The Micromegas chambers for the upgrade of the ATLAS forward muon detector

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on behalf of the ATLAS NSW Micromegas Group

INFN - Roma1 & LNF seminar

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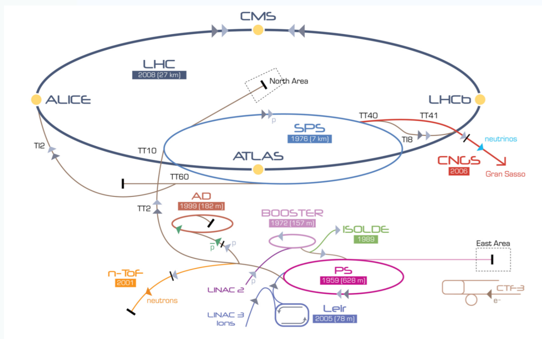
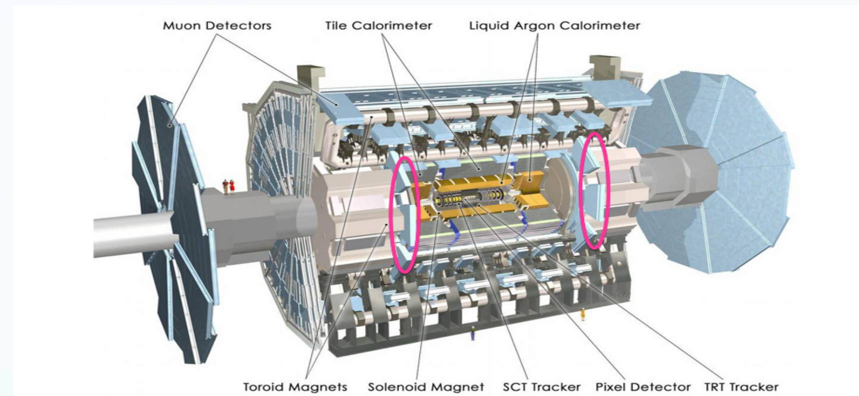
Outline

- Physics motivation for the upgrade
- The Micromegas for the ATLAS upgrade
- New Small Wheel Layout
- Construction and QA/QC procedures
- HV problems and solutions
- MM modules integration at CERN
- Wheel assembly
- Summary

LHC and ATLAS

- **ATLAS** is one of the main experiments at the Large Hadron Collider
- **LHC**: high-luminosity *p-p* collider at a maximum center-of-mass energy of 14 TeV
  - it can operate also with ion beams
  - It sets the present energy frontier for collider physics

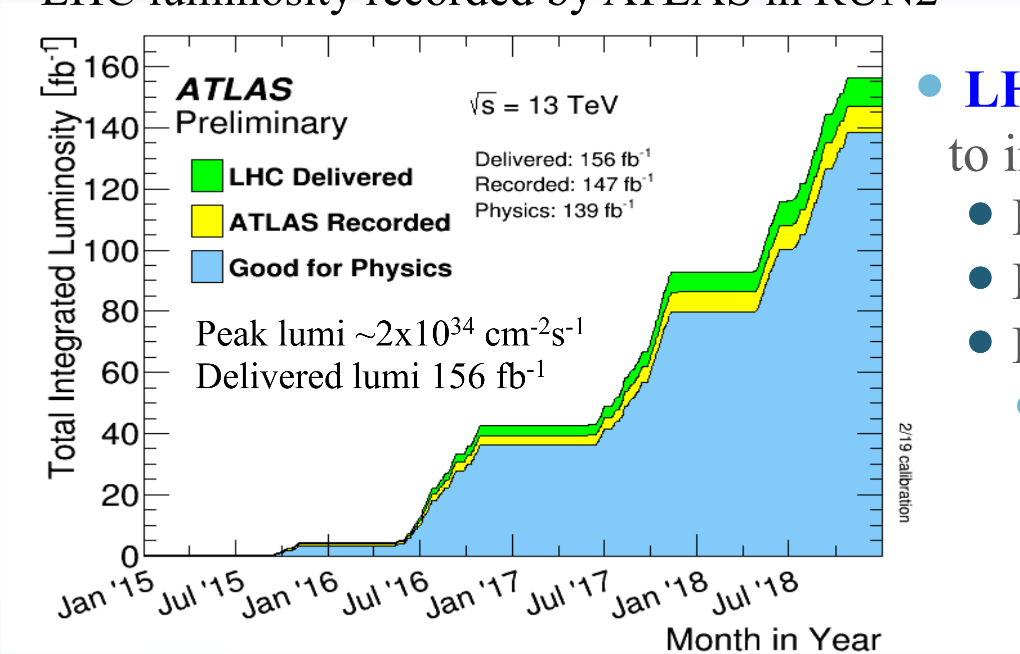




- Main Physics goals of the experiment:
  - ✓ Higgs boson discovery
  - Precision study of Higgs properties
  - Direct search for New Physics particles (as well as for inconsistencies in the SM)
- High energy is not enough: it needs also a huge amount of data for discoveries and to study rare phenomena

LHC and ATLAS upgrades

LHC luminosity recorded by ATLAS in RUN2



- **LHC** will undergo two major upgrades to increase the luminosity:
  - LS2: $L \gtrsim 2\times10^{34}$ cm^{-2}s^{-1}, L_{int} ~350 fb^{-1}
  - LS3: $L \sim$ 6-7x10^{34} cm^{-2}s^{-1}
  - Final integrated luminosity:
    - L_{int} ~3000 fb^{-1}

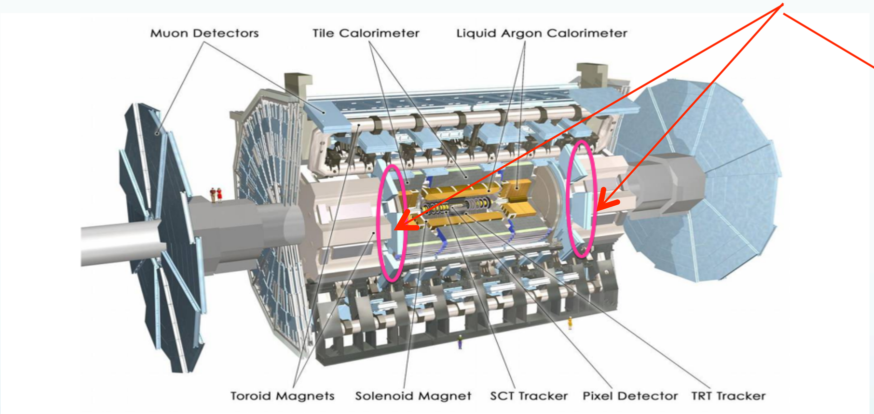
- All experiments must also be upgraded to cope with the increased rate of events
  - Long Shutdown 2 => experimental upgrade Phase-I
  - Long Shutdown 3 => experimental upgrade Phase-II
- This Seminar will focus on the ATLAS upgrade of the muon forward detector during the LS2

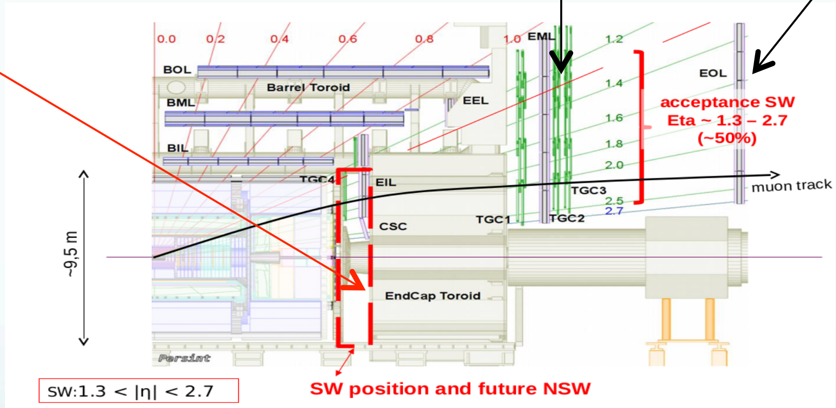
ATLAS Phase-I upgrade

- The main upgrade in Phase-I concerns the replacement of the innermost stations of the muon endcaps (forward & backward) system
  - from the **Small Wheel** to the **New Small Wheel**
  - they are located at z = ±7 m from the Interaction Point between the hadronic calorimeters and the endcap toroid, and cover the angular region **1.3<|η|<2.7**

SW and future NSW locations

Big wheels (middle EML and outer EOL)





The Small Wheel:

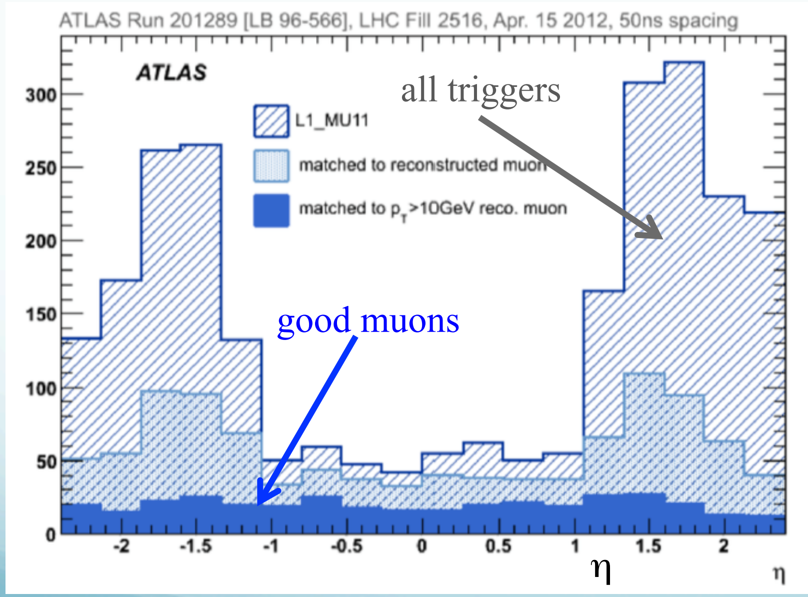
Monitored Drift Tubes (MDT) and Cathode Strip Chambers (CSC) for precise measurement of the η coordinate in different η intervals

Thin-Gap Chambers (TGC) for measuring the "second" coordinate and triggering

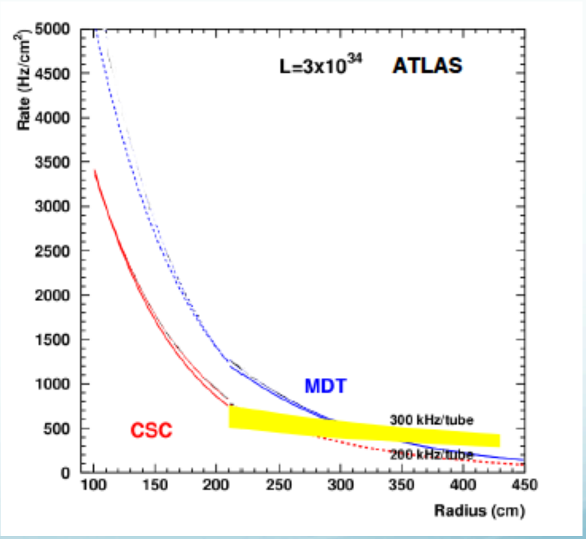
Why a New Small Wheel?

- The replacement of the present SW is needed:
  - to improve the trigger capabilities, maintaining a sustainable trigger rate (≲20 kHz) for p_T threshold of 20 GeV
  - because of the tracking-efficiency drop due to the very high hit rate

Trigger hit distribution (10-GeV p_T threshold)



Hit-rate (Hz/cm^2) extrapolation for $L = 3x10^{34}$ cm^{-2}s^{-1}



Plots from the NSW TDR

The New Small Wheel: requirements

- Basic concept: the performances should be at least as good at high luminosity ($L > 5\text{x}10^{34}$ cm^{-2}s^{-1}) as those of the SW at RUN-II luminosity
  - and no significant degradation for high fluxes and high cavern background

Triggering

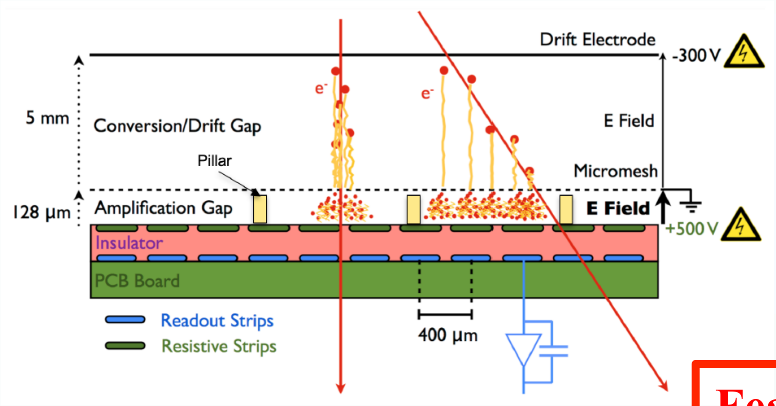
- **angular coverage: 1.3<|η|<2.5**
- latency, granularity and angular coverage consistent with those of the big wheel
- track-segment efficiency $\geq 95\%$
- track-segment angular resolution of 1 mrad

Tracking

- **angular coverage: 1.3<|η|<2.7**
- **p_T resolution: ~10% at 1 TeV** ➔ σ~100 μm per plane on a multilayer station
- track-segment efficiency ≥ 97% for muon with p_T>10 GeV
- measure the second coordinate with a resolution of 1-2 mm

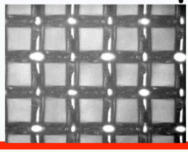
- **Redundancy:** Two multilayer detectors both providing info for tracking and trigger
  - **Micromegas chambers (MM)**: primary for high precision tracking
  - **small-Strip Thin-Gap Chambers (sTGC)**: primary for trigger purposes

The ATLAS resistive-strip Micromegas



Micromegas: MICRO MEsh GASeous detctor

- E_A/E_D ~100 => ~100% mesh transparency
- Gain ~10^4; ions collection time ~100 ns
- strip-width 300 µm (pitch 425-450 µm)
- mesh: 30 µm thick wires
  70 µm openings



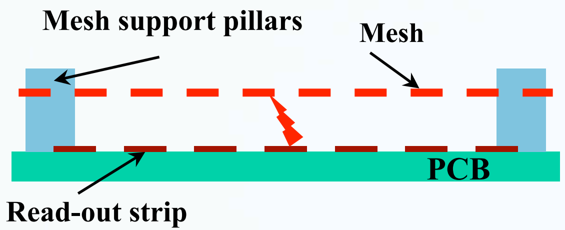
Working conditions

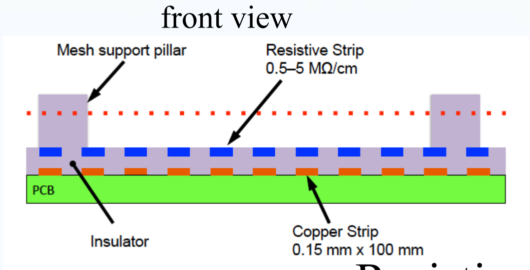
- Drift & conversion gap (5mm): HV_{drift}= -300V, E_D~600 V/cm
- Stainless-steel mesh grounded
- Amplification gap (128µm): HV_{RO}= 570V, E_A~50 kV/cm
- Gas mixture: 93% Ar - 7% CO_2 (further studies ongoing for alternative gas mixtures)

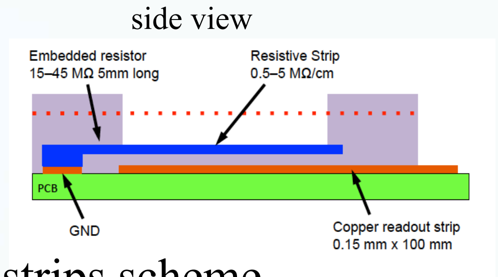
Features specific to ATLAS MM:

- Floating mesh: the mesh is integrated in the drift panel structure and not embedded in the anodic structure
  - necessary for large area detectors
  - the chamber can be re-opened for intervention
- Mesh at ground potential
  - easier construction procedure
  - allows separation of RO boards in independent HV sectors
- **Resistive strips** (~10MΩ/cm) are overlayed to copper signal strips
  - reduction of local current and of risk of discharges

Micromegas: resistive strips







Original scheme

- no resistive strips
- charge directly collected by RO strips

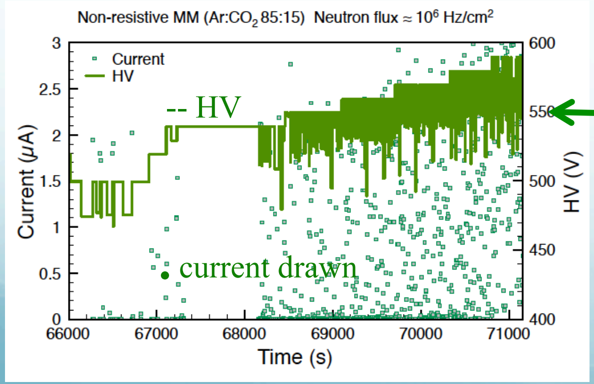
High spark probability for highly ionizing particles in a high rate environment

Dead time due to HV breakdown

Resistive strips scheme

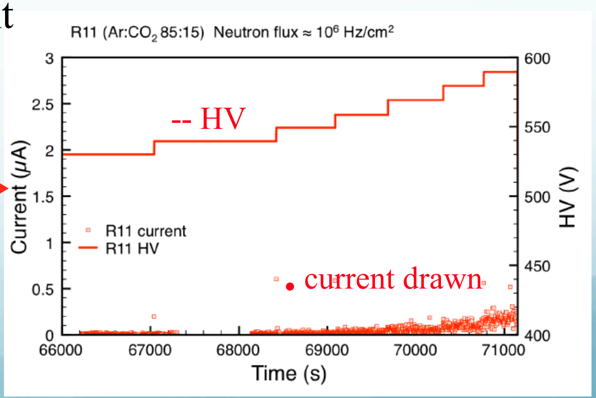
- strips with ρ ≳ a few MΩ/cm on top of readout strips, with a 50 μm kapton layer in between
- signal induced by capacitive coupling on RO strips
- resistive strips instead of a resistive layer to limit the spread of charge to neighbouring strips

Strong suppression of sparks also in very harsh environment

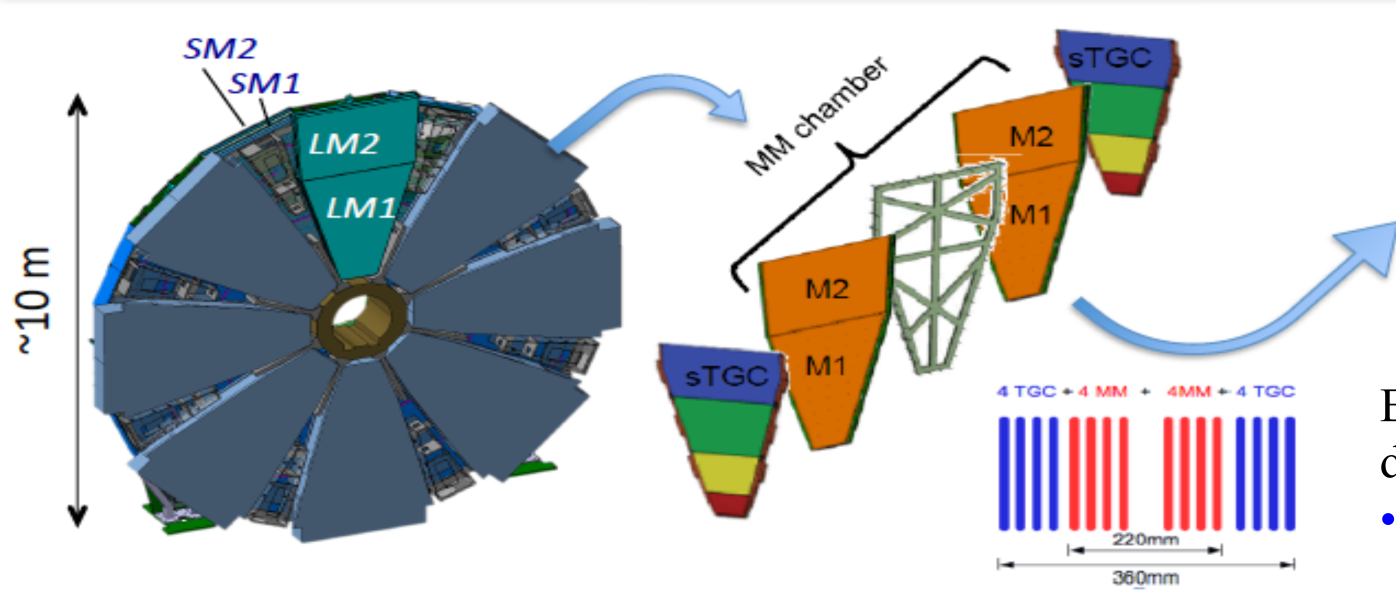


standard and resistive-strip MM under intense neutron flux

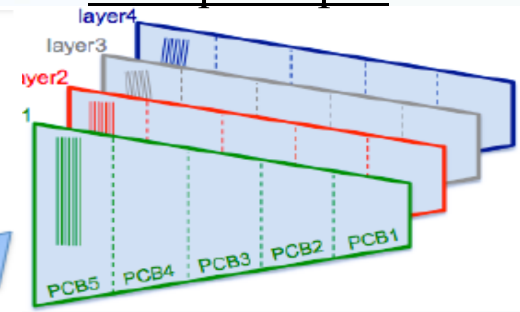
NIM **A640** (2011) 110



New Small Wheel layout



MM quadruplet



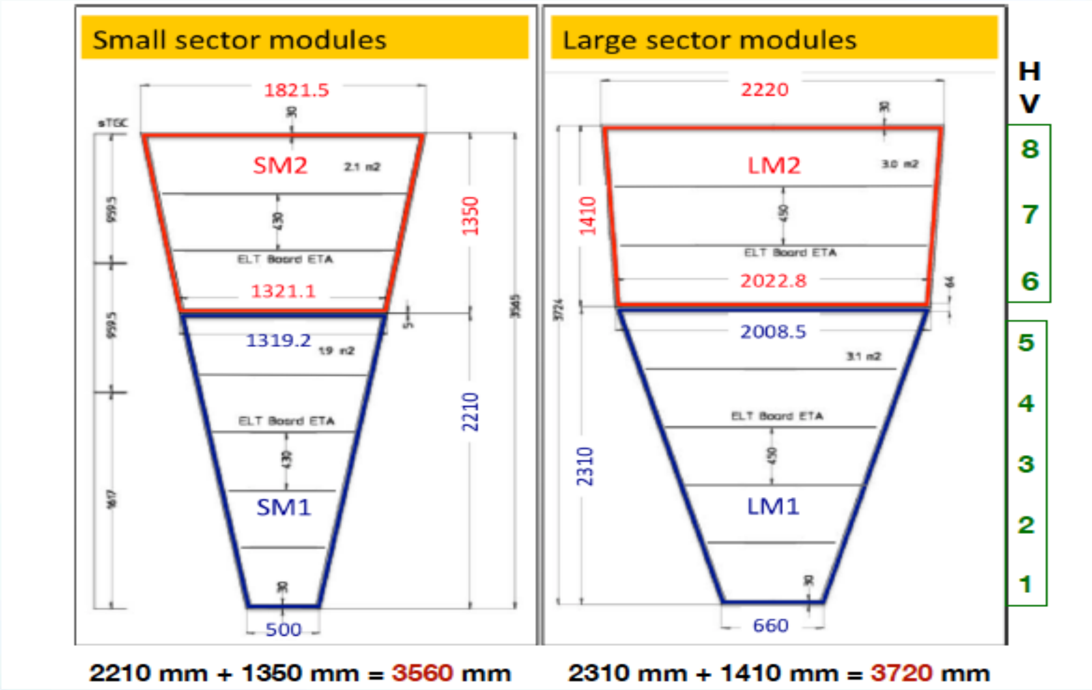
Each NSW has 16 sectors:
8 Large + 8 Small

Each Sector is a sandwich of
sTGC and MM quadruplets

Each MM module has 4 detection planes

- 2 planes with parallel strips (precision coordinate, "*eta*" strips)
- 2 stereo strip planes with +/-1.5° (2nd coordinate)

MM modules layout



Construction of the Micromegas modules

Large Module 1 (LM1):
France
CEA, Saclay

Large Module 2 (LM2):
Greece, Russia
Thessaloniki,
Dubna, CERN

Small Module 1 (SM1):
Italy/INFN
Pavia, Rome1, Rome3,
Frascati, Lecce, Cosenza,
Napoli.

Small Module 2 (SM2):
Germany
Munich, Freiburg, Würzburg,
Mainz.

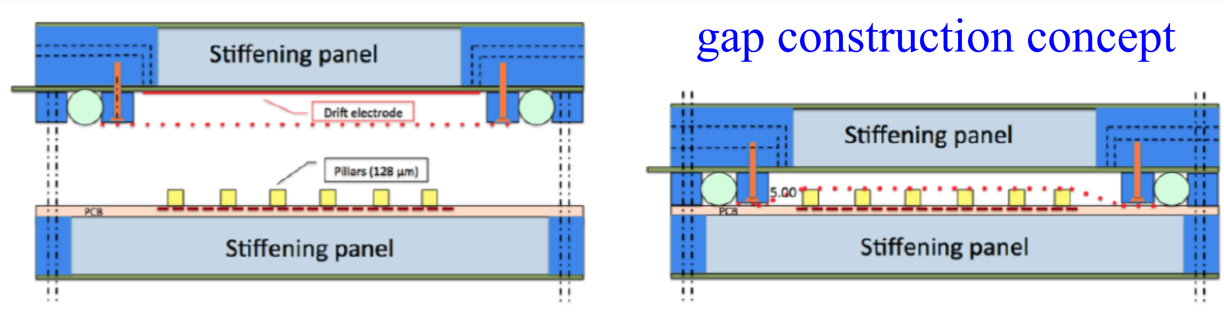
+ CERN
(initial design, PCB QA/QC)

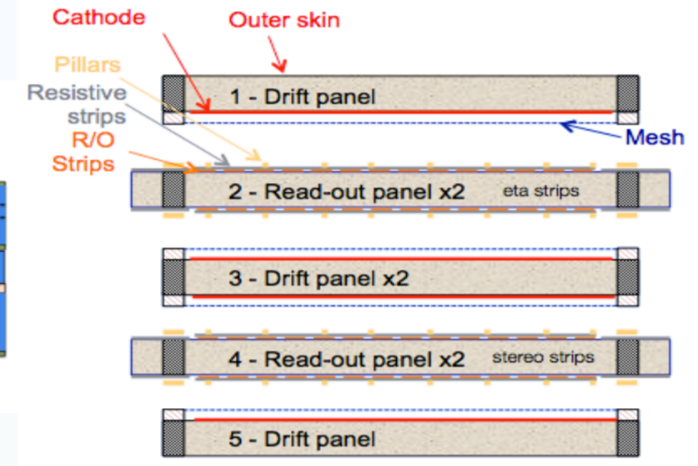
- **Total area > 1200 m^2**
- **>8000 readout channels per layer ➔ >32000 channels per quadruplet ➔ ~1M channels per Wheel**
- **HV: 8x2 = 16 independent HV sectors per layer**
  - in the final configuration two adjacent HV sectors will be powered by a single line

Micromegas construction

Construction concept

Cathode (*Drift*) and anode (*ReadOut*) planes built on sides of five panels stiffened through the use of honeycomb structures





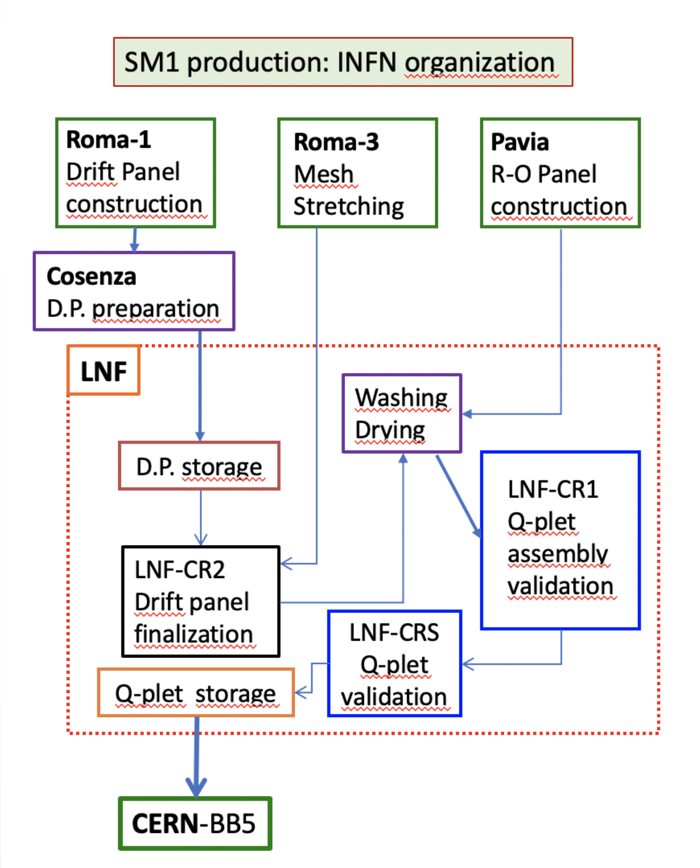
- Production concept is the same for all four module types
- Slightly different technical solutions adopted at the various production sites for both construction of single panels and module assembly
- Careful QA/QC program implemented to check all parts and production steps
  - we describe in detail the procedures adopted for the SM1 modules

Production of the SM1 modules: the Italian job

Seven "Sezioni INFN" participated to the construction of the SM1 modules. In particular:

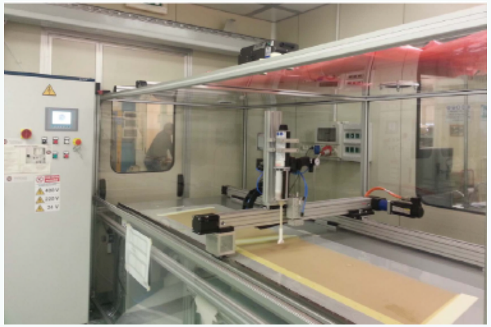
- **Pavia**: readout panels construction
- **Roma**: drift panels construction and finalization
- **Cosenza**: drift panel preparation
- **Roma 3**: mesh stretching
- **LNF**: final assembly of the chambers
- **Napoli** and **Lecce**: realization of mechanical parts

physicists and technicians contribution to activities at Frascati and CERN from all sites



- **33 chambers were assembled and fully tested**
- parts for 2 additional spare chambers prepared
- Construction completed in October 2020
- Everything is now at CERN
- Several solutions to problems found during construction introduced for SM1 modules and later adopted by the other construction sites

Drift panels construction @Roma



The programmable glue dispenser in the clean room at INFN Roma workshop

Drift panel in vacuum bag (under pressure of 100-150 mbar) for glue curing

- Drift Panels for **SM1** assembled with the **vacuum bag technique**
- PCBs aligned with copper side down on the granite table (8 μm *rms*) that guarantees a good panel planarity

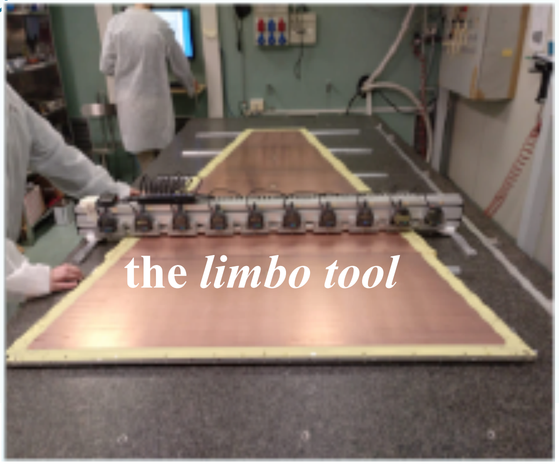
- The height of the panel is determined by the precision of the parts and by the amount of glue deposited => need controls on both!
- Dimensions of the components (PCB, frames, honeycomb) measured with a *linear height gauge* or the *limbo tool (*few micron precision).
- The glue is deposited manually on frames and by use of a programmable dispenser on the side of PCBs not covered by copper
- **outer panels** (Cu-cathode layer on one side only) built in a single step. Glue let curing in the vacuum bag for ~24 hours
- **central panels** (copper on both sides) built in two days, gluing one side at the time

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

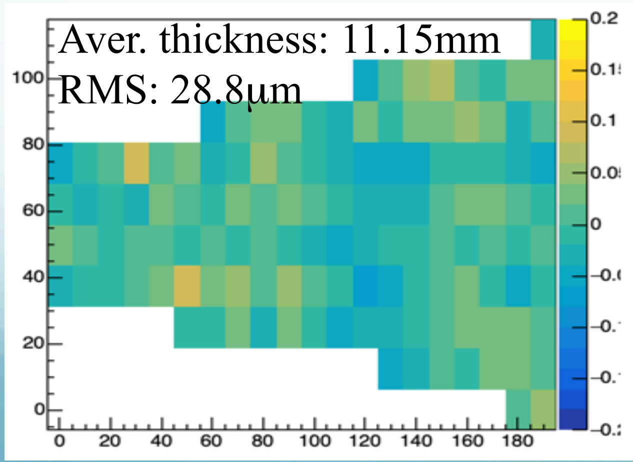
- **Panels in all other production sites** (both Drift and Readout) **assembled by using a stiff-back panel** (or a mixed technique), obtaining similar quality about planarity

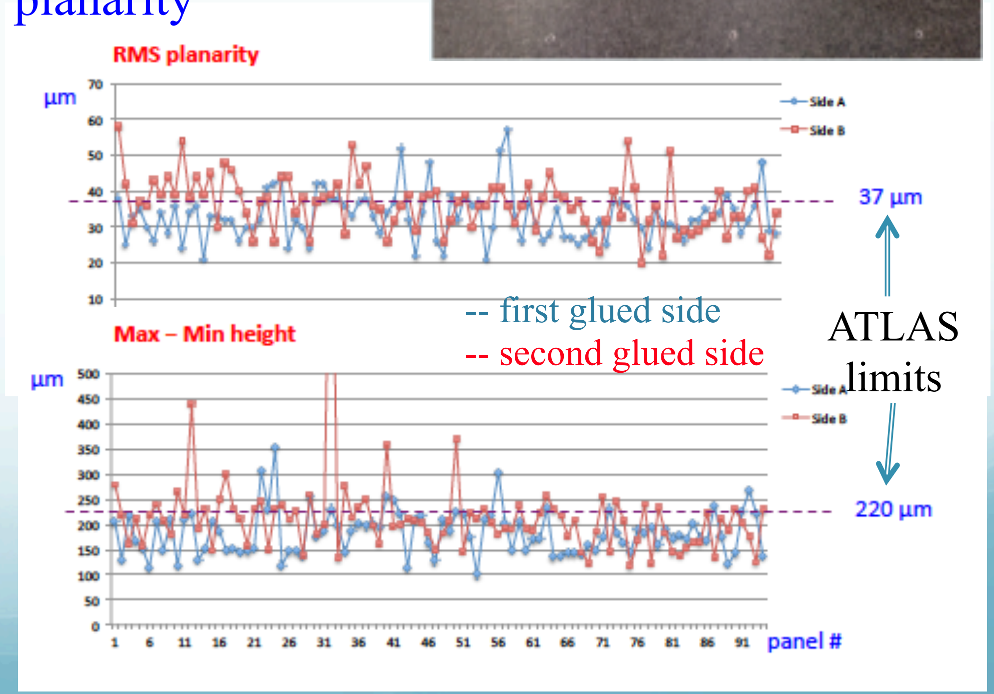
Drift Panels: planarity

- Height of the finished panel measured with the limbo tool on a 10 cm x 10 cm grid
- Data are fitted to find the best plane. Then we determine:
  - the maximum-minimum deviation w.r.t. the fitted plane
  - The RMS of the deviations w.r.t. the fitted plane
- Measures performed on both sides of the panels
- First glued sides have generally a better planarity



Deviation from planarity: 2D view

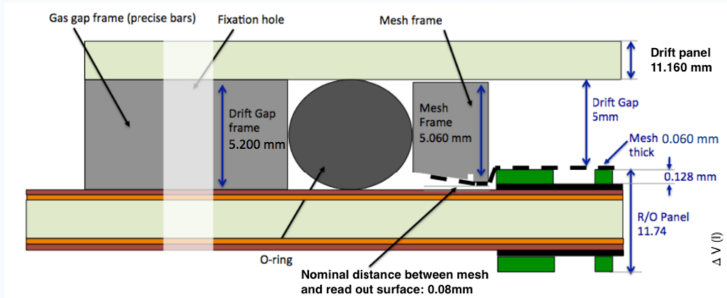


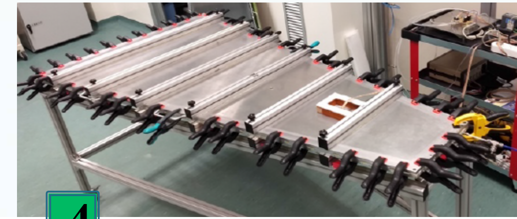


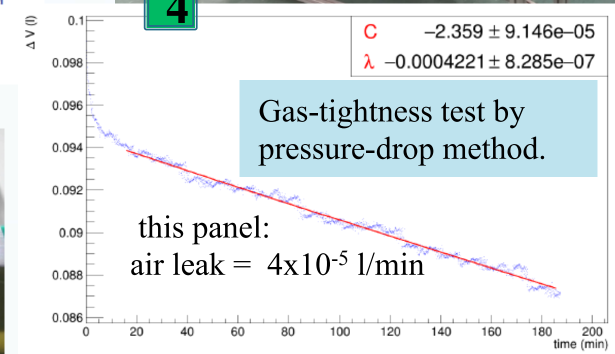
Mechanical finishing of drift panels @Cosenza

Operations sequence:

1. panel sealing with araldite
2. later remove glue excess
3. fixing interconnections
4. gas tightness tests
5. mesh frame mounting
6. gas tubes mounting
7. HV connector mounting
8. prepare O-ring for gas-gap closing at LNF

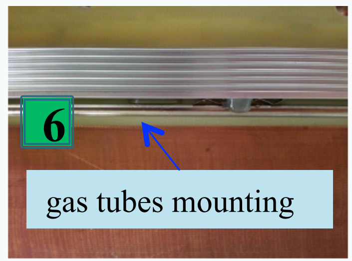




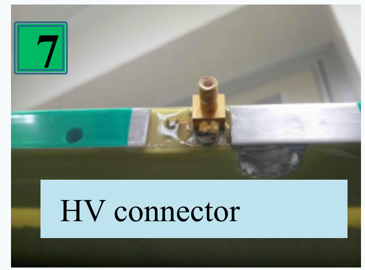


Gas-tightness test by pressure-drop method.

this panel:
air leak = 4×10^{-5} l/min



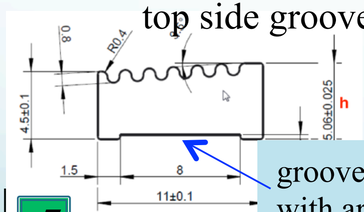
gas tubes mounting



HV connector

Panel coupled with an aluminum plate to form the gas gap, which is filled with air up to 3mbar overpressure. Then measure $\Delta p(t)$ and converto to $\Delta V(t)$. OK if $\Delta V(t) < 7.5 \times 10^{-5}$ l/min

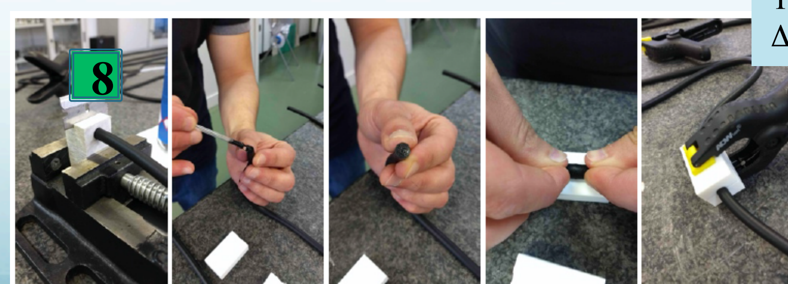
top side grooved



groove filled with araldite

mesh frame fixed with glue and screws (for mesh grounding)

O-ring preparation

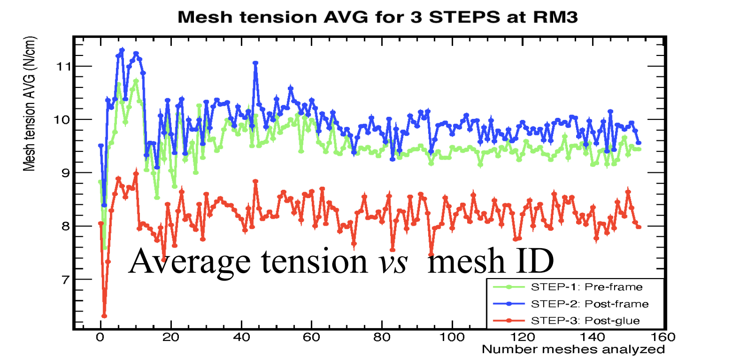


Mesh Stretching @Roma 3

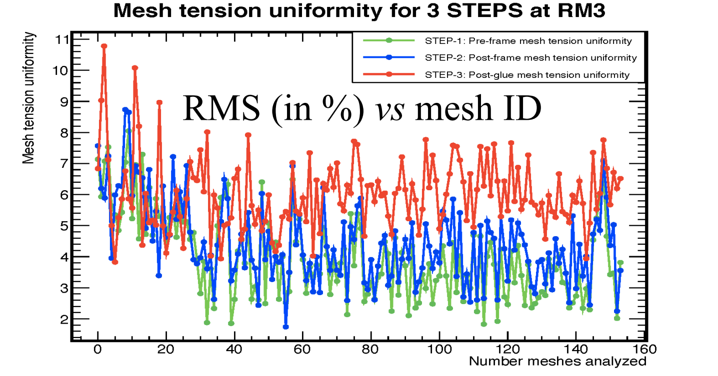
1. Mesh clamping and stretching (to ~10 N/cm) with a custom made device **(Step 1)**
2. Mesh gluing on trapezoidal transfer frame **(Step 2)**
3. Clamp release after glue curing and mesh cutting around frame **(Step 3)**
4. Perforations for interconnection holes

- Mechanical tension of the meshes is measured with a digital gauge after the 3 steps

Load cell-connected clamp



Trapezoidal frame



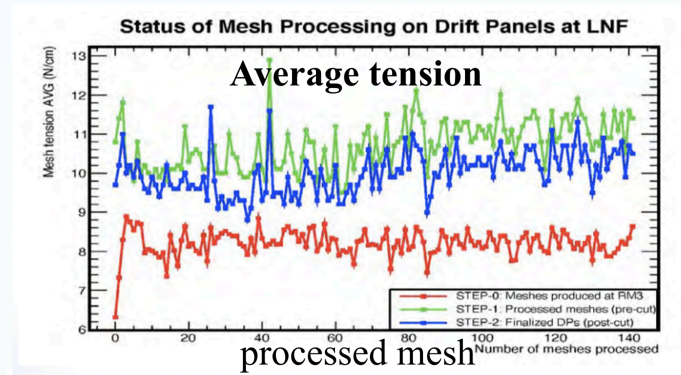
Mesh gluing on drift panel @LNF

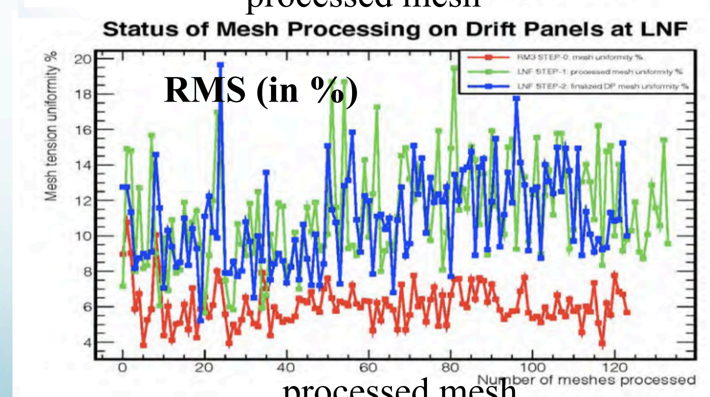
1. Mesh washing and drying for one day
2. Gluing on bare drift panels

Washed mesh on transfer frame

Mesh transfered on drift panel

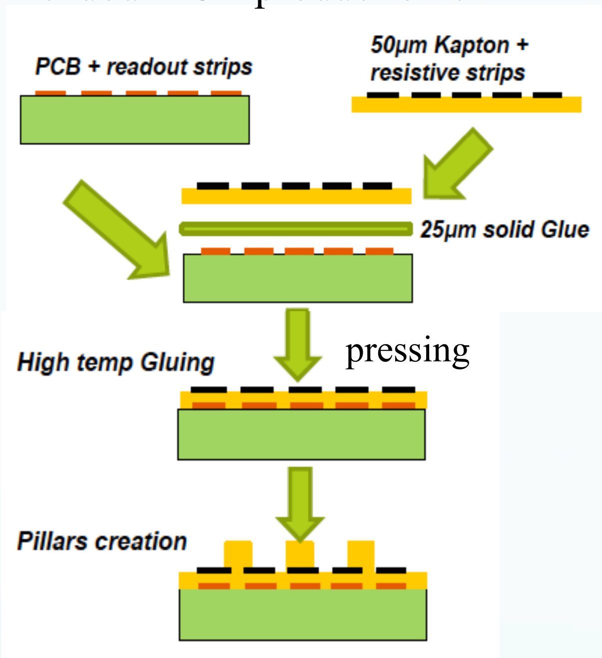
- Mechanical tension measured just after mesh gluing (**pre-cut**) and after removal of the transfer frame (**post-cut**)
- **Average and RMS slightly above specifics**

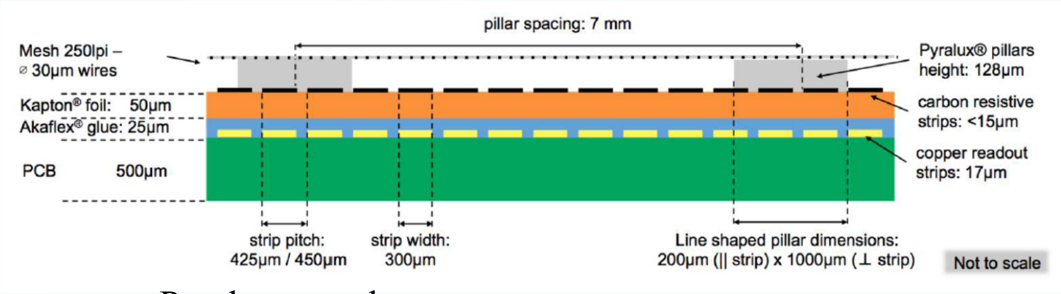




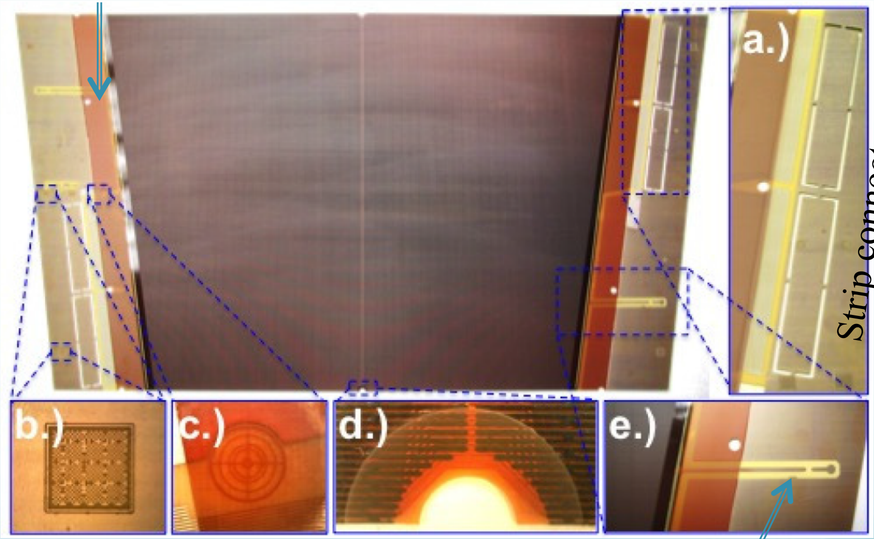
The MM anodic resistive board

Readout PCB production chart





Pyralux coverlay



Rasnik Mask

Interconnection hole

HV supply point with silver conduct line

Very complex production process, involving three different companies

- PCB production, RO strips and pillars: Eltos (Arezzo)
- Resistive-strip foils production: Matsuda Screen (Japan)
- resistive foil – PCB gluing: MDT (Milano)

QA/QC procedures implemented at each company.

Additional tests performed at CERN

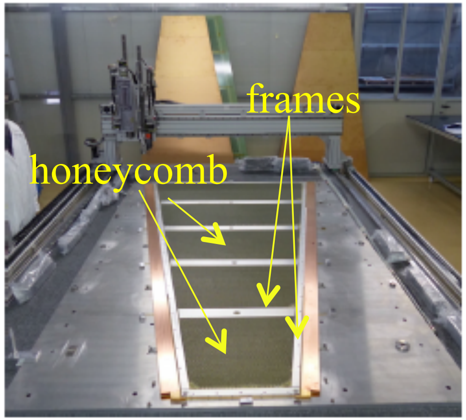
ReadOut panels construction @Pavia

The RO panels are built by using the stiff-back method

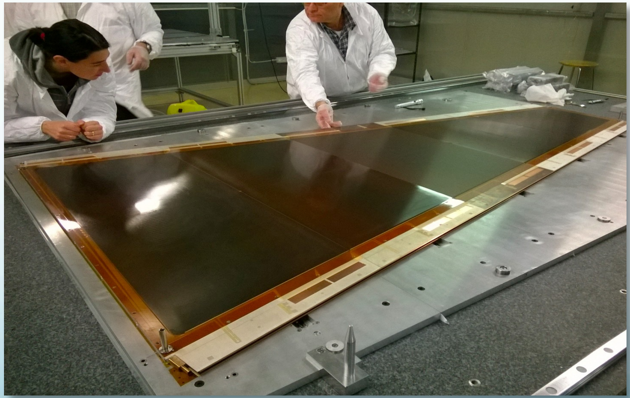
- one layer on the granite table, second layer on a separate stiff-back plane, held in position by vacuum pump
- after glue depositing the stiff back is rotated to match the two panels. Glue let curing for one day
- alignments between the PCBs of a layer controlled by using calibrated jig and Contact-CCD during construction

The rotating stiff-back

Readout panel under construction

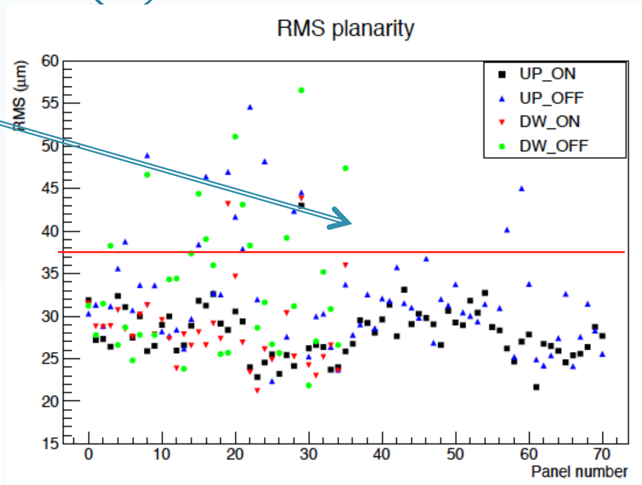


Finished Readout panel on granite table



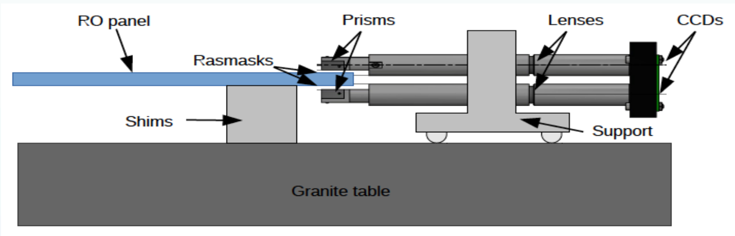
ReadOut panels construction @Pavia

- Requirements on **panels planarity** fully satisfied
  - The height of the panel is measured with a laser tracker.

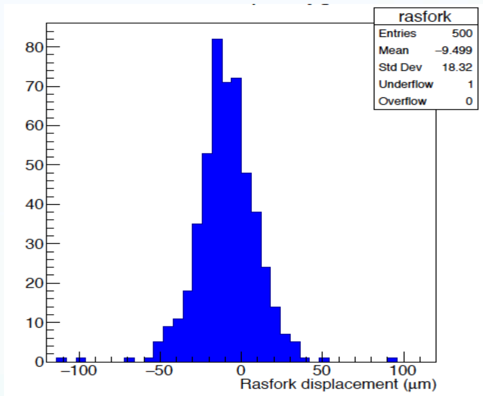


- Alignment between up and down layers measured via a rasfork tool

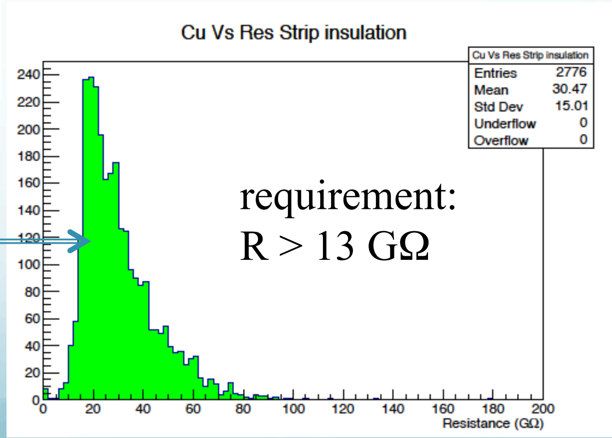
Concept of Rasfork measurements



Misalignment of the masks on opposite sides of a panel



- Electrical properties checked on individual PCBs and on the final panel
  - check of insulation between readout and resistive strips
  - check of insulation between the coverlay and the HV
  - measurement of resistance *vs* HV connection in several position inside the PCB plane

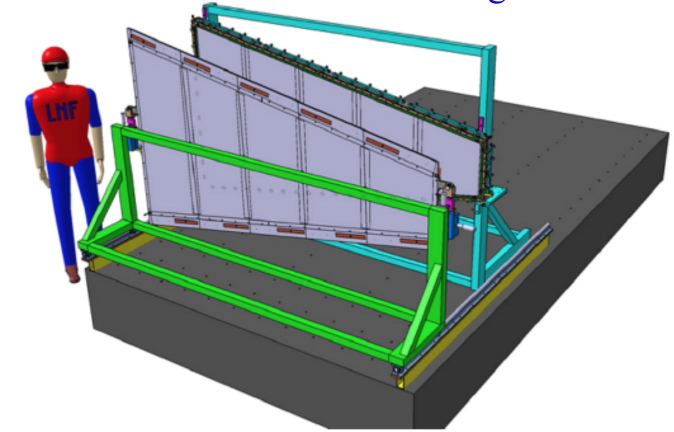


SM1 modules assembly @LNF

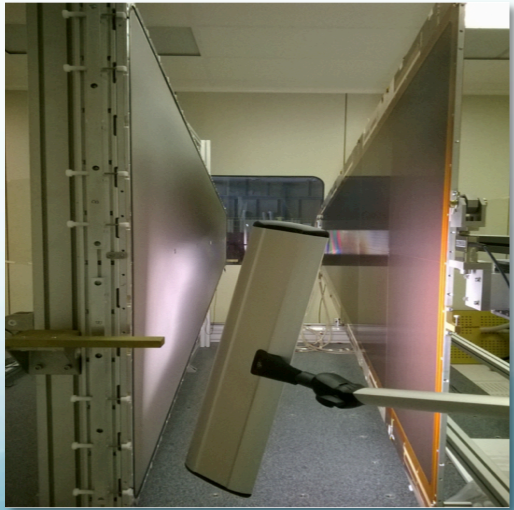
- The assembly of a module in the clean room must be performed very carefully
  - Slightly different methods and custom tools developed at each site

- Panels washed and then dried for a few days in a 40 degrees oven before assembly
- **A special assembly station** has been designed for the SM1 modules
  - allows to assemble the panels vertically, **keeping control of the alignment** with a load-cells system
- 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
- The completion of a module can take several days

SM1 module assembling tool

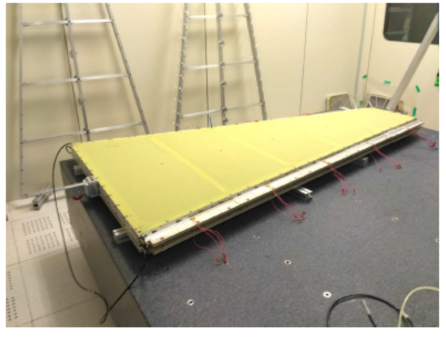


SM1 module assembling phase

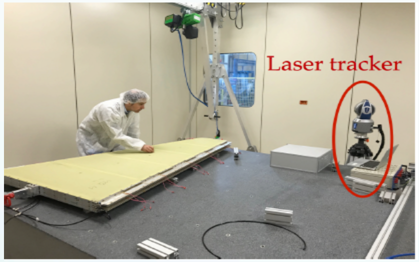


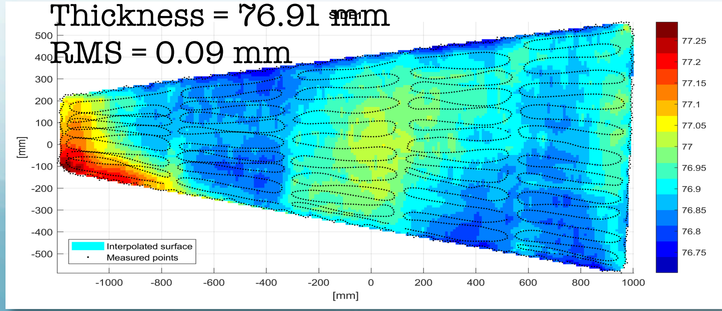
QA/QC on assembled modules

- Several tests and measurements performed on the final chamber
  - Module thickness and planarity measurement
  - Strips misalignments measurement between the RO panels
  - HV test with the standard gas mixture (Ar:CO2 = 93:7)
  - Gas tightness
  - Test with cosmic rays (Efficiency and HV scan)

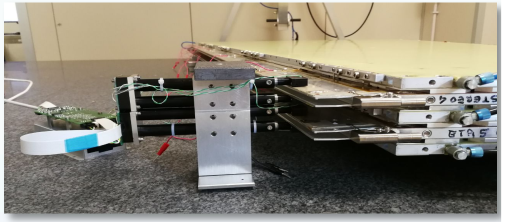


The planarity is measured with a laser tracker **(specific: RMS < 100μm)**

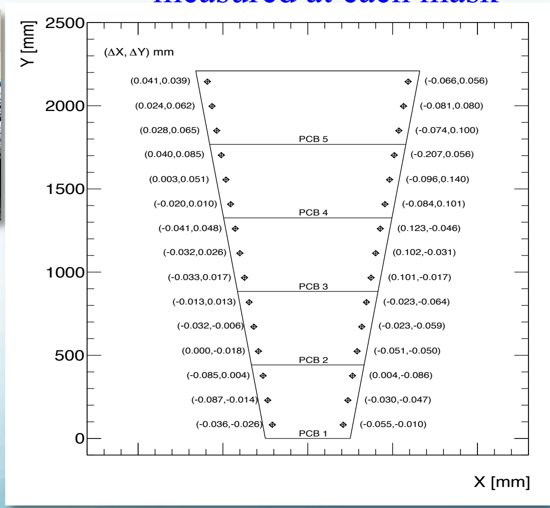




Relative layers alignment measured with the Rasfork



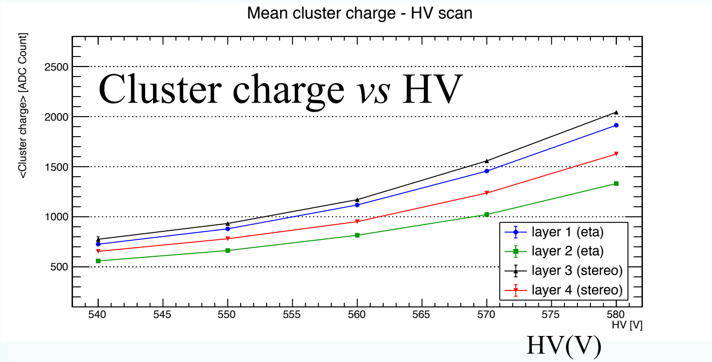
X-Y displacement measured at each mask

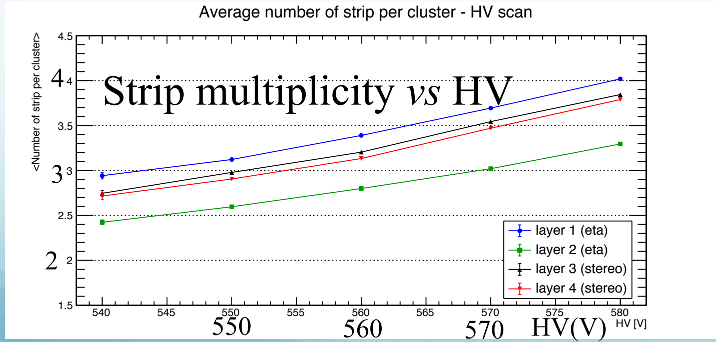


Cosmic rays tests @LNF

Report on Module 7 - HV scan results

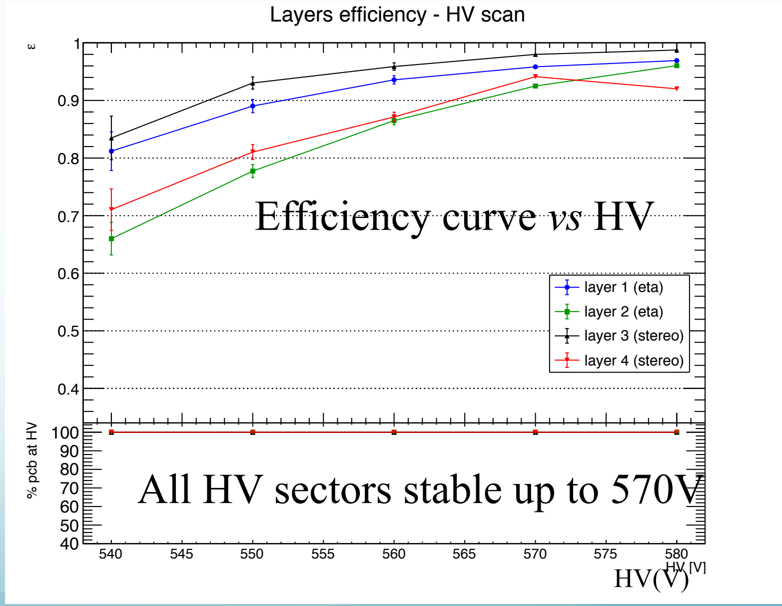
SM1 QUADRUPLET - MODULE 7
20MNMMMS100007
HV SCAN RESULTS





Main performed test

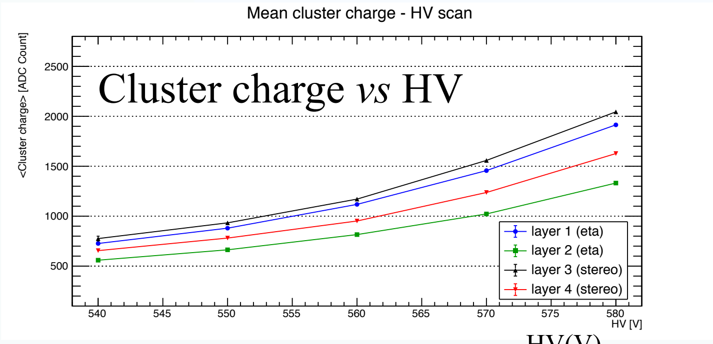
- HV scan: 520-540-550-560-570-580 V
- run at nominal HV (570 V) working point
  - cluster charge, strip multiplicity, efficiency
- data used to validate the chamber
- summary info stored in the NSW database

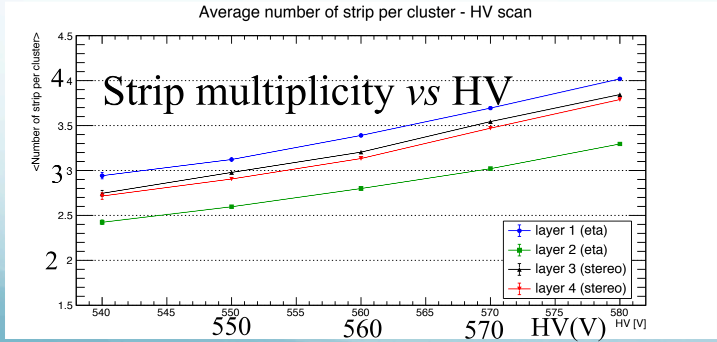


Cosmic rays tests @LNF

Report on Module 7 - HV scan results

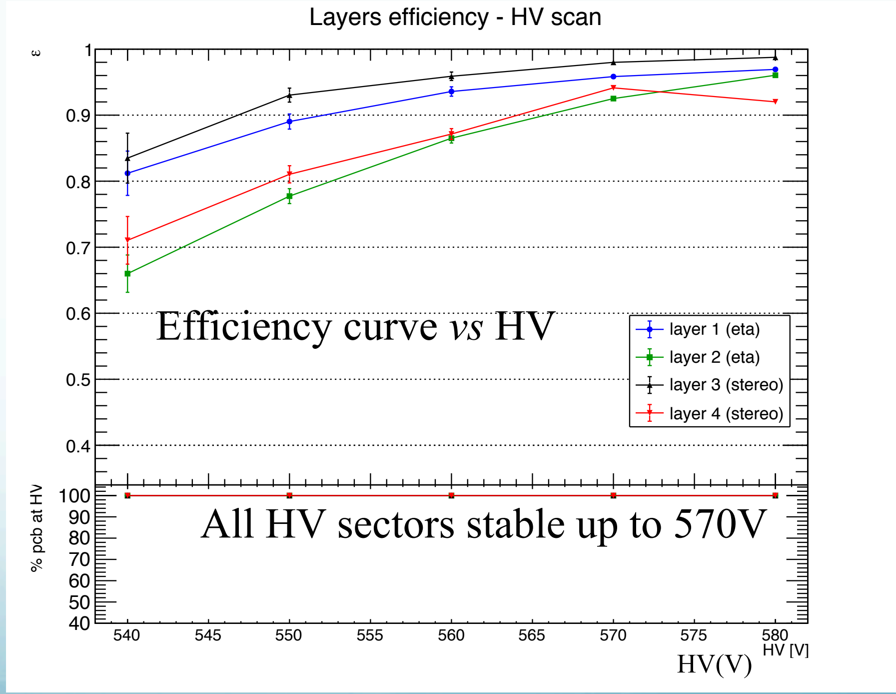
SM1 Quadruplet - Module 7
20MNMMMS100007
HV scan results





Efficiency of a layer determined from extrapolated tracks reconstructed with the other 3 layers

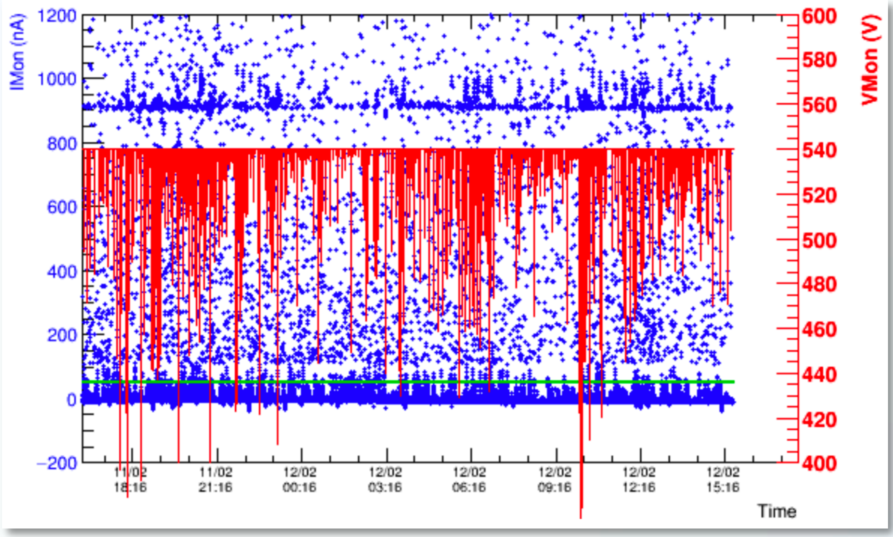
SM1 Quadruplet - Module 7
20MNMMMS100007



HV issues: studies and adopted solutions

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, mesh calendering)
  - Boards and panel cleaning
  - Effect of humidity inside the panels
  - Long term stability HV tests

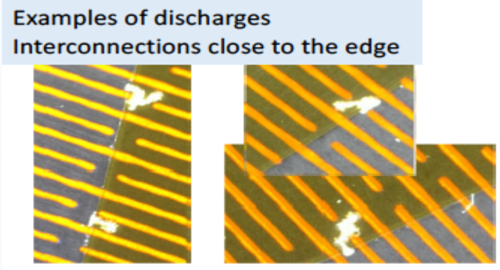


- Main issues identified to be:
  - **residual ionic contamination** of boards and panels from industrial processing and handling => **improve the cleaning procedures**
  - Possible effects from **mesh mechanical imperfections** => **implement mesh polishing**
  - Clear **correlation of currents with humidity** (FR4 and kapton foils are hygroscopic) => **increase gas flow rate and monitor humidity**
  - **(At later stage): low resistance close to the edges of the resistive strips layer**

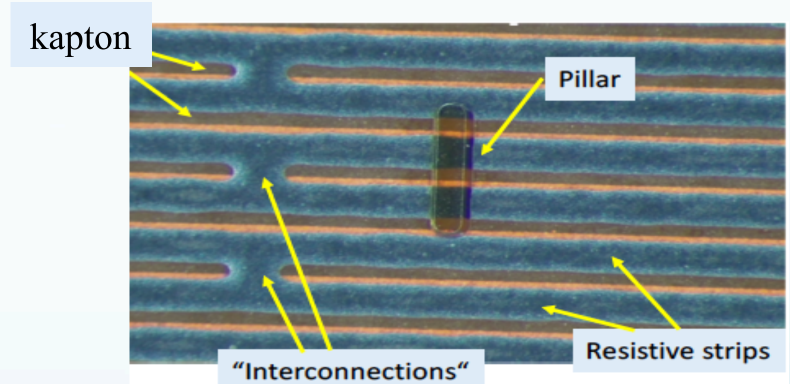
HV stability and board resistivity

FACTS

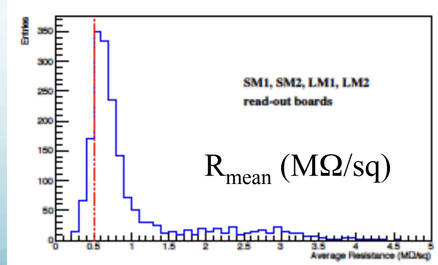
- Analysis of **discharges** showed that in many cases they are **localized on resistive strips junctions crossing the coverlay**
- Some PCB types were more affected than others by discharges
  - *e.g.* LM1 both stereo and eta, SM1 stereo but not eta panels

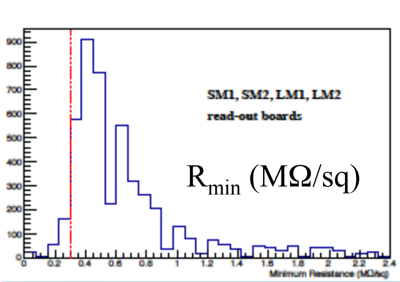


- **The resistive strip layout presents interconnections with a defined pattern**
- **The resistive strips layout is not the same for all PCB types**



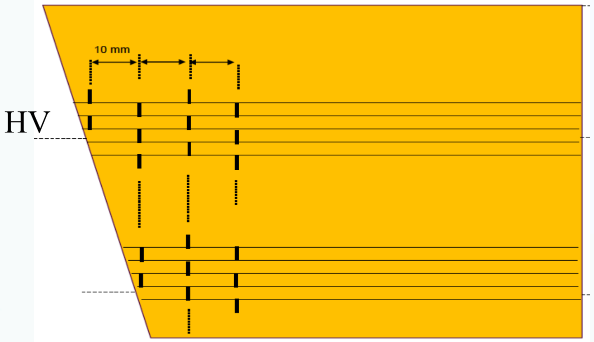
- The resistive strips of the ATLAS MM are ink-printed on a kapton support
- The **average square resistance** (R_{mean}) and the **minimum resistance** (R_{min}) distributions are in the left side of the accepted range
  - **In some cases below the lower limit (0.28 MΩ/□)**

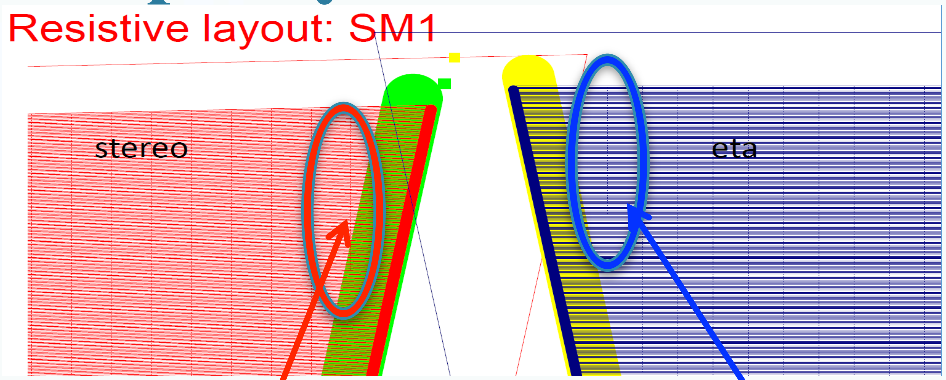




Resistive strips layouts

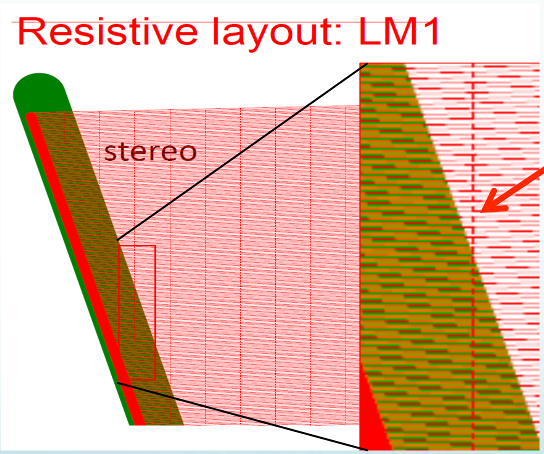
"Ladder" scheme of the interconnection layout

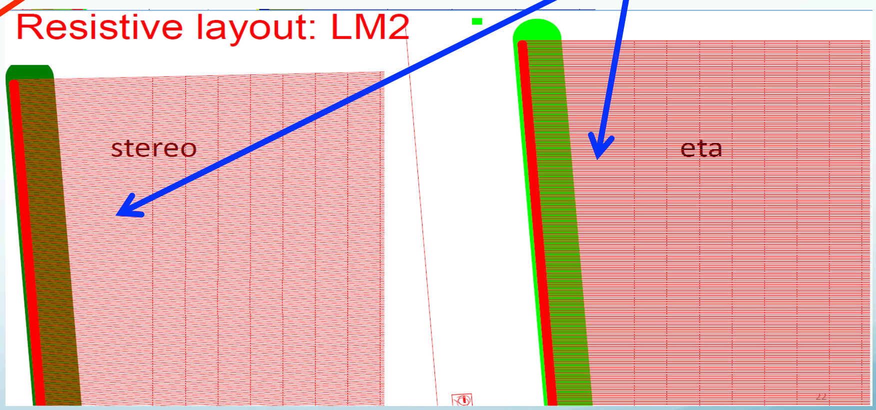




interconnection lines cross the coverlay

interconnection lines do not cross the coverlay

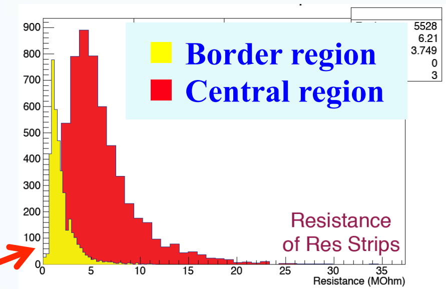




Among the most problematic panels were just SM1 stereo and LM1 (both types)

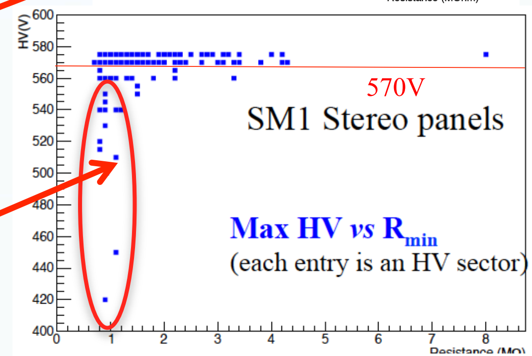
HV stability and board resistivity

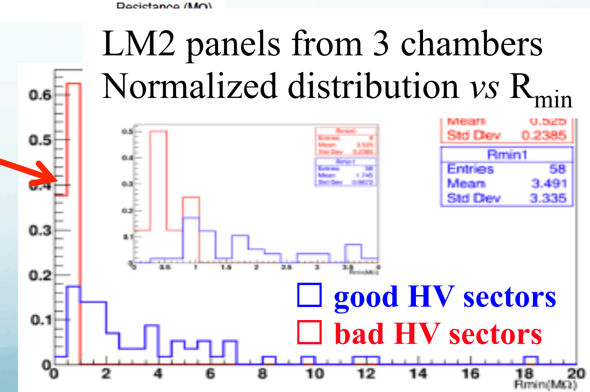
- Resistance measured w.r.t. the HV connection, with megger and a $1cm^2$ probe in different positions inside the MM panel
- **The minimum resistance** measured near the pyralux rim **is often very low (<0.4 MΩ)**
  - due to low resistivity of the resistive foils and/or to the particular strips pattern
- **Clear correlation between bad HV sectors and low values of R_{min}**
- Low resistance should not be a problem by itself (at least, above a certain value…)
- **BUT in presence of a defect** (RO board, mesh, impurities, humidity, etc.) **enhances the probability of having HV instabilities**



SM1 stereo panels measured in Pavia

Low-resistance points condensed close to the PCB edges

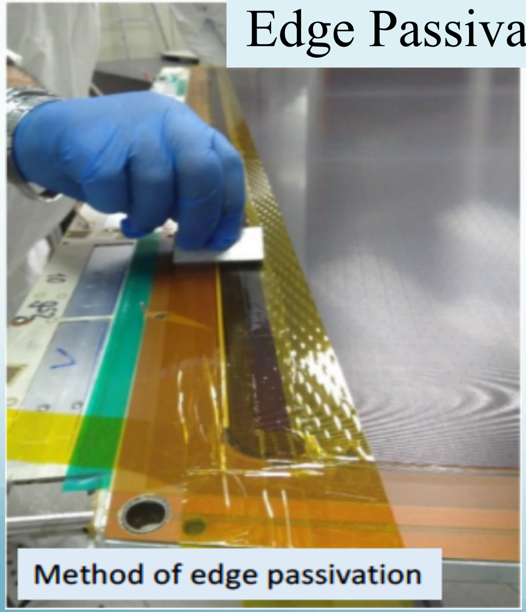


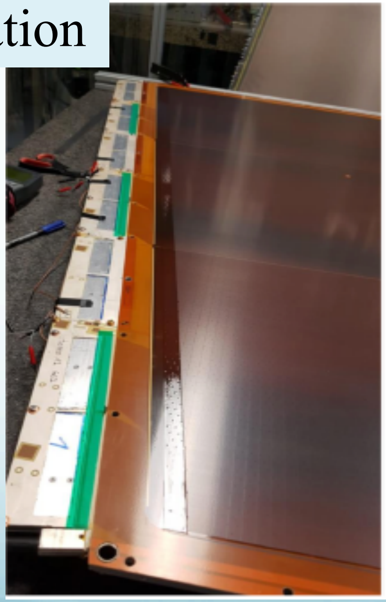


Resistance measurement and passivation

- A procedure (**edge passivation**) has been 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 $R_{min} > 0.8\ M\Omega$

Edge Passivation





The solution is not optimal, because we give up active area (lowering the geometrical acceptance of the detector) which in some cases is rather large
=> further studies performed and still ongoing to optimize the passivation and/or to increase PCB resistivity

- there are still a few chambers to be produced and some might be reopened

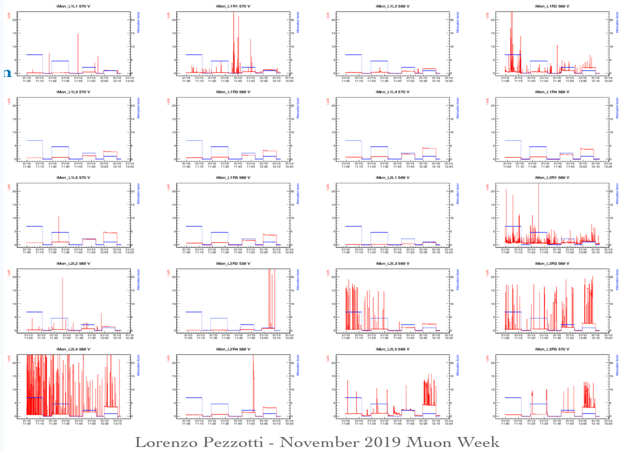
Effects of passivation

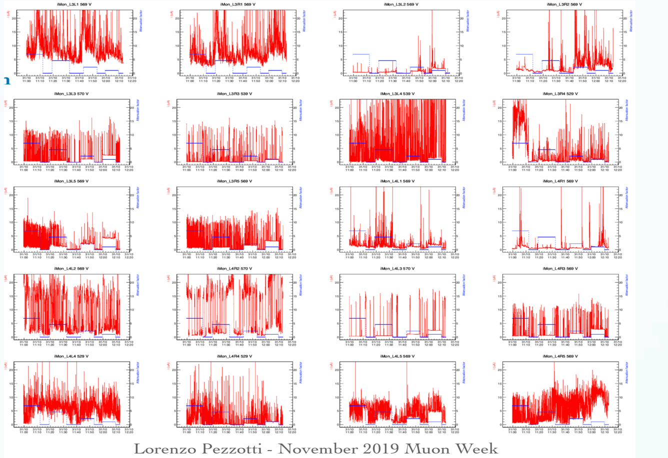
LM1 chambers under gamma irradiation at the GIF++ facility

LM1-M8

not passivated

24 HV sectors not passed requirements

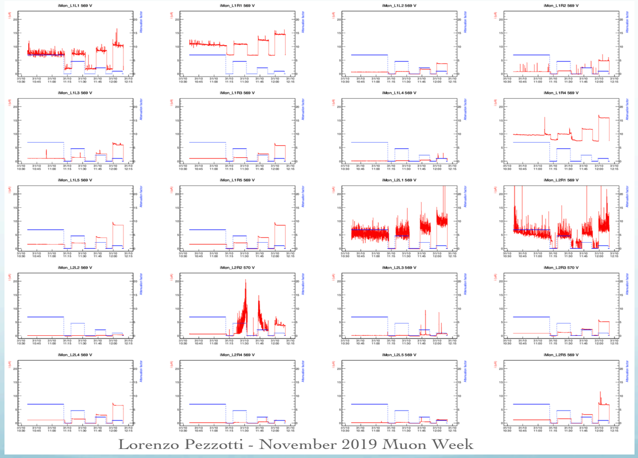


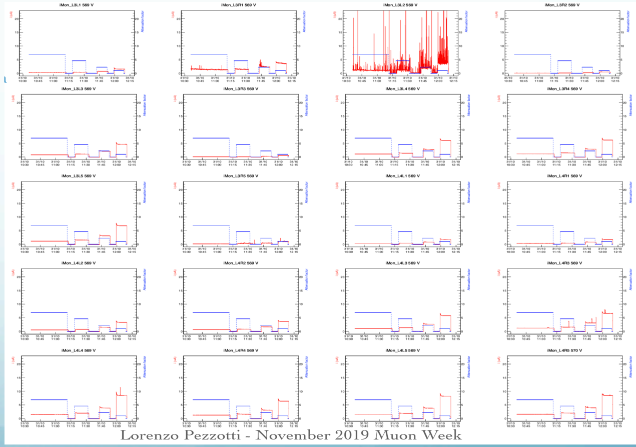


LM1-M5

passivated

6 HV sectors not passed requirements





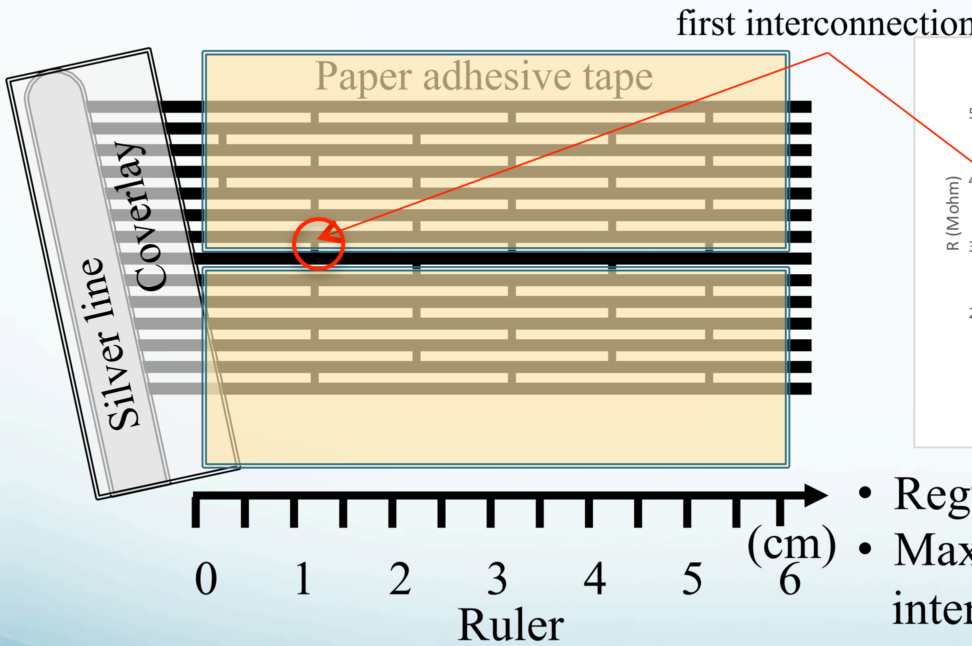
Effects of passivation

- The passivation had a very positive effect on **LM1** and **SM2** chambers in terms of HV stability
  - passivation generally of the order of few cm for **SM2** PCBs in Munich, and wider for **LM1** PCB in Saclay.
- **SM1** in Frascati: Stereo panels were critical (and mainly PCBs #3), eta panels less problematic because of favorable strip layout. Typical passivation area 0-3 cm wide.
- **LM2** in Dubna: most problems on PCBs #8, because of very low resistivity.

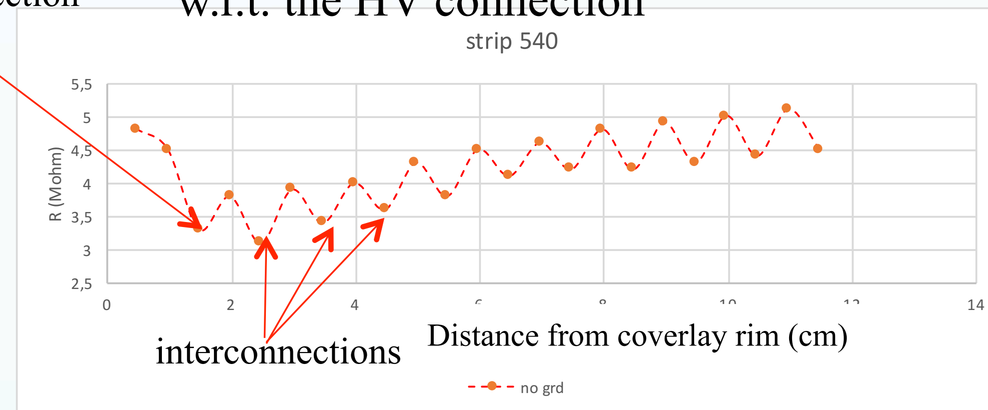
Not up to date	SM1 (18 Quads passed specs)	SM2 (18 Quads passed specs)	LM1 (7 Quads passed specs)	LM2 (7 Quads passed specs)
Passivated sections	380	324	80	3
Out of specs sections in passivated sections	14	7	8	-
Sections Non passivated	260	60	120	120
Out of specs in non passivated	12	8	37	30
Fraction of Bad sections passivated	3.7%	2.2%	10%	-
Fraction of Bad sections NON-passivated	4.6%	13.3%	31%	25%

Individual strip resistance measurements

- Measurement of strip resistance made by several groups with consistent results
- Here, we report those performed in Cosenza



R measured along a single strip w.r.t. the HV connection

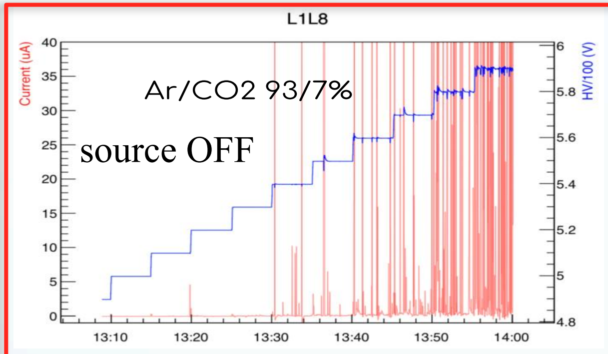


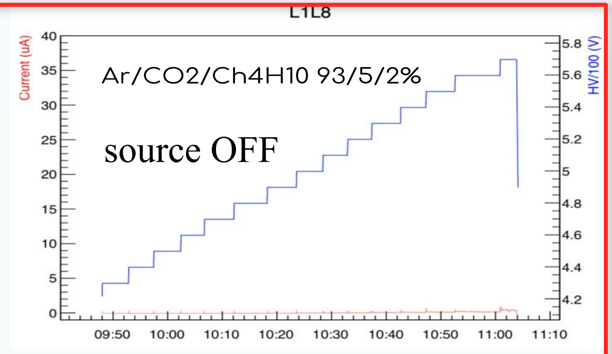
- Regular drops in correspondence of a strip
- Maxima seen in the middle of two consecutive interconnections
- Overall rising of the curve with distance (consistent with measurements with the 1 cm^2 probe)

Tests of different gas mixtures

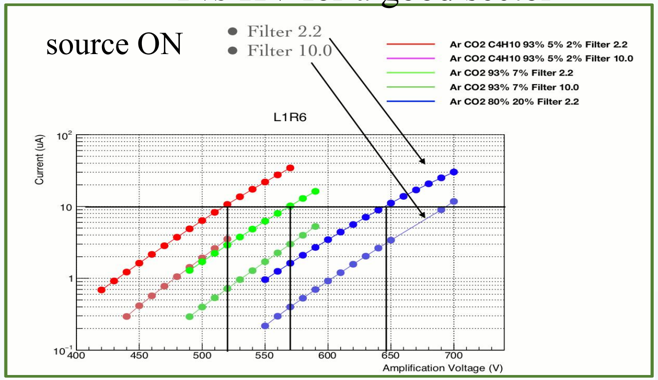
- Study the effect of alternative gas mixture on HV stability of the chambers performed by several groups.
- Shown here results obtained at the Gamma-ray Irradiation Facility (GIF++) at CERN, routinely used to validate production chambers

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





I *vs* HV for a good sector



- HV ramp up on bad-behaving MM sectors present a high spike rate:
  - **the addition of the small fraction of iC4H10 looks very effective in spike suppression**
- No significant difference seen in good-behaving sectors
- **iC4H10 allows to run at significantly lower amplification voltages**
  - **HV~500 V gives equivalent performances as 560-570 V in Ar:CO2=93:7**
- **Long-term "ageing" test** ongoing on two chambers with the ternary gas mixture

Module validation and integration at CERN

NSW MM integration activities

From the individual modules to the fully equipped MM Double Wedge (DW) at BB5 building

Integration Workflow

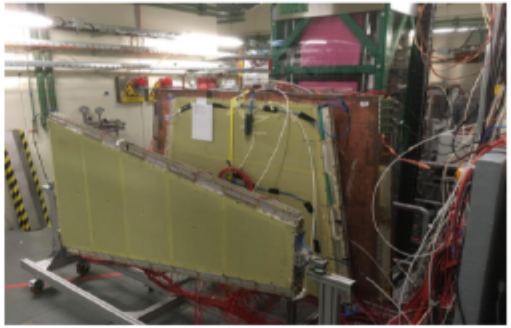
Gas Tightness
HV test

GIF++

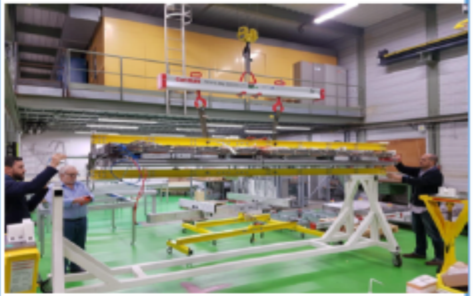
Mechanical Integration

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!

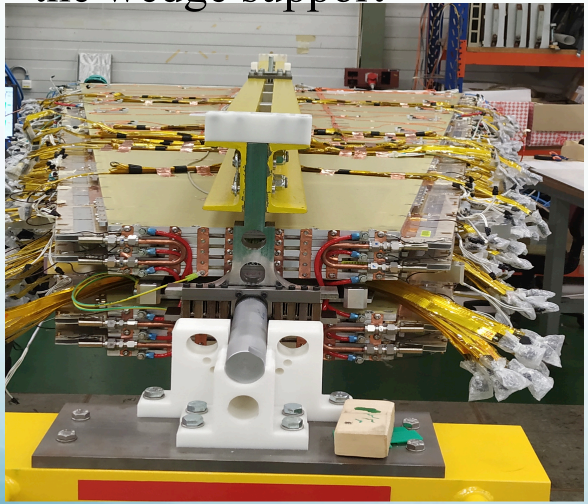
Testing the complete elex setup:
MMFE8/L1DDC/ADDC (FE/data concentrator/trigger) +optical Felix system

MM Double Wedge mounting

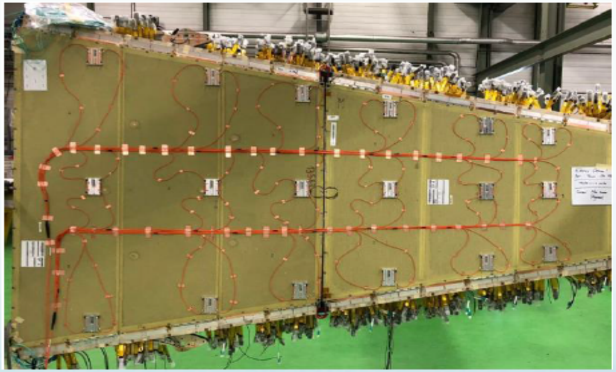
Installing gas distribution on the wedge support

Readout and Trigger cables installation

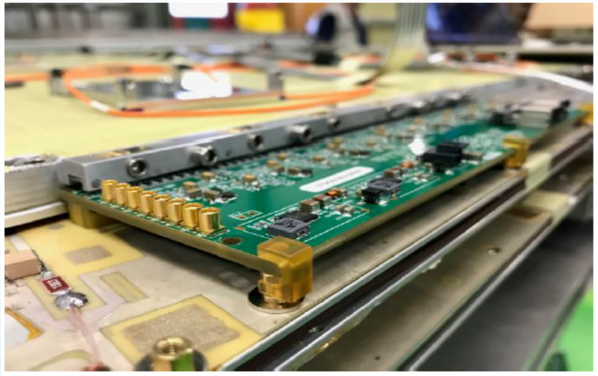
Placing of chamber on the wedge support



Both chambers on the wedge support

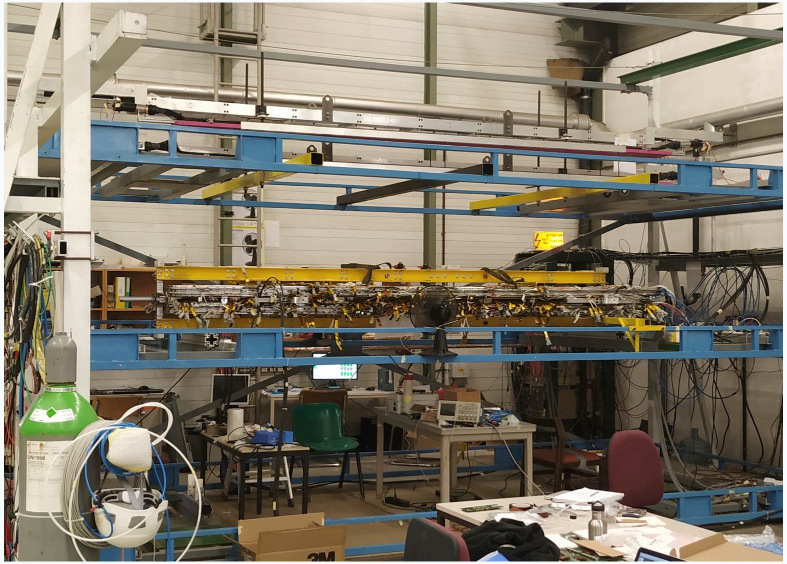


Routing of optical fibers for alignment



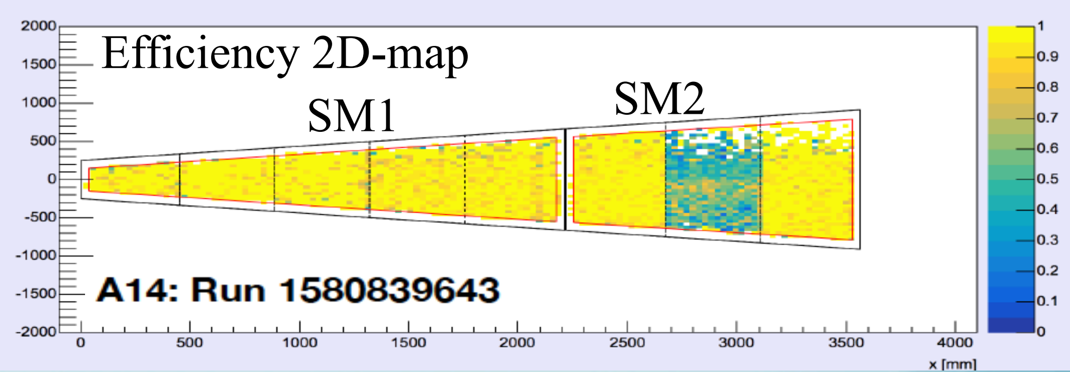
Installing Readout front-end cards

Validation of full Double Wedge with cosmic rays



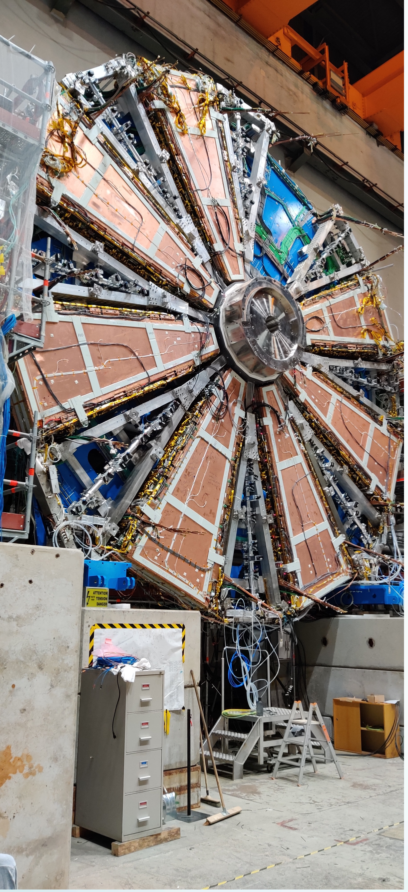
DW A14: Layer 1- IP side

HV mapping:
- 12 sectors at nominal voltage (570 V)
- 2 sectors in the Hospital line at 515 V

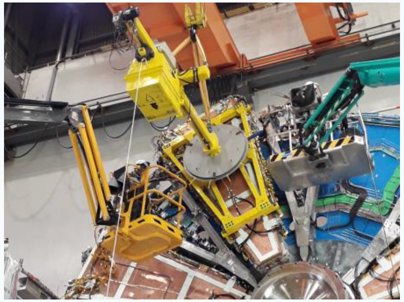


- DW final validation at Cosmic Ray test stand in the BB5 building
- Remapping HV
- Electronic installation and testing
- Data taking
  - Efficiency maps

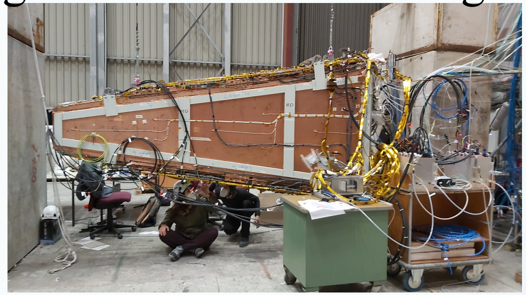
The wheels at B191: sector installing



- The two wheels are presently mounted in Building 191
- NSW sectors are completed by mounting the two sTGC
- The sector can then be installed on the wheel



Small sector A14 tested on ground after refurbishing



- After service installing and cabling, the wedges undergo the same tests as during integration:
  - gas leak, HV, electronic,…
  - new issues with electronic noise on the full sector

➔sector refurbishing with installation of Farady cages on part of the electronic board

Once fully installed and tested, the wheel will be ready to be transported to the experimental hall and eventually installed on the detector

Summary

- **Micromegas** chosen for **their great performances in tracking particles up to high fluxes** in view of the increasing luminosity of LHC
- **Many challenges** which have required further studies to be addressed
- Operation instabilities related to the **resistivity of the resistive strips** solved by introducing **the passivation procedure,** at the cost of loosing significant active area
- Studies ongoing to optimize the operating voltage point (gas mixtures), and to check the long term stability of the passivated chambers.

- Module production for NSW-A completed
  - Completion of the wheel in B191 foreseen for April
- All SM1 modules for NSW-C also completed
  - LM1 and LM2 production critical
- Completion of NSW-C in time for installation in the cavern possible, but with very limited contingency
- Work in progress to optimize NSW-C timeline by increasing the parallelization of the operations

MM module production status

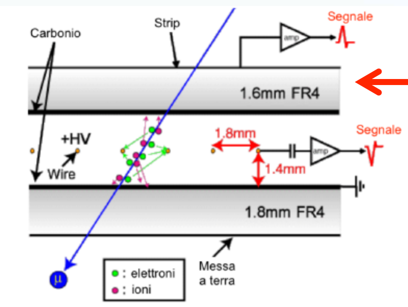
Type	NSW-A @CERN	NSW-C @CERN
SM1	100%	100%
SM2	100%	Jan. 2021
LM1	100%	April 2021
LM2	100%	April 2021

BACKUP SLIDES

The present Small Wheel

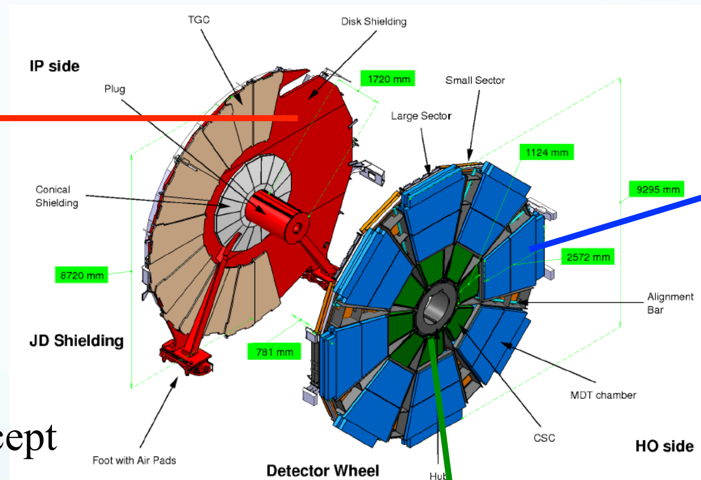
The present Small Wheels are based on three different technologies:

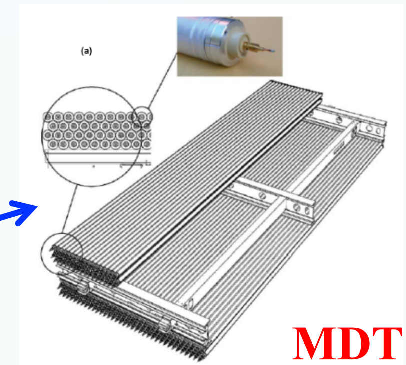
- Monitored Drift Tubes (MDT) and Cathode Strip Chambers (CSC) for precise measurement of the η coordinate in different η intervals
- Thin-Gap Chambers (TGC) for measuring the "second" coordinate and triggering



TGC

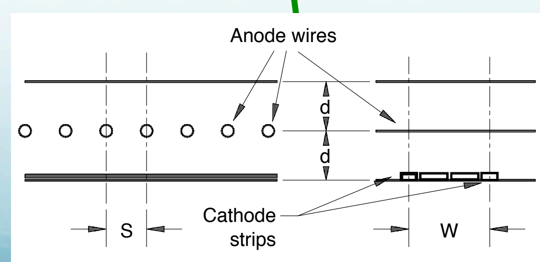
- based on MWPC concept
- in Run2 provided also contribution to trigger





MDT $(1.3 \leq |\eta| \leq 2.0)$

- precise tracking in the bending plane (η coordinate) at outer radii

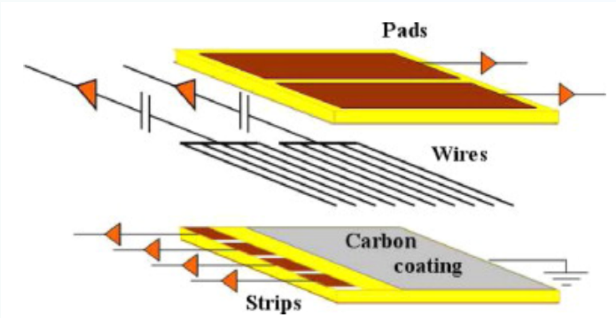


CSC $(2.0 \leq |\eta| \leq 2.7)$

- based on MWPC concept
- precision tracking in both coordinates
- cover the inner radii

The ATLAS sTGC

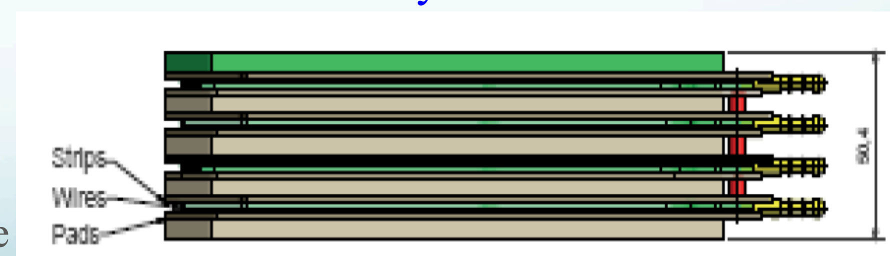
Sketch of a sTGC layer



A fully equipped sTGC chamber

- Strips pitch: 3.2 mm
- Signal readout from strips, wires and pads
  - pads used in a 3-out-4 coincidence to find tracks roughly pointing the IP
  - the pads also define the strips to be readout for measuring the bending coordinate
    - σ_η ~60-150 μm depending on track incident angle
  - wires are grouped to measure the azimuthal coordinate (10 mm resolution)

4 sTGC layers for each chamber



MM chambers construction challenges

The resistive MicroMegas chambers are frontier Micro-Pattern Gas Detector, designed and built for the first time on large dimensions (from 2 to 3 m^2).

MicroMegas construction challenges:

- Very high mechanical precision in order to get **~10% p_T resolution at 1 TeV**
  - strip alignment on each layer of **40 μm precision in η**
  - **planarity within 100 μm RMS**
  - **both requests challenging because of the large detector dimensions**
- **technological transfer of Readout PCBs production** with extremely high quality (pillars shape, resistivity homogeneity, quality of the PCB edges, strips quality,…)
- **stability against discharges** with an high electric field (~50 kV/cm) on the large surface and small amplification gap

Cosmic rays tests @LNF

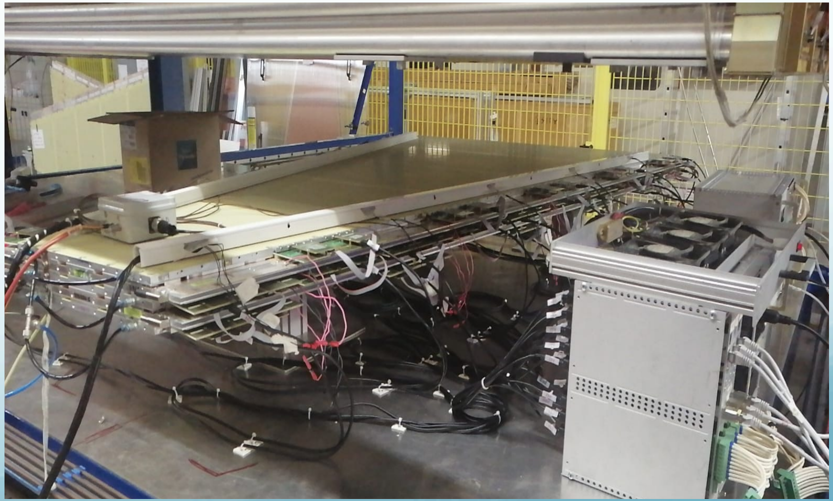
CRS to validate SM1 chambers:

- Trigger: 2 arrays of plastic scintillators coupled to PMTs -> 50 Hz (25cm x 150 cm)
- 35 cm Fe to cut muons at ~0.5 GeV
- Gas flux: **20 l/h** (chambers in series)
- Data taken when humidity inside gap RH ~10%

Main performed test

- HV scan: 520-540-550-560-570-580 V
- run at nominal HV (570 V) working point
  - cluster charge, strip multiplicity, efficiency

- data used to validate the chamber
- summary info stored in the NSW database



Cosmic rays tests @LNF

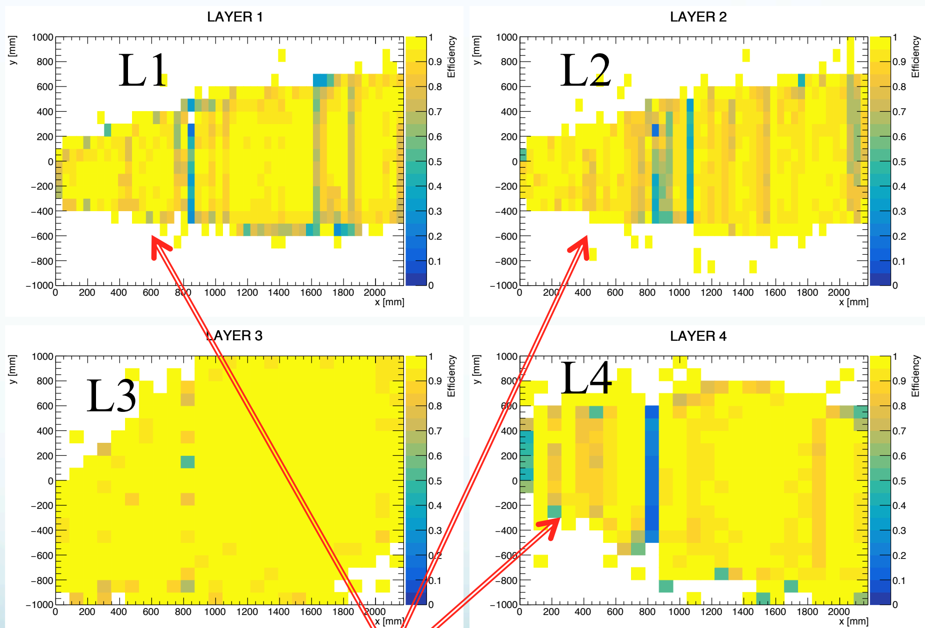
Report on Module 7 - Runs at full voltage (HV=570 V)

SM1 QUADRUPLET - MODULE 7

20MNMMMS100007

EFFICIENCY MAP AT 570 V

Efficency map @ HV = 570 V



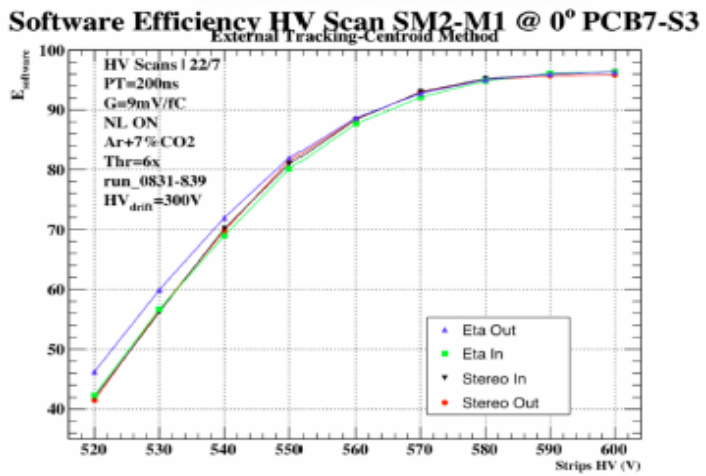
“dead” strips regions due to bad contacts or dead channels of the readout boards of the test stand

MM chamber validation

The chamber acceptance criterium

Given a HV "picture" (maximum HV per sector) obtained at the construction site a Qplet "global efficiency" ε_G (see definition below) is evaluated
Chambers are accepted if $\varepsilon_G > 80\%$

<u>All chambers delivered to CERN respect this criterium</u>
(more on chamber quality in Ivan's talk later)



Definition of ε_G

At the end of the HV conditioning period, a maximum stable HV, HV_{max} , is reached for each sector. HV_{max} is defined as the maximum HV for which the sector doesn't trip and operate with a spike rate less than 6/min, and an average current less than 50nA. A spike is defined as a current measurement in a second above 200 nA. Trip is defined by a maximum current of 2 uA and 30 s of trip time.
Once the HV picture is obtained, each HV_{max} value is converted in an efficiency applying a "universal" curve taken by the test-beam data obtained with the first production chamber. Such a curve is provided to all construction sites.
From the efficiency picture the average of all efficiencies is finally evaluated and the result is the value of ε_G .

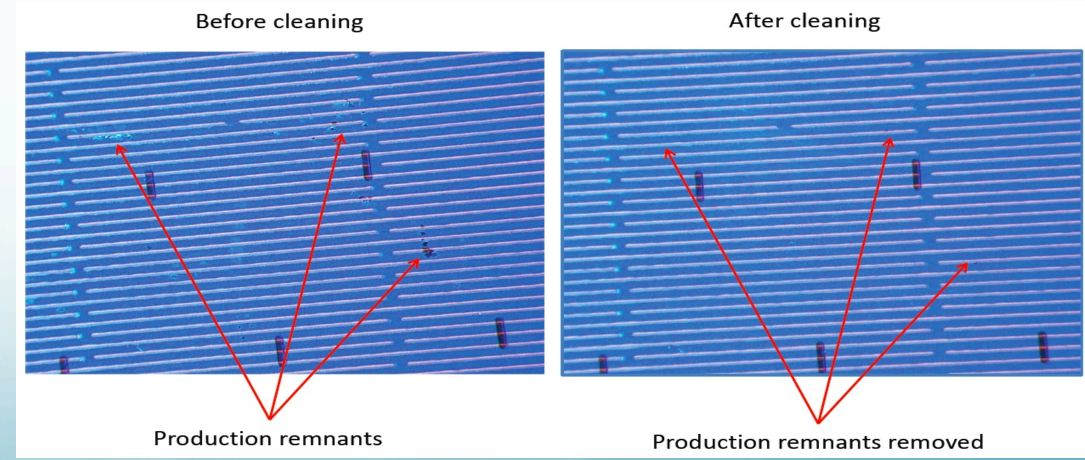
Updated cleaning procedures

Micropolishing cleaning procedure:

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

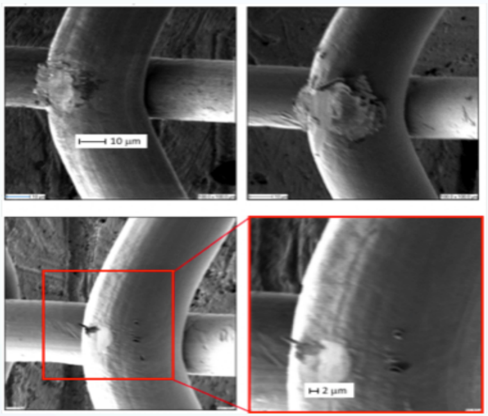
Main purpose of wet cleaning (and scrubbing):

- 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)



Mesh polishing

- 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**



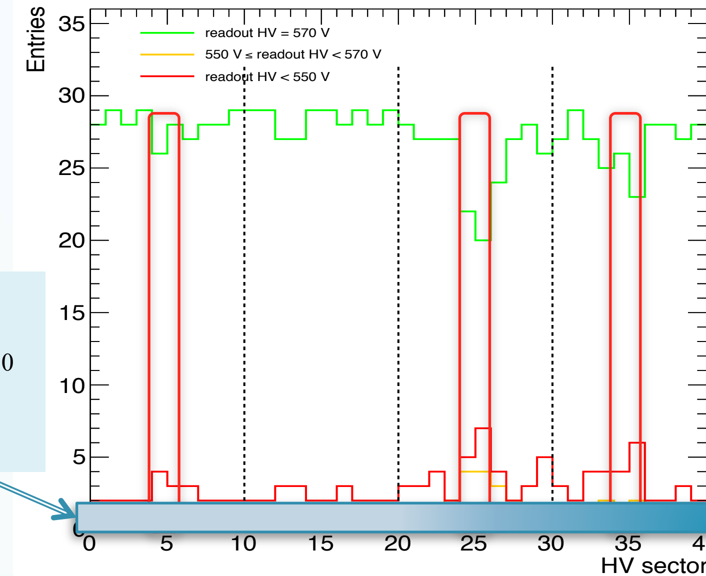
The described cleaning mesh polishing procedures has been adopted at all sites; significant improvements have been observed in HV stability
=> Production resumed **BUT still in most of the chambers a few HV sectors showed problems** so that investigations continued in parallel with the production

Effects of passivation

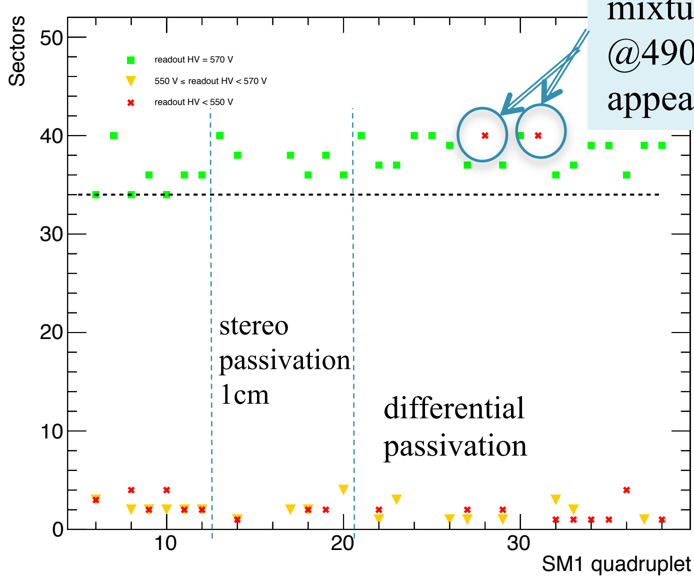
Summary of the HV behavior of SM1 at LNF validation step

- HV sectors categorized according to the maximum voltage reached in stable conditions
- 1 module: 4 layers with 10 HV sector each

HV behavior by HV sectors (all modules)



HV sectors behavior by module

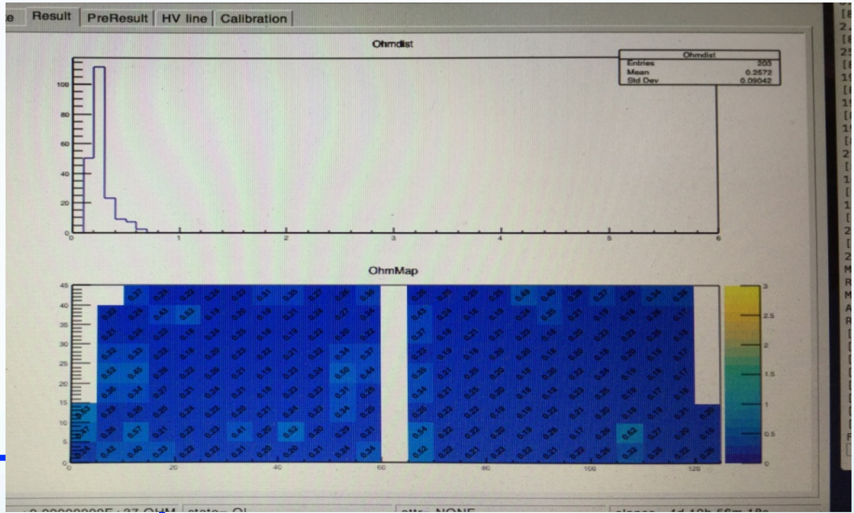


Two modules tested with a mixture containing a 2% iC_4H_{10} @490 V. They work fine but appear red in these plots

- Clear evidence of worst behavior of PCB#3 which had generally lower resistivity w.r.t. the others
- Significant improvement after the passivation procedure was introduced

Resistive foils – new production

- An additional production of resistive foils was needed due to additional test chambers production (M1-M4) and fail of further production phases.
- The total number of additional foils are approx. 650 foils (~30% of original production)
- Mean value of the resistivity is around 0.3MΩ/□
  - Target mean value is 0.84MΩ/sq.
  - Almost all foils are grade C (except, one A and one B)
  - Uniformity of the resistivity is Ok.



<u>Resistive foils categories criteria</u>

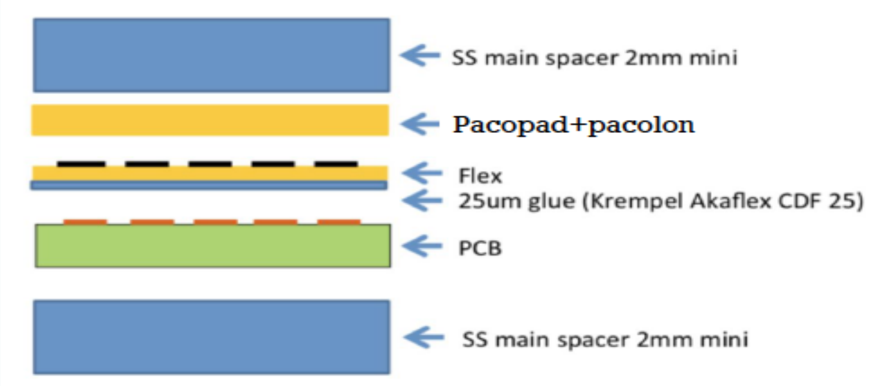
Average criteria: Avergage resistivity 0.28 <R <2.6MΩ/□

Oulier criteria:

- 99% of measured points within 0.28 <R <2.6MΩ/□ : Grade A
- 95% of measured points within 0.28 <R <2.6MΩ/□ : Grade B
- 95% of measured points within 0.21 <R <3.4MΩ/□ : Grade B-

Pressing tests to increase the strip resistivity

- New gluing/pressing procedure defined at CERN to increase the resistivity, and applied to the 500 foils of new production, after testing at CERN and Elvia factory
  - most foils promoted from grade C to grade A/B
  - main effect since to come from gluing at higher temperature



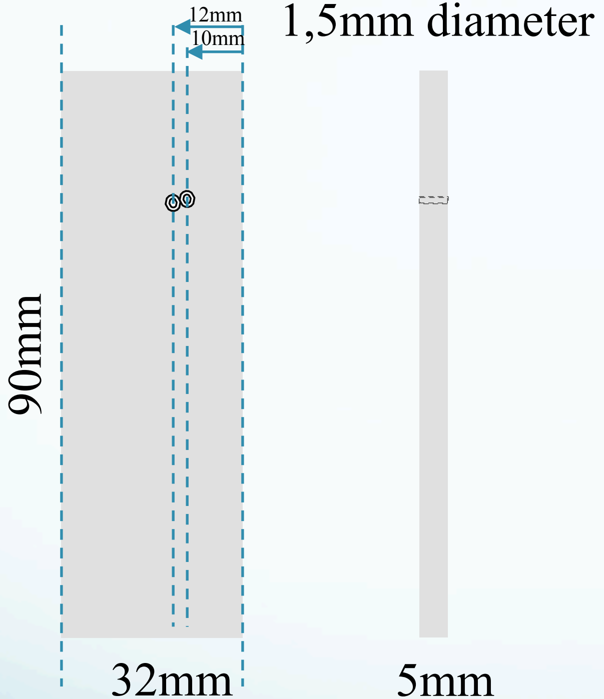
Standard procedure for gluing:
- Pacolon,
- Pressure of 14 bar,
- Temperature of 170°C.

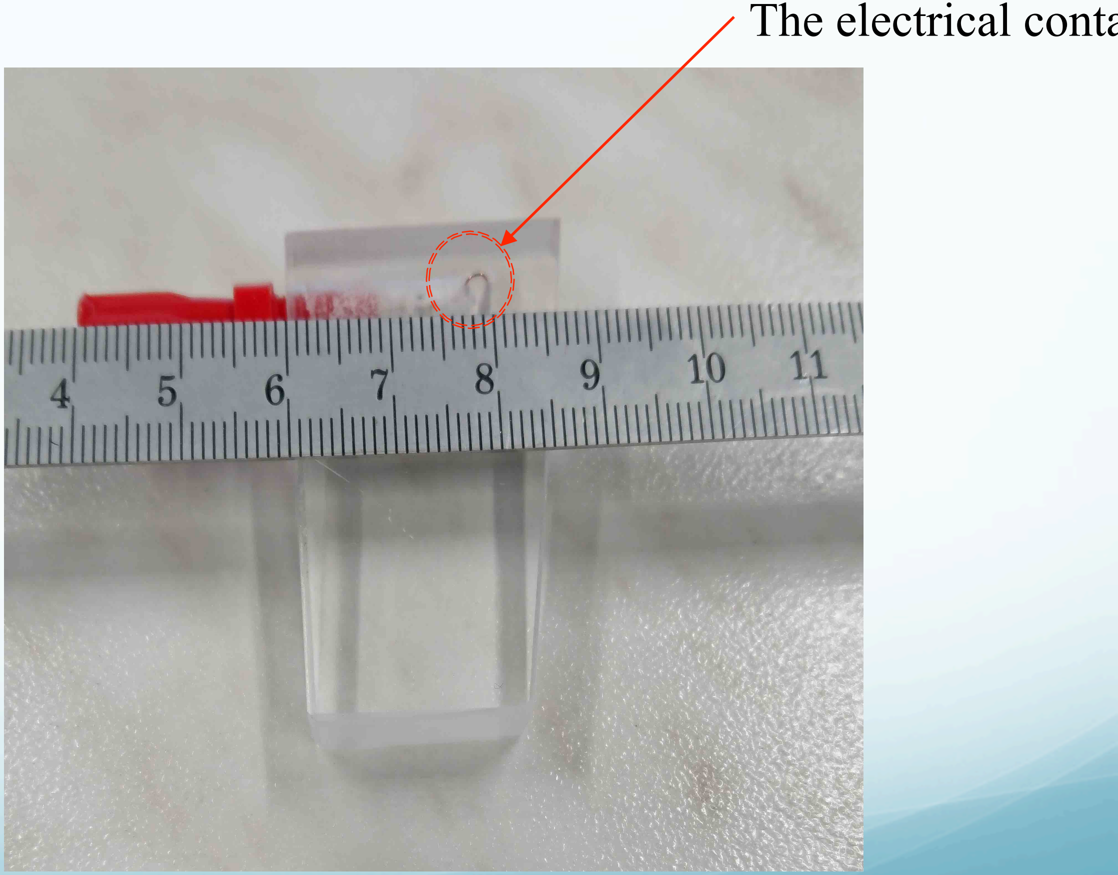
NEW PRESSING Procedure:
- Pacothane,
- Pressure of 12 bar,
- Temperature of 180°C.

- The new paste used for the last 150 foils has a slightly higher resistivity and viscosity
- Preliminary tests at CERN in January on several samples show cases of huge (unacceptable) increase of square resistivity, and quite non-uniformity among samples
- A first test was done at ELTOS on production foils in January
  - pressing with pacothane, at 14bar and 180°C for 1.5h → a big jump in resistivity observed (> 100 MΩ) in agreement with the test done at CERN
- More tests planned, to control uniformity and reproducibility, both at ELTOS and CERN.

Marco Schioppa

Probe single strip: 190um Cu wire, 0.5 mm long



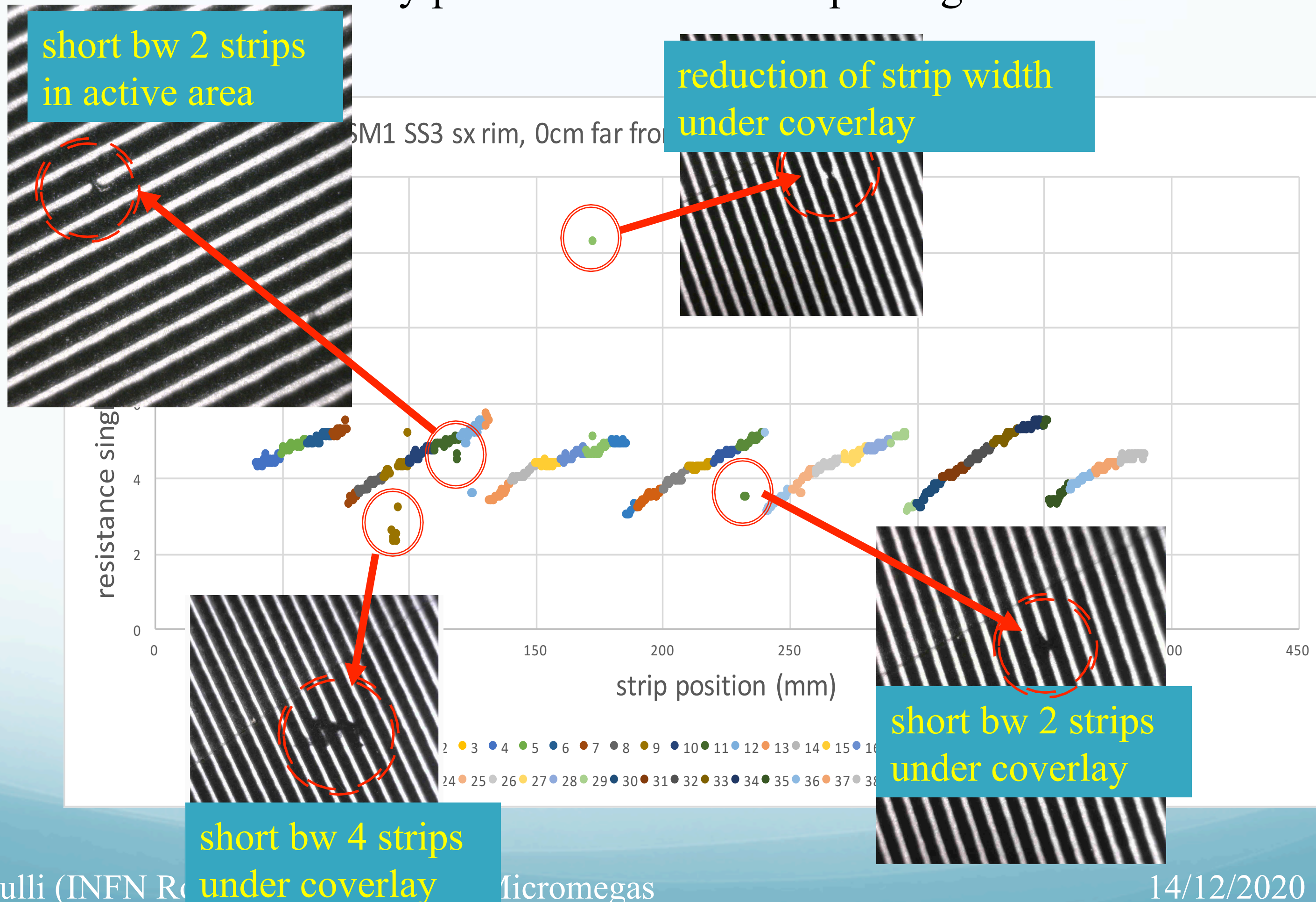


Synthetic glass is transparent and allow us to check the position of the probe. The wire must have diameter greater than the pillar height

Marco Schioppa

Individual strip resistance measurements

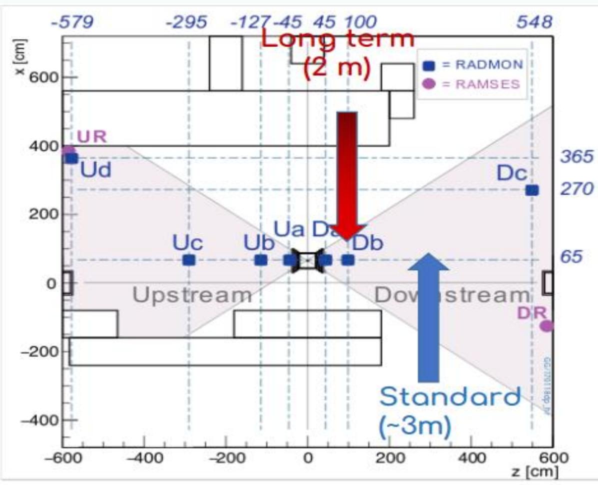
R measured close to the coverlay along the PCB side.
Every point is a different strip along the PCB side

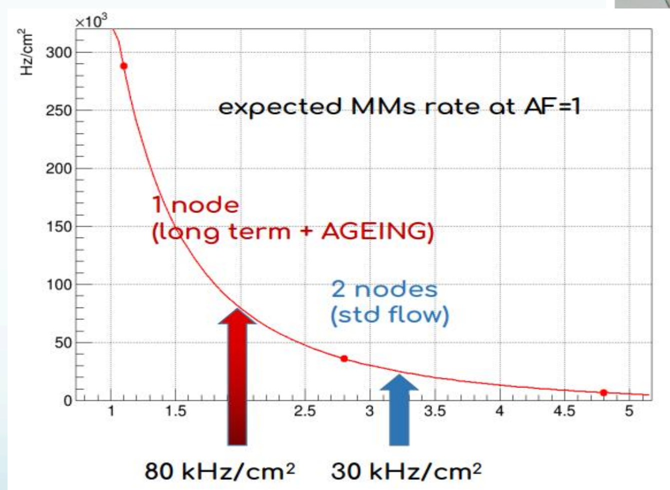


Tests of different gas mixtures at GIF++

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
- Both short and long term exposition tests performed





- Chambers at ~2m from the source
- Max rate: 80 kHz/cm^2 @ attenuation factor 1

- GIF++ routinely used to validate production chambers

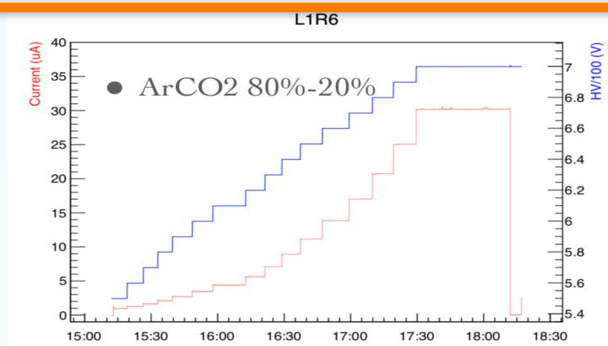
Effects on good and bad sectors

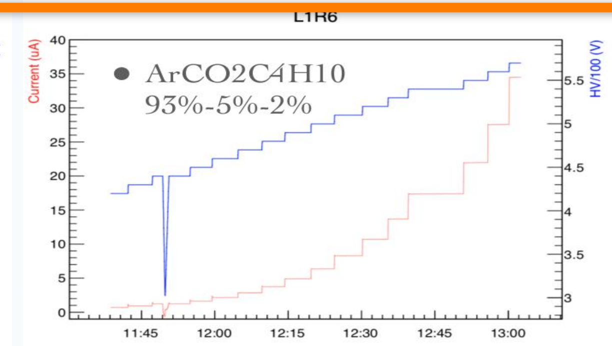
Gas mixtures under test:

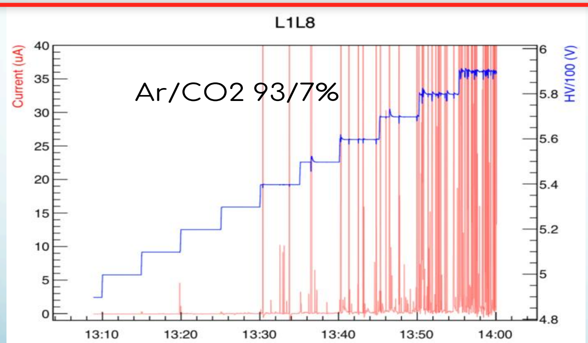
- $Ar:CO_2 = 93:7$ (standard)
- $Ar:CO_2 = 80:20$
- $Ar:CO_2:iC_4H_{10} = 93:5:2$

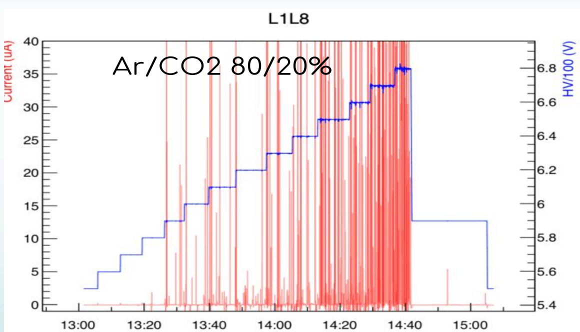
HV ramp up on good-behaving MM sectors:

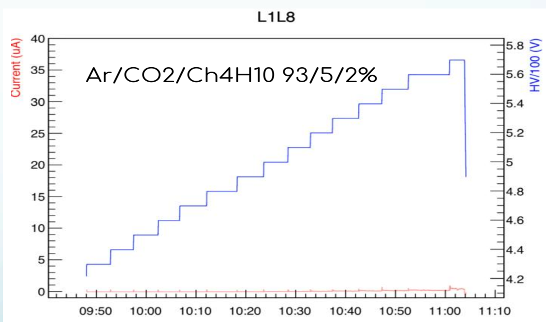
- smooth exponential rise up of the current
- no spikes









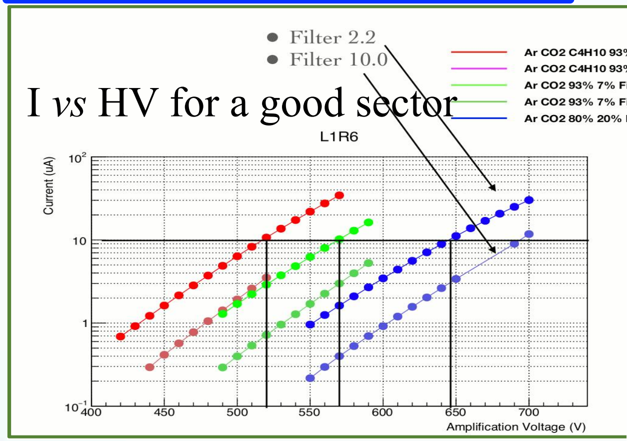


HV ramp up on bad-behaving MM sectors present an high spike rate:

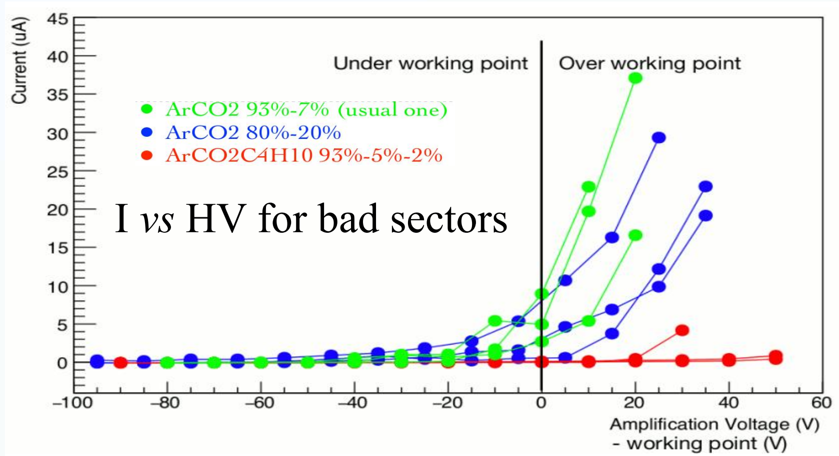
- not much difference between the two binary mixtures
- **the addition of the small fraction of iC4H10 looks very effective on spikes suppression**

Working point and I *vs* HV linearity

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

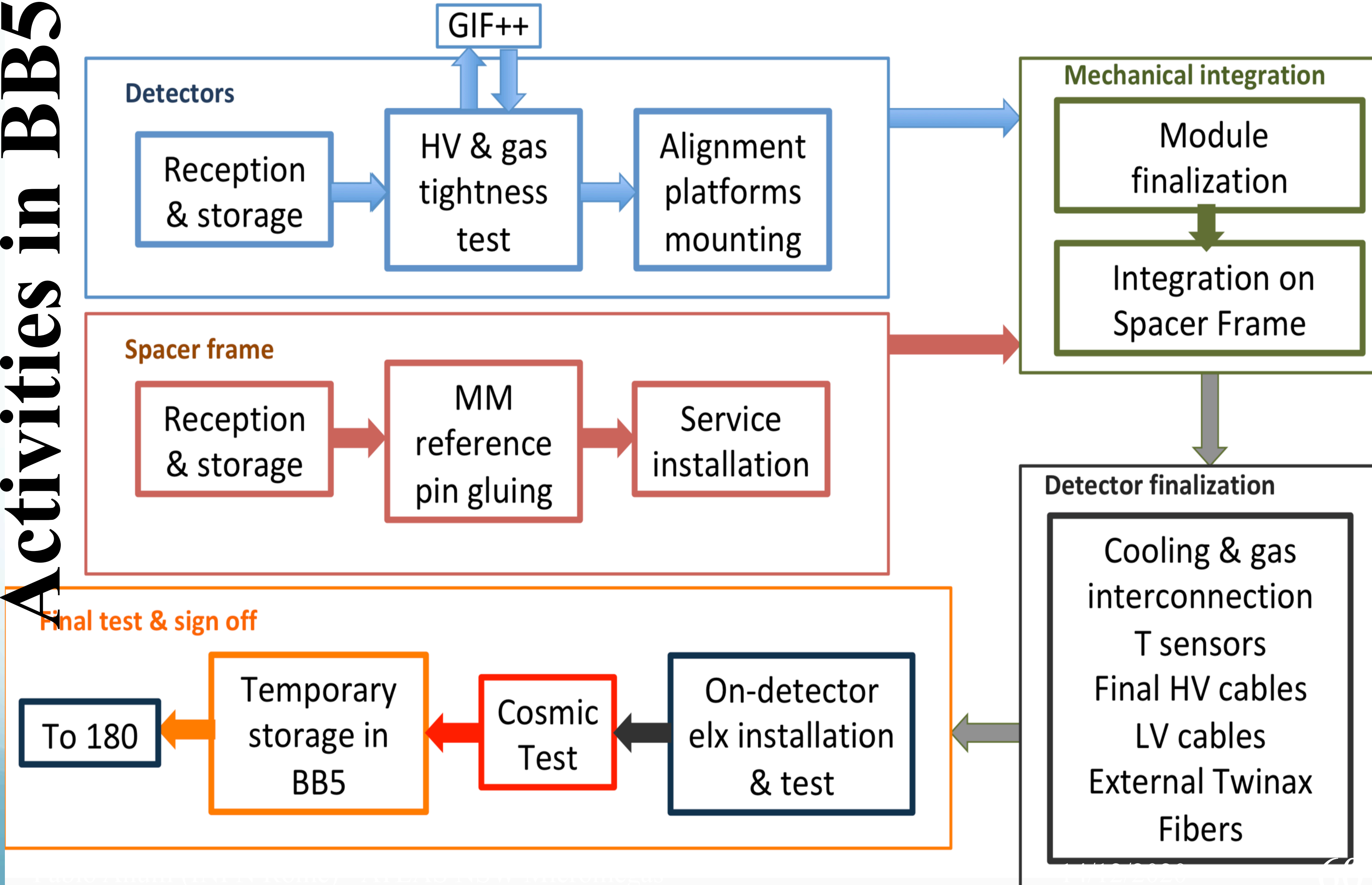


	Drift (V)	Work Point (V)
ArCO2 93%-7%	300/ 350	570
ArCO2 80%-20%	450	645
ArCO2C4H10 93%-5%-2%	250	520

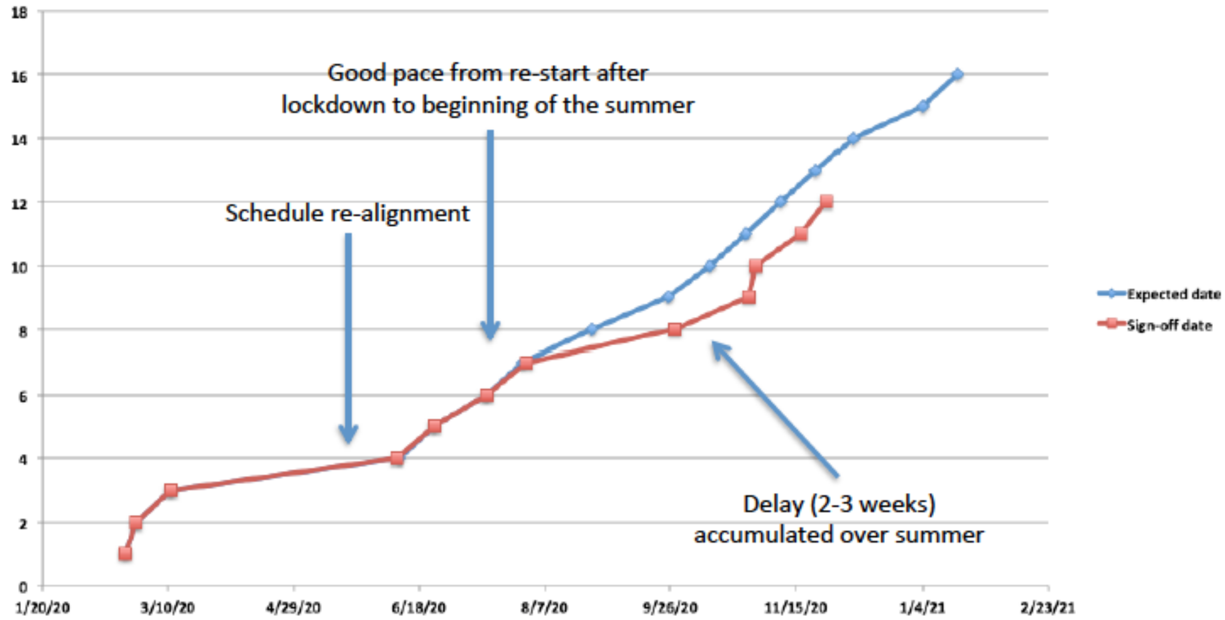


- **iC4H10 allows to run at significantly lower amplification voltages**
- The ratio of currents drawn (gain) at AF 2.2 and 10.0 decreases with HV as expected, but no real saturation effects observed
  - rough estimate: ~30% gain reduction for rates ~3 times HL-LHC
- **“Bad” HV-sectors behave better with the mixture with Isobutane**
- Bad breakdown observed with ternary mixture in a couple of cases (under investigation)
- **Long-term “ageing” test** ongoing on two chambers with the ternary gas mixture

Activities in BB5



NSW-A schedule: DW sign-off



- Delay over summer for specific problems / tests
- Expect to complete A07 before Christmas. Then A05 in January. NSW-A end of Feb.

NSW installation during LS2

NSW-A:

- Ready at B191 between March and May 2021
  - installed in ATLAS cavern and commissioned by end **August** (worst case scenario) ➔ **OK**

NSW-C:

- Main uncertainty source: sTGC production in Chile and Canada, and MM production in France and Russia → move part of the remaining sTGC production in Israel
- (Best estimate): **ready on surface by mid September 2021**
  - installed in ATLAS cavern by **end of January 2022** ➔ **At the limit of LHC schedule (Feb 1st 2022)**
  - work in progress to optimize NSW-C completion timeline by increasing the parallelization of the operations **=> Next review early 2021**