Overview of all superconducting splices in the LHC machine

N. Catalan Lasheras

Chamonix 2010 LHC Performance Workshop

25 January 2010

Chamonix 2010 LHC Performance Workshop 25 January 2010. N. Catalan Lasheras

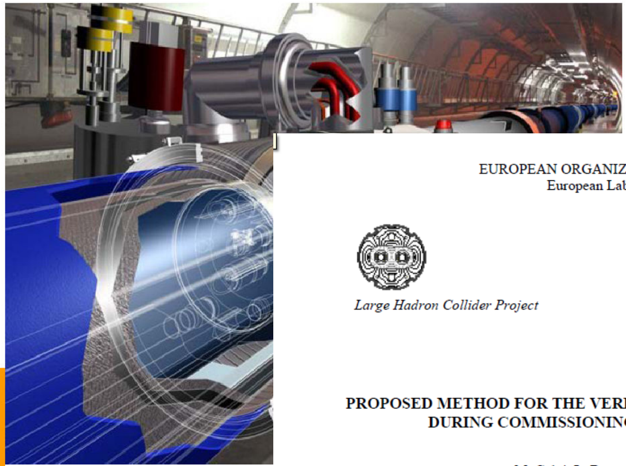
The making of the electrical interconnections in the LHC

Accelerator Technology Department

J.Ph. Tock on behalf of the AT-CRI-CI section:
- B. Skoczen,
- A. Bastard,
- T. Colombet,
- JM. Hubert
- A. Jacquemod,
- F. Laurent,
- L. Perrollaz,
- S. Triquet

Total current through one interconnection : about 110 000 A

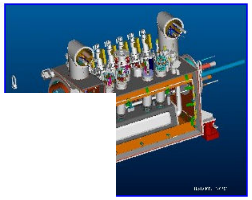
Interconnection Section , CERN, 1211 Geneva 23



Index of DFBX photos - Mozilla Firefox

http://tdpc02.fnal.gov/peterson/tom/DFBXimages/IndexDFBX.html

Images from the fabrication of the DFBX boxes (LBNL procurement of the LHC IR feed boxes) at Meyer Tool and Manufacturing, Inc.



…esy LBNL. (Click on the assembly model image above for a larger view.) Contact … content.

view, upgrade, and repair work

…nks to various documents)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
European Laboratory for Particle Physics

Large Hadron Collider Project

LHC Project Report 1004

PROPOSED METHOD FOR THE VERIFICATION OF THE LHC BUS DURING COMMISSIONING AT CRYOGENIC CONDITI…

M. Calvi, L. Bottura and F. Rodríguez Mateos

…t CERN includes the poweri… from 55 A to 11.8 kA. A large… s, which can only be validat… l effects related to possible fa… quench and detection currents, …del with the surrounding cool… completed with a sensitivity … rs. Finally, the implications … first powering are discussed.

CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.	LHC-MPP-ES-0002 ver.1.1
CERN Div./Group or Supplier/Contractor Document No.	TE
EDMS Document No.	1001985
Date: 2009-05-20	

Engineering Specification

ACCESS AND POWERING CONDITIONS FOR THE SUPERCONDUCTING CIRCUITS IN LHC

Abstract

Following the incident on 19 September 2008, more severe access restrictions to underground areas were introduced for the re-powering of electrical circuits with superconducting magnets. In this document two phases of powering are defined, phase I and phase II. During powering in phase I the current in the different electrical circuits is limited and the probability for massive accidental release of helium due to powering is considered to be negligible. The access conditions are much less severe than in phase II, where the circuits may be powered to their nominal current for the physics energy. The parameters for powering in phase I are defined.

Prepared by :	*Checked by :*	*Approved by :*
Matteo Solfaroli Hugues Thiesen Glyn Kirby Knud Dahlerup-Petersen Arjan Verweij Rob Wolf Jim Strait Rüdiger Schmidt	Jose Miguel Jimenez Lucio Rossi Ghislain Roy Laurent Tavian Mike Lamont Karl Hubert Mess Andrzej Siemko Magali Gruwe Laurette Ponce Serge Claudet Roger Bailey Gianluigi Arduini Jean-Paul Burnet	Frederic Bordry Paul Collier Steve Myers Lyn Evans Ralf Trant

PERFORMANCE OF THE SUPERCONDUCTING CORRECTOR MAGNET CIRCUITS DURING THE COMMISSIONING OF THE LHC

W. Venturini Delsolaro[1], V. Baggiolini[1], A. Ballarino[1], B. Bellesia[1], F. Bordry[1], A. Cantone[1], M. Casas Lino[1], A. Castaneda Serra[1], C. Castillo Trello[1], N. Catalan Lasheras[1], Z. Charifoulline[1], C. Charrondiere[1], K. Dahlerup-Petersen[1], G. D'Angelo[1], R. Denz[1], S. Feher[2], R. Flora[2], M. Gruwe[1], V. Kain[1], M. Karppinen[1], B. Khomenko[1], G. Kirby[1], A. MacPherson[1], A. Marqueta Barbero[1], K.-H. Mess[1], M. Modena[1], R. Mompo[1], V. Montabonnet[1], S. le Naour[1], D. Nisbet[1], V. Parma[1], M. Pojer[1], L. Ponce[1], A. Raimondo[1], S. Redaelli[1], V. Remondino, H. Reymond[1], D. Richter[1], G. de Rijk[1], A. Rijllart[1], I. Romera Ramirez[1], R. Saban[1], S. Sanfilippo[1], K. Schirm[1], R. Schmidt[1], A. Siemko[1], M. Solfaroli Camillocci[1], Y. Thurel[1], H. Thiessen[1], A. Vergara Fernandez[1], A. Verweij[1], R. Wolf[1], M. Zerlauth[1]

1 - CERN: European Organisation for Nuclear Research 2 - FNAL: Fermi National Accelerator Laboratory

Abstract

The LHC is a complex machine requiring more than 7400 superconducting corrector magnets distributed along a circumference of 26.7 km. These magnets are powered in 1446 different electrical circuits with currents ranging from 60 A up to 600 A. Among the corrector circuits the 600 A corrector magnets form the most diverse and differentiated group. About 60000 high current

MAGNET TYPES, TARGETS

Compared to the main magnets, the LHC correctors operate rather far from the critical current (table 1). On the other hand, the challenge of mass production called for a cheap and robust design [2], with relatively large mechanical tolerances. Therefore some training could be expected and was indeed observed during production (see below).

Outline

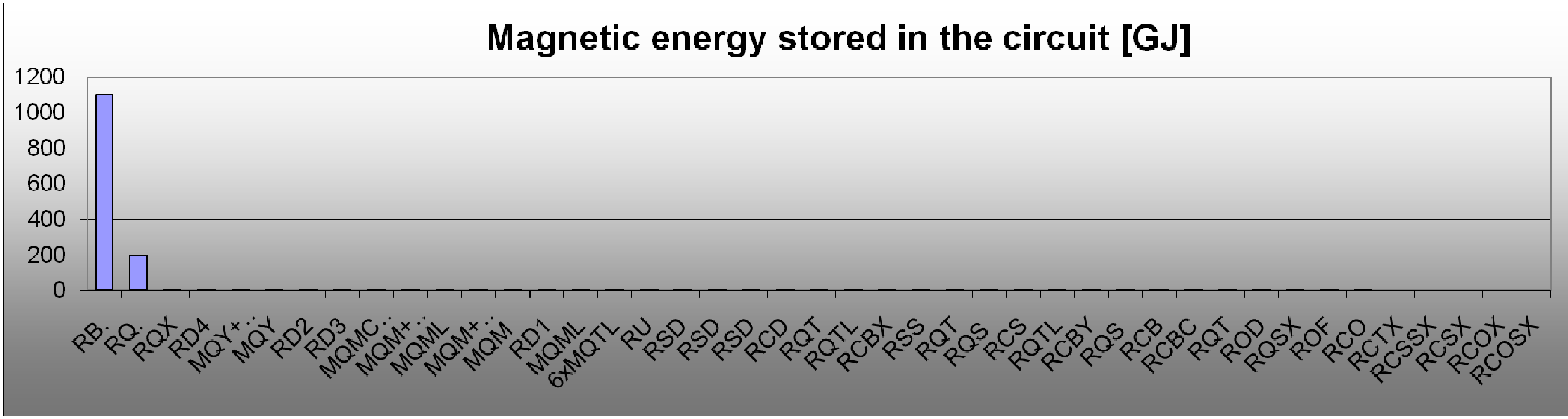
- Splices Inventory. Numbers and circuit criticality
  - Stored Energy
  - MIITs and hot spot temperature
- 600 A corrector circuits
  - Brief description
  - Line M and N. US welding
  - PCS measurements during HW Commissioning
  - Existing NC
- Inner triplet 13 kA splices
- Future
  - MCI
  - Missing studies

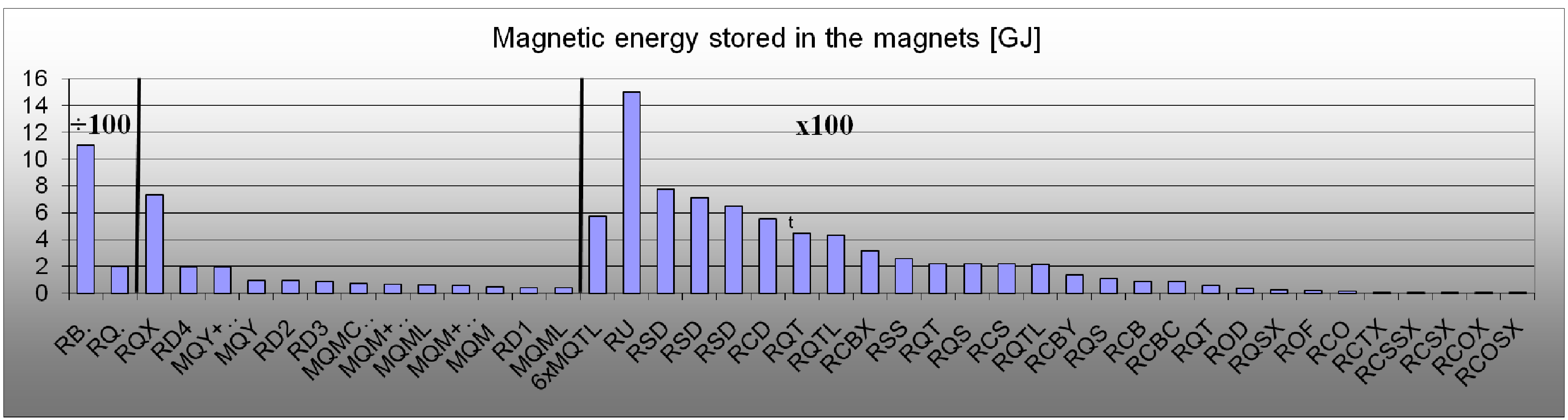
Superconducting splices. How many?

	Line	Magnet Splices	Interconnection splices	Current rating
RB	M3	9856	3372	13 kA
RQF/RQD	M1, M2	3940	6744	13 kA
Spool Pieces	M1, M2	30860	33920	600 A
Correctors	N	27006	16000	600 A
Individually powered magnets	N'	1644	532	6 kA
Inner triplet quads	N'	*80*	112	13 kA
Inner triplet correctors	N'	704	480	600 A

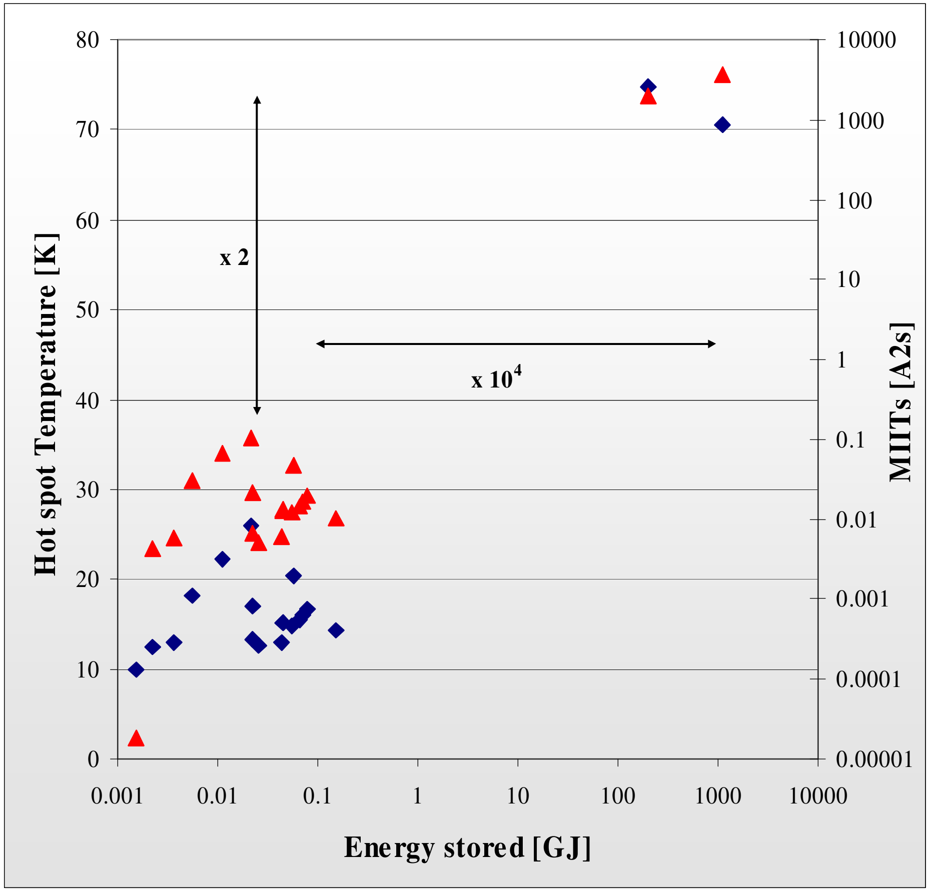
➔ More than 100000 (10^5) splices!!

Energy Stored in the magnets





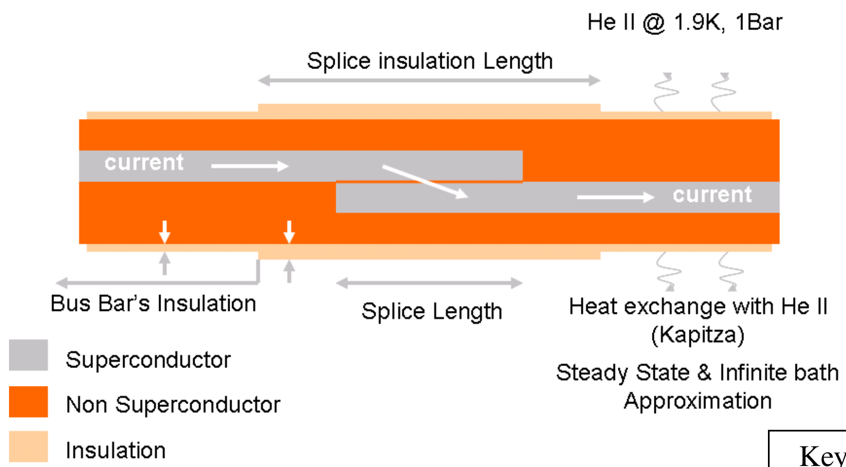
Criticality of a SC circuit



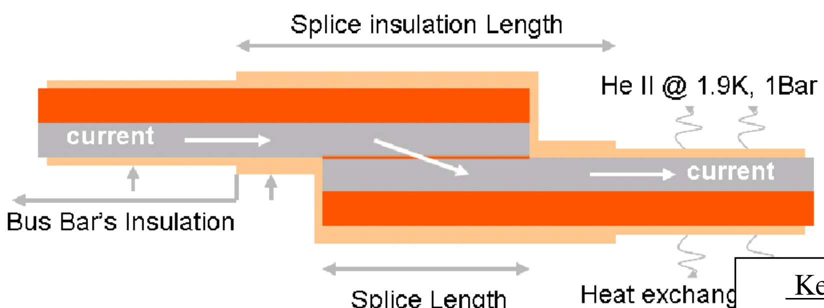
Quench of the bus-bar in adiabatic conditions.
Thanks to G. Kirby

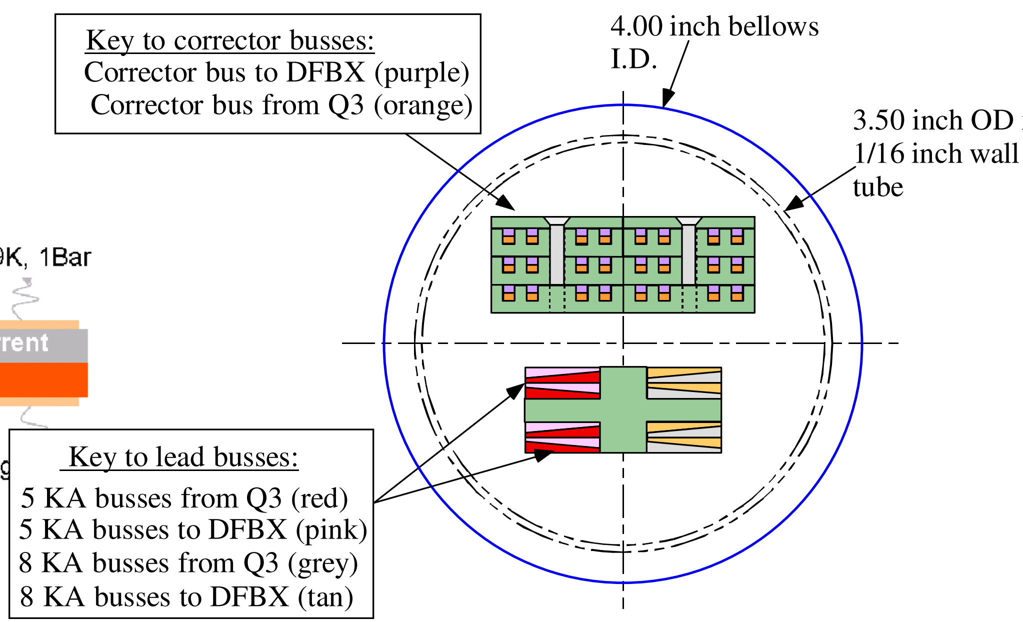
- Main circuits incorporate more protection
  - Cold diodes
  - Energy Extraction
  - Larger bus-bar cross-section
- MIITs and hot spot temperature estimated in the bus-bar according to real decay data and bus-bar section
  - Not a factor 10^4 but a factor 2
  - Always safe as in nominal conditions
- What about failures
  - In the quench detection?
  - In the EE switches opening?

Splice types in the LHC.



- Splices vary in length, copper to SC ratio, insulation, mechanical fixation
- You will hear in the following talks about 13 kA and 6 kA





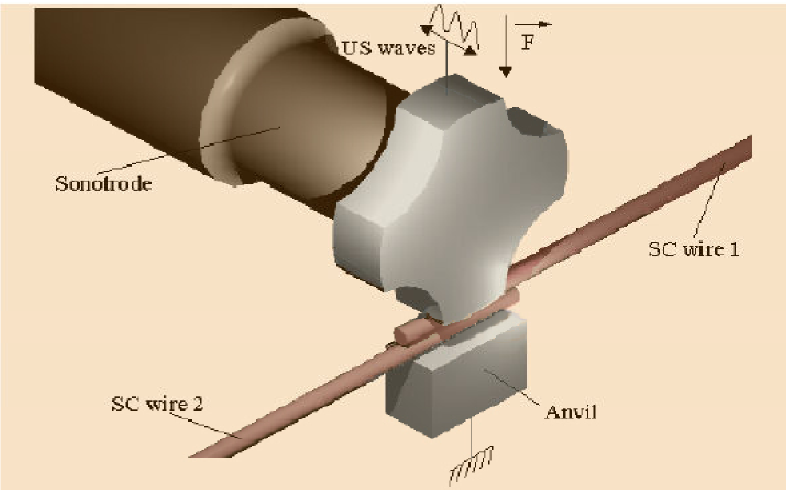
Corrector circuits 600 A. Lines M and N

The making of the electrical interconnections in the LHC

Accelerator Technology Department

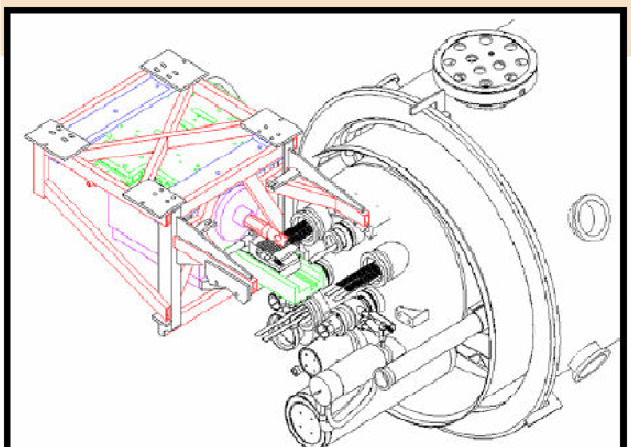
ANNECY lapp

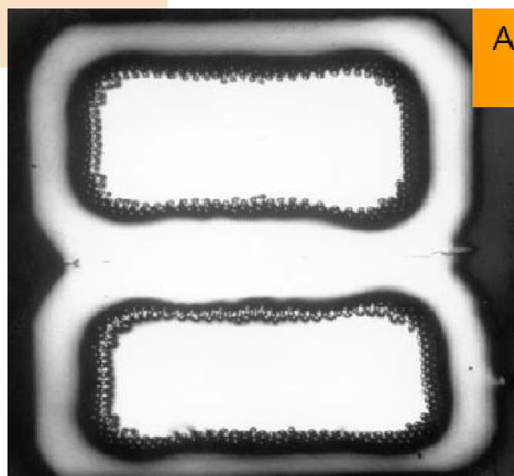
➔ **Spool pieces busbars : Junction technology : Ultrasonic welding**



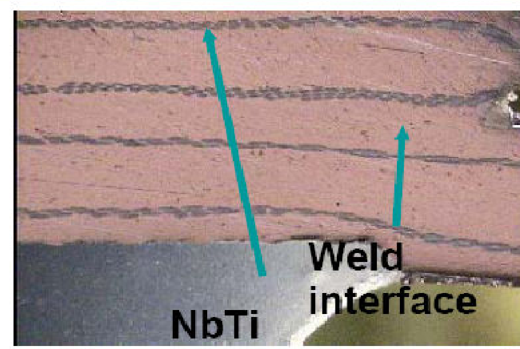
- Clean method (no flux)
- Oxyde destruction by friction
- Contact resistance between 3 and 5 nOhm

- High reproducibility and reliability
- On-line process control
- Mechanical resistance : equivalent to base material
- Fatigue life : more than 500 cycles at room and cryogenic temperatures





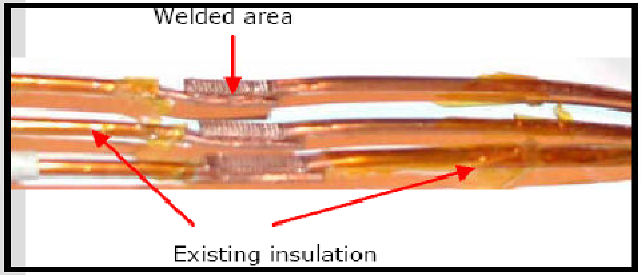
Achieved electrical contact resistance : 3 to 5 nOhm in average

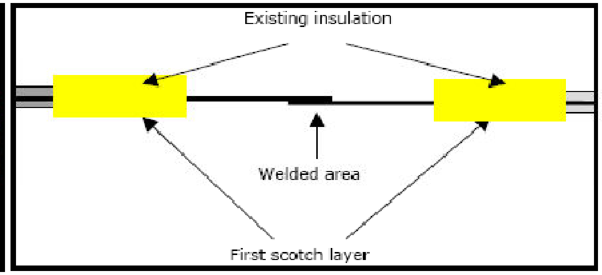


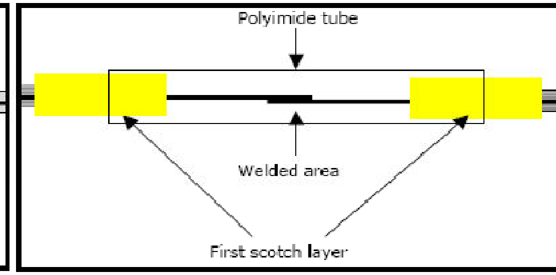
The making of the electrical interconnections in the LHC

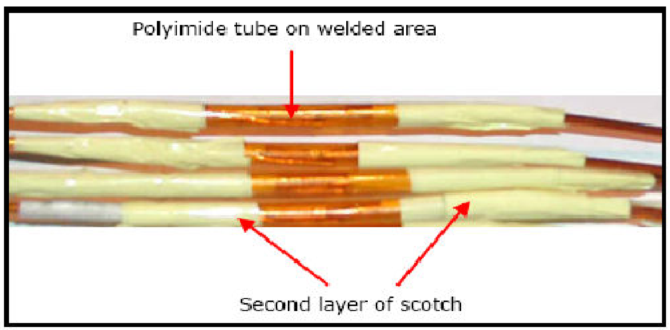
Accelerator Technology Department

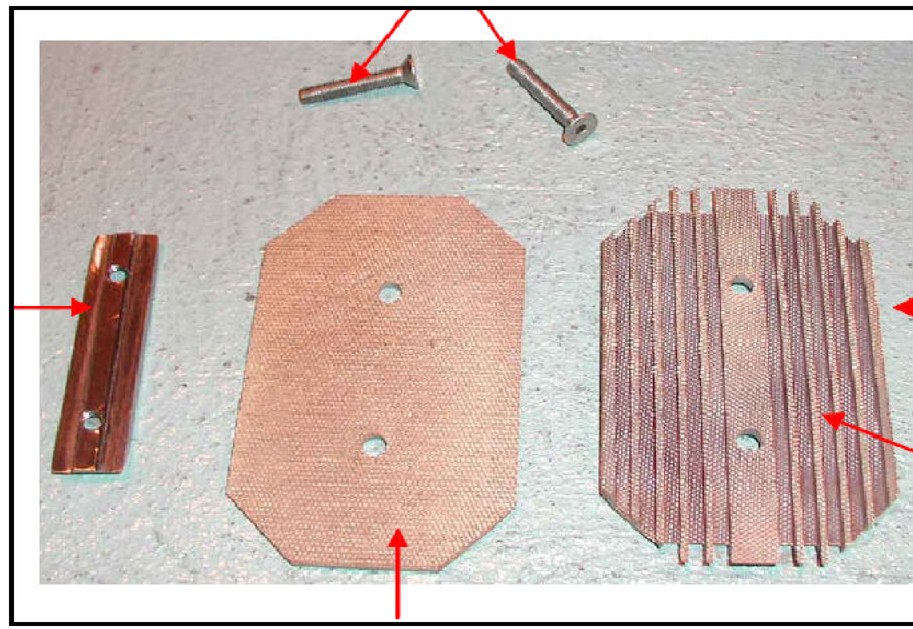
➔ Spool pieces busbars : Electrical insulation











The making of the electrical interconnections in the LHC

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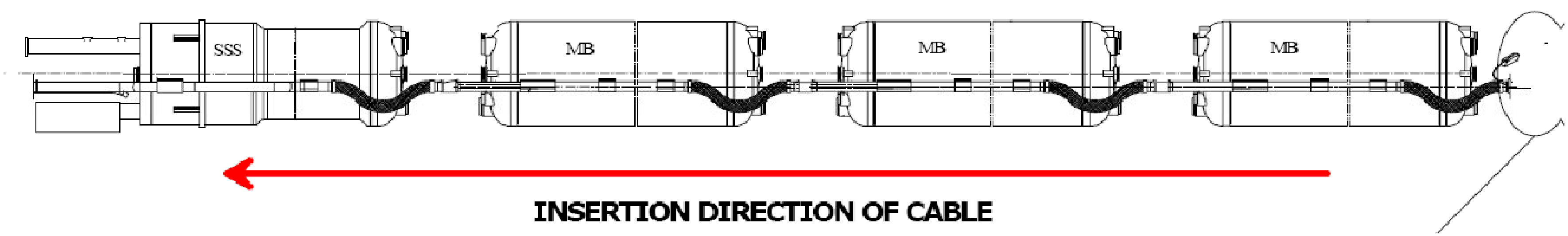
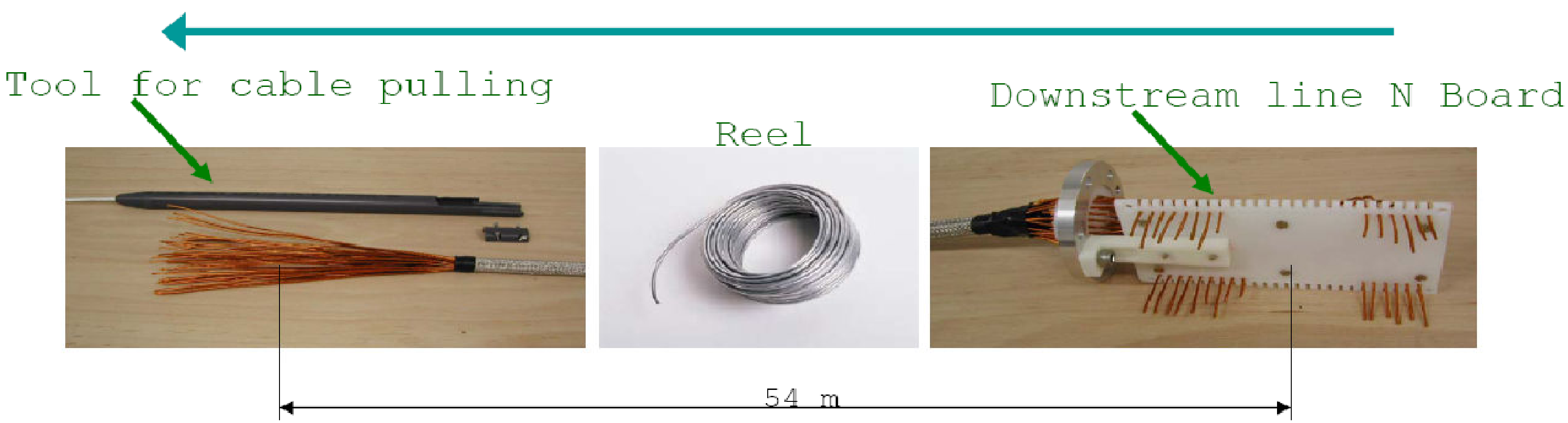
➔ Auxiliary busbars :Assembly procedure

HALF CELL



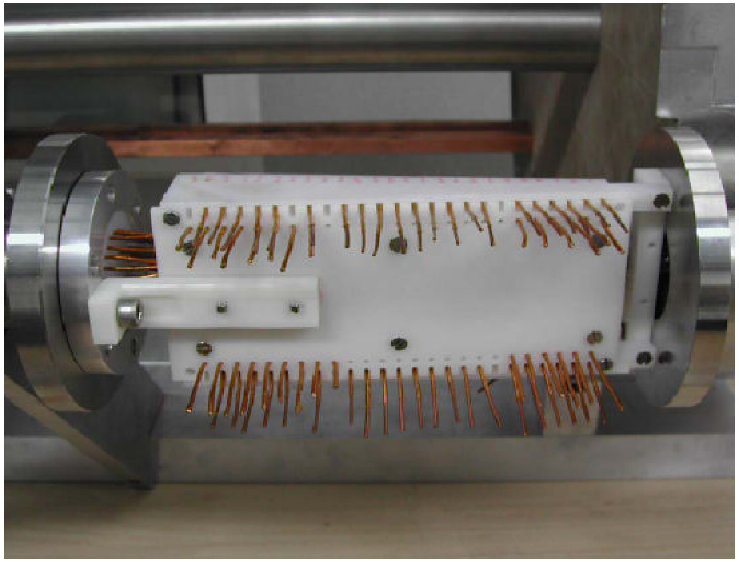


+ Fully assembled cable (Plug included) on a transport reel + Line N board components + Protection covers for transport + Wires identification + Certificate of conformity + Cable segment identifier

The making of the electrical interconnections in the LHC

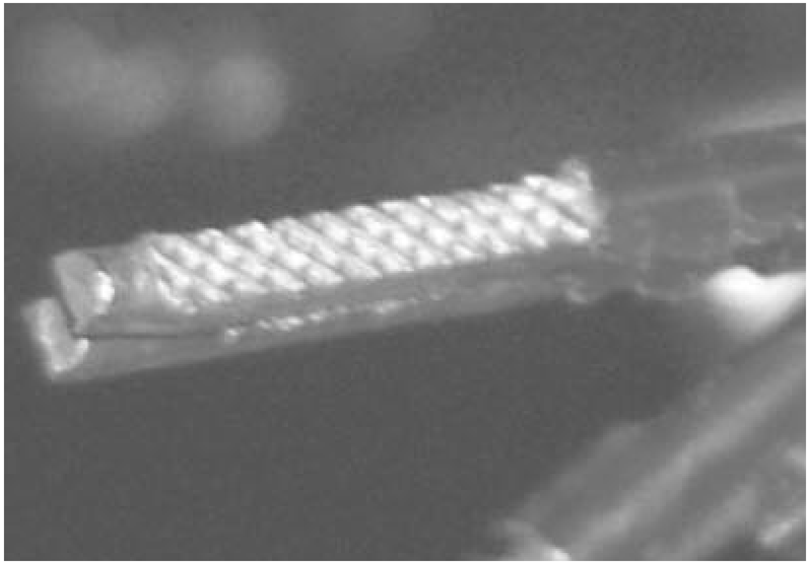
Accelerator Technology Department

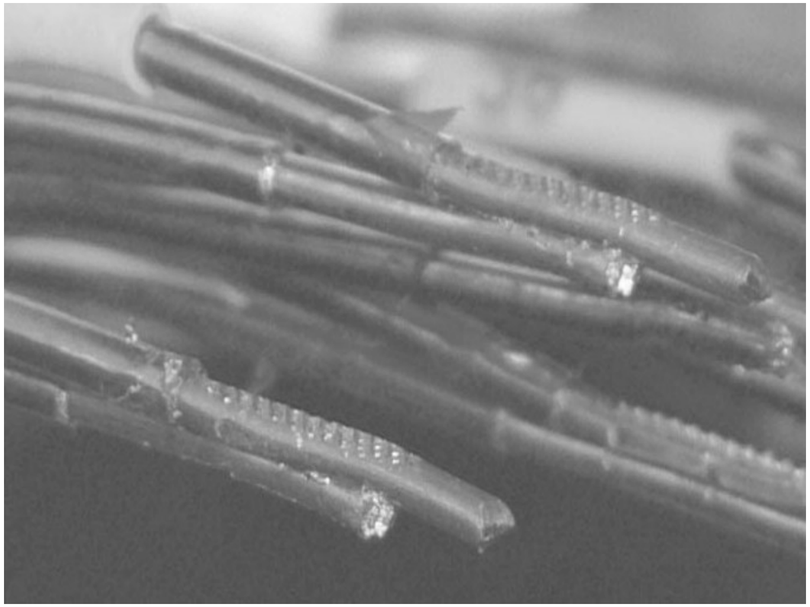
➔ Auxiliary busbars :Assembly procedure



Operation #LI-2-05 "Assemble the connection box"
Operation #LI-2-06 "*Perform electrical test*"
Operation #LI-2-07 "Weld line N auxiliary bus bars"
Operation #LI-2-08 "*Perform electrical test*"
Operation #LI-2-09 "Insulate electrically the aux. Bus bars"
Operation #LI-2-10 "*Perform electrical test*"

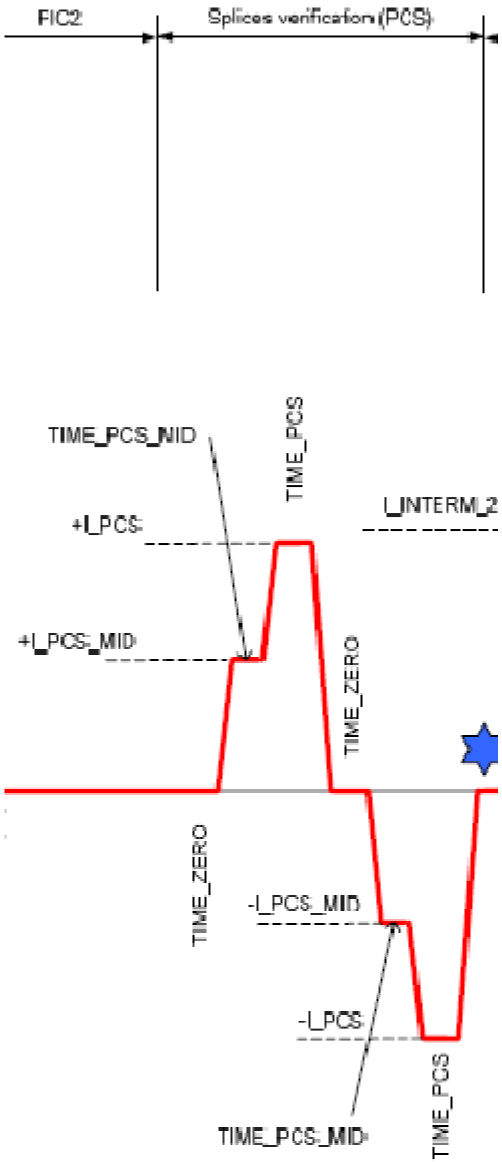
Ultrasonic welding

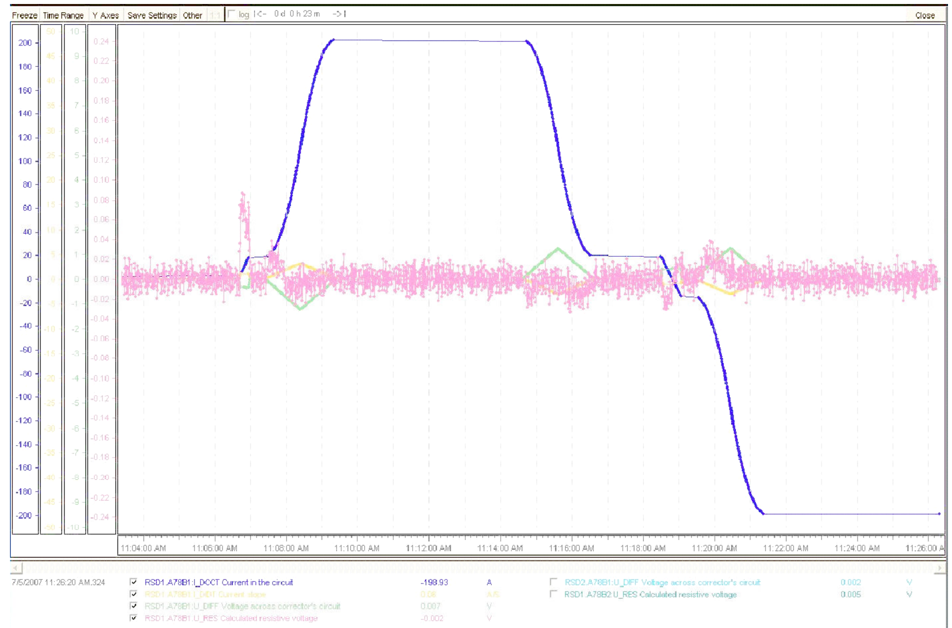




- Reported by D. Tommasini to MARIC on November 2006 after the inspection of the first installed sector
  - Presence of insulation between wires
  - Bad alignment with reduction of contact surface
- Cryolab measurements showed 4 to 19 nOhms
- US welding machines put in conformity
- Suspected interconnections re-done during following warm-up
- Test proposed during powering to spot catastrophic cases

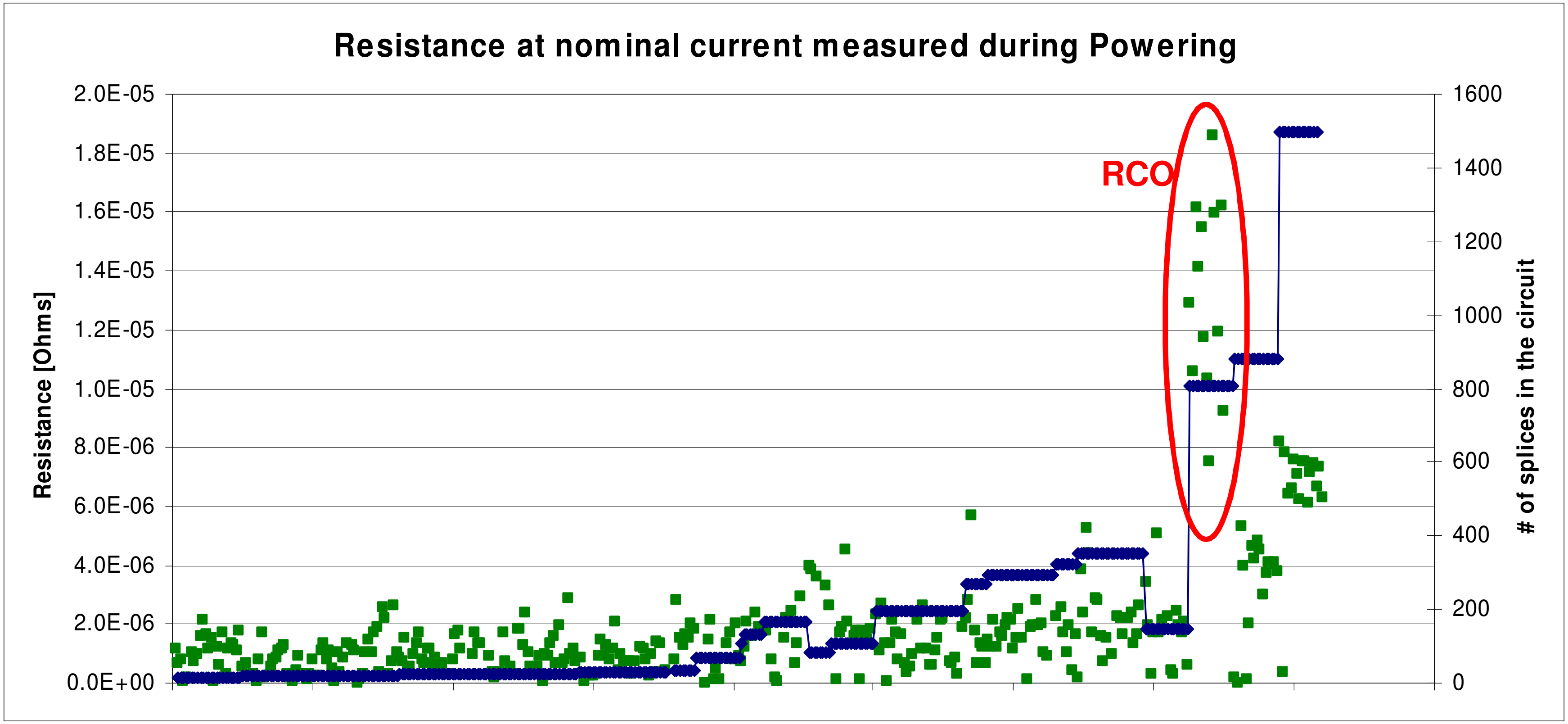
PCS splice verification





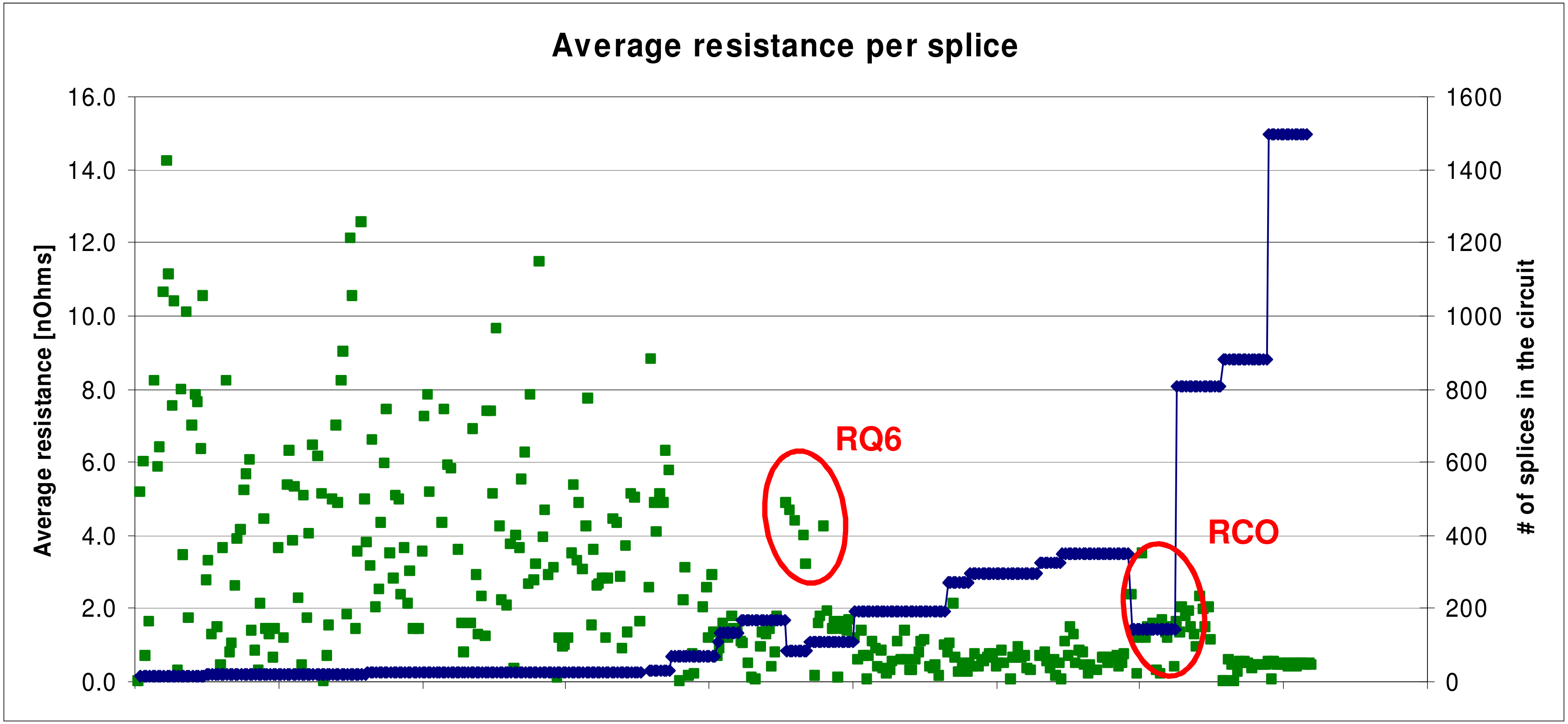
- ➔ Test systematically done during powering tests for all 600 A circuits
- ➔ Current plateau at minimum current (200 A). Resistance deduced from QPS voltage measurements.
- ➔ Repeated at nominal current. Data stored in MTF
- ➔ Assumed resolution < 1μOhm

Results from the last powering campaign



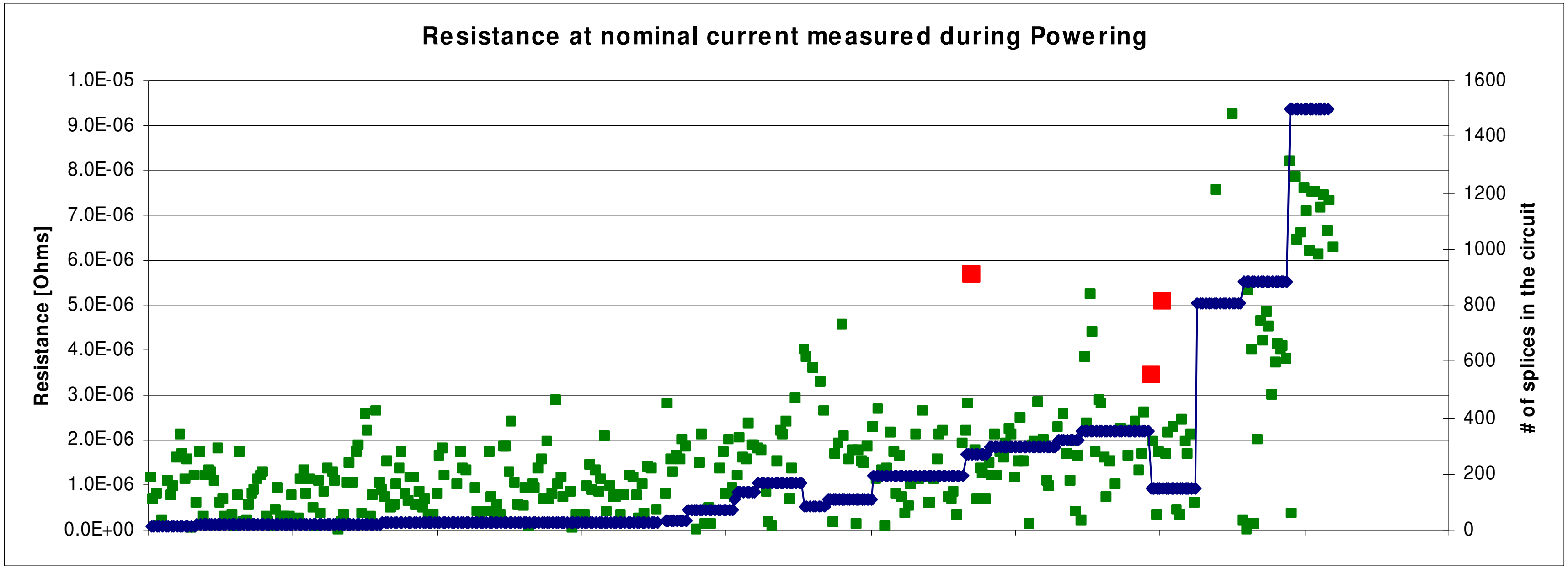
- ➔ Resistance is indeed proportional to the number of splices but noise is very high.
- ➔ Noise depends on the circuit type. Cable length, number of magnets and inductance.
- ➔ RCO circuit is a 120 A circuit and test is done at 100 A.

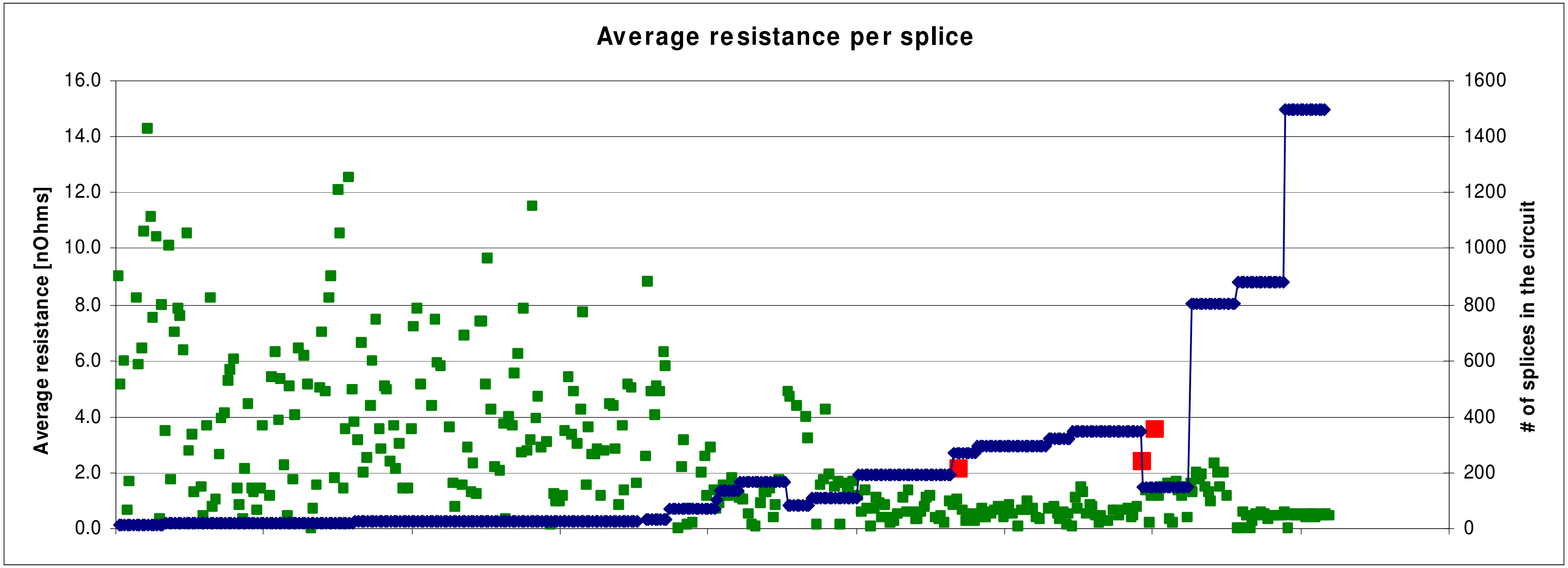
Results from last hardware commissioning campaign



- ➔ Expected value is between 4 and 6 nOhms
- ➔ RQ6 (6xMQTL) has a higher average splice value.
  - Systematic. May be due to internal splices in the magnet
- ➔ RCO splices are nominally higher than others

First circuits to verify and re-measure





Existing NC in 600 A circuits

Number:	955048	ver. 1
EDMS Id:	955048	
Initiated		

QN-ELQA-TP4E-ICC-RCO.A81B2-001
Giorgio D'ANGELO

Report - Non conformity
2008-08-27

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Description, External Reference and Keywords

Description: CL1, CL2 and coil resistance too high (measured 05/06/08). Origin to be investigated. To be checked with cryo.

External Reference

Given Comments (3 records) Hide

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Giorgio D'ANGELO on 2009-03-20, 14:50 said: Initiated comments
Since this circuit is not needed for the 1st run of LHC at 5 TeV, HCC decided to postpone investigation due to time constrain.

Giorgio D'ANGELO on 2009-04-09, 15:40 said: Initiated comments
Diagnostics performed on 26th of March 2009, shows that this circuit is open between position B12L1 and B11L1.
This circuit cannot be used until it is repaired (need to warm up the sector and open the interconnections).

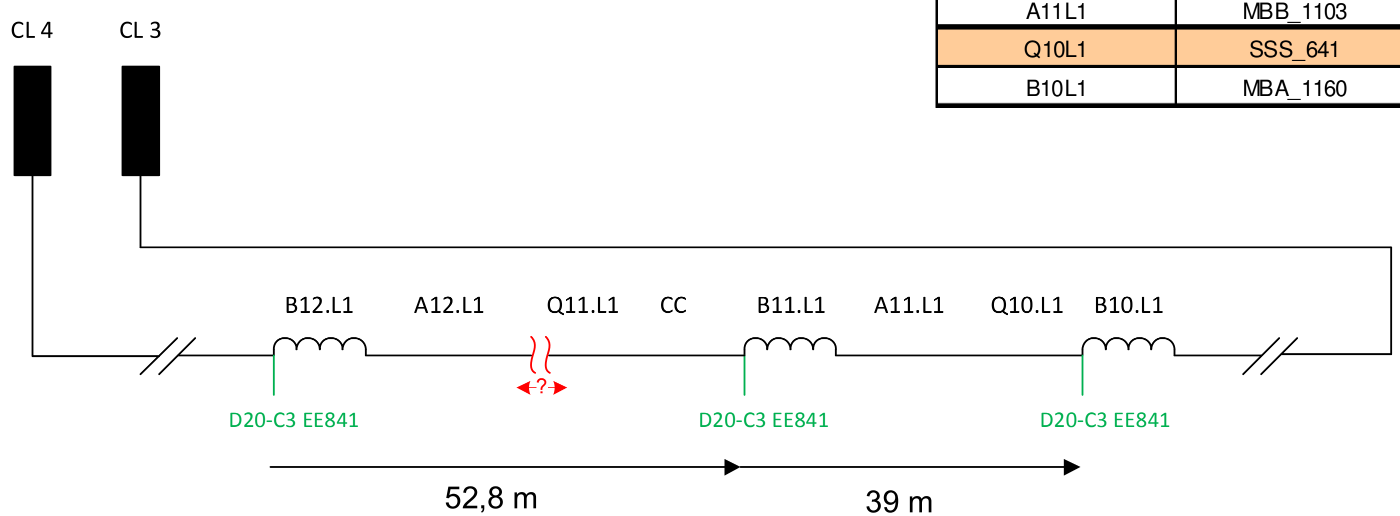
Giorgio D'ANGELO on 2009-10-08, 18:18 said: Initiated comments
This circuit was tested during TP4-E campaign (Oct.2009) and the problem is still present. Cold circuit is isolated from ground and other circuits.
It is condemned at the level of power converter.

EDMS Hyperlinks

Position:	Magnet name:	Upstream position:
C12L1	MBB_3094	26171.6225
B12L1	MBA_3174	26187.2825
A12L1	MBB_1144	26202.9425
Q11L1	SSS_524	26218.6025
	CC	26226.3475
B11L1	MBA_1158	26240.0642
A11L1	MBB_1103	26255.7242
Q10L1	SSS_641	26271.3842
B10L1	MBA_1160	26279.1292

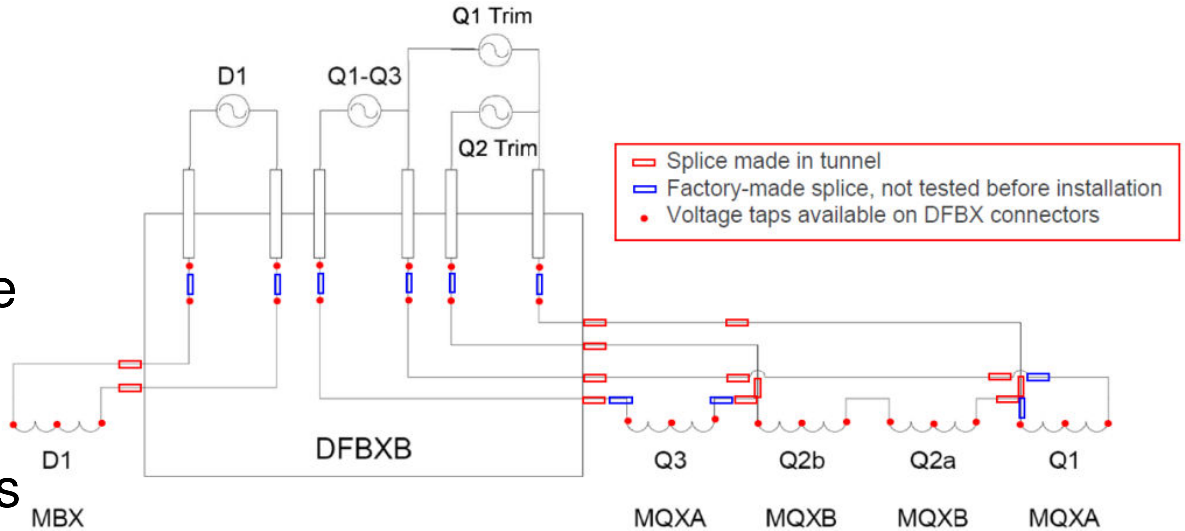
Sketch of the RCO.A81.B2 circuit - External aperture

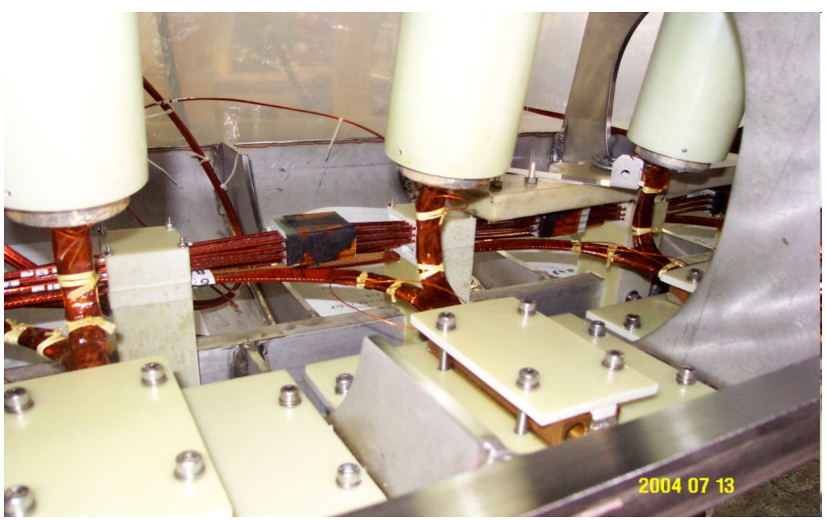
Circuit found open, at 1.9K, on 23/03/2009
between B12.L1 and B11.L1

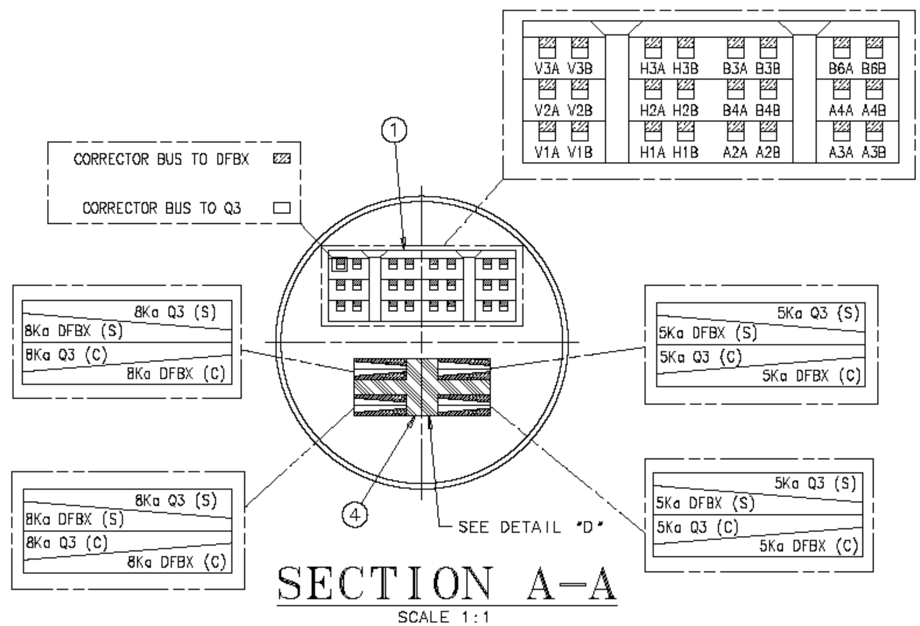


Inner triplet 13 kA splices

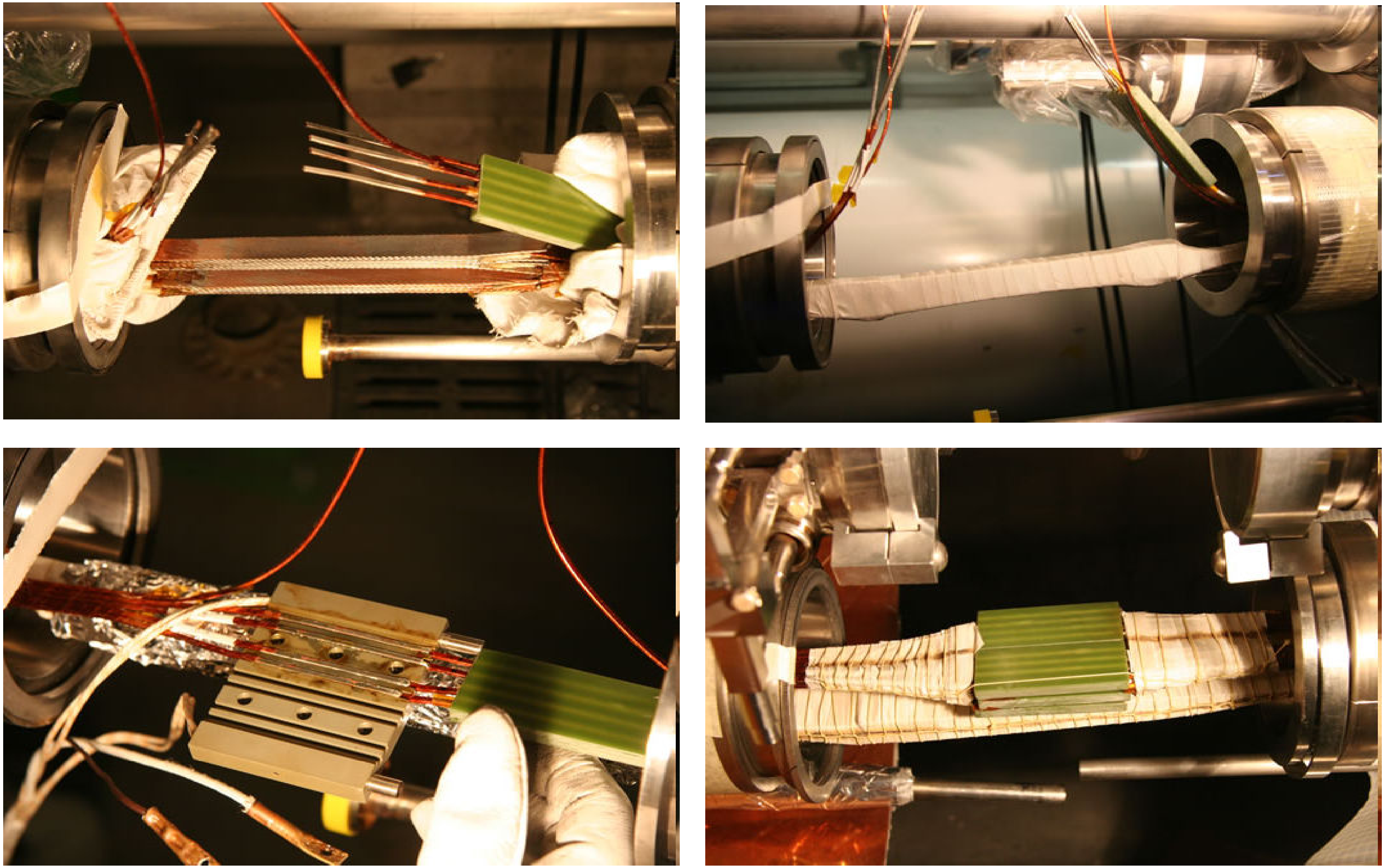
- Two double bus-bars Cu/SC
  - 5 kA and 8 kA
  - Brazed similarly to the 6kA flat cable
- All splices protected together with the magnets at a 100mV threshold







Inner Triplet splices during interconnection



NC 948545 on a 120 A octupole corrector

Number:	948545	ver.1
EDMS Id:	948545	
Initiated		

QN-ELQA-TP4E-ICC-RCOSX3.L1-001
Giorgio D'ANGELO

Report - Non conformity
2008-08-12

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Description, External Reference and Keywords

Description	During ICC measurement, coil seems too be resistive (about 1.1 e-3 Ohm). In agreement with Sandor Feher, it was decided to keep the circuit as it is. This magnet should be followed during the first steps of powering. This NC should be closed once the powering step is successfully achieved.
External Reference	
Keywords	

Special Properties

Class	Electrical / Instrumentation
Disposition	Decision Pending

Given Comments (1 record) **Hide**

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Richard MOMPO on 2009-07-16, 09:10 said: Initiated comments

During standard ELQA campaign at warm (TP4 tests) performed on 14/07/2009, circuit RCOSX3 was found open. After a basic investigation, the circuit is open below the cold vtaps of the 120 A current leads. This circuit is isolated from ground and from the other circuits.

EDMS Hyperlinks

This page https://edms.cern.ch/document/948545/1/TAB3

- ➔ As for the spool, high resistance was seen during the EIQA tests (>µOhm)
- ➔ Need to open the cryostat to locate and repair the fault

Conclusions

➔ What is the maximum credible incident (MCI) affecting each of these circuit types
  - Quench detection failing? Non propagating quench
  - Arcing in a spool piece next to M1, M2 line
  - ...?

➔ Work ahead of us:
  - Investigation of excessive resistance in 600 A circuits
  - Verify the splice parameters (mainly for US magnets)
  - Evaluate heating of the bus-bar under accidental conditions
  - …