

Consequences of warming-up a sector above 80 K

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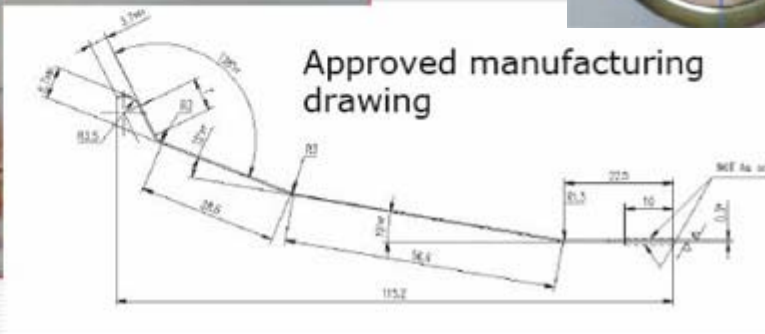
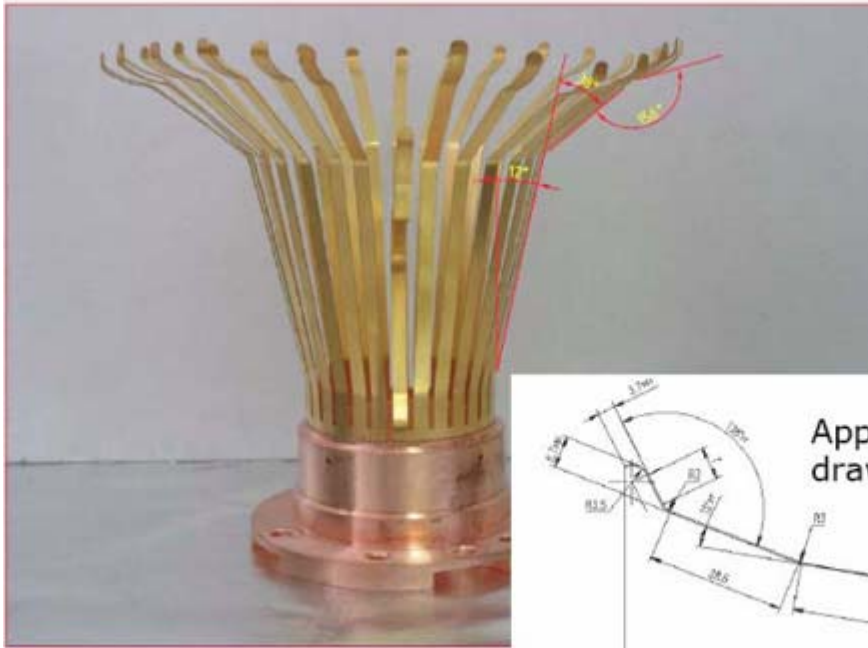
Outline

- Introduction
- Expected thermally induced movements
- Strategy on a fully warmed-up sector
 - For the PIMs
 - For the electrical quality controls
- Strategy on a partially warmed-up sector
 - Observed temperature profiles
 - Consequences for the PIMs
 - Consequences on the electrical quality controls

Introduction

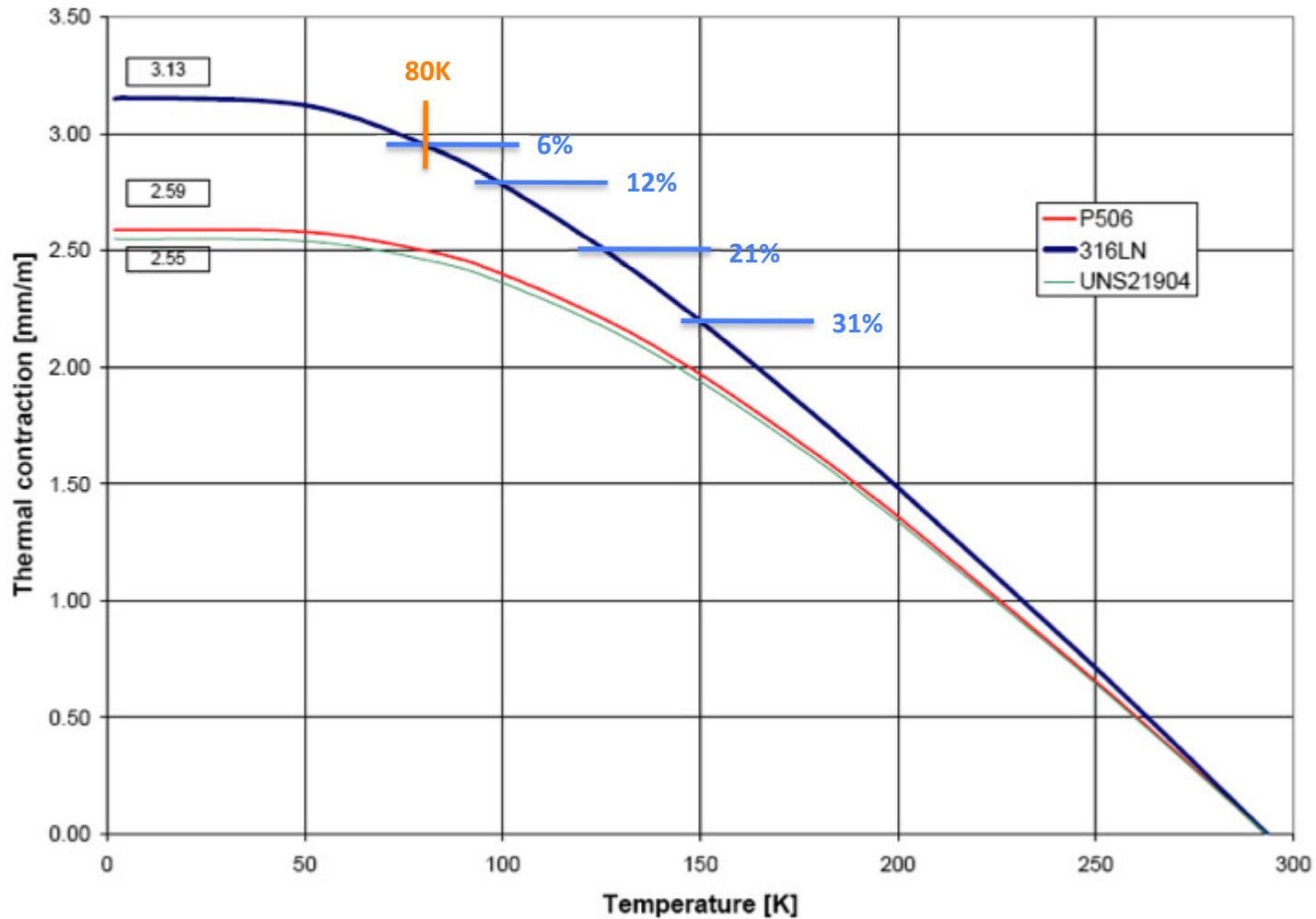
- First buckled PIMs found in Summer 2007
 - Found by chance by inspecting around the dipole which had to be exchanged
 - Reason traced back to a wrongly documented non-conformity

QQBI.26R7 V1 bending angles out of tolerance



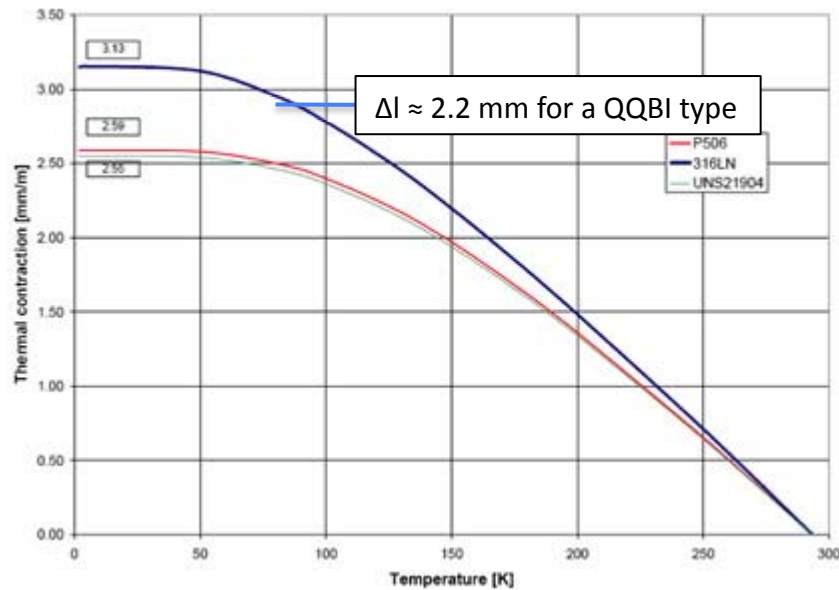
Thermally induced movements (1)

- Thermal contraction not proportional to T



Thermally induced movements (2)

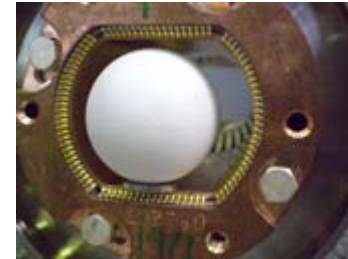
- Only about 6% of contraction between 80 K and 1.9 K
 - Safety no longer considered as an issue
 - PIMs should not be permanently deformed



- Can there be damages on electrical circuits?

Arc completely warmed-up: PIMs

- **Most, if not all, PIMs in the arc are non conform**
 - “Ball” or “Sputnik” test
 - Today from Q7 to Q7, endoscopic inspection between Q7 and DFB
 - Later from RT side of continuous cryostat
 - Repair both PIMs (line V1 and V2)
if a faulty one is discovered



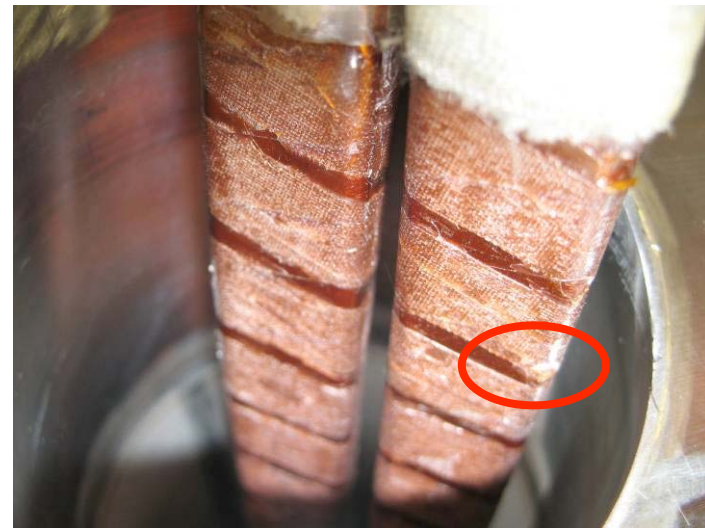
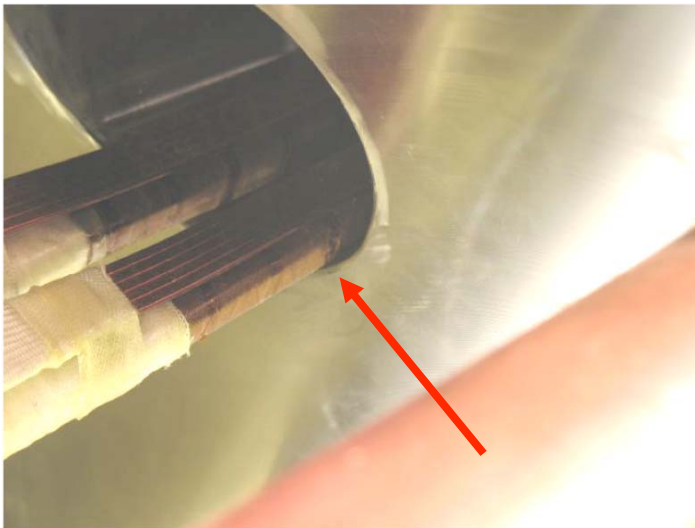
We may be safe at the next warm-up, but so far we have only the experience of the extremities of sector 4-5 (2 warm-up)

- Exchange the PIMs at the extremity of the arcs
 - Between Q7 and MBA
- Exchange PIMs between Q11 and interconnection cryostat

We will be safe during partial warm-up during 4 – 5 weeks

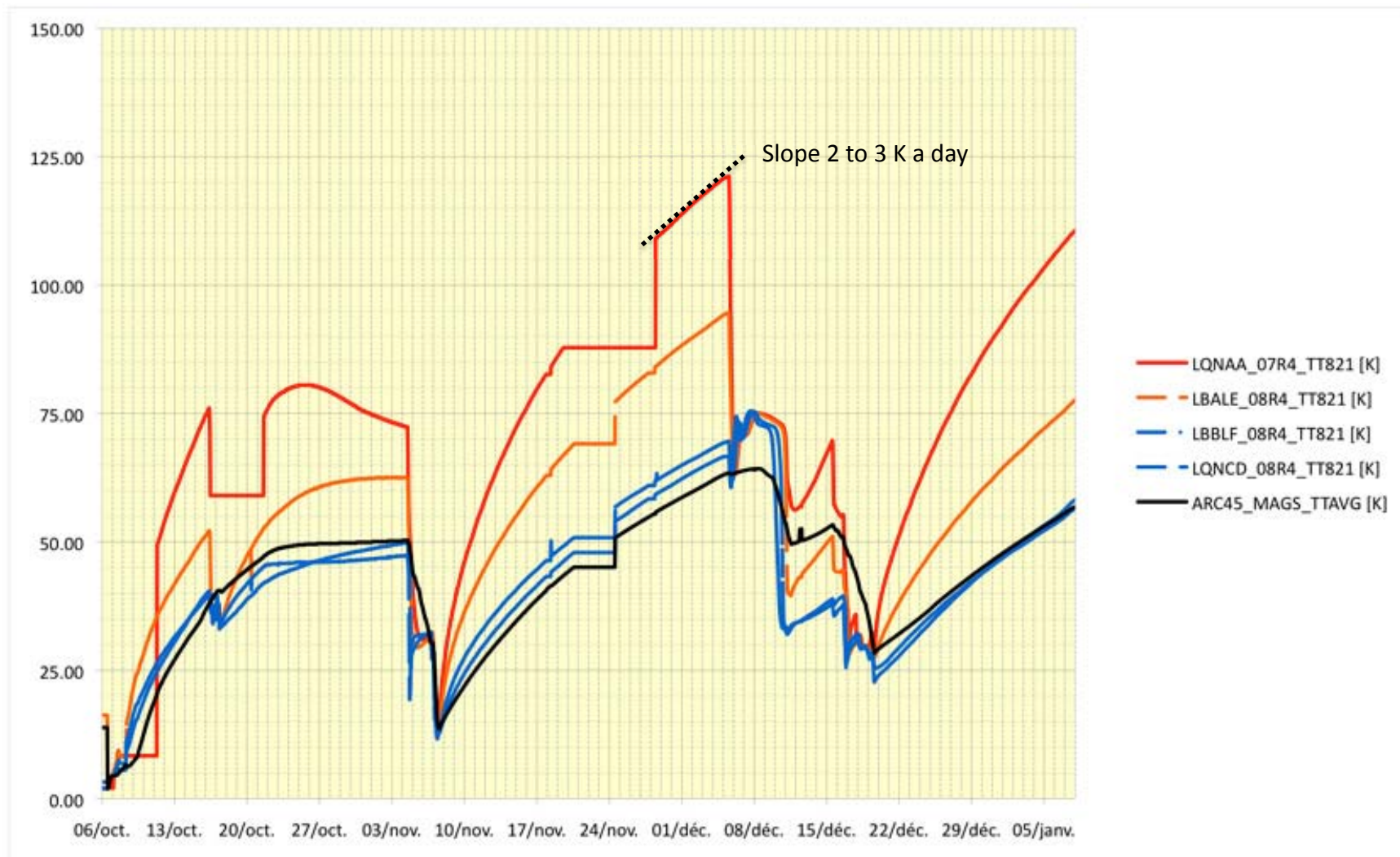
Arc completely warmed-up: EIQA

- Re-qualify the circuits (minimum HV test at cold)
 - There have been faults observed during cool-down
 - Interconnection cryostat
 - Q11L8: short during cool-down, disappeared after warm-up

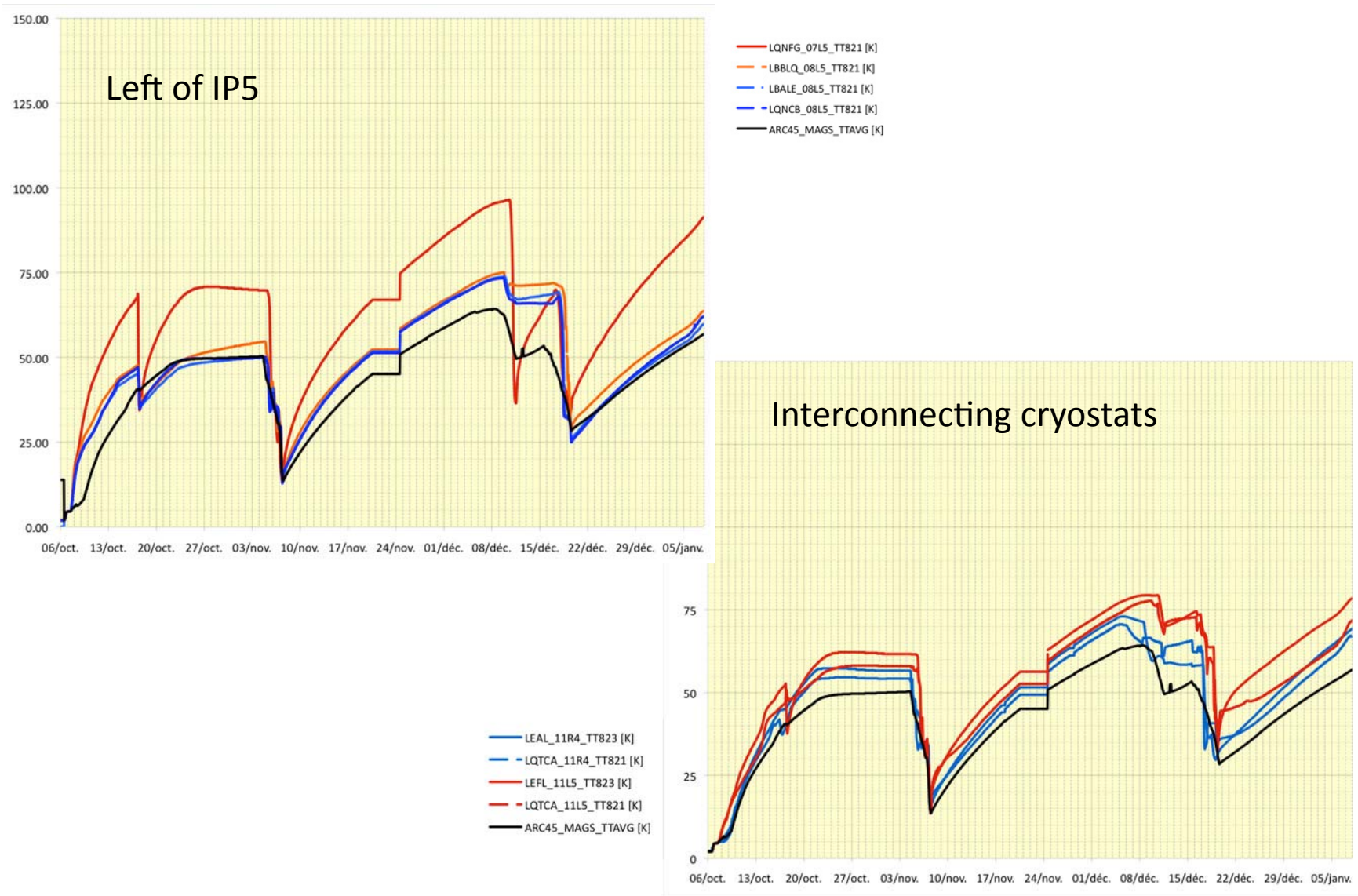


Electrical quality control is similar to leak detection on a vacuum system: **must be done after any intervention on the circuits**

Evolution of temperature in arc 4-5 right of IP4

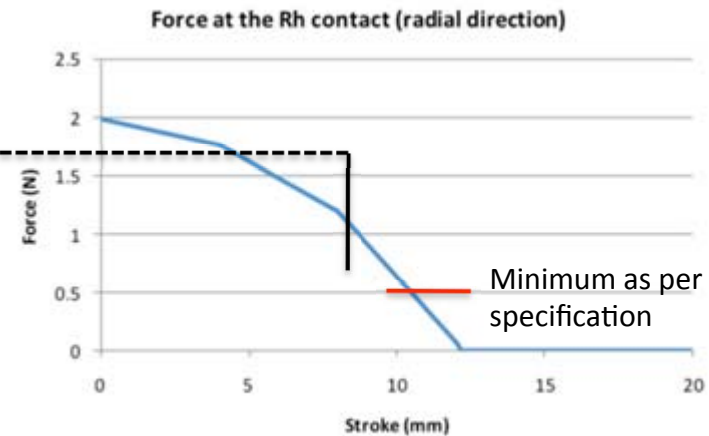
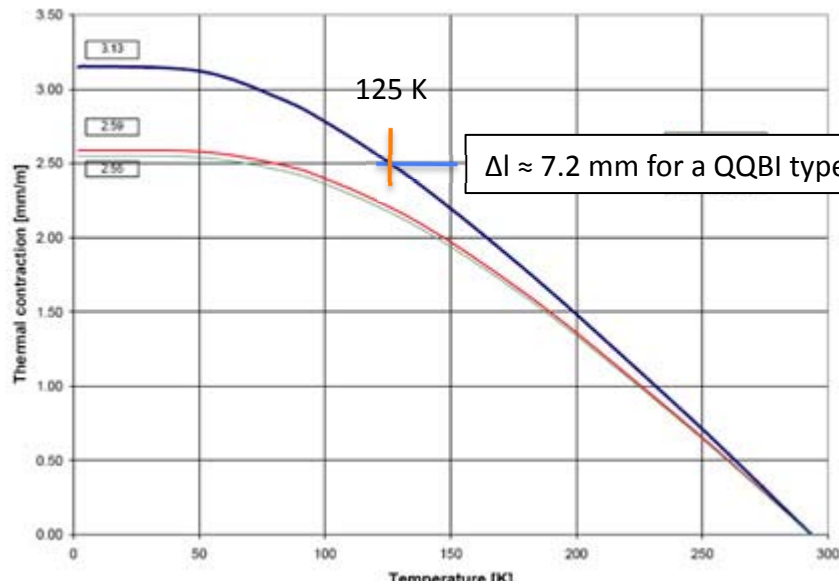


Evolution of temperature in arc 4-5

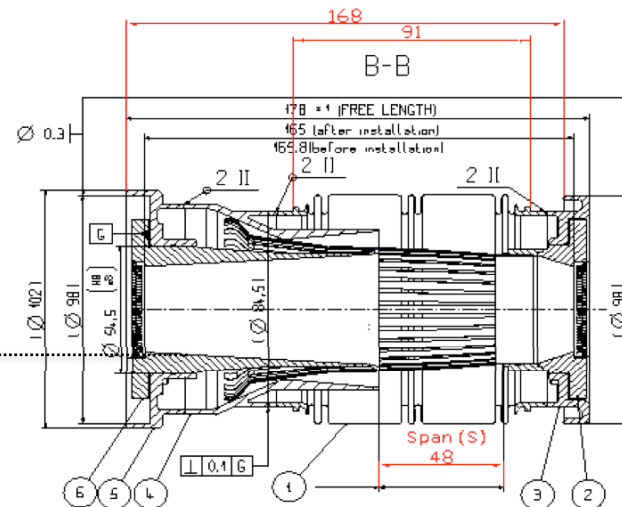
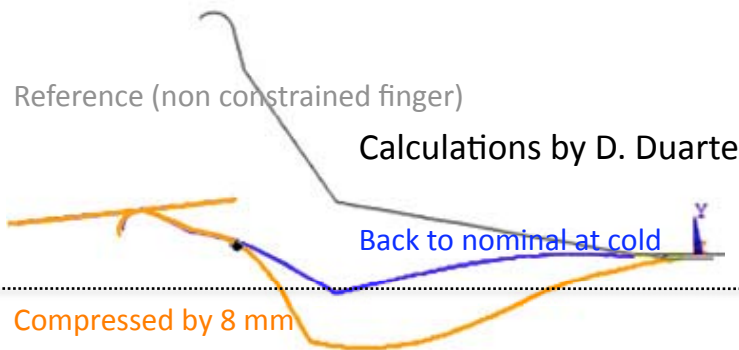


Consequence on the PIMs (1)

- The most vulnerable PIM is compressed by 7.2 mm
 - If both Q7 and downstream dipole are at 125 K



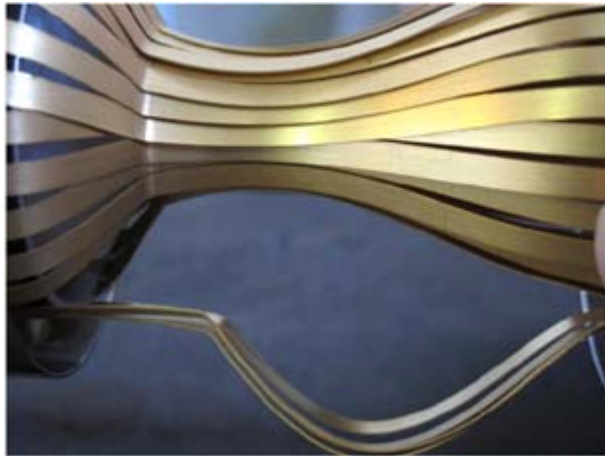
Residual force after cool-down of a partially buckled finger



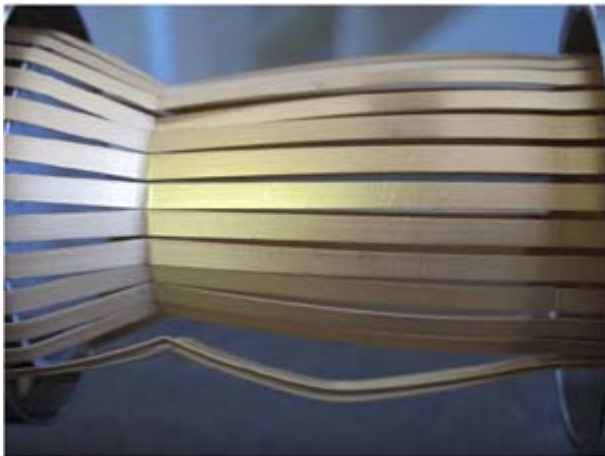
Consequence on the PIMs (2)

- Buckling tests

Compressed by 10 mm



Residual deformation after $x = 10$ mm



- At room temperature, in air
- Using real LHC components (recovered from 7-8)
- Block the fingers extremities in position to simulate 'cold welding' during a partial warm-up
- Measure initial finger diameter (d_1)
- Compress PIM by x mm, simulating a partial warm-up
- Return to installed position and measure finger diameter (d_2) – 'residual plastic deformation is ($d_1 - d_2$)'

Consequence on the PIMs (3)

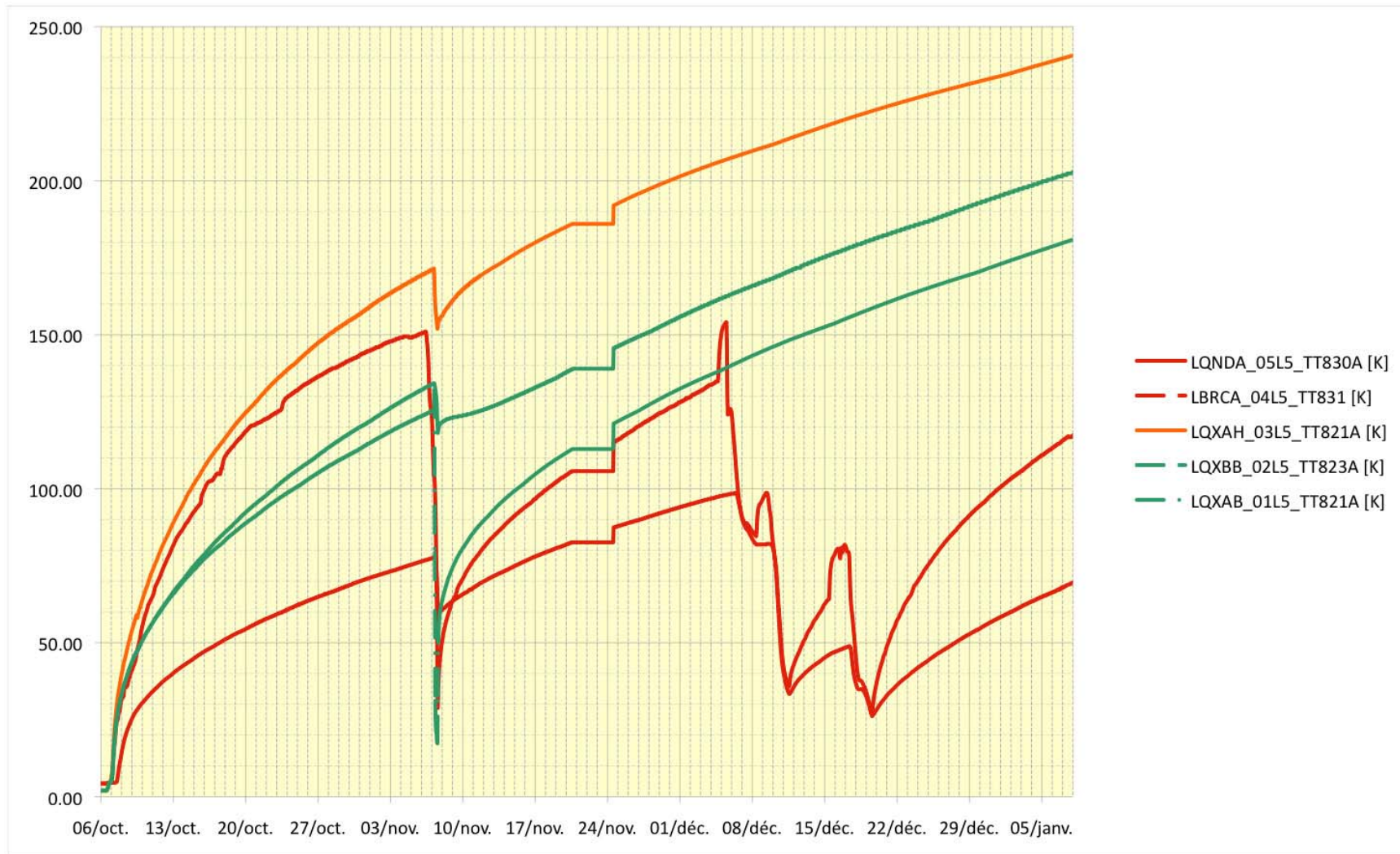
- Results of buckling tests

Compression from cold position	Residual plastic deformation (test1)	Residual plastic deformation (test2)
2 mm	-	0 mm
5 mm	0.5 to 2.5 mm	0.1 to 0.7 mm
7 mm	1.2 to 3.5 mm	1.2 to 2.6 mm
10 mm	2.5 to 6.7 mm	2.2 to 6.3 mm

- Application to observed temperatures in arc 4-5

Magnet 1 (temperature)	Magnet 2 (temperature)	Calculated compression
Q7R4 (121 K)	MBB (95 K)	3.6 mm
MBB (95 K)	MBA (70 K)	2.3 mm
MBA (70 K)	Q8R4 (67 K)	0.1 mm
-	-	-
Q8L5 (75 K)	MBA (75 K)	0.8 mm
MBA (75 K)	MBB (75 K)	1.1 mm
MBB (75 K)	Q7L5 (95 K)	1.5 mm

Evolution of temperature in LSS left of IP5



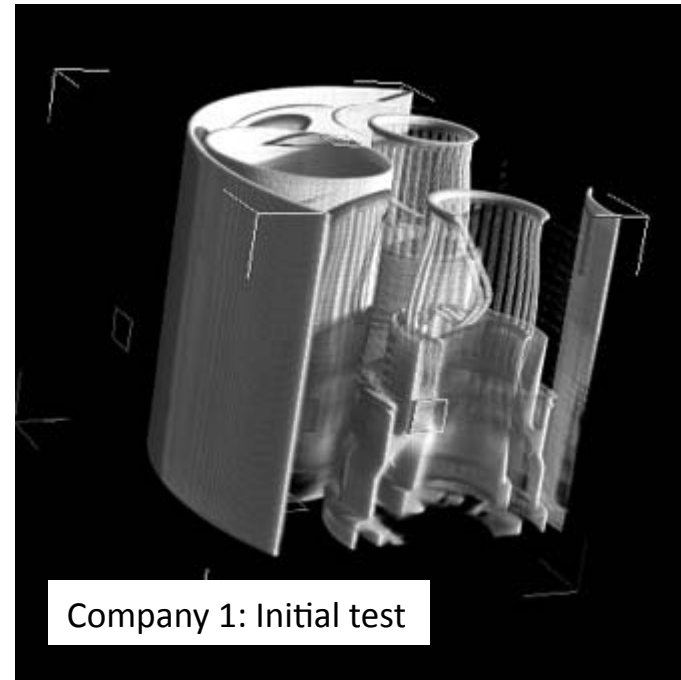
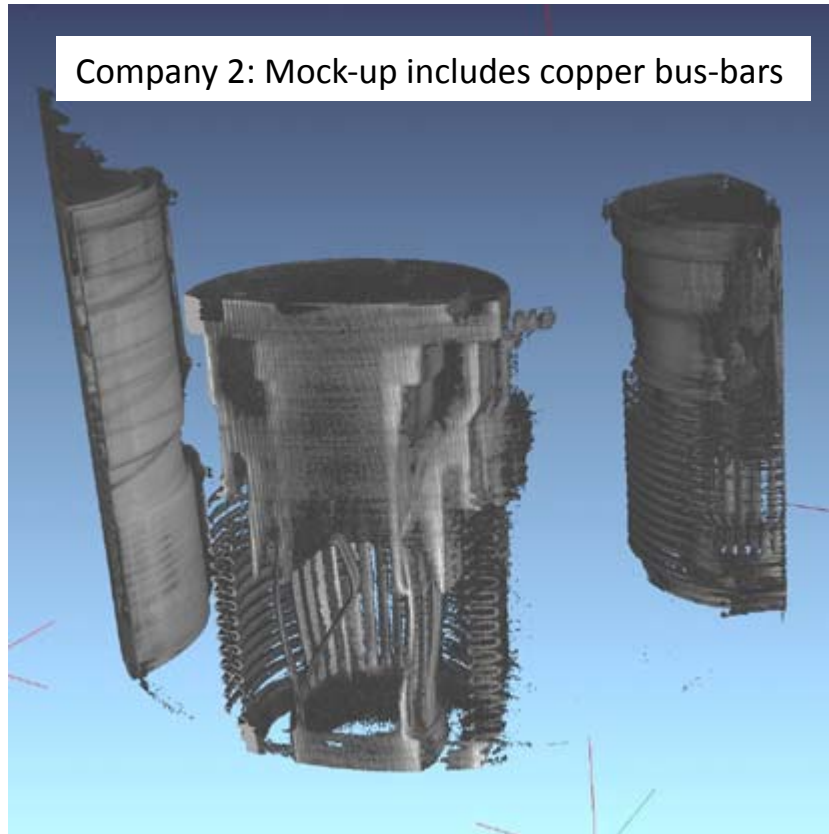
Consequence on the PIMs (4)

- So far, no buckled PIM found in LSS
 - Also non-conform, but seem less vulnerable
 - Shorter span
 - Not in all standalone cryostats
 - Triplet, D2Q4 and (only in IP4) Q5/D4 and D3/LU
- Proposal
 - Repair all PIMs in LSS during this shutdown
 - Priority on triplets (first activated -> ALARA)
 - If not possible (resources or time)
 - Inspect with endoscope and repair if required
 - Needs to be at room temperature
 - May need to vent neighbouring vacuum sector
 - Later in the year, use X-ray tomography



X-Ray Tomography

- Tests on a mock-up very convincing



Order to be placed this week after

- market survey
- invitation to tender
- “fast track” procedure at FC

Delivery expected early September 2009

What about EIQA?

- Displacement during 4 – 5 weeks maintenance
 - Below 20% of full expansion (to room temperature) on any part of magnets and bus-bars
 - Should no be a problem if everything is built as designed
 - But there is always a movement, even if it is only 6% at 80 K
- Consider
 - There can be (as yet not identified) unwanted contacts between insulation and other pieces
 - Was the case of the interconnecting cryostat
 - More than one cycle possible during a shutdown
 - E.g. longer than foreseen maintenance or tunnel repairs
 - Longer periods than 4 – 5 weeks -> higher temperatures
 - Minimise cryogenics operation during shutdown
 - To be considered once the PIMs at extremities of the arcs and the LSS are consolidated

Proposal for ELQA

- After a full warm-up
 - With modification of electrical circuits
 - (e.g. exchange of a magnet)

Full qualification at room temperature and at cold
(ELQA-TP4 and ELQA-DOC)

- Without modification of electrical circuits

High voltage qualification at cold (ELQA-TP4)

- After a partial warm-up

High voltage qualification at cold (ELQA-TP4)

- At cold means magnets not warmer than 2.1 K
- Foresee 2 weeks per sector
 - Some parallelism is possible

Conclusions

- Strategy to consolidate the PIMs now clear
 - Repair systematically the most vulnerable ones
 - Extremities of the arcs and LSS
 - Continue to use the “ball” or “sputnik” test when warm
 - Use X-ray tomography when in doubt
 - Available in August / September 2009
- Recommendation to perform EIQA
 - Full procedure after full warm-up and modifications
 - At least HV test after full warm-up without modifications or partial warm-up