Feedback from the HL-LHC IT String Day III and scope of the HL-LHC IT String Day IV

M. Zerlauth

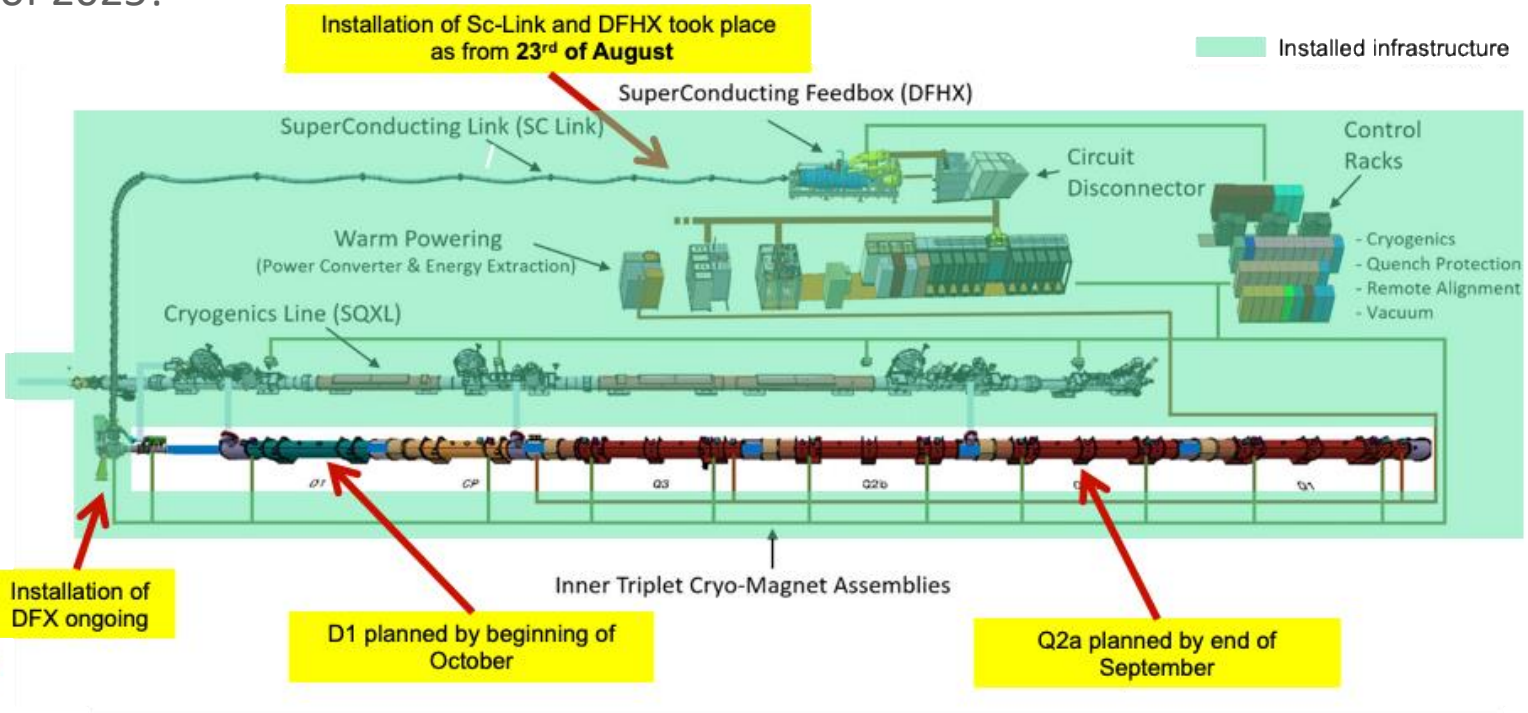
https://indico.cern.ch/event/1408524/

Welcome !

...to this 4th IT String Day, following earlier editions in Oct 2018, Sep 2022 and Oct 2023

IT String status in a nutshell

... IT String installation going strong! Focus of next months will be installation and interconnection of magnets, followed by preparations towards first cool-down in 2nd half of 2025!



HL-LHC IT String Day IV

- During the HL-LHC IT String Day III in 2023 key aspects were reviewed concerning the lessons learned during the installations and commissioning perform, the test program of the facility and status of test procedures for the IT String Hardware Commissioning and the associated software.

- **The main objectives of today's HL-LHC IT String Day IV are**
  - Present the lessons learned during the installations, individual system tests and short circuit tests as part of the hardware commissioning phase performed since the last IT String Day.
  - Describe the main upcoming activities, including: the sequence and target period for installation, and the readiness of procedures and tooling.
  - Confirm the test program for the HL-LHC IT String Hardware Commissioning and the HL-LHC IT String Specific tests. Report on the status of the test procedures for the IT String Hardware Commissioning and the associated software.

HL-LHC IT String Day III

- **Many thanks to**
  - **Advisor:** Dr. Rüdiger Schmidt, Dr. Philippe Lebrun
  - **Scientific Secretary:** Nicolás Heredia Garcia
  - **Link** for HL-LHC **IT String**: M. Bajko + entire team for the excellent preparation and for the organisation of the SM18 visit (during lunch break)
  - **All speakers and participants:** For their preparations, presentations and lively participation (while respecting the allocated time for presentations)!

- In the same spirit, the String Days will continue with dedicated and adapted content in the coming years to report on the advancement and the lessons learned from each phase of the facility.
  - Next year round we will be starting operation !!!

General summary and feedback received

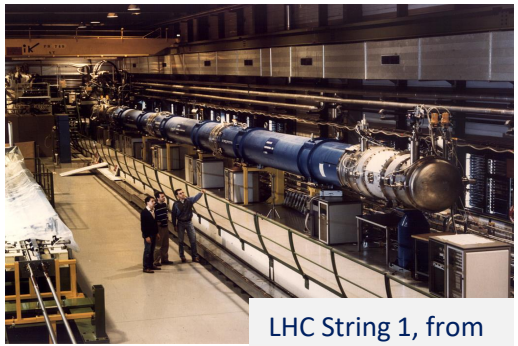
from advisors following String day III

(EDMS 2994942 and 187th TCC on 23rd Nov 2023)

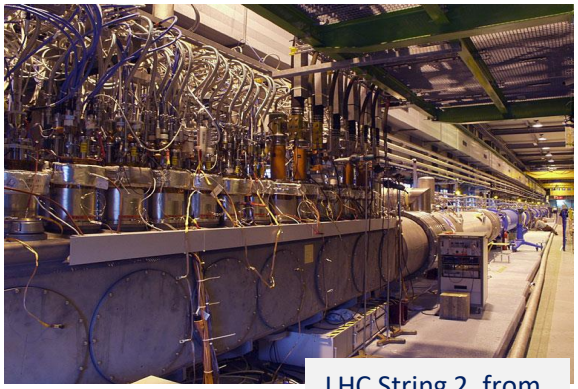
Magnet strings are an essential part of HEP projects

SSC String in Texas, USA

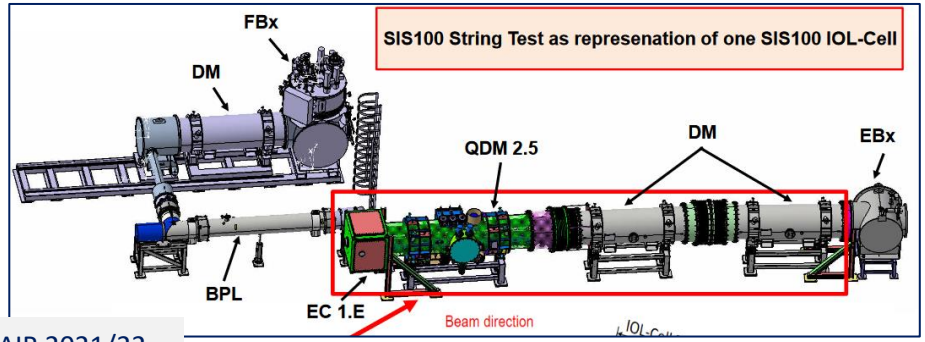
SSC Length 87 km
SSC Energy 20 TeV
Cancelled 1993



LHC String 1, from 1994 to 1998



LHC String 2, from 2000 to 2003



GSI FAIR 2021/22

With one main common goal – global system validation, joint learning + team building for the work in the tunnel

String 2 control room back in 2002?!

Comments from the advisor(s) - Introduction

- The HL-LHC IT String will deliver the **first complete experience of installing and operating the HL-LHC inner triplet magnet** zone.
- The **progress of the HL-LHC IT String project** is marked by **significant achievements**. The infrastructure is now predominantly in place. The project's upcoming milestone is the impending short circuit test.
- Already until now, **the IT String project has provided invaluable lessons** for HL-LHC, well before its completion in various categories, refining component construction details, preparing installation and operation, identifying and addressing non-conformities.
- Additionally, the project **facilitated the evolution of collaborative approaches** among different teams, defining effective ways of working together.
- **The substantial investment in the IT String Project promises considerable returns when the lessons learned are integrated into the preparations and execution of the tunnel activities of the HL-LHC project.**

HiLumi HL-LHC PROJECT

Comments from the advisor(s) – Some key points

- Methodology: Develop a robust methodology to incorporate IT String lessons into HL-LHC systematically.
  - Construction of DFHX Current Lead Connections Model, installation tests of the N-line in a mock-up, improvements of the connection of cooling tubes to the WCC, ...

- ‘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.
  - WCC and ACC Activities: Installation of Water-Cooled Cables (WCC) and Air-Cooled Cables (ACC) as well as Instrumentation, Software, and Trigger (IST) activities are progressing as planned, with minor technical adjustments that do not impact the String schedule. Valuable lessons learned are being applied to HL-LHC.
  - Control Cables: Ensuring the quality of control cables is important. Equipment owners bear the responsibility, with EN-EL overseeing specific verification processes. Given the large demand for cables in HL-LHC, a consistent testing strategy across various subsystems is required. A comprehensive review of these processes is proposed for HL-LHC.

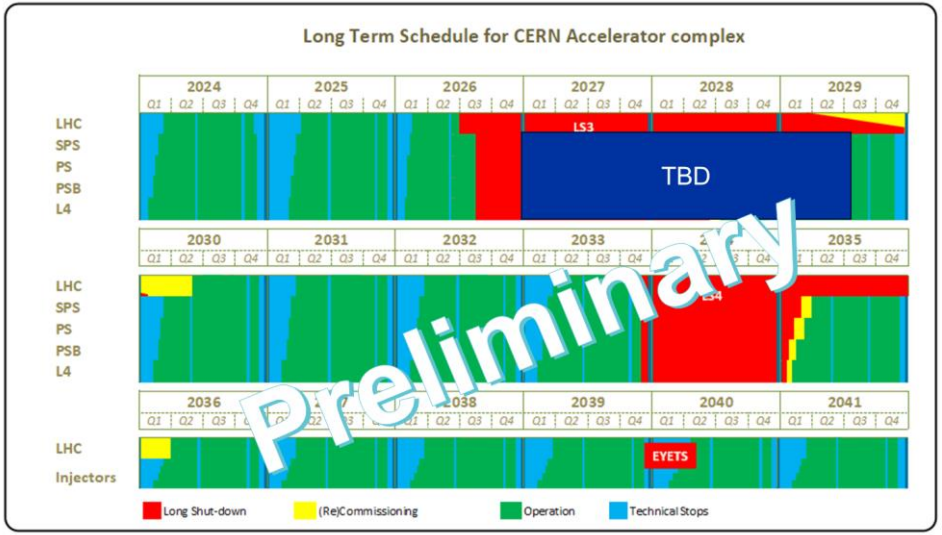
Comments from the advisor(s) – Some key points

- Non-conformities: It's imperative to document non-conformities comprehensively, to prevent their recurrence in the HL-LHC tunnel installation. Ensure a meticulous follow-up by the IT-String / HL-LHC project teams. Discussions focused on methods like tagging these issues in a database or Excel sheets for comprehensive documentation and easy accessibility.
  - Heat Load Assessments: Ongoing assessments are the evaluation of potential higher heat loads between the cold box and PCDS. These increased heat loads will not impact the efficient cooling of the String.

- Interconnections: Preparing the interconnection fabrication holds significant value for both String and HL-LHC. Consideration of starting interconnection work before the arrival of the final magnet (Q1) in September? Might make sense in the event of a delayed arrival of Q1.
  - The creation of a mock-up for N-line insertion is a very valuable initiative.

Comments from the advisor(s) – Some key points

- Schedule risks: The punctual delivery of cryo-magnets for the IT String stands as the most significant scheduling risk, in particular for Q1, with specific focus on avoiding delays caused by transport-related issues.
- Early scheduling of dry-runs has proven to be an important tool in the control room to enforce an early checkout of all software components necessary for the different commissioning phases.

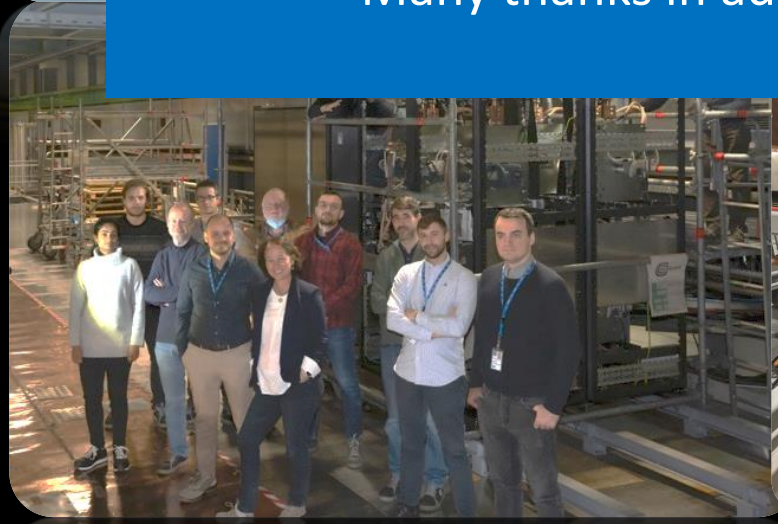


Comments from the advisor(s) – Some key points

- Communication: Sharing of milestone photos with team members enhances understanding and cohesion among different teams and could also find applicability in installing HL-LHC.
- Collaboration and communication: Effective collaboration and transparent communication between diverse teams are important for success. The expertise of the String team can provide vital support to the CPS team during this phase and alleviate workload from already heavily solicitated equipment teams.

- Engage BE-OP early to enhance String Tests and facilitate their learning from the IT String project for HL-LHC. Their expertise in software development could help to create software seamlessly integrable into HL-LHC. Such engagement will prepare BE-OP members for a role during the 3-year shutdown, in view of the subsequent commissioning and operation of HL-LHC.

Many thanks in advance for a day rich of discussions!
Questions?



HL-LHC IT String Day III on 16 October 2023

Comments and remarks from advisor(s)
HL-LHC Technical Coordination Committee (TCC)

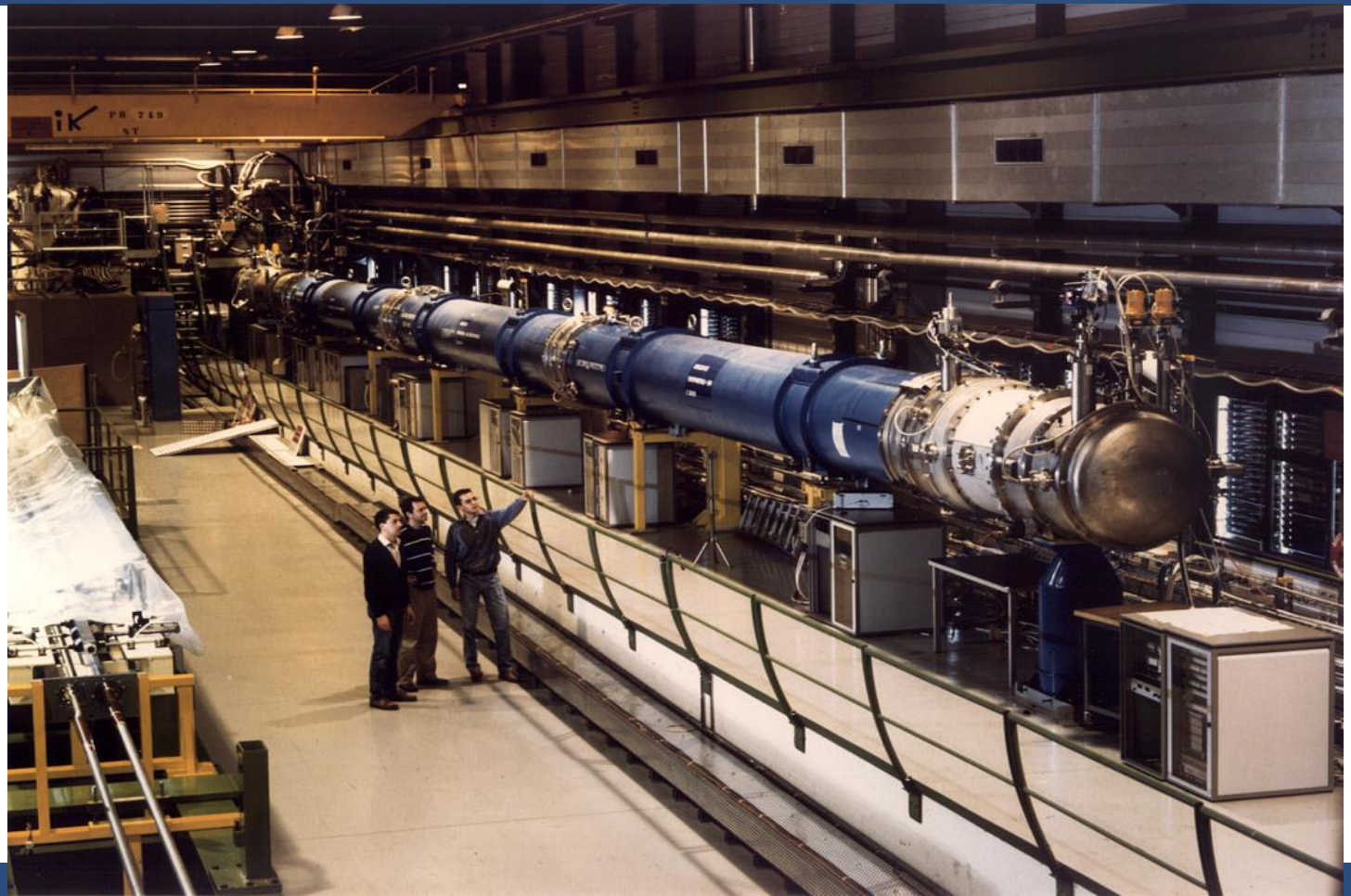
Rüdiger Schmidt (former CERN staff, now TU Darmstadt and GSI, user at CERN)
Assisted by Markus Zerlauth

String at the SSC (Superconducting Super Collider) 1993

SSC String in Texas, USA

SSC Length 87 km
SSC Energy 20 TeV
Cancelled 1993

LHC String 1, from 1994 to 1998



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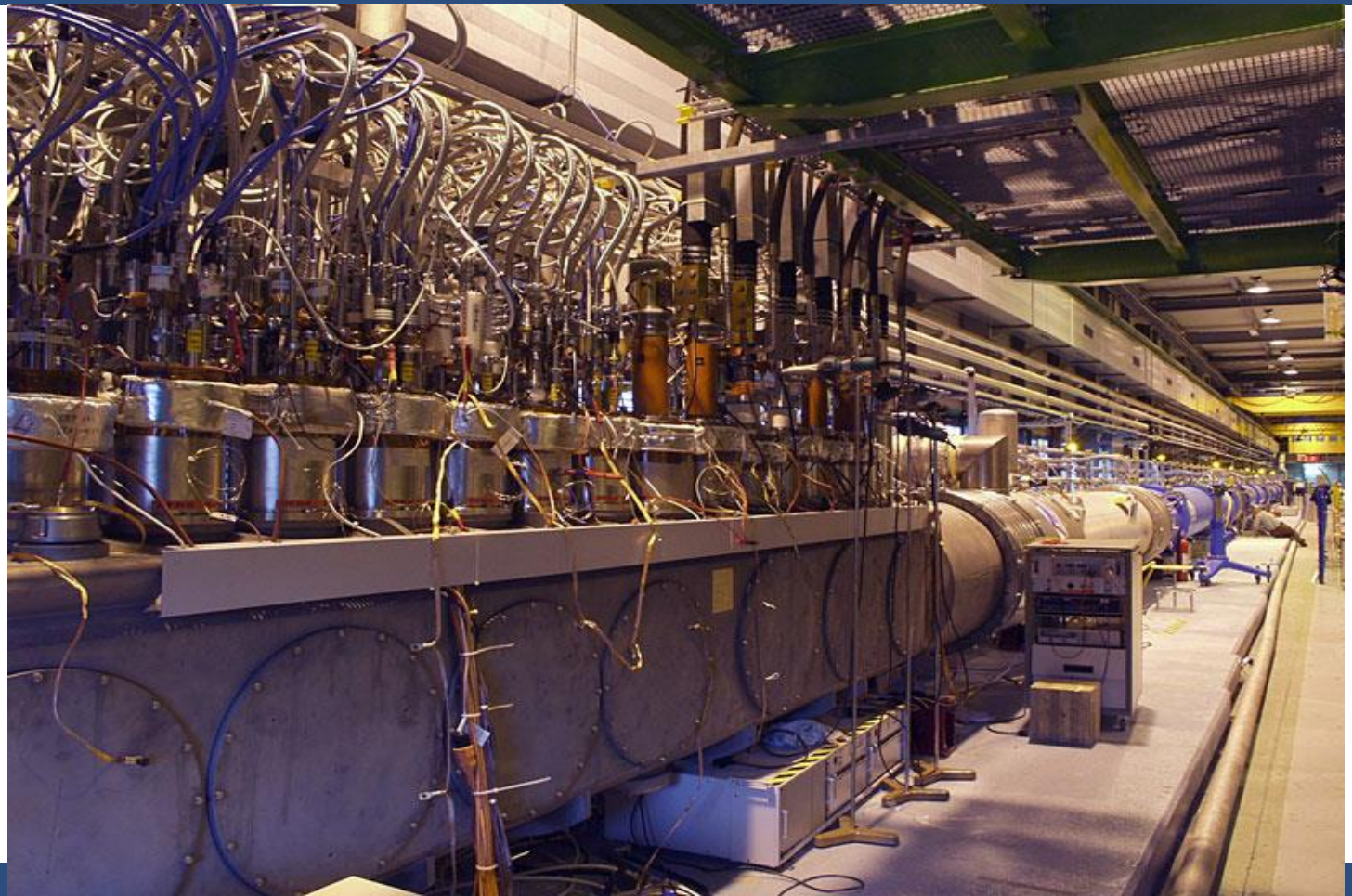
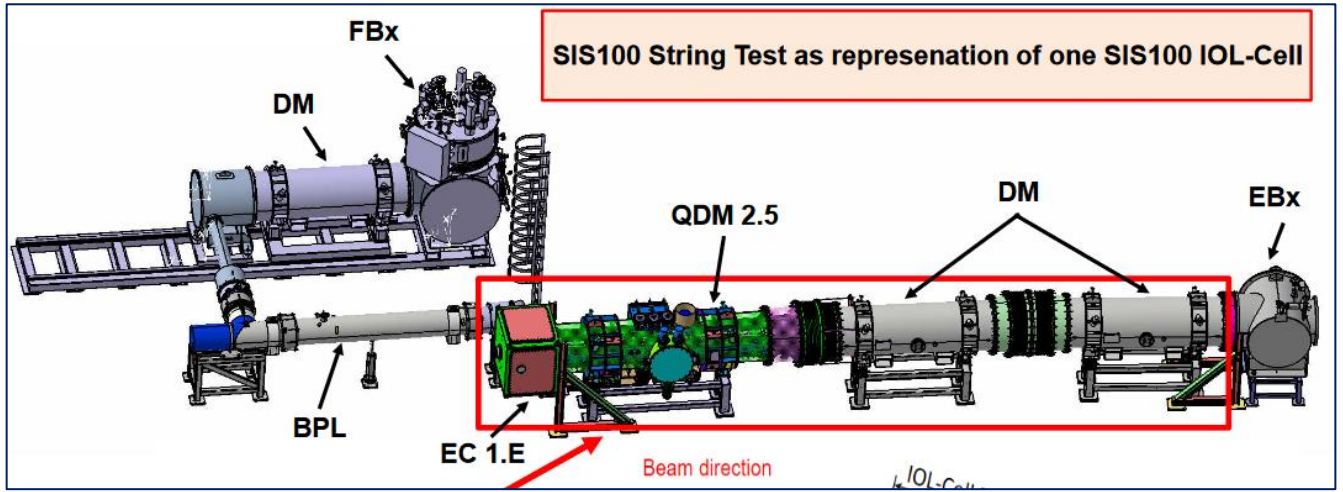
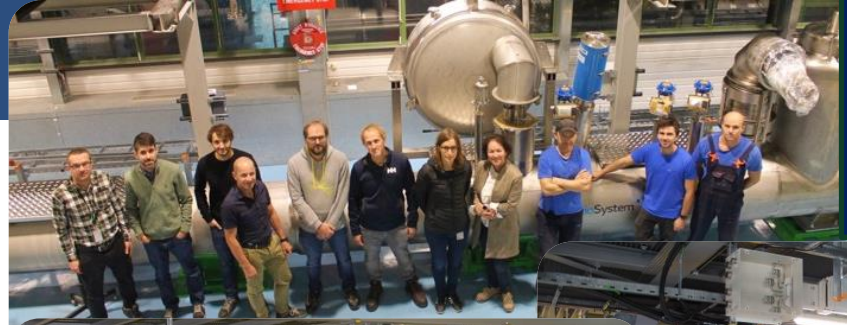
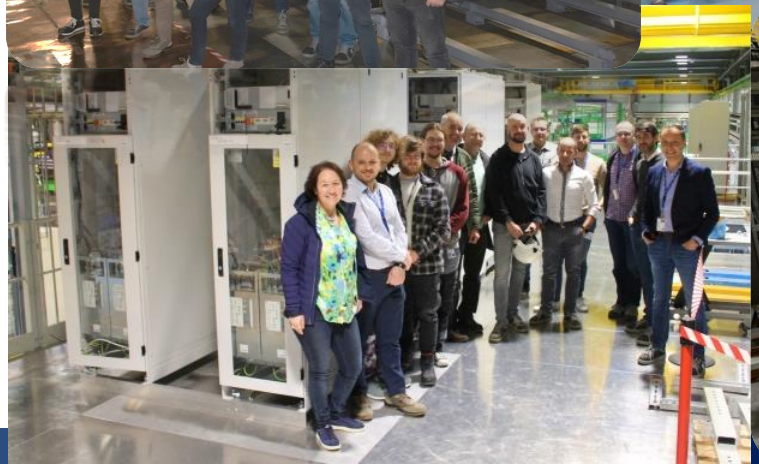
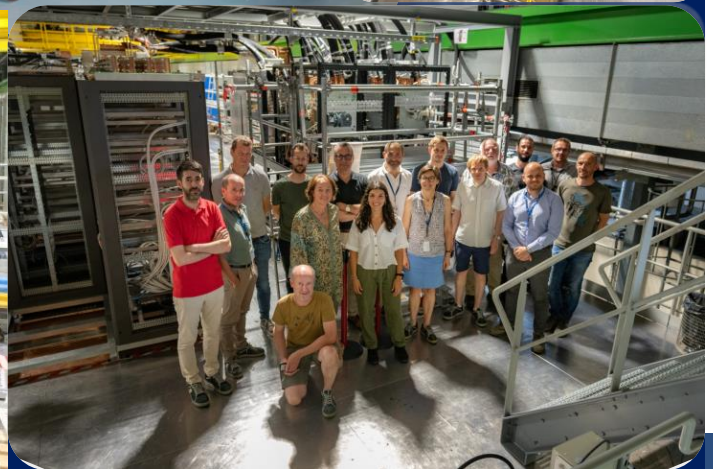



SIS100 String Test as represenation of one SIS100 IOL-Cell
FBx
DM
QDM 2.5
DM
EBx
BPL
EC 1.E
Beam direction

HL-LHC IT-String







Scope of the String III Day

- During the HL-LHC IT String Day II in 2022, key aspects were reviewed concerning the readiness and installation strategy for the HL-LHC IT String equipment, the test program of the facility and safety aspects during its installation and operation (advisors Ph.Lebrun and R.Schmidt).
- The main objectives of the HL-LHC IT String Day III are:
  - Present the lessons learned during the installations and commissioning performed since the last IT String Day.
  - Describe the main upcoming activities, including: the tools to be used, the sequence and the target period for installation, the validation tests and the safety measures to be applied.
  - Explore the test program for the HL-LHC IT String Hardware Commissioning and the HL-LHC IT String Specific tests.
  - Report on the status of the test procedures for the IT String Hardware Commissioning and the associated software.

The advisor(s) nominated by the HL-LHC Project Leader and TE Department Head will be asked to give their feedback and recommendations to the Management as well as to share their comments with the HL-LHC WP16 core team.

Acknowledgement

- **Chair**: Markus Zerlauth
- **Scientific Secretary**: Nicolás Heredia García
- **Link person** for the HL-LHC IT String (WP16): Marta Bajko

- Thanks to the String team for the excellent preparation and the SM18 visit.
- Thanks to speakers and participants: For their preparations, presentations and lively participation during the day.

- Many of the comments emerged from the discussions following the presentations, over coffee, and during (the very nice) dinner.

A detailed report with comments with more details will be available on EDMS.

Introduction

- The HL-LHC IT String will deliver the **first complete experience of installing and operating the HL-LHC inner triplet magnet** zone.

- The **progress of the HL-LHC IT String project** is marked by **significant achievements**. The infrastructure is now predominantly in place. The project's upcoming milestone is the impending short circuit test.

- Already until now, **the IT String project has provided invaluable lessons** for HL-LHC, well before its completion in various categories, refining component construction details, preparing installation and operation, identifying and addressing non-conformities.

- Additionally, the project **facilitated the evolution of collaborative approaches** among different teams, defining effective ways of working together.

- **The substantial investment in the IT String Project promises considerable returns when the lessons learned are integrated into the preparations and execution of the tunnel activities of the HL-LHC project.**

CMAC Summary at HL-LHC Cost & Schedule Review

- The IT String Test implementation is **progressing very well**, despite **some delays**.
- The Committee acknowledges that **the results of the tests are important to study and validate the collective behaviour** of the various systems and to provide feedback to the machine.
- Already **in the past**, the **IT String project has provided invaluable lessons** for HL-LHC, well before its completion.
- It is important to effectively integrate the all lessons learned from the String into the preparations and execution of the tunnel activities of the HL-LHC project.
- The resources allocated to IT string test should be closely monitored as well as overlap with LS3 schedule.

Recommendation: Effectively integrate the insights gained from the String project into the planning and execution of tunnel activities for the HL-LHC project.

Learning from the IT String for HL-LHC

- **Methodology:** Develop a robust methodology to incorporate IT String lessons into HL-LHC systematically.
  - Construction of DFHX Current Lead Connections Model, installation tests of the N-line in a mock-up, improvements of the connection of cooling tubes to the WCC, ...
- **Comprehensive Review Meetings:** to refine the installation and commissioning approach for HL-LHC, utilizing the experience to identify best practices and areas for improvement from the IT String. Such meetings will ensure the active involvement of different departments within the accelerators sector in HL-LHC.
- **Coordination and Safety:** Managing a multitude of multi-disciplinary co-activities during installation from both a coordination and safety perspective, as experienced in the IT String project, will be similar for HL-LHC.
- **Adaptations and Project Specifics**: Challenges during installation and commissioning led to necessary adaptations. It's required to differentiate between elements for HL-LHC and specific aspects encountered only for the IT String.

General Comments for the IT String Project -1

- **Delay:** Today, there is a delay of about 7-months in the IT String with respect to previous year's schedule. This delay is not expected to have an impact on the HL-LHC schedule.
- **'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.
- **Daily Activity Plan:** Having a detailed daily activity plan displayed in the control room during the installation process. Ensure that all teams working on the floor are actively involved and have a clear understanding of the ongoing activities throughout the day, possibly by organising short morning meetings.
  - An interesting method has been very successfully applied at GSI-FAIR, a large project with a budget ranging from 3 to 4 billion euros, which is currently in a comparable phase.
  - The organisation of a collaborative workshop with GSI-FAIR colleagues could be considered, to discuss approaches and lessons learned for installation and testing of complex accelerator subsystems.
- **Testing:** Mock-ups provide a controlled environment for testing, allowing for identification and resolution of potential issues before implementation.

General Comments for the IT String Project -2

- **Non-conformities:** It's imperative to document non-conformities comprehensively, to prevent their recurrence in the HL-LHC tunnel installation. Ensure a meticulous follow-up by the IT-String / HL-LHC project teams. Discussions focused on methods like tagging these issues in a database or Excel sheets for comprehensive documentation and easy accessibility.

- **Communication:** Sharing of milestone photos with team members enhances understanding and cohesion among different teams and could also find applicability in installing HL-LHC.

- **Documentation methods and tools**: developed for IT String have proven effective and can serve as a valuable basis for HL-LHC's tunnel project.

- **Safety:** Maintaining the presence of a few members of the String team on-site is critical for ensuring effective communication. Morning briefings and regular passages through the control room raise personnel awareness about ongoing activities and safety concerns and enhance the overall safety culture on-site, fostering an attentive and well-informed workforce.

Cold Powering System (sc link + DFHX + DFX)

- The **Cold Powering System (CPS) marks a pioneering endeavour** in accelerator technology, with innovative systems unprecedented in this field. Its installation within the String project poses significant challenges due to its complex nature.
- **Collaboration and communication**: Effective collaboration and transparent communication between diverse teams are important for success. The expertise of the String team can provide vital support to the CPS team during this phase and alleviate workload from already heavily solicitated equipment teams.
- **Installation Readiness Review:** Such review is advisable, to ensure all aspects of the transport and installation have been considered by the teams involved. Such an exercise would also help advancing the detailed preparations of this activity in the LHC tunnel.
- **Opportunity for Optimization**: The period from end-March/April to November 2024 offers a valuable chance to advance link installations and refine the system setup.

- **Schedule risks:** The punctual delivery of cryo-magnets for the IT String stands as the most significant scheduling risk, in particular for Q1, with specific focus on avoiding delays caused by transport-related issues.
- **Horizontal Test Benches:** Its completion is paramount for magnet testing, in particular benches F1 and A2 for testing the quadrupole magnets (except Q1), ensuring the successful testing of magnets before integration into the String.
- **Cryo-Magnets Powering:** A formal confirmation of the maximum current to be used during commissioning remains to be done. Such document could include the list of all NCs relevant to the powering tests of the IT String.
- **Planning:** Primary objective is planning for success. It might be wise to develop a response plan for potential cryo-magnet issues to ensure a swift resolution.
- **Q3 Non-Conformities and Repair:** Identified non-conformities necessitating reworking for HL-LHC compatibility as spare. Determining the optimal repair timeframe involves balancing project needs with expert availability and workforce planning. Discussions with management will align decisions with the magnet group's resource planning.

- **Heat Load Assessments:** Ongoing assessments are the evaluation of potential higher heat loads between the cold box and PCDS. These increased heat loads will not impact the efficient cooling of the String.
- **Temperature Plateaus:** The cool-down process had various temperature plateaus. Not all these plateaus are required for String and HL-LHC operation.
- **Leak Tightness Discussions**: Ongoing discussions persist on accurately interpreting leak tightness specifications throughout the entire chain. Is there an issue? To be addressed by VSC (e.g. are the specification clear and coherent, and well understood).
- **Vacuum System Monitoring**: Continuous monitoring of the CPS vacuum system, extending from F2 to the String, is in progress.
- **Vacuum System for CPS**: Decisions about bypass configurations between vacuum segments of the CPS are under consideration.

- **WCC and ACC Activities**: Installation of Water-Cooled Cables (WCC) and Air-Cooled Cables (ACC) as well as Instrumentation, Software, and Trigger (IST) activities are progressing as planned, with minor technical adjustments that do not impact the String schedule. Valuable lessons learned are being applied to HL-LHC.
- **Water Pipe Connection Challenges**: Unforeseen challenges arose in connecting flexible water pipes to WCC lugs, highlighting the need for a design solution addressing both current String issues and aligning with HL-LHC requirements.
- **Water cooling**: Testing has been done to identify efficient cooling solutions for water cooled cables, hydraulically cooling in series seems to be a promising strategy.
- **Cable trays:** Insufficient fixing of cable trays and insufficient stability of cable tray ends need to be addressed.

- **Interconnections:** Preparing the interconnection fabrication holds significant value for both String and HL-LHC. Consideration of starting interconnection work before the arrival of the final magnet (Q1) in September? Might make sense in the event of a delayed arrival of Q1.

  The creation of a mock-up for N-line insertion is a very valuable initiative.

- **Alignment system:** Detailed information on installation and commissioning was provided for the first time, this allows integration of the alignment system activities into the overall IT String project schedule. Ongoing emphasis is placed on the integration process, co-activity coordination, and alignment procedures.

  Risks for a potential interconnection damage were analysed, in the event of a serious failure of the alignment system. The String provides a valuable opportunity to validate the system before installation in HL-LHC, also reducing potential risks.

- **Control Cables**: Ensuring the quality of control cables is important. Equipment owners bear the responsibility, with EN-EL overseeing specific verification processes. Given the large demand for cables in HL-LHC, a consistent testing strategy across various subsystems is required. A comprehensive review of these processes is proposed for HL-LHC.
- **Readiness for powering:** Ensuring readiness for powering involves addressing the complexity of controls system deployment, with timely contributions from multiple departments. Ideas include software dry runs, readiness assessments, defining margins for debugging, and exploring potential post-Short-Circuit-Test debugging.
- **Early scheduling of dry-runs** has proven to be an important tool in the control room to enforce an early checkout of all software components necessary for the different commissioning phases.

- **IT String individual system & short circuit tests:** These processes and testing methodologies, refined through String project experiences, can be adapted for HL-LHC projects.
- **Engage BE-OP early** to enhance String Tests and facilitate their learning from the IT String project for HL-LHC. Their expertise in software development could help to create software seamlessly integrable into HL-LHC. Such engagement will prepare BE-OP members for a role during the 3-year shutdown, in view of the subsequent commissioning and operation of HL-LHC.
- **Comprehensive Testing Approach:** The testing phase should include realistic LHC current ramp functions across all circuits, involving the entire control system chain from LSA to power converters. Use of the transfer function model for the magnets can enhance the effectiveness of these tests.
- **Resource Management:** The commissioning and operation phase of the IT String is exciting. To address resource challenges, inviting external collaborators for an extended duration at CERN, as during LHC hardware commissioning, is worth considering. This could contribute to overcoming resource constraints.

Recalling the scope

- Present the lessons learned during the installations and commissioning performed since the last IT String Day – **DONE**
- Describe the main upcoming activities, including: the tools to be used, the sequence and the target period for installation, the validation tests and the safety measures to be applied – **DONE**
- Explore the test program for the HL-LHC IT String Hardware Commissioning and the HL-LHC IT String Specific tests – **DONE**
- Report on the status of the test procedures for the IT String Hardware Commissioning and the associated software - **DONE**

Final remarks

- The upcoming year is crucial for the IT-String and HL-LHC projects, as it will demonstrate how the installation of such complex systems works. Hopefully, this success will boost confidence for the HL-LHC installation during LS3.

- Consideration should be given to organizing a String Day IV between the completion of installation and the start of operation.....

Key Message:

Effectively integrate the insights gained from the String project into the planning and execution of tunnel activities for the HL-LHC project.

Outlook to 2027 ?

- The String has proven to be a valuable test bed where the validations of the technical systems required before series production and installation could be found. It is the experimental setup where the interplay of the different technical systems could be observed and a variety of measurements carried-out.

- It is thanks to the String programme that the actors who will be involved in the hardware commissioning of LHC approach this difficult task with self- confidence and enthusiasm.

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confidence and enthusiasm.

Proceedings of the 2003 Particle Accelerator Conference

the deviation is well corrected by iteration on the measured B_2/B_1 ratio as shown by the curves marked *feed-back*. In this case the tracking error on the B_2/B_1 ratio is definitely inside the range to be achieved for the tune feed-back system to lock, and in fact quite close to the range necessary to maintain the maximum allowed tune variation to within 3×10^{-3} as dictated by the nominal LHC performance.

The optimised current ramp was sent unchanged in a second cycle, with the aim to verify the reproducibility of the ramp. The result demonstrates that the reproducibility is excellent.

Quench protection

String 2 Phase 2 offered the unique occasion to test, for the first time, an LHC like quench protection system on the scale of an LHC full cell. During installation, commissioning and operation a variety of subjects like feasibility of the installation, required functionality as well as reliability and maintainability of the system were critically revised. The outcome confirmed the validity of the basic designs and the functionality of the system. Nevertheless a number of minor problems were identified and already successfully implemented into the latest designs for the LHC quench protection system. For example, the improved designs of quench detection boards and acquisition and monitoring controllers now offer an enhanced functionality and require a significantly lower level of maintenance than those currently installed

The values chosen for thresholds and discrimination time for the main bus-bars, the corrector magnets and their connecting bus bars were sound and only needed little corrections over the commissioning phase. They confirmed the calculations of the quench velocities.

COMMISSIONING

Procedures, which are expected to become the basis for the commissioning of the LHC sectors, were developed and tested for both the cryogenic system and the electrical system as a whole.

The tests preceding the powering of the circuits [6, 7] involved two phases: during the first phase the magnets and the power converters were not electrically connected and were tested separately. The former, involving the magnet side, were aimed at electrical insulation tests at different temperature levels during the cool down. Before the two sides were electrically connected, they were linked together by the interlock system (Powering Interlock System in LHC); the power converters were turned on and tested on a short circuit while the quench protection system was fired to verify the sequence of events. This was repeated for every circuit before the power converter was connected to the current leads on the electrical feed box. While this gradual powering is safe, it proves to be lengthy.

The final tuning of the systems took place following observation of faults induced by the operation in unison with other systems (e.g. false quench signals on the global detectors during converter turn-on and ramp-up).

The optimisation of operation by adapting procedures to particular cases also took place during this phase (e.g. avoiding full quench recovery procedures when auxiliary circuits trip).

The importance of the timing of the commissioning procedures and their dependence on temperature did not go unnoticed: the commissioning of the quench detectors across the superconducting part (few tens cm) of a current lead was found to be very tricky (!) after the lead had been cooled down.

A better understanding of the issues related to operating a particular system and observing the effects it can have on other systems took place during this phase. This stimulated the exchange of information between specialists.

CONCLUSIONS

The String has proven to be a valuable test bed where the validations of the technical systems required before series production and installation could be found. It is the experimental setup where the interplay of the different technical systems could be observed and a variety of measurements carried-out.

It is thanks to the String programme that the actors who will be involved in the hardware commissioning of LHC approach this difficult task with self confidence and enthusiasm.

REFERENCES

[1] The LHC Prototype Full-Cell: Design Study, LHC Project Report 170, March 1998.

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[3] E. Blanco et al. Nonlinear Predictive Control in the LHC Accelerator, ADCHEM 03: International Symposium on Advanced Control of Chemical Processes.

[4] R. Herzog, M. Calvi and F. Sonnemann: Quench propagation and heating in the superconducting 600 A auxiliary busbars of the LHC Advances in Cryogenic Engineering, Vol. 47 p575.

[5] R. Herzog, M. Calvi, F. Sonnemann and J.M. Pelegring-Carcelen: Quench propagation in the superconducting 6 kA flexible busbars of the LHC, Advances in Cryogenic Engineering, Vol. 47 p583.

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[7] R. Saban, What Have We Learnt from the String Programme (Design, Assembly, Experiments And Measurements)? Workshop on LHC Performance, Chamonix, March 2003.

- The String has proven to be a valuable test bed where the validations of the technical systems required before series production and installation could be found. It is the experimental setup where the interplay of the different technical systems could be observed and a variety of measurements carried-out.

- It is thanks to the String programme that the actors who will be involved in the hardware commissioning of LHC approach this difficult task with self- confidence and enthusiasm.

….and wishing the IT String project every success