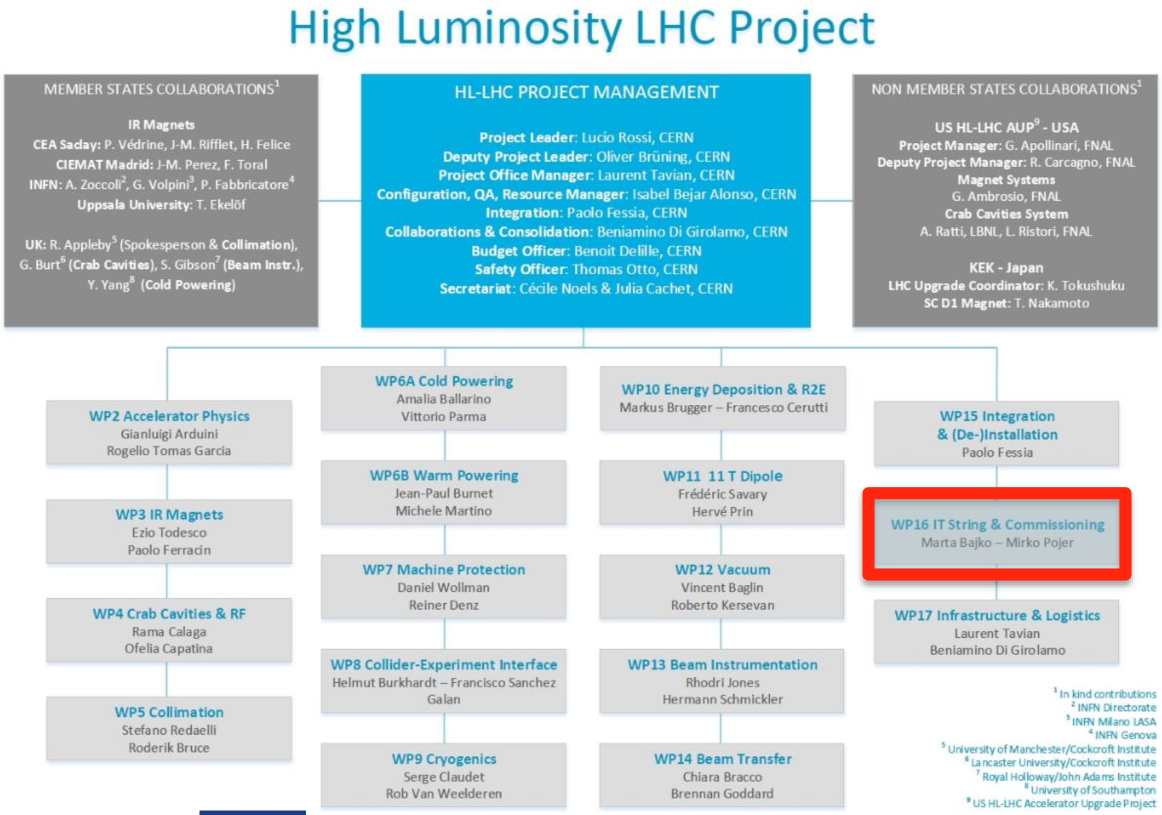
HL-LHC IT STRING

M. Bajko CERN

Outline of the presentation

- WP16 in the HL-LHC Structure and IT STRING Scope
- Brief return to the past
- Experience with LHC Triplet
- Relevance of HL-LHC IT String
- ID Card
- Main IT String components
- IT String schedule: conflicts and synergies
- Main IT String facilities
- Work status

The HL-LHC IT STRING in the organigram



Ref. HL_WP16 IT STRING Mandate: https://edms.cern.ch/document/1513780/1

[…] **THE WP16** covers the coordination of the commissioning of the HL-LHC equipment as part of the accelerator system. […] The first important system test will be the Inner Triplet (IT) STRING test.

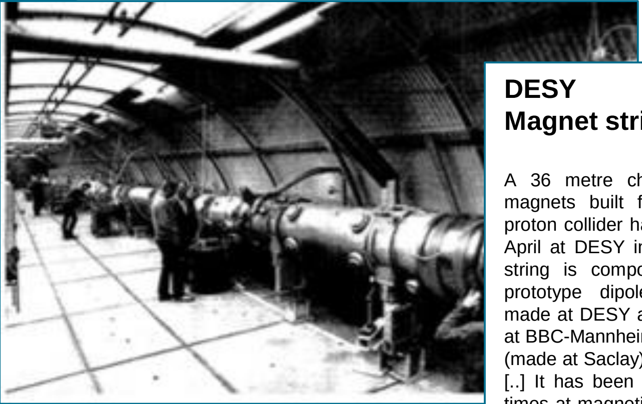
The IT STRING should comprises all magnets with their cold and warm powering and associated cryogenics systems from Q1 to D1 magnets including DFX. […] The IT STRING will have conditions as similar as possible to the operational ones and will constitute an integration and system test of the most critical part of the upgrade.

Ref. HL_WP16 Conceptual specification : *https://edms.cern.ch/document/1586706/1*

Previous experience - past

In the past **STRING tests** were run for

SSC
Hera
Tevatron,
RHIC and
LHC



DESY
Magnet string tests

A 36 metre chain of superconductive magnets built for the HERA electron-proton collider has been under test since April at DESY in Hamburg. The magnet string is composed of three full-sized prototype dipole magnets (with coils made at DESY and mounted in cryostats at BBC-Mannheim) and two quadrupoles (made at Saclay).
[..] It has been quenched more than 20 times at magnetic fields between 1.8 and 5.8 tesla, the latter corresponding to a proton beam energy of 1010 GeV

CERN Courier, December 1987

Hi Marta – I checked with Erich Willen, who was head of the magnet division at the time. **In RHIC, a full cell has two dipoles and two quads. There were two full cell tests set up in trenches in the floor of the magnet building.** The second one successful (magnets reached operating current), but no report exists.

At a later time, the first sector of magnets (1/6 on one ring) was installed in RHIC, cooled, and reached operating current. I am unaware of a report on this test. The tests were generally successful, but there were still a couple of problems that were found and fixed only after the full machine was installed.

Peter

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CONSTRUCTION AND INSTALLATION OF THE SSC ACCELERATOR SYS
TEST CRYOGENIC SYSTEMS

T. Ankermann, M. Freeman, T. Kobel

Process Systems International, Inc., 20 Walkup Drive,
Westborough, Massachusetts 01581-5003 U.S.A.

The Superconducting Super Collider Laboratory is installing three cryogenic systems for refrigerating superconducting magnets to the temperature range of 4.5-2.5K. The first of these three systems is dedicated to the Accelerator System String Test (ASST) which simulates the conditions of the Main Ring for a string of five magnets. The second cryogenic system will be installed adjacent to the first, and together they will be used to service the first actual sector (one-tenth) of the Main Ring. The third cryogenic system will be used for magnet performance testing at the Magnet Test Laboratory (MTL) and includes test stands to support five magnet tests running in parallel. This paper describes the cryogenic refrigeration hardware which has been constructed and reports on the progress of the installation and the commissioning of the ASST, MTL and N15B Cryogenic Systems.

BERKELEY LAB

Lawrence Berkeley National Labo
Lawrence Berkeley National Labo

Title:
The SSC Full Cell Prototype String Test

Author:
McInturff, A.D.

Abstract—At the conclusion of the S
string testing program in February, 1993,
analysis revealed that several substantiv
remained unresolved. These questions we
voltages to ground (>2 kV) measured d
conditions be substantially reduced, 2)
magnetic elements that became resis
controlled and 3) did the cryostats of th
provide adequate insulation and isolation to meet designed
refrigeration loads. To address these and other existing
questions, a prototypical full cell of collider magnets (ten
dipoles and two quadrupoles) was assembled and tested. At the
conclusion of this testing there were definitive answers to most
of the questions with numerical subs...
exception being the heat leak questio
other results and issues are presented in

THE LHC MAGNET STRING PROGRAMME : STATUS AND FUTURE PLANS

F.Bordry, J.Casas-Cubillos, P.Cruikshank, K.Dahlerup-Petersen, F.Rodriguez-Mateos, P.Proudlock, G.Riddone, R.Saban, R.Schmidt, L.Serio, C.Wyss, CERN, Geneva, Switzerland.

Abstract

String 1, with one twin aperture quadrupole and three twin aperture 10-m dipoles (MB1, MB2 and MB3) powered in series and operating at 1.9 K, has recently been dismantled after four years of operation interrupted by technical stops and shutdowns for upgrading or exchanging equipment. Following the validation of the main LHC systems (cryogenics, magnet protection, vacuum, powering and energy extraction) the experimental programme was oriented towards the optimisation of the design and the observation of artificially induced fatigue effects.
The design study for String 2 has been completed. This facility, which will be commissioned in December 2000, is composed of two LHC half-cells each consisting of one twin aperture quadrupole and three 15-m twin aperture dipoles. A cryogenic distribution line housing

Model-based predictive control (MBPC) algorithms were investigated in order to obtain a narrower control band compared to standard PID control loops [5,6]. Preliminary results were encouraging but the temperature operational range was limited because only linear approximations of the process were used. Future developments are the implementation of non-linear models into the MBPC controller. Before being able to power the magnets an in-situ calibration of the temperature sensors was necessary. The observed reproducibility between sensors was better than 0.01 K and no degradation was measurable during the 4 years of operation.
The String was controlled and monitored [7] from a dedicated control room but could be controlled from any remote terminal with appropriate privileges. Over 600 process variables were archived during the lifetime of the String every second and, transients on voltage taps,

Previous experience @ CERN

1994-1998 STRING-1

ONE HALF LHC CELL

3 MB (10 m) + 1 MQ

2000-2004 STRING-2

ONE FULL LHC CELL

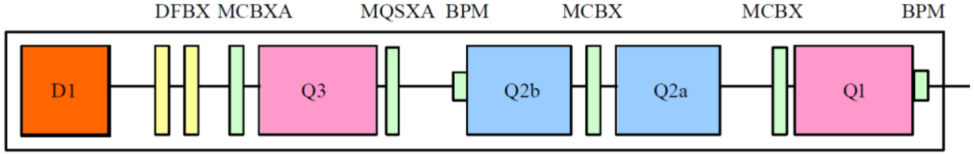
6 MB (15 M) + 2 MQ + CORRECTORS

'Validation of:

- Cryogenics,
- Vacuum
- Quench and protection
- Powering
- Accelerator relevant operation (e.g. quench propagation from magnet to magnet, tracking of MQ and MB)

Previous experience : LHC triplets

What have we learned from it?

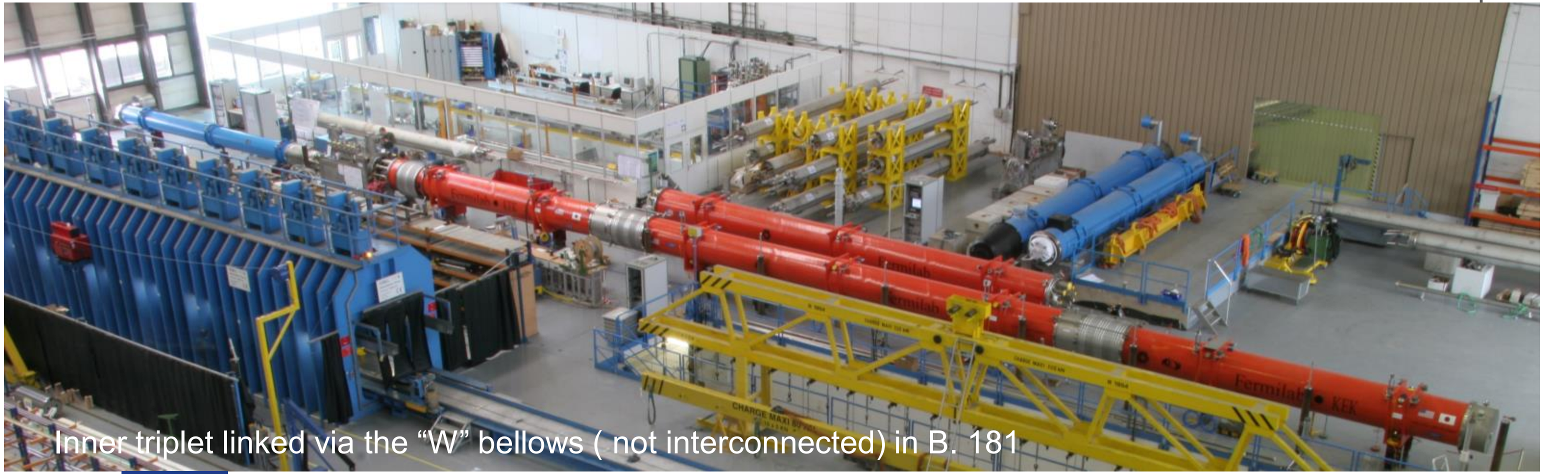


Ex. When pumping the vacuum magnets moved

2005 STRING of Q1 Q2 Q3

Validation of:

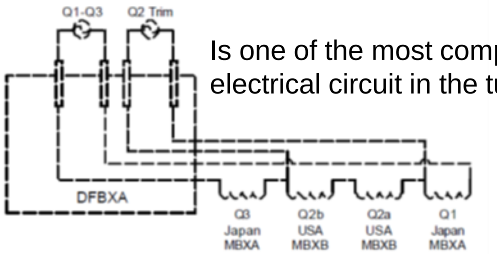
- ~~Cryogenics,~~
- (Insulation) vacuum
- ~~Quench and protection~~
- ~~Powering~~
- ~~Accelerator relevant operation~~



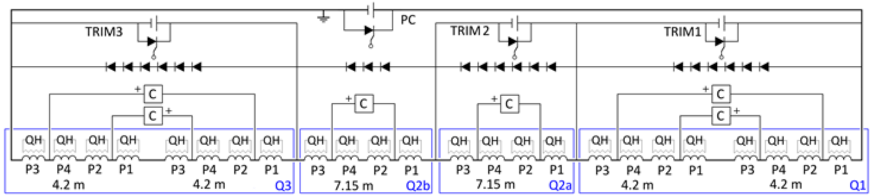
Inner triplet linked via the "W" bellows (not interconnected) in B. 181

Info from H. Prin

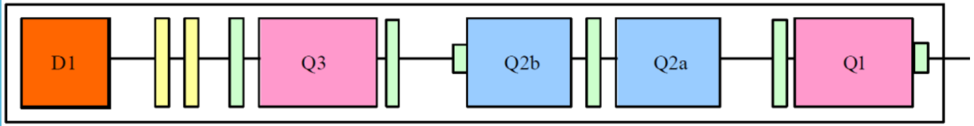
LHC vs HL-LHC triplet: few characteristics



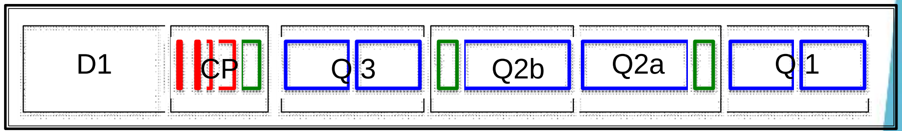
Is one of the most complex electrical circuit in the tunnel



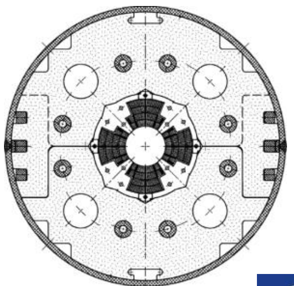
LHC



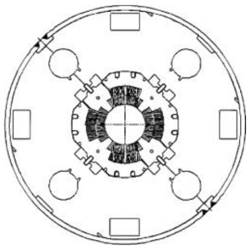
HL-LHC



MQXA



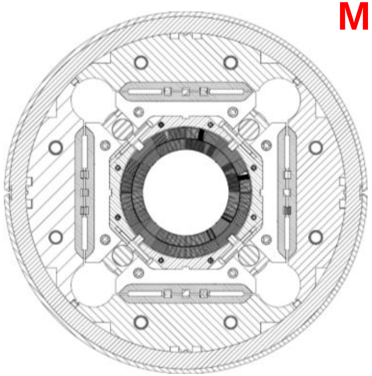
MQXB



Comparison of main magnet characteristics

- NbTi against Nb_3Sn technology
- 1.3-1.5 times the cold mass OD (to **630 mm)**
- 2.14 times the aperture: (to **150 mm)**
- ~ 4 times the e.m. forces in straight section
- ~ 6 times the e.m. forces in the ends
- 2- 4.8 times the stored energy (to **1.2 MJ/m**)

MQXF

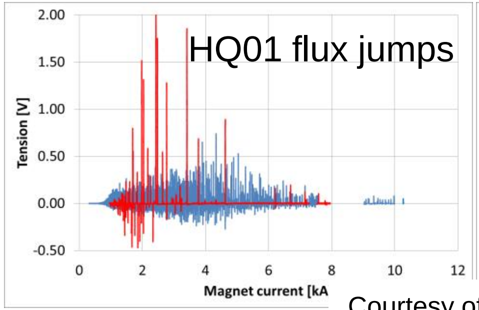


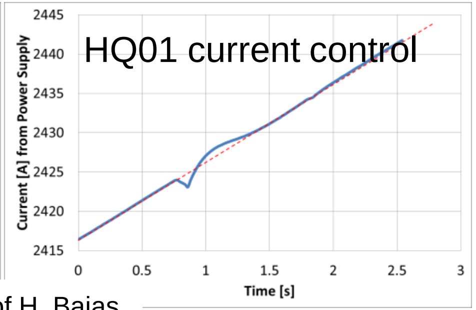
Courtesy of P. Ferracin and G. Willering and E. Ravaioli

Ex. of future experience to gain with IT String

Features related to Nb_3Sn :

- Flux jumps show up in Nb_3Sn magnets as a "noise", both in the terminal and compensated voltage
  - The effect ***propagates from one spot*** along the cable length
  - Poles are coupled magnetically, attempting to reduce flux changes
- ***Flux jumps*** are random in location, amplitude and occurrence
- They can influence powering (1 ppm control) as well as the detect-ability of normal transitions

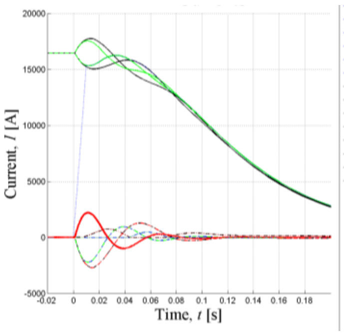




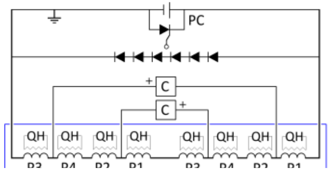
Courtesy of H. Bajas

Features related to the HL-LHC IT Circuit:

Cold masses powered and protected individually by ***cliq*** and quench heaters but once in a circuit the effect can propagate : the ***ringing***, the ***HV***. Return currents in the ***trim*** bus bars and main bus bars aswell as in the ***Sc link***

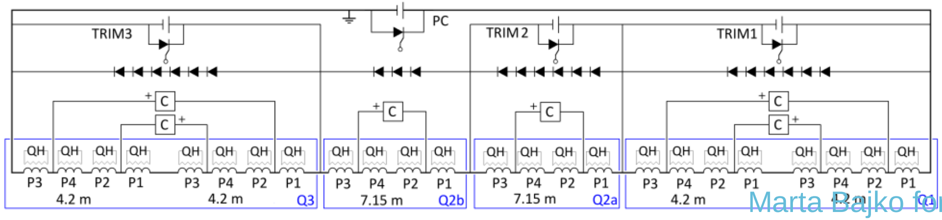


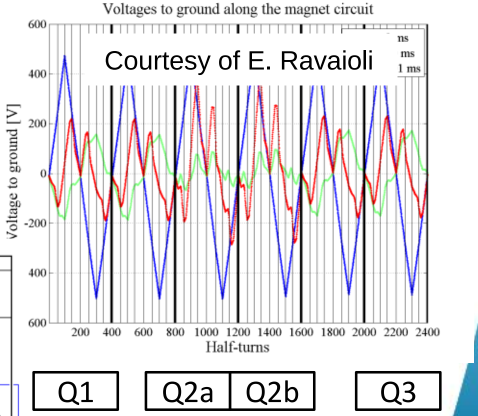
Cold mass test



All these aspects can be simulated **but test needs to validate the simulations**

Circuit test





HiLumi HL-LHC PROJECT

CERN

Relevance for the HL-LHC IT STRING

The HL-LHC IT-String can provide relevant experience (same object as in the LHC), validation (“first time” test) and advanced operation information on:

- Magnet positioning, alignment, interconnection procedures (do not under-estimate)
- Mechanical behavior of the IT continuous cryostat (Q1 to DFX) and other components (DSH, DFH) under pressure, vacuum, cool-down, operation and warm-up
- Cryogenic behavior and operation under static (and dynamic) conditions
- Insulation and beam vacuum static (and dynamic) behavior
- Powering behavior of the system with Sc links, dynamic response (and associated field quality), interaction of circuits
- Cross talk between magnets in operation and during a quench, detection, propagation and protection of the complete superconducting circuit

These aspects, especially the **collective behavior**, can only be tested in a representative test, a so-called STRING

GOALS in parallel:

GOALS in parallel:	**Develop methods, techniques** **Develop tooling** **Develop procedures**	for definition of	**Installations** **Test** **Operation**	to support	**HWC and OP of HL-LHC**

ID Card of HL-LHC IT-String

[…] a **FULL INTEGRAL TEST** of the equipment from **Q1 till D1** including the **DFX** is foreseen in the HL-LHC project, in CONDITION AS SIMILAR AS POSSIBLE to the operational one.

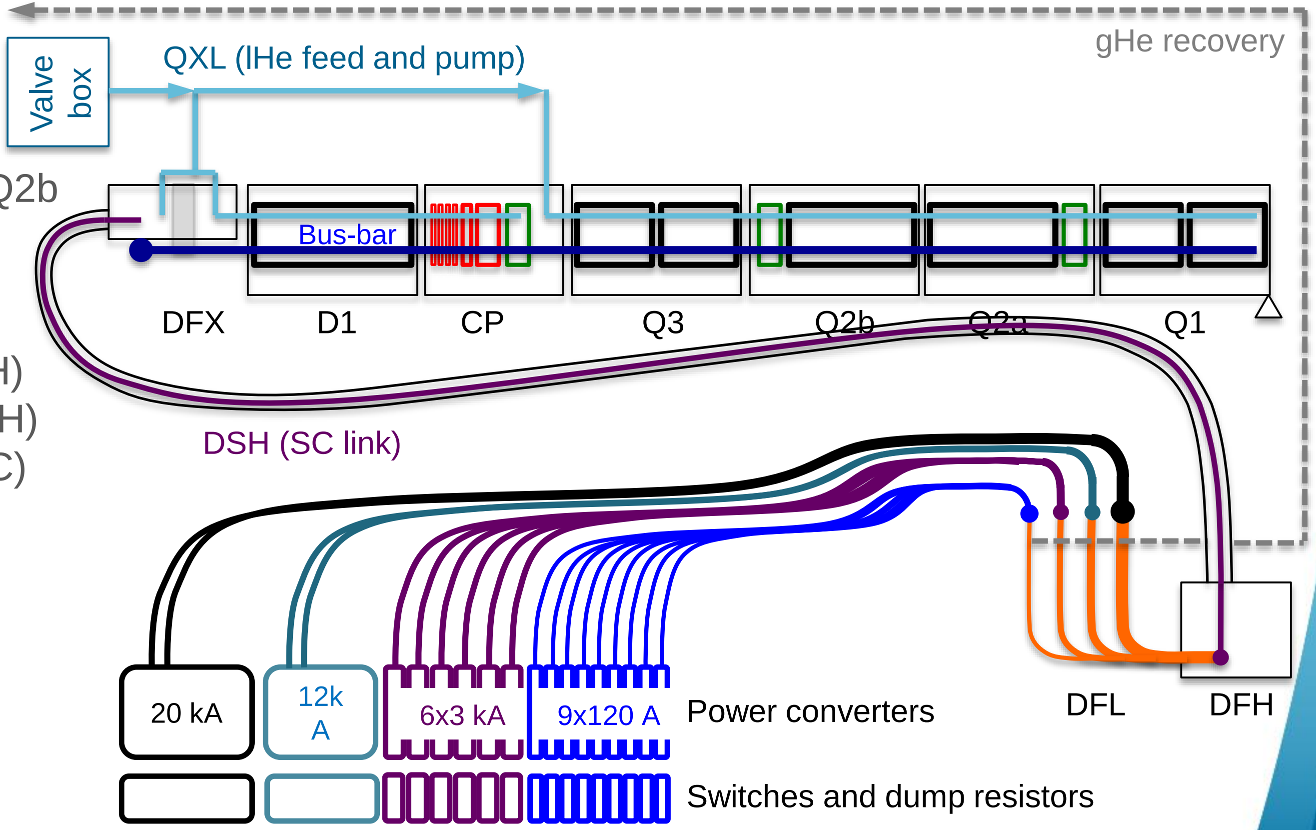
The IT STRING of the HL-LHC will be composed by systems previously tested individually at least in nominal operational conditions.

HL_WP16 Conceptual specification : *https://edms.cern.ch/document/1586706/1*

- Test Facility name: HL-LHC IT STRING
- Test Facility location: SM18 (b. 2173)
- Test date: 2021-2023
- Operational temperature: 1.9 K
- Operational current: 108% $I_{nominal}$ = 18 kA?
- Magnets: Q1, Q2a, Q2b, Q3, CP, D1
- Cold powering: SC link (60 m) HTS leads DFH and DFX,
- Warm powering: 1 x PC 18 kA , 3 Trim Q1-Q3, 6 x 2 kA , 1 x 12 kA, 9 x 0.1 kA
  Water cooled cables
- Protection: CLIQ , QH and EE

Main components and schematics

Magnets (D1 ,CP ,Q3 ,Q2a ,Q2b ,Q1)
Beam Screens
Connection Module (DFX)
Superconducting Link (DSH)
Current Leads (DFL and DFH)
Water Cooled Cables (WCC)
Power Converters (PC)
EE and Protection
Interlock and DAQ system



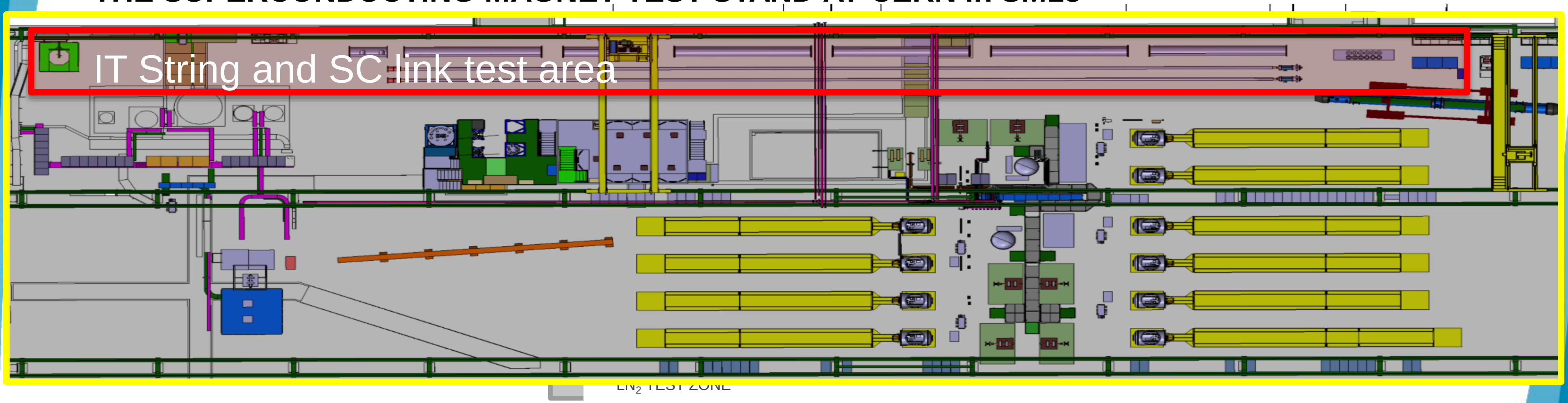
Location of IT STRING test: SM18

- Bdg. 2173 (a.k.a. SM18) has a surface of 7200 m^2, of which the magnets test stands occupy about 50%.

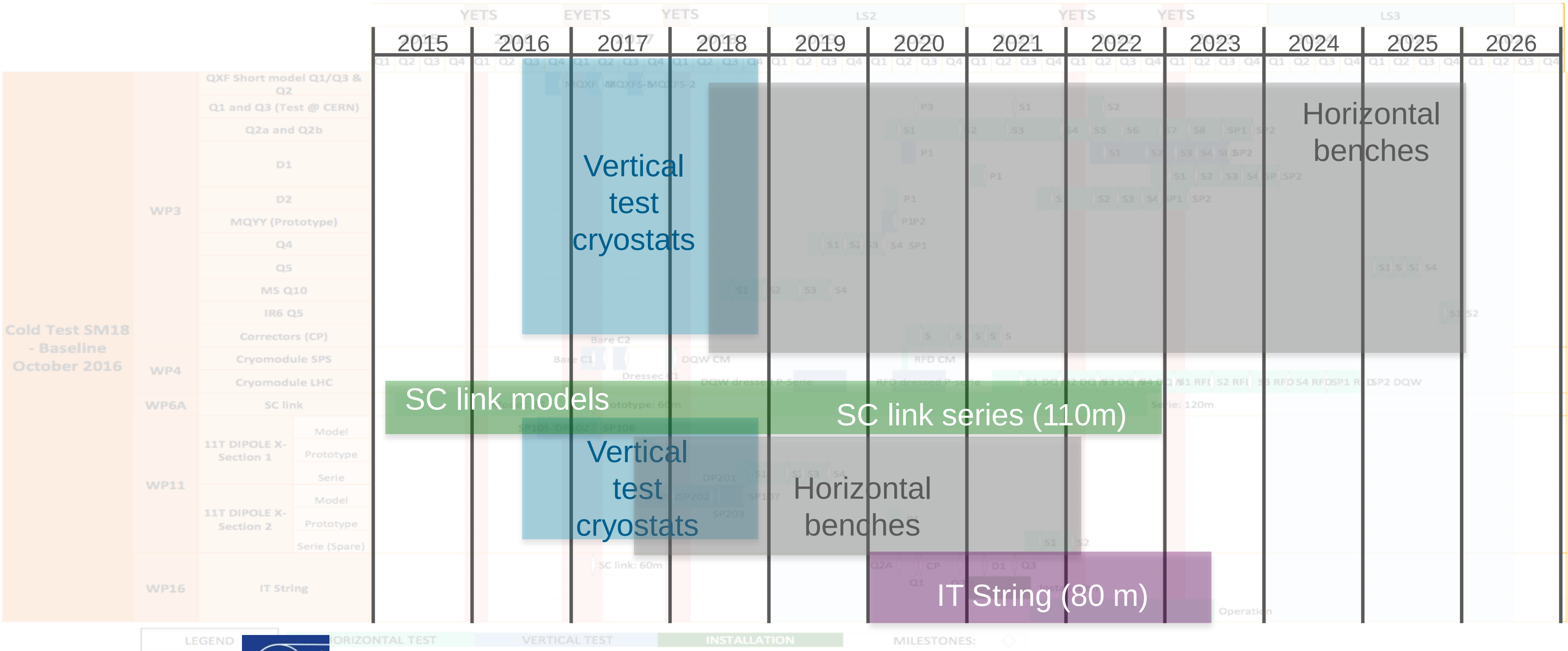
IT STRING test in SM18

Limitations in space in SM18

THE SUPERCONDUCTING MAGNET TEST STAND AT CERN in SM18



Conflict/synergy between test stands/IT String ?



Test stands collaborating for HL-LHC

Main Facilities needed for the HL-LHC IT STRING

UPGRADE DRIVEN BY the recommendation enabling to carry out the full test programme with no contraints

CRYOGENIC COOLING PRODUCTION: **+ 35 g/s LHe to 60 g/s**

NEEDS essentially for the running of the HL LHC IR STRING in parallel with magnet testing

DEMINERALISED WATER PRODUCTION: **150 m^3/h** ✓

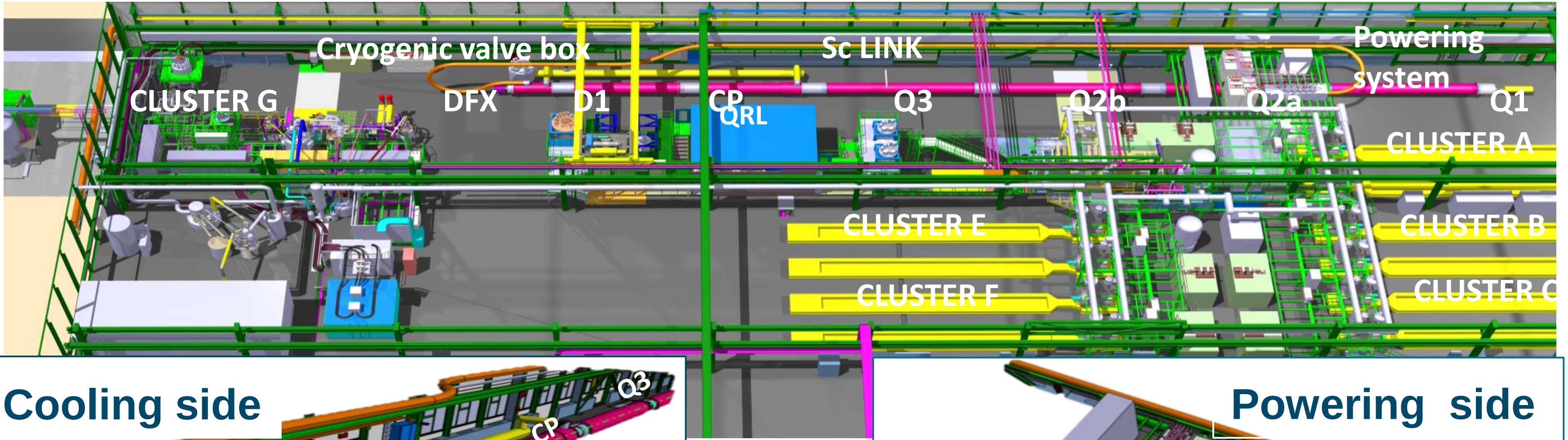
NEEDS FOR DEMINERALISED WATER ENTIRELLY COMING FROM MAGNET operation

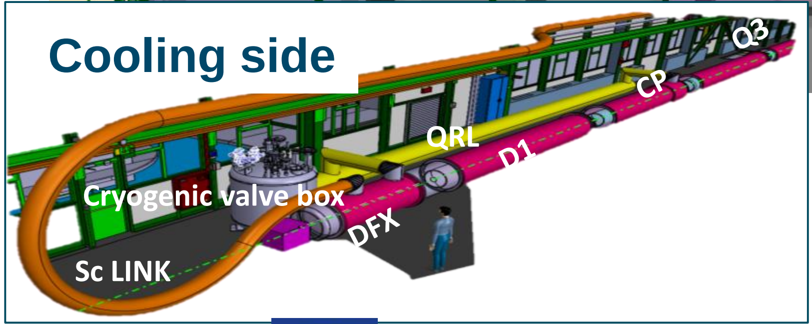
POWERING FROM THE NETWORK: **3 MVA**

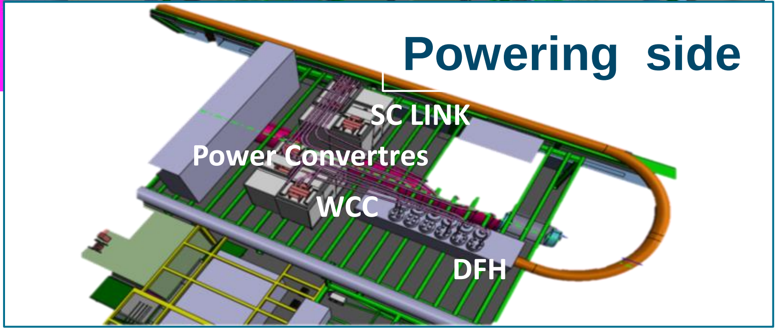
NEEDS FOR NEW OR MODIFIED PC COMING FORM MAGNETS and IR STRING

SM18-UPG project of the TE department under the responsibility of V. Mertens:
[..] the upgrade of all necessary services to cover the needs for the test stands operation (this includes the HL-LHC STRING as a test stand of a ***<u>complete</u>*** *system).*

Work in progress







Thanks to A. Kosmicki

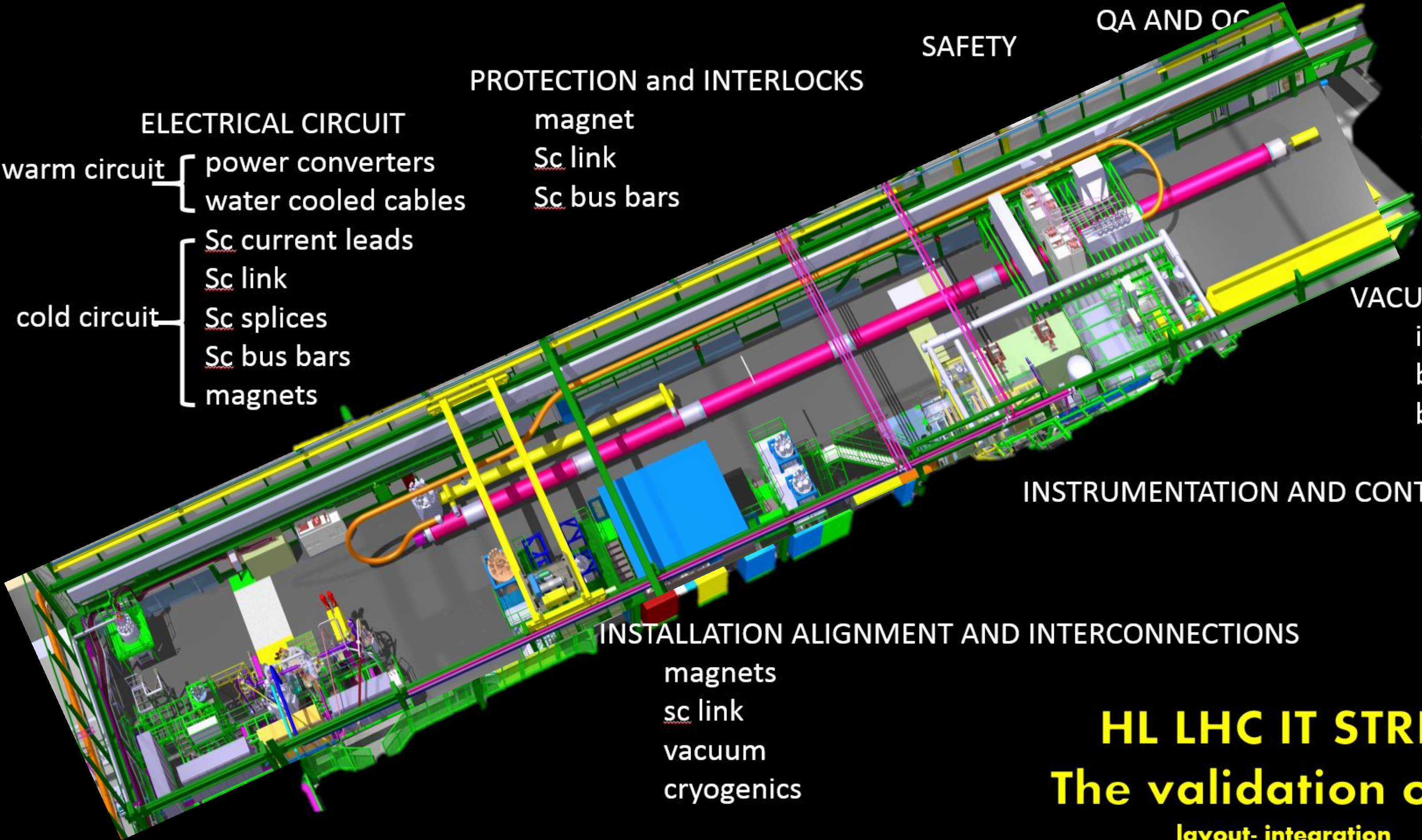
Current status

- Integration ongoing with all elements that we know today
- Budget estimation (5.8 MCHF) has been done and now is under verification
  The strategy is that
  - All main components are part of the concerned WPs (prototypes or series of WP3, WP6a and WP6b, WP7, WP12)
  - All components designed in purpose for IT STRING with the goal of the test stand optimisation (local cryogenics , water cooled cables. …) are part of WP16
  - All services are assured within the SM18 UPG project (financed by TE dep. and HL-LHC project)
- Manpower estimation has been done and now is under verification by WPs
- On-going discussions for complete test plan definition with
- WPs and different groups @CERN

HL LHC IT STRING TEST

The validation of a system

layout- integration
installation sequence and procedures
the collective behaviour of components



ELECTRICAL CIRCUIT

- warm circuit
  - power converters
  - water cooled cables
- cold circuit
  - Sc current leads
  - Sc link
  - Sc splices
  - Sc bus bars
  - magnets

PROTECTION and INTERLOCKS

- magnet
- Sc link
- Sc bus bars

SAFETY

QA AND QC

OPERATION

- field reference
- tracking

VACUUM

- insulation
- beam
- beam screen

INSTRUMENTATION AND CONTROL

INSTALLATION ALIGNMENT AND INTERCONNECTIONS

- magnets
- sc link
- vacuum
- cryogenics

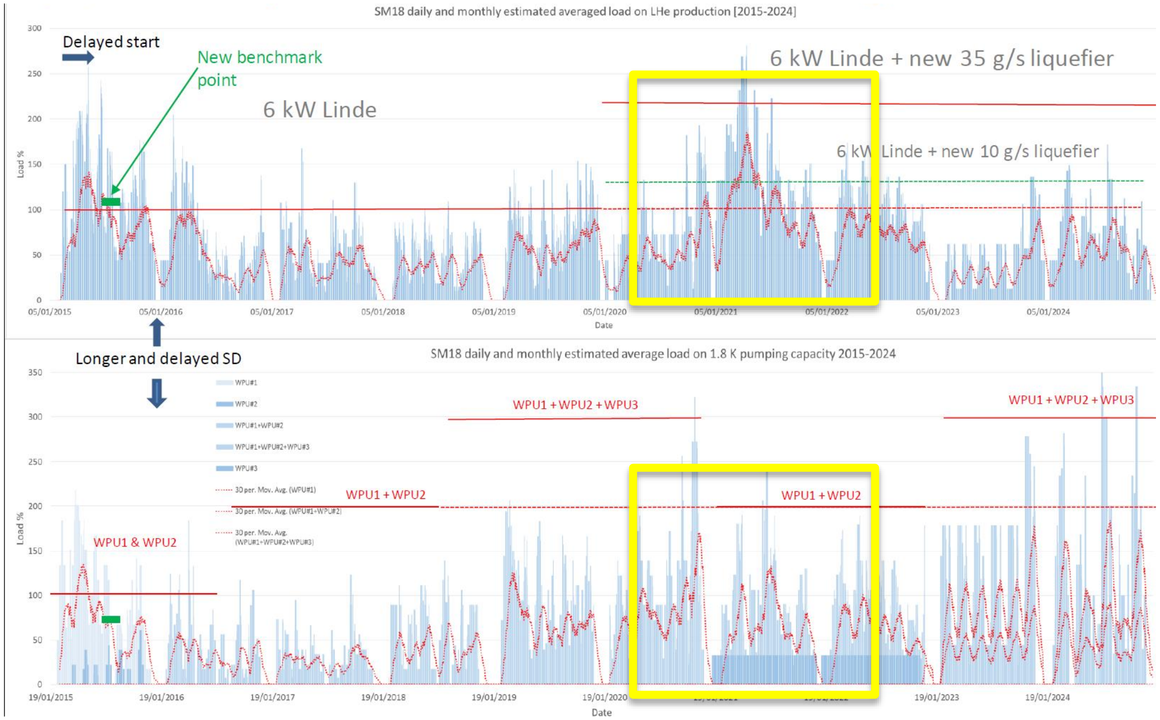
@SM18 2021-2023

Thanks for your attention

Spare Slides

logo
area

Test stands : cryogenics upgrade



An additional **35 g/s liquefier** (thus bringing the **total production capacity for LHe at 4.2 K to 60 g/s)**

The existing total pumping capacity in SM18 at **1.8 K is 12 g/s**, **combining** the capacity of **WPU1 and 2**.

If need for IR STRING a dedicated 3rd WPU shall be installed.

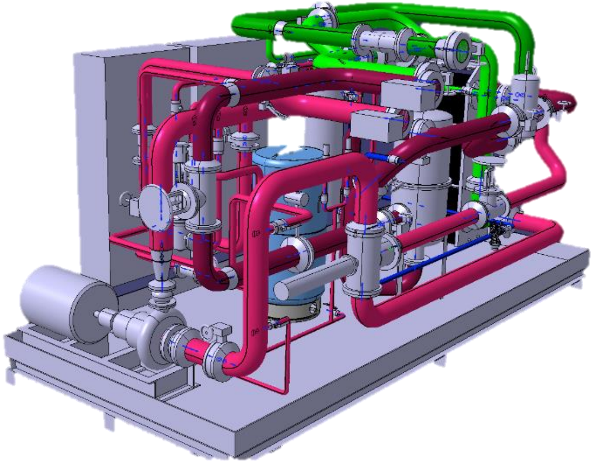
Ref. L. Serio

Foreseen for 2019

Test stands : demineralized water production

The demands for the magnet test stations, including the IT String, will rise to a peak need to 1.7 MW (142 m^3/h).

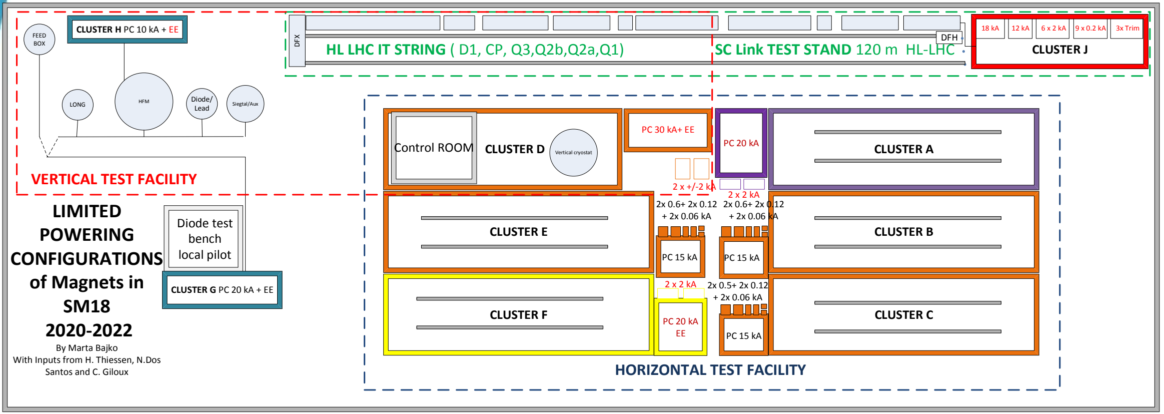
In the past SM18 had a demineralised water station with a thermal capacity of 800 kW limiting the operation to two test stands



Operational from April 2016

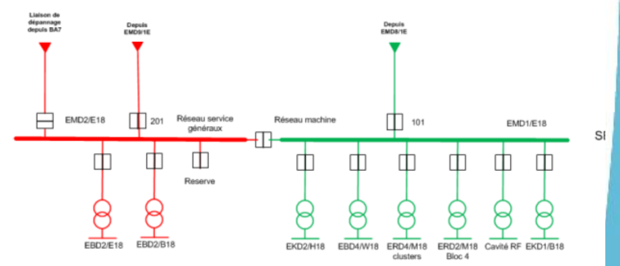
Ref. A. J. Broche

Test stand : electrical powering

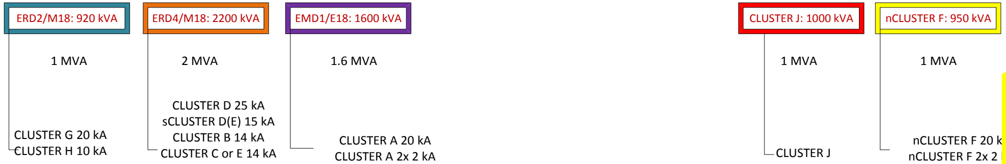


- 18 kV power consumption and margin

EMD201/E18		EMD101/E18	
Power available	18 MVA	Power available	18 MV
Maximum measured load	6.75MVA	Maximum measured load	7.85 M



Foreseen for 2019



The new transformer will feed HL-LHC IT STRING (Cluster J) and the new Cluster F with the 20 kA power converter.

TEST STAND	...pacity by ...nnection [MVA]
	2
Horizontal	2
IT STRING	3
Vertical	2

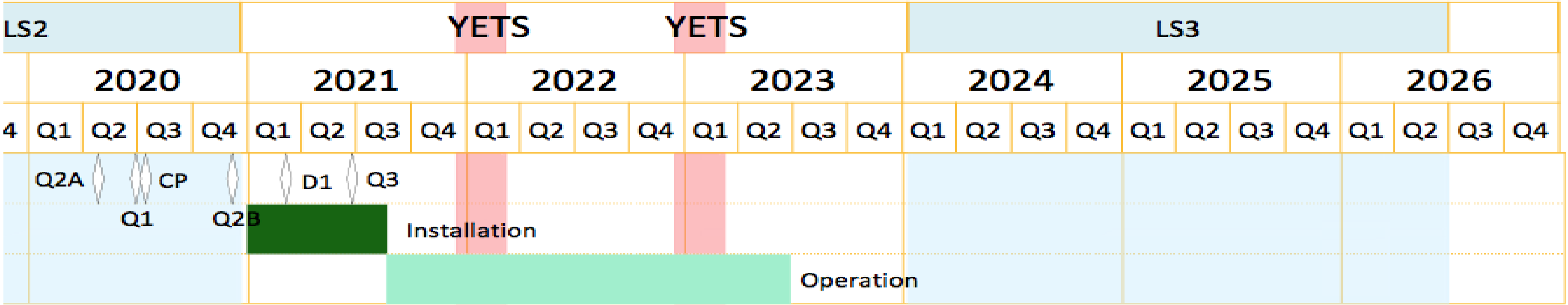
To allow some flexibility and margin with new requests that are not formulated yet, the proposal is to **INSTALL a TRANSFORMER OF a 3 MVA CAPACITY**

Ref. C. Giloux, F. Formenti, N. Dos Santos

Schedule

- Installation starts as soon as magnets are (individually cold tested) available and receptioned at CERN

  (3 months for transport from Japan (D1) and US (Q1/Q3), no re-testing planned)
- No staging, only one test phase (possibly several runs)



By courtesy of M. Barberan Marin