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# Development of Micromegas detectors for the upgrade of the ATLAS Muon Spectrometer

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**Summary.** — The Muon Sepctrometer of the ATLAS detector will undergo a major change in view of the LHC upgrade foreseen in 2018. In particular the two most internal detector wheels of the endcap part of the muon spectrometer (Small Wheels) need to be rebuilt with detectors capable to cope with the higher particle rate. We propose Micromegas detectors to be used both as trigger and tracking devices for the new Small Wheels. The most recent developments of Micromegas tailored to the ATLAS spectrometer upgrade will be illustrated: the development of resistive strip detectors to reduce the discharge probability, the construction of large-size ($\sim$ m$^2$) chambers, the optimization of working parameters and the innovative $\mu$TPC working mode that allows a local reconstruction of track segments.

PACS 29.40.Cs – Gas-filled counters: ionization chambers, proportional, and avalanche counters.
PACS 29.40.Gx – Tracking and position-sensitive detectors.
PACS 29.30.Aj – Charged-particle spectrometers: electric and magnetic.

## 1. – Introduction

The Phase-1 upgrade of the Large Hadron Collider will increase the LHC luminosity above the full design value of $1 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$, with a center-of-mass energy of 14 TeV and a bunch spacing of 25 ns. This upgrade is expected to happen during the long shutdown foreseen in 2018. With the luminosity increase the higher particle flow in the ATLAS [1] Muon Spectrometer (MS) will pose stringent requirements on the rate capability of the detectors. In particular, the technologies currently used in the Small Wheels of the MS, do not guarantee to properly work at luminosity above $5 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$.

(*) Muon Atlas MicroMegas Activity; https://twiki.cern.ch/twiki/bin/viewauth/Atlas/MuonMicromegas

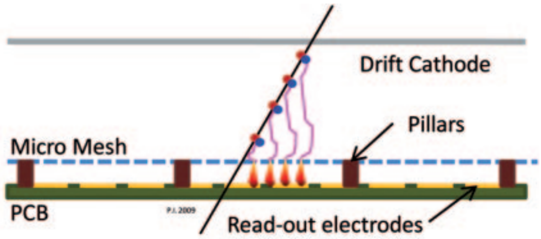


Fig. 1. – Sketch of a single micromegas detector layer for ATLAS.

For the construction of a New Small Wheel (NSW) the MAMMA Collaboration proposes to use Micromegas detectors which can provide both triggering and tracking capabilities. The requirement for a detector to be used for the NSW are: rate capability of 15 kHz/cm$^2$; high efficiency ($> 98\%$); spatial resolution of about 100 $\mu$m for impact angles up to 30°; good double-track resolution (few mm); trigger capability for bunch crossing identification; resistance to radiation; good ageing properties. Micromegas can fulfill all these requirements.

The proposed layout of the NSW is made of 128 micromegas chambers with a surface ranging between 0.5 and 2.5 m$^2$, each chamber comprises eight detector layers grouped in two quadruplets. Strips in $\eta$ (pseudorapidity defined as $\eta = -\ln(\tan(\theta/2))$, where $\theta$ is the angle with respect to the $z$-axis) and $\phi$ (the ancle in the $x$-$y$ plane) directions will give the measurement of both coordinates. The total detector surface is approximately 1200 m$^2$ and the total number of read-out channels is about 2 millions.

## 2. – R&D of micromegas for ATLAS

In 2007 the MAMMA Collaboration project started an R&D focused on the development of micromegas detectors for the upgrade of the ATLAS muon spectrometer. Figure 1 shows a sketch of a micromegas detector proposed for ATLAS: the amplification gap is 128 $\mu$m wide, the drift gap is 5 mm and the strip pitch is 500 $\mu$m. The baseline gas mixture is Ar : $CO_2$ 93:7. With this mixture and a drift field $\sim 600$ V/cm the maximum drift time in a 5 mm gap is about 100 ns, corresponding to 4 bunch crossings at LHC.

The main challenges to adapt the existing micromegas technology to an ambitious programme such as the ATLAS MS upgrade are: the construction of large-size detectors, the reduction of the spark probability and the tracking capability of a single plane for inclined tracks.

The production technique called *bulk* developed at CERN [2] opened the door to build larger-size detectors in a semi-industrial and reliable way. The efforts of the MAMMA Collaboration lead to the construction of prototype chambers of size $\sim 1.20 \times 1.20$ m$^2$ out of two detectors. The full industrialization of the production process is also being addressed in collaboration with the CERN RD51 Collaboration and specialized firms. First small prototypes have been already pruduced in industries and tested with promising results.

As other Micro Pattern Gaseous Detectors, standard micromegas are prone to spark. The solution to this problem is the introduction of a resistive layer on top of the read-out electrodes [4]. The effect of the resistive layer is to quench the discharge with a mechanism similar to the basic principle of resistive counters [3]. A specific R&D activity has been

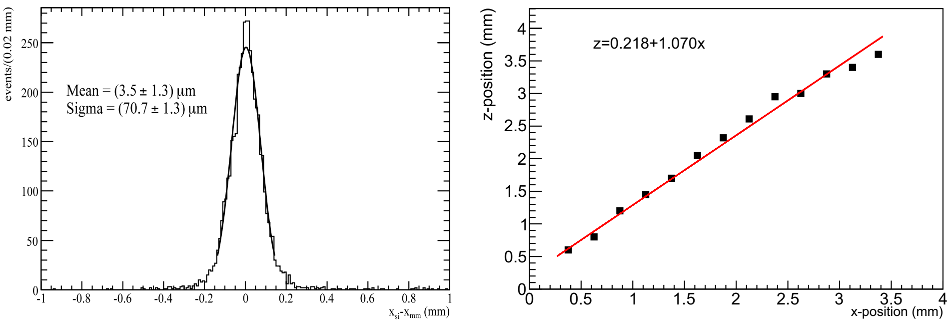


Fig. 2. – Left: spatial resolution for a micromegas with 250 $\mu$m strip pitch. Right: example of micromegas in $\mu$TPC mode.

carried out to optimize the resistive protection. In the final design the read-out strip plane is covered by an insulating layer and, on top of it, resistive strips facing the read-out strips are added. Test performed in neutron beam with particle flow up to $10^6$ Hz/cm gave excellent results demonstrating a suppression factor of spark intensity of about $10^4$. With this configuration the detector can safely work to higher amplification voltage at a gain above 10000.

The spatial resolution of micromegas with sub-mm strip pitch and analog read-out can easly go below 100 $\mu$m for perpendicular tracks by using the charge-centroid method, as shown in fig. 2, left. For impact angles(1) $\theta > 10°$ the centroid method cannot be applied anymore to guarantee the desired resolution.

We have proposed [5] to use micromegas in the $\mu$TPC mode which allows to perform a local track reconstruction in the 5 mm drift gap. This is possible with a good time resolution and highly segmented read-out electrodes: the position of each strip gives an $x$ coordinate, while the $z$ coordinate can be reconstructed from the time measurement of the hit after calibrating the $z$-$t$ relation ($z = t \cdot v_D$). An example on real test-beam data is illustrated in fig. 2, where a track with impact angle of $(44 \pm 1)°$ is reconstructed in a 4 mm drift gap. Preliminary results being encouraging, more extended tests of the $\mu$TPC principle with the final design of the ATLAS micromegas and the first prototype of the final read-out electronics are in preparation.

Other important results of the R&D activity are: the observation of an even more stable working condition of micromegas in the *inverted* configuration, *i.e.* with amplification field generated by grounding the mesh and putting HV on the read-out electrodes; and the very good performance of some prototype chambers installed for test purposes in the ATLAS cavern.

## 3. – Conclusions

The MAMMA Collaboration proposes to use Micromegas detectors for the Phase-1 upgrade of the ATLAS muon spectrometer. An intense R&D activity is demonstrating the feasibility of this project. In particular critical problems have been overcome:

(1) As impact angle we define the angle of the incoming particle with respect to a plane perpendicular to the strip plane, so that a perpendicular track has an impact angle equal to 0.

large size micromegas can now be built and the industrialization process is on the way; development of resistive micromegas has reduced the spark probability well below the acceptable limit and the $\mu$TPC concept allows to reconstruct track segments in single detector layer.

The R&D is not completed yet, but Micromegas are now a strong candidate for the ATLAS upgrade.

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