AVAILABILITY AND RELIABILITY OF CERN CRYOPLANTS

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the Cryogenics for Accelerator Group

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Outline

- Introduction
- Cryogenic systems layout
  - LHC Test String, LEP, LHC cryoplants
- Criticality analysis, maintenance and machine schedule
- Availability of cryoplants at CERN:
  - R&D: LHC Test String (tunnel cryogenics) performances
  - Operation: LEP cryogenic system performances
  - Operation of future machines: LHC refrigerators performances
- Present commissioning status of the cryogenic system of the LHC machine
- Overall availabilities and conclusions

EVENT	TIME
LEP approved (cryo)	1989
LEP construction and installation of the cryogenic plants	1992 – 1993
LEP commissioning of the cryogenic plants	1993-1995
LEP start of operation of cryogenic plants	1993
LEP upgrade	1998
LEP operation at full capacity	1999 - 2000
LHC approved	1994
LHC Test String 1 commissioning (R&D and prototype validation)	1994-1999
LHC Test String 2 commissioning (R&D and series equipement validation)	2001-2003
Cryoplants construction and installation (including distribution)	2001-2006
Cryoplants commissioning	2002-2006
LHC sectors test	2006-2007
LHC beam test (1 octant)	End 2006
LHC operation with beam	End 2007

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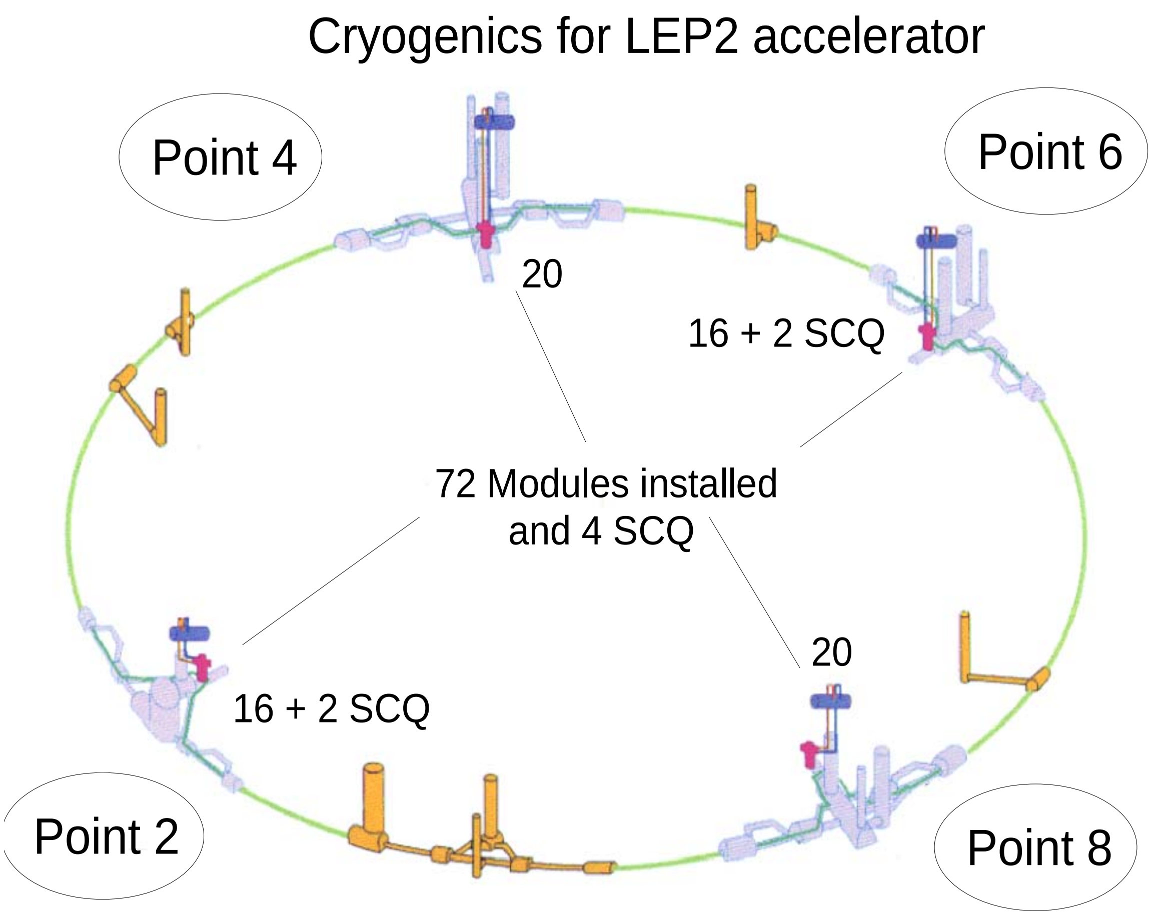
LEP cryogenic system layout

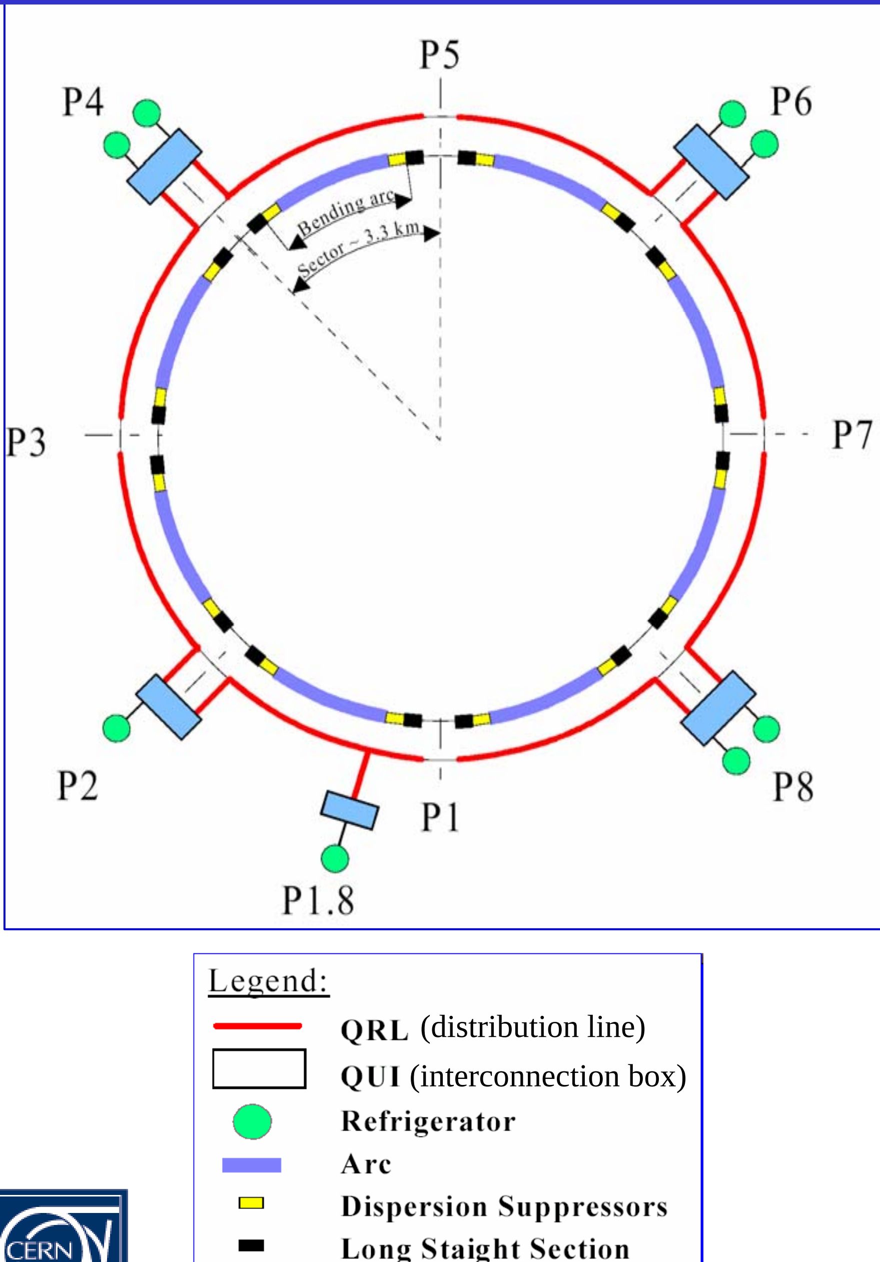


- LEP operation since 1989
- Installation of SC cavity modules and cryoplants from 1992
- Four 12/18 kW @ 4.5 K:

Storage tanks, compressor station, upper cold box (300-20 K)

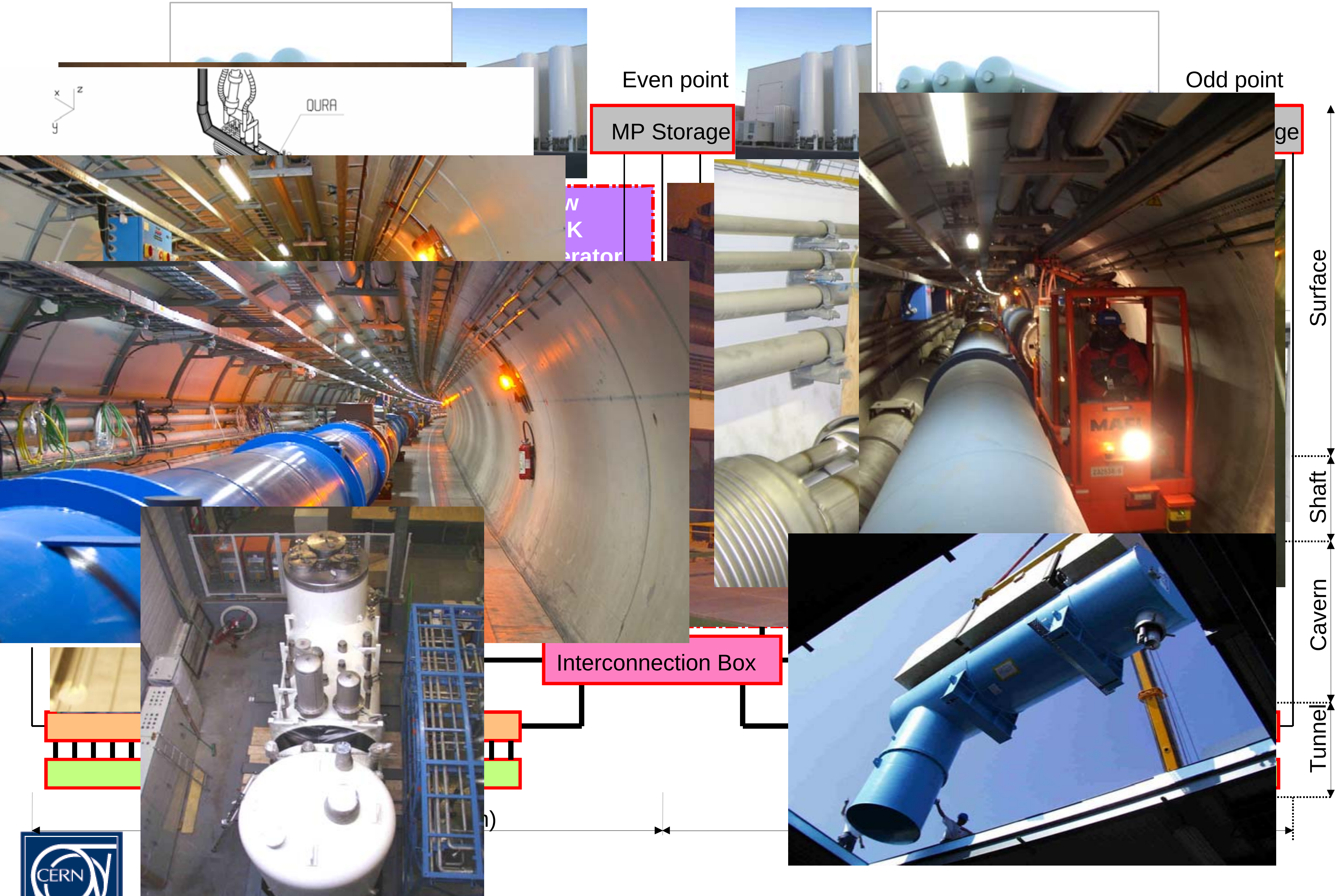
Lower cold box and distribution lines (200-250 m)

LHC cryogenic system layout 1/2

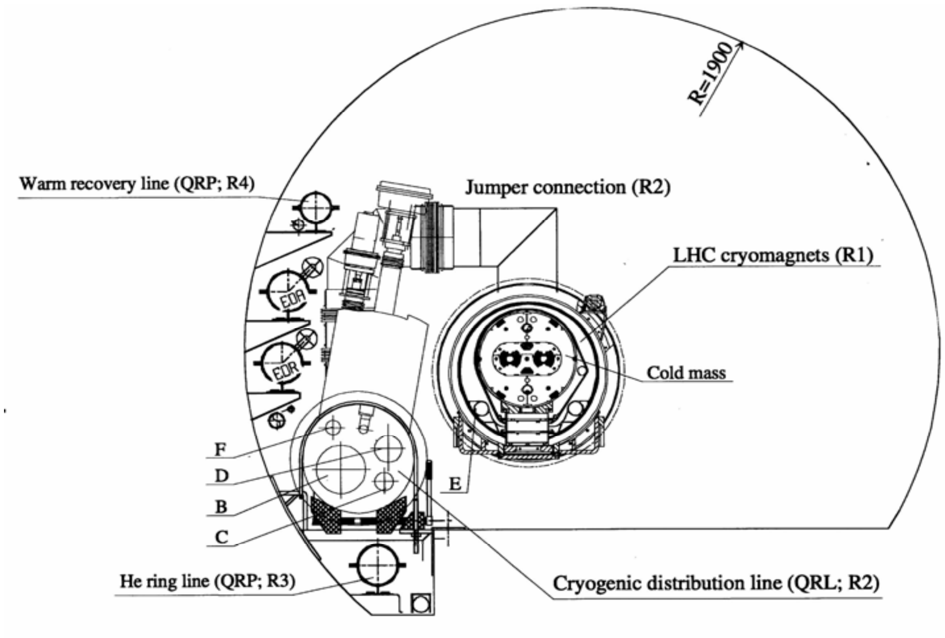


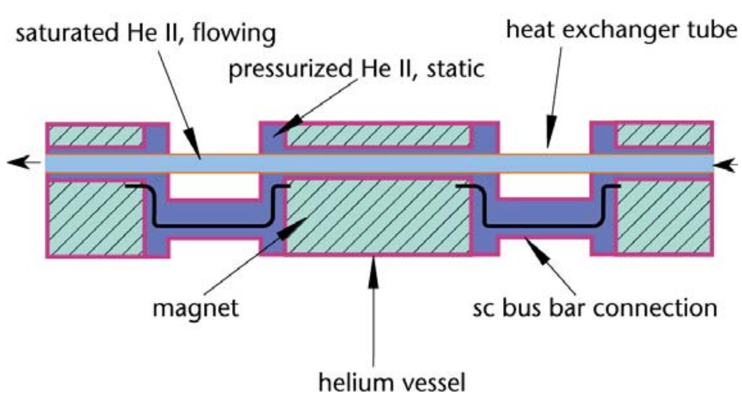
- 5 cryogenic islands
- 8 refrigerators
  - 2 at P4, 6 and 8,
  - 1 at P2
  - 1 at P1.8
- 1 refrigerator serves 1 sector (18 kW @ 4.5 K, 600 kW precooler)
- possibility to couple two refrigerators via the interconnection box → 2 refrigerators for 1 sector

LHC cryogenic system layout 2/2



Regular arc magnet test string and electrical feed box
Cooling with a 6 kW refrigerator (ex-LEP)
Pumping with warm and cold compressor system





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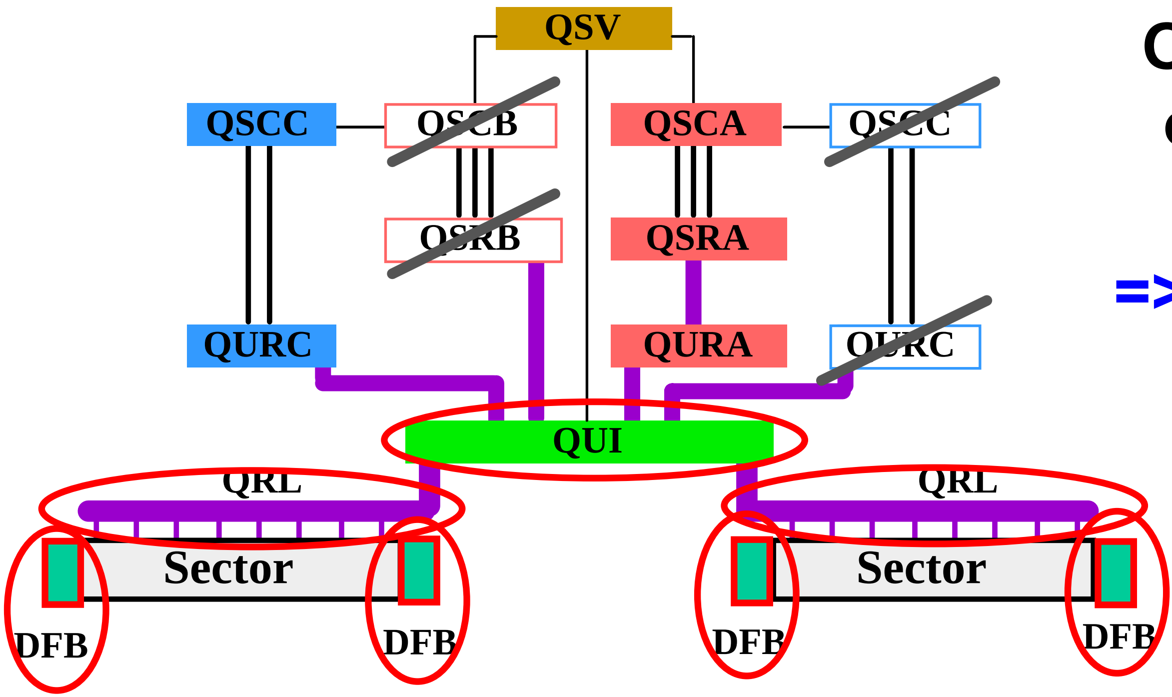
LHC system criticality analysis: possible failures

Failures: "major or first order failures" –

"something that breaks or something that does not work as expected"

- Systems failures (refrigerator 4.5 K and 1.8 K, cryogenic interconnection box, cryogenic distribution line, electrical distribution box)
- Higher heat loads
- Missing or failing instrumentation
- Impurities
- Loss of helium

Unlikely to occur during life-cycle, but possible!



One 4.5K Ref. or one 1.8K unit out of order:

=>Low intensity OK

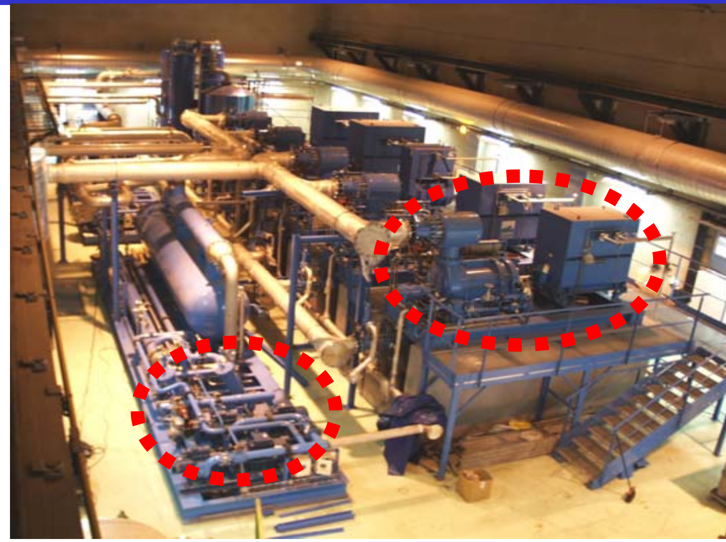
Transition:

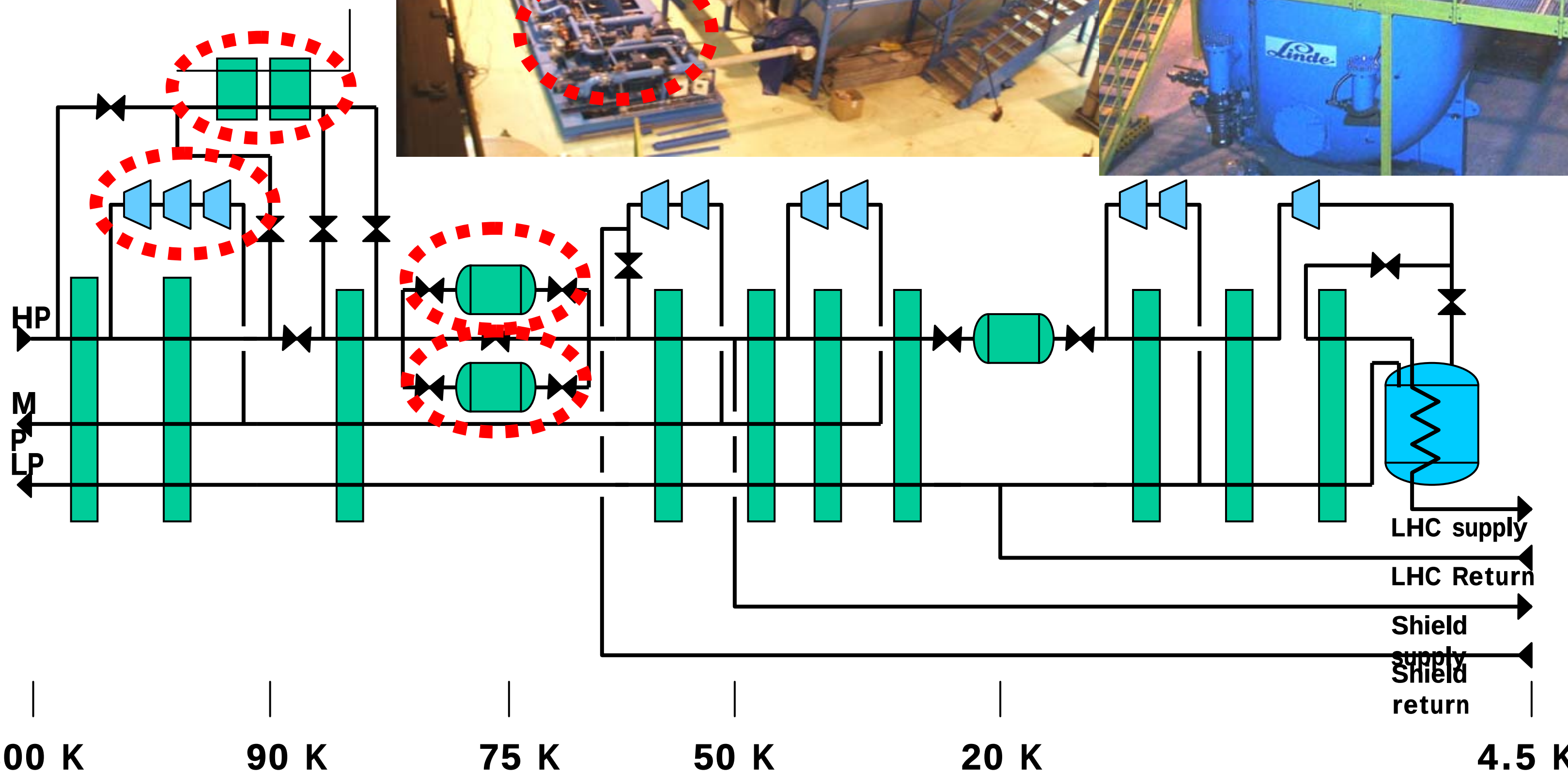
≈ 12 hours

Common parts (QUI-QRL-DFB), loss of vacuum :

=> Total stop of the machine

4.5 K Refrigerators





Failure of a rotating part

- Turbines: no spares at the moment, 10 h delay if spare available, otherwise degraded mode allows continuation of tests -> LN2 precooling
- Cold compressors: spares available, 10 hours delay, no degraded mode allowed
- Warm compressors: can use spare compressors capacity otherwise major SD or use of adjacent refrigerator
- Oil pumps -> redundancy

- From the cooling capacity point of view such failures would allow a degraded mode (spares, redundancy, adjacent refrigerator) but the operational constraints and the recovery time will increase

- Possible cause :
  - Degradation of insulation vacuum (leaks)
  - Loss of insulation vacuum
  - Faulty or badly installed components

- The cryogenic system should have sufficient spare capacity to cope with degraded mode or low intensity beam operation (until SD for intervention) apart of the loss of insulation vacuum that would provoke additional failures (e.g. loss of helium)

Missing or failing instrumentation (control sensors and actuators)

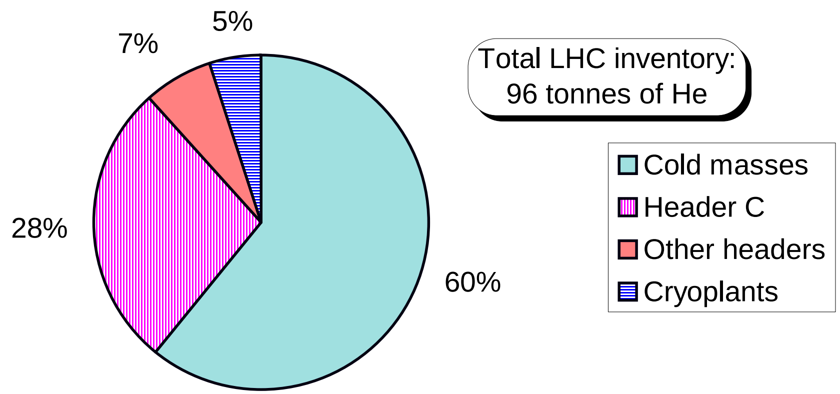
- Magnets temperature:
  - Redundancy
  - Other control options (opening valve characteristics, copy valve position of adjacent cells)
- Current leads temperature:
  - Redundancy
  - Other control options (valve characteristics against current)
- Level indicators:
  - Redundancy except for some standalone magnets (D2, D3)
  - Repair
- Valves:
  - In situ exchange (intervention of up to 1 week depending on valve position)

Impurities

Water	=>	Dryers up to 50 ppm(v)
Air	=>	Switchable 80 K adsorbers
H_2	=>	Single 20 K adsorber
Solid	=>	Cryo Interconnection boxes filters

- There should be sufficient capacity to filter gaseous impurities, but …
- Solid impurities would be a problem as they will clog the interconnection box filter (line D) provoking a stop of the cooling flow
  - It would mainly happen during the cooldown and the first few quenches
  - It requires few days to replace or clean the filter and reach again nominal conditions

- **Major losses due to long utilities stop (several hours):**
  - **Safety implications depending on location of losses (tunnel)**
  - **Delay in recovery the inventory from adjacent storage points (1 day) or market (few weeks) if helium not sufficient**



Utilities stops

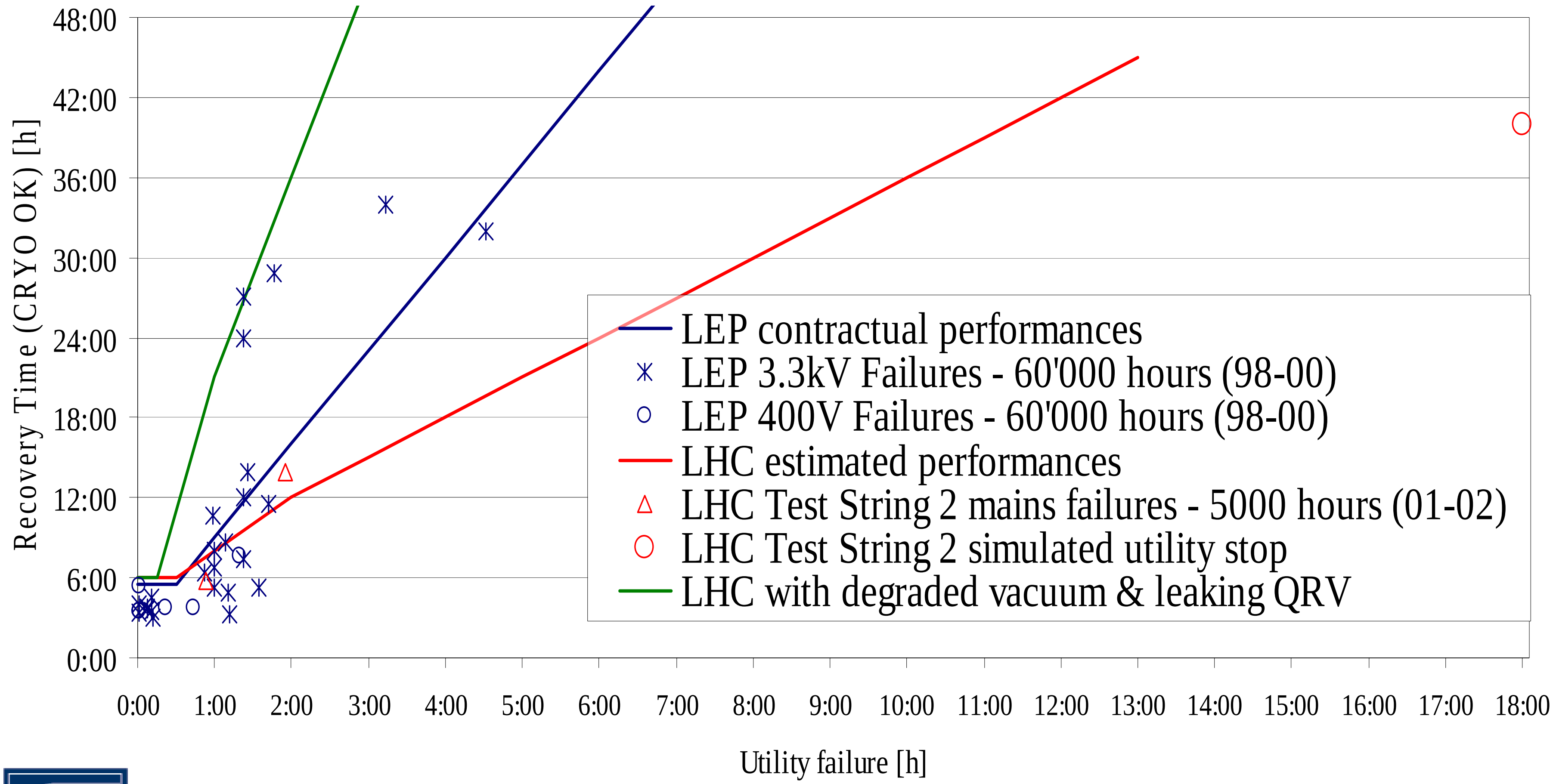
- **Electricity:**
  - 3.3kV Powering of main compressors (stop)
  - 400V Powering of heaters, pumps,… (Diesel back-up)
  - 24V Instrumentation (relays, 500 mA) (UPS)
  - 24V Control System & monitoring (4 –20 mA) (UPS)
- **Water:**
  - Cooling of compressor station (motors, helium, oil), turbines, vacuum pumps… (stop)
- **Compressed Air:**
  - Valves actuators (stop)
- **Controls :**
  - Networks: WFIP (only MB sensors redundant), Profibus (no redundancy -> stop for repair), Ethernet (stop)
  - PLC (stop and repair), SCADA (can run blind until something happens -> would be wise to stop powering)

Utilities failure recovery performances

Cryogenics is a recovery time amplifier

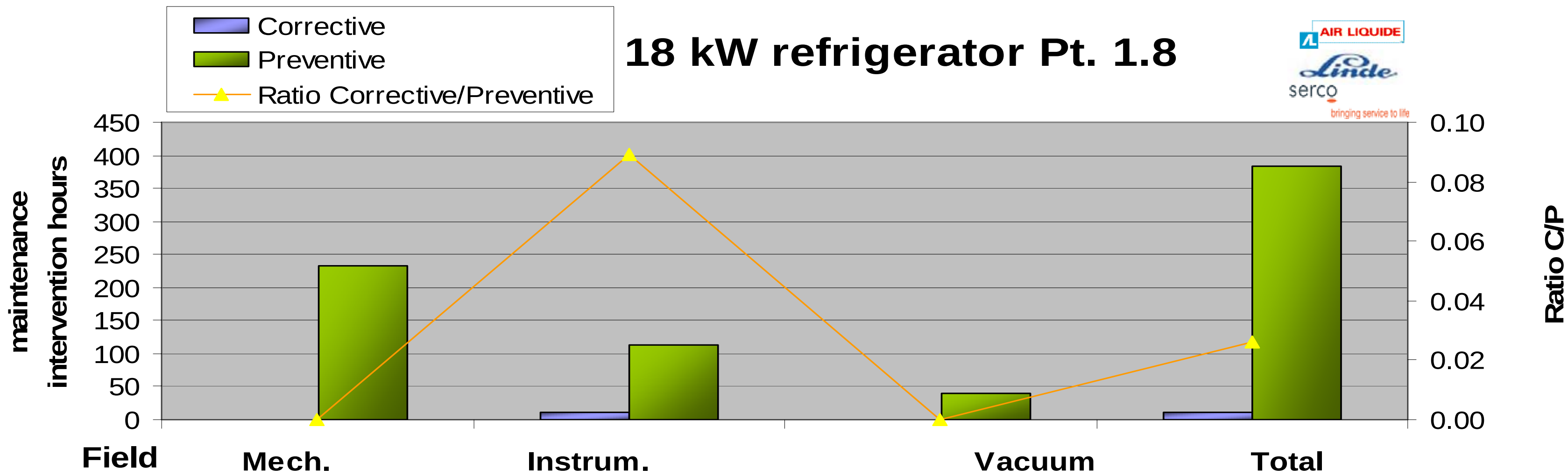
LEP contractual time recovery < 5.5 hours + 7*stop duration

LHC estimated time recovery < 6 hours + 3*stop duration



Maintenance and machine schedule

1. Corrective maintenance during the operational periods
   - when required if critical
   - ½ day every week for intervention
   - few days every month for MD runs
2. Preventive maintenance:
   - every winter shutdown on rotating machines, oil levels, filters, inspections, etc.
   - instrumentation and actuators calibration every two years
   - safety devices verification and validation every two years
3. Major overhaul of pumps (every 20'000 hours) and compressors (every 40'000 hours).
4. Spare parts: critical components are purchased using industrial methods for criticality analysis, ~2,2% cryoplant cost



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Coefficient of performance

- **Availability of cryoplants in operation is defined as:**

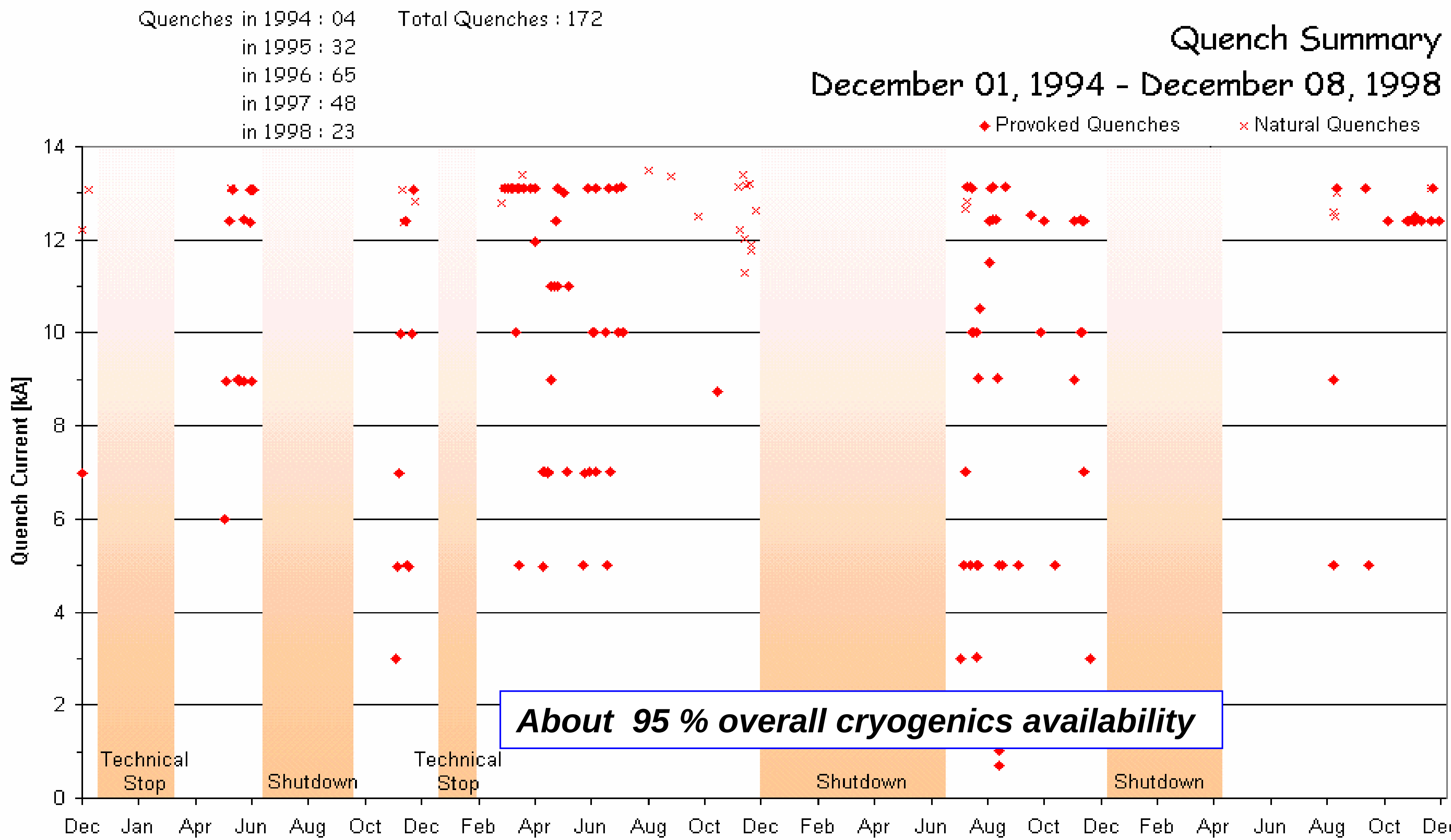
$$\boxed{\frac{hours - availability(CRYO - OK)}{hours - planned - operation}}$$

- **Hours of availability = authorisation (cryo OK signal) for client powering or testing**
- **Hours of planned operation = production year – shutdowns – planned stops**

- **For process stops, e.g. magnet quench, the recovery time is not taken into account in the period of unavailability if within average recovery delay**

- **For operation and utilities stops, the recovery time is taken into account in the period of unavailability**

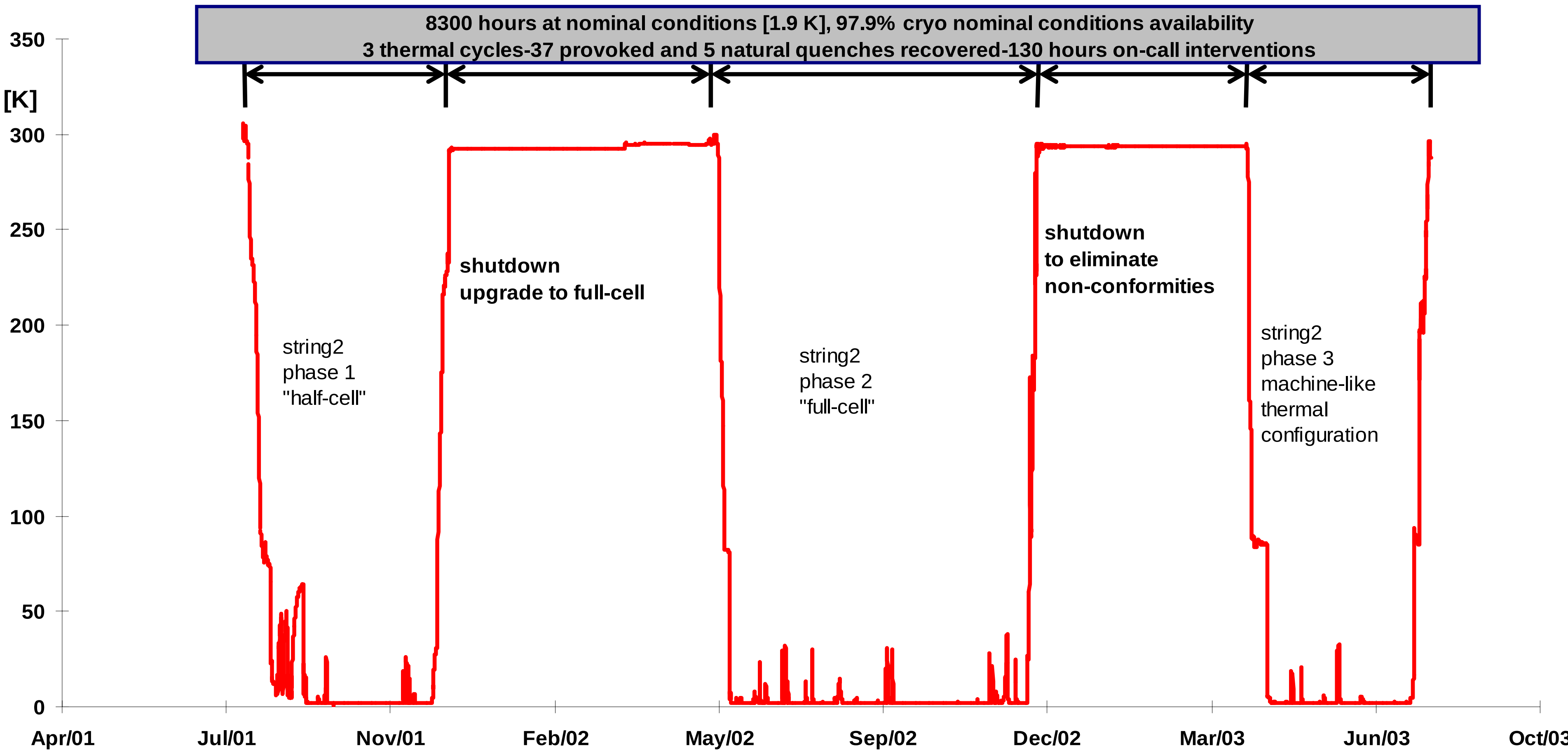
Availability of LHC Test String 1

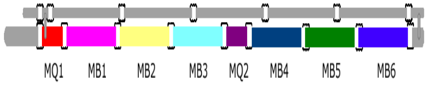


***20000 hours** of operation; almost **13000 hours** at **1.9 K**; **172 quench** recoveries*
***15 complete thermal cycles**;**3275** electrical cycles*
***2000 hours** with magnets powered at or above 800 A (**330 hours** at 13 kA)*

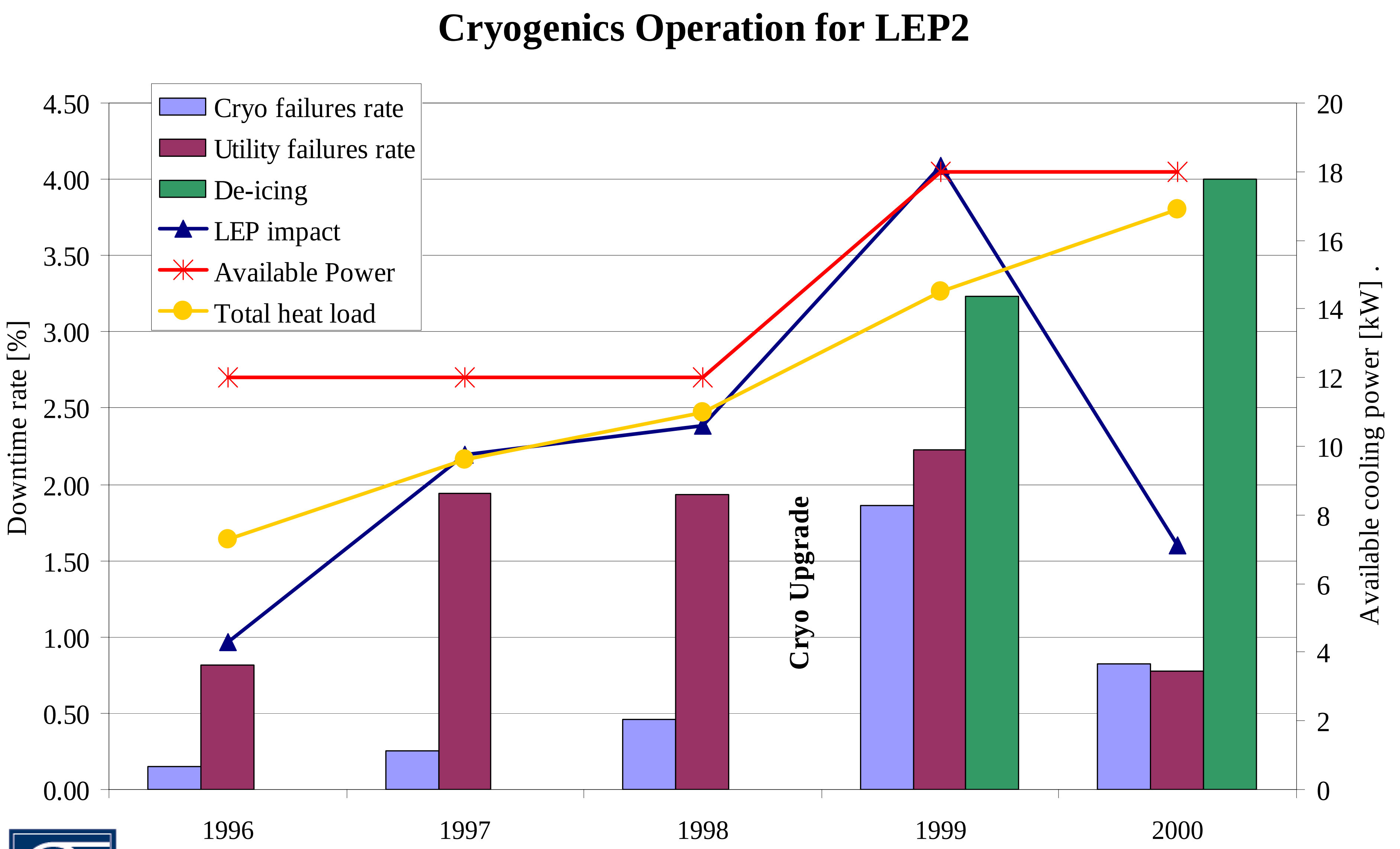
Availability of LHC Test String 2

1700 h at 1.9 K 20 quench recovered 98.8% cryo availability	4800 h at 1.9 K 17 quench recovered 96.2% cryo availability	1800 h at 1.9 K 5 quench recovered 98.7% cryo availability





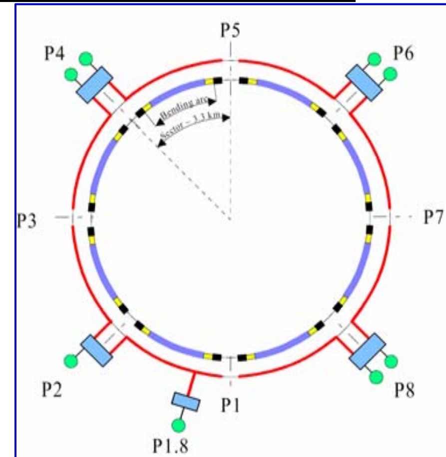
LEP cryogenic system performances



Availability of LHC refrigerators

TABLE 1. **Statistics and availability of LHC refrigerators from 2002 to date.**

	Production [h] or status [**C**-commissioning, **MO**-Major Overhauling] [performance in %]			
LHC point/sector/refr.	**2002**	**2003**	**2004**	**2005**
Point 1.8 / 1-2 - new	**6469** [98.9%]	**5700** [99.4%]	**7620** [99.9%]	**7600** [99.7%]
Point 2 / 2-3 – ex-LEP	Stand-by	Stand-by	**MO, C**	**C**
Point 4 / 3-4 – ex-LEP	Stand-by	Stand-by	Stand-by	**MO**
Point 4 / 4-5 - new	**C**	Stand-by	**C**	**C**
Point 6 / 5-6 - new	Installation	**C**	**C**	Stand-by
Point 6 / 6-7 – ex-LEP	Stand-by	Stand-by	Stand-by	Stand-by
Point 8 / 7-8 – ex-LEP	Stand-by	Stand-by	**MO**	**C**
Point 8 / 8-1 - new	**C** NA	**~600** NA	**1150** [99.1%]	**3000** [98.8%]



Overall availability of CERN cryoplants

Statistics and availability of CERN cryoplants

cryoplant	Years of operation	# of installations	Production [h]	PERFORMANCE IN [%]	Note
LEP cryogenics	1996-2000	4	20’000	97.7 (95.7)	Not including de-icing
LEP point individual refrigerator	1996-2000	1	30’000	98.9	Average
LHC Test String 1	1995-1999	1	20’000	95	*prototype*
LHC Test String 2	2001-2003	1	8’300	97.9	*commissioning*
LHC cryogenics	*2007-*	*8*	*6’000 / year*	*98*	*estimate*
LHC point 1.8	2002-2005	1	27’400	99.5	Production / buffer
LHC point 8	2004-2005	1	4’200	99.0	commissioning

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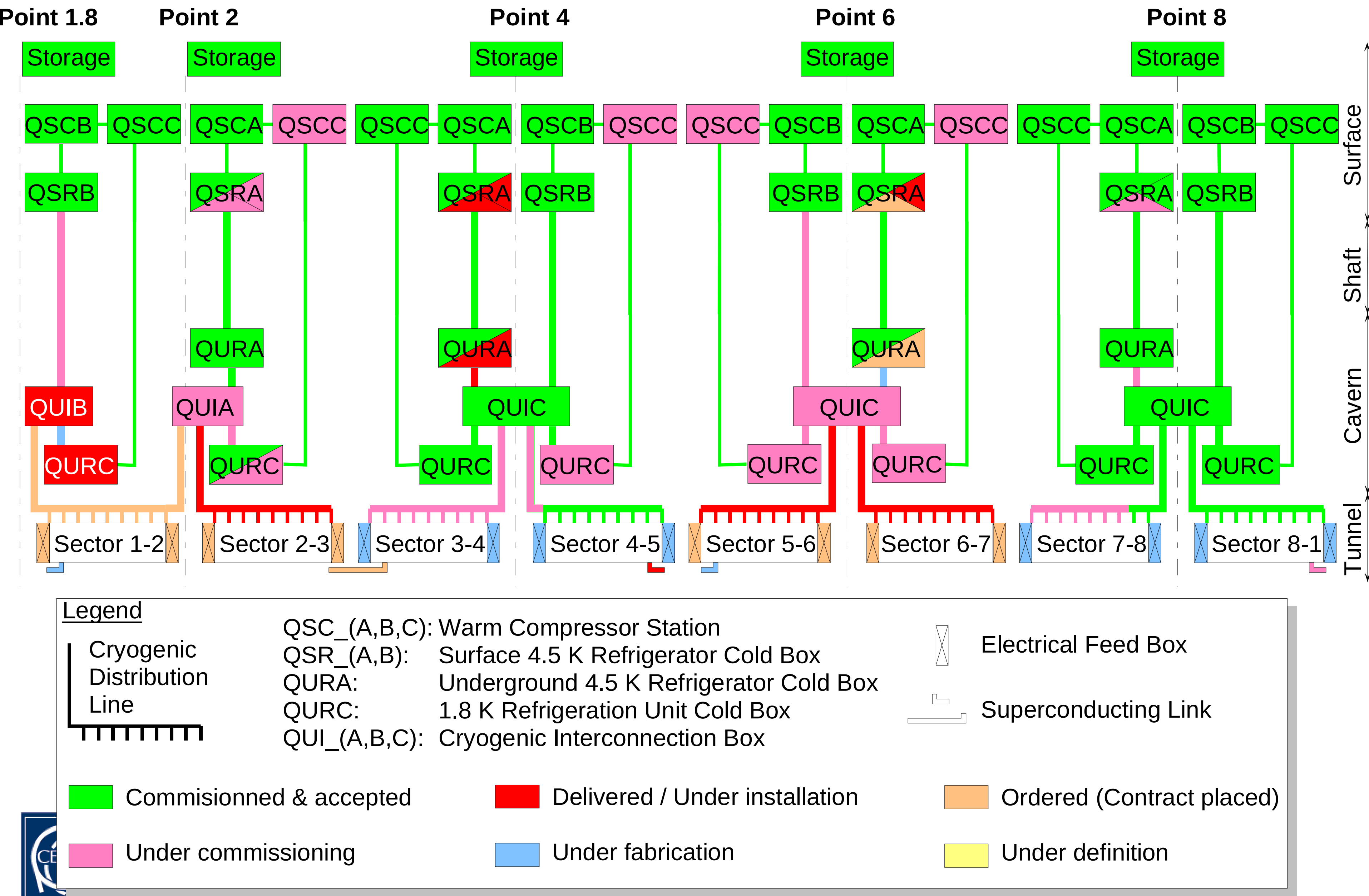
Present Cryogenics Overview



Conclusions

- Cryoplants availability above 99 % can be obtained with preliminary criticality analysis, built-in redundancy and overcapacity, preventive maintenance

- Usually more than 2/3 of stops are due to utilities (electricity, control system, water, etc.)

- The cryogenic system is usually a recovery amplifier, redundancy, overcapacity and preventive maintenance are essential to reduce the downtime

- Fast recovery with automated procedures, round-the-clock operators monitoring and training are necessary to limit the downtime

- Based on LEP operation and sub-systems commissioning experiences, the expected overall availability of the LHC cryogenic system should reach ~ 98 % once the first commissioning with beam is completed

- Commissioning of the LHC is in full swing:
  - Sub-systems commissioning and validation – Pt8 completed ; other points by the end 2006
  - Global validation of cryogenics production and distribution systems at Pt. 8– June 2006
  - Hardware commissioning of the two first full LHC sectors (Pt. 8) – end 2006
  - Colliding beam – end 2007