# IST and SCT in the HL-LHC IT String: Results

S. Yammine on behalf of the SVP and MCF

14th HL-LHC Collaboration Meeting, Genoa (Italy),
9th October 2024

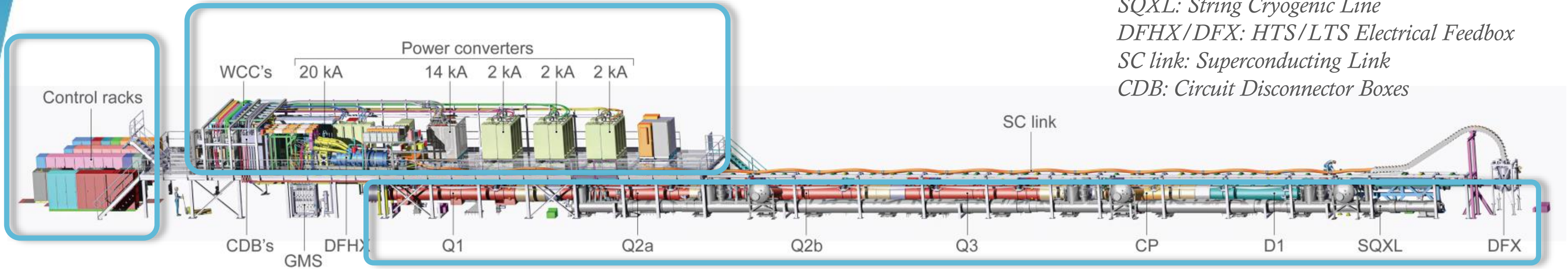
# Outline

- Introduction
- Quality Control Steps and Results
- Individual System Tests
  - Cryogenics
  - Warm Powering
- Short Circuit Tests
- Lessons Learnt from First IT String Operation
- Takeaway Message

# Overview of the HL-LHC IT String Systems

String Mezzanine: warm powering system and DFHX

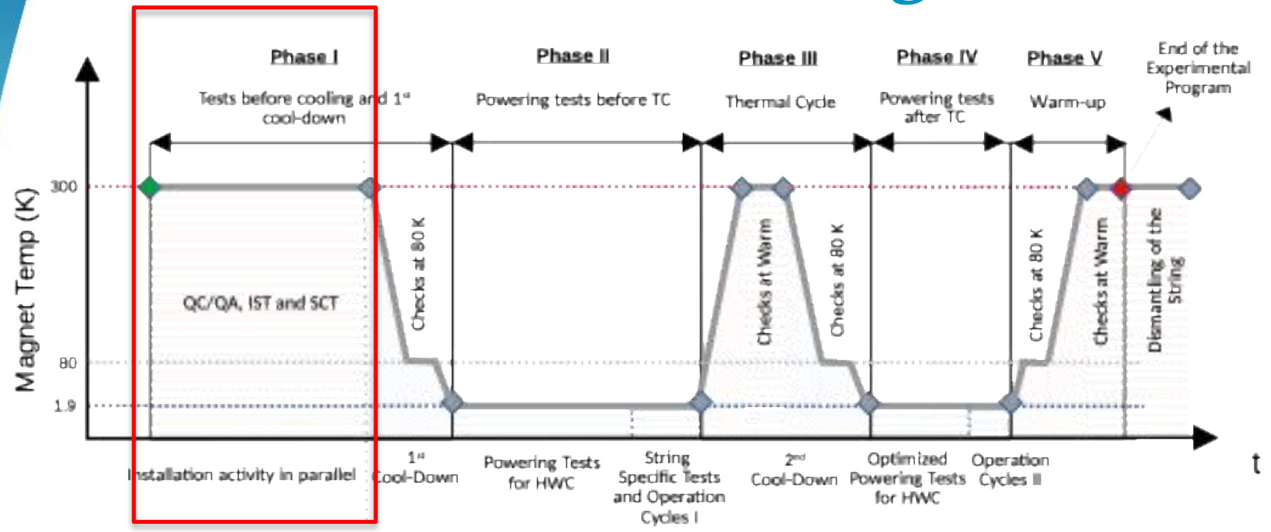
*WCC: Water-Cooled Cables*
*GMS: Gas Management System*
*SQXL: String Cryogenic Line*
*DFHX/DFX: HTS/LTS Electrical Feedbox*
*SC link: Superconducting Link*
*CDB: Circuit Disconnector Boxes*




Control and Quench Protection Racks

Magnet and cryogenic lines

# HL-LHC IT String Validation Program




*HL-LHC IT String Validation Program*
*EDMS no. [2664290]*

*QC: Quality Control*
*QA: Quality Assurance*
*IST: Individual System Tests*
*SCT: Short Circuit Tests*
*HWC: Hardware Commissioning*
*TC: Thermal Cycle*

***IST for:***
- *Cryogenic system*
- *Warm powering*
- *Quench protection*
- *Full Remote Alignment System (FRAS)*
- *Magnet mechanical transfer function*

***QA/QC:***
- *Electrical quality assurance*
- *Continuity and polarity control*
- *Pressure and leak tests*

***Powering Tests for HWC:***
- *Preparation for end-of-LS3 HWC*
- *From low to higher energy circuits*
- *Converter control loops*
- *Energy recovery mechanisms*
- *Quench detection and protection*
- *Performance of the link with magnets*
- *Cryogenics with magnets*
- *Movement of magnets after quenches and thermal cycle*

***String Specific Tests :***
- *Cryogenics bayonet heat exchanger tests*
- *Crosstalk studies*
- *Flux jump measurements*

***Operation Cycles :***
- *Powering endurance tests*
- *FRAS with and without current in magnets*
- *Powering cycles in synergy with BE-OP*

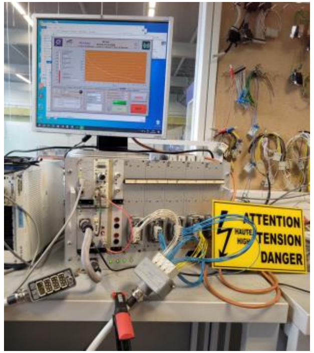
# *Quality Control Steps and Results*

# Electrical Withstand Test Results

Scope:

- Electrical tests are systematically done to ensure compliance the Electrical Design Criteria (EDC) documents specify voltage withstand of components connected to the magnet circuit (done in collaboration between Magnet Circuit Forum and ElQA team at CERN)

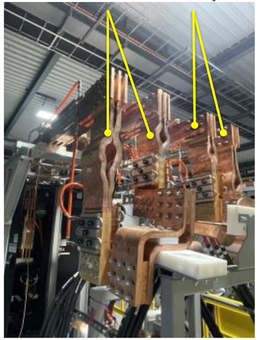
## Instrumentation Cables




Voltage tests passed beyond requirements; few continuity issues found and being addressed

## Water-Cooled Bus Bars

RD1 RQX



Non-conformities have been found and are being addressed by WP6b

## Water-Cooled Cables

Voltage tests passed according to EDC

In the upcoming weeks, the electrical tests will be performed on the SC link in the IT String and on the first arriving magnets (Q2a, D1 and then Q2b)

*See talk of G. West – THU AM*

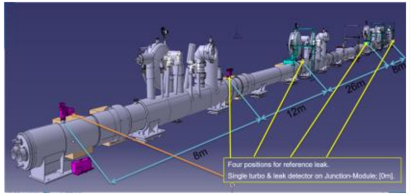
# Leak Tightness Test Results

*Courtesy of W. Maan*

Requirements:

- Helium volume to insulation vacuum: leak tightness qualification criteria < $10^{-9}$ mbar l/s
- Air to insulation vacuum volume: leak tightness qualification criteria < $10^{-9}$ mbar l/s

## Leak Tightness of the SQXL




Status: Leak tightness of the SQXL (vacuum-insulation volume to air and to helium volume) validated after localising and repairing several leaks

## Leak Tightness of the SC Link

Status: Activity started last week with pumping of the helium volume of the SC Link/DFHX

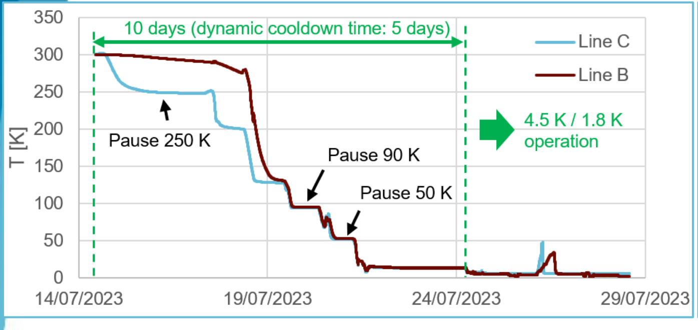
During magnet interconnections, systematic leak tightness will be validated using clam shells and a global check will be done at the end of the activity (planned for 2025)

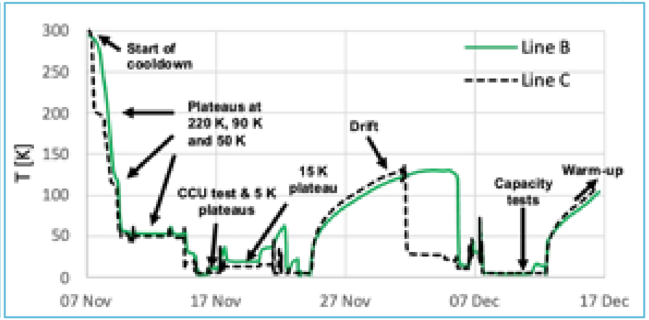
*See talk of S. Le Naour on magnet interconnections – same session*

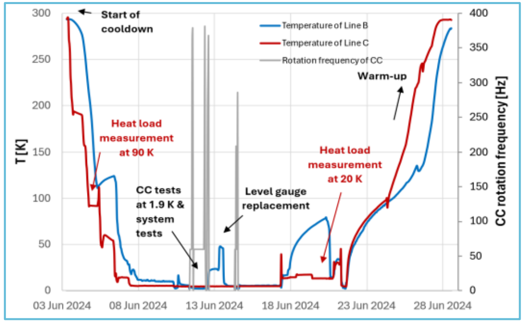
# *Individual System Test Results*

# Commissioning of the Cryogenic System without Magnets

*Courtesy of A. Onufrena, A. Perin et al.*




### Phase 1a

- First cool-down
- Mechanical integrity validated
- First findings: Heat load on some segments is higher than expected

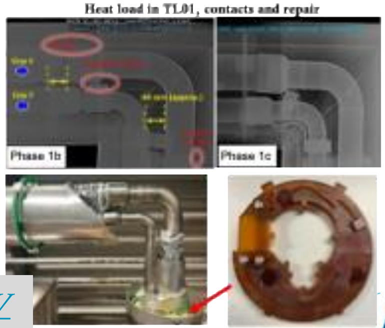
### Phase 1b

- System thermal characterization (heat loads, pressure drop)
- X-ray inspection of TL01 line at cold
- Further tuning of control loops and CCU logic test

### Phase 1c

- CCU logic validation
- TL01 repair validation and capacity measurements




*Courtesy of A. Onufrena, A. Perin et al. – more info in IT String Day IV*

# Highlight on the Results of the Cryogenics IST

## Heat Loads

| | Proximity cryogenics (PCDS), length ≈ 70 m | | | | Cryo distribution line (SQXL), length ≈ 60 m | | | Total (PCDS+SQXL), length ≈ 130 m | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TL01 Line C | TL02 Line D | TL03 Line B | TL05 Lines C/D/B | Line C | Line D | Line B | Line C | Line D | Line B |
| **Predicted [W]** | 7 | 13 | 9 | 10/10/10 | 9 | 33 | 15 | 26 | 56 | 34 |
| **Measured [W]** | 6 | 83 | < 9 | 15/5/7 | 29 | 60 | 12 | 50 | 148 | 28 |
| **Error [%]** | 20 | 15 | 34 | 22/22/29 | 23 | 16 | 24 | 18 | 14 | 22 |

$\dot{Q}$ on Line D inside TL02 is higher than expected

**Potential reasons for observed $\dot{Q}$**: Conduction / radiation from warm vacuum barriers (not the case during operation) and other sources under investigation

## Capacity Tests

**Goal**

- Validate that the cryogenic system can provide sufficient cooling for the magnets with highest heat dissipation during 19-minute nominal magnet ramp (14.6 A/s): 135 W (static) + 201 W (dynamic) → **336 W**

**Results**

- Cooling capacity (after TL01 repair): 6 g/s (cold powering) + **310 W** (magnets) at 1.8 K
- With the measured ***Δp* in Line B,** the current ramp will start at 1.8 K → magnets will drift in *T* by less than 0.1 K during the ramp and remain at around 1.9 K during ramp & nominal operation

**Conclusion**

- Cryogenic system has a sufficient cooling capacity to keep the magnets at 1.9 K during nominal operation

*Courtesy of A. Onufrena, A. Perin et al. – more info in IT String Day IV*

# Status and Results of the Warm Powering System IST

IST HL-LHC energy extraction system based on vacuum switches done according to test procedure *LHC-XMS-OP-0001*

- Visual inspection
- Voltage withstand tests
- Functional tests

IST HL-LHC circuit disconnector boxes done according to test procedure *LHC-XMS-OP-0005*

- Visual inspection
- Voltage withstand tests
- Functional tests

IST HL-LHC power converters done according to test procedure *LHC-XMS-OP-0005*

- Visual inspection
- Component Validation
- Calibration of DCCTs

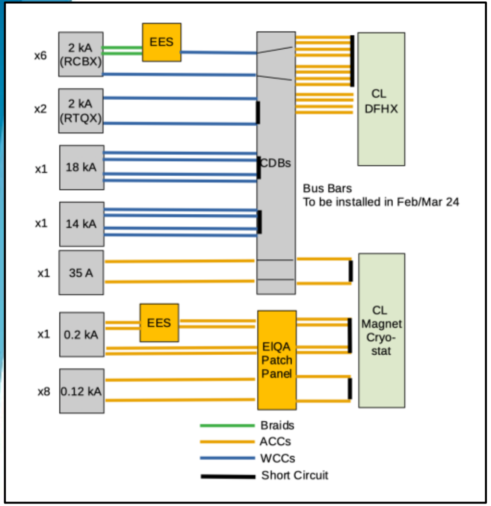
*See talk of M. Martino, TUE PM and H. Thiesen , THU AM*

# Next Steps for Individual System Tests

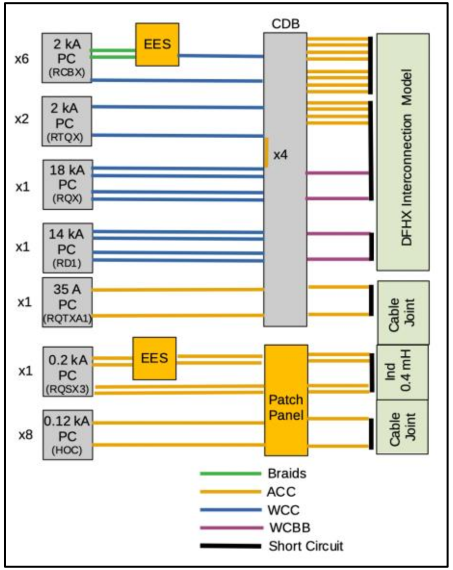
- Fully Remote Alignment System IST on the instrumentation will start as soon as the magnets magnets are installed, and the infrastructure is ready (few tests planned in 2024)
- FRAS motorization IST will be done after interconnections activities of the magnets (2025)
- Mechanical TF measurements are planned for Q1/Q2a before and after interconnections
- CLIQ and Quench Heater Power Supplies IST is planned to be executed before end of the year with dedicated discharge loads

## *Short Circuit Tests*

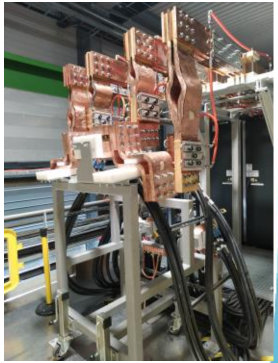
# Short-Circuit Test Overview

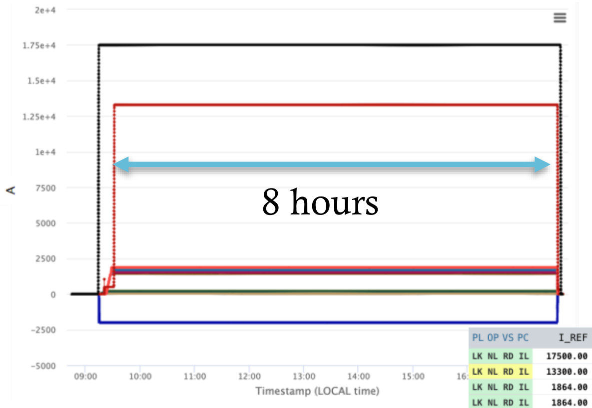



Phase 1 - Jan 2024
(without bus bars)




Phase 2 - May 2024
(complete setup)






Report on EDMS
3026392

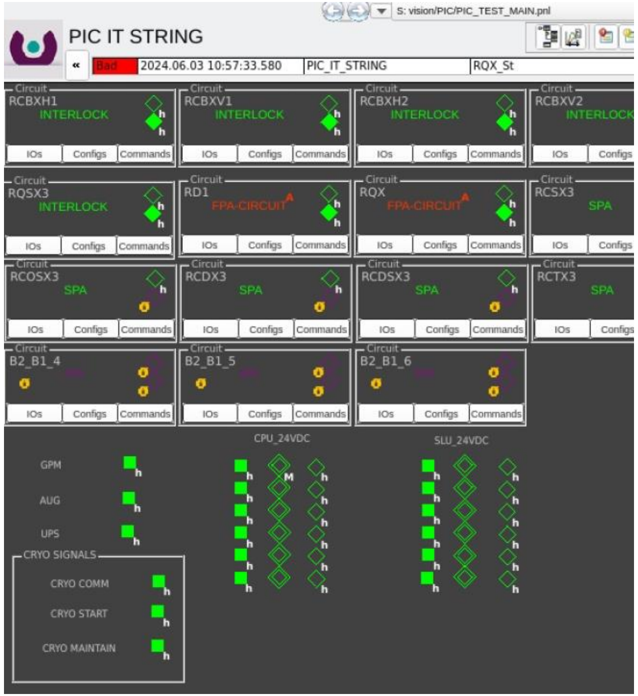
**Steps of the SCT**

- Interlock checks and PIC loop checks
- Extraction discharges
- 8 hr Heat-run at I_ult (~7.5 TeV)

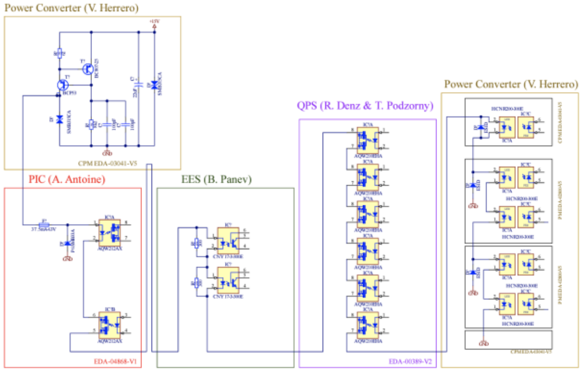
| PL OP VS PC | I_REF | I_MEAS | V_REF | V_MEAS | FGC 20 / 20 |
|---|---|---|---|---|---|
| LK NL RD IL | 17500.00 | 17499.59 | 0.97 | 0.97 | RPAFE.SM18.RQX.SF |
| LK NL RD IL | 13300.00 | 13299.93 | 3.82 | 3.83 | RPAFF.SM18.RD1.SF |
| LK NL RD IL | 1864.00 | 1864.02 | 5.91 | 5.92 | RPBAE.SM18.RCBXH1.SF |
| LK NL RD IL | 1864.00 | 1864.03 | 5.21 | 5.21 | RPBAE.SM18.RCBXH2.SF |
| LK NL RD IL | 1709.00 | 1709.04 | 4.14 | 4.15 | RPBAE.SM18.RCBXH3.SF |
| LK NL RD IL | 1532.00 | 1532.00 | 4.40 | 4.41 | RPBAE.SM18.RCBXV1.SF |
| LK NL RD IL | 1532.00 | 1532.03 | 4.21 | 4.23 | RPBAE.SM18.RCBXV2.SF |
| LK NL RD IL | 1441.00 | 1441.03 | 3.69 | 3.70 | RPBAE.SM18.RCBXV3.SF |
| LK NL RD IL | -2000.00 | -1999.97 | -2.80 | -2.78 | RPBAF.SM18.RTQX1.SF |
| LK NL RD IL | -2000.00 | -2000.00 | -2.67 | -2.67 | RPBAF.SM18.RTQX3.SF |
| LK NL RD IL | 35.00 | 35.00 | 8.71 | 8.71 | RPLAD.SM18.RTQXA1.SF |
| NL RD IL | 106.00 | 106.00 | 4.74 | 4.79 | RPLBB.SM18.RCDSX3.SF |
| NL RD IL | 106.00 | 106.00 | 4.71 | 4.75 | RPLBB.SM18.RCDX3.SF |
| NL RD IL | 115.00 | 115.00 | 4.98 | 5.01 | RPLBB.SM18.RCOSX3.SF |
| NL RD IL | 115.00 | 115.00 | 5.07 | 5.10 | RPLBB.SM18.RCOX3.SF |
| NL RD IL | 112.00 | 112.00 | 4.85 | 4.91 | RPLBB.SM18.RCSSX3.SF |
| NL RD IL | 112.00 | 111.99 | 4.81 | 4.84 | RPLBB.SM18.RCSX3.SF |
| NL RD IL | 94.00 | 94.00 | 4.15 | 4.18 | RPLBB.SM18.RCTSX3.SF |
| NL RD IL | 97.00 | 97.00 | 4.25 | 4.29 | RPLBB.SM18.RCTX3.SF |
| NL RD IL | 197.00 | 197.02 | 2.74 | 2.74 | RPMBG.SM18.RQSX3.SF |

# Validation of the Power Interlock Controller Loops

## PICv2 Controls Interface




## Loop Hardware Analysis and Tests



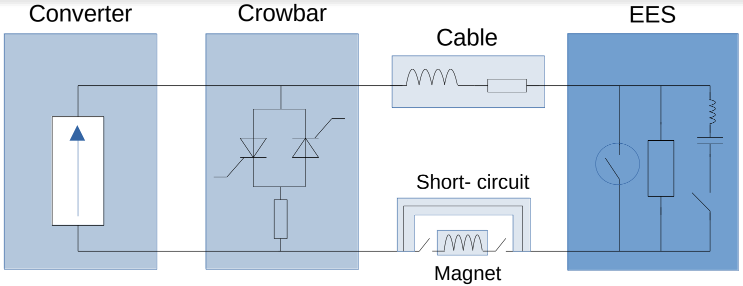

Example: FPA 200A/600A PC with EES

Results:

- All loops are conform, but tested without QDS except one circuit
- Agreement on solution among different stakeholders in collaboration with MCF, SY-EPC and TE-MPE

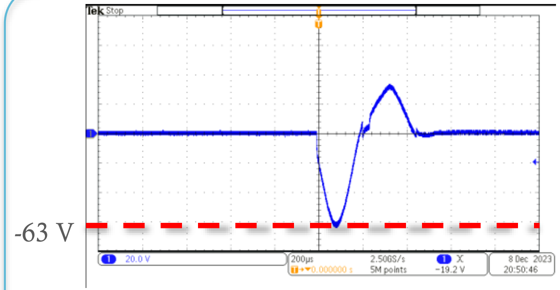
# Discharges of HL-LHC EES in SCT

EES discharge tests with SY-EPC and TE-MPE

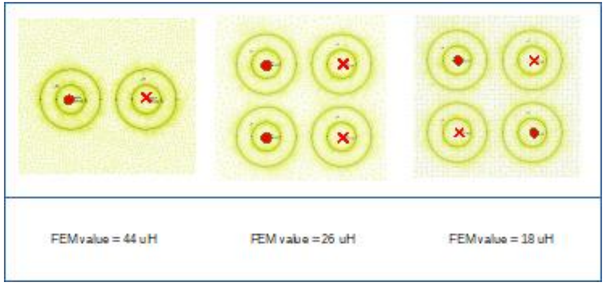



Accepted converter output voltage within ± 63 V

EES capacitor voltage for arc extinguishing up to 530 V




PC voltage vs. time
(case without additional inductance)

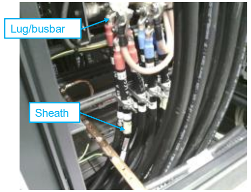



Estimation of cable inductance

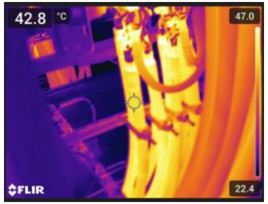
0.4 mH Inductor added for the 200 A circuit

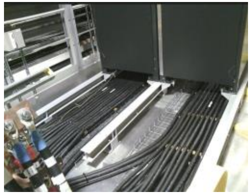
*See talk of H. Thiesen , THU AM*

# Thermal Performance of DC Cables

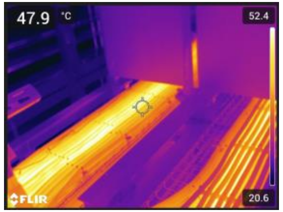



CDB Side



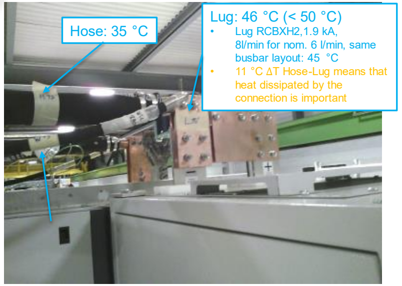
Cableways between CDB and DFHX




Max Lug: 50°C
(Spec: < 90 °C)

Max Sheath: 55°C
(Spec: < 86 °C)

*300 mm2 Air-Cooled Cables*




Power Converter Side
(water output)

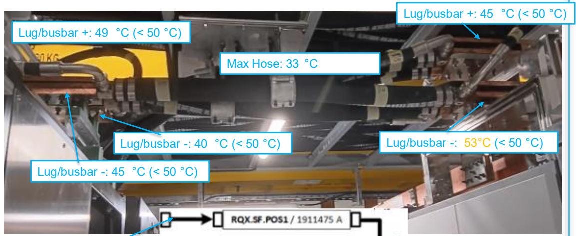
*RCBXH1 @ ~1.9 kA*

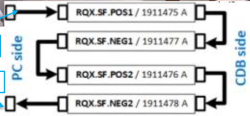

Max Lug: 46°C
(Spec: < 50 °C)

Max Hose: 35°C

*500 mm2 Water-Cooled Cables*

*RQX @ 17.5 kA for 2 hours*




Max Lug: 53°C
(Spec: < 50 °C)

Max Hose: 35°C

*1300 mm2 Water-Cooled Cables*

*Courtesy of J. H Emonds-Alt, M. Silva Marreiros – MCF no. 129*

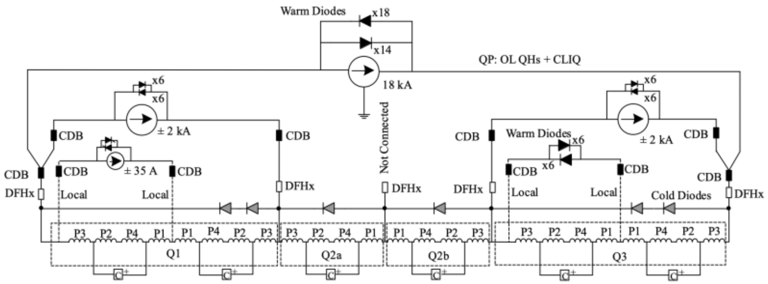
Report: EDMS no. 3020832

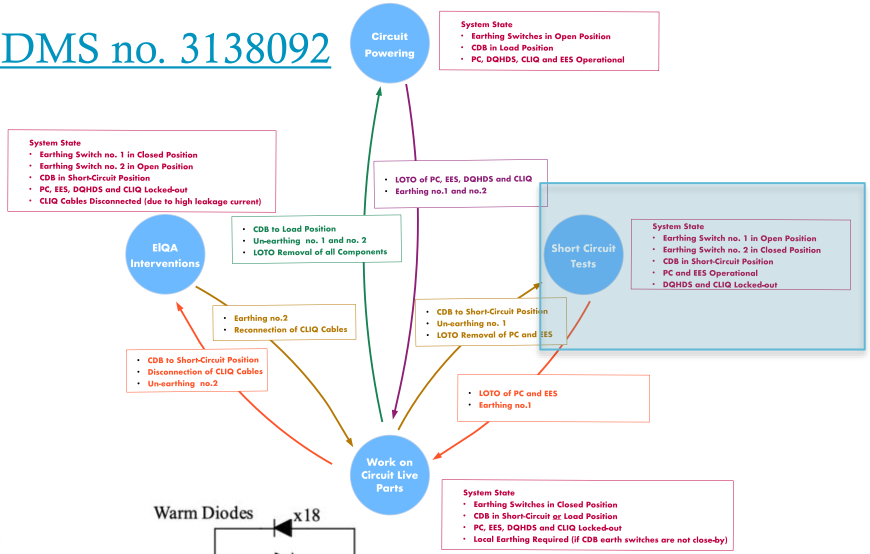
# *(Few of) Lessons Learnt from the First IT String Operation*

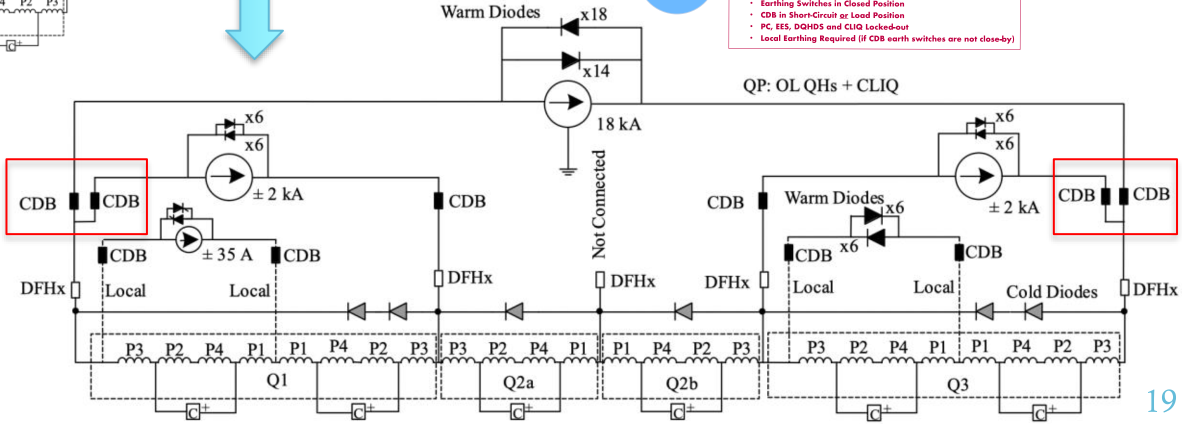
# Update of the IT Circuit Configuration

- Earthing of trims on the DFHX side for SCT with RQX baseline scheme leads to the automatic earthing of the 18 kA PC
- Circuit layout updated based on the experience from the HL-LHC IT String

EDMS no. 3138092



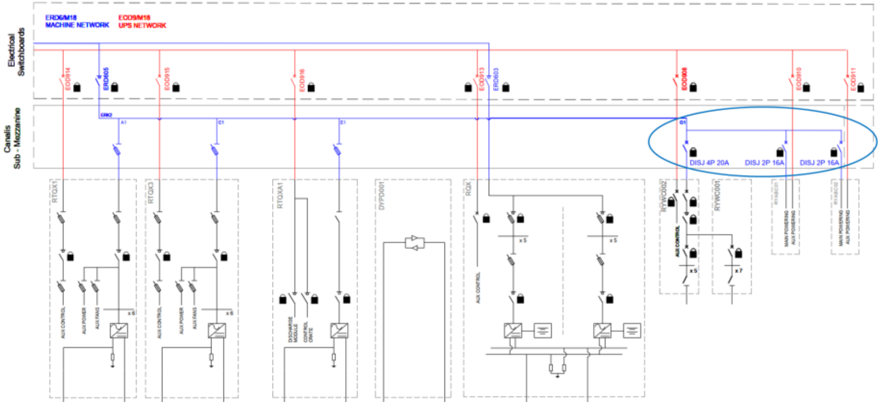



# Change of Supply Network for Optimal Operation

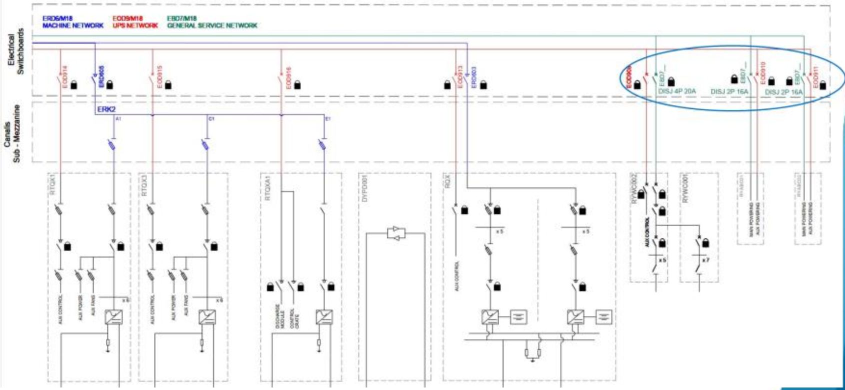
## Description

- 2xDCCT electronics racks and CDB control racks are supplied by ERD via a canalis busbar
- Lock-out at the ERD switchboard cut the three above mentioned elements which is heavy for operation
- Lockout can only be done individually on three instead of one switch (time consuming)

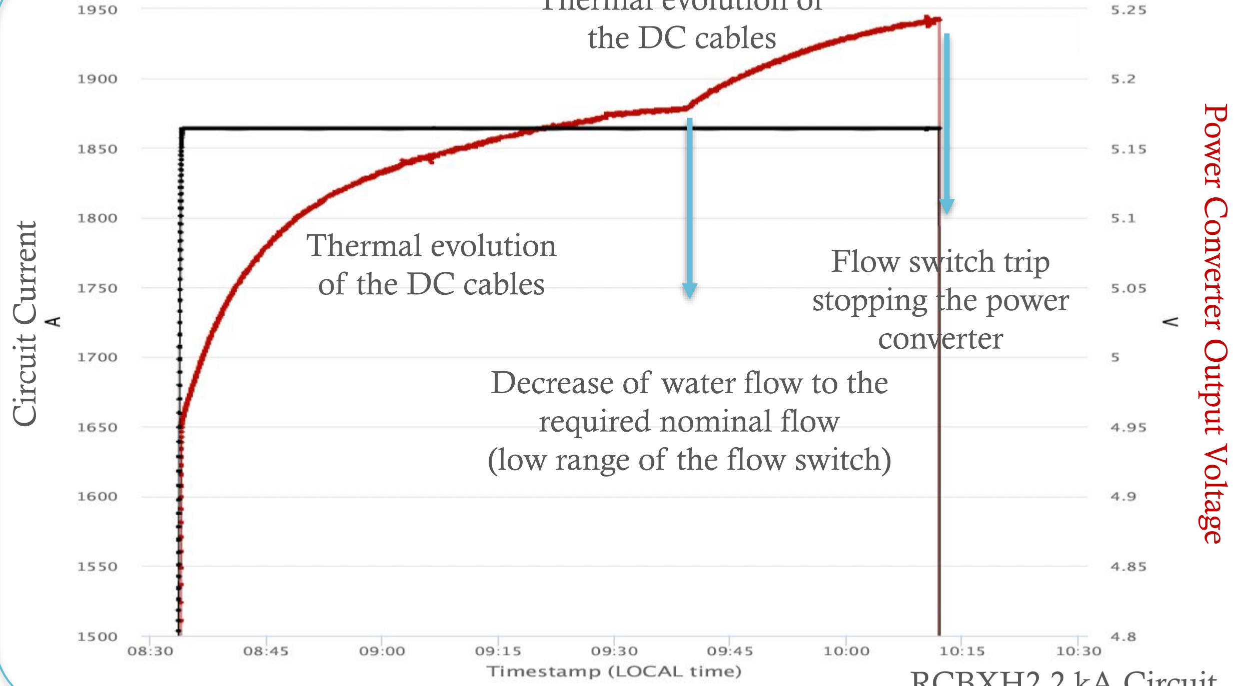



## Lessons Learned

- For the IT String, a change is done for the three elements to be supplied independently from the EBD switchboard
- Functionality to be implemented also for HL-LHC according to WP6b guidelines for granting a fully operational system and a simplified lockout of the triplet



# Flowmeters and Interlocks




RCBXH2 2 kA Circuit


Non-conformity has been written to adapt flow switch range to real needs (NCR no. 3025021)

- **'Low-tech':** In projects focused on high-tech components, activities seen as 'low-tech' tend to receive less attention. The String offers an opportunity to address these 'low-tech' activities, acknowledging their importance.

*R. Schmidt, Close out and executive summary from the IT String Day '23, in 187th TCC*

# Takeaway Message

- Strong QC plan is implemented in the IT String with the same requirements as for HL-LHC

- Individual system and short circuits tests have been successfully executed and the cryogenic and warm powering systems are fully qualified without magnets (few remaining non-conformities are being followed up).

- IST program will continue through 2024-2025 with exciting new activities in the IT String

- Lessons learned are systematically communicated and mitigations are proposed for both the IT String and for the HL-LHC

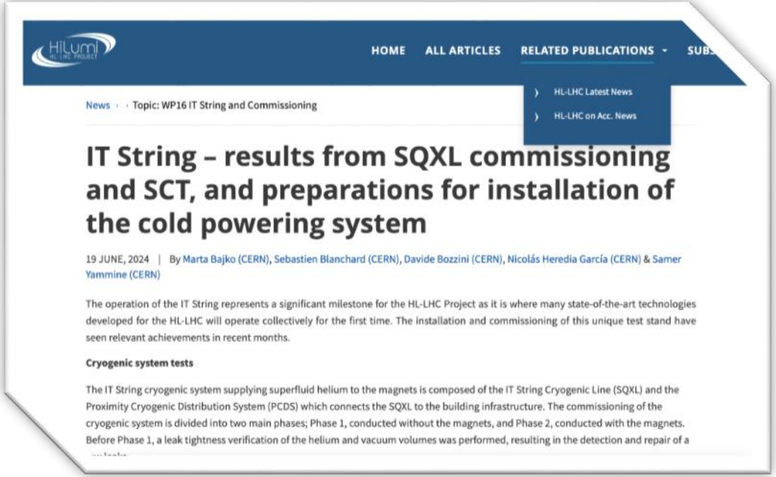
# HL-LHC IT String advancements and challenges for 2024

**The commissioning of key equipment on the metallic platform is now completed.**

3 MAY, 2024 | By WP16 HL-LHC IT STRING team

Figure 1: Part of the teams that made possible the execution of Short Circuit Tests in the HL-LHC IT String (Credit: CERN/ M. Cavazza)

[Accelerating News Article]



HOME ALL ARTICLES RELATED PUBLICATIONS SUB

HL-LHC Latest News

HL-LHC on Acc. News

News › Topic: WP16 IT String and Commissioning

## IT String – results from SQXL commissioning and SCT, and preparations for installation of the cold powering system

19 JUNE, 2024 | By Marta Bajko (CERN), Sebastien Blanchard (CERN), Davide Bozzini (CERN), Nicolás Heredia García (CERN) & Samer Yammine (CERN)

The operation of the IT String represents a significant milestone for the HL-LHC Project as it is where many state-of-the-art technologies developed for the HL-LHC will operate collectively for the first time. The installation and commissioning of this unique test stand have seen relevant achievements in recent months.

**Cryogenic system tests**

The IT String cryogenic system supplying superfluid helium to the magnets is composed of the IT String Cryogenic Line (SQXL) and the Proximity Cryogenic Distribution System (PCDS) which connects the SQXL to the building infrastructure. The commissioning of the cryogenic system is divided into two main phases; Phase 1, conducted without the magnets, and Phase 2, conducted with the magnets. Before Phase 1, a leak tightness verification of the helium and vacuum volumes was performed, resulting in the detection and repair of a

[HL-LHC Collaboration Board Newsletter]

**And many more collaborators…**

***Thank you for your attention***