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

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Outline

• General Introduction to New Small Wheel
• Detector and electronics
• Integration and commission
• Muon reconstruction
• Performance of NSW in the early data taking
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 Endcap with high background rates (up to 20 kHz/cm²) towards HL-LHC
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.

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)
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: ~2400m²
NSW Timeline:

- **TDR June 2013**
- **MMG+sTGC detector integration Dec 2018**
- **Side-A wheel completion July 2021 August 2021**
- **Commissioning in ATLAS Now**
- **Oct 2017 R&D and detector construction**
- **Dec 2019 First sector installation on JD**
- **Oct 2021 Side-C wheel completion**

*It will contribute to NEW precision and NEW physics in coming decades!*
After over ten-year efforts, NSW joined the Run-3 ATLAS data-taking on Jul. 5th of 2022!

We will now switch to the commission and performance of NSW in Run-3 data
99% MMG and 98% STGC HV channels could hold nominal HV with working gas components. MMG Ar:CO\textsubscript{2}:iC\textsubscript{4}H\textsubscript{10} (93:5:2); STGC CO\textsubscript{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

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 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).

- **Muon Hits**
  - Clusterization of Hits above threshold

- **STG+MMG Clusters**
  - Parttern finding and Transverse coordinate seeded

- **2D Track segment**

- **3D Track segment**

- **ATLAS Muon Spectrometer tracks**
  - Combine NSW segments with other muon subsystems

- **Combined Muon Tracks**
  - Combine with track segment in ATLAS inner detector

**Graphs:**
- **STGC Strip Cluster size**
- **Track reconstructed using 8 MM layers**
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).

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**MMG in 2023**

**STG in 2023**

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**MMG+ STG in 2022**

**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

Preliminary resolution performance

NSW MMG Z shifts by the alignment system

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.

Charge calibration
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.

**MMG** in Level-1 Trigger: 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.
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.

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

Challenges and opportunities ahead with more data and higher quality!
Backup
Backup: MMG electronics
Backup: STGC electronics
Backup: sTGC performance

Raw sTGC Strip Cluster Charge

- ATLAS NSW Preliminary
- $\sqrt{s} = 13.6$ TeV, Run 439519
- VMM Neighbour Logic: ON
- HV: 2.8 kV
- MPV: 487.50 fC
- No Pedestal Subtraction

sTGC Strip Cluster Size vs muon $\eta$

- ATLAS NSW Preliminary
- $\sqrt{s} = 13.6$ TeV, Run 439519
- VMM Neighbour Logic: ON
- HV: 2.8 kV
Backup: MMG performance

MM Cluster Size

ATLAS NSW Preliminary
\( \sqrt{s}=13.6 \text{ TeV}, \text{ Run 439519} \)
HV = 505 V
VMM Neighbour Logic: ON
VMM peak time: 200 ns

Mean: 4.83

MM Cluster Size vs muon \( \eta \)

ATLAS NSW Preliminary
\( \sqrt{s}=13.6 \text{ TeV}, \text{ Run 439519} \)
HV = 505 V
VMM Neighbour Logic: ON
VMM peak time: 200 ns
NSW preliminary performance in 2022 data

**sTGC Strip Cluster Charge vs muon \( \eta \)**

- **ATLAS NSW Preliminary**
  - \( \sqrt{s} = 13.6 \text{ TeV}, \) Run 439519
  - VMM Neighbour Logic: ON
  - HV: 2.8 kV
  - No Pedestal Subtraction

**Proportional to track path**

**MM Efficiency curve vs HV**

- **ATLAS NSW Preliminary**
  - \( \sqrt{s} = 13.6 \text{ TeV} \)
  - Run numbers: 437896, 437895
  - VMM Neighbour Logic ON
  - VMM peak time 200 ns

Q3, Q2, Q1