CERN

Cryogenics experience during Run2 and impact of LS2 on next run

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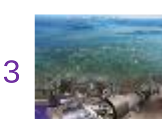
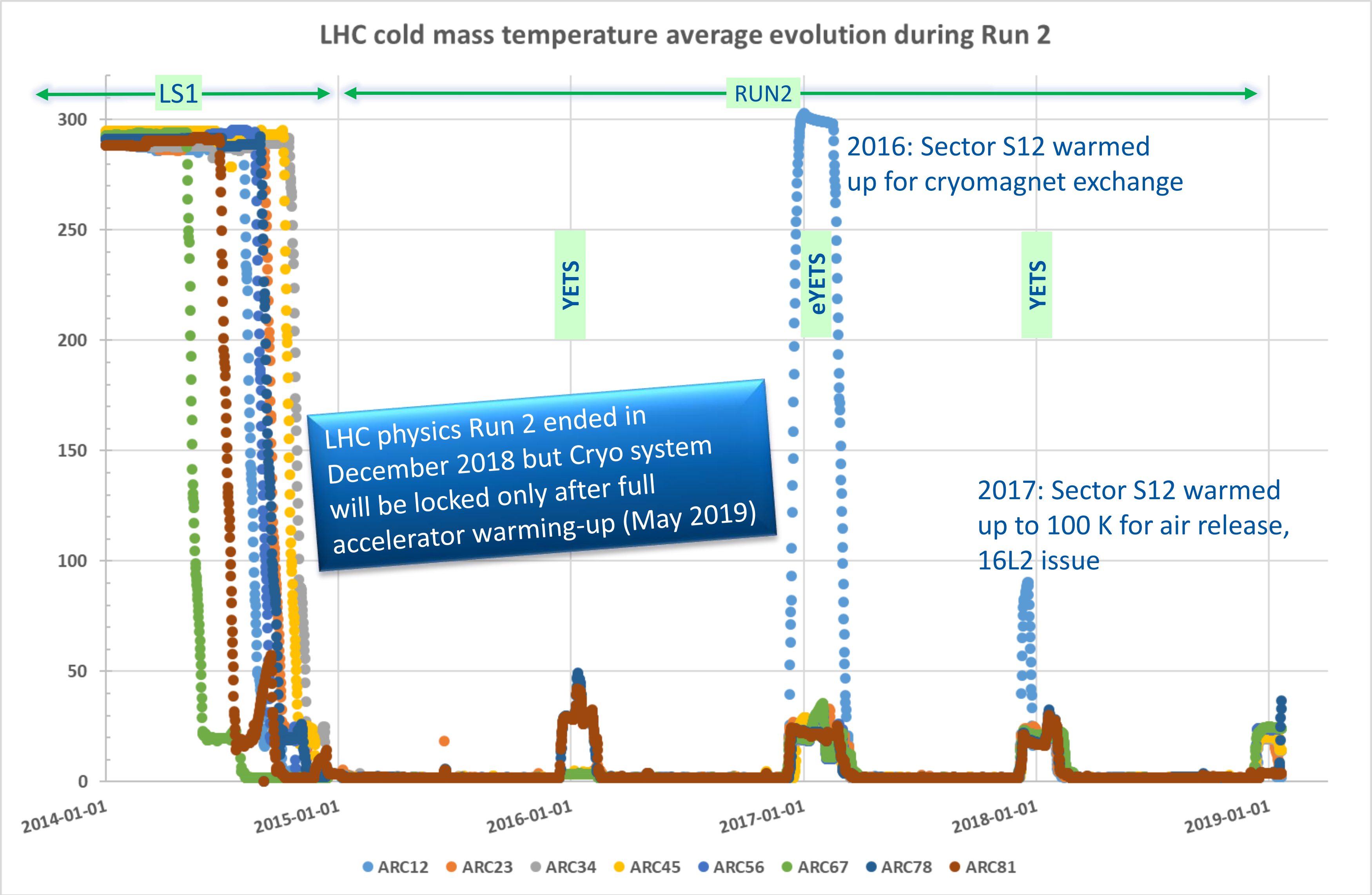
Agenda

- Cryogenic performance and availability for Run2
- LS2
  - Major maintenance & consolidations
  - Software upgrade & data analysis
- Run 3 expected cooling power limitations
- Conclusions & Perspectives

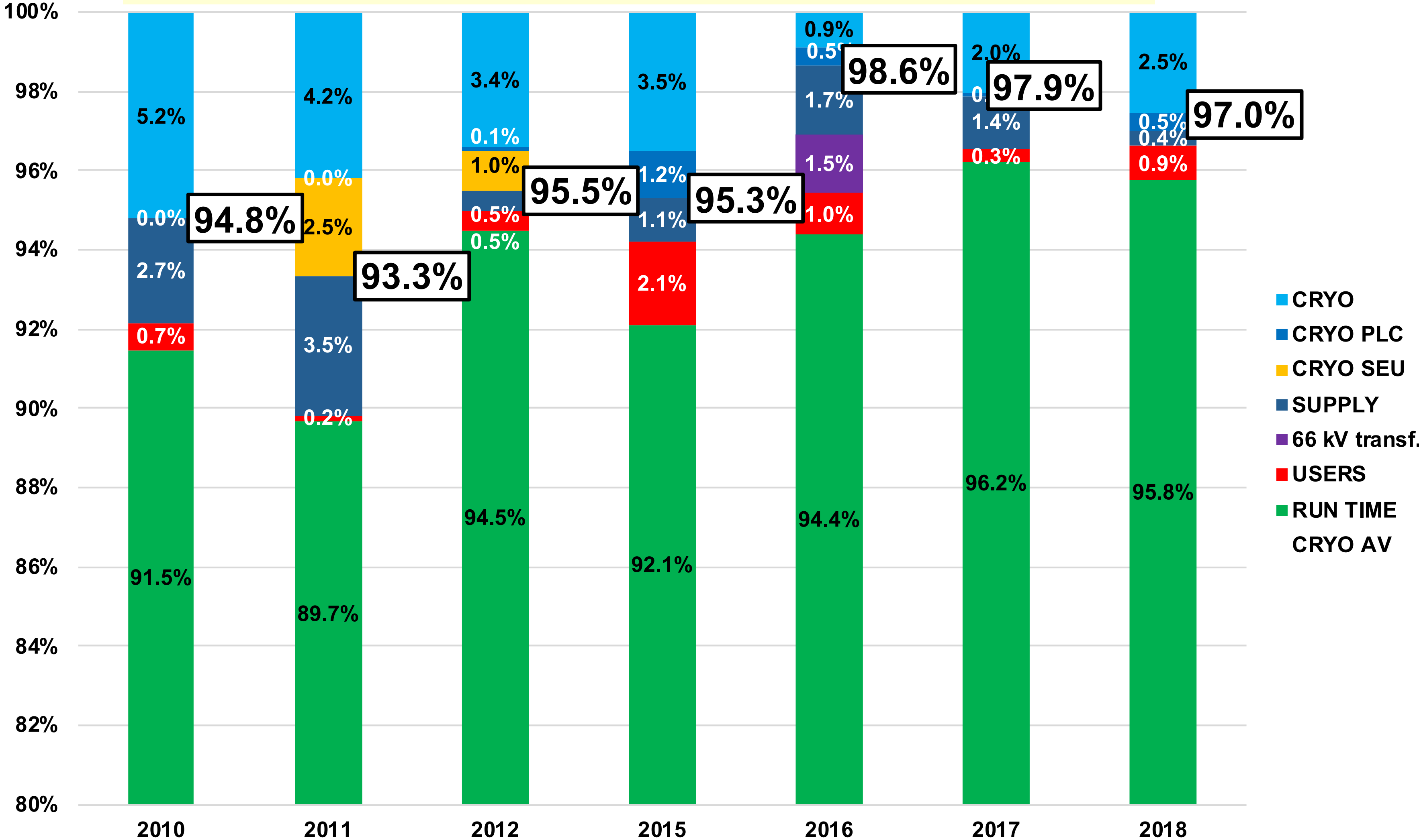


Temperature evolution of LHC cryomagnet during Run2

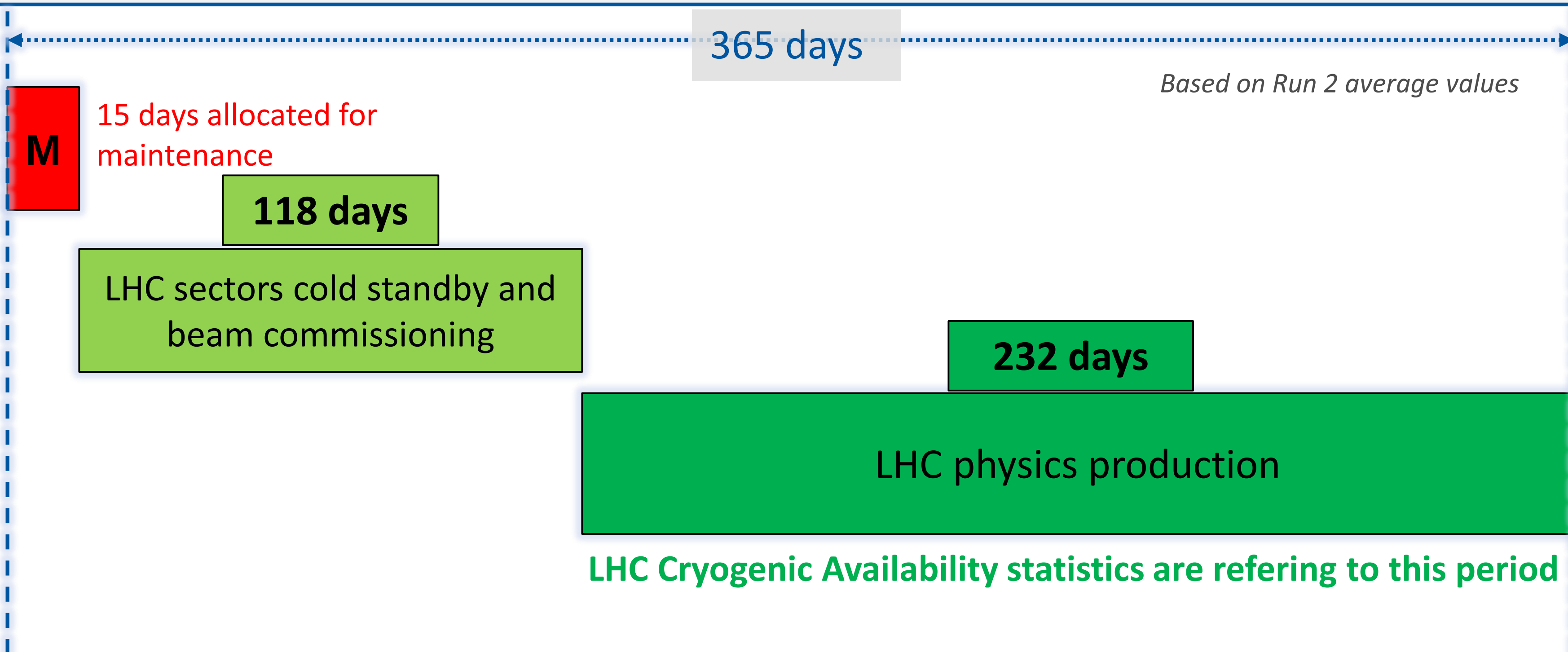


LHC Cryo availability since the beginning

On a long term trend, LHC cryo availability is now in the range 97 to 98 %

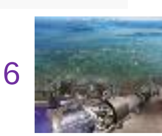


Run 2 allocated time distribution for Cryogenic equipment's



During YETS period, each cryo island must keep its 2 sectors in cold standby. For this purpose only one plant is stopped for maintenance at the same time (maximum maintenance duration of 15 days).
No major intervention is possible on the parts remaining cold.
For Cryogenic equipment, Run 2 duration is in the range 40000 running hours. This length is high compare to the Main Time Between Maintenance (MTBM) of equipment.

Run2 type duration (4.5 years of run) is the maximum acceptable limit for current equipment compatible with availability in the range 97 to 98%



LHC Cryo availability Run 2

Major leak in P8 cold box gives poor quality Supercritical Helium. As consequence, more than 60 Cryo Maintain losses linked to DFB stabilization

Mainly solved during YETS

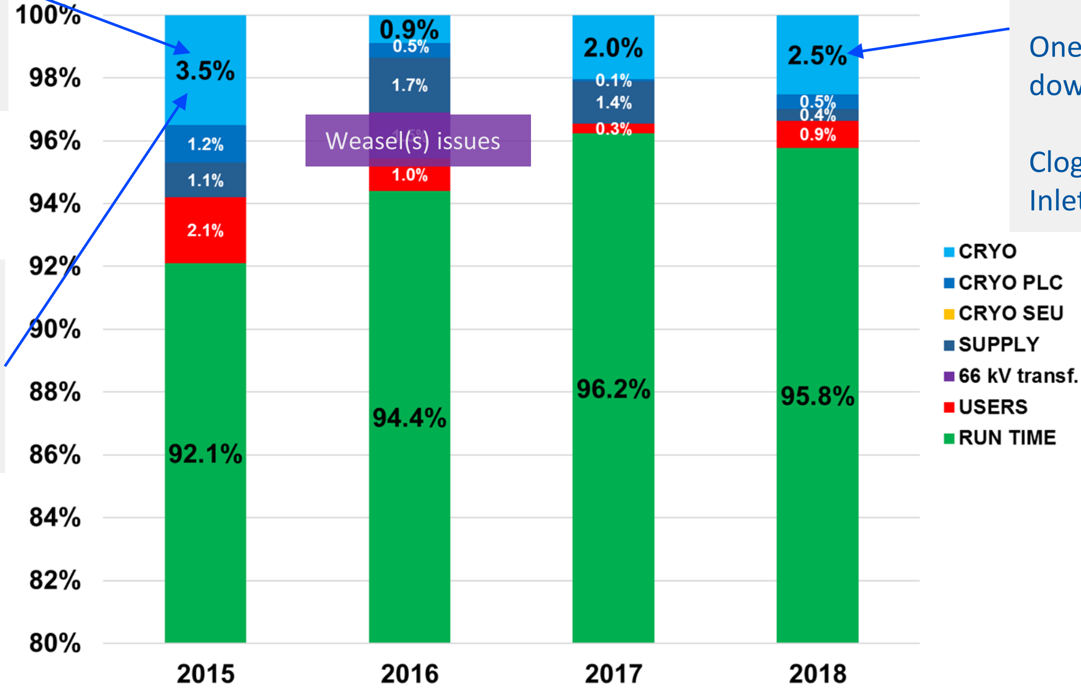
Multiple issues on electrical hardware, 24 VDC & instrumentation used for Cold compressor units

Mainly solved during YETS & eYETS

PLC issues

Should be fully solved during LS2

Weasel(s) issues

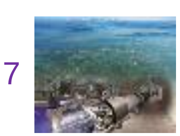


Multiple issues on faulty communication, electromagnetic sensitivity and instrumentation.

One Cold Compressor broke down.

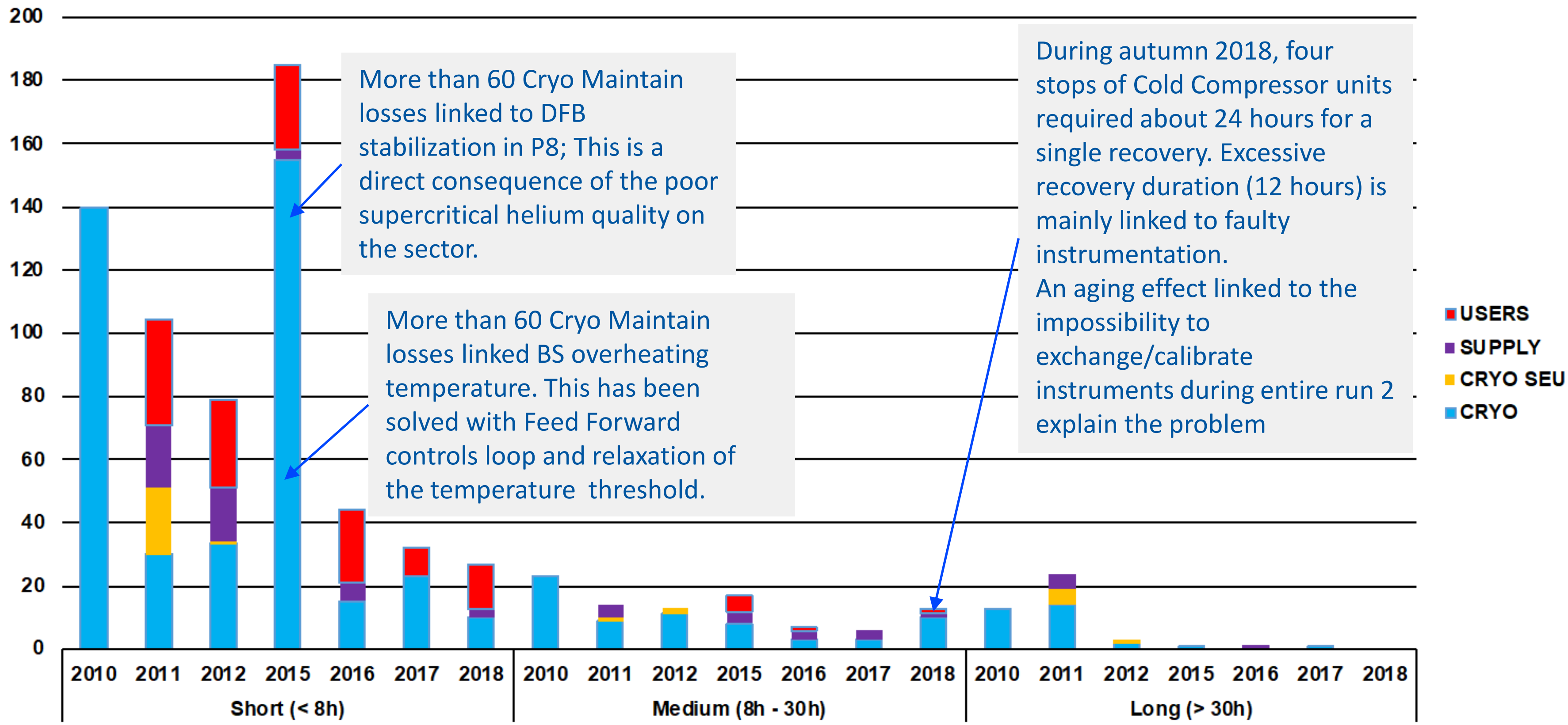
Clogging of Cold compressor Inlet filter (air leak!)

All theses issues not yet solved will be addressed and will drive choice for LS2 consolidations

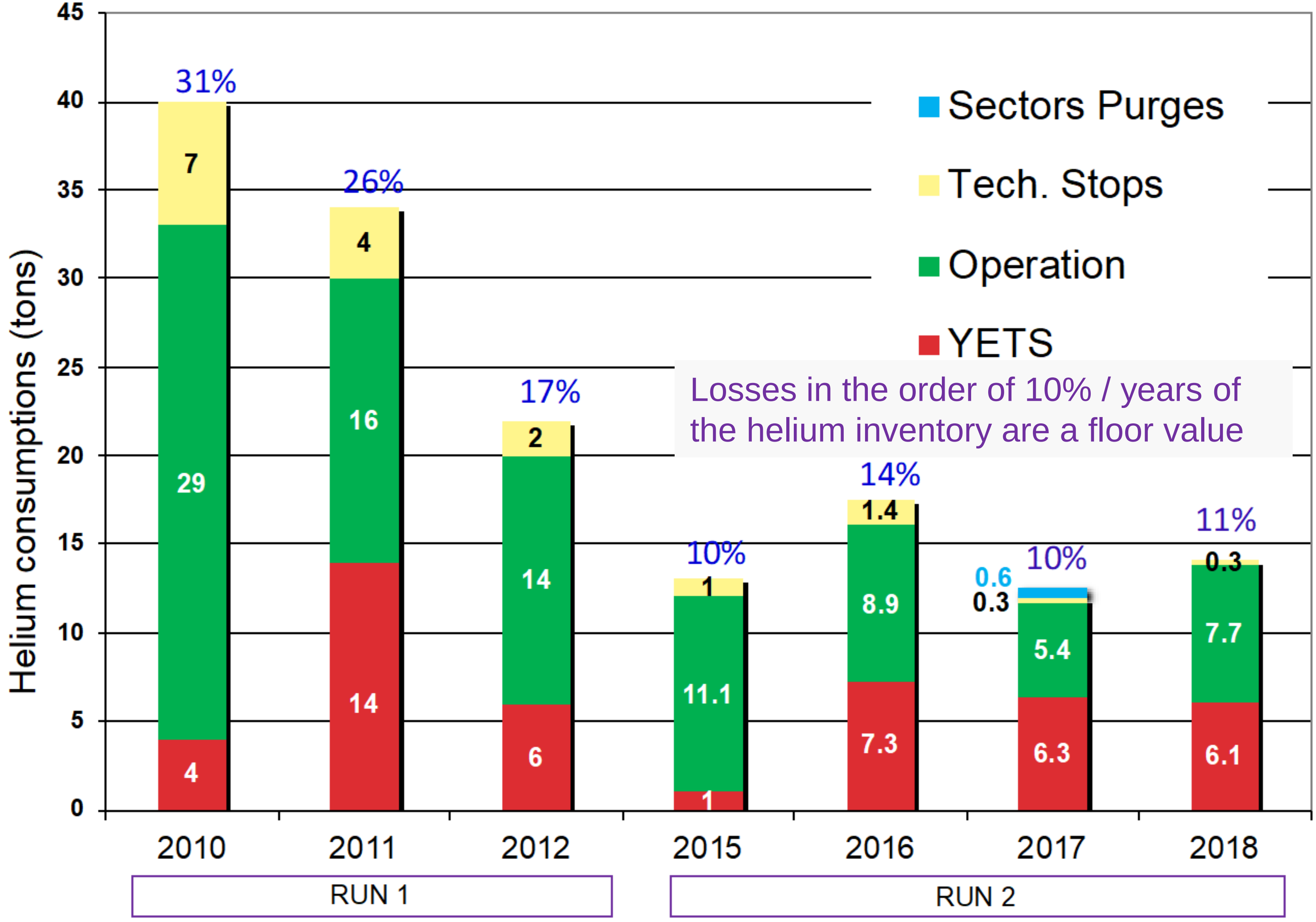


LHC Cryo availability distribution Run 1 & 2;

Statistical distribution according to the duration of the stops



LHC Cryo Helium balance overview over Run 1&2



Main control logic evolutions during Run2

- **Beam Screen** temperature control :
  - Feedforward control to anticipate beam induced heat loads (e-cloud).

	Run 1 (2008-2012)	Run2 2015	Run2 2016 / 2017	Run2 2018
ARC + IT Valves	FB	FB + Common FF	FB + Common FF	FB + Indiv FF
ARC + IT Heaters	FB	FB	FB + Common FF	FB + Indiv FF
SAM Valves	FB	FB	FB + Indiv FF	FB + Indiv FF
SAM Heaters	FB	FB	FB + Indiv FF	FB + Indiv FF

FB = Feedback Control / FF = Feed-Forward Control / Common FF = same QBS estimation for all half-cell

- **Inner Triplet** cold mass temperature control (from 2017 around P1/P5)
  - To avoid strong transients on Inner Triplet temperatures when collisions start (loss of CS/CM).
  - Pre-loading of inner triplets using electrical heaters when no collisions (~200 W / IT).
  - Feed-Forward control based on ATLAS/CMS luminosity signals to decrease heaters and open control valve to anticipate heat loads due to collision debris.
  - Successful transient management, validated at L=2e34 (High Pile-up test in Nov. 2017).

- **Interlock** and safety chain review on cryo refrigerators
  - Stop cryogenic plants only when it is necessary (following 3 undesired stops in 2017).
  - Complete review of interlocks done in 2017 to improve cryo availability.
  - Prototypes done in Jan 2018 on QSCB-4 & QSCA-6 for validation over 2018.
  - 1 undesired stop at QSCA-8 in 2018 would has been avoided with new interlocks (13h of CM loss).

Quick overview of maintenance/upgrade foreseen during LS2

Major overhauling

- Around Sixty warm compressors and as many electrical motor will be sent to manufacturer premises in Europe, for major overhauling.

- Around 8 to 10 Cold compressors cartridges will also be sent for major maintenance (50 % Europe, 50% Japan)

Major refurbishing

- The electrical cabinets of 4 compressor stations (from LEP era) will be totally refurbish

The maintenance plan and all standard maintenance are not described (~4000 work orders)

Quick overview of maintenance/upgrade foreseen during LS2

A major upgrade with new hardware models for Active Magnetic Bearing Controller and Variable Frequency Drive is foreseen. In parallel, the original local PLC delivered by the Cold Compressors supplier will be replaced with new PLC (Cern model).

Cold compressor main hardware & control logic evolution vs time

Cold compressor control process: From a “black box control” to a CERN in-house process control (to enhance operation and cryogenic performances).

LS1 major improvements :

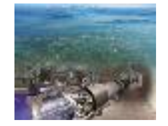
- All hardware VFD & AMB upgraded including an intensive R&D for the 1 type of AMB electronics
- R2E move finalized with good result since Run2 0 fault appeared.
- P2 ghost spike cadence from 3 in 1 year of operation reduced 1 event over a year.

Run2 major improvements :

- SVC immunity investigation
- P2 ghost spike investigation (to reduce to zero possible fault)
- CERN control prototype project for Linde CC. Successful validation end of the Run2

LS2 major improvements (foreseen) :

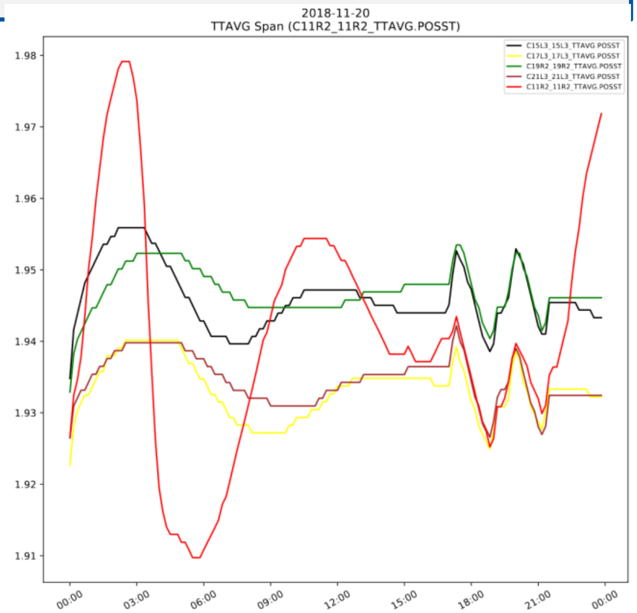
- Removal of local PLC (12 unit in total). Upgrade of all PLCs to M580 Schneider version (with BE-ICS)
- SVC immunity for all points.
- Improved CERN control project for the 2 suppliers (minimization period of reconnection).



Control logic upgrade foreseen during LS2

- Beam screen and Inner Triplet logic now optimized
  - No modifications expected for Run 3. Only fine re-tuning seems necessary.
- Interlock and safety chain review on 18 kW @ 4.5K cryoplants
  - During Run2, we had some full stop of Cryoplants linked to poorly calibrated interlocks. After analysis, some of them appears useless in LHC configuration.
  - Upgrade has been validated on 2 cryoplants in 2018 and will be deployed on the 6 other cryoplants during LS2.
- New script to optimise automatically the mass flow distribution over the sectors after cold-compressor trip
  - Currently a complex task: about 50 parameters to adjust manually over several hours.
  - Script: optimise the parameters according to the missing cool down energy in each cell.
  - Reduce manpower during the recovery after major trips.
  - Accelerate trip recoveries.
  - Under testing at P4 during early 2019.
- Automating of some manual operations to automatic sequences
  - Former LEP refrigerator warm-up.
  - Sector warm-up/cool-down.
  - Quench recovery (partially)
  - …

LHC Cryo data analysis foreseen during Run3



Abnormal heat load detected in 11R2 during Ion Run in Nov. 18

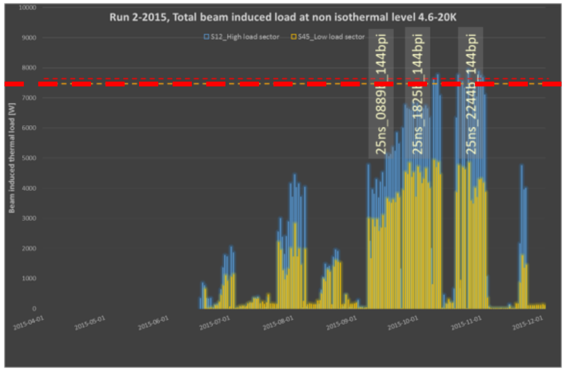
- **Data analytics on LHC cryogenics**
  - Detect problems not seen by conventional alarms
  - Anticipate a potential failure or loss of availability
  - Detect not optimized process and malfunctioning sensors
  - Prolong the life span of equipment
  - **Improve the cryo availability and performance**
- **How to perform such analysis ?**
  - Analyze the archived data with algorithms
  - Provide a daily report to experts/operators on the web
- **Prototype developed in 2018**
  - An automatic scan ("Ronde") in launched every night to analyze de previ
  - 320 jobs analyses XXX signals over LHC cryogenics
  - All potential problems are published on the web with corresponding trends
    - ✓ http://CryoDataAnalytics.web.cern.ch

- Beam screen heat load profiles estimation in instrumented half-cells are also made in this computing infrastructure after every beam dump

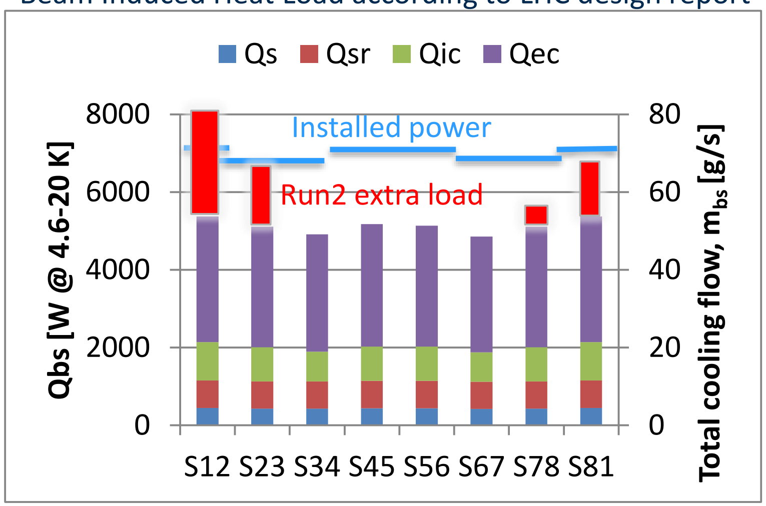
These tools will be ready and validated to assist cryo operation team for Run 3

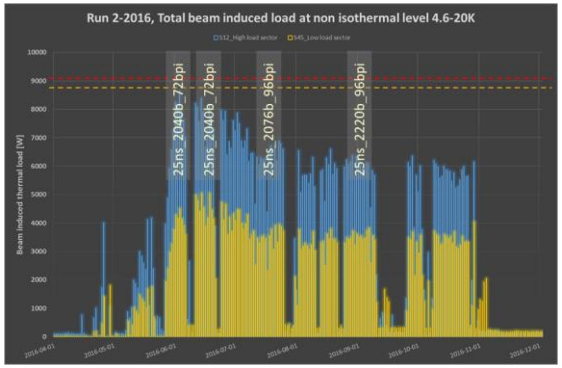
Beam induced heat load on Beam Screen @ 4.6-20K

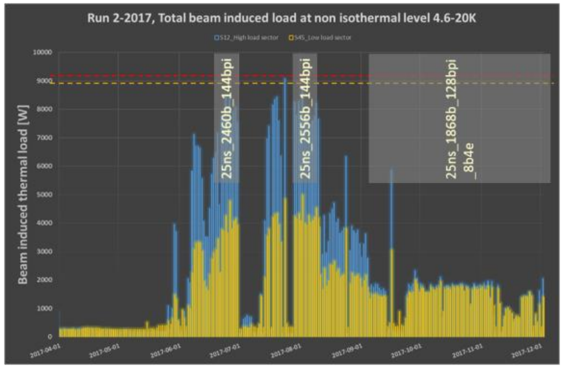
From the beginning of run 2, it quickly became obvious that the beam induced heat loads would exceed the installed powers on the Beam Screen cooling circuit of high load sectors.



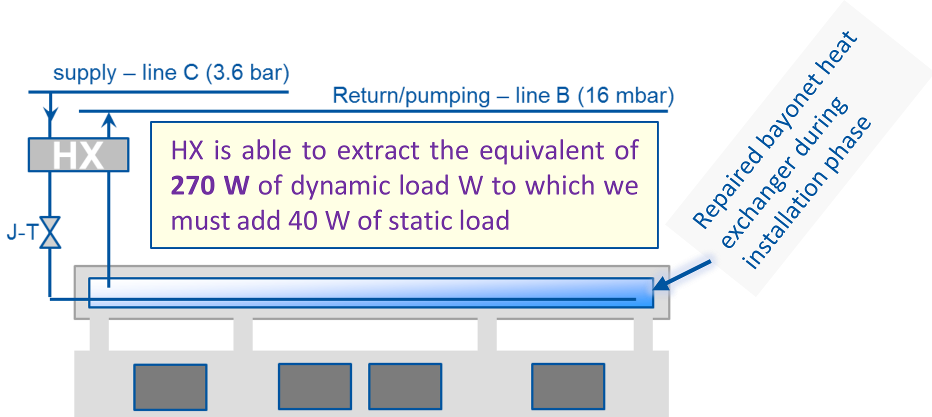
Beam Induced Heat Load according to LHC design report



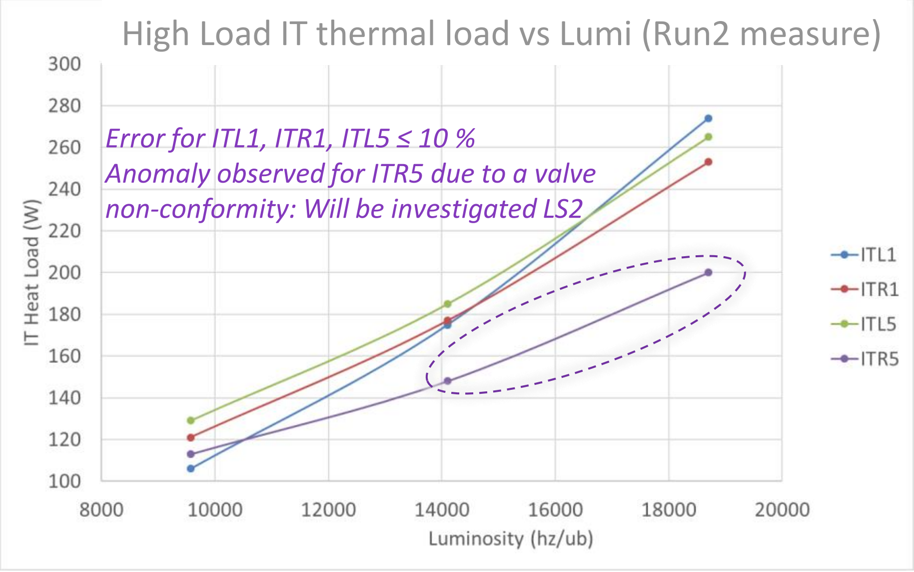




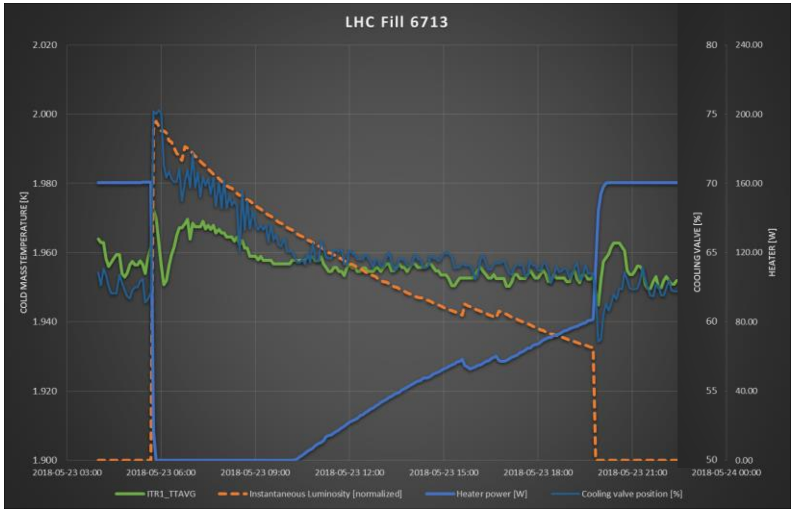
Beam induced heat load on Inner Triplet @ 1.9K



Recent tests shows that there is no operating margins by storing energy (Helium Temp. increase in the triplet). The origin is the saturation of the HX with bistable behaviour.



Typical 2018 Inner Triplet behavior during physics slot



- ITL1 & ITR1 were tested last week. We confirm that the limit of dynamic thermal loads is 270W
- The same test will be carried out before the LS2 warming up to confirm the limit values of ITL5 & ITR5

Combined global refrigeration power

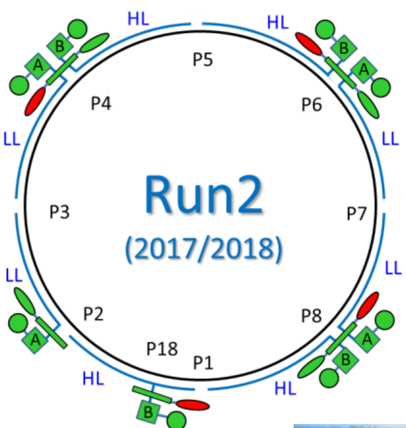
- The maximum guaranteed capacity for s1-2 BS cooling was measured as 200 W/hc.
  The measurements done in configuration of physics run 2017, for fill 5979 (configuration applied for 2018 operation is the same as in 2017).

- In case of ITR1 operation with 270 W on 1.9 K cooling loop (maximum guaranteed cooling capacity at 1.9 K) the related guaranteed capacity for BS cooling will be 195 W/hc

	S1-2	S2-3	S3-4	S4-5	S5-6	S6-7	S7-8	S8-1
Capacity (Design) [W/hc]	180	195	125	160	160	160	175	230
Configuration 2017	200	205	145	?	?	?	195	250
Combined global refrigeration [W/IT ; W/hc]	270 ; 195			270 ; 155	270 ; 155			270; 245

Dark blue: Measured value
Red: IT measure foreseen before LS2
Grey: Calculated value
Orange: Sectors (BS) measure foreseen before LS2

- Sectors 4-5, 5-6 and 6-7 will be measured in the coming weeks, but as thermally low loaded sectors they do not demonstrate operational constraints for LHC operation.



Run3 perspectives, cooling power point of view

Inner Triplets:

- Cryogenic capacity for ITs at P1 and P5 is limited. The guaranteed value for dynamic heat load compensation was measured and is equal to 270 W (306 W for total heat load). With such capacity, the luminosity could be increased up to an equivalent L_{peak}=2.2e^{34} Hz/cm^2 for 6.5 TeV and L_{peak}=2.05e^{34} Hz/cm^2 for 7 TeV.

Beam Screen:

- 5 sectors over 8 were measured. Sector 3-4 shows the capacity of 125 W/hc while sector 8-1 has 230 W/hc (design configuration).
- Developed Feed-Forward control logic allows for BS heat compensation in local cooling loops for any applied beam parameters injected up to now to the machine (for physics).

Combined global refrigeration:

- The global refrigeration capacity shall be considered as limits for future run of the machine.

Conclusions

- The experience gained during Run1 and Run2 was used to optimize the non-isothermal refrigeration capacity @ 4.6-20 K that is beyond the Design Report. In particular the refrigeration capacity transfer from the 1.9 K level to 4.6-20 K has been developed and put into service while maintaining an overall availability superior to Run 1. This configuration has demonstrated its ability to adapt to the current maximum thermal load and will be use during Run3.

- Our cryogenic team uses its analysis, process-calculation and simulation capabilities to develop and optimize the Feed Forward advanced control. The next step, already well advanced, will be to generate early warnings based on data mining.

- There are remaining topics on which a constant effort is requested. In particular a permanent monitoring is mandatory to prevent any massive oil pollution of the cold boxes. A strategy has been launched to “definitely” solve the Oil Removing System (ORS) potential issues. The second line of work is the continuous training of staff in charge of the operation in order to maintain a high level of requirement.

Thank you