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

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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

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

To provide adequate cooling for:

- 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

**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

Users at tunnel level
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

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

New HL-LHC Helium Refrigerators

CEC23 - Honolulu, July 2023
E. Monneret
### HL-LHC Refrigerators Operational and Loads Requirements

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Temperature level</th>
<th>Q10</th>
<th>Q13</th>
<th>Q11</th>
<th>Q12</th>
<th>Q20</th>
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<tbody>
<tr>
<td></td>
<td>1.9 K</td>
<td>4.5 K</td>
<td>4.5 K-25 K</td>
<td>4.5 K-300 K</td>
<td>60 K-90 K</td>
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<tr>
<td>Maximum Capacity</td>
<td>3760</td>
<td>-</td>
<td>1320</td>
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<td>Design Capacity</td>
<td>3250</td>
<td>700</td>
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<tr>
<td>Turndown</td>
<td>1100</td>
<td>-</td>
<td>700</td>
<td>10</td>
<td>6000</td>
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</table>

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

**Heat Loads to the Refrigerators**

![Pie Chart](image)

**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 >40,000 hours**
  - 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 N₂)
    - Heat recovery
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
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 misunderstanding

- 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)
  - Total adjudication Cost = CAPEX + OPEX (P1) + OPEX (P5)
  - Guaranteed Electricity input power (3.3.kV) times 2 Main Operation modes over 10 years
  - \( \text{OPEX} = (P_{DCTest} \times 52 000 + P_{TdTTest} \times 26 000) \times 0.075 \text{ CHF/kWh} \)
  - Electrical cost for adjudication

- Performance Test at CERN (Bonus/Malus)

  *Selection of single source for the two refrigerators*
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

LHC / HL-LHC Plan

<table>
<thead>
<tr>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
<th>Run 4 - 5...</th>
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<td>EYETS</td>
<td>LS2</td>
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<td>Diodes Consolidation LIU Installation Civil Eng. P1-P5 pilot beam</td>
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HL-LHC TECHNICAL EQUIPMENT:
- 30 fb⁻¹
- 190 fb⁻¹
- 450 fb⁻¹

HL-LHC CIVIL ENGINEERING:
- DEFINITION
- EXCAVATION
- BUILDINGS

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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