Repair and Consolidation Actions

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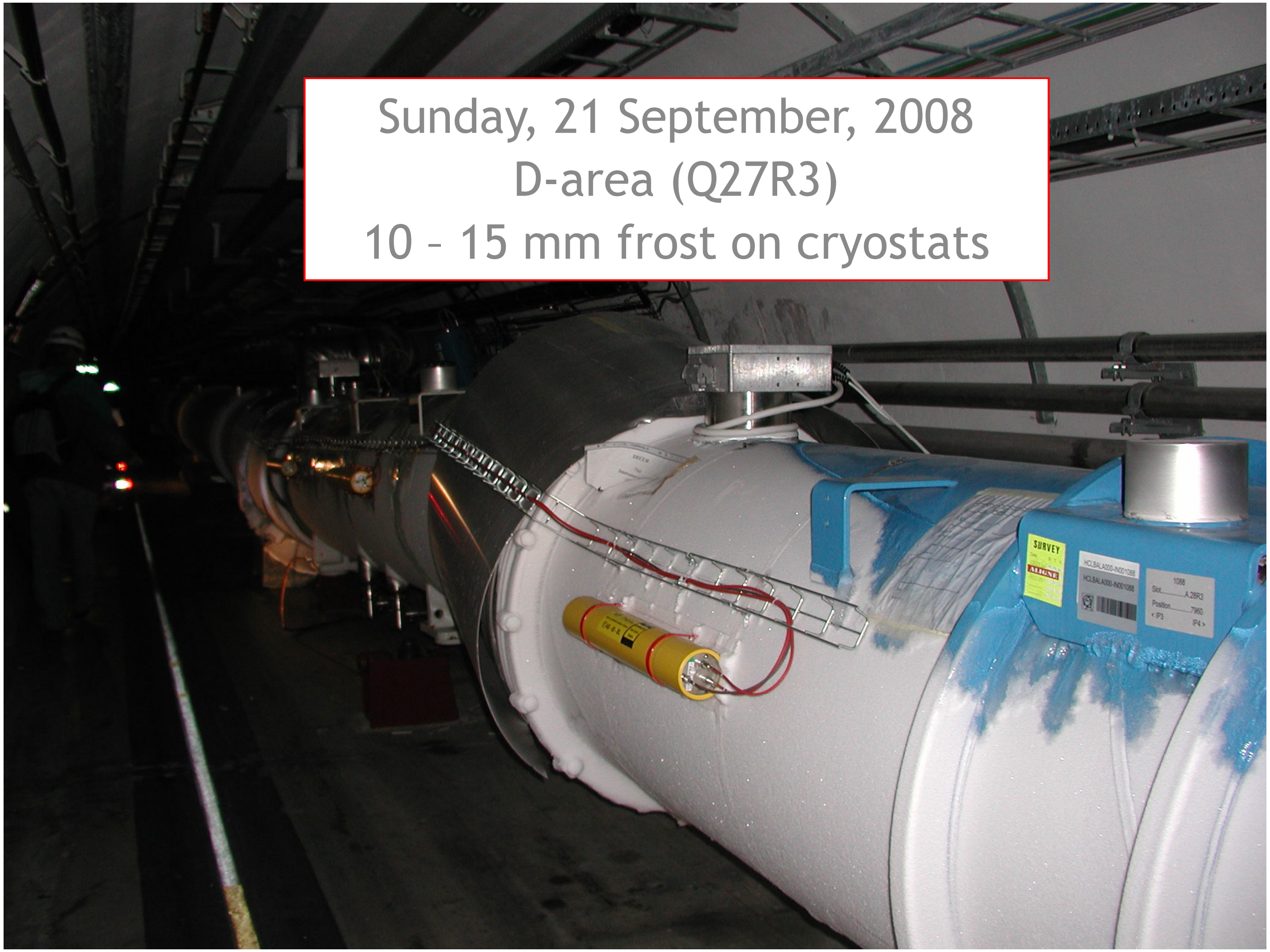
- Complement Steve Myers' presentation with more details
- some "bias" towards mechanical work (magnets, interconnections, cryogenics, vacuum)
- focus on a few detailed cases

20 minutes presentation, 5 minutes discussion: 30 slides

Outline

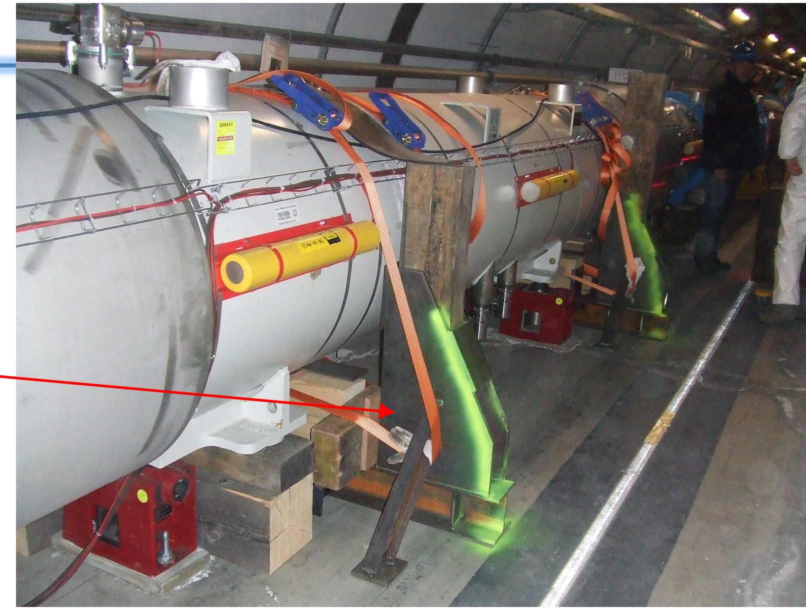
- Repairs Shutdown 2008-2009
  - Sector 3-4: magnets, cryogenics, vacuum
  - Other sectors: replaced dipoles, connection cryostats
- 13kA splices
- Consolidations Shutdown 2008-2009

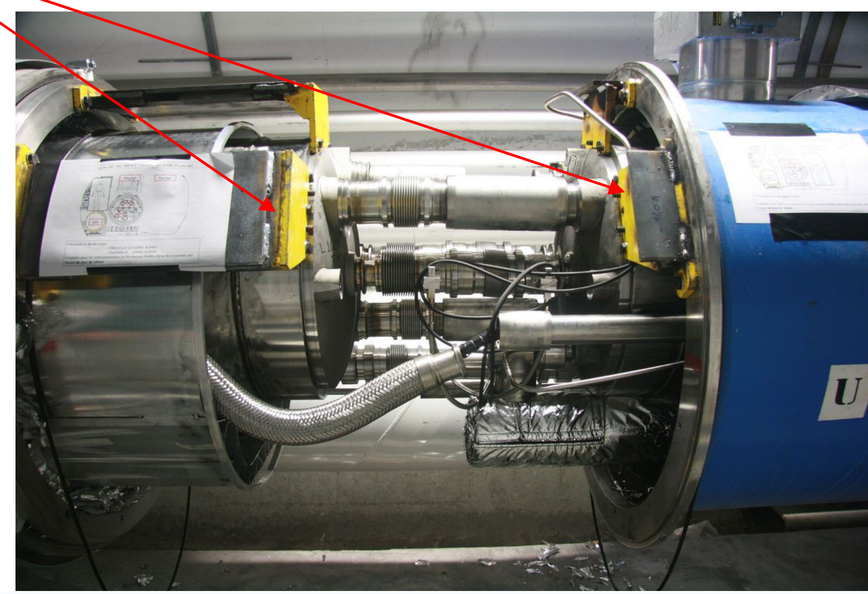
3-4 first inspection after the incident



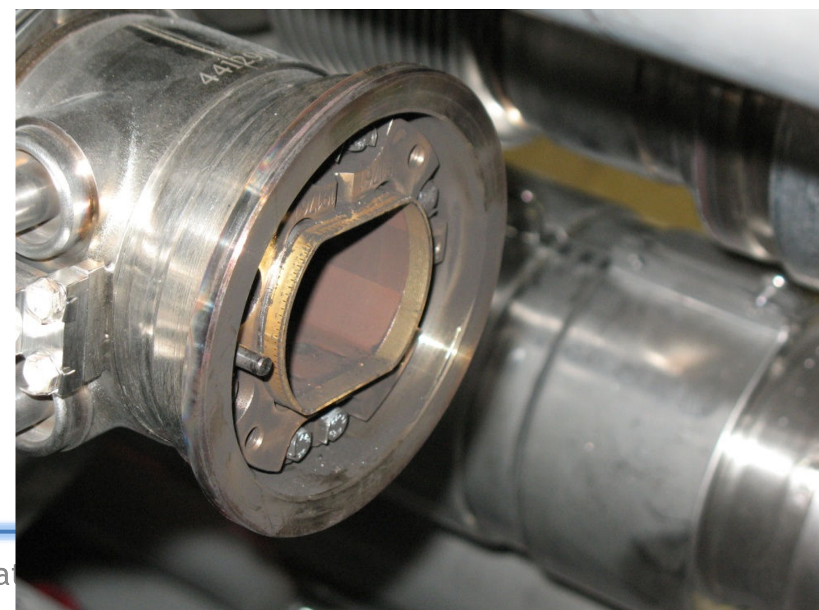
Tunnel work: safety first

- Phase 1 (started Monday 22 September, 2008): limited access, improved safety/stability by adding restraints between cryostats and ground;
- Phase 2: started opening interconnects October 6: further internal restraints added between cold mass and cryostat
- Phase 3: disconnections, transport of magnets to surface, cleaning of beamlines
- Last magnets returned to surface by early January 2009, in parallel first replacement magnets installed December 2008



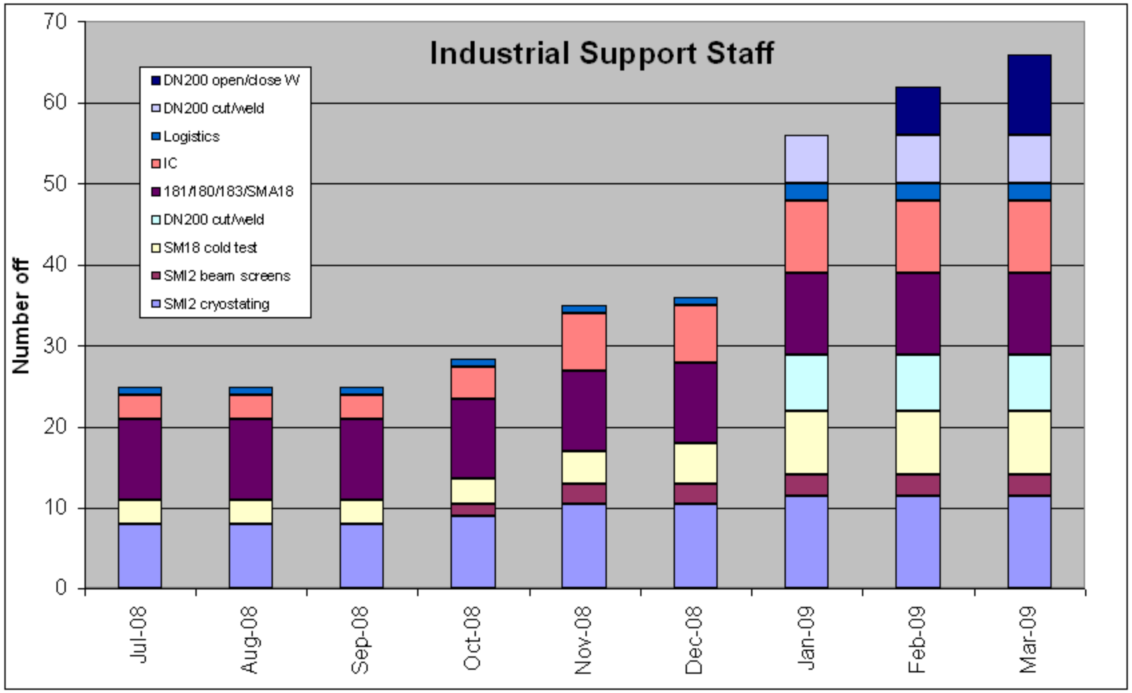


Tunnel work: disconnections



2008-2009 resources

\\cern.ch\dfs\Users\b\bertine\Documents\MyDocs\TE-MSC from 2009\Chamonix_Feb2009_F.Bertinelli\Organigram TE-MSC Jan 2009



- Over 200 workers during construction 2005-2007: IEG Main Contractor finished June 2008
- New “Main Contractor”: TE-MSC
- Core teams and competences were still present, rapidly increased again - FSUs
- Analysis Task Force (Ph. Lebrun)
- In October 2008 started joint TE-MSC and EN-MME Task Force
- Renewed Collaboration Agreement for Quality Control/ELQA with Krakow Institutes
- …

Sector 3-4: D-zone

Sector 3-4 Event Findings and Observations Summary

← Point 3 (Based on investigation and measurements by AT-MCS, AT-MEI, AT-VAC, TS-MME and TS-SU) Point 4 →

	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
SSS type								J,VB,Plugs								J
Δ Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Δ CM Longit.								<5	<5	<5	<5	<5	<5	<5	<5	<5
MLI&Cleannes Status																
CM Status																

	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
SSS type								J,VB,Plugs								J
Δ Cryostat (➡ +)	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
Δ CM Longit. (➡ +)	<5	<2	<2	-20	-67	-102	-144	<5	-190	-130	-60	<5	<2	<2	<2	<5
MLI&Cleannes Status																
CM Status																

	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
SSS type								J,VB,Plugs								J
Δ Cryostat	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
Δ CM Longit.	<2	<2	<2	<5	57	114	150	-45	230	189	144	85	50	35	<5	<5
MLI&Cleannes Status																
CM Status																

	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33	A34
SSS type								J,VB,Plugs								J,VB	
Δ Cryostat	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2	<2
Δ CM Longit.	<5	<5	<5	<5	19	77	148	<5	140	105	62	18	<5	<5	<5	<2	<2
MLI&Cleannes Status																	
CM Status																	

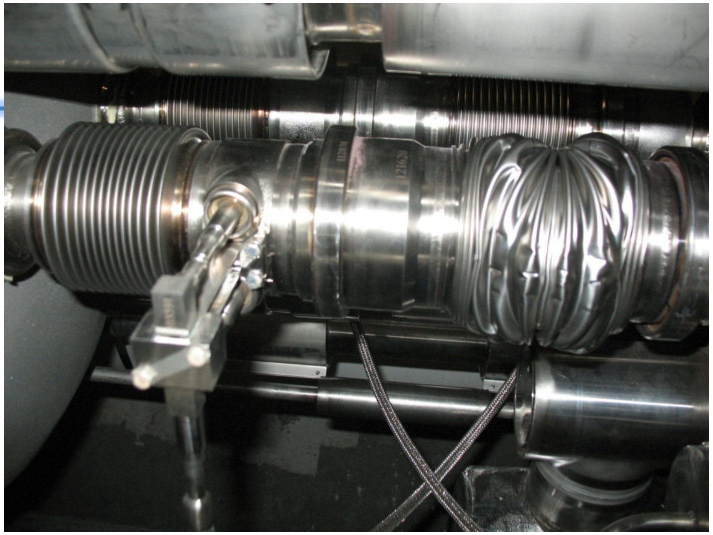
J,VB,Plugs	SSS type
(cyan)	Zone with magnets removed
(blue arrow)	Cold mass displacement
(green arrow)	Cryostat displacement
(red arrow)	Holes in LHe enclosure
(jumper symbol)	Jumper (to QRL) damaged
(yellow star)	Primary Electrical Fault
(red star)	Electrical interruptions
(magenta star)	Dipole in short circuit

(* Note: damages on Beam pipes Vacuum (PIMs, BS bellows, and CBT/BS pollution) also OUTSIDE zone Q19-Q33 (up to Q7.R3 and Q7.L4))

M.Modena, TE-MSC

23-Apr-09

Sector 3-4: extent of work



Magnets for 3-4:

MB	39
SSS	14

IC work in 3-4:

	W bellows opening		PIMs		M sleeves	13kA BB pairs			N-lines removed	jumpers
	fully	partially	V1	V2	M1, M2, M3	M1	M2	M3		Z and lines
Within D-zone (Q19R3 to Q33R3 included)	57		55	57	57	57	57	57	13	7
Outside D-zone (replace all QQBI PIMs, cleaning soot and MLI)										
Towards Point 3	35		15	30	1	1	1	1	0	0
Towards Point 4	32		28	28	2	0.5	0	1	0	0
Outside D-zone (for DN200 work only)		53								
Outside D-zone (other work)	6		6	3	6	2		1.5		
Total opened	183 86%		104 49%	118 56%	66 31%	60.5 29%	58 27%	60.5 29%	13 28%	7 25%
Total present	212		212	212	212	212	212	212	46	28

3-4 replacement magnets

- Intensive su
  - MB: 30 r
  - SSS: 7 n
  - ➢ Reconst

SPARES DIPOLES STATUS

STEPS		DIPOLE			
		TYPE A		TYPE B	
		QTY	ID	QTY	ID
COLD MASS	NON-CONFORM	15	1061 / 1072 / 1083 / 1084 / 1088 / 1089 / 1154 / 1241 / 1242 / 2100 / 2102 / 2171 / 2193 / 3103 / 3110	17	1109 / 1112 / 1132 / 1232 / 1235 / 1236 / 2040 / 2043 / 2055 / 2111 / 2194 / 2334 (ex1-2) / 2420 / 3096 / 3128 / 3409 / 3636 /
	CONFORM NOT TESTED	0		0	
	TESTED	0		0	
	(sick magnet)			0	
				0	

Legend

blue: type L

red: type R

black: no diode

UPDATED	23/10/2009	BY	N. Bourcey TE/MCS/CI

- Cold testing of 100% of reinstalled magnets (as in series production):
  - (re)introduced internal splice resistance measurements
  - Identified MB2420 with 30nΩ (inter-aperture splice), now repaired
  - Extensive thermal and quench cycling on MB2303 (50 nΩ), no degradation found

- Improved uniformity of work (tooling, methods, quality control) between surface and tunnel activities

3-4 interconnection work

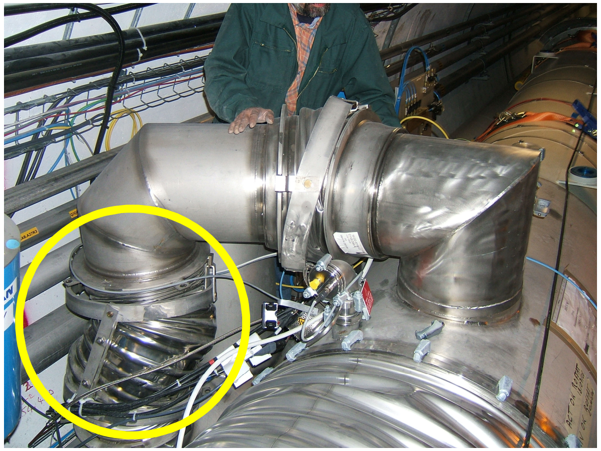
	"IC half-cell"		SSS Q30		MB A31		MB B31		MB C31		
	IC name	QBQI		QQBI		QBBI.A		QBBI.B		QBQI	
1	Magnet ready for installation		W15						W15		
2	Magnet transported		W15						W15		
3	Survey positioning / check		W16						W16		
4	QC: start IC	W16		W16				W16		W16	
5	BB: Busbar Brazing	W17		W16		W16		W16		W17	
6	QC: BB	W17		W16		W16		W16		W17	
7	insulate BB	W17		W16		W16		W16		W17	
8	US: ultrasonic welding spools	W17		W16		W16		W16		W17	
9	insulate spools	W19		W16		W16		W16		W19	
10	ELQA: PAQ	W17									
11	Insert N-Line	W18									
12	Cable N-Line	W18								W18	
13	ELQA: HVQN	W18									next half cell
											next half cell
										W19	
											all D-area
											next half cell
										W20	
											all D-area
										W21	
										W21	
								W21	W21	W21	
								W22		W22	
								W23		W23	

- First welding 18 February, 2009
- First soldering 24 February, 2009
- First ELQA test 18 March
- First leak test 8 April
- Last magnet lowered 30 April, 2009 (W18)
- Last IC closures 17 June, 2009 (W25).

➤ a complex chain of activities, 8 weeks from last magnet installation

QRL service modules: jumpers

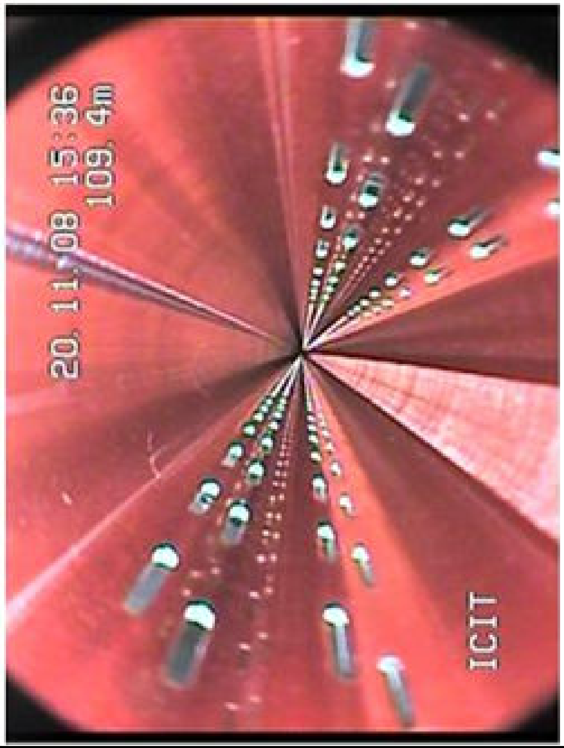
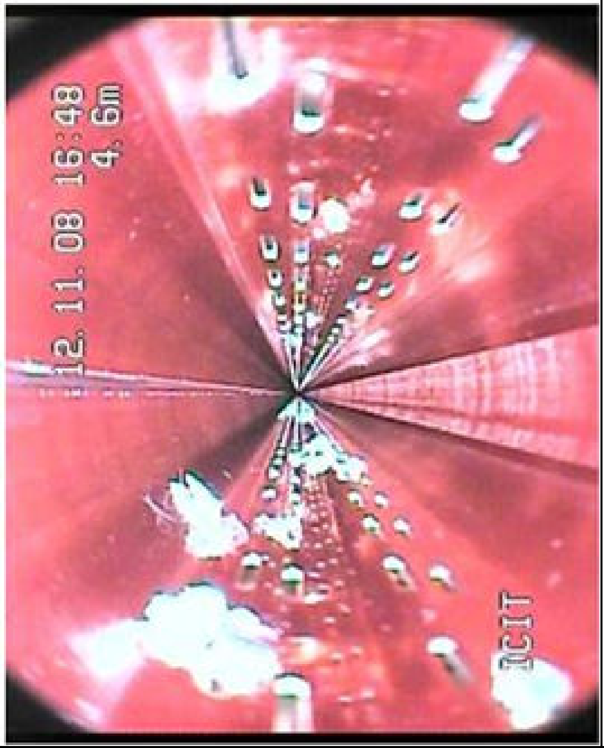
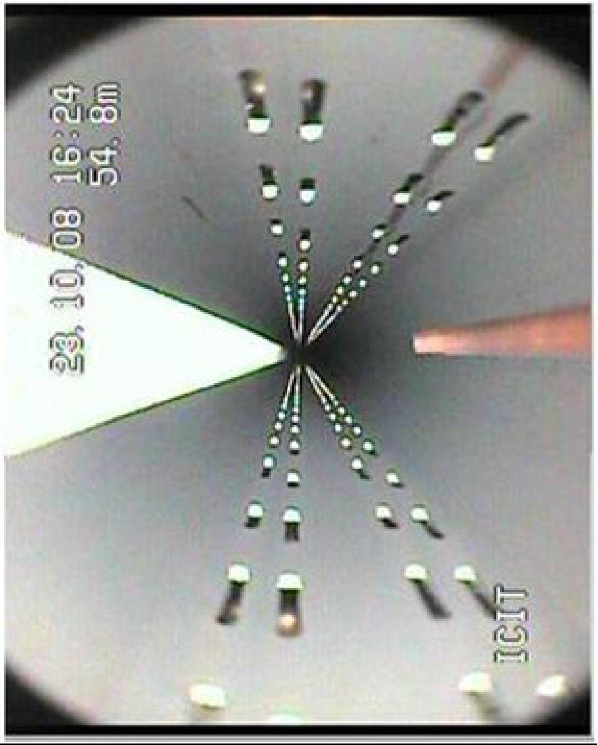
- First diagnostic:
  - Q23, Q27 & Q31 bellows deformed from displacement
  - Q25 collapsed bellows from inner pressure
- Second diagnostic, more detailed:
  - Some internal bellows damaged
  - some 80K vacuum barriers collapsed due to external over pressure
  - Some soot in QRL piping
- In situ repair



Courtesy O. Pirotte

Collateral damage beam vacuum

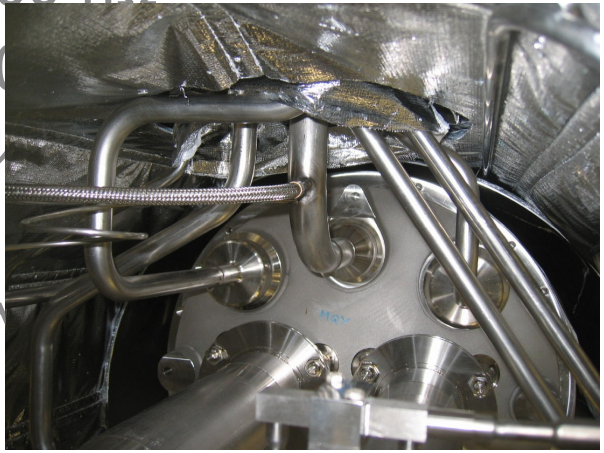
Beam vacuum affected over entire 2.7 km length of the arc.

Beam screen with clean copper surface	Beam screen contaminated with multi-layer magnet insulation debris	Beam screen contaminated with soot
		

≈ 60% of the chambers **≈ 20% of the chambers**

Other shutdown activities

- 5-6: shutdown planned for warmup in Octo
  - 3 connection cryostats (lyra insulation)
  - He level guards in arc SSS
- 1-2: warmup to remove MB2334 (B16R1) 1
- 6-7: warmup to remove MB2303 (B32R6) 5
- 4-5: warmup to compare 80K and 300K 13k measurements
- Stand Alone helium level gauges (3 week w cold sectors with partial warmup)
- 1R and 5L: triplets copper braid
- Connection cryostats (additional busbar insulation)
- RF ball test after warmup (no damage in 4-5!)
- 13kA splices conso
- and more …

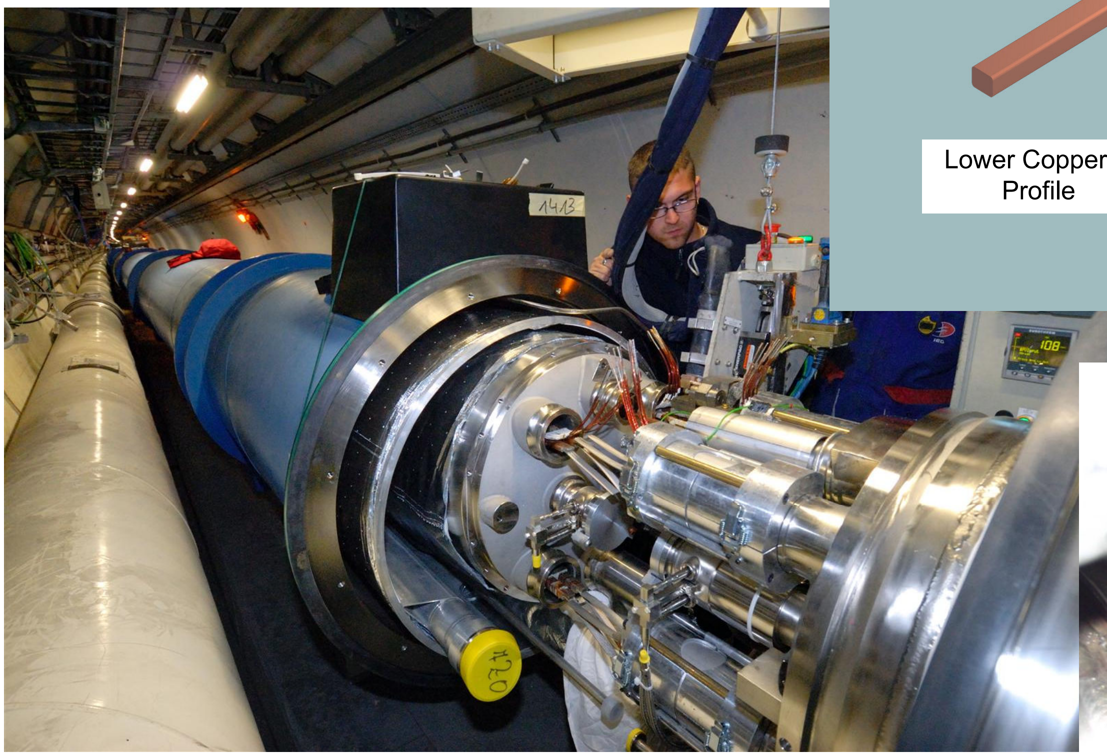


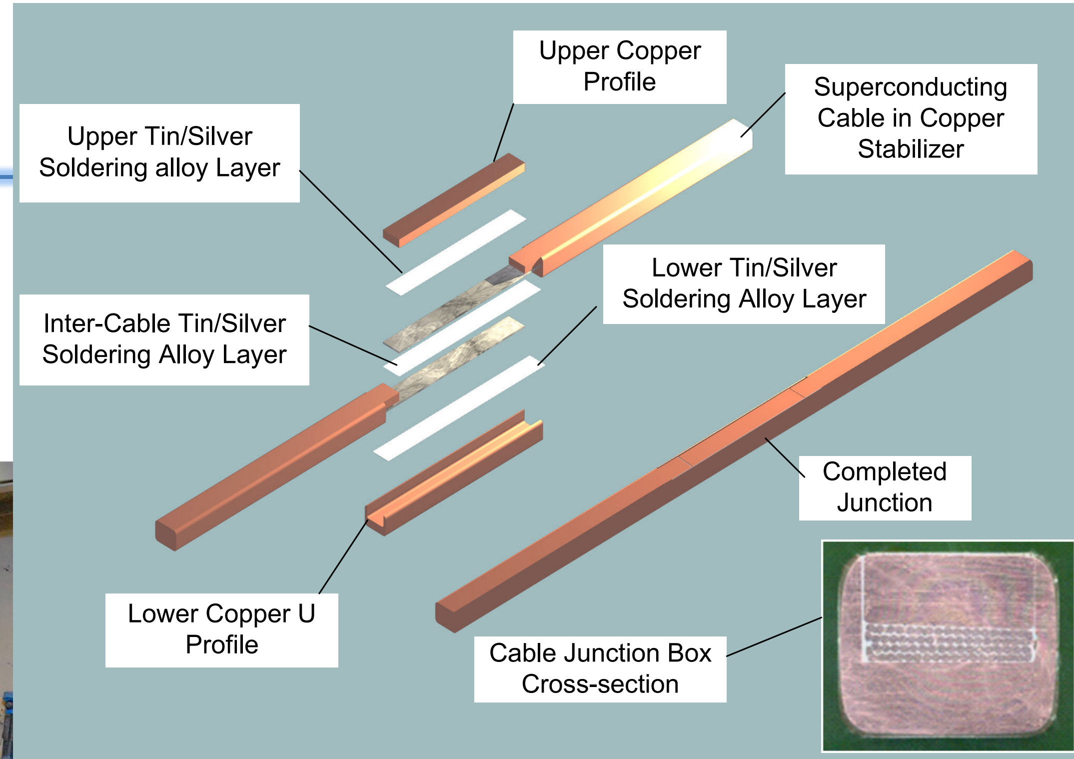
probably as much as we could handle …
(supervision, quality)

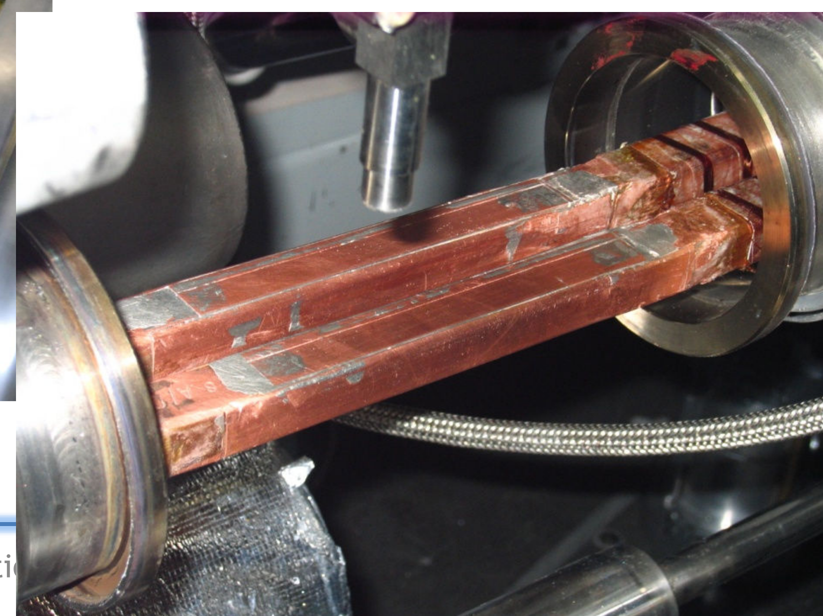
Outline

- Repairs Shutdown 2008-2009
- 13kA splices
- Consolidations Shutdown 2008-2009

13kA splices



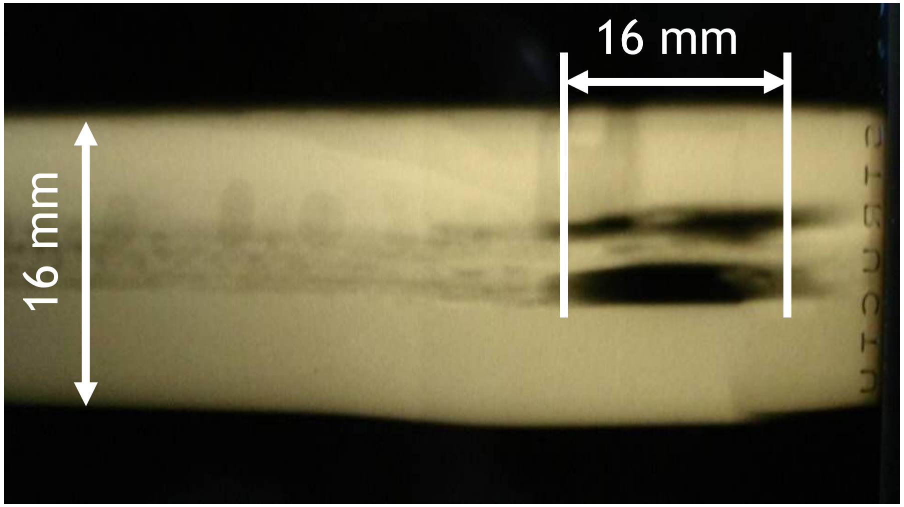




13 kA splices: copper continuity

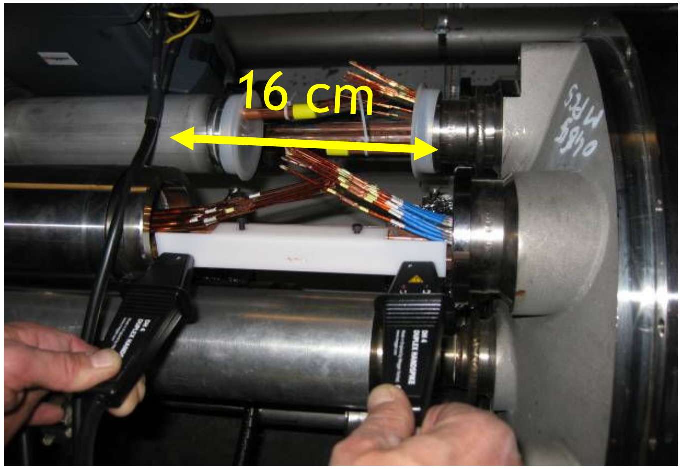
- In February 2009 (Chamonix meeting) an unprotected scenario for splice failure (in resistive state, i.e. quench conditions only) was discussed
- This important splice failure mechanism involves the simultaneous presence within the same cross-section of “lack of copper stabiliser continuity” and “naked SC cable” (i.e. non-stabilised)
- Previous experience (with X-rays, Cobalt or Iridium gamma sources, direction of exposure) had been unsuccessful (insufficient contrast): with Selenium it was finally possible to “see” inside splices

- A campaign of gamma-radiography showed that the “naked SC cable” situation was common: i.e. evidence of weakness in design
- Techniques (invasive and non-invasive) were developed to measure the copper continuity

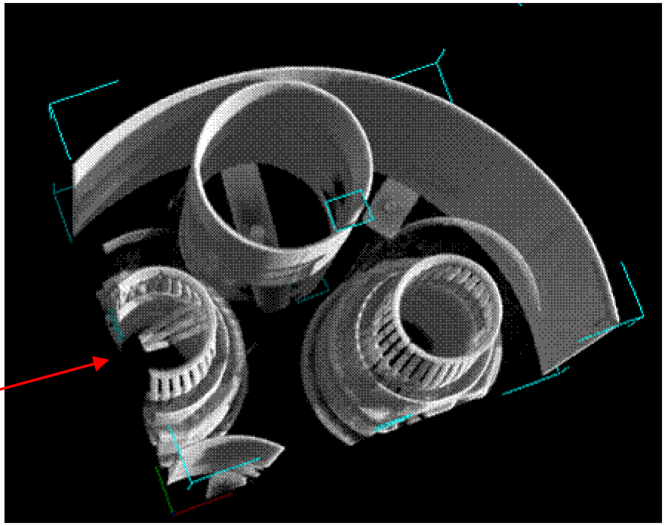


Invasive methods

- "Invasive" means we need access to the splice, i.e. opening the interconnect W bellows, removing thermal screens and MLI, cutting the M sleeve and removing the electrical insulation
  - R16 measurements: use micro-Ohmmeter ("Megger", "Biddle")
  - Gamma-ray radiography (Se source)
  - Ultrasound
  - "local" measurements, most precise, giving physical insight into defects

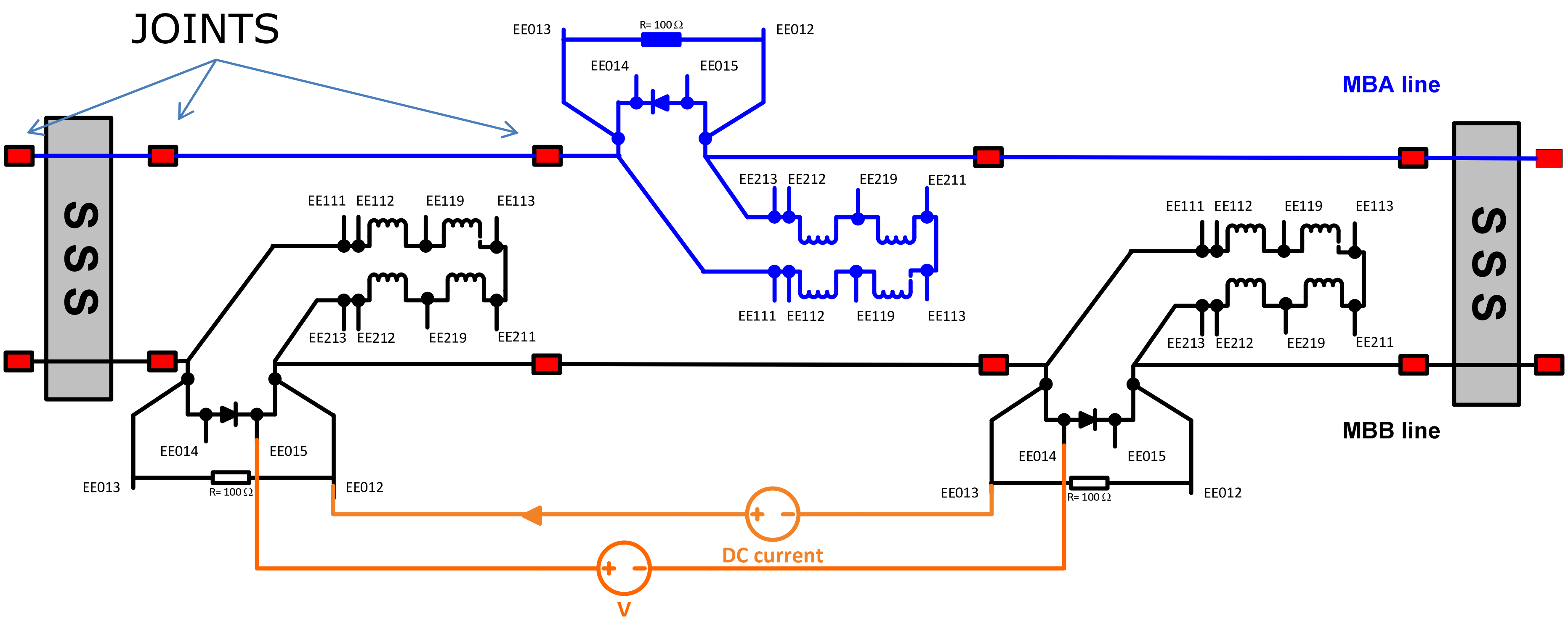


- Possible future: X-ray tomography (non-invasive, usable at cold!)



e.g.PIM RF fingers defect

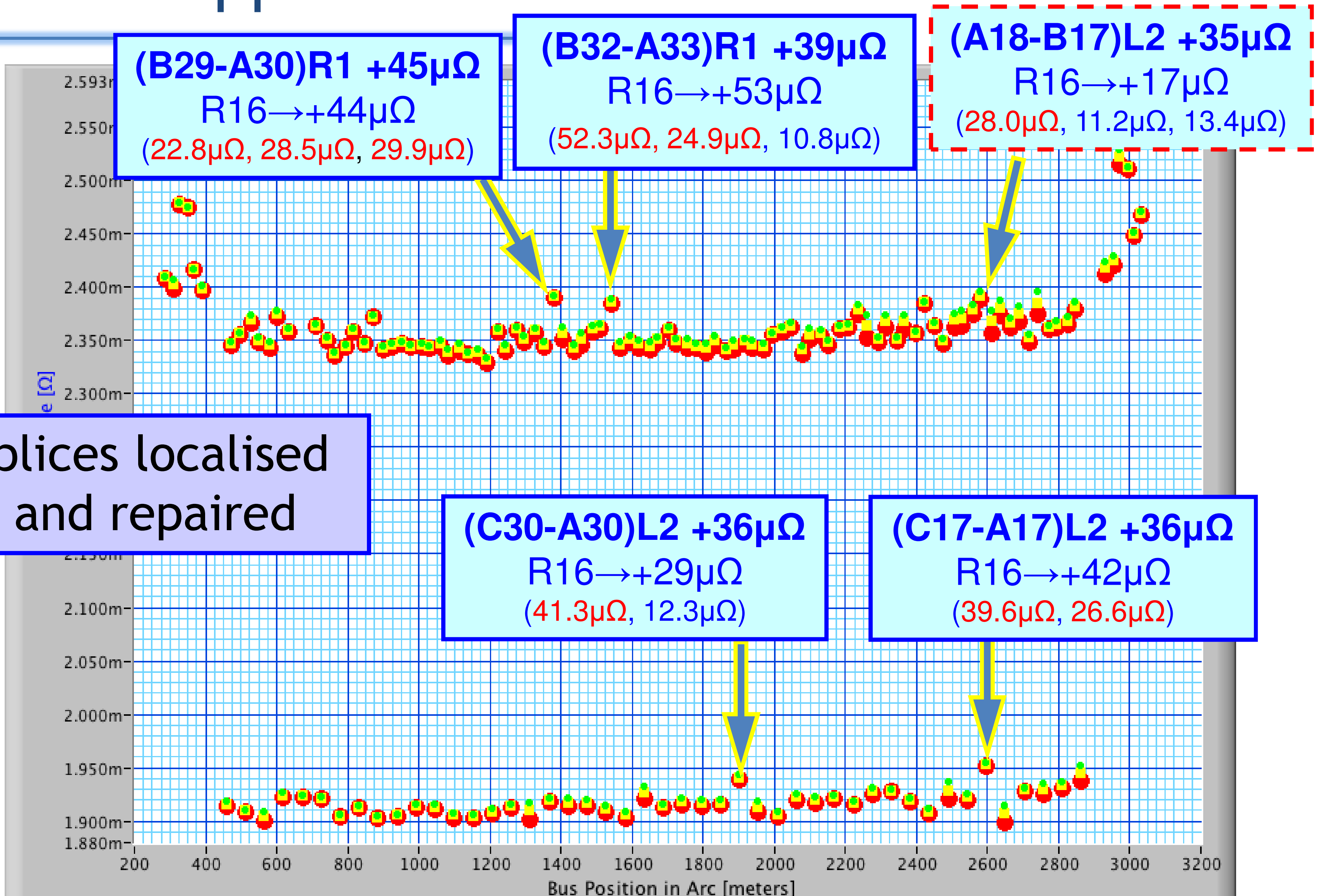
Non invasive copper resistance measurement



- Simplified schematics for two adjacent dipoles
- DC method (±1A) to measure bus segment resistance from external voltage taps
- Allows a "global" measurement

Done on MB and MQ, at 300K and/or 80K

1-2 M3 copper stabiliser resistance



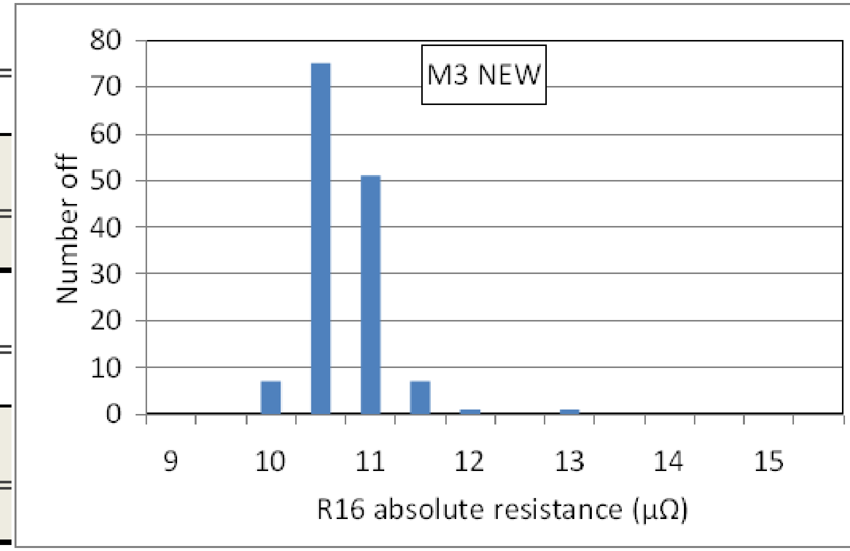
Splices localised and repaired

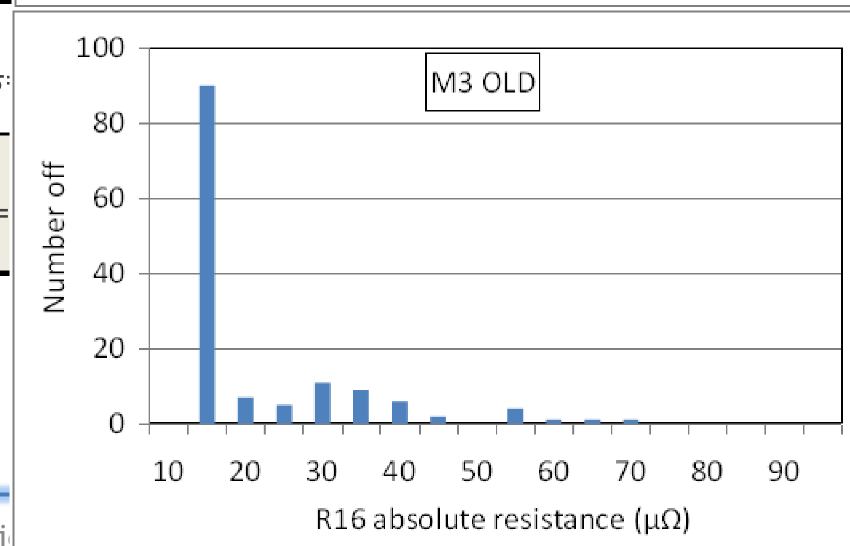
13kA splice interconnections 2009

	LHC2008 OLD	LHC2009 NEW
Qualifications	Equipment and operators	Re-qualified equipment and operators
Before soldering	Procedure for cable preparation	Added specific procedure for eventual desoldering Dimensional control of cables
Preparation of splice	Used standard pieces	Ad-hoc machining (length and transverse) Copper shims to fill gaps Additional Cu-Ag foil Kapton tape to minimise loss of molten Cu-Ag Records with photos
Heating	Inductive Record temperature and pressure of process	Inductive, higher temperature Added 2nd independent temperature recording
Production samples and audits	done	Done, more frequently
Quality control after soldering	Ultrasonics x4 sections Visual	Ultrasonics x6 sections and ends Visual, dimensional measurements Records with photos Measure R16 Gamma-radiography

13kA splice interconnections OLD vs NEW

	R-16 (μΩ)	R-8-connection (μΩ)	R-8-lyra (μΩ)
Average M1-NEW (85 splices)	17.9 (σ=1.1, max=21.7)	(σ=	
Average M1-OLD (54 splices)	22.9 (σ=8.9, max=60.4)	(σ=	
Average M2-NEW (81 splices)	17.7 (σ=0.9, max=22.5)	(σ=	
Average M2-OLD (47 splices)	21.2 (σ=6.4, max=47.9)	(σ=	
Average M3-NEW	10.5 7)	(σ	
	.8)	(σ=	





April 2009

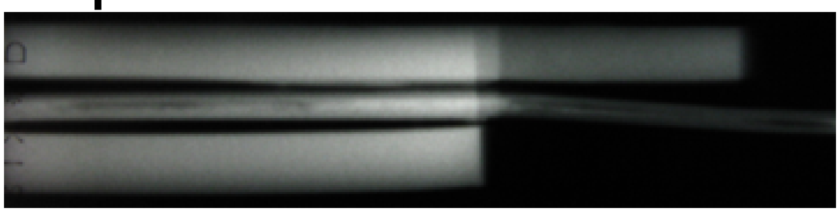
resistance

epair & consoli

To be improved for the next long shutdown

- How to reinject solder in busbar ends (e.g. after desoldering)
- How to avoid tin loss during soldering (specifically at busbar ends)
- Mechanical clamping if possible

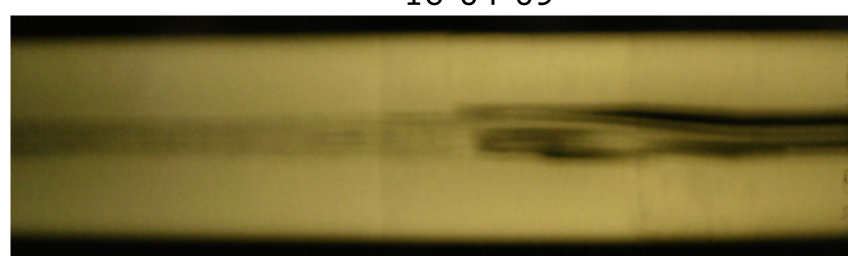
Dipole extremities in SMA18 (March 2009)



MB3118 M2 from the tunnel

before connection
8-04-09

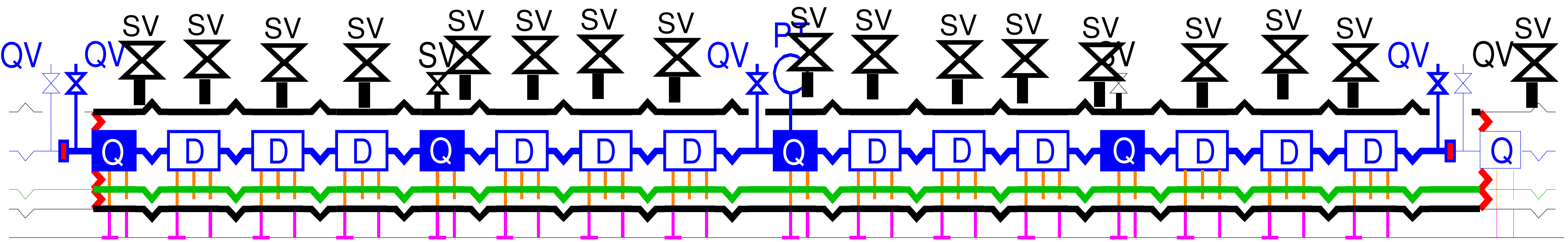
after connection
16-04-09



Outline

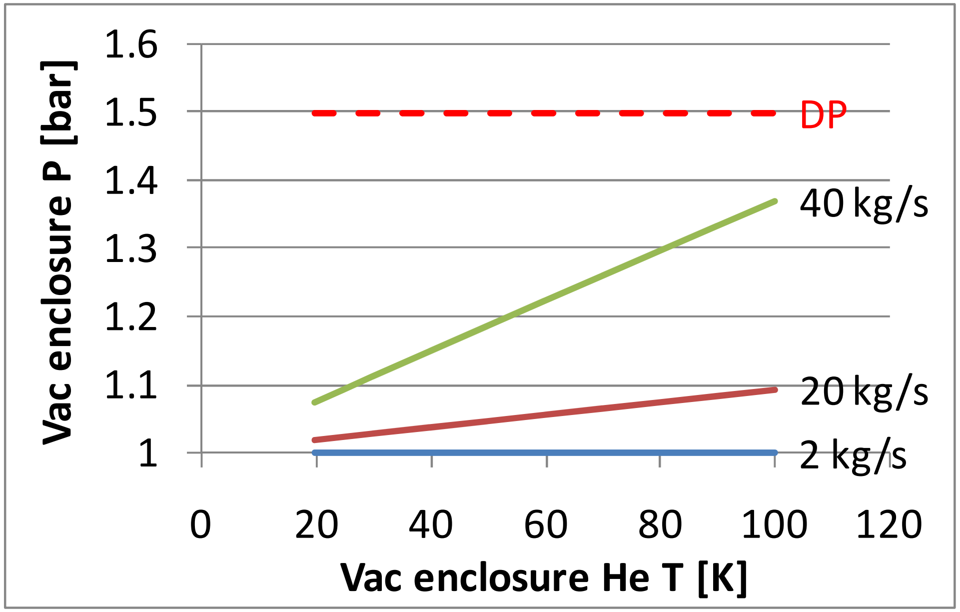
- Repairs Shutdown 2008-2009
- 13kA splices
- Consolidations Shutdown 2008-2009
  - Pressure relief nozzles ("DN200")
  - Ground anchoring SSS
  - nQPS

DN200 warm sectors: new scheme

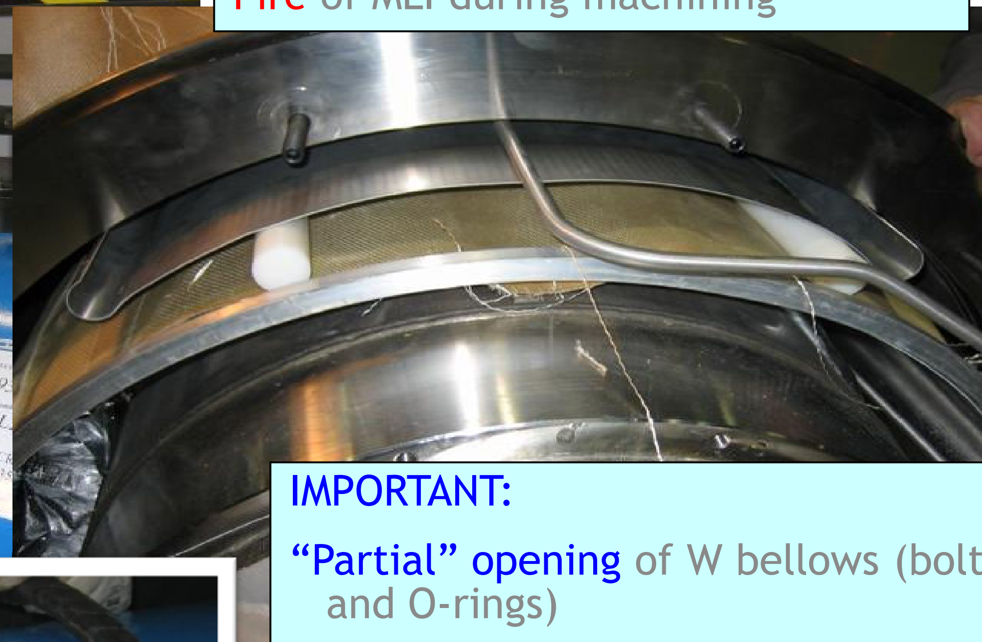


- Keep existing 2 DN90 relief devices
- Mount relief springs on 4 DN100 blank flanges
- Add 12 DN200 new relief devices (1 per dipole)

→ Cross section increase: x 33



DN200 implementation protection



No. 1 Risk:

Fire of MLI during machining

IMPORTANT:

"Partial" opening of W bellows (bolts and O-rings)

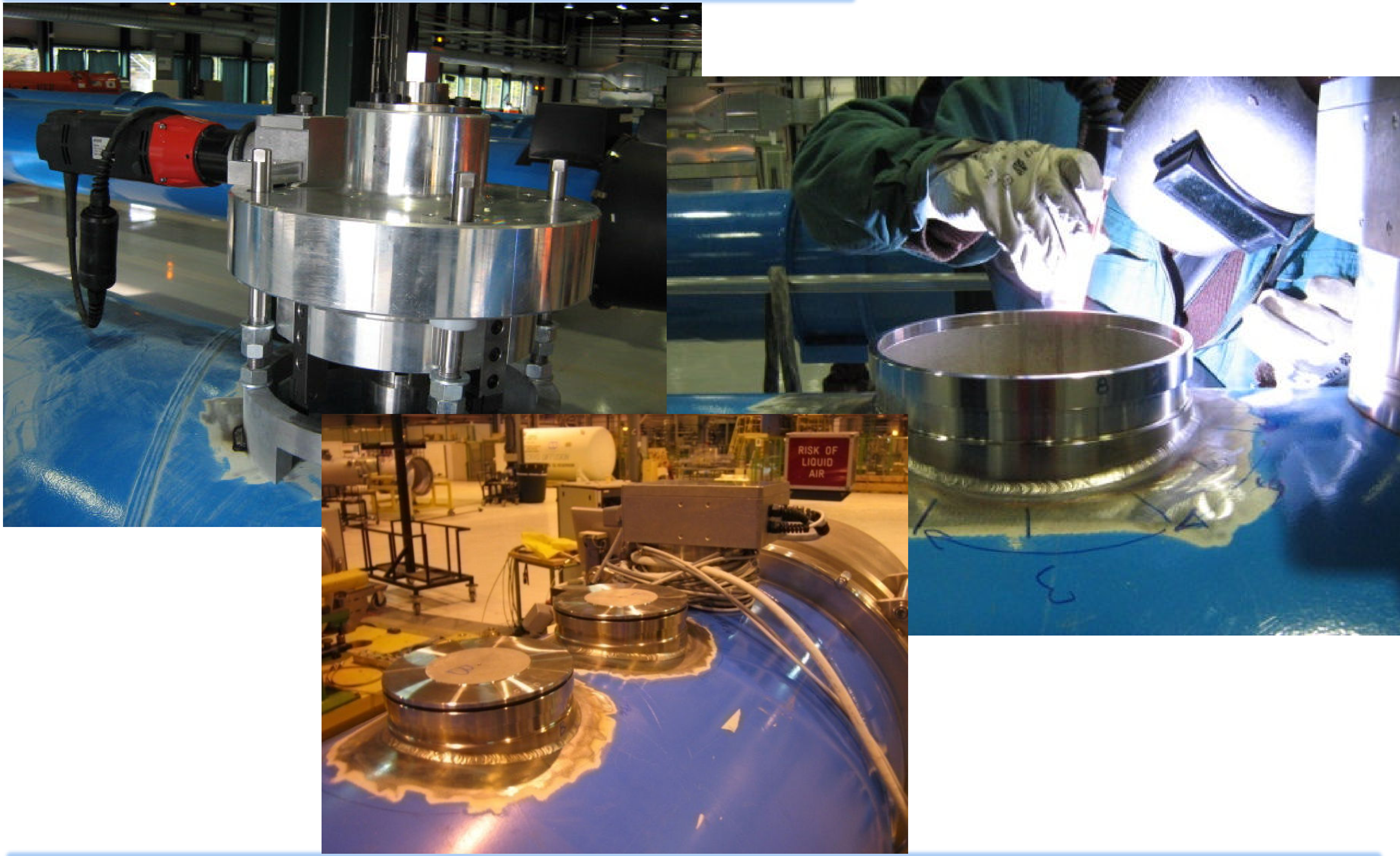
≠

"full" opening

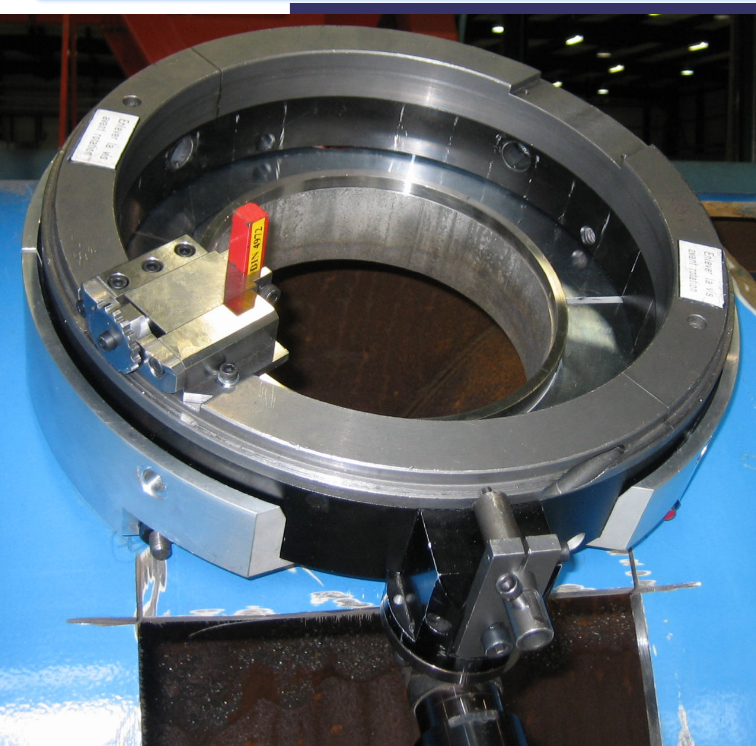
(cut welds of thermal screens, remove thermal screens and MLI, cut sleeves, remove insulation ...)

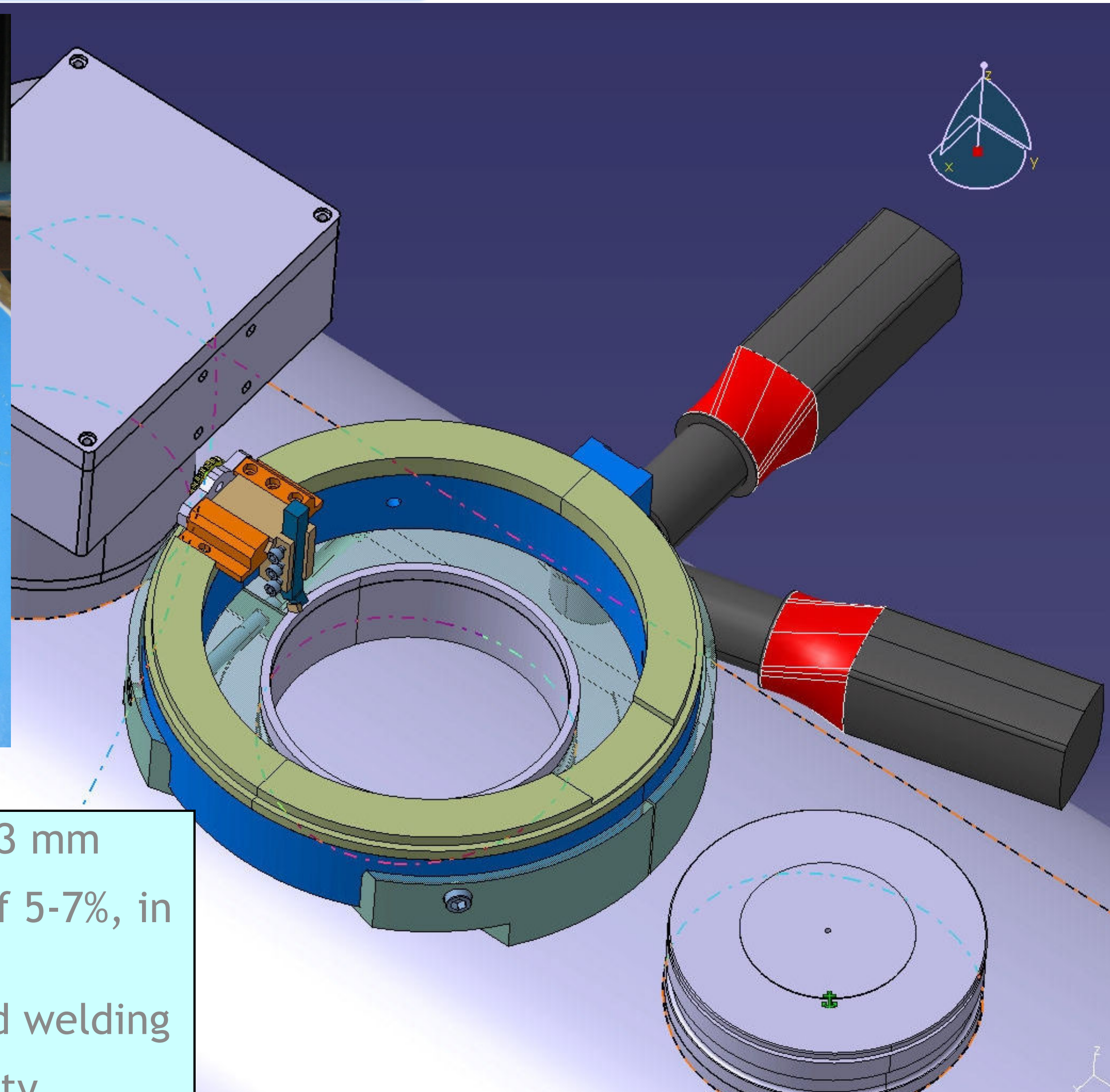
...and more risks

DN200 machining and welding



DN200 grinding of the sealing surface





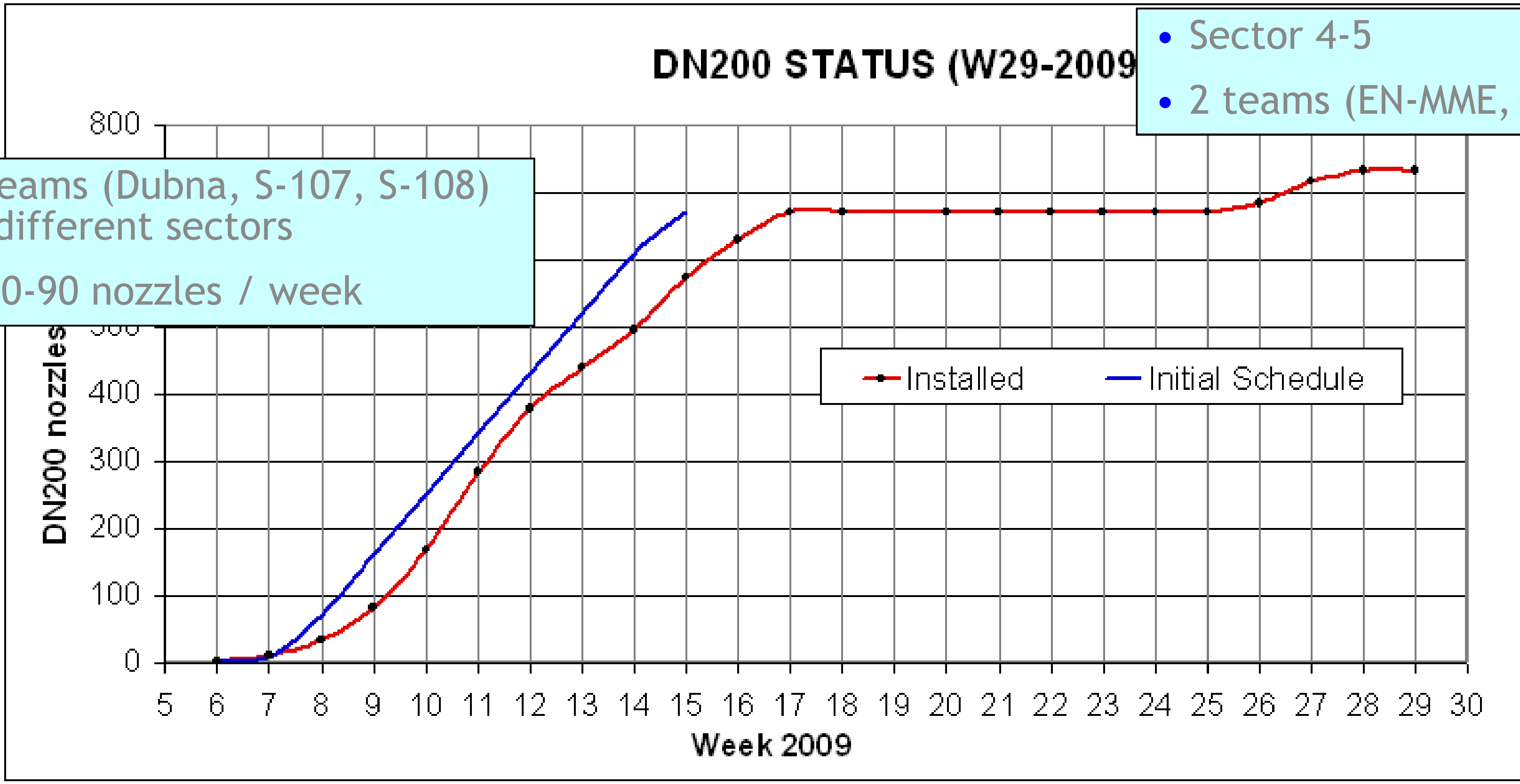
- Flatness specification < 0.3 mm
- In some sectors grinding of 5-7%, in other sectors 20-25%
- i.e. care in machining and welding
- ➢ Importance of teams quality

DN200 consolidation

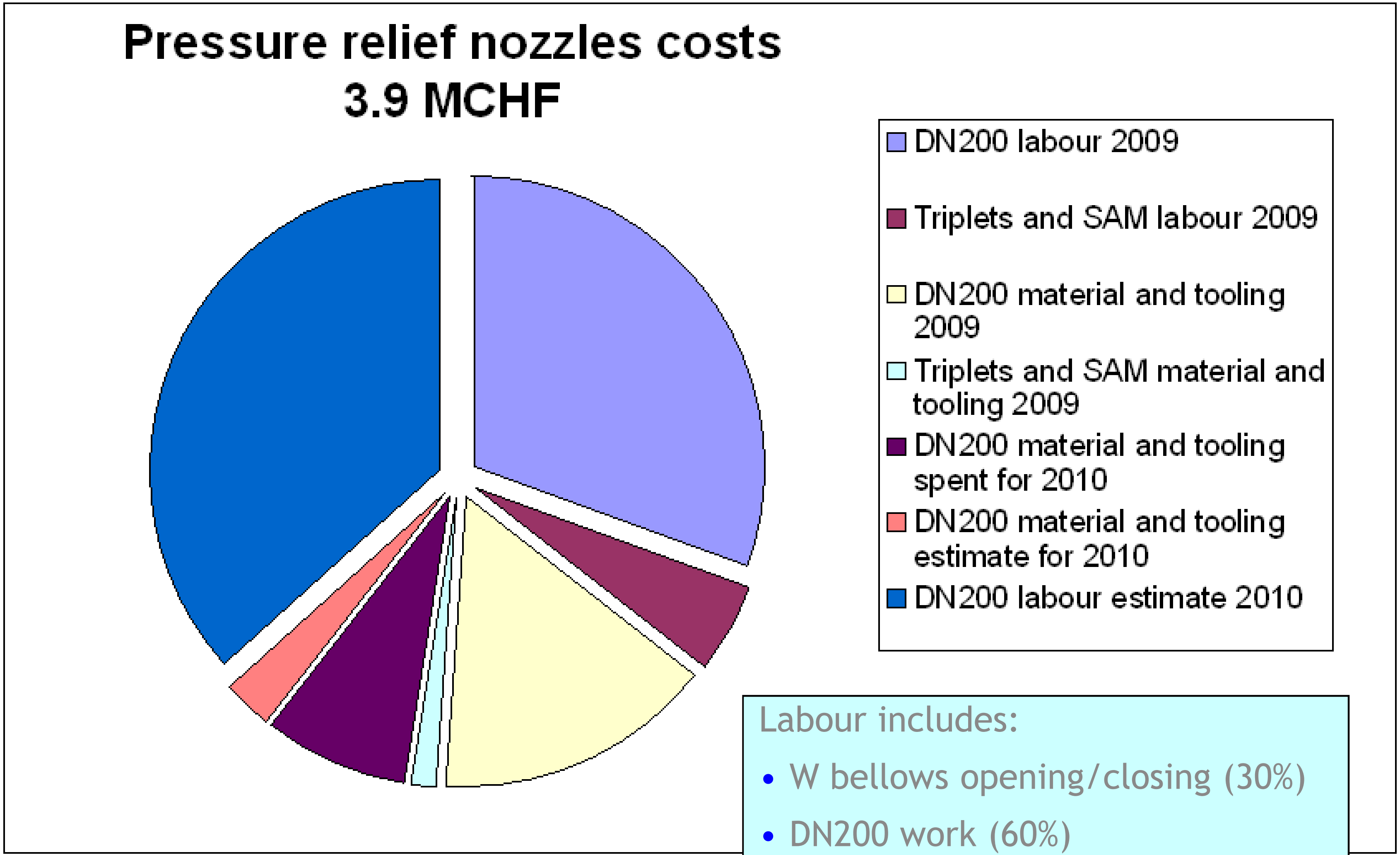
	SMA18	Sector 1-2	Sector 3-4	Sector 4-5	Sector 5-6	Sector 6-7	TOTAL
DN200	**35**	**168**	**169**	**60**	**168**	**168**	**733**
Magnets	**30**	**156**	**156**	**47**	**156**	**156**	**701**

- Sector 4-5
- 2 teams (EN-MME, S-108)

- 3 teams (Dubna, S-107, S-108) in different sectors
- ~ 60-90 nozzles / week



DN200 consolidation costs

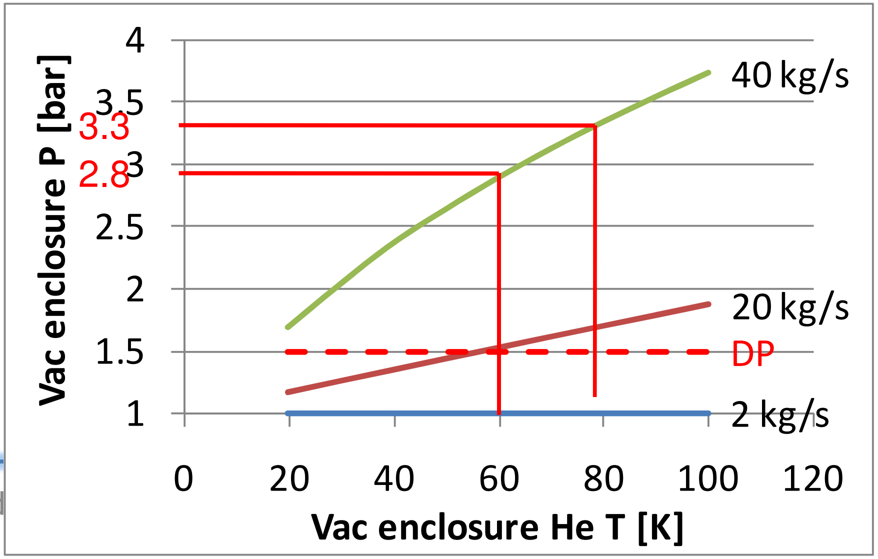


Labour includes:

- W bellows opening/closing (30%)
- DN200 work (60%)
- Welding quality control (10%)

DN200 special cases

- DS and mid-arc cells (x2 DN200)
- DFBs, DSLC, Stand Alone Magnets, Inner Triplets
- Interim measures in cold sectors (until next long shutdown)
- Personnel safety:
  - staging of opening to lower risks associated to multiple helium jams (remove 1 spring)
  - helium deflectors
  - paint on the floor



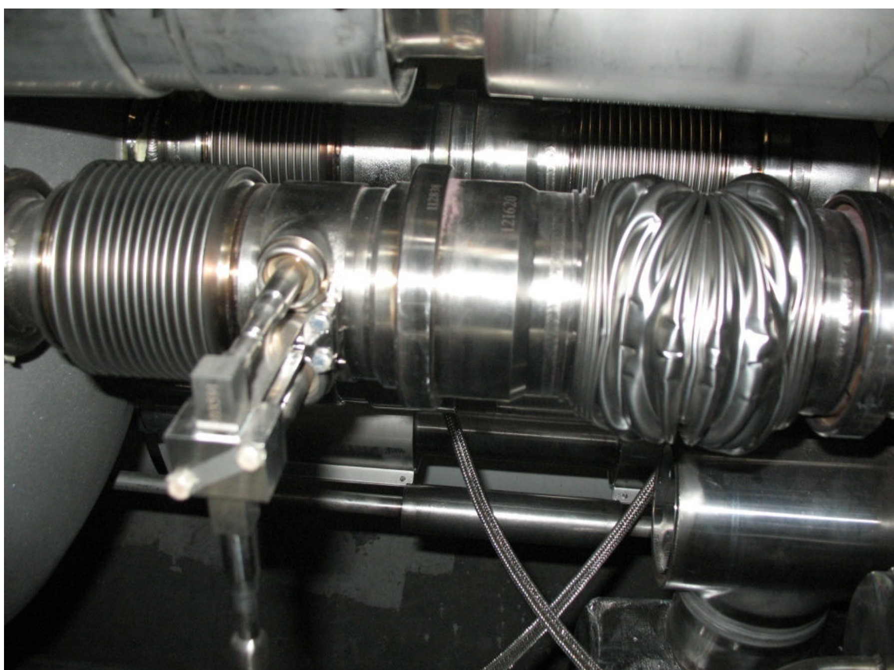
A stronger, safer LHC in 2009

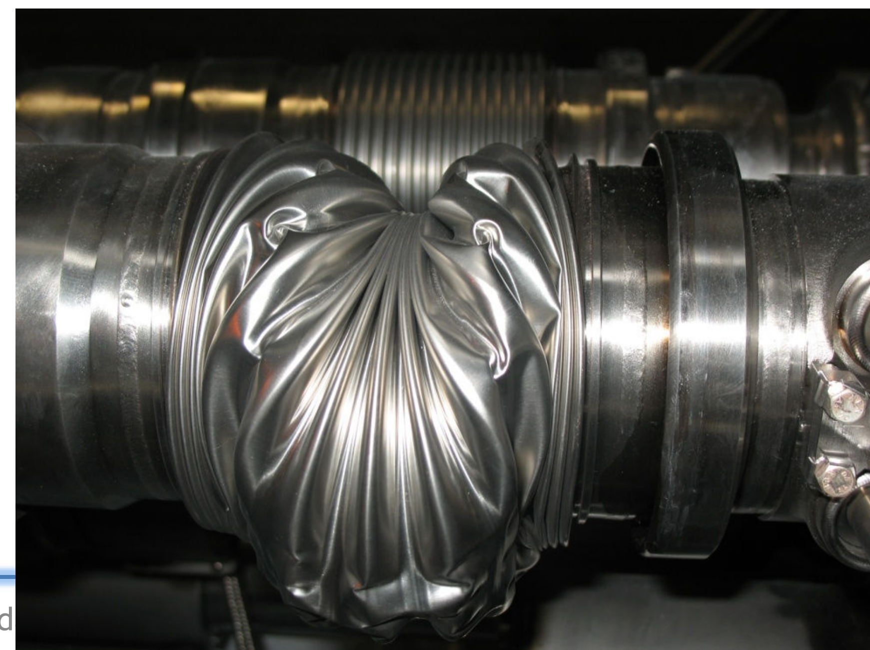
	LHC2008	LHC2009
Pressure relief nozzles Arc	x1 DN100 every 2nd SSS	added x1 (x2 in places) DN200 every MB
Stand Alone Magnets	none	x1 DN160 and x1 DN200 on neighbouring DFBM
Triplets & DFBX	x3 DN63	added x3 DN200
DFBA	x2 DN100 on HCM & LCM	x4 DN230 on HCM, x1 DN200 on LCM
Floor anchoring Arc	none	each SSS with vacuum barrier
Stand Alone Magnets	none	added to semi-SAM (e.g. Q4, D2)
Triplets & DFBX	Bumpers on Q1 and Q3	strengthened bumpers on Q1
DFBA	Bumpers on HCM	strengthened anchors on HCM (7-8, 8-1, 2-3)
Quench Protection System magnets	Individual, 100mV	unchanged
busbars and IC splices	Global, 1V	Magnet segments, 0.3mV
symmetric quenches	none	Individual, 200mV
Uninterrupted Power Supply		Doubled lines redundancy for nQPS
Radiation protection		Improved shielding of tunnel electronics against Single Event Upsets
Cryogenics		Additional LHe storage on site
Tunnel ventilation		Improved sectorisation for safety
HWC Powering procedures		Phases I and II, tighter access conditions, use nQPS to measure splice resistances

Thank-you for your attention

Supporting slides

Sector 3-4 => some pics



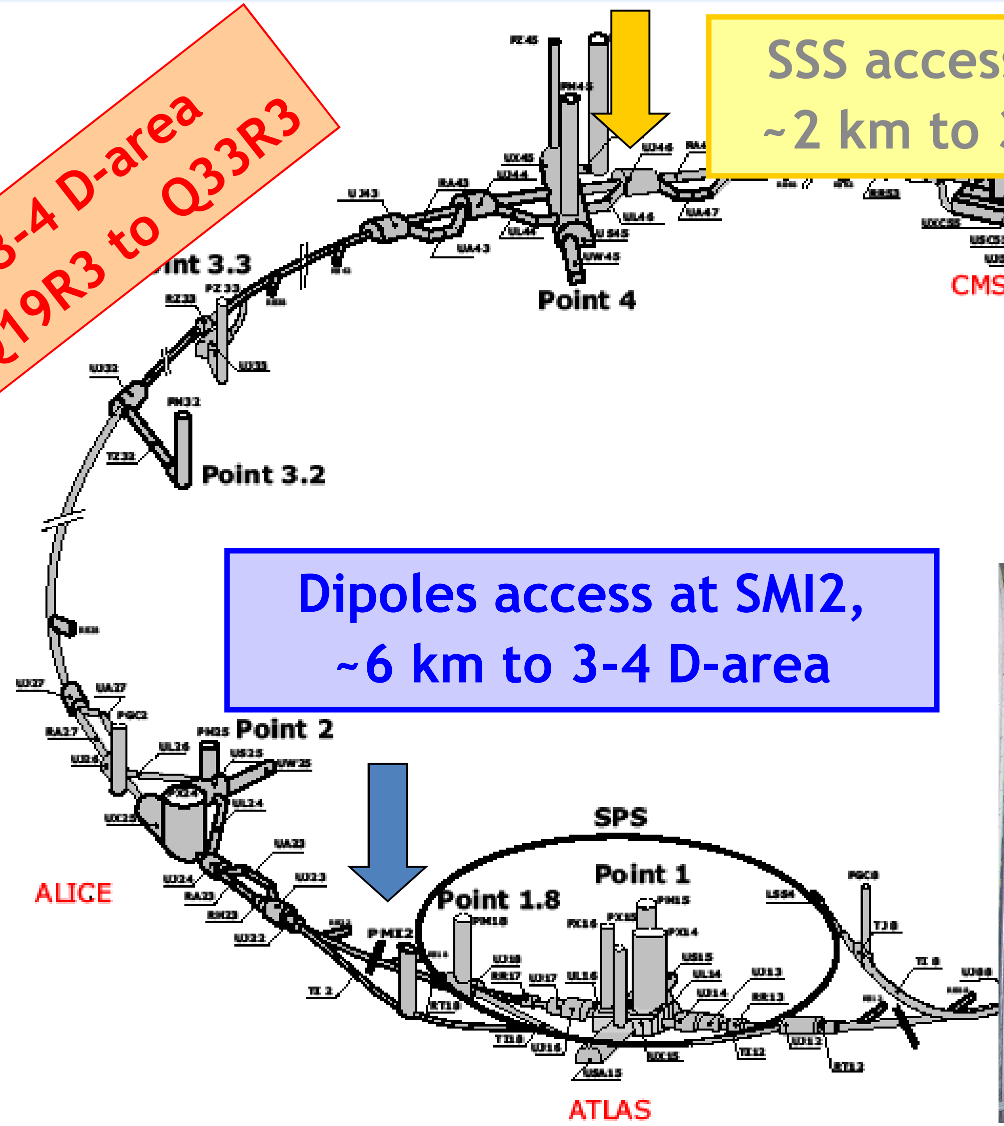


Magnet transport logistics: no accidents !!!

3-4 D-area
Q19R3 to Q33R3

SSS access at PX46,
~2 km to 3-4 D-area

Dipoles access at SMI2,
~6 km to 3-4 D-area

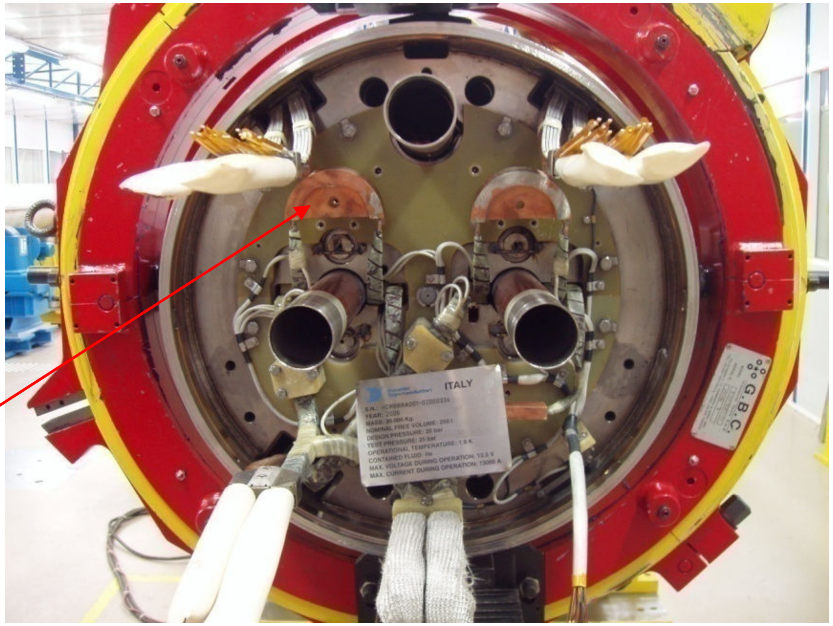


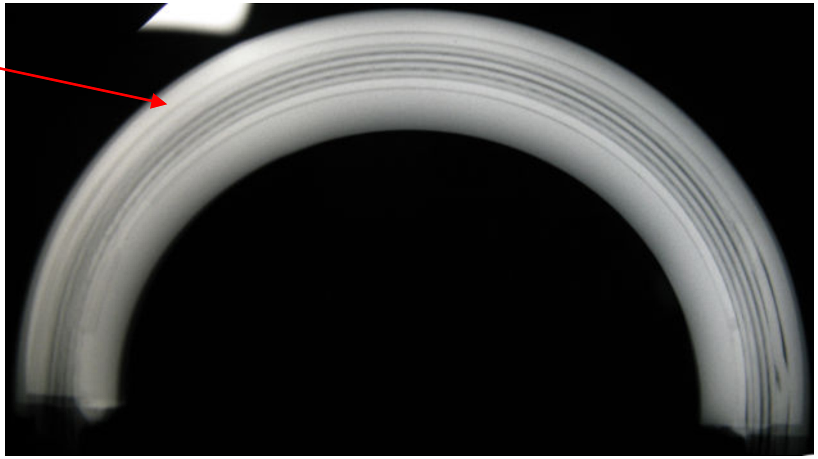
3-4 Lowering of last magnet

SSS279 down PX46 pit
30 April, 2009

Dipole MB2334 from Sector 1-2 (B16R1)

- 100 nΩ joint, internal to the dipole
- First identified by calorimetry at 1.9K, then by QPS snapshots (and visible also in original SM18 data)
- Decision to warm-up the whole sector 1-2 (December 2008)
- MB2334 returned to surface and opened
- Localised in internal inter-pole splice
- Gamma-ray radiography





➢ Lack of solder on joint, not properly brazed: first clear evidence of possible poor workmanship

- Also warmed-up Sector 6-7 (February 2009) to replace MB2303 (B32R6) with 50 nΩ joint (inter-pole)

Splice detection limits

circuit	splice type	splices per magnet	number of units	total splices
RB	inter pole	2	1232	2464
RB	int			
RB				
RB	i			
RB	in			
RQ				
RQ	i			
RQ	in			
total				

Detection limit of splice resistance for MB and MQ (nano-Ohm) Red: thermal measurements, blue QPS

	Interconnect splice		Magnet splice	
Sector	MB	MQ	MB	MQ
A12	30	60	10	60
A23	60	60	60	60
A34	60	60	60	60
A45	60	60	60	60
A56	30	30	5	5
A67	30	30	15	5
A78	30	30	10	5
A81	30	30	10	5

N. Catalan Lasheras, Z. Charifoulline, M. Koratzinos, A. Rijllart, A. Siemko, J. Strait, L. Tavian, R. Wolf
Electrical and calorimetric measurements and related software

Z. Charifoulline, Int Comm.

Splices and stabiliser measurements

Sector	Status on June 5 2009	Splices Calorimetric Ohmic		Stabilizers Biddle R16		Stabilizers Biddle	
		1.9K 7kA		Warm		80K	
		Dipoles	Quads	Dipoles	Quads	Dipoles	Quads
12	warm	Done	Done	Done	Done	No need	No need
23	2K						
34	warm			Done	Done	No need	No need
45	80K					Analysis	Problems
56	warm	Done	Done	Done	Done	No need	No need
67	warm	Done	Done	Done	Done	No need	No need
78	40K	Done	Done				
81	40K	Done	Done				

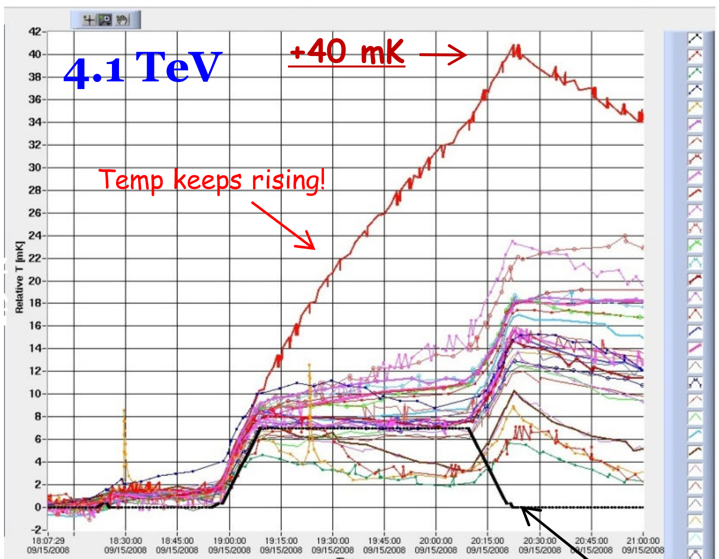
Calorimetry analysis

sensitivity ~40nΩ

- Logged cryogenic data revealed a temperature anomaly of some 40 mK in the cell of the incident during a previous (lower current) powering cycle.
- Data from other powering tests indicated the presence of another anomaly in sector 12. Calorimetry suggested a **~100 nΩ resistance**.

ΔT (mk)

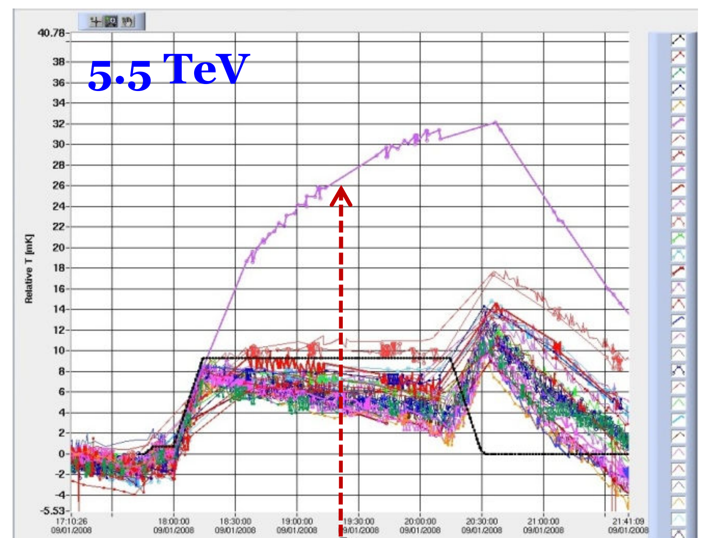
7 kA test on **Sector 34**



1 hour

Current in kA

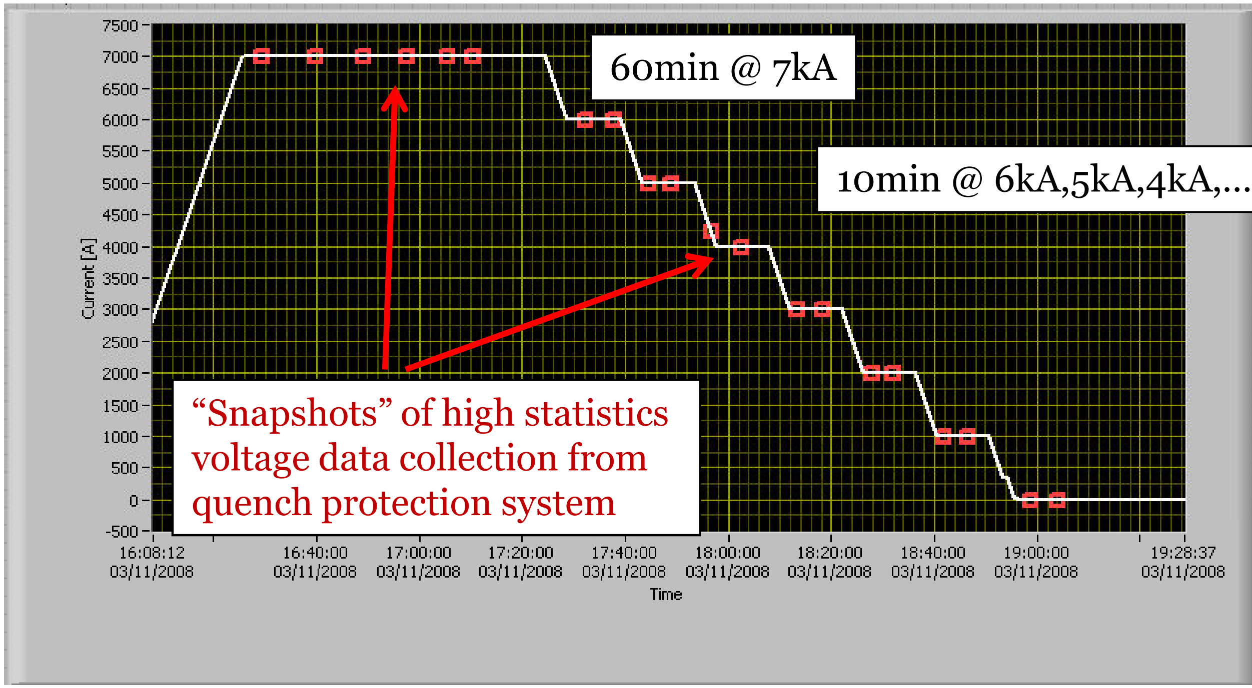
9.3 kA test on **Sector 12**



Suspicious cell
in S12

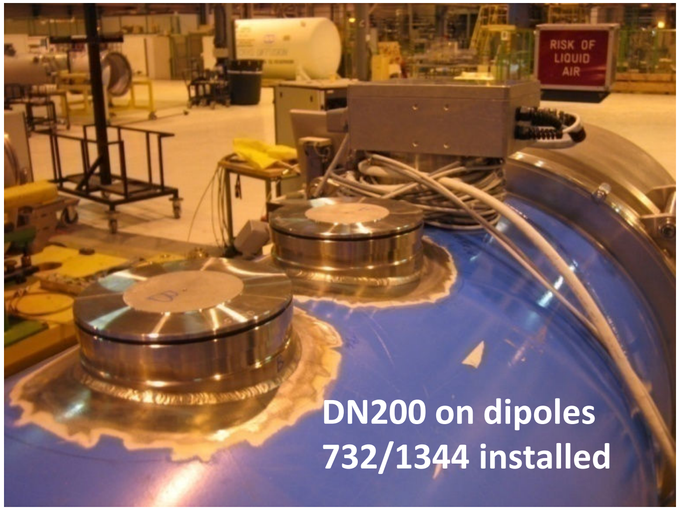
"Snapshots" analysis: inner magnet splices

sensitivity ~10nΩ

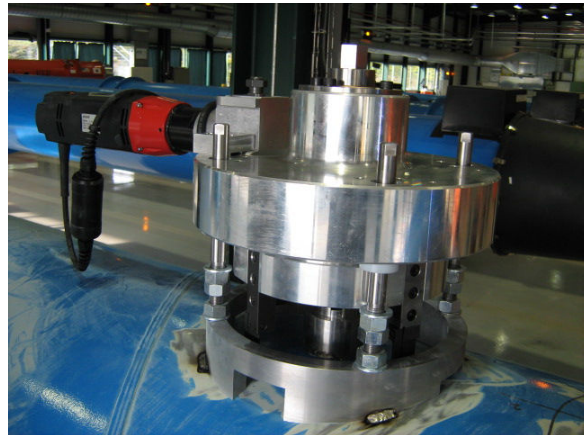


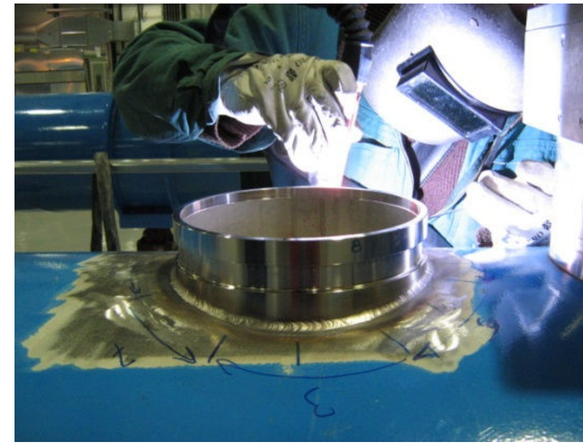
Plus data "mining" of cold test data in SM18 (PH collaboration), limit ~30nΩ

Cryostats protection and anchoring



DN200 on dipoles
732/1344 installed



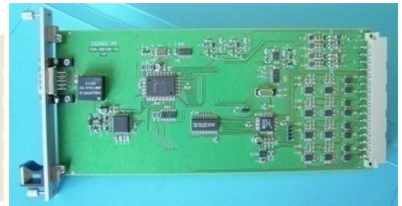


SSS anchoring
104/104 installed

The new Quench Protection System

DQQTE board for ground voltage detection

(total 1308 boards, 3 units/crate

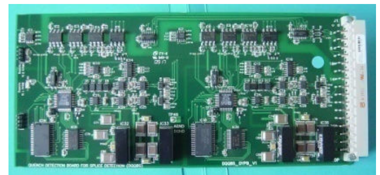


DQAMG-type S controller board

1 unit / crate, total 436 units

DQLPUS Power Packs

2 units / rack (total 872 units)

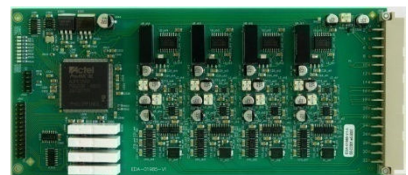


DQQBS board for busbar splice detection

5 such boards / crate, total 2180 units

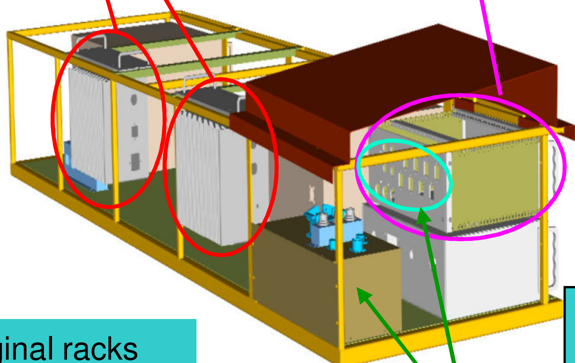
DQLPU-type S crate

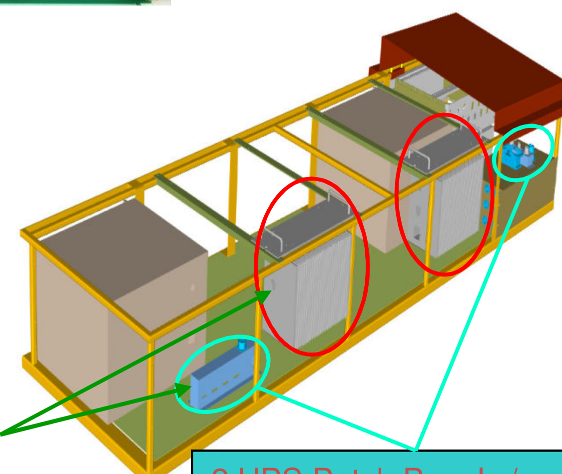
total 436 units



DQQDS board for SymQ detection

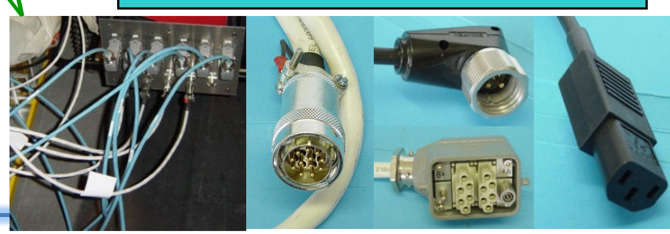
4 boards / crate, total 1744





'Internal' and 'external' **cables** for sensing, trigger, interlock, UPS power, uFIP (10'400 + 4'400)

Original racks



2 UPS Patch Panels / rack &
1 Trigger Patch Panel / rack
total 3456 panel boxes

First results from SC-BB splice measurements