



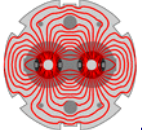
LHC status and commissioning

- Sector 34 incident – present understanding
- Picking up the pieces
- Making sure it doesn't happen again
- Schedule before beam
- Schedule 2009-2010
- Re-commissioning with beam
- 2009 – 2010 run

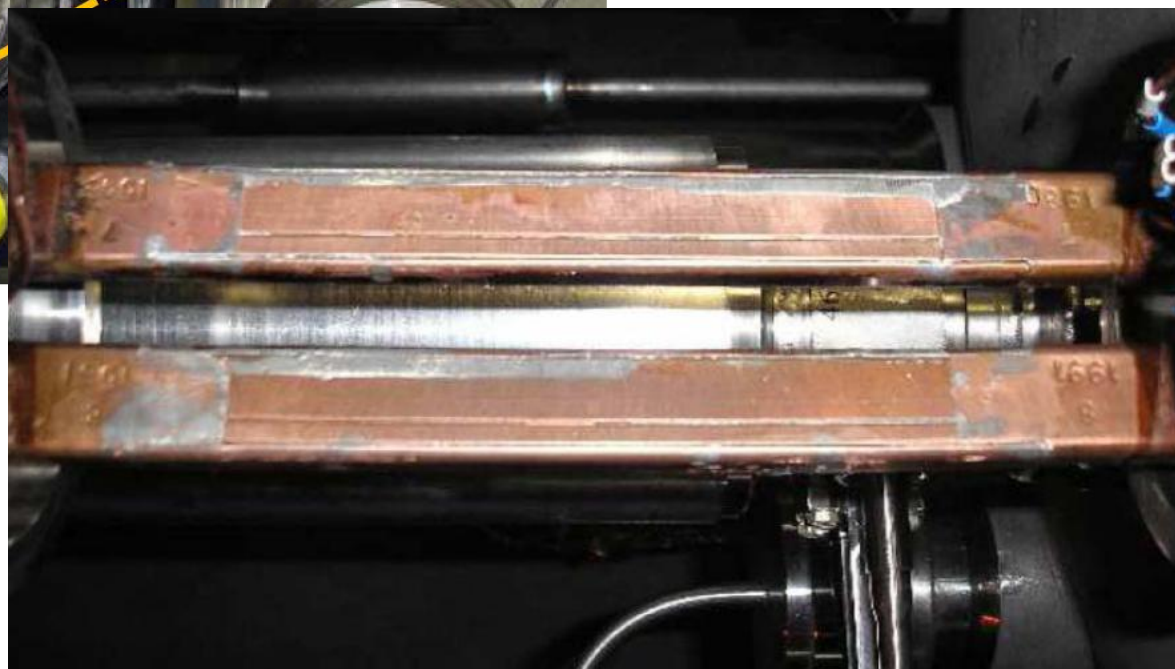
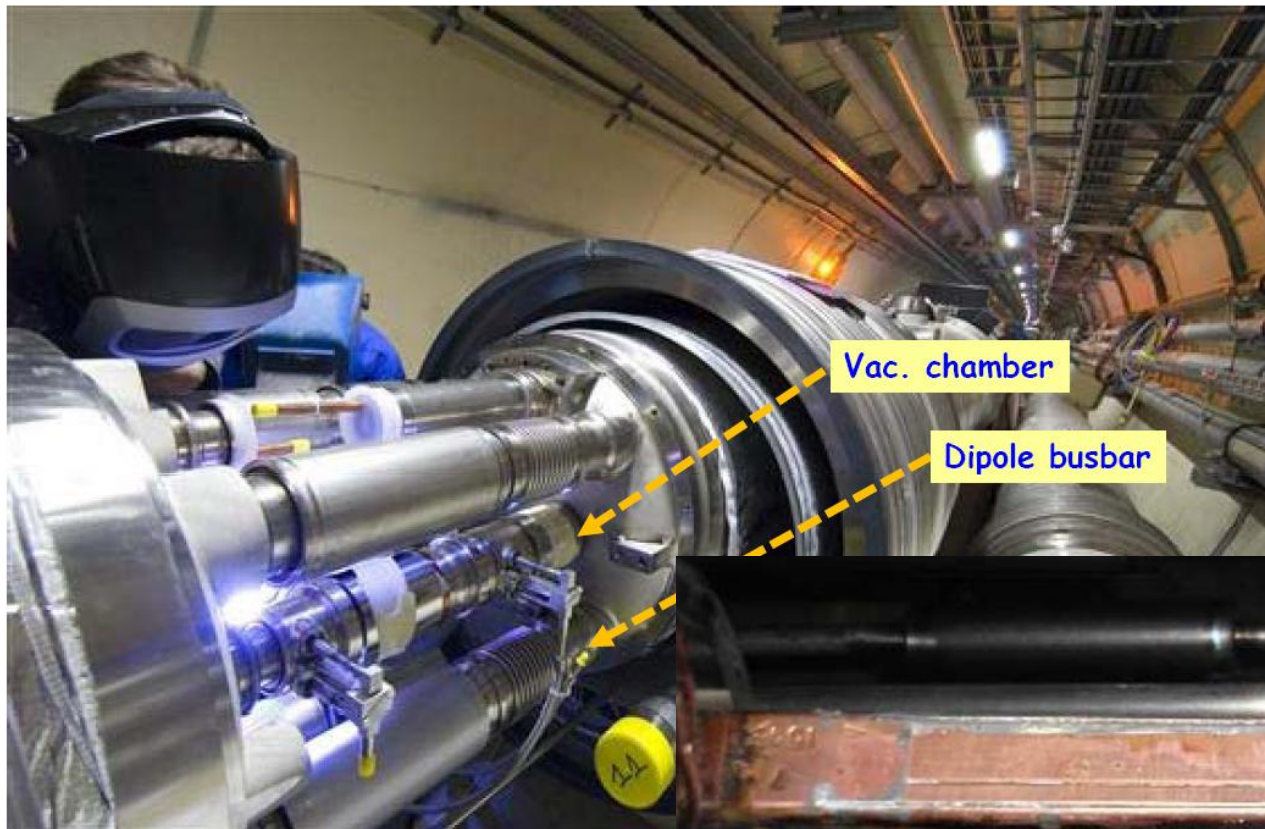
Mike Lamont



1. What went wrong

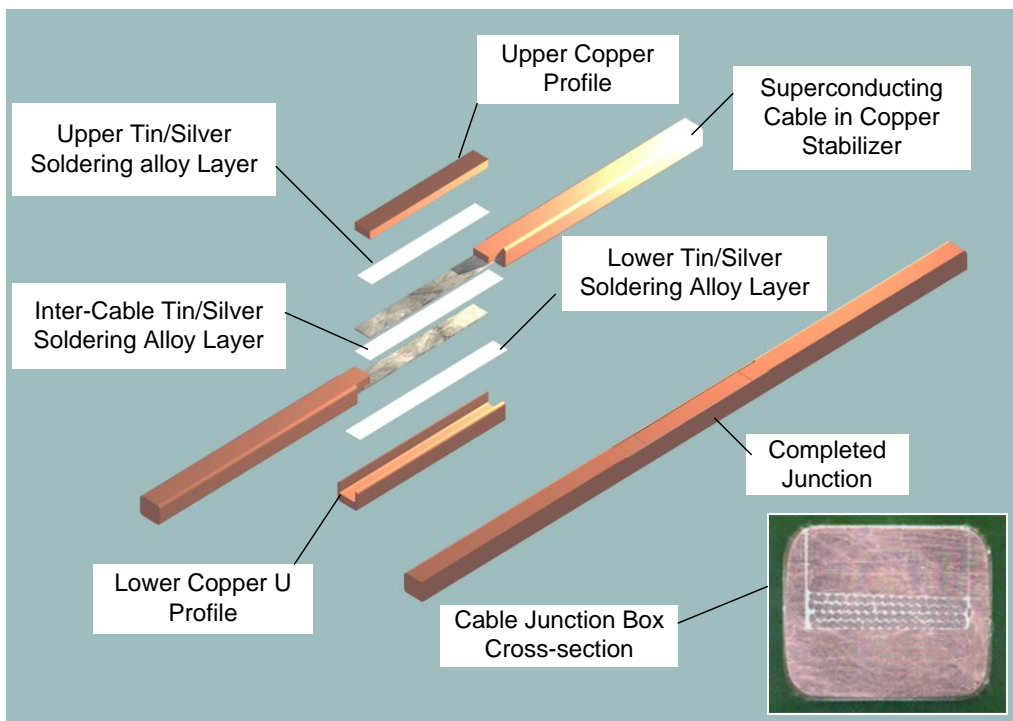


Ruptured bus-bar interconnection





Electrical joint in 12 kA bus bar



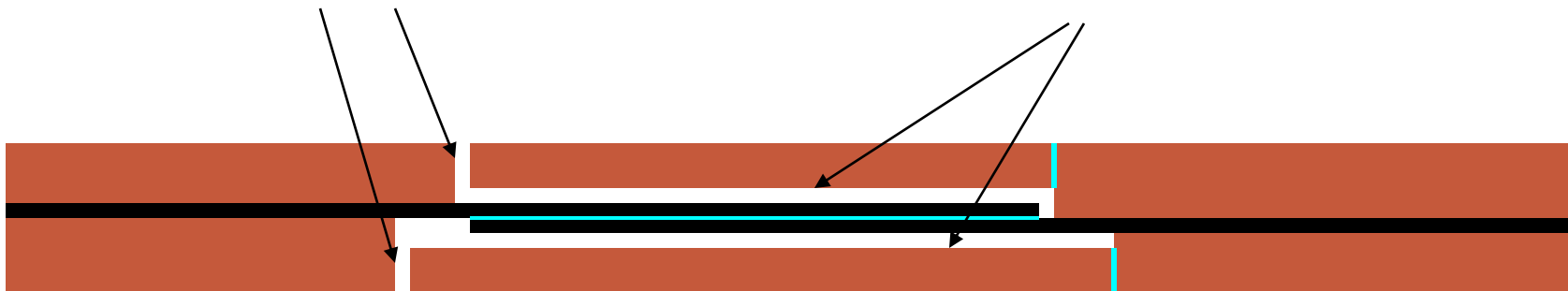
“What makes a good joint?”

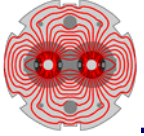
A. Verweij

A resistive joint of about $220 \text{ n}\Omega$ with bad electrical and thermal contacts with the stabilizer

No electrical contact between wedge and U-profile with the bus on at least 1 side of the joint

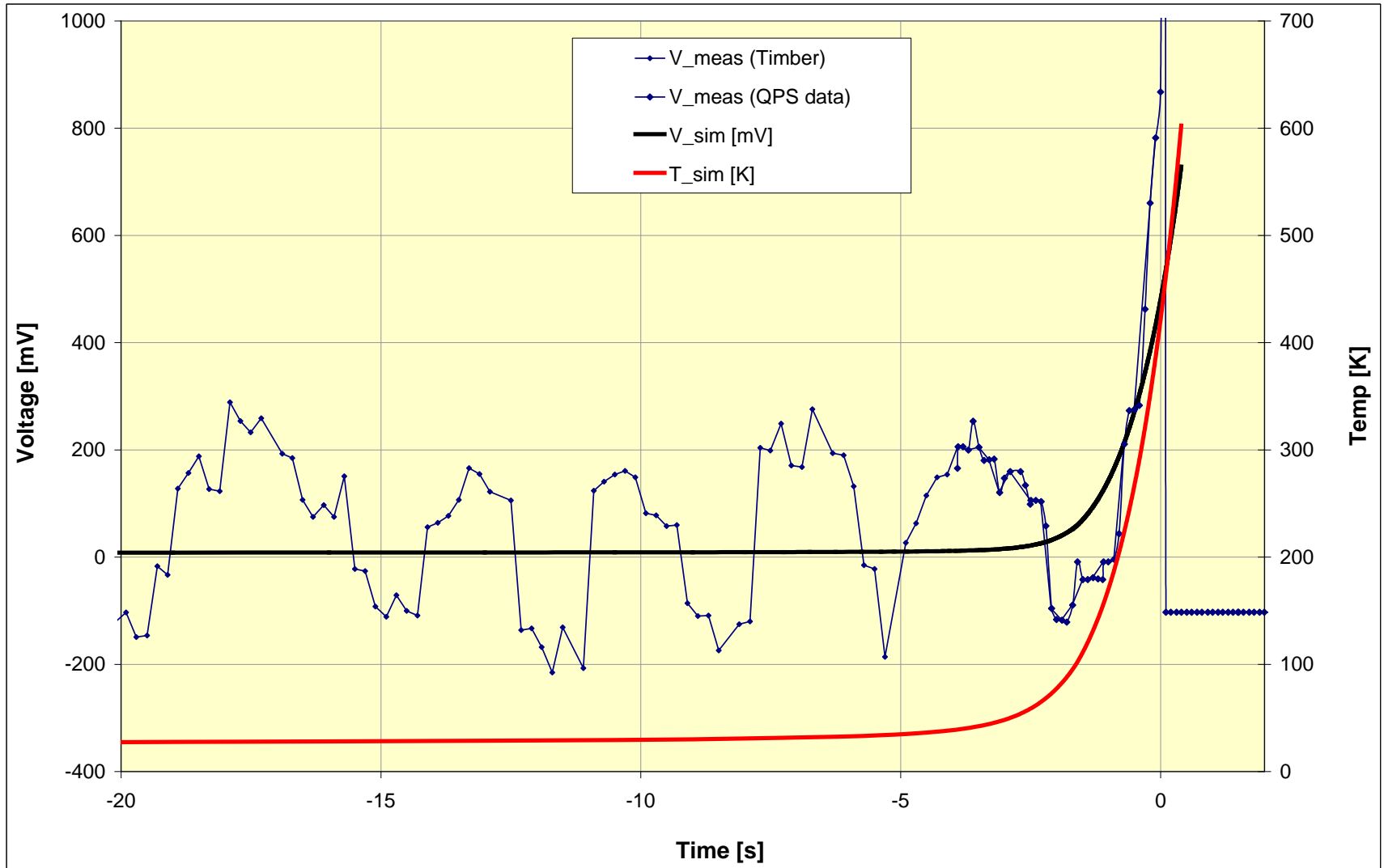
No bonding at joint with the U-profile and the wedge





Thermal runaway – model versus reality

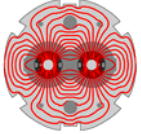
Voltage across the splice and temperature rise





2. Pick up the pieces

Message: huge amount of work required to repair the damage

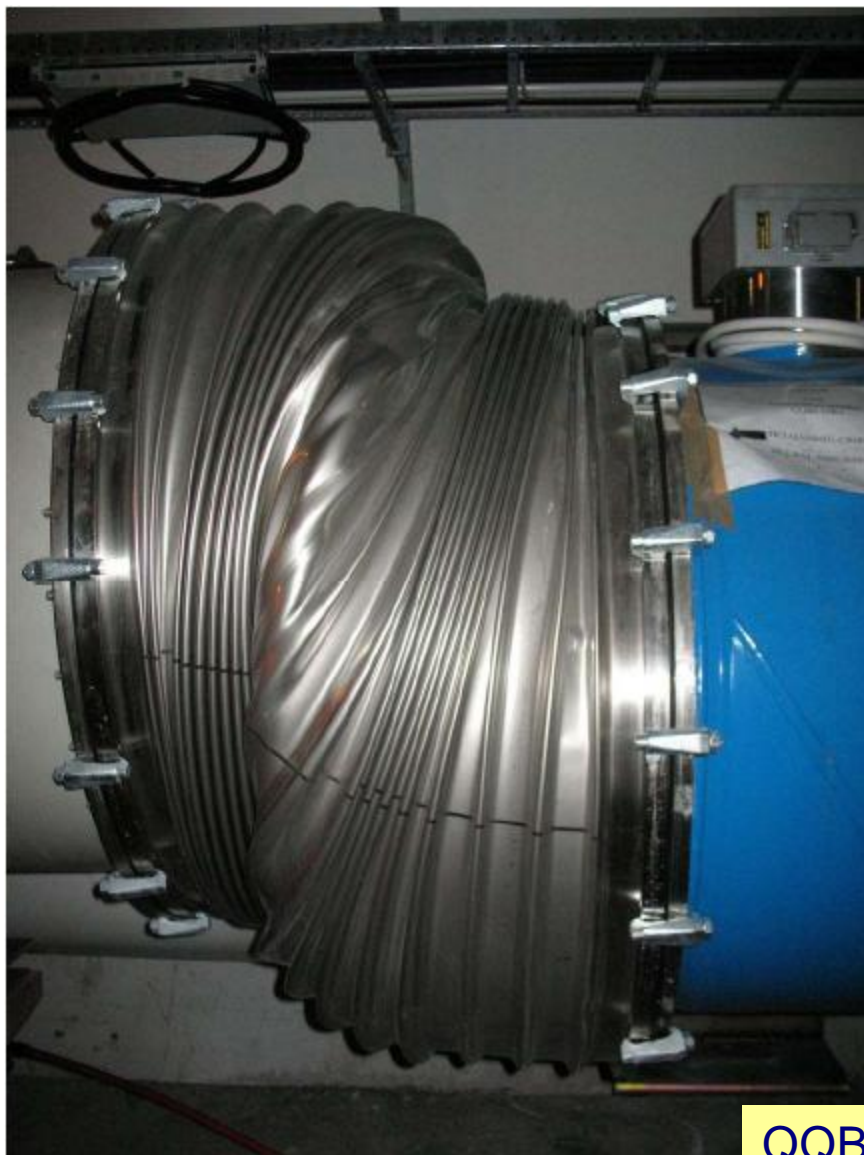


Fix the problem

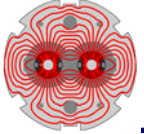
- Take all damaged magnets out
 - 53 total, 39 dipoles, 14 SSSs (Short Straight Section – quad++)
- Fix the cryogenics supply line
- Fix and clean the beam vacuum
- Repair the magnets
- Test repaired magnets and spares used
- Re-install
- Re-interconnect
- Cool
- Test



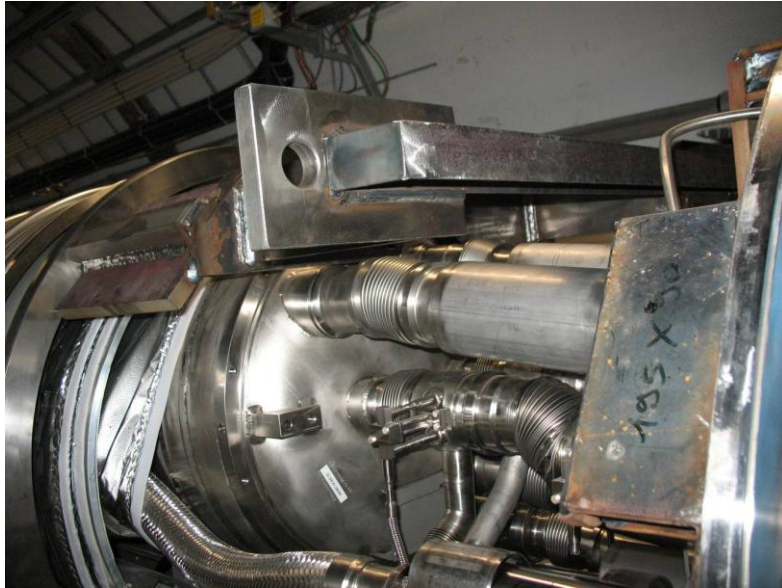
Damage: magnet displacements



QQBI.27R3



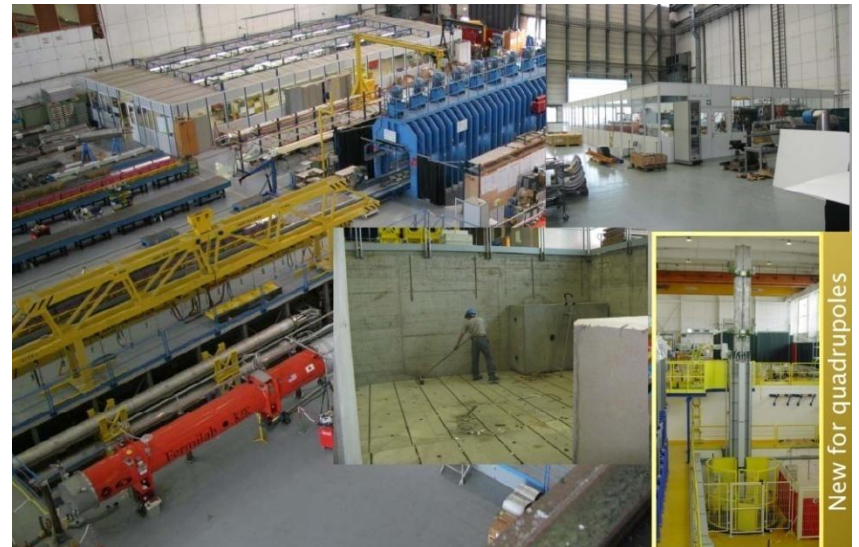
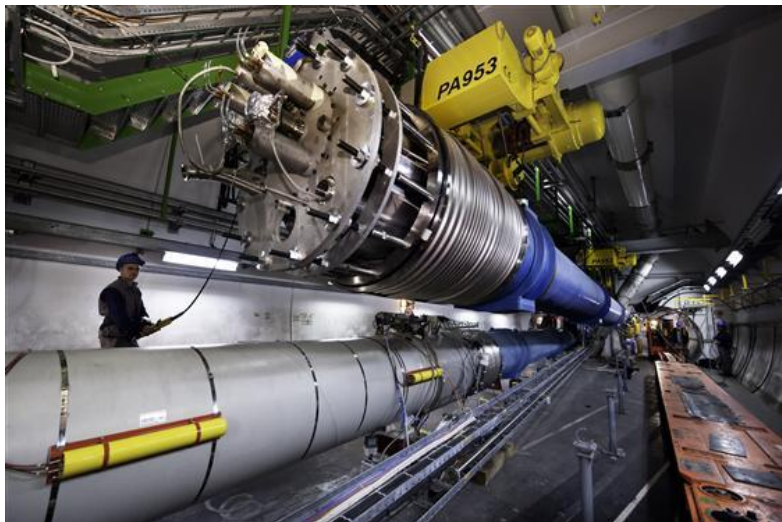
Remove and repair



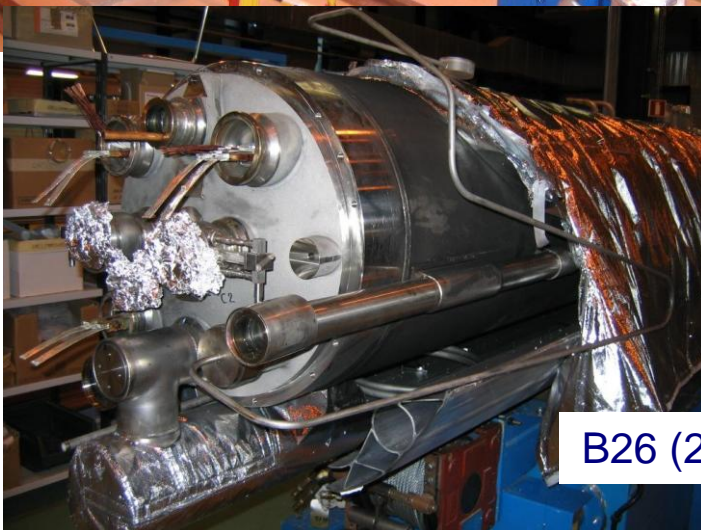
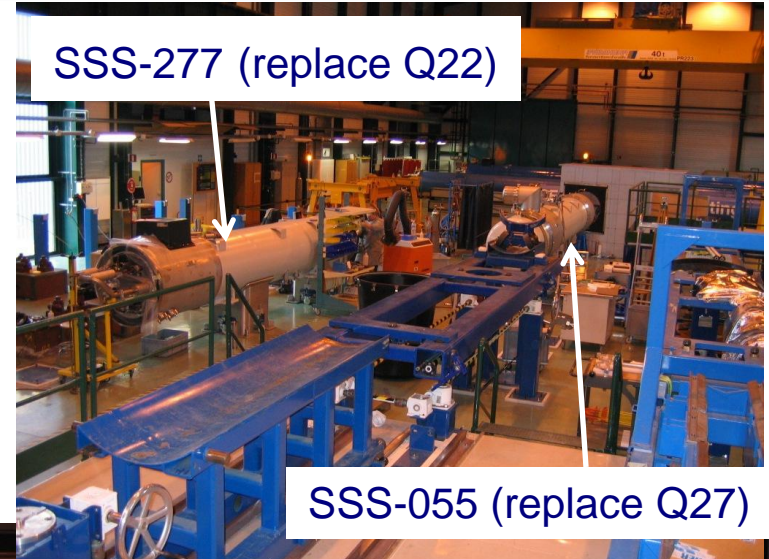
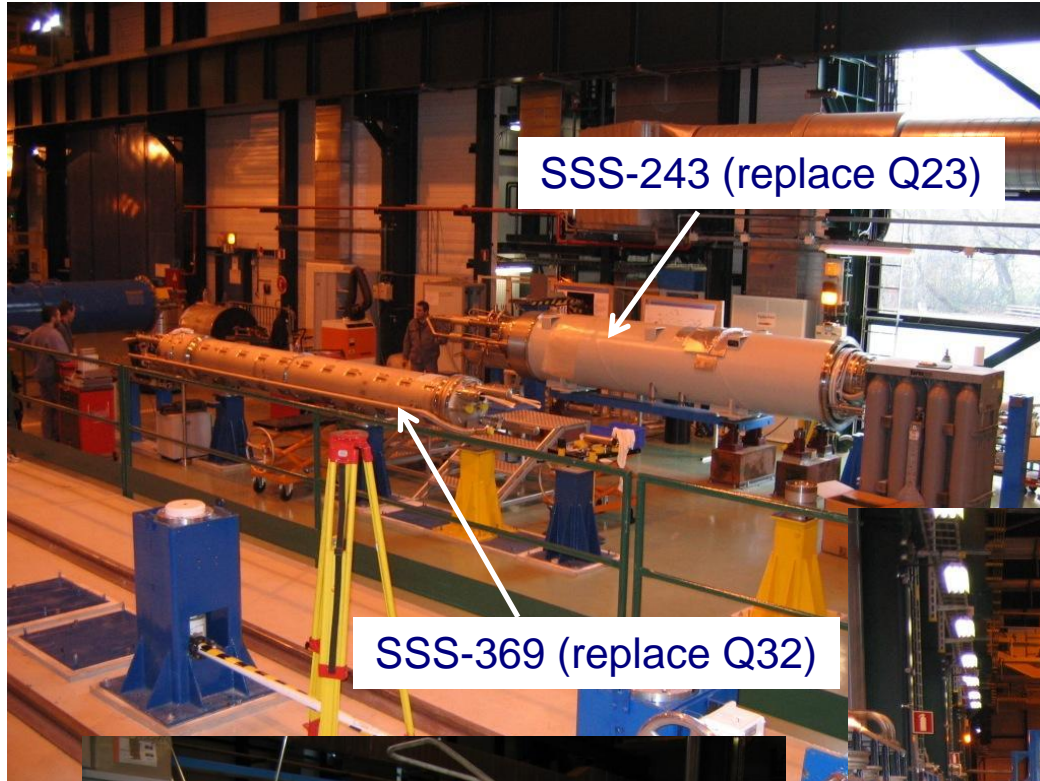
Remove damaged magnets

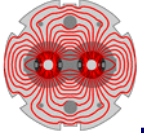


Preparation of recovery facilities

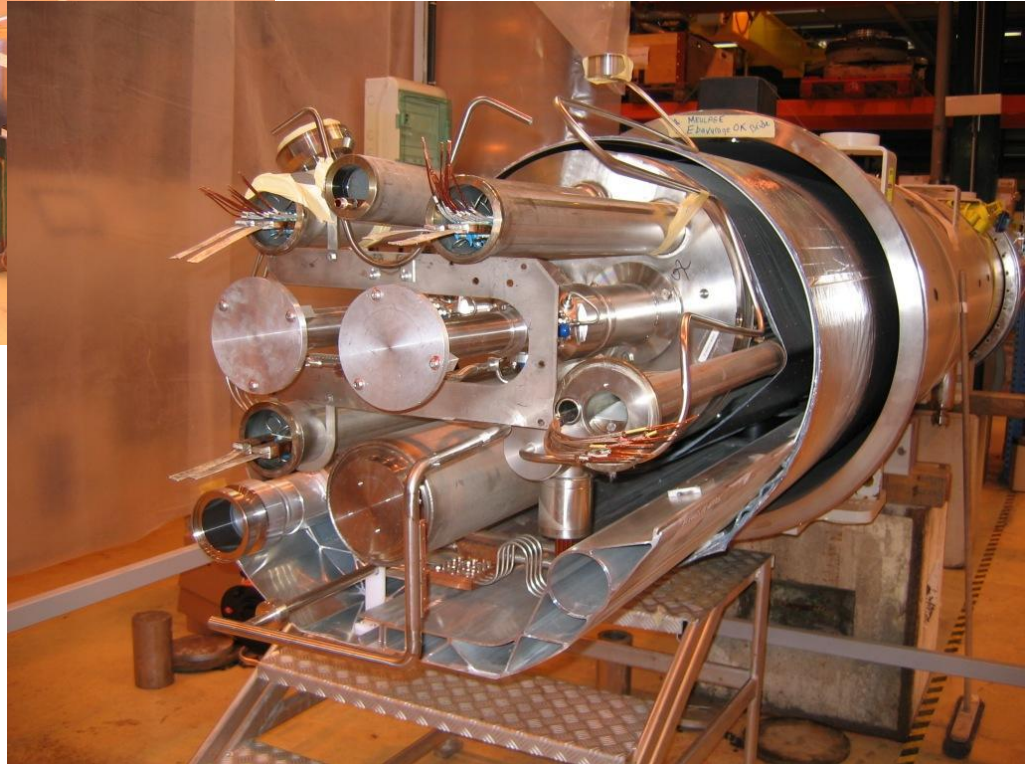


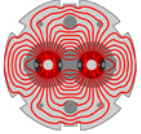
New for quadrupoles





Q32 SSS-200: under de-cryostating with Q31 and Q29





SMA18



A22 (1085)/ B22 (3118) / C22 (1071): under preparation for cold testing

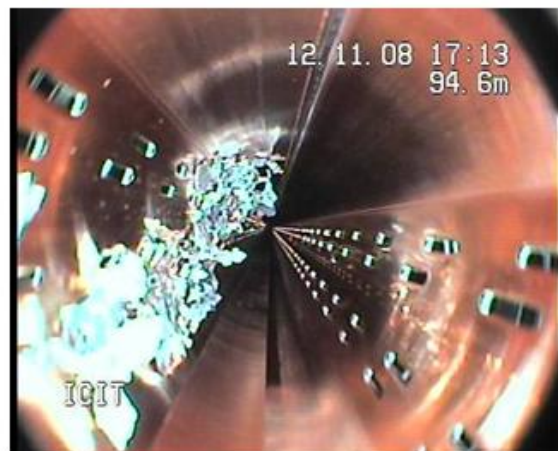


Beam Vacuum cleaning

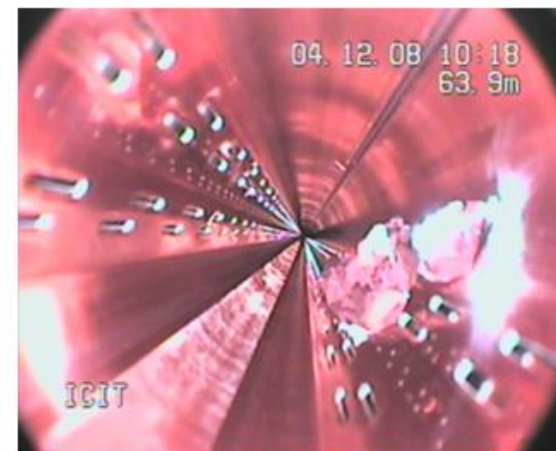
Beam Screens with MLI and Fibers



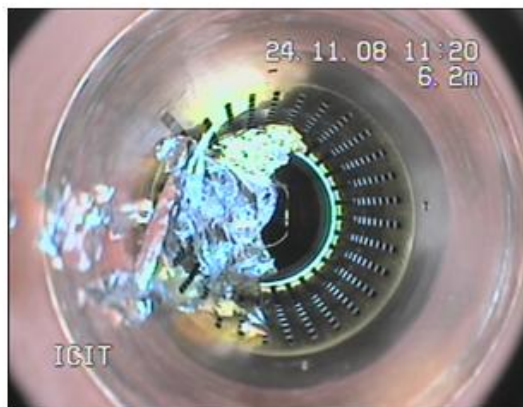
QBQI 8L4.V2



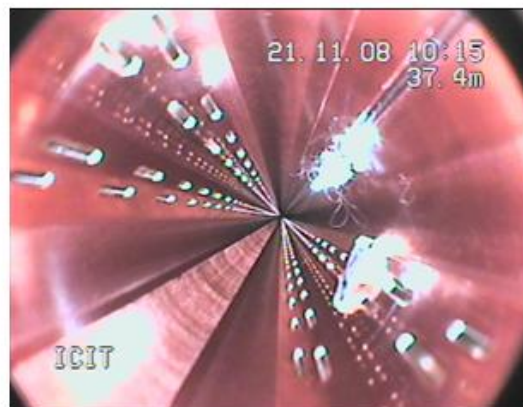
A10L4.V2



B9R3.V1



QBQI 14L4.V2



A13L4.V1



QBQI 12L4.V1



Beam Vacuum Contamination – S34

Point 3

mag.d	Inter. number	Element	BS V1	BS V2
	QDBI.7F3	Q7F3	MLI	MLI
	QDBI.7F3	Q7F3	MLI	MLI
217	QDBI.8F3	A8F3	MLI	MLI
3077	QDBI.8F3	B8F3	DUST	MLI
	QDBI.8F3	C8F3	DUST	MLI
2127	QDBI.9F3	A9F3	DUST	ok
2178	QDBI.9F3	B9F3	MLI	MLI
	QDBI.9F3	C9F3	DUST	ok
2073	QDBI.10F3	A10F3	MLI	ok
2178	QDBI.10F3	B10F3	DUST	ok
	QDBI.10F3	C10F3	DUST	ok
2172	QDBI.11F3	A11F3	MLI	MLI
1106	QDBI.11F3	B11F3	DUST	ok
0001	QDBI.11F3	C11F3	DUST	ok
	QDBI.11F3	D11F3	ok	DUST
2092	QDBI.12F3	A12F3	DUST	DUST
2173	QDBI.12F3	C12F3	ok	ok
0196	QDBI.12F3	D12F3	ok	ok
3088	QDBI.13F3	A13F3	DUST	DUST
1753	QDBI.13F3	B13F3	ok	DUST
2089	QDBI.13F3	C13F3	DUST	DUST
0277	QDBI.13F3	D13F3	DUST	DUST
1033	QDBI.14F3	A14F3	ok	DUST
1124	QDBI.14F3	B14F3	DUST	DUST
3401	QDBI.14F3	C14F3	DUST	DUST
0213	QDBI.14F3	D14F3	ok	DUST
1166	QDBI.15F3	A15F3	MLI	DUST
1064	QDBI.15F3	B15F3	ok	DUST
2059	QDBI.15F3	C15F3	ok	DUST
0225	QDBI.15F3	D15F3	ok	DUST
2096	QDBI.16F3	A16F3	ok	DUST
2185	QDBI.16F3	B16F3	ok	ok
2123	QDBI.16F3	C16F3	ok	DUST
0216	QDBI.16F3	D16F3	ok	ok
3155	QDBI.17F3	A17F3	ok	DUST
1181	QDBI.17F3	B17F3	ok	DUST
1113	QDBI.17F3	C17F3	ok	DUST
0218	QDBI.17F3	D17F3	ok	DUST
2080	QDBI.18F3	A18F3	ok	DUST
1147	QDBI.18F3	B18F3	ok	DUST
2083	QDBI.18F3	C18F3	ok	DUST
0197	QDBI.18F3	D18F3	ok	DUST
3176	QDBI.19F3	A19F3	ok	DUST
0391	QDBI.19F3	B19F3	ok	soot
3089	QDBI.19F3	C19F3	ok	soot
	QDBI.19F3	D19F3	ok	soot

MLI

~ OK

SOOT

* MLI :

DFBAR3 => A10R3

* ~ OK :

B10R 3 => A19R3

* Soot :

B

V.B

3152	QDBI.20F3	A20F3	ok	soot
110	QDBI.20F3	B20F3	ok	soot
2054	QDBI.20F3	C20F3	ok	soot
0195	QDBI.20F3	D20F3	ok	soot
2035	QDBI.21F3	A21F3	ok	soot
1092	QDBI.21F3	B21F3	ok	soot
1099	QDBI.21F3	C21F3	ok	soot
0225	QDBI.21F3	D21F3	ok	soot
1085	QDBI.22F3	A22F3	ok	soot
3118	QDBI.22F3	B22F3	ok	soot
1071	QDBI.22F3	C22F3	soot	soot
0203	QDBI.22F3	D22F3	soot	soot
1236	QDBI.23F3	A23F3	soot	soot
2193	QDBI.23F3	B23F3	soot	soot
1109	QDBI.23F3	C23F3	soot	hole
0233	QDBI.23F3	D23F3	soot	soot
1241	QDBI.24F3	A24F3	soot	soot
2055	QDBI.24F3	B24F3	soot	soot
3110	QDBI.24F3	C24F3	soot	soot
0189	QDBI.24F3	D24F3	soot	soot
1132	QDBI.25F3	A25F3	soot	soot
1084	QDBI.25F3	B25F3	soot	soot
3036	QDBI.25F3	C25F3	soot	soot
0219	QDBI.25F3	D25F3	soot	soot
1242	QDBI.26F3	A26F3	soot	soot
2111	QDBI.26F3	B26F3	soot	soot
2100	QDBI.26F3	C26F3	soot	soot
0208	QDBI.26F3	D26F3	soot	soot
2043	QDBI.27F3	A27F3	soot	soot
1089	QDBI.27F3	B27F3	soot	soot
1235	QDBI.27F3	C27F3	soot	soot
0220	QDBI.27F3	D27F3	soot	soot

SOOT

Plus

- Cryogenic Supply Line
- Beam Instrumentation
- Civil engineering
- Quench Protection system
- etc..

2103	QDBI.33F3	A33F3	MLI	ok
2182	QDBI.33F3	B33F3	MLI	ok
2189	QDBI.33F3	C33F3	MLI	ok
0227	QDBI.33F3	D33F3	MLI	ok
2177	QDBI.34F3	A34F3	MLI	MLI
1100	QDBI.34F3	B34F3	ok	ok
0146	QDBI.34F3	C34F3	ok	ok
0202	QDBI.34L4	C34L4	ok	ok
2121	QDBI.34L4	C34L4	ok	ok
1152	QDBI.34L4	C34L4	ok	ok
0220	QDBI.33L4	C33L4	MLI	MLI
2101	QDBI.33L4	C33L4	MLI	ok
1183	QDBI.33L4	C33L4	MLI	ok
1178	QDBI.33L4	A33L4	MLI	ok
0207	QDBI.32L4	C32L4	MLI	MLI
2084	QDBI.32L4	C32L4	MLI	ok
3080	QDBI.32L4	B32L4	MLI	ok
1146	QDBI.32L4	A32L4	MLI	ok
0191	QDBI.31L4	C31L4	MLI	MLI
1091	QDBI.31L4	C31L4	MLI	ok
2106	QDBI.31L4	B31L4	MLI	MLI
1249	QDBI.31L4	A31L4	MLI	MLI
0220	QDBI.30L4	C30L4	MLI	MLI
1111	QDBI.30L4	C30L4	MLI	ok
1065	QDBI.30L4	B30L4	MLI	MLI
2067	QDBI.30L4	A30L4	MLI	MLI
0222	QDBI.29L4	C29L4	MLI	MLI
1087	QDBI.29L4	C29L4	MLI	MLI
1238	QDBI.29L4	B29L4	MLI	MLI
3142	QDBI.29L4	A29L4	MLI	MLI
0205	QDBI.28L4	C28L4	MLI	MLI

~ OK

MLI

2183	QDBI.23L4	C23L4	MLI	ok
0209	QDBI.22L4	C22L4	MLI	MLI
2105	QDBI.22L4	C22L4	MLI	ok
2087	QDBI.22L4	B22L4	MLI	MLI
1165	QDBI.22L4	A22L4	MLI	MLI
0226	QDBI.21L4	C21L4	MLI	MLI
3389	QDBI.21L4	C21L4	MLI	MLI
3125	QDBI.21L4	B21L4	MLI	MLI
1080	QDBI.21L4	A21L4	MLI	MLI
0214	QDBI.20L4	C20L4	ok	MLI
3089	QDBI.20L4	C20L4	MLI	MLI
1070	QDBI.20L4	B20L4	MLI	MLI
3151	QDBI.20L4	A20L4	MLI	MLI
0234	QDBI.19L4	C19L4	ok	MLI
2174	QDBI.19L4	C19L4	MLI	MLI
3085	QDBI.19L4	B19L4	ok	MLI
2079	QDBI.19L4	A19L4	MLI	MLI
0211	QDBI.18L4	C18L4	ok	MLI
2045	QDBI.18L4	C18L4	MLI	MLI
1089	QDBI.18L4	B18L4	MLI	MLI
2181	QDBI.18L4	A18L4	ok	MLI
0216	QDBI.17L4	C17L4	ok	MLI
2169	QDBI.17L4	C17L4	MLI	MLI
2110	QDBI.17L4	B17L4	MLI	MLI
3158	QDBI.17L4	A17L4	MLI	MLI
0193	QDBI.16L4	C16L4	MLI	MLI
2107	QDBI.16L4	B16L4	MLI	MLI
2097	QDBI.16L4	A16L4	MLI	MLI
1237	QDBI.16L4	A16L4	MLI	MLI
0206	QDBI.15L4	C15L4	MLI	MLI

MLI

2125	QDBI.10L4	B10L4	MLI	MLI
1145	QDBI.10L4	A10L4	MLI	MLI
0630	QDBI.9L4	C9L4	MLI	MLI
3108	QDBI.9L4	B9L4	MLI	MLI
2115	QDBI.9L4	A9L4	MLI	MLI
0629	QDBI.8L4	C8L4	MLI	MLI
2196	QDBI.8L4	B8L4	MLI	MLI
2091	QDBI.8L4	A8L4	MLI	MLI
0632	QDBI.7L4	C7L4	MLI	MLI
0631	QDBI.7L4	B7L4	MLI	MLI

MLI

Point 4

* ~ OK :

A32R 3 => B34L4

* MLI :

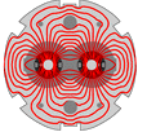
A34L4 => DFBAL4

Miguel Jimenez



3. Try and make sure it never happens again

1. Find any other bad splices
2. Improve protection
3. Reduce potential damage



Take remedial action

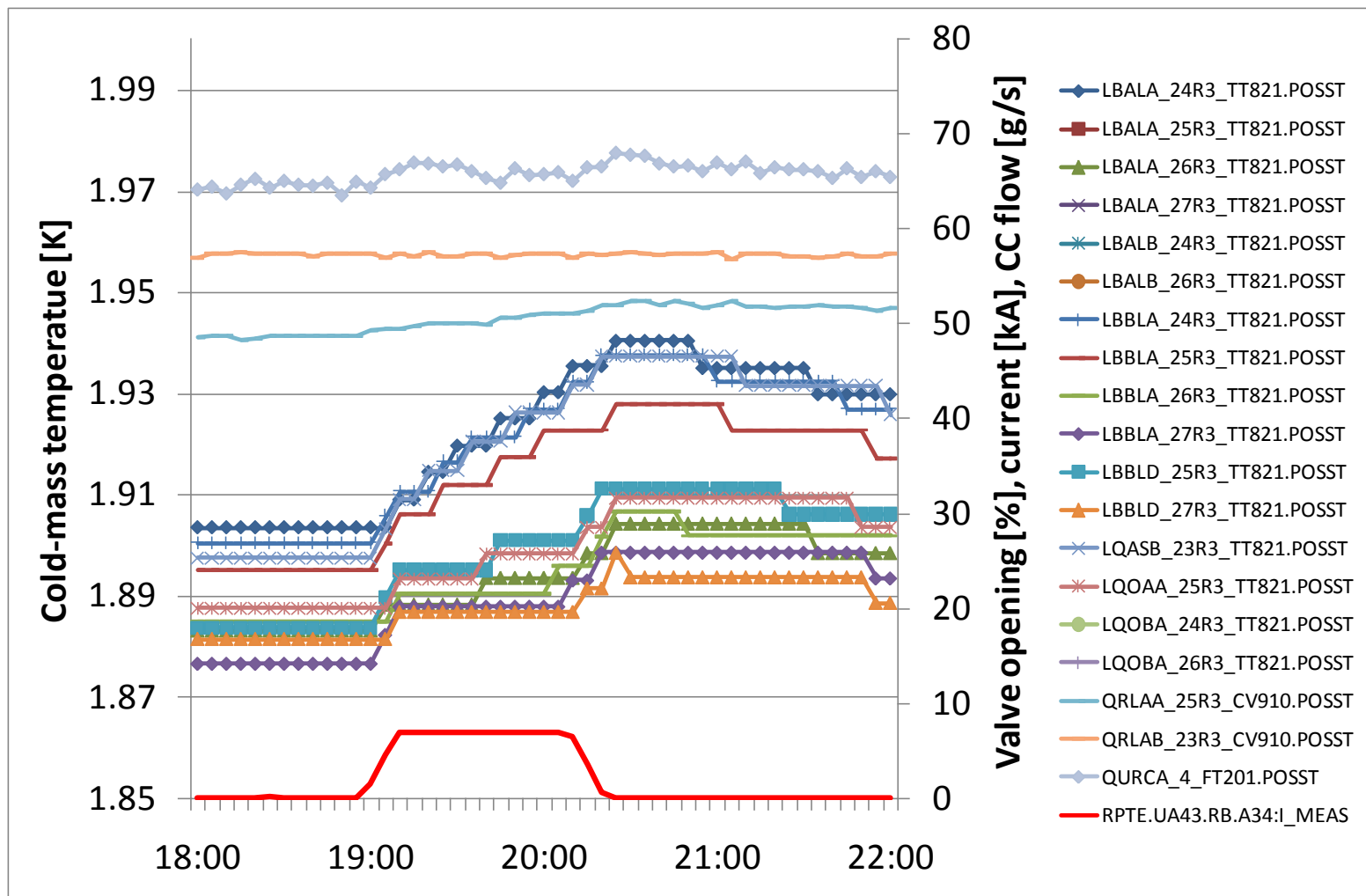
- Check all splices
 - QPS snapshot and calorimetry in situ (5/8 sectors)
 - Bus-bar splice resistance measurements by means of nano-voltmeters
 - Check old SM18 data
- Better protection
 - Extended QPS system – local rather than global bus-bar protection
- Minimize collateral damage
 - Anticipate Maximum Credible Incident (MCI)
 - New relief ports
 - New jacks

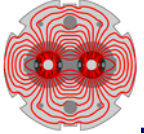


Calorimetry

Resistive heating of bad splices can be measured.

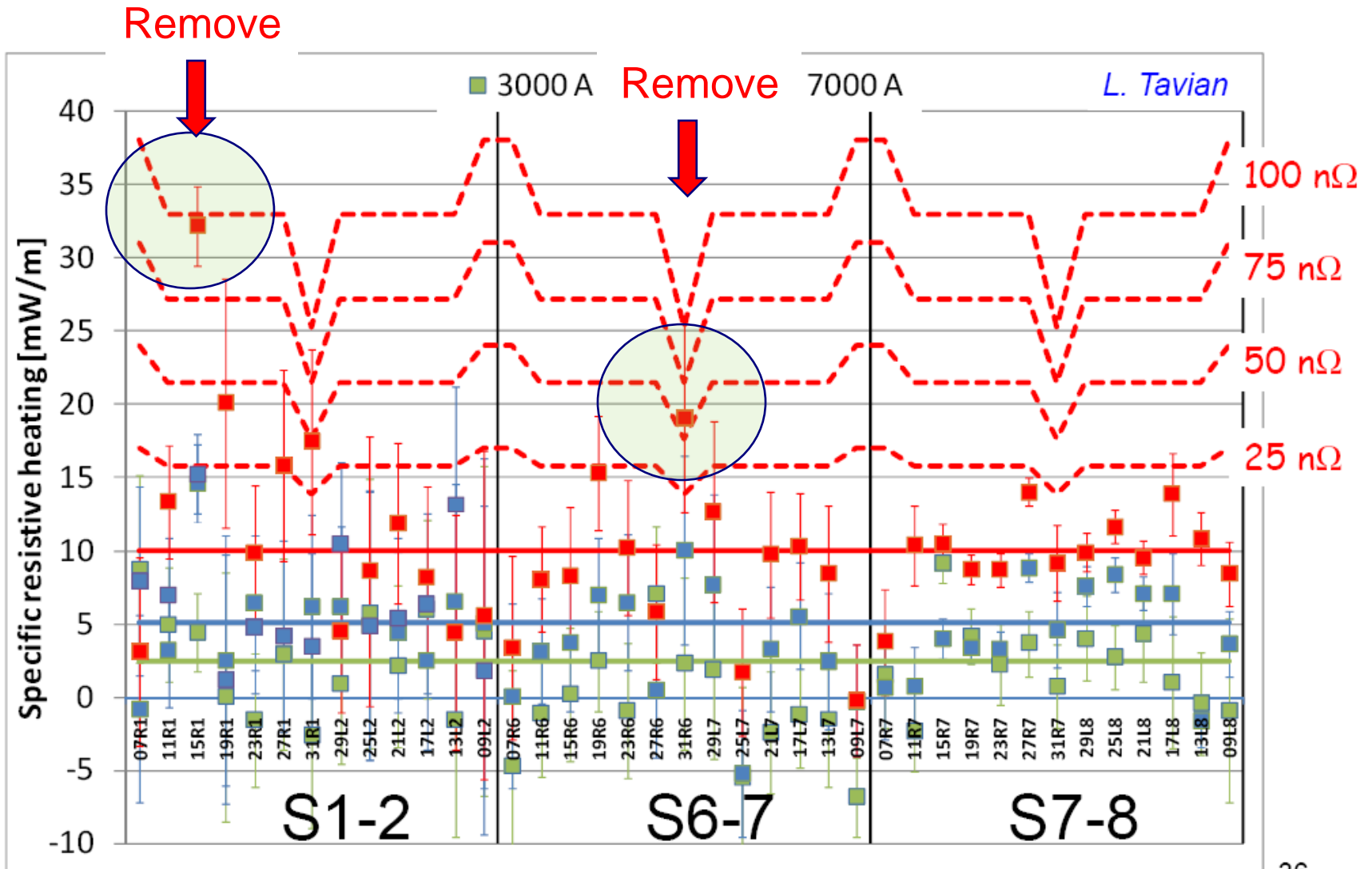
Temperature drift during 7 kA current flat top (15 Sep 2008)

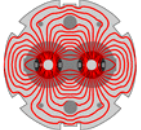




Calorimetry

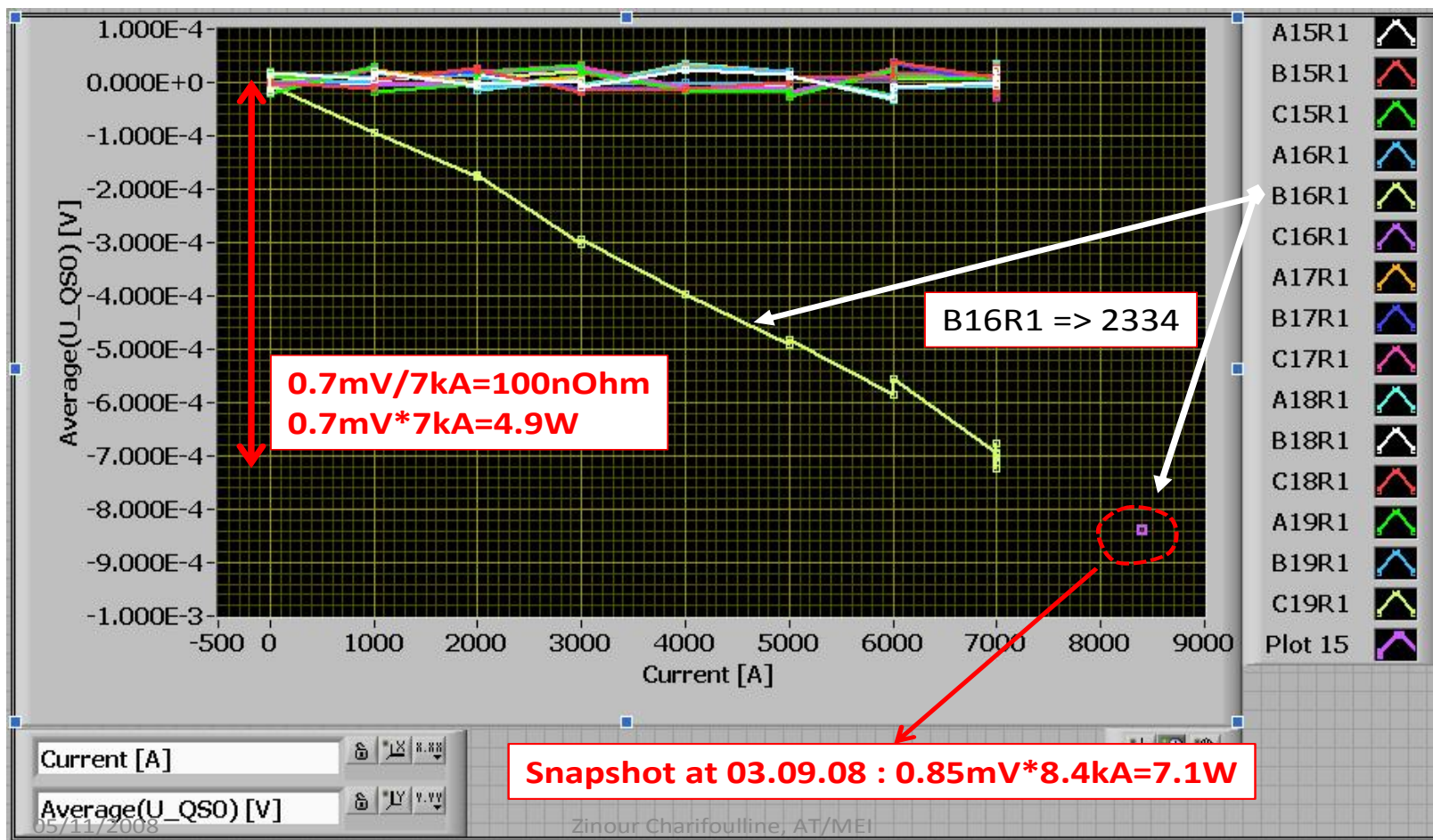
Measurements in cold sectors have revealed potential problems in splices inside magnets





QPS can also see "bad" splices

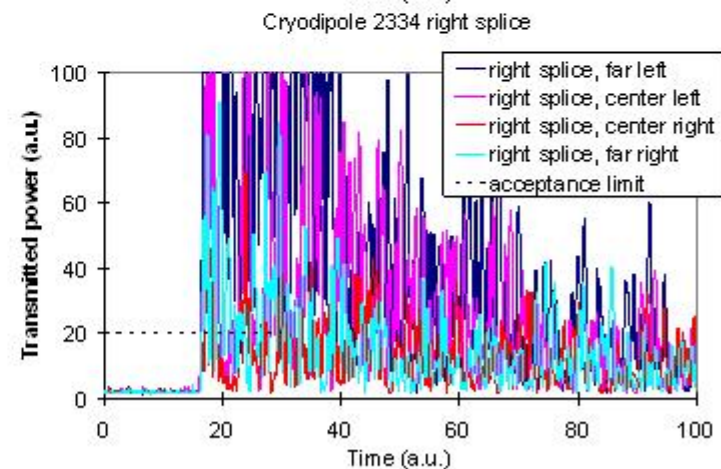
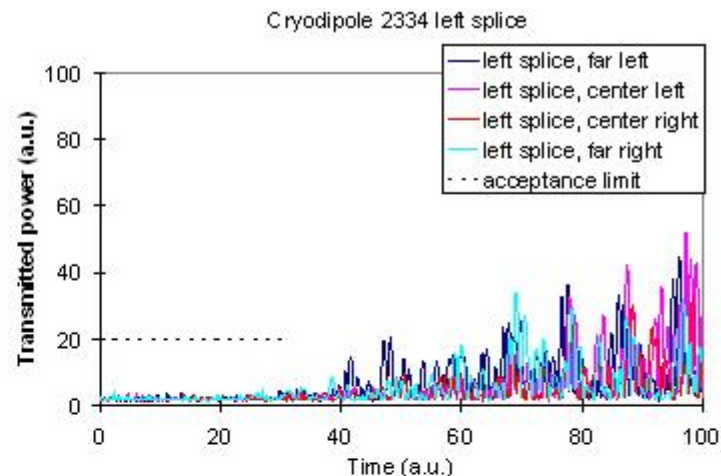
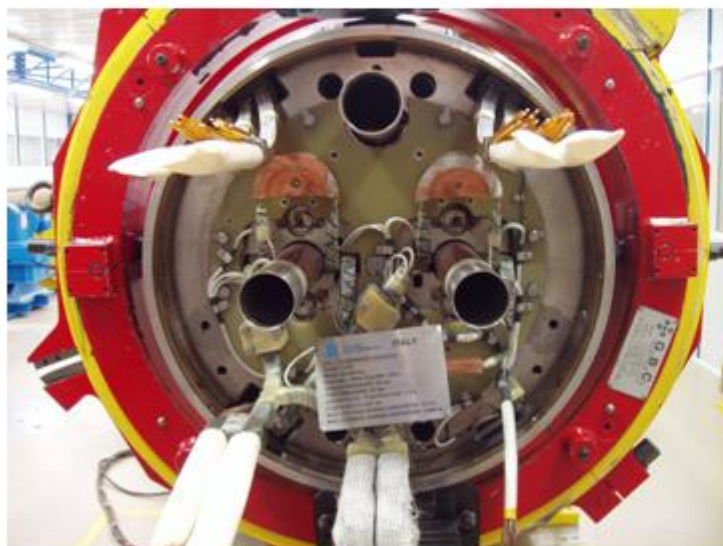
Sector A12: A15R1 – C19R1: Dipole Measurements made on 03.11.08





Ultrasound splices

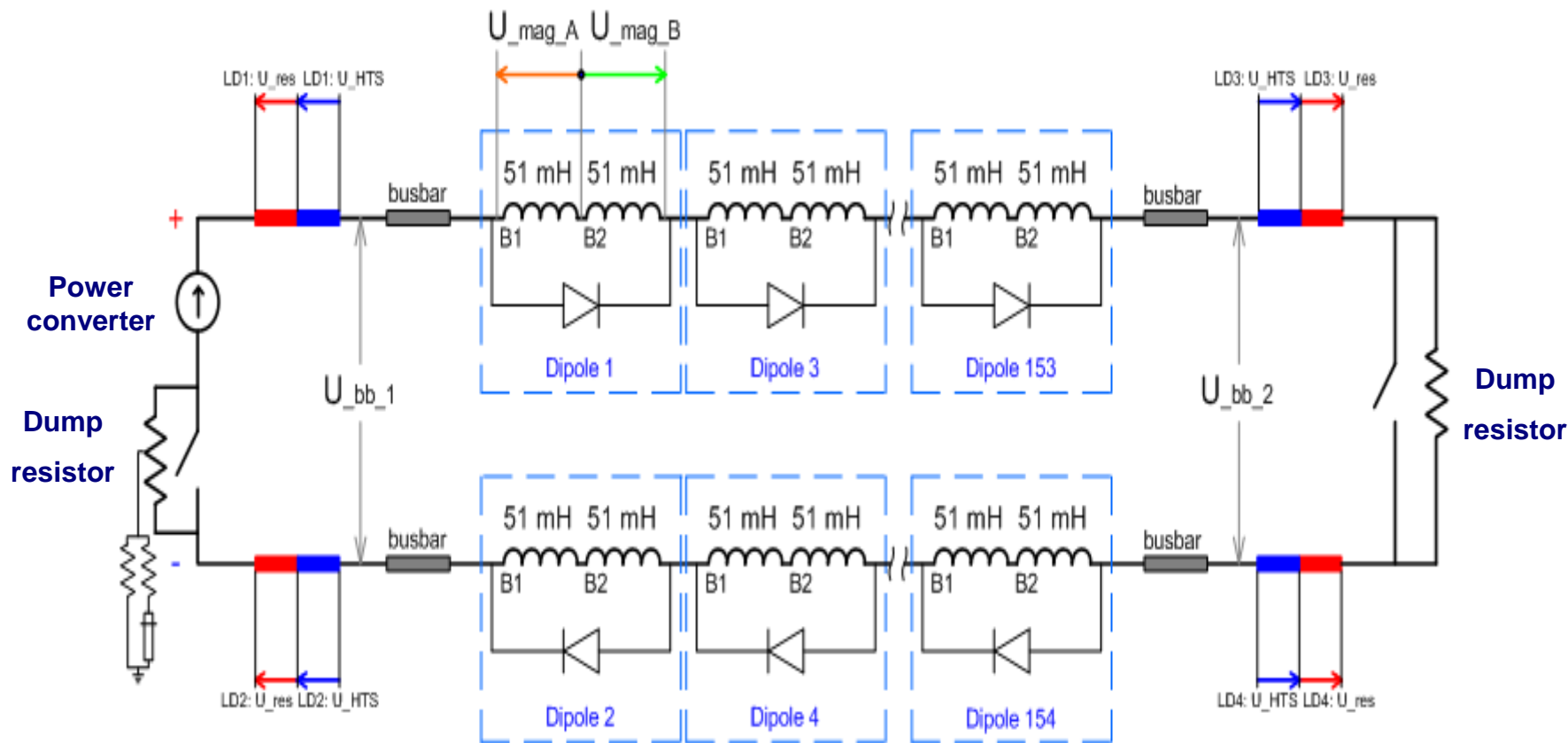
US inspection of defective inter-pole splice in MB 2334 has confirmed the US test to be a very useful QC tool.



Courtesy C. Scheurlein



Quench Detection

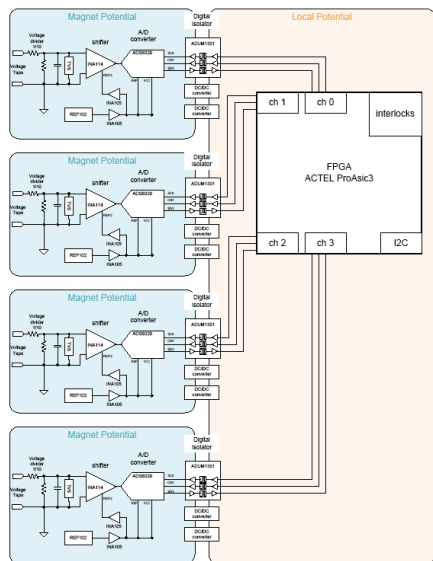


1. The quench is detected based on voltage measurements over the coils (U_{mag_A} , U_{mag_B}).
2. The energy is distributed over the entire magnet by force-quenching with quench heaters.
3. The power converter is switched off.
4. The current within the quenched magnet decays in < 200 ms, circuit current now flows through the 'bypass' diode that can stand the current for 100-200 s.
5. The circuit current/energy is discharged into the dump resistors.



Quench Protection System upgrade

- Upgrade required to cover:
 - local rather than global coverage of bus bars
 - symmetric quenches
- **Massive job**
 - New electronics
 - Massive cabling effort
- **QPS update is on the critical path for the re-start of LHC**



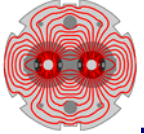
240 km of cables (= Chamonix – Venezia)

4400 individual cables

7800 connectors

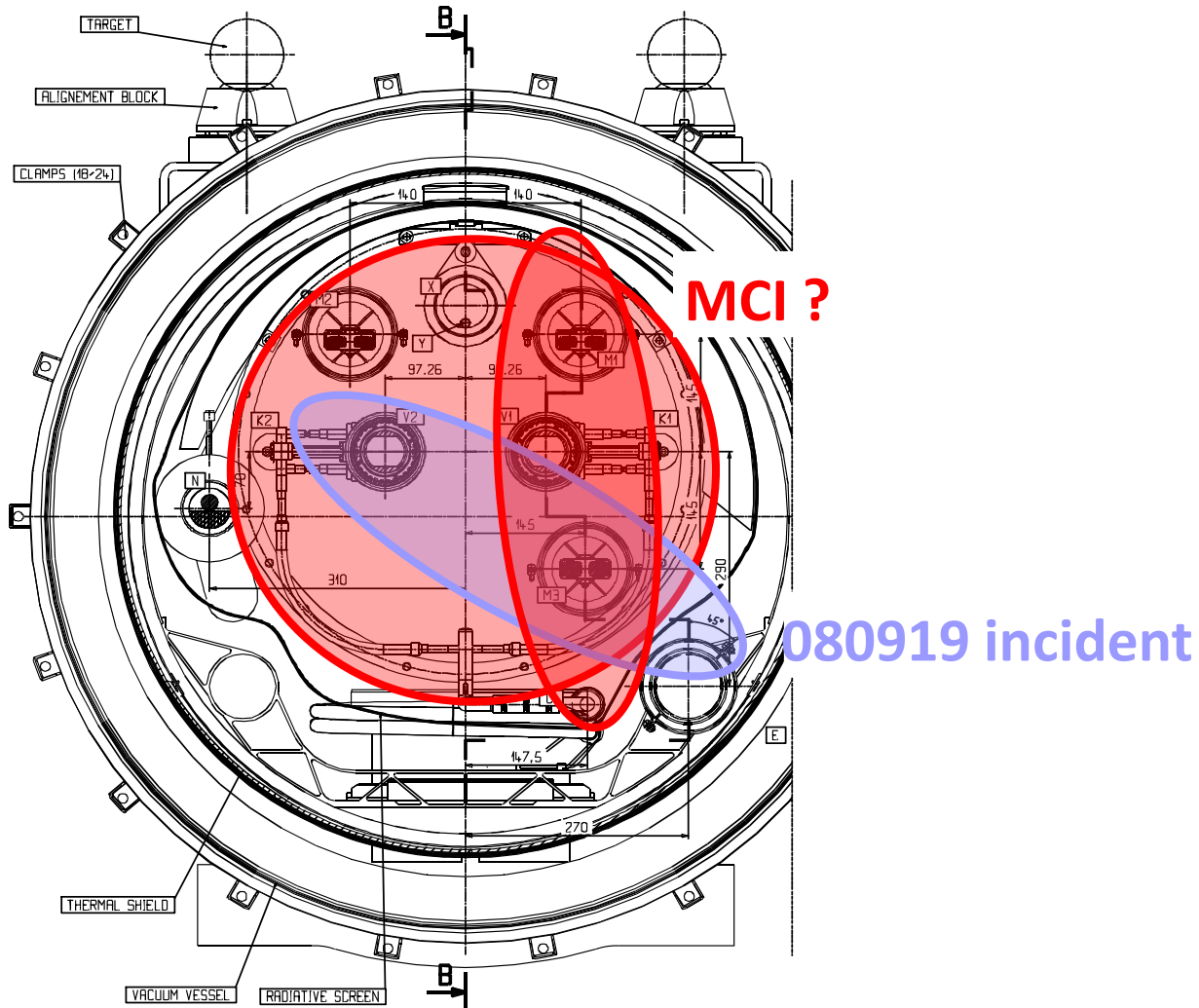
0 errors permitted





Maximum Credible Incident

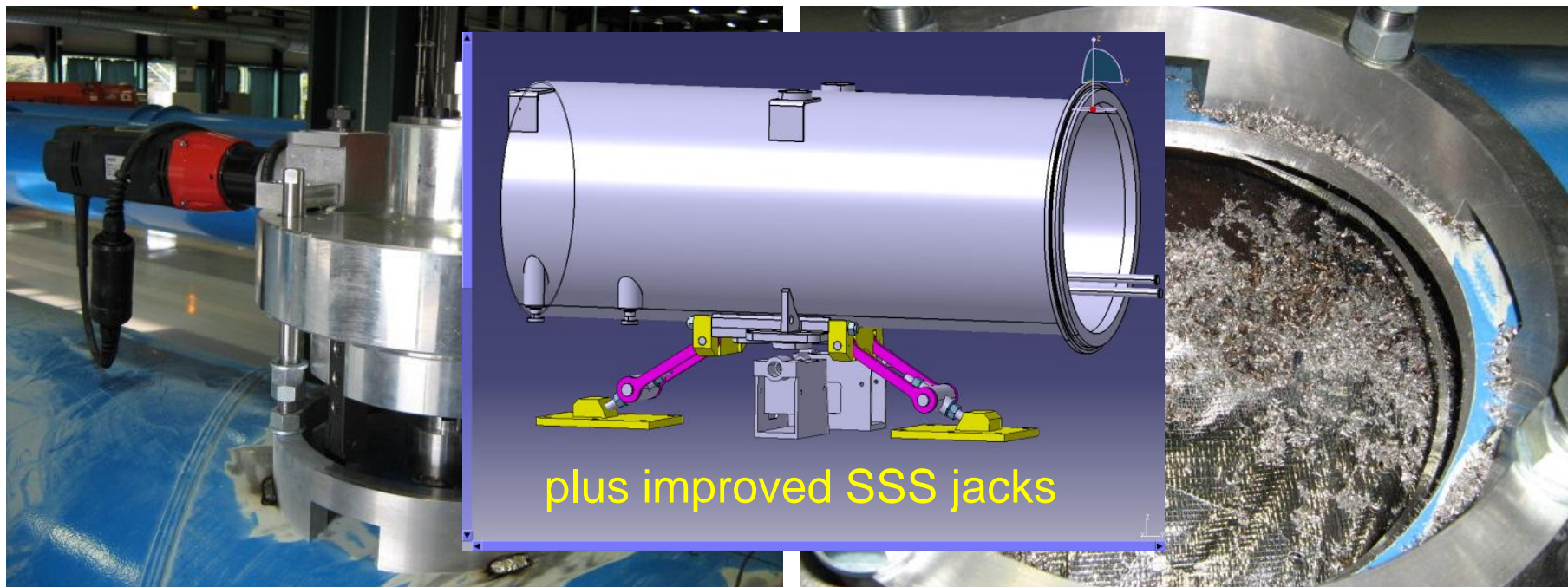
Alleviate knock-on effects - try and cater for the worst





Improved pressure relief

Additional relief valves on dipole vacuum enclosure



plus improved SSS jacks

- **Four warm sectors:** equip all dipoles with one DN200 flange and relief valve
- **Four cold sectors:** equip all SSS flanges with relief valves, fit relief valves on dipoles in 2010 shutdown

plus stand alone magnet and feed boxes

4. Schedule until beam

Message: There is a lot of work going on all around the ring:

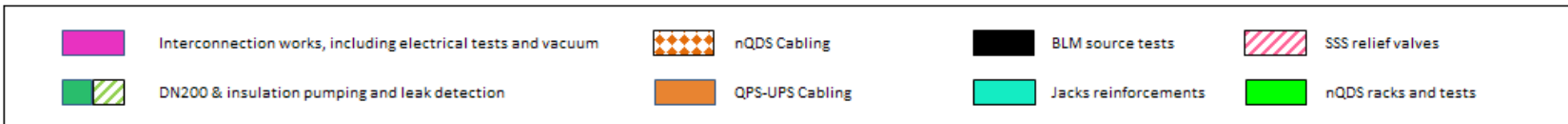
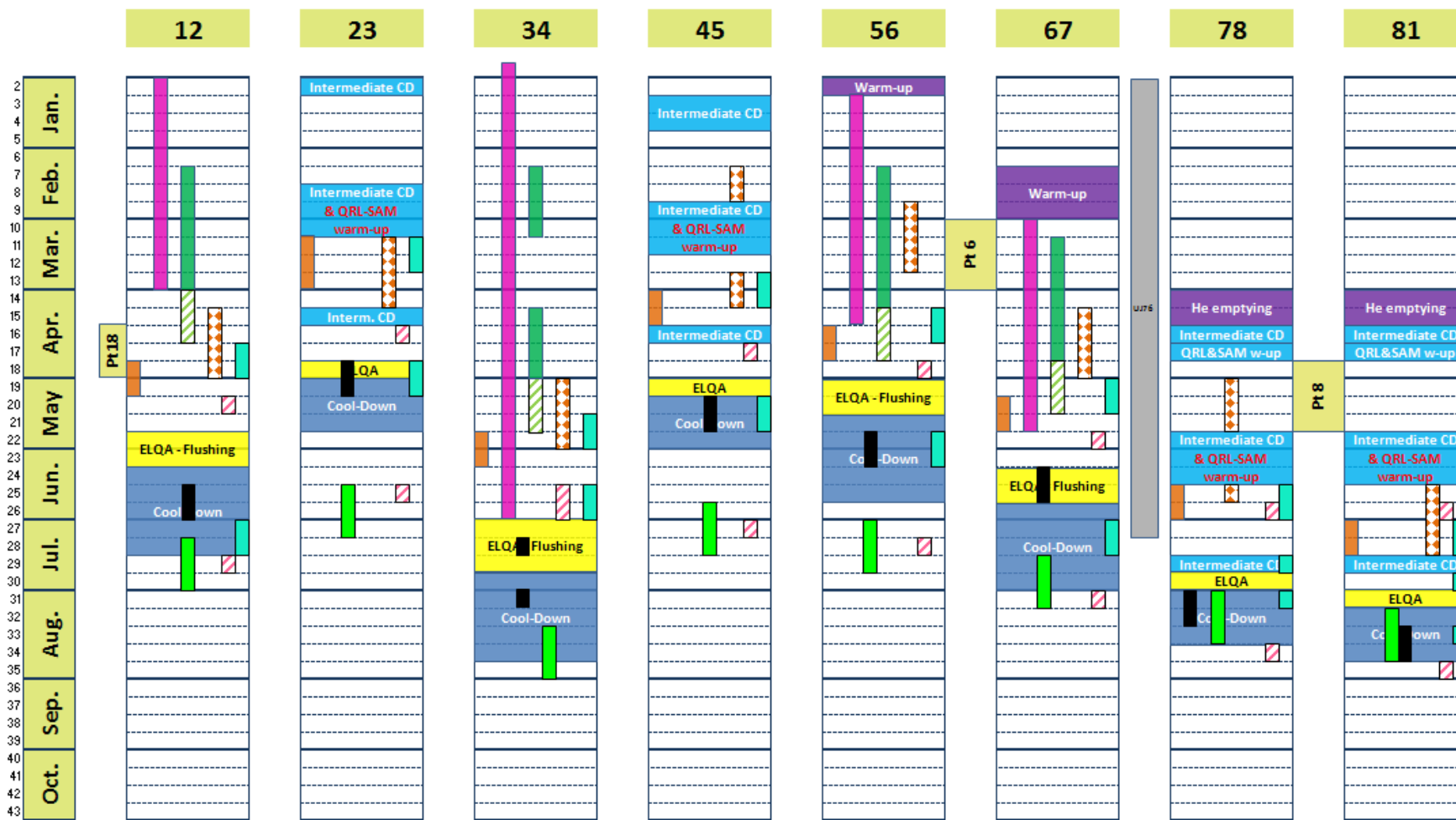
- repair
- consolidation





Chamonix - baseline decisions

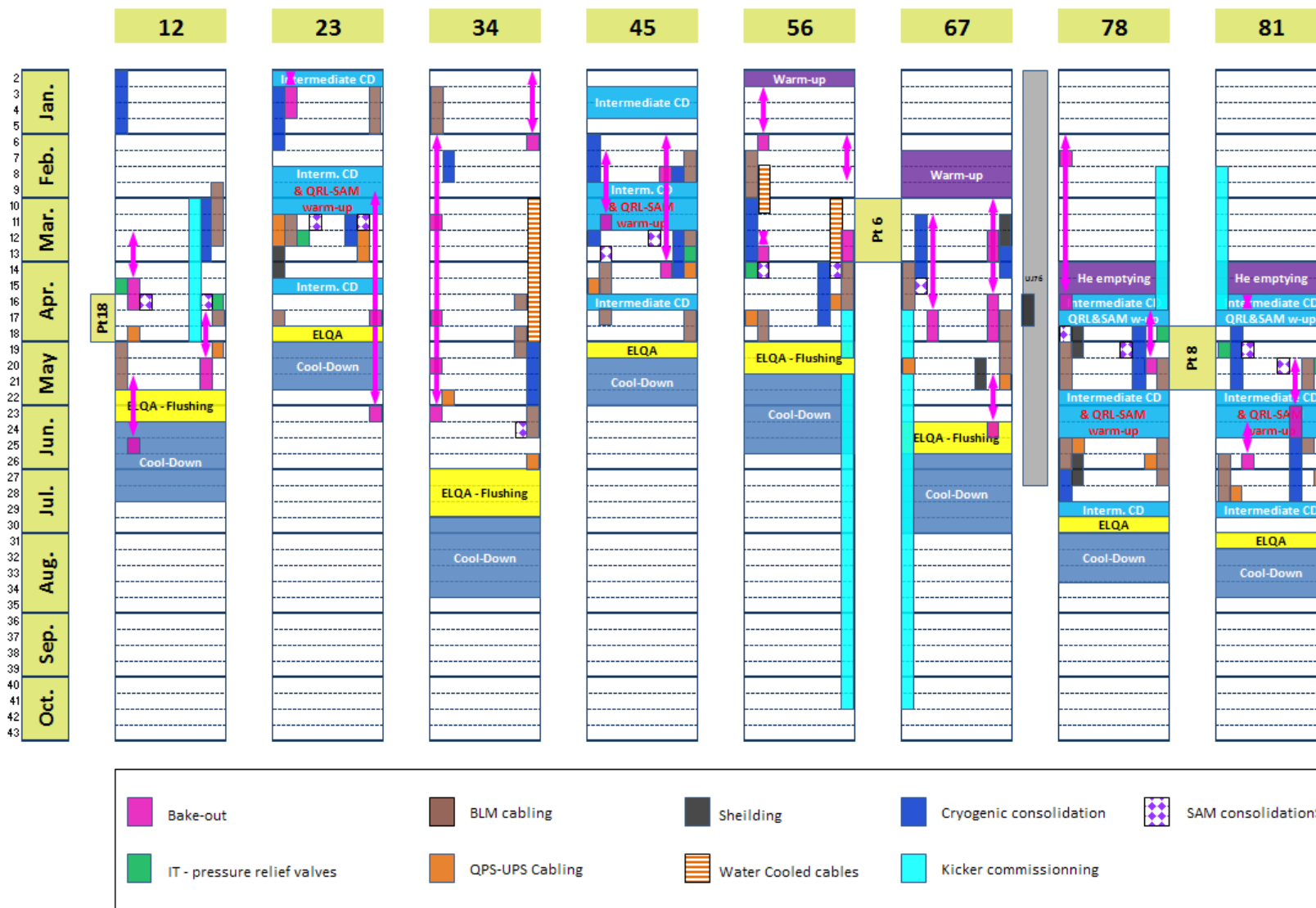
- Relief valves
 - 4 warm sectors
 - Inner triplets & stand alone magnets
 - Feed boxes
 - Compensatory measures on SSSs in cold sectors
- New quench protection system fully deployed in 2009
- Magnets out in S12 and S67
- Calorimetric, QPS, electrical measurements ASAP on all sectors not yet checked.





Long Straight Sections

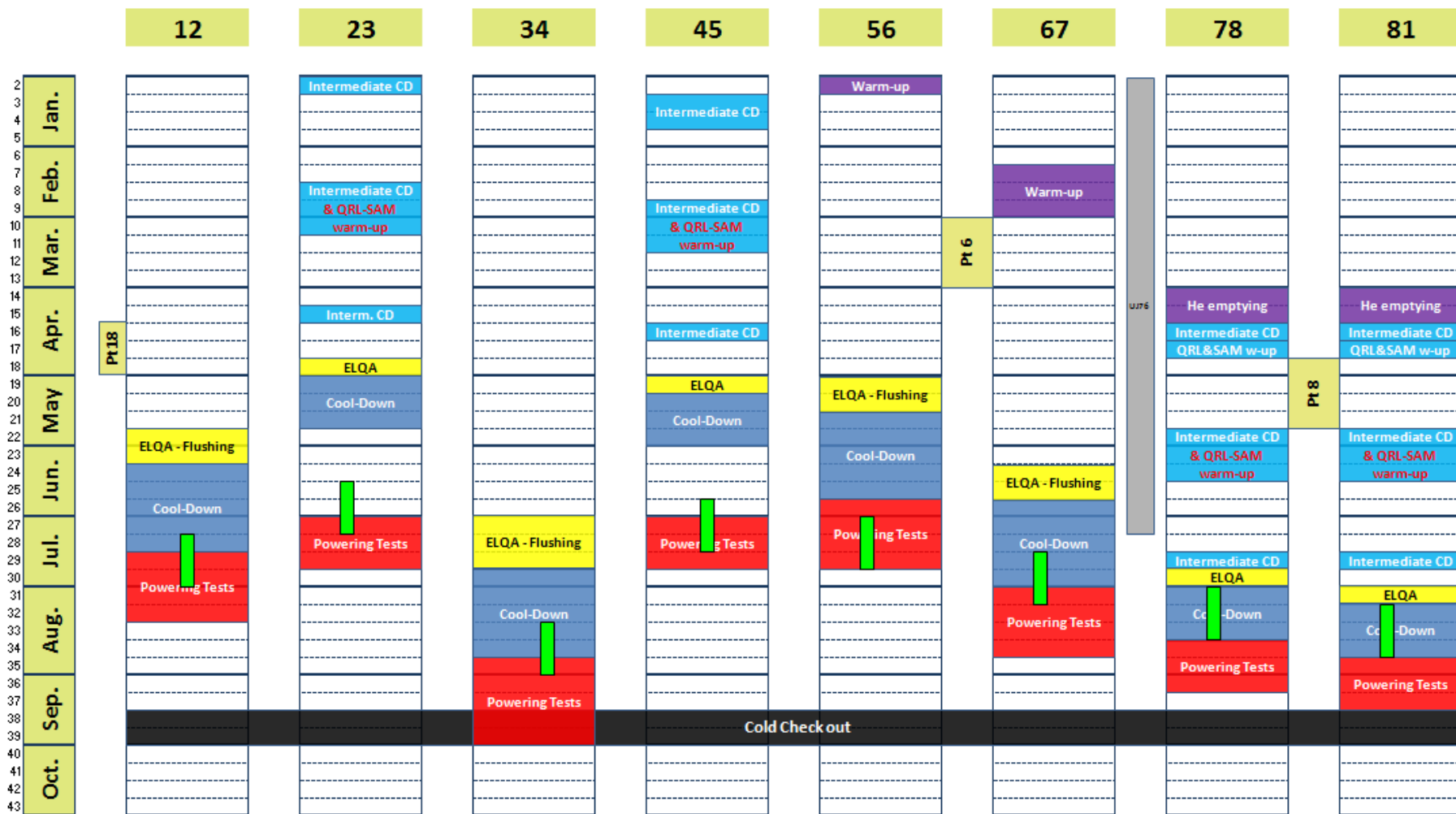
Katy Foraz





With powering tests

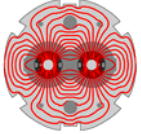
Katy Foraz



Fair to say that the schedule is very tight



4. Schedule with beam

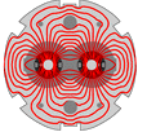


Schedule with running in winter months

- Gains 20 weeks of LHC physics (independent of “slip”)

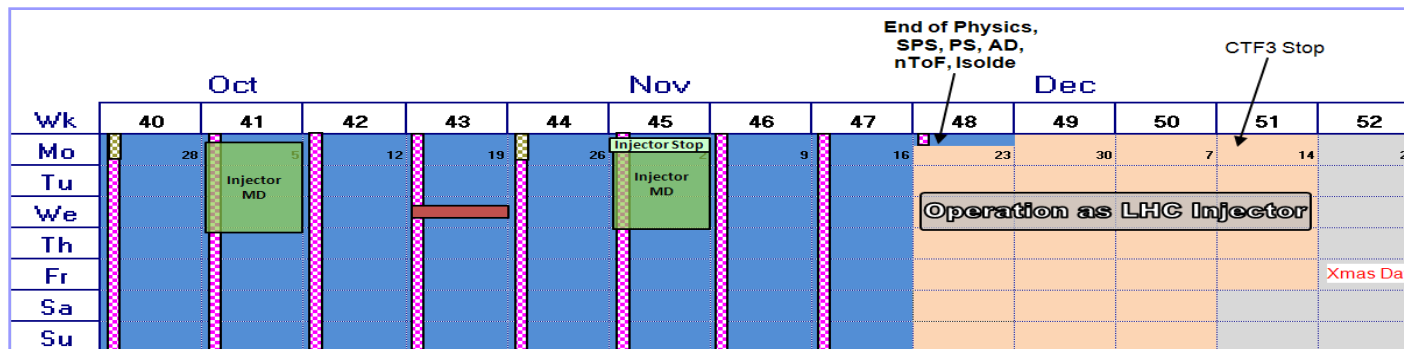
Year	2009												2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	
Baseline	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	SH	SH	SH	SH		
													24 weeks physics possible														
Base '1	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH		
													44 weeks physics possible														
Gain 20 weeks of physics in 2010 by running during winter months																											
												HIGH price Electricity															
Delay (4W)	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	

Steve Myers



Schedule outline

- Normal operation of the whole complex up to mid-November 2009.
- Operation of Linac2, PSB, PS and SPS with LHC beams only from mid-November to the beginning of April.
- Technical stop around Christmas
 - exact length to be defined.
- Normal operation of the whole complex from April until end October 2010.





5. Beam Commissioning

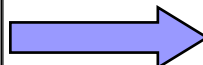
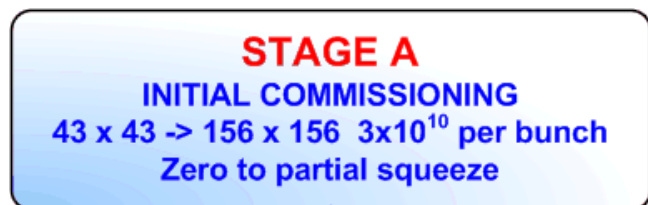


Beam – Chamonix baseline

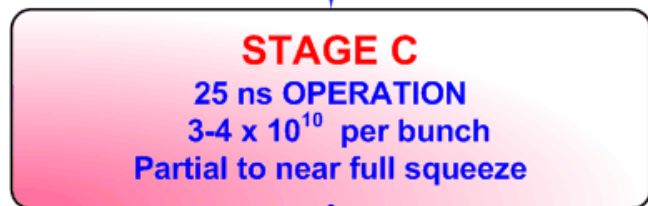
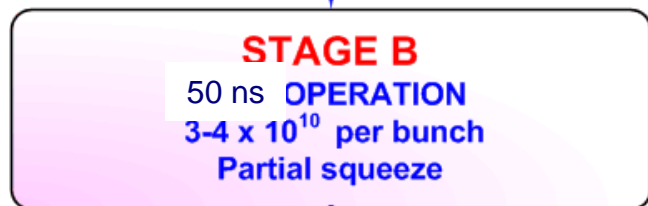
- 4 TeV “on the way” to 5 TeV (no higher in 2010)
- Physics at 5 TeV
- Start with low number of bunches, low intensity
 - increase slowly 1,4,12,43, 156....
- Estimated integrated luminosity
 - during first 100 days of operation.. $\approx 100 \text{ pb}^{-1}$
 - during next 100 days of operation.. $\approx 200 - 300 \text{ pb}^{-1}$
- End of 2010 run – one month ions



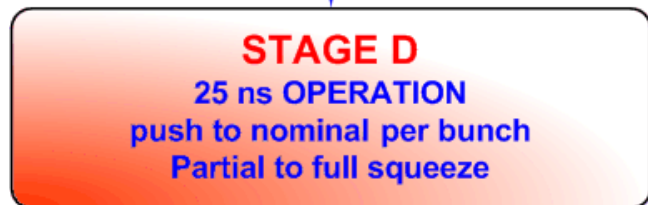
Commissioning stages



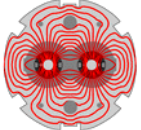
Safely establish colliding beams as quickly as possible



LONG SHUTDOWN



- Initial optics:
 - $\beta^* = 11$ m in IR 1 & 5
 - $\beta^* = 10$ m in IR 2 & 8
- Crossing angles off
 - Low bunch intensity
 - 1, 12, 43, 156 bunches per beam
 - No parasitic encounters - no long range beam-beam
 - Larger aperture in IRs

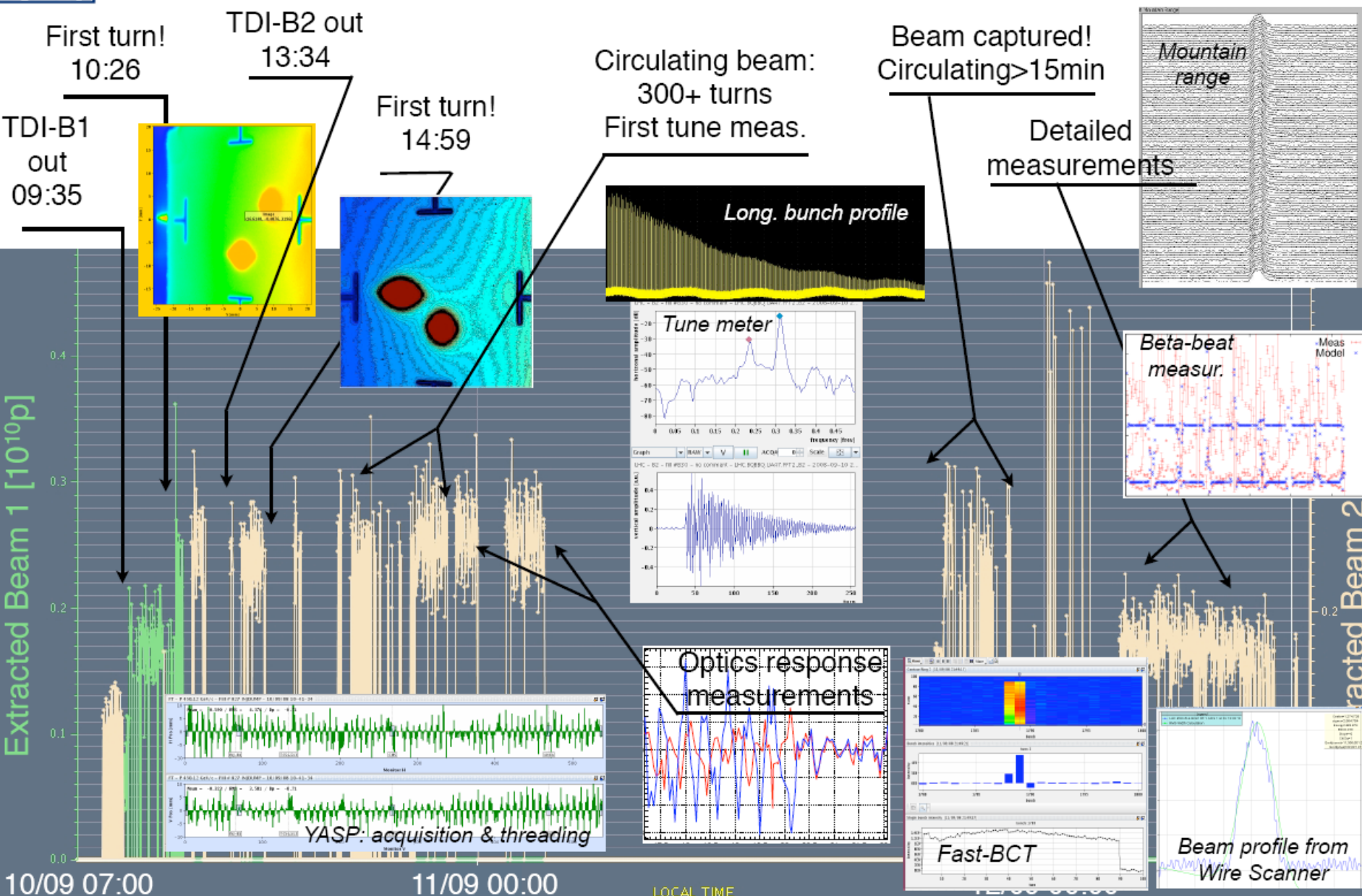
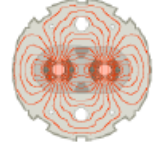


Beam Commissioning to 5 TeV Collisions

		Rings	Total [days]
1	Injection and first turn	2	1
2	Circulating beam	2	2
3	450 GeV - initial	2	3
4	450 GeV - detailed	2	3
5	450 GeV - two beams	1	1
6	Snapback - single beam	2	3
7	Ramp - single beam(s)	2	6
8	Ramp - both beams	1	2
9	7 TeV - setup for physics	1	1
10	Physics un-squeezed	1	-
	TOTAL TO FIRST COLLISIONS		22
11	Commission squeeze	2	6
12	Increase Intensity	2	6
13	Set-up physics - partially squeezed.	1	2
14	Pilot physics run		



Milestones of 60 hours of LHC beam





Stage A: First Collisions

- 2008 gives us some confidence in the machine
 - magnets, aperture, alignment, model, instrumentation, controls, key sub-systems...

- Approx 4 weeks to establish first collisions
 - Given reasonable machine availability (*caveat*)
 - Un-squeezed, low intensity
 - **Optimistic – but not without cause**

- Continued commissioning thereafter
 - Increased intensity
 - Squeeze

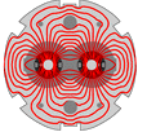
<p style="text-align: center;">RHIC 2000: - First beam April 3rd - First successful ramp: June 1st - First collisions June 12th</p>



2009 – 2010 - ball park

Month	No. Bunches	Protons per bunch	β^* [m]	% Nom	Peak luminosity cm-2s-1	Integrated luminosity
1	Beam Commissioning					
2	43	3×10^{10}	4	0.4	1.2×10^{30}	100 – 200 nb ⁻¹
3	43	5×10^{10}	4	0.7	3.4×10^{30}	~2 pb ⁻¹
4	156	5×10^{10}	2	2.5	2.5×10^{31}	~13 pb ⁻¹
5	156	7×10^{10}	2	3.3	4.9×10^{31}	~25 pb ⁻¹
6	720	3×10^{10}	2	6.7	4.0×10^{31}	~21 pb ⁻¹
7	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb ⁻¹
8	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb ⁻¹
9	720	5×10^{10}	2	11.2	1.1×10^{32}	~60 pb ⁻¹
10	lons					
Total						200 – 300 pb⁻¹

- Push: bunches per beam, β^* , bunch intensity
- N bunches displaced for LHCb



Assumptions

- 8 hour fill length
- 5 hour turn around
- 20 hour luminosity lifetime
- 40% machine availability
 - rest of time: commissioning, machine development, access, recovery etc.
- No squeeze beyond $\beta^* = 2.0$ m.
 - Aperture
- Intensity limited to around 10% of nominal



Intensity limit in 2010?

Ralph Assmann



Performance model to include

- energy dependence of cleaning efficiency
- quench limits.

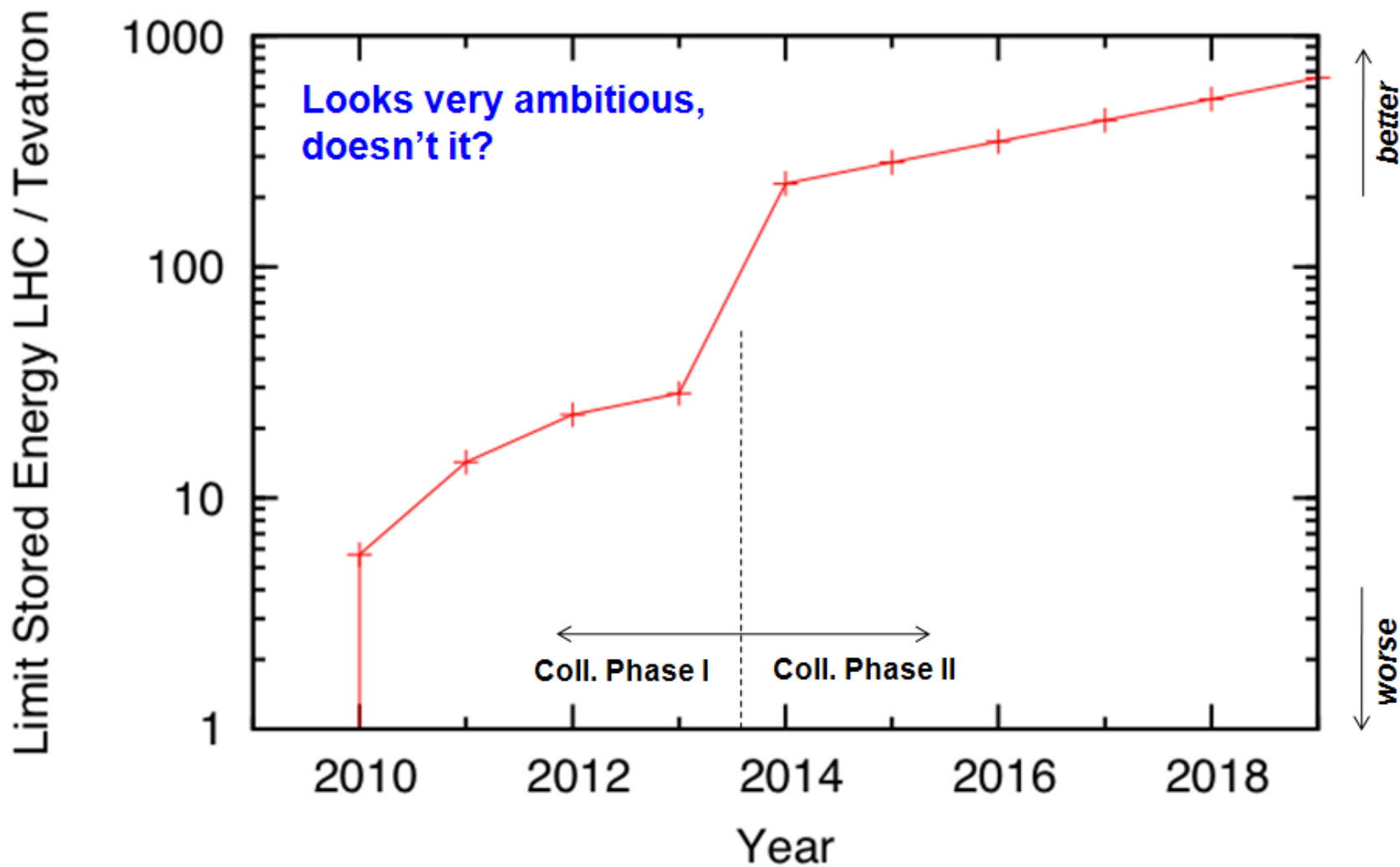
The calculated total intensity limits at 5 TeV:

- are compatible with the figures shown earlier (but not too much more)

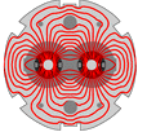
“Cassandra has always been misunderstood and misinterpreted as a madwoman or crazy doomsday prophetess.” L. Fitton



Stored energy



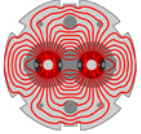
156 x 5 x 10¹⁰ at 5 TeV – 6 MJ – already 5*TeVatron



Stage B – 50 ns – just to make the point

- Up to 1404 bunches
- Parameter tolerances:
 - Tightened up. Optics/beta beating under control
 - Emittance conservation through the cycle
 - Collimator cleaning efficiency versus quench limit
- Commission crossing angles.
 - Injection, ramp and partial squeeze
 - Long range beam-beam, effect on dynamic aperture,
- Need for feedback
 - Orbit plus adequate control of tune and chromaticity through snapback.
- Lifetime and background optimization in physics
 - with a crossing angle and reduced aperture

Plus Machine Protection with increased intensity



Conclusions

- Open heart surgery on-going – starting the stitching up
- All splices to be measured carefully
- Preventive measures to be deployed:
 - Relief valves, extended Quench Protection...
- Beam scheduled for end September (tight)
- Run through the winter - 10 month physics run aiming to deliver a few 100s pb^{-1}

It's a beautiful machine but we will
have to progress carefully