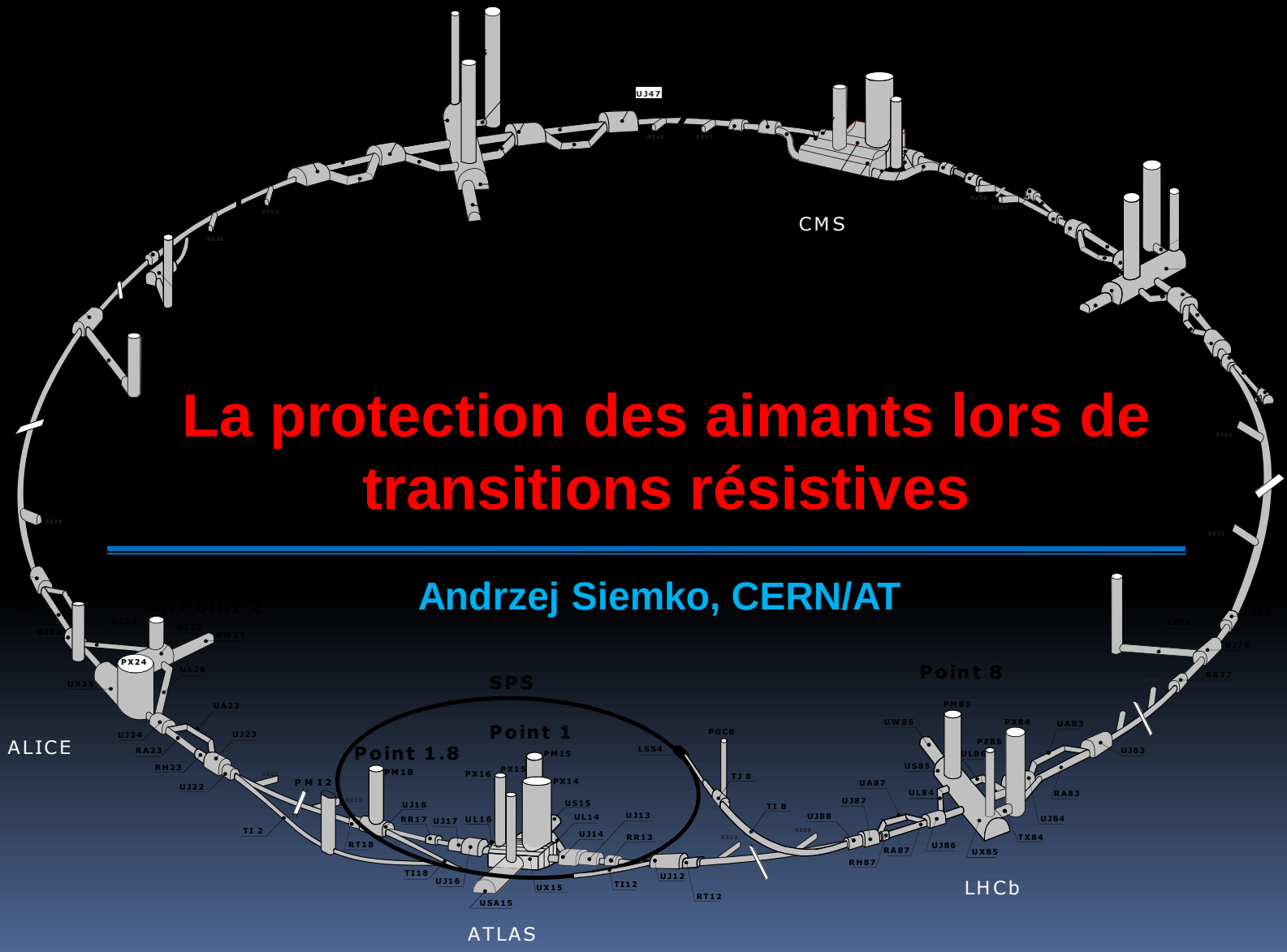
CERN

Organisation Européenne pour la Recherche Nucléaire



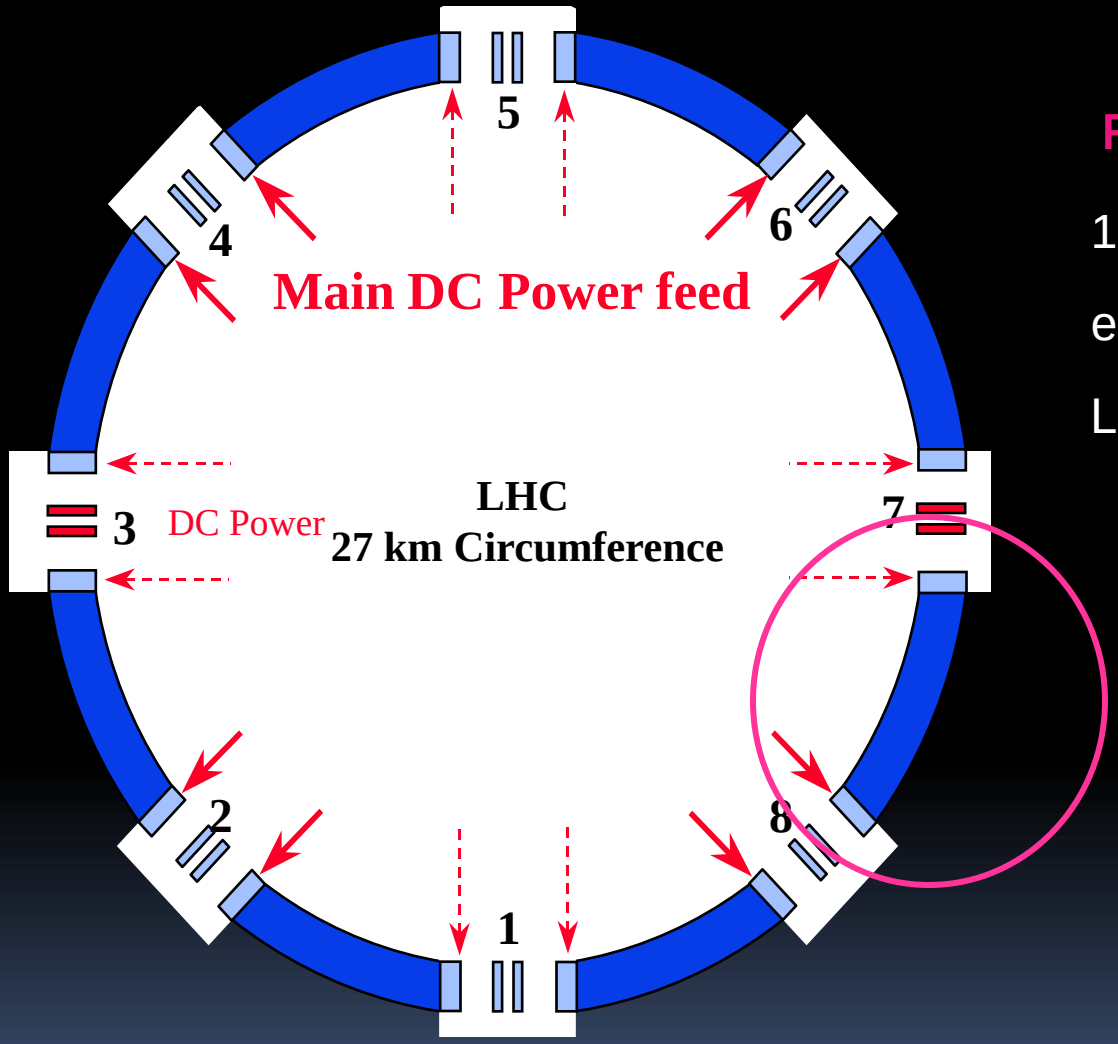
La protection des aimants lors de transitions résistives

Andrzej Siemko, CERN/AT

Contenu

- L'architecture magnétique du LHC
- Le phénomène du « Quench »
- Le système « Quench Protection » de protection des aimants supraconducteurs en cas de transitions résistives
- Aperçu sur l'opération du système cryogénique : protection hydraulique par vannes et lignes de décharge
- Conclusion

L’architecture magnétique du LHC



Powering Sector:

154 aimants dipolaires,

environ 44 quadripôles;

Longueur d’environ 3 km

LHC Sector

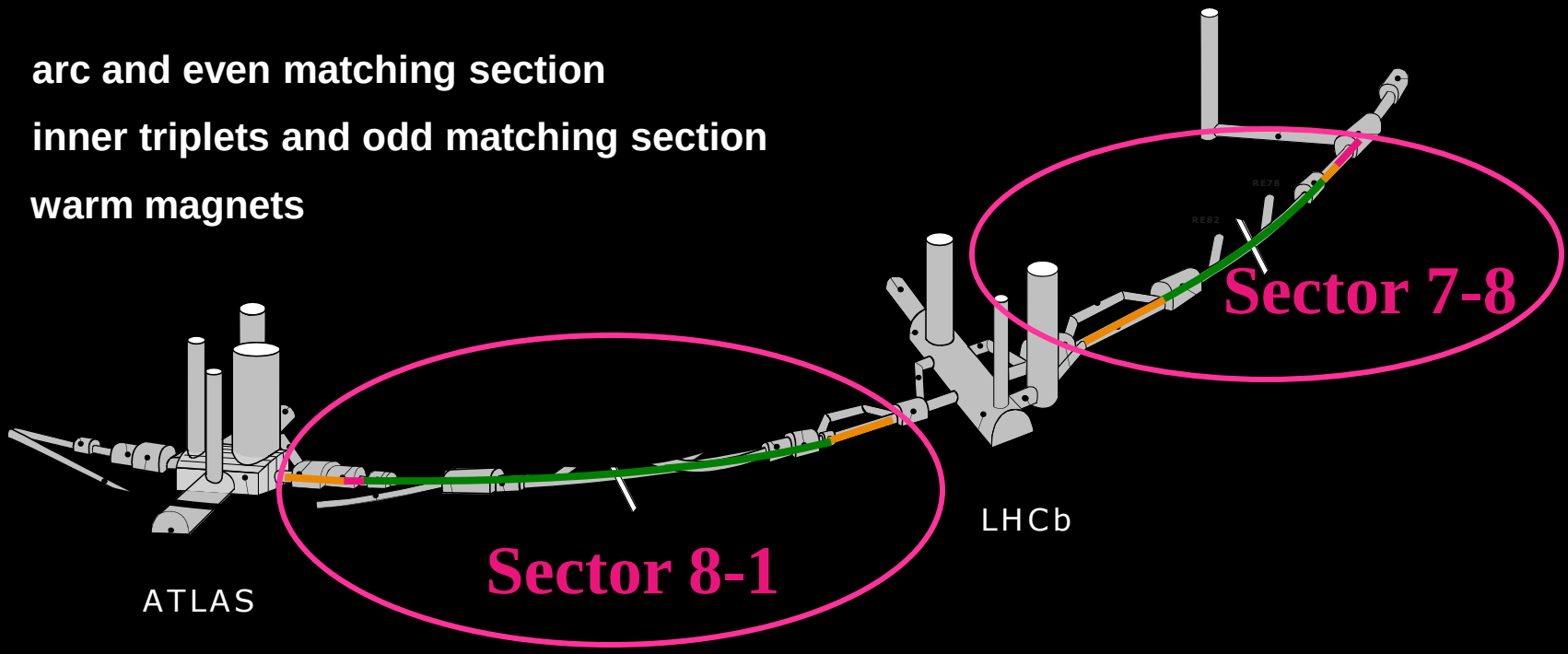
L’architecture magnétique du LHC se divise en huit secteurs principalement constitués de chaines d’aimants supraconducteurs, dipolaires ou quadripolaires raccordes en série

Sectorisation du LHC

arc and even matching section

inner triplets and odd matching section

warm magnets



Powering Sector:

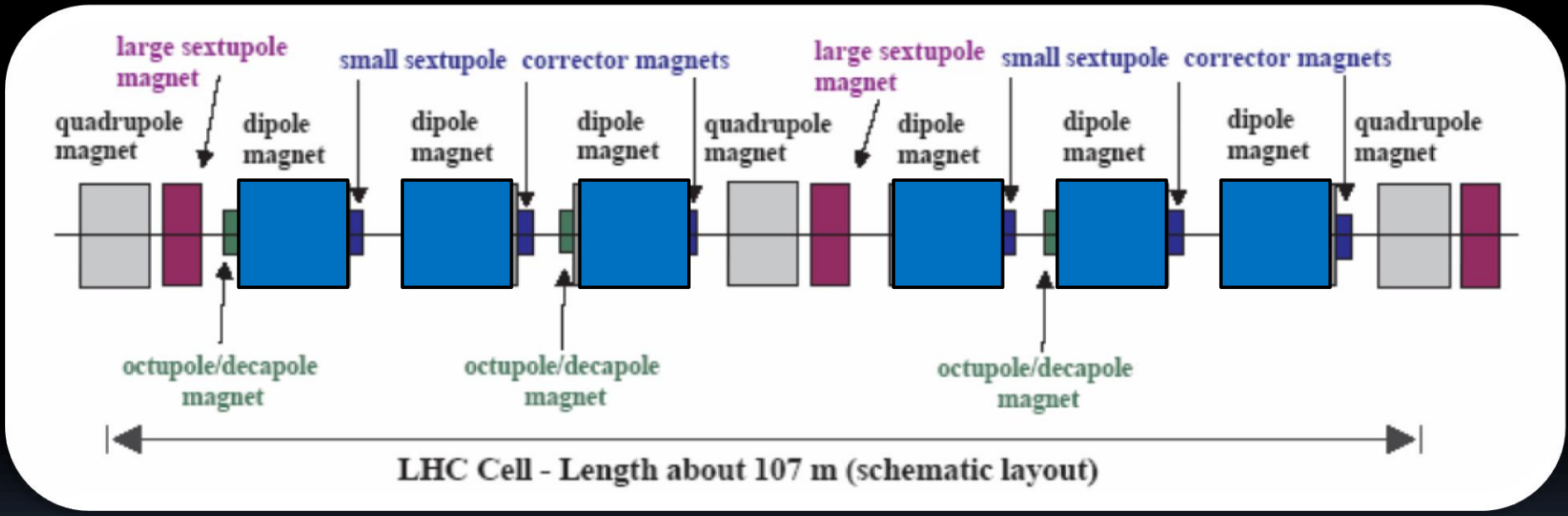
- ~210 cold circuits
- 190 orbit corrector circuits
- ~10 warm circuits

Powering Subsectors:

correspondent en général aux cryostats indépendants, facilitent la mise en opération

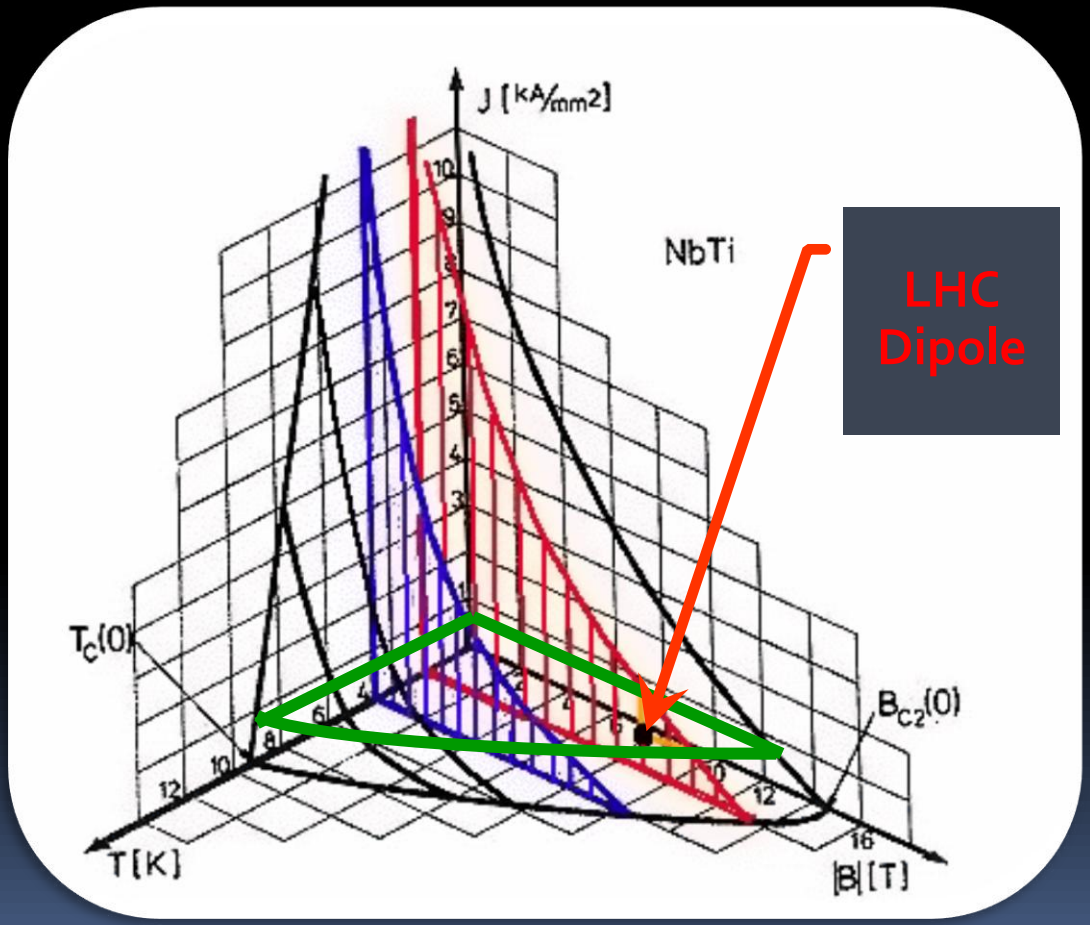
L'architecture magnétique du LHC

LHC Arc - Cellule élémentaire



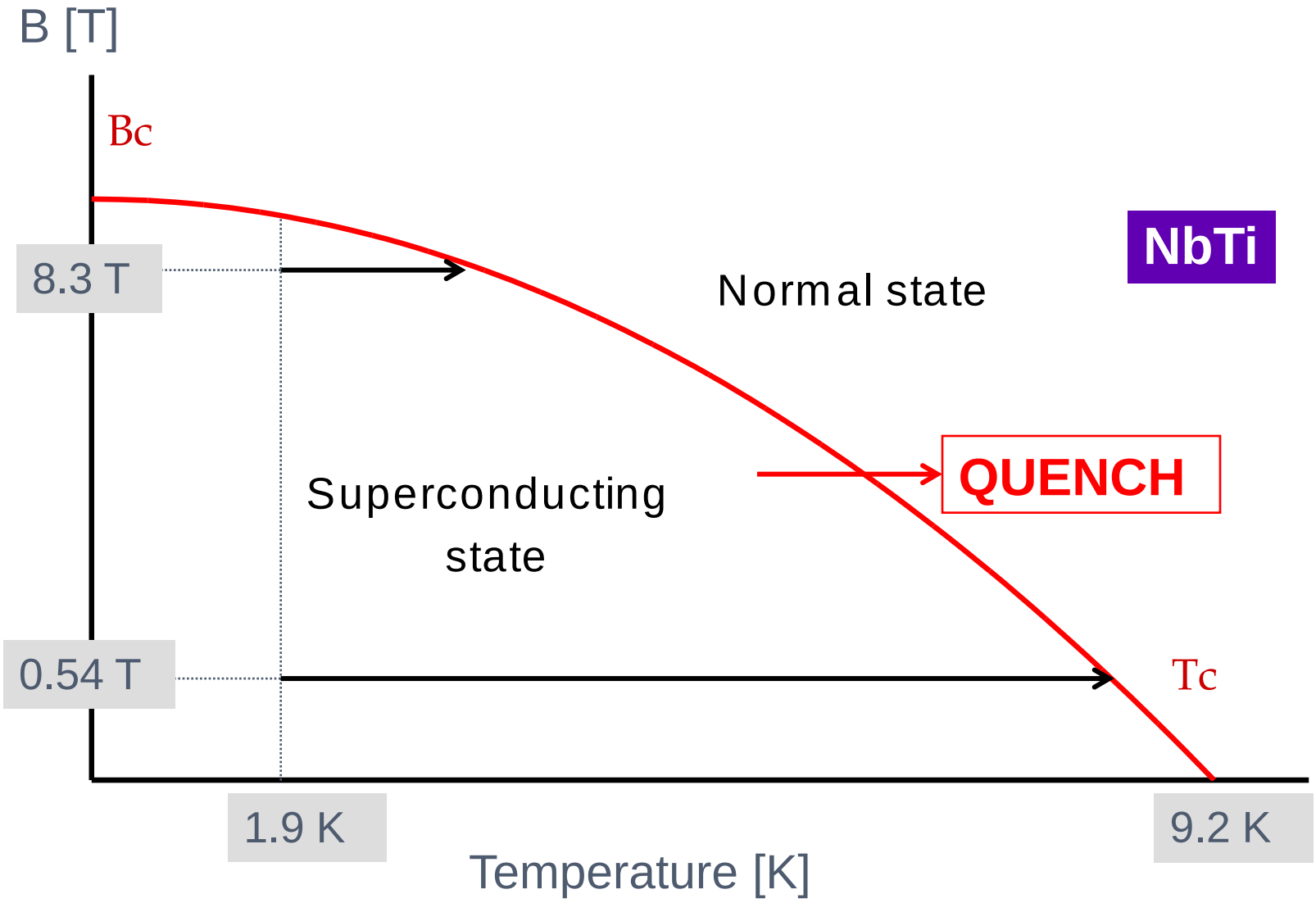
- 23 cellules (2.5 km) dans chaque secteur

Le phénomène du «quench»



- The superconducting state is defined by the critical surface
  - B (T), J (A/mm²), T (K)
- Magnets operate in conditions corresponding to a point beneath the critical surface
  - $T=T_{op}$, $J=J_{op}$, and $B=B_{op}$
- Increasing the current in the magnet the critical surface is crossed and a small volume V of superconductor becomes normal
- The volume *V* starts dissipating heat because of Joule effect, and its temperature increases

Le «quench»: Marge d'opération d'un aimant supraconducteur dipolaire

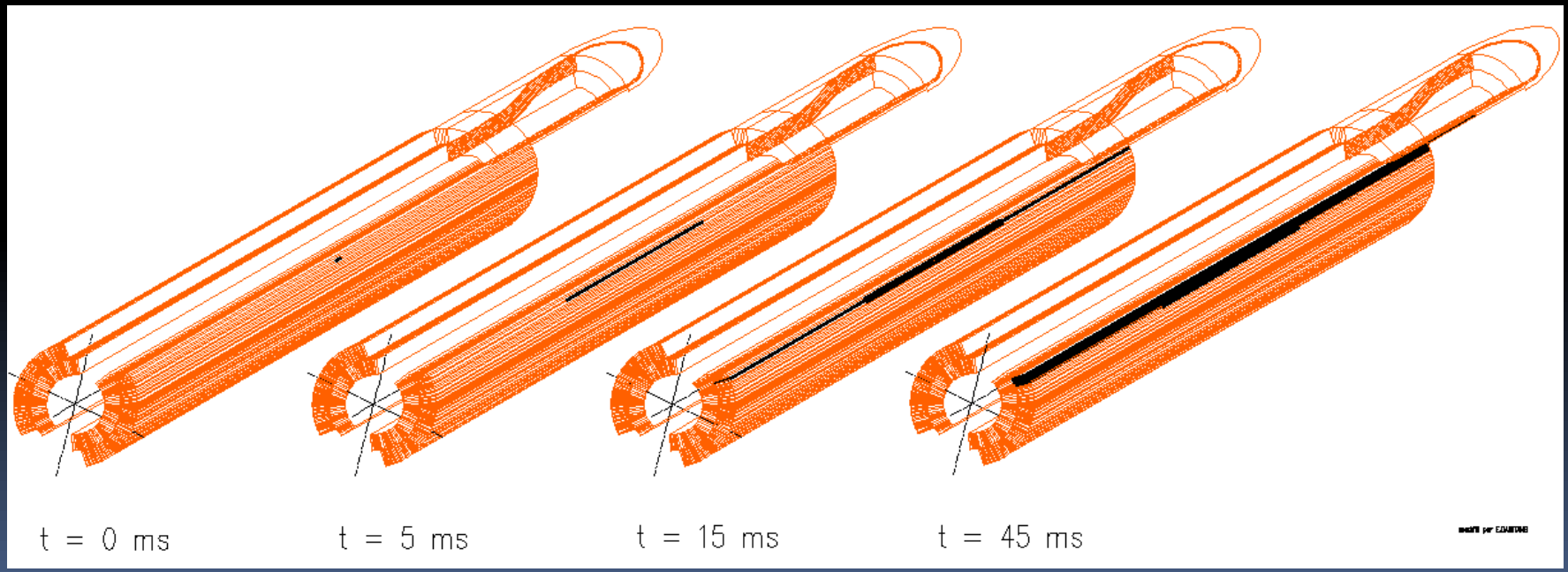


Des perturbations provoquer transitions résistives

- Pendant le fonctionnement, des perturbations peuvent entraîner une brusque transition résistive de l'aimant
  - Energy release in the magnet due to the beam losses
    - Beam losses from non-perfect setting up of cleaning
    - Fast beam losses
    - Beam gas scattering
  - Electrical disturbances
    - Non uniform current distribution in Rutherford cables
    - Strain dependence of critical current, flux jumps
  - Mechanical disturbances
    - Conductor motions
    - Structural disturbances: micro-fractures, cracks, etc.

La propagation des transitions résistives

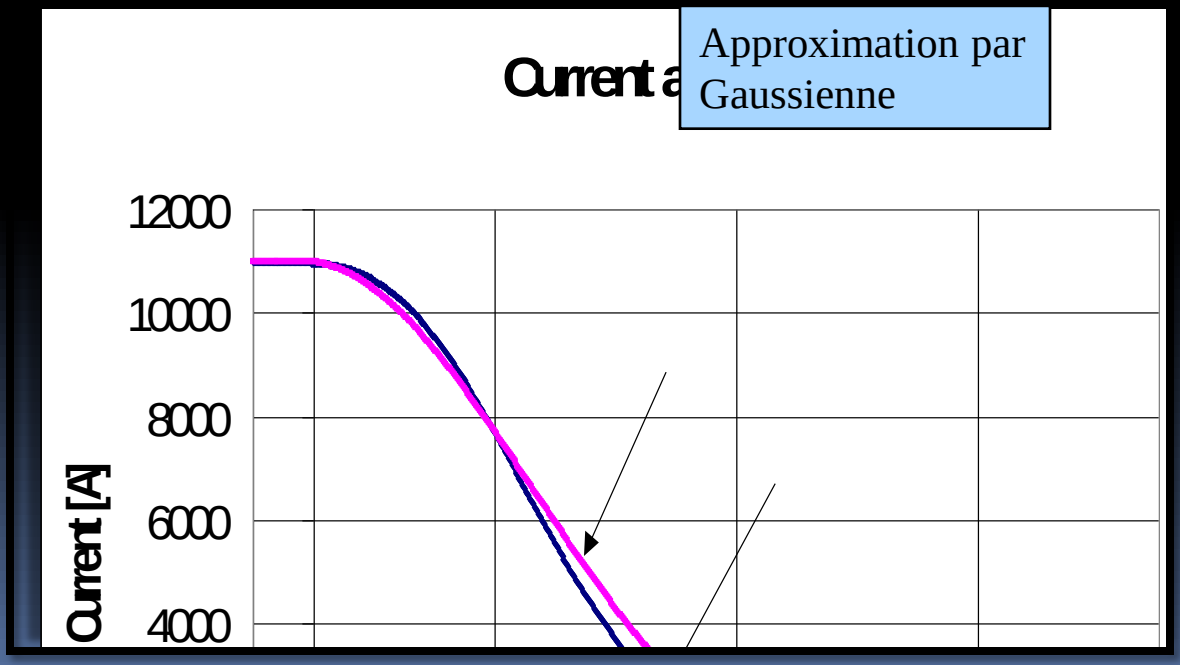
- In LHC dipoles a quench propagates along s.c. cables with average velocity of:
  - 20-30 m/s at 8.34T ↖ >500ms to quench one turn
  - 50-70 cm/s at 0.54T ↖ >21s to quench one turn
- At nominal field quench propagates transversally (turn-to-turn) every ca. 10ms

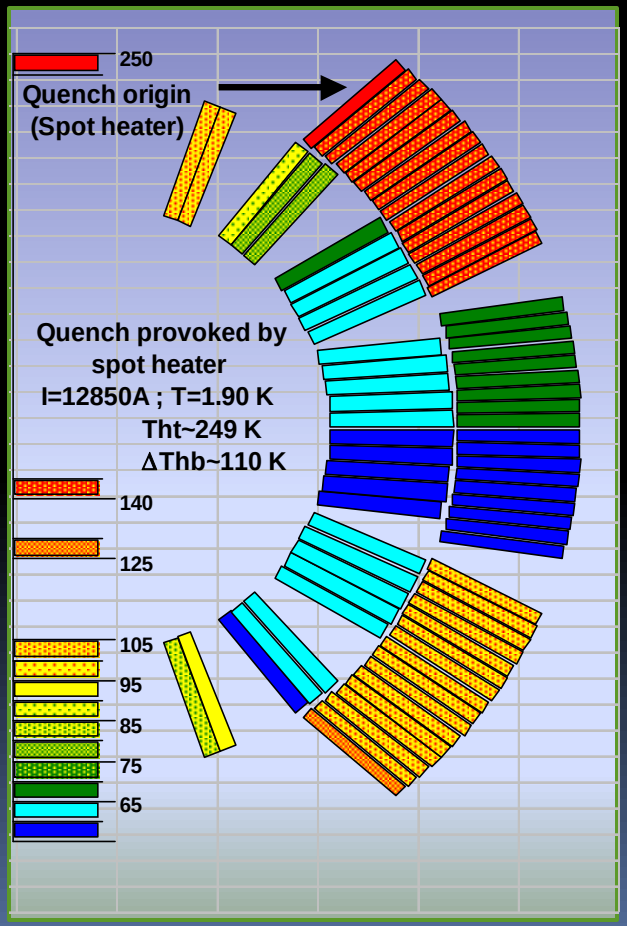


Le «quench»: une montée de température

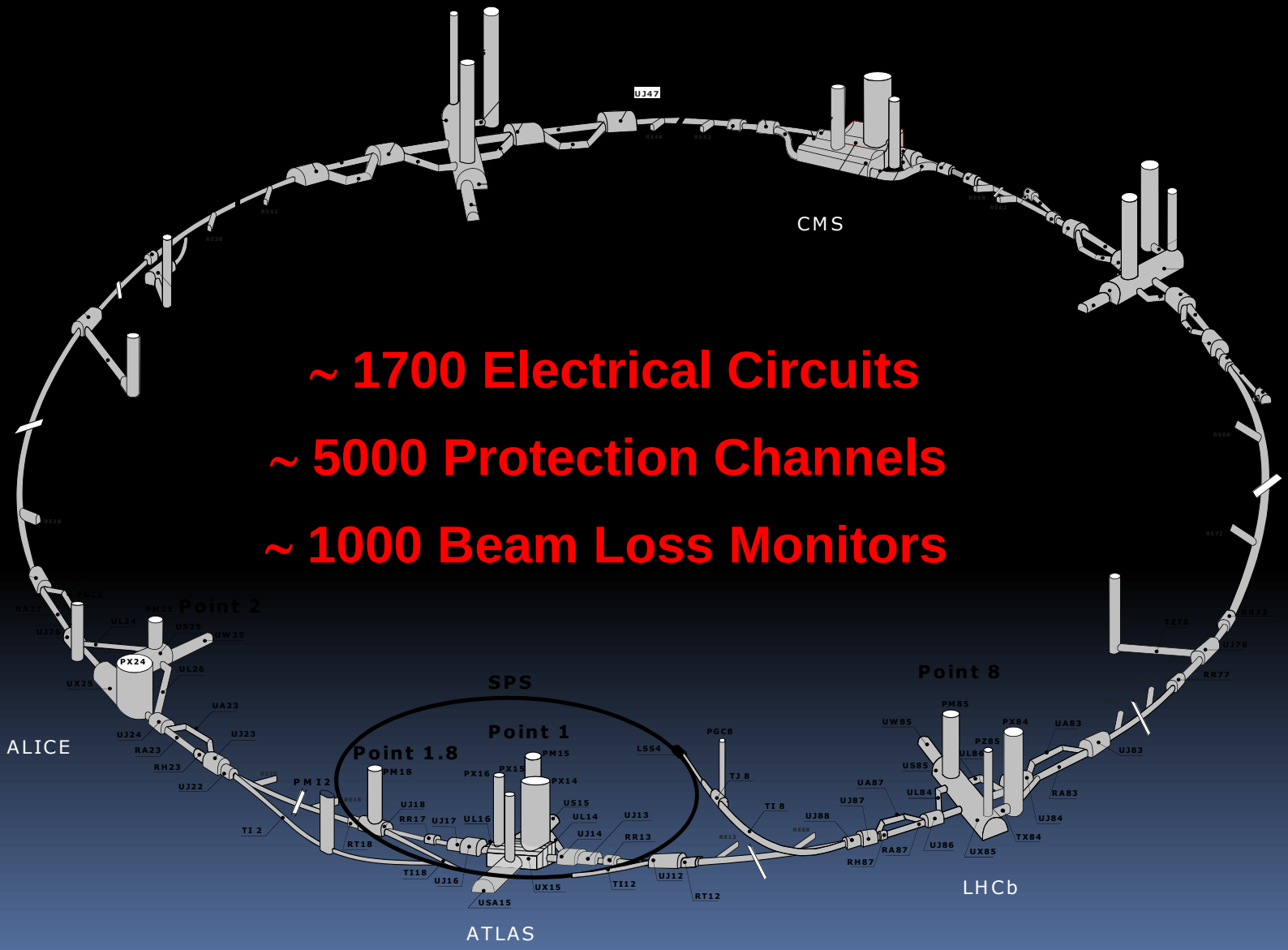
- Une fois que les chaufferettes de protection sont allumées, en moins d'une seconde l'énergie est dissipée dans l'aimant

Courant dans le dipôle après une transition résistive





La protection de circuits supraconducteurs du LHC



Energie stockée dans les aimants supraconducteurs

$$E_{\text{dipôle}} = 0.5 \bullet L_{\text{dipôle}} \bullet I^2_{\text{dipôle}}$$

Avec les valeurs d'opération:

$$E_{\text{dipôle}} = 7.1 \text{ MJ}$$

Pour les 1232 dipôles dans le LHC:

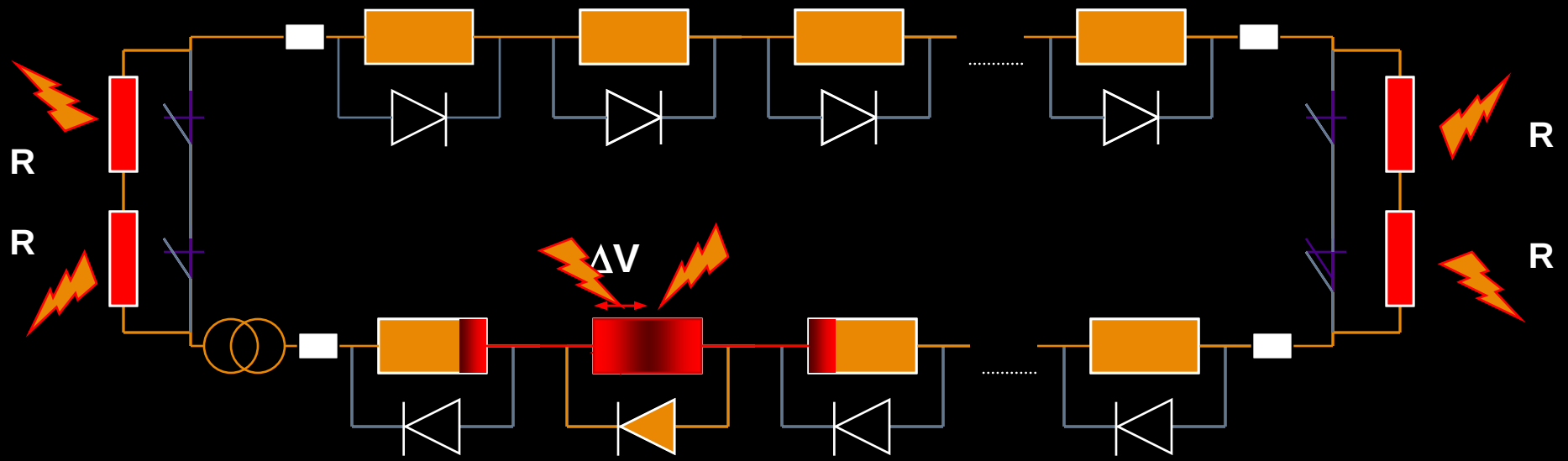
$$E_{\text{dipôle total}} = 8.65 \text{ GJ}$$

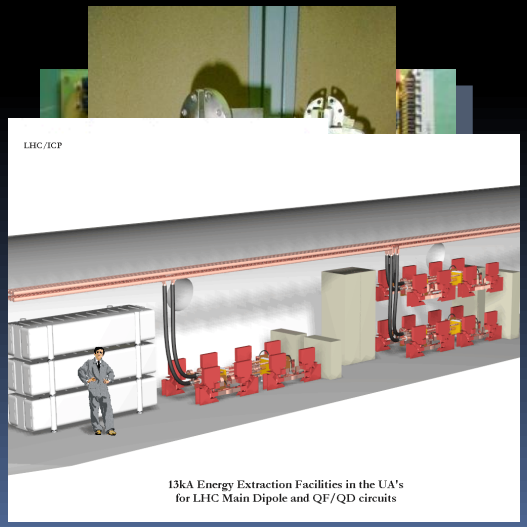
Ordres de grandeur

~9 GJ (1232 dipôles du LHC à 11850A)…

- Correspondent à l'énergie
  - de 1700 kg TNT
  - pour chauffer et fondre 11000 kg de cuivre
  - produite par une centrale nucléaire en 10 s

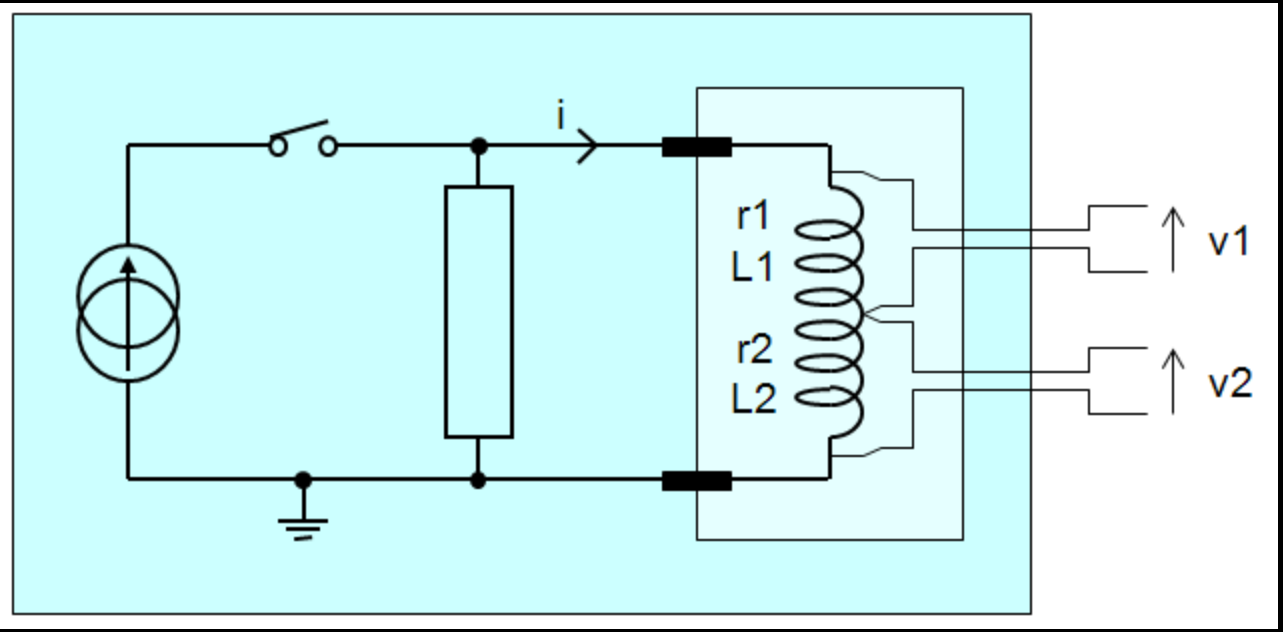
Quench Protection System (QPS)





1. Detection.
2. Propagation artificielle de la transition
3. Isolation de l'aimant qui transite
4. Ouverture des disjoncteurs de puissance
5. Extraction contrôlée de l'énergie de la chaîne τ=104s

Détection de transition résistive



$$v1 = r1.i + L1.\frac{di}{dt}$$

$$v2 = r2.i + L2.\frac{di}{dt}$$

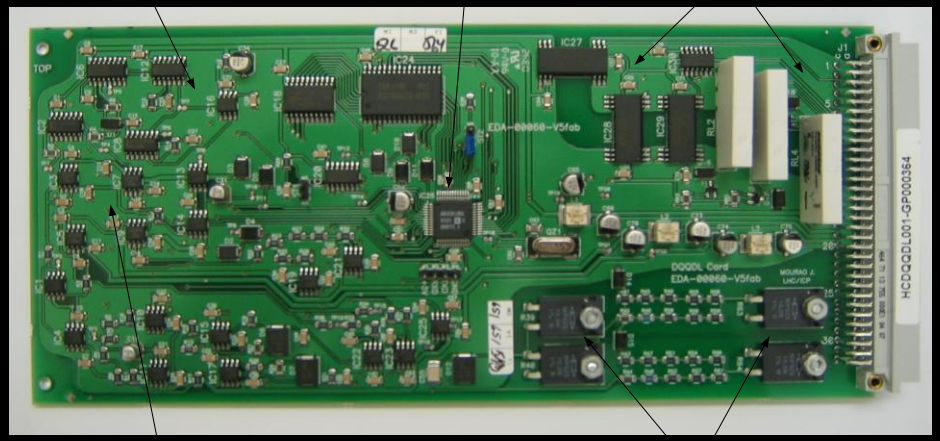
$$v1 - v2 = (r1 - r2).i + (L1 - L2).\frac{di}{dt}$$

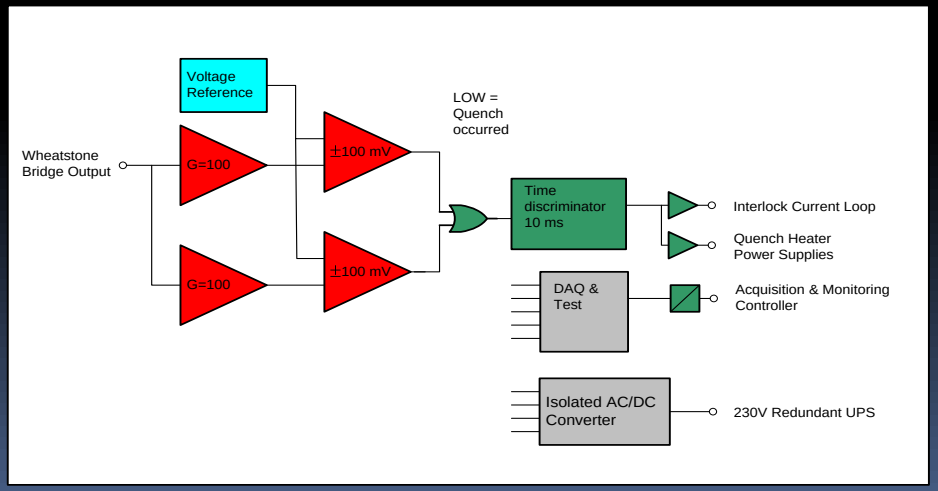
= 0 si supraconducteur

= 0 si les tensions se compensent

Électronique de protection des aimants supraconducteurs

- Analog bridge detector based on state of the art instrumentation amplifiers
- (2 out of 2) || (2 out of 2) hardwired multi-channel evaluation scheme
- Radiation tolerant
- Adjustment free – fixed threshold detector
- Digitally isolated interface – detector circuit on magnet potential
- On-board data acquisition system
- Cost efficient (2500 circuit boards in LHC)





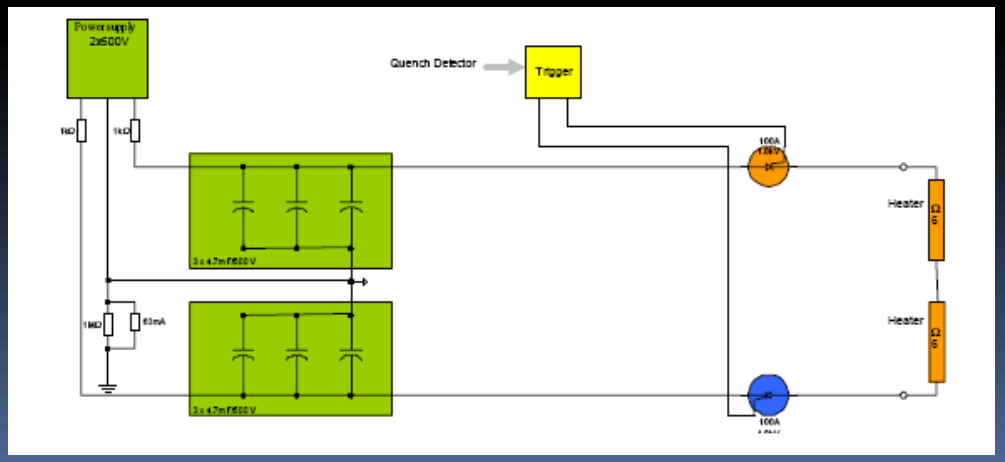
Électronique de protection des aimants supraconducteurs

- High precision digital systems with low detection threshold (U_{TH} = 3 mV) for the protection of HTS leads
- Fast DSP based systems for the protection of corrector and insertion region magnets (including superconducting busbars) and the inner triplets
- Both systems integrated into so-called Global Protection Unit
  - Simultaneous and independent protection of up to 4 superconducting circuits
  - Units control and trigger associated quench heater power supplies

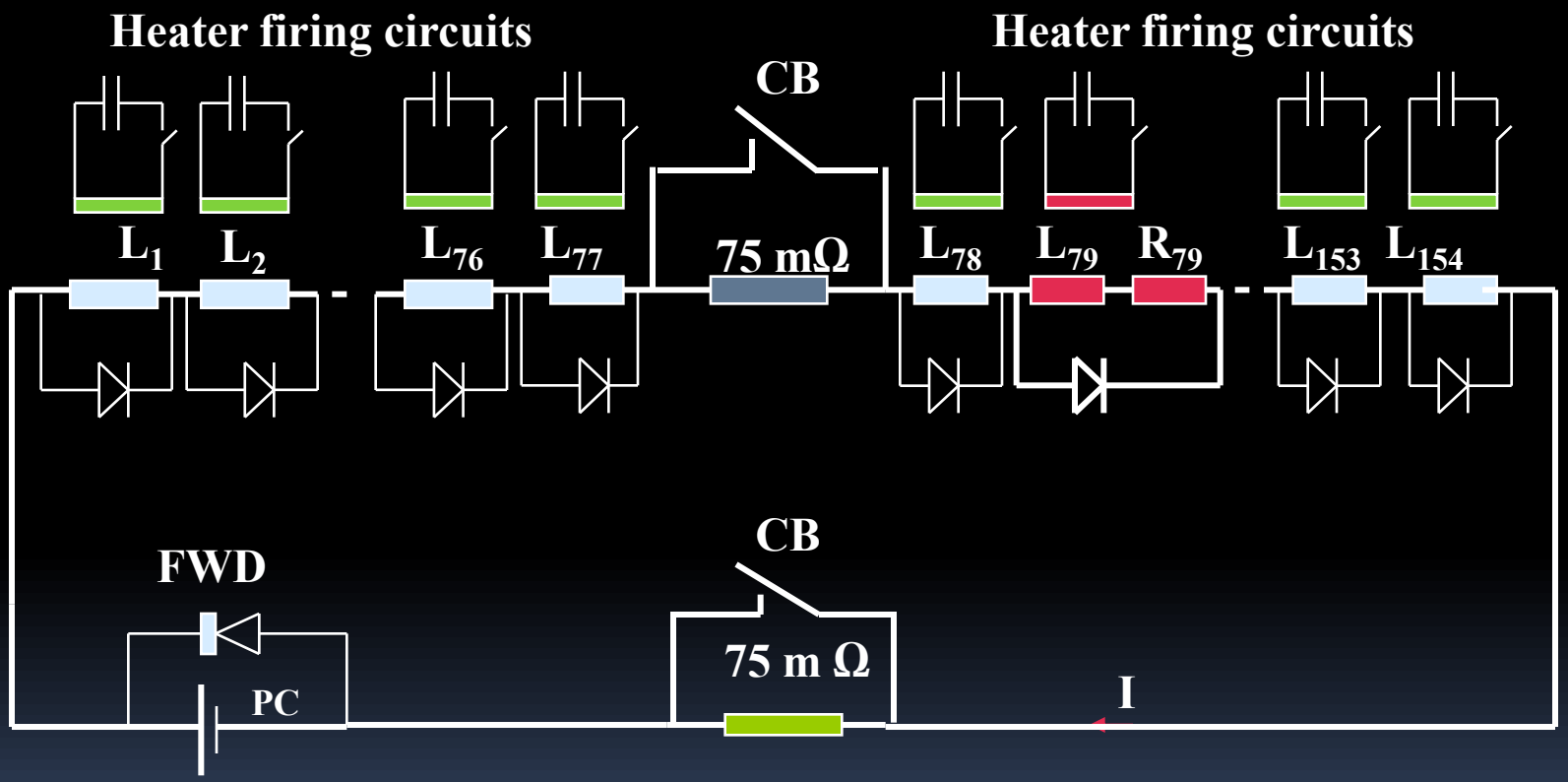
Type A Global Protection Unit for up to 4 corrector magnet circuits. The unit is attached to dedicated 600 A current sensors.

Électronique de protection des aimants supraconducteurs

- Active protection of superconducting magnets with quench heaters
  - Function based on a thyristor triggered capacitor discharge
  - 6200 units in LHC
- Extensive R& D program
  - Component lifetime (Aluminium electrolytic capacitors)
  - Radiation tolerance (main concern: thyristors)
  - Electromagnetic susceptibility
  - Large number of devices



Diodes de «by-pass» installées dans le bain d'hélium à 1.9 K

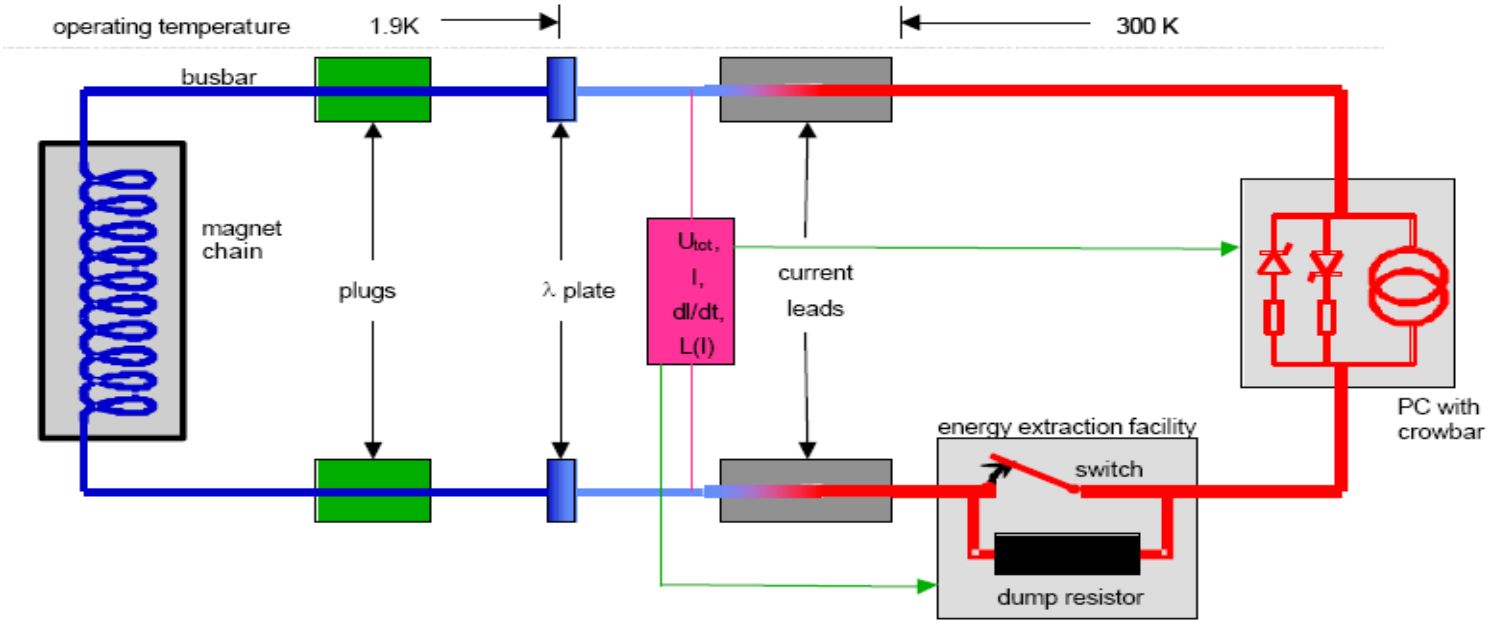


Simplified scheme with individual by-pass diodes for one LHC-Sector

Diodes de «by-pass»

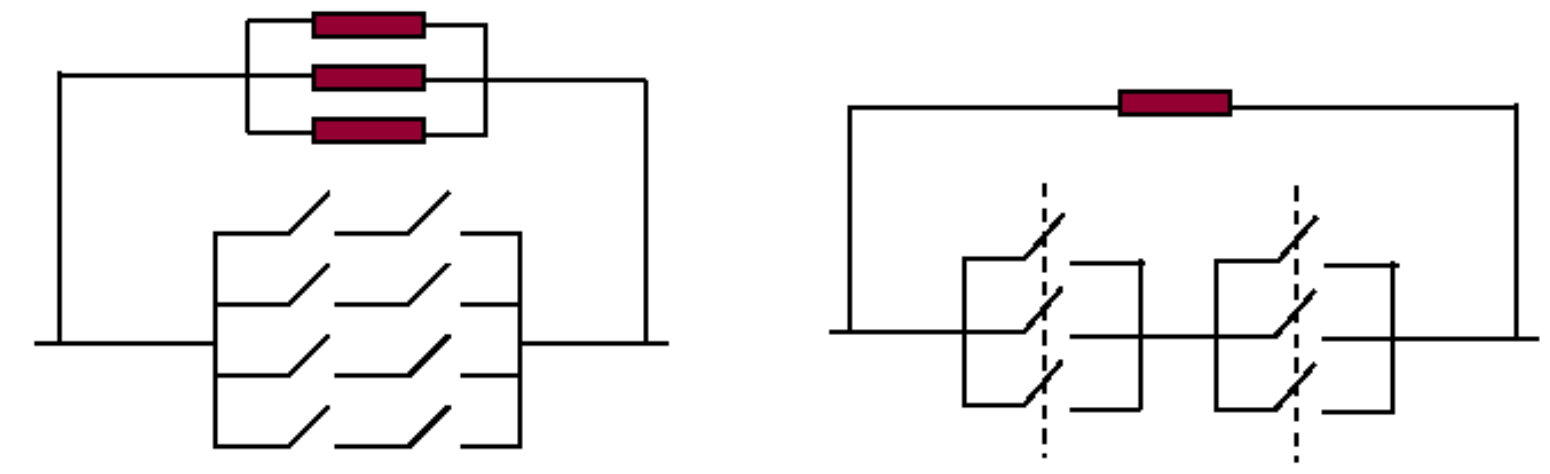
La protection des circuits d’aimants

Energy Extraction



Energy Extraction Systems

- The 200 Energy Extraction Systems represent 296 Tons of Components



13 kA

600 A

Disjoncteurs électromécaniques

Résistances de décharge

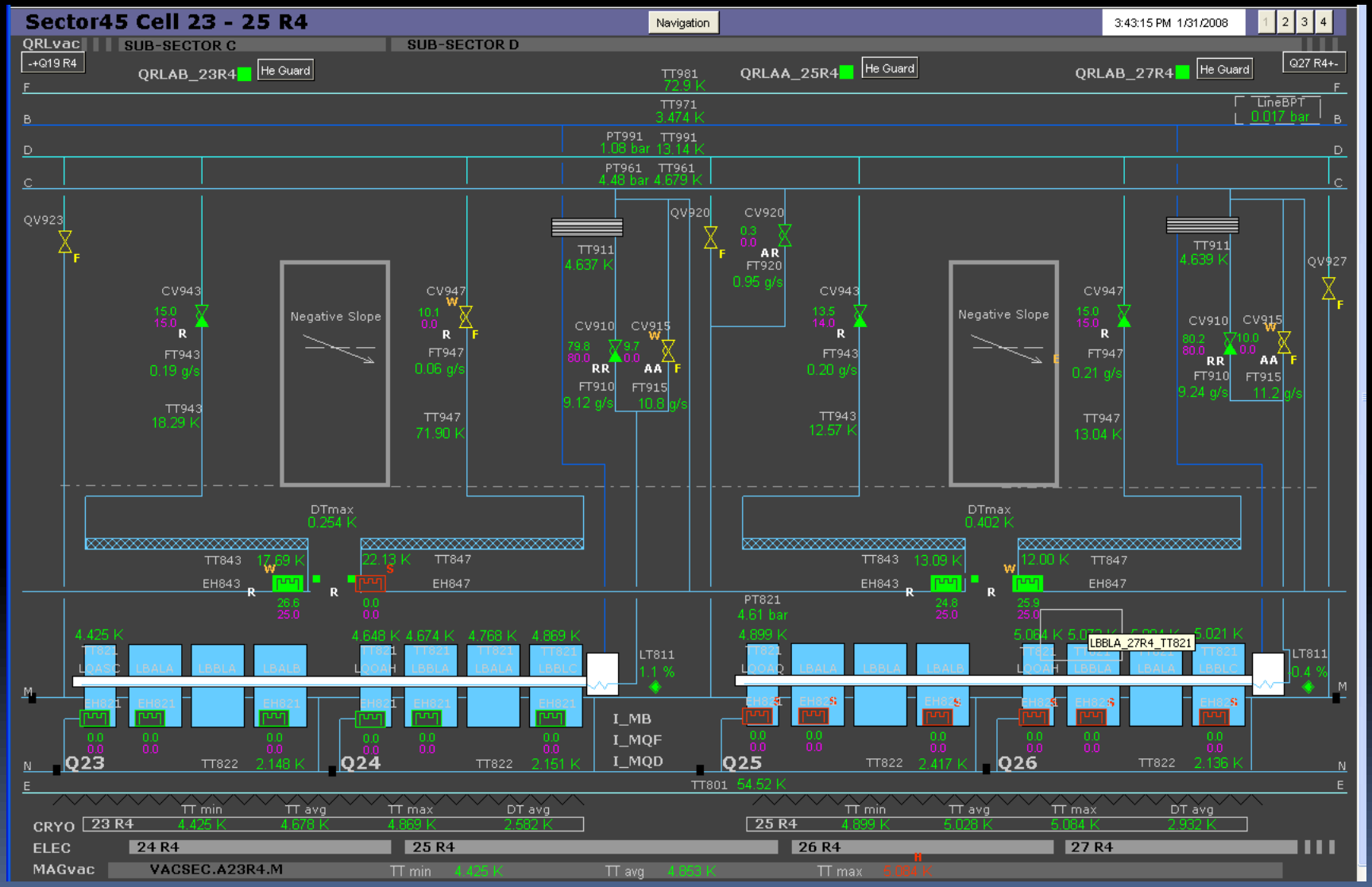
When will Energy Extraction be activated in the LHC?

- Energy Extraction is a part of the normal operating procedures in the LHC machine

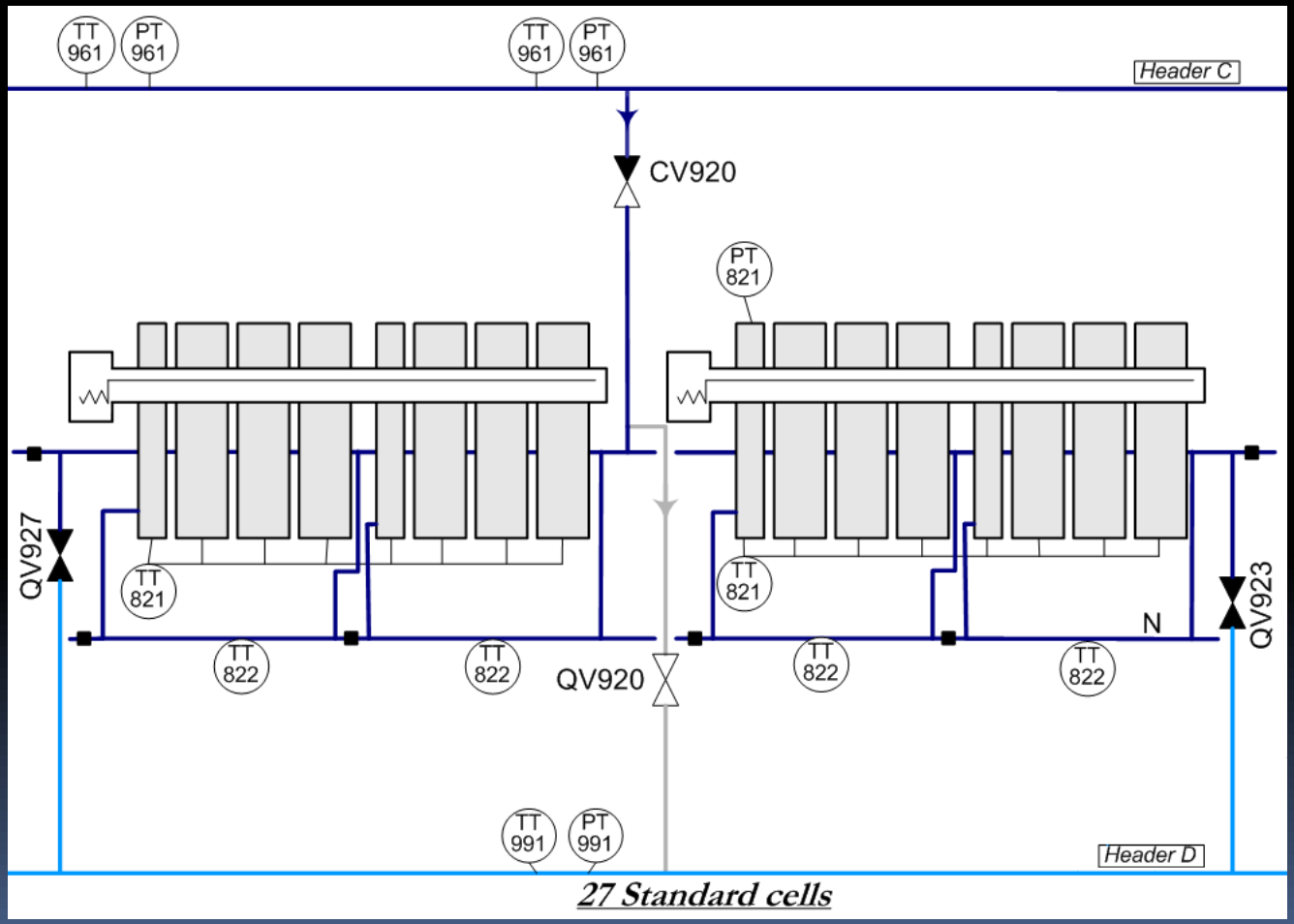
- Energy Extraction will NOT be used for the ordinary de-excitation of the magnet chains. Energy recuperation is possible in some of the circuits (e.g. in the Main Dipole circuits). Operating the converters in inversion will allow power feed-back to the Mains Grid.

- Energy Extraction will be used in following cases:
  - In the event of a quench in a magnet coil, a superconducting busbar or a current lead
  - In the event of a risk of damage to other components in the power circuit (e.g. no water flow for a certain time in the 13 kA water-cooled cables or problems in the by-pass crowbar system or failure in the extraction switches)

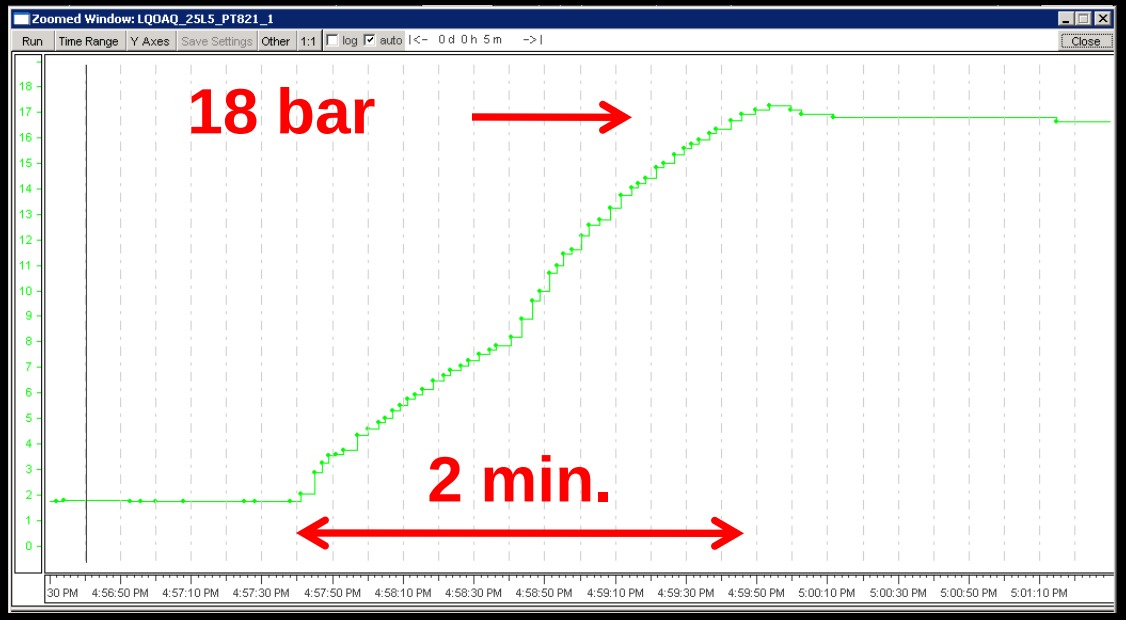
«Quench» - Protection hydraulique



Protection hydraulique par vannes et lignes de décharge

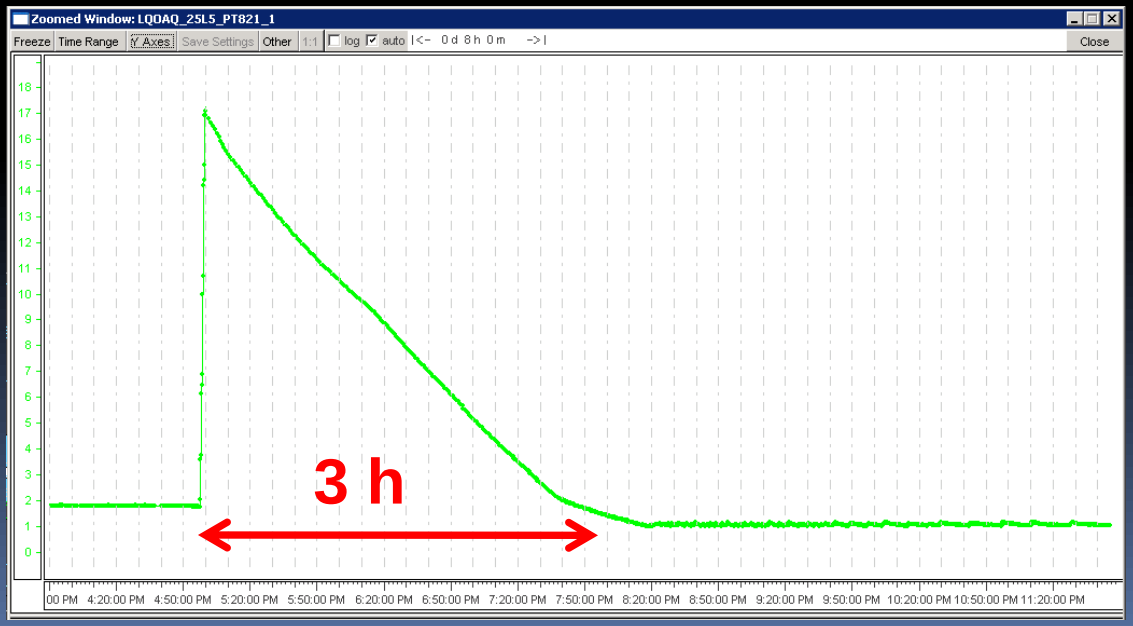


«Quench» - Protection hydraulique

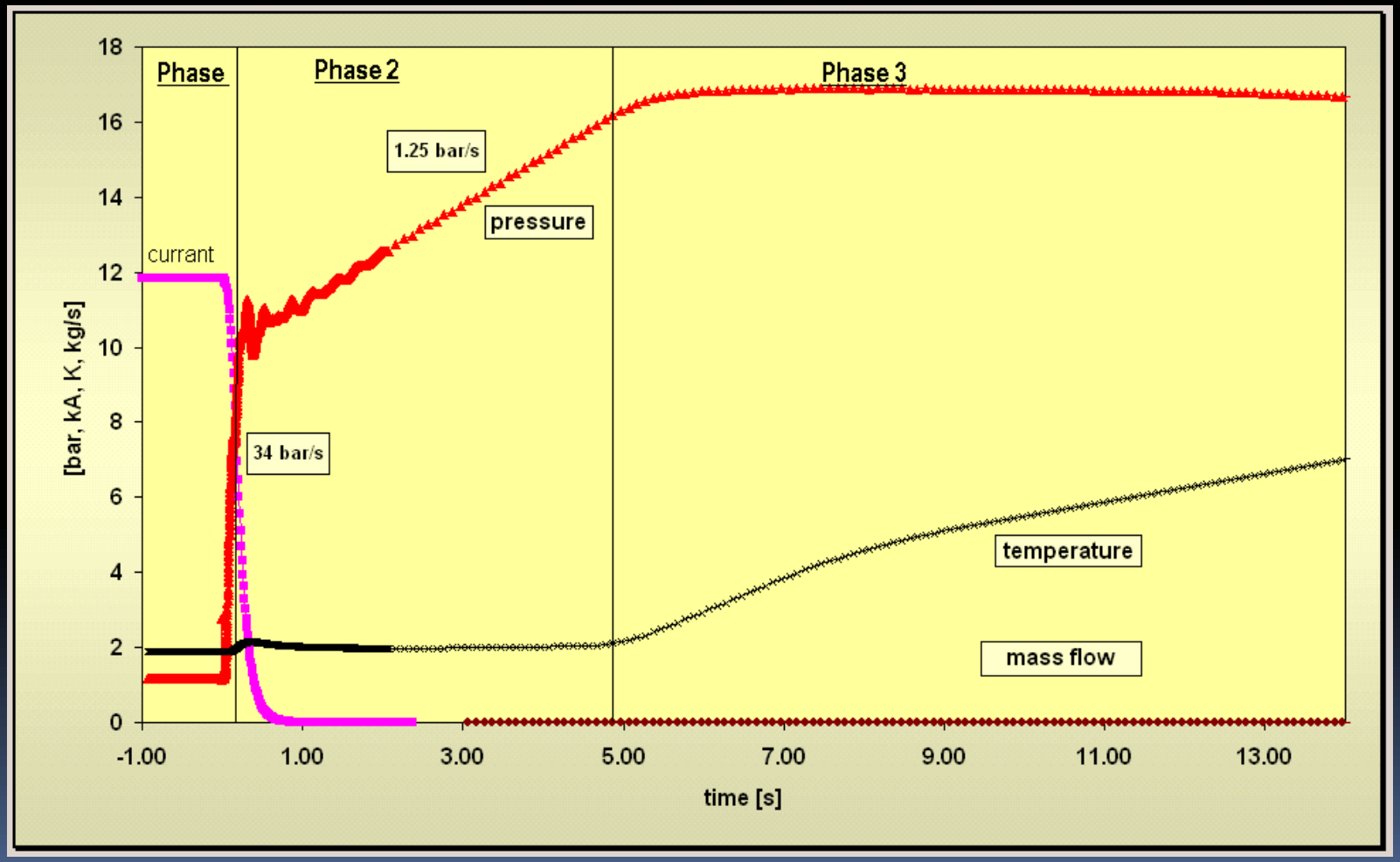


Pressure build-up

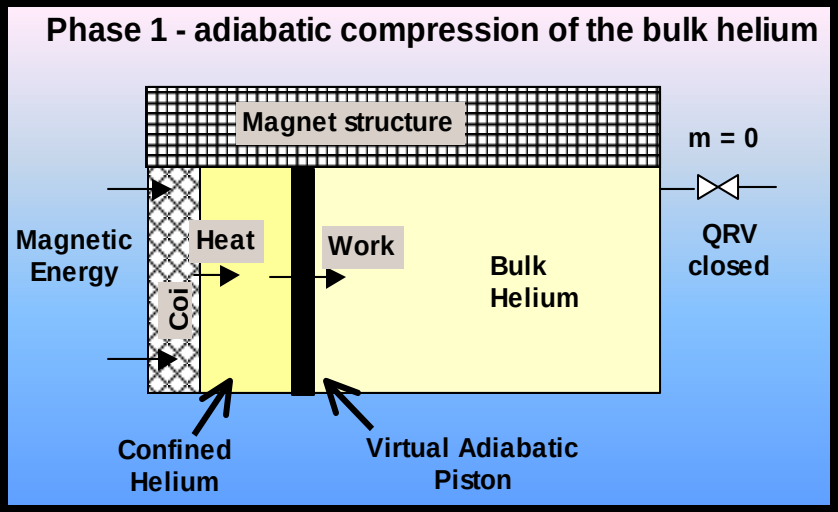
Pressure discharge

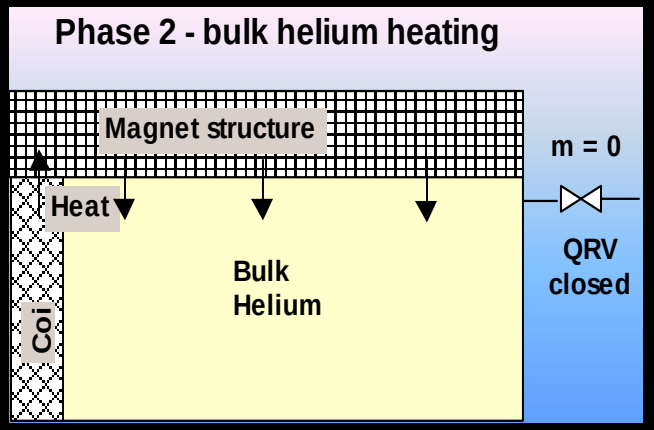


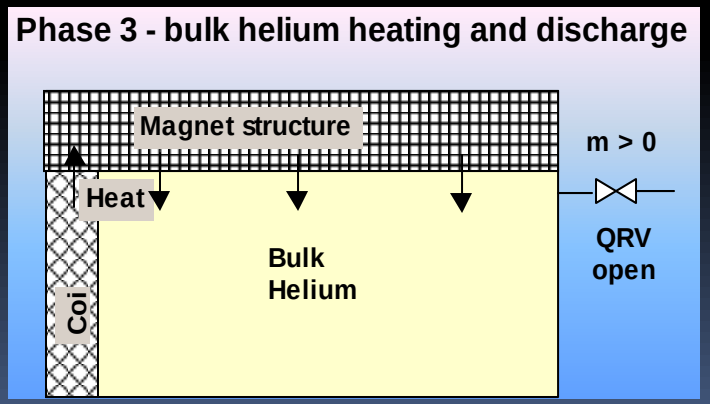
«Quench» - Protection hydraulique modélisation de processus



«Quench» - Protection hydraulique modélisation de processus







Energy balance			Time
	kJ	kW (av.)	s
1st phase	285	1074	0-0.26
2nd phase	217	46	0.26 - 4.7
3rd phase	3382	16	4.7 - 180
TOTAL	***3883***	***22***	

Conclusions

- The LHC as a project, it is much more complex and diversified than any other large accelerator project constructed to date
- The LHC magnet protection system is as well the most complex and diversified system of this type ever built
- The performance of the protection system is of fundamental importance for the collider and must be thoroughly validated before proceeding to run with significant stored beam energy
- Commissioning of the protection system in the first sectors is ongoing and already demonstrated correctness of the functional principles and required performance of the equipment

Remerciement

- K. Dahlerup-Pedersen
- R. Denz
- A. Vergara

Merci de votre attention