ELQA tests on instrumentation in HL-LHC

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Outline

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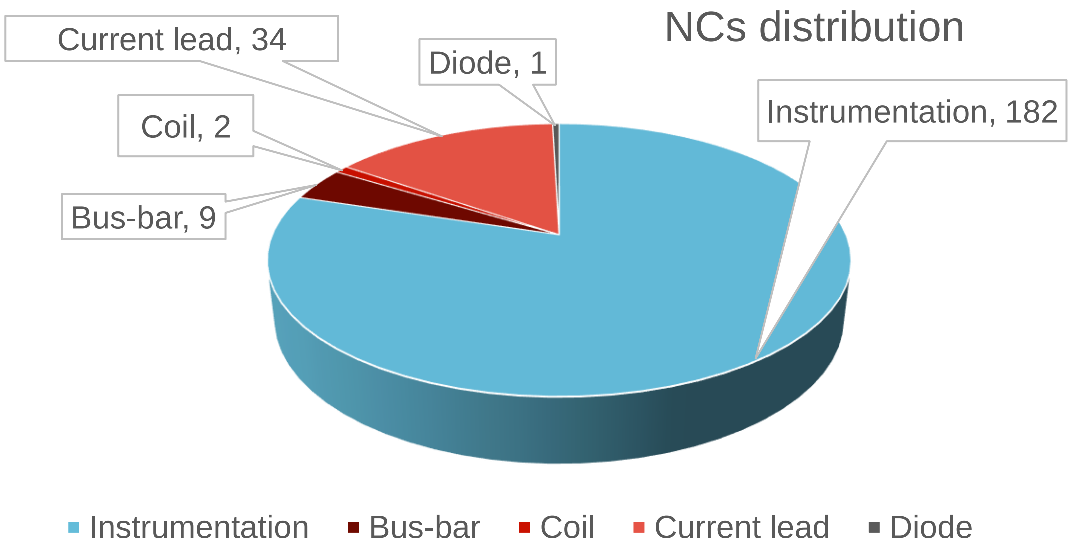
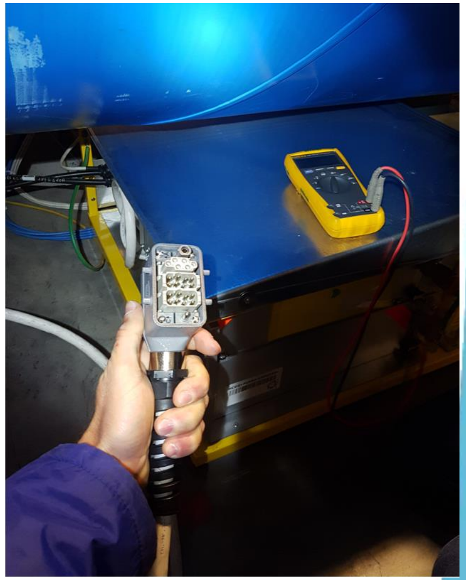
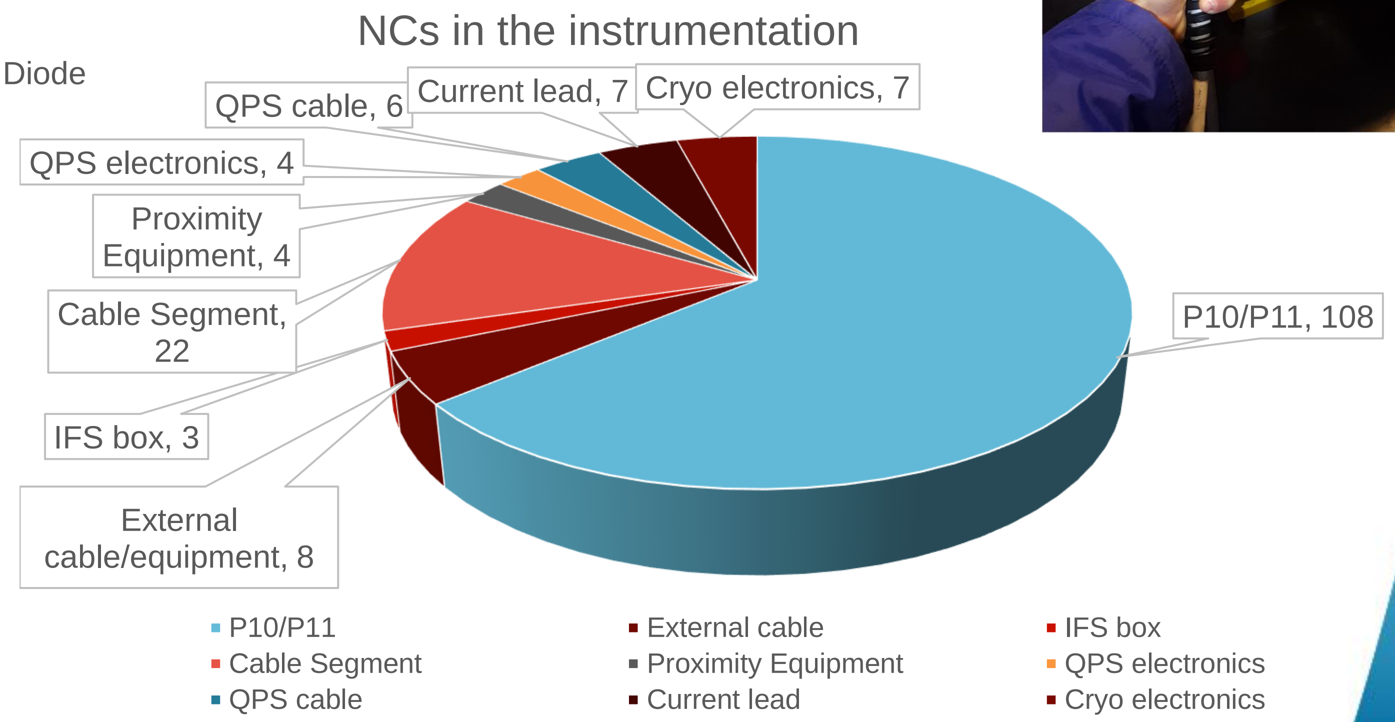
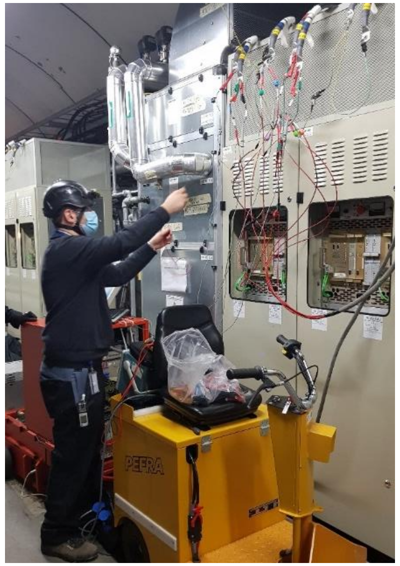
Statistics: NCs in LS2





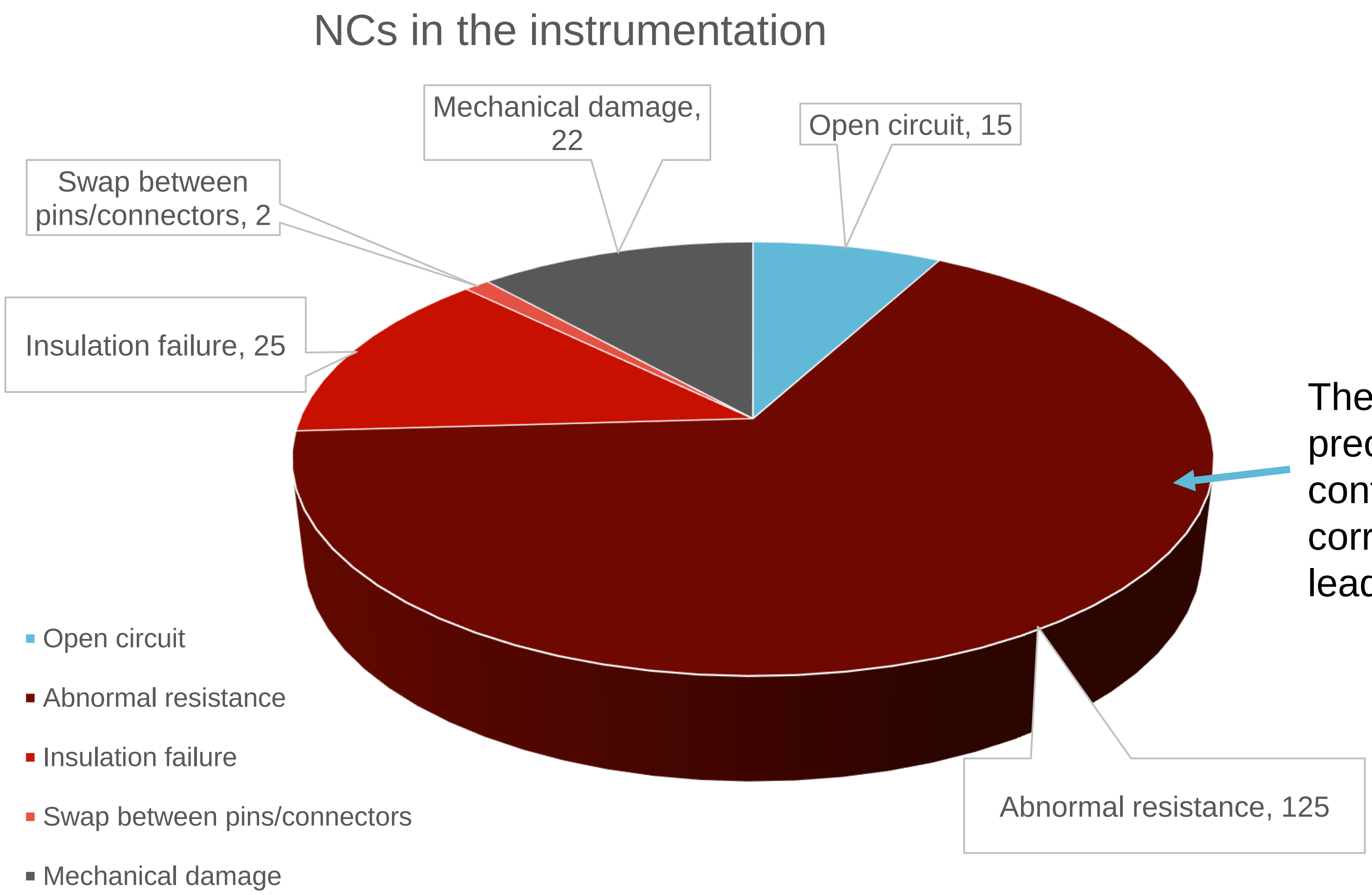




Last update: 06.10.2021

Nature of instrumentation NCs (LS2)

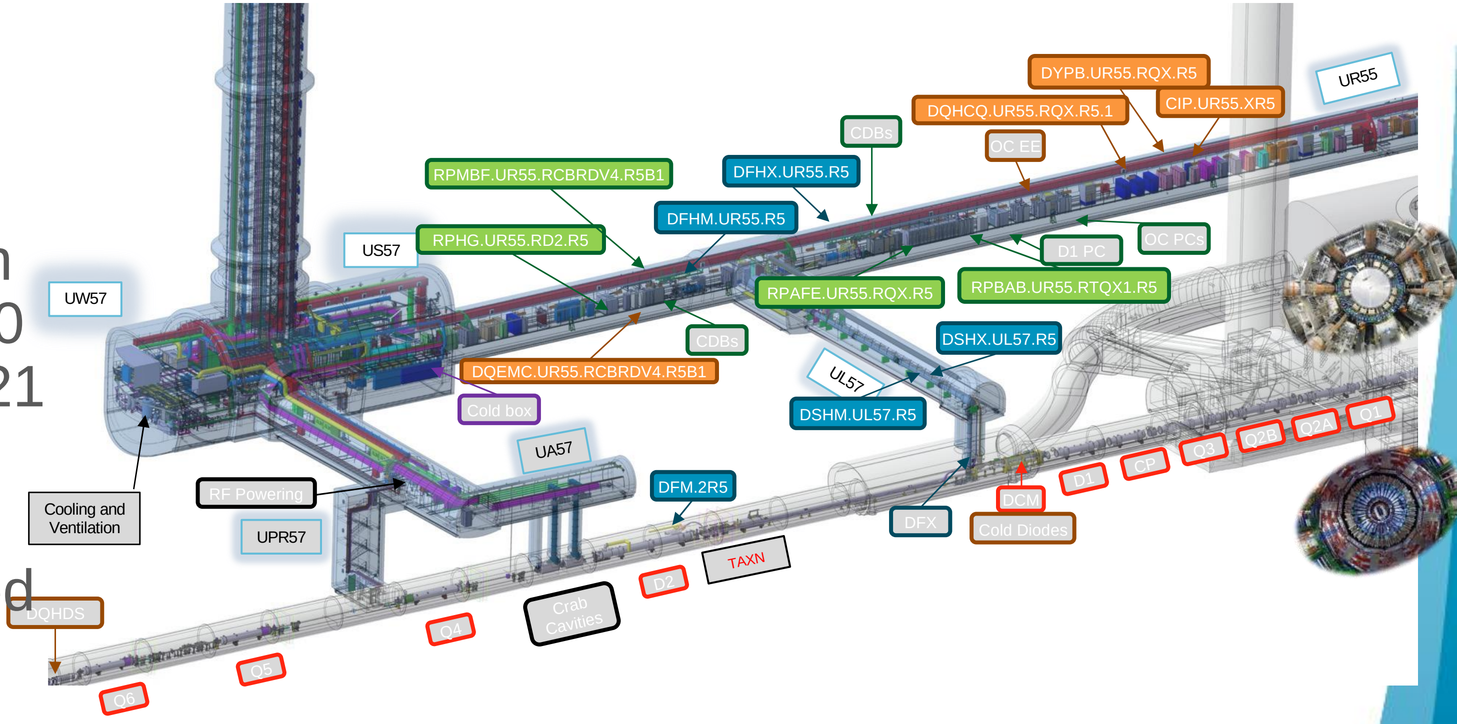
- The NCs are always checked and if the defect is in an accessible location – they are repaired
- In some cases the faulty elements are in the cold part and cannot be fixed, in such cases they remain marked as Open For Actions



These often are precursors of a faulty contact, if not corrected it could lead to spurious trips

HL-LHC specificity

- Instrumentation in HL LHC circuits needs to be particularily well designed and tested due to high reliability requirements imposed by radiological activation
- Large number of instrumentation wires (the main IT circuit has 270 V-taps, 48 quench heaters and 21 current leads)
- Multiple galleries where the instrumentation cables are routed
- Complex circuit topology
- New magnet construction technology
- Long superconducting link



List of planned ELQA tests

- A number of tests is directly targeted at testing the instrumentation

ELQA „building blocks”:

- HVQ – High Voltage Qualification
- TFM – Transfer Function Measurement
- IRC – Instrumentation Resistance Check
- ICC – Instrumentation Configuration Check
- TDR – Time Domain Reflectometry
- COC – Continuity of Conductor check
- QHR – Quench Heater Resistance measurement
- DVC – Diode opening Voltage Check
- TSQ – Temperature Sensor Qualification

New ‘standard’ measurement to obtain references for possible future fault diagnostics

New reference measurements (TDR)

- TDR (Time Domain Reflectometry) is used for diagnostics and localisation of faults in cables
- Instrumentation cables for SC magnets typically are not designed for high frequency, therefore many reflection occur naturally at the level of connectors and non-homogeneous cable routing
- Typically for such cases a reference of a good cable is needed: detecting deviations may point to a fault location
- Introduction of TDR as a standard measurement performed on all instrumentation wires aims at obtaining such reference for future and also will identify large unexpected impedance changes, which could be caused by cable/connector defects
- Measurements will be acquired with the new multichannel TDR tester (in development)
- Measurement results will be stored for future reference in the ELQA database

Tests during HL-LHC circuit assembly

Tests during HL-LHC circuit assembly

Several qualification sets will be performed at each circuit assembly stage to:

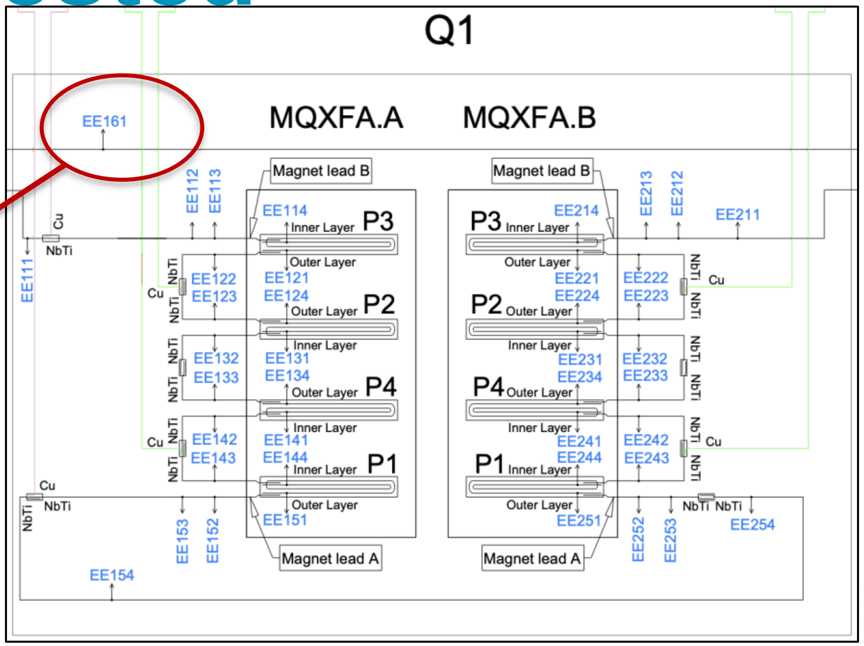
- Detect defects in components
- Verify polarity of connected components
- Detect defects in instrumentation
- Detect assembly defects

Before the assembly starts individual components will be tested

	SLC	MIC-W	IT-PAQ	ITIV	ITIC
HVQ	✓	✓	✓	✓	✓
TFM	✓	✓		✓	
IRC	✓	✓		✓	
ICC	✓	✓	✓	✓	
TDR	✓	✓			✓
COC	✓			✓	✓
QHR		✓			
DVC		✓			
TSQ	✓	✓			

SLC – Superconducting Link Check
MIC-W – Magnet Instrumentation Check – after transport
IT-PAQ – Inner Triplet Partial Assembly Qualification – after transport
ITIV – Inner Triplet Interconnection Verification
ITIC – Inner Triplet Instrumentation Check

How magnet V-taps are tested



Equipment concerned:

- Magnet V-taps are routed via a capillary tube
- Standard HL feedthrough systems
- Standard HL IFS systems
- ‘Return busbars’ are equipped with V-taps
  - These V-taps are treated the same as magnet V-taps

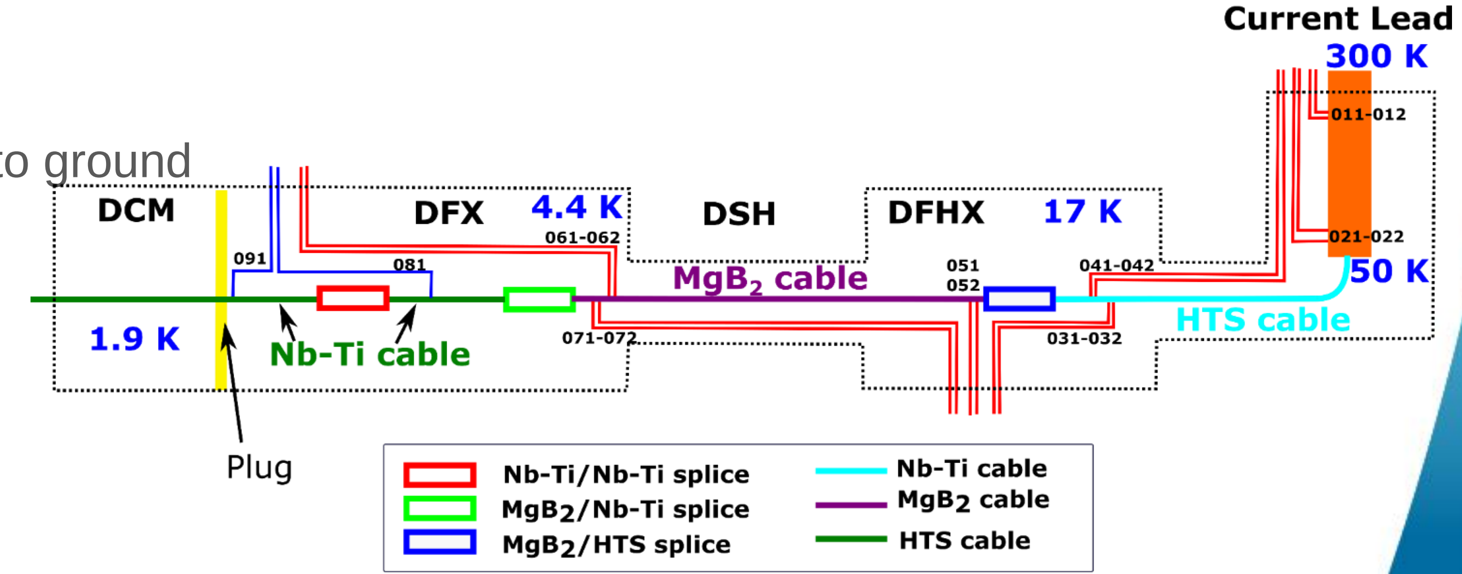
Tests:

- Magnet is tested in air (during initial manufacturing, before helium exposure) at a relatively high voltage (3680 V for MQXF magnets). If the V-taps are connected at this stage they are tested as well
- For some magnets the capillary tube is formed after the magnet is exposed to helium. For these cases the capillary tube is tested (after wire insertion and capillary tube forming, before welding to the coldmass) at 3 kV, 30 s, while the magnet and instrumentation wires are short-circuited and grounded
- The final tests are performed at cold together with magnets:
  - Test station stage – 2 * V_{sim} + 500 [V]
  - Tunnel stage – 1.2 * V_{sim}

V_{sim} – worst case scenario voltage to ground in the magnet circuit

How SC link V-taps are tested

- V-tap bundle present in the link is tested together with the busbars
  - The V-taps 011-072 (except 061-062) are attached in their nominal position during the assembly of the cold powering system and are tested together with the link conductors
- V-taps 061-062 are connected via WIB
  - These V-taps up to the WIB are tested together with the busbars
  - Between WIB and IFS box dedicated tests are needed before connection
- Other V-taps (081, 091) are assembled in the tunnel during the DCM installation. They need to be tested at that stage:
  - HV test before connection
  - Sequence and continuity before and after connection
- V-tap insulation tests:
  - 3 kV, 30 s
  - Configuration: Wire to wire and to ground



Tests of warm instrumentation cables

Taking into account that:

- EDC for warm components (EDMS 2824470) requires 2.7 kV for QDS wires and 3.2 kV for QH wires
- EN-EL will test the instrumentation (signal type) cables at 0.5 kV, 30 s
- Cable production batches will be different than what was available so far
- For HL-LHC the batch/manufacturer will likely not be the same as in the IT String

It is proposed to:

- Perform a representative sample test of each type of cable: including connectors and workmanship
  - Test the leakage currents at required levels, the ultimate breakdown level and possibly assess signs of high voltage insulation degradation
- Perform a set of ELQA tests on each warm instrumentation wire at the required voltage level after the installation of most of components (during magnet interconnetion phase)

How the electronics connected to instrumentation is tested

- Electronics connected to circuit potential needs to withstand possible voltage levels that could appear during operation and during tests
- Affected electronics:
  - Current Lead Heating System
  - Cryogenic Electronics
  - QDS Electronics
  - QH Power Supplies
- Tests are performed by equipment owners during Individual System Tests
- *Voltage levels are given in the following slides*
- *These components will see the systematic ELQA tests performed on complete circuits during commissioning phases. These will be repetitively performed during Long Shutdowns. These test voltages are given in slide 19*

Voltage level definition

- During circuit operation all circuit components could be subject to high voltage
- The voltage to ground and to neighbouring circuits is assessed for each type of equipment and each circuit, including selected failure scenarios
- Safety margins are applied following the formula:

$$V_{test} = 2 * (V_{sim} + V_{neighbour}) + 500 \ [V]$$

- During installation and component manufacturing the tests are performed by the equipment owners
- These tests in principle are **not repeated** on a regular basis, only when a new piece of equipment is installed
- More details: https://edms.cern.ch/document/2824470

Voltage levels during machine assembly

Equipment	Required voltage [kV DC]	Duration [s]	Max. leakage current
Current Lead Heating System	2.0	60	No breakdown, 10 μA
Cryo Instr. Wires at RT (Incl. Cable Segments)	2.0 (3)	60	No breakdown, 10 μA
Cryogenic Electronics	2.0	60	No breakdown, 10 μA
QDS Electronics	2.7	60	No breakdown, 10 μA
QDS Instr. Wires at RT	2.7 (4)	60	No breakdown, 10 μA
QDS/ElQA Input Patch Panel	2.7	60	No breakdown, 10 μA
HOC QDS/ELQA Input Path Panel	1.2	60	No breakdown, 10 μA
QH Wires	3.2 (4)	60	No breakdown, 10 μA
Splitting Modules for DFHX/M	2.7	60	No breakdown, 10 μA
QH Power Supplies	1.1	60	No breakdown, 10 μA

(3) Wire-by-wire test is not required, but only the full cable to ground.

(4) Wires are rated below the required voltage. Dedicated pre-qualification tests will be done on wire samples to validate up to required test voltages.

HOC – High Order Correctors

Extract from: https://edms.cern.ch/document/2824470

Tests performed only during system integration by the equipment owners, not a recurrent test.

Additional leakage current limits

- During the ELQA on complete circuits (*more details in next slides*) all connected components will contribute to the leakage current of the circuit
- The leakage current of single components must remain in the background of cold parts of the circuit
- Additional leakage current limits are imposed to all instrumentation components
  - Test level: **1 kV**
  - Duration: **60 s**
  - Leakage current: **0.1 uA/component** (wire, channel)

ELQA on complete circuits

ELQA on complete circuits

- Complete circuits will be tested at warm and at cold to:
  - Verify circuit readiness for cooldown and powering
  - Detect faults in circuits
  - Detect faults in instrumentation
- Faults could be introduced by:
  - Rapid flows of helium in cold-masses and lines
  - Thermal contractions
  - Human interventions
- Electrical connections are made at the level of:
  - CDBs for feeding current; *max. 6 A, typically up to 1 A*
  - Dedicated ELQA connectors at the level of QDS racks (‘ELQA ports’); *current can be fed via instrumentation, limitation at 0.5 A*
  - DQLIM for testing the quench heaters
  - CLIQ units for testing the CLIQ leads and CLIQ cables
  - For Corrector Package circuits at the level of the ELQA rack
- Full circuits will be tested including Quench Detection electronics and cryogenic readout conditioners. Exceptions:
  - Power Converters (PCs) will be disconnected during tests
  - For the 120 A circuits it is necessary to disconnect the SK-LEAD connectors that go to PCs
  - CLIQ units might need to be disconnected due to relatively significant leakage currents

Voltage levels during complete circuit tests

The voltage levels during the final ELQA of complete circuits is given by the tunnel stage test levels of associated magnets in the circuit

- List of EDC documents: https://edms.cern.ch/project/CERN-0000229487

Powering location	Circuit type	ElQA Test Voltage [V]	Test Duration	Max. leakage current [μA]
DFHX	RQX	**804**	30	10
	RCBX	300	30	10
	RD1	480	30	10
Local	RQSX3	290	30	10
	RC(S,O,D,T)(S)X3	150	30	10
DFHM	RD2	**940**	30	10
	RCBRD	680	30	10

Conclusions

- Instrumentation in HL LHC circuits needs to be particularily well designed and tested due to high reliability requirements imposed by radiological activation
- Multiple tests on each instrumentation wire for magnets and associated cold powering components will be performed
  - Instrumentation present in cryostats will be tested at several stages
  - Warm instrumentation cables will be tested by ELQA in addition to standard tests during cable installation
  - Samples of warm instrumentation cables will be validated before the installation starts
  - Electronics that is connected to circuit potential will be tested by equipment owners during IST
- Test voltage levels are defined for all components by EDC documents