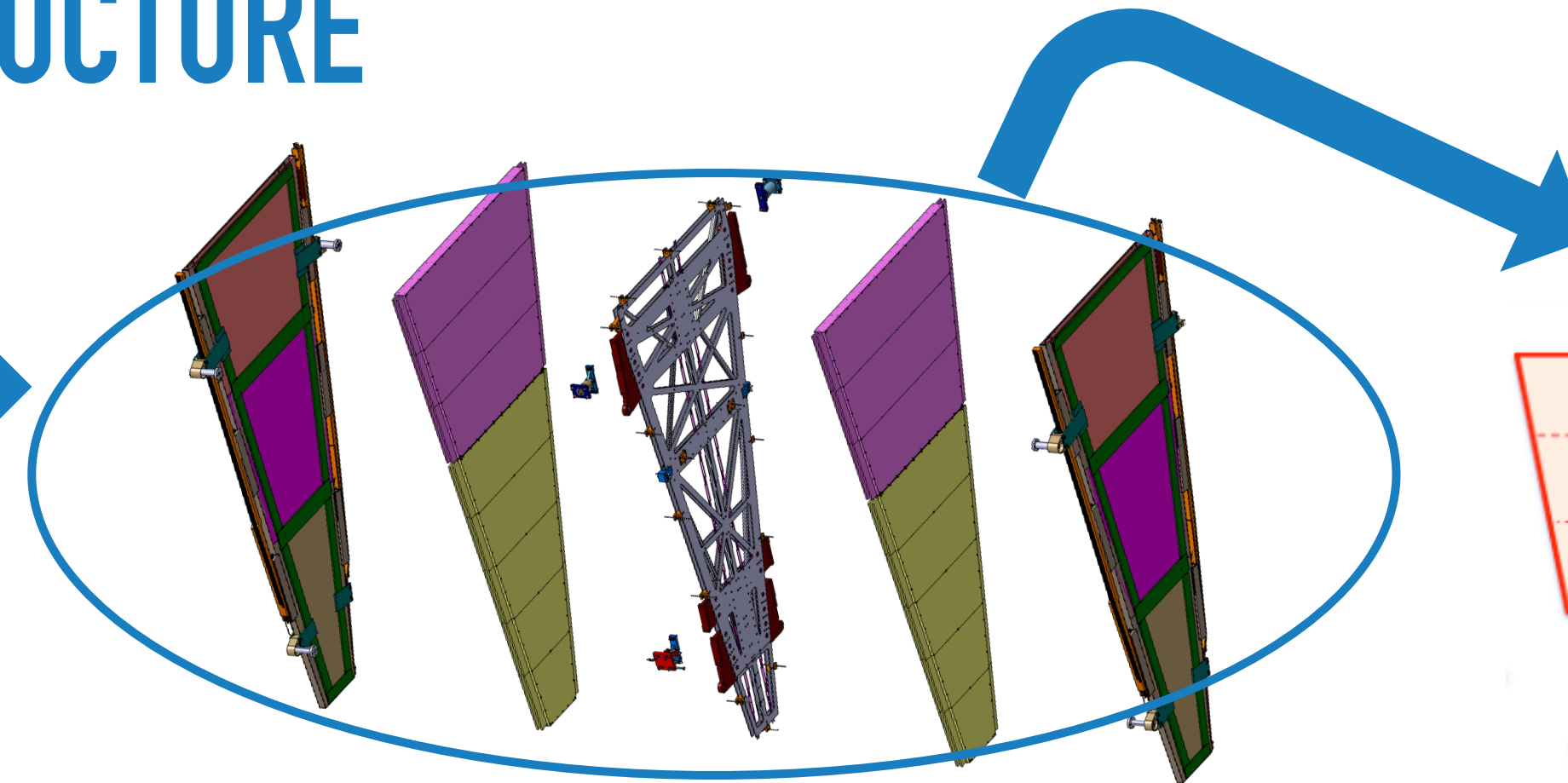


- ▶ In the ATLAS **Muon** Spectrometer, the highest background rates are seen in the innermost stations of the endcaps - the **Small Wheels**
- ▶ The **New Small Wheels** aim to replace the present Small Wheels with new detectors and electronics, which can cope with the HL-LHC pile-up and background, and which can provide improved triggering
- ▶ One of the main upgrades of Long Shutdown 2

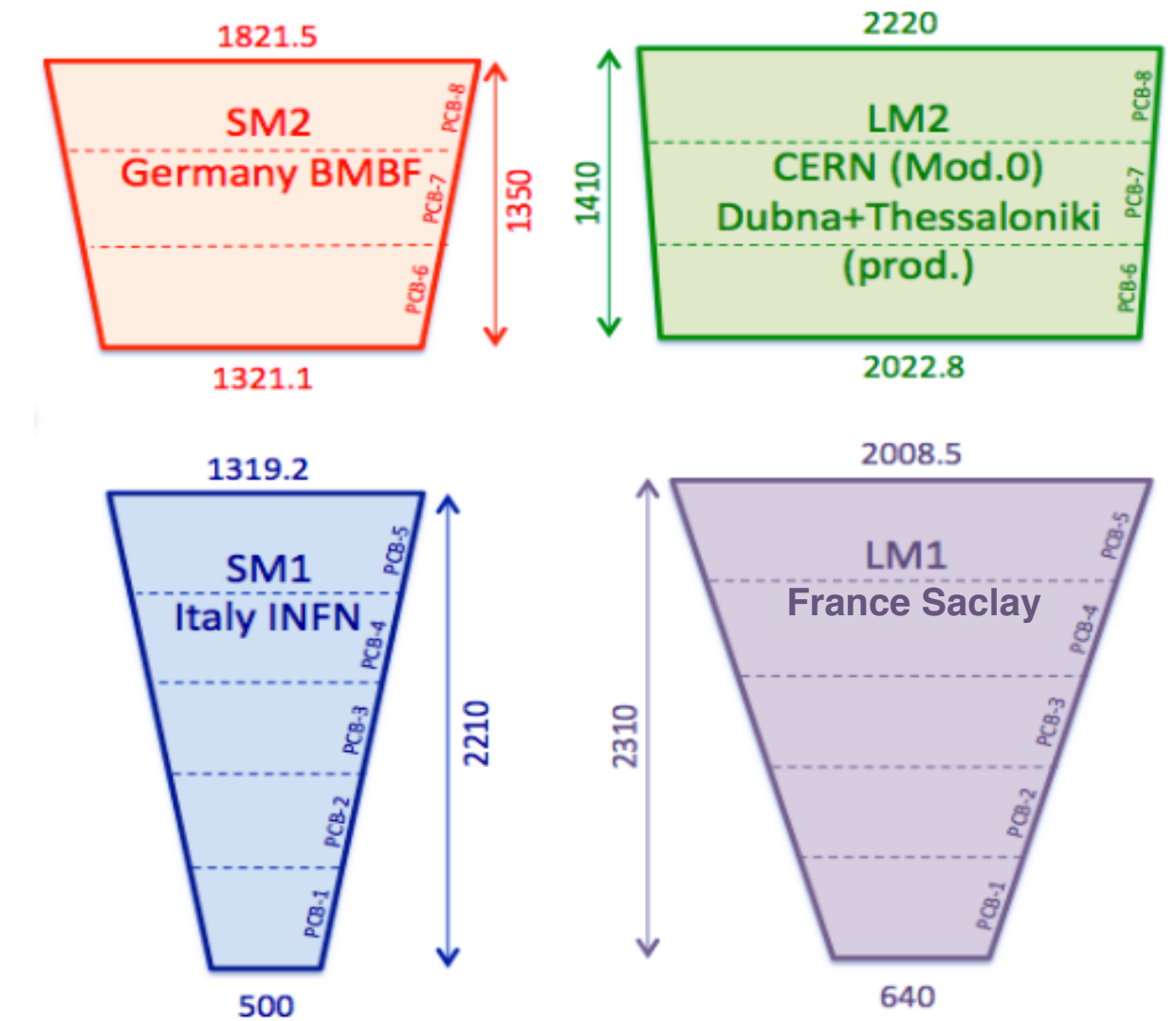
NEW SMALL WHEEL SUBSTRUCTURE



2 wheels
8 Small Sectors (IP Side)
8 Large Sectors (HO Side)
Total 32 Sectors
for the 2 wheels



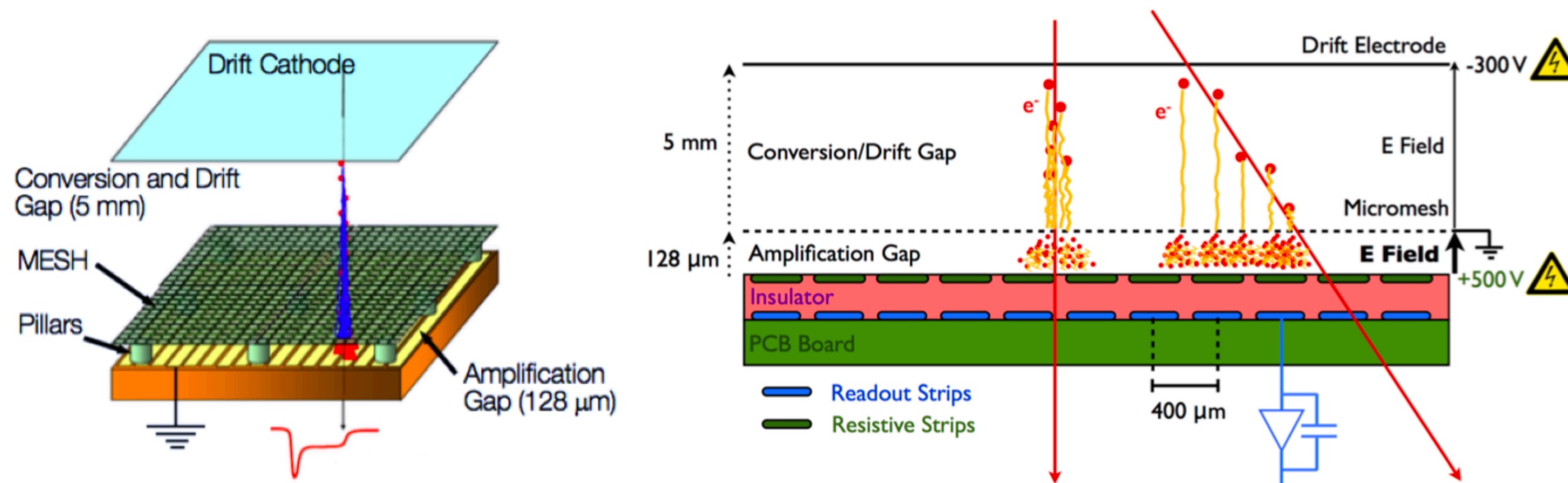
Each Sector is made of
2 MicroMegas Wedges
packed by 2 sTGCs



MicroMegas Wedges
are composed by
4 different Modules
(2 Small and 2 Large)
built in 5 different countries

MICROMEKAS DETECTOR

Layout:



New Small Wheel Requirements:

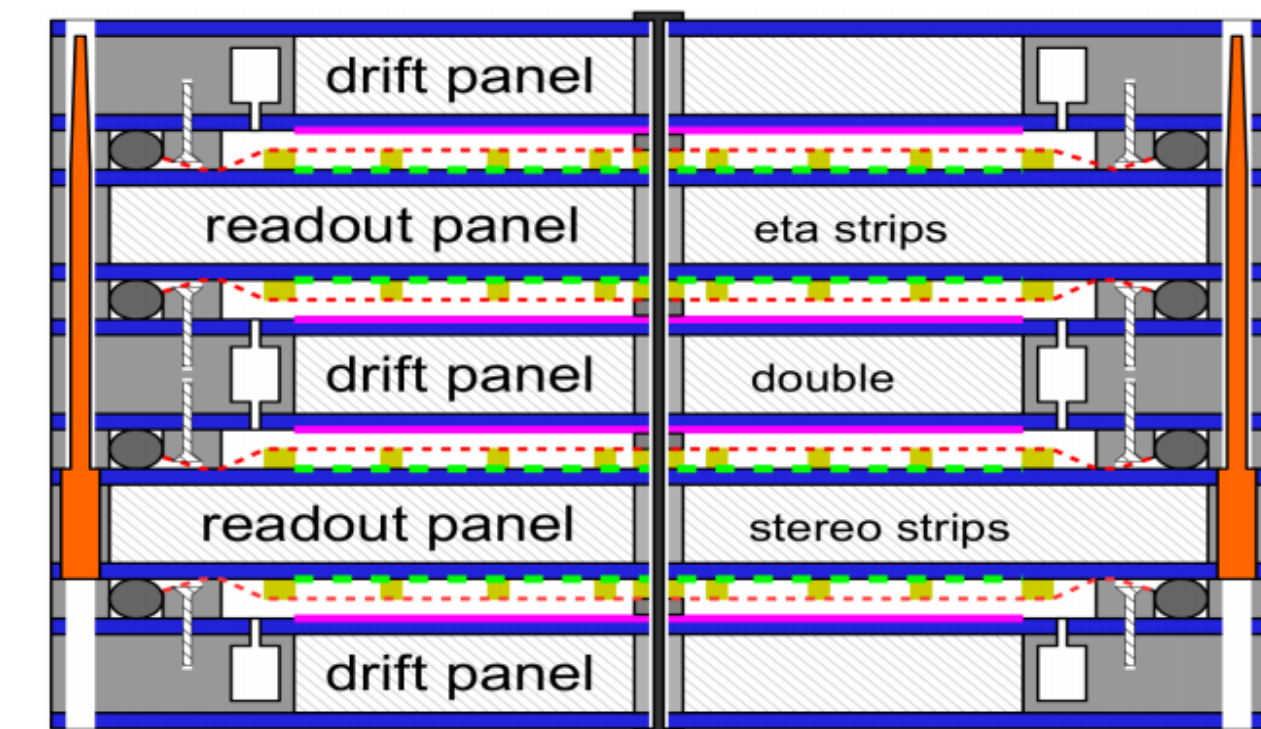
- ▶ Overall tracking efficiency $>97\%$ for $P_T > 10$ GeV
- ▶ 15% resolution at 1 TeV \rightarrow Spatial resolution of $\sim 100 \mu\text{m}$
- ▶ Rate capability above 15 kHz/cm^2
- ▶ Provide additional triggering information to sTGC detectors

Characteristics:

- ▶ Gas mixture 93% Ar and 7% CO_2
- ▶ Strip resistivity $\sim 10 \text{ M}\Omega/\text{cm}$
- ▶ 300 V drift amplification voltage and ~ 570 V avalanche amplification voltage
- ▶ 5 mm drift gap and $128 \mu\text{m}$ avalanche region
- ▶ 10^4 amplification
- ▶ 100 ns signal creation time

Micromegas Chambers (Quadruplets) Structure:

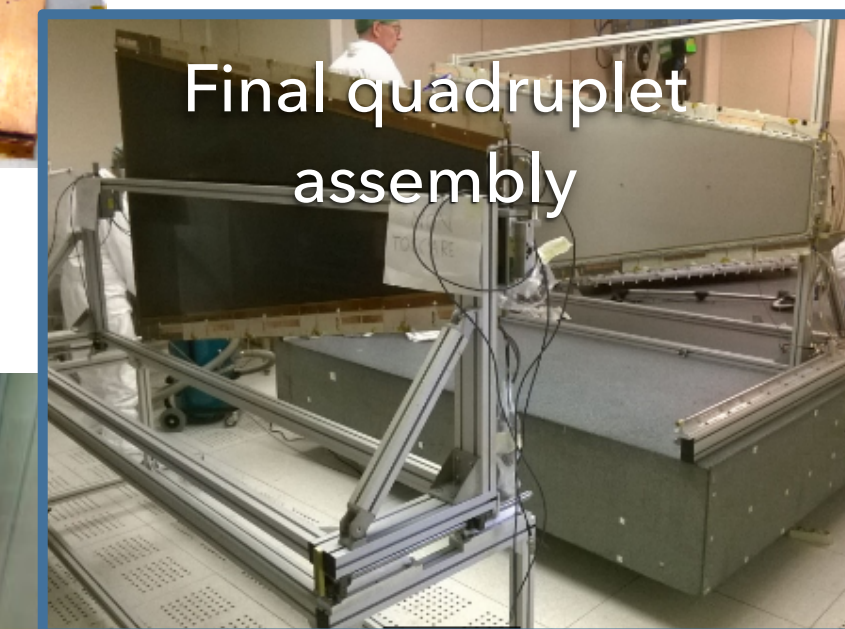
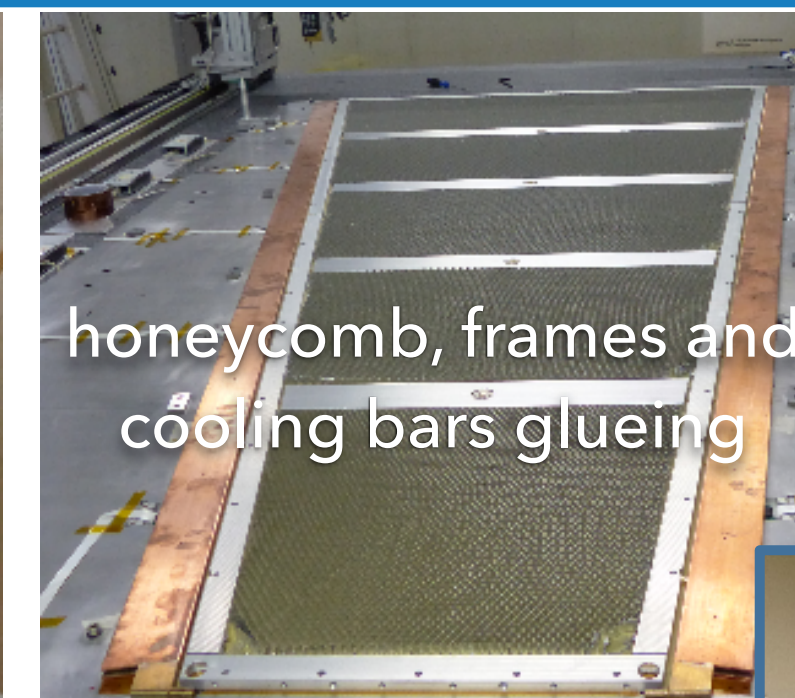
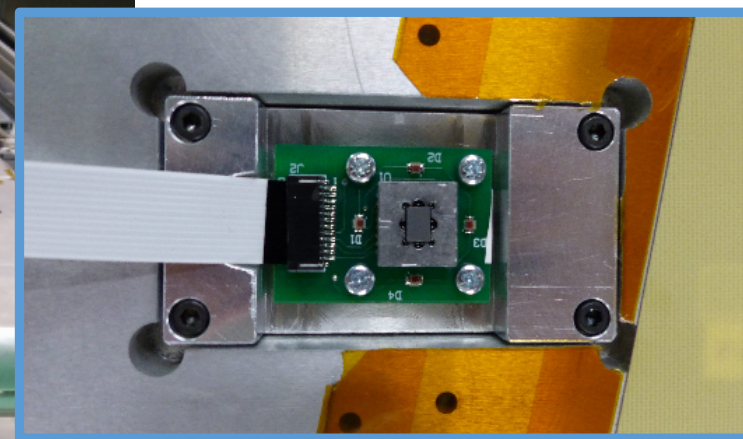
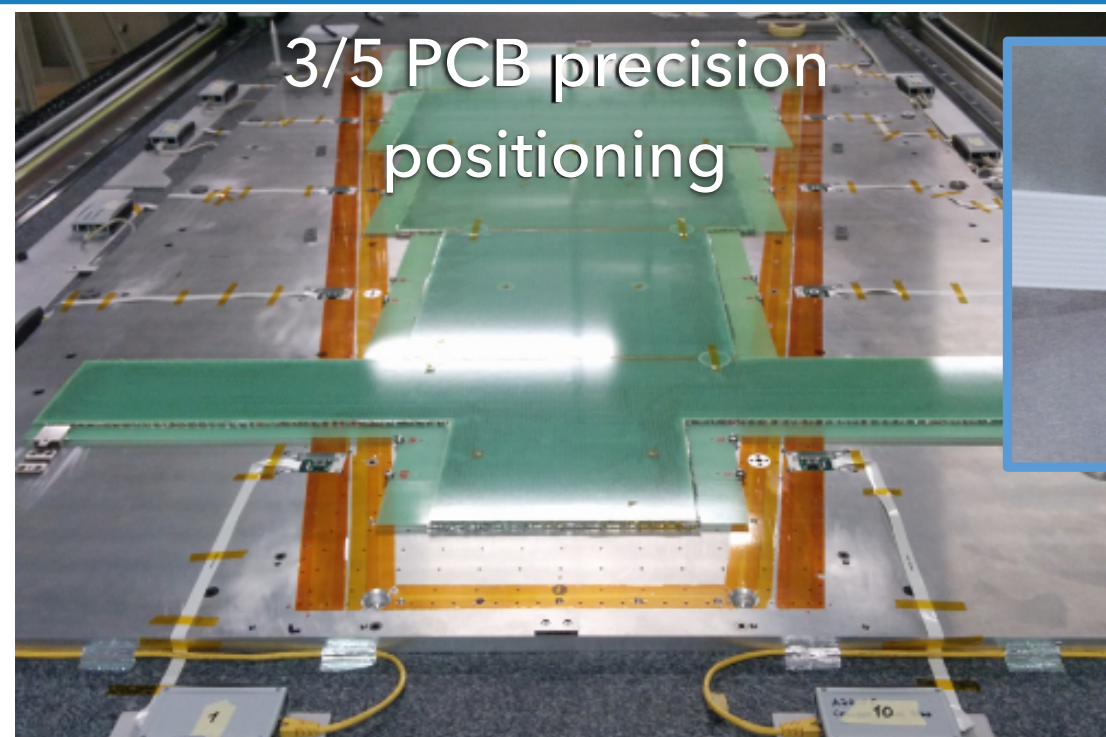
- ▶ 2 readout panels with double readout side (eta and stereo)
- ▶ 1 double drift panel (inner) with 2 meshes
- ▶ 2 single drift panels (outer) with 1 mesh each



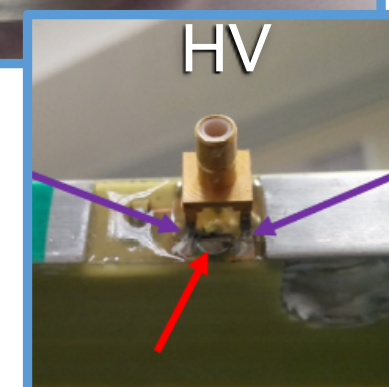
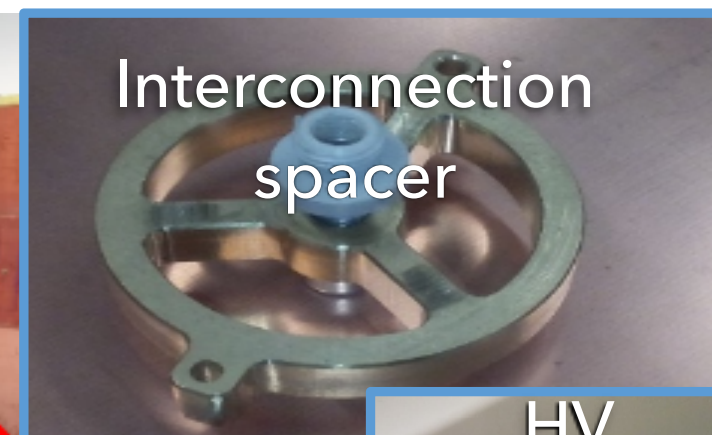
QUADRUPLETS CONSTRUCTION

More at ICHEP2020: Dimitris Fassouliotis's talk [[link](#)]

READOUT PANEL ASSEMBLY



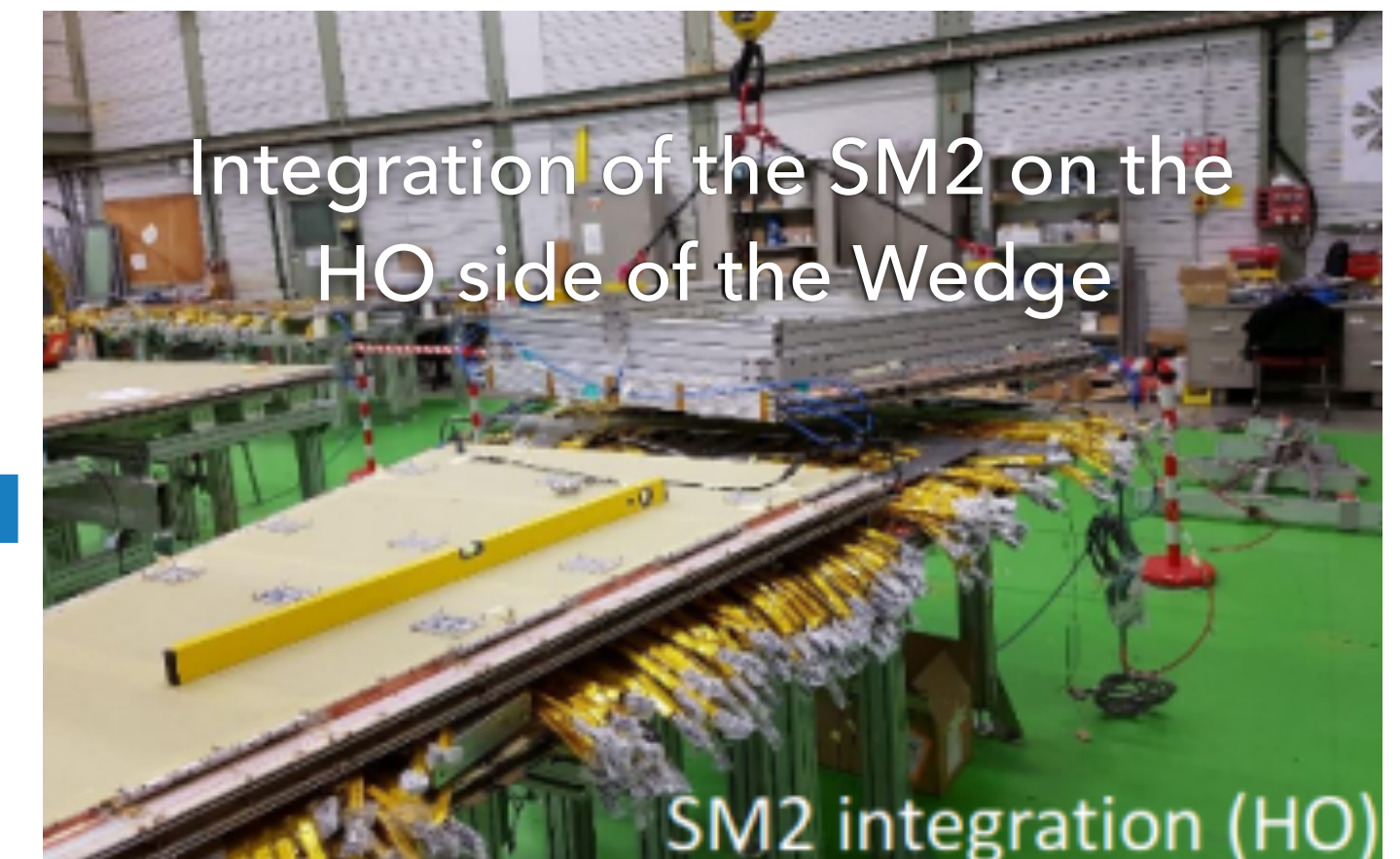
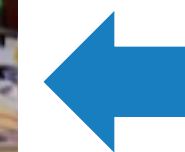
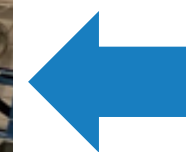
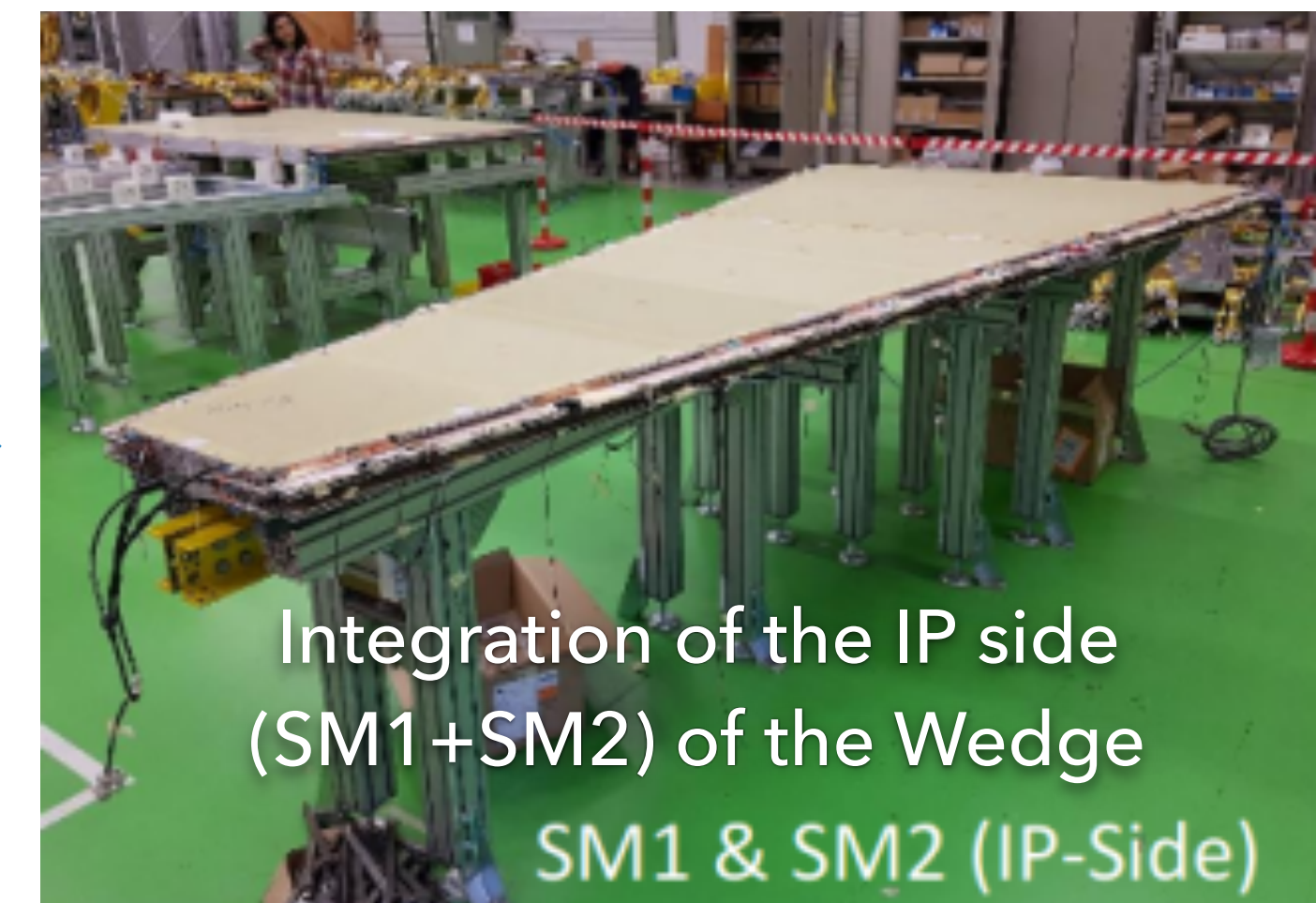
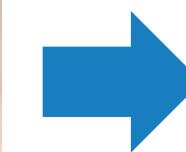
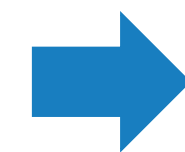
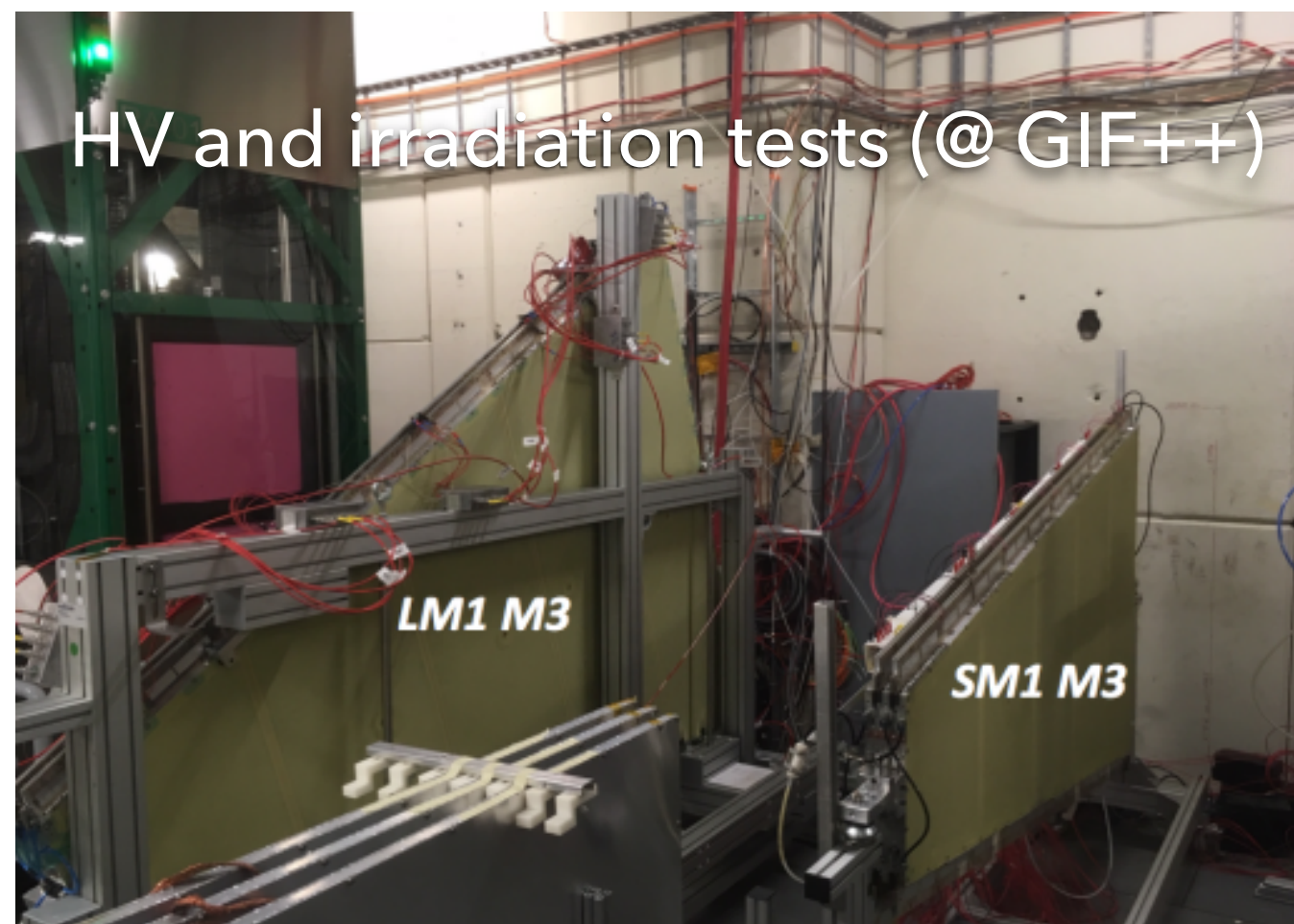
Sent to CERN for Integration



DRIFT PANEL AND MESH

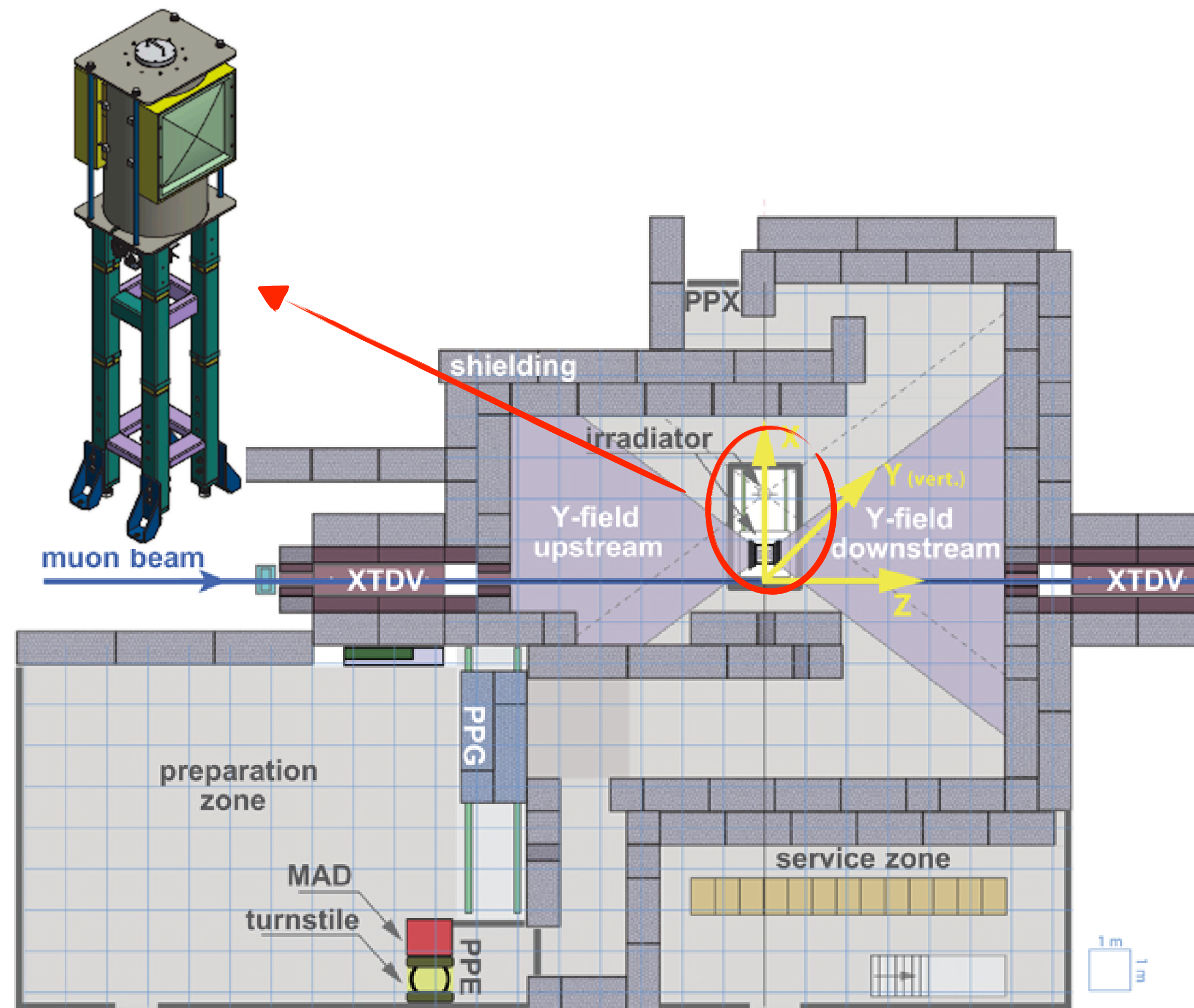
INTEGRATION WORKFLOW

More at ICHEP2020: Theodoros Vafeiadis's talk [\[link\]](#)



GAMMA RAY IRRADIATION FACILITY (GIF+++)

- ▶ A ~ 14 TBq ^{137}Cs source and a set of filters are used to module the intensity of the flux against the chambers
- ▶ The ^{137}Cs isotope provides a spectrum of 662 KeV photons in the GIF++ bunker
- ▶ The irradiator uses a set of lens-shaped filters to guarantee an almost constant photon field per planes
- ▶ Up to now, 70% of production chambers have been tested at GIF++

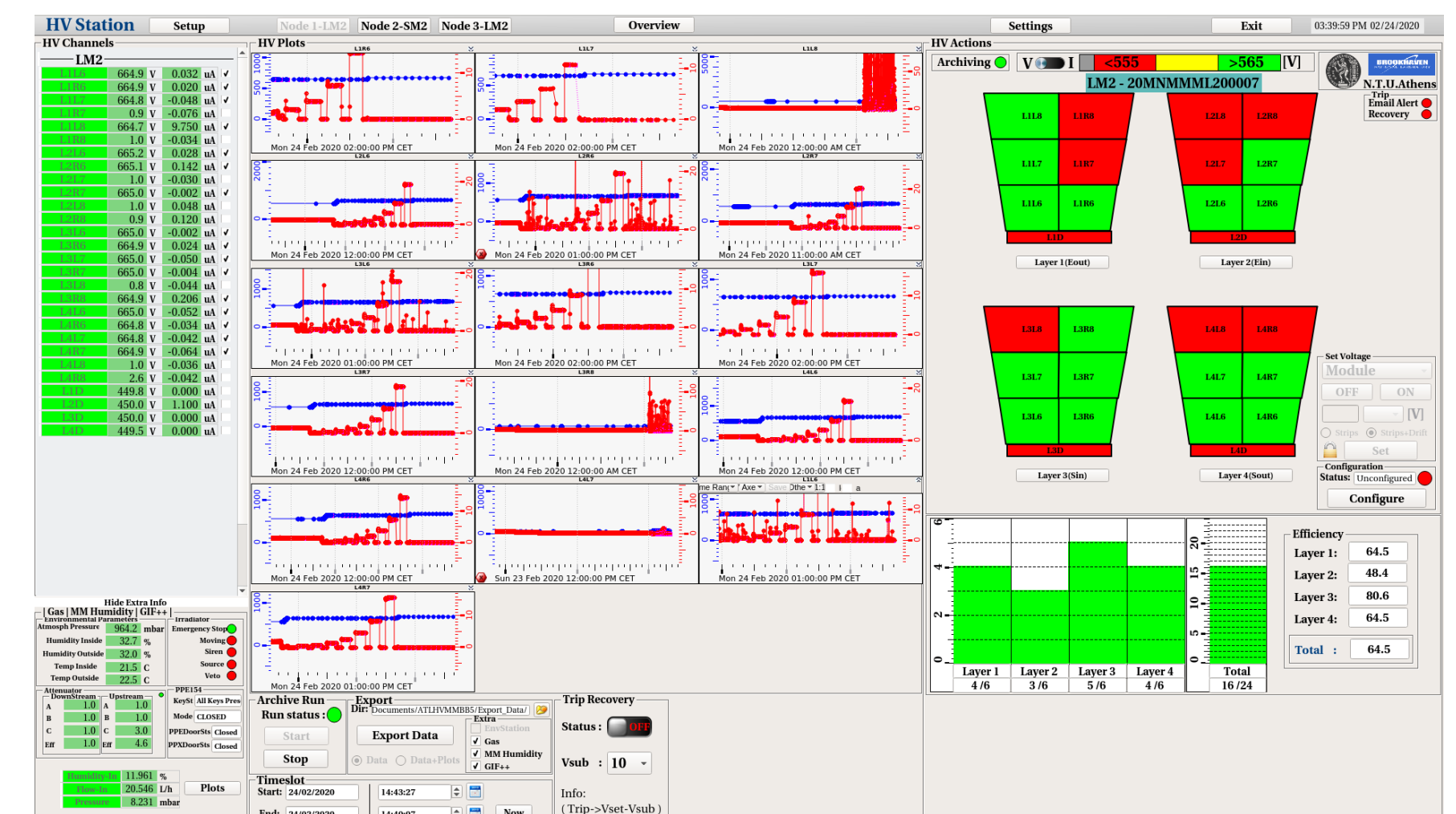


MICROMEKAS CHAMBERS IRRADIATION TESTING

- **Conditioning:** 24 hours needed to completely fill the chamber with new gas and bring relative humidity below 12%
- Each sector (40 sectors per type 1 modules and 24 sectors per type 2 modules) is independently powered and monitored
- The Micromegas chambers are controlled and monitored with a dedicated **Detector Control System**
- The current value at the amplification stage and spike rate are estimated at **4 different radiation levels**

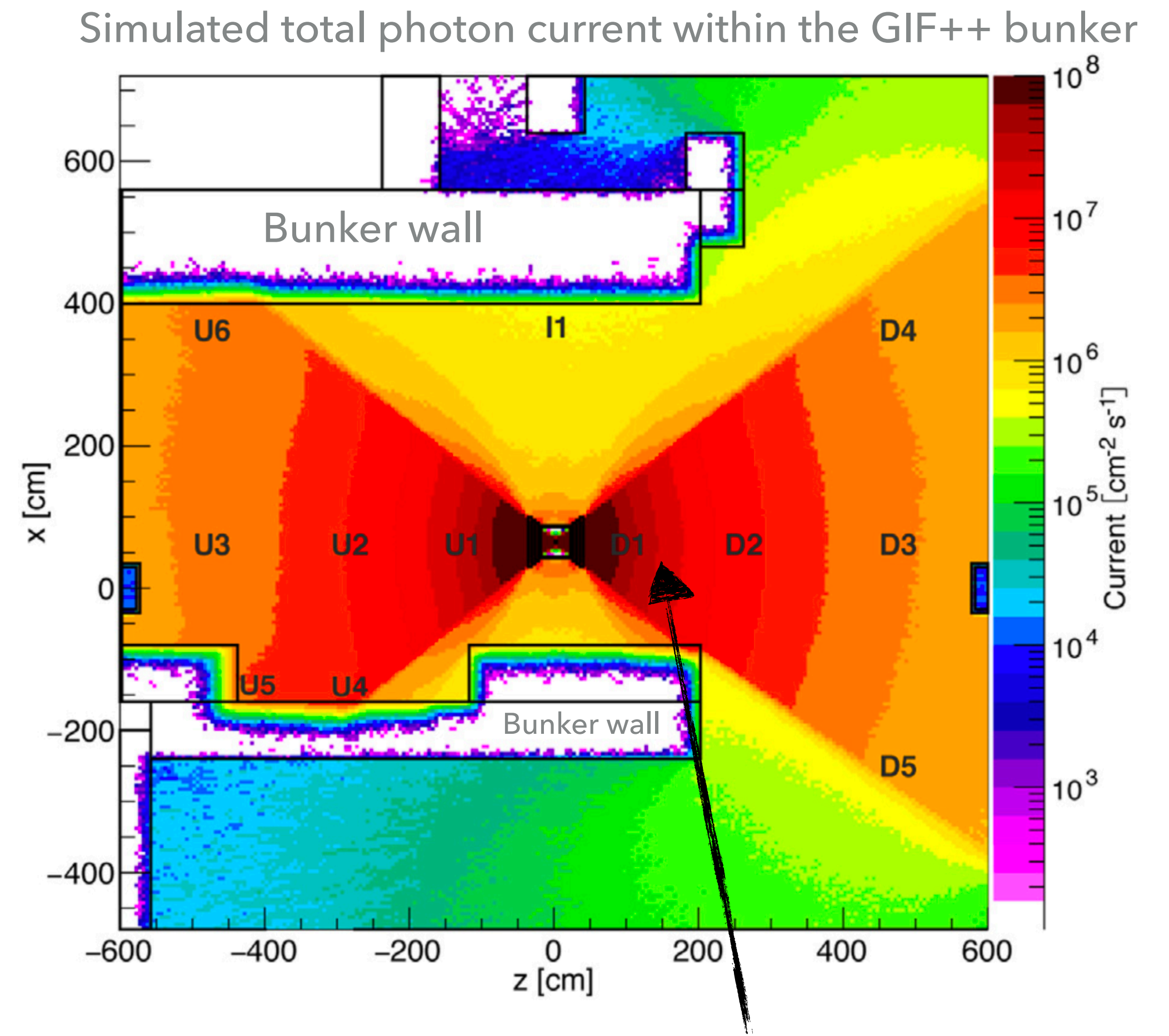


Need to know the actual photon flux!



GAMMA RAY IRRADIATION FACILITY (GIF++)

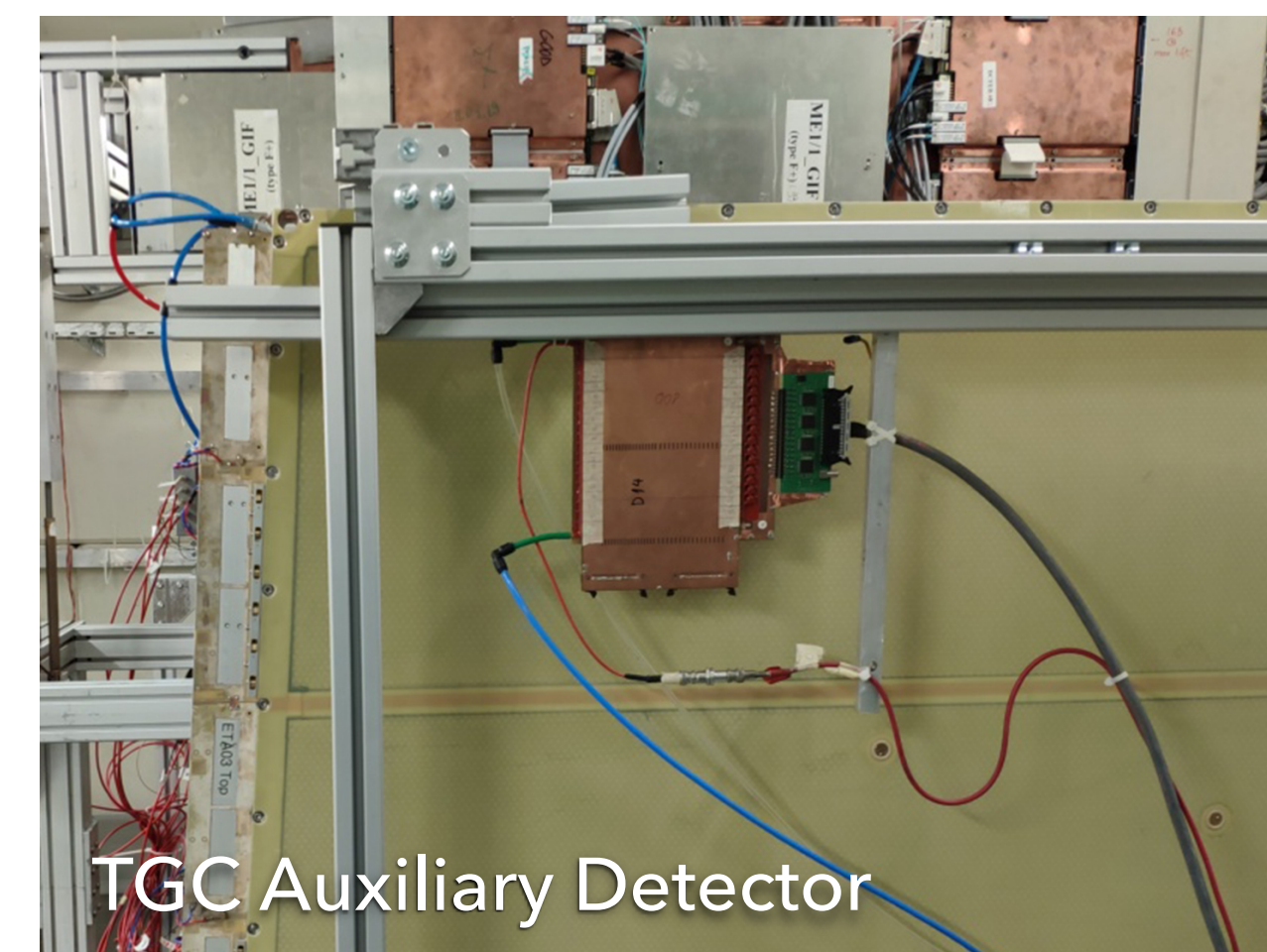
- ▶ A $\sim 14 \text{ TBq } ^{137}\text{Cs}$ source and a set of filters are used to modulate the intensity of the flux against the chambers
- ▶ The ^{137}Cs isotope provides a spectrum of 662 KeV photons in the GIF++ bunker
- ▶ The **irradiator** uses a set of lens-shaped filters to guarantee an almost constant photon field per planes
- ▶ Best knowledge of the **irradiation field** comes from detailed **simulations** [1]



We performed a rate measurement close to point D1 at $\sim 1.5 \text{ m}$ from the radiator walls

GAMMA RAY IRRADIATION FACILITY (GIF++)

- ▶ A $\sim 14 \text{ TBq } ^{137}\text{Cs}$ source and a set of filters are used to module the intensity of the flux against the chambers
- ▶ The ^{137}Cs isotope provides a spectrum of 662 KeV photons in the GIF++ bunker
- ▶ The **irradiator** uses a set of lens-shaped filters to guarantee an almost constant photon field per planes
- ▶ To estimate the photon flux an auxiliary **TGC chamber** has been placed close to a MM chamber



GAMMA RAY IRRADIATION FACILITY (GIF++)

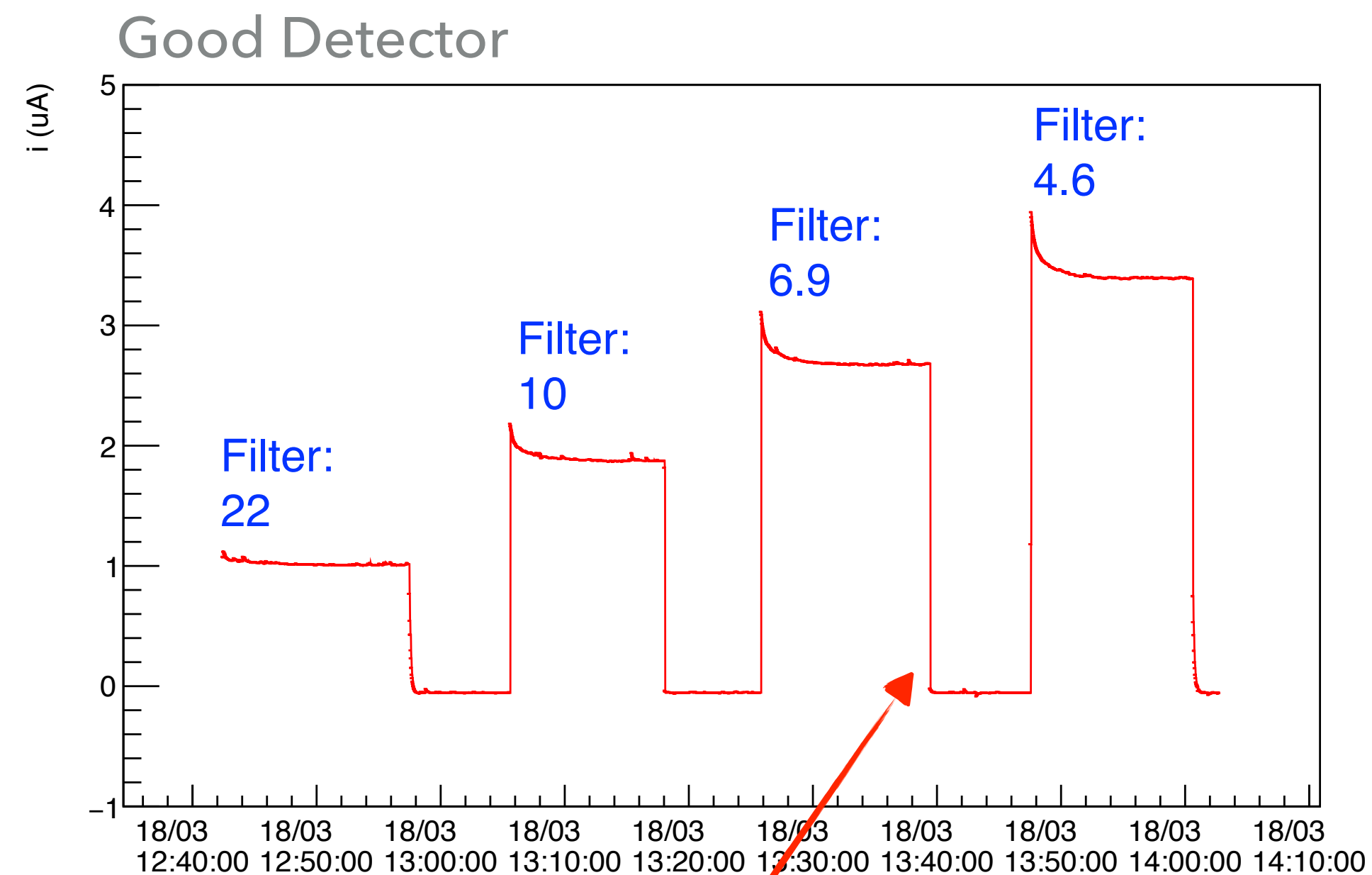
GIF++ rate measured at ~1.5 m from the radiator walls

Nominal att.	Rate (TGC) kHz/cm ⁻²	Charge per e ⁻ pC	Error pC	Rate (MM) kHz/cm ⁻²	Error kHz/cm ⁻²
1.0	16.8	9.2	± 0.1	37.6	± 9.5
2.2	8.9	8.4	± 0.1	19.6	± 5.0
4.6	4.6	8.1	± 0.2	10.2	± 2.6
6.8	3.5	7.9	± 0.3	7.7	± 2.6
10.0	2.4	8.1	± 0.7	5.3	± 1.3
21.5	1.2	8.1	± 0.7	2.7	± 0.7
46.0	0.6	8.1	± 1.5	1.3	± 0.3
68.0	0.5	7.9	± 2.0	1.1	± 0.3
100.0	0.3	5.8	± 2.9	0.7	± 0.2

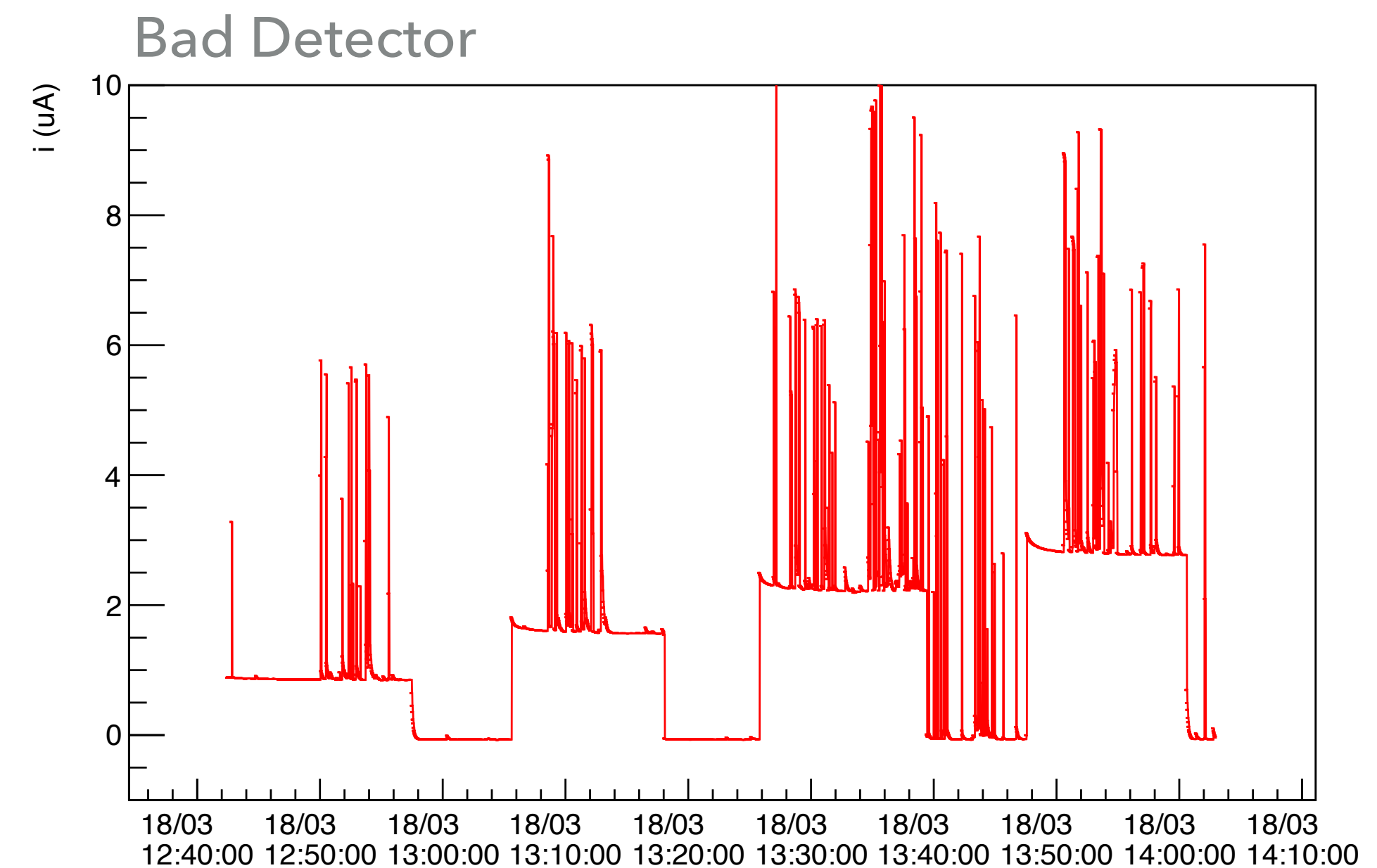
- By taking into account a TGC sensitivity of 0.217% at filter 1, we estimate a photon flux of $7.7 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$, in good agreement with GIF++ simulations
- At GIF++ we reach effective radiation fields up to a factor 2.5 higher than the one foreseen at the High-Lumi operation stage

MICROMEKAS CHAMBERS IRRADIATION TESTING

- ▶ We estimate the spike rate for each HV channel of the chamber with and without radiation
- ▶ In case of severe spiking, the HV of the avalanche region is lowered

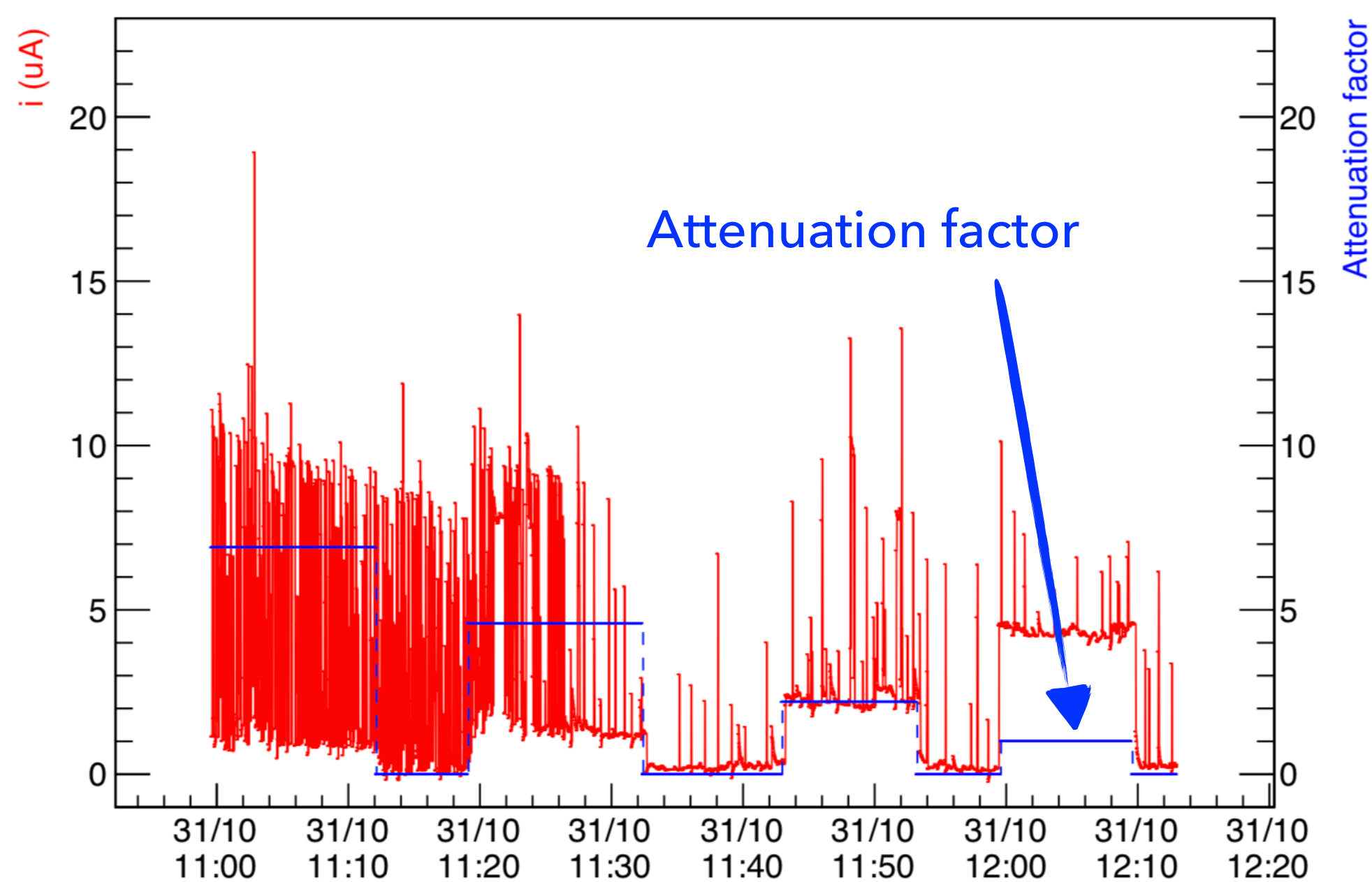


Current at the amplification stage

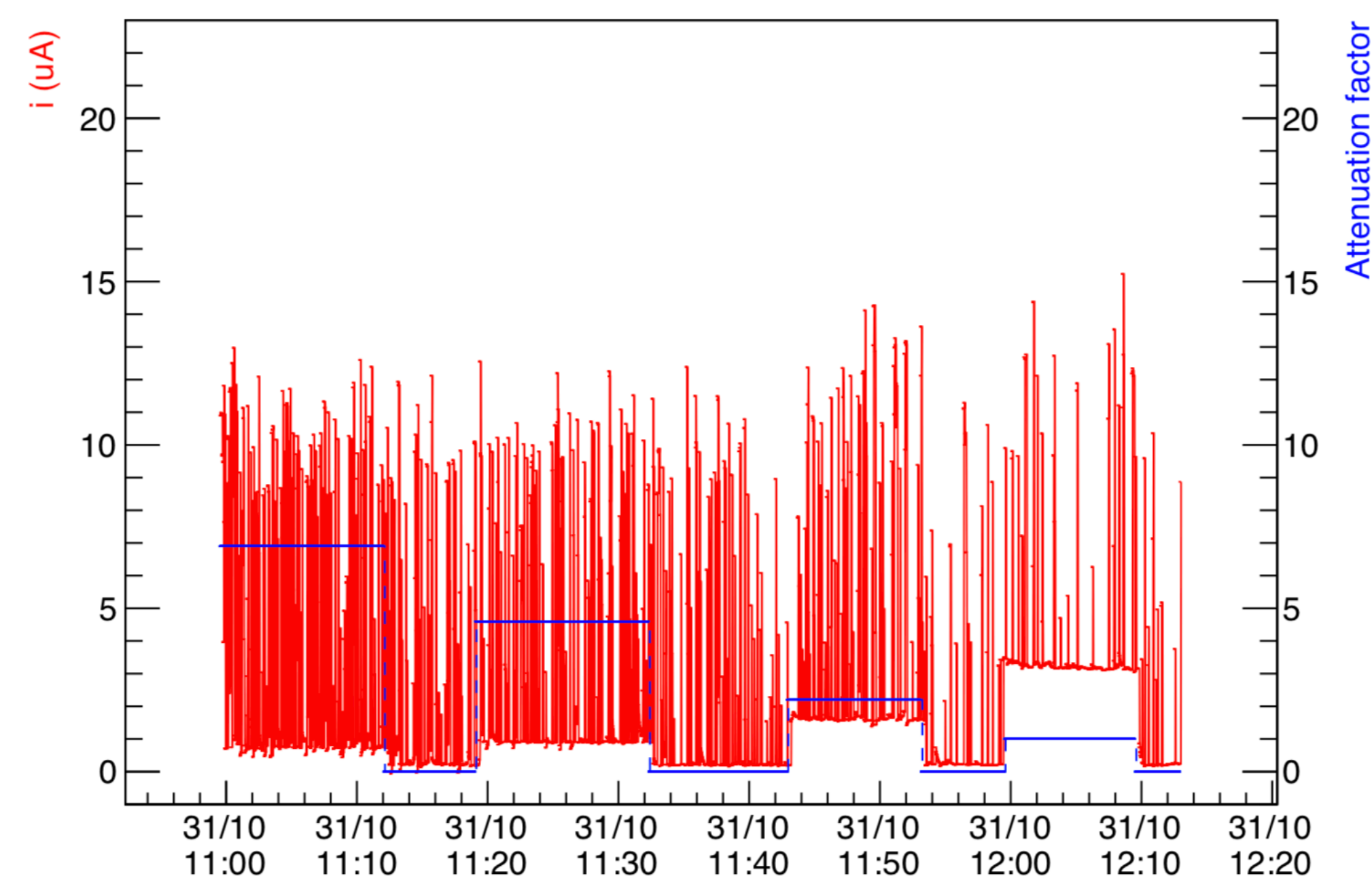


MICROMEKAS CHAMBERS IRRADIATION TESTING

- ▶ Several sectors with spiking issues found during the first half of 2019
- ▶ Defects in design? Not perfect cleaning? Mesh stretching? Relative humidity correlation? Readout panel correlation?



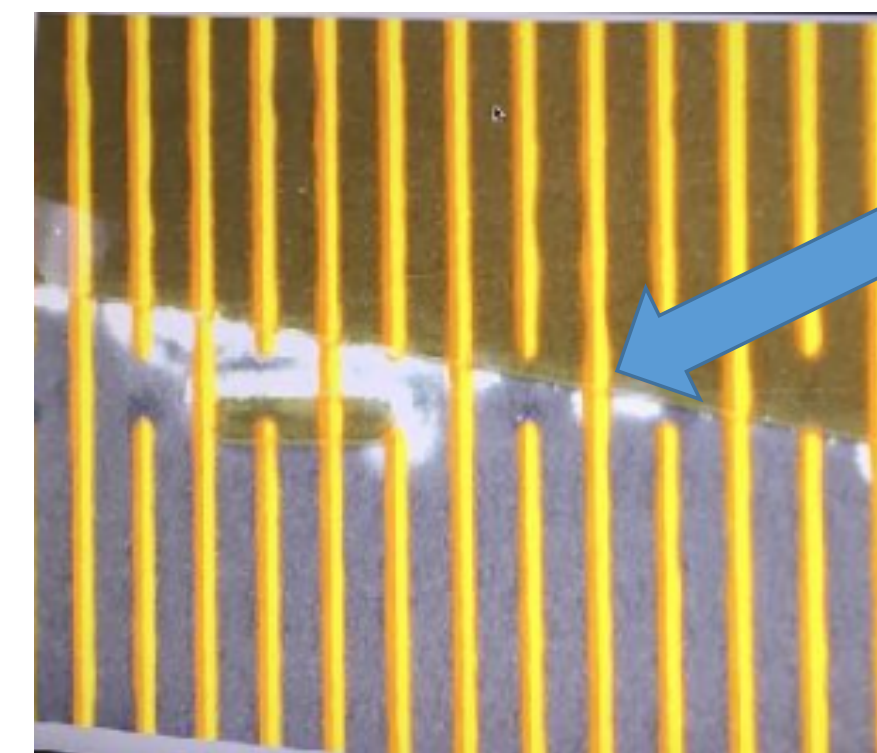
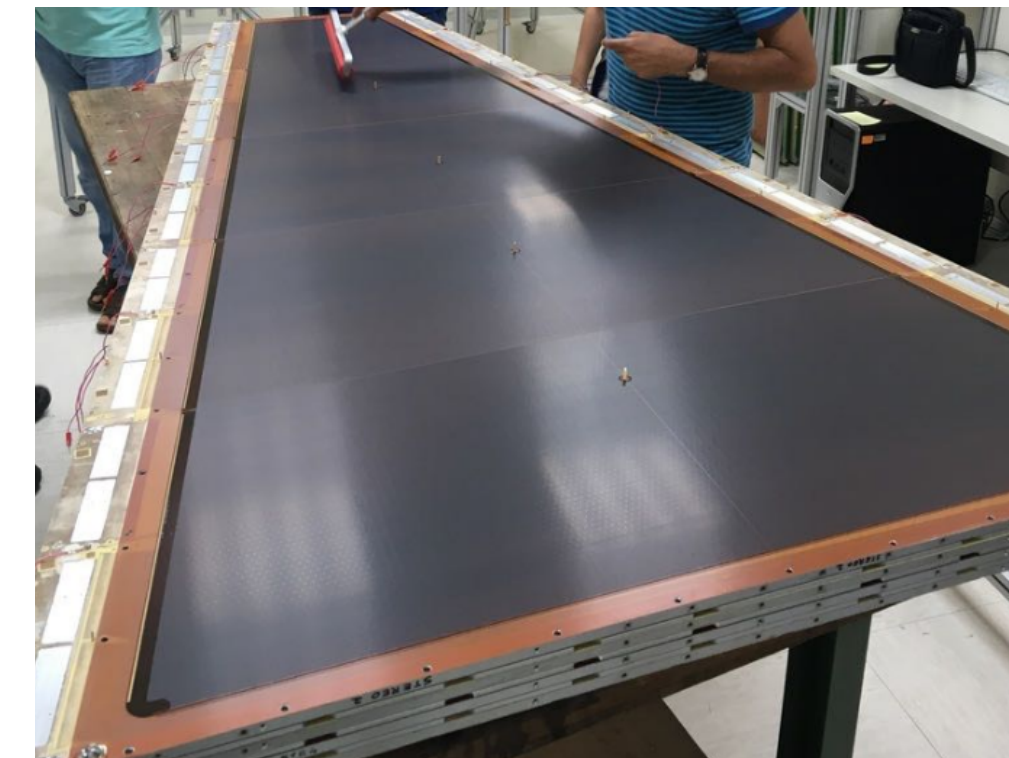
Current at the amplification stage



Example: LM1 M8 PCB 5 layer 3 at GIF++

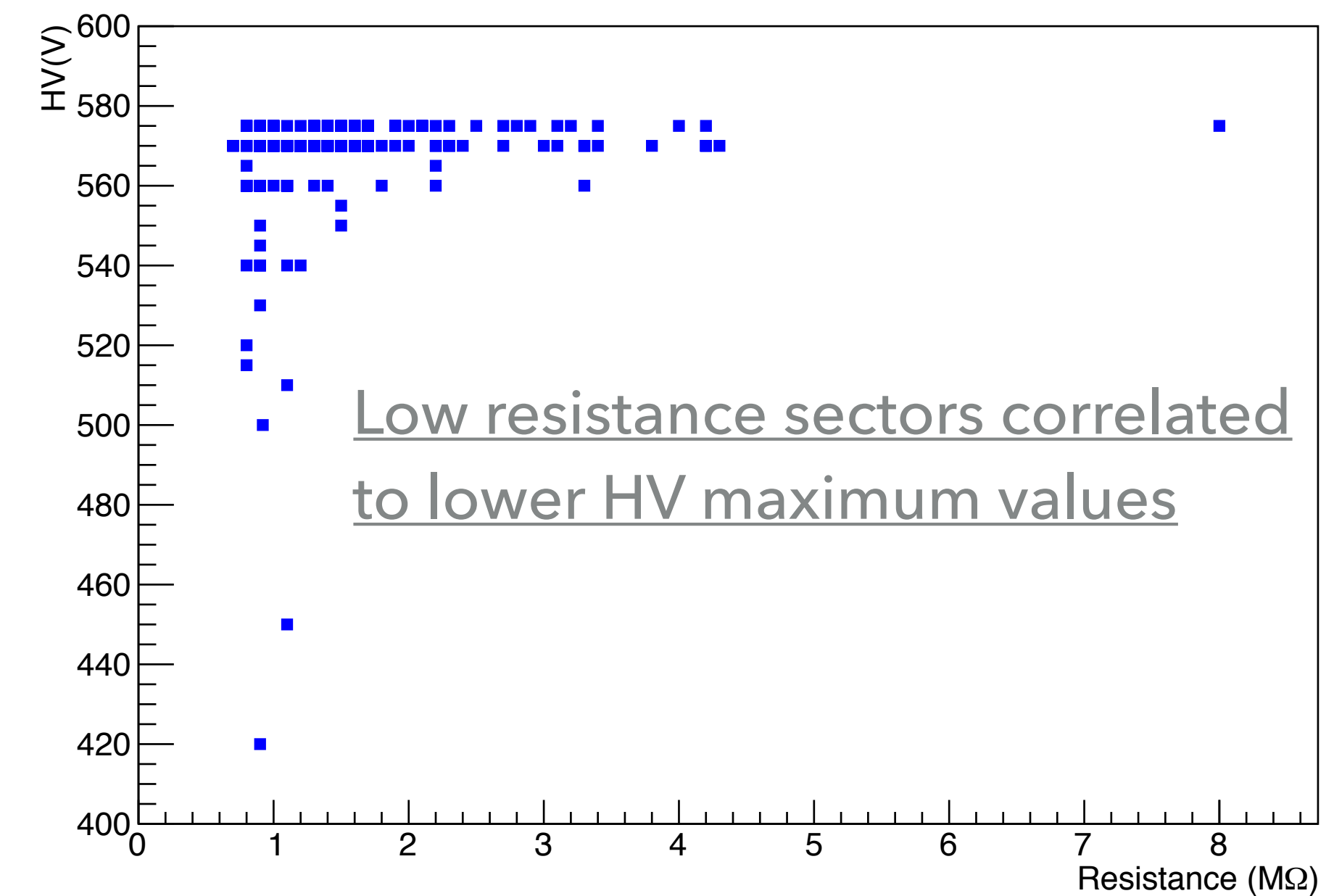
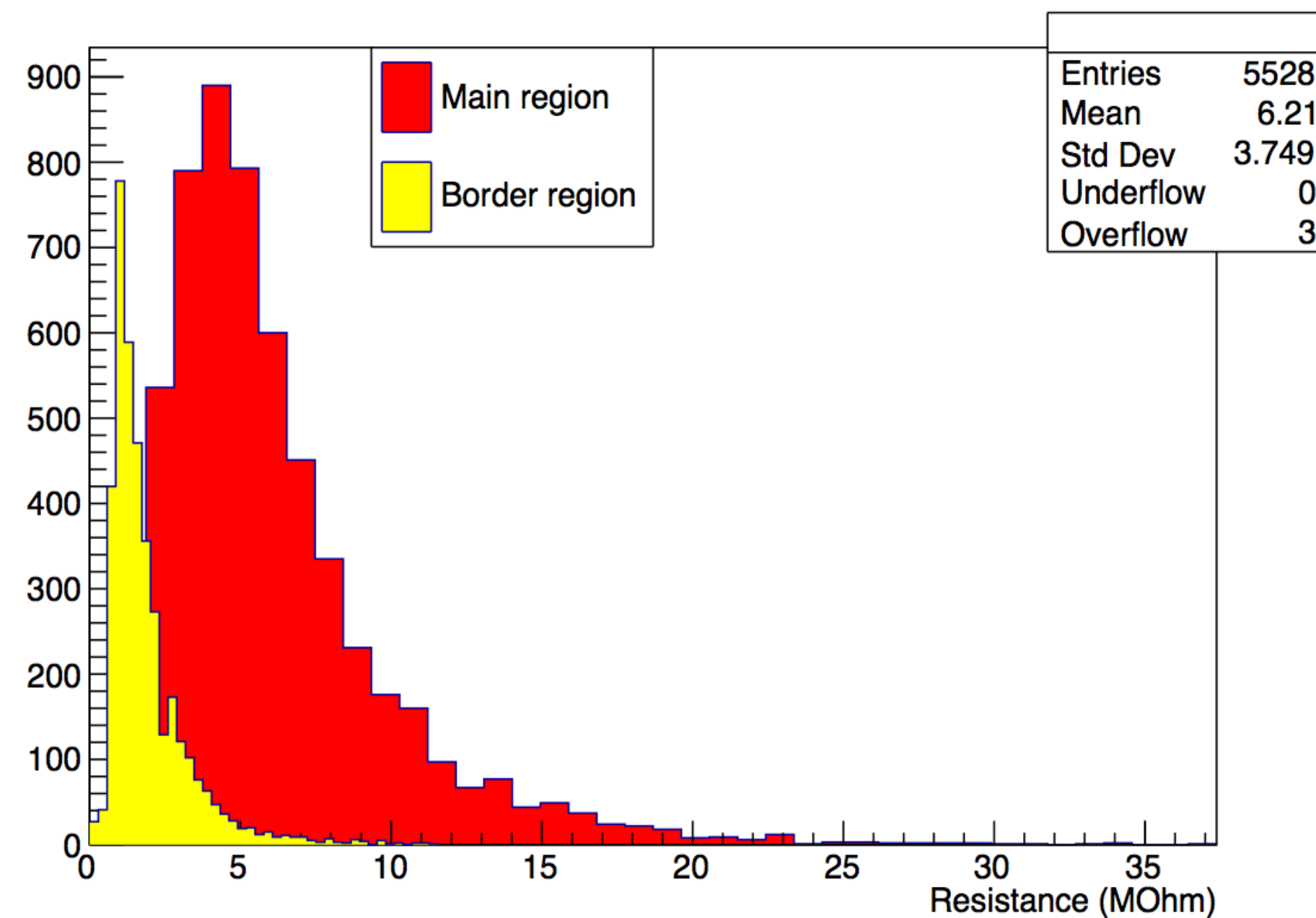
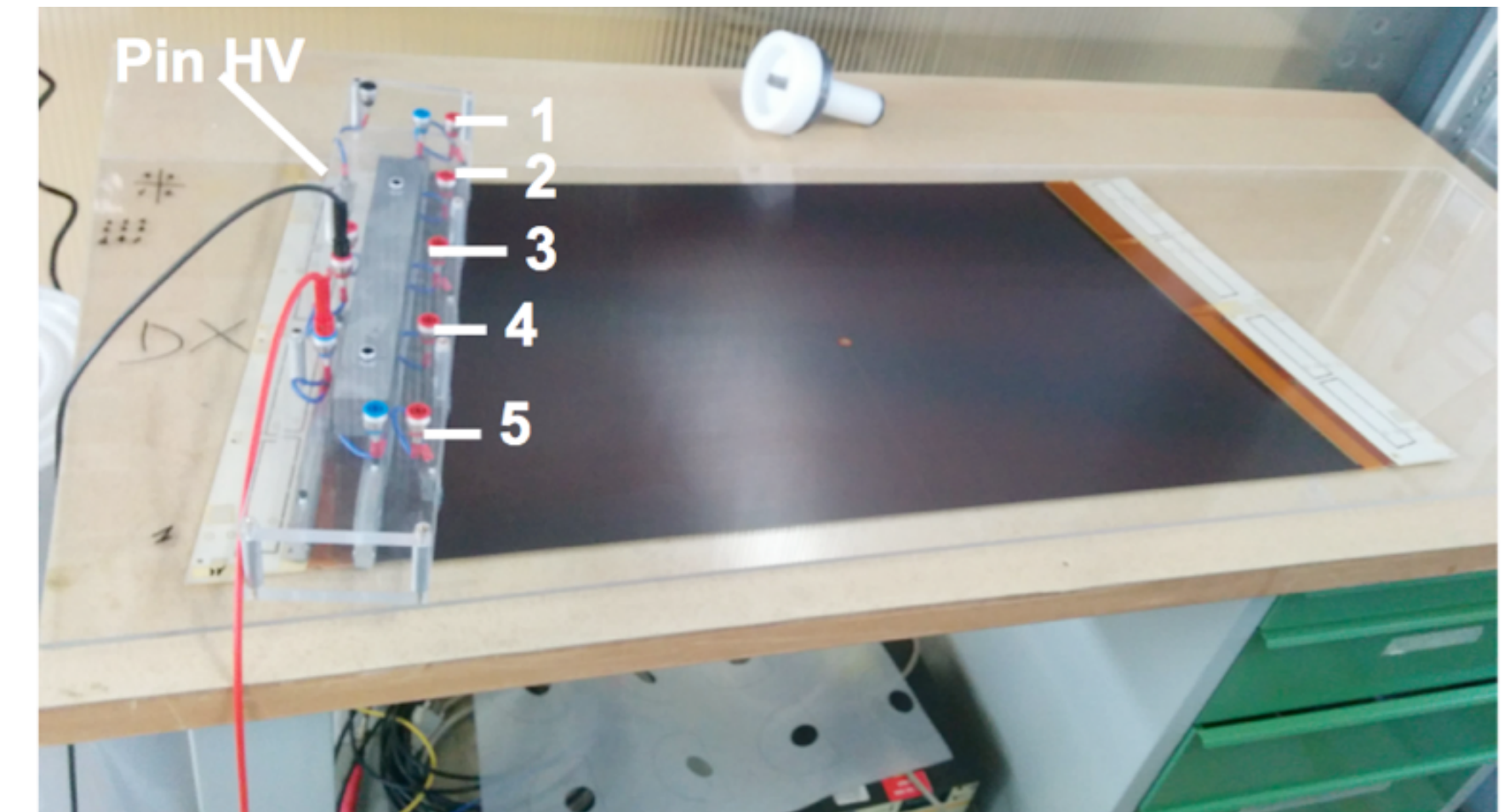
MICROMEKAS READOUT PANELS ELECTRICAL TESTS

- ▶ The first hint on the HV instability source came from an SM1 type chamber after two months of irradiation at GIF++
- ▶ Chamber went back to Frascati, where it was opened to inspect the effect of a long term irradiation
- ▶ **Strong signs of discharges close to the HV distribution line** and interconnections were found. This triggered the investigations on the resistivity of resistive strips close to the HV line distribution



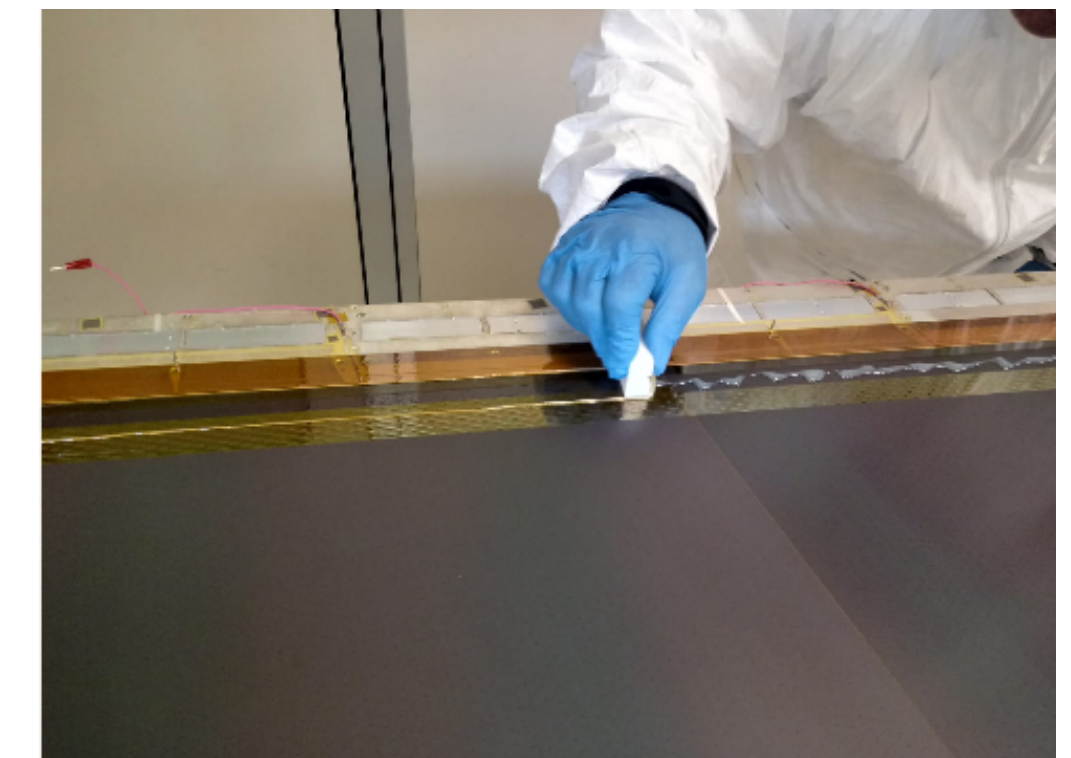
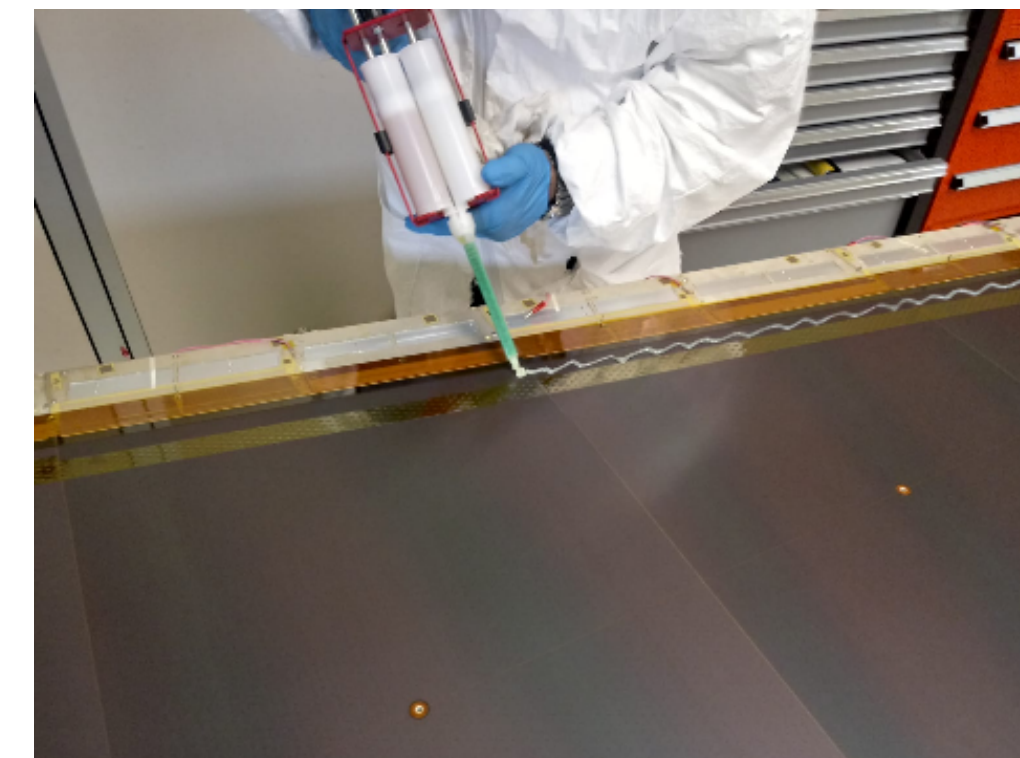
MICROMEAS READOUT PANELS ELECTRICAL TESTS

- ▶ Resistive strips resistance measured with a 1x1 cm² probe
- ▶ **Red:** PCB main region
- ▶ **Yellow:** at 1 cm from the HV line: several values below 1 MΩ

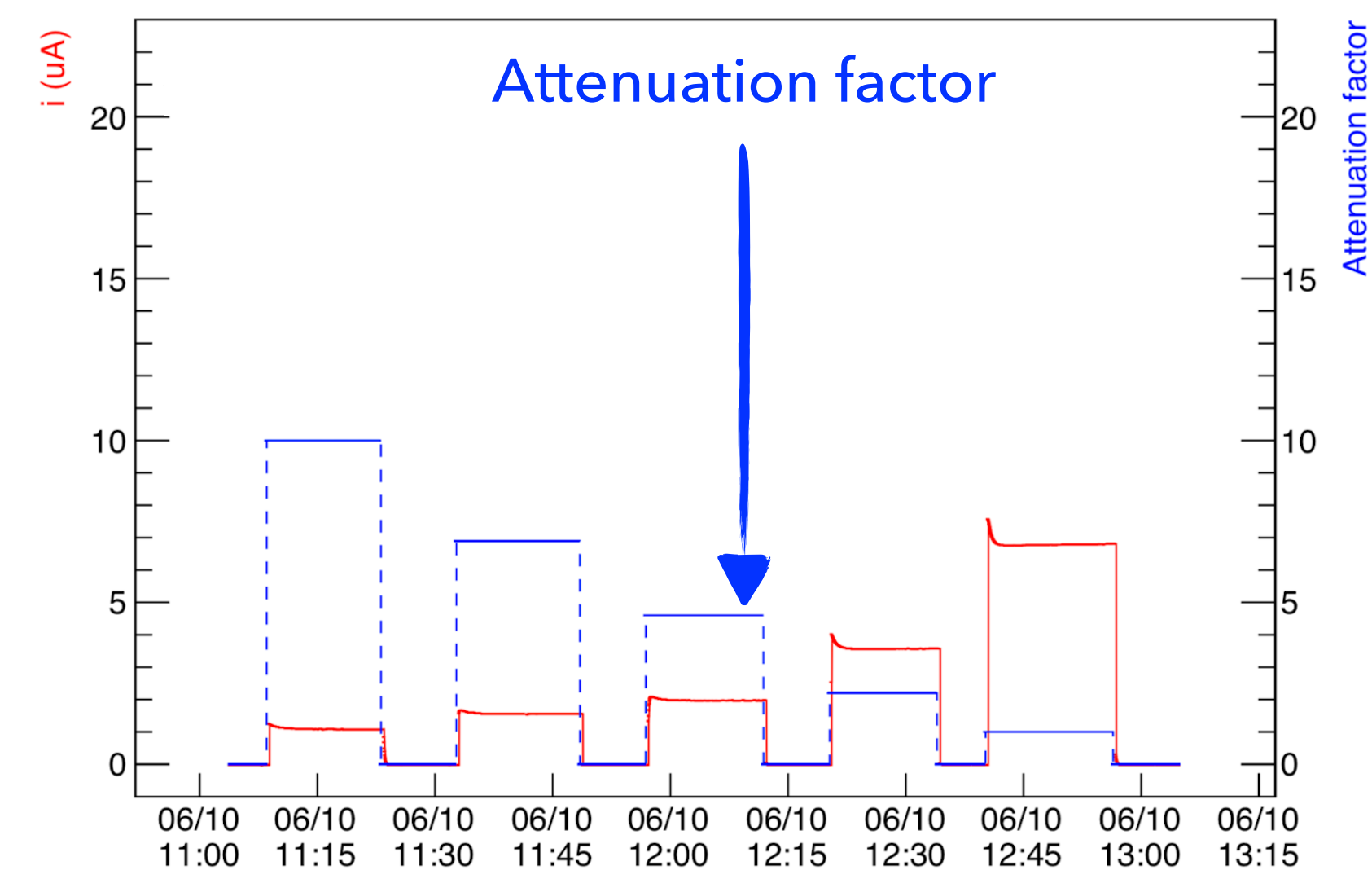
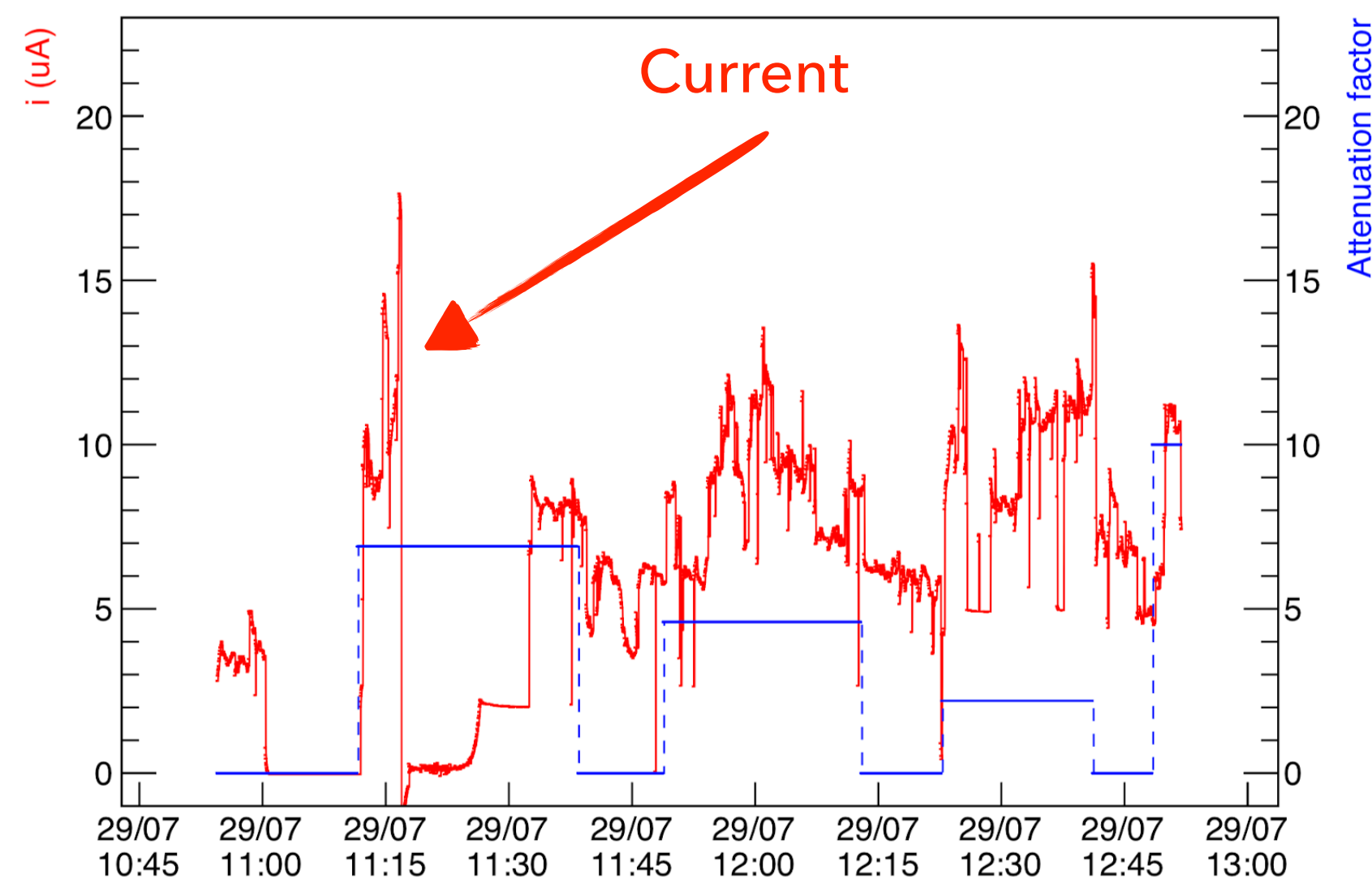


PASSIVATION

- Passivation is applied to the strip borders using a thin Araldite film. The passivated area is defined by a kapton tape barrier. Width of the passivated area is chosen in order to reach $R \sim 0.8 \text{ M}\Omega$

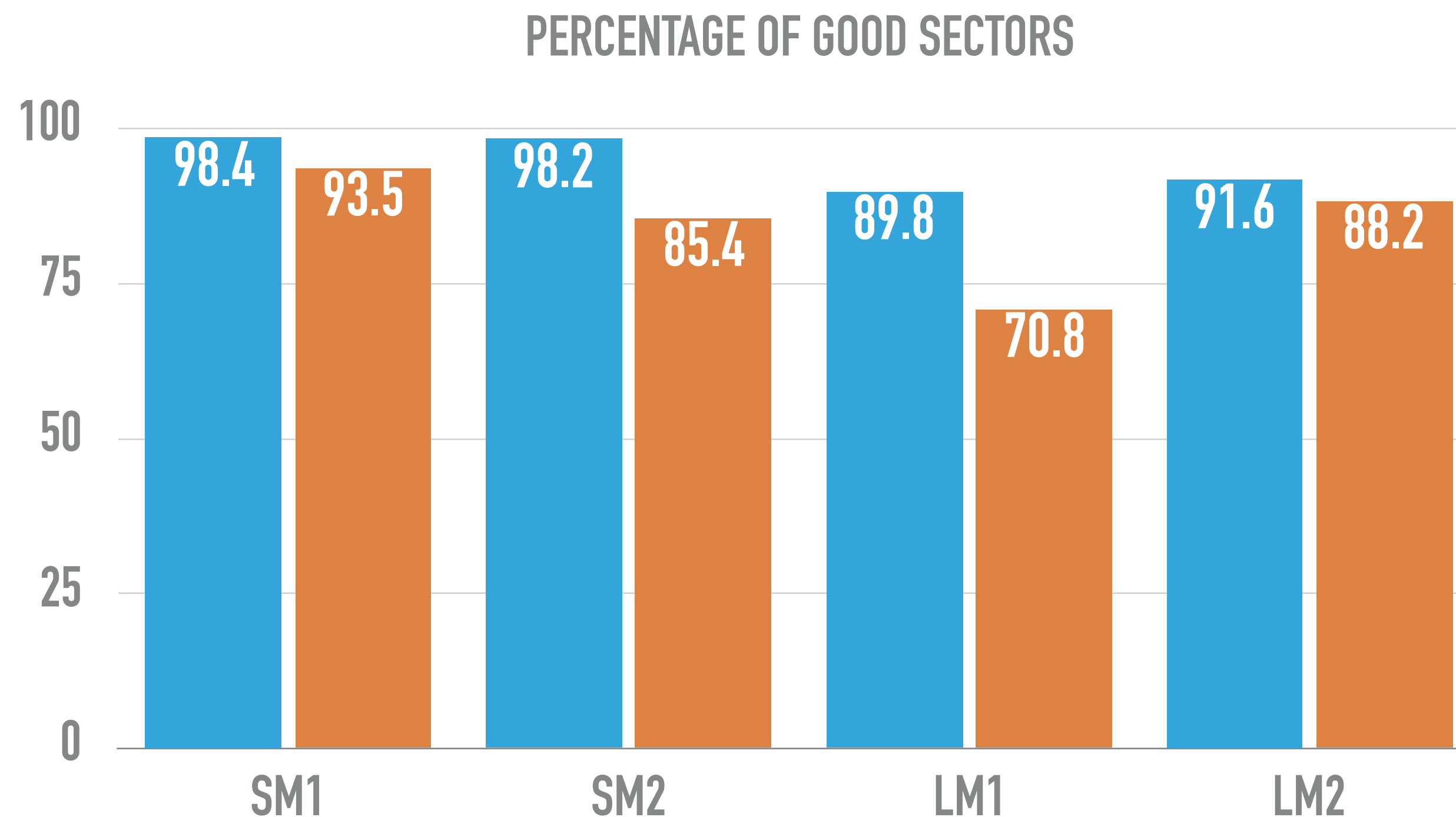
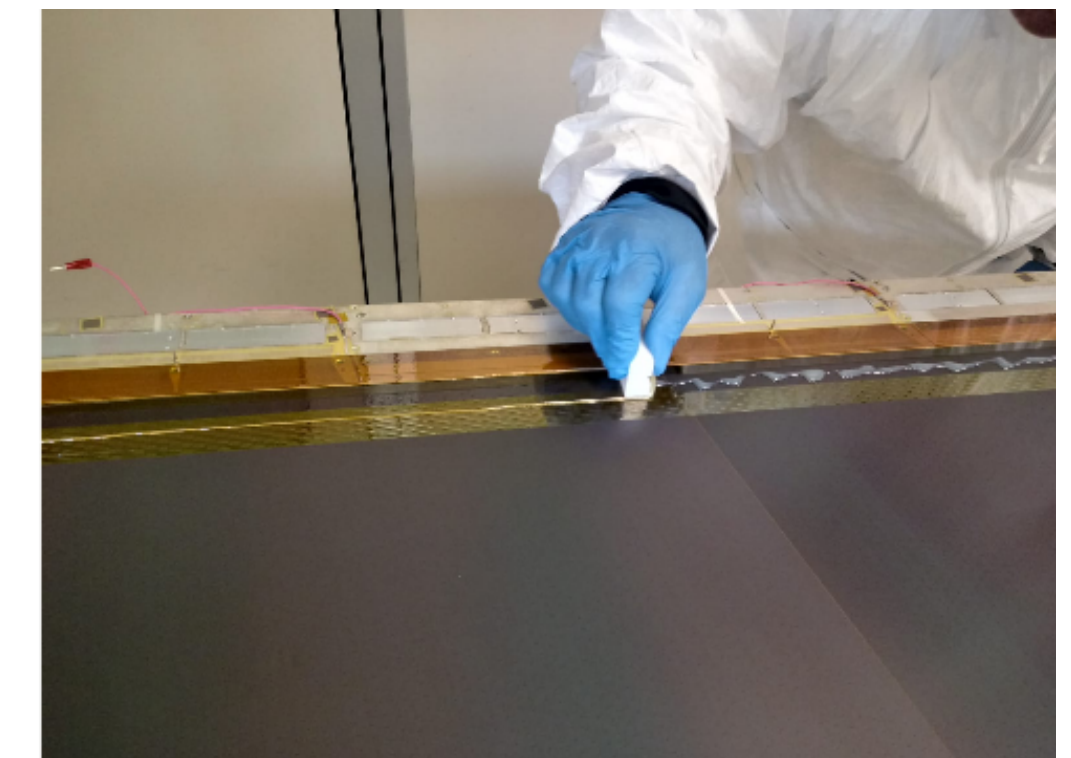
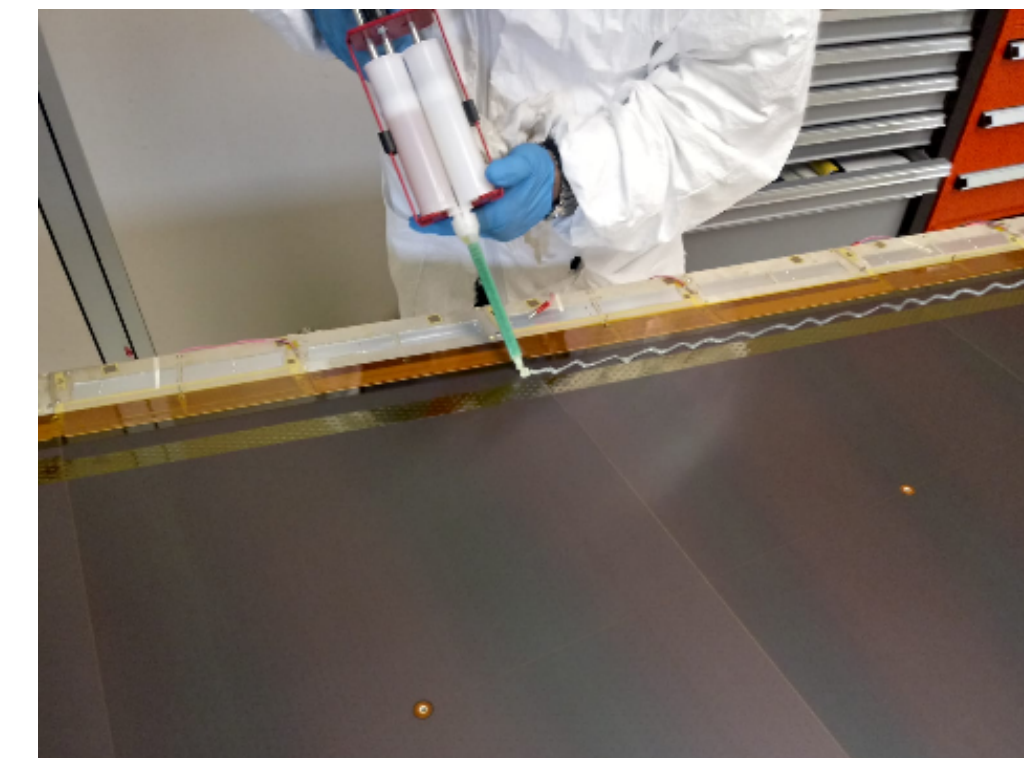


Example: SM2 type chamber not passivated vs. passivated



PASSIVATION

- Passivation is applied to the strip borders using a thin Araldite film. The passivated area is defined by a kapton tape barrier. Width of the passivated area is chosen in order to reach $R \sim 0.8 \text{ M}\Omega$



Passivated
Non Passivated

Fraction of good sectors per module type

A "good" sector has $HV > 565 \text{ V}$ and spike rate $< 6 \text{ spikes/min}$

Statistics over all chambers at present integrated on NSW Side A

GAS MIXTURES

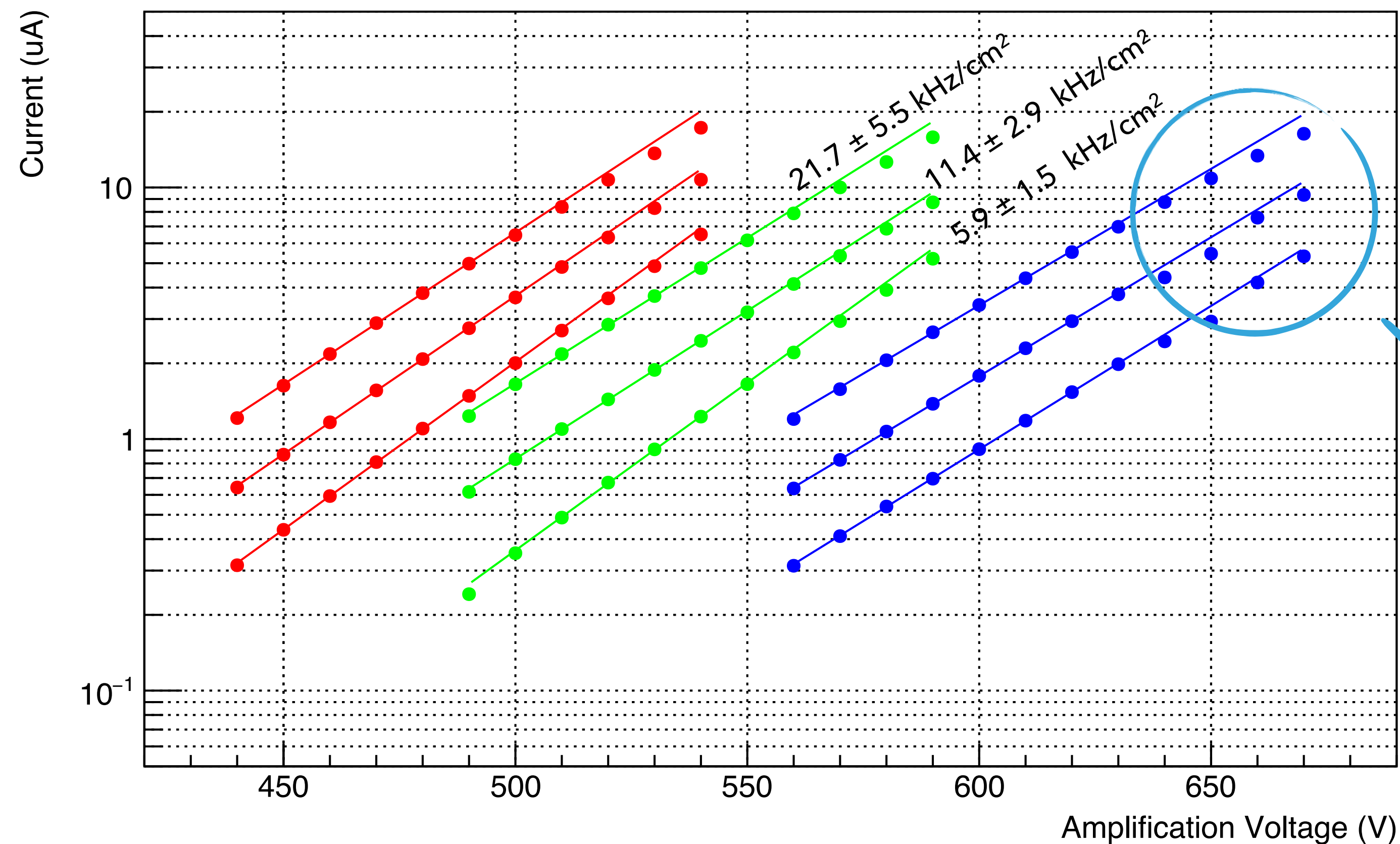
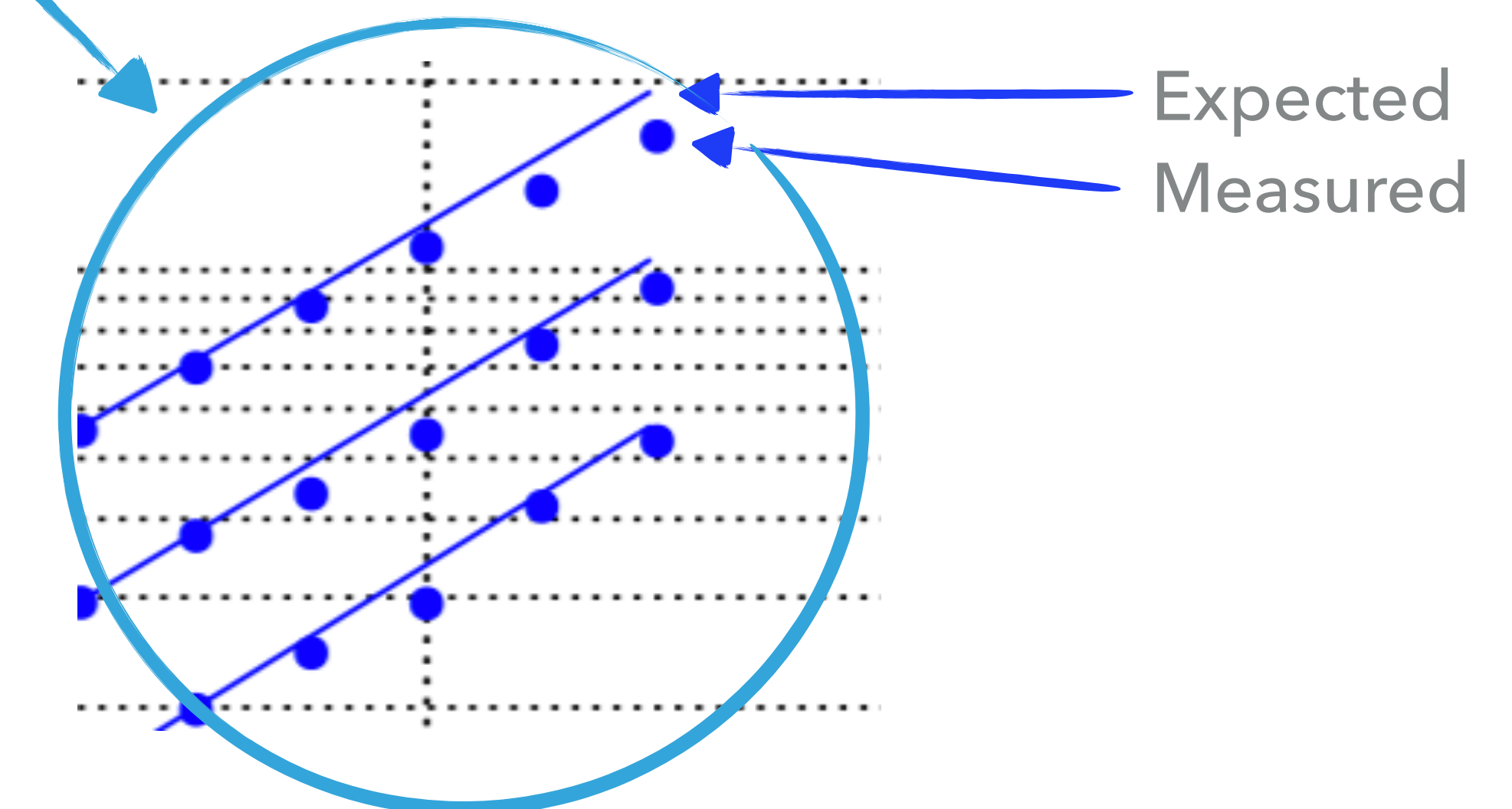
Example: LM2 type chamber at GIF++

New gas mixtures are under study at GIF++ to further reduce the HV issues (standard **Ar/CO₂ 93%/7%**):

- ▶ **Ar/CO₂ 80%/20%**
- ▶ **Ar/CO₂/C₄H₁₀ 93%/5%/2%**

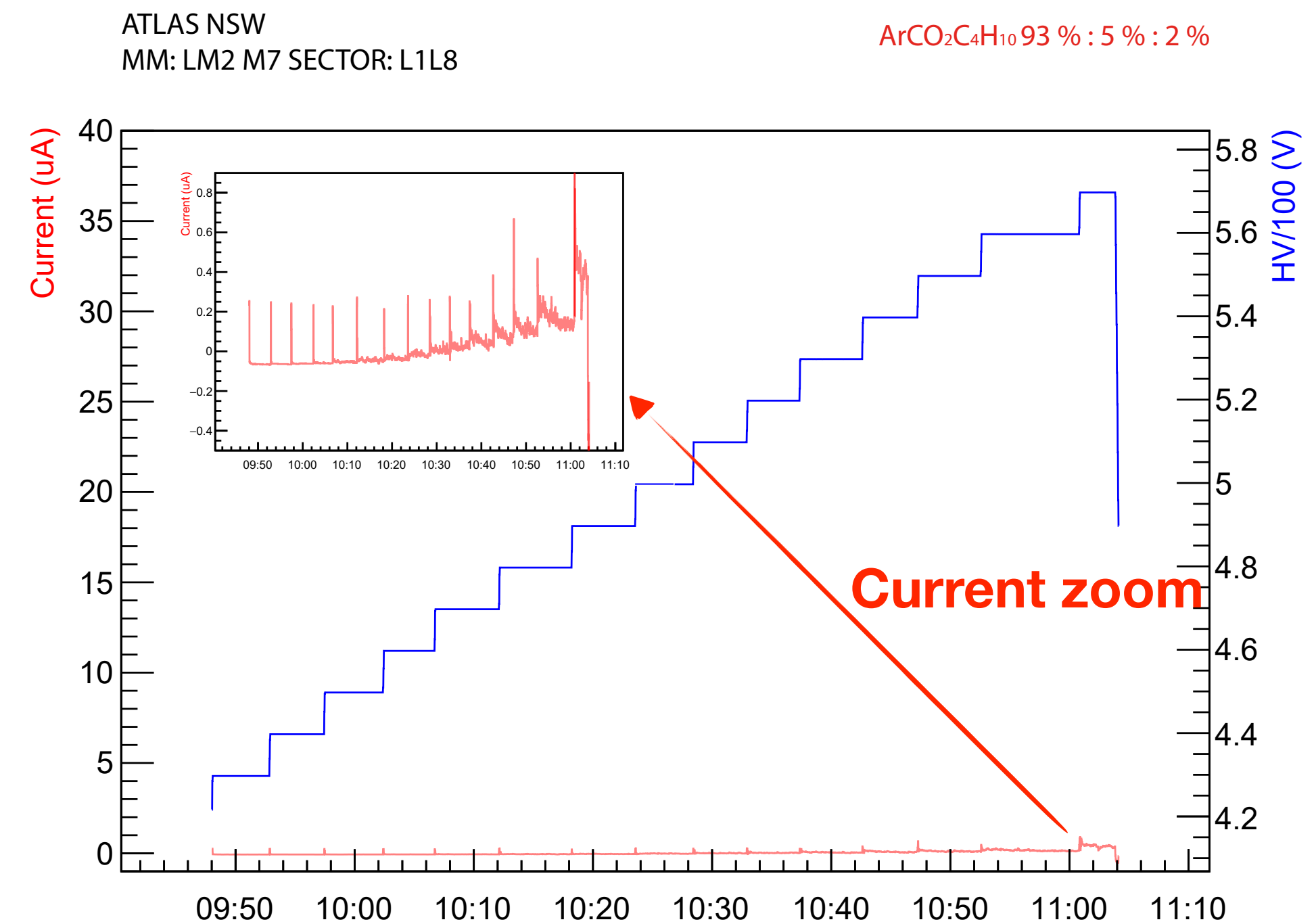
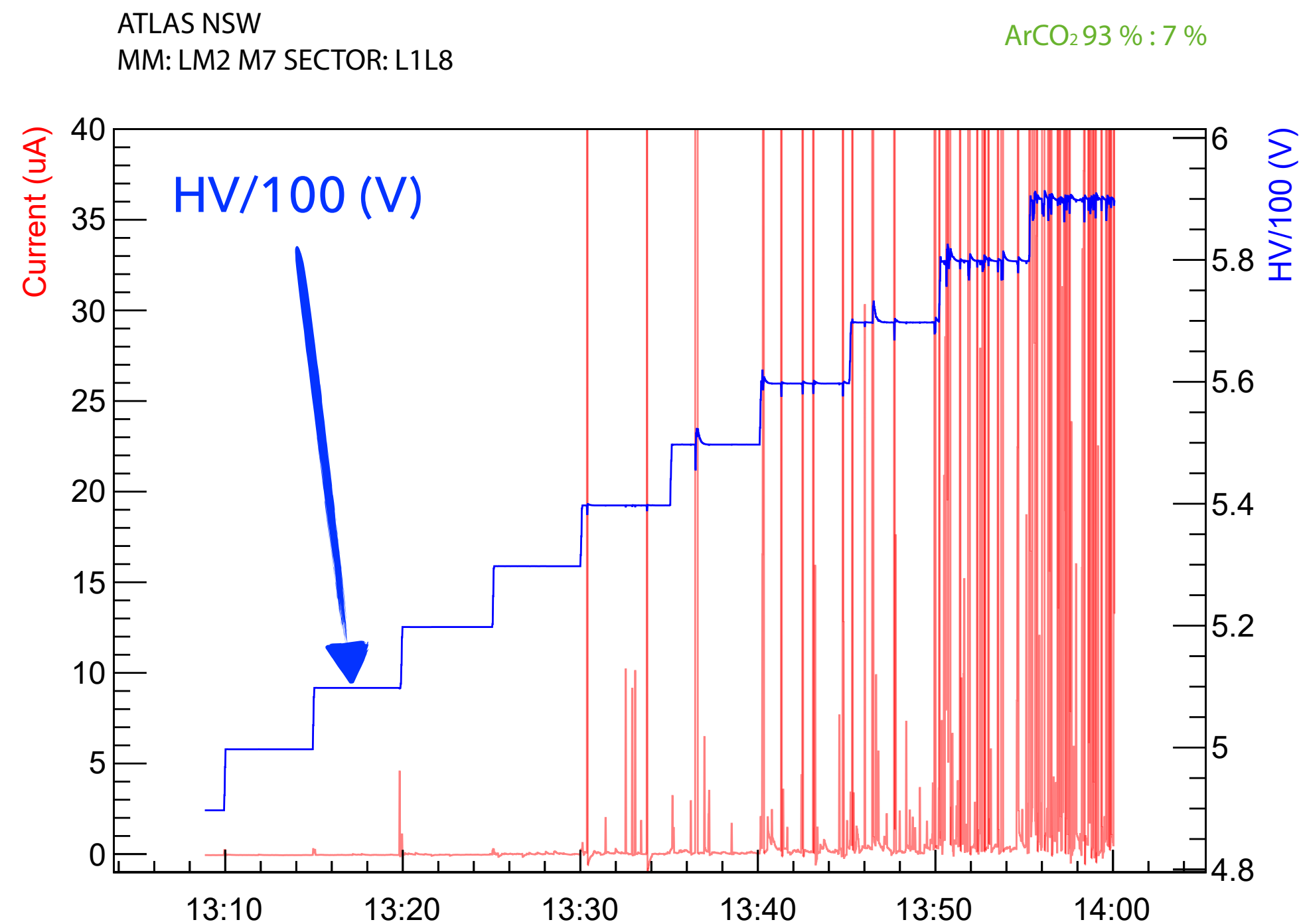
An exponential fit to data up to the working point - 20 V is extrapolated at higher voltages.

Indications of a saturation effect (voltage drop) for high currents.



CURRENT (IN)STABILITY

- ▶ We checked the impact of different gas mixtures on the current stability with and without irradiation
- ▶ Monitored current for several HV values without radiation



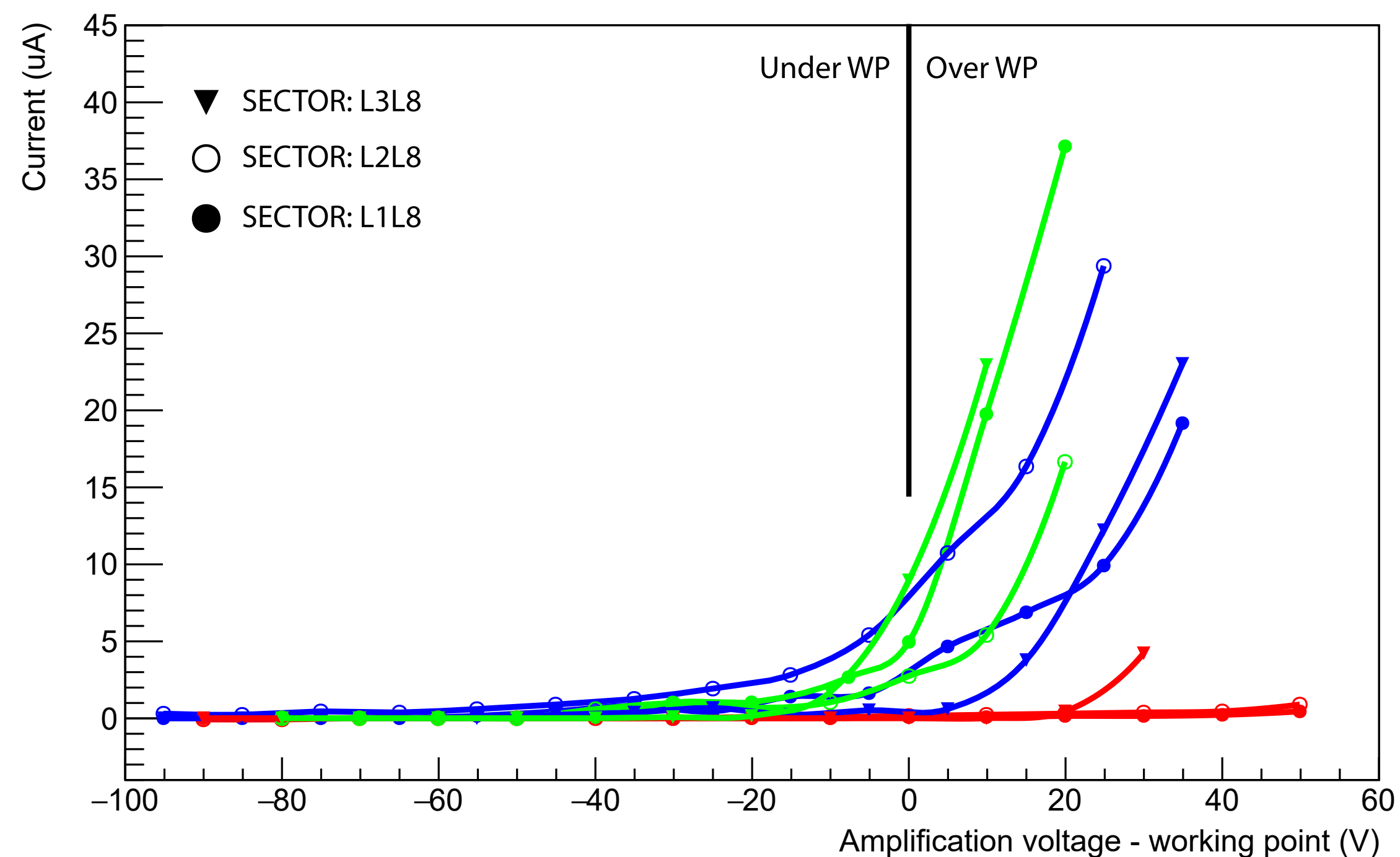
- ▶ Excellent improvement in spikes suppression comes from isobutane acting as a quencher

CURRENT (IN)STABILITY

- ▶ Average current for several HV values without radiation, i.e. current only due to spikes

ATLAS NSW
MM: LM2 M7

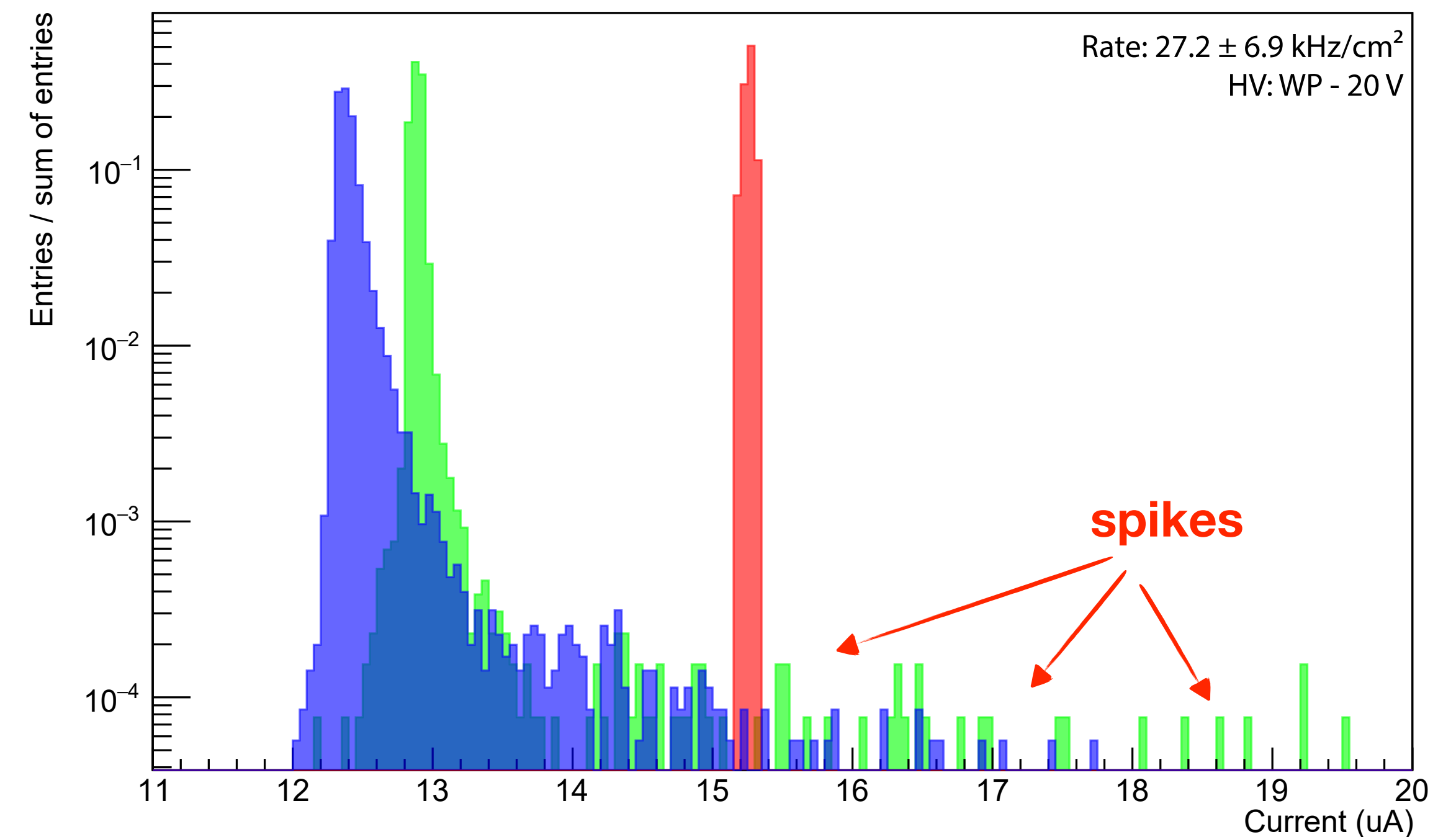
ArCO₂ 93 % : 7 %
ArCO₂ 80 % : 20 %
ArCO₂C₄H₁₀ 93 % : 5 % : 2 %



- ▶ Monitored current values at fixed HV when the chamber is exposed to radiation

ATLAS NSW
MM: LM2 M7 SECTOR: L1L8

ArCO₂ 93 % : 7 %
ArCO₂ 80 % : 20 %
ArCO₂C₄H₁₀ 93 % : 5 % : 2 %



- ▶ Excellent improvement in spikes suppression comes from isobutane acting as a quencher

STATUS AND CONCLUSIONS

- ▶ Micromegas chambers integration proceeded smoothly during all 2019 and beginning of 2020
- ▶ HV/spikes issues considerably reduced thanks to the passivation technique
- ▶ Isobutane enriched gas mixtures are good candidates for further spike mitigation
- ▶ At present NSW Side A close to full integration!

NSW Side A

MM small sectors

MM large sectors

NSW Side C

MM small sectors

MM large sectors



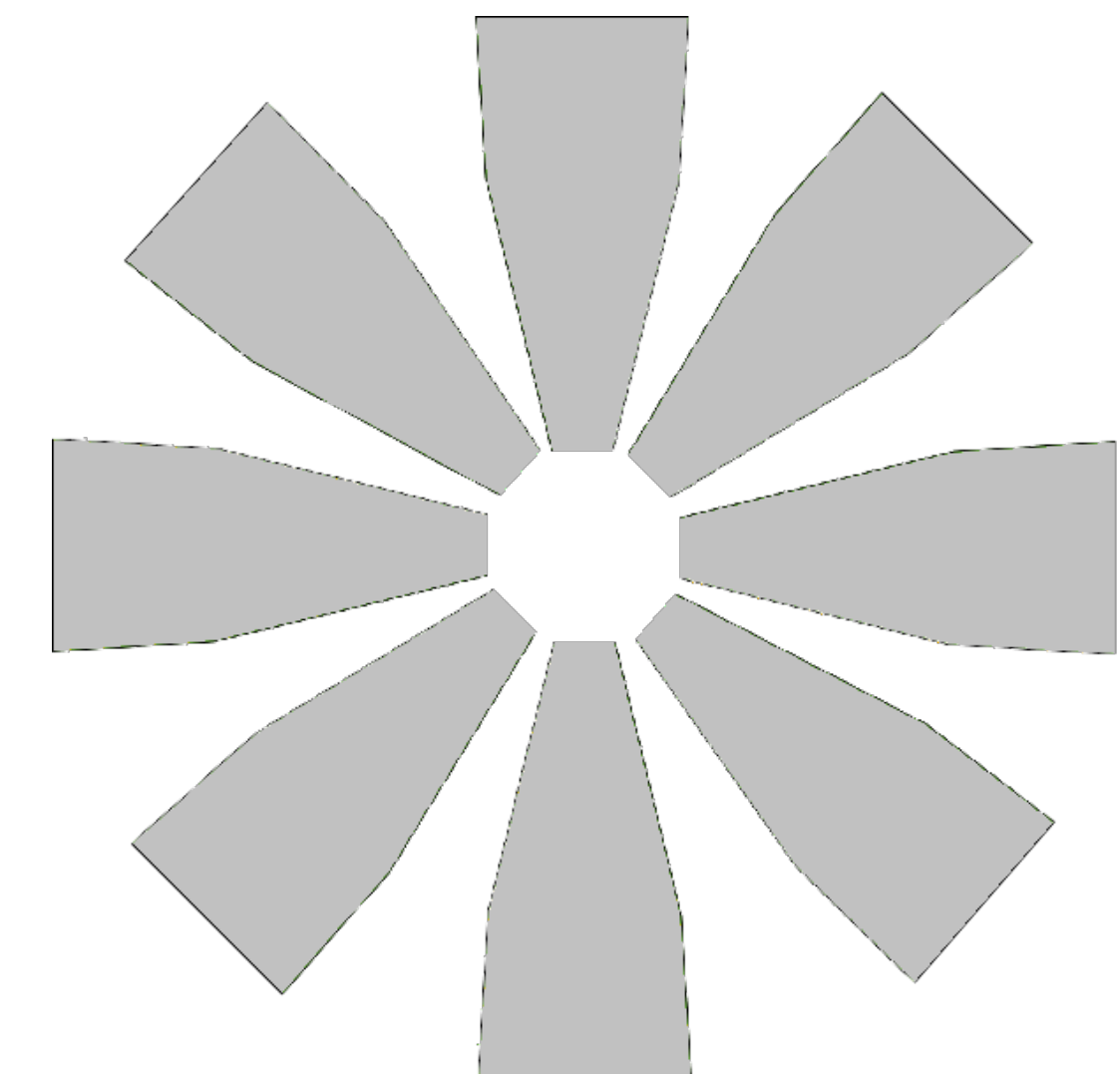
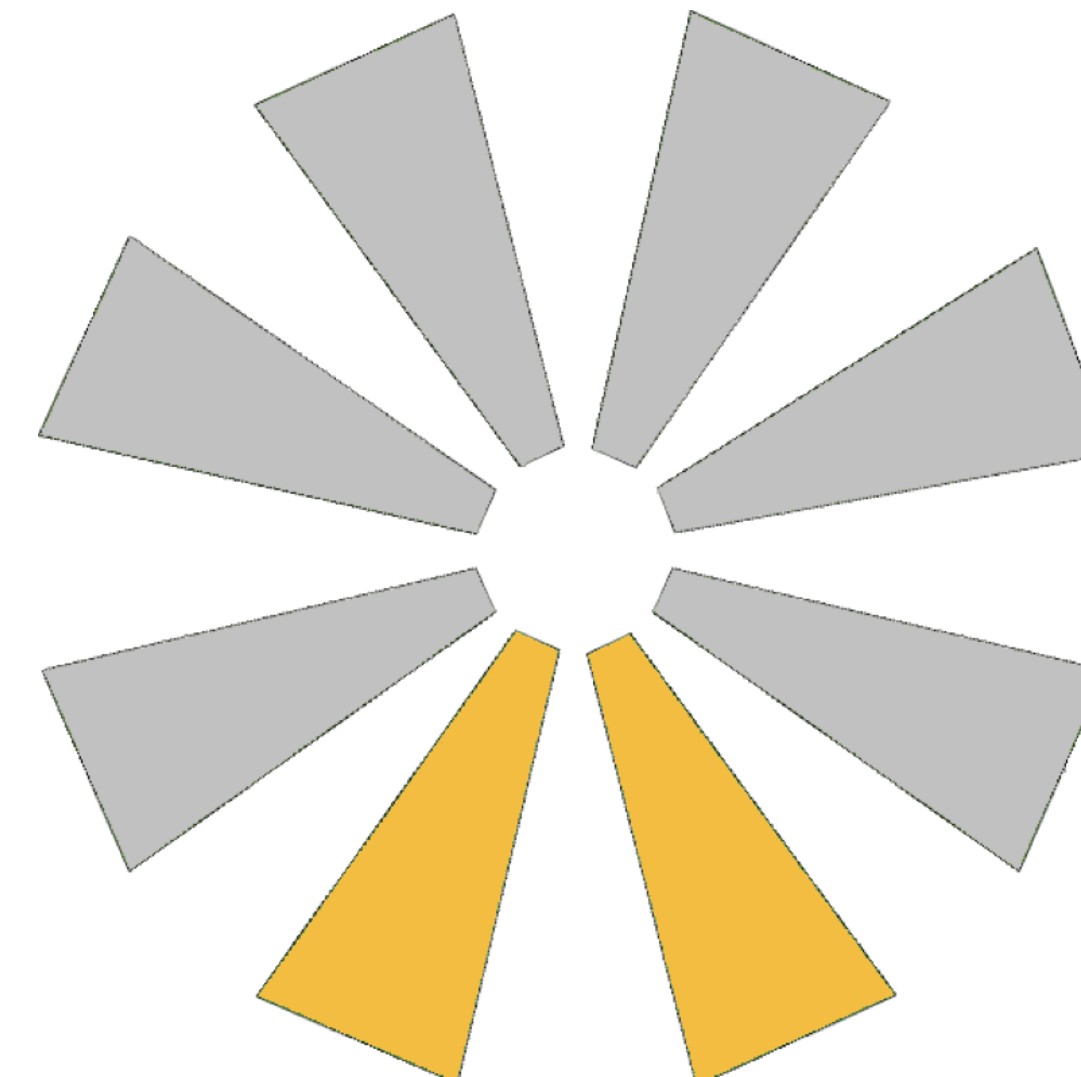
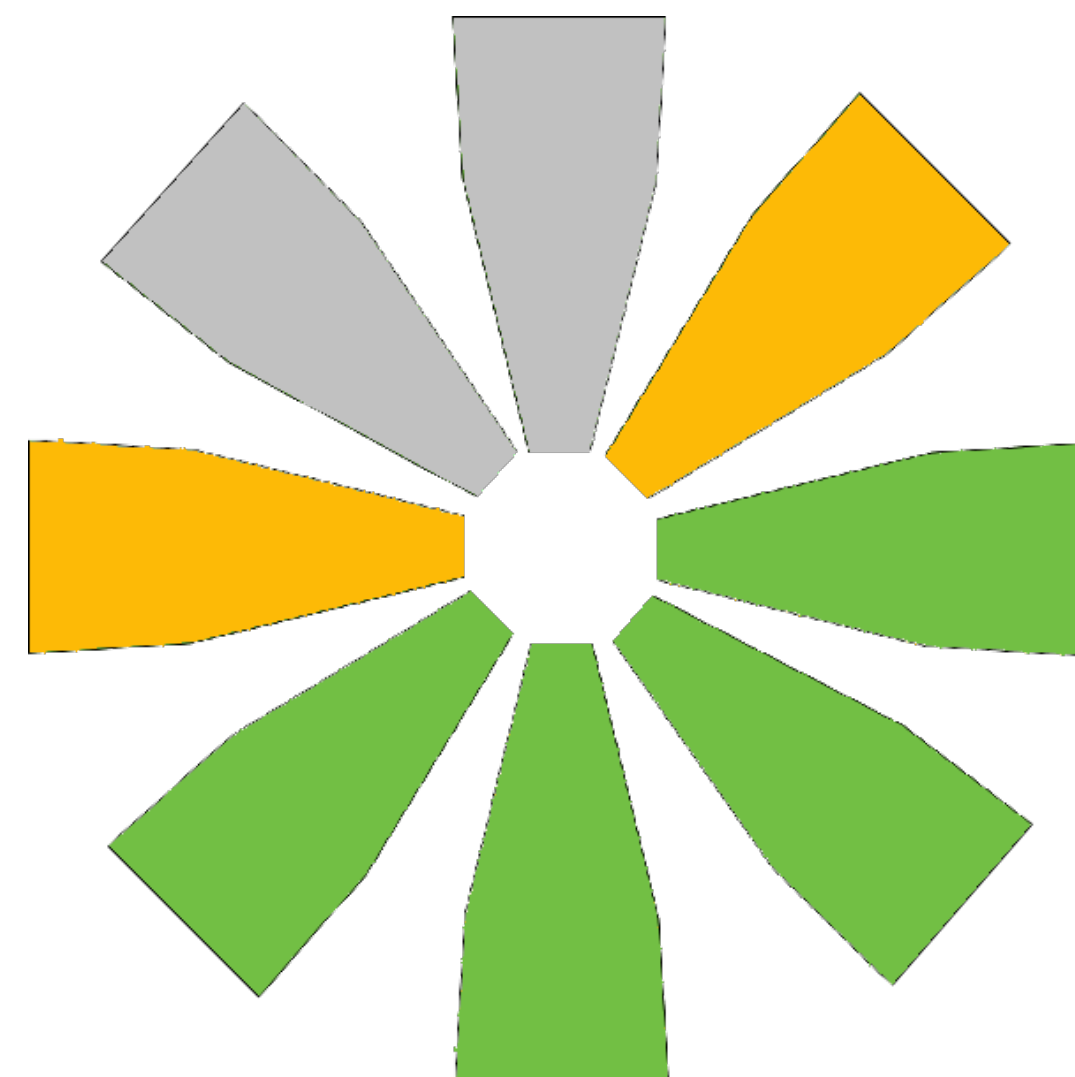
Complete



Under integration



Under construction / shipment



BACKUP



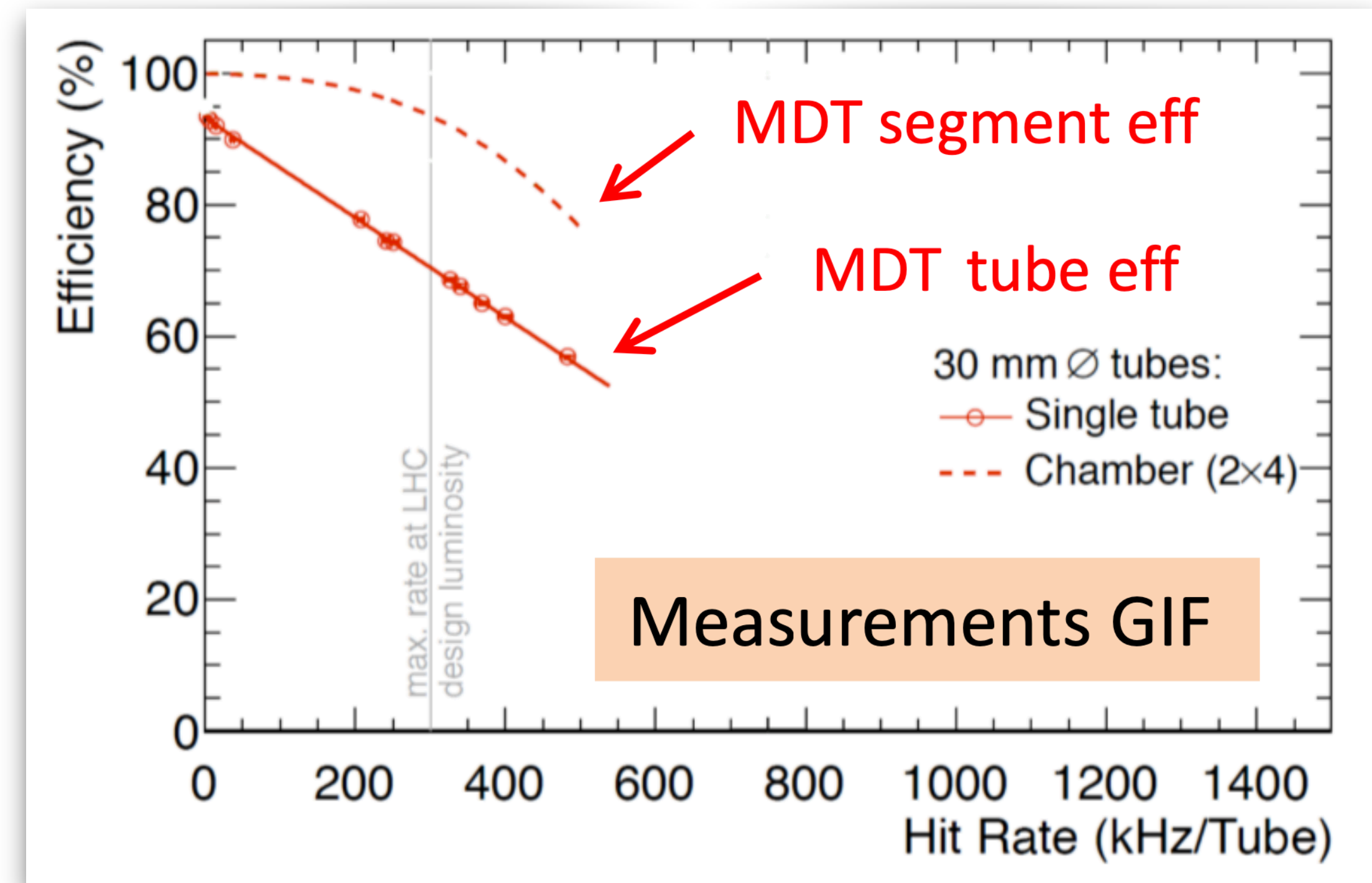
MOTIVATIONS

- ▶ The ATLAS detector, as the other LHC experiments, was originally designed for an LHC luminosity of $10^{34} \text{ s}^{-1} \text{ cm}^{-2}$, and about 10 years of operations

Small Wheels limitations:

- ▶ Drift tubes with 30mm diameter loose efficiency (and resolution) above $L = 2\text{-}2.5 \times 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$.

HL-LHC luminosity: $5\text{-}7 \times 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$

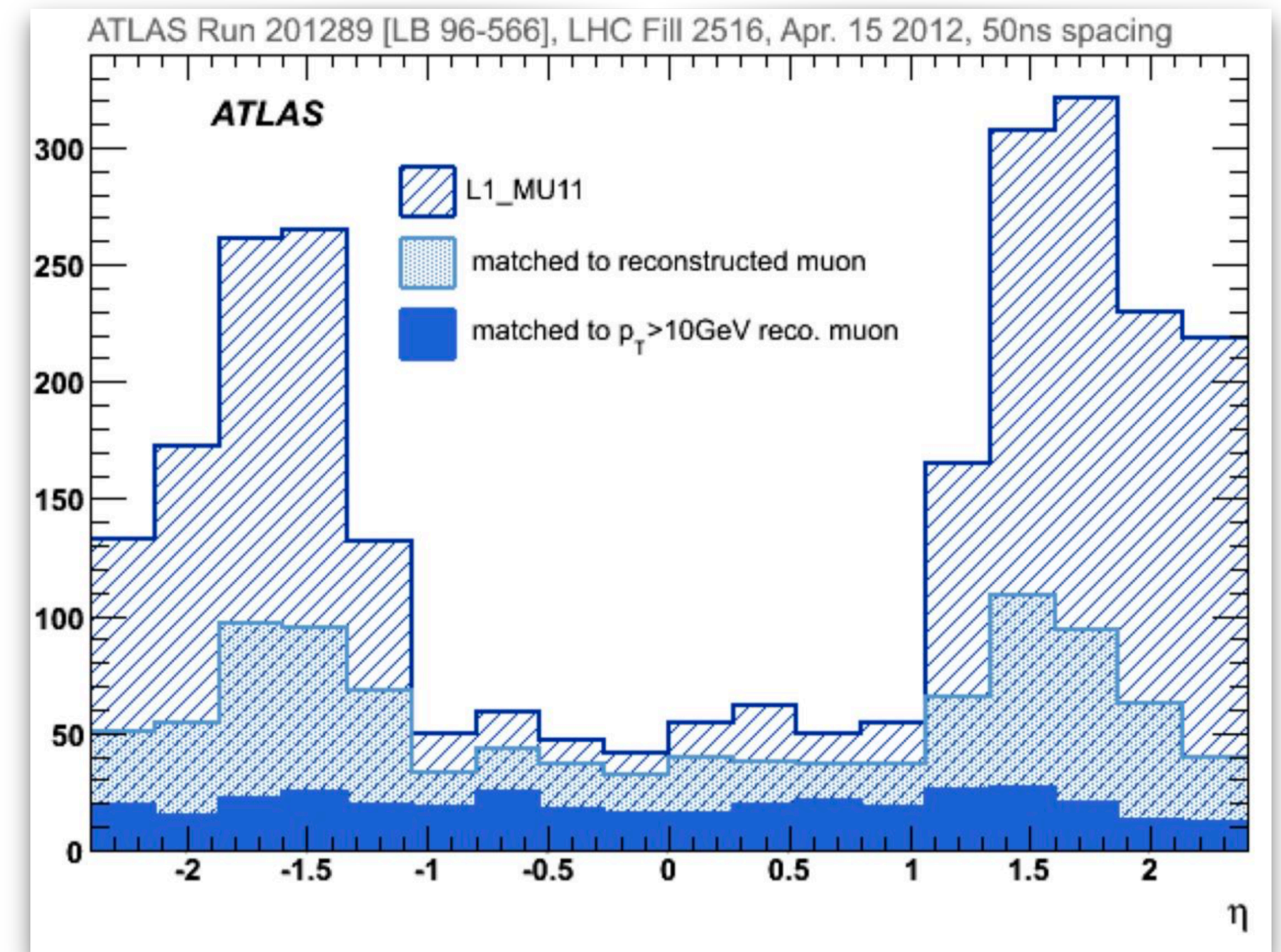


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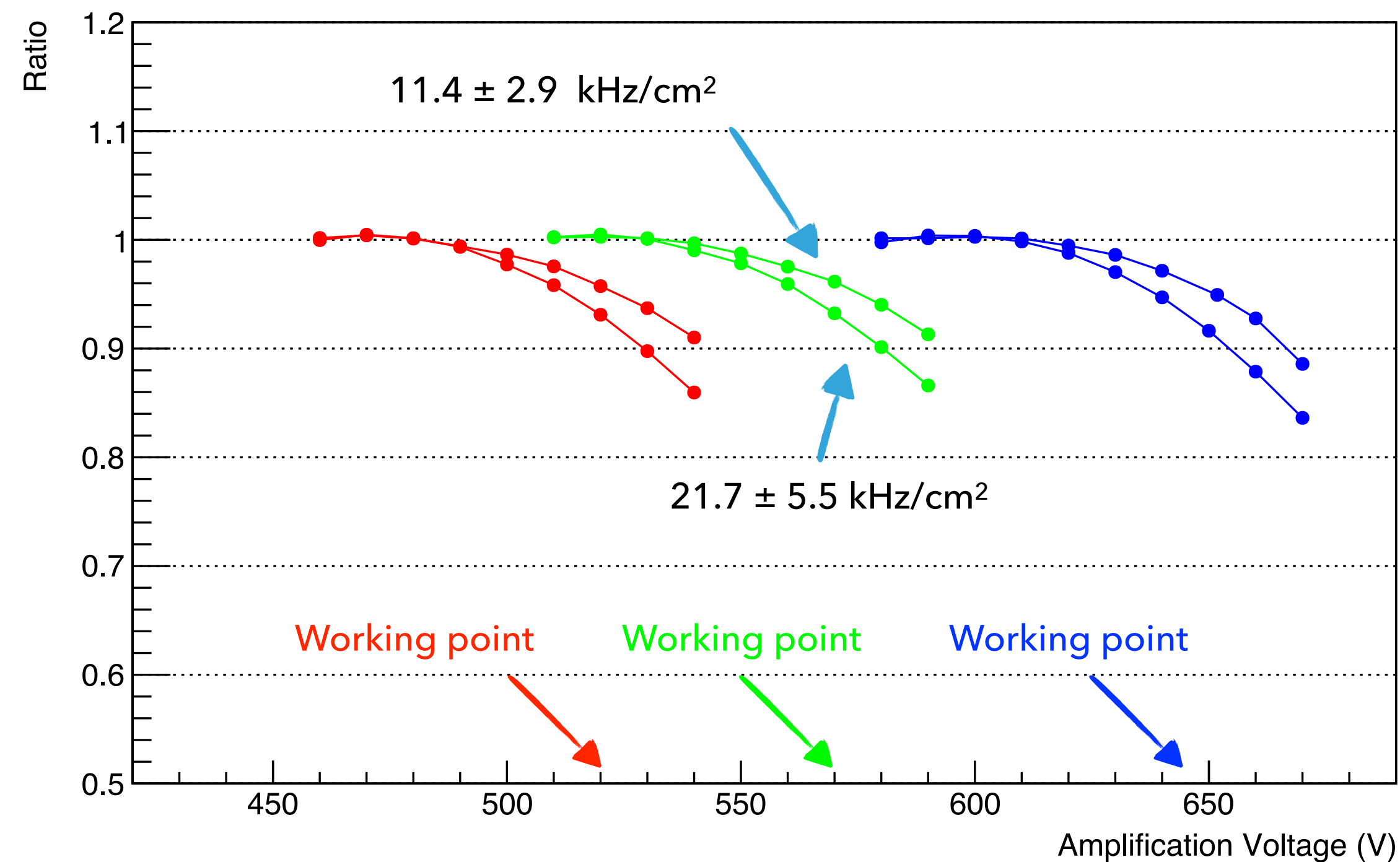
Small Wheels limitations:

- ▶ Drift tubes with 30mm diameter loose efficiency (and resolution) above $L = 2\text{-}2.5 \times 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$.
HL-LHC luminosity: $5\text{-}7 \times 10^{34} \text{ s}^{-1} \text{ cm}^{-2}$
- ▶ L1 trigger in forward region consists only of coincidences between the Big Wheel TGCs. No matching with tracks directions → Dominated by “fake” muons, getting worse with HL
- ▶ Pattern recognition becomes more challenging the higher the pile up and background rates are



GAS MIXTURES

Ratio between the fitted extrapolation
and the measured current



Example: LM2 type chamber at GIF++

New gas mixtures are under study at GIF++
to further reduce the HV issues (standard

Ar/CO₂ 93%/7%):

▶ Ar/CO₂ 80%/20%

▶ Ar/CO₂/C₄H₁₀ 93%/5%/2%

Working points

Gas	Drift V	HV V
ArCO ₂ 93 % : 7 %	300	570
ArCO ₂ 80 % : 20 %	450	645
ArCO ₂ C ₄ H ₁₀ 93 % : 5 % : 2 %	250	520