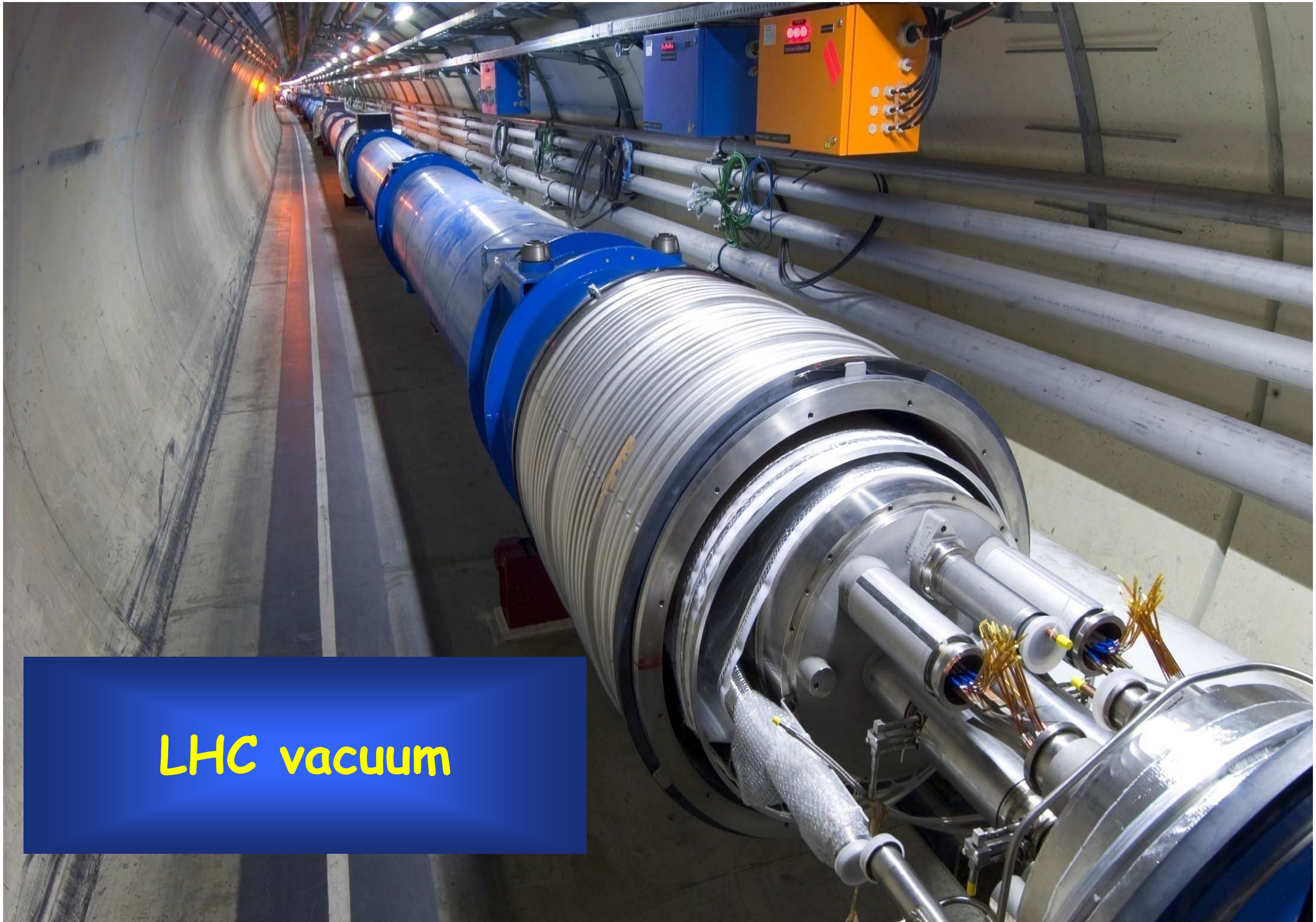

# LHC vacuum

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November 2007

# Description of LHC Vacuum Systems
## Introduction

- The LHC has 4 different Vacuum Systems belonging to two types of vacuum applications & technologies
  - **Insulation Vacuum Systems**
    - Cryogenic line QRL
    - Magnet Cryostats

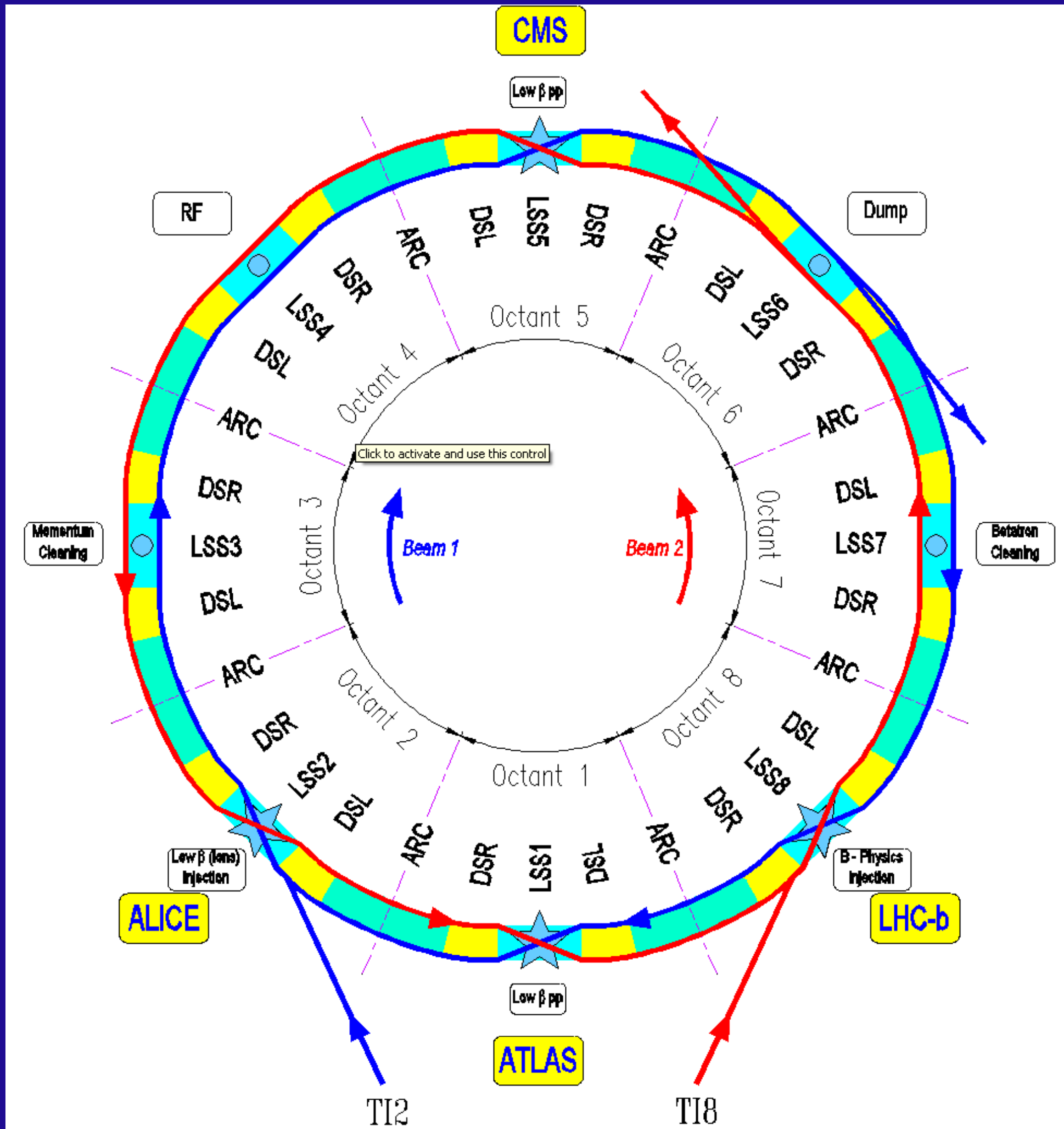
  ***The main purpose of the insulation vacuums is to decrease the heat exchange between the cryogenic lines/fluids and the external envelope at ambient temperature (RT).***

  - **Beam Vacuum Systems**
    - Cold Beam Vacuum
    - RT Beam Vacuum

  ***The main purpose of the beam vacuums is to ensure the required the beam lifetime and luminosity while decreasing the beam/gas scattering and therefore the background to the experimental regions and the induced radiation to the surrounding equipments***

  ***As a general rule in the LHC, the two circulating beam vacuums are kept whenever possible completely independent. Exceptions can be found in the experimental regions and in the injection kickers in 5L2 and 5R8.***

# Description of LHC Vacuum Systems
## General Layout of LSS




Attention…

*Vacuum crew uses :*

Blue beam instead of Beam 1

*and*

Red beam instead of Beam 2

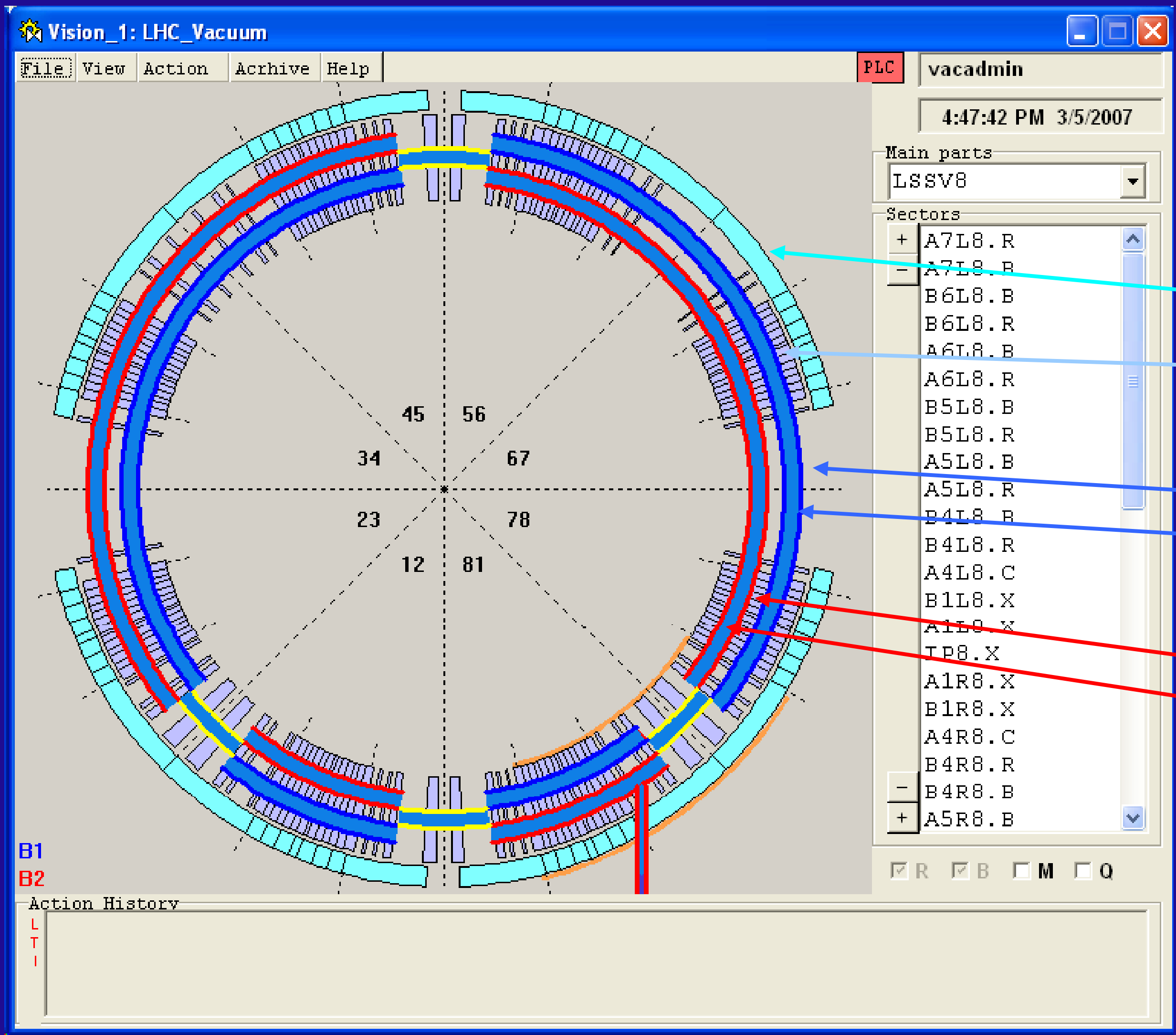
# Different vacuum

- Combined
  - **2 vacuum chamber**
  - **Same vacuum sector**
    - Experimental zones D1-D2 & MKI (2&8)
- Blue or Red
  - **1 vacuum sector per beam**

- Point X
  - **1 vacuum sector same chamber for the 2 beams**
    - Tan –Tan (1&5)
    - D1 –D1 (2&8)

# Description of LHC Vacuum Systems

## Vacuum Supervision Interface




QRL Insulation Vacuum

Magnets Insulation Vacuum

**BLUE Beam or Beam 1**
**Beam Vacuum**
**Sector Valve Chain***

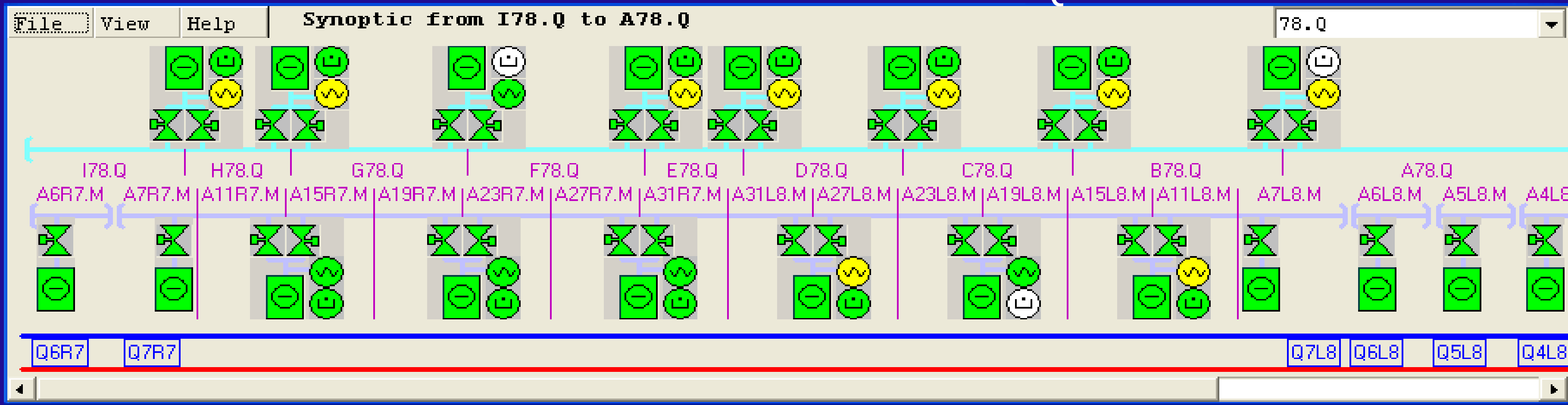
**RED Beam or Beam 2**
**Beam Vacuum**
**Sector Valve Chain***

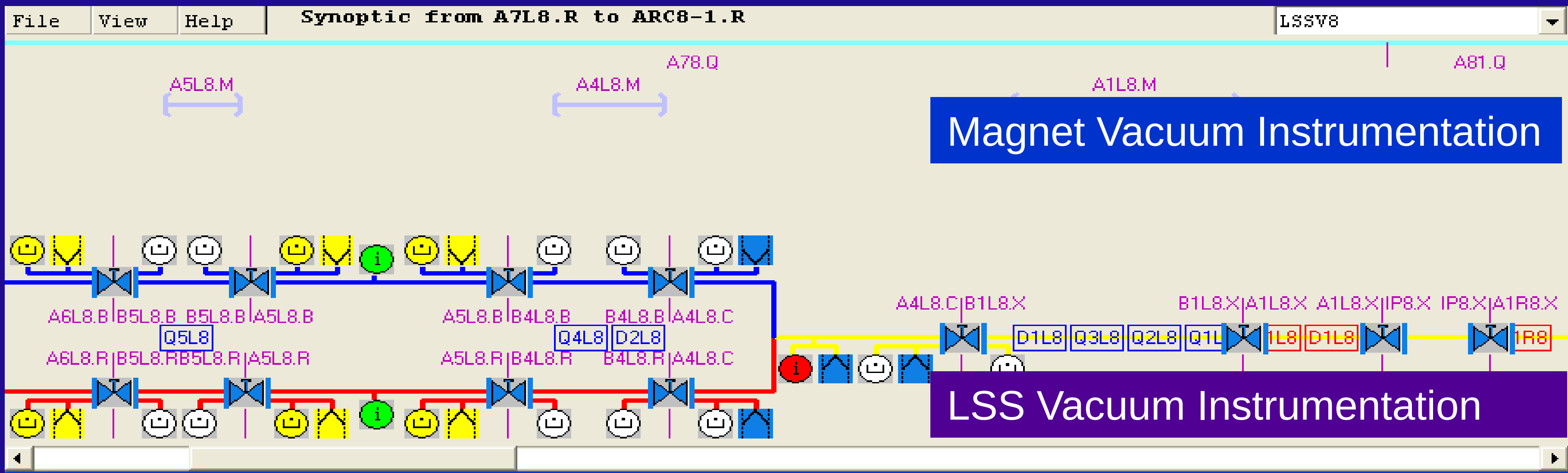
**Red = Valve(s) closed**
**Green = all valves opened**
**Blue = Control Problem or undefined position**

# Description of LHC Vacuum Systems

## LHC Vacuum Instrumentation

QRL Vacuum Instrumentation



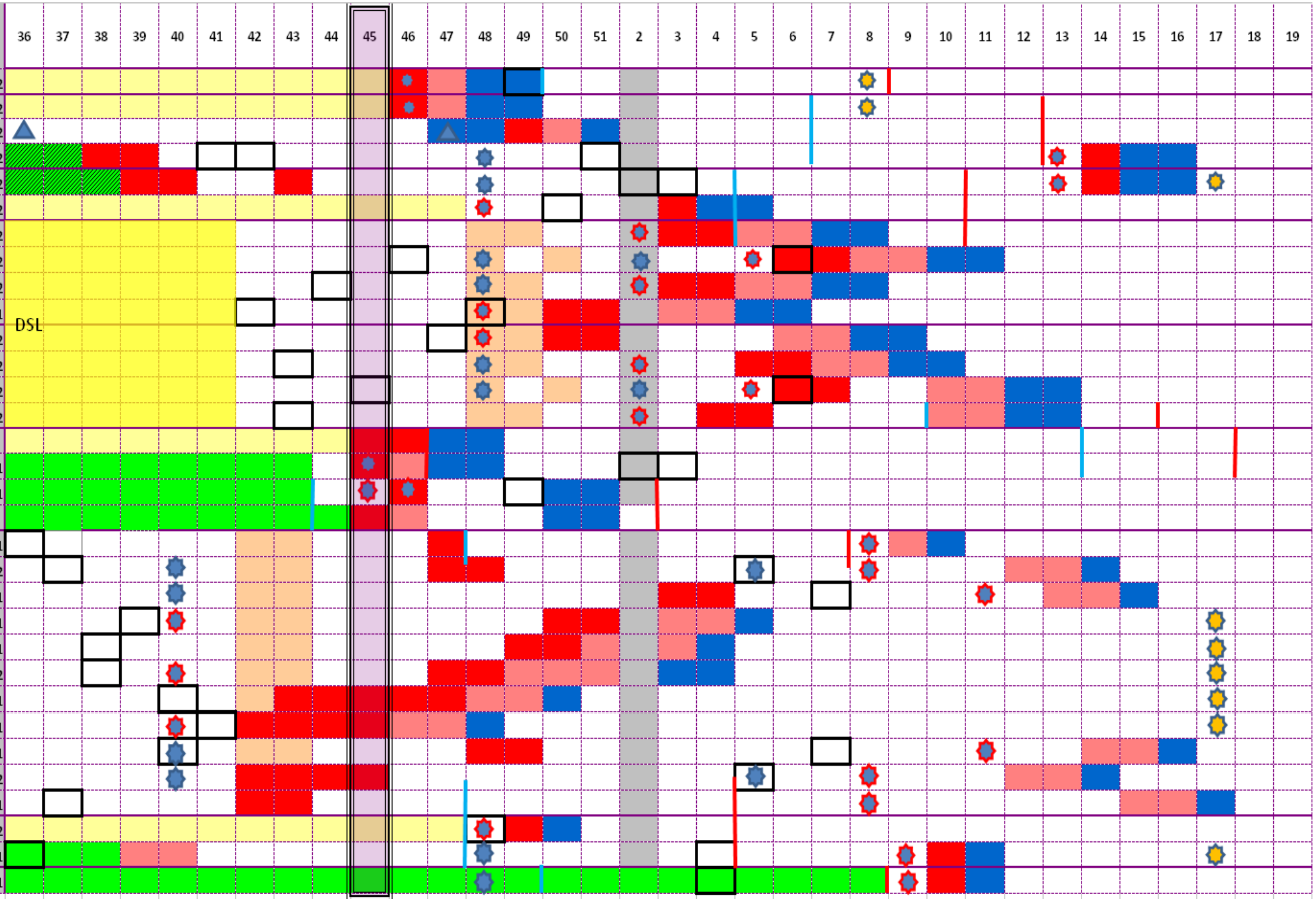
# symbols

| | VGF | VGI | VGM | VGR | VGP | VPI | VPGF | VVS |
|---|---|---|---|---|---|---|---|---|
| | Full-Range | Ion Gauge | Membrane | Pirani | Penning | Ion pump | Fixe pumping group | Sector valves |
| ON | | | | | | | | OPEN pas d'interlocks |
| ON Underrange | | | ou pas connectée | | | | ON mais 1 pompe ou vanne fermée ou OFF | |
| ON avec Warning | | | | | | | | |
| OFF | | | | | | | | |
| OFF avec Erreur ou ON&OFF en meme temps | | | | | | | | CLOSE mais peut etre ouverte |
| Pas de comm avec le PLC ou pas de validity bit ou ni ON ni OFF | | | | | | | | |
| | | | | | | | ? | OPEN & CLOSE à la fois |
| | | | | | | | close dans le detail du groupe | OPEN avec des Warning |
| | | | | | | | sur la vanne qd impossible à ouvrir | CLOSE et ne peut pas etre ouverte |
| | | | | | | | | UNDEFINED mais sans interlock |
| | | | | | | | | UNDEFINED avec pb interlock Pression |
| | | | | | | | | CLOSE avec pb interlock Pression |

# Interaction <> hardware commissioning

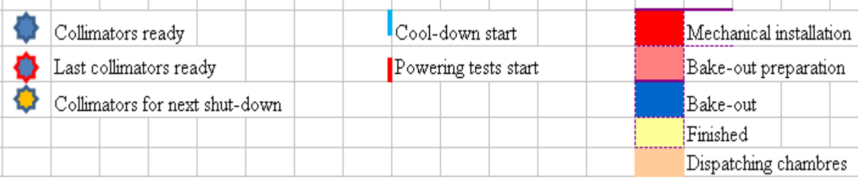
- Vacuum installation and conditioning is quite independent from hardware commissioning.
- Cross talk only at planning level.
- Vacuum system interact with the hardware commissioning only via the Beam Interlock System.
- The vacuum interact with the personnel protection system .
- 4 Electron stopper Iss 4
  - **to stop electron emission during RF conditioning**
  - **controlled from access system and RF group**
- 2 Access safety block Iss 3 to be IN during LHC general access.
  - **controlled via the access system**
- Are both on vacuum chain of Beam Interlock System.

| | Inst | B prep | Bake |
|---|---|---|---|
| A4L1 | 1 | 2 | 2 |
| A4R1 | 1 | 2 | 2 |
| AI5L2 | 1 | 2 | 2 |
| A4L2 | 2 | 2 | 2 |
| A4R2 | 2 | 2 | 2 |
| A6R2 | 1 | 2 | 2 |
| A7L3 | 2 | 2 | 2 |
| B5L3 | 2 | 3 | 2 |
| A5L3 | 2 | 2 | 2 |
| A4L3 | 2 | 2 | 1 |
| A4R3 | 2 | 2 | 2 |
| A5R3 | 2 | 2 | 2 |
| B5R3 | 2 | 3 | 2 |
| A7R3 | 2 | 2 | 2 |
| D5R4 | | | |
| B4L5 | 1 | 1 | 1 |
| B4R5 | 1 | 1 | 1 |
| A6R5 | | | |
| A7L7 | 1 | 1 | 1 |
| A6L7 | 2 | 2 | 2 |
| B5L7 | 2 | 2 | 1 |
| A5L7 | 2 | 2 | 1 |
| A4L7 | 2 | 2 | 1 |
| IP7 | 2 | 3 | 2 |
| A4R7 | 2 | 2 | 1 |
| A5R7 | 2 | 2 | 1 |
| B5R7 | 2 | 2 | 1 |
| A6R7 | 2 | 2 | 2 |
| A7R7 | 1 | 1 | 1 |
| A6L8 | 1 | 2 | 2 |
| A4L8 | 1 | 2 | 1 |
| A4R8 | 1 | 2 | 1 |




| | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Installation | 0 | 0 | 1 | 2 | 1 | 0 | 3 | 5 | 3 | 6 | 5 | 4 | 3 | 4 | 4 | 3 | 0 |
| Total Bake-out preparation | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 1 | 2 | 2 | 2 | 0 |
| Total Bake-out | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 6 | 2 | 4 | 3 | 0 |

| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total Installation | 4 | 4 | 2 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Total Bake-out preparation | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 0 | 0 | 0 |
| Total Bake-out | 1 | 3 | 3 | 1 | 2 | 3 | 2 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 1 | 0 | 0 |



# Actual hardware installation state

- Lss 1&5 will be under nominal vacuum end November.
  - **Neg activated between Q7-Q1**
- Lss 2&8
  - **On 2 left to be installed MKI and TDI**
  - **On 8 under nominal vacuum except region between D1 D2 (due to collimator installation next year)**
- Lss 4
  - **BGI on the right side to be installed before end November, the rest under nominal vacuum.**
- Lss 3&7
  - **1 step > collimators installation end of the year**
  - **2 step > collimators installation during January**
  - **Vacuum at nominal end of march**

# Actual state of Vacuum Beam Interlock

- Lss 1/4/8 test ongoing
- All ring will be ready at the beginning of the year
- Ready mean tested standalone with simulation.
- Then the planning of the hardware commissioning will lead the complete test with the Beam Interlock System
  - **Test equipment signal locally**
  - **Test the continuity of the signal to the BIS**
  - **Test the functionality of the interlock >> Beam Dump**

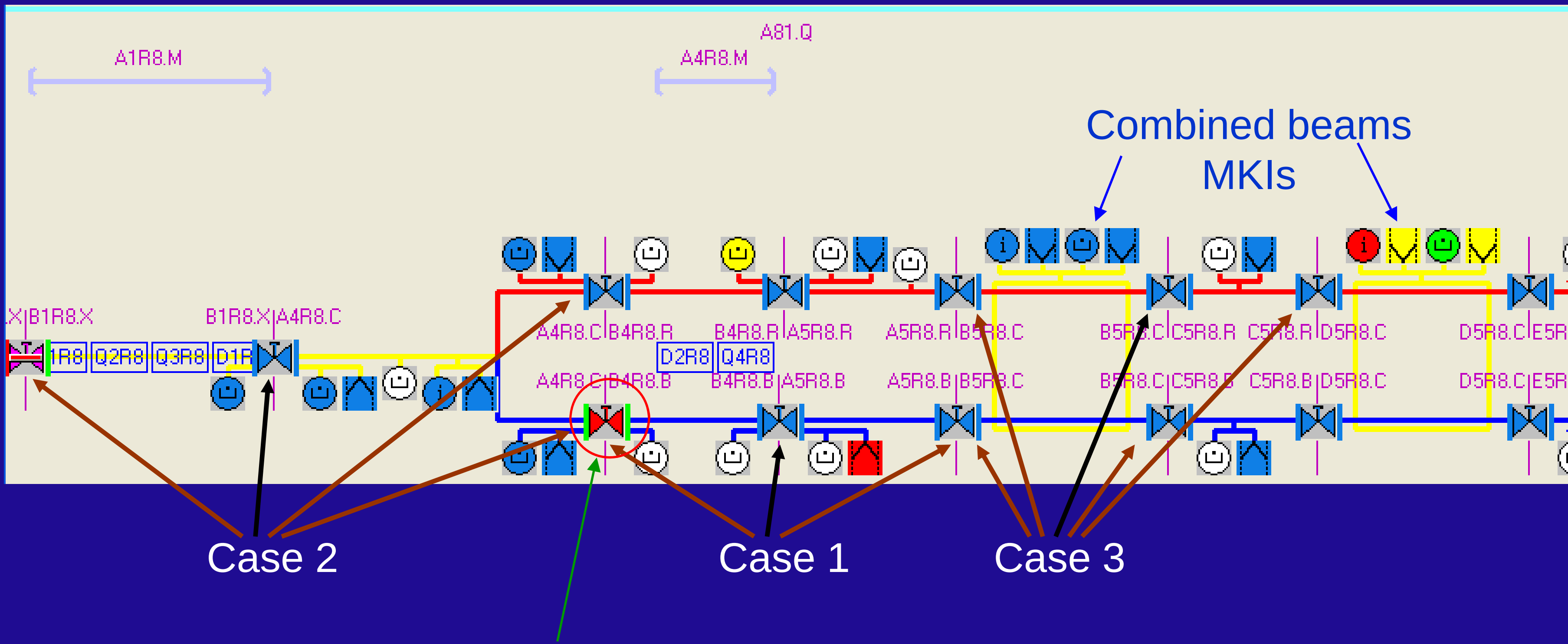
# Vacuum Beam Interlock

- Sector valve will open and will send the TRUE signal to the BIS for each Beam and each point if:
  - **status of sector valves Open**
  - **the pressure is < $10^{-7}$**
  - **the magnet standalone (q1-q6) temperature is ok**

- The vacuum Beam Interlock will become False if:
  - **The pressure is bad > $10^{-7}$**
  - **An alarm is generated which will generate the False signal to the BIS and a Beam Dump will follow.**
  - **The vacuum Beam Interlock will wait the confirmation of the beam dumped to close the concerned valve.**

# Description of LHC Vacuum Systems
## Vacuum systems Protections (interlocks) [2/2]

Beam Vacuum Sector Valves Closure

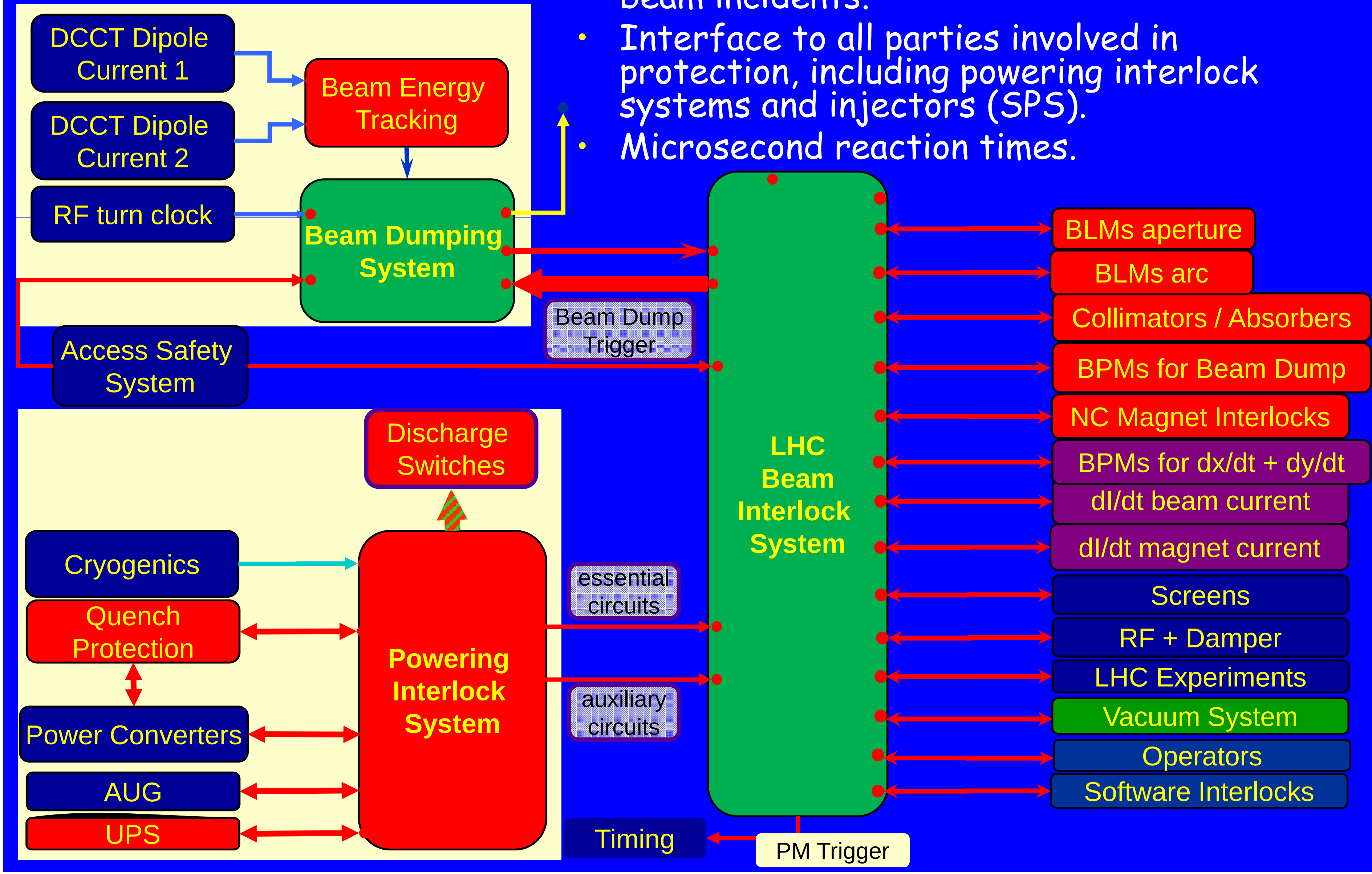



Green : Valve can be opened

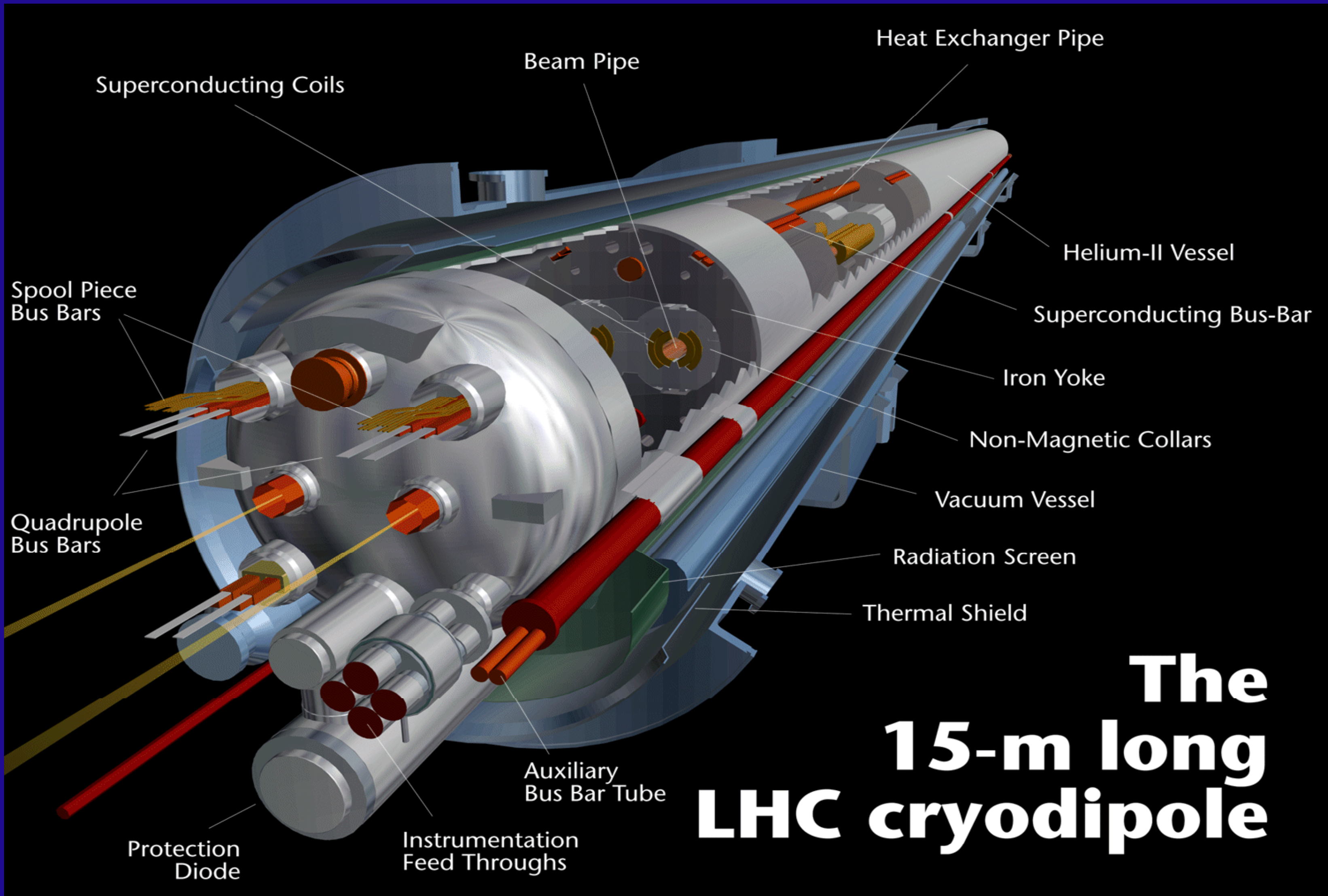
Red : An interlock is detected

# Beam Interlock System and Inputs

- Protection for the entire machine against beam incidents.
- Interface to all parties involved in protection, including powering interlock systems and injectors (SPS).
- Microsecond reaction times.



# Description of LHC Vacuum Systems
## LHC Cryodipole



# Description of LHC Vacuum Systems

## QRL and Cryostat Insulation Vacuum Systems

- ☞ The insulation vacuum is a primary vacuum between the inner cold cryogenic lines wrapped with super insulation layers and the outer envelope e.g. pipe or magnet cryostat.
- ☞ Before the cool down, this vacuum is pumped out with mobile and fixed turbomolecular pumping stations down to a pressure in the $10^{-2}$ or $10^{-3}$ mbar range (1 or $10^{-1}$ Pa).
- ☞ The cool down will bring a huge additional pumping of the water which is the dominant gas in this pressure range. Then, the mobile pumping units are removed, the fixed pumping station remain in place in order to pump the gasses during the warming up.

- ☞ What's the cryopumping? Effect and Limitations

- Description of a magnet cryodipole
- Sectorisation of the QRL insulation vacuum
- Sectorisation of the Magnet cryostat insulation vacuum

# Description of LHC Vacuum Systems
## Cold Beam Vacuum Systems [1/2]

- The LHC has cold beam vacuums mainly in the arcs (8 x 2 x 2.8 km) and in all standalone magnets in the long straight sections (LSS) e.g. quadrupole, dipoles and inner triplets.
- The two beams (Blue/1 and Red/2) are kept independent and are isolated in the absence of cool down from the RT parts by sector valves to avoid cross contamination between the non baked cold beam vacuums [cold bore and beam screen] and the RT parts with NEG coatings. In the absence of cool down, the rather high static pressure ($10^{-4}$ mbar) will partly saturate the surrounding NEG coatings.
- The cold beam vacuum in each magnet is composed by a cold bore attached to the magnet coils and a beam screen inserted in the cold bore. The main purpose of the beam screen is:
  - **To reduce the heat transfer from the beam induced heat losses e.g. image current, beam-gas scattering, photons and electron cloud (at much higher bunch intensities),**
  - **To reduce the gas induced desorption by transferring the gas through the beam screen holes to the cold bore.**

# Description of LHC Vacuum Systems
## Cold Beam Vacuum Systems [2/2]

- The cold beam vacuum is pumped down using mobile turbo molecular pumping stations down to a pressure in the $10^{-6}$ mbar range.
- Then the cool down will bring a huge additional pumping speed of the water which is the dominant gas in this pressure range (non baked system). Once the magnets are at nominal operating temperature, the mobile pumping stations are removed from the machine remaining only the cryogenic pumping.
- At this stage, the main limitation comes from the fact that nor hydrogen nor Helium gas are pumped by surfaces with temperatures above 4.5 K.

# Description of LHC Vacuum Systems
## RT Beam Vacuum Systems [1/4]

- The LHC has RT beam vacuums only in the long straight sections (LSS) and in the 4 experimental areas. The total length for both beams is around 7 km.
- The two beams (1/Blue and 2/Red) are kept independent and are isolated in the absence of beam from the cold parts by sector valves to avoid cross contamination between RT parts and non baked cold parts.
- The RT beam vacuums are composed by vacuum chambers, interconnecting bellows and beam related equipment such as collimators, beam diagnostics and RT magnets in a few zones (IR2, IR3, IR7, IR8).

# Description of LHC Vacuum Systems
## RT Beam Vacuum Systems [4/4]

- The very low pressure required is obtained by NEG coated chambers and ion pumps. As for the cold beam vacuum, the pump down is obtained using mobile turbo molecular pumping stations. Once under vacuum, all components are baked at a nominal temperature of 250°C. Some components are exceptions and are baked at a lower temperature: BPM, BCTs, BGI.
- A bake out temperature above 200°C allows simultaneously the surfaces degassing and the activation of the NEG coatings which provide a urge additional distributed pumping speed except for neutral gasses and methane. Consequently, ion pumps are used to pump these gasses.
- This coating has other advantages such as the low secondary electron yield i.e. NEG coatings can be used as an electron cloud suppressor and they have also a low electron, ion and photon induced desorption yields.

# Description of LHC Vacuum Systems

## Vacuum systems Protections (interlocks) [1/2]

*In the LHC, the cold beam vacuum sectors are always surrounded by RT beam vacuum sectors as the RT beam vacuum sectors can have cold or RT beam vacuum sectors at their interfaces.*

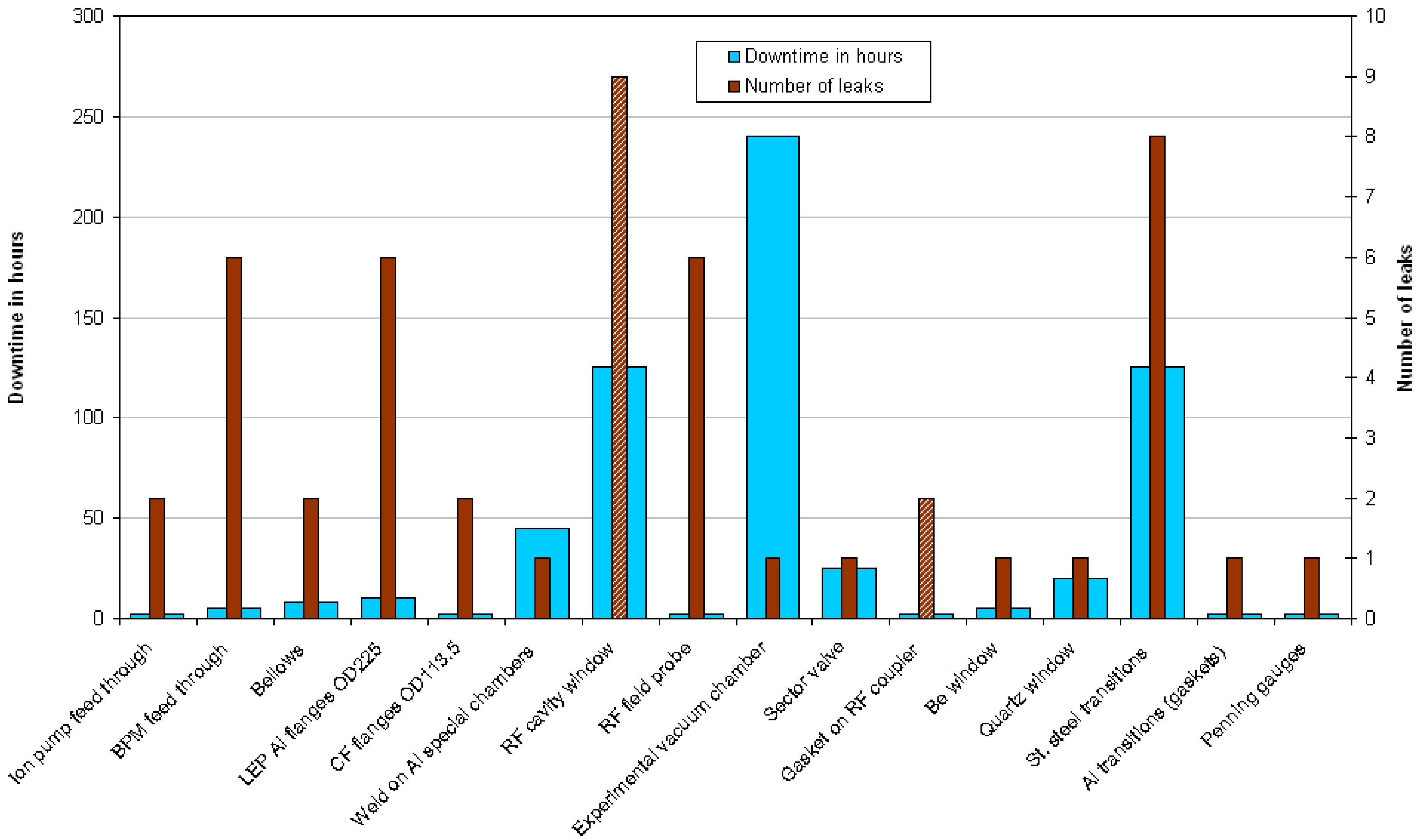
- **Sector Valve Opening**

  The opening of a sector valve isolating a Cold / RT beam vacuum is allowed only if:
  - The magnet is at his nominal temperature and the Penning of the Cold beam vacuum sector indicate pressures below $10^{-7}$ mbar
  - The Penning gauge of the RT beam vacuum indicate pressures below $10^{-7}$ mbar
  - For an interface between two RT beam vacuums, the Penning gauges of both sectors shall indicate a pressure below $10^{-7}$ mbar
- **Sector Valve Closing**

  A vacuum interlock by the ion pumps and Penning gauges located upstream and downstream of the sector valve (n) will fire the beam dump and then the sector valves (n), (n-1) and (n+1) will be closed. As a general rule, 3 or 4 signals are used to interlock the valve closure and the interlock will be triggered when n-1 signals are positive.

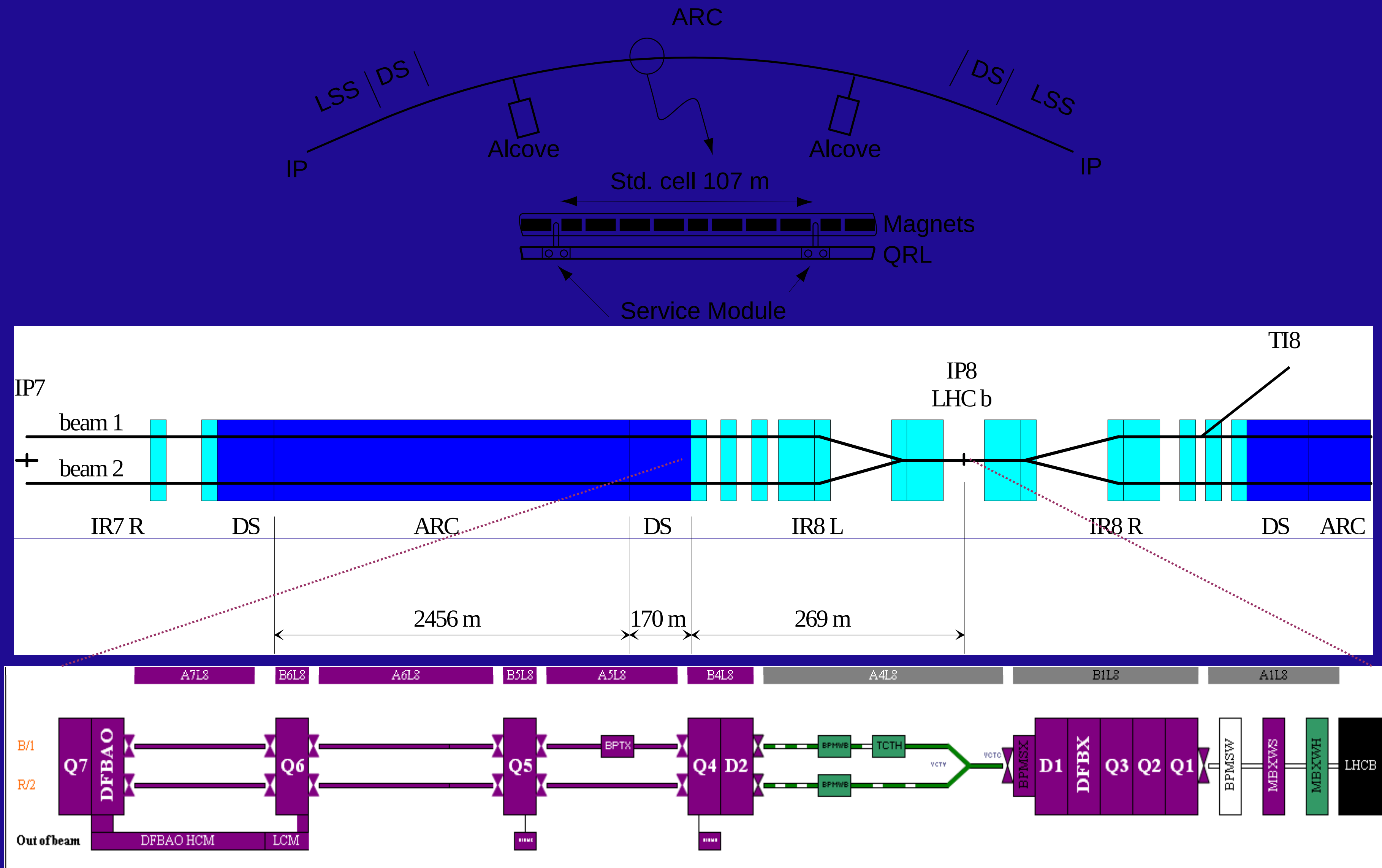
# Problems expected during the Operation

## LEP Statistics



# Description of LHC Vacuum Systems

## LHC Vacuum Sectors



# Architecture of the BEAM INTERLOCK SYSTEM

Beam-1 / Beam-2 are Independent!

20 Users per BIC
Half maskable
Half un-maskable

- fast reaction time (~ μs)