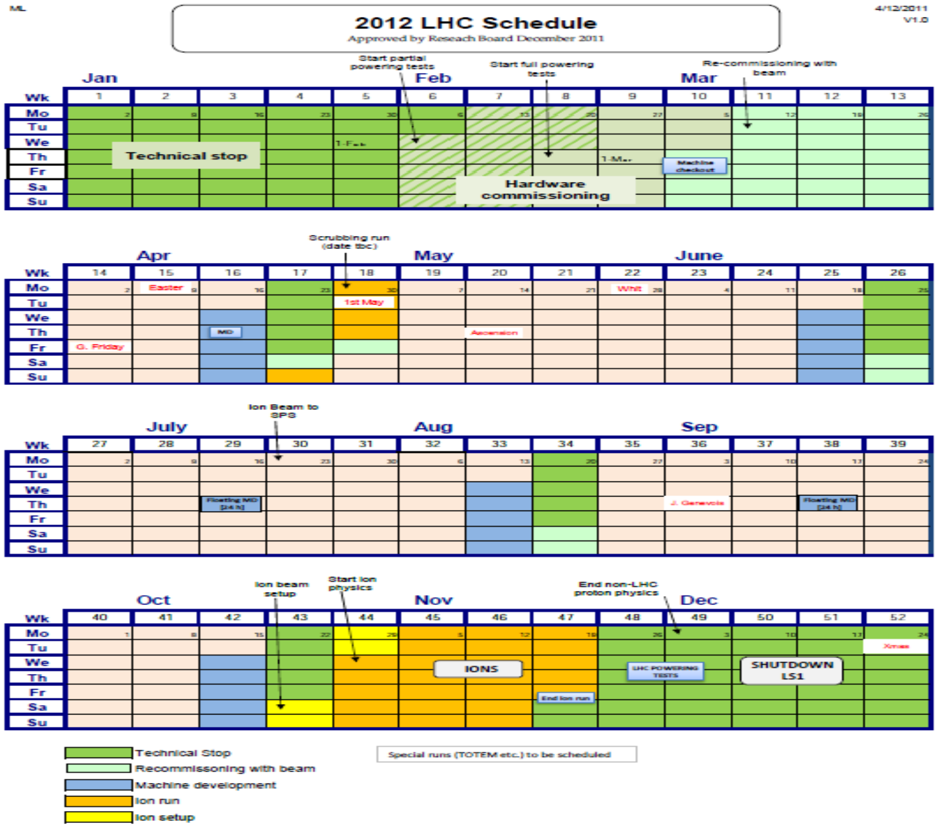
Acknowledgements: all material is from K. Foraz, J-P Tock, F. Savary and others
References: Second LHC Splice Review, November 28-30, 2011
https://indico.cern.ch/conferenceDisplay.py?confId=157231
R2E review, November 21-24, 2011
http://indico.cern.ch/conferenceDisplay.py?confId=157386

MIRKO POJER

LHC 2013/2014 PLANNING & OVERVIEW OF MAIN ACTIVITIES
OP DAY 2012

SHORT AND LONG TERM



LHC long term planning

	J	F	M	A	M	J	J	A	S	O	N	D
2011		1	2	3	4	5	6	7	8	9	IONS	
2012			1	2	3	4	5	6	7	8	IONS	
2013	LS1 - SPLICE CONSOLIDATION											
2014									RECOM	RECOM	1	2
2015	1	2	3	4	5	6	7	8	9	10	IONS	
2016		1	2	3	4	5	6	7	8	9	IONS	
2017		1	2	3	4	5	6	7	8	9	IONS	
2018	LS2											
2019		1	2	3	4	5	6	7	8	9	IONS	
2020		1	2	3	4	5	6	7	8	9	IONS	
2021		1	2	3	4	5	6	7	8	9	IONS	
2022	HL-LHC upgrade											

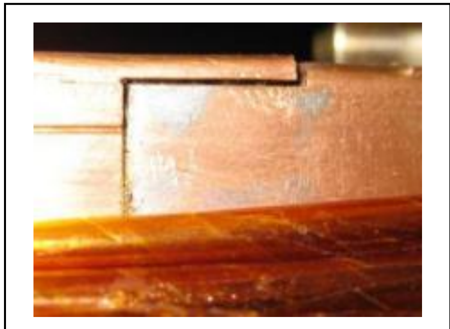
Technical stop or shutdown
Proton physics
Ion Physics
Recommissioning

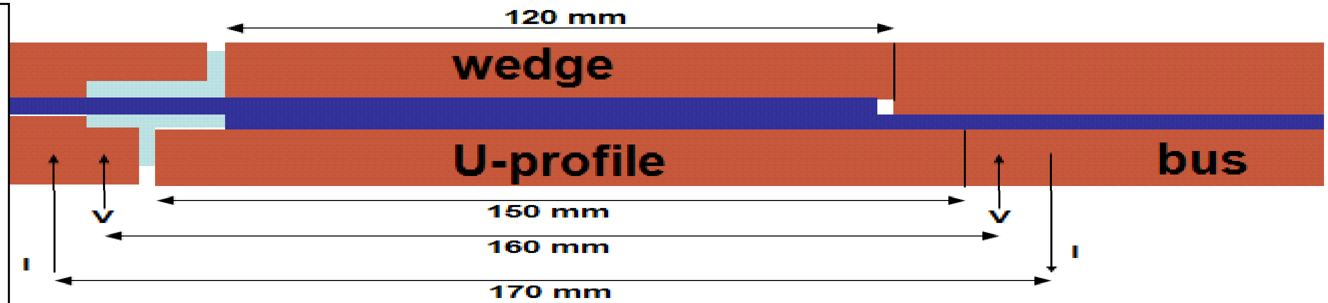
- **Preliminary powering tests at the end of 2012 run (find other possible limitations)**
- **20 months** from Beam OFF to Beam ON
  - Including powering tests, warm-up, cool-down
  - Total duration agreed between experiments and machine
    - LHC machine: 20 months
    - ALICE: 12 months (up to 15 months)
    - ATLAS: 15 months (but from April '13)
    - CMS: 20 months
    - LHCb: 12 months
- **Beam back somewhere in July 2014**
- **No Xmas break in 2014???**

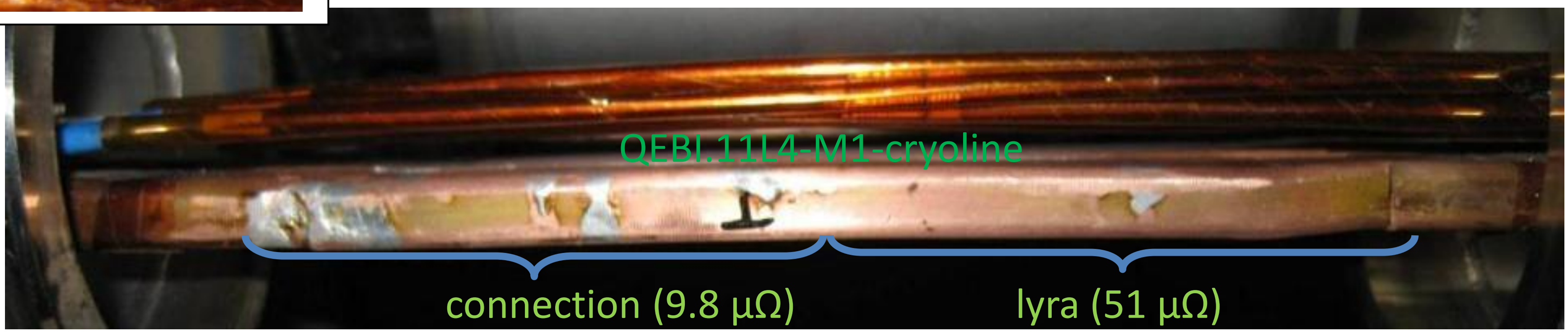
- **<u>Priorities for the LHC interventions</u>**:
  - P1: Beam (safely) to 6.5-7 TeV, nominal performance
    - Superconducting circuits consolidation
  - P2: Reliable operation
    - R2E relocations
    - maintenance
  - P3: others

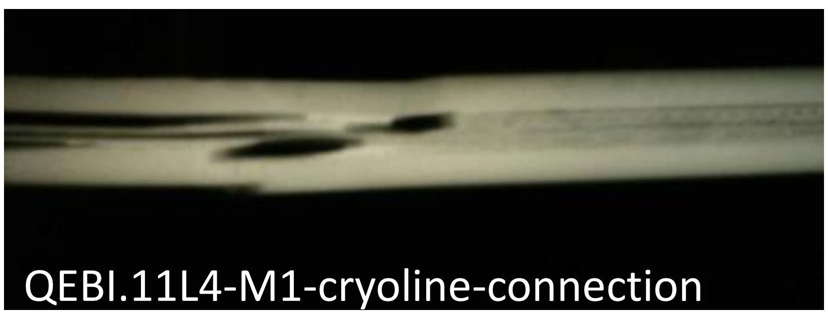
- Resources are attributed according to these priorities
- Procurement contract and resources recruitment is done accordingly

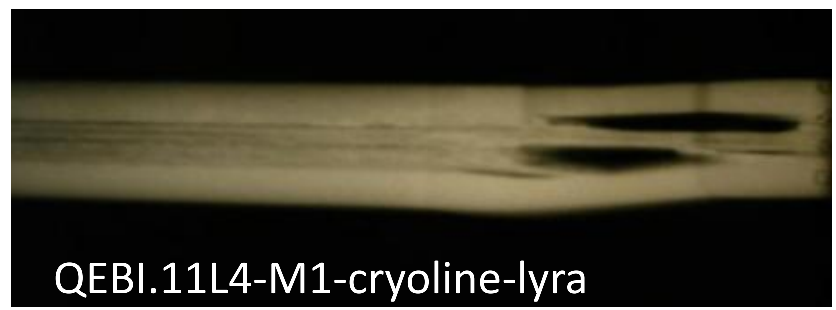
- **<u>What has to be done to consolidate the superconducting circuits</u>**:
  - **Main splices in the arc**
  - DFBA circuits
  - Replace cryo-magnets
  - Consolidate connection cryostats
  - Other activities not linked directly to SC circuits:
    PIMs, Helium level gauges, Y lines, DN200, …











2009 strategy: repair all bad splices above 40 μΩ for dipoles and 80 μΩ for quadrupoles (ideal values are: RB->9.45 μΩ, RQ->16.0 μΩ) [R16 meas.]

Powering and ELQA tests prior to Warm-up (4+4 d)
- qualify circuits except mains to 7TeV
- fault localization..

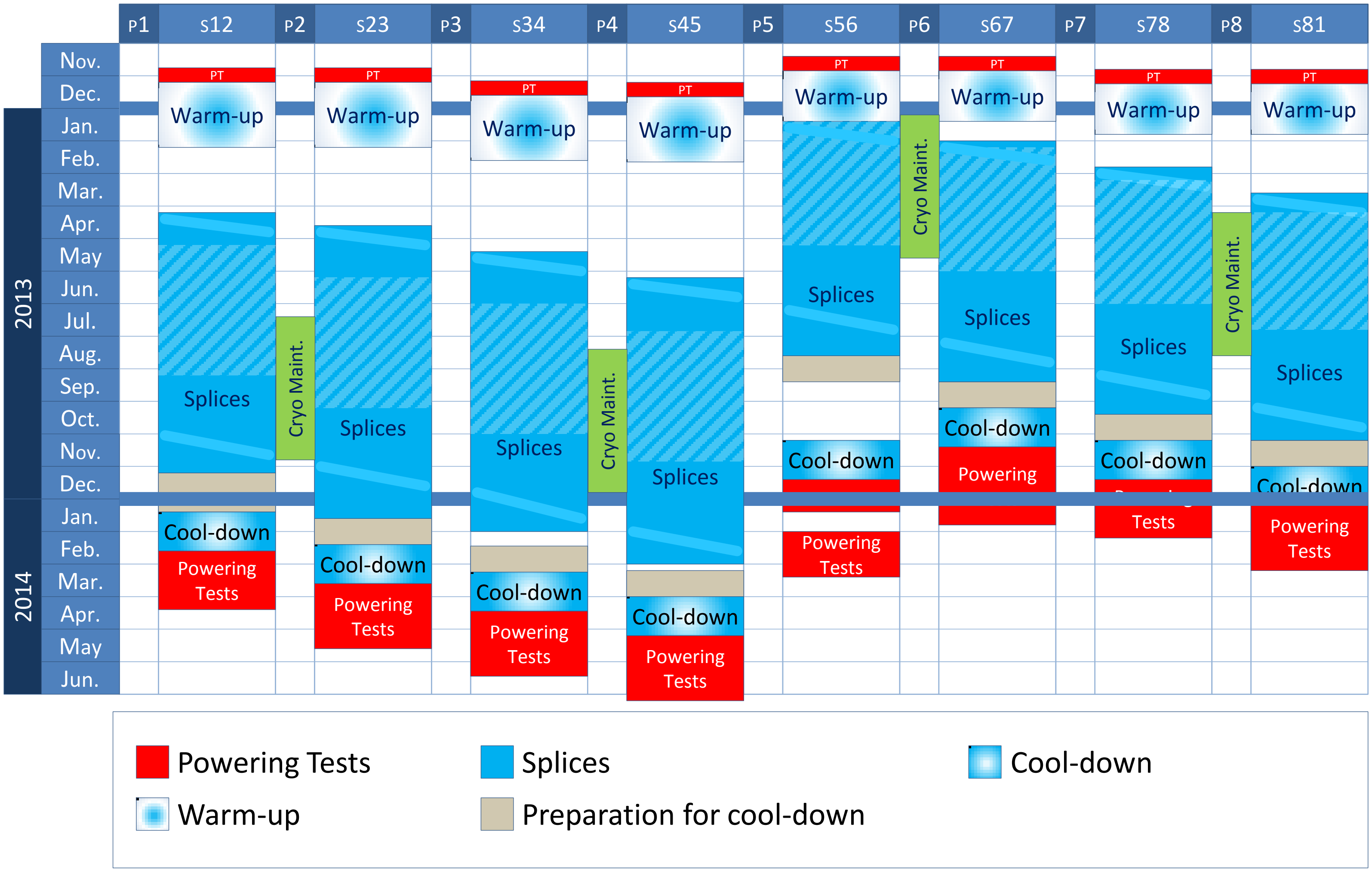
Warm-up: incl. vacuum leak tests at 80K (1wk) to localize leaks

Maintenance and consolidation

Flushing, pressure test, ELQA @ warm, cool-down

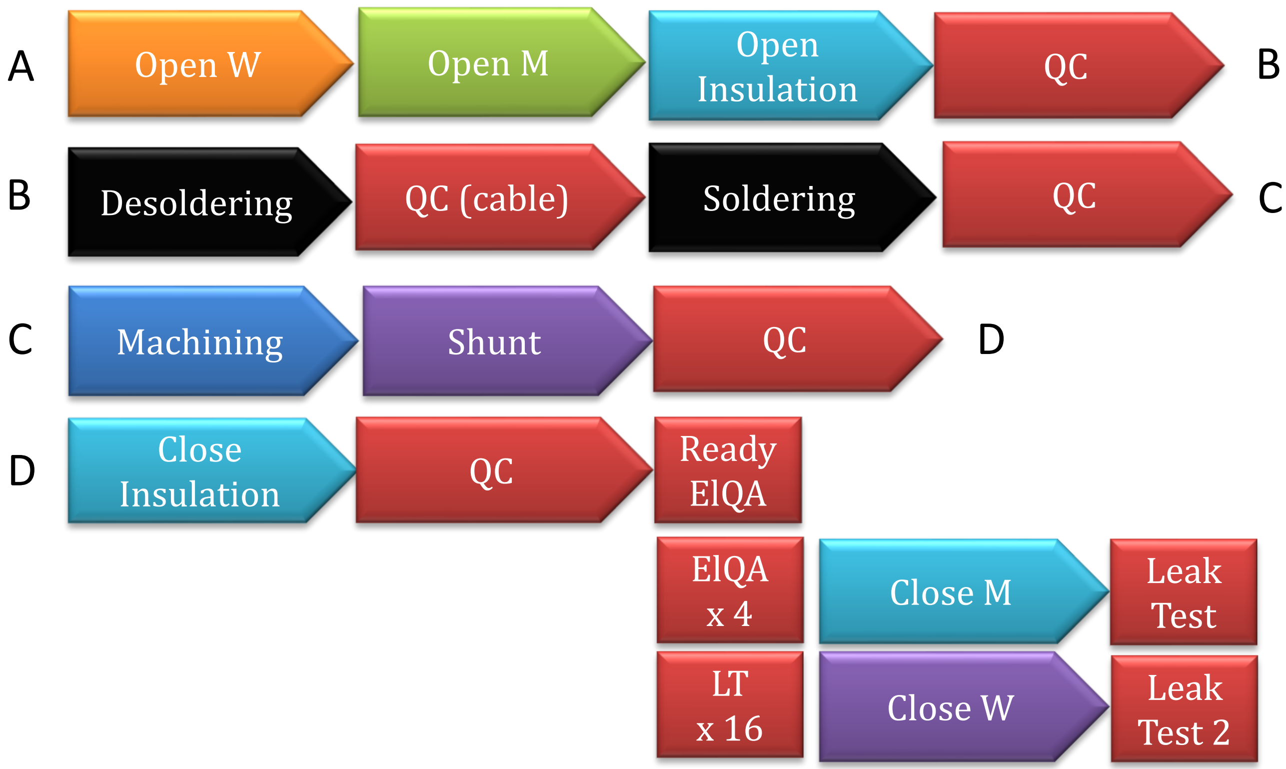
Powering tests

SPLICE CONSOLIDATION: GLOBALLY

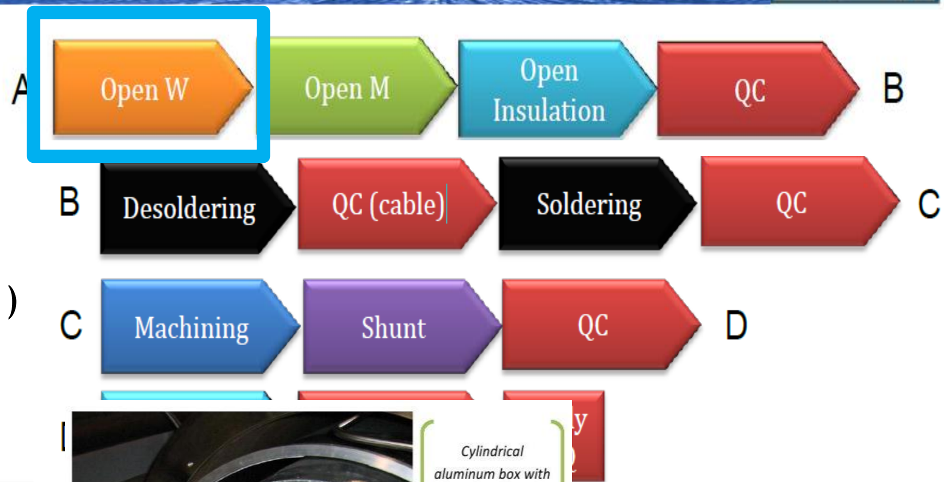


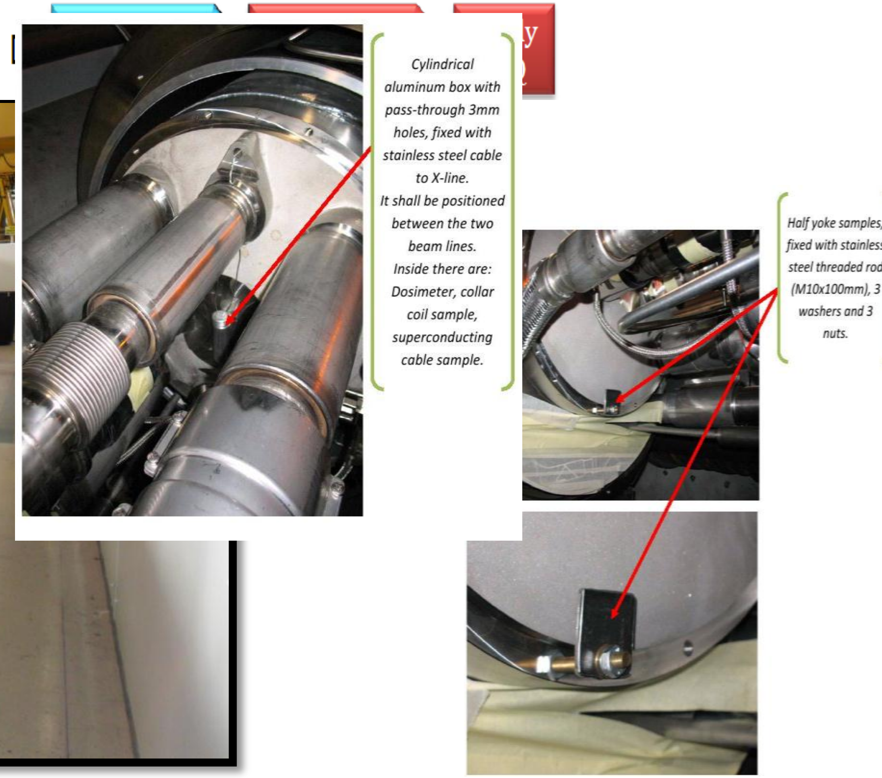
Cryogenics : 18 weeks per cryoplant+ Maintenance of all the equipment: CV, EL, RF…

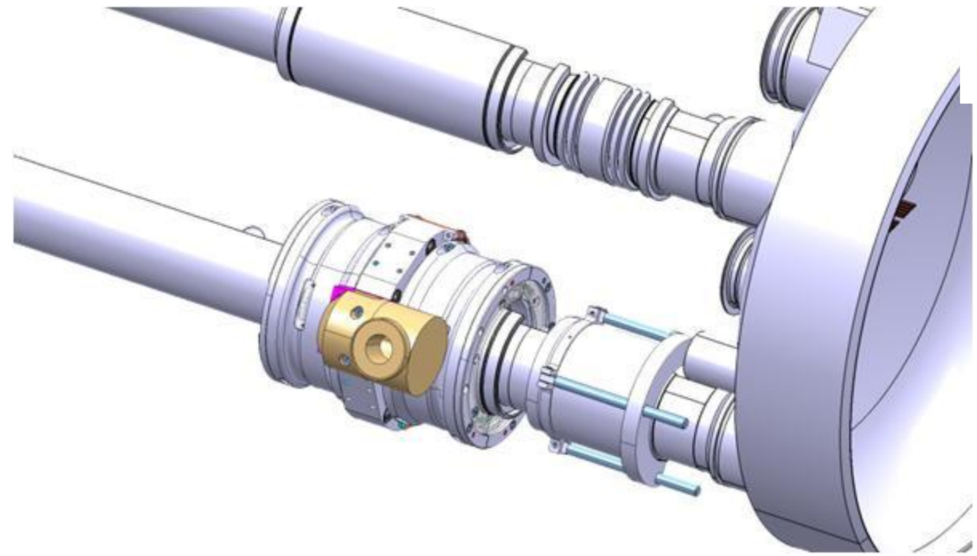
Splice consolidation: the work-flow

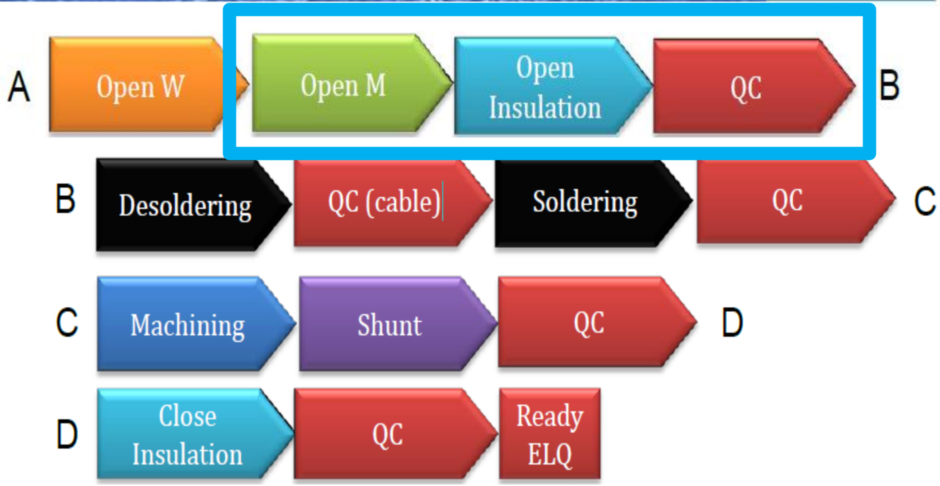


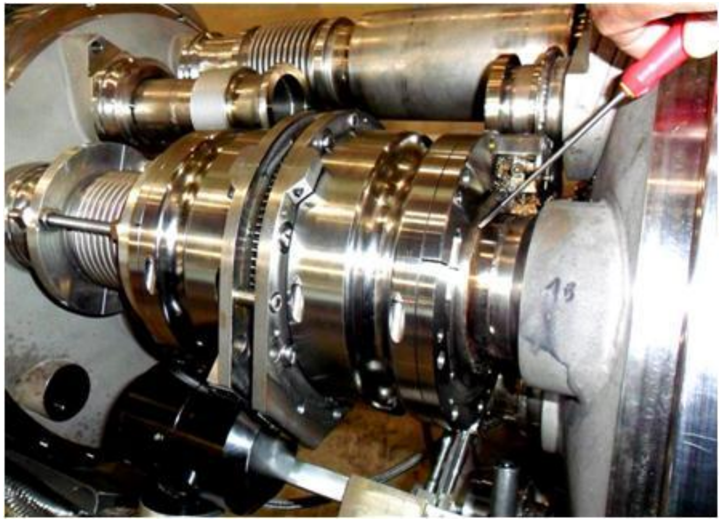
- Open interconnections for:
  - Consolidation of main splices
  - Installation of DN200
    - Partial opening first
  - Recovery of RP samples (LHC-LI-EC-0001)
  - Special interventions





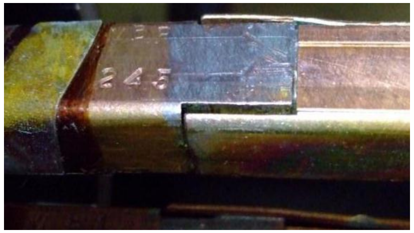




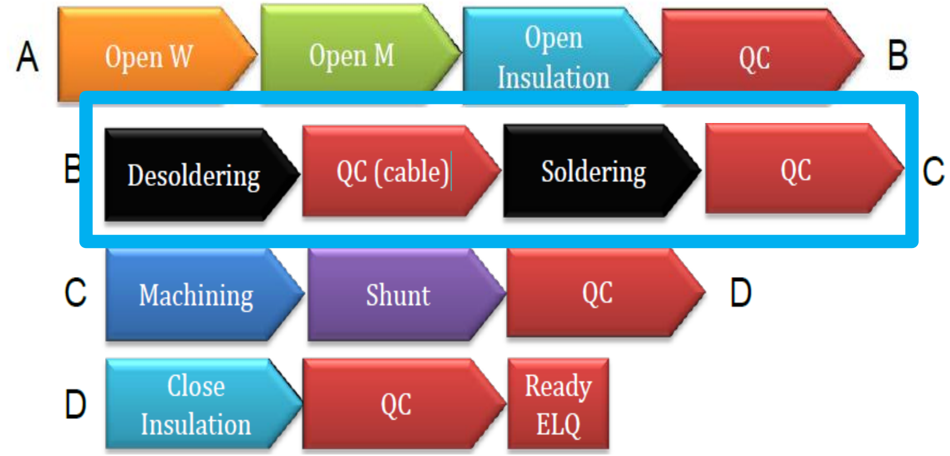


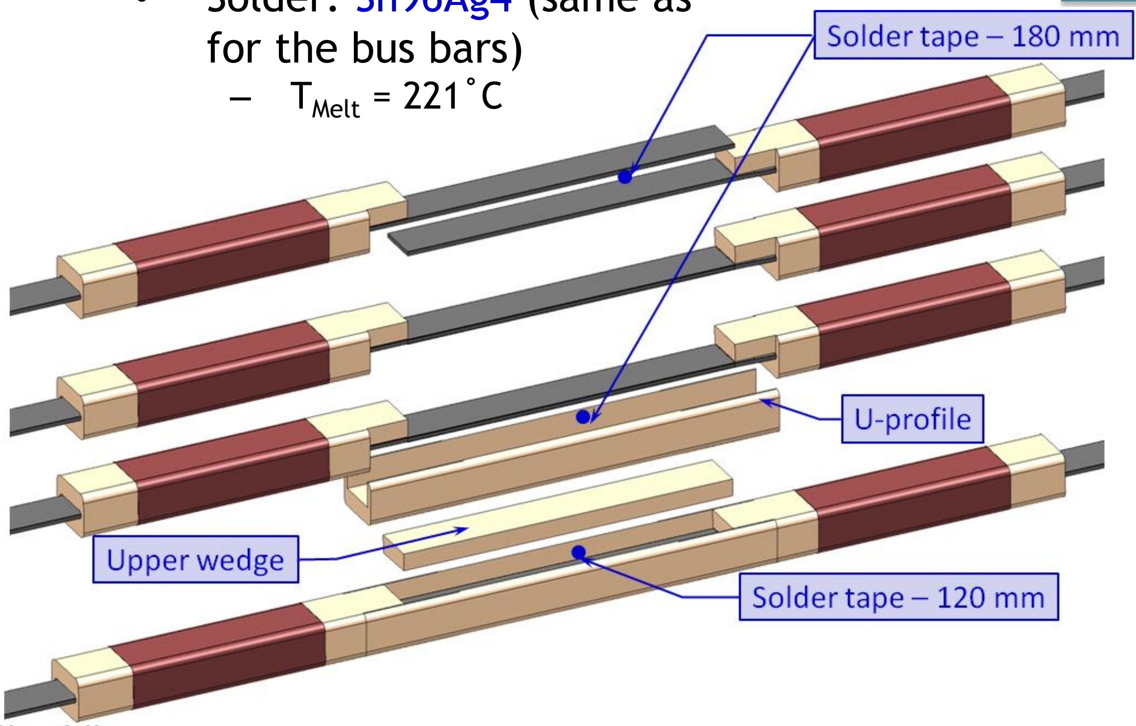
QA/QC check immediately after removal of old insulation:

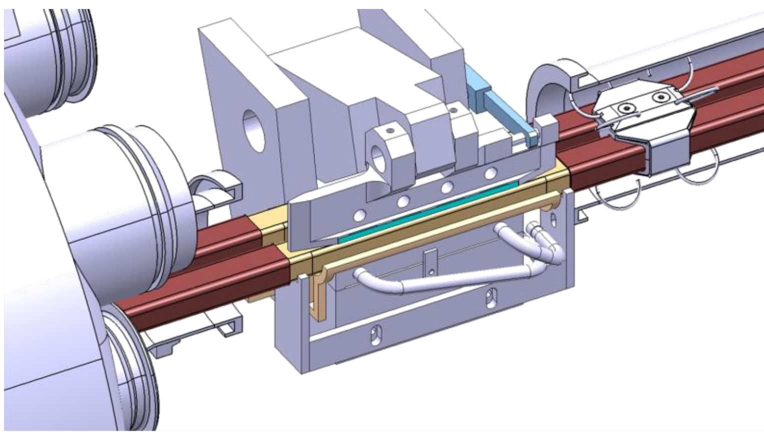
- Geometry (alignment - gaps) by go/no go gauge and visual aspect
- R-measurements



- **<u>Desoldering / Resoldering</u>** is an option
  - There are 10170 main splices in the LHC, of which about 15% need to be re-done
- Induction heating
- Soldering temperature (plateau) $T_0 = 240^\circ C$
- Solder: Sn96Ag4 (same as for the bus bars)
  - $T_{Melt} = 221^\circ C$

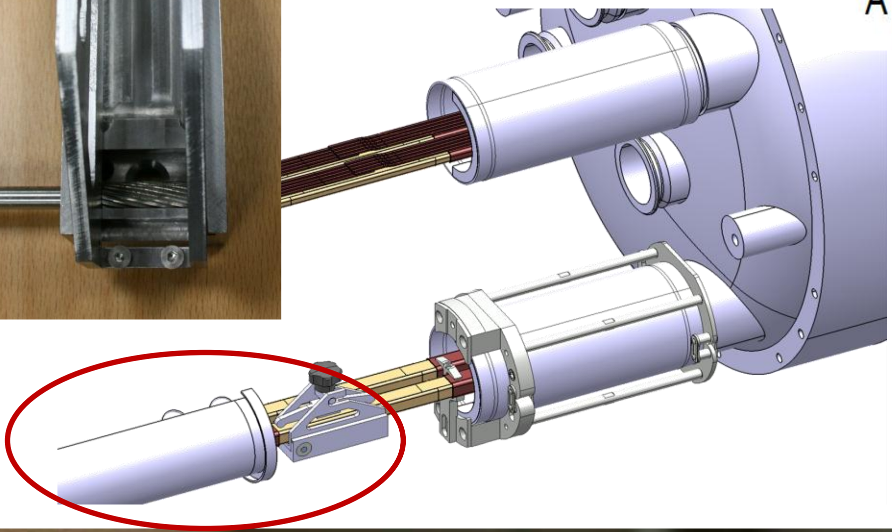


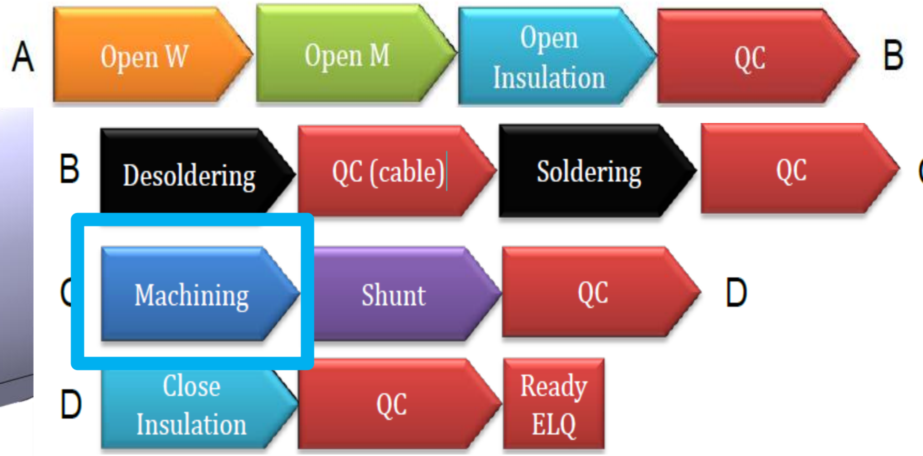




Courtesy F. Savary

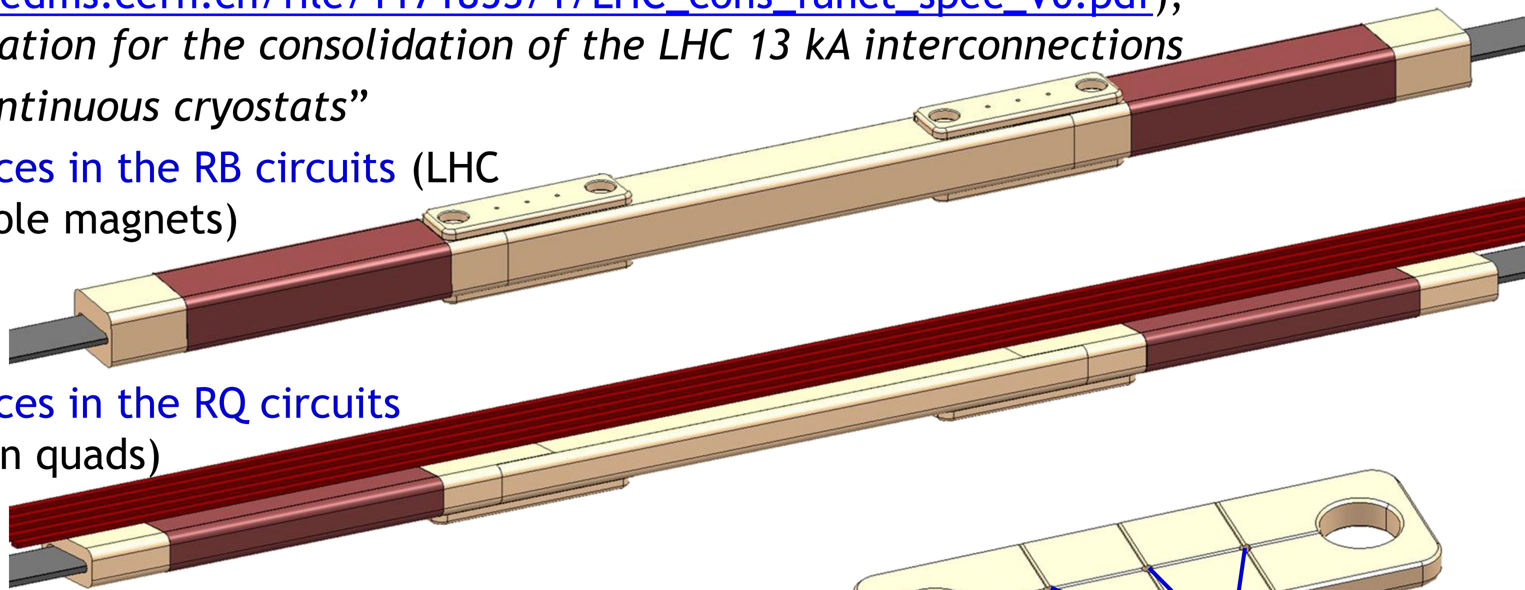
BB MACHINING



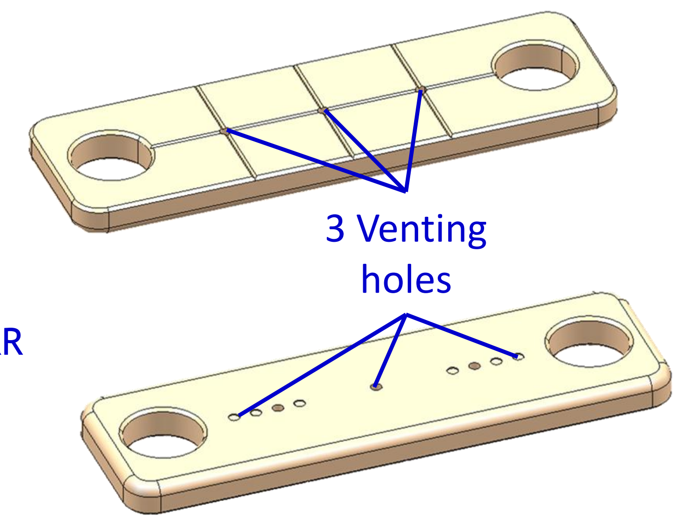


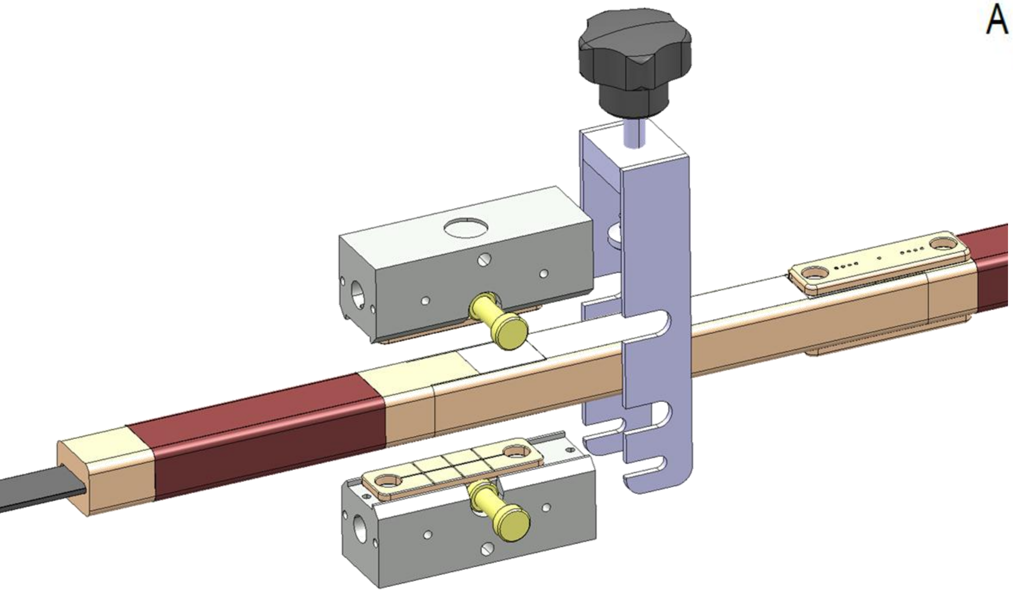
THE SHUNT

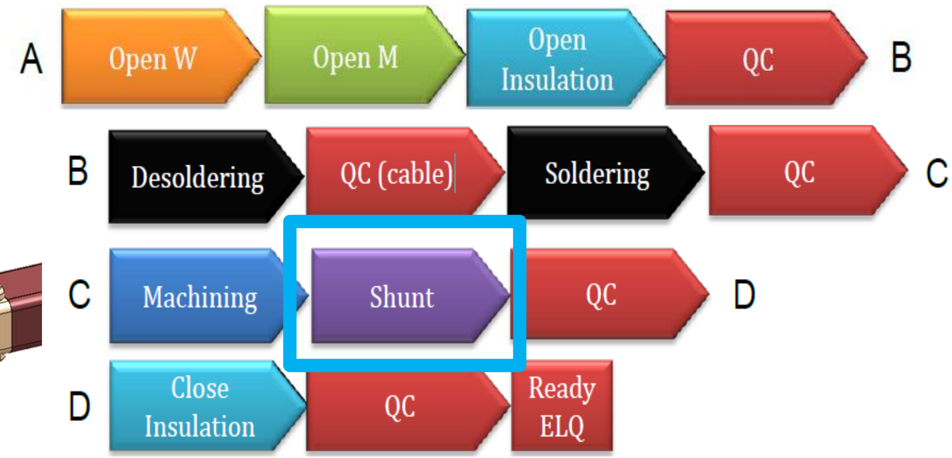
- Functional requirements as per EDMS #1171853 (https://edms.cern.ch/file/1171853/1/LHC_cons_funct_spec_V0.pdf), *"Specification for the consolidation of the LHC 13 kA interconnections in the continuous cryostats"*
- 3390 splices in the RB circuits (LHC main dipole magnets)
- 6780 splices in the RQ circuits (LHC main quads)



- 3390 x 4 = 13560 dipole shunts for RBs
- 6780 x 2 = 13560 quadrupole shunts for RQs
- The main features of the shunt are
  - Copper annealed at 400 °C for 2 hours to maximize RRR
  - Rounded edges to avoid tendency to arc ignition
  - One hole for a pilot T-probe to steer the T cycle
  - 3 venting holes and transverse/longitudinal grooves at the back side to facilitate flow/migration of solder on the entire contact surface
  - 2 holes of Φ 7 mm for filler material (Sn60-Pb40)



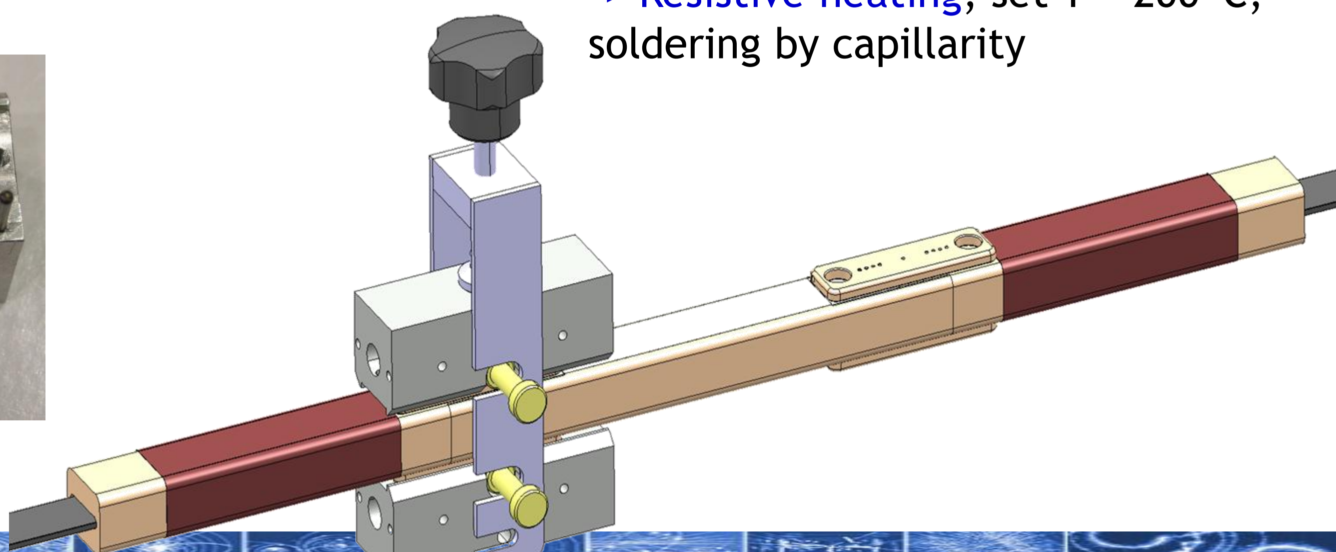




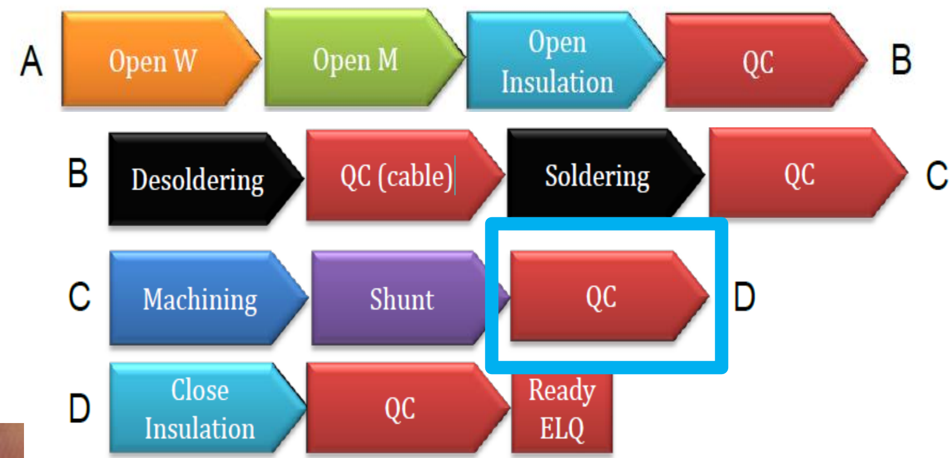
Solder: Sn-Pb (60Sn/40Pb)

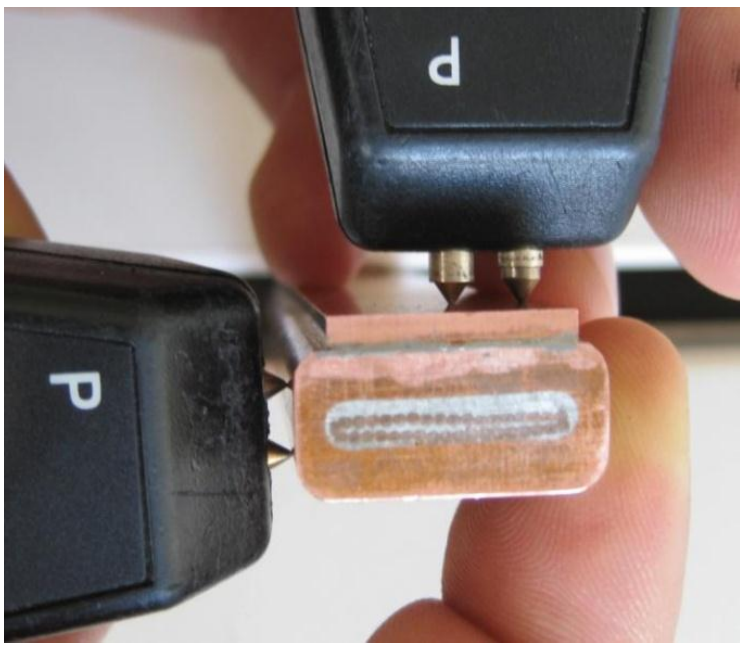
Melting T of Sn-Pb < Melting T of Sn-Ag

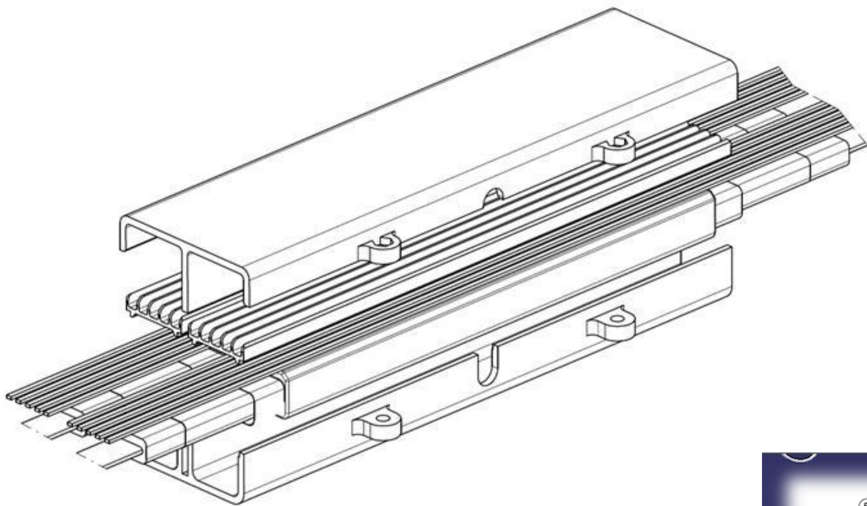
-> Resistive heating, set T = 200°C, soldering by capillarity



- Visual inspection, photos
- R_RT-top-side
- R_8/R_16





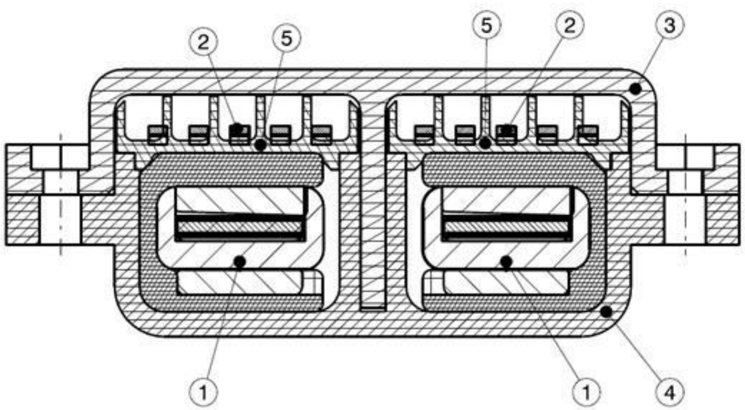


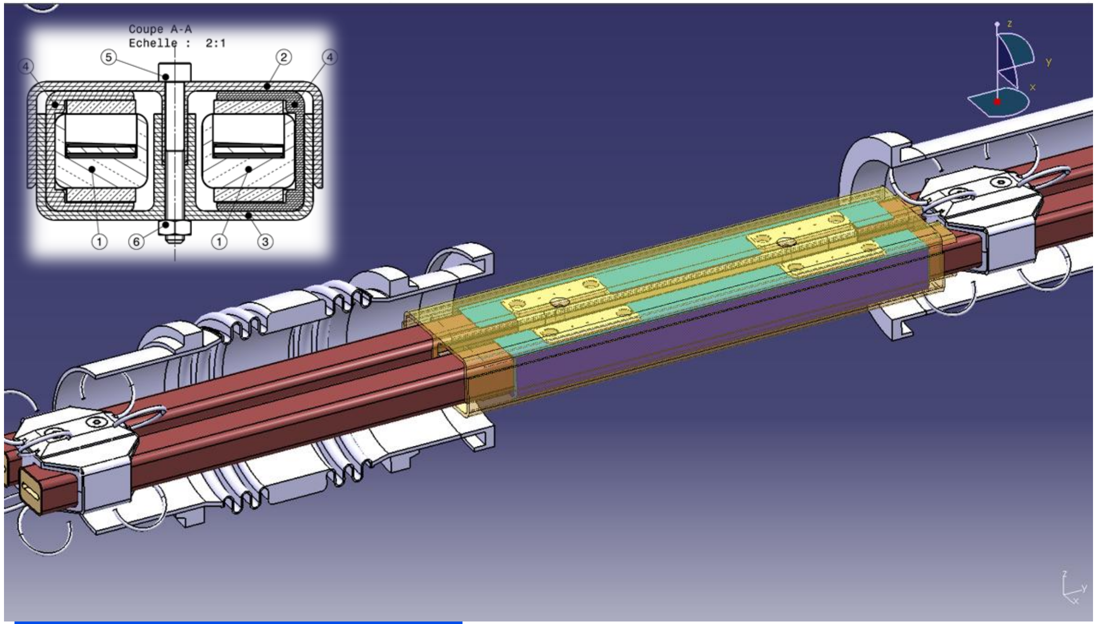
A → Open W → Open M → Open Insulation → QC → B

B → Desoldering → QC (cable) → Soldering → QC → C

C → Machining → Shunt → QC → D

D → **Close Insulation** → QC → Ready ELQ

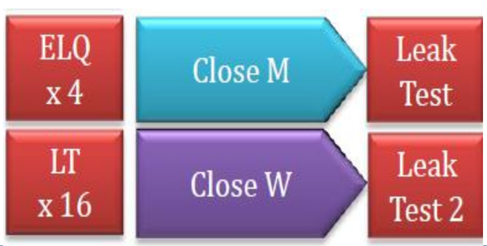




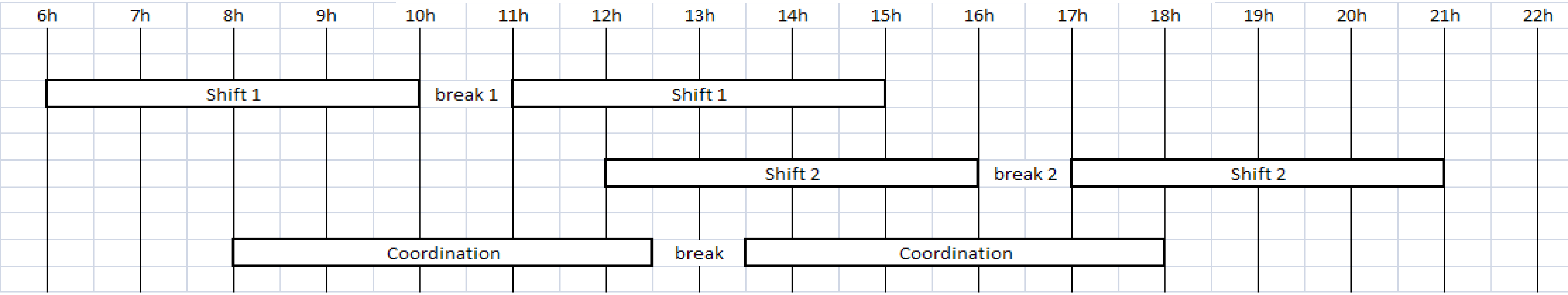
Courtesy H. Prin

- Visual inspection
- Geometrical check
- Photos

Define ELQA procedures, sequence, constraints
- Before / After M sleeves welding
- Length of the chain ?
- Non-conformities / specificities (spool pieces)
- After consolidation : @warm, @ cold,…

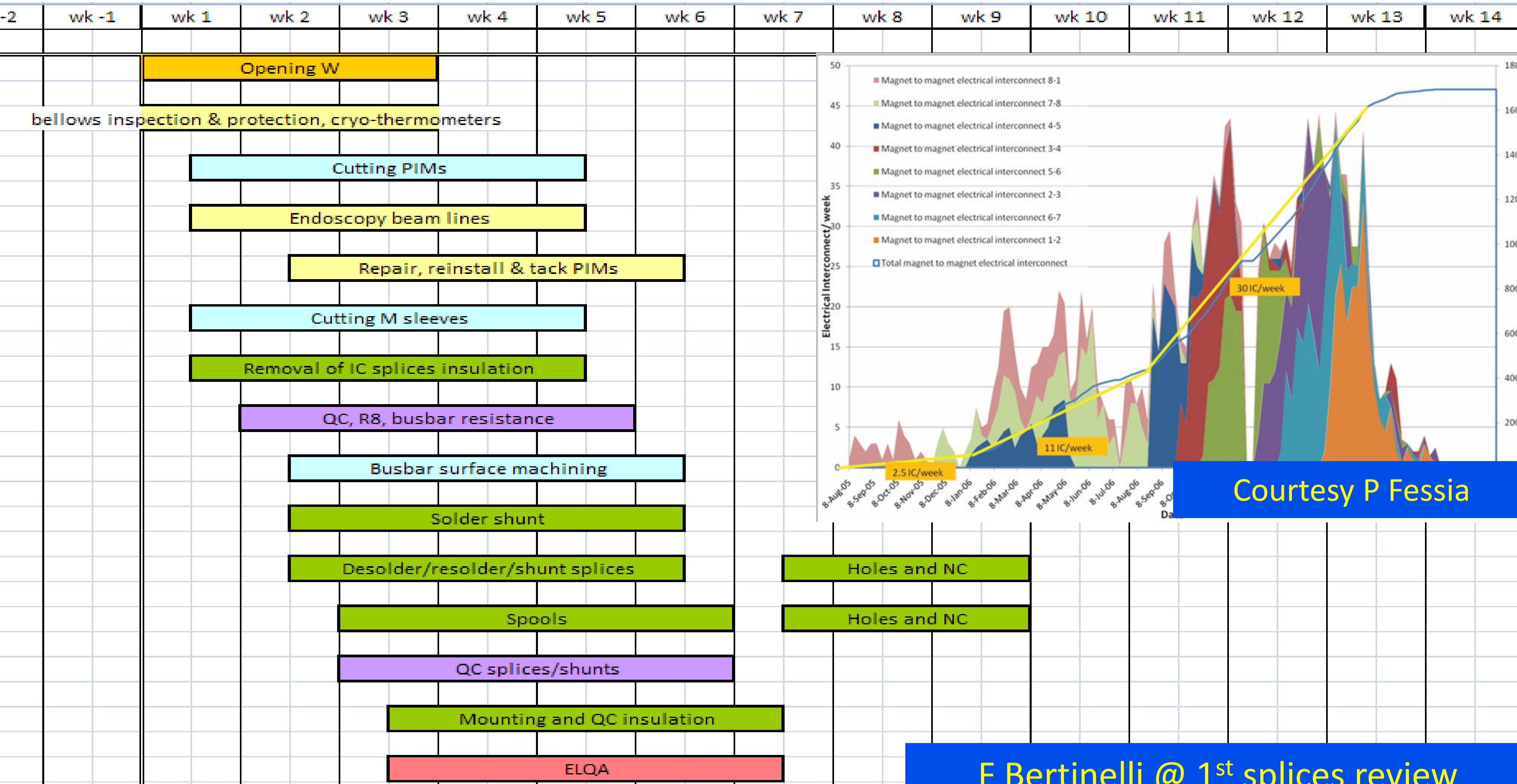


A typical day



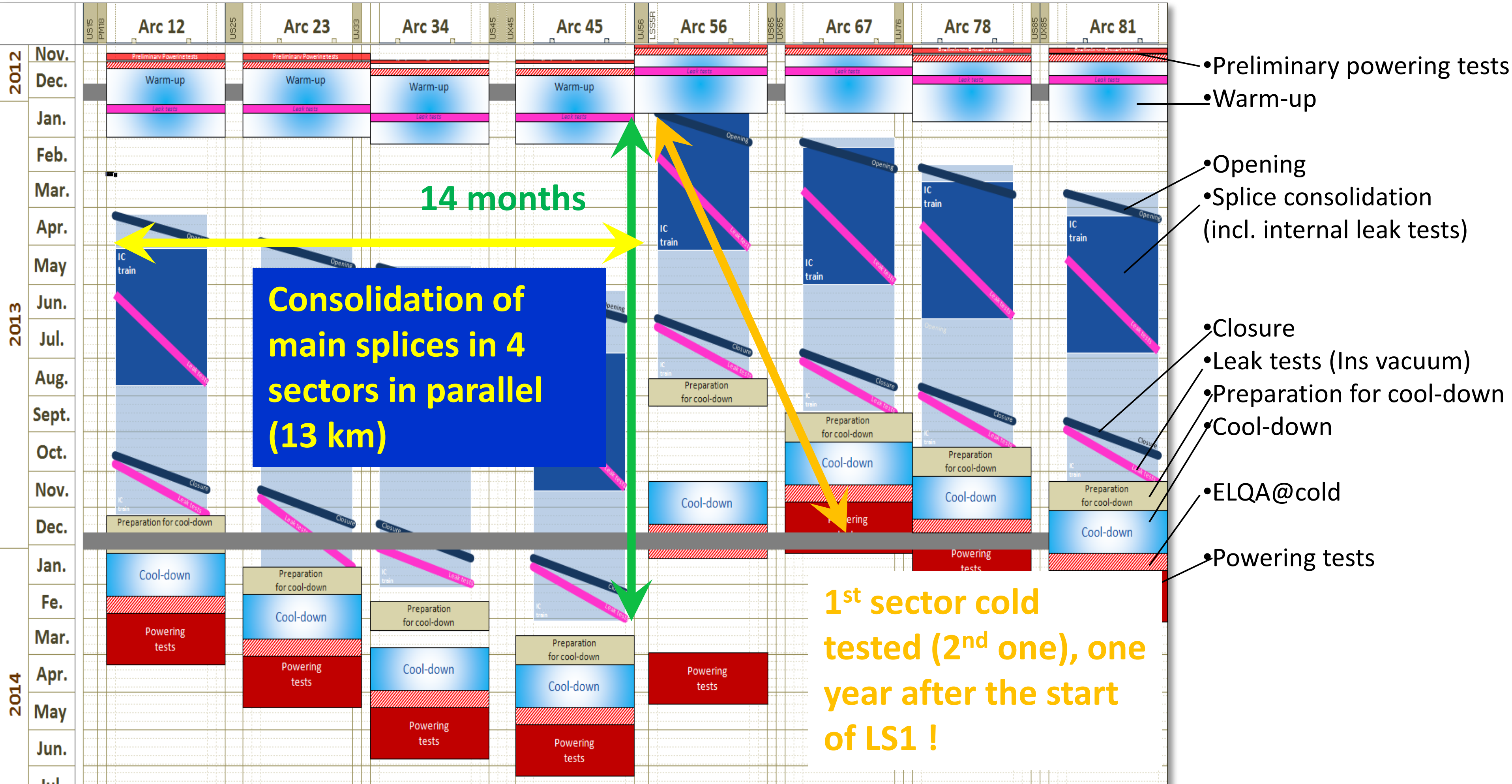
- Shift 1 for production and non-interfering test
- Shift 2 for tests on chains of magnets, preventing other activities
- Night for transport
- 5/7 days

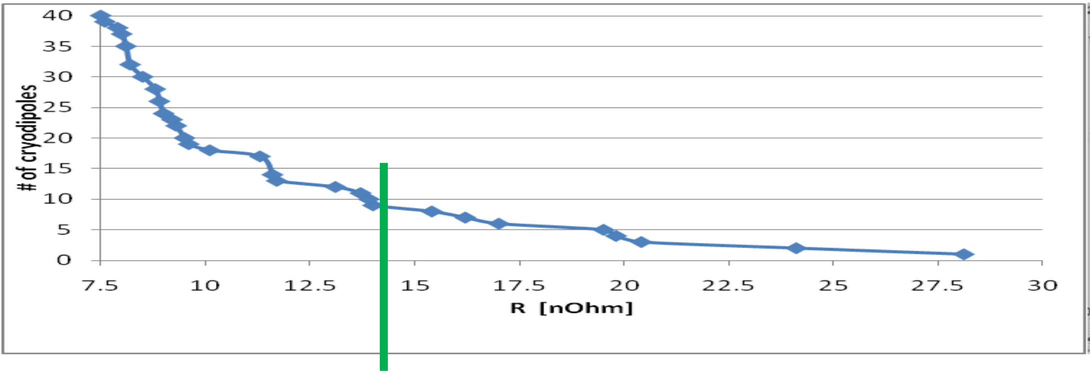
4 weeks for each activity so 53 IC/week
Dimensioned to 60 IC/week: 10% margin
Remember : Series installation at 30 IC/week !

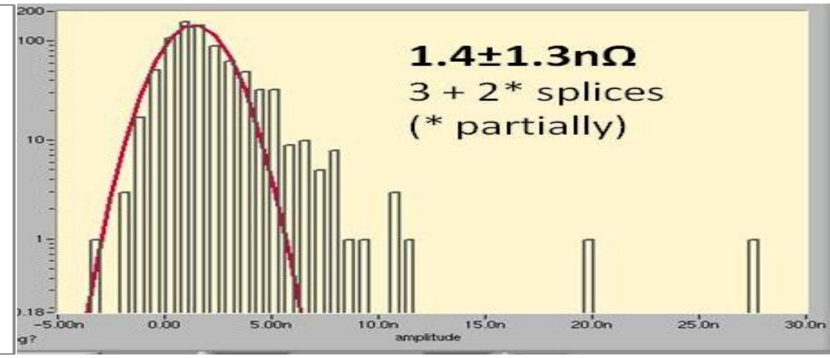


Courtesy P Fessia

F Bertinelli @ 1st splices review


Arc 12
Arc 23
Arc 34
Arc 45
Arc 56
Arc 67
Arc 78
Arc 81
2012
Nov.
Dec.
2013
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sept.
Oct.
Nov.
Dec.
2014
Jan.
Fe.
Mar.
Apr.
May
Jun.
Jul.
Warm-up
IC train
Preparation for cool-down
Cool-down
Powering tests
14 months
Consolidation of main splices in 4 sectors in parallel (13 km)
1st sector cold tested (2nd one), one year after the start of LS1 !
•Preliminary powering tests
•Warm-up
•Opening
•Splice consolidation (incl. internal leak tests)
•Closure
•Leak tests (Ins vacuum)
•Preparation for cool-down
•Cool-down
•ELQA@cold
•Powering tests





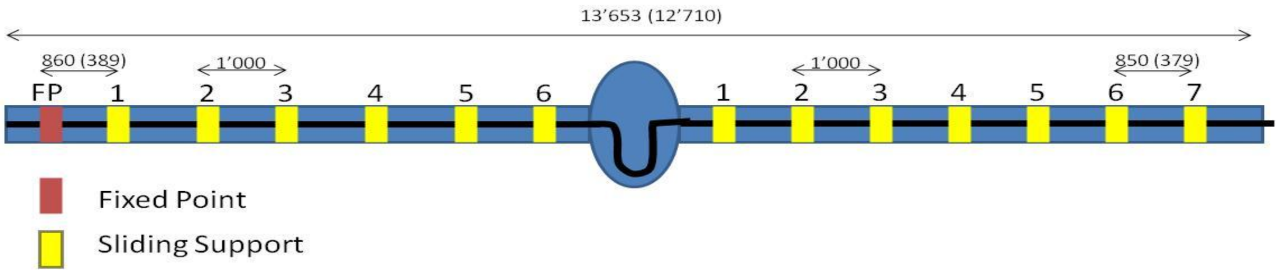
High internal splice resistance

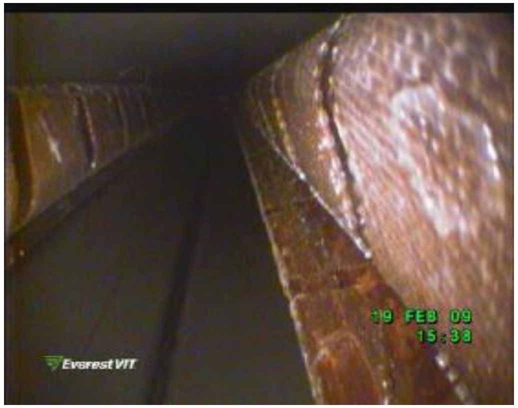
- 13 (+2?) dipoles will be replaced, plus 4 quadrupoles

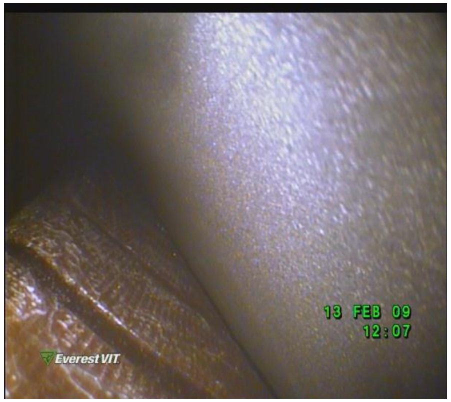
CRYO-MAGNETS TO BE REMOVED DURING LONG SHUTDOWN 1

	Type		Magnet	Problem	Input	EDMS	Slot	IC Up	IC Down	Sector	To be changed	Remarks 1	From LMF	Deadline	Location	Activity	Remarks 2
1	Dip	BR	2387	High Resistance	Zinur		LBBRD.33R1	QBBI.B33R1	QBQI.33R1	12	Yes	Res. 20.4ηΩ		26/10/12			
2	Dip	AR	2373	High Resistance	Zinur		LBARB.30R1	QBBI.B30R1	QBQI.30R1	12	Yes	Res. 19.8ηΩ		26/10/12			
3	Dip	BR	2395	High Resistance	Zinur		LBBRD.15R1	QBBI.B15R1	QBQI.15R1	12	Yes	Res. 17.0ηΩ		26/10/12			See also NCR 1004184
4	Dip	BR	2377	High Resistance	Zinur		LBBRA.33L2	QBBI.B33L2	QBBI.A33L2	12	Yes	Res. 16.2ηΩ		26/10/12			
5	Dip	AR	2372	High Resistance	Zinur		LBARB.29L2	QBBI.A29L2	QBQI.29L2	12	Yes	Res. 15.4ηΩ		26/10/12			
6	Dip	AR	2413	QH damaged	ELQA	1004191	LBARA.22R1	QQBI.21R1	QBBI.A22R1	12	Yes	Will be replaced by 2171		26/10/12	SMA18		
7	Dip	BL	2357	High Resistance	Zinur		LBBLA.23R2	QQBI.22R2	QBBI.A23R2	23	Yes	Res. 28.1ηΩ		26/10/12			
8	Dip	AL	2353	High Resistance	Zinur		LBALA.15L3	QQBI.15L3	QBBI.B15L3	23	Yes	Res. 24.1ηΩ		26/10/12			
9	Dip	AL	2336	High Resistance	Zinur		LBALA.25R2	QBBI.A25R2	QBBI.B25R2	23	Yes	Res. 19.5ηΩ		26/10/12			
10	Dip	AL	2138	QH damaged	ELQA	1061212	LBALA.31R4	QBBI.A31R4	QBBI.B31R4	45	Yes	Will be replaced by 1061		26/10/12	SMA18		
11	Dip	BL	2214	QH damaged	ELQA	961338	LBBLC.17R4	QBBI.B17R4	QBQI.17R4	45	Yes	Will be replaced by 1132		26/10/12	SMI2	Stripping	
12	Dip	BR	1007	Breakdown at 1.9kV	ELQA	1060444	LBBRA.30R7	QBBI.A30R7	QBBI.B30R7	78	Yes			26/10/12			
13	Dip	BR	2007	QH damaged	ELQA	1017215	LBBRA.21L8	QBBI.B21L8	QBBI.A21L8	78	Yes			26/10/12			Older NCR
14	Quad		512	High Resistance	Zinur		LQTAB.7R3	QDQI.7R3	QQBI.7R3	34	Yes	Res. 26.9ηΩ	30/06/12	26/10/12			LMQTF
15	Quad		243	No MQS	BE/ABP	103939	LQATD.23R3	QBQI.23R3	QQBI.23R3	34	Yes	Will be replaced by 233		26/10/12	180	To cryostat	LQASB.23R3
16	Quad		55	No MQS	BE/ABP	103939	LQATD.27R3	QBQI.27R3	QQBI.27R3	34	Yes	Will be replaced by 230		26/10/12	SMI2	Cryostating	LQASB.27R3
17	Quad		606	Warm corrector	BE/ABP	831927	LQNMA.5L8			78	Yes		30/06/12	26/10/12			
18	Dip	AL	2438	Wrong Beam Screens	VSC	985318	LBALA.26R3	QQBI.26R3	QBBI.A27R3	34	Probably	Input from BE		26/10/12			
19	Dip	BL	2252	Wrong Beam Screens	VSC	985318	LBBLA.32R3	QBBI.A32R3	QBBI.B32R3	34	Probably	Input from BE		26/10/12			

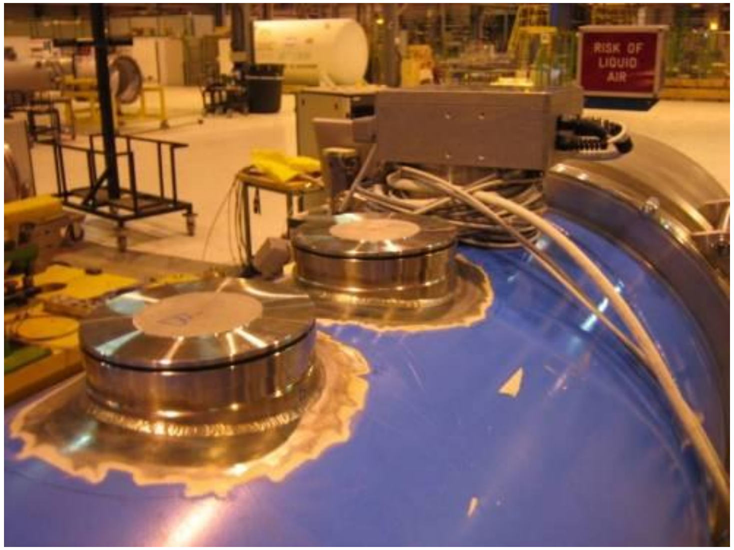
- <u>The plan is :</u>
  - Measure and if necessary consolidate the CC 11L8
  - Consolidate the CC in 11L3 & 11L1
  - Measure / ***inspect all the CCs to check no displacement***





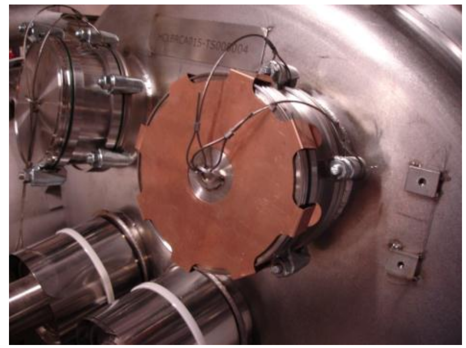


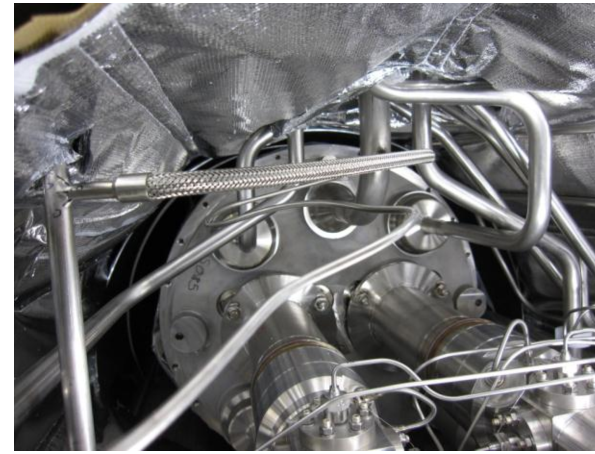
To be installed during LS1 in 23, 45 (part), 78 & 81
About 600 units



OTHER INTERVENTIONS

- <u>Consolidation of SAM Helium level gauges and DN160</u>
  - It is planned to consolidate the 2 remaining ones: Q6R2&L8





- <u>Repair of leaking Y-lines</u>
  - It is planned to consolidate the 2 known cases (S78:17-19R7 & S81:19-22R8)

- <u>PIMs (# 45 to be replaced)</u>
  - Buckled during warm-up ≈ 18 (RF ball test)
  - Heavily damaged : ≤ 10
  - Preventive replacements : Arc extremities 18/32 in baseline

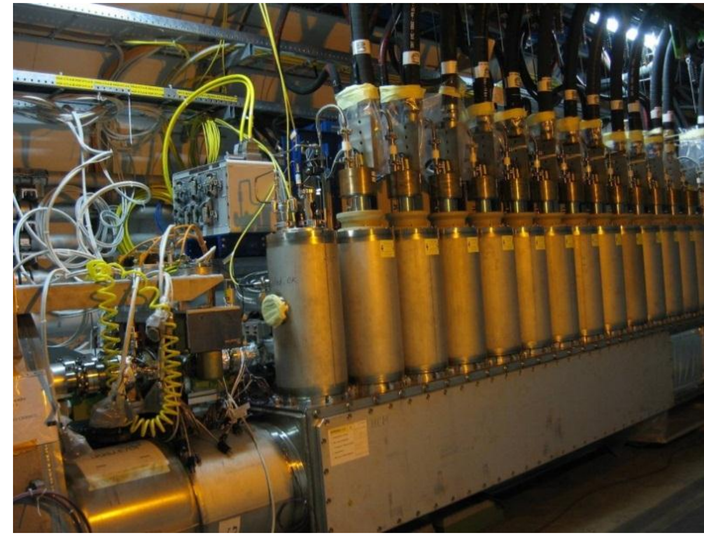
	1-2		2-3		3-4		4-5		5-6		6-7		7-8		8-1	
	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2	V1	V2
QQBI.7R	1.0	1.0	0	0	1.0	1.0	0	0	1.0	1.0	0	0	1	1	0	0
QBQI.8L	1.0	1.0	0	0	1.0	1.0	0	0	0	0	1.0	1.0	0	0	0	0

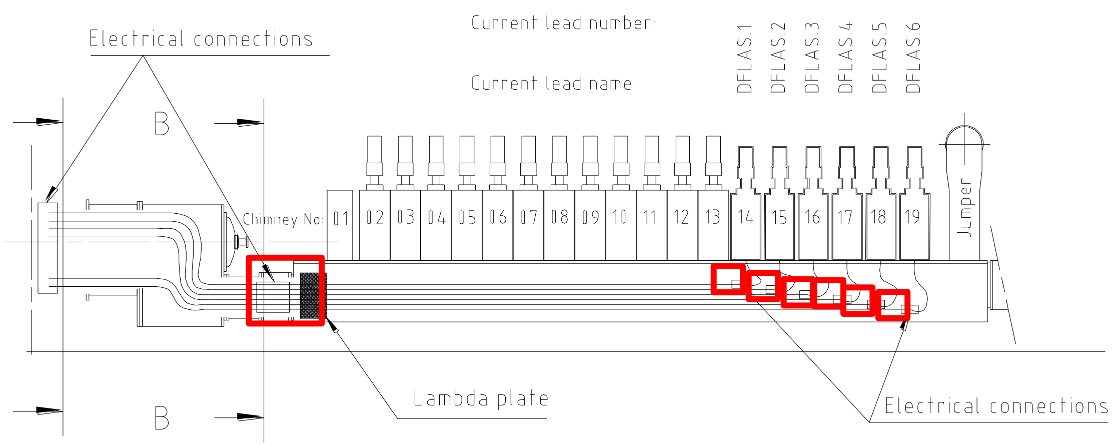
The cryogenic electrical feedboxes of the LHC (DFBs)

- **16 DFBA : powering the arcs**
- 23 DFBM: powering of standalone magnets in LSS
- 5 DFBL : powering of the superconducting links
- 8 DFBX : powering the triplets

52 DFBs, 39 variants

> 1400 current leads

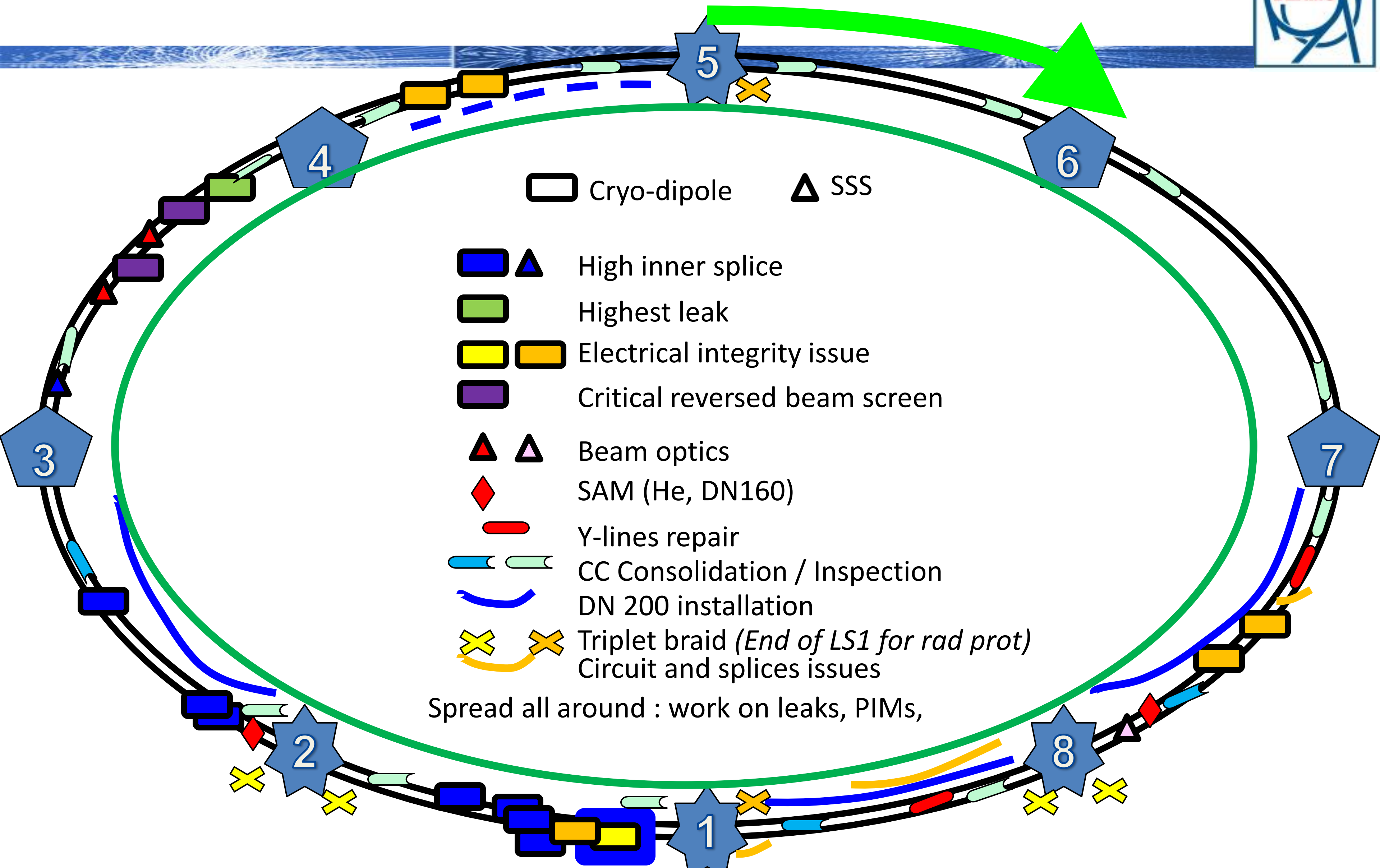




Courtesy A. Perin

- Many variants
- No spare of complete DFB -> repair or rebuild

- High current cable connection done as in the machine
- All but 2 can be consolidated in situ (study ongoing for the 2 singularities)
- Between 50 and 60 weeks for consolidation



Goal : Special interventions completed before the train arrives : To be checked

Long Shutdown 1 - F. Bordry

Consolidation of the superconducting circuits: JPh Tock (?)

Open/Close IC [DN200]
A Musso (?) #32
- -Opening/ Closure of IC
  Partial and complete
  W bellows & ther. shields
- -Installation of DN200

Main arc splices cons. "The train"
F Savary (H Prin) #52
- -Sleeves cutting
- -BB surfacing
- -Shunt installation
- -Splice de-&resoldering (15%)

Quality Assurance
R Ostojic (?) #39
- -Electrical QC: C Scheuerlein #17 (P Thonet)
- -Welding QC: JM Dalin
- -Beam vacuum QC: C Garion
- -Open/close IC QC: D Bodart
- -QA manager support

Special interventions "SIT"
N Bourcey (G Maury TBC) #15
- -Cryomagnets exchange
- -Connect. Cryostat cons.
- -PIMs
- -Specific issues
- -**Heavy NC**

TIG welding
S Atieh (?) #14
- - Orbital & manual

DFBA
A Perin (?) [#12 (TBC)]
- -Splices and BB

ELQA [TE-MPE]
K Dahlerup (G D'Angelo) #23
- -Continuity
- -HV test

Leak Test [TE-VSC]
P Cruikshank (?) #19
- -Beam lines
- -Cryogenics lines
- -Insulation vacuum

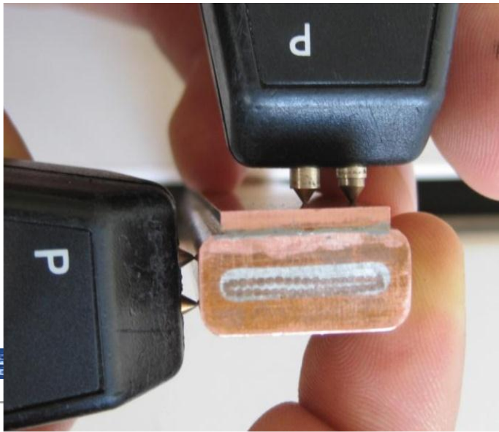
Project Office M Pojer (?) #11
- -Radiation protection
- -Safety
- -Access
- -Pressure test
- -Coordination with
  Survey, BLM, Instrumentation, Transport, LS1 planning, QPS, cryogenics,…
  Test teams on a chain of IC
- -Reporting tools

- Each of the 10170 LHC main interconnection splices needs to be controlled before and after consolidation
- Each shunt needs to be controlled separately

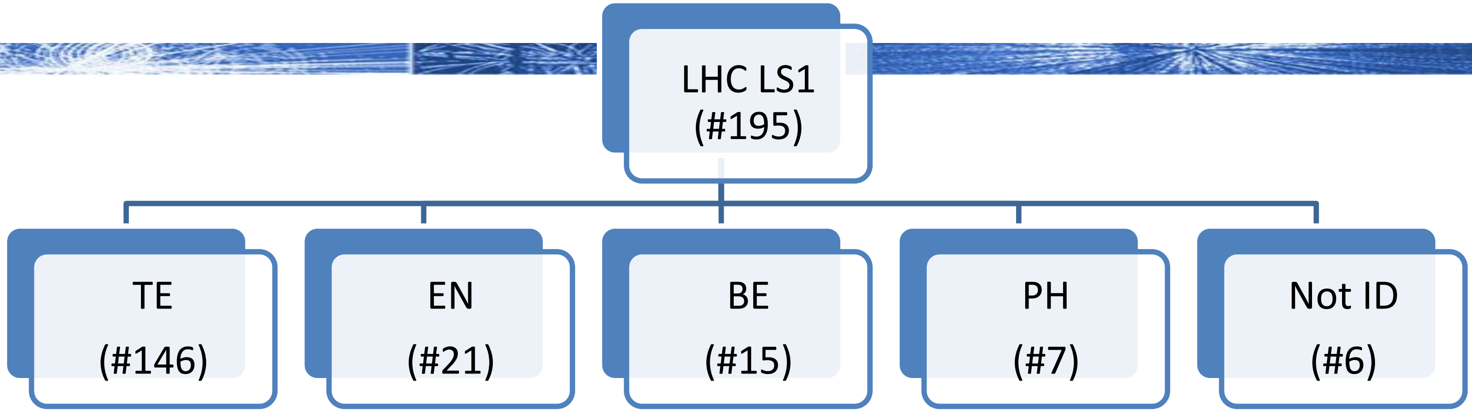
- R-8 acceptance threshold values for existing splices
  - Redo a splice when additional R-8 exceeds 5 μΩ (dipole R-8>10.6 μΩ; quads R-8>14.3 μΩ) [5 μΩ excess resistance corresponds with a non-stabilised cable length of about 4 mm; the safe currents for a splice with 4 mm non-stabilised cable are 17.2 kA and 15.4 kA for quadrupole and dipole splices, respectively - A. Verweij and D. Molnar]
- Geometrical acceptance criterion and test
  - to be able to put shunts without machining too much Cu from the existing busbars and splice profiles
  - to be able to put the splice insulation on the consolidated splice (maximum misalignment over the 150 mm: horizontal ±3mm, vertical ±5mm, EDMS Nr. 1171853)

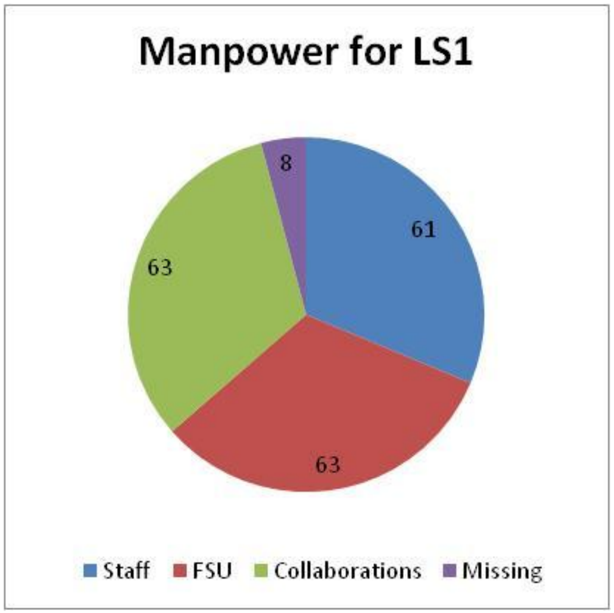
- Redo "new" splices that will be produced during LS1 when:
  - $R\text{-}8_{dipole}>7.6$ μΩ; $R\text{-}8_{quad}>12.3$ μΩ.

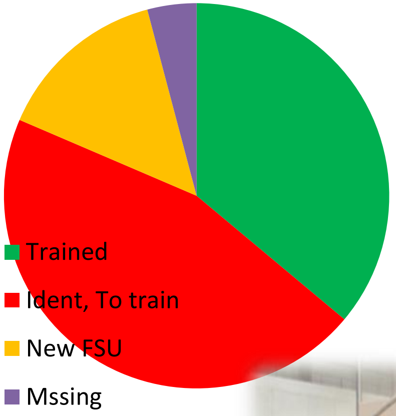
- QC on shunts: a defect area of 9 × 13 mm², i.e. 52% of overlap area (neglecting the hole) is detectable by an additional R_RT-top-side of up to 0.7 μΩ.



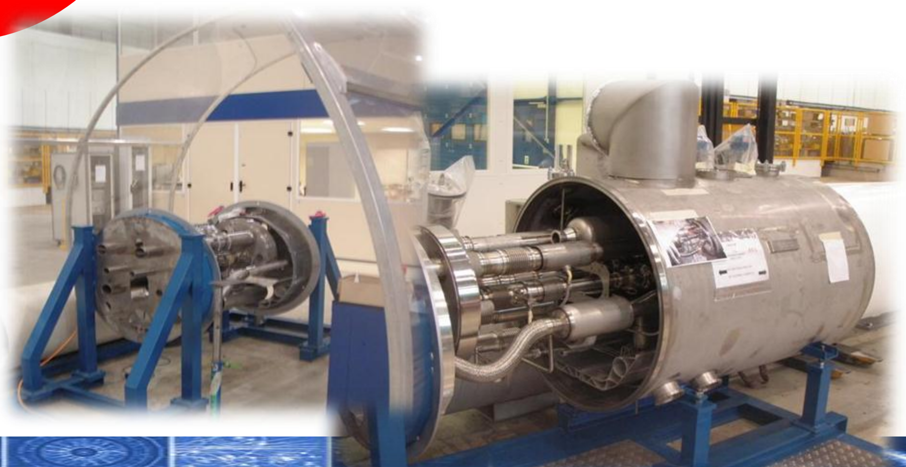
RESOURCES



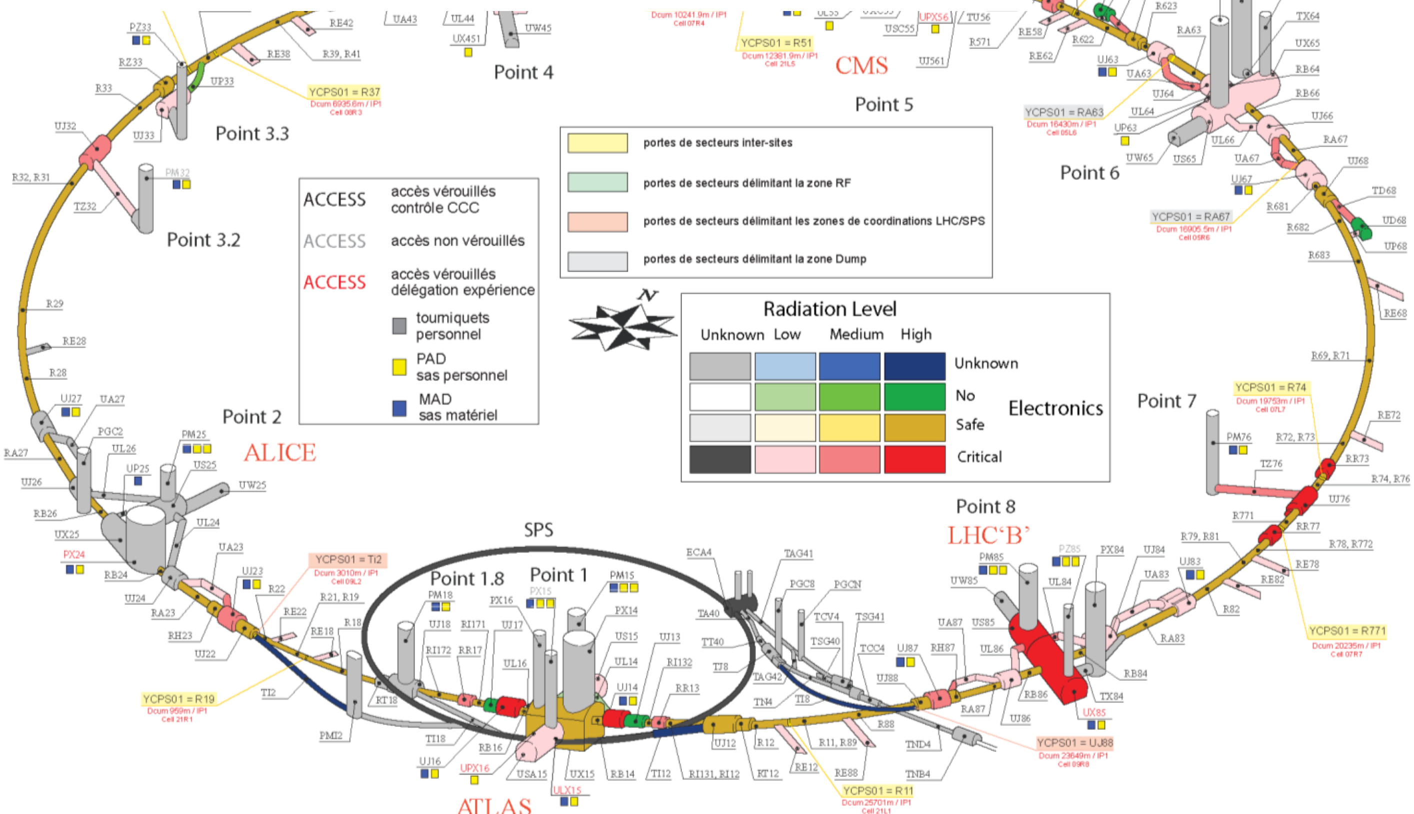




> 60% have to be trained !
Some rotation in staff (Collaborations)
> 200 individuals
<u>*Challenge to have this in parallel with work in tunnel*</u>



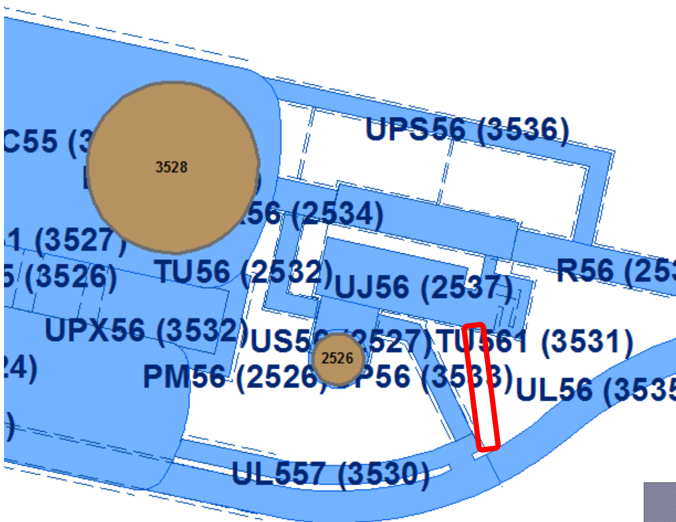
- 4 critical areas:
  - UJ56 --> displacement of all electronics (safe room)
  - UJ14/16 --> displacement of all electronics in ULs
  - Point 7 --> displacement of remaining electronics of UJ76
  - UX85

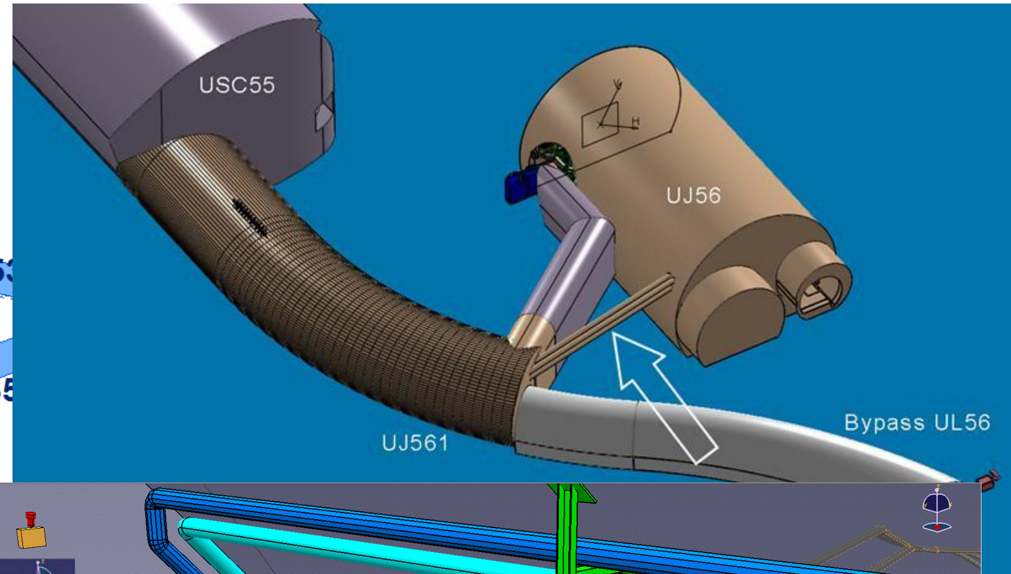


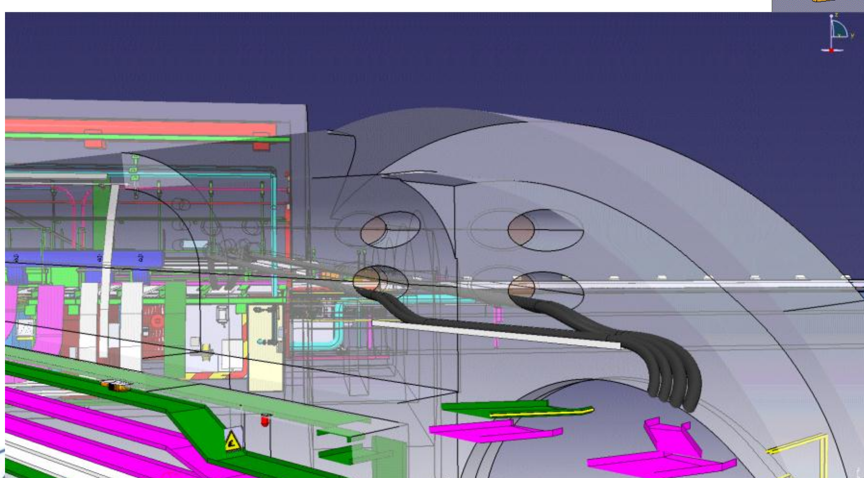
https://r2e.web.cern.ch/R2E/

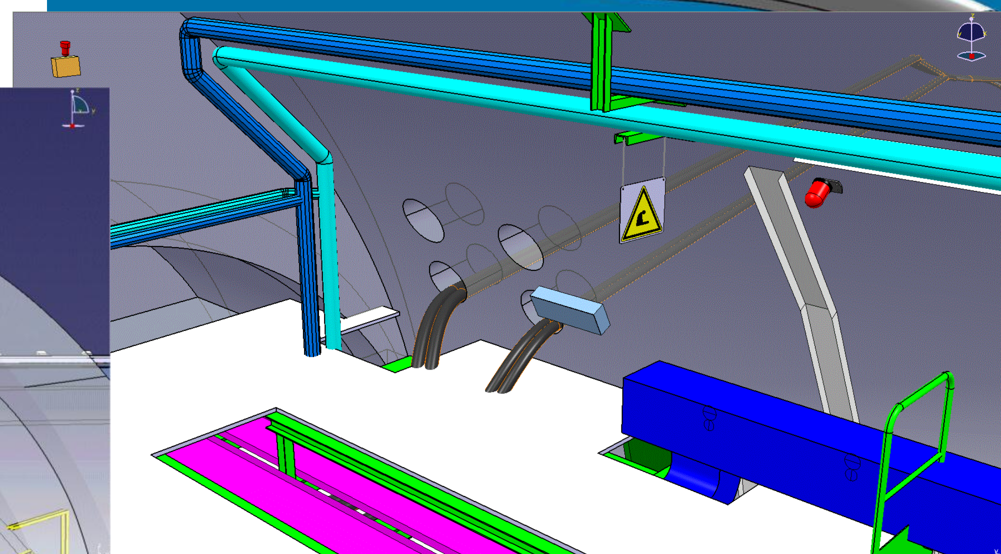
Courtesy J. Crespo Bisquert

- 4 ducts Ø400mm (16m long)





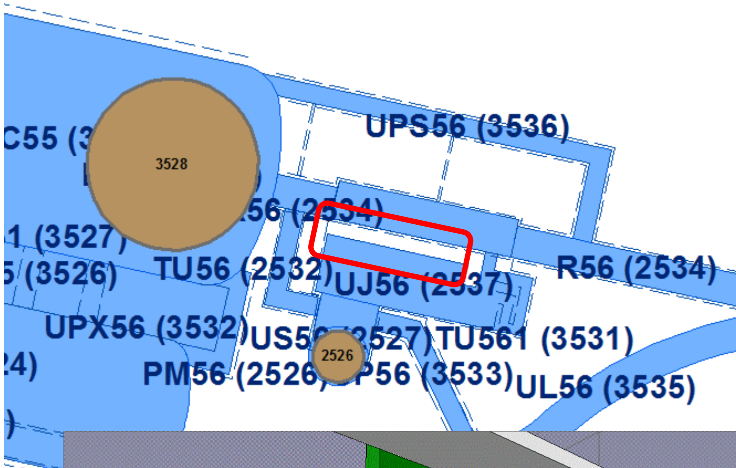


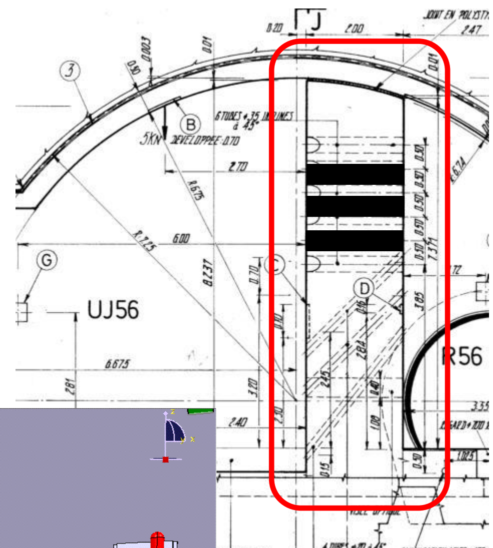


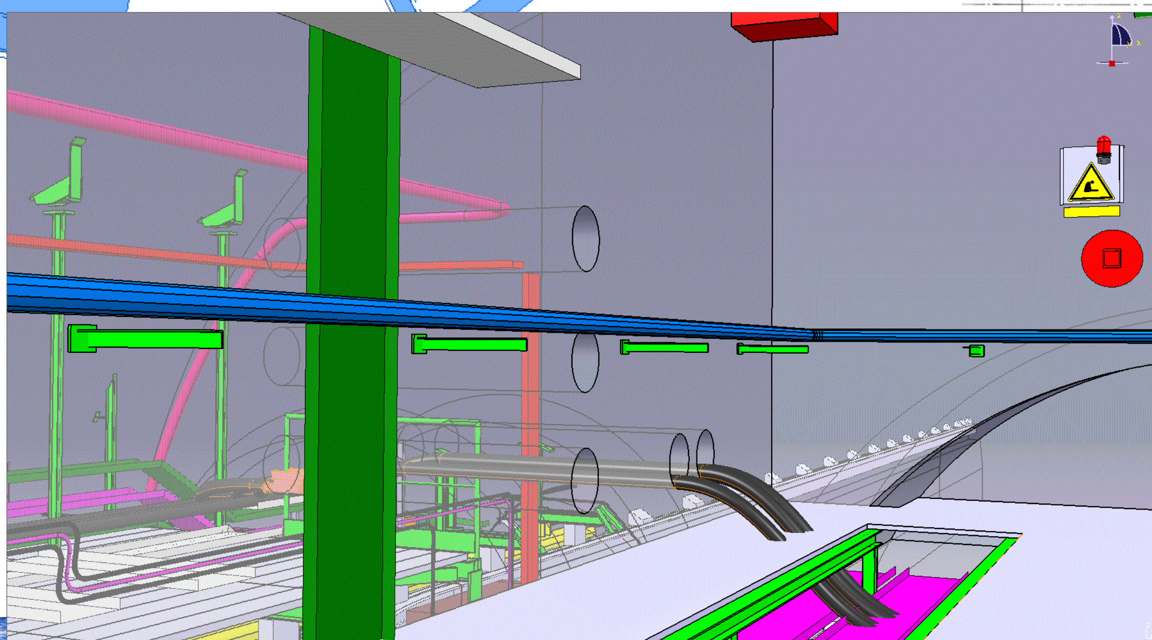
UJ56

Courtesy J. Crespo Bisquert

- 5 ducts Ø350mm (2m long)

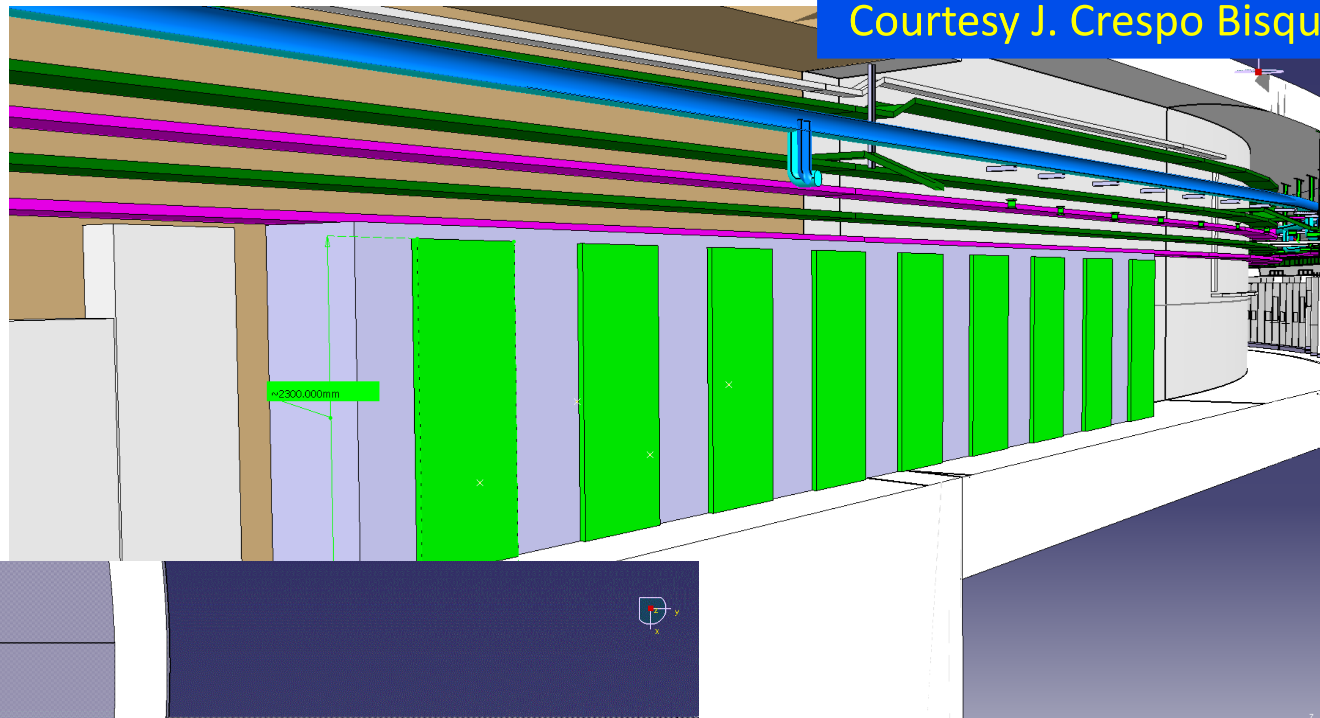


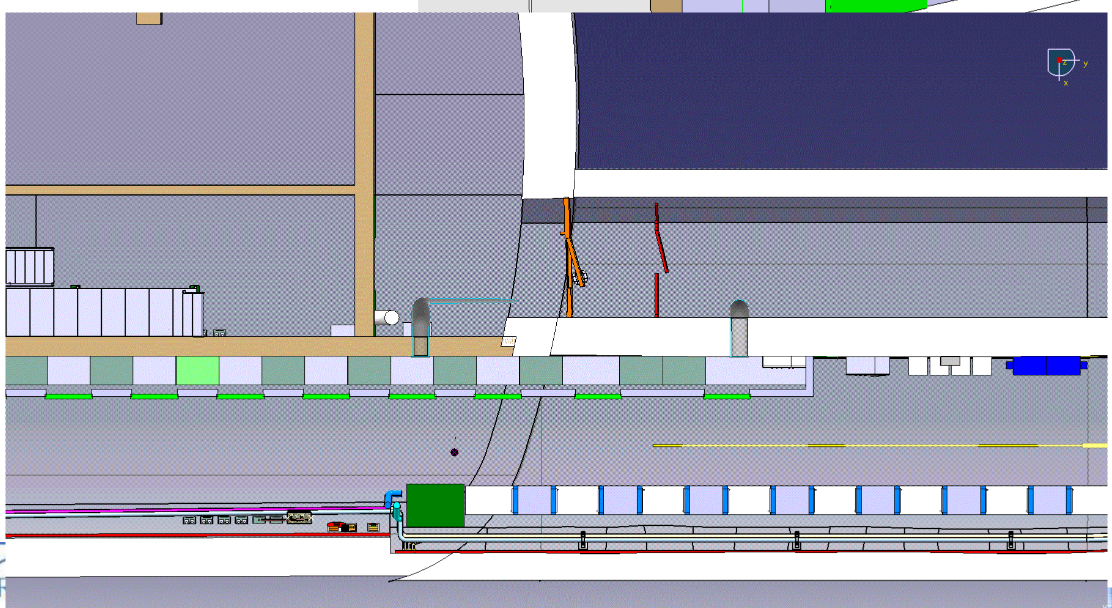


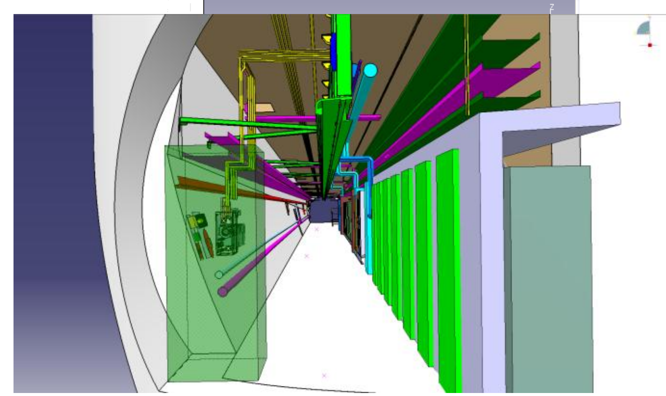


Safe room in UL55

Courtesy J. Crespo Bisquert

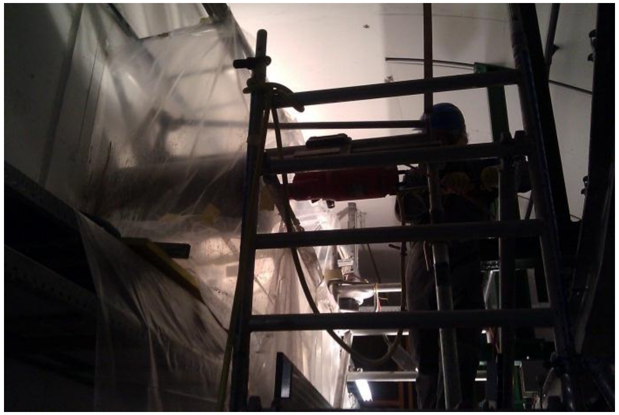






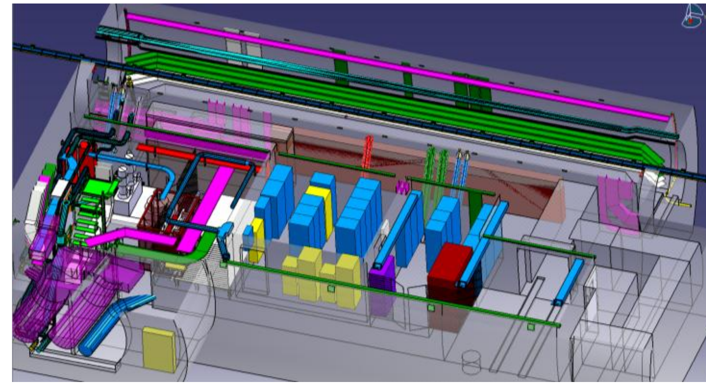
32

Point5 during Xmas break



POINT 7

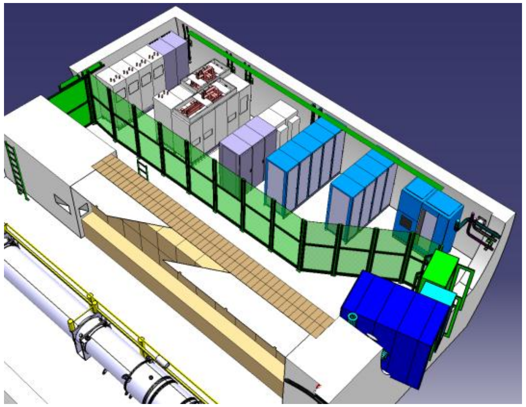
- Definition in progress
- Hot discussions around the safe room

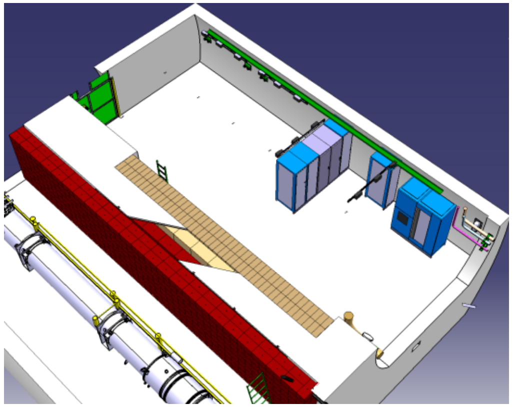


Ventilation ducts to be dismantled

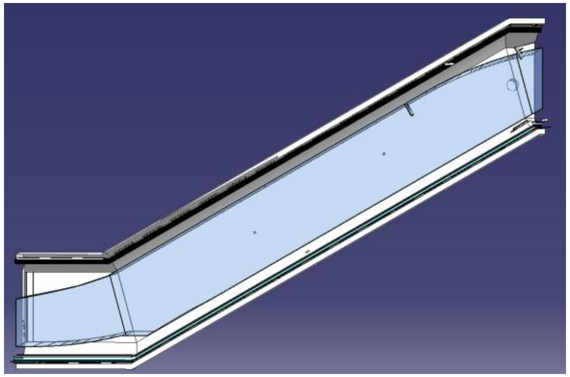
Wall to be demolished

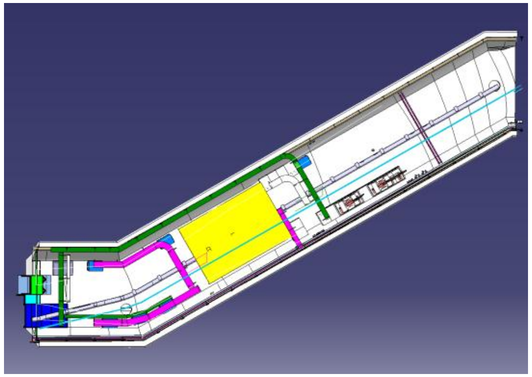
- Shielding installation during Xmas break
  - **UJ16**



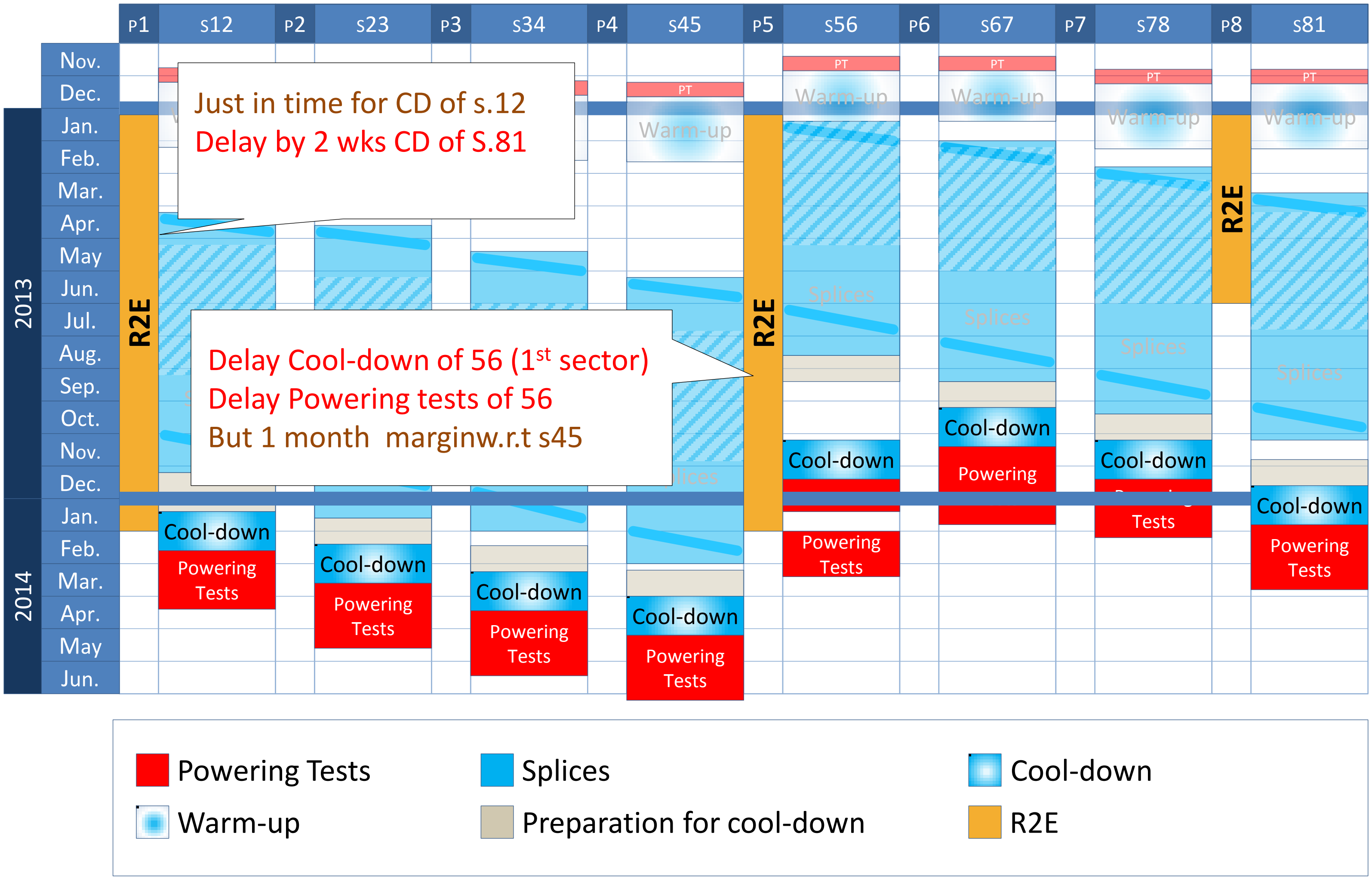


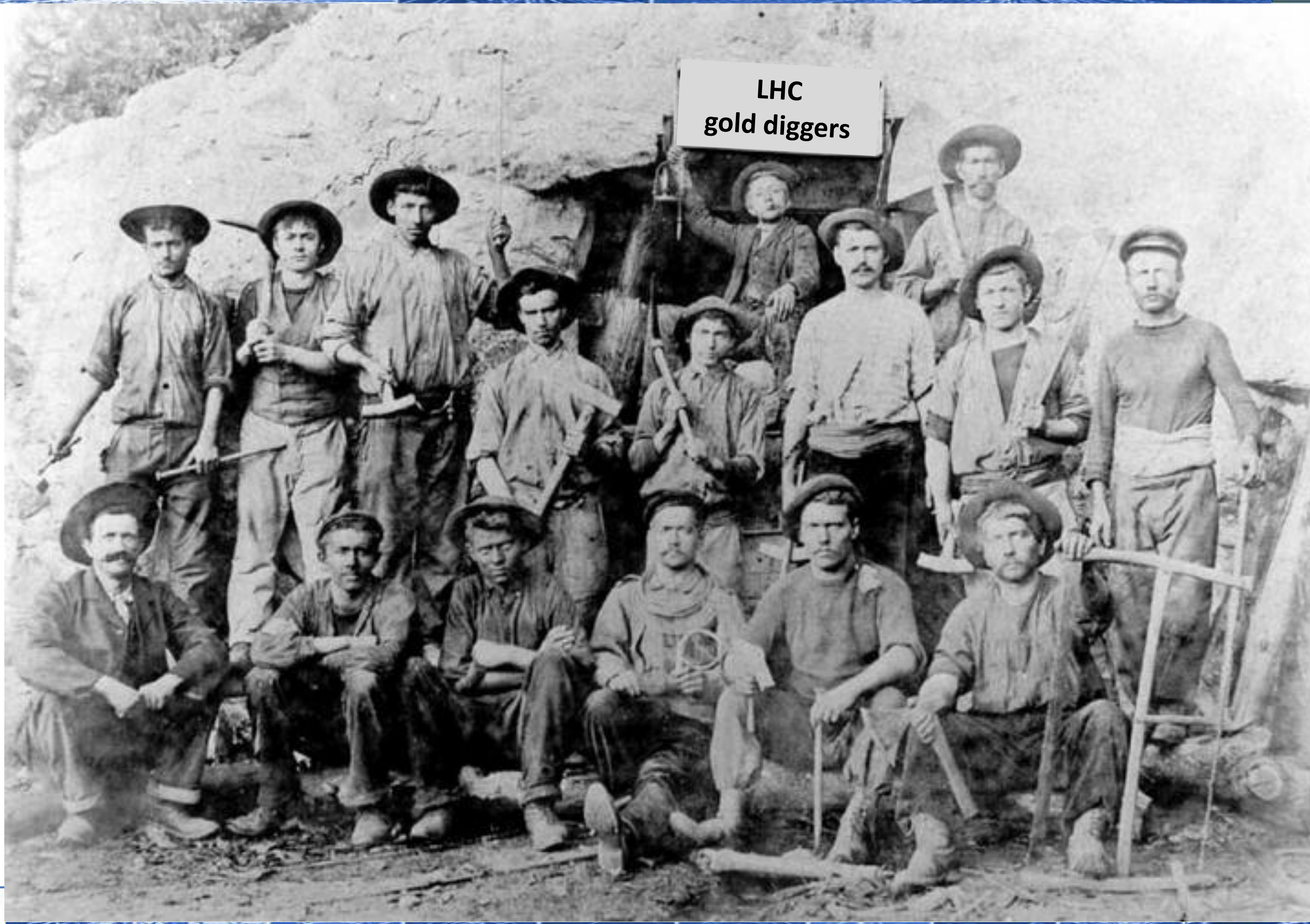
  - **UL16**



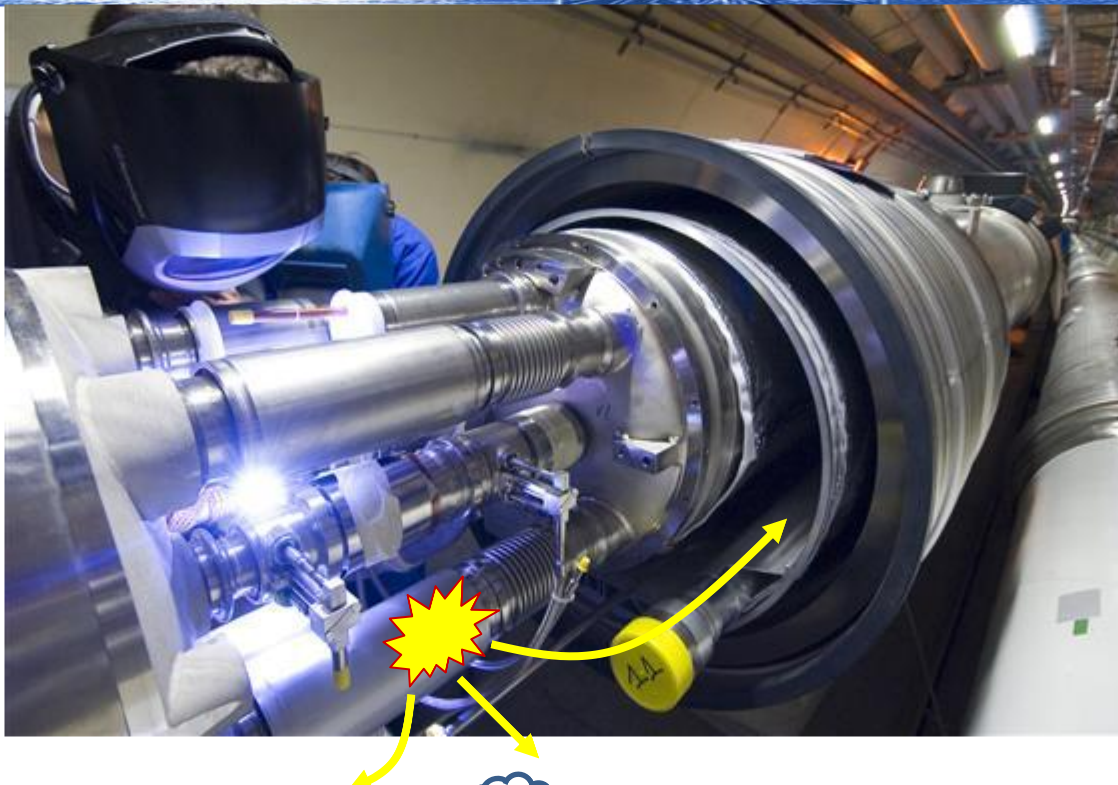


R2E & DRAFT GENERAL SCHEDULE



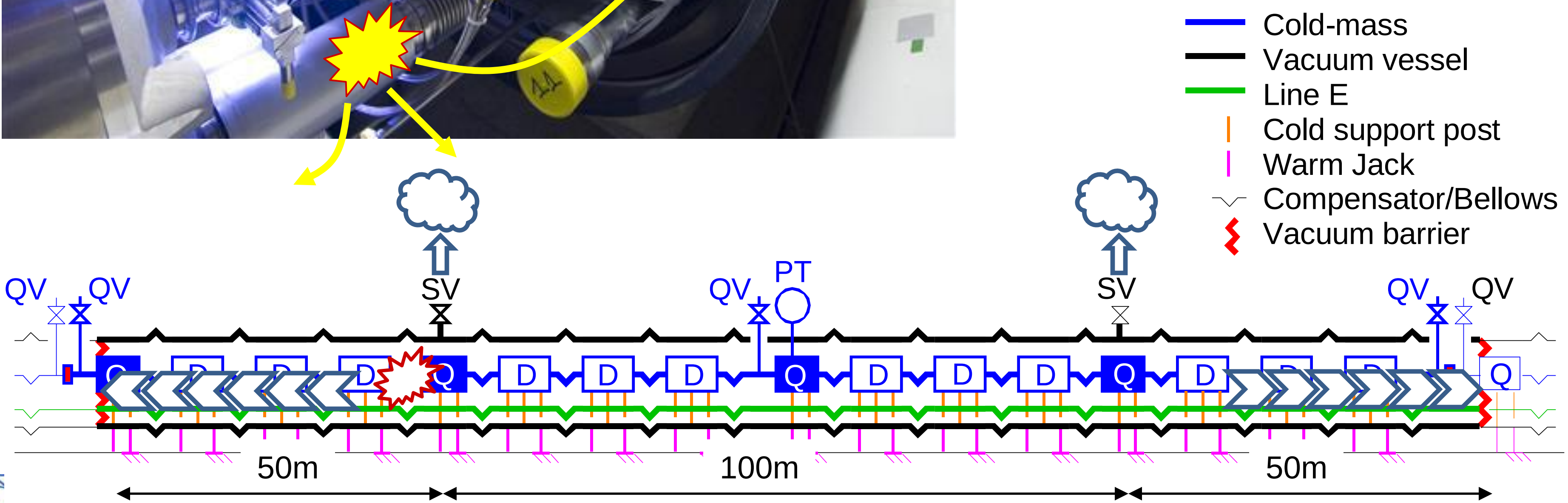

LHC
gold diggers

Spare slides

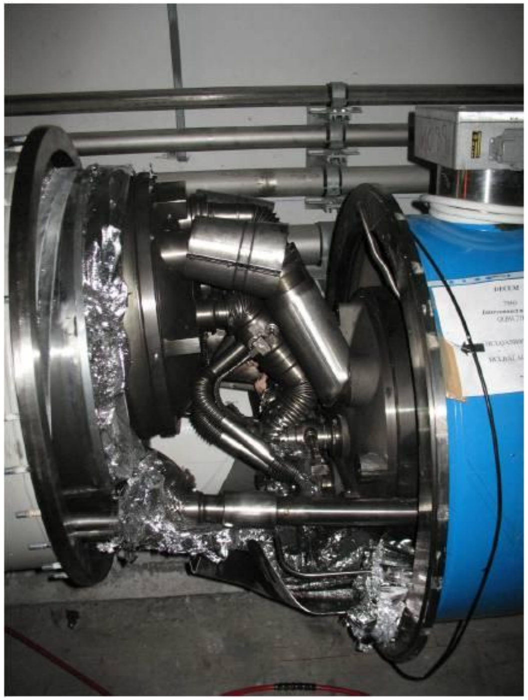


Electrical arc developed which punctured the helium enclosure, producing helium release into the insulation vacuum

Large pressure wave travelled along the accelerator in both directions



SOME IMAGES



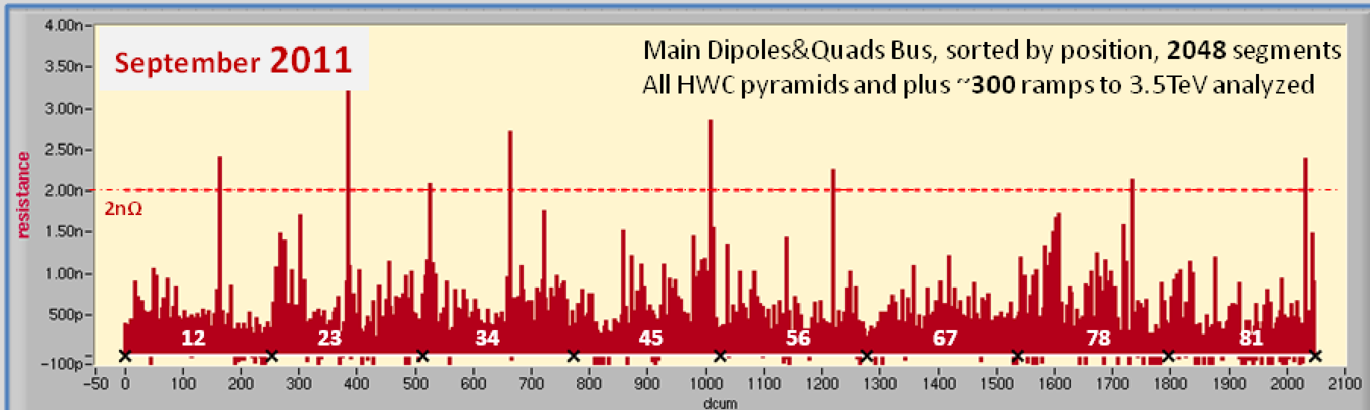
Redo splices in the segments with high 1.9 K excess resistance

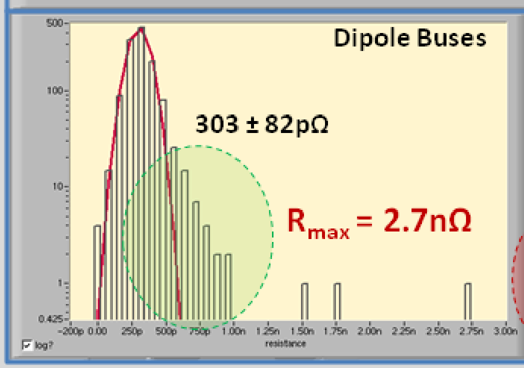
TE

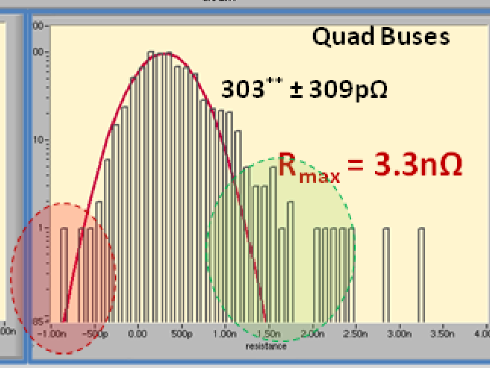
Maximum Splice Resistance in a Bus Segment over LHC ($R_{spl,max}$ *)

(*) $R_{spl,max} = R_{segment} - (n-1) \cdot R_{spl,average}$

Zinour Charifoulline







Top 10 Splice Resistances

MQ.A23	MQ.33L3.B2	<->	MQ.33R2.B2	3.29E-09
MQ.A45	MQ.12L5.B2	<->	MQ.11L5.B1	2.86E-09
MB.A34	MB.A31L4	<->	MB.C31L4	2.72E-09
MQ.A12	MQ.26L2.B1	<->	MQ.28L2.B1	2.41E-09
MQ.A81	MQ.12L1.B2	<->	MQ.11L1.B1	2.39E-09
MQ.A56	MQ.20L6.B1	<->	MQ.22L6.B1	2.26E-09
MQ.A78	MQ.21L8.B2	<->	MQ.19L8.B2	2.13E-09
MQ.A34	MQ.10R3.B1	<->	MQ.8R3.B1	2.08E-09
MB.A34	MB.C19L4	<->	MB.B20L4	1.76E-09
MQ.A78	MQ.22R7.B1	<->	MQ.20R7.B1	1.72E-09
~~MQ.A81~~	~~MQ.11R8.B2~~	~~<->~~	~~DFLAS.7R8.4~~	~~2.02E-09~~

(**) number of splices in the quads segments corrected, 1.3 added

11/22/2011 ZCh, TE-MPE/CP 5

Quality Assurance
R Ostojic #39

-Electrical QC: C Scheuerlein #17
See presentation
-Welding QC: JM Dalin
Operators, tooling, procedures qualification
QC during production (Visual inspection)
Off-line samples
-Beam vacuum QC: C Garion
Protection and inspection of Bellows, PIMs
Endoscopy of beam lines
-Open/close IC QC: D Bodart
Visual inspection
Protection of critical surfaces
-QA manager support
Tooling, inspection, reporting

The QA manager will:

- Coordinate QA activities
- Ensure that an adequate level of Quality Assurance is applied, especially in terms of traceability (MTF) and documentation
- Ensure a timely management of the non-conformities, minimizing the impact on the overall schedule
- Ensure that production parameters are analysed in time to give an early warning in case of drift.
- Identify as early as possible critical issues that could jeopardize the consolidation work

In total about 300 000 room temperature resistance measurements need to be done!
More than 20000 photographs need to be taken only for the main interconnection splices.

Estimated time for repairing/replacing DFBs

There are 39 variants of DFBs (including DFBXs): no spare complete DFB -> repair or rebuild

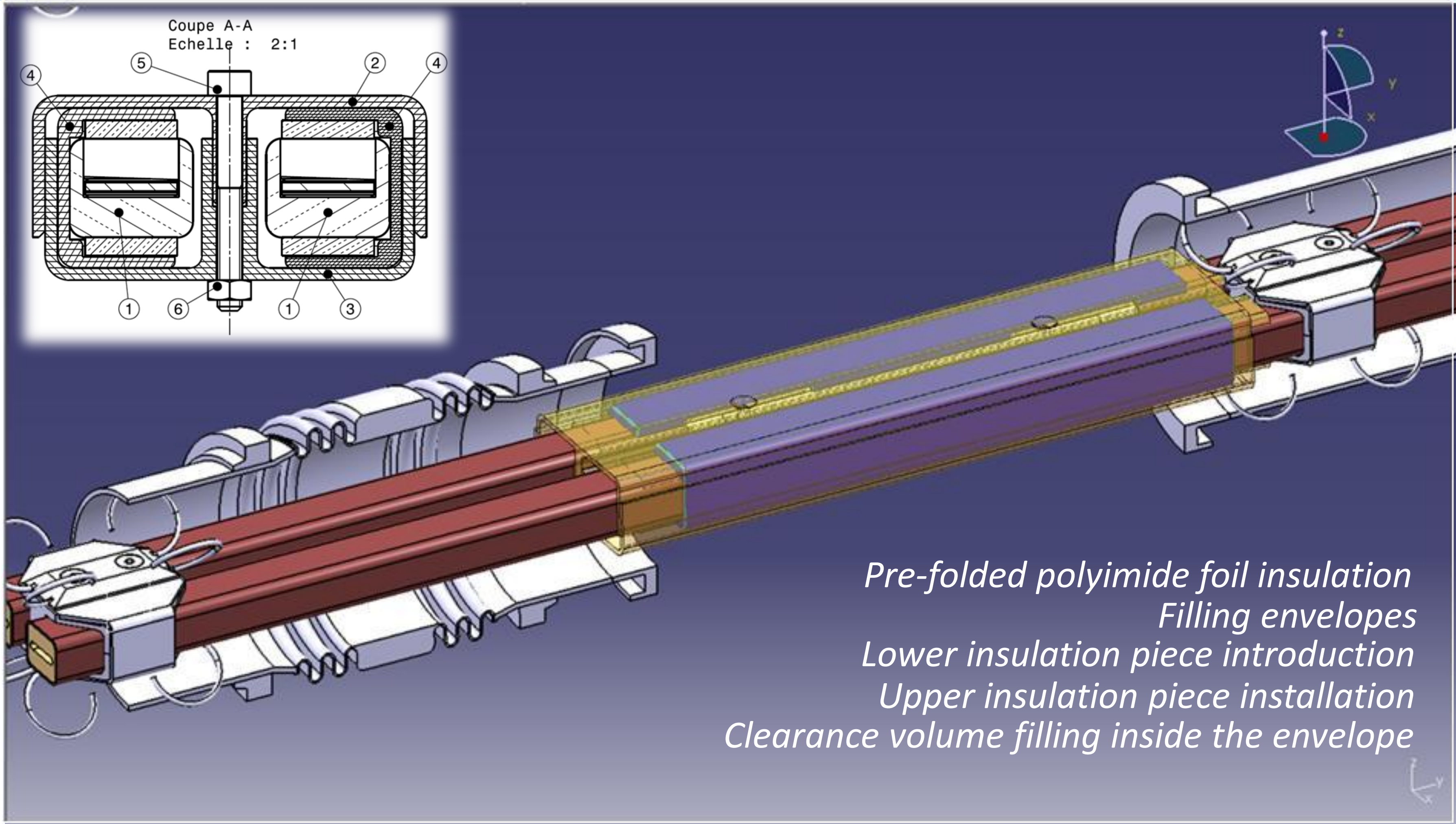
Current lead replacement: warm-up + 1 week repair + cool-down

52.5 days (cf. P. Cruikshank, Cham. 2010) + 5 days = 57.5 days (8 weeks)

Estimated times for workshop repair

Operation	DFBM/L	DFBA (repair)	DFBA (rebuild)	
			Sector	New DFBA
Warm-up	2 weeks (local warmup)	4 weeks (sector warmup)	4 weeks (sector warmup)	
Disconnect + transport	1 weeks	3 weeks	3 weeks	
Disassemble DFB + repair + Reassemble & test	8 weeks	12 weeks	-	6 months (parallel assembly)
Transport + reconnect	4 weeks	6 weeks	6 weeks	
Vacuum + ELQA	1 week	3 weeks	3 weeks	
Cooldown (+ tuning)	2 weeks	4 weeks	4 weeks	
ELQA + HWC	1 week	3 weeks	3 weeks	
Total	**18 weeks (5 months)**	**35 weeks (9 months)**	**41 weeks (10 months)**	

For DFBX similar to DFBA except local warm-up possible. In situ repair could be possible for DFBXs in some cases



Reinforcement of the present bus bar insulation
Blockage of the main 13kA interconnects and of the shunt
Simple and easy assembly accommodating large variation geometry

Courtesy H. Prin