Cryogenics for HL-LHC: from cooling requirements to procurement and future challenges

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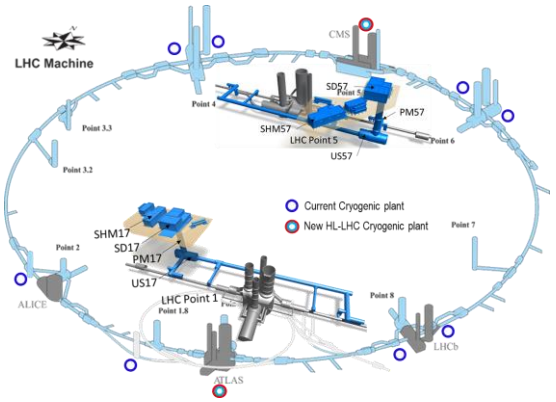
25th Apr 2023

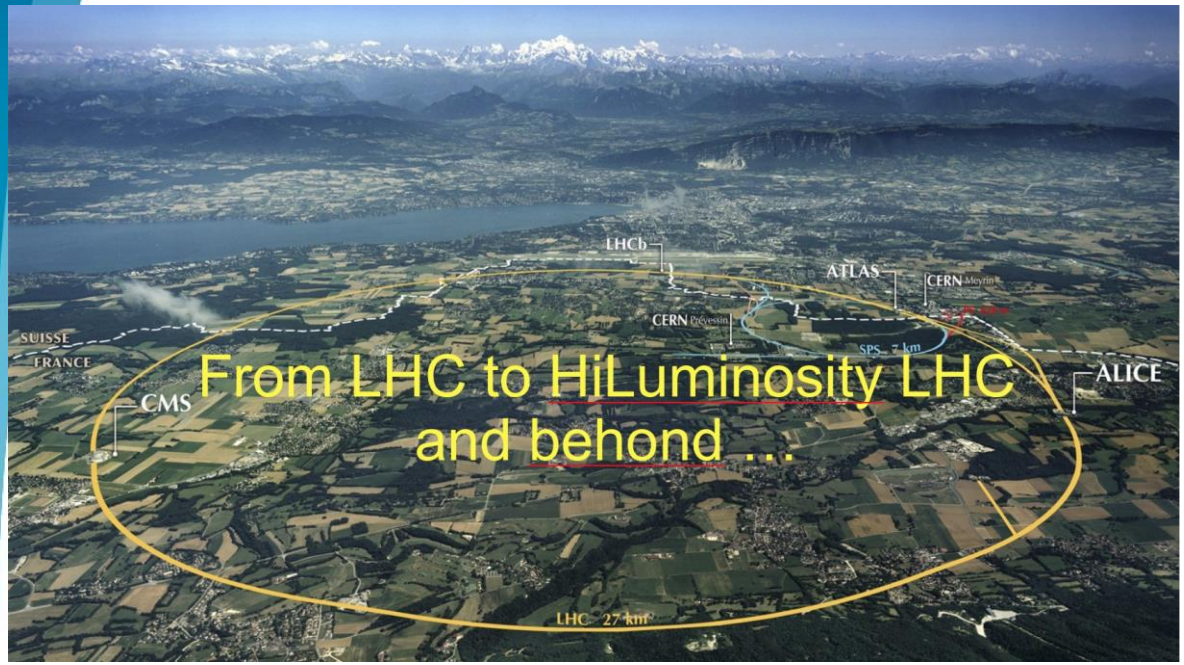
CERN,
Geneva (CH)

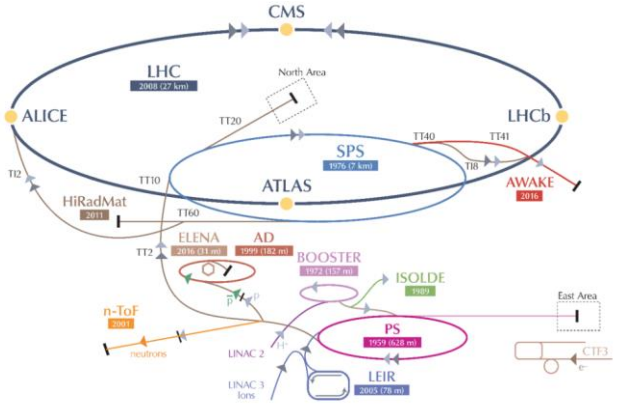
Content

- Brief introduction to CERN, LHC and HL-LHC
- HL-LHC Cryogenic scope and architecture
- Refrigerators and Cryogenic distribution line
- Complementary items
- Schedule
- Summary



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

The LHC accelerator

proton-proton collisions at 2 x 7 TeV, 500 MJ stored energy

24 km of superconducting magnets (8.33T) @ 1.9K, 140t Helium

2007-2009: Cool-down and commissioning
2010-2012: Collisions and Higgs boson discovery

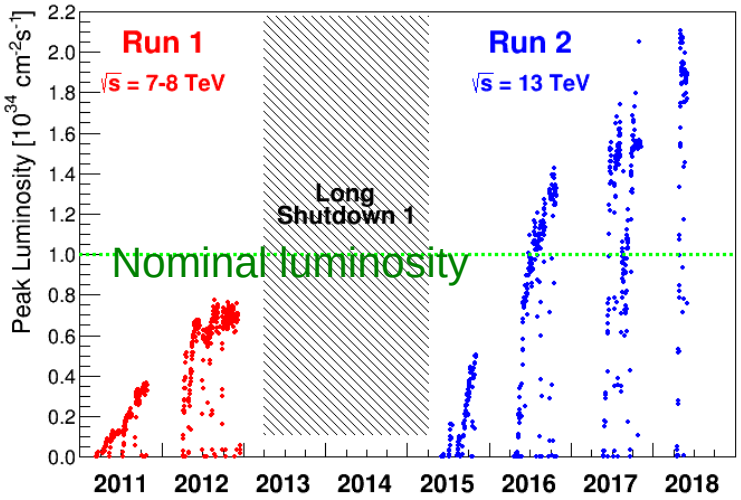
2012

Since: much more Higgs and all kind of physics,

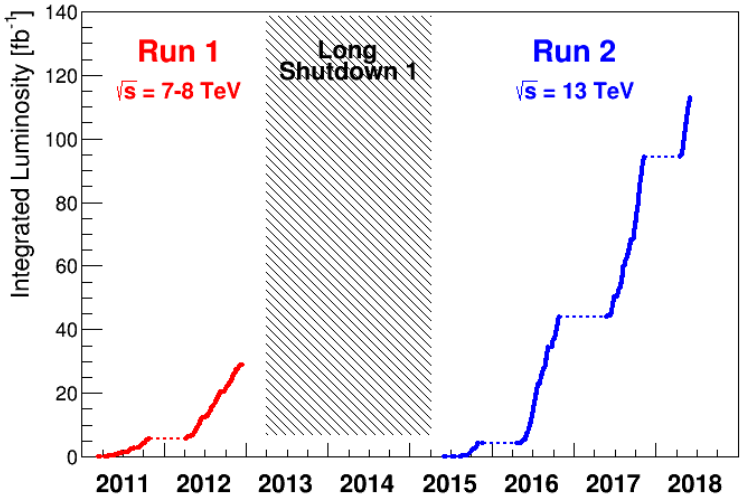
Keep going like this ?!?

Basic KPIs of a collider

Peak Luminosity
=> Performance



Integrated Luminosity,
=> Qualification – Global availability - Time



“ The potential of the facility”

“What allows science” (statistics)

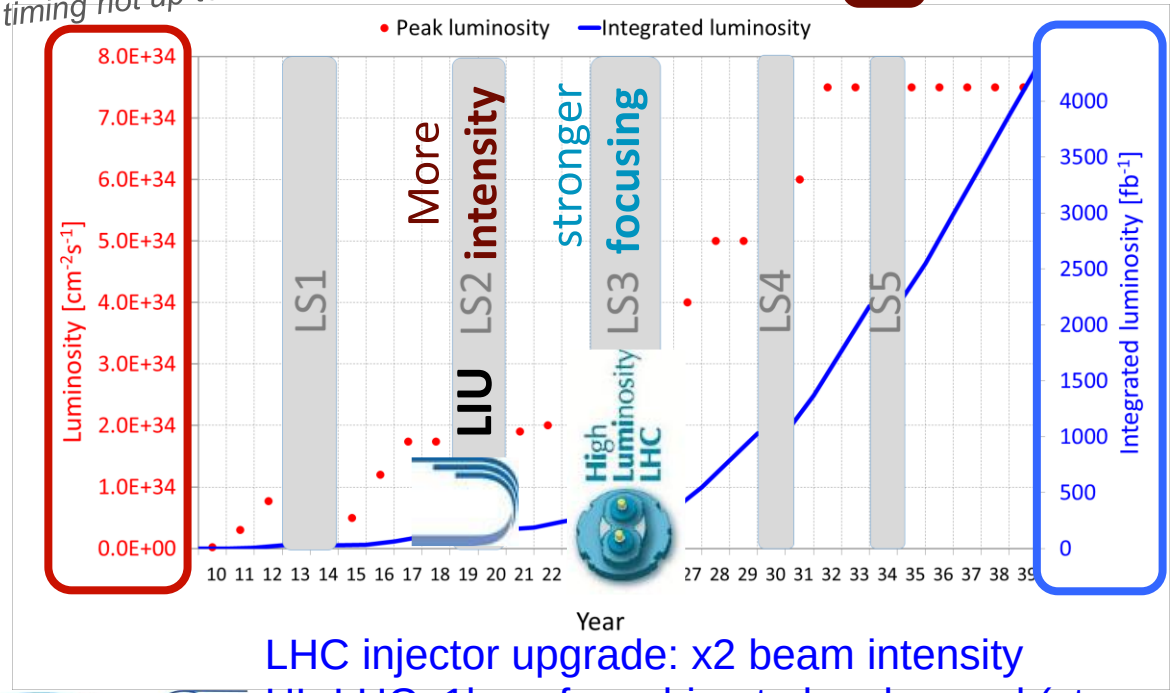
Towards higher collision rates

New discoveries or precision measurements need integrated luminosity !!!

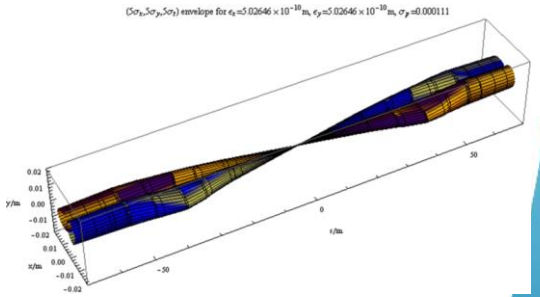
Plans as defined few years ago, timing not up-to-date

$$\text{Luminosity} = f * \frac{N^2}{4\pi\sigma^2}$$

Need for more protons in a smaller area !!!



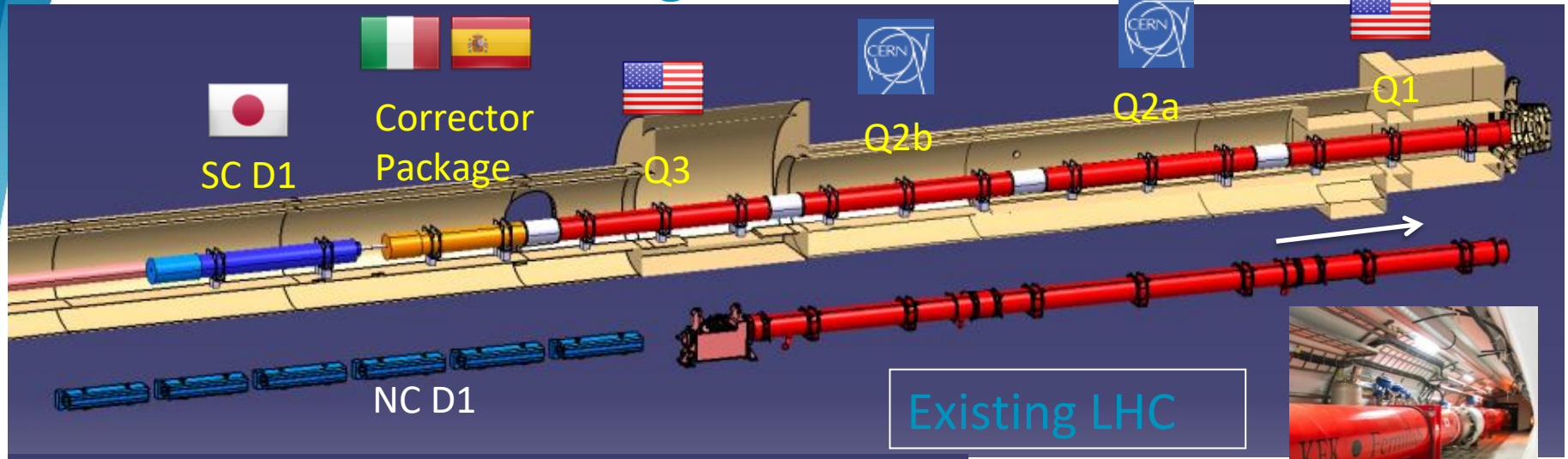
Target for physics: doubling integrated Luminosity for each new run

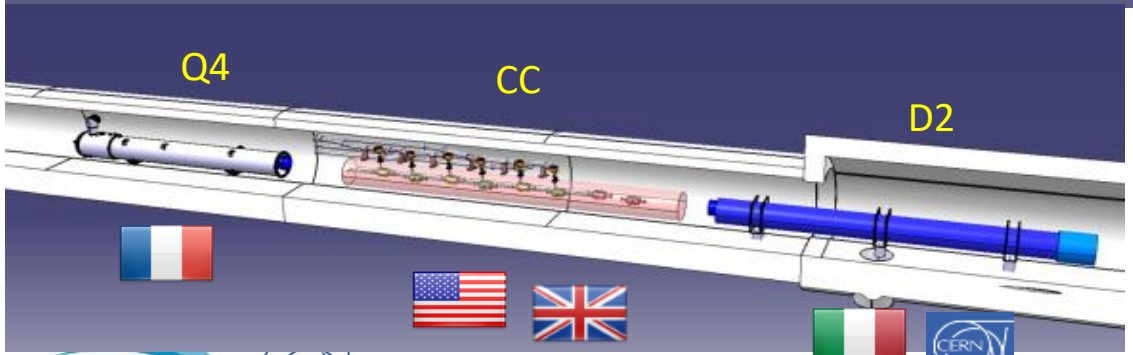


LHC injector upgrade: x2 beam intensity

HL-LHC: 1km of machine to be changed (stronger focussing quadrupoles)

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

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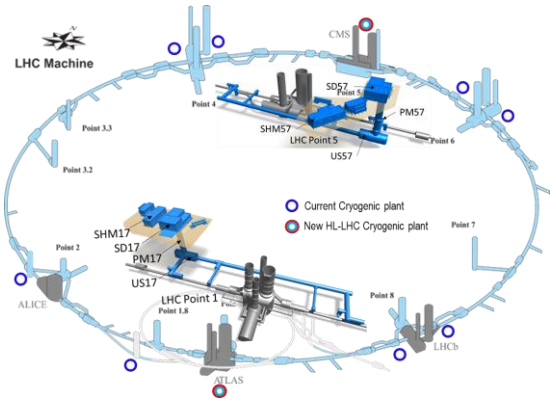
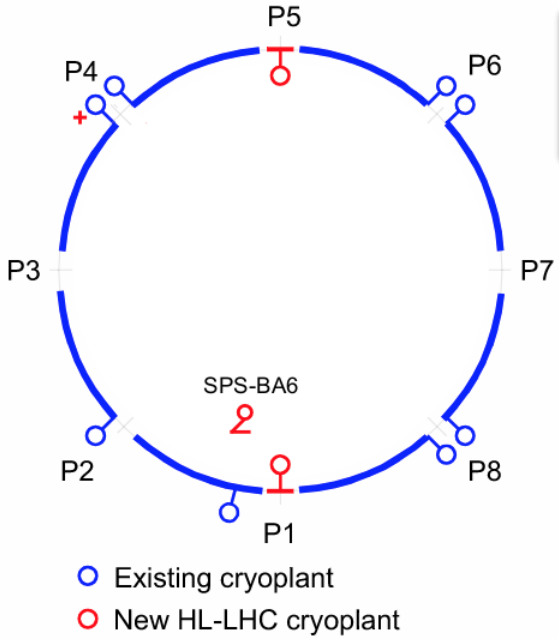


HiLumi-Cryogenics, Global scope overview



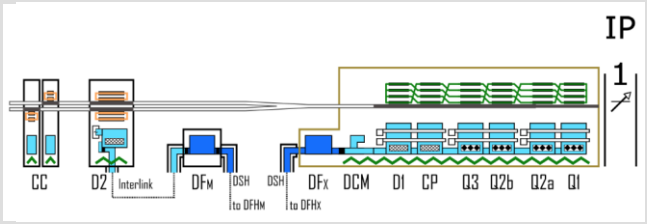
P1-P5: 2 new cryoplants (~14 kW @ 4.5 K incl. 3.25 kW @ 1.9 K) and 2 x 750m cryo-distribution for high-luminosity insertions

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

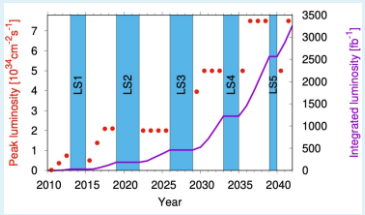
SPS-BA6: SRF test facility with beam primarily for Crab-Cavities

To provide adequate cooling for:

P1-P5 machine devices



HL-LHC performance



Other test facilities related activities are not part of this WP9-Cryogenics

HL-LHC P1/P5 Cryogenic architecture

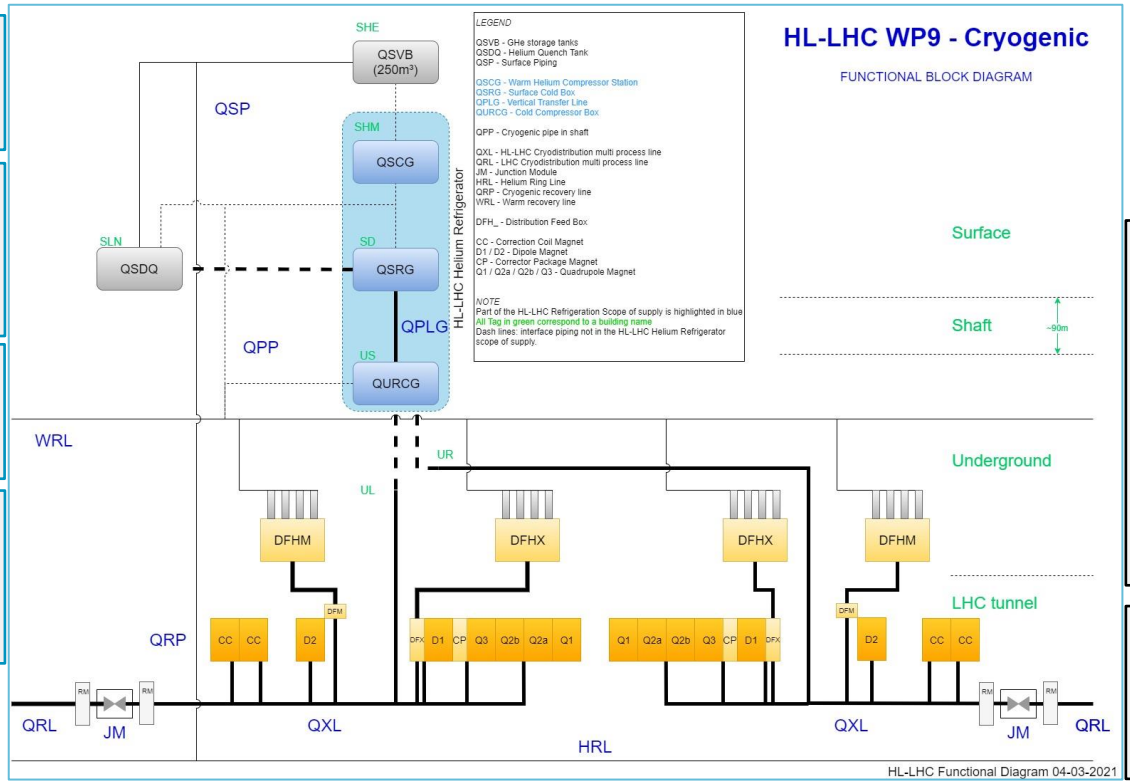
QSRG : Compressor station providing gaseous helium **20 B**

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

QPLG : Vertical transfer line (~100 m height)

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

Users at tunnel level

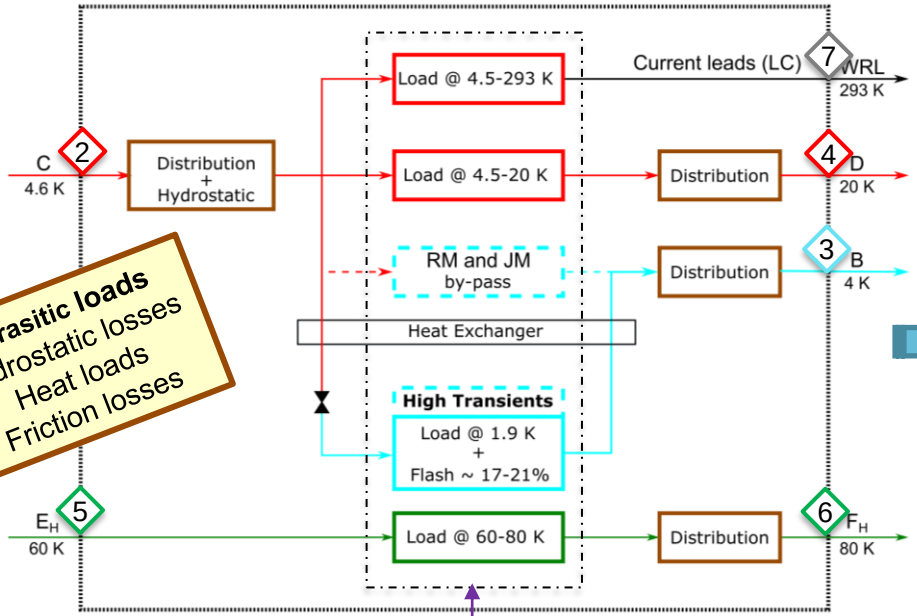


QXL : Distribution line distributing C,E and returning B,D,F

- 70 m for the common branch
- 270 m for the long branch
- 60 m for the short branch

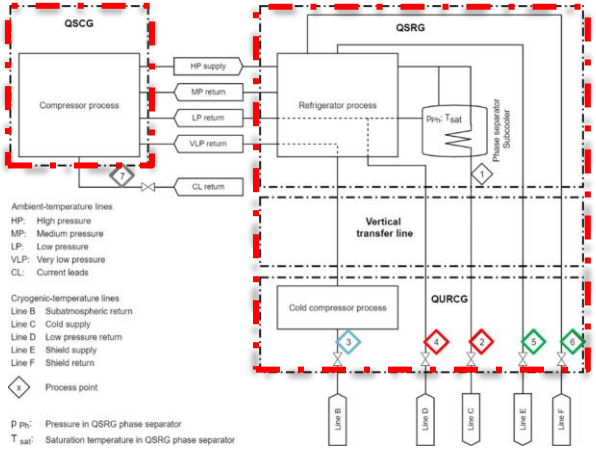
RM/JM : Return module and junction module at extremities for transient handling and back-up

From cooling requirements to refrigeration capacity



Parasitic loads
Hydrostatic losses
Heat loads
Friction losses

Limits of supply for Refrigerator delivery



1. Evaluation of Heat loads at User level **considering**
2. Parasitic loads from distribution to be taken into account

3. Proper evaluation of Refrigerator supply to proceed with Call for Tender.

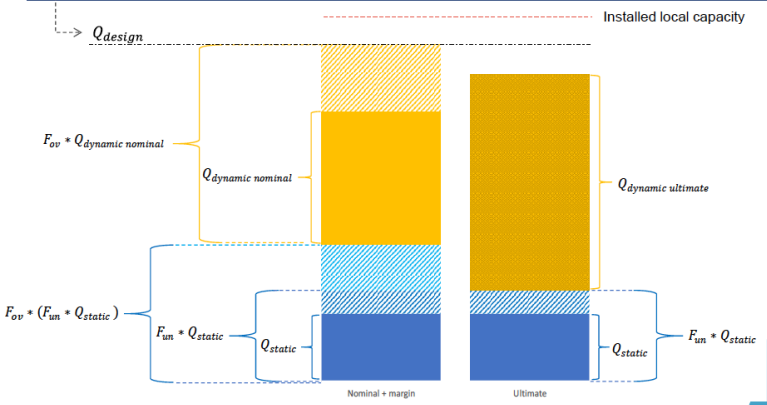
Heat Load Review, methodology

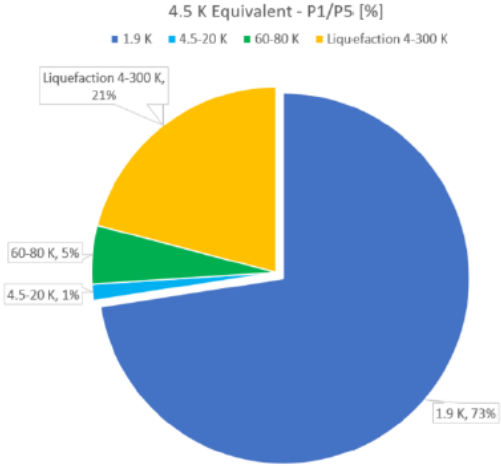
A consistant management of heat loads uncertainties & necessary over-capacity

Methodology

- Design cooling capacity Q_{design} is calculated for each temperature level taking into account an uncertainty factor F_{un} applied only on the static heat loads and an overcapacity factor F_{ov} applied only on the Nominal conditions (7 TeV and 5L0).
- According to the design status (conceptual, detailed or advanced) the F_{un} factor could vary from 2 to 1.25.
- The installed local capacity should be at least as high as the design capacity.

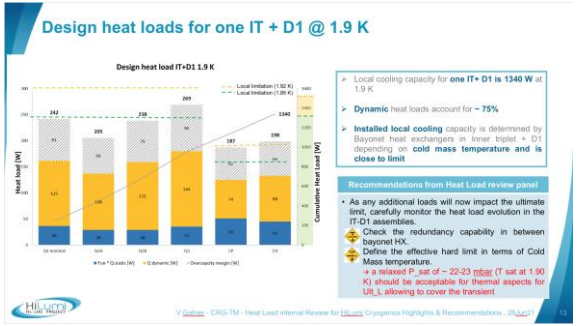
$$Q_{design} = Max\left[\ F_{ov} * \left(F_{un} * Q_{static} + Q_{dynamic\ nominal}\right)\ ;\ F_{un} * Q_{static} + Q_{dynamic\ ultimate}\ \right]$$

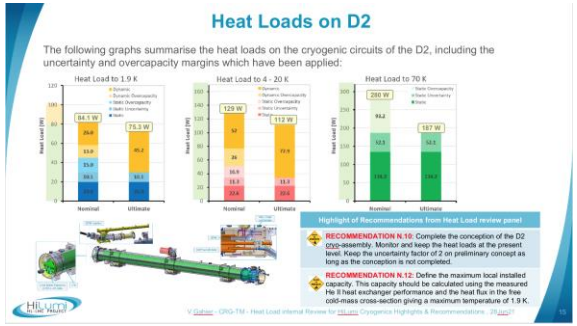


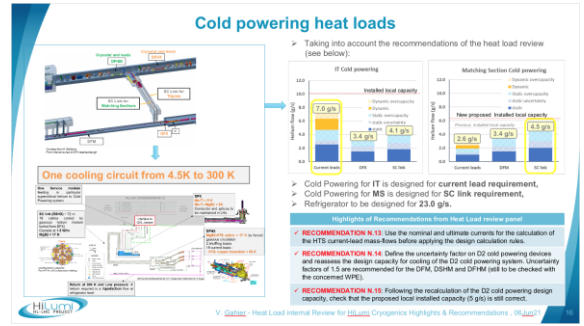


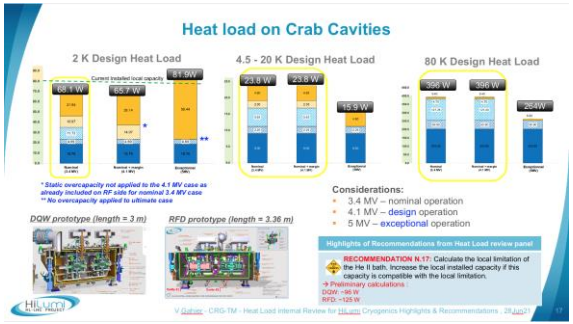
Outcome 1 => 2 refrigerators of 14kW@4.5K, including 3.25kW@1.9K

Heat Load Review, detail









The total design heat load at 1.9 K is very close to the limit of the installed local cooling capacity for all users

All parties involved shall be aware of the situation

⇨ It is time to freeze the configuration and commit on these figures considering fabrication and installation phase

Outcome 2 => No point to install more capacity if you cannot distribute it !!!

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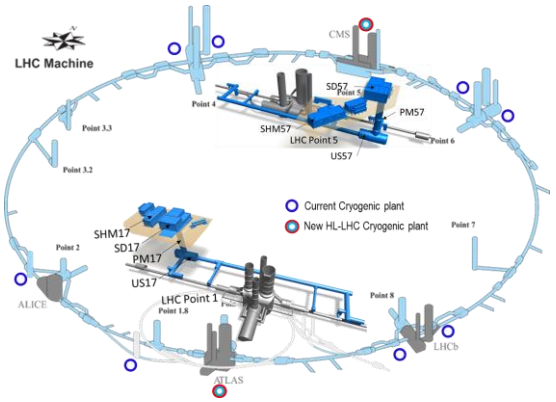
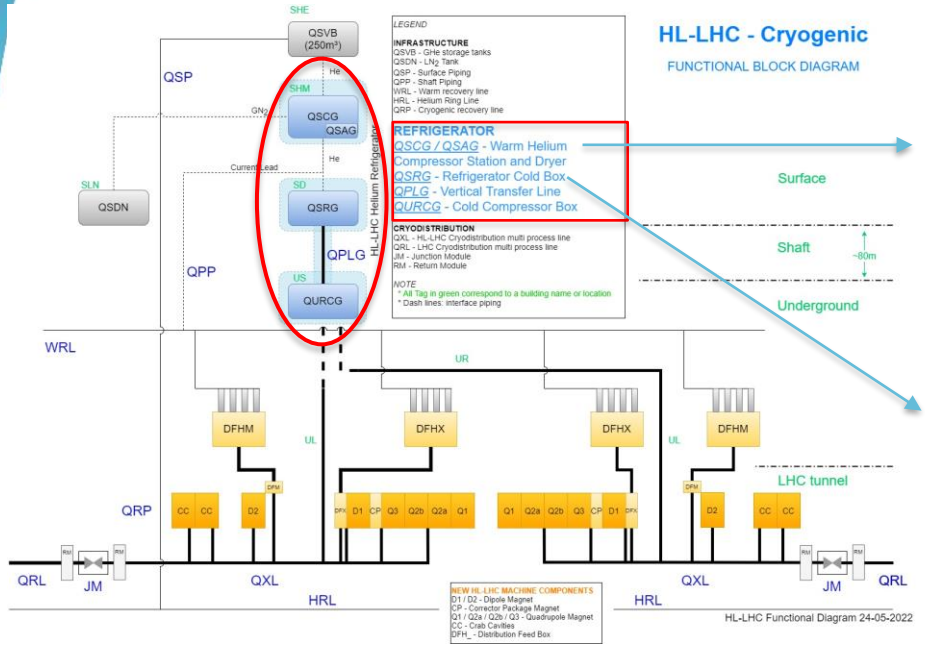


Helium Refrigerators at LHC P1 and P5 for HL-LHC

P1-P5 Cryogenic Architecture



Helium Refrigerators

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

LHC Helium Refrigerators

similar capacity required for P1 and for P5, in addition to 8 existing

Compressor station
(100t, 4MW input power)

Cold boxes from world wide leading industries
(>100t, Heat exchangers, expansion turbines, valves, controls)

Tendering process & contractors

- Q2-Q3 2020: Market Survey **to qualify firms**
- Q1-Q2 2021: **Process & feasibility studies**
  (minimised 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)**
- Capacity tests at CERN (bonus/malus)

Selection of single source for the two refrigerators

Linde Kryotechnik AG

Linde Engineering Dresden

with major partners identified

ENERPROJECT GAS COMPRESSION SOLUTIONS

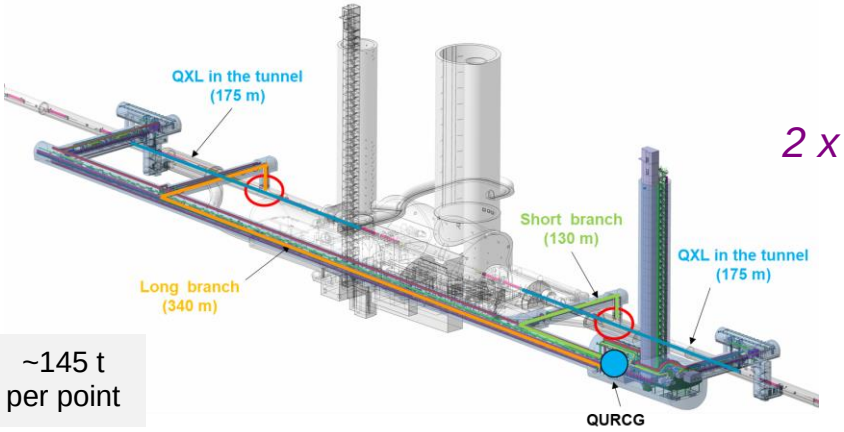
AQUAGAS

KASAG

DEMACO

PBS

Cryogenic distribution line at P1 and P5

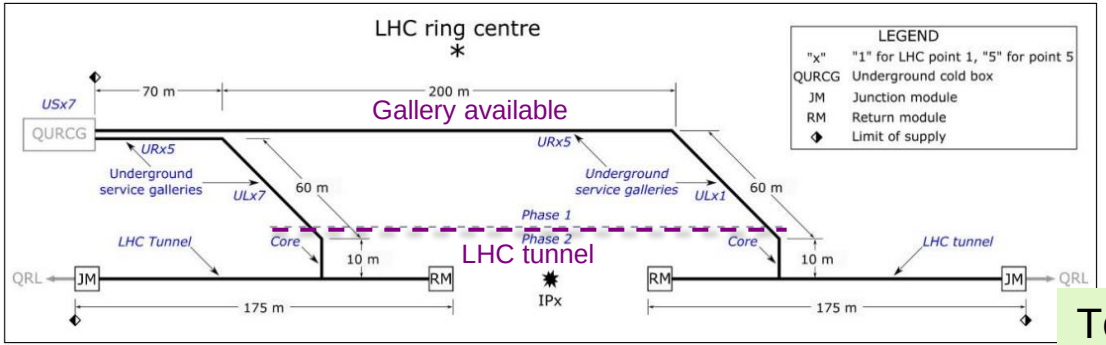


~145 t
per point

Cryogenic Distribution Lines

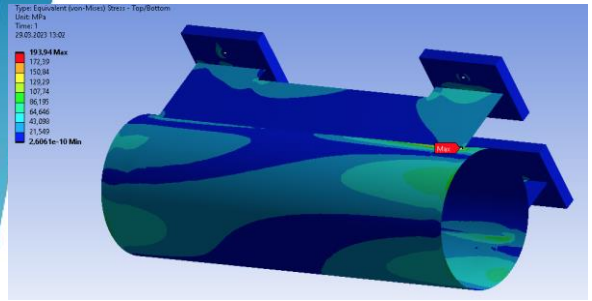
2 x 750 m, 5 process pipes, vacuum insulated
(Diam 40 to 273, 650 to 800mm)

LHC Line

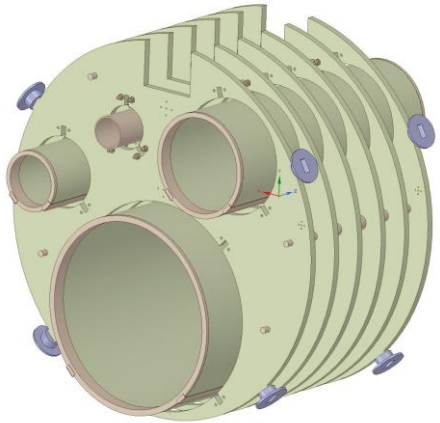


Tendering process Q1-Q2_2022,
Contract signed Dec'22

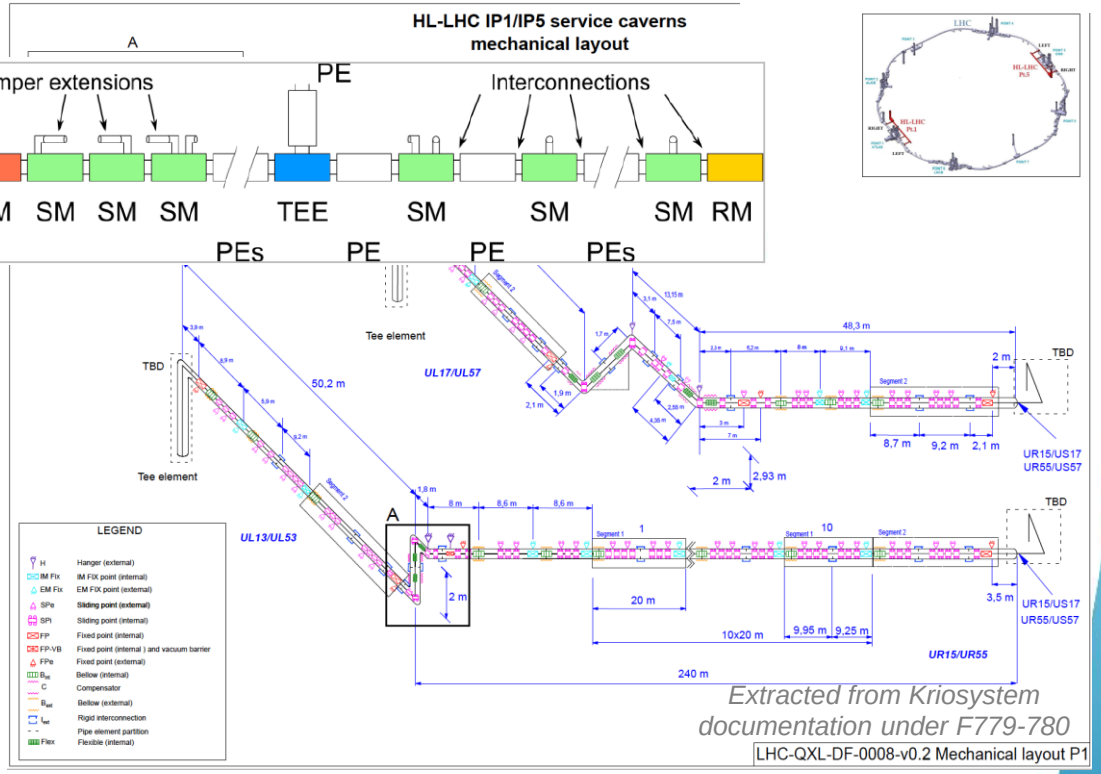
Preliminary design started with



External fixed support



Internal sliding support



3D models and internal piping design being reviewed

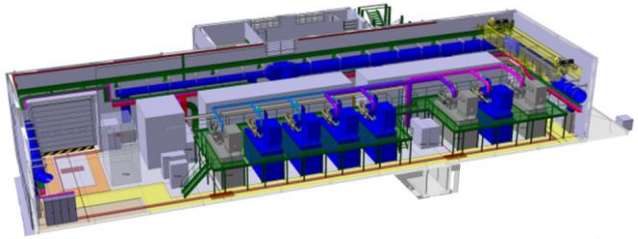
new HL-LHC buildings already done !!!

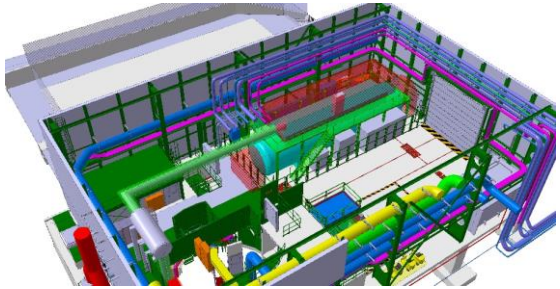
Civil Engineering @ LHC P1 Sept. 2022

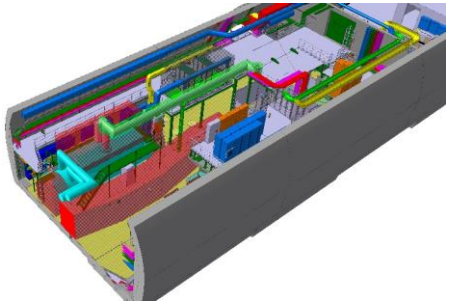
SHM – Compressor Station

SD – Refrigerator Cold Box

US – Cold Compressors Box







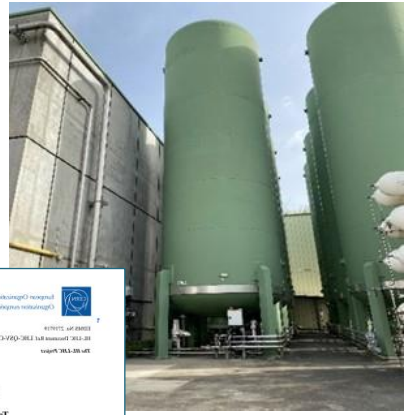
CERN HL-LHC Refrigerators Conceptual Design
14kW@4.5K including 3.25kW@1.9K

Procurement of storage tanks and piping

Industrial sub-systems, illustrations from LHC existing similar equipment

(58) existing 250 m

GHe 250 m3



GHe 80 m3

Industrial stainless steel piping

LN2 existing 50 m3

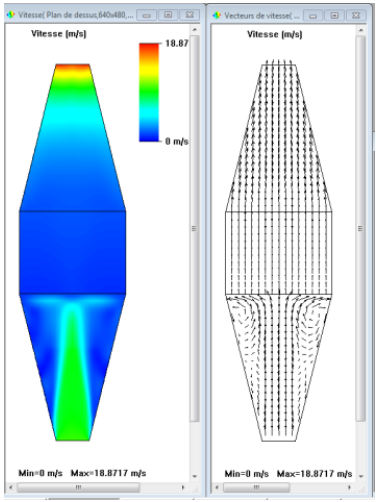
Necessary tenders done, results submitted for approval from our governing bodies (Jun'23),
=> Contracts to follow

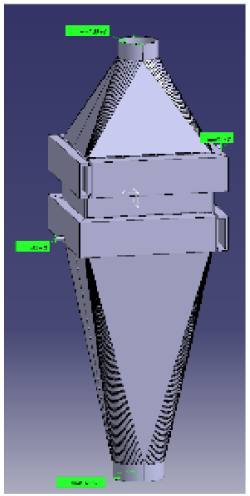
Some specific developments

A selection based on items developped for LHC or specifically for HL-LHC

Subcooling Heat exchangers

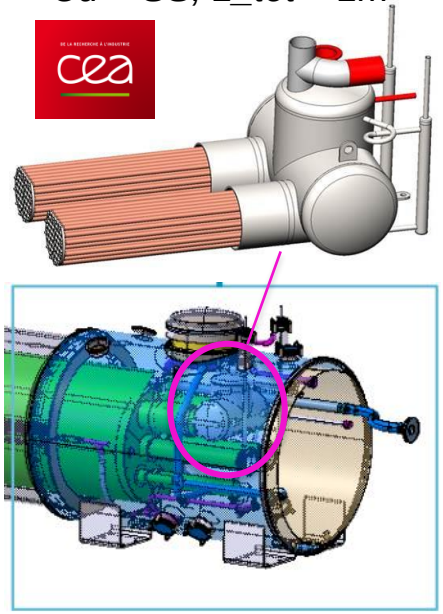
Block ~ 20 x 30 cm, L_tot ~ 1m





HeII Heat exchangers

Cu + SS, L_tot ~ 1m



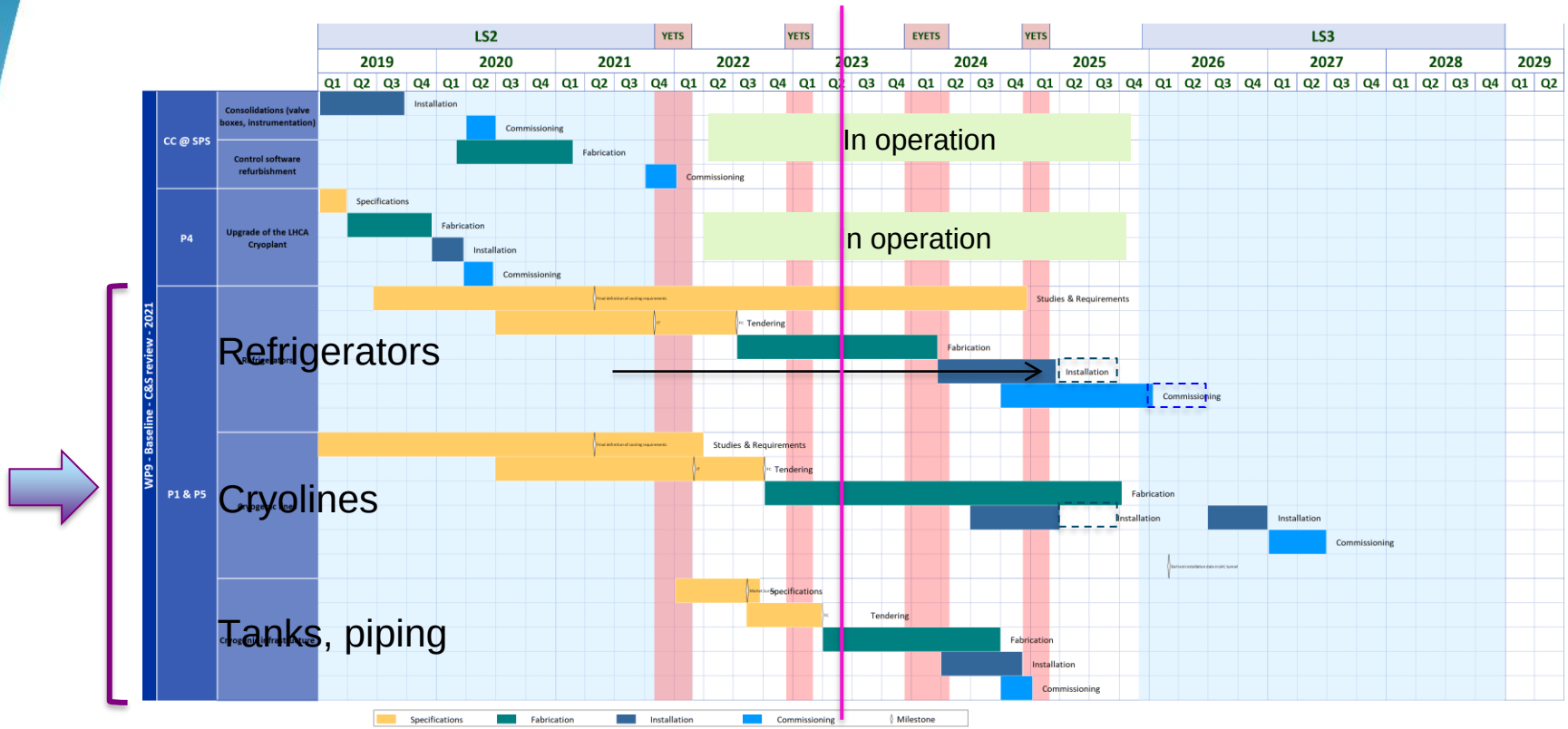
Instrumentation

Accuracy few mK @ 1.9K

Long block

Short block

Masterplan of HL-WP9-Cryogenics



Summary

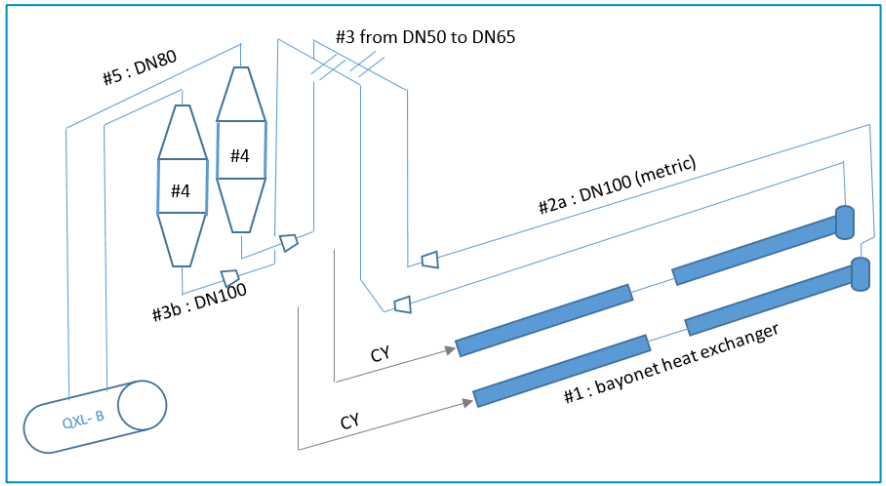
- Cooling requirements reviewed mid 2021, allowing to confirm the refrigeration capacity with final tuning of the global cryogenic architecture
- Major tenders (Refrigerators, cryogenic distribution line) done following process & technical feasibility studies with shared cost risks for post-covid & Ukraine impacts, continued efforts to get industrial contracts on good tracks
- Procurement of complementary items (gaseous tanks, piping, items as LHC spares, existing QRL cryoline refurbishment) started, to be continued
- Instrumentation and controls activites now well structured and delivering
- Contracts and team in place with objective to commission the refrigerators in 2026, cool-down magnets in 2028 for operation with beams to resume in 2029 for a decade of new physics results !!!

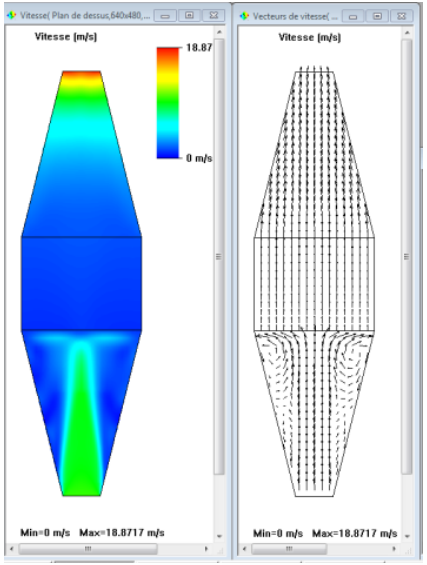
Complements

Recent progress & Perspectives

Revisiting distribution line & interfaces

Parallel HX scenario studied to overcome:
- pressure drop issue on VLP
- capacity of cooling loop (bayonets of the magnets and not cryo equipment)
- distribution (parallel CY-bayonets)

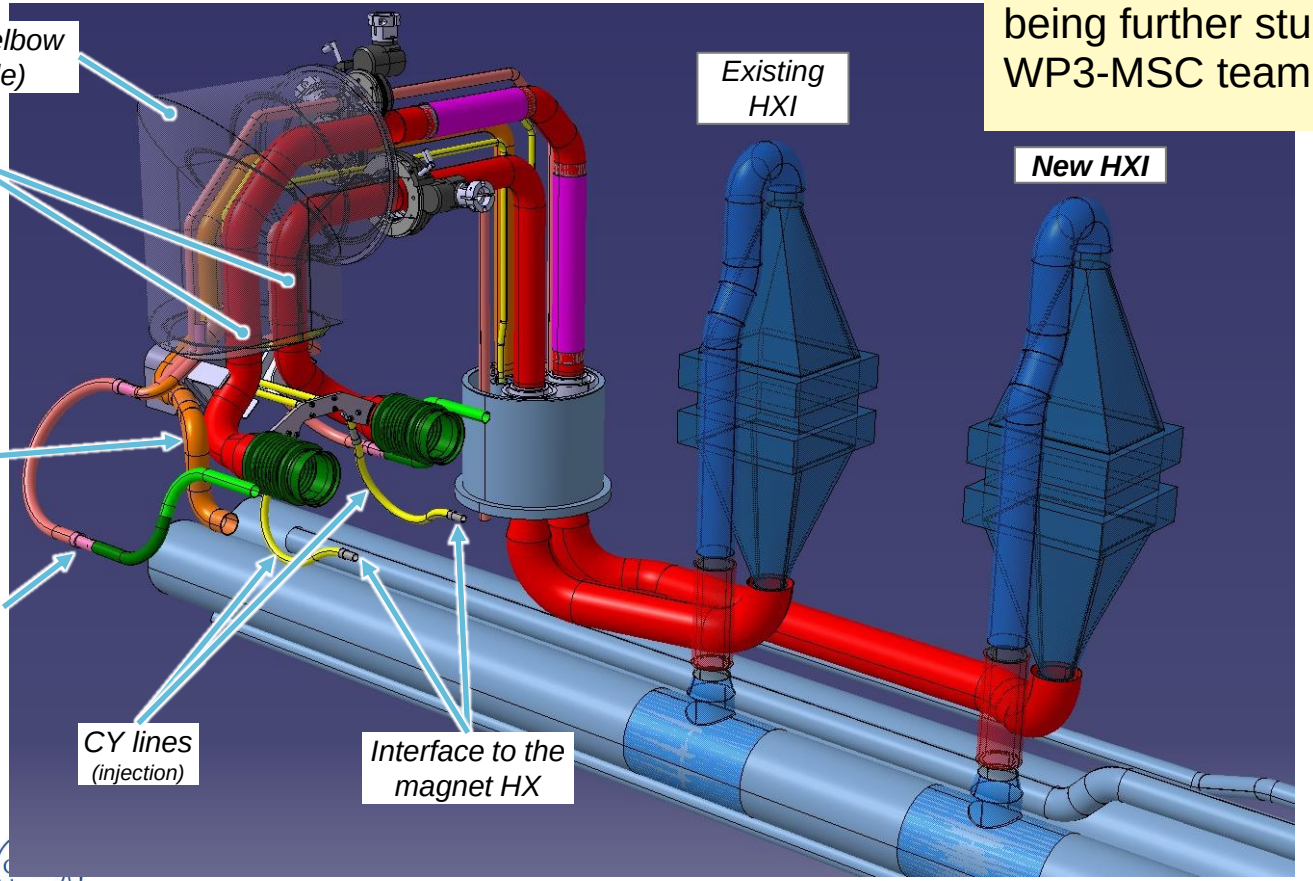




Study asked to original manufacturer (LHC, 20 yrs ago), now with modern numerical tools:
- Confirmed "jet" at inlet cone-HX
- possibility to shorten outlet cone

IT side: potential pipe routing

No show-stopper identified, being further studied with WP3-MSC team



Feasibility study