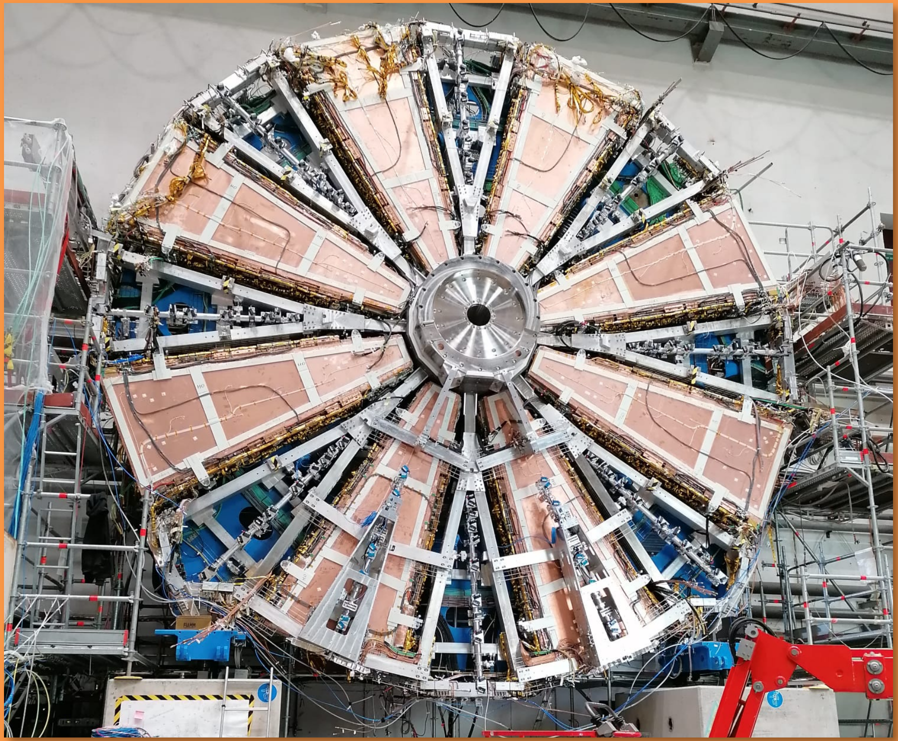
Update on production and stability of the ATLAS/NSW MicroMegas chambers



Giada Mancini - LNF INFN

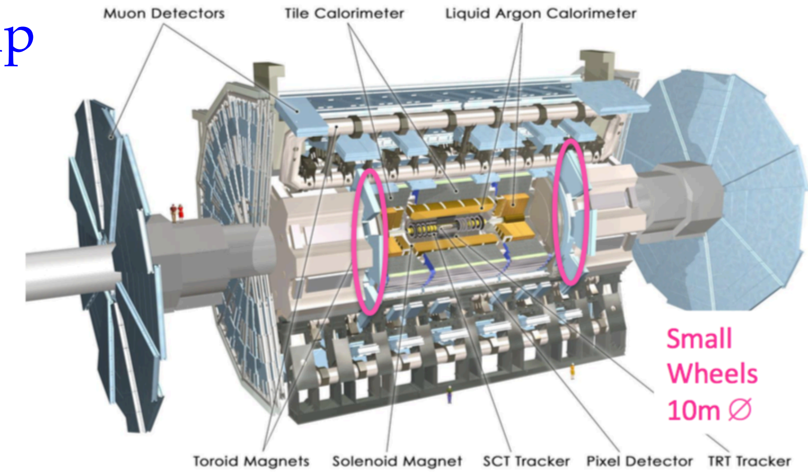
on behalf of the ATLAS NSW MicroMegas group

Outline

- Micromegas for the ATLAS NSW Phase I Upgrade
- HV stability issue, resistivity issue, passivation solution
- Test with different gas mixtures (mainly ternary mixture adding 2% Isobuthane)
- Pure Argon test to recover a resistive behaving section
- Status of the Upgrade

NSW performances

The NSW will replace the innermost end-cap station of the Muon Spectrometer



- **Main ATLAS upgrade during the LS2 (Phase-I)**
- Designed to operate also at HL-LHC luminosity $\gtrsim 5\times10^{34}$ cm^{-2}s^{-1} (Phase-II)
- **Angular coverage: $1.3<|\eta|<2.7$**

  Located at $z = \pm7$m from IP the first MS station in the forward region (End-Cap)
- **Goals:**
  - p_T resolution: ~15% at 1 TeV ➔ ~100 mm per plane on a multilayer station
  - able to cope with high fluxes and reject fake muon triggers
- Improvements in technologies needed both for precision tracking and trigger

Present SW

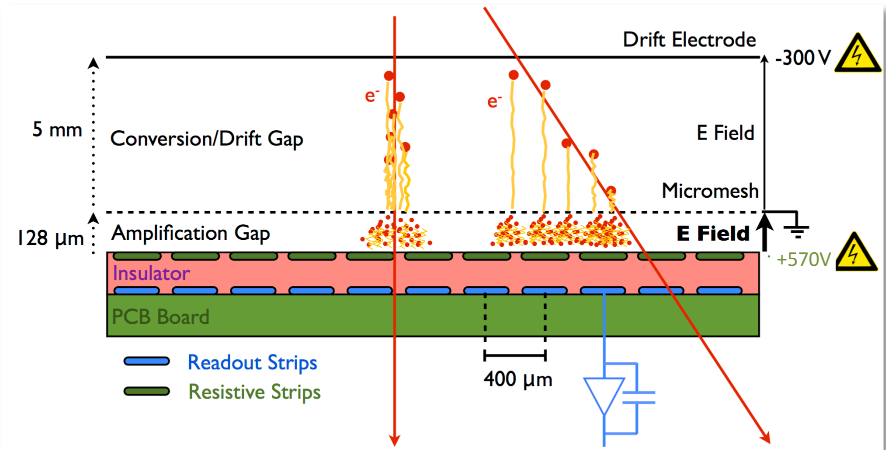
- **CSC** and **MDT** for precision coord.
- **TGC** for the 2nd coord.
  - **trigger up to $\eta < 2.0$**

➔

NSW

- **Micromegas** primary precision tracking
- **sTGC** primary for trigger

The ATLAS resistive strip MicroMegas

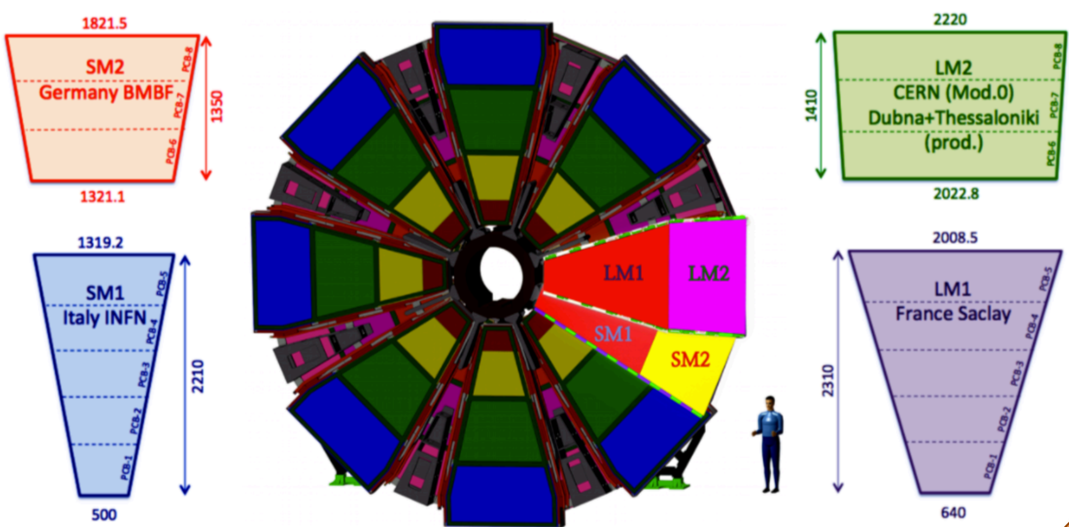


Working conditions:

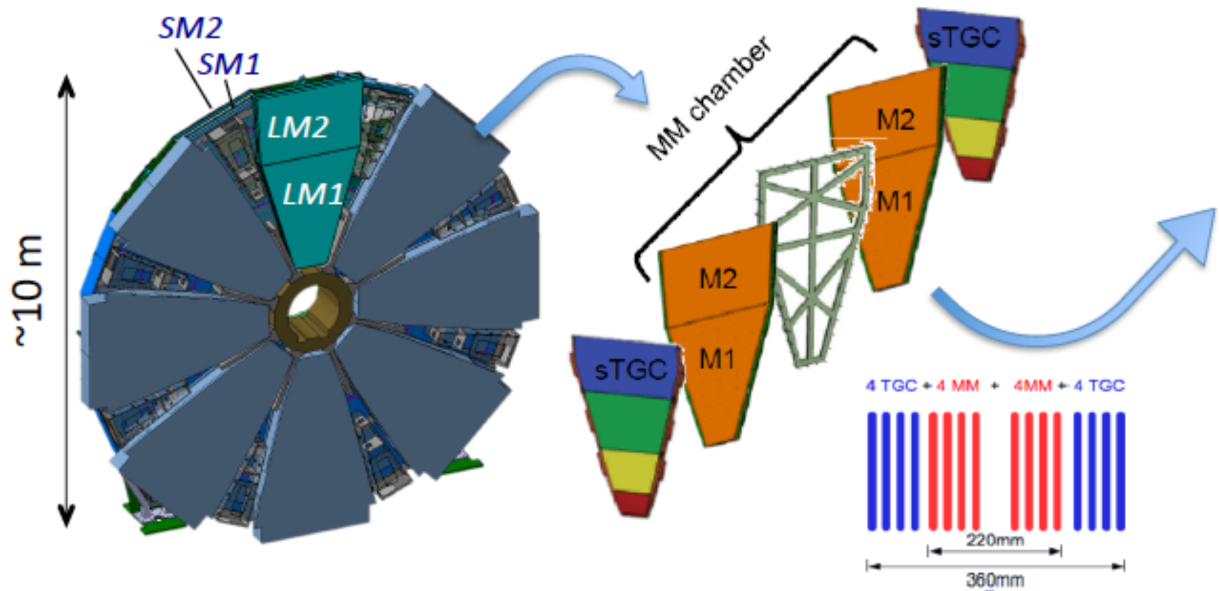
- gas: 93% Ar - 7% CO_2 (further studies ongoing)
- conversion gap 5 mm, amplification gap 128 μm
- HV (metallic mesh grounded):
  - Conversion: HV_{drift}= -300 V, h=5mm, E_C~600 V/cm
  - Amplification: HV_{RO}= 570 V, h=128μm, E_A~50 kV/cm
- resistivity strip≈10 MΩ/cm (to reduce the probability of discharges) are overlyed to copper signal strips
- Copper signal strips: width 300 μm, strip pitch 425-450 μm
- Mesh integrated in the drift panel structure

NSW, wheel structure:

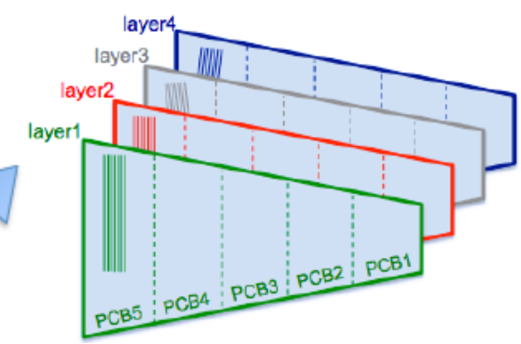
- 8 large sectors (LM) and 8 small ones (SM) (2 MM modules per sector)
- MM aim: **precision tracking** (between 2 sTGC chambers for trigger)
- 4 type of chambers: LM 1-2, SM 1-2
- production shared between several institutes: Italy (SM1), Germany (SM2), France (LM1), Russia/Greece (LM2 – CERN for drawings and first prototypes)



NSW Layout



MM quadruplet



Each MM module has 4 detection planes

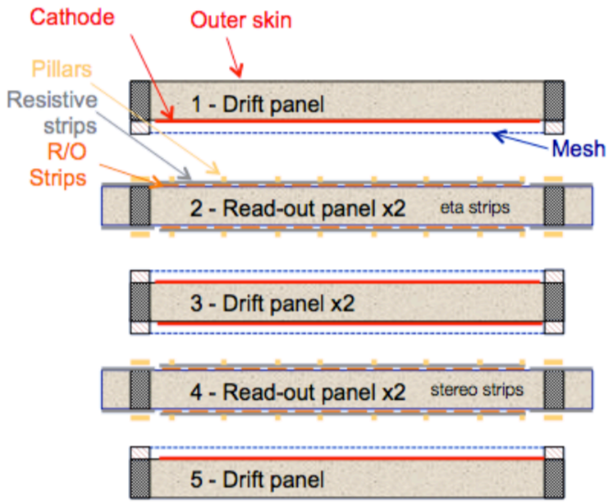
Each NSW has 16 sectors:
8 Large + 8 Small

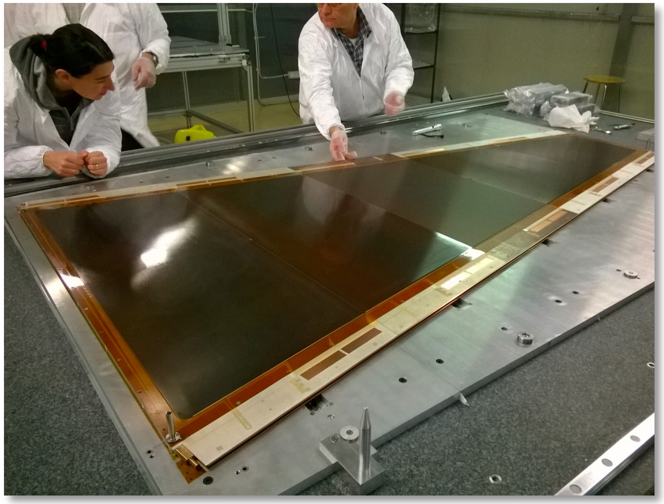
Each Sector is a sandwich of
sTGC and MM quadruplets

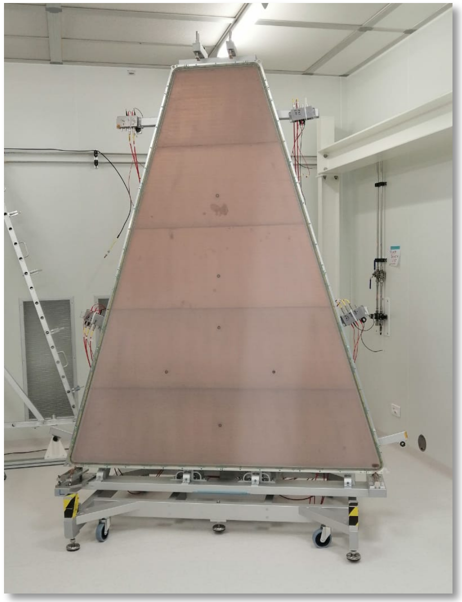
- **>8000 ch. per layer -> >32000 ch. per quadruplet -> ~1M ch. per Wheel**
- **8x2 = 16 independent HV sectors per DW layer**

MM quadruplet:

- **Cathode (Drift) and Anode (ReadOut) planes built on sides of 5 panels stiffened trough the use of honeycomb structures**
- 2 read out panels (1 eta and 1 stereo with strips inclined by ±1.5° in order to reconstruct the 2nd coordinate) -> RO pcbs are based on boards done in industries
- 3 drift panels (cathode pcbs + glued meshes)







The resistive MicroMegas chambers are frontier Micro-Pattern Gas Detector which are designed and built for the first time on large dimensions O(m^2).

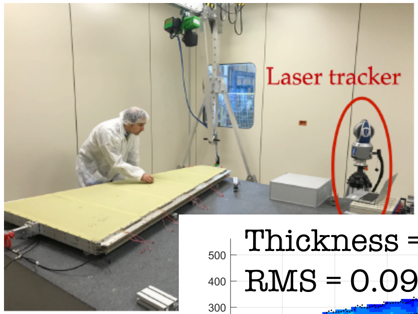
MicroMegas construction challenges:

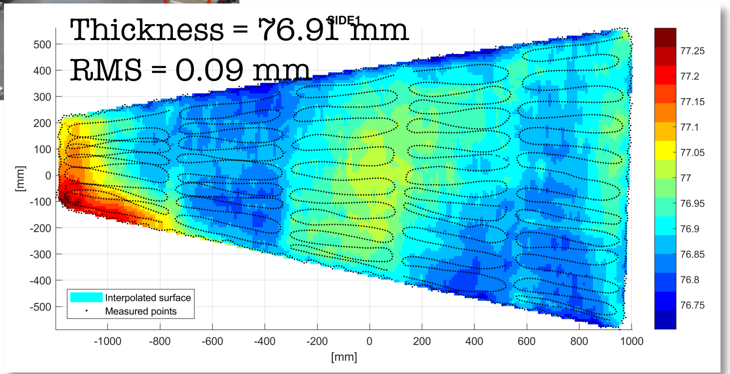
- Very high mechanical precision in order to get **~15% p_T resolution at 1 TeV**
  - strip alignment on each layer of **40 μm of precision in η**
  - **planarity within 100 μm RMS**
  - **both request challenging because of the large detector dimensions**
- **technological transfer of Read-out PCBs production** with extremely high quality (pillars shape, resistivity homogeneity, quality of the PCB edges)
- **stability against discharges** with an high electric field (~50 kV/cm) on a surface of O(m^2)

MM modules Assembly

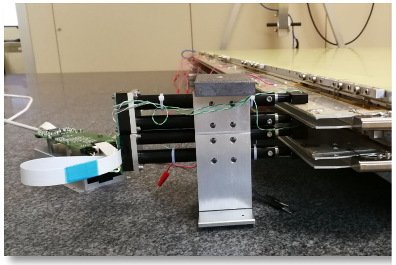
- Production concept is the same for all four module types
- Slightly different technical solutions adopted at the various construction sites for both construction of single panels and module assembly
- The assembling of a module (few days) must be performed very carefully
  - After each gas gap is closed, test for HV stability are performed before working on the panel for the next gap
  - After all gaps are closed a test for gas leaks is also performed
- Careful QA/QC program implemented to check all parts and production steps

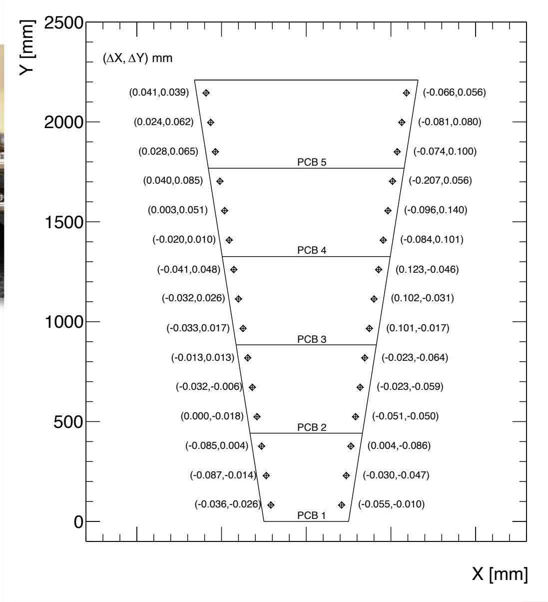
Planarity of the module measured with a laser tracker **(specific: RMS < 100mm)**





Relative layers alignment measured with the RASNIK technique

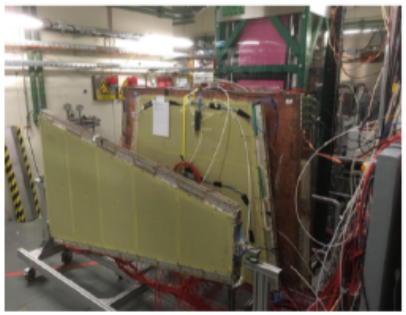




NSW MM Integration activities

Integration Workflow

Gas Tightness HV test | GIF++ | Mechanical Integration | Services | Elex+Cosmics



Gas tightness: 4 MM can be tested in parallel
HV: 3 MM tested in parallel
GIF++: 2 MM in parallel

All **lifting/rotating tools** for SM1/SM2/LM1/LM2 available for the Small and Large Wedge mounting

LV/HV/optical fibers/ data cables (TwinAx)/ Temperature probes

--> 54 km of TwinAx cable being covered with Kapton!

Testing the complete elex setup: **MMFE8/L1DDC/ADDC (FE/data concentrator/trigger) +optical Felix system**

- DW final validation at CRS
- Remapping HV
- Electronic installation
- Data taking and efficiency maps

Chambers tested at the Gamma Ray Irradiation Facility (GIF++), North Area of SPS at CERN

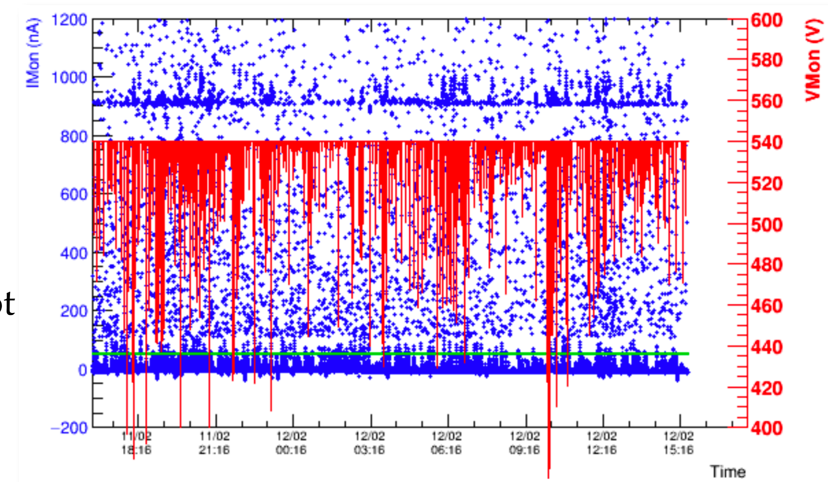
- The facility uses a ^{137}Cs source of di ~13 TBq (662 keV)
- Filters used to adjust the flux intensity
- Now up to 4chambers in GIF++ (both short and long tests performed)

If NA: hospital facility for refurbishment of all modules type at CERN!

- HV stability issue
- Resistivity issue -> Passivation
- New HV scheme

HV stability issues

- Jan 2018: issues of HV Stability with first production MM NSW Quadruplets:
  Several HV sectors showing high currents and in some cases were prone to discharging
- Restarted a limited R&D Program addressing:
  - Maximum sustainable voltage without high currents nor frequent discharges
  - Critically revisit possible design issues (identification of weak points) in both Drift and RO panels
  - Mesh type (grid sizes selected mesh demonstrated not to be optimal, mesh calendering)
  - RO boards and panel cleaning
  - Effect of humidity inside the panels
  - Long term stability HV tests

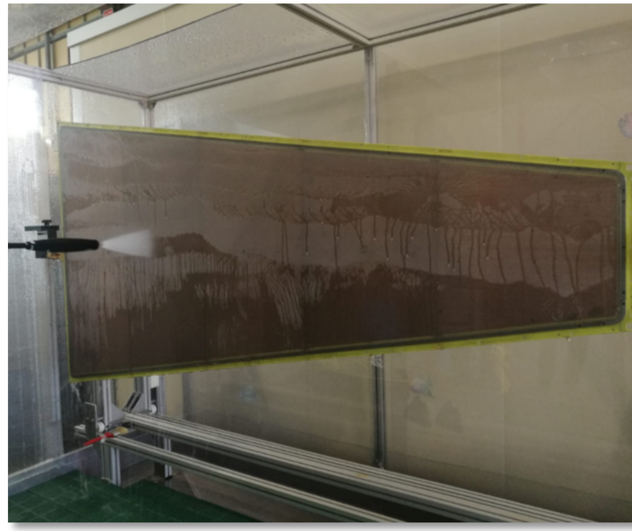


Main issues identified to be:

- **residual ionic contamination** of boards and panels from industrial processing and handling => **improve the cleaning procedures**
- Possible effects from **mesh mechanical imperfections** => **implement mesh polishing**
- Clear **correlation of currents with humidity** (FR4 hygroscopic - board dimension affected by humidity: ~400 mm/m from 0 to 50% RH) => **increase gas flow rate and monitor humidity**

Micropolishing cleaning procedure:

- Hard and soft brushes to distribute detergents
- Accurate washing with hot and demineralized water
- Drying in a box with a ventilation system at ~40°

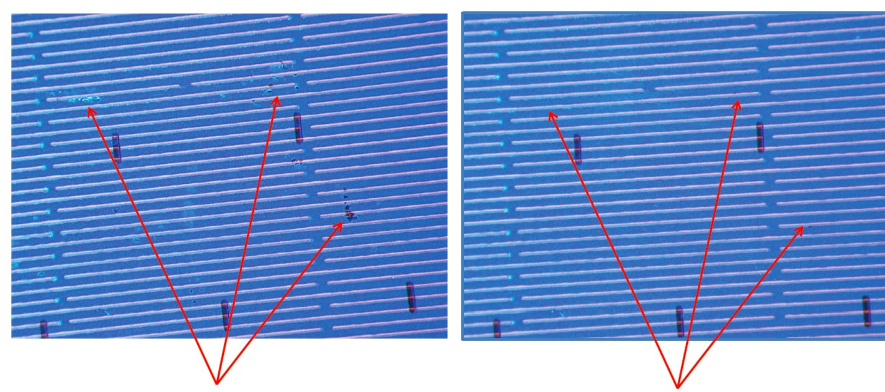


Main purpose of wet cleaning (and scrubbing):

- remove remnants from the PCB production: dirt and solid deposits from the RO boards -> mostly responsible of "ionic component"
- remove dirt from the mesh (and trapped wires/chips)

Before cleaning

After cleaning

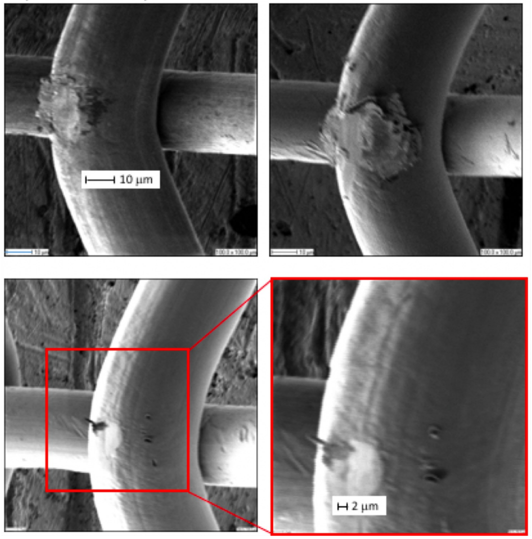


Production remnants

Production remnants removed

The mesh grids used for the ATLAS MM are not flattened by calendering and may present some imperfections, which can produce discharge if pointing toward the resistive strips

-> polishing with a very fine sandpaper to remove or smooth these imperfections



The described cleaning procedure, together with the mesh polishing has been adopted at all sites and large improvements have been observed in HV stability behavior.

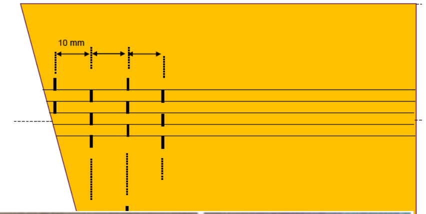
-> Production resumed BUT still in all chambers few HV sectors have problems so that further investigations went ongoing in parallel with the production.

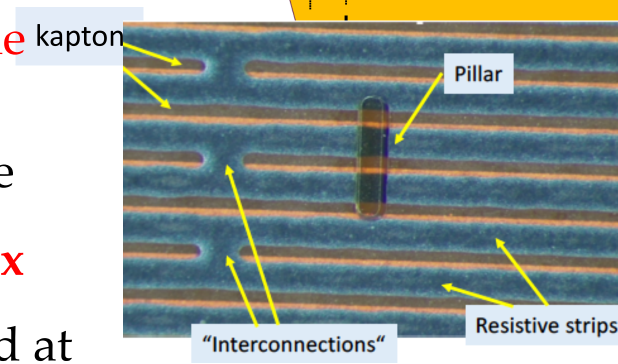
HV stability and board resistivity

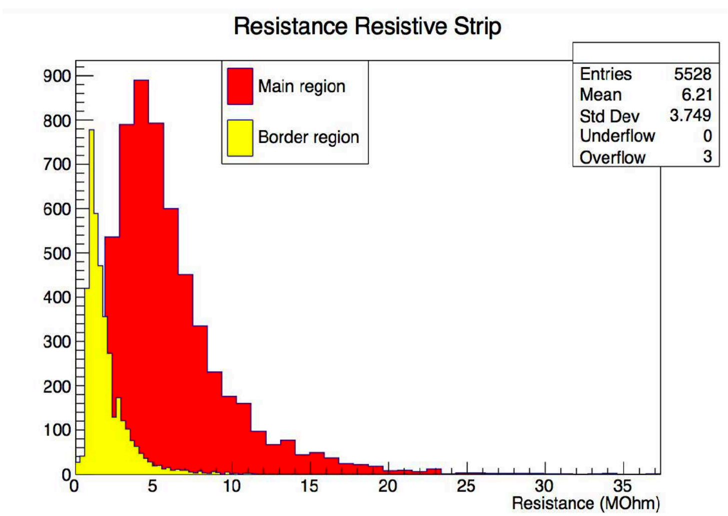
The resistive strips of the ATLAS MM are ink-printed on a kapton support

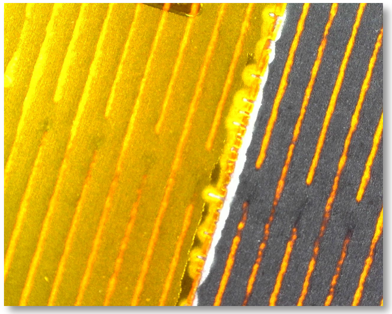
The resistive strip layout presents interconnections with a defined pattern -> to have more uniform resistivity in the board

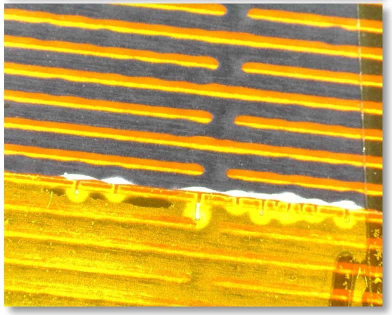
Analysis of **discharges** showed that in many cases they are **localized on resistive strips junctions crossing the piralux rim, the edge of the active area** (1cm wide zone passivated at the factory)

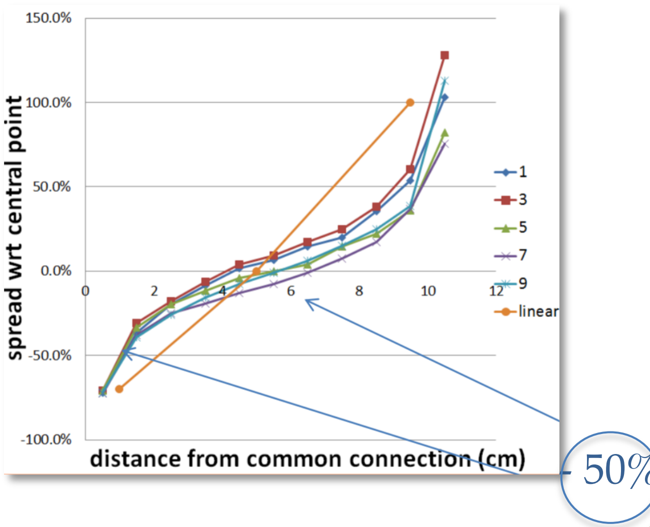




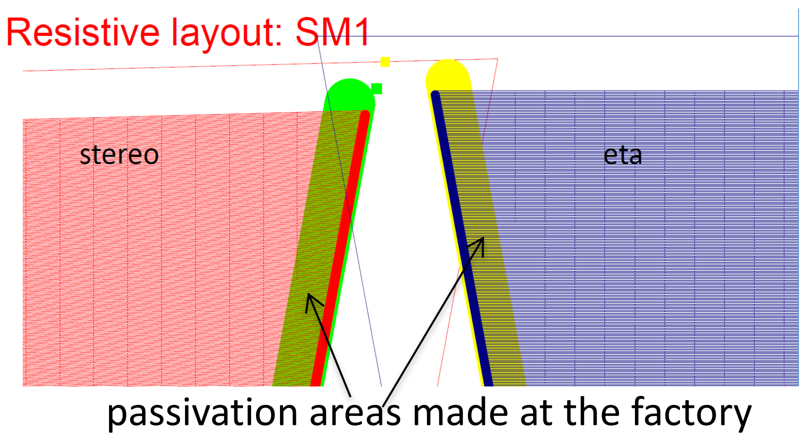


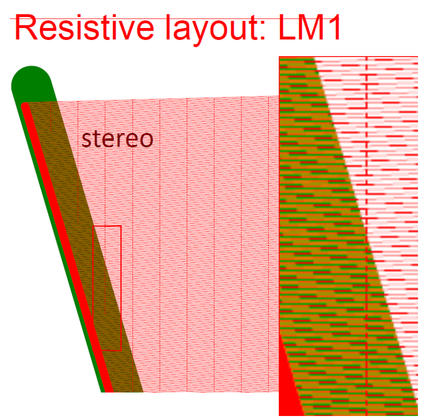




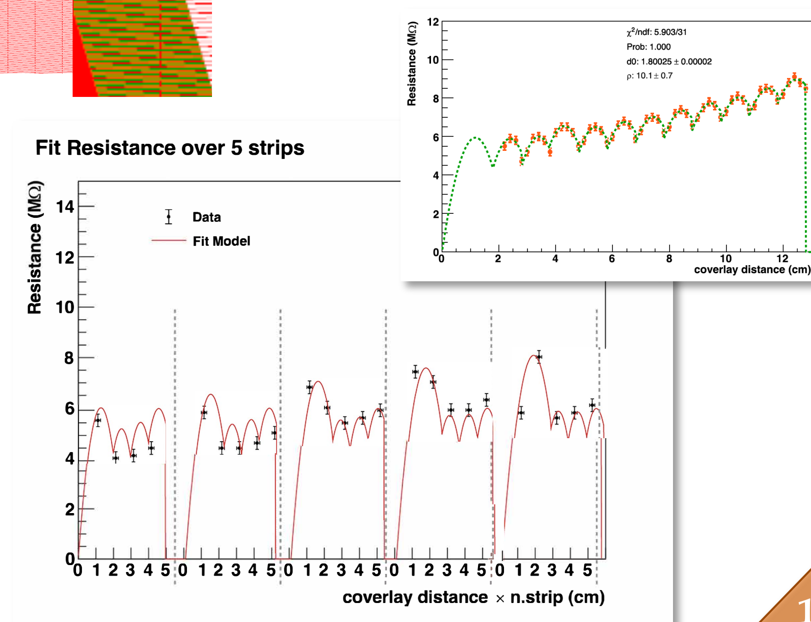


- **The resistive strips layout is not the same for all PCB types (**some PCB types were more affected than others by discharges)
  - For example LM1 both stereo and eta, SM1 stereo but not eta panels





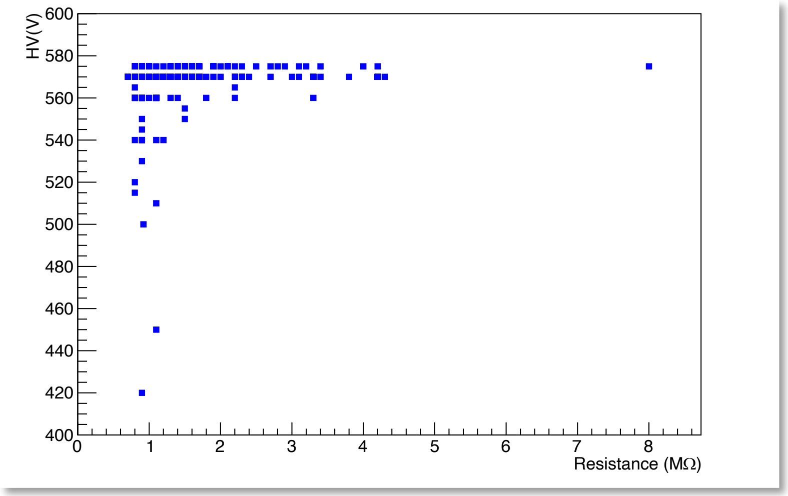
- Resistance locally can be significantly lower than what obtained with $1cm^2$ probe
- Strong dependence on the layout
- Local defects can be undetected
- Local resistance behavior can be predicted via simulation



Passivation:

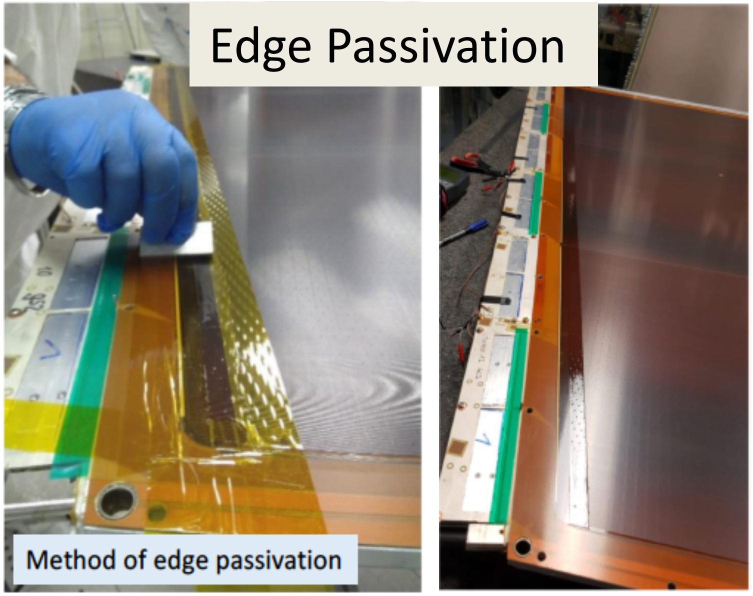
Resistance measured with megger and a 1cm^2 probe, at different distances from the pyralux rim applied by the PCB factory, w.r.t. the silver line

The minimum resistance (R_{min}) measured near the edge of the active area **is sometimes very low (<0.4 MΩ)**



Clear correlation between bad sectors and R_{min}!

Edge passivation established to mitigate this problem (initially for the SM1 stereo panels, then extended to all construction sites)-> passivation of a region along the sides of the PCB through deposit of a thin layer of araldite, wide enough that the first active area has a R_{min} >1 MΩ



The solution is not optimal, because we give up active are (lowering the geometrical acceptance of the detector) which in some cases is rather large

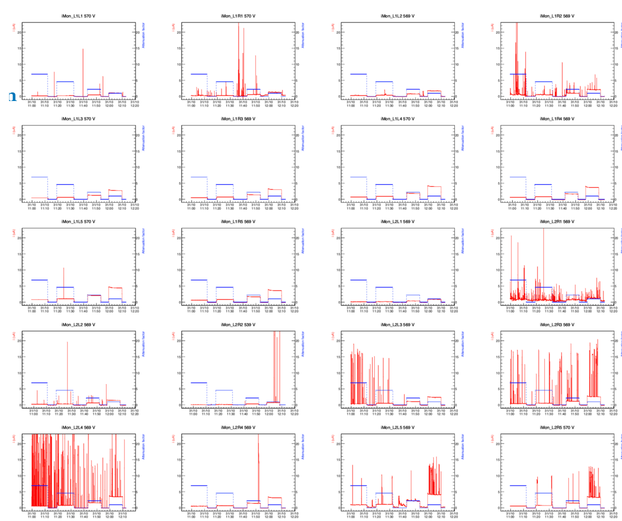
Effects of passivation

LM1 chambers under gamma irradiation at GIF++

LM1-M8

not passivated

24 HV sectors not passed requirements



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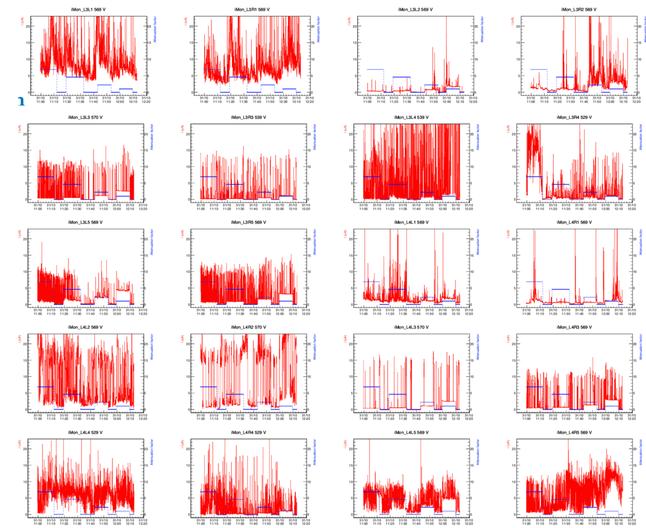

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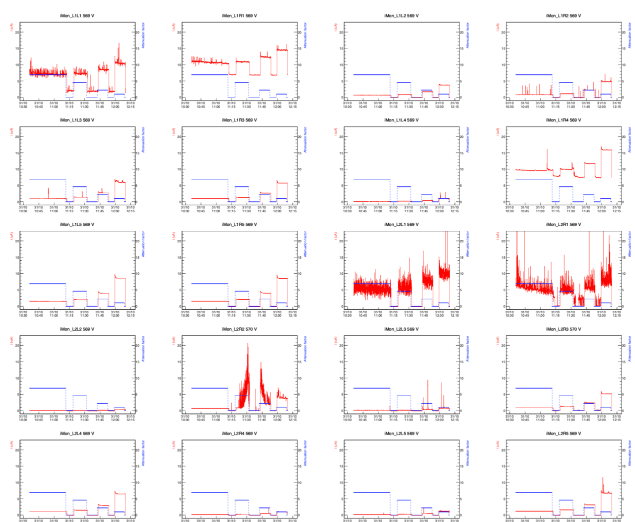
LM1-M5

passivated

6 HV sectors not passed requirements



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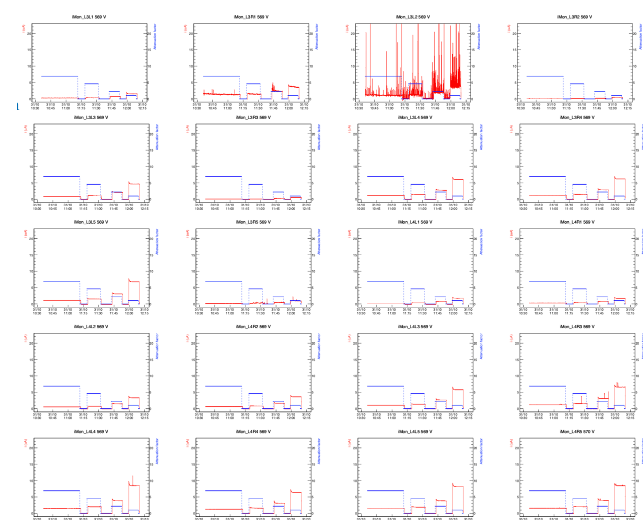

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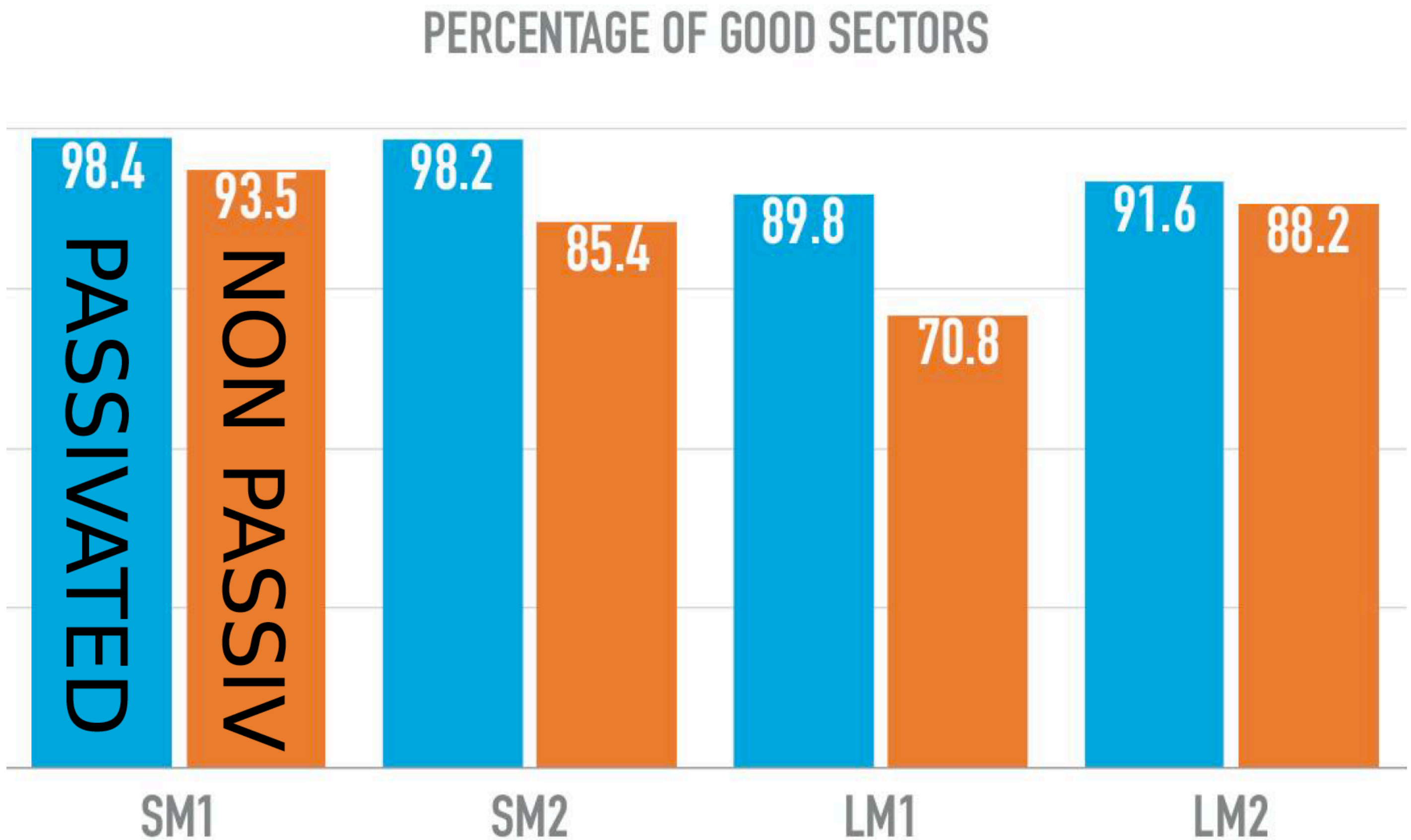
Effects of the passivation are confirmed by the percentage of good sectors (i.e. HV>=560V) for the chambers on the DW integrated so far

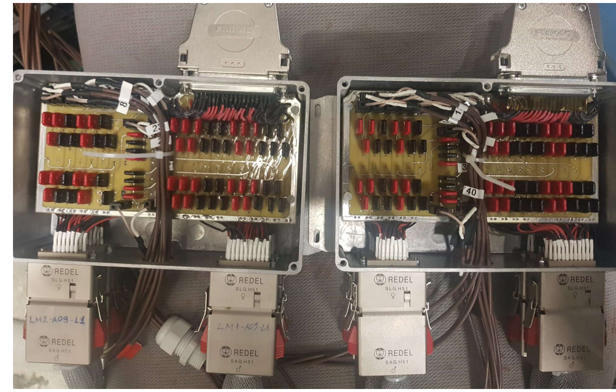


HV new scheme to cope with weak HV sections

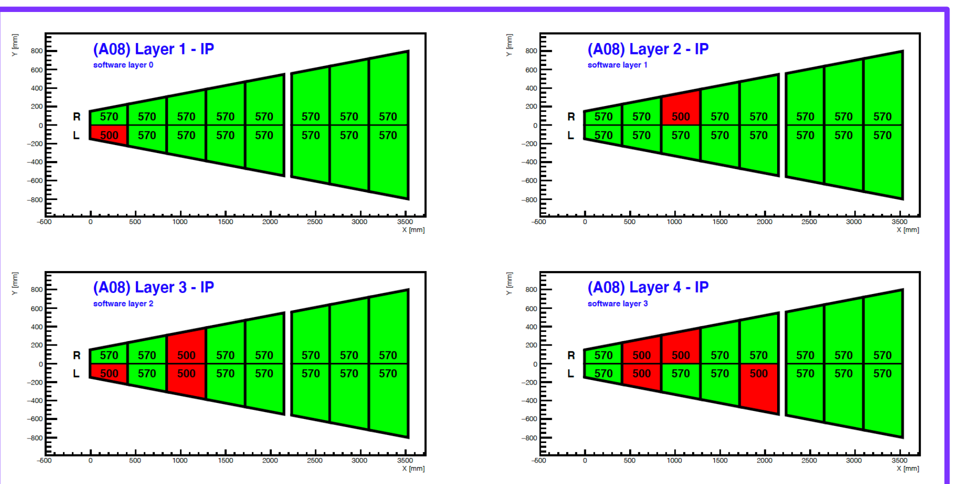
New splitter boxes needed to go from the layer granularity scheme to the so called half granularity scheme:

OLD: 1 HV channel per chamber layer + only 1 HOL available per chamber (20 HV channels per DW): weak channels either off either at the lower HV value for each chamber

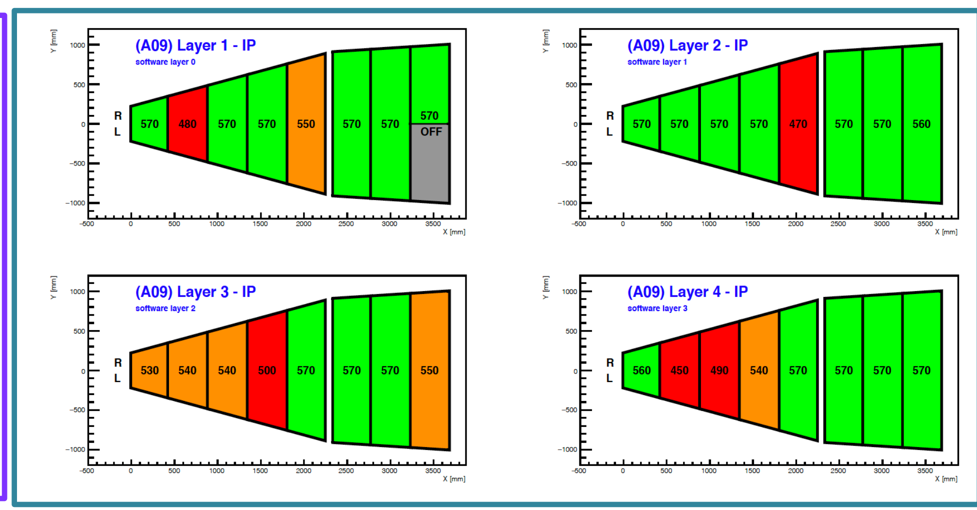
-> NEW: 1 pcb per HV ch, 2 adiacent HV sections (64 HV ch per DW)!



Old scheme



New scheme



Succesfully tested! Possibility to remove jumpers to unplug bad HV sections.

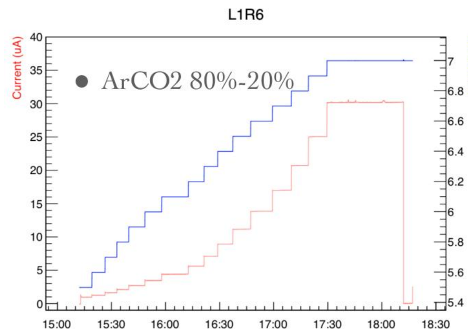
- Ongoing studies:
  - Test on different gas mixtures at GIF++ under gamma irradiation and at the DW Cosmic Stand in bb5
  - Test with pure Argon to recover resistive behaving sections
  - Test taking data with high current

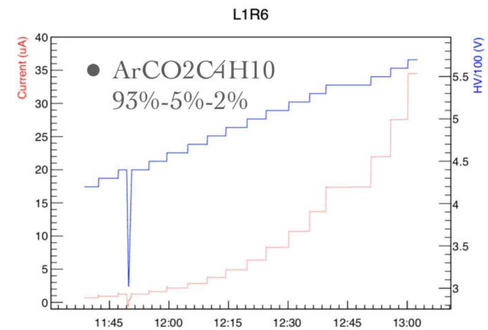
Test on different gas mixtures at GIF++

Test on different gas mixtures, aiming to optimize the **behavior under HV in terms of stability, current values, working point**

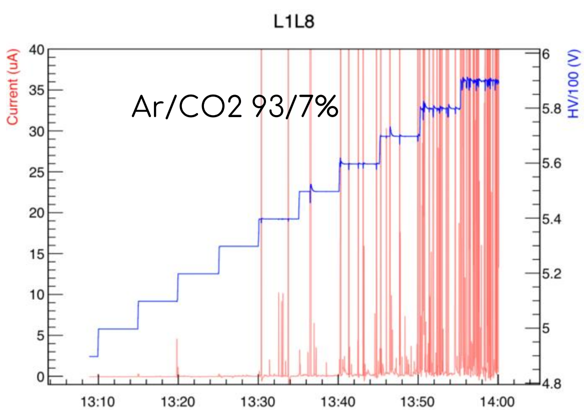
Gas mixtures under test:
- $Ar:CO_2 = 93:7$ (standard)
- $Ar:CO_2 = 80:20$
- $Ar:CO_2:iC_4H_{10} = 93:5:2$

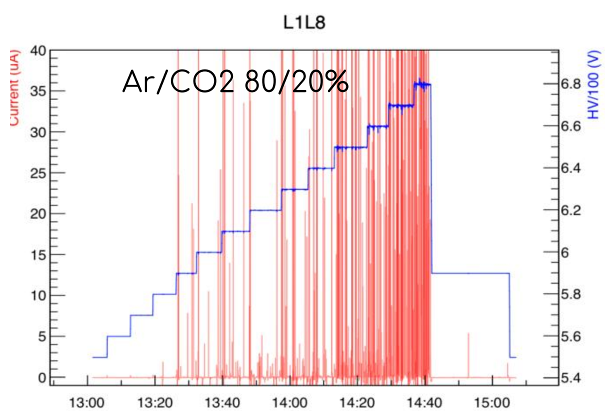
HV ramp up on good-behaving MM sectors:
- smooth exponential ramp up of the current
- no spikes

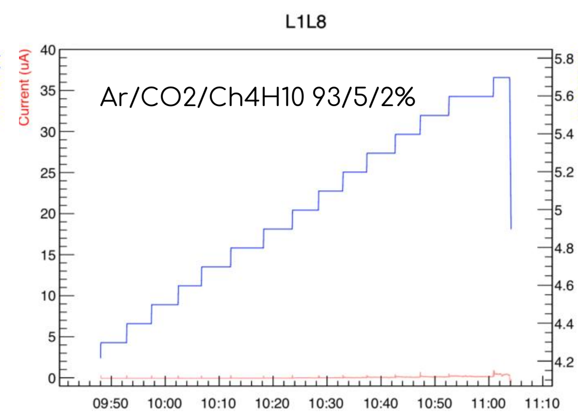




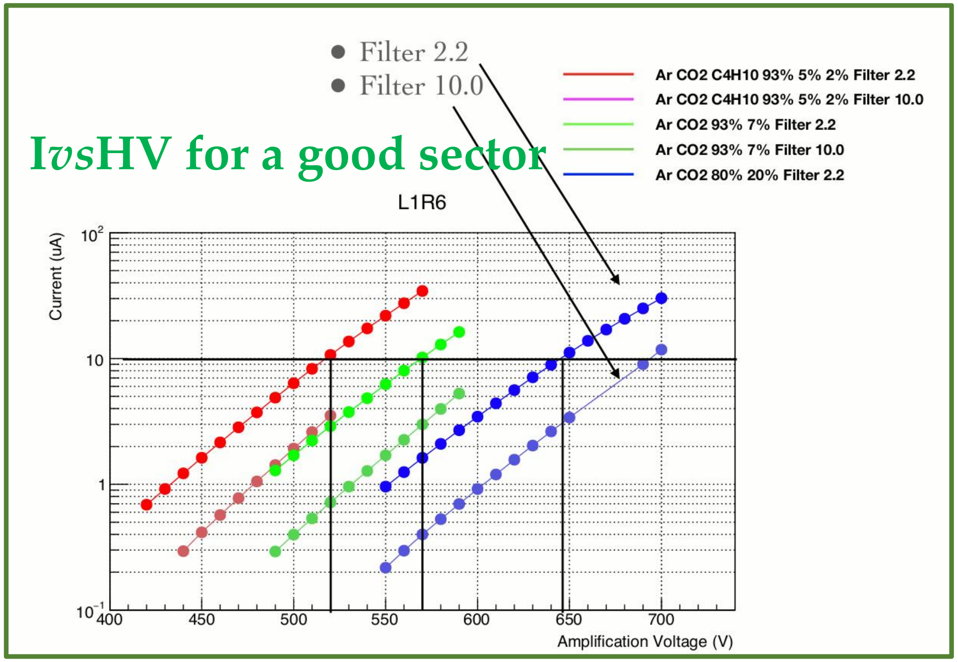
HV ramp up on bad-behaving MM sectors, presently high spike rate:
- not much difference between the two binary mixtures
- **the addition of the small fraction of iC4H10 very effective on spikes suppression**



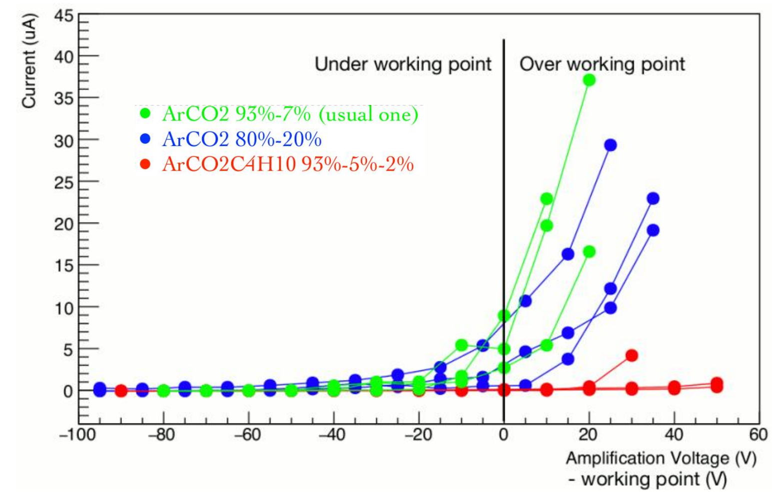




Test on different gas mixtures at GIF++



IvsHV for bad sectors



- **iC4H10 allows to run at significantly lower amplification voltages**
- "Bad" HV-sectors behave better with the Isobutane enriched mixture
- Mixture with 20% CO_2 also look slightly better than the standard mixture

C4H10 seems to improve the sparking picture for NSW MMs

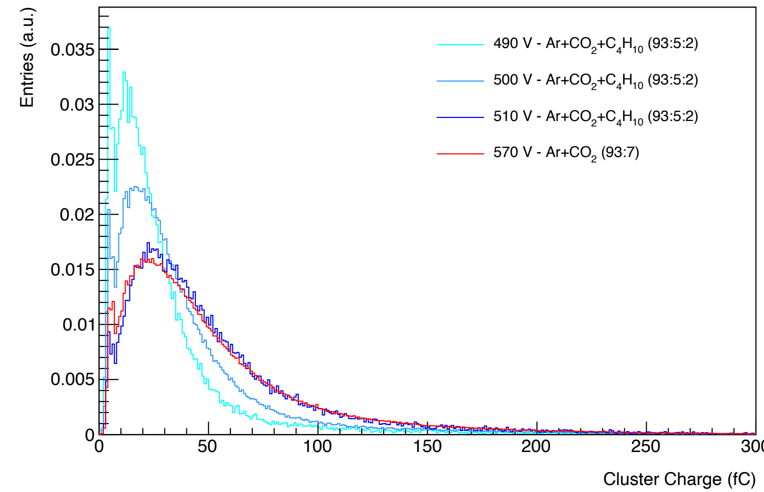
-> tends to create deposit (mainly for wire chambers)

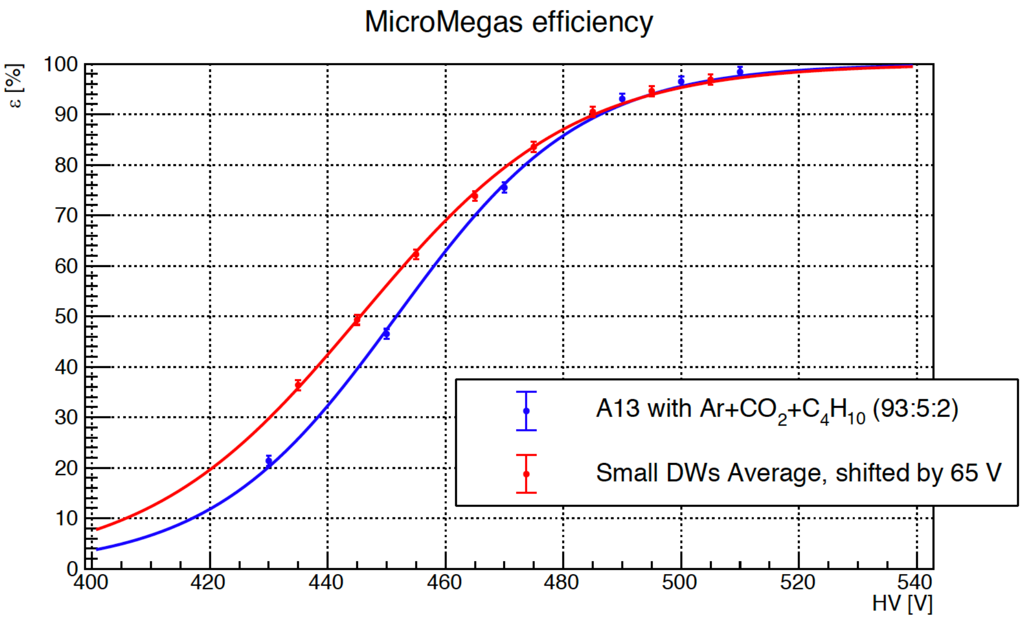
-> MM and in general MPDGs are known to behave better in term of ageing

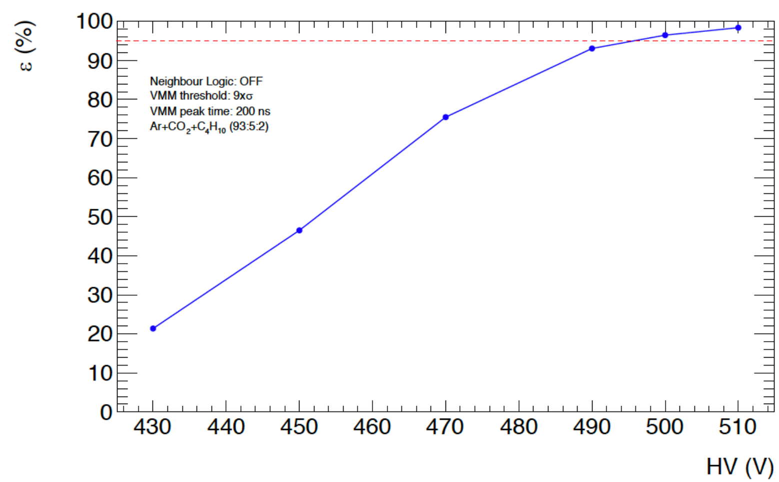
Results have been confirmed by several tests at costruction sites and by tests on Large DW at the DW Cosmic Station in bb5:

Isobutane allows to lower the working HV point while keeping:

- Same efficiency @ 495 V
- Same cluster charge @ 507 V
- Same strip charge/uTPC @ 520V







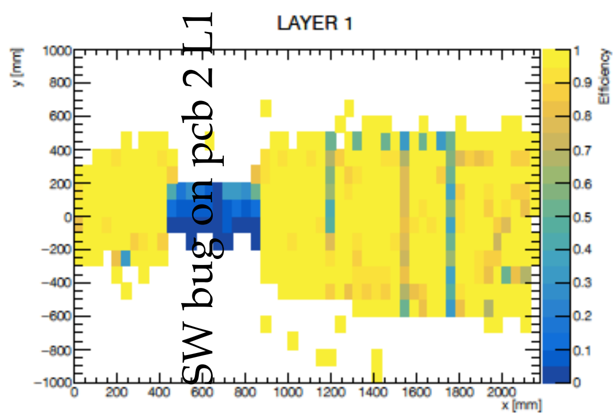
Test on different gas mixtures

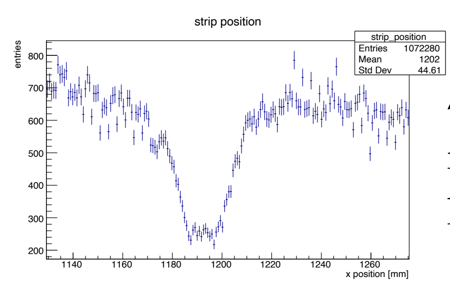
Long-term aging test on resistive MM performed with this gas mixture.

SM1 M31 has been tested at GIF++ under Iso enriched gas mixture for 4 months:

- L1L3 and L3L2 became resistive (L1L3 6.6 MΩ resistor -> succesfullty tried data taking in this demanding situation)
- L4L3 high current above 350V -> tested with pure Argon curing (Rui's recipe)

Sector (Layer PCB side)	HV [V]	Efficiency [%]	Sector (Layer PCB side)	HV [V]	Efficiency [%]
L1 1 PIN (L)	570	98.4	L2 1 PIN (L)	570	95.9
L1 1 NO-PIN (R)	570		L2 1 NO-PIN (R)	570	
L1 2 PIN (L)	570	3.8	L2 2 PIN (L)	560	94.5
L1 2 NO-PIN (R)	0		L2 2 NO-PIN (R)	570	
L1 3 PIN (L)	570 drawing 80uA	97.0	L2 3 PIN (L)	570	98.8
L1 3 NO-PIN (R)	560		L2 3 NO-PIN (R)	570	
L1 4 PIN (L)	570	96.3	L2 4 PIN (L)	570	97.9
L1 4 NO-PIN (R)	550		L2 4 NO-PIN (R)	570	
L1 5 PIN (L)	570	91.9	L2 5 PIN (L)	570	96.6
L1 5 NO-PIN (R)	570		L2 5 NO-PIN (R)	570	
L3 1 PIN (L)	570	96.9	L4 1 PIN (L)	570	97.0
L3 1 NO-PIN (R)	570		L4 1 NO-PIN (R)	570	
L3 2 PIN (L)	0	2.7	L4 2 PIN (L)	570	95.1
L3 2 NO-PIN (R)	570		L4 2 NO-PIN (R)	570	
L3 3 PIN (L)	570	75.5	L4 3 PIN (L)	530 with Keithley	78.9
L3 3 NO-PIN (R)	510		L4 3 NO-PIN (R)	570	
L3 4 PIN (L)	570	92.6	L4 4 PIN (L)	570	96.8
L3 4 NO-PIN (R)	530		L4 4 NO-PIN (R)	570	
L3 5 PIN (L)	570	97.0	L4 5 PIN (L)	570	90.4
L3 5 NO-PIN (R)	570		L4 5 NO-PIN (R)	550	
Module area at 570 V: 75.7 %			Mean efficiency = 84.7 %		
Total module bad sectors (HV < 550 V): 5 (12.5 %)			Mean efficiency without bad PCBs (3) = 94.8 %		

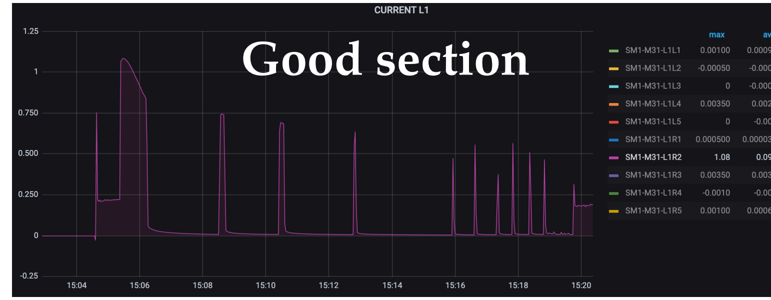




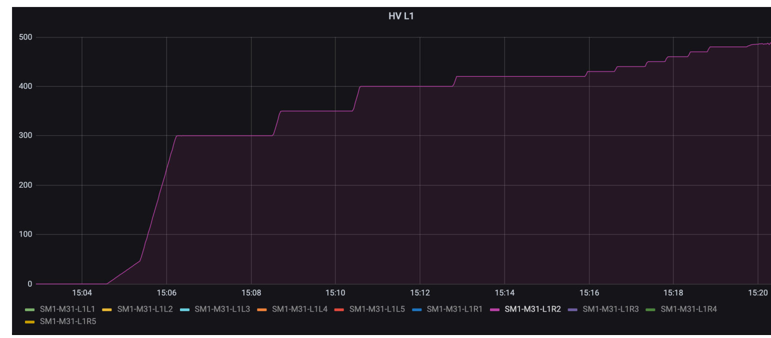
'hole' reveals resistor's place

Recovery procedure tried in pure Argon for M31 with Rui.

One highly problematic channel (L4L3) have been powered with the Keithley power supply up to 460 V in pure Argon.

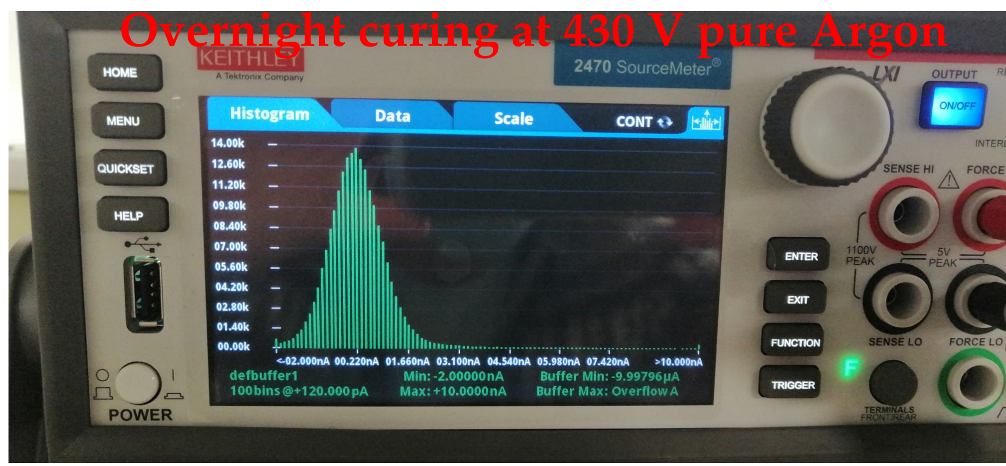


The idea: try to use Argon to clean the region by means of sparks -> need to stay in the working region

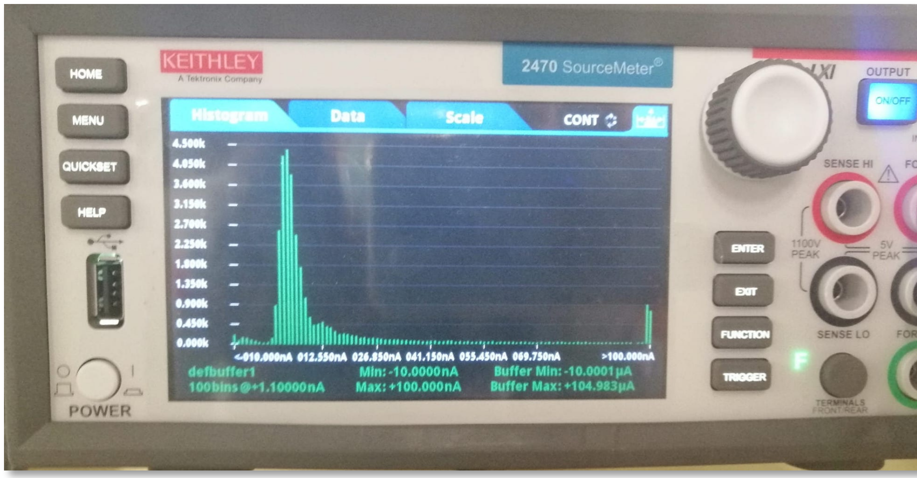


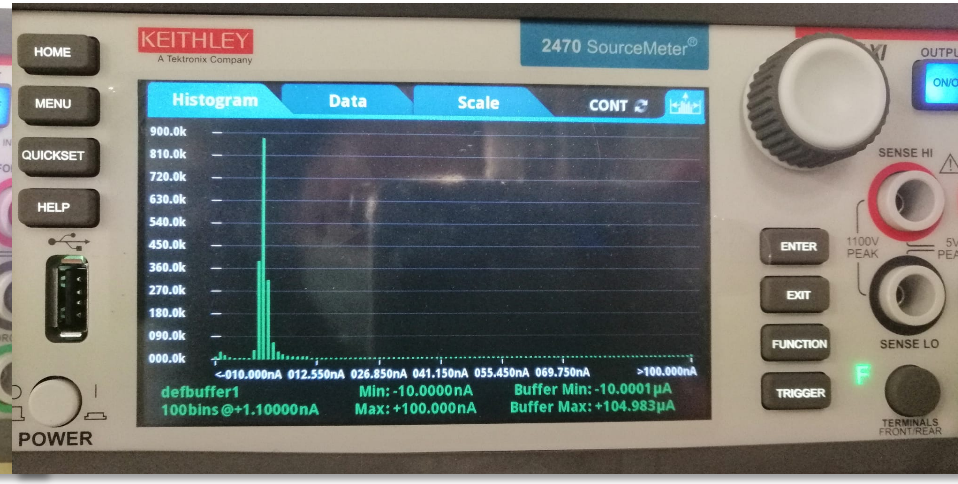
We used a very good sector to define the break down HV in pure Argon: 480 V
Then the aim was to try to go slowly up to that value using Keithley fo the bad behaving sector:

- First day up to 430V (easy up to 400V, then by steps of 5 V), left for the night, then next day up to 460V
- only 24 h
- need longer time to go further



L4L3 With Keythley at 530 V in ArCO2





L4L3 at 490 V in Iso

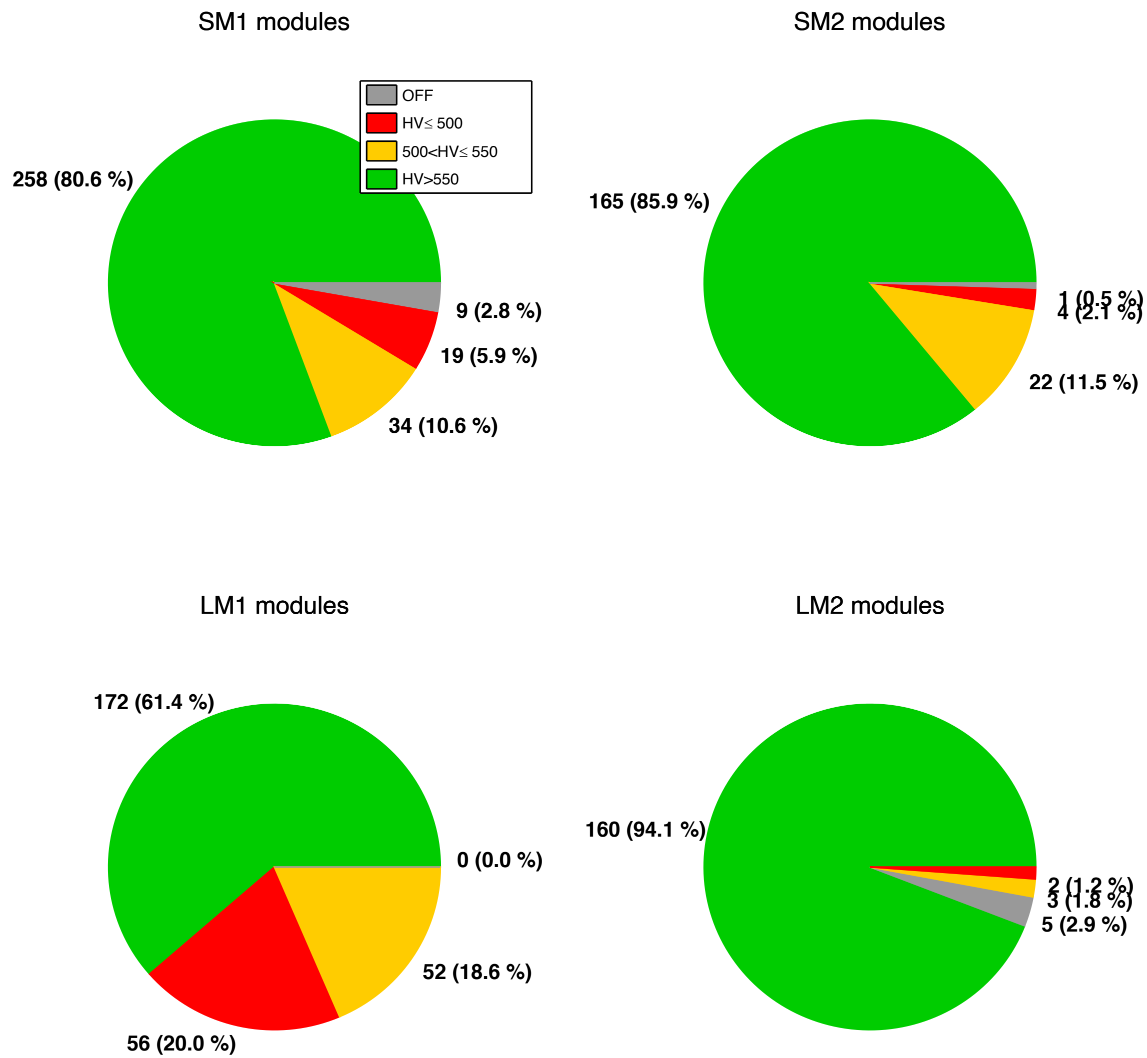
- M31 has been reopened at the hospital facility at CERN
- Visual inspection on this particular section has not shown signs of problems in the active area
- Not conclusive but promising

- NSW status up to now

Production wise:
- SM1 finished
- SM2 finished
- LM1 7 chambers to go
- LM2 6 chambers to go
- 3 chambers to be refurbished at CERN

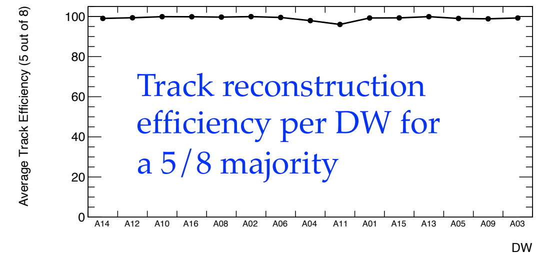
NSW A HV Status

HV statistics per pcb (half granularity scheme) on all the DW validated and accepted so far; i.e. 1 to go for the NSW A!

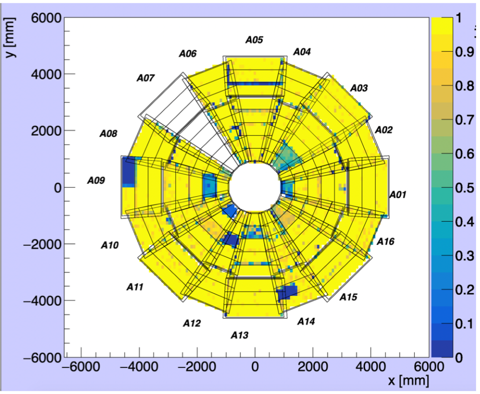


NSW A Status

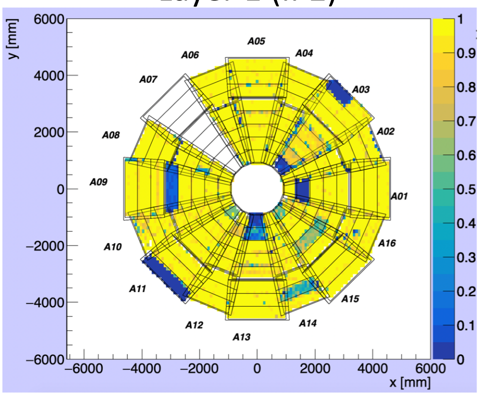
Display *on the wheel* of the measured efficiency for each layer of the NSW A measured with cosmics at the DW CRS in bb5



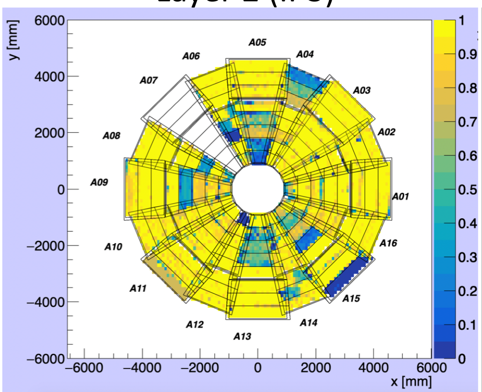
Layer 0 (IP1)



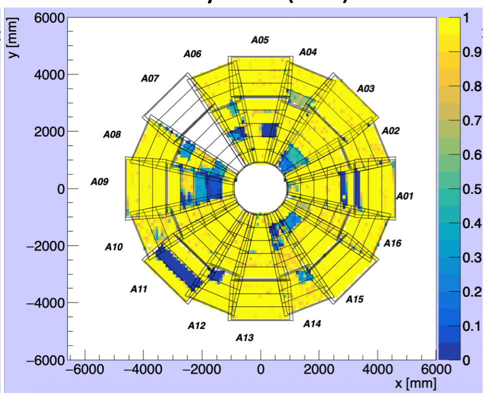
Layer 1 (IP2)



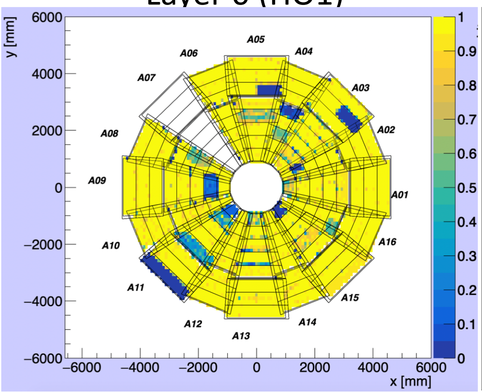
Layer 2 (IP3)



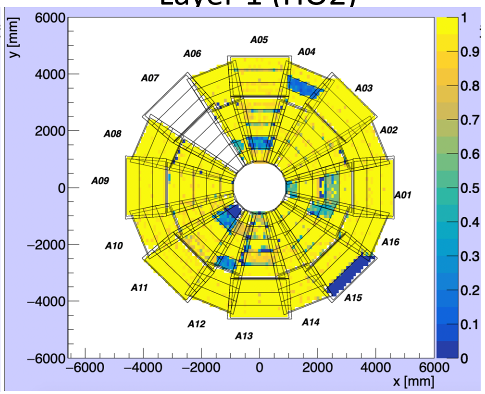
Layer 3 (IP4)



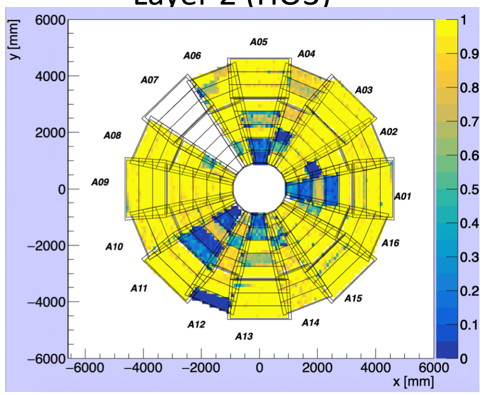
Layer 0 (HO1)



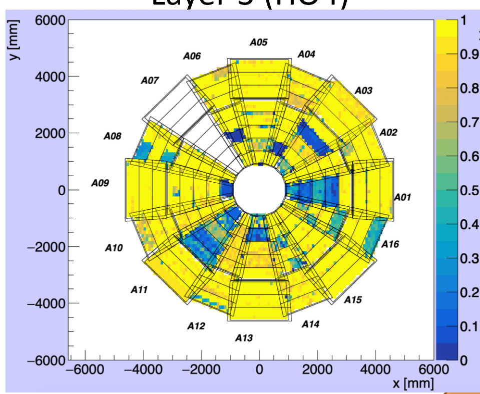
Layer 1 (HO2)



Layer 2 (HO3)



Layer 3 (HO4)



Conclusions

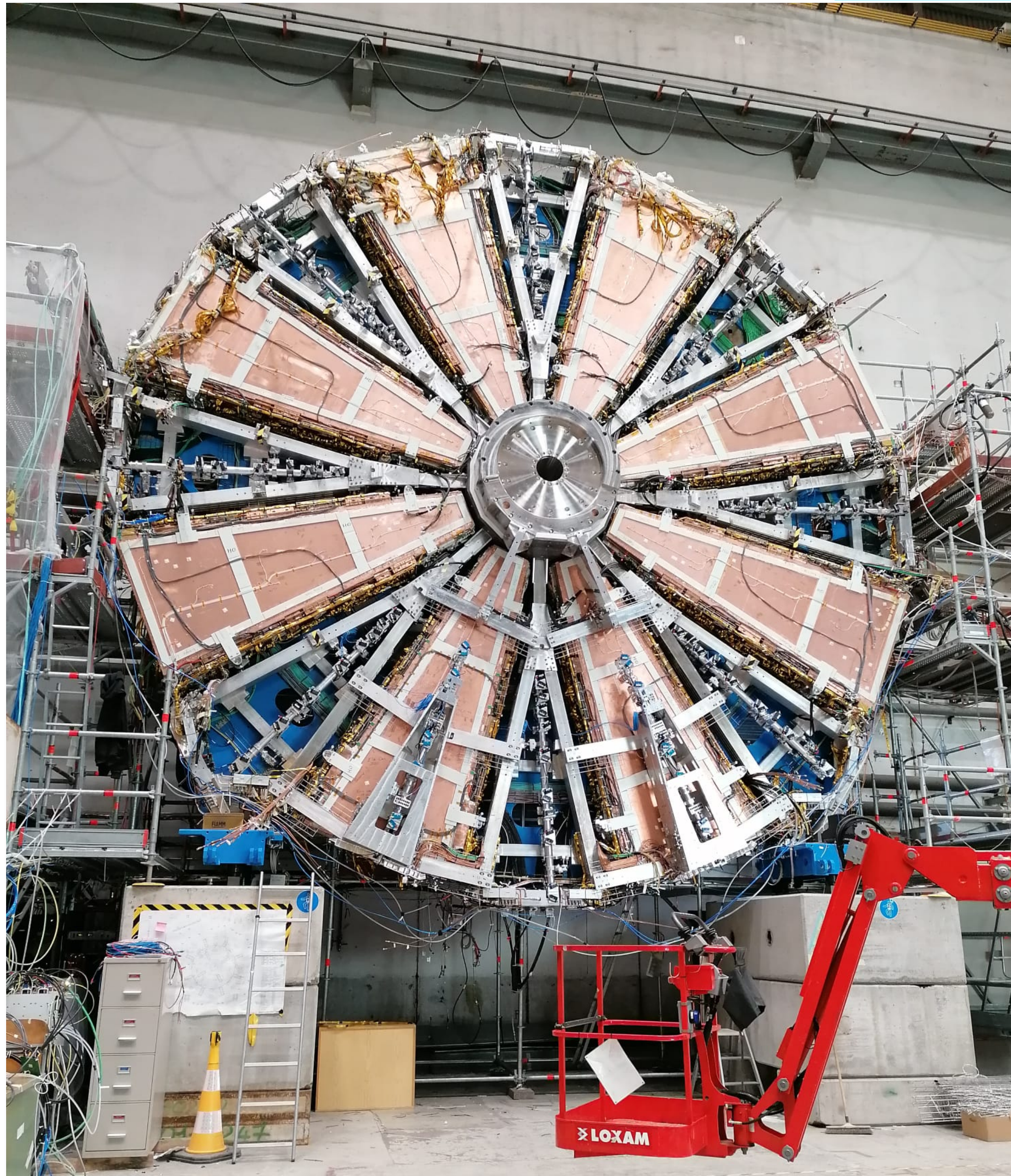
- Micromegas have been chosen for **their great performances in tracking particles up to high fluxes** in view of the increasing luminosity of LHC
- The **construction of such large area detectors presented many challenges** which have required further studies to be addressed
- The combination of the **low resistivity of the produced resistive foils** and a non-optimal **layout of the resistive-strip interconnection path**, produced **regions in the proximity of the silver line unprotected against discharges**
  - **The introduction of the passivation procedure allowed to cure the majority of HV issues but with the cost of** loosing some active area (particularly important for the smaller PCB at large eta)
- Studies with Isobuthane enriched gas mixture show promising results in terms of improving the HV stability of the chambers -> long term tests ongoing
- Test of possible curing with pure Argon started -> promising to recover sectors!

Conclusions

NSWA ->

DWs ready to go

on the wheel!



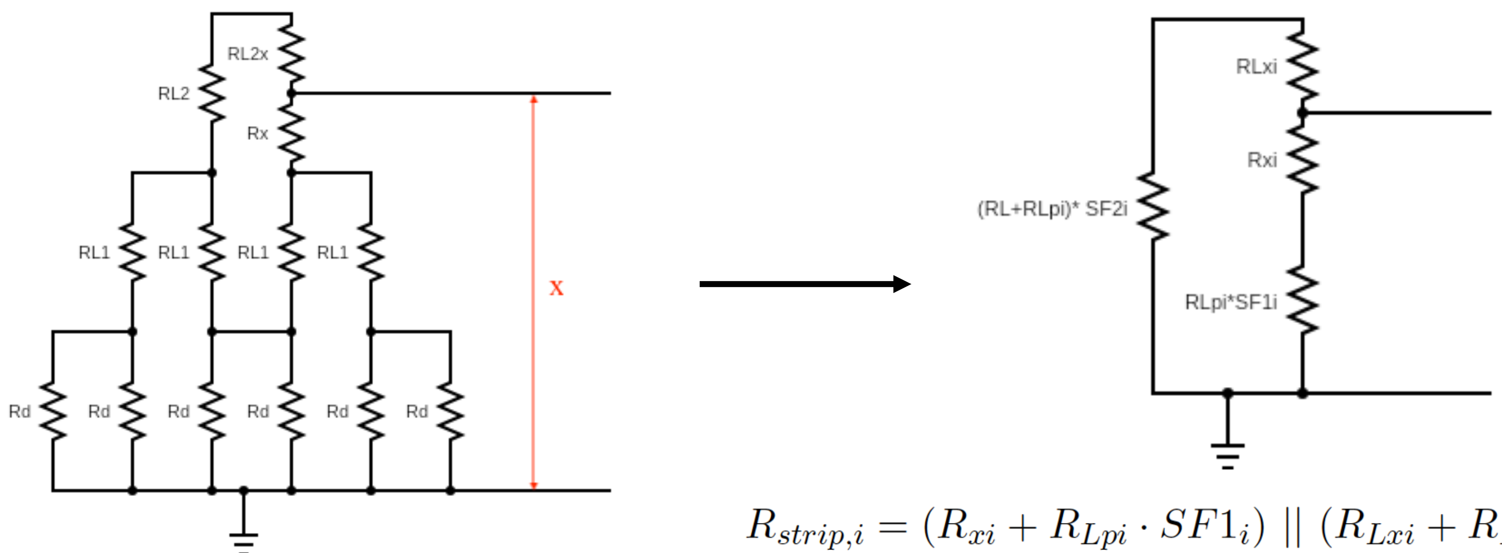
Thanks for your attention

Backup

PCB circuit model

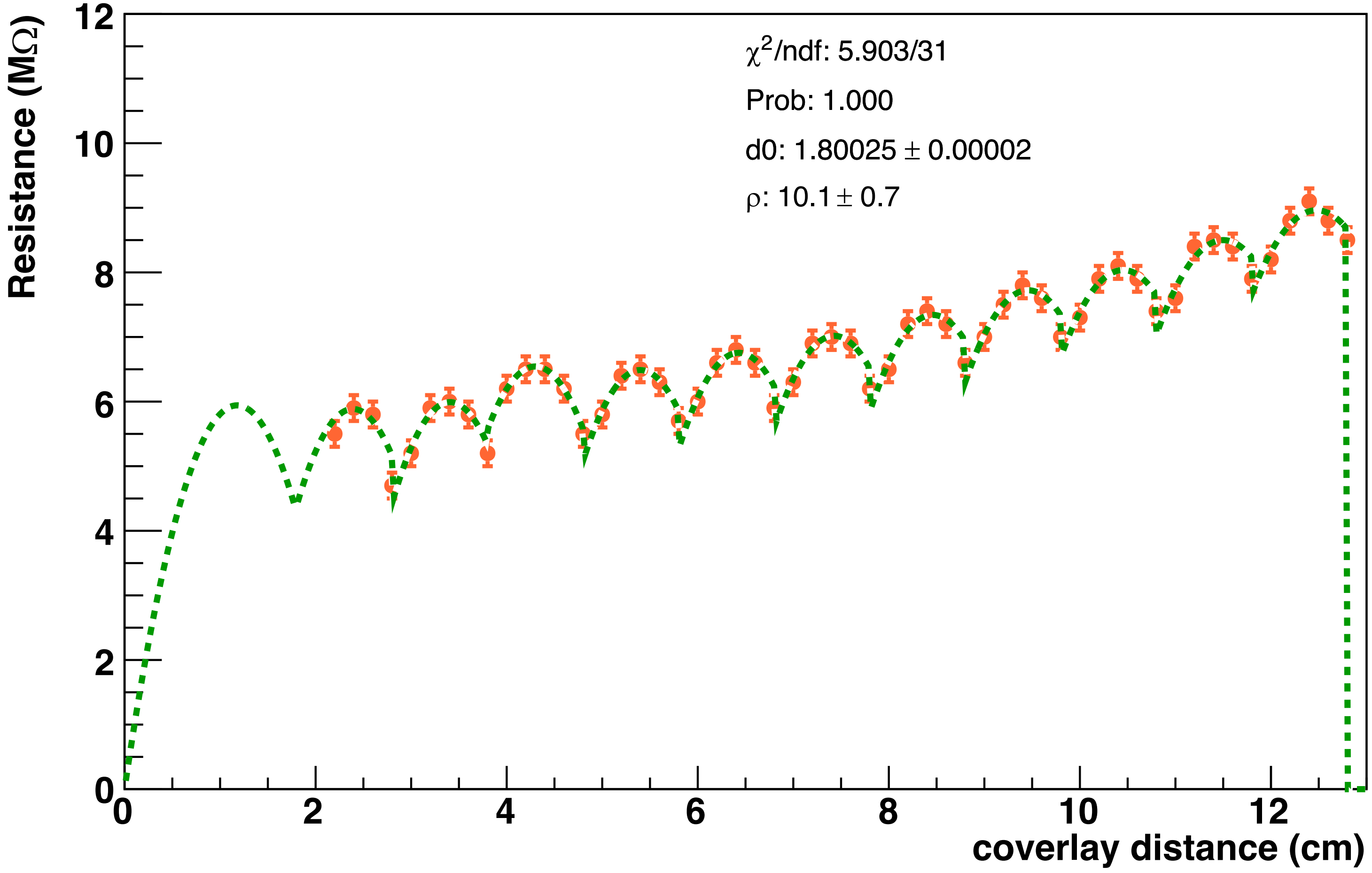
Build a model of the resistive PCB circuit to see the behavior of the resistance as function of the PCB layout

- Start from a simplified circuit scheme (on the right)
- 1D model of one strip as a step function based on the interconnection step *i*:
    - remap R of each ladder step in effective resistances which take into account the contributions of other parallels in the circuit which has been neglected introducing Scale Factors (SF) → Recursive model



$$R_{strip,i} = (R_{xi} + R_{Lpi} \cdot SF1_i) \; || \; (R_{Lxi} + R_{Lpi} \cdot SF2_i)$$

- Cosenza electrical resistance measurements on one strip (2 mm sample)
  → 1D model fit data up to twelfth interconnection



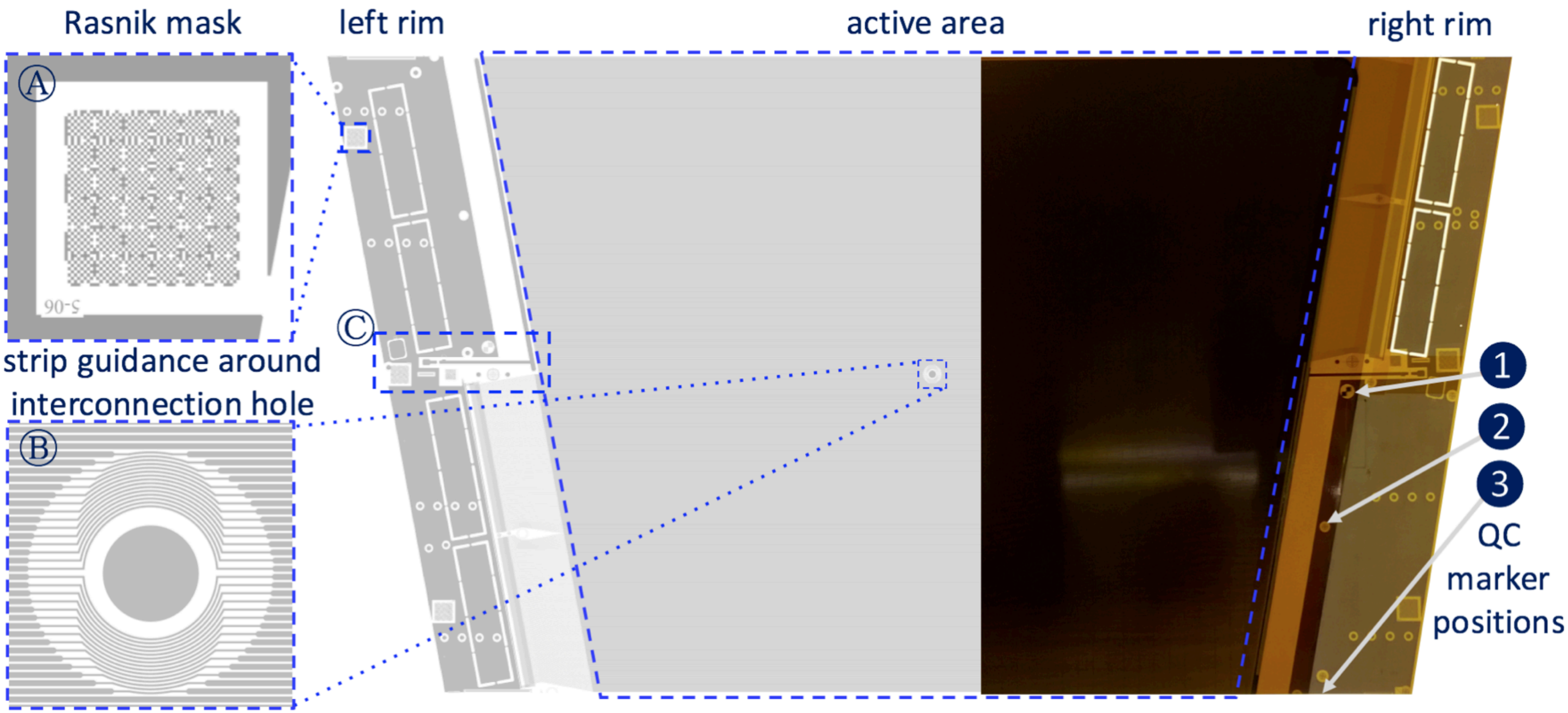


Figure 3. Drawing of a Micromegas anode PCB copper pattern (left) and picture of the finalized board (right). The location and structure of Rasnik masks (A), strip routing around holes (B) and the center of the rim area (C) (see figure 4) are shown, as well as the location of three quality control markers (see figures 5, 6 and 7).

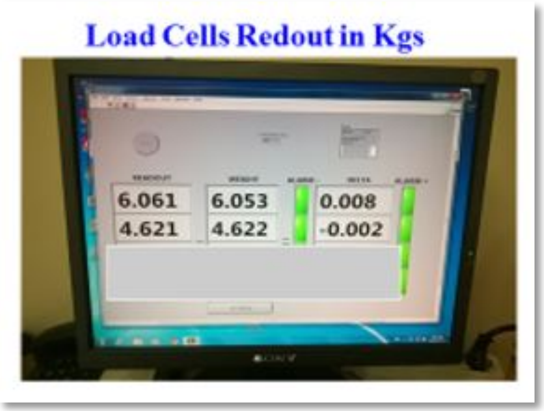
Dry cleaning and HV tests:

- Remove dust
- Clean with dedicated roller the surface of PCBs and Mesh using also a nitrogen gun
- check HV tests using the MeshTool
  -> HV test in air and gas leak test performed gap by gap
- Insert the 10 Pins 2mm diameter to align the Front End electronic boards

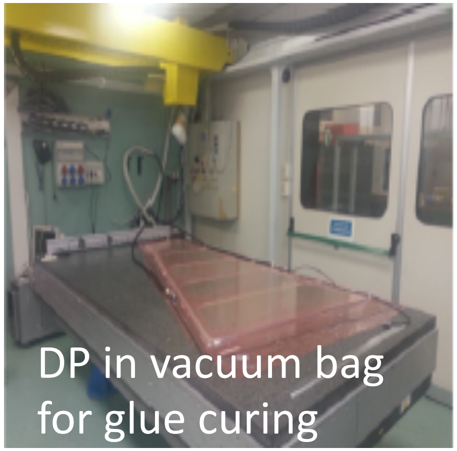
Alignment

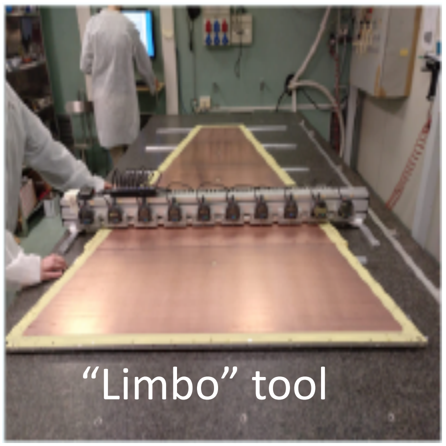
Panels need to be aligned one with respect to the other by alignment pins:

- Load Cells used on both sides of the panel
- Weight of panel loaded on alignment pins displayed on screen
- Micrometric screws turned slowly to reduce it as much as possible (< 200-300 gr)
- Then the panel is pushed towards the assembly structure



Drift panels construction



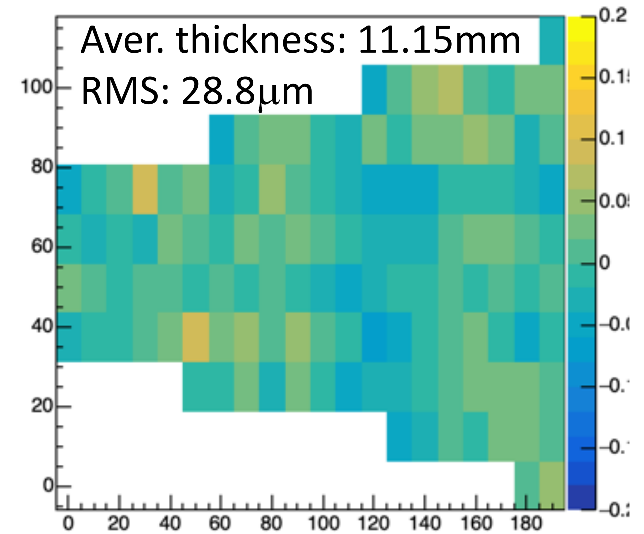


- Drift Panels for **SM1** assembled with the **vacuum bag technique** in Rome

- Dimensions of the components (PCB, frames, honeycomb) checked before use. The height is measured with a *linear height* or the *limbo tool*. In both cases the precision is of few microns.

- After panel assembly a HV of 1kV is applied between cathode and GND to check the electrical insulation.

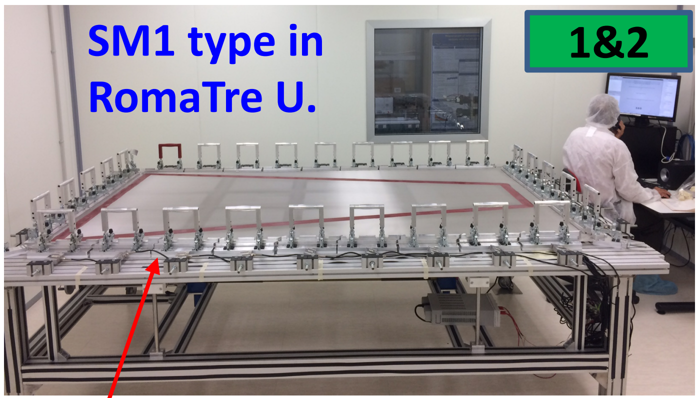
- The planarity (RMS) and the thickness are measured using the *limbo tool*.
- Requirements (RMS < 37μm)



- **Panels in all other production sites** (both Drift and Readout) **assembled by using a stiff-back panel** (or a mixed technique), obtaining similar quality about planarity

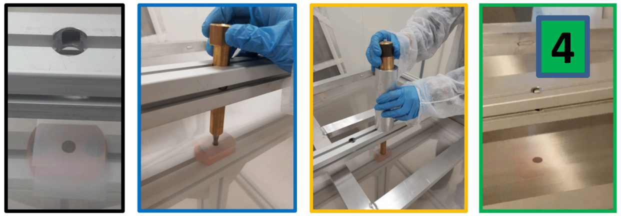
Mesh Stretching

1. Mesh clamping and stretching (to ~10 N/cm) with a custom made stretching device
2. Mesh gluing on trapezoidal transfer frame
3. Clamp release after glue curing and mesh cutting around frame
4. Perforations for interconnection holes
5. Washing and polishing with fine sandpaper
6. Gluing on bare drift panels

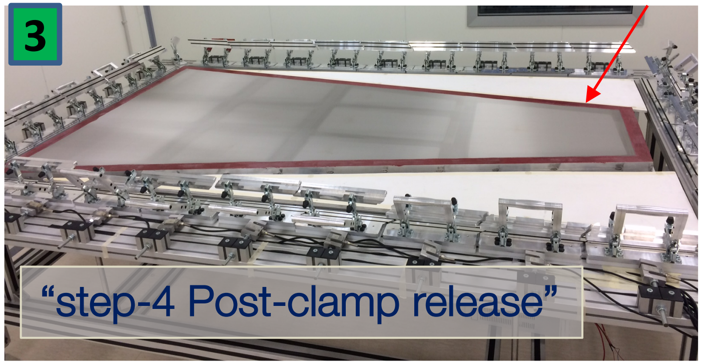


Load cell-connected clamp (28)

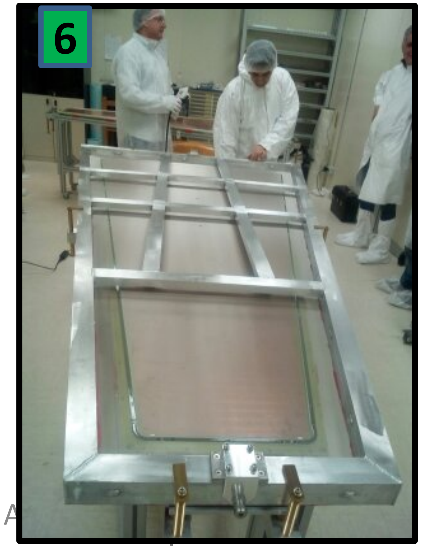
Mesh perforation



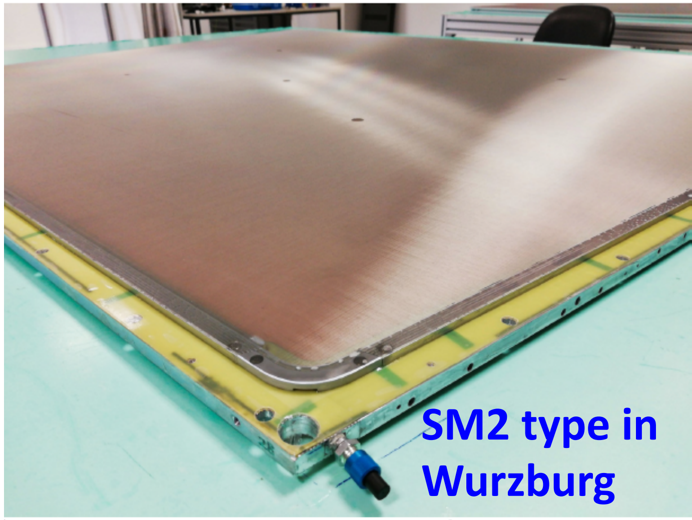
Trapezoidal frame



Mesh transfered on drift panel



The final Drift Panel



ReadOut panels construction

- **All RO panels are built by using the stiff-back method** (first layer on the granite table, second layer on a separate stiff-back plane)

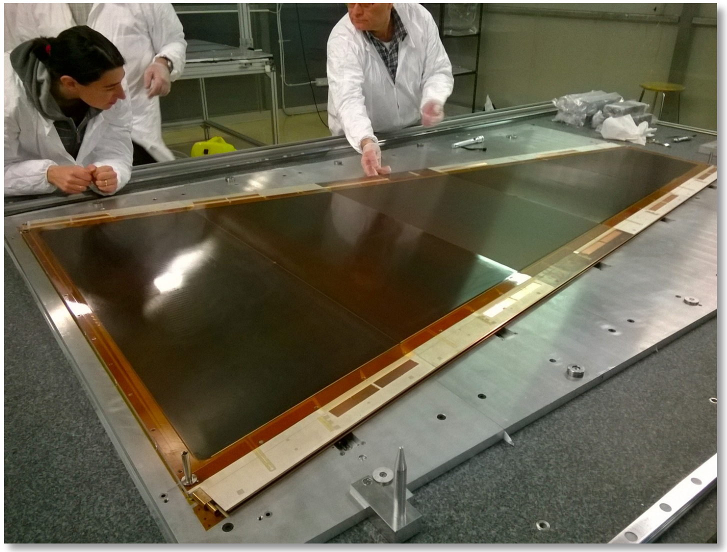
- Requirements on panels planarity fully satisfied in all production sites

- QA/QC on alignments between PCBs and between layers of paramount importance
  - absolute alignment of the strips $\Delta\eta < 40\ \mu m$
  - relative alignment of the layers $\Delta\eta < 60\ \mu m$

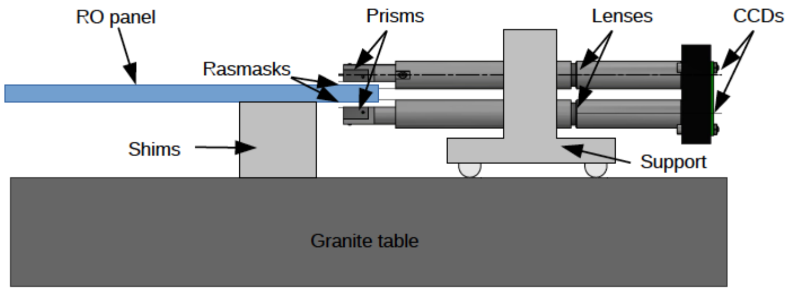
- Alignments between PCBs performed by using calibrated jig and Contact-CCD or gantry/optical CMM systems, depending on sites, during construction

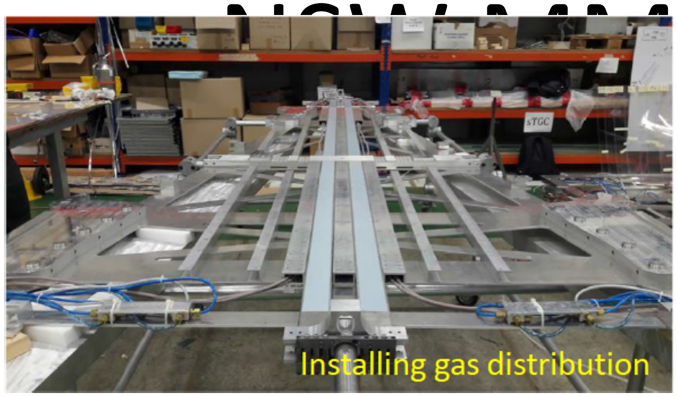
- Alignment between up and down layers measured via a rasfork tool (RASNIKtechnique)

ReadOut panel on granite table in Pavia

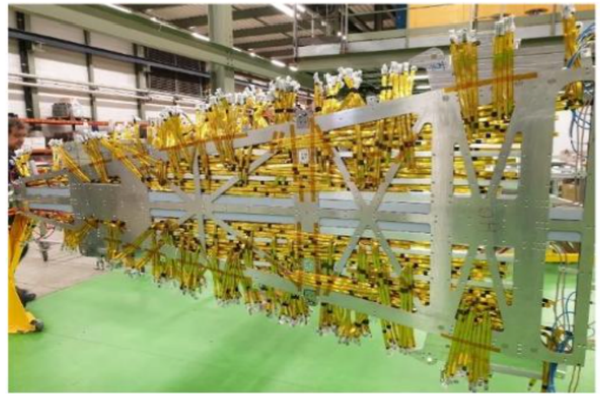


Concept of Rasfork measurements



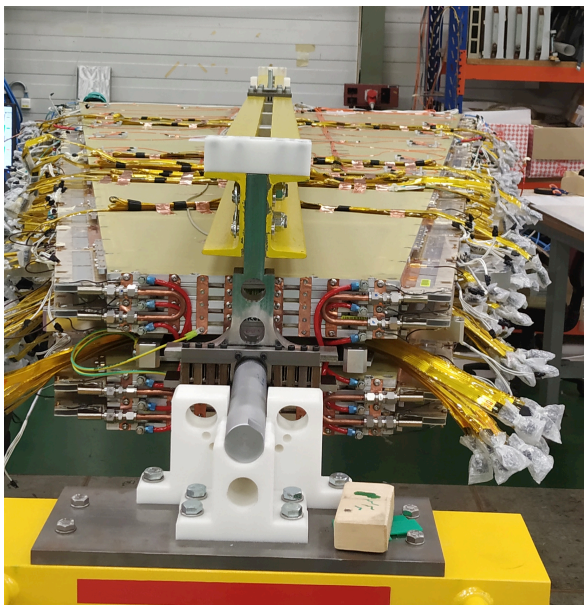


Installing gas distribution on the wedge support

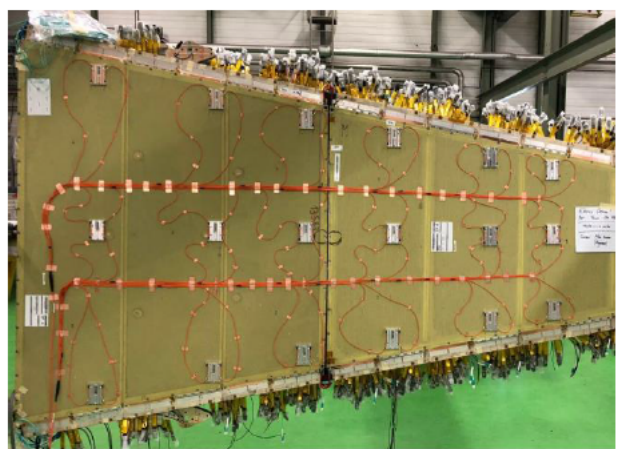


Readout and Trigger cables installation

Placing of chamber on the wedge support



Both chambers on the wedge support

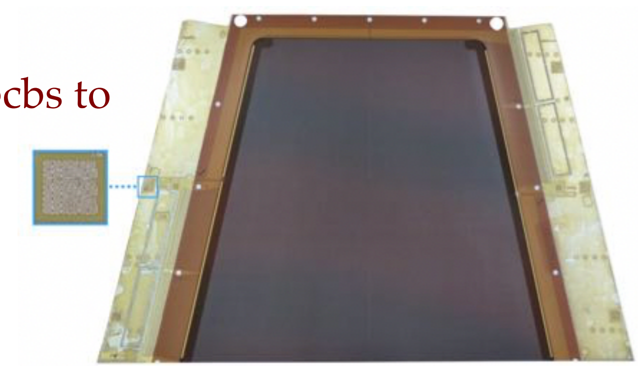


Routing of optical fibers for alignment

Installing Readout front-end cards

Alignment:

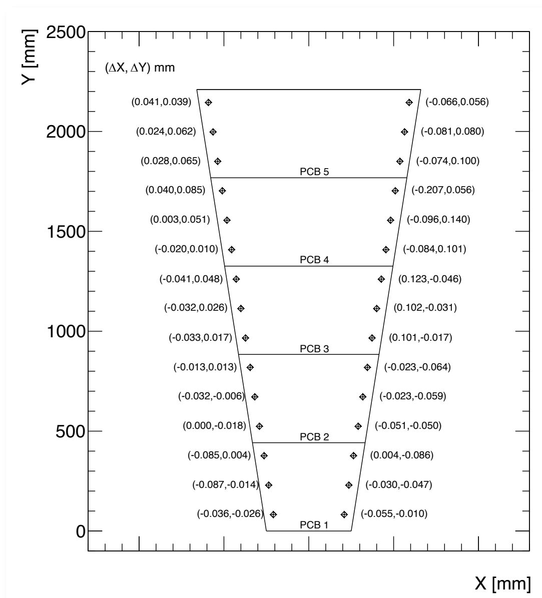
- mechnical supports to the PCB during panel construction
- coded masks read by contact-CCD on the external side of pcbs to ensure for the alignment and rotation of the strip:
  - absolute alignment of the strips $\Delta\eta < 40\ \mu m$
  - relative alignment of the layers $\Delta\eta < 60\ \mu m$

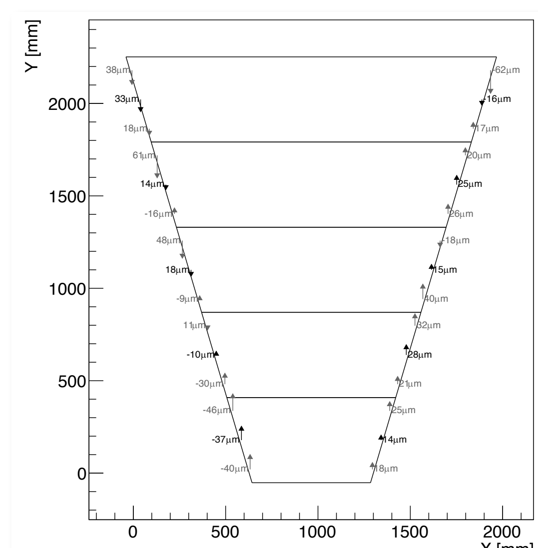


Rasnik technique:

optical measurements of reference masks etched on the boards, aligned with the strips.

Return the relative alignments of boards side-to-side measuring position bias between top and down masks at <10 μm

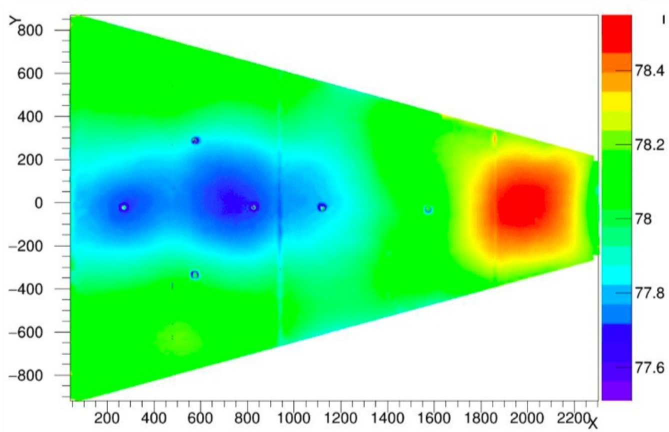




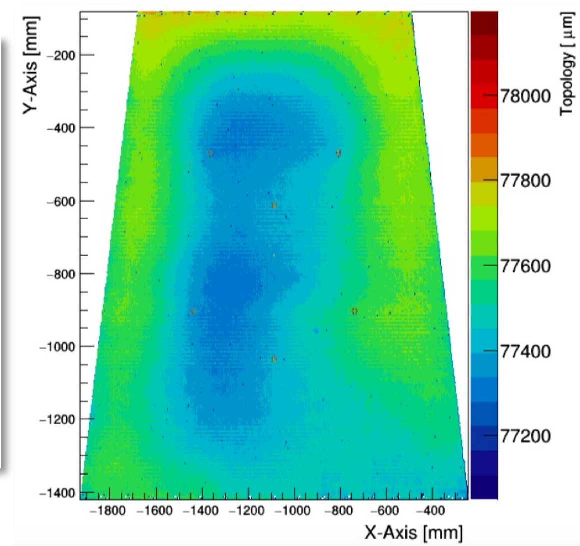
Planarity

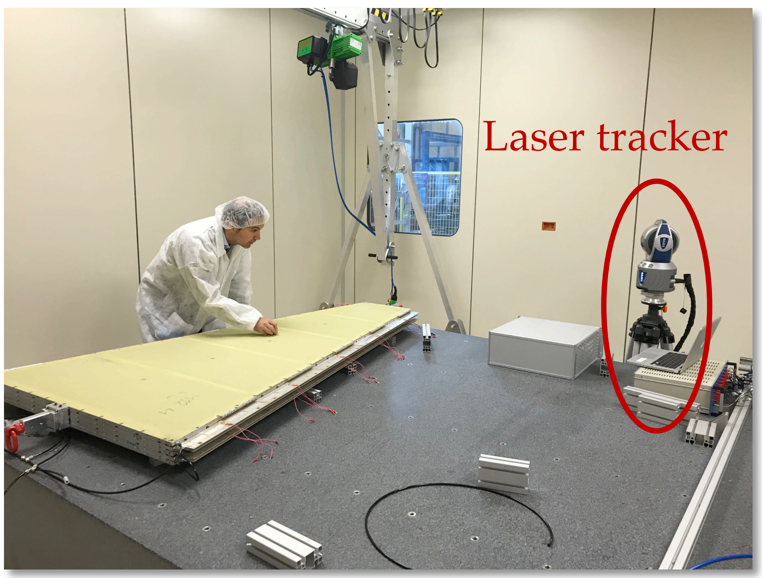
- Measurement of the planarity of the chambers surfaces via different methods
- Maps of the 2 surfaces
- Fit of the point-clouds
- Thickness: Δz between sides
- RMS ~100 μm

Thickness = 78.06 mm
RMS = 0.18 mm

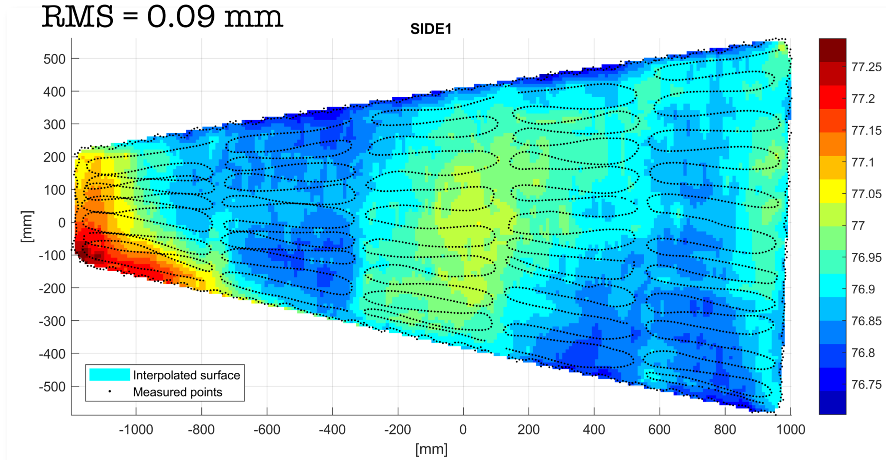


Thickness = 77.51 mm
RMS = 0.11 mm





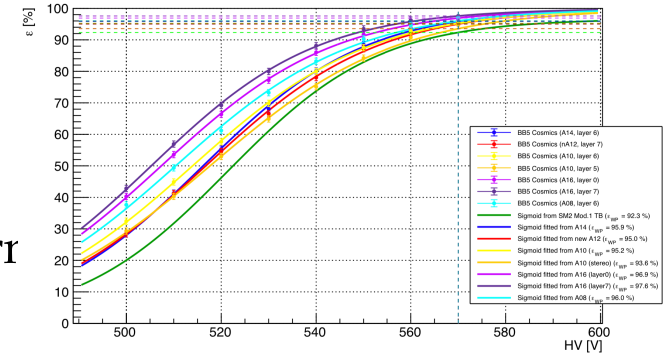
Thickness = 76.91 mm
RMS = 0.09 mm



Effects of passivation

HV nominal efficiency on NSWA integrated sectors

- Nominal Efficiency in Ar-CO2 used to validate the chambers (from NSWA Small DW statistics)
- Same criteria to validate in HV the DWs (with the turr on curve taken with SM2 Mod0 during testbeam)



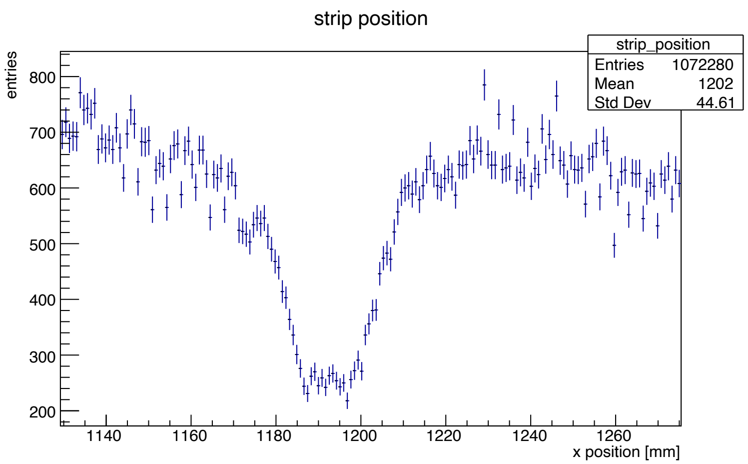
Summary of the HV Results of the Small DW validated so far:

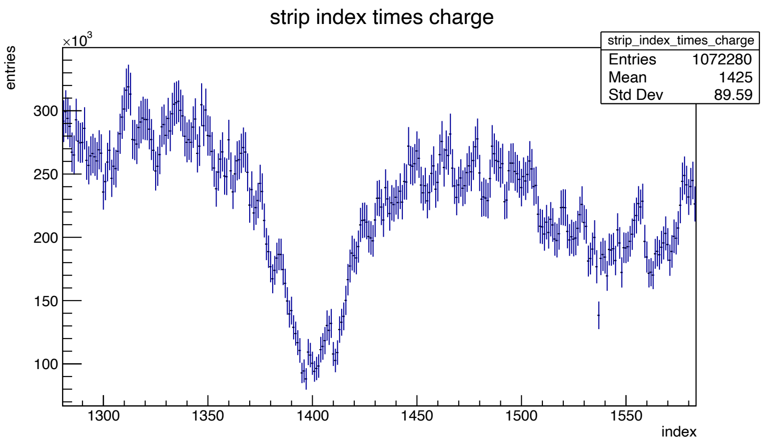
	Passivation	NE DW
A14	1/4	92.6%
A12	Yes	91.9%
A10	Yes	95.6%
A16	3/4	91.6%
A02	Yes	93.4%
A08	Yes	90.1%
A06	Yes	89.3%
A04*	3/4	85.3%

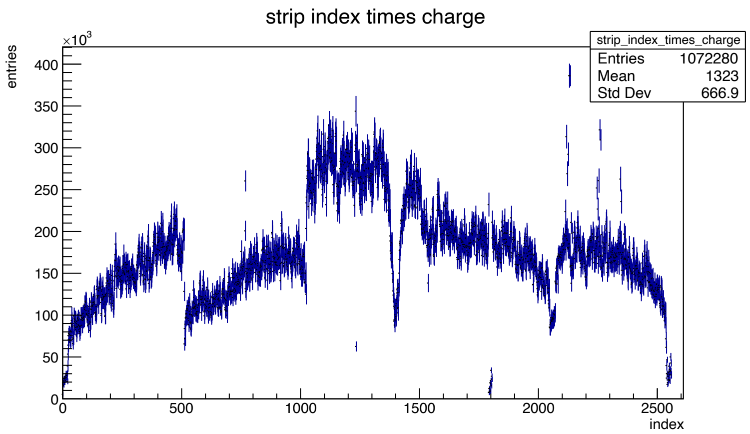
	Passivation	NE DW
A13* -> NA	No	53.9%
A11*	1/4	71.9%
A01*	Yes	80.6%
A15*	2/4	84.8%
A07*	Yes	81.2%
A05*	Yes	89.1%
A09*	3/4	85.3%
A03*	Yes	86.9%

* Tested with the new splitter box

- A13 tested in Iso -> Whole DW working perfectly at 490 V, but 2 sections at 480 V
- A11 tested in Iso -> Whole DW working perfectly at 490 V, but 2 sections off and 1 at 350 V as from Ar-CO2 test







Clear 'hole' in correspondace to the short region:
blind analysis see later

Introduction

GAS time line	20 Jul 2020	28 Aug 2020	7 Sept 2020	30 Sept 2020	16 Jan 2021
SM1 M31	in bunker Ar/CO2	switch to ISO	back to Ar/CO2	back to Iso	back to Ar/CO2

	14 Aug 20 (Ar/CO_2)	3 Sept 20 (Isob)	1 Oct 20 (Isob)	15 Nov 20 (Isob)	17 Dec 20 (Isob)	16 Jan 21 (Isob)	18 Jan 21 (Ar/CO2)
L1L3	570 V - 0.5 s/m	lost (resistive) 6% RH, 30 l/h	<= loss @30 mC				confirmed loss
L2L2	565 V - 0 s/m	490 V - 0 s/m	lost (resistive) 5% RH, 30 l/h	<= loss @30 mC			confirmed loss
L3L2	490 V - 0.24 s/m	490 V - 0.2 s/m	490 V - 0 s/m	lost std capacitive behaviour but unstable if HV>300 V 8% RH, 18 l/h	<= loss @1 mC		confirmed loss
L2L5	570 - 0.95 s/m	490 V - 0.4 s/m	**490 V - 4 s/m**	**strong spikes @ 490 V** tripping, switched off and slow recovery started	320 V slowly recovering	500 V - 0 s/m recovered	confirmed recovery
L4L3	540 V - 1.2 s/m	490 V - 0.4 s/m	490 V - 0 s/m	490 V - 7 s/m	lost (resistive) 7% RH, 18 l/h	<= loss @1 mC	confirmed loss
L1L5	570 V - 1 s/m	490 V - 0.5 s/m	490 V - 0.5 s/m	515 V - 7 s/m	recovering	520 V - 0 s/m	550 V noisy
L3R4	570 V - 2.8 s/m	490 V - 0.4 s/m	490 V - 0 s/m	475 V - 7 s/m	recovering	490 V - 0 s/m	520 V noisy