ATLAS New Small Wheel performance studies with LHC Run-3 data

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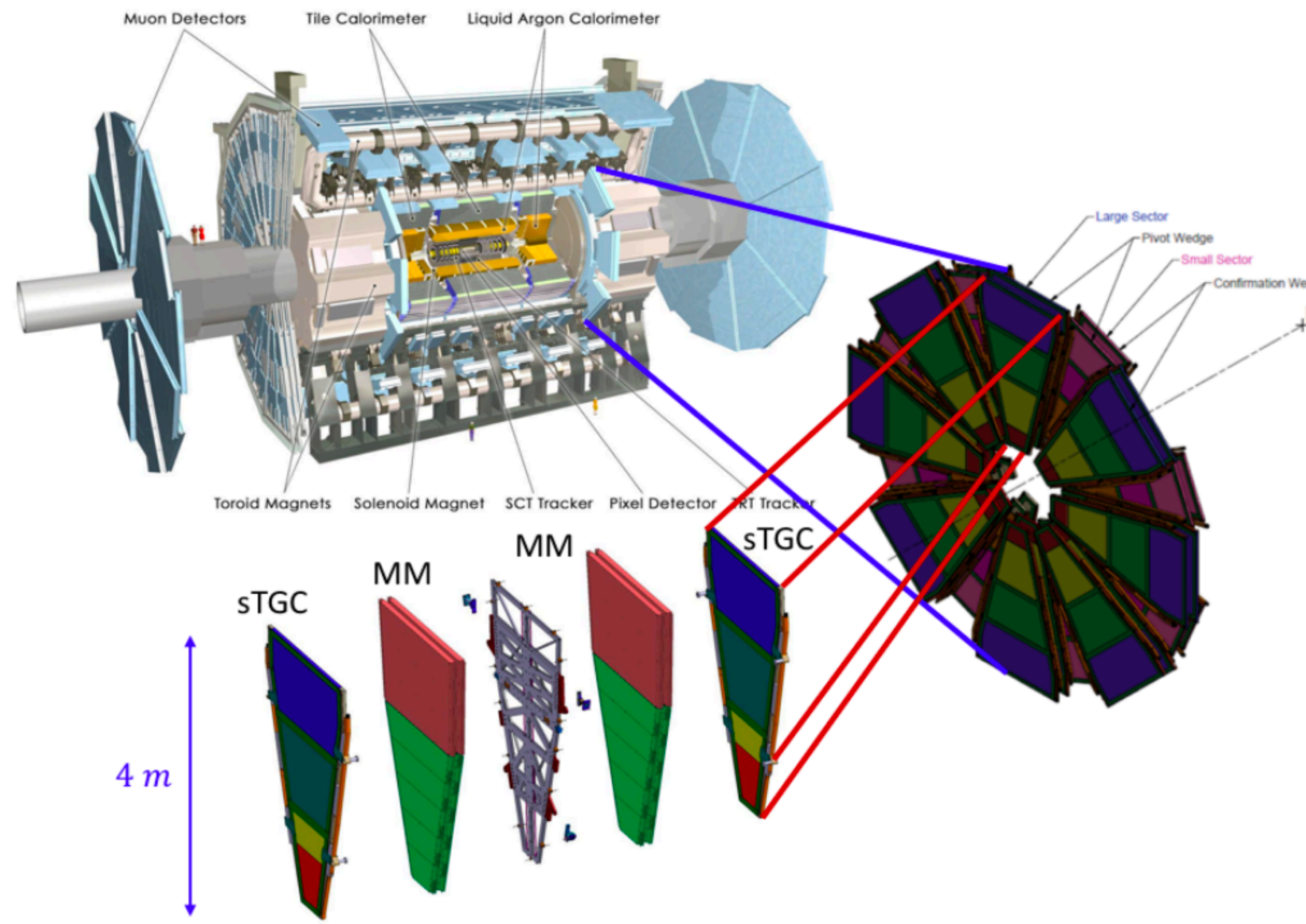
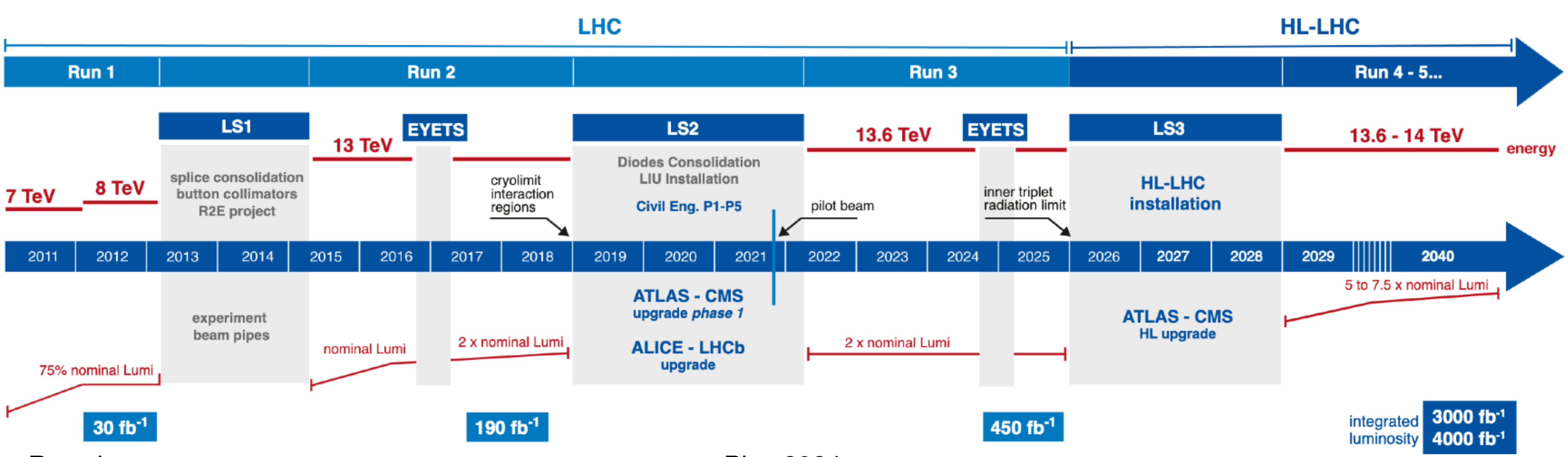
On behalf of the ATLAS collaboration

16th Pisa Meeting on Advanced Detectors

The ATLAS New Small Wheel upgrade

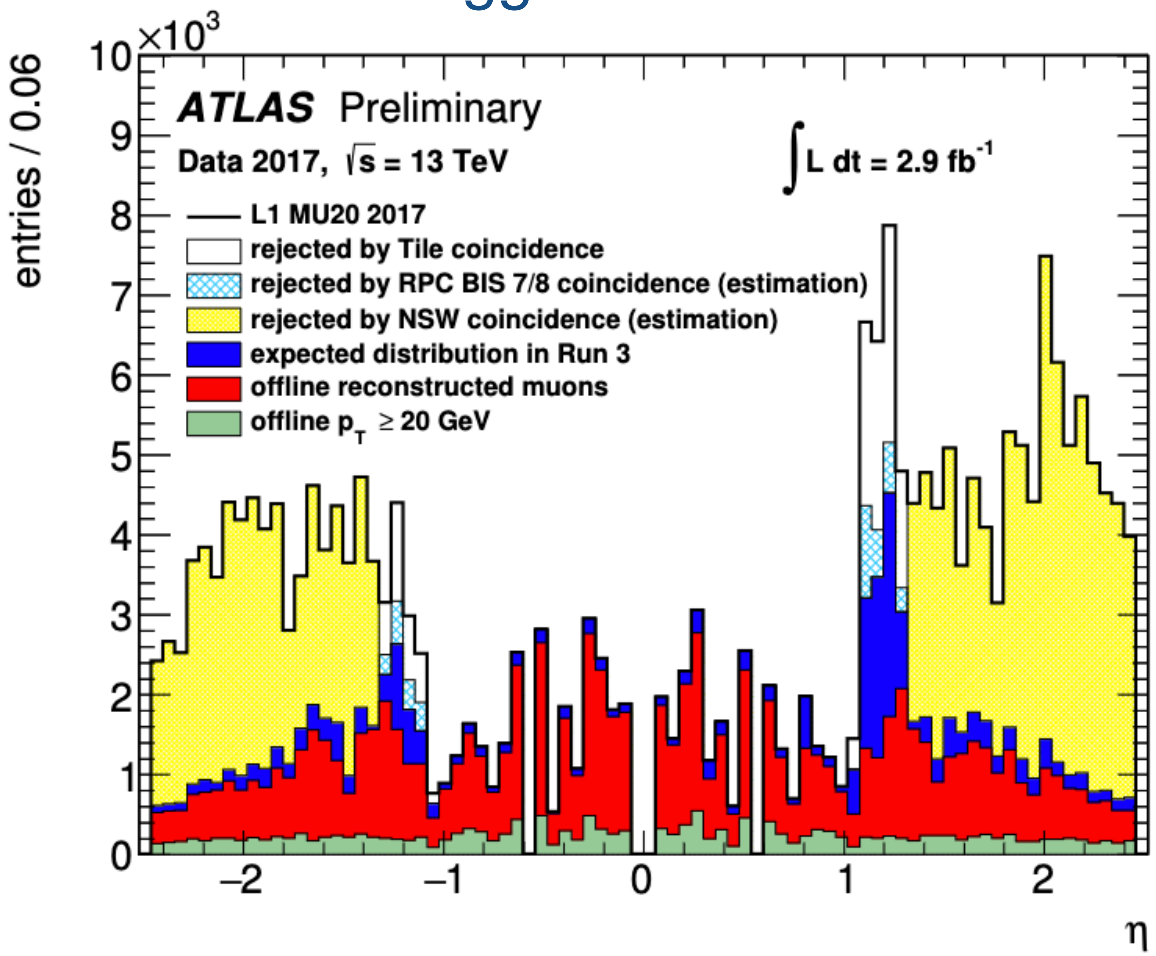
- Main ATLAS phase-1 upgrade project
- Designed to deal with the increasing LHC luminosity
  - 2×10^{34} $cm^{-2}s^{-1}$ (run-3, ongoing) up to 7.5×10^{34} $cm^{-2}s^{-1}$ (Hi-Lumi LHC from 2029)
- Reduce LVL1 muon trigger rates in the endcaps
  - Allow to keep the muon p_T thresholds used in run-1 and run-2
- Guarantee high-resolution (standalone) tracking, in particular for high muon momenta, up to $|\eta| < 2.7$
  - ~15% momentum resolution at 1 TeV



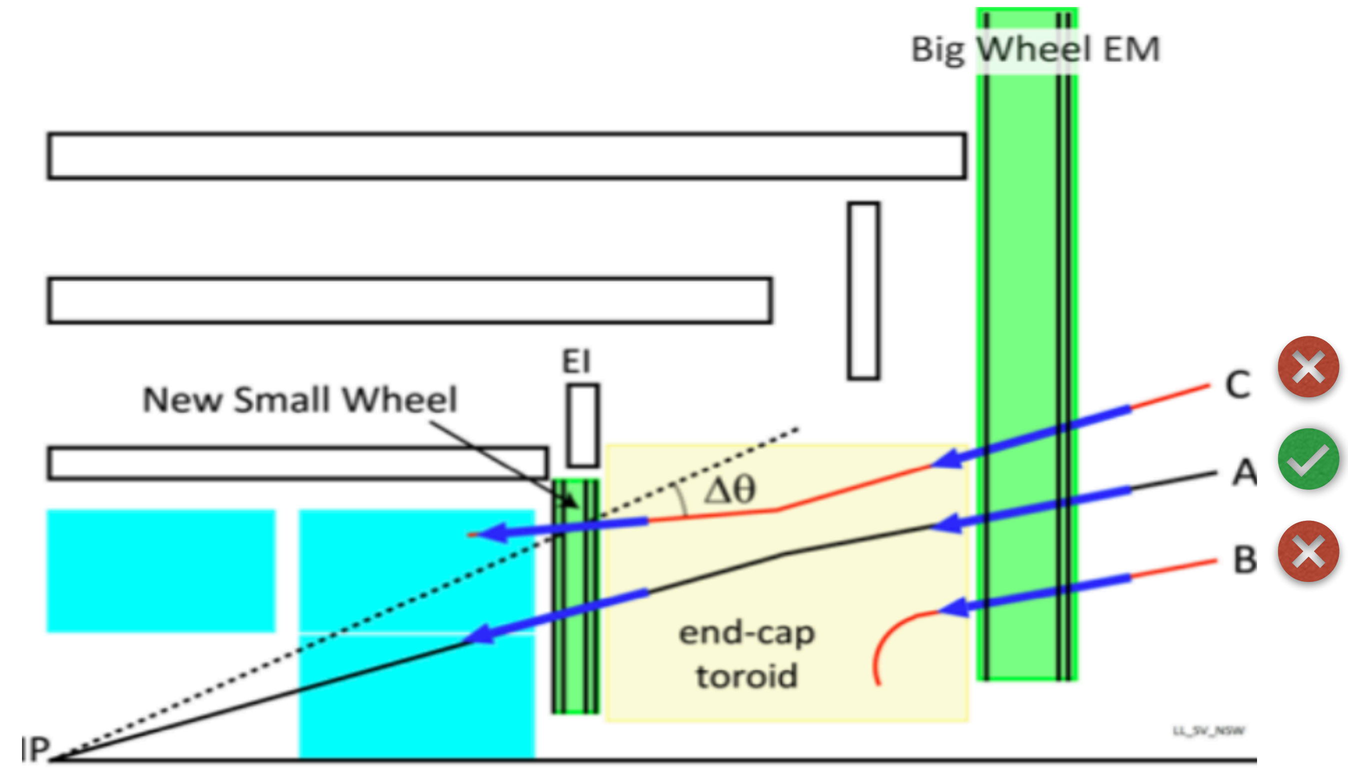


The ATLAS New Small Wheel upgrade

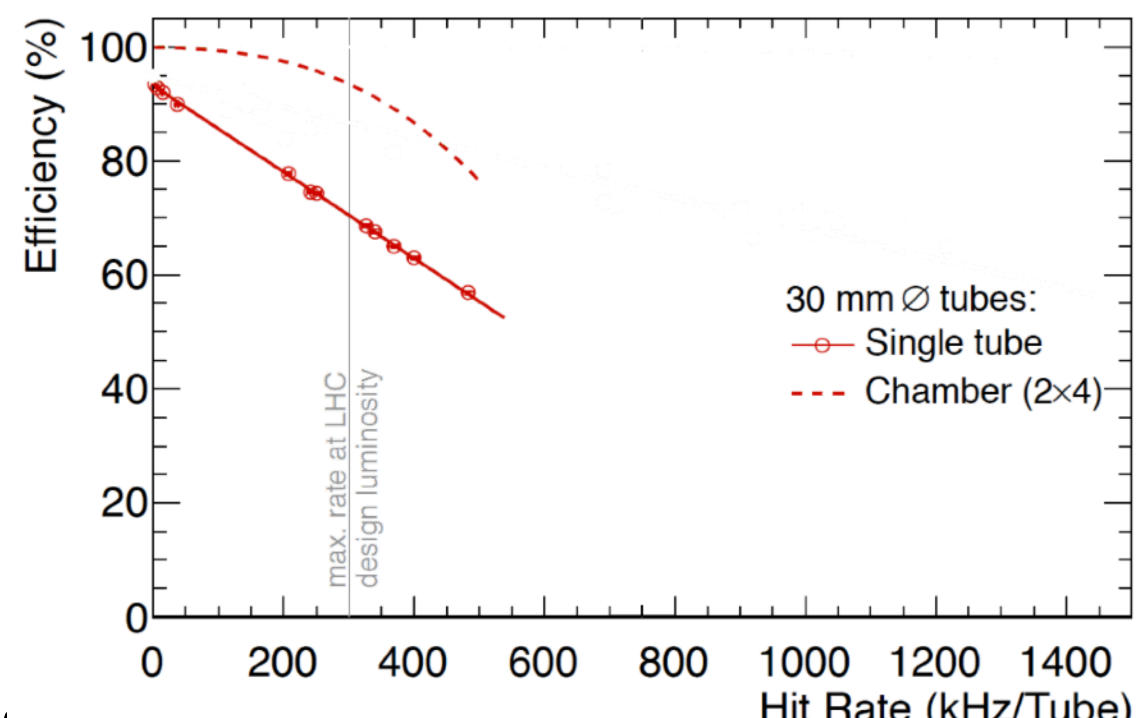
LVL1 trigger rates in run-2



NSW - Big Wheel (BW) coincidence upgrade

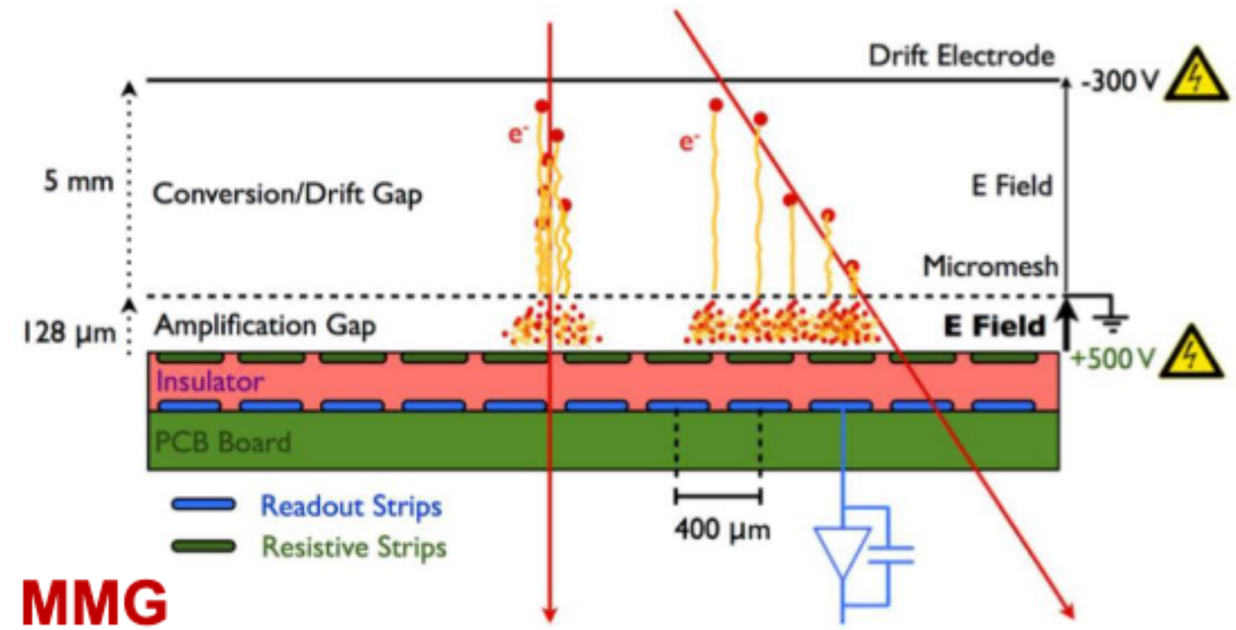


MDT single-tube and tracking efficiency vs rate per tube

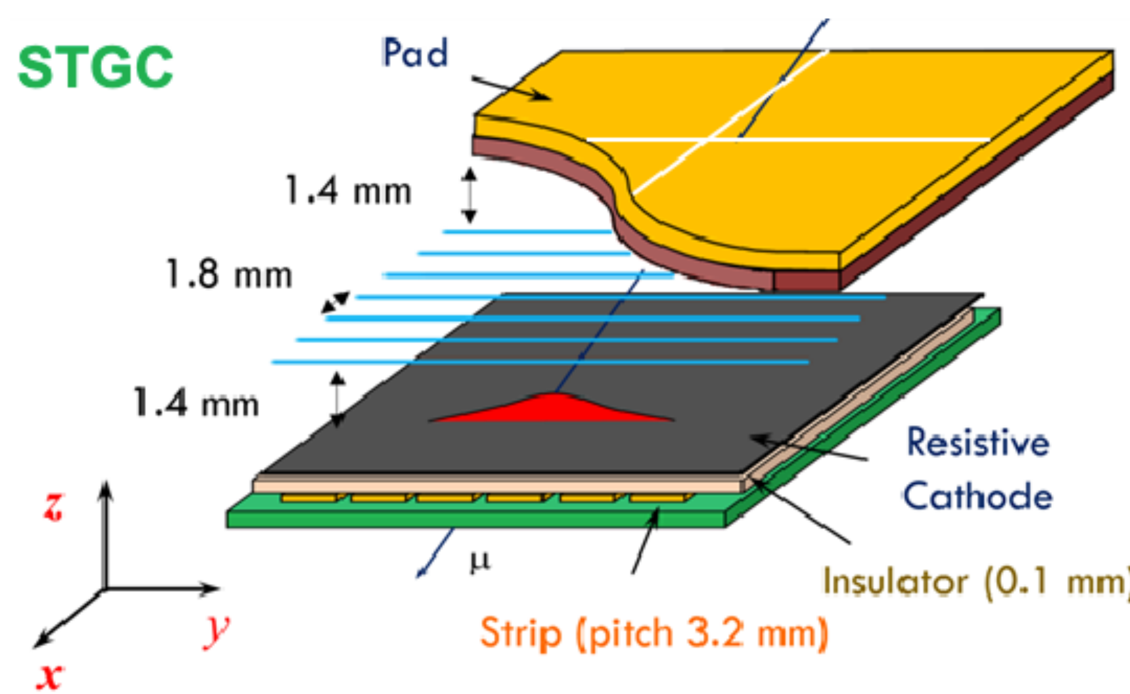


The New Small Wheel detectors

- Two novel technologies employed:
  - Resistive Micromesh-Gaseous Structure: Micromegas **(MM)**
    - Gas mixture Ar:CO_2:iC_4H_{10} 93:5:2%
  - Resistive cathode small-strip Thin-Gap Chambers **(STGC)**
    - Gas mixture n-Pentane:CO2 45:55 %



- Both detectors can contribute to both trigger and tracking
- Each sector has **8+8 layers** (MM+STGC)



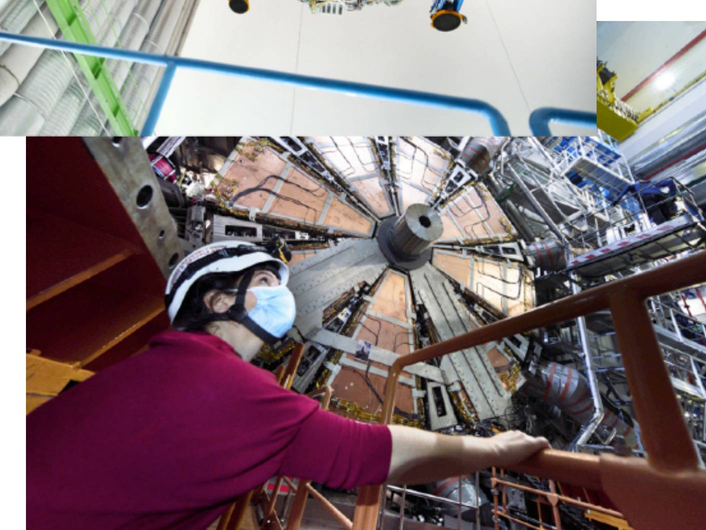
- Number of channels ~25x legacy system
  - MM: **2.1M** channels
  - STGC: **280k strips + 46k pads + 28k wires**

NSW timeline

- NSW Technical Design report in **June 2013**
- Until **2018** R&D and detectors construction
- **2018**: start of MM + STGC detector integration
- **Dec 2019**: Installation of the first sector in the surface building
- **August 2021**: completion of side-A wheel and installation at P1
- **October 2021**: completion of side-C wheel and installation at P1
- **July 2022**: start of LHC run-3

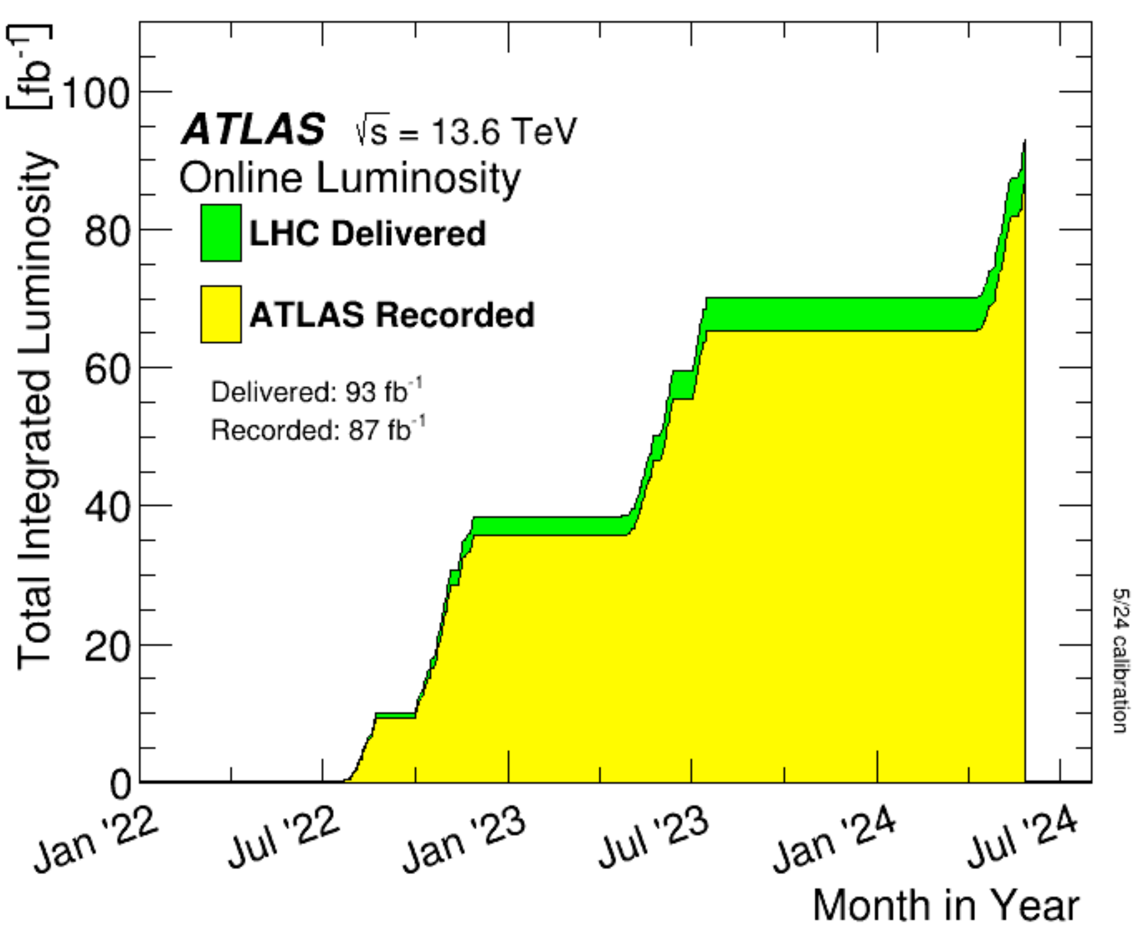


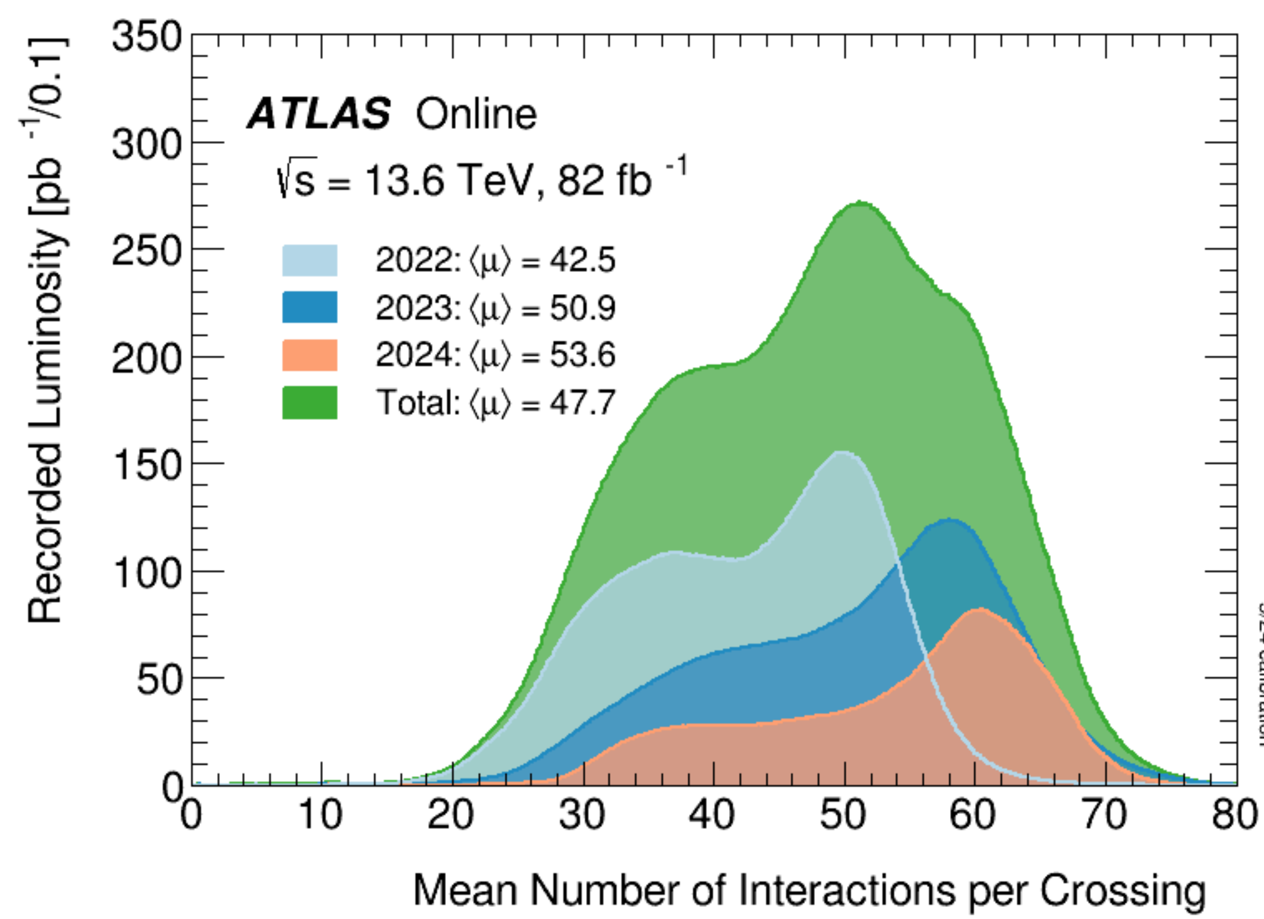




The LHC run-3 ATLAS dataset up to now

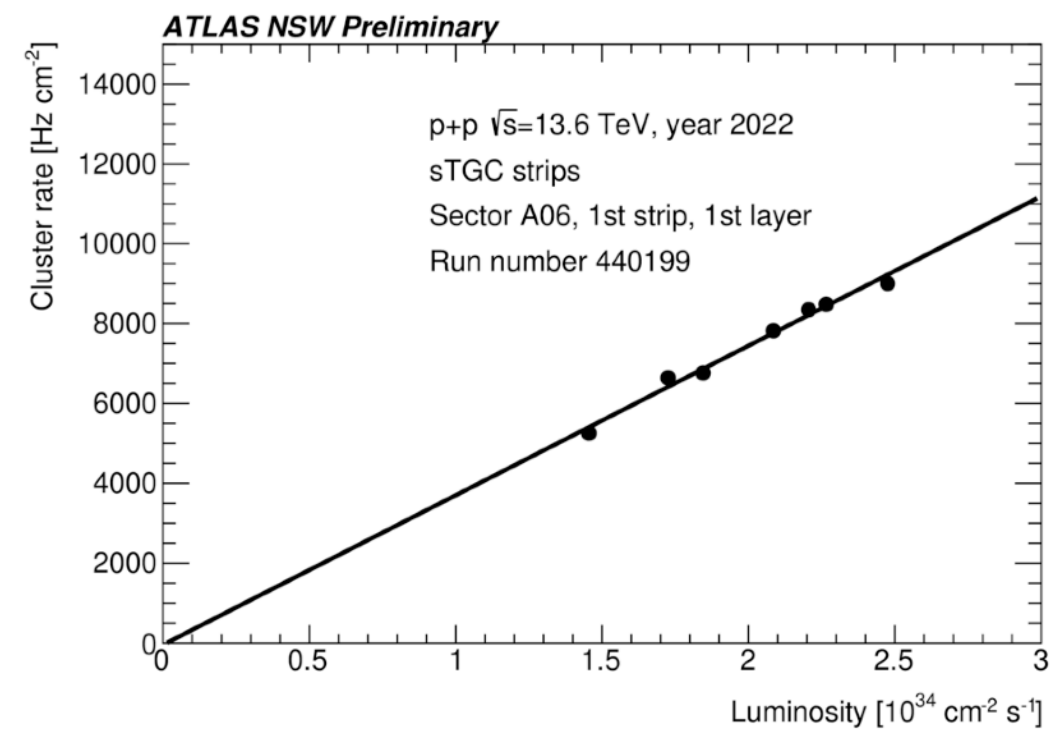
- Although the first year was considered a commissioning year for the NSW, both MM and STGC have been included in the combined ATLAS DAQ since the beginning of run-3 in 2022

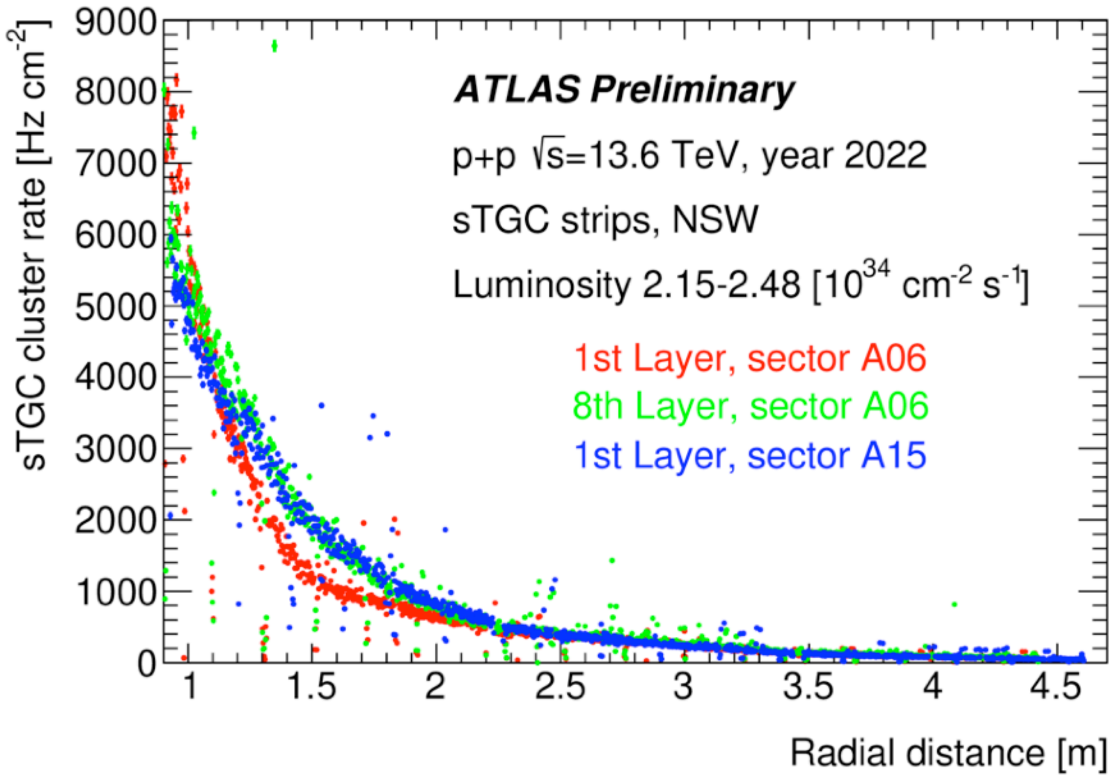


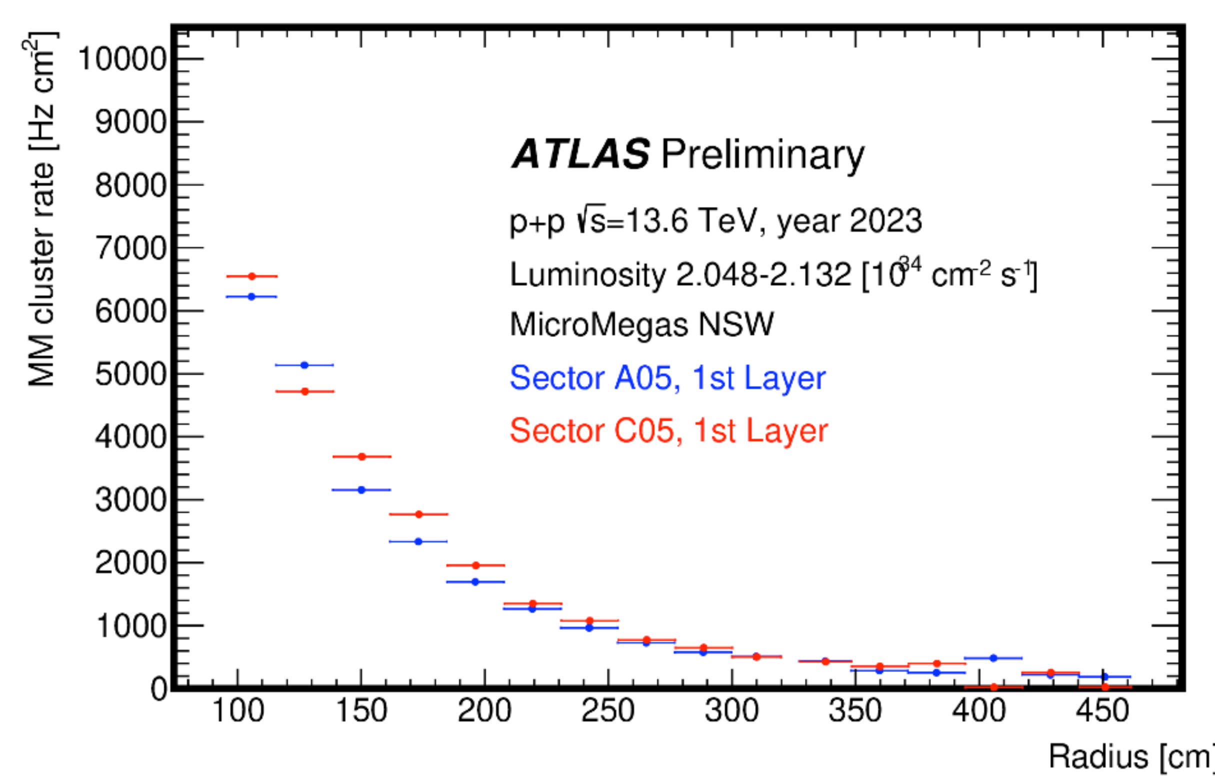


Observed rates

- Main contribution to the hit rates is coming from cavern background
- Estimates before run-3 from run-2 extrapolations and G4/Fluka simulations
    - Expected larger backgrounds than in run-1 and -2, due to reduced forward shielding
- First direct rates measurements are in relatively good agreement with those extrapolated from run-2 (within ~30%)

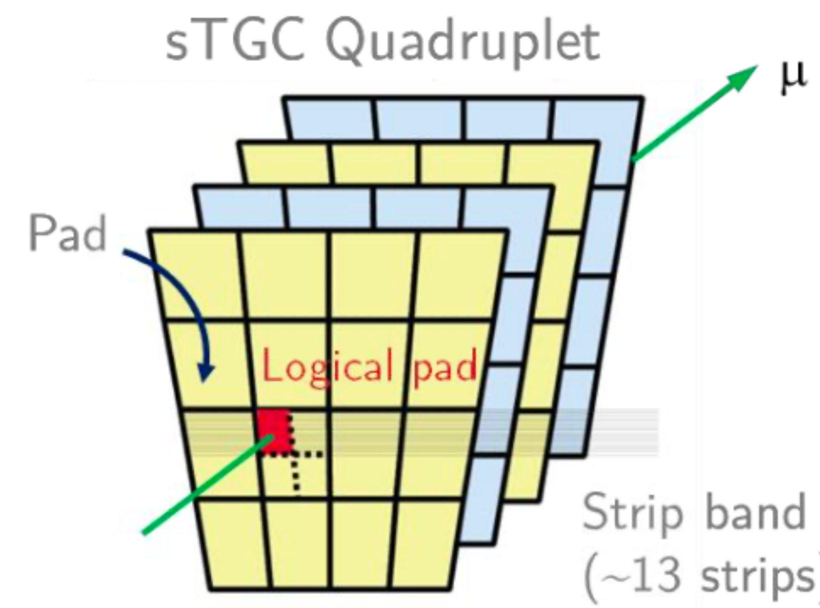


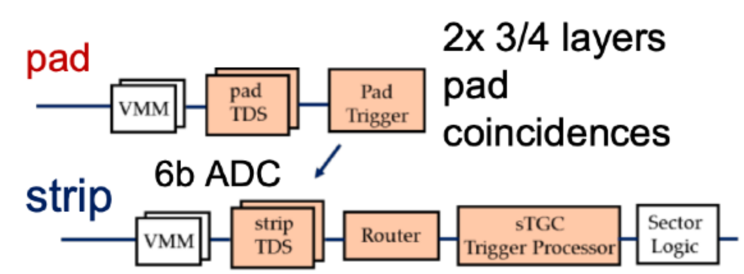


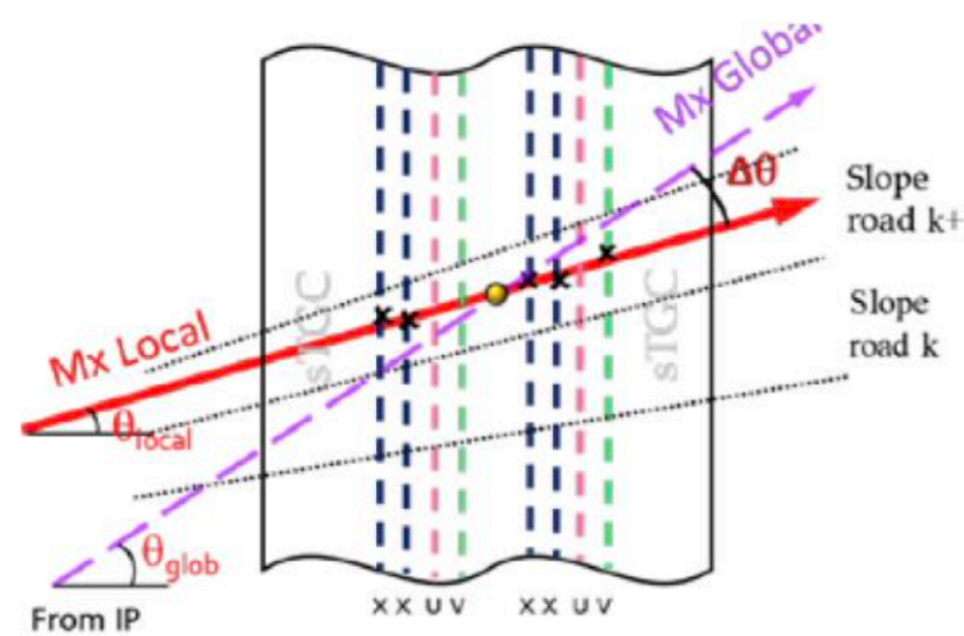


The NSW trigger

- STGC L1 trigger
  - **Pad trigger** coincidence (**3/4** or **2/4** per wedge)
  - Also select charge information from the strips in a band in the region of interest
    - Centroid position for segment reconstruction
- MM L1 trigger
  - Use the addresses of the earliest strips in each VMM (64 strips) across multiple layers
- Strip triggers very important for phase-II
  - More complex topological L0 triggers require ~1 mrad segment angular resolution
- The NSW trigger is since 2023 actively contributing to the forward background suppression
  - **STGC PAD trigger only** for the moment

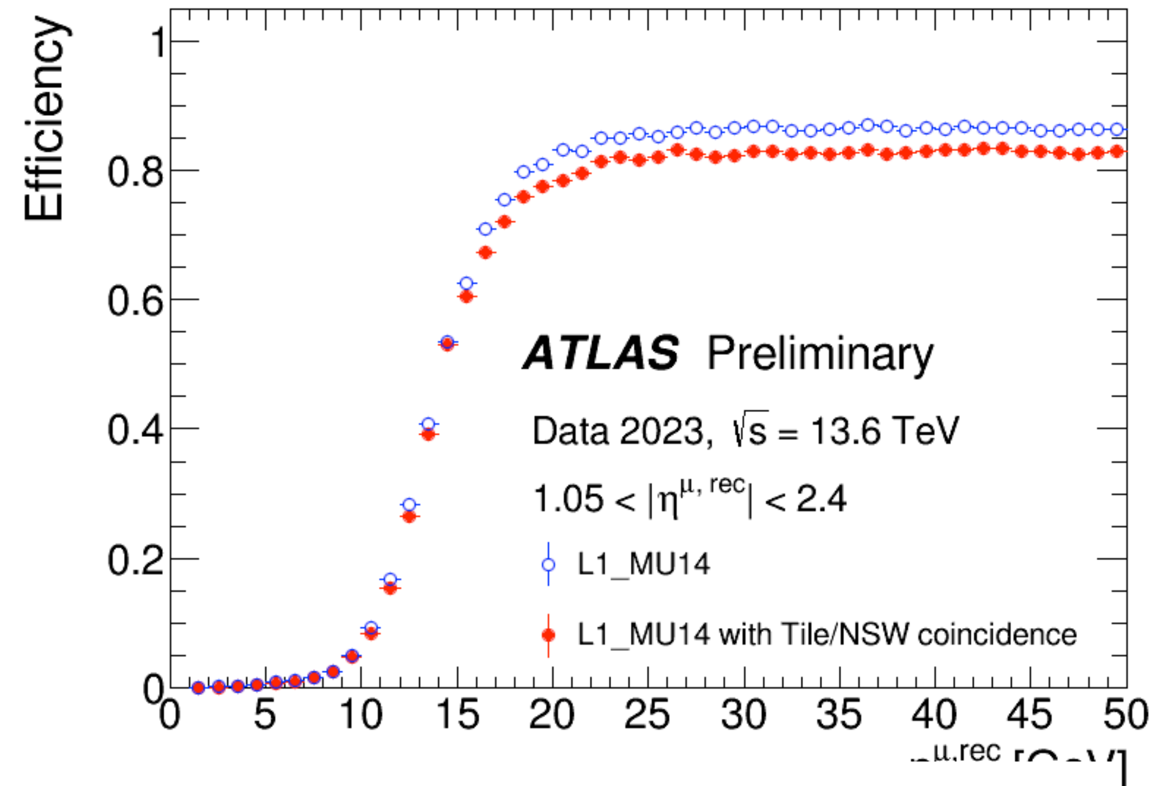


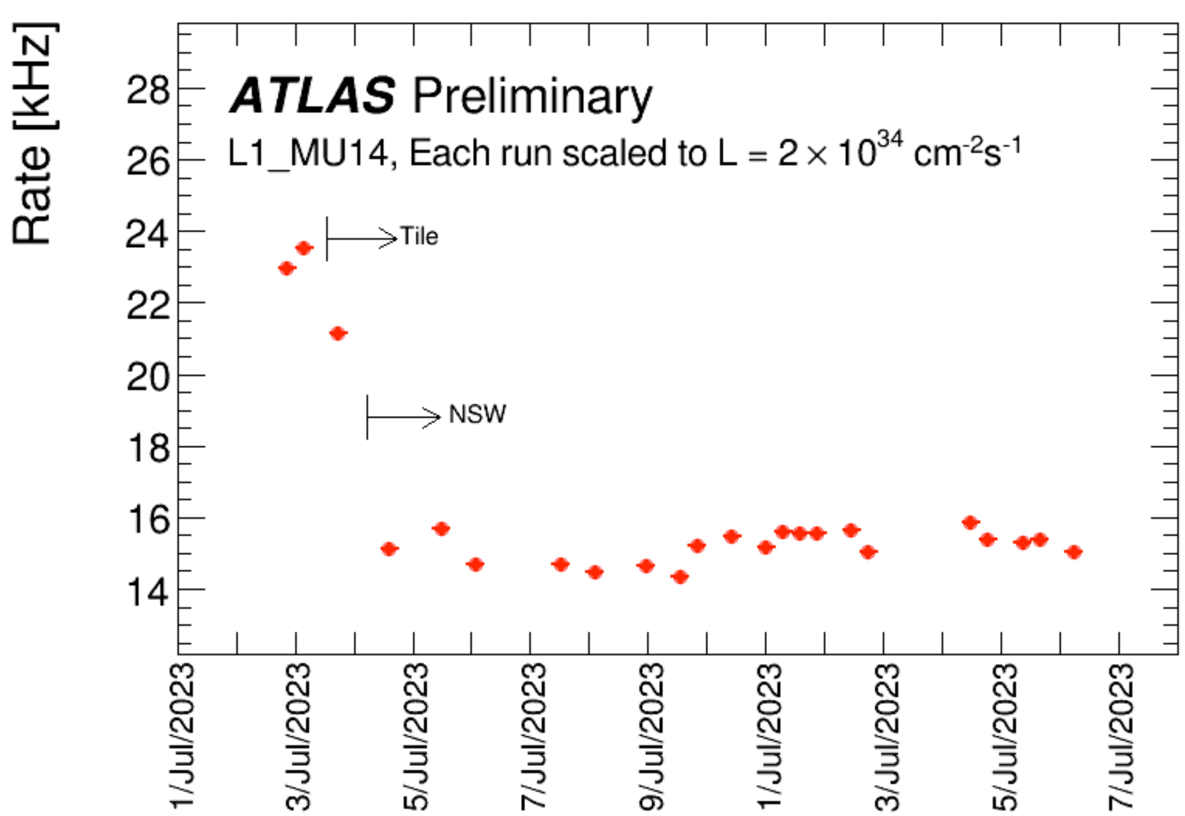


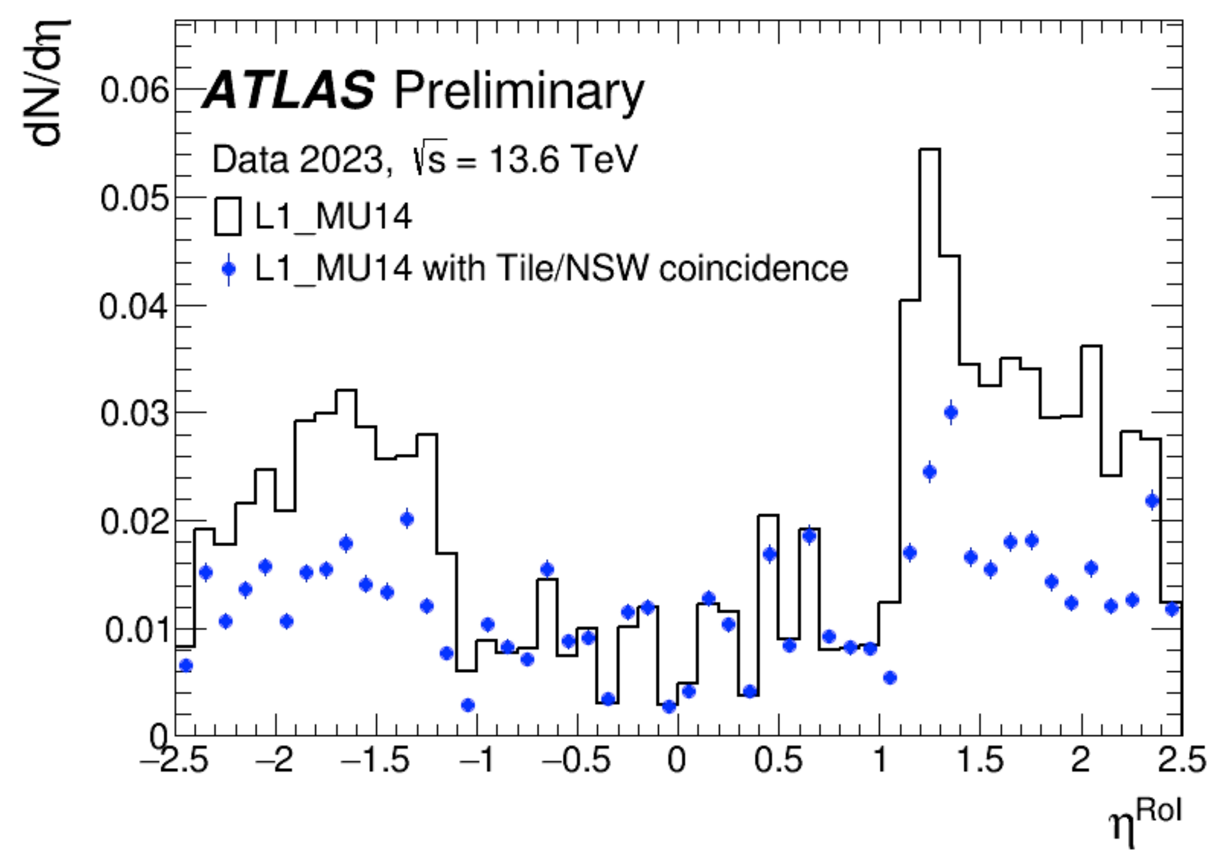


Trigger performance in 2023

- During 2023, the STGC Pad trigger was added to the L1 coincidence
    - Muon BW + Tile Calo + NSW
- Overall reduction of the L1 rate by **~30%**
    - Endcap efficiency reduced by **~4%**

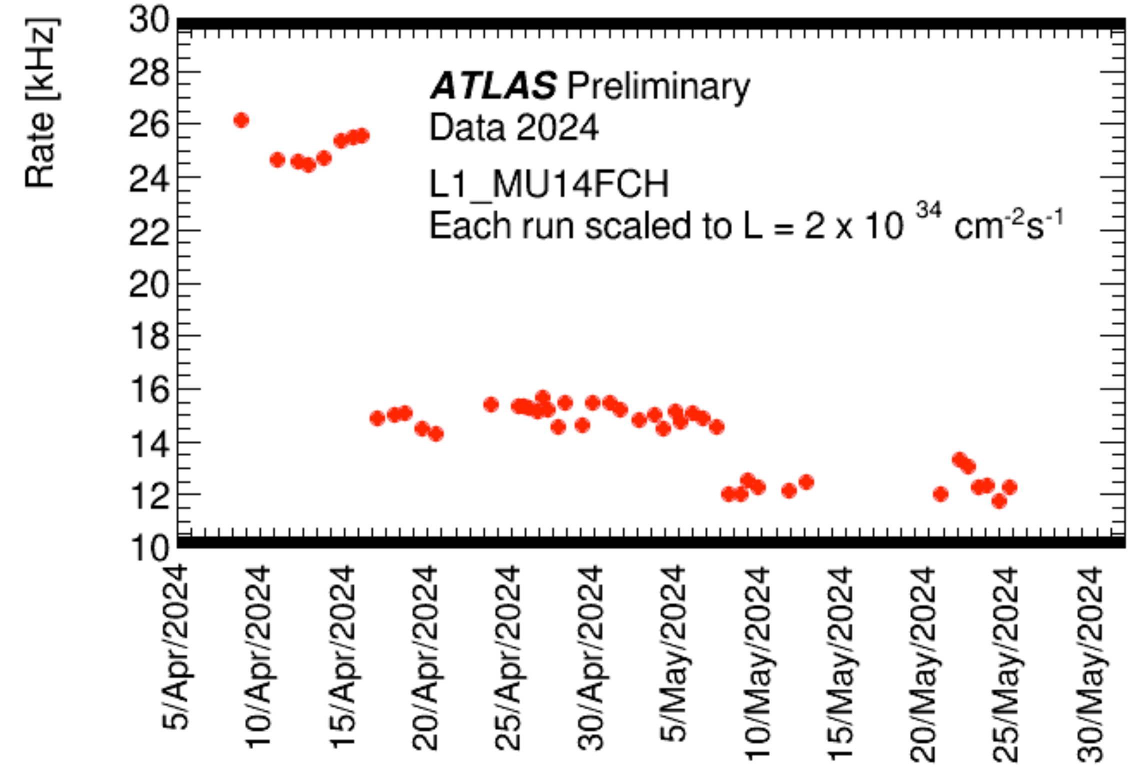


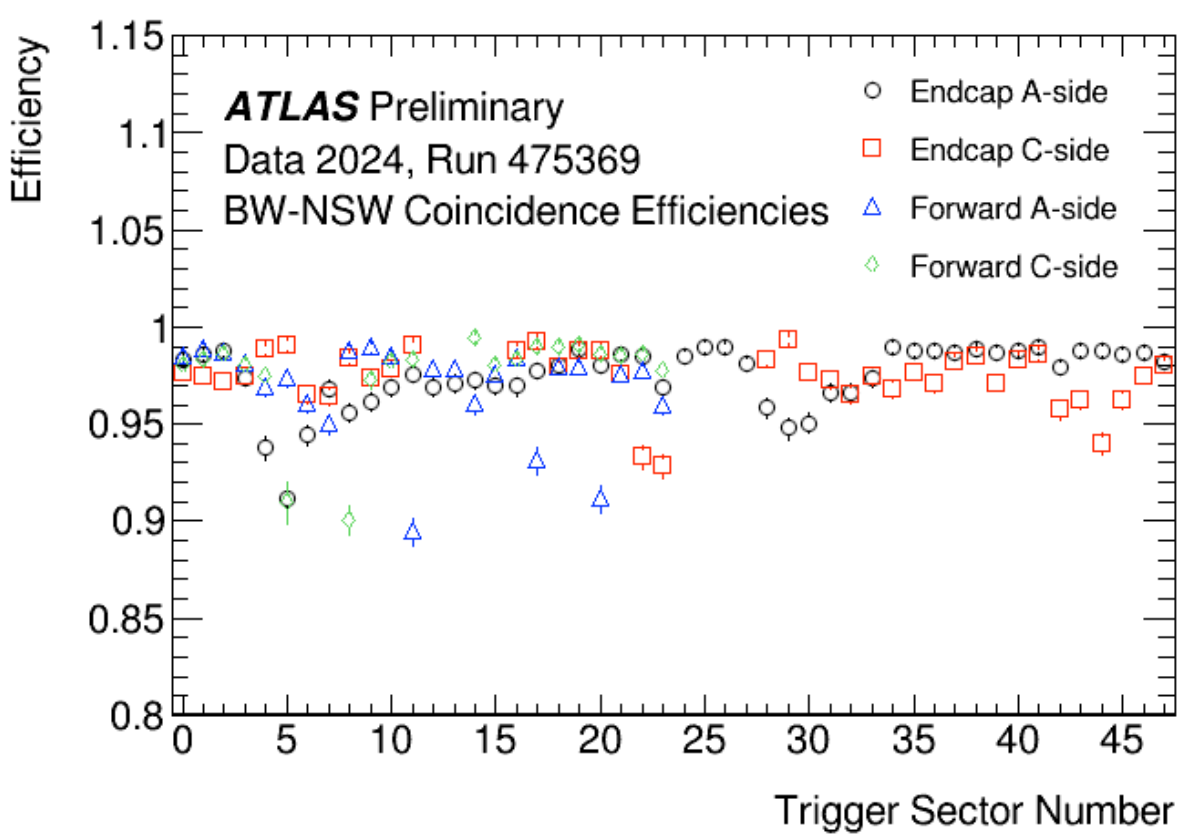


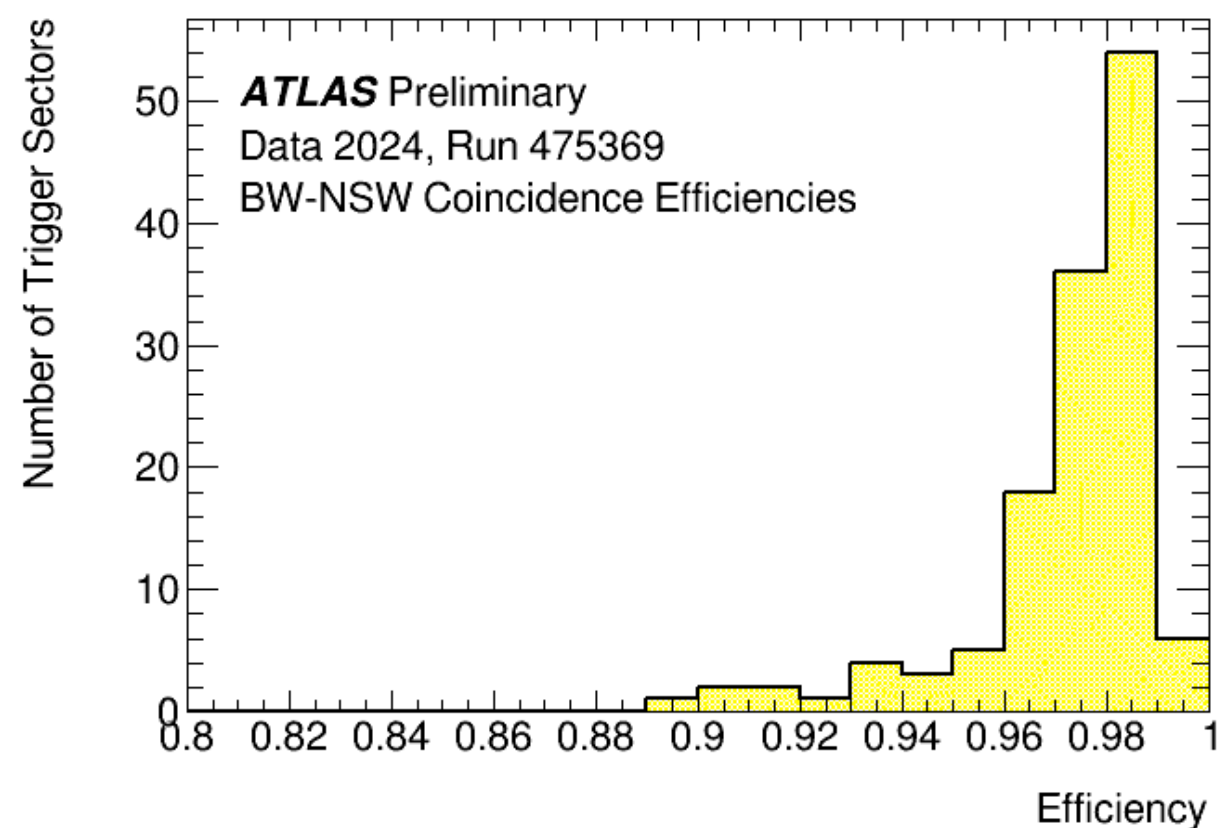


Trigger performance in 2024

- Tilecal-NSW-BW coincidence re-activated after a few runs from the re-start
  - Only STGC-PAD trigger
  - At first 65% of the NSW trigger sectors, then 85%
  - About 10 kHz L1 rate reduction
  - Efficiency loss significantly reduced well below 4%
- Integration of the MM segments in the trigger processor coincidence ongoing

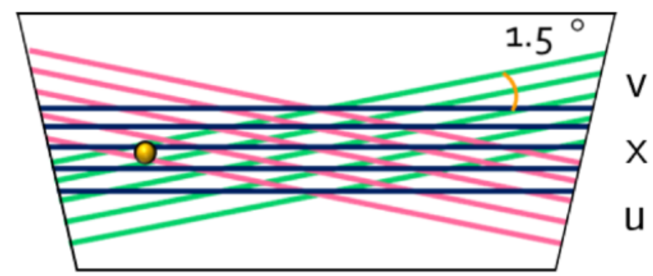




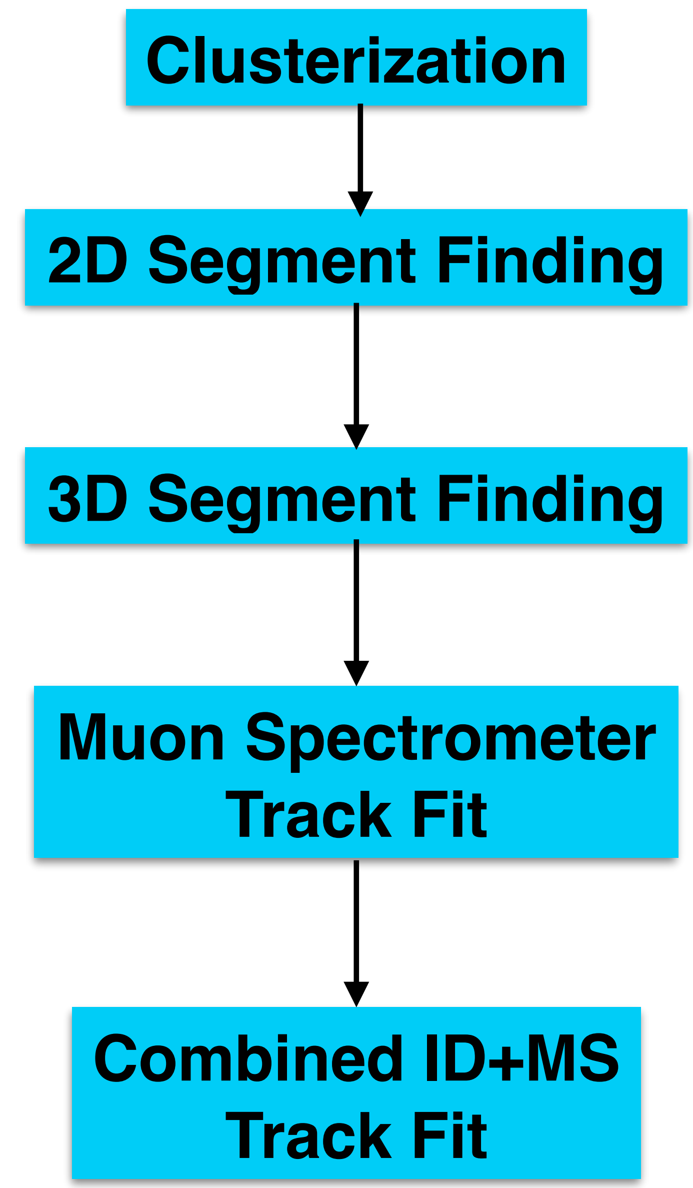


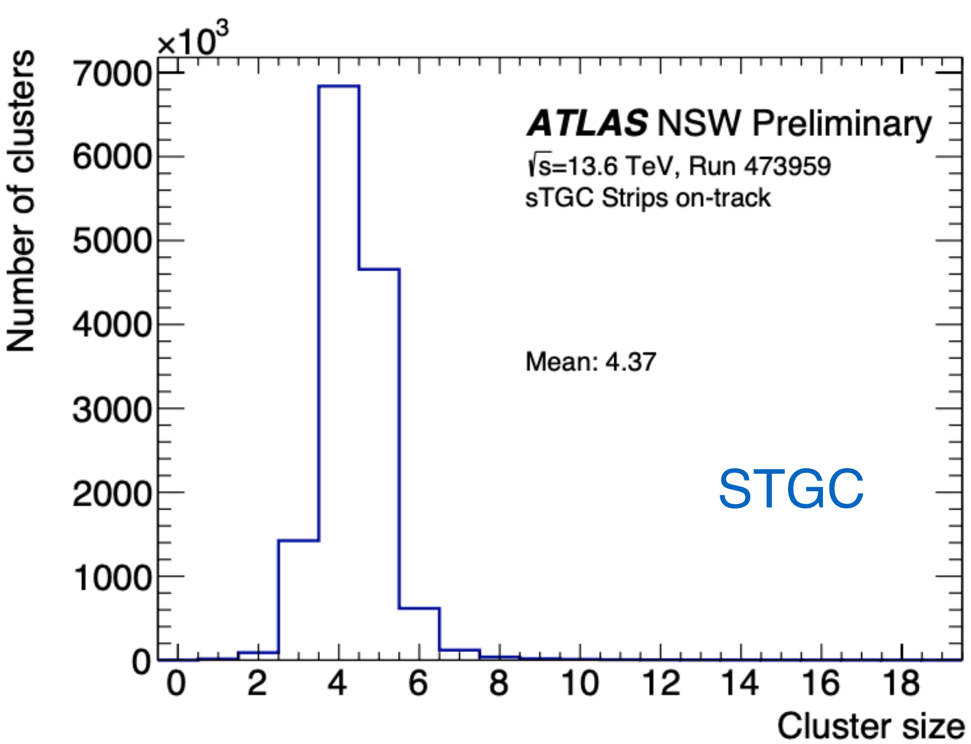
Reconstruction with the NSW

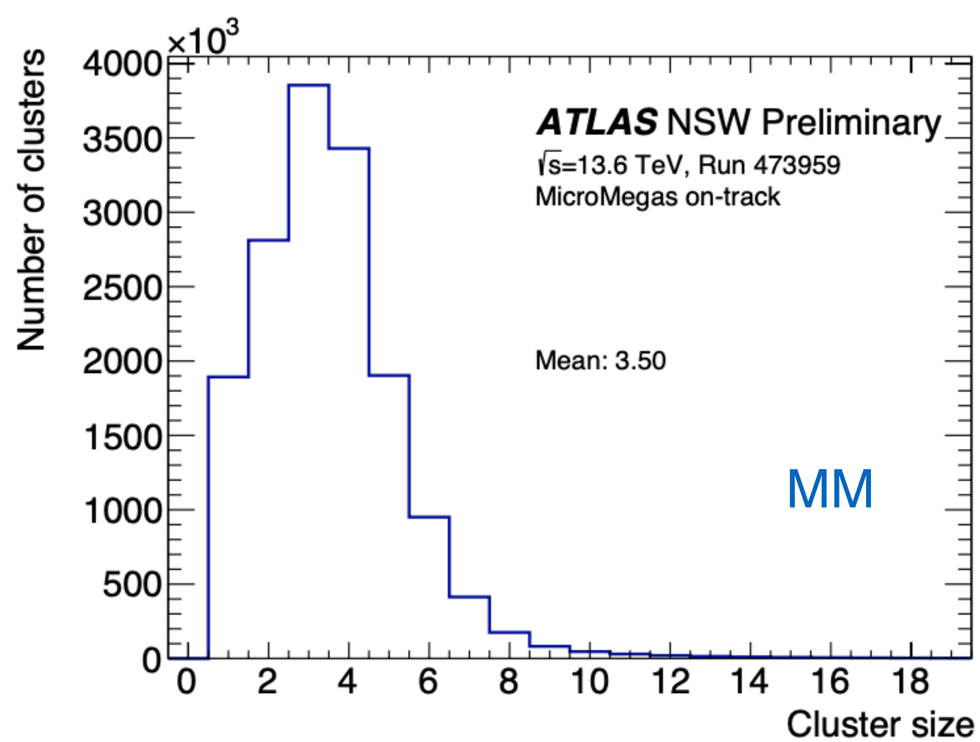
- The NSW is fully integrated in the ATLAS simulation and reconstruction framework since the start of run-3
- MM and STGC strips are clusterized and the clusters are combined in track segments across the detector layers
    - Second-coordinate (azimuthal - phi) measurement from MM stereo strips and from STGC Pads/Wires
    - B-field corrections on 3D segments



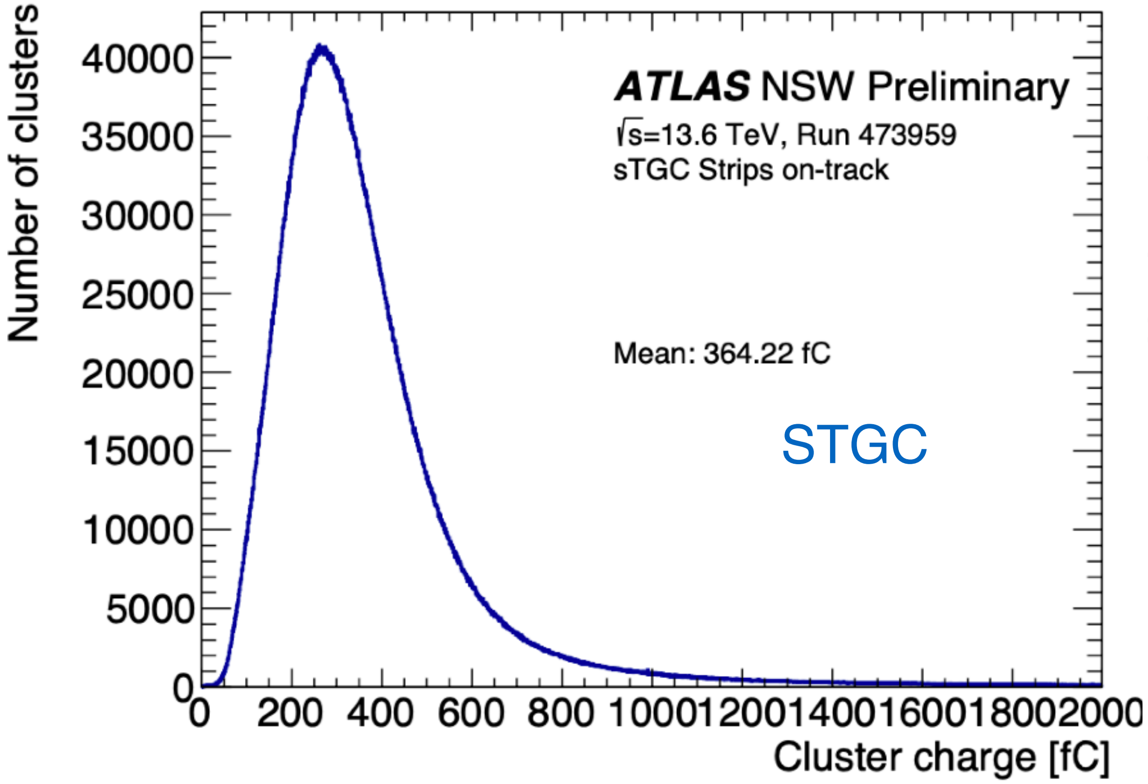
x: horizontal strips (2 planes per Quad.)
u,v: stereo strips (1 each per Quad.)

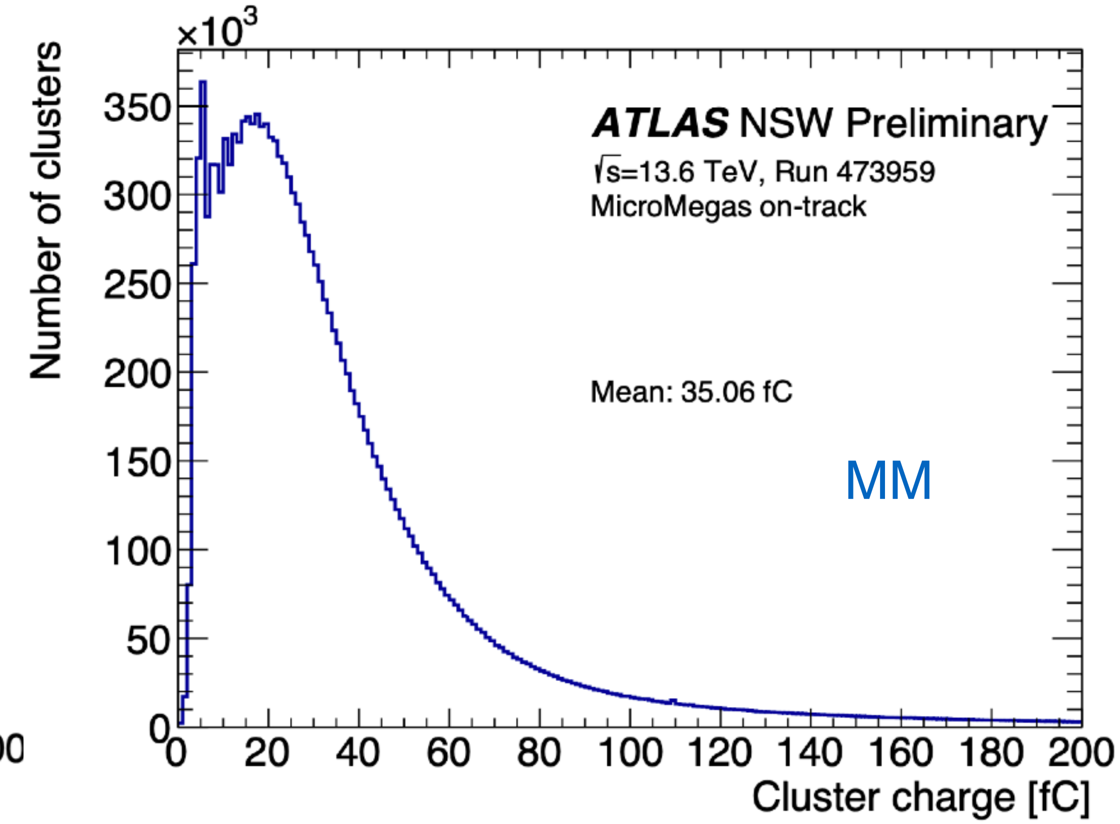




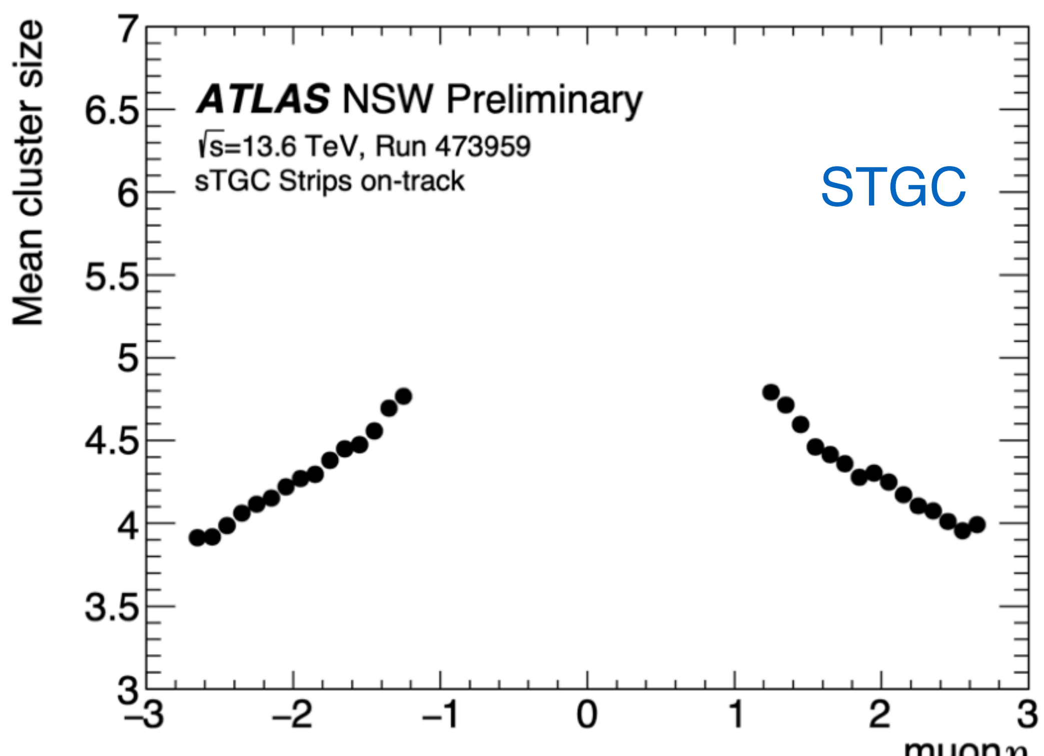


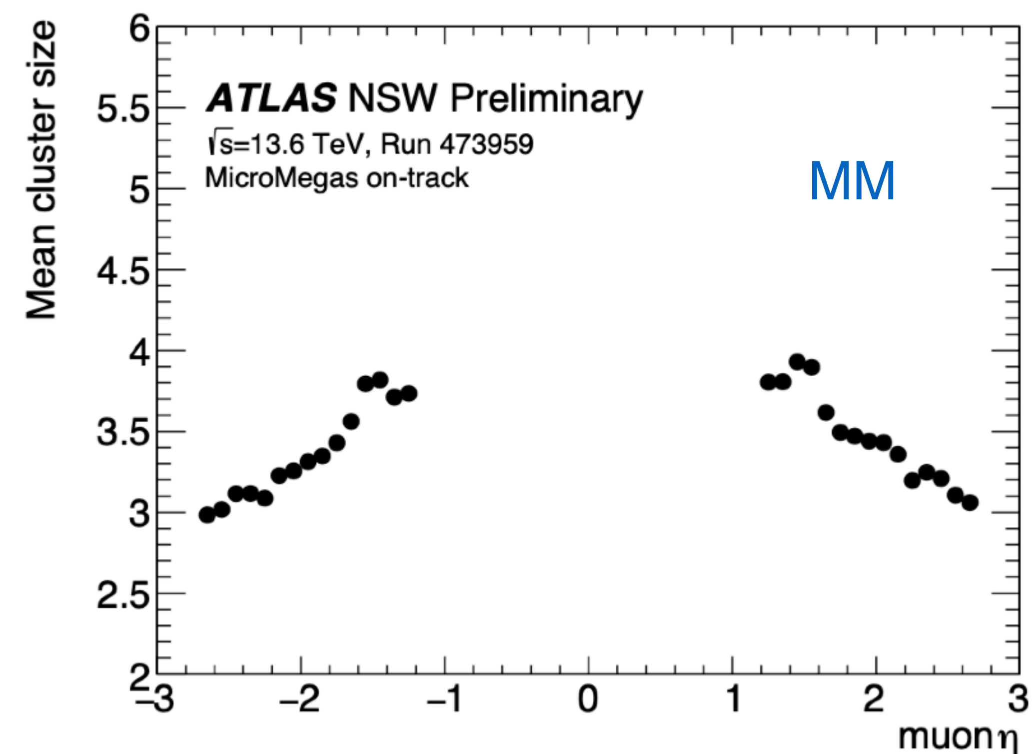
Clusters properties





- Cluster charges and sizes, 2024 data

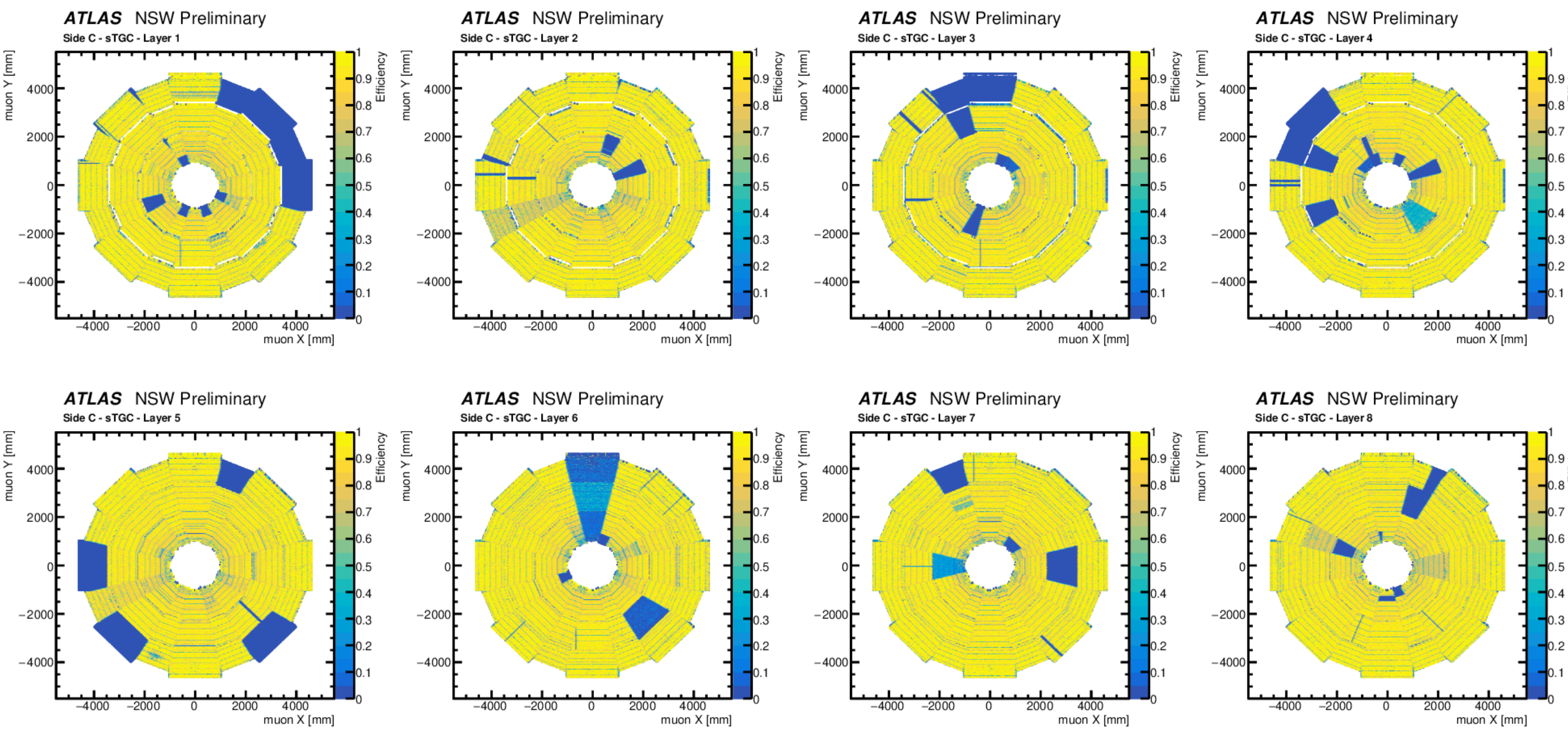




More on the MM cluster properties in the [poster by V. D'Amico]

Detector efficiencies in 2023

- STGC efficiencies (a single "typical" run from 2023)
  - Inefficient regions are mostly caused by HV trips of single layers

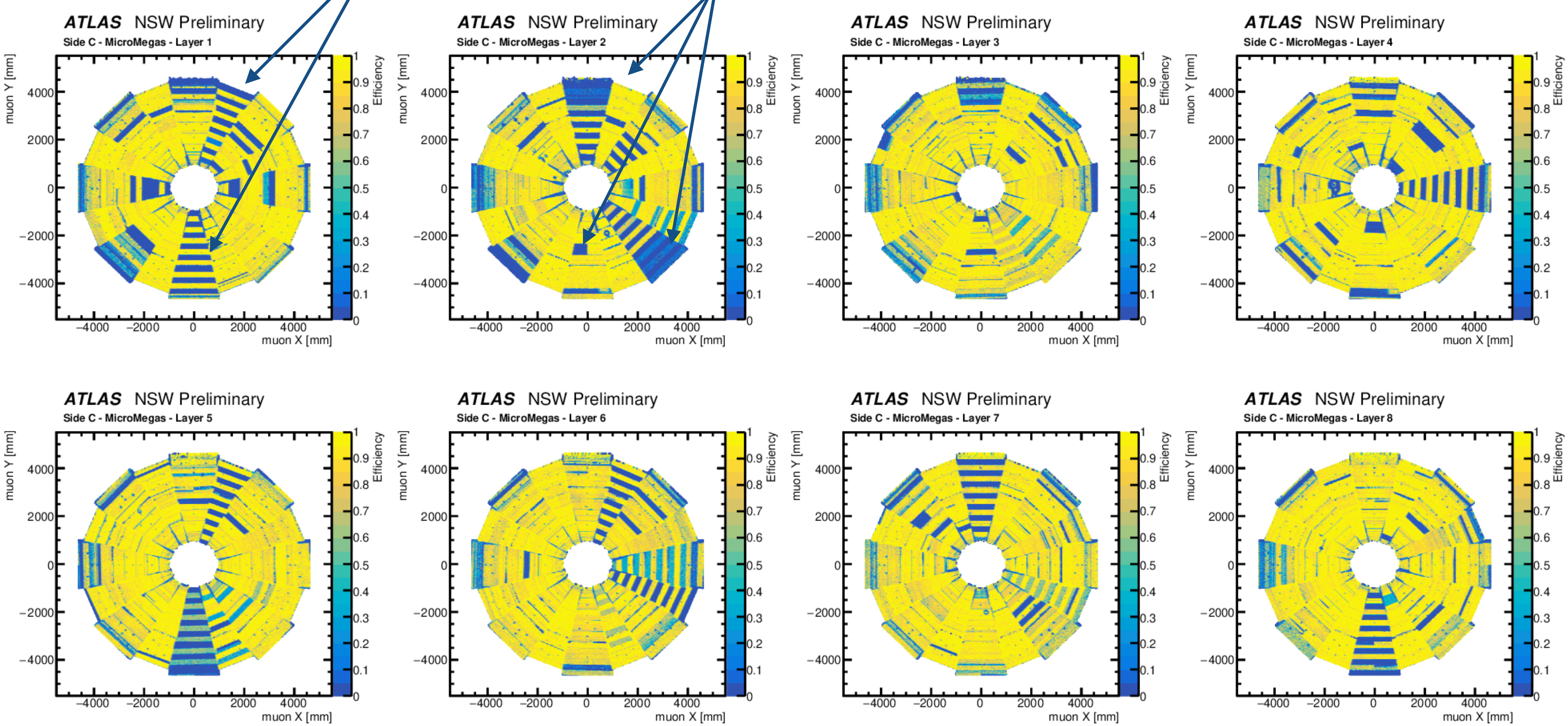


Detector efficiencies in 2023

- MM efficiencies (an example run from 2023)

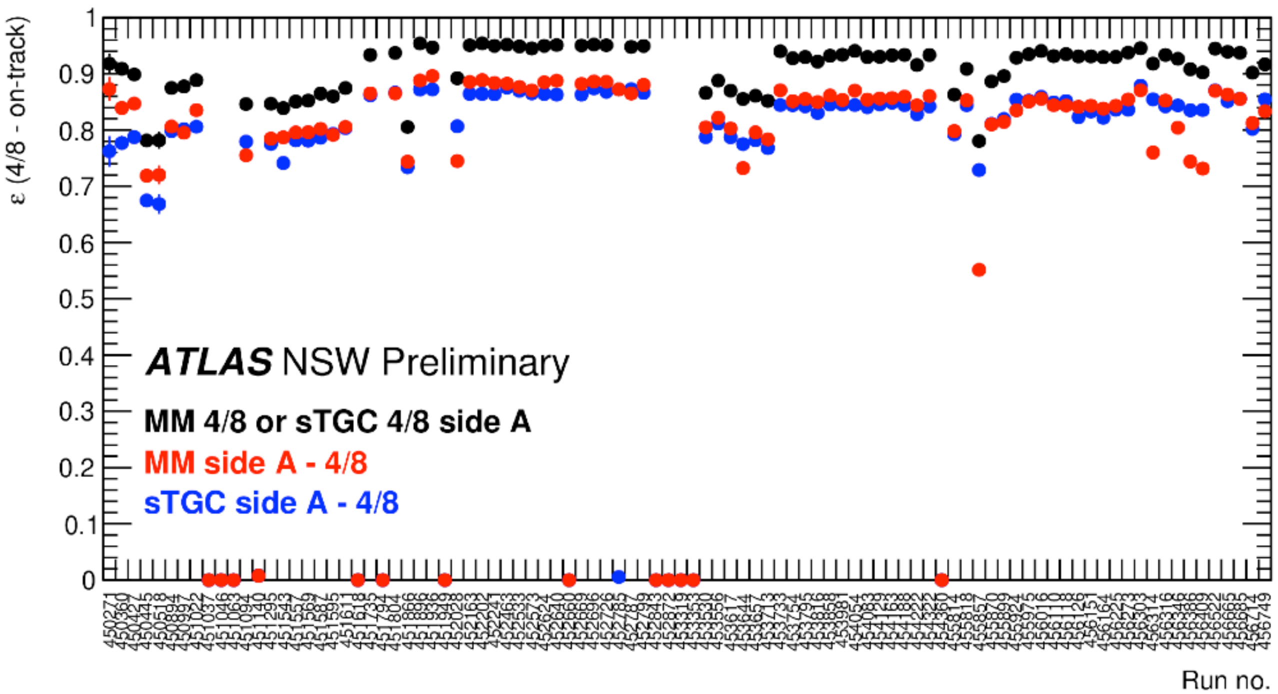
DAQ/LV failures
(e-link removals)

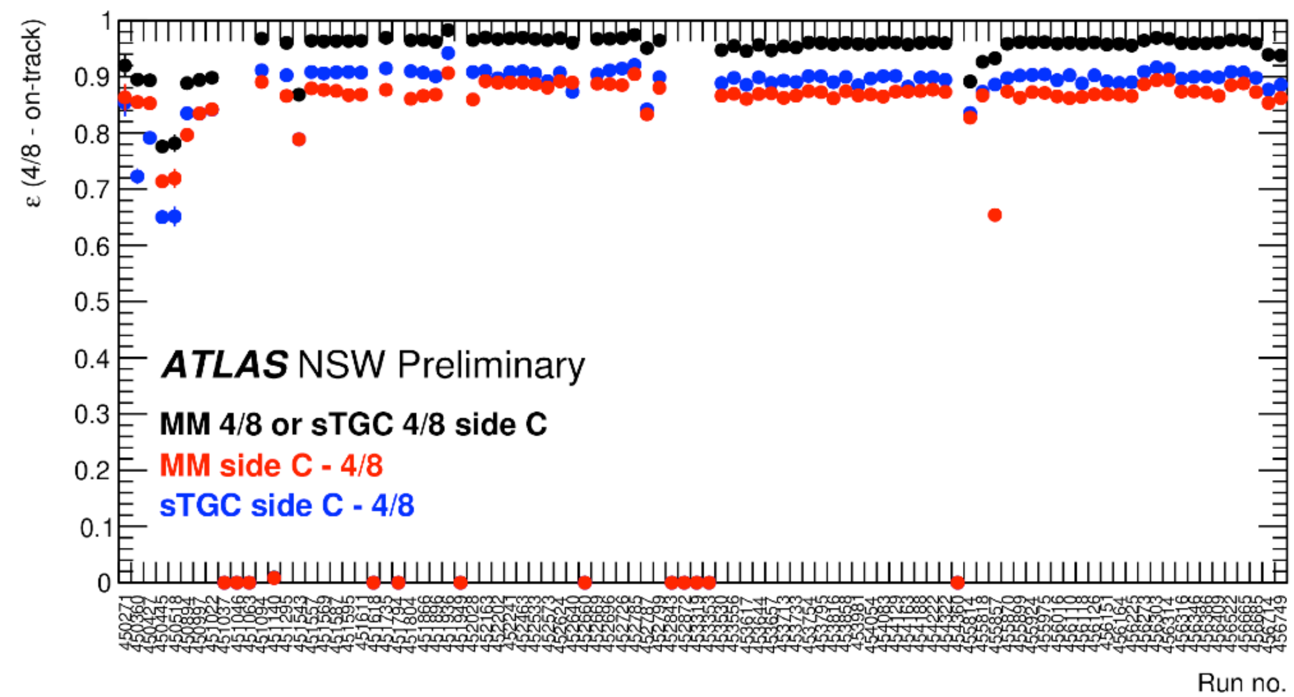
Run dependent
temporary HV issues



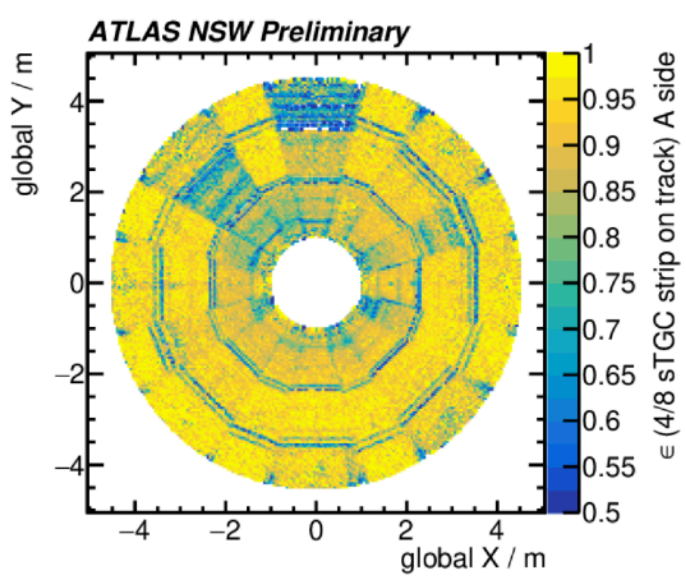
Tracking efficiencies - 2023

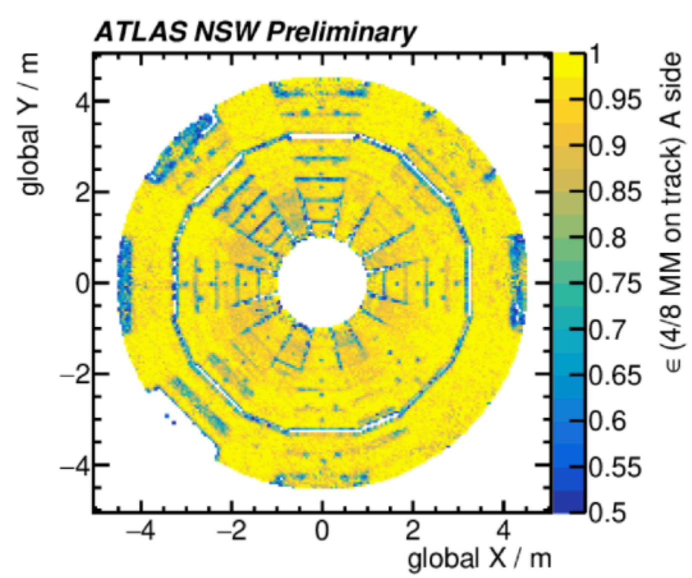
- In order for the NSW to contribute to the tracking with acceptable resolution, a reasonable criterium is to request **4/8 MM or STGC** clusters
- **Above 95%** for most of 2023 (average single-layer ~70-80%)

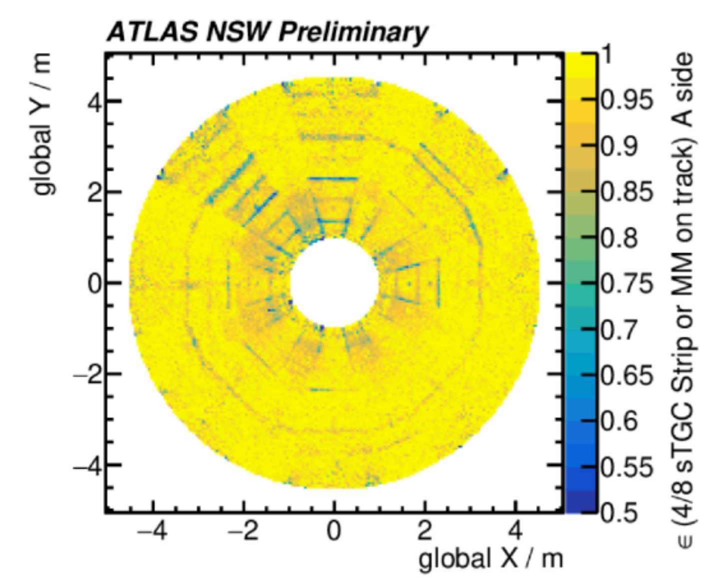




STGC/MM/Combined tracking efficiency from an example run

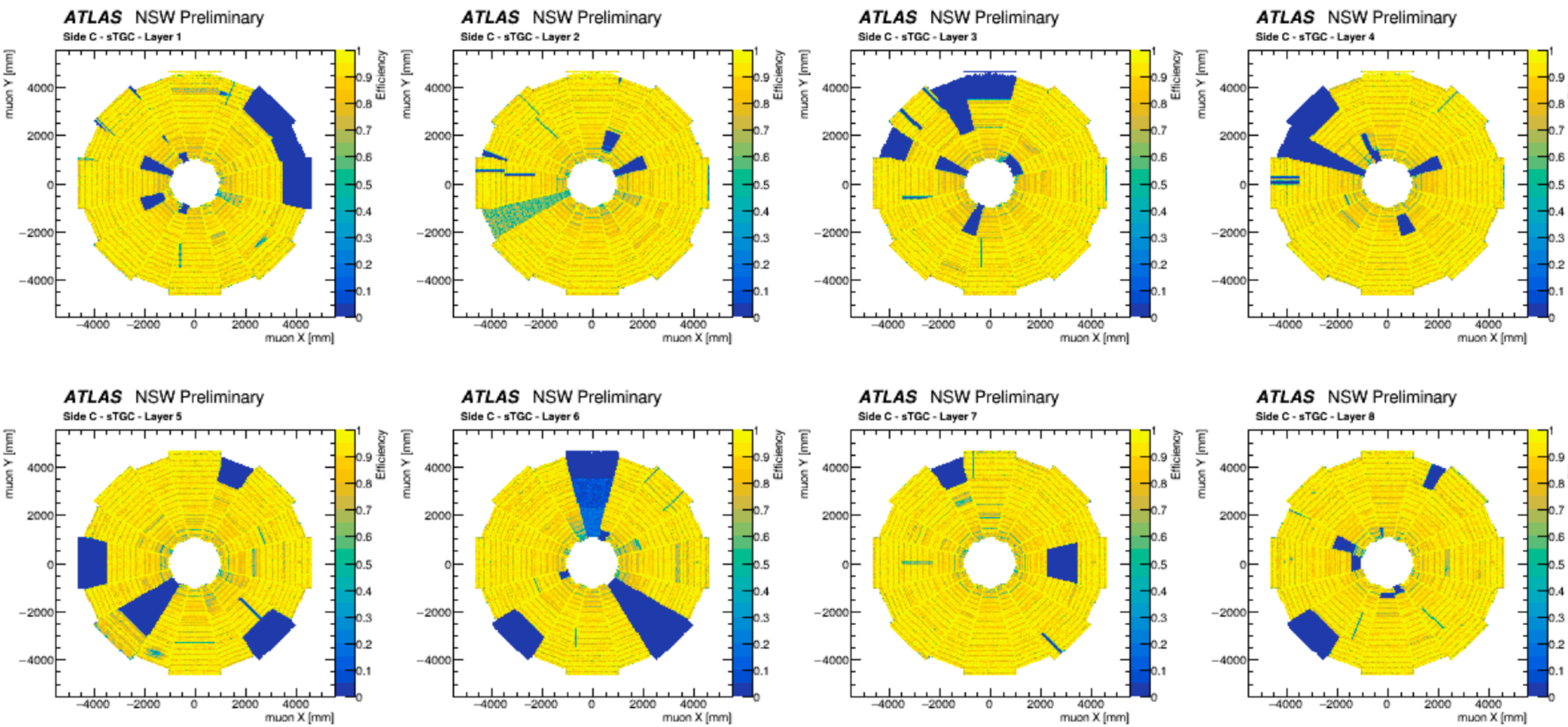






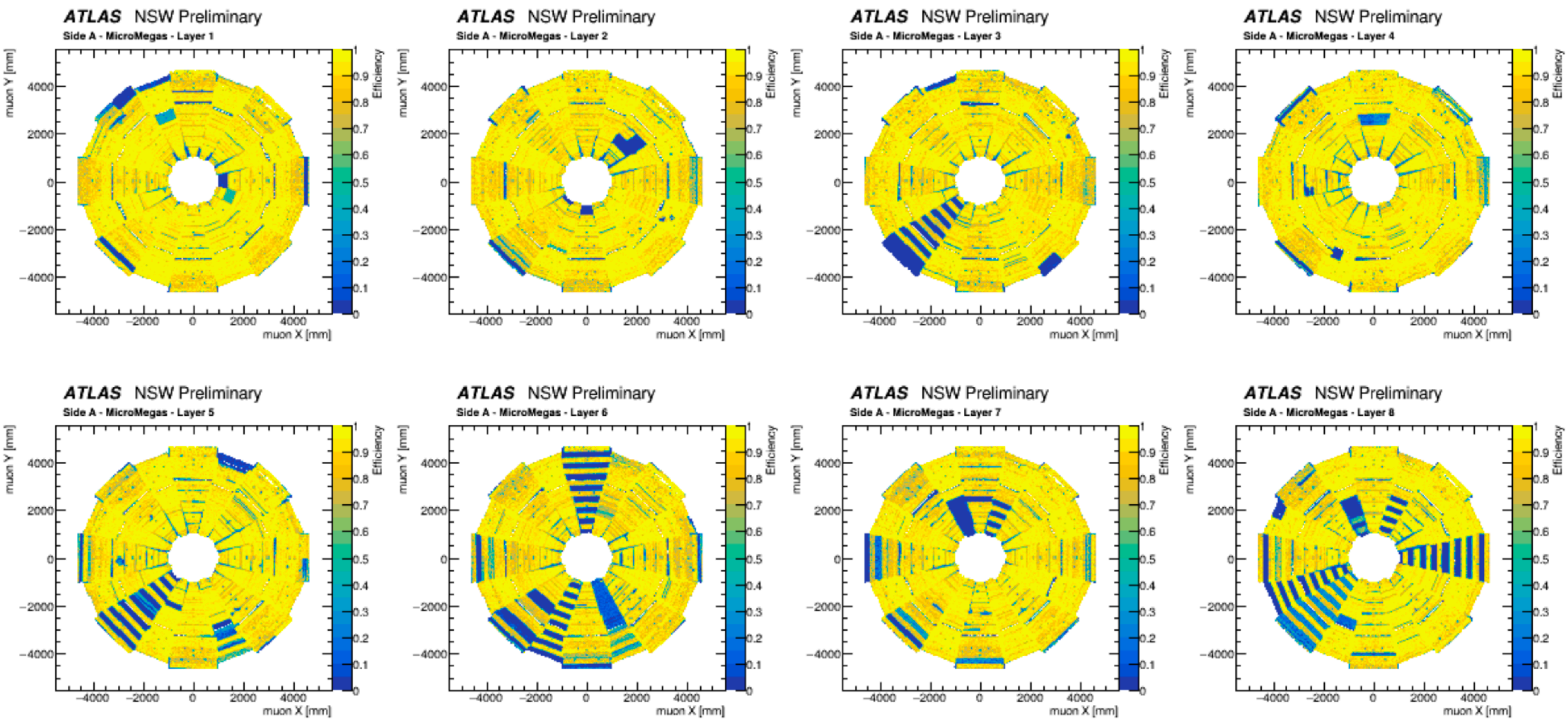
Detector efficiencies in 2024

- STGC efficiencies (a single example run from 2024)



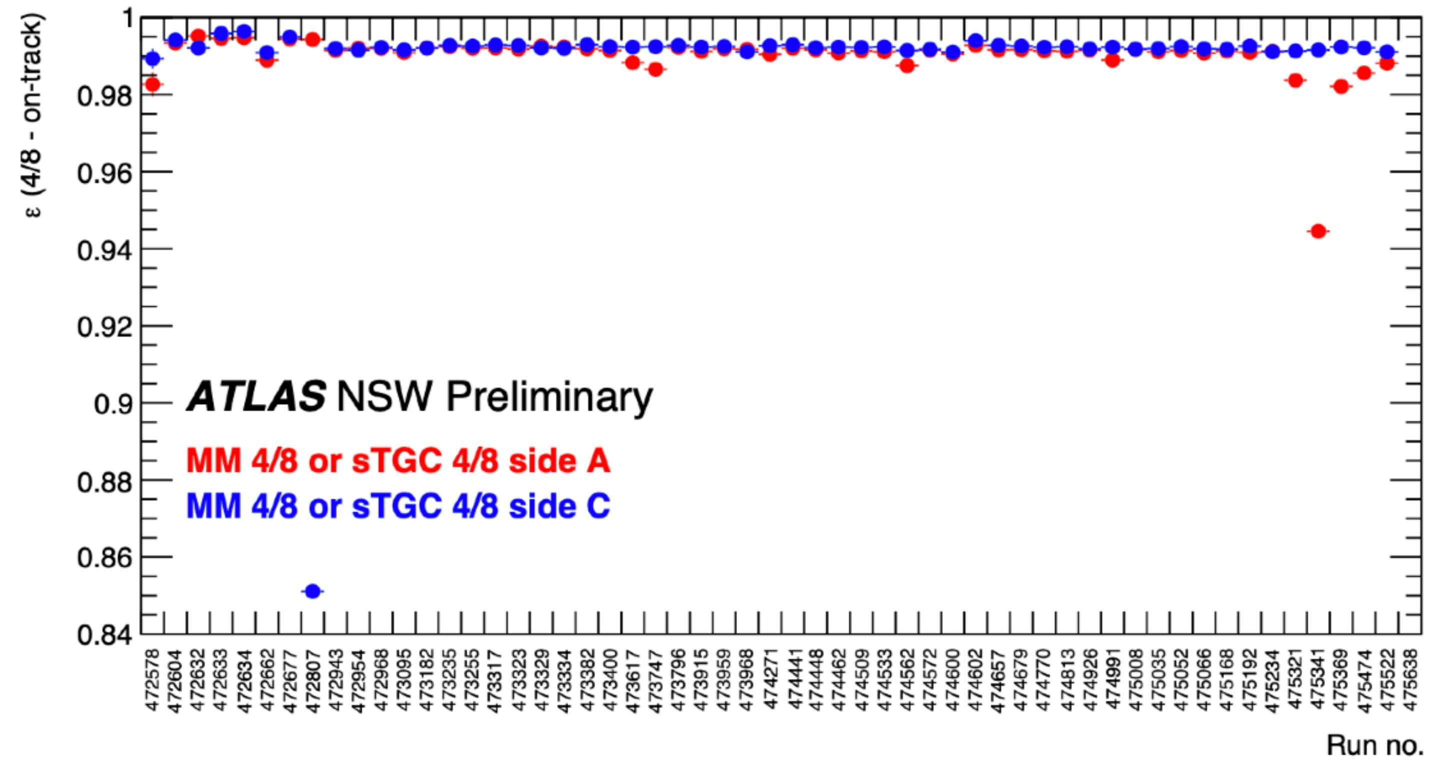
Detector efficiencies in 2024

- MM efficiencies (a single example run from 2024)
  - Some significant effects have been partially mitigated

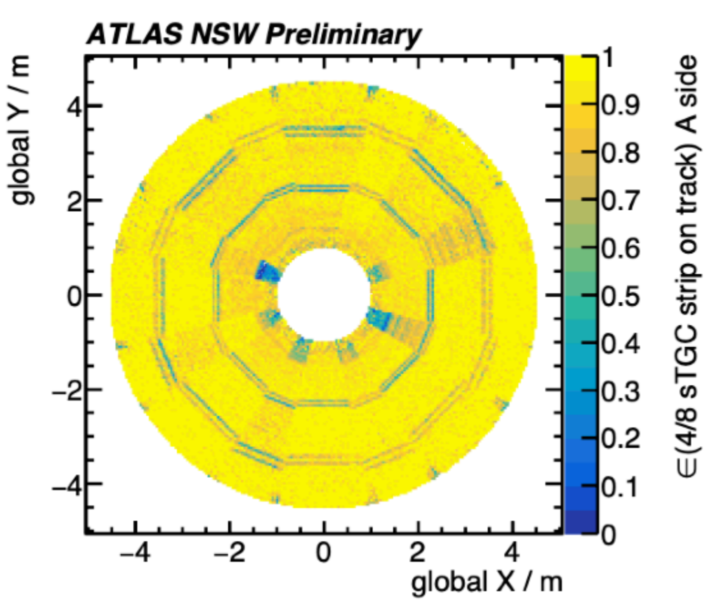


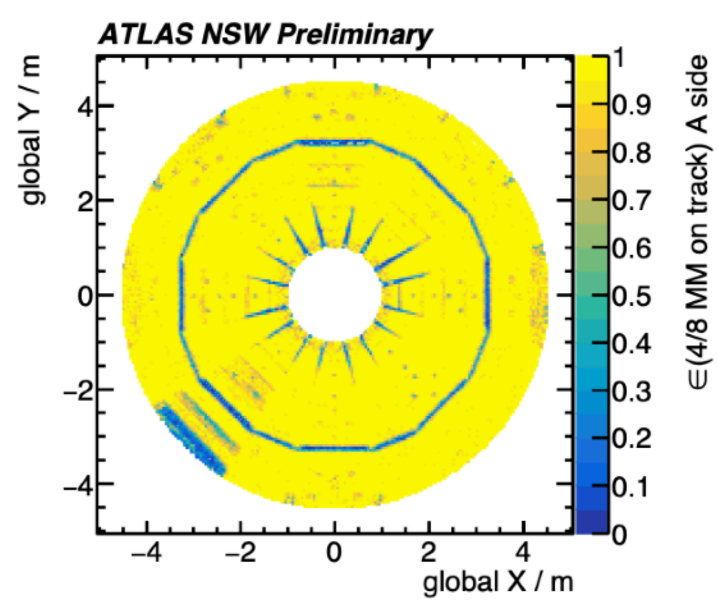
Tracking efficiencies 2024

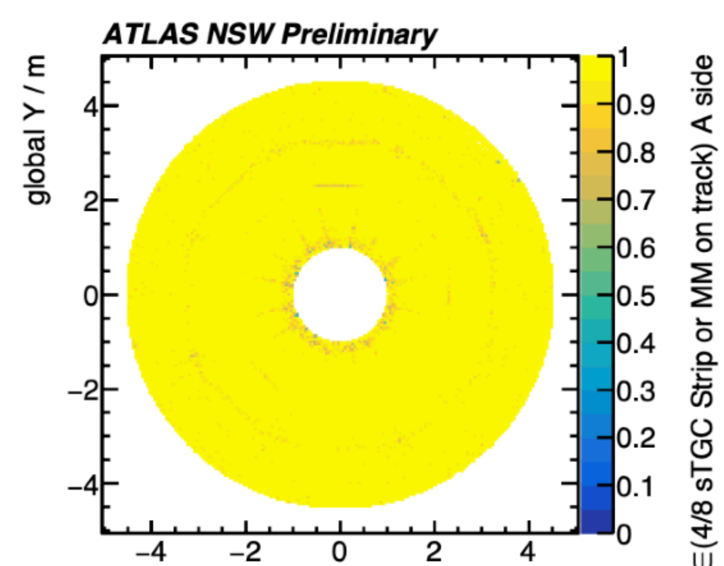
- In 2024, applying the same track selection criteria, the efficiency improved to **~99%**
- Rather stable during these first weeks of data-taking



STGC/MM/Combined
tracking efficiency
from an example run



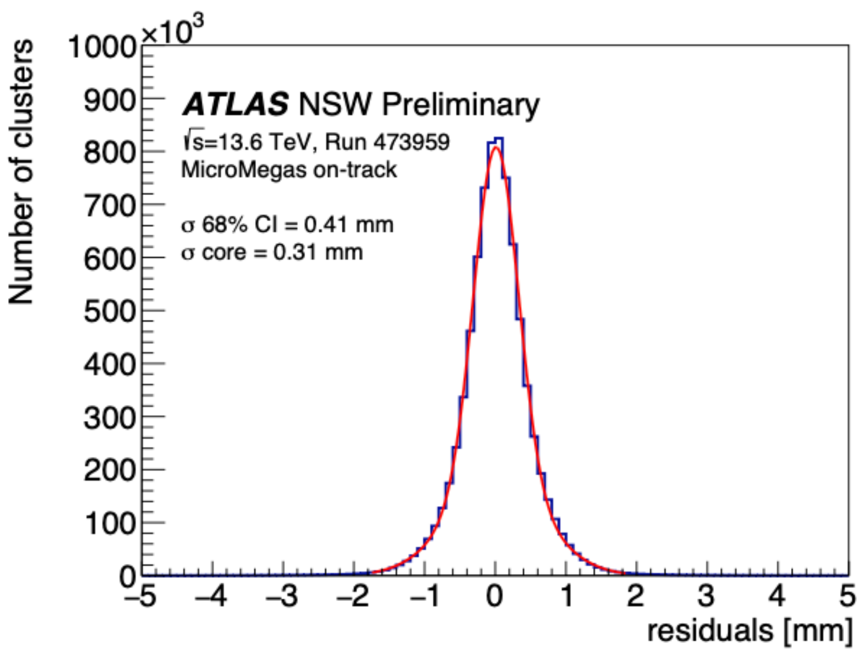




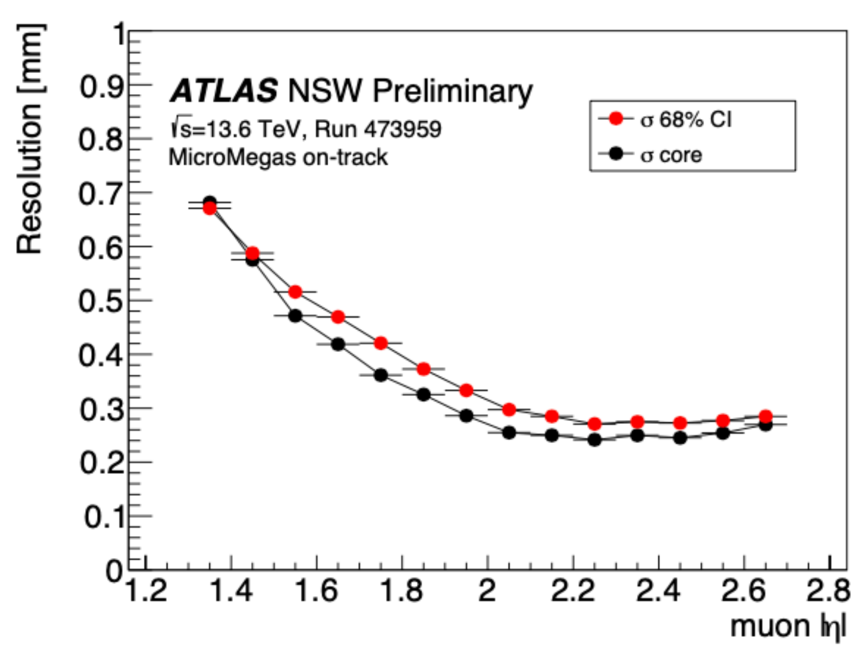
MM Resolutions

- Using for the moment the centroid cluster position
  - Charge-weighted average strips positions
  - Other reconstruction methods (e.g. using MM time information and cluster shape analysis) are under validation and will be introduced soon
    - Will reduce the η dependency and should improve the overall resolution
- Preliminary alignment
- Average resolution ~350 µm

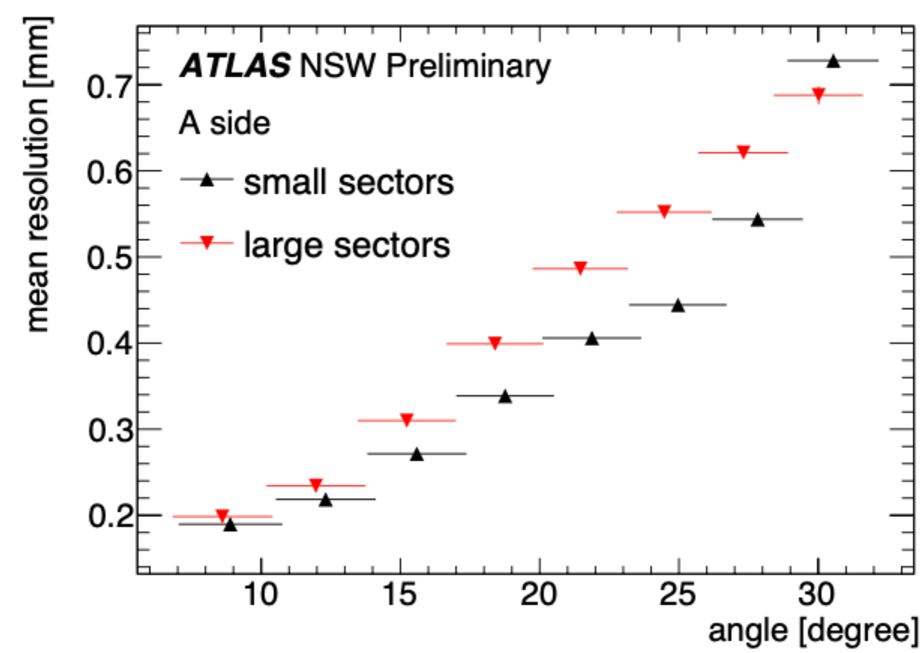
Average resolution



Tracking resolution



Layer-layer

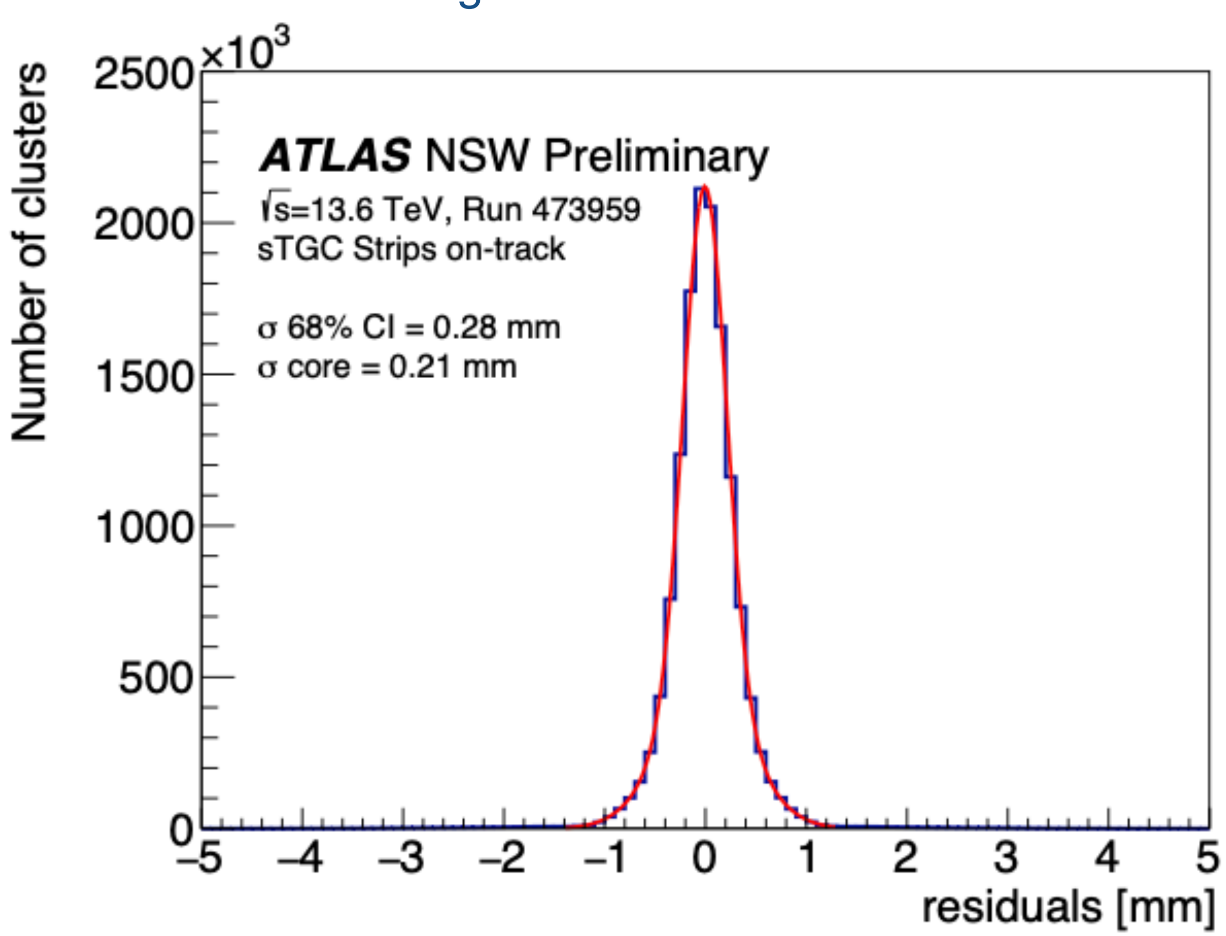


- Looking at the layer-layer difference allows to partially disentangle residual alignment and geometry deformations effect from the pure detector resolution

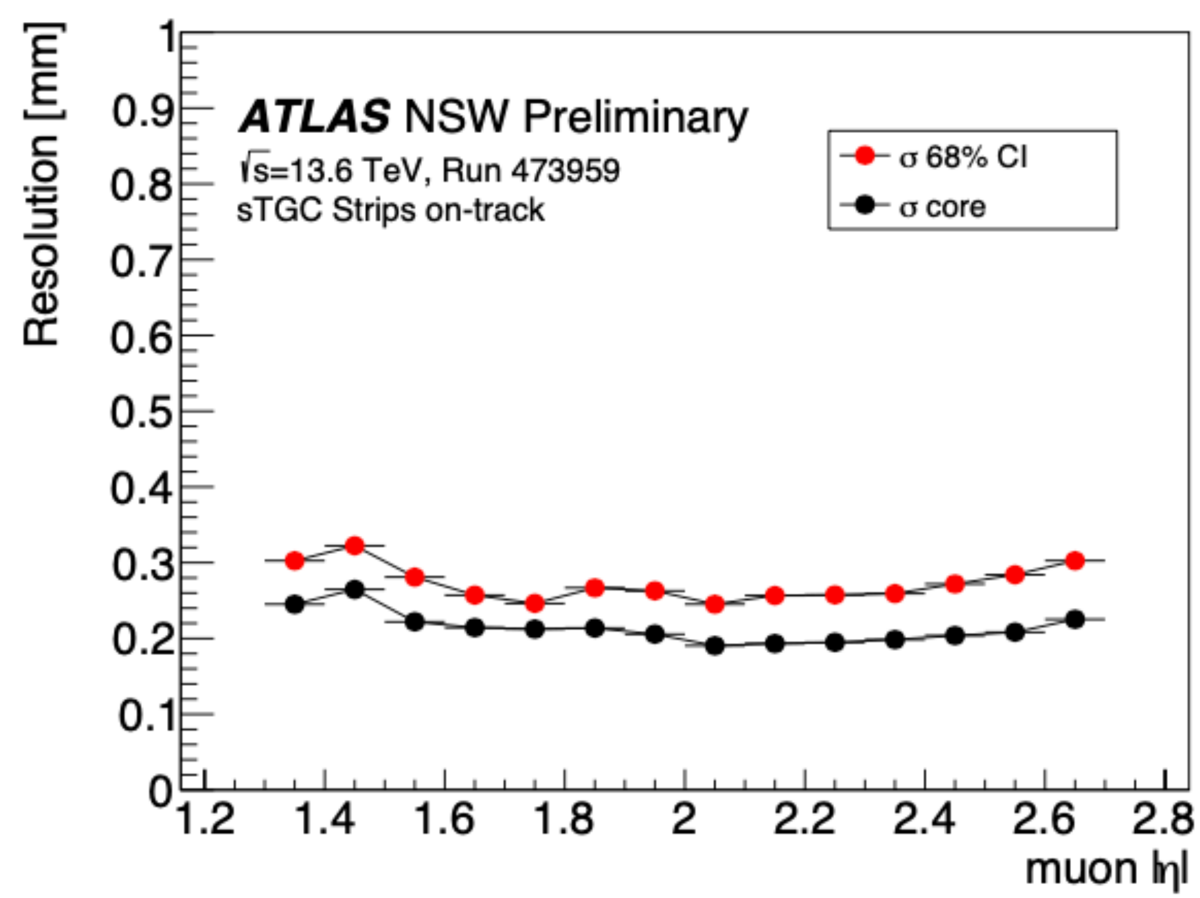
STGC resolutions

- Cluster position reconstruction with the centroid method
  - Tails are slightly more significant than in the MM case
- Preliminary alignment corrections
- Average core resolution ~ 250 μm
- Position reconstruction methods with cluster shape analysis under validation

Average resolution



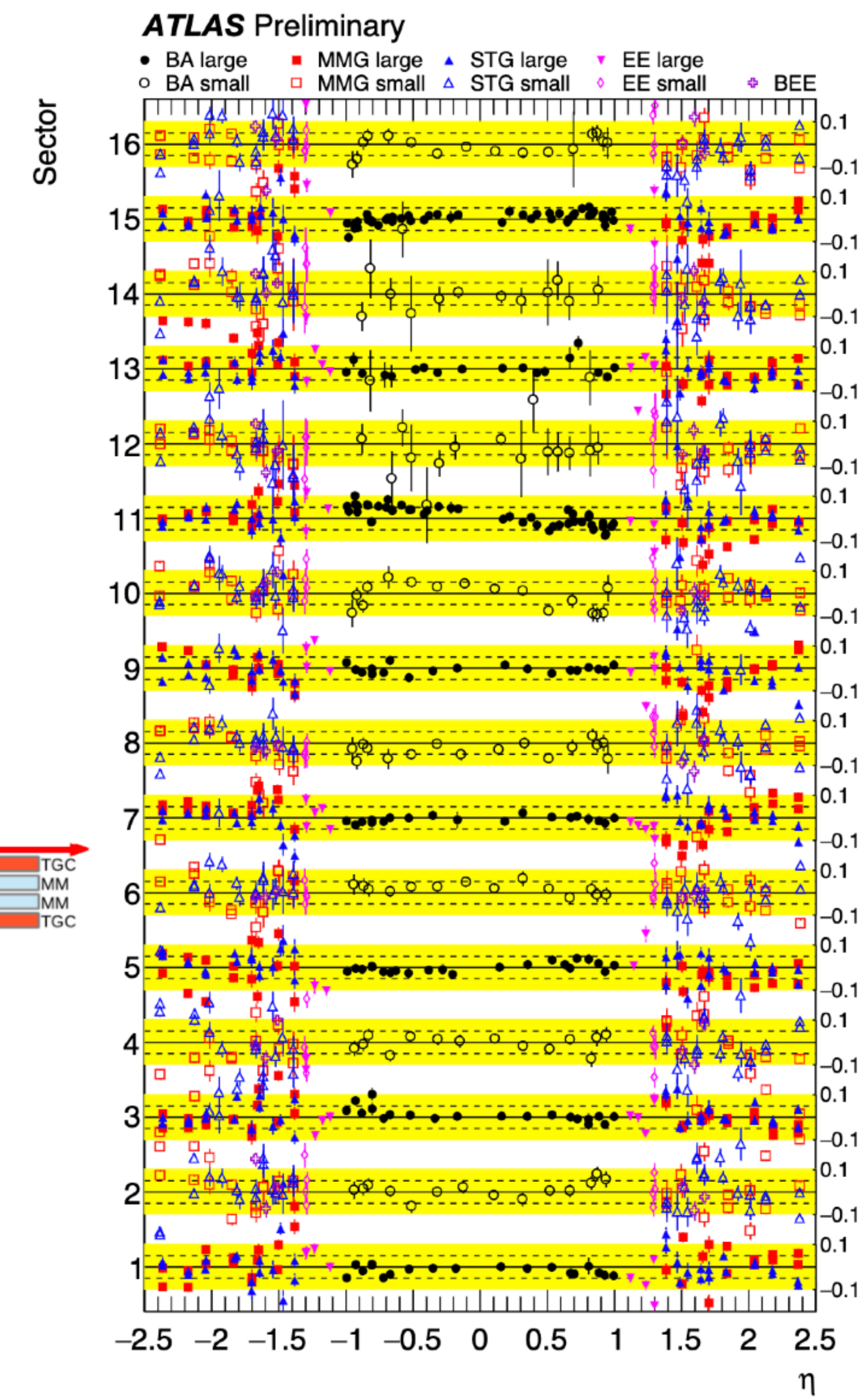
Tracking resolution

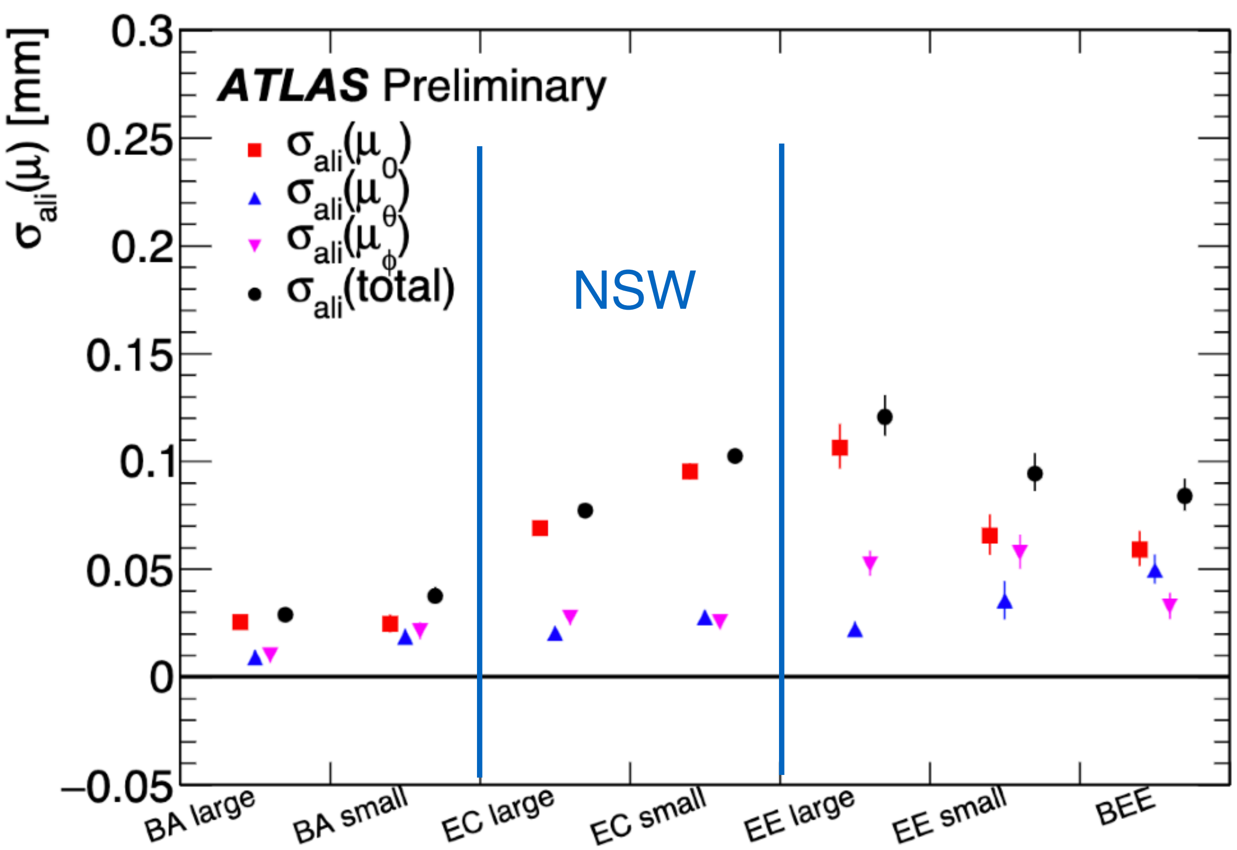


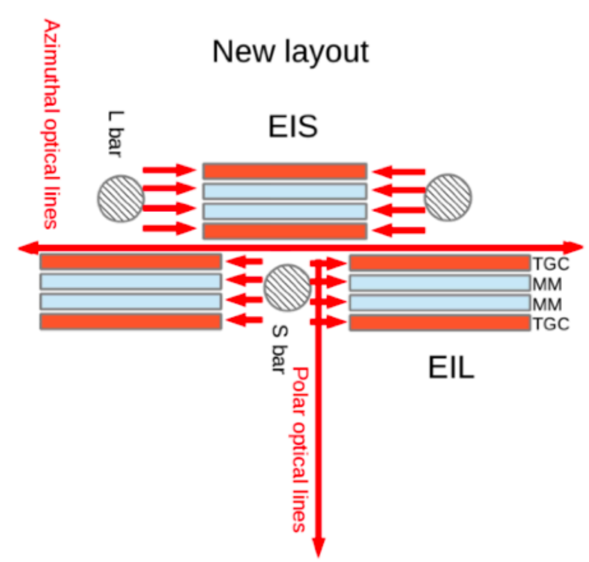
Alignment

- Optical alignment providing an independent set of corrections for each MM and STGC quadruplet
  - Translation, rotation and deformations
- Alignment uncertainty parametrized as an uncertainty on the global MS track sagitta
- After the analysis of the toroid-off runs:
  - Sagitta uncertainty from the alignment is at the moment **~ 80-100 µm** in the NSW region

Sagitta bias in toroid-off runs







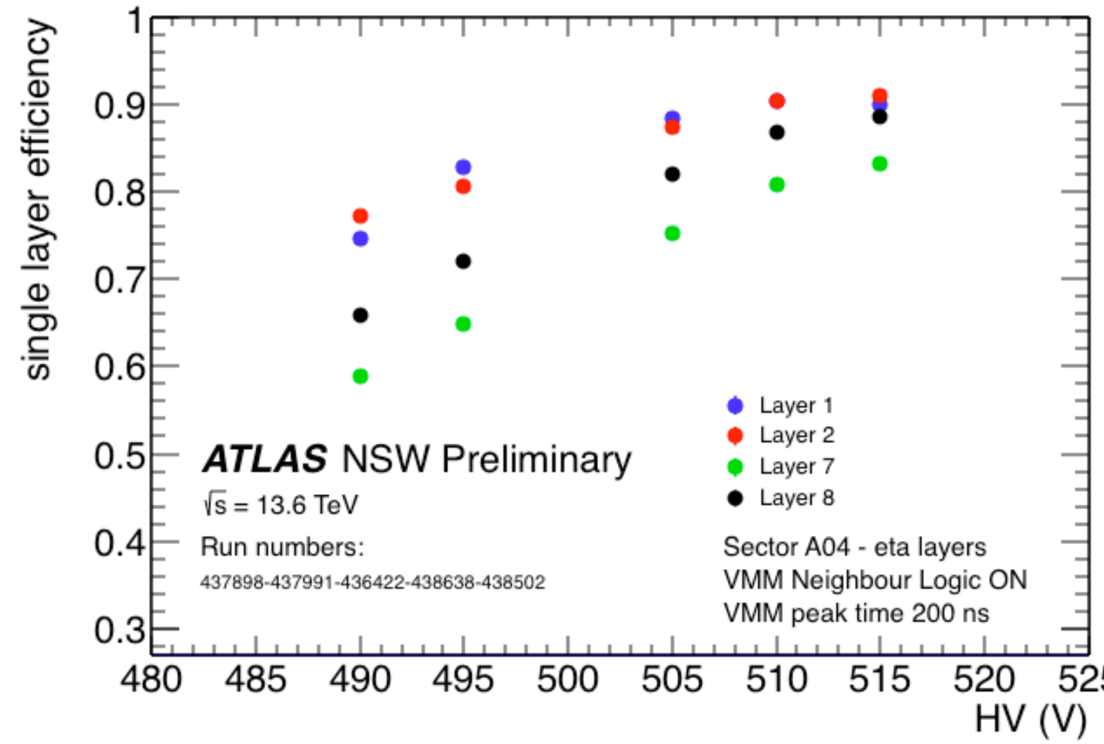
Summary

- The two New Small Wheels have been successfully built, commissioned and installed in ATLAS for run-3
- Both NSW sub-detectors, the MicroMegas and the Small Strip Thin Gap chambers, have been included in the DAQ and offline SW since the start of run-3 in 2022
- STGC pad trigger included in the ATLAS L1 sector logic in 2023
  - Large improvement in background rejection, as expected, for a small efficiency reduction
  - Developments ongoing on MM and STGC strip trigger
- Alignment precision reached ~80-100 μm
- Tracking efficiency now overall reaching 99%
- The NSW is actively contributing to all run-3 ATLAS Physics analyses
- Many optimizations towards performance improvement are still ongoing, on e.g.:
  - Detector resolutions
  - Detector efficiencies
  - Alignment and as-built geometry

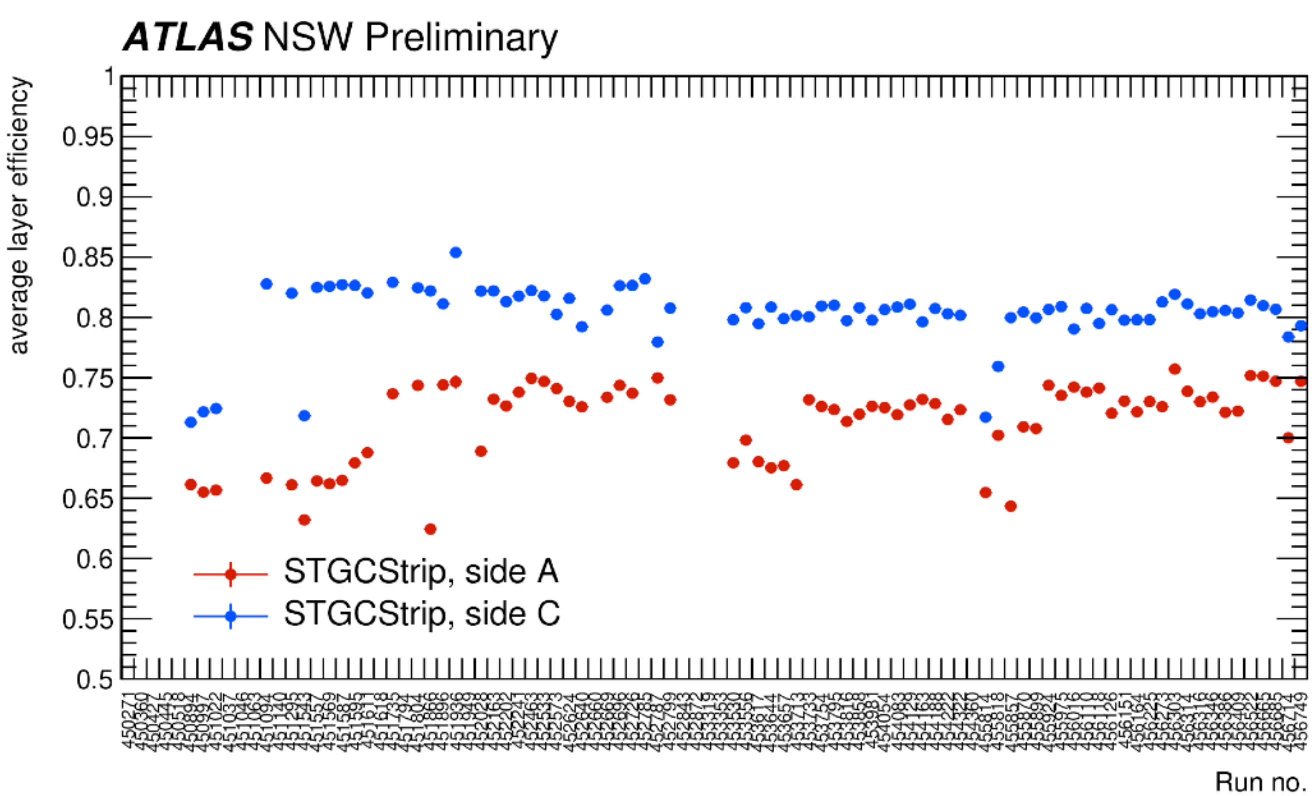
Backup Slides

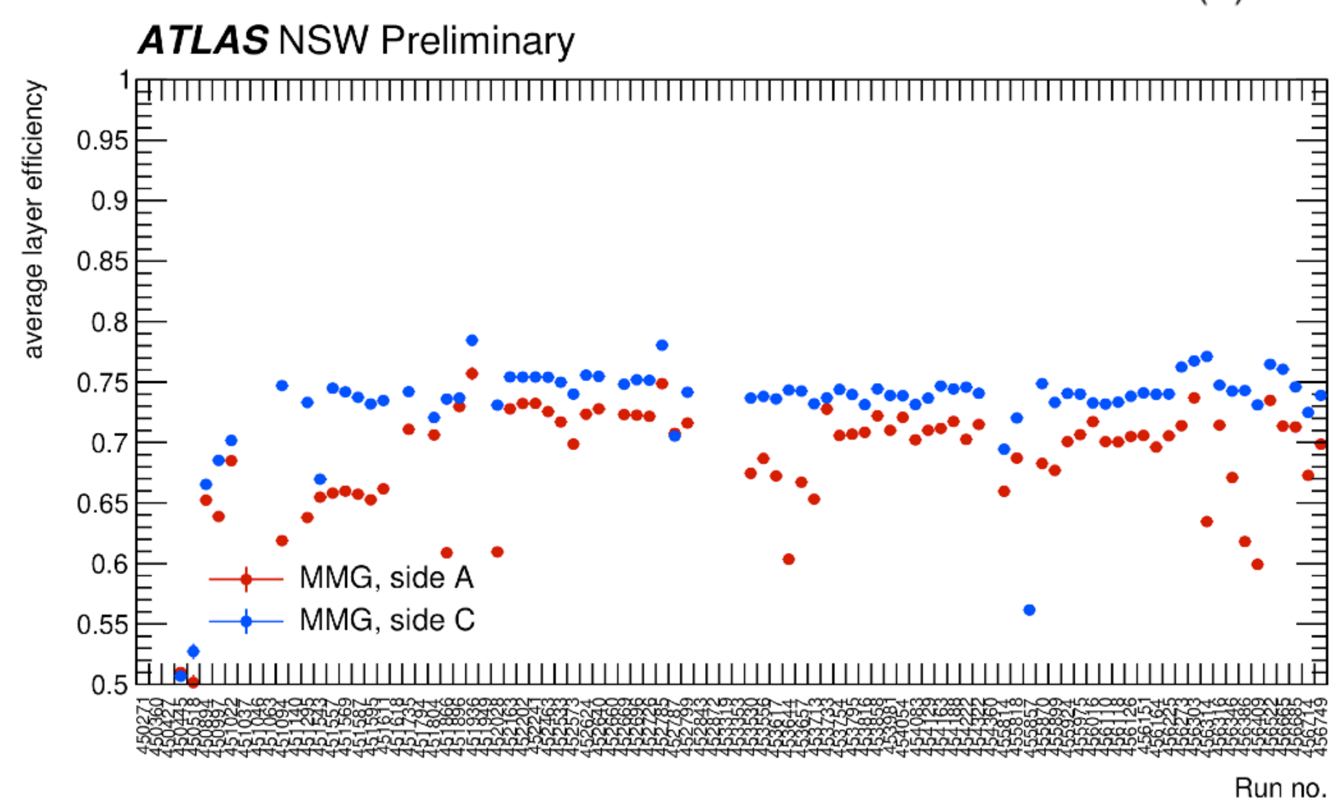
STGC and MM layer efficiencies

MM HV Scan in a single sector



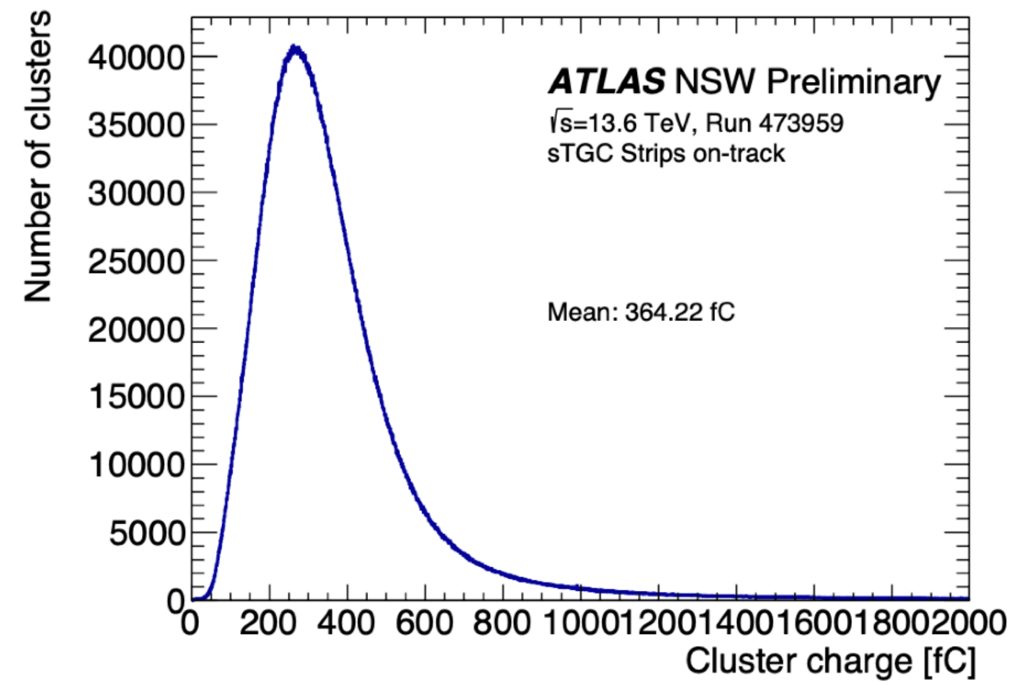
- Average single-layer efficiencies

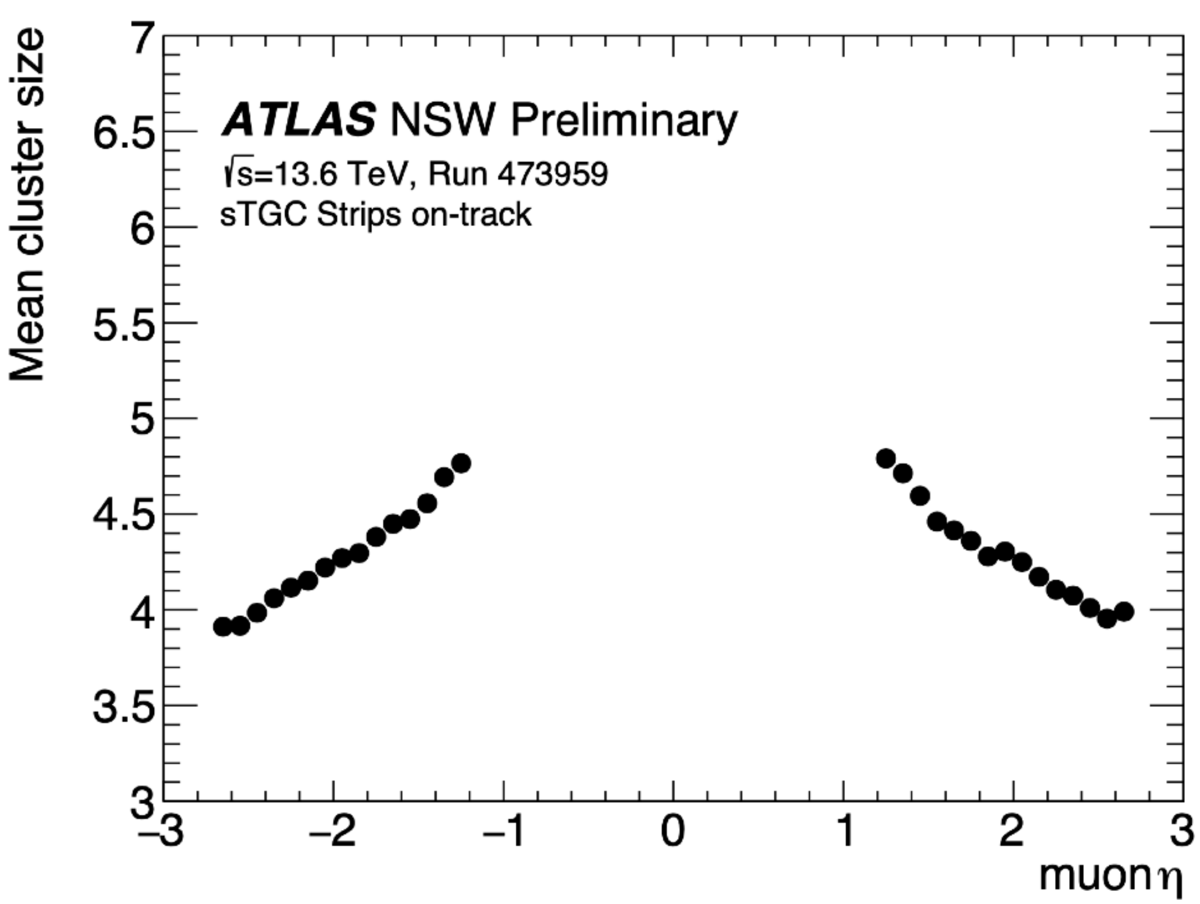


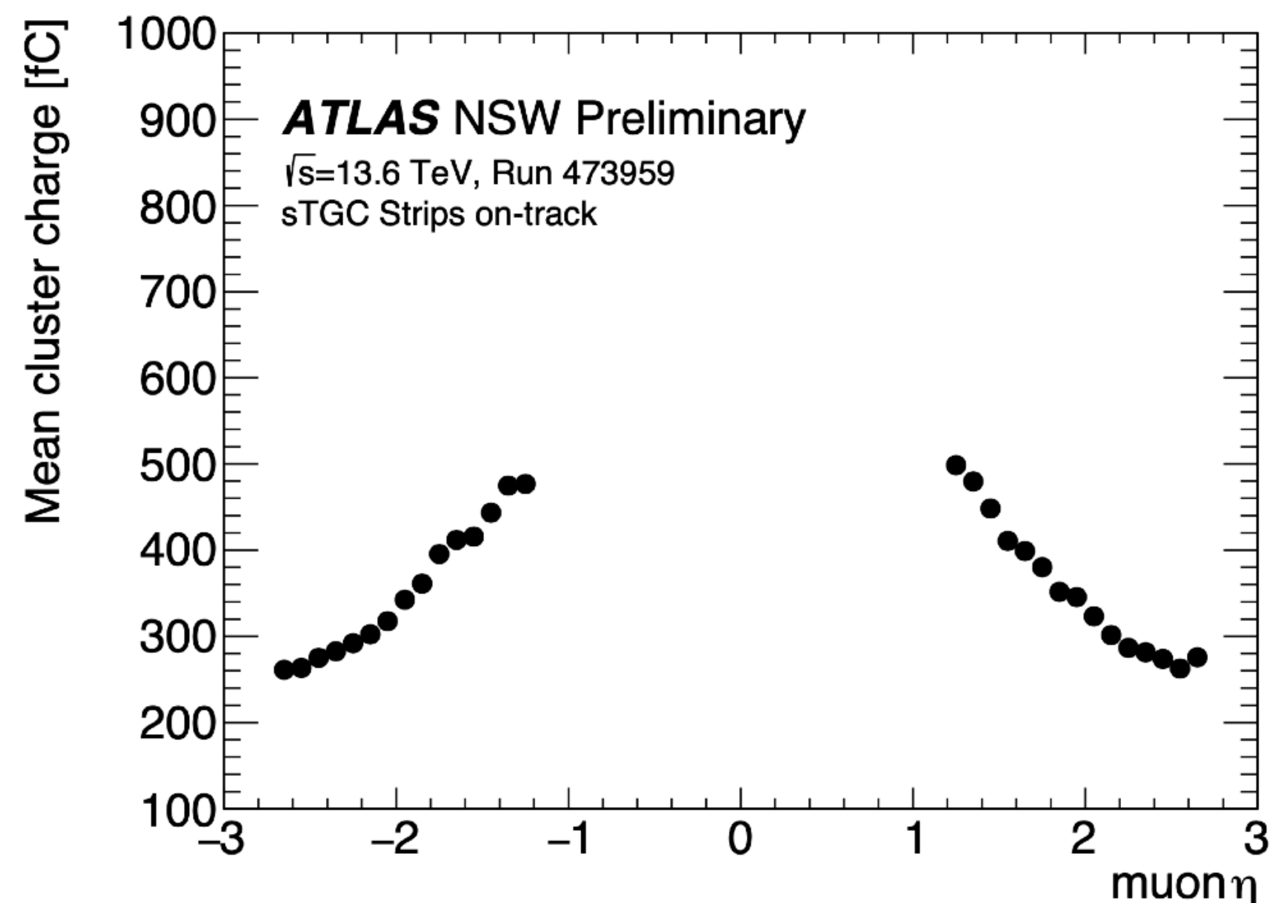


STGC Clusters properties

- Cluster sizes and charges, 2024 data

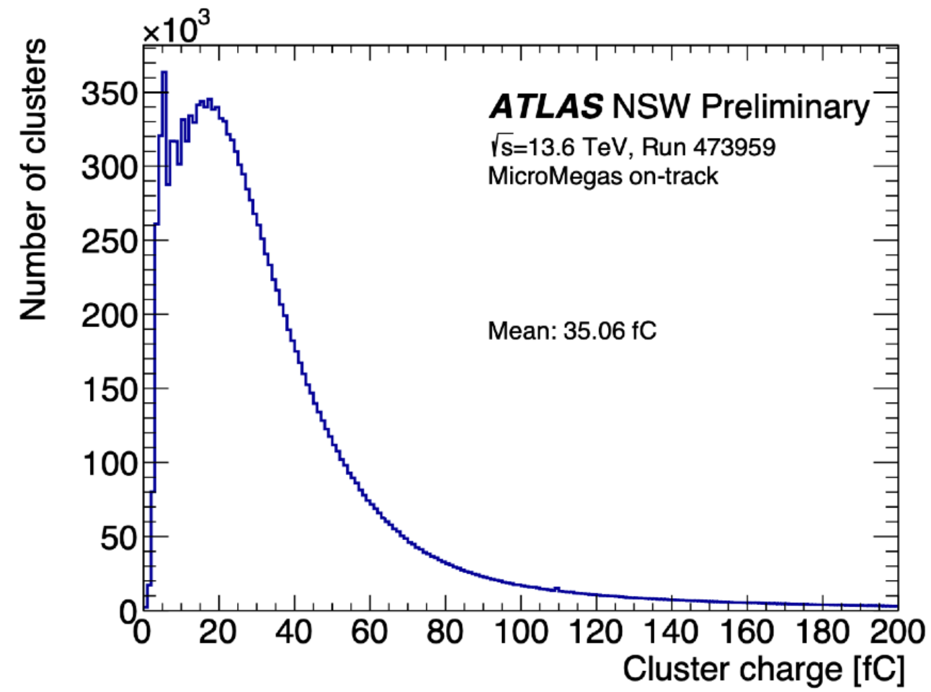


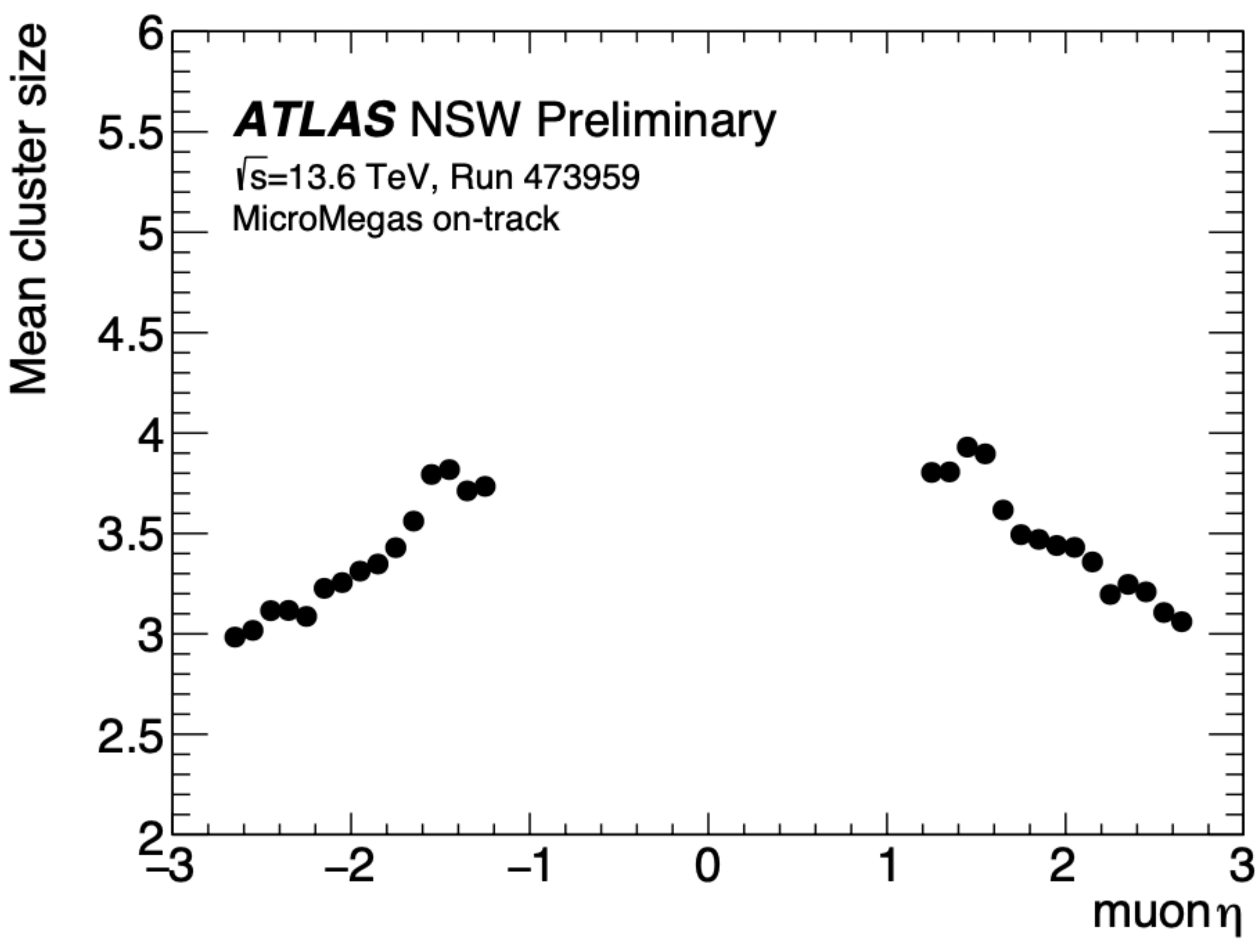


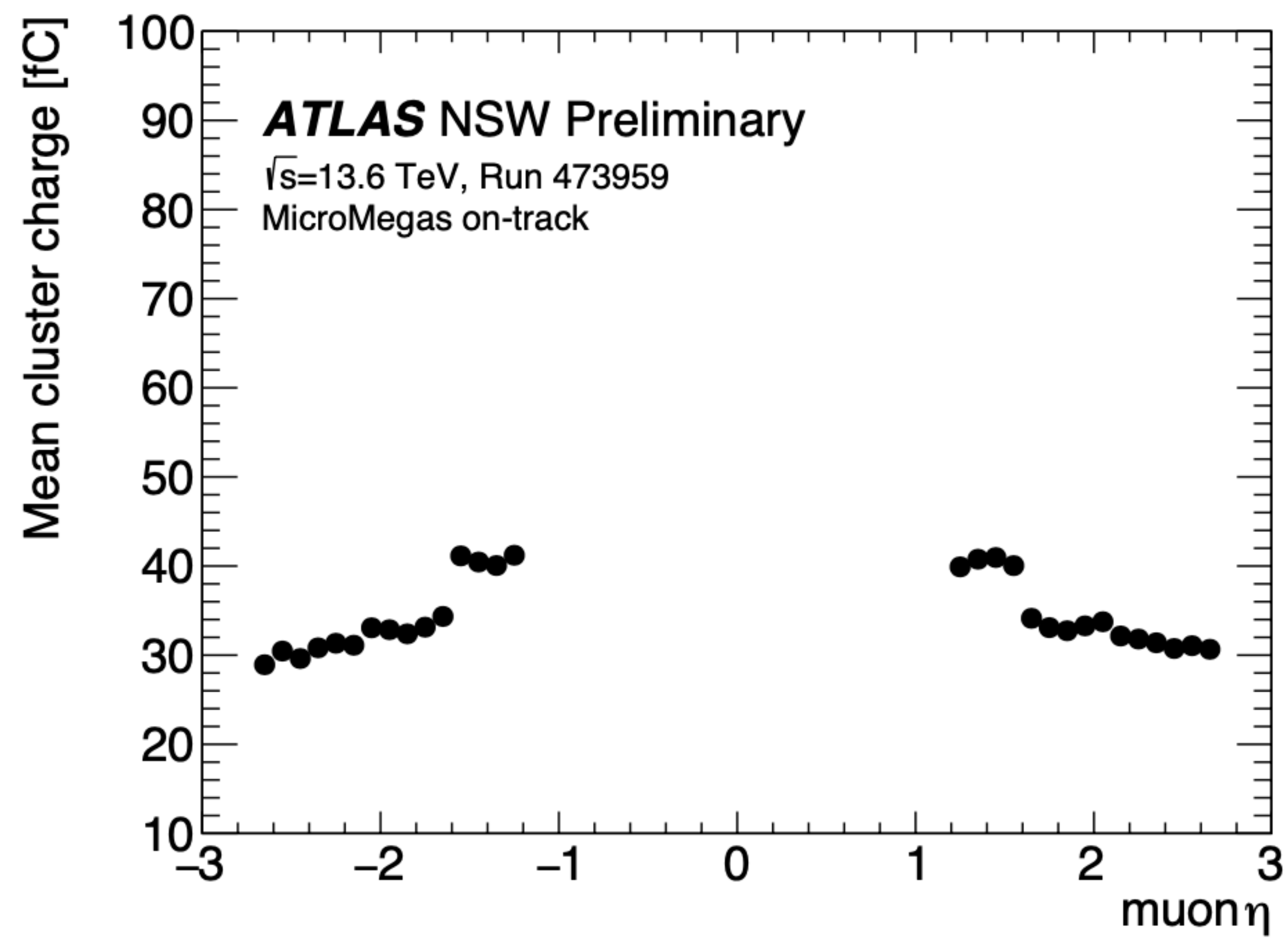


MM clusters properties

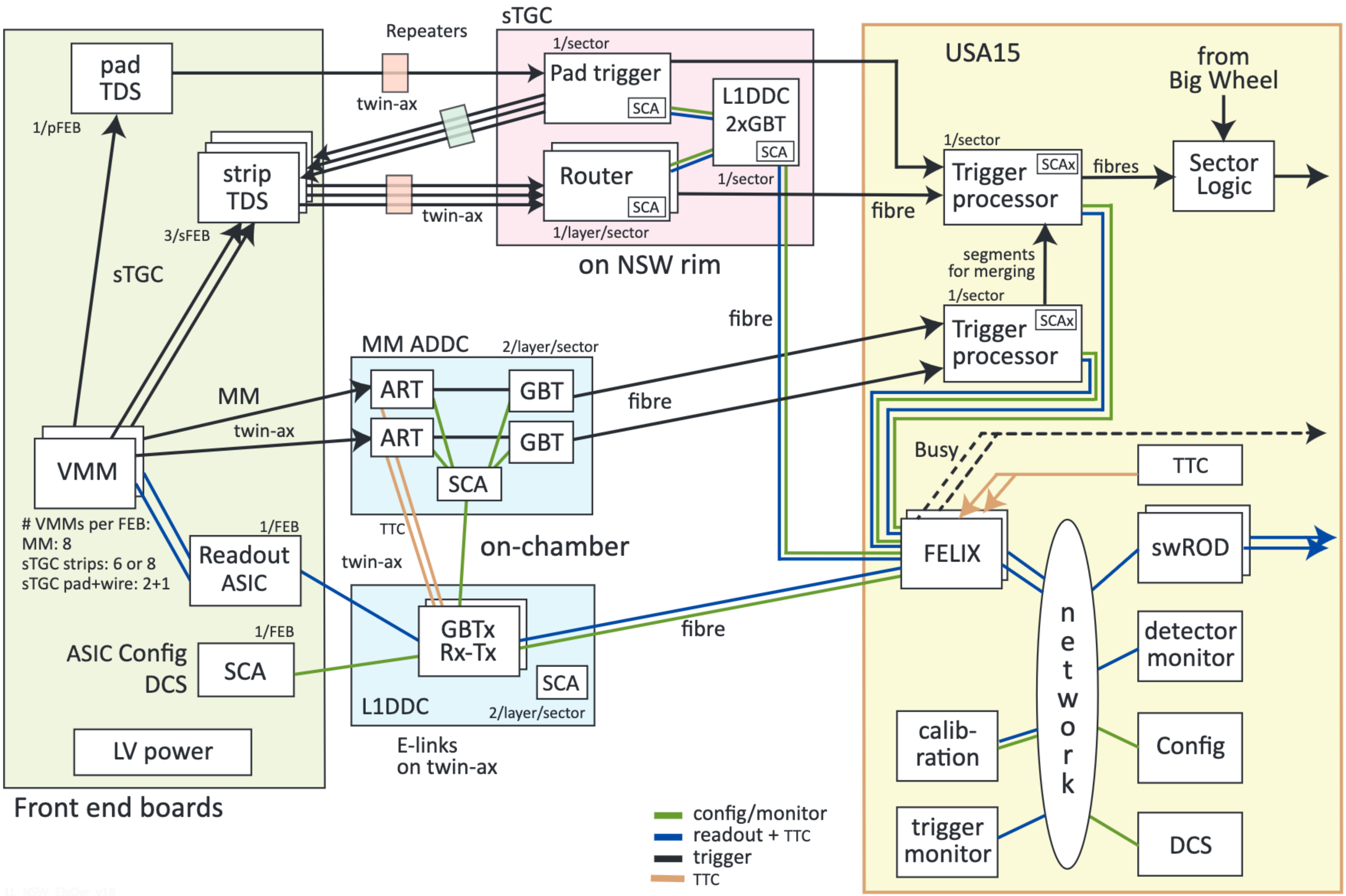
- Cluster size and charge, 2024 data
  - MM operating at 505 V







NSW Electronics



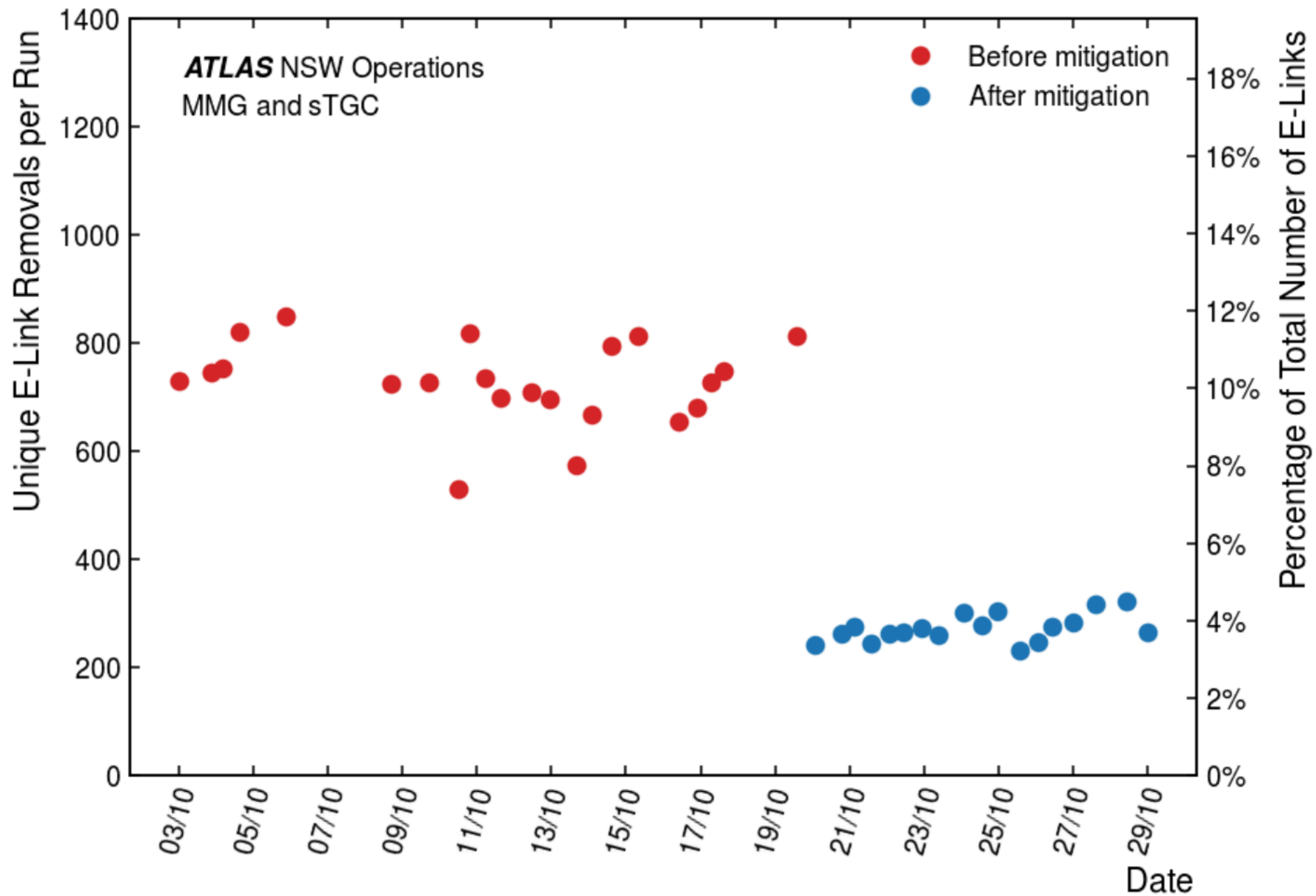
NSW Electronics

- NSW has more than 50K rad-tolerant front-end ASICs with >70M configuration registers

- VMM ASIC: baseline, threshold, pulser, charge and time
  - 64-channel ASIC with charge amplifiers and ADCs for charge, time measurements
  - Pulser for PDO (charge) and TDO (time) calibration
- ROC ASIC; TTC and VMM data decoding
  - Readout control ASIC: distribute TTC and get L0 data from 8 VMM per FEB
- TDS ASIC: strip charge, pad trigger
  - Trigger Data Serializer: prepares trigger data and performs pad-strip matching for STGC
- GBTx: elink data sampling phase
  - Gigabit transceiver for transmission of readout, TTC and slow-control data
- GBT-SCA: slow control data sampling phase
  - Slow control ASIC for the configuration of Front-end ASICs and Front-end monitoring

e-links removal mitigation

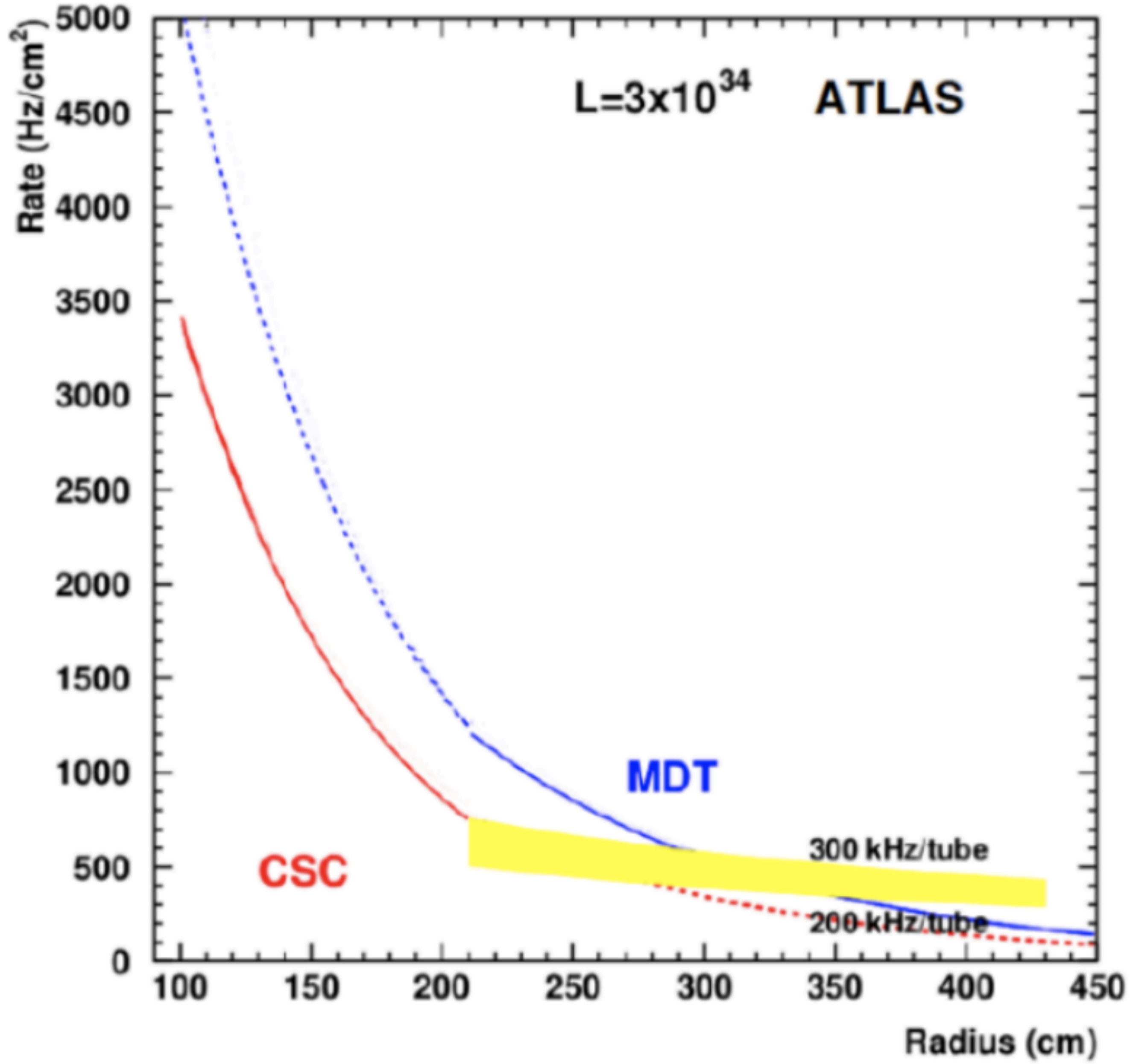
- GBTx issue mitigation (200 kHz SCA reset signal)



Rates

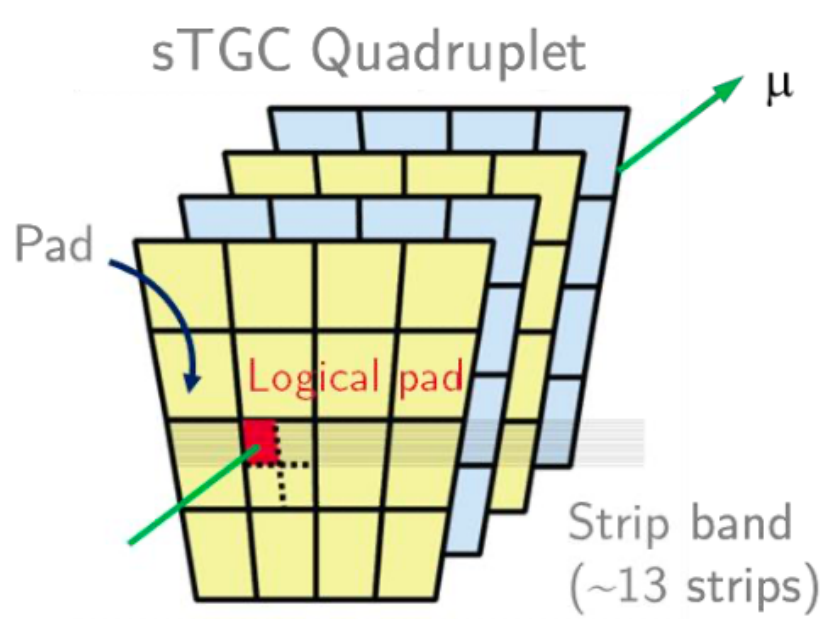
- Extrapolations from run-2 MDT and CSC rates

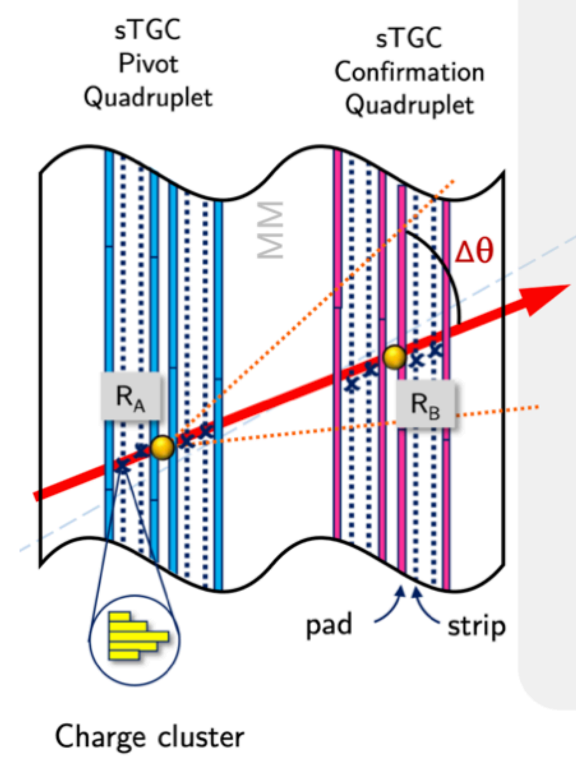
NSW TDR ATLAS

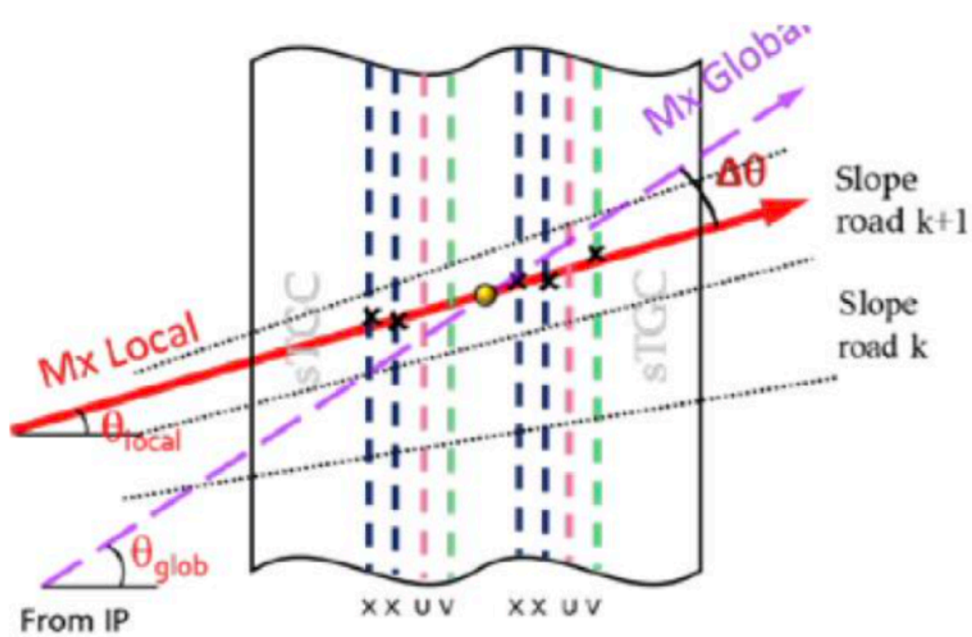


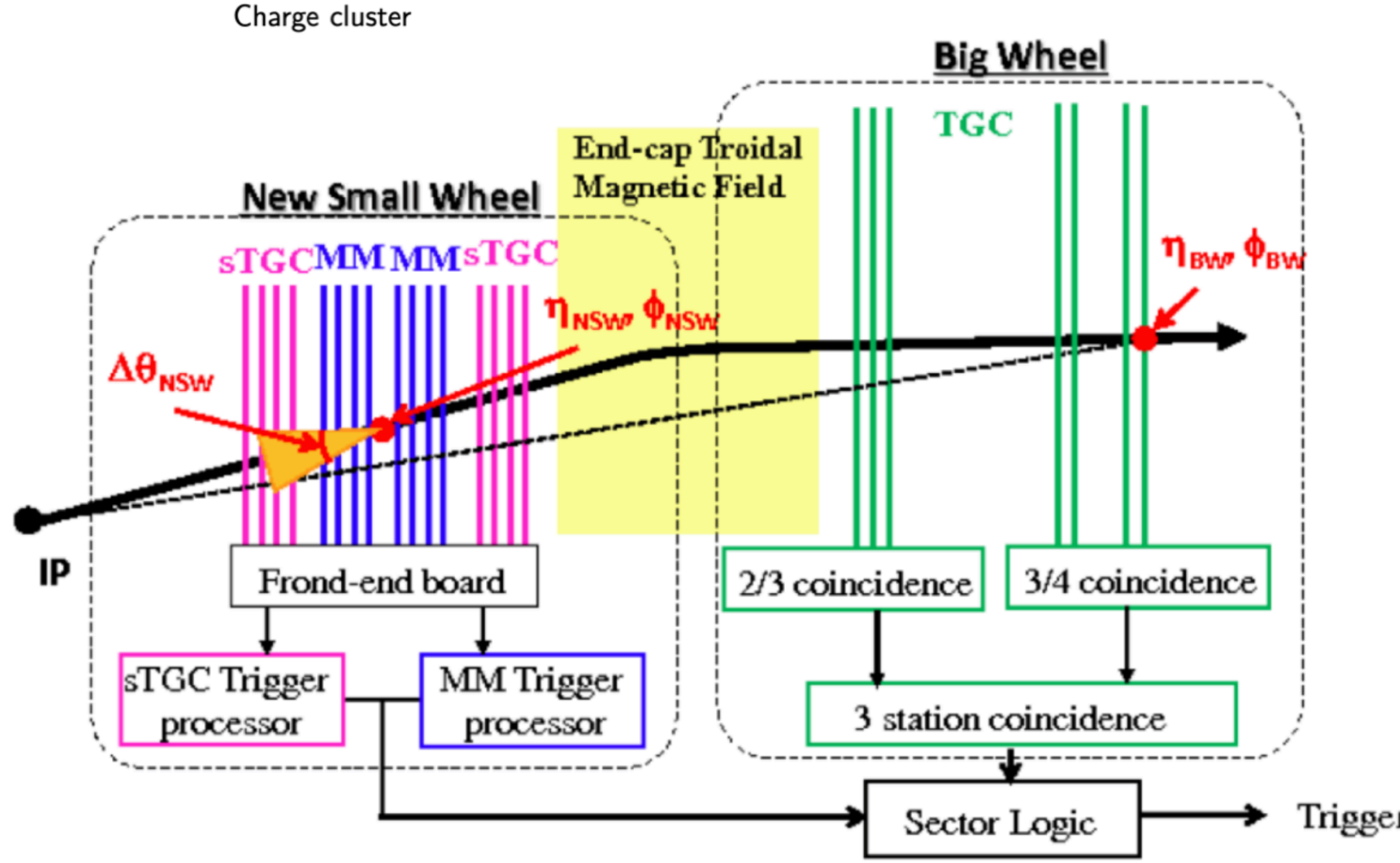
Trigger coincidence

- NSW - BW coincidence



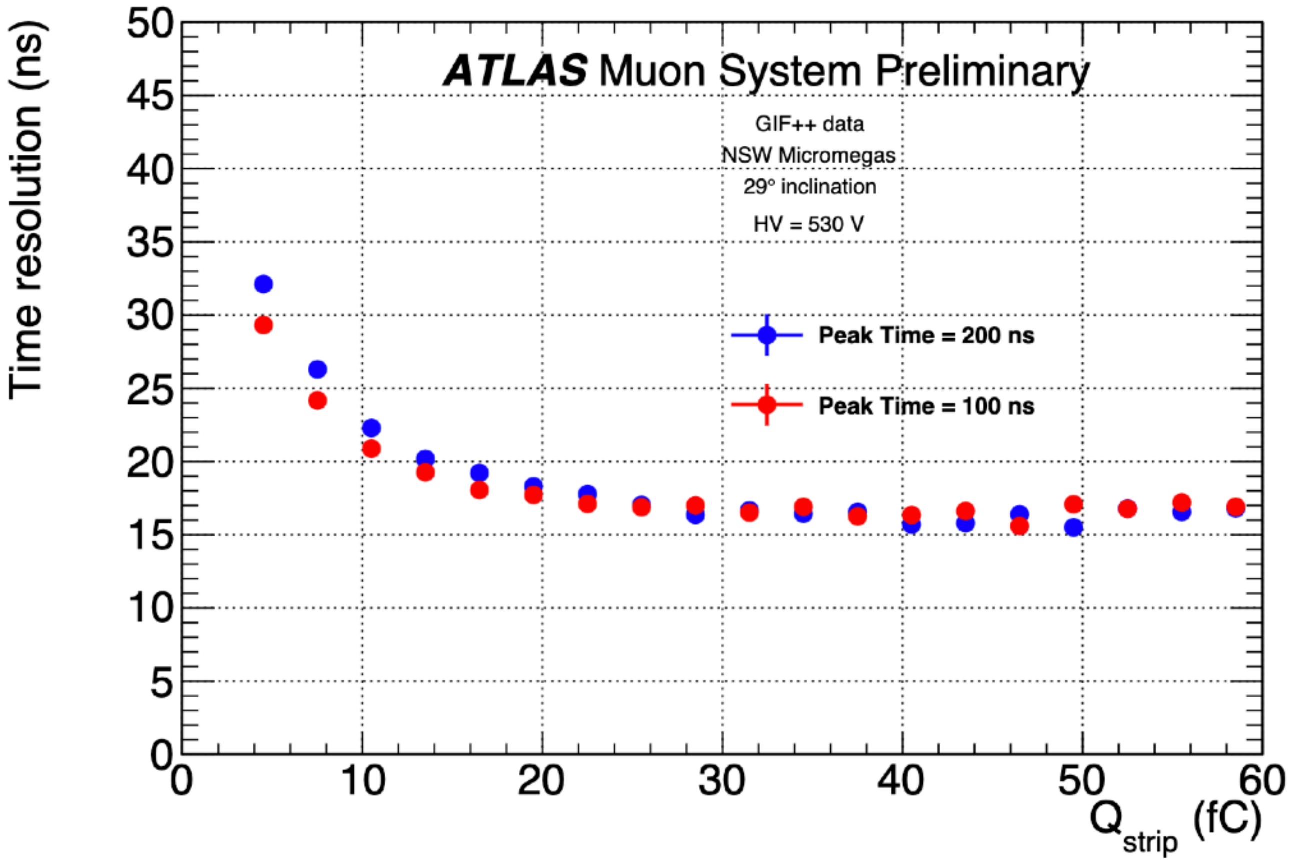


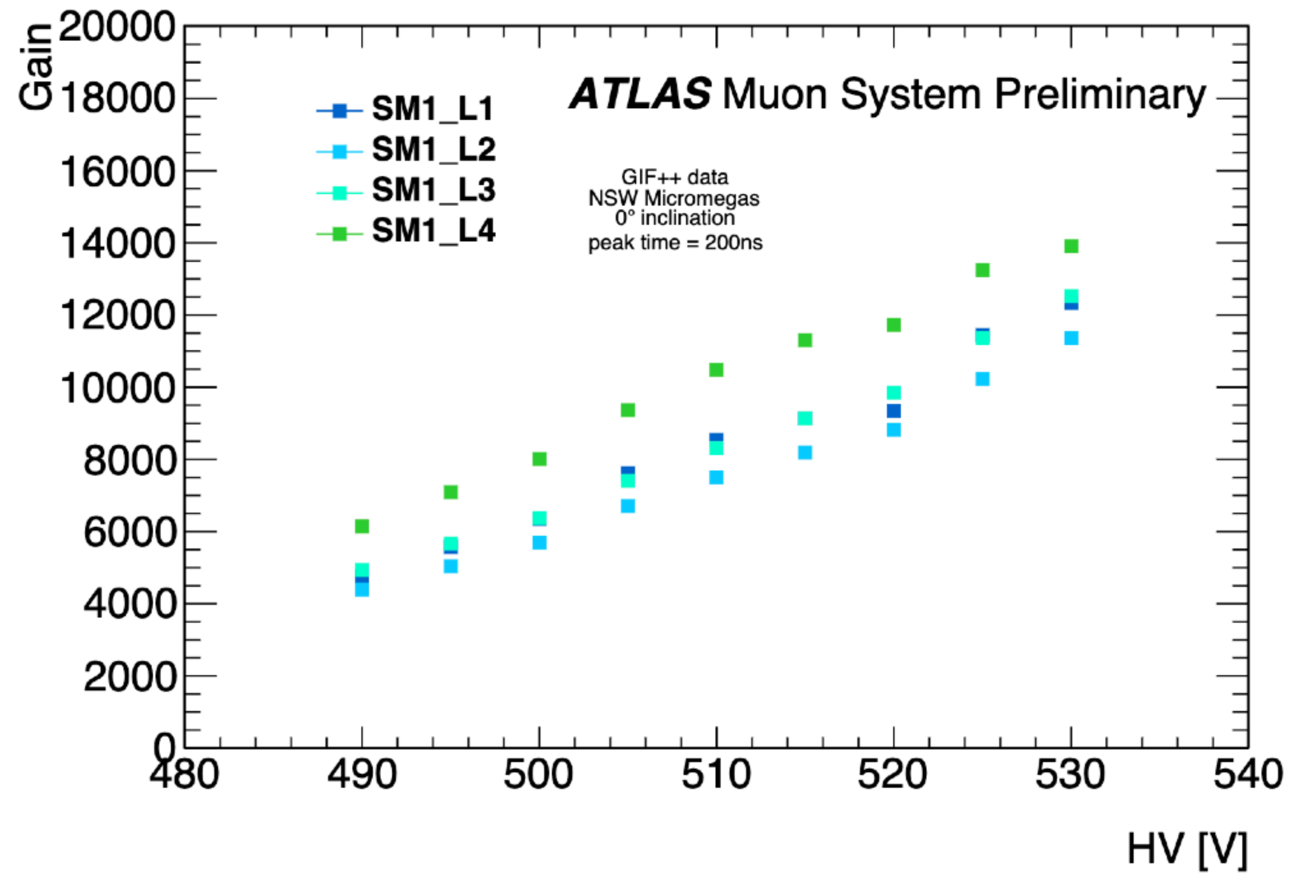




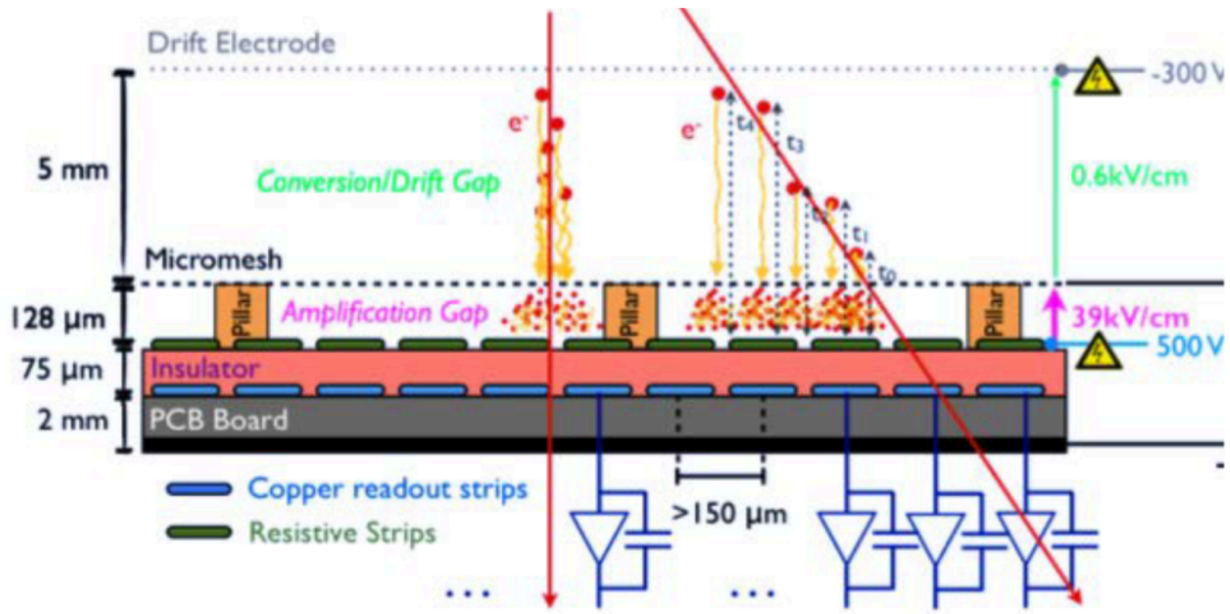
MM gas gain and time resolution

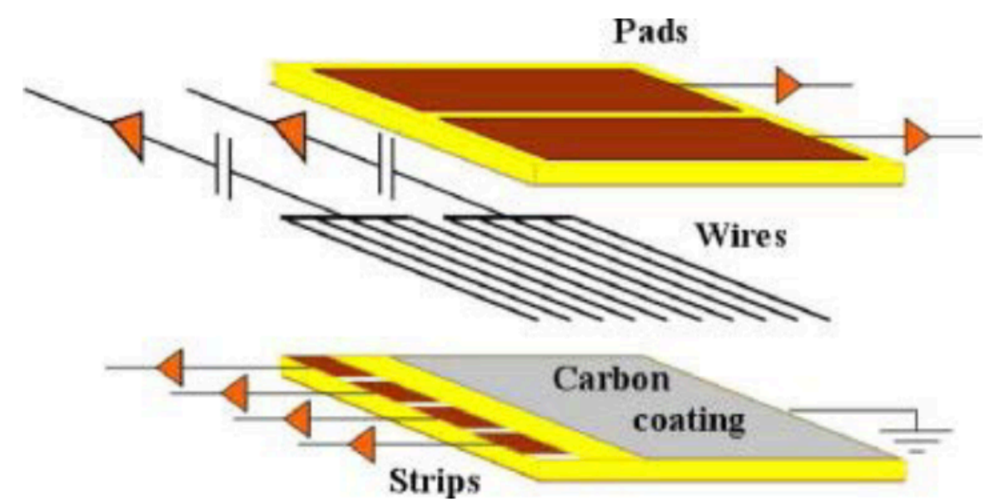
- MicroMegas cluster properties measured at the GIF++ test beam
- One SM1 Module

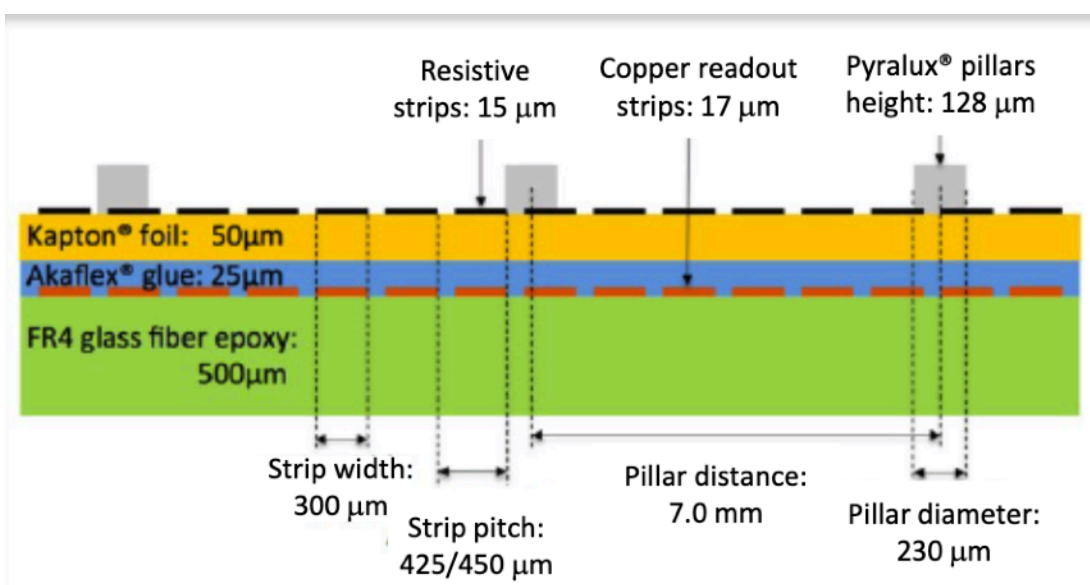


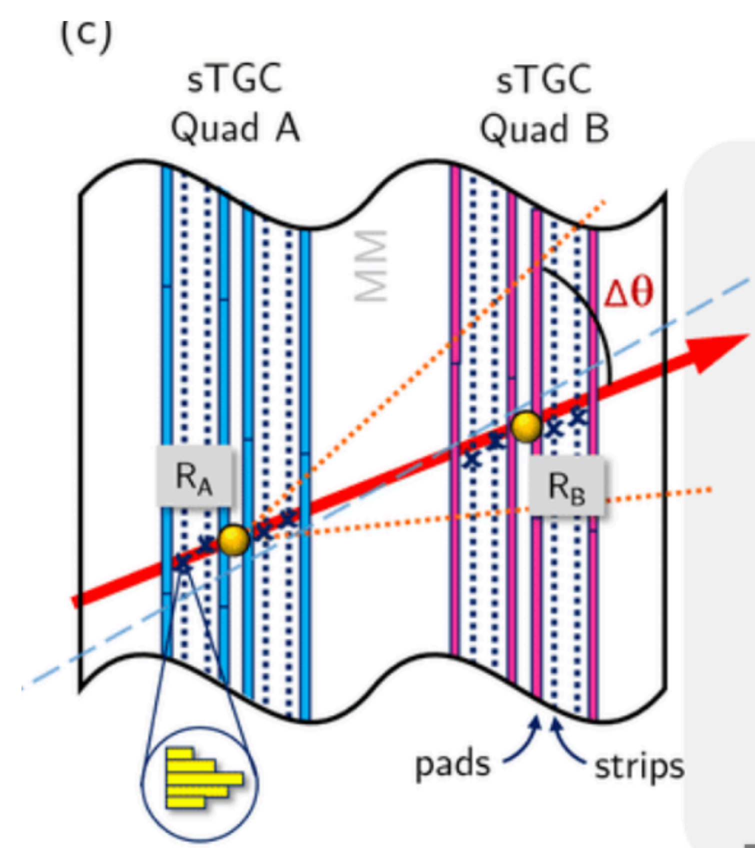


MM and STGC


Drift Electrode
-300 V
5 mm
Conversion/Drift Gap
0.6kV/cm
Micromesh
128 µm
Amplification Gap
Pillar
39kV/cm
500 V
75 µm
Insulator
2 mm
PCB Board
Copper readout strips
Resistive Strips
>150 µm

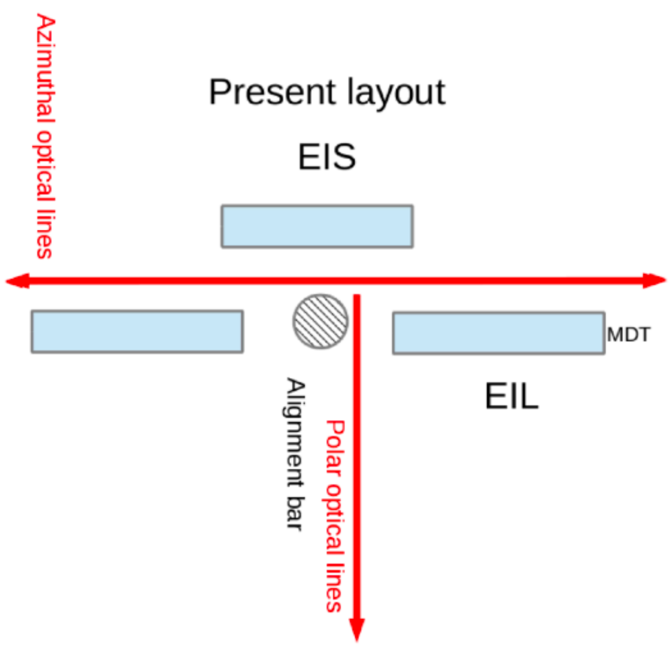

Pads
Wires
Carbon
coating
Strips

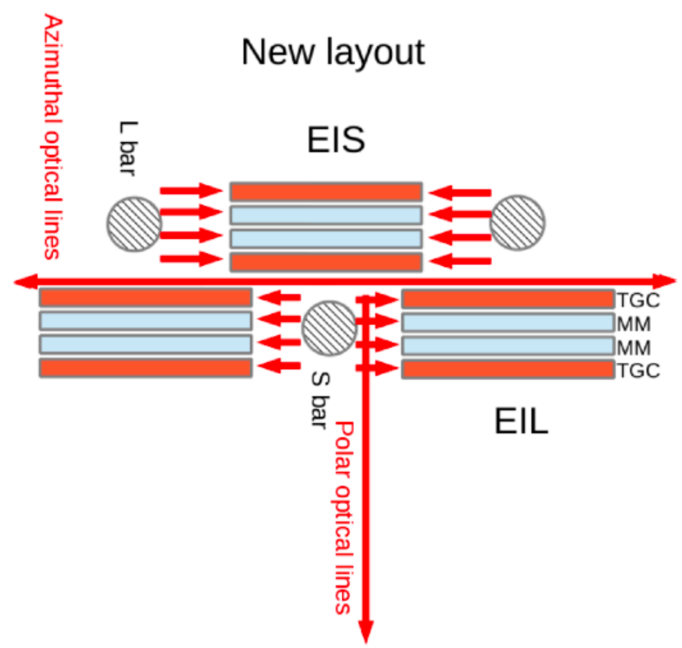

Resistive
strips: 15 µm
Copper readout
strips: 17 µm
Pyralux® pillars
height: 128 µm
Kapton® foil: 50µm
Akaflex® glue: 25µm
FR4 glass fiber epoxy:
500µm
Strip width:
300 µm
Strip pitch:
425/450 µm
Pillar distance:
7.0 mm
Pillar diameter:
230 µm

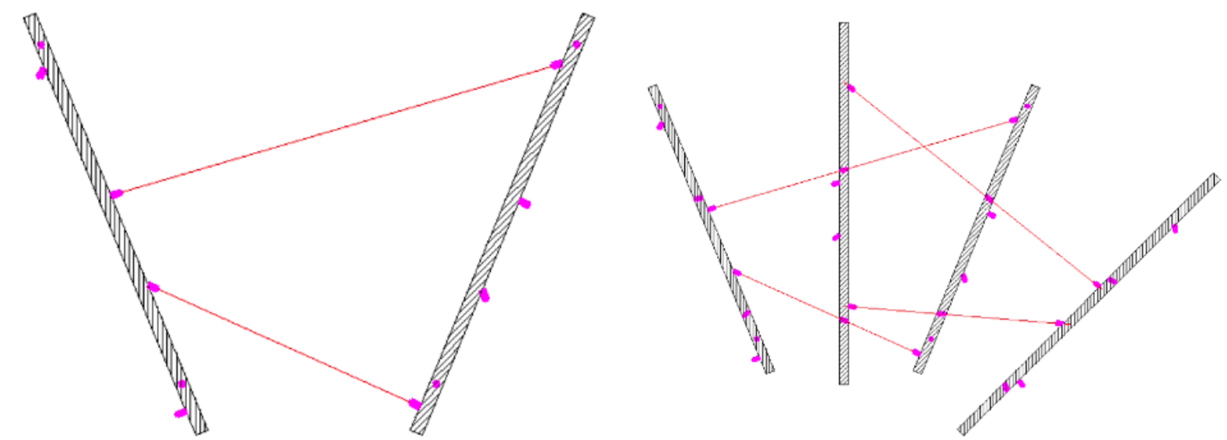

(c)
sTGC
Quad A
sTGC
Quad B
MM
Δθ
R_A
R_B
pads
strips

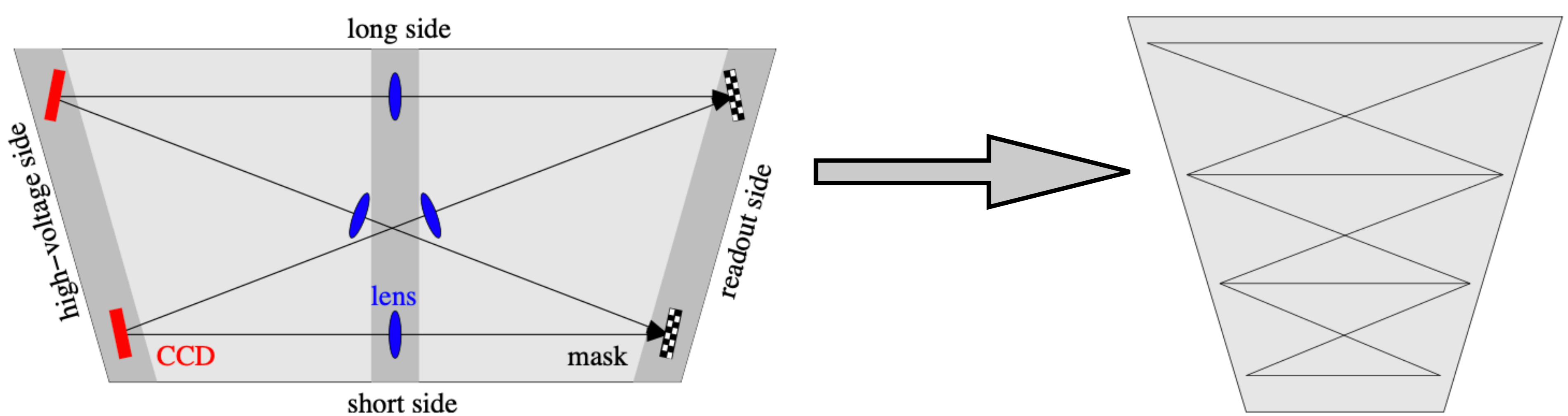
Alignment system

- Legacy system vs the NSW









Muon momentum resolution

- Momentum calibration with the J/ψ and Z decays
  - MC scales and resolutions are corrected to take into account residual alignment, resolution and other systematics
- Calibration for ID, MS standalone and combined (ID+MS) tracks