Description of STAARQ test stand for the quench detection and first results of the new digital MSS*

*MSS = Magnet Safety System

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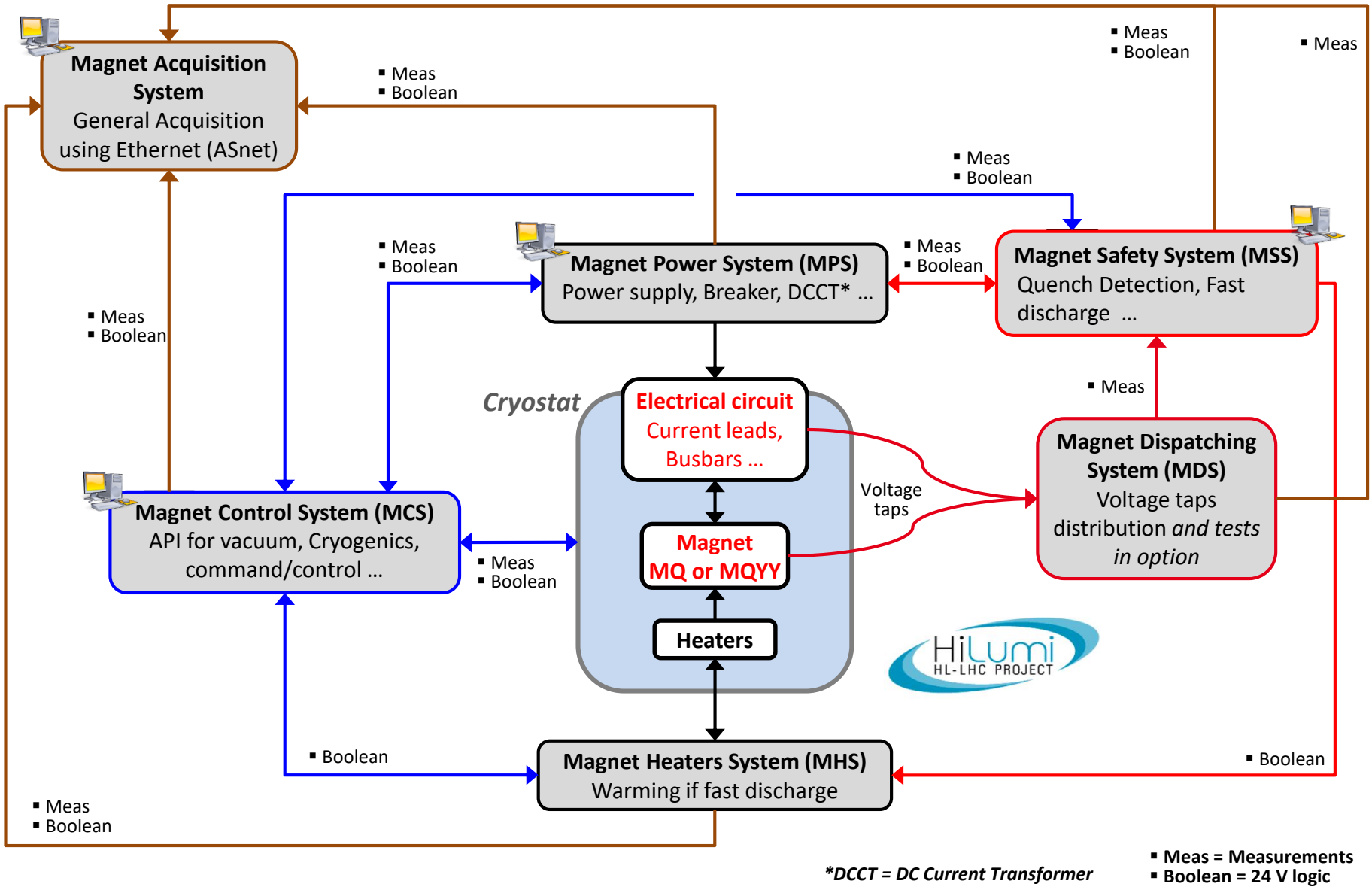
- **Irfu/DIS/LEI**

Irfu: *Institute of Research into the Fundamental Laws of the Universe*
DIS: *Systems Engineering Department*
LEI: *instrumental electronics laboratory*

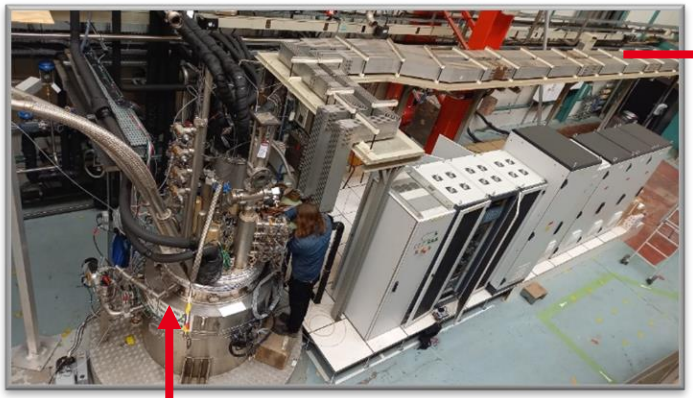
Outlines

- **STAARQ test stand:** Overview of the main subsystems
- **Layout and architecture**
  - Main cabinets for the instrumentation
  - Focus on the Magnet safety system
- **Digital MSS**
  - Hardware description and main submodules
  - Software description and main functionalities
- **Results**
  - Quench detection
  - Sensitivity of the measurements
  - False quench detection immunity
- **Conclusion**

STAARQ test stand – Overview of the main subsystems



STAARQ – General layout of the instrumentation



from **Magnet Power System** *(not shown)*

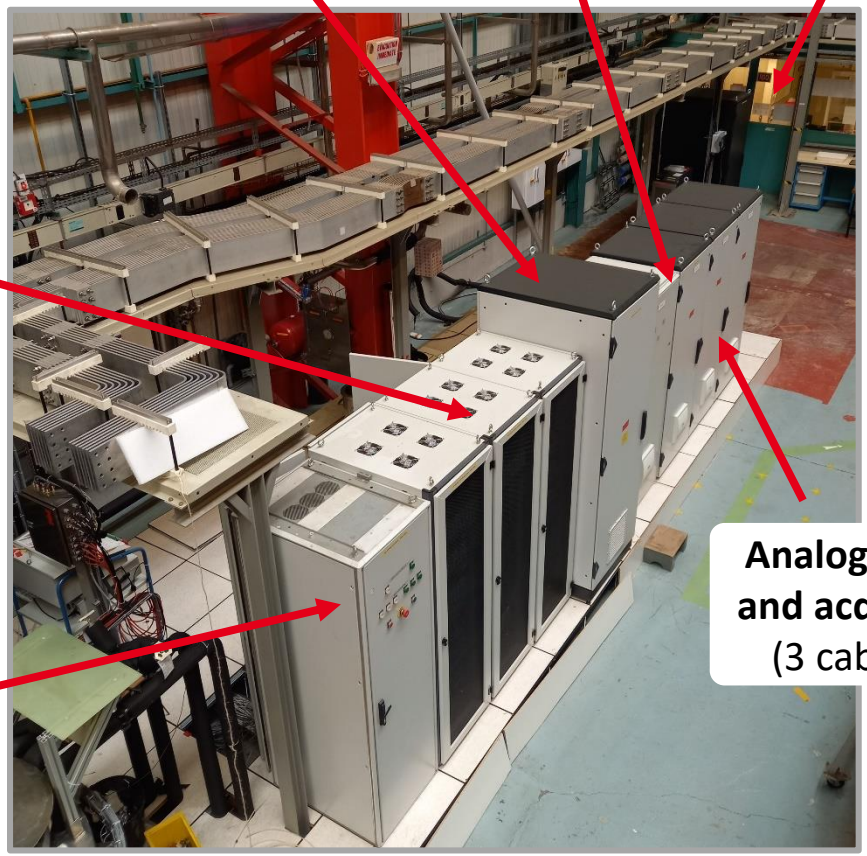
Control Room and NAS* disk

Digital MSS (1 cabinet)

Dispatching (1 cabinet)

Cryostat

Magnet Control System (3 cabinets)



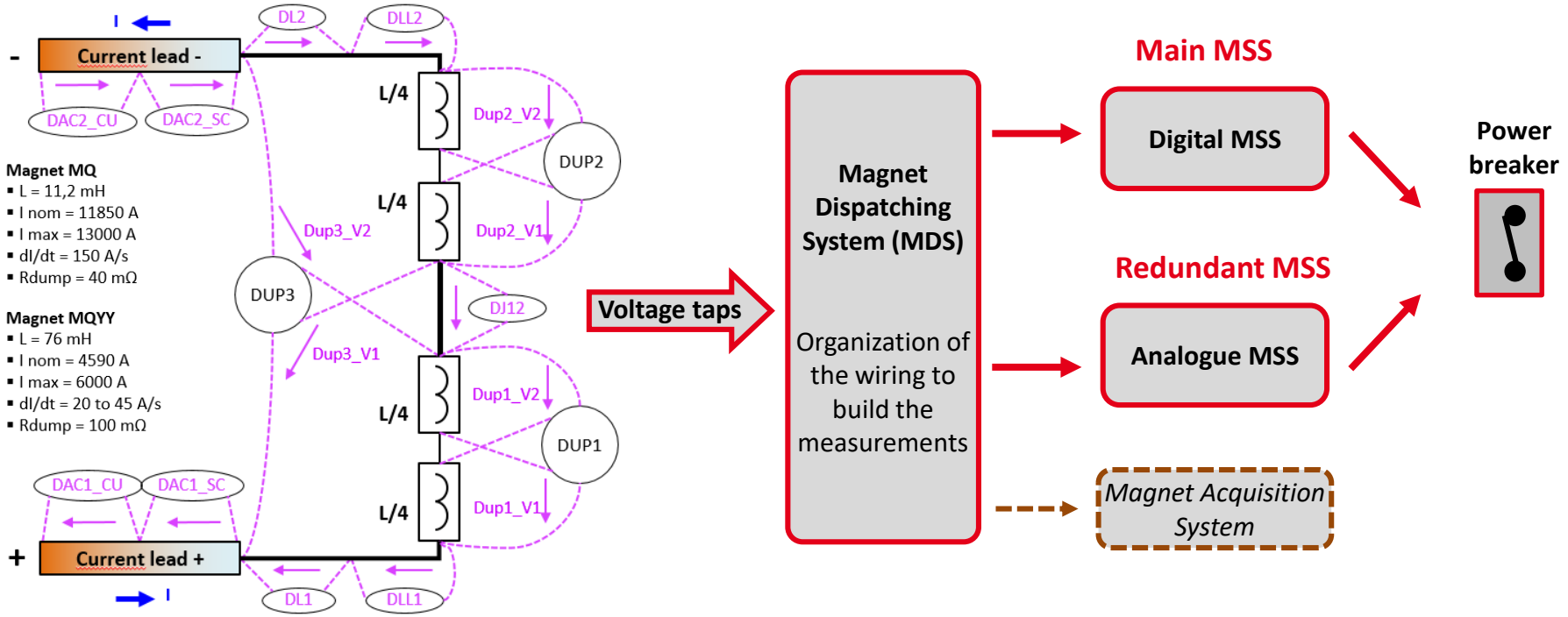
Analogue MSS and acquisition (3 cabinets)

Magnet Heaters System (1 cabinet) *CERN - CEA*

**NAS = Network Attached Storage*

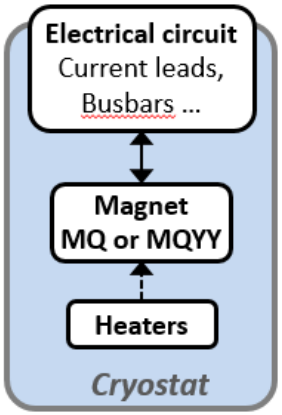
Architecture of the magnet safety system

- Two MSS in redundancy for the quench detection
  - A digital MSS (new system)
  - An analogue MSS (well-known MSS used for several magnets)
- **The digital MSS is configured to first detect the quench**



(Only the voltage taps and the measurements for the MSS are represented)

DISPATCHING cabinet for MQ and MQYY magnets



Voltage taps

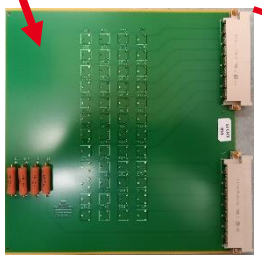
Front view

Rear view

- Digital MSS
- Analogue MSS
- Acquisition

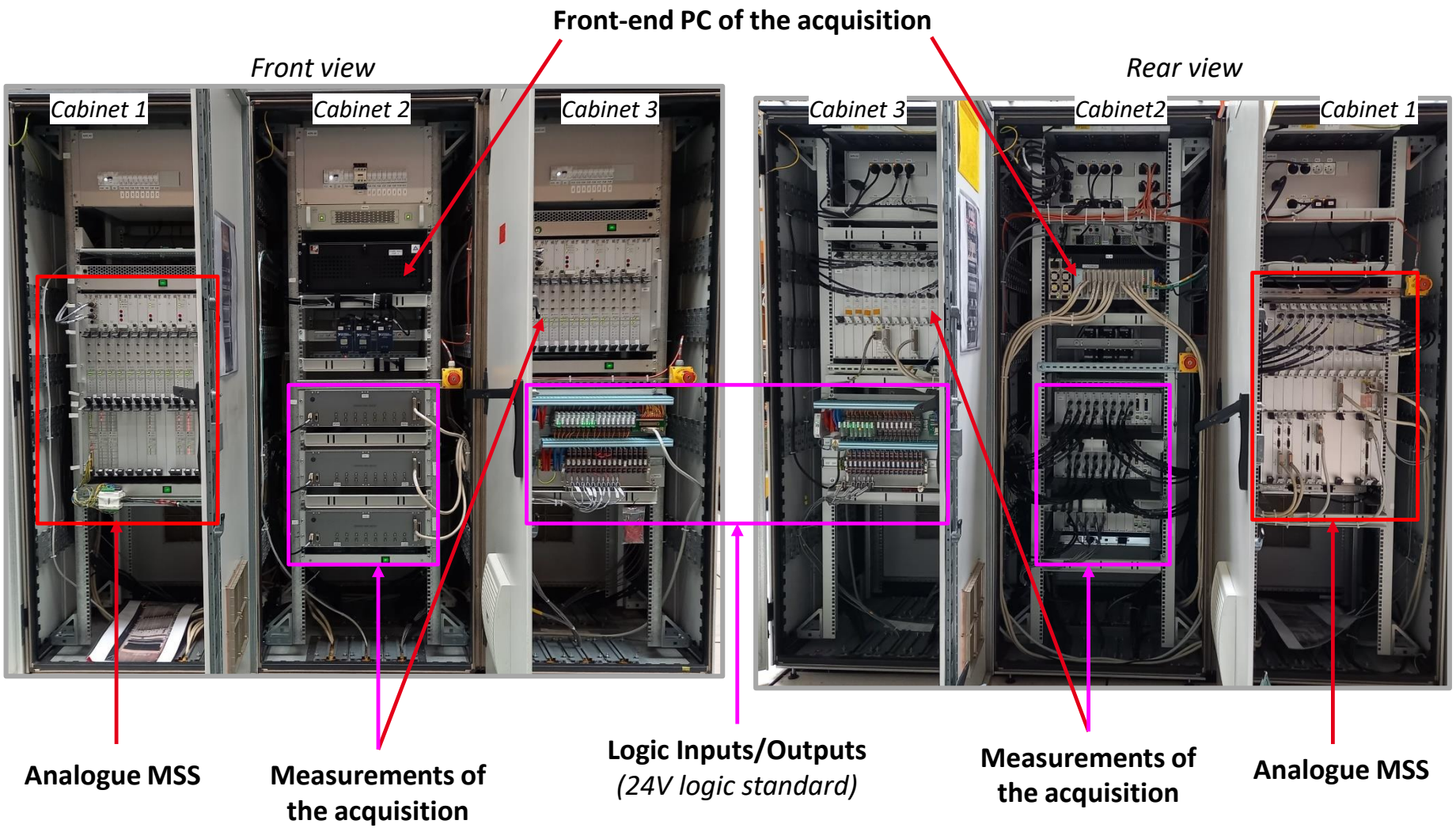
Measurements

- Internal connections of VT wires to a set of backplanes
- Each board can select 2*2 VT to make 2 measurements



- **Connectors, cables and wires can withstand high voltage (tested at 1500 V for STAARQ)**

Cabinets of the analogue MSS and the acquisition



- **New subsystems designed for the digital MSS** and compatible with the existing analogue MSS/Acquisition

Digital MSS cabinet

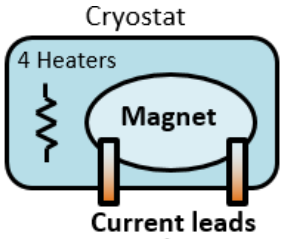
- **23 measurements (48 max) – 11 quench detectors (24 max)**
- **9 logic outputs (16 max) - 3 logic inputs (16 max)**

Graphic user interface for the command/control and the monitoring

Ethernet

cRIO 9039 for MSS Digital processing

Logic I/O ***ADC***



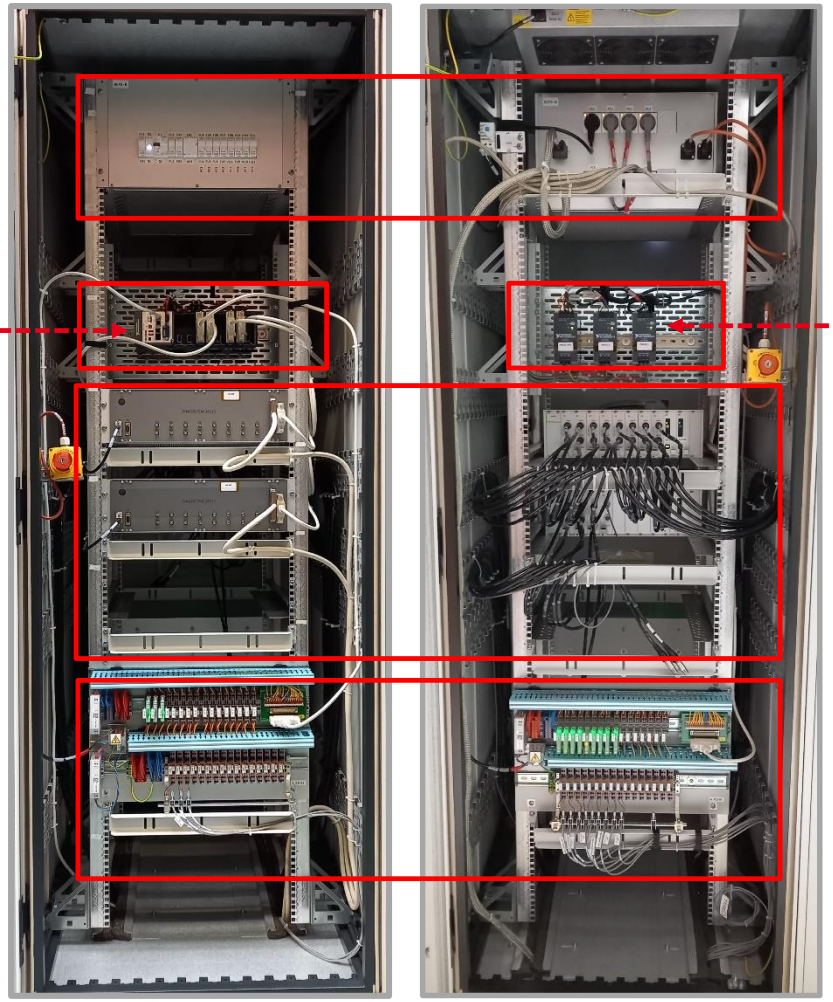
Measurements from DISPATCHING and DCCT

Inputs/Outputs (24V logic)

- **Power Supply**
- **Power contactor**
- **DCCT***
- **…**
- **Cmds/Ctrls**

***DCCT = DC Current Transformer**

Front view *Rear view*



Main supplies distribution
Vrms = 230 V ; Irms= 1,15 A (from a UPS)

24V Power supplies
- cRIO 9039
- Measurements chassis

HV isolated analogue measurements from
- Current leads (CL)
- Busbars
- Magnet coils

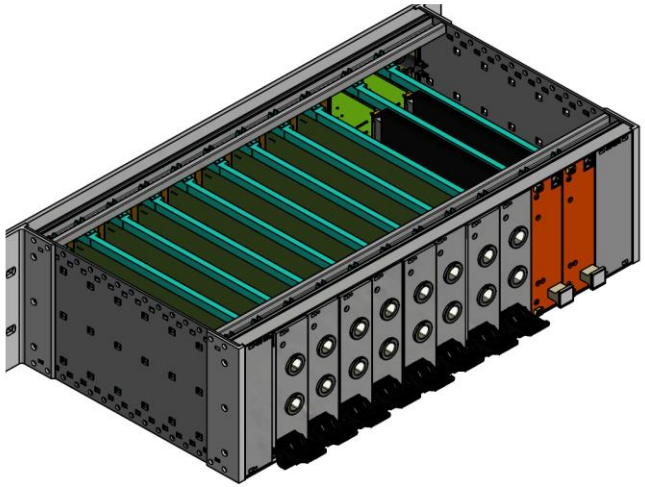
Logic Inputs/Outputs
- Power contactor command (out)
- Emergency Stop (in)
- ….

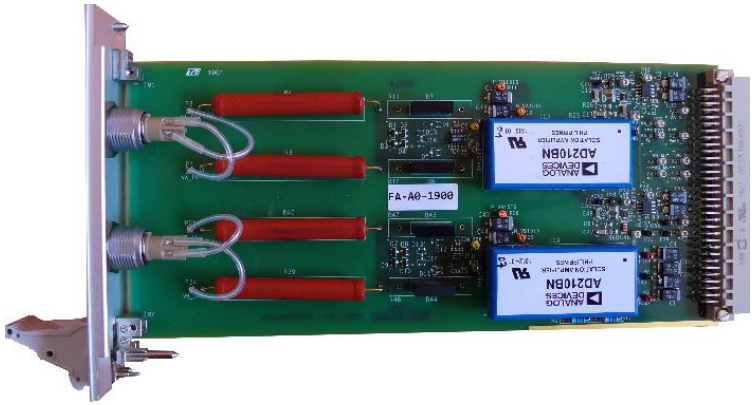
(24 V logic standard)

High voltage isolated analogue Front End chassis (FEAI)

8 boards/16 channels by chassis

- The chassis works like an isolated voltmeter





16 high voltage isolated inputs

Rear side

Front side

Not used

+24V

± 10 V test points

Magnet Acquisition System

2 Channels

- Gain 1 to 500 - Bandwith = 900 Hz
- ± 10 V differential and single ended outputs
- Isolation working voltage = 3,5 kV

NI 9220 (cRIO)

- 16 ADC – 16 bits
- +/- 10V differential
- Fs = 100 kHz
- Simultaneous sampling

Interfaces for logic Inputs/Outputs

cRIO logic modules

- **One module for inputs**
  - 16 channel inputs
  - Connected to the **NI 9425**

NI 9425 (cRIO)
- 32 logic inputs (24V)
- td = 8µS

- **One module for outputs**
  - 16 channel outputs
  - Connected to the **NI 9477**

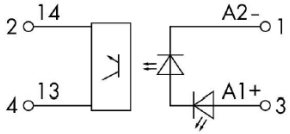
NI 9477 (cRIO)
- 32 logic outputs (24V)
- td = 8µS

Easy troubleshooting

- On the shelf devices
- Pluggable static relay
- No operation of connection or disconnection.

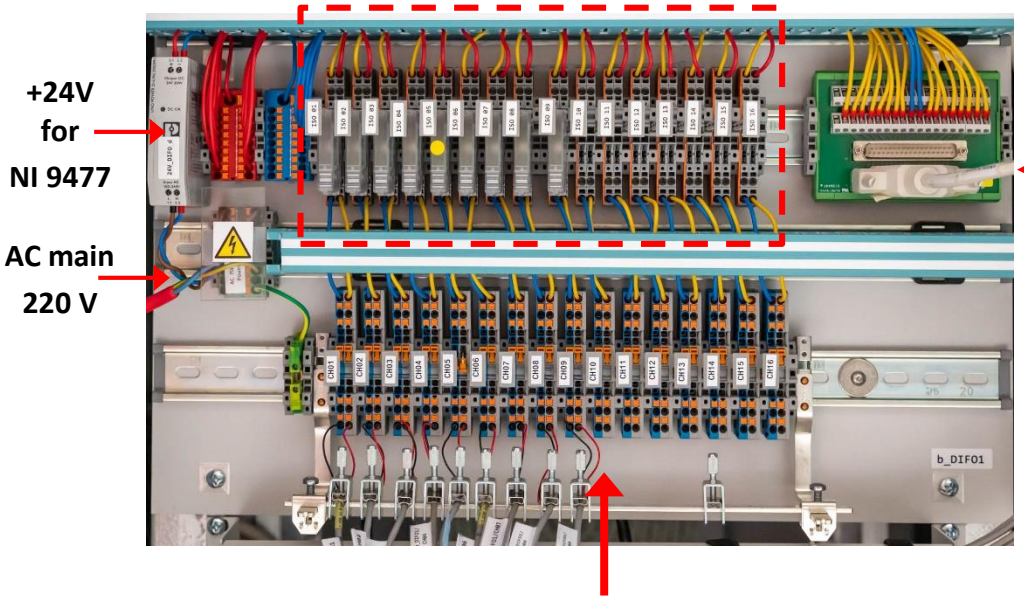
Example: Interface for logic outputs (up to 16)

Pluggable static relay



- Wago 2042-7204
- Input 24V, 7mA
- Output 24V , 100 mA max
- Drop out-time ≤ 20 µS
- Working Isolation = 250V
- State led: green

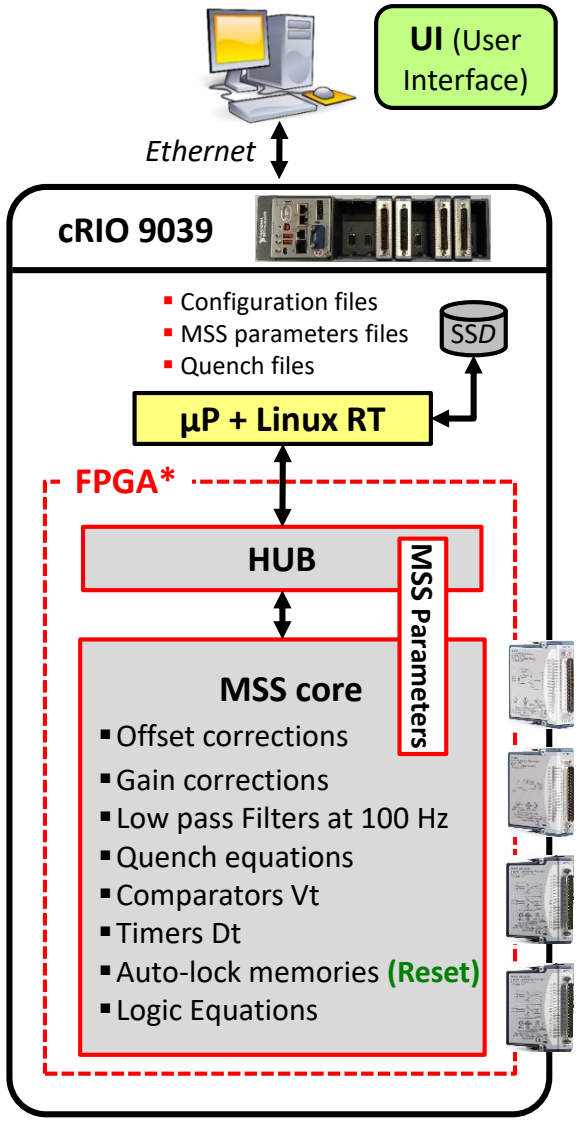
Up to 16 static relays



NI 9477 (cRIO)

24V logic signals for the magnet installation

cRIO9039 and MSS software - Overview and main features



*FGPA for Field-programmable gate array

The MSS software (LabVIEW) is split in 4 layers

- **UI - User Interface (PC windows)**
  - configuration operations
  - Normal operations and Monitoring
  - *After configuration, the MSS cabinet can run in stand alone if the UI is not needed or Ethernet is lost*

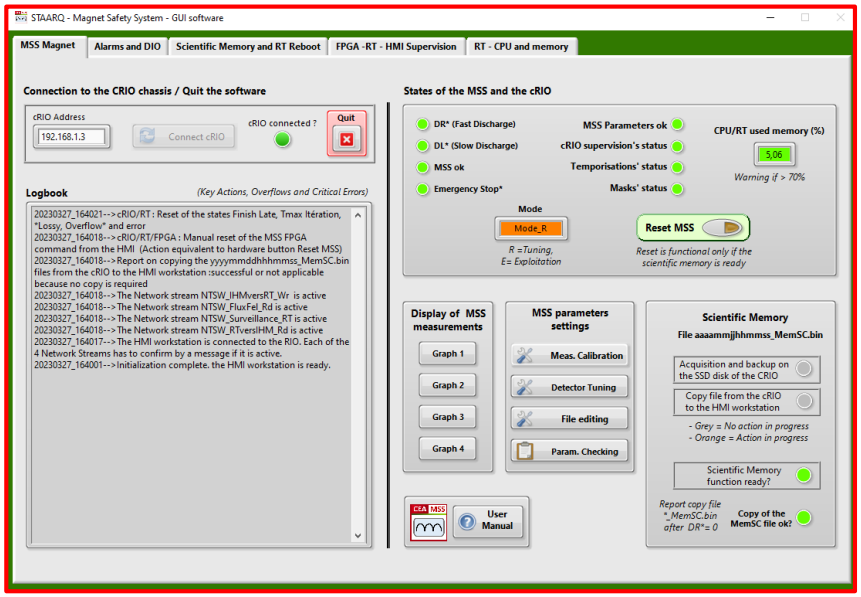
Windows Icon

- **RT - Real Time software (µP + Linux RT)**
  - Interfaces and data streaming with FPGA
  - Monitoring of cRIO operation (µP activity, memory occupation …)
  - Storage of the basic files needed by the MSS software
  - Acquisition of a Quench file when a quench occurs
  - *The µP can be reset without disturbing the FPGA*
- **HUB (FPGA)**
  - Interface , data streaming between RT and MSS core
  - Example: MSS parameters writing in the MSS core
- **MSS core (FGPA)**
  - Processing @ 10 kHz for the quench detection
  - *MSS core can run alone after MSS parameters configuration (upper soft layers not needed)*

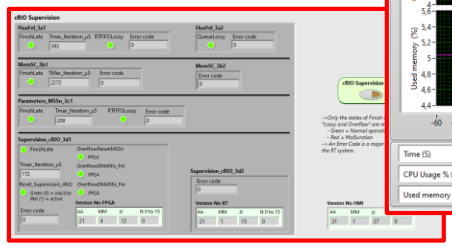
*Take note: Quench files analysis is made off line with a separate **Viewer software***

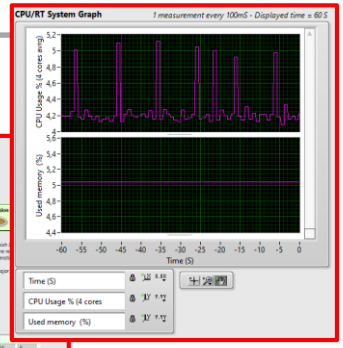
Windows Icon

MSS software – Main functionalities of the User Interface

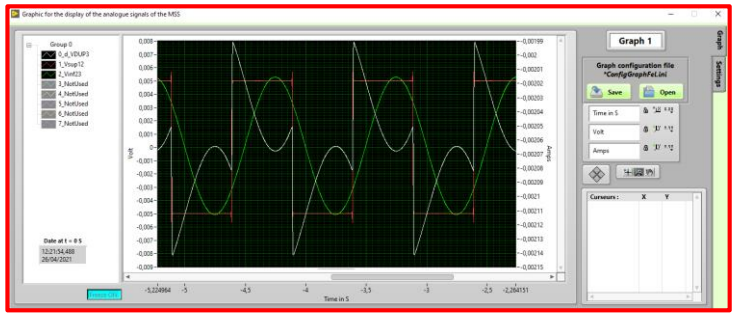


cRIO monitoring

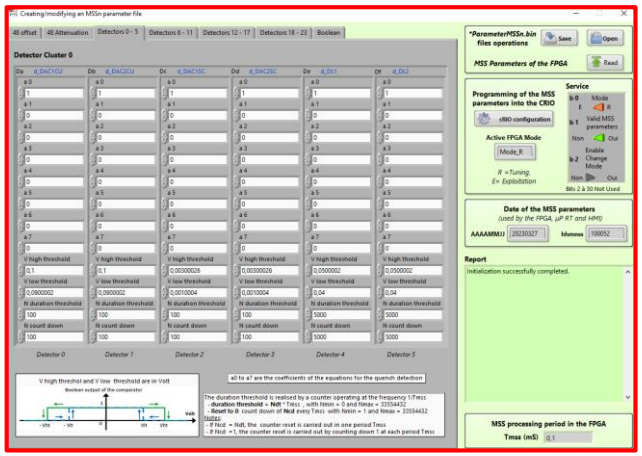


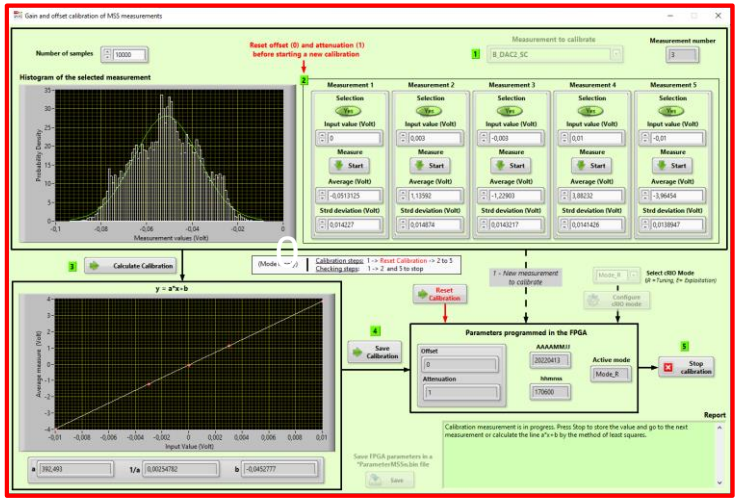


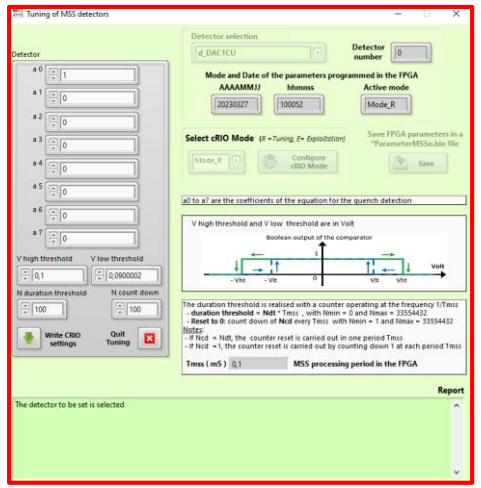
4 Graph displays "Oscilloscope"



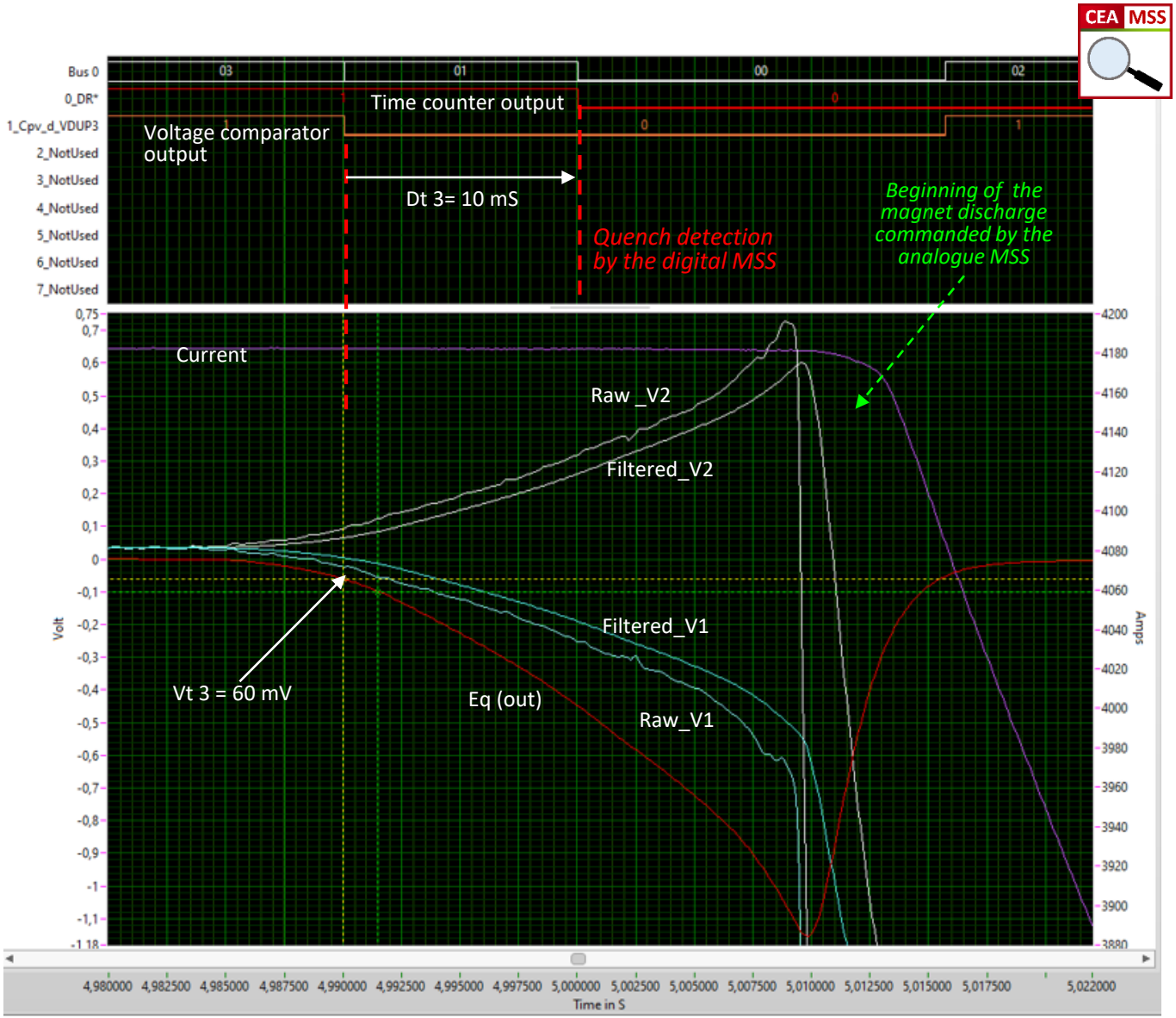
MSS parameters configuration tools

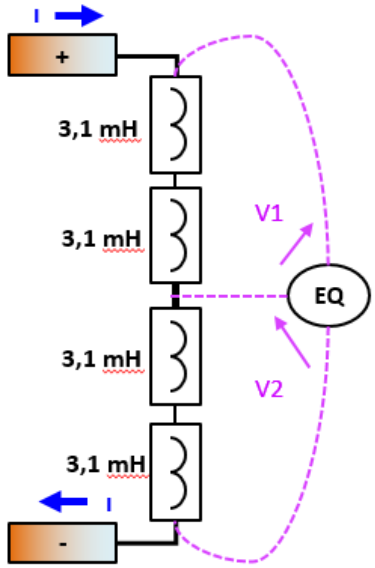






Q4 magnet tests (march 2021) – View of a quench detection





Eq and Threshold Parameters

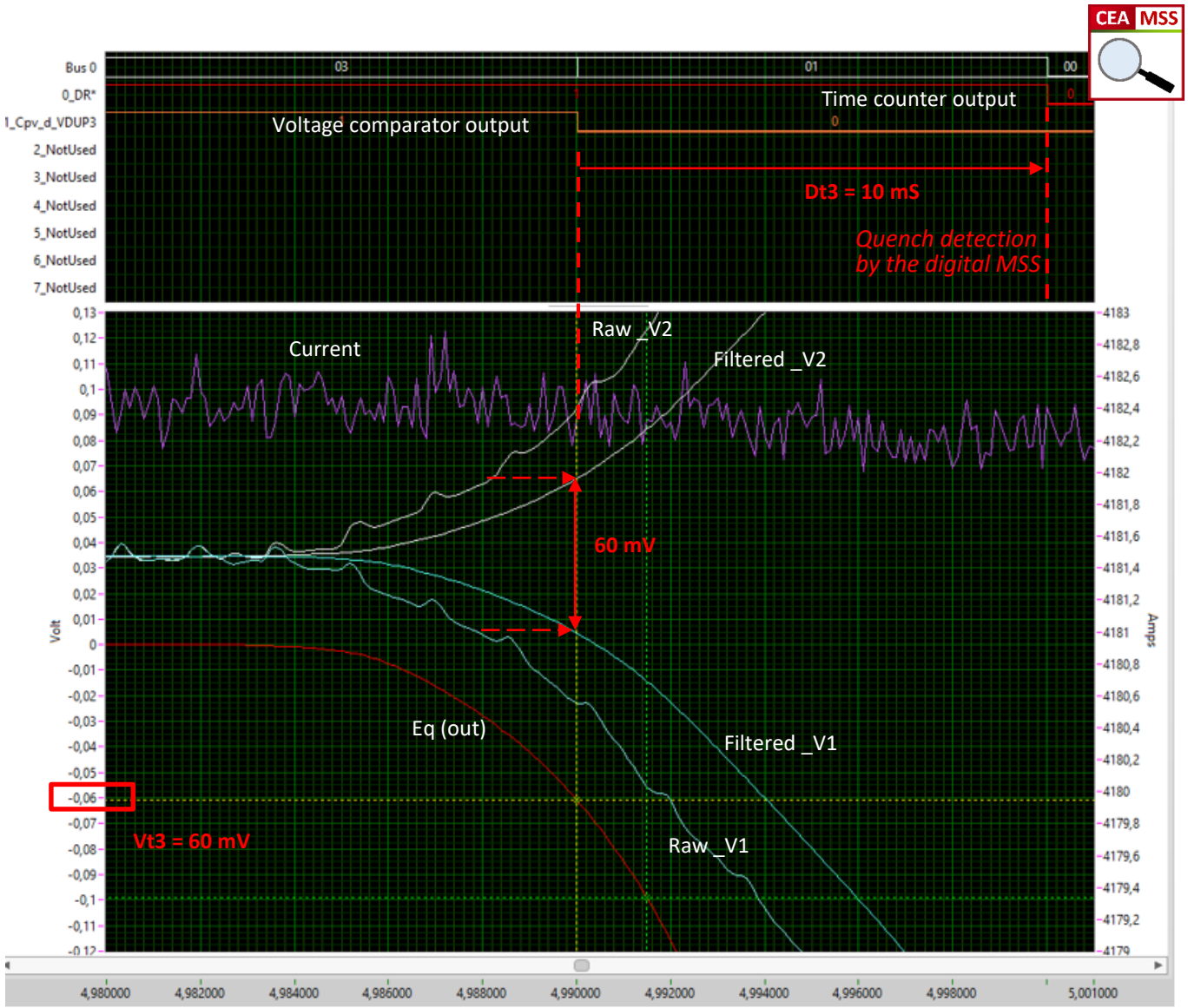
- Eq = V1 – V2
- Vt3 = 60 mV
- Dt3 = 10 mS

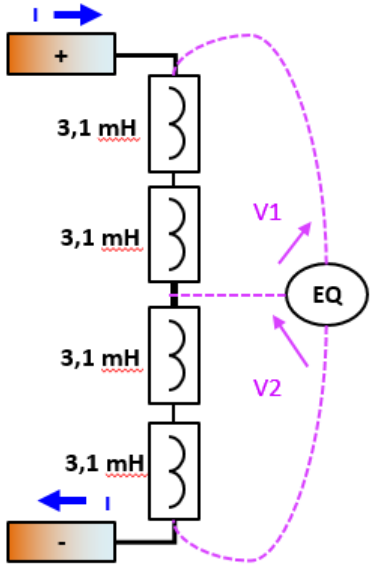
Initiation of a Quench:

- Current rise at ≈ 5,5 A/s until quenching
- Quench at I = 4180 A

Take note: *For this test, the digital MSS was not connected to the power breaker and the analogue MSS had a voltage threshold of 100 mV.*

Q4 magnet tests (march 2021) – View of a quench detection - Zoom





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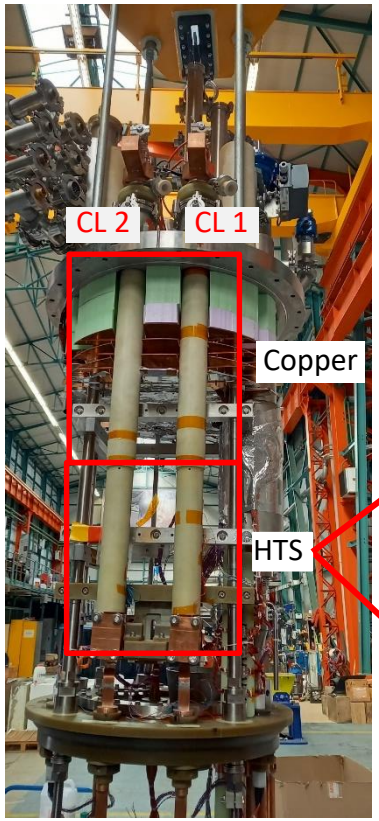
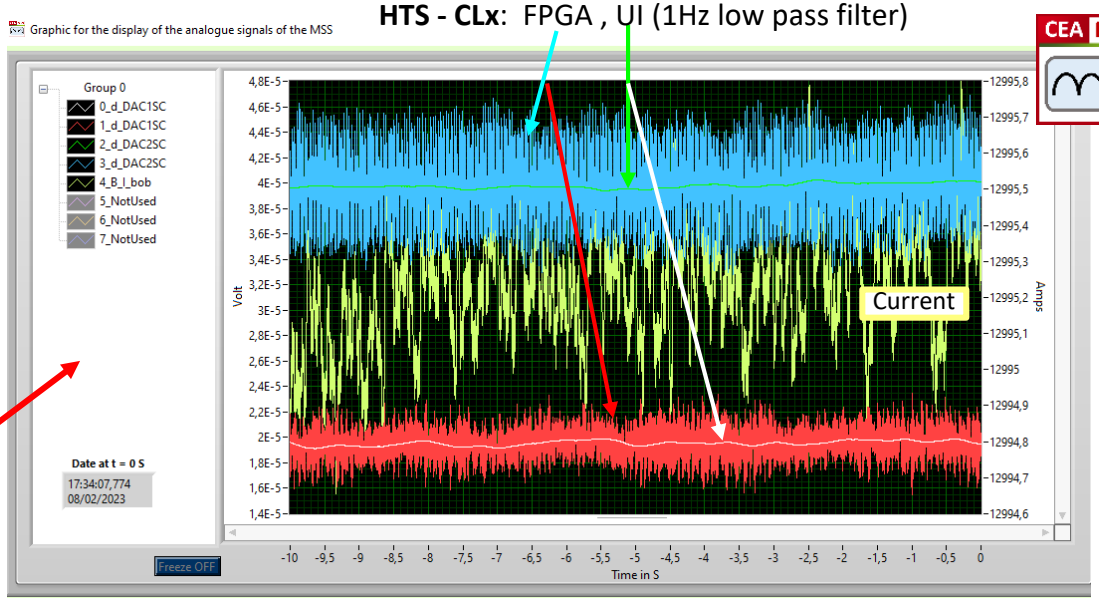
Tests of STAARQ current leads at 13 kA (February 2023)

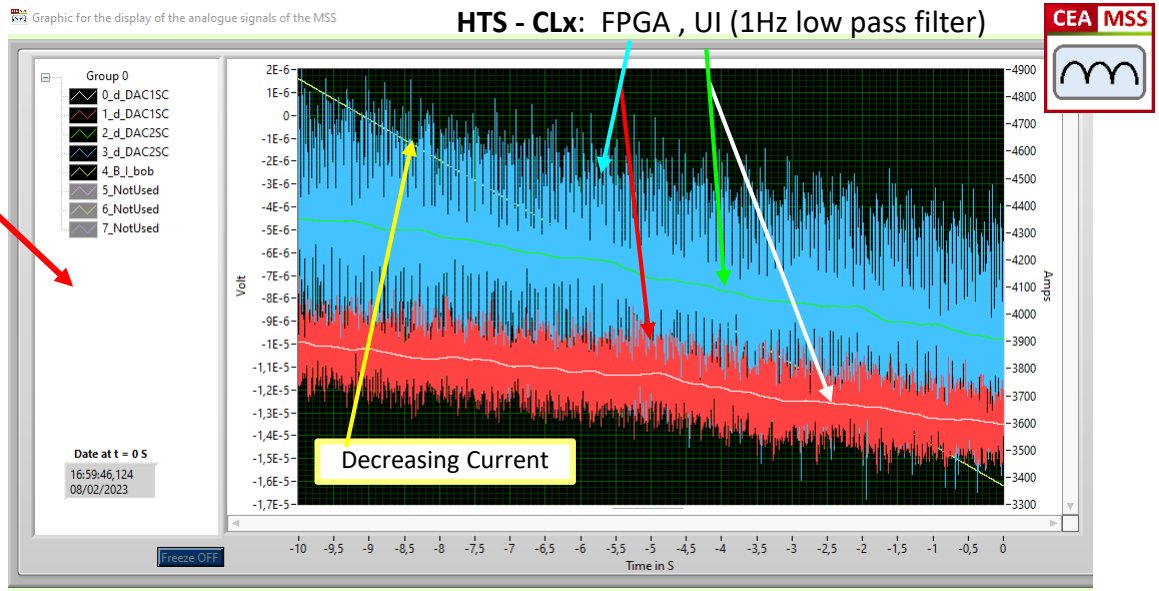
STAARQ Current leads 1 & 2



HTS - CLx: FPGA , UI (1Hz low pass filter)



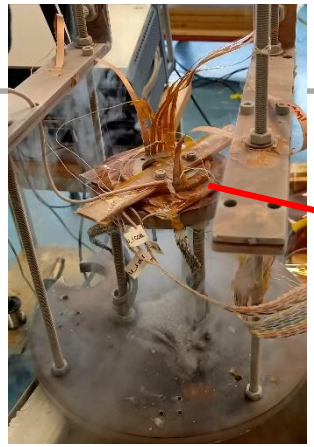
HTS - CLx: FPGA , UI (1Hz low pass filter)

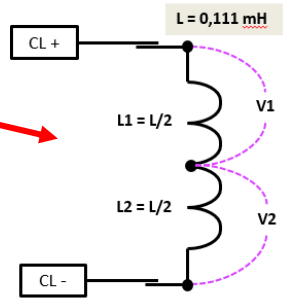


Take note:

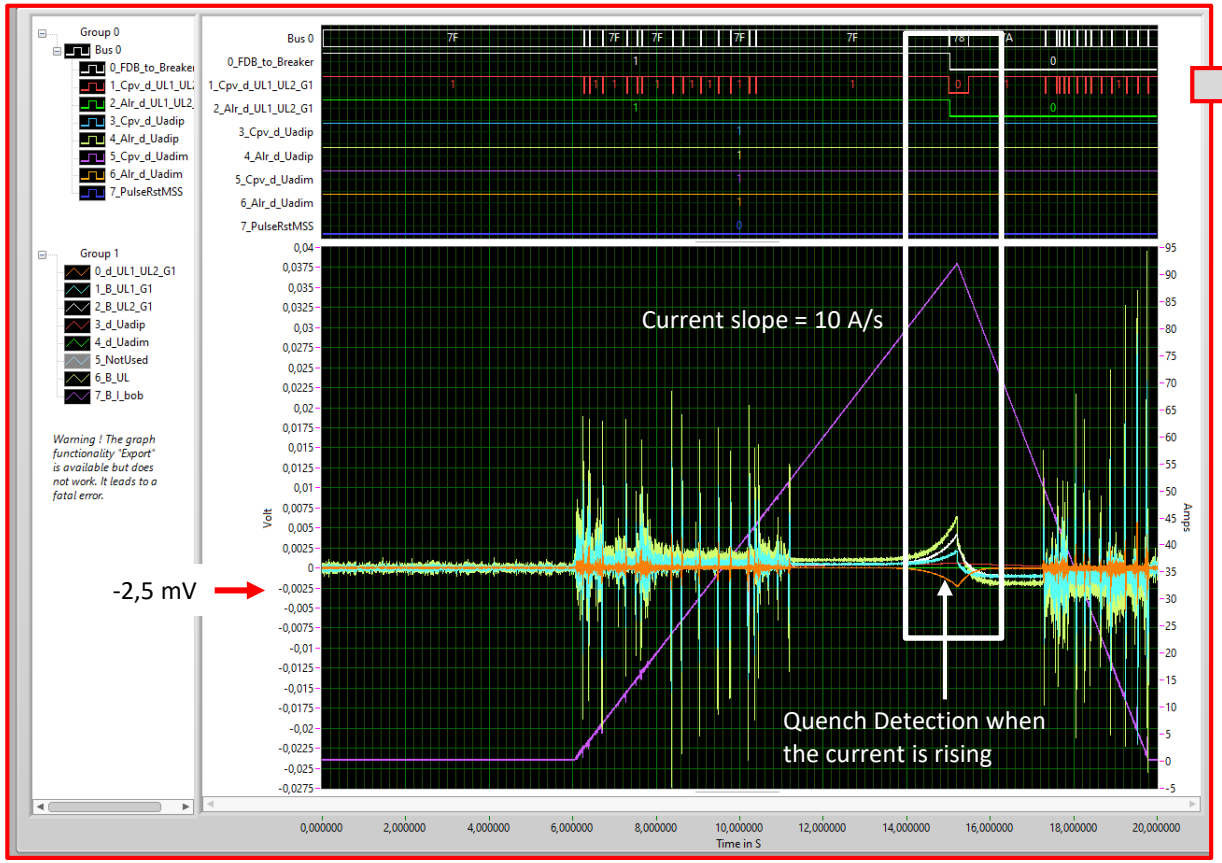
- The two CL are short-circuited
- Measurements Calibration for ± 25 mV input range
- Offset after calibration ± 100 µV
- MSS parameters: Vt = 3 mV and Dt = 10 mS

False quench detection immunity (December 2022)

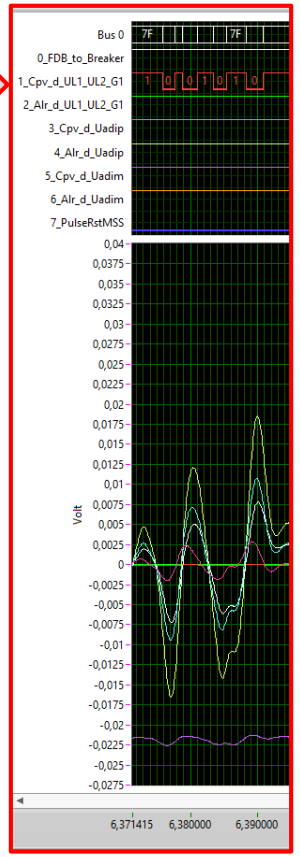




- **Eq and Threshold Parameters**
  - Eq = V1 – V2
  - Vt = 1,5 mV
  - Dt = 10 mS
- Current rise at 10 A/s until quenching
- The regulation of the power supply is noisy below 55 A
- **No False quench detection**



ZOOM



Conclusion

- **MSS for STAARQ are installed and tested**
  - Ready for the commissioning of STAARQ test stand
    - June or September 2023
  - The digital MSS is the main MSS
  - The analogue MSS is used in redundancy

- **The digital MSS is the new standard for CEA/Irfu projects**
  - R3B magnet (GSI - Germany)
    - upgrade of the analogue MSS
  - ASTERICS (GANIL linear accelerator in France – NEWGAIN injector)
    - 47 measurements
    - 20 quench detectors

MSS software – Synoptic of the cRIO main functionalities

User Interface
- Configuration operations
- Normal operations and Monitoring

Logic I/O (24V)
- Emergency Stop
- Command to open the power breaker
- Others - - -

cRIO 9039

Analogue measurements

Button **Reset MSS**

4 * Networkstreams (FIFO using TCP/IP)

Ethernet

FPGA

MSS core (10 kHz)

Digital processing for the quench or default detection

- *Sampling at Fe=100 kHz*
- *Down-sampling to 10 kHz*
- *Time stamping*

- Reset MSS
- Acquisition Ready
- Date RT

Timestamped DATA MSS bunches (10 kHz)

HUB

Asynchronous data/events

10 kHz -->1 kHz

MSS parameters reading (50 mS)

MSS Parameters
Memory 1
Memory 2

<< Reset MSS
<< Acquisition Ready
<< Date RT
<< Reset DMA Ovflw
>> DMA Ovflw
>> N° bitstream

DMA FIFO

DMA FIFO

DMA FIFO

DMA FIFO

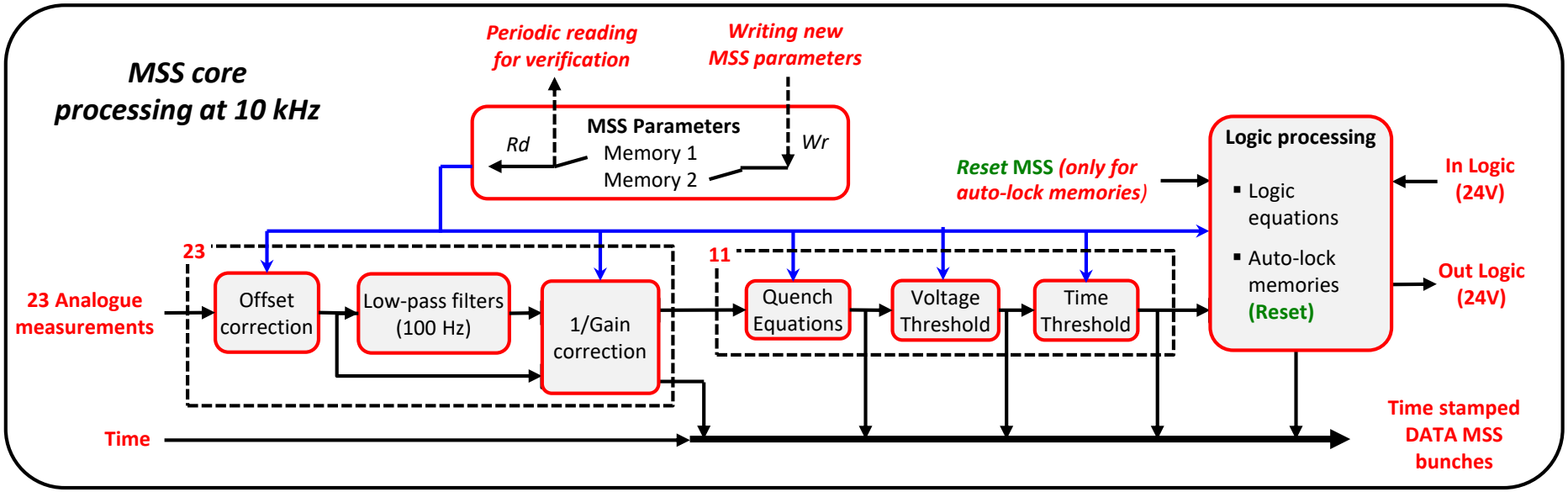
µP & Linux RT

- cRIO monitoring
- Data monitoring
- Data acquisition & Quench files
- Rd/Wr MSS Parameters
- Verification

- Configuration files
- Quench files
- MSS parameters files

SSD

MSS software - FPGA processing for quench detection



- **MSS core I/O**
  - Measurements and time at 10 kHz for the MSS core
  - Time stamped Data MSS bunches at 10 kHz for the HUB.
  - Logic Inputs/Outputs:
    - Emergency Stop
    - Command to open the power breaker
    - Others ….
    - **Reset MSS** with a weaker priority than the default/quench detection
  - The HUB does the writing and the reading of the MSS parameters (*periodic reading to verify values with the Real Time software)*