LHC Performance Workshop
LS1 Session
Cryogenic system: strategy to achieve nominal performance and reliable operation

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Chamonix 2012, 08 February 2012

LS1 cryogenics strategy

- Nominal performance recovery
  - Safety (personnel, hardware, He inventory)
  - Cryogenic equipment
- Reliability/availability improvement
  - Cryogenic equipment (hardware)
  - Spare strategy (hot vs stored)
  - Redundancy
  - Upgrades (sectorization, …)

Nominal performance recovery: Safety first

	Resp.	Status
Personnel		
IT (& RF?) SV collectors		Y
DFB deflectors		
Machine platforms		Y
Helium ring line (HRL) sectorization		Y
Instrumentation air panel for cryo consig	G	Y
Tunnel ventilation conditions (P, T, v)	E-CRG	Y
Machine		
Safety valve consolidatio	TE-MSC/CRG	Y
SV final design insta	TE-VSC	Y
Beam vacuum	TE-VSC	Y
Machine	EN-MEF + ?	Y
Detectors (		
He inventory		
Helium rin RL) sectorization	TE-CRG	Y
Quench line nsolidation (in case of massive quenches)	TE-CRG	Y

About on tracks!
Responsibilities for machine platforms to be consolidated.

Y: planned & approved

Nominal performance recovery: Hardware

	Resp.	Status
Machine		
DFB consolidation (Splice, DFBX CL, flexible hoses	TE-CRG	Y
Inner triplet braids	TE-MSC	Y
Y lines	TE-MSC	Y
Leaks (in S3-4, P8…)	SC/MSC/CRG	Y
Beam screen circuit (Q6R5)	G/MSC/VSC	Y
Instrumentation NC	TE-CRG	Y
Distribution		
Leak in S4-5	TE-CRG	Y
Stand-alone magnet	TE-CRG/MSC	Y
Instrumentation NC	TE-CRG	Y
Detectors (N/A)		
Cryoplants		
Leaks in LN2 precoolers	TE-CRG	Y
Instrumentation NC	TE-CRG	Y

On tracks!
Special attention on newly approved consolidation!
(DFBA 13 kA splices)

Y: planned & approved

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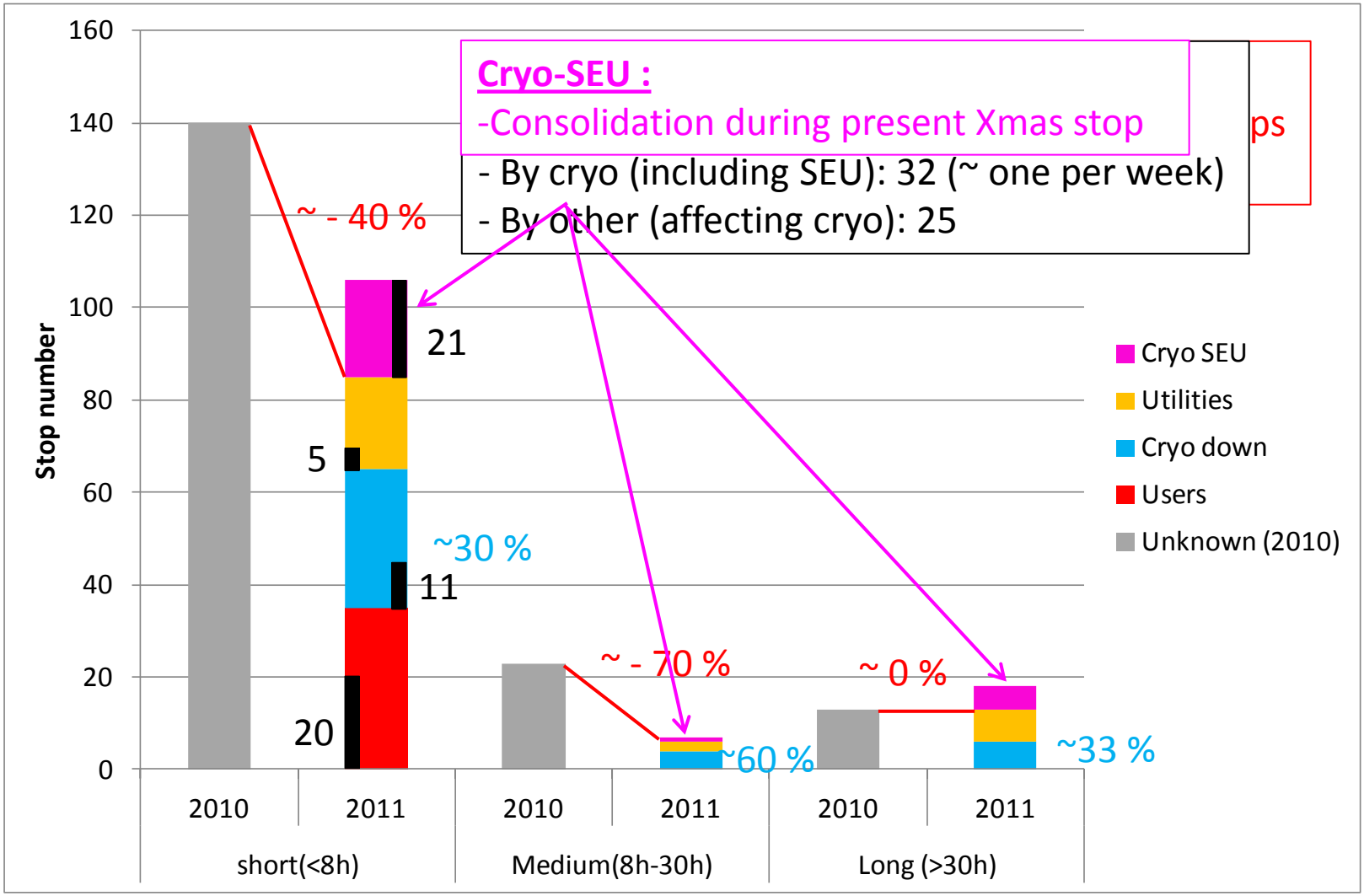
Reliability / availability data: Cryo stops



S. Claudet *et al*

Reliability / availability data: 2011 medium and long cryo-failures

Point	Date	Equipment	Origin	Action / Decision	Treated for	
					2012	> LS1
P2	26 Apr	Cold compressor magnetic bearings	Old card type on pre-series	Cards upgraded after failure	Yes	Yes
P4	18 Aug	Cold compressor	Lost of instrumentation with diagnostic issue	TT replaced, new diagnostic and degraded restart procedures	Yes	Yes
P4	16 Nov	Cold compressor frequency drive	CC4 power card 1st error	Systematic HW exchange every 10 y	No	Yes
P4	20 Nov	Cold compressor frequency drive	CC4 power card 2nd error	Systematic preventive renewal	Yes	Yes
P4	28 Nov	Superconducting link	Common vacuum of the DSLC with a DFBLC heater vacuum	Separation of vacua per type	Yes	Yes
P8	13 May	PLC (4.5 K plant)	PLC 1st crash	Considered as “normal” MTBF (1/y)	No	No
P8	25 May	PLC (4.5 K plant)	PLC 2nd crash	Crashed PLC CPU systematic replacement by now	Yes	Yes
P8	18 Jun	Screw compressor	Early bearing damage due to balancing piston depressurization	Consolidation done during Xmas’11 stop	Yes	Yes
P8	13 Aug	Cold compressor	Hard landing of CC4 rotor	New procedure to shorter the recovery time	Yes	Yes
P8	1 Nov	Oil valve positioner	Positioner failure	Considered as “normal” MTBF (1/y)	No	No

No medium/long stops at P6 → Confidence in room for improvement!

S. Claudet

Reliability / availability data: 2011 cryo near-misses

Point	Equipment	Origin	Action / Decision	Treated for	
				2012	> LS1
P2	Screw compressor	Compressor failure	**Shared operation** P18/P2	No, but	Yes, if
P2	Valve bellows	Big leak on a valve bellows (Ex-LEP)	**Cannibalization** of components on the P8 stopped plant Consolidation budget for LS1	No, but	Yes
P2	Cold compressor electronics	Electronic card failure	**Cannibalization** of components on the P6 stopped plant Additional spare ordered	Yes	Yes
P4	Screw compressor	Compressor failure	**Shared operation** with adjacent plant	No, but	Yes, if
P4	Cold compressor electronics	Electronic card failure	**Cannibalization** of components on the P8 stopped plant Additional spare ordered	Yes	Yes
P8	Screw compressor	Compressor failure	**Shared operation** with adjacent plant	No, but	Yes, if

No, but: 2011 mitigation measures still possible

Yes, if: new spare strategy for compressors to be approved and implemented

S. Claudet

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  - Upgrades (sectorization, …)

Reliability/availability improvement : Hardware

	Mode	Resp.	Status
Maintenance and major overhauling	S, T	TE-CRG	Y
Machine			
SEU consolidation (see A.L. Perrot talk)		TE-CRG	Y
Stand-alone magnet level capillaries (3 O		TE-MSC	Y
DFBAO & DFBMJ instabilities		TE-CRG	Y
Distribution			
Line B mixing chamber i	T	TE-CRG	N
Quench valve contr ovement	T	TE-CRG	N
Cryoplants			
SEU co Perrot talk)	S	TE-CRG	Y
New linde	T	TE-CRG	Y
Ex-LEP consolidation	S	TE-CRG	Y
Cryoplan onfiguration for cooldown (bypass)	T	TE-CRG	N
Dryers for ATLAS (MR) and CMS	S	TE-CRG	Y

All improvements for steady-state modes will be treated during LS1 !

S: Improvement for **S**teady-state (with beam)

T: Improvement for **T**ransients (e.g. recovery time, Cool-down…)

Y: planned & approved N: Not planned

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  - Upgrades (sectorization, …)

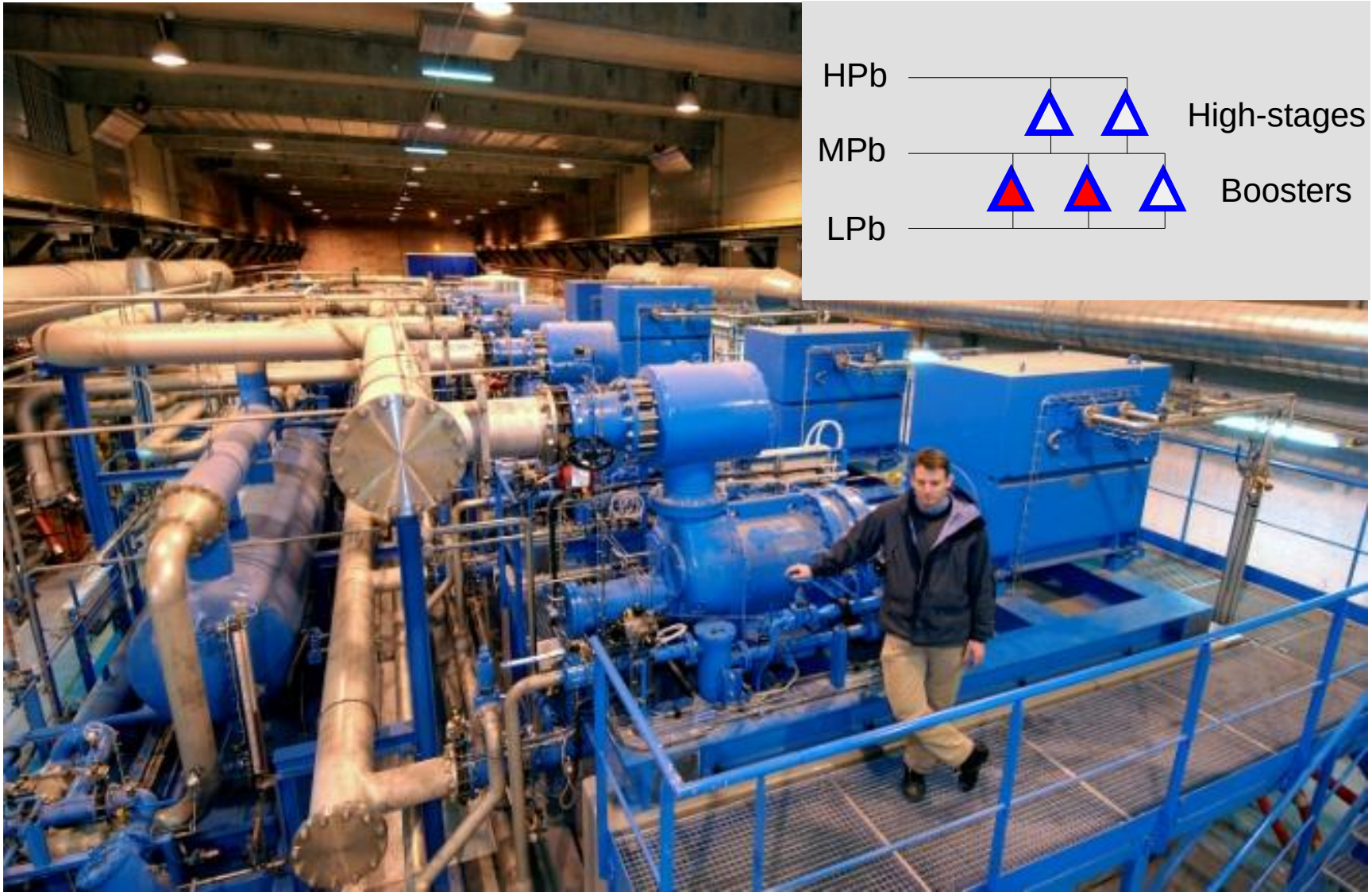
Reliability/availability improvement : Spares, redundancy & upgrades

	Resp.	Status
Spare strategy (hot vs stored)		
Warm compressors (LHC and its detectors)		S
Electrical motors (LHC and its detectors)		N
Special electronic equipment (Safety PLC, VFD		N
Turbines, Cold compressors		Done
Redundancy		
Better sharing of HP-MP-BP fl	TE-CRG	N
2 cryoplants with one 1.8	TE-CRG	Done
24 V electrical supp tectors)	TE-CRG	N
Upgrades		
Sectoriz ovement	TE-CRG	S
LN2	TE-CRG	S
Rot es above typical standard	TE-CRG	N
Inter dancy	TE-CRG	N
ATLAS bution (decoupling toroid / solenoid)	TE-CRG	Y

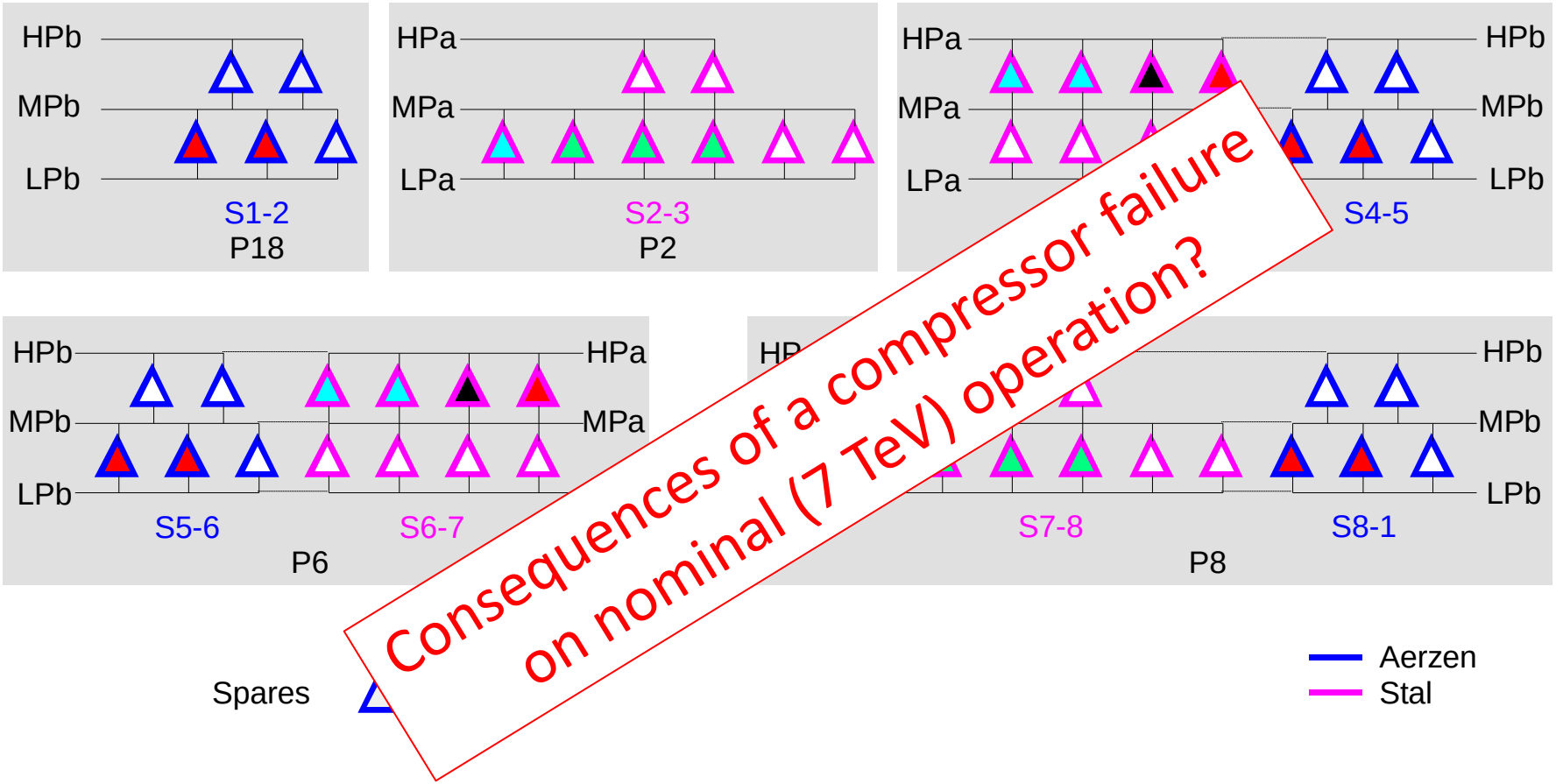
Warm-compressor spare strategy & sectorization improvement need urgent approval (procurement delays)!

Y: planned & approved **N: Not planned** **S: Under Study**

A typical warm compressor station of LHC



4.5 K cryoplant compressors: Present situation



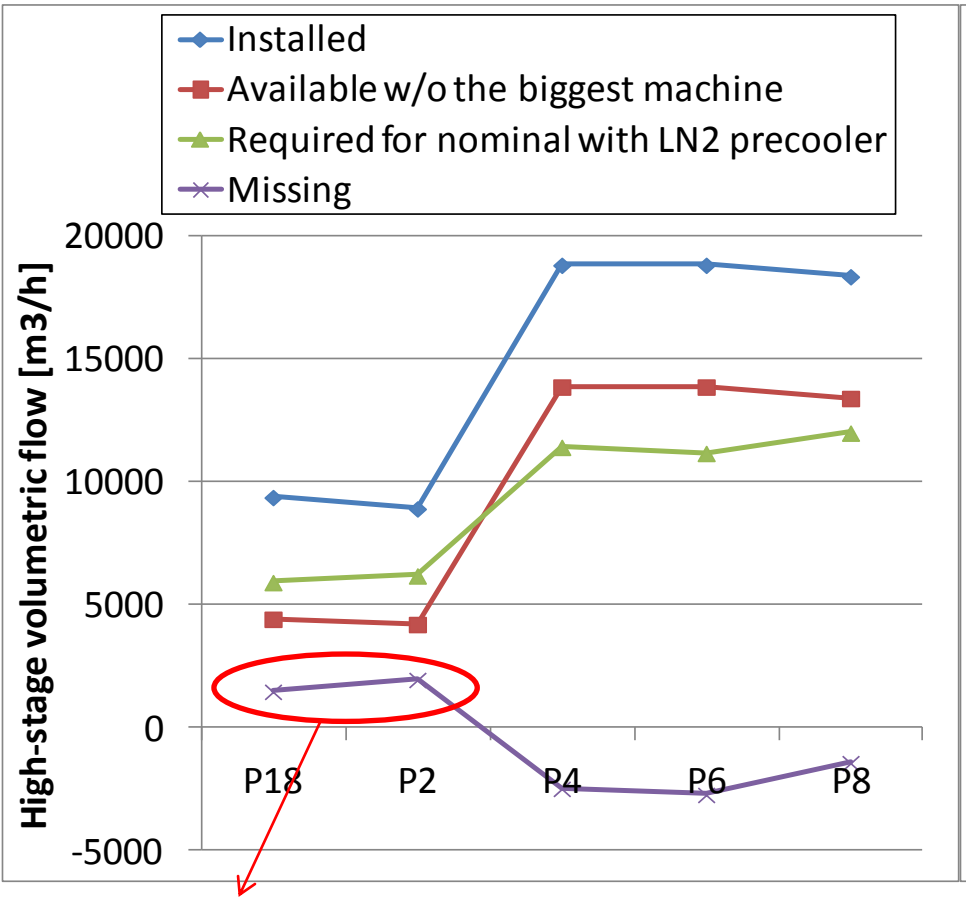
9 types of compressors:

- 2 Aerzen types (536M & 536H)

- 7 Stal types (S73_lp, S73_hp, S75, S87, S89, S93_lp & S93_hp)

Installed vs required volumetric flows

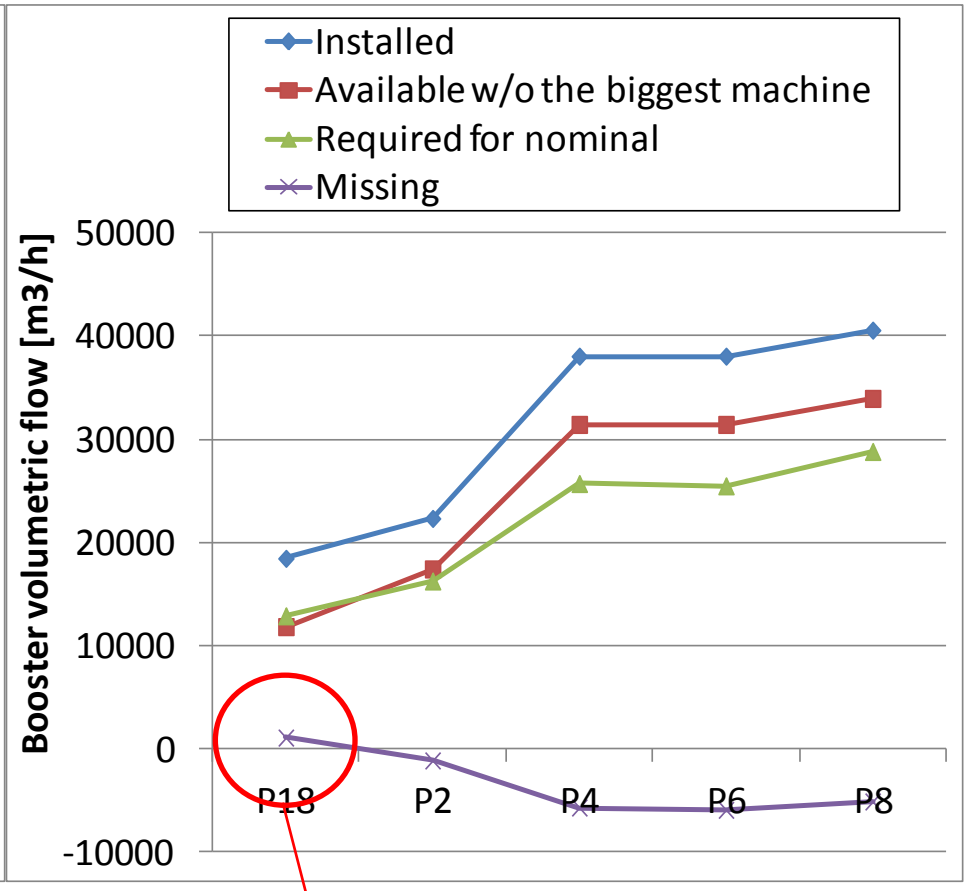
High-stages



~1500 m3/h or ~265 g/s @ 4 bar missing at P18

~2000 m3/h or ~350 g/s @ 4 bar missing at P2

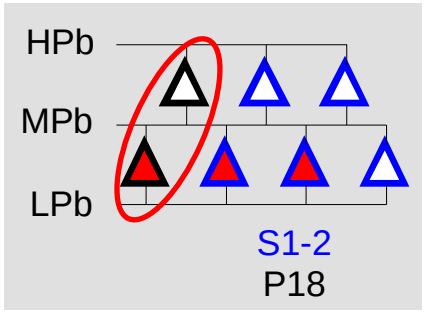
Boosters

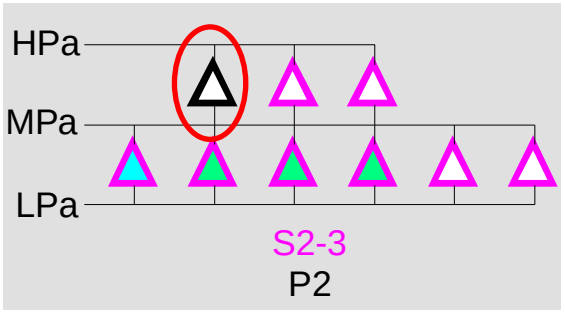


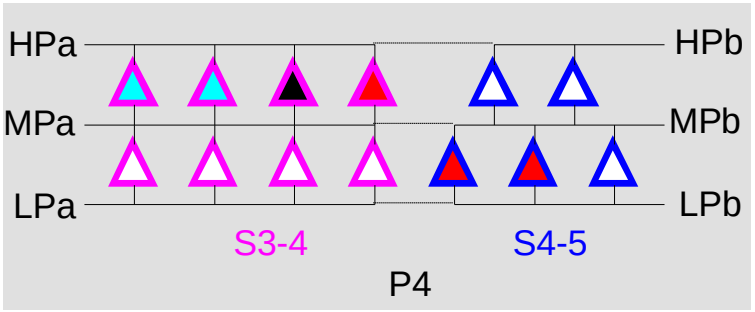
~1050 m3/h or ~50 g/s @ 1.05 bar missing at P18

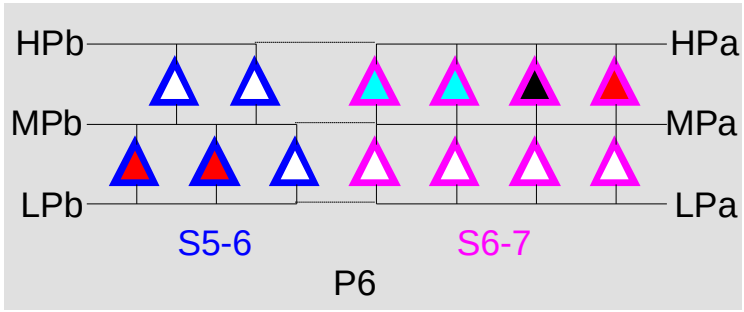
K. Brodzinski

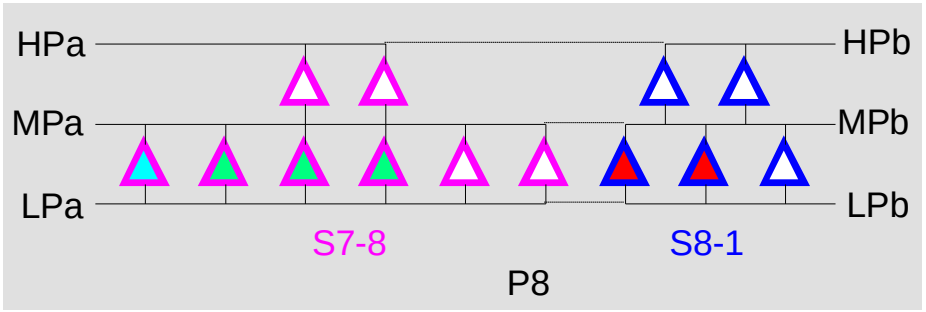
4.5 K cryoplants: Nominal capacity consolidation











Spares 

Aerzen (existing)
Stal (existing)
New

- To guarantee nominal operation with minor MTTRestore (~1 day)
  - Hot spares at P18 and at P2
  - Stored spares for the other plants:
    - Use of LN2 precooling to save HP flow (LN2 consumption compensated by electrical power saving but logistics to be reliable)
    - Exchange of compressor during the next TS (or 3 additional days to restore)
  - Review of the plant LP, MP, HP by-passes
- But: How many stored spares are required?
  Stal spares are not available any more on the market! (repair and major overhauling still possible)
  Space for the hot spare at P2 is not available !

How many spares are required for the compressors?

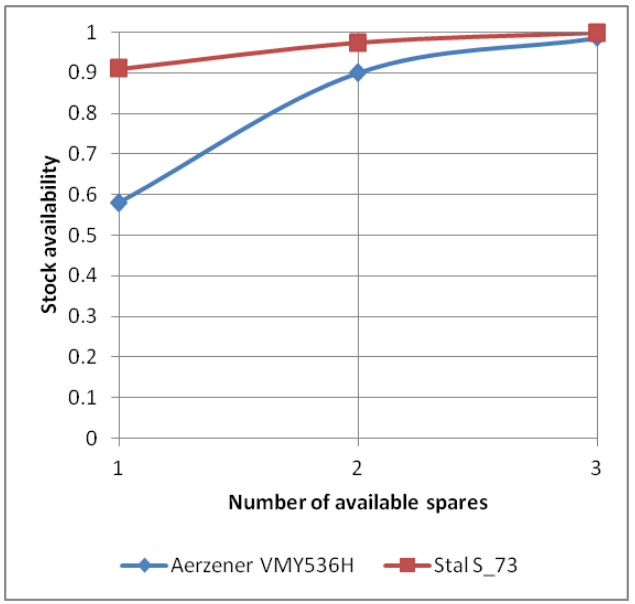
Case 1: Failure rate $\lambda = 0$ (7 types concerned)

Within the observation time no failure has occurred. The observation time might be too short? A failure can occur tomorrow!

A spare should be available (stored/hot) in those cases where the impact of a compressor failure is major or catastrophic for the scientific objectives of LHC.

Case 2: Failure rate $\lambda > 0$ (2 types concerned)

What stock availability can be guaranteed with 1, 2 or 3 spares taking into account the repair time of the compressors?



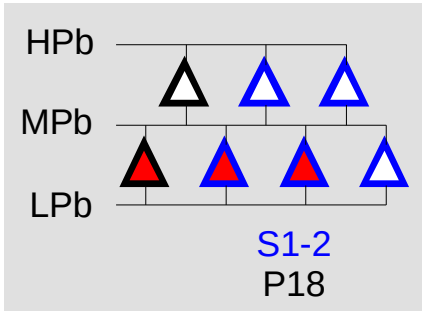
		Aerzen VMY536H	Stal S73
Failure rate λ estimation from available data	[h^{-1}]	6×10^{-6}	6×10^{-6}
Population on LHC	[-]	12	6
MTTRepair from recent experience	[h]	7200	2500

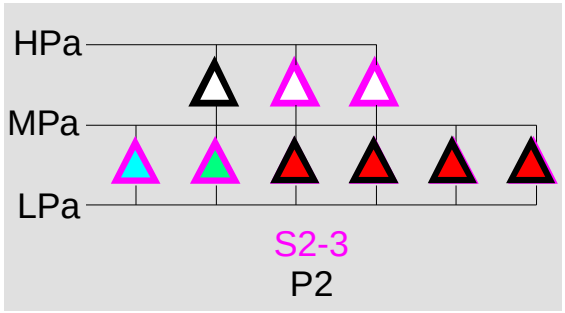
Stock availability = probability to fulfil spare part demand		
Spares	Aerzen VMY536H	Stal S73
1	0.58	0.91
2	0.9	0.974
3	0.986	0.998

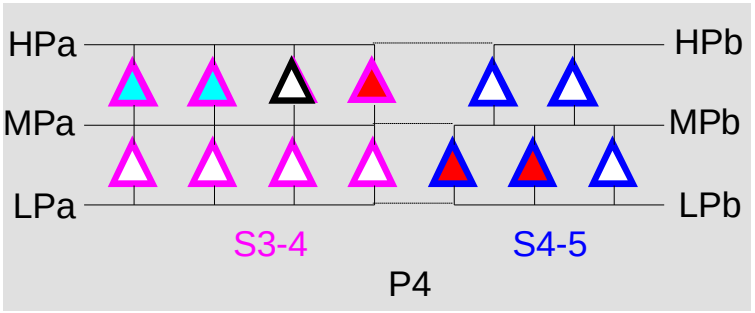
G. Perinic , A. Perin

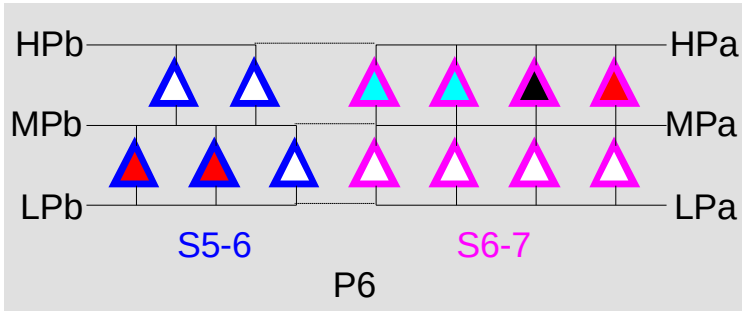
Proposed strategy for 4.5 K cryoplants

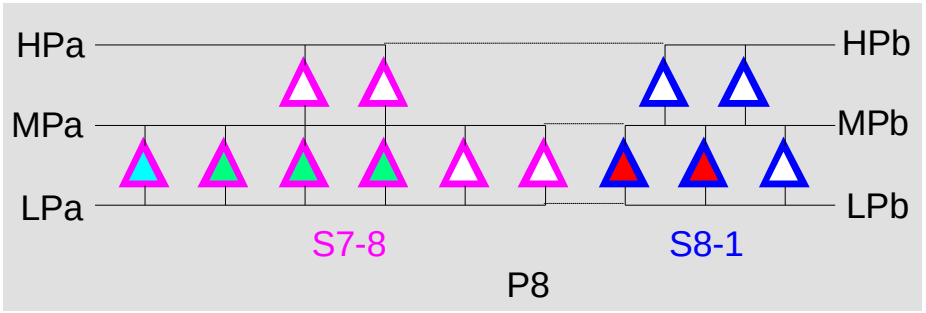
- Use as spares some existing Stal compressors at Point 2 and Point 4
- Install new compressor skids with larger capacity (To free slot space)
- Complete the missing spares

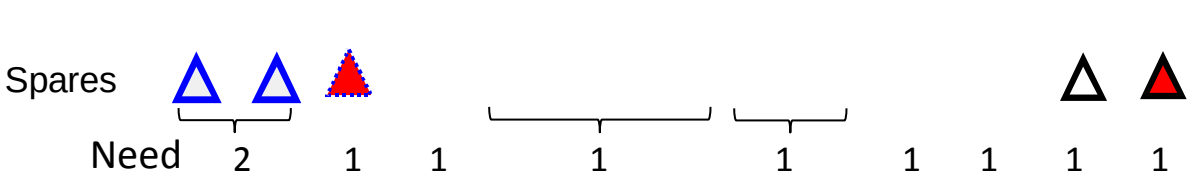






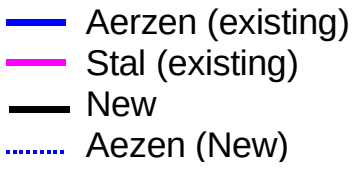




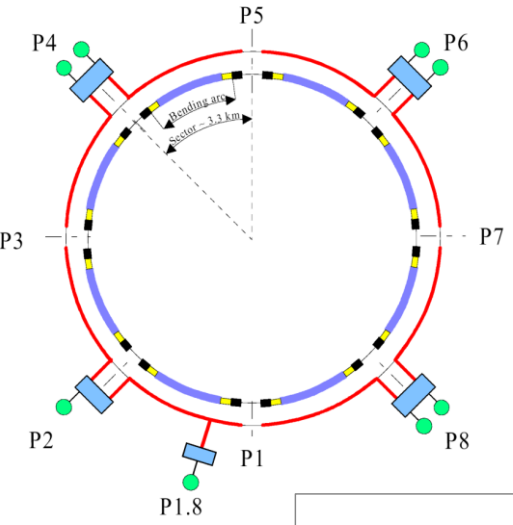


for stock availability > 90 %

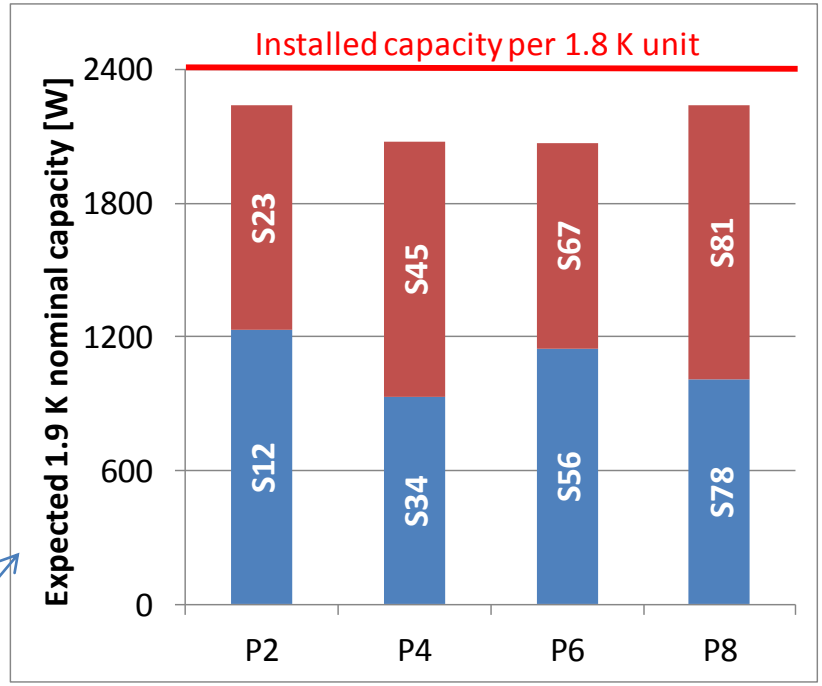
For stock availability > 97 %, 1 additional skid and 1 additional spare are required)



Warm compressors of 1.8 K refrigeration units (CCS)



Sector	Normal	Back-up
S12	CCSb P18	CCSa P2
S23	CCSa P2	/
S34	CCSa P4	CCSb P4
S45	CCSb P4	CCSa P4
S56	CCSb P6	CCSa P6
S67	CCSa P6	CCSb P6
S78	CCSa P8	CCSb P8
S81	CCSb P8	CCSa P8

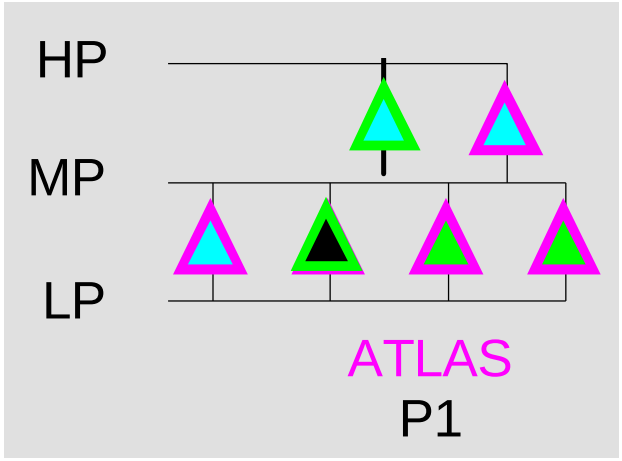


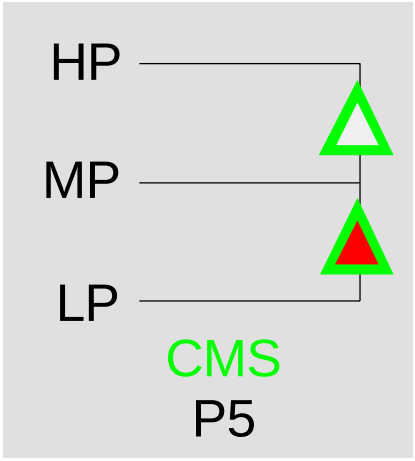
Static heat inleaks → Sector measurements (5 over 8)
Resistive heating → Splice resistance measurements
DR nominal beam-induced heating

No redundancy for S23, i.e. for a MTTR < ~1 day
→CCSa at P2 needs a hot spare
→Stored spares for the other points

Proposed solution for detectors

- 2011 configuration: no spare available, some extra capacity in ATLAS booster
- Xmas'11 configuration: one hot spare installed for ATLAS
- May'12 configuration: 2 new spares for CMS (already ordered)
- LS1 upgrade: Booster upgrade for ATLAS (already ordered) and 2 hot-spare skids for CMS

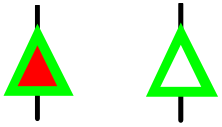




Stal
Howden

Spares

LHC Stal spares available for ATLAS as well!



Summary of compressor spare/redundancy

- LHC 4.5 K cryoplants: depending on the stock availability (>90 or >97 %)
  - 8 to 9 new compressor skids to be procured and installed (4 to 4.5 MCHF)
  - 3 to 4 additional spares to be procured (0.9 to 1.2 MCHF)
- LHC 1.8 K units
  - 1 new Kaeser compressor skid to be procured and installed (~0.5 MCHF)
  - 1 additional Mycom spare to be procured: (~0.5 MCHF)
- ATLAS and CMS cryoplants
  - 2 new compressor skids to be procured and installed (0.6 MCHF)
- Space for spare storage: 15 to 17 compressors (+ 8 electrical motors): ~100 m^2
- Resource needs:
  - ~7 to 8 MCHF (including ~1.5 MCHF non-competitive & ~0.6 MCHF on Team budget)
  - Manpower from TE-CRG, EN-EL and EN-ICE

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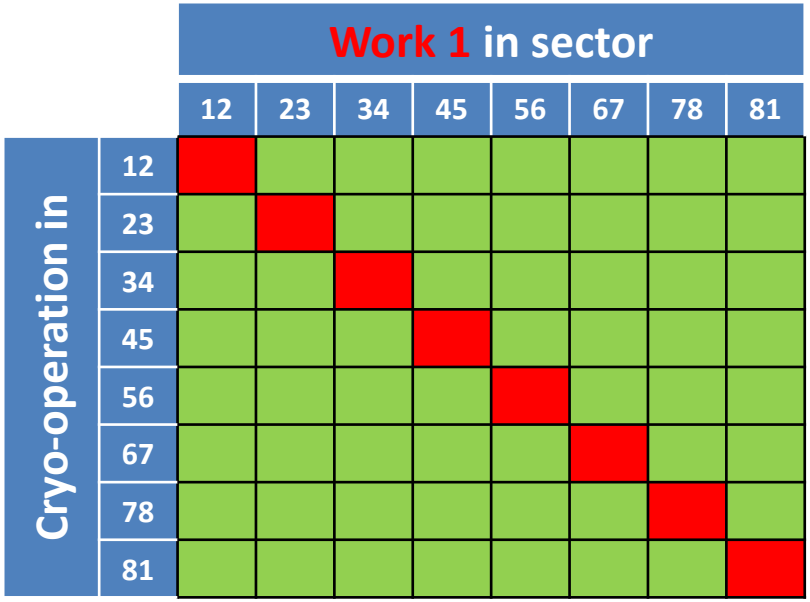
Sectorization in between sectors: Present situation

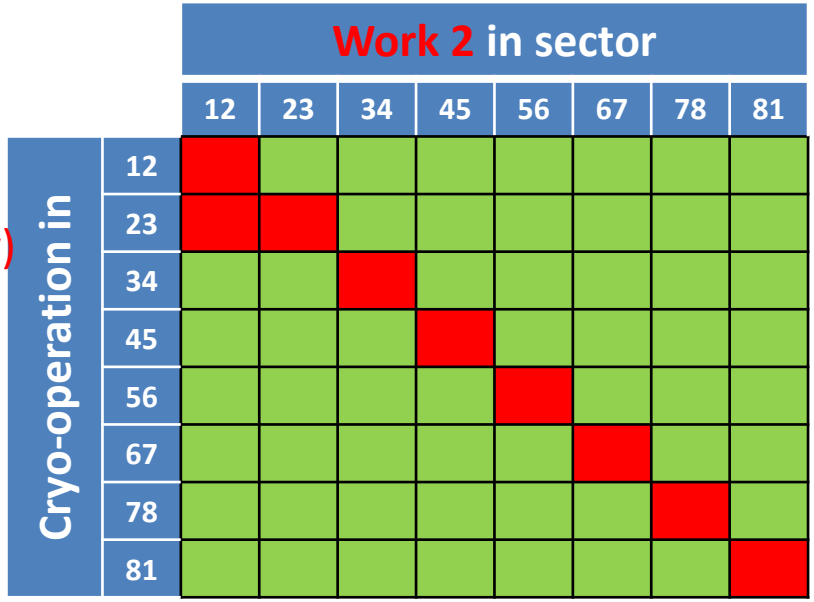
Work 1 : Opening of
- M lines, CC CM
- RF cavity CM
-V, W line

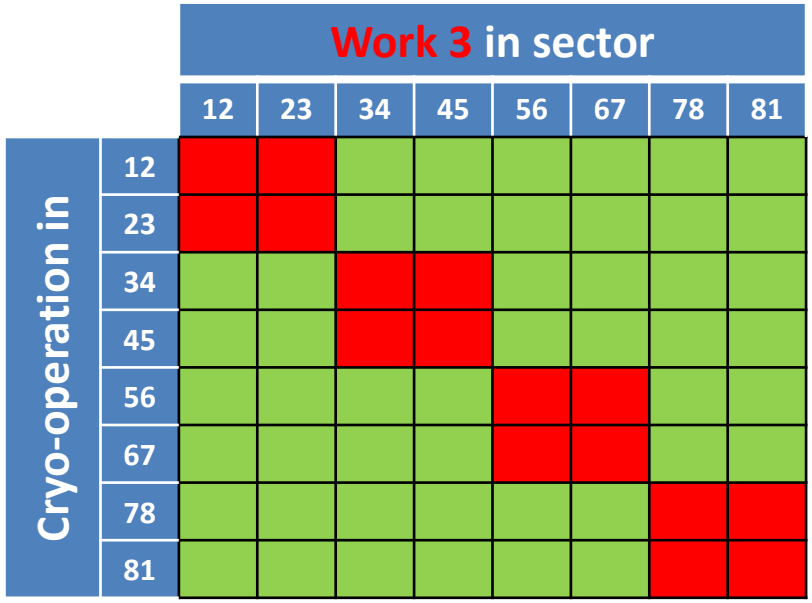
(e.g. Splice/diode repair)

Work 2 : Opening of
- E, F lines
- C, C', BS lines
- D line, SAM CM

(e.g. Q6 level capillary)







Work 3 : Opening of
- B, X, Y lines

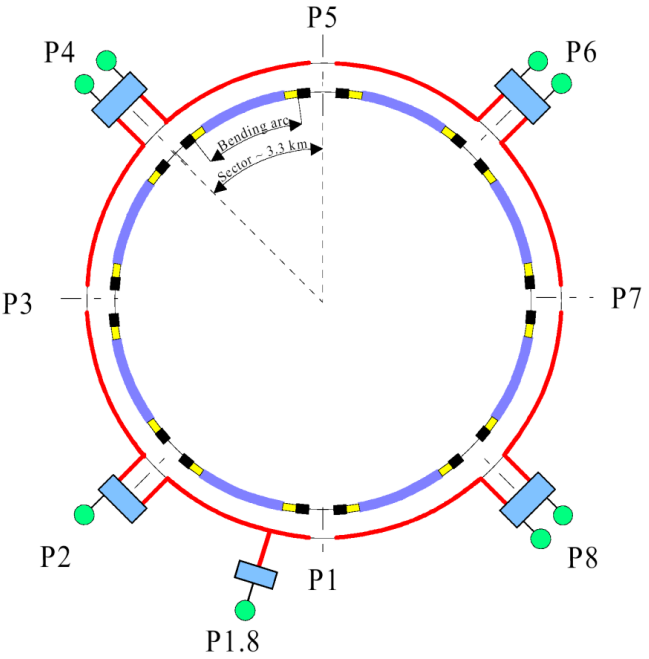
(e.g line Y repair or magnet removal)

Sectorization improvement: New valve integration

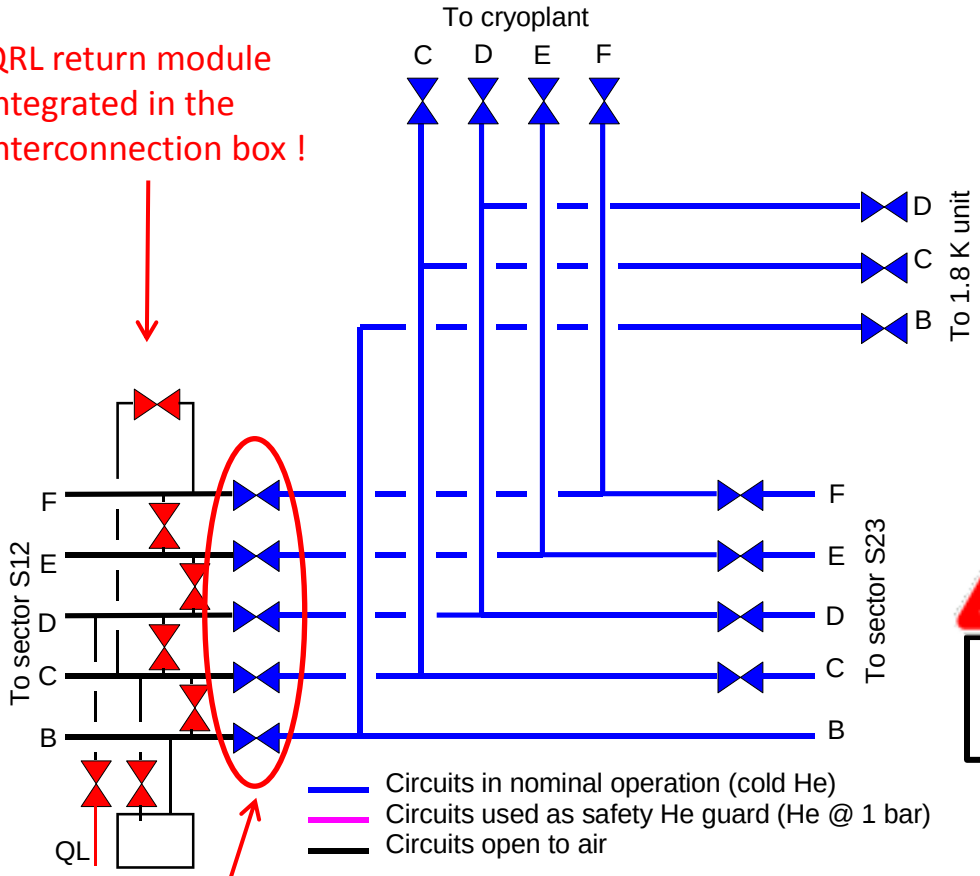
Possible in S23, S34, S45, S56, S67, S78 & S81 (7 sectors):
~150 kCHF per sector
~1 MCHF for 7 sectors
What about S12?

G. Ferlin

Sectorization: P2 configuration



QRL return module integrated in the interconnection box !



Today, no solution for work 2 and Work 3 in S12 in parallel with cryo operation in S23 !

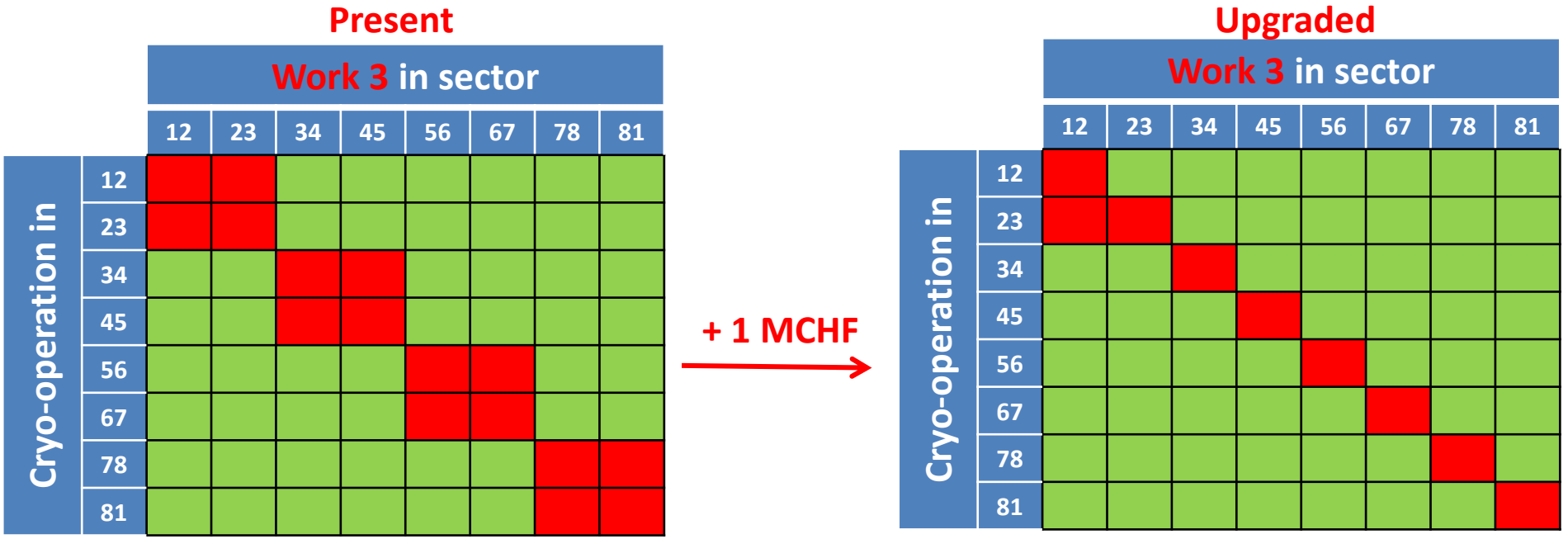
Sectorization in between sectors: Summary

Work 1 : Opening of - M lines, CC CM - RF cavity CM -V, W lines	**Work 2** : Opening of - E, F lines - C, C', BS lines - D line, SAM CM	**Work 3 :** Opening of - B, X, Y lines

Work 1 → Ultimate sectorization already existing

Work 2 → Present sectorization does not allow Work 2 in S12 in parallel with cryo-operation in S23. Today no straight forward improvement envisaged.

Work 3 → the sectorization could be improved at the same level than Work 2 by upgrading the interconnection boxes → budget: ~ 1 MCHF



Conclusion

- Consolidation for nominal performance recovery of cryogenics is about on tracks

- Improvement of the cryogenic availability:
  - Some measures already taken → 2012 objective: overall cryo-availability improvement from 90 % to 95 %
  - Direct cryo-downs (including SEU) represent 50 % of the total stops
    → improvement of user and utility stabilities is also important
  - Some long cryo-stops avoided in 2011 thanks to cannibalization and operation sharing of non-used cryoplants
    → no more possible for nominal operation after LS1
    → A strategy of warm compressor spares is proposed: additional budget estimated to ~7-8 MCHF and manpower need must be consolidated.

- Improvement of sectorization in-between sectors:
  - Already optimized for Work 1 (e.g. splice/diode repair)
  - Optimized on 7 sectors for Work 2 (e.g. intervention on SAM CM, on BS)
  - Could be improved on 7 sectors for Work 3 (e.g. Magnet removal)
    → ~ 1 MCHF for interconnection box upgrade