ATLAS New Small Wheel Performance Studies After First Year of Operation

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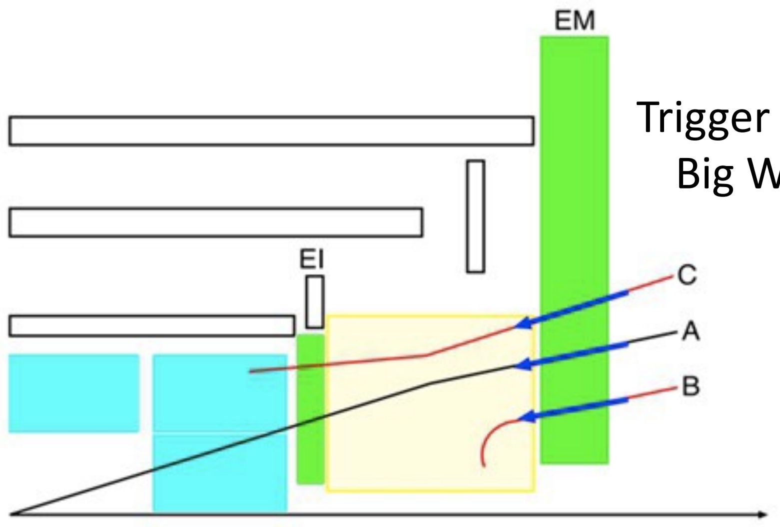
Outline

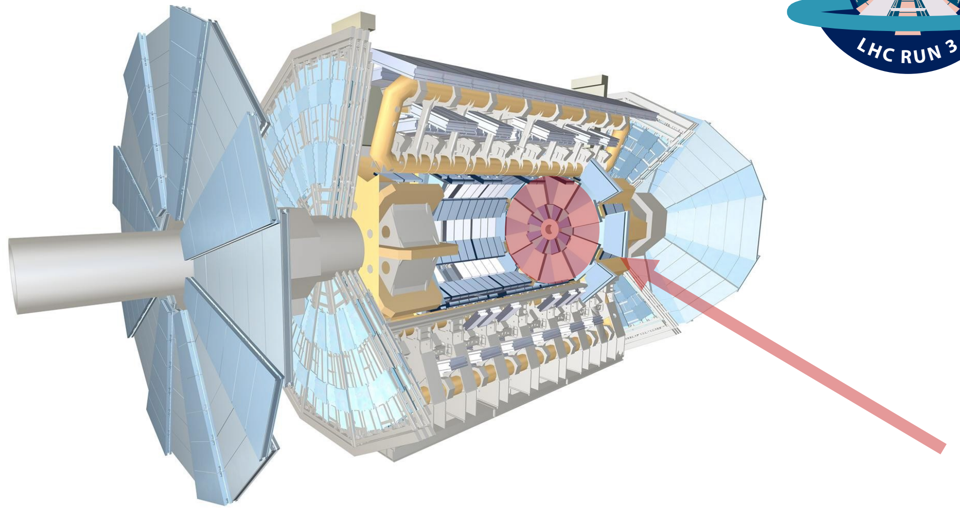
- ➢ General Introduction to New Small Wheel
- ➢ Integration and commissiong
- ➢ Alignment correction
- ➢ Particle rate measurements
- ➢ Efficiency studies
- ➢ Resolutions
- ➢ Trigger integration

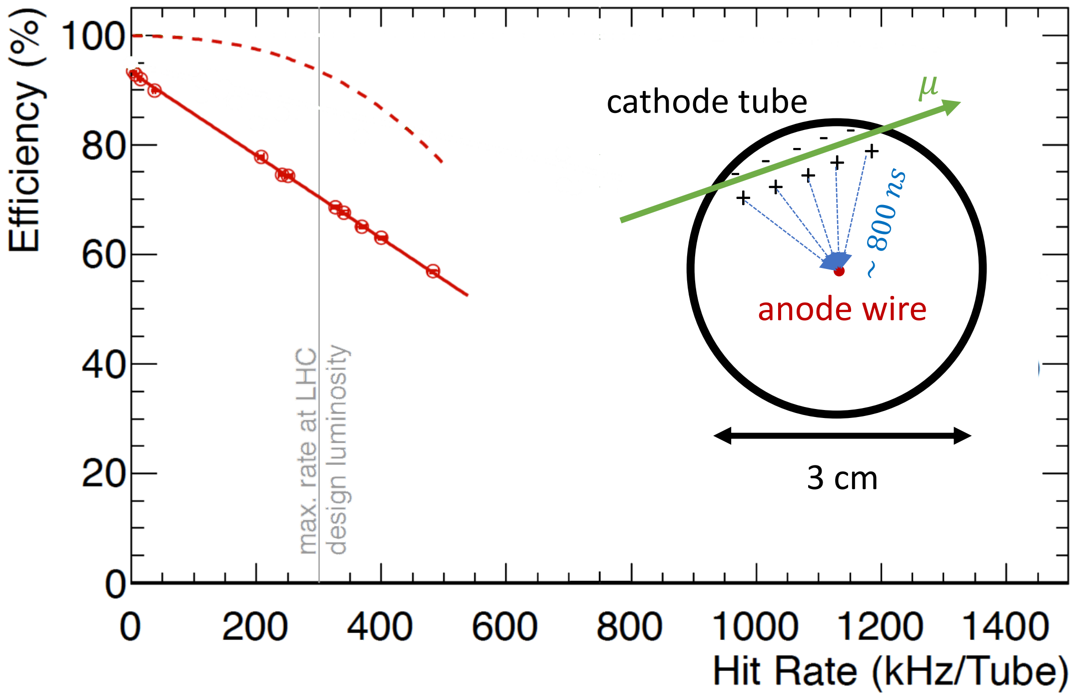
Lowering of the New Small Wheel in the ATLAS Cavern

Effects of the increase of the LHC Instantaneous Luminosity



Trigger mostly given by the Big Wheel (EM station)





➢ **Trigger**

With the ''old'' Small Wheels it is impossible to distinguish between cases:

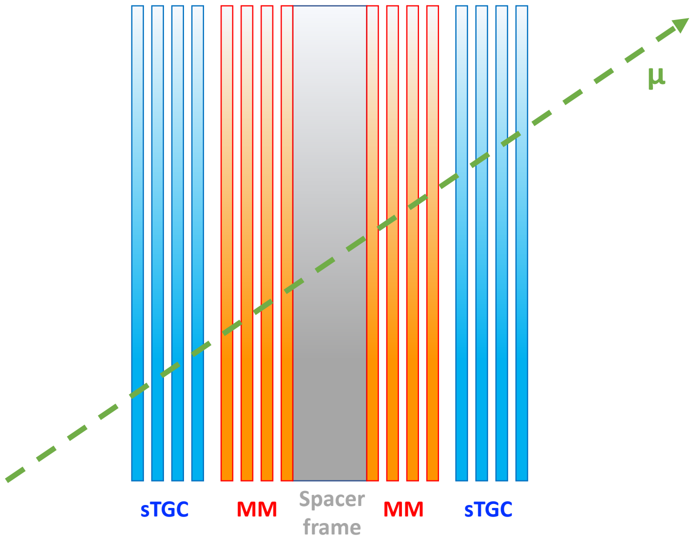
A. an high p_T track coming from the interaction point;
B. a track with low p_T created in the toroid;
C. Multiple scattering.

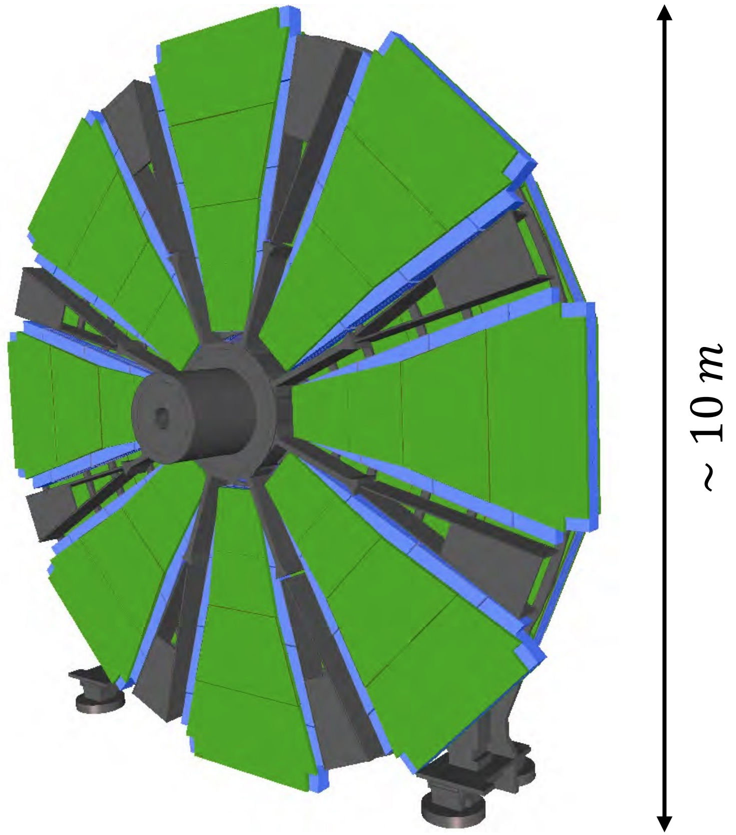
➢ **Tracking**

With the old Small Wheels the reconstruction efficiency decreases.

New Detectors are needed with trigger capabilities and to handle the high flux!

The New Small Wheel (NSW) Upgrade Project



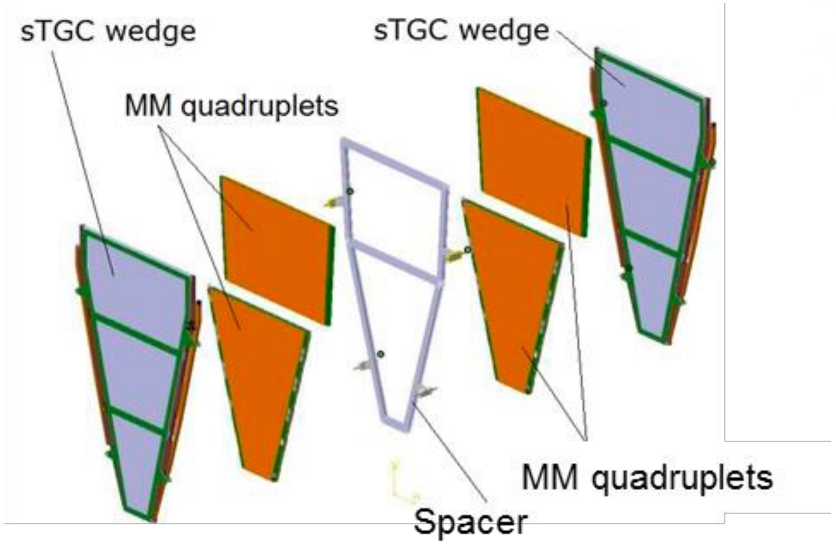


Two technologies
- **MicroMegas**
- **small strip Thin Gas Chambers** (sTGC)

8+8 layers to have redundancies and reconstruct the second coordinate

16 "petals" (8 small + 8 large)

Two wheels, one per end-cap side (side A, side C)



$$\frac{\sigma(p_T)}{p_T} < 15\% \text{ (@ 1 TeV)}$$

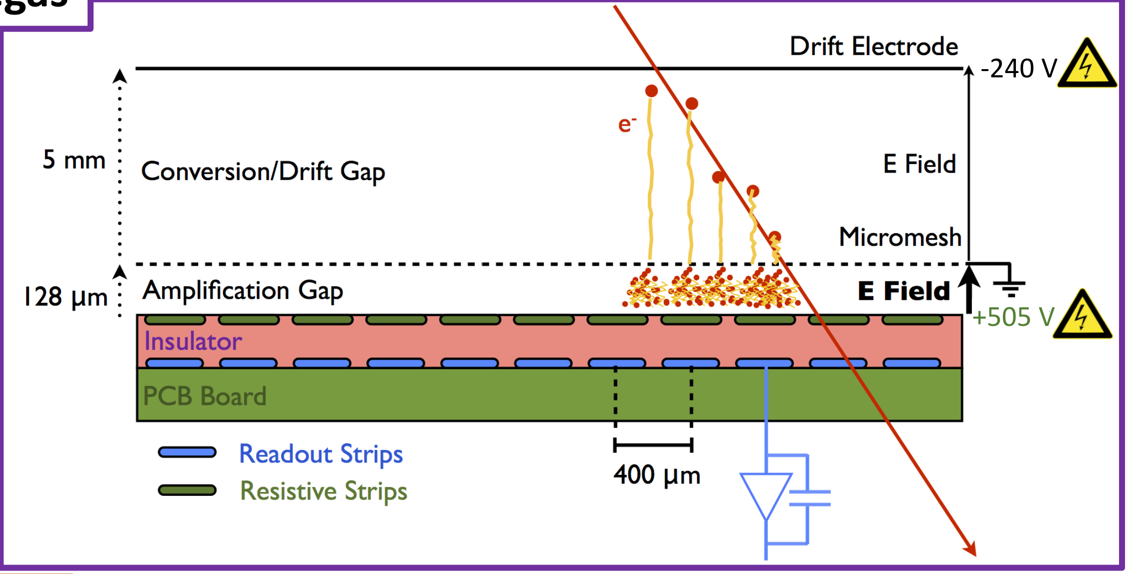
$\Longrightarrow$ single point resolution ∼100 µm

Local angular resolution for the trigger: **1 mrad**

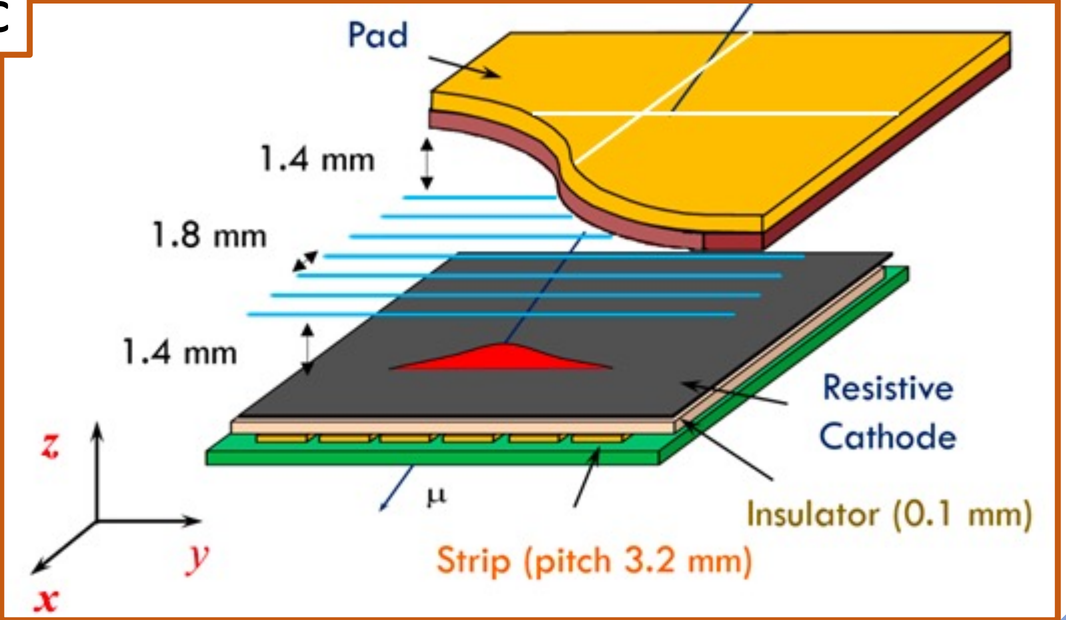
The two detector technologies

- 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

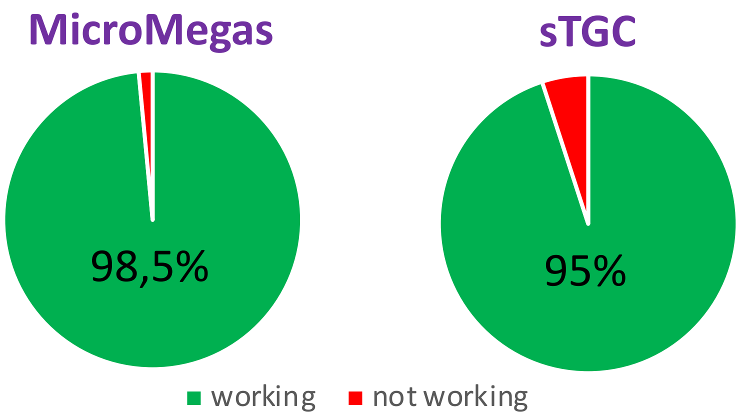


sTGC

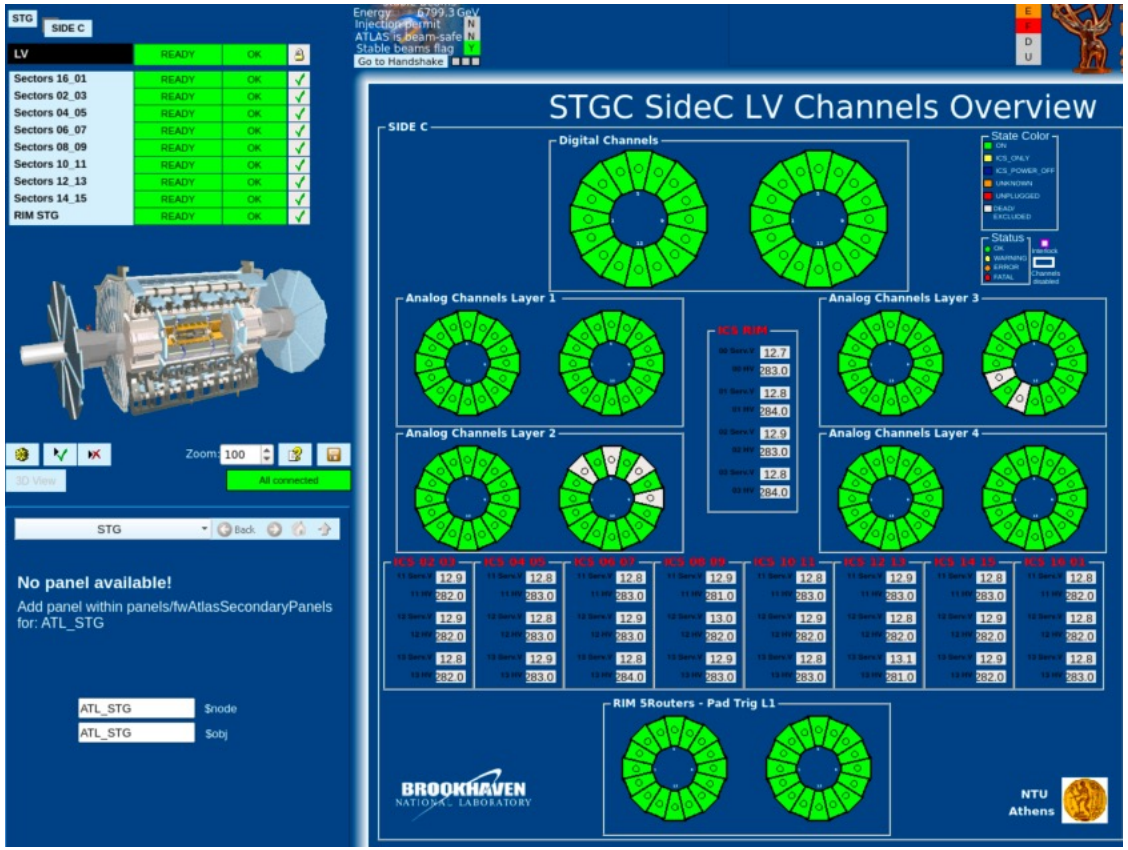


NSW status in Run3 – detector conditions

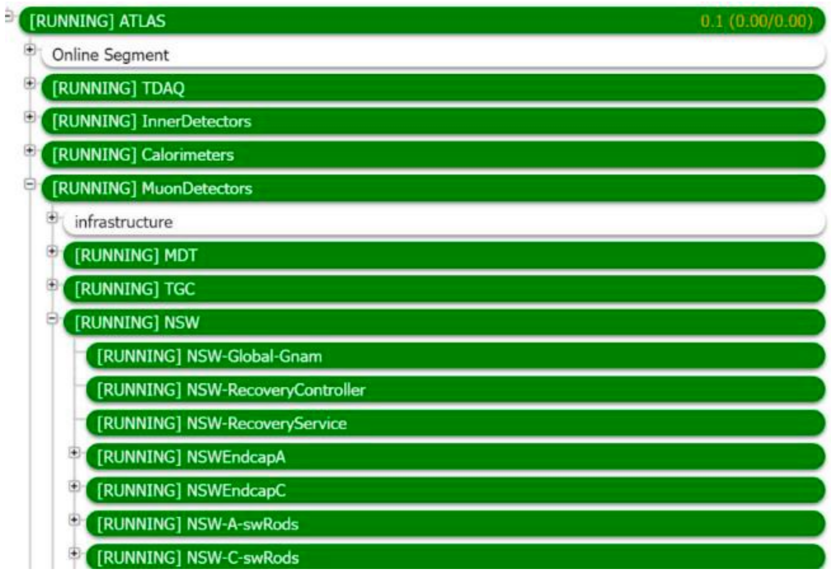
channel HV status



Inclusion of NSW DCS in the ATLAS DCS main panel



Both NSWs are interfaced in ATLAS DAQ for data-taking



Control and Monitoring for:

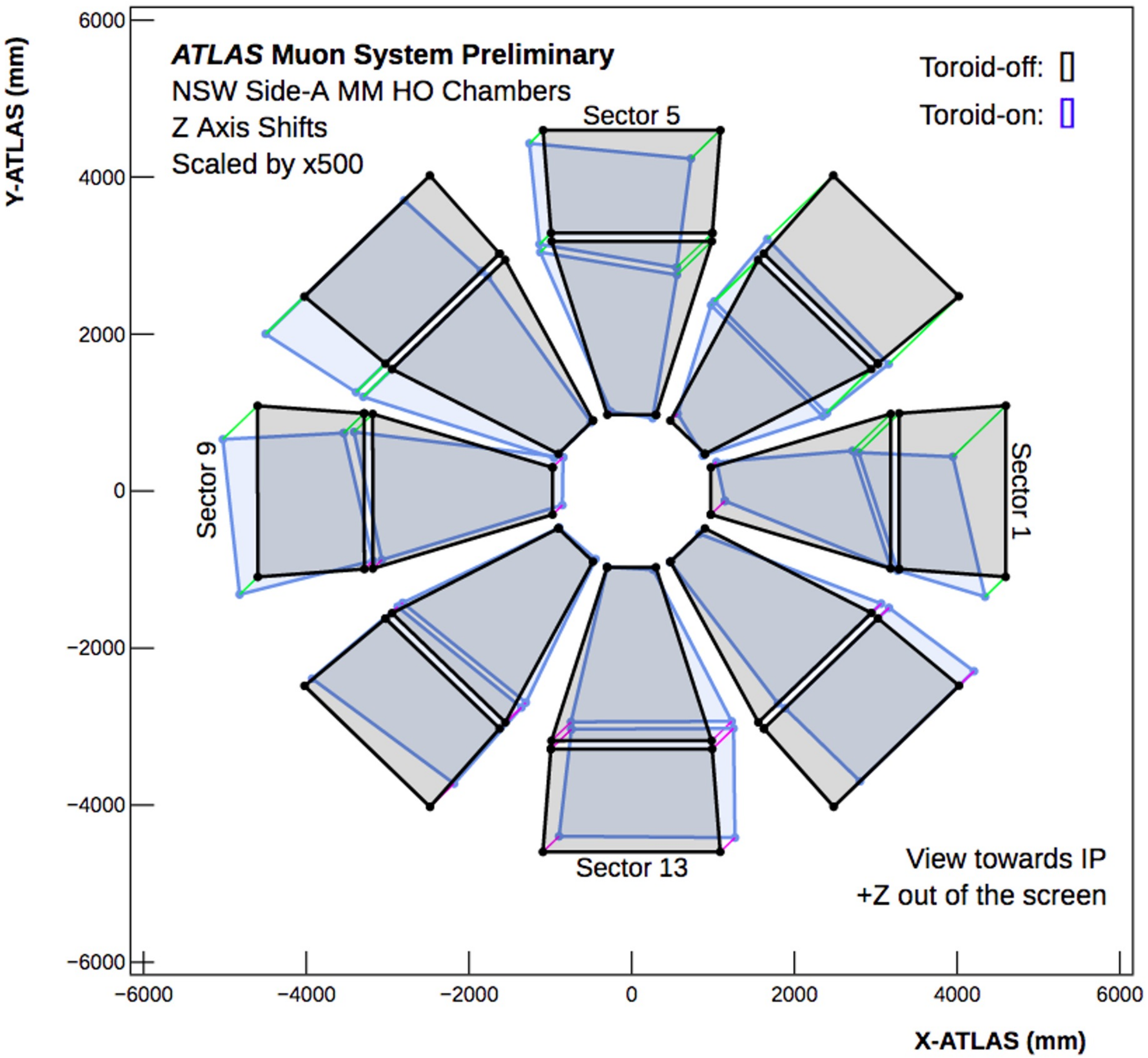
- Detector HV
- Electronics LV
- T-sensorB-sensor
- Cooling, Gas

NSW sector alignment

- Movements/deformations monitored by optical alignment system
- 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

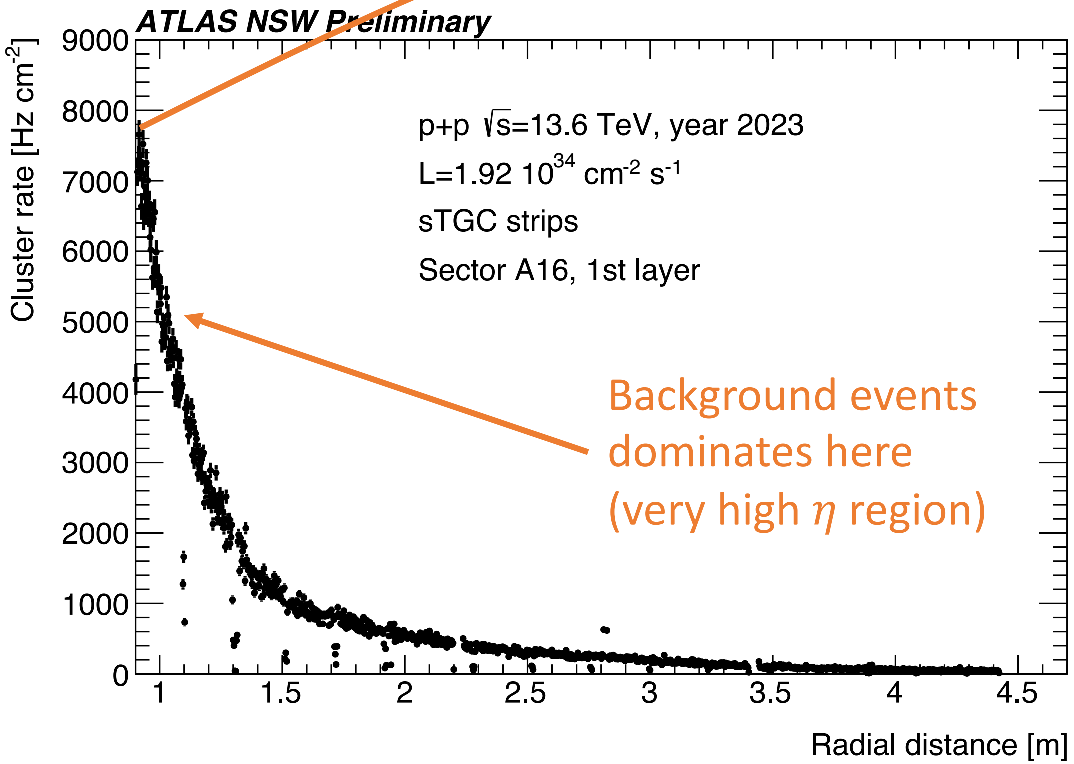
Z-shift (x500 -> exaggeration!)

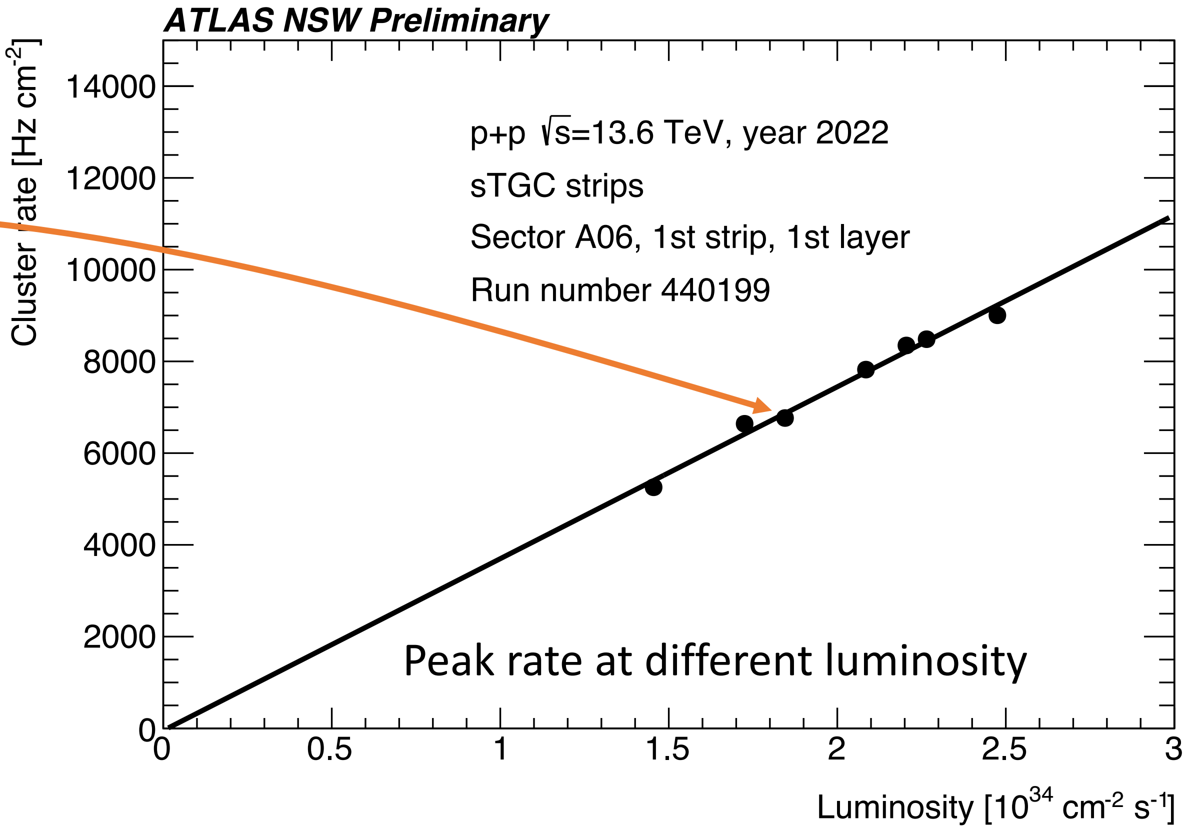
Z-shift > 0: green   Z-shift < 0: magenta



NSW preliminary performance – particle rate measurements

Rate measurement as a function of the radial distance from the interaction point performed using the sTGC

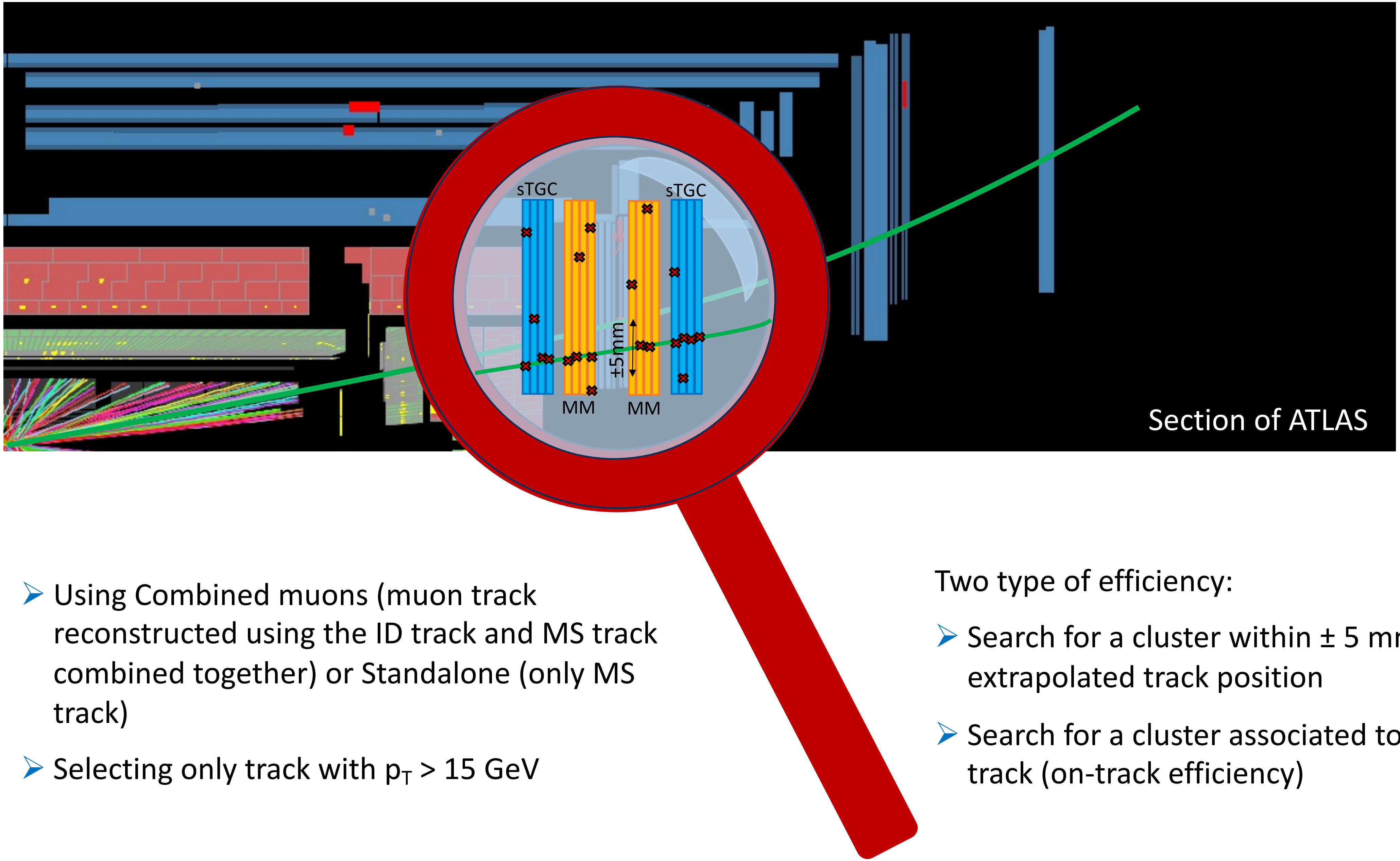




Expected particle rate @ $5 \cdot 10^{34}$ cm^{-2} s^{-1}: 18 kHz/cm^2

Within the design goal of the NSW (20 kHz/cm^2)

Efficiency measurements



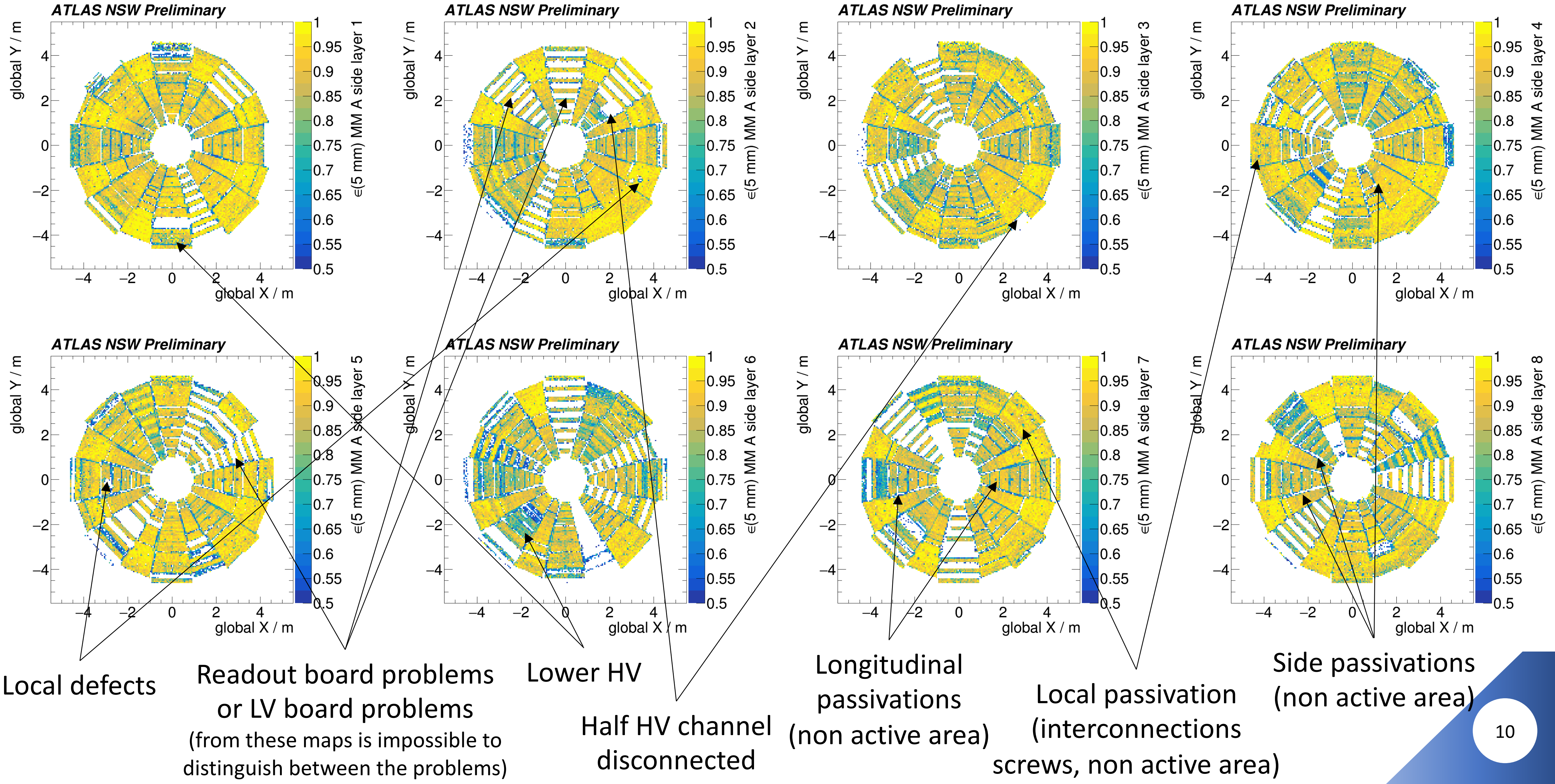
- Using Combined muons (muon track reconstructed using the ID track and MS track combined together) or Standalone (only MS track)
- Selecting only track with $p_T > 15$ GeV

Two type of efficiency:

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

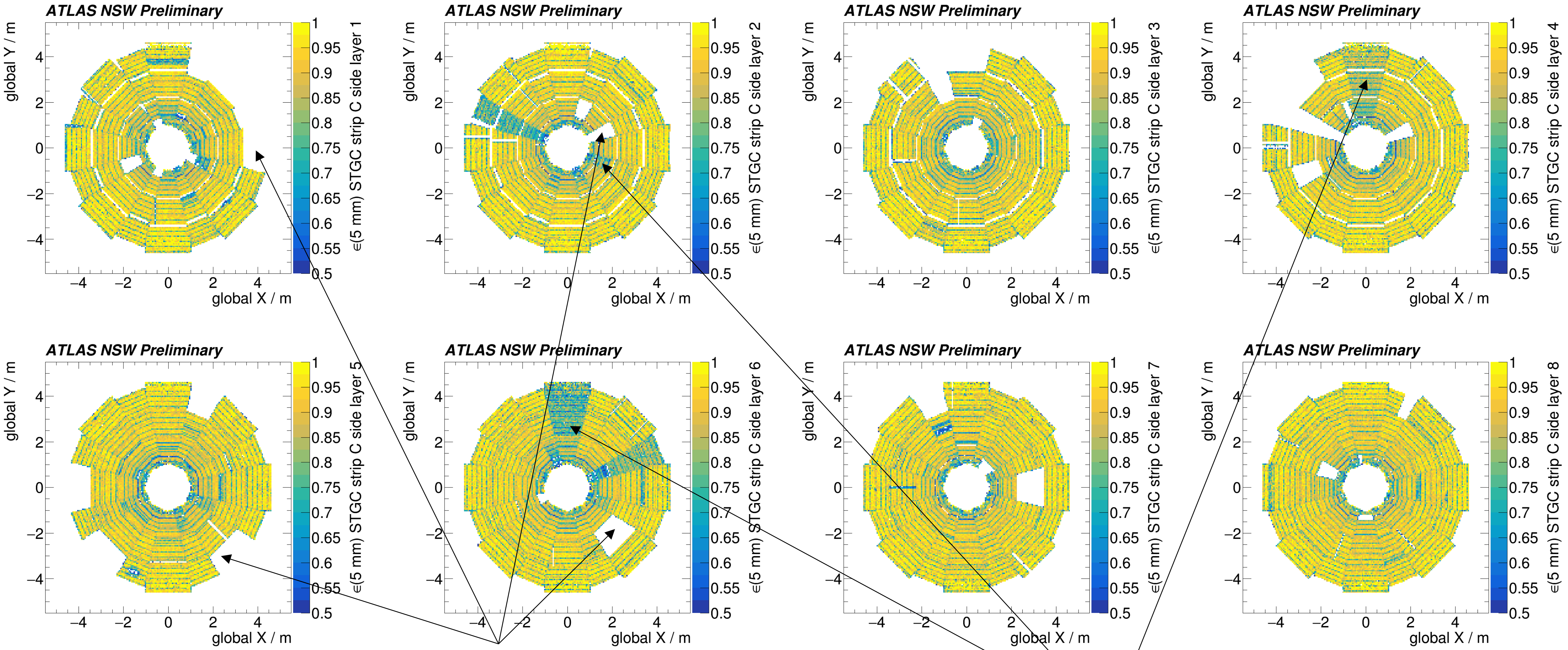
±5 mm

NSW preliminary performance – Single layer efficiency (MM)



NSW preliminary performance – Single layer efficiency (sTGC)

±5 mm



Readout board problems
or
HV channel disconnected
(from these maps is impossible to distinguish between the problems)

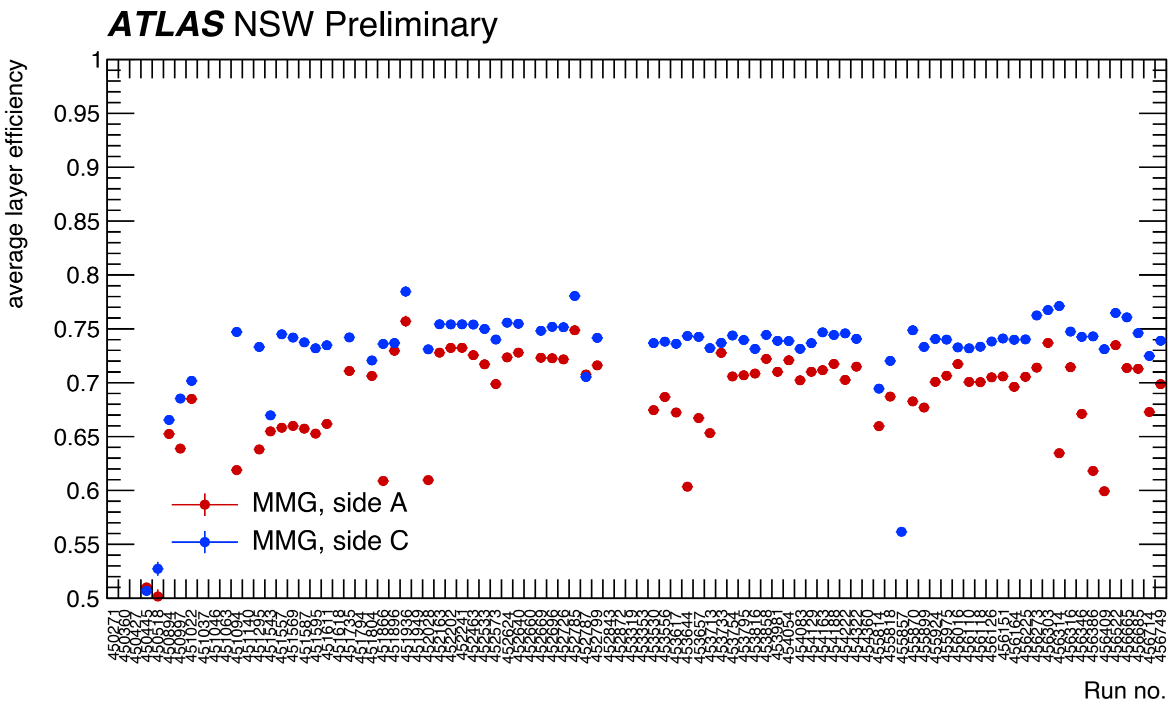
Lower HV or
trips during the run

±5 mm

NSW preliminary performance – Single layer efficiency

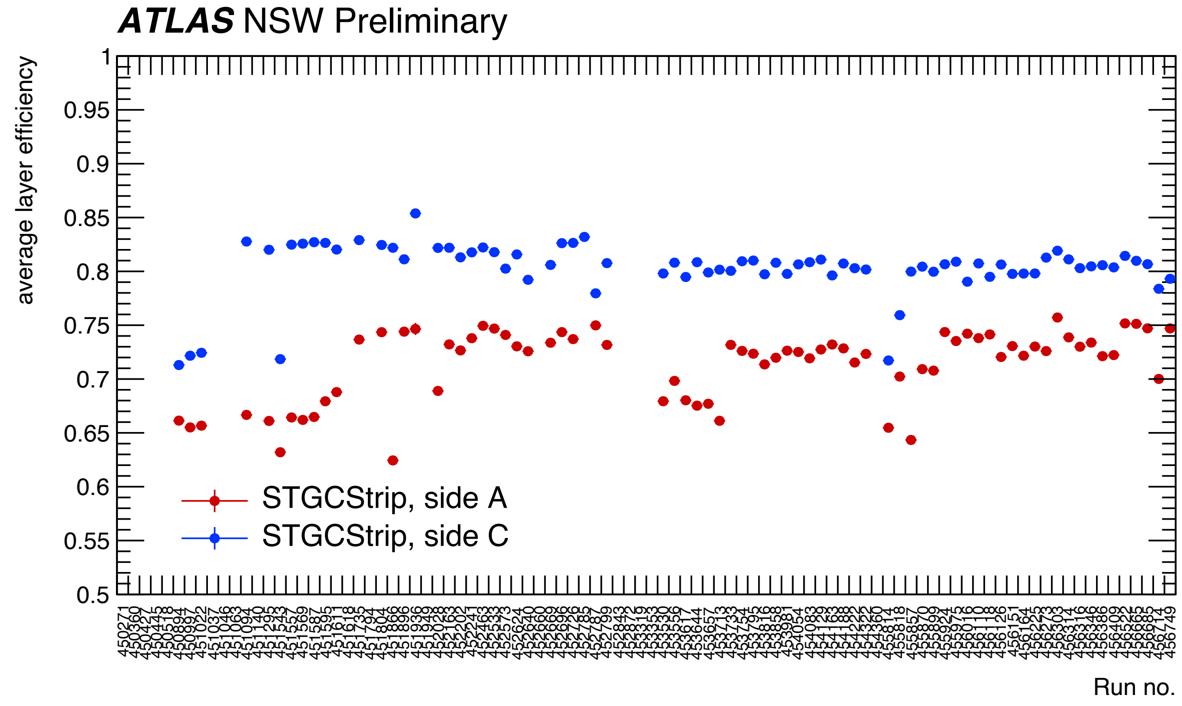
Average efficiency of each MicroMegas/sTGC layer as a function of the Run Number (time).

- Average single layer efficiency ~65-85%, constant behaviour as a function of the time



Mar 2023 Jul 2023

time



Mar 2023 Jul 2023

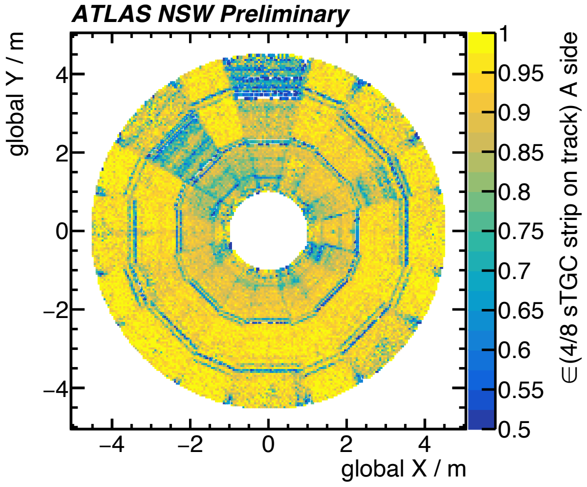
time

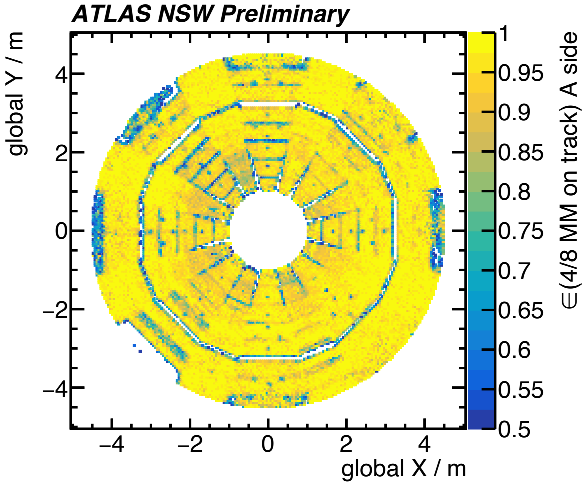
NSW preliminary performance – reconstruction efficiency (maps)

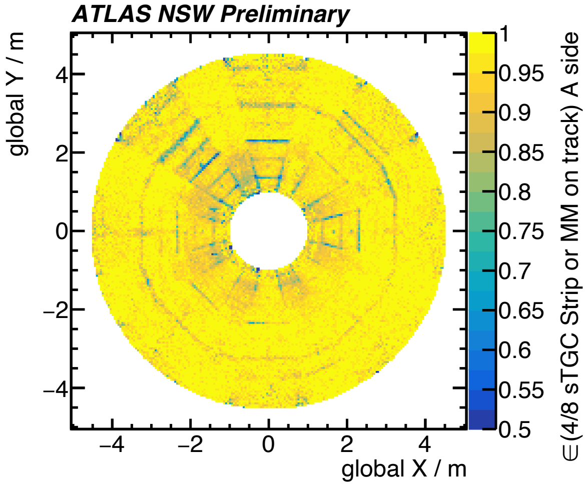
on-track

	≥4/8 sTGC layer on-track	≥4/8 MicroMegas layer on-track	≥4/8 sTGC layer or ≥4/8 MicroMegas layer on-track

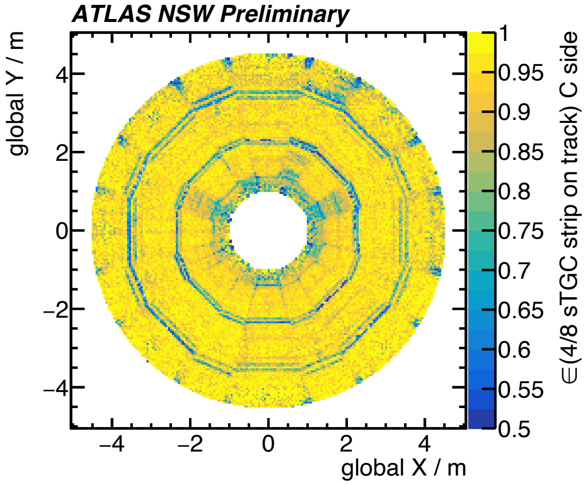
Side A

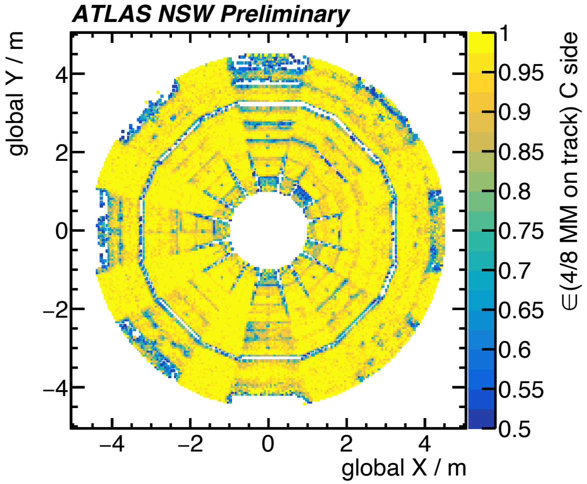


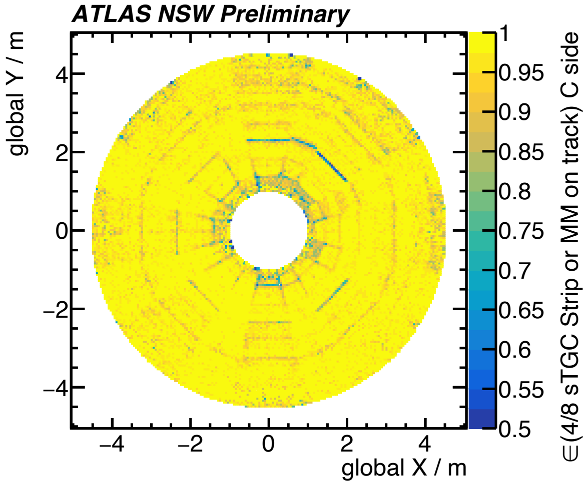




Side C





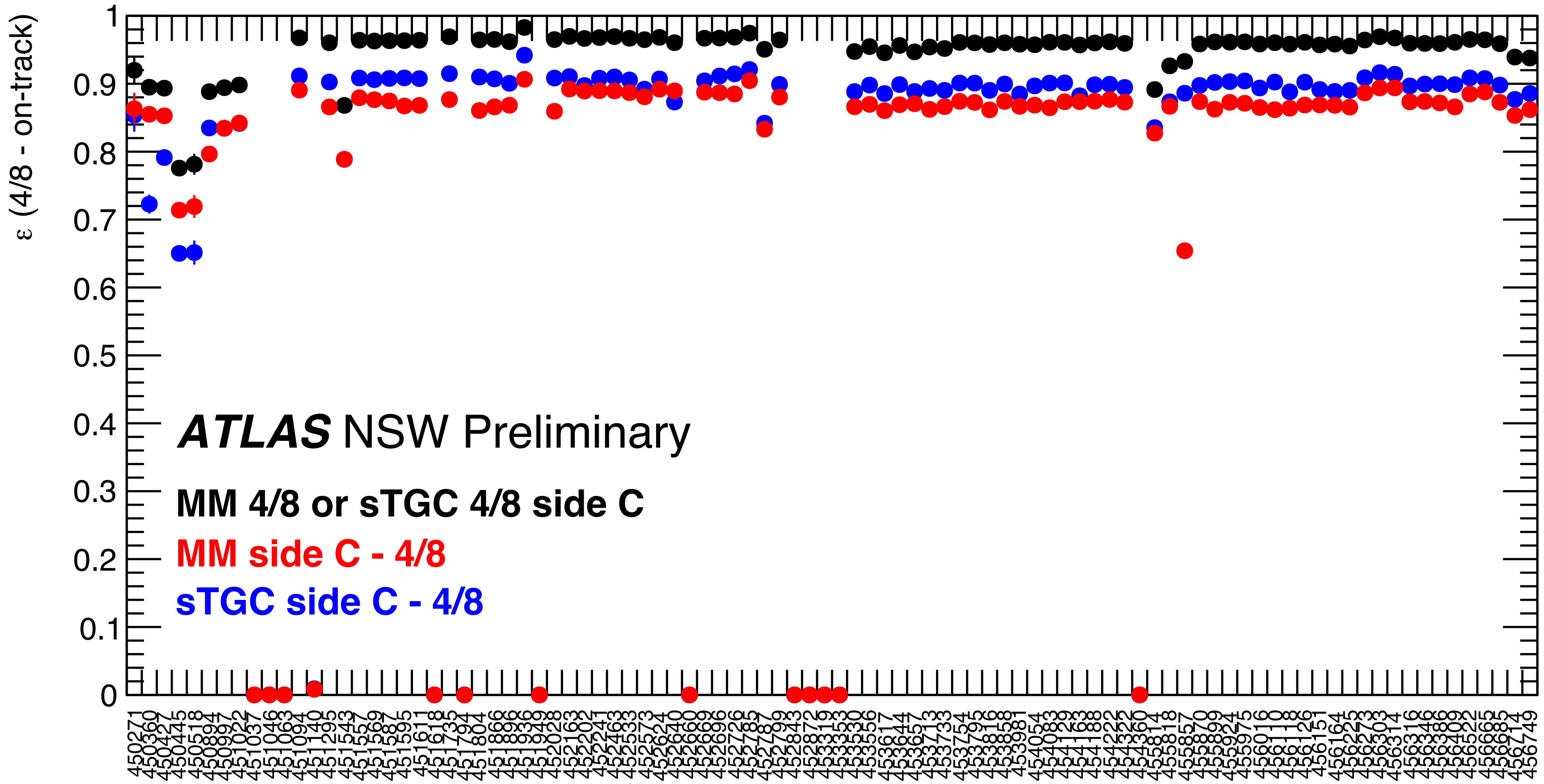


Ongoing validation to use this majority in the muon reconstruction as a quality criteria

Track reconstruction is good (> 95%) thanks to the high-redundancy of the NSW

NSW preliminary performance – reconstruction efficiency

on-track



Mar 2023

Jul 2023

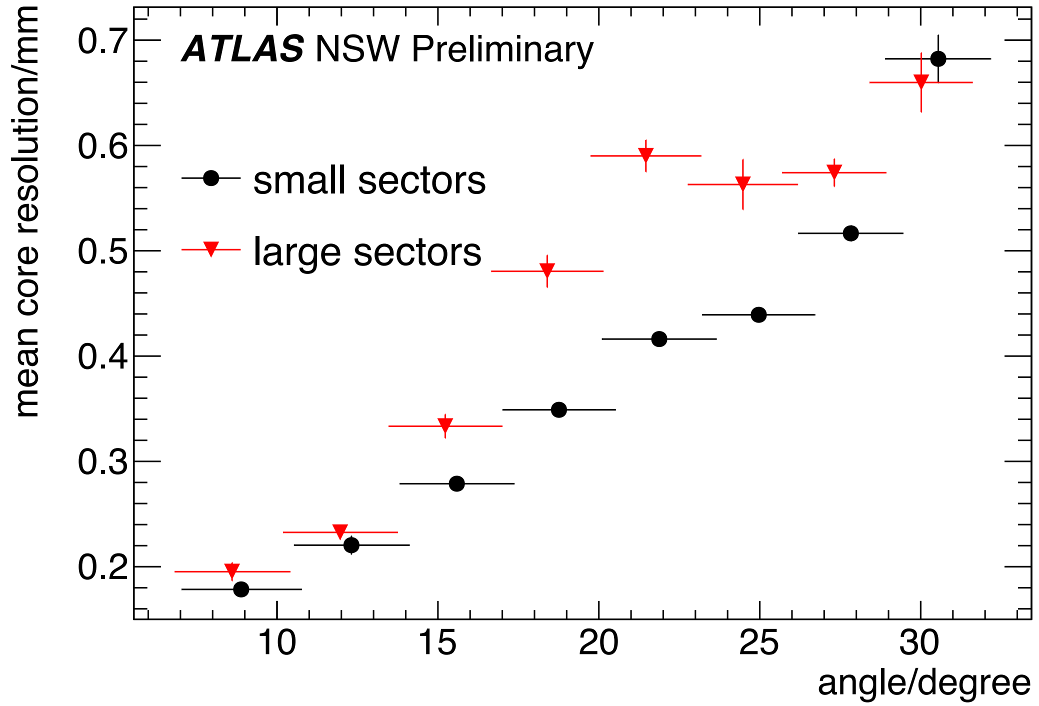
time

Very constant behaviour after first period

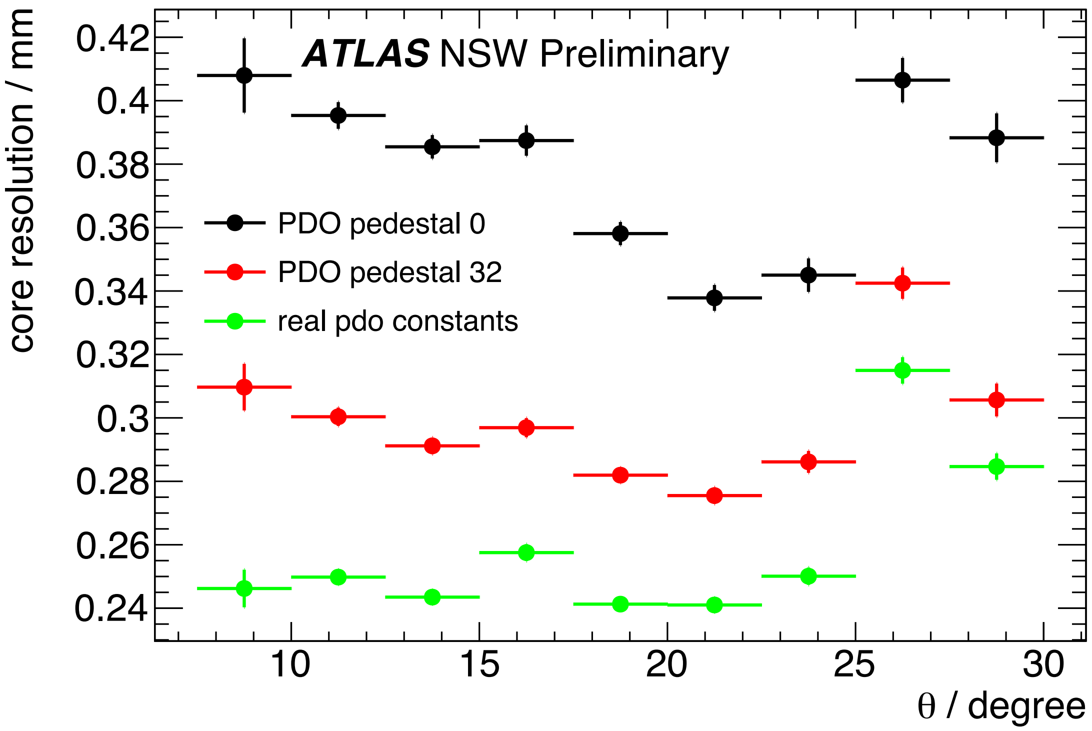
NSW reconstruction efficiency > 95%

NSW preliminary performance – Resolution

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

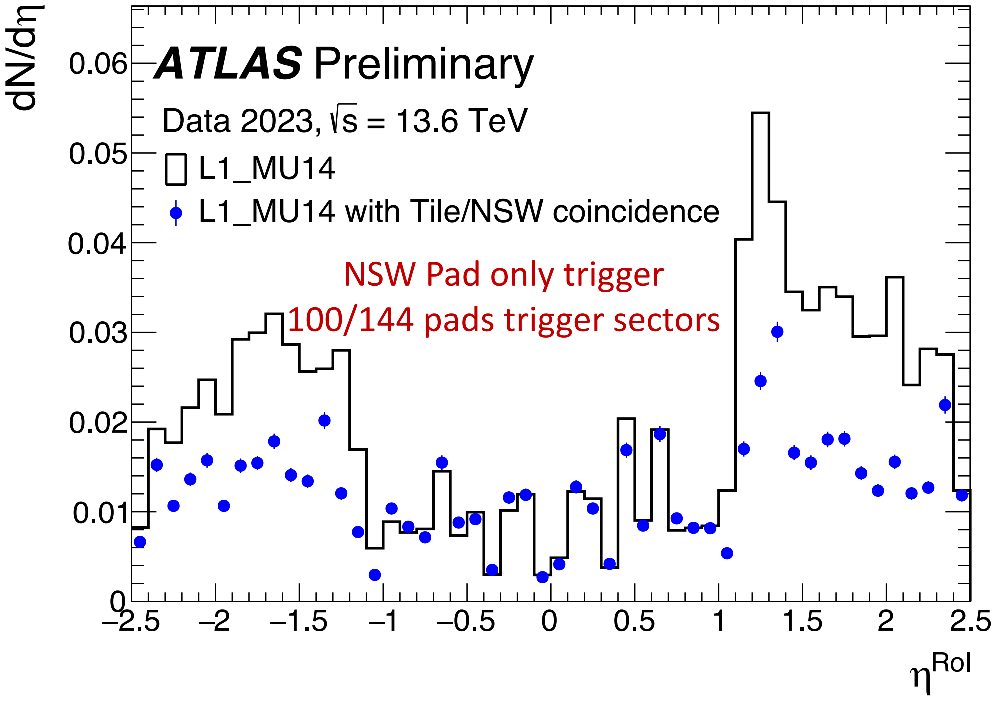


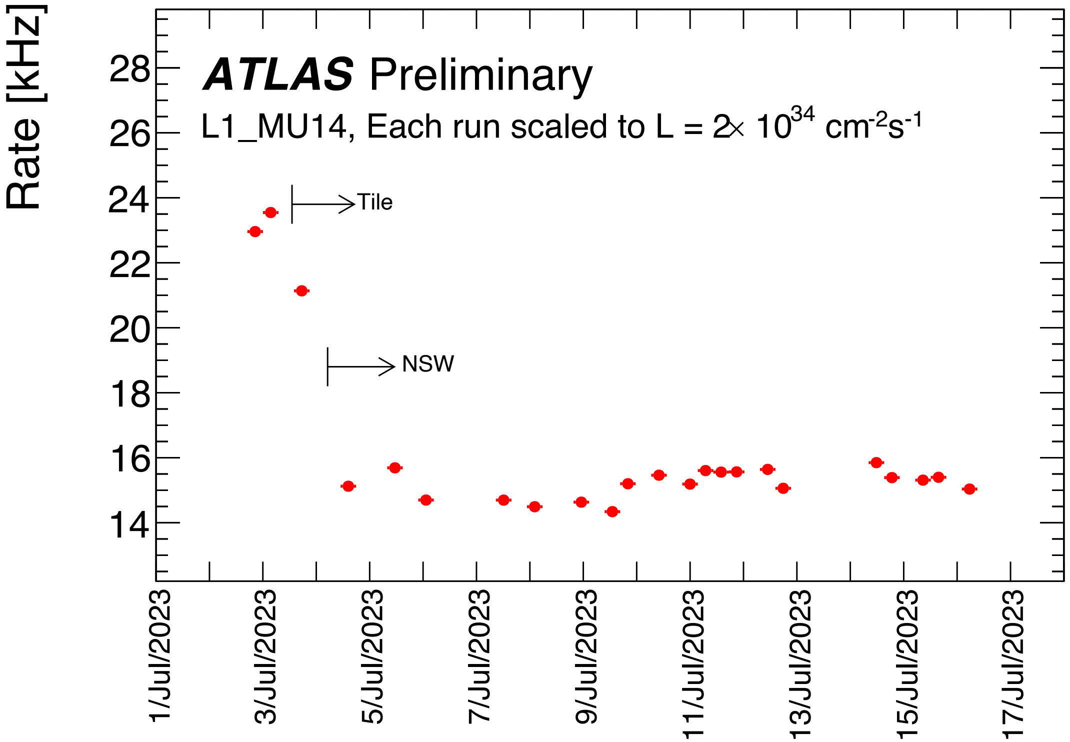
- MicroMegas resolution obtained with the layer-layer cluster position difference (taking into account the track inclination)
- Less effect on the mis-alignment with this method



- sTGC resolution obtained with the track- cluster position difference
- Resolution improves after the charge calibration
- Less effect on the mis-alignment with this method

NSW Level-1 trigger



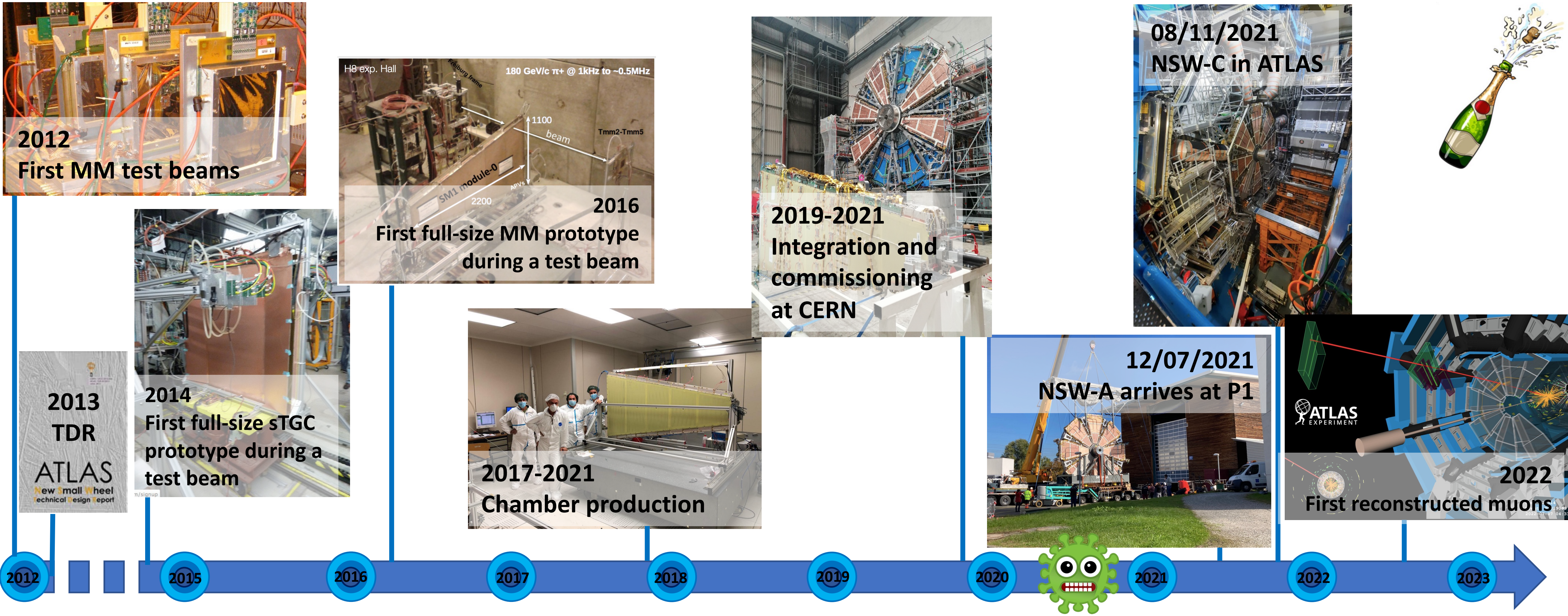


- **sTGC Pads** in Level-1 Trigger:
  pad coincidences to define a smaller region of interest and select fast charge information from a band of strips for centroid reconstruction.

- **MMG strips** in Level-1 Trigger (integration ongoing):
  reconstruct slopes pointing to IP based on addresses of earliest threshold-crossing strips among multiple layers.

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.

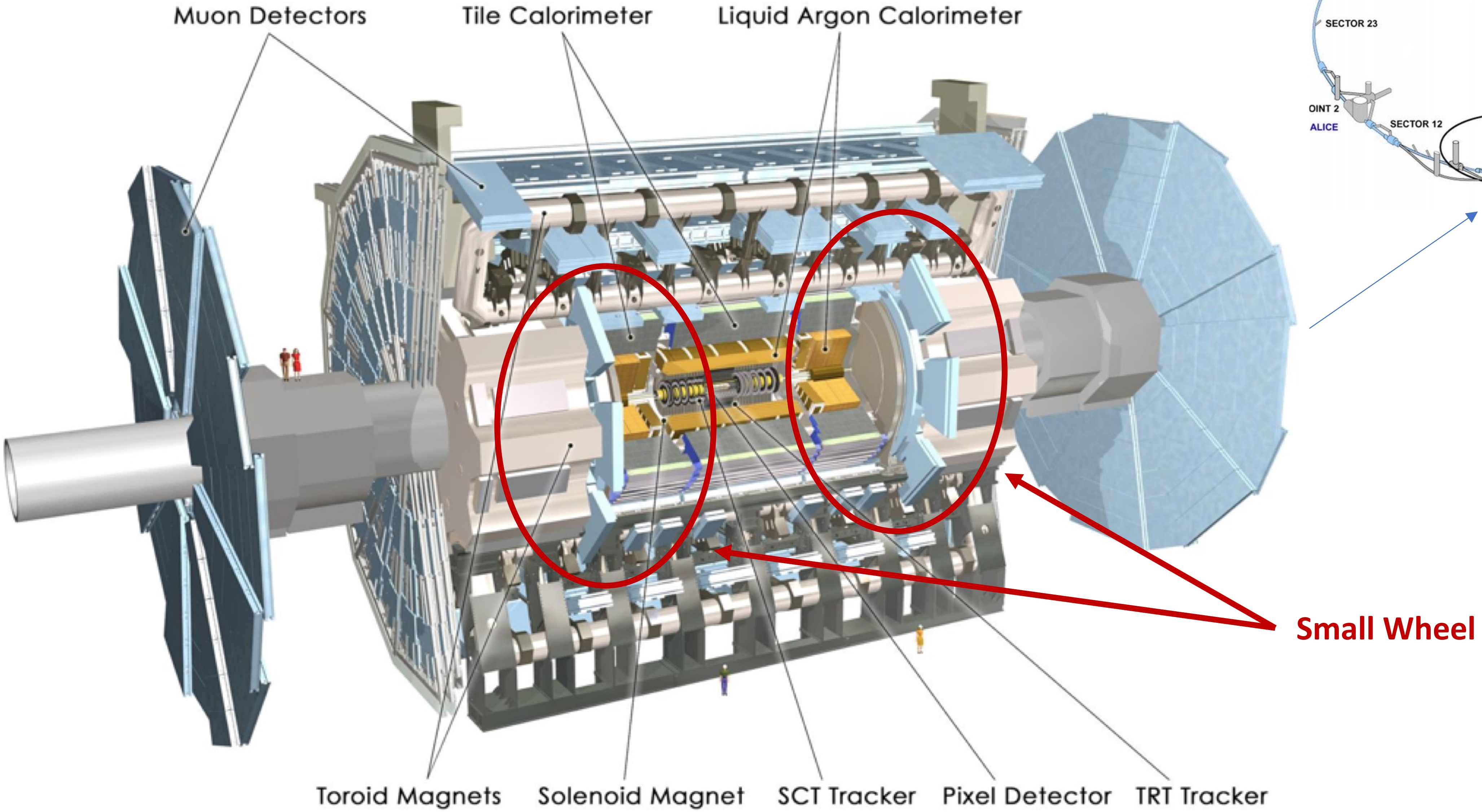
- Rate reduction with Tile: ~2kHz
- **Rate reduction with NSW (sTGC): ~6kHz**

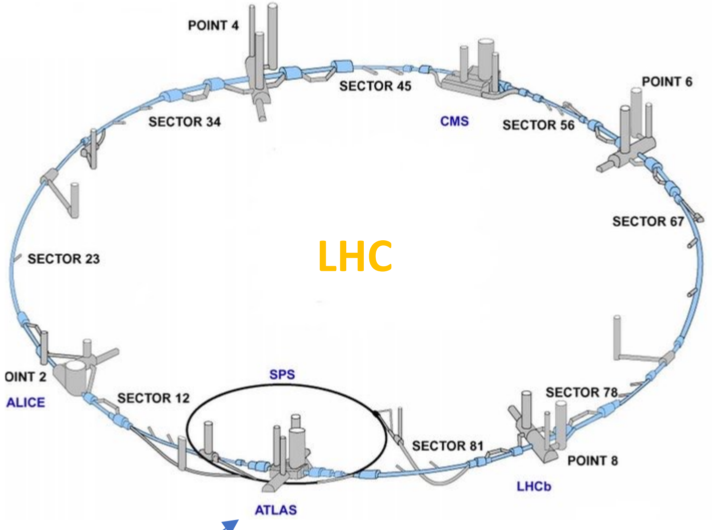


- The New Small Wheel was one of the largest projects to upgrade experiments at the LHC.
- More than 10 years were needed to complete it, with several issues addressed, including COVID.
- The New Small Wheel is now in ATLAS!
- There are still problems to be solved (both detector side and acquisition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

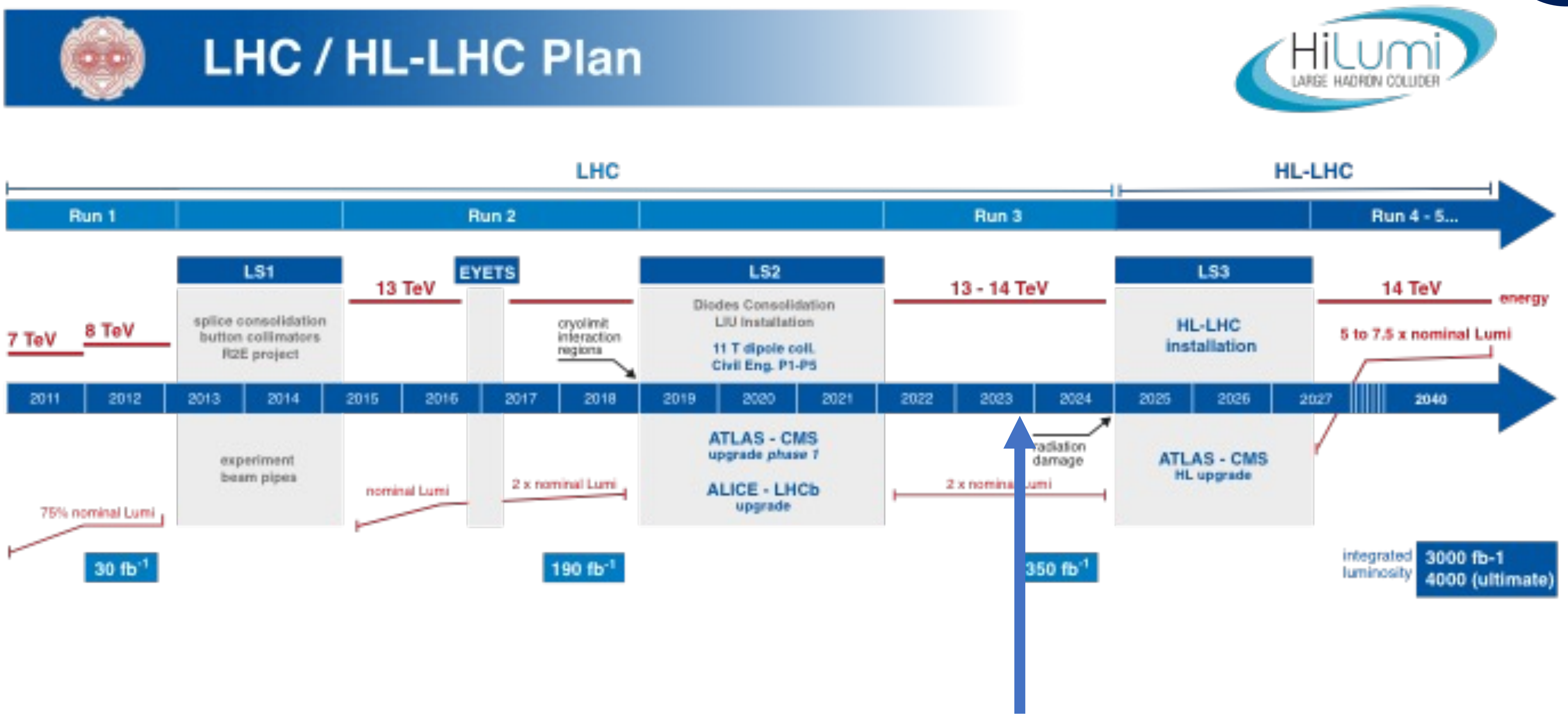
BACKUP

The ATLAS detector

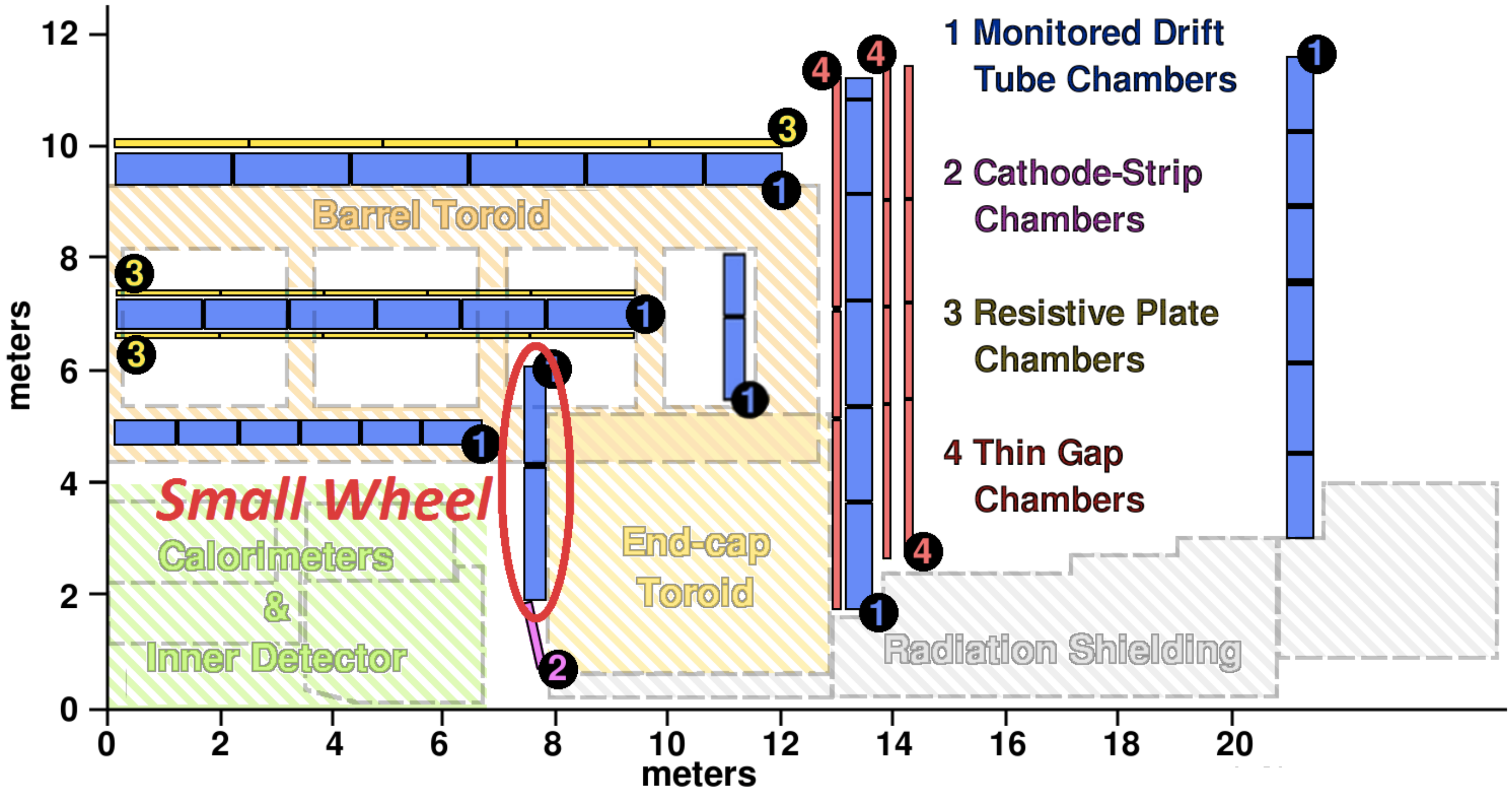




LHC / HL-LHC plan

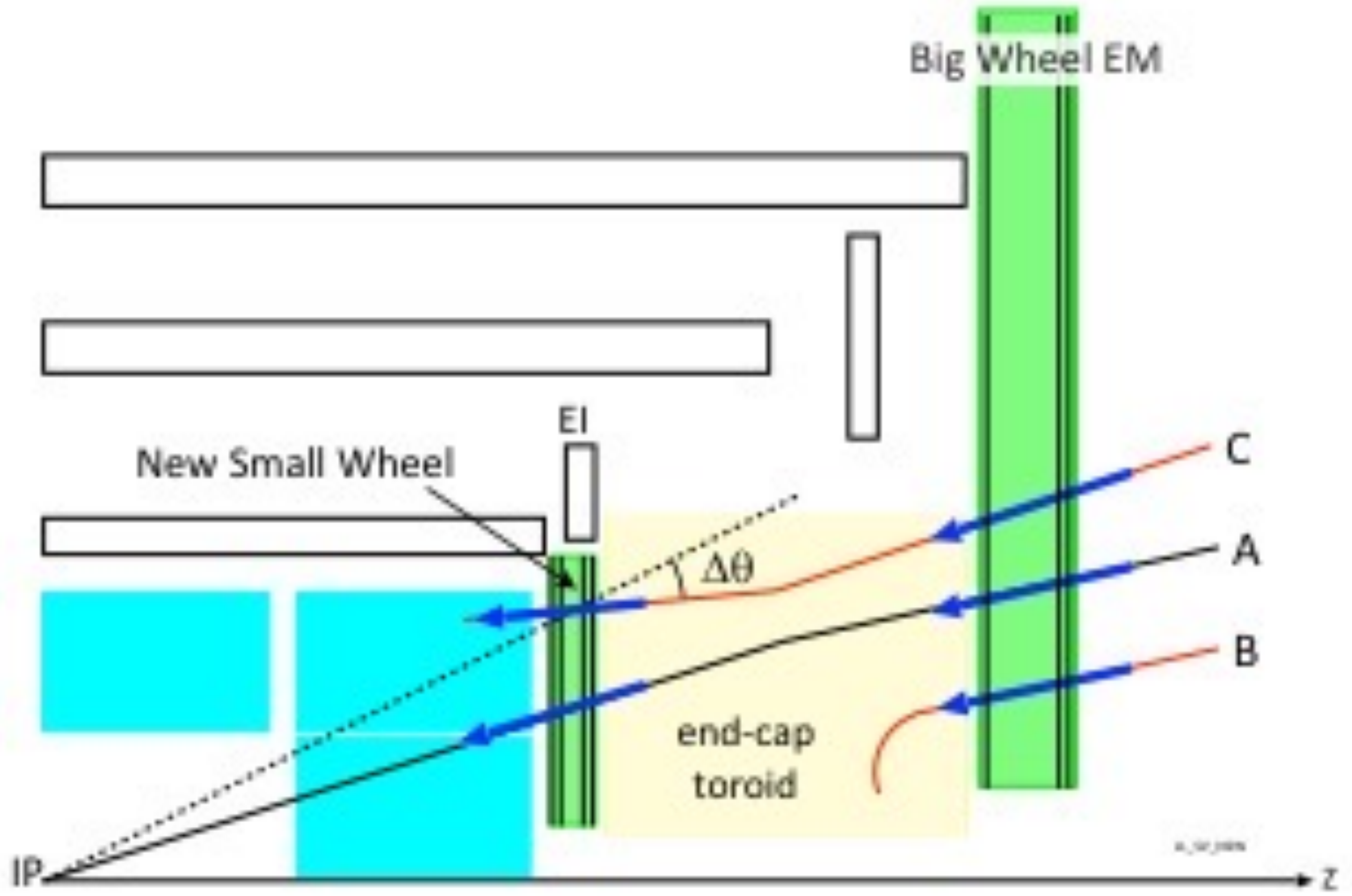


ATLAS Muon Spectrometer



1. Monitored Drift Tubes (End-cap + Barrel) - tracking
2. Catode Strip Chambers (End-cap) - tracking
3. Resistive Plate Chambers (Barrel) - trigger
4. Thin Gap Chambers (End-cap) - trigger

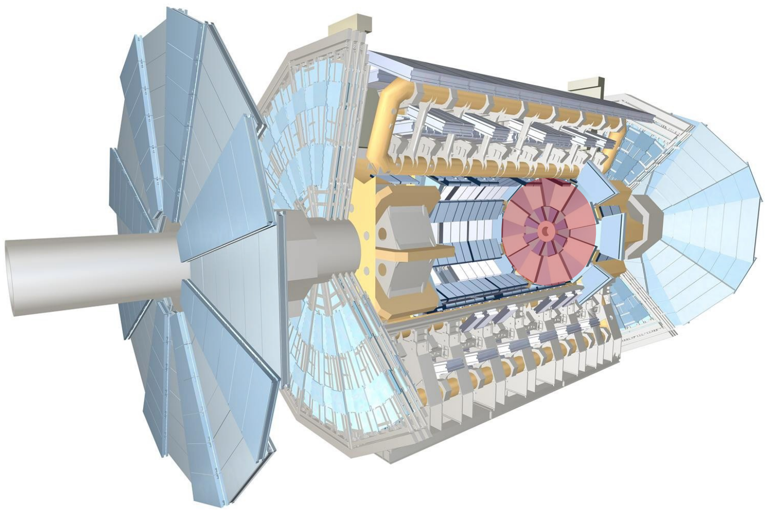
ATLAS trigger logic – end-cap



With NSW:

- Only track A will be accepted
- Track B is discarded since it is not pointing to the IP (created in the passive materials)
- Track B is discarded since it is not pointing to the IP (multiple scattering)

The New Small Wheel project

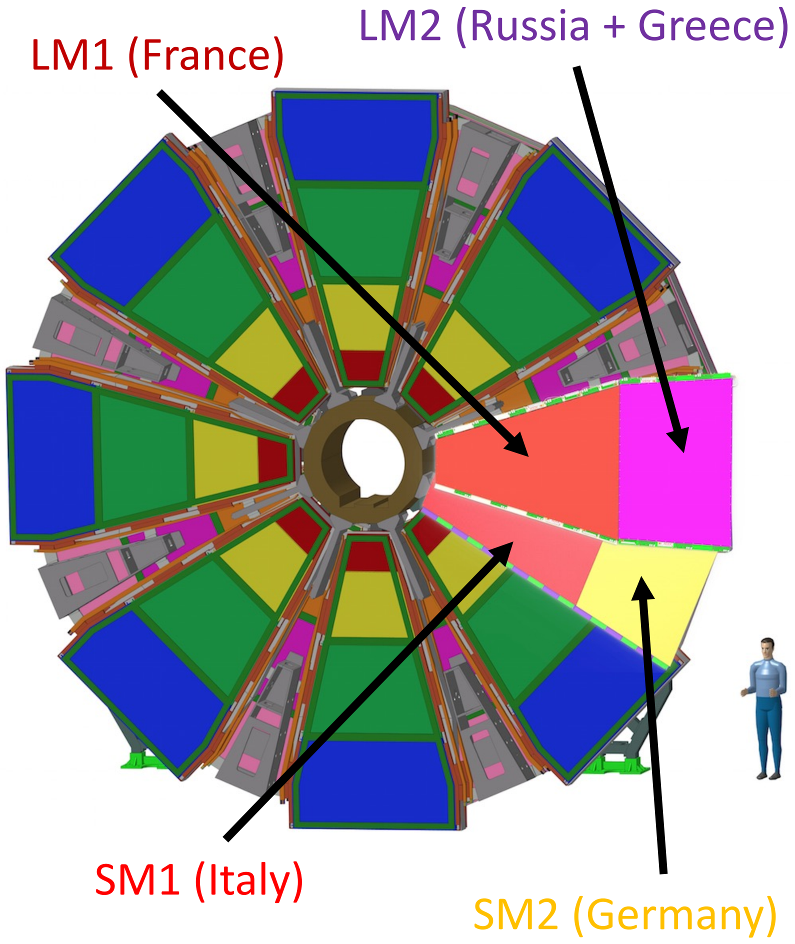


Two detector technologies:

- **MicroMegas** (primarily for tracking)
- **small-strip Thin Gas Chambers** (primarily for trigger)

16 layers to have redundancies and to reconstruct also the second coordinate

16 "petals" [8 small + 8 large]

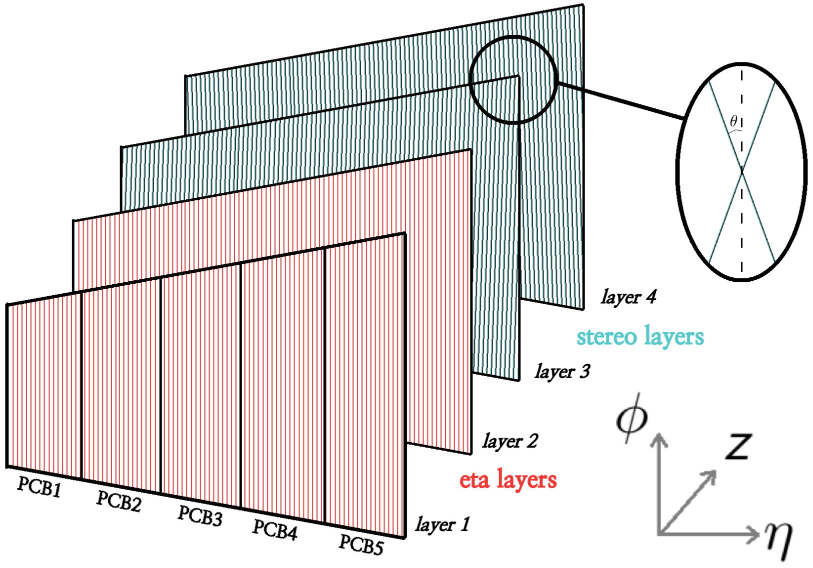


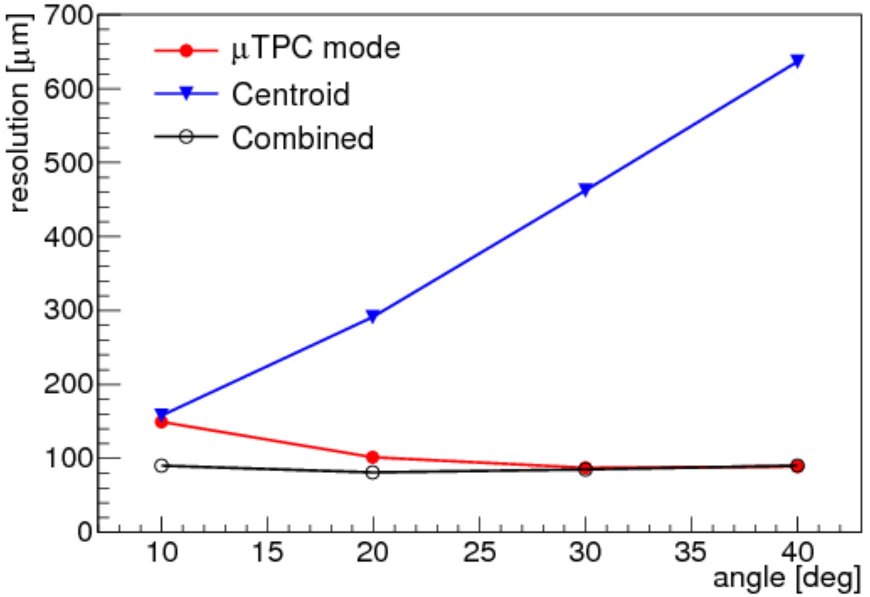
$$\frac{\sigma(p_T)}{p_T} < 15\% \text{ (@ 1 TeV)}$$

$\Longrightarrow$ single layer position resolution of ∼100 µm

$\Longrightarrow$ alignment readout elements ∼100 µm

The ATLAS resistive MicroMegas chambers – working principle





NSW Design/Requirements:

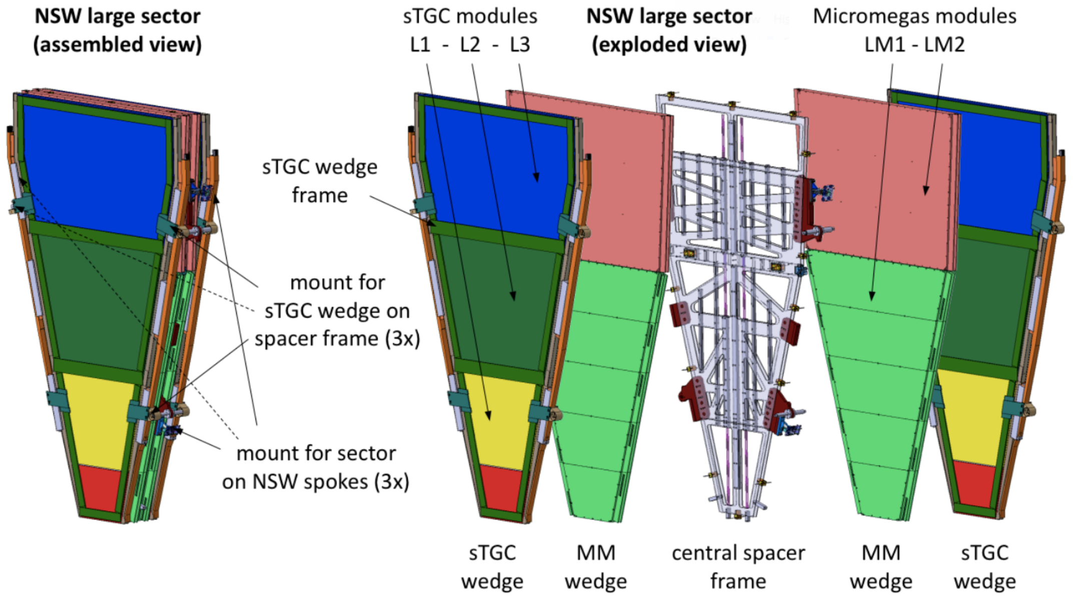
- Reduce fakes trigger rate at L1;
- Reconstruct online muon tracks with 95% efficiency;
- Excellent spatial and angular resolutions: < 50 µm and < 1 mrad;
  - for offline momentum reconstruction;
  - for online matching with Big Wheel;
- Good spatial resolution on the second coordinate: < 2/3 mm
  - for a better pointing of the primary vertex;
- Operate for the entirely of Run-3 and HL-LHC programme.

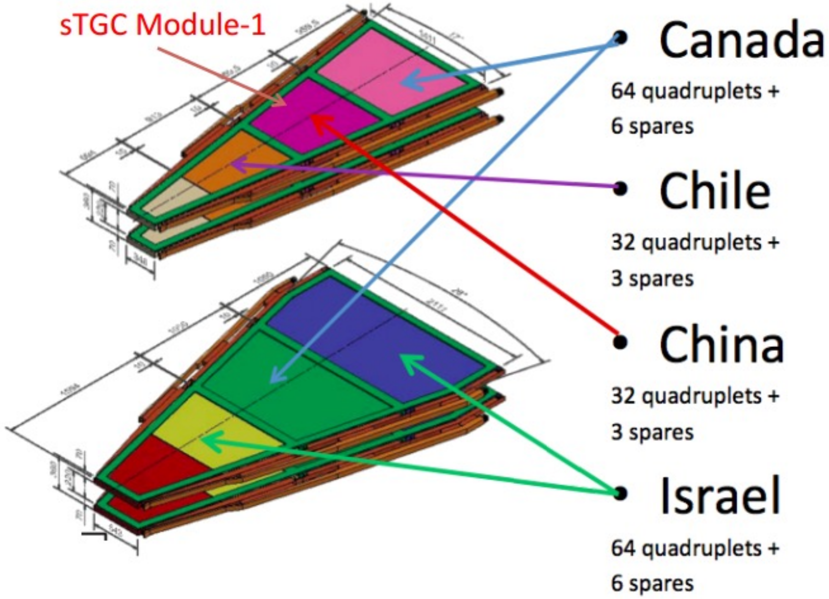
$\frac{\sigma(p_T)}{p_T}$ **< 15% (@ 1 TeV)**

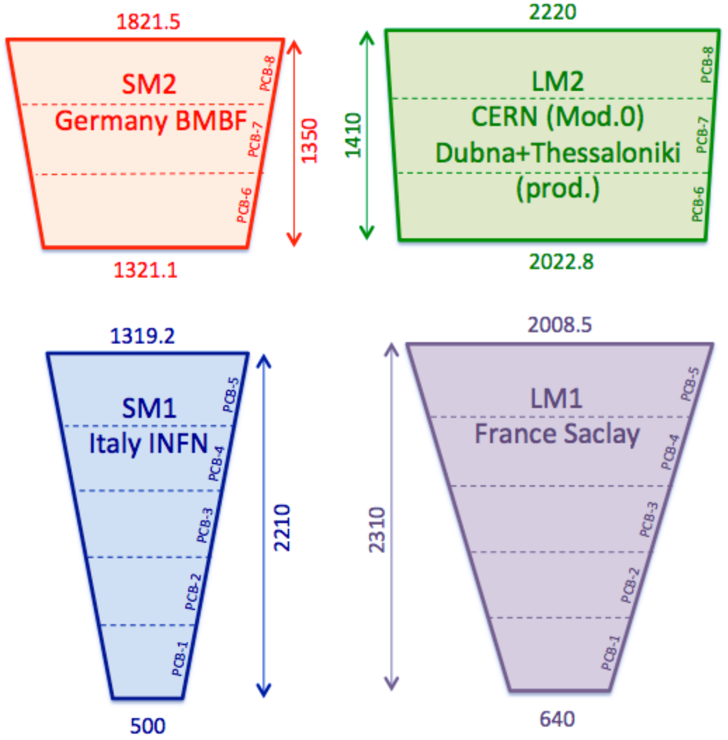
⟹ single layer position resolution of ∼150 µm

⟹ alignment readout elements ∼100 µm

NSW sectors

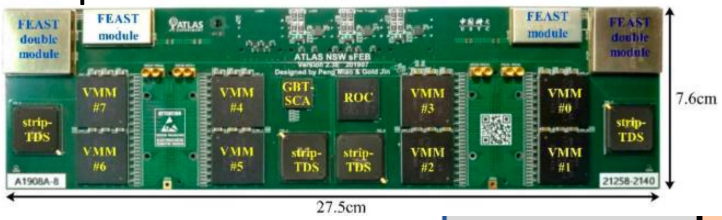

NSW large sector
(assembled view)
sTGC modules
L1 - L2 - L3
NSW large sector
(exploded view)
Micromegas modules
LM1 - LM2
sTGC wedge
frame
mount for
sTGC wedge on
spacer frame (3x)
mount for sector
on NSW spokes (3x)
sTGC
wedge
MM
wedge
central spacer
frame
MM
wedge
sTGC
wedge


sTGC Module-1
Canada
64 quadruplets +
6 spares
Chile
32 quadruplets +
3 spares
China
32 quadruplets +
3 spares
Israel
64 quadruplets +
6 spares

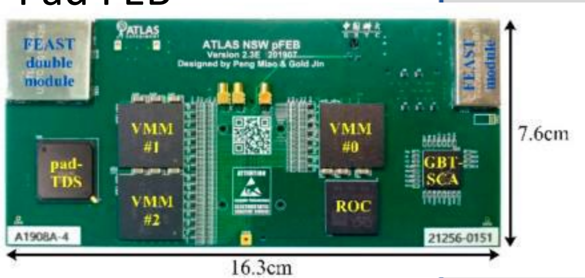

1821.5
SM2
Germany BMBF
1350
1321.1
PCB-8
PCB-7
PCB-6
2220
LM2
CERN (Mod.0)
Dubna+Thessaloniki
(prod.)
1410
2022.8
1319.2
SM1
Italy INFN
2210
500
PCB-5
PCB-4
PCB-3
PCB-2
PCB-1
2008.5
LM1
France Saclay
2310
640

NSW electronics

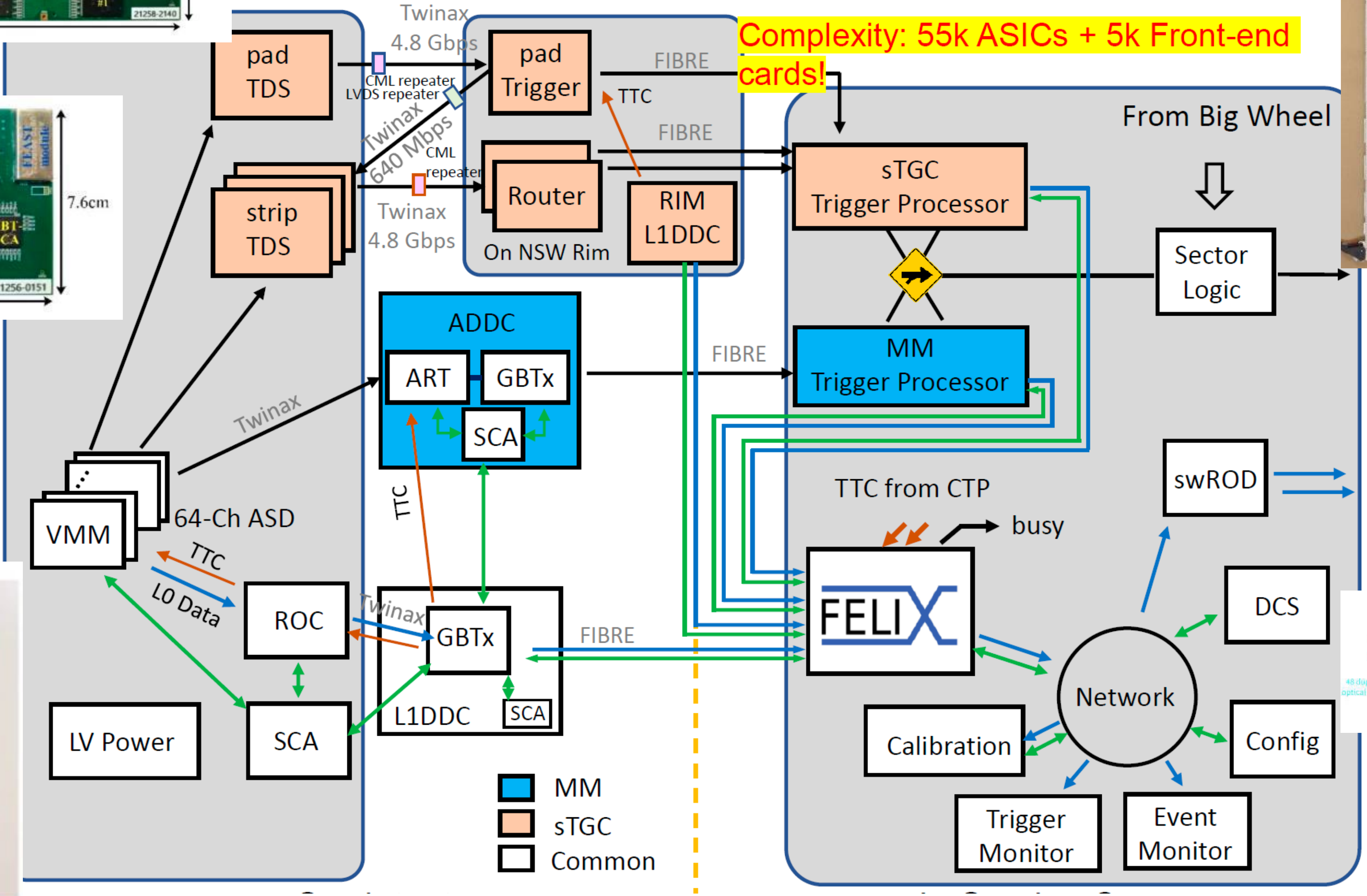
Strip FEB



Pad FEB

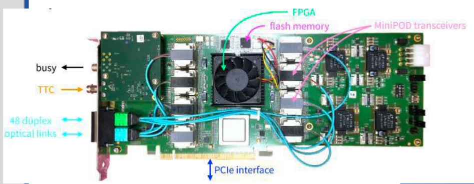


Complexity: 55k ASICs + 5k Front-end cards!



Sector Logic Board

Pad Trigger Board

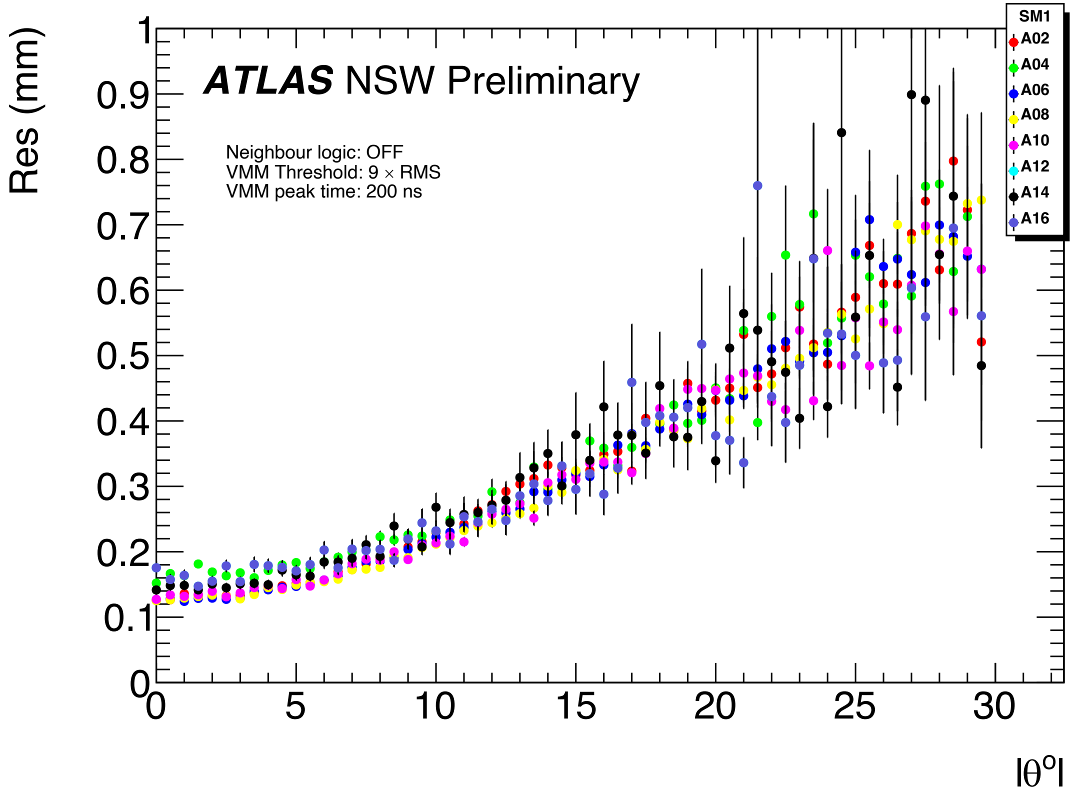


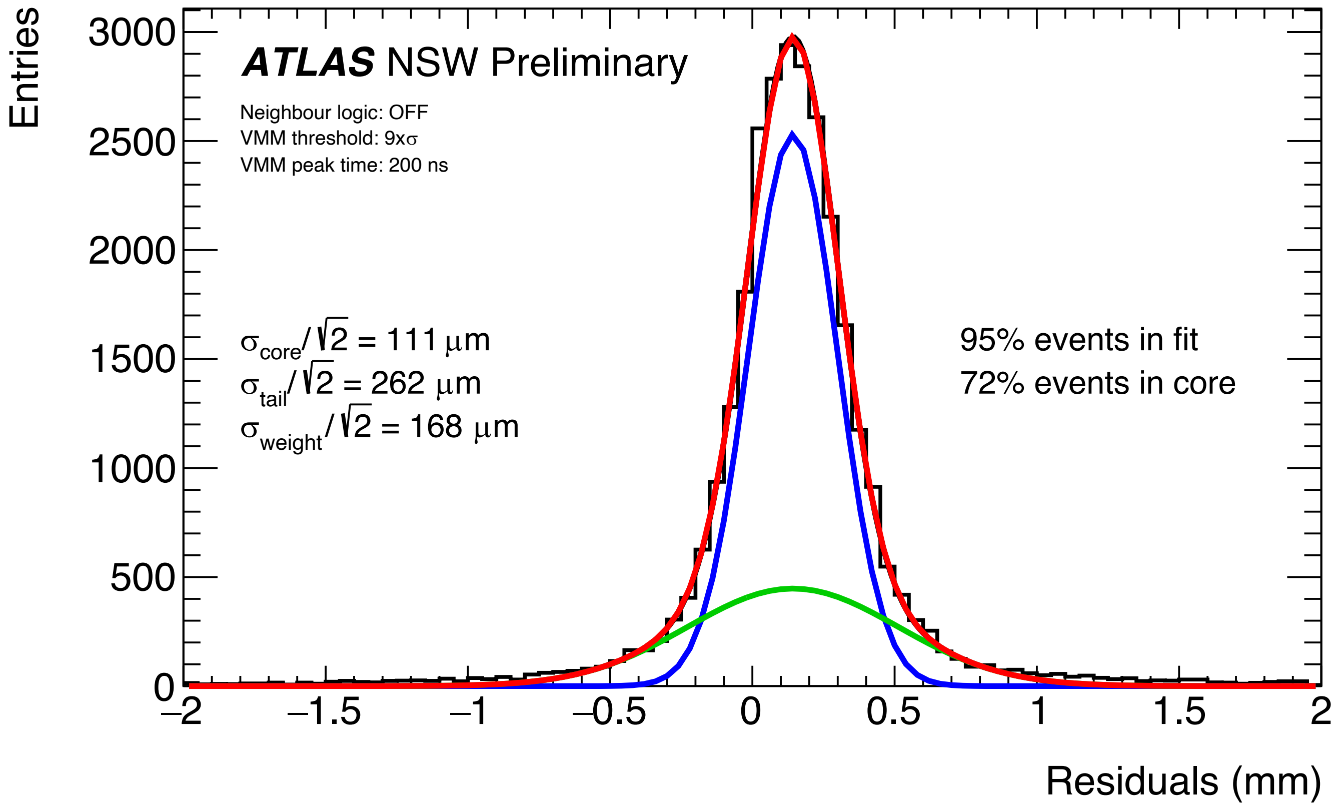
Felix Card

NSW electronics

- NSW uses more than 50k radiation-tolerant Front-end ASICs with 70+ million configuration registers! Calibrations are complicated and vital
- **VMM ASIC**: baseline, threshold, pulser, charge & time
  64-channel mixed signal ASIC with charge amplifiers and ADCs for charge, time measurements
- **ROC ASIC**: internal phase –TTC & VMM data decoding
  Readout control ASIC distributes TTC signals and aggregate L0 data from 8 VMMs per Front-end Board
- **TDS ASIC**: strip charge, pad trigger, benefit-cost ratio
  Trigger Data Serializer ASIC prepares and serializes trigger data and performs pad-strip matching for sTGCtrigger purposes
- **GBTx**: e-link data sampling phase
  Gigabit transceiver for the transmission of readout, TTC and slow control data between Front-end and Back-end
- **GBT-SCA**: slow control data sampling phase
  Slow control ASIC for the configuration of Front-end ASICs and the environmental monitoring of Front-end electronics

- Centroid resolutions measured using the reconstructed track with the other layers



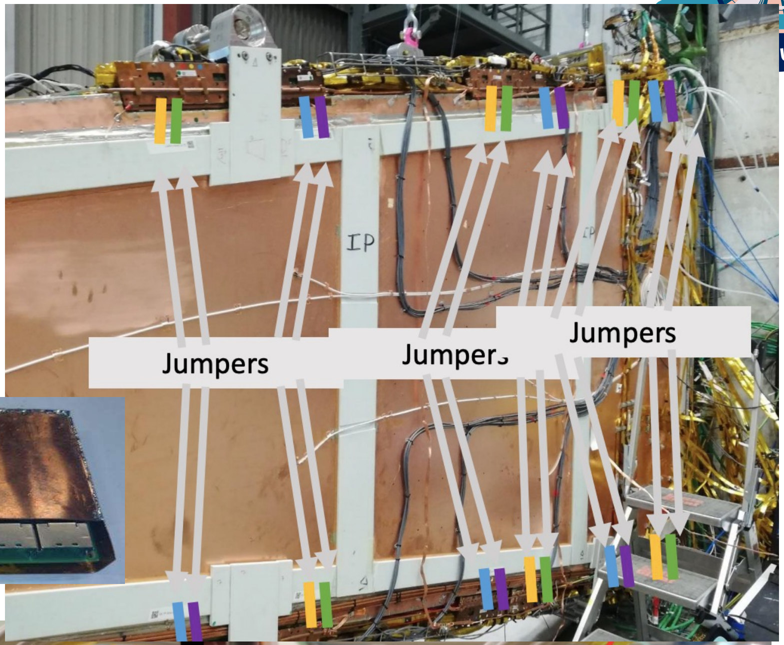


Measurements a bit worst than expected due to multiple scattering + mis-alignment between layers (not considered)

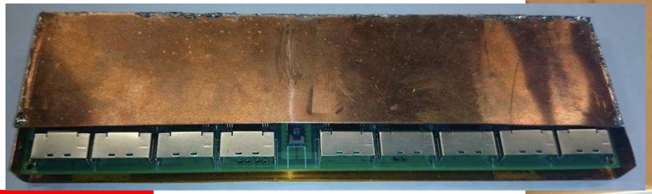
Expected $50\ \mu m$ of track reconstruction resolution in the NSW ⇒ $150\ \mu m$ of resolution per plane

Reducing Sectors noise

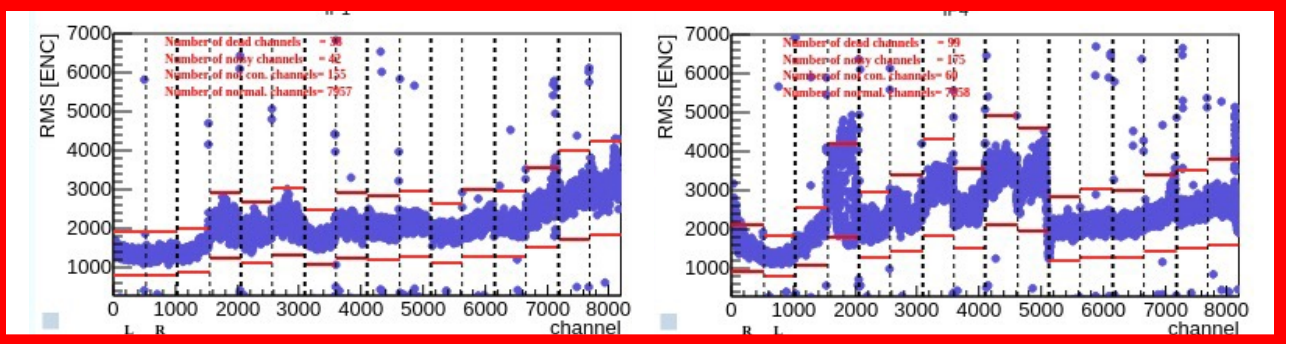
- Recent commissioning activities have lead to the discovery of increased noise in the sectors on wheel (both sTGC and Micromegas)
- Task force formed to investigate and potentially mitigate the problem.

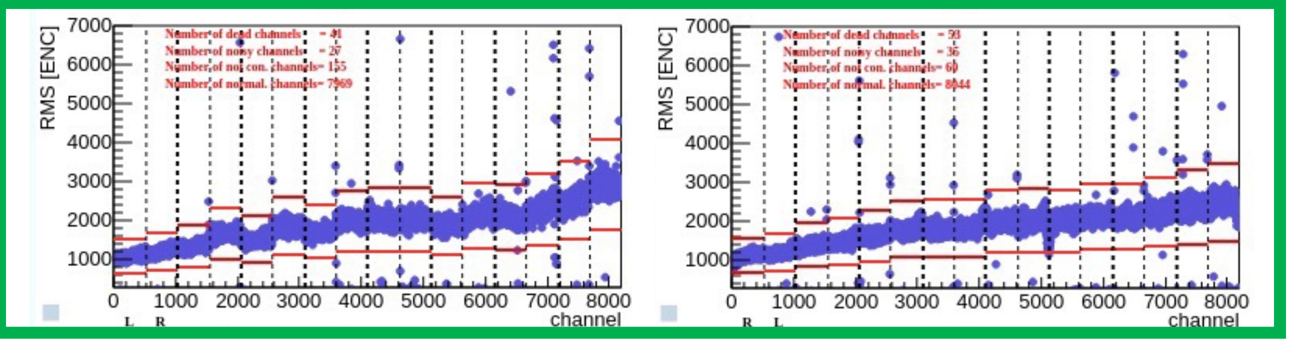


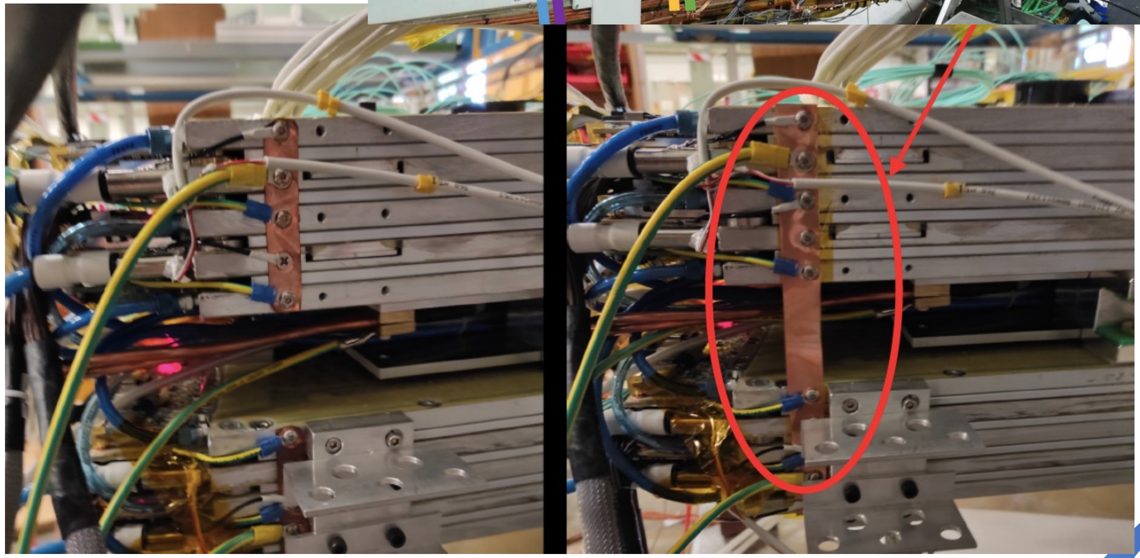
- Modification of grounding scheme and the addition of grounds on detector have further improved noise levels.
- Addition of Faraday cages on some specific electronics boards.



- **Before** and **After** the modifications on the MM layers

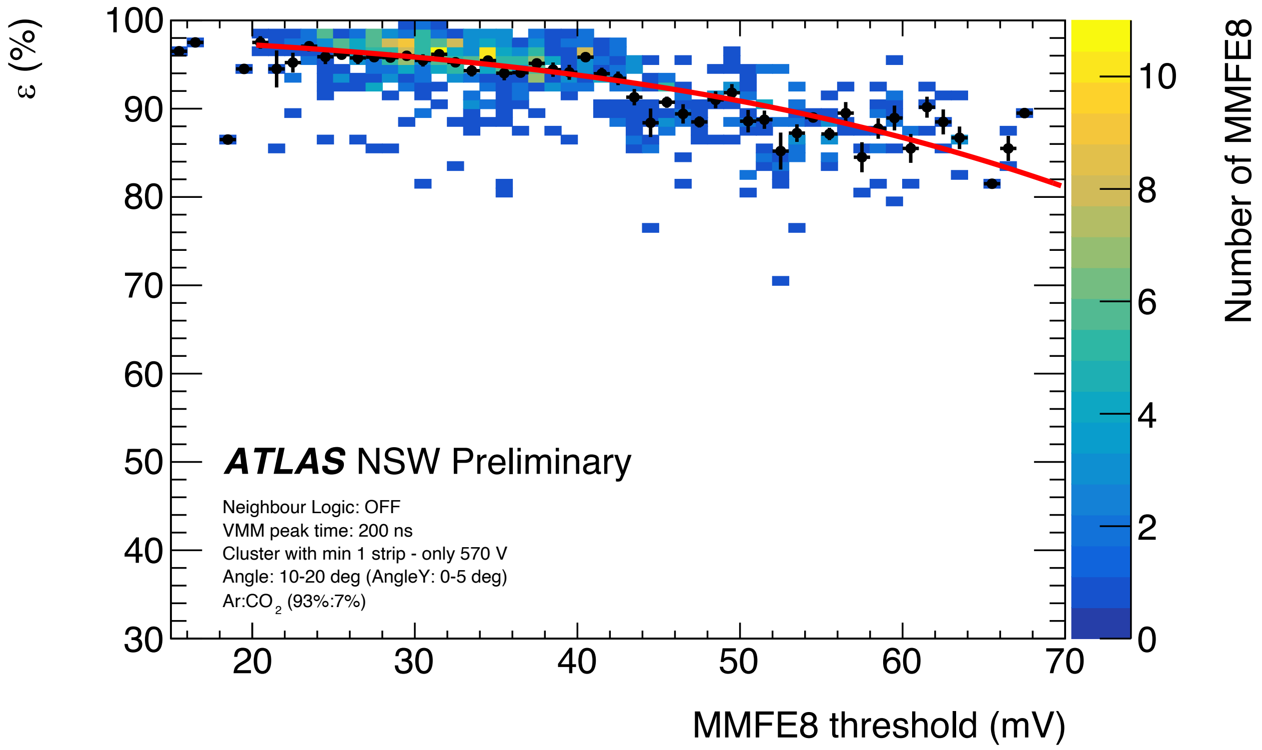


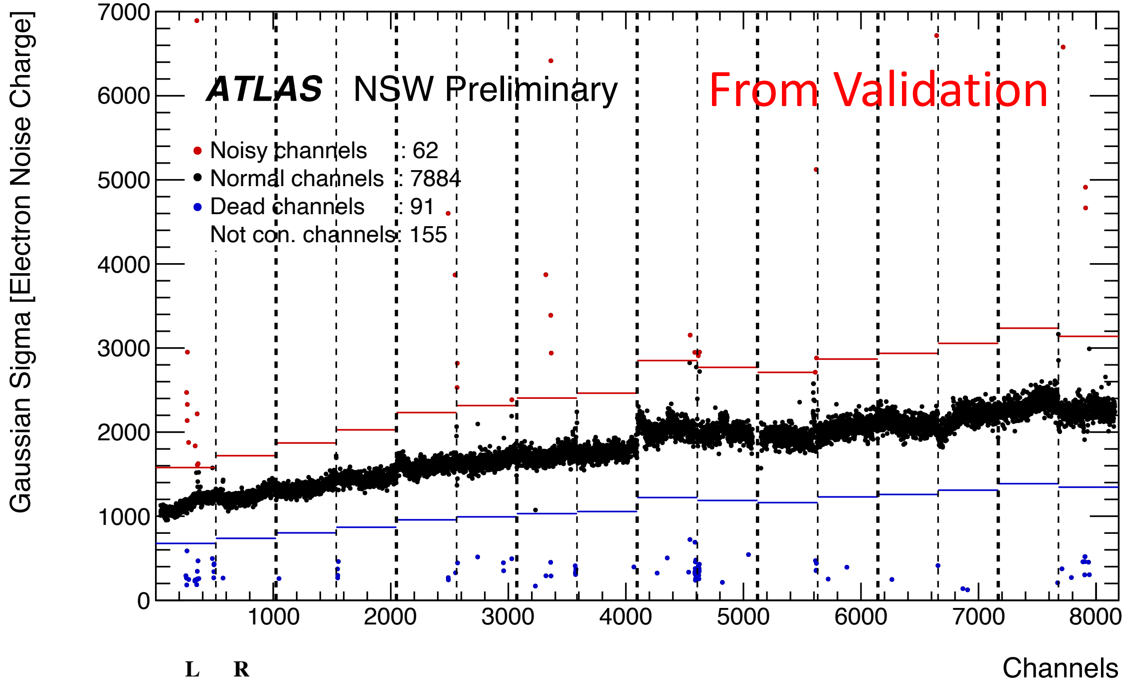




MM performance analysis – noise

- Noise increase with the strip number due to capacitive effects between the strips (expected)
- Studies made at the cosmic stand (controlled situation) show that increasing the strip charge thresholds, the effect on the single plane efficiency is negligible





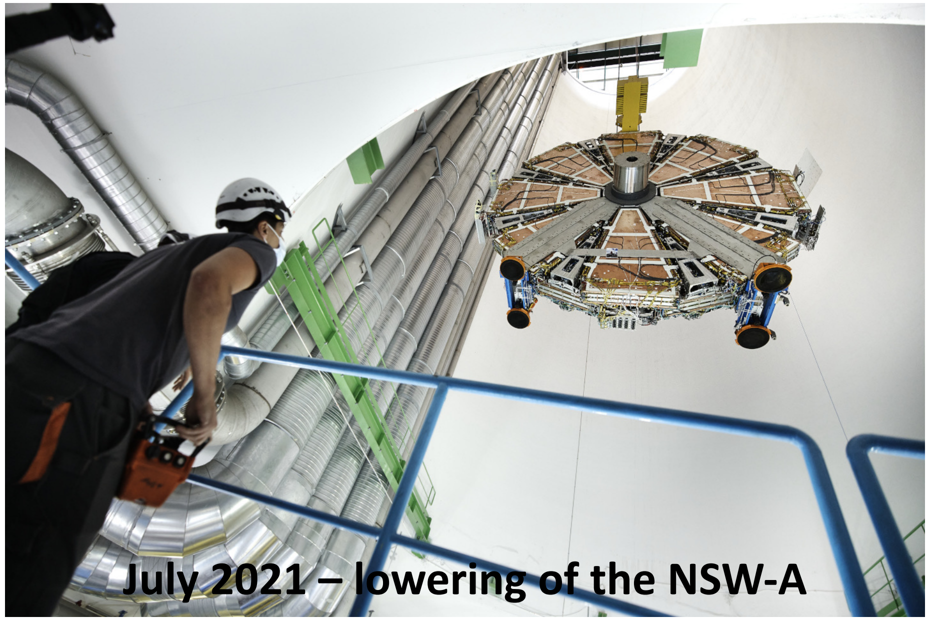
The noise problem on the Wheel now is solved!

NSW-A steps

Sept 2019 – during CERN open days (before COVID!)

June 2021 – first NSW completed

July 2021 – NSW-A ready to go in the cavern

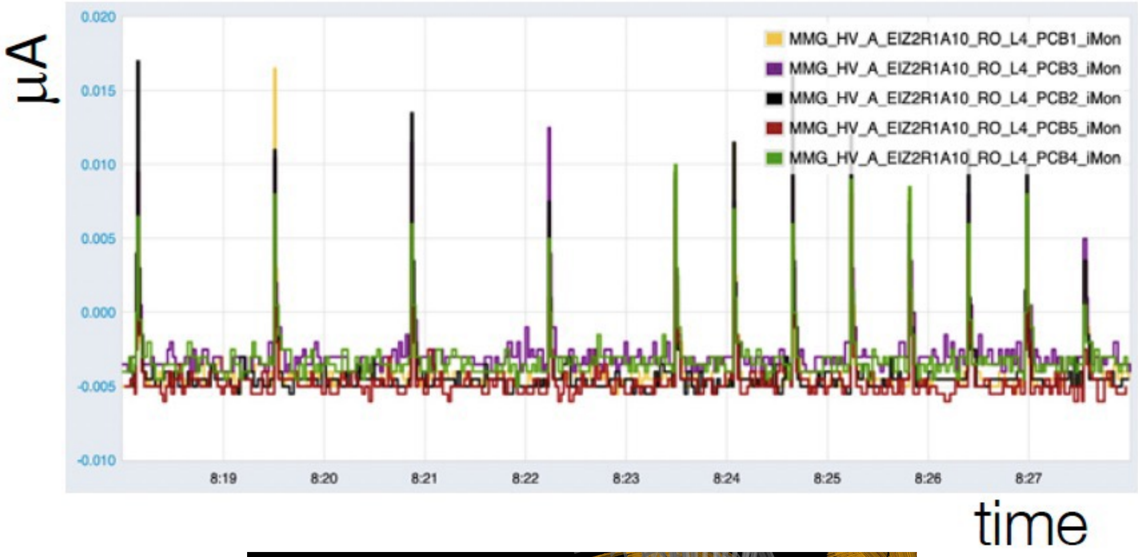


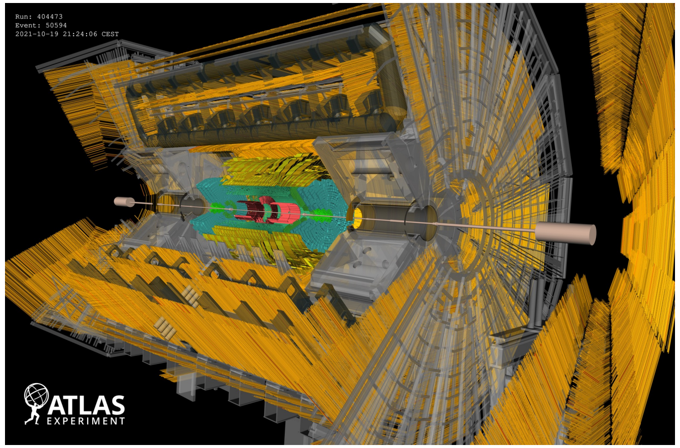
July 2021 – lowering of the NSW-A

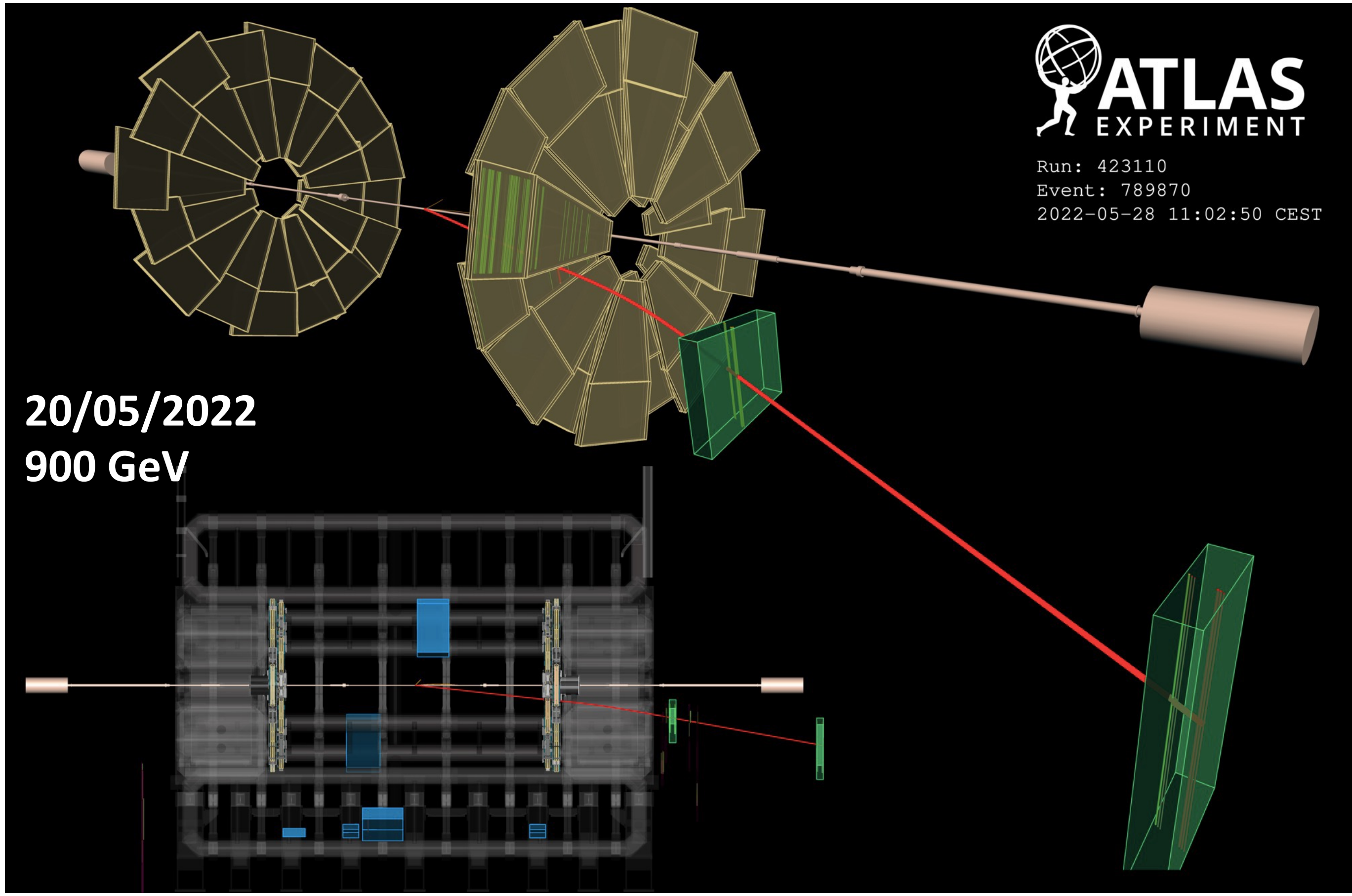
July 2021 – Finally in ATLAS

First signals, first muons

From the **LHC splashes** (7th may 2022) to the first **Run 3 collisions** in ATLAS.

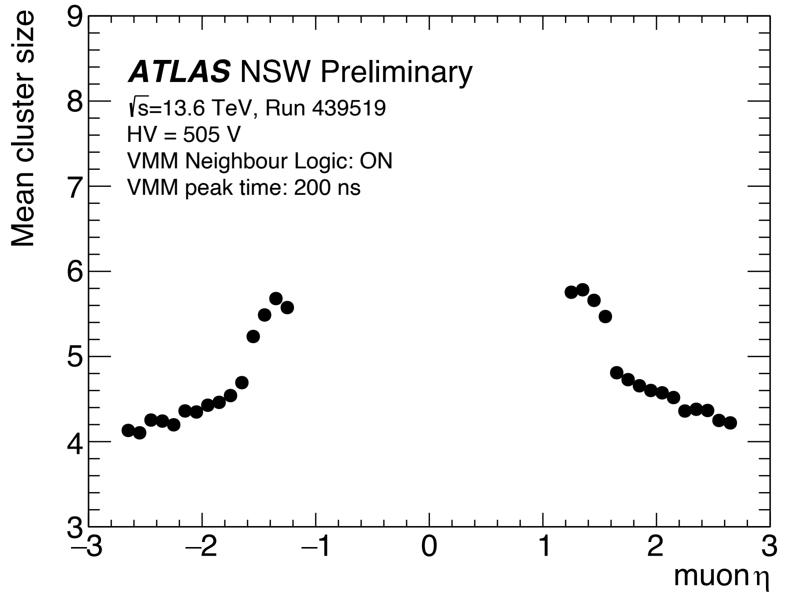




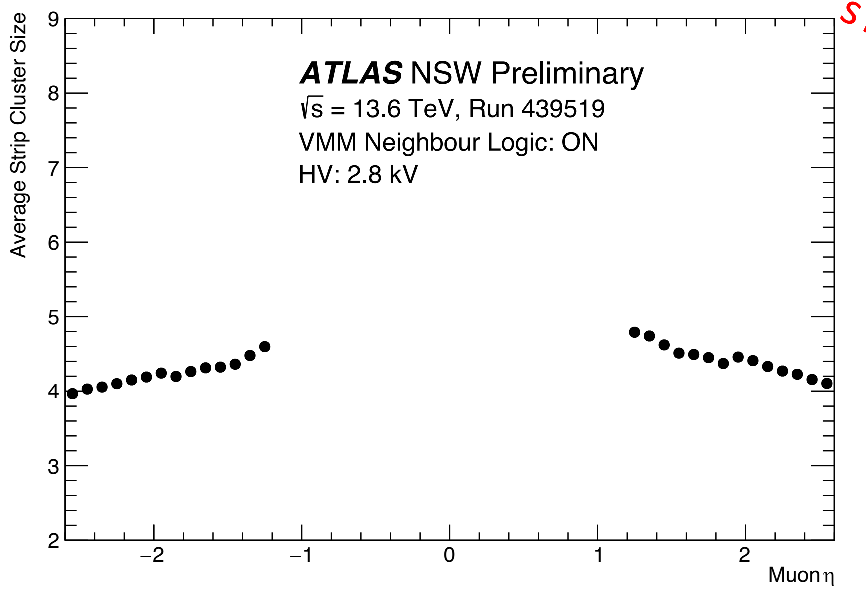


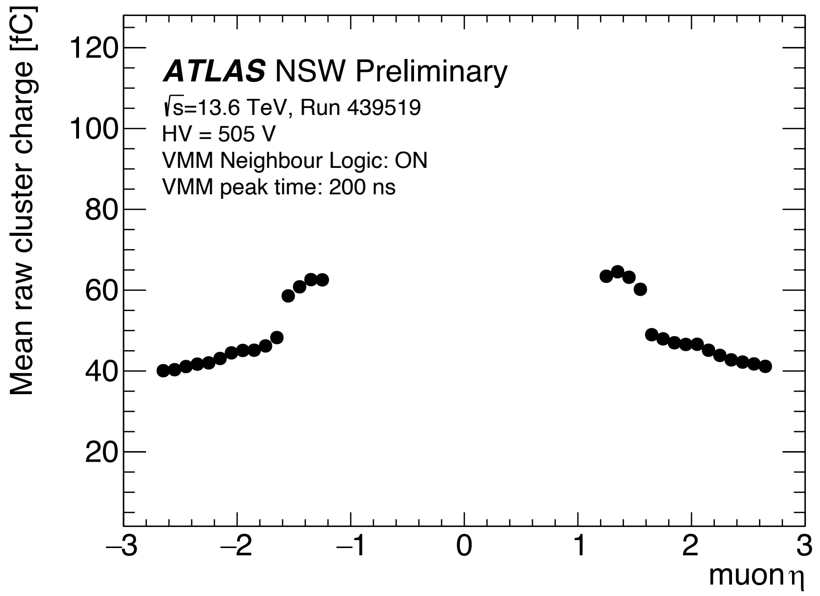
NSW preliminary performance – raw distributions

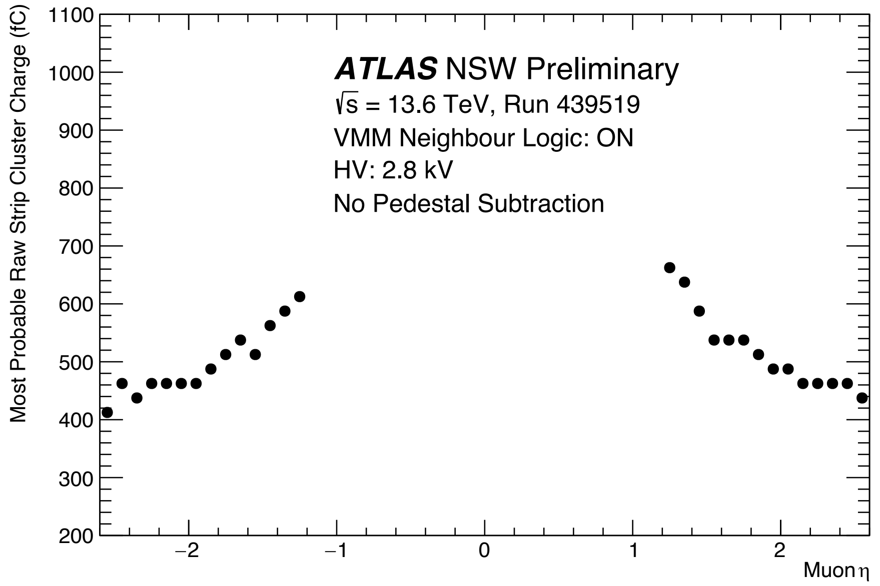
MicroMegas



sTGC







L1 – Trigger efficiency