Ready for LHC Run III

The ATLAS New Small Wheel and the MicroMegas chambers performances

International Conference on Micro Pattern Gaseous Detectors 2022
Weizmann Institute of Science, Rehovot, Israel
Giada Mancini on behalf of the ATLAS Muon Spectrometer System

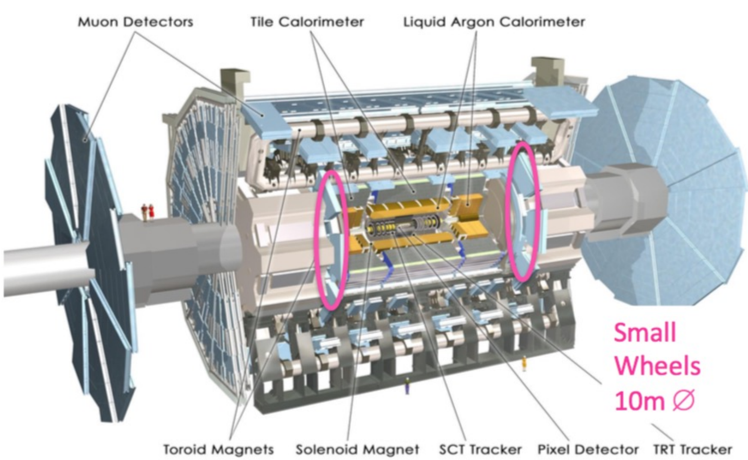
Introduction

ATLAS Muon New Small Wheel (NSW) Upgrade:

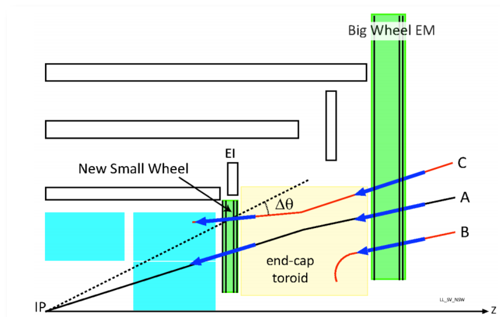
- Replace innermost Muon station in the forward region (Small Wheel) to improve LV1 trigger & maintain good tracking at End-cap towards HL-LHC runs with high background rates (up to 20 kHz/cm^2)
- Readout channels (25xold SW): MM: ~ 2.1 M, sTGC: ~ 280 k (strip) + 46 k (pads) + 28 k (wires)pics

Detector area: ~2400 m^2

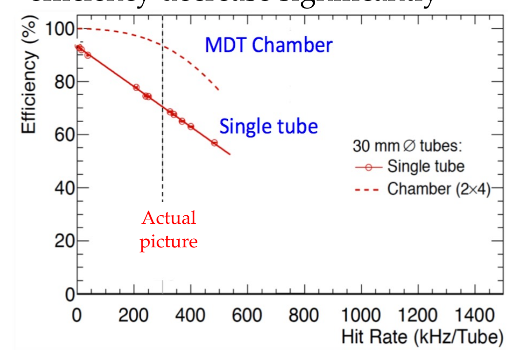
Both technologies provide precision trigger and tracking for muons in the ATLAS forward region.



Level 1 End-Cap trigger, dominated by fake trigger events (type B e C)



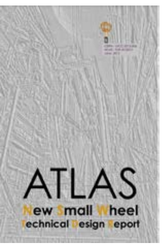
HL-LHC: (MDT) expected frequency > 500 kHz / tube
-> efficiency decrease significantly

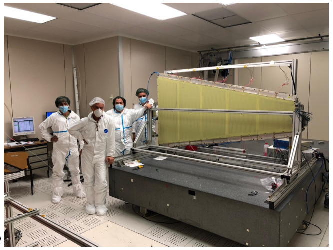


- For offline muon construction: 15% p_T resolution at ~1TeV -> 97% segment reconstruction efficiency for muon p_T>10 GeV with 30 μm spatial resolution
  - MM: ~100 μm spatial resolution per detector plane with single layer efficiency > 90%
- For online (Level-1) triggering: segments measurements with up to 1 mrad pointing accuracy (Phase-II requirement)
- Able to cope with the increasing background particle flux (pileup) as the luminosity increases

Roadmap

ATLAS TDR



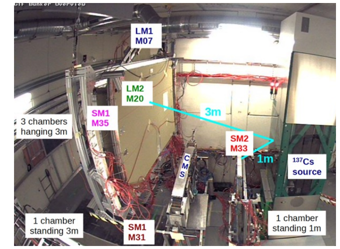


Module production
2018-2020

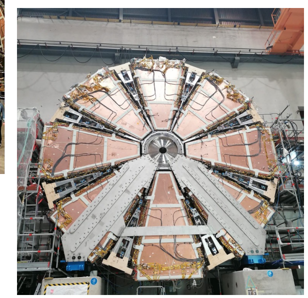
Integration at
CERN
2019-2021

NSW A End Surface
Commissioning
18/06/21

NSW C End Surface
Commissioning
08/10/21



MM validation
of the ternary
gas mixture
2018-2022



NSWs Underground
Commissioning
10/21-04/22

2013

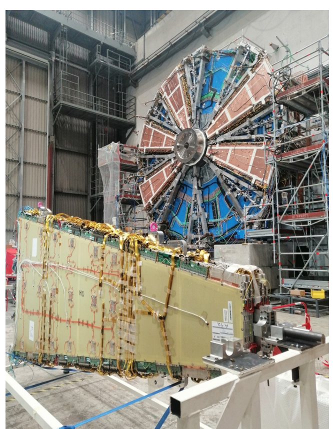
2019

2020

2021

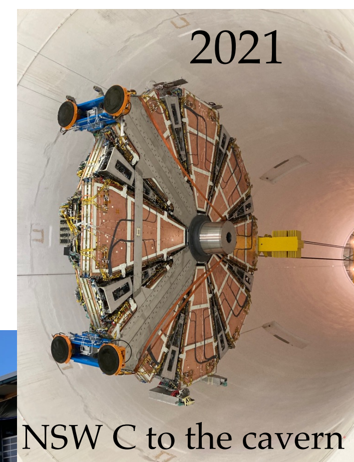
2022

1° sector on the Wheel
12/2019



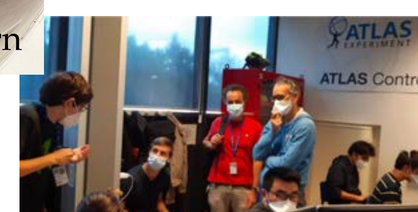
Surface Commissioning
2019-2021

NSW A to the cavern
12/07/21

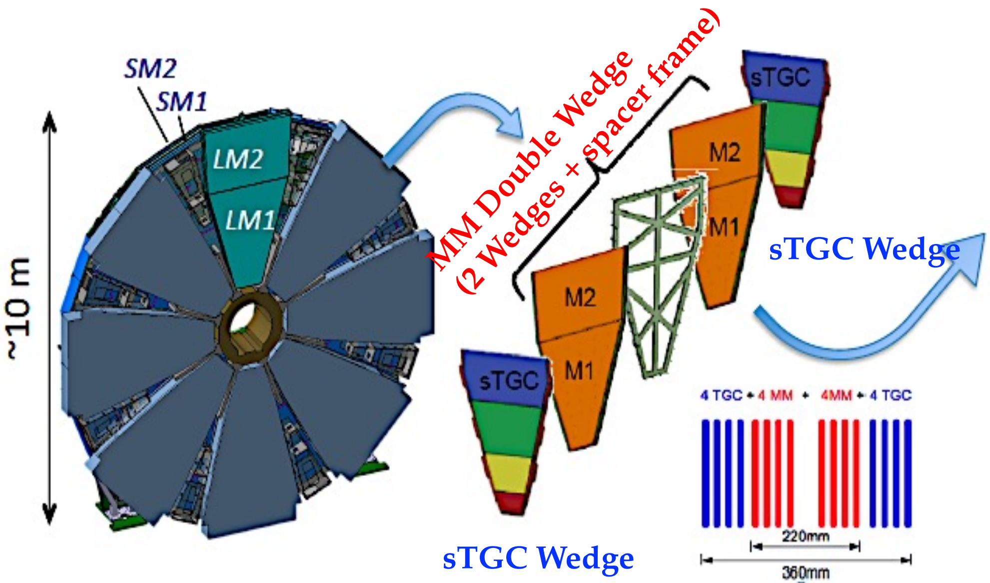


NSW C to the cavern

NSWs Running in ATLAS
since 05/22



New Small Wheel layout



Each of the 16 NSW sectors (Large and Small) is composed by:

- 1 MM Double Wedge
- 2 sTGC Wedges

Each wedge (MM and sTGC) is a detector quadruplet.

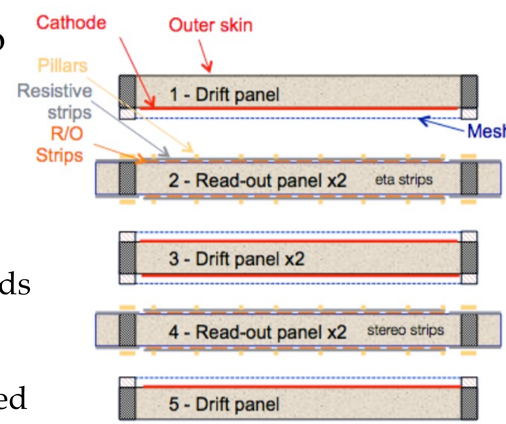
MM detectors were build for the first time on O(m²) dimensions! -> Huge achievement!!!

MM quadruplet:

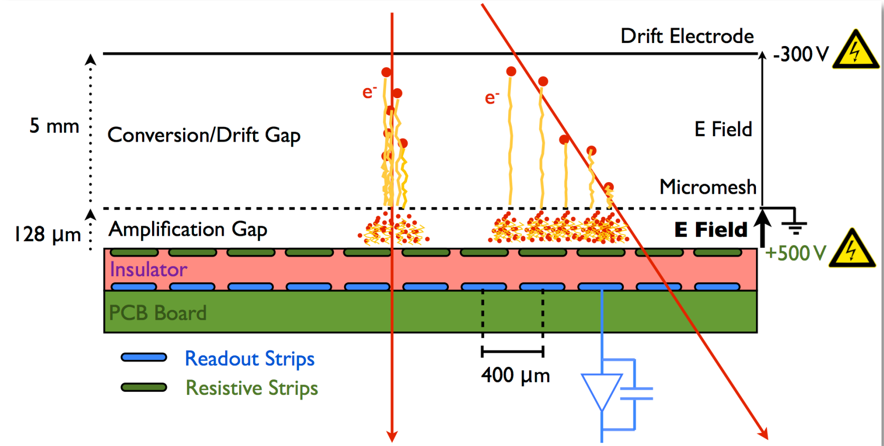
2 layers to read the precision coord. and 2 stereo layers ±1.5° for the 2nd coordinate

- 5 stiff panels needed to form 4 gaps when coupled
  - stiff panels to guarantee planarity:

    Read out panels with 3-5 pcbs based on boards done in industries (industrial limitation on dimensions), drift panel (cathode pcbs + glued meshes)



The MM detectors within the ATLAS NSW

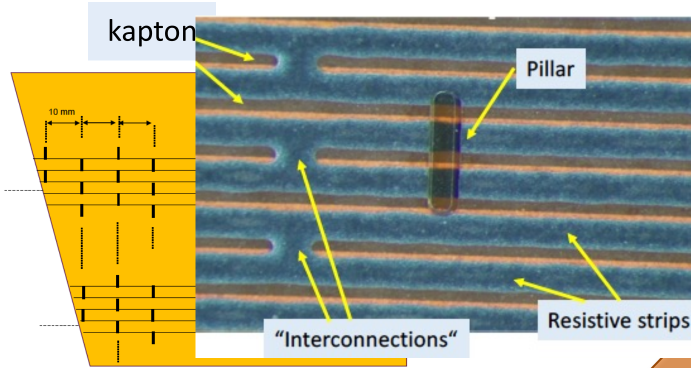


MM Working conditions:

- conversion gap 5 mm, amplification gap 120 μm
- stainless-steel mesh grounded: 30 μm thick wires 70 μm openings
- strip width 300 μm, strip pitch 425-450 μm
- HV (mesh to ground):
  - Conversion: HV_{drift}= -240 V, h=5mm, E_D~480 V/cm
  - Amplification: HV_{RO}= o(500) V, h=120μm, E_A~42 kV/cm
- ternary gas mixture $Ar:CO_2$:Iso 93:5:2 at HV_{RO}= 505 V (started with $Ar:CO_2$ 93:7 at HV_{RO}= 570 V)
- resistivity strip ≈ 10 MΩ/cm (introduced to reduce the intensity of discharges)
- E_A/E_D ~ 90% => high mesh transparency
- Gain ~10^4; ions collection time ~100 ns

Features specific to ATLAS MM:

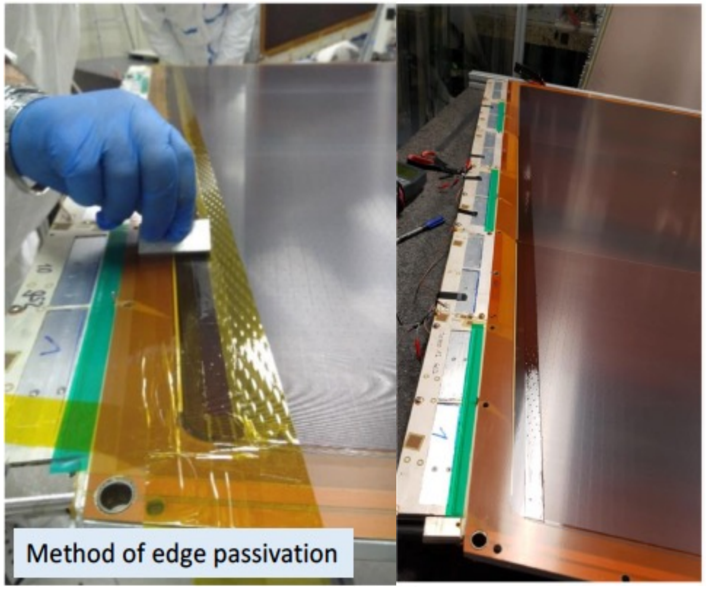
- Mechanically floating mesh: the mesh is integrated in the drift panel structure and not embedded in the anodic structure
  - necessary for large area detectors (first time o(m^2))
  - the chamber can be re-opened for intervention
- Mesh at ground potential
  - easier construction procedure
  - allows separation of RO boards in independent HV sectors
- Resistive strips are overlayed to copper signal strips
  - reduction of local current and of risk of discharges
  - resistive layout (screen printing technique) with equidistant interconnections to have uniform resistance across the pcb

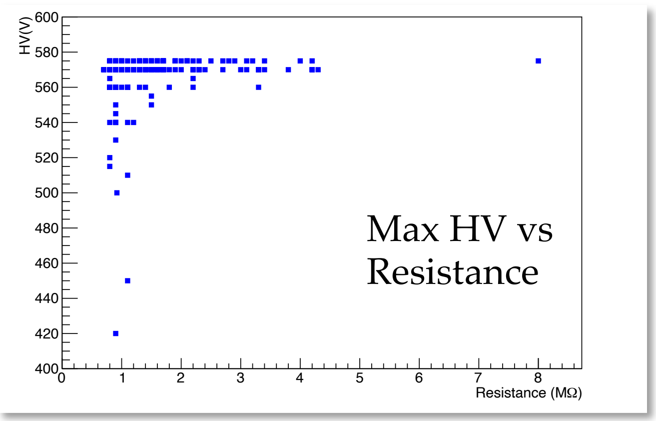


HV stability issues

The main issues affecting the HV stability were 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** => **monitor humidity and increase flux**
- **Low resistance of resistive layer:**
  - marginal resistivity of the foils (resistivity dependance on batches) -> *more in P. Iengo'talk on thursday*
  - strong dependence on the layout (design issue)
  - **Clear correlation between HV bad sectors and R_{min}!**
  - **=> edge passivation**
- **Low quenching gas mixture! => following slide**



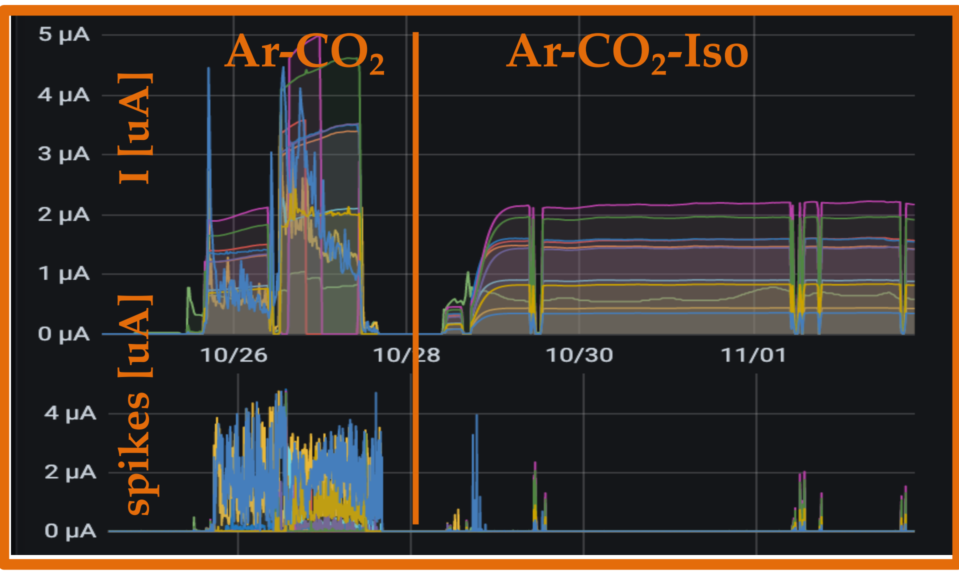


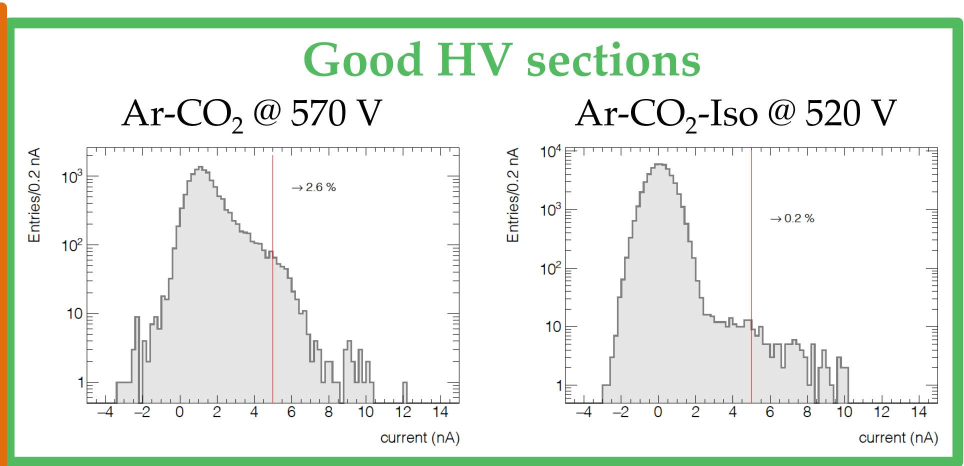
Plus: New HV scheme for ATLAS, 3 times more HV channels to cope with weak sections

Isobuthane enriched gas mixture

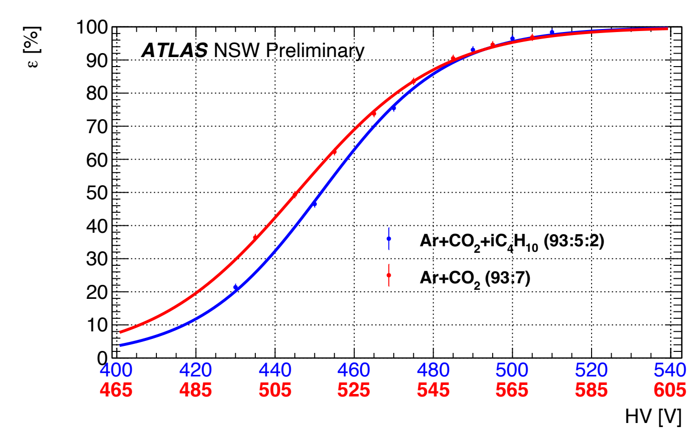
Ternary gas mixture (Ar-CO_2-Iso 93-5-2):

- **Iso allows to run at significantly lower amplification voltages**
- **Bad** HV-sectors behave better with the Isobutane enriched mixture
- Isobuthane addition improves the sparking picture for NSW MMs





iC$_4$H$_{10}$ allows to lower the working HV, wrt 570 V in Ar-CO_2 having better stability, higher gain and better performances!



Cope with residual HV issues

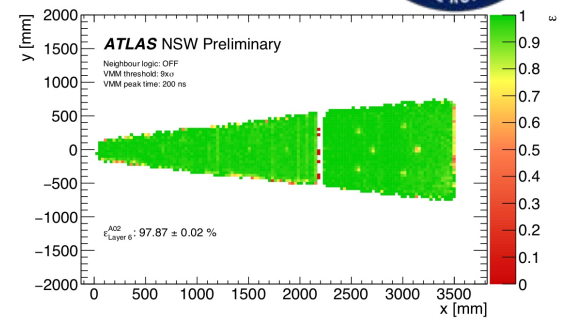
Chamber testing: for single layer fully working (elex and HV)

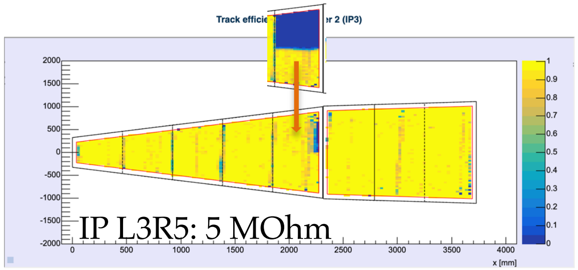
we achieved efficiencies at the level of 98% via self-tracking

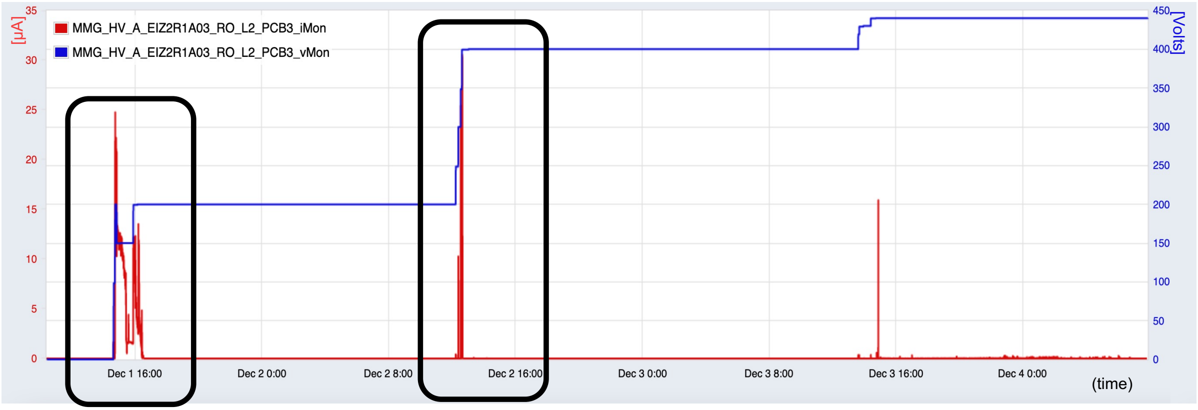
Even after passivation still 2-10% of weak HV channels in Ar-CO2

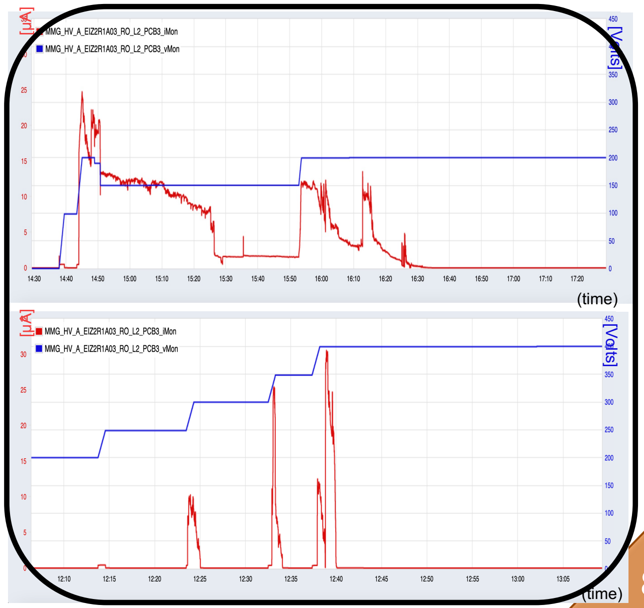
- Resistive pcbs -> high stable currents coherent with an equivalent resistor in the amplification gap of 5-10 MOhm -> weak known points of the pcbs
    - Instead of having OFF sections we only loose few cm
    - Resistive layout allows for Voltage drop only on small region
- Curing: pure Argon to clean the region by means of sparks *(Rui De Oliveira)*

  1st round Feb22 on 13 ch -> 50% successful treatments -> ch at nominal HV
    - Standard procedure during shutdown period: 2nd round during the past weeks (28 channels)









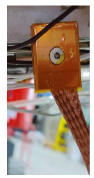
Commissioning: noise issue addressed!

NSW's elex system is based on the VMM ASIC, which connects to the detector readout to provide trigger and tracking muon data to the ATLAS experiment

LowVoltage, DAQ and Elx (VMM):

- Elx noise issue faced during wheel A commissioning ->

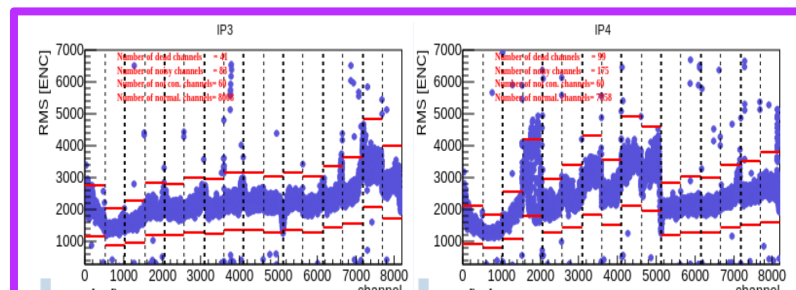
  Main issues identified in the grounding quality and in the power distribution!

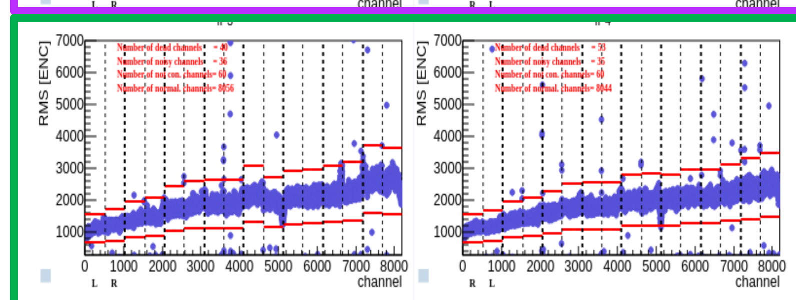


Solutions:

- Grounding reinforced on large bases and RO pcbs
- Implementations of faraday cages on trigger elex boards on the chamber
- **Power Distribution**
  - Low Voltage power supply refurbishment
    - Adding output common mode filter capacitive filter to cut the common mode noise (2-10 MHz)
  - Improved grounding of the power modules of the T-sensors
- **Similar issue observed by sTGC, similar solutions**

Before and after modifications

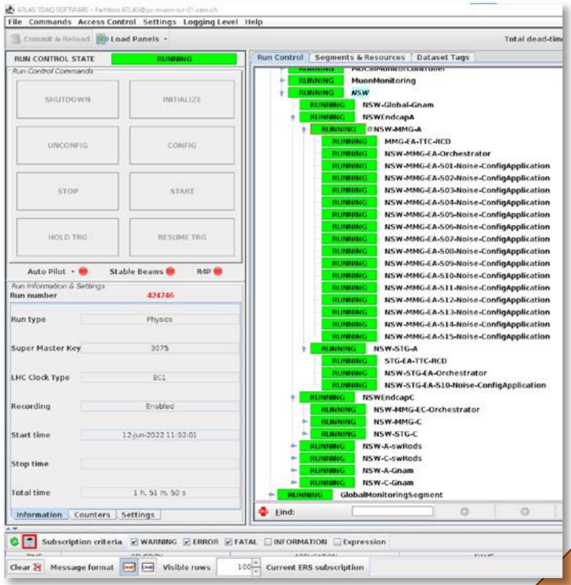




NSWs successfully integrated into the ATLAS Muon Central DCS and in the ATLAS TDAQ!

NSW employs new generation DAQ developed for the ATLAS Run-3: FELIX (Front End LInk eXchange) system + software ROD (swROD). -> Extremely tight schedule for DAQ commissioning **(used for the first time at large-scale in ATLAS)!**

- Many calibrations required for the detector and DAQ operation: from optimization of Front-end analog circuits, correct timing of detectors to ensuring electronics synchronization and data communication stabilities
- Experienced DAQ instabilities with Felix buffer filling and data link de-synchronization while including more sectors or at higher (>10kHz) trigger rate.

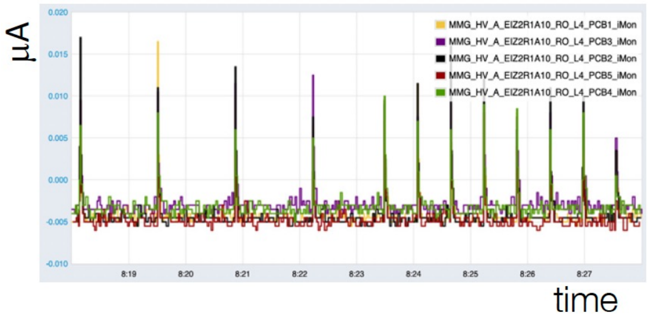


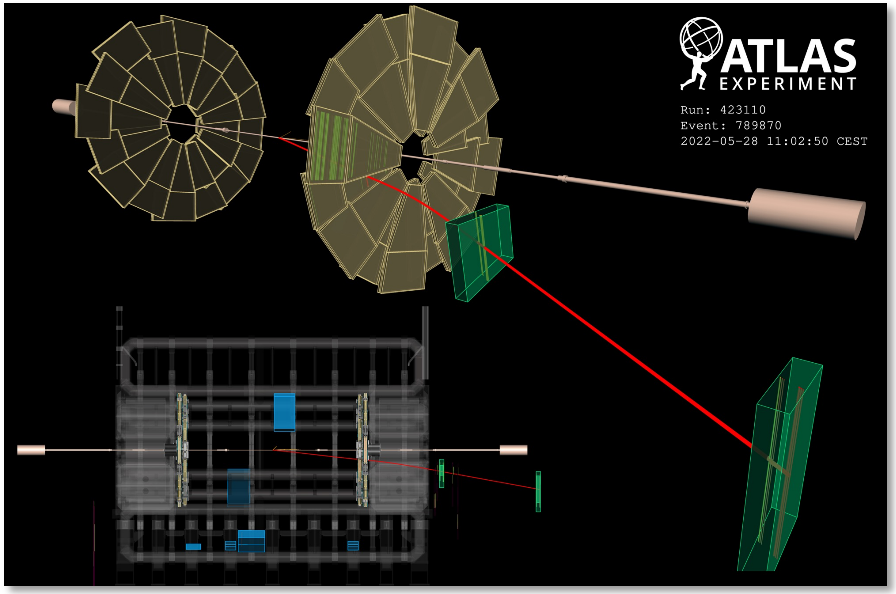
- Integration in the ATLAS TDAQ partition since May: from a few sectors to entire wheel.
- 5/Jul-Nov22 -> Early Run3 started! NSW have been joining the ATLAS data taking with nice results!

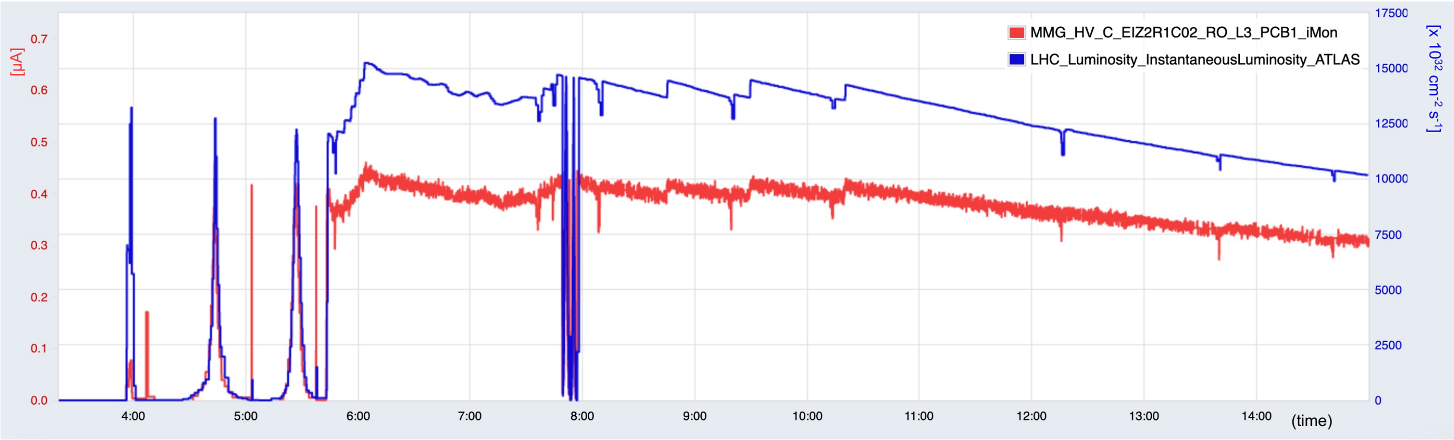
From the beam splashes from LHC (7 May 2022) to the ATLAS Early Run 3 started on 5 July 2022!

Currents of MM detectors are following the LHC Istantaneous Luminosity amazingly!

MM current with LHC splashes



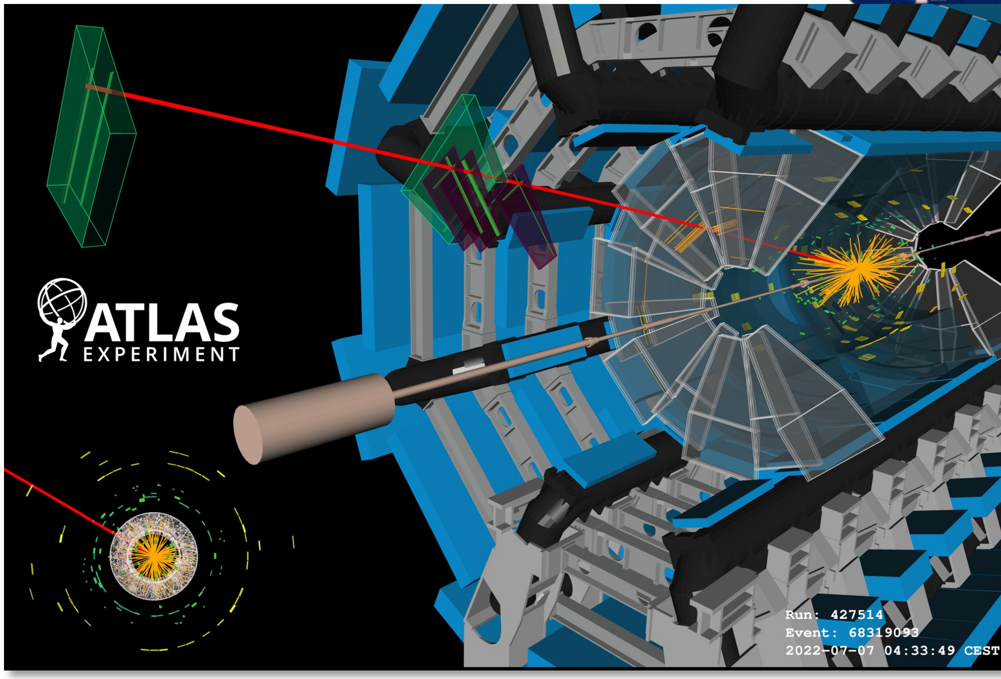




NSWs in ATLAS

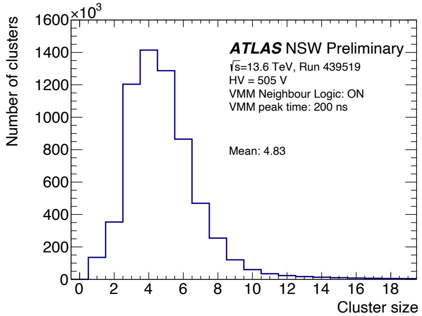
- Muons reconstructed by the Inner Detector + Muon Spectrometer traversing the psudorapity region competing to the NSW are reconstructed in the NSW layers.

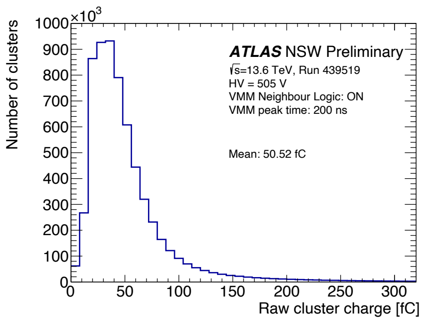
Performances of the MM layers are studied in terms of number of clusters, cluster dimensions and efficiencies as a function of the HV applied to the anode in a spatial window of 5mm wrt the reconstructed track.



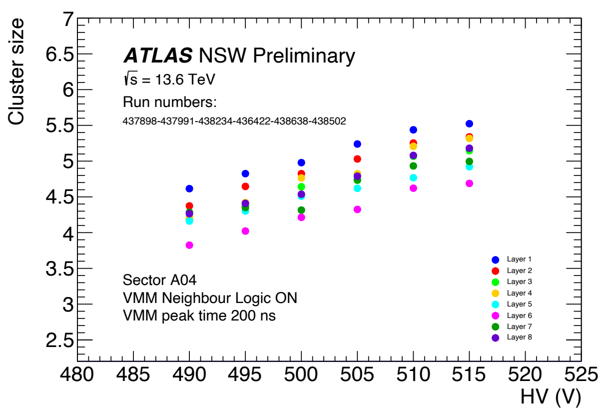
Very Preliminary Plots*!

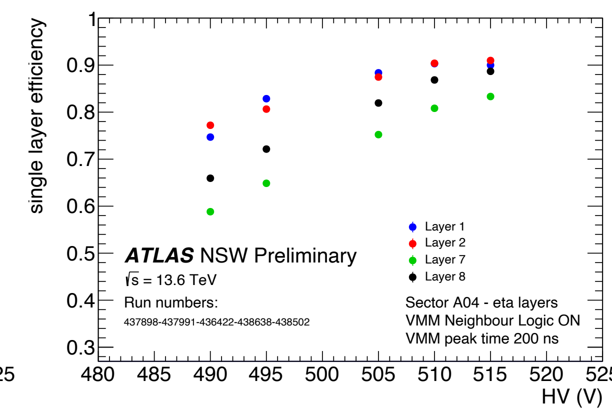
*full system still undergoing operational tunings and improvements





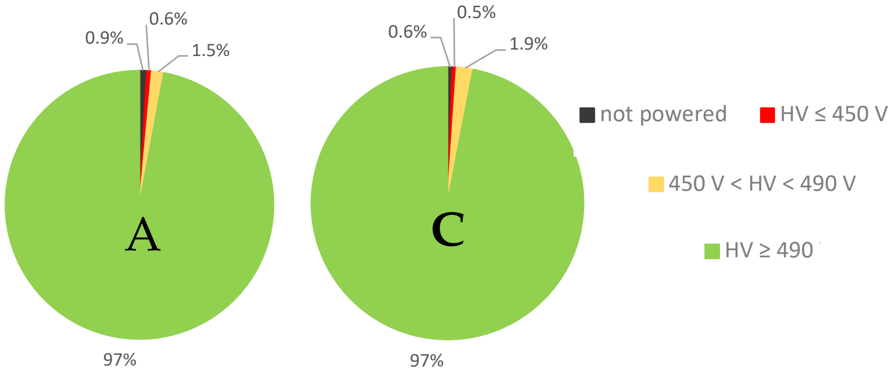
HV scan of cluster size and single layer efficiency



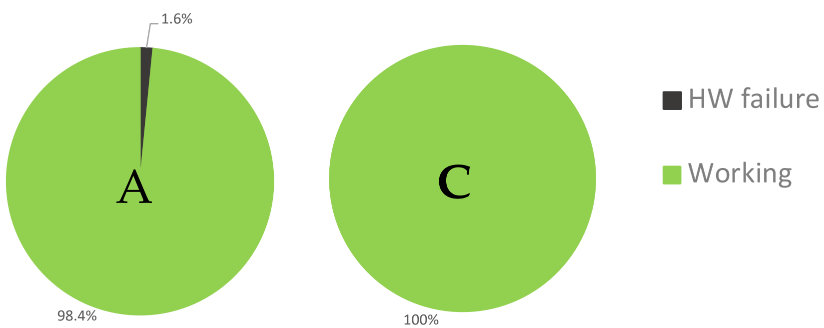


NSWs in ATLAS

NSW HV and LV status:

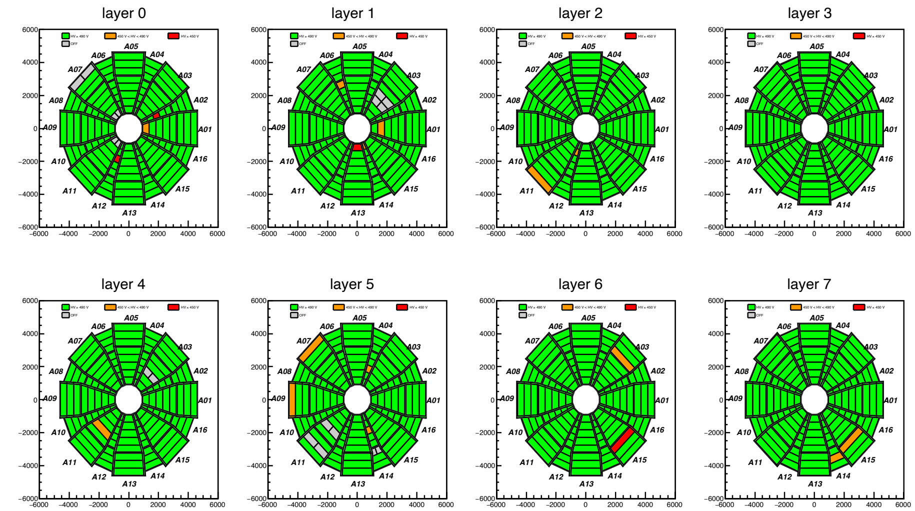


2 Drifts not working:
A2 SM1 IP Layer 3, C15 LM1 IP Layer 2

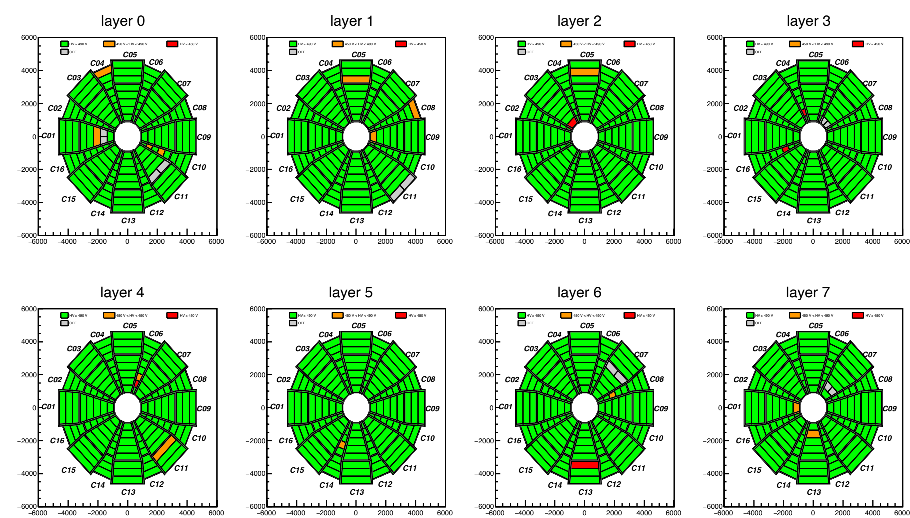


Hardware failure as from Low Voltage known issues that cannot be solved during standard interventions.
Wheel A:
- A4 affecting 8 MMFE8
- A6 affecting 16 MMFE8
- A14 affecting 8 MMFE8

A: **HV pcb by pcb**



C: **HV pcb by pcb**



Conclusions

- The New Small Wheel upgrade: largest ATLAS phase-I upgrade project.

  It aims at improving Level-1 muon trigger and tracking in the ATLAS forward region towards HL-LHC runs.

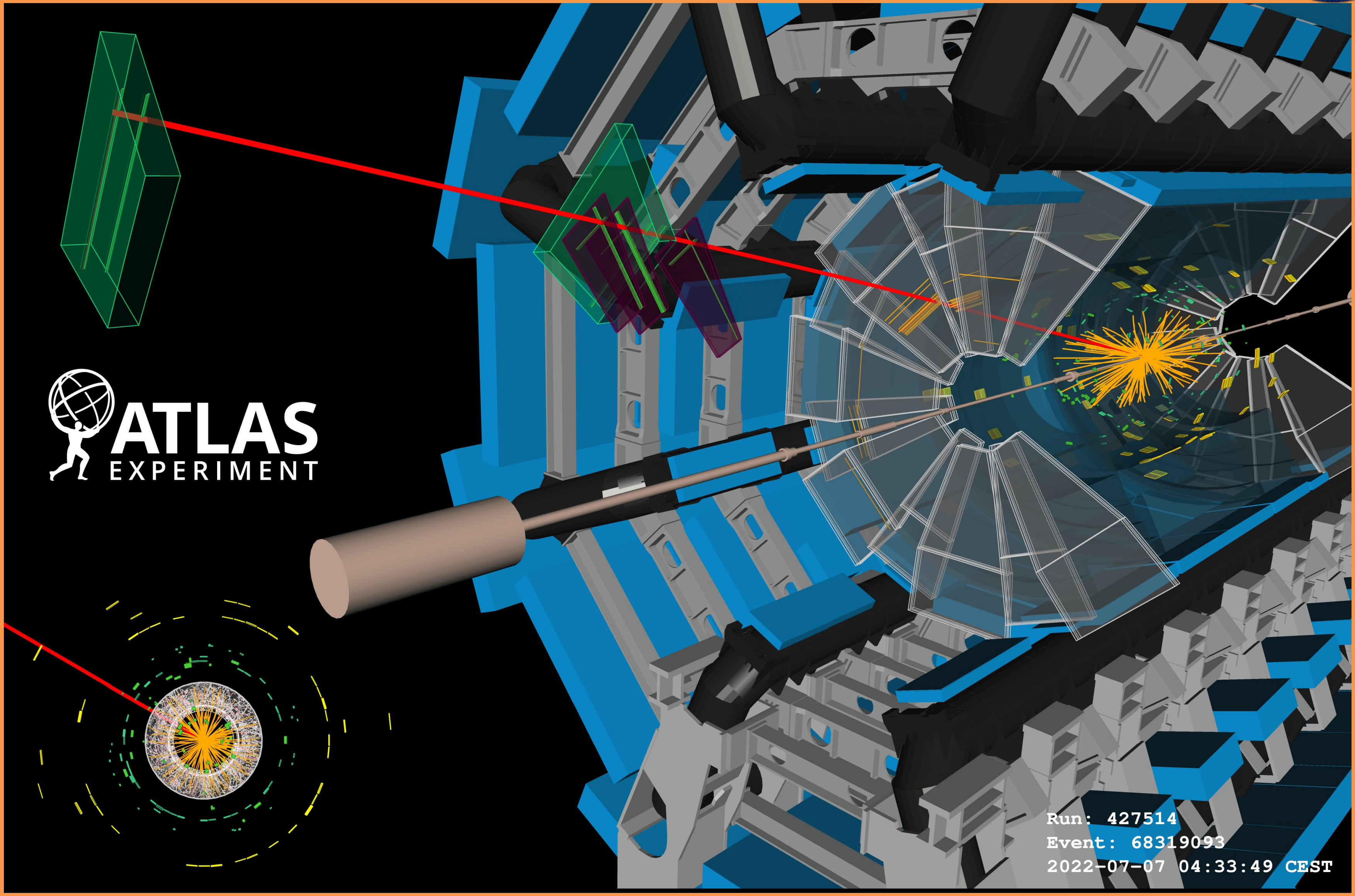
- With all the knowledge acquired in the past years we managed to address the main issues affecting the MM detectors

- Detectors have been fully commissioned and installed in the ATLAS cavern: Milestone for ATLAS during LHC Long Shutdown 2! -> Good progress during Commissioining 2022

- This huge achievement has been possible thanks to the commitment and dedicated effort of hundreds of people! ()

- Intense and continuous efforts to understand and improve the performance of the system!

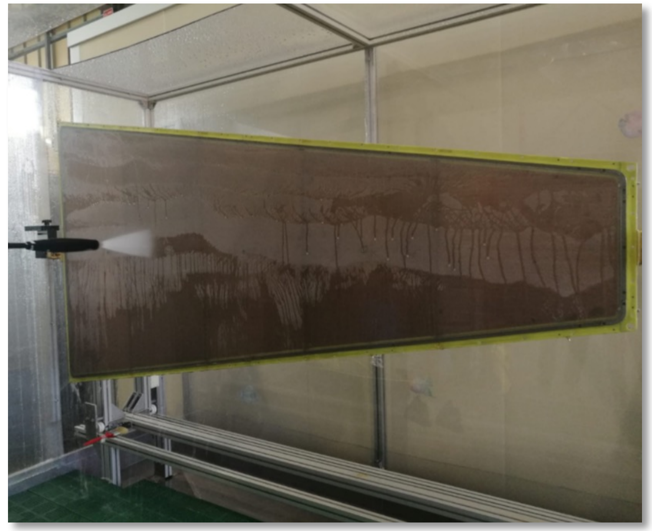
Thanks for your attention!



Updated cleaning procedure

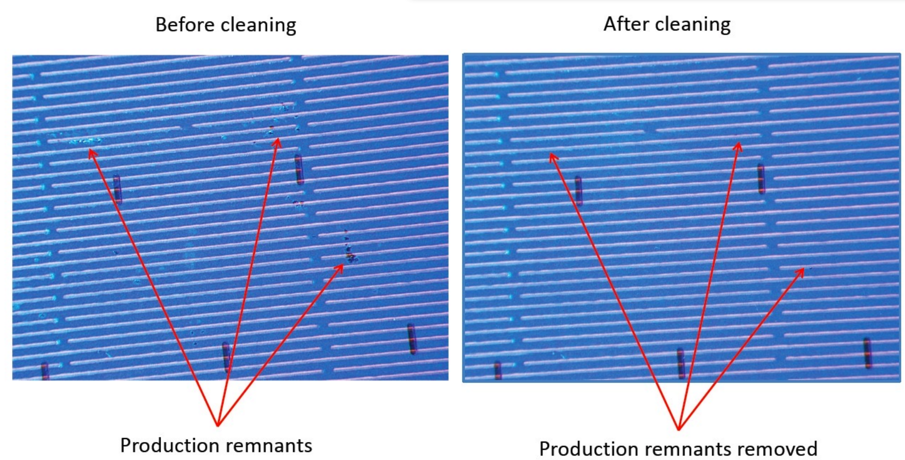
Micropolishing cleaning procedure:

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



Main purpose of wet cleaning (and scrubbing):

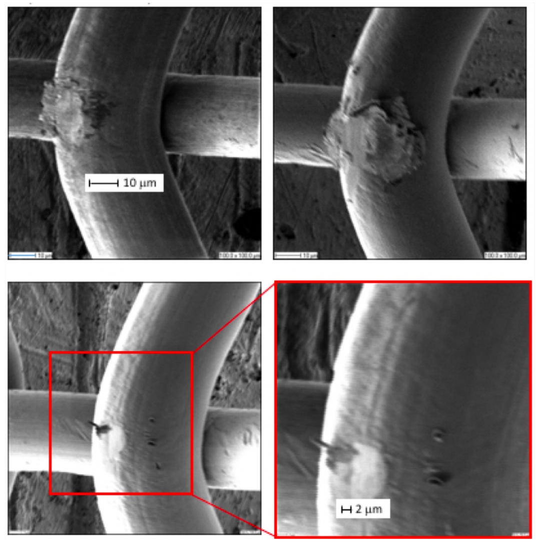
- remove remnants from the PCB production: dirt and solid deposits from the RO boards -> mostly responsible of "ionic component"
- remove dirt from the mesh (and trapped wires/chips)



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

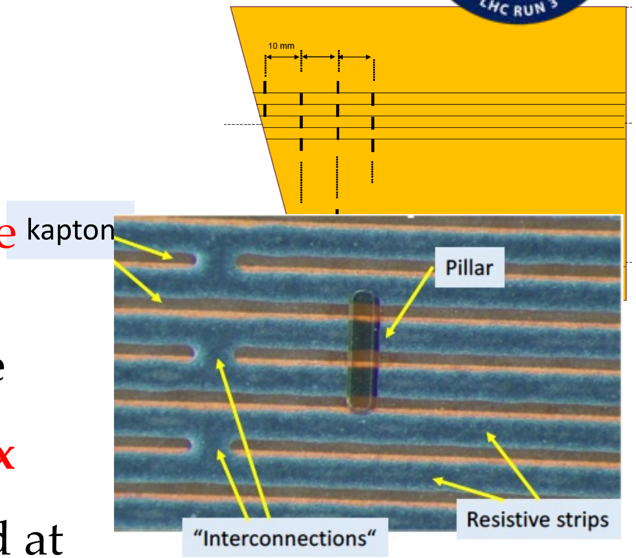


The described cleaning procedure, together with the mesh polishing has been adopted at all sites and large improvements have been observed in HV stability behavior.

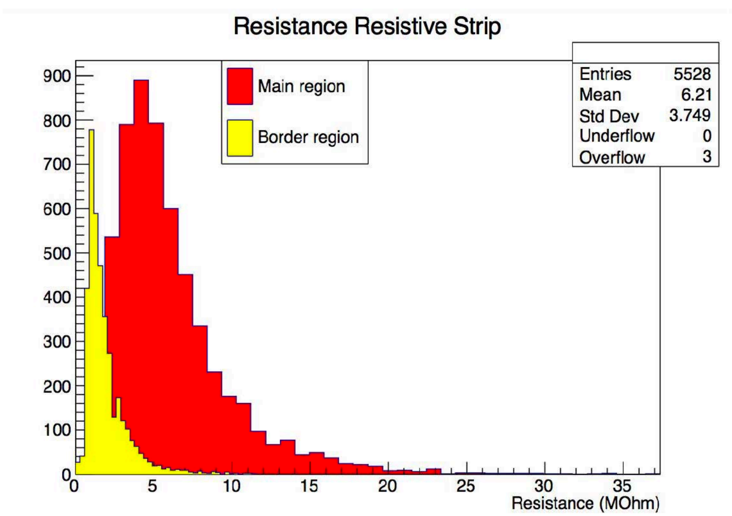
-> Production resumed BUT still in all chambers few HV sectors have problems so that further investigations went ongoing in parallel with the production.

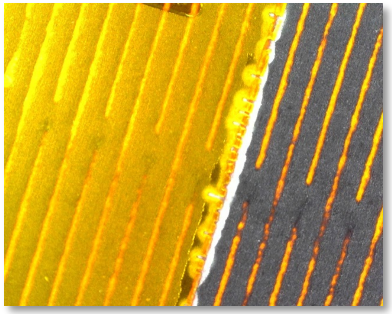
The resistive strips of the ATLAS MM are ink-printed on a kapton support

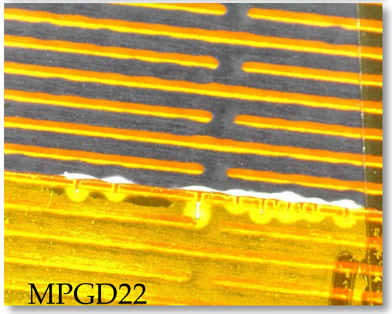
The resistive strip layout presents interconnections with a defined pattern -> to have more uniform resistivity in the board

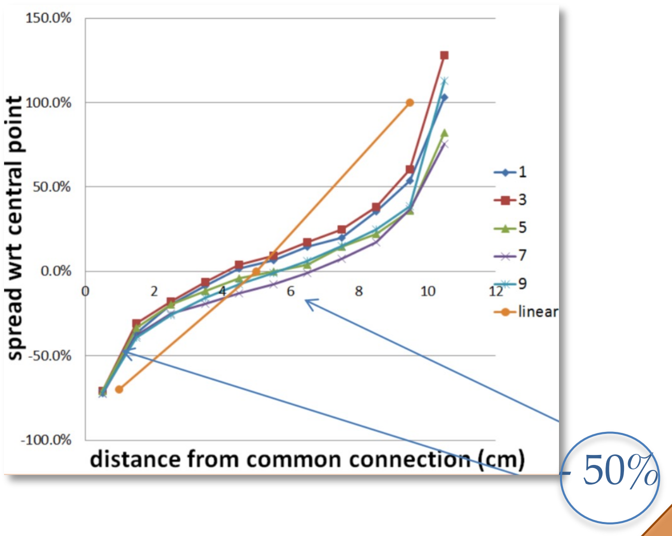


Analysis of **discharges** showed that in many cases they are **localized on resistive strips junctions crossing the piralux rim, the edge of the active area** (1cm wide zone passivated at the factory)





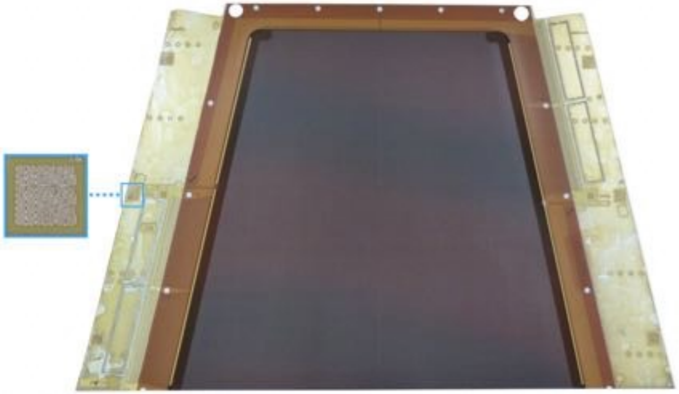




The resistive MicroMegas chambers are frontier Micro-Pattern Gas Detector which are designed and built for the first time on large dimensions O(m^2).

MicroMegas construction requirements and challenges:

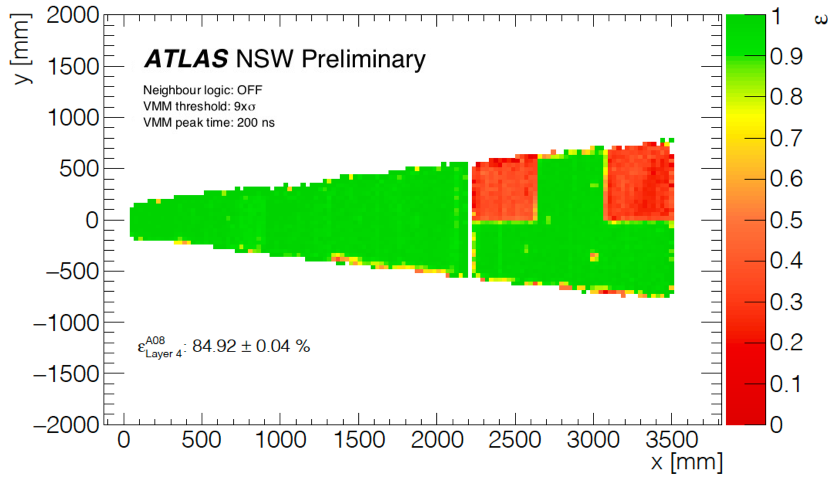
- strip alignment on each layer of **36 μm of precision in η** on positions of strips over meters
  - mechanical supports to the PCB during panel construction
  - coded masks read by contact-CCD on the external side of pcbs
  - optical measurements (**Rasnik technique**) of reference masks etched on the pcb boards



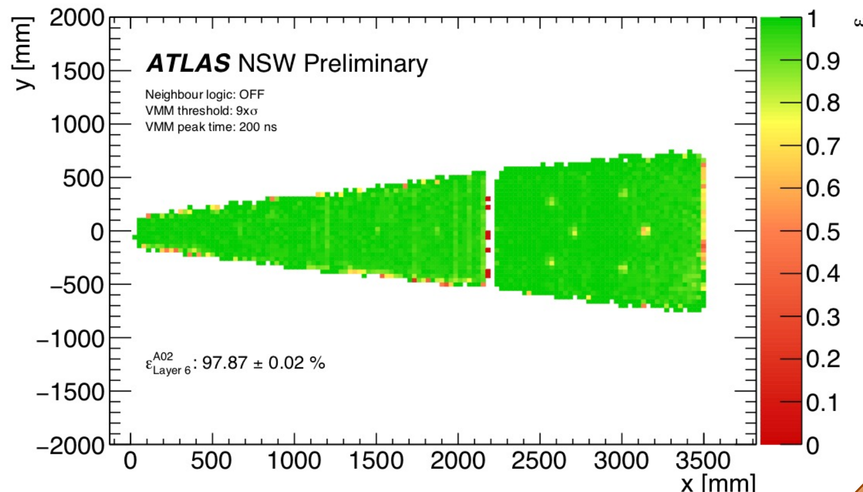
- **planarity within 100 μm RMS**
- **technological transfer of Read-Out pcbs production** with extremely high quality (pillars shape, resistivity homogeneity, quality of the pcb edges)
- **stability against discharges** with an high electric field (~45 kV/cm) on a surface of O(m^2)

Efficiencies of MM during surface commissioning

- **Full test with cosmics on MM Double Wedges (DW) using the self-tracking method**
- 1 MM Double Wedge (1 sector) is made of 8 senstitive layers
  - Each layer is made of 8 adiacent pcbs (industrial limitation on dimensions) and 16 HV sections (channels)
- Weak HV sections must be operated at lower amplification voltage -> clear impact on the efficiency
- for single layer fully working (elex and HV) we achieved eff at the level of 98%
- Different gas mixtures have been studied to cope with weak HV sections (as will be shown later in the talk)



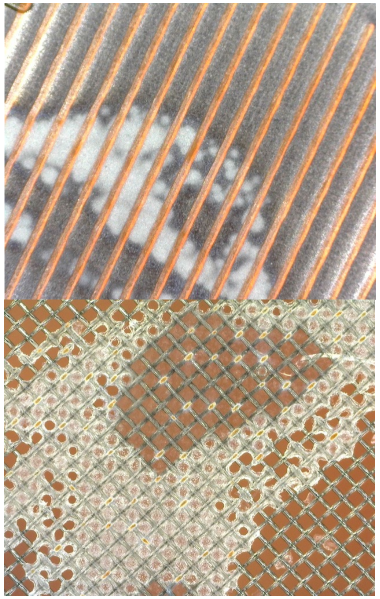
- 2 weak sections at 500 V

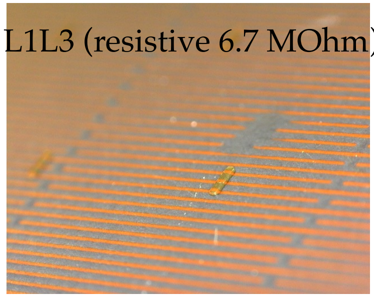


SM1 M31 (1 month at GIF, 6 mAs/cm^2):

- This chamber experienced 2 sectors going bad under Iso-run
- Has been reopened and inspected for hydro-carbon remnants or carbon deposit due to isobutane -> the issues as been identified as weak points (glue on the mesh, resistive blob)
- No issues to be related to isobutane found
  - both spots were removed to be investigated further by cutting off the resistive layer and Araldite protection applied -> nothing found
- After reassembly the chamber was perfectly working and tested with cosmics
- **Defects lead to bad behaviour independently to the gas mixture!**

L3L2 (glue on the mesh)



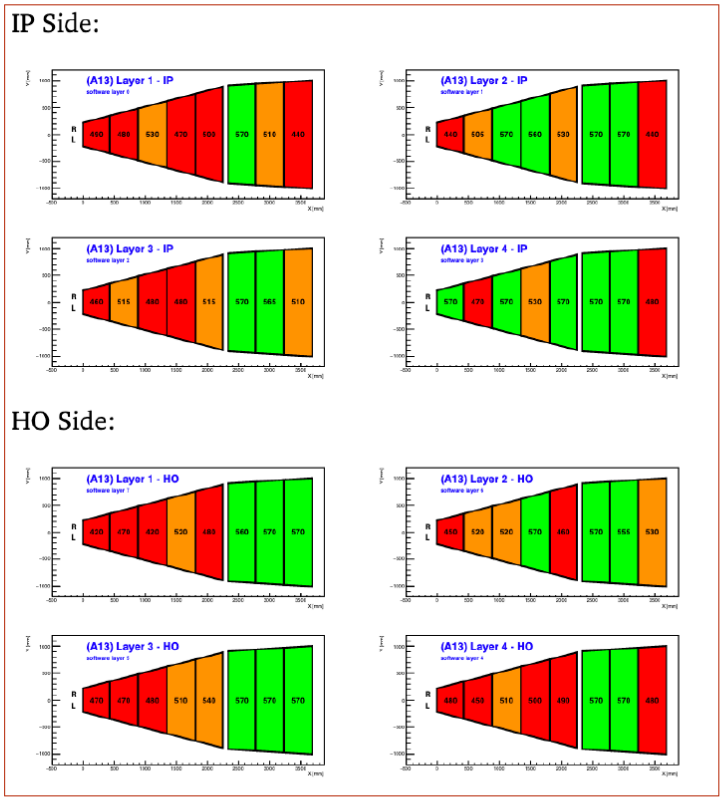

L1L3 (resistive 6.7 MOhm)

Sector (Layer PCB side)	HV [V]	Efficiency [%]	Sector (Layer PCB side)	HV [V]	Efficiency [%]
L1 1 PIN (L) L1 1 NO-PIN (R)	570 570	98.6	L2 1 PIN (L) L2 1 NO-PIN (R)	570 570	98.6
L1 2 PIN (L) L1 2 NO-PIN (R)	570 570	98.2	L2 2 PIN (L) L2 2 NO-PIN (R)	570 570	98.8
L1 3 PIN (L) L1 3 NO-PIN (R)	570 570	98.4	L2 3 PIN (L) L2 3 NO-PIN (R)	570 570	98.8
L1 4 PIN (L) L1 4 NO-PIN (R)	570 570	98.5	L2 4 PIN (L) L2 4 NO-PIN (R)	570 570	98.0
L1 5 PIN (L) L1 5 NO-PIN (R)	570 570	95.0	L2 5 PIN (L) L2 5 NO-PIN (R)	570 570	96.4
L3 1 PIN (L) L3 1 NO-PIN (R)	570 570	98.0	L4 1 PIN (L) L4 1 NO-PIN (R)	570 570	91.4
L3 2 PIN (L) L3 2 NO-PIN (R)	530 570	88.8	L4 2 PIN (L) L4 2 NO-PIN (R)	560 570	95.4
L3 3 PIN (L) L3 3 NO-PIN (R)	570 570	97.4	L4 3 PIN (L) L4 3 NO-PIN (R)	570 570	95.9
L3 4 PIN (L) L3 4 NO-PIN (R)	570 570	94.2	L4 4 PIN (L) L4 4 NO-PIN (R)	570 570	97.2
L3 5 PIN (L) L3 5 NO-PIN (R)	570 570	97.5	L4 5 PIN (L) L4 5 NO-PIN (R)	570 570	95.5
Module area at 570 V: 96.1 %			Mean efficiency = 96.5 %		
Total module bad sectors (HV < 550 V): 1 (2.5 %)			Mean efficiency without bad PCBs (1) = 96.9 %		

HV picture of oldA13 under binary and ternary gas mixture:

Ar:CO_2 93:7 vol%
nom. HV: 570 V

Ar:CO_2:iC_4H_{10} 93:5:2 vol%
HV: 500 V



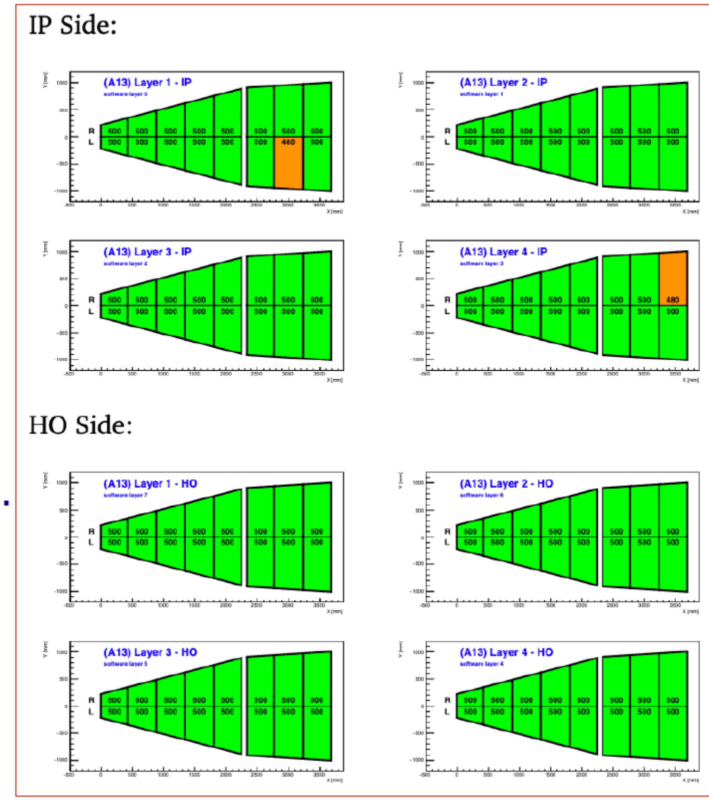
green:
sector is on nominal HV

red:
sector is below nominal HV

-2% of CO2

+2% of Isob.

non-burning
non-explosive
gas-mixture

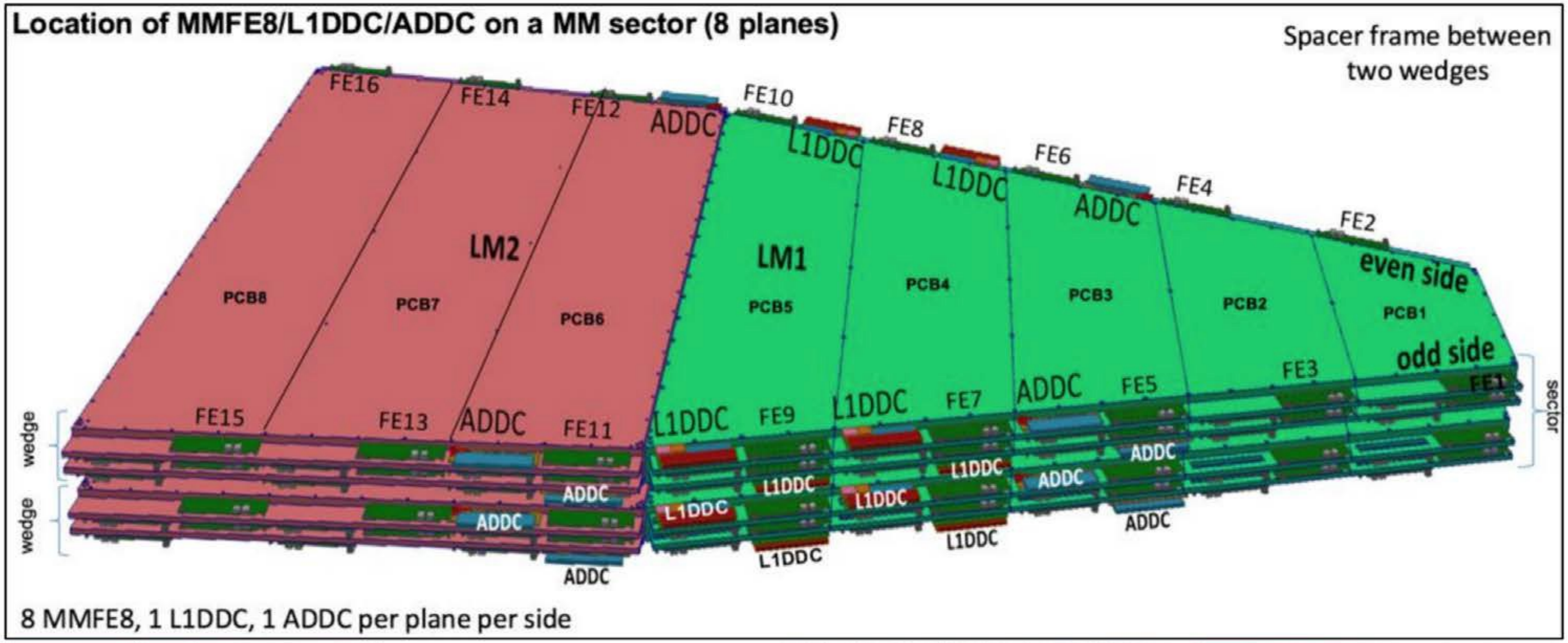


insufficient performance

almost perfect performance
similar efficiency @ cosmics

substantial improvement of the performance of DW A13 using Ar:CO2:iso 93:5:2 vol%

MMG Front-end Electronics



Introduction: NSW Electronics