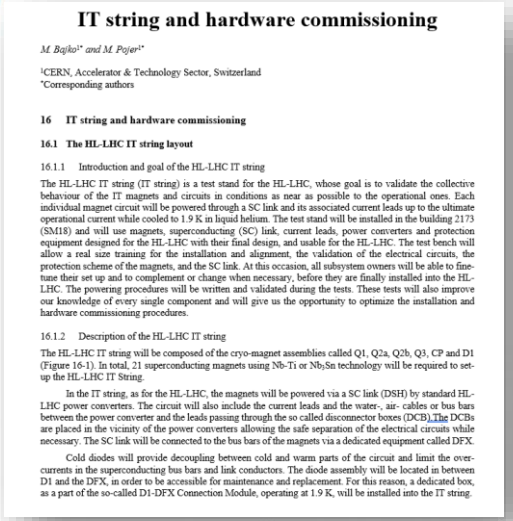

# HL-LHC IT String :Status and Perspectives

M. Bajko

TE-MPE-SF/HL-LHC WP16

On behalf of the WP16 team and the collaborators of 13 over the 20 WPS of HL-LHC and associated groups of CERN

# The IT STRING Scope



**IT string and hardware commissioning**

*M. Bajko[1]* and M. Pojer[1]**

[1]CERN, Accelerator & Technology Sector, Switzerland
*Corresponding authors

**16 IT string and hardware commissioning**

**16.1 The HL-LHC IT string layout**

16.1.1 Introduction and goal of the HL-LHC IT string

The HL-LHC IT string (IT string) is a test stand for the HL-LHC, whose goal is to validate the collective behaviour of the IT magnets and circuits in conditions as near as possible to the operational ones. Each individual magnet circuit will be powered through a SC link and its associated current leads up to the ultimate operational current while cooled to 1.9 K in liquid helium. The test stand will be installed in the building 2173 (SM18) and will use magnets, superconducting (SC) link, current leads, power converters and protection equipment designed for the HL-LHC with their final design, and usable for the HL-LHC. The test bench will allow a real size training for the installation and alignment, the validation of the electrical circuits, the protection scheme of the magnets, and the SC link. At this occasion, all subsystem owners will be able to fine-tune their set up and to complement or change when necessary, before they are finally installed into the HL-LHC. The powering procedures will be written and validated during the tests. These tests will also improve our knowledge of every single component and will give us the opportunity to optimize the installation and hardware commissioning procedures.

16.1.2 Description of the HL-LHC IT string

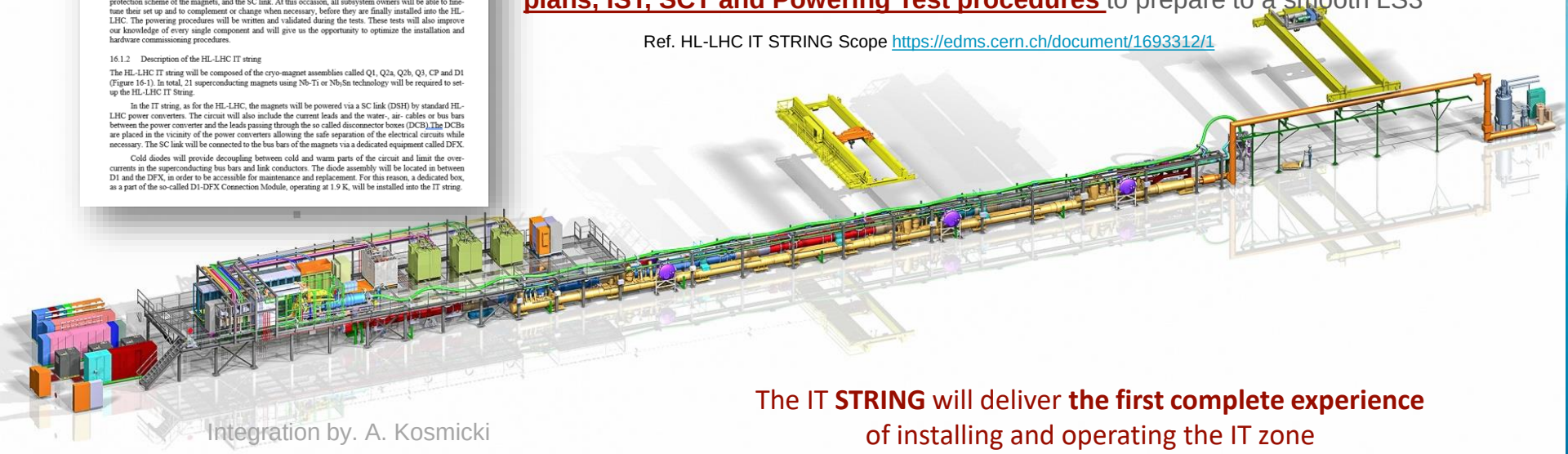
The HL-LHC IT string will be composed of the cryo-magnet assemblies called Q1, Q2a, Q2b, Q3, CP and D1 (Figure 16-1). In total, 21 superconducting magnets using Nb-Ti or $Nb_3Sn$ technology will be required to set-up the HL-LHC IT String.

In the IT string, as for the HL-LHC, the magnets will be powered via a SC link (DSH) by standard HL-LHC power converters. The circuit will also include the current leads and the water-, air- cables or bus bars between the power converter and the leads passing through the so called disconnector boxes (DCB). The DCBs are placed in the vicinity of the power converters allowing the safe separation of the electrical circuits while necessary. The SC link will be connected to the bus bars of the magnets via a dedicated equipment called DFX.

Cold diodes will provide decoupling between cold and warm parts of the circuit and limit the over-currents in the superconducting bus bars and link conductors. The diode assembly will be located in between D1 and the DFX, in order to be accessible for maintenance and replacement. For this reason, a dedicated box, as a part of the so-called D1-DFX Connection Module, operating at 1.9 K, will be installed into the IT string.

The ***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 (magnets, magnet protection, cryogenics of the magnets andof the superconducting link, magnet powering, vacuum, alignment, interconnections between magnets, and the superconducting link itself). Another key motivation is to test and optimize the **QC plans, IST, SCT and Powering Test procedures** to prepare to a smooth LS3

Ref. HL-LHC IT STRING Scope https://edms.cern.ch/document/1693312/1



Integration by. A. Kosmicki

The IT **STRING** will deliver **the first complete experience** of installing and operating the IT zone

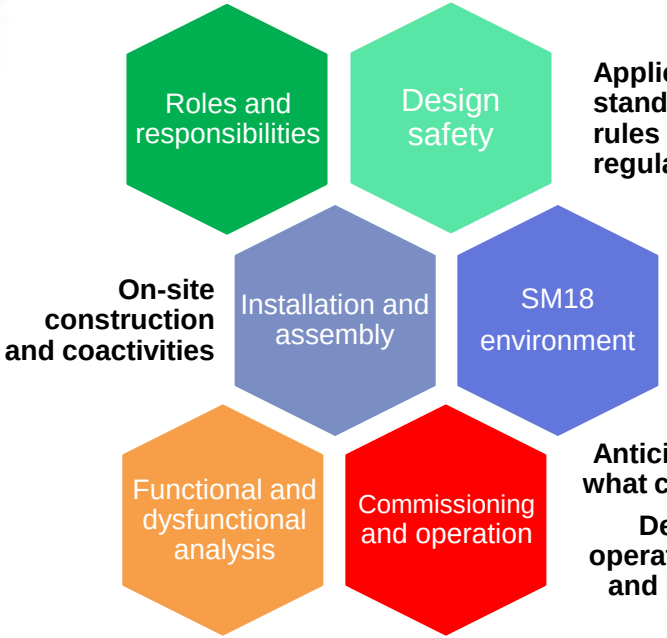
# OUTLINE

- STATUS
  - STRING Safety
  - STRING Installation
  - STRING Validation Program
  - Software and Control
  - Lessons Learned
- SCHEDULE AND RESOURCES VS LS3
- NEXT STEPS
- SUMMARY

# HL-LHC IT STRING SAFETY

See Presentation of D. Bozzini, Room 4L Wednesday 9h40 WP16 session:
“Safe intervention during operation on the electrical circuits of the IT String”

# IT STRING – SAFETY




**Applicable standards, norms, rules and regulations**

**On-site construction and coactivities**

**Anticipate/identify what can go wrong.**

**Define safe operational modes and procedures**

- Sc-Link installation
- Control cabling
- CLIQ racks installation
- JACKS installation

- Assembly of DFX
- Assembly of DFHX proximity equipment

Design / integration

Construction and Installation

Assembly

System tests, commissioning Operation

- SQXL commissioning
- Power converters IST
- Warm powering short circuit tests

Dismantling

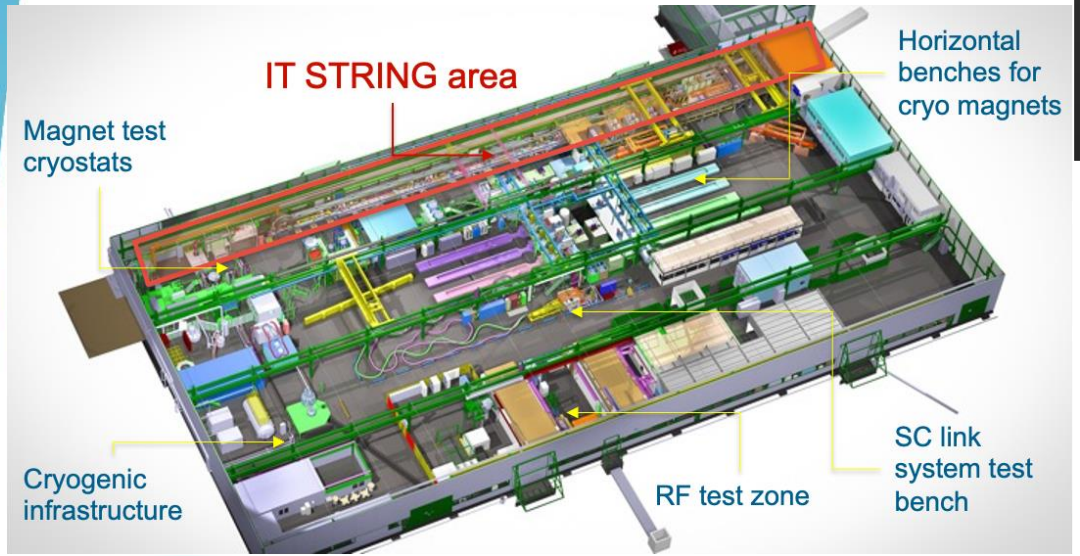
# IT STRING – Increasing ACTIVITIES

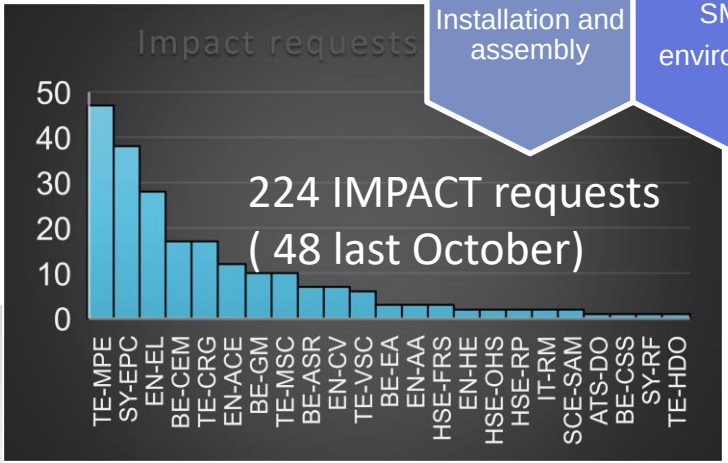
Installation and assembly

SM18 environment

**8** Departments,

**23** Groups involved in-situ



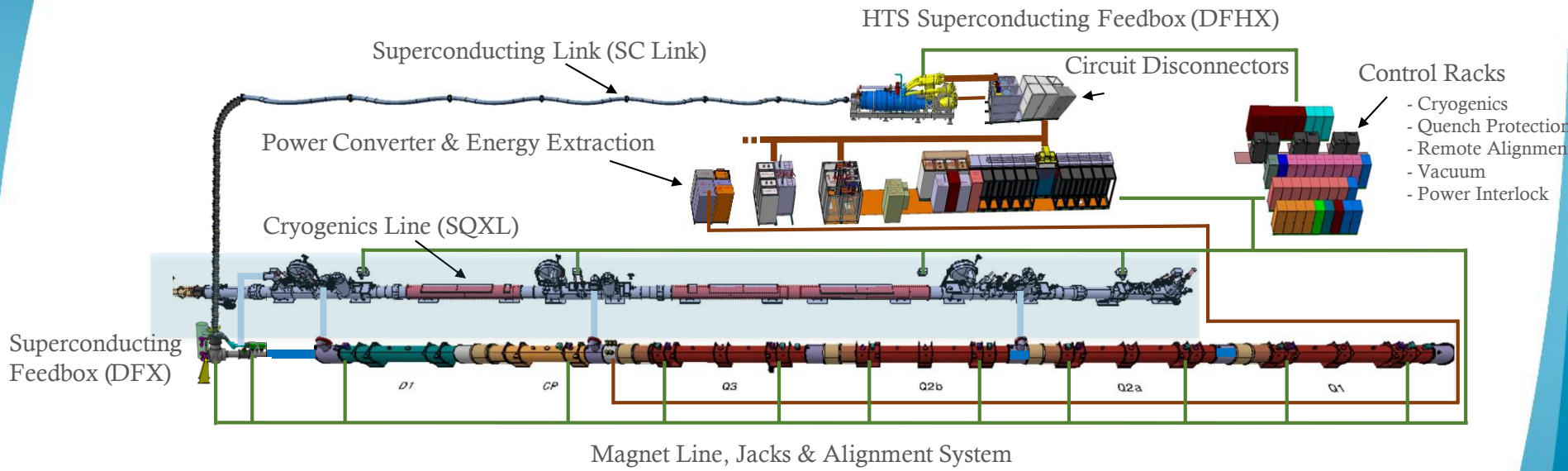

High degree of adherence to IMPACT tool which contributes to a smooth coordination of multi-disciplinary activities.

**YOU ARE WELCOME TO VISIT US!**

Instructions for visits are in EDMS 3072722

# HL-LHC IT STRING INSTALLATION

# STATUS of the CRYOGENIC INFRASTRUCTURE




See Presentation of V. Gahier, Tuesday 12h30 Plenary session:
"Cryogenics: status and perspectives towards installation"

# CRYOGENIC EQUIPMENT

TE-CRG (WP9) and TE-VSC

PCDS, SQXL and associated CONTROL installation including the Cold Compressor and he GMS for the DFHX all **COMPLETED**

Warm Quench Buffer

TL05

SQXL

Gas management DFHX

2 x 15 kW heaters

Gas management panel

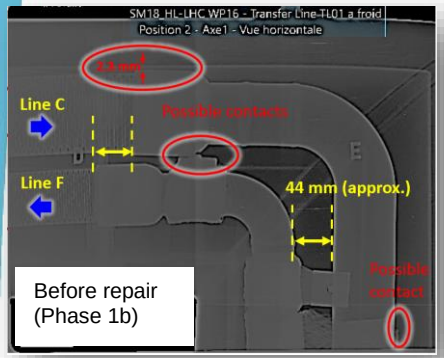
by. A. Onufrena

# CRYOGENIC EQUIPMENT COMMISIONING

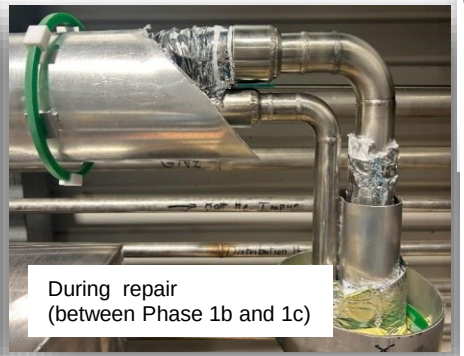
**Phase 1a:** Mechanical integrity validation during controlled cooldown (2023)

## Phase 1b

Thermal performance validation: 6 g/s (cold powering) + 300 W at 1.8 K (magnet cooling) → allows to operate the magnets; Heat loads on TL01 was 10-20 W higher than expected ; Cold compressor (CCU): Repairs performed and validated while the planned logic demonstrated lack of maturity (2024)

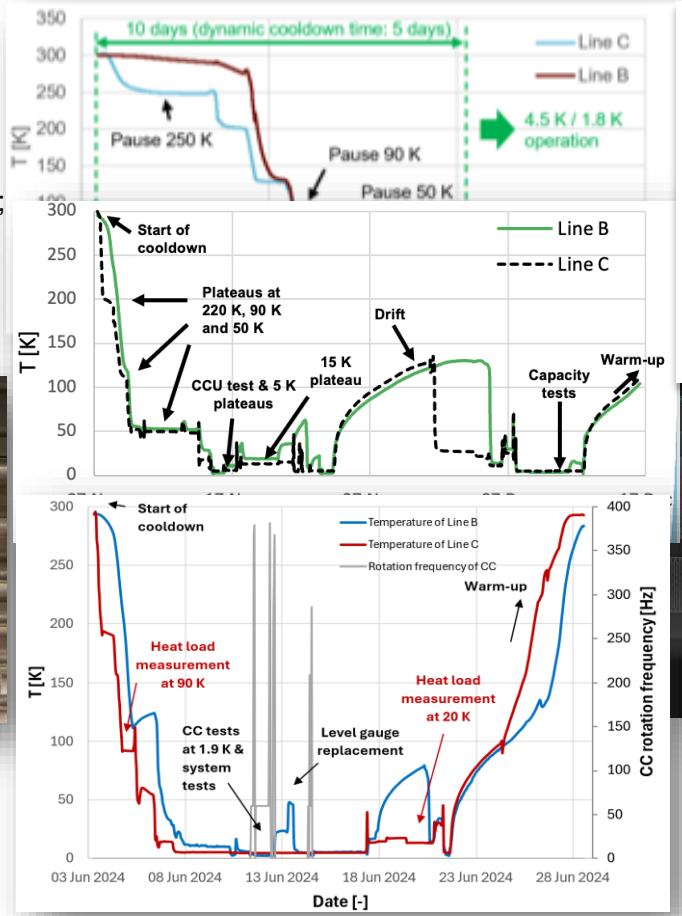


Before repair (Phase 1b)

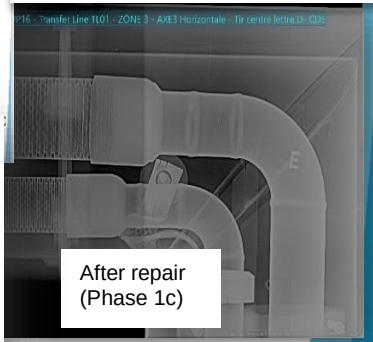

During repair (between Phase 1b and 1c)

## Phase 1c

CCU control logic validation; Thermal characterisation of the system (TL01 repair validation); Further heat load and system cooling capacity assessment (2024)

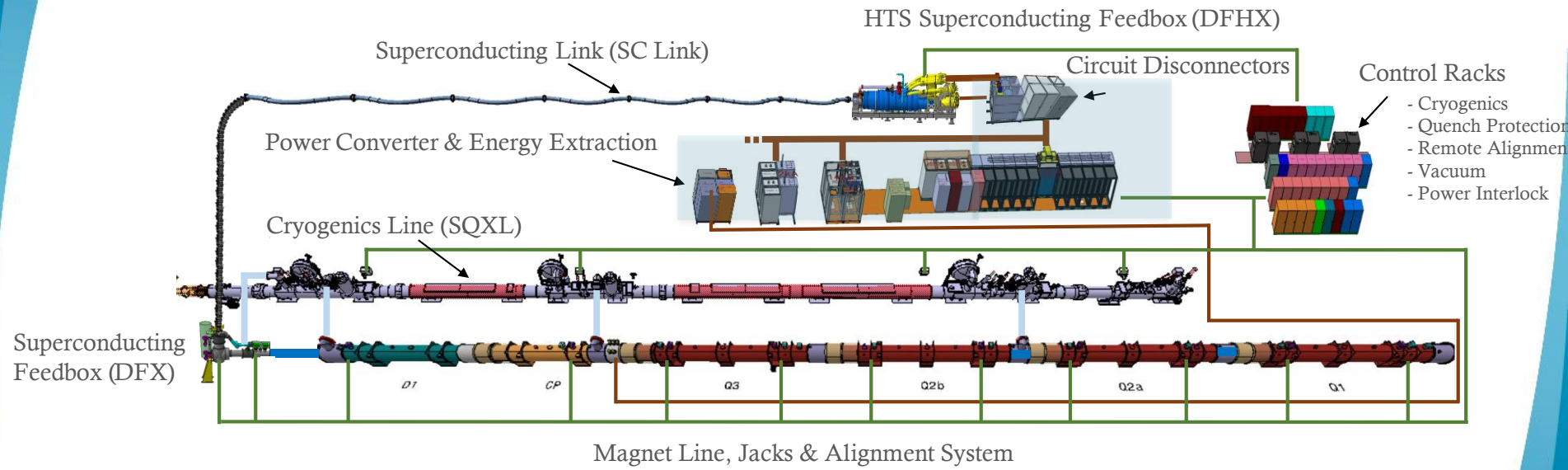



The cryogenic system has a sufficient cooling capacity to keep the magnets at 1.9 K → system has been validated for the IT String operation


After repair (Phase 1c)

by. A. Onufrena

# WARM POWERING SHORT CIRCUIT TEST




See Presentation of M. Martino. Tuesday 14h40
Plenary session: “WP6B outlook in IT String operation “

# THE IT STRING: an ELECTRICAL INSTALLATION

AC network, WCC, ACC, CDB, PC, EE, PIC, WC all in COMPLI

## HSE Inspection

IAD ELEC N° 050 2023

Vérification initiale des installations électriques permanentes , effectuée dans le cadre des articles R.4226-14 et R.4226-15 du
Mise à disposition de photographies des observations

CERN
2173
SM18: HALL D'ASSEMBLAGE DES AIMANTS
SE18
01630 PREVESSIN

2173
_LH-LHC IT-STRING_

CERN
FINANCE AND ADMINISTRATIVE PROCESSES D
Accounts Payable/Bureau des factures
(4-3-017)
1211 GENEVE 23
SUISSE

CERN
2173
SM18: HALL D'ASSEMBLAGE DES AIMANTS
SE18
01630 PREVESSIN

16/11/2023

LEULLIETTE DAVID

Schéma E36784302301R001

Observation(s) constatée(s)

19/11/2023

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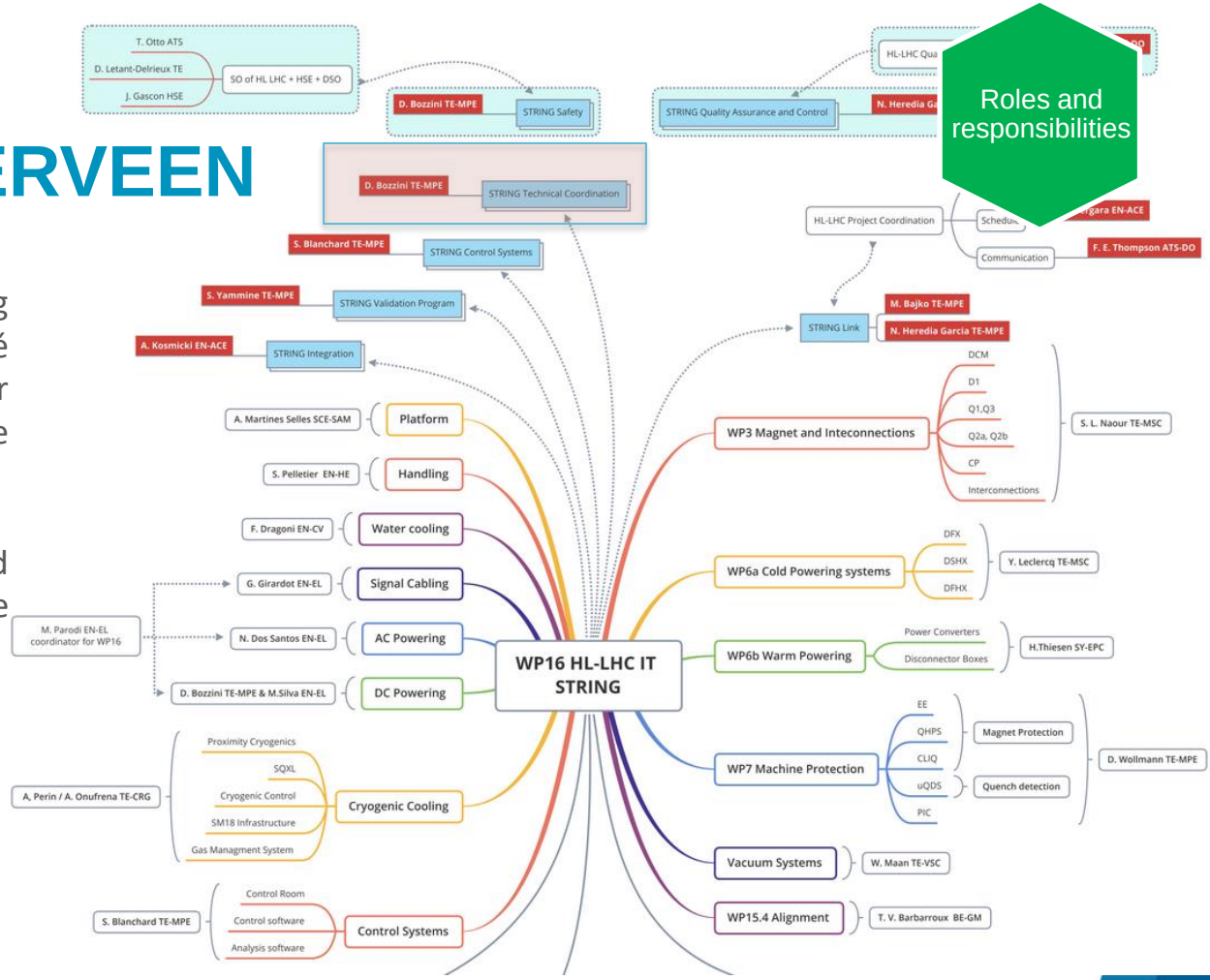
EDMS no. 3006292

W6b, WP7, WP16
( EN-EL, EN-CV)

# WHO CAN INTERVEEN

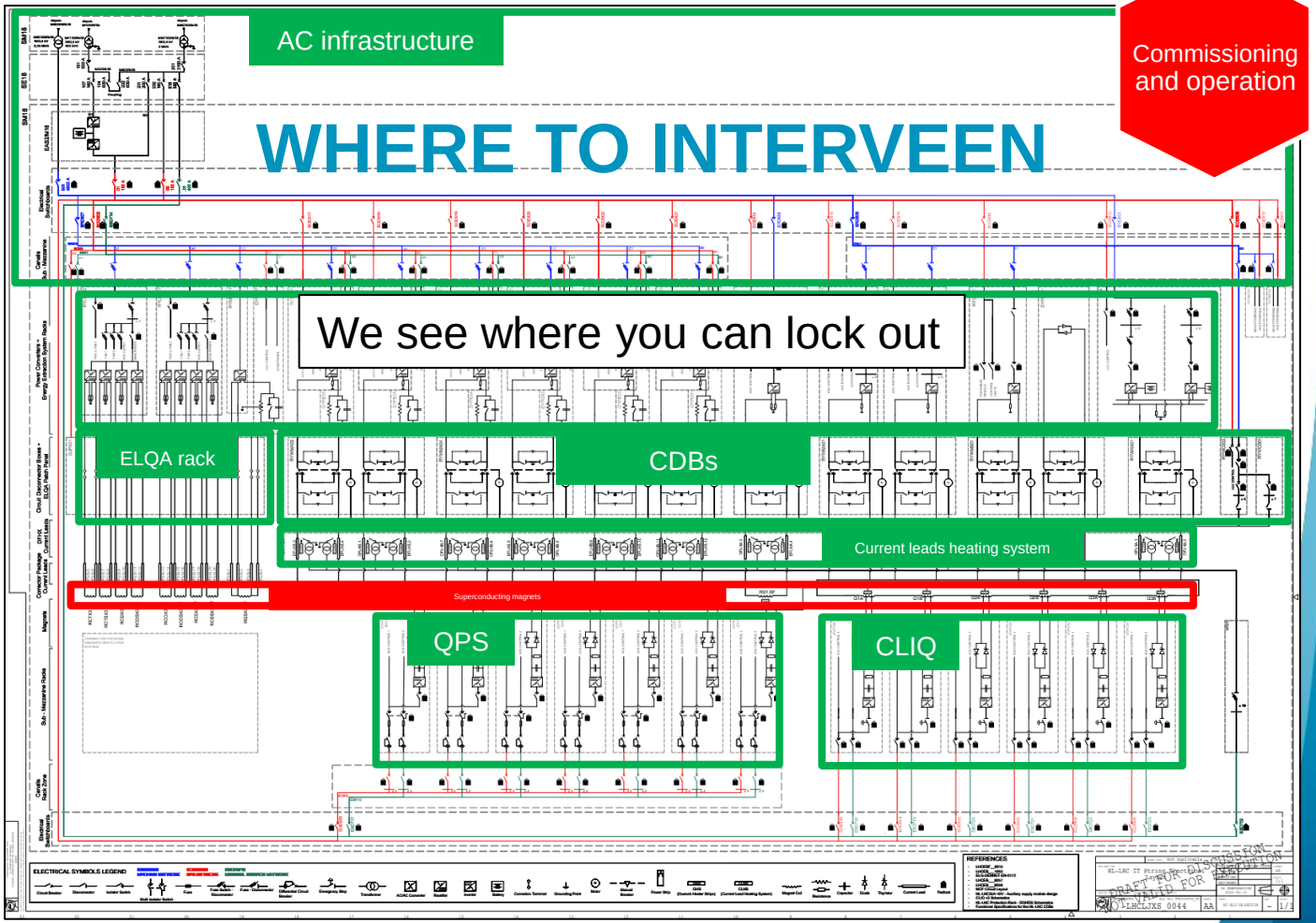
As from January 2024 the IT String implemented the role of ‘’chargé exploitation’’ – technical coordinator with a mandate to prepare and manage the totality of the interventions.

The role has been described and mandate given to D. Bozzini ( S. Yammine in case of absence).



Commissioning and operation

# WHERE TO INTERVEEN




**Since January 2024**

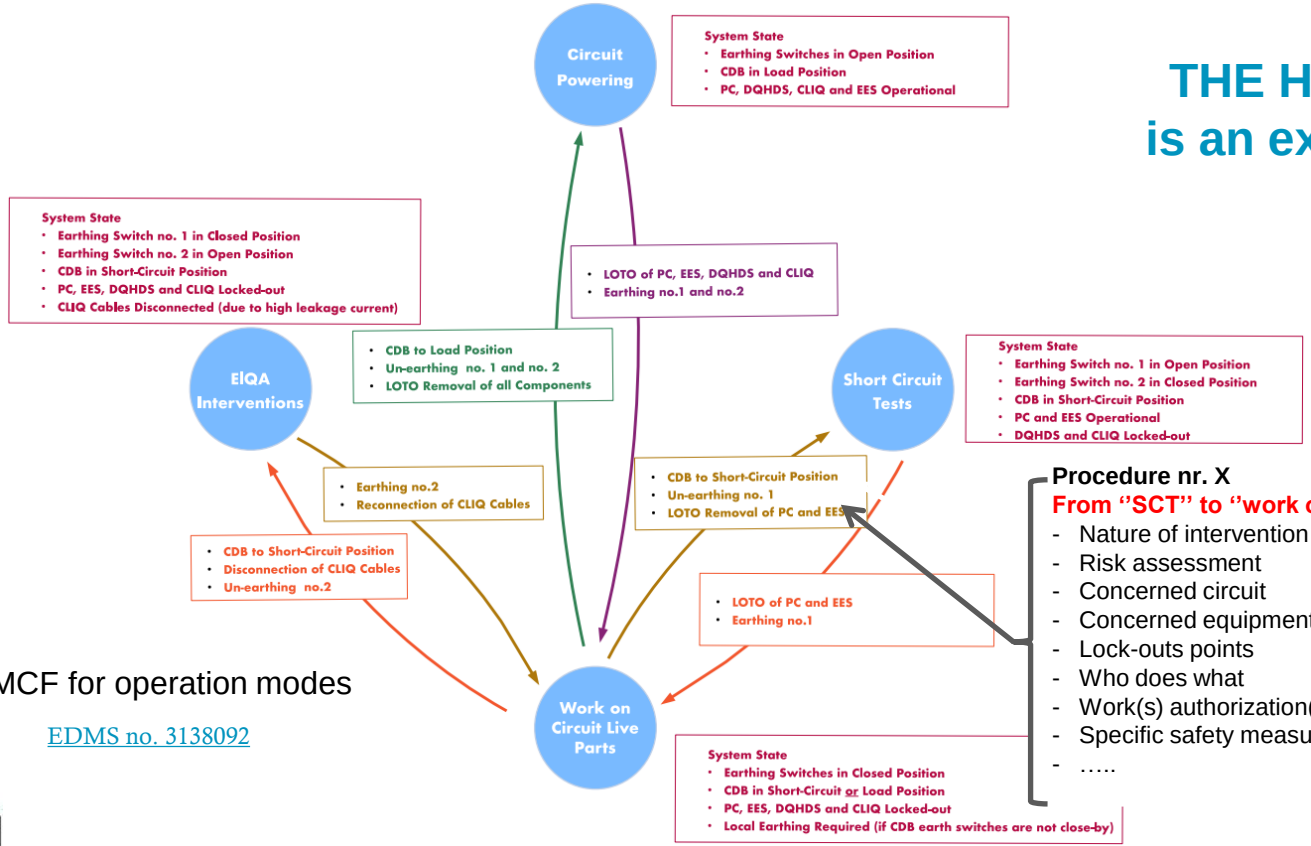
- 18 lock-out requests
- 21 work permits
- 5 electrical separation of networks

**According to NF C 18 510**

# HOW TO SWITCH OPERATIONAL MODES

Commissioning and operation

## THE HL-LHC IT STRING is an example for the ESP

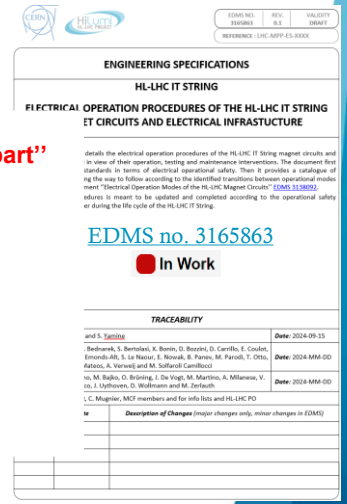



**Procedure nr. X**

**From ''SCT'' to ''work on circuit live part''**

- Nature of intervention
- Risk assessment
- Concerned circuit
- Concerned equipment
- Lock-outs points
- Who does what
- Work(s) authorization(s)
- Specific safety measures
- …..

specified procedures for IT String by D. Bozzini, S. Yammine


ENGINEERING SPECIFICATIONS

HL-LHC IT STRING

ELECTRICAL OPERATION PROCEDURES OF THE HL-LHC IT STRING ET CIRCUITS AND ELECTRICAL INFRASTUCTURE

EDMS no. 3165863

In Work

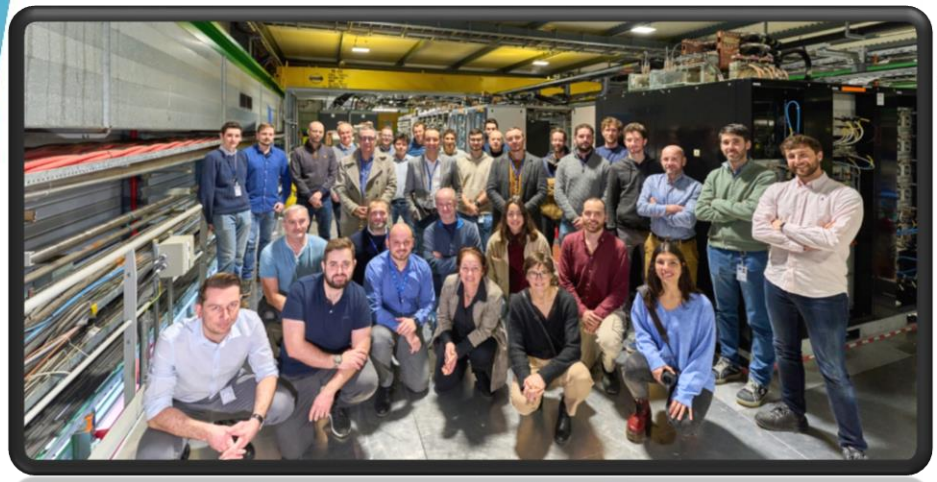
TRACEABILITY

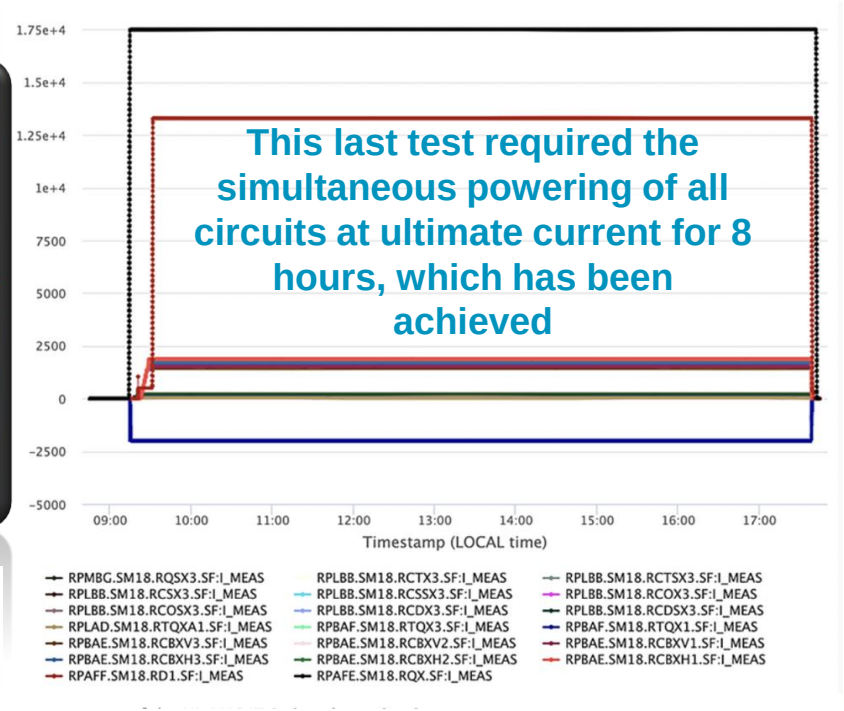
MCF for operation modes

EDMS no. 3138092

# SHORT CIRCUIT TEST (SCT)

The steps executed during short-circuit tests included the validation of interlocks, the tuning of control loops, the discharge of the energy extraction system and power converter, and the 8-hour heat run test for thermal validation.

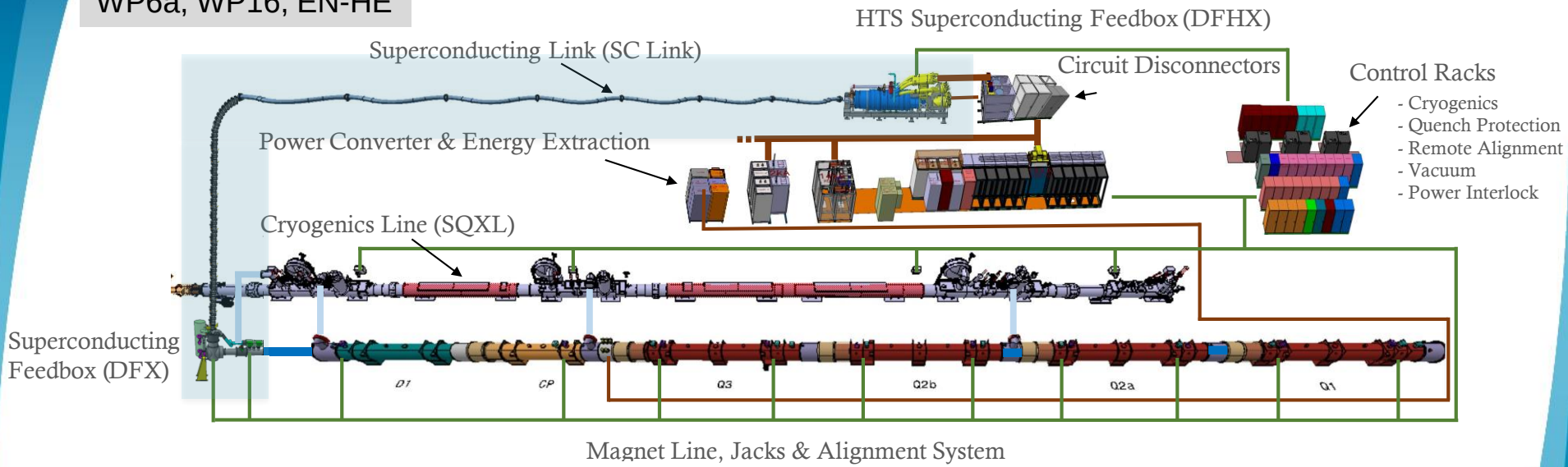


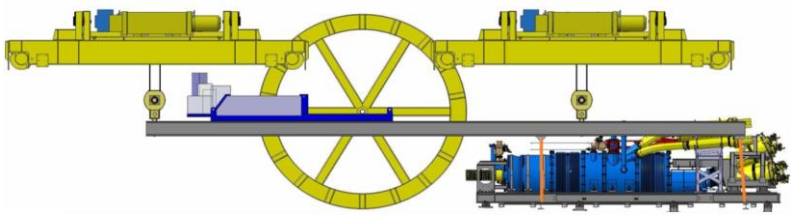



See Presentation of S. Yammine, Room 4L Wednesday 11h30
WP16 session: “IST and SCT in the IT String: results ”

# STATUS of COLD POWERING

WP6a, WP16, EN-HE

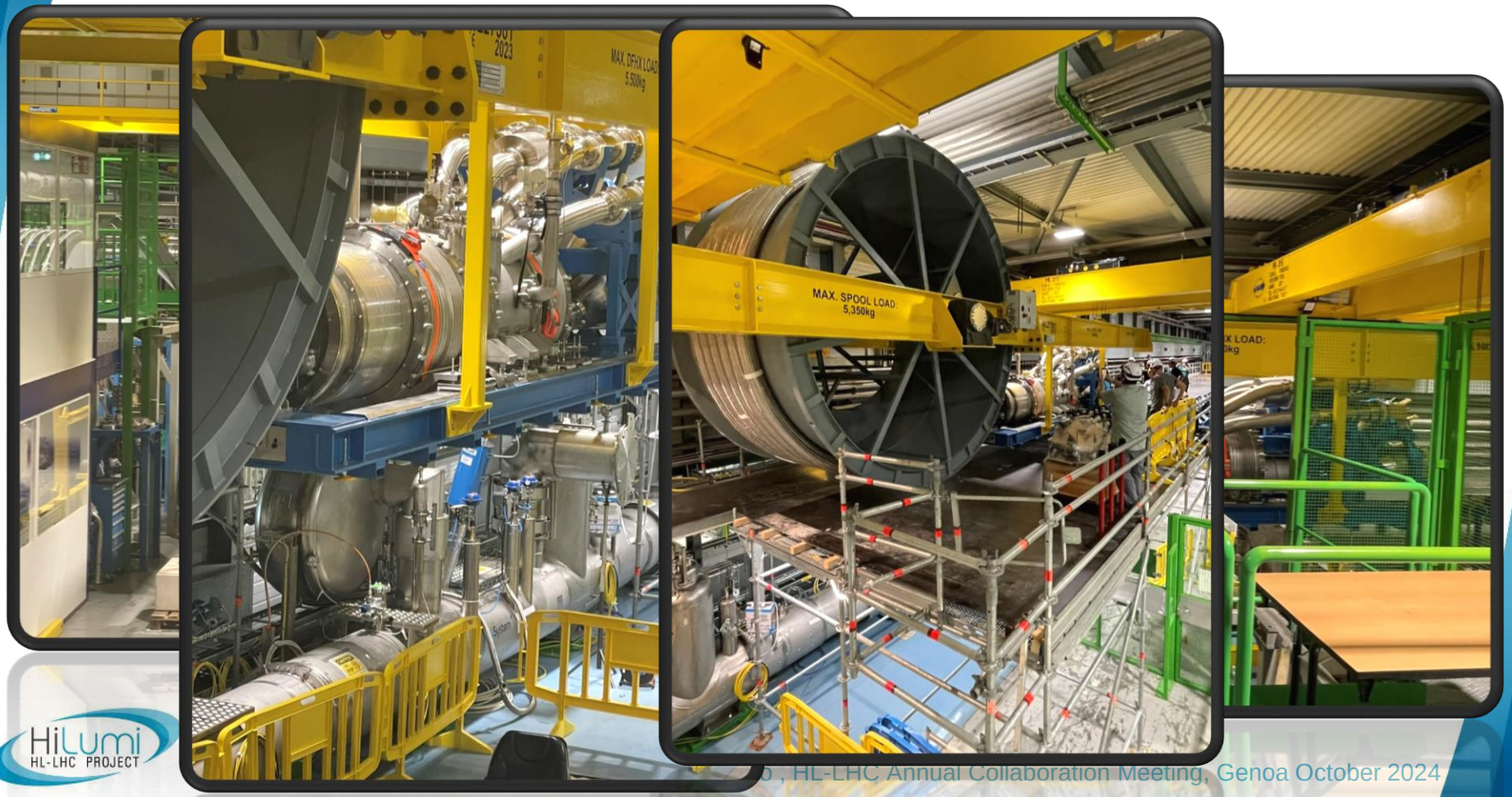


[…] unique set of challenges, primarily centered around the handling of the SC link connected to the DFHX and its positioning on the platform.

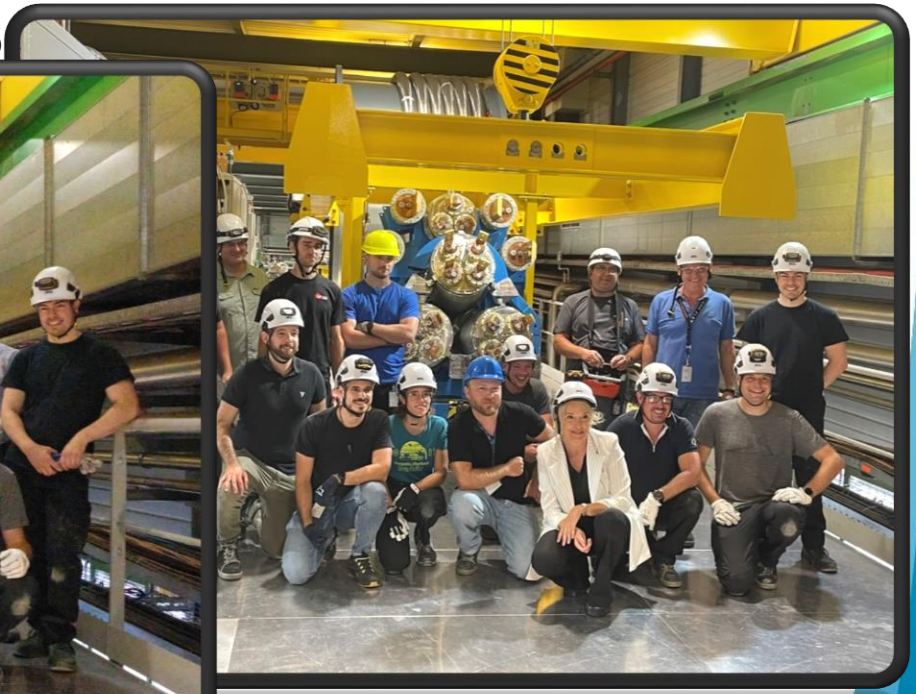
See Presentation of Y. Leclerc, Room 4L Wednesday10h
WP16 session: “Sc link Installation into the IT String”

# Sc Link INSTALLATION IN THE IT STRING



# COLLABORATIVE EFFORTS of WP16, WP6a with the key actors of EN-HH

With modest, but key participation of WP16

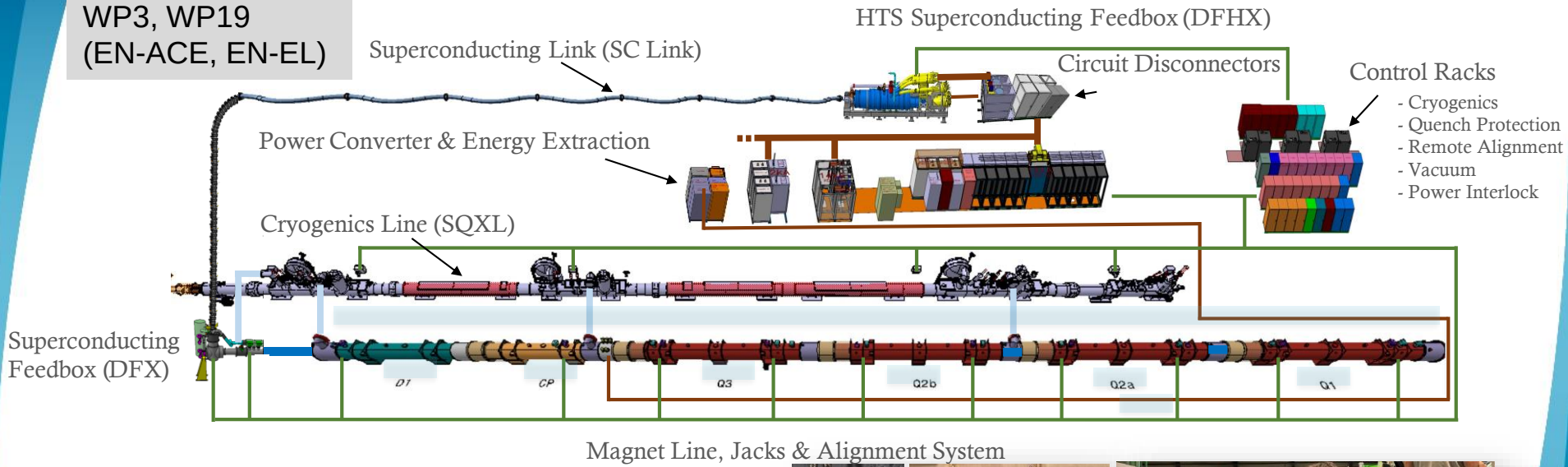


An extraordinary milestone of the WP6a team

See Presentation of A. Ballarino, Tuesday 14h Plenary session:
“Qualification of the first Cold Powering System for the HL-LHC triplets “

# STATUS of ALIGNMENT EQUIPMENT

WP3, WP19
(EN-ACE, EN-EL)



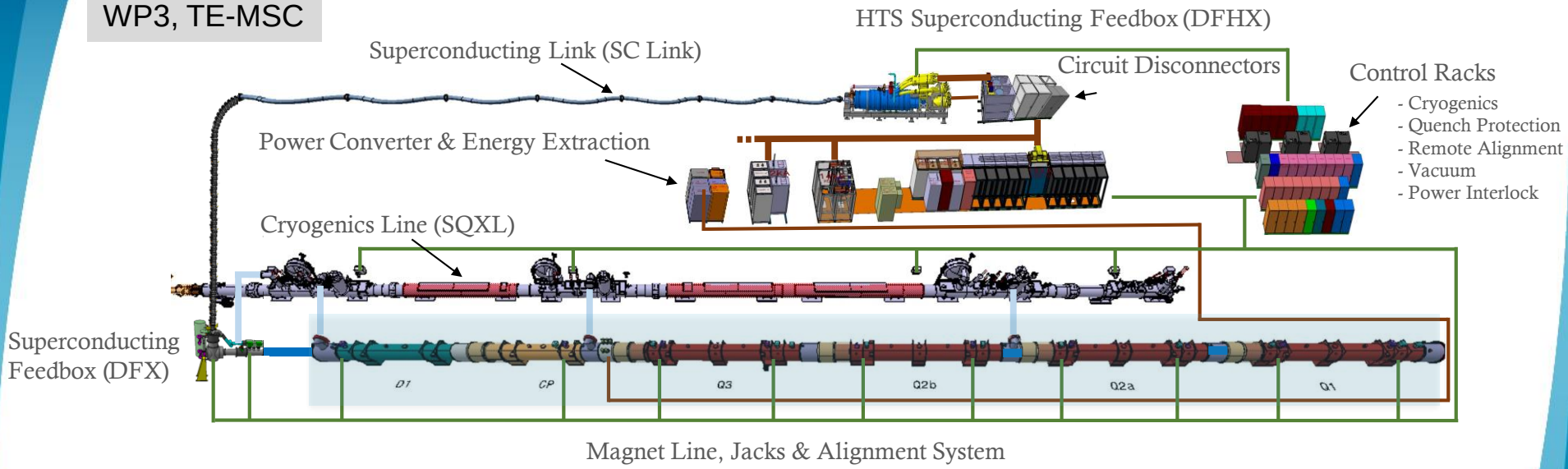

Installation started with the

A. Jack's positioning
B. WPS cable (WP19)
C. FRAS (OF deployment)

See presentation of WP2/3/19 Thursday at 11h in DAD.

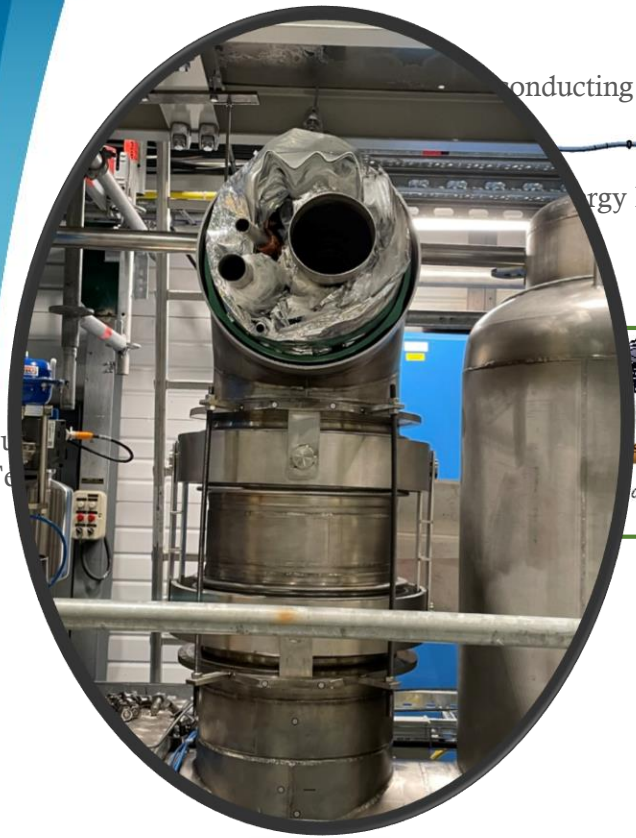
# STATUS of CRYO COLD MAGNETs

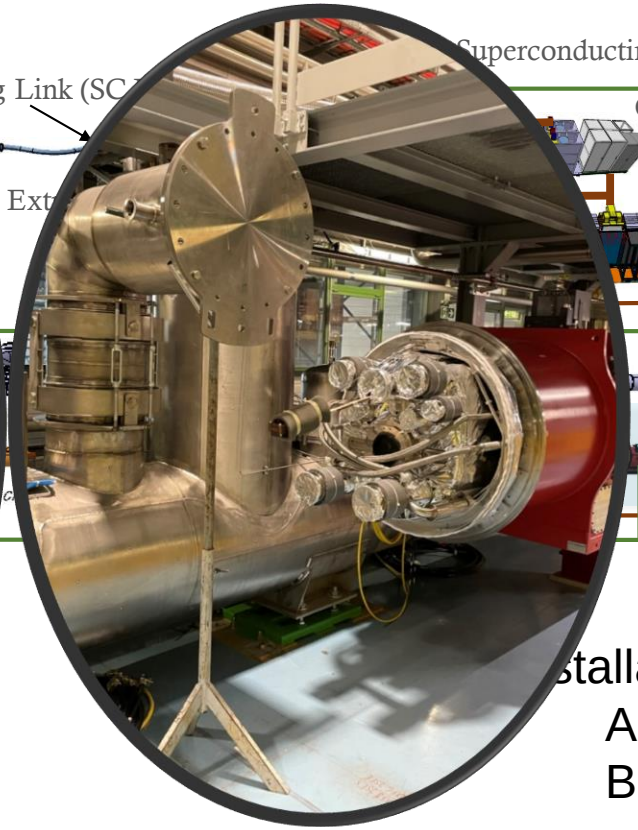
WP3, TE-MSC




See Presentation of E. Todesco, Monday 10h Plenary session: " Status of WP3"

# CRYO COLD MASS Installation








tallation started:

A. Jumper preparation
B. First Cold Mass Installed

See Presentation of S. Le Naour, Room 4L Wednesday 11h WP16 session: “Cryo magnet installation into the IT String ”

# HL-LHC IT STRING MAGNETS READINESS

| | D1 | CP | Q3 | Q2b | Q2a | Q1 |
|---|---|---|---|---|---|---|
| Cryostating **Phase 1** | HCQBXF_S007-CR000001 | HCQCXF_S006-CR000001 | HCQQXF_SC002-FL000001 | HCQQXF_SB014-CR000001 | HCQQXF_SA008-CR000001 | HCQQXF_SC002-FL000002 |
| Cold test | Test report | Mg tested individually **SM18 Test bench Oct → end Nov *** | | | Test report | IN PROGRESS At FNAL |
| Cryostating **Phase 2** | HCQBXFC006-CR000001 | HCQCXFC010-CR000001 | Oct → Dec 2024 * | WORK IN PROGRESS → End Nov 2024 * | HCQQXFG005-CR000001 | Reception at CERN Nov 2024 * for Phase 2 |
| Critical nonconformities | - | | QH issue NCR 2769128 NCR 2883868 | Performance limitation NCR 2638374 NCR 2687264 | QH issue NCR 3069797 | |
| ID card | EDMS 3117914 | | | | EDMS 3127310 | |
| MAB | EDMS 31265 | | | | EDMS 3164 | |

* According to WP3 planning V46 (07/2024)

Performance limitation taken into account in the HWC parameters EDMS 2771118

The delay of the Q1 do not prevent the connection of the other cryo-magnets and interlink (DCM).

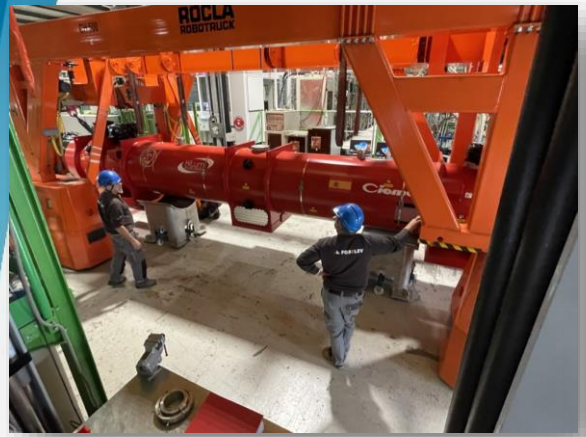
All cryo-magnets are available before the end of year 2024, but Q1.

By S. Le Naour

# Q2a cold mass installation by EN-HE teams

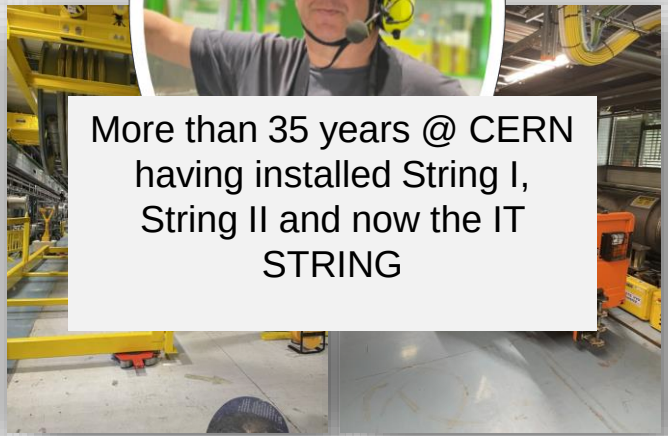

An extraordinary milestone of the WP3 team

# A REMARKABLE EN-HE CONTRIBUTION

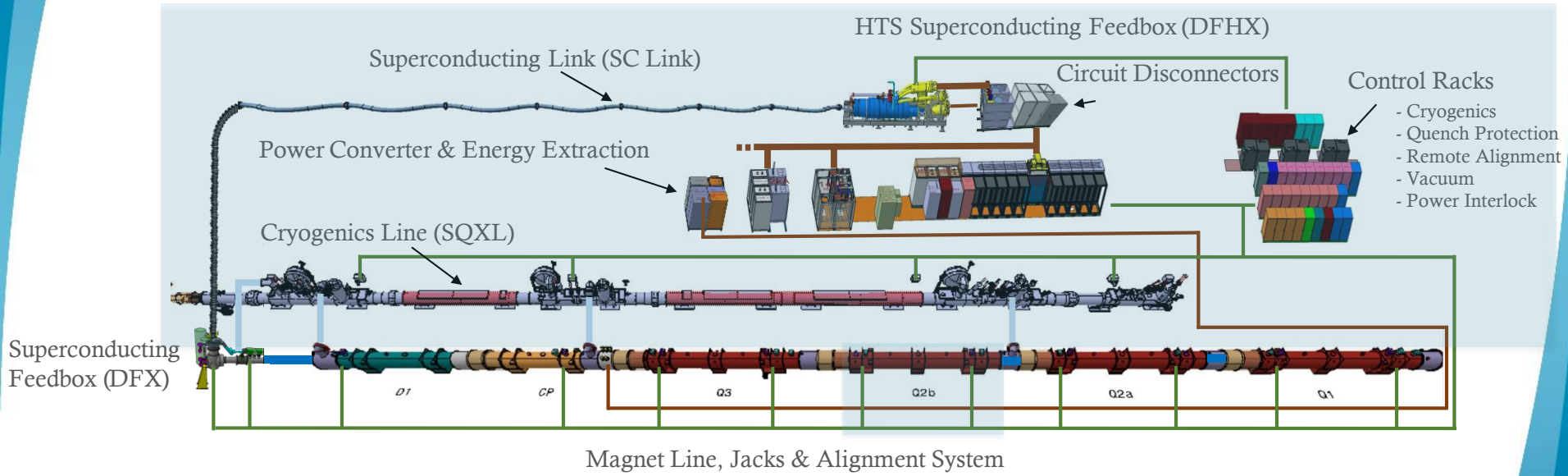




More than 35 years @ CERN having installed String I, String II and now the IT STRING



# READINESS OF THE HL-LHC IT STRING

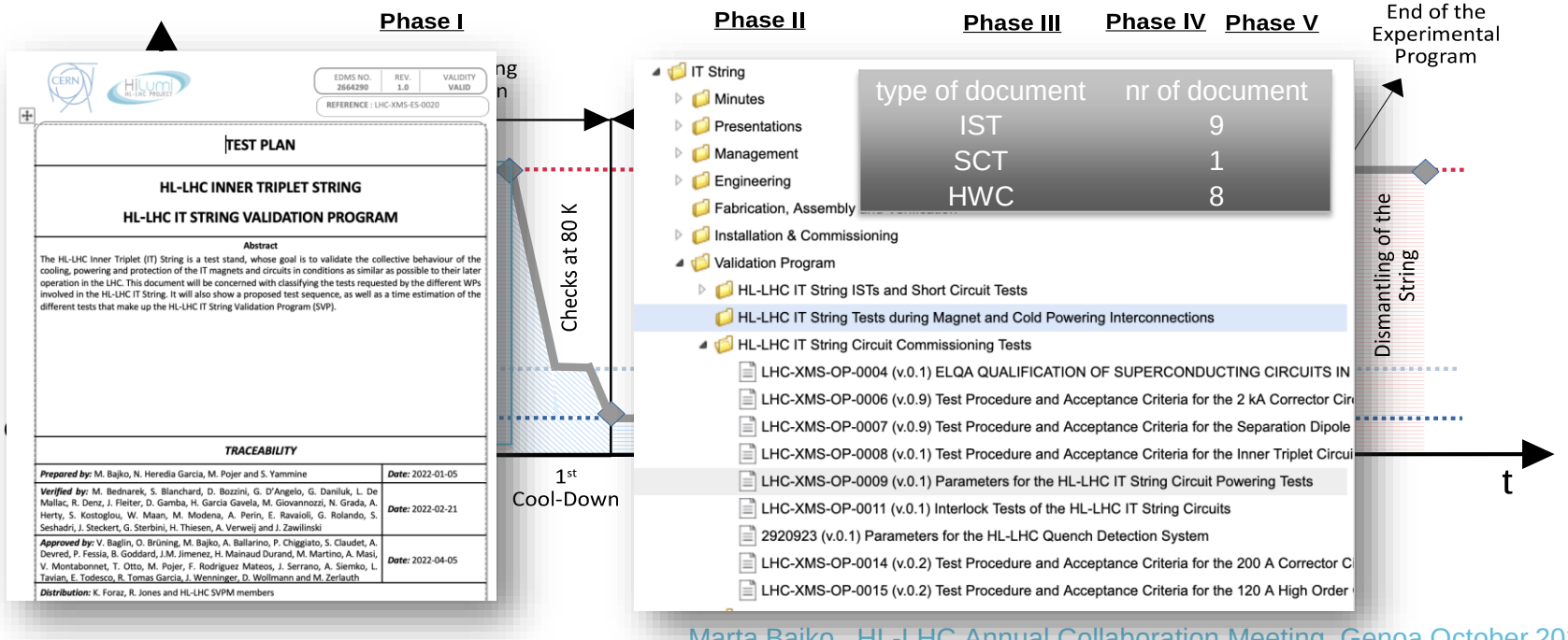


# HL-LHC IT STRING VALIDATION PROGRAM

See Presentation of S. Yammine, Room 4L Wednesday 9h10 WP16 session:
“From HWC of the IT String to the HWC of the HL-LHC: status and preparation”

# STRING VALIDATION PROGRAM

The ***scope*** of the IT STRING is to represent, 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 and optimize the **QC plans, IST, SCT and Powering Test procedures** to prepare to a smooth LS3



# WP16
# HL-LHC IT STRING and HL-LHC HWC

*Extr*

The **HL-LHC IT STRING** will serve as a
bed [….]. The HL-LHC IT STRING sh
therefore validate operational m
[…] in view of the hardw
commissioning and operation perio
the HL-LHC era. […]

**The present reporting is esser
done in this part**


**COMMISSIONING** phase should
all equipment that will be installed in the
]. The hardware commissioning (HWC)
the preparation and execution of detailed
ding their *individual system tests* and a
*paign*, […] consolidated operational tools
*idation of the superconducting circuits*.

**WC Procedures, Software and Control
specific, but destinated to HL-LHC**

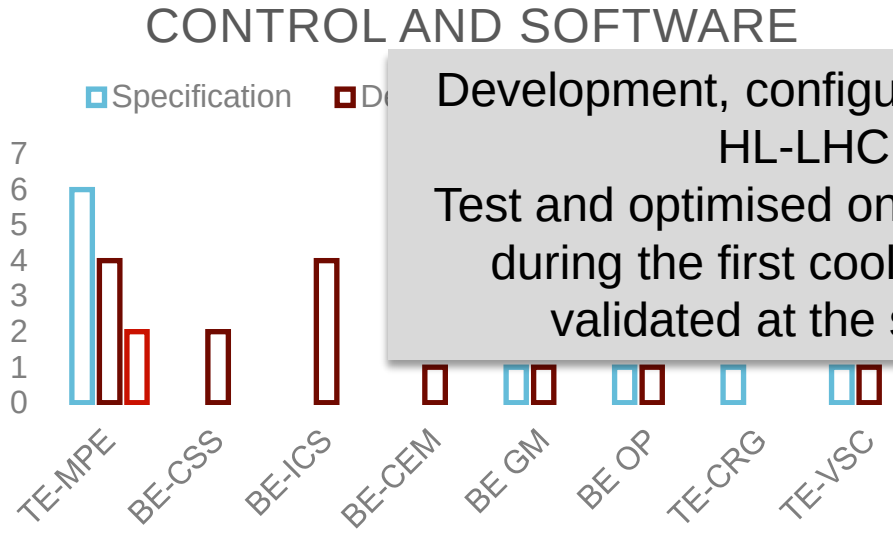
Preparation done by MCF, MP3 to be applied to the WP16 String to optimise and validate for the HWC of the HL-LHC

See Presentation of S. Yammine, Room 4L Wednesday9h10 WP16 session:
"From HWC of the IT String to the HWC of the HL-LHC: status and preparation"

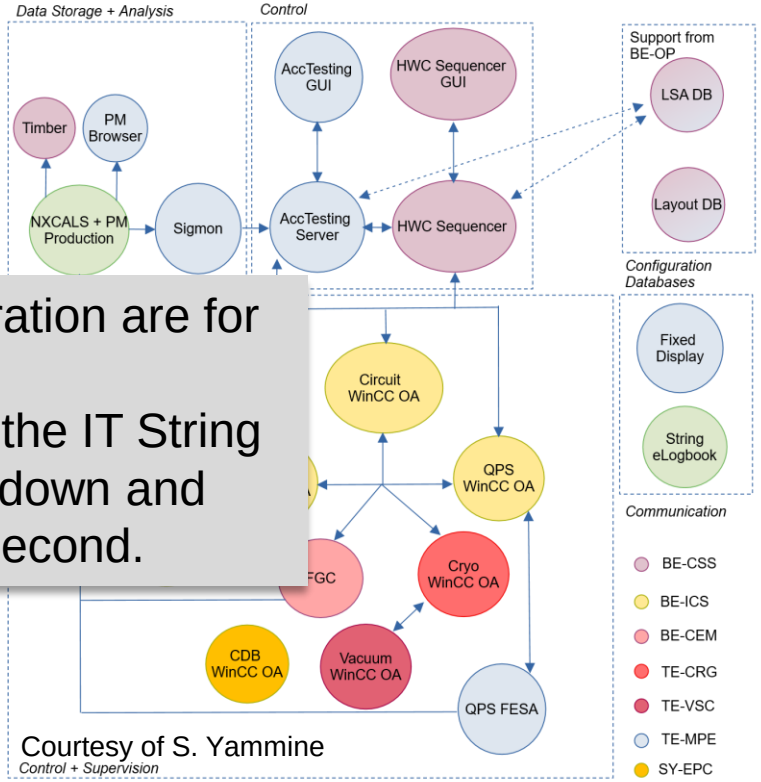
# CONTROL AND SOFTWARE FOR IT STRING

| | |
|---|---|
| DEPARTMENTS | 3 |
| GROUPS | 9 |

| | |
|---|---|
| Specification | 5 |
| Develeopment | 7 |
| Scripts/Notebook | 1 |




Development, configuration are for HL-LHC
Test and optimised on the IT String during the first cool down and validated at the second.




Courtesy of S. Yammine

# CONTROL AND SOFTWARE MILESTONES

# LESSONS LEARNED

# Lessons Learned 1

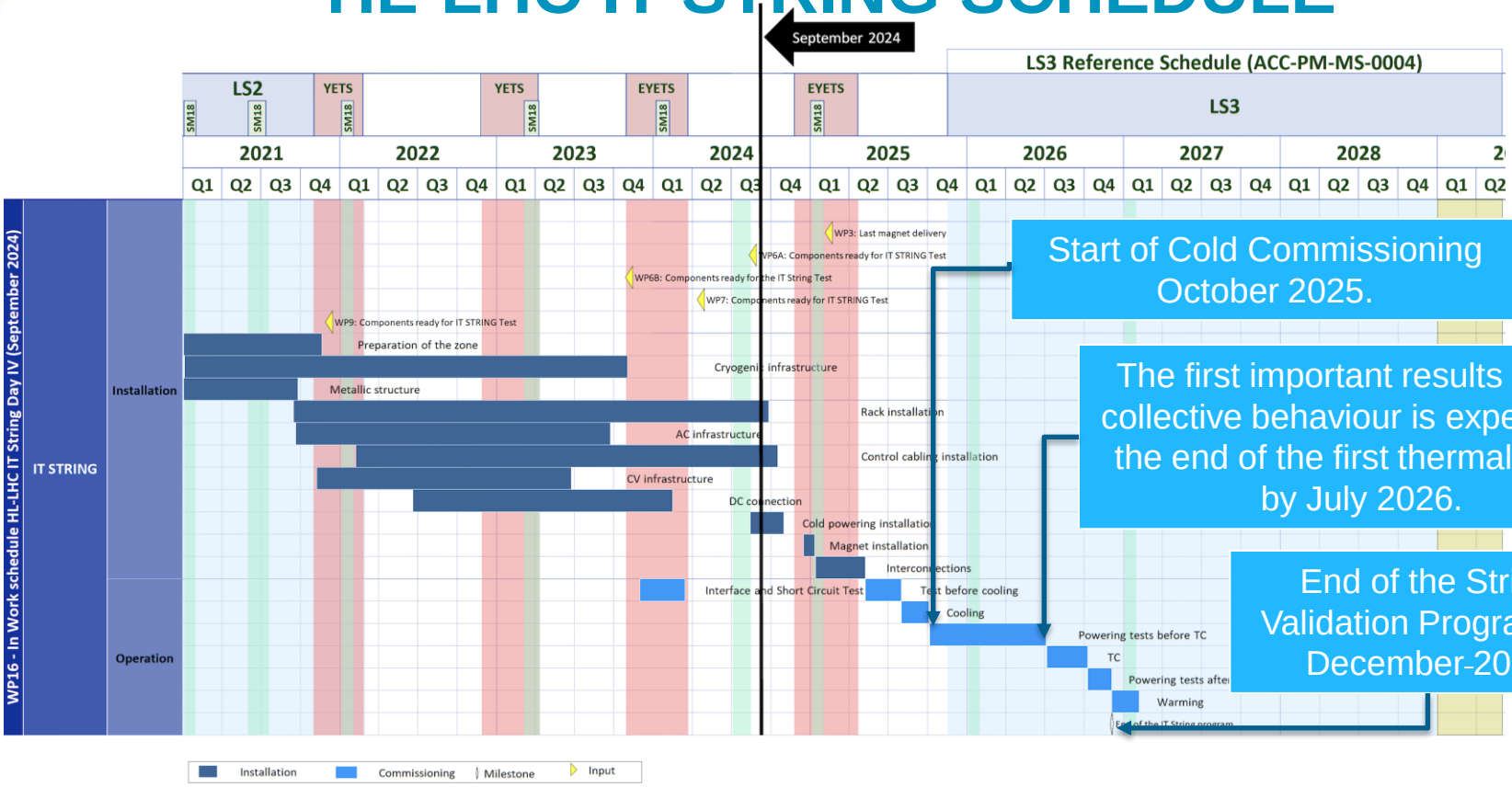
- Design
  - Water Cooled Cables: optimisation by standardisation
  - Water Colling: Study the option of series or parallel feeding of cables and choose based on measurements and simulations
  - Air cooled cables and DFHX interface optimisation with ultra flexible cables
- Integration
  - Very tight space: absolute necessity to integrate the “as built” as we are even sensitive to fabrication and assembly tolerances; Investment in a tool with EN ACE that will allow QC in situ;
- Safety
  - Operational safety now relays on clear procedures and single drawing allowing all lock outs and changes of phases. It result to be an example for the ESP.

# Lessons Learned 2

- Installation
  - Simple, low tech can turn to be much expensive and longer due to problems in specification and quality of the implementation
  - Dummy tests: step by step of critical installation process leads to success of the most complex system. Tools to perform test (as the short circuit mock up) is an added value when optimising the schedule
- Schedule
  - Flexibility allowed to gain a lot of time: changing the sequence of installations from the baseline ( ideal one)  to the feasible one counting on availability of equipment
  - Planned schedule and duration of activities was not achieved for several reasons: low priority, early stage of production, working in the shadow of delayed equipment ect. In conclusion the schedule lof the IT String is not representatives for the HL-LHC.
- Operation
  - As built instrumentation drawing for the IT String circuits will allow to integrate in a clear way all NC related to the electrical circuits.

# HL-LHC IT STRING SCHEDULE RESOURCES WRT LS3

# HL-LHC IT STRING SCHEDULE




Start of Cold Commissioning October 2025.

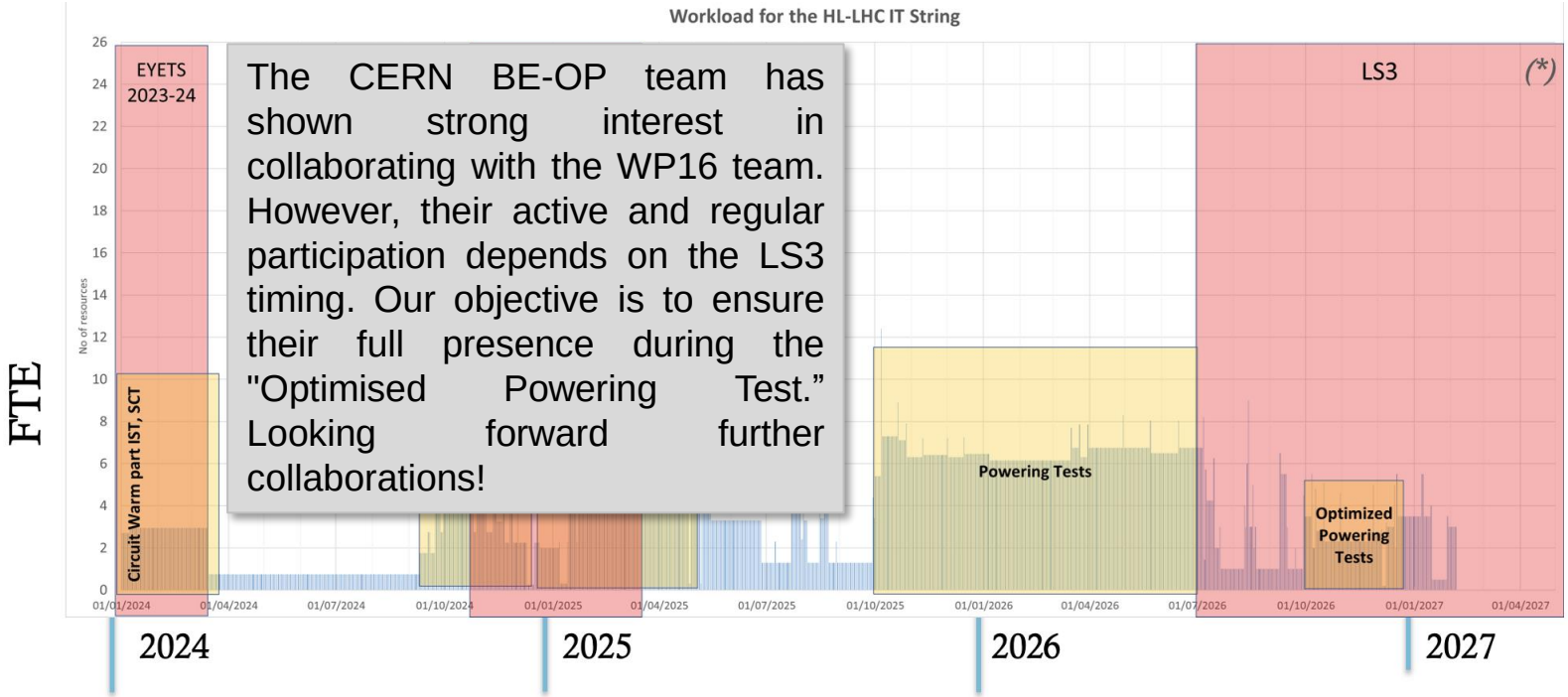
The first important results on the collective behaviour is expected at the end of the first thermal cycle: by July 2026.

End of the String Validation Program by December-2026

This planning does not integrate the annual SM18 shut down period for 2025/2026, and is conditioned by the delivery of the Q1

# RESOURCES during LS3

The overlap with **LS3 does not imply major conflicts** . A study is done ( and is updated at every baseline change) , showing the needs of STRING .

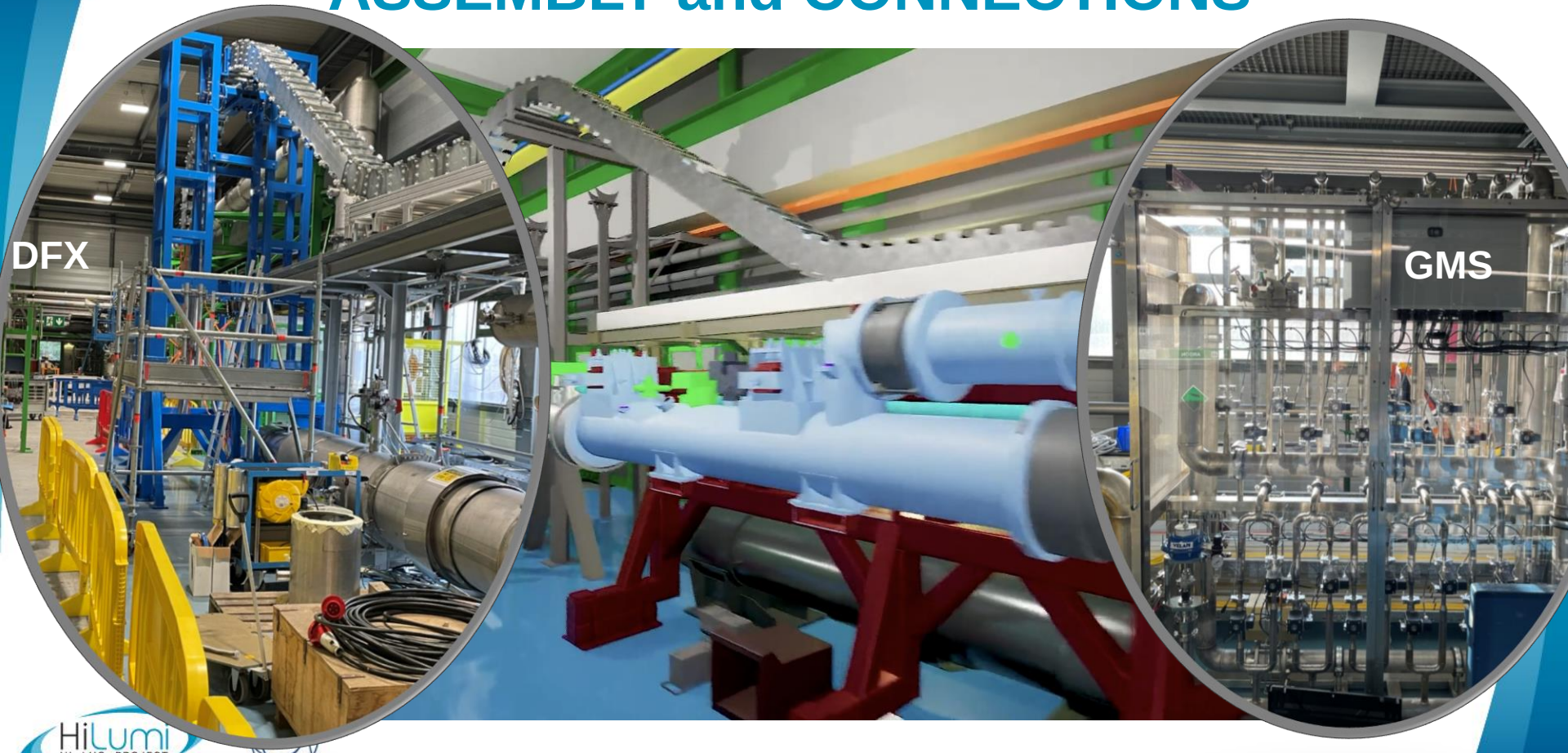



The CERN BE-OP team has shown strong interest in collaborating with the WP16 team. However, their active and regular participation depends on the LS3 timing. Our objective is to ensure their full presence during the "Optimised Powering Test." Looking forward further collaborations!

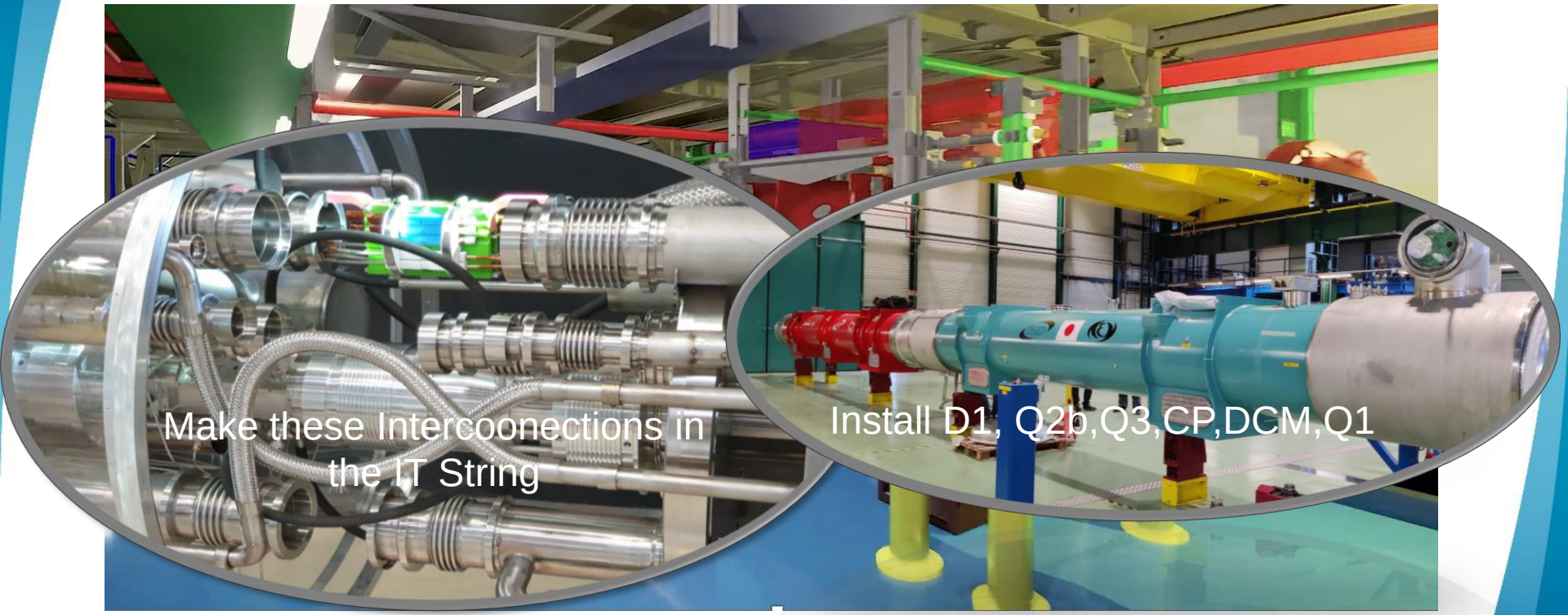
*(*) Already anticipated LS3 shift to end of June 26 – HL-LHC CSR24 will refer to LS3 planning starting on Nov. 25*

# NEXT STEPS

# ASSEMBLY and CONNECTIONS

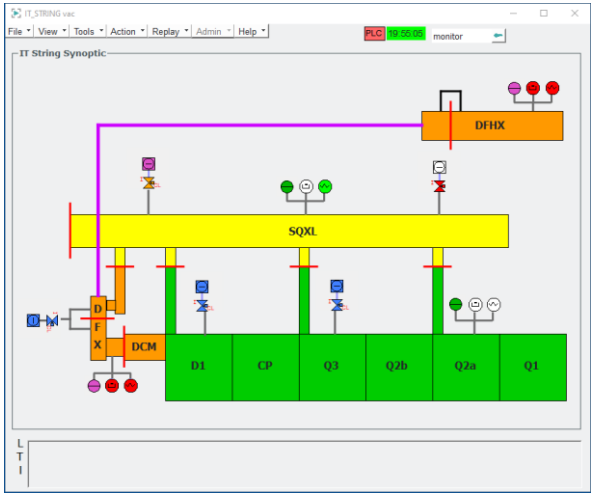


# INSTALLATION and INTERCONNECT



# PERFORM of QC TESTS

## Leak detection





## ELQA

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

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

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

# BE READY FOR THE COLD COMMISIONING

IT String Mock up by
A. Kosmicki EN-ACE

CERN HiLumi HL-LHC PROJECT

| EDMS NO. | REV. | VALIDITY |
|---|---|---|
| 2771114 | 0.9 | DRAFT |

REFERENCE : LHC-XMS-OP-0007

**4.5 PLI2.F23 & PLI3.F23 & PLI4.F23 & PNO.F23: QDS-PROVOKED QUENCH**

The aim of this test is to check the circuit and QH discharges triggered via the QDS. The provoked quench will be trigged by generating a test signal on one of the current lead detectors. The current profiles of the tests are shown in Figure 7 and the acceptance criteria are listed in Table 6.

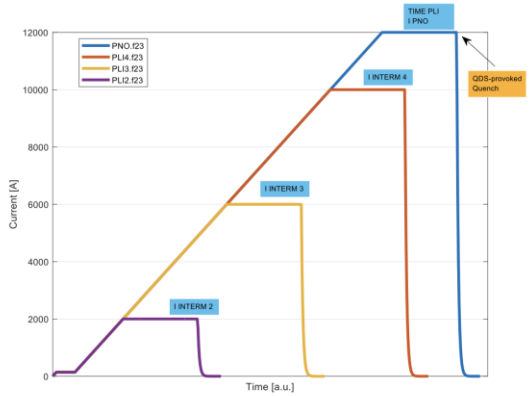



**Figure 7 - Current during QDS-provoked quench**

# SUMMARY

- **STRING Integration and Installation**
  - Major infrastructure is in place and commissioned. The goal of 2023 to perform the SCT achieved. Major component delivery : SC link and the first magnets in place.
- **STRING Validation Program- Control and Software**
  - Work advanced  on the HL-LHC HWC procedures, together with the HL-LHC like software and control layers in 2024. Dry runs planned.
- **STRING Safety**
  - Safety is closely followed. On the activity/coactivity side is to remark that 222 IMPACT request from 22 different groups are processed or in process. The most challenging activity the installation of the Sc link system is behind us.
- **STRING Operation and Resources**
  - The Operation structure, roles and responsibilities has been defined and documented. BE-OP presence in the STRING is conditioned by the LS3 timing. We are looking after collaborations.
- **Schedule**
  - The start of the cold commissioning is foreseen by  October 2025. First important results on the collective behaviour is expected at the end of the first thermal cycle: by July 2026. End of the String Validation Program is planned by December 2026.

# Thank you for your attention

# HL-LHC IT STRING MODUS OPERANDI

# STRING OPERATION

## STRUCTURE, ROLES AND RESPONSABILITIES

**HL-LHC IT String Operation**

M. Bajko

*CERN, TE Department, Genève 23, CH-1211, Switzerland*

The HL-LHC IT String is the test stand to validate the collective behavior of the Inner Triplet (IT) magnets and circuits in conditions as near as possible to the operational ones. This document describes the modus operandi of the hardware commissioning and the operation of the HL-LHC IT String.

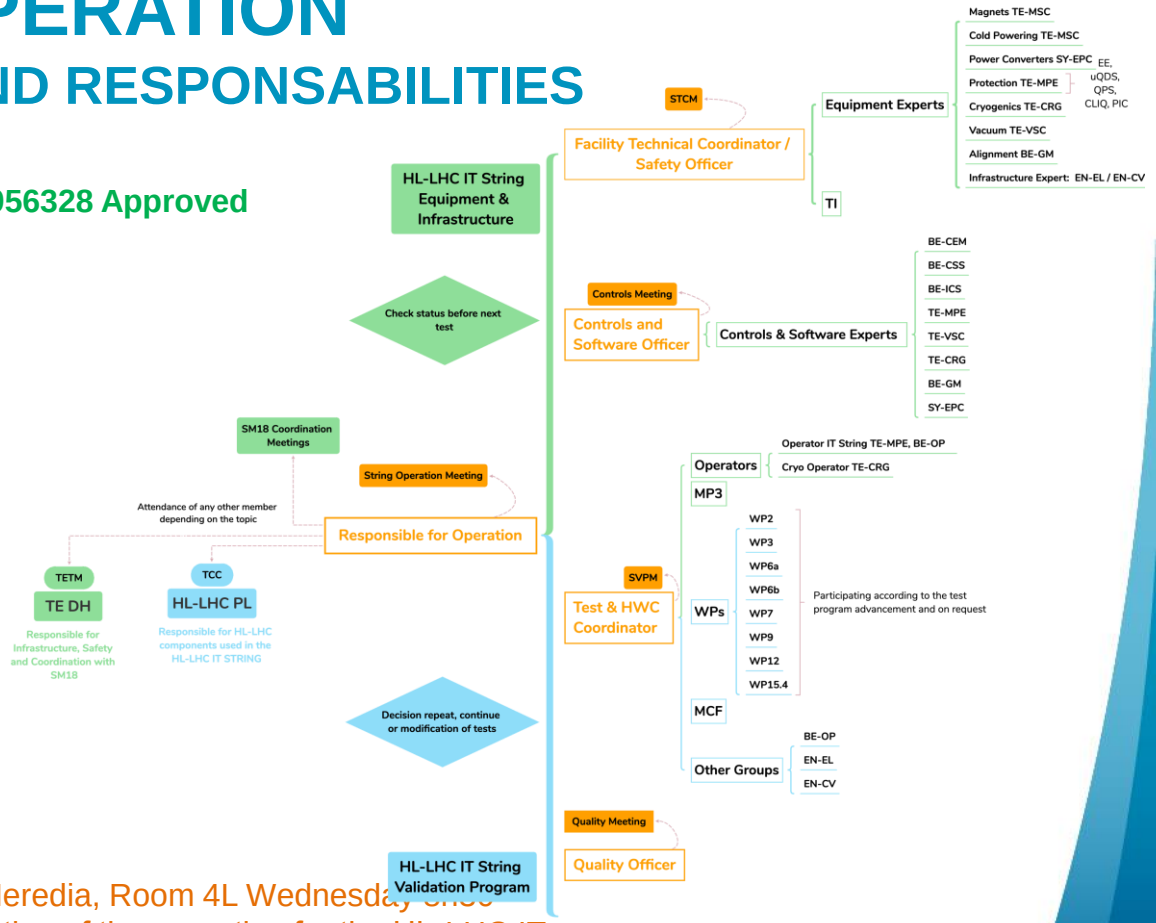
**EDMS 2956328 Approved**

### 1. Introduction

The goal of the HL-LHC project is to upgrade the existing LHC machine by incorporating new technologies that enable it to achieve its objectives [1]. The individual component tests do not fully capture their behavior when integrated into the HL-LHC, where several components are interconnected through a common electrical and cooling circuit. The HL-LHC IT String test stand allows for the comprehensive validation and testing of an entire Inner Triplet (IT) region of the HL-LHC under normal operational conditions, providing insight into the collective behavior of its components [2]. The HL-LHC IT String represents a significant intermediate milestone for the HL-LHC project, enabling system integration verification and smooth hardware commissioning of the final machine.

### 2. Description of the HL-LHC IT String

The HL-HLC IT String is installed in a surface building and functions as a representative model of the Inner Triplet (IT) region located on the left side of the HL-LHC at Point 5 as shown in Fig.1. However, the HL-LHC IT String setup does not replicate the tunnel inclination, does not include the modified matching section region and exclude the beam screen from the setup.




See Presentation of N. Heredia, Room 4L Wednesday, WP16 session: "Organisation of the operation for the HL-LHC IT String"

# POSITIONING OF THE SC LINK EXTREMITY BY WP6A