Applications of MPGD in ATLAS

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Summary

✓ Large area MicroMegas detector for the ATLAS-NSW phase 1 upgrade
✓ Muon large $\eta$-tagger for phase 2 upgrade
✓ Conclusions
Large area MicroMegas detector for the ATLAS-NSW phase 1 upgrade

✓ Motivations for ATLAS-NSW upgrade
✓ Adopted technology for NSW: MM and sTGC
✓ ATLAS-NSW detector structure
✓ Construction techniques of large area resistive MM in ATLAS
  • RO panel
  • Drift panel
  • Panels assembly
  • QA/QC for throughout the whole process
✓ Test beam on module 0
✓ MM mass production
Motivations for ATLAS-NSW

- The Small Wheel (Innermost Endcap Muon Station) is positioned in the region with highest background rates in the ATLAS Muon Spectrometer.
- The present system is based on Cathode Strip Chambers (CSCs), Monitored Drift Tubes (MDTs) and TGC for particle tracking.
- Operation at HL-LHC luminosity (Phase-2) up to $\sim 7 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$.
- Expected rates at HL-LHC up to 15 kHz/cm$^2$ → present detectors performance severely affected.
  - Spatial resolution is deteriorated
  - Efficiency decreases
  - Trigger bandwidth limit exceeded due to fake triggers
- Replace with novel high-rate capable detectors.
Requirements for ATLAS-NSW

- Hit rate up to \( \sim 15 \text{ kHz/cm}^2 \)
- Maintain momentum resolution and keep single muon trigger under control
  - Precision tracking: 15% \( P_T \) resolution at 1 TeV \( \rightarrow \sim 30 \mu \text{m} \) super-point spatial resolution (on a multilayer station)
- Trigger: Angular resolution
  - Phase1: NSW confirmation of Big Wheel tracks (angular cut of +/- 7 mrad)
  - Phase2: 1 mrad after Big Wheel upgrade
The MICROMEshGASeous detector

MM are parallel-plate chambers (about 5mm wide) where the amplification (up to $10^5$) takes place in a thin gap, separated from the conversion region by a fine metallic micro-mesh, supported by ~100 µm high insulating pillars.

Charge is collected on the anode readout board, generally realized with suitable segmented standard PCB.


- High granularity ✓
- Low occupancy ✓
- High rate ✓
The MICROMEshGASeous detector

**Two Different Operation Modes**

- By measuring the average of Charge collected in few strips for Normal Tracks
- By measuring the signal arrival Time in more strips for Inclined Tracks (μ-TPC)

- Wide drift region (typically a few mm) with moderate electric field of about **500 V/cm**
- Narrow (100 µm) amplification gap with high electrical field (40–50 kV/cm)
- A factor $E_A/E_D \approx 70–100$ is required for full mesh transparency for electrons
- With typical drift velocities of 50 µm/ns (better if saturated) electrons need 100 ns for a 5 mm gap and Spatial Resolution of about **100 µm** or better can be achieved.
Bulk MM

The bulk MM: In 2006 the first Bulk MM was produced at Cern. In the bulk MM the mesh is embedded in the PCB

- New mesh used for bulk MM.
- Woven wire mesh, wire diameter about 20-30 µm and about 80% transparency.
- Largely produced for serigraphic application.
- Electroformed micromesh was normally used before.

The Insulator (Vacrel 8100 in this case) is photosensitive and can be removed by etching, creating the pillars.
From bulk MM to ATLAS-MM structure

At this first stage the greatest “enemy” of MMs was the discharges, sparks between mesh and strips, in particular with high flux of ionizing particles.

The main limitation for very large diffusion of MicroMegas in the very beginning

- Sparks dumped by the high resistivity strips, typical value is 1MΩ
- Resistive strips at high voltage and mesh at ground is a more safe and easy configuration
- RO strips are strongly coupled to resistive one

 Resistive Strips

MAMMA Collaboration, NIM A640 (2011)
MAMMA activities

**MAMMA: Muon Atlas MicroMegas Activity**

A synergy of the Atlas Collaboration + the RD51 Collaboration (MPGD) + the Cern PCB Laboratory (Rui de Olivera)

With this new scheme many small MM prototypes have been produced at Cern and tested in various test beam for different geometry, gain, gas mixture, magnetic field effect...
ATLAS-NSW detector layout

Combination of sTGC and MicroMegas quadruplets: 4+4+4+4 detector planes

- 4 sTGC + 4 MM + 4 MM + 4 sTGC

Dimensions:
- 220 mm
- 360 mm

Structure:
- 1024 Strips
- PCB: ~ 420mm wide
- S/L M1: 5PCB
- S/L M2: 3PCB

Each NSW has 16 sectors:
- 8 Large + 8 Small

CERN-LHCC-2013-006 ATLAS-TDR-020
Large area resistive MM in ATLAS

Panel is a sandwich of 0.5 mm PCB skin with honeycomb in the middle and frames in the perimeter and in the joint of two adjacent PCB. Honeycomb and frames in Al.

Different Panels are needed for a Quadruplet:
- RO Panels (Eta and Stereo)
- Two External Drift Panels
- One Central Drift Panel

For each gas gap an unique Mesh is glued on the drift panel, using a custom frame that define the 5 mm height

Slow bi-component epoxy is used as glue

Engineering challenges for MM precision chambers:
- Alignment of the strips on each detection layer
- Flatness < 37 μm rms and < 110 μm max dev wrt nominal
- 30 μm rms in η and 80 μm rms in z

Five panels joined to make a detector unit (Quadruplet) with 4 gas gaps.
Large area resistive MM construction 1/5

**RO PCB**

- Board dimensions up to 45x200 cm² with 1022 strips/boards (strips 425 or 450 μm pitch)
- Pillars: height 128 μm
- Several types of alignment masks
- Long phase of technology transfer
- **First production for the modules-0 NOT satisfactory**
- Pre-series for production: very good improvement in the quality and process flow
- Position of strips on planes: 40 μm (max dev.)
- Relative alignment of the two sides of the readout panel: 60 μm (max dev.)
- Relative alignment of the two readout panels: 60 μm (max dev.)

- Resistive foils by screen-printing
- “Ladder pattern” (connections every 10 mm):
  - Homogeneous resistivity (independent from distance)
  - Insensitivity to broken lines

Typical resistivity:
~ 10-20 MΩ/cm
(~300-600 kΩ/□)
Large area resistive MM construction 2/5

- Panel structure: sandwich of 5(M1) or 3(M2) PCB boards – honeycomb + structural frames – 5(M1) or 3(M2) PCB boards
- PCB positioning: precision pin-holes and precision washer alignment through optical masks
- Stiffback technique for assembling:
  - Strips alignment at level of 30 μm rms
  - Planarity Requirements: 37 μm RMS. For example SM1 (Pavia) M05:
    - Eta panel 22 μm
    - Stereo panel 26 μm
Large area resistive MM construction 3/5

Drift panels …

… with mesh

- Similar construction concept as for the readout panels
- Same planarity requirements as RO panels
- Floating mesh for large area MM assembly
- Mesh tension ~10 N/cm, uniformity 10%

Completed Drift Panel (mesh protected with mylar)
Panel assembly

Vertical Assembly
Alignment of eta Vs Stereo
Readout Panel ensured by
alignment pins

An example: SM1 module 0

Crucial: Alignment of the two readout
panels at < 60 \mu m rms

- First assembly 2016 April 15\textsuperscript{th}
- 2\textsuperscript{nd} module closure end of May, then
  shipping to CERN for Test-Beam in June
  → superb achievement!
Large area resistive MM construction 5/5

QA/QC for throughout the whole process

- Most relevant
  - Thickness using linear height, limbo, callipers
  - Planarity using Digimatic Limbo and/or 3D machine
  - Strip alignment using laser and/or rasnik
  - Mesh tension using tensiometer
  - Gas tight using pressure drop and/or gas flow method
  - Electrical insulation of cathode and resistive strips
  - HV test
  - Cosmic ray test
  - Commissioning in GIF++
Test beam on module 0

Cern H8 Pion beam 180 Gev/c (Beam spot 1x1 cm²)

SM1 Module 0
- quadruplet, 425µm strip pitch
- L1 & L2 vertical strips (eta),
- L3 & L4 ±1.5° w.r.t. vertical axis (stereo)
Preliminary results on spatial resolution

- Perpendicular incident beam on PCB5 = longest strips
- Nominal High voltage settings:
  - HV_ampl = 570 V (E=4.4x10^7 V/cm)
  - HV_drift = 300 V (E=600 V/cm)
- Ar/CO₂ 93/7 @ 20 l/hour

**Preliminary result: Spatial Resolution of the precision coordinate (η)**

Well within requirements

\[ \sigma_{\text{gauss}} = 81 \mu m \]

Evts in fit range = 95%

**Preliminary result: Spatial Resolution of the second coordinate (φ)**

...and in good agreement with expectations

\[ \sigma_{\text{gauss}} = 2.4 mm \]

Evts in fit range = 95%

2nd coordinate from the stereo planes, compared with y-coord from reference chambers
Preliminary results on efficiency

Efficiency in different positions of PCB5

- Cluster efficiency: presence of one cluster for any reference track
- Track-based efficiency: one cluster within given distance from the reference track impact on SM1

- Cluster efficiency very close to 100% for all layers
- Layers 2 and 3 observed to have slightly lower gain (and efficiency) [gas leaks - ... - under investigation]

Track-based efficiency: (-1.5 : +1.5 mm)

Circle efficiency

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Cluster Efficiency

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Track-based Efficiency

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Layer 1
Layer 2
Layer 3
Layer 4

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PCB5 PCB4 PCB3 PCB2 PCB1

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NSW Preliminary

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Layer 1
Layer 4

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x position [mm]

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Cluster Efficiency

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Track-based Efficiency

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Layer 1
Layer 2
Layer 3
Layer 4

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PCB5 PCB4 PCB3 PCB2 PCB1

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x position [mm]
Preliminary results on strip alignment

Measurements at different vertical positions, along the strips (yellow spots)

For each y-position measure $\Delta x$ between layer $i$ and layer-1 using reference tracks defined by the small bulk MM in the beam setup

- Measured a maximum deviation of +/- 80 $\mu$m
- The effects are both shifts and rotation
- Under investigation at the construction site
- The second Mod0 (called 0.5) has been built using 20 C-CCD cameras to control the alignment
ATLAS-MM mass production

**MM Sharing**

- 4 different types of MM quadruplets, 2 for small (SM1, SM2) and 2 for large sectors (LM1, LM2)
  - Inner modules (SM1, LM1): 5 Boards
  - Outer modules (SM2, LM2): 3 Boards
- For each type 32 chambers have to be built (overall total: 128)
- Quadruplet construction is done in institutes, distributed over several countries

![Diagram showing distribution of MM quadruplet construction across Small and Large Sectors modules.](image-url)
ATLAS-MM mass production

SM2 – Germany - BMBF
- Module-0 done
- Module-0.5 in construction

LM1 – France - Saclay
- Infrastructure and tooling is ready
- Module-0 in construction

LM2 – Dubna/Thessaloniki
- Module-0 done
- Module-0.5 in construction
Muon large $\eta$-tagger for ATLAS phase 2 upgrade
Muon large $\eta$-tagger for ATLAS phase 2 upgrade

$R_{ext} = 93$cm
$R_{int} = 25$cm
Thickness = 5cm
Requirements

• The aim is to tag muons in extremely high particle rate (up to 10 MHz/cm²)

• To minimize the occupancy, pixel or small pad readout are needed. Micro-Pattern-Gaseous-Detectors is a suitable technology for this purpose
**Pixelated MicroMegas**

- Able to reach 10MHz/cm² with 190µm resolution
- Tested without HV instabilities

**Precision timing**

- Use of pico second Timing resolution
- Reduction of rate by Rejecting out-of-time Particles
- May allow to use Short strips rather than Pixels
- Reduction of number of channels
- Δt < 30 ps

![Diagram of detector technology](image)

Test results:

- Cluster efficiency: 0.999 @plateau
- Tracking efficiency: 0.983 @plateau

![Graph showing gain vs. efficiency](image)
**μ-RWELL**

- Combination of MicroMegas (resistive readout for discharge protection) and GEM (holes for avalanche)
- Simple and compact detector structure
- No gluing, no spacers, no stretching, no rigid frames
- Easy and efficient assembly
- Suitable for large area application
- Cost effective

**μ-PIC for HL-LHC**

- μ-PIC with resistive cathode
- Spark rate reduction using resistive cathode
Conclusions

✓ Large Area Resistive MicroMegas is a suitable technology to upgrade the ATLAS forward muon spectrometer (first time in HEP experiments)
✓ MM construction methods have been refined & tested: tooling and quality control procedures; construction and assembly methods; planarity and alignments; etc.
✓ TB done on SM1 Module-0 with very satisfactory results
✓ All module-0.5 construction are near completion
✓ Series production has started and, despite a very tight schedule, will be ready for the Long Shutdown 2
✓ Muon η-tagger seems worthwhile for ATLAS
✓ Many studies still needed and on-going
Thanks for your attention