The NSW project for the Phase I upgrade of the ATLAS Muon Spectrometer (focusing on Micromegas)

HEP 2021
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- Introduction
- MM Chamber construction and quality control on production sites
- MM Assembly, integration, installation
- MM Quality assurance and commissioning
I. Mesolongitis, S. Maltezos  Design of a Differential Safety Mechanism (DSM) Dedicated to the NSW Micromegas Wedges

T. Geralis  Research activities of the ATLAS NCSR Demokritos group

A. Kourkoumeli-Charalampidi,  Surface commissioning of the Micromegas detectors for the muon spectrometer NSW of the ATLAS experiment

S. Maltezos, Methods used for Gas Tightness Test and percent Oxygen Monitoring of the NSW Micromegas Detectors of LHC-ATLAS Experiment

I.M. Maniatis, Construction and operation of large scale Micromegas detectors for the ATLAS Muon upgrade

M. Perganti, Performance of the final New Small Wheel Micromegas sectors for the ATLAS Muon Upgrade

O. Zorba, ATLAS NSW Upgrade – sTGC Trigger and Commissioning

F. Trantou, A program to drive the ATLAS Local Trigger Interface (ALTI) at the ATLAS experiment

P. Tzanis, The Detector Control System of the New Small Wheel for the ATLAS experiment

S. Tzanos, The Detector Control System for the magnetic field sensors of the sTGC detector in New Small Wheel Phase I upgrade of ATLAS detector

I. Drivas-Koulouris, Implementation of the DCS System for the validation of MM HV Boards and the DCS System of the new BIS78 Chambers for the upgrade of muon system of the ATLAS Experiment

M. M. Prapa, The Fake Sector Logic for the ATLAS Muon Trigger system
Introduction: The New Small Wheel

Current Small Wheel → CSC, MDT (tracking), TGC (trigger)

NSW →

Micromesh Gaseous Structure (Micromegas) primarily tracking

Small strip Thin Gap Chambers (sTGC) primarily trigger

- Main ATLAS very challenging upgrade during the Long Shutdown 2 (Phase-I)
- Designed to operate also at HL-LHC luminosity \( \geq 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)
- Angular coverage: \( 1.3 < |\eta| < 2.7 \)
- 10 meter diameter - Located at \( z \) 7m from IP
Introduction: NSW motivation

**Current Small Wheel**
- Single muon trigger suffers from large amount of fakes
- MDTs loose resolution and efficiency when going significantly beyond original LHC design luminosity
- CSC loose tracking efficiency from limitation of 4 layers

**NSW**
- Reduce substantially single muon trigger fake rate
- Maintain excellent efficiency and resolution of tracking at very high rates
- 16 active layers → redundancy for tracking and pattern recognition

NSW ~2.5million readout-channels ≈ full muon spectrometer
Introduction: NSW layout

- NSWs preserve the geometry and segmentation of present SWs
- 8 Large and 8 Small sectors with Micromegas and sTGC on each side
- Installed on mechanical support which combines the NJD steel disk (shielding, flux return) and aluminum structure (spokes) bolted on it
- Spokes support the detectors and hold the alignment bars
- Installation plan: First the Small sectors - Then the Large sectors
- Each sector consists of 2 sTGC and 2 Micromegas wedges
- The two Micromegas wedges are placed on an aluminum support (spacer frame) to make a double wedge
**Introduction: Micromegas Operational principle**

**Micromegas**

**Operational principle**

**ATLAS Micromegas characteristics**

- **NSW Micromegas are resistive for spark protection.** Cu strips are covered by a Kapton layer with resistive screen pattern (graphite) printed on it. HV is applied on the resistive layer.
- The mesh is integrated in the drift panel structure and not coupled with the pillars
- Strip width 300 μm (pitch 425-450 μm)
- The mesh is at ground potential
- Drift gap (5 mm), $H_{V_{\text{drift}}} = -300 \text{V}$, $E_C = 600 \text{ V/cm}$
- Amplification gap (128 μm), $H_{V_{\text{RO}}} = 570 \text{ V}$, $E_A = 45 \text{ kV/cm}$
- Baseline gas mixture: 93% Ar - 7% CO$_2$
Each Mixcromegas Double Wedge is composed by 2 wedges with 4 layers each
4 η layers for measuring the η coordinate
4 stereo layers with inclined strips (+/-1.5°) to provide 2nd coordinate
Each wedge has 2 modules (quadruplets) 1 & 2

- 128 modules of 4 different types
- Surface /module /layer 2-3 m²
- Total area larger than 1200 m² → The largest Micromegas project
Cathode \textit{(drift)} and anode \textit{(read-out)} planes built on sides of five panels stiffened through the use of honeycomb structures.

Careful QA/QC program implemented to check all parts of production steps.

Work flow:

- Drift panels (bare) → 3x
- Drift panels with mesh → 1x
- Cleaning & Drying
- Quadruplet + HV testing
- Final test (cosmics)
- Ship to CERN

Start to finish for building a module (quadruplet) 10-12 weeks.

All MM modules have been constructed.
• The production and test of **96+9 Drift panels** equipped with mesh sent to Dubna for the chamber assembly (quadruplet)
• New Laboratory for detector construction established (360 m²)
• New Clean Room (145 m², Grade D)
• **Production started July 2017 – ended January 2020**
Chamber production: Quality control

QA/QC per panel and/or quadruplet

- Thickness
- Planarity
- Gas tightness
- Alignment
- HV stability
- Efficiency
- Gain homogeneity

SM1 gas tightness

ATLAS limit

SM1 module thickness (mm)

SM2 Thickness 77.8 ± 0.2 mm

LM1 example of RasFork alignment measurement

LM2 panel to panel rotation

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Chamber production: HV stability

End 2017 → Issues of HV Stability with first production MM NSW Quadruplet
High currents and discharges - concern for possible permanent damages
Jan 2018 → R&D focused on the cause of sparks and possible means of protection

Spark causes
• Residual material humidity
• Residual ionic contamination
• Mesh mechanical imperfections
• Other imperfections

➢ Jan 2019: Evidence of discharge happening close to the boundary of the active area

Spark protection
➢ Act on the resistive layer
➢ Increase HV granularity
➢ Modify gas mixture (under validation)

➢ Detailed quality control of PCBs targeting imperfections
➢ Thorough cleaning/drying of panels prior to assembly
➢ Polishing of mesh
➢ Reduce relative humidity inside chamber ≤ ~15%

Insufficient spark suppression due to low resistivity in localized spots

Passivation of a region along the sides of the PCB through deposit of a thin layer of araldite, in order to increase the minimum resistivity of the active area
Several tests to ensure stability under HV operation

Nominal HV is 570 V (with ArCO$_2$ 93:7 gas)

- **128 HV sections per sector**
- Test are performed by ramping the HV and recording the current & the spark rate
- Modules which presented issues were sent for irradiation scan
- Categorize HV sections on their quality --- Nominal, reduced, disconnected sections
- **Average DW efficiency per layer has to be higher than 85%**
- Finalize the HV configuration and confirm efficiency from cosmic
- Validate HV stability once again at 191 after installation on NSW

- In the initial HV configuration 16 HV positive channels (1/layer/module) and 4 HV channels for hospital lines were designed
- In the final configuration 64 HV channels are used (1/PCB)
**Study of gas to Ar-Co$_2$-isobutane 93:5:2**

**Motivation:** Performance of old (non-passivated) A13 DW (studied at BB5) – Similar behavior was verified with other DWs

**Decision after:** Irradiation of 1-2 chambers @ 5-10 HL-LHC years and 3-4 chambers @ 1 HL-LHC year at GIF++

**Ar:CO$_2$ 93:7 vol%**
nom. HV: 570 V

**Ar:CO$_2$:iC$_4$H$_{10}$ 93:5:2 vol%**
HV: 500 V

- **green:** sector is on nominal HV
- **red:** sector is below nominal HV
- **-2% of CO2**
- **+2% of Isob.**
- **non-burning non-explosive gas-mixture**

**insufficient performance**

**almost perfect performance similar efficiency @ cosmics**

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Integration and commissioning activities are performed at CERN in parallel in two buildings BB5

- Components tests
- Mechanical assembly
- Integration
- Elx test and calibration
- Cosmic rays test

191

- Installation on NSW
- Services connection
- Surface commissioning

Integration and commissioning

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The NSW DAQ architecture lies on the newly introduced readout scheme of ATLAS. It uses the final FELIX based readout system for all the data taking.

Read-out Validation
65536 read out channels / sector

Read out for LHC Run III, detector quality control

Read out for HL-LHC

Trigger path

The data acquisition system is fully functional for the needs of the commissioning.
Integration: Electronic boards

Each Micromegas double-wedge
Has 65536 read out channels
Combines 4 different types of elx boards
- 128 MMFE8 -- MicroMegas Front-End
- 16 L1DDC -- Level-1 Data Driver Card
- 16 ADDC -- Address in Real Time Data Driver Card
- 16 LVDB -- Low Voltage Distribution Board

All the cards are fully tested on the bench before installation on the detector

ADDCs and L1DDCs (for both MM and sTGCs) were validated in 2019 by NTUA, NCUA, Univ. of WA and NCSR Demokritos teams
Alignment of MMFE8 channels with the strips of the detector proved to be another great challenge

Combination of the quality of:
• Chamber alignment pins
• PCBs
• MMFE8 alignment sockets
• Zebra connectors

Even after the development of the MCAT special tool it requires on average 3-4 days for 2 persons
1st Sector Installation

Grabbing of the sector

Adjusting center of gravity

Moving towards the wheel

Set orientation to 22.5 deg

Installation Fixation on NSW A

Ready for survey

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Services connection and validation

Connections
- Cooling system
- Gas system
- Low voltage cables (40 with 248 pins/sector)
- High voltage cables (8 with 144 pins /sector)
- Read out fibers (48 pairs/sector)
- Temperature sensor cables

Validation
- Survey and alignment
- Cooling system
- Gas tightness measurement
- Monitoring of electronics
- Temperature, current monitoring of LV system
- Read out fibers
- Cable routing and envelop specifications

Water input and output temperatures

Temperatures on detector

Electronic components monitoring
Commissioning of the 1st sector on NSW

- Confirmed the installation procedure
- Confirmed similar electronics performance after the installation
- Confirmed similar HV operational behavior
- Finalized the steps of the commissioning
- Optimized several preparatory details
- Improved software for the data analysis
- Gained confidence that certain issues can be treaded after installation
Commissioning of the 1\textsuperscript{st} sector on NSW

- Confirmed the installation procedure
- Confirmed similar electronics performance after the installation
- Confirmed similar HV operational behavior
- Finalized the steps of the commissioning
- Optimized several preparatory details
- Improved software for the data analysis
- Gained confidence that certain issues can be trenched after installation

However, at the time:

- Not the final LV power supply (ICS not available)
- Not the final LV cables routing

Comparison at integration and after installation
Commissioning of 2 first sectors on NSW

An unexpected challenge

1) With the final LV power supplies and the final cable routing →
The noise levels have increased a lot in specific areas

Multi-parametric problem:
- Grounding scheme LV PS
- Grounding scheme detector
- Ground loops with sTGC
- ICS Power supply
- NGPS and controller
- Cable shielding
- Cable routing
- Emitted noise
- Elec. contacts through mount points
- Other effects

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Increased noise levels - Challenge and solutions
Huge amount of efforts to scrutinize every aspect of the issue

- Insufficient shielding of the feasts of ADDCs → Induced noise on surrounding MMFE8s → Faraday cage around ADDCs
- Improve Digital ground on DWs
- Improve cable shielding
- Reinforce ground connections on DWs with extra clamps
- Improve noise filtering of ICS by introducing additional filter capacitors

Refurbishment of all side A DWs
Baselines are studied in order to

- Identify and correct misalignment between chamber and board strips causing sorts between neighboring channels (making them unusable)
- Check for noisy or dead channels
- Baselines are measured again at 191 after installation to ensure that no one board or connector was moved and evaluate the noise conditions on NSW
- Estimate the dead and noisy channels

For every channel a different threshold is set

- VMM is the first level readout having 64 channels
- Each VMM has a slightly different response
- For each VMM a global threshold is set
- Then for each channel the threshold can be further calibrated up to 30 ADC counts (trimming)
- 3 sets of thresholds of different tightness are produced
Commissioning: Different sets of data taking

Different kind of data taking runs are performed
- Noise runs — varying thresholds, trigger frequency
- Pulse runs — varying pulse height, channels
- Cosmic runs — varying thresholds
- Runs to validate the trigger path

In order to
- Identify dead-noisy channels
- Check electronics response
- Check detector performance

Occupancy - noise run

Occupancy - pulse run

Efficiency map from cosmic run

Swapped twinax cables at L1DDC

Section at lower HV

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Double wedge Assembly and integration at BB5

S. Kompogiannis  
Muon Week 3/6/2021

- 2 integration tables Large DWs
- 5 rotation stations in use
- All SFs are finished
- All but 2 DWs of side C are left for mechanical assembly
- All but 3 DWs of side C are left for service completion

T. Alexopoulos  
Muon Week 3/6/2021

- 3 rotation stations in use for elx integration and validation
- 6 SS and 1 LS of side C have been validated
- End of integration of all side C sectors by August 2021
A. Kourkoumeli-Charalampidi
Muon Week 3/6/2021

• Last large sector installed on May 28th
  Despite noise issues that delayed commissioning
• All SS side A have been commissioned
• 5 LS side A have been commissioned
• Commissioning preparation has started on side C
• Side A will be fully commissioned in two weeks
Commissioning at P1

K. Ntekas
Muon Week 1/6/2021

• NSW-A expected to be installed in the cavern mid of July
• All the equipment needs to be configured, tested and commissioned before connecting to the detector
• Only production software and tools should be used at P1
• New DCS architecture and its integration with the muon DCS has been finalized
• **NSW A will be commissioned at P1 in parallel with NSW C at 191**
• Byte-stream to RDO conversion (both MM and sTGC)
• Mapping between online and offline IDs
• **Common tool to be used by DAQ and Athena is implemented**
• Include passivation in digitization and reconstruction
• Preliminary implementation of passivation already in Athena
ATLAS NSW is (a) the largest ATLAS phase I upgrade and (b) the larger Micromegas project curried out so far.

In the last three years huge effort has been set to understand and overcome a variety of challenges.

Passivation, increase of HV granularity is approved and possible modification of operation gas used to mitigate HV stability issues.

All the detector modules have been produced. Most of them have been mechanically assembled and will be fully integrated by ~ August 2021.

Having solved the noise issues, installation and commissioning proceeds at full speed.

Side A will be fully commissioned at 191 in a few days and be moved to P1 at mid July.

Schedule for side C is still very tight (10/2021) but feasible.

Next big challenge is the commissioning of NSWs at P1.

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Back up slides
Introduction: Motivation

Table 1.1: Expected Level-1 rate (based on 2011 data at 7 TeV) for luminosity $3 \times 10^{34} \, \text{cm}^{-2} \, \text{s}^{-1}$, $\sqrt{s} = 14 \, \text{GeV}$ and 25 ns bunch spacing for different $p_T$ threshold with and without the NSW upgrade. The extrapolation uncertainty to 14 TeV is also shown.

<table>
<thead>
<tr>
<th>L1MU threshold (GeV)</th>
<th>Level-1 rate (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T &gt; 20$</td>
<td>60 ± 11</td>
</tr>
<tr>
<td>$p_T &gt; 40$</td>
<td>29 ± 5</td>
</tr>
<tr>
<td>$p_T &gt; 20$ barrel only</td>
<td>7 ± 1</td>
</tr>
<tr>
<td>$p_T &gt; 20$ with NSW</td>
<td>22 ± 3</td>
</tr>
<tr>
<td>$p_T &gt; 20$ with NSW and EIL4</td>
<td>17 ± 2</td>
</tr>
</tbody>
</table>

Table 1.2: The efficiency for $WH$ associated production $pp \rightarrow WH$ with $W \rightarrow \mu\nu$ and two decay modes of a 125 GeV SM Higgs boson to $H \rightarrow b\bar{b}$ and $H \rightarrow W^+W^- \rightarrow \mu\nuqq'$. 

<table>
<thead>
<tr>
<th>L1MU threshold (GeV)</th>
<th>$H \rightarrow b\bar{b}$ (%)</th>
<th>$H \rightarrow W^+W^-$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T &gt; 20$</td>
<td>93</td>
<td>94</td>
</tr>
<tr>
<td>$p_T &gt; 40$</td>
<td>61</td>
<td>75</td>
</tr>
<tr>
<td>$p_T &gt; 20$ barrel only</td>
<td>43</td>
<td>72</td>
</tr>
<tr>
<td>$p_T &gt; 20$ with NSW</td>
<td>90</td>
<td>92</td>
</tr>
</tbody>
</table>

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Introduction: sTGC operational principle

- Primarily used for triggering;
- CO₂-n-pentane gas (55%-45%);
- Wire, pad, and strip readouts;
- Strip pitch, 3.2 mm, much smaller than TGC, hence “small”;
- Pads for local triggering;
- Good timing resolution with short drift time for electrons;
- Construction sites: Canada, Chile, China, Israel, Russia.

Schematic diagram of sTGC
Introduction: Test beam results

Micromegas

sTGC

Efficiency

Resolution
Chamber production: PCB quality control

Dedicated lab at CERN for PCB QA/QC

0. shelf & table
   unwrapping
1. computer table
   logistics
2. tool chest
   QC tests
3. top light table
   visual inspection, electrical tests, repairs
4. back light table
   agreement btw. holes & Cu pattern, edge precision & straightness, pillar pattern
5. rasmask granite table
   absolute dimensions & shape O(30μm)
6. granite table
   pillar height measurement
7. table
   resistivity mapping
8. table
   strip capacitance measurement
9. self
   storage of boards when QC has finished

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Cleaning protocol at production sites

Micropolishing cleaning procedure:
- Hard and soft brushes to distribute detergents
- Accurate washing with hot and demineralized water
- Drying in a box with a ventilation system at ~40°

Main purpose of wet cleaning (and scrubbing):
- remove remnants from the PCB production: dirt and solid deposits from the RO boards -> mostly responsible of “ionic component”
- remove dirt from the mesh (and trapped wires/chips)
LM2 drift panels construction @ Thessaloniki

Steps of construction:
1. Assembly and gluing of the aluminum frame → Trapezoidal frame with three sub-areas
2. Panel gluing is a one step process using the vacuum table method
3. Under-pressure of about 100 mbar on vacuum tables → PCBs mimicking table’s planarity
4. Kapton tape attached along PCB junctions to reassure sealing
5. 3 kg of glue is distributed on aluminum frame and PCBs
6. Honeycomb is placed inside frame’s sub-areas
7. Second table (movable) is rotated and placed on top of the first one standing on ten high precision spacers
8. 20 hours glue curing with under-pressure

Steps after gluing:
1. PCB excesses remove
2. Sealing PCB junction to prevent gas leaks
3. Mesh frame gluing
4. Interconection drift spacers gluing
5. Gas pipes gluing
6. HV conectors gluing
7. Mesh stretch to a certain mechanical tension
8. Mesh gluing on a transfer frame (mandatory for movement from stretching machine to bare panel)
9. Perforation of mesh around the interconection area
10. Mesh gluing on bare panel
11. Mesh excesses remove

Quality control
- Planarity
- Thickness
- Gas tightness
- Mesh tension

Mesh tension mapping
Uniformity better than 10%
Chamber production: HV stability - Passivation

Passivation is performed using a thin Araldyte film.

Width of passivated area such that $R > 0.8 \ \Omega$
The method of passivation was used for all the modules from one point and on, to mitigate the HV stability issues.

As a result there is a small decrease of the active area in the overlapping small – large sector regions.