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Micromegas Detectors for the Upgrade of the ATLAS Muon Spectrometer

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Abstract: The upcoming luminosity upgrades of the LHC accelerator up to an ultimate value of $5\times10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ require a replacement of the innermost forward muon tracking stations (Small Wheels) of the ATLAS detector in 2018 and 2019. These New Small Wheels (NSW) will contain resistive strip micromegas and small-strip Thin Gap Chamber detectors. The resistive strip micromegas detector concept is presented, together with the μTPC track reconstruction technique for a single plane track angle measurement. The mechanical layout of the NSW micromegas chambers is discussed as well, as the features of the specially designed front-end electronics. A pre-series micromegas chamber will be installed within ATLAS already in 2014. It will be integrated into the ATLAS data acquisition system with help of a custom micromegas Read Out Driver (ROD), based on the Scalable Readout System (SRS).

Keywords: Muon spectrometers, Micropattern gaseous detectors, Detector design and construction technologies and materials.

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1. Status of the present ATLAS forward muon system

The Large Hadron Collider (LHC) at CERN started physics operation in 2009 and is currently in its first intensive maintenance phase, the Long Shutdown 1 (LS1), where consolidation and upgrade work allows to operate at the design values for luminosity and energy of $1\times10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and 14 TeV during the next run period.

The Long Shutdown 2 (LS2) period in 2018 and 2019 will then allow to increase the luminosity beyond the design value to about $2-3\times10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Further upgrade phases after 2022 will finally increase the luminosity to ultimate values up to $5\times10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The present muon forward trigger configuration of the ATLAS[1] detector is based only on decisions of the Thin Gap Chamber (TGC) detectors of the second out of three end-cap stations (EM, or "Big Wheel", see the yellow box in Figure 1). Geometrically, this trigger system alone is not able to distinguish between particles originated from the interaction point, or from other uncorrelated sources, as depicted in Figure 2, as the incident angle is only measured locally.

Therefore the endcap muon trigger selection is presently confronted with a large number of "fake" triggers, like the cases B and C illustrated in Figure 2. As the uncorrelated particle flux background within the ATLAS detector increases at least proportionally with the luminosity, the resulting trigger rate will furthermore increase the demands on the data acquisition system of the ATLAS detector.

An increase of the trigger energy threshold to reduce the trigger rate is highly undesirable, leading to a significant loss of physics data that include muons with transverse momentum of 10 to 20 GeV.

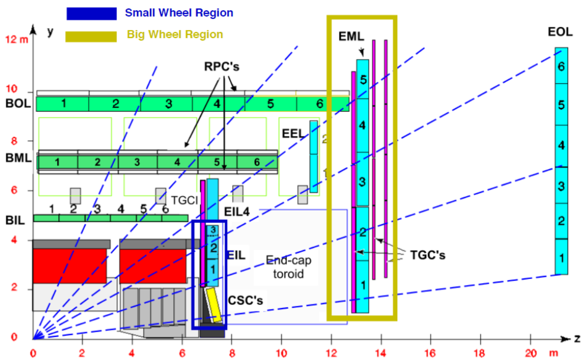

Figure 1. Quadrant of the ATLAS muon spectrometer, with barrel layers (green) and end cap stations (blue). The innermost end cap station is referred to as Small Wheel. Trigger chambers with angular reconstruction capability are included only in the EML part, see the yellow box[2].

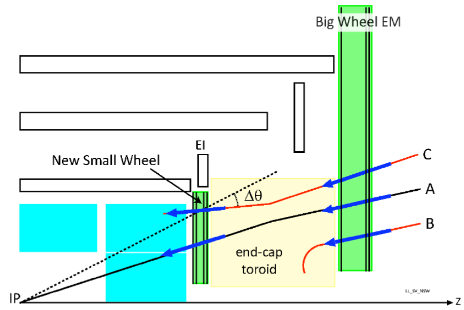

Figure 2. Samples of particle trajectories that fire a muon trigger based on the track reconstruction of only the Big Wheel detectors. Only the case A represents a muon from the interaction point. Cases B and C represent uncorrelated particles that could be excluded when an innermost station (New Small Wheel) refines the selection by an additional angular measurement[2].

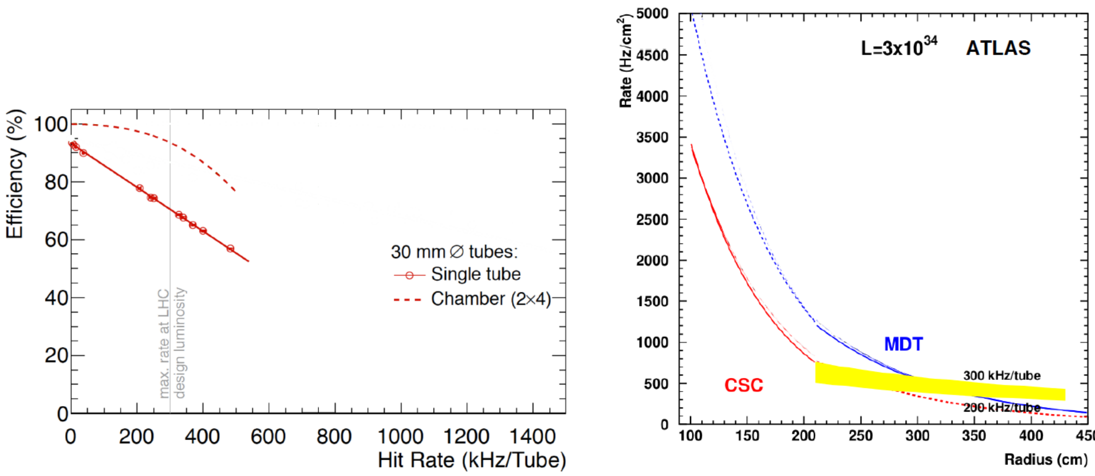

Figure 3. Left: Degradation of Small Wheel MDT detector tracking efficiency with increasing hit rate. Above the LHC design luminosity the efficiency for a MDT chamber with 2×4 tube layers decreases rapidly (dashed line). Right: Expected hit rates in the Small Wheel region for a luminosity of $3 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (right). The rate exceeds the capabilities of the inner parts of the presently installed MDT chambers[2].

The innermost elements of the ATLAS muon system in forward direction are the Small Wheel (SW) stations. Currently Cathode Strip Chambers (CSC), Thin Gap Chambers (TGC) and Monitored Drift Tubes (MDT) are used for precision track reconstruction.

With the increased background particle hit rate at future luminosity upgrades, the track reconstruction efficiency of the MDT detectors decreases to an unacceptable level, see Figure 3.

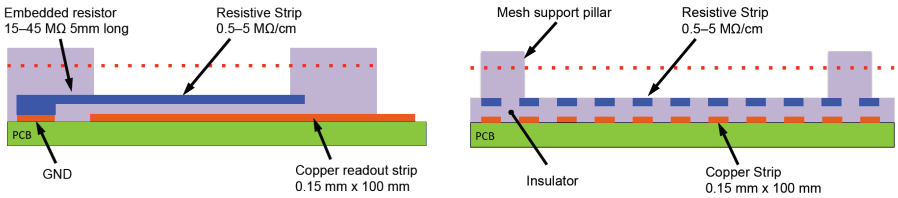

Figure 4. Schema of the resistive strip micromegas principle. An additional layer of high resistivity strips covers the readout strips for efficient discharge protection and high efficiency[2].

2. The New Small Wheel project

To alleviate the future limitations mentioned in section 1, the ATLAS collaboration decided to replace the present Small Wheels with New Small Wheels (NSW) during the LS2 period in 2018 and 2019.

These detectors will occupy the same location and envelope as the present system, but are equipped with two fully redundant and high-rate capable detector technologies, micromegas[3] and small-strip Thin Gap Chambers (sTGC). These detector systems allow to overcome the efficiency limitation, as well as the fake trigger issue. The NSW detectors will contribute to the muon trigger system with high angular resolution of 1 mrad, to reject triggers from particles that do not originate from the interaction point.

This article describes the micromegas detectors of the NSW stations.

2.1 Resistrive Strip micromegas

Micromegas detectors are planar gaseous detectors, with three main components:

A drift region is defined by a copper cathode and a fine woven metallic mesh with an electric field of around 600 V/cm applied in between. Ionizing particles crossing this volume generate electron-ion pairs, the electrons drift towards the mesh. An anode readout structure below the mesh is separated by a 128 μm thick amplification volume, where a high electric field of around 40 kV/cm is applied. The electric field configuration guides most of the drift electrons through the mesh into the amplification region, where an avalanche process generates a charge signal on the readout structure.

The occasional occurrence of non-destructive discharges in between mesh and anode and thus potential inefficiency during the restoration of the amplification field is effectively suppressed by the addition of a layer of resistive strips on top of the copper readout strips, separated from them by a thin insulationg layer[4]. The electron signal on the resistive strips capacitively couples to the copper strips which are read out using charge sensitive frontend electronics. See Figure 4 for a schematic view of the detector layout.

2.2 TPC like track reconstruction method

Tracks of crossing particles are reconstructed by the charge signal on the readout strips. For perpendicular incidence this is the weighted sum of the strip charges (centroid method). Generally, more than one strip shows a signal due to induction and electron diffusion during drift and amplification process, and the coupling of the signal to neighboring strips.

For inclined tracks also the arrival time of the electrons on the different readout strips is used to reconstruct the track angle in a single detector plane, the so called µTPC mode, similar to Time Projection Chambers, as shown in Figure 5.

The results obtained using the µTPC method show an excellent agreement with simulations, see Figure 6. The well understood remaining systematic discrepancy between incident angle and reconstructed angle is due to coupling of the signal in between neighboring strips, and can be easily corrected for.

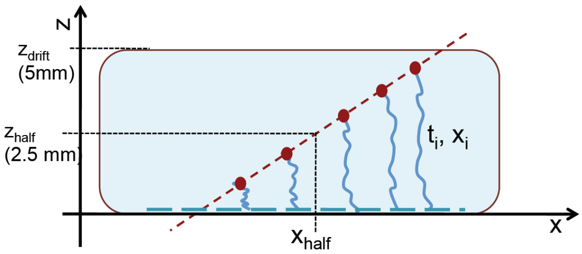

Figure 5. Principle of µTPC track angle reconstruction. With known drift time, the drift distance for electrons arriving on different readout strips can be calculated from the signal arriving time. This allows to calculate the particle angle within a single detector plane[2].

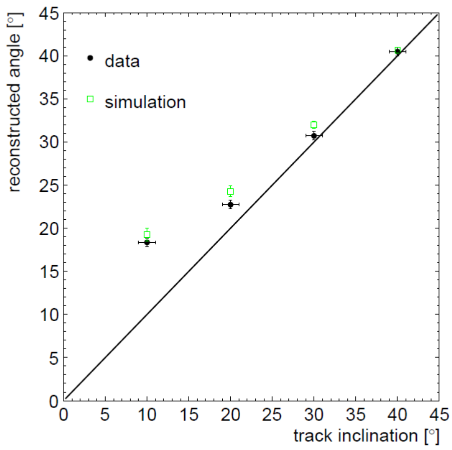

Figure 6. Comparison of micromegas reconstructed track angles from a test beam experiment with known incident angle and simulations. The systematic deviation of the reconstructed from the incident angle is mostly due to capacitive signal coupling between adjacent strips and can be corrected for[5].

The centroid method shows best results for perpendicular incident, whereas the µTPC method shows a better resolution with increasing track angle. The combination of both methods enables an angle independent resolution below 100 µm over the full angular acceptance of the NSWs, see Figure 7.

2.3 NSW sector layout

The NSWs need to fit the envelope of the present Small Wheels. The system will be build from two interleaving different types of sectors, large and small ones. Adjacent sectors overlap for full coverage. There are a total of 16 sectors per wheel, Figure 8 shows the layout.

Each micromegas sector is subdivided into an inner and an outer module, for a total of four different module types. These will be produced in France, at institute consortia in Italy and Germany, and in a collaboration between Russia, Greece and CERN.

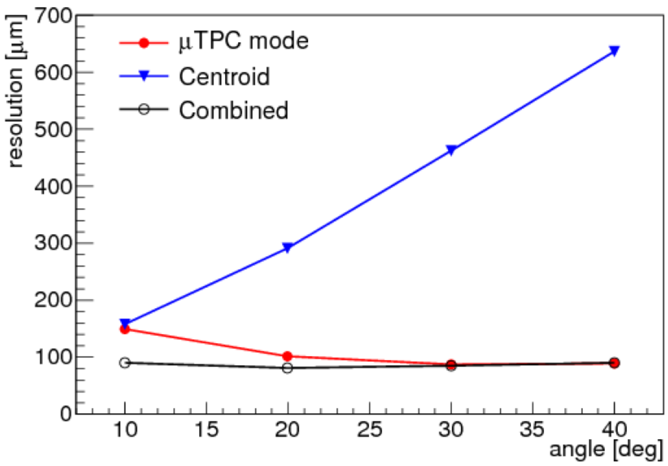

Figure 7. Obtained micromegas spatial resolutions with the centroid method and the μTPC method for different incident angles. The centroid method works best for low angles, whereas the μTPC method achieves best results at large angles. The combination of both methods ensures a spatial resolution below 100 μm over the relevant range of angles in the NSW[2].

Each NSW sector consists of eight layers of sTGC detectors and eight layers of micromegas, each divided in two quadruplets as shown in Figure 9. The sTGC layers are optimized for triggering and are therefore located on the outer faces. They are not shown in detail in Figure 9.

Each of the micromegas quadruplets consists of four detection layers, made from five aluminum honeycomb sandwich panels, faced with standard FR4 printed circuit board material, that also carries the striped readout structures. The size of the four different types of quadruplets ranges up to about 3.1 m^2 for a single detector unit. The readout planes will have a strip pitch of 450 μm. Two of each quadruplet planes carry strips at a stereo angle of $\pm 1.5^\circ$ compared to the other two for a second coordinate measurement of particle tracks. The total number of readout channels is 1 M per wheel.

In order to achieve the required particle tracking resolution of ≤100 μm, it is necessary to assemble the quadruplets and modules with a mechanical precision of ≤40 μm, and therefore precision tooling must be used during construction.

2.4 Readout electronics

To read out the NSW precision tracking and fast triggering data with high performance, a common frontend ASIC has been developed for both, sTGC and micromegas detectors, called VMM[6].

The VMM features on-chip digitization providing the following output: pulse height and timing together with a neighboring logic for signal tails below the threshold. This represents an effective zero suppression of channels without physics signal. The first iteration of the chip (VMM1) that did not contain the digitization logic yet has been successfully tested. The version VMM2 is presently being produced and contains every functionality except for the redundant storage of register contents that is necessary to achieve radiation insensitivity of the chip configuration data. The NSWs will be equipped with the final and complete version VMM3.

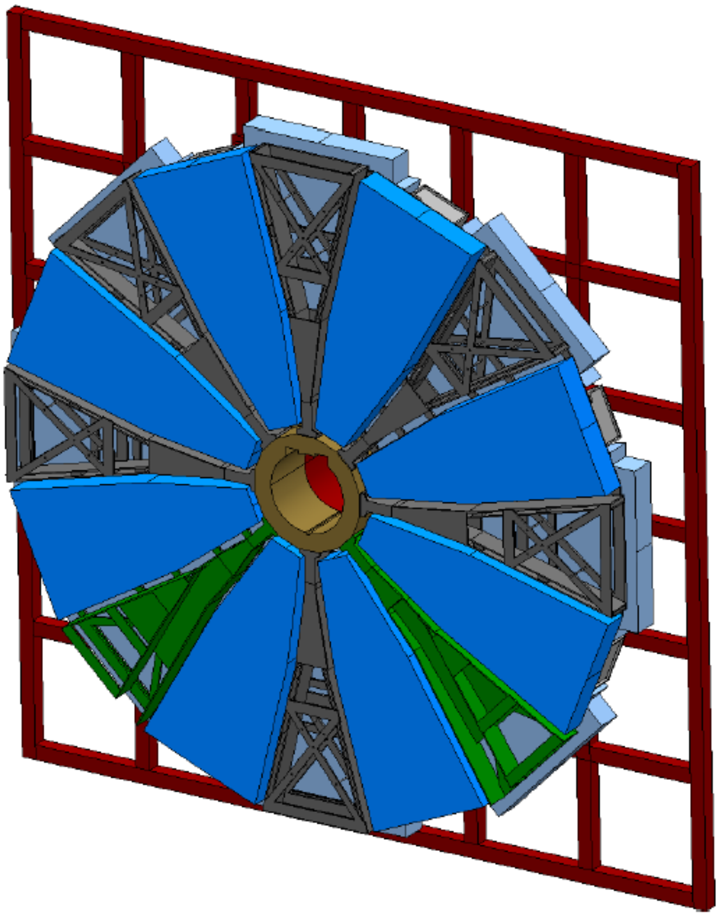

Figure 8. Schematic drawing of the NSW layout. The front face shows the small sectors, whereas the large sectors are installed on the back side in an interleaving fashion[2].

Figure 10 shows the installation of the different electronics components, as well as the eight-fold segmentation of the readout boards forming a sector. Five boards belong to the inner module, three boards to the outer one.

3. Pre-Series micromegas installation in ATLAS

The presently ongoing Long Shutdown 1 offers the opportunity to install a pre-series micromegas chamber on one of the Small Wheels for operation within ATLAS already during the RUN II period 2015 - 2017.

A four-layer trapezoidal chamber with a design very close to the final NSWs micromegas detectors is being produced for installation in summer 2014. The chamber will be installed within unoccupied space on a Small Wheel CSC module, and will be fully integrated into the ATLAS data acquisition chain for a particle track comparison with the Small Wheel measurements on an event-by-event basis.

Therefore an ATLAS compatible Read Out Driver (ROD) has been developed[7], based on the RD51[8] Scalable Readout System (SRS)[9].

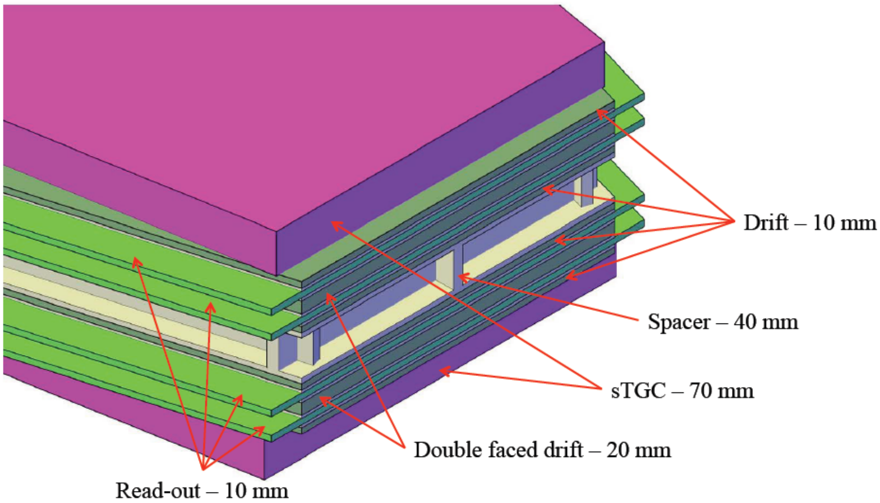

Figure 9. Schematic view of the NSW sector structure. Micromegas detectors are divided in two quadruplets of four detection layers each. A detailed view of the sTGC construction is omitted in the Figure[2].

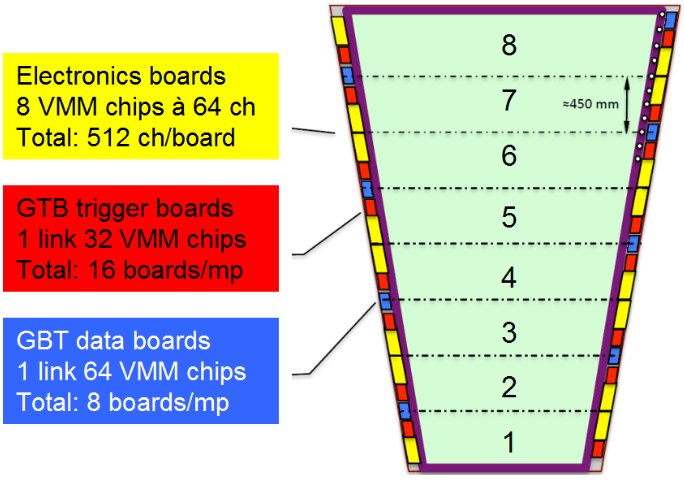

Figure 10. Distribution of the readout electronics components for a NSW micromegas sector. The subdivision in the inner and outer module lies in between readout boards number five and six and is not shown here.

The micromegas ROD has been successfully tested at different occasions, including the Cosmic Ray Facility (CRF) of the Munich University in Garching, see Figure 11. Here a large m^2-sized prototype micromegas chamber (L1) has been integrated into the data acquisition system. As the CRF makes use of ATLAS MDT chambers for reference track measurement, its electronics layout is very similar to the ATLAS environment.

In addition the readout system has been successfully operated in stand-alone mode within the ATLAS environment itself during the last months of 2012 LHC operation before the beginning of shutdown LS1, together with five small prototype micromegas detectors that were operated smoothly during the RUN I period[10].

Figure 11. The Munich University Cosmic Ray Facility, with two $9\,\mathrm{m}^2$ BOS MDT chambers for cosmic muon reference tracking, together with a prototype micromegas chamber in between, being read out by the SRS based Micromegas ROD.

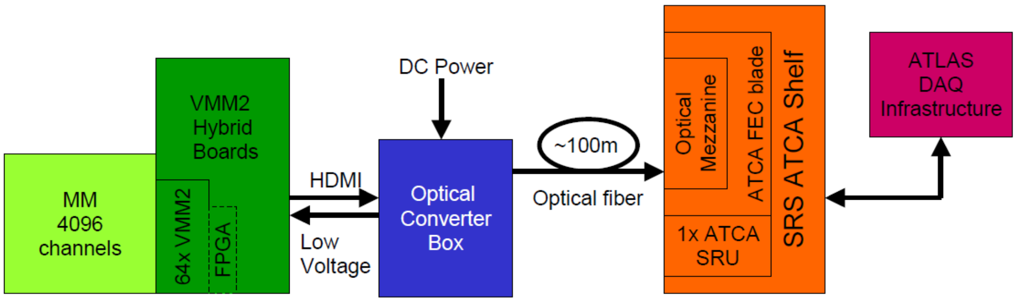

Figure 12. Schematic drawing of the electronics components that will integrate a pre-series micromegas detector into the ATLAS data acquisition system already in the run period prior to the NSW installation[7].

Figure 12 shows a scheme for the integration of the micromegas chamber into the ATLAS data acquisition environment by means of ATCA form-factor SRS electronics.

4. Conclusion

Future LHC luminosity upgrades will lead to rates in the ATLAS Small Wheels that are too high for the presently installed forward muon detectors.

During the LHC Long Shutdown 2, the innermost endcap muon stations will be replaced by New Small Wheels, which contain resistive strip micromegas as precision tracking and trigger devices.

This high-rate capable technology shows an excellent spatial resolution over a large range of track angles. Its integration into the muon trigger will resolve issues with fake muon triggers.

The size of the single detector modules reaches up to 3.1 m^2, containing more than 80 k readout channels each, for a total of 1 M channels per wheel, resulting in the largest micromegas detector system ever built.

A pre-series micromegas chamber with 4096 channels will be installed on a Small Wheel already in 2014. Its integration into the ATLAS data acquisition infrastructure yields the opportunity to operate this chamber with four readout planes under real LHC conditions, and to study its performance within the ATLAS muon tracking system.

Acknowledgments

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References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider* 2008 *JINST* **3** P08003.

[2] ATLAS Collaboration, *ATLAS New Small Wheel Technical Design Report ATLAS - TDR-20-2013*.

[3] Y. Giomataris, P. Rebourgeard, J. Robert, G. Charpak, *Micromegas: a high-granularity position sensitive gaseous detector for high particle-flux environments*, *Nucl. Instrum. Meth. A* **376** (1996) 29 - 35.

[4] T. Alexopoulos et al., *A spark-resistant bulk-micromegas chamber for high-rate applications*, *Nucl. Instrum. Meth. A* **640** Issue 1 (2011) 110 - 118.

[5] J. Bortfeldt, *Development of Floating Strip Micromegas Detectors*, *Dissertation, LMU Munich* 2014.

[6] G. De Geronimo et al., *VMM1 - An ASIC for Micropattern Detectors*, *IEEE Transactions on Nuclear Science* **60** (2013) 2314 - 2321.

[7] A. Zibell, *High-Rate Irradiation of 15mm Muon Drift Tubes and Development of an ATLAS Compatible Readout Driver for Micromegas Detectors*, *Dissertation, LMU Munich* 2014.

[8] L. Ropelewski et al., *R&D Proposal Development of Micro-Pattern Gas Detector Technologies*, *CERN-LHCC-2008-011. LHCC-P-001* (2008).

[9] S. Martoiu, H. Muller, A. Tarazona, J. Toledo, *Development of the scalable readout system for micro-pattern gas detectors and other applications*, 2013 *JINST* **8** C03015.

[10] T. Alexopoulos et al., *Using Micromegas in ATLAS to Monitor the Luminosity*, *ATL-MUON-PUB-2013-002* (2013).