ELectrical Quality Assurance (ELQA) scope of work and electrical design criteria

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ELQA related presentations:

- ELQA scope of work and electrical design criteria *(Tuesday PM - WP3/WP7)*
- ELQA tests for the HL-LHC IT String *(Thursday AM - IT String - WP16/WP1/WP3/WP6A/WP7/WP9)*
- ELQA scope of work for SC links *(Thursday PM - WP6A/WP7)*

Outline

- Introduction to ELQA
- Electrical Design Criteria (EDC)
- Components' lifecycle
- Qualification „building blocks"
- Hardware and software
- Summary

ELQA - introduction

- Test superconducting circuits and magnets (at warm, cold and during thermal transitions)
- Detect non-conformities, signs of faults, ageing, degradation
- The test results are assessed according to defined acceptance thresholds and also they are traced over time to find possible trends and signatures of faults that may develop
- The objective is to validate circuits for thermal cycles and operation at high currents

ELQA has been regularly performed starting from the LHC assembly phase (~2005) until today

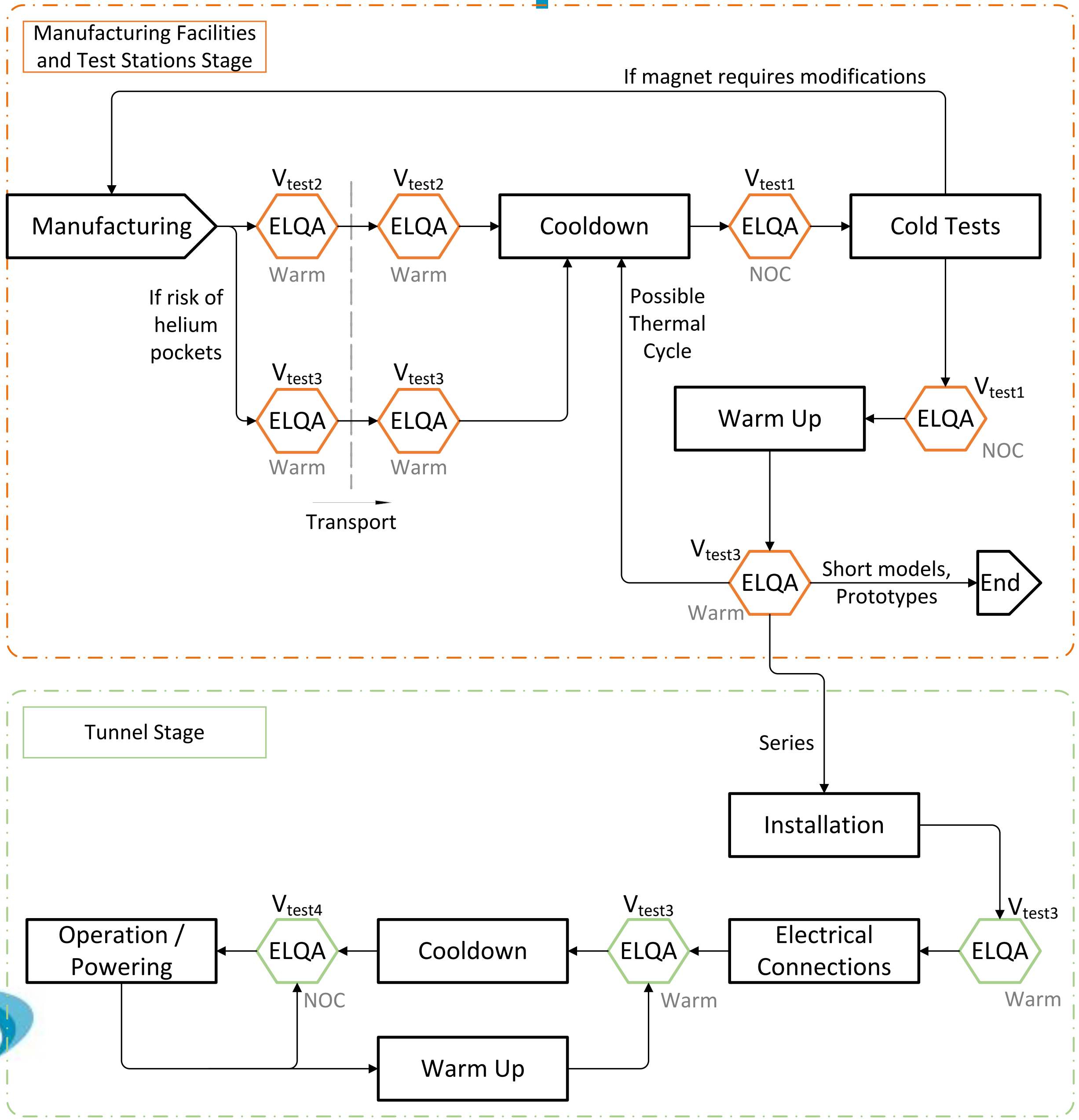
Electrical Design Criteria

- For each magnet (and cold powering component) an EDC document was created
- Lifecycle is described
- The necessary voltage withstand levels and test levels at various conditions and at various manufacturing stages were defined

- Documents can be found here: https://edms.cern.ch/project/CERN-0000229487

- List of magnet types:
  - MQXF
  - MBXF (D1)
  - MQSXF
  - MC(S,O,D,T)(S)XF
  - MCBXF
  - MBRD (D2)
  - MCBRD

Components' lifecycle

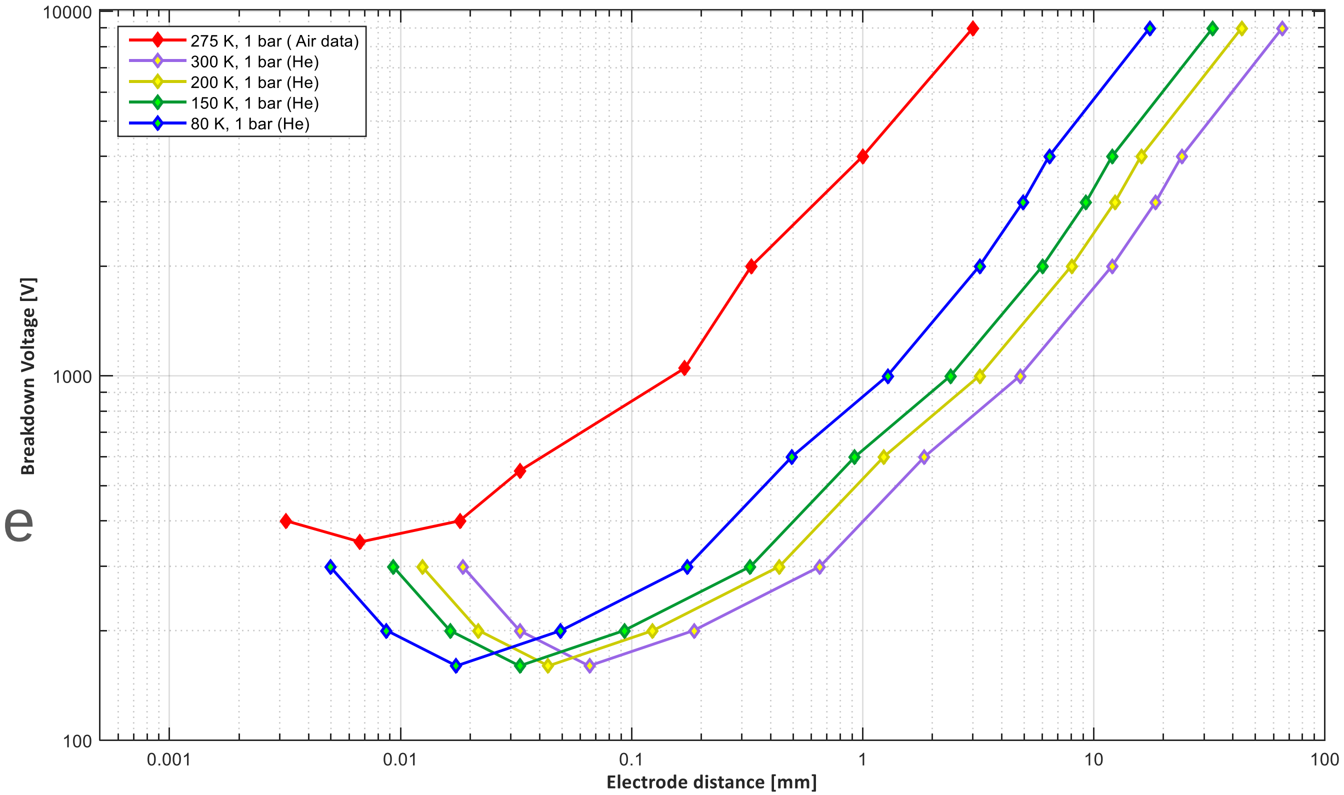


Following the Electrical Design Criteria documents the ELQA tests at an adapted level of voltage need to be performed at multiple stages of a component lifecycle

NOC – Nominal Operating Conditions

Helium influence on voltage withstand

- Voltage withstand of a gap between two bare conductors is given by the medium present in the gap
  - Air
  - GHe at warm
  - GHe at cold
  - LHe
- For gases Paschen law describes the breakdown voltage as a non-linear function of:
  - Pressure
  - Distance
- To perform a comparable HV insulation test of a component in various conditions an approximate scaling factor can be deduced

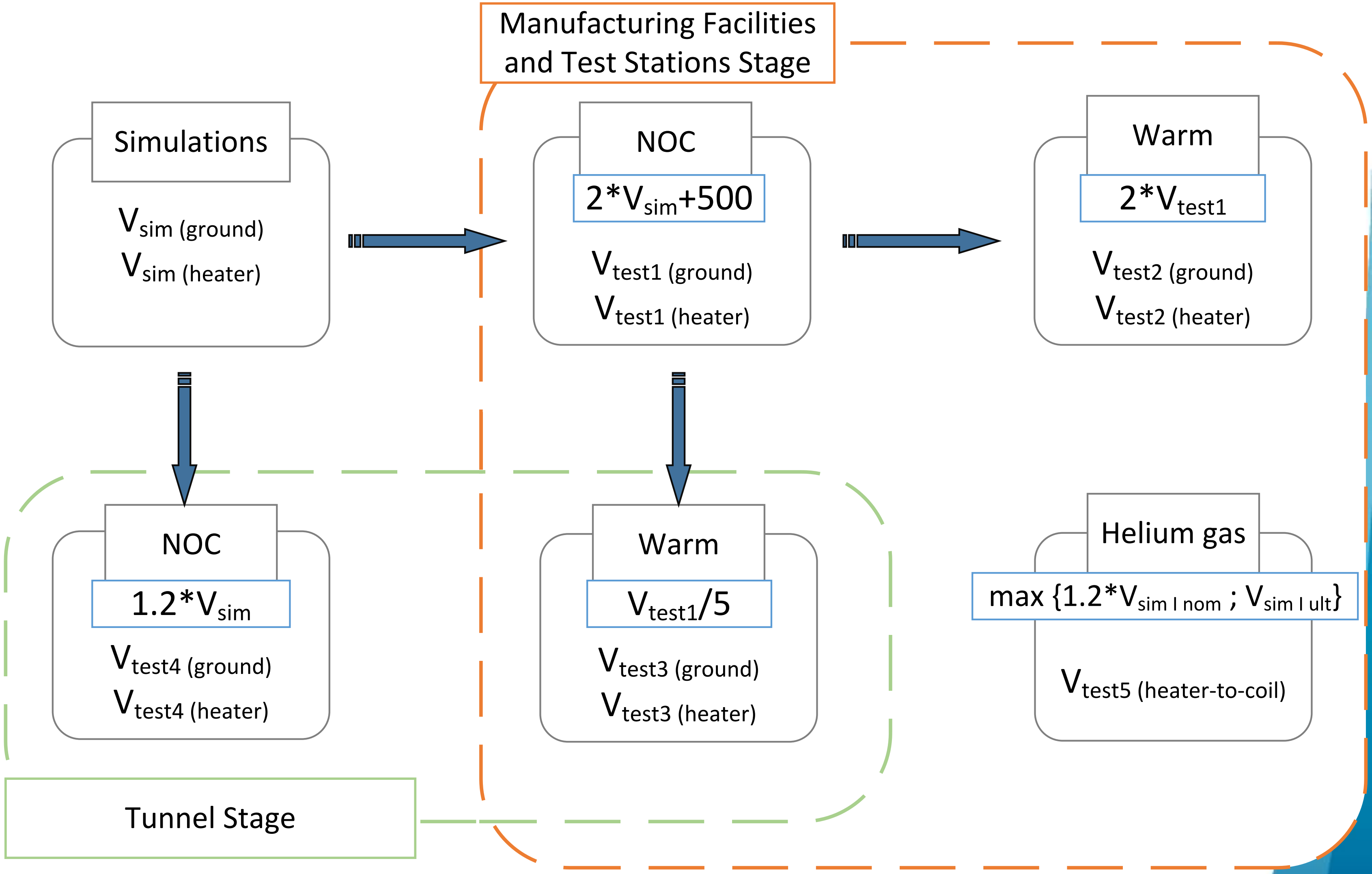


Liquid helium has a dielectric strength of about 10 kV/mm at T=1.9 K and p=920 mbar

HV test levels definition

Test levels summary:

Test level	Conditions
V_{test1}	NOC in a test station
V_{test2}	Warm in air in a test station
V_{test3}	Warm after the magnet was exposed to helium
V_{test4}	NOC in the tunnel
V_{test5}	gHe conditions at a cryogenic temperature (100 K)



Test strategy

- All cold powering components are tested at multiple stages during manufacturing, in test stations, during installation in the tunnel and following thermal cycles in the tunnel
- All test levels are adapted to the **worst case realistic scenario** that a component may experience
- The test voltage levels are **highest during the initial stages**
  - The objective is to intercept as many faults as possible at an early stage so that the long term stability and smooth operation can be ensured
- Tests at warm require particular **attention if the magnet has seen helium**
  - Impregnated coils may have enclosed pockets or cracks that vent very slowly
  - Test voltage needs to be scaled down (wrt the test levels at cold) to be compatible with possible gHe presence to avoid further degradation of these weaknesses
  - When test voltage is scaled down due to gHe presence, the test result will only be representative if gHe is indeed present
- At the tunnel stage at cold the test voltages give only 20% margin wrt the worst case scenario
  - It is **necessary to identify faults that can affect operation**
  - It is very hard to replace certain components in the tunnel, especially at cold
  - Minor faults and weaknesses that do not directly affect the operation should not be triggered in this configuration

ELQA is not only HV testing

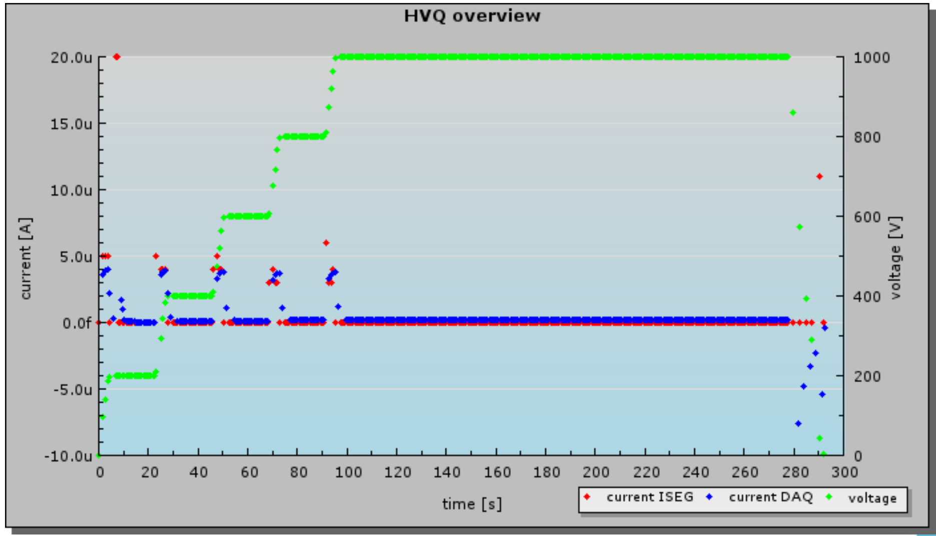
- Insulation HV tests are one of the main types of qualification
- Multiple complementary tests have to be executed to validate the electrical integrity and to ensure the validity of the HV tests, in particular a conductor must be tested for continuity before the insulation test

ELQA „building blocks”:

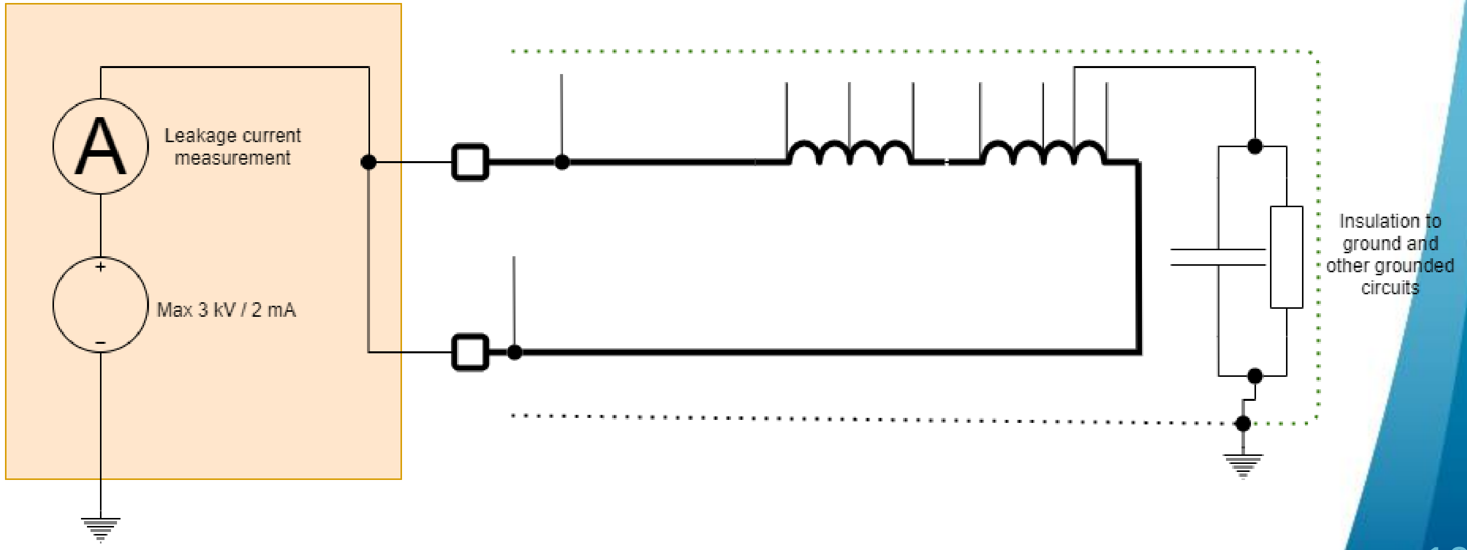
- HVQ – High Voltage Qualification
- TFM – Transfer Function Measurement
- IRC – Instrumentation Resistance Check
- ICC – Instrumentation Configuration Check
- TDR – Time Domain Reflectometry
- COC – Continuity of Conductor check
- QHR – Quench Heater Resistance measurement
- DVC – Diode opening Voltage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

HVQ – High Voltage Qualification

- Each component (circuit, part of a circuit, bus-bar, instrumentation wire, quench heater or cryo heater) is tested individually with respect to ground using a DC voltage source limited to a current of 2 mA
- During the test of a given circuit, all neighbouring circuits (the same electrical safety sub-sector) are grounded
- Applied test voltages are defined for each component at each configuration and for warm and cold tests

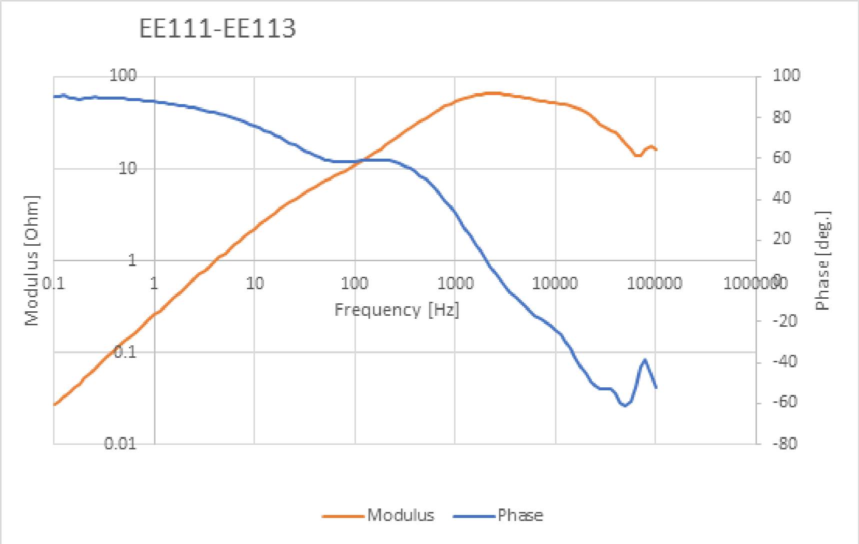


- Leakage current is measured, recorded in the central database and compared with predefined thresholds and with values measured on the tested component in the past

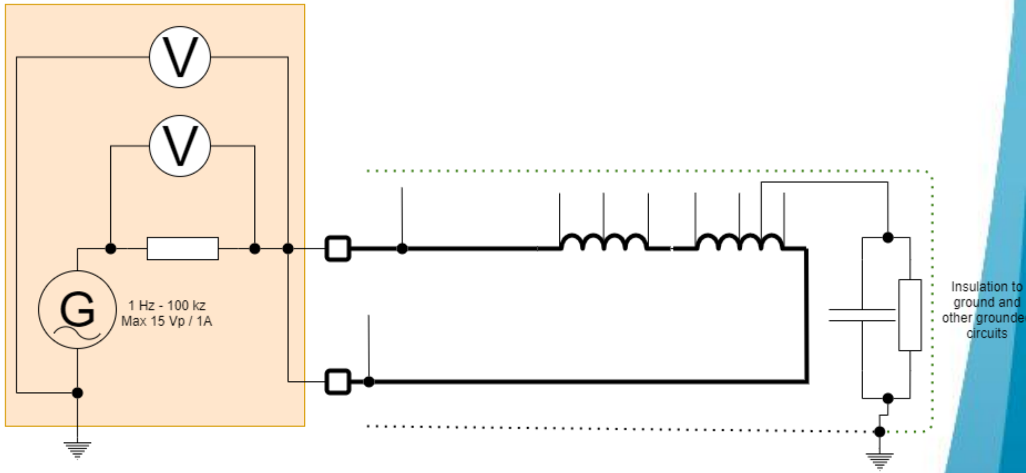


TFM – Transfer Function Measurement

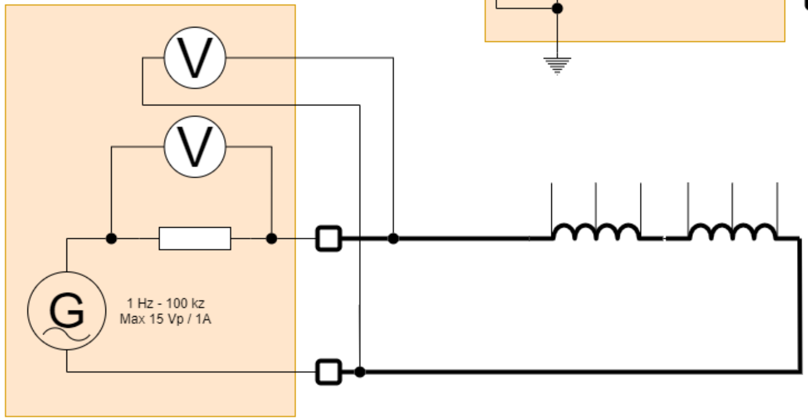
- During this test the impedance as a function of frequency is measured
- The results of these measurements are used to detect possible circuit anomalies
- The impedance is measured by applying a sinusoidal signal with maximum amplitude of 10 V and maximum current of 1 A
- The frequency range is 0.1 Hz - 100 kHz



Principle of TFM vs. GND measurement



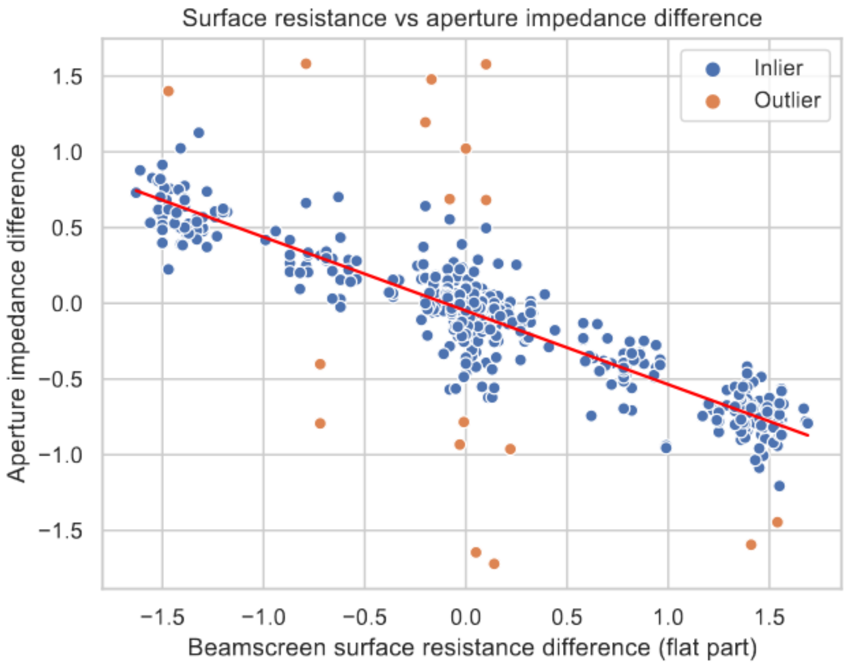
Principle of TFM measurement

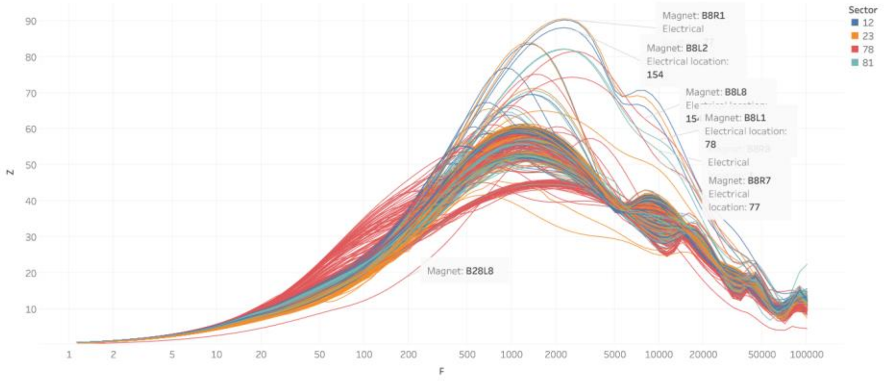


- Other „building block” tests are described in details in the document **EDMS 2746933**
- All HL-LHC ELQA procedures, hardware and software will be verified in the IT string

Data analysis

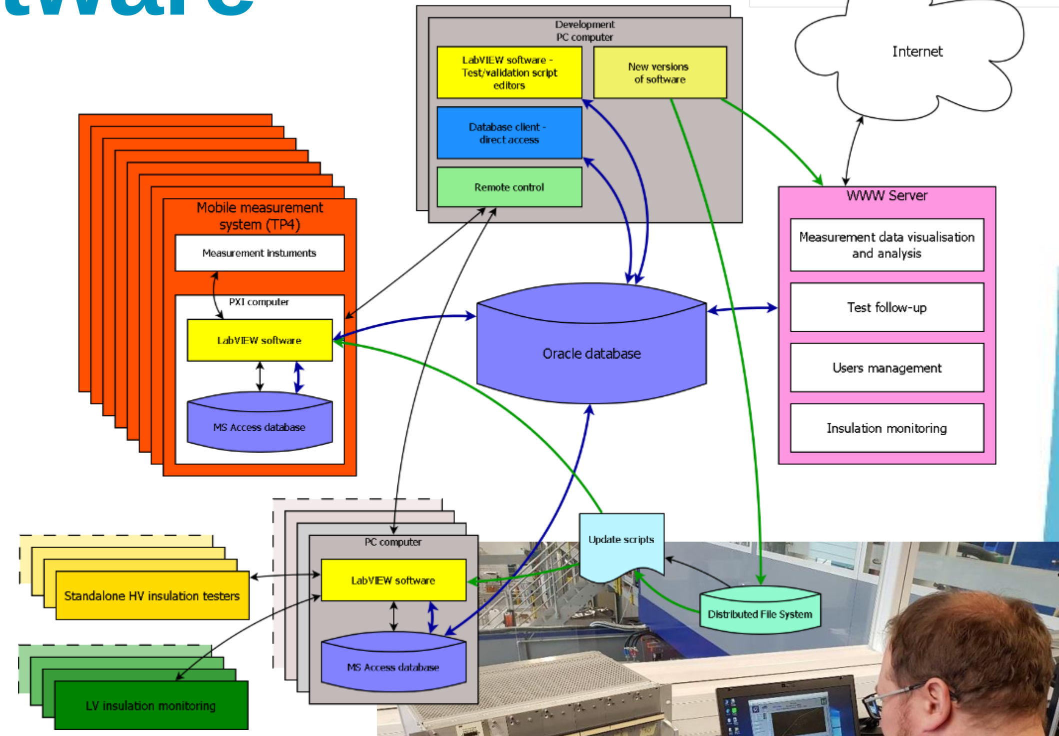
- All collected test results are stored in a central database
- ELQA at the tunnel stage is repeated periodically: before/after thermal cycles or technical stops
- Trends over time for each measured electrical parameter are evaluated
  - Precursor detection
  - Ageing detection
  - Circuit’s health assessment
  - Influence of consolidation works on circuit parameters
- In case of failure of any component in a circuit the ELQA measurements become the reference that can be used for fault localisation

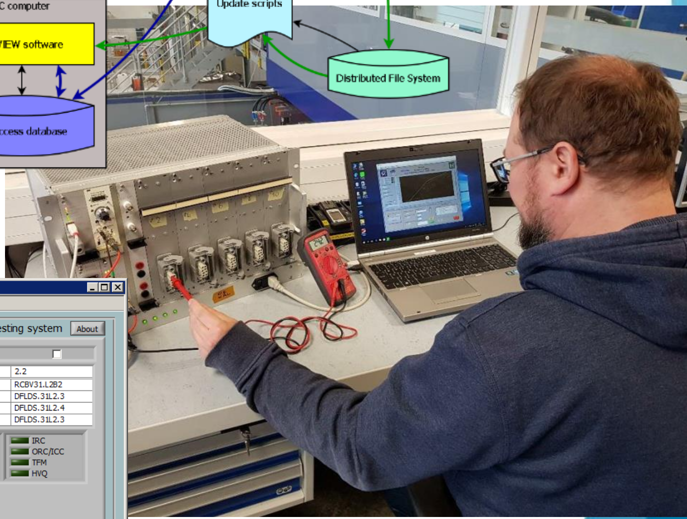


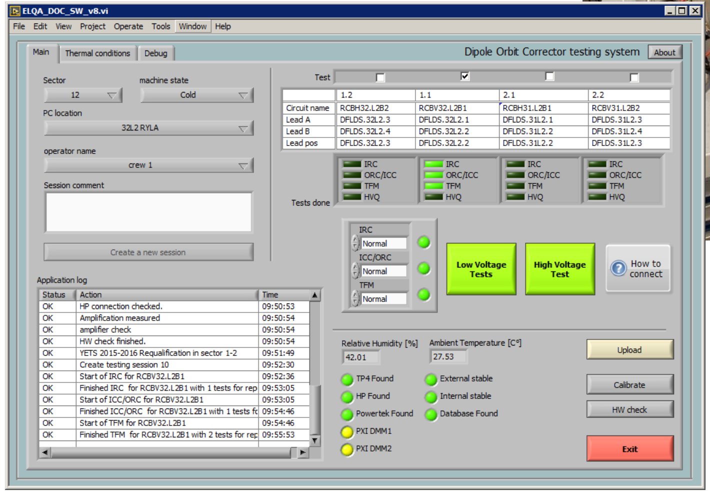


Hardware and software

- The ELQA hardware and software covers all needs for tests of regular LHC circuits and magnets
- Dedicated hardware for qualification of HL-LHC components is being developed
  - New configurations need to be tested
  - New tests will be added
  - Development started
  - Type tests performed
  - Collaboration with HNINP, addendum is being finalised







Summary

- ELQA on HL-LHC superconducting electrical circuits (including the IT string test) will be performed by the ELQA team (TE-MPE-PE)
- For each magnet (and each major cold powering component) an Electrical Design Criteria document was created
  - Components' lifecycle is defined and HV test levels at each stage are defined
- ELQA program is being finalised and the details will be verified in the IT String
- Detailed analysis of acquired data is part of the ELQA
- Dedicated hardware for qualification of HL-LHC components is being developed


Thank you for
your attention!