Study of the performance of the MicroMegas chambers for the ATLAS Muon Spectrometer Upgrade

Marco Vanadia, on behalf of the ATLAS Muon Collaboration

Sapienza University of Rome & INFN

ANIMMA 2015, 23/04/2015
The ATLAS experiment

- Biggest detector at a collider, working @ Large Hadron Collider
- \( pp \) collisions @ 7-8 TeV (13 soon!) + \textit{heavy ions}
- Key detector systems for this talk:
  - trigger system: 40 MHz → \( \lesssim 1 \) kHz!
  - muon spectrometer with MDT, RPC, CSC and TGC chambers working in a toroidal magnetic field

Multi-purpose detector, able to measure precisely what we already know and to search for the unexpected!
The near and far future for ATLAS and the LHC

2010-2012: Run-1, 25 fb$^{-1}$ @ 7-8 TeV, Higgs discovery (ATLAS+CMS), > 400 published papers

NOW: energy → 13 TeV, new energy frontier, new physics discovery potential

2018: Phase-I upgrade, 2× design luminosity and a long run scheduled (>300 fb$^{-1}$)
- main difficulties: dealing with trigger rate and higher enviromental background!
  - if trigger thresholds become too high, we lose efficiency on physics (see plot on the right)

Long term: Phase-II upgrade and a long physics program at ≈5× design luminosity!
The hit rate in the detector increases linearly with the luminosity. This is particularly problematic in the forward spectrometer.

At the maximum Run-4 luminosity of $5-7 \cdot 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ in the innermost part of the forward spectrometer the hit rate can be as high as 15 kHZ/cm$^2$.

To achieve the demanding performance goal for ATLAS, a complete replacement of the Small Wheel is needed.

The New Small Wheel will employ MicroMegas (MM) and small-strip Thin Gap Chambers (sTGC).
Triggering with the New Small Wheel

- Currently trigger chambers are in Middle station. In the figure on the right, tracks A, B and C would be accepted by the trigger system.
- With the New Small Wheel only tracks pointing to the interaction point will be accepted (track A in the figure).

The NSW will employ 8 sTGC and 8 resistive MM layers.

The trigger rate is significantly reduced with the New Small Wheel.

\( \sqrt{s} = 14 \text{ TeV} \) \( L = 3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1} \)

**ATLAS**
MicroMegas prototypes for the New Small Wheel

MicroMegas chambers are MicroPattern Gaseous Detectors introduced in the 90s\(^1\)

- **Drift region**: \(\approx 5\) mm with low electric field
- **Grounded mesh** (325 lines/inch)
- **Amplification region**: thin gap (128 \(\mu m\)) with high electric field, fast ions evacuation \(\rightarrow\) high rate tolerance

- Inclined tracks fire many strips, by measuring time of arrival of signal track reconstruction inside MM is possible: \(\mu\)TPC reconstruction\(^2\)
- One of the most relevant breakthroughs achieved within the Muon Atlas MicroMegas activity: resistive strips for spark-protection (see *NIM A640 (2011) 110-118*) capacitatively coupled with readout strips.
- NSW: 4 MM-layers chambers in Ar/\( CO_2 \) 93/7

**The challenge**: MM chambers with an unprecendent size (up to 3 m\(^2\)) and a high construction precision required to satisfy the demanding performance

---

\(^1\)NIM A376 (1996) 29-35
\(^2\)NIM A617 (2010) 161-165
Extremely wide performance analysis program ongoing within the MAMMA (Muon Atlas MicroMegas Activity) collaboration to

- test the prototype chambers and the r/o electronics, measure the basic properties (gain, transparency ...), find the optimal working point (HV...)
- fully characterize the MicroMegas performance (resolution, efficiency ...) for tracks with varying inclination with/without a magnetic field
- develop and optimize the track reconstruction strategies and software

with the final goal of obtaining a single-layer spatial resolution $\approx 100\mu m$ and a reconstruction efficiency $>95\%$ for tracks up to $30^\circ$ within a B field up to 0.3 T

**Test beam**

- Several test beam campaigns performed to study MM prototypes performance
- 10x10 cm$^2$ bulk prototypes and 100x50 cm$^2$ 4-layers chamber have been studied
- Performed measurements with perpendicular and inclined tracks, with/without magnetic field, for different working points (HV, gas mixture, ...)

**Other testing activity**

- Cosmic rays test-stands
- X-ray guns for gain and mesh transparency measurements
- Irradiation tests for ageing and radiation hardness studies
Single-strip response

- Strips signal is read out by APV25 hybrid cards \(^1\) through the Scalable Readout System \(^2\).
- Output is charge vs time distribution sampled every 25 ns.
- Maximum of the distribution is the charge read by the strips.
- With a fit on the rising time, time of arrival of the signal can be measured.
- As a baseline, a fit with a Fermi-Dirac function is performed, the flex of the curve \(t_{FD}\) is used as time of arrival of the signal.

\[ FD(t) = \frac{A}{1 + e^{-(t-t_{FD})/\beta}} + C \]

---

\(^1\) Nuclear Instruments and Methods in Physics Research A 466 (2001) 359–365
\(^2\) JINST 6 C11028
Position reconstruction with a MicroMegas layer

**Centroid method**
- select a cluster of neighbouring strips
- reconstruct position as average of strip positions weighted by their charge
- well performing for perpendicular tracks

**μTPC method\(^1\)**
- time measured for each strip
- knowing \(v_{drift}\), track reconstruction can be performed
- well performing for inclined tracks

---

\(^1\) NIM A617 (2010) 161-165
Spatial resolution has been measured for centroid and \( \mu \text{TPC} \) reconstruction as the width of the difference between 2 chambers for \( 10 \times 10 \text{ cm}^2 \) "T" (0.4 mm strip pitch) and "Tmm" (0.25 mm strip pitch) prototypes.

- Double gaussian fit performed to take into account long tails (noise, events with multiple tracks, residual cross-talk ...)
- In the NSW tracks will be inclined by 8°-32°
- >100 \( \mu \text{m} \) resolution achieved combining centroid and \( \mu \text{TPC} \) in this range (and beyond)
Reconstruction optimization: correction for capacitative coupling btw strips

- Signal in first and last strip in a cluster is often just due to capacitative coupling → they introduce a bias in the $\mu$TPC track reconstruction

- A correction technique has been developed, by filtering low-charged strips at the cluster ends

- Fine tuning of the charge position assignment along the strip width
Efficiency measurements

- Left: centroid hit position in a MM prototype with 2D readout. The effect of the pillars is clearly visible.
- Bottom: measurement of reconstruction efficiency done extrapolating track from telescope of reference chambers, for perpendicular (left) and 30° inclined tracks (right).
- The impact of pillars is higher for perpendicular tracks, as expected.
- A very high efficiency is achieved.
First 4-layers prototype: the MMSW chamber

- MMSW chamber: \(1.2 \times 0.5 \text{ m}^2 \times 80 \text{ mm}\) built @ CERN
- 4 detection layers, 1024 strips each (0.415 mm pitch, drift gap 5 mm)
  - 2 back-to-back layers for precision coordinate
  - 2 planes with -1.5° and +1.5° inclined strips (stereo)

The layers with stereo strips will be used in ATLAS to measure the second coordinate, with a resolution of 2-2.5 mm required by the trigger system.

MMSW chamber will be installed in the ATLAS detector during Run-2!
Performance of the first 4-layers prototype

The prototype has been tested at CERN test beam facilities during the last year

- Measured resolution for first and second coordinate are well within specifications
- A ≈98% per-layer reconstruction efficiency has been measured for perpendicular tracks
For a given angle of inclination, there is a “critical” value of the $B$ field causing a “focusing” effect on drift $e^-$.

The $\mu$TPC resolution degradation can be compensated by combining with the centroid reconstruction.

Studies are ongoing on recent test-beam data to optimize reconstruction within $B$ field.

Note: resolutions are larger here due to lower amplification of the working point of these test beam data.
Test of prototypes in magnetic field is one of the main current topics of activity within our collaboration.

Here showing a measurement performed on test beam data of the drift velocity $v_{drift}$ as a function of the $B$ field.

From the width of the distribution of time measurements from a chamber, since the gap size is known, $v_{drift}$ can be measured.

In magnetic field this must be corrected for the effect of the Lorentz angle, since $v_{drift}$ is not parallel to the $E$ field.

Results in good agreement with simulation (Garfield).
Irradiation tests

- Small prototypes (bulk MM) thoroughly tested with X-rays, neutrons, $\gamma$ and $\alpha$
- Equivalent of $\gg 5$ years of high luminosity LHC simulated
- No evidence of ageing effects have been measured

**X-ray irradiation test**

- Exposure: 918 mC for $4 \text{ cm}^2$ in 21.3 effective days. 225 mC/cm$^2$ (32 mC/cm$^2$ estimated for 5 years of HL-LHC)
- Mesh current stable and in line with reference not-irradiated detector

**Neutron irradiation**

- Flux: $3 \cdot 10^{12} \text{ n/(hour} \cdot \text{cm}^2\text{), 5-10 MeV, corresponding to 2 years of HL-LHC}$
- Mesh current stable during the whole testing period
After many years of **R&D** and **breakthroughs** in the technology in the context of the ATLAS upgrade, the MicroMegas are now mature detectors to be installed over large areas at HEP experiments.

Very wide program of studies, measurements and tests ongoing within the **Muon ATLAS MicroMegas Activity**.

Tests have been performed on small $10 \times 10 \text{ cm}^2$ prototypes, proving that the **demanding performance requirements** for the ATLAS New Small Wheel are met.

During last year **started to test chambers close to the final design**, i.e. with floating mesh and composed of 4 resistive MicroMegas planes.

These tests have been very successful as well, these chambers have **high efficiency** and very good resolution.

Main focus is now on fully characterizing and optimizing the performance of these MicroMegas chambers within a magnetic field.

4-layers prototype MMSW will be included in the ATLAS detector for Run-2!
BACKUP