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LHC Cryogenics Availability & Helium Management from Run 1 to Run 2

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Fermi National Accelerator Laboratory

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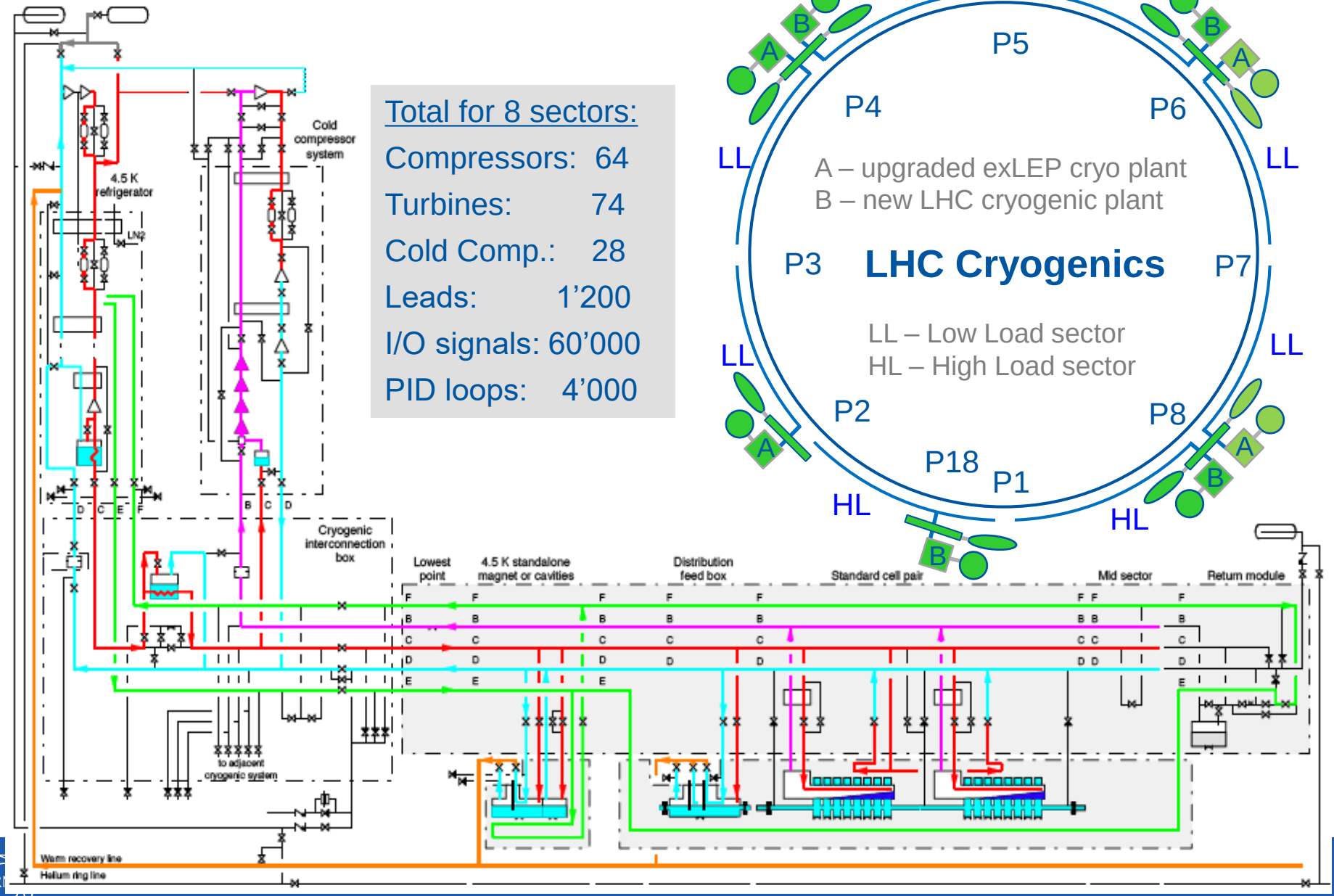
LHC Cryogenic System Architecture



Total for 8 sectors:

Compressors: 64

Turbines: 74

Cold Comp.: 28

Leads: 1’200

I/O signals: 60’000

PID loops: 4’000

LHC CRYOPLANTS RELIABILITY

Run 2 main failures impacting availability

2015

3 turbines failures on 4.5 K refrigerators

1 warm compressor failure on 4.5 K refrigerator

16 RFL valves failures

4 PLCs failures

1 major internal helium leak towards vacuum chamber on 4.5 K refrigerator

2016

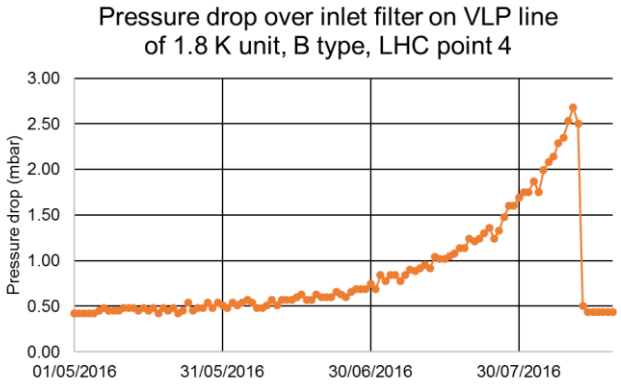
1 motor degradation on 4.5 K refrigerator

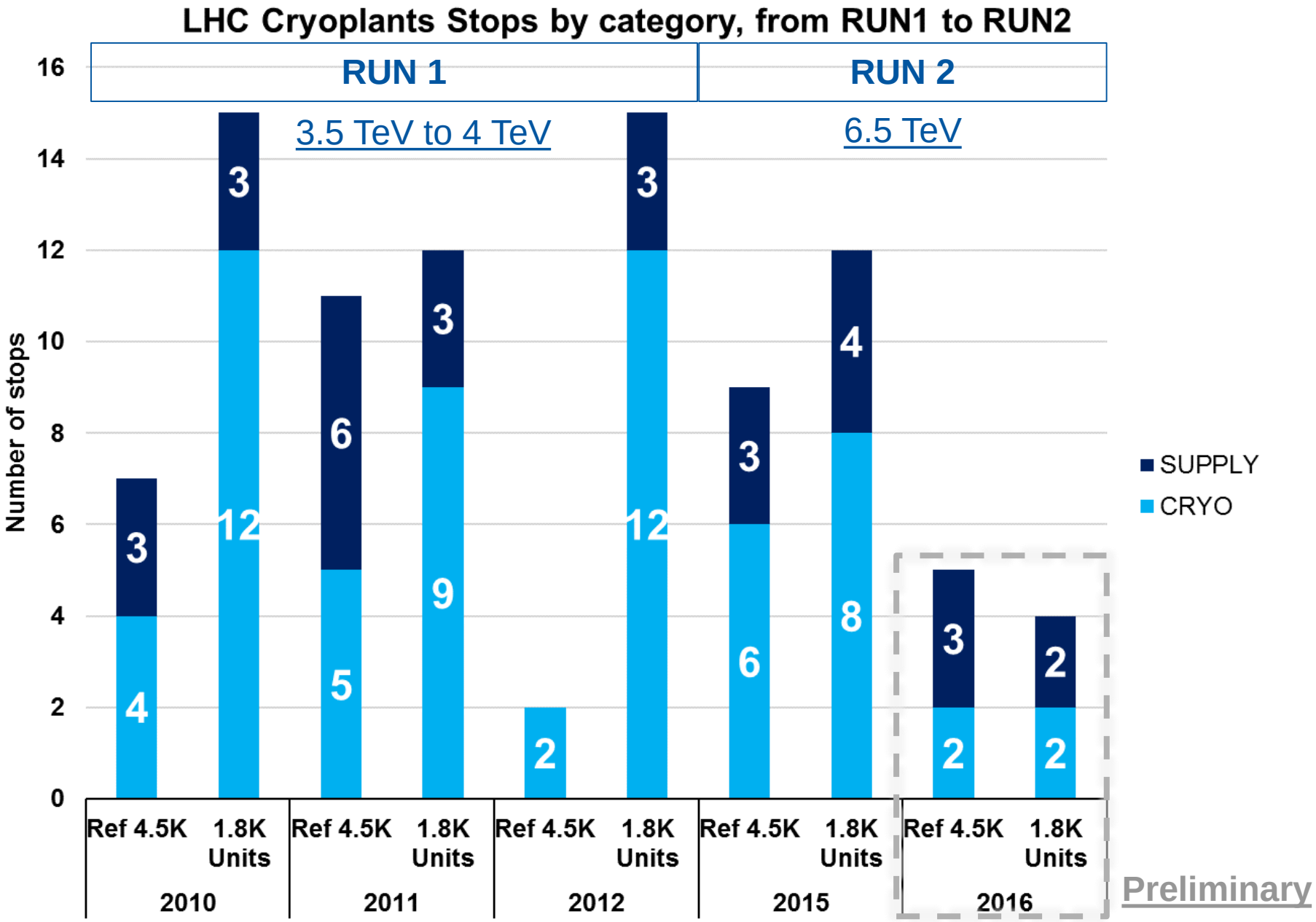
1 warm compressor degradation on 4.5 K refrigerator

1 PLC failure

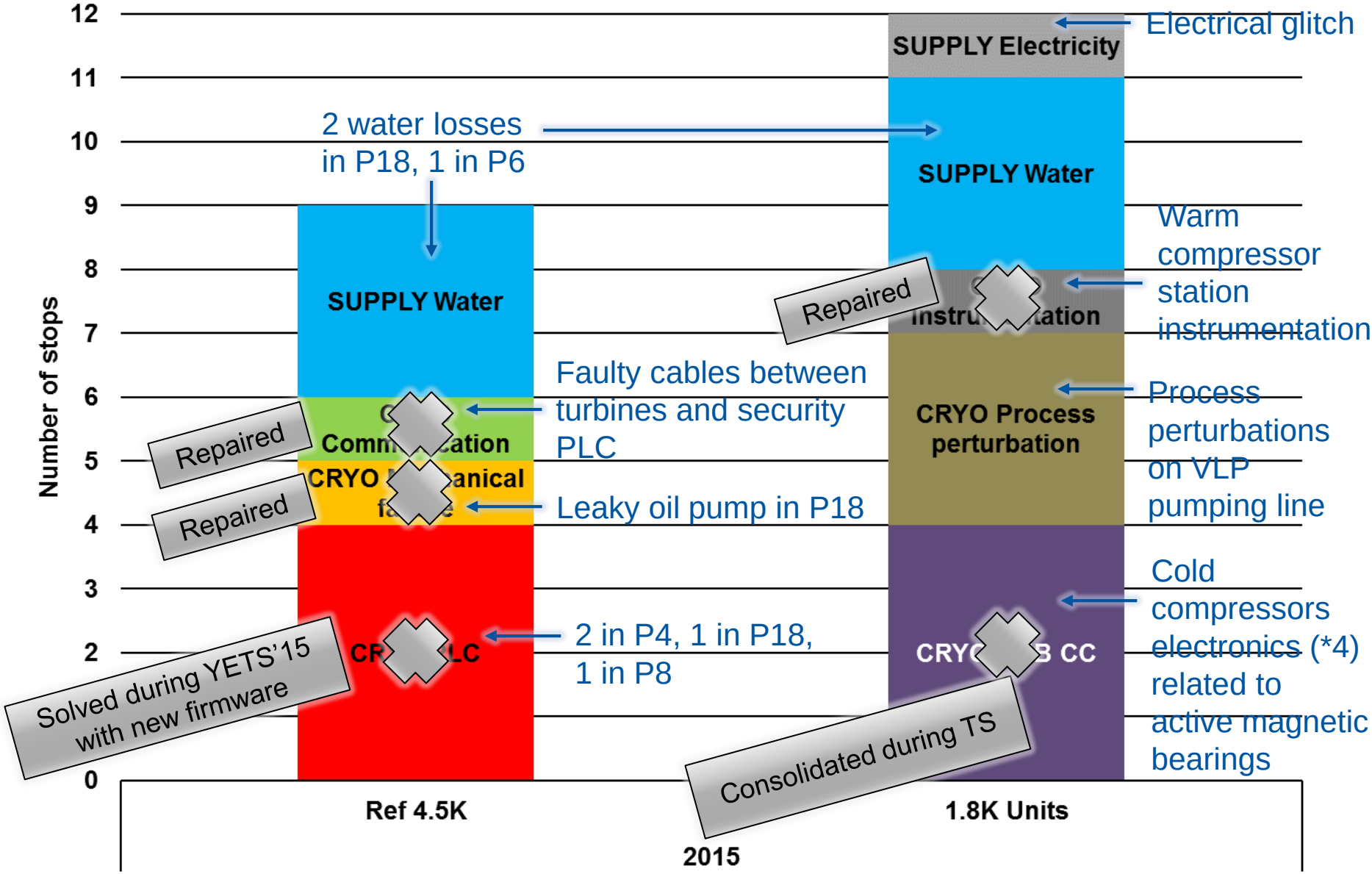
Additional problem encountered in 2016:

1 smooth clogging of inlet filter on the VLP line of a 1.8 K unit (yet no induced downtime)

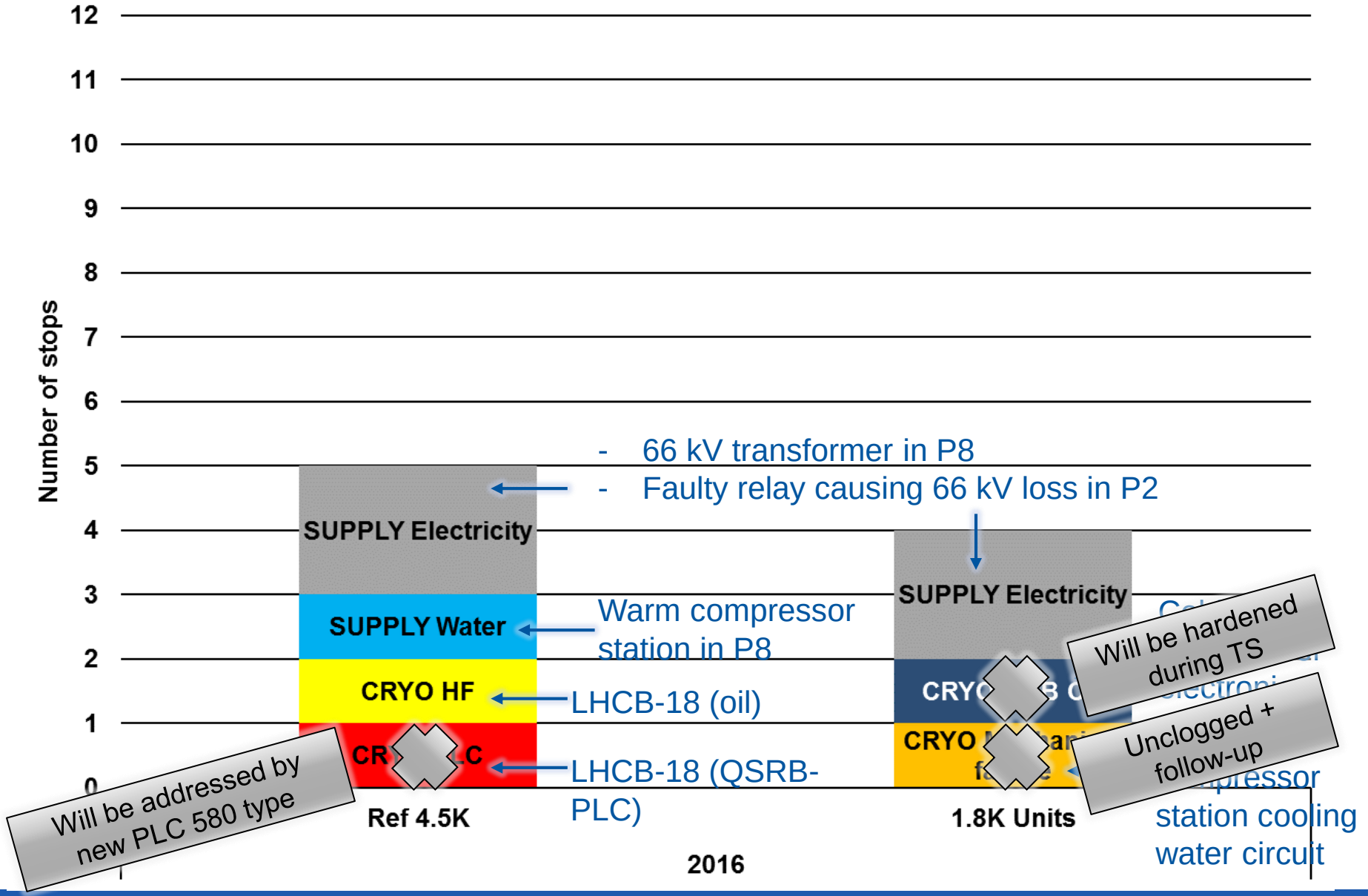



LHC Cryoplants Stops by category, from RUN1 to RUN2
RUN 1
RUN 2
3.5 TeV to 4 TeV
6.5 TeV
Number of stops
0
2
4
6
8
10
12
14
16
SUPPLY
CRYO
Ref 4.5K
1.8K Units
2010
2011
2012
2015
2016
Preliminary

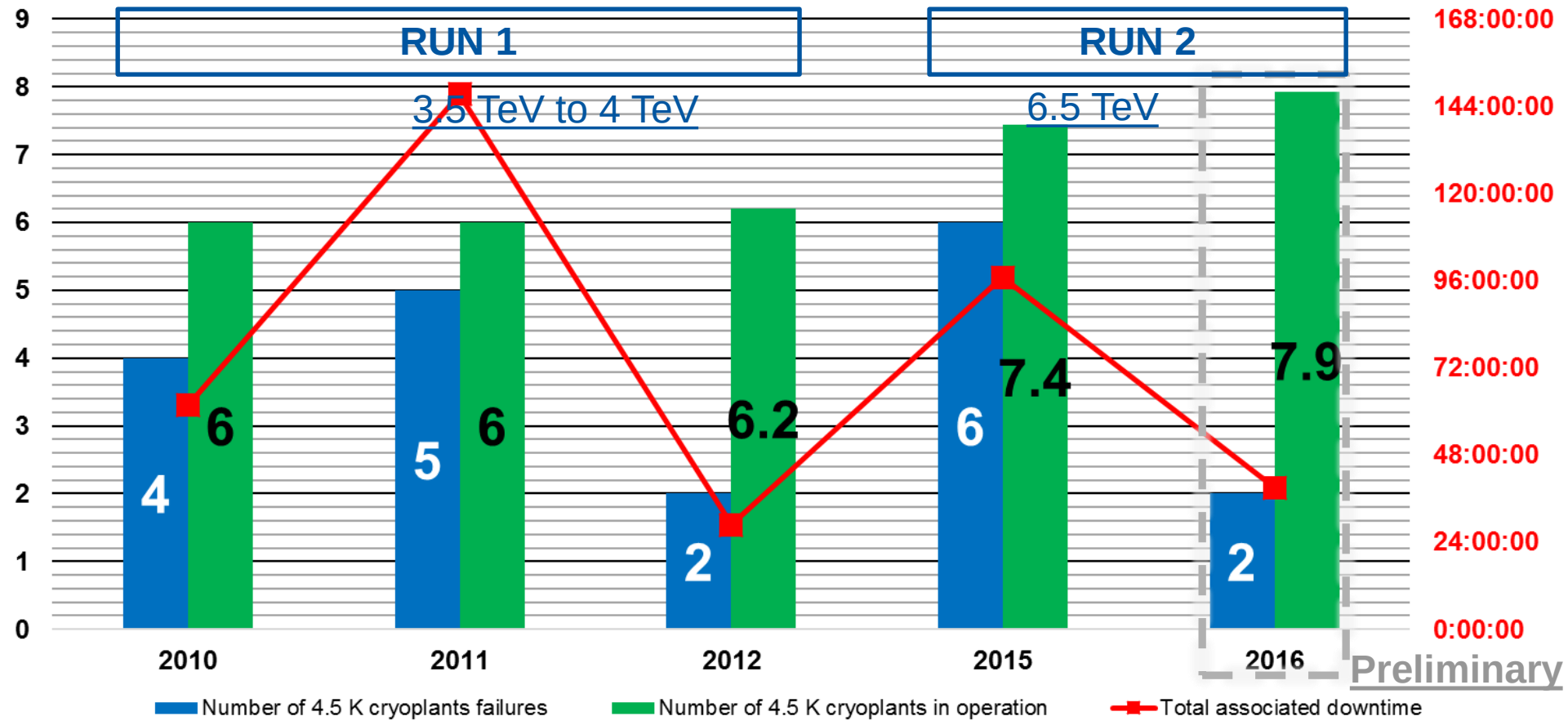
2015 LHC Cryoplants Stops by category



2016 LHC Cryoplants Stops by category



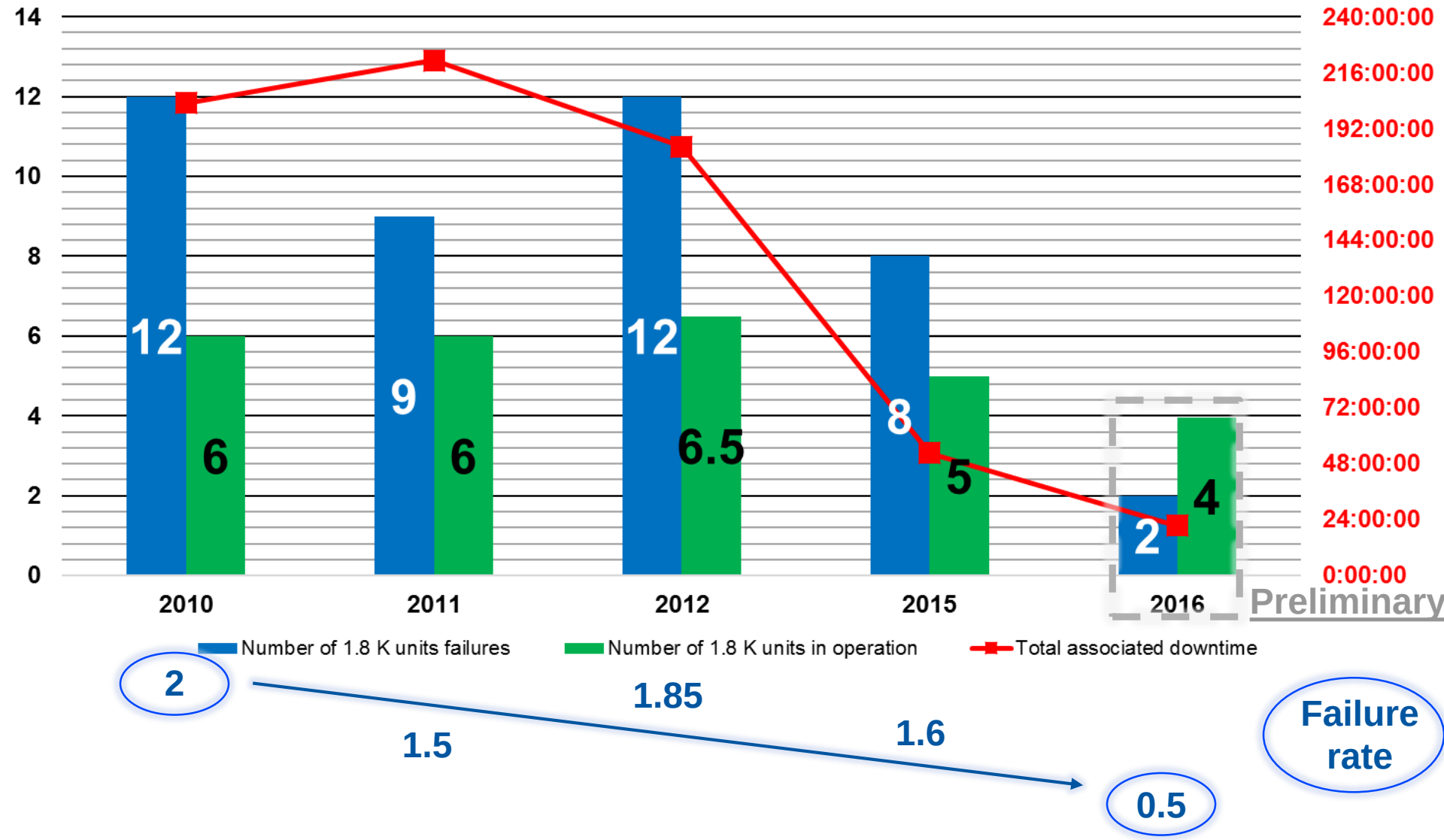
LHC 4.5 K Cryoplants Reliability



0.67 → 0.83 → 0.32 → 0.81 → 0.25

Failure rate

LHC 1.8 K Units Reliability

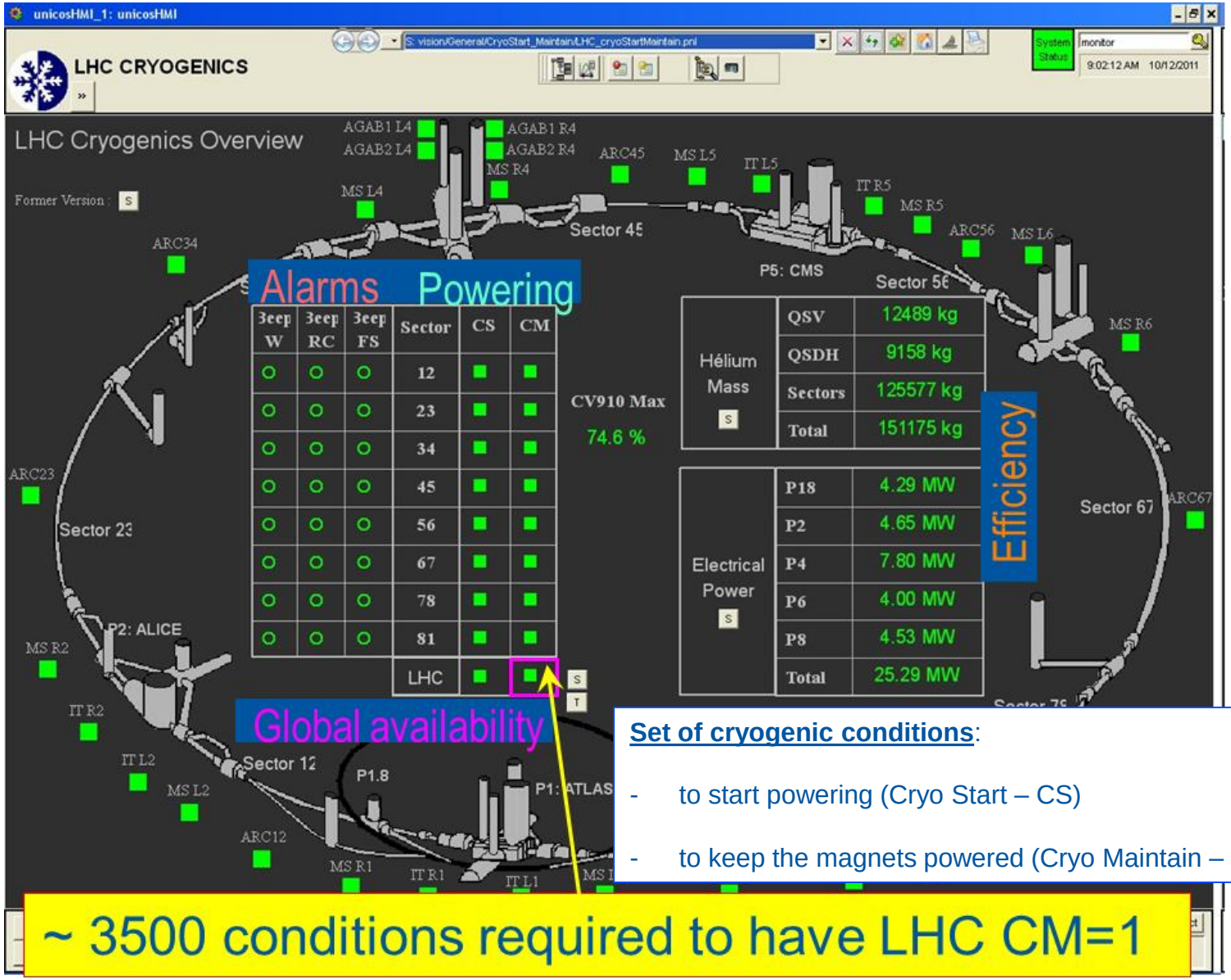


2 → 1.5 → 1.85 → 1.6 → 0.5

Failure rate

LHC CRYOGENIC SYSTEM AVAILABILITY

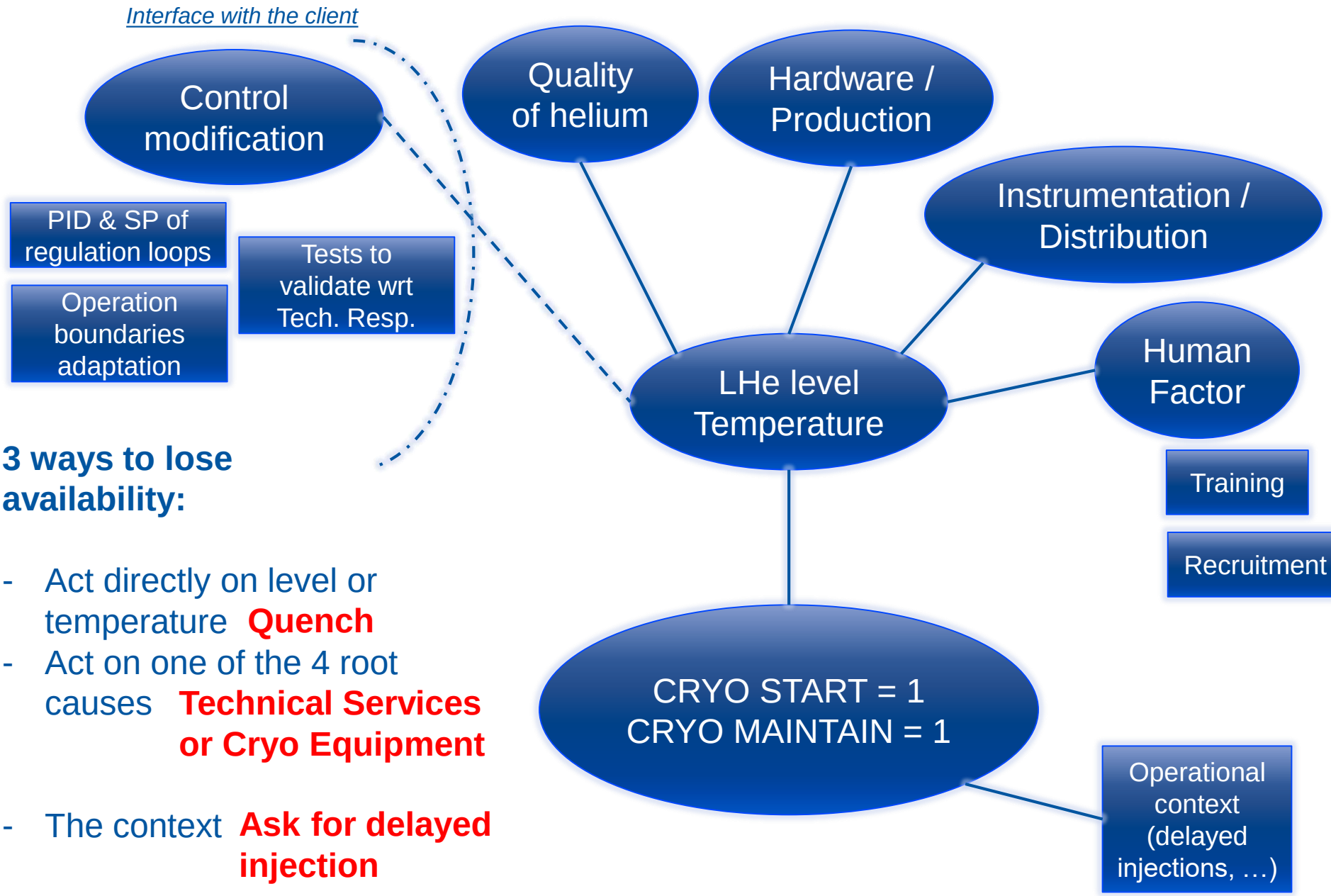
Cryogenic conditions definition



Set of cryogenic conditions:

- to start powering (Cryo Start – CS)
- to keep the magnets powered (Cryo Maintain – CM)

~ 3500 conditions required to have LHC CM=1



3 ways to lose availability:

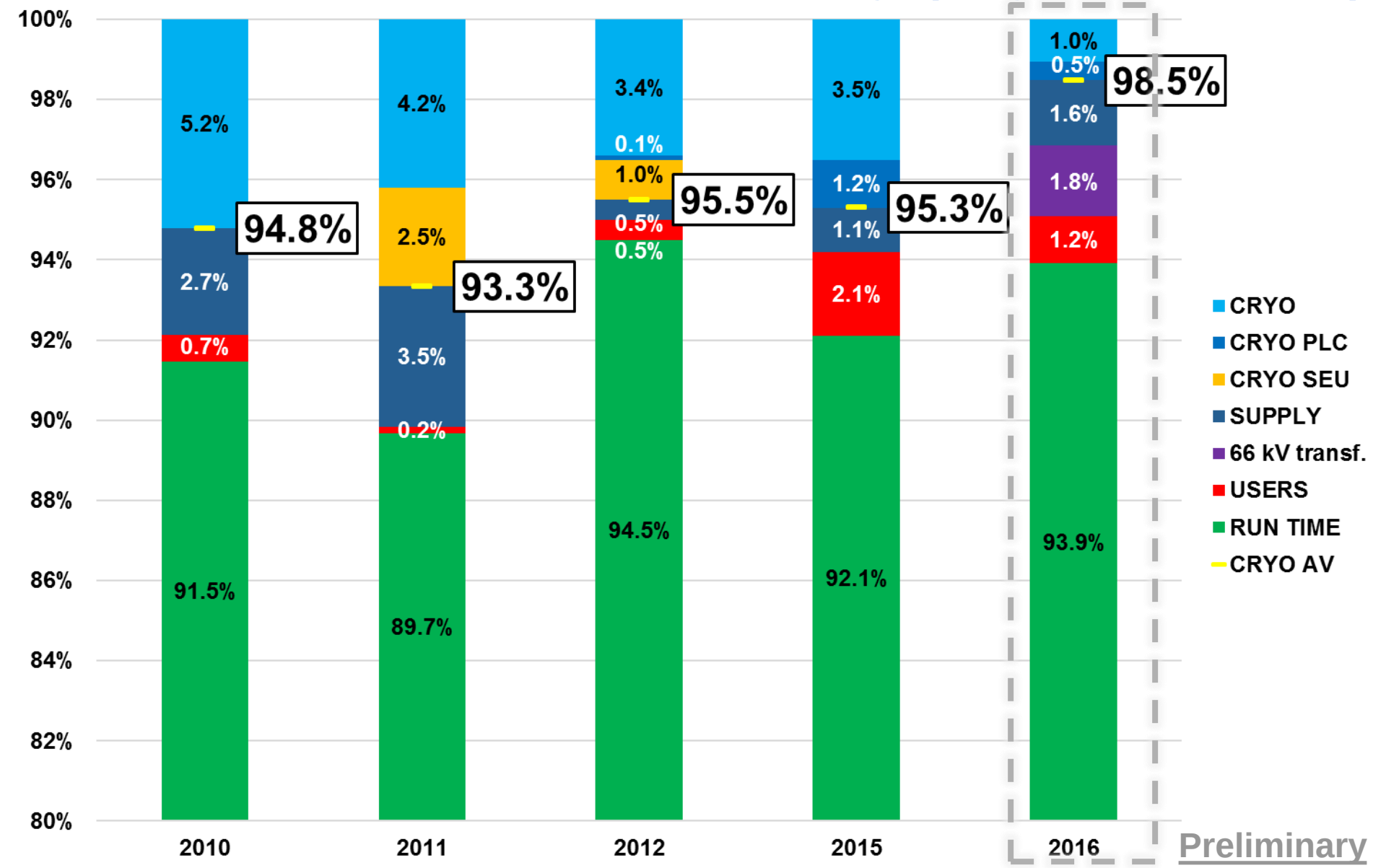
- Act directly on level or temperature **Quench**
- Act on one of the 4 root causes **Technical Services or Cryo Equipment**

- The context **Ask for delayed injection**

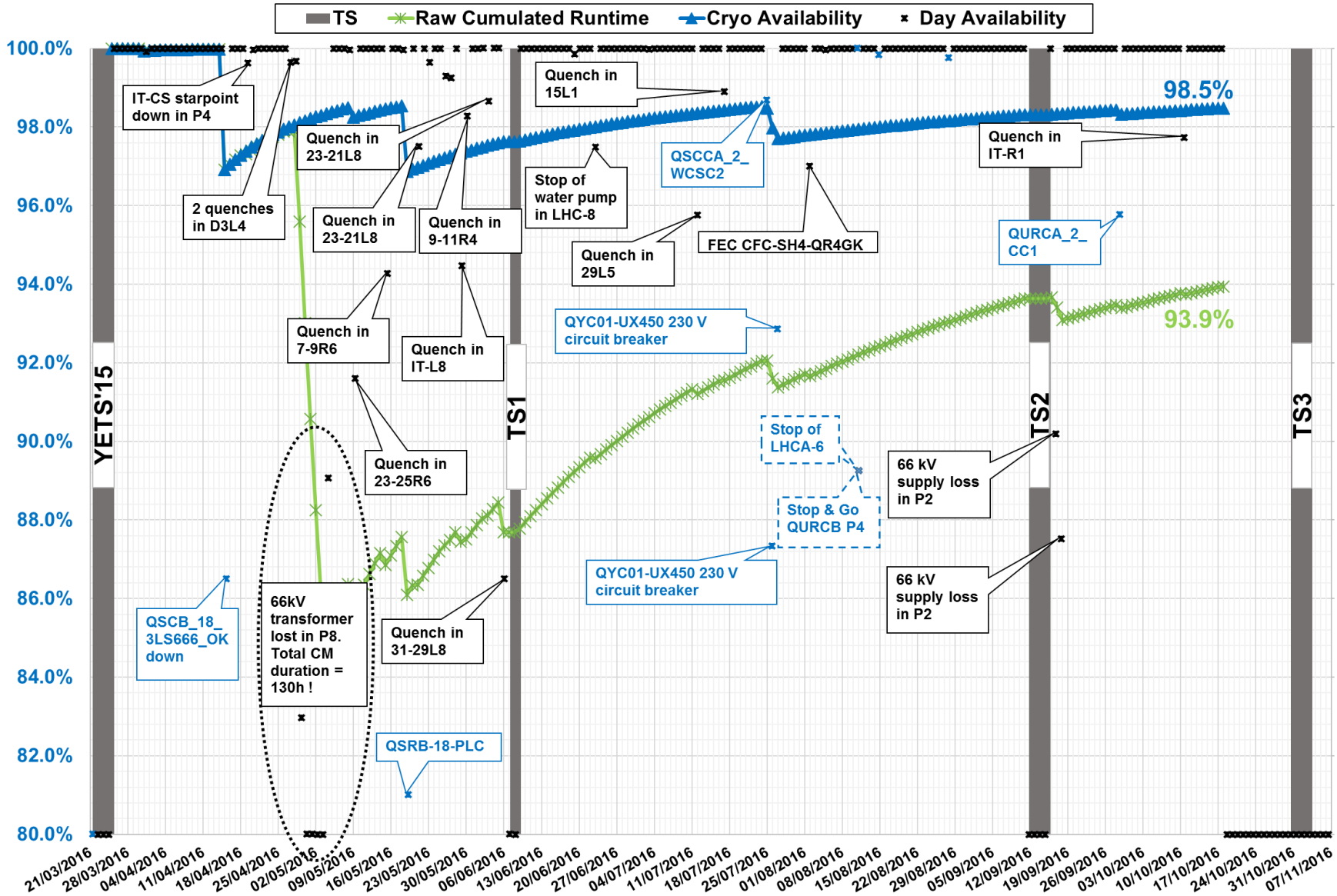
Availability losses categorization

AFT category	AFT sub-category	Sub systems used for statistics	Comments
CRYOGENICS	EQUIPMENT	CRYO-PROD-4.5K	Compressors, ORS, dryers, turbines, ADS - any mechanical failure
		CRYO-PROD-1.8K	Compressors, ORS, turbines, ADS - any mechanical failure
		CRYO-PROD-QUI	Any failure related to QUI
		CRYO-PROD-VAC	Insulation vacuum of cold boxes and QUI
		CRYO-PROD-INSTRUM	Valves, electrical heaters, sensors
		CRYO-PROD-CONTROL	Software
		CRYO-PROD-PLC	Surface installations PLCs
		CRYO-PROD-SEU	Single event upsets in electronics due to radiation in operation environment
		CRYO-PROD-OTHER	Other cryo production related issue
		CRYO-TUNNEL-INSTRUM	Sensors, electrical heaters (except for EH893, under TE-MPE responsibility), valves
		CRYO-TUNNEL-CONTROL	Software
		CRYO-TUNNEL-PLC	Tunnel installations PLCs
		CRYO-TUNNEL-SEU	Single event upsets in electronics due to radiation in operation environment
		CRYO-TUNNEL-OTHER	Other cryo tunnel related issue
		CRYO-OP-PNO-DFB	LHe level oscillation in a distribution feed box
		CRYO-OP-PNO-SAM	LHe level oscillation in a standalone magnet
		CRYO-OP-PNO-REF	Refrigerator tuning not optimized
		CRYO-OP-PNO-BSCR	Beam screen regulation related issue
		CRYO-OP-PNO-HF	Human factor in cryogenics operation, causing downtime (human or procedure)
		CRYO-OP-PNO-OTHER	Other non-optimization leading to downtime
	USERS	USERS-QUENCH	Quench
		USERS-QPS	Quench protection system related issue
		USERS-ELQA	ELQA
		USERS-OTHER	Other users related issue
	TECHNICAL SERVICES	TECHNICAL SERVICES-CV	Cooling and ventilation
		TECHNICAL SERVICES-EL	Electricity
		TECHNICAL SERVICES-CAIR	Compressed air
		TECHNICAL SERVICES-SECTORS VAC	Insulaiton vacuum in sectors
		TECHNICAL SERVICES-NET	Controls / Network
		TECHNICAL SERVICES-EH893 DFB	Top flange heaters of distribution feed boxes (under TE-MPE responsibility)
		TECHNICAL SERVICES-OTHER	Other technical services related issue

LHC RUN 2 Overall availability (Cryo Maintain)



Typical follow-up



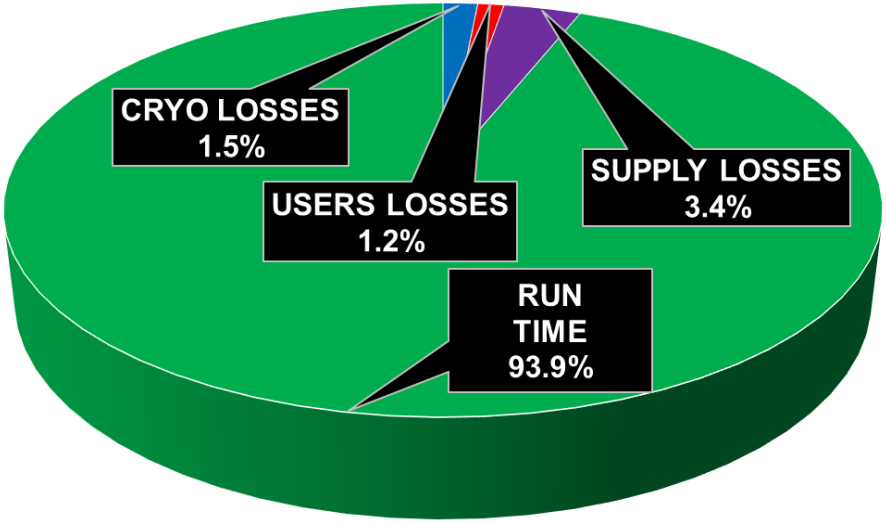
2015 to 2016 Overall availability (Cryo Maintain)

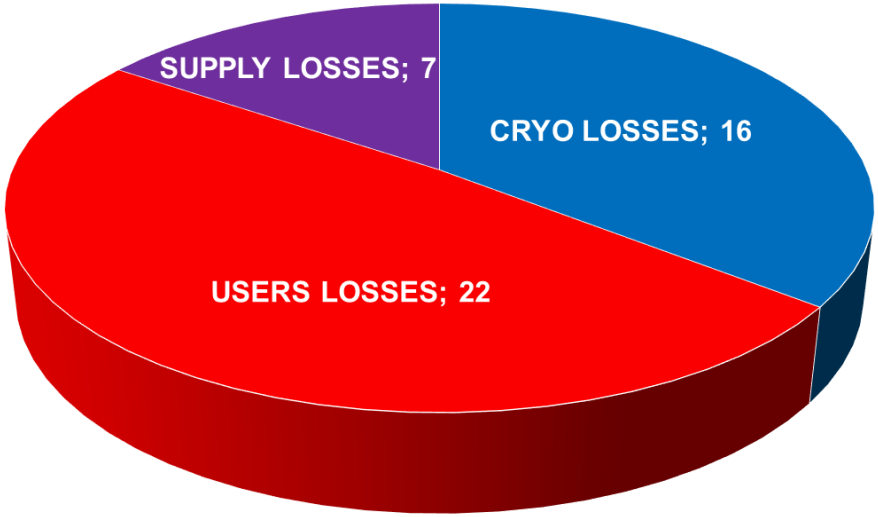
CRYO LOSSES		USERS LOSSES		SUPPLY LOSSES		TOTAL LOSSES	
Number	Time	Number	Time	Number	Time	Number	Time
164	273:29:00	**32**	122:19:00	**7**	61:43:00	**203**	457:31:00

2015

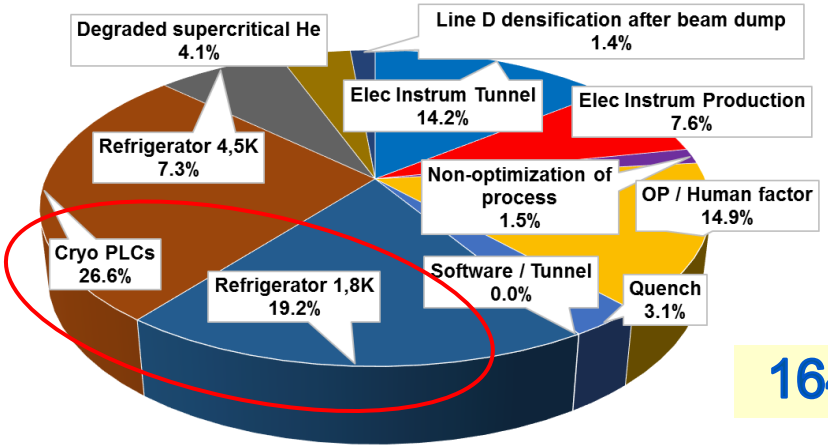
2016

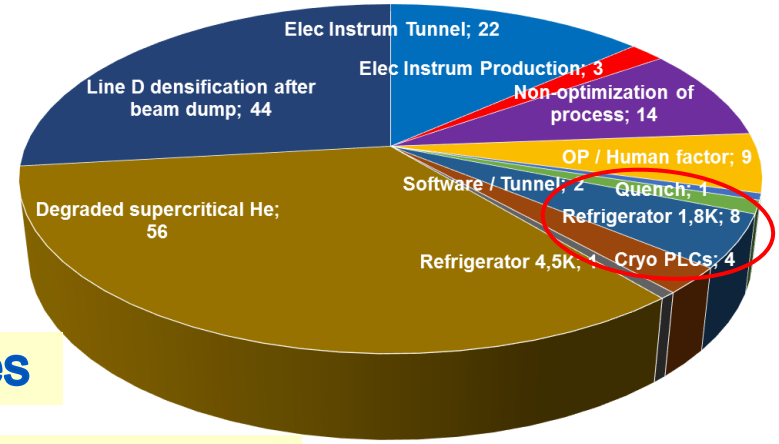
CRYO LOSSES		USERS LOSSES		SUPPLY LOSSES		TOTAL LOSSES	
Number	Time	Number	Time	Number	Time	Number	Time
16	73:21:00	**22**	55:26:00	**7**	163:27:00	**45**	292:14:00





2015 Cryo availability (Cryo Maintain)





164 losses

Total down time = 273 h 29 min

The most time consuming losses:

PLC: 4 failures with 26.9% ⇒ **solved during YETS'15**

Cold compressor: 8 failures 19.4 % ⇒ **solved during Technical Stops**

Human factor 15.1% (mainly late TS1 recovery)

Elec. Instrum. Tunnel 13.3 %

4 above contributors:
➔ 75% of the down time

The most frequent losses (main contributors):

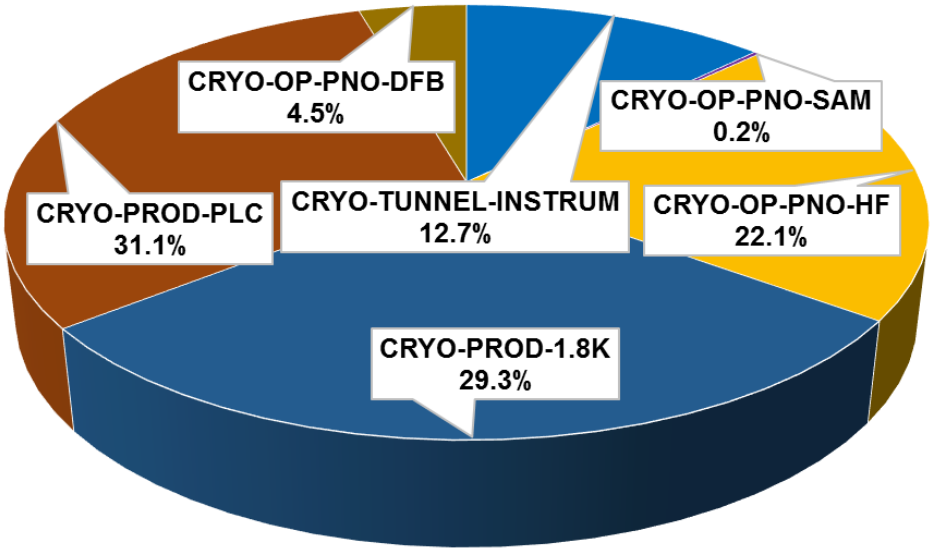
Electrical feed boxes He level (60 losses)

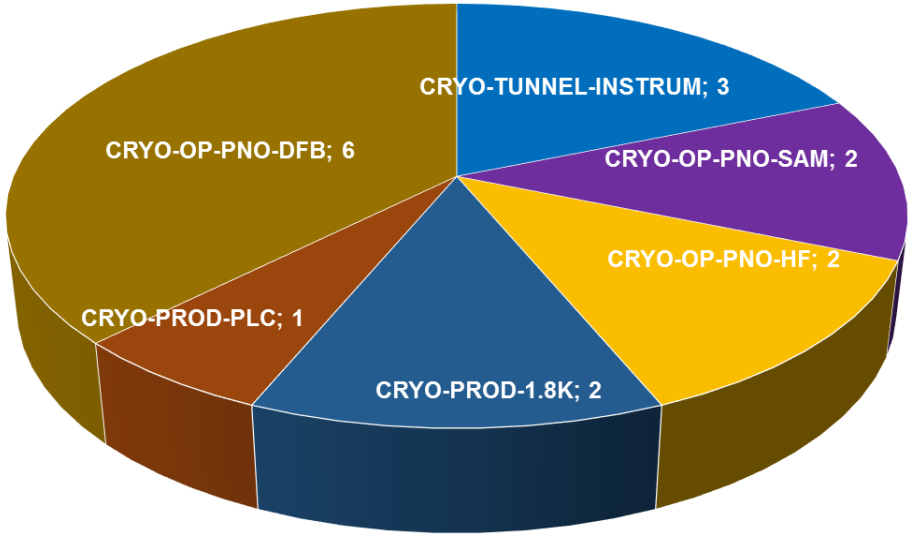
=> solved during YETS'15 with QSRB-8 repair (SHe of better quality) + adaptation of operational thresholds and fine tuning of controllers

NB: YETS = Year End Technical Stop

2016 Cryo availability (Cryo Maintain)

	Total	CRYO-TUNNEL-INSTRUM	CRYO-OP-PNO-SAM	CRYO-OP-PNO-HF	CRYO-PROD-1.8K	CRYO-PROD-PLC	CRYO-OP-PNO-DFB
Number	16	3	2	2	2	1	6
Duration	73:21:00	9:19:00	0:10:00	16:13:00	21:31:00	22:50:00	3:18:00

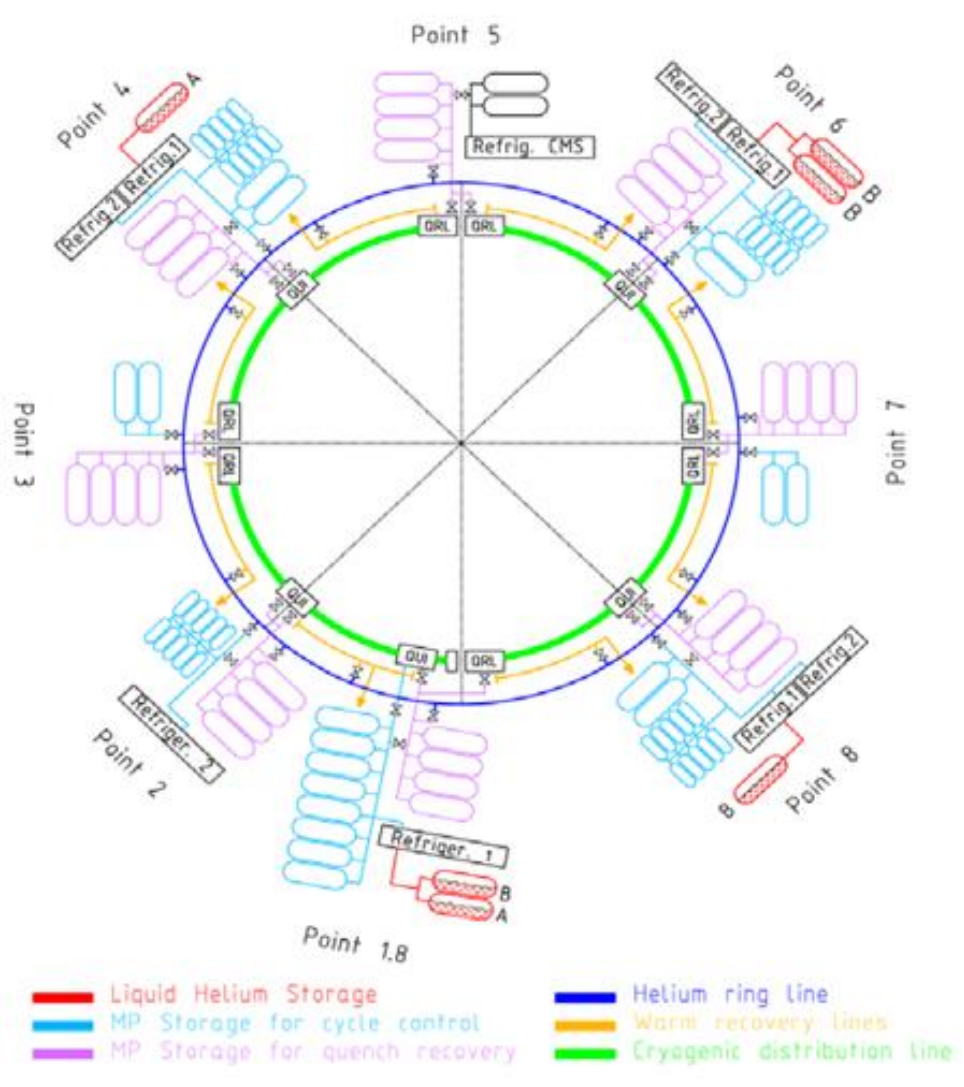


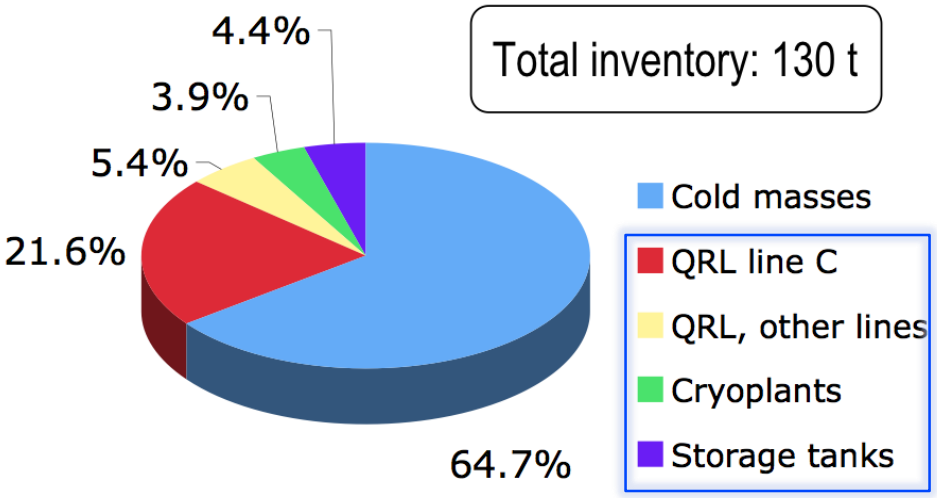


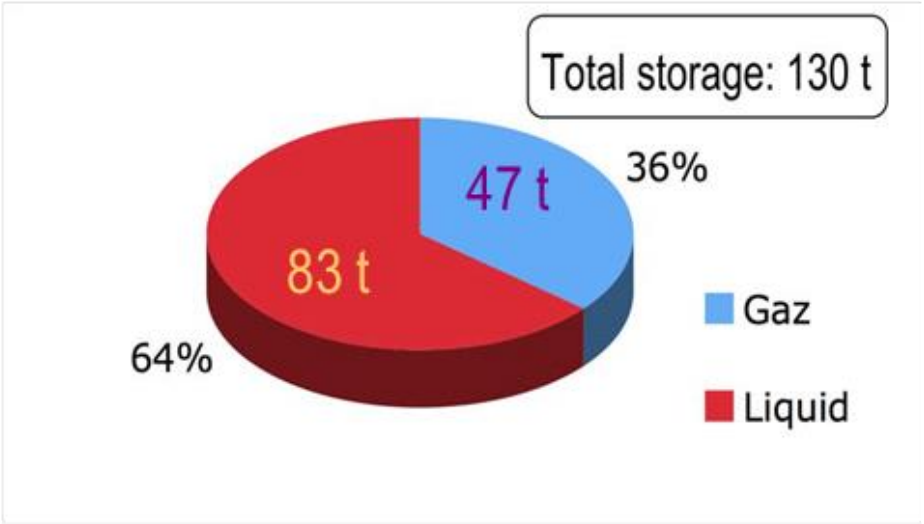
2016 RUN 2 CRYO Availability Summary	
Due Operation Time	4813:21:00
Cryo losses	1.5%
Total Cryo Downtime	73:21:00
Cryo Availability for 8 sectors	**98.5%**
Delayed injections	22:21:13
Cryo Availability counting delays	**98.0%**

LHC HELIUM INVENTORY MANAGEMENT

LHC helium inventory storage

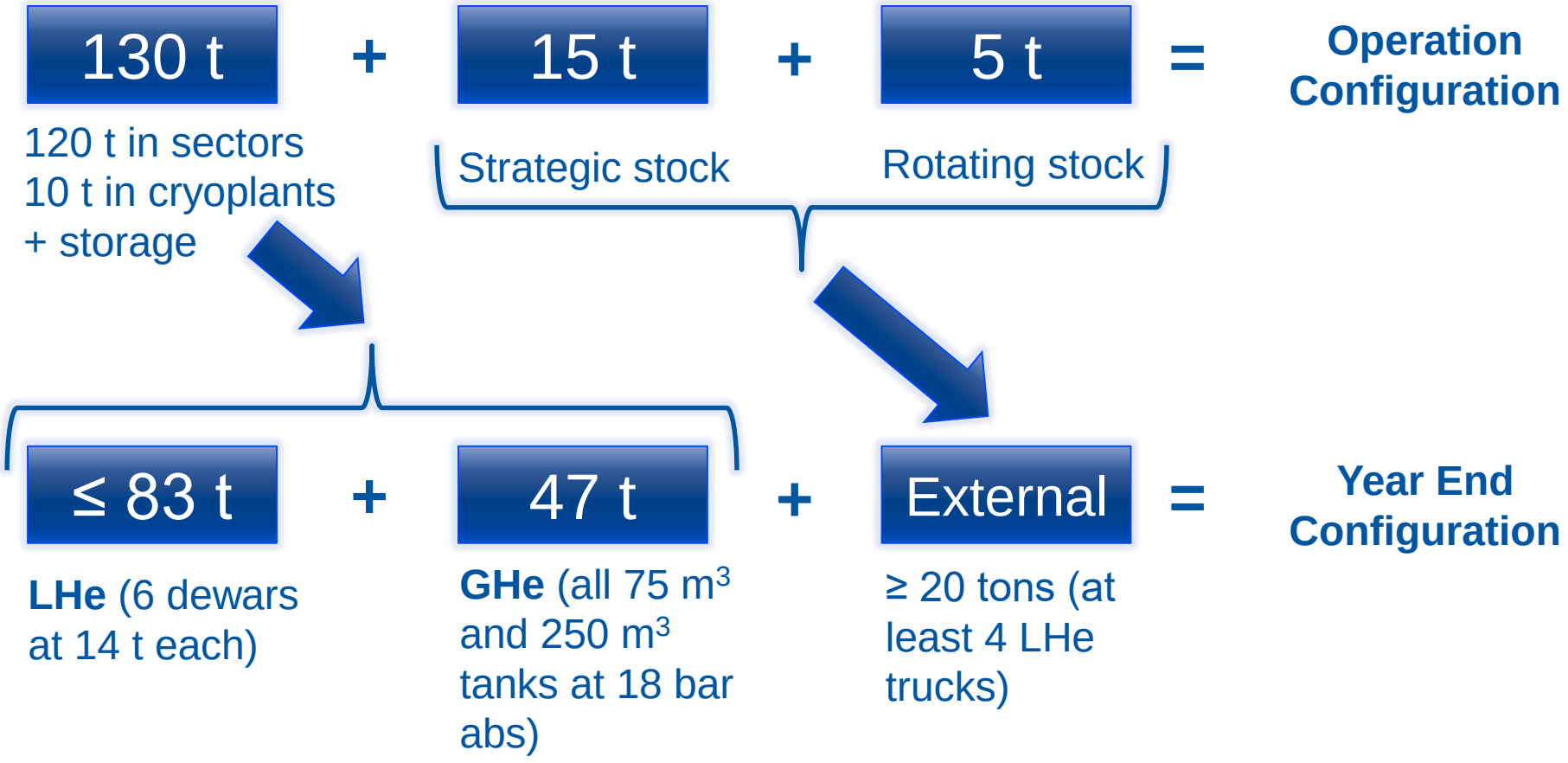






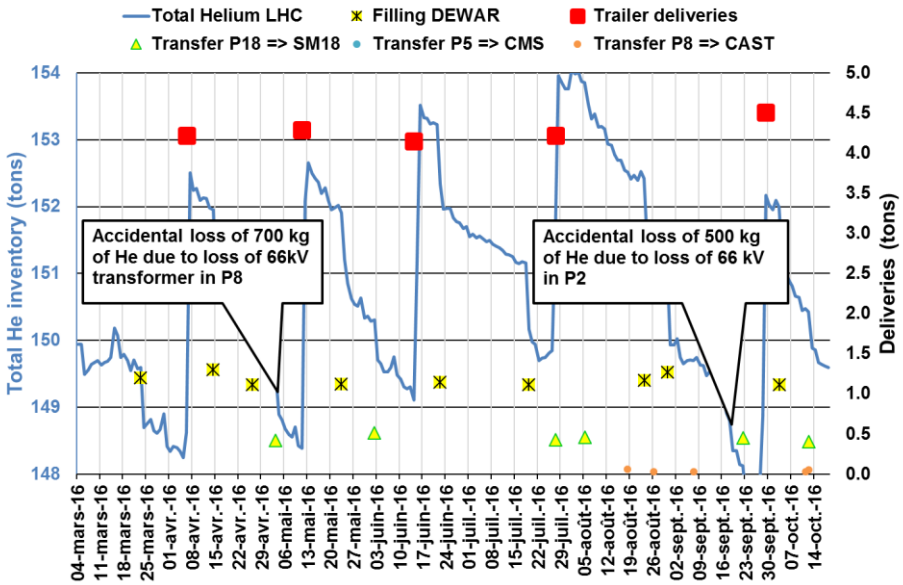
LHC helium inventory management

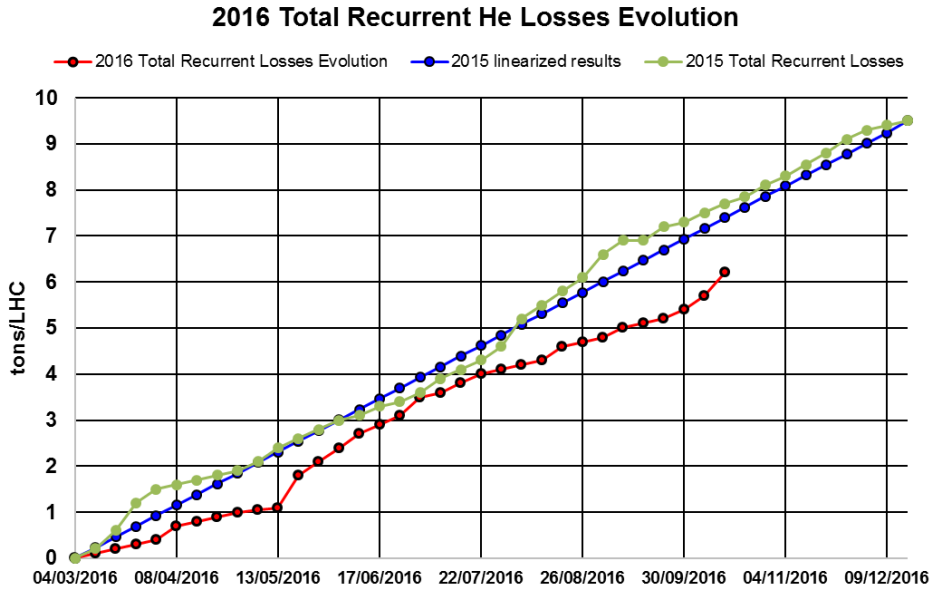
150 metric tons of helium



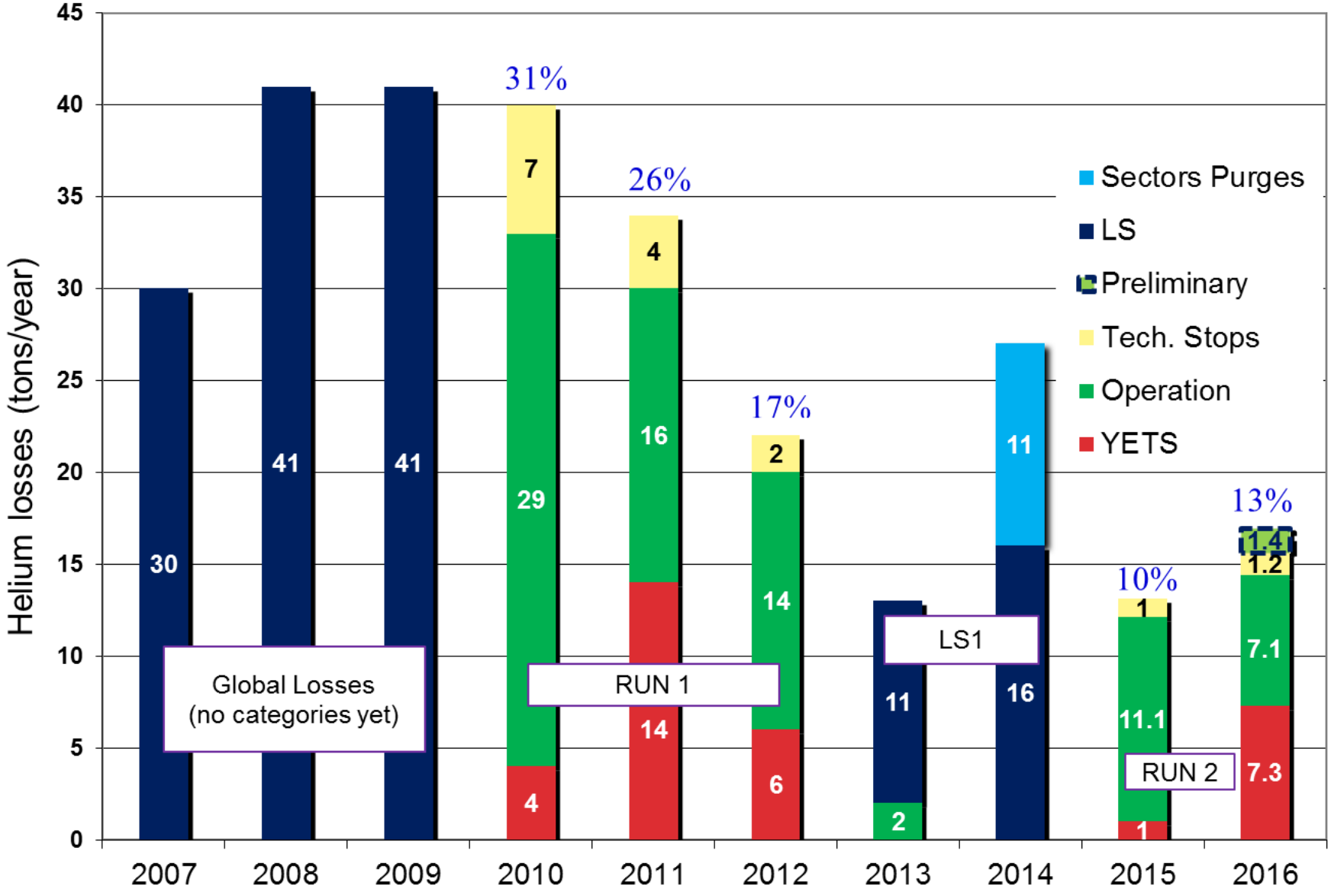
Typical helium inventory follow-up

Inventory on	04/03/2016	149.9	tons
Trailers received	5 trailers	21.4	tons
Deliveries to Experiences & Test Facilities		-13.4	tons
Identified accidental losses		-1.9	tons
Recurrent losses		-6.5	tons
Inventory on	**18/10/2016**	**149.6**	**tons**





Helium consumptions and losses



Main actions

Our main goal: reduce our recurrent He losses and improve the precision of our balance.

How ?

- Look for He losses in ventilation: surface installations check regularly, tunnel installations to be done during next Technical Stop and Extended Year End Technical Stop – *in progress*

- Systematic check of gaseous storage installations (as it is one of the major contributors to our recurrent losses)

- On-line follow-up accuracy checks – improvements

- Operational consumptions acounting: around 500 kg of He per year for the whole machine regarding adsorbers and dryers regenerations – shall be extracted from our recurrent losses – *in progress*

Conclusions and perspectives

- Experience from RUN 1 allowed for maintaining high level of availability as well as reducing helium losses

- Large LS1 campaign permitted to solve all RUN 1 non-conformities to restart with highly reliable and consolidated hardware for RUN 2

- Extensive follow-up of the origins of the downtime allowed for proposing adequate mitigation solutions to encountered problems, thus improving our hardware reliability and finally our availability

- Some room available for ongoing improvements regarding hardware reliability and helium inventory accountability

THANK YOU !

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