

Development and test of the DAQ system for a Micromegas prototype to be installed in the ATLAS experiment

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Abstract. A Micromegas (MM) quadruplet prototype with an active area of 0.5 m^2 that adopts the general design foreseen for the upgrade of the innermost forward muon tracking systems (Small Wheels) of the ATLAS detector in 2018-2019, has been built at CERN and is going to be tested in the ATLAS cavern environment during the LHC RUN-II period 2015-2017.

The integration of this prototype detector into the ATLAS data acquisition system using custom ATCA equipment is presented. An ATLAS compatible Read Out Driver (ROD) based on the Scalable Readout System (SRS), the Scalable Readout Unit (SRU), will be used in order to transmit the data after generating valid event fragments to the high-level Read Out System (ROS). The SRU will be synchronized with the LHC bunch crossing clock (40.08 MHz) and will receive the Level-1 trigger signals from the Central Trigger Processor (CTP) through the TTCrx receiver ASIC. The configuration of the system will be driven directly from the ATLAS Run Control System. By using the ATLAS TDAQ Software, a dedicated Micromegas segment has been implemented, in order to include the detector inside the main ATLAS DAQ partition. A full set of tests, on the hardware and software aspects, is presented.

1. The ATLAS New Small Wheel upgrade project

The Large Hadron Collider (LHC) at CERN will increase the instantaneous luminosity up to $5 - 7 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ over the coming decade, undergoing several upgrades. As a consequence of this upgrade program, the innermost end-cap stations of the ATLAS [1] Muon Spectrometer will be replaced with the so-called New Small Wheels (NSW) [2] during the LHC long shutdown in 2018/2019, in order to deal with the increased background hit rate as well as the increased fake triggering rate.

Each NSW will consist of 16 overlapping small and large sectors, with two multilayers of four small-strip Thin Gap Chambers (sTGC) and four Micromegas (MM) [3] detector planes (Figure 1). Both detector technologies will be used for triggering and precision tracking measurements, with the sTGCs as main triggering system and the Micromegas as main tracking system.



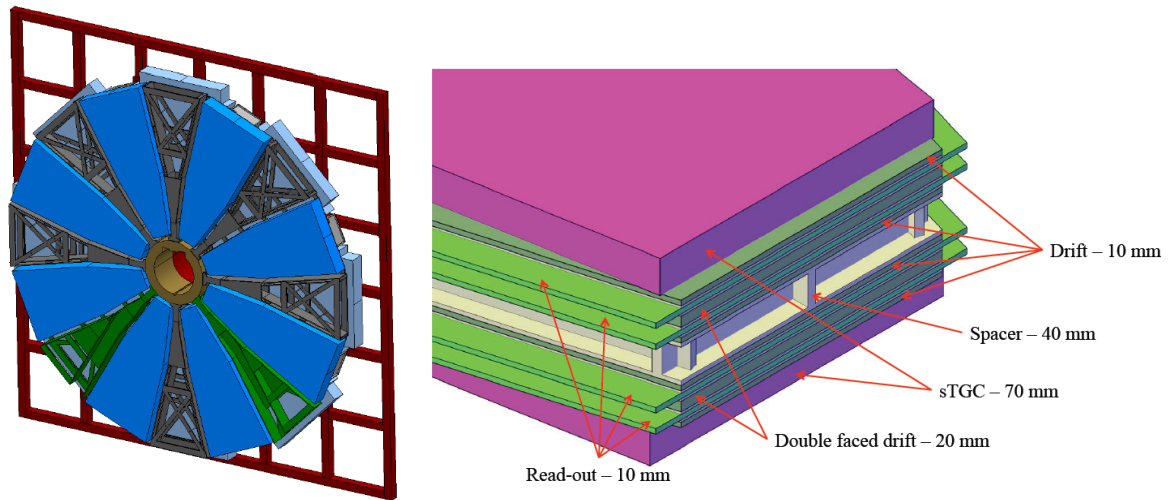


Figure 1. Left: Schematic drawing of the New Small Wheel layout, Right: Sector composition. Large and small sectors are installed in an interleaving arrangement, consisting of multiple layers of Micromegas and sTGC detectors, the latter are not shown in detail. Drift and read-out are terms referring to the different types of panels used in the construction [2].

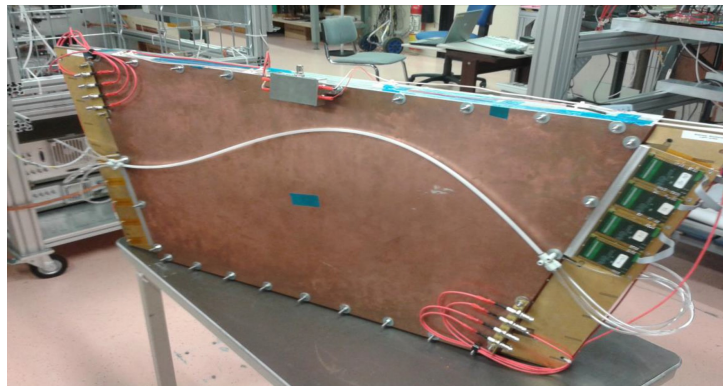


Figure 2. The MMSW prototype chamber, following the general NSW Micromegas design. It contains four active layers with an active area of 0.5 m^2 per plane with 1024 readout strips each.

2. The Micromegas Small Wheel (MMSW) prototype

A Micromegas quadruplet prototype detector [4] (Figure 2) with an active area of 0.5 m^2 per layer has been built, following the general design foreseen for the ATLAS NSW Micromegas detectors. Each layer consists of 1024 readout strips with a strip pitch of $415 \mu\text{m}$. The prototype detector is based on the resistive-strip technology [5], where the copper readout strips are covered with a highly resistive strip pattern, separated by an insulating layer of $50 \mu\text{m}$ Kapton foil. Using this technology, signals are coupled onto the copper readout strips capacitively, whereas the resistive layer provides an excellent protection from discharges within the amplification region.

3. MMSW installation in ATLAS

Preliminary characterization of the MMSW prototype chamber has been performed in laboratory conditions at CERN using cosmic rays and X-ray irradiation, as well as in several test beam campaigns. Furthermore, in order to investigate the behavior of the chamber under

expected experimental conditions, this prototype detector will be installed within the ATLAS experimental cavern during this year (2015).

The first location foreseen for installation is the scaffolding structure at the ATLAS cavern wall in the forward direction, a few floors above the beam pipe. In this place, muons originating in proton collisions hit the chamber at 20° angle with respect to the beam pipe. This angle is deemed optimal for studies of the Micro-TPC angular reconstruction method.

During an upcoming intermediate shutdown the chamber is foreseen to be moved on to one of the present Small Wheels, in order to test and verify the functionality of the custom electronics and front-end chips foreseen for the NSW upgrade.

The full integration of the detector and its readout schema into the ATLAS Data Acquisition (DAQ) chain, as an independent and additional subsystem, will allow a comparison of the recorded muon tracks with measurements from the other ATLAS sub-detectors, on an event-by-event basis.

4. MMSW readout in ATLAS with the Scalable Readout System (SRS)

The task of interfacing the MMSW detector to the ATLAS TDAQ system can be performed by using hardware components from the Scalable Readout System [6] (SRS) series electronics, developed within the RD51 [7] collaboration.

4.1. The ATLAS Trigger and DAQ system

To reduce the data rate from the initial nominal 40 MHz bunch crossing rate, the ATLAS TDAQ system uses a two-stage triggering system during the LHC Run-II period. The Level-1 trigger implemented in dedicated hardware provides a fixed-latency trigger signal for the subsystems, indicating events to be further processed at a maximum rate of 100 kHz. For each Level-1 trigger data are moved from the front-end electronics to the sub-detector specific hardware components called Read Out Drivers (ROD). Event data built in RODs is subsequently moved to the Read Out Systems (ROS) via an ATLAS specific optical fiber protocol, the so-called S-Link [8].

The ROS PCs consist of Commercial Off The Shelf (COTS) server hardware with broadband ethernet connectivity and custom hardware for S-Link data reception. A further reduction of the data rate down to the level that can be recorded is performed via software algorithms, running on PC farms, the so called High Level Trigger (HLT). Using the HLT decisions for each Level 1 trigger, the data buffered on the ROS gets either deleted or permanently stored.

4.2. SRS Scalable Readout Unit (SRU) as ATLAS ROD

An optional hardware item of the SRS readout chain is the Scalable Readout Unit (SRU) FPGA board. Several hardware features are available on the board, in order to interface the SRU as fully compliant ATLAS ROD module. These include:

- (i) A TTCrx [9] receiver ASIC, used to receive triggers and asynchronous data from the ATLAS trigger network, as well as the LHC bunch crossing clock for synchronous operation
- (ii) LEMO00 plugs for miscellaneous purposes like the connection to the ATLAS BUSY tree structure
- (iii) SFP+ plugs for network connectivity and data connection to the ATLAS ROS via an emulated S-Link
- (iv) 40 RJ45 plugs with LVDS signal pairs, using the Data Trigger Clock and Control (DTCC) link [10] protocol for communication and readout of the front-end electronics, as well as synchronization and trigger propagation.
- (v) A Gigabit ethernet port for slow control commands

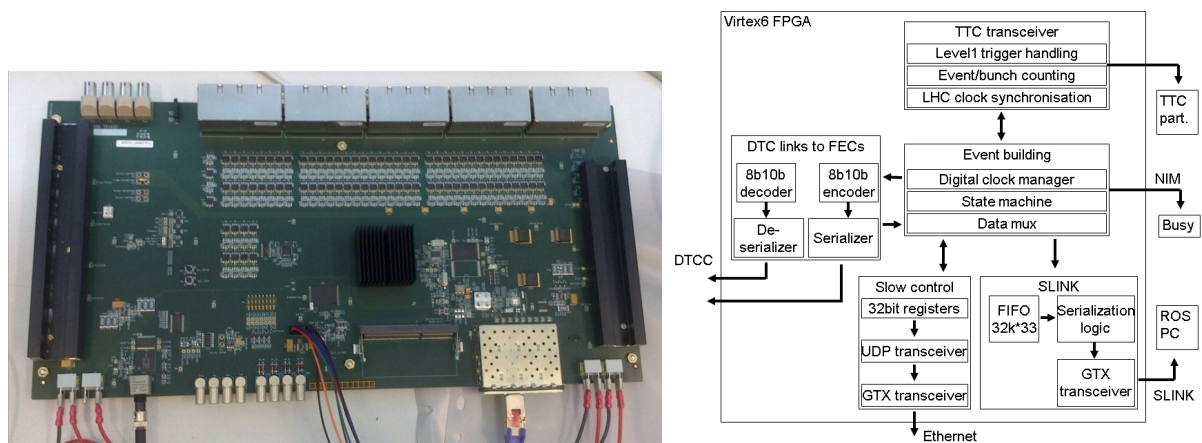


Figure 3. Left: The SRU FPGA board, Right: Coarse schematic view of the Micromegas ROD firmware functionalities and connections.

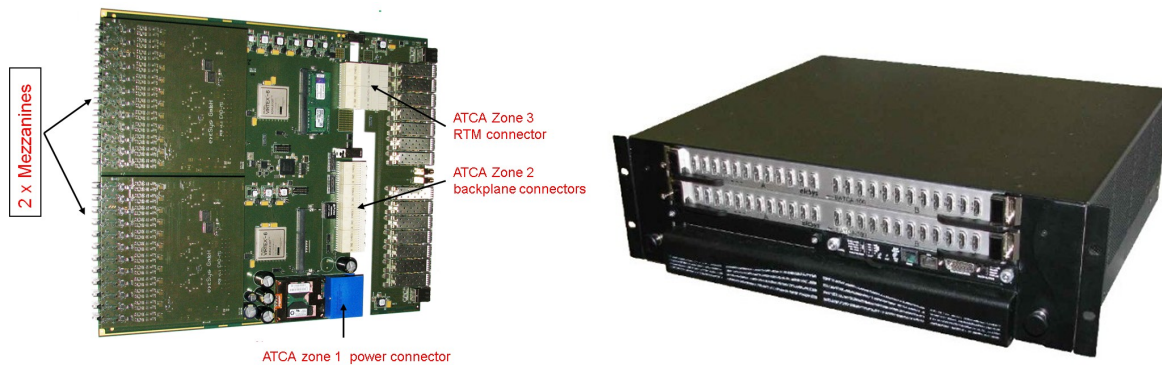


Figure 4. Left: Photograph of an ATCA FEC blade with two mezzanine boards for cable based connectivity to the front-end electronics. Right: A 19" ATCA shelf with two blades inserted.

A firmware for the SRU Virtex6 FPGA has been developed, that incorporates all necessary functionality in order to allow the SRU to be fully integrated into the ATLAS infrastructure. It generates valid event fragments as a dedicated subsystem [11]. Figure 3 shows a photograph of the SRU board, as well as a schema of operation and connectivity.

4.3. SRS expansion by use of ATCA modules and Optical Converter boxes

The SRS system utilizes the so-called Front End Concentrator (FEC) cards to interface the DAQ system to the front-end chips. This card type is being used successfully in custom 6U Eurocrates. In order to achieve higher integration and also better performance, this card type has been redesigned using the Advanced Telecommunications Computing Architecture (ATCA) technology. Using a modern Xilinx Virtex6 FPGA, the ATCA FEC blade can carry different types of mezzanine boards, to interface to the front-end electronics via either copper based links or optical fibers [12]. This card type is currently in the test phase. Figure 4 shows two photographs of the system.

In order to cross the distance from the ATLAS experimental cavern to the counting room via optical fiber, another optional SRS component becomes necessary, the Optical Converter (OC) box (Figure 5). This component interfaces the optical fiber connecting to the ATCA FEC

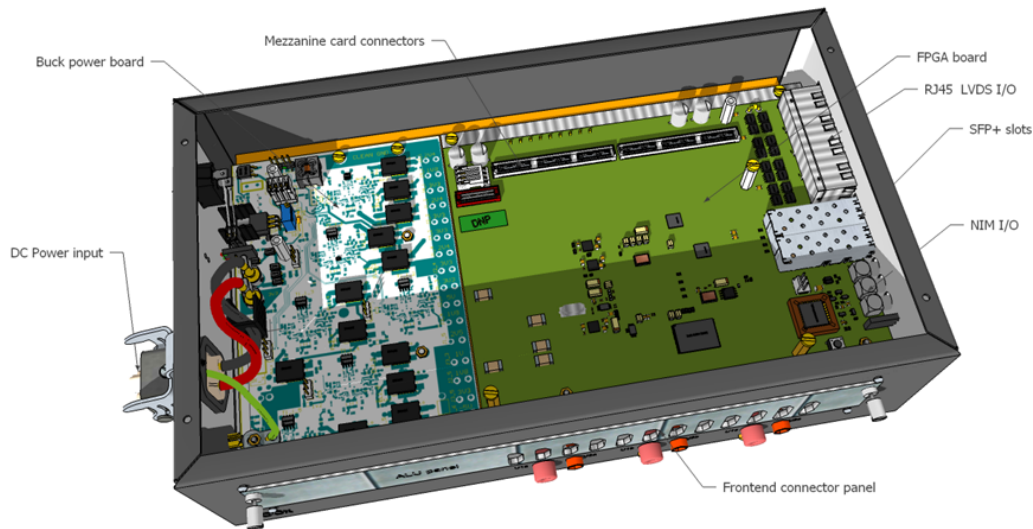


Figure 5. Rendering of the OC box. Only the FPGA base board is visible, the mezzanine card for front-end connectivity is not shown.

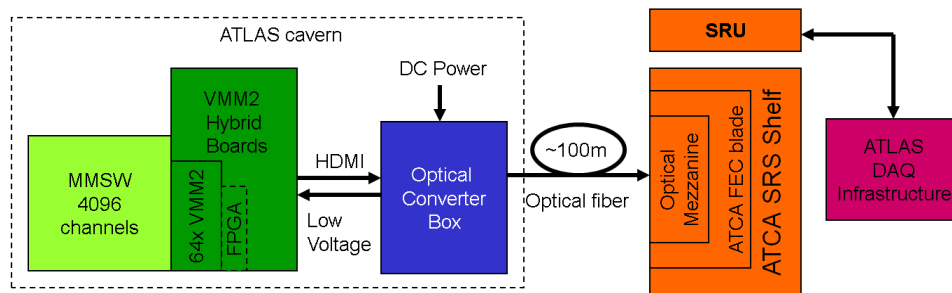


Figure 6. Schematic drawing of the electronics components that will be used for the integration of the MMSW chamber into the ATLAS data acquisition system during Run-II period.

blade for the transmission of clock, triggers, data and slow control, as well as to the front-end electronics via copper cable. In addition, this module contains a number of DC/DC converters in order to power the front-end electronics with low voltage from a single unregulated power supply. The OC box uses the same mezzanine cards for front-end connectivity as the ATCA FEC blades. The OC box is currently in the development stage, Figure 6 shows the concept.

5. Status of the DAQ integration

Up to now, the dedicated front-end electronics for the NSWs, consisting of the VMM [13] ASIC chips together with specialized triggering and readout front-end boards, as well as the OC box are not yet available.

Nevertheless, the SRU module alone has been fully integrated into the ATLAS readout chain, inserting fully valid ATLAS event fragments without detector data included. For this scope, a configuration database that describes all the necessary modules needed to interact with the SRU has been implemented using the ATLAS Online TDAQ software [14]. In addition the ROD Crate DAQ framework [15] was used in order to implement the communication libraries for the data

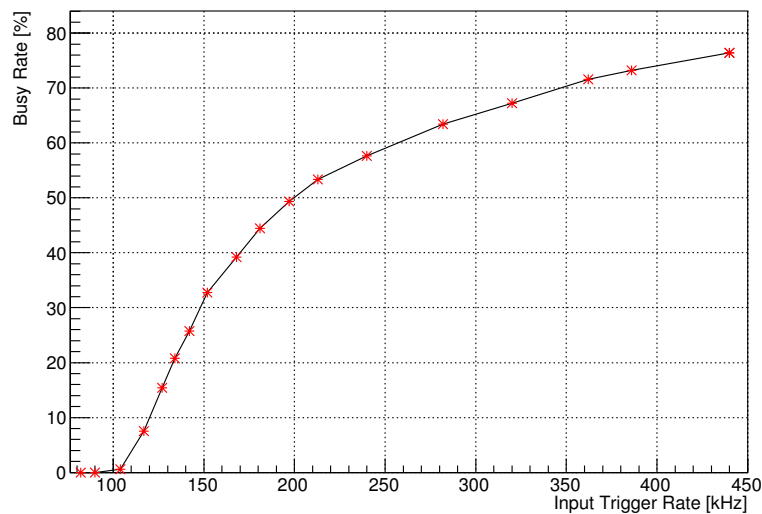


Figure 7. Measurement of the Micromegas ROD Busy rate as a function of Level 1 trigger rate. The busy rate at the 90 kHz measurement point is zero.

acquisition functionality. A dedicated Micromegas segment has been successfully tested and is running within the ATLAS Online TDAQ together with the other sub-systems.

As part of the integration tests, it has been verified that the present Micromegas readout system does not introduce additional busy time to the ATLAS detector. Figure 7 shows the results of a measurement of the fraction of busy time as a function of Level 1 trigger input rate. The maximum expected trigger rate during the RUN-II period is 100 kHz. The SRU busy fraction at 90 kHz is measured to be zero. The rise of the curve above 100 kHz is the result of the bandwidth limitations of the common ATLAS upstream systems; the SRU hardware and firmware alone could stand a much higher trigger rate of up to 1 MHz.

6. Summary

As a consequence of the future LHC luminosity upgrades, the ATLAS Small Wheel systems will be replaced by New Small Wheels during the shutdown period in 2018/2019, using the Micromegas and sTGCs detector technologies.

A Micromegas prototype detector, which closely follows the design of the New Small Wheel detectors, has been built and thoroughly tested. It will be installed within the ATLAS cavern in order to investigate its performance under the experimental conditions of the New Small Wheels.

To allow a direct comparison of this prototype's measurements with the other subsystems data, a fully ATLAS compatible Read Out Driver has been developed, based on hardware components from the Scalable Readout System. In addition, all necessary libraries and software modules have been created in order to integrate the system into the ATLAS TDAQ software.

Although several components of the Micromegas readout chain are not yet available or not yet in their final configuration, the integration of the Read Out Driver into the ATLAS systems has been fully performed and verified. Valid event fragments with no detector data included are being produced, without the generation of additional busy time for the ATLAS detector.

Acknowledgments

This research has been supported by the German Federal Ministry of Education and Research (BMBF) and the Wolfgang-Gentner-Programme of BMBF.

References

- [1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST **3** S08003 (2008).
- [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] M. Bianco et al., *Construction of a large-size four plane micromegas detector*, Technology and Instrumentation in Particle Physics 2014, PoS(TIPP2014)058.
- [5] T. Alexopoulos et al., *A spark-resistant bulk-micromegas chamber for high-rate applications*, Nucl. Instrum. Meth. A **640** Issue 1 (2011) 110 - 118.
- [6] S. Martoiu, H. Muller, A. Tarazona, J. Toledo, *Development of the scalable readout system for micro-pattern gas detectors and other applications*, Journal of Instrumentation Topical Workshop on Electronics for Particle Physics 2012 (TWEPP12) Volume 8 (2013).
- [7] L. Ropelewski et al., *R&D Proposal Development of Micro-Pattern Gas Detector Technologies*, CERN-LHCC-2008-011. LHCC-P-001 (2008).
- [8] H.C. van der Bij, R.A McLaren, O. Boyle, G. Rubin, *S-LINK, a data link interface specification for the LHC era*, IEEE Transactions Nuclear Science **44** (1997) 398 - 402.
- [9] J. Christiansen, A. Marchioro, P. Moreira and A. Sancho, *Receiver ASIC for Timing, Trigger and Control Distribution in LHC Experiments*, IEEE Transactions Nuclear Science **43** (1996) 1773 - 1777.
- [10] A. Tarazona et al., *A point-to-point link for data, trigger, clock and control over copper or fibre*, JINST **9** T06004 (2014).
- [11] 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.
- [12] M. Bianco, P.J. Loesel, S. Martoiu, O. Sidiropoulou and A. Zibell *Development and test of a versatile DAQ system based on the ATCA standard*, Technology and Instrumentation in Particle Physics 2014, PoS(TIPP2014)202.
- [13] G. De Geronimo et al., *VMM1 - An ASIC for Micropattern Detectors*, IEEE Transactions on Nuclear Science **60** (2013) 2314 - 2321.
- [14] G. Avolio, M. Caprini and G. Lehmann Miotto *The integrated graphical user interface of the trigger and data acquisition system of the ATLAS experiment at the LHC*, International Conference on Computing in High Energy and Nuclear Physics (CHEP) 2010, doi:10.1088/1742-6596/331/2/022032.
- [15] S. Gameiro et al., *The ROD Crate DAQ software framework of the ATLAS Data Acquisition System*, IEEE Transactions on Nuclear Science **53** (2006) 907-911.