2nd workshop on Magnet test stands, May 8, 2018

Good Practices for Cryogenics Operation At CERN SM18 : Design, Safety, Planning

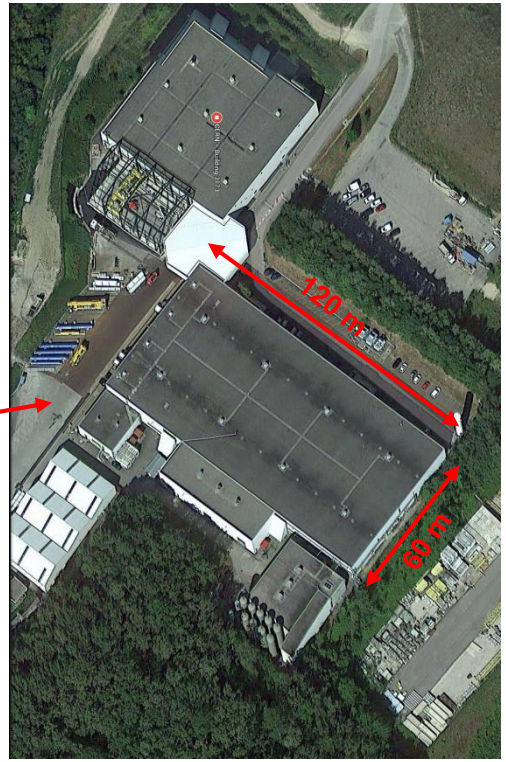
P. Gayet, J.P. Lamboy, A. Perin, R. Lamy

CERN, 1211 Geneva 23, Switzerland

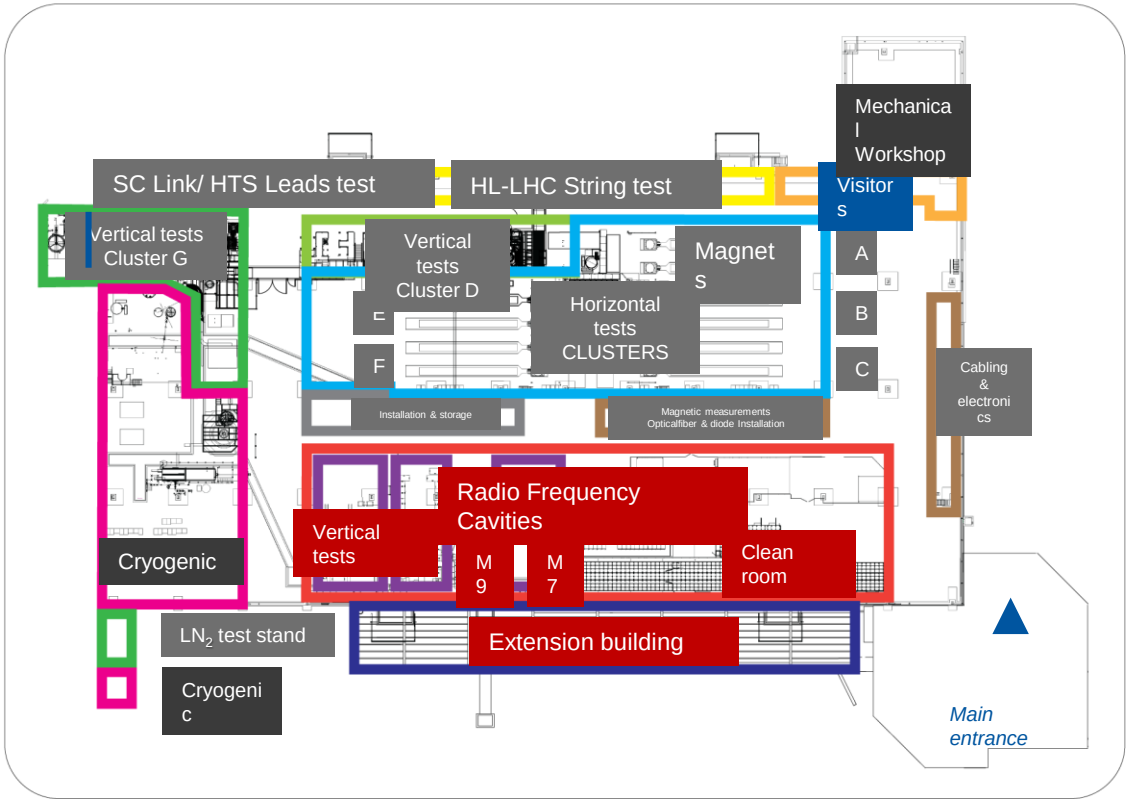
The SM18 cryogenic test facility

- SM18 is the main test facility for testing **prototype and series superconducting accelerator magnets and RF cavities**. This is, for example, where all of the (more than 1400) LHC series magnets and superconducting RF cavities were tested.
- Unique facility with exceptional testing capabilities.
- Since the initial LHC test program conclusion, the cryogenic infrastructure has been reconfigured and has very efficiently fulfilled the requirements of the test programs
- Superconducting Magnets and RF cavities will be essential components of The LHC CERN flagship accelerators and experiments.
- All these devices require an extensive R&D program and individual tests at 4.5 K (and above) or 1.9 K-2 K on series devices before installation.

SM18 facility location at CERN



SM18 a test hall shared by Magnets and Radio frequency



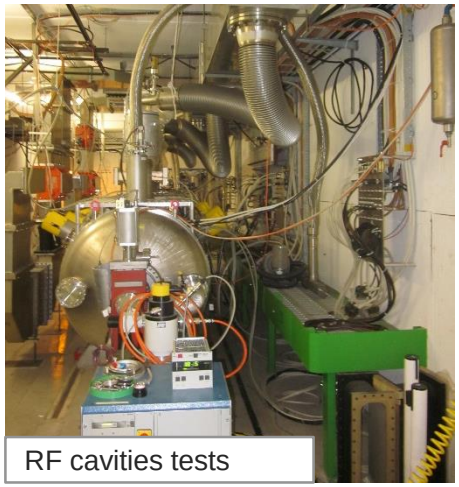
Some of the test systems in SM18

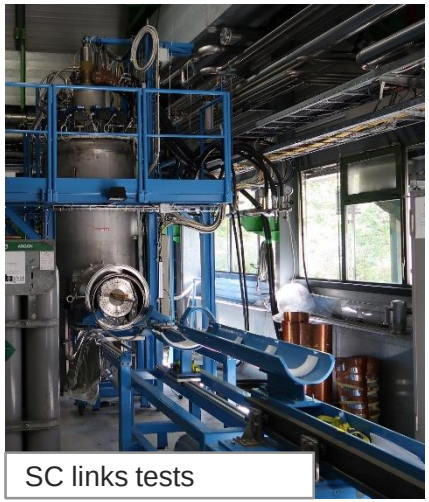

Horizontal magnets test benches

Hor. Magn, feed box


Vertical magnet tests


Vertical magnet tests


RF cavities tests

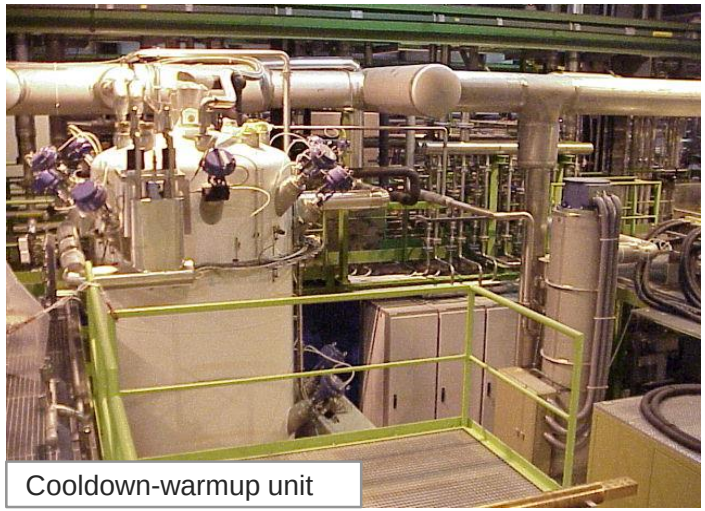

SC links tests

Some devices of the cryogenic infrastructure


Cold box


Purification units


Low pressure compressors

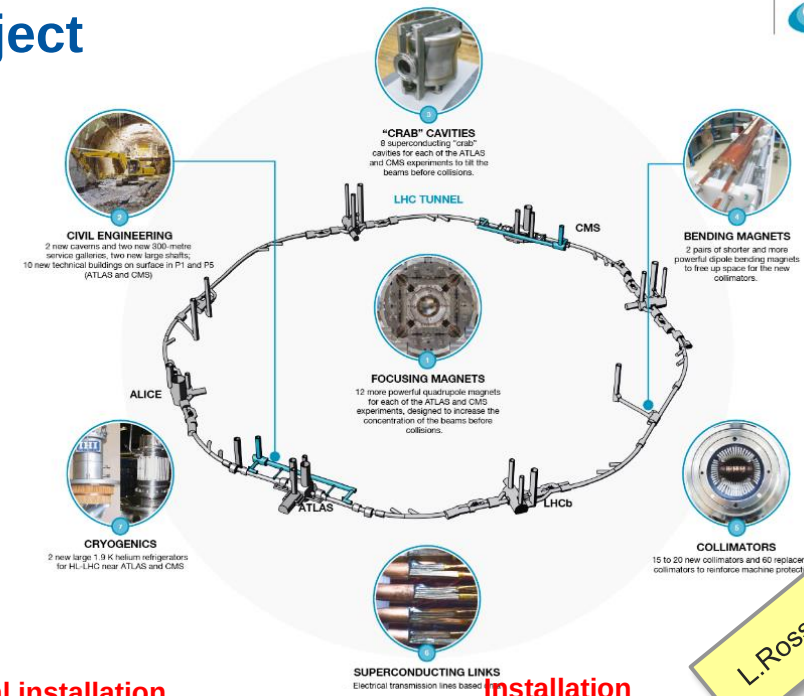

Cooldown-warmup unit

The SC devices for the HL-LHC project

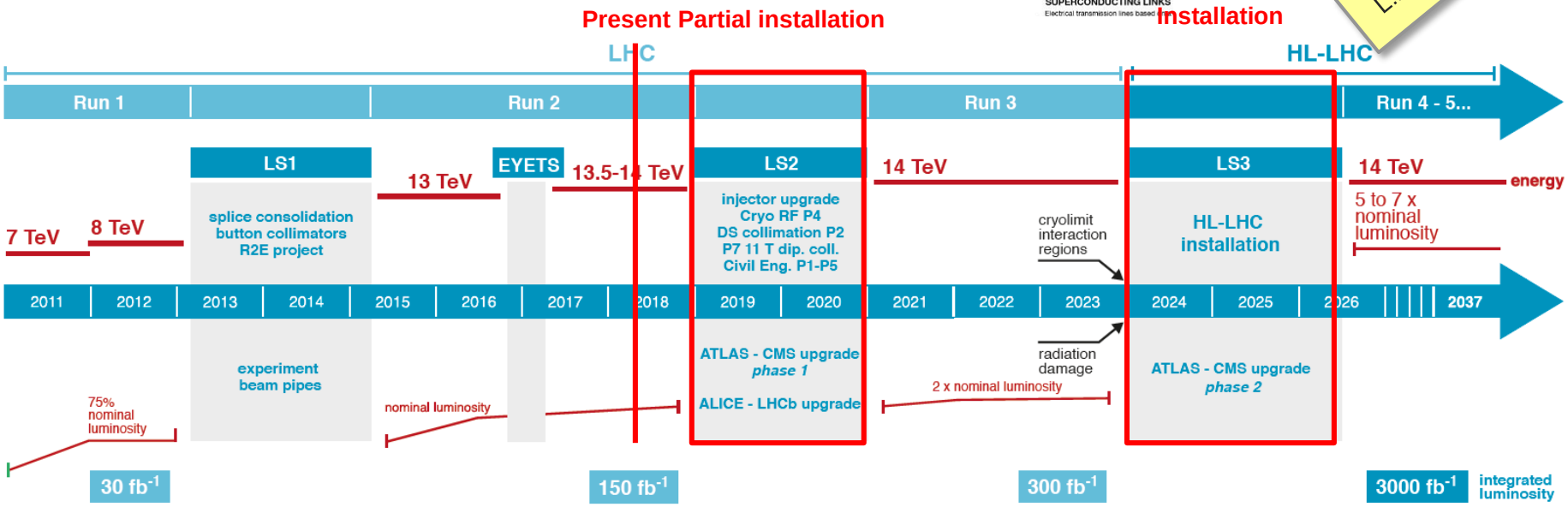
- 11T dipoles (2020)
- Triplet magnets (IP1 & 5)
- Standalone magnets
- SC links
- Crab RF cavities

Installation planned for 2024

Requires: R&D and tests of series

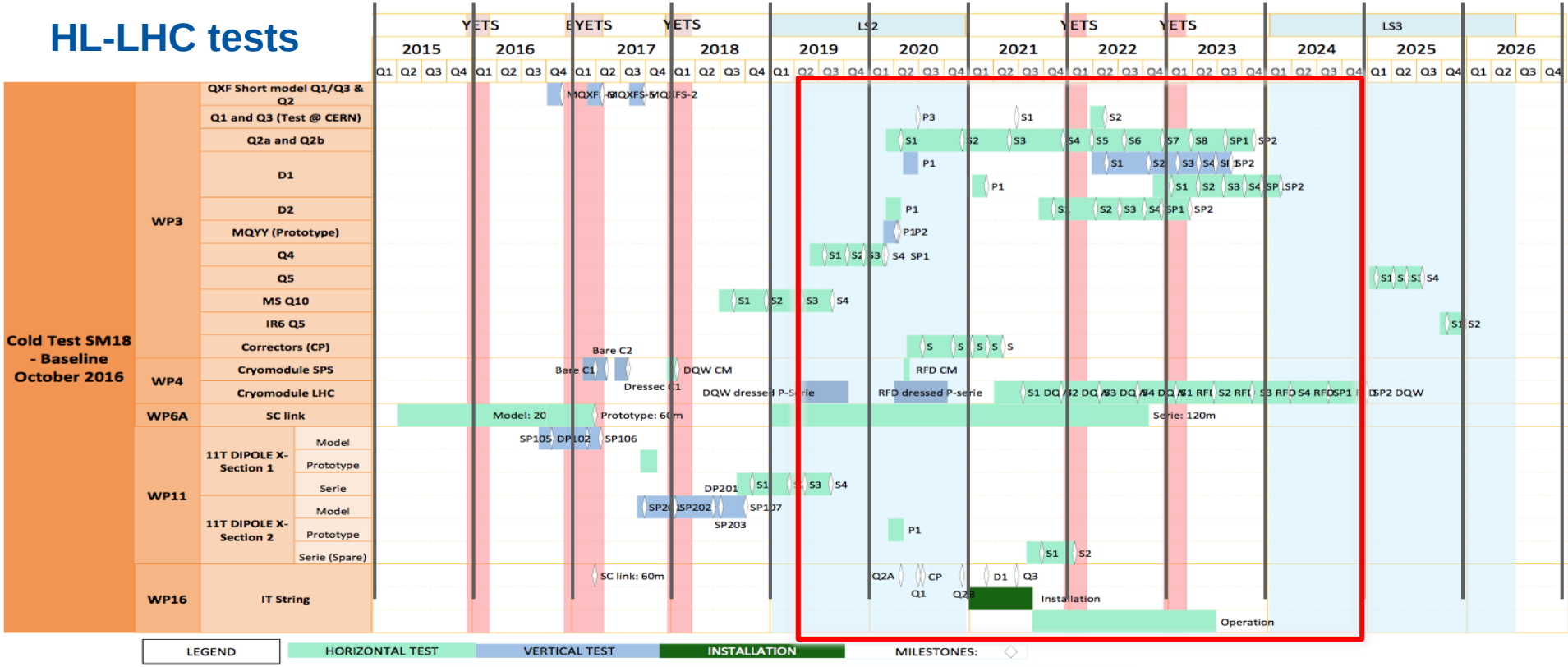


L.Rossi, CERN



SM18 Test program until 2024

HL-LHC tests



+ Spare magnets and other spare

+ other systems and devices tests!

Objectives of the upgrade

- The future HL-LHC project, planned for 2024, will :
  - Require a significant increase in the number of tests, already started and accelerating in 2020
  - Cover the 2017-2023 period and beyond

<u>The infrastructure upgrade of SM18 shall therefore allow to :</u>

- increase the testing rate and parallel testing capabilities
  -> increase LHe production and 1.8 K pumping capacity

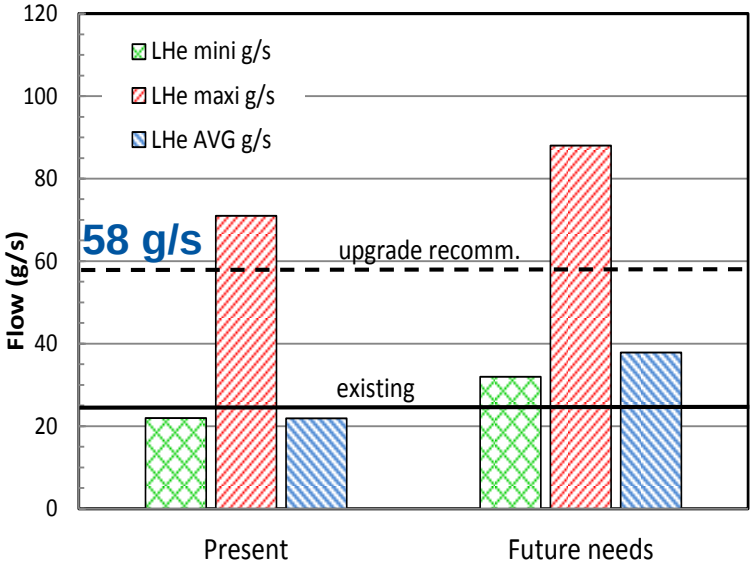
- increase availability
  -> implement redundancy

- fulfil the cooling needs for HL-LHC String (triplet Q, SC link and feed box)
  -> additional and dedicated equipment

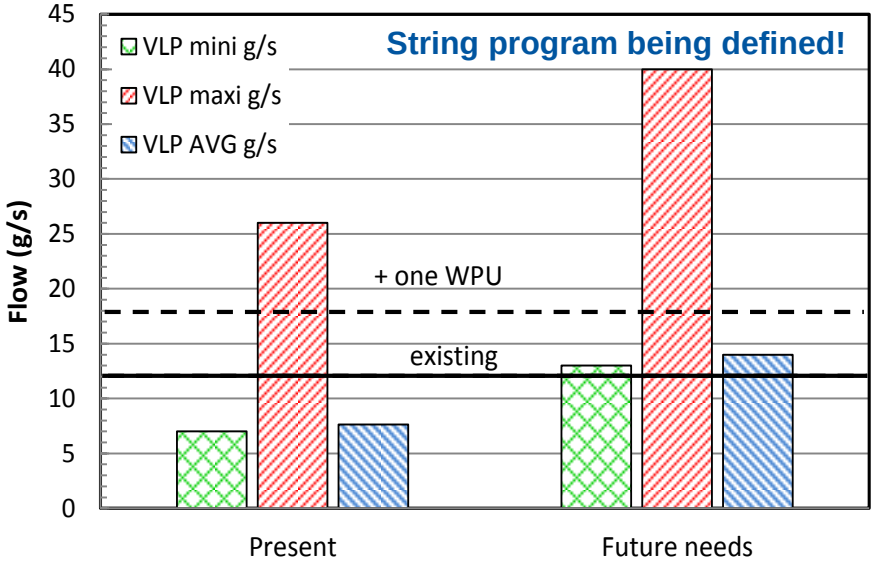
Initial Requirements for the cryogenic infrastructure

Based on test program: assumptions for covering the requirements for the main test benches:

- Magnet test benches: 2 vertical and 2 horizontal magnets cold tested / month with 2 magnets powered simultaneously.
- Superconducting Cavities: 1 cavity test/2 weeks in vertical test benches and 1 cryomodule test every 6 month in horizontal test benches.
- Parallel test of a superconducting link and/or the IT String (based on 2016 data)
- Possibility of additional individual systems tests on dedicated facilities



Liquefaction

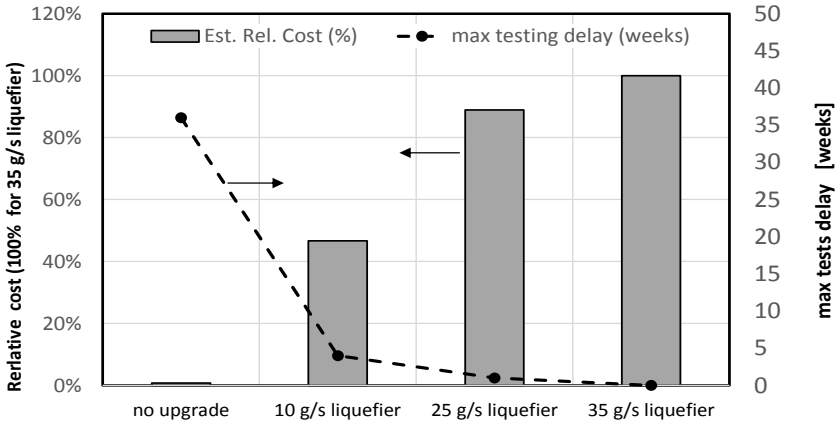


Low pressure pumping

Liquid helium supply upgrade

A total liquefaction capacity of 60 g/s, i.e **an upgrade of 35 g/s** with respect to the existing capacity, has been estimated to ensures a supply liquid helium compatible, with margin, with the requirements of the test program.

An analysis has been performed to evaluate the potential gain and risk of more limited upgrades.



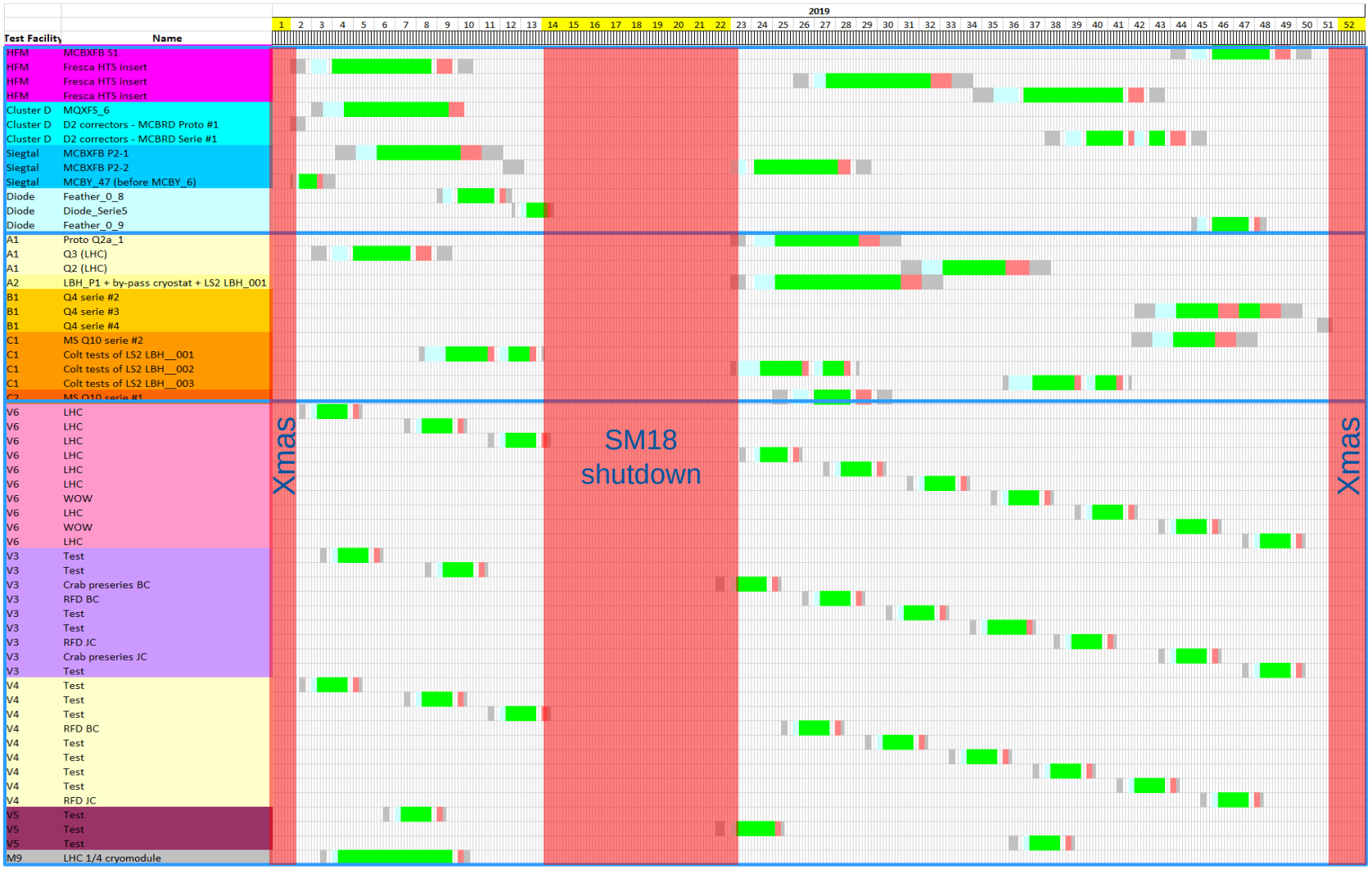
With significant risk of delay for more limited upgrades: **the decision taken to select a 35 g/s upgrade. Order placed in 2017 for a new liquefier to be delivered in April 2019.**

As the **full 35 g/s capacity** will not be required permanently, the specification required also **an optimized operation mode of 17.5 g/s**, but with a maximum electrical power consumption of 1.5 MW at full capacity.

Fully redundant for LHe with existing cryoplant that will be essentially dedicated to the HL-LHC string tests

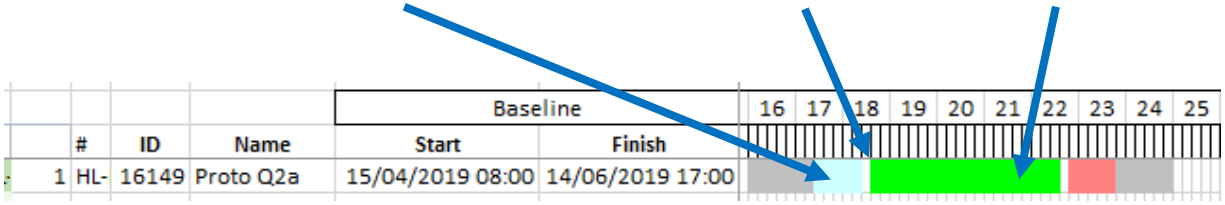
Test Planning to re-evaluate consumption

Test allocation in benches → to avoid overallocation



Consumption Calculations 1

- 3 Phases are taken in account :
  - Cool-down / Stanb-By / Testing



	#	ID	Name	Baseline Start	Baseline Finish
1	HL-	16149	Proto Q2a	15/04/2019 08:00	14/06/2019 17:00

- For each tests, 2 resources are evaluated
  - Liquid helium (LHe)
  - Pumping capacity (VLP)
- Consumption calculation give a value per day.

Synthesis of Consumption

FACILITY	USER	Cryostat volume			purge and		Thermal Shield		Cool down 80k		Cool down and Filling			ng		1.9K Phase							Evaporation	Warm up	
		Total volume	1.9K bath volume	4.5K bath volume	Time	GHe Loss	Time	GHe Loss	Time	GHe flow	Time	LHe mass	LHe mass fl	ss	quench recovery time	nb of quench per day	LHe Mass	Current leads MF	Cold return MF	COL MF	Buffer MF	Screen MF	VLP MF	Lhe total MF	Time	Time	GHe MF
		m3	m3	m3	h	kg	h	kg	day	g/s	h	kg	g/s		h		kg	g/s	g/s	g/s	g/s	g/s	g/s	g/s	h	day	g/s
CLUSTER G	LONG	1.72	1.20	0.52	1.5	1					40	800	6		2	2	188 - (Vaimant * 147)	0.8	0.5	0.6			2	3.9	6	5	
	Siegtal	1.08	0.72	0.36	1.5	0.9					24	230	3		1	2	188 - (Vaimant * 147)	1.4	0.3				1	2.7	6	5	
	HFM	7.56	4.14	3.42	13	20			3	80	37	1200	9		4	2	785 - (Vaimant * 147)	1.25		0.1	1.5	1.1	4	6.45	9	5	
	Diode	0.45		0.45	2	0.4					2	15	2													2	
CLUSTER D	Cluster D	5.06	3.95	1.11	13	25			3	80	6	520	24		4	2	450	2.4		0.2	0.6	0.5	4	7.7	5	3	
HORIZONTAL TEST BENCH	izontal dip	5.06	3.95	1.11	12	20			0.5	90	24	850	10		2.25	2		2	5				1.5	4	2	12	90
	orizontal S				12	20			0.17	90	8	300	10		2.25	2	75	2	5				1.5	4	2	4	90
RF VERTICAL CRYOSTATS	V3	4.00			14.5	4.1	5.5	1.5			6	450	21				300						2	2	15	6	
	V4	4.00			14.5	4.1	5.5	1.5			6	450	21				300						2	2	15	6	
	V5	2.37			1.5	2.3	8	1.5			8	150	5												3	4	
	V6	3.80			12	4					10	900	25				300						2	2	15	5	
RF BUNKER MODULE	M7																						4	5			
	M9																						4	5			
OTHERS	SCLink																										
	GReC																										
IT STRING	String								1.5	90	36		20						15	6			4.5	12			

FACILITY	USER
CLUSTER G	LONG
	Siegtal
	HFM
	Diode
CLUSTER D	Cluster D
HORIZONTAL TEST BENCH	izontal dip
	orizontal S
RF VERTICAL CRYOSTATS	V3
	V4
	V5
	V6
RF BUNKER MODULE	M7
	M9
OTHERS	SCLink
	GReC
IT STRING	String

- Synthesis of all ers
- Value of this tal ulated from real operation value culation have been made.
- This table is us ption estimation calendar

Consumption Calculations 2

Cooldown :

Cooldown is separated in 2 phases

- CD to 4.5 K (Half the time of the scheduled CD)
- CD to 1.9 K (Half the time of the scheduled CD)

4.5K CD calculation* :

$$LHe = LHe_{Static4.5K} + \frac{(LHe_{CD4.5K} - LHe_{Static4.5K}) * T_{CD4.5K}}{T_{CDReal} * 0.5}$$

1.9K CD calculation* :

$$LHe = LHe_{Static1.9K} + \frac{(LHe_{CD1.9K} - LHe_{Static1.9K}) * T_{CD1.9K}}{T_{CDReal} * 0.5}$$

$$VLP = VLP_{Static1.9K} + \frac{(VLP_{CD1.9K} - VLP_{Static1.9K}) * T_{CD1.9K}}{T_{CDReal} * 0.5}$$

With :

- $Lhe/VLP_{static4.5K/1.9K}$: LHe/VLP conso. in stable 4.5K / 1.9K (g/s)
- $Lhe/VLP_{CD4.5K/1.9K}$: Lhe/VLP conso. in Cooldown 4.5K / 1.9K (g/s)
- $T_{CD4.5K/1.9K}$: Time seen in operation for 4.5K / 1.9K Cooldown (s)
- T_{CDReal} : Cooldown time scheduled by the planning (s)

StandBy* :

- $LHe = LHe_{Static1.9K}$
- $VLP = VLP_{Static1.9K}$

Testing phases* :

$$LHe = \frac{LHe_{Static1.9K} + (LHe_{CD1.9K} - LHe_{Static1.9K}) * T_{QRecov} * Nb_{Qperday}}{T_{Day}}$$

$$VLP = \frac{VLP_{Static1.9K} + (VLP_{CD1.9K} - VLP_{Static1.9K}) * T_{QRecov} * Nb_{Qperday}}{T_{Day}}$$

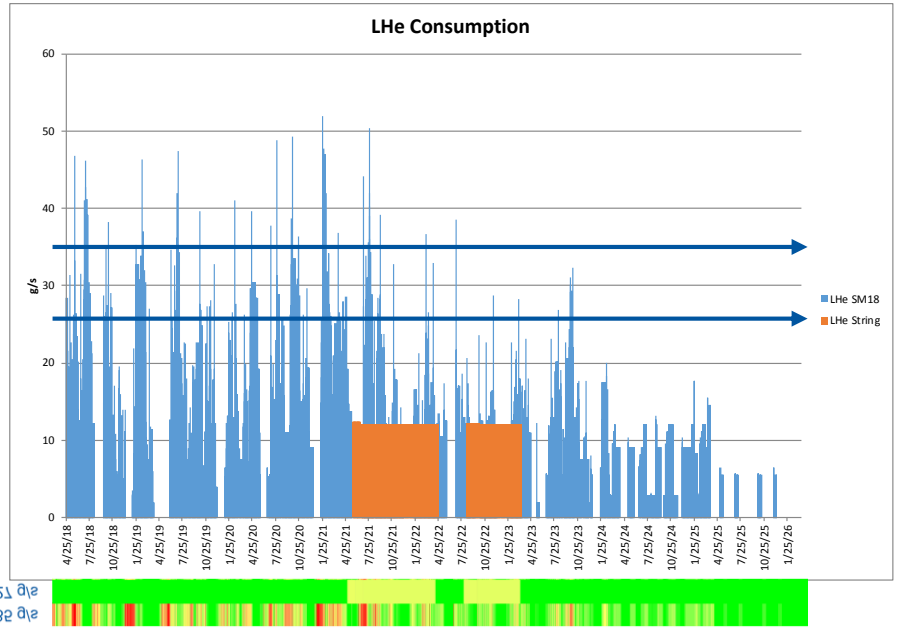
With :

- $Lhe/VLP_{static1.9K}$: LHe/VLP conso. in stable 1.9K (g/s)
- $Lhe/VLP_{CD1.9K}$: Lhe/VLP conso. in Cooldown 1.9K (g/s)
- T_{QRecov} : Quench recovery time (s)
- $Nb_{Qperday}$: Number of quench per day (no unit)
- T_{Day} : seconds in a day (s)

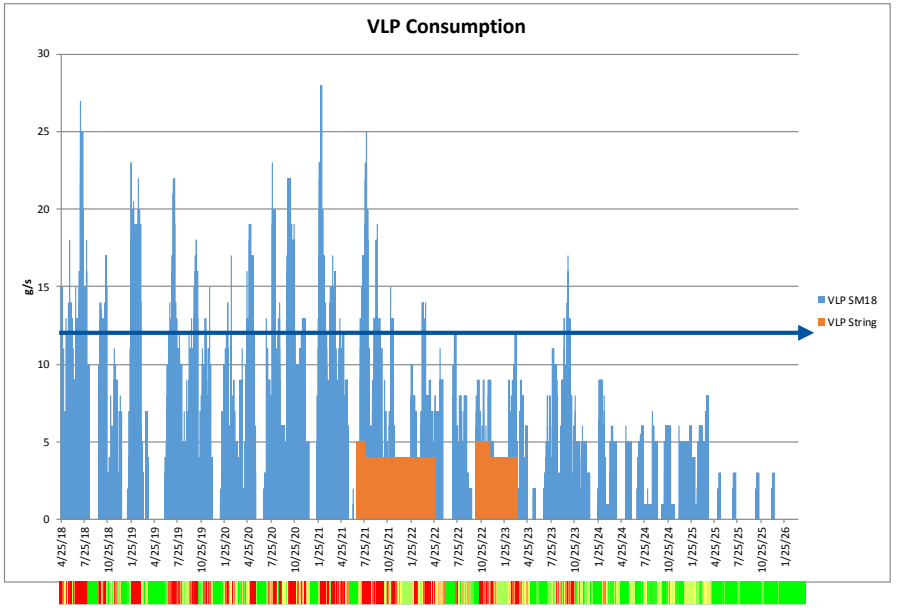
*All values come from the synthesis table seen before

Present Requirements for the cryogenic infrastructure

Based on the planned test program



Liquefaction



Low pressure pumping

Based on this calculation it has been decided to pursue the installation of the New liquefier, and to keep the present pumping capacities.

However if needed:

- We plan to extend the work duration in two shifts
- We can modify the test planning to smooth the peaks
- We will improve the automation performances

The current SM18 cryogenic infrastructure

Key figures:

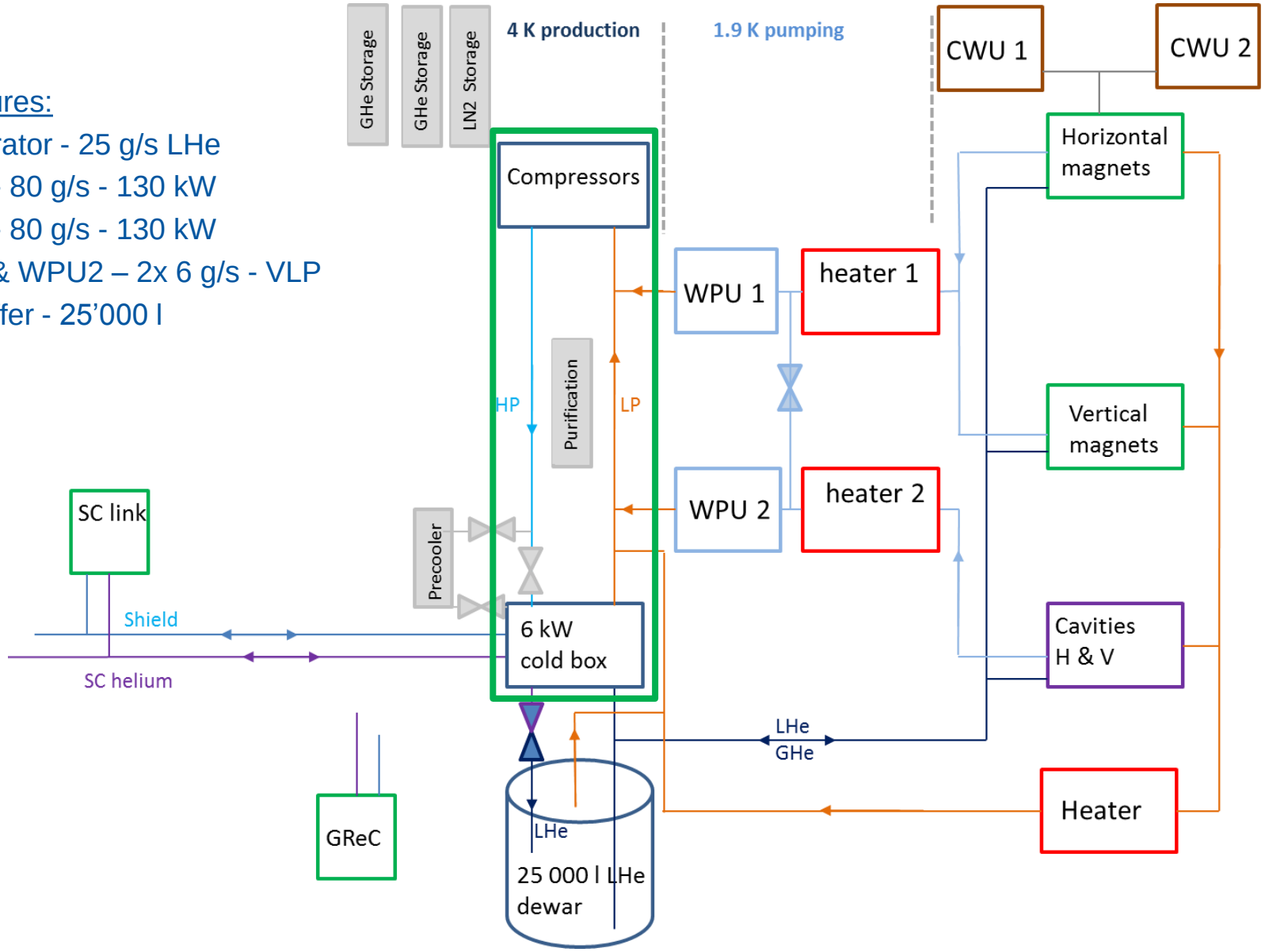
Refrigerator - 25 g/s LHe

CWU1 - 80 g/s - 130 kW

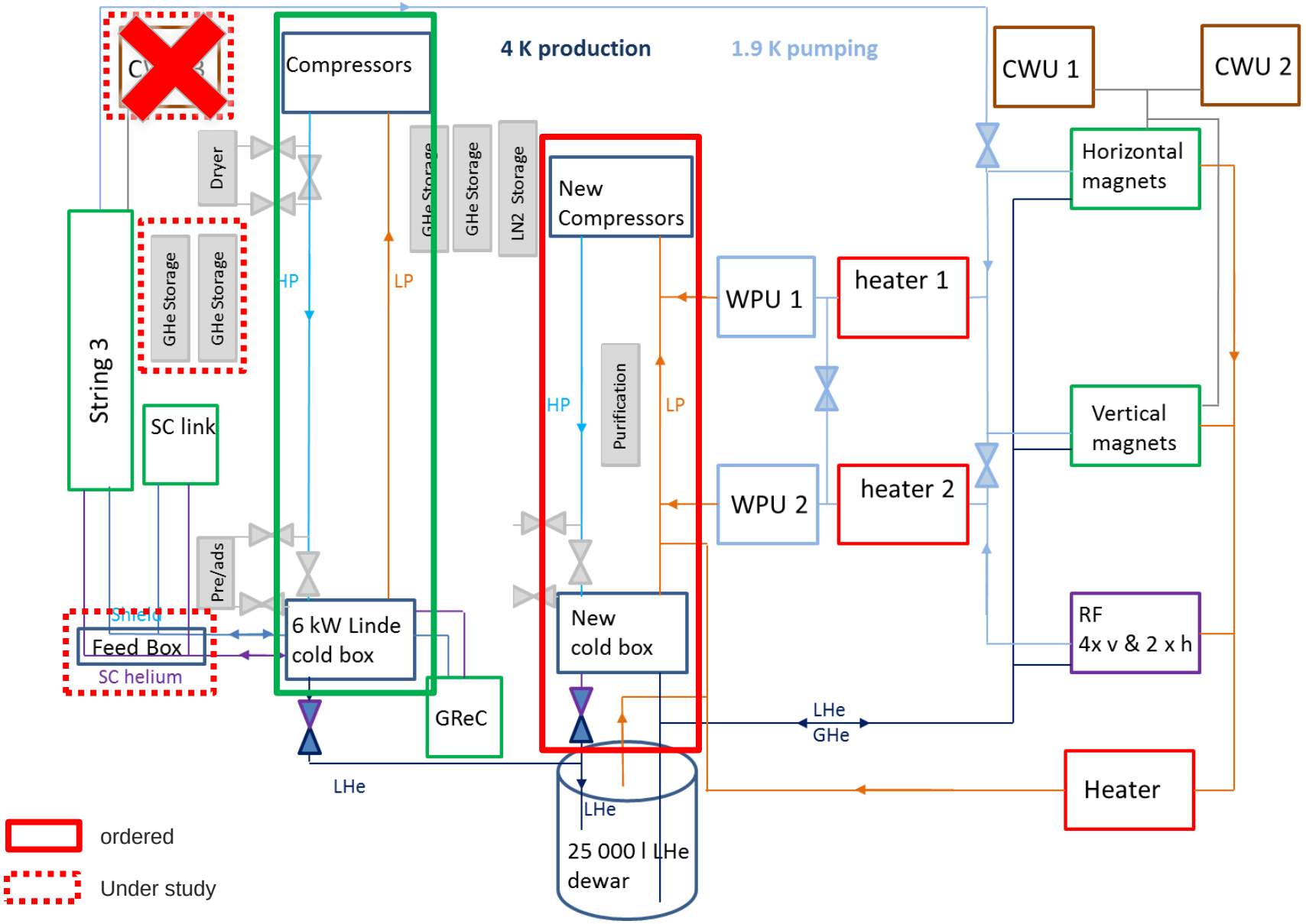
CWU2 - 80 g/s - 130 kW

WPU1 & WPU2 – 2x 6 g/s - VLP

LHe buffer - 25’000 l



The future upgraded SM18 cryogenic infrastructure



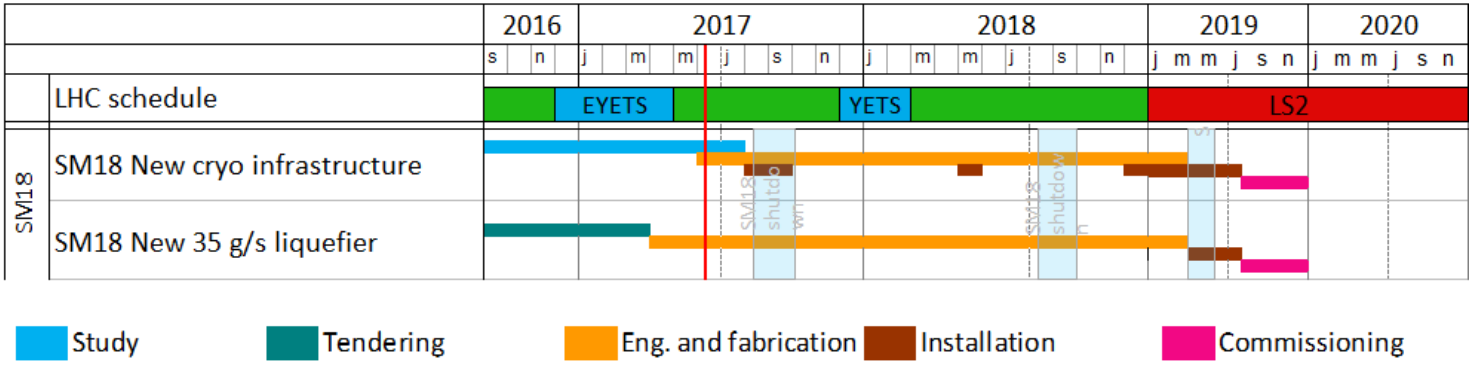
The SM18 upgrade and schedule

Other systems upgrade: mostly linked to the HL-LHC string, but not finalized yet

- Cooldown / warmup units
- Warm helium storage

Utilities upgrade: (major upgrade ongoing) compatible with additional capacity.

Schedule

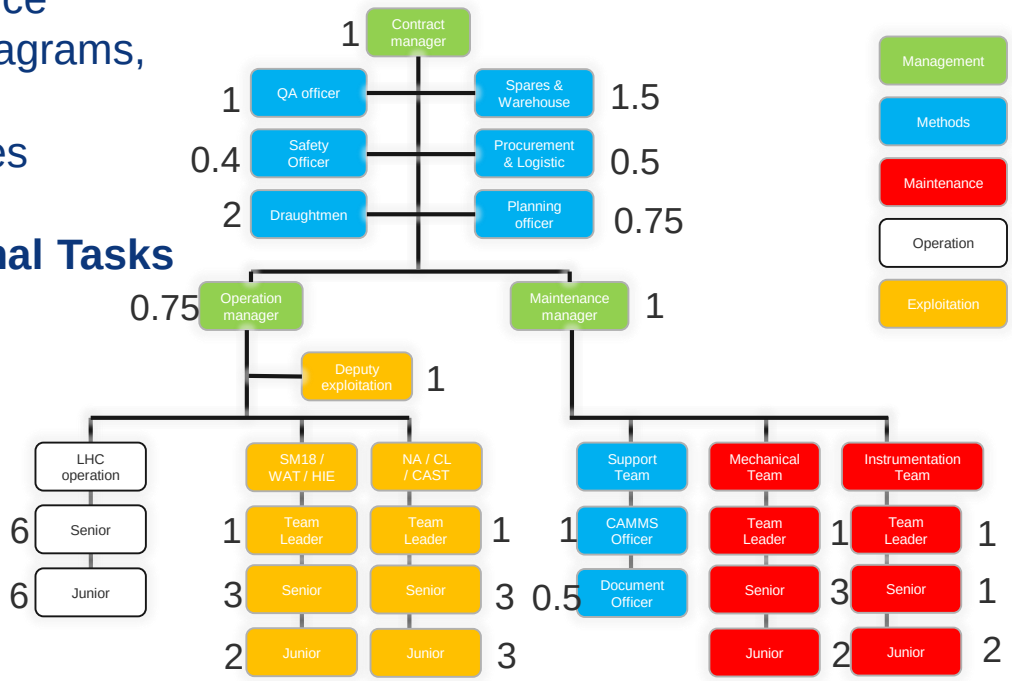


2 Month Shut Down in April May 2019
Full implementation to be operational in fourth quarter of 2019.

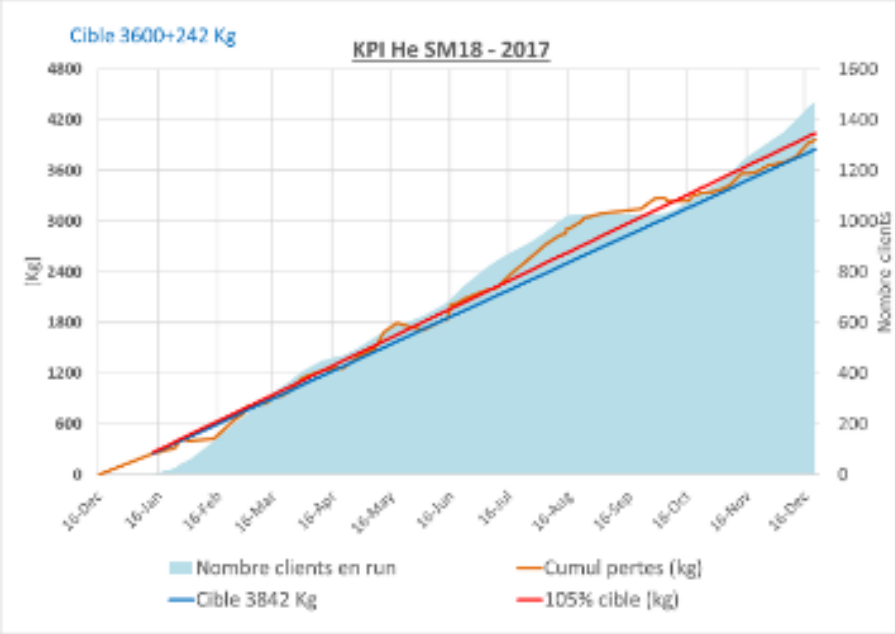
CRG Operation & Maintenance Contract

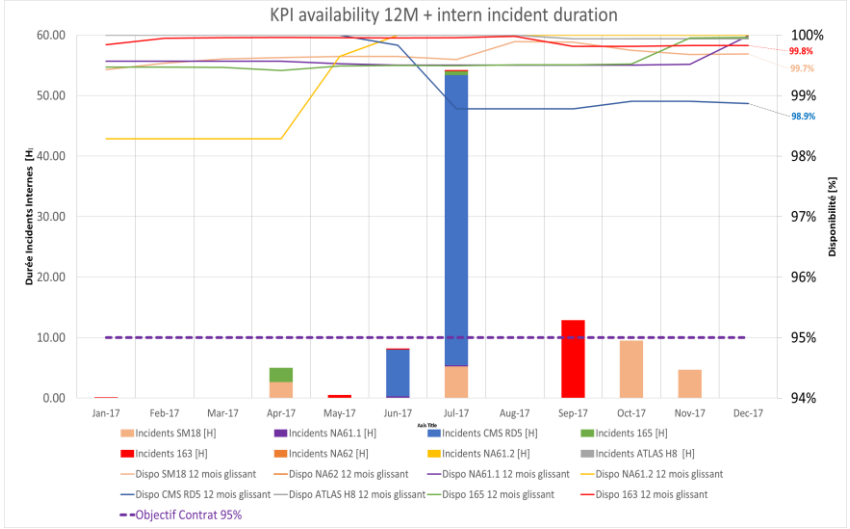
From mid 2016 the CRG M&O contract foresees to :

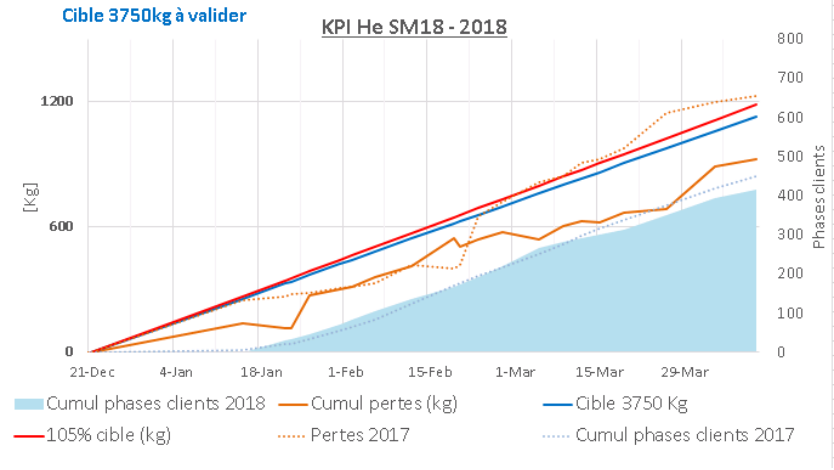
- **Operates and Maintains** (Task Oriented) the LHC Accelerator and Associated Detectors.
- **Exploits** (Operates and Maintain with result oriented payments) the Non LHC Test Facilities and Experiments.
- **Manages the Methods** (Lump sum) :
  - CAMMS : (INFOR-EAM) Maintenance Documentation & Drawings (P&I Diagrams, Electrical Schemas)
  - Spare parts management and Stores keeping
- **Performs a limited number of Additional Tasks**

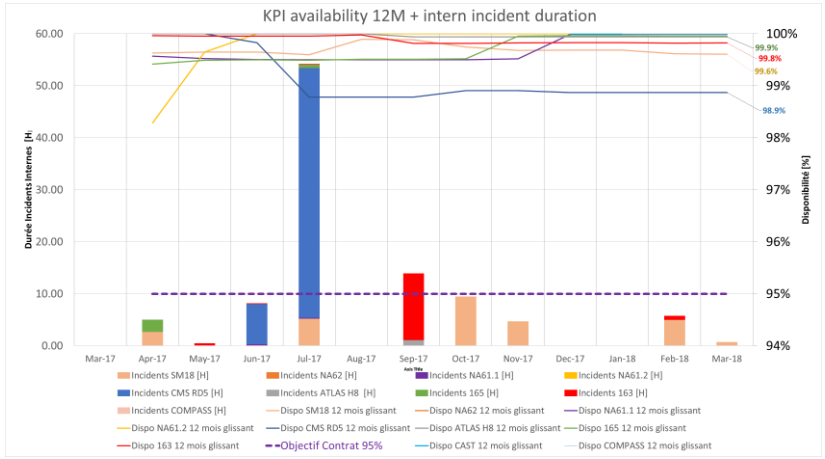


The SM18 Performances : He and Availability KPIs



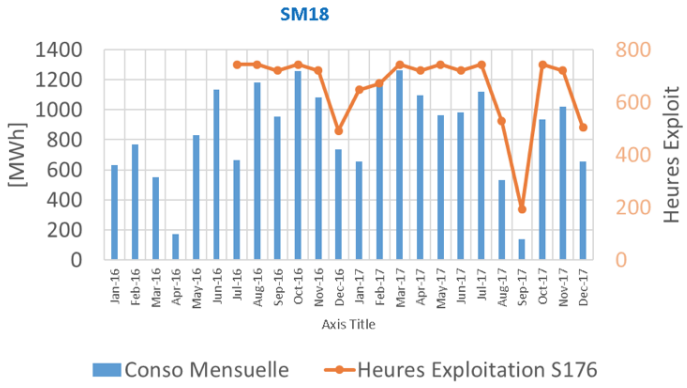


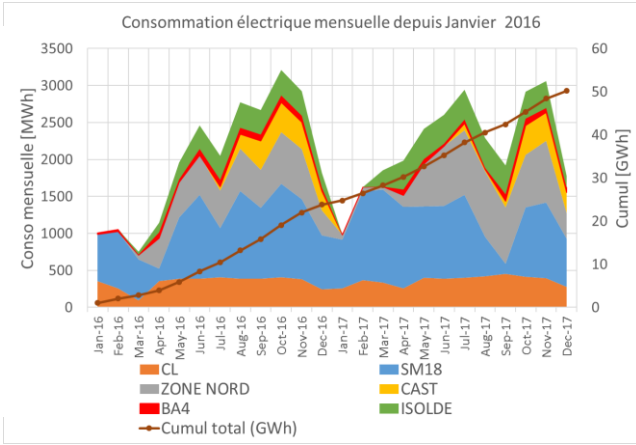


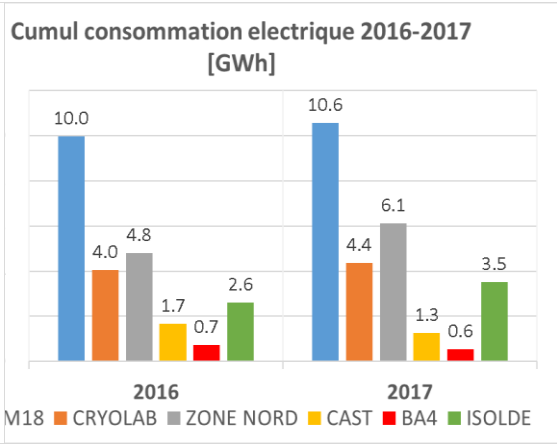


SM18 additional KPIs : Energy; LN2 usage

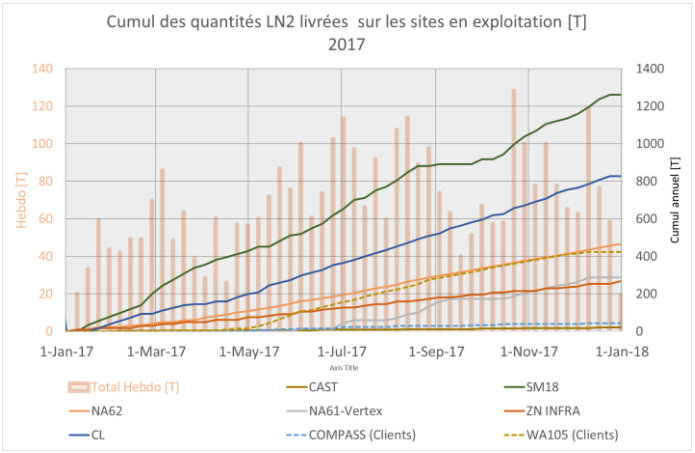
% of energy consumption in addition to the standard historic consumption with respect to the client loads (last 3 operation years at CED) for the boosting of the cold boxes for the installations under performance obligations







% of nitrogen used in addition to the standard historic consumption with respect to the client loads (last 3 operation years at CED) for the boosting of the cold boxes for the installations under performance obligations



Conclusions

- The SM18 is a unique equipment to test and validate the HL-LHC components
  - It allows the validation of both magnet and RF equipment

- The study performed to evaluate the requirements for the future SM18 cryogenic infrastructure showed
  - that an increase of 35 g/s in the peak liquefaction capacity **was necessary** from 2019 to comply with the requirements of CERN new projects.
  - That the upgrade of the low pressure pumping capacity, **is not necessary**
  - Possible other upgrades include an additional cooldown/warm-up unit for the HL-LHC string and additional helium warm storage buffers are still studied

- Following the outcome of the study, a new optimized 35 g/s liquefier has been ordered in 2017 and will be installed in April 2019 and commissioned at fall

- With the planned upgrade, fully operational in 2020, the SM18 cryogenic infrastructure will comply with the testing requirements of the HL-LHC project and with future CERN R&D programs

- From mid 2016 the operation of the facility has been subcontracted with performance incentives
  - In 2017 the performances have been very good with a good commitment of the contractor resources.