The Micromegas chambers for the ATLAS New Small Wheel upgrade

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on behalf of
the ATLAS Muon Collaboration

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Introduction

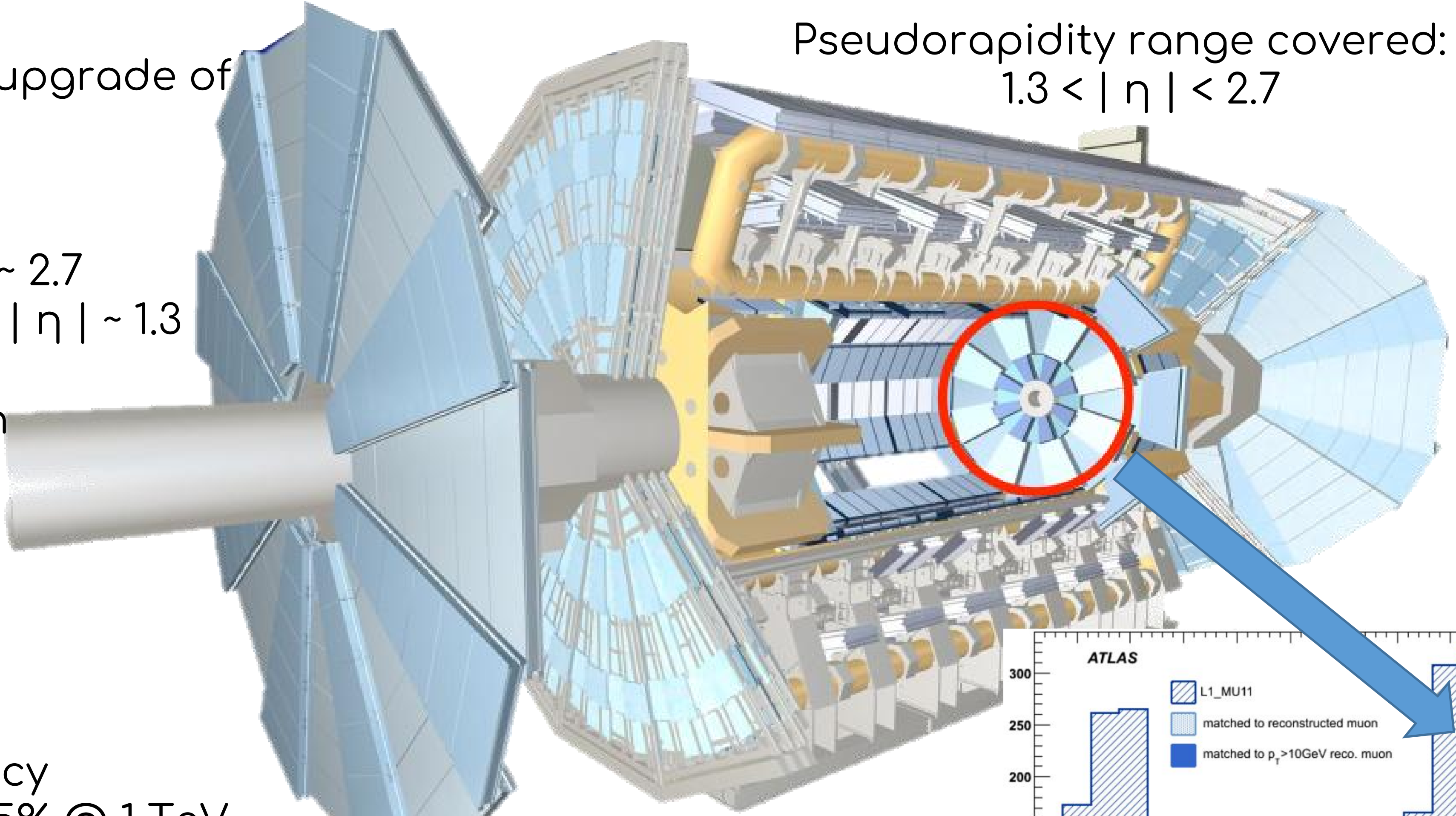
The New Small Wheel

One of the most important upgrade of the Long Shutdown 2

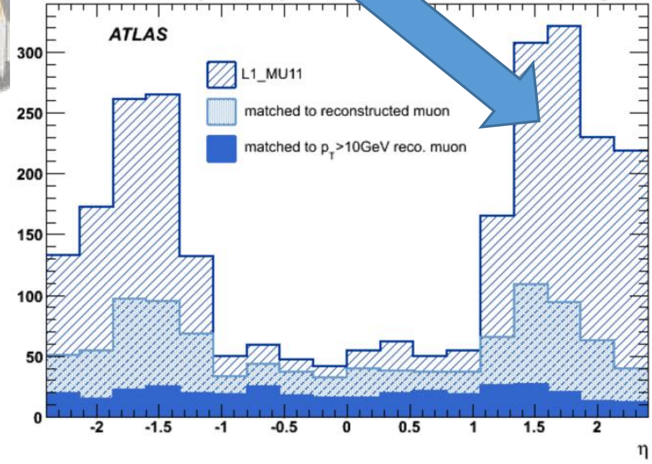
Expected to work at
~ 15 kHz/cm^2 @ | η | ~ 2.7
~ 500-600 Hz/cm^2 @ | η | ~ 1.3

=>MDTs efficiency reduction at high rate
to cope with the High Lumosity LHC Phase

Pseudorapidity range covered:
1.3 < | η | < 2.7



Single muon trigger efficiency
- P_T resolution better than 15% @ 1 TeV
- Huge **fake trigger rate** in the endcap region

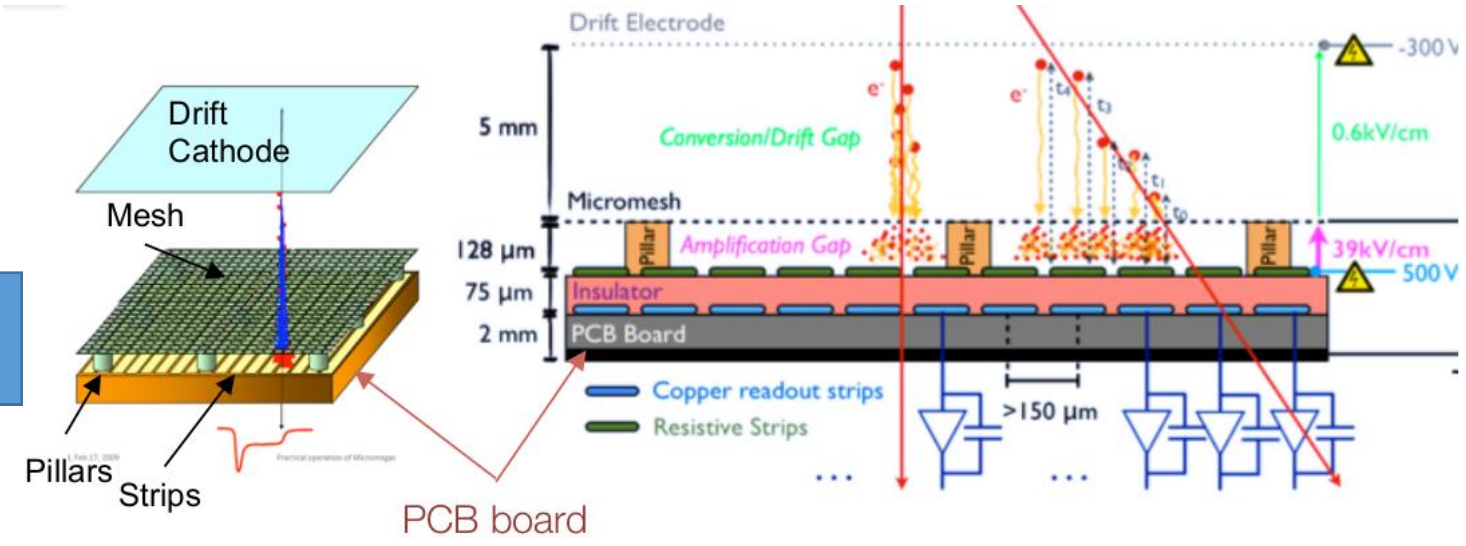


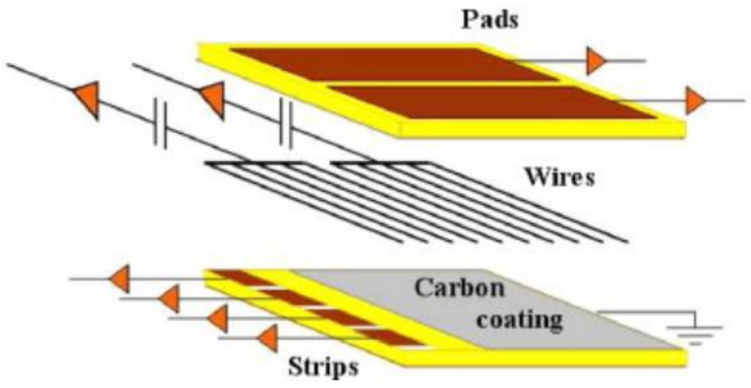
1 mrad + 100 μm (single hit) resolution needed

The New Small Wheel - detectors

MicroMegas
with Resistive Strips technology
as a Precision Tracker

- Spatial resolution ~ 100 µm
- Resistive anode strips to suppress discharge influence on efficiency
- Compromise to reach the rate capability required
- Providing online segments for trigger



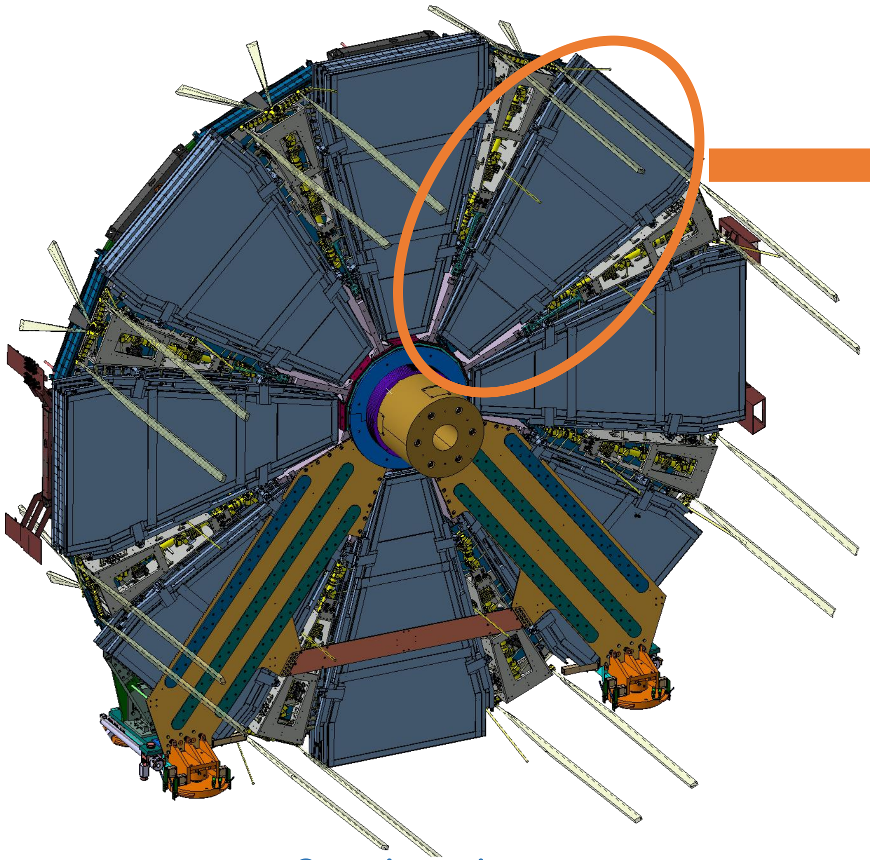


Small Thin Gap Chambers
as a primary trigger in the End Cap

- Bunch iD with good timing resolution
- Online track vector with <1 mrad resolution
- pads: region of interest
- strips: track info (strip pitch 3.2 mm)
- wire groups: coarse azimuthal coordinate

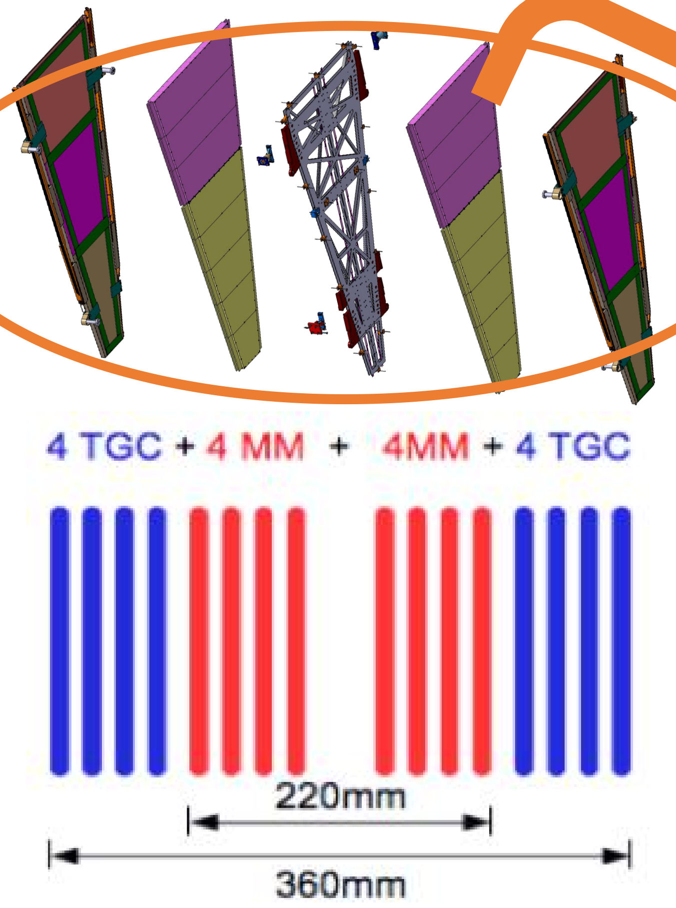
see Dennis Pudzha's talk

The New Small Wheel - substructure

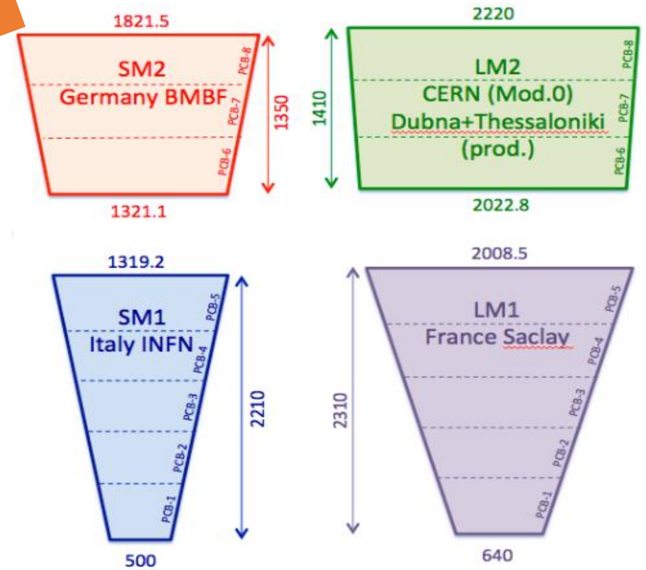


2 wheels
8 Small Sectors (IP Side)
8 Large Sectors (HO Side)

Total 32 Sectors
for the 2 wheels



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



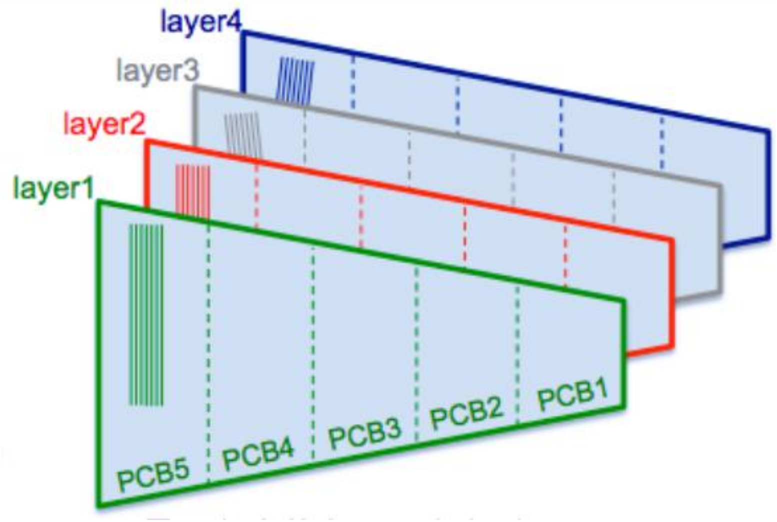
MicroMegas Wedges

are composed by

4 different Modules
(2 Small and 2 Large)
built in 5 different countries

The New Small Wheel - MicroMegas modules

Each module is composed by
4 layers - 3 or 5 PCB (see next slide)



2 planes with parallel strips
-> eta precision coordinate

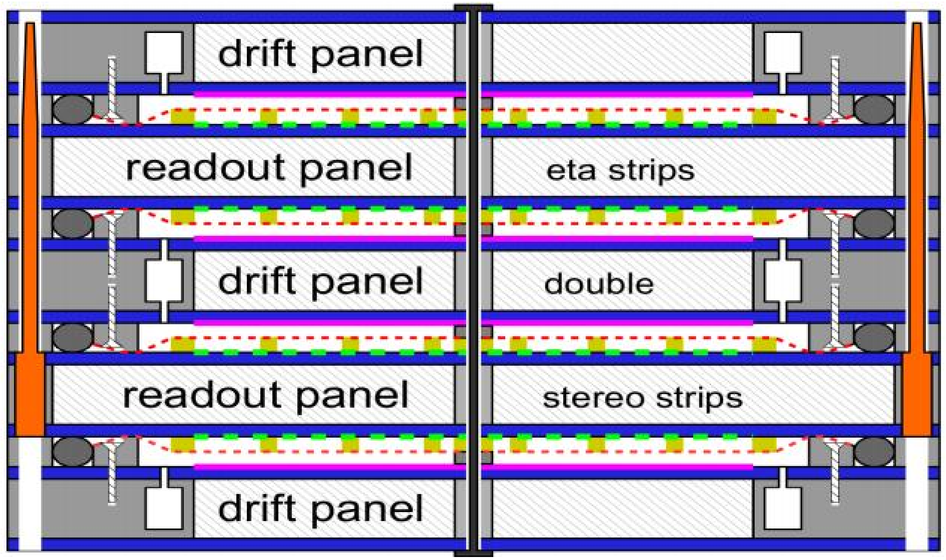
2 planes with 1.5° inclined strips
-> 2nd (phi) coordinate through stereo strips

Quadruplet:

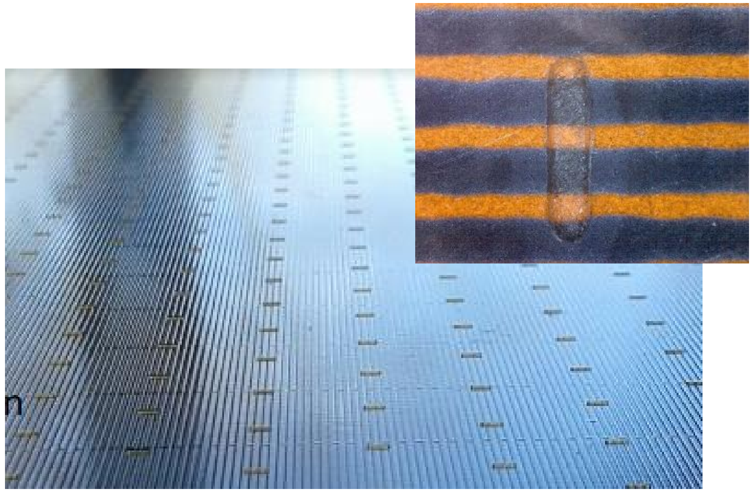
128 μm amplification gap, 5 mm drift gap

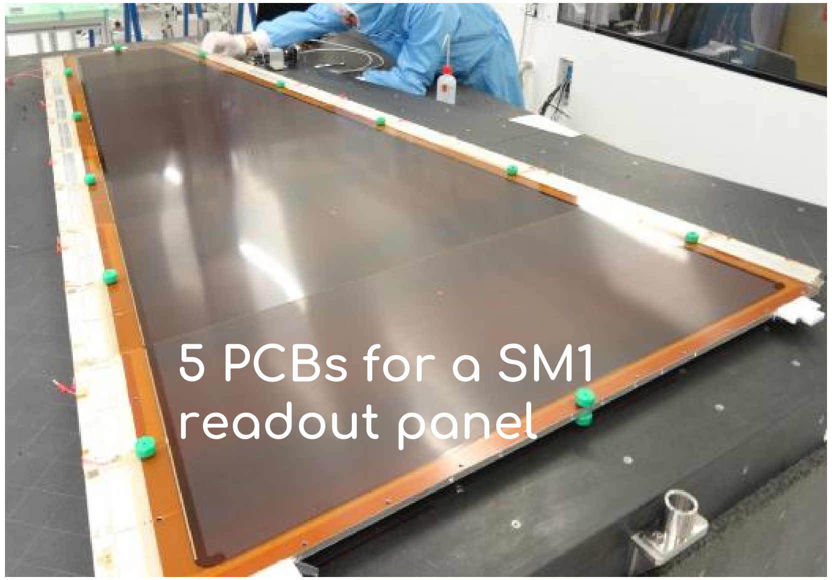
- 2 readout panels (eta or stereo) with double readout side
- 1 double drift panel (inner) with 2 meshes
- 2 single drift panels (outer) with 1 mesh each

→ **32 different types of readout** boards
→ 2176 PCB boards produced

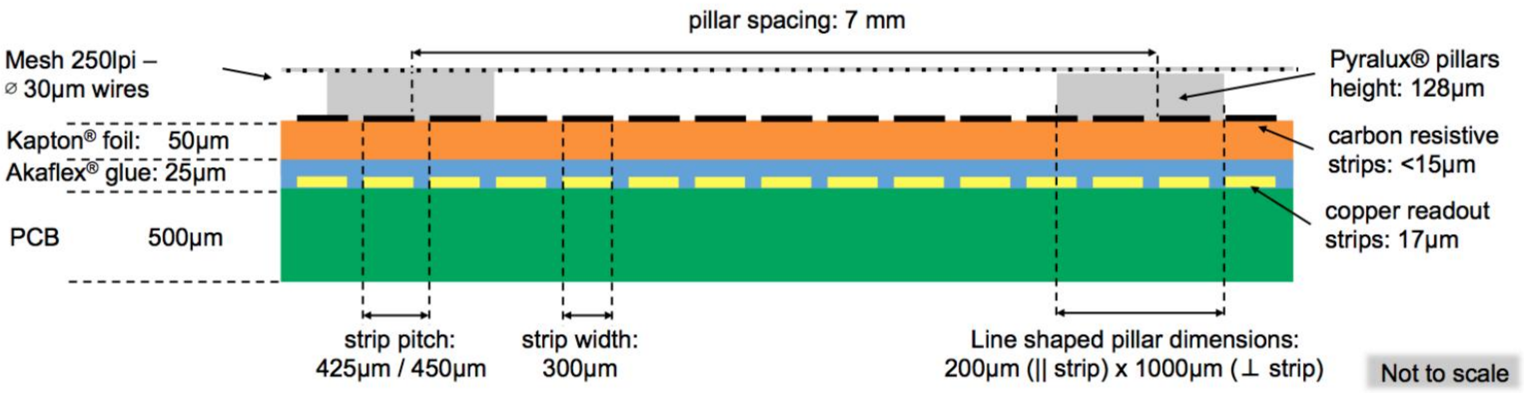


The New Small Wheel - MM Resistive Anode





PCB structure



Board dimensions: from 45x30 up to 45x220 cm^2

- 1022 strips/boards
- Strip width: 300 µm
- Strip pitch: 425/450 µm
- Pillar distance: 7.0 mm
- Readout strips pitch: 425 or 450 µm
- Pillar size: 1000x200 µm
- Pillars height: 128 µm

Resistivity
~800 kΩ/☐

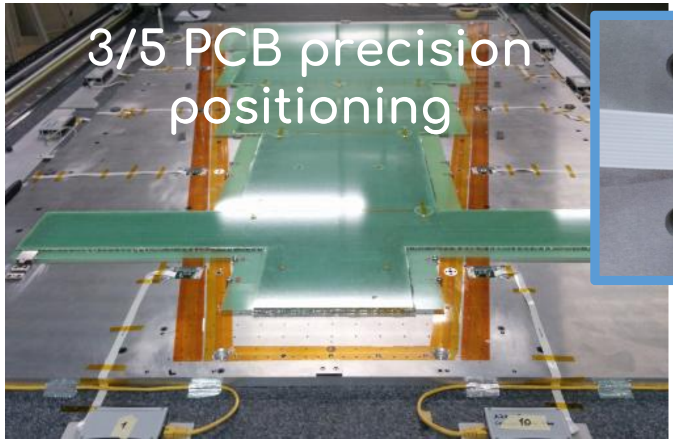
Alignment requirements:
30 µm RMS in η
80 µm RMS in z

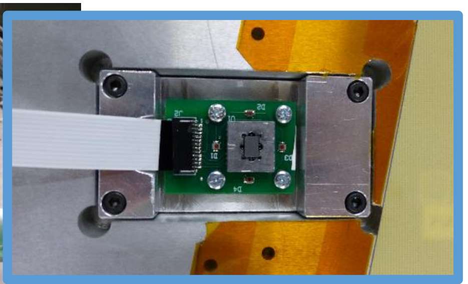
Modules Production

Modules Production - Construction Cycle

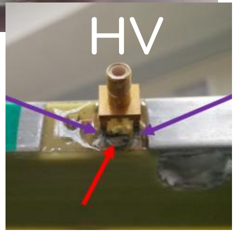
Poster session:
Irakli Minashvili

readout panel assembly





A CCD reading
a Rasnik mask



drift panel and mesh

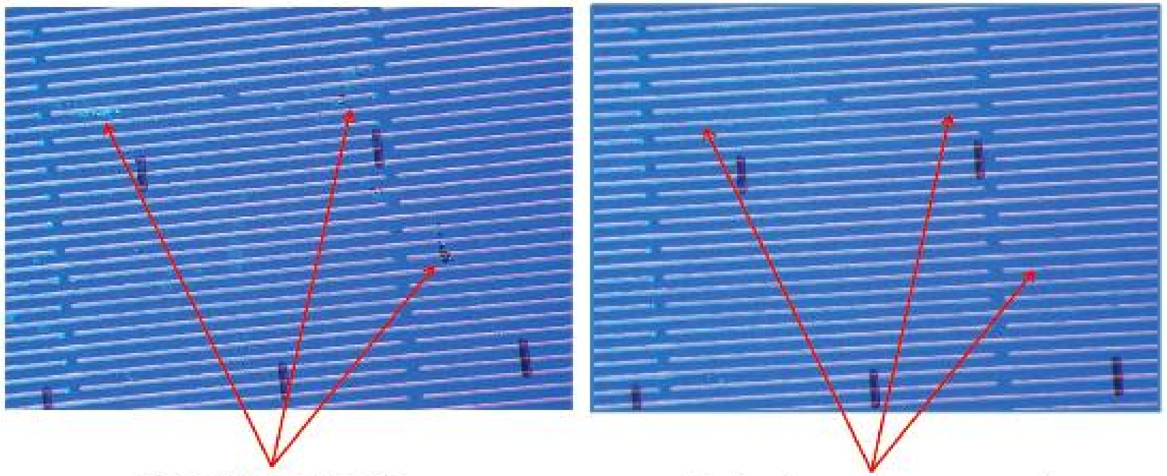
Modules Production - Construction Cycle: cleaning

Cleaning procedures:

readout panels

Before cleaning

After cleaning



Production remnants

Production remnants removed

Micropolishing cleaning procedure:

1. Hard and soft brushes with detergents
   (CIF - gentle polish action)
2. Washing
   with hot and demineralized water
3. Ventilated Oven-Drying at ~40°

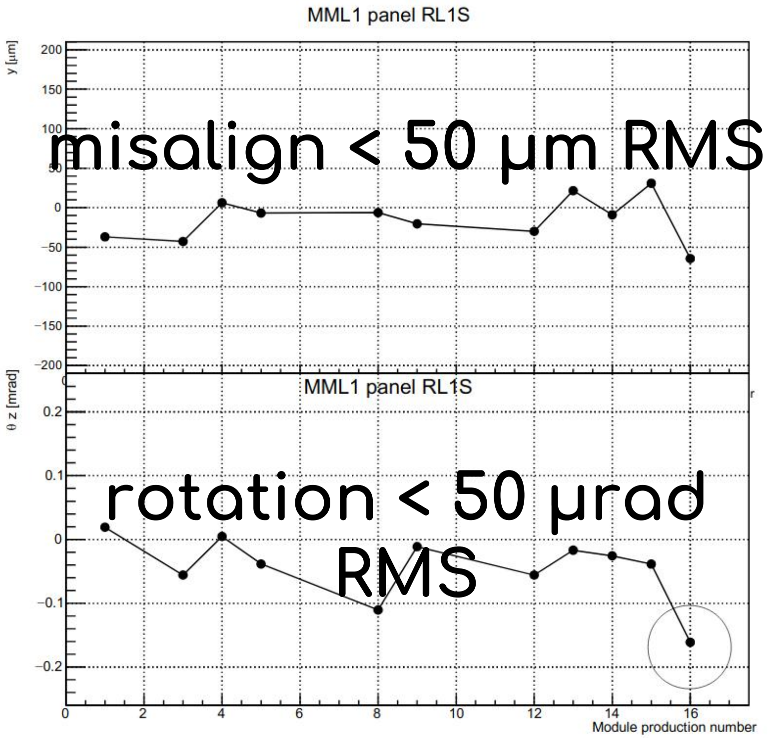
Modules Production - Mechanical tests on RO panels and assembled quadruplets

Mech Precision & Planarity

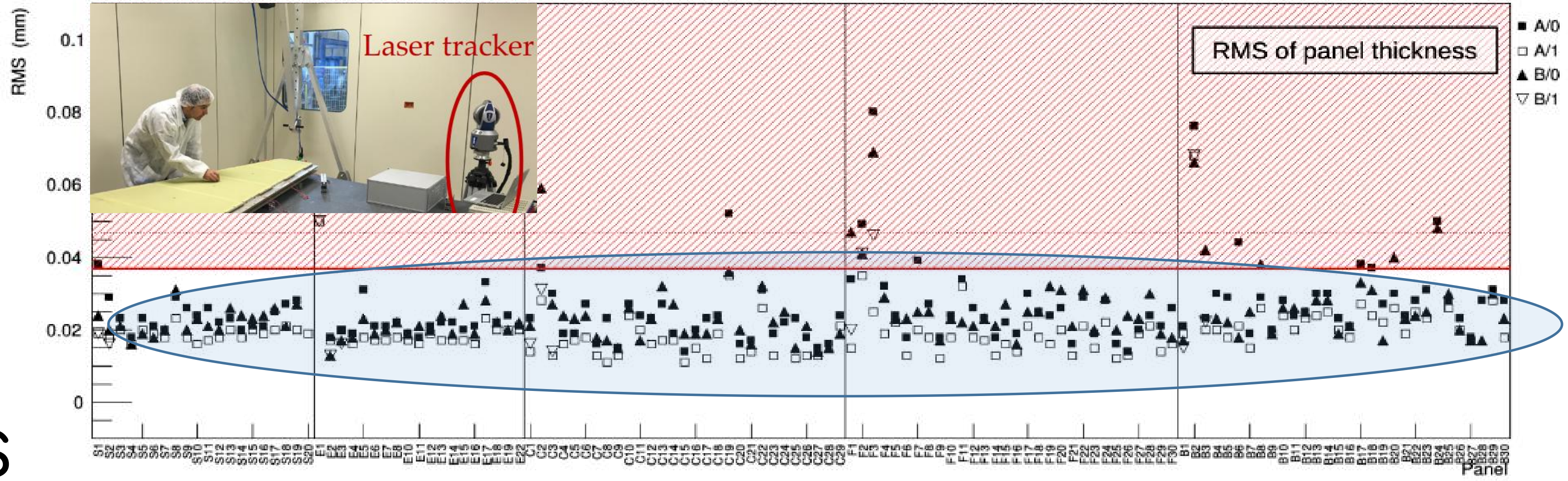
LM1 (ex)
panel to panel alignment
within a module:

misalign < 50 µm RMS

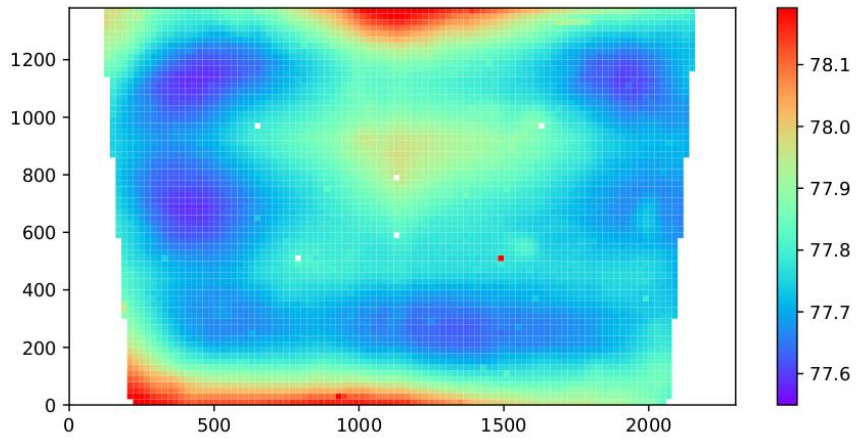
rotation < 50 µrad RMS

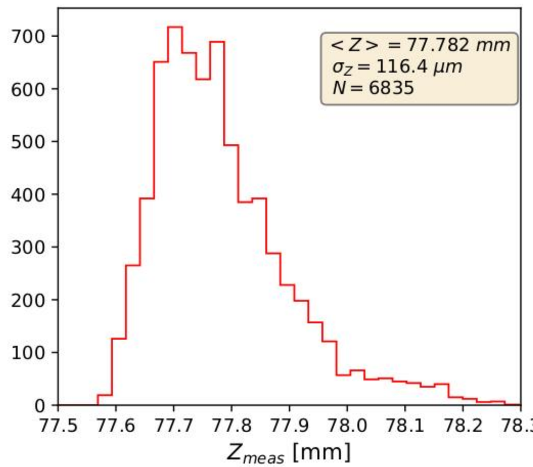


LM1 (ex) panel planarity (RMS): 20 µm



LM2 final module planarity (RMS): 117 µm



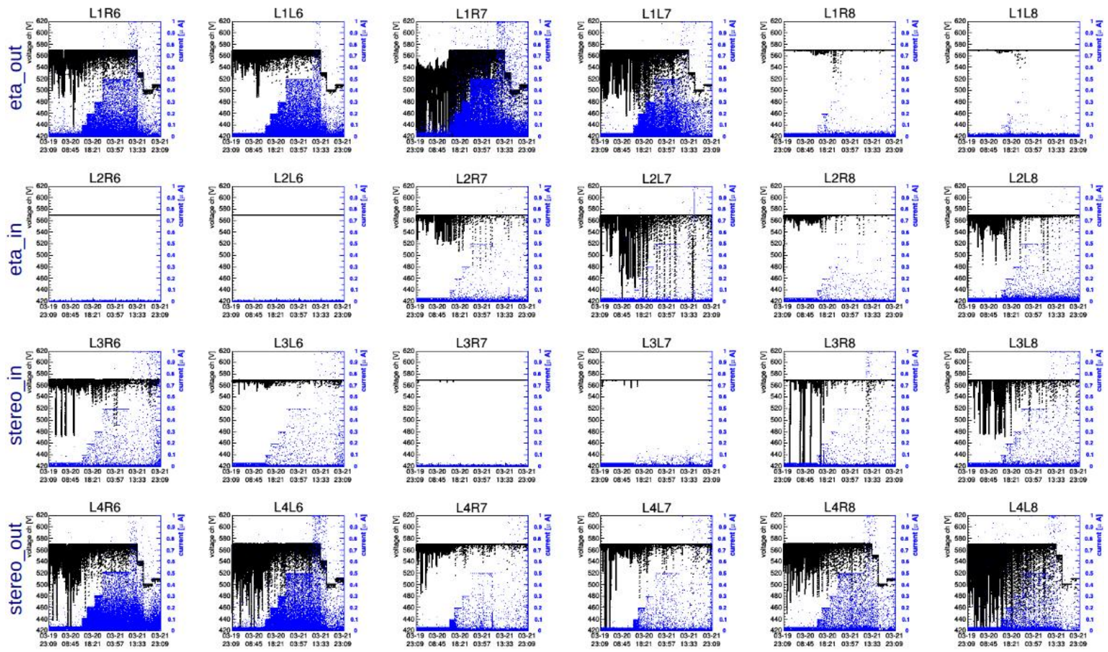


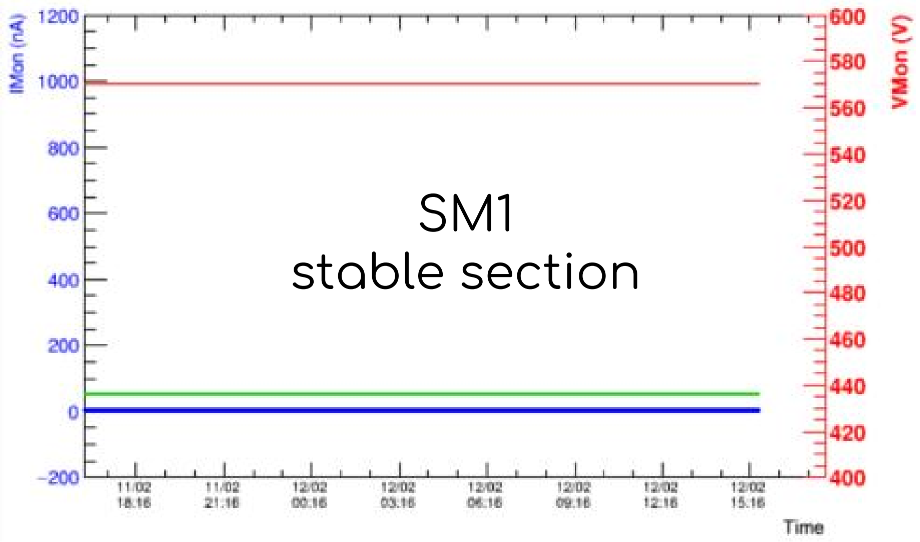
Modules Production - HV conditioning:
==> first HV stability issues observed

Stable HV conditions needed:

1. defects in the design?
2. dirt?
3. Mesh type?
4. Readout panels issue?
5. RH correlation?

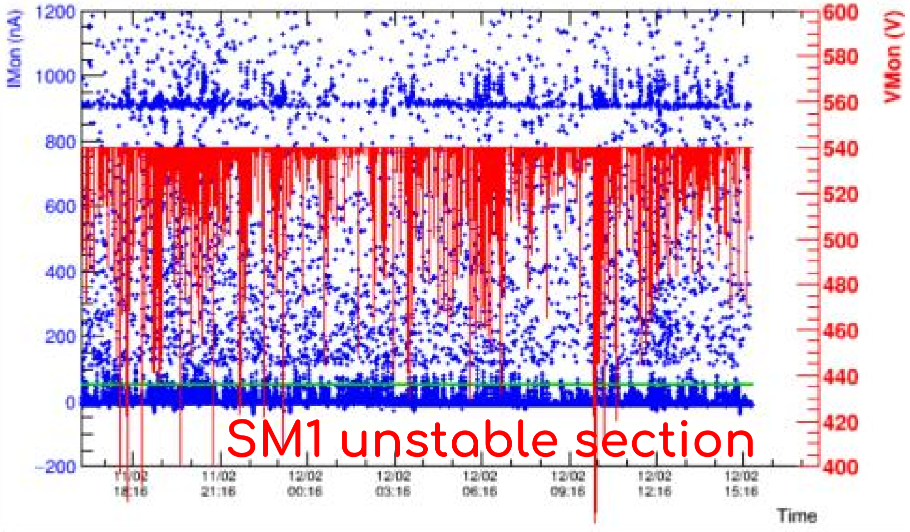
SM2
HV stability test





Need to get some margin around working point

570 V in Ar/CO_2 93/7



Evidences of effects of low resistivity on the HV stability

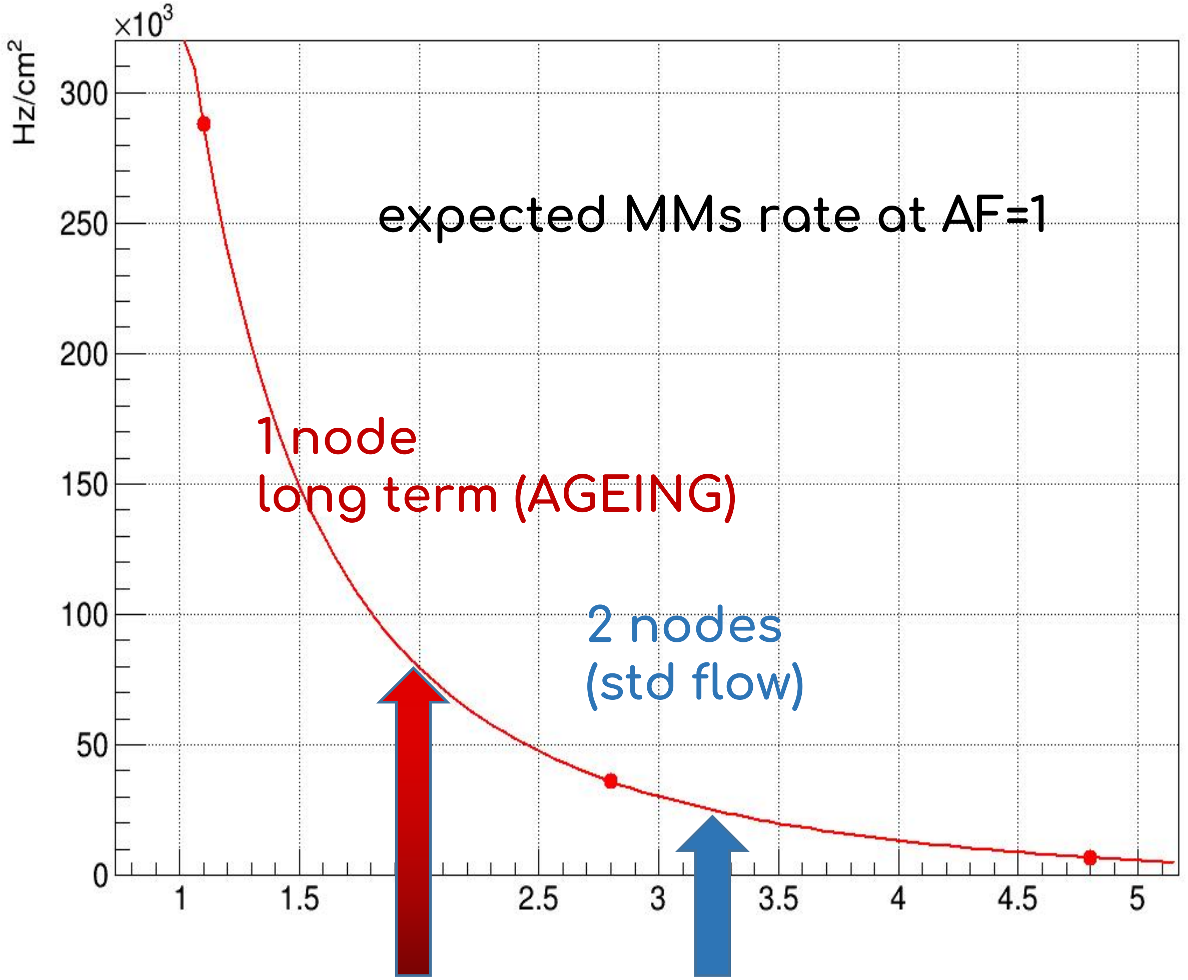
a SM1 MM chamber after 2 months of irradiation @ GIF++

studies on correlations between unstable sections and low resisitivity PCBs

Solutions applied

MM validation & integration - HV/irradiation studies

14 TBq Cs137 source of **662 keV** photons



80 kHz/cm² 30 kHz/cm²

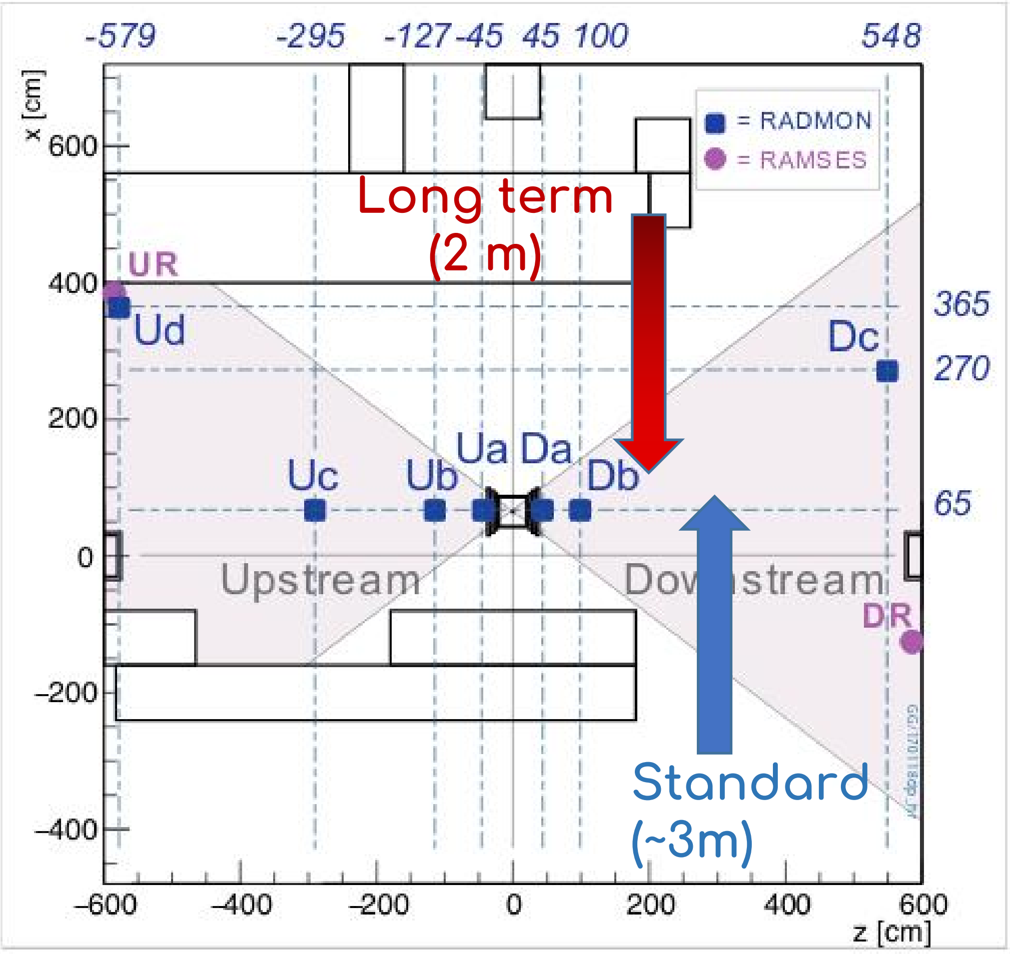
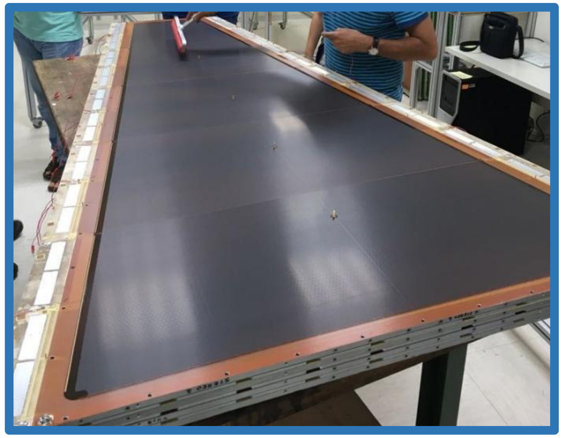
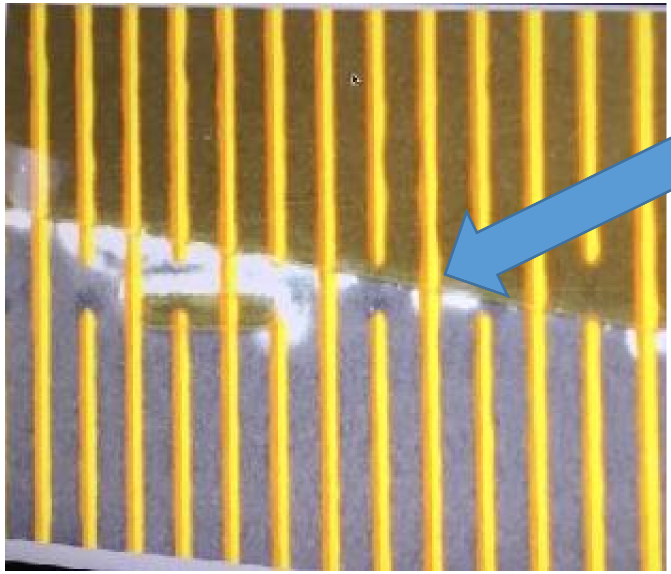


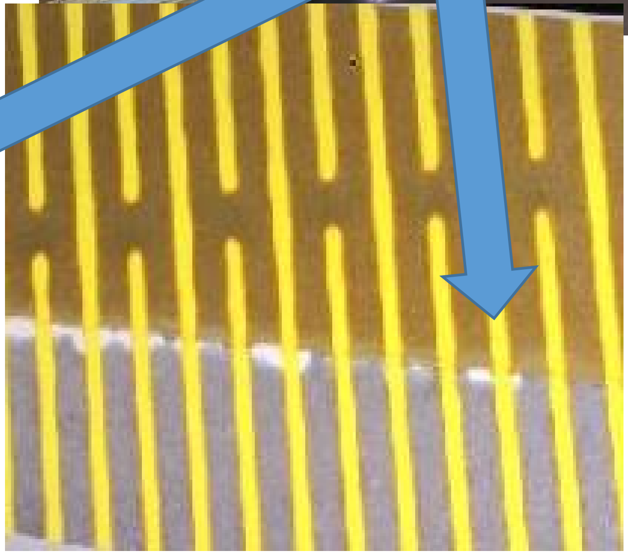
Fig. 8a, from D. Pfeiffer et al., NIM_A_866(2017)91–103

HV stability - Causes



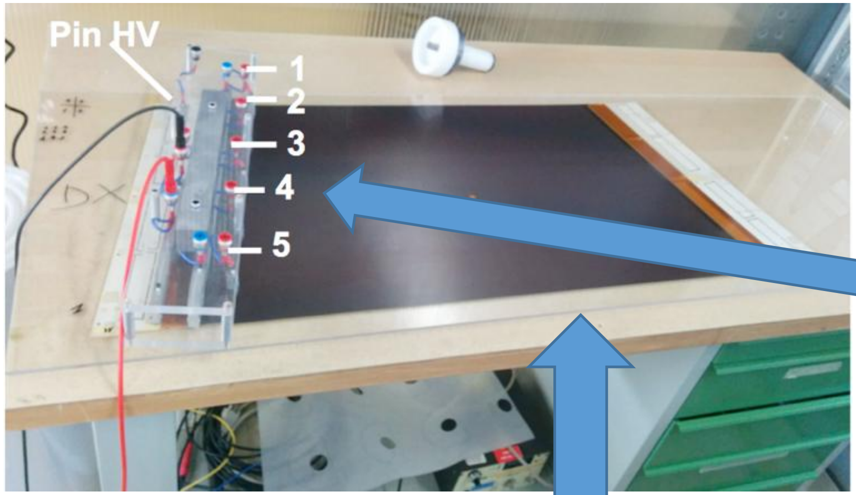
Strong discharges along
the piralux rim
(closest point to the HV
distribution line)
and interconnections
found after the long term
irradiation studies at GIF++

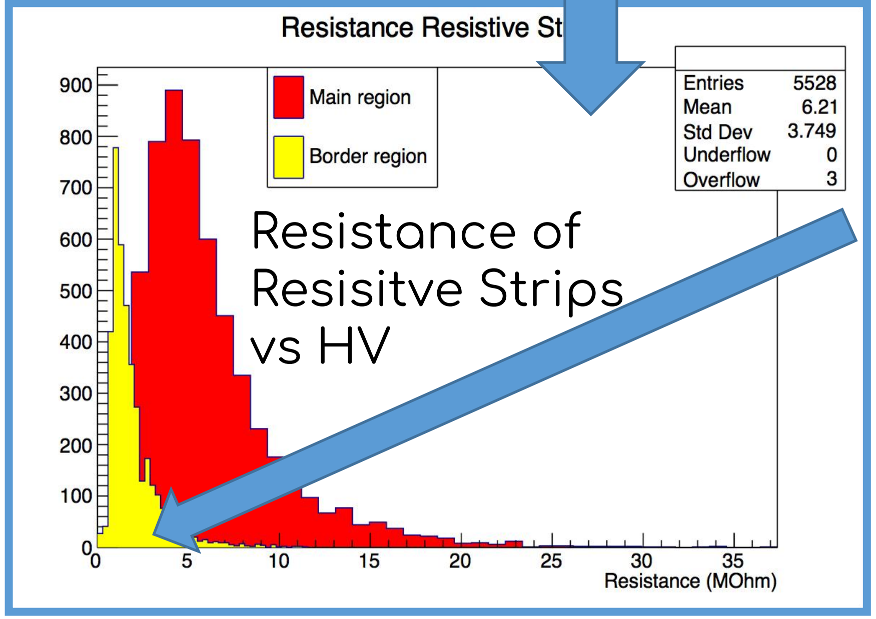




This triggered
investigations on the
resistance of the strips
pattern to the HV line and
strip resistivity

Modules Production - Electrical tests on RO panels before assembly





Electrical tests

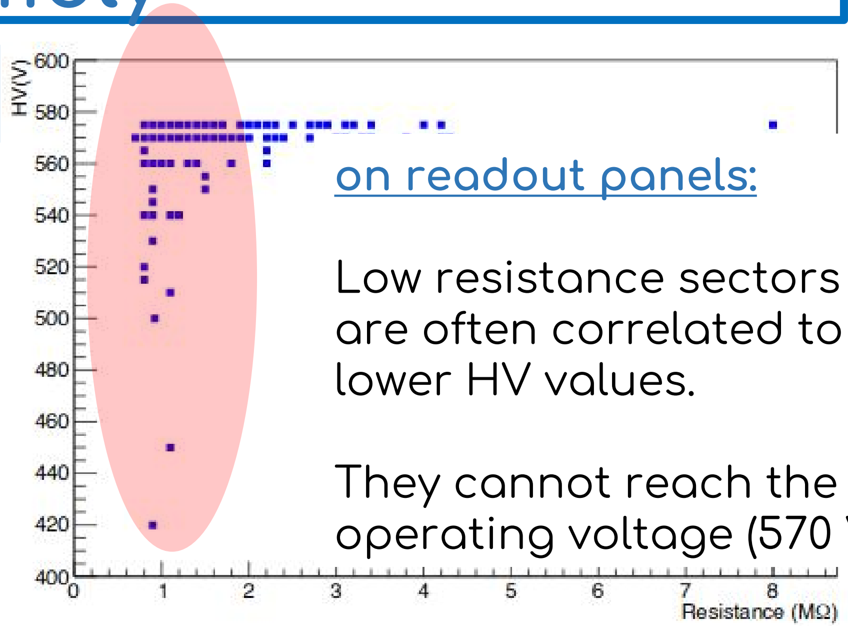
on PCBs

Resistive strips resistance vs silverline (HV stability)

Measured with a 1x1 cm^2 probe

Yellow: @ 1 cm from the HV line:

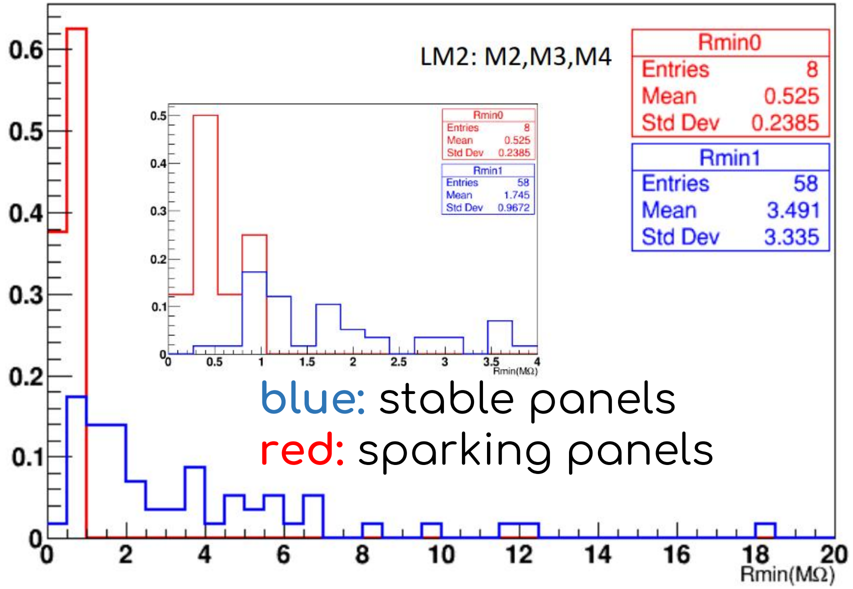
several measurements < 1 MΩ!



on readout panels:

Low resistance sectors are often correlated to lower HV values.

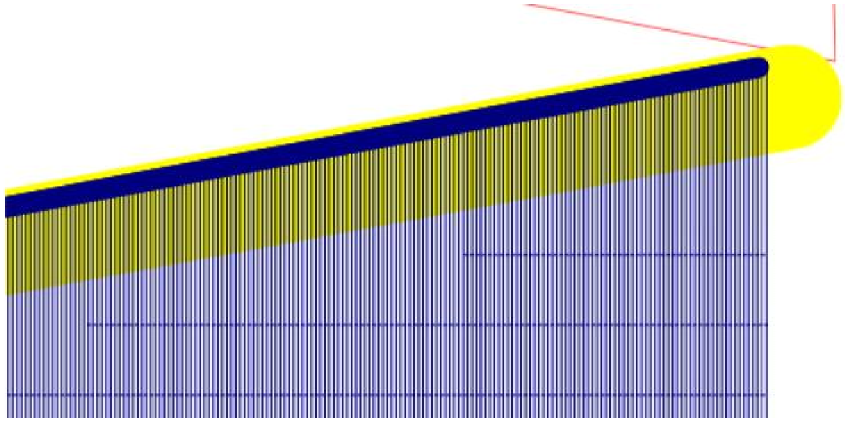
They cannot reach the operating voltage (570 V)



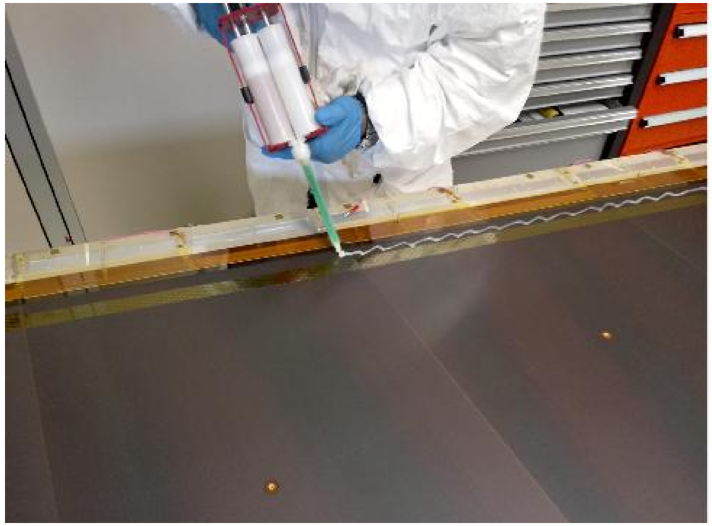
blue: stable panels
red: sparking panels

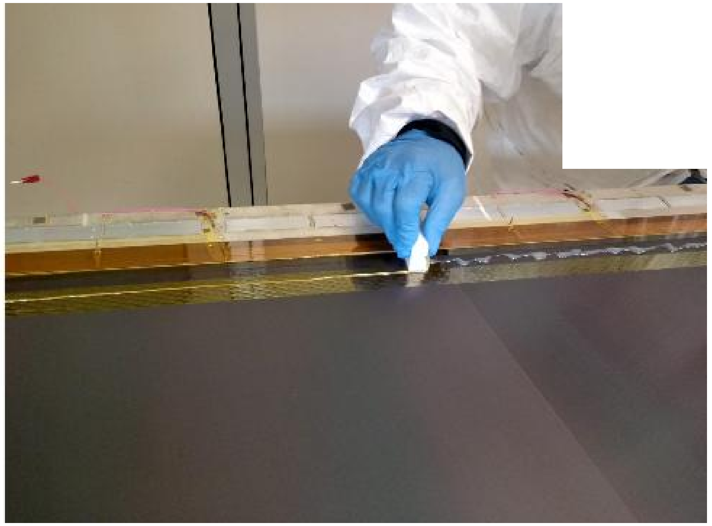
How to increase the HV stability - Passivation

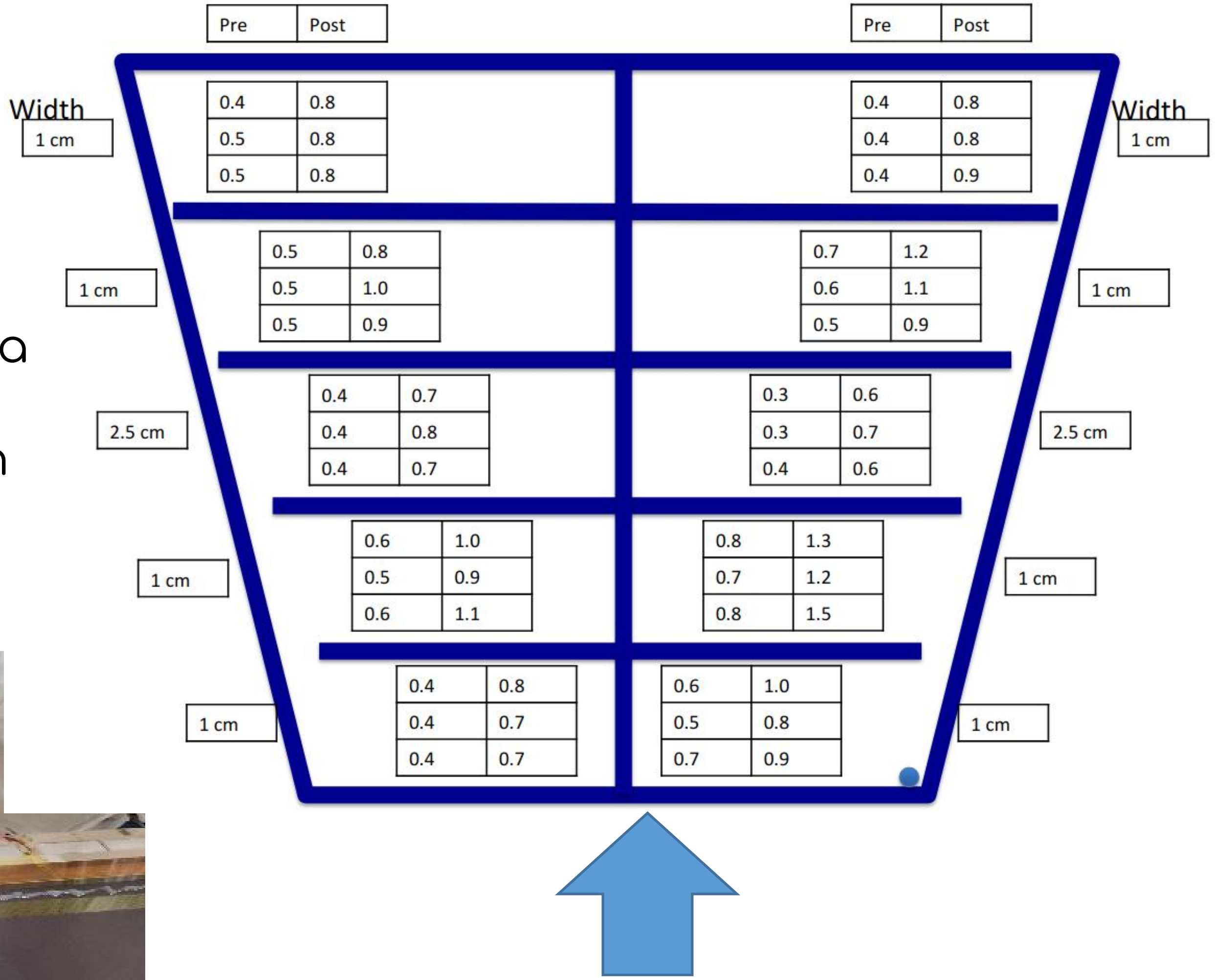
Passivation is performed using a thin Araldyte film. The passivated area is defined by a kapton tape barrier.



Width of passivated area is chosen in order to reach R>0.8 MΩ



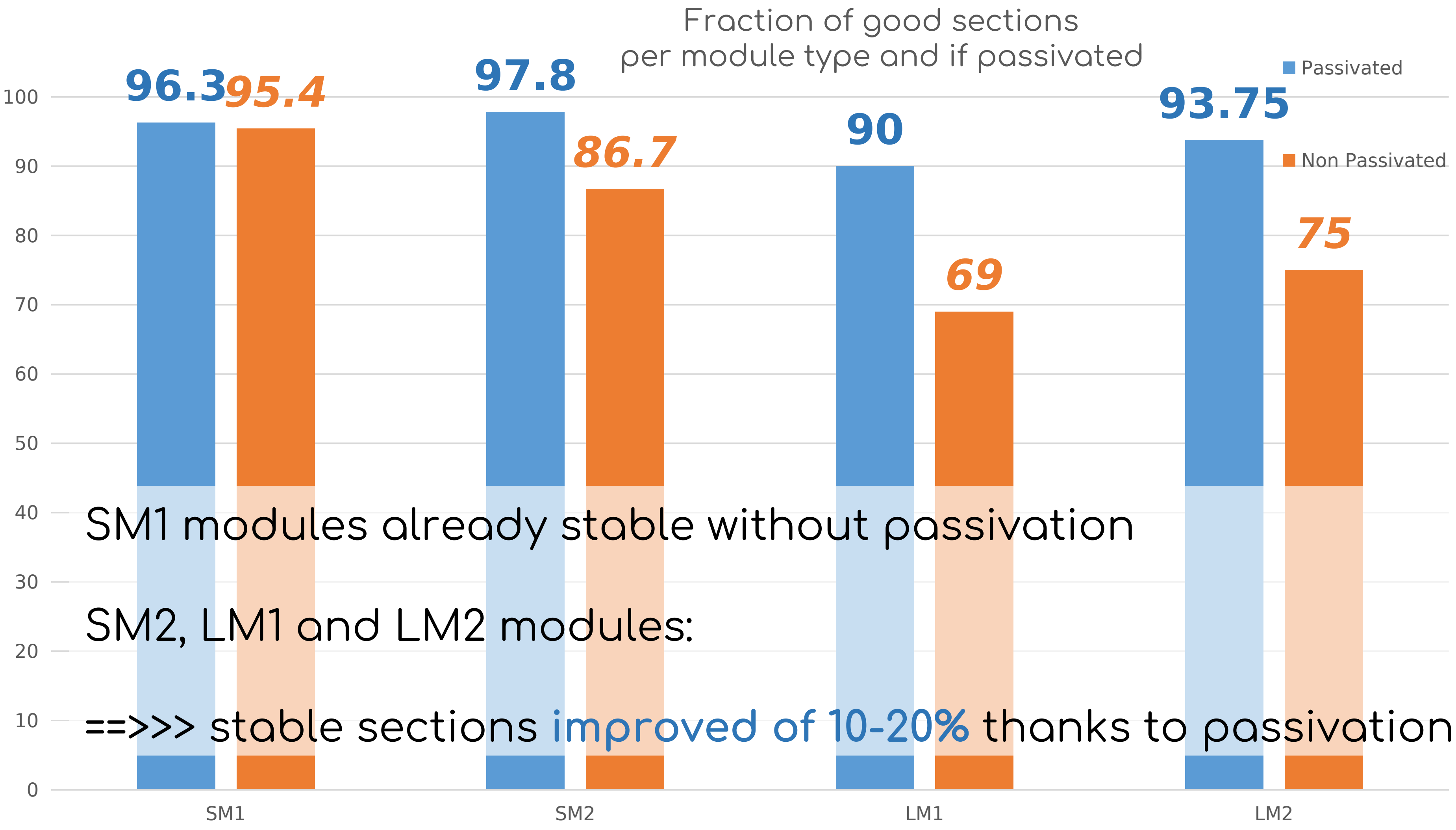




Pre-post passivation resistance measurements (MΩ) @ 1 cm from coverlay

How to increase the HV stability - Passivation

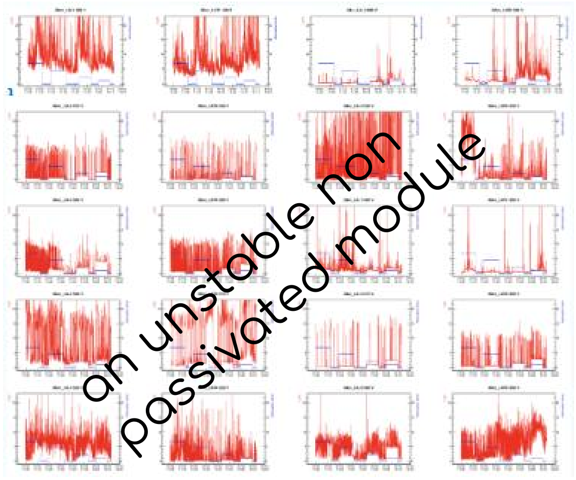
A “good” sector: HV>565 V, spike rate < 6/min

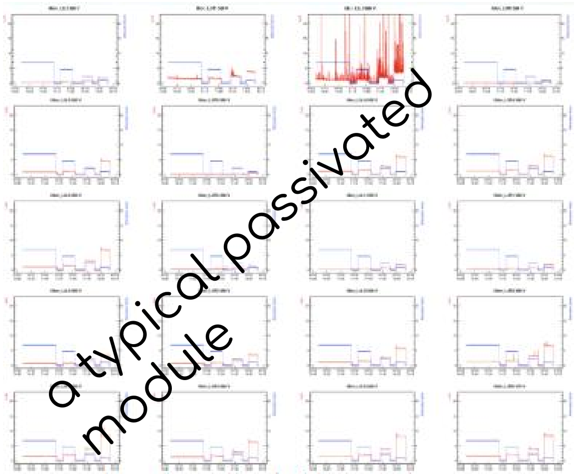


SM1 modules already stable without passivation

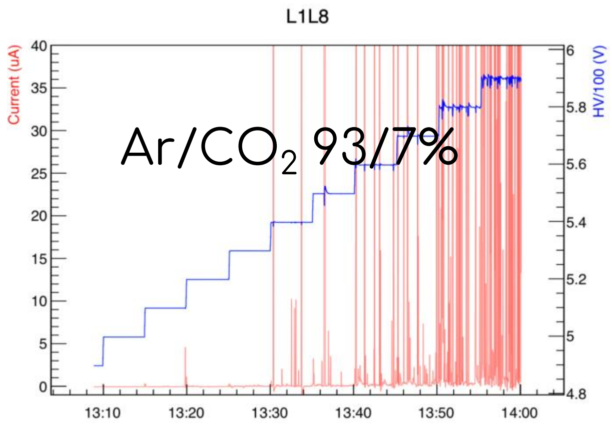
SM2, LM1 and LM2 modules:

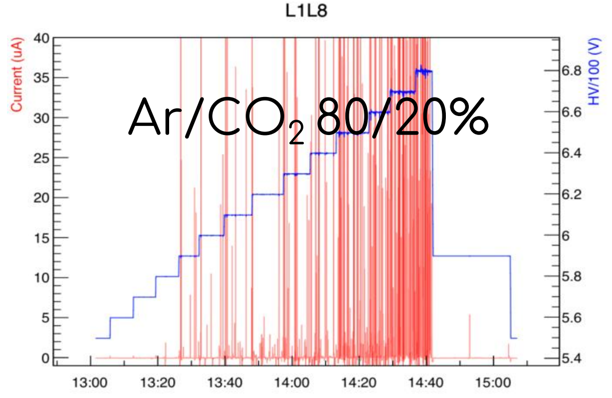
==>>> stable sections improved of 10-20% thanks to passivation

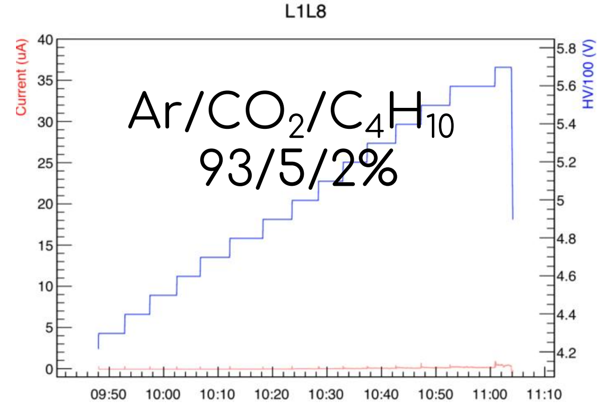




How to increase the HV stability - Gas Mixtures





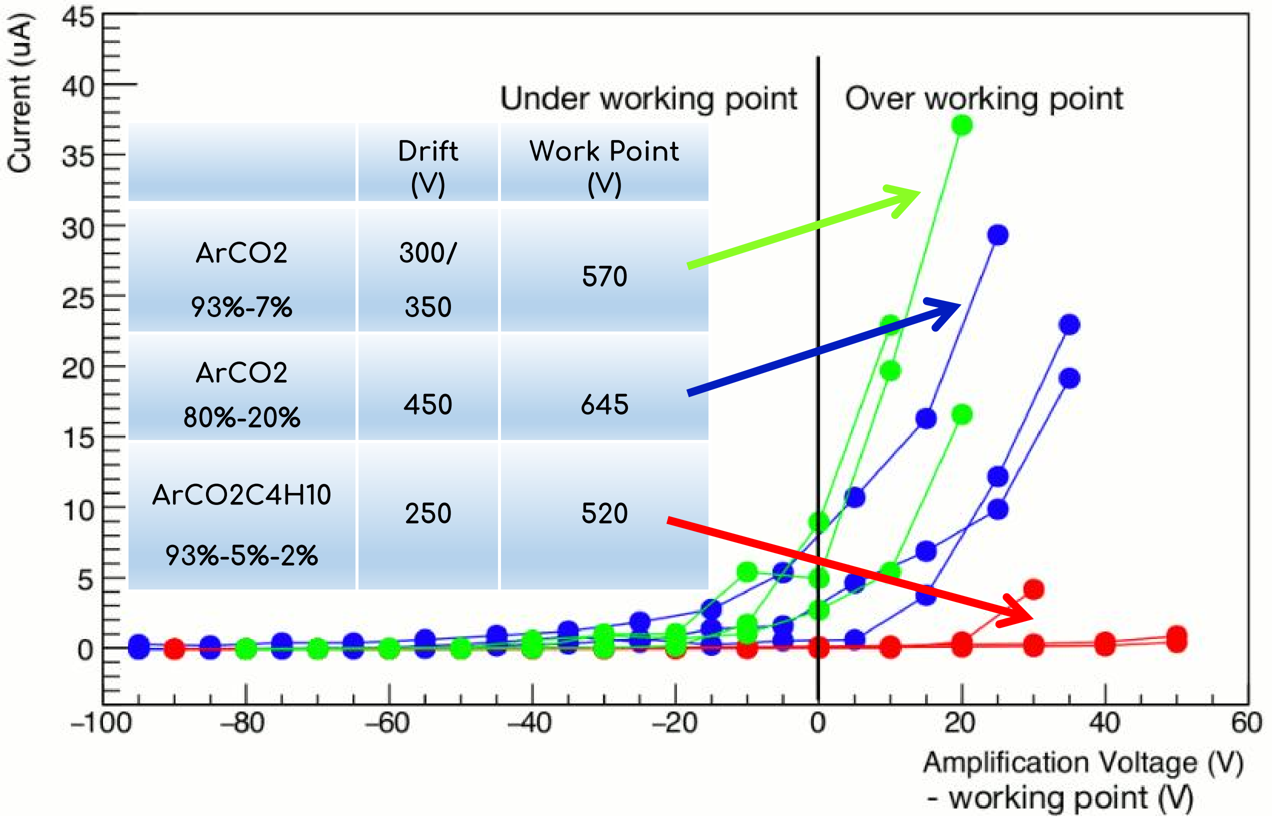


New gas mixtures have been studied (standard Ar/CO_2 93/7%) :
Ar/CO_2 80/20%
Ar/CO_2/C_4H_{10} 93/5/2%

The isobutane seems to be really effective to shunt the spikes and to reduce the dark current level

Ageing studies are ongoing at the GIF++ in order to check the impact of using isobutane on the long term operation of the detector.

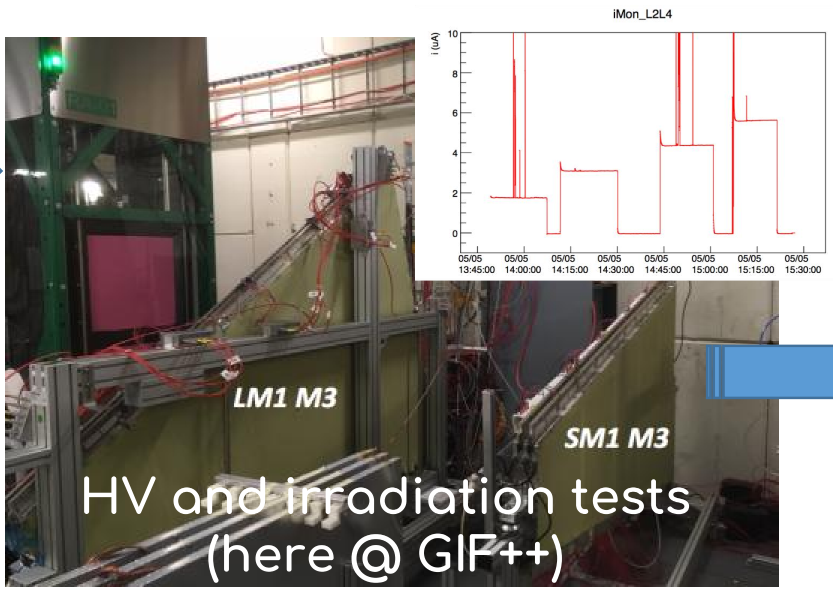
Timing issue:
most likely not feasible within the installation schedule.



MM Validation and Integration of Double Wedges @ CERN

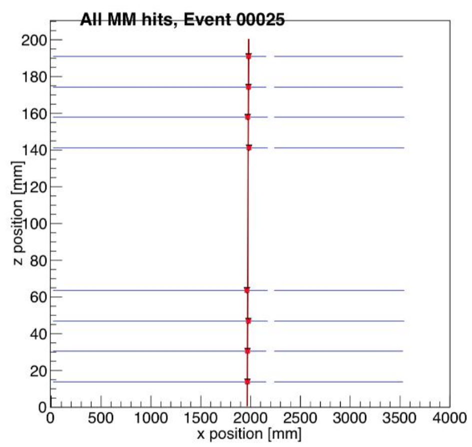
MM validation & integration - Workflow

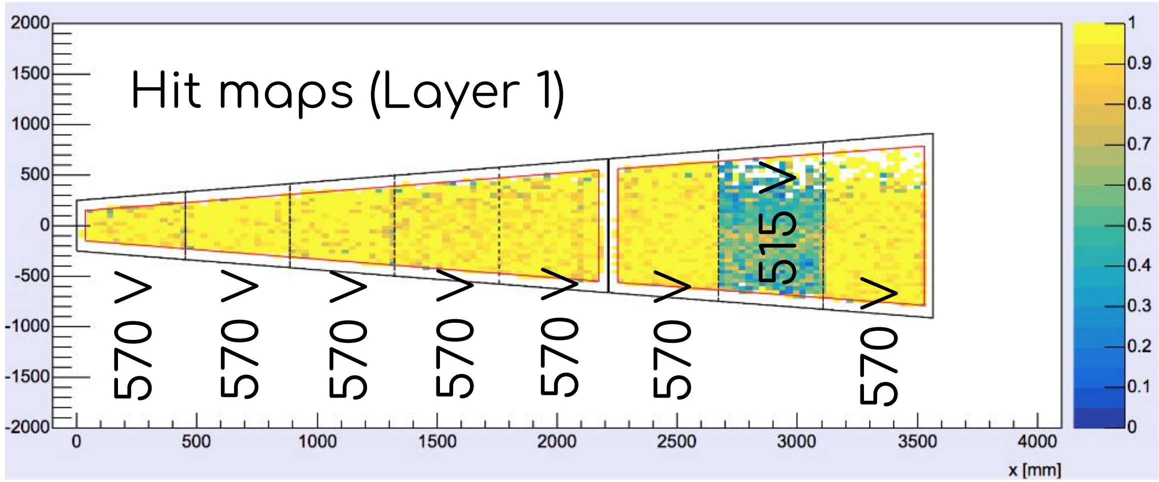
General scheme of MM integration into Double Wedges

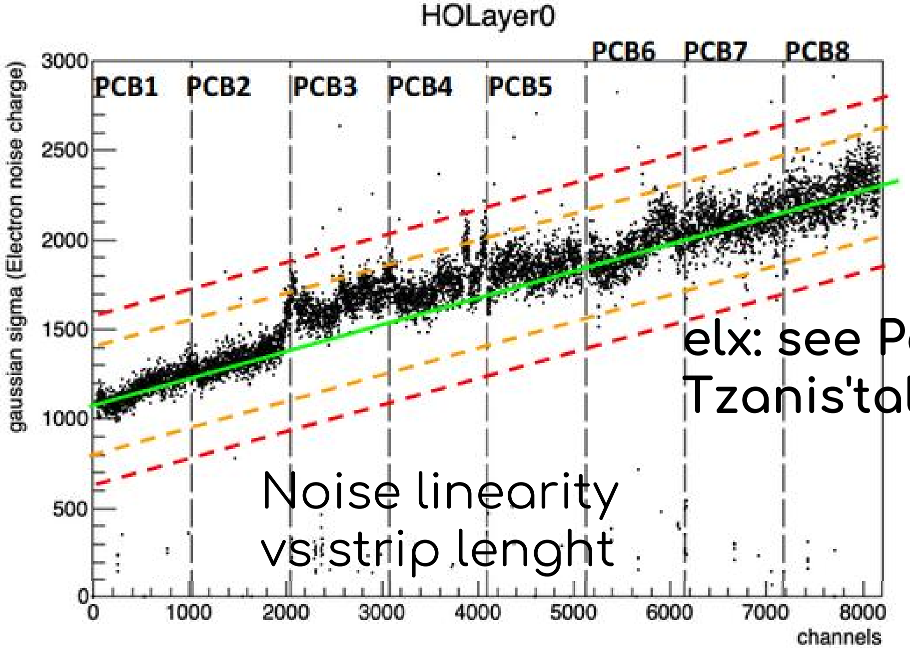


MM validation & integration - first DW A14

NON PASSIVATED

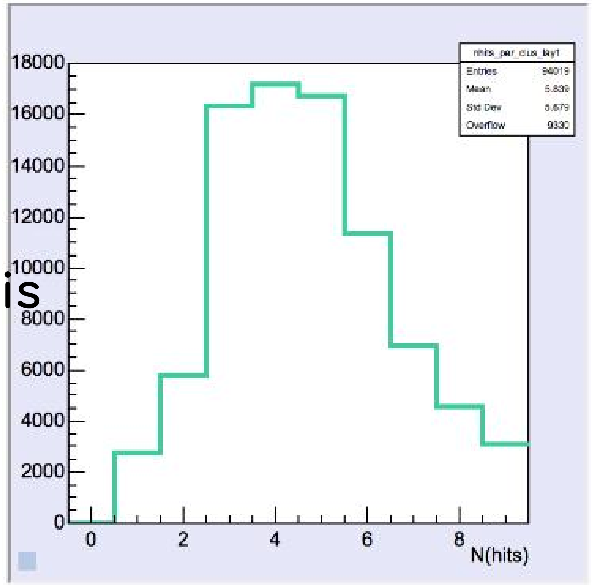




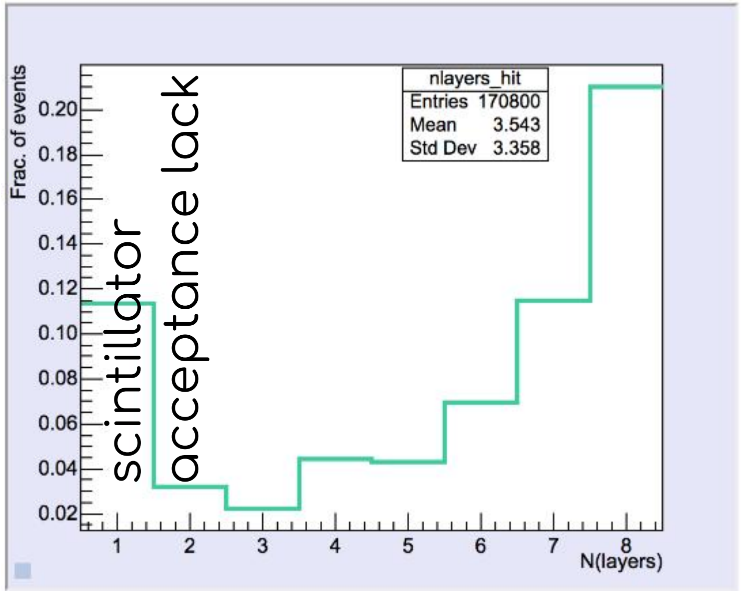


elx: see Polyneikis Tzanis'talk

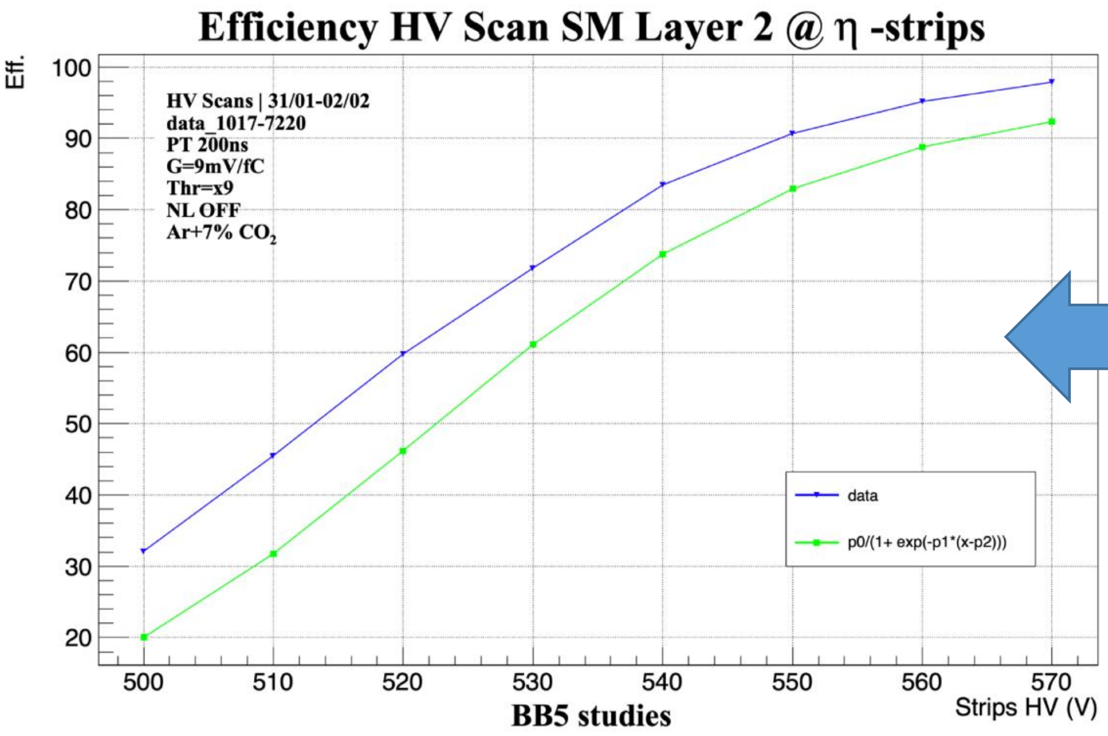
Cluster Size



N layers with hits



MM validation & integration - first DW A14 NON PASSIVATED



Blue: measured track efficiency at the Cosmics Stand for the Small DW A14 (Wheel A). First VMM chip version used.

Green: measured track efficiency for SM2-M1 at H8 testbeam @ CERN in summer 2018.

The A14 efficiency is higher than the one measured @ H8 (higher thresholds because of VMM noise).

Measured average Tracking efficiencies per layer for the A14 Small DW:

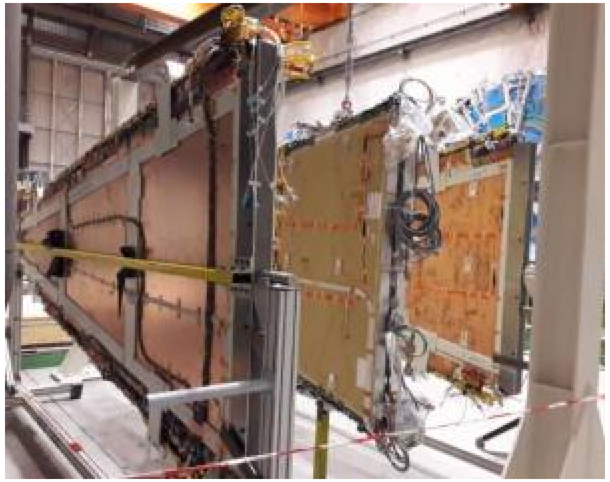
in average well above 90%
IP side lower then HO (gas flow/RH?)

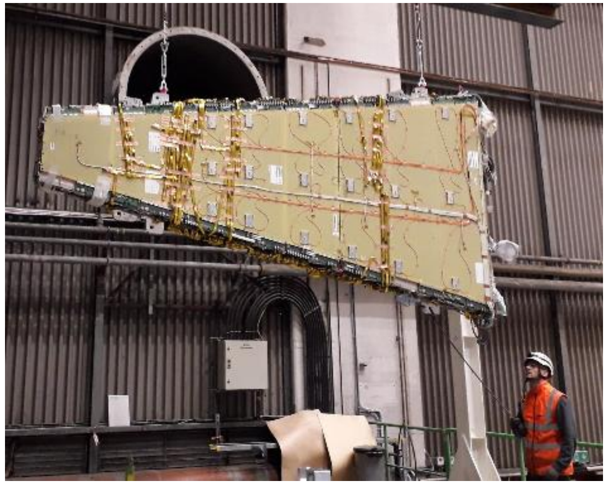
==> A14 is a non passivated Small DW

IP SM1+SM2	Efficiency (Cosmic Muons)	
Layer 1	85.4	%
Layer 2	89.1	%
Layer 3	84.1	%
Layer 4	85.3	%

HO SM1+SM2	Efficiency (Cosmic Muons)	
Layer 1	98.1	%
Layer 2	97.2	%
Layer 3	92.8	%
Layer 4	90.8	%

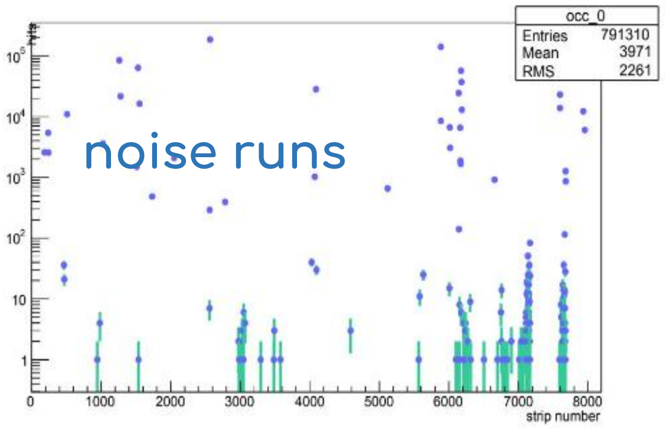
First attempt to Sector (MM +sTGC) installation on NJD

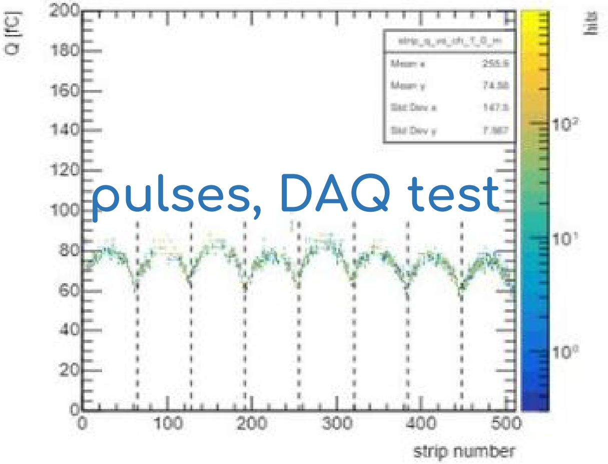


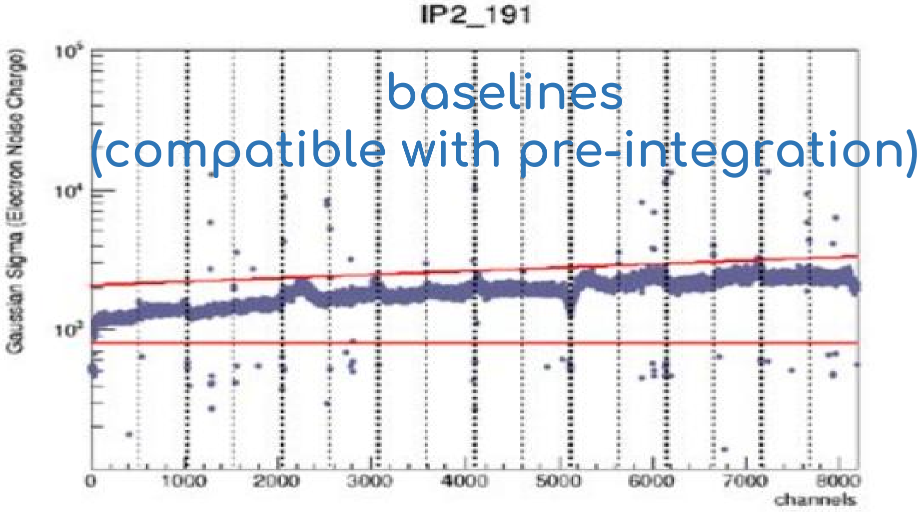


- Gas leak tests & flushing
- HV: confirm behavior
- Baselines, thresholds, noise runs, calibrations
- Pulsing & patterns
- Trigger path validation
- Few cosmics for sign-off, to validate whole readout+chamber chain
- System tests: latency, high rate, Sector logic

VERY GOOD FIRST PICTURE!

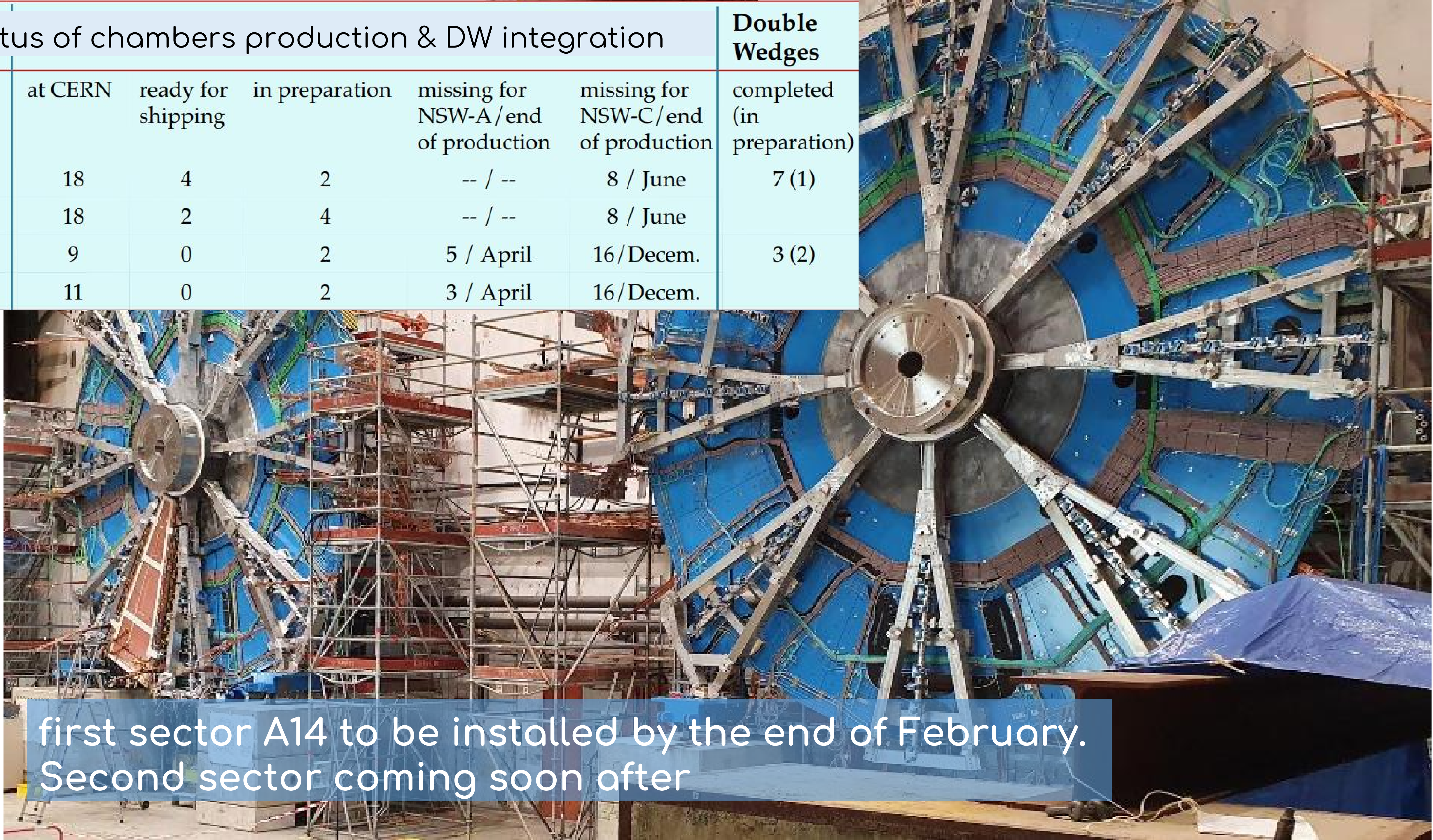






Status of chambers production & DW integration

						Double Wedges
	at CERN	ready for shipping	in preparation	missing for NSW-A/end of production	missing for NSW-C/end of production	completed (in preparation)
SM1	18	4	2	-- / --	8 / June	7 (1)
SM2	18	2	4	-- / --	8 / June	
LM1	9	0	2	5 / April	16/Decem.	3 (2)
LM2	11	0	2	3 / April	16/Decem.	



first sector A14 to be installed by the end of February.
Second sector coming soon after

A14 Sector installed tonight!!!!!

Summary and conclusions

Micromegas technology has been chosen for the ATLAS NSW upgrade
==>to reach HL-LHC constraints as a main tracking detector

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==>(resolution + detector spark protection + rate capability compromise)

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==> found to be correlated to low resistance of resistive strip anode
==> applied solutions
+ passivation in order to deactivate the region where $R<0.8$ MΩ

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Passivation played a fundamental role to get rid of the issue but in some cases significant loss of active area
==> several solutions under study (passivation with polyurethane, grinding, new foil production procedure)

Production of NSW-A:
+ 87,5% of modules produced
+ 10/16 sectors ready (+ 3 under integration)

Production of NSW-C:
+ 25% of modules produced

Integration activities @ CERN fully operational

- The first full sector (MM+sTGC) installed on the wheel A for testing the integration procedure! (A12-to be then removed)
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- The second full sector being installed just after A14!

- On time to install the first wheel at the end of the year

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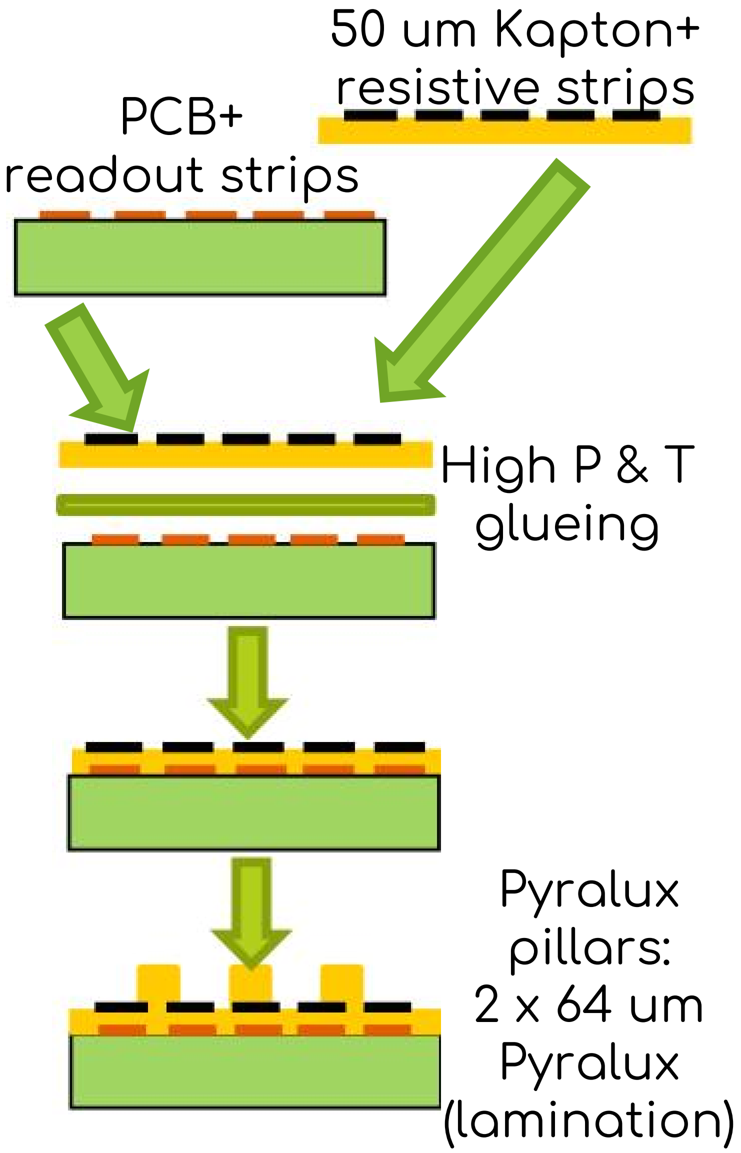
THANKS FOR THE ATTENTION!

BACKUP

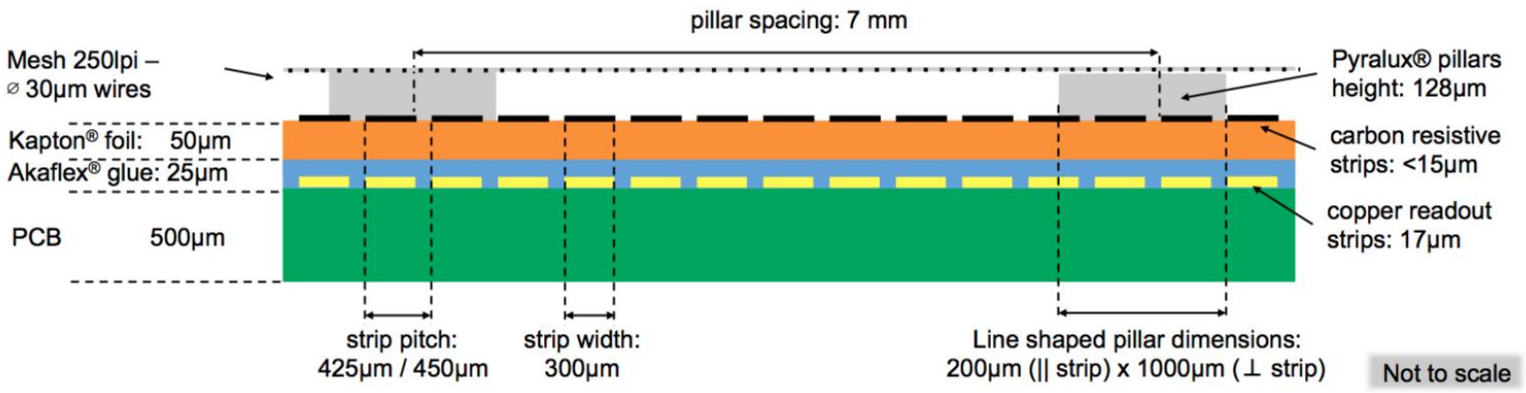
MM requirements and challenges

1. Strip alignment per each layer over O(m2)
    - 30 μm RMS in η
    - 80 μm RMS in z
2. Planarity within 100 μm RMS
3. Technological transfer to industry of Readout PCBs production at very high quality
4. HV Stability at high electric field (~50 kV/cm) on wide surfaces O(m2)

The New Small Wheel - MM Resistive Anode



PCB structure



Board dimensions: from 45x30 up to 45x220 cm^2

- 1022 strips/boards
- Strip width: 300 µm
- Strip pitch: 425/450 µm
- Pillar distance: 7.0 mm
- Readout strips pitch: 425 or 450 µm
- Pillar size: 1000x200 µm
- Pillars height: 128 µm

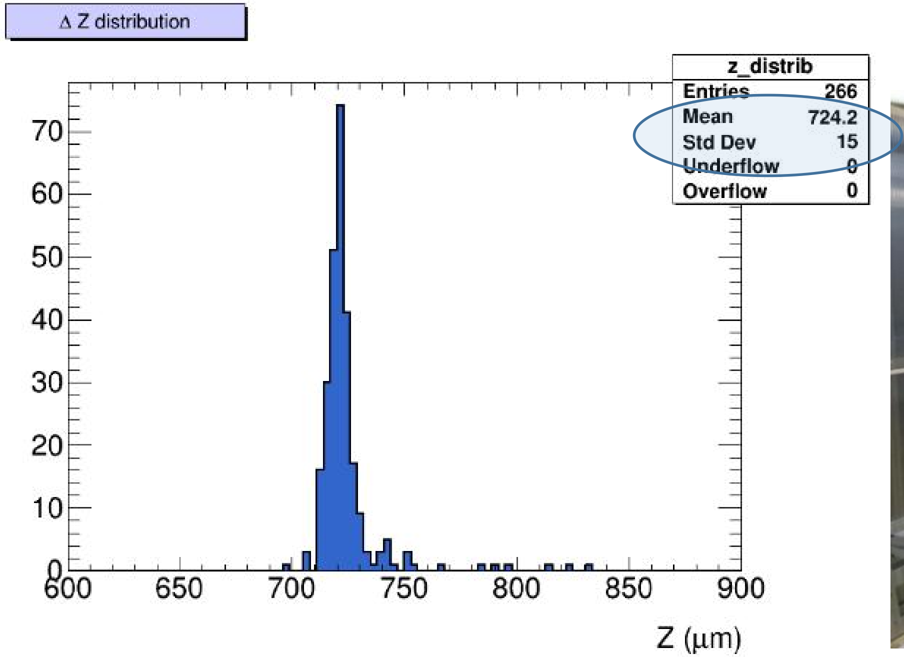
Resistivity
~800 kΩ/□

Alignment requirements:
30 µm RMS in η
80 µm RMS in z

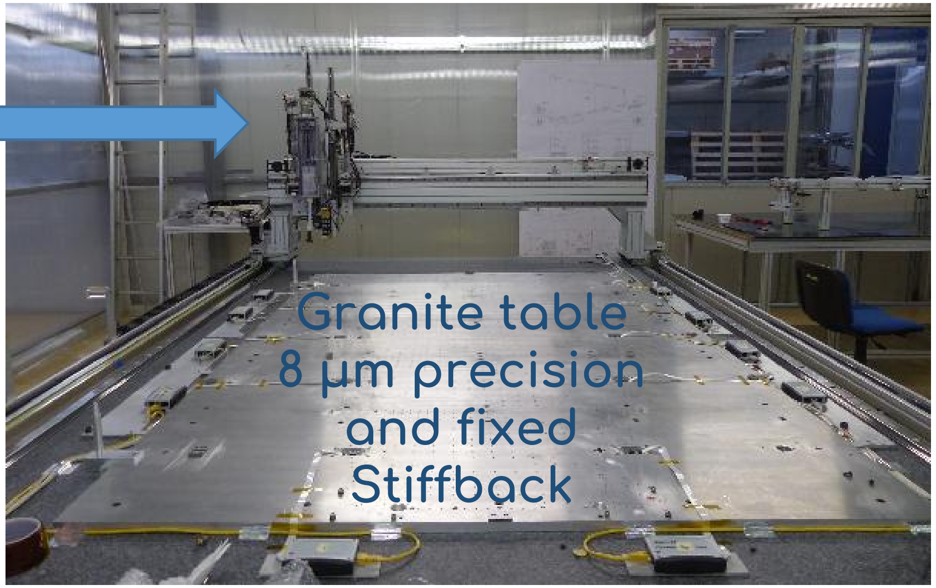
Modules Production - Construction Cycle and tests

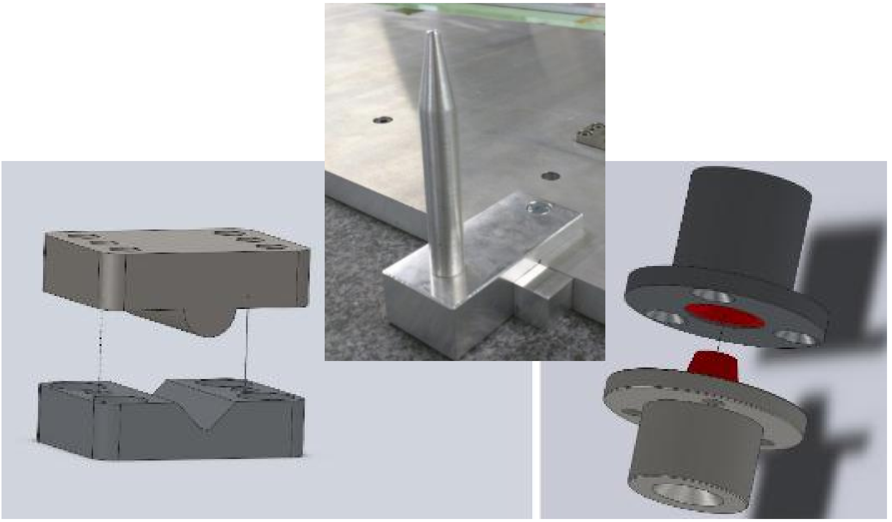
Panel Construction Tools & Procedure

Distribution of planarities for 5 PCBs within the **20 μm as expected**

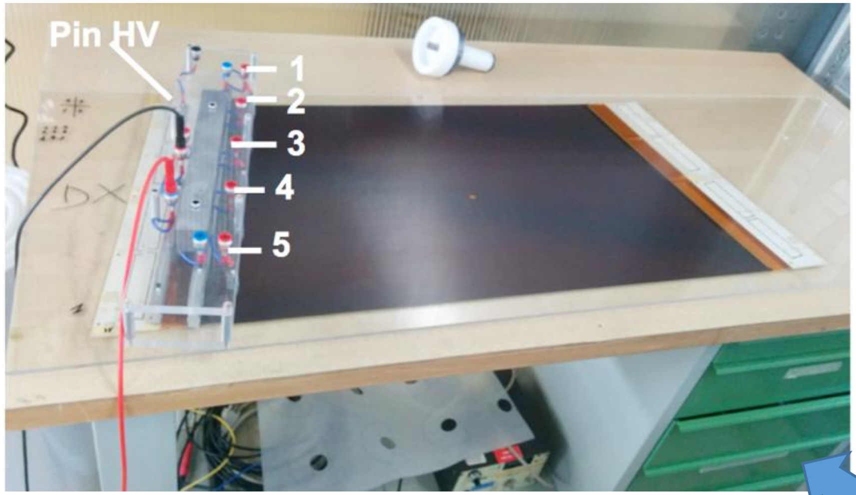


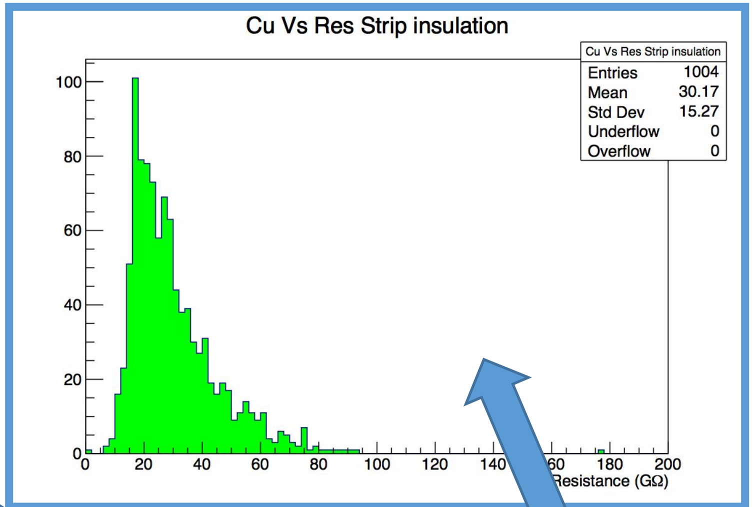
Coordinate Measuring Machine (blu laser)
+
glueing machine





Modules Production - Electrical tests on RO panels before assembly

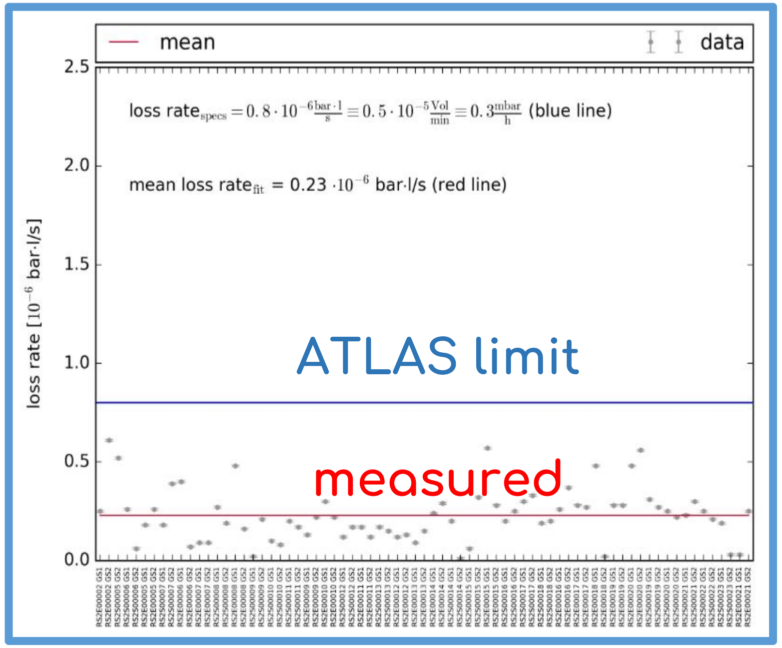


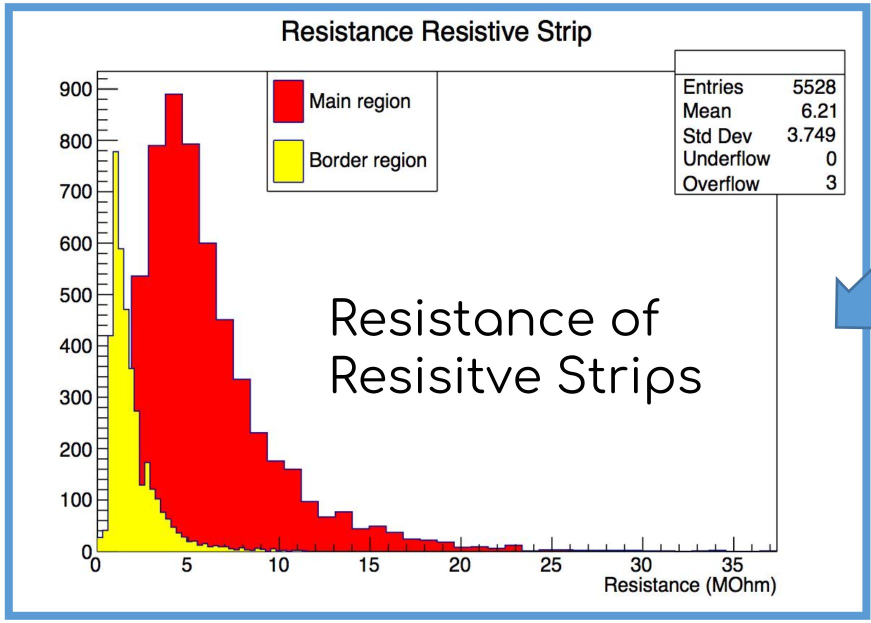


Leakage

Usually very well within the limits

SM2 Readout panel leak





Electrical tests

Resistive strips resistance vs silverline (related to HV stability)

Copper-Resistive layers decoupling also tested

Modules Production - Construction Cycle and tests

Dry cleaning, tests and alignment:

Remove dust with dedicated roller
HV shorts check with MeshTool
Gas leak test gap by gap
Insert 10 Pins to align the FE boards

Detector Assembly:

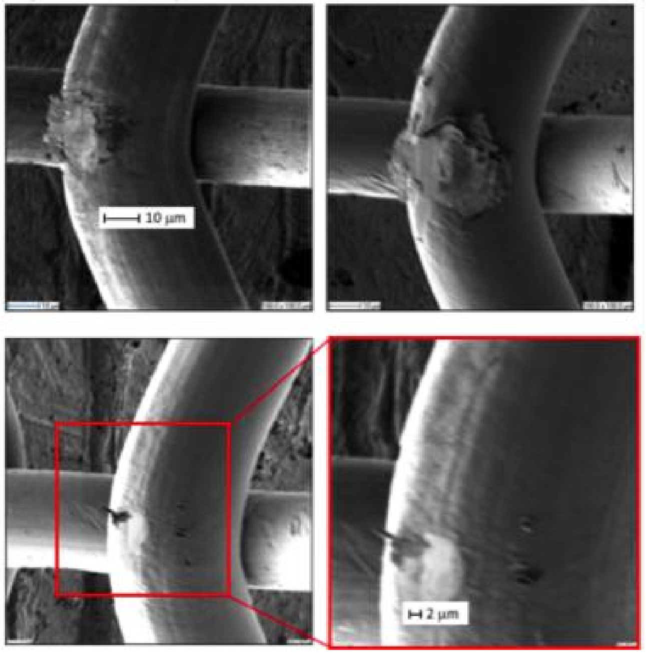
Load Cells to balance the weight of panels on alignment pins

Then the panel is pushed towards the assembly structure

Modules Production - Construction Cycle: cleaning

Cleaning procedures:

mesh



The Mesh grids used for the ATLAS MM are not flattened by calendering.

They may present imperfections and produce discharges if pointing toward the resistive strips.

Polishing and cleaning procedure:

1. Wet sandpaper (2500) to remove defects
2. wet the mesh by hot water (40 - 45)° C
3. brush with degreaser solution
   (10 g NGL in 1.5 l hot water) on both mesh face
4. wait 10' for the degreaser to act
5. rinse the two mesh faces with hot water and brush
6. rinse the two mesh with demineralized water

Modules Production - Construction Cycle and tests

Mesh studies:

HV stability

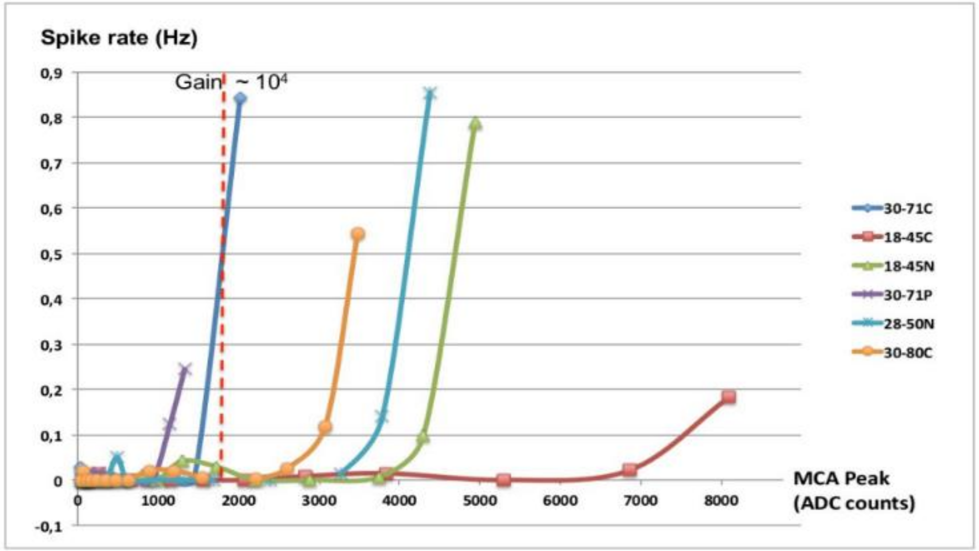
Type (d-a μm)	Comment
18-45 N	Non calendered
18-45 C	Calendered
28-50 N	Non calendered
30-71 P	Non calendered; Manually polished
30-71 C	Calendered
30-80 C	Calendered

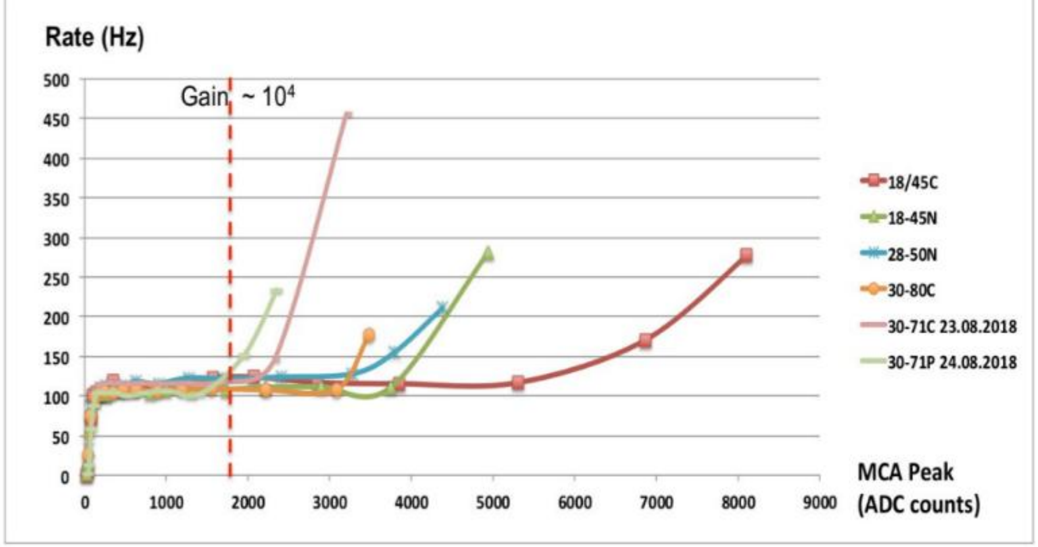
Experimental conditions

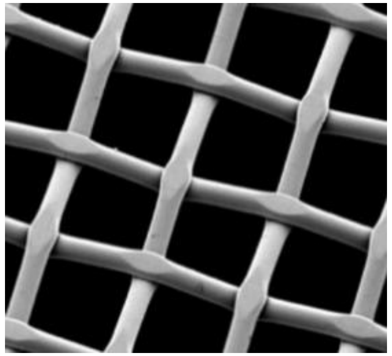
- 5.9 keV photons from a ^{55}Fe source
- photon rate ~ 100 Hz/cm^2
- measured both peak amplitude and rate

Main results:

-> same gain reached at lower HV for smaller spacing mesh
-> best results with 1. calendered 2. small spacing grid
Unfortunately not available at large enough surface
Thus sanding applied to all NSW production







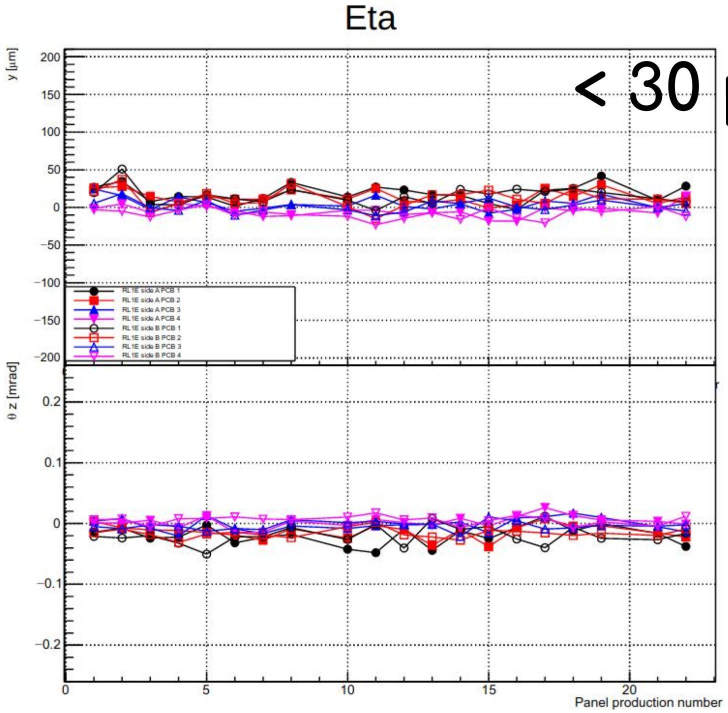
a calendered mesh

Modules Production - Construction Cycle and tests

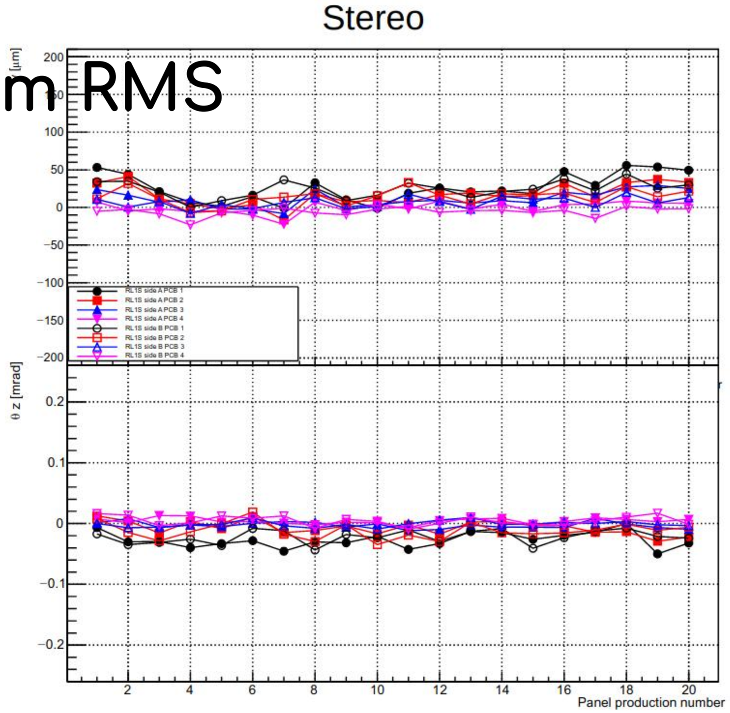
Mech Precision: alignment

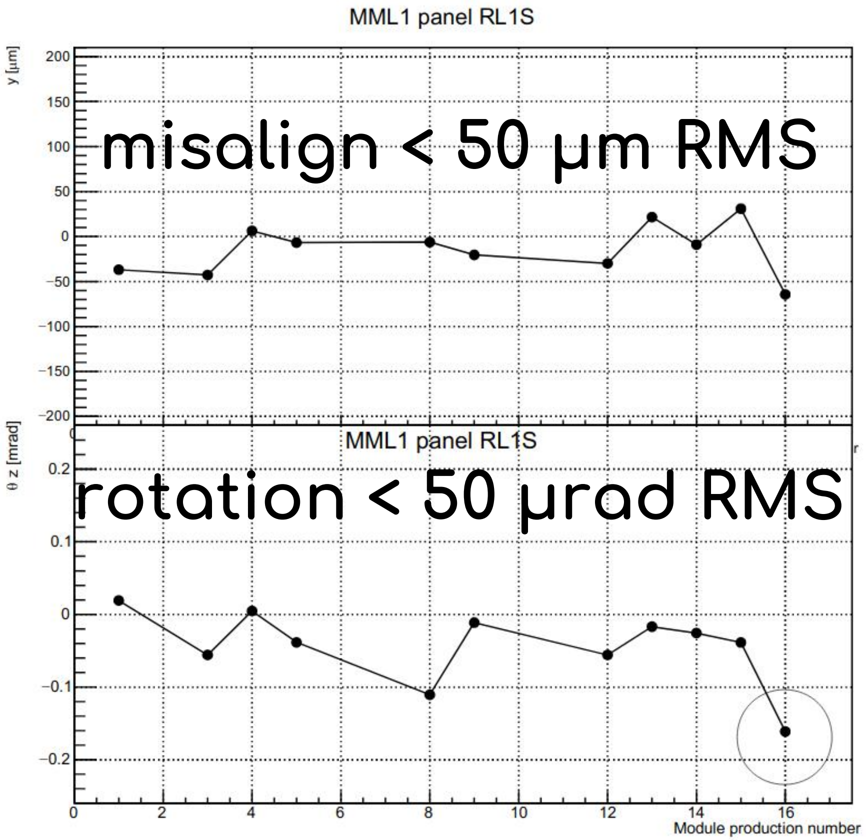
LM1 (ex) PCBs alignment:

LM1 (ex) panel to panel alignment within a module:



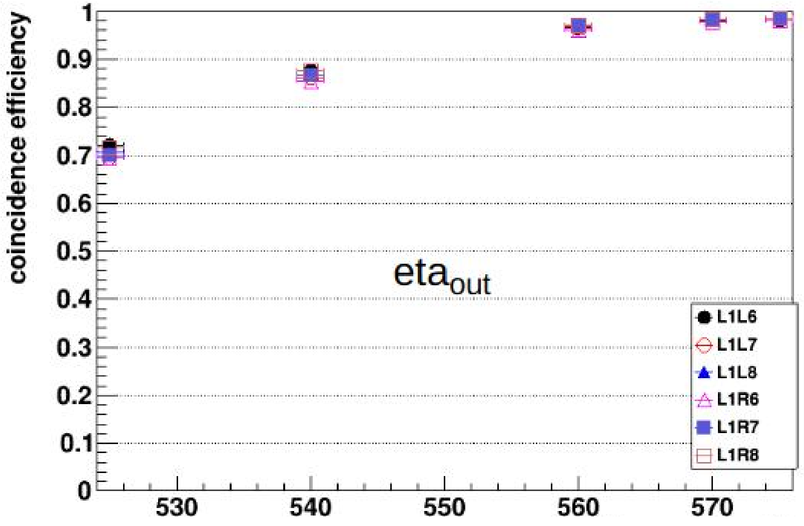
< 30 µm RMS





Modules Production - Construction Cycle and tests

SM2 module turn on curve

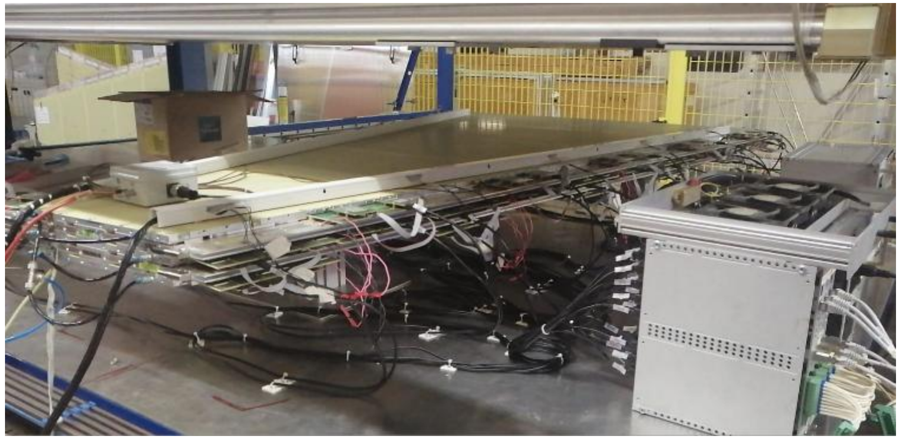


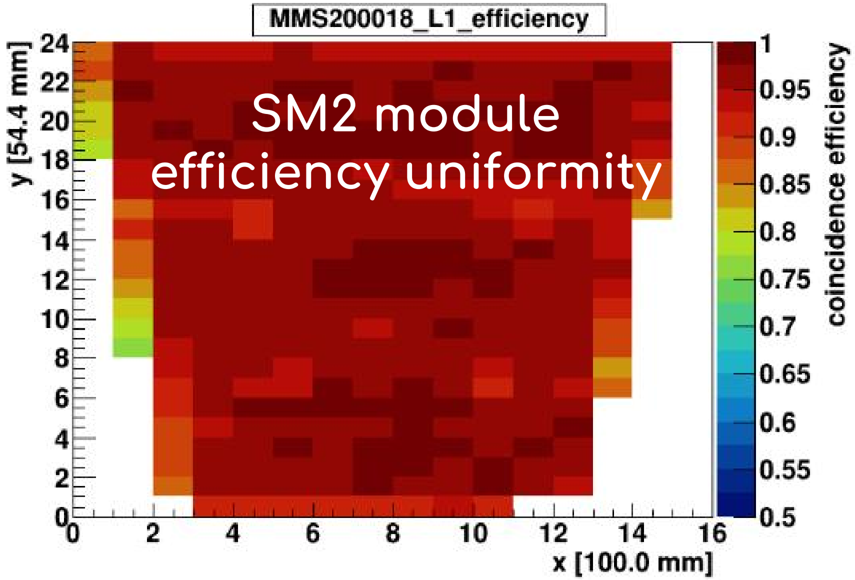
Efficiency

APV25 with samplings of 25 ns

LNF interface cards with 2 adiacent strips

SM1 Cosmic stand



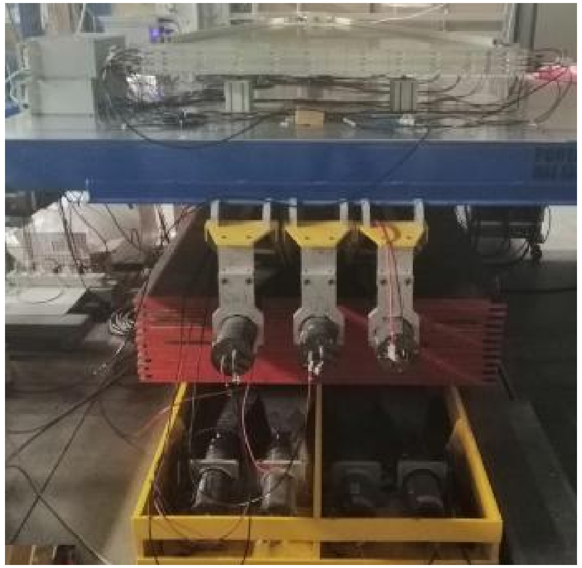


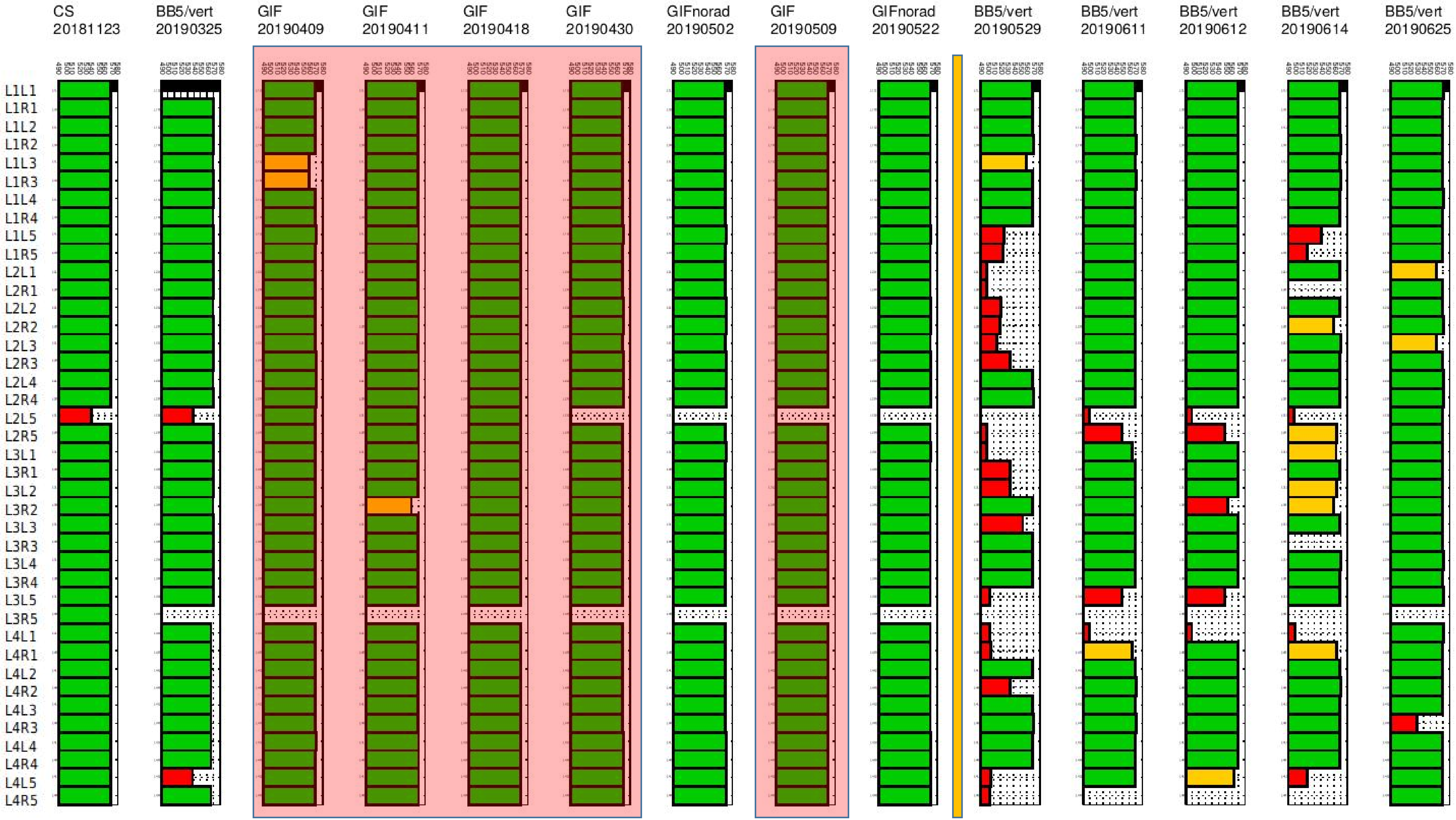
Trigger:

2 arrays of plastic scintillators

PMTs -> 50 Hz (25cm x 150 cm)

35 cm Fe to cut muons at ~0.5 GeV




CS
20181123
BB5/vert
20190325
GIF
20190409
GIF
20190411
GIF
20190418
GIF
20190430
GIFnorad
20190502
GIF
20190509
GIFnorad
20190522
BB5/vert
20190529
BB5/vert
20190611
BB5/vert
20190612
BB5/vert
20190614
BB5/vert
20190625
L1L1
L1R1
L1L2
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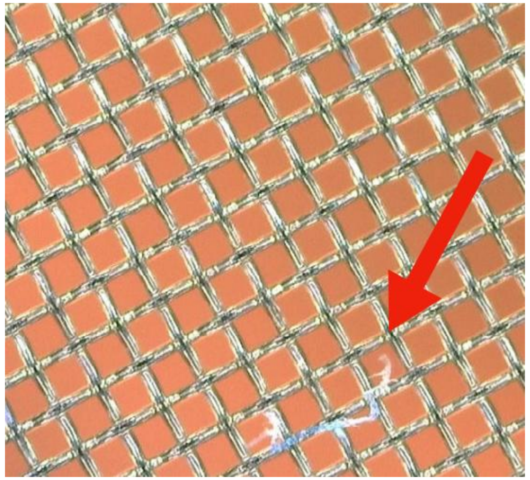
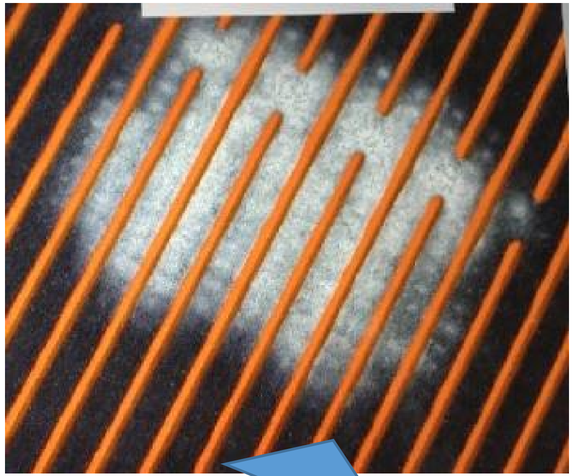
L4R5

HV stability - Causes

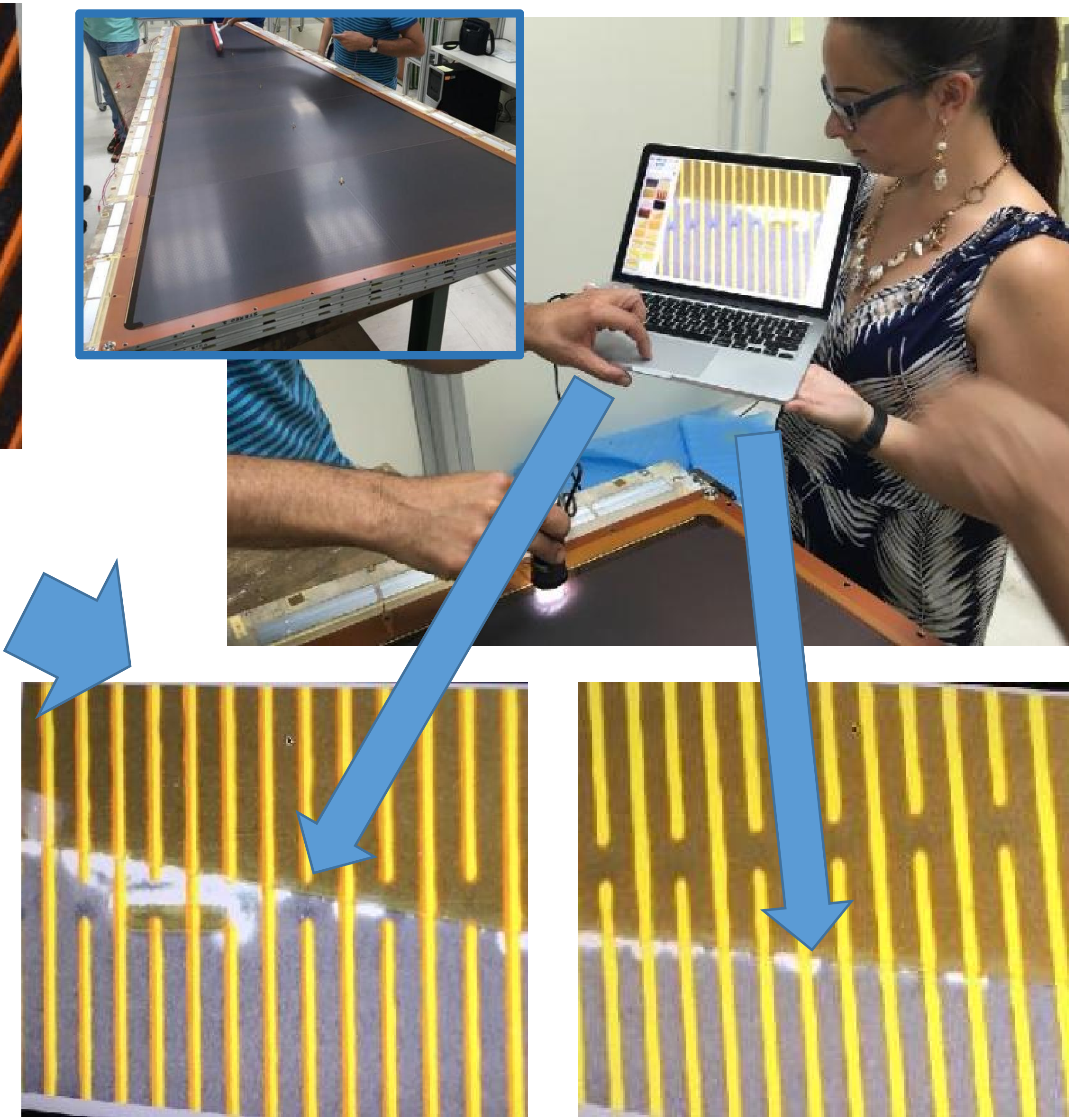


Local dirt on the mesh



Strong discharges along the piralux rim and interconnections found after the long term irradiation studies at GIF++

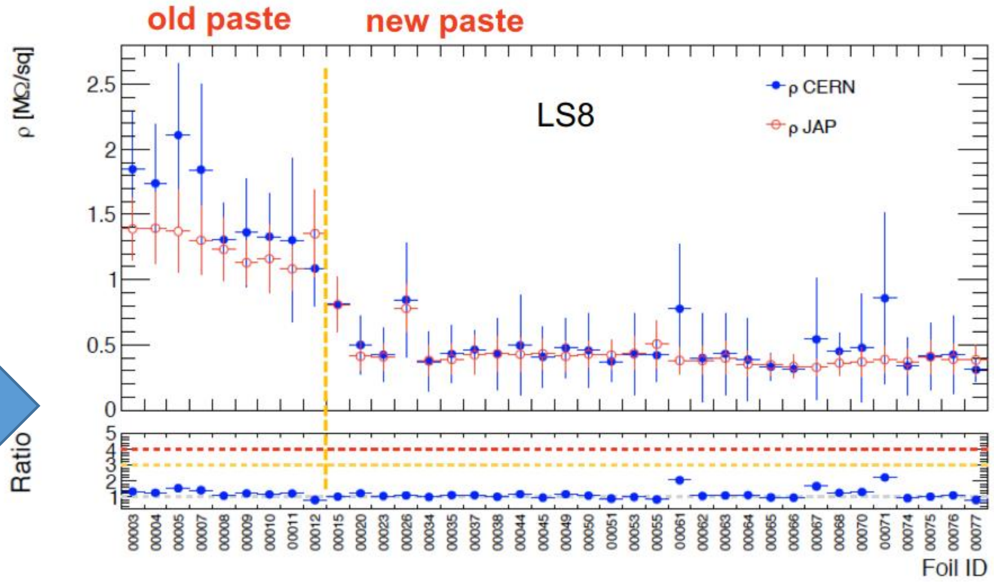
This triggered investigations on the resistance of the strips pattern



How to increase the HV stability - Resistive Paste

ESL Paste type

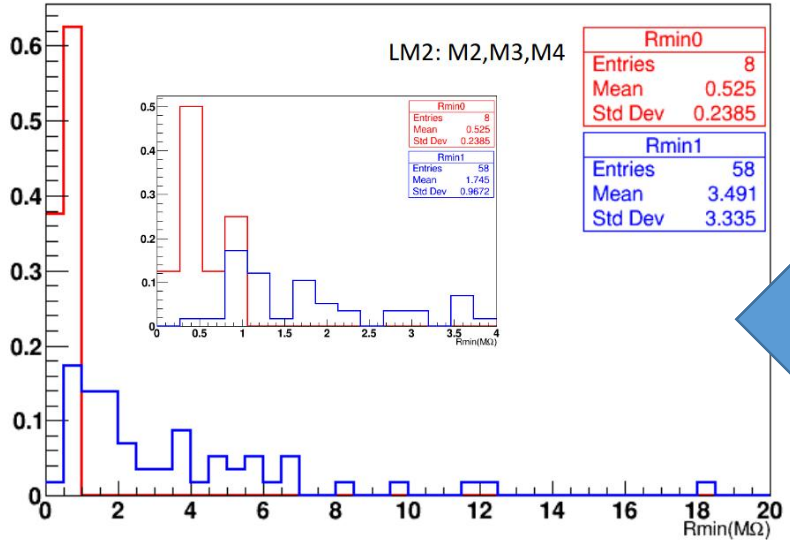
"Old" paste (same batch used in pre-series) :
Resistivity ~1MΩ/sq.
Good resistivity
12 foils done, then no more available...



"New" paste
Resistivity ~0.4-0.5MΩ/sq
70 foils... much worse

Resistive foils lamination

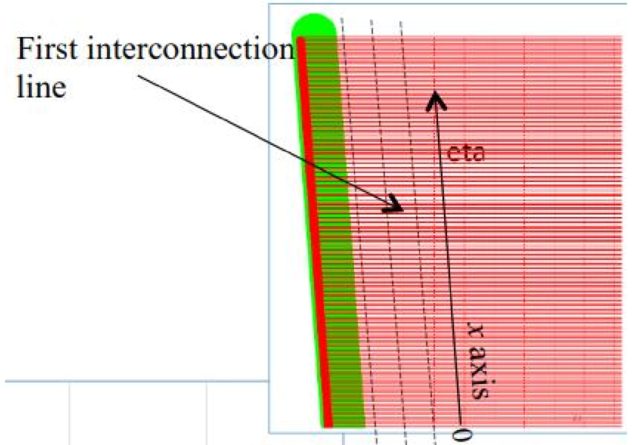
done through
in line 'pumice' (Al powder bath).
manually with following steps
- Sandpaper 2500
- CIF cleaning
- Rinsing
- Mild micro-polishing bath

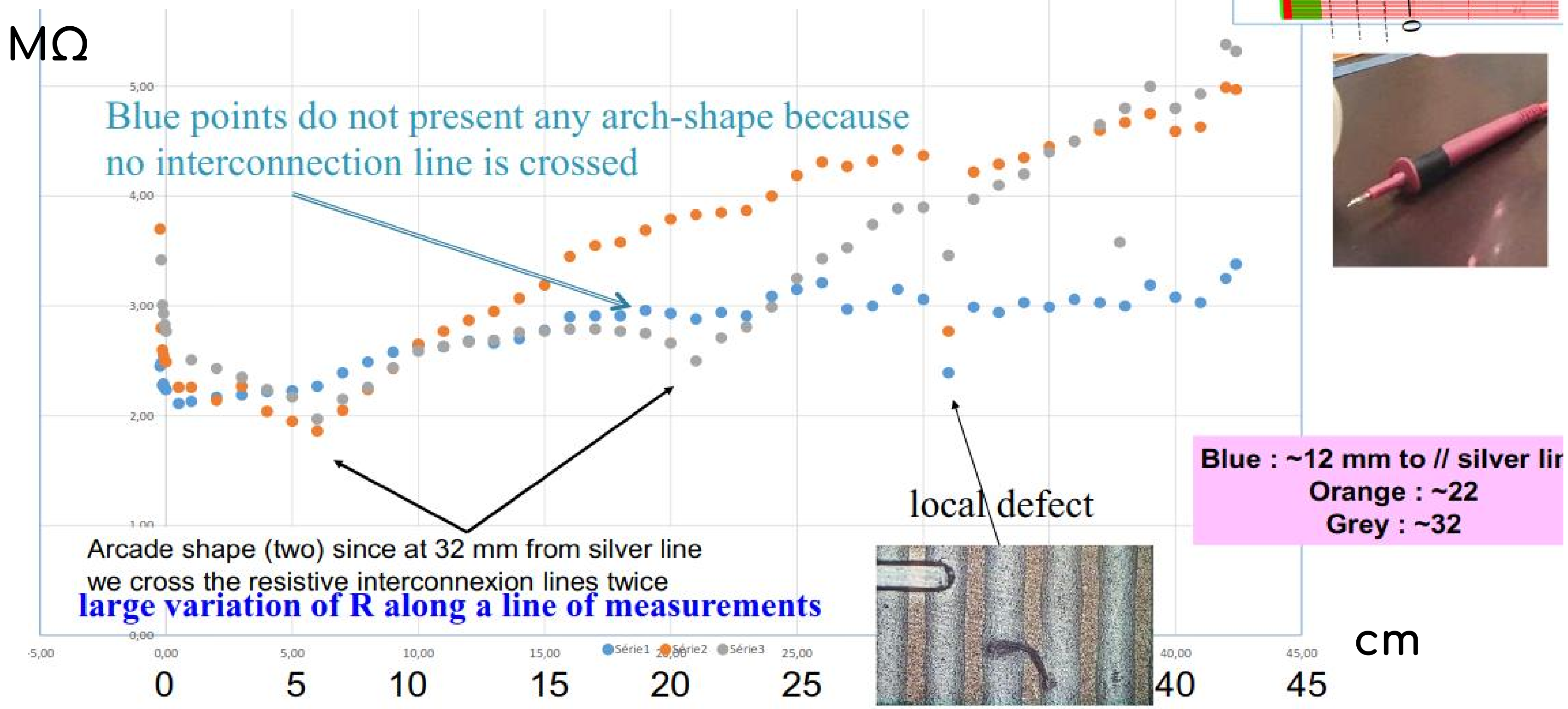


Correlation between **Resistance and HV behaviour** when foils are mounted in a chamber

HV stability - Causes

Individual strip resistance measurements
on a LE8 board
(LM2 type Micromegas)





Several measurements with a multimeter on lines parallel to the silverline

showed

1. no low resistance values along the line closer to the silver line (far from first interconnection line)

2. low periodic resistance values while getting closer to the first interconnection line

3. local defects can be also detected

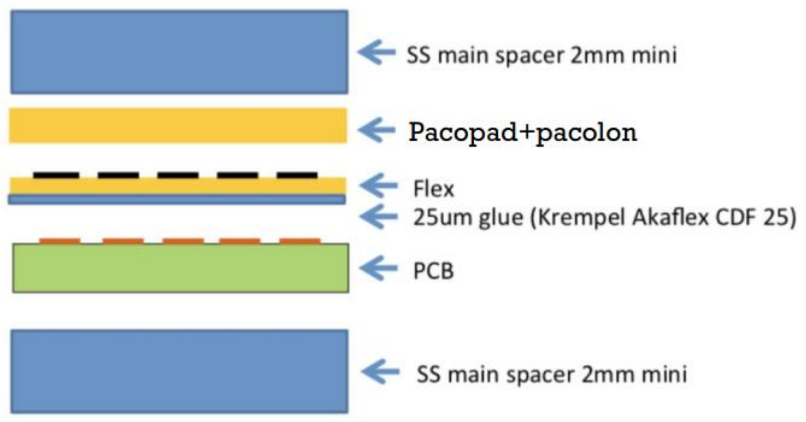
How to increase the HV stability - Resistive Paste

New paste and foil production procedure under study.:
500 new foils produced in grade A/B by pressing at lower pressure and higher temperature
Target mean value is 0.84MΩ/sq.

Resistive foils categories criteria
Avergage resistivity 0.28 <R <2.6MΩ/sq
Outlier criteria:
•99% of measured points 0.28 <R <2.6MΩ/sq: Grade A
•95% of measured points within 0.28 <R <2.6MΩ/sq: Grade B
•95% of measured points within 0.21 <R <3.4MΩ/sq: Grade B-

Last 150 foils made with a paste at higher resisitivity following the same procedure:
==> showed strong resistance increase (cracks?)

	Before pressing		After pressing	
	Up [MΩ/sq]	Down [MΩ/sq]	Up [MΩ/sq]	Down [MΩ/sq]
new 1-③	1.25	1.92	>100	>100
new 1-④	0.98	1.65	>100	>100
new 2-②	0.90	1.15	13	8.2
new 2-③	1.47	1.20	7.3	5.9
old 2-③	0.62	0.69	2.9	12.2



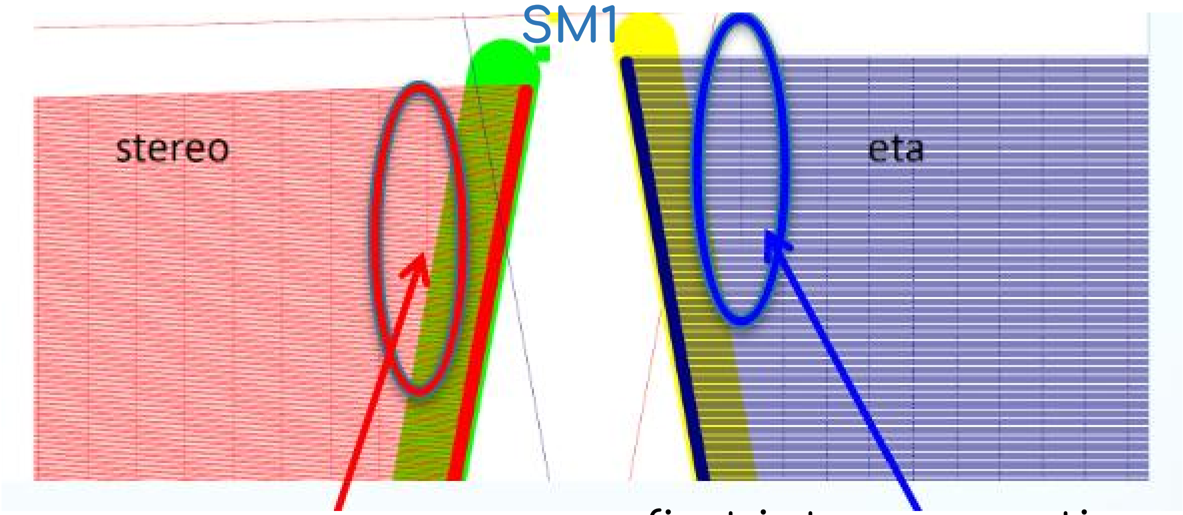
Standard procedure for gluing:

•Pacolon
•Pressure of 14 bar
•Temperature of 170°C

NEW PRESSING Procedure:

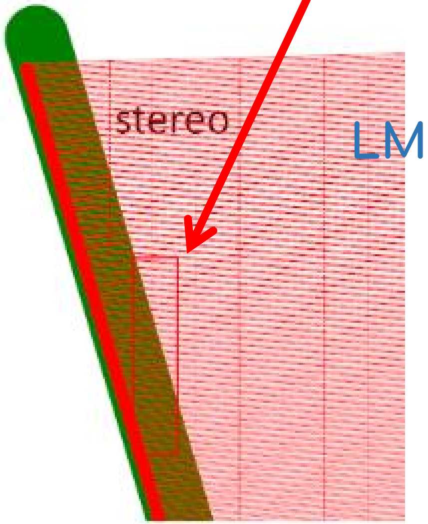
•Pacothane
•Pressure of 12 bar
•Temperature of 180°C

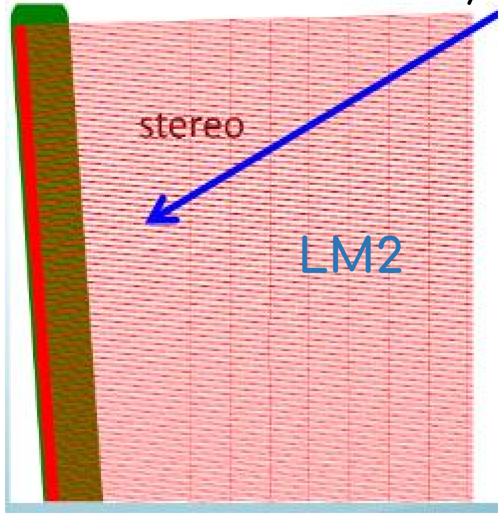
HV stability - Causes

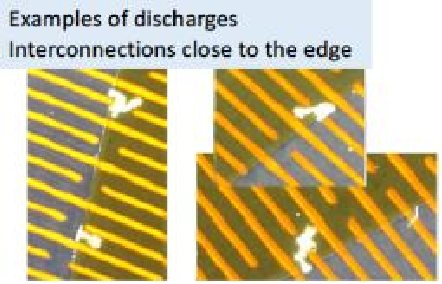


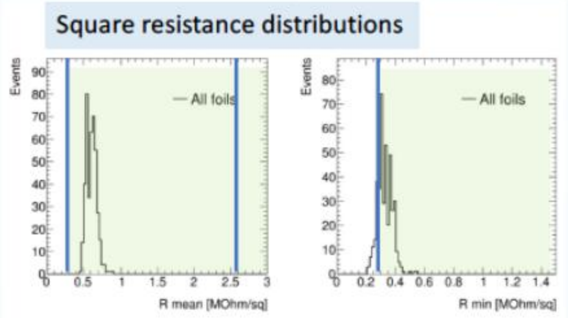
first interconnection cross the coverlay

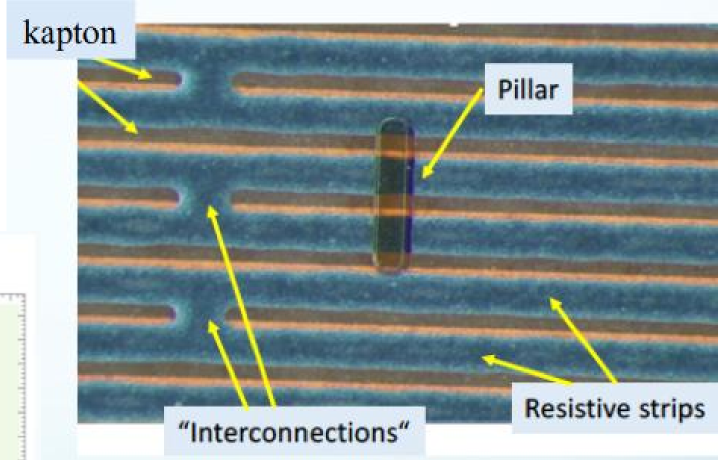
first interconnection DO NOT cross the coverlay





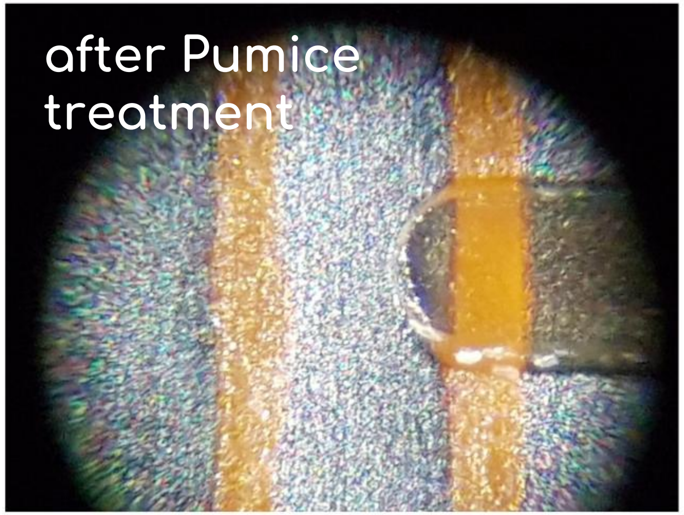


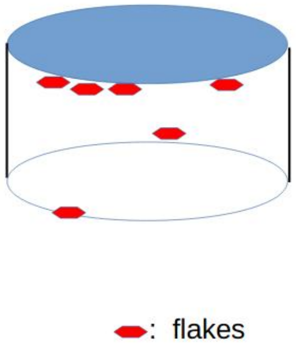


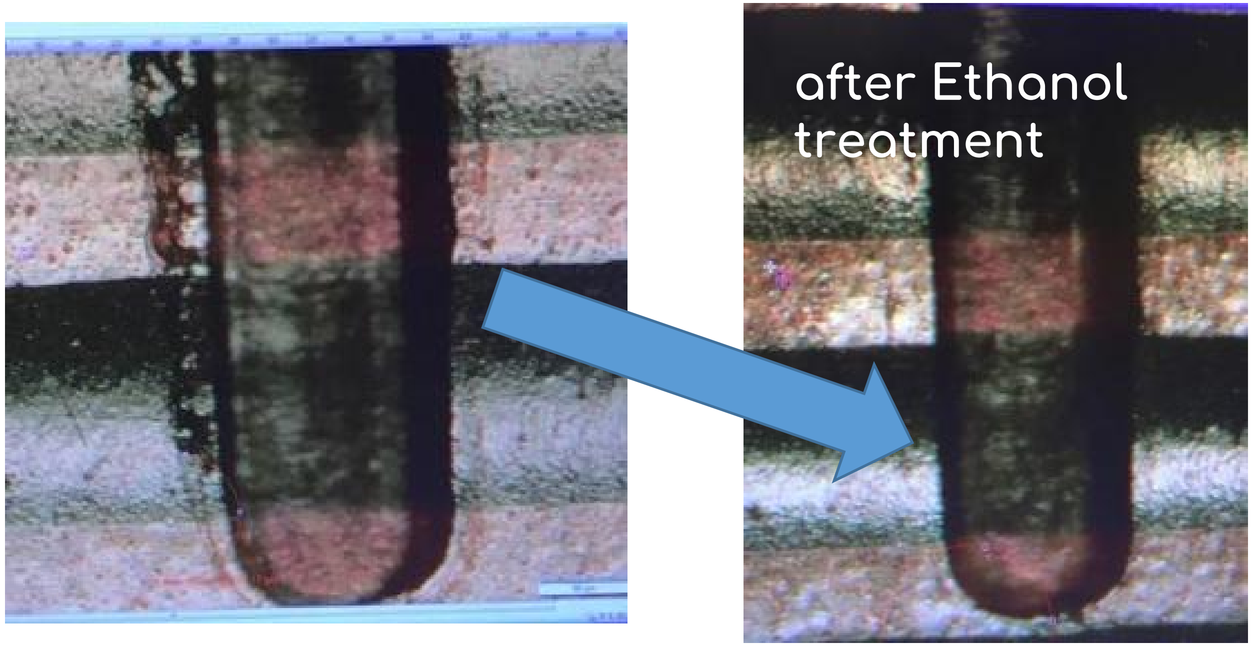


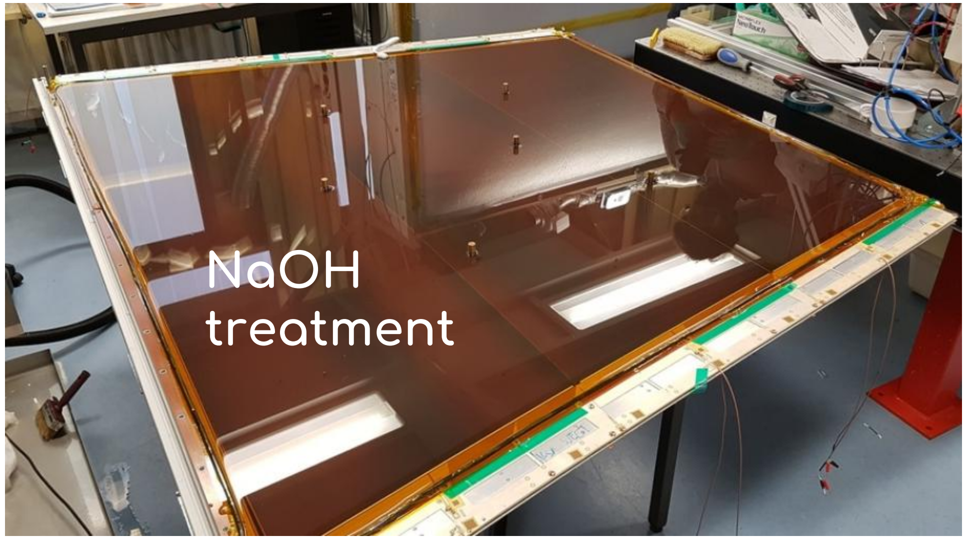
- Resistive strips are screen-printed on a kapton support
- Average resisitivity are at the lower limits of acceptance
- Minimum Resistivity is often below the limit (0.28 MΩ/□)
- Interconnections on the resistive strip layout
  ==> locally lower resistivity
- Resistive strips layout is different between PCB types
- In many cases the discharges localized on resistive strips interconnection crossing the coverlay
- Some PCB types more affected than others
- e.g. LM1 both stereo and eta, SM1 stereo, not eta panels

How to increase the HV stability - additional curing tested









Pumice powder brushing

NaOH bath

Ethanol bath

were tried to remove dirt flakes around pillars.
No clear response on the effectiveness

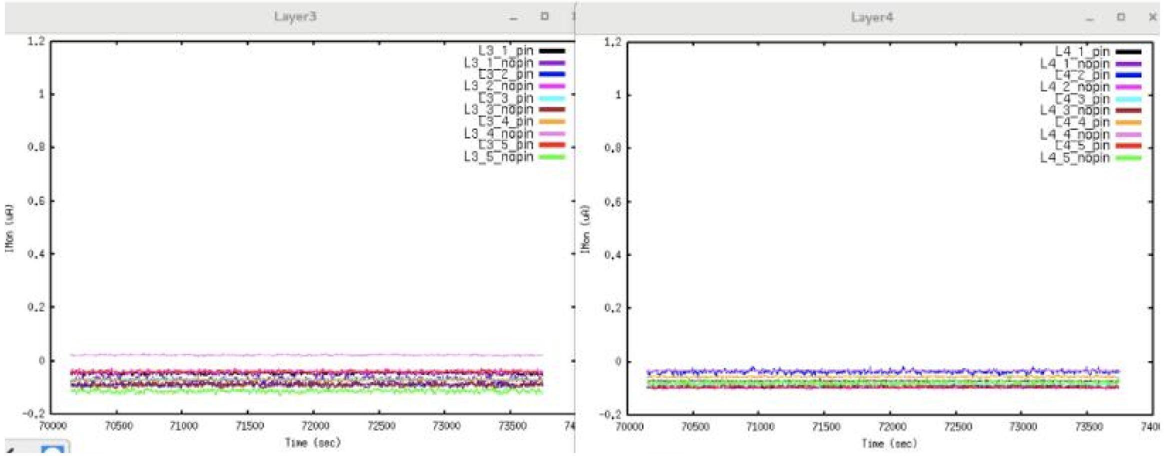
How to increase the HV stability - additional passivation tecniques

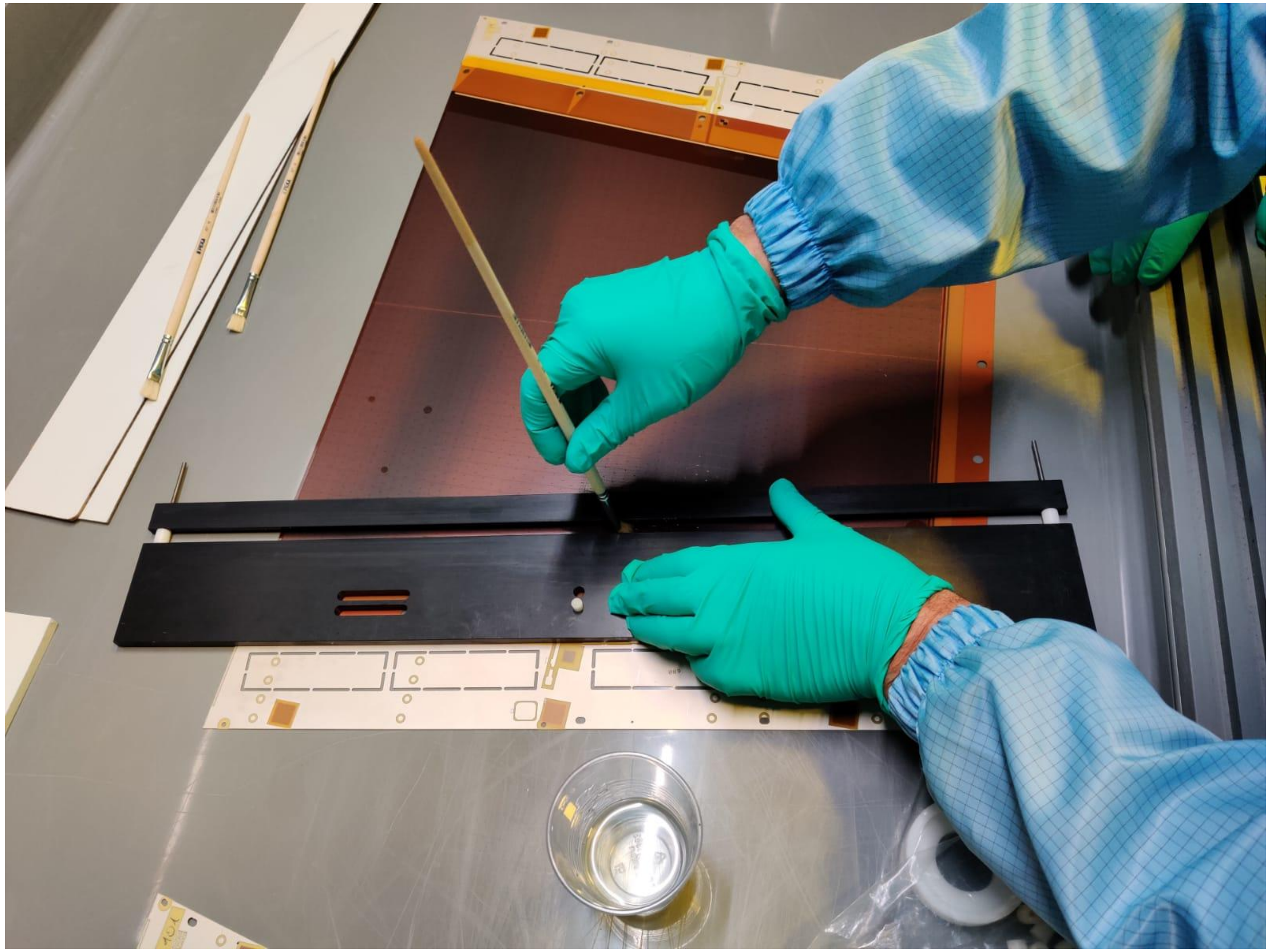
Polyurethane

Polyurethane is applied using a paintbrush(10-20 μm)

Dielectric constant 3-6 (Araldyte : ~4)
RH absorption < 1% (same for Araldyte)
Radiation hardness compatible to Araldyte

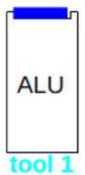
L3 L4 at 570 V

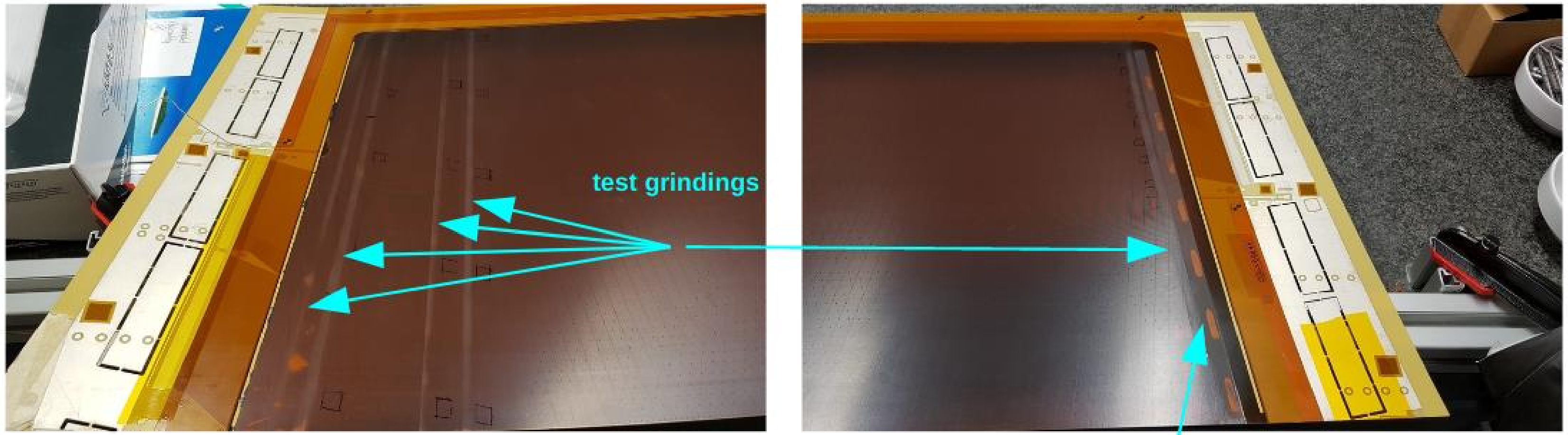


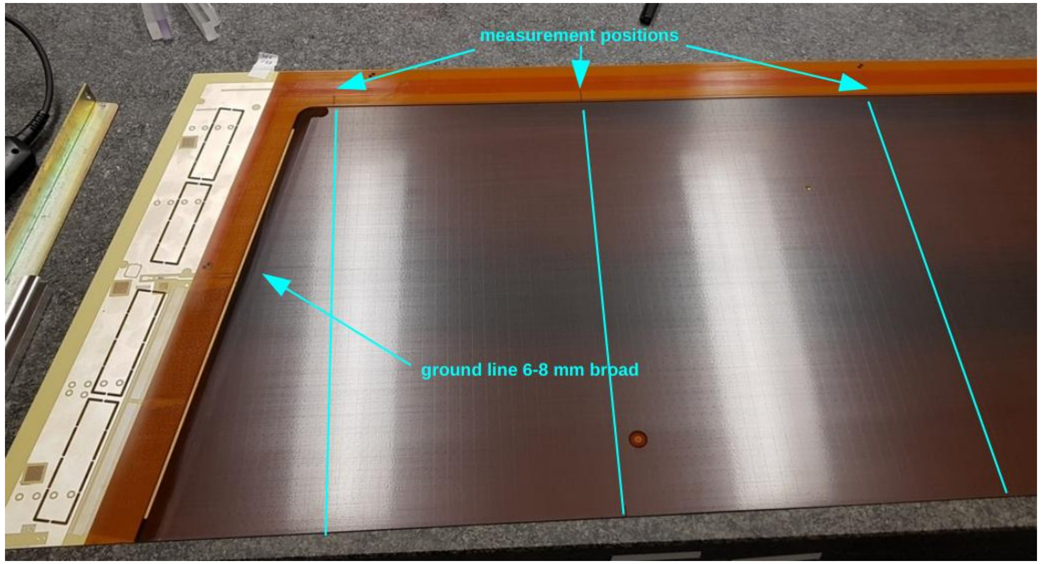


How to increase the HV stability - improve resistance

Grinding







Main idea is to make the strips thinner in a region of ~ 1 cm in order to increase resistivity for the whole resistive stips panel

two approaches used:

1. grinding non-continuos areas along the coverlay
--> doesn not solve isolated strips problems

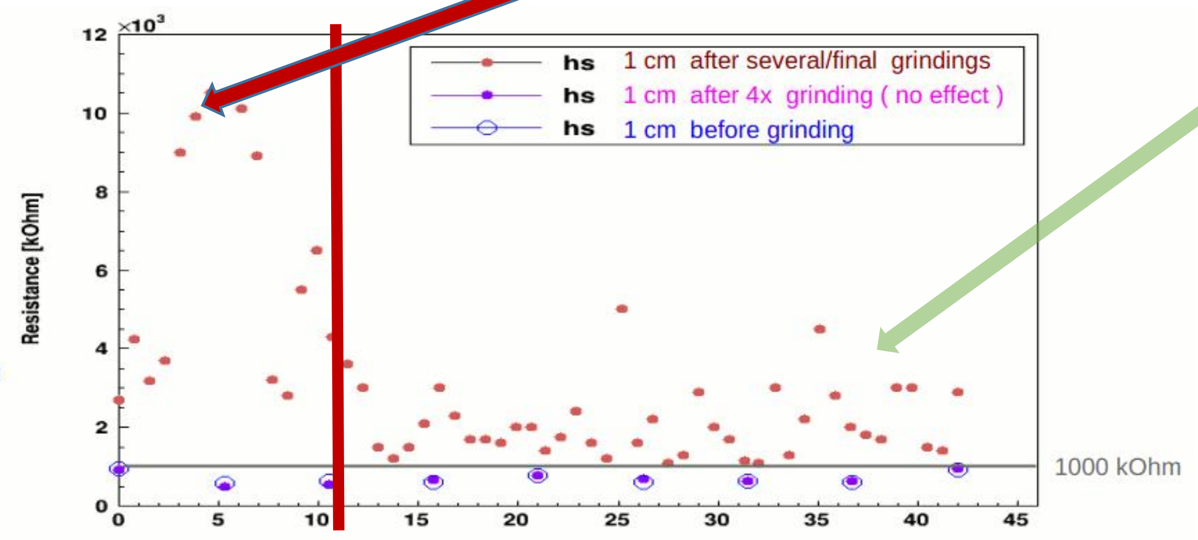
2. uniform grinding
--> good results!

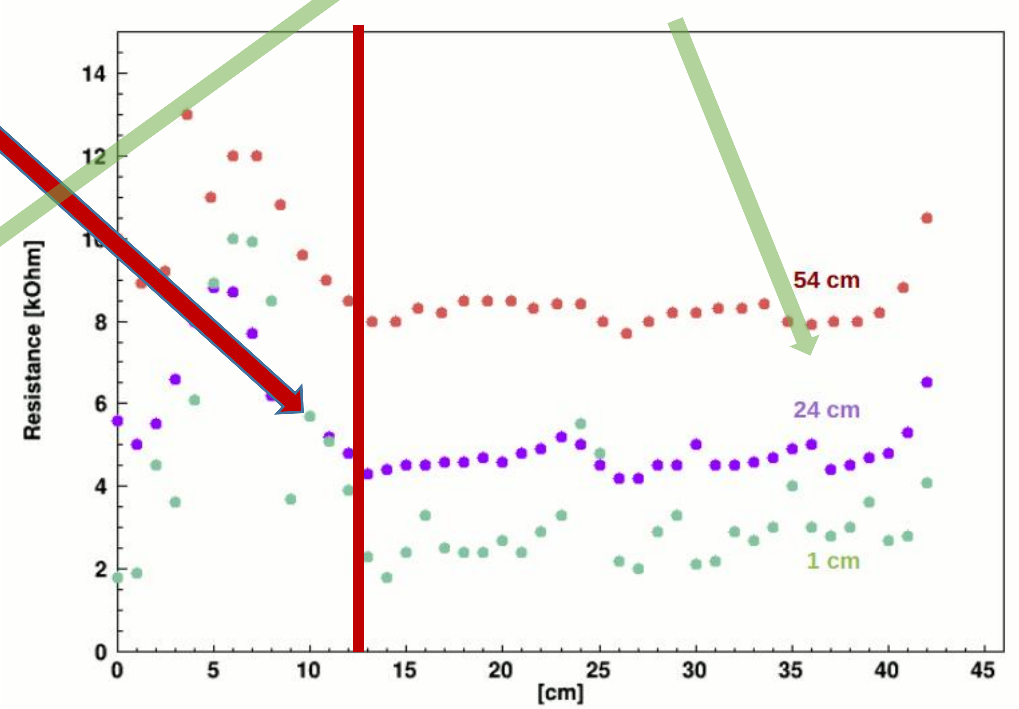
How to increase the HV stability - improve resistance

Grinding

too much grinding

very good results





@ 1 cm from the coverlay:

- before grinding Res<1 MΩ

- after grinding Res ~ 1-11 MΩ

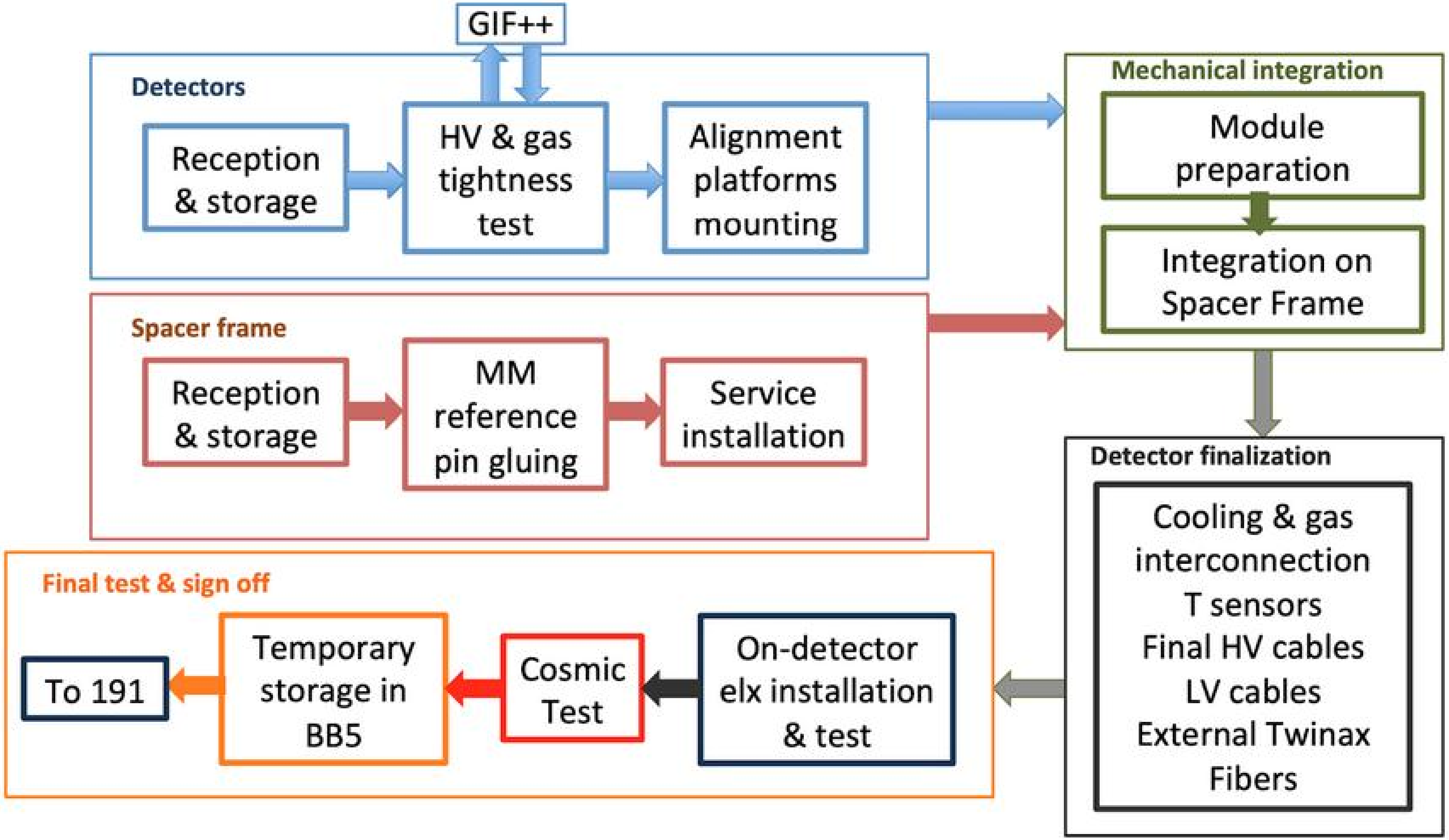
@ 1 cm from the coverlay after several grinding: Res ~ 2 MΩ

@ 24 cm (1/4 of a panel) : Res ~ 5 MΩ

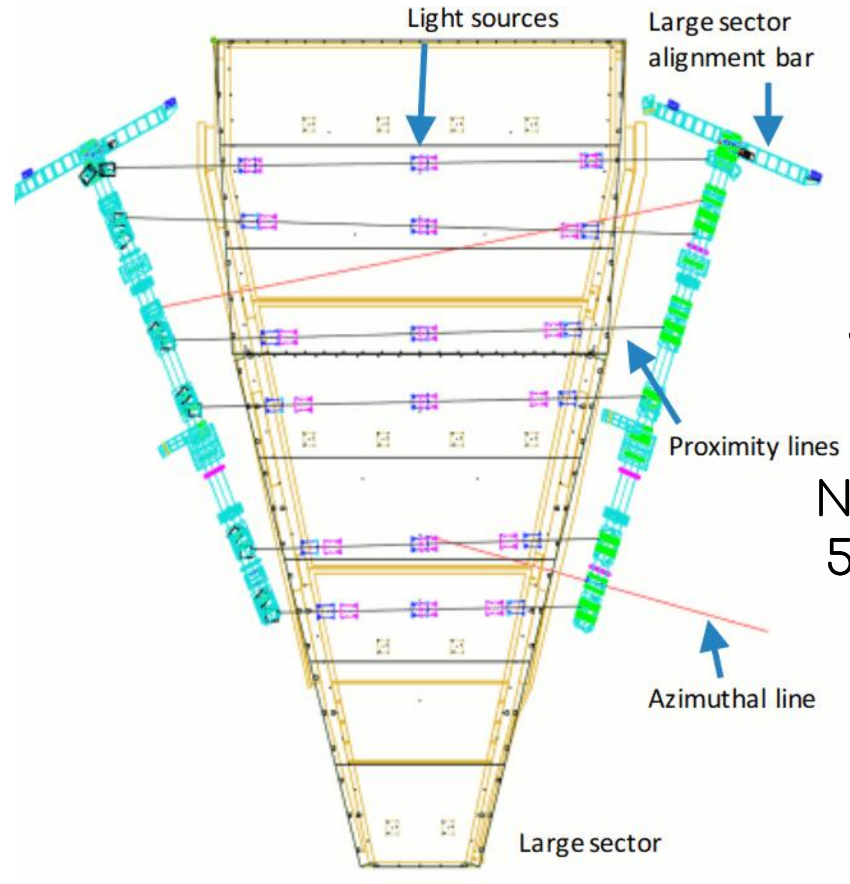
@ 54 cm (1/2 of a panel): Res ~ 9 MΩ

MM validation & integration - Workflow

General scheme of MM integration into Double Wedges

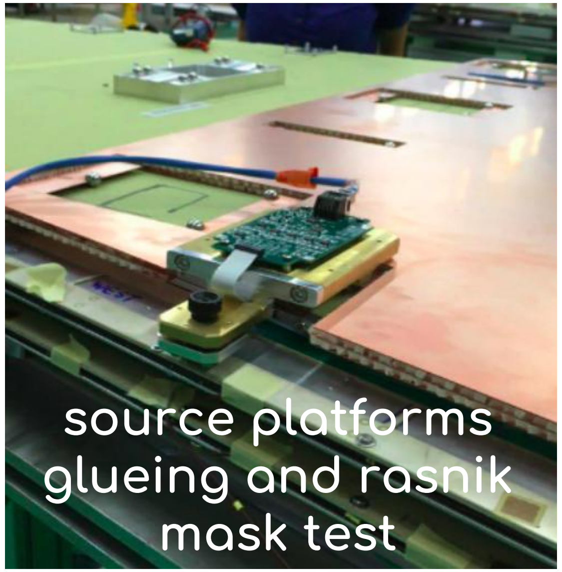


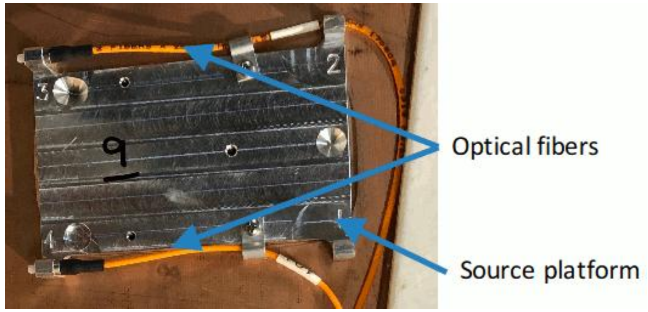
MM validation & integration - Alignment

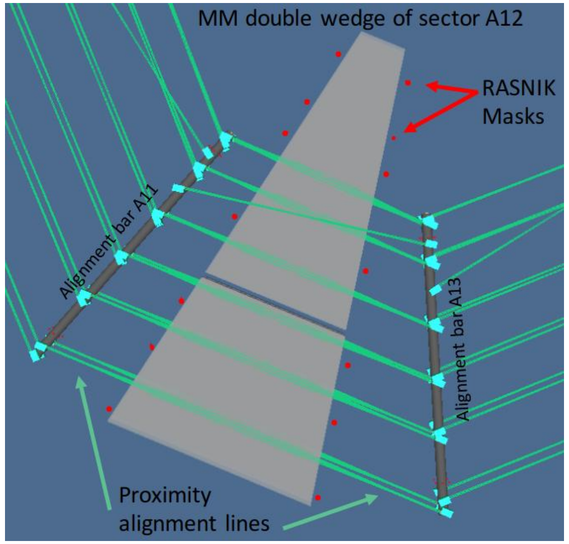


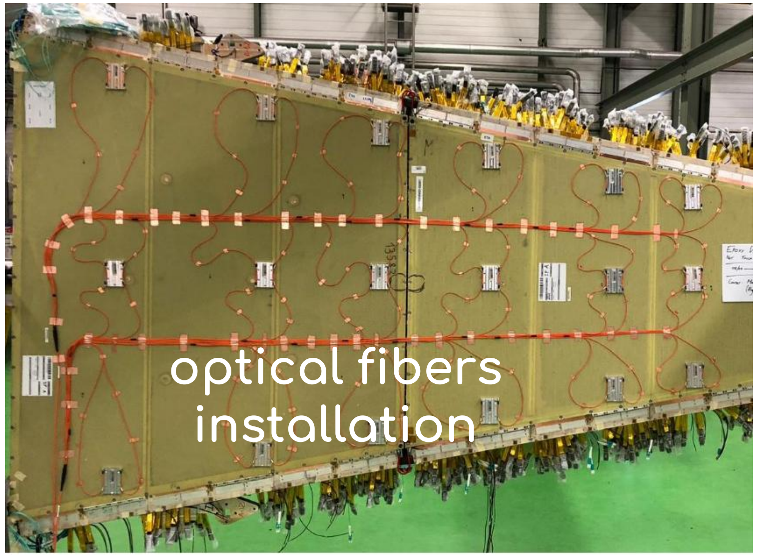
NSW MM sector alignment system:

1. light sources installed on DW
2. rasnik mask measurement define a local coordinate system for the DW
3. optical fibers are installed to power the light sources
4. alignment bars on JD (mechanical NSW frame) read the light (align < 50 μm)
5. the strips position can be inferred by rasnik + alignment bar position





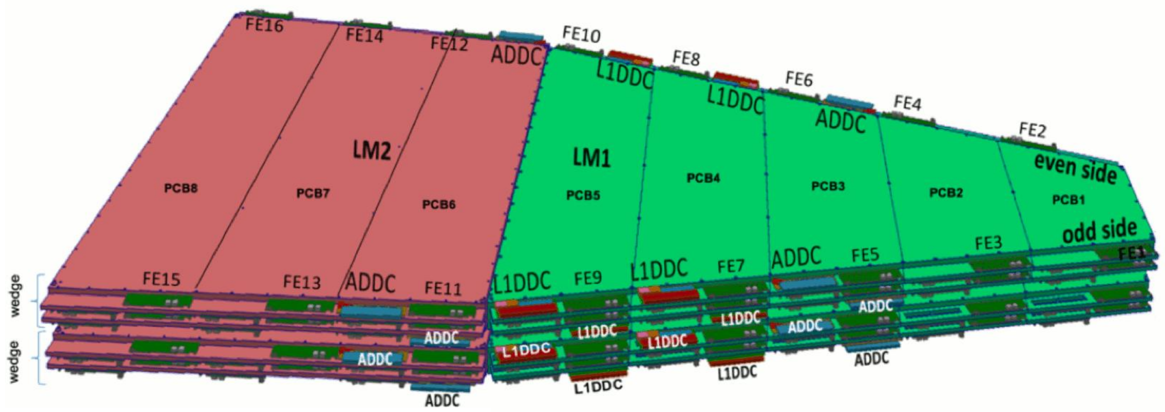




MM validation & integration - Electronics

Each MM DW holds

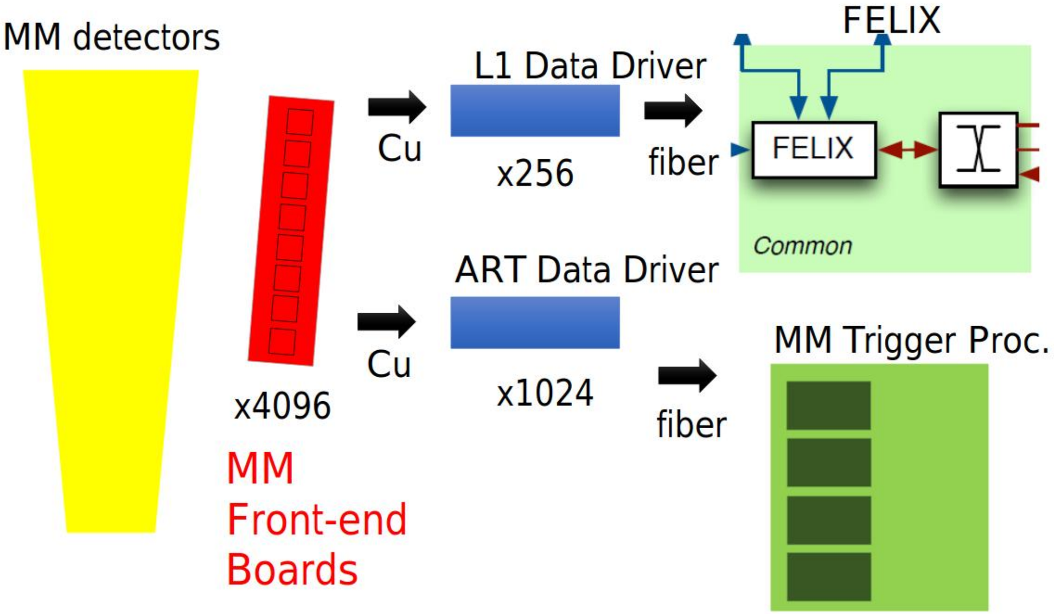
- 128x MMFE8
  x 8 VMM chips
- 16x L1DDC
- 16x ADDC
- 16x LVDB

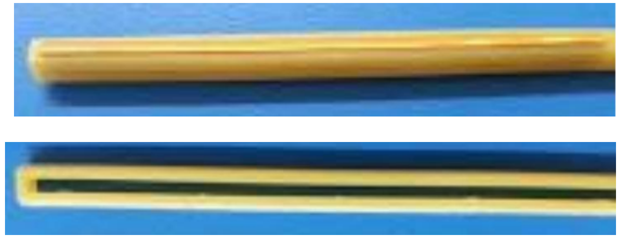


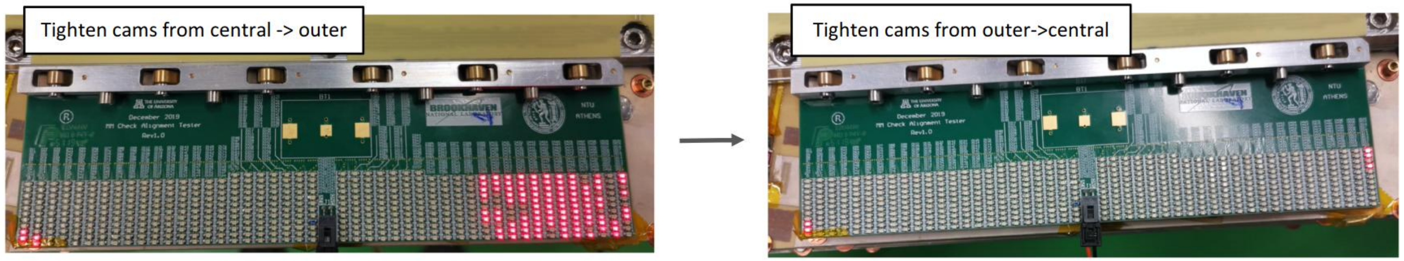
Complex alignment procedure of the zebra connector and MMFE8

correct zebra/MMF8 coupling

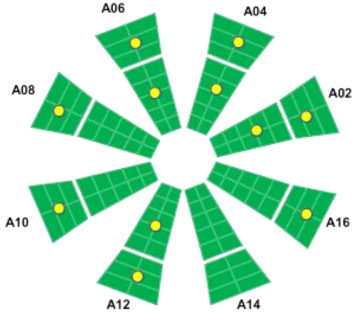
correct centering / cam tightening

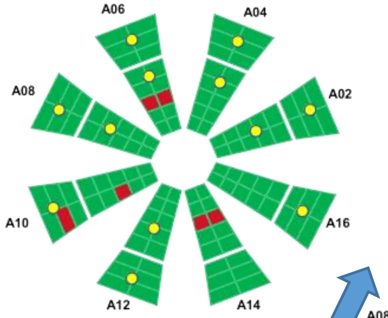


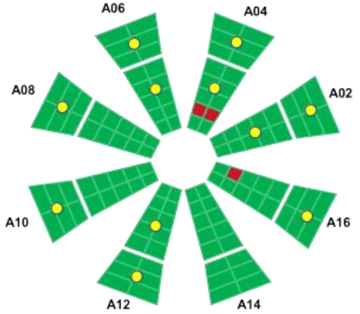


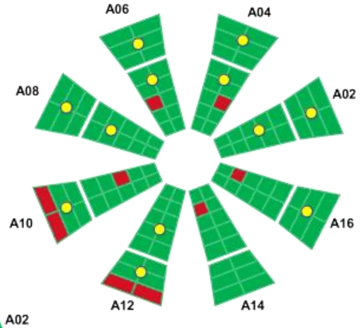


MM validation & integration - NSW-A SDWs HV

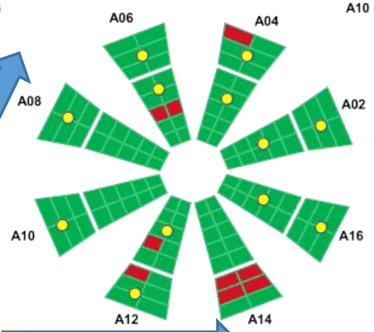


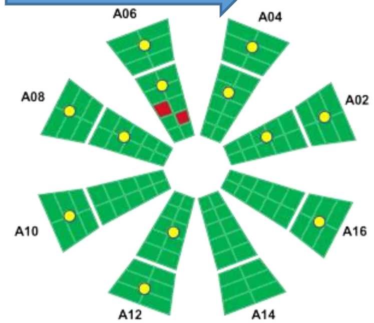


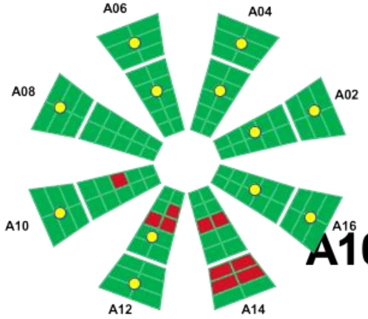


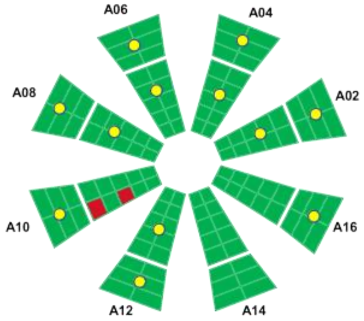


NSW A Small Sectors L1-2-3-4 (from IP side)





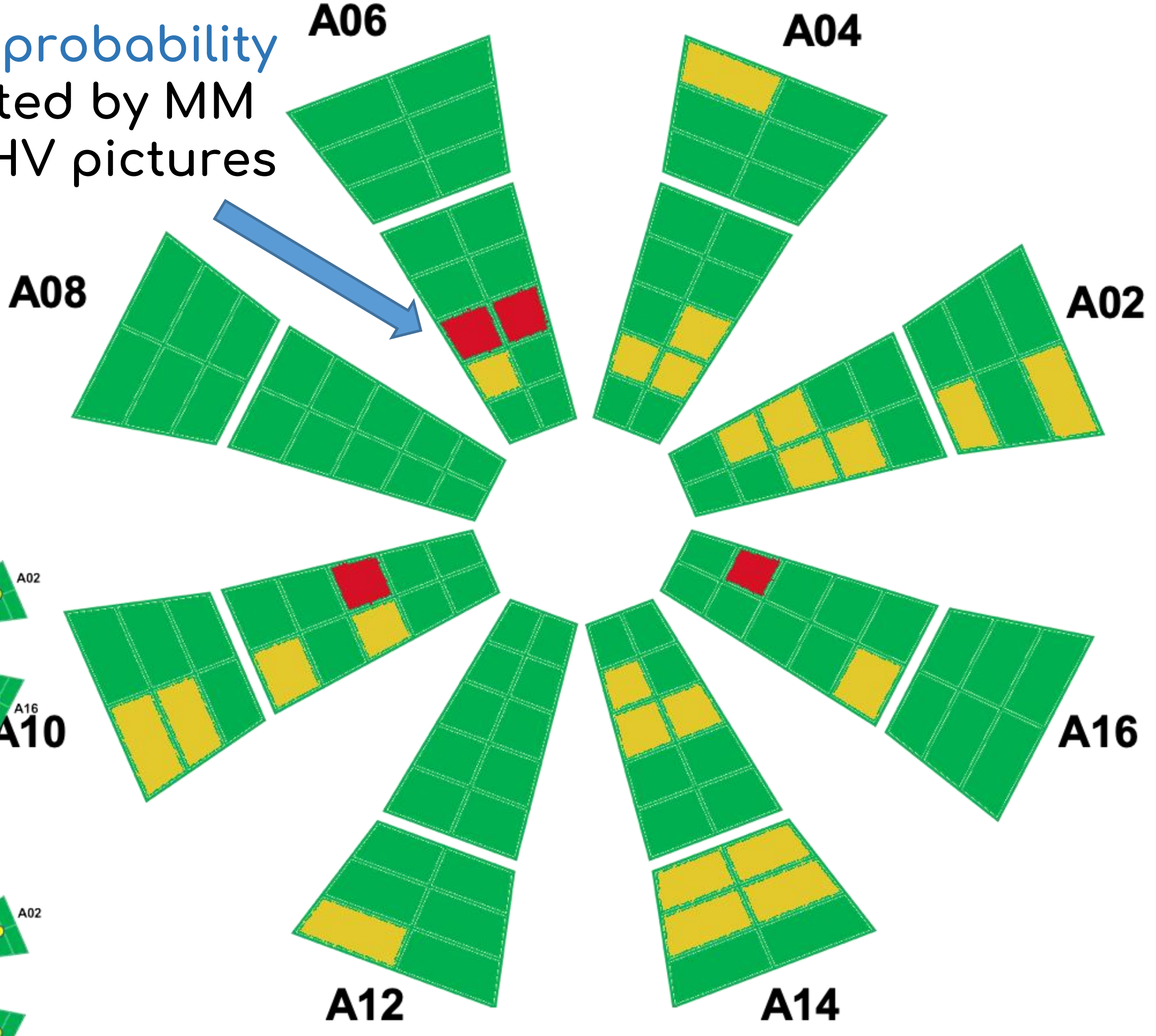




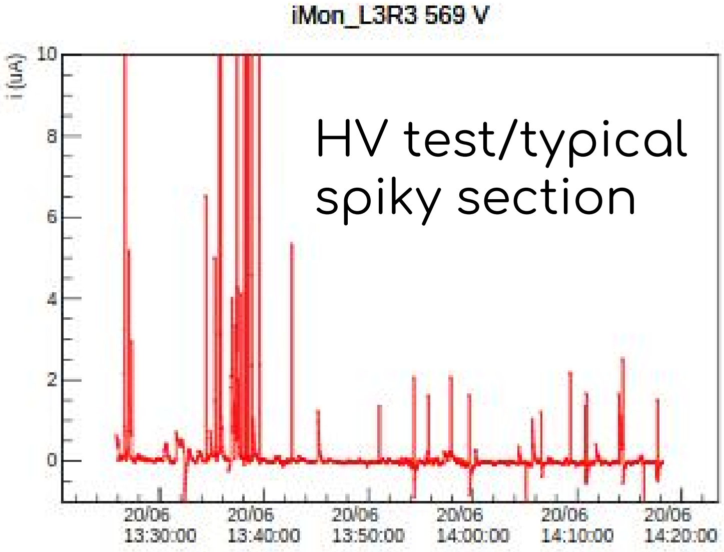
NSW A Small Sectors L5-6-7-8 (from IP side)

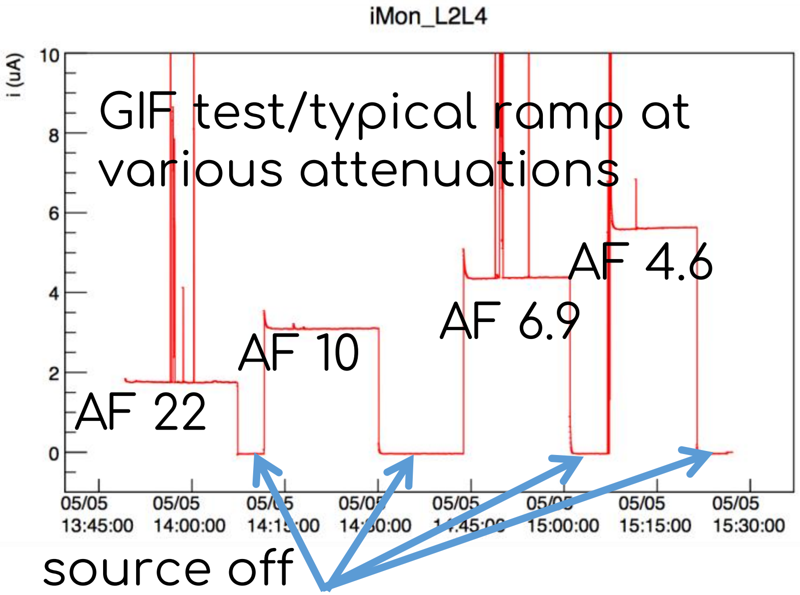
HV picture:
green: 570 V (nominal)
red: < 560 V
yellow: passivated modules

Majority6 probability as expected by MM modules HV pictures

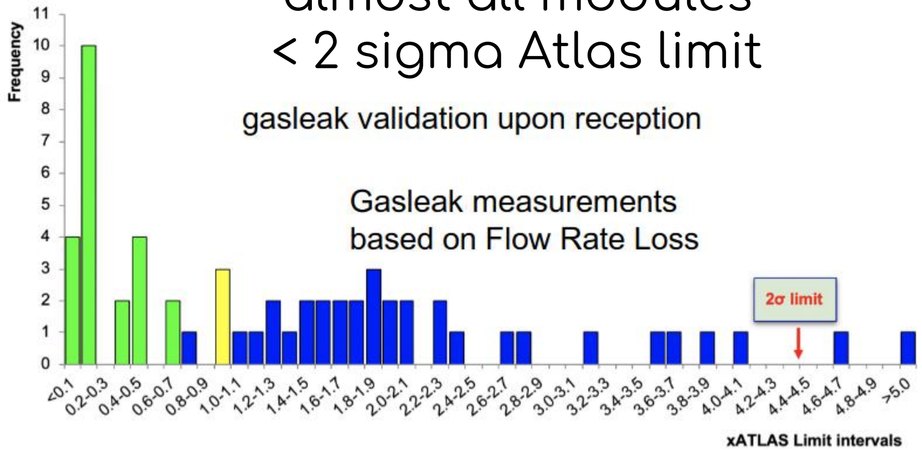


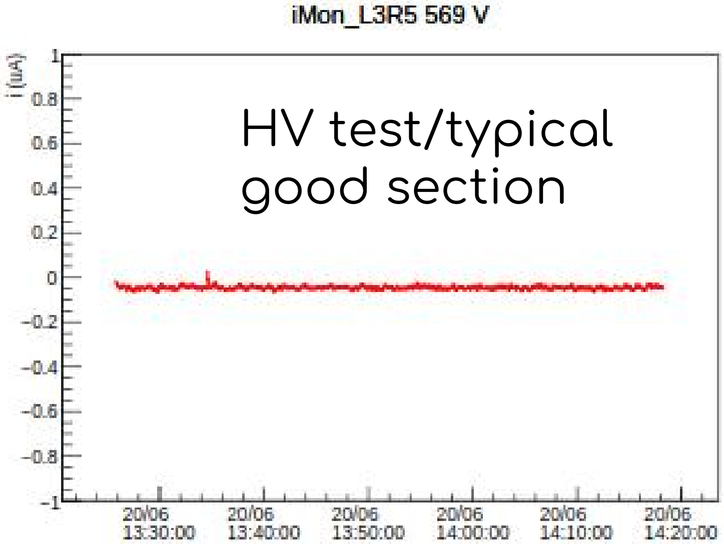
MM validation & integration - HV/irradiation studies





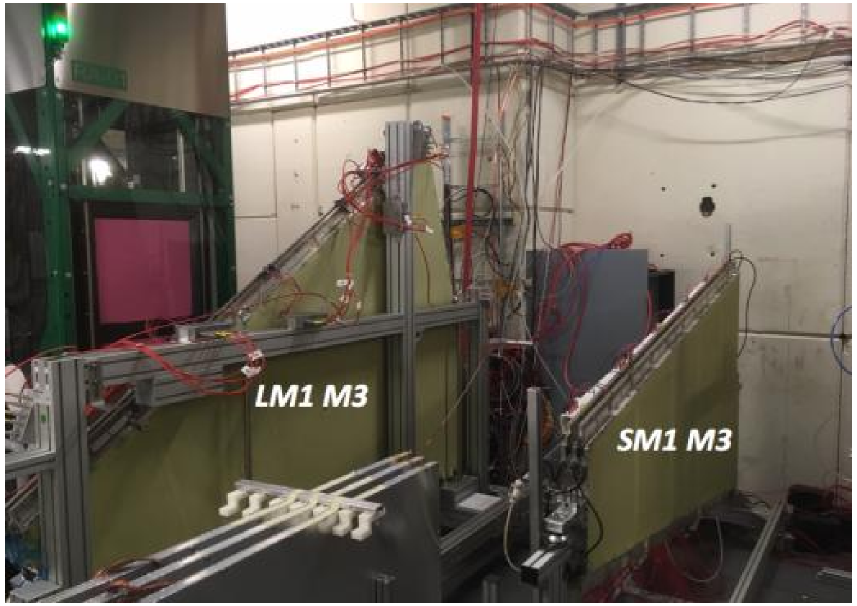
Gas leak results on 59 modules:
almost all modules
< 2 sigma Atlas limit





MM modules HV and current behavior are tested with and without irradiation @ bdg 899 and GIF++ irradiation facility at CERN.

HV stability and response linearity vs particle flow is checked. Weak points are identified



MM validation & integration - Mechanical Integration