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The Detector Control System of the New Small Wheel for the ATLAS experiment

Polyneikis Tzanis[1,2]
[1] National Technical University of Athens, Heroon Polytechniou 9, Zografou, Greece
[2] Brookhaven National Laboratory, Upton, NY 11973-5000, U.S.A.

E-mail: `polyneikis.tzanis@cern.ch`

Abstract. The ATLAS Muon Spectrometer is going through an extensive Phase I upgrade to cope up with the future LHC runs of high luminosity of up to instantaneous luminosity of $7.5 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. The luminosity increase drastically impacts the ATLAS trigger and readout data rates. The present ATLAS Small Wheel Muon detector will be replaced with a New Small Wheel (NSW) detector which is expected to be installed in the ATLAS underground cavern by the end of the Long Shutdown 2 of the LHC. Due to its complexity and long-term operation, the NSW requires the development of a sophisticated Detector Control System (DCS). The use of such a system is necessary to allow the detector to function consistently and safely as well as to function as a seamless interface to all sub-detectors and the technical infrastructure of the experiment. The central system handles the transition between the probe's possible operating states while ensuring continuous monitoring and archiving of the system's operating parameters. Any abnormality in any subsystem of the detector triggers a signal or alert (alarm), which alerts the user and either adapts to automatic processes or allows manual actions to reset the system to function properly.

1. ATLAS New Small Wheel

In order to efficiently handle the increased luminosity that will be provided by the High-Luminosity LHC (HL-LHC), the first station of the ATLAS [1] muon end-cap system (Small Wheel, SW) will need to be replaced. The New Small Wheel (NSW) [2] will have to operate in a high background radiation region (up to $22\,\mathrm{kHz/cm}^2$) while reconstructing muon tracks with high precision as well as providing information for the Level-1 trigger. The detector technologies to be used come from the family of gaseous detectors, the first is called small-strip Thin Gap Chambers (sTGCs), and the second comes from the category of micro-pattern gaseous detectors and is named Micromesh Gaseous Structure (Micromegas (MM)) [3]. The new experimental layout will consist of 16 detection layers in total and 8 layers per detection technology (8 layers sTGC and 8 layers Micromegas), as shown in Fig. 1. The sTGC detectors are designed to provide fast trigger and high precision muon tracking under the HL-LHC conditions. On the other hand, Micromegas detectors have a small conversion region (5 mm) and fine strip pitch (0.5 mm) resulting in excellent spatial resolution and are primarily used for precise tracking.

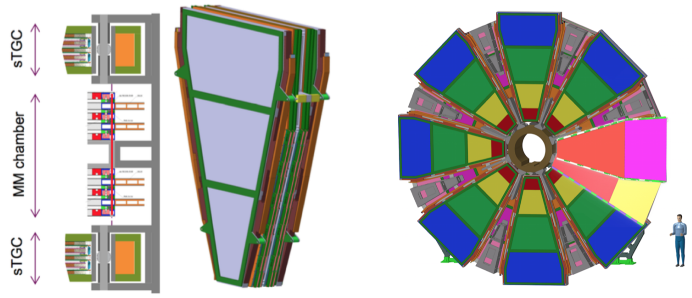


Figure 1. A graphic representation of the NSW sector (left) which consists of 8 layers of Micromegas in the inner part and sandwitched by 4+4 layers of sTGC detectors in the outer parts and view of the NSW (right) with 16 sectors in total.

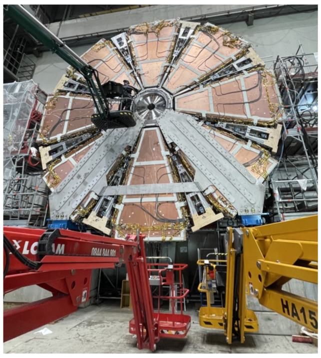


Figure 2. Photograph of the current status of the NSW during the commissioning phase.

Some of the NSW highlights are:

- New detector technologies
- Custom ASICs and electronic boards
- New readout system based on Front End LInk eXchange (FELIX)
- 2.5 Million readout channels
- Common Configuration, Calibration & DCS path
- New Power supply system
- Plenty of ATLAS & CERN infrastructure

1.1. Hardware

A brief overview of the NSW hardware and infrastructure is displayed in Fig. 3. The NSW infrastructure consists of High Voltage power supplies, Low Voltage power supplies, Electronics boards, Gas/Cooling devices, ATCA & VME crates, temperature & bField sensors, Detector Safety Systems(DSS) and LHC Beam infrastructure.

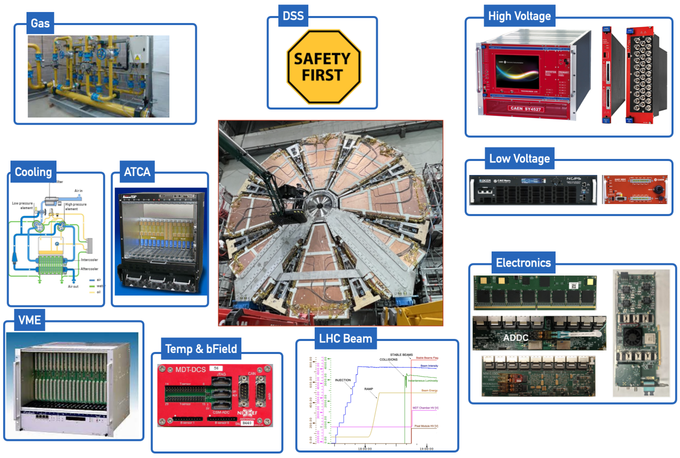


Figure 3. A brief overview of the NSW hardware.

1.2. DCS for Integration & Commissioning

In order to operate and control hundreds of different devices and hardware of the NSW, a Detector Control System (DCS) have been developed. The DCS is simply a Supervisory control and data acquisition (SCADA) system equipped with User Interfaces (UIs), automated scripts and control/monitor functionality. Prototype DCS projects has been developed in order to support the integration phase of the project. The majority of projects already deployed at integration & commissioning sites for further optimisations. The low-level segment of the projects has been fully deployed, with the main components (hardware's daisy chain, OpcUa Servers, fwComponents, Datapoints schema, etc.) being fully functional. Commissioning of the whole NSW hardware via the DCS.

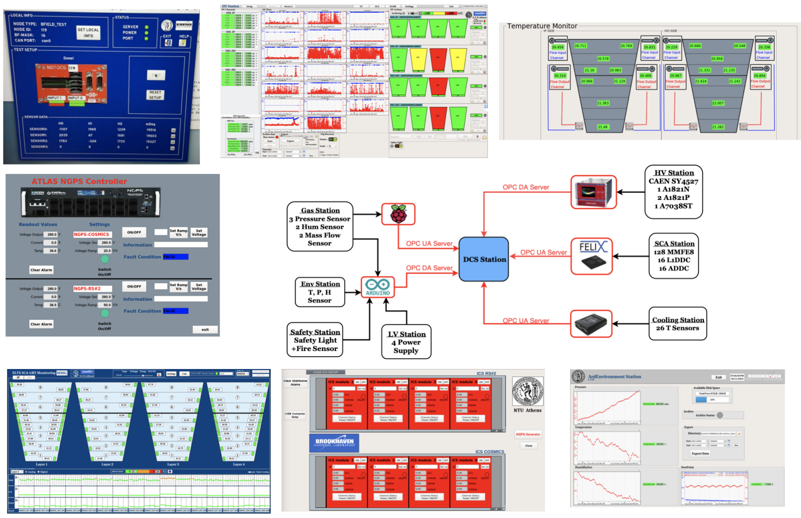


Figure 4. A overview of the NSW DCS prototype which is used during the integration and commissioning phase of the NSW.

2. ATLAS Detector Control System

The ATLAS DCS [4] has the task to permit coherent and safe operation of ATLAS and to serve as a homogeneous interface to all sub-detectors and the technical infrastructure of the experiment. The DCS must bring the detector into any desired operational state, continuously monitor and archive the operational parameters, signal any abnormal behavior. The DCS was designed and implemented within the frame of the Joint Controls Project (JCOP)[5], a collaboration of the CERN controls group and DCS teams of the LHC experiments. Standards for DCS hardware and software were established together with implementation guidelines both, commonly for JCOP and specifically for ATLAS. JCOP combines common standards for the use of DCS hardware based on SCADA system Siemens, WinCC Open Architecture, also known as PVSS with its older name, where it serves as the basis for all DCS applications. Fig. 7 depicts the architecture of DCS which can be divided into Front-End (FE) equipment and a system Back-End (BE). FE includes equipment DCS, including customized electronic systems and related services such as high voltage power supplies and cooling circuits. The BE system uses the software WinCC, integrating front-end control systems into the JCOP framework components to facilitate the integration of standard hardware devices and the implementation of homogeneous control applications. The two ends of DCS communicate mainly through the industrial protocol bus CAN, while the communication standard OPC is used as a communication software protocol. The system BE is organized hierarchically on three levels, the Local Control Stations (Local

Control Stations (LCS), the Sub-detector Control Stations (SCS)) and the Central Control Stations (Global Control Stations (GCS)). In total, BE consists of more than a hundred computer stations connected to a distributed system. Communication between subsystems of the system is handled by WinCC via a local area network. A distributed finite state machine, Finite State Machine (FSM), represents the complete hierarchy of the BE system as it integrates more than 10 million data elements into a single tree structure and ensures proper operation and efficient handling errors in each operating layer. The most important element of this system is the structure datapoint (DP), which plays the role of the global variable network. Each element (element) of this structure has a unique name and configurability, and special DPs are used to read data from the hardware components updated by the interface OPC client-server communication.

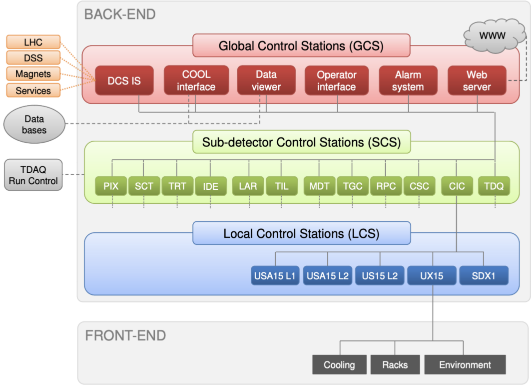
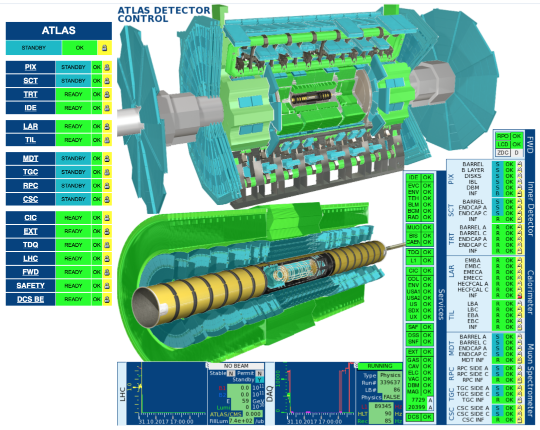


Figure 5. Graphical representation of the DCS architecture of the experiment ATLAS divided into 3 levels: GCS, SCS and LCS.



ATLAS			
STANDBY	OK		
PIX	STANDBY	OK	
SCT	STANDBY	OK	
TRT	READY	OK	
IDE	READY	OK	
LAR	READY	OK	
TIL	READY	OK	
MDT	STANDBY	OK	
TGC	STANDBY	OK	
RPC	STANDBY	OK	
CSC	STANDBY	OK	
CIC	READY	OK	
EXT	READY	OK	
TDQ	READY	OK	
LHC	READY	OK	
FWD	READY	OK	
SAFETY	READY	OK	
DCS BE	READY	OK	

Figure 6. Operator interface (FSM Screen) showing the detector in STANDBY configuration during LHC ramp-up. The top hierarchy level object is shown together with its children objects (top left) and the associated main panel (bottom right). The UI allows the navigation to any FSM object and associated panel within the whole ATLAS DCS hierarchy. On the top right, a list of objects with non-OK Status allow shortcut navigation to problems.

Each node FSM has a unique name based on the subsystem name and its functionality following the conventions of ATLAS DCS and the state in which they are specified by a corresponding internal DP. The type of object FSM which defines the basic functionality of the node and its components, depends on the functional purpose and position of the element in the DCS architecture hierarchy. The main graphical user interface of ATLAS DCS with all subsystems integrated into a hierarchical structure FSM is illustrated in Fig. 8. The FSM is based on a strict hierarchical structure that constitutes parent-child relationships, where in tree construction commands are passed from parents to children, and situations from children to parents. This way, when some action is required on all children it is extremely efficient to command a higher node and correspondingly the status of the higher node summarizes the status of all nodes of any generation. All nodes are in a predefined state and only accept predefined commands as defined in the FSM type to which they belong. The DCS is operated from two primary, remotely accessible user interfaces – the FSM Screen for operation of the detector

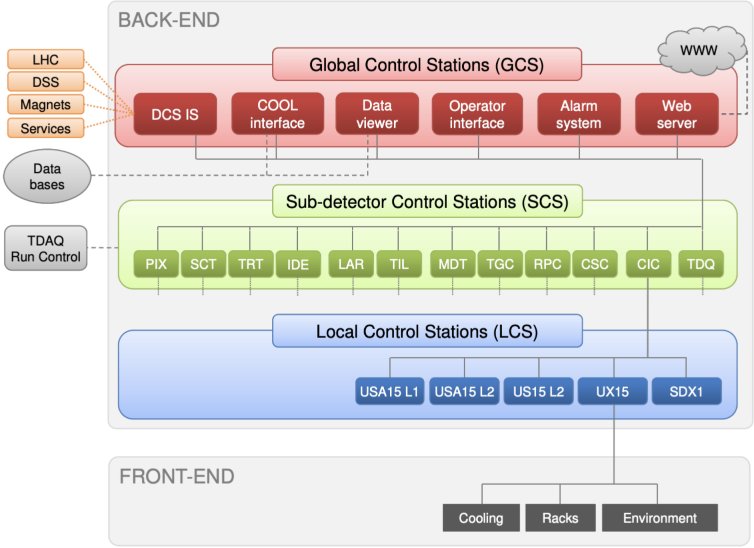
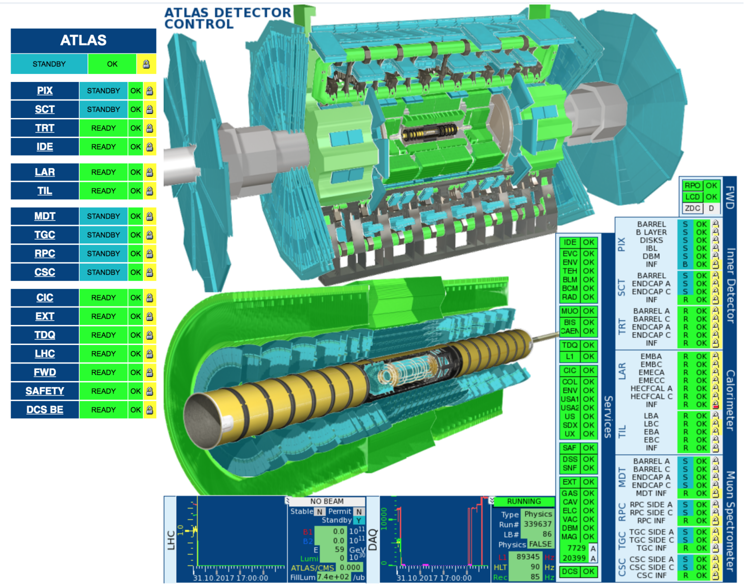


Figure 7. Graphical representation of the DCS architecture of the experiment ATLAS divided into 3 levels: GCS, SCS and LCS.

Finite State Machine hierarchy (see Fig. 8) and the Alarm Screen for alarm recognition and acknowledgment. Static status monitoring is provided by web pages on a dedicated web server allowing to quickly visualize all high level FSM user interface panels world-wide and without additional load of BE control stations.



ATLAS		
	STANDBY	OK
PIX	STANDBY	OK
SCT	STANDBY	OK
TRT	READY	OK
IDE	READY	OK
LAR	READY	OK
TIL	READY	OK
MDT	STANDBY	OK
TGC	STANDBY	OK
RPC	STANDBY	OK
CSC	STANDBY	OK
CIC	READY	OK
EXT	READY	OK
TDQ	READY	OK
LHC	READY	OK
FWD	READY	OK
SAFETY	READY	OK
DCS BE	READY	OK

Figure 8. Operator interface (FSM Screen) showing the detector in STANDBY configuration during LHC ramp-up. The top hierarchy level object is shown together with its children objects (top left) and the associated main panel (bottom right). The UI allows the navigation to any FSM object and associated panel within the whole ATLAS DCS hierarchy. On the top right, a list of objects with non-OK Status allow shortcut navigation to problems.

3. NSW Detector Control System

Due to it's complexity and long-term operation, the NSW requires the development of a sophisticated Detector Control System (DCS). The use of such a system is necessary to allow the detector to function consistently and safely as well as to function as a seamless interface to all sub-detectors and the technical infrastructure of the experiment.

3.1. Architecture

The NSW DCS architecture and it's integration with the ATLAS DCS have been finalized and projects will closely follow the existing look, feel and command structure of Muon DCS, to facilitate the shifter and expert operations. The current plan is to have 2 new sub-detectors, MMG (Micromegas) and STG (sTGC). The top node of both MMG and STG will propagate its state and receive commands from the ATLAS overall DCS. An overview of ATLAS MUO DCS structure with NSW DCS integration and brief structure of the sub-detector node structure is displayed in Fig. 9.

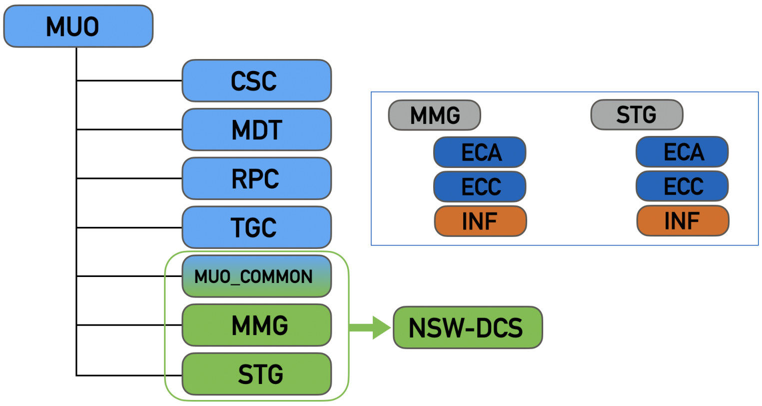


Figure 9. The overview of the ATLAS MUO DCS structure with NSW DCS integration and brief structure of the sub-detector node structure.

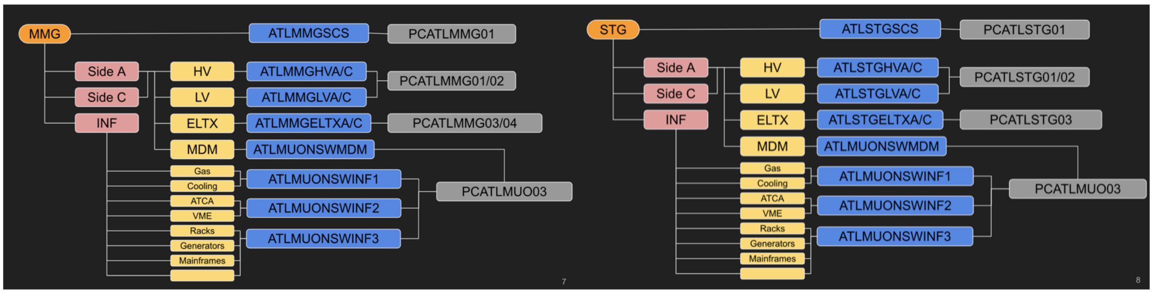


Figure 10. The overview of the NSW structure and project/server allocation.

3.2. Projects

3.2.1. High and Low Voltage

High and Low voltages for MMG and sTGC are supplied by the widely used CAEN [6] system, which is developed for the LHC experiments. Communication with the control machines is achieved through OPC UA server-client connection. Side A and C, NSW OPC UA servers, are deployed on the host servers while the OPC UA clients, running on the same machines, gather the address space of the individual channel parameters and transmit them to the projects. The system architecture consists of mainframes, which house the branch controllers, connected with the Low Voltage (LV) and High Voltage (HV) crates. The MMG and sTGC will use the same basic layout for the Low Voltage. The LV for the electronics boards, both on-chamber and on the rim, is regulated and distributed by means of DC/DC distributors, called Intermediate Conversion Stage (ICS) and placed on the rim. 136 such devices are to be deployed. The control and monitoring communication path is based on CAEN EASY6000 system. Eleven CAEN mainframes of type SY4527 will control all LV and HV for NSW. Each HV branch controller is connected with a set of Embedded Assembly SYstem (EASY) crates, which are connected as a daisychain. HV Crates and boards are supplied with an external DC power of 48V generated by separate AC-DC converters, while the LV ICS crates are powered from primary generators with adjustable voltage output. The mainframes, generators and branch controllers are located in ATLAS Underground Service areas while while EASY crates and boards in the ATLAS cavern.

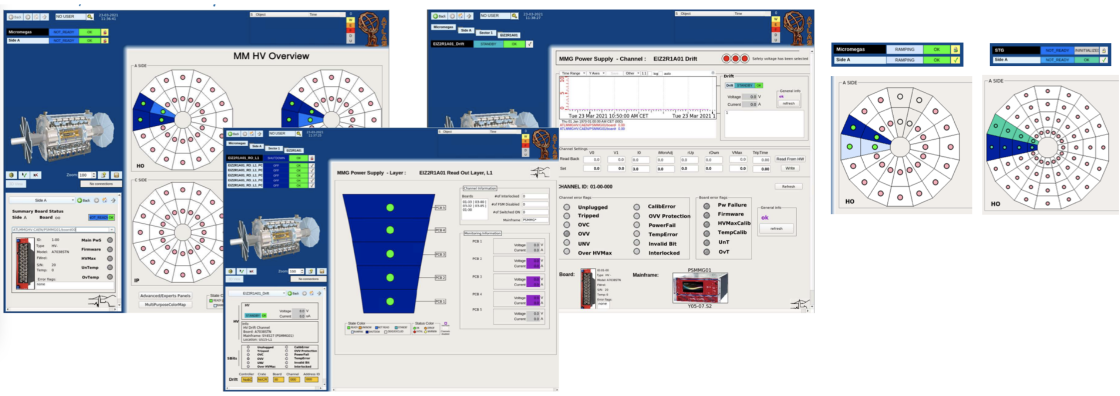


Figure 11. The DCS FSM and panels for the NSW High Voltage monitoring.

Figure 12. The DCS FSM and panels for the NSW Low Voltage monitoring.

3.2.2. Temperature and bField

The environmental parameters monitoring comprises 64 MDT Device Modules (MDM) which will be attached on the wheels and will serve to monitor the detector surface temperatures. They will be also used for measuring the magnetic field (attached on sTGC chambers). The system will be included in the current muon temperature and magnetic field monitoring. MDMs are Radiation and Magnetic tolerant, based on Embedded Local Monitor Board technology. Every NSW Sector will have 36 T-Sensors on chamber and 16 for cooling channel monitoring. The CanOpen OPC UA Server is the interface between hardware and projects, wedges monitoring and cooling temperature sensor alarm handling. Each of the large sTGC sectors has four Bfield sensors that are connected through MDM and read out via the Controller Area Network (CAN) protocol.

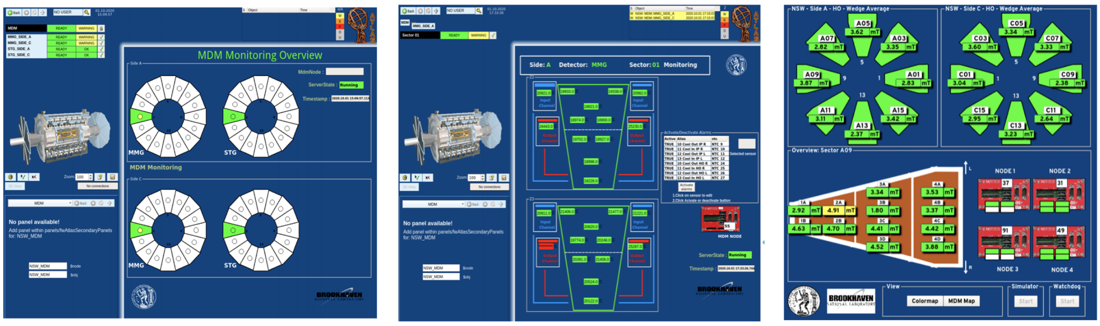


Figure 13. The DCS FSM and panels for the NSW MDM T-Sensor temperature and bField monitoring.

3.2.3. SCA Electronics

The NSW electronics for the trigger and Data Acquisition (TDAQ) path of both detectors is divided into two major categories, on-detector and off-detector electronics and the DCS, Configuration and Calibration back-ends [8], as shown in Fig.14. A common readout path and a separate trigger path are developed for each detector technology. The electronics design of such a system is implemented in about 8000 frontend boards including the design of a number of custom radiation tolerant ASICs capable to drive trigger and tracking primitives to the backend trigger processor and readout system. The NSW electronics are supplied with the GBT-SCA ASIC (Giga-Bit Transceiver - Slow Control Adapter) [7] which is part of the Gigabit Transceiver Link (GBT) chipset and its purpose is to distribute control and monitoring signals to the front-end electronics embedded in the detectors. Also, the SCA provides a number of user-configurable electrical interface ports, able to perform concurrently at transfer operations. The user interface ports are: 1 SPI master, 16 independent I^{2}C masters, 1 JTAG master and 32 general-purpose IO signals with individual programmable direction and interrupt generation functionality. It also includes 31 analog inputs multiplexed to a 12-bit Analog-to-Digital Converter (ADC) featuring offset calibration and gain correction as well as four analog output ports controlled by four independent 8-bit Digital-to-Analog Converter (DAC). The electronics system is using the SCA chipset for three different applications:

- **Monitoring**: Perform the front-end monitoring of the various power and temperature sensors directly connected to the ADC channel of the SCA. The monitoring application is shown in Fig. 15.
- **Configuration**: Perform the configuration of the ASIC chipsets which are placed on front-end boards using the SCA SPI and I^{2}C masters.

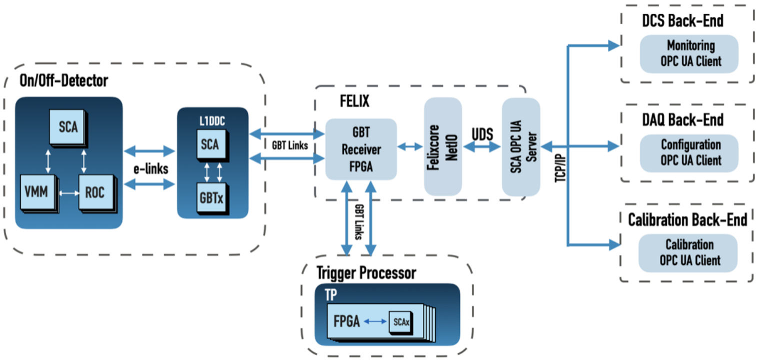


Figure 14. Overview of the on/off-detector electronics and the DCS, Configuration and Calibration path via the SCA, the FELIX and the SCA OPC UA Server. A common readout path and a separate trigger path are developed for each detector technology. The communication chain starts in the control room with an OPC-UA client, which is the first step into our detector control system. Configuration and monitoring data is requested and sent from here to the OPC-UA server and next to the FrontEnd Link Exchange (FELIX) PCs, which lie in the underground service area. Then, through radiation-hard fibers, we reach the GBTx chips, which implement the optical links, to finally arrive to the SCA.

- **Calibration**: Perform the VMM calibration using an ADC channel of the SCA.

Front-end monitoring using the SCA OPC UA server to read temperatures (NTC) and voltage levels for all front-end boards including the boards on NSW Rim will be used. Some control will be also available using I/O to power on/off cards on sTGC trigger path (RimL1 can power cycle PadTrigger/Router). DCS interlocks based on the on-detector electronic temperatures will be developed. In total 60 FLX cards distributed in 30 FELIX hosts will serve 6976 SCA.

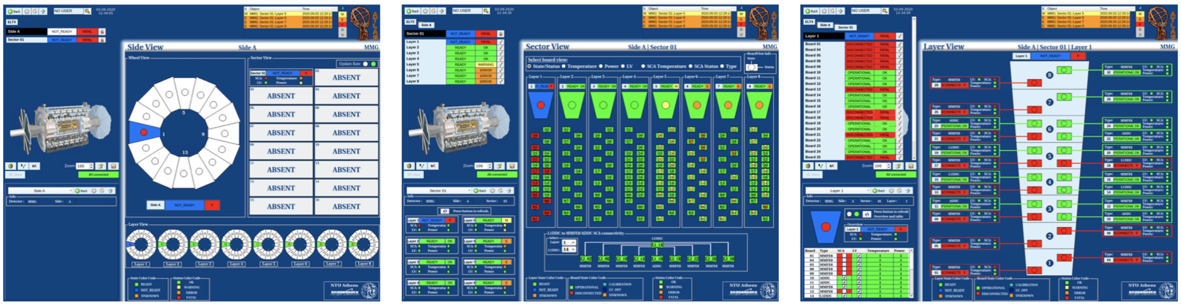


Figure 15. The DCS FSM and panels for the NSW Electronics monitoring.

4. Conclusions

The NSW is a fully redundant trigger and tracking detector system supported by an advanced electronics scheme and ready to handle the challenges of increased instantaneous luminosity at the HL LHC. Due to it's complexity and long-term operation, the NSW requires the development of a sophisticated DCS. Prototype DCS projects has been developed in order to support the integration phase of the project. The low-level segment of the projects has been fully deployed with the main components being fully functional. NSW DCS architecture and it's integration with the ATLAS DCS have been finalised. Currently we are on the phase of NSW DCS optimization towards ATLAS cavern installation.

Acknowledgments

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