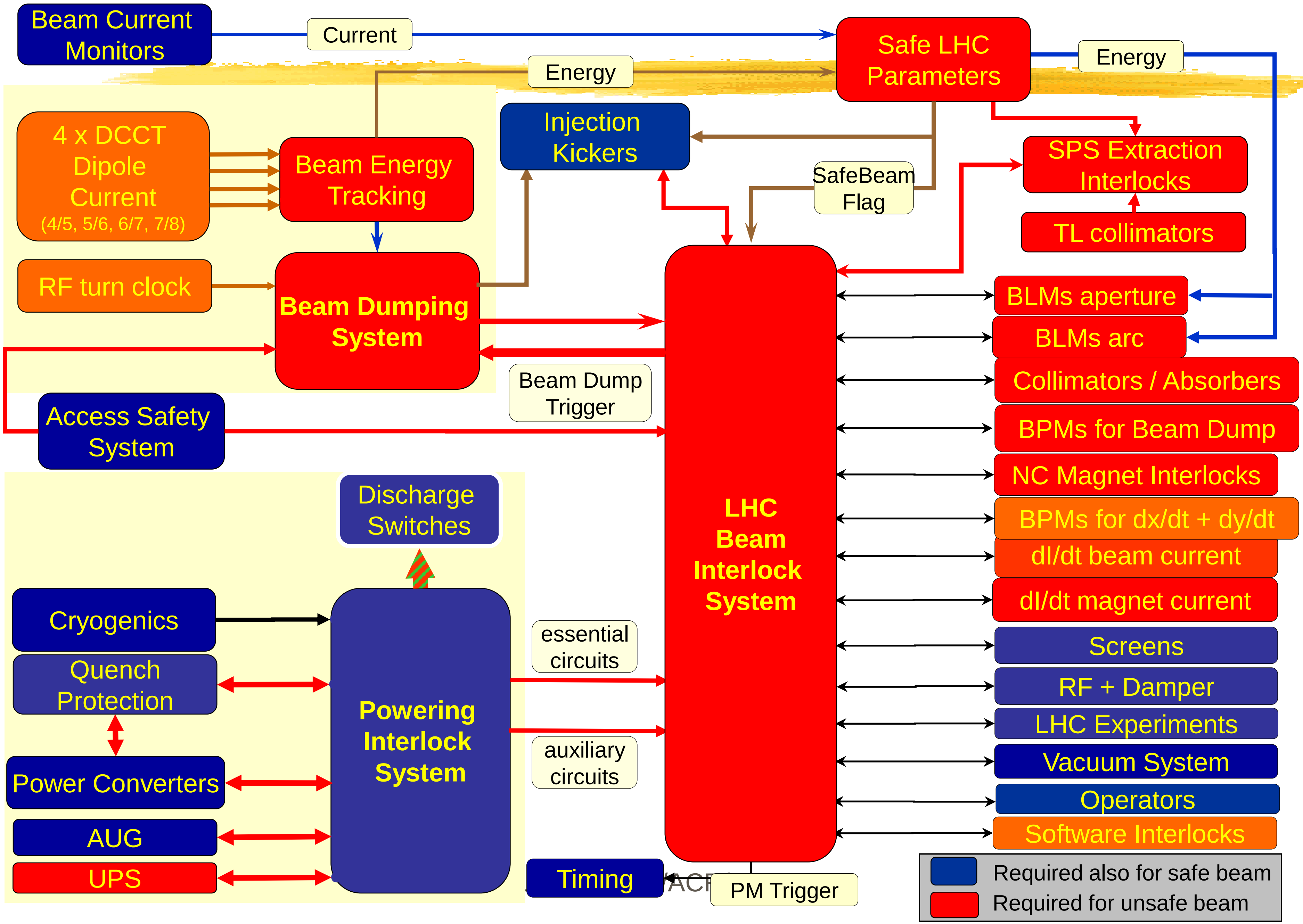
Interface between the cryogenic system and the powering and beam interlock system

L. Serio on behalf of CFAWG

Outline

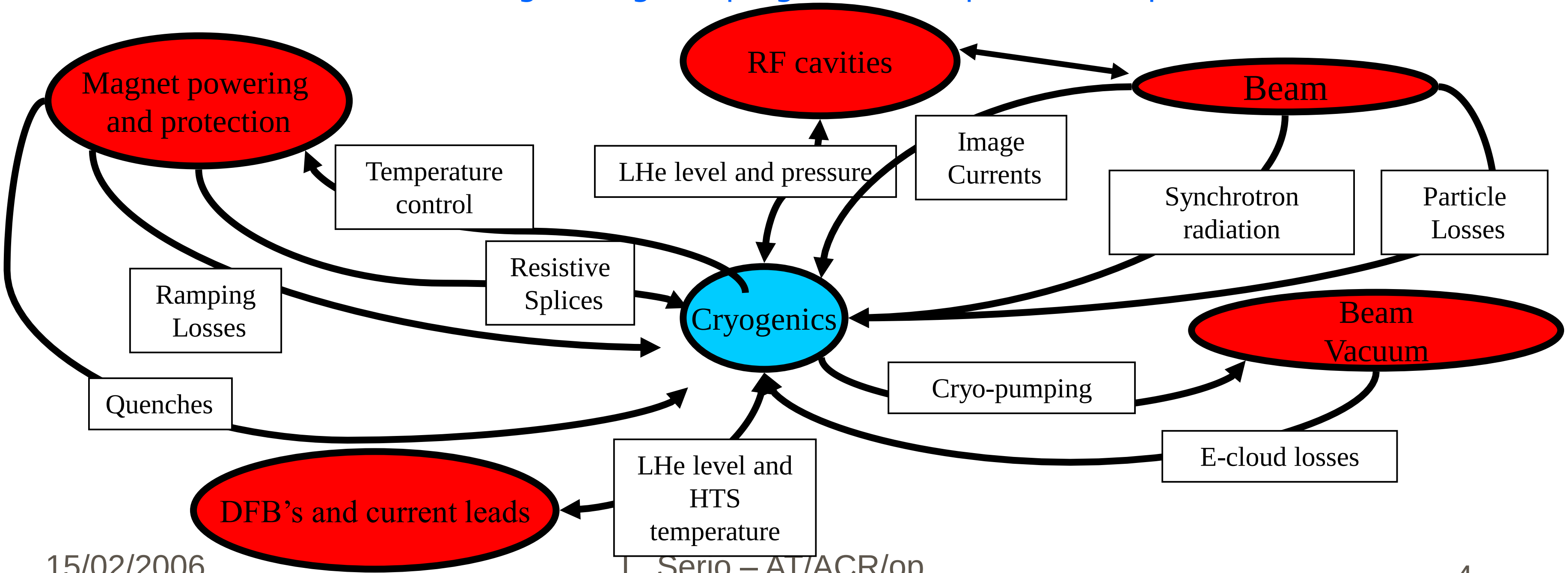
- Introduction
  - Machine protection layout
  - System interaction
  - Cryogenic system layout
  - How cryogenic operators will monitor the system
  - Cryo ok conditions and powering zones
- Cryogenic system transients
  - Injection, fast current discharge, quench recovery
- Cryo Ok considerations and strategies
- Conclusions and alternative strategies

Machine Protection System and connected equipment



Relationship between cryogenics, magnets and beam

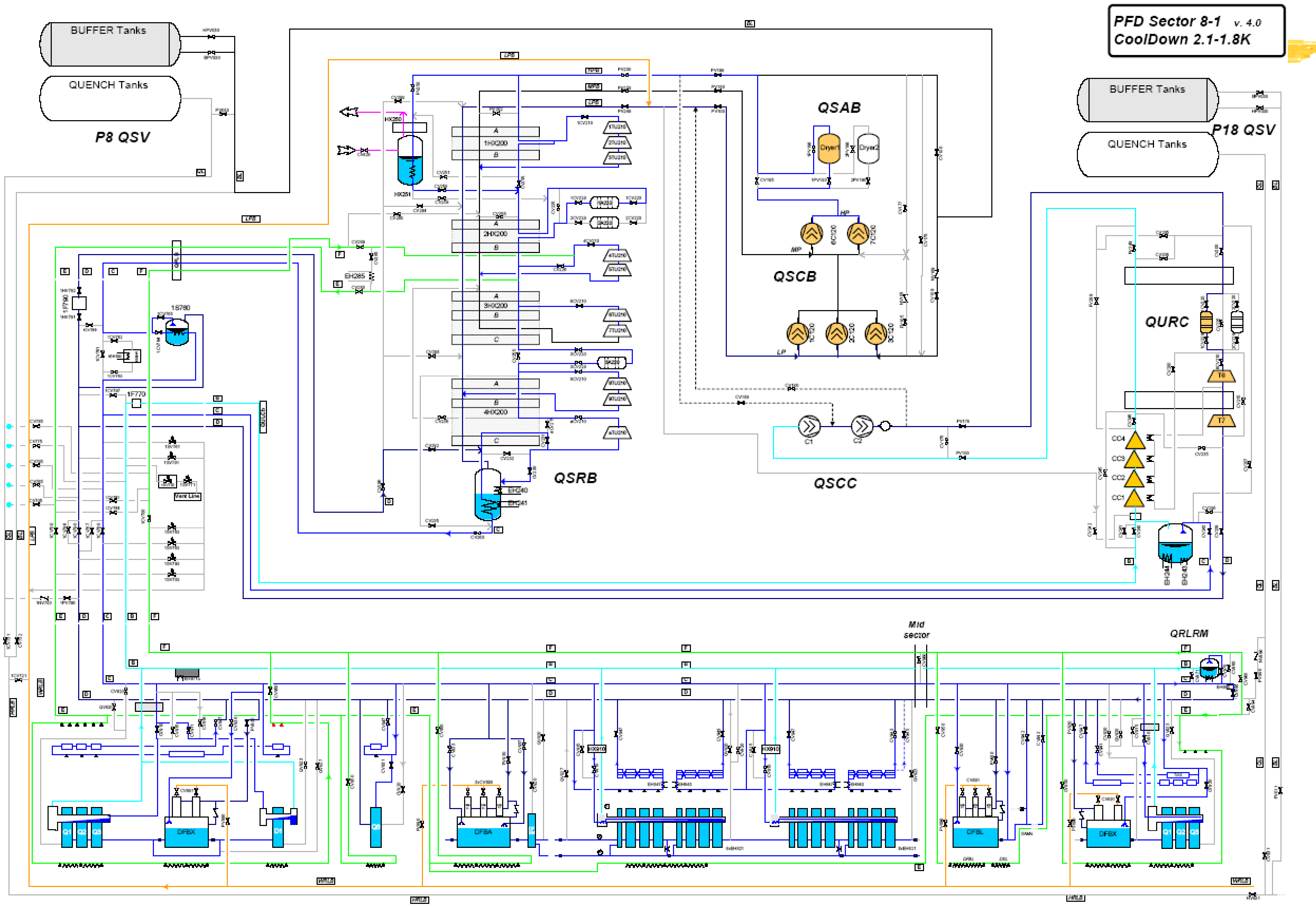
1. Strong reciprocal relationship between the beam and cryogenics
   1. The beam can increase rapidly the thermal loads -thus requiring fast and precise adaptation of the cryogenic system- and eventually quench one or several magnets
   2. Cryogenics can provoke a beam dump if magnets temperature control performances are not correctly tuned and monitored
   3. Cryogenics can disrupt the beam if an incorrect beam screen temperature control provokes gas desorption
2. Strong reciprocal relationship between the magnets powering and cryogenics
   1. Magnet powering requires accurate preparation of the cryogenic system and constant monitoring during ramping to avoid operational quenches



LHC Cryogenic system operation

- 8 sectors
- 8 refrigerators
- 8 cold compressor systems
- 5 Cold interconnecting boxes
- 25 km of cryostats in superfluid helium
- 1400 control loops for c.l. control [powering]
- 320 control loops for magnets T control [powering/beam]
- 600 control loops for beam screen T control [beam]
- few 1000's control loops for cryo operation

Sector Process Flow Diagram



HOW CRYO OPERATORS VERIFY CRYO OK CONDITIONS

CRYO OK conditions

- **CRYO OK for powering:**
  - Superconducting magnets OK
    - Magnets below threshold (1.95 K or 5 K)
    - Beam screen temperature below 25 K
    - Line D (T lowest point above 5 K) and Quench Tanks empty (pressure)
  - DFB's OK
    - Liquid helium level above threshold in DFB (to cover LTS-HTS joint)
    - Current leads temperature below threshold (60 K)
  - RF OK
    - Liquid helium level in RF cavities above threshold and pressure below 1.6 bar (redundant with RF ?)
  - DSL OK
    - DSL temperature below threshold (6 K)
  - Sector refrigerators OK
    - (compressors, cold compressors and turbines running, phase separator above 50 %)
  - Ethernet communication OK

  - The CRYO OK authorise powering
  - The CRYO OK do not abort powering

Powering zones

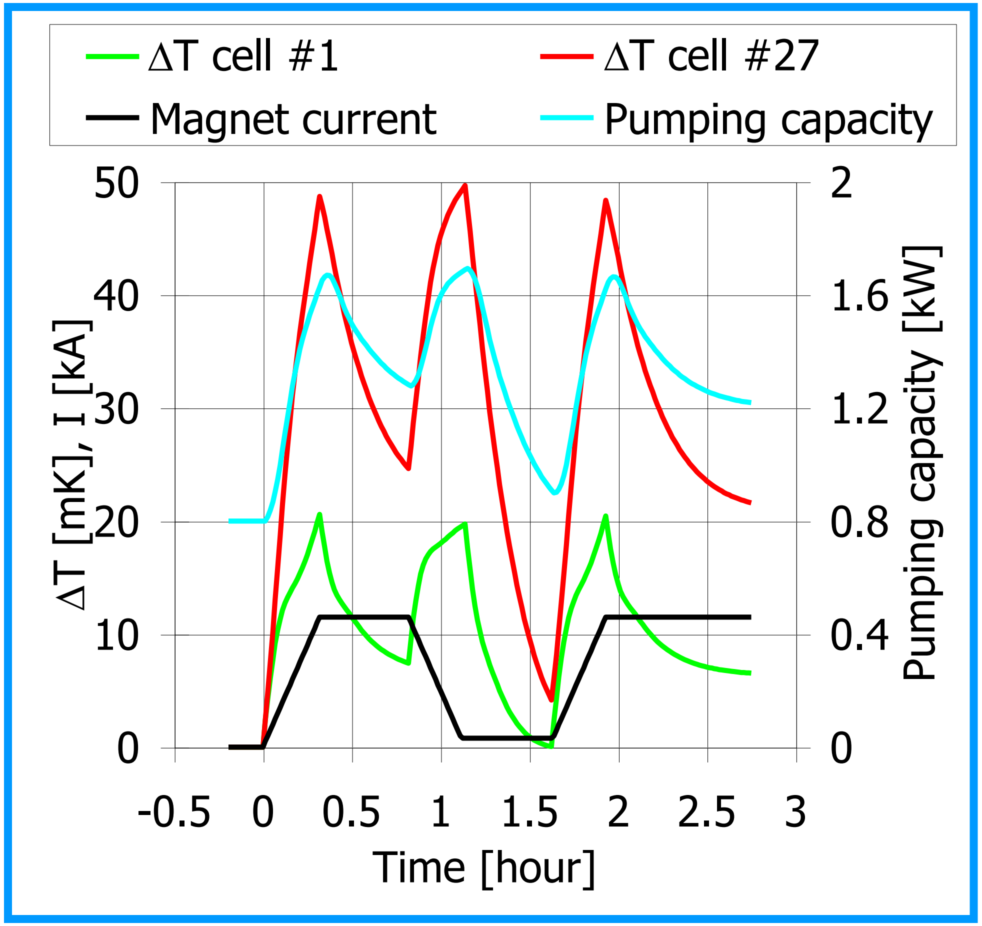
- PHYSICS
  - 1 powering zone for each sector
- COMMISSIONING
  - Powering zones for each continuous cryostat (total of 28 powering zones for the machine)

  or

  - Matrix to enable/disable CRYO OK for powering zone for each circuit

Cryogenic system transients: injection

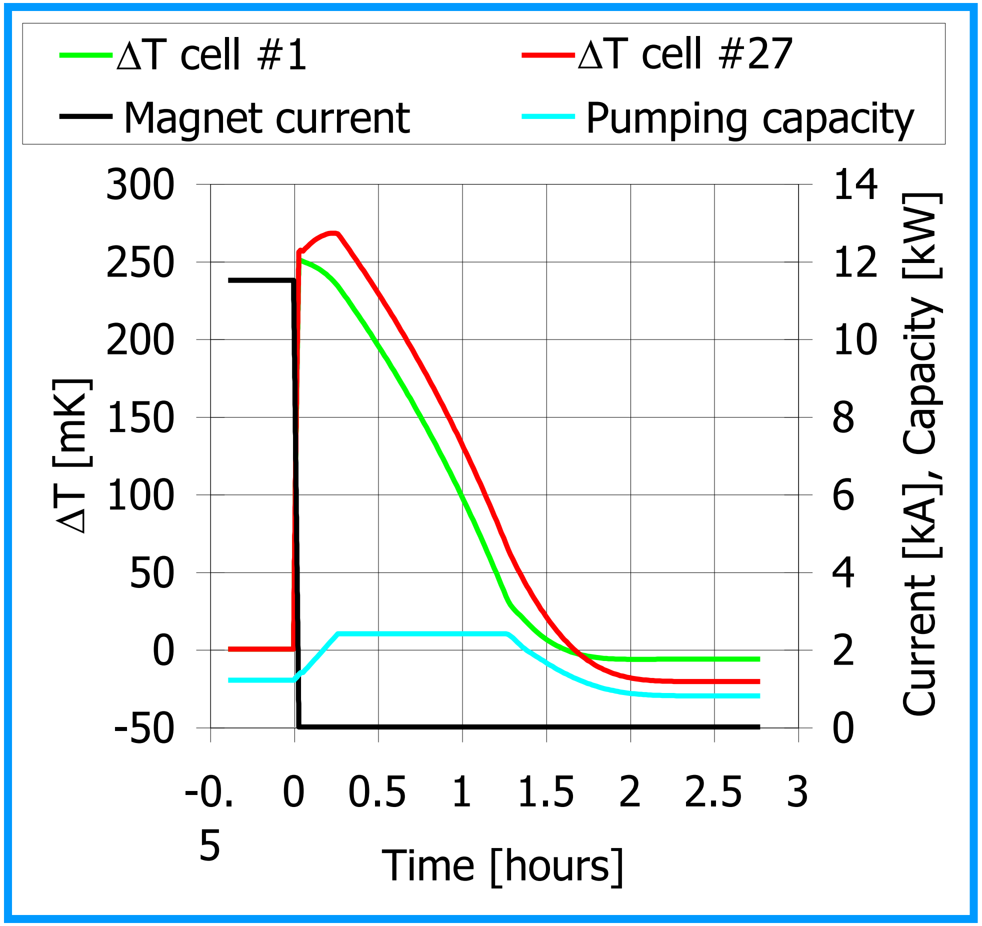
- Temperature Excursion during Injection Sequence



Heat partially buffered by He content (15 l/m)

Maximum temperature excursion: 50 mK

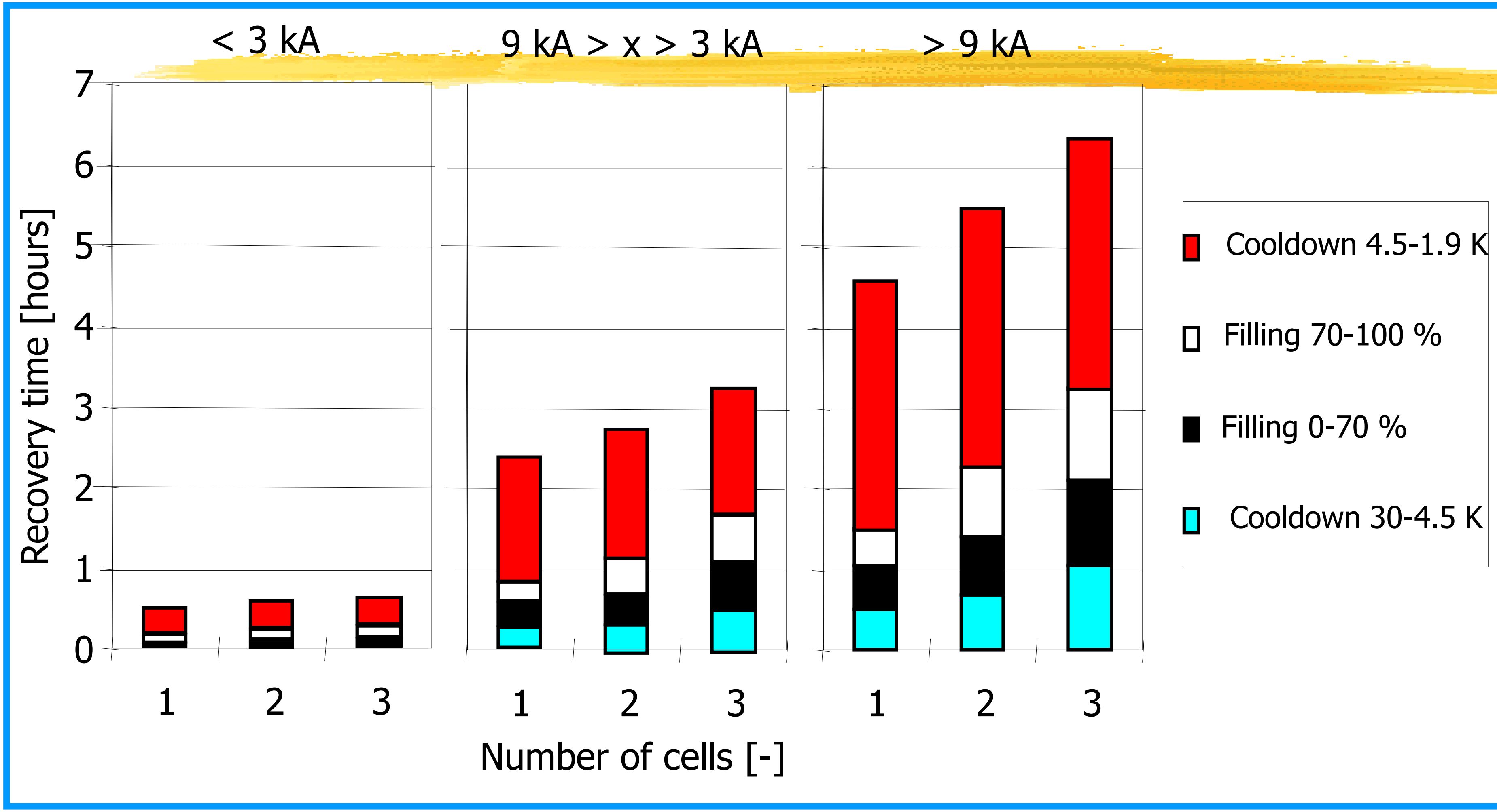
Cryogenic system transients: Fast current ramp-down



Magnet temperature remains below Tλ (He stays in superfluid state)

Recovery time: 2 hours

Cryogenic system transients: quench recovery



- ✓Quench propagation limited to 1 cell
- ✓Several cells or sector recovery anyway limited by cooling power available(up to 48 hours)

CRYO OK considerations

- CRYO OK ensures that the required conditions to power the magnets are met
- CRYO OK gives sufficient margins to "reliably" operate cryogenic equipment (temperatures, pressures, levels)
- CRYO OK does not protect equipment (quench protection, voltage taps, beam monitors, etc.)
- Without CRYO OK the machine can still run (even for several minutes)

RESULTS OF CRYO OK STRATEGIES

- CRYO OK AUTHORIZING ONLY
  - Quench not avoided without operator intervention
    - If correctly judged increased availability of the machine
    - Increase risk on magnet damage (?)
    - Recovery time (only cryo) of about 5 hours
- CRYO REQUEST FOR SLOW CURRENT DISCHARGE
  - Quench probably avoided without operator intervention
    - Decreased availability of the machine
    - Recovery time for each discharge of few minutes
- CRYO REQUEST FOR FAST CURRENT DISCHARGE
  - Quench avoided without operator intervention
    - Decreased availability of the machine
    - Recovery time for each discharge of about 2 hours

Comparison of CRYO OK conditions

- CRYO OK AUTHORIZING ONLY
  - Advantages
    - Can optimize/decide the best moment to abort
    - Increase availability of the system
  - Disadvantages
    - Increased risk of quench
    - Requires constant presence of cryo operator (3x8 shift)
- CRYO REQUEST OF A CURRENT DISCHARGE
  - Advantages
    - Unmanned cryo operation possible
  - Disadvantages
    - Decreased availability of the system

CONCLUSIONS: What solution to adopt ?

- CRYO OK AUTHORIZING ONLY
  - During HC to find the correct settings and therefore maximize the availability of the system
    - Logic for cryo request for current discharge implemented, monitored but not wired to PIC
  - Presence of cryo operator on shift to tune, monitor and find best suitable parameters for cryo OK
- CRYO REQUEST FOR A SLOW CURRENT DISCHARGE
  - Once the system is well known and the settings have been fully validated at different operating conditions
  - It might be required from the beginning if no sufficient resources to have cryo operator in shift

  - Is the beam screen temperature required for cryo request for discharge conditions ?

Conclusions: alternatives

- **CRYO OK for powering:**
  - Superconducting magnets OK
    - Magnets below threshold (1.95 K or 5 K)
    - Beam screen temperature below 25 K
    - Line D (T lowest point above 5 K) and Quench Tanks empty (pressure)
  - DFB's OK
    - Liquid helium level above threshold in DFB (to cover LTS-HTS joint)
    - Current leads temperature below threshold (60 K)
  - RF OK
    - Liquid helium level in RF cavities above threshold and pressure below 1.6 bar (redundant with RF ?)
  - DSL OK
    - DSL temperature below threshold (6 K)
  - Sector refrigerators OK
    - (compressors, cold compressors and turbines running, phase separator above 50 %)
  - Ethernet communication OK
- **CRYO request for current ramp-down or discharge:**
  - Magnets above (2 K or 4.7 K)
  - Liquid helium level below threshold in DFB (to cover LTS-HTS joint)
  - Liquid helium level in RF cavities below threshold or pressure above 1.6 bar
  - Current leads temperature above threshold (60 K)
  - DSL temperature above threshold (6 K)
  - **i.e. consider only conditions that will rapidly (few minutes) provoke a quench (magnets, current leads, bus-bars)**