Going towards LHC Run2 CRYOGENICS

5th Evian Workshop

2-4 June 2014

SESSION 4 - Systems 2 - Status and commissioning plans (HW perspective)

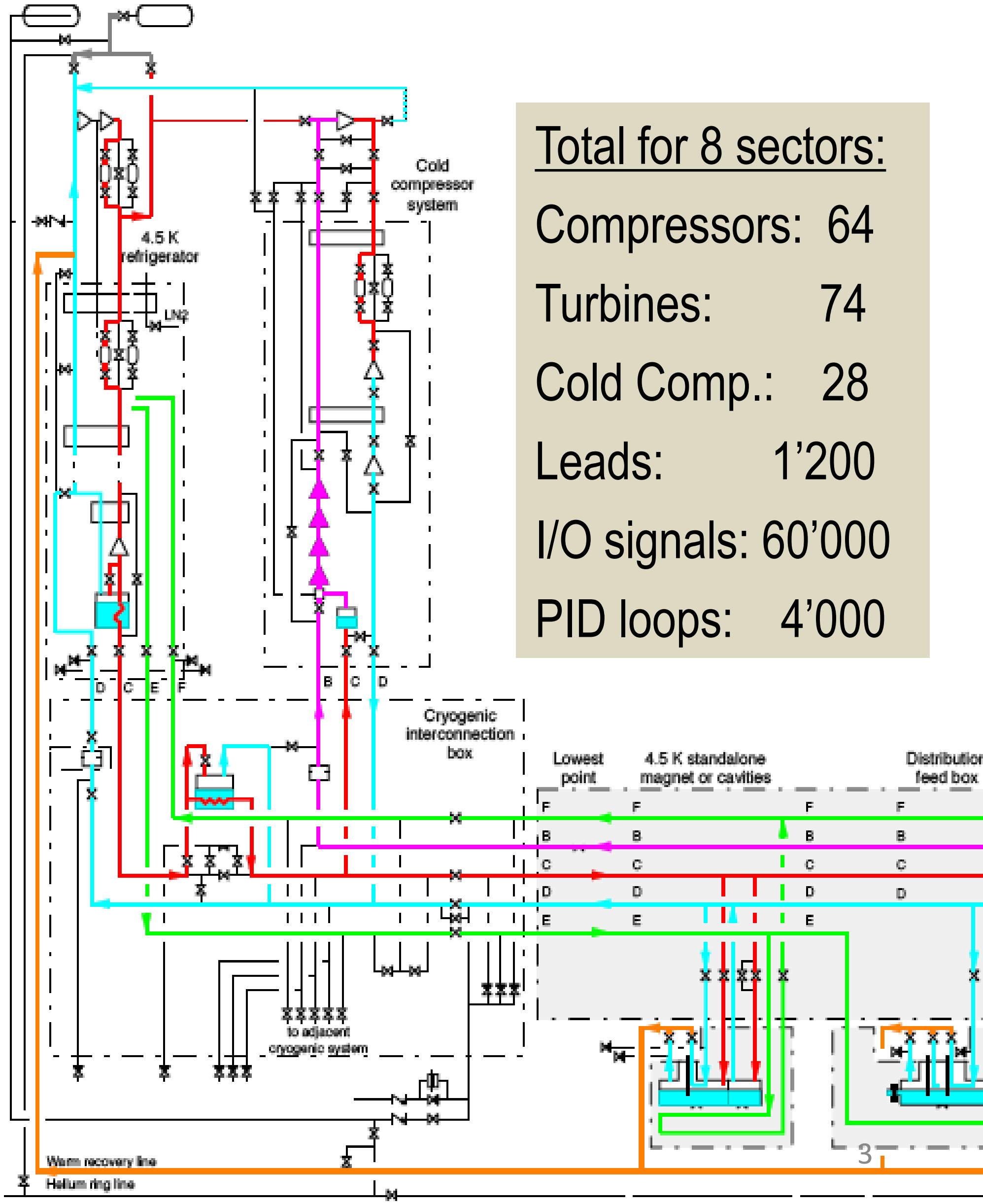
Krzysztof Brodzinski

on behalf of the cryogenic team
with contribution from L. Tavian, S. Claudet and G. Ferlin

Contents

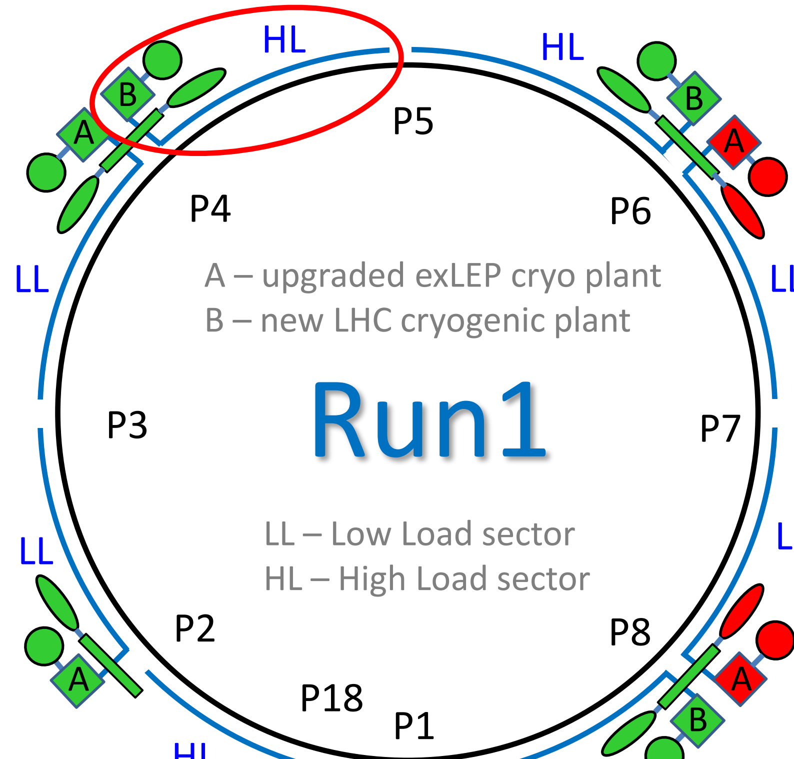
- Introduction – cryogenic infrastructure and Run1 key numbers
- LS1 activities – brief
- **Run2 configuration – operation scenarios**
  - Possibilities for cryo-plant reconfiguration and recovery times
  - Non conformities
  - Recovery from quenches
- **Run2 beam parameters – cryogenic limits and margins**
  - Scrubbing and impact of e-cloud
  - Available margins
- Conclusions

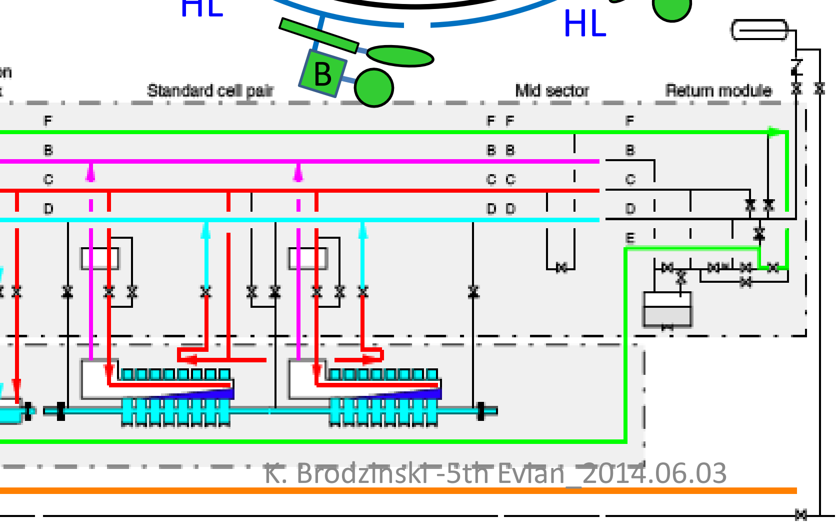
Cryogenic infrastructure



Total for 8 sectors:

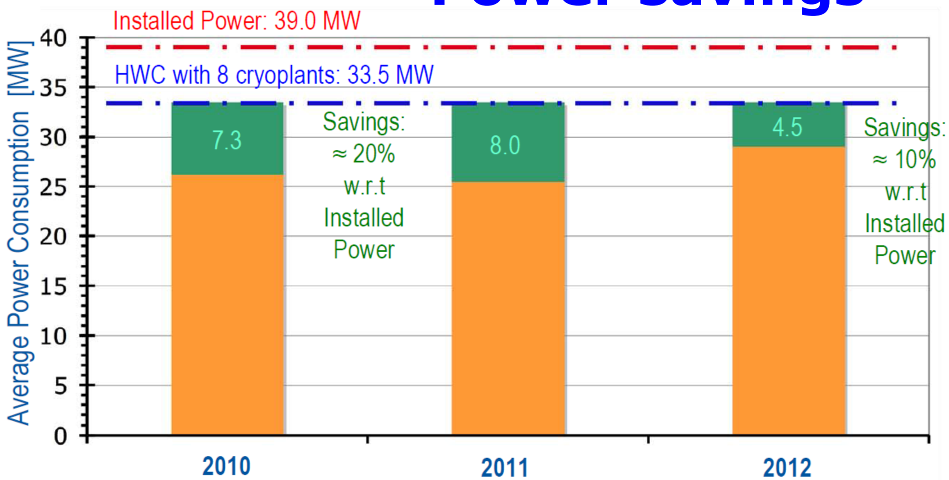
Compressors:	64
Turbines:	74
Cold Comp.:	28
Leads:	1'200
I/O signals:	60'000
PID loops:	4'000



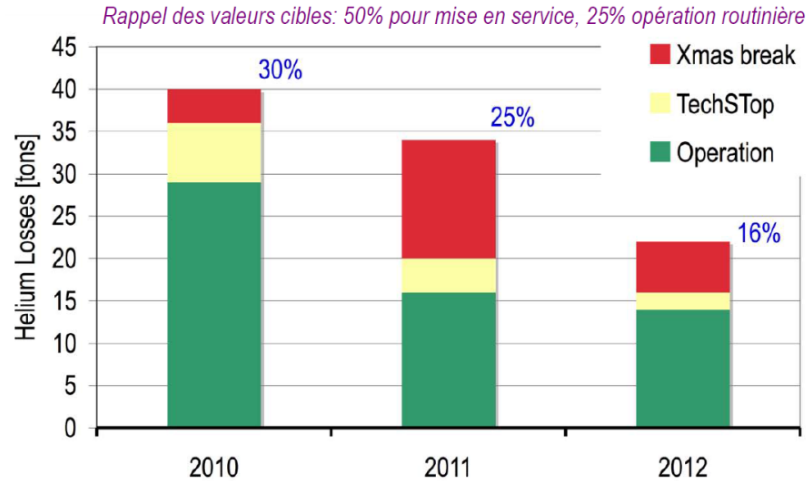


Run1 – some numbers

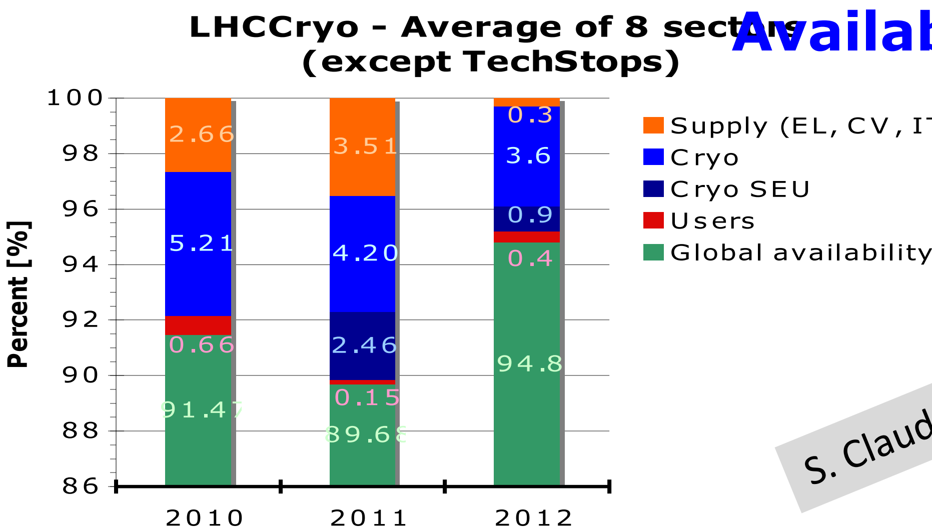
Power savings



Helium loses



Availability



S. Claudet

2012:

- Excellent utilities & interface
- Excellent mitigation of SEU
- Continued improved Cryo availability

Main LS1 activities

Maintenance of all warm compressors and their electrical motors

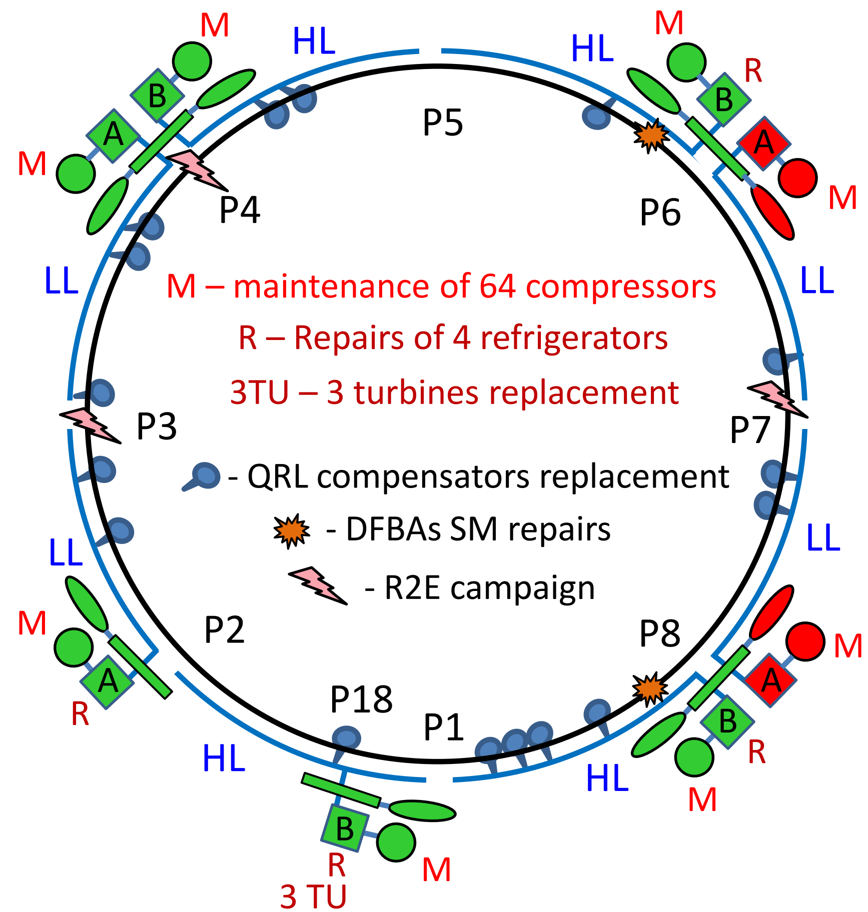
Run 1 – known 2 main refrigerators to be repaired
LS1 – 4 refrigerators repaired (2 repairs done on LN2 pre-coolers)

Run1 – 1 QRL leak to be repaired
LS1 – 16 QRL interconnections repaired

Run1 and LS1 – planned replacement 71 QRL cryogenic valves (38 on beam screen circuit to increase cooling capacity of the loop) – activity underway

DFBAO, DFBAK – bellows replacement (EN-MME)

R2E (radiation to electronics) – at P3,4 and 7

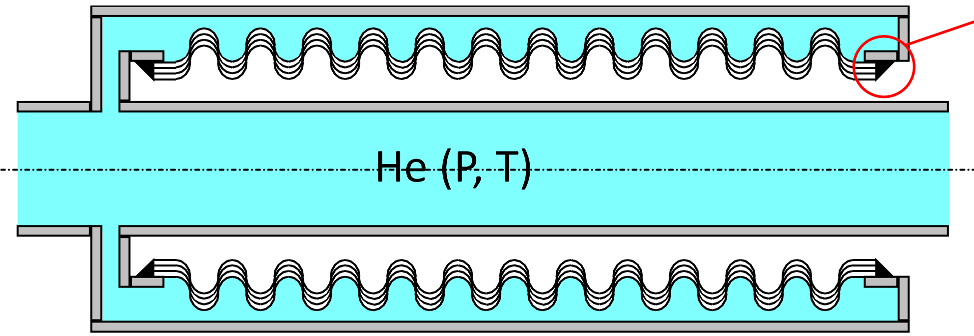


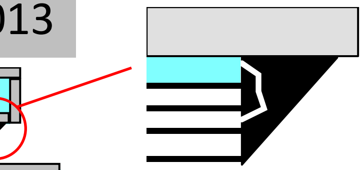
… and many other small activities not visible on large scale.

LS1 was (still is) a big effort of different teams involved focusing on Run2 preparation.

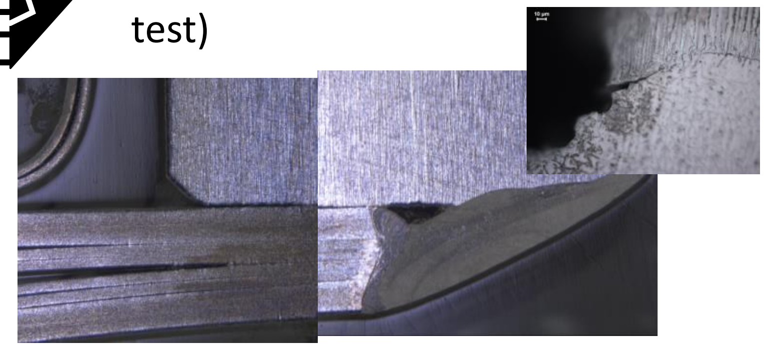
QRL bellows damage mechanism

DD/LT, TE-CRG, TEMB, Monday 29th of July 2013

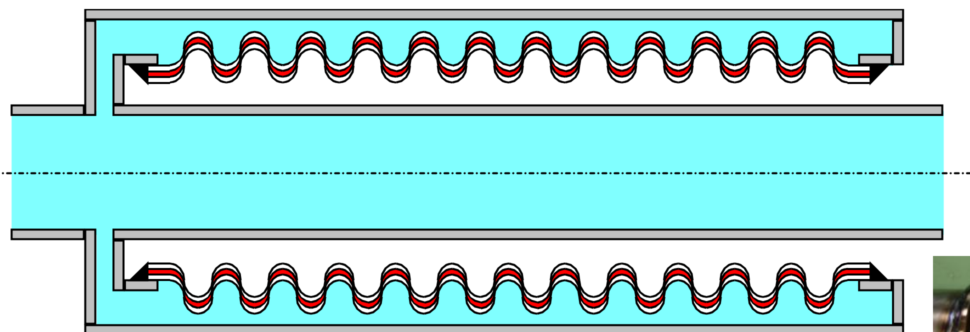




A leak (not seen during global leak test)

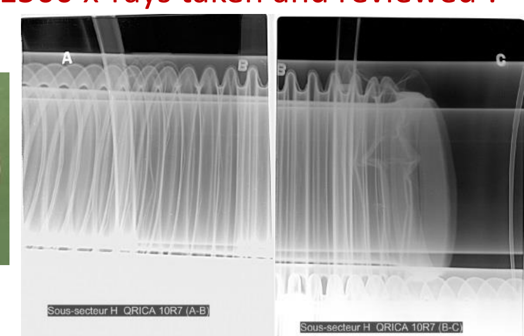


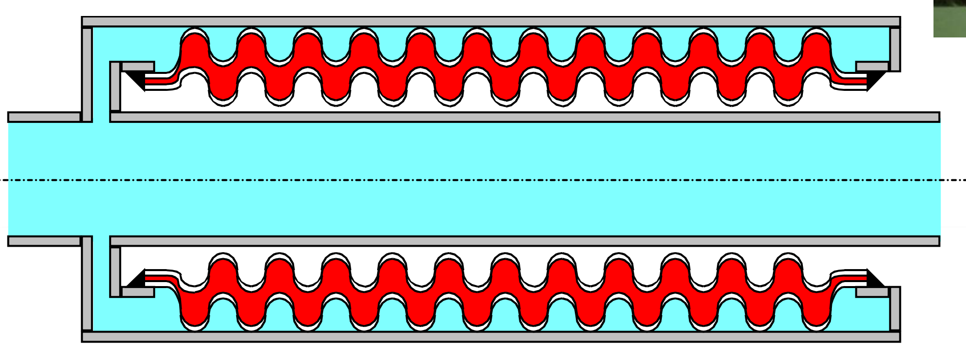
Metallographic analysis by EN-MME (S45, 14R4)



Filling of the inter-layer space with time (3-4 years of operation)

~1500 x-rays taken and reviewed !



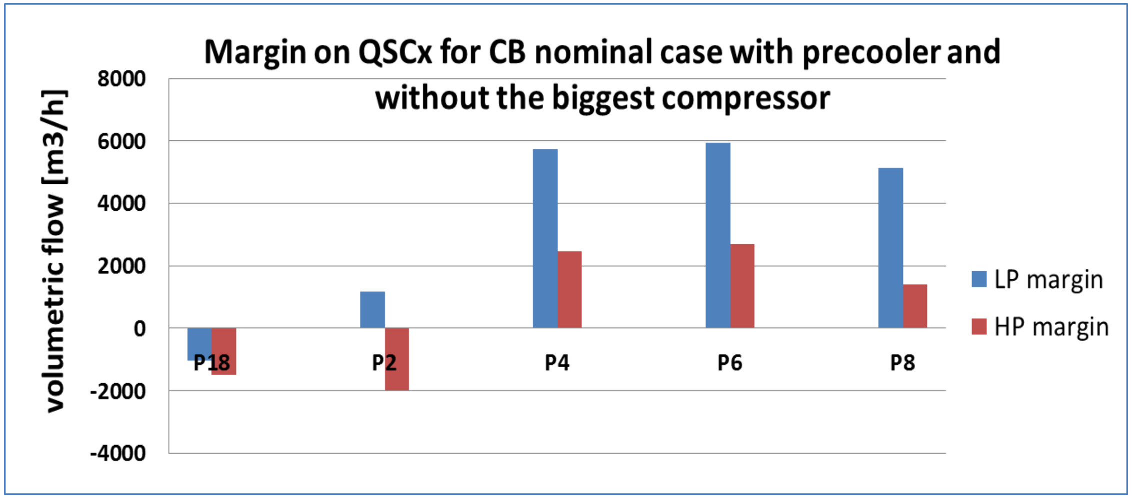


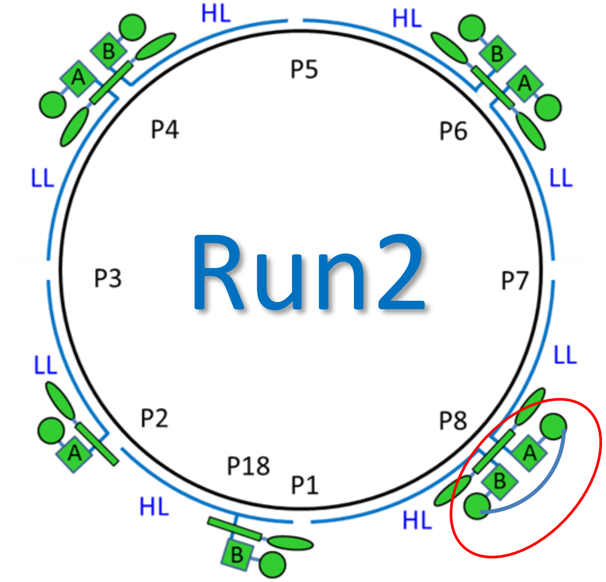
Pressure increase of the inter-layer space during warm-up → compensator collapsing !

Run2 configuration – operation scenarios

Run2 – operation scenarios 1/4

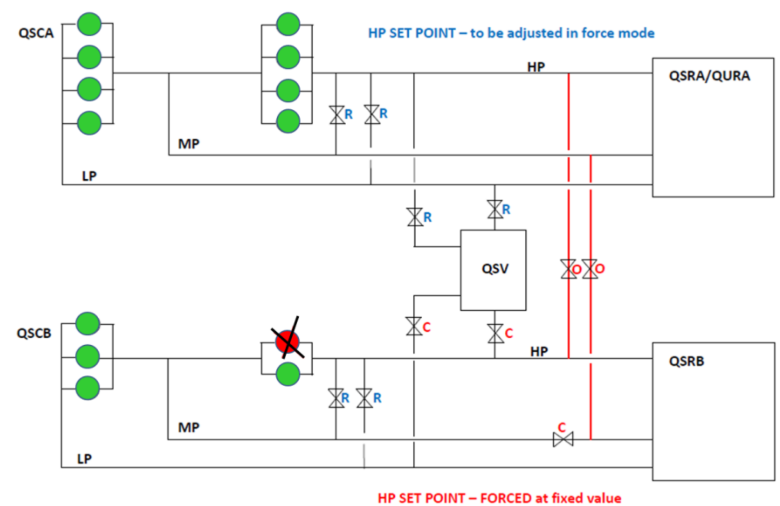
Operation scenarios (failures and solutions):
1. Failure of a compressor in CS





- Configuration tested during Run1
- P6 and P8: time needed for reconfiguration and recovery ~1 day
- P18 and P2HP: time needed for spare installation and recovery: 3-4 days
- Run1 failures: 2 compressors, 1 capacity problem with slide valve and 1 electrical motor

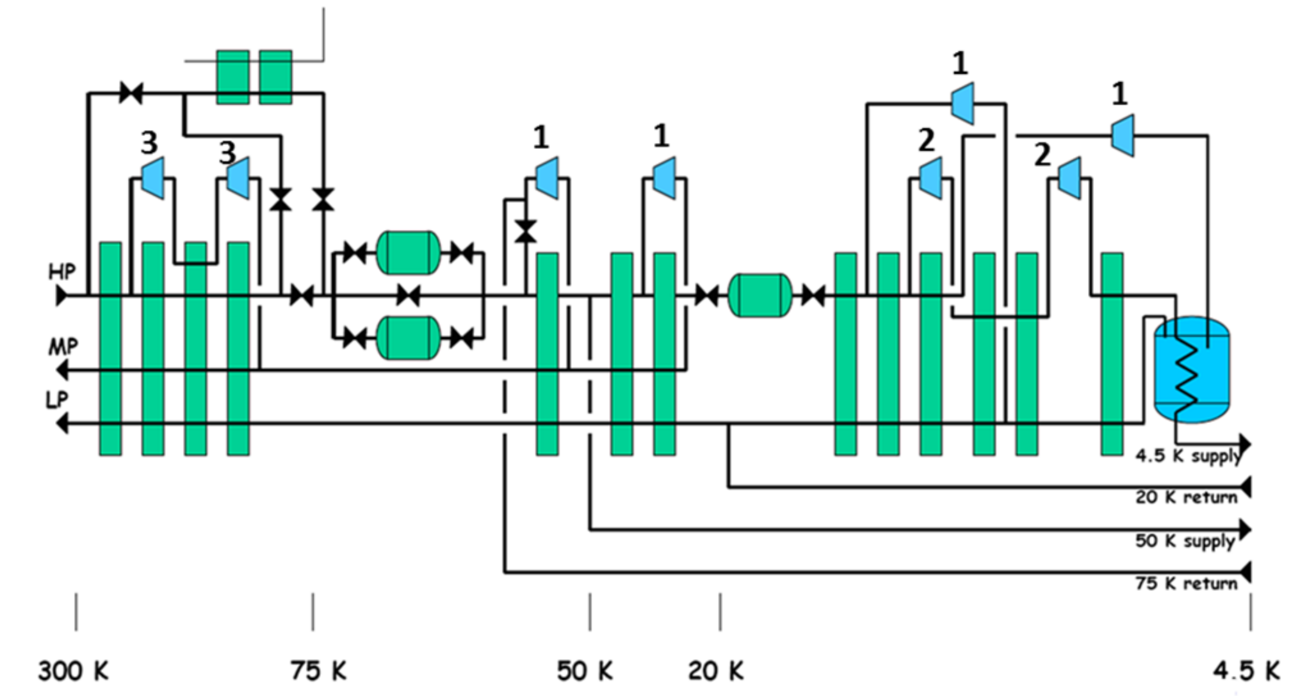
Remark: spares are available in storage for all compressors types (spare management finalized during LS1)



Nominal cooling power

Run2 – operation scenarios 2/4

Operation scenarios (failures and solutions):
2. Failure of a turbine in 4.5 K refrigerator



3 category of criticality for TUs

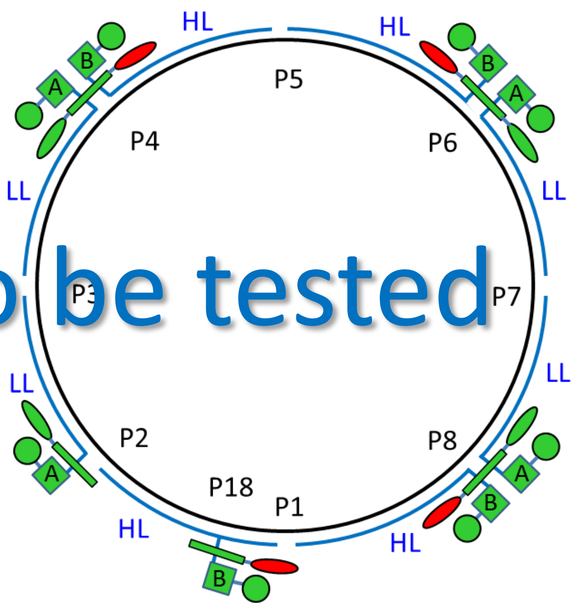
3 - Operation without this turbine is possible with nearly no loss in refrigeration power as the refrigeration power loss can be compensated with LN2.
2- Operation without the turbine is possible with a moderate loss in refrigeration power.
1 - Operation without the turbine results in a considerable loss in refrigeration power.

- Type 3 turbines can be replaced with LN2 pre-cooler – configuration tested during Run1, time needed for configuration – transparent for operation if no NC and done by experienced operator (All pre-coolers operational for Run2 (1 repaired in ~2007, 2 other repaired during LS1)
- Type 2 turbine: spare TU available in the storage, replacement and recovery during 1 day
- Type 1 turbine: spare TU available in the storage, replacement and recovery between 1 and 2
- Noticed ~10 failures during Run1

Nominal cooling power

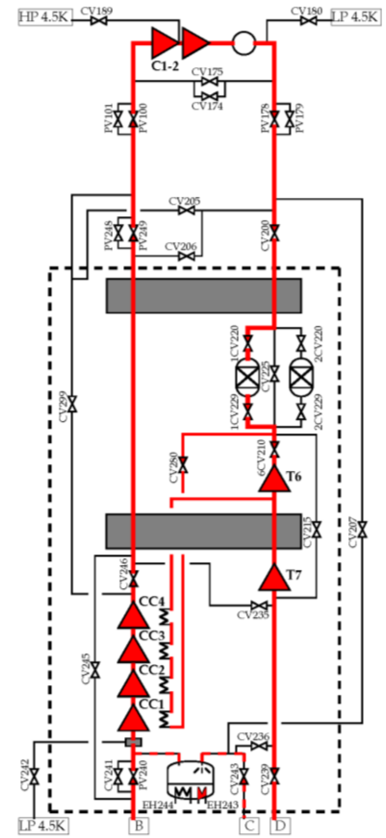
Run2 – operation scenarios 3/4

Operation scenarios (failures and solutions):
3. Failure of a cold compressor in 1.8 K pumping unit



To be tested

There is 7 types of 28 cold compressors



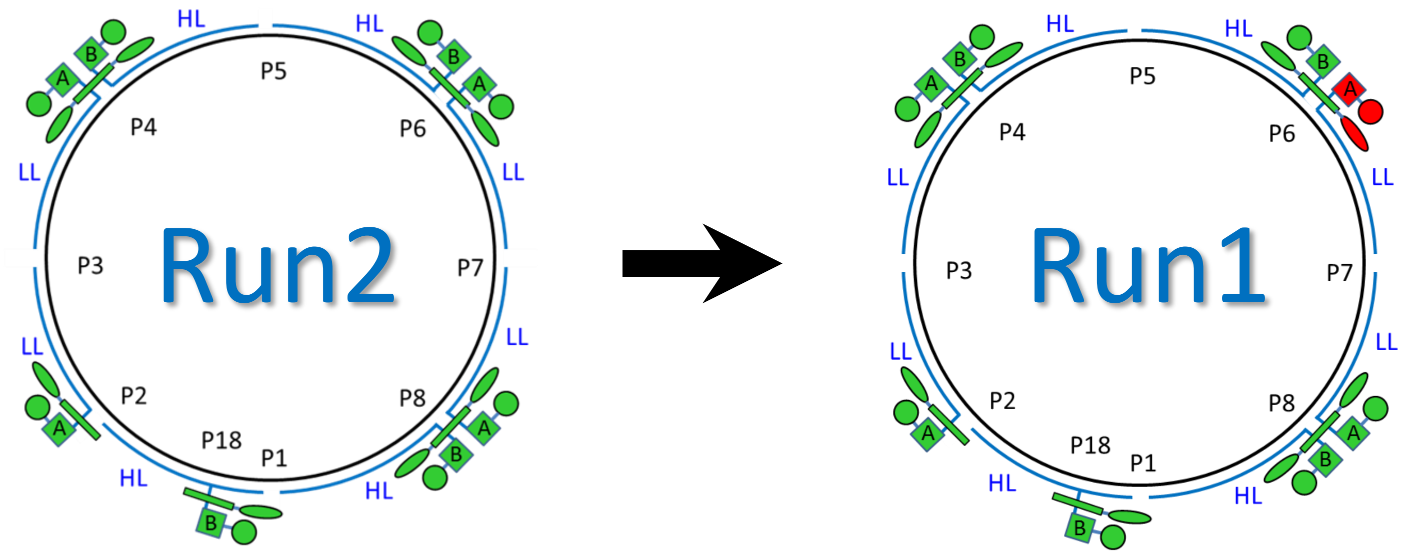
- All types of cold compressors are covered by a spare kept in storage,
- Time needed for compressor replacement and recovery between 2 and 3 days depending on sector (never done during Run1 operation but 3 replacements done during TS)

- Theoretically one pumping unit should be enough to cover heat load from 2 sectors – configuration of run with two 4.5 K cold boxes and 1.8 K pumping unit was never done and is to be tested (could be applicable at P4, P6 and P8 in case of failures)

Nominal cooling power

Run2 – operation scenarios 4/4

Operation scenarios (failures and solutions):
4. Major failure of a cryoplant



- It is very unlikely that we will have to go back to Run1 configuration, however such possibility is valid for major failures at P6 or P8 (P4 difficult because of RF load).
- Time needed for reconfiguration and recovery: 2-3 days
- Such solution will impose the run with reduced beam parameters
  - loss of A has less impact on operation than loss of B (not valid for P2)
  - loss of any machine at P4 has more impact on operation than at P6 or 8

Reduced cooling power

Non conformities

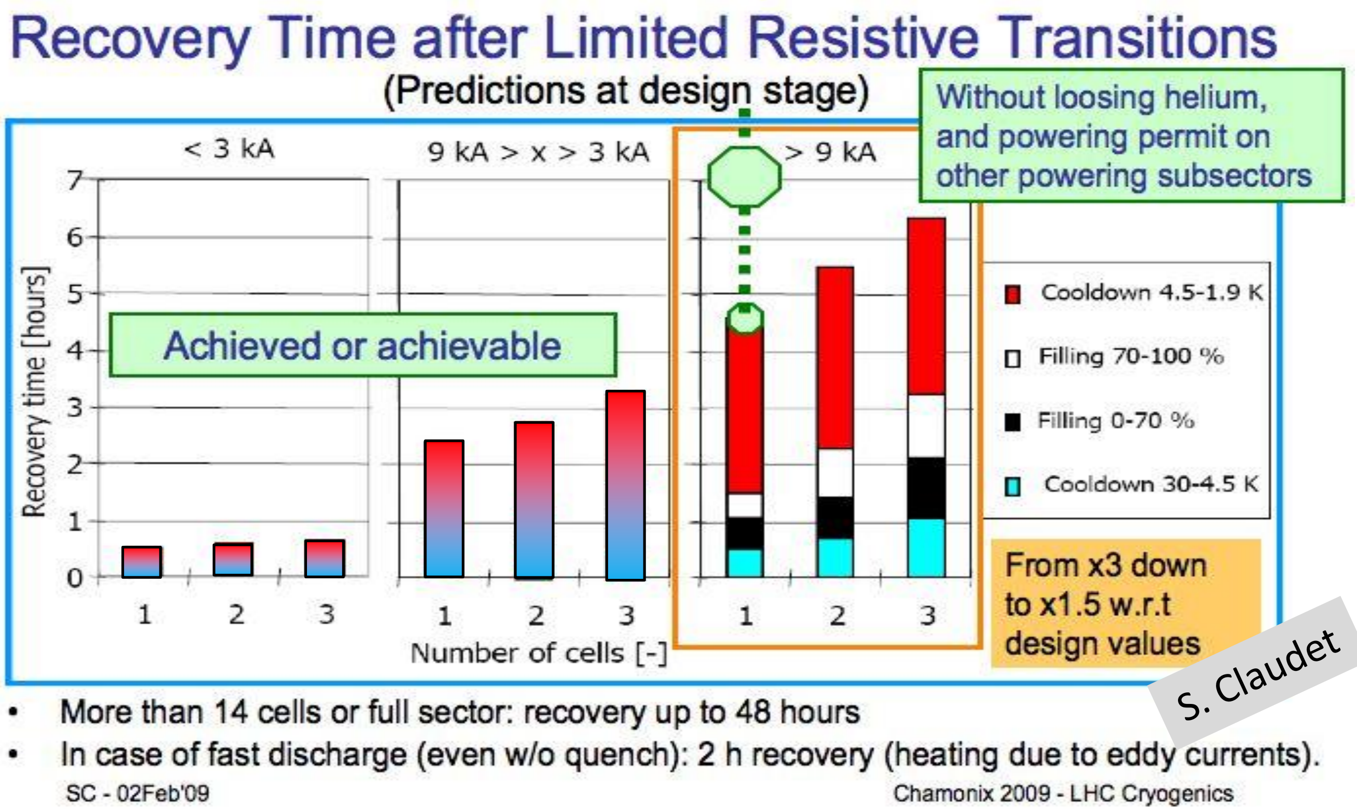
Sector 8-1: Helium leak from QRL header D to insulation vacuum
rate: 1.6 E-6 mbarl/s @ 10 bar, 1.4 E-7 mbarl/s @ 1 bar,
longitudinal localization: ~ 60m from QRL vacuum barrier behind Q24R8 at dcum 24455 m
VSC and CRG statement: use as is with monitoring and pumping capacity increase if needed

Sector 1-2: Helium leak from QRL header C to insulation vacuum with
rate: 1.7 E-5 mbarl/s @ 10 bara
Longitudinal localization ~Q13L2
VSC and CRG statement: investigation underway, possible replacement of the QRL components to be taken into consideration during LS1 slot for NCs repairs.

Both leaks represent weak points on the machine but with their present rates, applying adequate vacuum pumping capacity, should have no negative impact on cryogenic capacity.

(Situation valid for today)

Quenches – recovery times



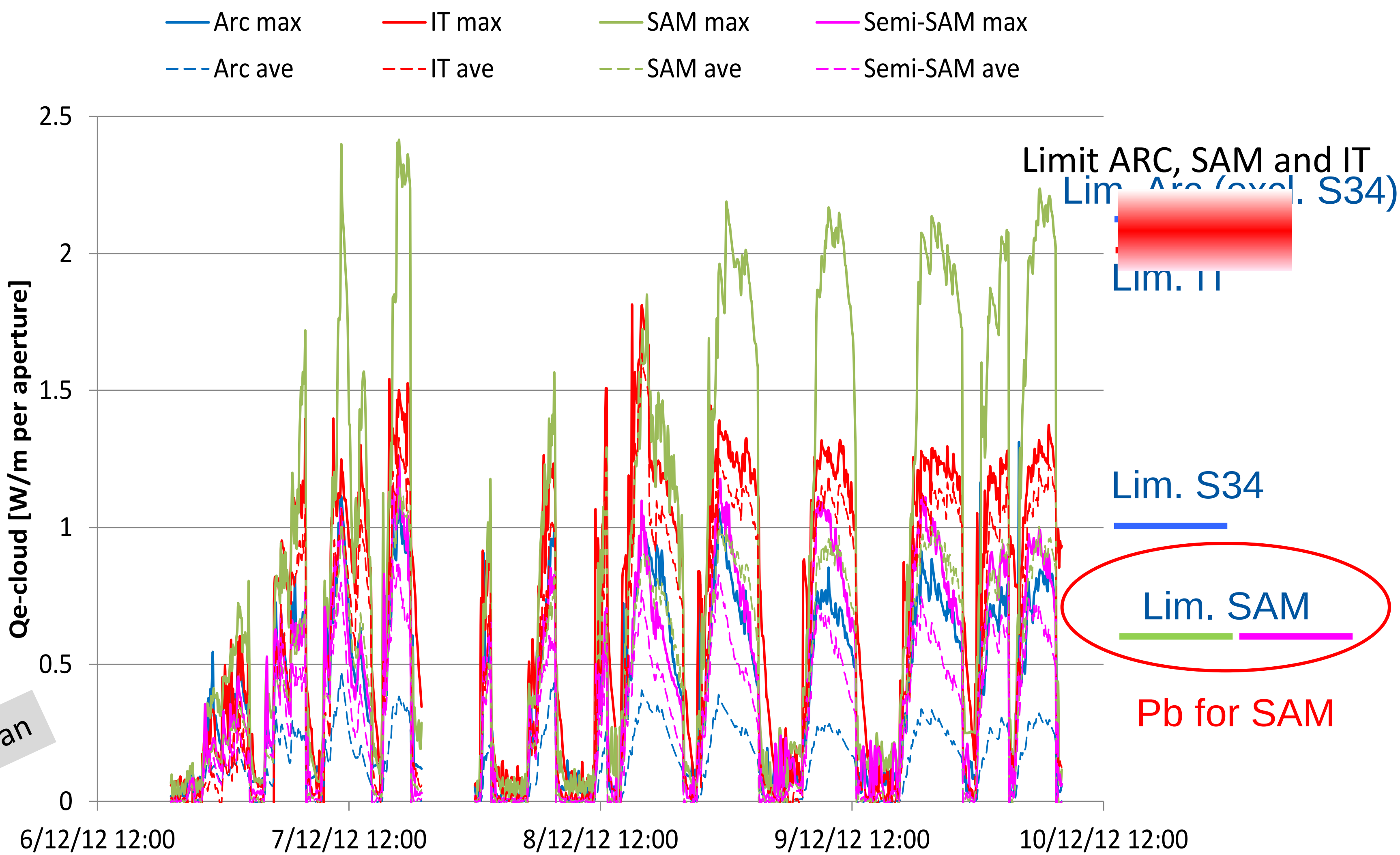
- Run1 – experience with some “easy quenches” with no QV valves opening,
- Until now experience for quenches recovery with current above 6.5 kA comes from before Run1 quench training (already 5-6 years ago),
- New learning with quench training and recovery to be envisaged for Run2

Run2 beam parameters – cryogenic limits and margins

Main reference:
Laurent Tavian, “Performance limitations:2012 review and 2015 outlook – cryogenics”; Evian 2012 Session 4, Part I.

Beam screen – scrubbing limits

25 ns scrubbing run (Dec'12): e-cloud deposition



Beam screen – scrubbing limits

- Replacement of all BS valves in s3-4 to go back at cooling level of other sectors
- Replacement (upgrade) of 38 BS valves on SAM and semi-SAM to reach the same level of cooling capacity as for ARCs

	Inventory	Length [m]	Local limitation (BS cooling loop and valve): CV kvmax [m3/h] Old	CV kvmax [m3/h] New	Qbs max [W/m per aperture] Old	Qbs max [W/m per aperture] New	Qbs 25 ns 2015 [W/m per aperture]	Remaining for beam scrubbing [W/m per aperture] Old	Remaining for beam scrubbing [W/m per aperture] New
SAM Type 1	Q5R1 Q6R1 Q6L5 Q5L5 Q5R5 Q6R5 Q6L1 Q5L1	8.2	0.02	0.05	1.0	2.4	0.4	0.6	2.1
SAM Type 2	Q6L4 Q6R4 Q5L6 Q4L6 Q4R6 Q5R6	6.9	0.03	0.05	2.3	3.9	0.5	1.8	3.4
	D3L4 D3R4	11.2	0.03	0.05	1.5	2.4	0.3	1.1	2.1
	Q6L2 Q6R2 Q6L3 Q6R3 Q6L7 Q6R7 Q6L8 Q6R8	12.0	0.03	0.05	1.4	2.3	0.3	1.1	2.0
	Q5L2 Q5R2 Q5L8 Q5R8	13.0	0.03	0.05	1.3	2.1	0.3	1.0	1.8
Semi-SAM	Q5D4L4 D4Q5R4	16.7	0.05	0.1	1.6	3.2	0.5	1.1	2.8
	D2Q4R1 Q4D2L5 D2Q4R5 Q4D2L1	19.4	0.05	0.1	1.4	2.8	0.4	1.0	2.4
	Q4D2L2 D2Q4R2 Q4D2L8 D2Q4R8	22.8	0.05	0.1	1.2	2.4	0.4	0.8	2.0
IT	ITL1 ITR1 ITL5 ITR5	35.0	0.26		5.7		3.3	2.4	
	ITL2 ITR2 ITL8 ITR8	45.0	0.26		4.4		2.5	1.9	
Arc half cell	S12 S23 S45 S56 S67 S78 S81	53.5	0.39		2.4		0.3	2.1	
	S34	53.5	0.22	0.39	1.3	2.4	0.3	1.0	2.1

Status :
Arc s3-4 – done

SAM and semi-SAM:
s1-2, s2-3, 6-7, s78 – done
S8-1 – partially done
S3-4, s4-5, s5-6 – to be done

L. Tavian

Global limitation (Cryoplant) 25ns 2015	Qbs max	Qbs 25 ns 2015	Remaining for beam scrubbing
kW per sector	14.8	5.3	9.5
Average W/m per aperture	2.4	0.9	1.6

To adapt cryo tuning of local cooling loops in the proper way the current ramp signal is necessary – discussions with BE underway

IT cold mass and secondaries – limits

Lmax compatible with local margin: 1.75E34

	Run 3134					25 ns 2015	50 ns 2015			
Nb [p per bunch]	1.52E+11					1.15E+11	1.60E+11			
nb [-]	1374					2760	1380			
E [TeV]	4					6.5	6.5			
L [Hz/cm2]	6.70E+33					1.00E+34	1.00E+34			
	Qs [W]	Qrh [W]	Qbgs [W]	Qsec [W]	Total [W]	Total scaled [W]	Total scaled [W]	Locally installed [W]	Local margin [W] 25 ns 2015	Local margin [W] 50 ns 2015
Arc cell	18	2.3	2	0.0	23	27	26	90(1)	63	64
DS cell	25	1.9	2	0.0	29	33	32	140(1)	107	108
ITL1	60	0.6	0.6	60	121	208	208	320(2)	112*	112*
ITR1	52	0.6	0.6	60	113	200	200	320(2)	120	120
ITL2	110	0.6	0.8	0.0	111	113	113	140(1)	27*	27*
ITR2	50	0.6	0.8	0.0	51	53	53	140(1)	87*	87*
ITL5	50	0.6	0.6	60	111	198	198	320(2)	122	122
ITR5	47	0.6	0.6	60	108	195	195	320(2)	125*	125*
ITL8	80	0.6	0.8	3.6	85	86	86	140(1)	54*	54*
ITR8	46	0.6	0.8	3.6	51	52	52	140(1)	88*	88*

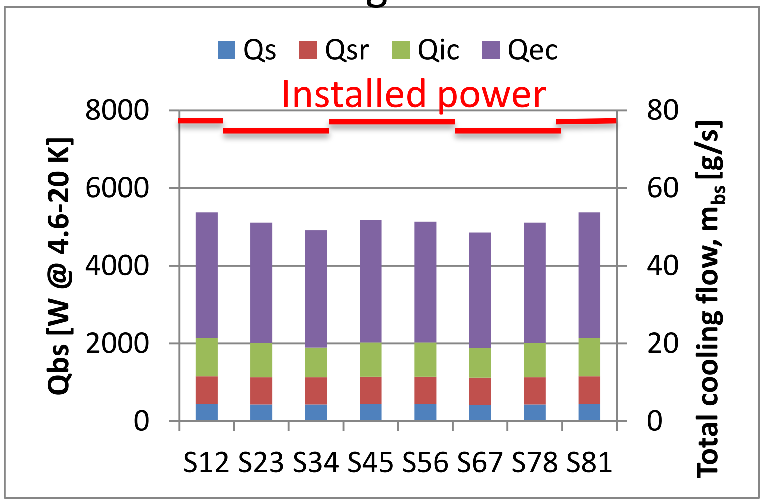
(1): limited by sub-cooling heat exchanger
(2): limited by bayonet heat exchanger (IT)
*: could be jeopardized by NC braid

L. Tavian

LS1 activity:
All IT have been consolidated, all related braids have been put in right place.

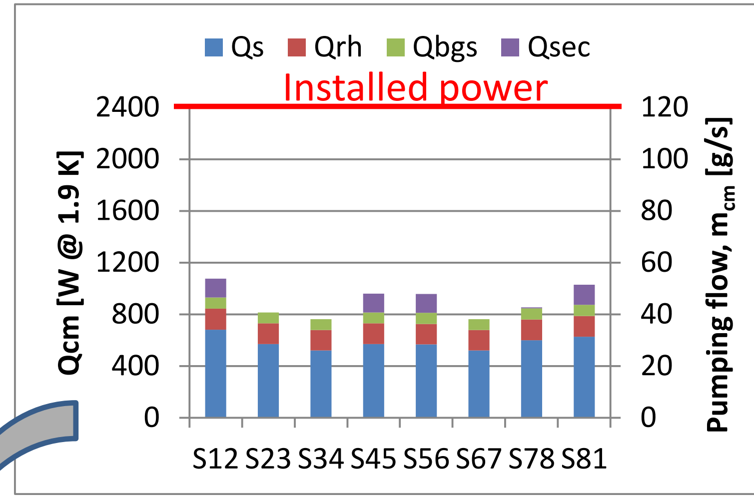
Global cooling power – limits and margins

BS cooling circuits

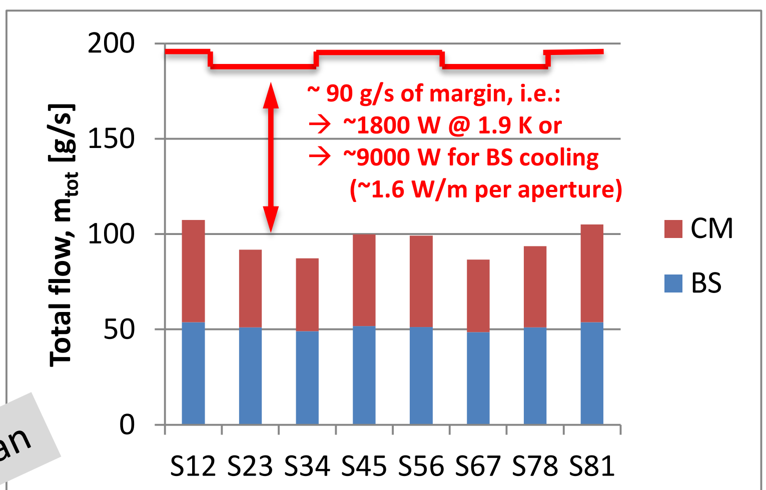


Bunch length has a secondary impact on increase of the heat load.

1.9 K cold-mass circuits

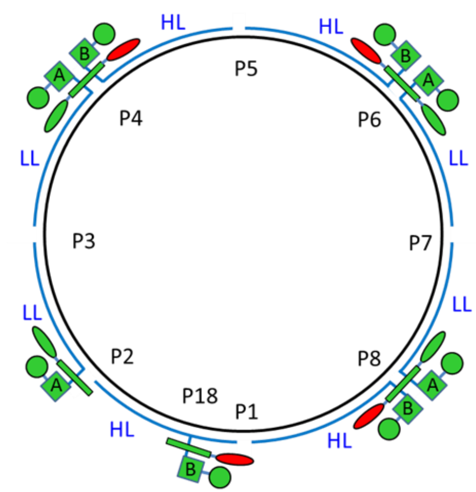


Regarding 1.8 K refrigeration machines



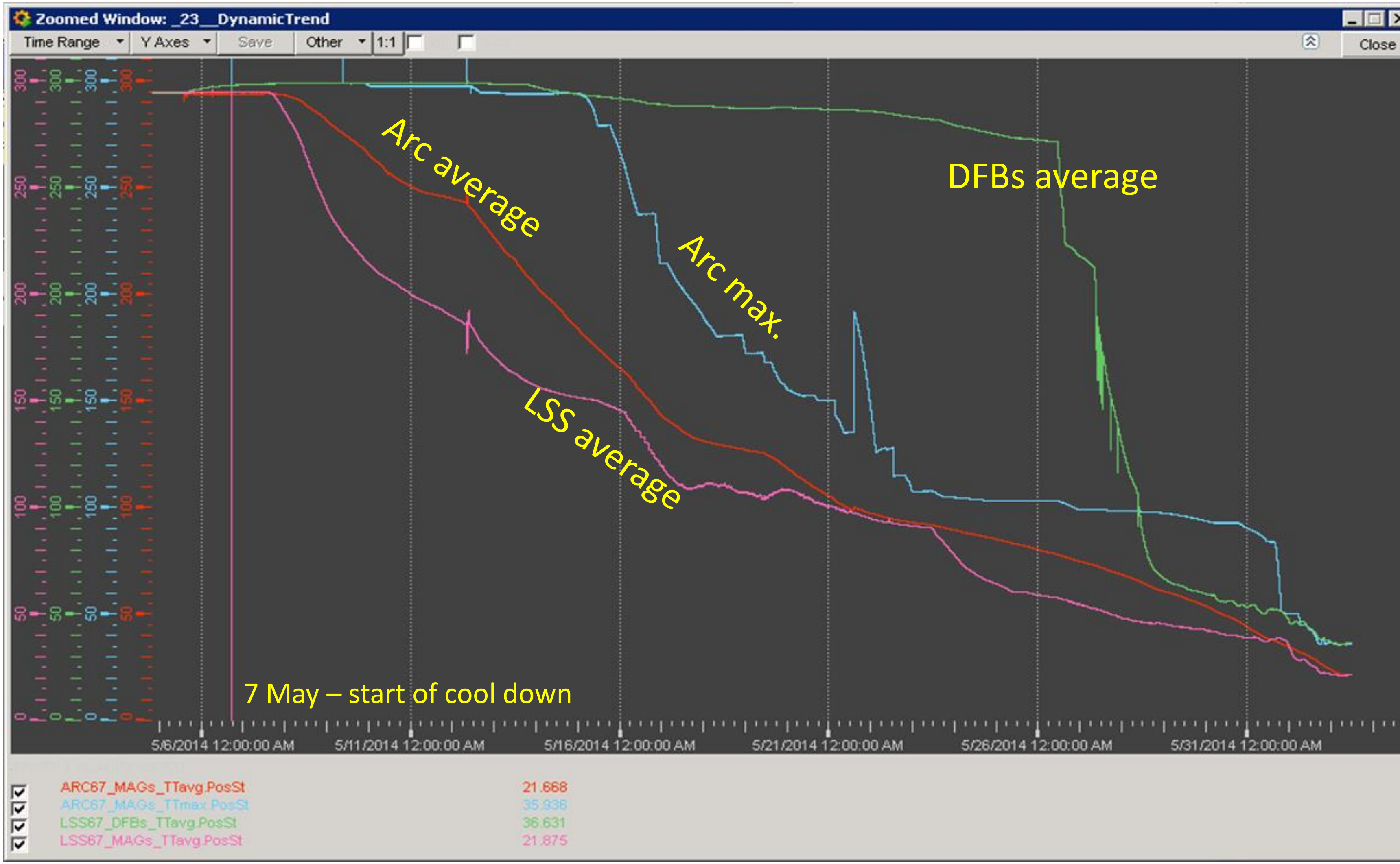
L. Tavian

Regarding main refrigerators



Recoveries similar to P8 Run1 configuration

Sector 6-7 – cool down status



Sectors: 6-7, 8-1 and 1-2 – pressure tested, Sector 2-3 to be pressure tested on 5th June

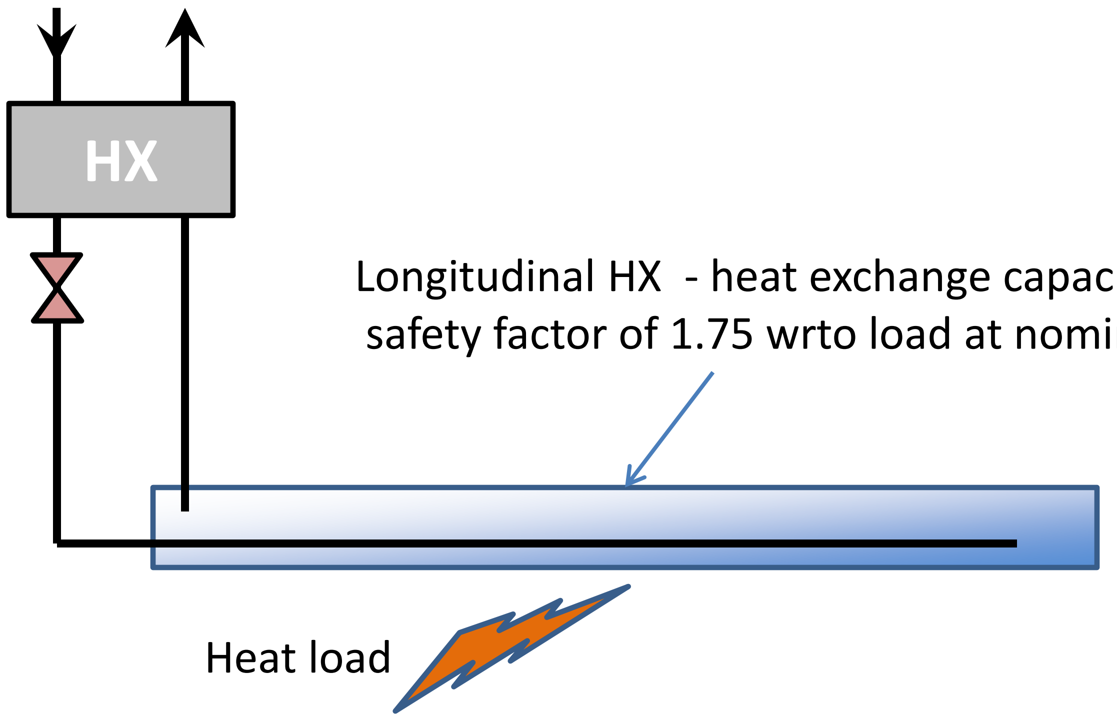
Sectors: 3-4, 4-5, 5-6 and 7-8 – LS1 activity

Conclusions

- Gained large experience from Run1 with availability at ~95 % (2012), helium losses reduction and power savings … but now with 1/4 of new operators in the team (came during LS1) and 80% of team members who never participated in complete cool down and hardware commissioning,
- Large LS1 campaign allowed for maintenance and to resolve all Run1 NCs (all warm compressors and electrical motors maintenance, delicate repairs work on refrigerators and DFBs, large campaign for QRL bellows replacement and R2E activity and comissioning),
- Operation reconfiguration possibilities on the cryogenic plants give good feeling to cope with possible failures keeping cooling capacity at nominal level,
- Local cooling capacity of the beam screen was homogenized and upgraded to ~2 W/m what allows for full usage of cryo plants available capacity (estimated at ~1.6 W/m per aperture)
- IT cold mass cooling power has a safety factor of 1.75 wrto heat load from nominal luminosity
- Global cooling capacity safety factors: ~1.8 on 4.5 K refrigerators – will be used for electron cloud thermal load, factor >2 on 1.8 K pumping units,
- Cool down of first sector goes smoothly w/o particular problems

Thank you!

Backup slide 1



Backup slide 2

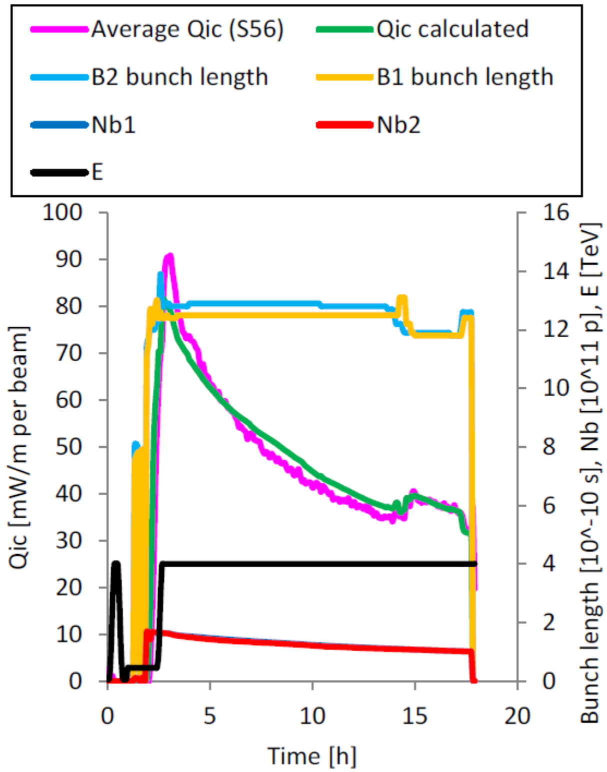


Figure 1: *Qic* evolution in the arcs for run3133

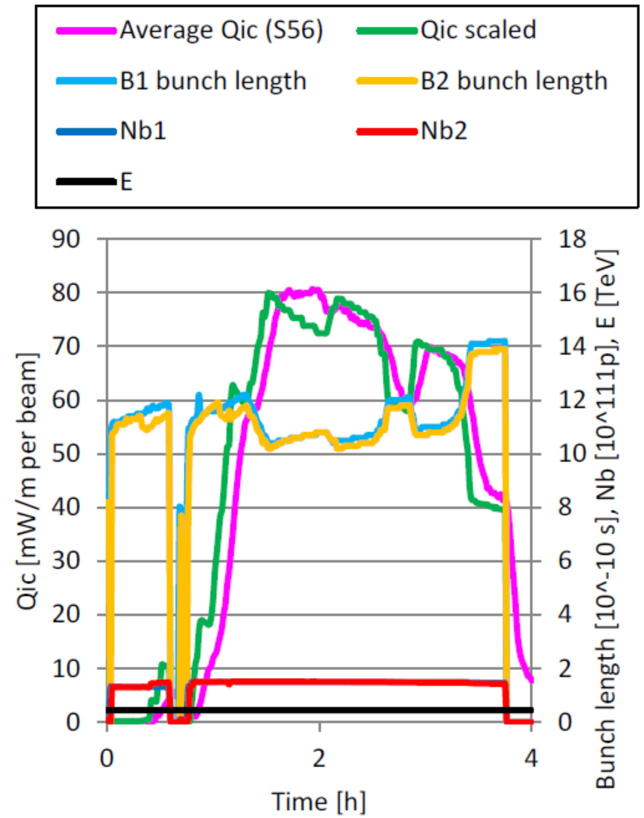


Figure 2: *Qic* evolution in the arcs for run3345

$$Qdbs = Qsr + Qic + Qec$$

Could be neglected for analyzed case

$$Qic = Qic_{nom} \cdot \left(\frac{Nb}{Nb_{nom}}\right)^2 \cdot \frac{nb}{nb_{nom}} \cdot \left(\frac{0.60 \cdot E + 2.80}{E_{nom}}\right)^{0.5} \cdot \left(\frac{\sigma}{\sigma_{nom}}\right)^p$$

Reference and more information: L. Tavian, Evian 2012