Design and Construction of Large Size Micromegas Chambers for the ATLAS Phase-1 upgrade of the Muon Spectrometer

Fabien Jeanneau – CEA-Saclay/Irfu on behalf of the Atlas muon collaboration
The Small Wheel (Innermost Endcap Muon Station) is the region with highest background rates in the ATLAS Muon Spectrometer.

The current system is based on Cathode Strip Chambers (CSCs), Monitored Drift Tubes (MDTs) and TGC for particle tracking and triggering.

Located between endcap calorimeter and endcap toroid.

Pseudorapidity coverage: 
\[ 1.3 < |\eta| < 2.7 \]
New Small Wheel Motivations

**TRIGGER**

L1 trigger relies only on Big Wheel (fake triggers)
Cannot distinguish cases:
- A (real high-p_T track)
- B (low-p_T particle created in toroid)
- C (multiple scattering)

Foreseen for Phase-1 upgrade in 2018-19

→ Extension of L1 trigger coverage to \( \eta = 2.6 \) with angular resolution of 1 mrad

**TRACKING**

At \( 5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1} \) (luminosity of HL-LHC) the maximum expected rate in the NSW is about
15 kHz/cm^2 (>1.5 MHz/MDT_tube) (incl. a safety factor of 2)

MDT: Efficiency drops significantly (dead time) and resolution is degraded (gain loss – space charge)
CSC: Limit reached even earlier (only 4 detection layers)

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Detector choice

Combination of sTGC and Micromegas (MM) multiplets: 4+4+4+4 detector planes

sTGC (small strip TGC) primary trigger detector
- Bunch iD with good timing resolution
- Good online space resolution for NSW track vector with <1 mrad angle resolution

Micromegas (MM) primary precision tracker
- Good Space resolution \( \sim 100 \, \mu m \), independent of angle
- Good track separation (0.45 mm readout granularity)
- Provide also online segments for trigger

- Conversion gap: 5 mm
- Amplification gap: 128 \( \mu m \)
- Mesh supported by pillars
- Strip pitch \( \sim 0.45 \, mm \)

- Common front-end ASIC: VMM under development at BNL.
- Work together to make a robust detector for the high rate region of very limited access
- The NSW will operate from 2019 until 2032 \( \rightarrow \) ROBUSTNESS and REDUNDANCY
**MM specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>1200 m²</td>
<td>Large area detector</td>
</tr>
<tr>
<td>Rate up to 15 kHz/cm²</td>
<td>High rate capability</td>
</tr>
<tr>
<td>n, gammas, hadrons background</td>
<td>No aging effect observed</td>
</tr>
<tr>
<td>Tracking precision independent from incident angle</td>
<td>Position resolution ~100µm (+µTPC mode)</td>
</tr>
<tr>
<td>Trigger capability</td>
<td>Angular resolution (~1 mrad for a multilayer)</td>
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**Resistive anode (to solve the discharge issue)**

- Voltage drop due to sparking
- Neutron flux: $10^6$ Hz/cm²

**Mesh attached to the drift panel (large area detectors) and grounded**

- Position resolution obtained in test beam for different incident angles (impact angle in NSW between 8 and 32°)
- See M. Vanadia’s talk

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The Layout of the NSW

Non-IP side:
Large sectors, covering area from \( r = 92 \) to 465 cm

IP side:
Small sectors, covering area from \( r = 90 \) to 445 cm

16 Sectors:
8 Small + 8 Large

Sectors:
sTGC and MM “wedges” + central spacer frame

**New Small Wheel Sector and its components**

- 2 Multilayers per sector
- Each ML: 4 MM and 4 sTGC planes

MM Chambers

sTGC

LM1

LM2

SM1

SM2

NSW Sector

sTGC-Wedges

MM Layers or Gas Gaps

MM Station M2

MM Quadruplet M1

Multilayer sequence

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Construction sites:
- **SM1** → Italy/INFN
- **SM2** → Germany
- **LM1** → France/Saclay
- **LM2** → Russia/Dubna – Greece/Thessaloniki (+ Cern)

**Inner module:** 5 boards  
**Outer module:** 3 boards
**Mechanical precision**

**Requirements for a µ momentum resolution of 15% @ 1 TeV in Atlas**

<table>
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<th>Requirement</th>
<th>Precision</th>
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<tr>
<td>Precision of strip position in Eta (precision coordinate)</td>
<td>30 µm r.m.s.</td>
</tr>
<tr>
<td>Precision of strip position in Z (perpendicular to the detection plane)</td>
<td>80 µm r.m.s.</td>
</tr>
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- **Eta precision**
  - Board positioning
  - RO panel: side/side alignment
  - Modules on spacer frame

- **Z precision**
  - Panel thickness and planarity
  - Precision of assembly frames
  - Gas gap height

- Thermo-mechanical deformations under control
  - Monitored and corrected by alignment system
Readout boards

PCB + readout strips

50µm Kapton + resistive strips

25µm solid Glue

High temp Gluing

Pillars creation

Typical resistivity ~ 10-20 MΩ/cm (~300-600 kΩ/☐)

2 techniques: sputtering or screen printing

512 readout strips per side for Zebra connection (no connector soldered on the boards)
Panel construction

Board positioning (strip alignment in one side)
- Precision hole in readout board (target)
- Precision washer aligned using rasmasks
- Circle and slot

Stiffback method  
**Planarity: min/max 110 µm**

(panel thickness/planarity and side/side alignment)
- Vacuum suction of the first boards on granite table (flatness of 1st side)
- Glue distribution
- Positioning of frames, inserts, honeycomb, etc. + curing
- Vacuum suction of first half-panel on the stiffback (flatness)
- Vacuum suction of the second boards on granite table (flatness of 2nd side) + glue
- Positioning of 1st side (stiffback on precision shimes) on 2nd side (side-to-side alignment + panel thickness)

Positioning precision 10-15 µm
Module assembly

- **Alignment pin/insert**
  - Readout panels alignment
  - Dedicated tool
  - Fixation to spacer frame

- **Interconnections**
  - Drift gap height
  - Control and monitor deformations with alignment platforms
  - Module stiffness
  - Minimize deformation of outer drift panels due to gas pressure

- **Spacer frame**
  - module/module alignment

Simulation of a half-panel deformation

LM2 → 7 interconnections
100µm deformation for 2 mbar of gas overpressure
Mechanical prototype

Materials
Aluminum frames
FR4 sheets
Honeycomb (aluminum, nomex)

Each module is heated and deformations are measured on a CMM

Thermo-mechanical simulations

Max deviation = 55 µm
Max deviation = 59 µm
Max. deviation = 38 µm
Max. deviation = 37 µm

Measurements

22 °C → 24 °C → 28 °C → 22 °C
Alignment system

- Reference alignment bars are fixed and precisely positioned on the NSW structure (taking into account other bars, Big Wheel and Outer wheel)
- Camera + lens define precise alignment lines
- Source platform glued on external drift panels (close to frame or interconnections) using a precise jig and alignment pin for reference
- Measurement of position and global deformation of the modules
- Combined for MM and sTGC
Functional prototypes and mockups

**Micromegas SW**
- 2 identical detectors: one for test beams and one installed in Atlas for RUN2
- 1.2x0.5 m² (upper half of CSC slot)
- Configuration close to final module

**Mockup for services integration**

**Operational Multi-layer**
- X-Y Quadruplet
- Tests of alignment with coded masks

**Mechanical prototype**
- Interconnection fixation
- Quadruplet assembly

**2 boards**
- 3 interconnections

**Cooling tube**
Conclusion

• First time Micromegas detectors will be used on a very large scale to build large area chambers in a particle physics experiment

• The ATLAS NSW Upgrade will enable the Muon Spectrometer to retain its excellent performance

• Design and construction methods have been refined and tested to achieve the Atlas requirements:
  – Alignment of strip and panels
  – Control of deformation
  – Assembly methods
  – Tooling design

• Module-0 construction will start soon
  – First module-0 should be ready in July
  – Second module-0 is foreseen for end 2015

• Transition to series production end 2015/beg 2016

• End of production mid 2017 (2 modules/month/sites)