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

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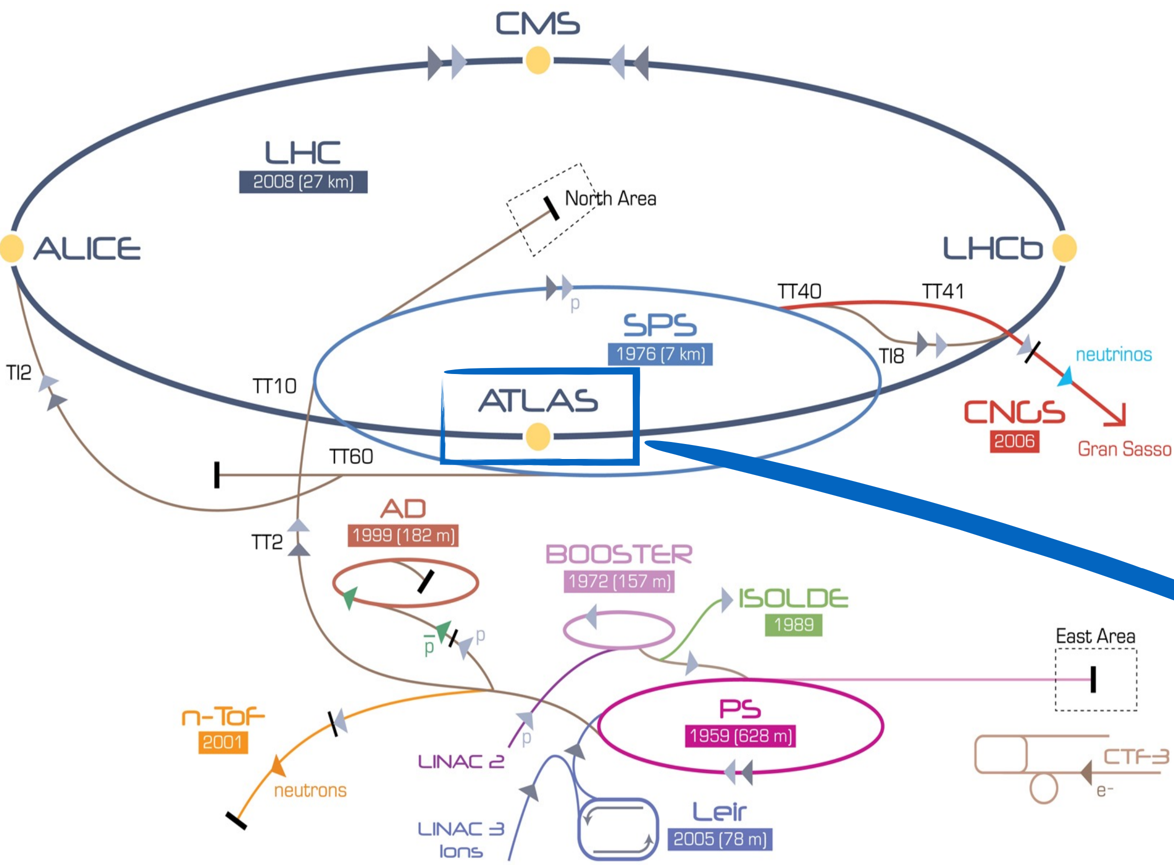
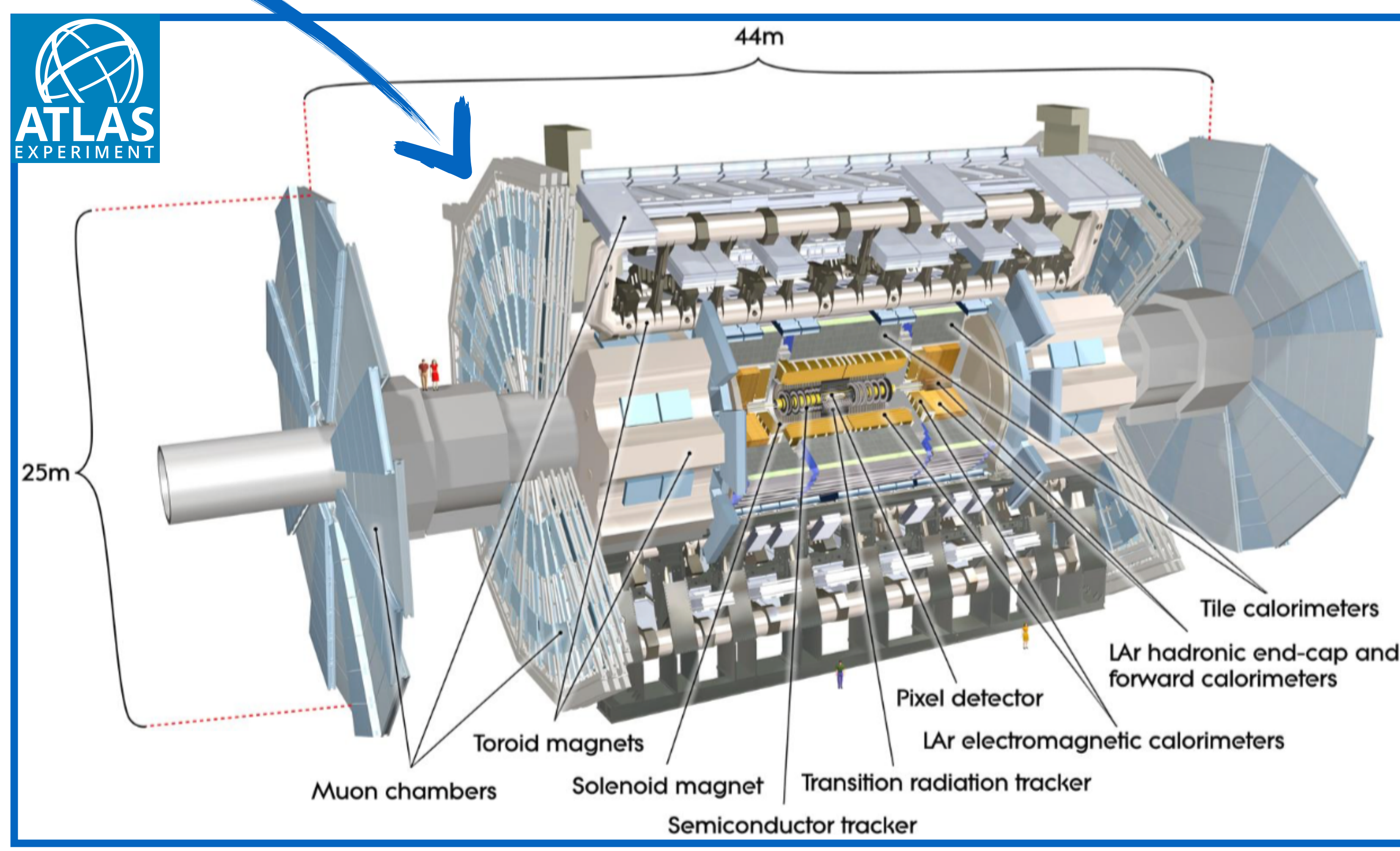
Large Hadron Collider

The European Organisation for Nuclear Research:



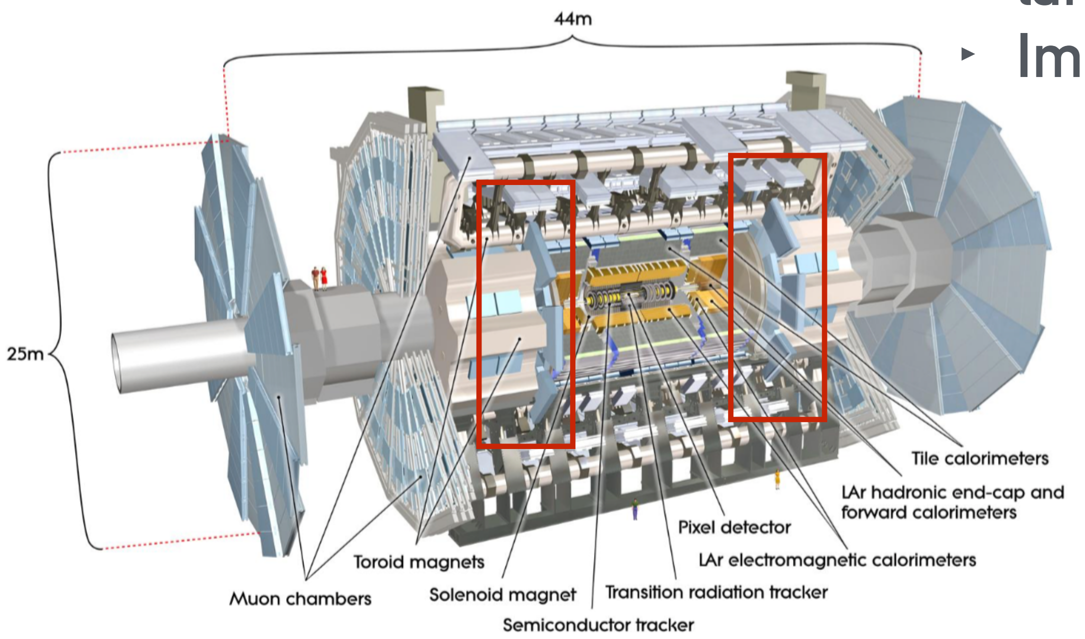
- French-Swiss borders @ 60-100m underground!
- 27 km circumference
- Provide beams of p-p, p-Pb, or Pb-Pb ions
- Plenty of experiments

- Largest of four LHC experiments
- 7000 tonnes, ~100 million read-out channels, 3000 km of cables
- Contains 11 sub-detectors of different technologies in layer structure
- Built and operated by collaboration of >3000 physicists
- Operation with collisions since end 2009

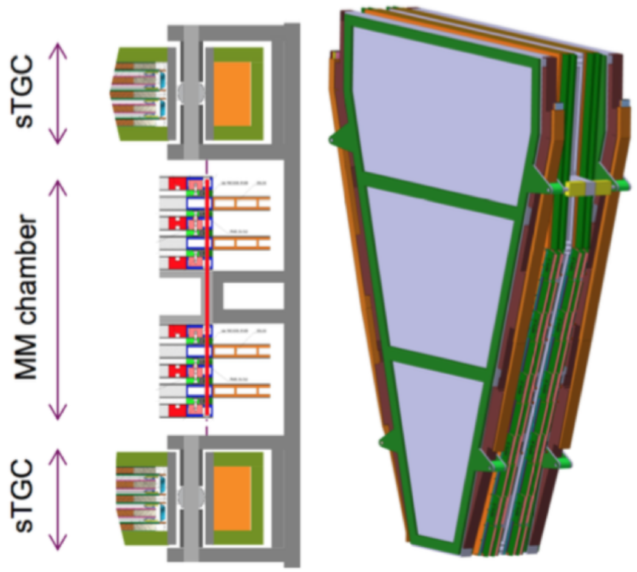


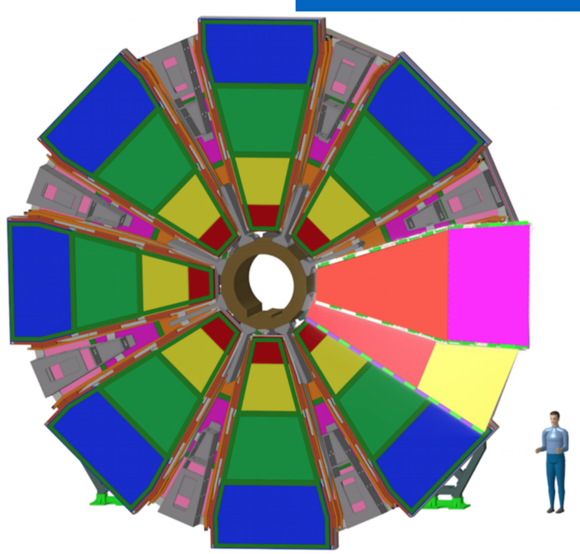
New Small Wheel

- The New Small Wheel (NSW) upgrade will replace the current Small Wheel of the ATLAS muon spectrometer to handle larger particle rates
- Important for Run 3, vital for High Luminosity LHC (2028)



New Small Wheel





The NSW will provide high precision muon track reconstruction and trigger information to ATLAS, at high rates, thus eliminating the issues of the present SW.

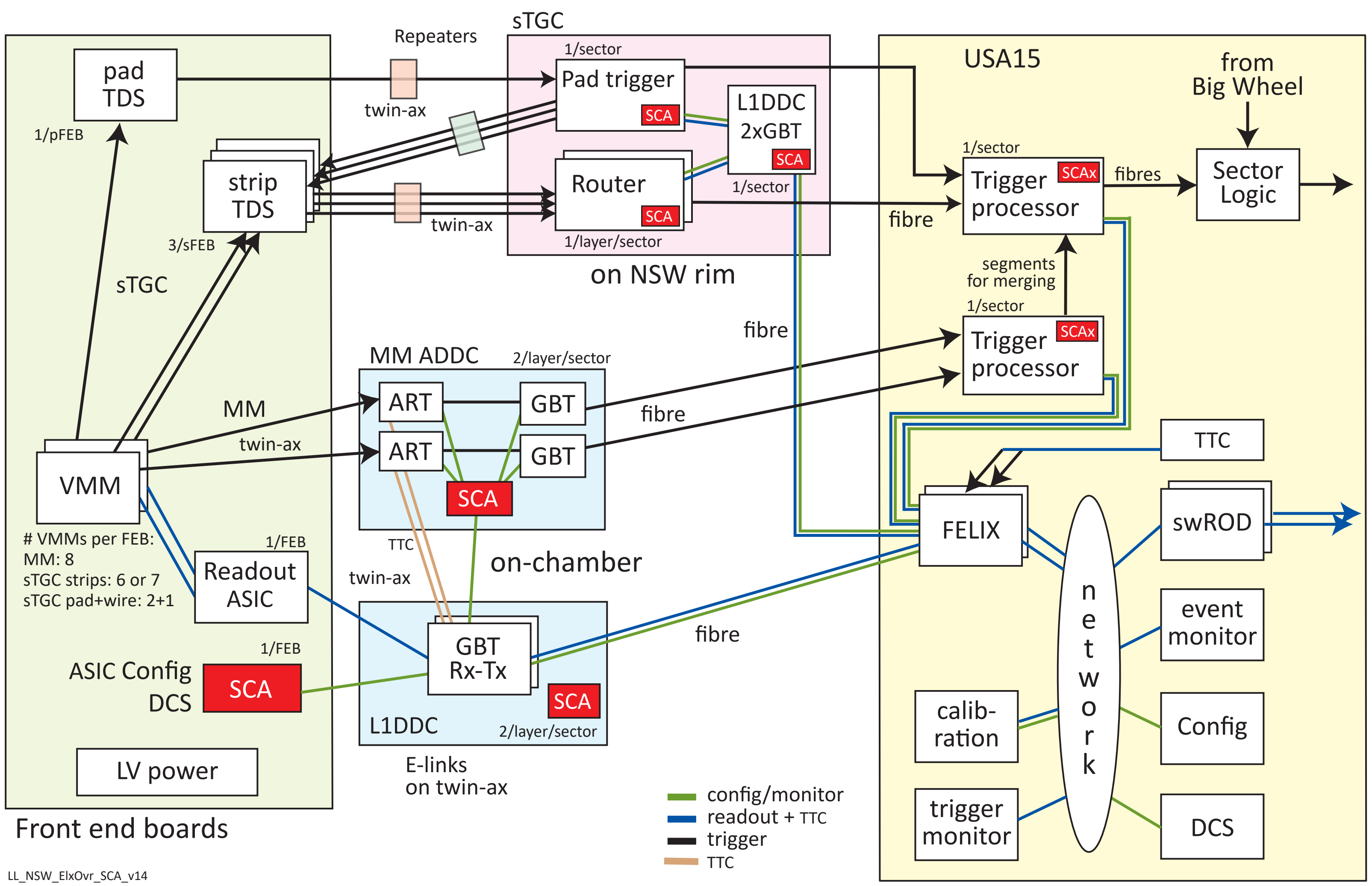
- 16 sectors for each NSW
- 16 layers for each sector

The NSW detectors:

- Micromegas (MM), mainly for precision tracking, also for trigger
- small Thin Gap Chambers (sTGC),mainly for trigger, also for precision tracking

NSW Electronics Overview

The New Small Wheel is a fully redundant trigger and tracking detector system, adequately supported by an advanced electronics scheme and ready to handle the challenges of increased instantaneous luminosity at the High Luminosity LHC.



Is NSW electronics system really "Small"?

- Separate configuration/monitor, readout and trigger path
- ~2.4 millions readout channels
- ~7.5k electronics boards
- ~60k ASICs
- ~100k parameters for monitor
- ~1M registers for Configuration

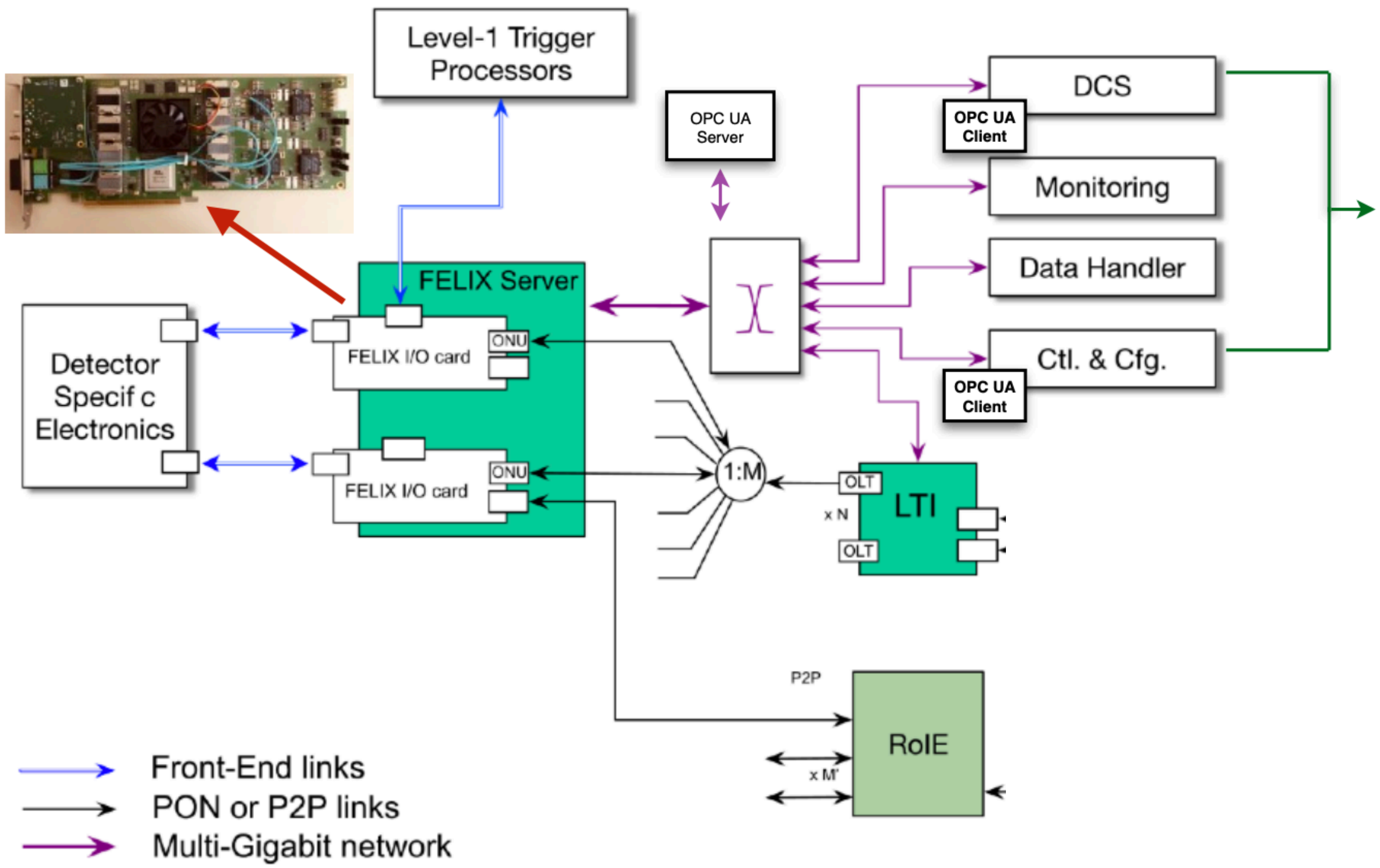
- 54k on detector readout ASICs read out by E-links to GBTx ASICs
- 1024 on-detector trigger encoders configured by 512 GBT-SCAs
- 256 Router FPGAs and 32 Pad Trigger FPGAs on the rim of the NSW
- All of the above configured and monitored by ~6400 GBT-SCA ASICs
- 64 FPGAs for Trigger Processor in USA15

E-links used for:

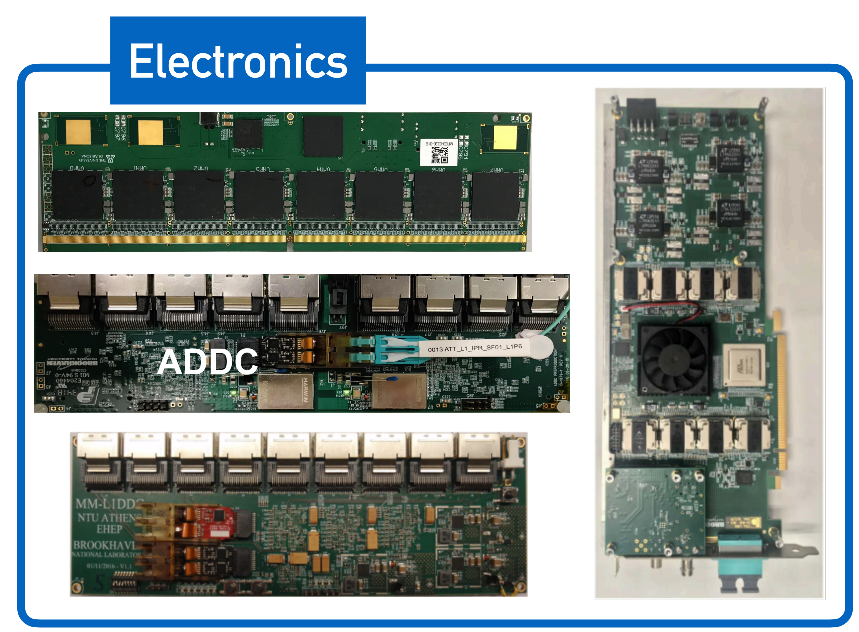
- L1 Accept data + Data monitoring
- BC clock and TTC signals
- Configuration of ASICs
- Monitoring temperatures and voltages
- FPGA configuration

NSW Electronics Architecture

- The NSW Electronics architecture lies on the newly introduced readout scheme of ATLAS
- It has mainly three new hardware components:
  - FELIX - Optical link aggregator system / TTC distributor / Busy. This is a server PC which host two BNL712 PCIe boards (24 optical links / each on NSW)
  - Data handler server or swROD system - Software based readout driver
  - ALTI TTC system - Replacement module of the legacy TTC system (vi/vx LTP)

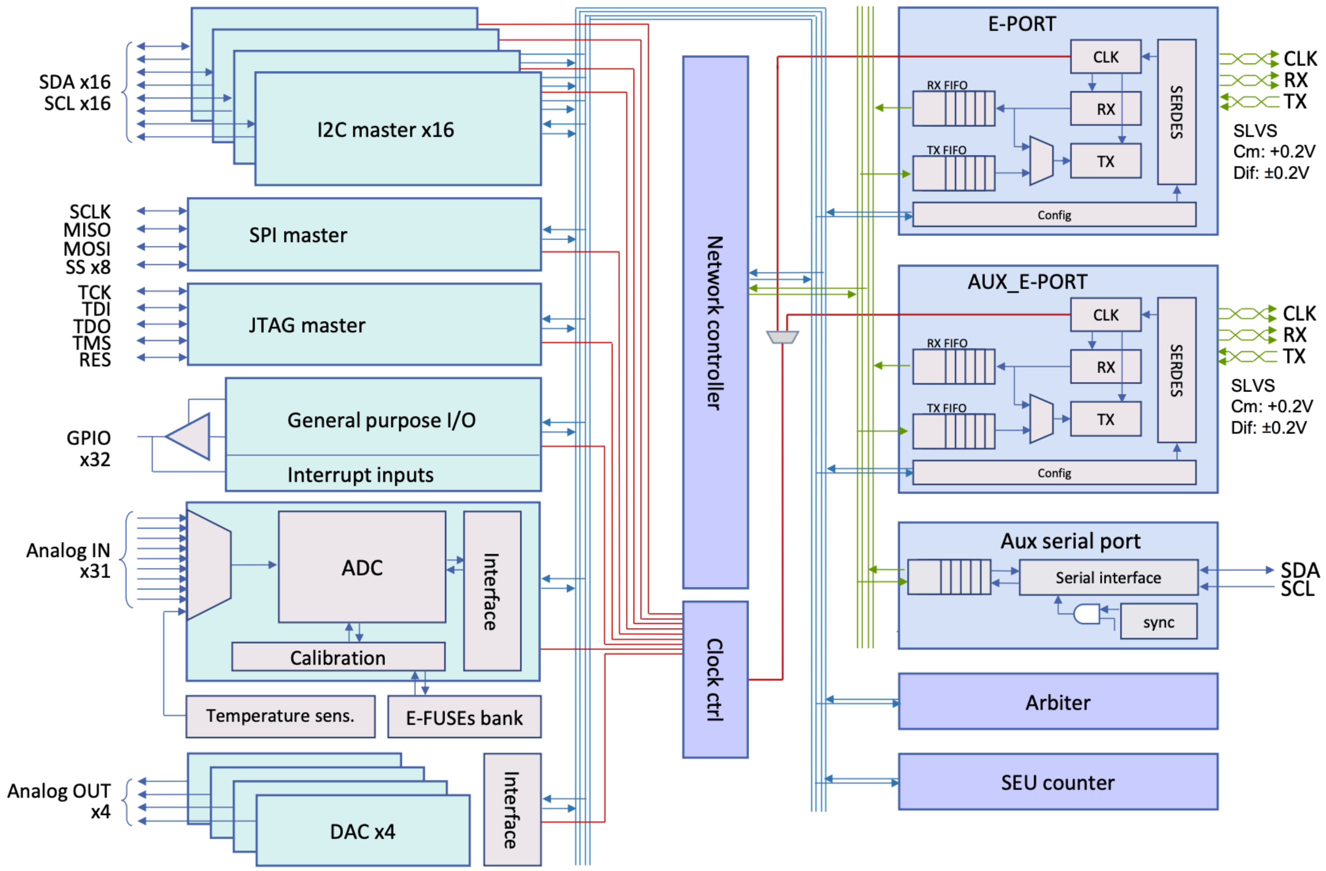


- DCS, Calibration & Configuration share the common path to the detector electronics (through GBT-SCA) and the SCA OPC UA Server which developed by ATLAS Central DCS



GBT-SCA

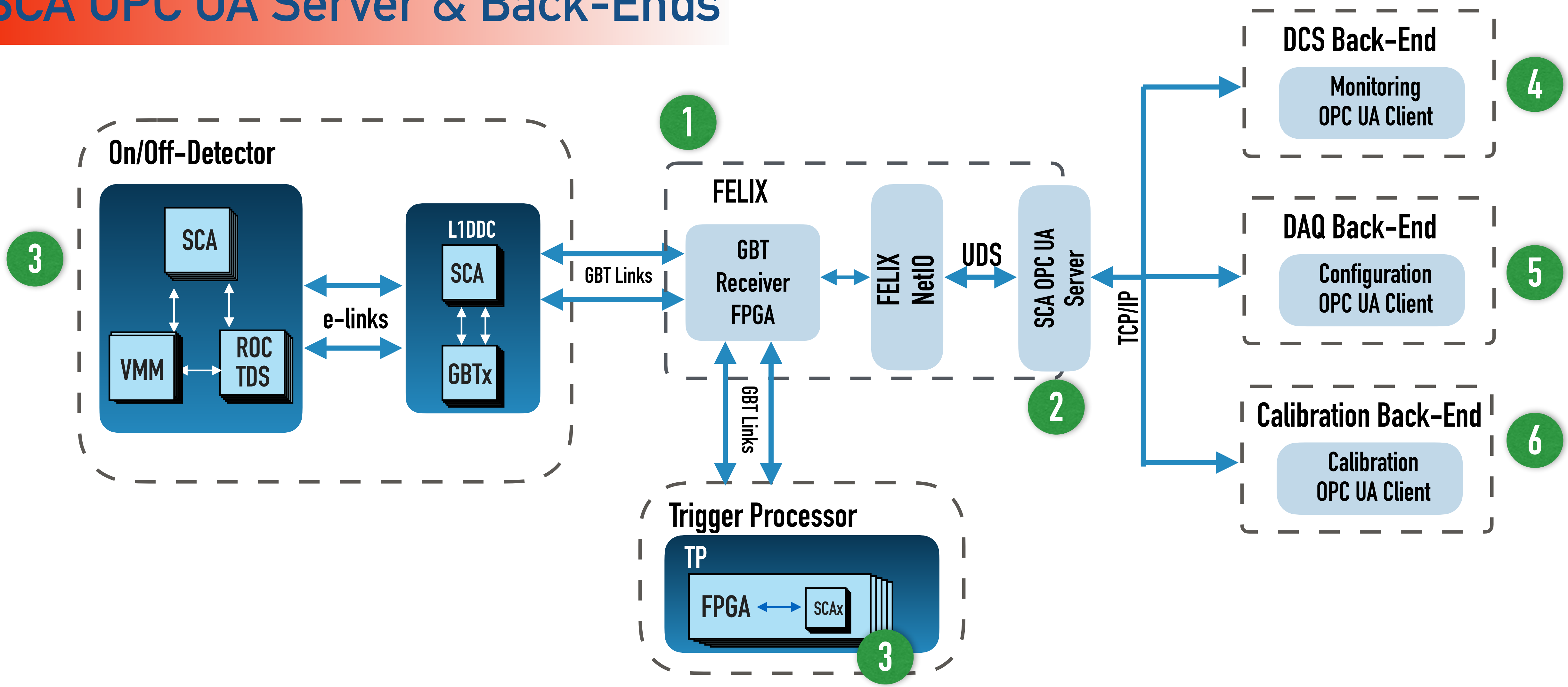
The GBT-SCA ASIC (Giga-Bit Transceiver - Slow Control Adapter) is the part of the GBT chipset which purpose is to distribute control and monitoring signals to the front-end electronics embedded in the detectors.



The user interface ports are:

- 1 SPI serial bus master Interface
- 16 independent I²C master serial bus channels
- 1 JTAG master Interface
- 4 DAC (8-bit)
- 32 General Purpose digital IO lines (GPIO)
- 31 ADC (12-bit)

SCA OPC UA Server & Back-Ends

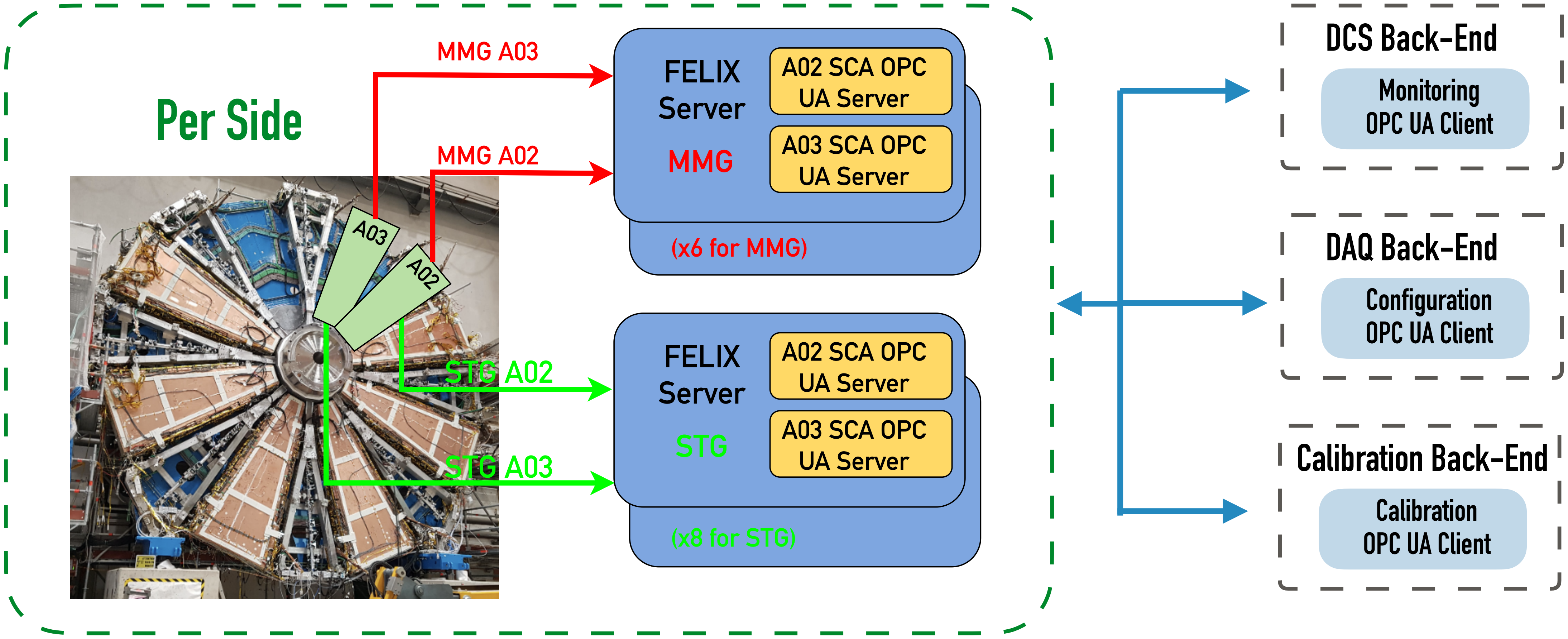


1. Prepare FELIX by configuring the e-links ports
2. Initialise SCA OPC UA server by indicating the e-links to connect to
3. Establish communication between SCAs and SCA OPC UA Server via the FELIX
4. Monitor the various temperature and voltage levels of the electronics via SCA OPC UA Server and DCS
5. Configuration of the various electronics via the SCA OPC UA Server and the NSWConfiguration
6. Calibration of the various electronics via the SCA OPC UA Server and the NSWCalibration

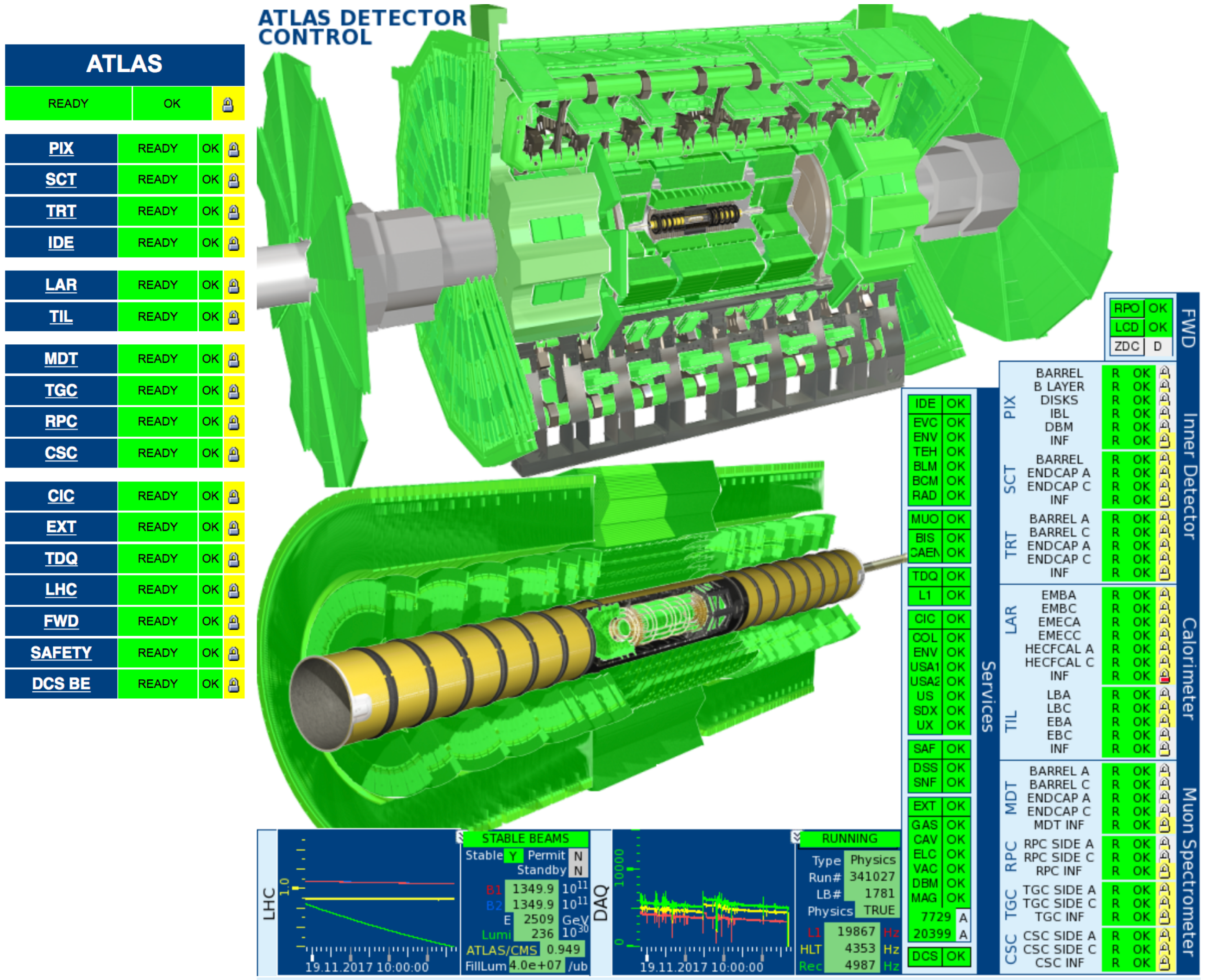
System setup

The system setups consists of:

- 28 FELIX servers (12 for MMG, 16 for STG)
- 32 SCA OPC UA Servers
- 1 SCA OPC UA Server per sector

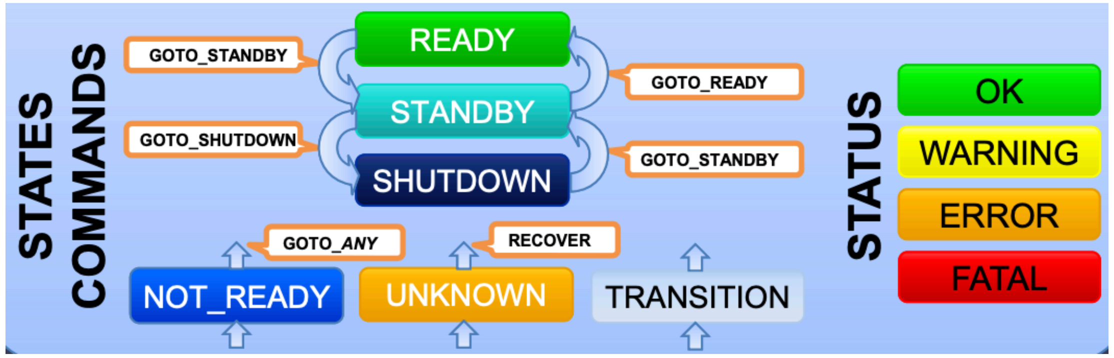


ATLAS Detector Control System



State Machine Hierarchy

- Detector control mapped to state machine hierarchy above SCADA layer
- Using JCOP FSM software framework
- Device States are propagated upwards using state rules, Commands propagated downwards
- Error handling upwards using parallel tree of Status objects linked to device alarm



Operator Control

- Alarm Screen enabling quick recognition and response to problems
- Homogeneous navigation through state machine hierarchy for operator with custom HMI
- Each state machine object has associated panel (synoptics, trends etc.)
- Access control mechanism
- Web monitoring, no load on Back-End, history mode

NSW Detector Control System

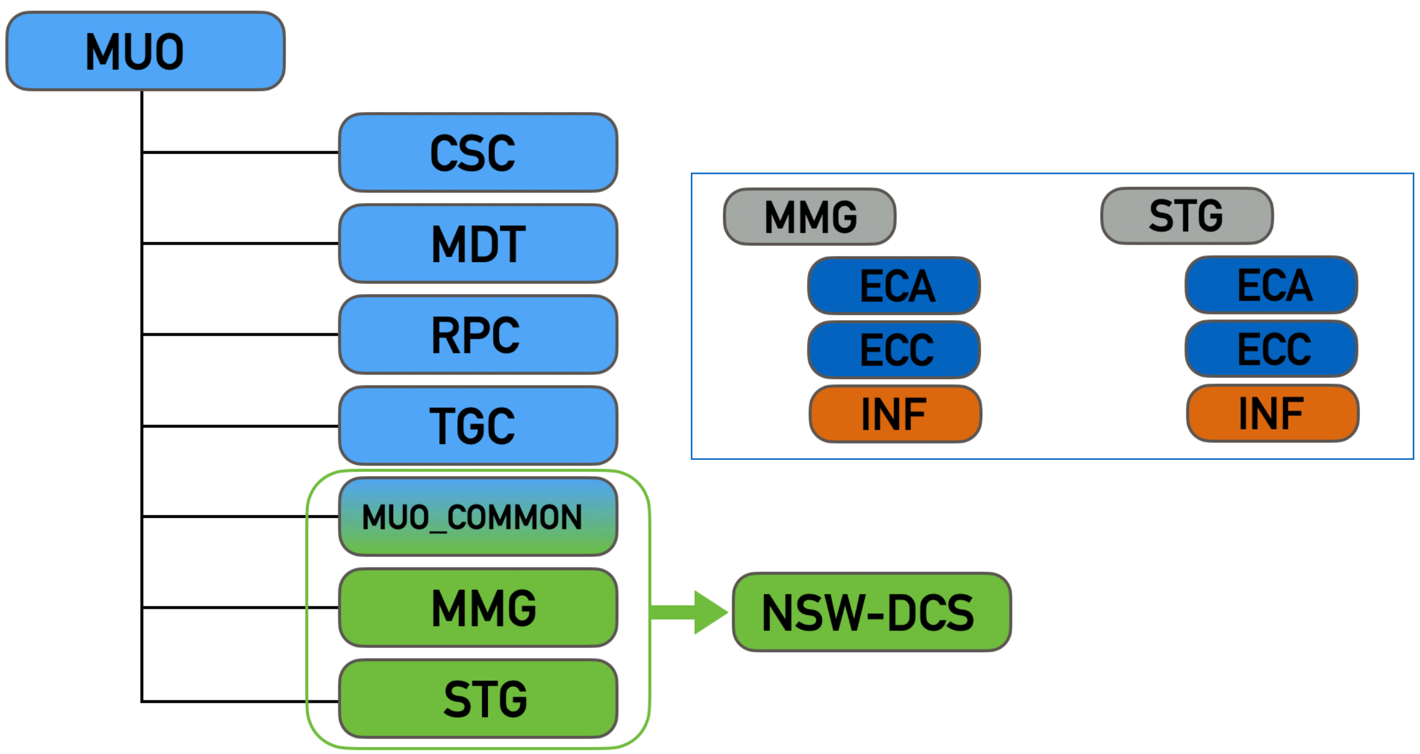
Due to its complexity and long-term operation, the NSW requires the development of a sophisticated DCS. The use of such a system is necessary to allow the detector to function consistently and safely as well as to function as a seamless interface to all sub-detectors and the technical infrastructure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

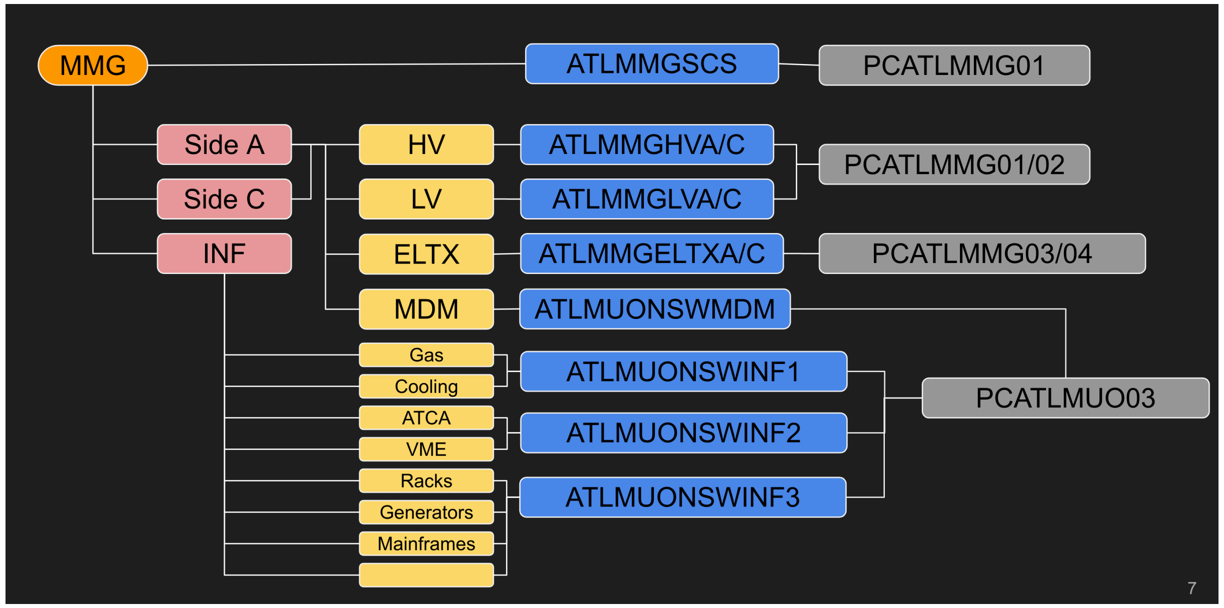
The plan is to have 2 new sub-detectors:

- MMG (Micromegas)
- STG (sTGC)

<u>Main projects:</u>

- High Voltage
- Low Voltage
- ELTX-SCA
- MDM-ELMB
- VME-ATCA
- Cooling
- Gas
- Infrastructure

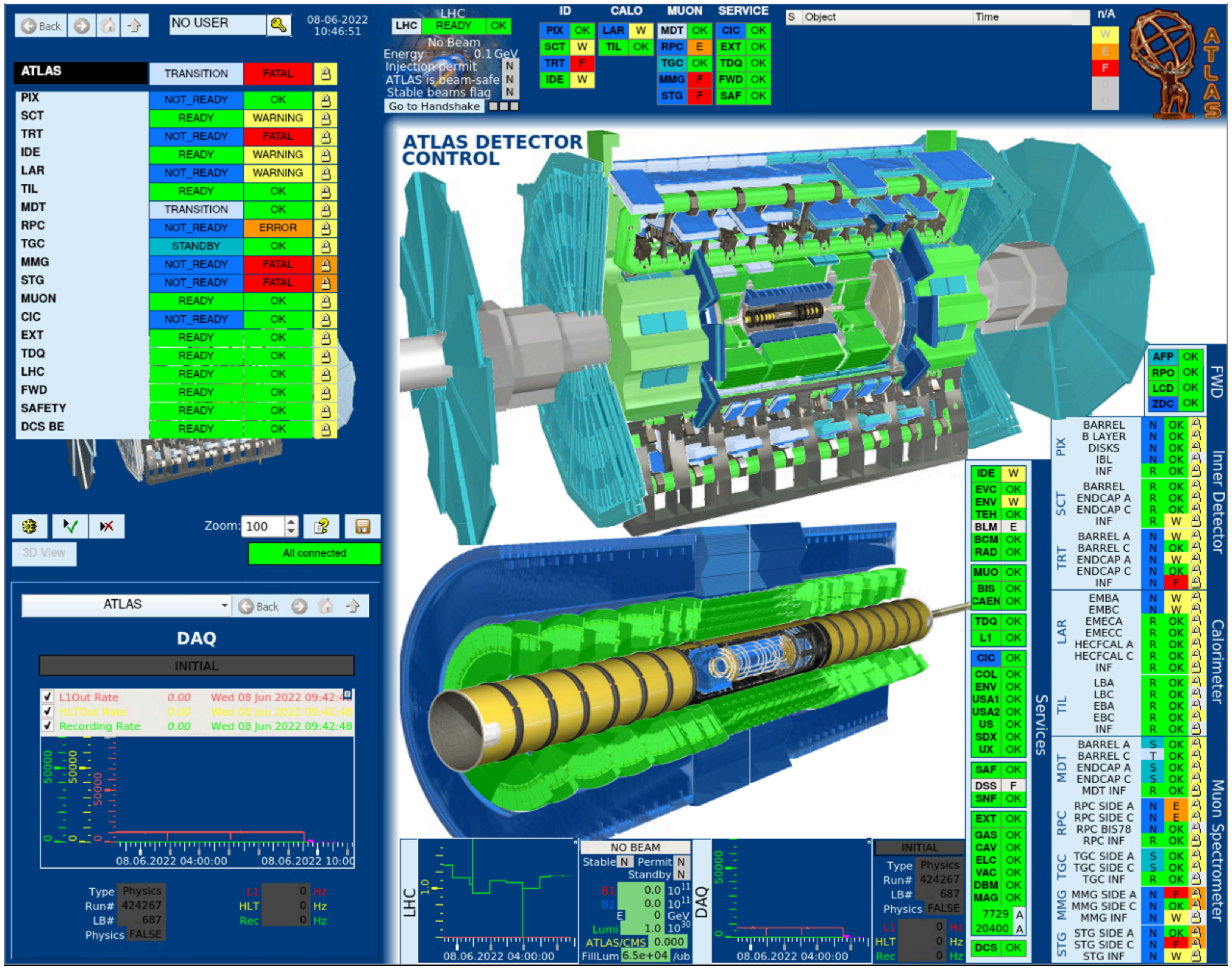


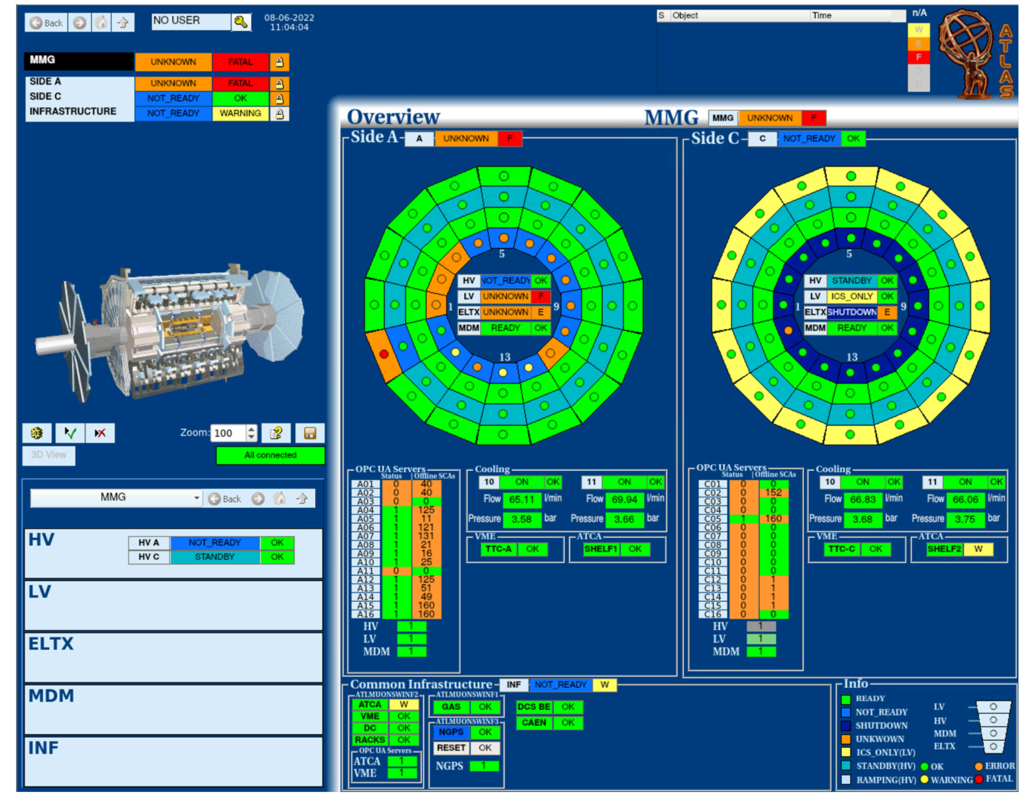


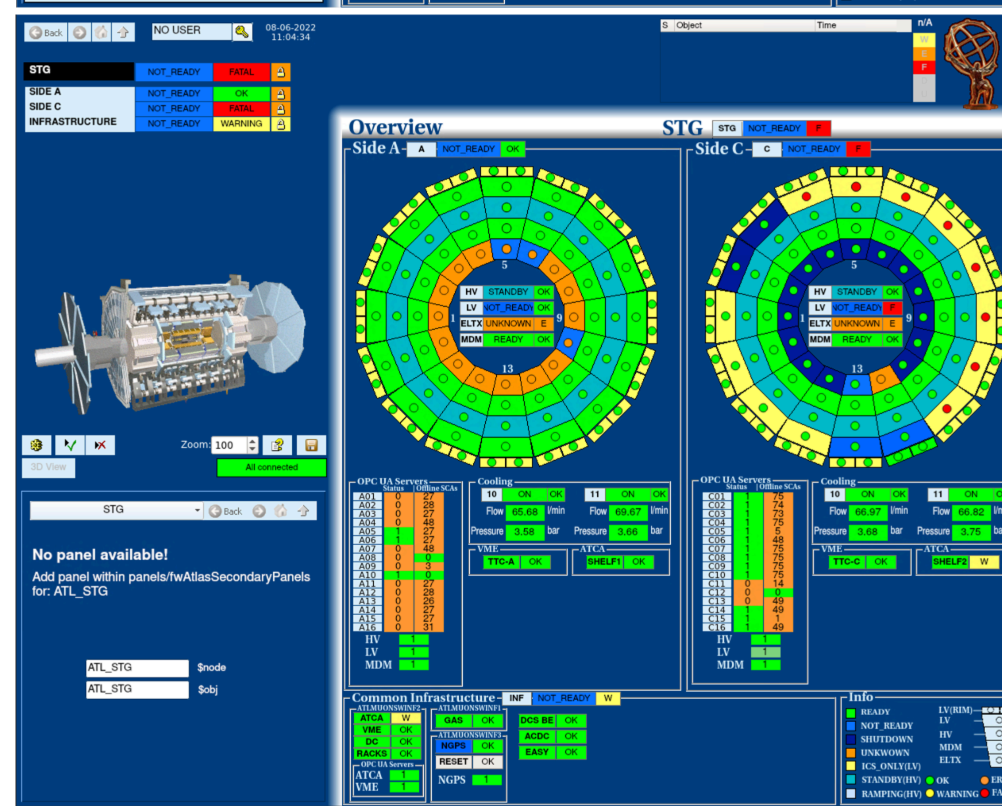
NSW DCS architecture and it's integration with the Muon DCS have been finalised. The top node of both MMG and STG will propagate its state and receive commands from the ATLAS overall DCS.

ATLAS DCS Integration

- Since 1 week, MMG&STG DCS have been integrated into the ATLAS & Muon DCS !!!

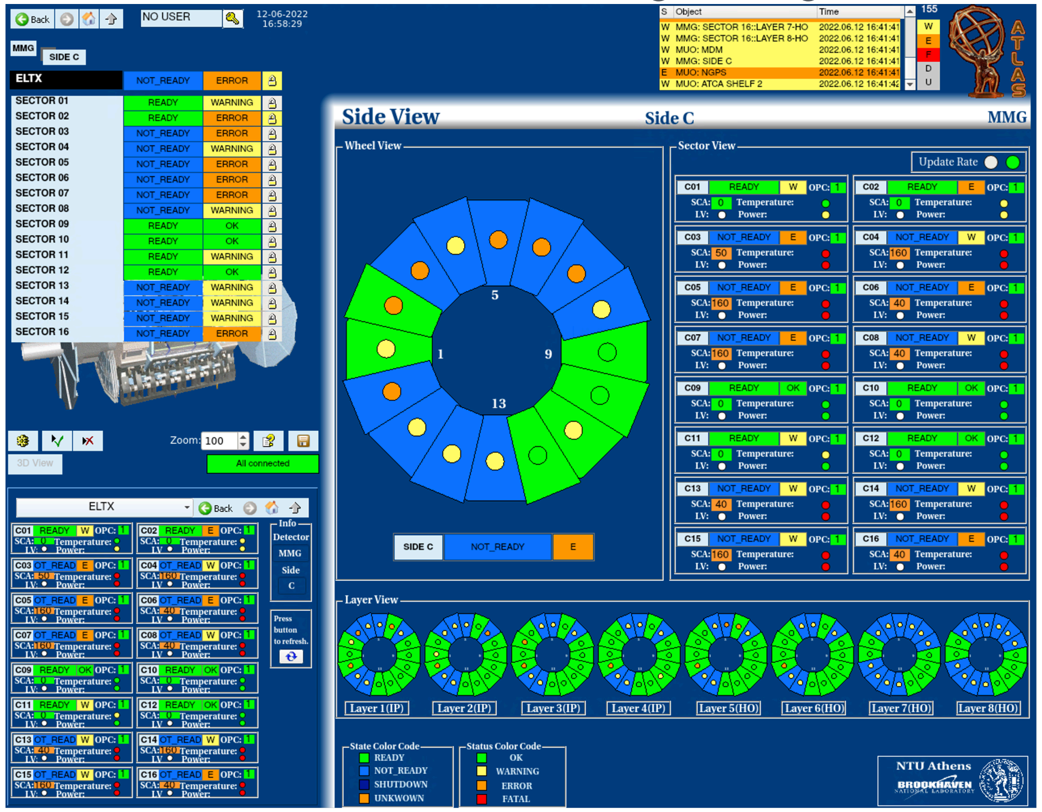






Electronics control system

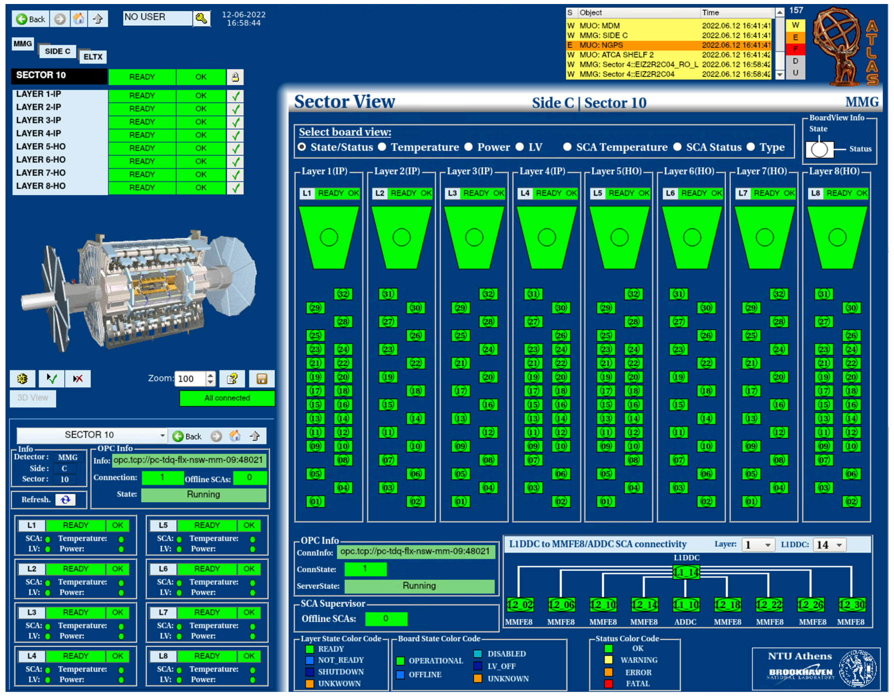
For the NSW electronics safe operation, an advanced control system within the ATLAS DCS is required for the electronics monitoring using the SCA chip, which is installed on the 7000 front-end boards of the NSW.

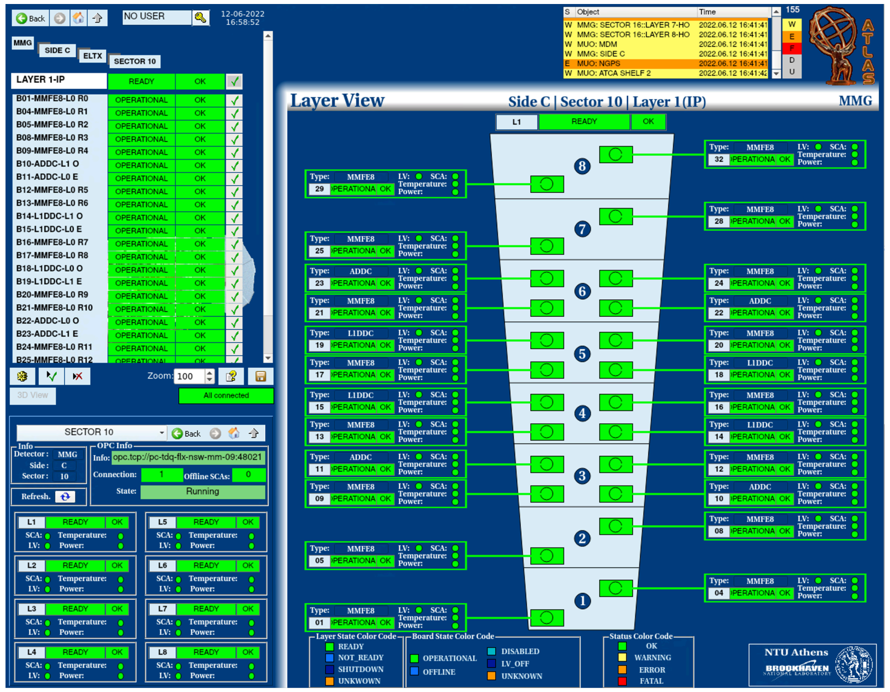


Features:

- ~7000 GBT-SCA
- Run over the common SCA OPC UA Server
- ~100k parameters
  - Power & temperature sensors
  - On-chip temperatures and information
  - Diagnostics information
  - Alarm handling on each parameter
- Following Muon's existing look and command architecture
- Hierarchy of Finite State Machine (FSM)
- Facilitate the shifter/expert operations

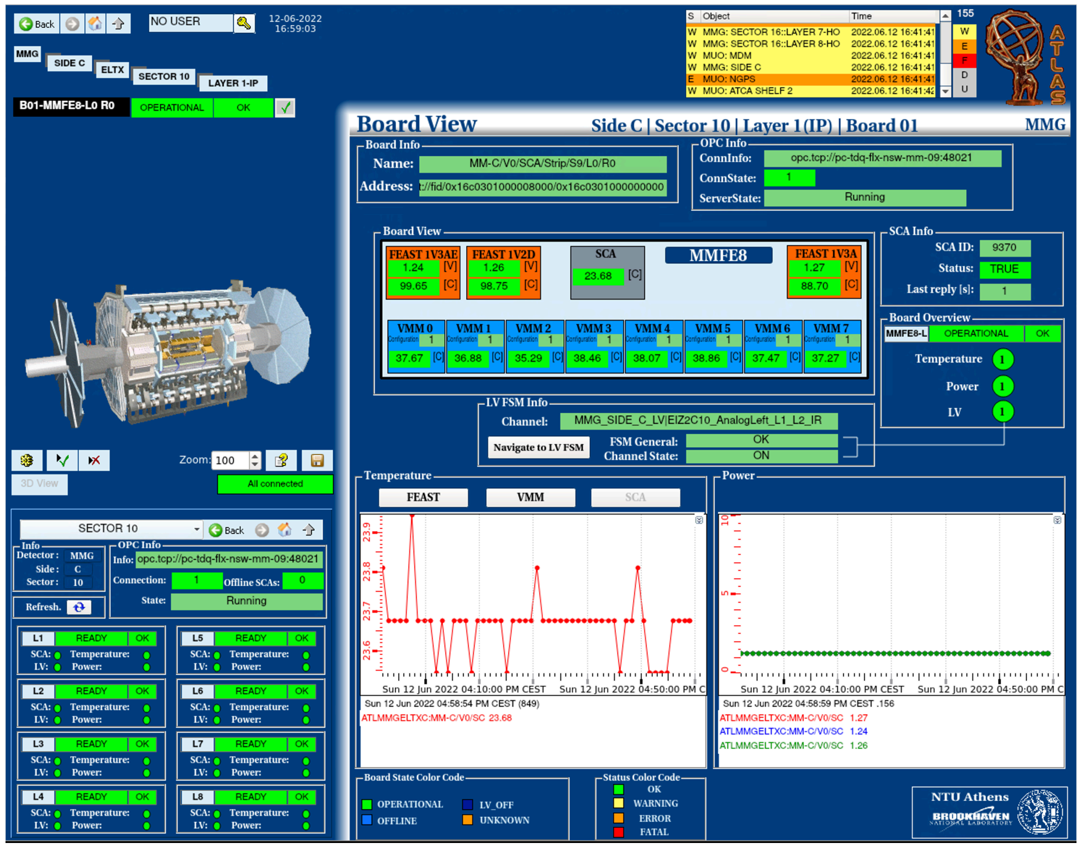
For each individual layer, a main panel has been developed, providing the user with useful information, reflecting the state and status of the detector.



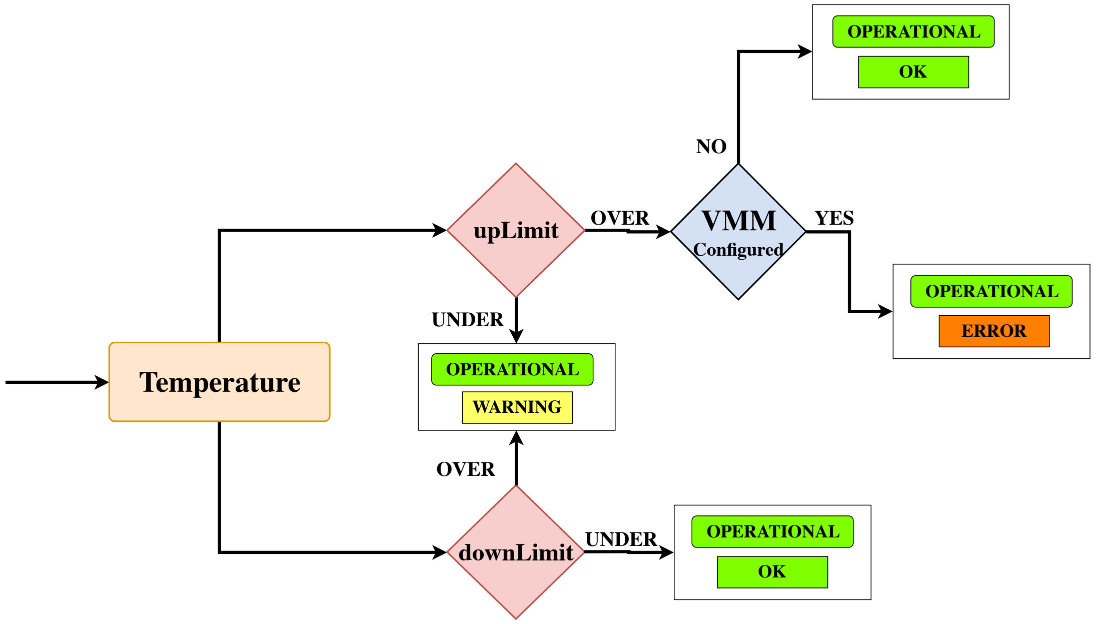


DAQ-DCS Interaction

DCS and DAQ are on the same SCA OPC UA path



- On FEBs equipped with VMM, SCA Analog Input common for VMM calibration and temperature monitoring
- Thus, during calibration VMM shows fake temperature values so a DDC plug between DCS-DAQ should be implemented
  - Solution found via the common SCA OPC UA Server!
  - Central DCS developed the FreeVariable concept, which is a OPC UA item which can be controlled and monitored in both DCS and DAQ clients.
  - So, during Calibration run, the DCS will monitor the configuration status for this specific VMM of the FEB and the alarm will be disabled corresponding FEB's VMM



- More DAQ-DCS interaction:
  - FELIX monitoring
  - GBT e-link health status

Summary

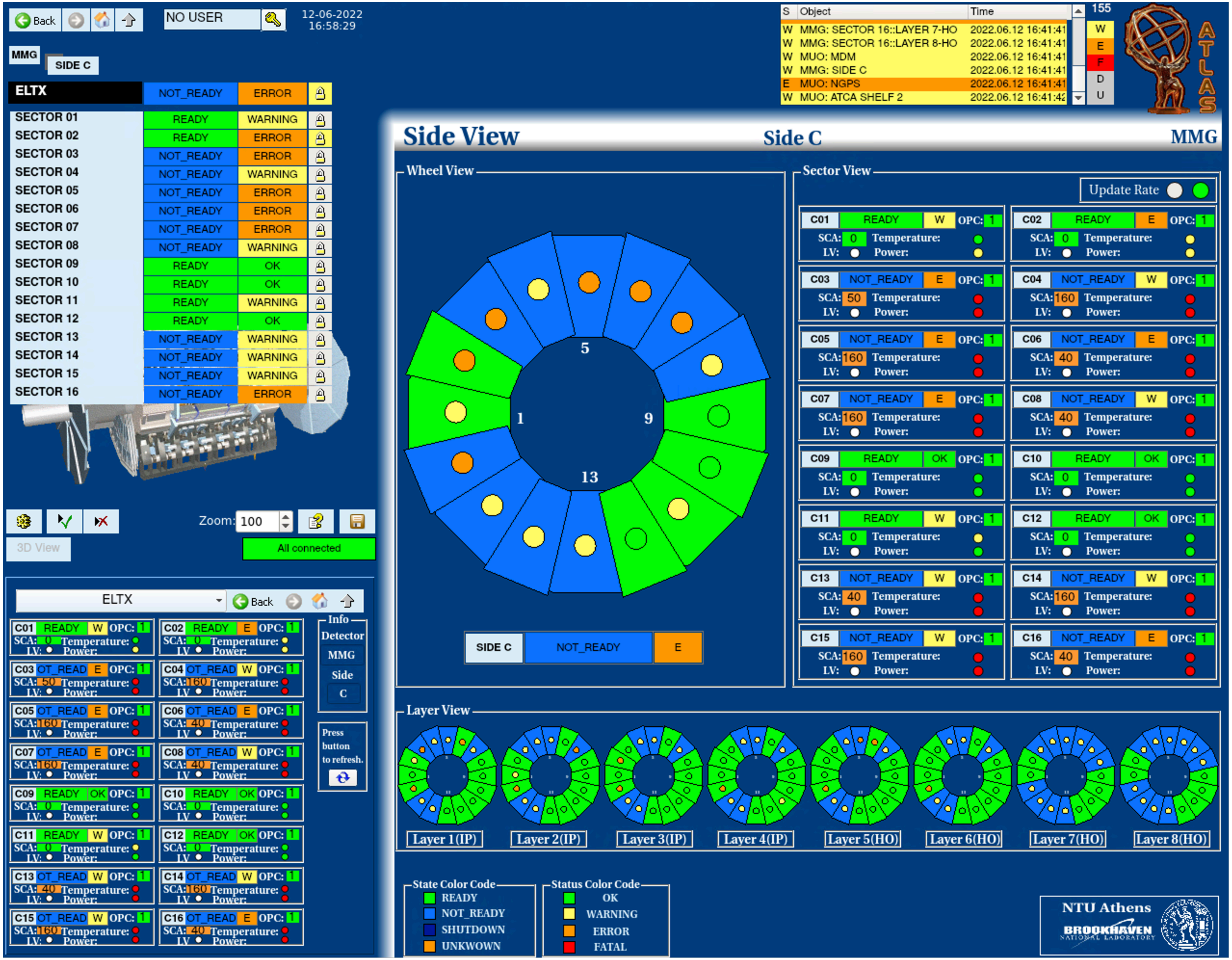
- The NSW is a fully redundant trigger and tracking detector system supported by an advanced electronics scheme and ready to handle the challenges of increased instantaneous luminosity at the HL LHC
- Due to its complexity and long-term operation, the NSW requires the development of a sophisticated DCS
- The NSW Electronics system is really challenging due to the massive number of boards (ASICs, FPGAs)
- Another challenge is the dependance of the NSW DAQ on new technologies based on FELIX and GBT-SCA
- Use of common SCA OPC UA Server path in order to simplify the NSW DCS/DAQ procedure
- System setup, architecture, operation and technical reviews have been finalised
- The NSW Electronics control system has been implementation into ATLAS & Muon DCS!
- Continuous optimisation is on-going

Thanks for your attention!

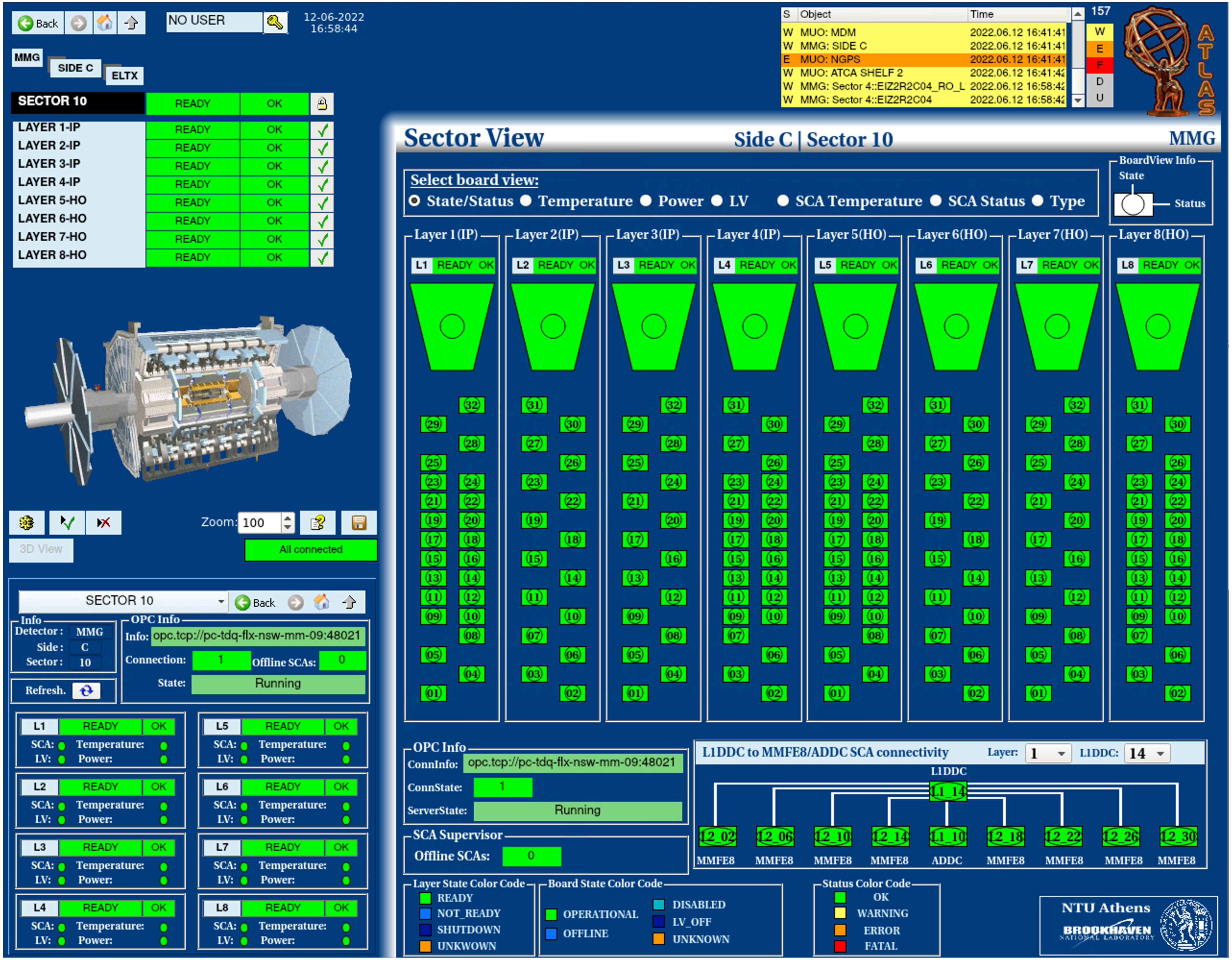
- Questions ?
- Comments ?

Back Up

ELTX DCS


Back
NO USER
12-06-2022
16:58:29
S Object Time
W MMG: SECTOR 16::LAYER 7-HO 2022.06.12 16:41:41
W MMG: SECTOR 16::LAYER 8-HO 2022.06.12 16:41:41
W MUO: MDM 2022.06.12 16:41:41
W MMG: SIDE C 2022.06.12 16:41:41
E MUO: NGPS 2022.06.12 16:41:41
W MUO: ATCA SHELF 2 2022.06.12 16:41:42
155
W
E
F
D
U
ATLAS
MMG
SIDE C
ELTX NOT_READY ERROR
SECTOR 01 READY WARNING
SECTOR 02 READY ERROR
SECTOR 03 NOT_READY ERROR
SECTOR 04 NOT_READY WARNING
SECTOR 05 NOT_READY ERROR
SECTOR 06 NOT_READY ERROR
SECTOR 07 NOT_READY ERROR
SECTOR 08 NOT_READY WARNING
SECTOR 09 READY OK
SECTOR 10 READY OK
SECTOR 11 READY WARNING
SECTOR 12 READY OK
SECTOR 13 NOT_READY WARNING
SECTOR 14 NOT_READY WARNING
SECTOR 15 NOT_READY WARNING
SECTOR 16 NOT_READY ERROR
Zoom: 100
3D View
All connected
ELTX
Back
Info
Detector
MMG
Side
C
Press button to refresh.
Side View
Side C
MMG
Wheel View
5
1
9
13
SIDE C NOT_READY E
Sector View
Update Rate
C01 READY W OPC: 1
C02 READY E OPC: 1
C03 NOT_READY E OPC: 1
C04 NOT_READY W OPC: 1
C05 NOT_READY E OPC: 1
C06 NOT_READY E OPC: 1
C07 NOT_READY E OPC: 1
C08 NOT_READY W OPC: 1
C09 READY OK OPC: 1
C10 READY OK OPC: 1
C11 READY W OPC: 1
C12 READY OK OPC: 1
C13 NOT_READY W OPC: 1
C14 NOT_READY W OPC: 1
C15 NOT_READY W OPC: 1
C16 NOT_READY E OPC: 1
SCA: Temperature:
LV: Power:
Layer View
Layer 1(IP)
Layer 2(IP)
Layer 3(IP)
Layer 4(IP)
Layer 5(HO)
Layer 6(HO)
Layer 7(HO)
Layer 8(HO)
State Color Code
READY
NOT_READY
SHUTDOWN
UNKWOWN
Status Color Code
OK
WARNING
ERROR
FATAL
NTU Athens
BROOKHAVEN NATIONAL LABORATORY

ELTX DCS


Back
NO USER
12-06-2022
16:58:44
MMG
SIDE C
ELTX
SECTOR 10 READY OK
LAYER 1-IP READY OK
LAYER 2-IP READY OK
LAYER 3-IP READY OK
LAYER 4-IP READY OK
LAYER 5-HO READY OK
LAYER 6-HO READY OK
LAYER 7-HO READY OK
LAYER 8-HO READY OK
Zoom: 100
3D View
All connected
S Object Time
W MUO: MDM 2022.06.12 16:41:41
W MMG: SIDE C 2022.06.12 16:41:41
E MUO: NGPS 2022.06.12 16:41:41
W MUO: ATCA SHELF 2 2022.06.12 16:41:42
W MMG: Sector 4::EIZ2R2C04_RO_L 2022.06.12 16:58:42
W MMG: Sector 4::EIZ2R2C04 2022.06.12 16:58:42
157
W E F D U
ATLAS
Sector View
Side C | Sector 10
MMG
Select board view:
State/Status Temperature Power LV SCA Temperature SCA Status Type
BoardView Info
State
Status
Layer 1 (IP) Layer 2 (IP) Layer 3 (IP) Layer 4 (IP) Layer 5 (HO) Layer 6 (HO) Layer 7 (HO) Layer 8 (HO)
L1 READY OK
L2 READY OK
L3 READY OK
L4 READY OK
L5 READY OK
L6 READY OK
L7 READY OK
L8 READY OK
SECTOR 10
Info
Detector: MMG
Side: C
Sector: 10
Refresh.
OPC Info
Info: opc.tcp://pc-tdq-flx-nsw-mm-09:48021
Connection: 1
Offline SCAs: 0
State: Running
SCA: Temperature:
LV: Power:
OPC Info
ConnInfo: opc.tcp://pc-tdq-flx-nsw-mm-09:48021
ConnState: 1
ServerState: Running
SCA Supervisor
Offline SCAs: 0
L1DDC to MMFE8/ADDC SCA connectivity
Layer: 1
L1DDC: 14
L1DDC
L1_14
L2_02 L2_06 L2_10 L2_14 L1_10 L2_18 L2_22 L2_26 L2_30
MMFE8 MMFE8 MMFE8 MMFE8 ADDC MMFE8 MMFE8 MMFE8 MMFE8
Layer State Color Code
READY
NOT_READY
SHUTDOWN
UNKWOWN
Board State Color Code
OPERATIONAL
OFFLINE
DISABLED
LV_OFF
UNKNOWN
Status Color Code
OK
WARNING
ERROR
FATAL
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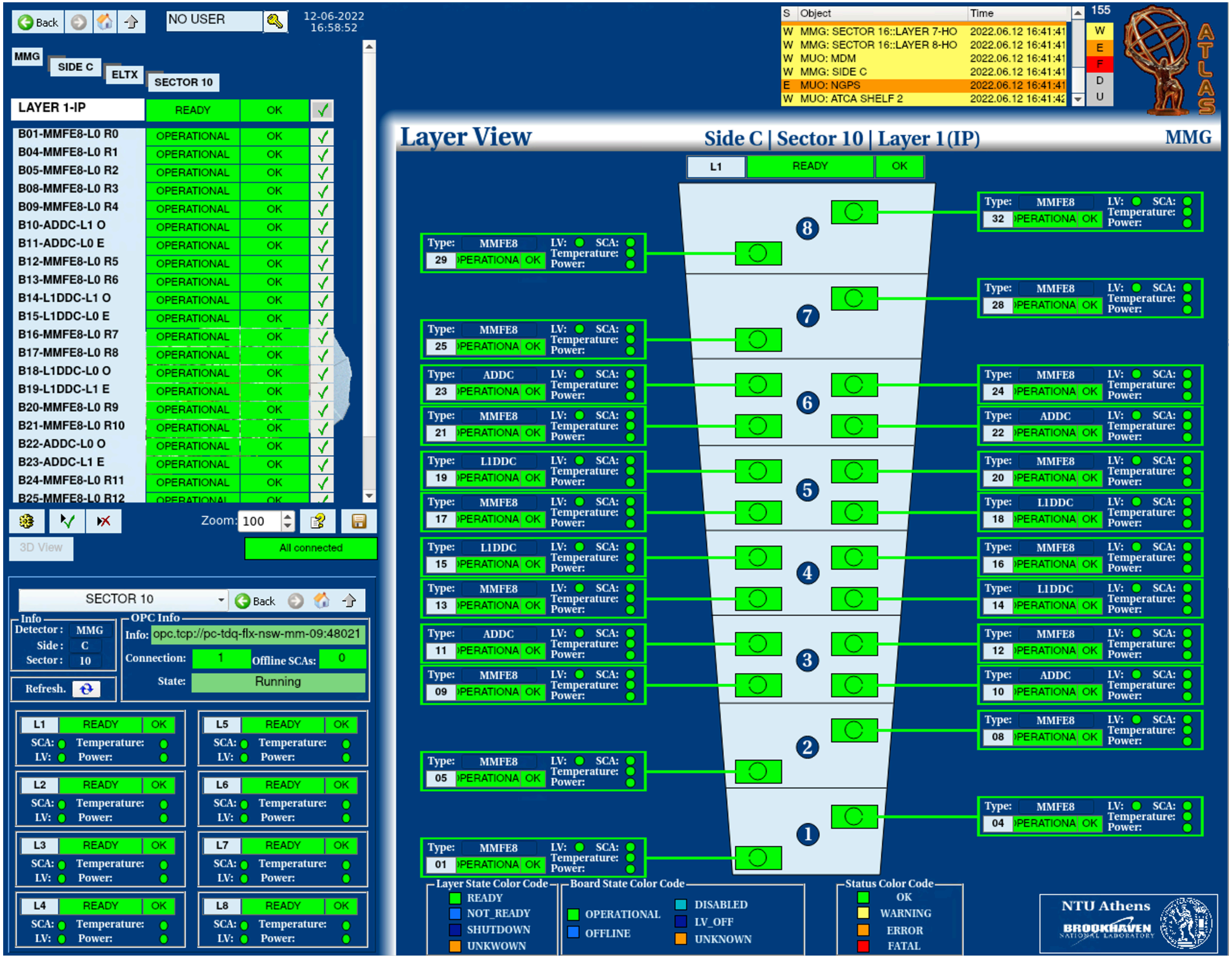
ELTX DCS


Back
NO USER
12-06-2022 16:58:52
MMG
SIDE C
ELTX
SECTOR 10
LAYER 1-IP READY OK
B01-MMFE8-L0 R0 OPERATIONAL OK
B04-MMFE8-L0 R1 OPERATIONAL OK
B05-MMFE8-L0 R2 OPERATIONAL OK
B08-MMFE8-L0 R3 OPERATIONAL OK
B09-MMFE8-L0 R4 OPERATIONAL OK
B10-ADDC-L1 O OPERATIONAL OK
B11-ADDC-L0 E OPERATIONAL OK
B12-MMFE8-L0 R5 OPERATIONAL OK
B13-MMFE8-L0 R6 OPERATIONAL OK
B14-L1DDC-L1 O OPERATIONAL OK
B15-L1DDC-L0 E OPERATIONAL OK
B16-MMFE8-L0 R7 OPERATIONAL OK
B17-MMFE8-L0 R8 OPERATIONAL OK
B18-L1DDC-L0 O OPERATIONAL OK
B19-L1DDC-L1 E OPERATIONAL OK
B20-MMFE8-L0 R9 OPERATIONAL OK
B21-MMFE8-L0 R10 OPERATIONAL OK
B22-ADDC-L0 O OPERATIONAL OK
B23-ADDC-L1 E OPERATIONAL OK
B24-MMFE8-L0 R11 OPERATIONAL OK
Zoom: 100
3D View
All connected
SECTOR 10
Info
Detector: MMG
Side: C
Sector: 10
OPC Info
Info: opc.tcp://pc-tdq-flx-nsw-mm-09:48021
Connection: 1
Offline SCAs: 0
State: Running
Refresh.
L1 READY OK
L2 READY OK
L3 READY OK
L4 READY OK
L5 READY OK
L6 READY OK
L7 READY OK
L8 READY OK
SCA: Temperature:
LV: Power:
S Object Time
W MMG: SECTOR 16::LAYER 7-HO 2022.06.12 16:41:41
W MMG: SECTOR 16::LAYER 8-HO 2022.06.12 16:41:41
W MUO: MDM 2022.06.12 16:41:41
W MMG: SIDE C 2022.06.12 16:41:41
E MUO: NGPS 2022.06.12 16:41:41
W MUO: ATCA SHELF 2 2022.06.12 16:41:42
155
W E F D U
ATLAS
Layer View
Side C | Sector 10 | Layer 1 (IP)
MMG
L1 READY OK
Type: MMFE8
LV: SCA:
Temperature:
Power:
Type: ADDC
Type: L1DDC
OPERATIONAL OK
01 05 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 28 29 32
1 2 3 4 5 6 7 8
Layer State Color Code
READY
NOT_READY
SHUTDOWN
UNKWOWN
Board State Color Code
OPERATIONAL
OFFLINE
DISABLED
LV_OFF
UNKNOWN
Status Color Code
OK
WARNING
ERROR
FATAL
NTU Athens
BROOKHAVEN NATIONAL LABORATORY

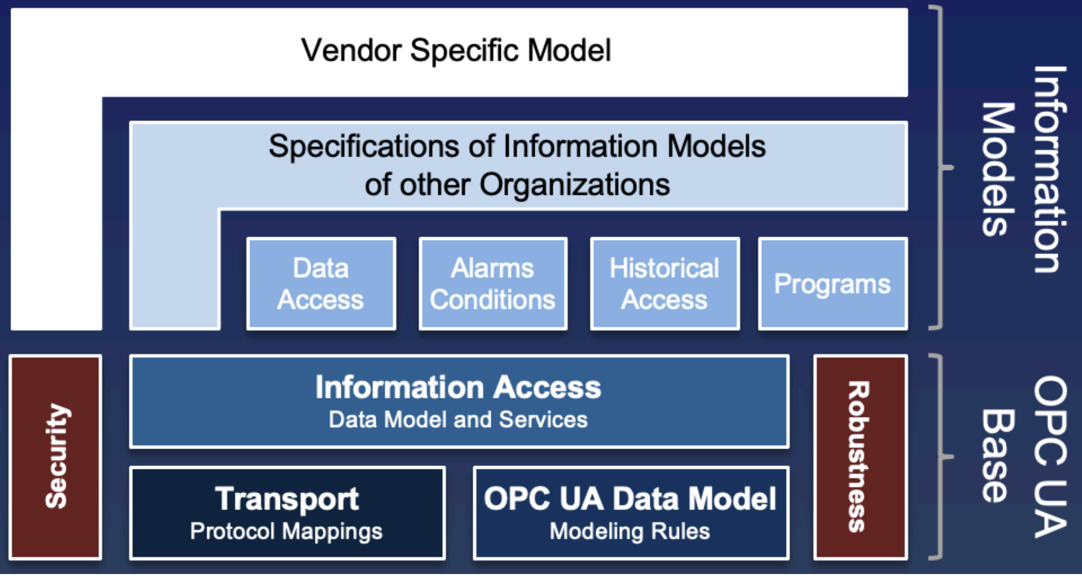
OPC Unified Architecture

OPC Unified Architecture

Unified Architecture

Industrial machine-to-machine communication protocol for interoperability

- Originally developed by OPC Foundation for IoT applications (keyword Industry 4.0)
- OO Information modeling capabilities
- Enhanced security, performance and scalability
- Supports buffering, session mgmt, pub-sub, per-connection heartbeats/timeouts, discovery
- Multi-platform implementation, lightweight ➲ embedding possible
- Commercial SDKs available with stack from OPC foundation or open source stack implementations (C, C++, Java, JS, Python) for servers and clients



➲ Excellent experience in ATLAS since 2012

- Fully supported by JCOP
- Still requires expertise and effort in programming with OPC UA …

➲ Provide development environment and generate OPC UA related code?