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ATLAS New Small Wheel Performance Studies with first data of LHC Run3

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on behalf of the ATLAS Muon collaboration

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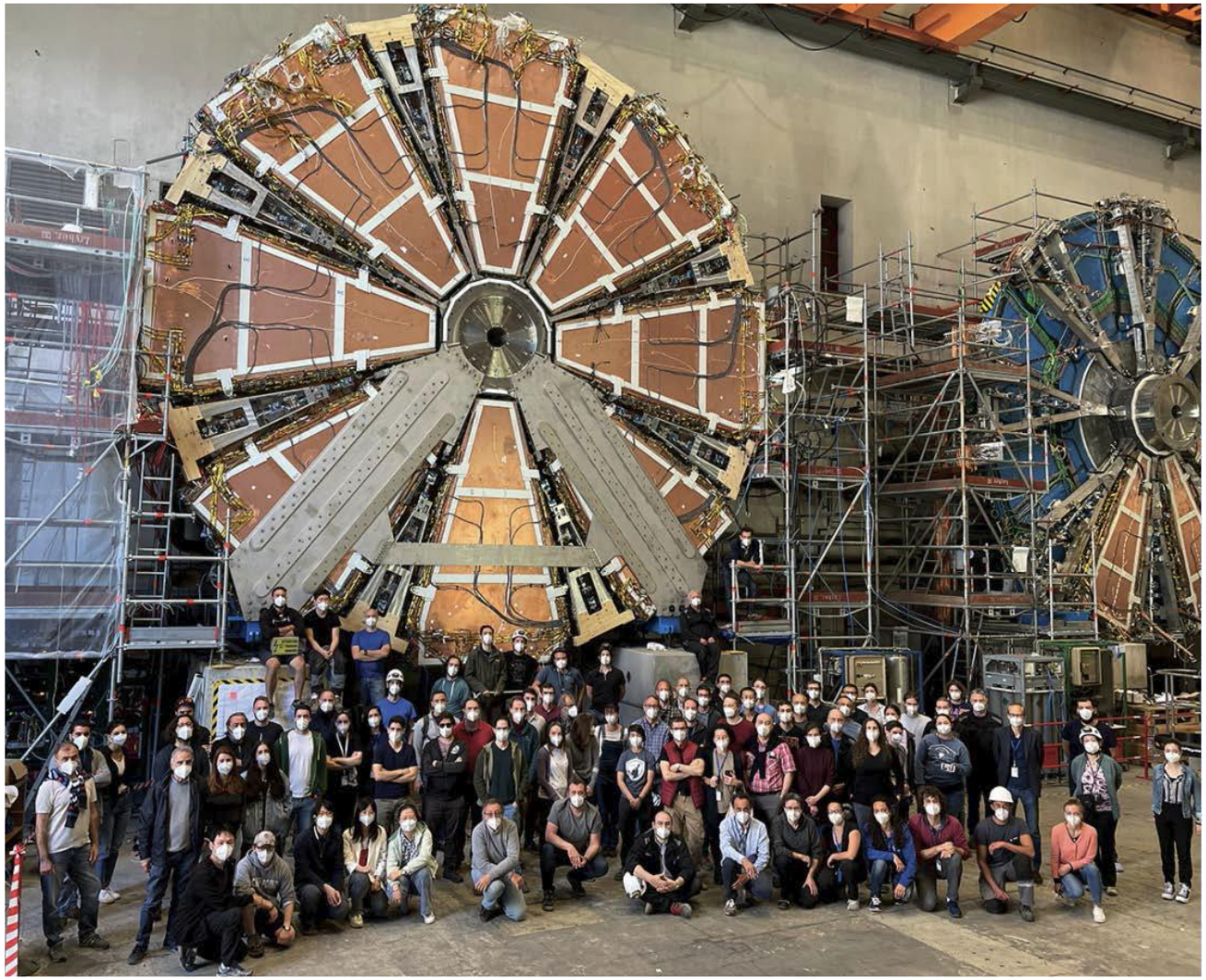
UNIVERSITY OF MICHIGAN

Outline

- General Introduction to New Small Wheel
- Detector and electronics
- Integration and commission
- Muon reconstruction
- Performance of NSW in the early data taking



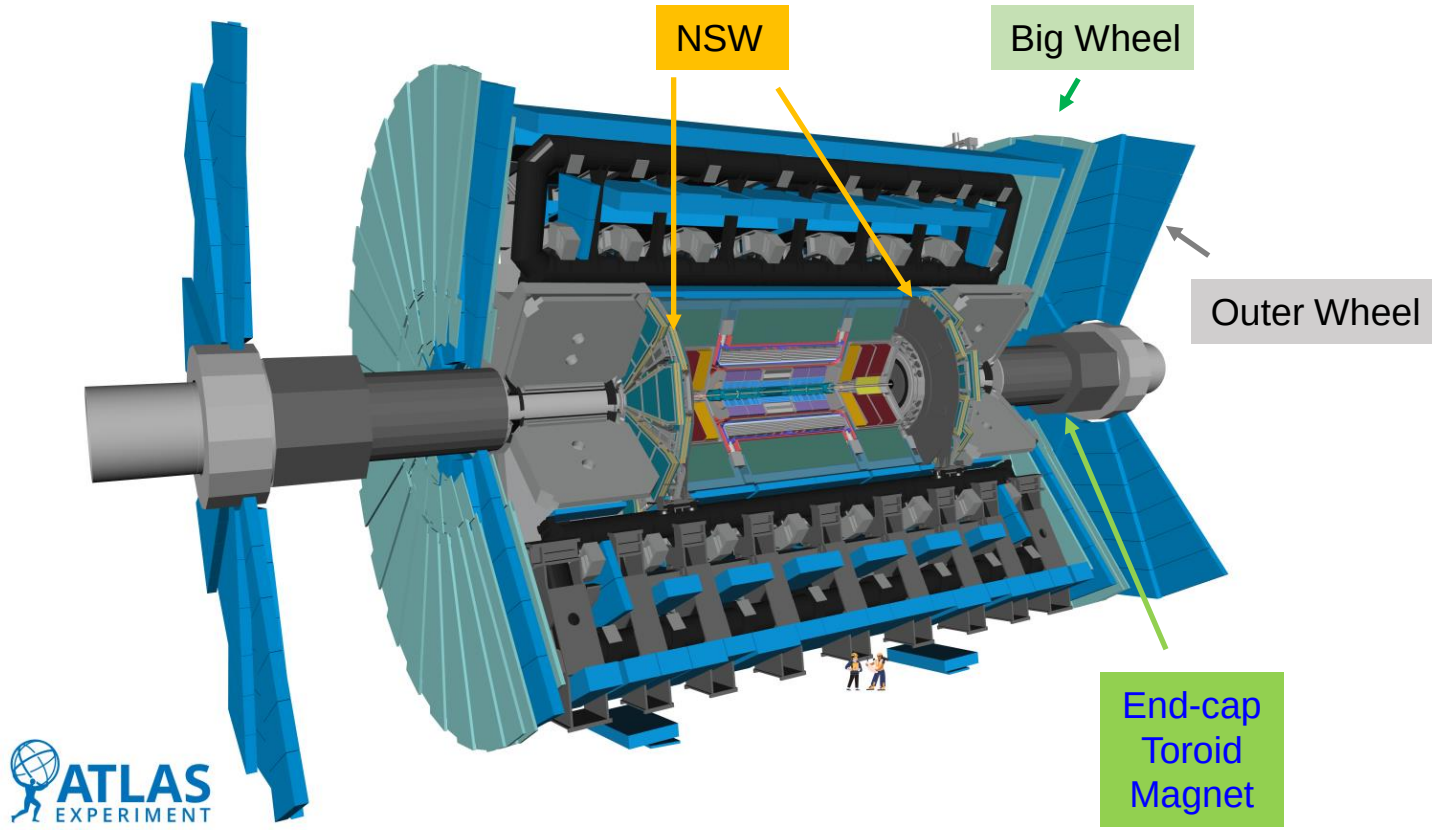
ATLAS and the New Small Wheel Project

ATLAS went through major hardware upgrade during LHC Long Shut 2 (2019-2022) to improve trigger and maintain remarkable detector performance in high pile-up environment after Run 2.

Muon New Small Wheel (NSW) Upgrade: [ATLAS-TDR-020]

- Replacing innermost Muon station in the forward region with completely new detector to provide good trigger and tracking at End-cap with high background rates (up to 20 kHz/cm$_2$) towards HL-LHC

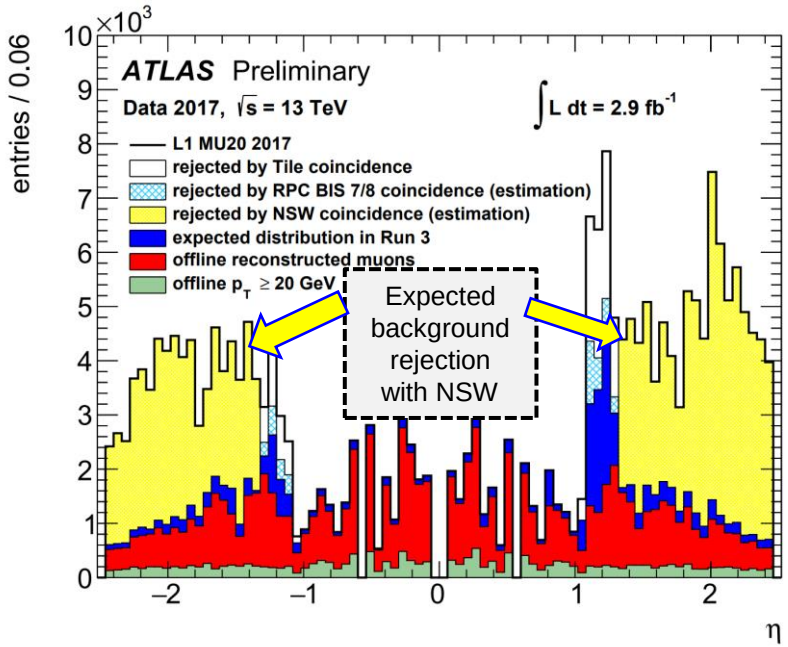
Muon detector stations at the Endcap



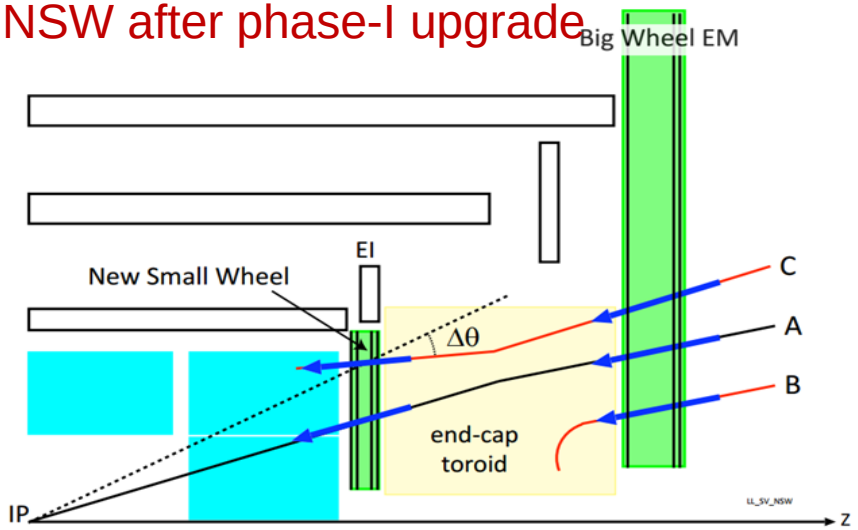
Muon Level-1 trigger at Endcaps

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

Expected Level-1 muon trigger rate reduction w. NSW



Level-1 Muon trigger at End-cap with NSW after phase-I upgrade



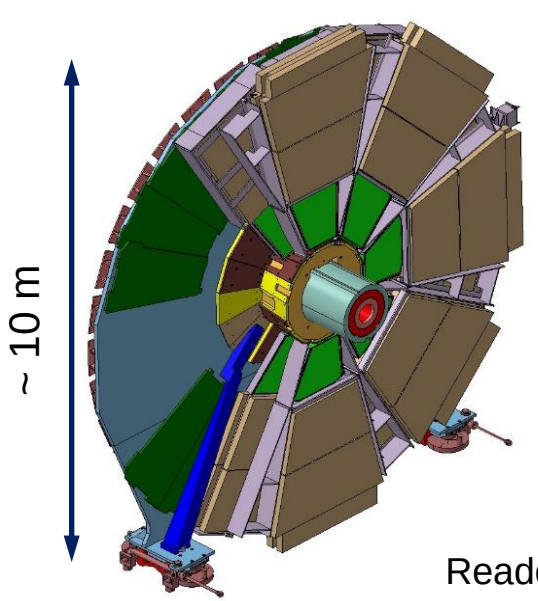
NSW- to meeting phase-I & phase-II upgrade goals:

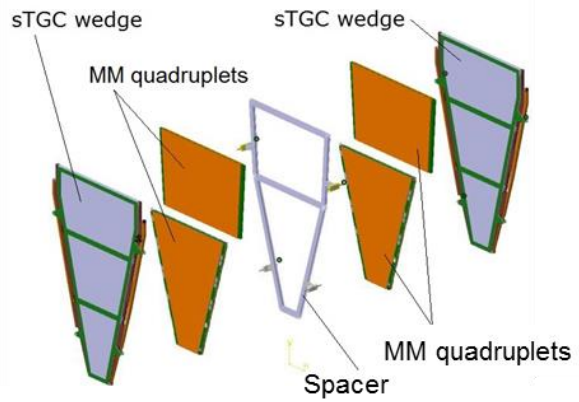
- Offline muon construction: 15% p_T resolution at ~1TeV/c. 97% segment reconstruction efficiency for muon p_T >10 GeV/c.
- Online (Level-1) triggering: segments measurements with up to 1 mrad pointing accuracy (Phase-II requirement)

Muon NSW detector

Two Novel Gaseous Detector Technologies Employed:

- Resistive Micromesh Gaseous Structure, Micromegas (MMG)
- Resistive cathode Small-strip Thin Gap Chamber (STGC)



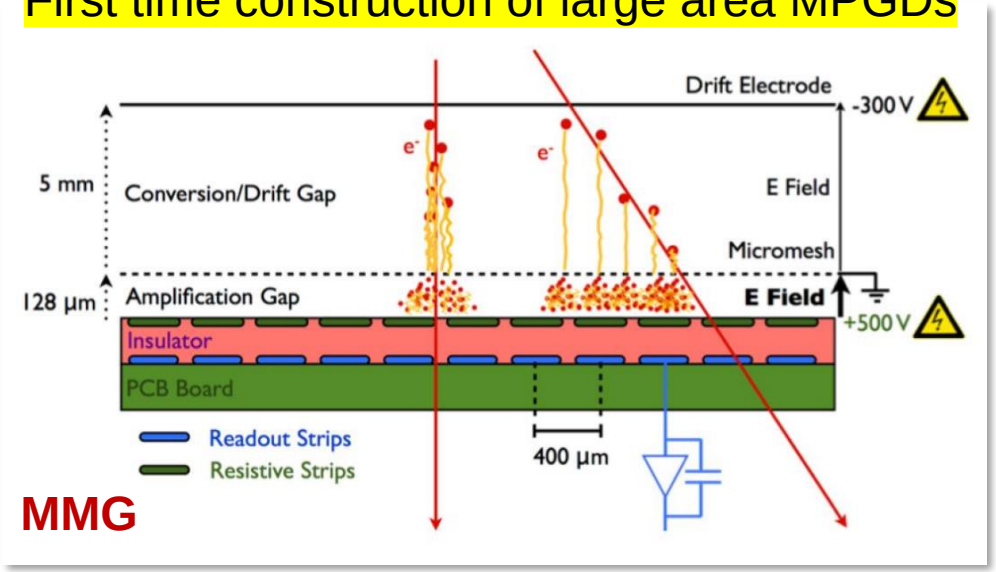


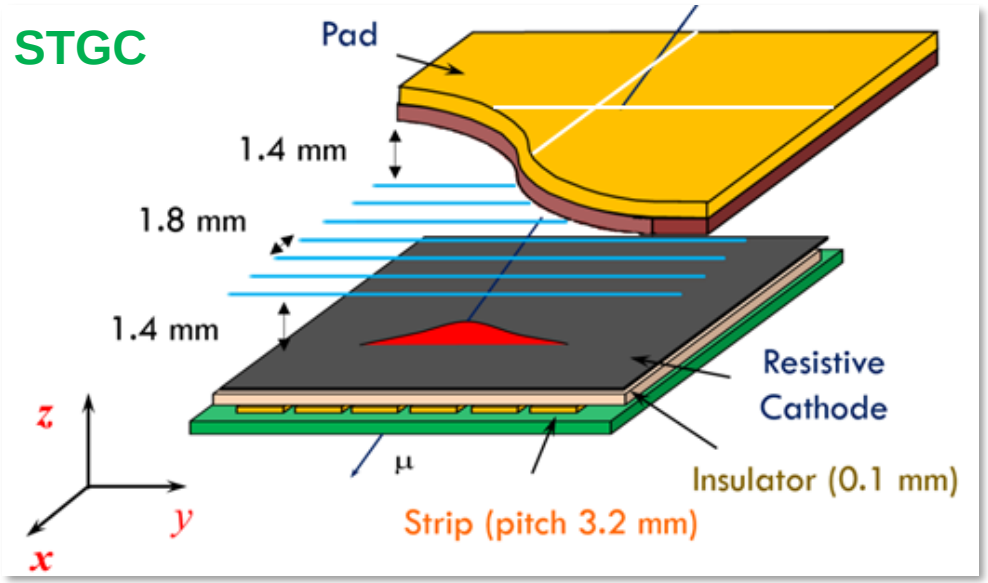
Readout channels (25x replaced system):

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

Detector area: ~2400m^2

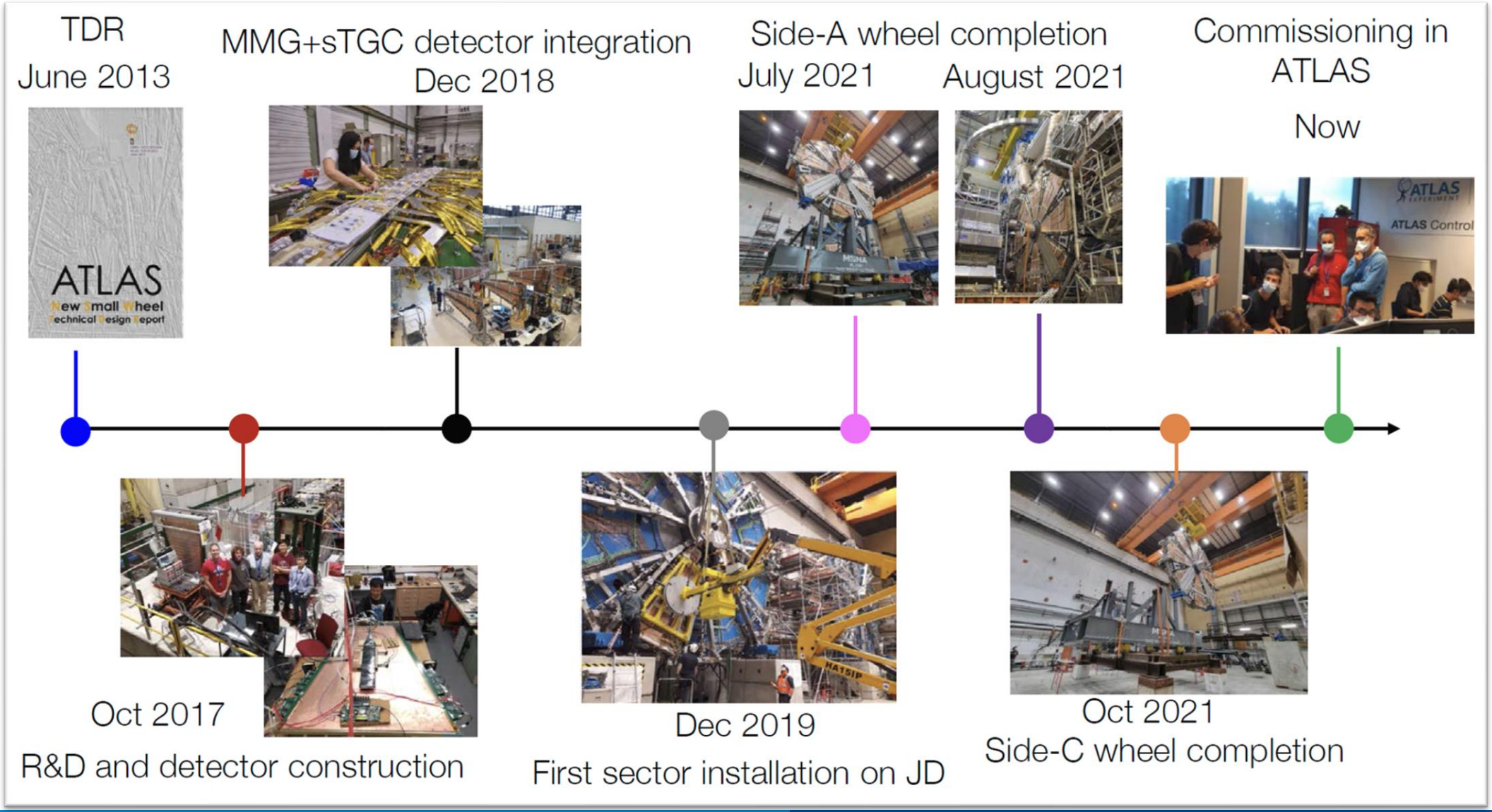
First time construction of large area MPGDs





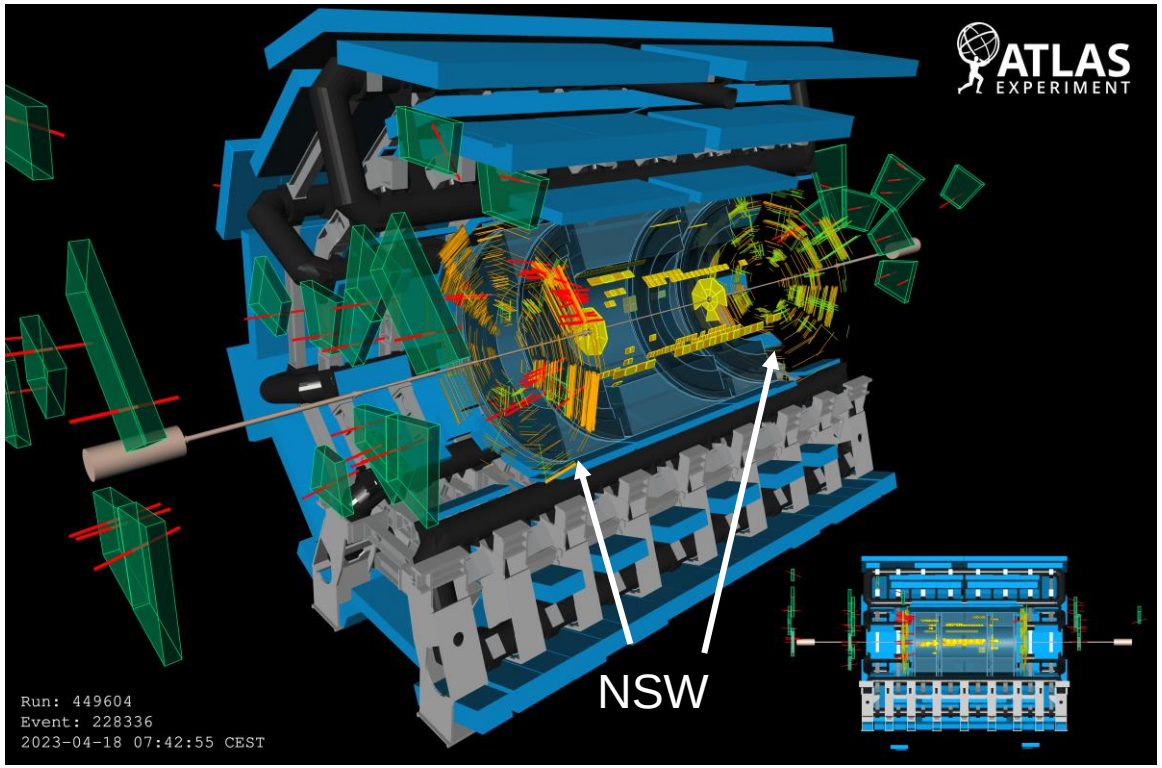
NSW Timeline:

It will contribute to NEW precision and NEW physics in coming decades!

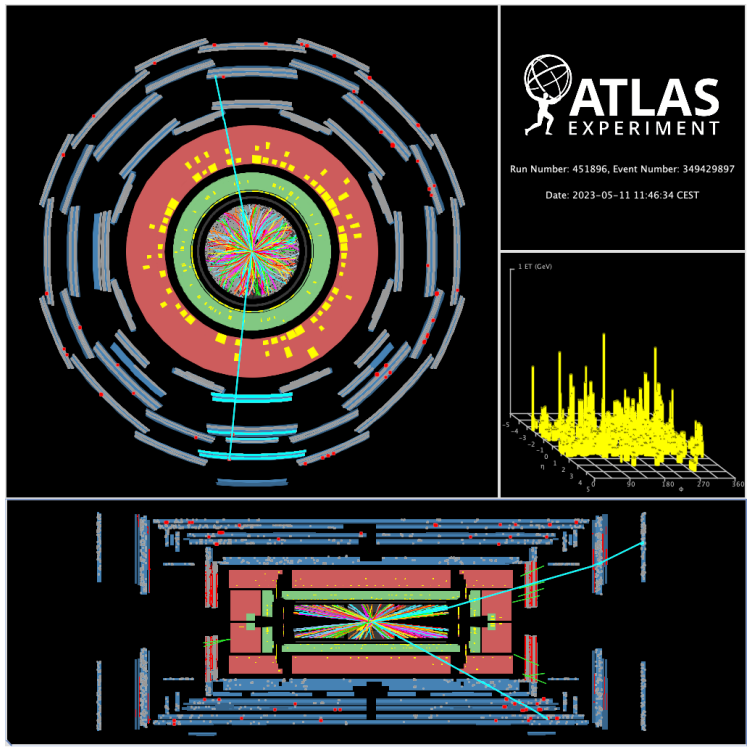


NSW in the ATLAS detecting system

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



Display of di-muon event recorded with NSW segments

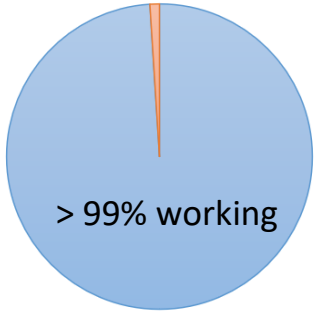


We will now switch to the commission and performance of NSW in Run-3 data

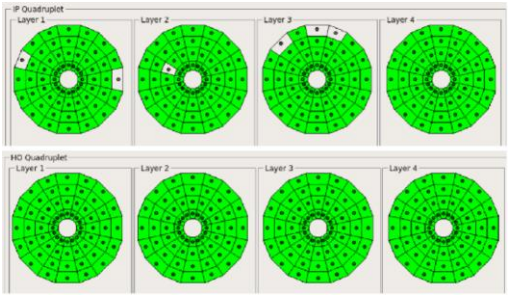
NSW status in Run-3 data taking

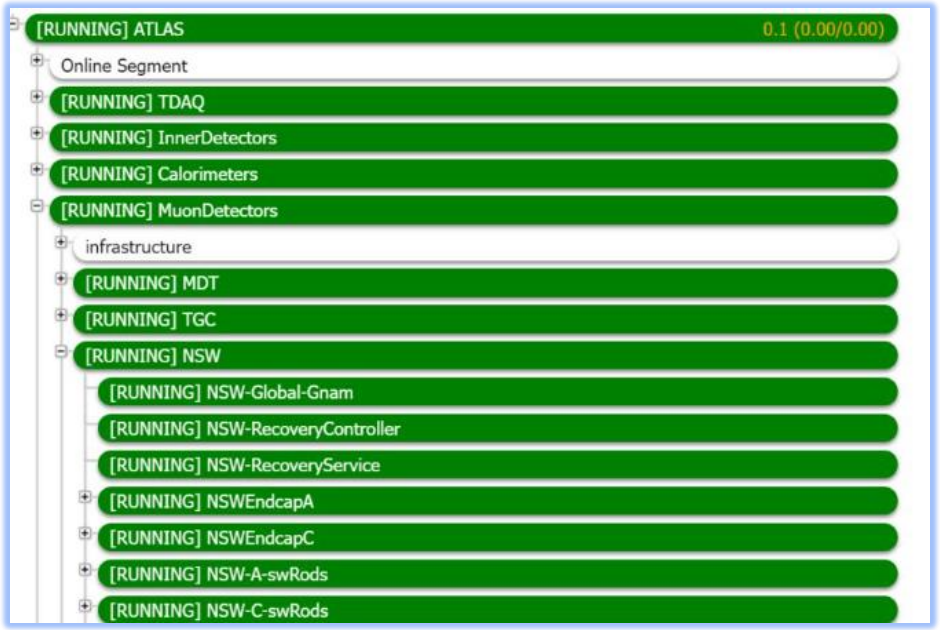
- 99% MMG and 98% STGC HV channels could hold nominal HV with working gas components. MMG Ar:CO2:iC_4H_{10} (93:5:2); sTGC CO_2:n-pentane (55:45).
- Cooling, HV and LV are operational with DCS (Detector Control System)
- Both NSWs are interfaced in ATLAS DAQ for data-taking

MMG HV general status

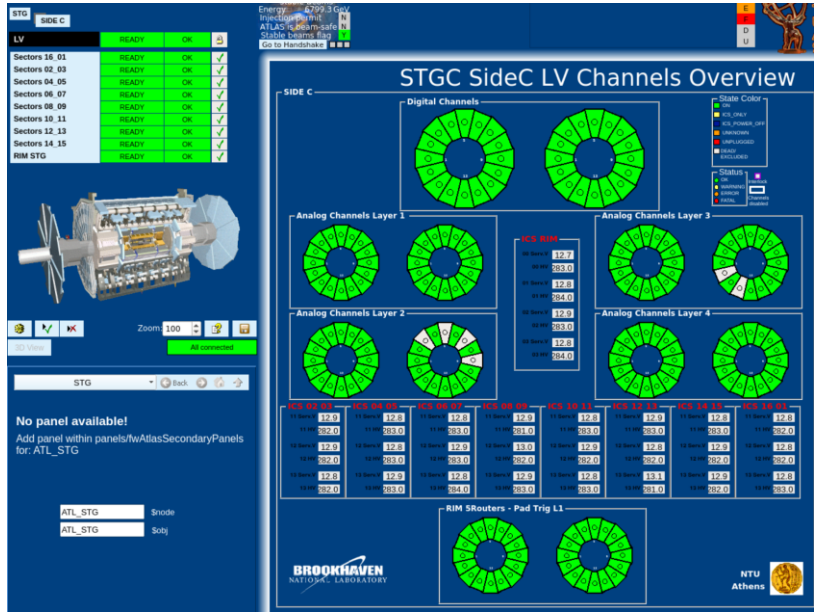


STGC HV Status side C





Inclusion of NSW DCS in the ATLAS DCS main panel

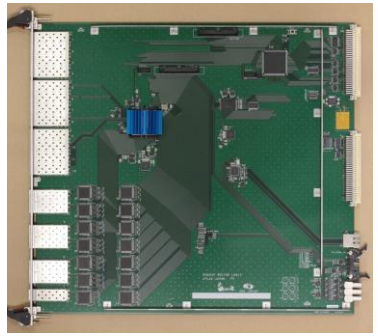


Control and Monitoring for:

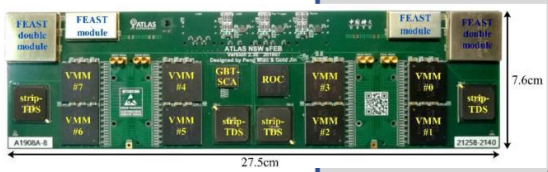
- Detector HV
- Electronics LV
- T-sensor B-sensor
- Cooling, Gas
- …

NSW Electronics

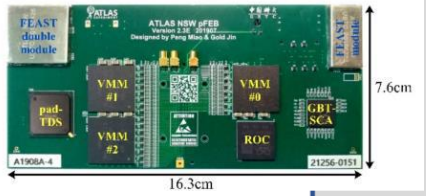
Sector Logic Board



Strip FEB

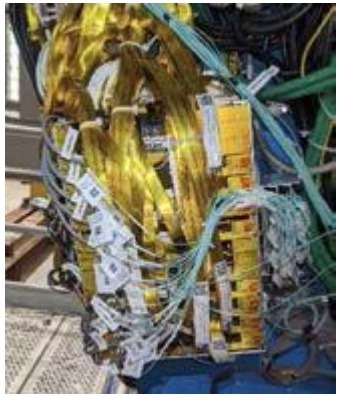


Pad FEB



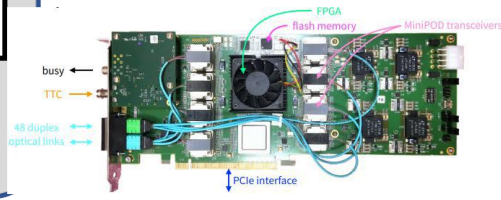
Complexity: 55k ASICs + 5k Front-end cards!

Rim Electronics



Pad Trigger Board

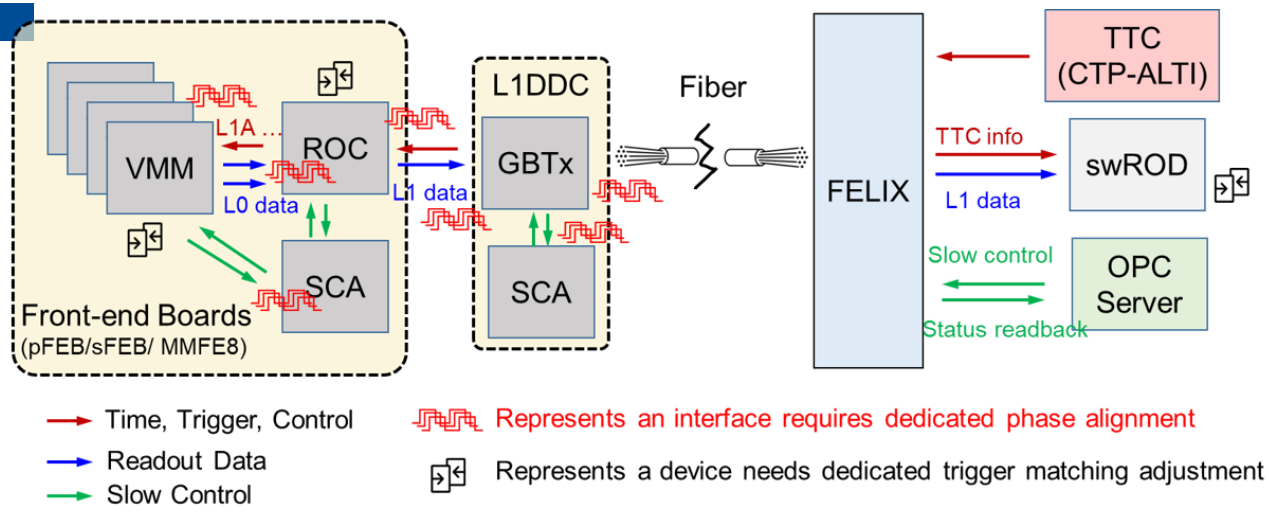
Felix Card



NSW DAQ commission and calibrations:

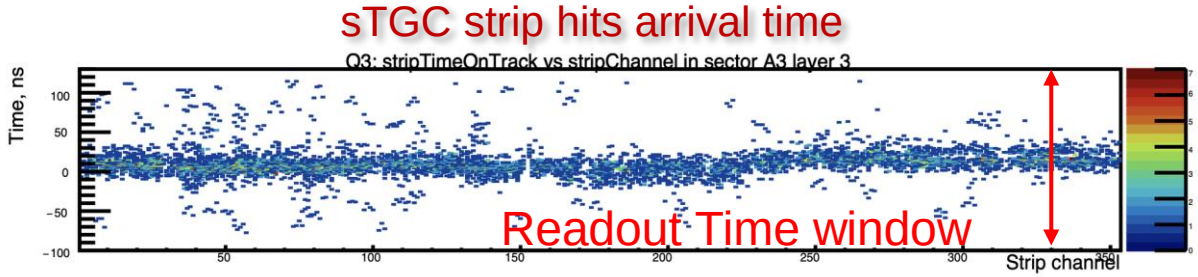
NSW uses more than 50k radiation-tolerant Front-end ASICs with 70+ million configuration registers! Calibrations are complicated and vital (backup)

- 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 sTGC trigger purposes
- GBTx: elink 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



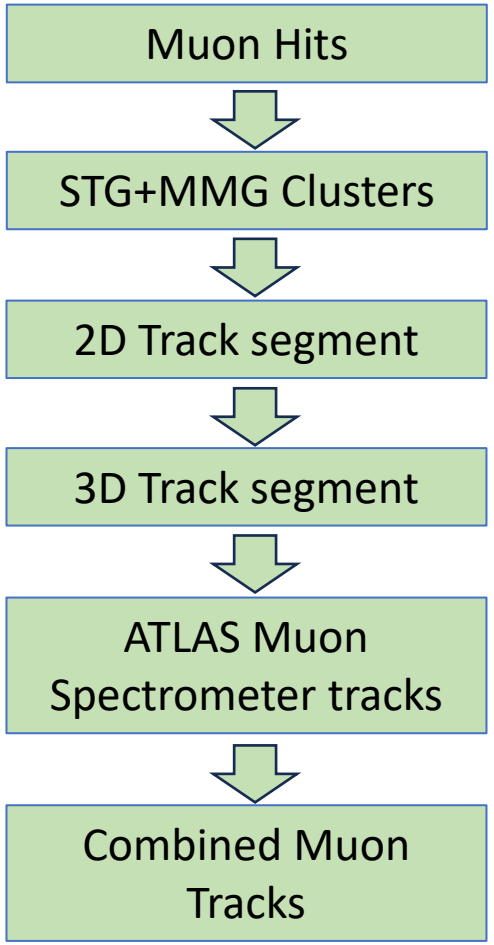
Additional calibrations:

- PDO (Peak Detector Output) for cluster reconstruction
- Timing window latency
- TDO (Time Detector Output)



Muon Reconstruction with NSW

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

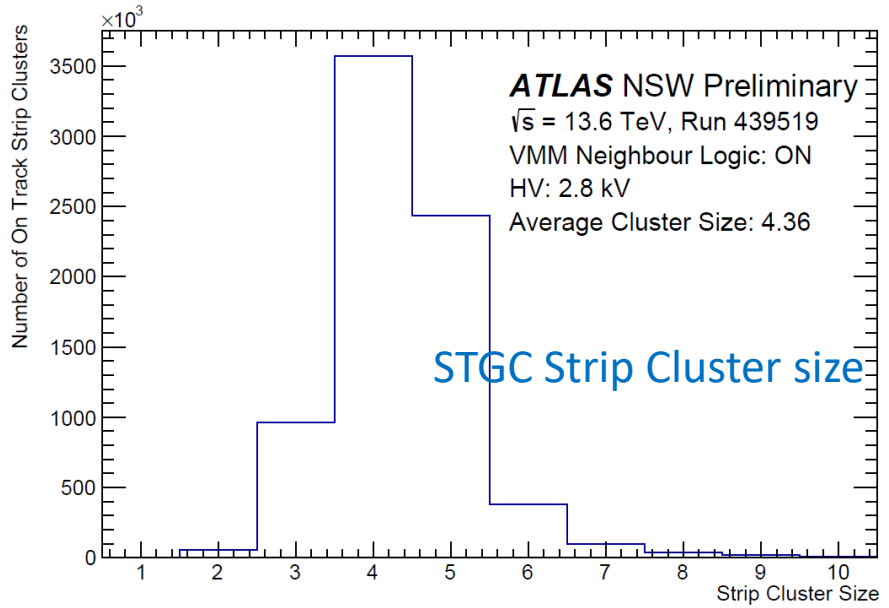


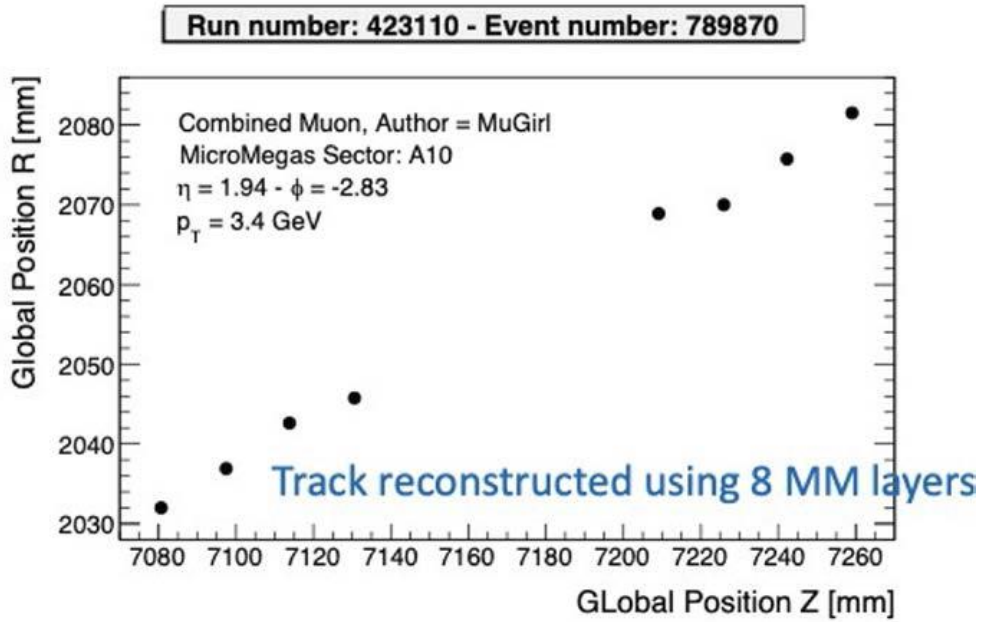
Clusterization of Hits above threshold

Parttern finding and Transverse coordinate seeded

Combine NSW segments with other muon subsystems

Combine with track segment in ATLAS inner detector



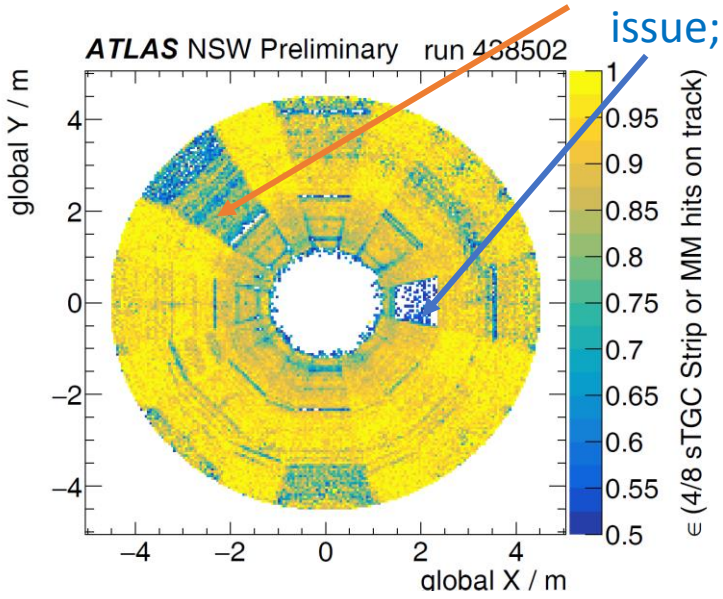


NSW preliminary performance in Run-3 data

The inclusion of NSW in Run-3 demanded unbelievable expertise and efforts; the commission demands further long-term commitment and the understanding is developing.

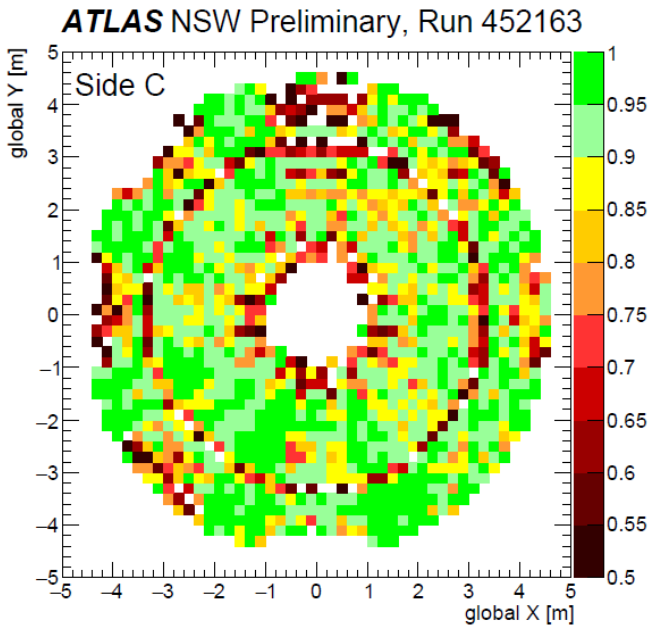
Various performances in early Run3 (2022) will be illustrated first, many have been significantly improved during Year-End Technical Stops (YETS).

In-situ detector/DAQ issue; fixed in YETS



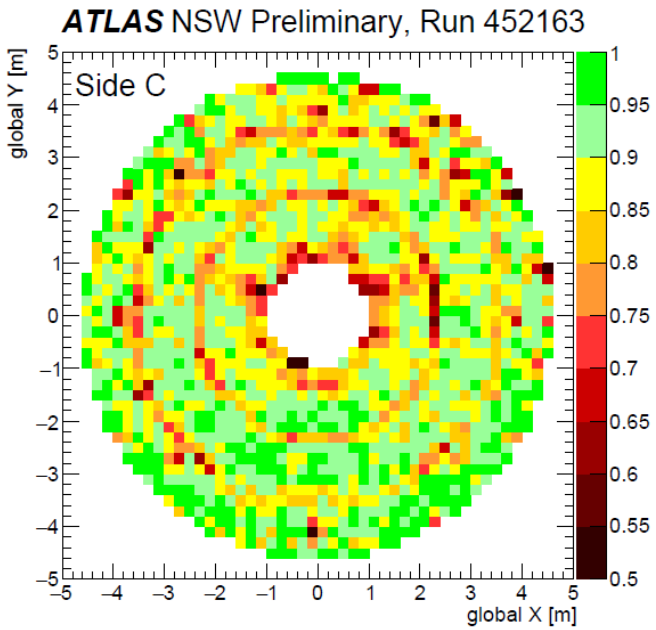
MMG+ STG in 2022

MMG in 2023



+

STG in 2023



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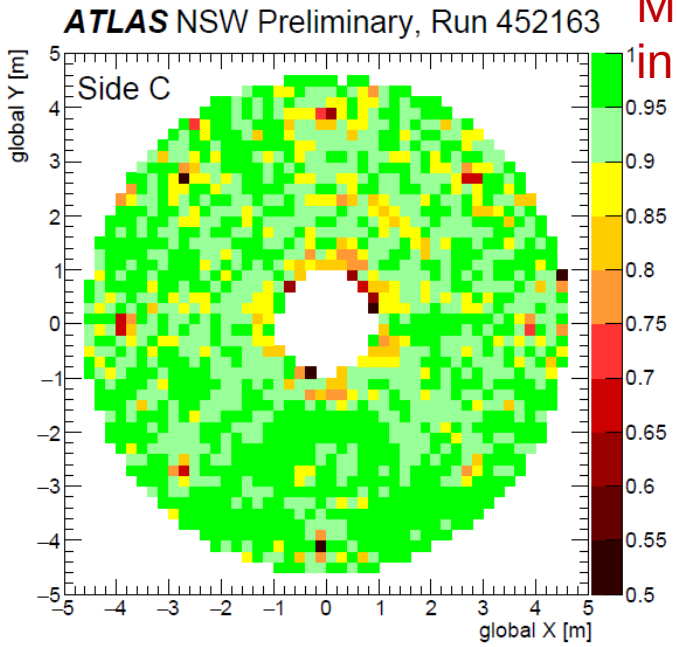
MMG+ STG in 2023

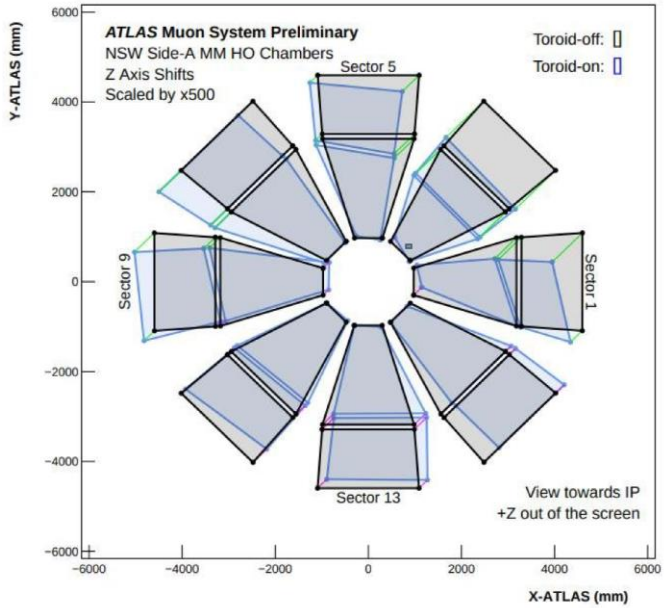


Alignment & Resolution

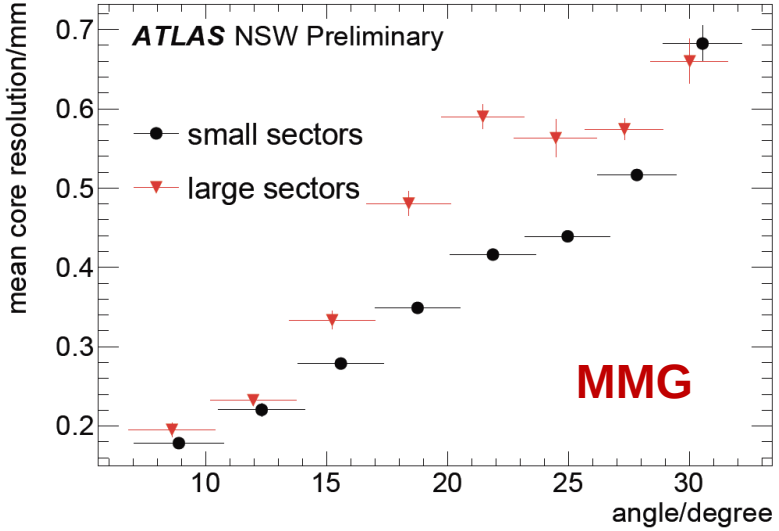
An optical based alignment system installed and commissioned for tracking the movement, deformation of the NSW detectors.

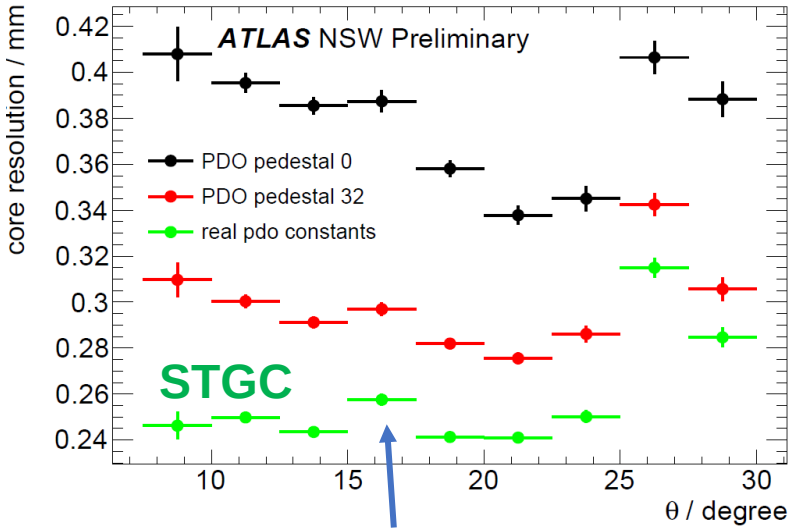
Detailed studies are continuous to understand the detector movement and NSW alignment performance with offline tracks, benefiting from dedicated Toroid-ff Alignment Runs

NSW MMG Z shifts by the alignment system



Preliminary resolution performance





Charge calibration

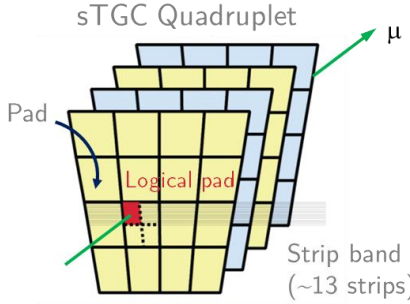
spoiled by effects from the residual misalignments and the as-built geometry that are currently under study

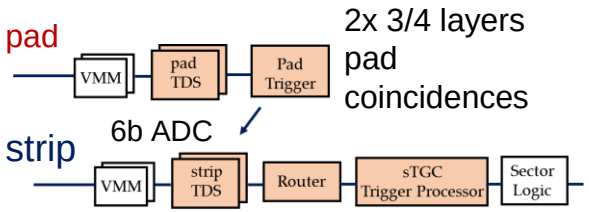
Absence of corrections degraded the resolution (worse with higher angles).

Optimized and closer to target resolution in data taking 2023.

NSW and Level-1 trigger:

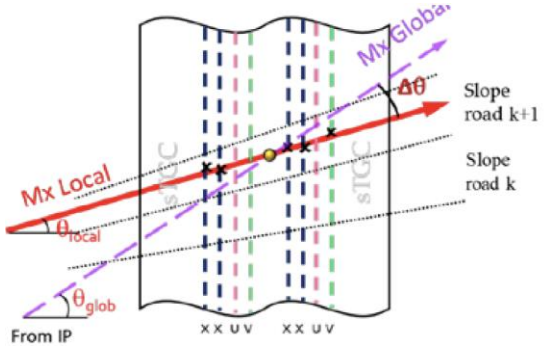
sTGC in Level-1 Trigger: pad coincidences to define a smaller region of interest and select fast charge information from a band of strips for centroid reconstruction.

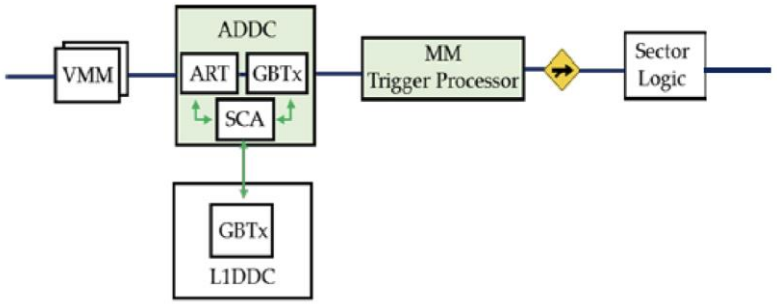




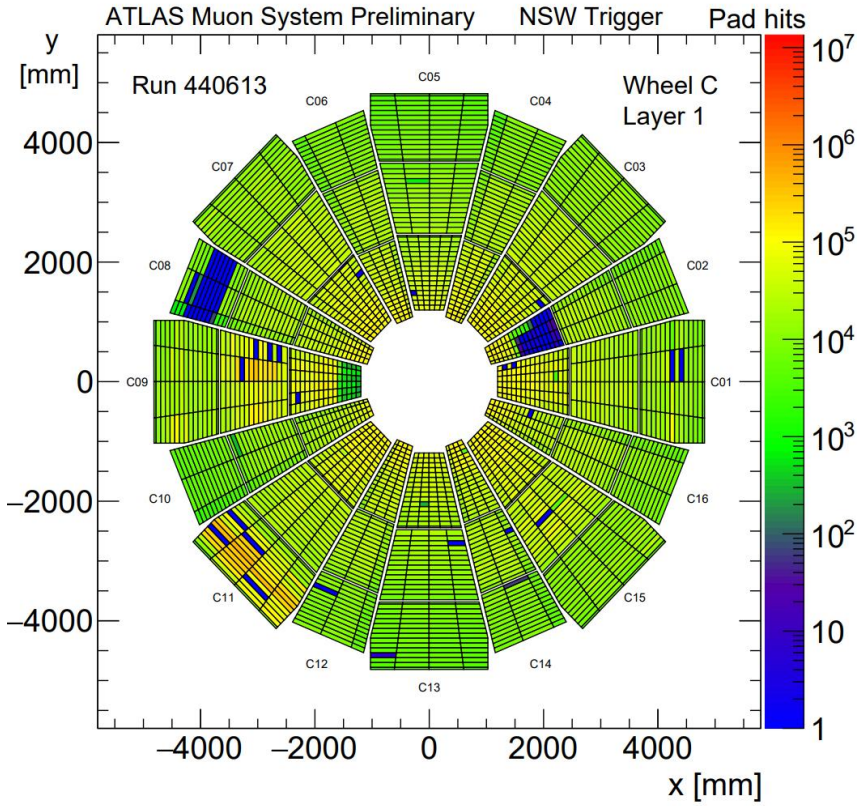
TDS: trigger data serialize ASIC for trigger data preparation, strip-pad match

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





Pad trigger occupancy



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.

Summary

The performance has been significantly upgraded during YETS based on the experience of data 2022.

The New Small Wheel upgrade:

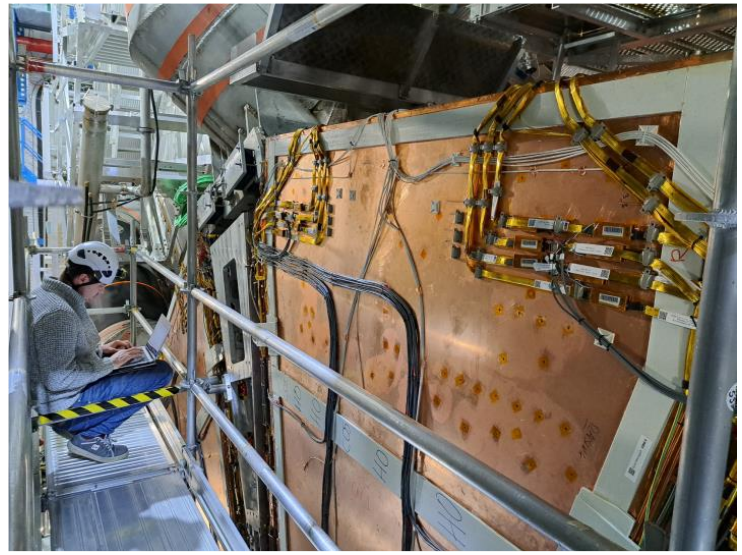
- largest ATLAS phase-I upgrade project.
- Improving the Level-1 muon trigger and tracking in the ATLAS forward region towards HL-LHC runs.

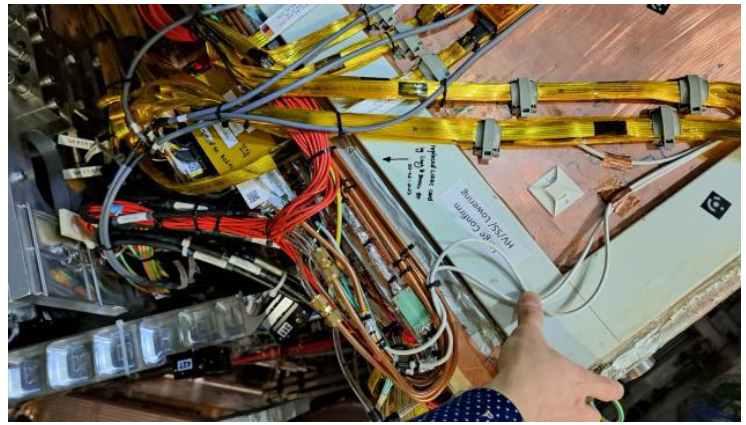
NSW with two innovative sub-detectors, Micromegas (MMG) and small-strip Thin Gap Chambers (STGC)

- fully commissioned and installed in the ATLAS cavern: Milestone for ATLAS during LHC Long Shutdown 2.

NSW joined the ATLAS Run-3 data taking in the very first day with solid performance during months of data taking!

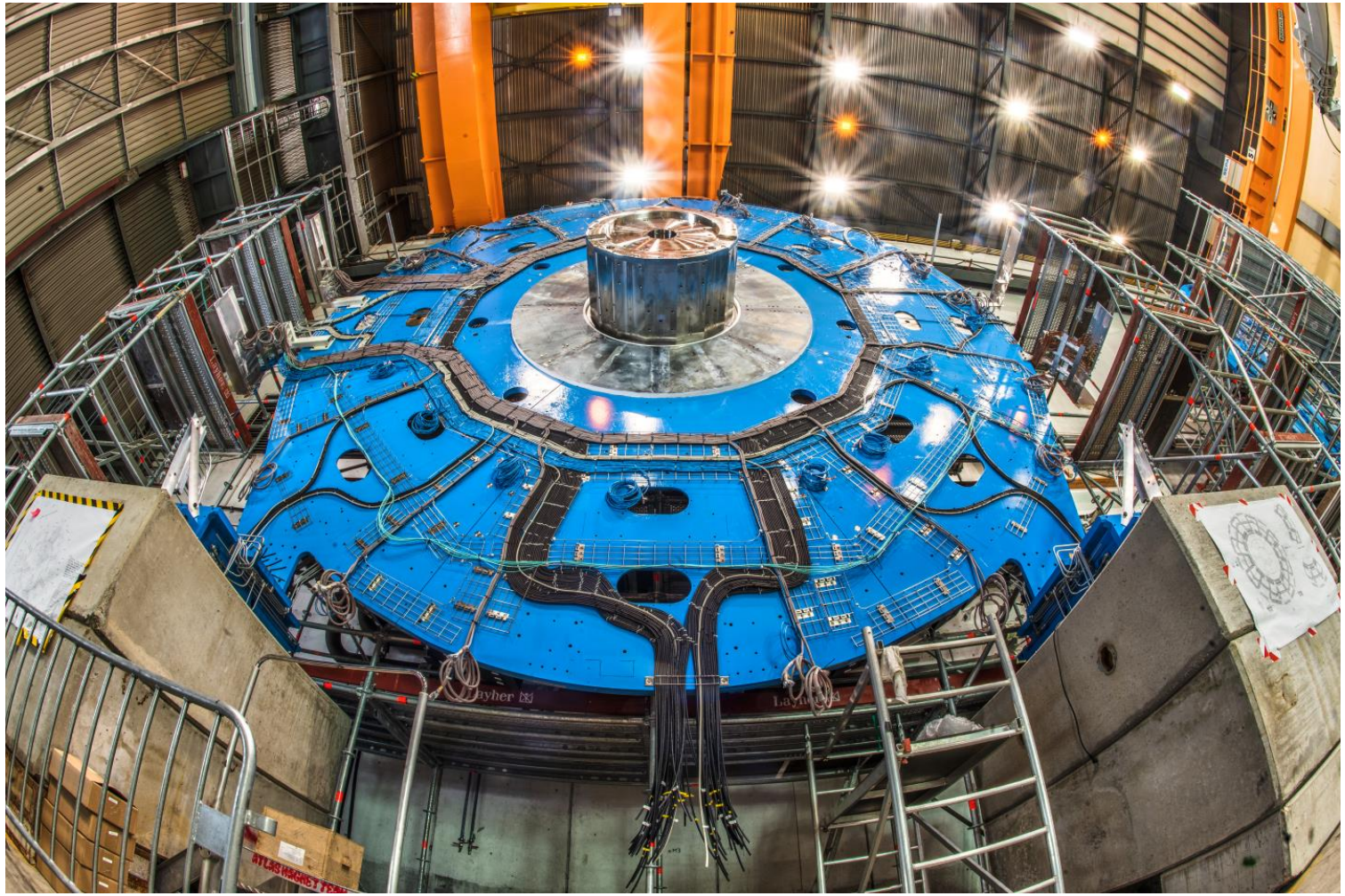
- Already significantly improved the end-cap L1 trigger in recent runs.

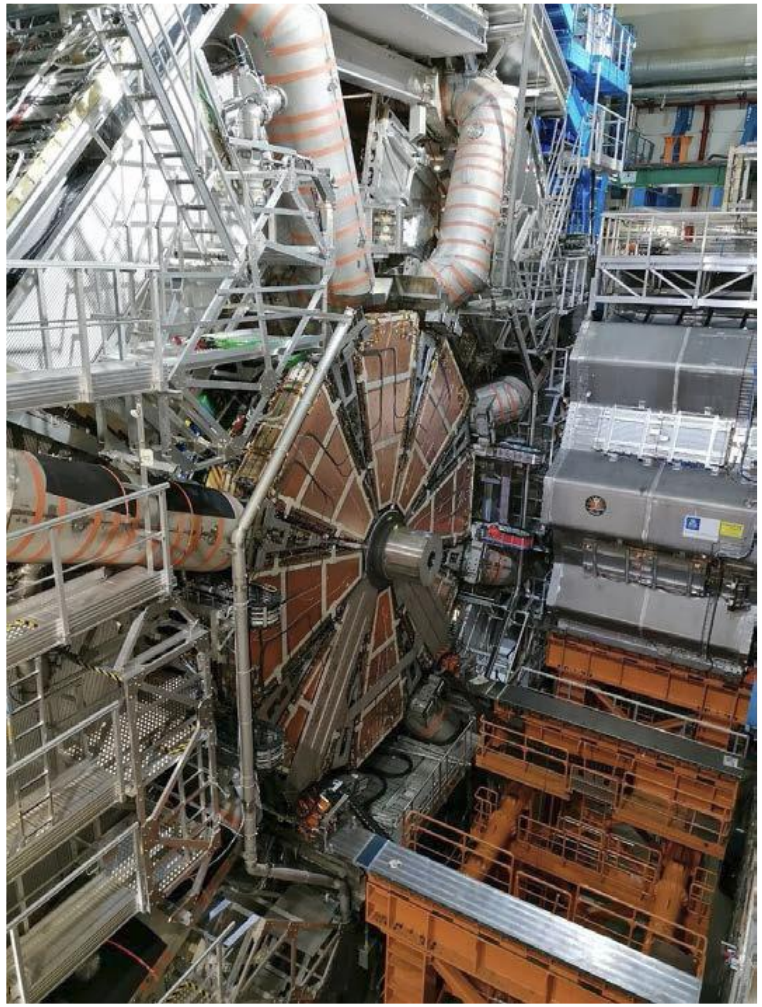




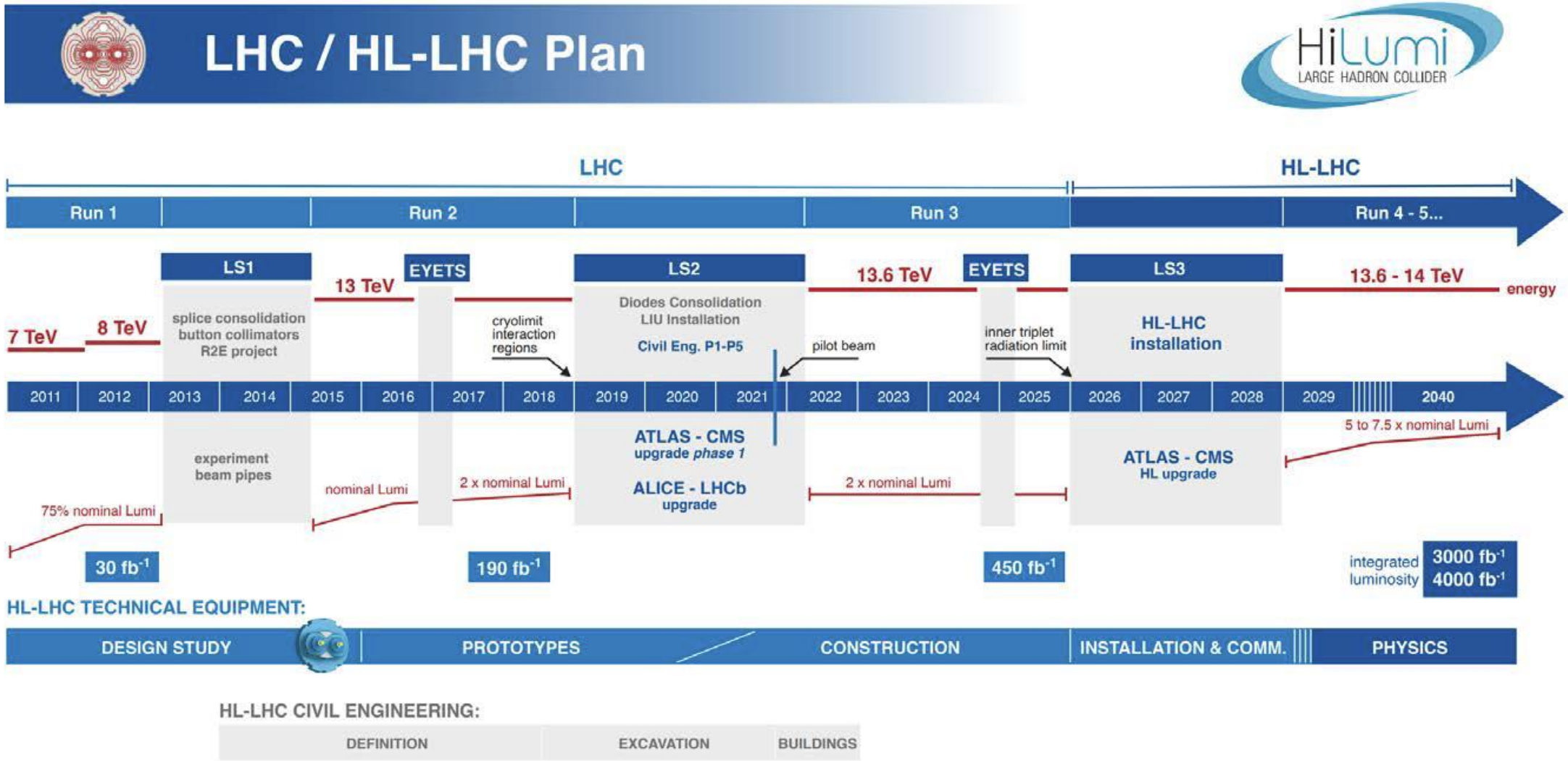
Challenges and opportunities ahead with more data and higher quality !

Backup

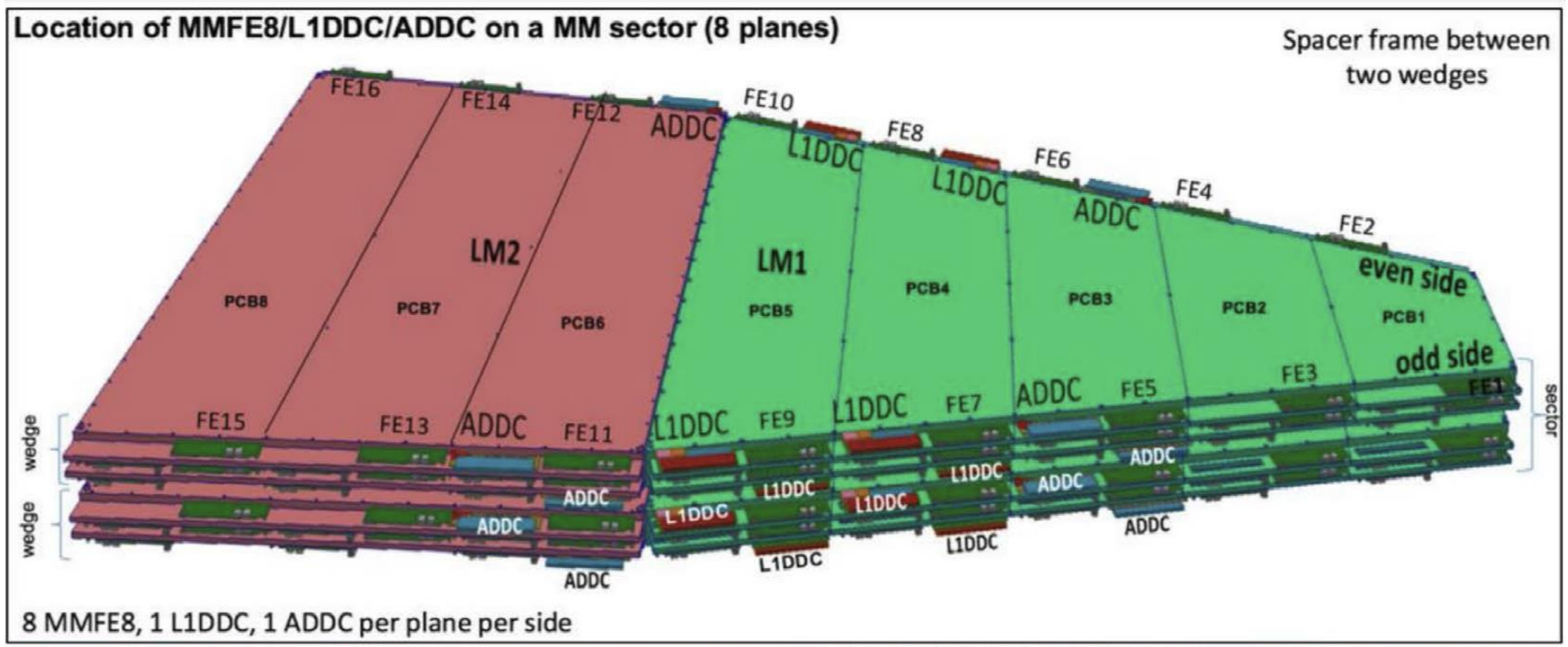




Backup

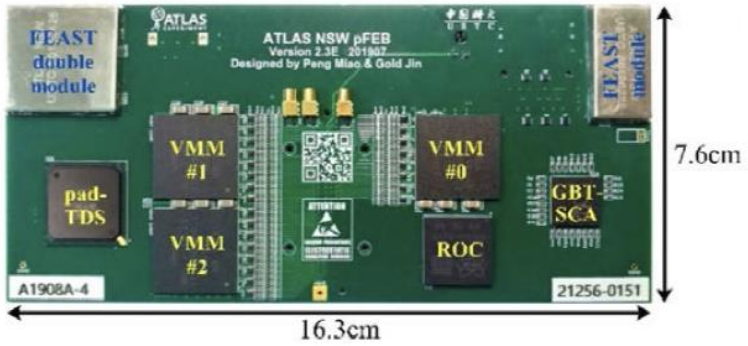

LHC / HL-LHC Plan
HiLumi
LARGE HADRON COLLIDER
LHC
HL-LHC
Run 1
Run 2
Run 3
Run 4 - 5...
LS1
EYETS
LS2
EYETS
LS3
7 TeV
8 TeV
13 TeV
13.6 TeV
13.6 - 14 TeV
energy
splice consolidation
button collimators
R2E project
cryolimit
interaction
regions
Diodes Consolidation
LIU Installation
Civil Eng. P1-P5
pilot beam
inner triplet
radiation limit
HL-LHC
installation
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2040
5 to 7.5 x nominal Lumi
experiment
beam pipes
ATLAS - CMS
upgrade phase 1
ALICE - LHCb
upgrade
ATLAS - CMS
HL upgrade
75% nominal Lumi
nominal Lumi
2 x nominal Lumi
2 x nominal Lumi
30 fb-1
190 fb-1
450 fb-1
integrated
luminosity
3000 fb-1
4000 fb-1
HL-LHC TECHNICAL EQUIPMENT:
DESIGN STUDY
PROTOTYPES
CONSTRUCTION
INSTALLATION & COMM.
PHYSICS
HL-LHC CIVIL ENGINEERING:
DEFINITION
EXCAVATION
BUILDINGS

Backup: MMG electronics

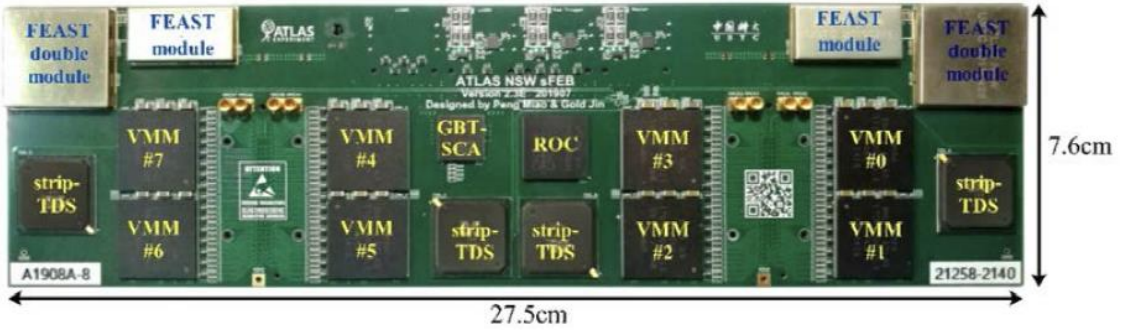


Backup: STGC electronics

pFEB



sFEB



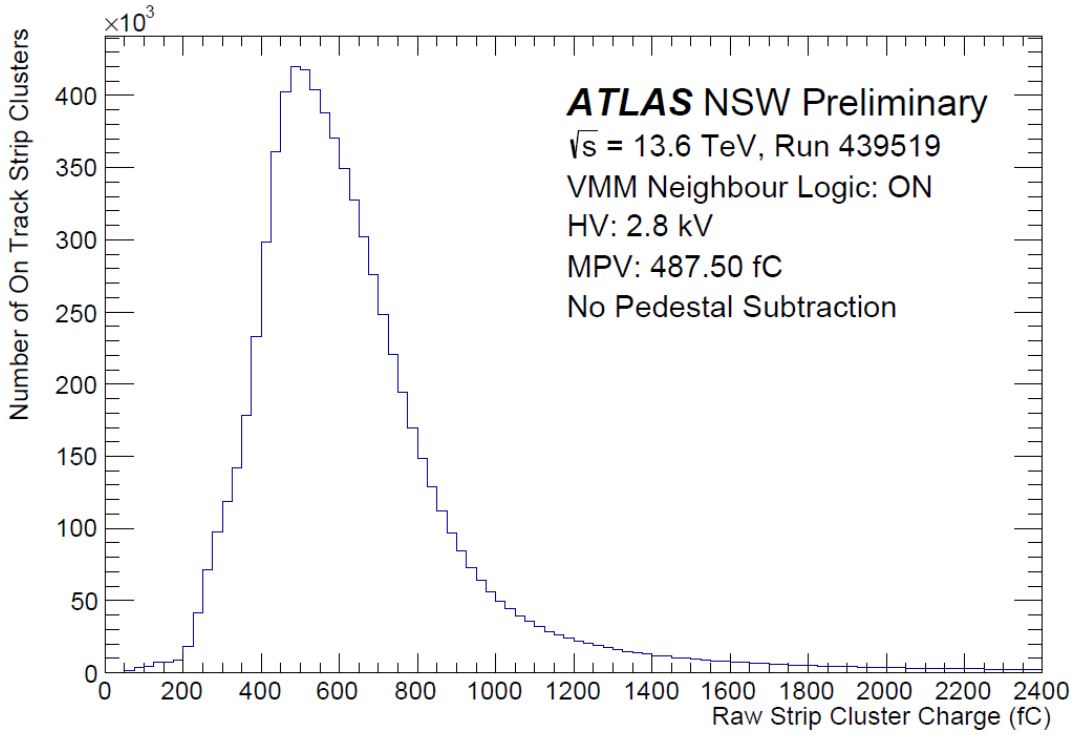
Pad Trigger Board

Rim L1DDC

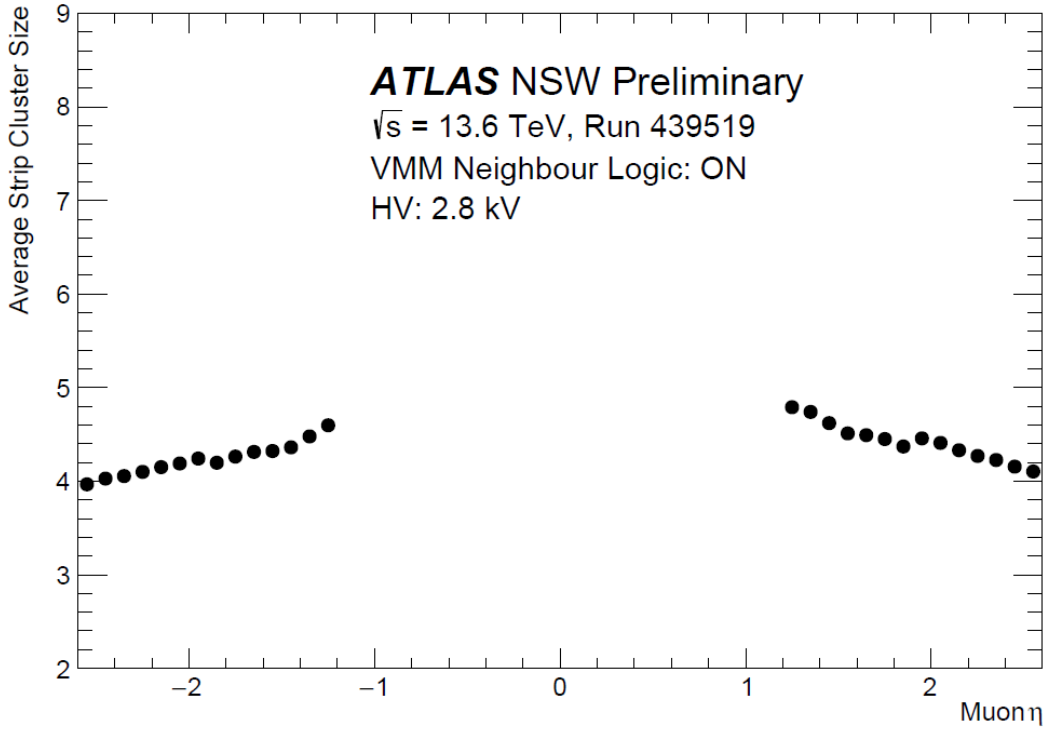
8x Router

Backup: sTGC performance

Raw sTGC Strip Cluster Charge

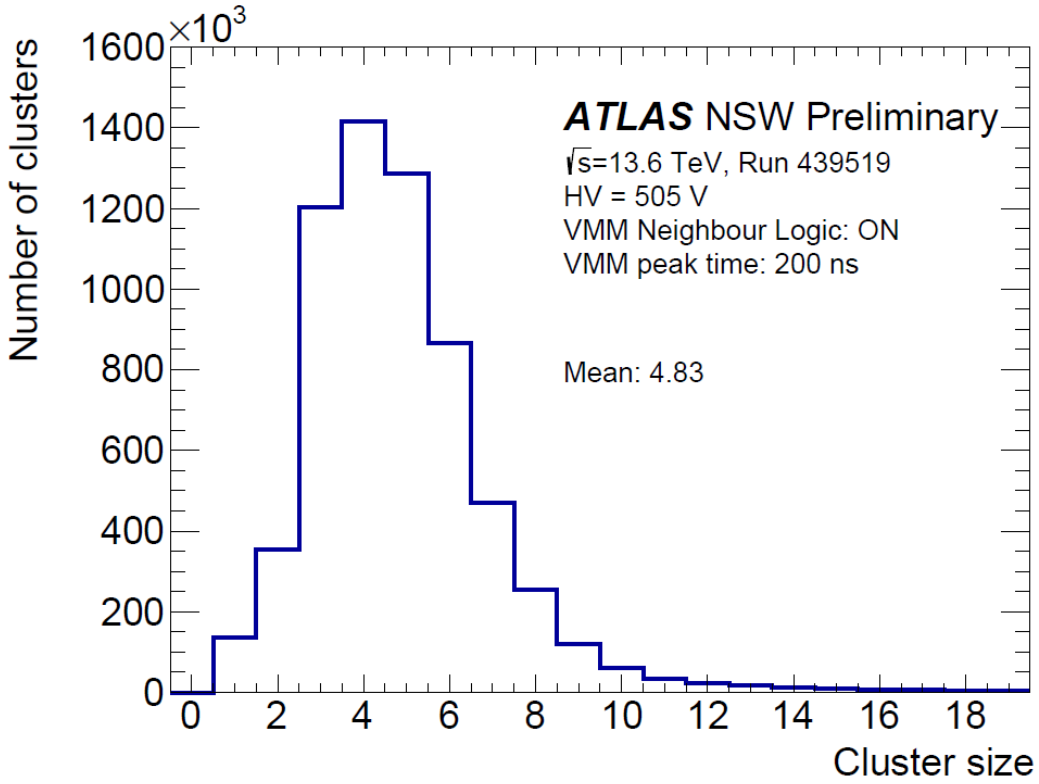


sTGC Strip Cluster Size vs muon η

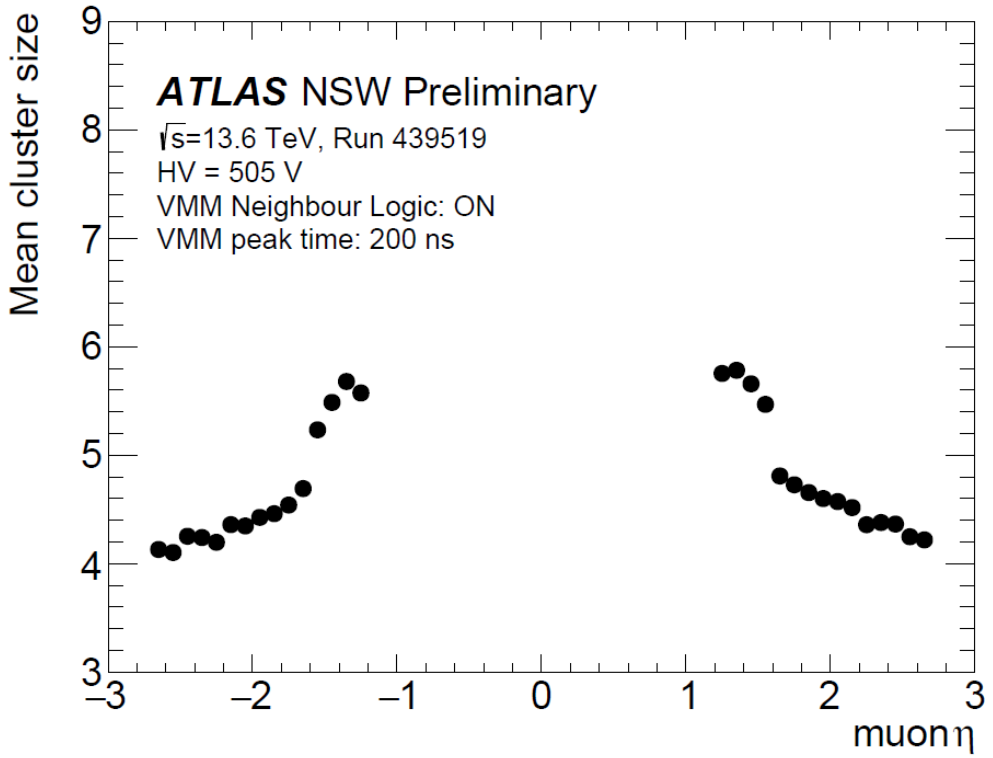


Backup: MMG performance

MM Cluster Size



MM Cluster Size vs muon η



NSW preliminary performance in 2022 data