TRIUMF

ATLAS New Small Wheel Performance Studies with First Data of LHC Run3

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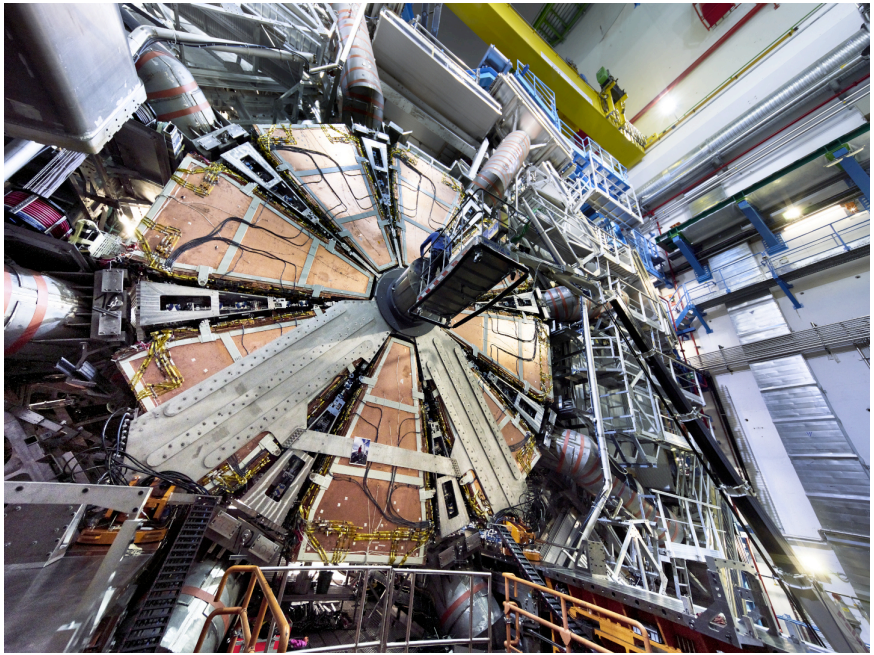
on behalf of the ATLAS Muon Spectrometer System

TIPP 2023 Cape Town

ATLAS EXPERIMENT

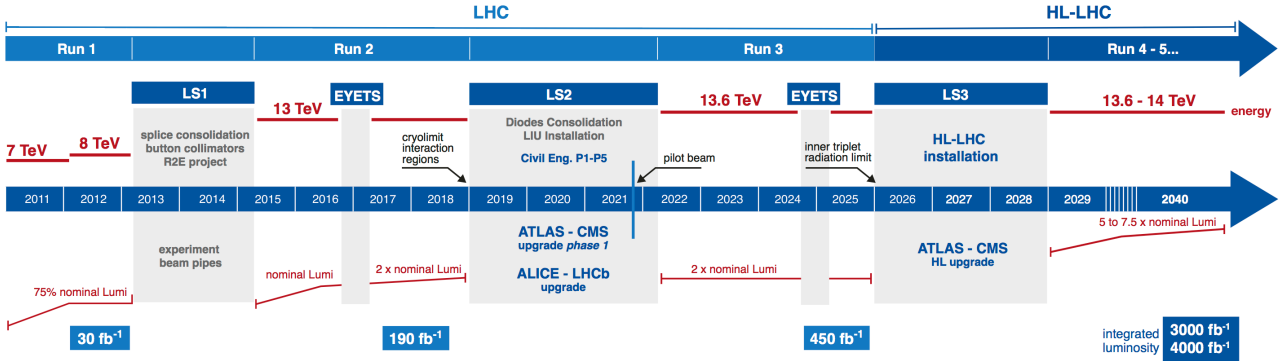
Outline

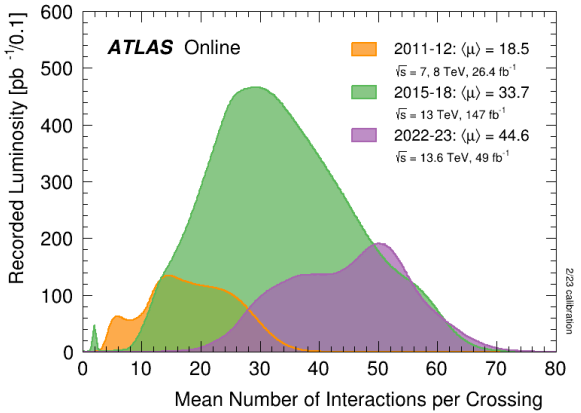
- Introduction to the ATLAS New Small Wheel
- Detector operation
- DAQ Commissioning
- Muon Reconstruction
- Trigger
- Summary



LHC

- LHC plans included two major upgrades to increase the luminosity:
  - LS2: $L \gtrsim 2x10^{34}\ cm^{-2}s^{-1}$, L_{int} ~350 fb^{-1} (about 55 p+p interactions per bunch crossing = pile-up)
  - LS3: L ~ 5-7.5 $x10^{34}\ cm^{-2}s^{-1}$, final integrated luminosity: ~3000 fb^{-1} (pile-up of about 140-200)

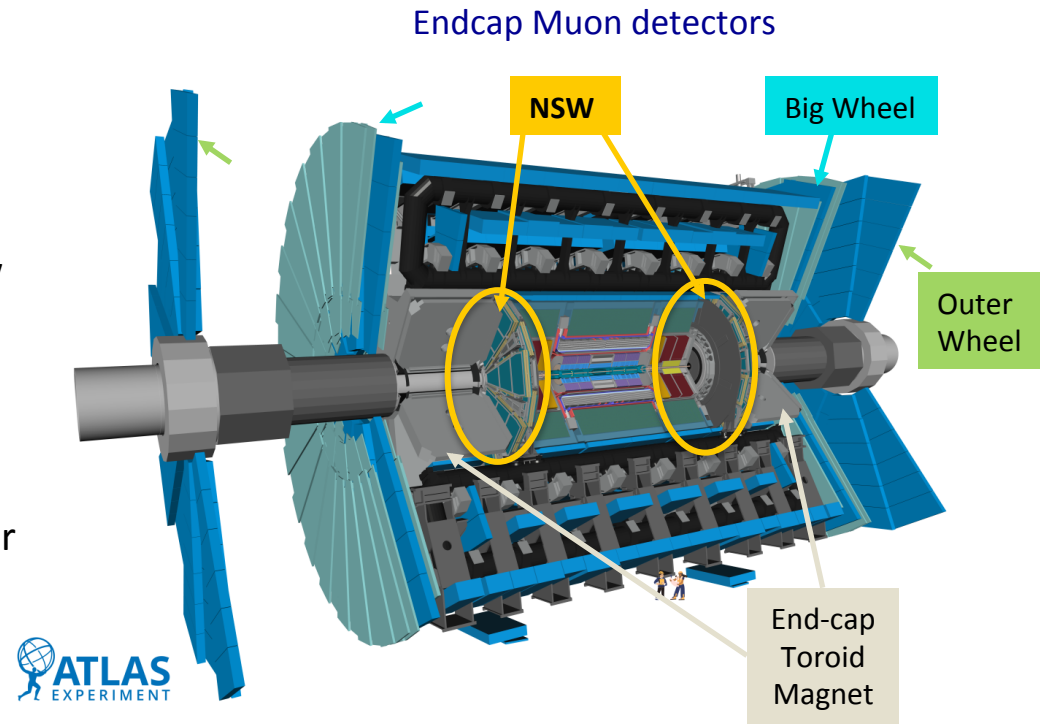




Experiments need to be upgraded to cope with the increased instantaneous luminosity

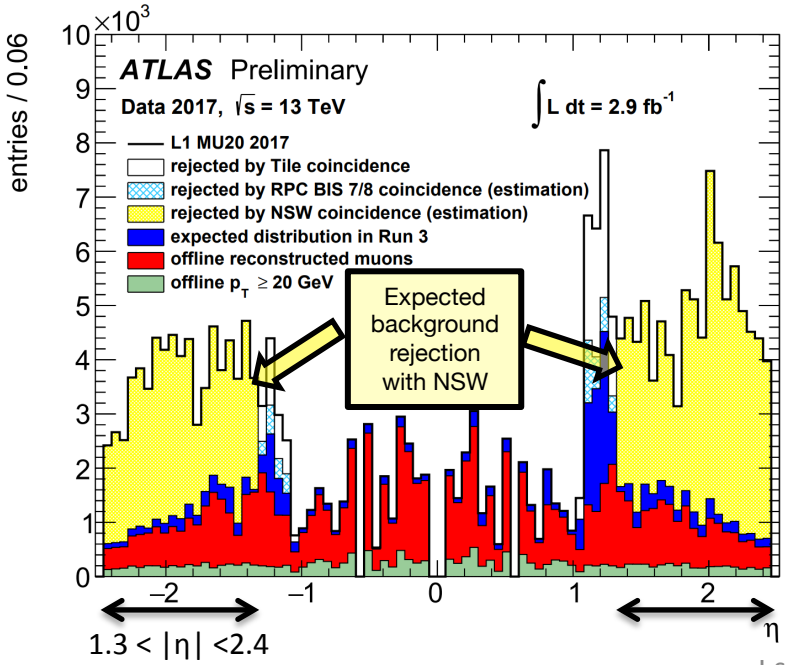
ATLAS New Small Wheel upgrade

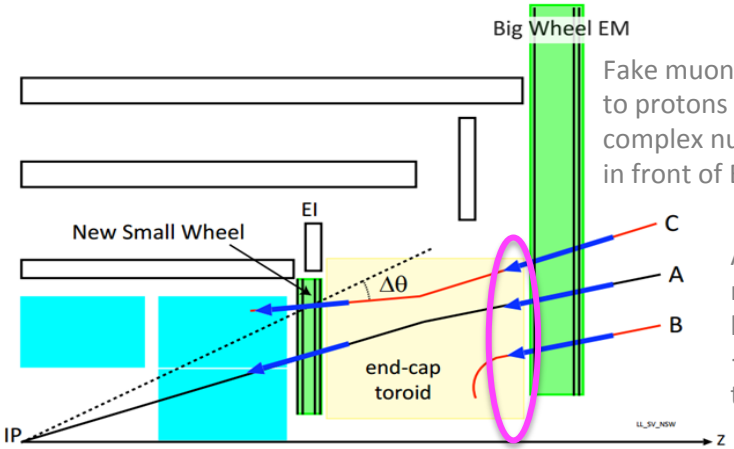
- During LS2 ATLAS went through a major hardware upgrade in the Muon System.
- Replaced the **innermost Muon station in the endcap** region with completely new detector: the New Small Wheel (NSW).
- Improve **trigger** and maintain **tracking** performance for forward muons in the **high pile-up** environment from Run 3 and under high background rates (up to 20 kHz/cm^2) of HL-LHC from Run 4



Muon Endcap Level 1 trigger

NSW is designed to provide precision **trigger** (1.3 < |η| <2.4) and **tracking** (1.3 < |η| <2.7) for muons in the ATLAS forward region.





Fake muons are mainly due to protons resulting from complex nuclear reactions in front of EM station.

Adding trigger measurement before the field → sharper trigger threshold

Offline muon **reconstruction**:

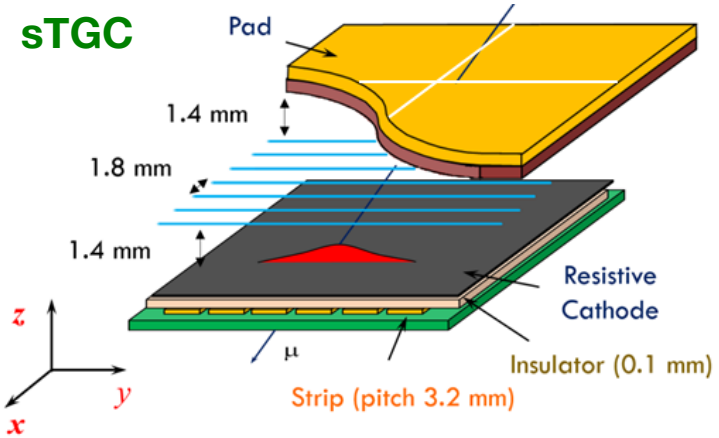
- 15% p_T resolution at ~1 TeV
- 97% reconstruction efficiency for muon p_T >10 GeV

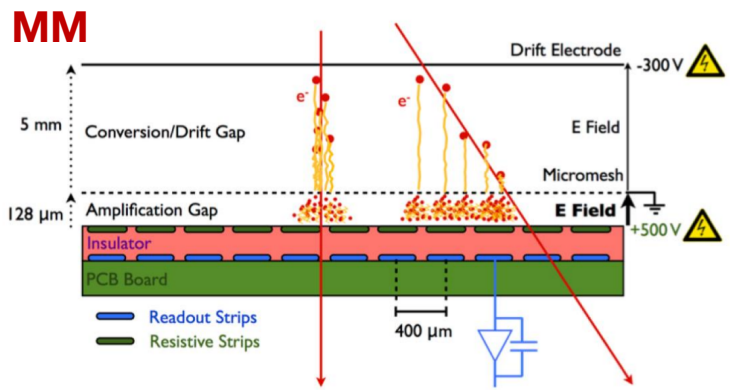
Online (Level-1) **triggering**:

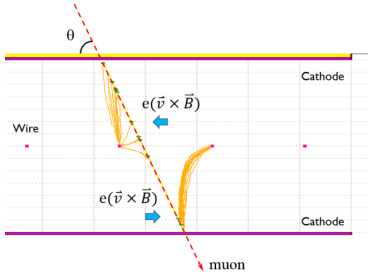
- Up to 1 mrad pointing accuracy (HL-LHC requirement)

NSW detector technologies

- Two Novel Gaseous Detector Technologies Employed:
  - Resistive cathode Small-strip Thin Gap Chamber (sTGC)
  - Resistive MicroMesh Gaseous Structure, Micromegas (MM)







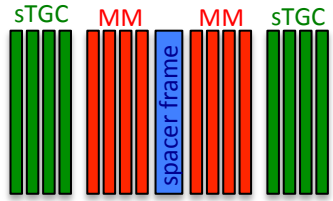
sTGC Reads out both cathodes:
strips → η coordinate
pads → coarse η/φ granularity (trigger RoI)
wires → coarse phi coordiante

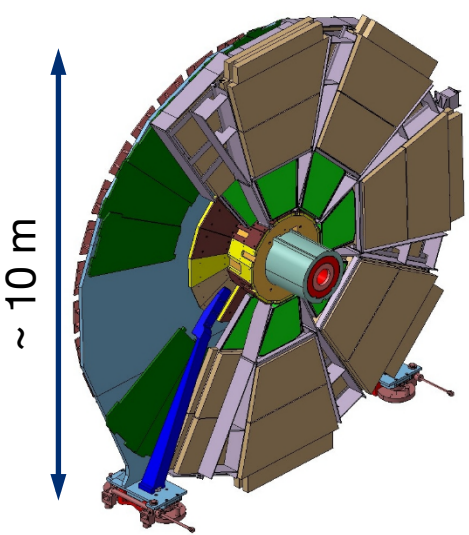
First time construction of **large area** Micro Pattern Gaseous Detectors:
Addition of resistive strips on top of a thin insulator directly above the readout electrode → spark intensity largely reduced

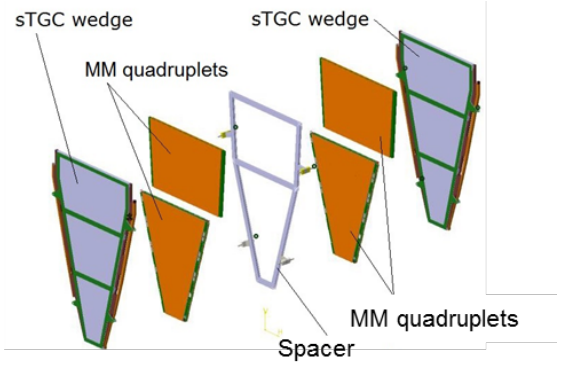
Layers with **η-Strips** and layers with **stereo-strips** (±1.5°)
For large angle tracks, possibility to use **µTPC** reconstruction

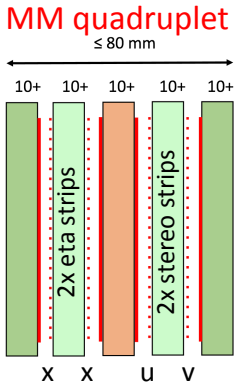
NSW detector geometry

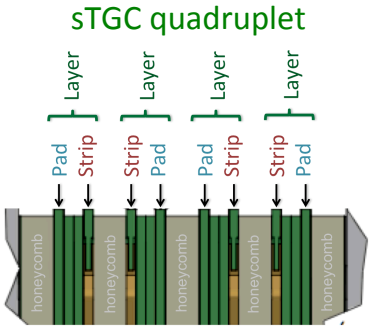
- Detectors organized in **quadruplets**.
- 2-3 Quadruplets glued/screwed into wedges. sTGC/MM **sandwich**:
- Total of **16 measurement layers**: redundancy is key!











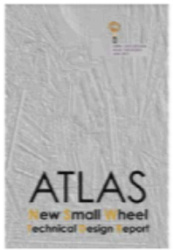
Readout channels (25x more than the “old” small wheel):

- MM: ~ 2.1M
- sTGC: ~ 280k (strip) + 46k (pads) + 28k (wires)

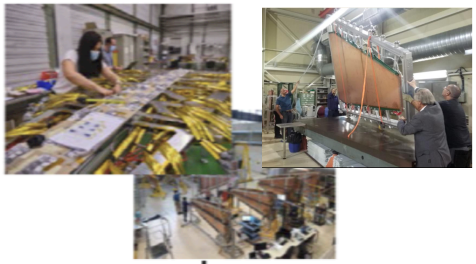
Detector area: ~2400m^2

NSW from conception to operations

TDR
June 2013

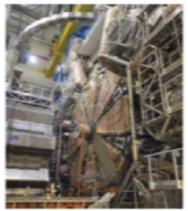


MMG+sTGC detector integration
Dec 2018



Side-A wheel completion
July 2021

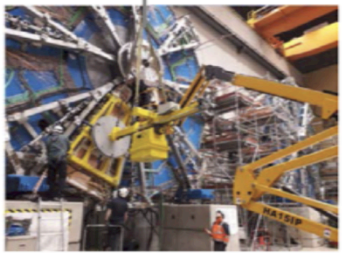
August 2021



Commissioning in ATLAS
2022

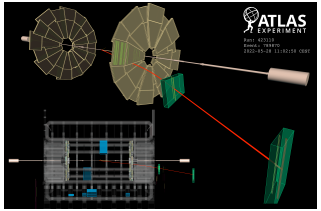
2014 Test of Module -1

Oct 2017
R&D and detector construction



Dec 2019
First sector installation on JD

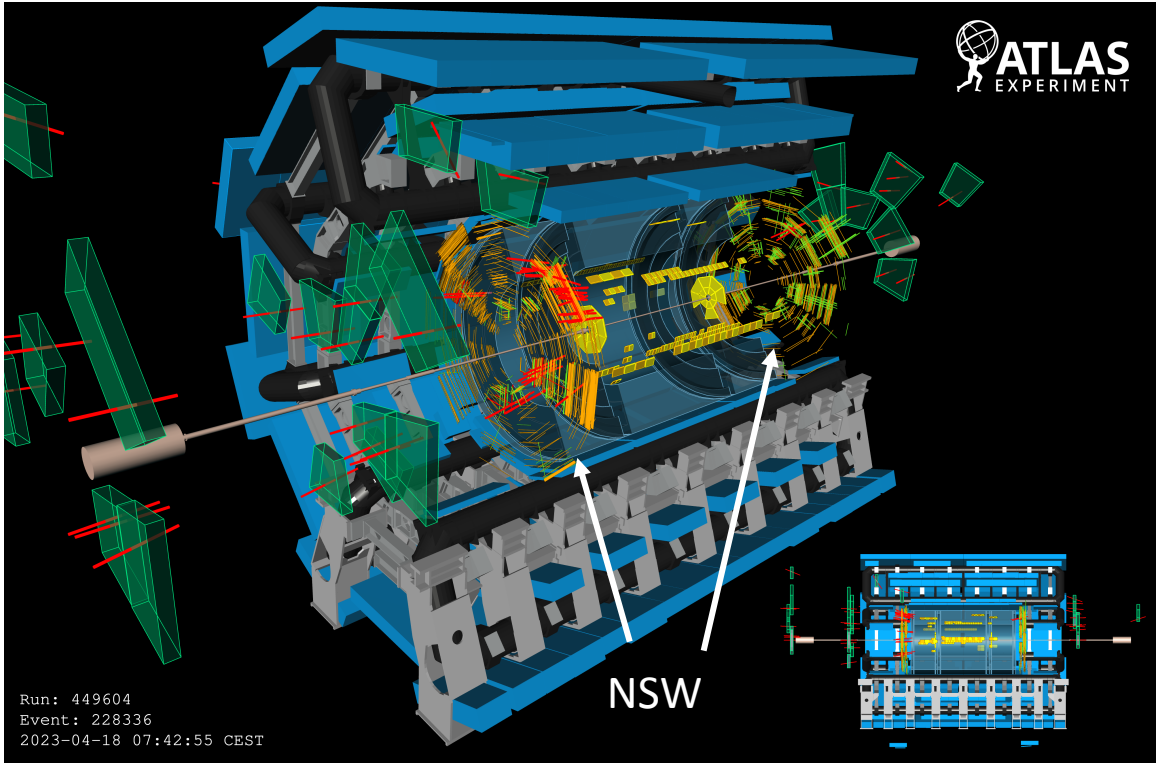
Oct 2021
Side-C wheel completion



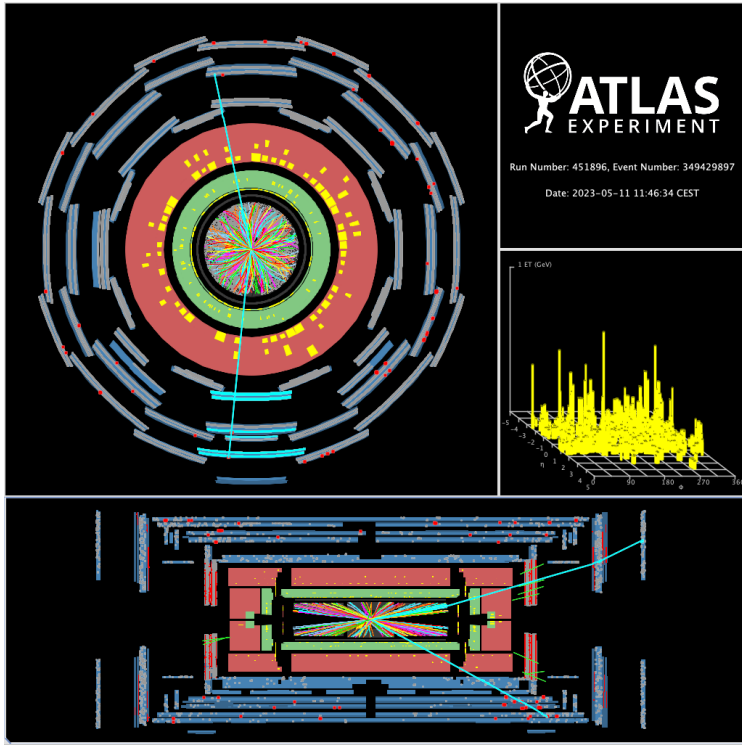
Contributing to ATLAS physics 2023

NSW integrated in ATLAS

After >10-year efforts, NSW joined the Run-3 ATLAS data-taking on Jul. 5th of 2022!



Di-muon event recorded including NSW segments

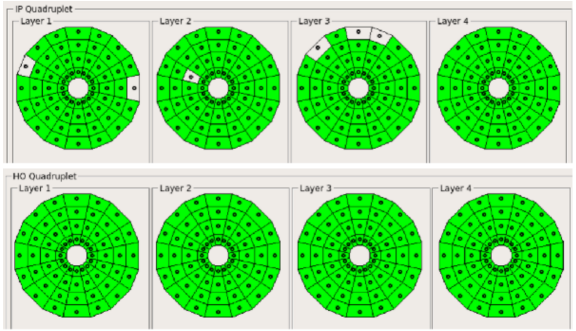


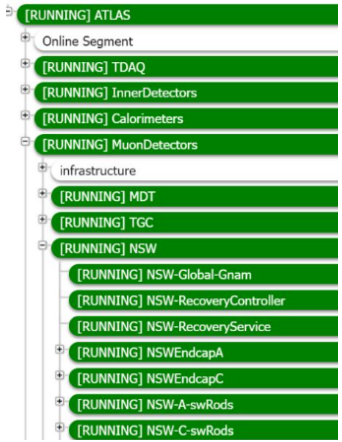
Data-taking with NSW

Detector status at installation in the cavern:

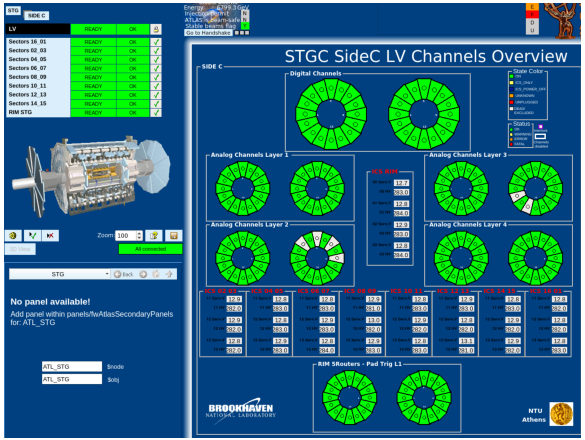
- 99% MM and 98% sTGC HV channels holding **nominal HV**.
- Gas mixture: sTGC CO2:n-pentane (55:45). MM Ar:CO2:iC4H10 (93:5:2)
- Cooling, HV, and LV: operational
- NSWs are **included in the Detector Control System** (DCS) panel and interfaced in ATLAS DAQ for data-taking

sTGC HV Status side C





NSW included in the ATLAS partition



DCS: Control and Monitoring of:

- Detector HV
- Electronics LV
- Temperature sensors
- B-Field sensors
- Cooling
- Gas
- …

DAQ commissioning

NSW uses more than 50k radiation-tolerant Front-end ASICs with 70+ million configuration registers!

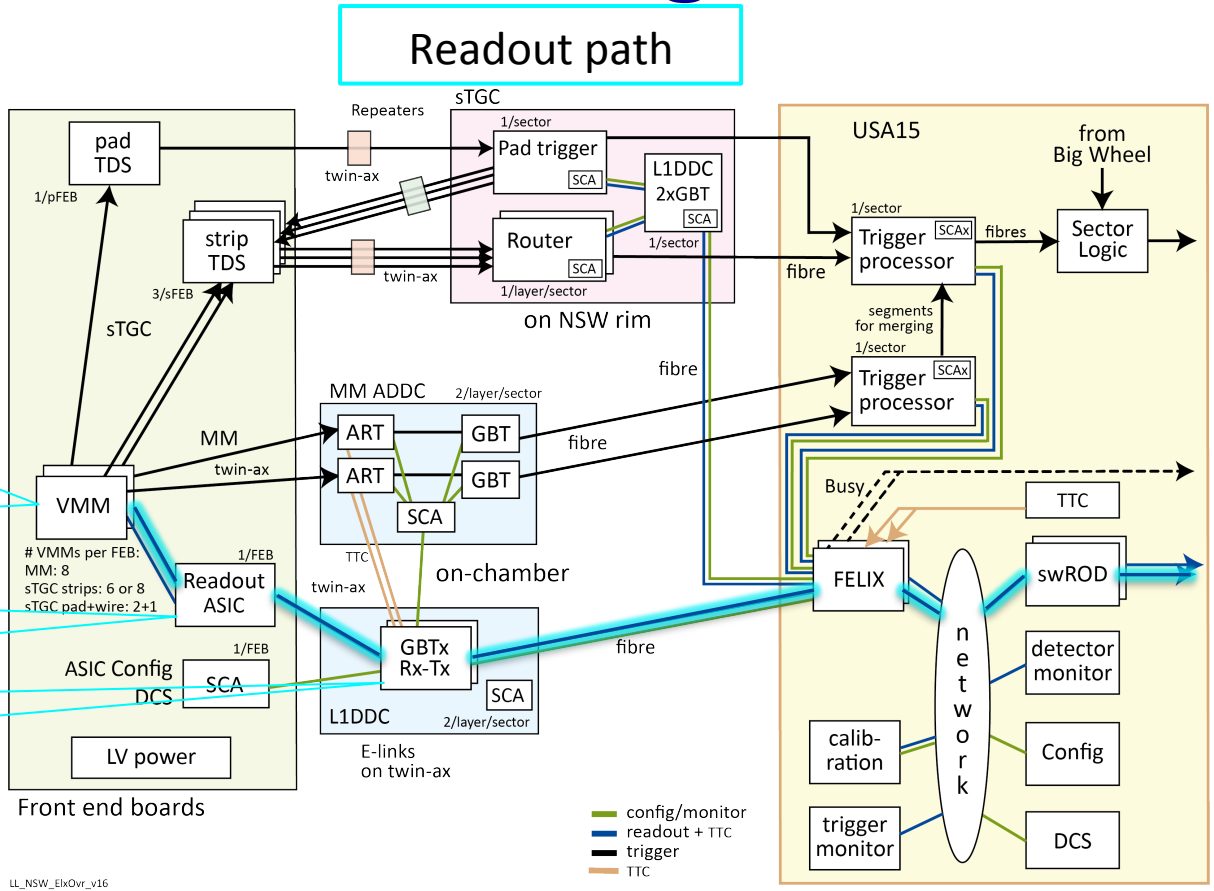
Plenty of calibrations needed, some examples:

charge amplifiers and ADCs: baseline, threshold, pulser, charge, time

readout control: internal phase for data decoding and aggregation

transceiver for **data transmission between Front-end and Back-end**: data sampling phase

Big challenge to **understand and automatize** all **calibrations**



Muon Reconstruction

The NSW is fully integrated into the ATLAS muon reconstruction software (ATHENA).

Muon Hits

sTGC+MM Clusters

2D Track segment

3D Track segment

ATLAS Muon Spectrometer tracks

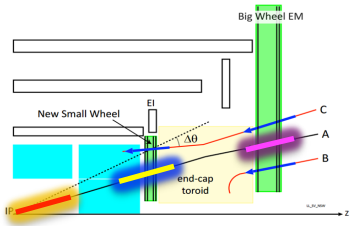
Combined Muon Tracks

Hits Clusterization

Pattern finding,
seed for transverse coordinate

Addition of azimuthal coordinate in fit

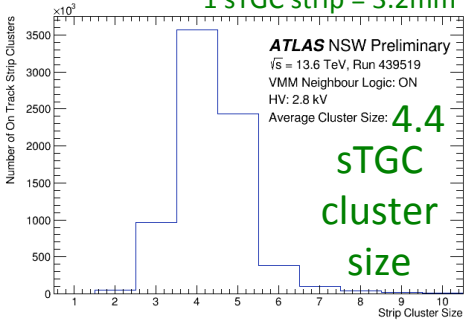
Combine NSW segments with segments in other muon subsystems



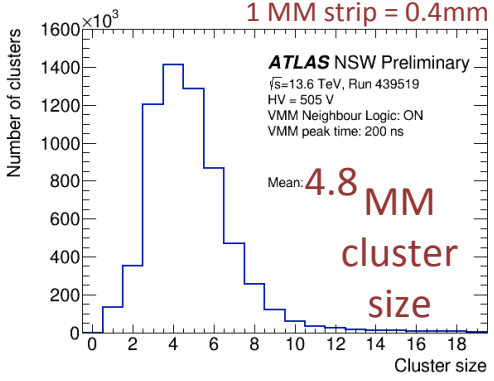
Combine with track segment in ATLAS inner detector

Currently improving cluster position corrections and optimizing track fitting

1 sTGC strip = 3.2mm

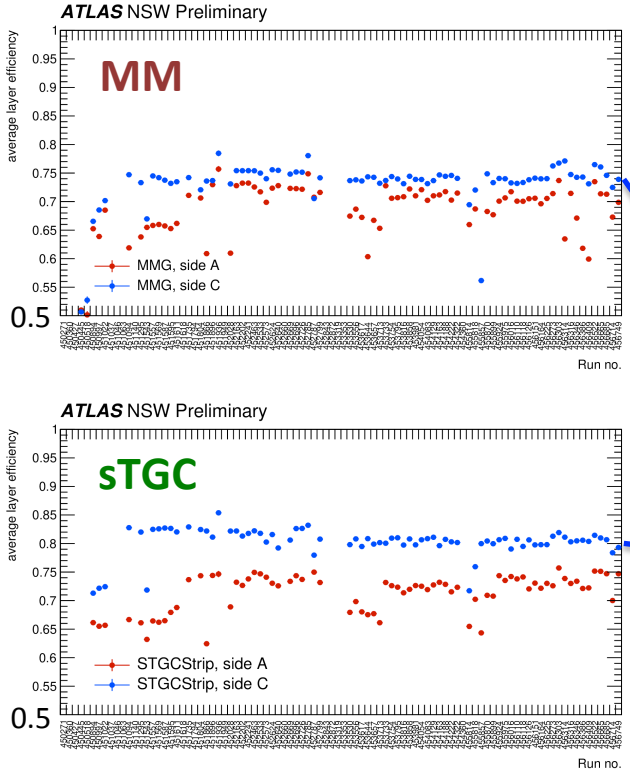


1 MM strip = 0.4mm



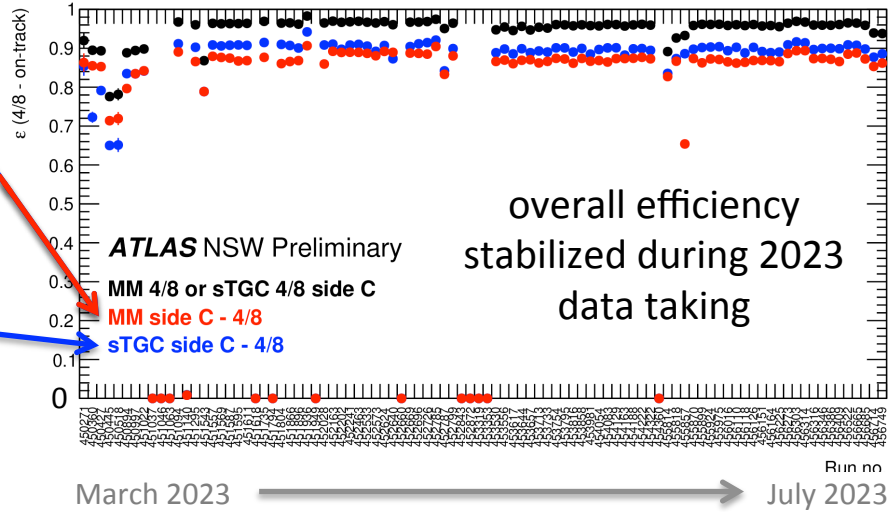
NSW Performance (Efficiency)

Average single-layer efficiency vs run number



Please note the different Y-axis range!

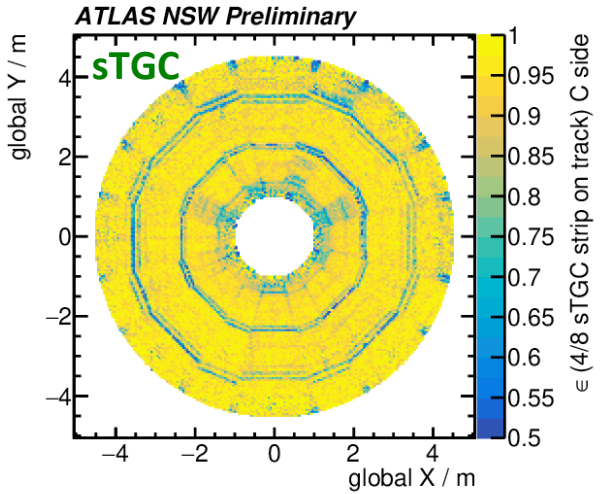
- Various detector and readout issues during the run can affect the single-layer efficiency
- **Redundancy** is key to maintain a high overall efficiency!
- 4 measurements are necessary to be able to independently seed and reconstruct a segment in the NSW

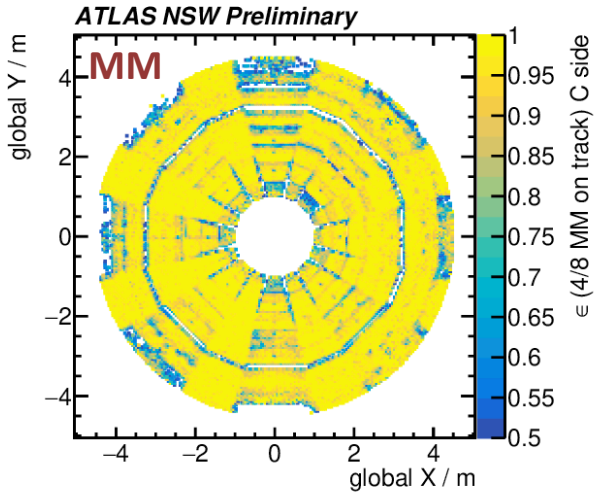


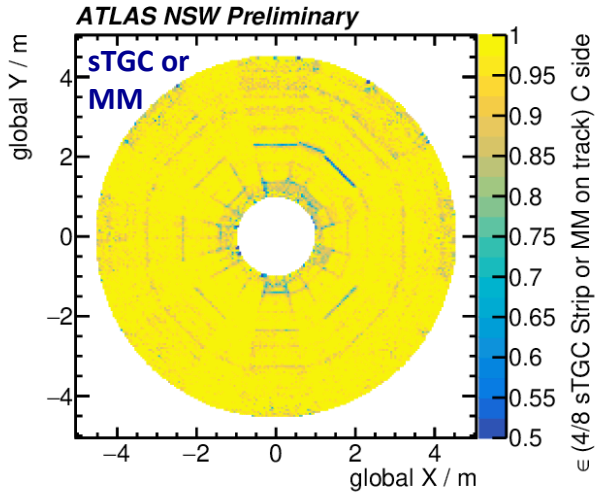
NSW Performance (Efficiency)

- The two technologies are independent and complementary → good overall coverage
- Continuous efforts to identify inefficiency sources and improve the performance when possible
  - Interventions during end-of-the-year shutdown or LHC downtime

4-out-of-8 Efficiency for an example run, side C



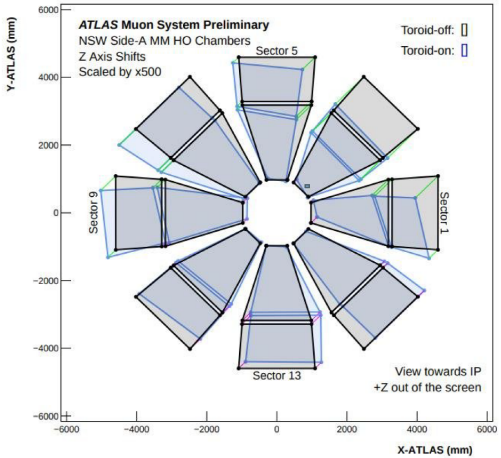




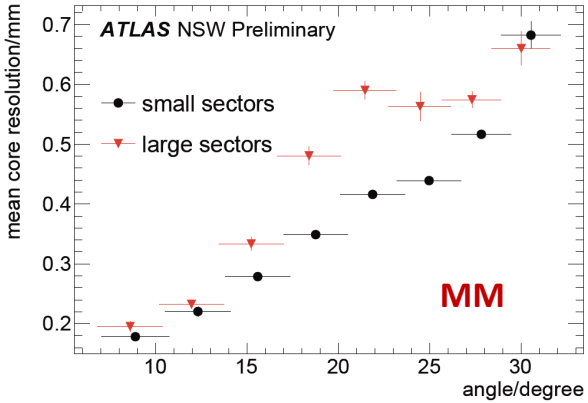
Alignment and resolution

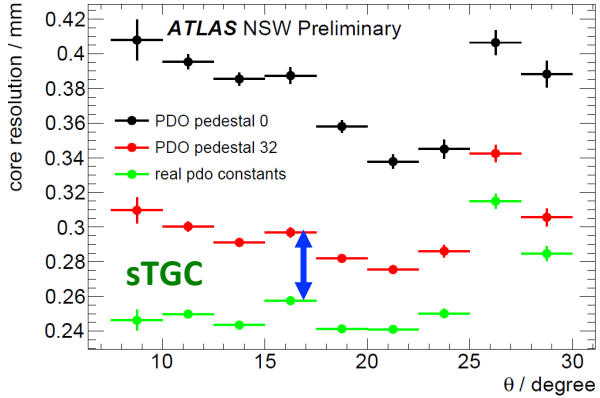
Optical-based alignment system has been installed and commissioned
Tracking the position and **deformations** of the NSW detectors
Use offline tracks in dedicated toroid-off alignment runs

NSW MM z shifts



Preliminary resolution performance (using cluster centroid)



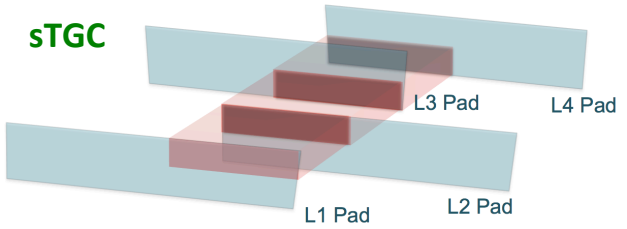


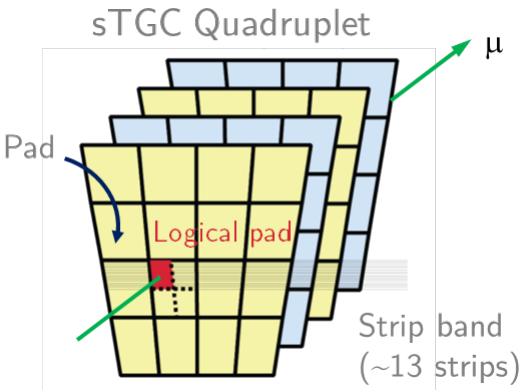
Effect of channel-by-channel charge calibration

Integration of the **alignment** information in the **reconstruction** being commissioned.
Also working on improving **residual misalignments**, through the use of an “as-built” geometry

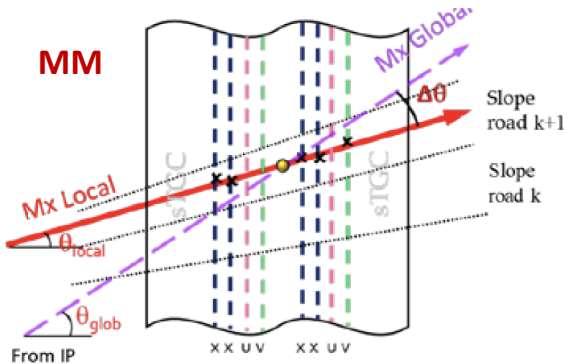
NSW Level-1 Trigger

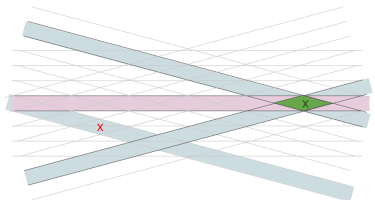
- **sTGC trigger** is designed to minimize input data by reading out only the strips in a region of interest defined by the pads
- Each **“logical pad” coincidence selects one “strip band” to be read out** for centroid reconstruction
- **MM trigger** is designed to be independant and complementary, and provide higher position resolution
- It considers only the strip with the **earliest signal**, and finds **coincidences** across layers within a 8-strip **“slope-road” pointing** to the interaction point





sTGC Pads are staggered in both directions → the “logical pad” is ¼ of the pad area



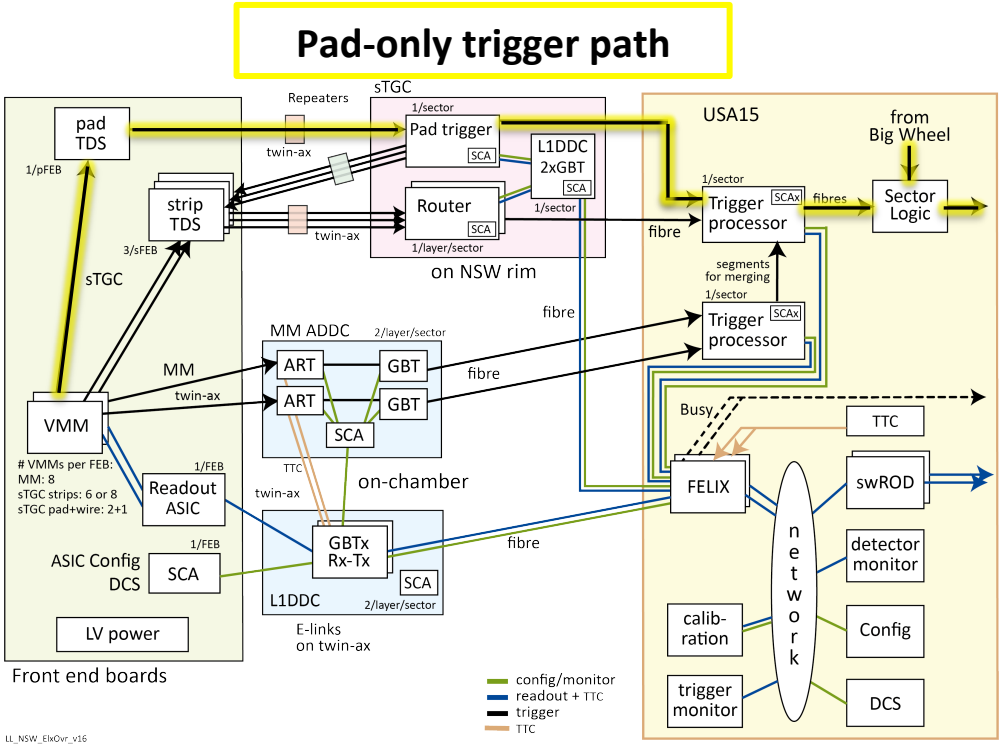


η-Strips and stereo-strips coincidence

NSW Level-1 Trigger

- **sTGC and MM trigger candidates** are designed to be **merged** before checking **coincidence** with the outermost endcap muon station, the “Big Wheel”

- Currently a pad-only trigger path has been **successfully integrated in the full trigger chain** using a 5/8 pad coincidence logic
- NSW is **participating in the ATLAS trigger decision** in 100/144 trigger sectors, using a relaxed coincidence window

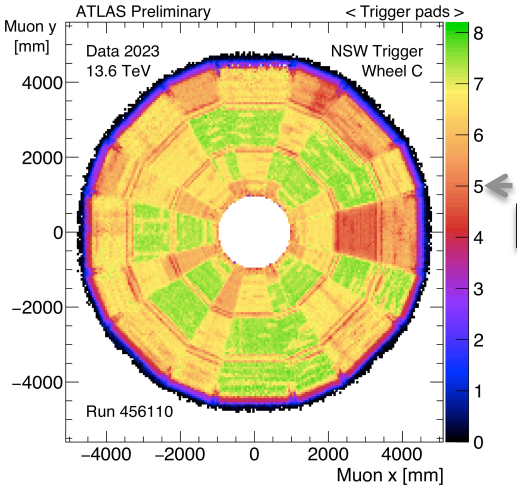


Comissioning of the MM and sTGC strip path is ongoing (sTGC strip path is a requirement for HL-LHC)

NSW Level-1 Trigger

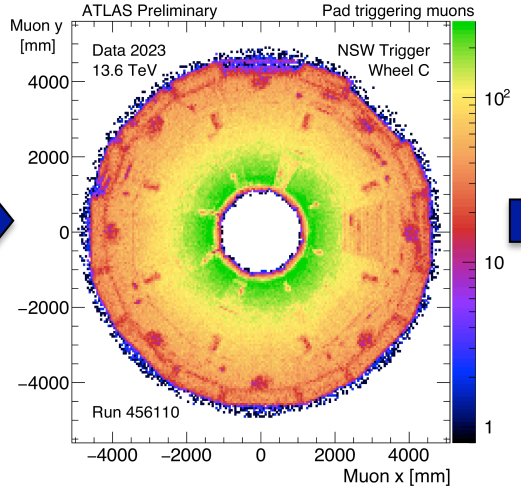
Ongoing efforts to optimize of the logic and improve efficiency at every level
Using the pad-only path, effect on the ATLAS trigger efficiency is 4%

<N> PadTrigger hits per muon

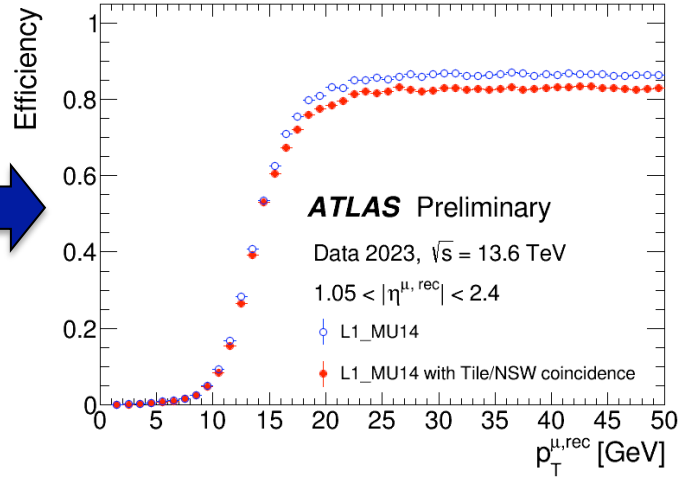


5/8 coin logic = 3/4 && 2/4

Number of muons triggered by the PadTrigger



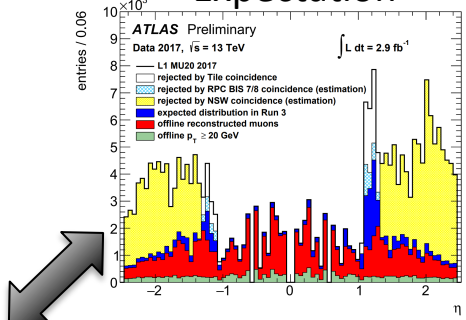
Effect of requiring the NSW coincidence in the Level-1 trigger

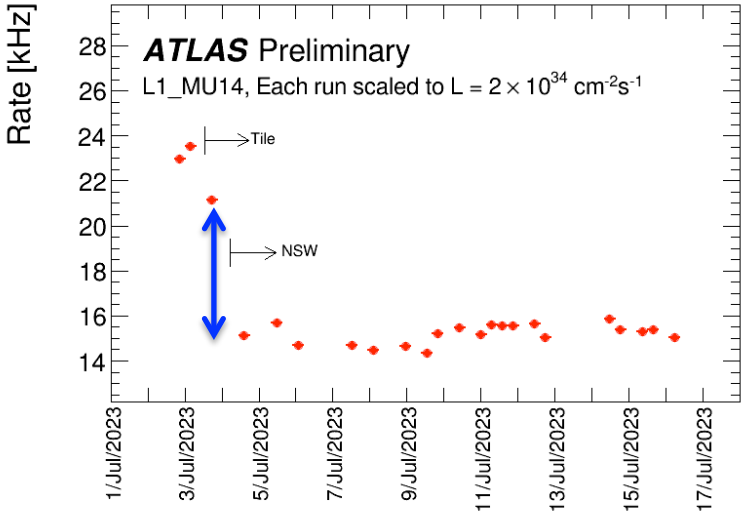


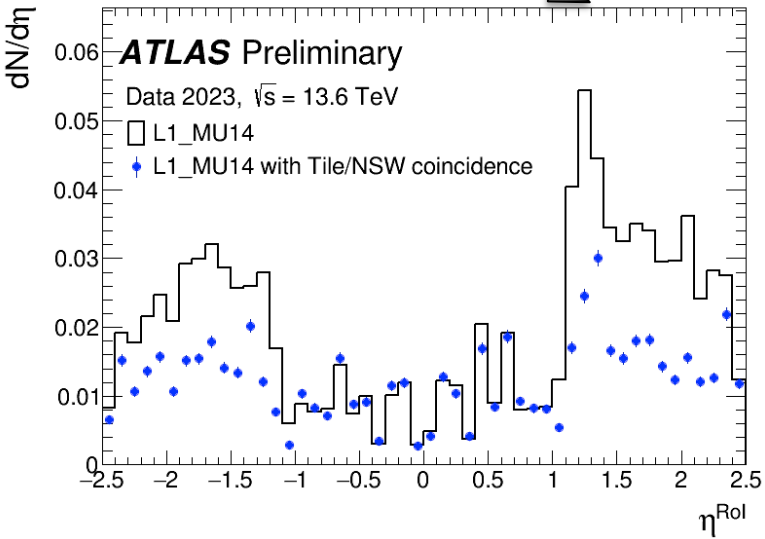
NSW in ATLAS Trigger

- Trigger rate already **reduced by 6kHz** with the inclusion of the pad-only NSW trigger coincidence (in 100/144 trigger sectors)
- Studies ongoing, plenty of room for **improvements**

Expectation





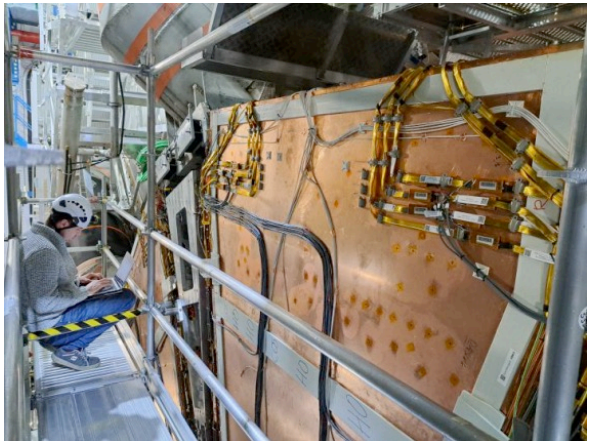


Asymmetric background dominated by low-p protons

Summary

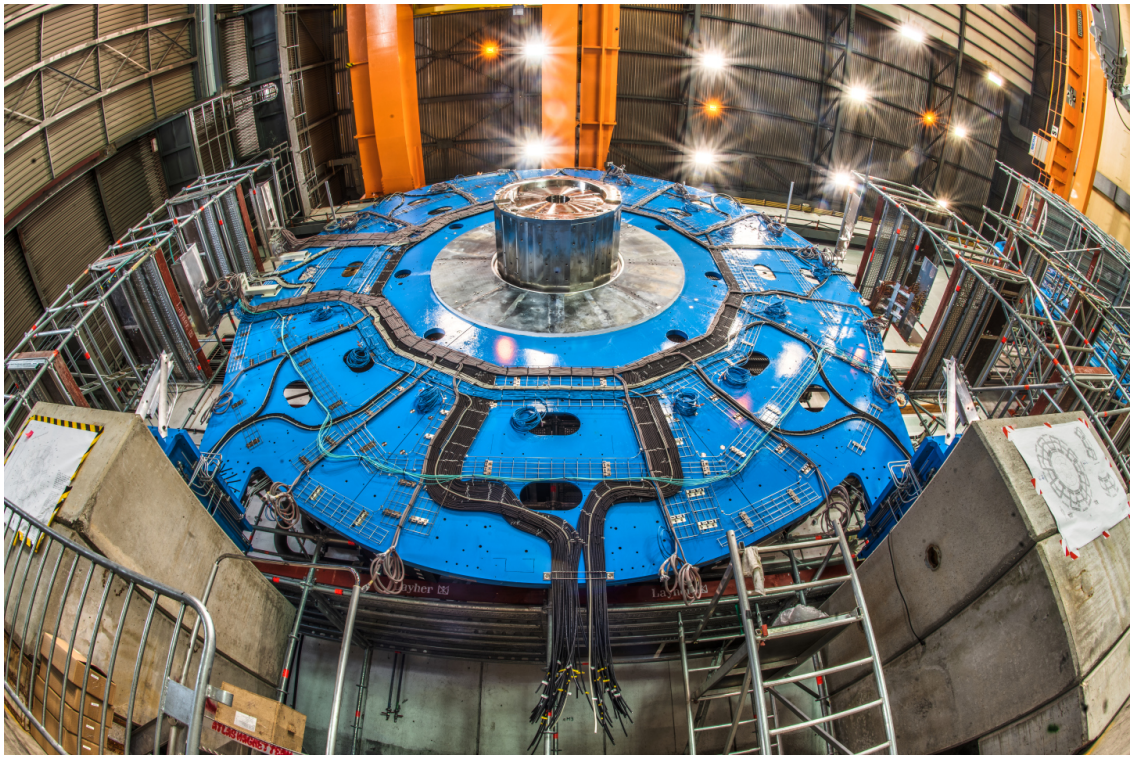
- The NSW was ATLAS largest LS2 upgrade project.
  - Uses two **new** sub-detector **technologies**: MM and sTGC
  - Uses **new DAQ system** at large scale for the first time
- Hardware was fully commissioned and **installed in the ATLAS cavern** during LHC's Long Shutdown 2 → **outstanding** achievment!

- The New Small Wheel **participating** in the **ATLAS Run-3** data taking
- While **trigger and DAQ commissioning is being finalized**, NSW is already **providing significant improvement** on the Level-1 muon trigger and tracking in the ATLAS forward region.



Hardware interventions during technical stops and LHC downtime

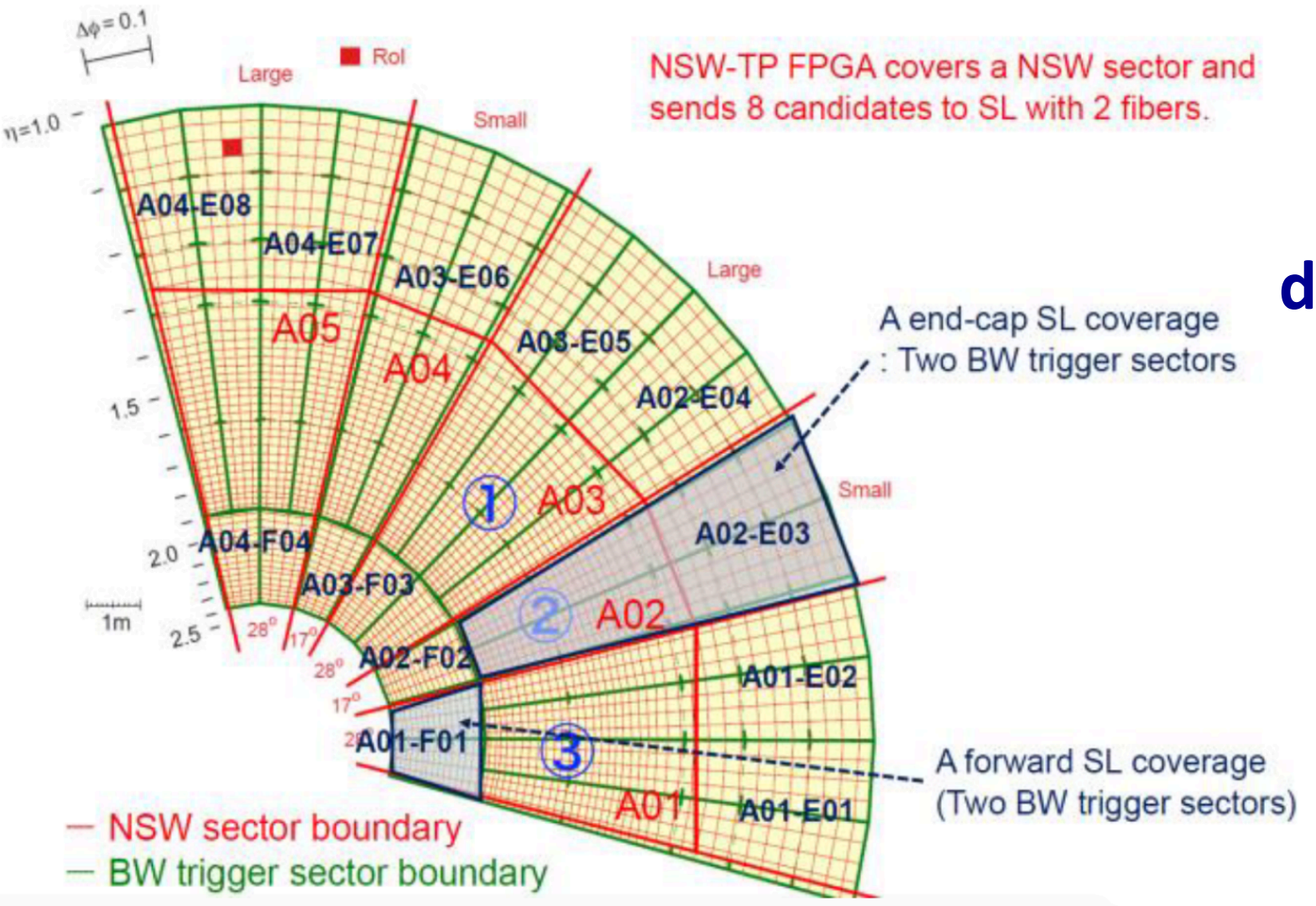
Thank you for your attention



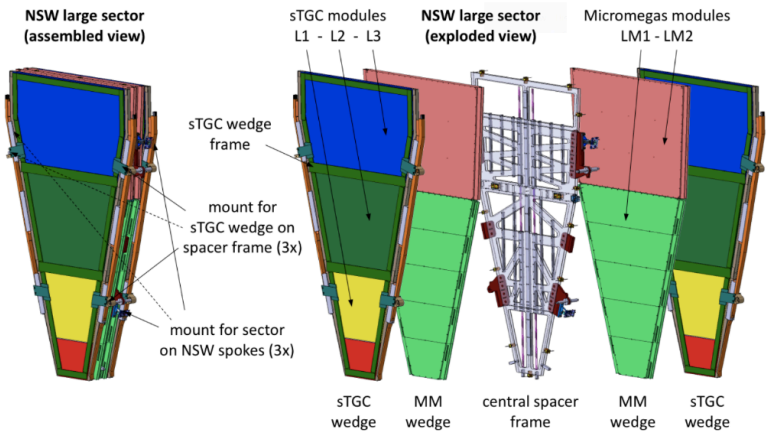
References

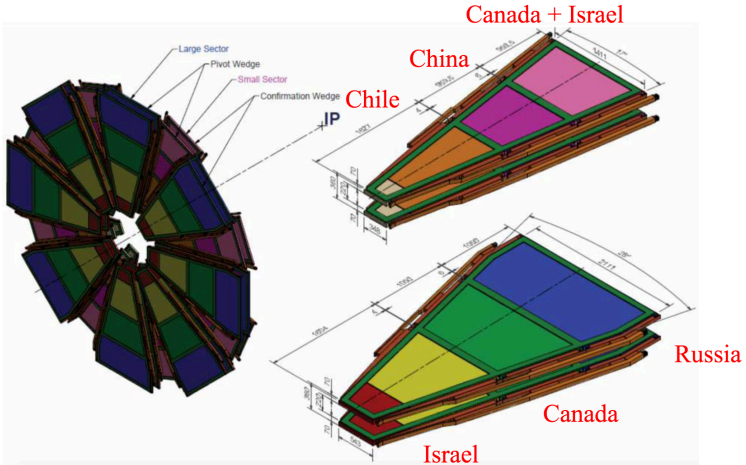
- NSW Technical Design Report:
  - https://cds.cern.ch/record/1552862/files/ATLAS-TDR-020.pdf
- ATLAS Run-3 paper:
  - https://arxiv.org/abs/2305.16623
- ATLAS Run-3 luminosity
  - https://twikiai.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun3
- The New Small Wheel Electronics
  - https://arxiv.org/pdf/2303.12571.pdf

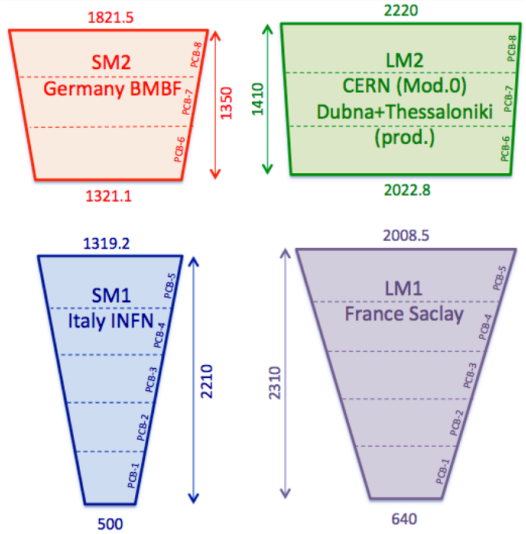
Trigger Sector definition



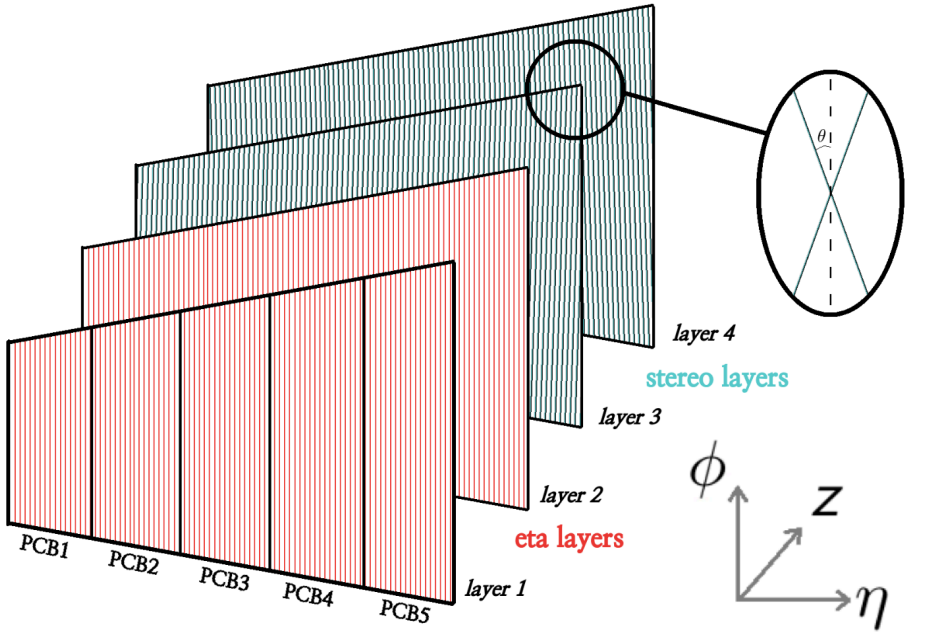
NSW Geometry







MM geometry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stereo layers
layer 3
layer 2
eta layers
layer 1
PCB1
PCB2
PCB3
PCB4
PCB5
θ
ϕ
z
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