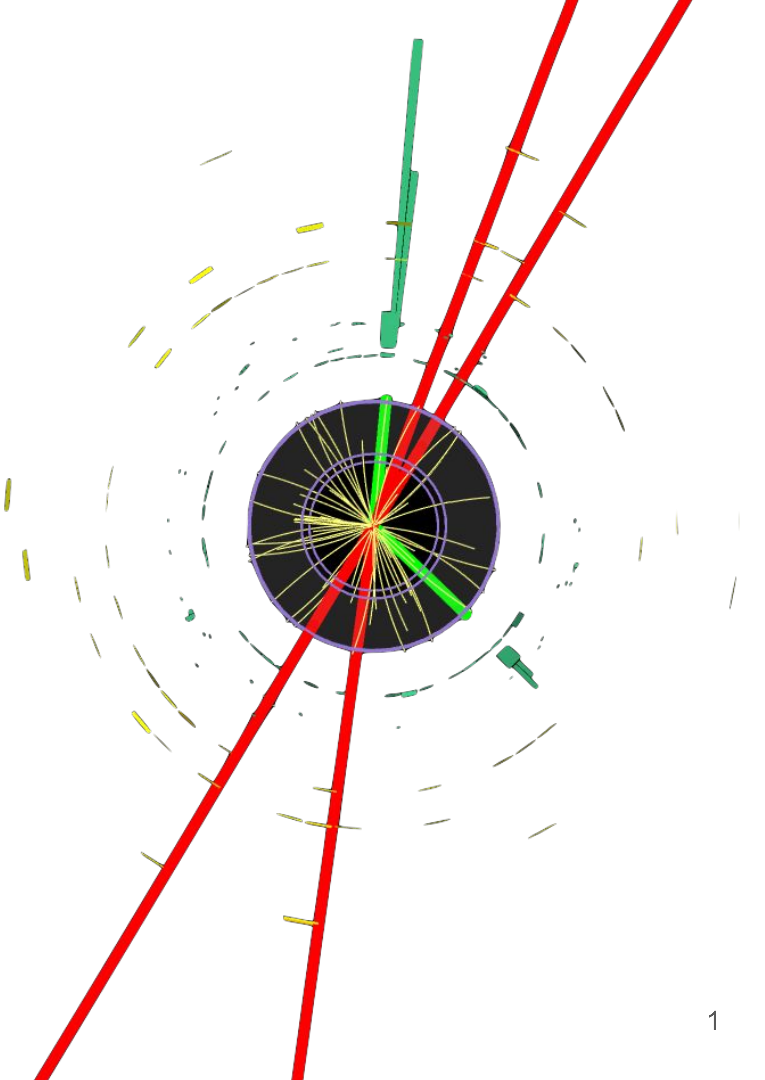
ATLAS Micromegas Performance Studies with LHC Run3 Data



14th Oct 2024

Simone Francescato on behalf of the ATLAS Muon Community

HARVARD UNIVERSITY

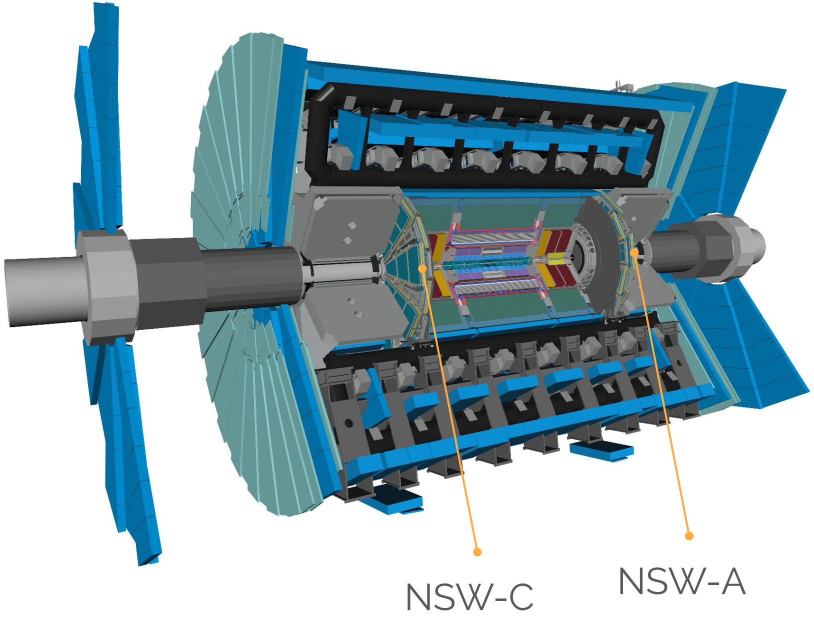
ATLAS EXPERIMENT

NSW for ATLAS Phase-I

NSW has been the main ATLAS Phase-I upgrade
- need to cope with increasing LHC luminosity
  - $2{\cdot}10^{34}\ cm^{-2}s^{-1}$ (run-3, ongoing)
  - $7.5{\cdot}10^{34}\ cm^{-2}s^{-1}$ (HL-LHC)

Targets
- **reduce muon endcap background trigger rate** to keep muon momentum thresholds as low as in Run2

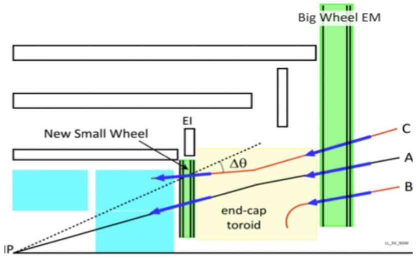
- provide **high resolution tracking** at high momenta
  - aiming at 10% muon momentum resolution at 1 TeV, for $|\eta|$ up to 2.7

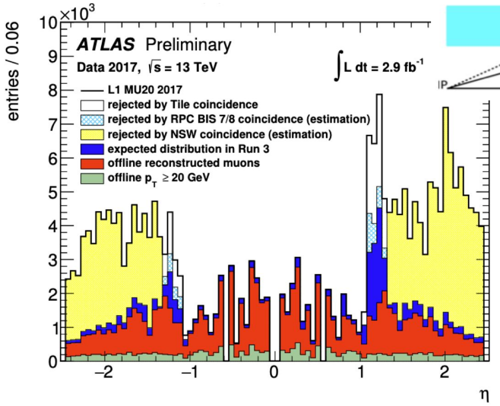


NSW for ATLAS Phase-I

Total L1 Trigger rate is limited to 100 kHz
- need to keep p^{μ}_{T} > 20 GeV trigger unprescaled
- need to keep muon purity high in the endcap
  by rejecting fakes

→ NSW confirming Big Wheel trigger coincidences

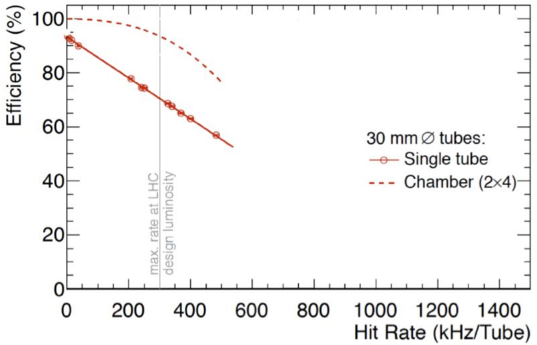




A: ✅ pointing to IP
B: ❌ not pointing
C: ❌ BW only

Expected MDT efficiency drop
with the higher hit rates

→ NSW need to restore high tracking efficiency,
using new generation detectors

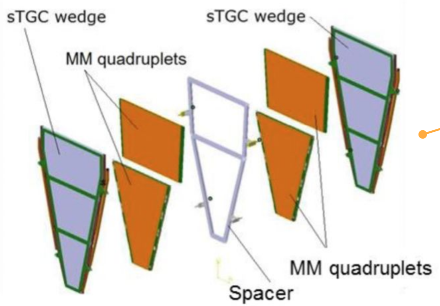


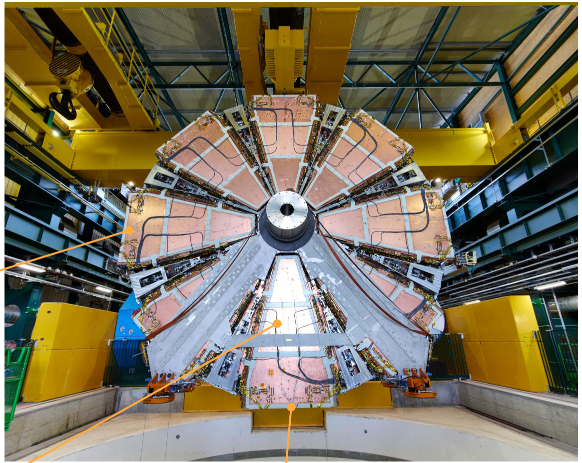
NSW design

2 wheels
- one in each detector end-cap
- each wheel with 16 sectors

Equipped with 2 gas detectors
- Small Strip Thin Gap Chambers (sTGC)
- MicroMegas chambers (MM) - **this talk!**

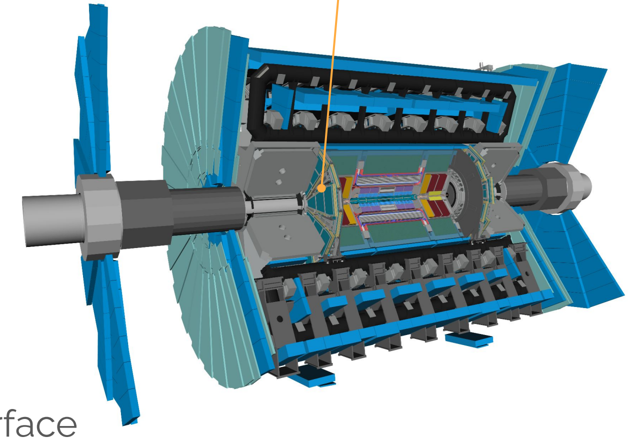
16 active detector layers (8+8)
to have high redundancy
for muon triggering and tracking
- sTGC: 350k channels
- MM: 2.1M channels
- VMM as a common FE chip
- FELIX as detector interface





For each technology
2 chamber sizes:
large and small

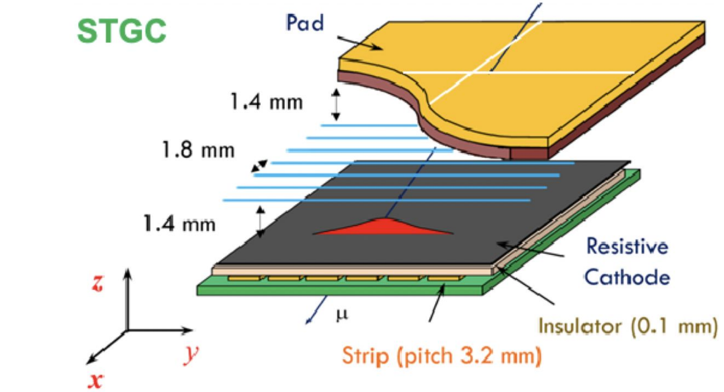
MM: this is the **largest surface MPGD system**!
- 10 m in diameter
- 8 layers of ~160 m^2 surface



NSW design

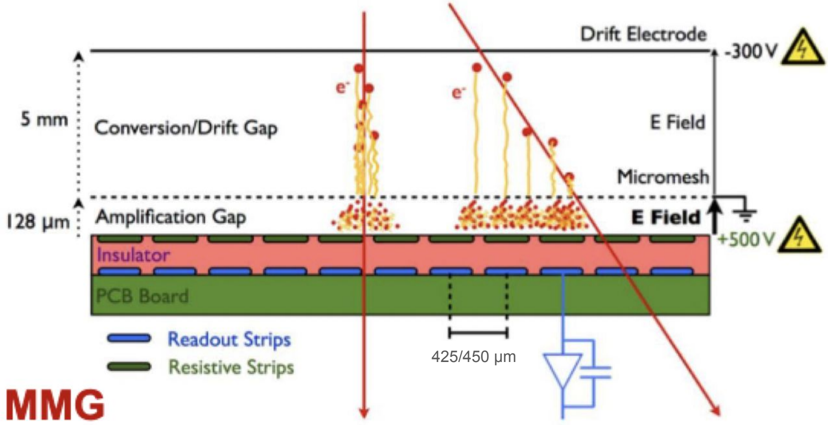
Small Strip Thin Gap Chambers

- CO_2:n-pentane 55:45
- Pads for fast coarse trigger information
- Strips with pitch of 3.2 mm for precise spatial resolution
- Wires for second coordinate in offline reconstruction



MicroMegas

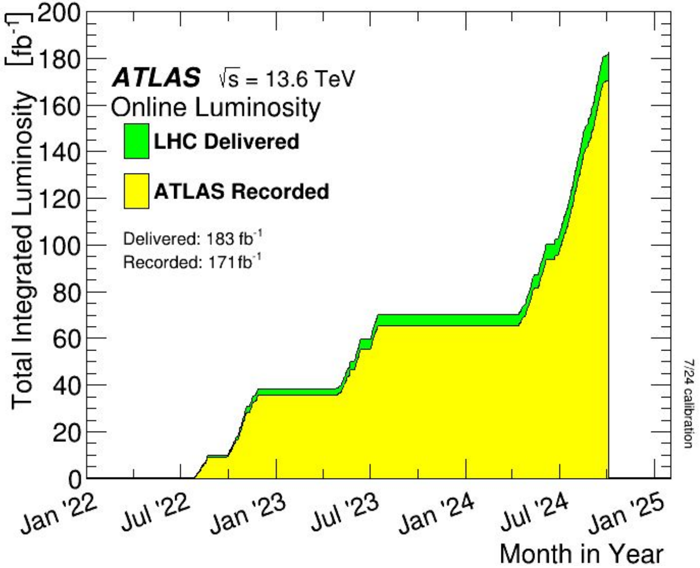
- Ar:CO_2:iC_4H_{10} 93:5:2
- 5 mm drift gap and 128 μm amplification gap
- Readout strips covered by resistive strips for spark protection
- 425/450 μm pitch for precise spatial resolution
- 4 layers for the precision coordinates η
- 4 layers with stereo strips, tilted by ±1.5° for ϕ

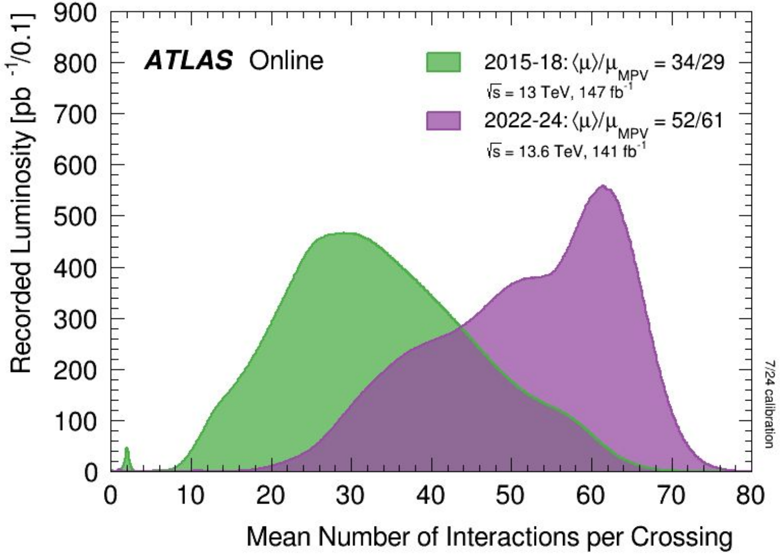


NSW during Run3

NSW has been included in ATLAS since the beginning of Run3 in 2022

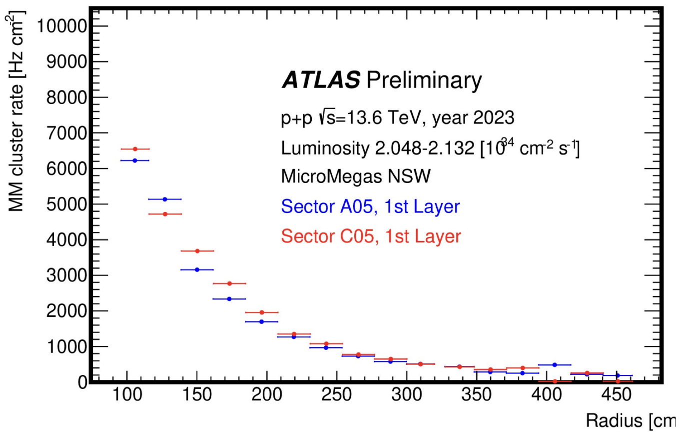
- first year considered for commissioning but we gained a lot of “detector experience”
- ATLAS crossed the 100 fb^{-1} milestone in 2024: NSW trigger rejection critical to keep dead-time low

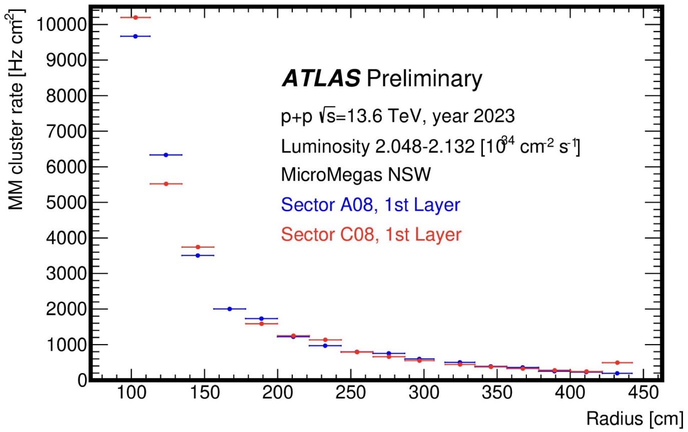




Incoming rates

Preliminarily measured incoming hit rates (vs luminosity and distance from the beam line and from the interaction point) **using 2023 data**
- main contribution from cavern background
- current measurements slightly higher than extrapolated Run2 data: ~30% increase
  (also considering ATLAS shielding reduction)

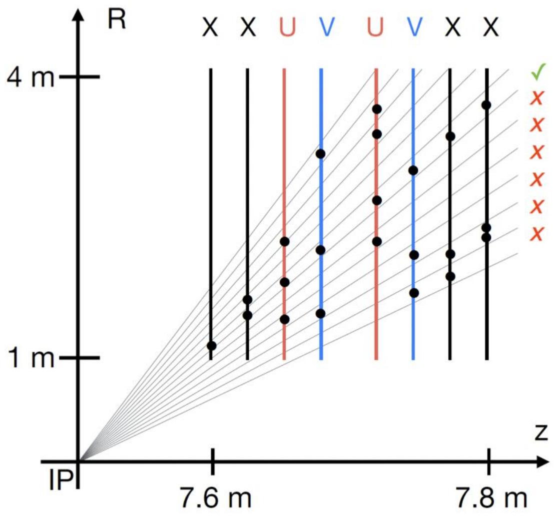




NSW Trigger

sTGC has been initially designed to be the main source of fast triggers for the NSW/L1 Muons but **MM is currently playing an important role to ensure high efficiency and rejection power**

MM trigger in a nutshell
- VMM ART hits (fastest strip per BC, among the 64 VMM channels) are collected, grouped, and send to FPGA-based trigger boards
- 6/8 coincidence with 8-10 strip roads (pointing to IP) within 8 BCs
- local fast linear fit to extract (R,ϕ,Δθ) coordinates

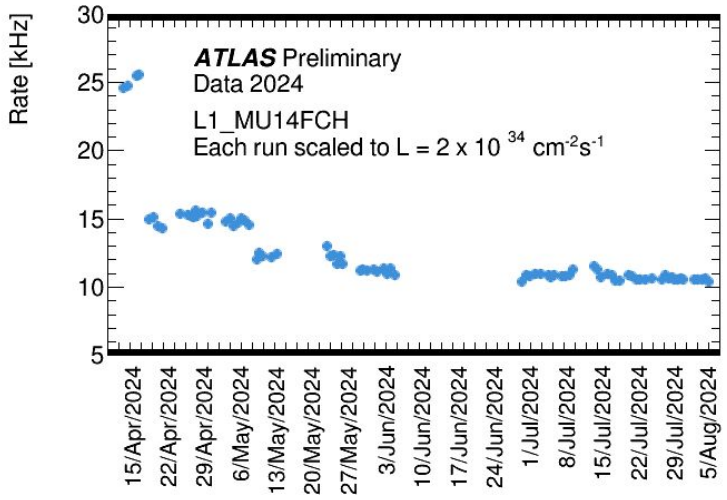


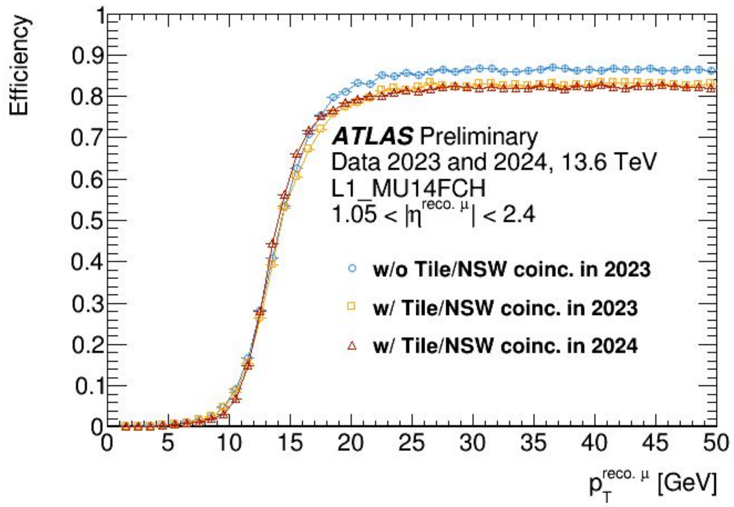
MM segments are merged to sTGC ones and sent to the ATLAS Endcap Muon trigger

NSW Trigger - performance in 2024

MM Trigger fully included in ATLAS by the end of May 2024
- enhancing the efficiency for all NSW sectors above 95%
- allowing the inclusion of all NSW sectors in the Endcap coinc.
- reducing fakes even further
- MM Trigger fake rate at sub% level

Date	Integration of NSW in L1Muon	
	sTGC pad	MM
At the end of 2023 pp run	70%	-
16 April	67%	-
7 May	87%	A10
24 May	92%	A08/A10/A12/C15
28 May (Run 476718)	100%	100%

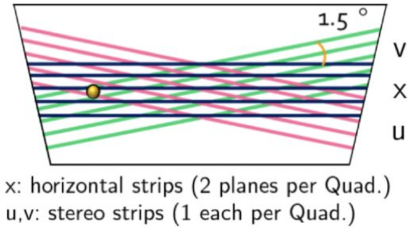


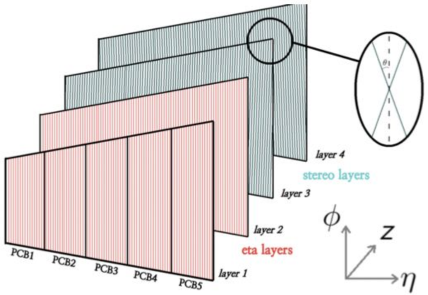


Muon reconstruction with MM

MM is fully integrated in the ATLAS muon reconstruction since the start of Run3

Roadmap from MM to muons:
1) MM and hits are clusterized
2) Position of the clusters is computed
3) Clusters on different layers are combined in track segments across the NSW layers
4) (MM+sTGC) segment positions are used to fit combined muons



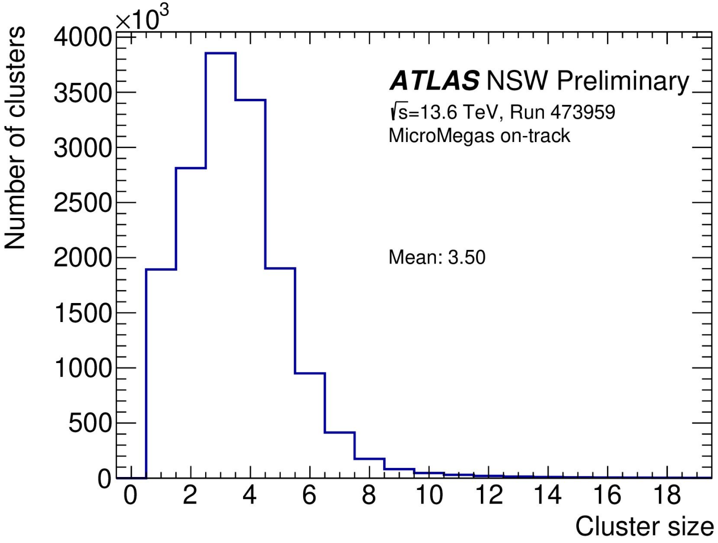


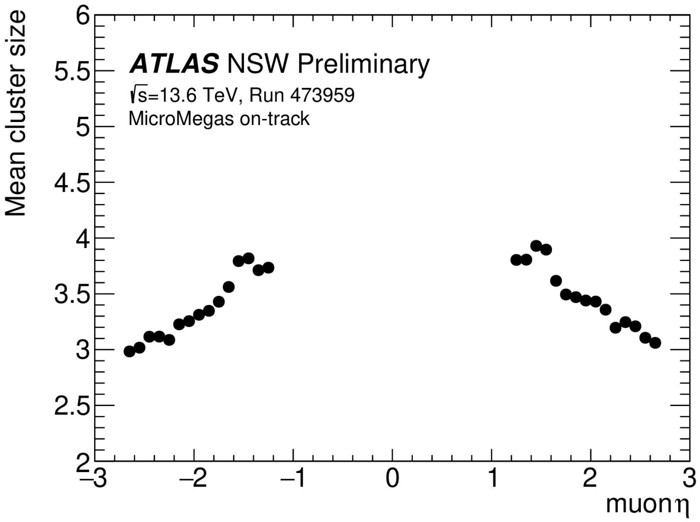
Second coordinate (ϕ) is extracted using MM stereo strips
All the known B-field effects are applied

More results from irradiation facility here and backup

MM cluster properties - size

MicroMegas strip cluster size for clusters associated to a muon Combined (ID+MS) or Standalone (MS-only) track with momentum >15 GeV from pp collisions at 13.6 TeV in 2024

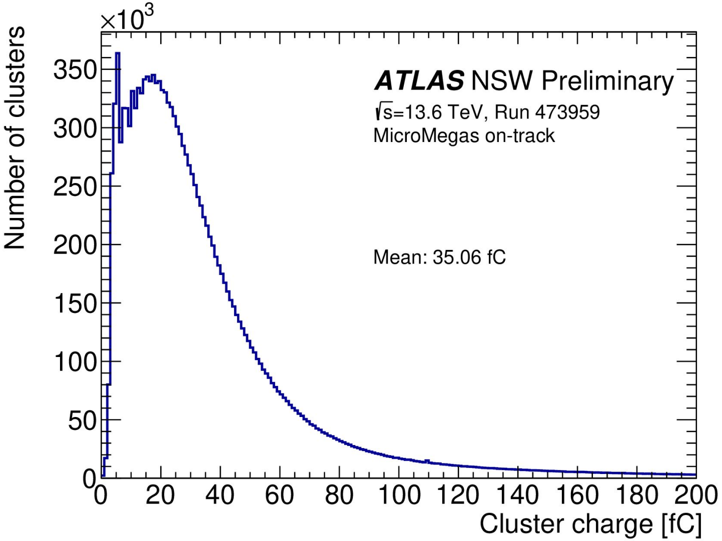


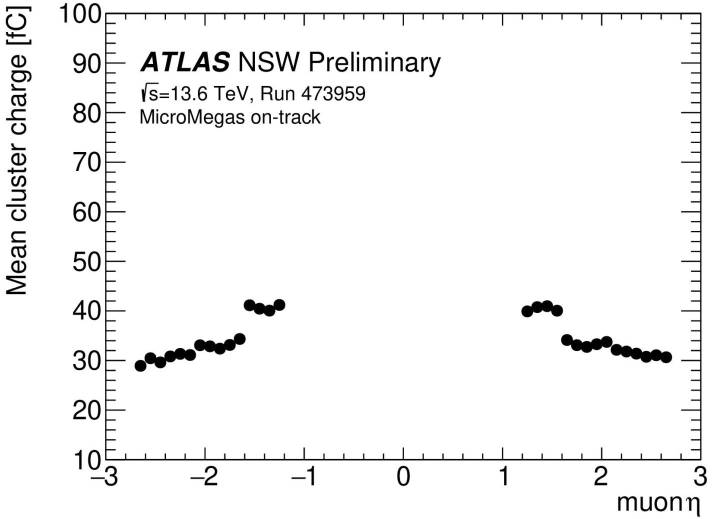


More results from irradiation facility here and backup

MM cluster properties - charge

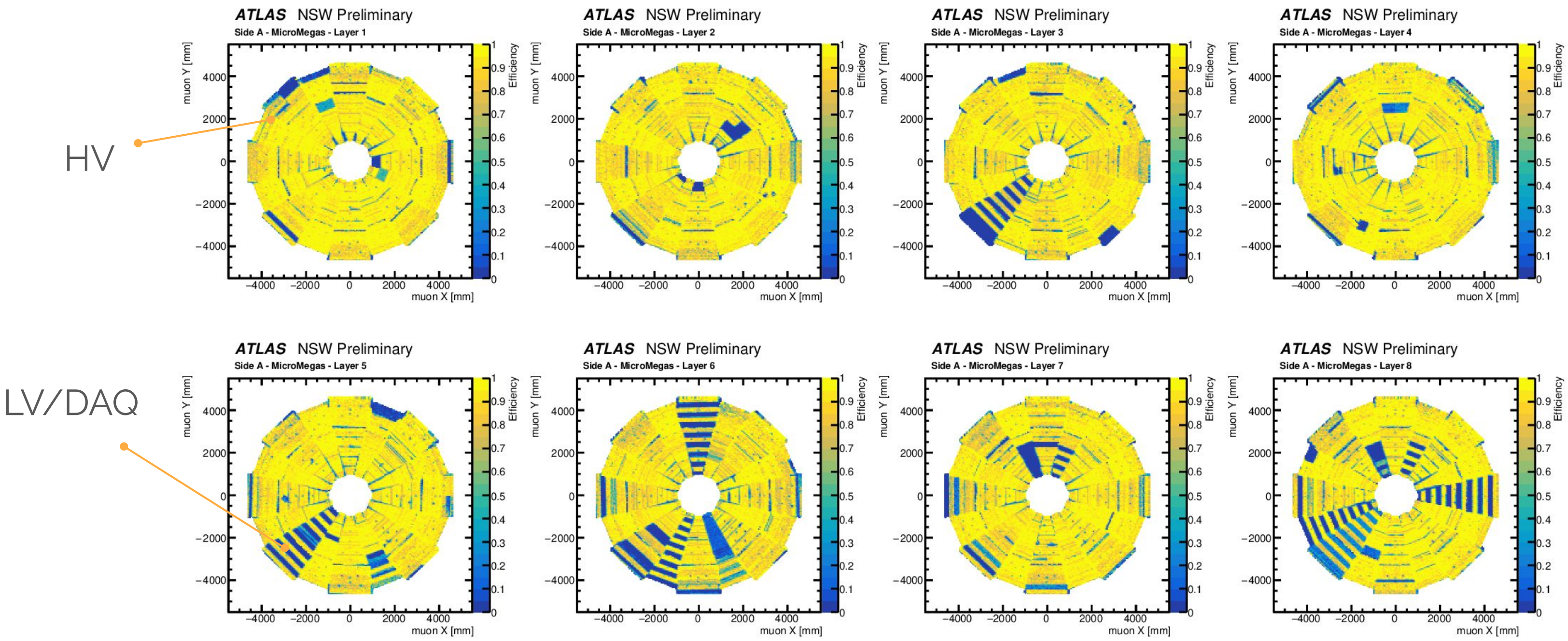
MicroMegas strip cluster charge for clusters associated to a muon Combined (ID+MS) or Standalone (MS-only) track with momentum >15 GeV from pp collisions at 13.6 TeV in 2024





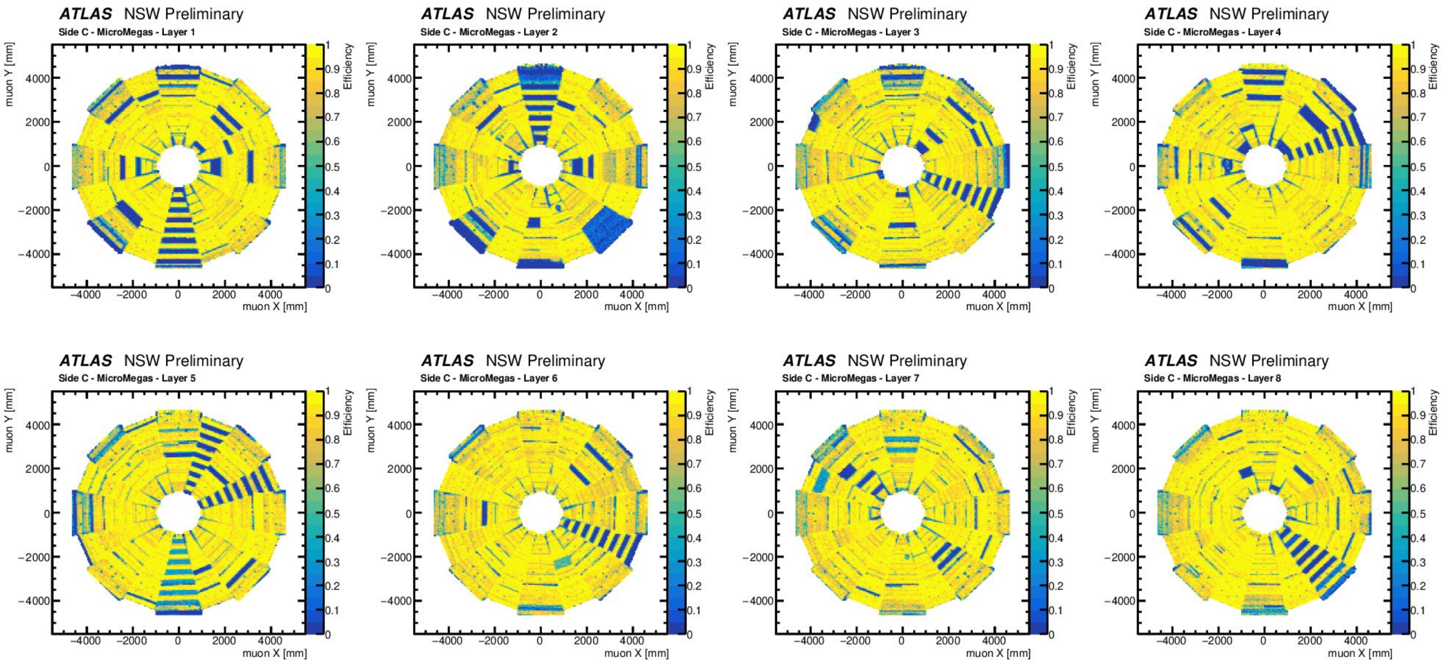
MM efficiency - side A

MM detector layer efficiencies evaluated asking for a cluster within 5 mm of the muon track
- Local regions of inefficiencies due to HV/LV/DAQ problems during the run
- Efficiencies above 90% for regions not affected by these problems



MM efficiency - side C

MM detector layer efficiencies evaluated asking for a cluster within 5 mm of the muon track
- Local regions of inefficiencies due to HV/LV/DAQ problems during the run
- Efficiencies above 90% for regions not affected by these problems



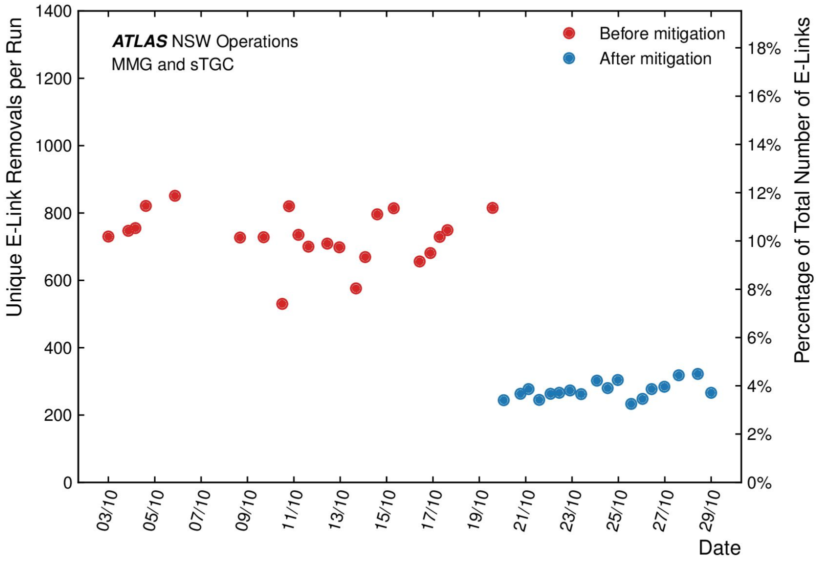
HV issues: 2%
(stable and static)

LV/DAQ issues: 5%
(dynamic)

MM efficiency - LV/DAQ

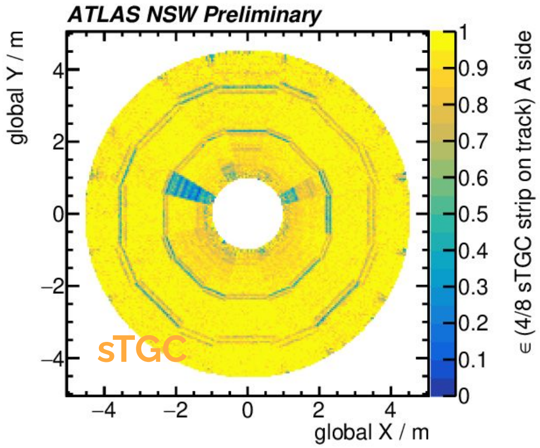
There has been a huge effort for solving DAQ problems
- unstable readout infrastructure
- huge amount of readout channels to configure, calibrate and monitor

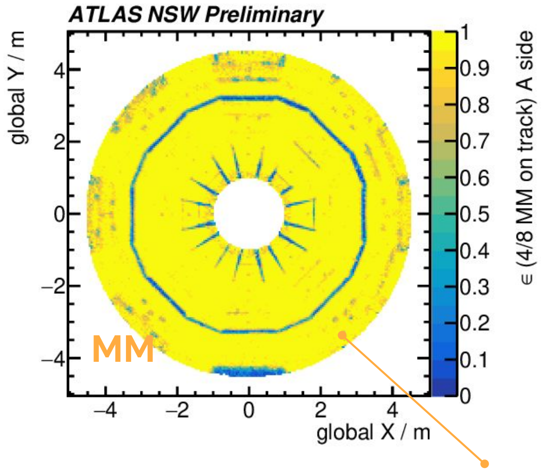
Factor 2 reduction in LV boards/DAQ issues achieved at the end of 2023
- observed stable situation across 2024

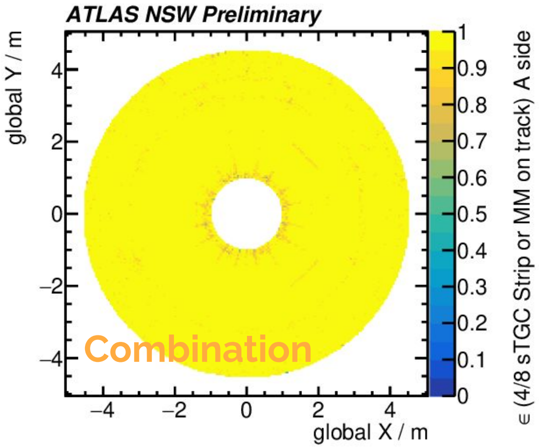


MM tracking efficiency

NSW "tracking" efficiencies evaluated asking of minimal amount of clusters on-track:
- requiring 4/8 MM layers for muon reconstruction definition at high momenta
 in order for the MM/NSW to contribute to the tracking with acceptable resolution





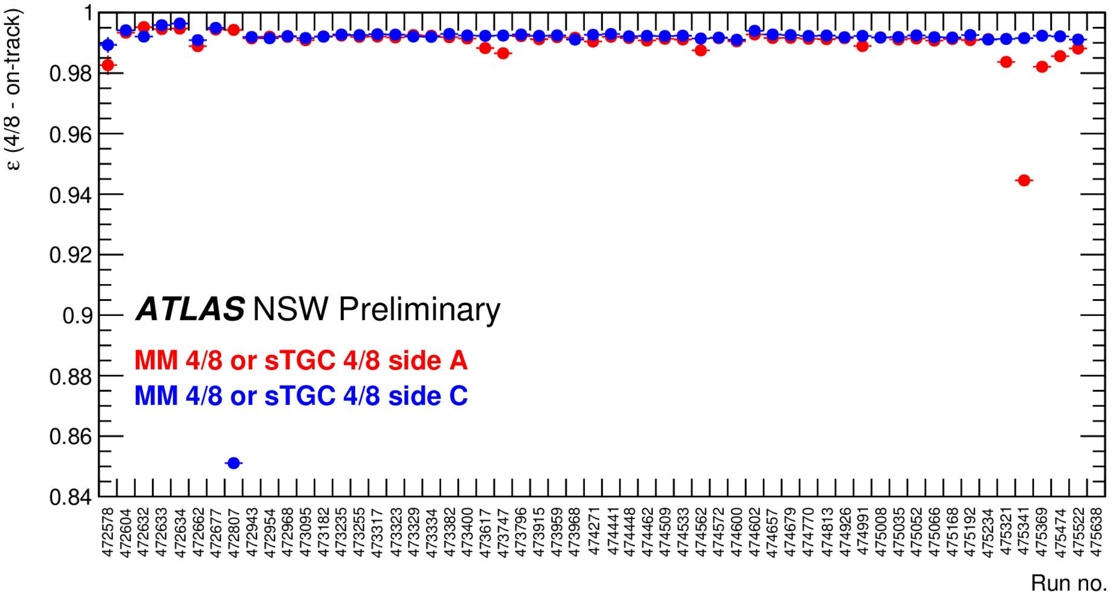


Tracking efficiency: 95% for MM

MM efficiency - stability over time

Average single layer efficiency is stable at 70-80% (including all the effects)

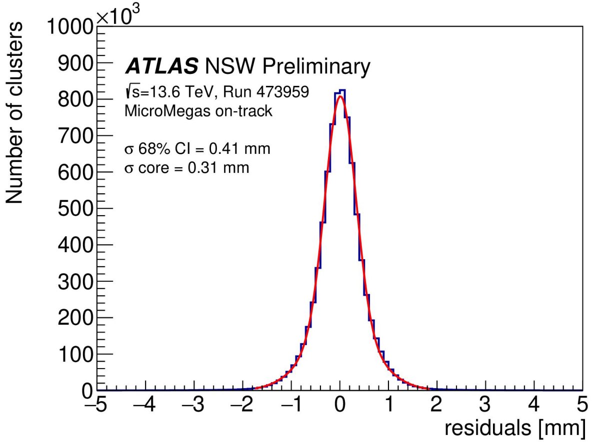
Average 4/8 (MM or sTGC) layers on-track efficiencies > 99% stably in 2024

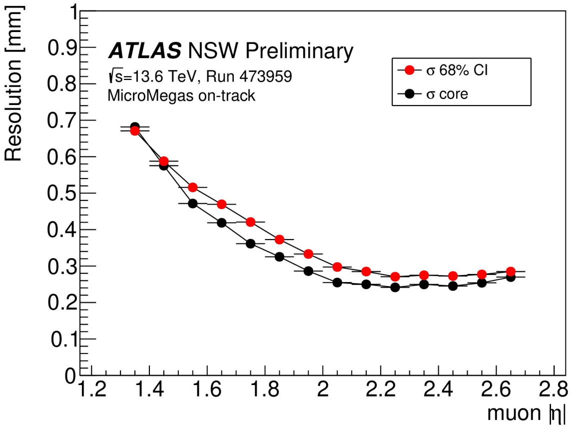


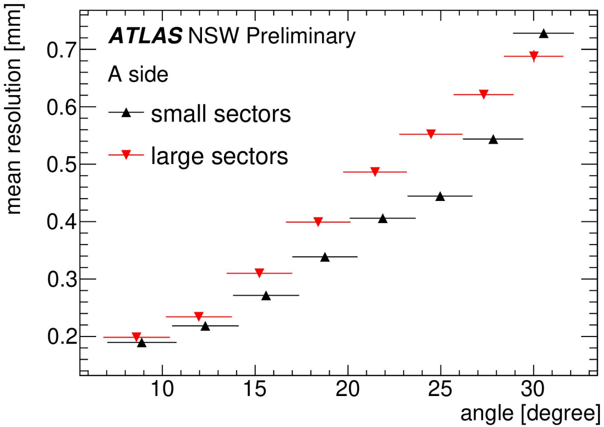
MM resolutions

Using the centroid cluster position (for now)
- Charge-weighted average strips positions
- Other methods (e.g. using time information and cluster shape) under validation
- Trying to reduce the η dependency too

Preliminary alignment used:
- Looking at the layer-layer difference allows to partially disentangle residual effects





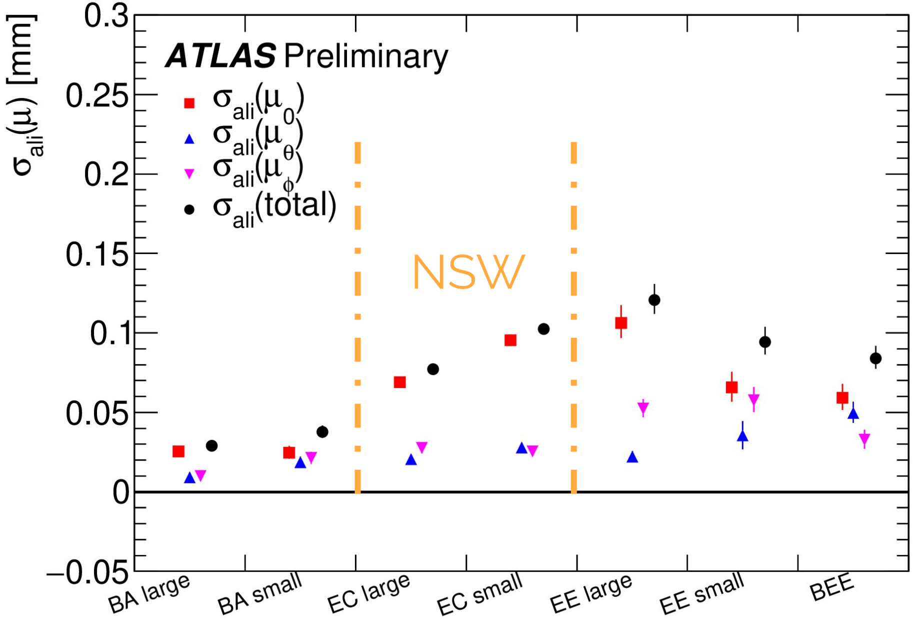


NSW alignment

Optical alignment providing an independent set of corrections for each MM quadruplet is in place
- translation, rotation and deformations

Alignment uncertainty parametrized as an uncertainty on the global track sagitta

Sagitta uncertainty from the alignment is at the moment ~ 80-100 μm
(also using toroid-off measurements)



An eye on the future

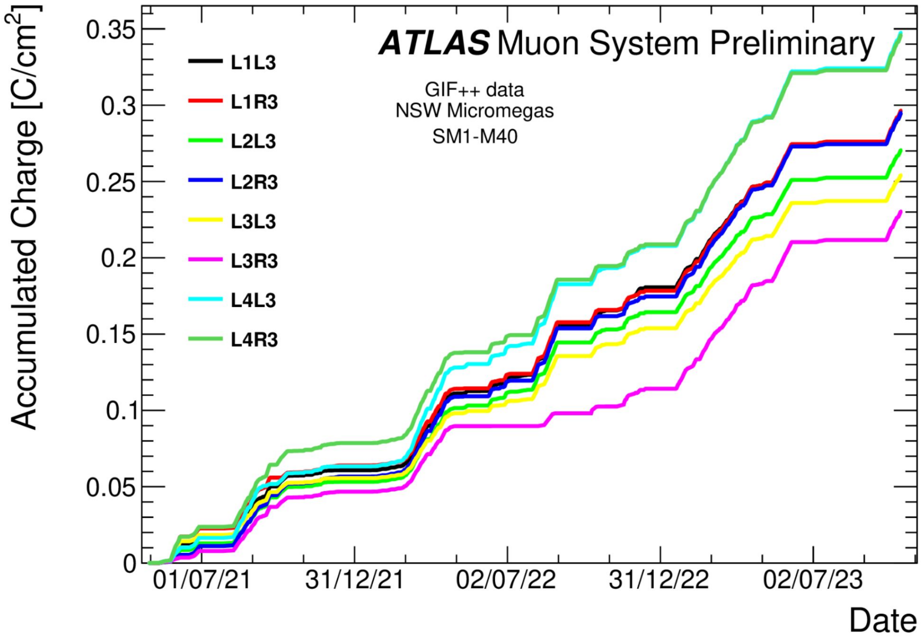
More results from irradiation facility again [here]

Irradiation studies at GIF++ facility of ATLAS Micromegas detector are being carried on continuously

Operating chambers at 520 V

An accumulated charge of
- 0.34 C/cm^2 = 5 years of HL-LHC at 520 V for the strip closest to the beam line.
- 0.29 C/cm^2 = 10 years of HL-LHC at 520 V for a strip half a meter higher

Great stability has been observed



Summary

NSW MM chambers has been successfully built and commissioned for ATLAS Run3

MM detectors are fully included in the online DAQ and offline software since the start of 2022 and are actively contributing to all ATLAS Run3 analyses

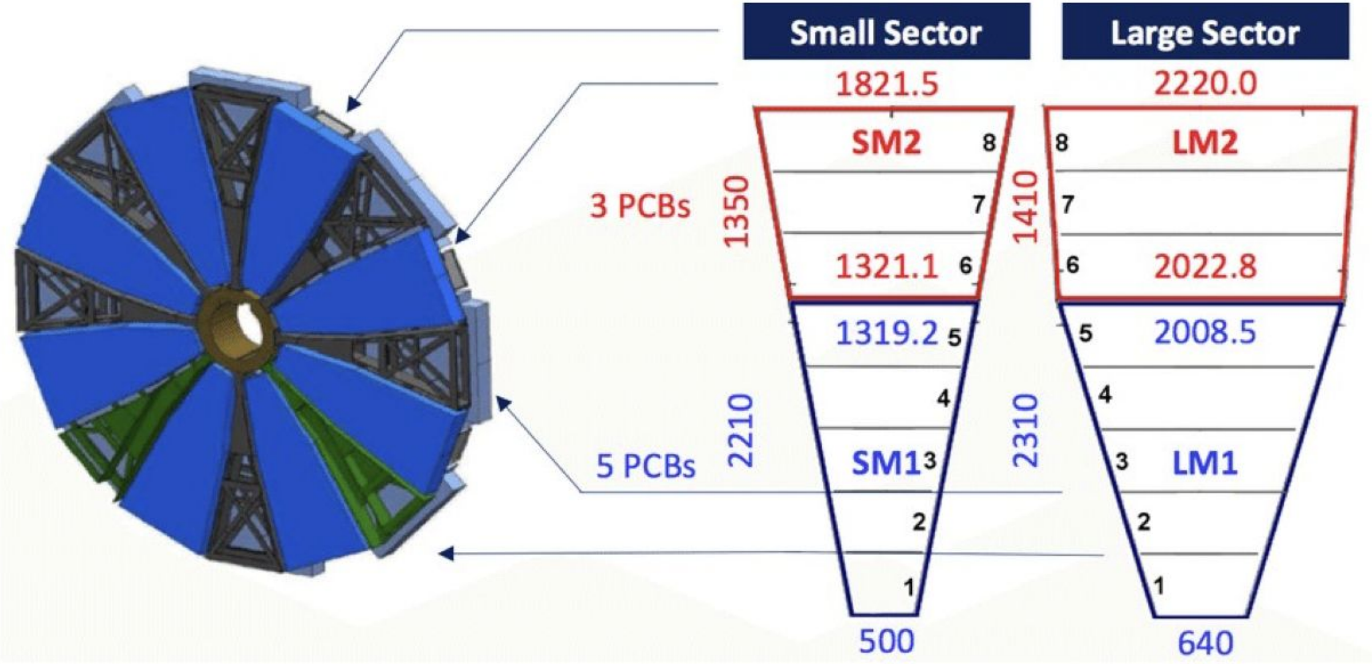
MM Trigger finally fully operational in 2024
- taking part in the ATLAS trigger decision for enhanced efficiency and increased fake rejection
- development ongoing for improve more and more the trigger segment resolutions

Tracking efficiency is at the level of 95% for MM

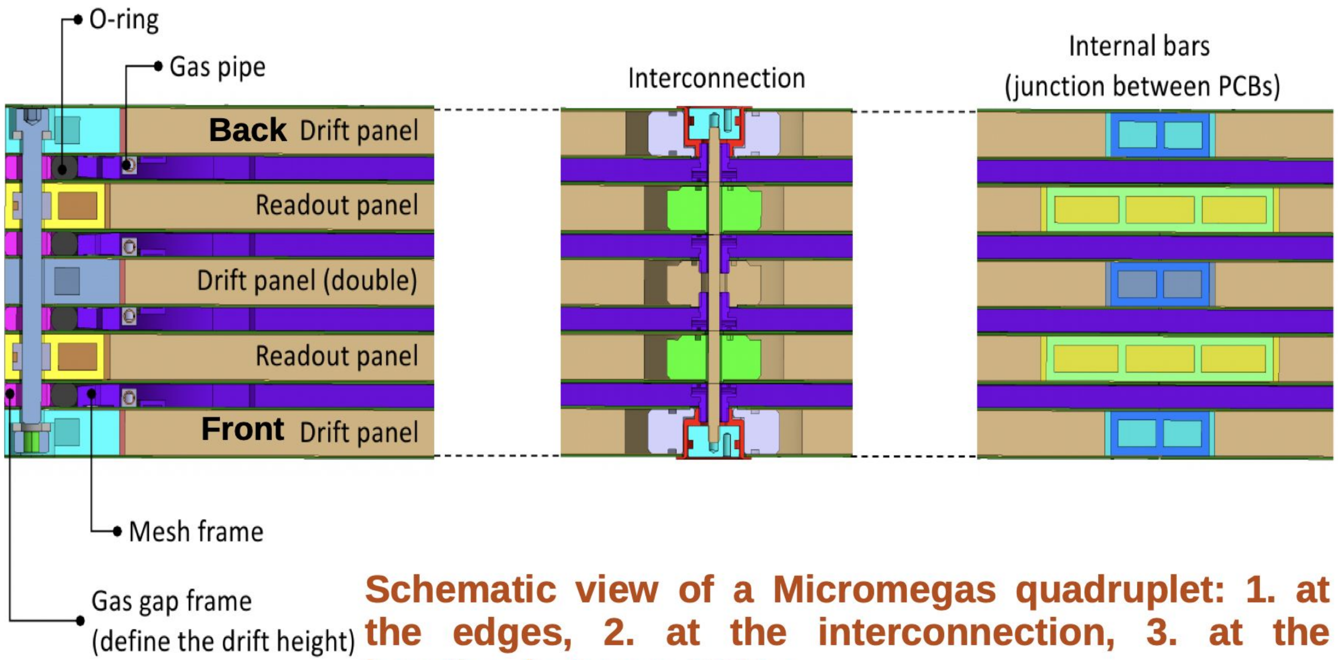
Optimization ongoing to improve resolutions: now at 200-700µm

Backup!

NSW MM - dimensions



NSW MM - structure



Schematic view of a Micromegas quadruplet: 1. at the edges, 2. at the interconnection, 3. at the junction between PCBs.

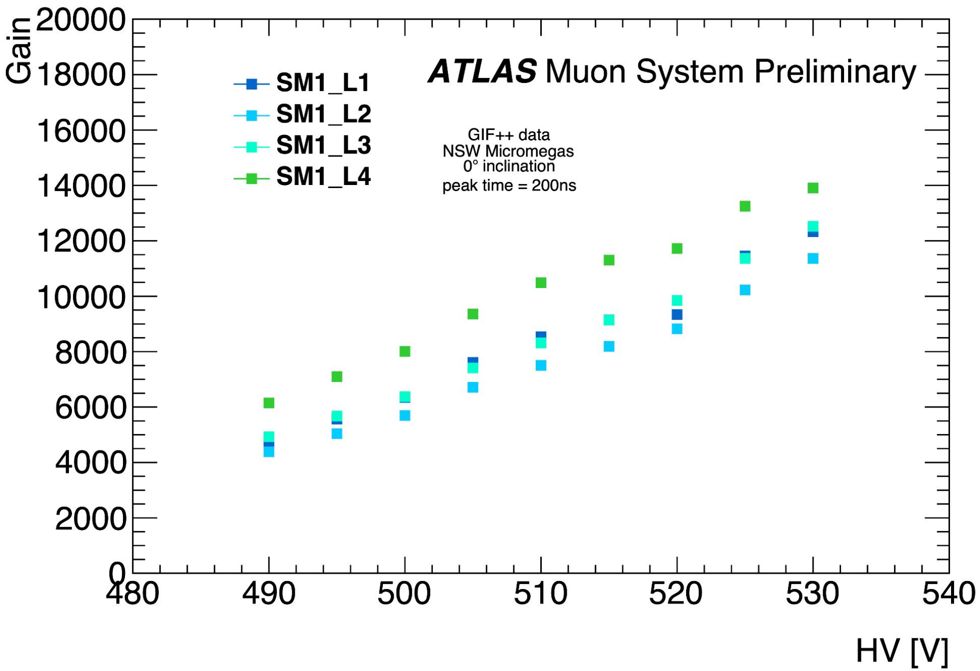
GIF++ - gain

VMM settings:
- threshold x9 RMS
- peak time = 200 ns
- neighbour logic
o
ff

Cluster definition:
- minimum 1 firing strip
- 2 holes allowed but not consecutive

Gain is calculated from the ratio between the mean cluster charge in fC and average number of ionization electrons produced by a 120 GeV muon in 5 mm:

Gain = <cluster charge>/50e



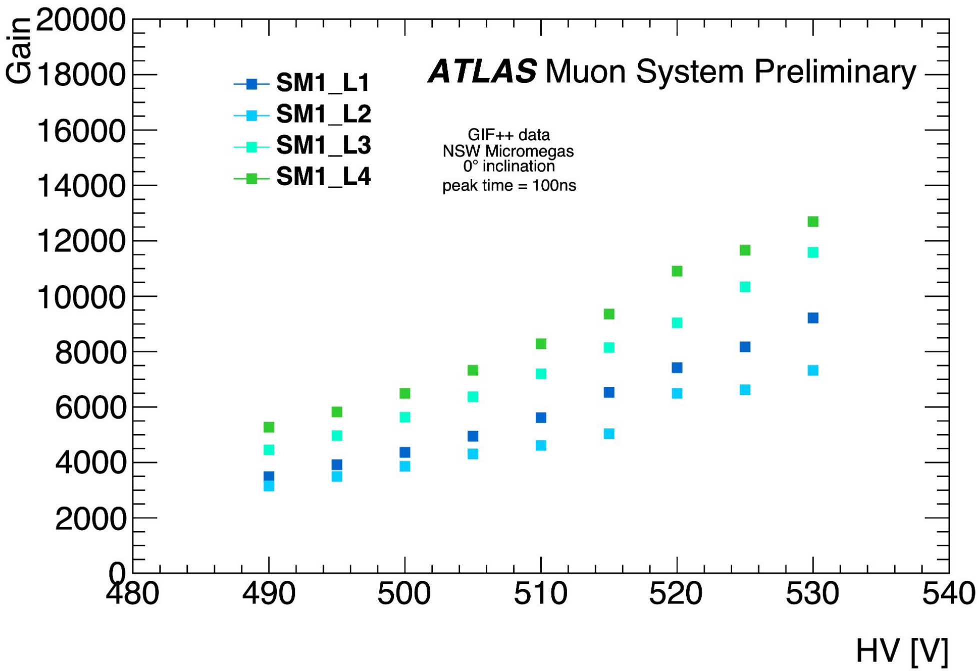
GIF++ - gain

VMM settings:
- threshold x9 RMS
- peak time = 100 ns
- neighbour logic
o
ff

Cluster definition:
- minimum 1 firing strip
- 2 holes allowed but not consecutive

Gain is calculated from the ratio between the mean cluster charge in fC and average number of ionization electrons produced by a 120 GeV muon in 5 mm:

Gain = <cluster charge>/50e

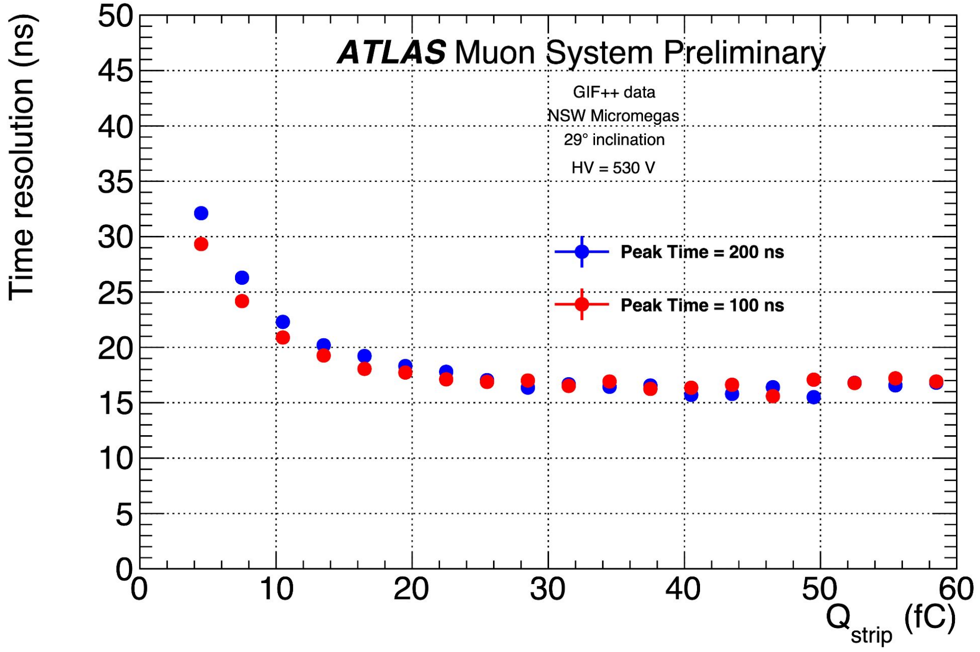


GIF++ - time resolution

VMM settings:
- threshold x9 RMS
- peak time = 200 ns
- neighbour logic off

Cluster definition:
- minimum 1 firing strip
- 2 holes allowed but not consecutive

The time resolution recipe:
- take on-track clusters
- get the residuals of their times vs expected drift time
- gaussian fit and extract std. dev.



GIF++ - resolution vs irradiation