Two new Helium Refrigerators for the LHC accelerator upgrade (HL-LHC) at CERN; From Concept and Tender to Contract

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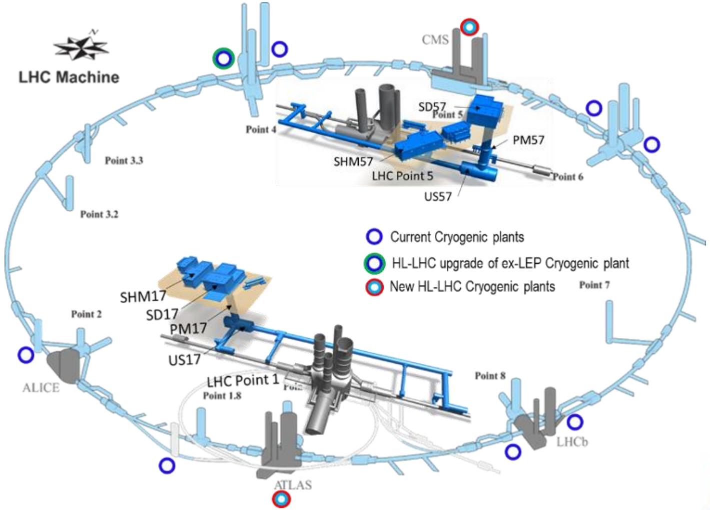
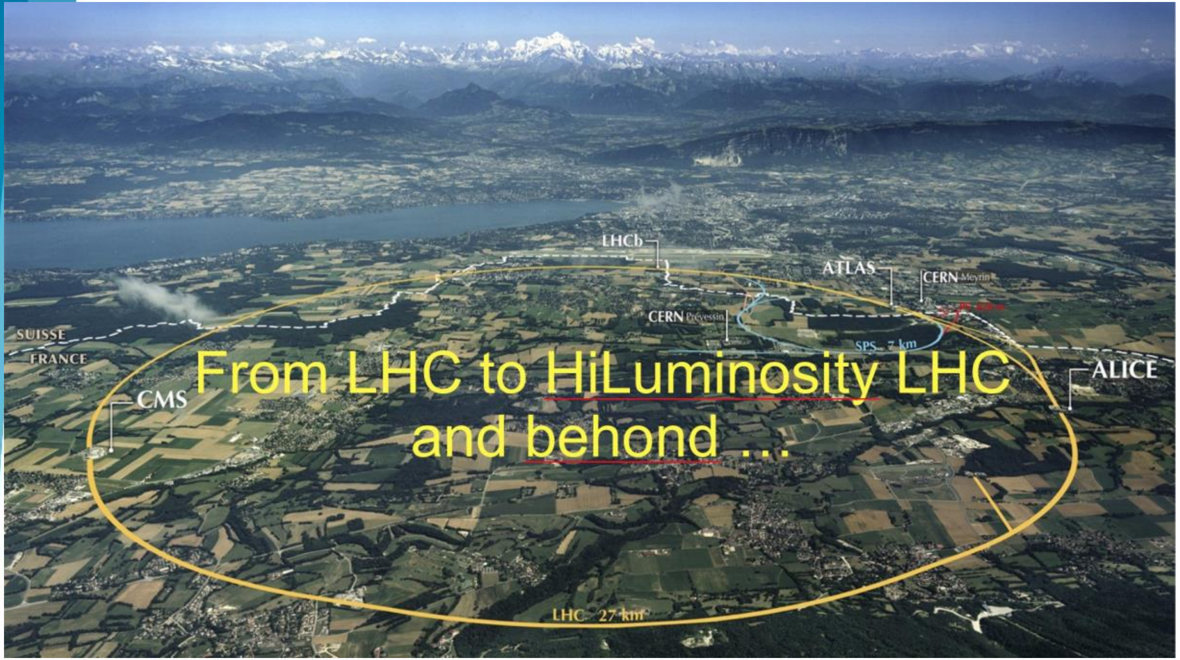
25th CEC/ICMC
Session C4Or1B: Large Scale Refrigeration / Liquefaction V
Honolulu, 13th July 2023

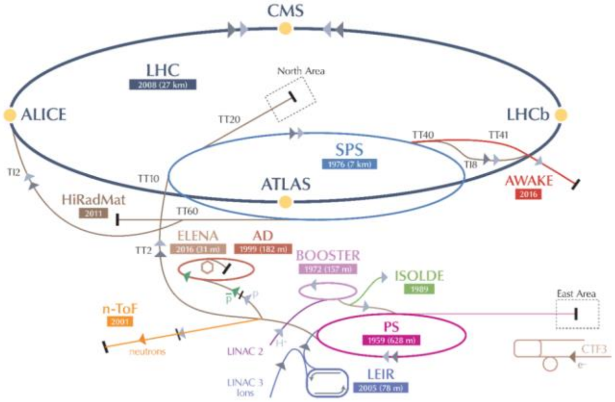
Outline

- Introduction, CERN and Cryogenic System from LHC to HL-LHC
- HL-LHC Cryogenic System Architecture
- HL-LHC Refrigerators Technical Requirements
  - Operational and Loads Requirements
  - Concept and Specific Requirements
  - Testing Methodology
- HL-LHC Refrigerators Project Status
  - Tendering and evaluation
  - Status & Schedule
- Conclusion & Challenges



CERN in Brief





Funded in 1954 as "Science for Peace"

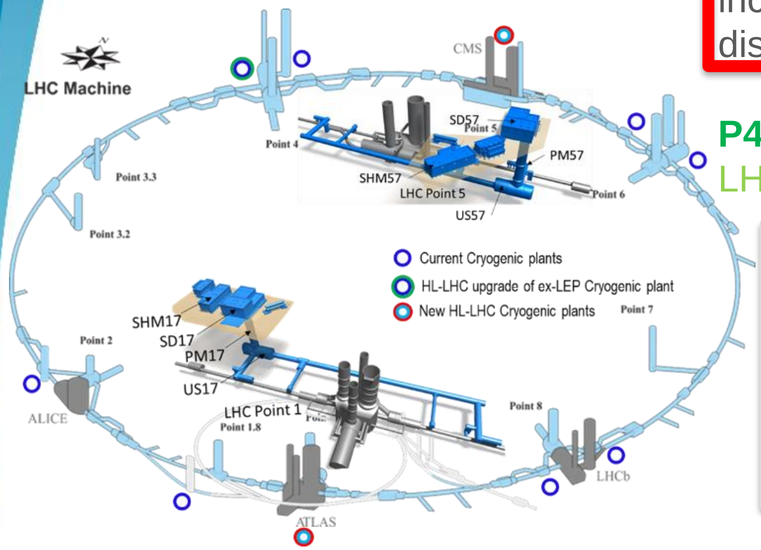
Now with 23 member states

2'300 staff, 1'600 others & 10'500 users

1'200 MCHF annual budget (pro GDP)

A very large technical site for a series of accelerators, detectors and computing serving particle physics towards high energies and diversity

Introduction, CERN Cryogenics; from LHC to HL-LHC

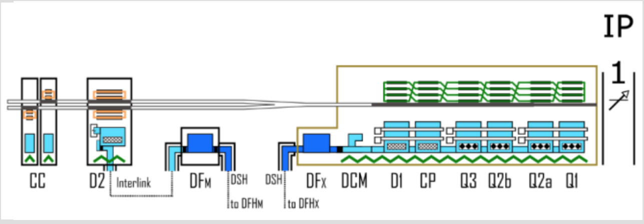


P1-P5: 2 new cryoplants (~14 kW @ 4.5 K incl. 3.25 kW @ 1.9 K) and 2 x 750m cryo-distribution for high-luminosity insertions

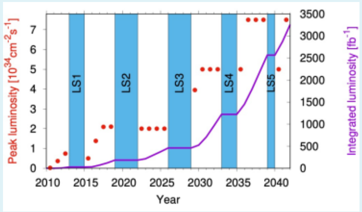
To provide adequate cooling for:

P4: upgrade (+2 kW @ 4.5 K) of an existing LHC 18 kW @ 4.5K cryoplant

P1-P5 machine devices



HL-LHC performance



- HL-LHC project at CERN to increase the Peak Luminosity to a factor of 5 to 7 w.r.t the nominal
- Higher luminosity = higher cryogenic heat loads

HL-LHC P1/P5 Cryogenic Architecture

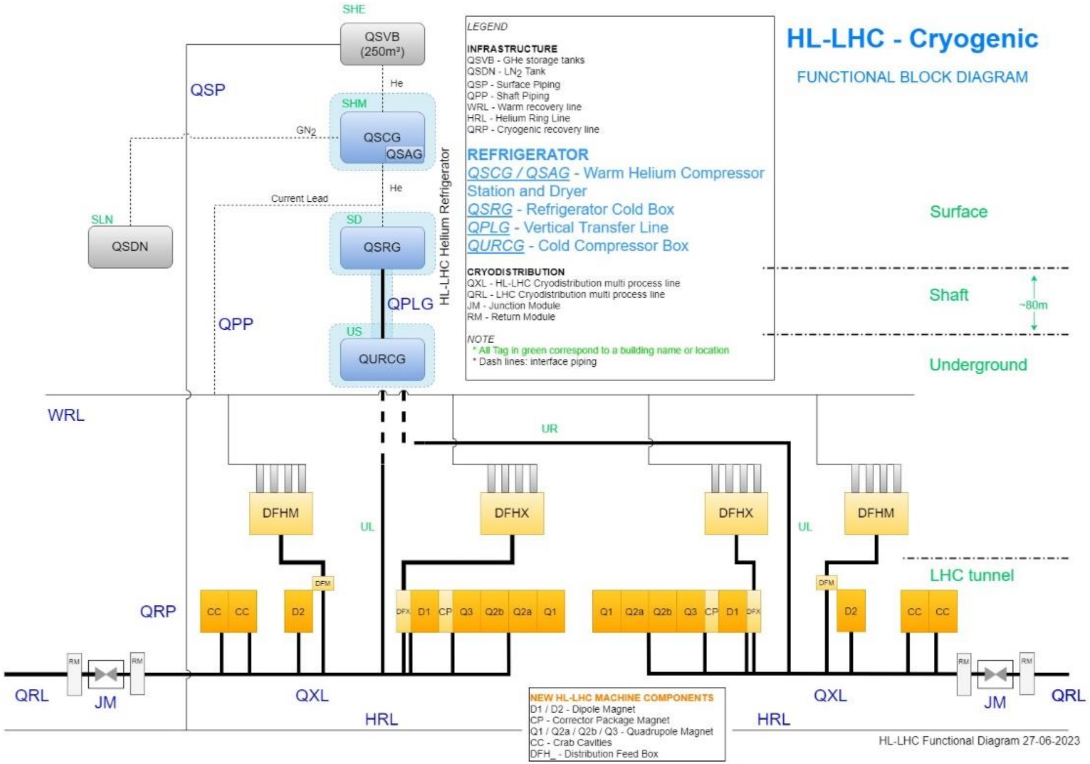
QSRG : Compressor station providing gaseous helium **20 B**

QSRG : 4.5K refrigerator providing supercritical helium at **3 bara and 4.6 K**

QPLG : Vertical transfer line (~80 m height)

QURCG : Cold compressor box providing cooling capacity at **1.8 K**

Users at tunnel level



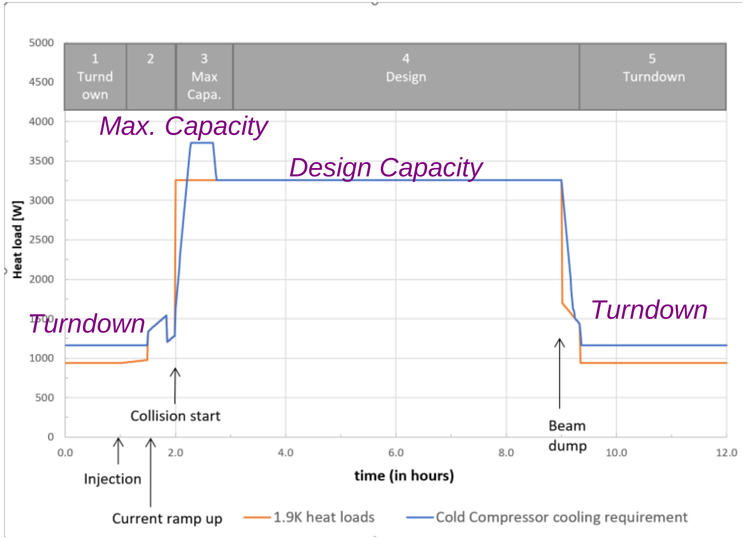
QXL : Distribution line distributing C,E and returning B,D,F
- 70 m for the common branch
- 270 m for the long branch
- 60 m for the short branch

RM/JM : Return module and junction module at extremities for transient handling and back-up

HL-LHC Refrigerators Operational and Loads Requirements

- HL-LHC Operation Modes
  - The Maximum Capacity mode
  - The Design Capacity mode
  - The Turndown mode

- HL-LHC Transient Modes
  - Cooldown – Magnet quench training and Cold-stand-by mode during technical stops
  - Warm-up or Long shutdown for major maintenance
  - Any component or utilities failures



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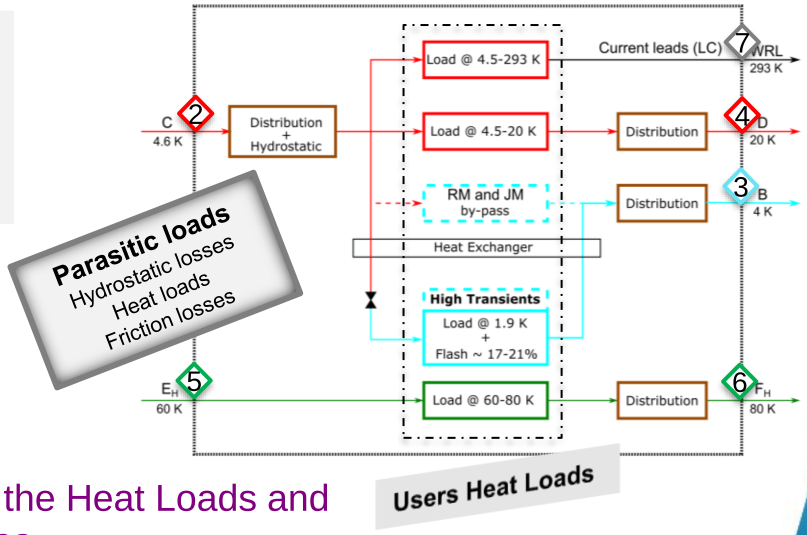
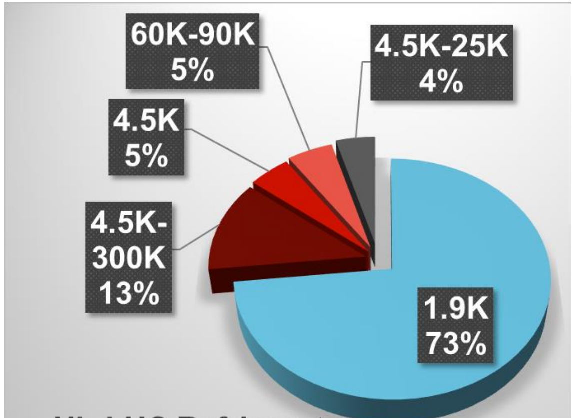


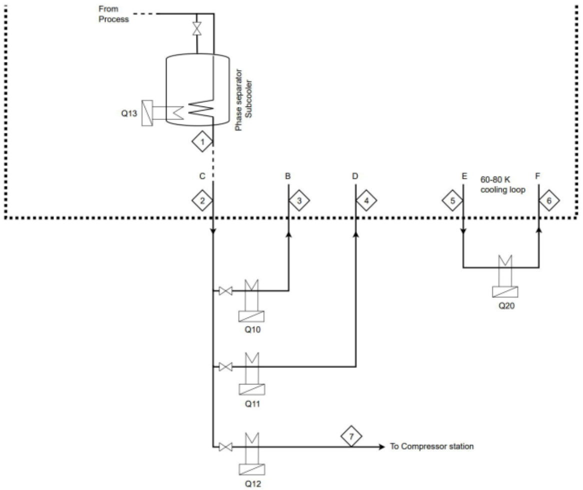
Definition of all operation modes & the Heat Loads and Process Interfaces

HL-LHC Refrigerators Operational and Loads Requirements

Operation mode	Q10	Q13	Q11	Q12	Q20
Temperature level	1.9 K	4.5 K	4.5 K-25 K	4.5 K-300 K	60 K-90 K
Maximum Capacity	3760	-	1320	23	13000
Design Capacity	3250	700	1320	23	13000
Turndown	1100	-	700	10	6000



HL-LHC Refrigerators 4.5K Equivalent Heat Loads

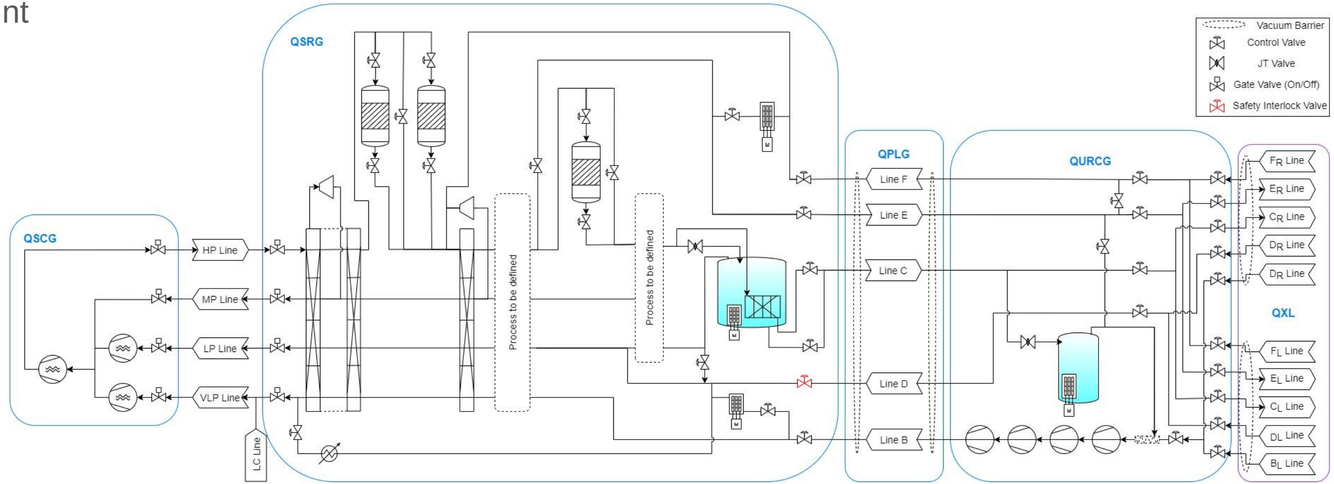


- Heat Loads to the Refrigerators
  - Q10: Superconducting magnets
  - Q11: crab cavities beam screen and heat intercept
  - Q12: non-isothermal cooling of the electrical feedbox system, including the MgB2 superconducting link (< 20 K) and the HTS currents leads (< 50 K)
  - Q13: Margin and Test
  - Q20: Thermal Shield

2 x 14kW@4.5K, including 3.25kW@1.9K

HL-LHC Refrigerators Concept and Requirements

- Integrated 1.9K Mixed cycle / 4 pressures
- **4 floating pressures** including the LP (with ~75% of loads at 2K and almost no load at 4.5K, no need to impose a fix LP)
- **4 Cold Compressors** (to maintain a high suction pressure for the VLP warm compressor and preserve its volumetric and isothermal efficiency)
- No request for multiple warm compressor per compression stage – see fallback solution with JM
- A single cold compressor box integrating the safe isolation valves and the distribution on both side of the insertion point

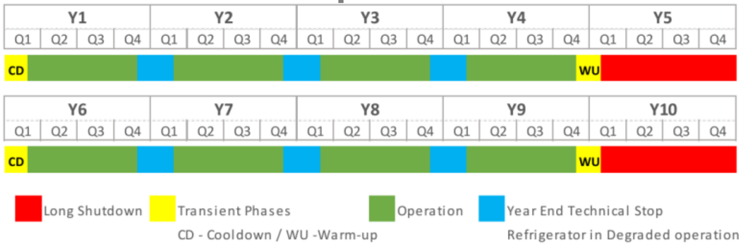


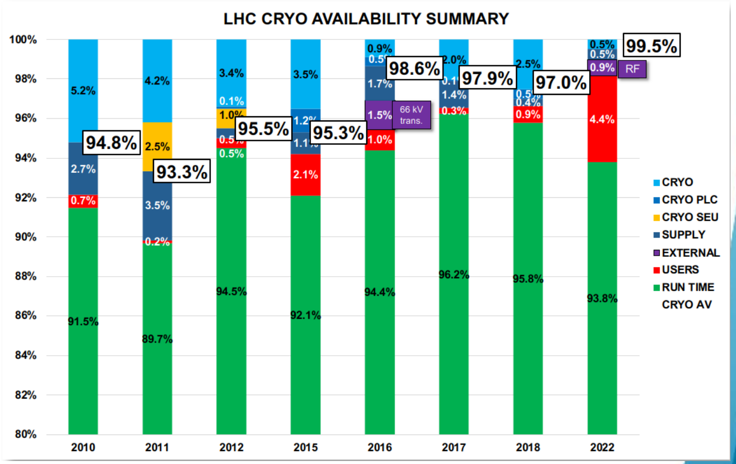
☑ Process Feasibility studies with Air Liquide and Linde Kryotechnik

HL-LHC Refrigerators Concept and Requirements

- Basis for Design
  - Design based on industrial cryogenic technology and a **MTBM >40´000hours**
  - Refer to **European or international standards** for rotating machine and heat exchangers
  - A targeted **Availability >99%** (current LHC availability)
  - Preservation of the **Environment**
    - Noise
    - No release to atmosphere (except He and N_2)
    - Heat recovery

HL-LHC Operation Plan





HL-LHC Refrigerators Concept and Requirements

- Specific Requirements (compared to LHC refrigerators)
  - Single **Dryer** – By-pass and helium cooling after regeneration
  - **Heat Recovery** – HP stage, in serie with main oil cooler with by-pass
  - **Buildings** – Already built ! (profit from civil engineering work for the new pit, cavern and galleries made during LS2)
  - **Control System** – Hardware and software managed by CERN

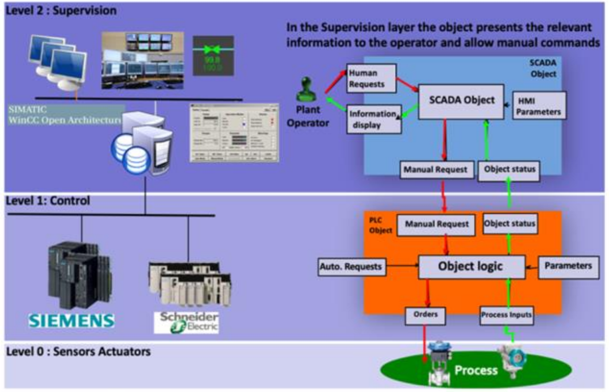
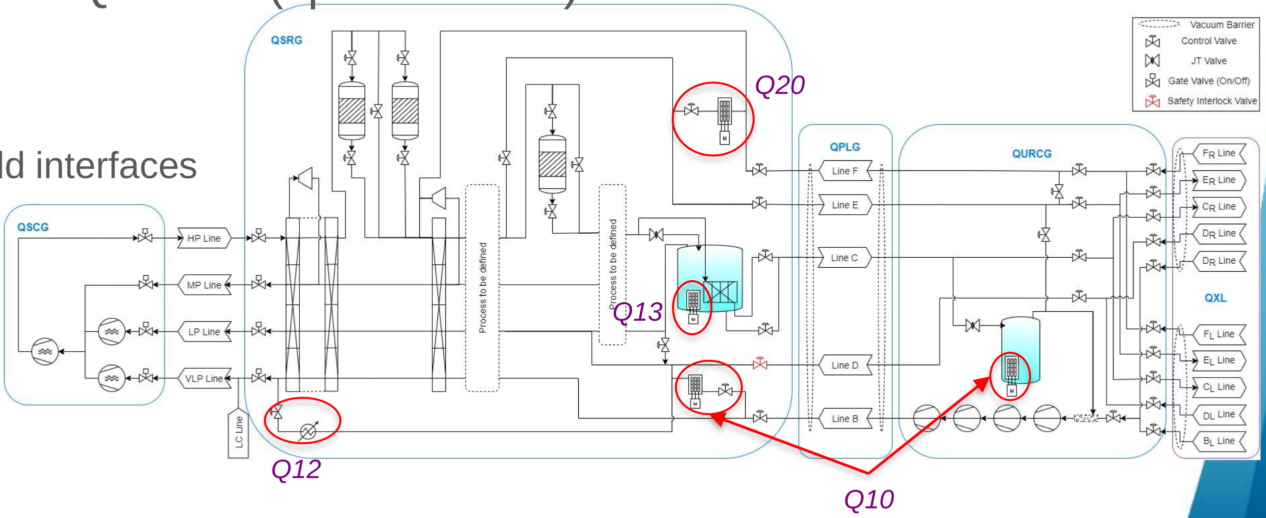


Fig. 6 UCPC Control & supervision layer integration

HL-LHC Refrigerators Testing Methodology

- Individual Test of each sub-system tested starting by the QSCG - logic sequence
- Final Performance test done with built-in heaters and flow meters
- CCs transient mode – flow variation +/-7g/s
- Minimize heater test in QURCG (space limited)
- Not tested
  - Q11
  - Heat loads at the cold interfaces

Testing methods definition are as important as the definition of loads requirements for a Contract



HL-LHC Refrigerators Tender and Evaluation

- Mid 2020: **Market Survey** to qualify firms
- Early 2021: **Process & feasibility studies -** minimized risk of mis-understanding
- Q4-21-Q2-22: **Invitation to Tender** (extended)
  - A set of requirements (performance, technology) to allow industry to provide the optimum for a given scenario

- Adjudication: CAPEX + OPEX (10 years)

$$\text{Total adjudication Cost} = \text{CAPEX} + \text{OPEX (P1)} + \text{OPEX (P5)}$$

Guaranteed Electricity input power (3.3.kV) times
2 Main Operation modes over 10 years

$$\text{OPEX} = (P_{DCTest} \times 52\,000 + P_{TdTest} \times 26\,000) \times 0.075\ \text{CHF/kWh}$$

Electrical cost for adjudication

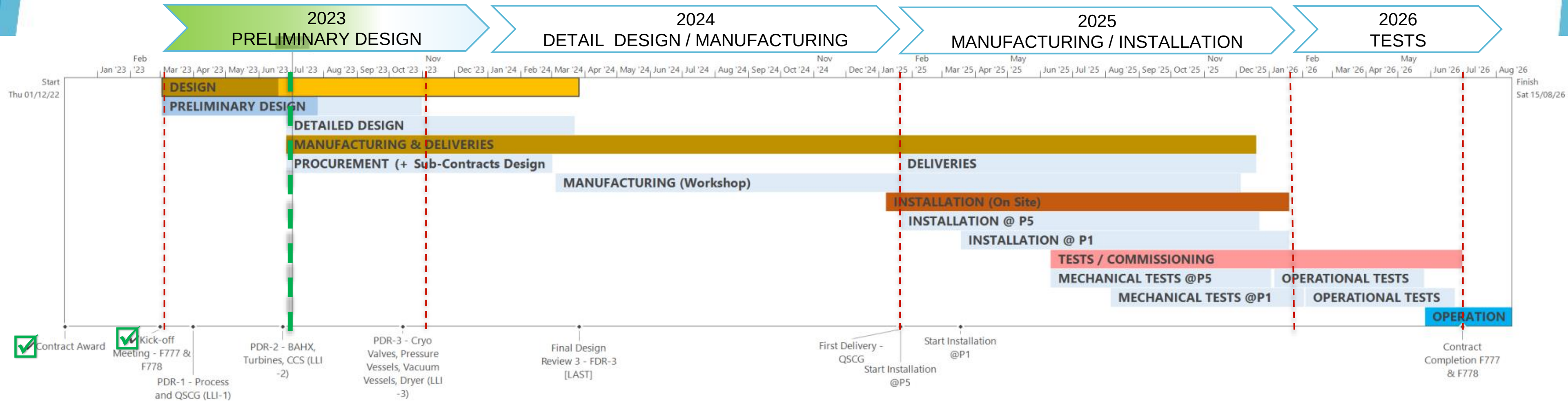
- Performance Test at CERN (Bonus/Malus)

Selection of single source for the two refrigerators

Linde Kryotechnik AG

HL-LHC Refrigerators – Status and Schedule

- 3.5 years Contract
- Under Preliminary design phase (60% completed)
- Early 2025 – First Delivery
- 2026 – Commissioning and Performance Test



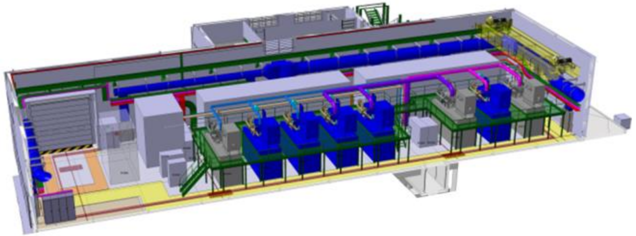
new HL-LHC buildings already done !!!

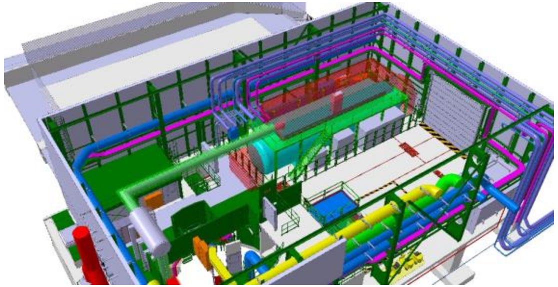
Civil Engineering @ LHC P1 Sept. 2022

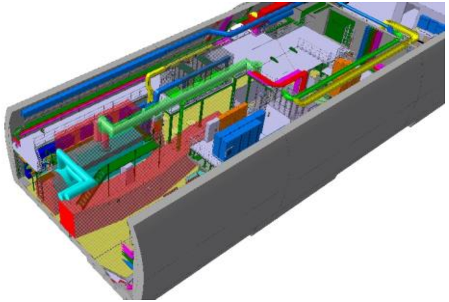
SHM – Compressor Station

SD – Refrigerator Cold Box

US – Cold Compressors Box







CERN HL-LHC Refrigerators Conceptual Design
14kW@4.5K including 3.25kW@1.9K

Conclusion & Perspectives

- The HL-LHC Refrigerators are built upon the strong foundation of lessons learned from the LHC
  - Technical Expertise – Process, rotating machinery, operation and maintenance
  - Project management
  - Heat loads assessment with Users to a robust cryogenic architecture
- Prior the Tender a Process Feasibility Studies performed with Air Liquide and Linde Kryotechnik
  - To validate the CERN concept
  - To clarified the specific requirements
- Successful Tender
  - In a difficile international context (COVID-19 and Ukraine invasion) – 6 months
  - Contract made on cost effectives solutions based on materials and the European consumer indexes to share the risks
- Contract in place, already running at nominal
- Challenges - QURCG design (in cavern and handling in an 80m deep pit with limited space)
- Schedule
  - On time for performance assessment and running-in phase – 2026
  - Cooldown of HL-LHC machine in 2028 / Operation with beams to resume in 2029

Thank You

For additional question
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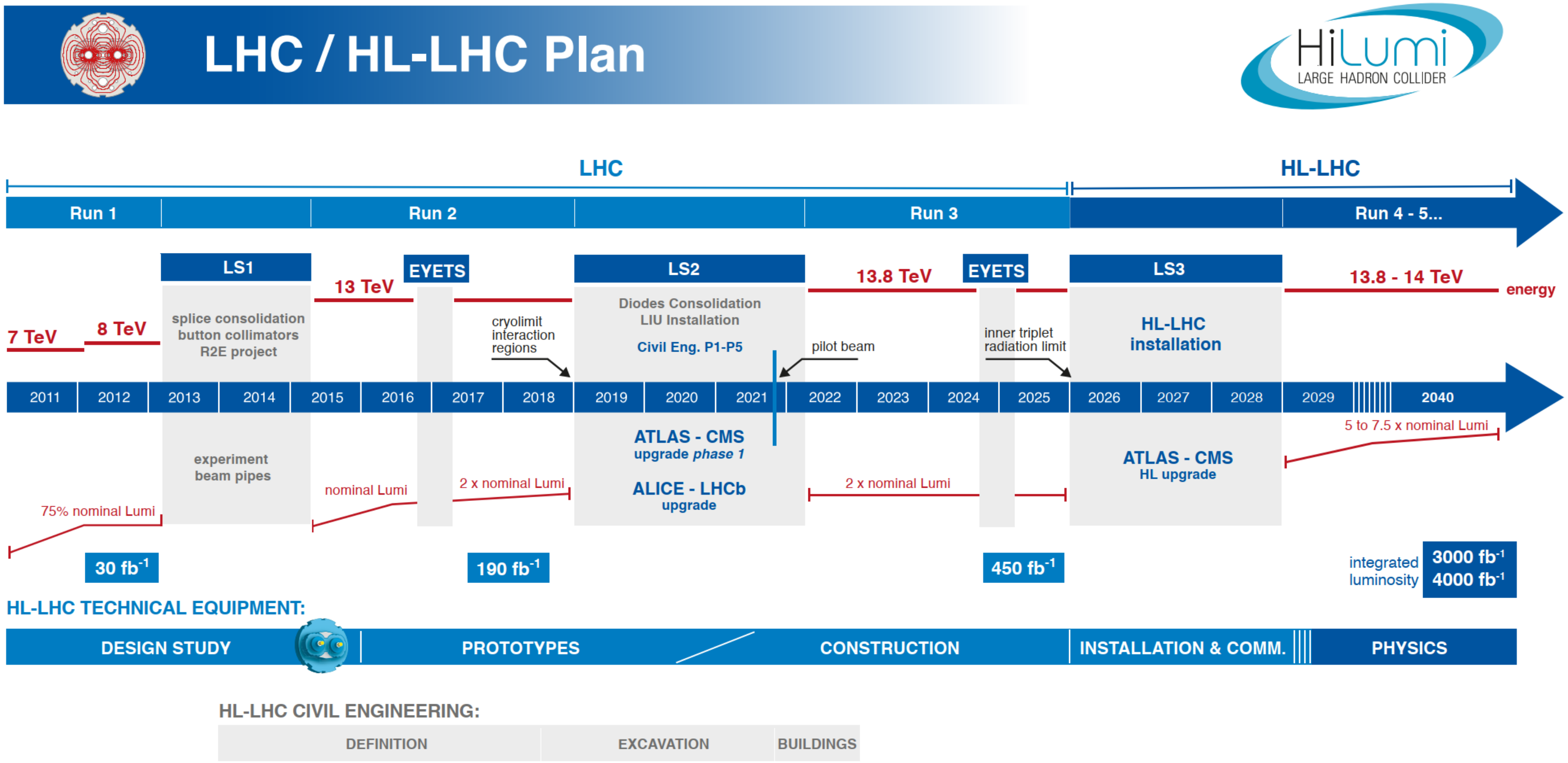
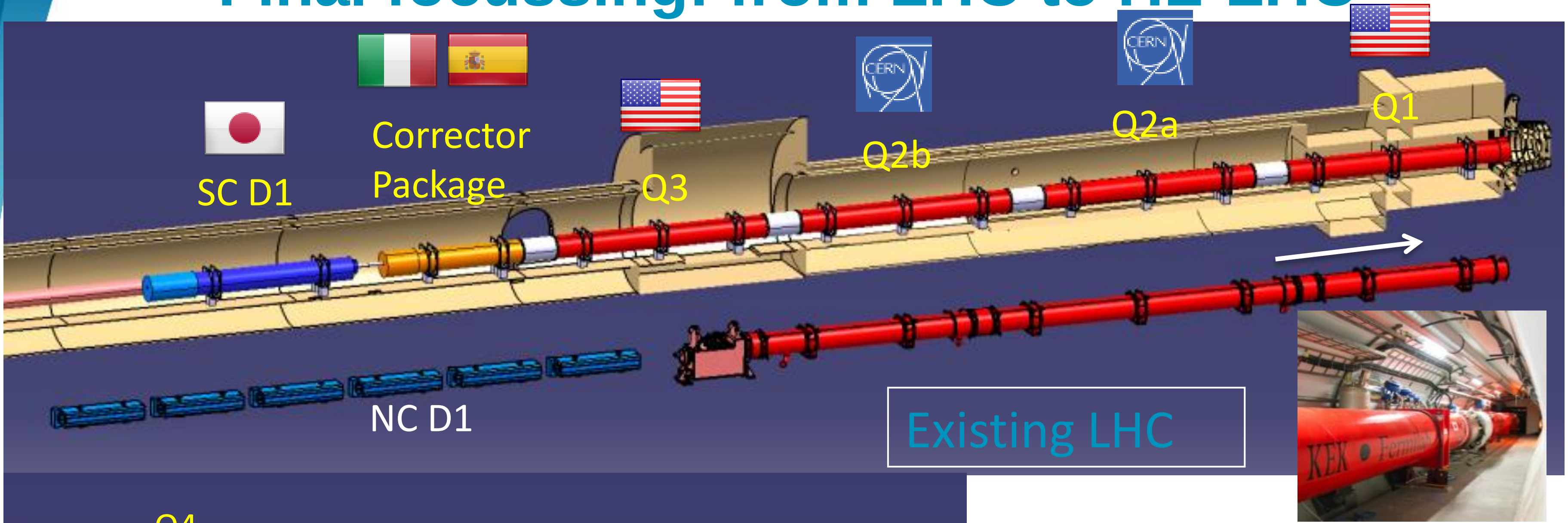
Acknowledgements:
CERN Cryogenic and Procurement groups
Technology Department
HL-LHC project management team

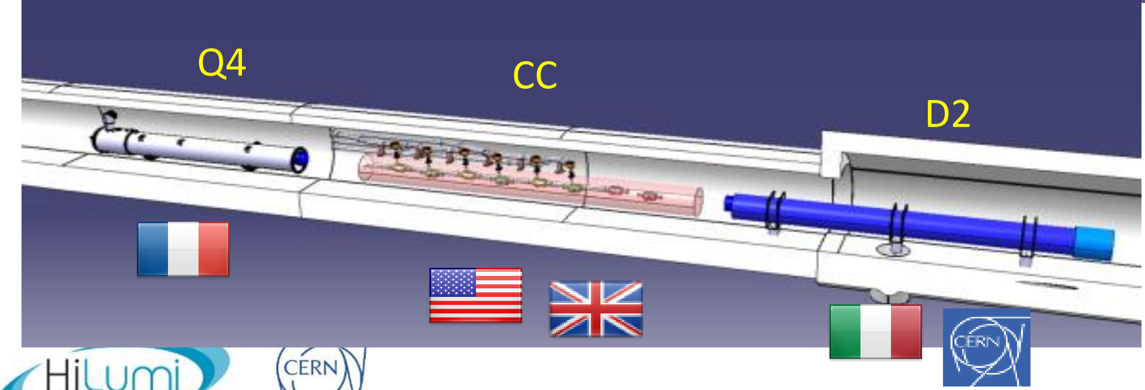
BACK-UP….

HL-LHC Schedule



Final focussing: from LHC to HL-LHC





HL-LHC relies on more powerful final focussing quadrupoles, associated recombination dipoles and crab cavities,

Local heat loads expected x5 w.r.t LHC