LHC Performance Workshop – Chamonix, 25–29 January, 2010

Summary Session 2 – Magnets and Splices Consolidation Shutdown 2010/2011

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CERN Main Auditorium, 5 February, 2010 (15 minutes)

A “reshuffling of presentations” with bias towards “hotter” topics,

- apologies to some speakers …

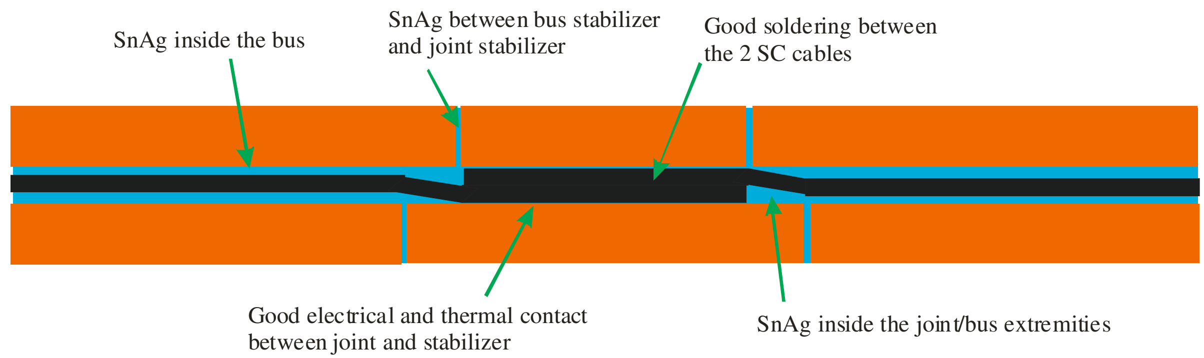
22 slides

6 presentations

- Overview of all superconducting splices in the LHC
  (20') Nuria Catalan Lasheras TE/MPE
- Minimum requirements for 13 kA splices
  (25') Arjan Verweij TE/MPE
- Status of splices in 13 kA circuits
  (25') Paolo Fessia TE/MSC
- Status of splices in 6 kA circuits
  (25') Jean-Philippe Tock TE/MSC
- Scenarios for consolidations intervention
  (20') Francesco Bertinelli TE/MSC
- Dipoles retraining for 7 TeV
  (20') Ezio Todesco TE/MSC

13 kA interconnection splices

Good splice
(R=0.3 nΩ)



Defect A:
Unsoldered splice
(R>>0.3 nΩ)

Defect **A** is very likely to be found using the monitoring feature of the nQDS system, which should reveal all bad splices with a resistance larger than a few nΩ.

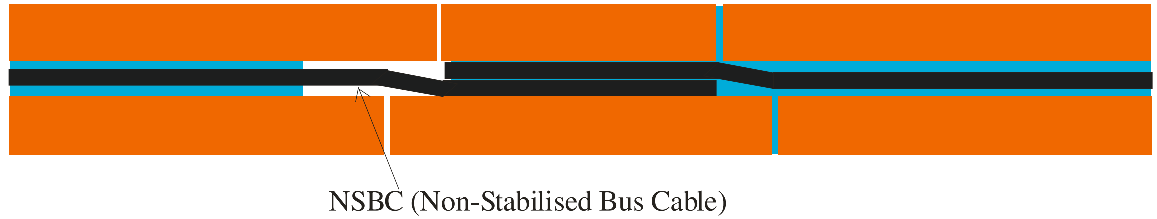
Additionally, the sub mV detection threshold on the bus segments will trigger before the resistive dissipation will cause the SC-to-normal transition followed by a thermal runaway.

Defect **A** is mechanically weak (even if it has a resistance of a few nΩ), and running the machine with such a defect presents a serious risk!!! ⇨ see M. Koratzinos, P. Fessia

A. Verweij

Modelling of splice defects

Defect B:
Soldered splice with *outside* void and/or lack of bonding

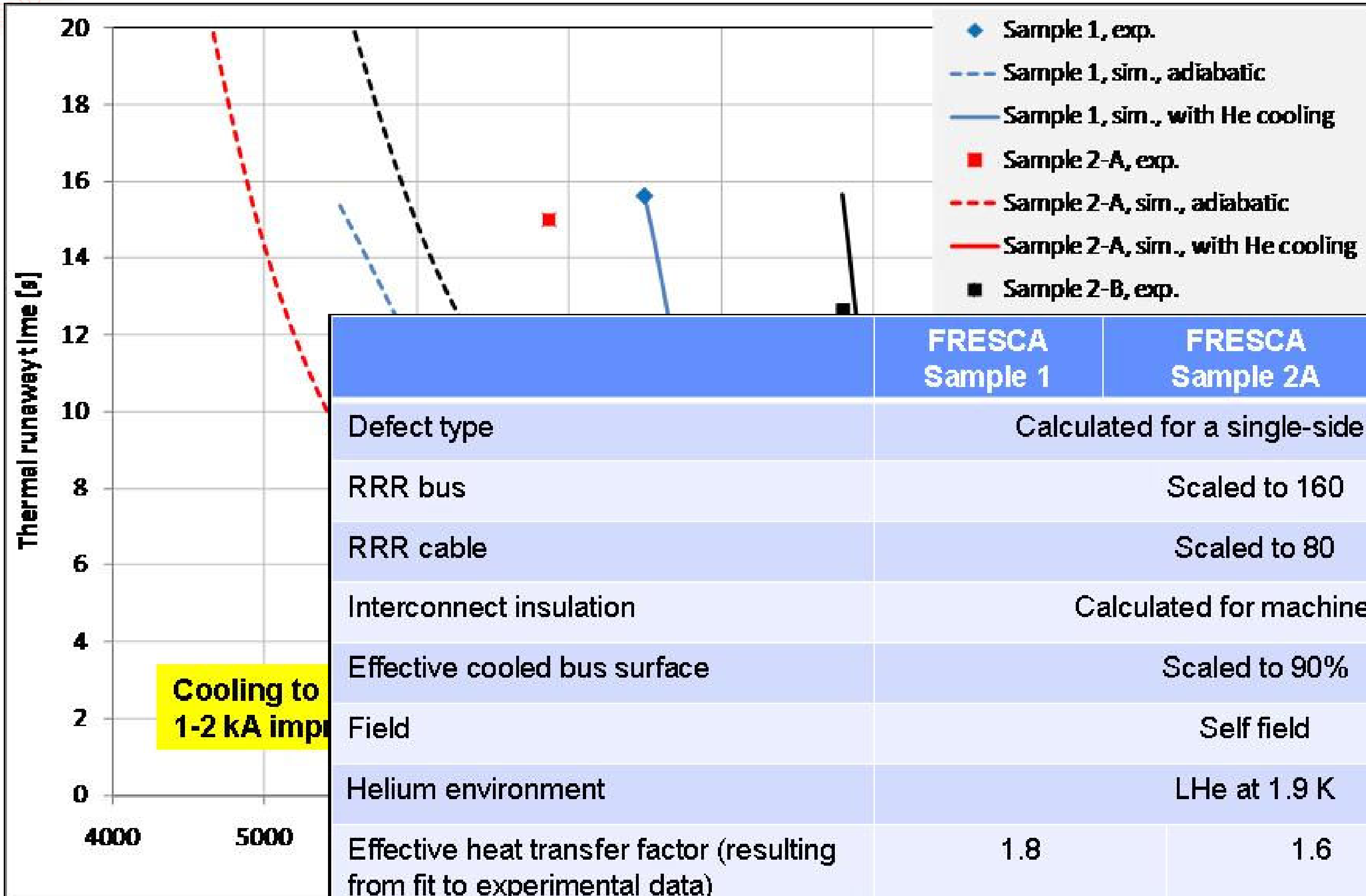


Defect C:
Badly soldered splice ($R>0.3$ nΩ) with *inside* void and/or lack of bonding

Defect D:
Splice with void and/or lack of bonding and small amount of SnAg in vertical gap

- Defects B, C, and D can be present on 1 or 2 sides of the joint.
- Single sided defects **B** and **C** are the worst case scenarios, assuming that the defect size is estimated from a R_{16} measurement or from a $R_{segment}$ measurement (30-100 m long). These defects have been used in the FRESCA tests.
- Defect **D** is the predominant defect in the machine. The stabiliser-stabiliser contact in the vertical gaps may degrade in time.
- Maximum safe operating currents are given for single-sided defect **B** (or **C**) as a function of the additional resistance R_{addit} (at 300 K), with $R_{addit}=R_{16,defect}-R_{16,good}$.

FRESCA tests determine heat transfer



	FRESCA Sample 1	FRESCA Sample 2A	FRESCA Sample 2B
Defect type	Calculated for a single-sided defect B		
RRR bus	Scaled to 160		
RRR cable	Scaled to 80		
Interconnect insulation	Calculated for machine type		
Effective cooled bus surface	Scaled to 90%		
Field	Self field		
Helium environment	LHe at 1.9 K		
Effective heat transfer factor (resulting from fit to experimental data)	1.8	1.6	0.89
I_{safe} for R_{addit}=67 μΩ with τ=10 s (RQ)	7.13 kA	7.03 kA	6.95 kA
I_{safe} for R_{addit}=26 μΩ with τ=20 s (RQ)	11.95 kA	11.48 kA	11.06 kA

A. Verweij

Safe operating energy

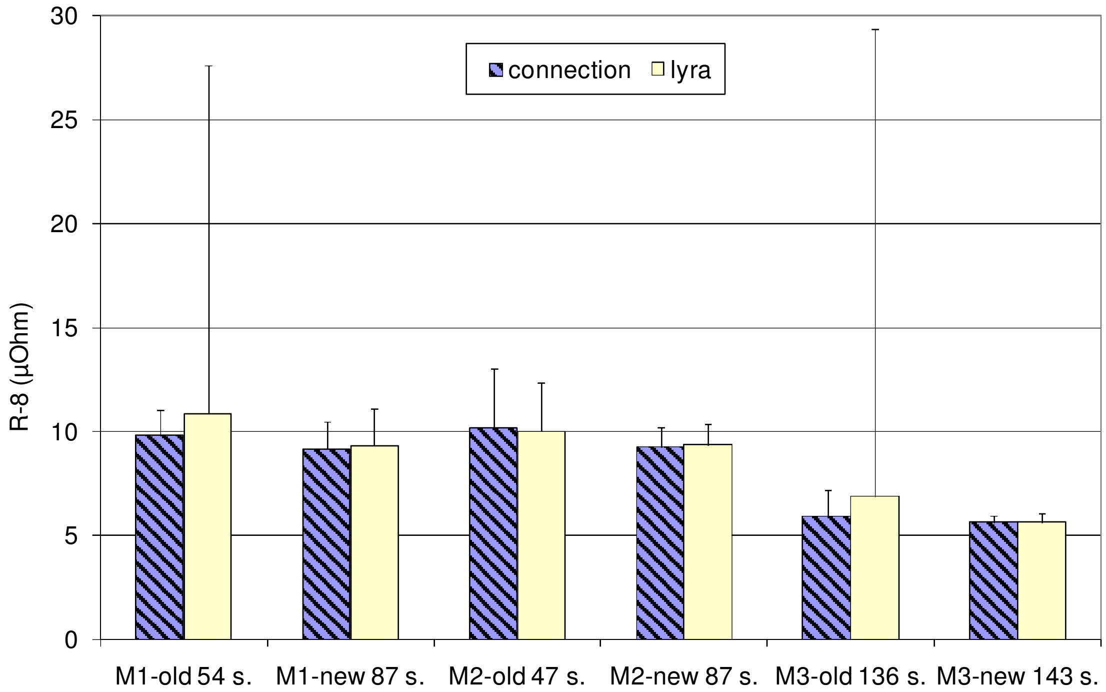
Energy	τ_{RB} [s]	Max. $R_{addit,RB}$ [$\mu\Omega$]	τ_{RQ} [s]	Max. $R_{addit,RQ}$ [$\mu\Omega$]
3.5 TeV	50	76	10	80

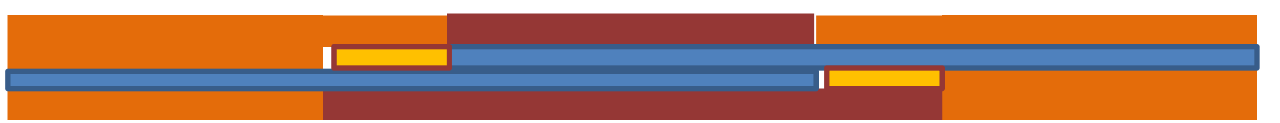
- 3.5 TeV operation is "just OK" wrt estimated worse splice of 90 μΩ:
  - Conservative assumptions for RRR, ⇨ ongoing tunnel measurements
  - One versus two-sided defects, …
- 5 TeV operation requires repair (and previous localisation !) of the highest resistance outlier splices
  - High current pulsing /thermal amplifier diagnostics?
- 7 TeV operation requires extensive consolidation of splices for safest long-term performance
  - Segment measurements at warm (or any other temperature) are not accurate enough to detect these small resistance values
  - R_{addit} may degrade during the lifetime of the LHC
  - Especially for small resistances, the measured R_{addit}(300 K) may not be representative for R_{addit}(10 K)
  - a shunt has to be added on all 13 kA joints, also on those with small R_{addit}. Joints with high R_{addit} or joints with large visual defects should be resoldered and shunted

A. Verweij

13kA interconnection splices

- Improvement and better understanding of splice process and quality during 2008-09 shutdown
- Further improvements seek additional safety margin for 7 TeV and long-term





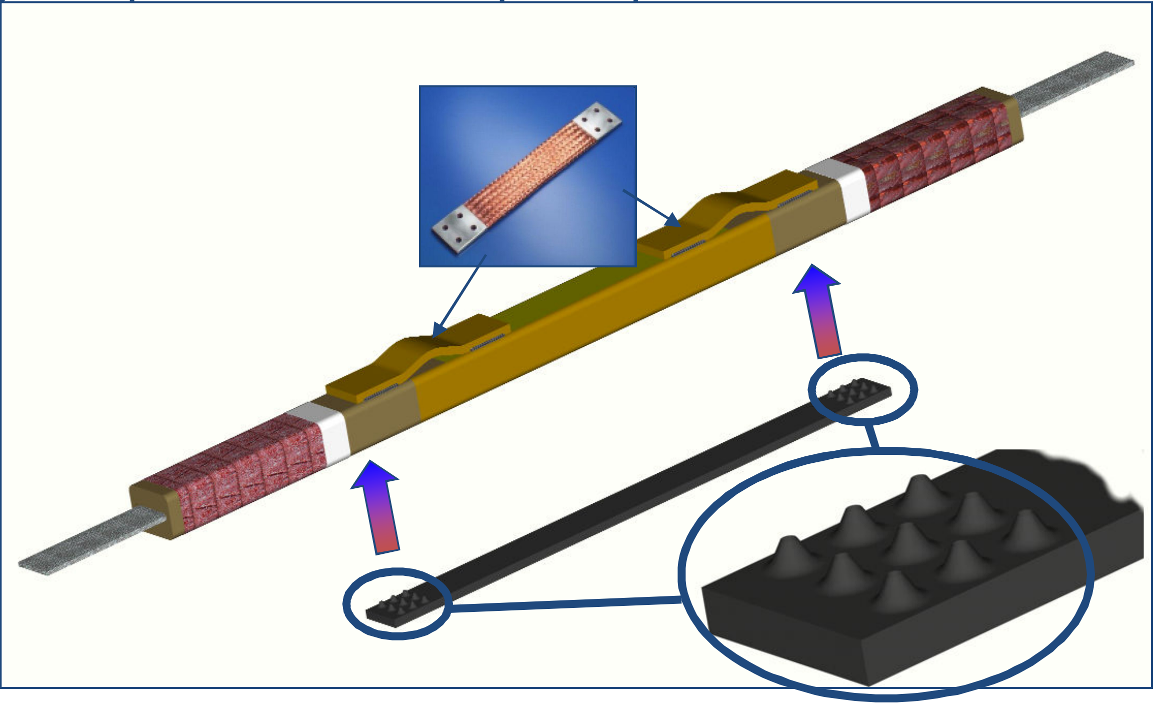
P. Fessia

- Quantitative QC absolutely necessary
- Ongoing improvement studies (induction coil design)

13kA IC consolidation: shunt & clamp

Apply a 2 x 15 mm copper section in parallel to the copper to copper junction complying with the following requirements:

- Do not melt or interfere with the existing junction ⇨ Solder using Sn-Pb in order to have lower melting temperature than the base Sn-Ag soldering (183^{0}C vs. 221 ^{0}C)
- Apply it without cutting the spools above the quadrupole bus bar
- Accommodate the shap
- Being redundant by des
- Be easily inspected and
- Be of rapid installation
- Use "small" tooling allo
- Use of tooling easy to m
- Possibly industrially bas



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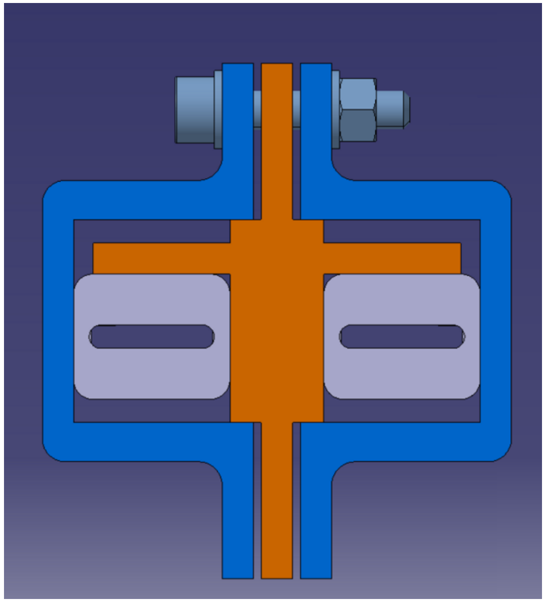
13kA IC consolidation: insulation

- Provide electrical insulation. Bus bars are protected with polyimide 15 mm wide, 50% overlapped and they are separated by 12 mm of He. Total distance for electrical path 27 mm. This is equivalent to 4 KV at 1 bar.
- Accommodate the new shunt
- Accommodate the differences in bus bar geometry due to shape defects
- Provide enhanced cooling
- Block lateral movement during the ramp up in current



> Proof of principle to be done through FRESCA tests ASAP

P. Fessia

Open all IC for 7 TeV consolidation of 13kA splices?

For 7 TeV operation (5 TeV is a different story …):

- Experience from 2008-2009 shutdown:
  - 236 splices with R16 measured (biased sample from segment measurements);
  - 58 redone from R16, 43 redone from visual (considerable…);
  - by considering unbiased data, ~15% splices would need redoing from R16 alone;
  - but segment measurements cannot identify them precisely enough (for MQ in particular), plus need to open all M sleeves for a given segment, estimate ~90% of sleeves;
  - if in addition we consider repairs from visual and preference towards systematically adding a shunt/clamp, we conclude:

➢ Open all W interconnects and cut open all M sleeves, make local R16 measurement, redo ~20% splices, add shunt to 100% splices

F. Bertinelli

Additional magnets/splices work

DN200 (arc pressure relief nozzles)	7-8, 8-1, 2-3, 4-5 (partly)
"Single event" splices for 5 TeV (warm)	~10 MB segments above 35μΩ, but MQ?
"Single event" splices for 5 TeV (cold)	~5 segments above 1-2nΩ
Connection cryostats	7-8, 8-1, 2-3, 4-5
Vacuum leak	3-4, others?
N line conne	
6kA praying l	
Spool conne	
Replace magnets? (damaged nested bellows, SC cable, cold IFS box, quench heaters ...)	~2-4 cases (e.g. QBBI.10R7, QBQI.10L5 araldite repair)
Y-lines	7-8, 8-1, others?
Damaged radiation/thermal screens	All sectors
Standalone Magnets (He level gauge)	7-8, 2-3
DFBA flexibles to check	
PIMs	RF ball test, a few preventive replacements, no global replacements?
...	35 NCR, "closed with warning", HWC cases

- a considerable amount of non-standard work !!!

F. Bertinelli

So how long will a shutdown take?

The size of this new task compares to series production:

- will not require some activities (e.g. jumpers, N-line) …
- but will require to « undo » before « redoing » (e.g. cut welds, desolder): repair ≠ new
- on the good side: all magnets are in place (except if …)

Resources used in IC series production:

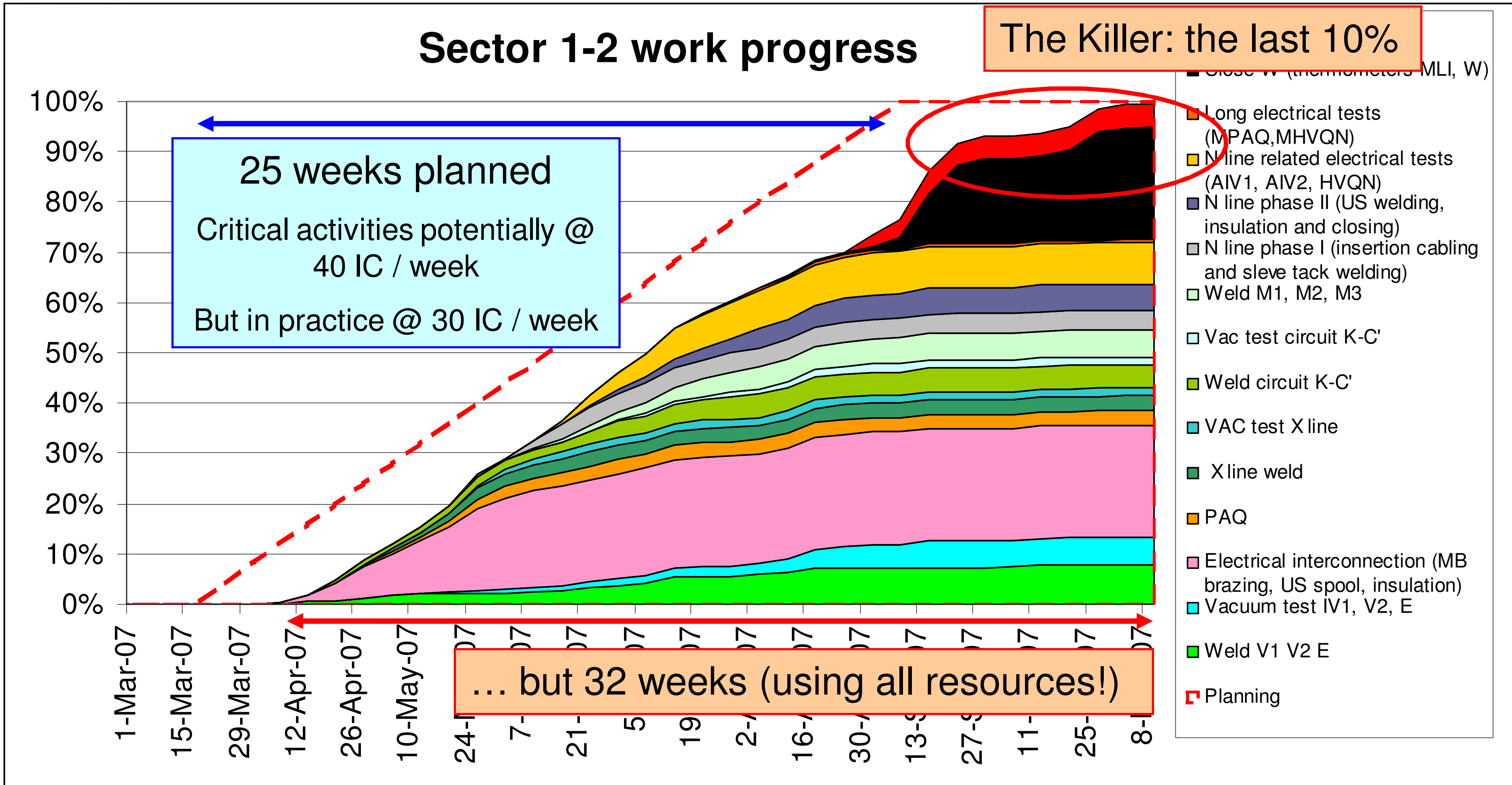
- IEG (Main Contractor) ~100 workers
- activities were organised for 40 IC/week
- CERN ~100 workers for coordination, QC (including ELQA and VAC), troubleshooting, special activities
- 2.5-3 years

Resources used in 2008-09 IC shutdown:

- CERN ~100 workers

F. Bertinelli

Series experience: 1-2, the last sector



Courtesy P. Fessia

Estimate of IC resources needed

Activity	Quantity	Existing at CERN	To come in addition	Comments
Opening W	100%	0	12	FSUs as in 2008-09
VAC QC bellows and protection	100%	2	2	
Cutting M sleeves	100%	6	5	1 Team Leader, 7 mechanics cutting, 3 helpers

- to work on 1 "IC train" (but coordinate 2-3 sectors at the same time),
- 100 persons needed,
- of which ~ 40-45 are present (at CERN) with skills and experience,
- ~60 need to be integrated in addition (as in 2008-2009), e.g. FSUs, collaborations
- beware the risk of excessive parallelism (QC, supervision, coordination)
- remember the "last 10% effect"

Note: impact of this work on magnet repair/rebuilding, triplet project,…
May prefer to introduce additional resources earlier (now?).

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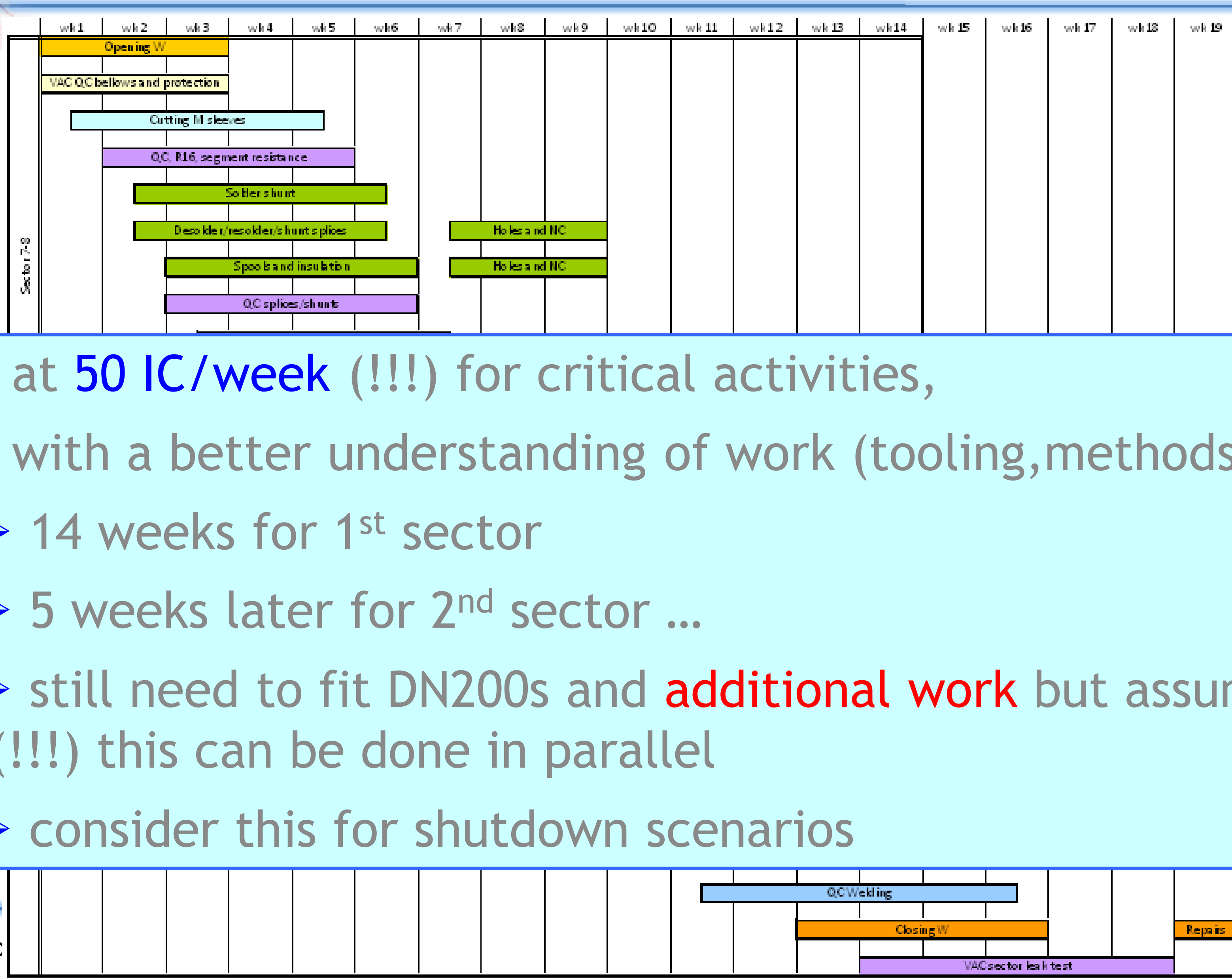
Length of shutdown: estimate 2, @50 IC/week



- at 50 IC/week (!!!) for critical activities,
- with a better understanding of work (tooling,methods …)

➢ 14 weeks for 1st sector

➢ 5 weeks later for 2nd sector …

➢ still need to fit DN200s and additional work but assume (!!!) this can be done in parallel

➢ consider this for shutdown scenarios

F. Bertinelli

Some shutdown scenarios @50 IC/week

	1st sector	Last sector	Comments
All sectors	14 weeks	49 weeks	1 shutdown, no physics for 1 year
4 secto 7-8, 8-1			
2 secto 7-8, 8-1			ork, r?
…			

- To get the full picture need to include:
  - Physics time (specifically for 2011),
  - Radioprotection/ALARA principles,
  - Risk of this IC work:
    - Time taken,
    - Number of new resources introduced,
    - Amount of parallelism
  - Additional IC work (specifically for 5 TeV)

F. Bertinelli

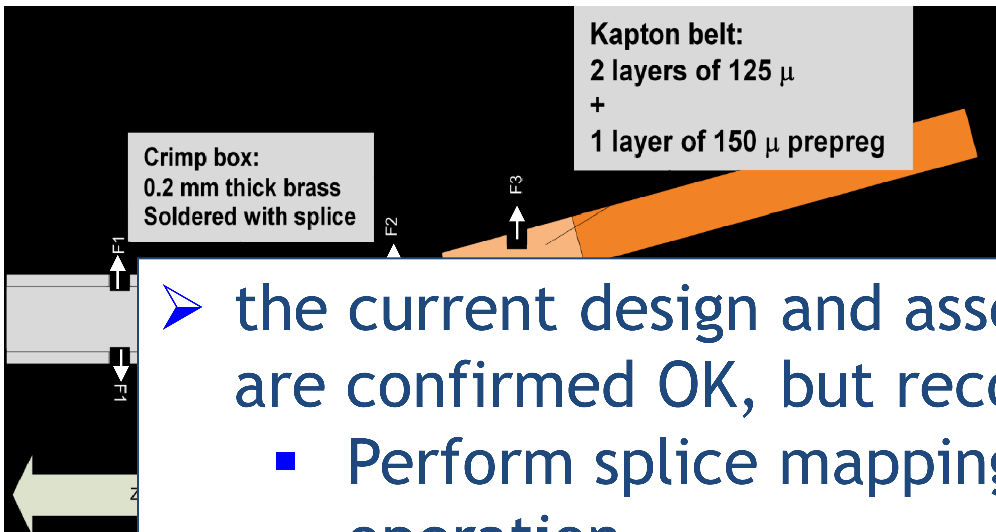
The “other” splices

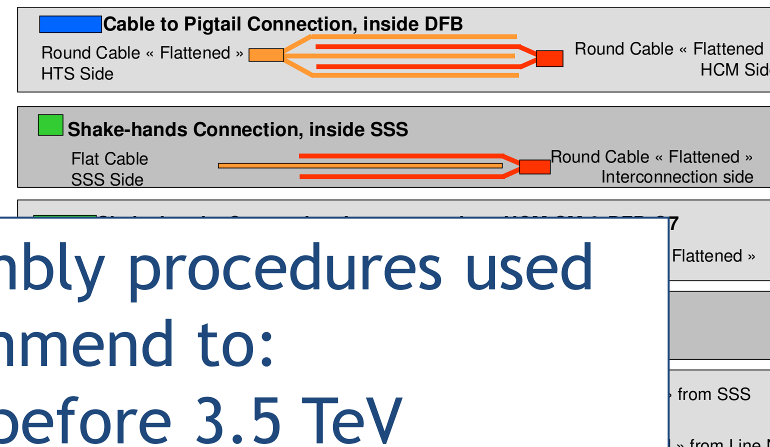
- A Task Force was set up in November 2009 (35th LMC, 4 Nov. 2009)
- Mandate:
  - To review the status of all superconducting splices in the LHC machine and prepare the necessary consolidation actions for 7 TeV operation.
- Time frame: 6-8 months starting November 2009, so that the shutdown 2010-2011 can be adequately organized.
  - ➢ may now need to review resources and timeframe in the light of Chamonix 2010
- WEB site: www.cern.ch/LHCsplices

F. Bertinelli

6 kA praying hands splices

- Analysed Q7L2 from current lead to current lead;
- Several splice types present in the same line
- FRESCA tests and structural analysis





- the current design and assembly procedures used are confirmed OK, but recommend to:
  - Perform splice mapping before 3.5 TeV operation
  - Implement the nQPS splice protection scheme
  - Inspect 7-8 when possible
  - Further FRESCA test with fracture analysis

J.-P. Tock

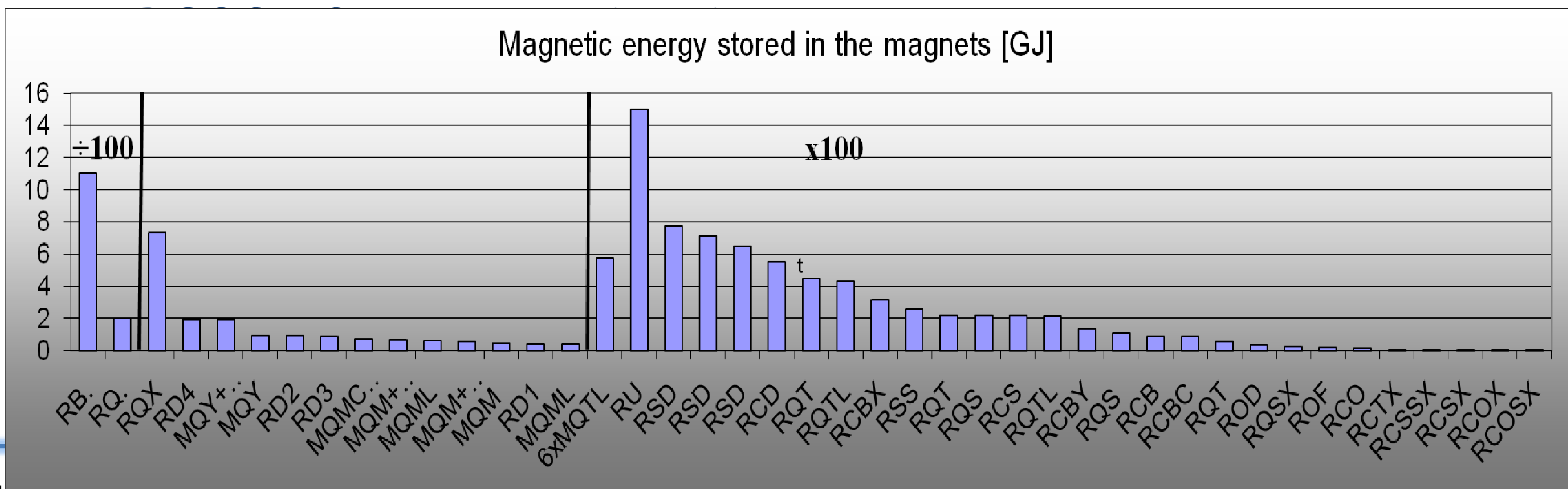
Overview of other superconducting splices

For other splices (600A …) there are no showstoppers but in general there is a huge amount of study (100 000 splices!) so w.r.t. the original timeframe:

- set work priorities or reorganise work (additional resources)
- Consider a “double failure” risk analysis

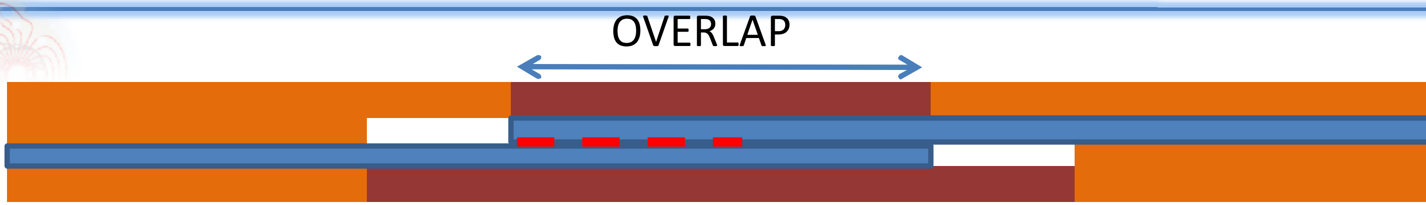
A few known cases for intervention

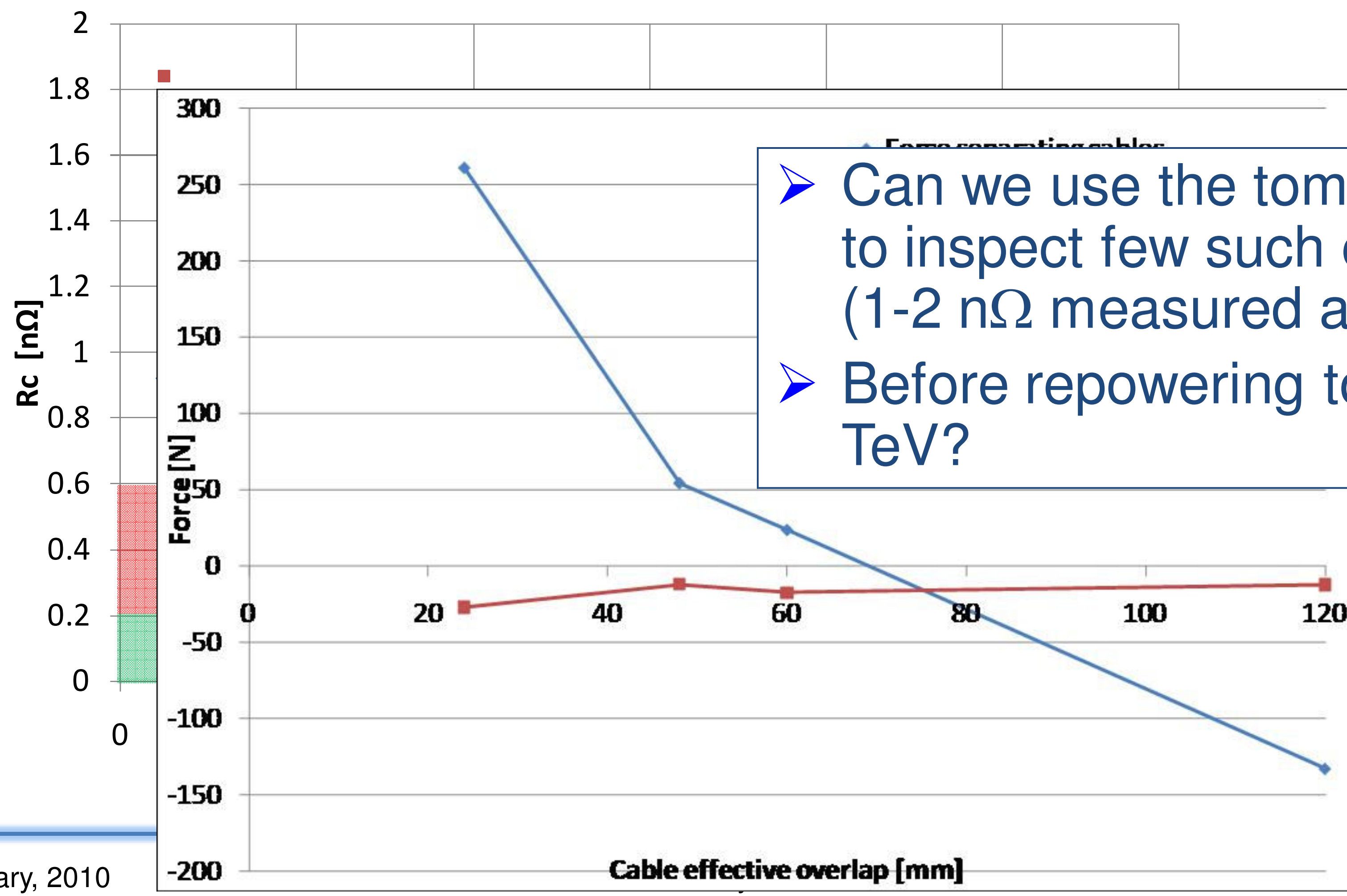
- RCO.QA81.B2 open circuit



N. Catalan Lasheras

Splice resistance at cold vs. effective splice length





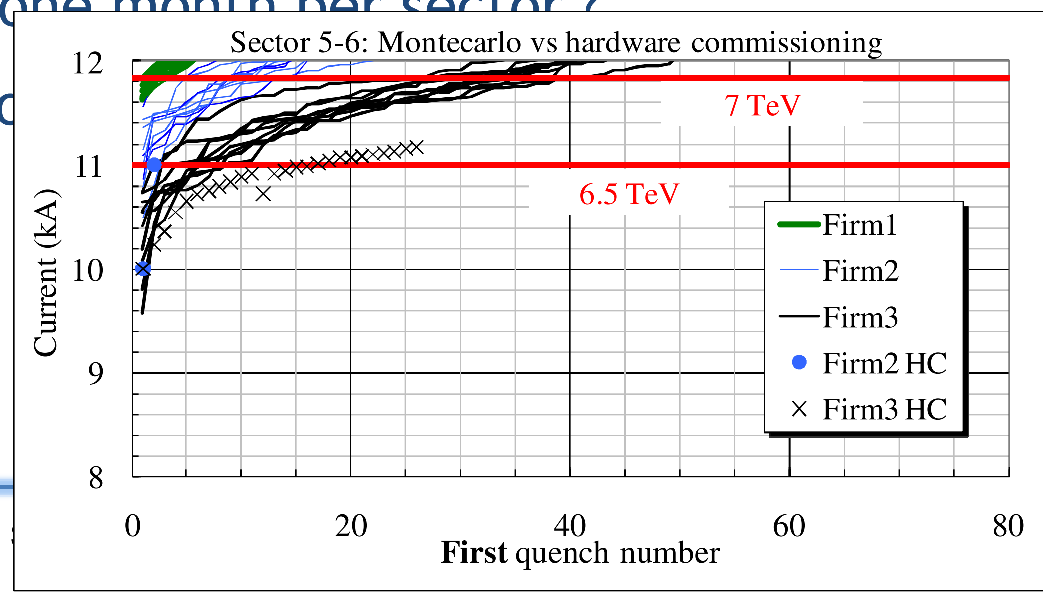
- Can we use the tomograph to inspect few such cases (1-2 nΩ measured at cold)?
- Before repowering to 3.5 TeV?

P. Fessia

Magnet training for 7 TeV

2008 experience in 5-6: trained up to 6.6 TeV, but slow training of Firm3 dipoles

- Forecast:
  - For 6.5 TeV a short training is expected (10-15 quenches per octant), needed time: a few days of training per sector
  - For 7 TeV we have no experience – lower bound: MonteCarlo method, at least 50 quenches needed per octant, Needed time: one month per sector ?
- Firm3 anomaly under ongo
  data, location of quench,



E. Todesco

Thanks for your attention

Acknowledgements and thanks: Organisers and invitation to Chamonix2010, Chamonix Speakers, Interconnections Teams, LHC Splices Task Force …