Development of Micromegas detectors for the ATLAS Muon System upgrade

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On behalf of the MAMMA* Collaboration

*Muon ATLAS MicroMegas Activity

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Introduction

- LHC schedule: towards 3000 fb$^{-1}$

2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
... 2030?

LHC start-up $\sqrt{s} = 900$GeV

$\sqrt{s} = 7$TeV rising to 8TeV, $\mathcal{L} = 6 \times 10^{33}$cm$^{-2}$s$^{-1}$, bunch spacing 50ns

Go to design energy and nominal luminosity

$\sqrt{s} = 13$-14TeV, $\mathcal{L} = 1 \times 10^{34}$cm$^{-2}$s$^{-1}$, bunch spacing 25ns

Injector and LHC Phase-I upgrade to full design luminosity

$\sqrt{s} = 14$TeV, $\mathcal{L} = 2$-3$ \times 10^{34}$cm$^{-2}$s$^{-1}$, bunch spacing 25ns

HL-LHC Phase-II upgrade, crab cavities, new IR, ...

$\sqrt{s} = 14$TeV, $\mathcal{L} = 5 \times 10^{34}$cm$^{-2}$s$^{-1}$ (luminosity levelling) 25ns

https://indico.cern.ch/getFile.py/access?contribId=31&sessionId=5&resId=1&materialId=slides&confId=164089
Upgrade of ATLAS Muon Spectrometer

- Small Wheel muon chambers need to be upgraded in phase I
  - Present detectors will reach their rate limit at $\sim 5\times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
  - Reduce the fake rate at $p_T > 20\text{GeV}$ (at present small wheel not used in LVL1 trigger)
  - Improve $p_T$ resolution to sharpen thresholds
The New Small Wheel

- Reduction of fake rates with NSW:
  - 0. w/o NSW
  - 1. requiring the presence of a segment in NSW
  - 2. requiring NSW segment pointing to IP (\(\theta<1\text{mrad}\))
  - 3. requiring NSW segment matching in \((\eta,\phi)\) the EM muon chamber trigger segment

Reduction of L1_MU20 trigger rate

Efficiency of L1_MU20 trigger

- Three options proposed for NSW:
  - sMDT+sTGC
  - sMDT+mRPC
  - Micromegas
The MAMMA Project

Today:
MDT chambers (drift tubes)
TGCs for 2\textsuperscript{nd} coordinate (not visible)

Replace the muon chambers of the Small Wheels with 128 micromegas chambers (0.5–2.5 m\textsuperscript{2})

- Combine precision and 2\textsuperscript{nd} coord. measurement as well as trigger functionality in a single device
- Each chamber comprises eight active layers, arranged in two multilayers
  \Rightarrow a total of about 1200 m\textsuperscript{2} of detection layers
  \Rightarrow 2M readout channels
- Project started in 2007
  - Proto-Collaboration MAMMA (Muon Atlas MicroMegas Activity) formed with 15 groups involved
  - Napoli involved since the beginning, Frascati recently joined, others interested
Micromegas (I. Giomataris, G. Charpak et al., NIM A 376 (1996) 29) are parallel-plate chambers where the amplification takes place in a thin gap, separated from the conversion region by a fine metallic mesh.

- The thin amplification gap (short drift times and fast absorption of the positive ions) makes it particularly suited for high-rate applications.

Micromegas operating principle

- No space charge effect
- Intrinsic rate limit ~200 MHz/cm²
Performance & $\mu$TPC mode

Performance requirements for the Small Wheel chambers

- Rate capability $15 \text{ kHz/cm}^2 \ (L \approx 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1})$
- Efficiency $> 98$
- Spatial resolution $\approx 100 \mu\text{m} \ (\Theta_{\text{track}} < 30^\circ)$
- Good double track resolution
- Trigger capability (BCID, time resolution $\leq 5\text{–}10 \text{ ns}$)
- Radiation resistance
- Good ageing properties

Micromegas as $\mu$TPC
- Can deliver track vector in single plane for track reconstruction at LVL1 trigger

Addressed problems:
1. Tracking for inclined tracks
2. Large-size detectors
3. Sparks

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Event display from TB

- Vertical track

Three chambers in stack

| MM1 | MM2 | MM3 |

Charge (200 e-)

Time (25 ns)

Strip number (250μm pitch)
Event display from TB

- Two Inclined tracks (~40°)

Run: 6248, Event: 10

Tracks separated by 5mm

Two chambers in stack

MM1

MM2
A production technique developed in 2006 (bulk-micromegas) opened the door to industrial fabrication.

Reliable production of large size Micromegas is possible!

The largest MM ever built:

250 µm strip pitch

$\sigma_{MM} = 36 \pm 7 \mu m$

Gain Efficiency

$\text{Ar:CF}_4:i\text{C}_4\text{H}_{10} (88:10:2)$
Sparks: problem and solution

- Small defects or impurities on the detector surfaces trigger discharges (breakdowns). Even in device of good quality, when the avalanche reaches Raether limit \((10^6-10^7 \text{ e-})\) a breakdown appears in the gas, often referred as ‘spark’

- Sparks lead to a partial discharge of the amplification mesh \(\rightarrow\) HV drop & inefficiency during charge-up; not acceptable at LHC.
  Risk of damaging for chamber and FE-elx

- Sparks can be drastically reduced by adding a resistive layer on the r/o strips

- Specific R&D to optimize the resistive protection

- Excellent results

![Graphs showing current vs. time and gain vs. voltage for non-resistive and resistive MM in neutron beam tests.](image)

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13/04/12
Micromegas in ATLAS

- Four small MM chambers were installed in ATLAS behind the last muon station in April 2011 and smoothly operated all along the 2011 (background measured to be $\sim 3$ Hz/cm$^2$ at $L=10^{34}$ cm$^{-2}$s$^{-1}$; $\sim 3$ times lower than nearby EOL MDT)

- First large size resistive MM assembled and tested in muon beam in 2011 to be installed in the ATLAS cavern on the small wheel for test

- A small prototype has been installed to evaluate the possibility to replace the Minimum Bias Trigger Scintillator of ATLAS with Micromegas

- Integration in the ATLAS acquisition system
Summary & Plans

- The Small Wheels of the ATLAS Muon Spectrometer need a major upgrade to cope with the LHC phase-1 luminosity
- Micromegas fulfil all of the Small Wheel requirements
- We found an efficient spark-protection system that is easy to implement; sparks are no longer a show-stopper
- MMs are very robust and (relatively) easy to construct; large-area resistive-strip chambers can be built and they work very well
- Good single-plane tracking performance can be obtained by exploiting the μTPC mode
- From the three original proposals for the NSW a ‘mixed’ option is now under discussion in the collaboration:
  - TGC+Micromegas
- Decision to be made this year, installation of NSW in 2018.
Backup Slides
Introduction
The problem of the fake rate

Current LVL1 end-cap trigger
- Only the vector $BC$ at the Big Wheels is measured
- Momentum defined by assumption that track originated at IP
- Random background tracks can easily fake this
- Currently 96% of forward high-$p_T$ triggers (at LVL1) have no track associated with them

Proposed LVL1 trigger
- Add vector $A$ at Small Wheel
- Powerful constraint for real tracks
- A pointing resolution of 1 mrad will also improve $p_T$ resolution
The bulk-Micromegas

- A production technique developed in 2006 (bulk-micromegas) opened the door to industrial fabrication
- Big effort for going to large dimensions
- In 2007 production of the first large MM prototype for ATLAS (50x60 cm², the largest MM at the time)
- In 2010 production of a CSC-size Micromegas

Reliable production of large size Micromegas is possible!

- Other improvements in the segmentation of the r/o electrodes
- 2D (xy) and 3D (xuv) r/o strips showed encouraging results
Demonstrated performance

- Standard micromegas
- Safe operating point with efficiency ≥99%
- Gas gain: 3–5 x 10^3
- Very good spatial resolution

Spatial resolution (mm)

Mean = (3.5 ± 1.3) μm
Sigma = (70.7 ± 1.3) μm
(MM + Si telescope)

σ_{MM} = 36 ± 7 μm

250 μm strip pitch

Inefficient areas

Ar:CF_4:iC_4H_{10} (88:10:2)
Resistive-strip protection concept

Mesh support pillar

Resistive strip 0.5–100 MΩ/cm

PCB

Insulator

Cu readout strip

Embedded resistor 50 MΩ 5mm long

Resistive Strip 0.5–100 MΩ/cm

PCB

GND

Copper readout strip
A tentative Layout of the New Small Wheels and a sketch of an 8-layer chamber built of two multilayers, of four active layers each, separated by an instrumented Al spacer for monitoring the internal chamber deformations.