Micromegas Chambers for the ATLAS Muon Spectrometer Upgrade

Design and performance studies

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on behalf of the ATLAS Muon Collaboration
1. The ATLAS New Small Wheel Upgrade Project (NSW)
   - Motivation of the upgrade
   - NSW layout & expected performance

2. Micromegas Detector Technology (MM)
   - Main characteristics
   - Construction of large MM modules
   - The ATLAS Micromegas Quadruplet prototype (MMSW)

3. Performance studies of micromegas prototypes
   - Hit & Track Reconstruction performance
   - Performance inside magnetic field
   - MMSW performance studies

4. Conclusions
The ATLAS upgrade is motivated primarily by the high background radiation that is expected at $\mathcal{L} = 5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, after the High Luminosity LHC (Phase II) upgrade (2025).

Muon Spectrometer upgrade will be essential already for $\mathcal{L} = 2 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$, after Phase I upgrade (2020).

- Current SW detectors (MDT, CSC, TGC) inefficient at increased particle rate ($\sim 15\text{kHz/cm}^2$ for HL-LHC).
- Muon trigger rate will exceed the bandwidth available to the muon system ($\sim 20\text{kHz}$).

Degradation of single hit & segment efficiency, due to dead time from background hits.

Endcap muon triggers are dominated by fakes due to background (>90%).
New Small Wheel system, with high rate capability, to be included in the Level-1 trigger.
- Minimise fake triggers by reconstructing high quality \((\sigma_\theta \sim 1\text{ mrad})\) IP pointing segments.
- Precision tracker (100\(\mu\text{m}\)) efficient for the expected high rate after the luminosity increase.

**sTGC (mainly for triggering) & Micromegas (mainly for tracking) detectors, both providing tracking and triggering information, combined into a fully redundant NSW system!**
Planar structure with two asymmetric E-field regions, separated by a metallic micromesh.

- **Drift Gap** (5 mm), \( E_{\text{drift}} \approx 0.6 \text{kV/cm} 
- **Amplification Gap** (128 μm), \( E_{\text{amp}} \approx 39 \text{kV/cm} 
- **Gas** mixture Ar+7% CO₂, gain \( \sim 10^4 

- \( e^- \) drift towards the mesh (95% transparent) in \( \sim 100 \text{ns} \).
- Avalanche formation in the amplification region (1 ns) with fast ion evacuation (\( \sim 200 \text{ns} \)).
- The detector becomes **spark tolerant** by adding a layer of resistive strips (5–20 MOhm/cm).
  \( \rightarrow \) **High rate capability**! (Tested up to 70 kHz/cm²)

Fine readout segmentation \( \Rightarrow \) **Excellent spatial resolution** BUT large # of channels (2M for NSW!).
Functional prototypes up to 2.4 m$^2$ have been built and tested at CERN.

Mechanical precision studies are ongoing including building several large mechanical prototypes (ATLAS requirements). The position of any chamber element on the precision coordinate should be known with an RMS of less than 30 $\mu$m (80 $\mu$m for the coordinate transverse to the chamber plane)!

Need to control mechanical deformations

Panel deformation due to 3 mbar gas overpressure has been measured in a large prototype (single gap with mesh).

$$\langle \text{Def} \rangle = 140 \mu m, \text{Def}_{\text{max}} = 300 \mu m$$

Deformation mitigation with interconnection screws.

Mechanical simulation studies for defining the number and position of interconnections.
Micromegas Detector Technology (MM)  The ATLAS Micromegas Quadruplet prototype (MMSW)

- **First MM 4plet ever built** with structure similar to the one foreseen for the NSW.
- 2 double sided readout boards, 1 double sided and 2 single sided drift panels ($1\text{m} \times 0.5\text{m}$).
- Comprises 4 readout layers, 1024 readout strips each, with a pitch of 415 $\mu$m.

For more info see poster N05-4 dedicated to the MMSW prototype, by M. Bianco: "Characterization and Commissioning of the ATLAS Micromegas Quadruplet Prototype"

- **First test of a stereo readout strip layout with MM.**
- Strips are rotated by $\pm 1.5^\circ$, with respect to the precision strips, on two planes for 2$^\text{nd}$ coordinate reconstruction.

Combining the 2 stereo readouts, the reconstruction accuracy for the second coordinate is expected to be $\sim 2.2\text{mm}$ (assuming $\sim 80\mu\text{m}$ for a single layer).

Preliminary results on MMSW test beam studies will be presented in the performance section of the talk!
Muon Atlas Micromegas Activities (MAMMA) Collaboration

R&D of Micromegas detectors for the ATLAS Muon spectrometer upgrade (NSW).

Several test beam periods (since 2008) studying different Micromegas prototypes ((non)resistive, small, large, multi-readout, multi-layer etc.) in various beam and magnetic field conditions.
Micromegas will be the main precision tracker of the NSW (required spatial resolution 100 μm).

**Hit & Track reconstruction**

- Using charge amplitude (Centroid hit)
  - Accuracy rapidly decreasing for larger track angles.
- Using time information (μTPC segment).
  - Performance improving with increasing cluster size.

**Tracks expected @ NSW 8° – 30° ⇒ So we are relying mostly on μTPC.**

**Refinement of μTPC recipe** (Significant improvement)

- Correct for capacitive coupling between strips.
- Fine tuning of the primary e⁻ position assignment along the strip width.
- Implement pattern recognition techniques for track identification (Hough transform)

Combination of centroid & μTPC provides spatial resolution < 100 μm independently of track incident angle!
Multi-directional magnetic field in the ATLAS SW region with intensity up to 0.4T.

- The drift path of the ionisation $e^-$ is deviated from the electric field lines.
- The deviation can be quantified using data. ⇒ Measurement of the Lorentz angle.
- The electron drift paths become longer inside magnetic field. ⇒ Measurement of the drift velocity.

Measurements show good agreement with Garfield simulations. ⇒ Micromegas performance inside magnetic field is well understood!
Test of the MMSW 4plet in $p, \pi^+$ beam ($6 - 9 \text{GeV/c}$) using a micromegas reference telescope (CERN, PS T9-10, August-October 2014).

- $\sim 98\%$ efficiency for all 4 layers (2\% inefficiency due to pillars).
- Precision coordinate hit reconstruction with $\sim 75 \mu\text{m}$ accuracy.
- Spatial resolution for the $2^{\text{nd}}$ coordinate $\sim 2.2 \text{mm}$.

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Conclusions

The ATLAS NSW Upgrade will enable the Muon Spectrometer to retain its excellent performance also beyond design luminosity and for the HL-LHC phase
- Deployment of a new Micropattern Gaseous Detector (MPGD) technology, Micromegas, for the first time in a very large scale experiment.
- Production of Micromegas planes to cover a total active area of \(\sim 1200 \text{m}^2\)!
  - Series production & mechanical precision challenges.

Extensive performance studies show that Micromegas fulfill the ATLAS requirements
- Excellent spatial resolution \((< 100 \mu\text{m})\) independent of the track incident angle.
  - Refinement \(\mu\)TPC technique correcting for effects due to neighbouring strips capacitive coupling.
- Studies inside magnetic field do not show any sign of degraded performance.
  - Chambers perform flawlessly with magnetic field intensities up to 1T.

First test of the ATLAS-like prototype (MMSW 4plet) was very successful
- Reconstruction of the precision coordinate with an uncertainty of \(\sim 75 \mu\text{m}\).
- 2\(^{nd}\) coordinate reconstruction using stereo readout strip configuration performs as expected, spatial resolution \(\sim 2.2\text{mm}\).

Next years are expected to be even more busy, series production, development of new electronics & testing, following the NSW project schedule...
Thank you