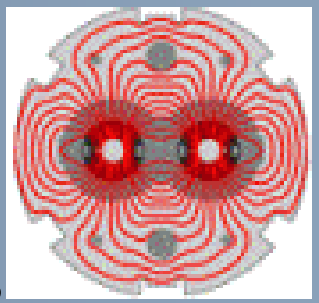
What else needs to be done, to reach 5 TeV and beyond? Consolidation and commissioning of essential magnet powering systems



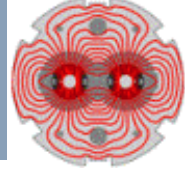
Preconditions for operating at 5 TeV in 2010

Session 1 - 25th January 2010

W. Venturini Delsolaro

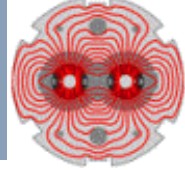
With many thanks to
Z. Charifoulline, N. Catalan Lasheras, K. Dahlerup Petersen, S. Claudet,
M. Giovannozzi, R. Mompo, A.Perin, O. Pirrote, L. Tavian, J. P. Tock, Y. Thurel

Content



- Engineering changes after the incident of 19th September 2008, which need considering for running at higher energies
  - DN200 (installation not complete)
  - nQPS
  - New energy extraction resistors
- Non conformities
  - Magnet circuits
  - Vacuum and Cryogenics
- Summary

Content



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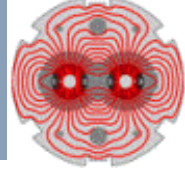
New dump resistors (ECR 1013572)



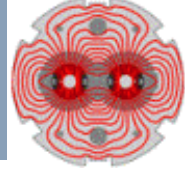
Higher dump resistances/shorter extraction times →
Tolerate higher joint resistances

circuit	$R_{dump\ old}$ (mΩ)	$R_{dump\ new}$ (mΩ)	Tau old (s)	Tau new (s)
RB	73	146	104	52
RQF/RQD	8.4	28.4	31.3	9.2

Drawbacks:
Higher $di/dt = -I_0/\tau\ Exp(-t/\tau)$ → (risk of spurious QPS triggers)
Higher voltages (switch limit, PC, QPS)

Wish to keep as short as possible time constants also at higher energy, but ….

Limitations on extraction voltages



- Switch arc chambers: 1000 V for RB, 200 V for RQF/D
- PC: $I < 1000/R_{dump}$ for RB, $I < 5000/R_{dump}$ for RQF/D (in case of single earth fault)
- Voltage limitation for the Symmetric quench detection input (depends on the-unknown-number of simultaneous quenches)
- Dump resistor (heating): 51 s ok for 5 TeV

From 25th LTC minutes*: "decay time of 68 s could be used for 5 TeV operation and 51 s for 4 TeV operation fulfilling all requirements For the quadrupoles the corresponding numbers were 15 s and 10 s "*

from the approved ECR: 51 s ok for 4 TeV…"*provided that the common mode limit of the PC is raised by 4%*"

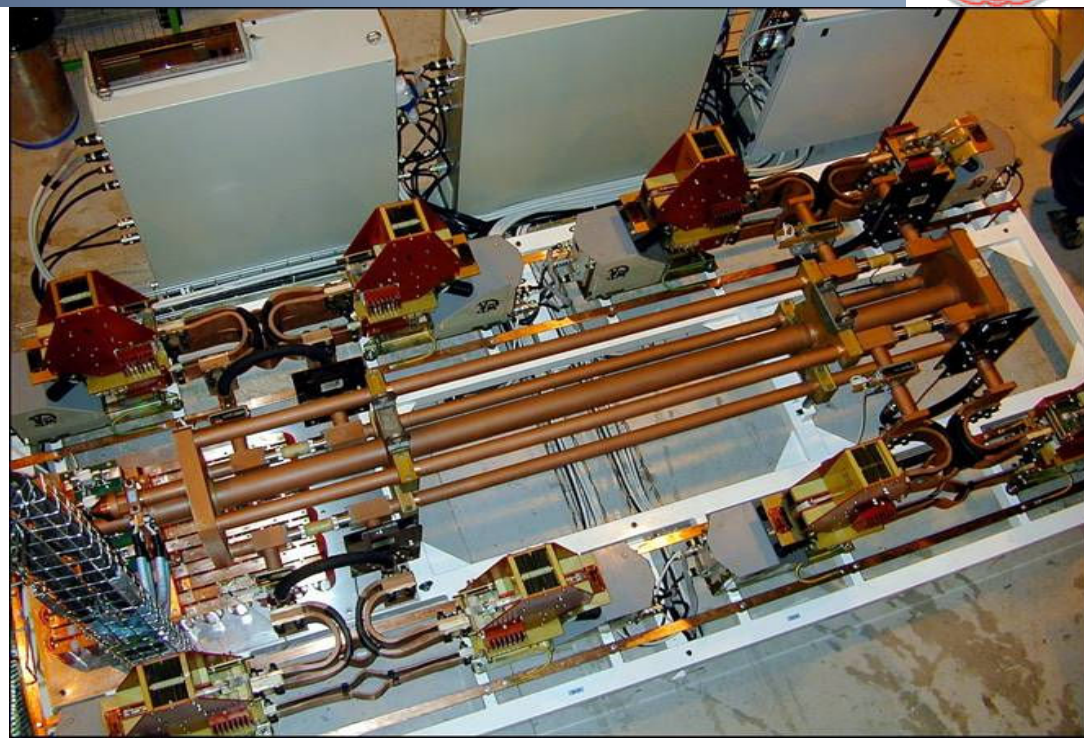
Snubber capacitors

In parallel with the dump resistors:
4x13 mF for the RB,
4x40 mF for RQF/D

Reduce peak di/dt

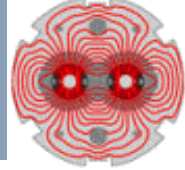
Reduce the voltage wave amplitude

Push the rise of the voltage to later time when the switch is open and the arc is extinguished



NB: the PC limit in case of earth fault, for the RB, is by design the same as the one of the switch, but is not affected by the capacitor!

Snubber capacitors



Measurements of commutation over-voltages were done to validate the design choices

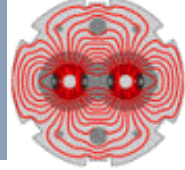
(Arcs are difficult to simulate, need extensive testing in the lab)

Planned to fully equip 1 sector for the 3.5 TeV run, to gain experience

The rest will be tested during beam operation and will have to be installed before the run at 5 TeV

Installation will take at least 2 days per sector, (parallelism possible)

QPS old and new



- "Old" QPS: protection threshold was raised up to 240 mV for few magnets giving triggers due to transient aperture unbalances at switch opening.

  OK for higher energies? (yes, up to 5 TeV)

  OK for smaller time constants? ($I_{max} \approx 150\ \tau$)

- Symmetric quench detectors can fire heaters in case of spurious triggers, due to small differences of inductance between magnets, or voltage waves

  Ok for smaller time constants? Problem of "blinding"

- New extended bus-bar protection, very many channels, very sensitive, very low thresholds.

Is inductive compensation valid at all energies?

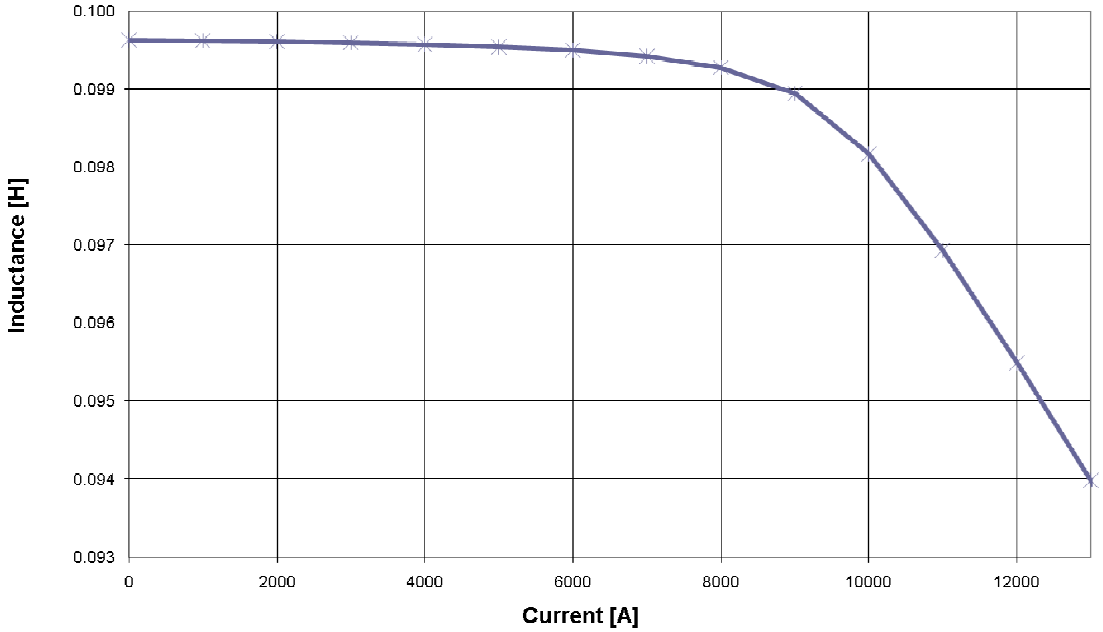
Inductive compensation of nQPS

$V_{splice\ res} = V_{bb} - L_{bb}\,(di/dt)_{calc.}$

$(di/dt)_{calc.} = V_{dipole}/L_{dipole}$

$L_{dipole} = f(i)$

1% change
between 2 and 9kA



→ at 5 TeV and 10 A/s we should develop 20 μV for a perfect splice
→ ≈ 250 μV during fast discharge with τ=68 s

OK, and it can be further reduced by compensating at higher current

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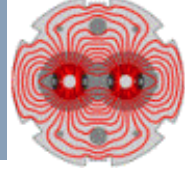

- Engineering changes after the incident of 19th September 2008, which need considering for running at higher energies
  - nQPS
  - New energy extraction resistors
- **Non conformities**
  - **Magnet circuits**
  - **Vacuum and Cryogenics**
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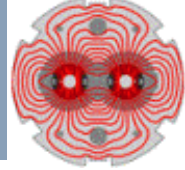
Magnets limitations (I): weak MCBY



Most difficult case: RCBYHS5.R8B1: I_PNO=30 A with nominal di/dt.

13 A required at 3.5 TeV - 48 A at 5 TeV (for different optics).

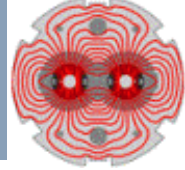
Was tested with a different power converter (600 A) giving the same result (Y. Thurel, EDMS 1053978)

Fault mechanism is not understood (seems coming from the magnet: weak inter-turn insulation is not at all excluded)

Present solution: limiting the current, the current ramp rate, or both

some of these are needed to generate the crossing angle, the limitations introduce constraints on the possible physics schemes

Magnets limitations (II): 600 A



RCBX circuits, limitation on di/dt and d^2i/dt^2 due to:

vapor cooled leads: present solution is not the best!
More robust alternatives should be pursued now (ALARA)

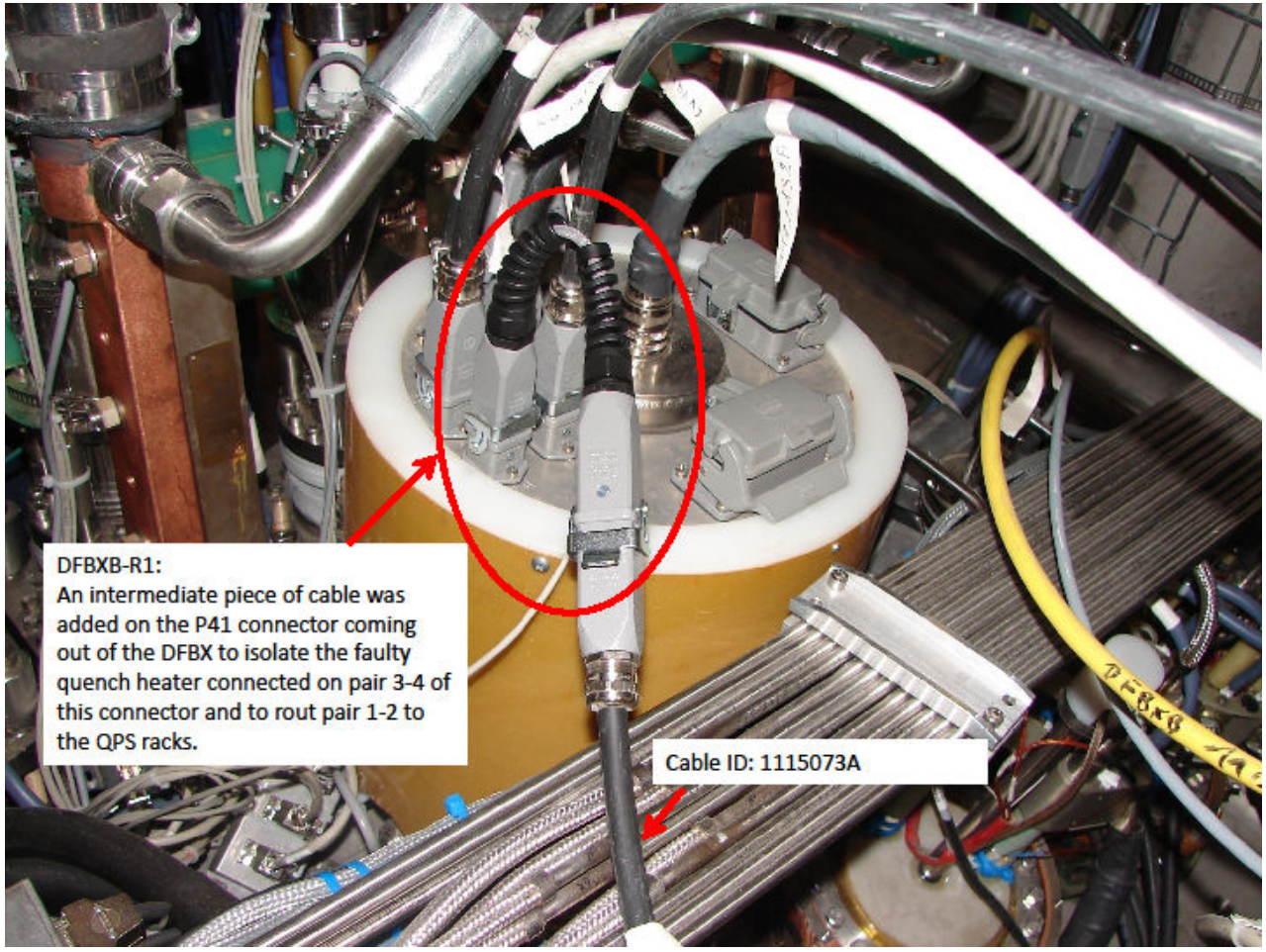
QPS sensitivity to ramp rates and acceleration: dedicated MP3 study aimed at relaxing protection thresholds

Other 600 A sensitive to ramp rates :
QPS calibration will be enforced by the sequencer,

in some cases the problem is still the 0V crossing of the power converter
Not a hard limit for 5 TeV, but may limit flexibility, for example on crossing schemes

Magnets limitations (III): RQX.R1

- RQX.R1 non conform quench heater . Was Ok for 3.5 TeV with the remaining heater. New configuration not yet validated for 5 TeV



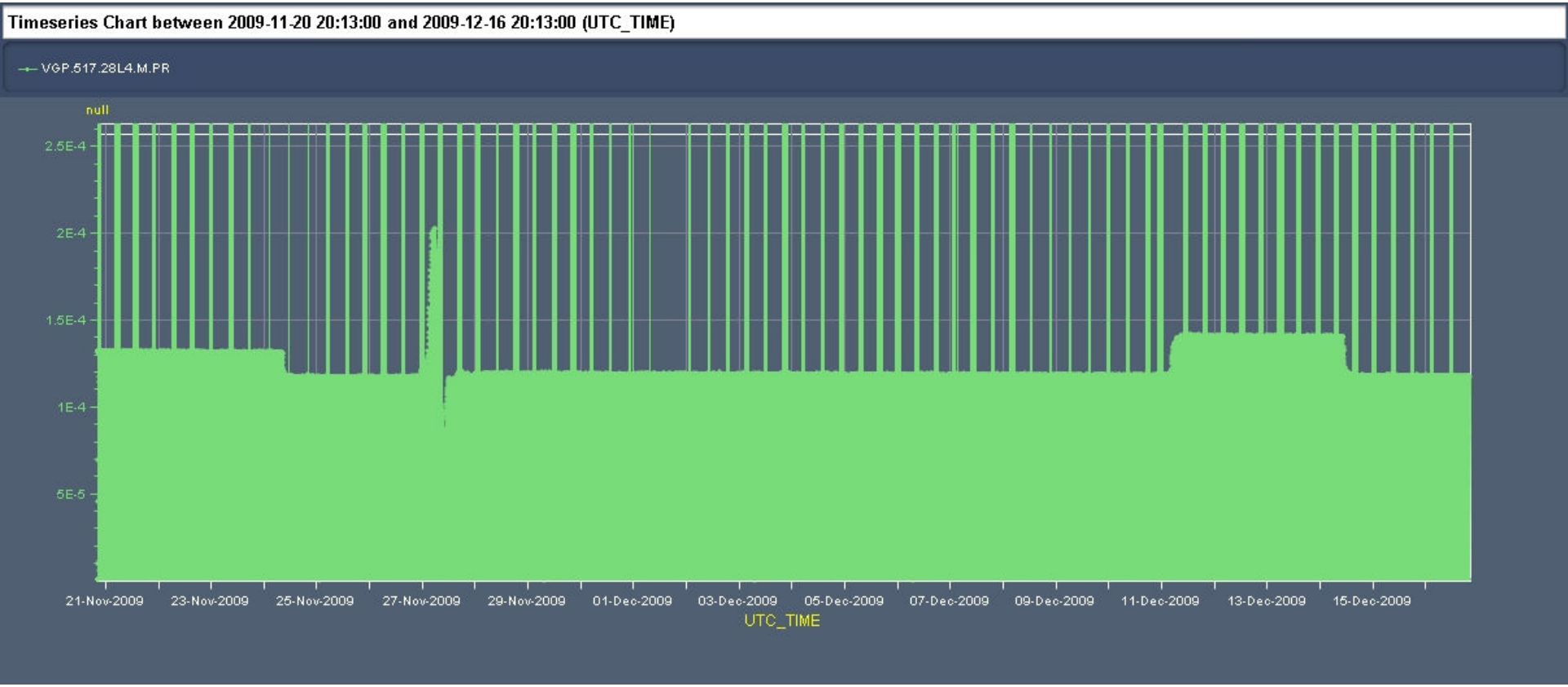
Cryogenics: Leak in sector 34 insulation vacuum

~ 2 mbar l s^{-1}, middle of arc 34

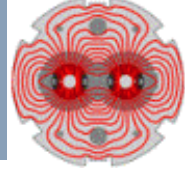
additional heat load 200 W/subsector

2 additional turbo pumps, can survive with one (happened in 09)

Evolution during 2009 run with beam (from logging db)



Leak in sector 34 (cont.)



• Was ok for operation at 1.2 TeV, what changes at higher energies? Locally, cooling power available and static heat load will not change, ~ 70 W still available at the leaky subsector

• Dynamic heat load during the ramp will be larger

Will be taken by the superfluid's enthalpy.

Temp. increase during nominal ramp from design report: 50 mK

Measured during "calorimetry" set up (10 mK to 7 kA, with real He volume)

• Heat deposition during fast discharge from 9 KA: will also be larger with reduced time constants, but after an energy dump there is time to re-cool down

→ Should be OK

→ Reminder: the availability of cryogenics can only be lower at higher energy (current leads, heat load from cycles, quench recoveries)

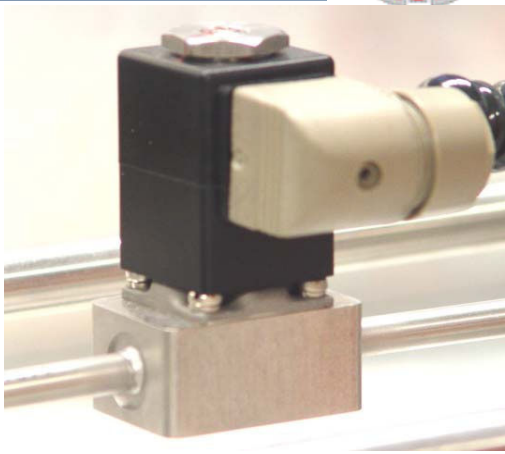
Other cryogenics concerns: regulation valves

CL gas flow control valves.
Some get blocked or develop mechanical hysteresis; depends on regulation mode, ON OFF or PID

Phenomenon is current independent,
Impacts on availability of the cryogenics

Possible actions: replace defective valves, change material/configuration/valve design
Huge job: 1200 valves, procuring, integration.

Problematic valves being changed.
Necessarily gradual process



Other cryogenics concerns: Quench lines

Surface quench buffers 1000 m3
Pipelines not conform at odd points: sliding points are fixed, cable trays were added around the bottom elbows
Total thermal shrinking ~ 300 mm

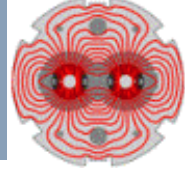
When cooling down, these lines would break

Quench buffers are thus halved,
In case of big quench, inventory at risk!

Solution is being studied, but not likely to have it for the 2010 run

Courtesy N. Veillet

Content



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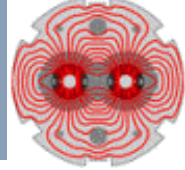
Summary 1: needed for 5 TeV

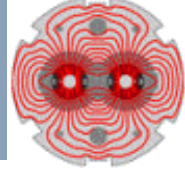


- Snubber capacitors
  - If possible 1 sector equipped for the 3.5 TeV run
  - Other sectors equipped before stepping up the energy: max (?) 2 weeks

- Reduce R_{dump} (at least τ=68 s for RB, τ=15 s for RQF/D)
  - Should be quick
  - The value of R_{dump} for 5 TeV depends on risk assessment:
  - ECR 1013572 states: 68 s for the dipole circuit only allows 4.5 TeV

- Bring RB, RQF and RQD circuits from 6 kA to 8.5 kA. (Still below the training quench region)
- MQY circuits (Q4-Q6) from 1.9kA to 2.7 kA
- MQM circuits (Q6-Q10) from 2.8 kA to 3.85 kA

Summary 2 consolidation



- RQX.R1: “reduced” heaters configuration to be qualified for 5 TeV (measurements on a healthy homologue) : what if it is not ok?
- RCBYHS5.R8B1 and weak MCBY: prepare fallback solution?

- Potentially impacting on availability:

1. MCBX (if possible, change CL regulation process, revisit thresholds)
2. Other 600 A (improve PC 0V crossing, QPS automatic calibration)
3. DFB: carry out valve consolidation
4. Leak in sector 34 (requires warm up to repair: see impact on availability during the run at 3.5 TeV)
5. Quench lines: can probably wait for long shutdown