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Study of the performance of the Micromegas chambers for the ATLAS muon spectrometer upgrade.

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ABSTRACT: Micromegas (Micro Mesh Gaseous Structures) chambers and sTGC (small-strip Thin Gap Chambers) have been chosen for the upgrade of the forward muon detectors of the ATLAS experiment to provide precision tracking and trigger capabilities. The Micromegas chambers for ATLAS have been designed to allow operation in a high rate environment, to guarantee a resolution below 100 μm per point on a large area and to provide a fast trigger signal. In the last months several tests have been done on small area prototypes in order to verify that the requirements on resolution and rate capabilities are well matched. The results of the performance studies done on beams at CERN and of the ageing studies done at Saclay, are presented.

KEYWORDS: Gas Detectors; LHC; spatial resolution.

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Contents

1. Introduction

Starting from 2019, the Large Hadron Collider (LHC) will provide proton-proton collisions at the center of mass energy of 14 TeV with a luminosity that, in two separate steps (phase-I and phase-II), will reach $5\times10^{34}\text{cm}^{-2}\text{s}^{-1}$, a value exceeding the project luminosity by a factor 5. A total integrated luminosity of 3000 fb^{-1} should be collected in a time of the order of 10 years. Such an upgrade scenario is particularly demanding for the detector regions where a large flux of particles is expected, in particular the forward regions. For these regions a detector upgrade program is in progress.

The most relevant phase-I upgrade concerning the ATLAS muon spectrometer is the realization of the so called "New Small Wheels" (NSW in the following) [1]. These completely new detectors will replace the present two Small Wheels, and will be installed in the forward region at a distance of about ±7 meters along the beams from the interaction region, covering the pseudo-rapidity region $1.3<|\eta|<2.7$. The NSWs will provide both tracking and triggering capabilities.

In the following, after a description of the motivations and the main features of the NSW project, the Micromegas chambers (MM) that will be used in this project are described, and the main test-beam and irradiation tests results are presented.

2. The New Small Wheel project

The need of a New Small Wheel is based on two independent motivations, one related to tracking efficiency, the other one related to the trigger rate.

The main precision tracking detectors of the Muon Spectrometer are the MDT chambers. MDT tubes have a diameter of 3 cm and a maximum drift time of about 700 ns. At a rate exceeding

$\sim$300 kHz/tube a sizeable efficiency loss is observed, affecting the overall chamber reconstruction capability. Such a rate corresponds to the maximum expected rate at the LHC design luminosity ($1 times\ 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$).

The present forward muon trigger scheme is based on the coincidence of different layers of the TGC chambers in the so called Big Wheel, standing 6 m behind the Small Wheel. Due to the lack of a pointing criterium, this trigger is strongly affected by background particles, like halo particles, or punch-through muons, 95% of muon triggers collected in this region in standard ATLAS operation are indeed fake triggers. A trigger station in the position of the Small Wheel, able to point to the interaction region with a resolution of O(mrad), will reduce the overall trigger rate by a factor of at least 3. This will allow to run the single muon trigger with a p_T threshold of 20 GeV without any prescale. This is required in order to avoid efficiency losses in the main physics analyses.

Based on these two motivations, two different detector technologies have been chosen for the NSW: the sTGC (small-strip Thin Gap Chambers) will give the main trigger signal profiting from an improved spatial resolution, resulting in a O(mrad) angular resolution at trigger level; the Micromegas will give the precision points to determine the trajectory of the muon before the Endcap Toroid entrance without significant efficiency loss due to the high rate. A single hit resolution below 100 μm is requested for the Micromegas chambers. For each wheel the detectors will be arranged in 16 sectors for a total diameter of about 10 m. MM will consists of 2 independent "quadruplets" with 2 doublets each, for a total of 8 active layers crossed by the muon tracks.

3. The Micromegas chambers for the New Small Wheel upgrade project

The concept of the Micromegas has been developed in the ’90s [2] in the context of the so called MPGD, Micro Pattern Gaseous Detectors. The principle of operation of this detector is shown in Figure 1. A few mm gap between two parallel electrodes is filled with a gas mixture. The anode is segmented in metallic strips with a pitch of few hundred microns, and above it, at a distance of about 100 μm determined by special pillars built on the strip plane, a metallic mesh is deposited and tensioned. The electric field between the mesh and the metallic strips (the so called amplification region) is held at a large value (of order of 40$\div$50 kV/cm), while the electric field between the mesh and the cathode (the so called drift region) is much lower (of order of 600 V/cm).

Due to the high ratio between the two electric fields, the metallic mesh is essentially transparent for the ionization electrons produced in the drift region, so that they drift to the mesh, pass in the amplification region, where the avalanche takes place, and finally the signal is collected by the metallic read-out strips. Moreover, due to the field configuration, the large amount of positive ions produced in the amplification region during the avalanche, are almost entirely collected by the mesh and evacuated in a short time (of order of 100 ns) thus reducing possible spatial charge effects affecting the dead time of the detector.

The design of the Micromegas chambers for the NSW has to take into account the following specific conditions of operation.

- Muons in the NSW are expected to come at angles with respect to the direction perpendicular to the chambers, in the range 8$\div$35°. This implies that the μTPC operation mode (see below) has to be used.

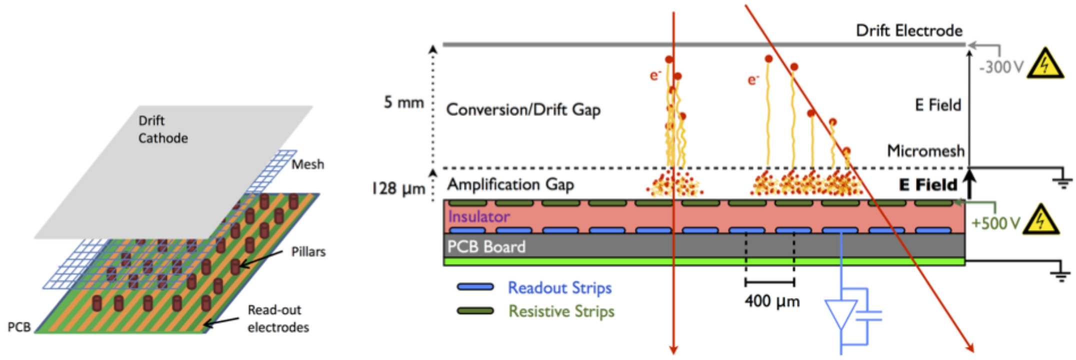

Figure 1. (Left) Exploded view of a Micromegas chamber including read-out electrodes with strips, pillars, mesh and drift cathode. (Right) Principle of operation of a Micromegas chamber. Resistive strips running above the read-out strips are also shown. The dimensions given refer to the Micromegas chambers used in the NSW.

- High fluxes of heavily ionizing particles, each releasing more than 10^3 ionization electrons (N_e) in the drift gap are expected at LHC. Given the required amplification gain G of at least 10^4, sparks are expected to happen ($N_e \times G > 10^7$). To overcome this problem by making inoffensive the possible sparks, resistive strips above the read-out strips are posed according to the scheme shown in Figure 1 and described in Ref.[3].

- A magnetic field of up to 0.3 T is present in the NSW region with different orientations. Corrections have to be applied to account for the corresponding Lorentz angle effects.

- Strip positions must be known with precision of better than 50 μm, so that the construction procedure has to guarantee such a precision and, at the same time, alignment tools have to be foreseen for the detector.

All these points have been addressed in the last years with a vast campaign of tests. In the following some of these tests are reported and discussed.

The NSW Micromegas will be operated according to the following parameters: drift gap = 5 mm, amplification gap = 128 μm, strip pitch = 400÷450 μm, strip width = 300μm; gas mixture Ar-CO_2 (93-7), HV_{drift}=300 V, HV_{ampl}=550 V. With these operating conditions, the drift velocity is about 5 cm/μs resulting in a maximum drift time of 100 ns.

4. Test results

Small size prototypes of Micromegas chambers have been exposed to beams with two main objectives: determine efficiency and spatial resolution for tracks in the angular range expected at LHC, and study the effects of the magnetic field on the chamber operation. Moreover irradiation campaigns simulating the typical exposures of several LHC years have been done aiming to see if ageing effects are significant.

Figure 2 shows the typical setup of the test-beam at the H6 line of SPS at CERN, providing 120 GeV pions. The prototypes used are 10×10 cm^2 chambers with either 400 or 250 μm pitch with resisitve strips operated in the gas and HV conditions given above. Typically eight of such chambers are used, to provide full tracking. The chambers can be rotated in such a way to provide runs with the beam at angles θ with respect to the chamber between 0 and 40° ($\theta = 0$ corresponding to orthogonal beam).

The results shown below concerns the "precision coordinate", namely the one whose strips run parallel to the resistive strips.

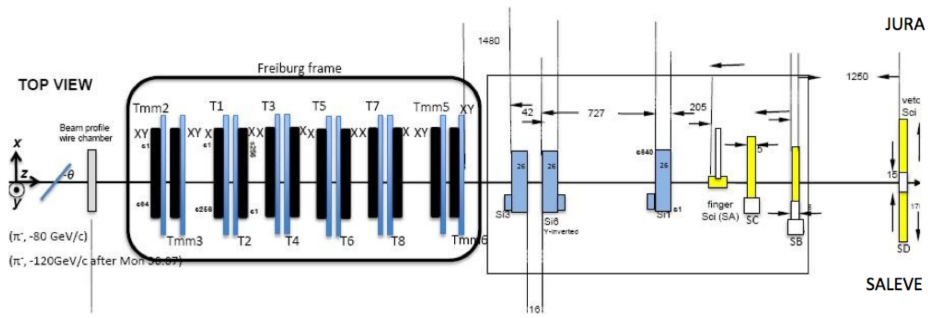

Figure 2. Schematic diagram of the H6 test-beam setup in July 2012. The twelve MM chambers are indicated in the common frame. The results reported here are given for the Tn chambers characterized by a strip pitch of 400μm, operated at the standard ATLAS working point described in the text.

4.1 Efficiency and spatial resolution

The chamber efficiency is determined by tracking using all chambers apart from one and looking for hits in the remaining chamber. Global 1÷2% inefficiencies are observed for runs with tracks at θ=0. Figure 3 shows the distribution of the position of the inefficiencies. This plot illustrates that inefficiencies are mostly due to the pillars where the mesh is held tensioned (see above), that are "towers" with 300 μm diameter and 2.5 mm pitch. The expected dead area due to pillars is $\pi(0.3/2)^2/2.5^2 = 1.1\%$ in agreement with measurement. Apart from pillars the detector is fully efficient.

The precision coordinate x can be obtained in two ways: either making the charge centroid of the fired strips (that is the best algorithm for almost orthogonal tracks) or using the so called "μTPC mode" [4] for tracks at larger values of θ. The μTPC concept is described in Figure 4. It requires: the measurement of the ionization electrons drift time on each strip; the determination through a linear fit of the "tracklet" parameters, as shown in Figure 4; finally the evaluation of the x coordinate of the track at half gap x_{half}.

The spatial resolution is determined as a function of θ using both algorithms, by taking the distribution of the differences between the reconstructed positions in two adjacent chambers and dividing the width by $\sqrt{2}$, the effect of the beam angular spread being negligible. The results, shown in Figure 5, indicate clearly the opposite behaviours of the two methods as a function of the angle θ. Moreover, for each event the two algorithms are combined giving an x value having a resolution that is well below 100μm in the full angular range. Such a combination profits from the observed anti-correlation in the position reconstruction between the two methods.

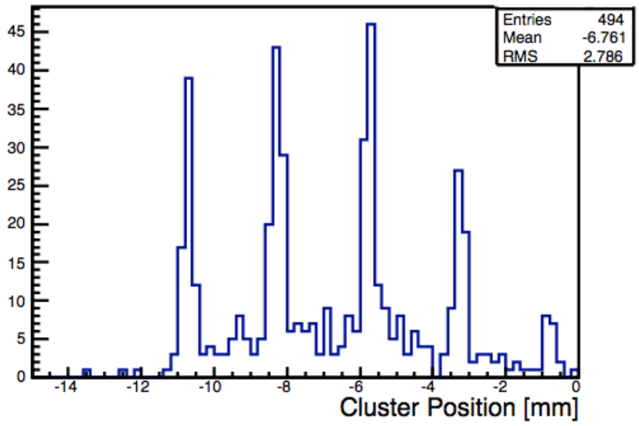

Figure 3. Distribution of the positions of the tracks impinging on a chamber when no hits are observed in the chamber. The peaks are clearly due to the pillars as discussed in the text.

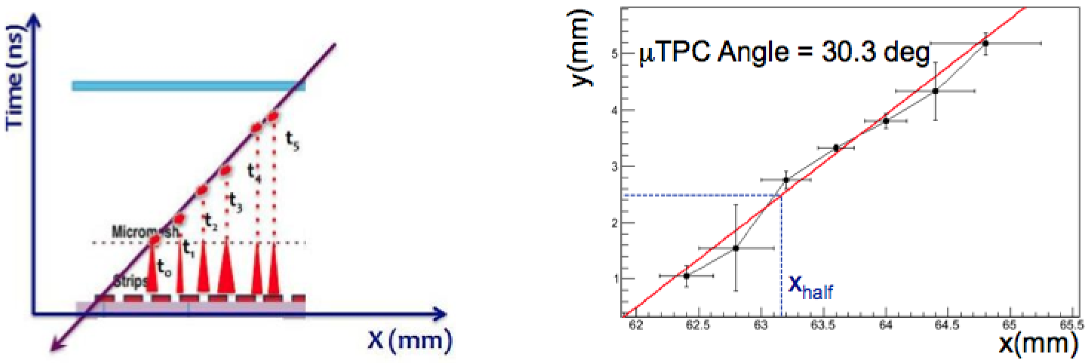

Figure 4. (Left) Concept of μTPC mode. The measurement of the strip signal times, once the drift velocity is known, allows to reconstruct the tracklet. (Right) Example of a tracklet in test-beam data. The error-bars on the points depend on the charge collected by each strip. The definition of the x_{half} is also shown.

4.2 Behaviour in magnetic field

A magnetic field component orthogonal to the electric field directly affects the drift motion of the ionization electrons, and systematically biases the measurement of the precision coordinate x. The typical displacements expected in the working conditions of the ATLAS Micromegas are of the order of 2.5 mm $\times$ B(T), so that systematics of the order of hundred microns are expected in the NSW region for both centroid and μTPC reconstruction. "Singular" configurations are expected when θ is close to the Lorentz angle. In these focusing configurations the ionization cluster is conÞned to a very small number of strips. On the other hand, when the Lorentz angle has different sign with respect to θ the ionization cluster is spread over a larger number of strips (defocusing configuration). The effect is schematically described in Figure 6

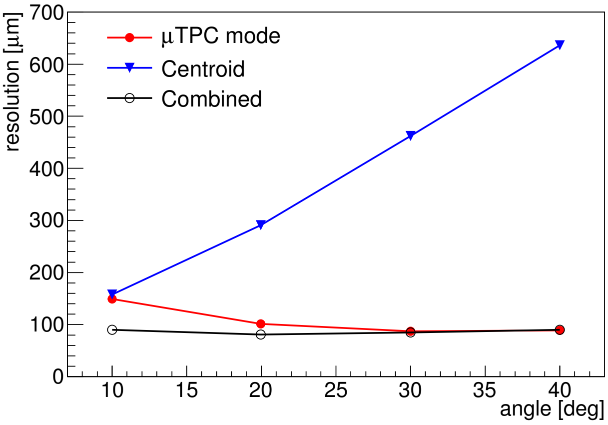

Figure 5. MM spatial resolution as a function of the beam incidence angle. Resolutions obtained using the charge centroid and the μTPC mode are compared, together with the one obtained by combining the two methods. In the NSW the typical angles of incidence are expected to be between 8 and 35 ^{o}.

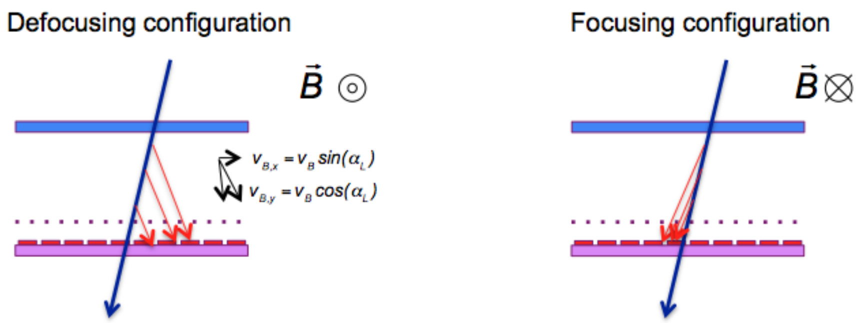

Figure 6. At a given angle θ of the track on the MM chamber, a focusing or defocusing effect of the Lorentz angle is expected, depending on the sign of the magnetic field.

A dedicated test-beam has been carried out at the CERN H2 beam, with the MM chambers inside a magnet providing a field of variable intensity orthogonal to the electric field of the chambers. The Lorentz angle has been measured at different values of the magnetic field and has been compared to simulations based on Garfield [5]. A good agreement is found, as shown in Figure 7.

Spatial resolutions for two different values of θ ($\pm$ 10°) and magnetic field values up to 1 T are shown in Figure 8 for both charge centroid and μTPC method. As can be seen the resolution is at the same level of the B=0 measurement. In the "singular" configuration (B=0.2 T at $\theta = -10^o$) the centroid method allows to recover the resolution worsening of the μTPC method.

Particular care is needed to avoid biases in the measurement. MM chambers mounted in doublets with the read-out electrodes back-to-back allow a self-correction, since the effect of the Lorentz angle in the two gaps is equal and opposite, provided that the magnetic field is uniform among the two gaps, as shown in Figure 9. For this reason all chambers will be mounted in this

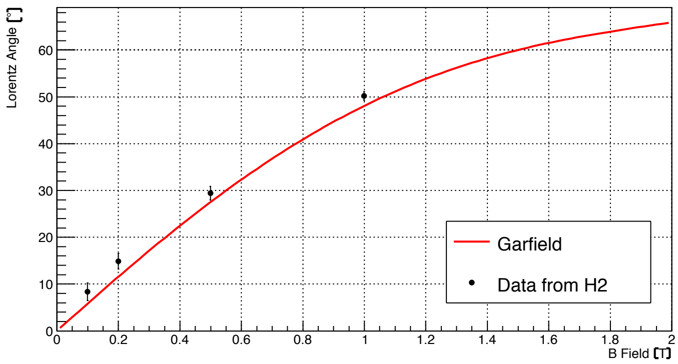

Figure 7. Measured values of the Lorentz angle compared to the Garfield predictions. The results are in good agreement. The measurement shows that at fields of 0.3 T, as present at the location of the NSW, we expect Lorentz angles of up to 20^o.

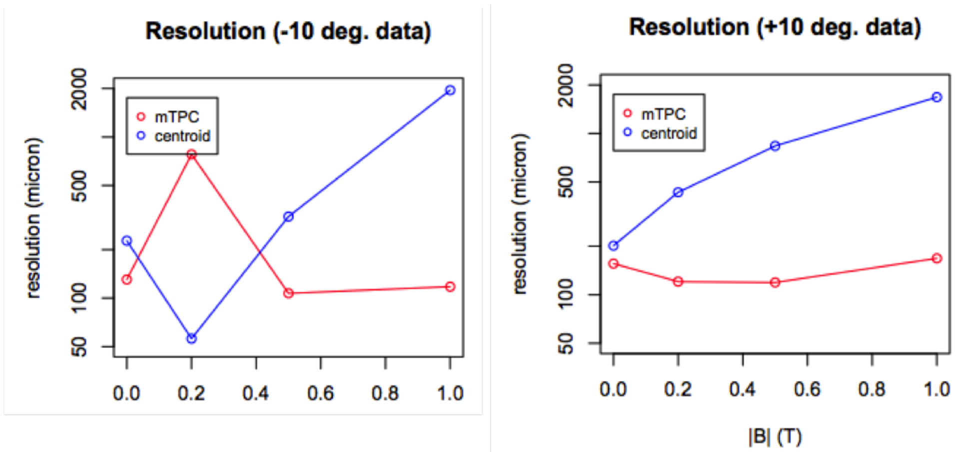

Figure 8. Spatial resolutions as a function of the magnetic field for two angular configurations, namely $\pm 10^o$. Note that the resolution is slightly worse with respect to the one shown above, since in this test, the HV_{drift} was held at a lower value.

configuration.

4.3 Ageing tests

An extensive program of ageing tests of small Micromegas prototypes (10×10 cm^2) has been carried out at Saclay in 2012 [6]. The general concept is to expose one chamber to a full irradiation with X-rays, neutrons, γ rays and α particles, simulating a charge deposit equivalent of $5\div10$ years at the high luminosity LHC, and compare it to another unexposed chamber. In the end both chambers are tested with a muon beam to measure efficiency and spatial resolution. The results, shown in Figure 10 show no significant effect.

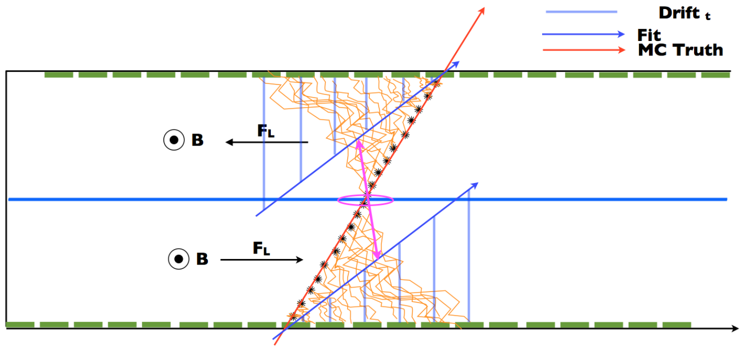

Figure 9. Schematic view of the effect of a magnetic field on a Micromegas doublet. The Lorentz force in the two gaps acts in the opposite direction, so that the mean of the coordinates measured in the two chambers provides a bias-free estimator of the precision coordinate.

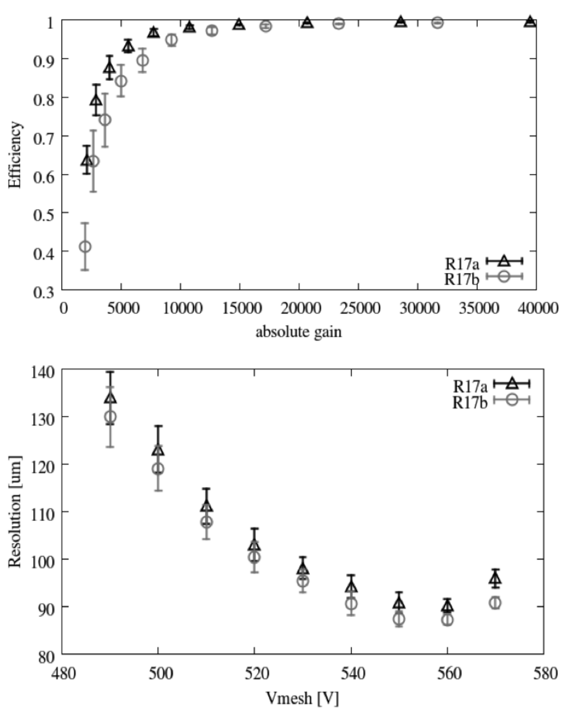

Figure 10. (Upper) Chamber efficiency as a function of the absolute gain for the irradiated (R17a) and unirradiated chamber (R17b). (Lower) Comparison of spatial resolution (charge centroid for $\theta = 0$ tracks) for R17a and R17b chambers as a function of HV_{ampl}. Note that HV_{ampl}=550 V (the optimal resolution) corresponds to a gain of about 20000. In both cases no significant deterioration is observed.

5. Summary and outlook

The Micromegas chambers have been chosen as one of the detector technologies for the upgrade of the ATLAS muon spectrometer in the forward region. The tests done on small size prototypes show that these detectors provide the required performance in terms of efficiency, spatial resolution and operation in the expected magnetic field. Moreover, no significant ageing effects from irradiation similar to those expected at High luminosity LHC have been observed. In the next months the collaboration will build the first large size detectors and will have to prove that the required mechanical accuracy and the required performance can be maintained over large dimensions. Subsequently serial production will be started to allow an installation in ATLAS by 2018.

Acknowledgments

References

[1] The ATLAS Collaboration, *New Small Wheel, Technical Design Report*, CERN-LHCC-2013-006.

[2] Y. Giomataris, P. Rebourgeard, J. Robert, and G. Charpak *A High granularity position sensitive gaseous detector for high particle flux environments*, Nucl.Instrum. and Meth. **A376** (1996) 29-35.

[3] T. Alexopoulos, J. Burnens, R. de Oliveira, G. Glonti, O. Pizzirusso, P. V., G. Sekhniaidze, G. Tsipolitis, and J. Wotschack, *A spark-resistant bulk-Micromegas chamber for high-rate applications*, Nucl.Instrum. and Meth.. **A640** (2011) 110-118.

[4] T.Alexopoulos et al., *Development of large size Micromegas detector for the upgrade of the ATLAS muon system*, Nucl.Instrum. and Meth.. **A617** (2010) 161-165.

[5] R.Veenhof, *Garfield - simulation of the gaseous detectors*, http://garfield.web.cern.ch/garfield/

[6] J.Galan et al., *An ageing study of resistive Micromegas for the HL-LHC environment*, JINST **8** (2013) P04028.