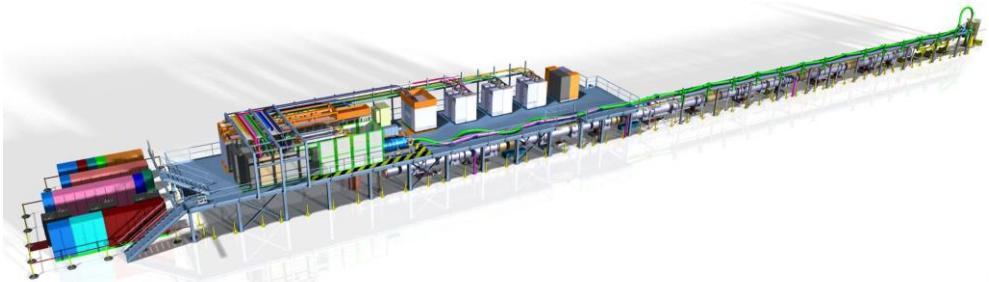
IST, SCT and Powering Test for the HWC of the HL-LHC IT String

S. Yammine on behalf of the SVP, MCF and MP3 members

HL-LHC IT String Day IV – 2024-09-27

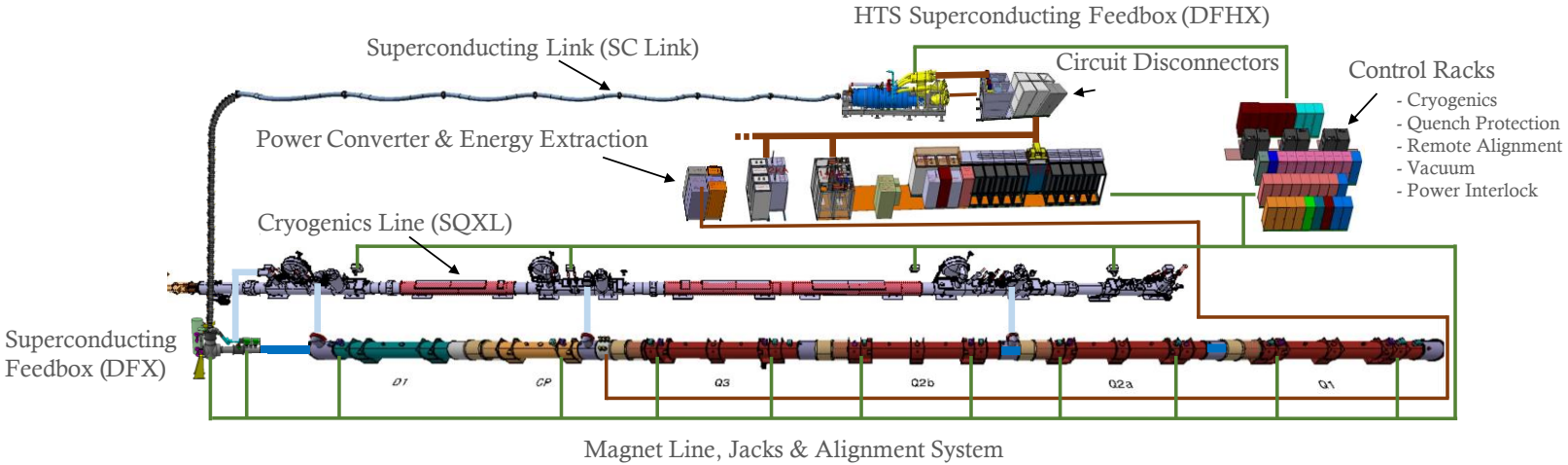


Outline

- Introduction
- Quality Control and Individual System Tests
- Short Circuit Tests
- Powering Tests for the Hardware Commissioning
- Takeaway Message

Introduction

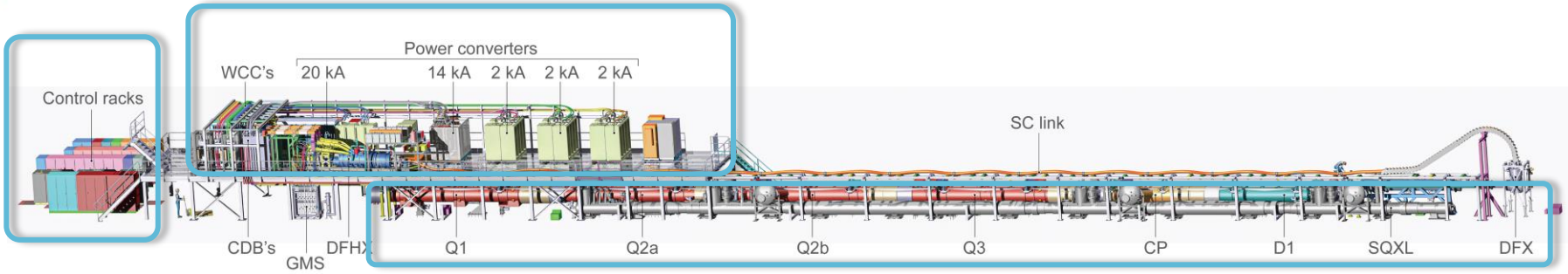
HL-HLC IT String Systems and Scope



- Scope of the IT String is to represent, as best as reasonably achievable in a surface building, the various operation modes to **study and validate the collective behaviour** of the different systems of the HL-LHC's IT zone.
- Another key motivation is to test the **integration, interfaces and installation procedures** on surface before going into the tunnel with much restricted conditions.
- Few differences w.r.t. tunnel configuration: SQXL includes more instruments, no beam-position monitors, no slope, beam-screens and beam vacuum excluded, etc.

HL-HLC IT String Integration Overview

String Mezzanine (~ part of HL-LHC UR Gallery)

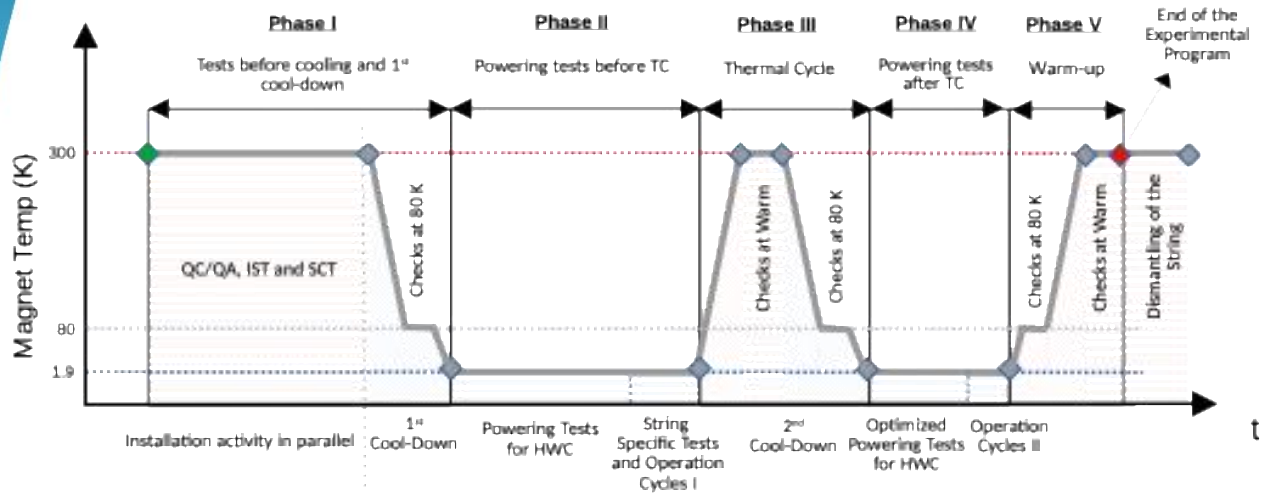


Control Racks
(~ UR, UL, etc.)

Magnet and cryogenic line (~ machine tunnel L5, without slope)

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

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*

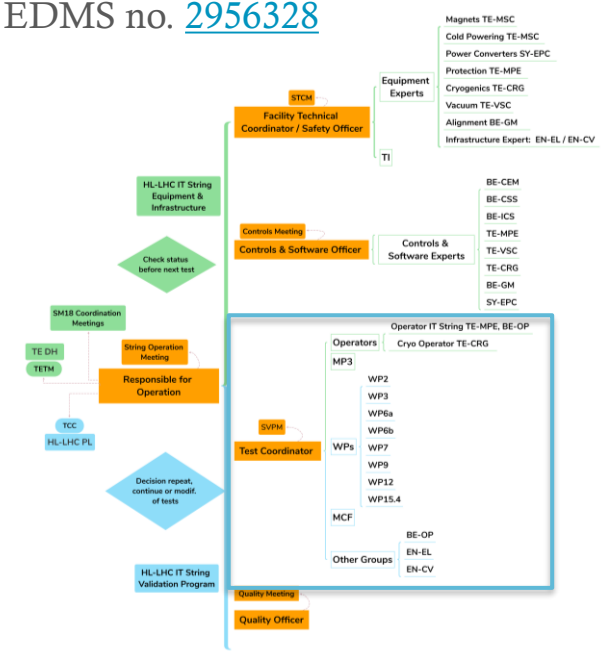
Powering Tests for HWC:
- *Preparation for end-of-LS3 HWC*
- *From low to higher energy circuits*
- *Converter control loops*
- *Energy recovery mechanisms*
- *Quench detection and protection*
- *Performance of the link with magnets*
- *Cryogenics with magnets*
- *Movement of magnets after quenches and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

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

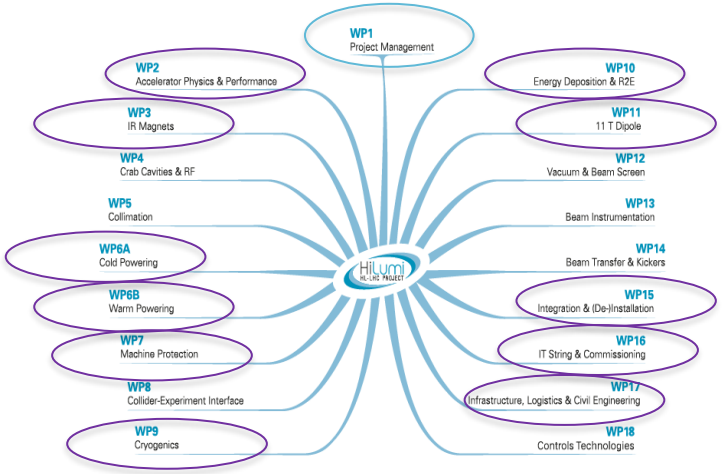
Operation Cycles :
- *Powering endurance tests*
- *FRAS with and without current in magnets*
- *Powering cycles in synergy with BE-OP*

Coordination of the String Validation Program

EDMS no. 2956328



String Validation Program Meetings



HL-LHC Magnet Circuit Forum (link) as forum to discuss the HL-LHC circuits systems;

Test plan, procedure and results are documented as presented by N. Heredia and systematically reported in the concerned forums (MCF, SVPM and TCC)

LHC Magnet Circuits, Powering and Performance Panel - MP3 - (link) as responsible of the HWC powering procedures

Quality Control and Individual System Tests

Test Procedures for HL-LHC IT String and HL-LHC

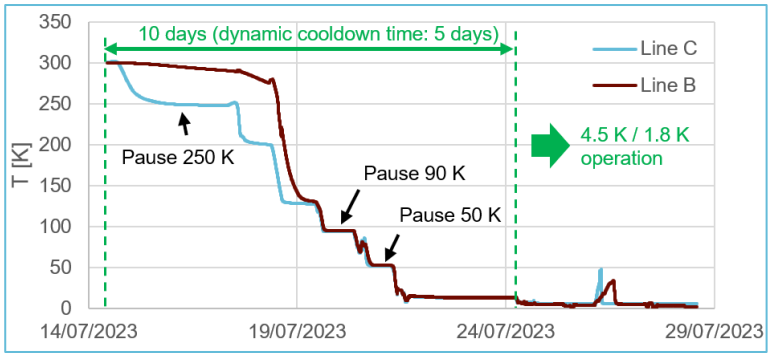
Type	Test Procedure	EDMS no.	Doc. Status	Activity Status in String
IST	Energy Extraction Systems in the HL-LHC IT String	2744520	Released	Done in Q1 24
IST	Water-Cooled Cables in the HL-LHC IT String	2744521	Released	Done in 23
IST	PC and the Circuit Disconnector Boxes in the HL-LHC IT String	2767662	Released	Done in Q1/2 24
IST	Full Remote Alignment System in the HL-LHC IT String	2783832	Draft Version (to be launched soon)	Start in Q4 24
IST	Quench Heater Power Supplies in the HL-LHC IT String	3118980	Eng. Check	Start in Q4 24
IST	CLIQ in the HL-LHC IT String	3118978	Under Approval	Start in Q4 24
IST	Quench Detection and Supervision System in the HL-LHC IT String	2912337	To be done	Start in Q4 24
IST	Cryogenic System in the HL-LHC IT String - Phase 1a	2910866	Released	Done in Q3 23
IST	Cryogenic System in the HL-LHC IT String - Phase 1b	2974487	Released	Done in Q4 23
SCT	HL-LHC Inner Triplet String Short Circuit Tests	2744522	Released	Done in Q1/2 24

Collaborative work with Work Packages and String Validation Program members

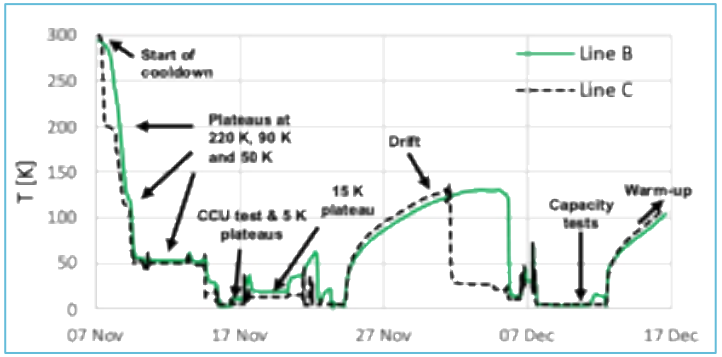
Electrical Design Criteria for HL-LHC IT String and HL-LHC

EDMS No.	Title
1963398	HL-LHC Electrical Design Criteria for the HL-LHC Inner Triplet Magnets
2060633	HL-LHC Electrical Design Criteria for the High Order Corrector Magnets
2187266	HL-LHC Electrical Design Criteria for the D1 Dipole
2363905	CIEMAT - MCBXF - ELECTRICAL DESIGN CRITERIA
2363906	IHEP - MCBRD - ELECTRICAL DESIGN CRITERIA
2363904	INFN - MBRD - D2 - ELECTRICAL DESIGN CRITERIA
2824470	Electrical Design Criteria for the HL-LHC Circuit Components operating at Room Temperature
2826527	Electrical Design Criteria for the HL-LHC Superconducting Link System
3002227	HL-LHC Electrical Design Criteria for the D1-DFX, D2-DFM Interconnection modules and Superconducting busbars in HL-LHC Line N1 and Line N2

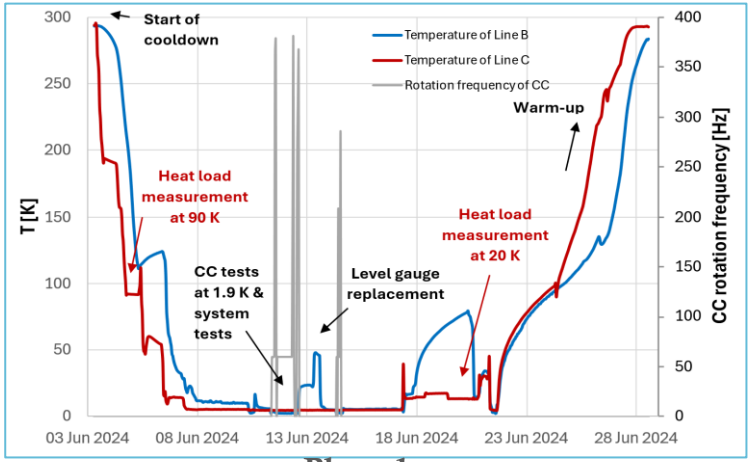
Commissioning of the Cryogenic System without Magnets



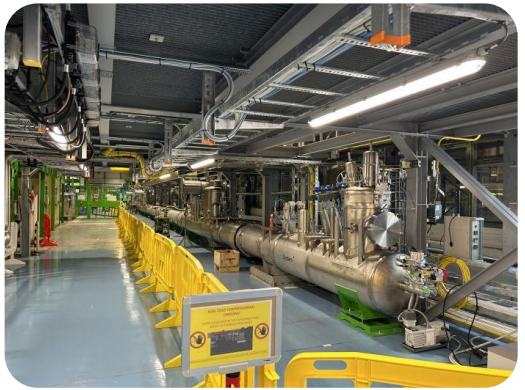
Phase 1a



Phase 1b



Phase 1c



SQXL in the HL-LHC IT String

More information in talk of A. Onufrena

Lessons Learned from Cryogenics Commissioning

- From a test coordination point of view, the clear line of responsibilities was not always clear for leak tests, localisation and analysis in the cryogenics line insulation vacuum
- Exercise in the HL-LHC IT String has incited several discussions for the leak tightness specifications and checks of HL-LHC.
- Non-conformities on two lines appeared during cool-down which help the cryogenics team to evaluate the QA/QC plan for the HL-LHC where the baseline is to cool-down only 1 IP side out of the 4
- Discussions on the status of the cryogenic system after commissioning where it was decided to keep it under vacuum at room temperature to replicate HL-LHC process
- Strategy has quickly been revised due to required intervention to resolve a mechanical conflict between SQXL and Q2a magnet

Warm Powering IST and SCT – Systems Installed

HL-LHC 18kA PC with Energy Storage (Battery) Systems - Proto

HL-LHC 14kA PC – Proto

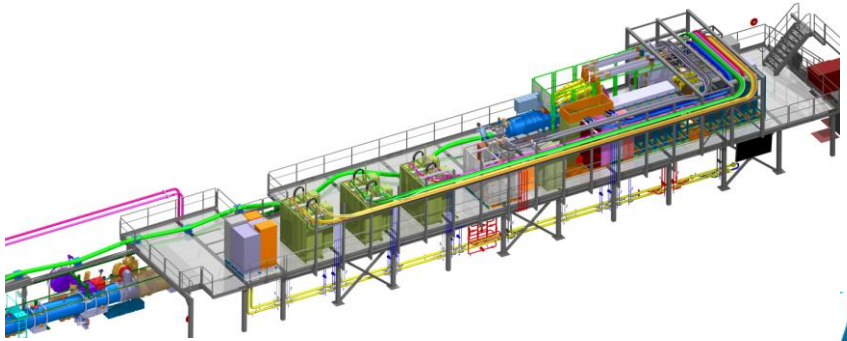
Prototype PICv2
(New PIC for HL-LHC and planned to be deployed in LHC)

HL-LHC Energy Extraction Systems
(based on Vacuum switches)

HL-LHC 2kA PC – Pre-series

HL-LHC CDB – Pre-series

HL-LHC Power Converters and CDBs



Warm Powering IST and SCT – Systems Installed

AC Powering
- General Services / EBD
- UPS / EOD
- Machine Network / ERD

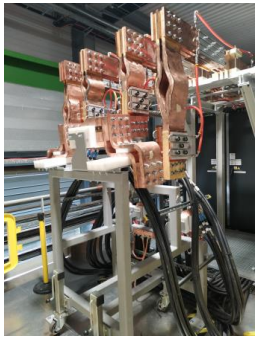
Water-Cooled Cables

Air-Cooled Cables

DC Connection Model

Signal and Controls Cables
(400 out of 600 cables)

Water-Cooling System
(config for HL tested –
ECR by L. Tavian)



Water-Cooled Bus Bars

Test Sequence for Warm Powering IST and SCT

1. Control, Signal and Power Cables QC | Water Cooling Network QC | Electrical Distribution Network QC
2. Water Cooled Cables IST — *LHC-XMS-OP-0002*
3. Connection of Systems to Infrastructure (Power Cables, Electrical Distribution and Water Cooling)
4. HSE Inspection (Hydraulic and Electrical)
5. Power Converter and CDB IST | Energy Extraction System IST — *LHC-XMS-OP-0001*, *LHC-XMS-OP-0005*
6. Short Circuit Tests (with PICv2) — *LHC-XMS-OP-0003*

QC: Quality Control
IST: Individual System Tests

Finalized in 2023
Reported by in String Day III - link

- Interlock checks
- PIC loop checks
- Extraction discharges
- Heat-run tests at ultimate current (~7.5 TeV)

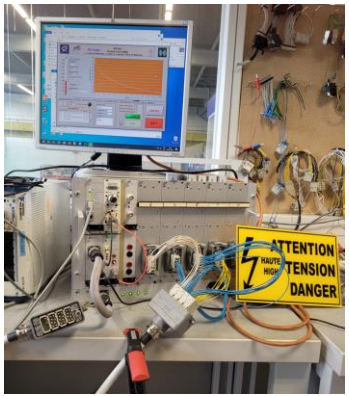
Highlight 1 - Electrical Tests on the QDS Cables

More information in talk of M. Bednarek

Scope:

- EDC specifies voltage withstand beyond "spec" value for chosen QDS and QH power supply cable types
- Strategy of producing samples with same team and testing them to pre-validate design and craftsmanship

Sample Cables and Test Setup:



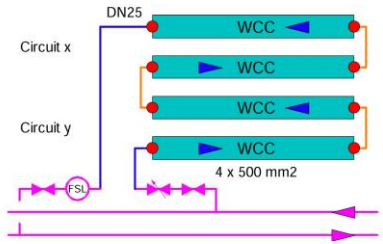
Test Results:

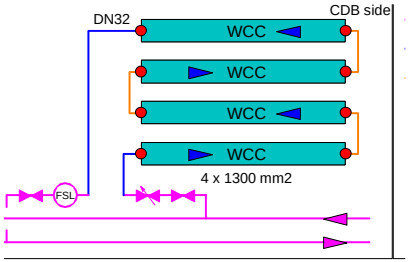
Cable identifier	Cable used	Connectors	Continuity	HV
P151 1-DPQ06	DRAKA CERN NE18 12W03	4x8 pin	OK	OK
P152 2-DPQ09	CERN 04.10.20.140.4 NG18 2019/10	4x2 pin	OK	OK
P143 3-DPC04	CERN 04.10.20.140.4 NE26 2022/10	4x8 pin	OK	OK
P144 4-DPC05	CERN 04.10.20.140.4 NE26 2022/10	2x12 pin	Not OK	OK
P145 5-DPC05	CERN 04.10.20.140.4 NE26 2022/10	2x12 pin	OK	OK*
P146 6-DPC06	DRAKA CERN NE36 14w05	3x12 pin	Not OK	OK
P147 7-DPC06	DRAKA CERN NE36 14w05	3x12 pin	Not OK	OK
P141 8-DPQ05	DRAKA CERN NE18 12w03	4x8 pin	OK	OK
P149 9-DPQ04	CERN 04.10.20.140.4 NE26 2022/10	4x6 pin	OK	OK
P150 10-DPQ13	DRAKA CERN NE48 19w07	4x12 pin	Not OK	OK
P145 11-DPQ08	DRAKA CERN NE18 12W03	4x8 pin	OK	OK*
P146 12-DPQ07	DRAKA CERN NE18 12W03	3x8 pin	OK	OK
P147-1 13-DPQ12	CERN 04.10.20.140.4 NE26 2022/10	4x8 pin	OK	OK
P147-2 14-DPQ03	CERN 04.10.20.140.4 NE26 2022/10	4x8 pin	Not OK	OK
P148-1 15-DPQ11	DRAKA CERN 12W03 NE18	3x8 pin	Not OK	OK
16	DRAKA CERN 12W03 NE18	3x8 pin	OK	OK
P143 17	DRAKA CERN NE36 14w05	4x8 pin	Not OK	OK
P143 18	DRAKA CERN NE36 14w05	4x8 pin	OK	OK
P143 19-DPQ10	DRAKA CERN NE36 13W41	4x8 pin	Not OK	OK*
P143 20	DRAKA CERN NE36 14w05	4x8 pin	Not OK	OK
P221 21-DPH04	CERN 04.10.10.571.6 2022. Black colour.	1x4 pin + 2x3 pin	OK	OK*
P221-1 22	CERN 04.10.10.571.6 2022. Black colour.	1x4 pin + 2x3 pin	OK	OK*
23-DPV12	DRAKA CERN NE36 13W41	1x32 pin	OK	-

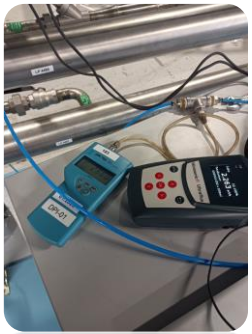
** Tests passed initially with a leakage current at a higher level than for other cables. Subsequent tests did not detect any weakness. Possibly the initial high leakage current was a result of humidity trapped in the cable insulation that dried out after some time.*

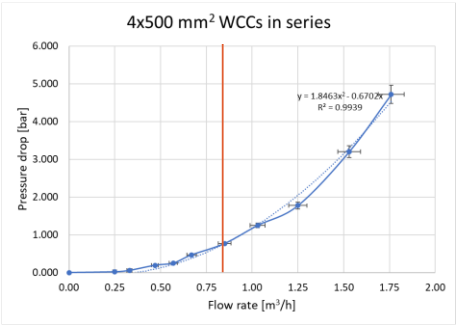
Continuity non-conformities are communicated and studied by EN-EL with answers given to the String team and soon to the HL-LHC project

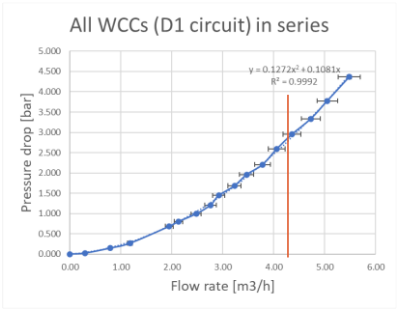
Highlight 2 – WCC Cooling Configuration











Courtesy of F. Dragoni – MCF no. 129

Configuration for HL-LHC proposed in ECR no. 2953127 is tested and confirmed for HL-LHC

Outcome of Warm Powering IST

- QC and IST of the warm powering systems (Power Converters, Energy Extraction Systems, DC Cables, Circuit Disconnector Boxes) and the connecting infrastructure has been successfully executed with sometimes more time than initially planned

- Design choices for HL-LHC are systematically validated and sometime adjusted, e.g. water connections on 2 kA PCs to reduce the pressure drop.

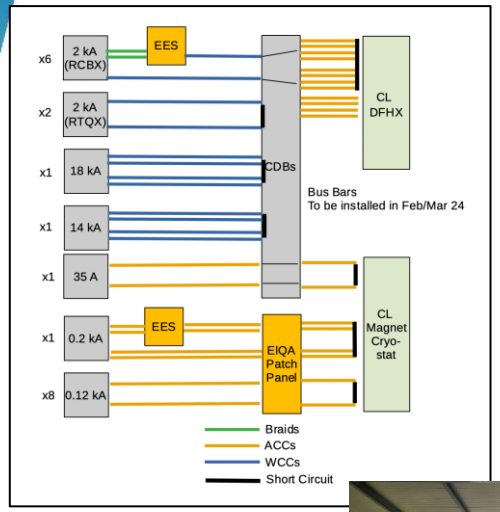
- Issue with cabling specifications (e.g. inverting function positions) identified and communicated to teams for corrective actions for the HL-LHC

Next Steps for Individual System Tests

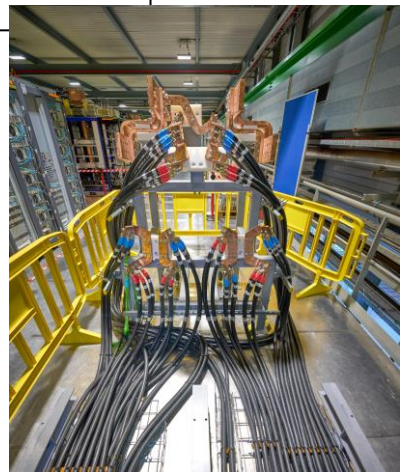
- Leak and Electrical tests on the SC link system are planned in two phases in 2024 (one before the DFX assembly and one after)
- Fully Remote Alignment System IST on the instrumentation will start as soon as the magnets magnets are installed, and the infrastructure is ready (few tests planned in 2024)
- 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
- Preparation of the procedure for the QDS and supervision system IST is ongoing with the main part of the tests done when magnets are cold (on critical path in the SVP)

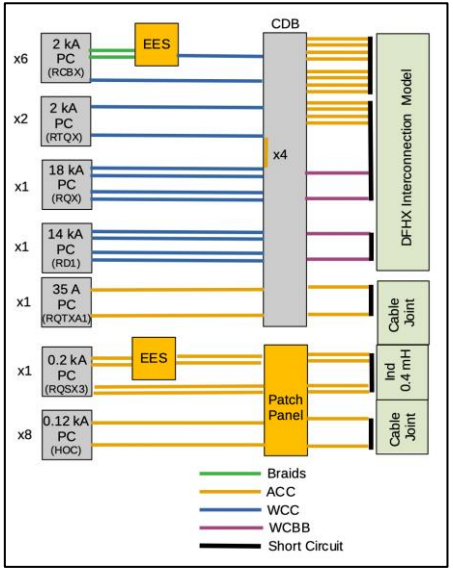
Short Circuit Tests

Short-Circuit Test Configuration

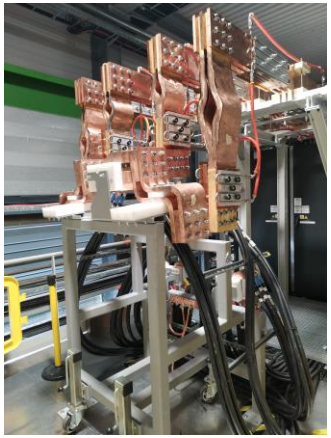


Phase 1 - Jan 2024



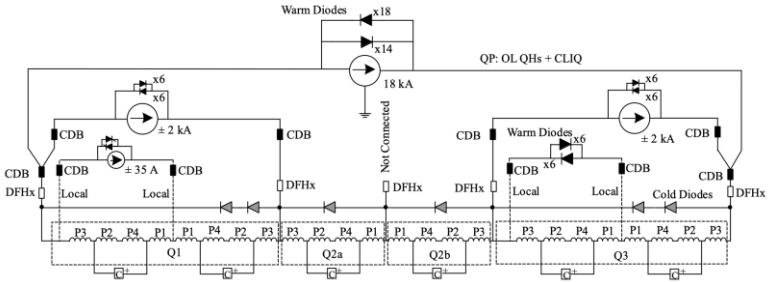


Phase 2 - May 2024

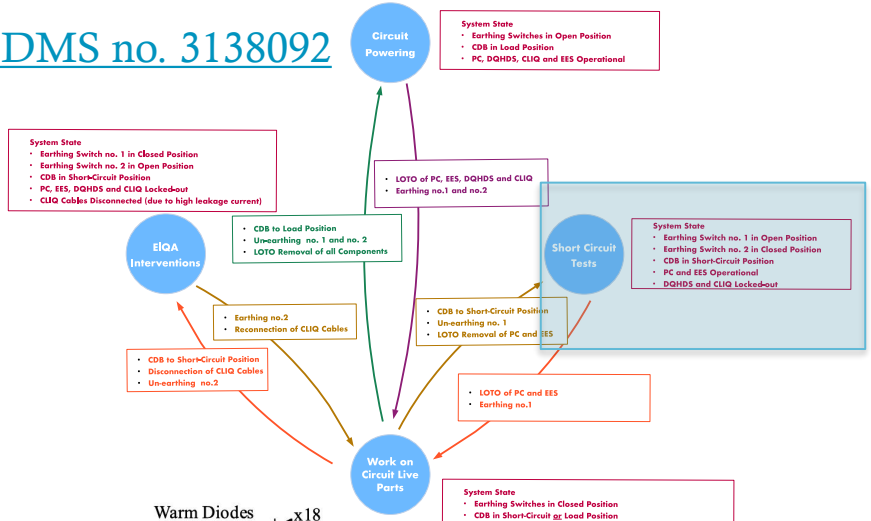


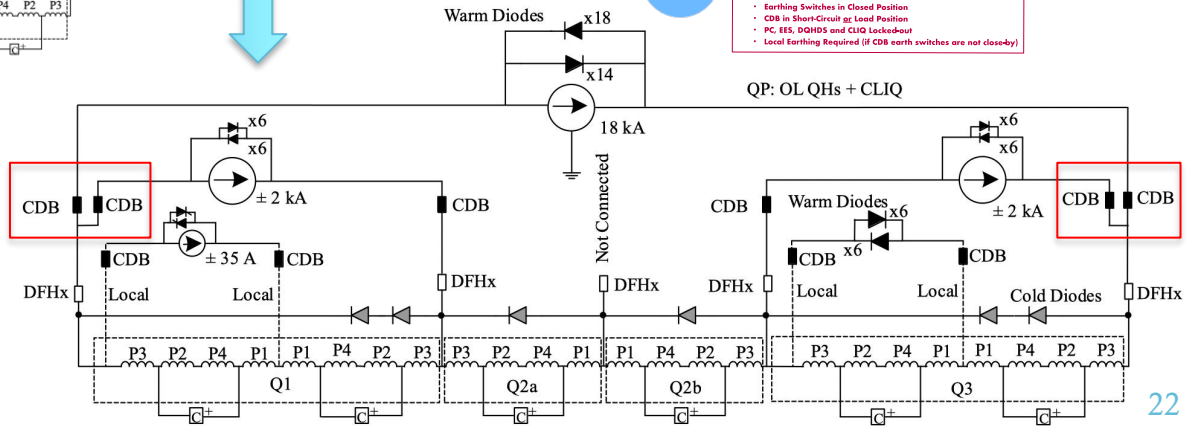
Highlight 1 - Update of the IT Circuit Configuration

- 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



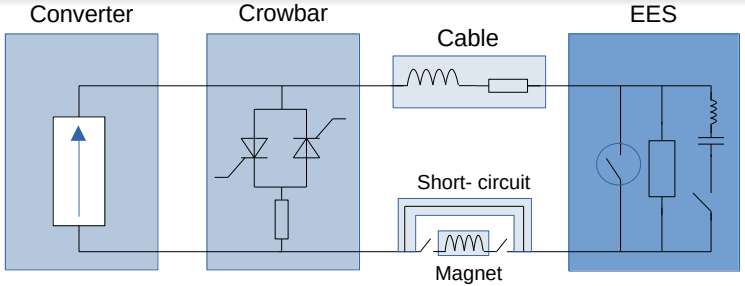
EDMS no. 3138092





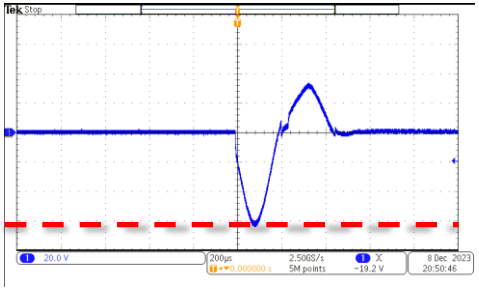
Highlight 2 - HL-LHC RQSX3 Discharges

EES discharge tests with SY-EPC and TE-MPE

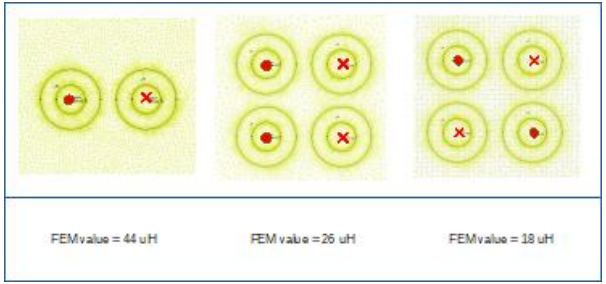


Accepted converter output voltage within ± 63 V

EES capacitor voltage for arc extinguishing up to 530 V



PC voltage vs. time
(case without additional inductance)

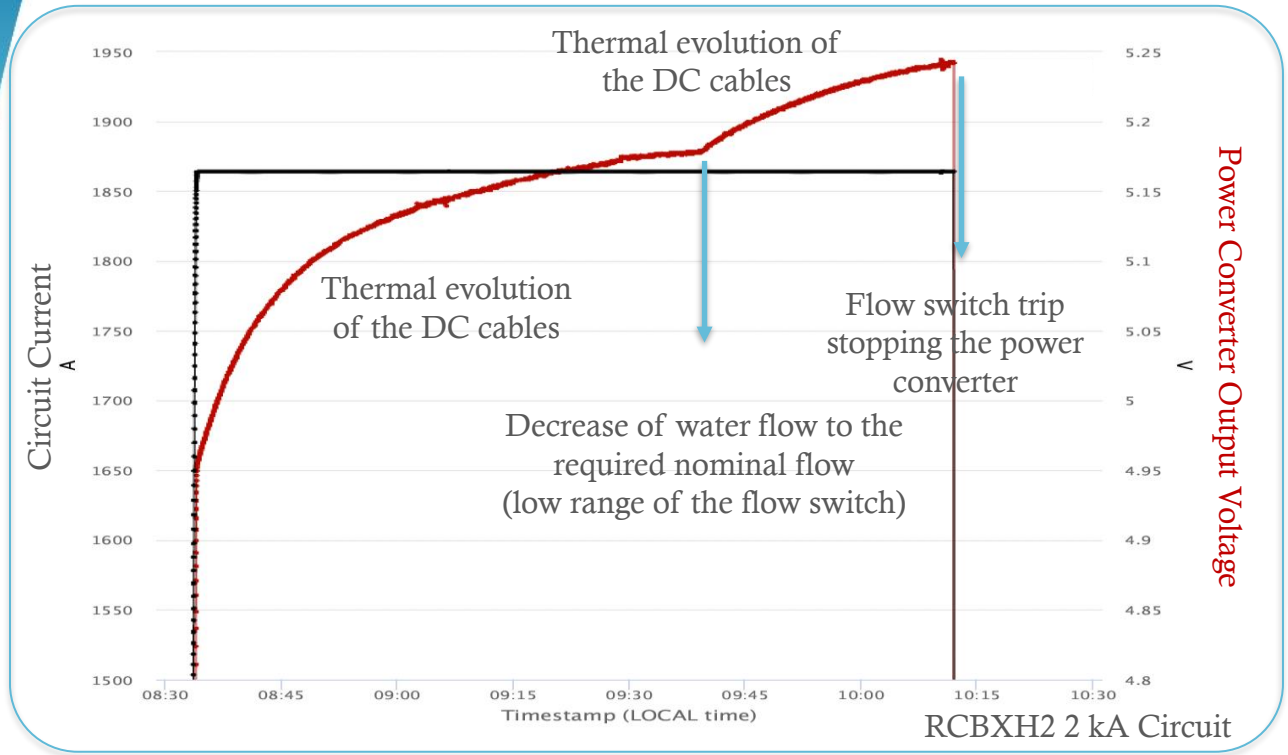


Estimation of cable inductance

0.4 mH Inductor added for the 200 A circuit

Courtesy of V. Raul Herrero and B. Panev – Follow-up of MCF no. 116 (link)

Highlight 3 – Trip on the FS during Heat Run

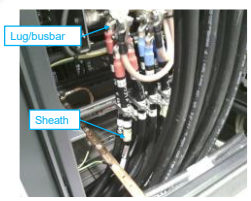


Non-conformity has been opened to adapt flow switch range to real needs (NCR no. 3025021)

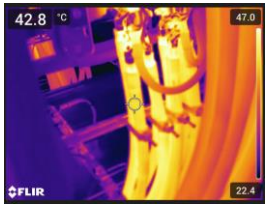
- **'Low-tech':** In projects focused on high-tech components, activities seen as 'low-tech' tend to receive less attention. The String offers an opportunity to address these 'low-tech' activities, acknowledging their importance.

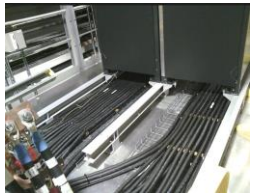
R. Schmidt, Close out and executive summary from the IT String Day '23, in 187th TCC

Highlight 4 - Thermal Performance of DC Cables

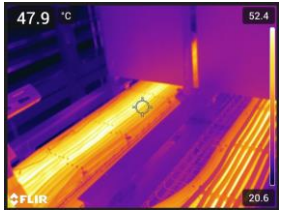


CDB Side





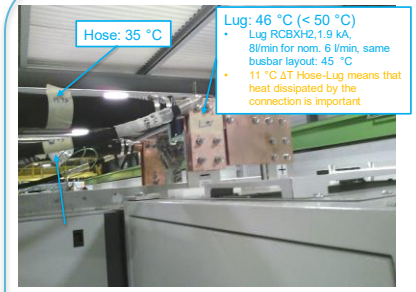
Cable ways between CDB and DFHX



Max Lug: 50°C
(Spec: < 90 °C)

Max Sheath: 55°C
(Spec: < 86 °C)

300 mm2 Air-Cooled Cables



RCBXH1 @ ~1.9 kA

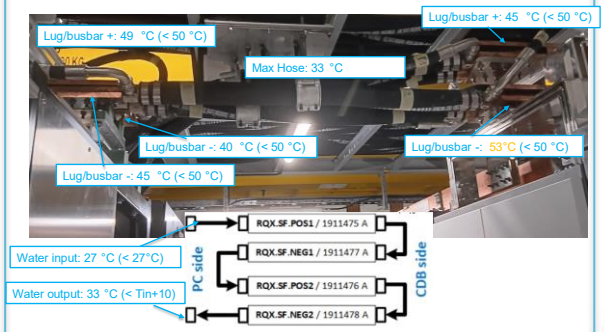
Power Converter Side (water output)

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

Lessons Learned from Warm Powering SCT

- "Low-Tech" issues and resolution are often the most time-consuming during tests, which proves the benefits of planning IST and SCT as soon as possible when equipment are ready
- Use of the DFHX current leads and short-circuit model has proved to be highly beneficial for routing the cables, pre-aligning the bus bars and for validating the full warm-powering systems
- Interfaces remain critical subjects that need often several iterations, and it is where a coordination team's functions are essential.
- Where interface documents are not written, mistakes are often found (e.g. 120 A PC position in rack and link to PIC). It is highly recommended to create interface documentation for a smooth implementation in the HL-LHC.

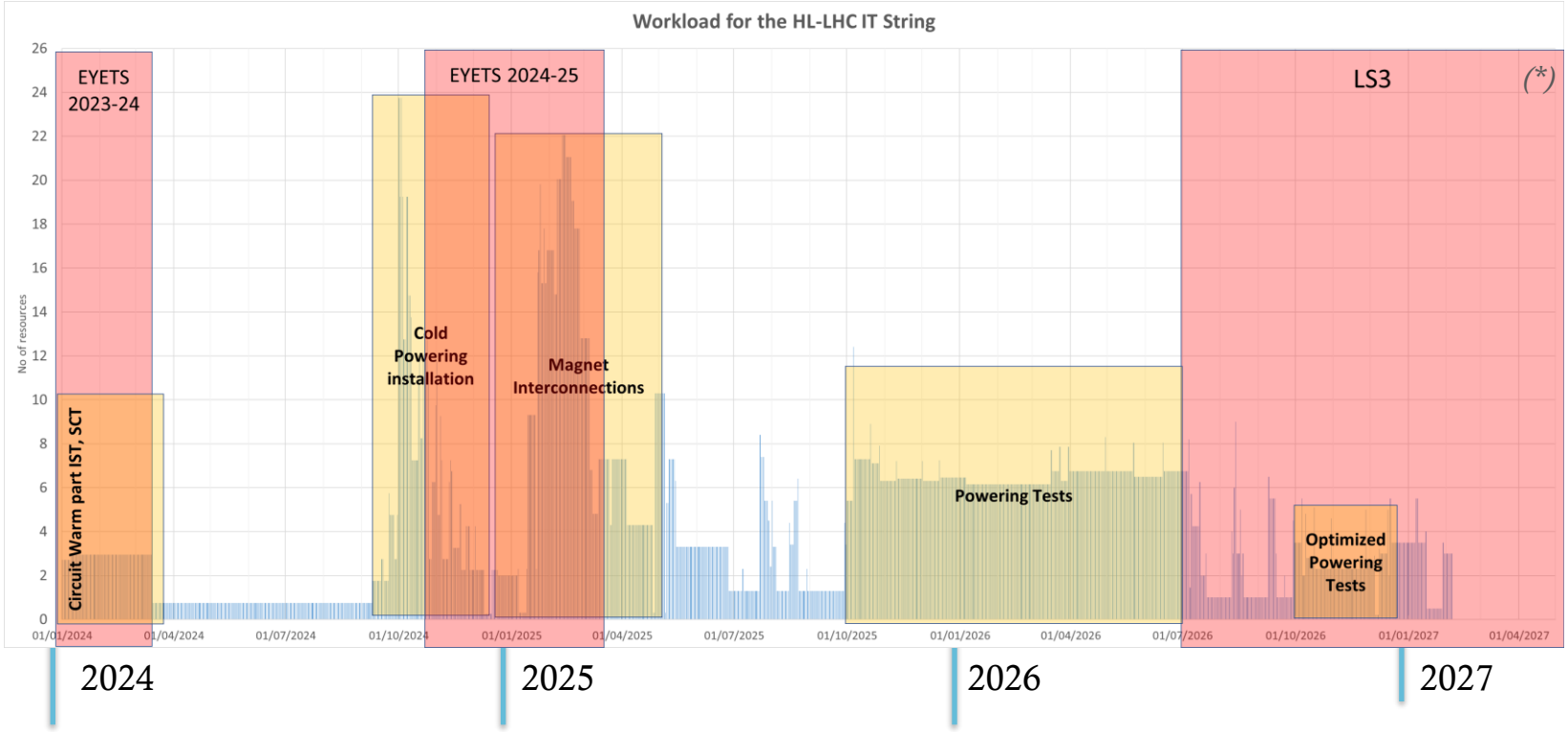
Powering Tests for the Hardware Commissioning in the HL-LHC IT String (and beyond)

Test Procedures for HL-LHC IT String and HL-LHC

Type	Test Procedure and Acceptance Criteria	EDMS no.	Doc. Status	Activity Status in String
HWC	ElQA Qualification of the Superconducting Circuits in the HL-LHC IT String	2746933	Draft Version	Start in Q4 24
HWC	Interlock Tests of the HL-LHC IT String Circuits	2797308	In preparation - planned for Q1 25	Start in Q4 25
HWC	Powering of the HL-LHC Inner Triplet (RQX)	2771115	In Preparation - planned for end of 24	Start in Q4 25
HWC	Powering of HL-LHC Separation Dipole (RD1)	2771114	Under Approval	Start in Q4 25
HWC	Powering of the HL-LHC IT Orbit Correctors (RCBX)	2771111	Under Approval	Start in Q4 25
HWC	Powering of the HL-LHC 200 A RQSX3 Circuit	2922509	Eng. Check	Start in Q4 25
HWC	Powering of the HL-LHC High Order Corrector (120 A) Circuits	2922510	Eng. Check	Start in Q4 25
HWC	Parameters for the HL-LHC Circuit Powering Tests	2771118	Eng. Check	Start in Q4 25
HWC	Parameters for the HL-LHC Quench Detection System	2920923	In Preparation - planned for Q1 25	Start in Q4 25

Collaborative work with Work Packages, MP3, HL-LHC Magnet Circuit Forum and String Validation Program members

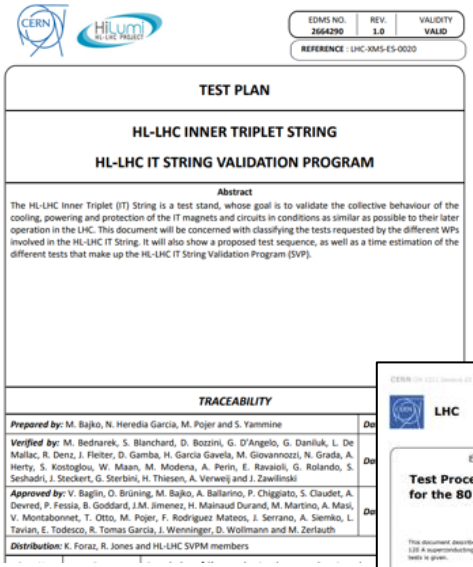
Activities of the HL-LHC IT String vs. LHC



(*) *Already anticipated LS3 shift to end of June 26 – HL-LHC CSR24 will refer to LS3 planning starting on Nov. 25*

From String Validation Program Phases to HL-LHC HWC

HL-LHC IT STRING Validation Program Document
(Goals and Methods)
LHC-XMS-ES-0020, EDMS no. 2664290


EDMS NO. 2664290 | REV. 1.0 | VALIDITY VALID
REFERENCE : LHC-XMS-ES-0020

TEST PLAN

HL-LHC INNER TRIPLET STRING

HL-LHC IT STRING VALIDATION PROGRAM

Abstract

The HL-LHC Inner Triplet (IT) String is a test stand, whose goal is to validate the collective behaviour of the cooling, powering and protection of the IT magnets and circuits in conditions as similar as possible to their later operation in the LHC. This document will be concerned with classifying the tests requested by the different WPs involved in the HL-LHC IT String. It will also show a proposed test sequence, as well as a time estimation of the different tests that make up the HL-LHC IT String Validation Program (SVP).

TRACEABILITY

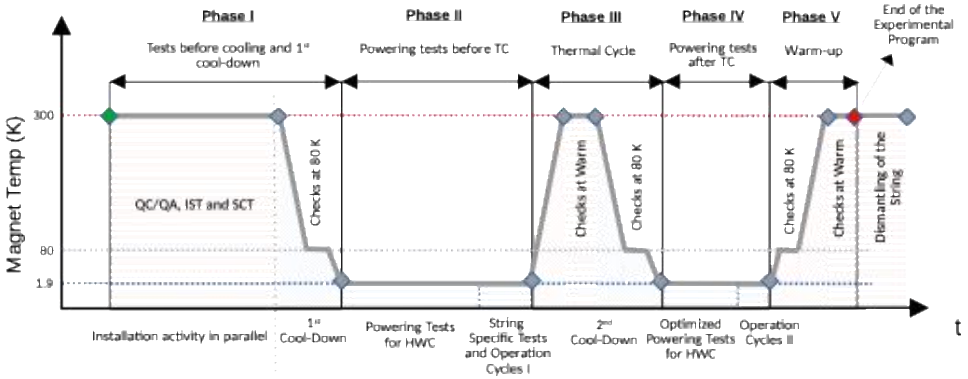
Prepared by: M. Bajko, N. Heredia Garcia, M. Pojer and S. Yammine

Verified by: M. Bednarek, S. Blanchard, D. Bozzini, G. D'Angelo, G. Daniluk, L. De Mallac, R. Denz, J. Fleiter, D. Gamba, H. Garcia Gavela, M. Giovannozzi, N. Grada, A. Herty, S. Kostoglou, W. Maan, M. Modena, A. Perin, E. Ravaioli, G. Rolando, S. Seshadri, J. Steckert, G. Sterbini, H. Thiesen, A. Verweij and J. Zawiliński

Approved by: V. Baglin, O. Brüning, M. Bajko, A. Ballarino, P. Chiggiato, S. Claudet, A. Devred, P. Fessia, B. Goddard, J.M. Jimenez, H. Mainaud Durand, M. Martino, A. Masi, V. Montabonnet, T. Otto, M. Pojer, F. Rodriguez Mateos, J. Serrano, A. Siemko, L. Tavian, E. Todesco, R. Tomas Garcia, J. Wenninger, D. Wollmann and M. Zerlauth

Distribution: K. Foraz, R. Jones and HL-LHC SVPM members


LHC
EDMS NO. 874722 | REV. 4.2 | VALIDITY DRAFT
REFERENCE LHC-MPP-HCP-0005
ENGINEERING SPECIFICATION
Test Procedure and Acceptance Criteria for the 80 A and 120 A Dipole Corrector Circuits



First implementations of the HL-LHC procedures fully inspired from LHC procedures of similar circuits and time for optimisation

LHC HWC Procedures


HARDWARE COMMISSIONING PROCEDURE

HL-LHC INNER TRIPLET STRING

TEST PROCEDURE AND ACCEPTANCE CRITERIA FOR THE 2 KA RCBX CORRECTOR CIRCUITS

Abstract

This document describes the test procedure and the acceptance parameter specification for the 2 kA RCBX superconducting circuits of the HL-LHC Inner Triplet (IT) String test facility. A list of the parameters to acquire during the tests is also detailed.

TRACEABILITY

Prepared by: S. Yammine on behalf of the MP3 — Date: 2022-11-11

Verified by: A. Antoine, B. Bordini, D. Bozzini, Z. Charifoulline, R. De Maria, R. Denz, J. Fleiter, V. Gahier, D. Gamba, M.A. Gallilee, J.C. Garnier, N. Heredia Garcia, V. Herrero Gonzalez, S. Le Naour, B. Panev, J.C. Perez, A. Perry, G. Rolando, M. Saffioti-Camilleri, J. Steckert and H. Thiesen, G. Willering, MP3 members, MCF members and SVPM members — Date: ZDYY-MM-DD

Approved by: M. Bajko, A. Ballarino, S. Claudet, P. Craievich, A. Devred, M. Martino, V. Montabonnet, Y. Papaphilippou, M. Pojer, F. Rodriguez Mateos, E. Todesco, R. Tomas Garcia, D. Wollmann, A. Verweij and M. Zerlauth — Date: ZDYY-MM-DD

Distribution: Standing members of MP3, MCF and SVPM

Rev. No.	Date	Description of Changes (major changes only)
0.1	2022-11-11	Draft version for engineering check

Final version of HL-LHC procedures ready for validate for the HL-LHC HWC

HL-LHC HWC Procedures

LS3 HL-LHC HWC

Powering of the HL-LHC IT Circuit in the String

Recommendation for String Day III to follow-up the String maximum commissioning currents

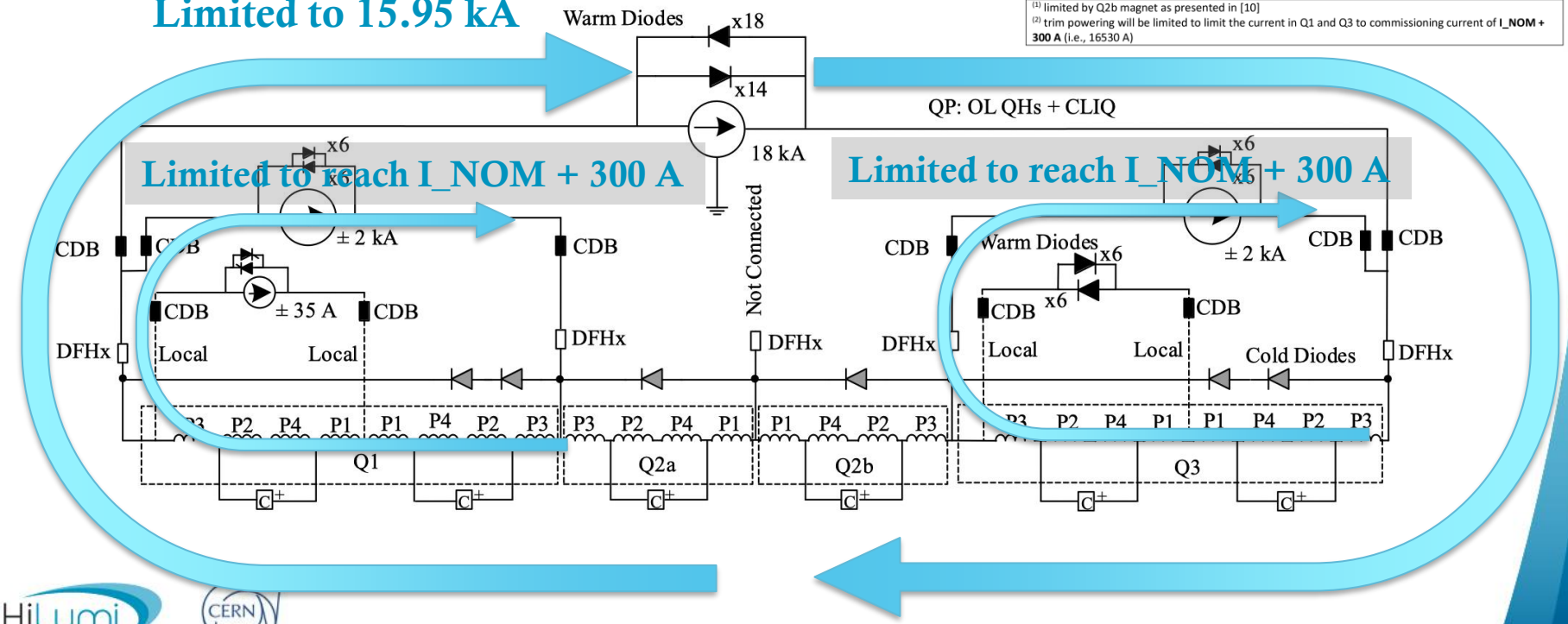
EDMS no. 2771118

Table 1: Powering test parameters for the Inner Triplet (RQX.SF) and D1 (RD1.SF) circuits

Circuit Name	Branch Name	I_PNO [A]	I_DELTA [A]	I_NOM [A]	I_ULT [A]	DIDT_PNO [A/s]	ACC_PNO [A/s²]
RQX.SF	RQX.SF	15950(1)	0	16230	17500	14.6	0.73
	RTQX1.SF	2000(2)	-	-	-	2.09	0.16
	RTQX3.SF	2000(2)	-	-	-	2.09	0.16
	RTQXA1.SF	35(2)	-	-	-	3.32	0.35
RD1.SF	NA	12110	100	12110	13231	12	2

(1) limited by Q2b magnet as presented in [10]
(2) trim powering will be limited to limit the current in Q1 and Q3 to commissioning current of **I_NOM + 300 A** (i.e., 16530 A)

Limited to 15.95 kA



More information on NC in talk of S. Le Naour

Ongoing Work on Powering Tests

- Main work is ongoing in collaboration between MCF, MP3 and SVPM to draft the test procedures and acceptance criteria documents with 4 out of 5 documents already launched on EDMS

- The test steps are being prepared to be integrated in AccTesting, HWC sequencer and the relevant controls infrastructure in line with the LHC (roadmap presented 32nd ATS Common Hardware & Software Technologies Technical Board (CTTB) meeting)

- Involvement of BE-OP confirmed to test powering and FRAS operation cycles foreseen in the LHC which led to transfer of few tests to after the Thermal Cycle to coincide with LS3 even with LS3 shift

Takeaway Message

- HL-LHC IT String Validation Program document (EDMS no. 2664290) has proven to be an essential document and a strong basis for the detailed discussions. WP16 considers that a similar approach for HL-LHC HWC is highly beneficial.

- 2023 and 2024 were eventful years for HWC and lessons learned from the HL-LHC IT String are systematically submitted to the concerned teams and are already resulting in some actions 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).

- Finalization of the procedures for the circuit powering is underway for tests in 2025-2026.

- Test procedures for the String IST, SCT and Powering Tests are considered an important cornerstone for HL-LHC hardware commissioning.

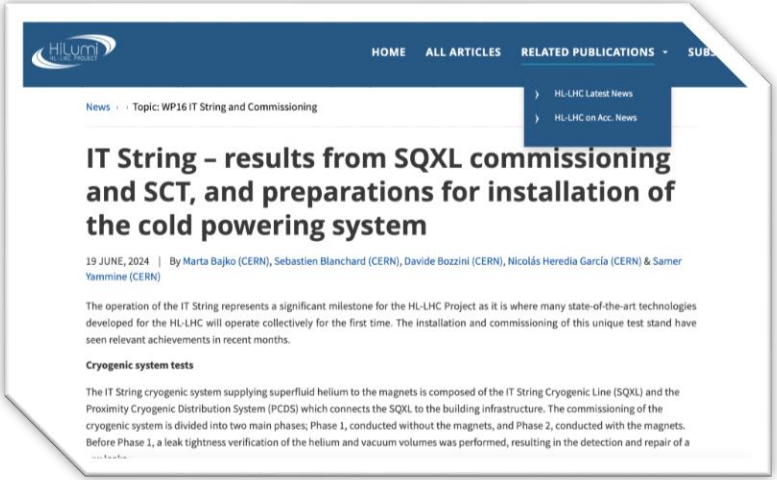
HL-LHC IT String advancements and challenges for 2024

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]



[HL-LHC Collaboration Board Newsletter]

And many more collaborators…

Thank you for your attention!