DETECTOR CONTROL SYSTEM FOR THE ATLAS MUON SPECTROMETER AND OPERATIONAL EXPERIENCE AFTER THE FIRST YEAR OF LHC DATA TAKING*

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Abstract

Muon Reconstruction is a key ingredient in any of the experiments at the Large Hadron Collider LHC. The muon spectrometer of ATLAS comprises Monitored Drift Tube Chambers (MDTs) and Cathode Strip Chambers (CSCs) for precision tracking as well as Resistive Plate (RPC) and Thin Gap (TGC) Chambers as muon trigger and for second coordinate measurement. Together with a strong magnetic field provided by a super-conducting toroid magnet and an optical alignment system a determination of muon momentum with high precision up to the highest particle energies accessible by the LHC collisions is provided.

The Detector Control System (DCS) of each muon sub-detector technology must efficiently and safely manage several thousand of LV and HV channels, front-end electronics initialization as well as monitoring of beam, background, magnetic field and environmental conditions. This contribution describes the chosen hardware architecture, which as much as possible tries to use common technologies, as well as the implemented controls hierarchy. Emphasis is given to reviewing the experience from the first year of LHC and detector operations, and to lessons learned for future large scale detector control systems.

INTRODUCTION

The Muon Spectrometer forms the outermost layer of the ATLAS [1] detector, as shown in Fig. 1, covering a rapidity range up to $\eta = 2.7$. It comprises four different detector technologies who have been chosen for optimal performance, as either trigger or precision tracking muon chambers, and according to particle rates. Track reconstruction is based in the full muon spectrometer except the innermost region of the endcap ($2.0 < \eta < 2.7$) on in total 380000 **M**onitored **D**rift **T**ubes (MDTs) of 3 cm diameter and up to 6m in length, which are assembled into in total 1150 MDT chambers. Chambers are equipped with an alignment system to in situ monitor and record chamber deformation and relative displacements between chambers, which is required to achieve the design track reconstruction resolution of $50\,\mu$m per muon station. In the region of high-

est background rate, 32 **C**athode **S**trip **C**hambers (CSCs) take the role of tracking detectors. CSCs are multi-wire proportional chambers whose wires are oriented in radial direction and with a segmented cathode. Track reconstruction is done by a fit to the charge distribution, resulting in a track resolution per plane of $< 60\,\mu$m.

Resistive **P**late **C**hambers (RPCs) are used as trigger chambers in the muon barrel; ATLAS RPCs are built as a doublet of gas gaps, each formed by 2 bakelite plates separated by a 2mm spacer. Perpendicular readout strips on both sides of the gas gaps allow 2-dimensional track coordinate determination and by requiring a particle track to fall into a predefined geometrical road efficient and fast triggering on muons with a defined momentum. In the endcap region, **T**hin **G**ap **C**hambers (TGCs) are used as trigger chambers; TGCs are multi-wire proportional chambers with a wire-to-wire distance smaller to the wire-to-cathode distance and operated in quasi-saturated mode. In total there are 3588 TGC units, forming 3+2+2 layers in each side's big wheel and 2 layers in the small wheel. Some operating parameters of the 4 detectors are summarized in Table1.
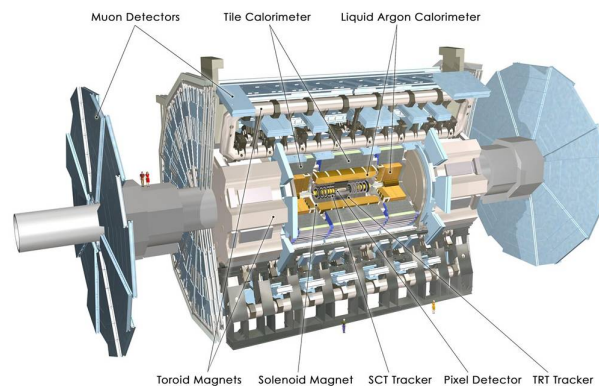

Figure 1: Schematic view of the ATLAS Detector. Elements shown in light blue belong to the Muon Spectrometer which forms the outer most layer of the detector and is split into a cylindrical Barrel part and a set of disk like wheels known as Endcaps.

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Table 1: Important Operating Parameters for the 4 Detector Types used in the Muon Spectrometer

	#Chambers	Gas Mixture	Nom. HV	#Readout Ch.
MDT	1150	$Ar:CO_2\,93:7$	3080V	380k
CSC	32	$Ar:CO_2\,80:20$	1800V	31k
RPC	544	$C_2H_2F_4$:i-C_4H_{10}: SF_6 94.7:5.0:0.3	9600V	360k
TGC	3588	CO_2:n-Pentane 55:45	2800V	320k

MUON DCS

The primary tasks of the Muon DCS are

- Controlling the detector power system
- Monitoring environmental conditions and accordingly adjusting operating parameters to maximize efficiency
- Monitoring parameters like voltages, temperatures and RPC trigger rates of the on-chamber electronics
- Monitoring the detector gas system and reacting to changed or abnormal situations by eg adjusting the detector HV
- Configuring the MDT and TGC frontend electronics
- Reacting on information from the DAQ, reinitializing chambers when needed (MDT)
- Controlling/reading out the optical alignment system
- Archiving all relevant information on the detector status as needed for physics data analysis and to trace problems

Power System

For CSC LV, power supplies from Wiener's [2] Maraton series are used; for all other muon LV and HV the commercial EASY[1] system from CAEN [3] was chosen. CAEN's EASY solution is based on a master-slave architecture with a controlling mainframe which houses a set of branch controllers, which each act as master for a chain of up to 6 EASY crates which in turn house the actual LV and HV boards. Crates and boards are compatible with operation in magnetic field and under radiation conditions as those present in the ATLAS experimental cavern during beam operation, while the mainframe and branch controllers are located in a non-hostile area accessible also during beam operation. Table2 summarizes equipment type and the number of devices in use. The RPC system differs from the other muon subdetectors in so far as it contains CAEN ADC and DAC boards in addition to LV and HV types. ADC boards are used for all RPC environmental monitoring and for measuring HV currents on individual gap level; DAC channels are used to control the threshold for the RPC frontend electronics, a function being taken

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[1]**E**mbedded **A**ssembled **Sy**stem

by a different hardware for MDT and TGCs as explained in the next section. The choice of components in the RPC DCS was driven by the strategy to have a single hardware technology, the CAEN EASY solution, to interface to DCS [4].

Table 2: Muon CAEN Power System Equipment

	Type	# Devices	# Ch.	
CSC	A3540AP	12	144	HV
MDT	A3540AP	204	2448	HV
	A3016	32	192	LV
	A3025	113	452	LV
	A3486	20	40	AC/DC
RPC	A3512AP	49	294	HV
	A3009	80	1280	LV
	A3025	100	400	LV
	A3801	50	6400	ADC
	A3802	24	3072	DAC
	A3086	35	70	AC/DC
TGC	A3535AP	126	4032	HV
	A3025	74	296	LV
	A3050D	24	48	LV
	A3100	74	74	LV
	A3486	30	60	AC/DC

ELMB Based Monitoring And Control

Besides the power system, Muon DCS relies heavily on so called **E**mbedded **L**ocal **M**onitoring **Boards** (ELMBs), which have been custom developed for use in ATLAS and other LHC experiments. Each ELMB, which is magnetic and radiation tolerant, contains a 64 channel 16-bit ADC, 18 general digital IO lines, 8 digital inputs and 8 digital outputs, plus a CAN interface to communicate with. For a detailed description of the ELMB please refer to [5] and [6]. Muon DCS uses around 1300 ELMBs, in a version known as MDM or **MDT** **D**CS **M**odule with a custom firmware and motherboard in the MDT system and around 1500 ELMBs in the TGC system.

MDT MDMs are used to monitor environmental conditions, reading out approximately 14000 temperature probes installed on the MDT chambers, 1650 3D hall probes for determination of the magnetic field map in the ATLAS toroid magnet region and more than 50000 voltage and temperature values from the MDT frontend electronics cards. The MDM in addition handles the initialization of the frontend electronics by downloading configuration parameters to the boards via JTAG. More details can be found in [7].

In the TGC system, ELMBs supply more than 8000 thresholds for the frontend electronics ASD chips, readout and monitor around 3700 chamber displacement sensors and 1600 temperature probes as well as configure and monitor over 23000 on chamber ASICs. A dedicated firmware
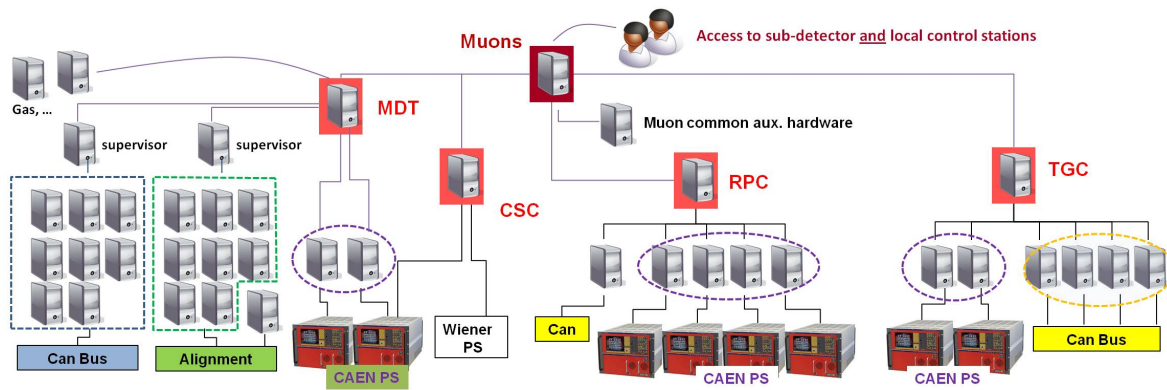
Figure 2: Muon DCS computer hierarchy. MDT MDM and barrel alignment systems have an additional supervisor layer between device layer and subdetector control station. In this the muon DCS system differs from any other ATLAS subdetector control system.

together with custom TGC DCS-PS boards allows detailed monitoring of the chambers' charge spectrum and thus low level information on the detector performance itself. For further details, refer to [8].

MDT Optical Alignment System

The third set of hardware handled by the Muon DCS system is the optical alignment system [9],[10]. Optical alignment is based on monitoring and ananalyzing patterns imaged onto CCD cameras along so called optical lines. Within MDT chambers, alignment lines monitoring deformations consist of a patterned mask, a light source, a lense and the CCD camera. The assembly is known under the name RASNIK [11]. The system is implemented following a hierarchical structure with 3 layers, achieving a high level of multiplexing; acquisition of images is done using 8 PCs and commercial framegrabber video cards. In the endcap the RASNIK technology is complemented by so called BCAM modules, readout in this case is via dedicated multiplexers implemented as VME modules. The results of the image analysis in both cases are stored in a database and used in muon track reconstruction to correct for changes in muon chamber positions.

DCS Software and Architecture

The Muon DCS controls layer has been implemented using the commercial SCADA system PVSS [12] as integrated part of the overall ATLAS DCS system. Components of the common JCOP framework [13] have been used where possible. A total of 40 PCs, running both Windows (XP and 2003) and Linux (SL5) as operating system is used for running the DCS software layer, following a hierarchical architecture (Fig. 2) with a separation between a low-level device layer handling communication with the various hardware and a higher layer of supervisors and so called sub-detector control stations, one per muon technology, dedicated to user interactions and combining information from the different parts of the system. In 2010 an addi-

tional layer and node 'MUON' was added which combines information from the various muon sub-detectors and allows unified/common operation; this was driven by ATLAS shift operations moving towards combining shift tasks.

CAEN and Wiener hardware is interfaces to PVSS via the OPC servers provided by the manufacturer; ELMBs are controlled via CanBus from Kvaser PCI cards; for interfacing the Can communication to PVSS the ATLAS developed CanOpen OPC server is used in case of MDTs and a custom PVSS driver in case of TGCs.

OPERATIONAL EXPERIENCE

Power System

The CAEN power system hardware overall is performing as expected, with a board failure rate, usually on individual channel level, well below the 10% level allowed for in maintenance and spares planning. An initial high failure fraction for the TGC A3535 type HV boards was traced to an underdimensioned electronics component which makes the boards very sensitive to any excessive heat e.g. in case of a failure of the rack cooling. Additional checks and actions have thus been added to DCS to detect such situations and react by turning off concerned equipment.

One type of problem still seen from time to time and without yet an optimal way found to handle is boards for which the output voltage V_{out} exceeds the set voltage V_{set}, in some cases by several 100V for HV channels and occassionally exceeding even the hardware voltage limit. 2 cases of broken wires in the CSC system are believed to have been caused by such overvoltage. A second issue are occassional losses of communication with individidual EASY boards, mostly after a power cut, which in the beginning required an access to the ATLAS experimental cavern for a manual reset. To adress this problem, at the beginning of 2011 the so called 'Muon CAEN Reset Network' has been implemented which allows a DCS controlled remote reset of boards. An extension to the reset of branch controllers is planned for the shutdown at the end of this year.

One unexpected finding was that the CAEN OPC Server Event Mode, which became available with CAEN's OPC server version 3, turned out as unsuitable for the use for both MDT and TGC systems[2], due to the large number of HV channels which undergo ramping all at the same time. During the ramp phase the large amount of data updates overloads the OPC server leading to crashes and data loss. Reverting back to the previous polling mode and tuning extensively the OPC group configuration an acceptable and stable situation was found; For the future and possible hardware upgrades, improving the sustainable refresh intervals for HV and LV readings via the OPC chain and PVSS seems however highly desirable. In addition, rare but recurring cases of a full hangup of the communication with the power system have been and are observed. To deal with this a set of watchdog and alert mechanisms has been implemented which proved to allow spotting such problems immediately.

ELMB based Functionality

Experience with the ELMB based part of Muon DCS is very good with an excellent reliablity of the used hardware components. In the full muon system only 2 out of more than 2500 ELMBs failed up to now; both were of MDT MDM type. In the first case the communication with the node via CAN was no longer working; in the second only the ADC part was affected.

The MDT frontend electronics initialization done via JTAG from DCS works very well. With a scheme were string download to the chamber electronics is carried out in parallel on all 96 CanBusses in the MDT system the full detector can be reinitialized in approximately 2.5 minutes. Further improvements are under discussing by storing configurations in the MDM's memory and handling sending the predefined configuration to the MDT chamber electronics by an updated MDM firmware. This would eliminate the current need for sequential string download to chambers on the same CanBus.

Operator Interactions and User Interface Layer

Substantial efforts have been spent during the last year in unifying user interfaces as exposed to non-expert shifters, among other things by developing a set of libraries for a uniform geomtrical representation of the the 4 muon subdetectors and status information on their various components. As an example, the top layer Muon Shifter UI panel is shown in Fig. 3.

CONCLUSIONS

The first full year of LHC operations has proven the chosen design for the Muon DCS a good one, both with respect to hardware and software architecture. No major problems or showstoppers have been found. Feedback gained from

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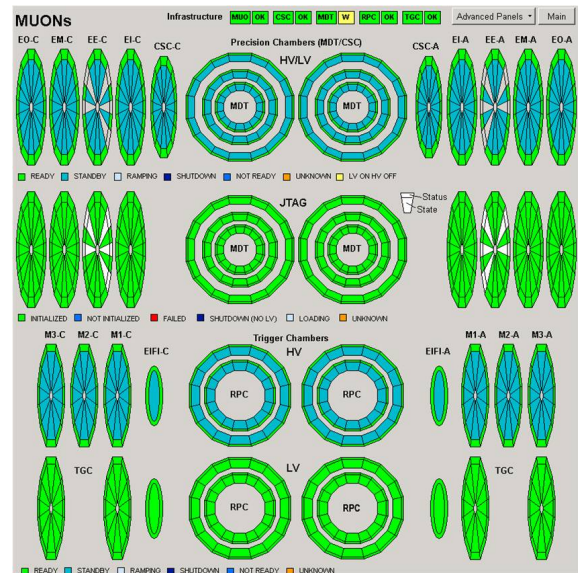[2]no such problems are present in the RPC system

Figure 3: Example of a Muon shifter User Interface panel.

shifter operations has lead to several additions and additional efforts of unification, a work which is still ongoing.

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