Performance studies of Micromegas detectors in ATLAS with Run3 data

Giada Mancini on behalf of the ATLAS Muon Spectrometer System

Outline

- MicroMegas for the ATLAS Upgrade of the New Small Wheels
- NSW running status
- Preliminary performances results

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)

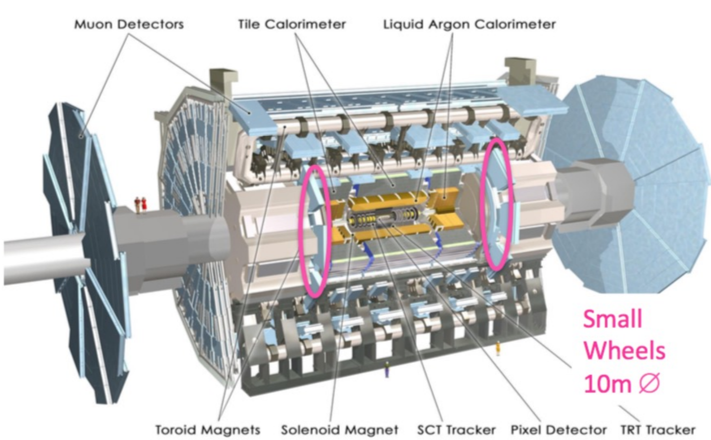
All experiments must also be upgraded to cope with the increased rate of events

Introduction

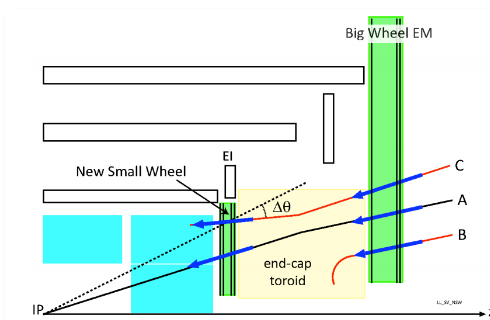
ATLAS Muon New Small Wheel (NSW) Upgrade to cope with the increasing background particle flux (pileup) as the luminosity increases :

- Replace the Small Wheels, 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
  - **~100 μm spatial resolution per detector plane** with single layer efficiency > 90%
  - **segments measurements with up to 1 mrad pointing accuracy** (Phase-II requirement)

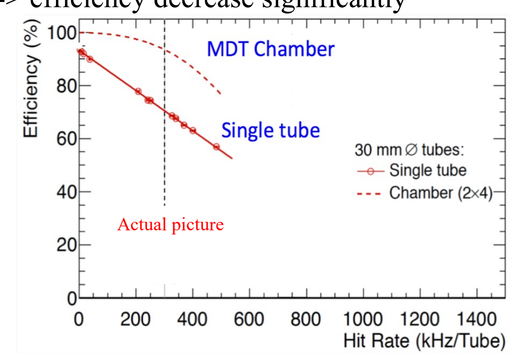
Two technologies (MM + sTGC) for precision trigger and tracking of muons in ATLAS forward region



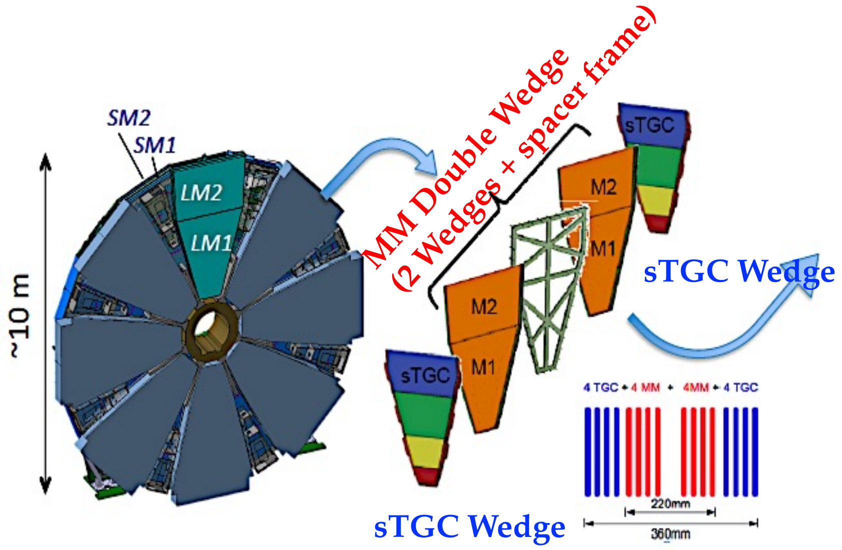
Level 1 End-Cap trigger, dominated by fake trigger events (type B e C)



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



MM detectors in the ATLAS NSW



Each of the 16 NSW sectors is made by:

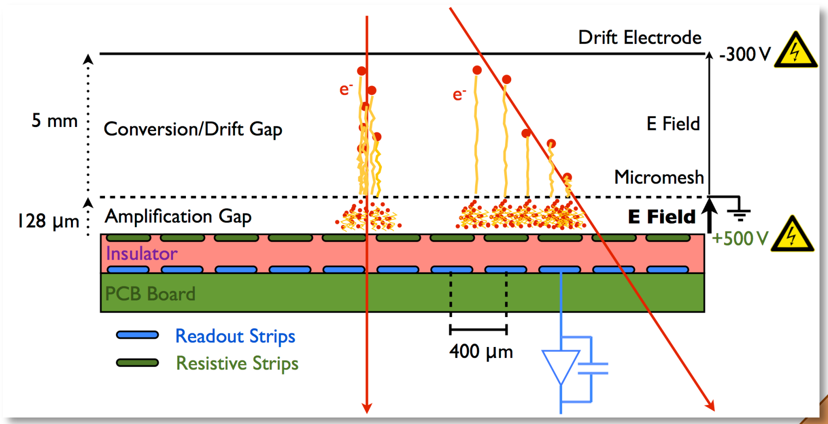
- **1 MM Double Wedge**
- **2 sTGC Wedges**

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, chamber can be re-opened for intervention
- Mesh at ground potential
  - easier construction, allows for 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 interconnections to have uniform resistance on the pcb

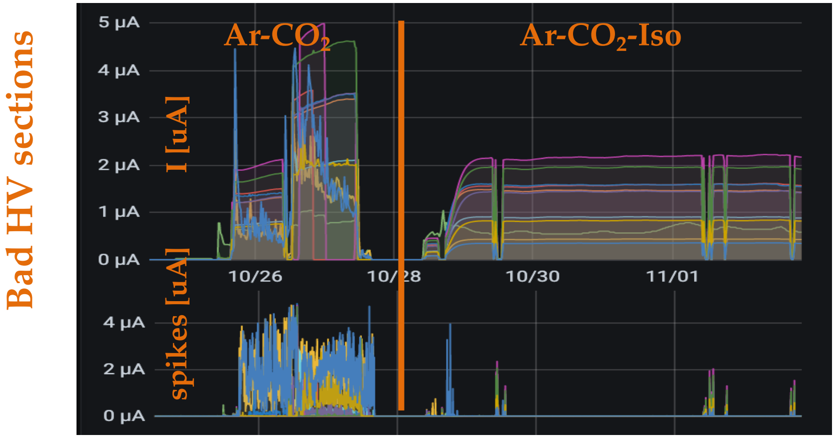


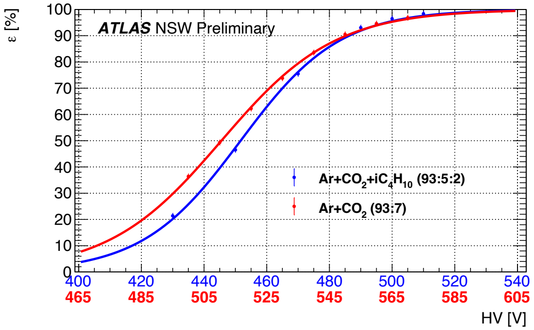
On HV stability

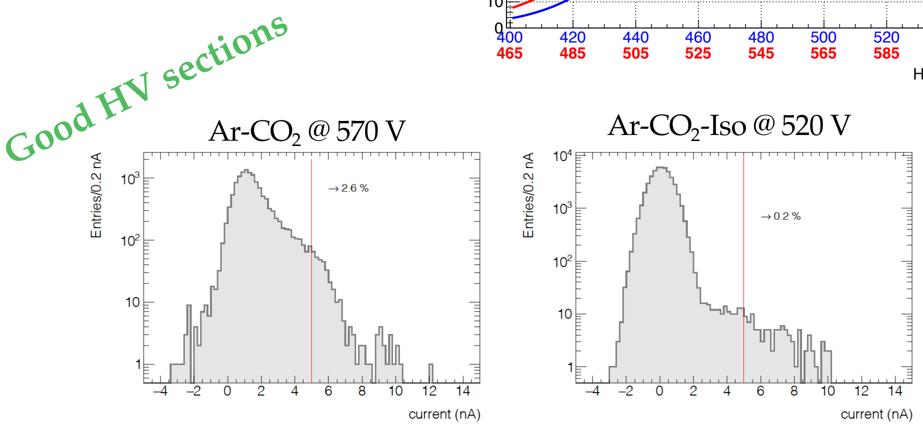
- **Adding stronger quencher: ternary gas mixture (Ar-CO_2-Iso 93-5-2):**

  Allow for operation stability and reduce sparking rate

  Reducing operating voltage by 55 V



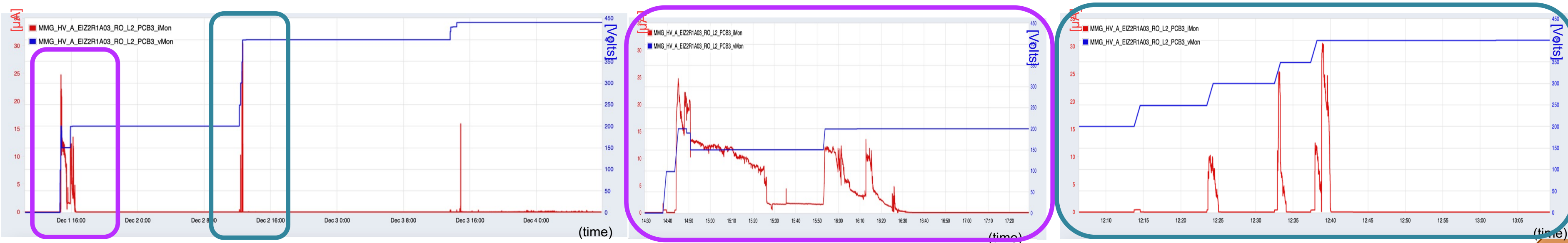




- **Curing with pure Argon to clean the region by means of sparks**

  Standard procedure during shutdown period

  ~ 50% successful treatments -> now channels reaching at nominal HV



NSWs status in ATLAS

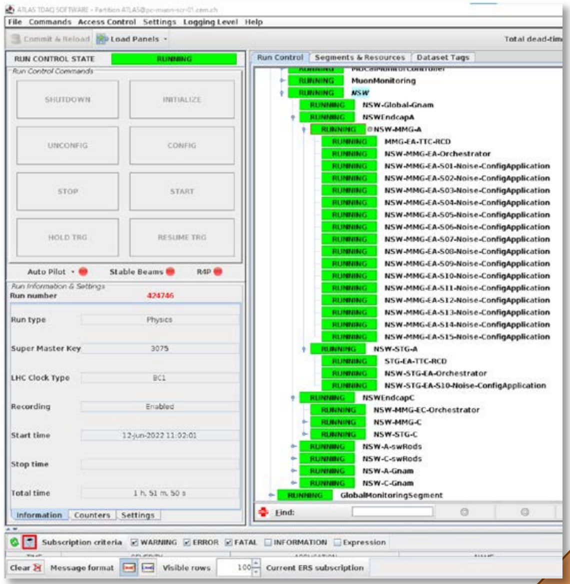
NSWs successfully integrated into the ATLAS Muon Central DCS and in the ATLAS TDAQ!

NSW employs new generation DAQ developed for the ATLAS Run-3: FELIX (Front End LInk eXchange) system + software ROD (swROD) -> will be the standard for Phase2!

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!

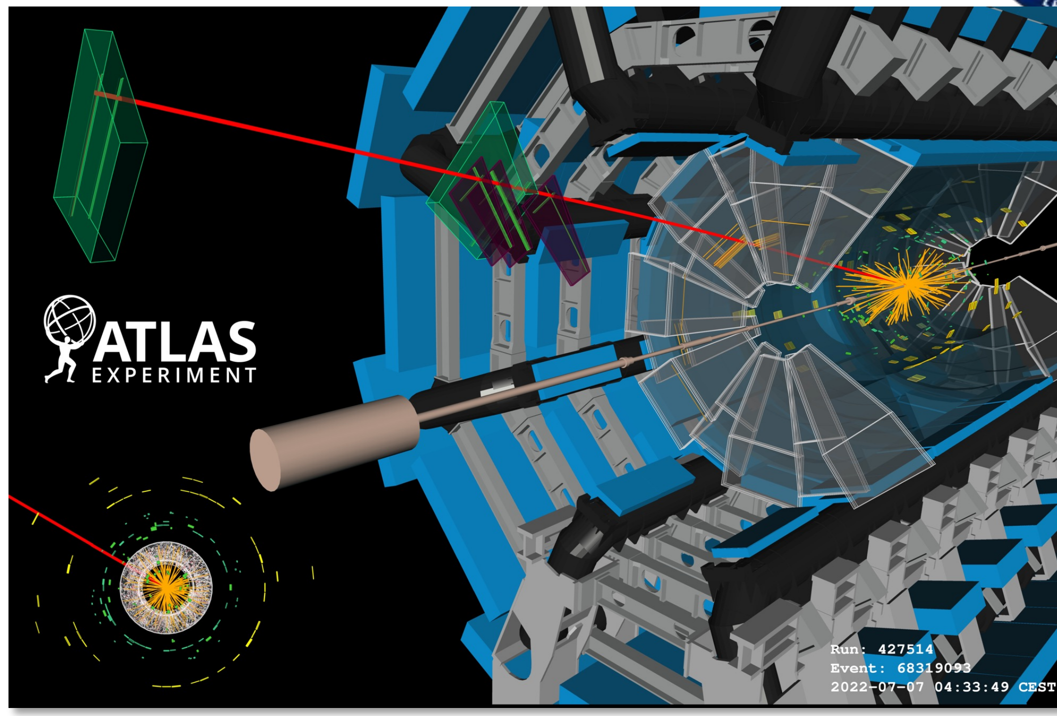


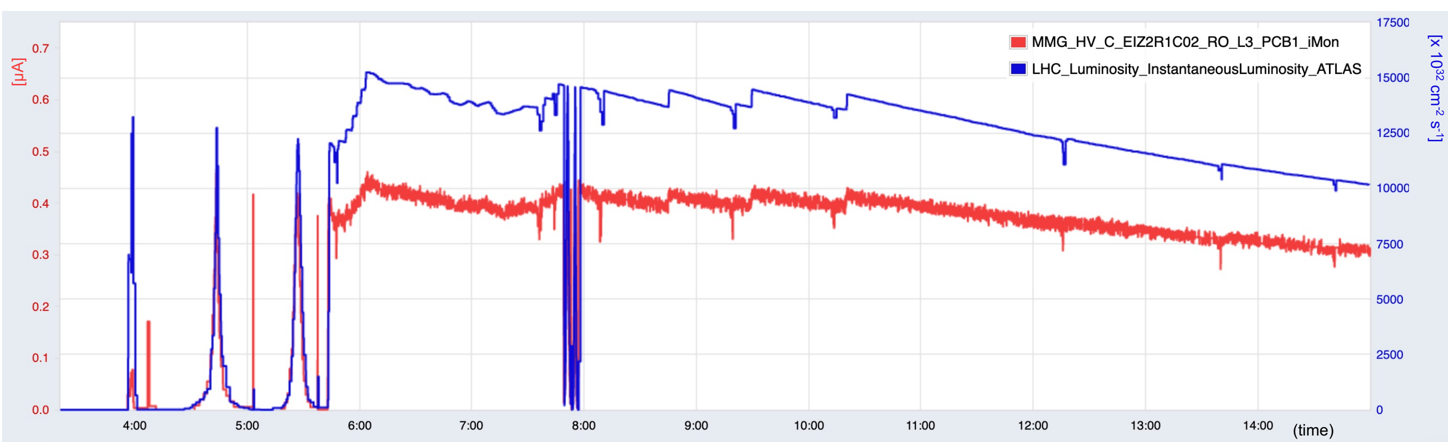
- 5/Jul-Nov22 -> Early Run3 started! NSW have been joining the ATLAS data taking with nice results!

NSWs in ATLAS

ATLAS Early Run 3 started on 5 July 2022!

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



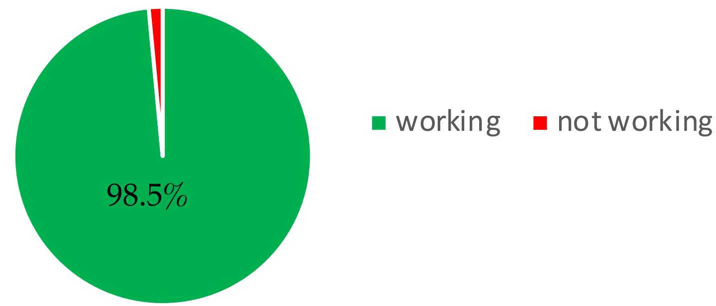


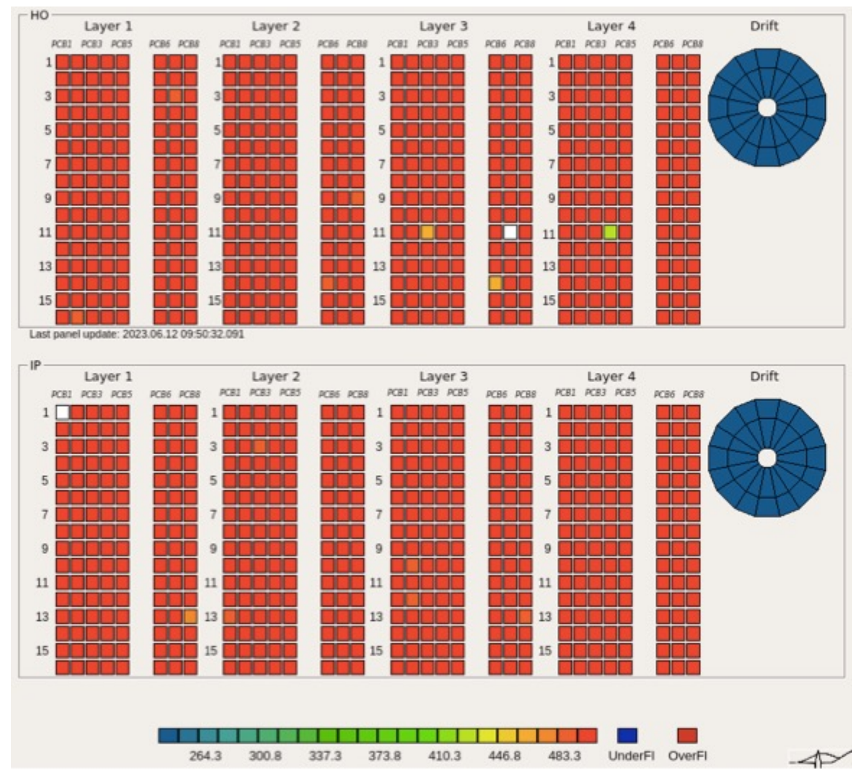
NSWs in ATLAS: HV status

HV status:

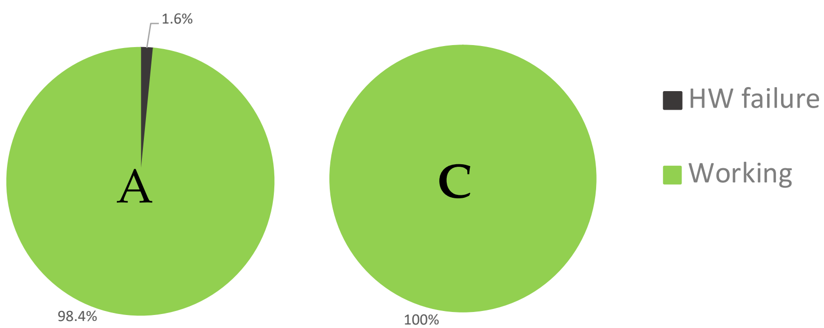
- Operating voltage: 505 V (Ar:CO_2:Iso)
- ~1% channels at not nominal HV
- 1.5% HV channels disconnected or disabled (including 1 drift channel)
- margin to push amplification higher

MM HV A+C





LV status:



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

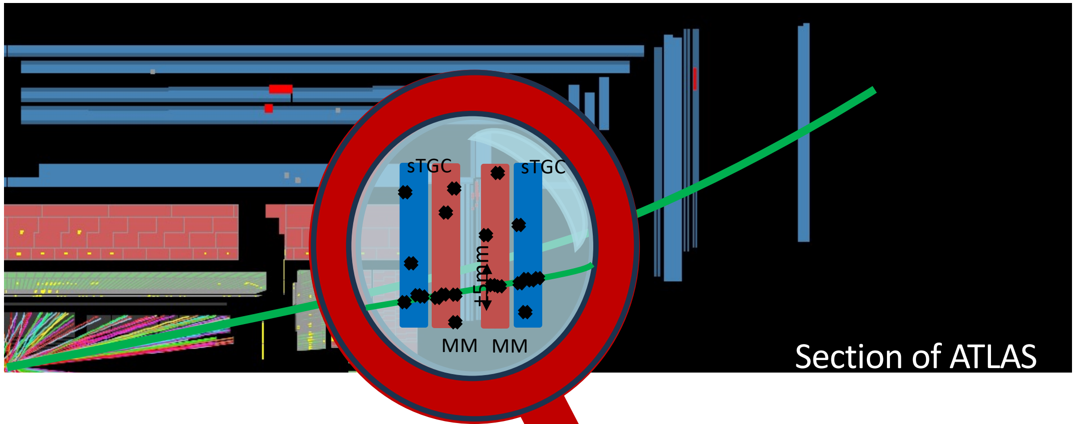
Performances

Muon Selection:

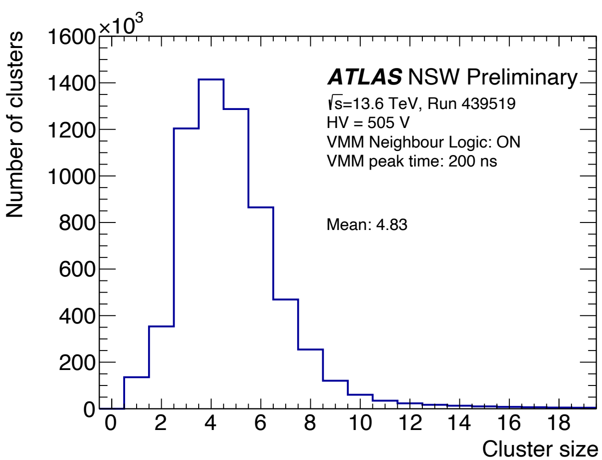
- Using Combined muons (muon track reconstructed using the ID track and MS track combined together) or Standalone (only MS track)
- Selecting only track with $p_T > 15$ GeV

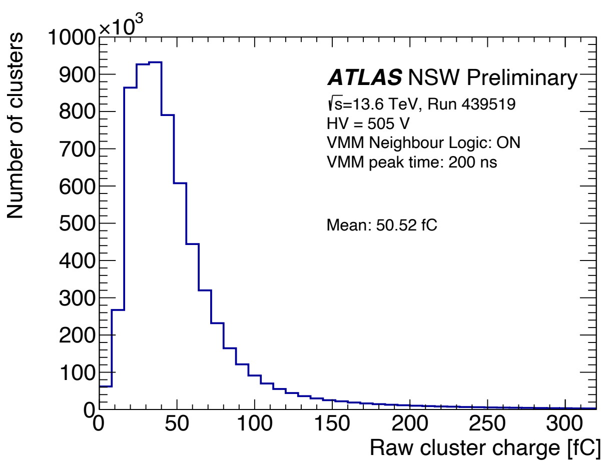
Efficiency presented:

- Searching for a cluster within ± 5 mm wrt the extrapolated track position
- Searching for a cluster associated to the muon track (on-track efficiency)



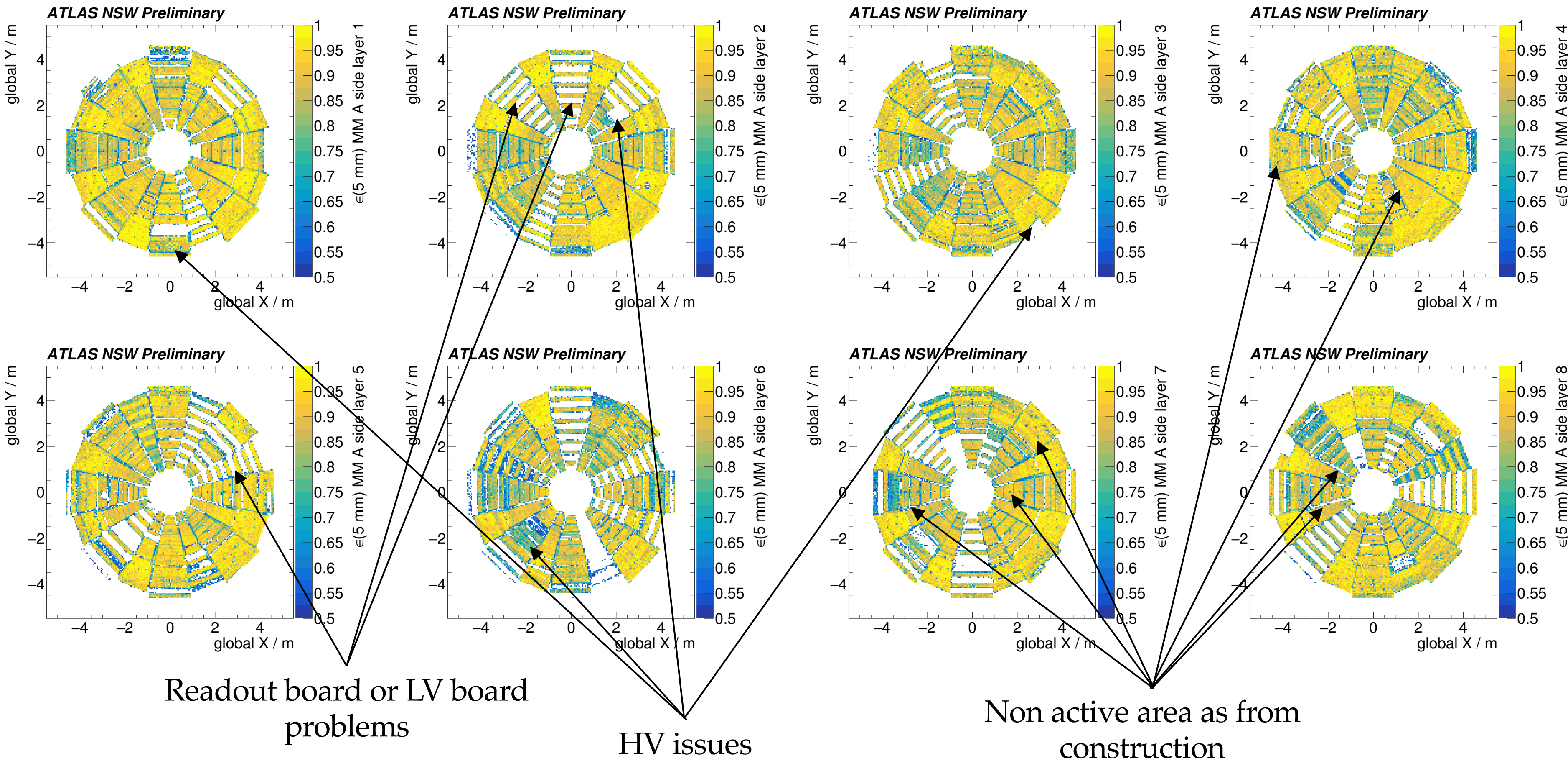
Performances of the MM layers are studied in terms of number of clusters, cluster dimensions and efficiencies in a spatial window of 5mm wrt the reconstructed track.





NSW Preliminary Performance: MM Single layer efficiency

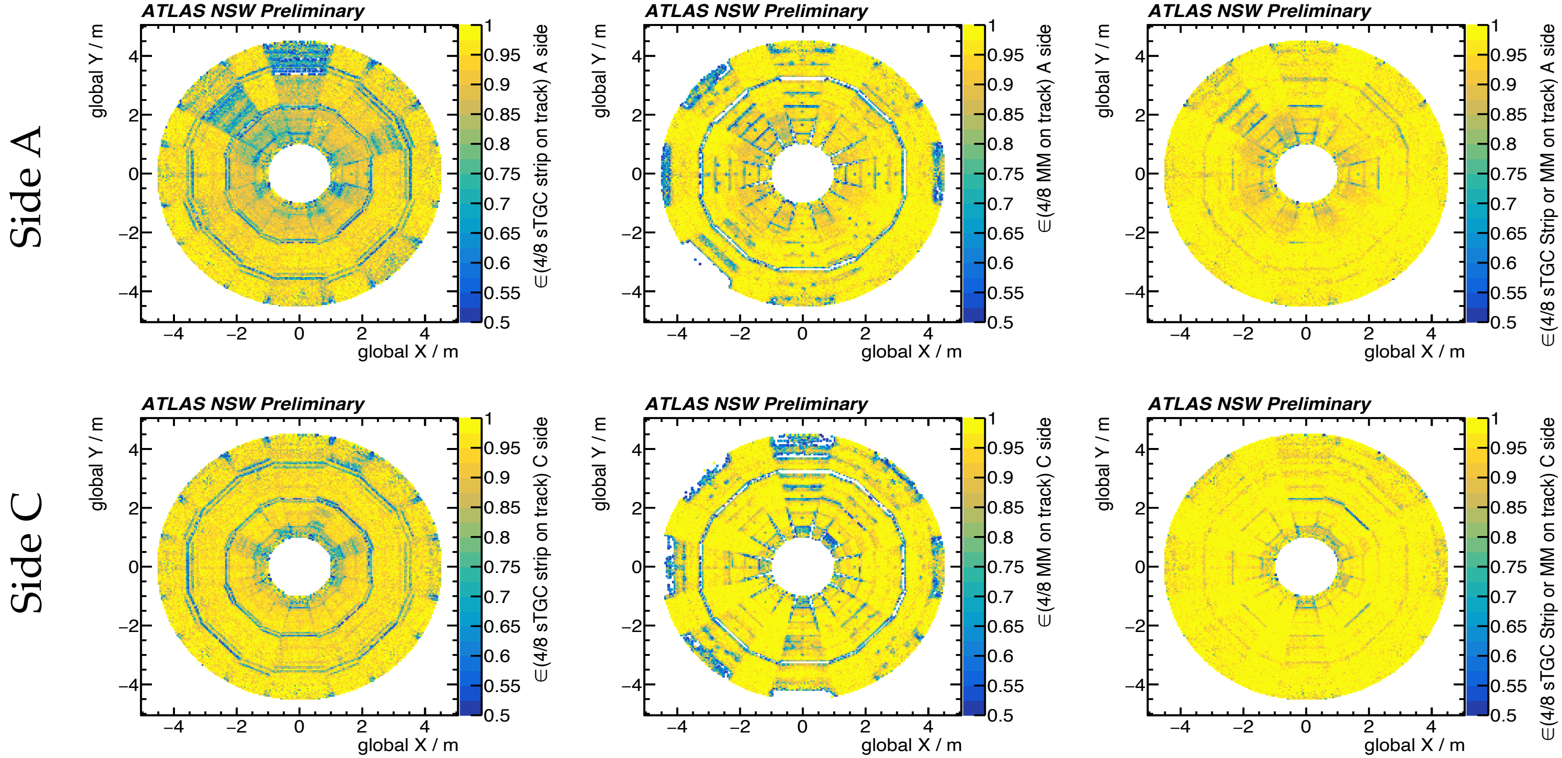
- Layer by layer efficiency with cluster selected within ± 5 mm wrt the extrapolated track position
- Inclusive of all inefficiencies (detector, HW, DAQ)
- Wheel A as an example



NSW Preliminary Performance: Reconstruction efficiency

- Track reconstruction with clusters associated to the muon track (on-track efficiency with at least 4/8 detector layers)
- **Track reconstruction is > 95% thanks to the high-redundancy of the NSW**
- Ongoing validation to use this majority in the muon reconstruction as a quality criteria

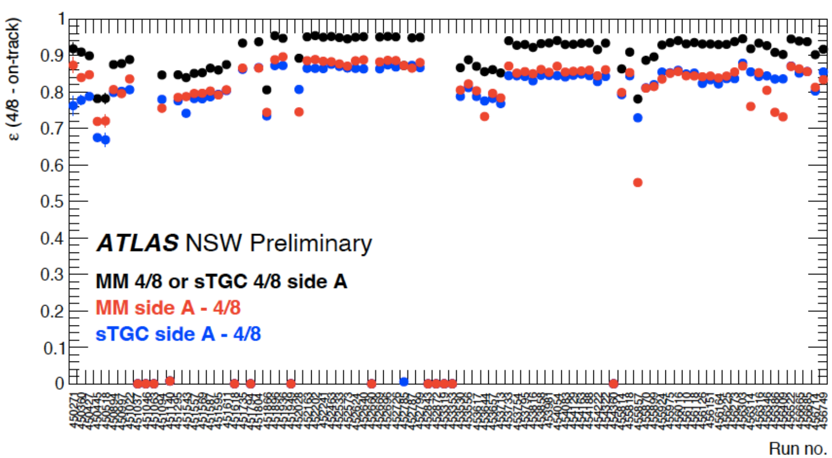
≥4/8 sTGC layers on-track | ≥4/8 MM layers on-track | ≥4/8 sTGC OR ≥4/8 MM layers on-track

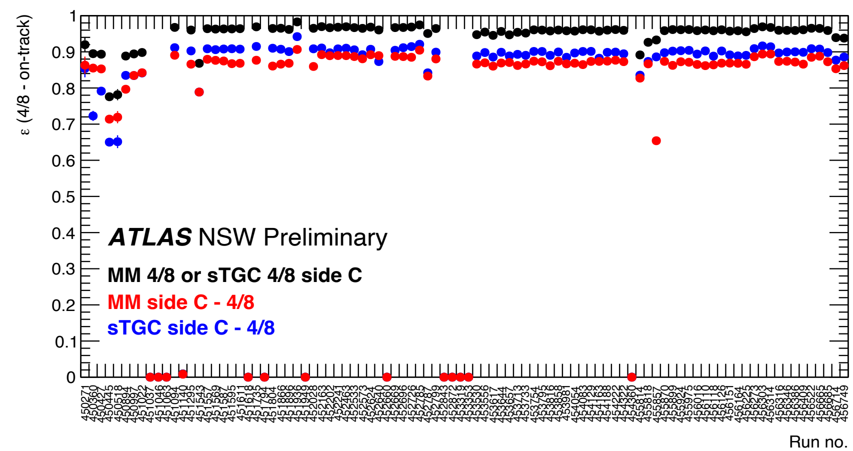


NSW Preliminary Performance: Reconstruction efficiency

Very constant behaviour (plots from 2023 March-July) after first period

- efficiencies ranging from 70-95% on average
- situation much more improved wrt to the 2022 preliminary results, mainly drawn by DAQ issues
- still room for improvements





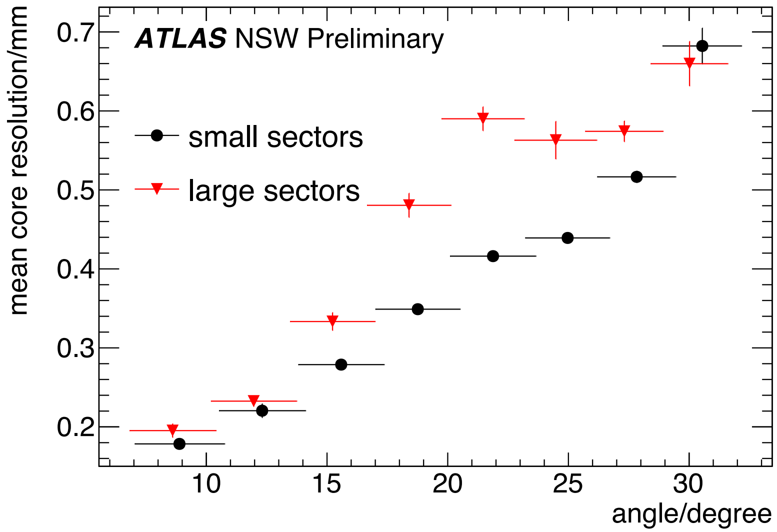
NSW Preliminary Performance: Resolution

- Single layer resolution still sub-optimal, spoiled by effects from residual layer-layer mis-aligment and from the as-built geometry
- Substantial improvement in resolution expected
  - once all effects are corrected (ongoing)
  - with new time-based reconstruction methods

MM resolution as a function of angle θ

for muons tracks with a reconstructed $p_T > 15$ GeV

- MicroMegas resolution obtained with the layer-layer cluster position difference (taking into account the track inclination)
- Less effect on the mis-alignment with this method
- Cluster centroid method in agreement with expectation of simulation



NSW Sector Alignment

Movements and deformations are monitored by optical alignment system mounted on the spokes

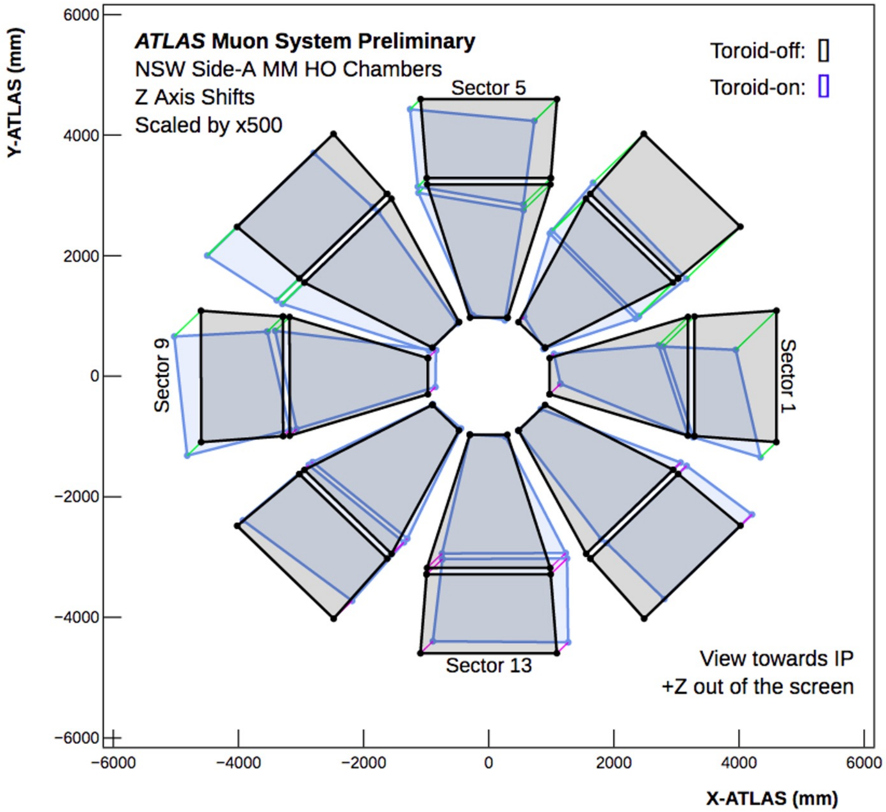
- Both wheels tilt away from IP / towards HO when toroid is ON (magnetic field exerting a force on some element of the NSW)

- On average 1mm shift, but up to 2.7mm
  - NSW-A tilts towards +Z
  - NSW-C tilts towards -Z

- Same behaviour for old small wheel

Z-shift (x500 -> exaggeration!)

Z-shift > 0: green Z-shift < 0: magenta



NSW Preliminary Performance: Trigger

NSW requirements have been designed targeting the requirements imposed by the HL-LHC running conditions -> Full potential of the NSW trigger is needed for HL_LHC

Level-1 trigger

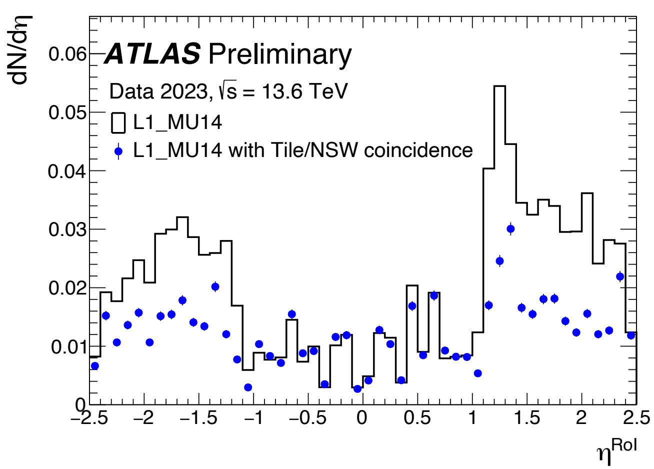
- **sTGC Pads:**

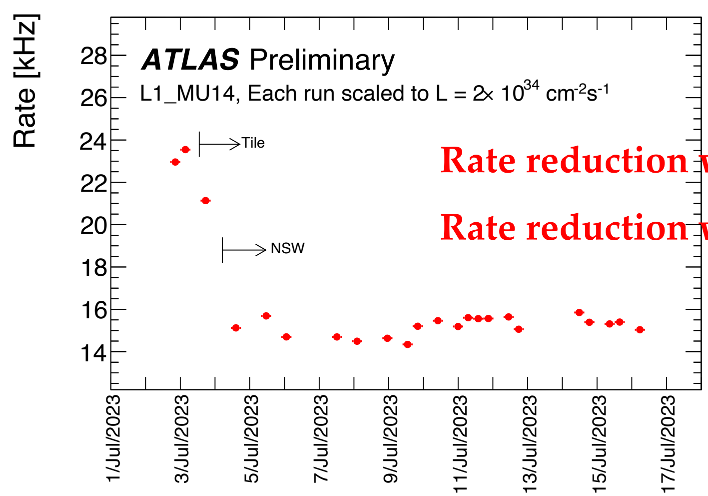
  pad coincidences to define a smaller region of interest and select fast charge information from a band of strips for centroid reconstruction

- **MMG strips (integration ongoing):**

  reconstruct slopes pointing to IP based on the earliest threshold-crossing strips among multiple layers

Already in 2023 -> Full Trigger Chain has been successfully integrated into Level-1 trigger very recently, to release the high-rate pressure and improve efficiency in end-cap!!!





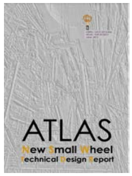
Rate reduction with Tile: ~2kHz

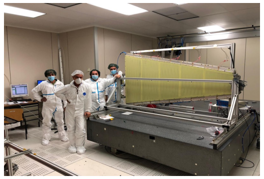
Rate reduction with NSW (sTGC): ~6kHz

Conclusions

- The New Small Wheel was one of the largest projects to upgrade experiments at the LHC
- Almost 10 years were needed to complete it, with several issues addressed, including COVID
- The New Small Wheel is now in ATLAS!
- There are still problems to be solved (both detector side and acquisition side) but at present the New Small Wheel collects data, contributes to the trigger, and are used for muon reconstruction.

ATLAS TDR



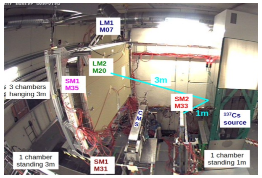


Module production
2018-2020

Integration
at CERN
2019-2021

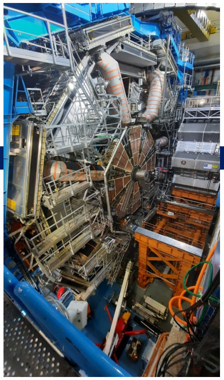
NSW A End Surface
Commissioning
18/06/21

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

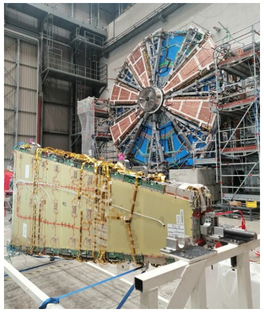
2019

2020

2021

2023

1° sector on the Wheel
12/2019

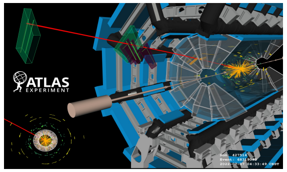


Surface Commissioning
2019-2021

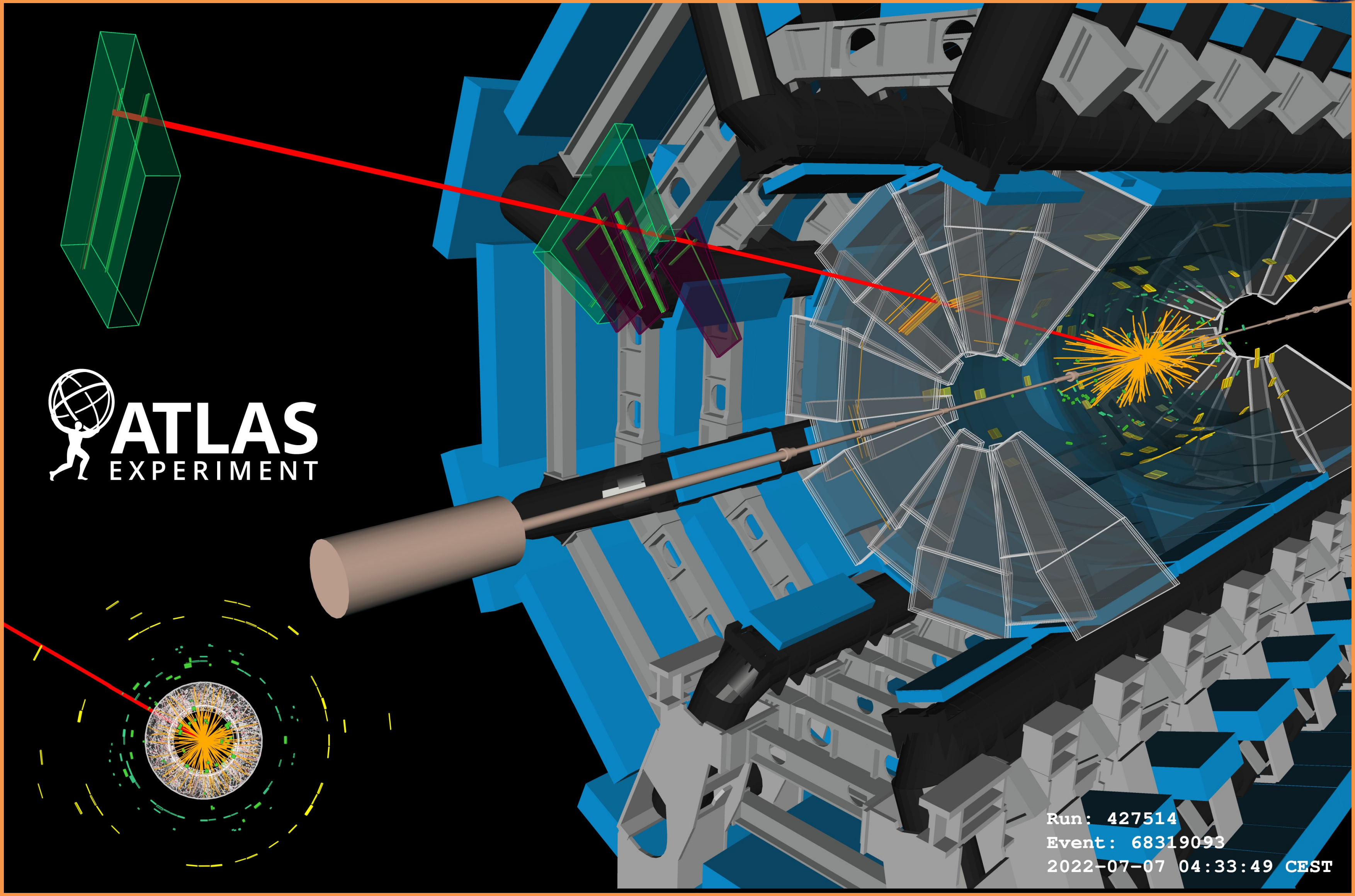
NSW A to the cavern
12/07/21

NSW C to the cavern

NSWs Running in ATLAS
since 05/22

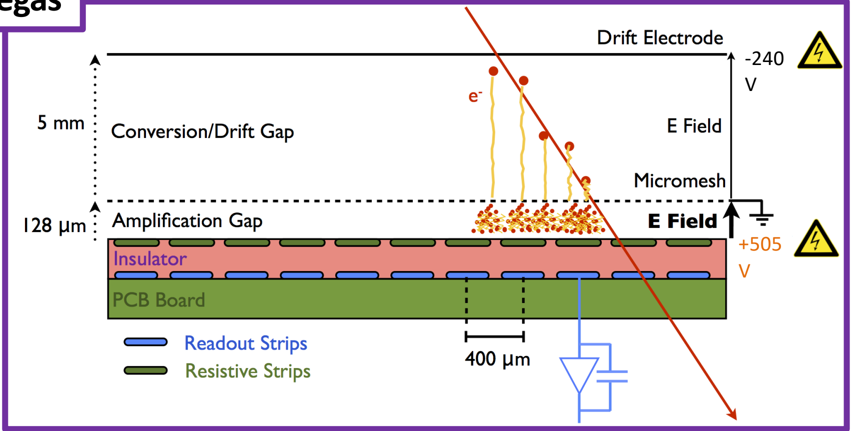


Thanks for your attention!

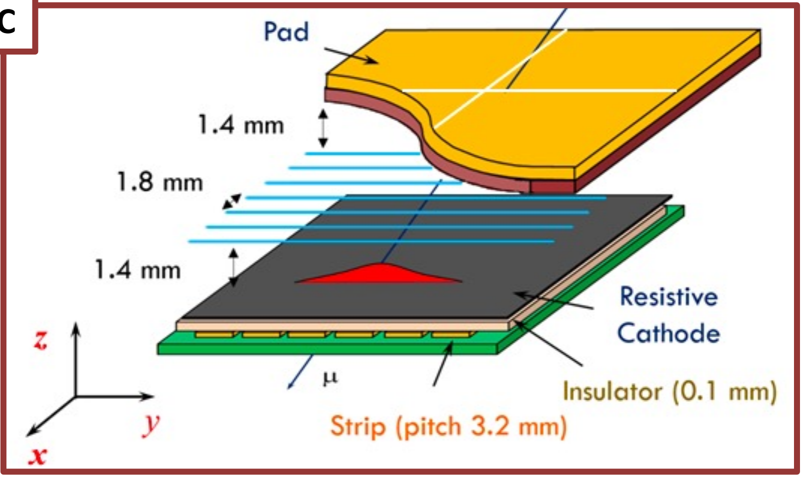


- Gas detector, $Ar:CO_2:iC_4H_{10}$ (93:5:2) for MicroMegas, $CO_2:n-pentane$ (55:45) for sTGCs.
- Temporal resolution of 15/20 ns for MicroMegas and ~15 ns for sTGCs.
- Spatial resolution ~100 μm per layer.
- Resolution of a few mm on the second coordinate for pointing at the interaction vertex.

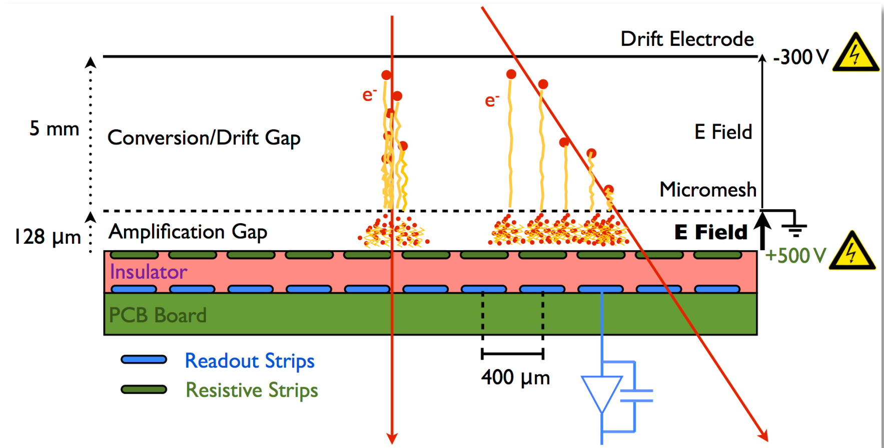
MicroMegas



sTGC



The MM detectors within the ATLAS NSW

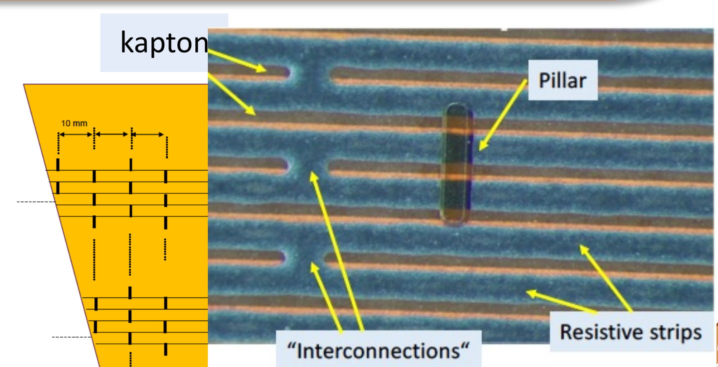


Features specific to ATLAS MM:

- 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

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

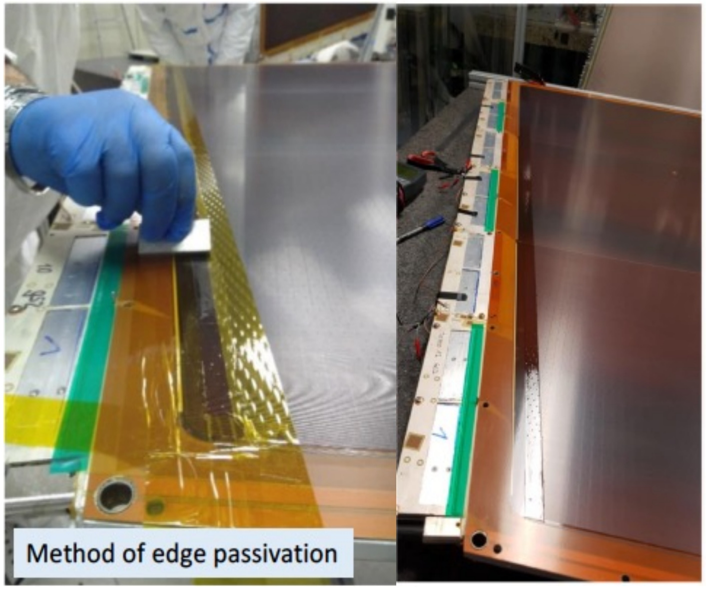


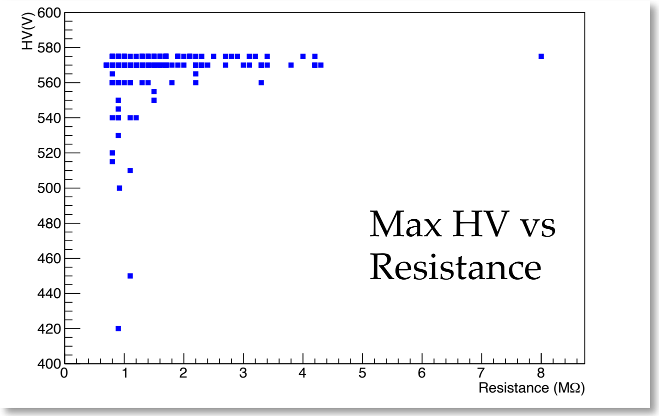
HV stability issues

The main issues affecting the HV stability were identified to be:

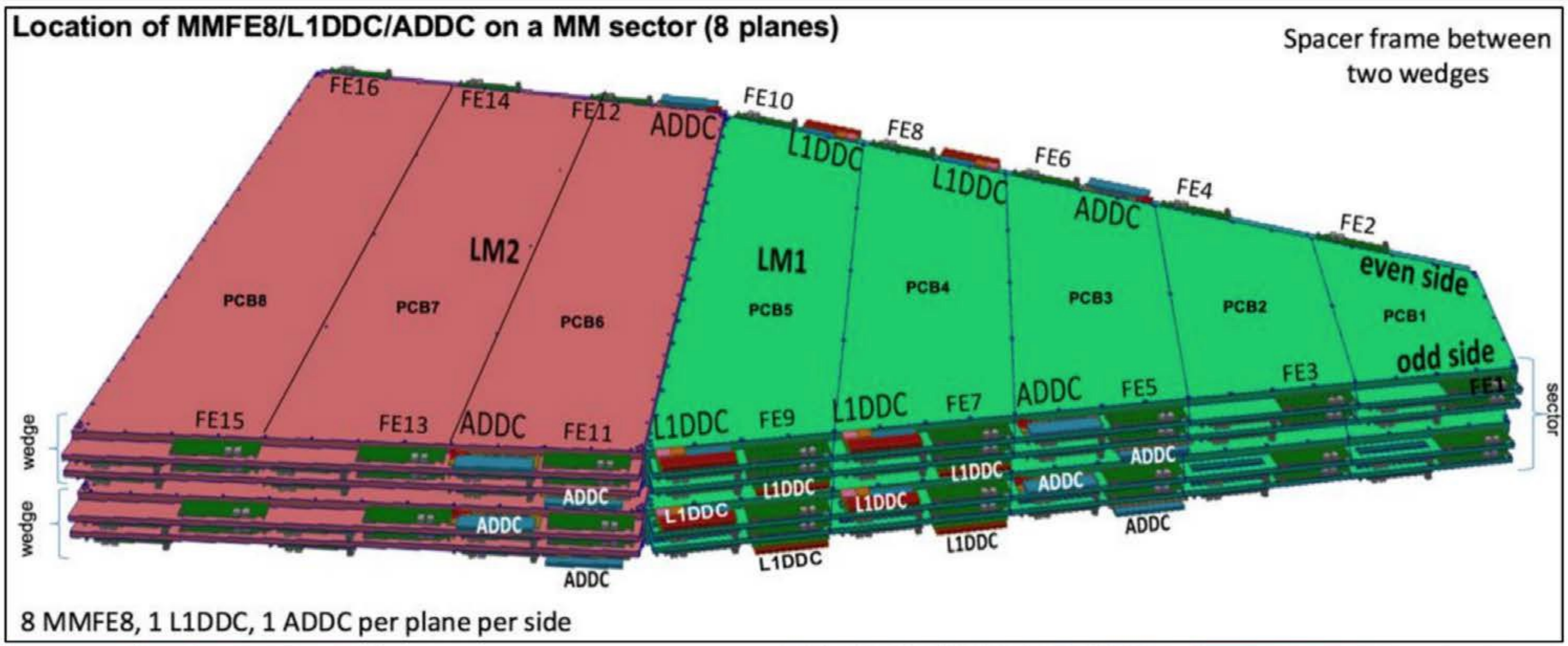
- **Residual ionic contamination** of boards and panels from industrial processing and handling => **improve the cleaning procedures**
- Possible effects from **mesh mechanical imperfections** => **implement mesh polishing**
- Clear **correlation of currents with humidity** => **monitor humidity and 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





MMG Front-end Electronics



Introduction: NSW Electronics

Complexity: 55k ASICs + 5k Front-end cards!