Rotating machinery for LHC Cryogenics: first analysis of reliability and origins of downtime

LHC Cryo-OP

ICEC/ICMC

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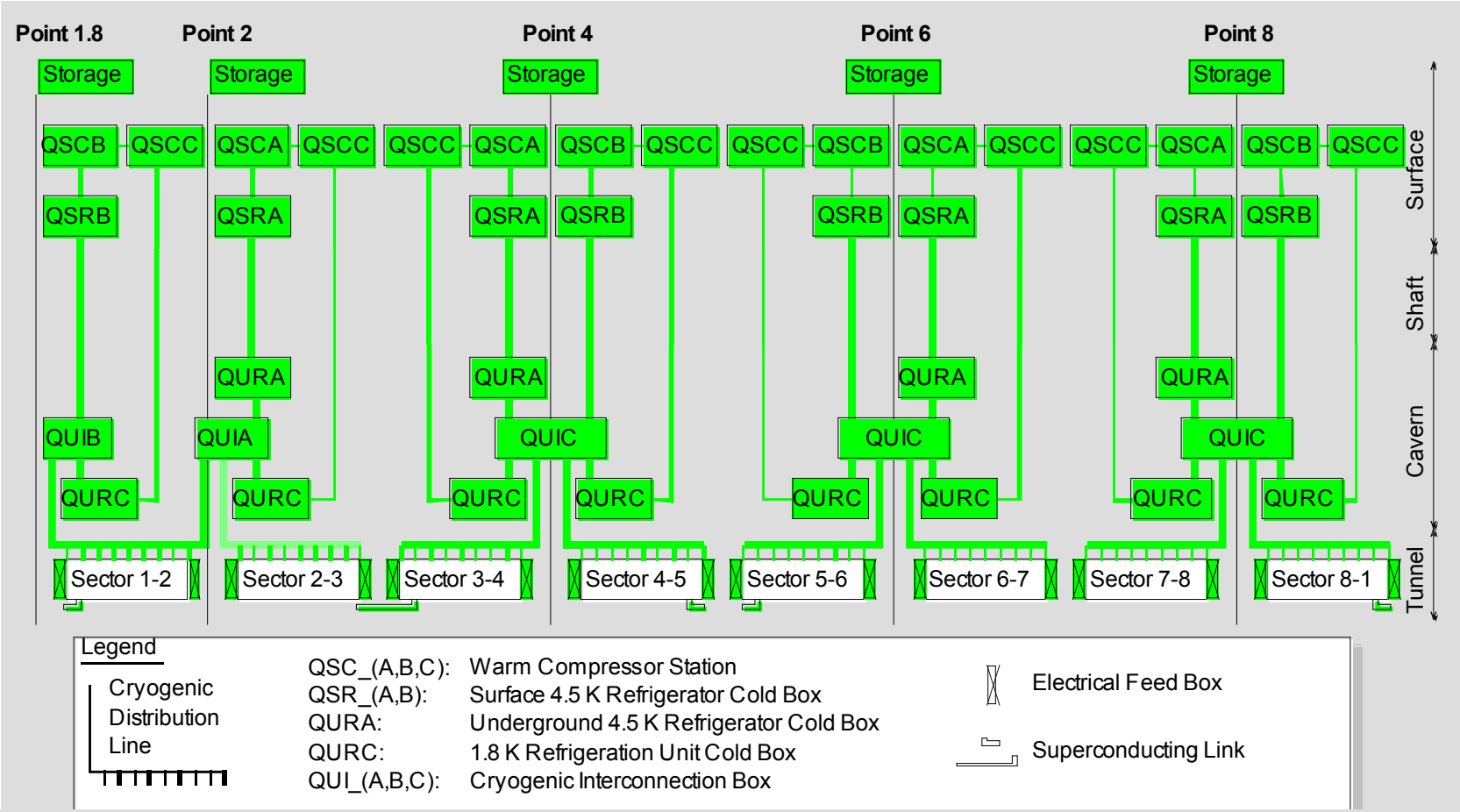
LHC Cryogenics

Content

- Introduction and context
- Analysis of failures and downtime:
  - Operation failures: Availablity
  - Breakdown: Reliability
- Summary

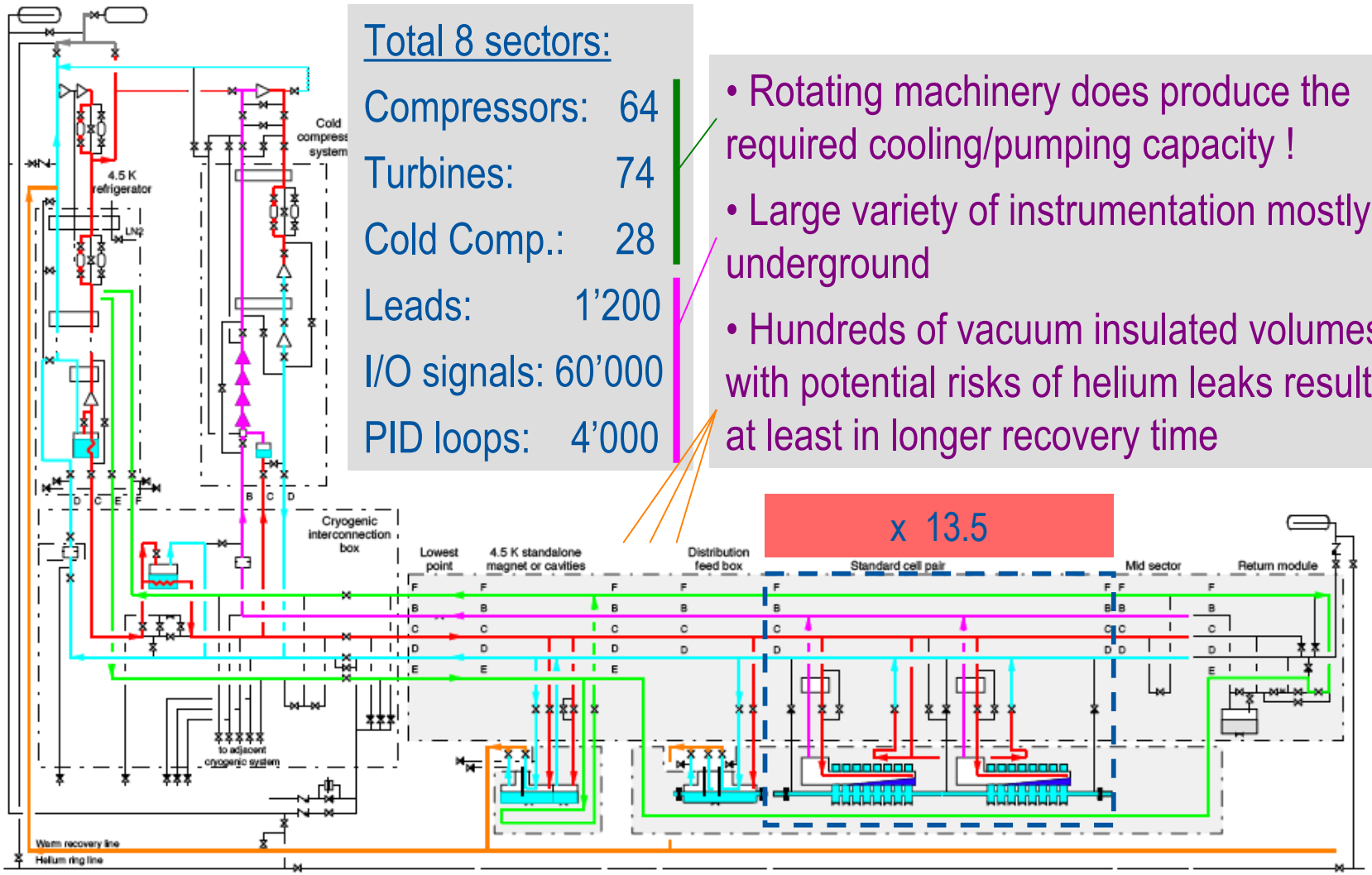
LHC Cryogenics architecture



Large variety of configuration, with provision to use 1 cryoplant on 2 sectors for helium management and up to “low intensity” physics

(Flexibility in case of failure of a component, already used before LS1)

1/8e of LHC: production-distribution-magnets



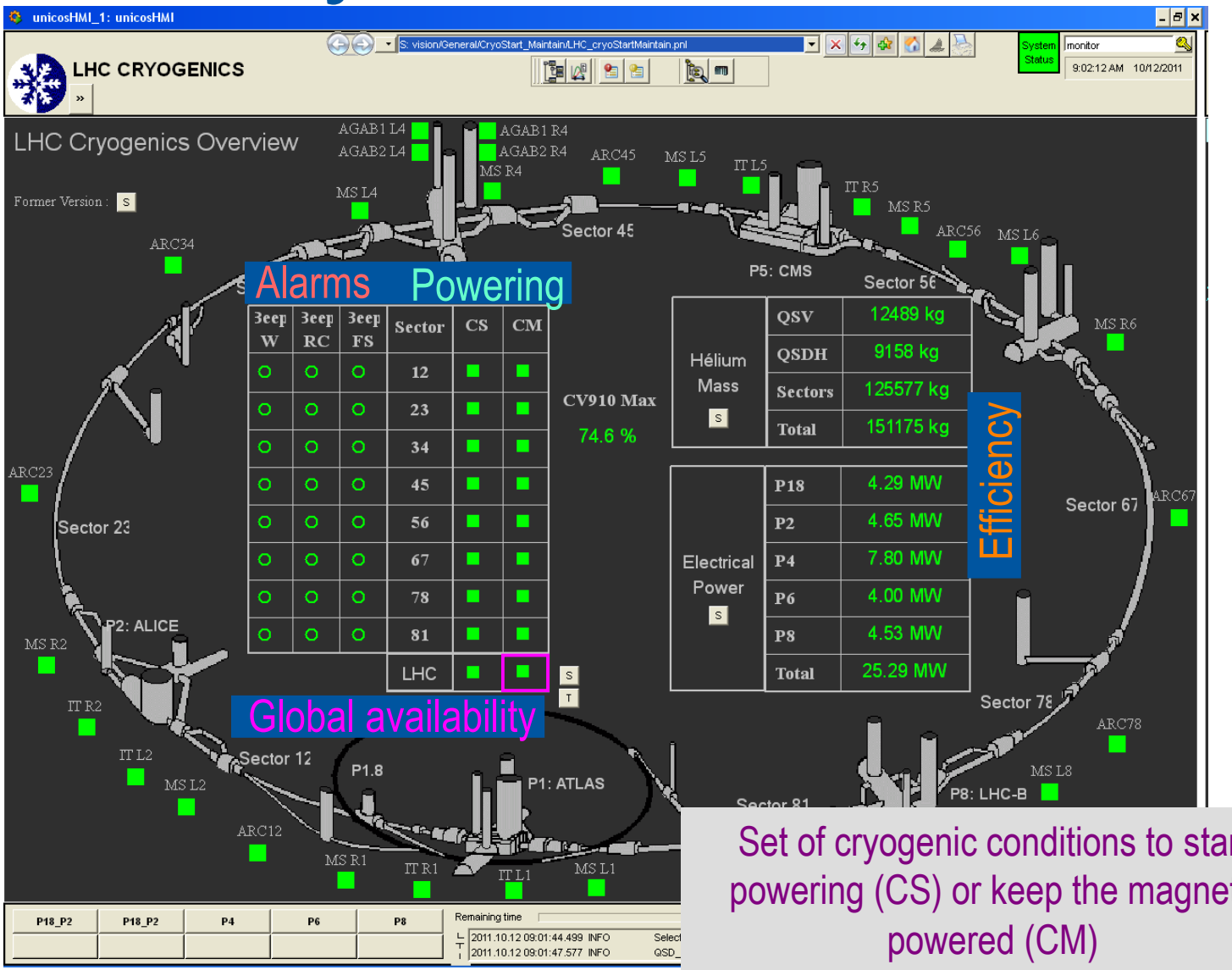
Total 8 sectors:

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

- Rotating machinery does produce the required cooling/pumping capacity !
- Large variety of instrumentation mostly underground
- Hundreds of vacuum insulated volumes, with potential risks of helium leaks resulting at least in longer recovery time

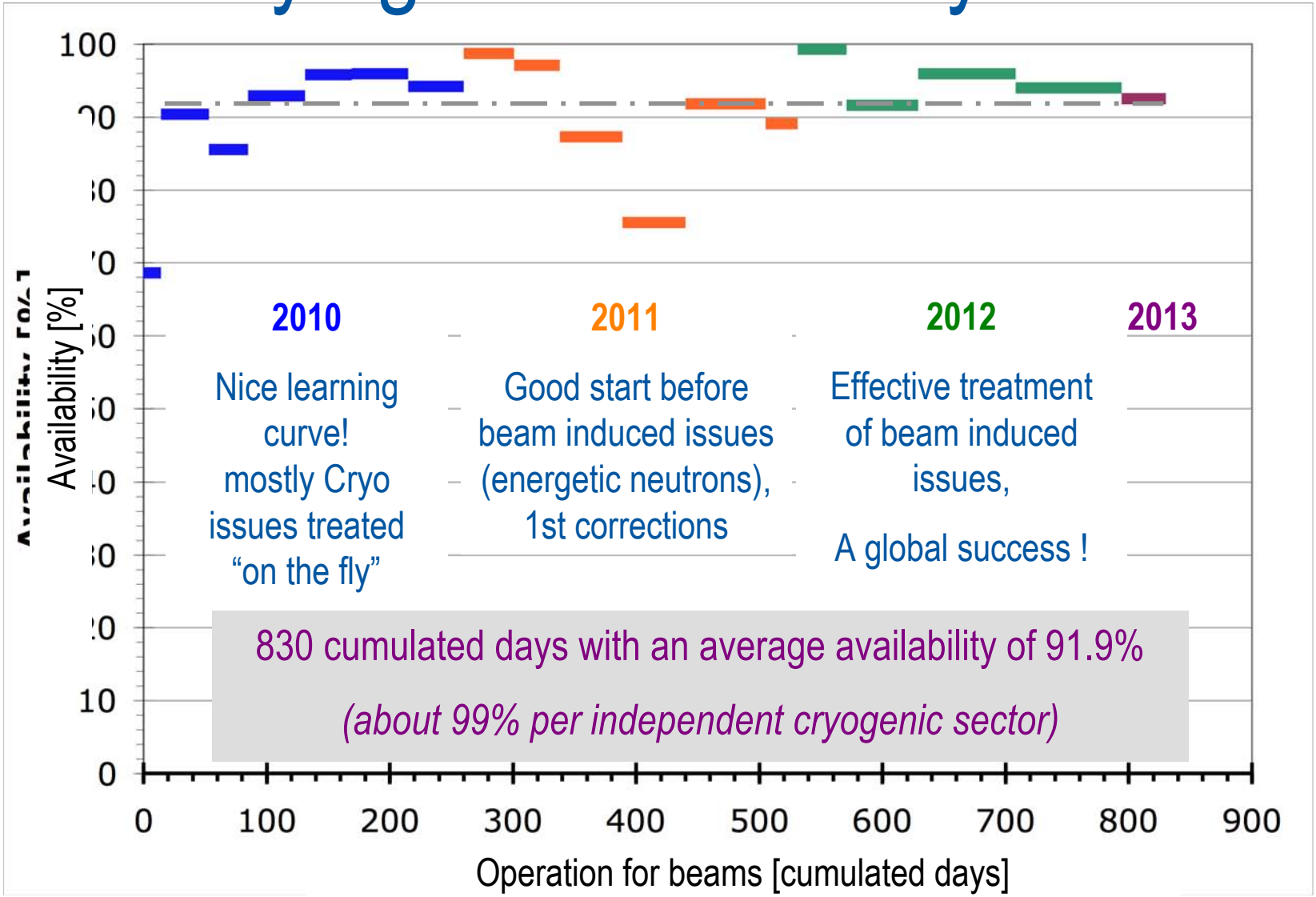
x 13.5

Availability, criteria to be used



Set of cryogenic conditions to start powering (CS) or keep the magnets powered (CM)

LHC Cryo global availability



Sensitivity to post-LS1 beams

LS1: Long shut-down No1

- Higher energy:
  - x 4 heat load (Ri2 with I x 2), towards nominal
- Higher luminosity:
  - Local effect expected (inner triplets focussing quadrupoles)
- Lower bunch spacing (25ns):
  - Identified valves changed not to limit performance
  - Significant effect expected during scrubbing runs to cure e- clouds effects
  - No effect expected during “physics” operation
- Expected effect: periodic capacity change
  - Cabled signal “ramp” expected to help tuning cryo-controls

  => We should be able to handle the corresponding transients

Less capacity margin (installed-required) => sensitivity to previous “near-miss”

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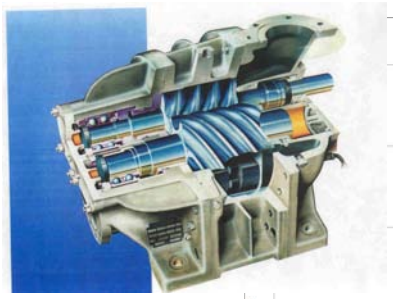
Screw Compressors + motors

Availability

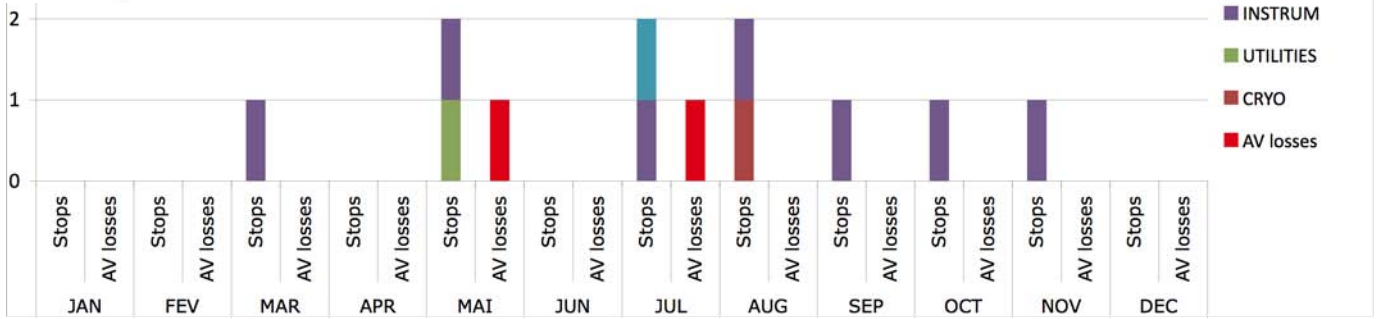


2/10

Instrumentation:

7/10

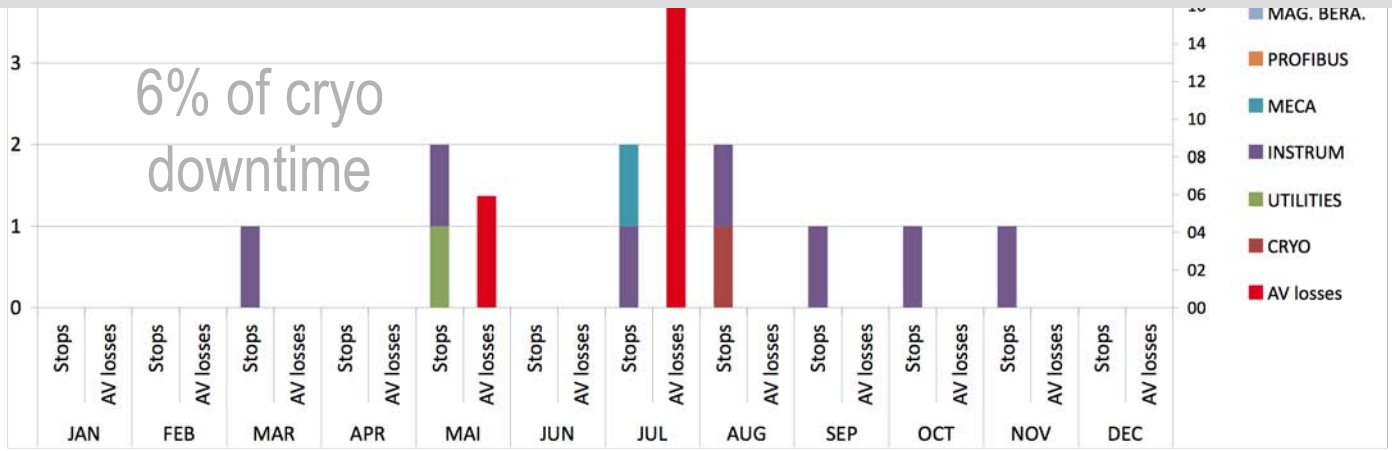
Number of stops



With less capacity margin, some compressors failures would induce downtime

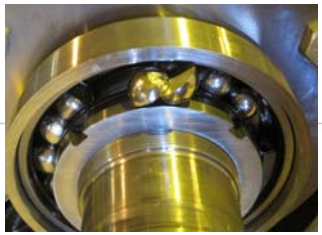
6% of cryo downtime

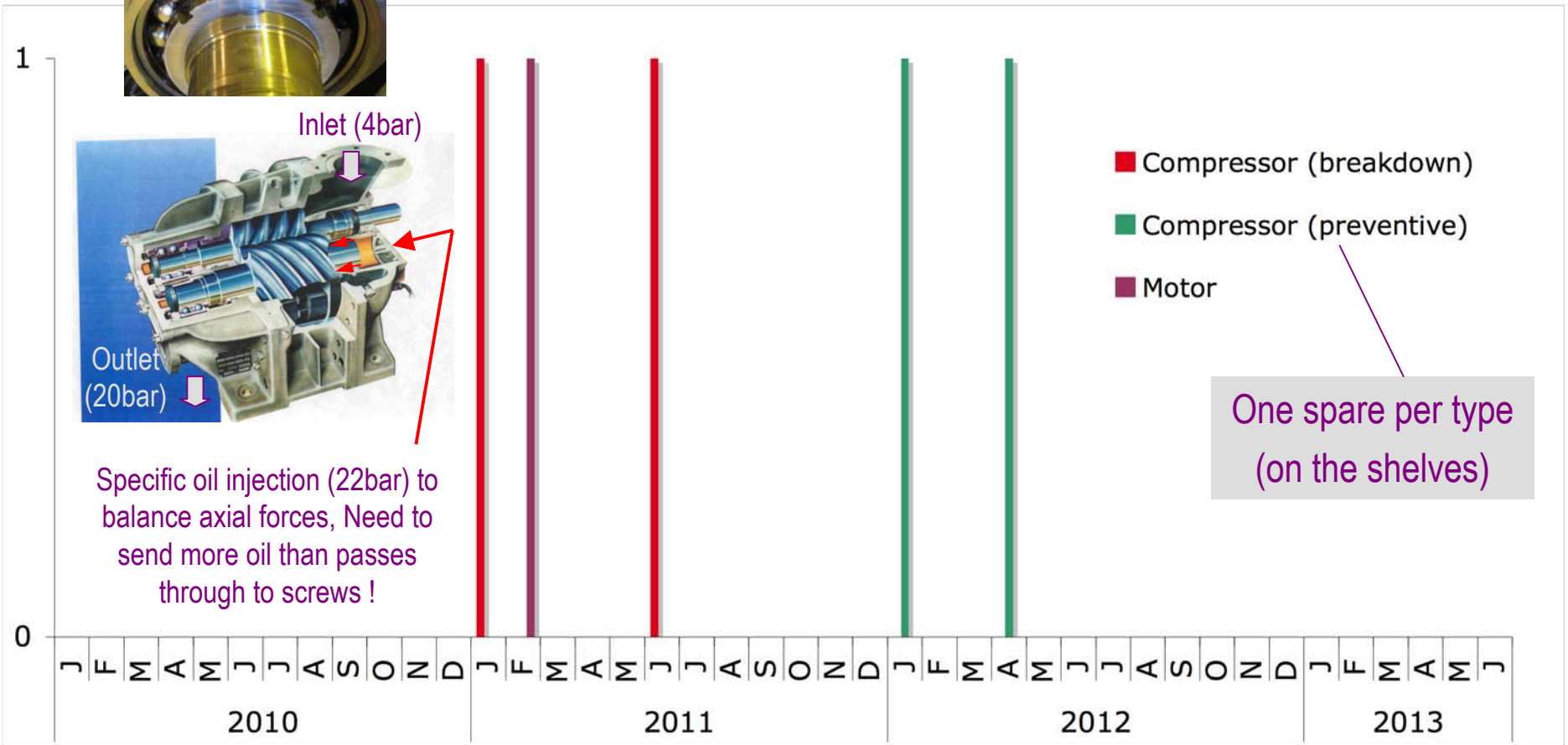
Time to recover [hr]



Screw Compressors + motors

Reliability

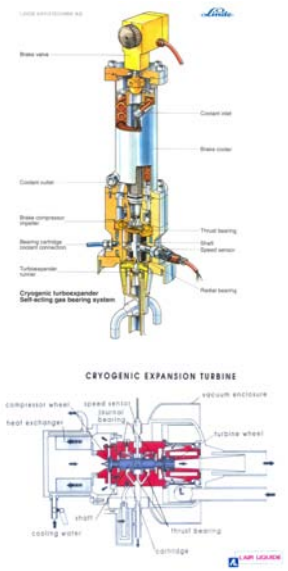


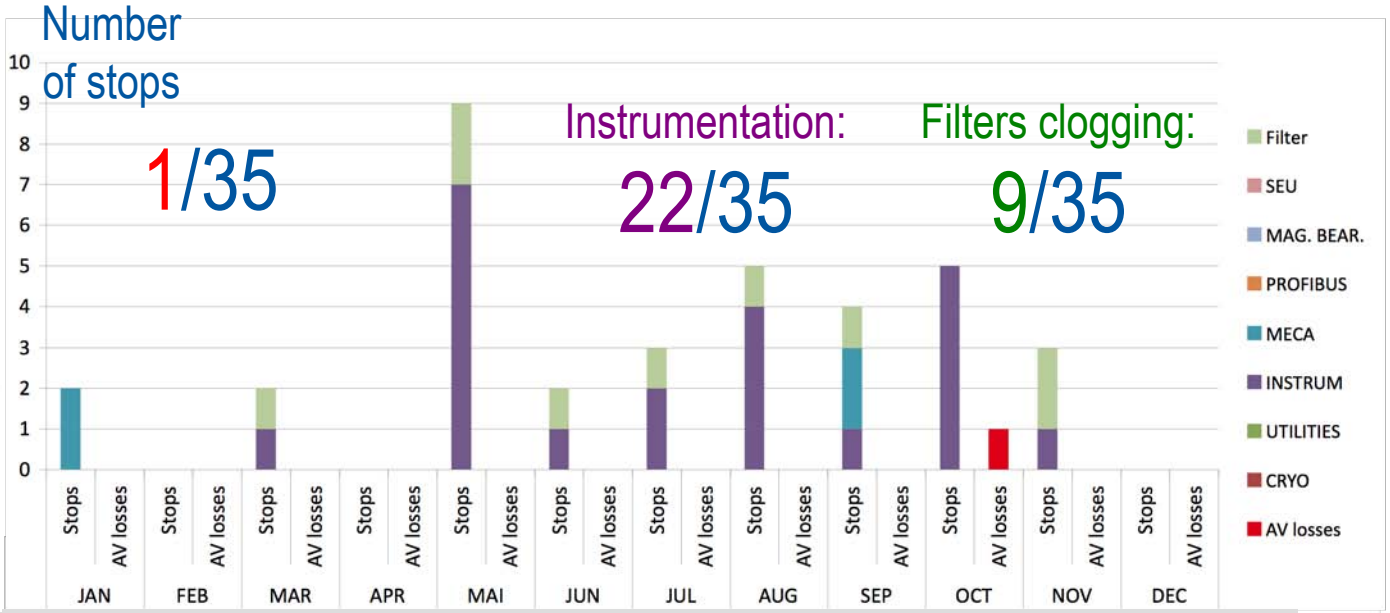


No issues since, and findings during major overhaul under investigations (no major issues so far)

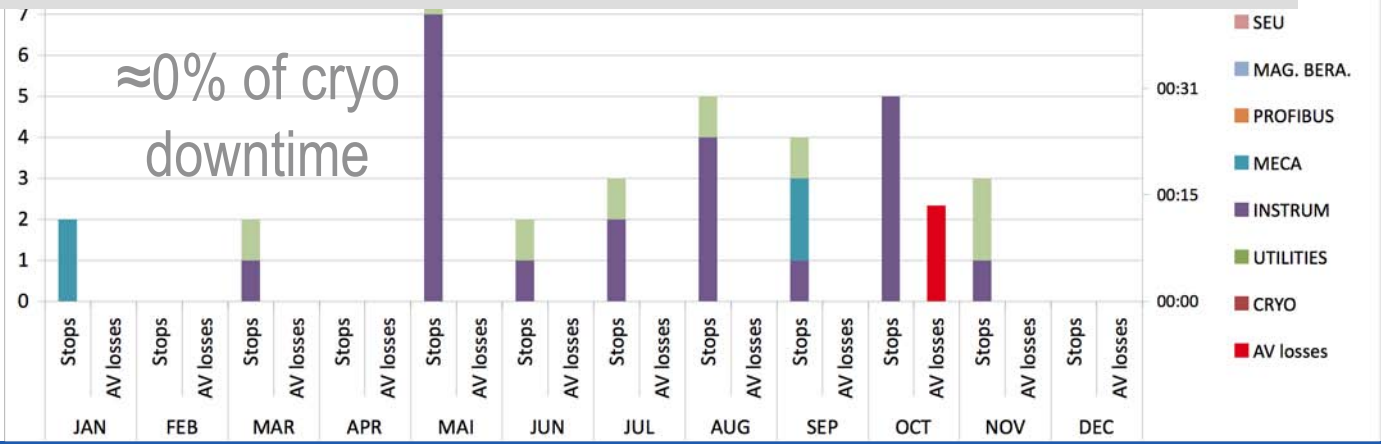
Turbines

Availability





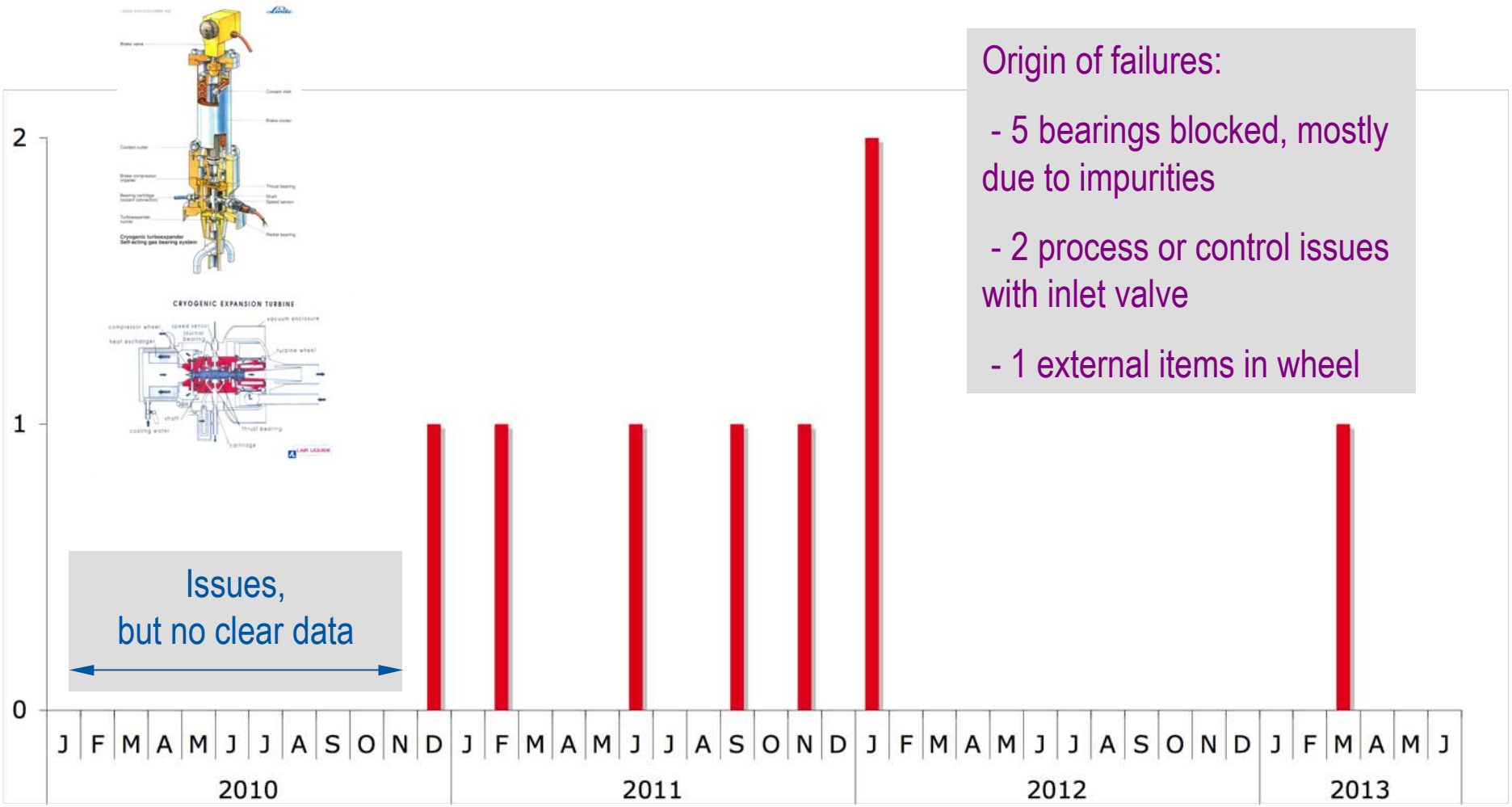
Low temperature turbines issues will become more visible



Time to recover [hr]

Turbines, breakdowns

Reliability

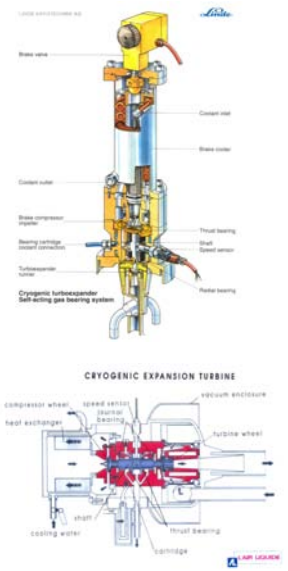


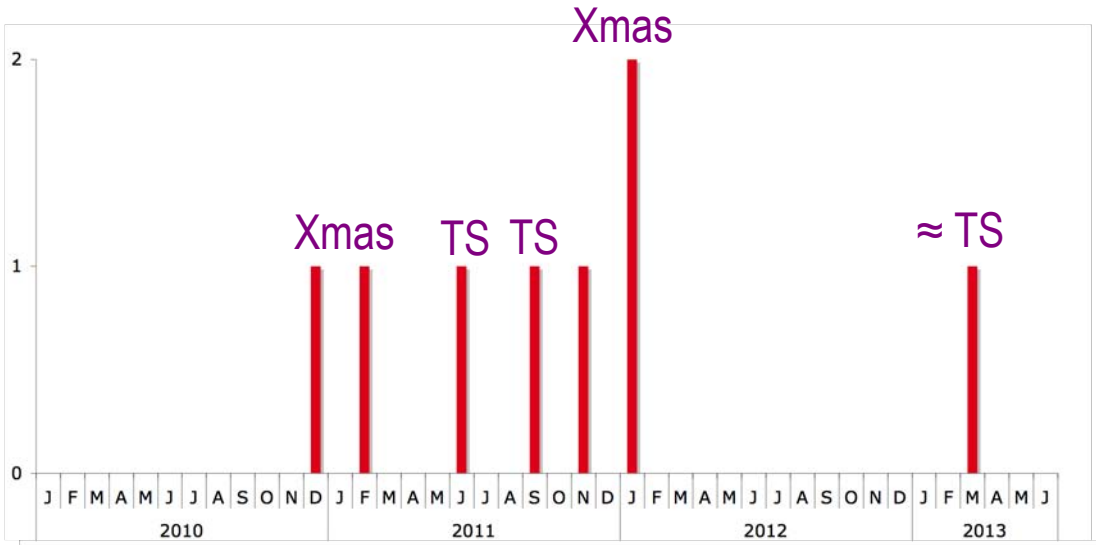
Origin of failures:

- 5 bearings blocked, mostly due to impurities
- 2 process or control issues with inlet valve
- 1 external items in wheel

Turbines, breakdowns

Reliability

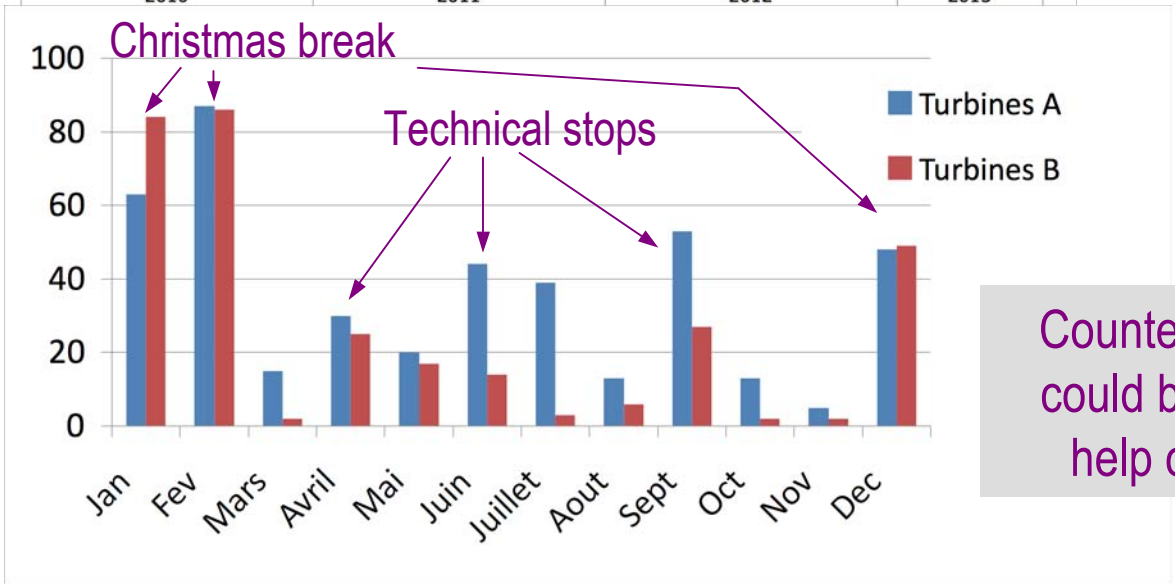




Clear effect of the transients and massive start/stop of turbines on the breakdown statistics

(could be expected, but demonstrated here!)

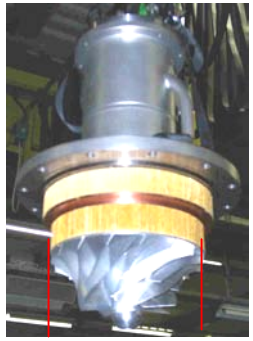
Number of start / stops



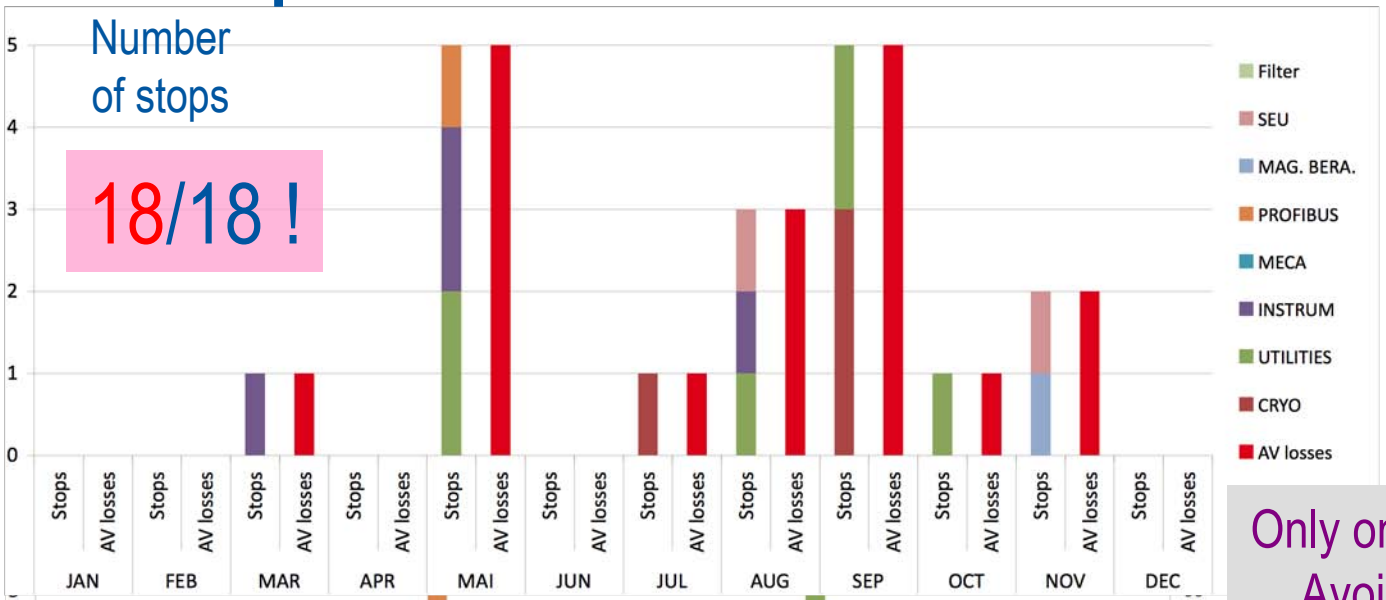
Counters and warnings could be established to help operation team

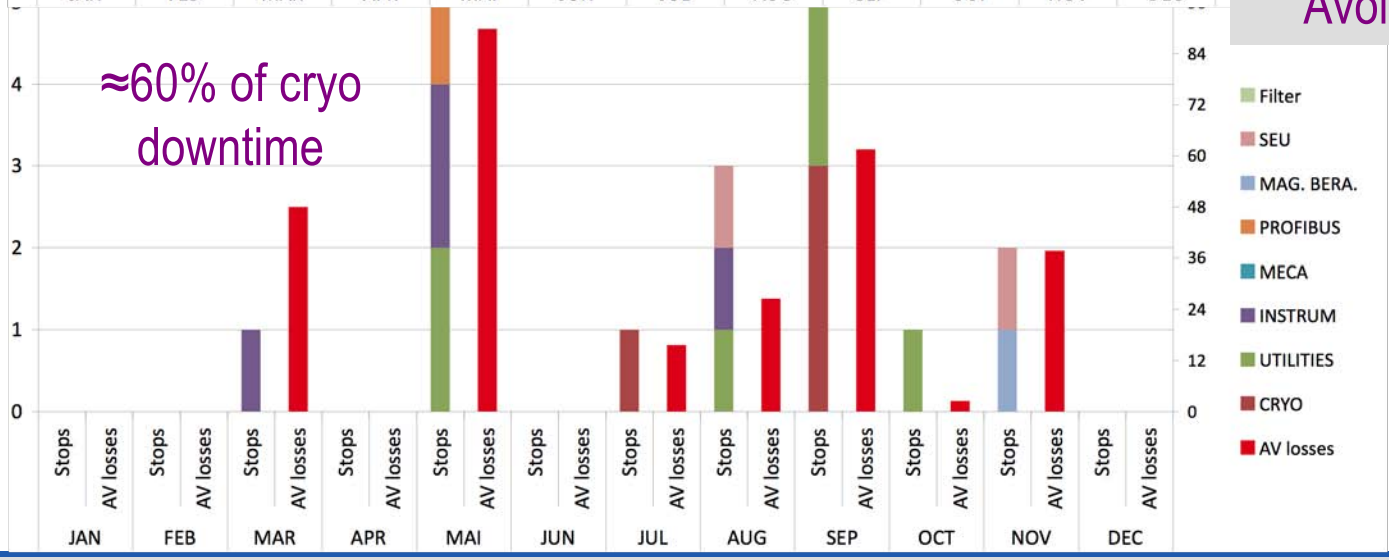
Cold Compressors

Availability



Diam: 250mm



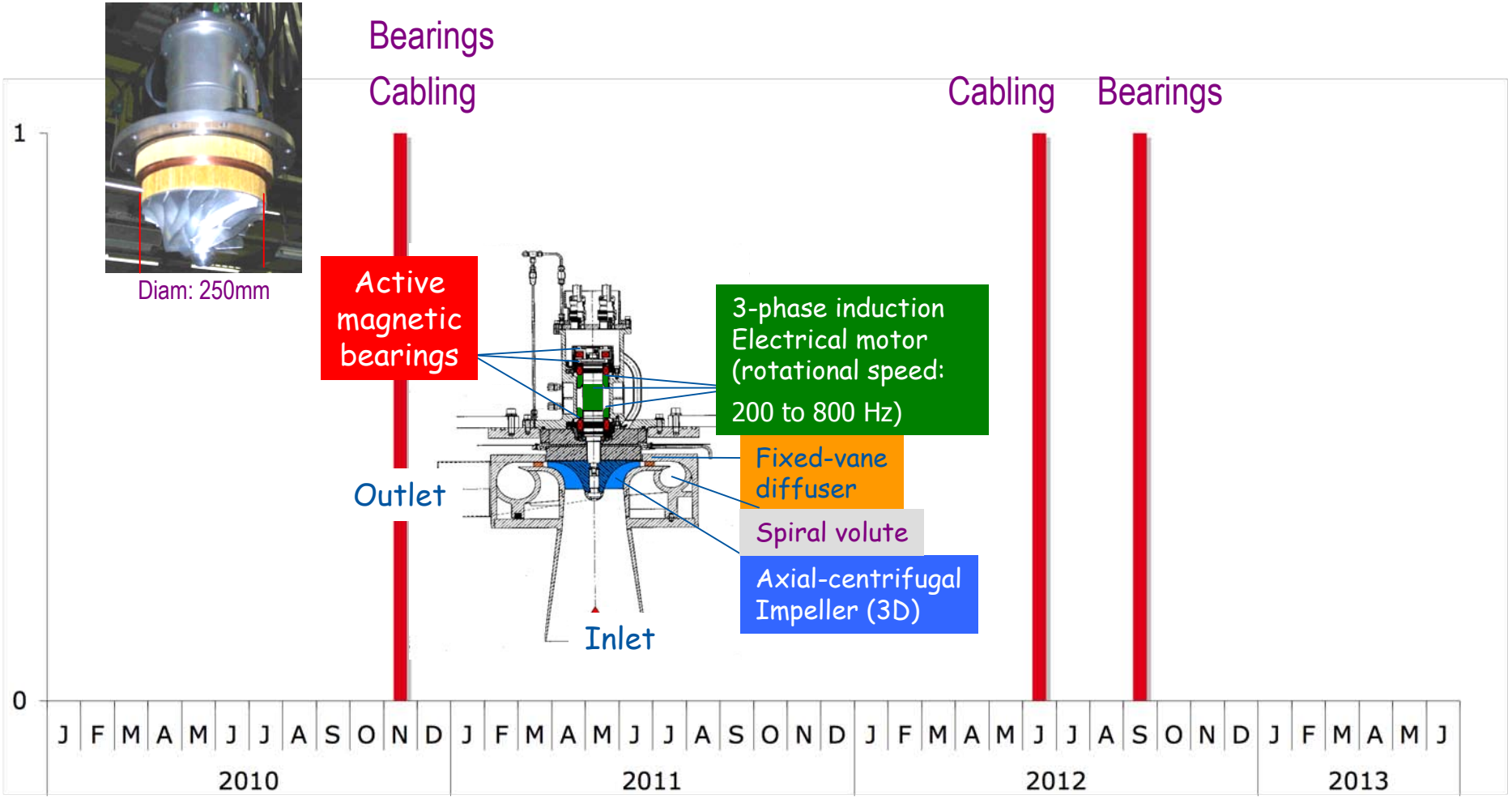


Only one way out: Avoid stops !

Time to recover [hr]

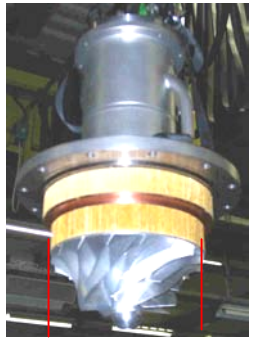
Multiple efforts to help reducing cold-compressors related failures (on-going process): Process controls algorythms, Relocation of sensitive electronics (P4, P8)

Cold Compressors



Better control and possible anticipation for bearings required (periodic bearings checks)

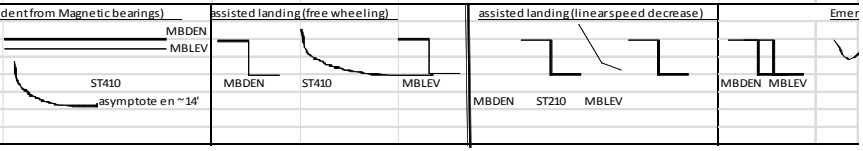
Cold Compressors



Diam: 250mm

After each stop of cold compressors, an analysis of the digital input and speed signal is performed and logged with categories:

- smooth and nominal stop
- assisted landing
- emergency landing on touch down bearings



No	Machines	Date	Error categories: Independant from PMA (Paliers Mag. Actifs) sub-category	doubt	link	Overload PMA -Assisted landing sub-category	doubt	link	Ha sub-category	doubt
	QURCA_P	08_02_12				linear		CC208022012assisted lineard		
	QURCA_P4	13_02_12								
2	QURCA_P8	08_03_12	Independant		CC408032012independant					
3	QURCB_P8	04_05_12	Independant		CC404052012independant					
4	QURCA_P8	05_05_12	Independant		CC405052012independant					
5	QURCA_P8	08_05_12				strange		CC208052012assisted strange		
6	QURCA_P8	09_05_12							Hardware	
7	QURCB_P8	26_05_12				linear		CC326052012assisted linear		
8	QURCB_P4	08_07_12	Independant		CC4_08072012_independant					
9	QURCB_P4	05_08_12							Hardware	
10	QURCB_P4	27_08_12							Hardware	
11	QURCB_P8	21_09_12							Hardware	
12	QURCB_P8	21_09_12	Independant		CC421092012independant					
13	QURCB_P8	22_09_12	Independant		CC422092012independant					
14	QURCA_P4	123_11_12							Hardware	
15										
16										
17										
18										
52										
53										

Periodic tests to evaluate the status of the bearings have been started together with the manufacturers, with plans to use the outcome for conditional maintenance

Summary

- The availability and reliability have been improved during run 1 with results fully compatible with LHC physics program.
  However, increased beam performance will require continued efforts!

- For each type of rotating machinery, an analysis of operation failures was performed, with identification of possible improvements to be done, mostly instrumentation and filters, plus specificities for cold compressors

- For each type of rotating machinery, an analysis of breakdown was performed, with identification of possible additional criteria to be looked at, mostly a start counter for turbines and stop analysis for cold compressors

- Efforts in logging data and events with appropriate signification should be reinforced, both from operation (e-logbook with dedicated sheet including origin of failure) and maintenance (methods, breakdown reports and analysis)

Thanks for your attention !

Selection of typical LHC cryogenic hardware

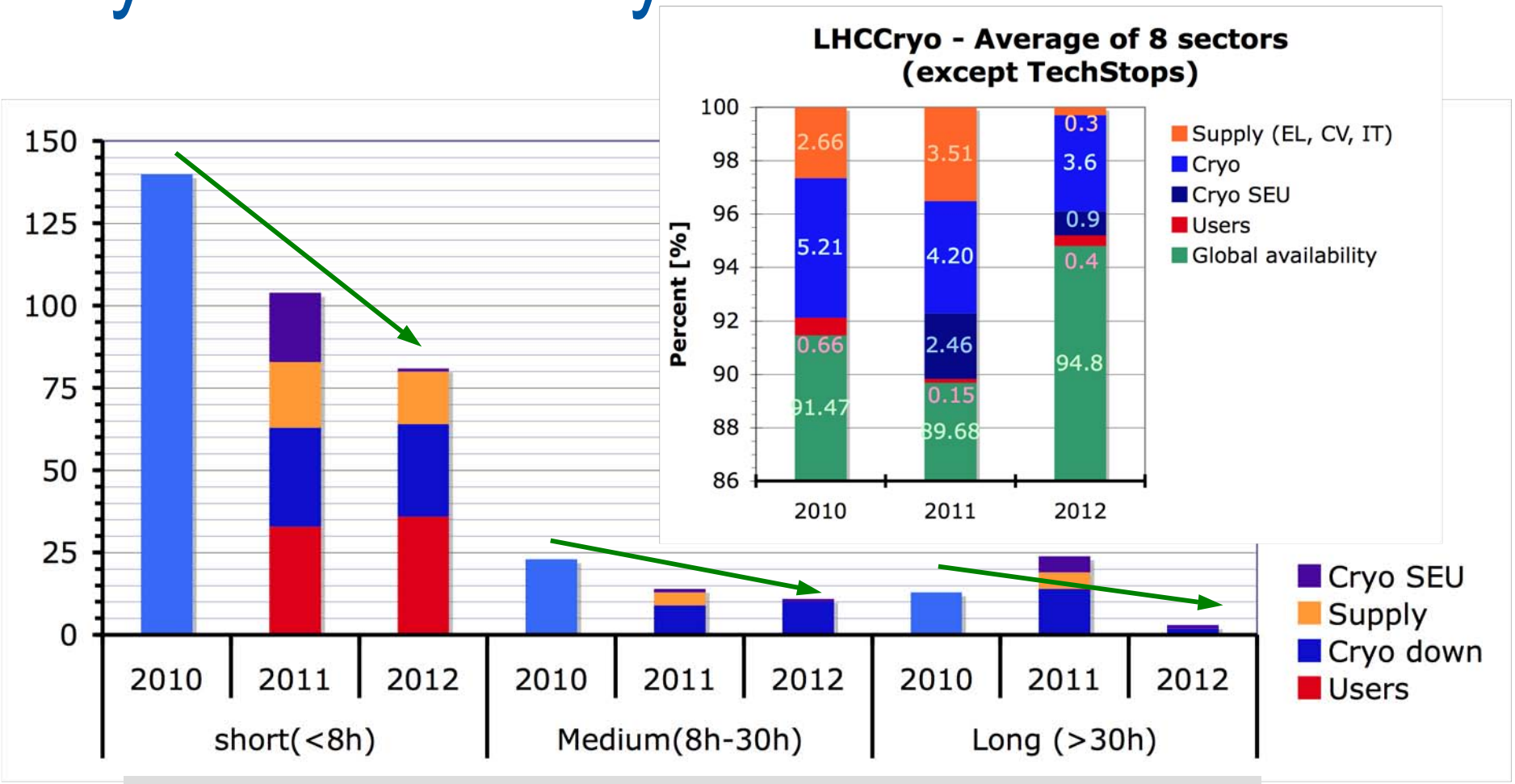
33 kW @ 50 K to 75 K - 23 kW @ 4.6 K to 20 K - 41 g/s liquefaction

4.2 MW

Diam: 250mm

48 boxes

Systematic analysis of downtime



From the books:

Immediate effect of (good!) practice

Annoying if frequent, to be kept low with moderate efforts

Serious cases requiring specific monitoring and significant efforts

Criticality Analysis

- Summer student: Jimmy MARTIN
  - Functional analysis
  - Critical analysis

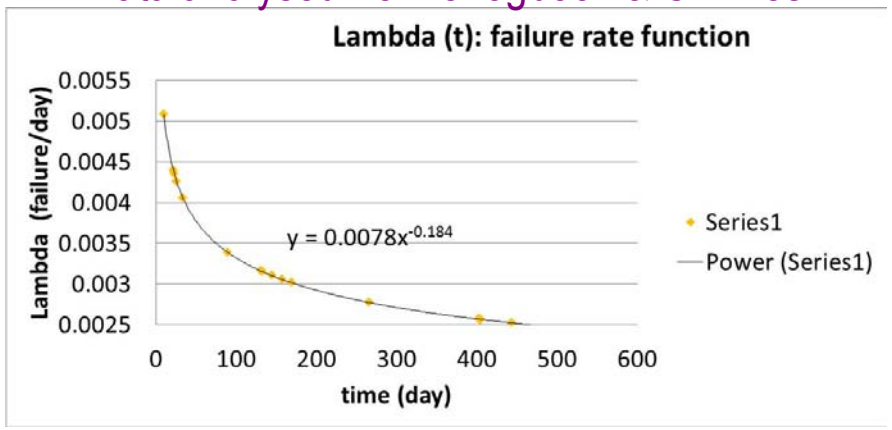
Occurence

Failure rate	N < 10	10 ? N < 20	20 ? N < 30	30 ? N
Decrease				
Stable				
Moderate increase				
Serious increase				

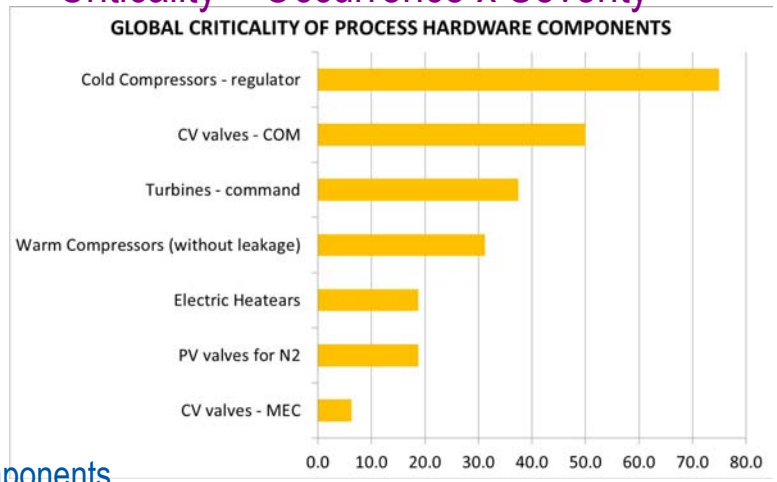
Severity

	T < 8h or CM=1	8h ? T < 18h	18h ? T
CM=0' <2			
2 ? 'CM=0' < 4			
4 ? 'CM=0'			

Data analysed from e-logbook & CM files



Criticality = Occurrence x Severity

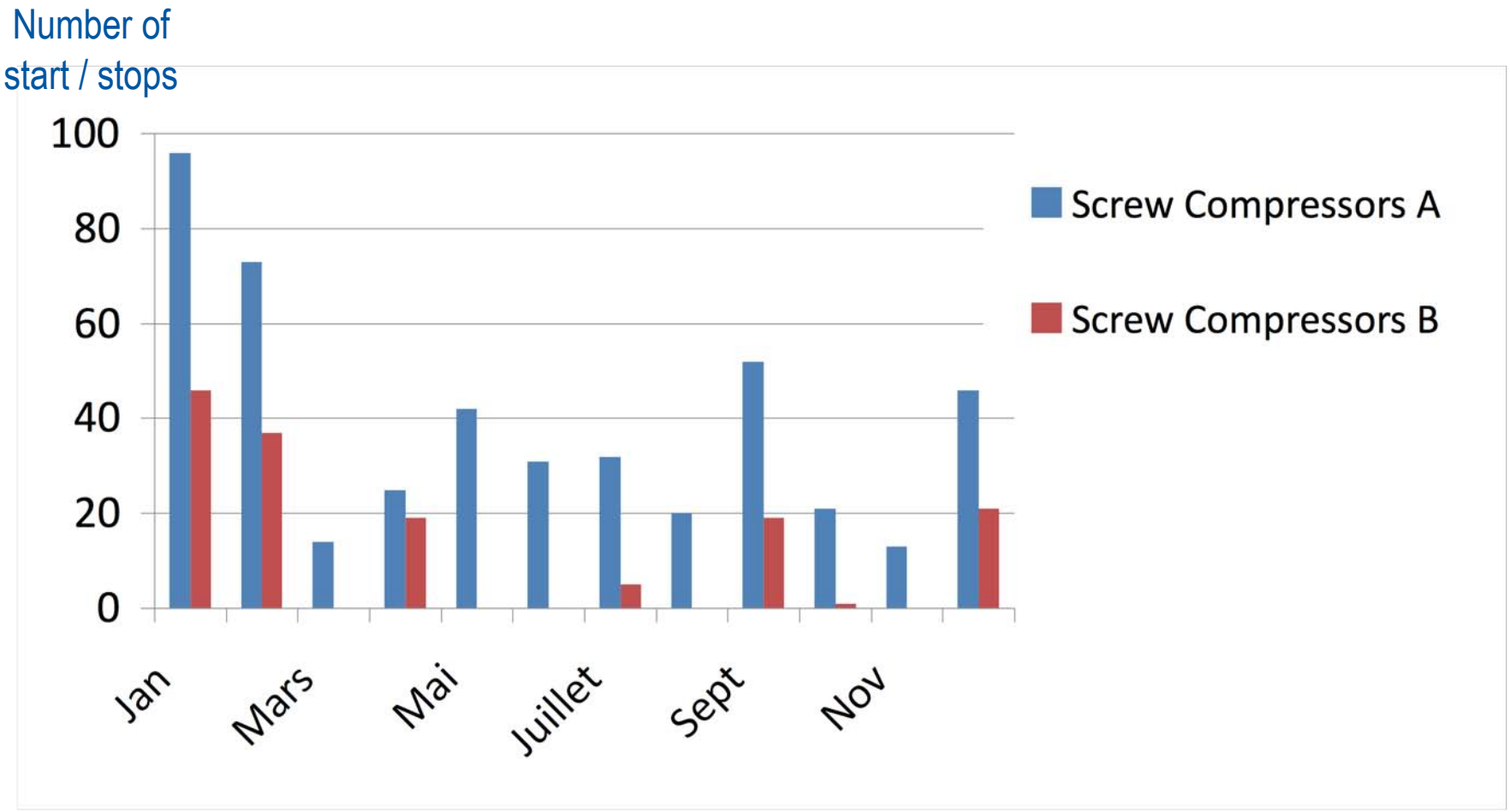


- Being continued:
  - Analysis by individual failure mode for few significant components
  - Cryo-Maintain loss table to be detailed down to component failure (mode)

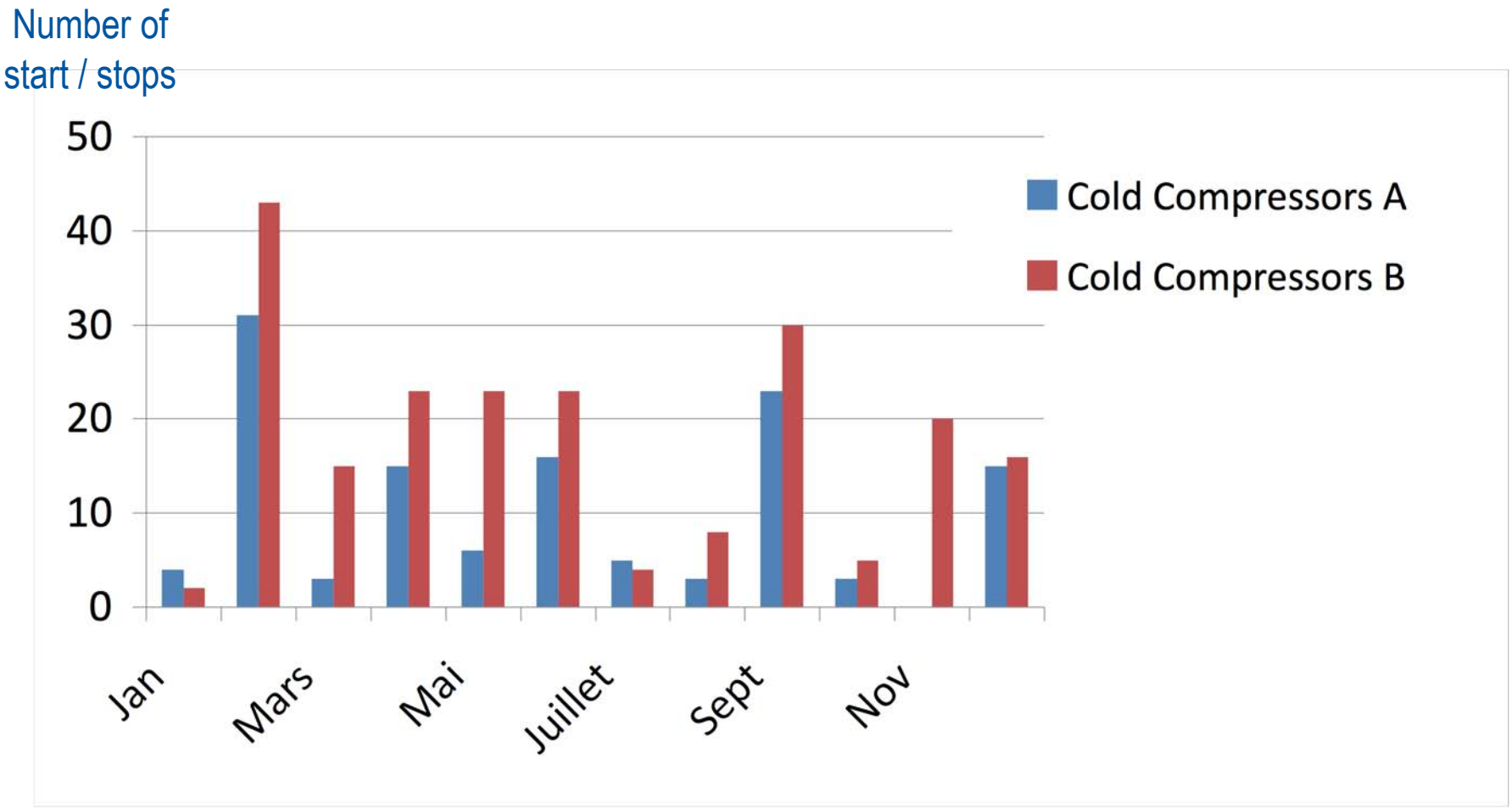
A nice try which confirmed the observed tendency, but stored data not adapted for such a treatment

Useful anyhow to get familiar with the field, with required tools improvement identified

Screw Compressors + motors



Cold Compressors



Turbines

Maximum monthly number of start for a turbine