ATLAS New Small Wheel Performance Studies with LHC Run3 data

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Carleton University

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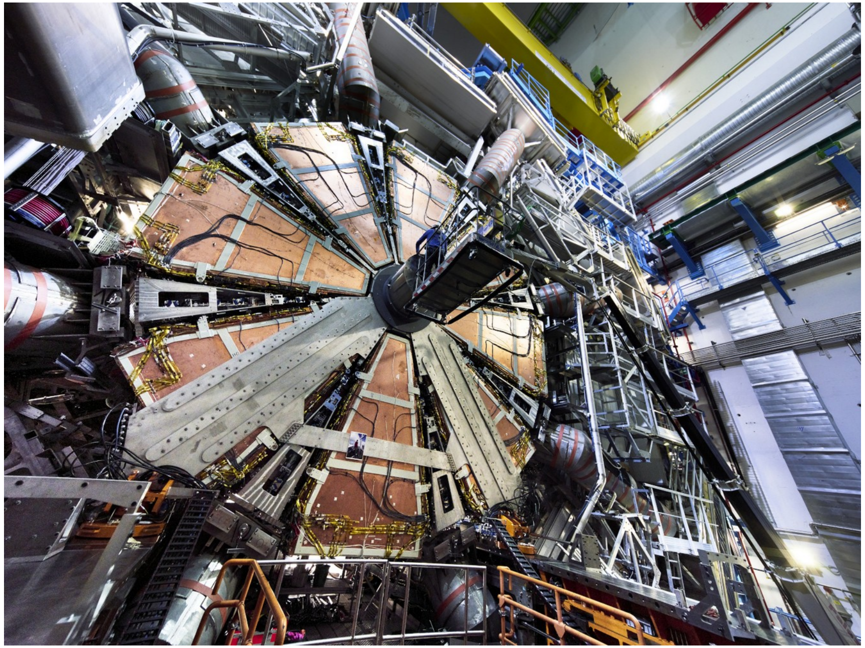
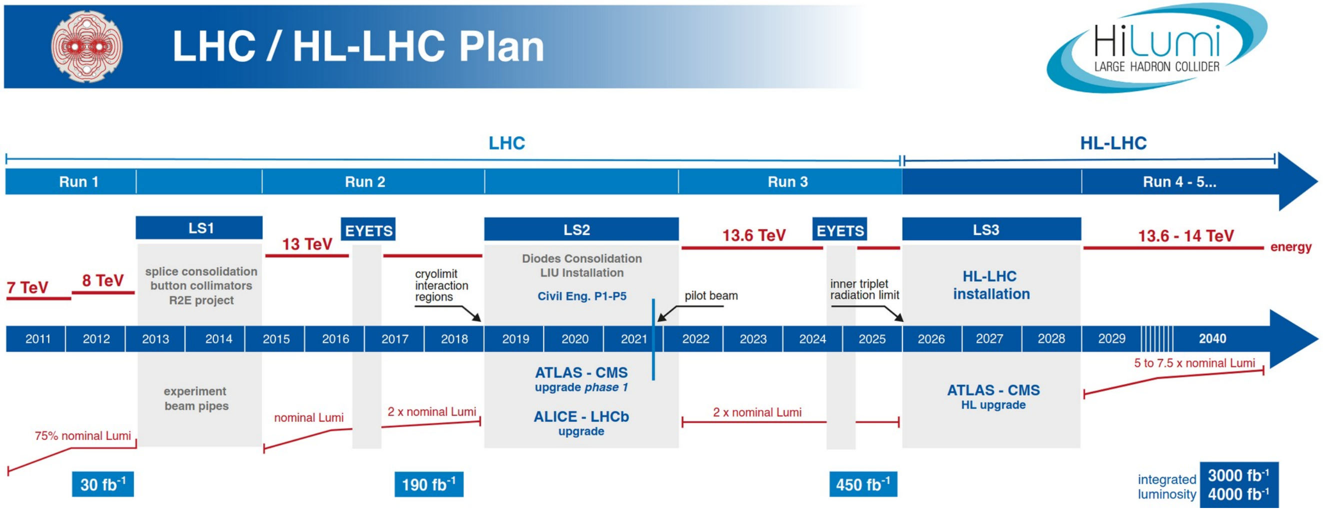


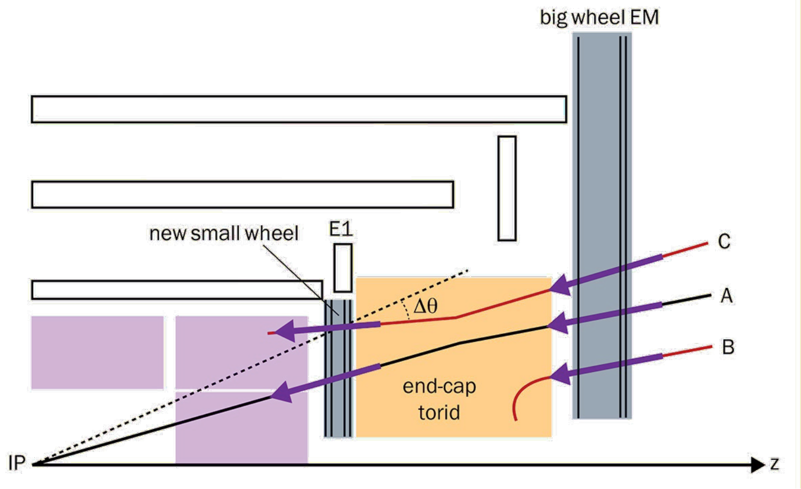
LHC Upgrades

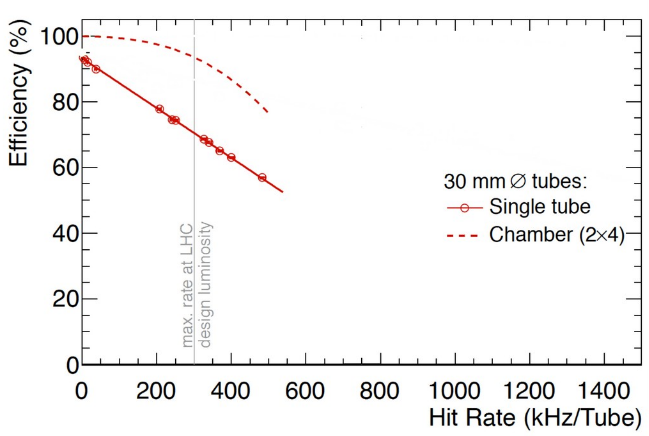
- LHC undergoes several updates to reach higher luminosity
- Ultimate goal after LS3 (2026-2028): L ~ 5-7.5x10^{34} $cm^{-2}s^{-1}$ (about 140-200 p+p interactions per bunch crossing)
- Experiments need to be upgraded in order to deal with the increased instantaneous luminosity

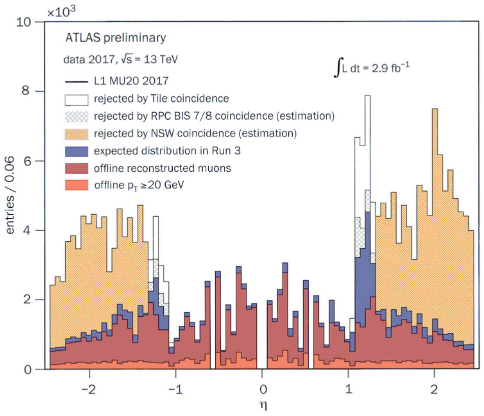


Motivation for the New Small Wheel

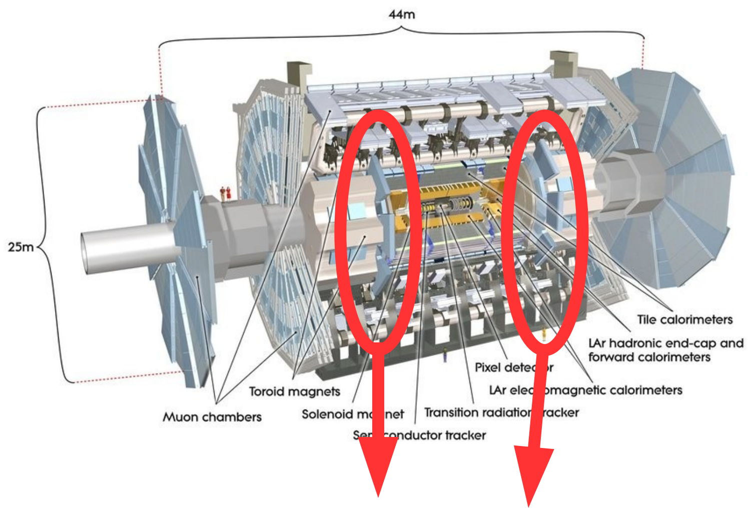
- Goals of the NSW:
  - Reduce muon fake trigger rate in end-cap region
  - Provide precise tracking despite high background particle rate
- Requirements on the NSW:
  - Provide an online segment angle measurement of 1 mrad precision to validate trigger by big wheel
  - Muon <σ_{Pt}/Pt> < 15% @ 1Tev → 150-175 μm single layer resolution

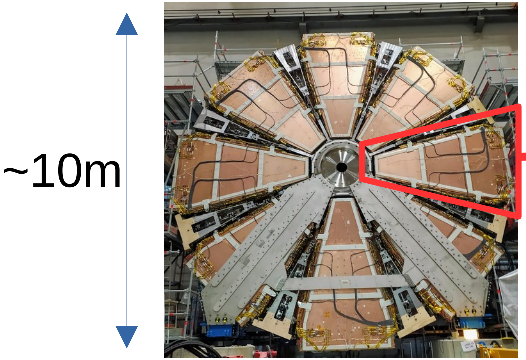


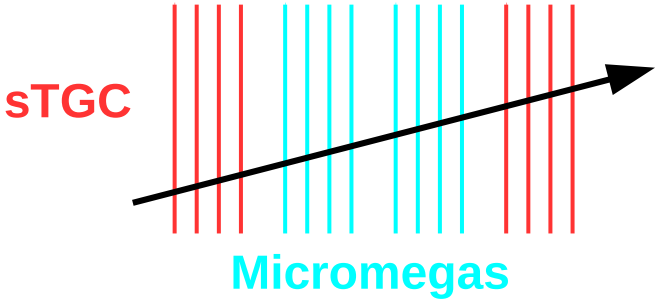




NSW Structure

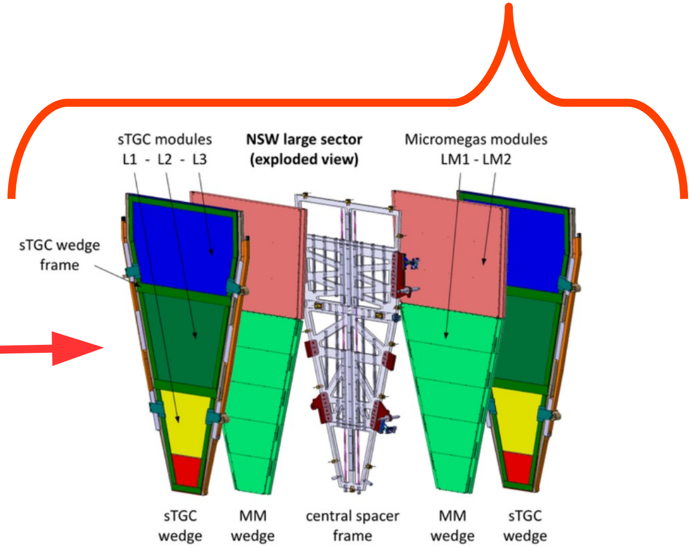






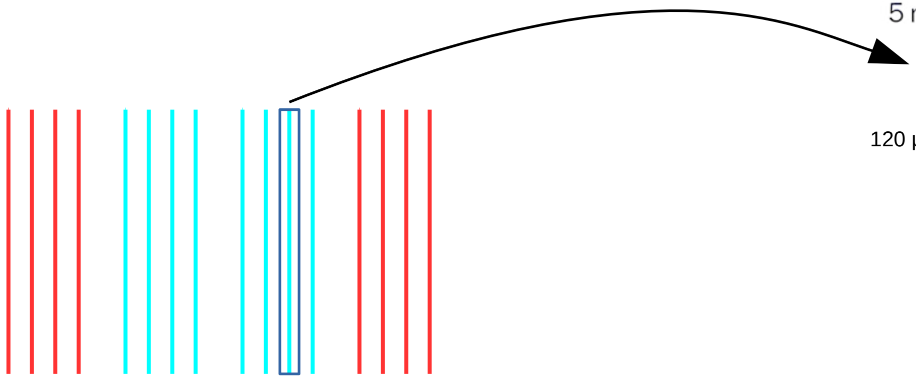
- 16 active layers
- 2 technologies

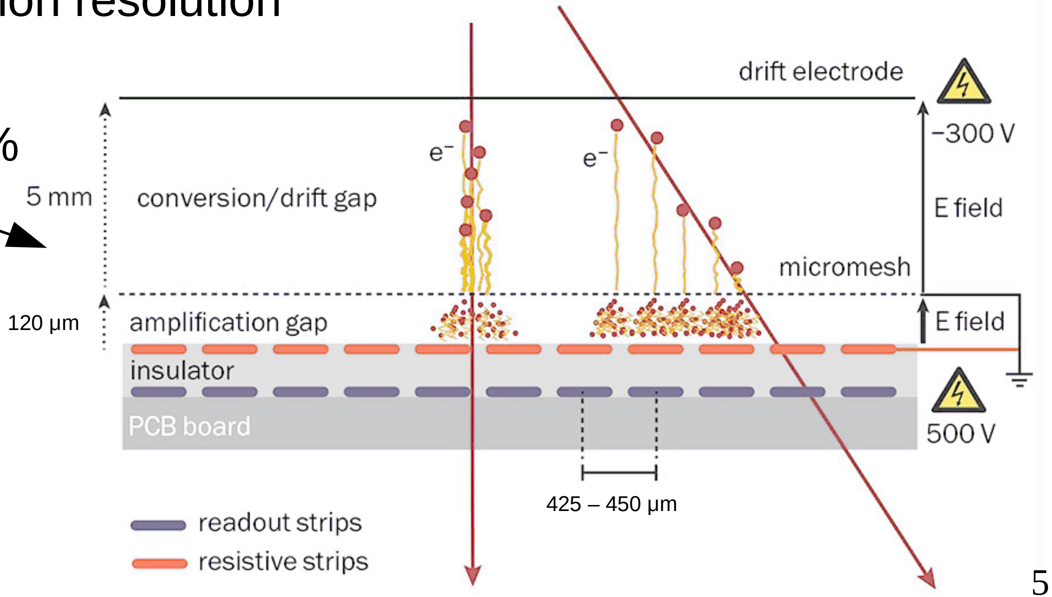
→ high redundancy



Micromegas

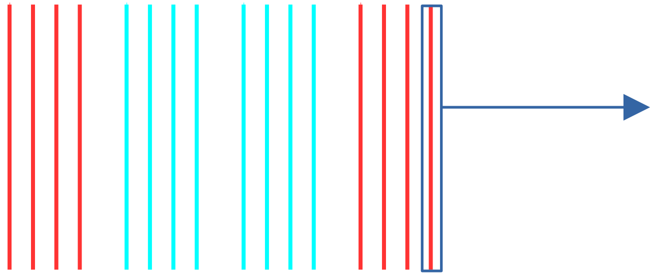
- Micromegas = Micro Mesh Gaseous Structure
- Two gas gaps: separated by stainless steel mesh
- 120 μm thin amplification gap → high rate capability
- Narrow readout strips → excellent position resolution
- Resistive layer → spark protection
- Gas mixture: $Ar:CO_2:iC_4H_{10}$ 93%:5%:2%

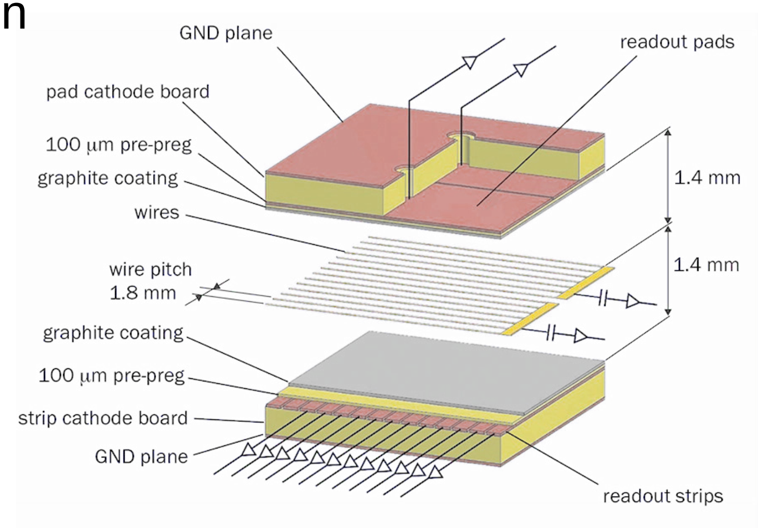




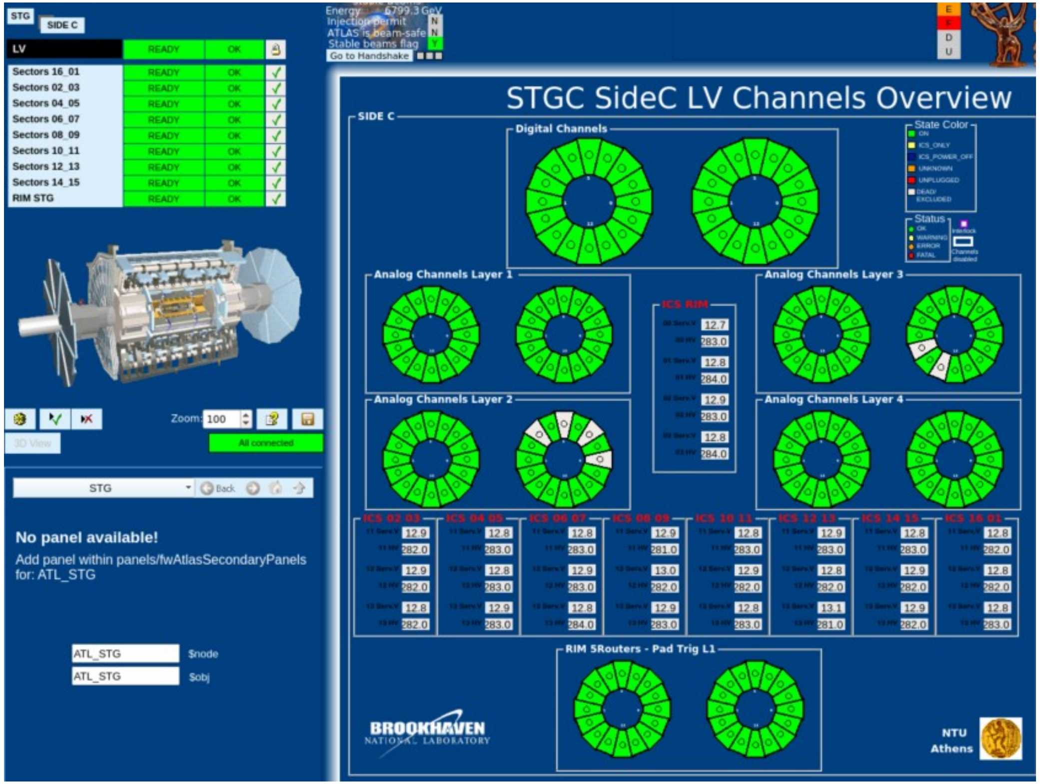
small-strip Thin Gap Chambers

- Multiwire proportional chamber with pad/strip segmented cathodes
- Narrow gas gap for excellent time resolution → BC identification
- Pads: coarse and fast information for trigger
- Strips: excellent spatial resolution for trigger and offline track reconstruction
- Wires: provide 2nd coordinate in offline reconstruction
- Operating gas: 55%:45% CO_2:n-pentane





NSW Integration into ATLAS



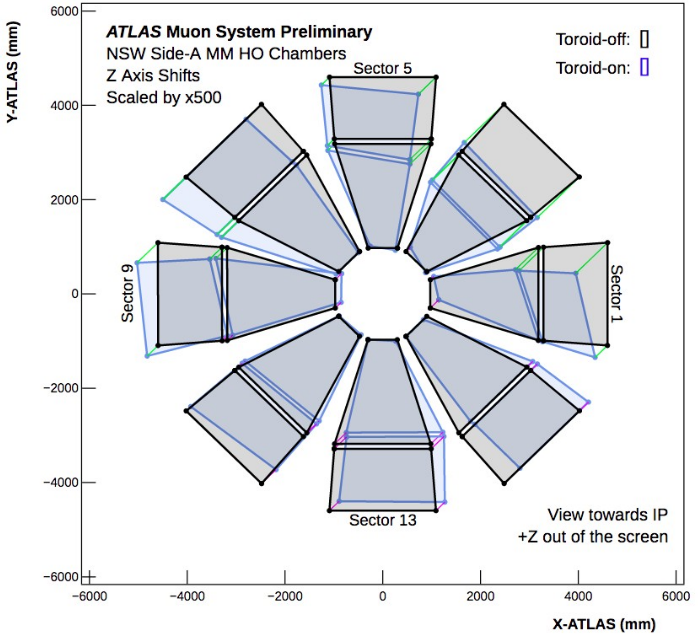
- Both NSWs are fully integrated into the ATLAS TDAQ and Detector Control Systems since the start of run 3 (2022)

Alignment

- Movement/deformations of ATLAS muon spectrometer monitored by optical alignment system
- Absolut alignment determined from mechanical surveys and toroid off runs
- Both NSWs tilt up to 2.7 mm (on average 1mm) when toroid is switched on

[µm]	$\sigma_{\text{ali}}(\mu_0)$	$\sigma_{\text{ali}}(\mu_\theta)$	$\sigma_{\text{ali}}(\mu_\phi)$	$\sigma_{\text{ali}}(\text{total})$
BA large	25 ± 2	9 ± 1	10 ± 1	29 ± 2
BA small	25 ± 4	19 ± 3	21 ± 4	38 ± 4
EC large	69 ± 3	20 ± 1	28 ± 2	77 ± 2
EC small	95 ± 4	28 ± 2	26 ± 2	103 ± 3
EE large	106 ± 10	22 ± 3	52 ± 6	121 ± 9
EE small	66 ± 9	36 ± 9	58 ± 8	94 ± 9
BEE	59 ± 8	50 ± 7	33 ± 6	84 ± 7

Endcap aligned with <= 100um precision, further improvements under study



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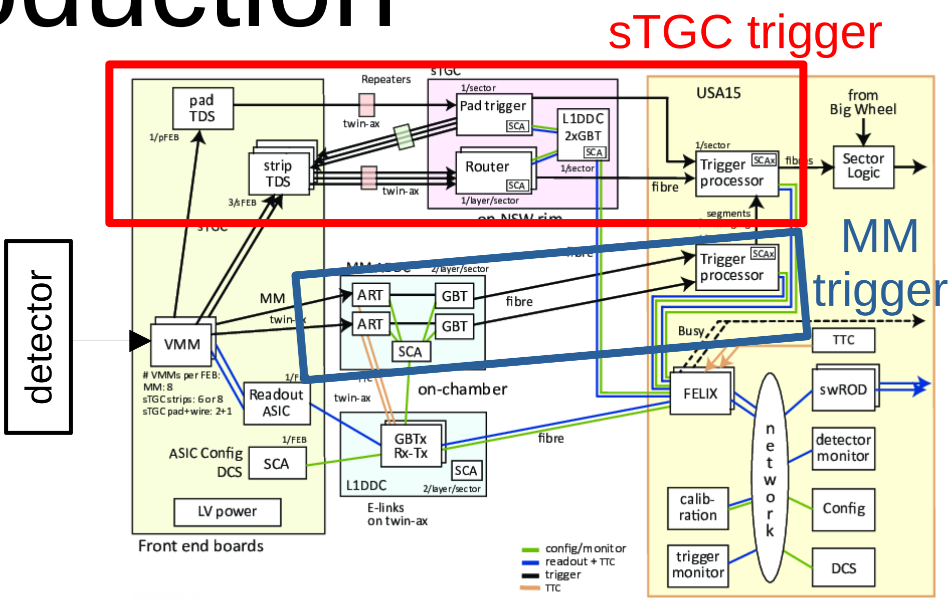
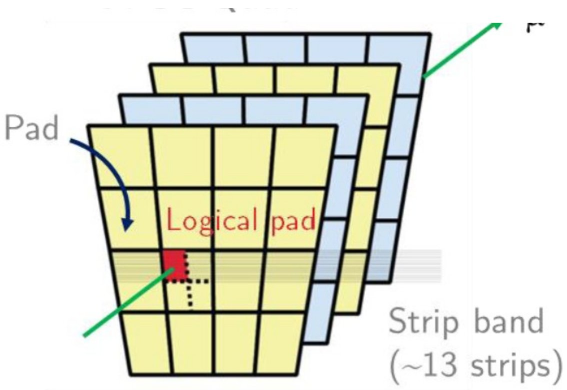
Trigger Introduction

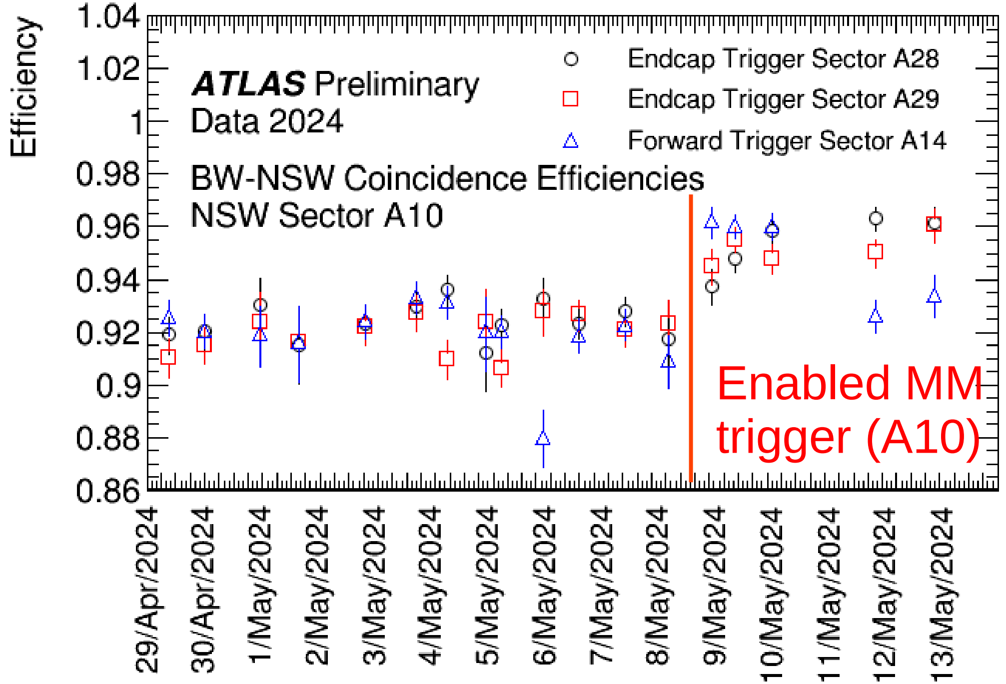
- Two sTGC trigger levels:
  - Pad trigger: fast coarse information, seeds strip trigger (deployed in 2023 data taking)
  - Strip trigger: Reconstructs strip cluster and uses them for precise measurement of the segment angle (under commissioning, needed for HL-LHC)
- Independent MM trigger (recently deployed)
- Merged MM and sTGC trigger segments forwarded to sector logic





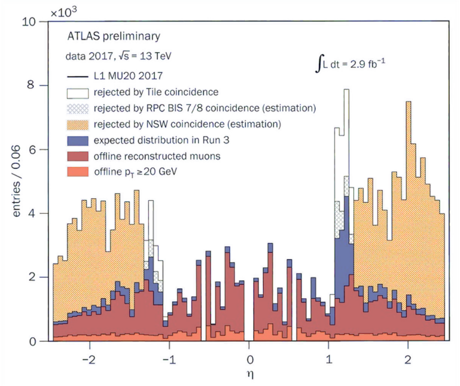
Trigger Efficiency

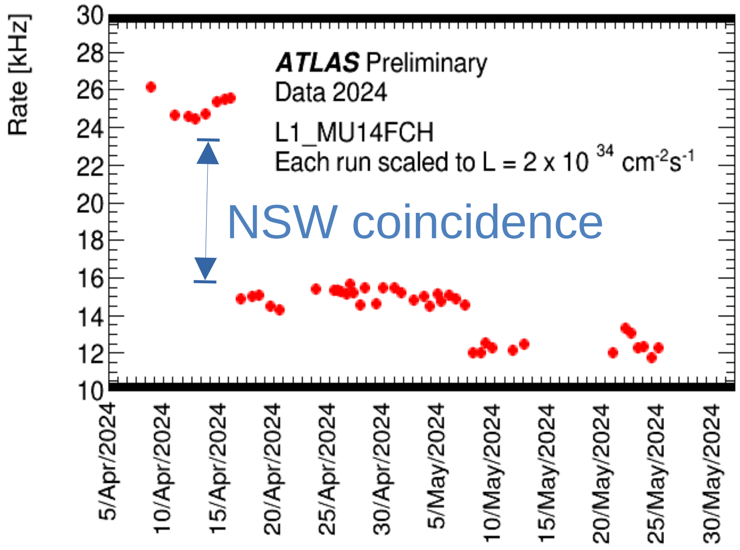
- 2024 data taking started with NSW Pad trigger coincidence → efficiency loss of 8% by invoking the NSW in the coincidence expected due to geometrical reasons and local inefficiencies
- Enabling Micromegas, in the NSW trigger (merging of sTGC Pad and MM segments) improves efficiency

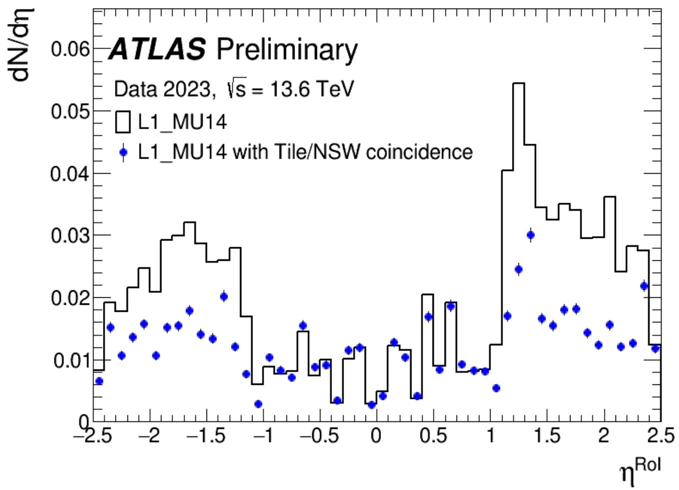


Pad Trigger Results cont.

- Coincidence between TGC Big Wheel, Tile calorimeter and NSW reduced Muon L1 rate by 13 kHz
- Including the MMs (21st of May) increased rate by 1 kHz but also improved efficiency

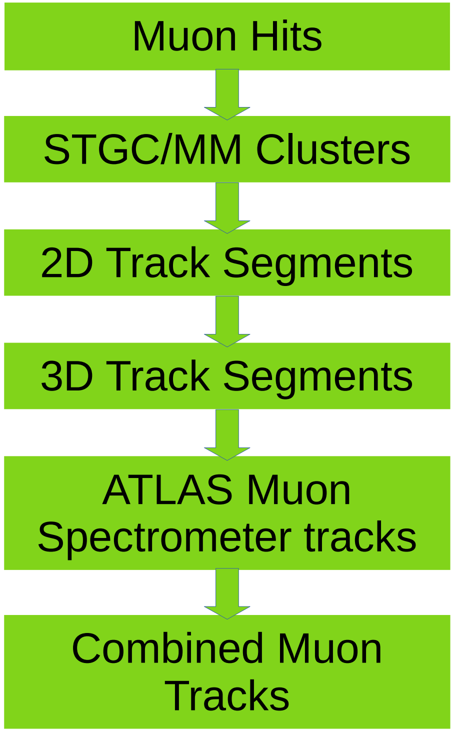


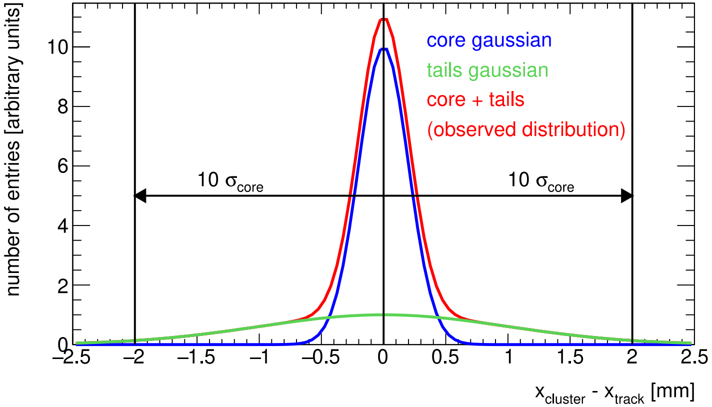


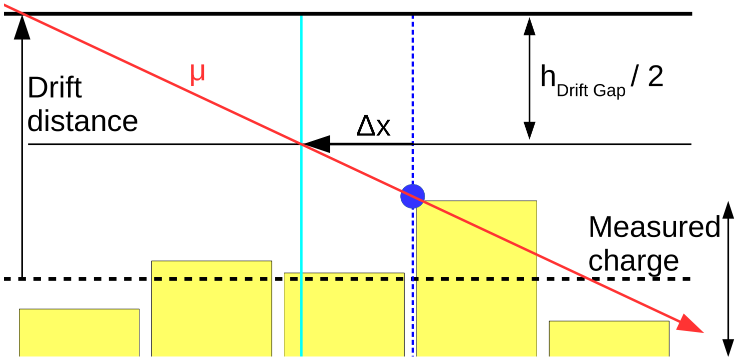


Muon Reconstruction

- The NSW is fully integrated into the ATLAS simulation and reconstruction software athena





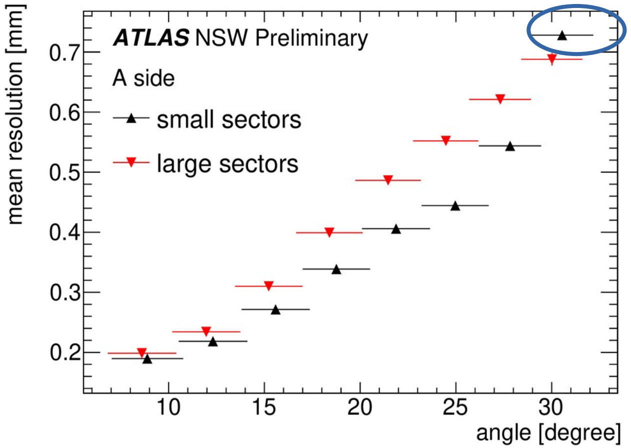


- Resolution extracted with double Gaussian fit to track or layer residual; quoting core Gaussian
- Alternative method: Quote 68% confidence interval
- Cluster position currently reconstructed by charge centroid
- Improved methods under study

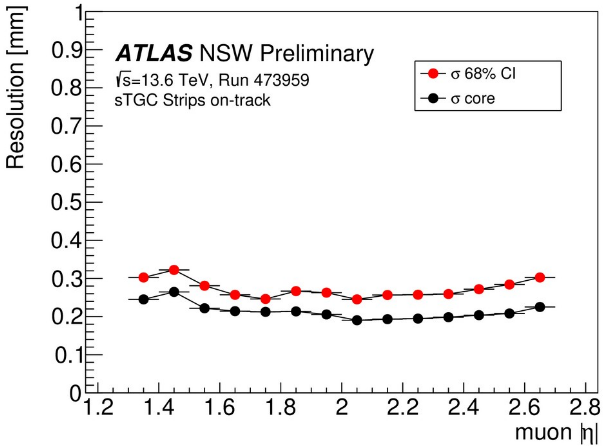
Reco Resolution

- Single layer resolution still sub-optimal:
  - Affected by layer-layer misalignment and residual global misalignment
  - Huge improvement expected once those corrections are in place; efforts ongoing
  - Further improvements expected from improved cluster position reconstruction methods (MM: use time information; sTGC: fit charge profile with gaus/parabola)

MM spatial resolution between clusters on two back to back layers

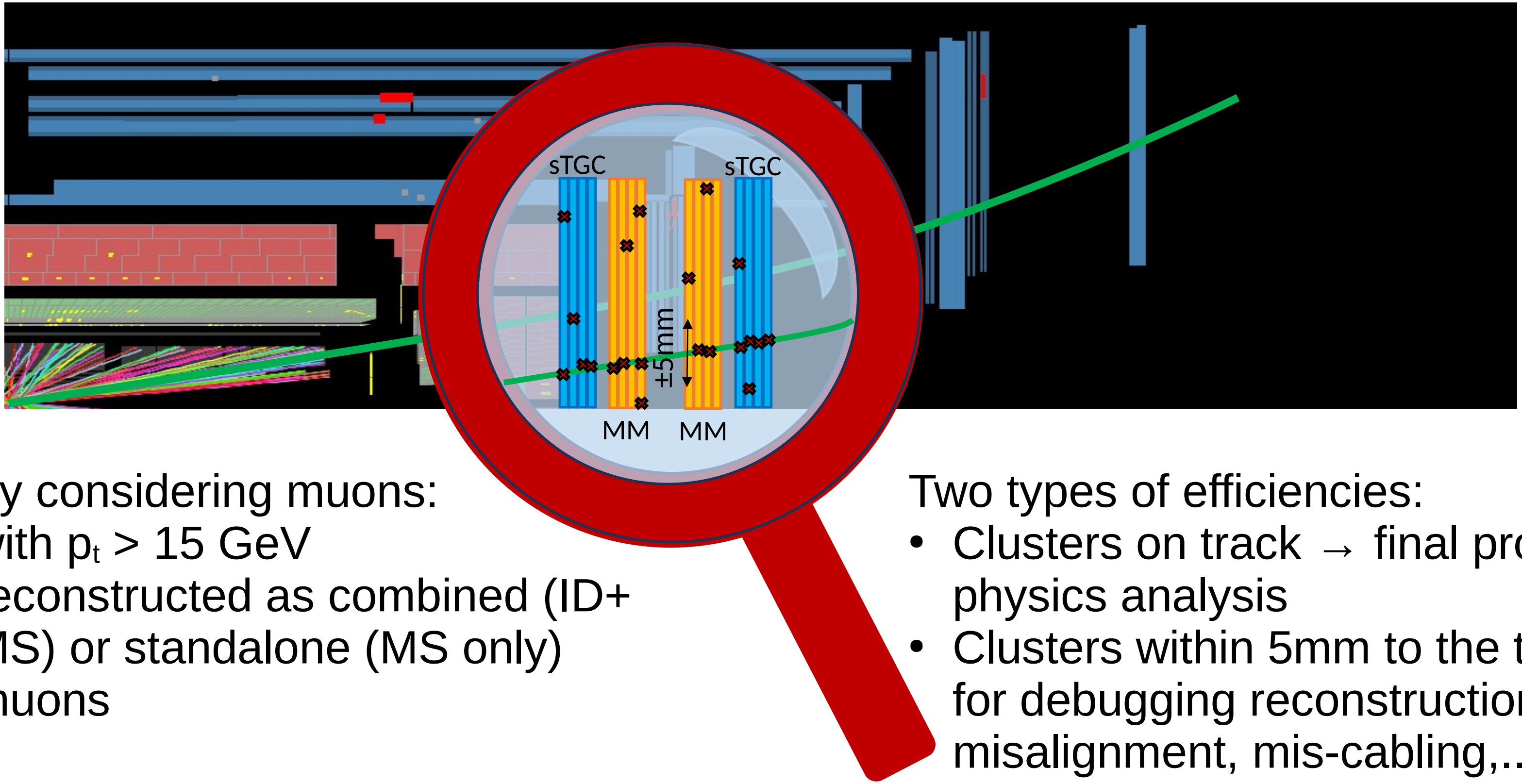


B-Field effect; correction under study



sTGC spatial resolution between a cluster and a combined muon track

Efficiency Measurement



- Only considering muons:
  - with $p_t > 15$ GeV
  - reconstructed as combined (ID+ MS) or standalone (MS only) muons

Two types of efficiencies:

- Clusters on track → final product for physics analysis
- Clusters within 5mm to the track → useful for debugging reconstruction and initial misalignment, mis-cabling,...

+- 5 mm

MM Single Layer Efficiency

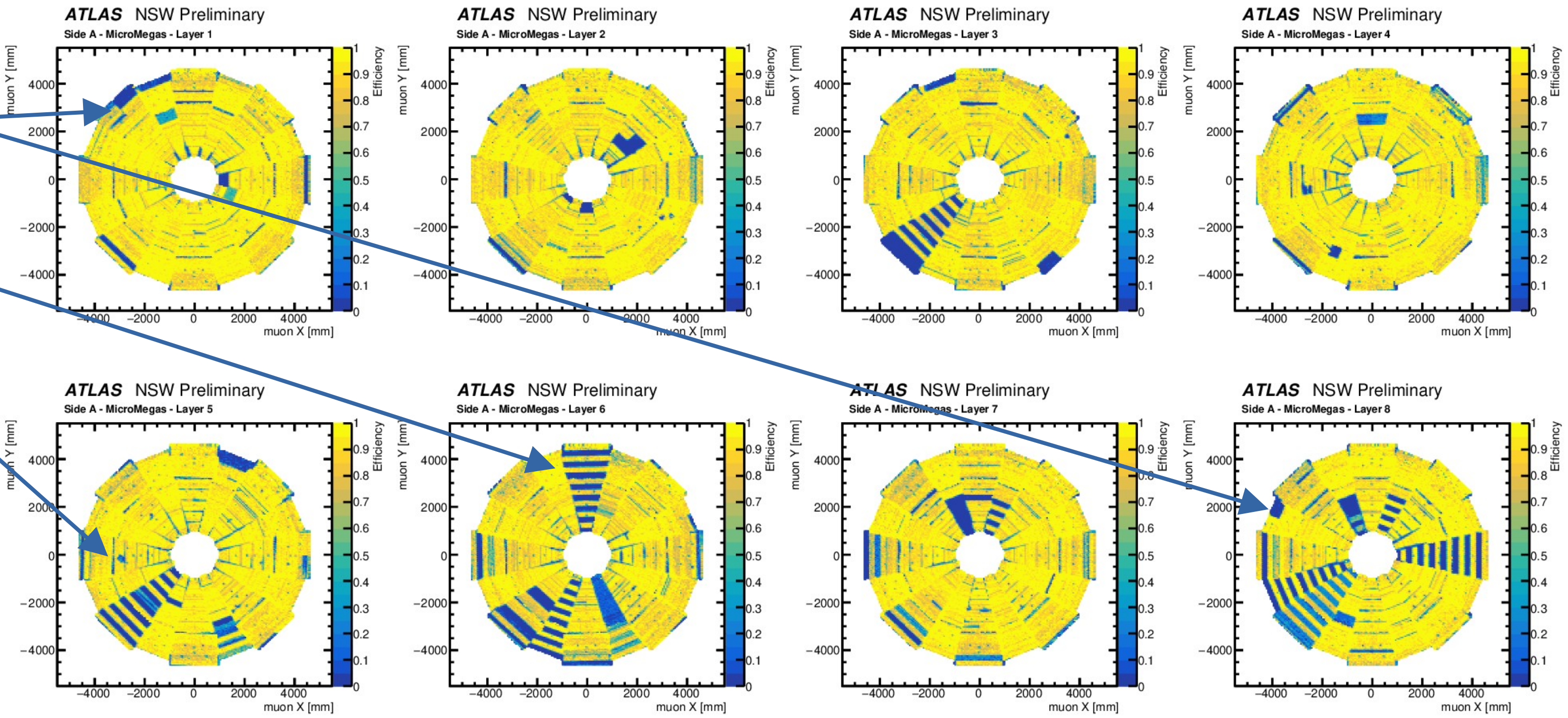
- Inefficient regions due to LV/HV/readout problems
- Efficiency > 90% for regions not affected by above problems

Data taken in April 2024

Half HV section disconnected

LV / readout board problem

Local defects



Readout stability strongly improved compared to 2023

+- 5 mm

sTGC Single Layer Efficiency

- Inefficient regions due to LV/HV/readout problems
- Efficiency > 90% for regions not affected by above problems

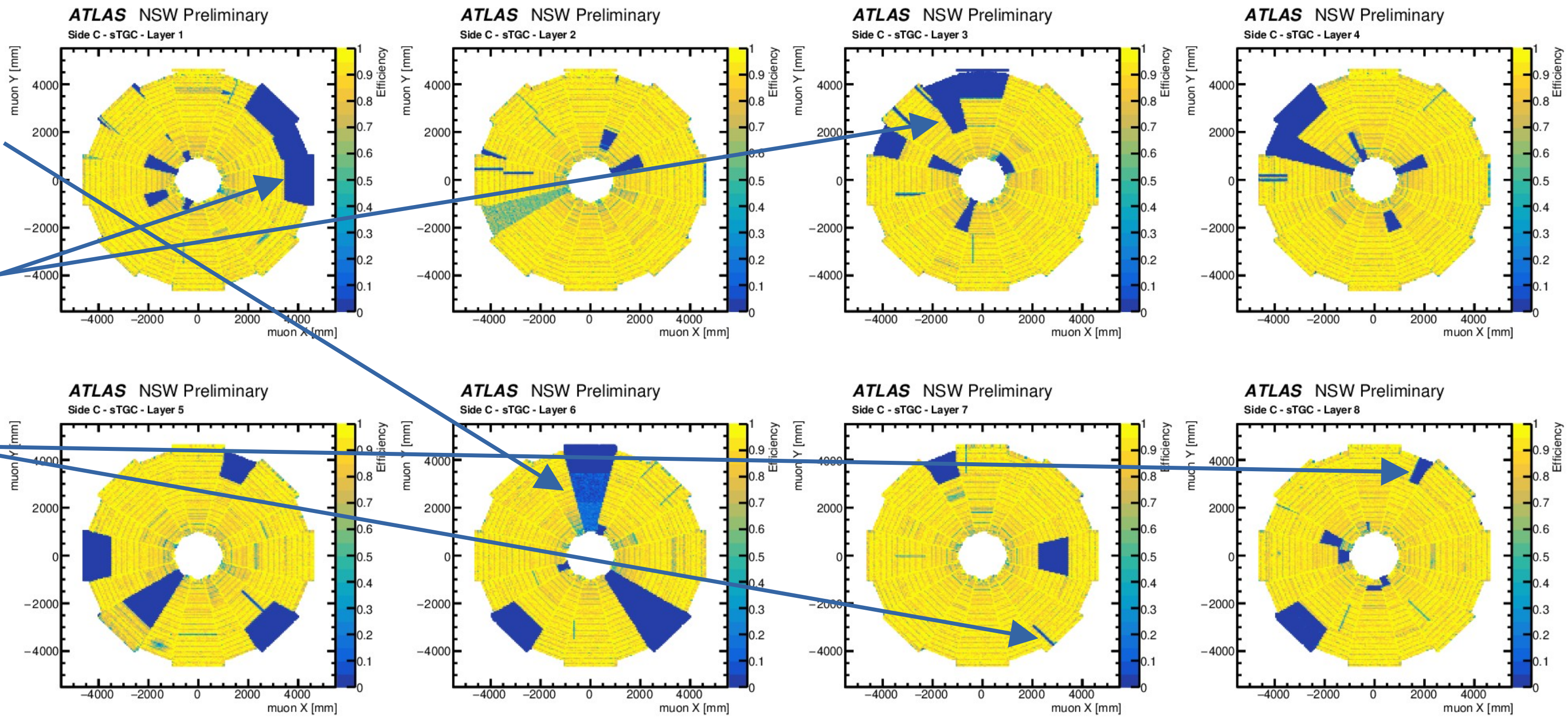
Data taken in April 2024

HV trip or readout dropped during run

HV/ LV / readout board problem

Wire group disconnected

Readout stability strongly improved compared to 2023



on track

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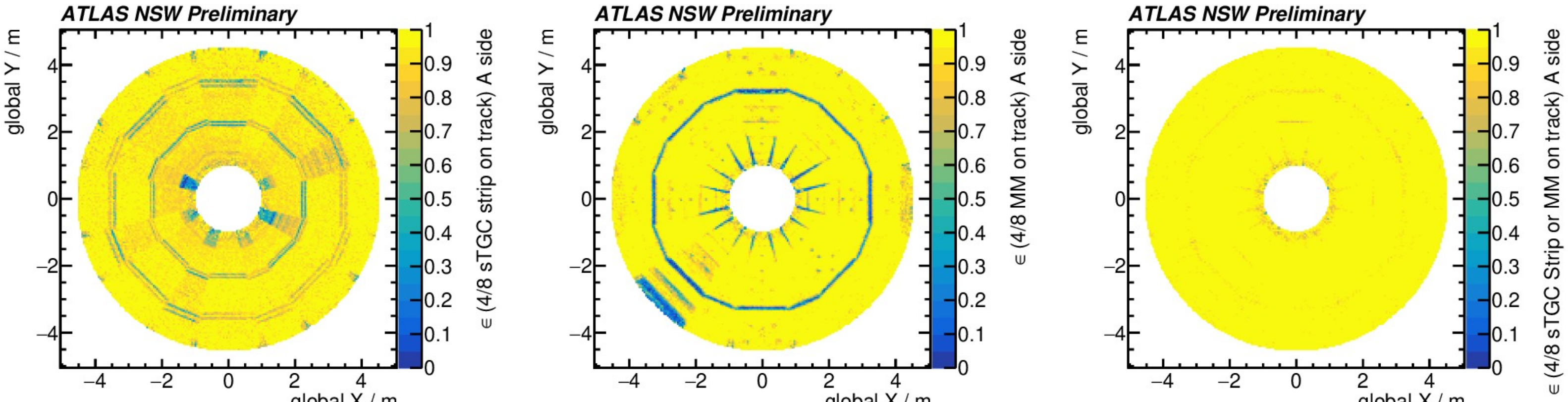
NSW for Physics Analysis

- Physics working points require a definition of having a NSW segment contributing to the reconstructed muon; e.g. require 3 stations for highPt muon WP
- Defined the OR of having 4/8 layers with a hit on track in either technology as input for the WP → makes use of the high redundancy
- Average 4/8 layers efficiency is > 95%



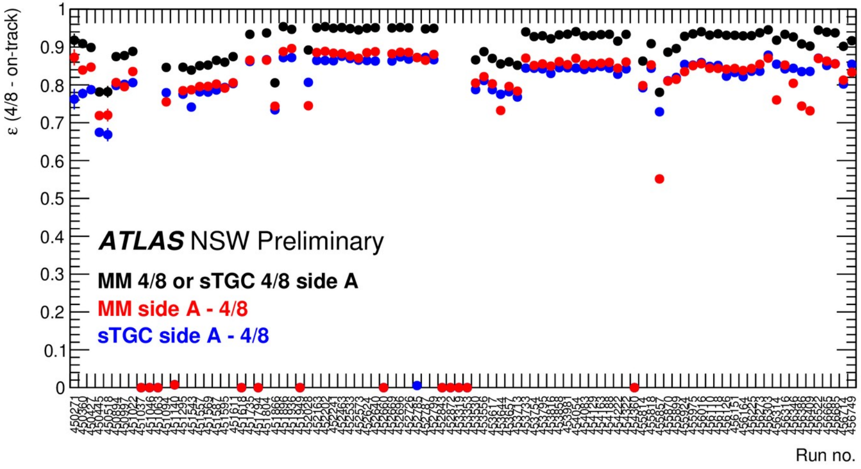
sTGC MM sTGC || MM

on track

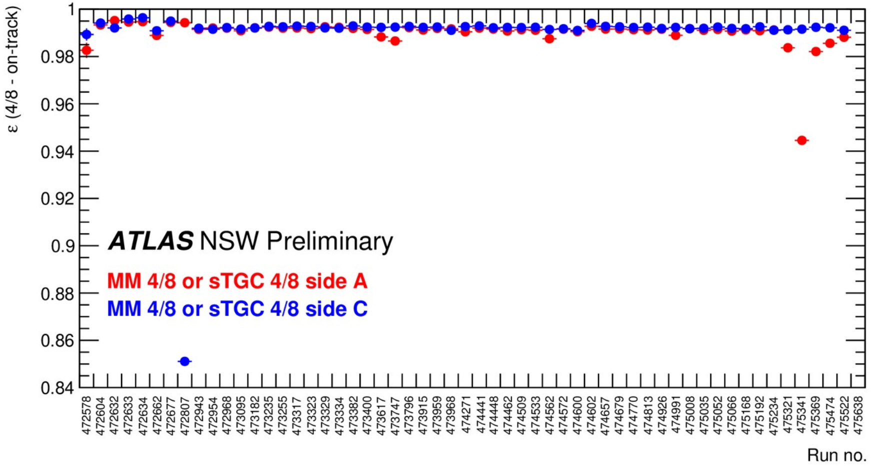
4/8 Layers Efficiency over Time

- 4/8 efficiency stable over time and > 95% (2023) and >= 99% (2024)

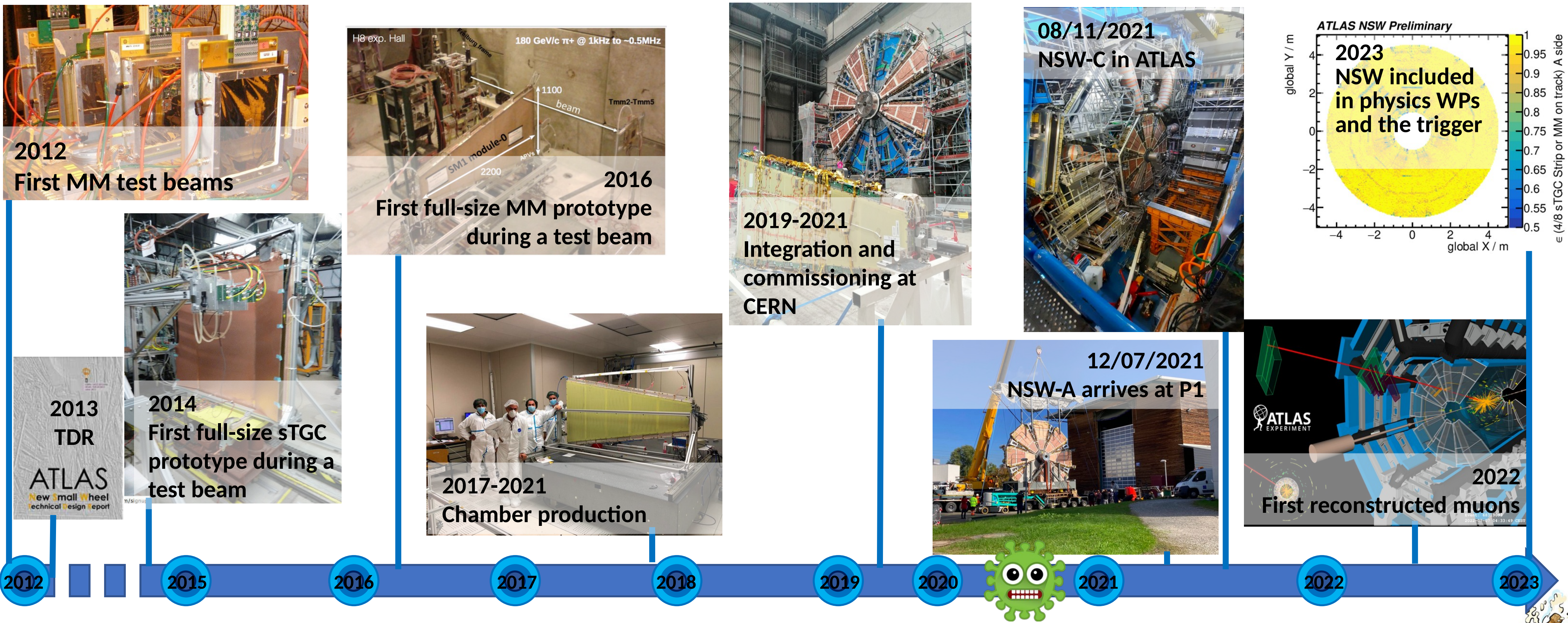
  → The NSW is contributing the ATLAS muon reconstruction with a high efficiency



March 2023 → July 2023



April 2024 → May 2024



- The NSW was one of the largest phase 1 upgrades in the LHC experiments
- Despite many problems to overcome both NSWs are installed in ATLAS → outstanding achievement
- There are still problems to be solved, but the NSW is already significantly contributing to the ATLAS muon trigger and tracking in the forward region

Backup

Background Rates

- MM detectors show higher rate than sTGCs due to higher sensitivity to photons and neutrons
- Strong dependency of the rate to the layer position along the beam line
  - Small sectors are closer to IP → show higher rate