Performance studies of Micromegas detectors in ATLAS with Run3 data

XII International Conference on New Frontiers in Physics, Crete

Paolo Massarotti on behalf of the **ATLAS Muon Spectrometer System**

Outline

- ✓ Introduction to the New Small Wheels detector of ATLAS
- ✓ MicroMegas (MM) performances
- ✓ Conclusions

Follow the next talk about the NSW of the Muon spectrometer of ATLAS:

Performances of the small-strip Thin Gap Chambers (sTGC's) in the New Small Wheels of ATLAS , Sonia Kabana

LHC upgrades

LHC two major upgrades to increase the luminosity:

- **LS2: L ≳ 2x10^{34} cm^{-2}s^{-1}, Lint ~350 fb^{-1}** (about 55 p+p interactions per bunch crossing)
- **LS3: L ~ 5-7x10^{34} cm^{-2}s^{-1}, final integrated luminosity: ~3000 fb^{-1}** (about 140-200 p+p interactions per bunch crossing

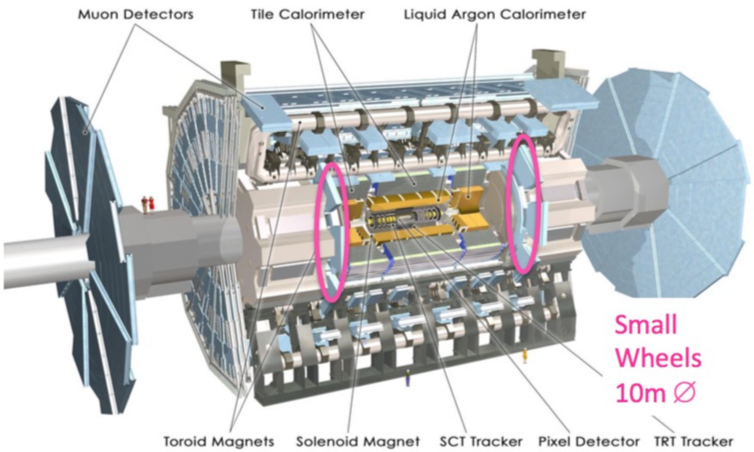
All experiments must also be upgraded to cope with the increased rate of events

The New Small Wheel Project

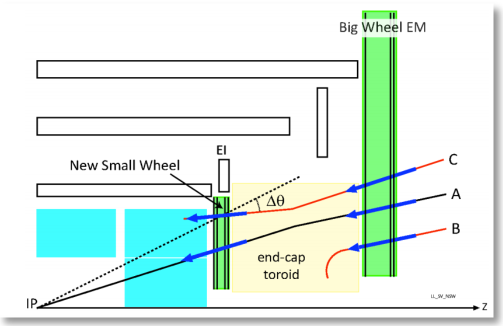
ATLAS Muon New Small Wheel (NSW) Upgrade to cope with the increasing background particle flux (pileup) as the luminosity increases :

- Replace the Small Whells, the innermost Muon station in the forward region **improving L1 trigger & maintain good tracking performances at End-cap** (HL-LHC runs with high background rates, up to 20 kHz/cm^2)
- Detector area: ~2400 m^2
- Higher channel granularity (**25x** old SW): MM: ~ 2.1 M, sTGC: ~ 280 k (strip) + 46 k (pads) + 28 k (wires) pics
- **Requirements**
  - **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%
  - segments measurements with up to 1 mrad pointing accuracy (Phase-II requirement)

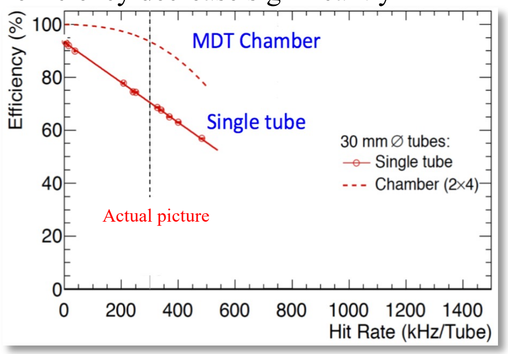
Both technologies provide precision trigger and tracking for muons in the ATLAS forward region.



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

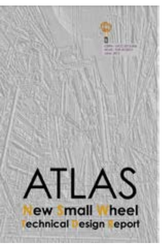


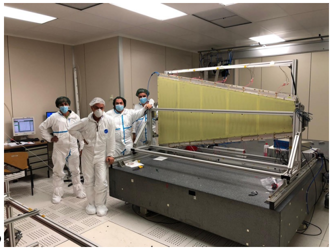
HL-LHC: (MDT) expected frequency > 500 kHz / tube
-> efficiency decrease significantly



Roadmap

ATLAS TDR



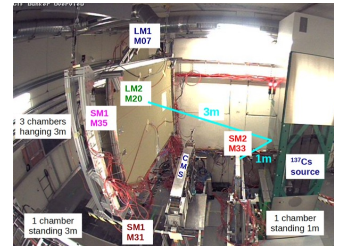


Module production
2018-2020

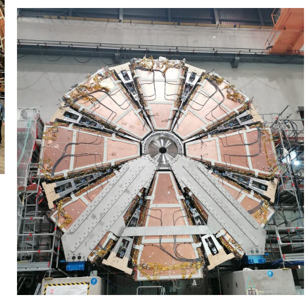
Integration at
CERN
2019-2021

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

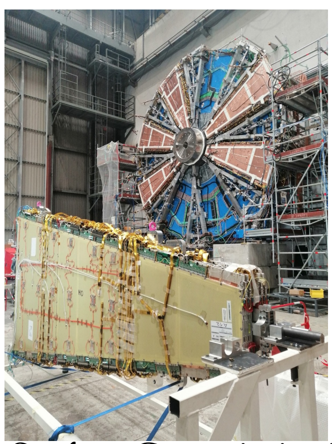
2019

2020

2021

2023

1° sector on the Wheel
12/2019

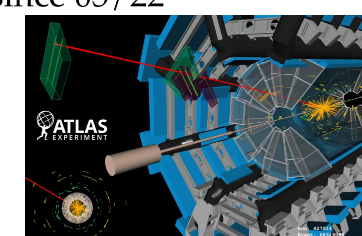


Surface Commissioning
2019-2021

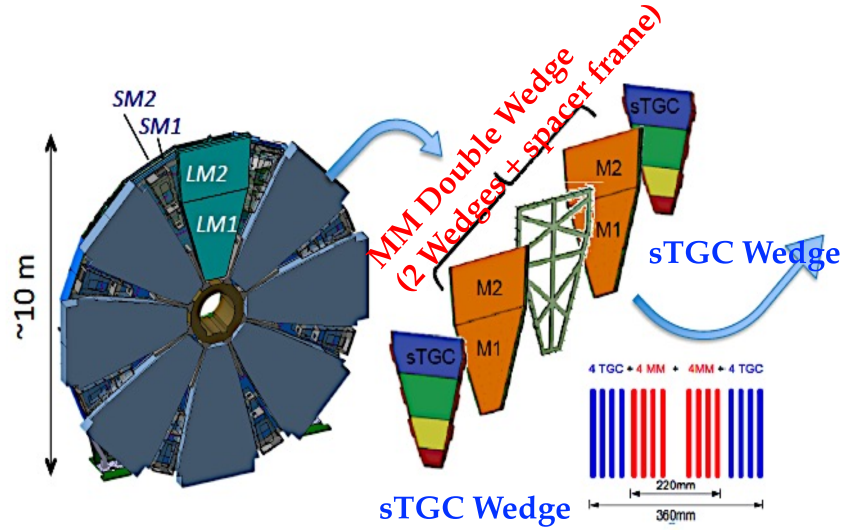
NSW A to the cavern
12/07/21

NSW C to the cavern

NSWs Running in ATLAS
since 05/22



The MicroMegas detectors within the ATLAS NSW



Each of the 16 NSW sectors is made by:

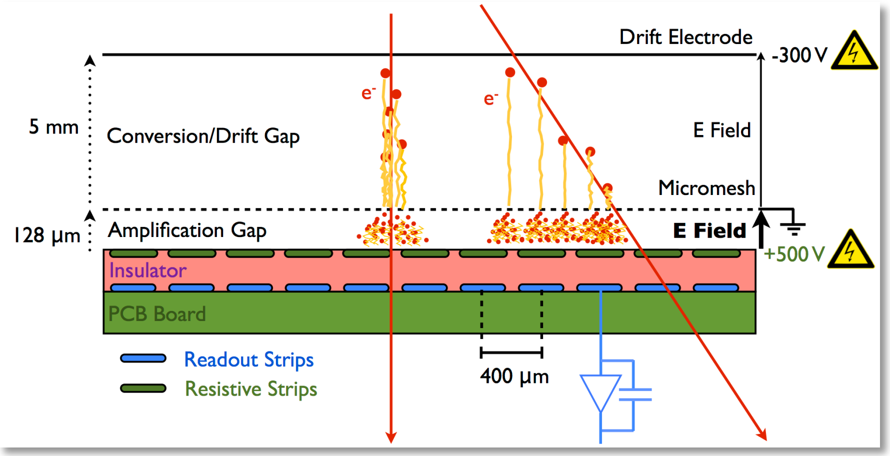
- **1 MM Double Wedge**
- **2 sTGC Wedges**

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

MM detectors were build for the first time on O(m²) dimensions!

Features specific to ATLAS MicroMegas:

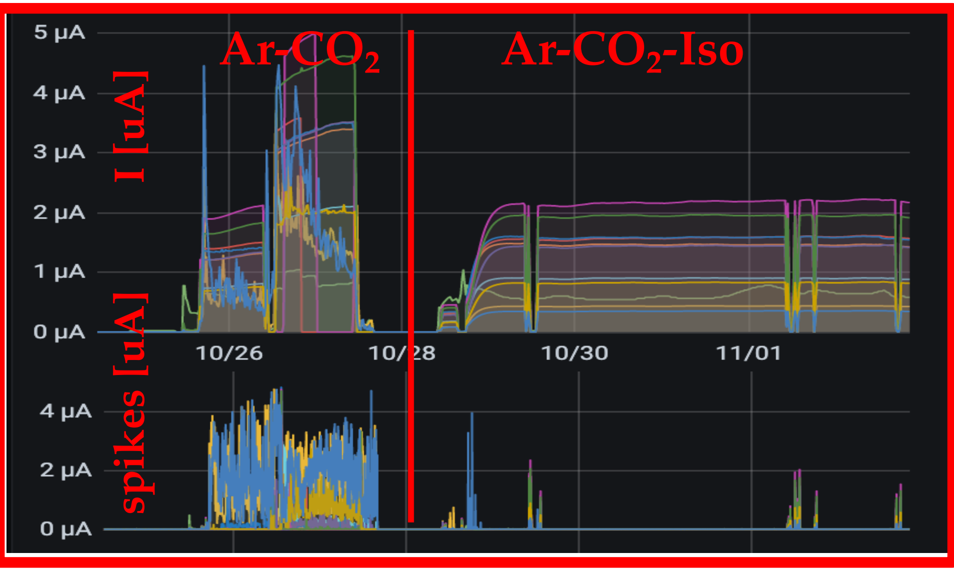
- Mesh integrated in the drift panel structure and not embedded in the anodic structure
  - necessary for large area detectors
  - the chamber can be re-opened for intervention
- Mesh at ground potential
  - easier construction procedure
  - allows separation of RO boards in independent HV sectors
- Resistive strips 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



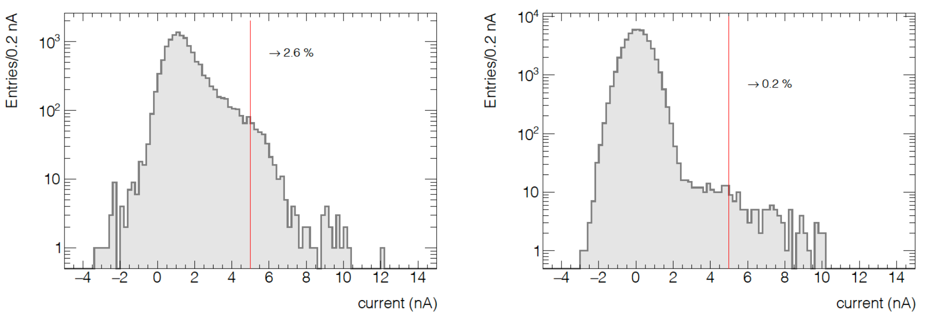
Isobuthane enriched gas mixture

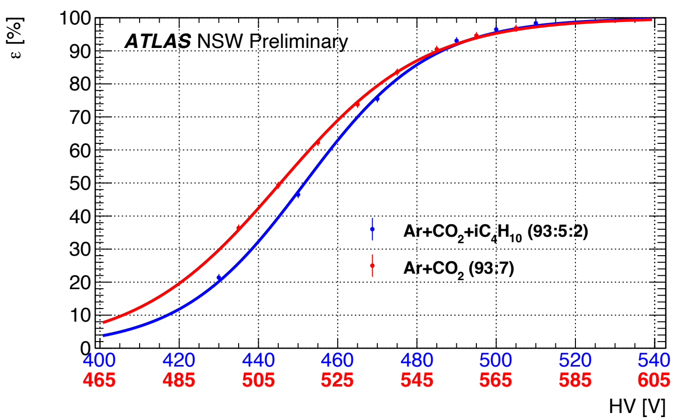
Adding stronger quencher: ternary gas mixture (Ar-CO_2-Iso 93-5-2):

- **Allow for operation stability and reduce sparking rate**
- Reducing operating voltage by 55 V



Good HV sections





Residual HV issues

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

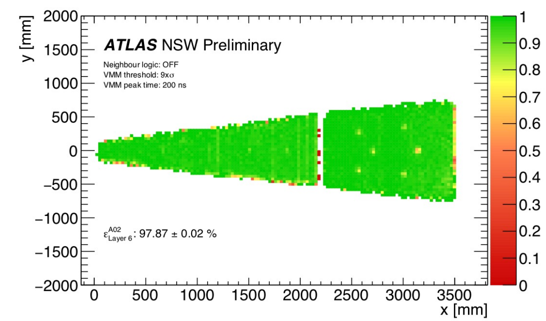
using self-tracking technique we achieved efficiencies at the level of 98%

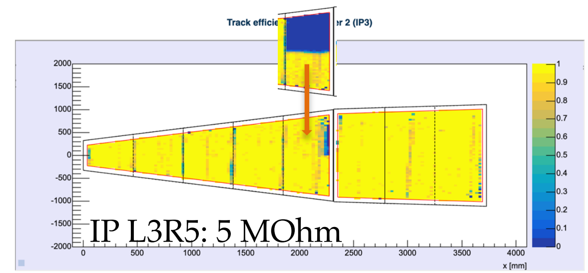
Still few % of weak HV channels

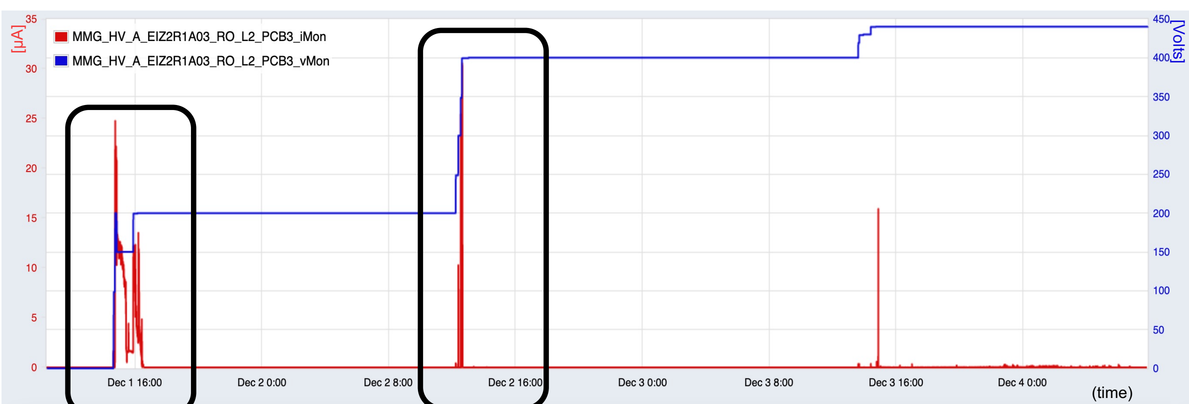
- **Resistive pcbs -> high stable currents coherent with an equivalent resistor in the amplification gap of 5-10 MOhm** -> known weak point of the pcbs
    - Instead of having not working sections we only loose few cm
    - Resistive layout allows for Voltage drop only on small region
    - About 4% of the RO channels
- **Curing: pure Argon to clean the region by means of sparks**

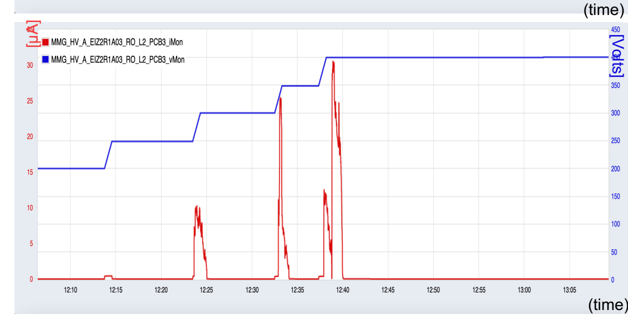
  Standard procedure during shutdown period

  50% successful treatments -> now channels reaching nominal HV



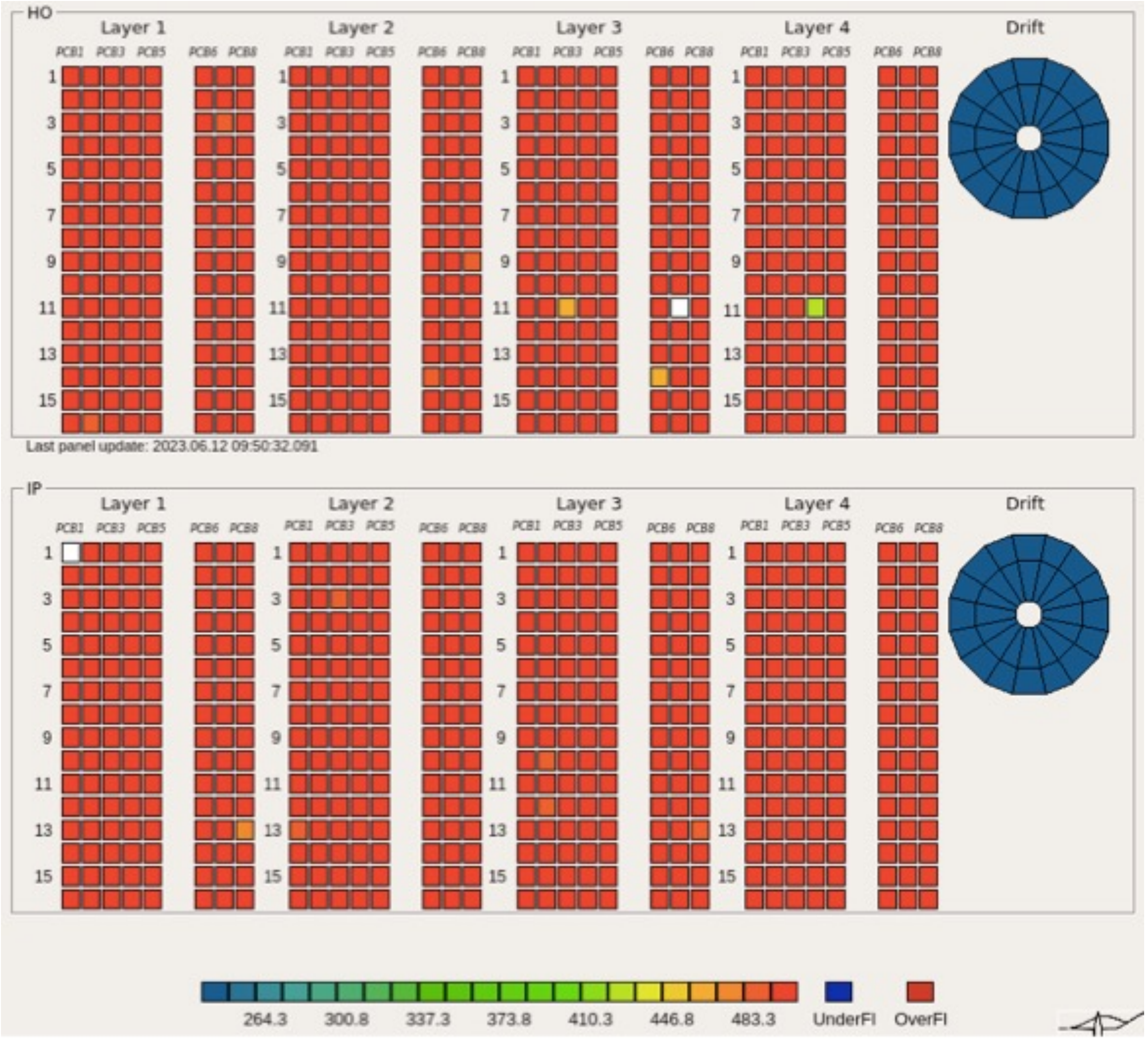






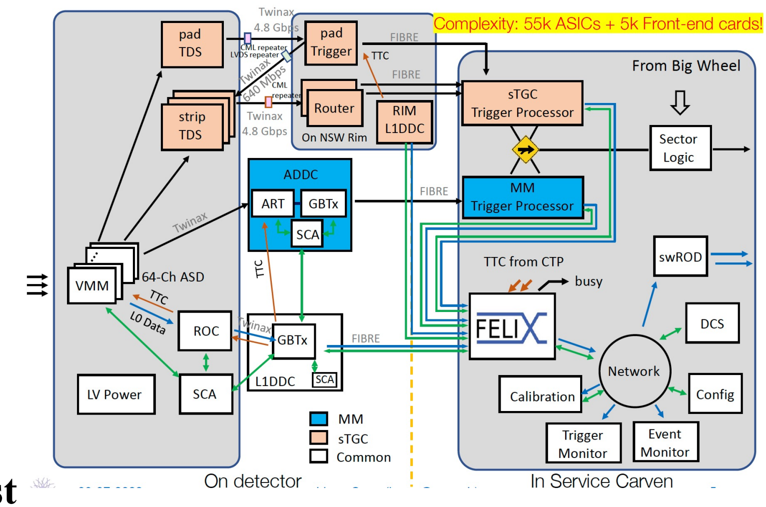
NSWs in ATLAS: HV status

Operating voltage: 505 V; few unstable channels: margin to push amplification higher
1.5% HV channels disconnected or disabled (including 1 drift channel)



NSWs in ATLAS: TDAQ

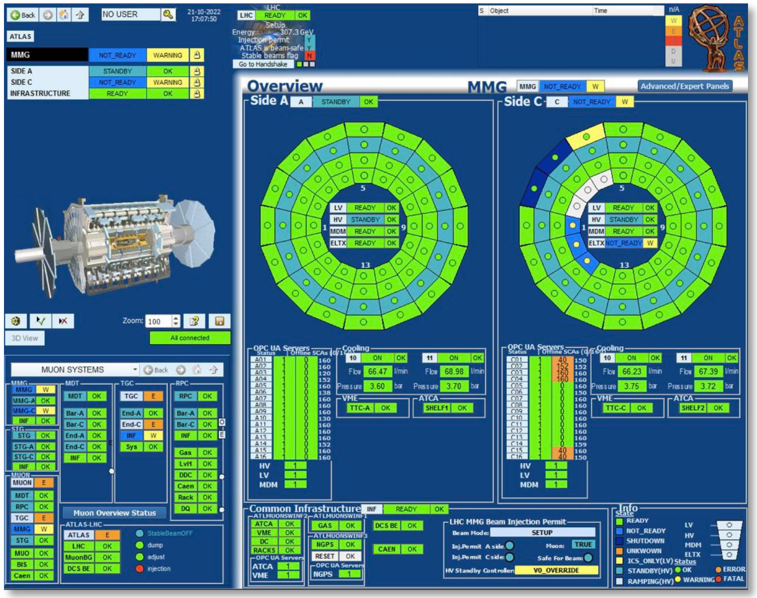
NSWs successfully integrated into the ATLAS Muon Central DCS and in the ATLAS TDAQ!



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.

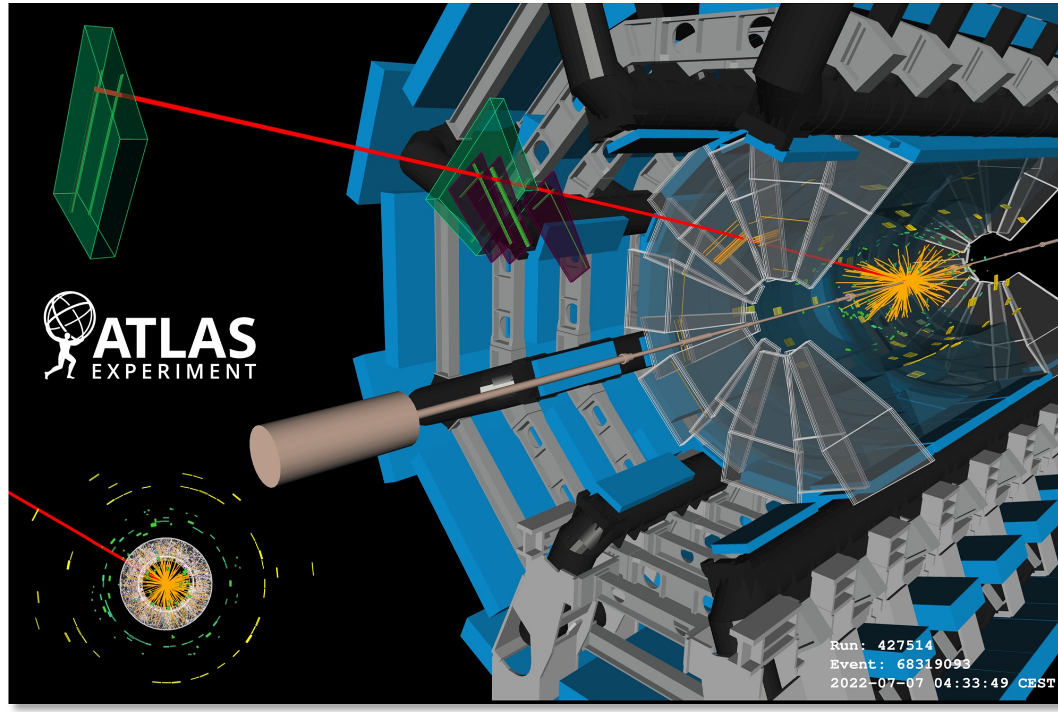


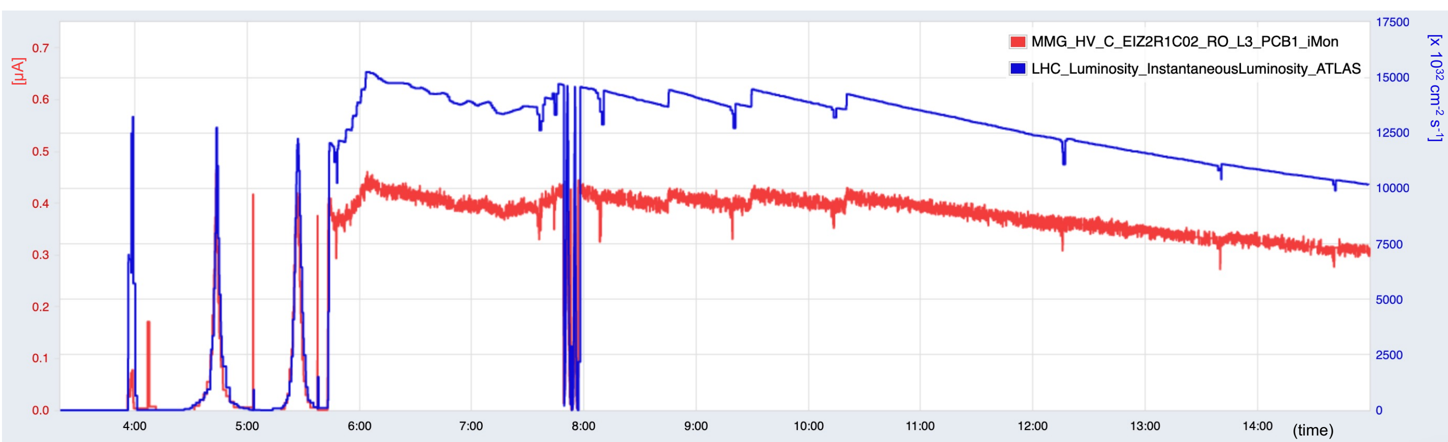
Situation continuously improving!

NSWs in ATLAS

ATLAS Early Run 3 started on 5 July 2022!

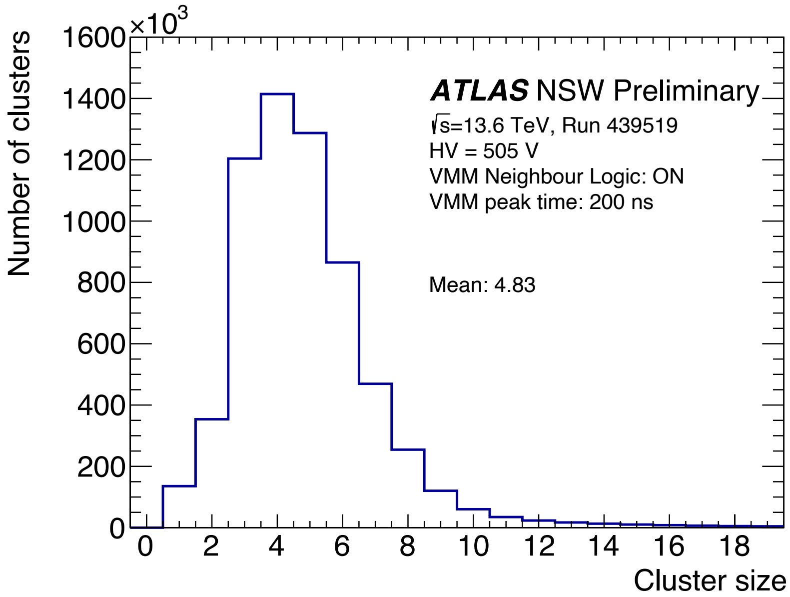
Currents of MM detectors are following the LHC Istantaneous Luminosity amazingly!

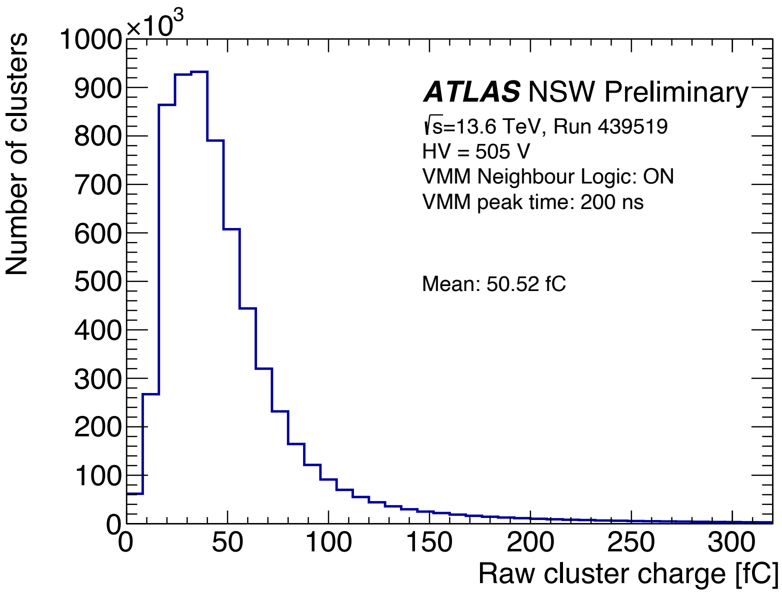




MM performances: number of cluster and cluster size (2022 data)

- Muons reconstructed by the Inner Detector + Muon Spectrometer traversing the 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.





MM performances: cluster size and single layer efficiency vs HV (2022 data)

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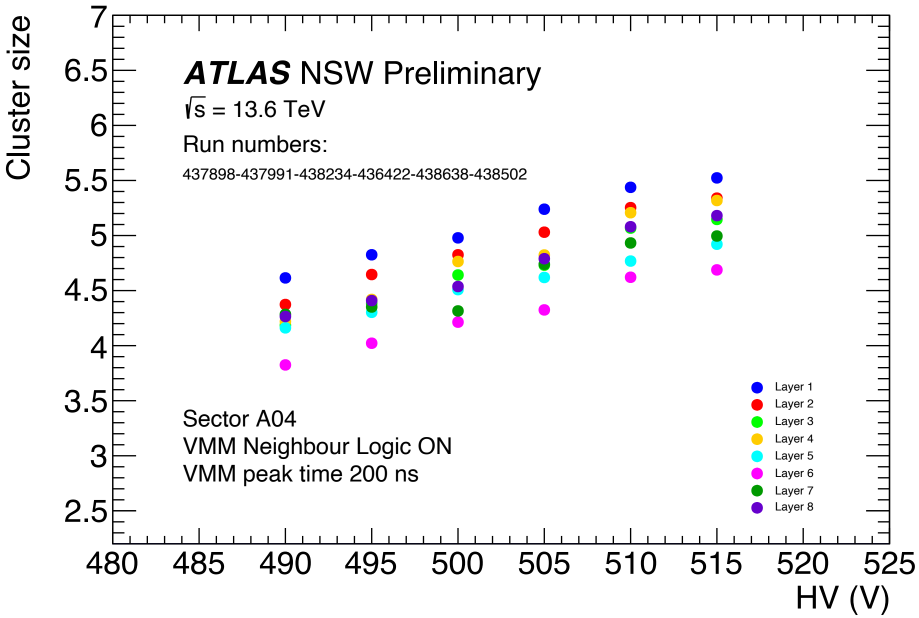
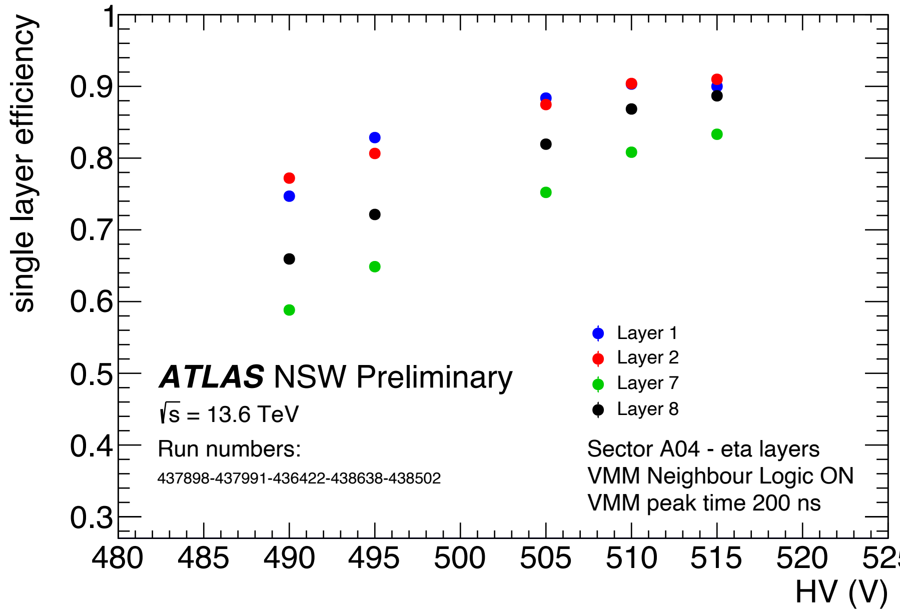
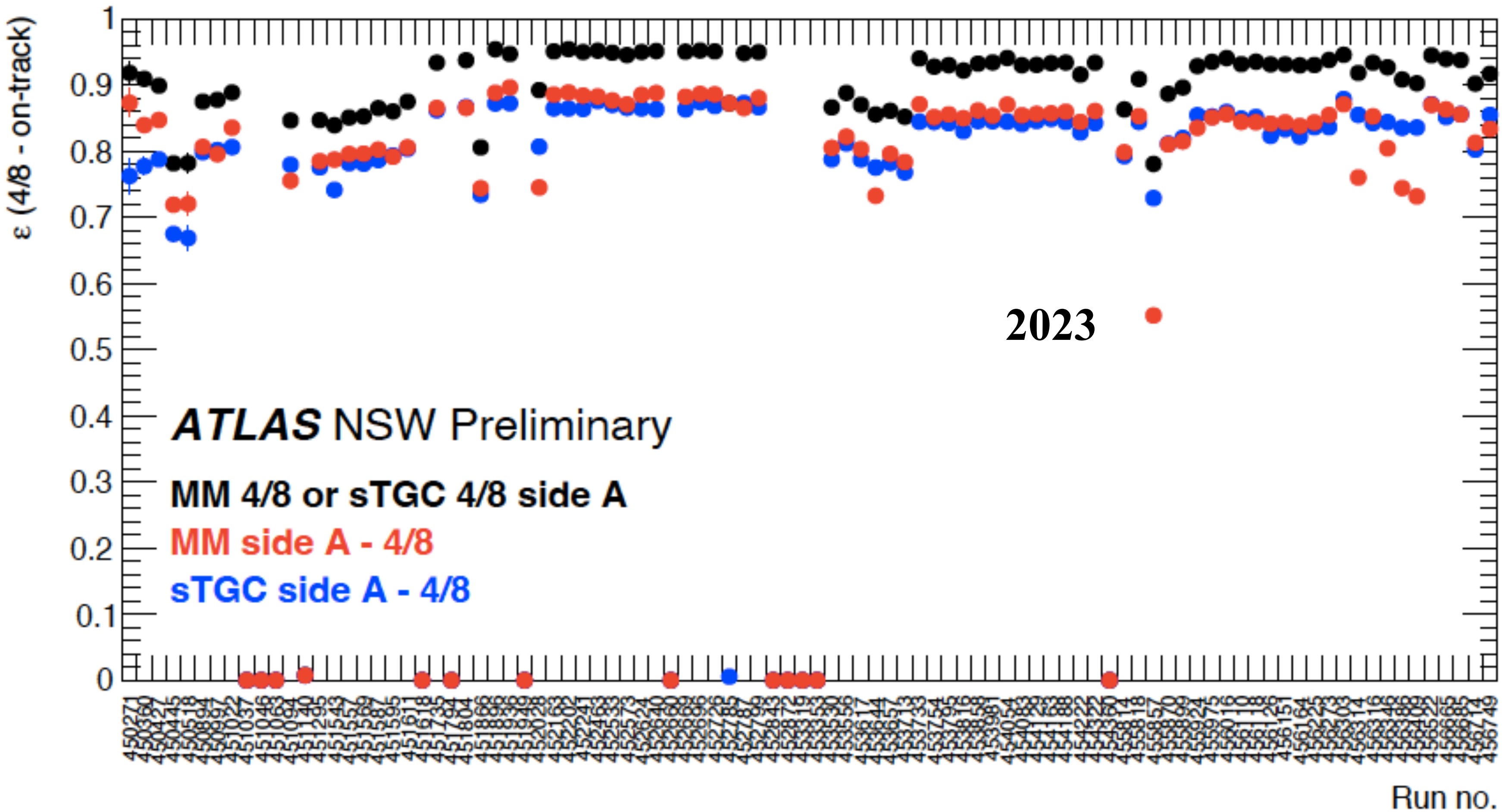
- Performances of the MM layers are studied in terms of **number of clusters, cluster dimensions and efficiencies as a function of the HV applied** to the anode in a spatial window of 5mm wrt the reconstructed track.
- **HV scan of cluster size and single layer efficiency (2022 data)**





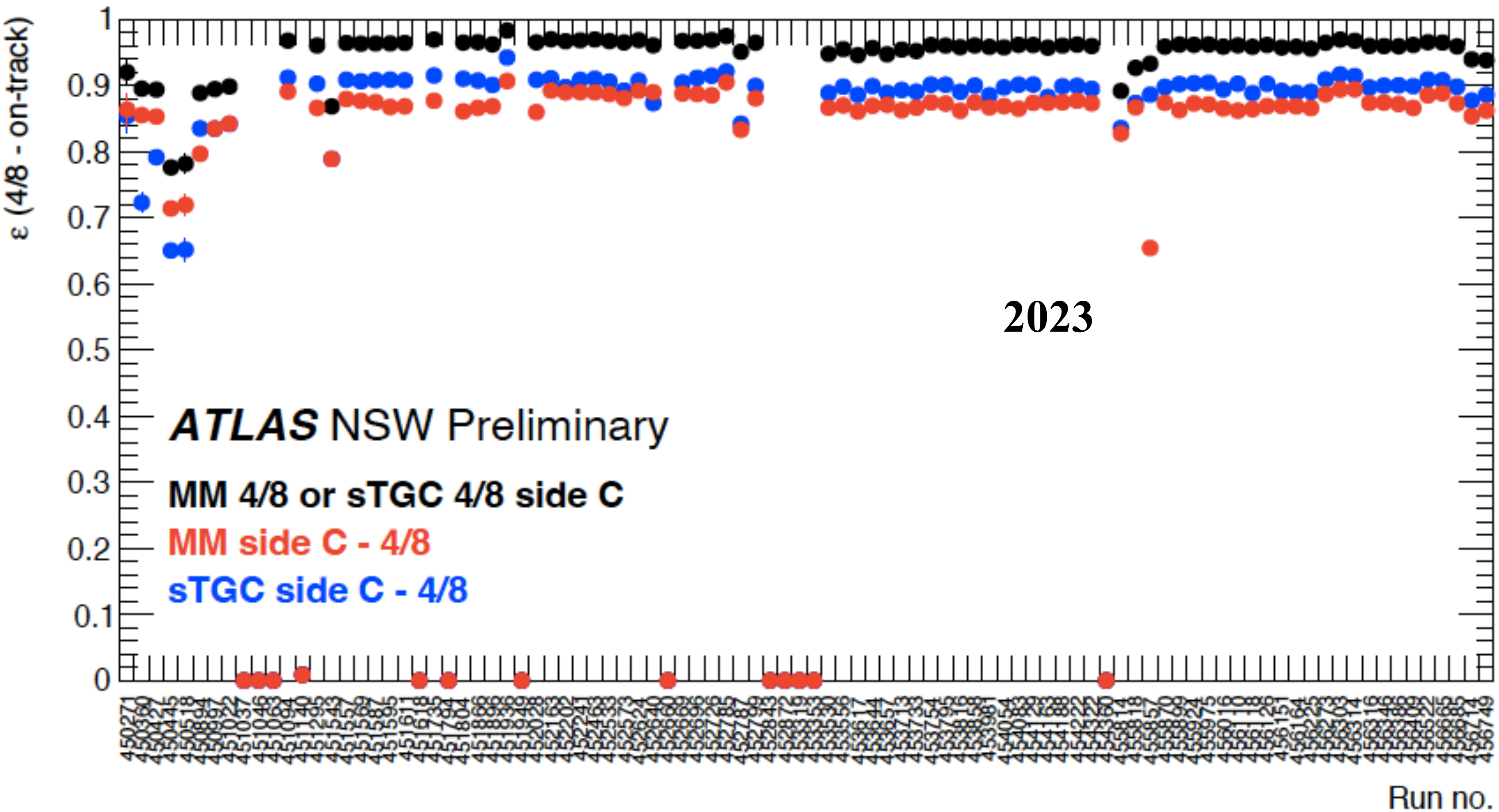
Reconstruction efficiency measured in p+p collisions at 13.6 TeV: Wheel A

Reconstruction efficiency for having at least four out of eight layers for MMG only, STG only, MMG+STG vs Run#, inclusive of all inefficiencies (detector, HW, DAQ)
Only combined or standalone muon tracks with a reconstructed p_T >15 GeV

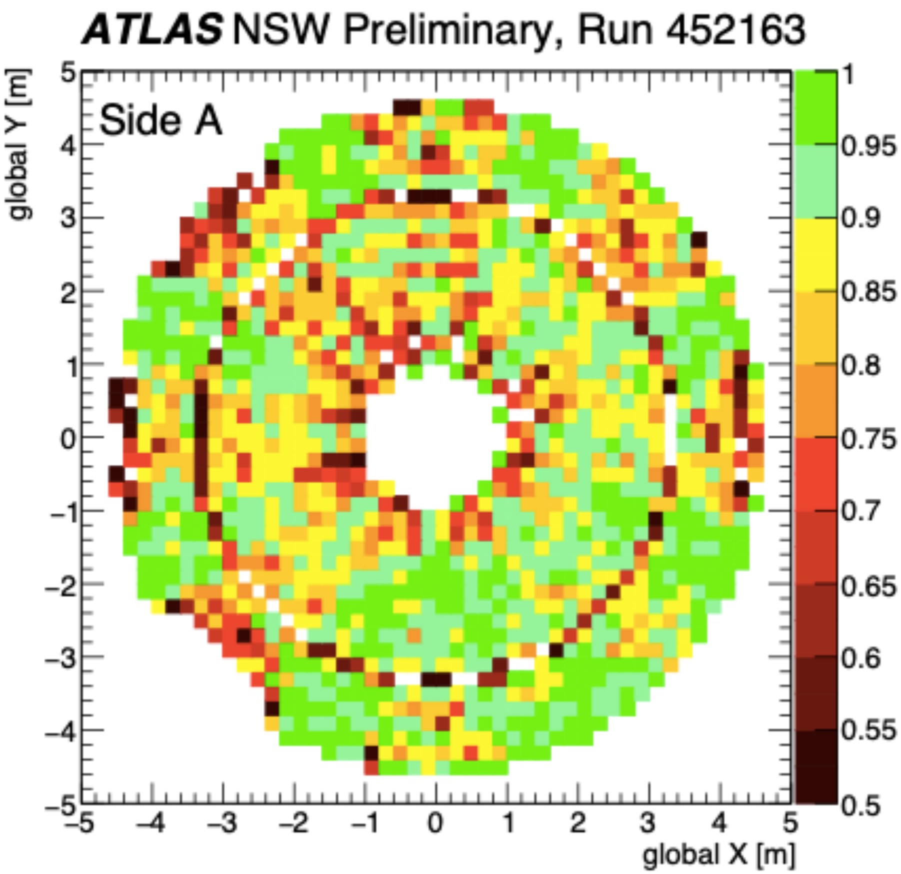


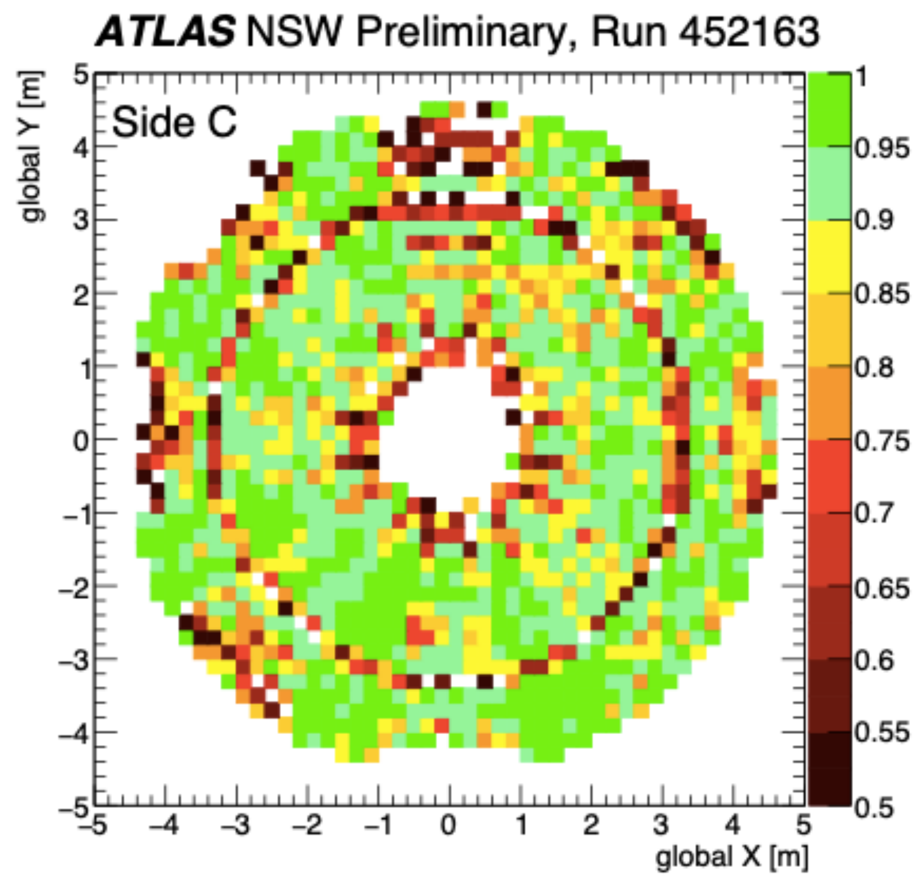
Reconstruction efficiency measured in p+p collisions at 13.6 TeV: Wheel C

Reconstruction efficiency for having at least four out of eight layers for MMG only, STG only, MMG+STG vs Run#, inclusive of all inefficiencies (detector, HW, DAQ)
Only combined or standalone muon tracks with a reconstructed p_T >15 GeV



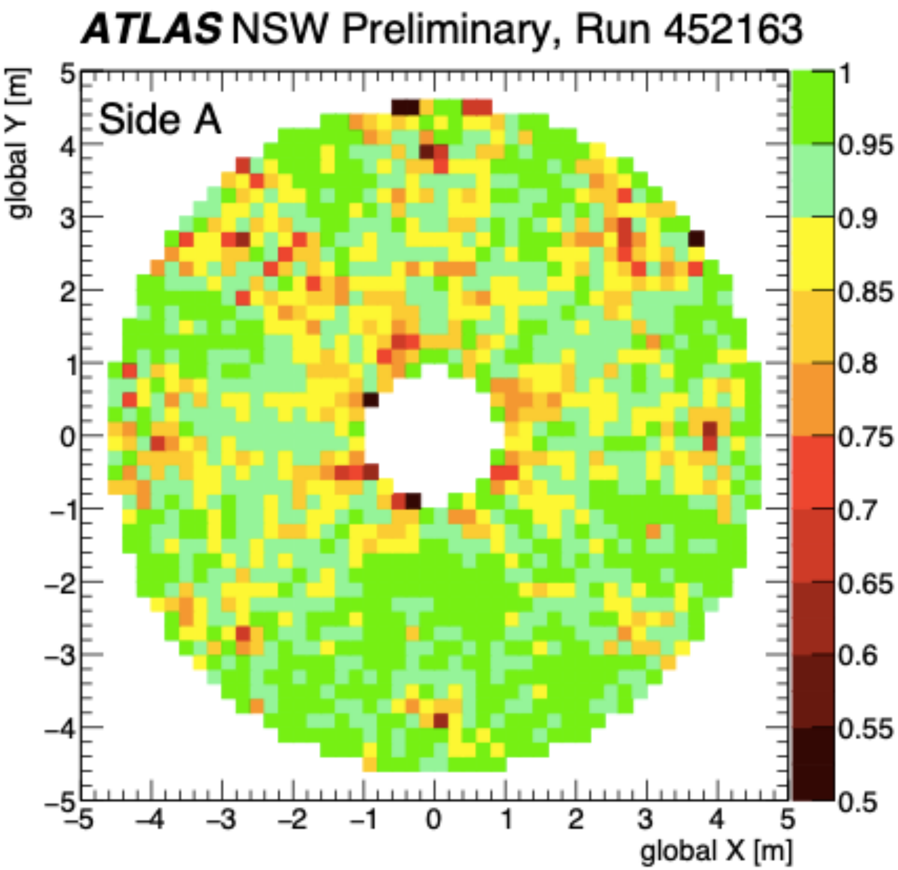
MM efficiency measured in p+p collisions at 13.6 TeV

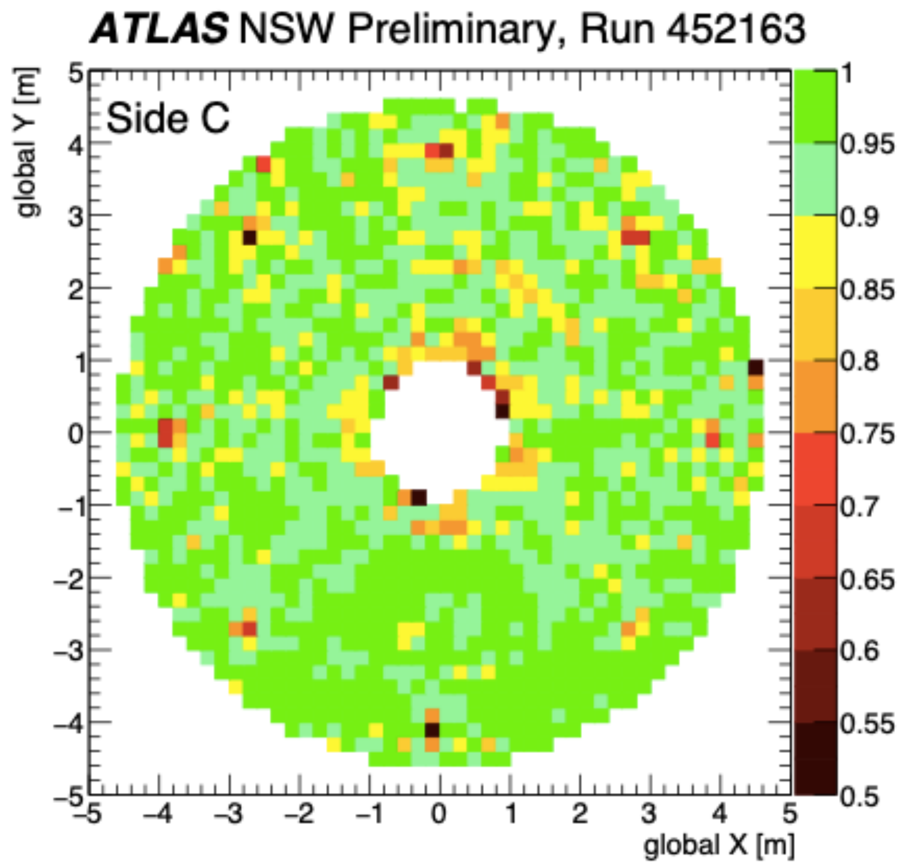




Efficiency for having at least four out of eight layers MM associated to a muon track.
Regions of low efficiency can be explained by detector or readout issues at the time of data taking
Only combined or standalone muon tracks with a reconstructed p_T >15 GeV

NSWS efficiency measured in p+p collisions at 13.6 TeV

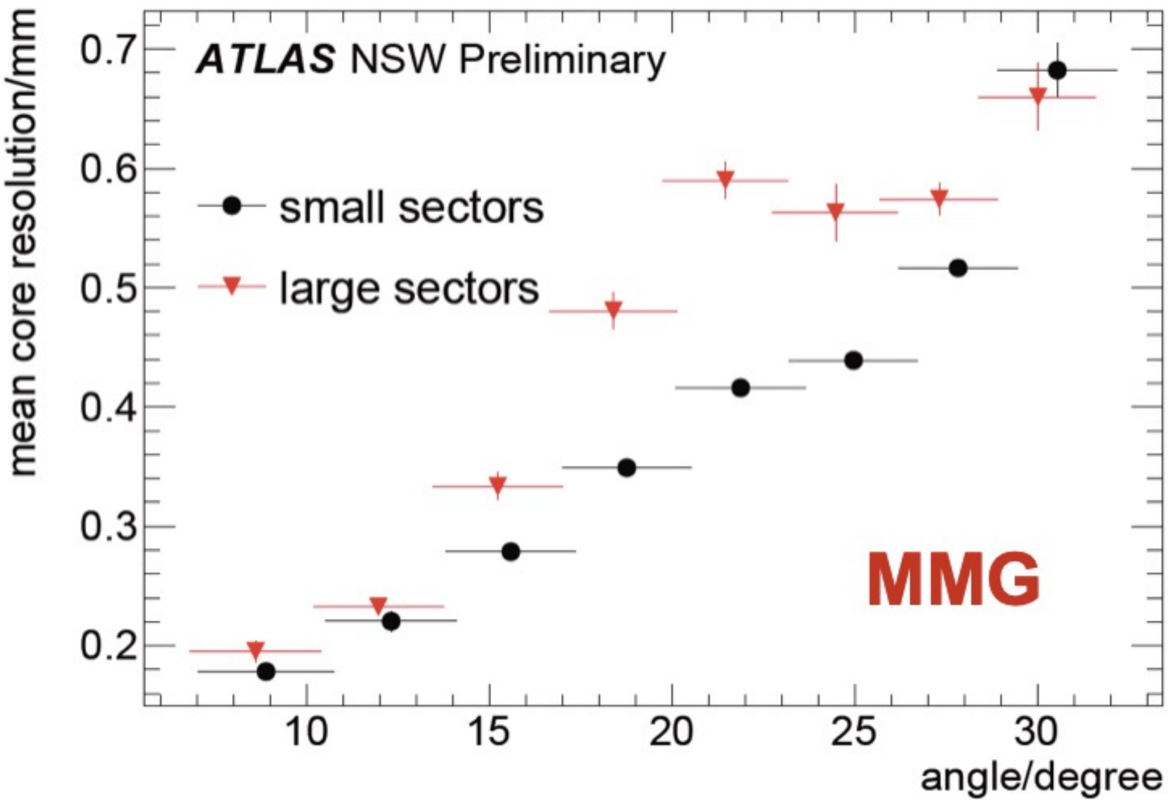




Efficiency for having at least four out of eight layers of either Micromegas or sTGC strip associated to a muon track. This plot indicates the efficiency with which the NSW is contributing to the muon track reconstruction in ATLAS. Regions of low efficiency can be explained by detector or readout issues at the time of data taking

Only combined or standalone muon tracks with a reconstructed p_T >15 GeV

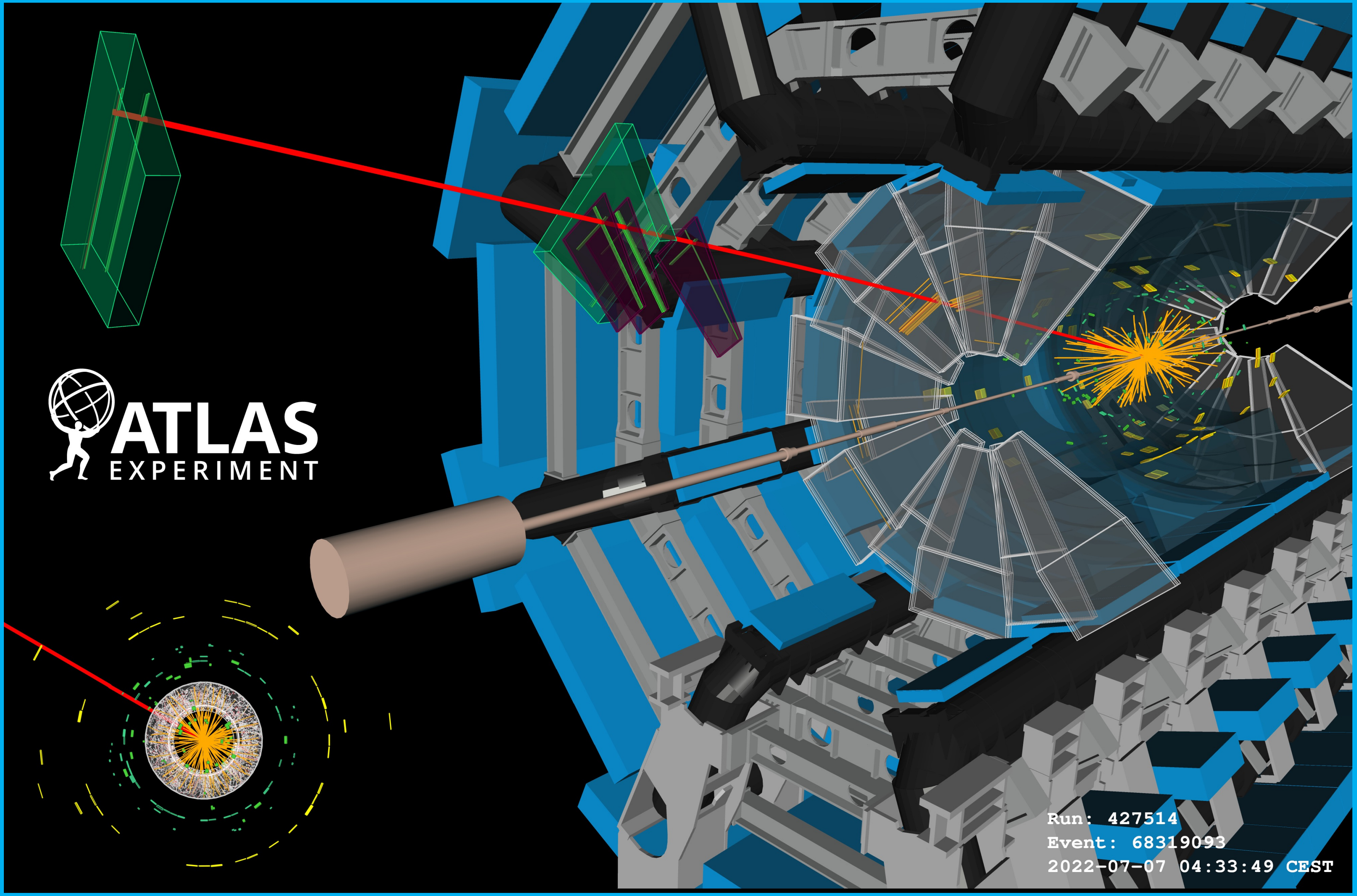
MM resolution measured in p+p collisions at 13.6 TeV (2022 data)



MM resolution as a function of angle θ, for muon tracks with a reconstructed $p_T > 15$ GeV
Cluster centroid method in agreement with expectation of simulation.
Improvements from μTPC (precise calibration and time alignment needed)

Conclusion

- The New Small Wheel upgrade was the **largest ATLAS phase-I upgrade project**
- The NSWs is running and took **first data** from p+p collisions in the begin of **Run3 in May 2022**
- NSW integrated in the ATLAS Trigger (sTGC only)
- Intense and continuous efforts to understand and **improve the performance of the system**
- **Preliminary performances satisfactory!**


ATLAS
EXPERIMENT
Run: 427514
Event: 68319093
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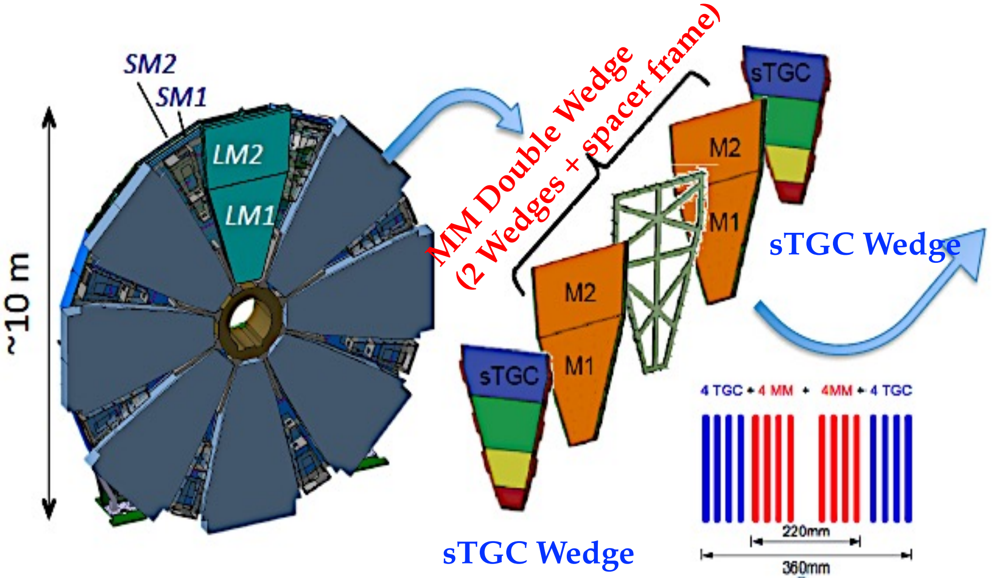
New Small Wheel layout



Each of the 16 NSW sectors is made by:

- 1 MM Double Wedge
- 2 sTGC Wedges

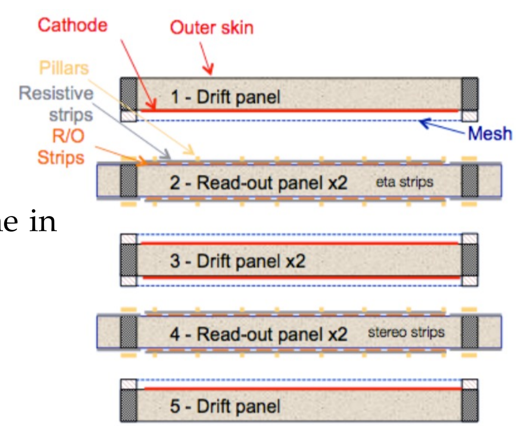
Each wedge (MM and sTGC) is a detector quadruplet.

MM detectors were build for the first time on $O(m^2)$ dimensions!

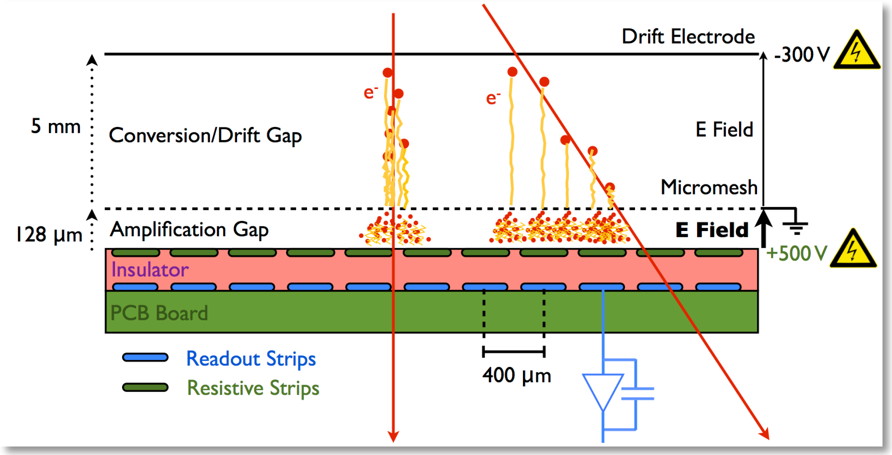
MM quadruplet:

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
- ✓ 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



Features specific to ATLAS MM:

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  - necessary for large area detectors
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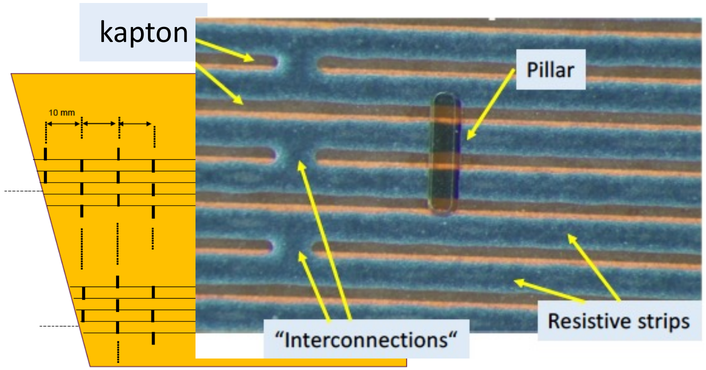
- Mesh at ground potential
  - easier construction procedure
  - allows separation of RO boards in independent HV sectors
- Resistive strips are overlayed to copper signal strips
  - reduction of local current and of risk of discharges
  - resistive layout (screen printing technique) with equidistant interconnections to have uniform resistance across the pcb

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



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
- Possible effects from **mesh mechanical imperfections**

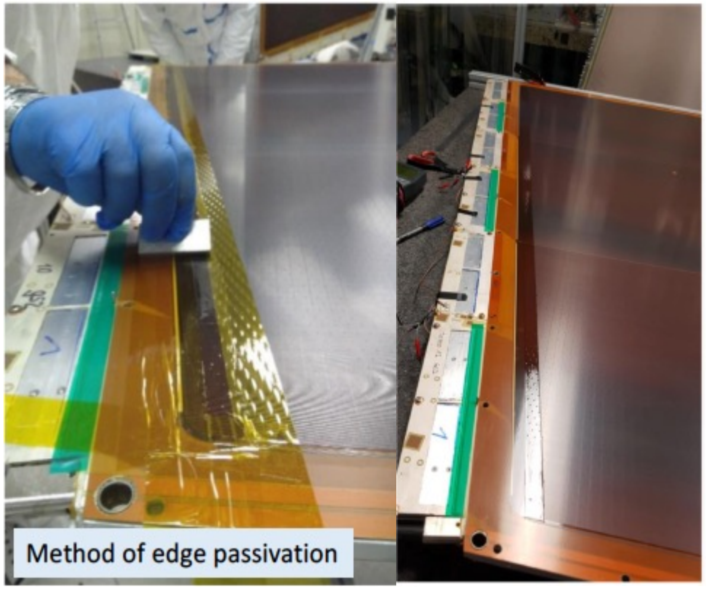
  Clear **correlation of currents with humidity**

Solutions

✓ **improve the cleaning procedures**

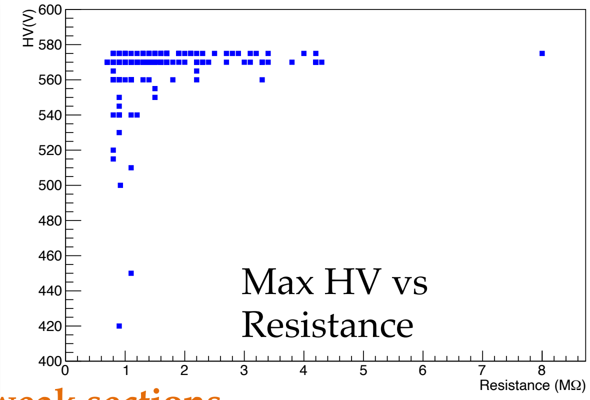
✓ **implement mesh polishing**

✓ **incerase flux and monitor humidity**



Low resistance of resistive layer:

- marginal resistivity of the foils (resistivity dependance on batches)
- strong dependence on the layout (design issue)
- **Clear correlation between HV bad sectors and R_{min}!**

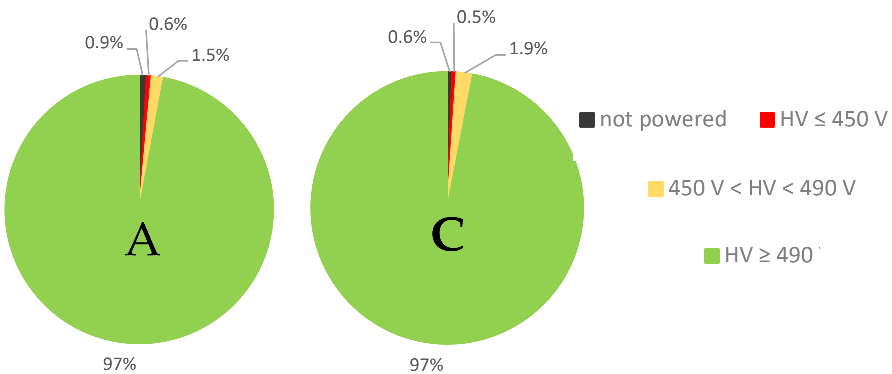


Solutions

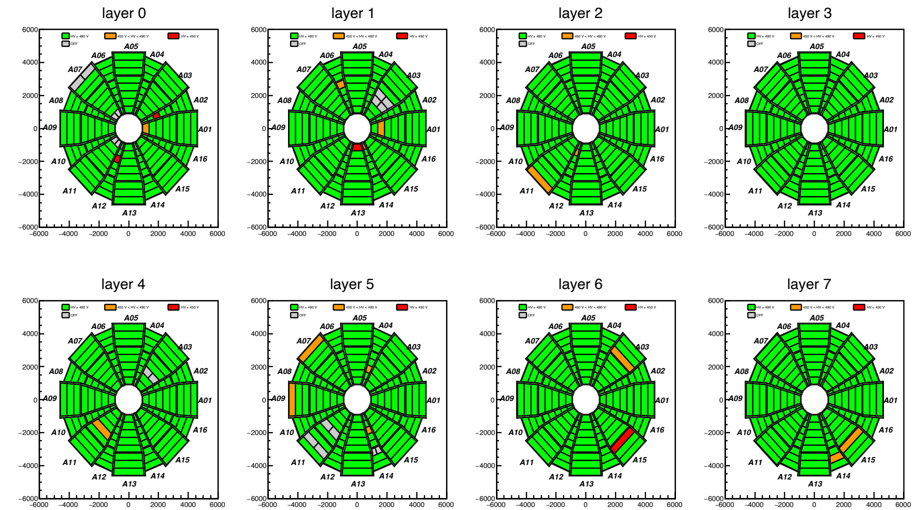
✓ **edge passivation**

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

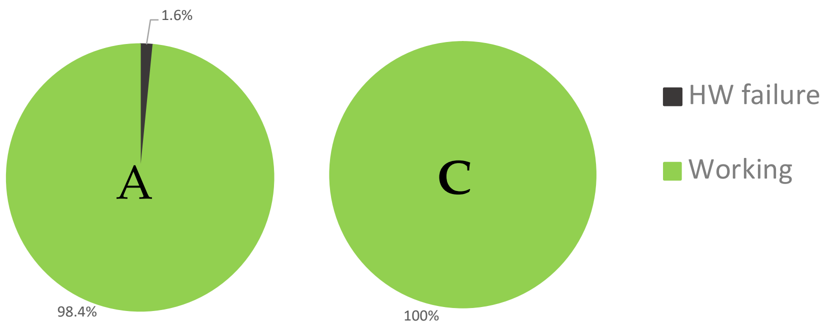
NSWs in ATLAS: HV status



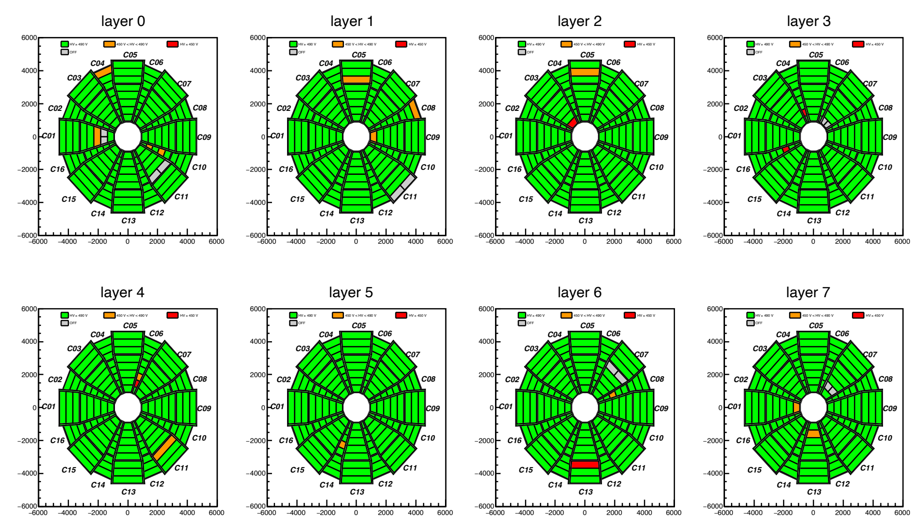
A: **HV pcb by pcb**



1 Drifts not working



C: **HV pcb by pcb**



Hardware failure for Elex Low Voltage **(11 channels)** known issues

NSWs in ATLAS: DCS

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

- Integration in the ATLAS TDAQ partition since May:

  from a few sectors to entire wheels
- **5/Jul -> Early Run3 started!** NSW have been joining the ATLAS data taking with nice results!

GIF++ long term studies

^{137}CS 662 keV Gammas 14 TBq: 15 kHz/cm^2 at 3m distance