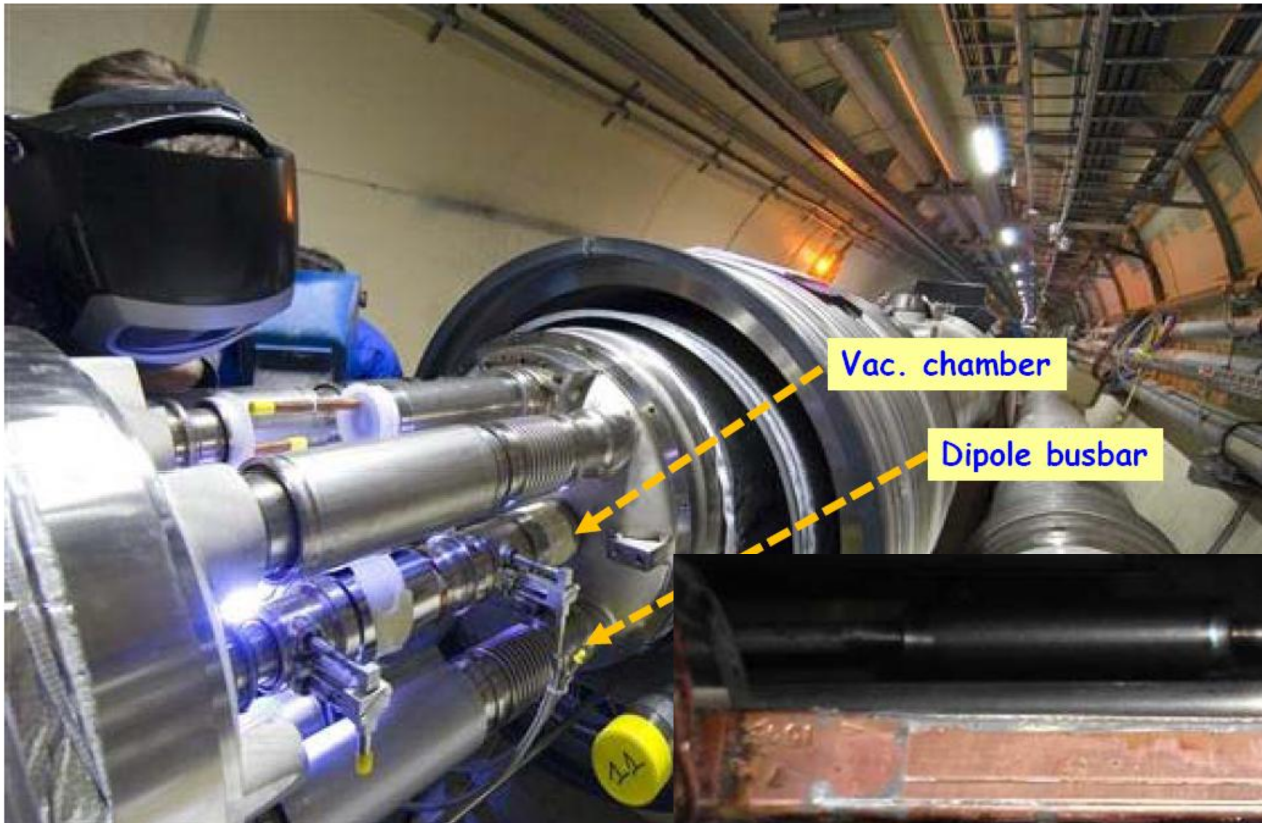
LHC status and commissioning

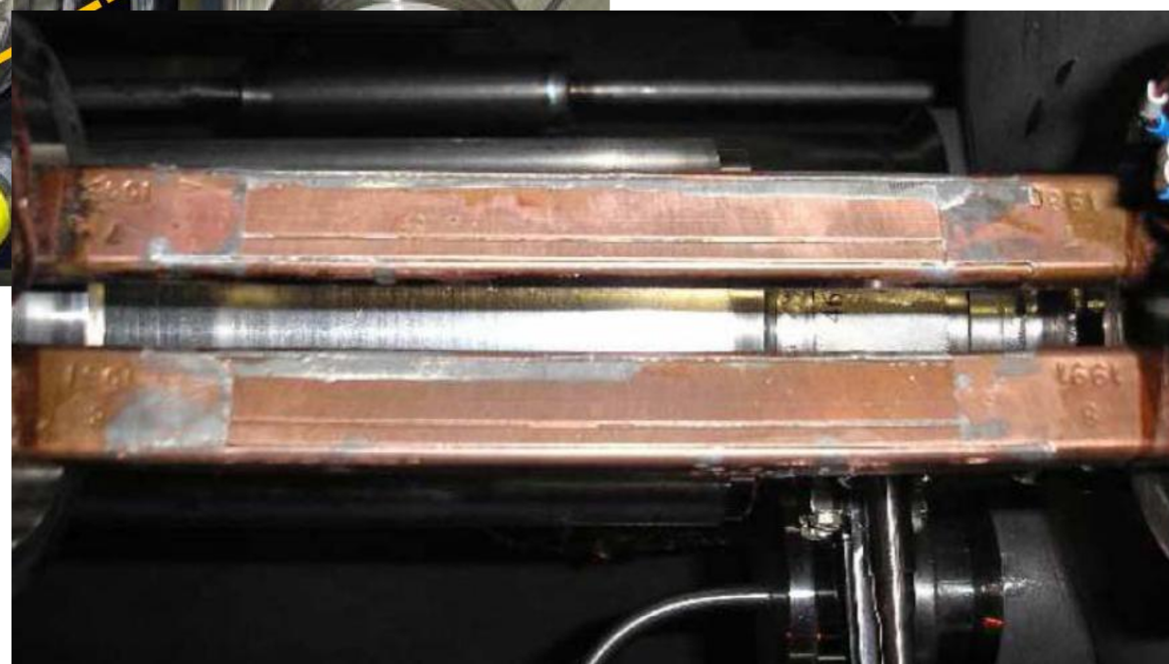
- Sector 34 incident – present understanding
- Picking up the pieces
- Making sure it doesn't happen again
- Schedule before beam
- Schedule 2009-2010
- Re-commissioning with beam
- 2009 – 2010 run

Mike Lamont

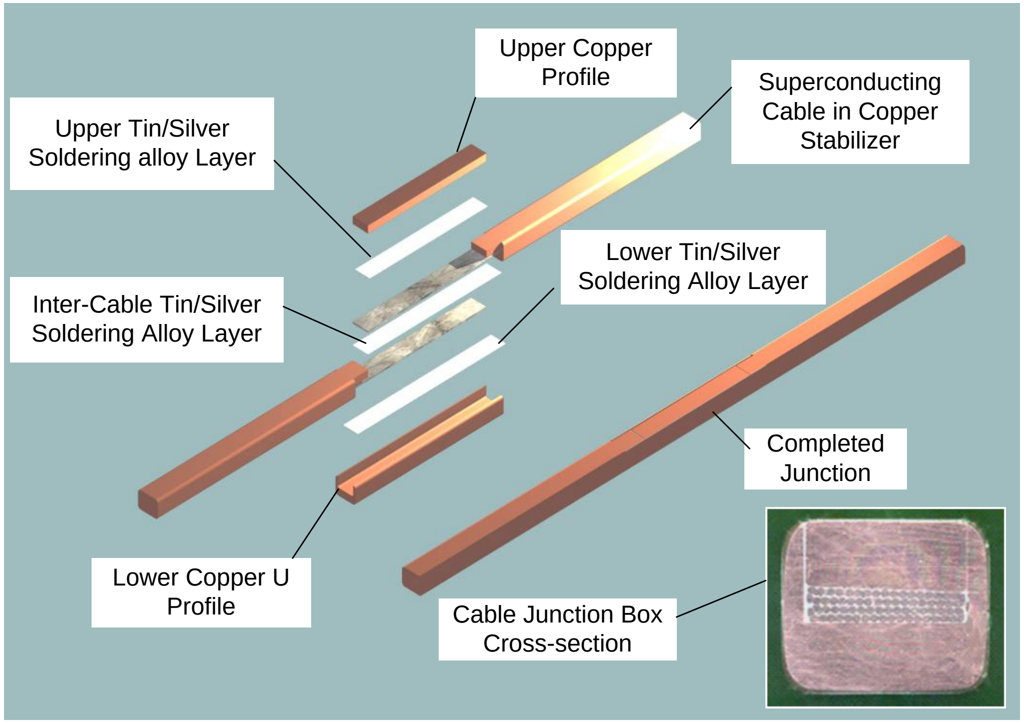
1. What went wrong

Ruptured bus-bar interconnection





Electrical joint in 12 kA bus bar



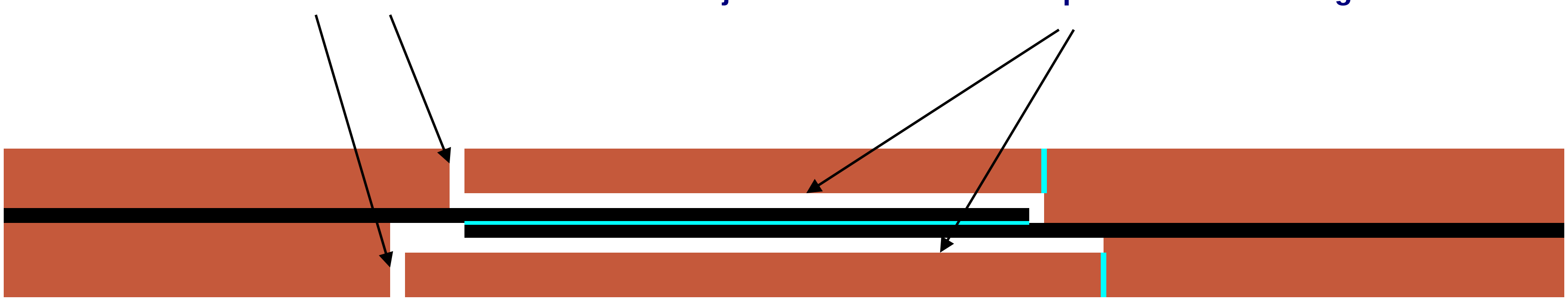
"What makes a good joint?"

A. Verweij

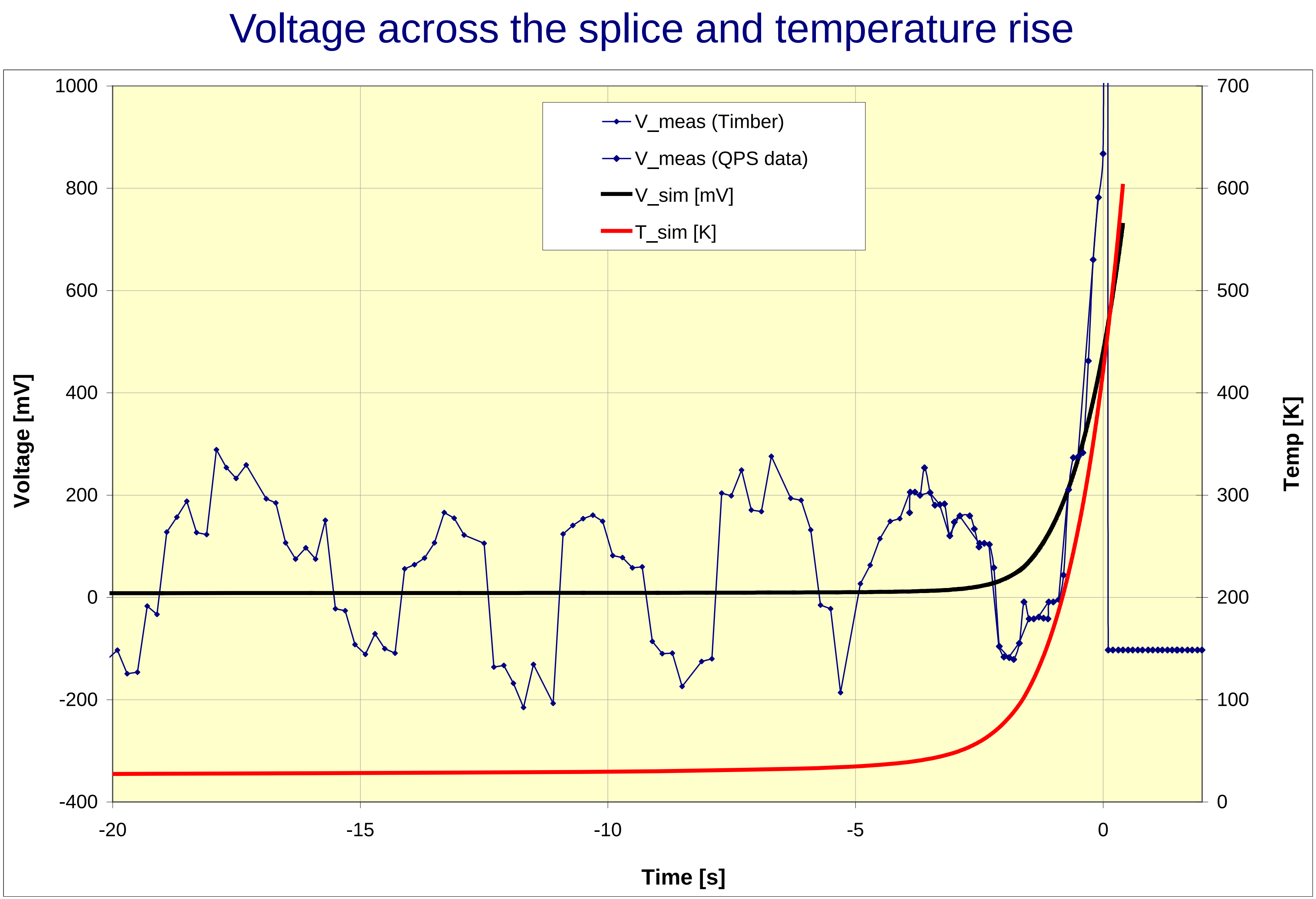
A resistive joint of about 220 nΩ with bad electrical and thermal contacts with the stabilizer

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



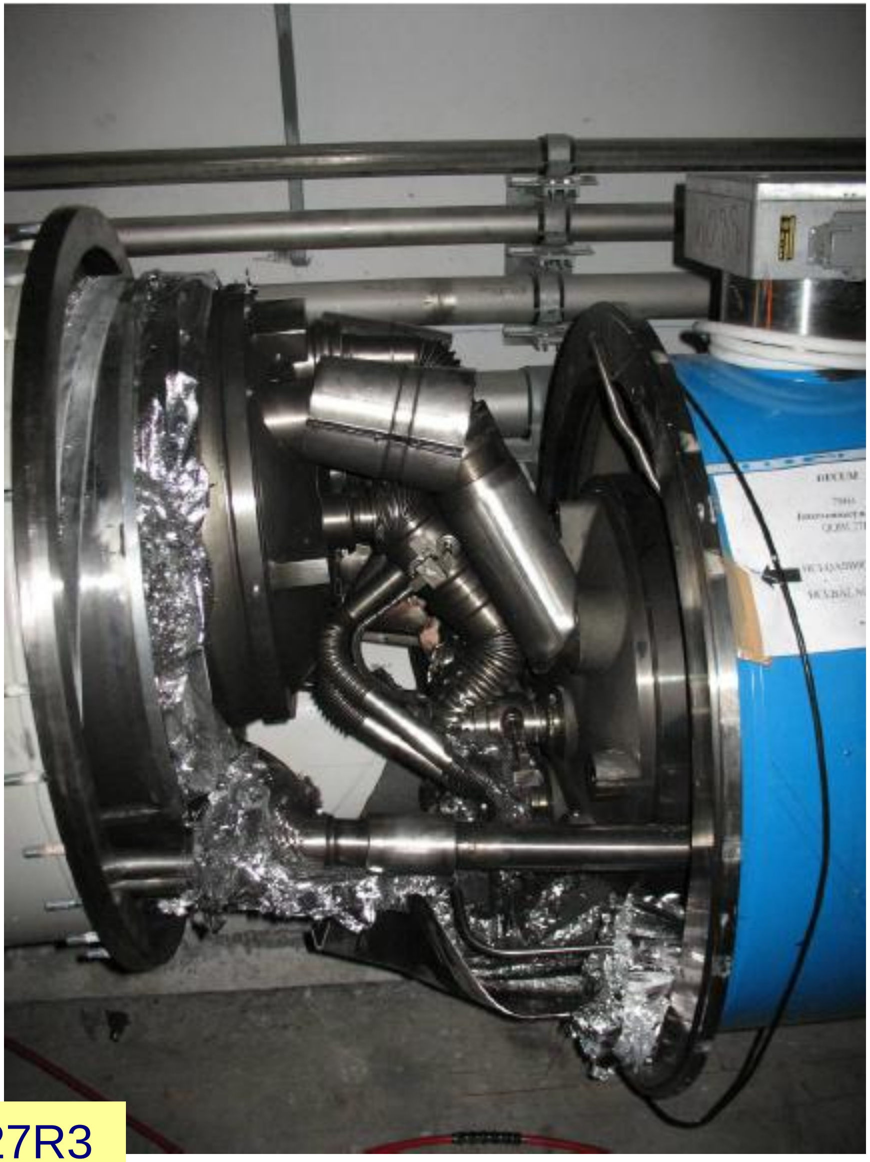
2. Pick up the pieces

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

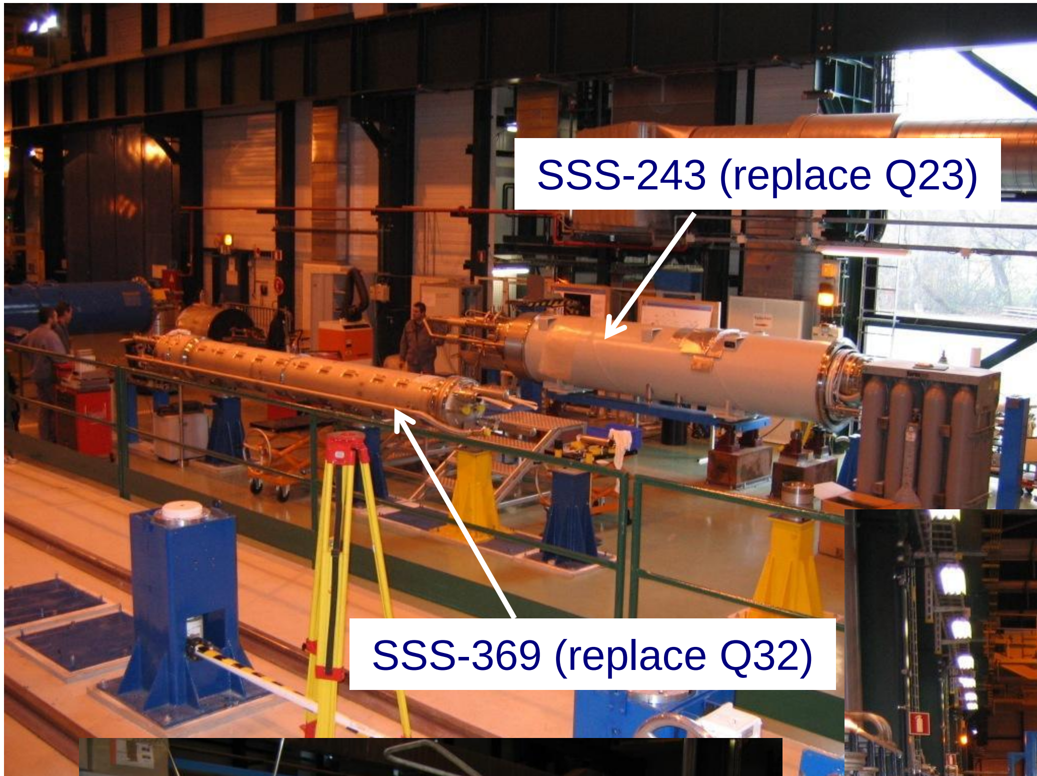
Remove and repair

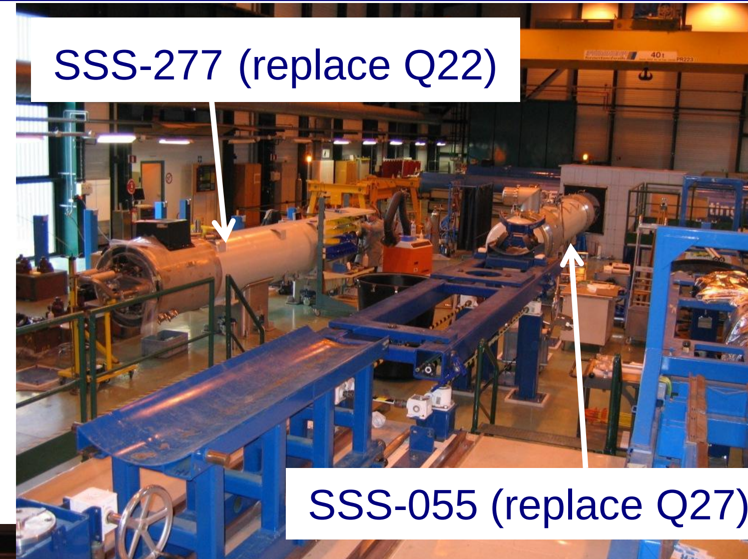
Remove damaged magnets

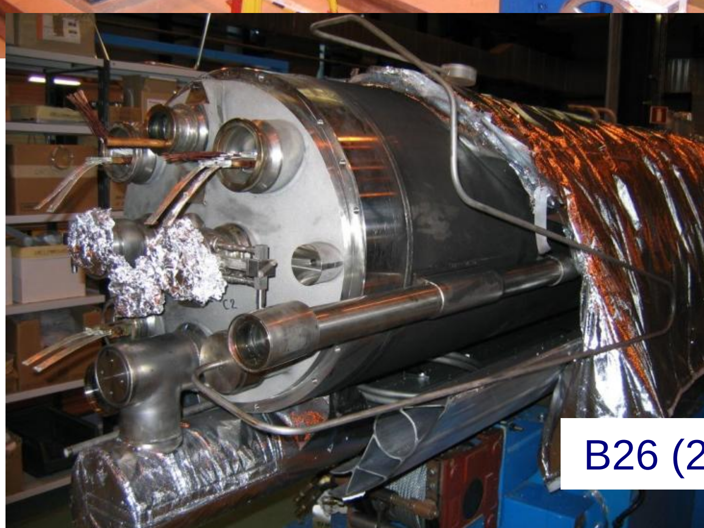
Preparation of recovery facilities

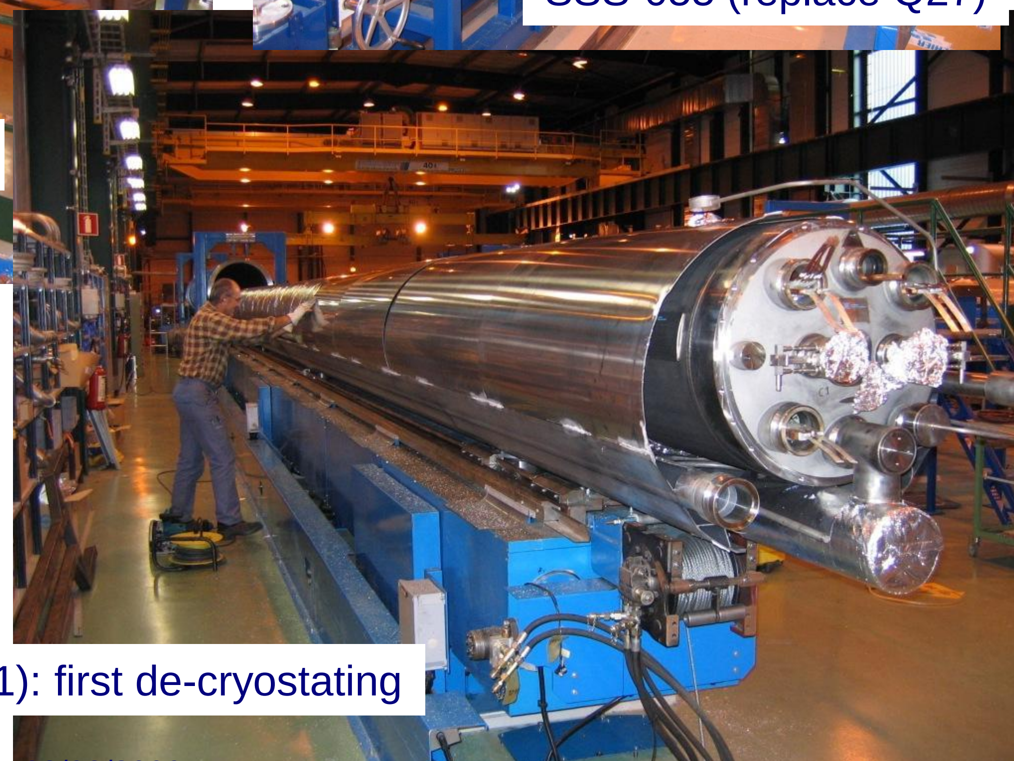
SMI2

Lucio Rossi



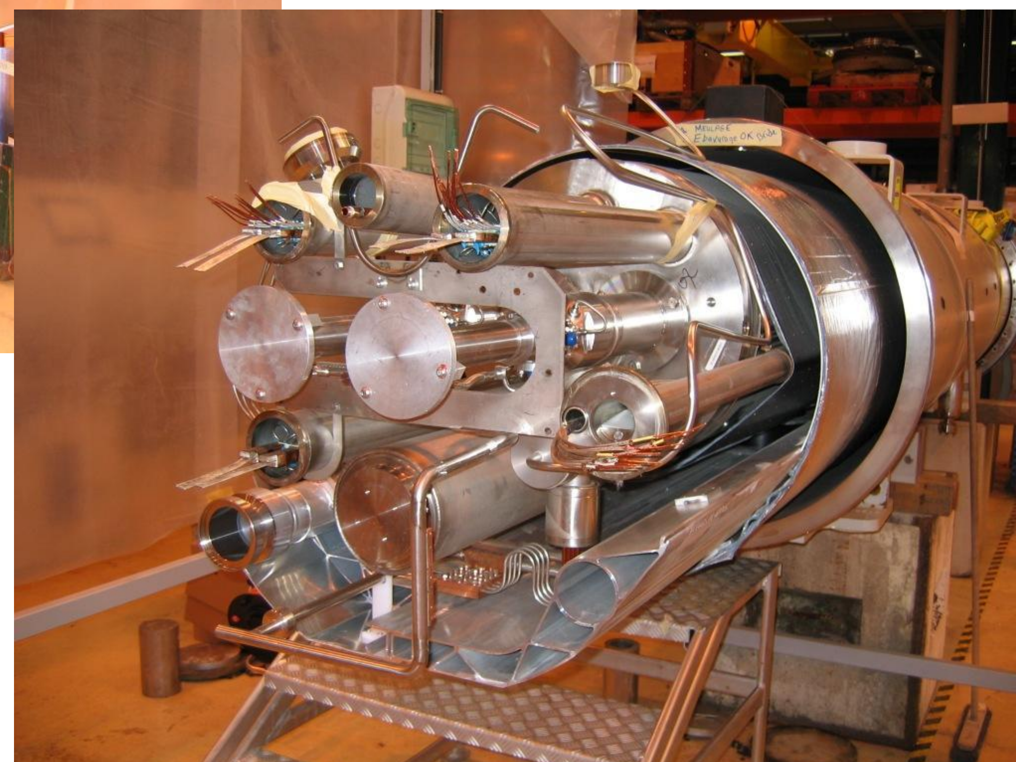






904

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



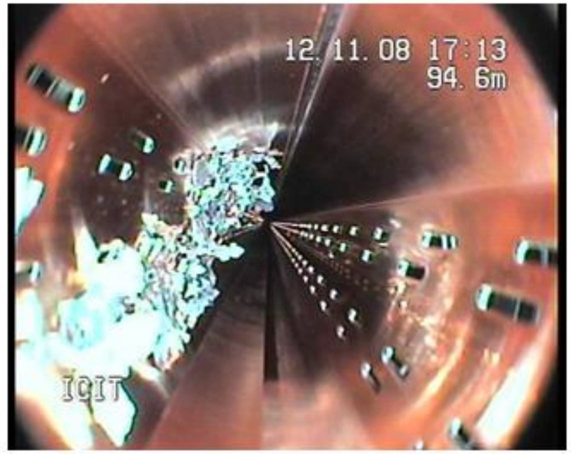
SMA18

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

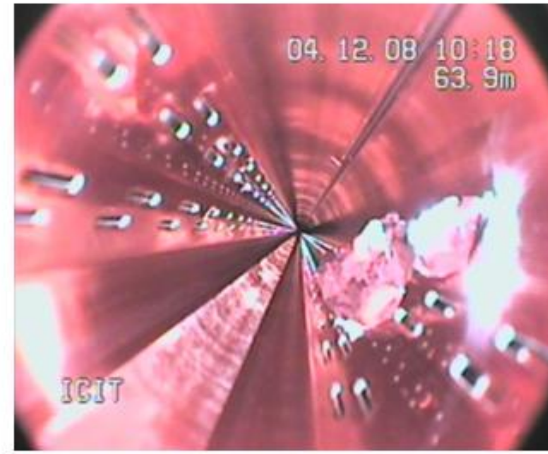
Beam Vacuum cleaning

Beam Screens with MLI and Fibers

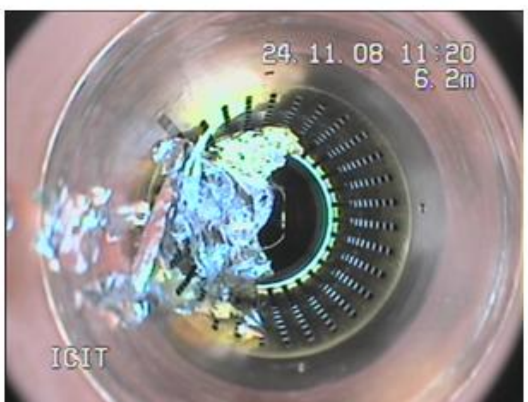
QBQI 8L4.V2



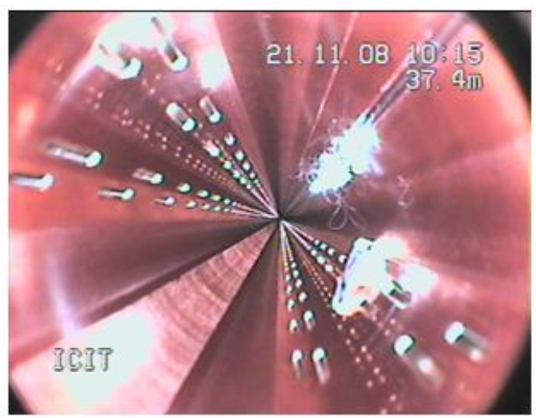
A10L4.V2



B9R3.V1



QBQI 14L4.V2

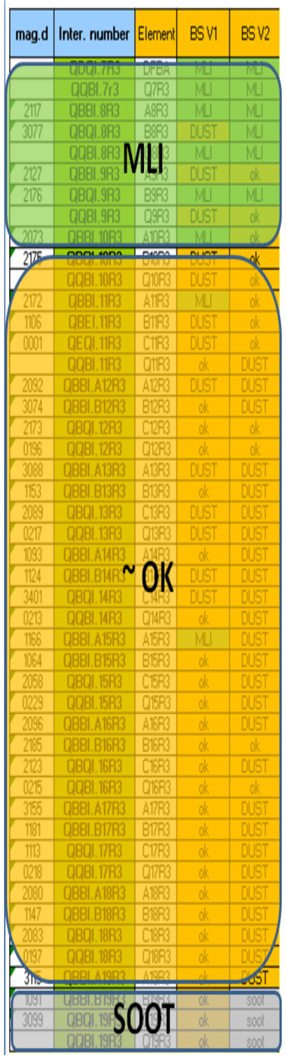


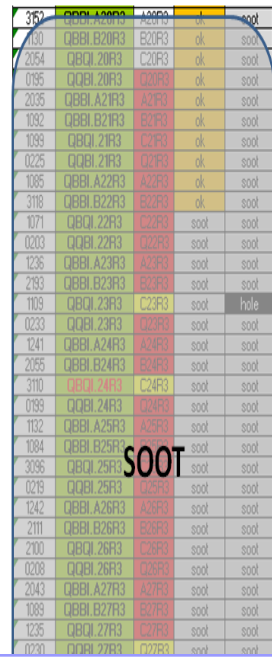
A13L4.V1

QBQI 12L4.V1

Beam Vacuum Contamination – S34

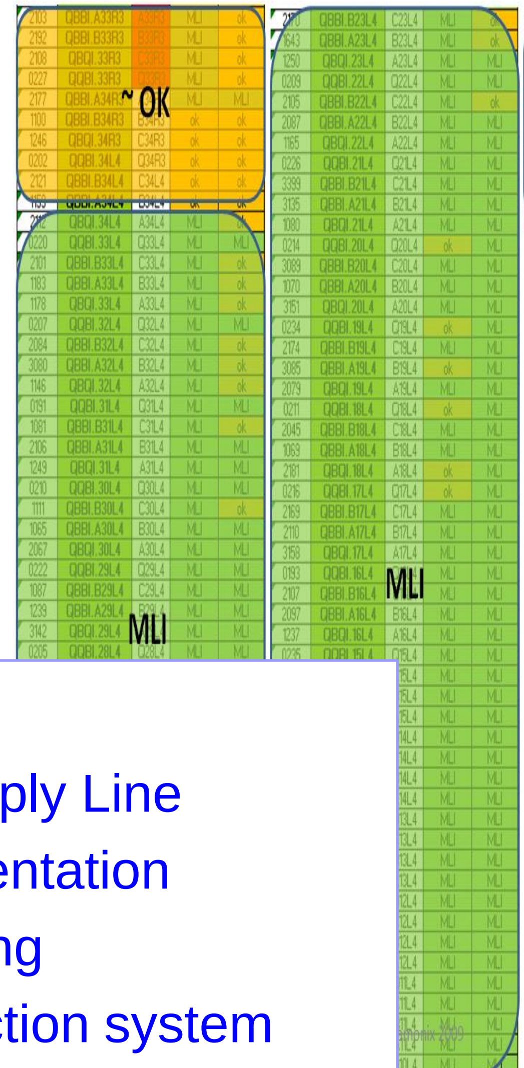
Point 3

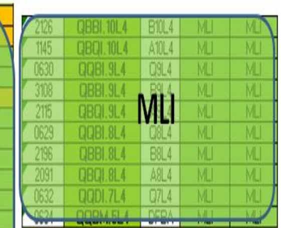




- MLI :
  DFBAR3 => A10R3
- ~ OK :
  B10R 3 => A19R3
- Soot :
  B

V. B





Point 4

- ~ OK :
  A32R 3 => B34L4
- MLI :
  A34L4 => DFBAL4

5

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

Miguel Jimenez

3. Try and make sure it never happens again

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

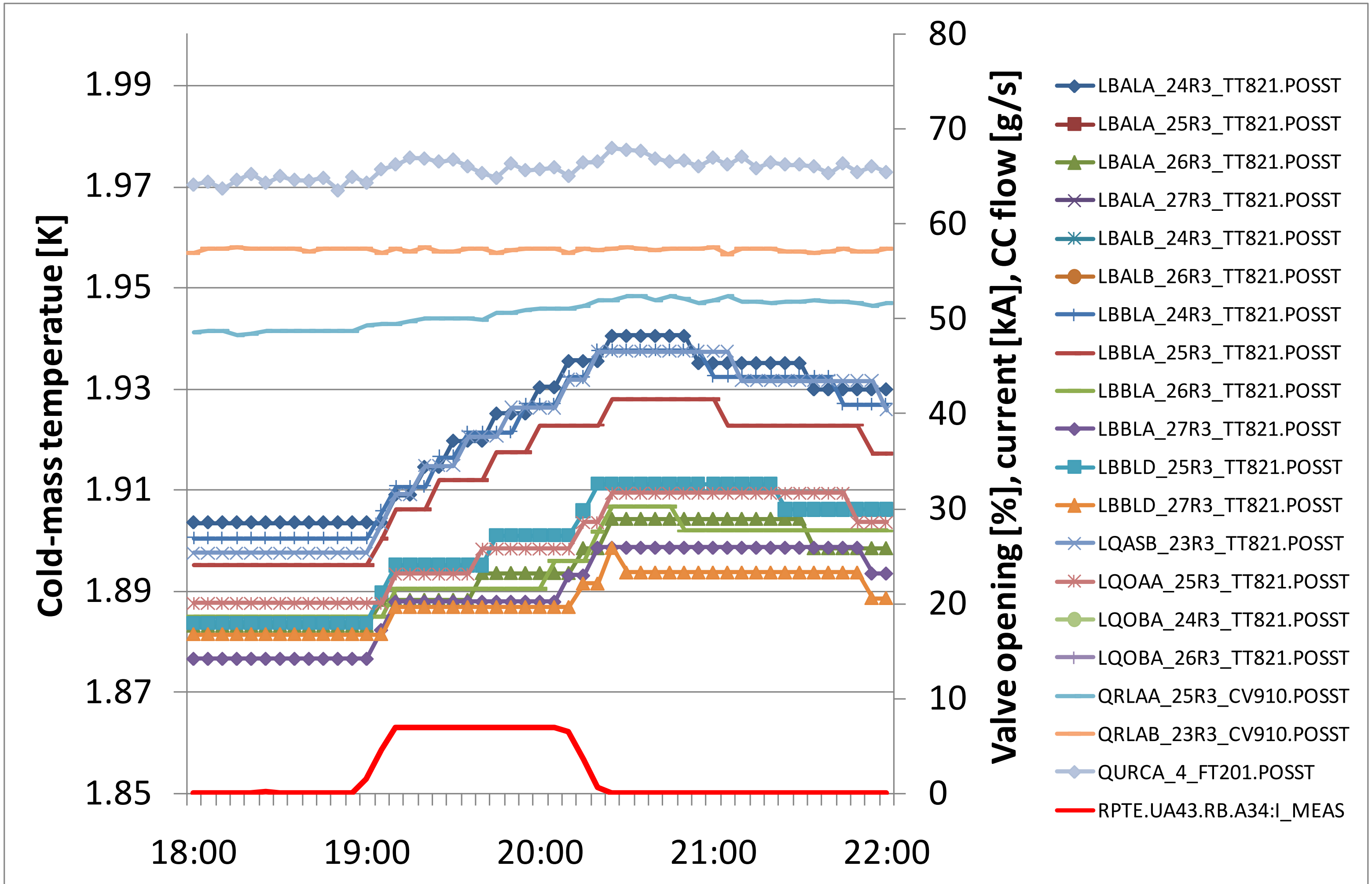
Take remedial action

- 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

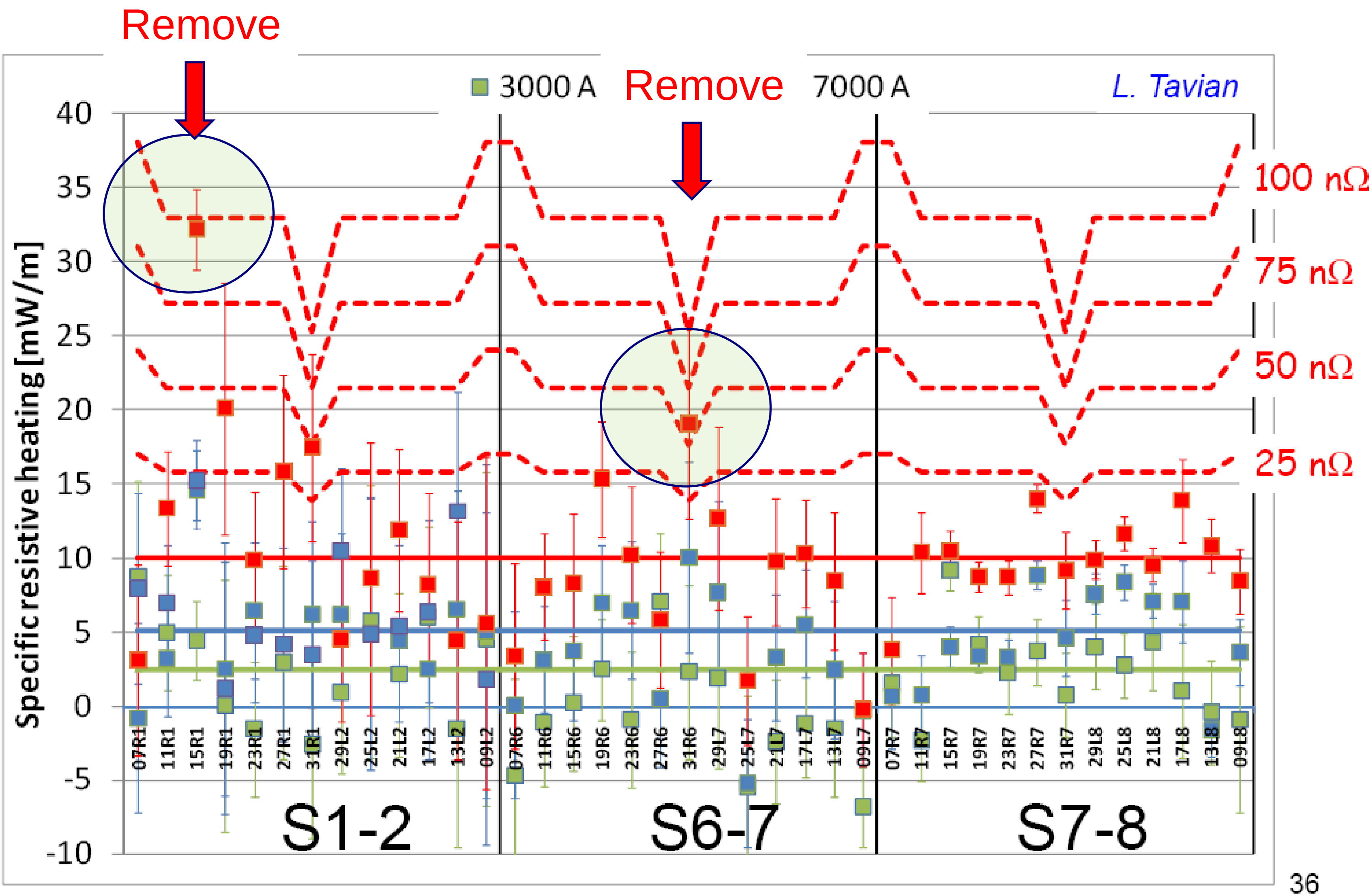
Resistive heating of bad splices can be measured.

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



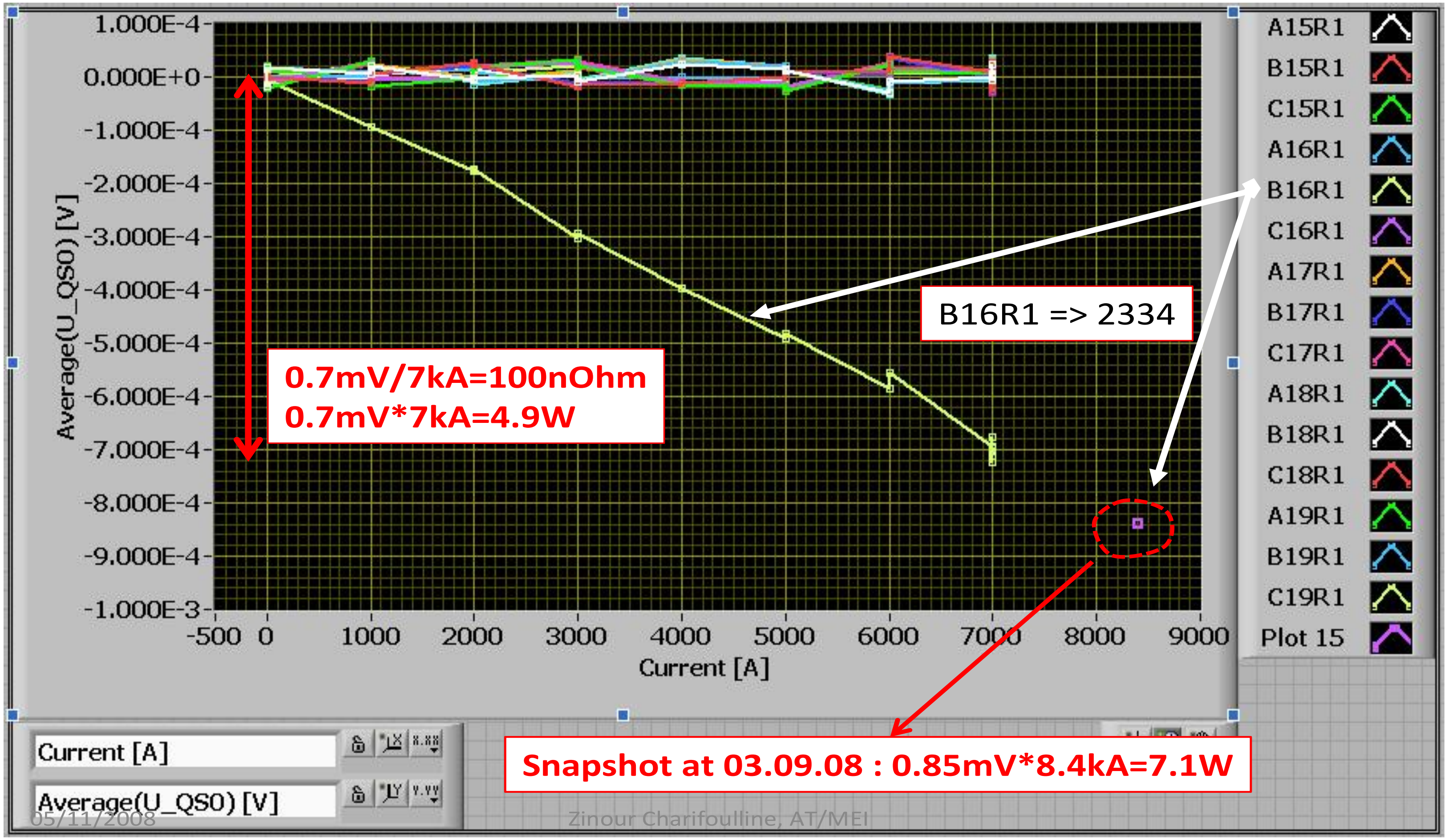
Calorimetry

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



QPS can also see "bad" splices

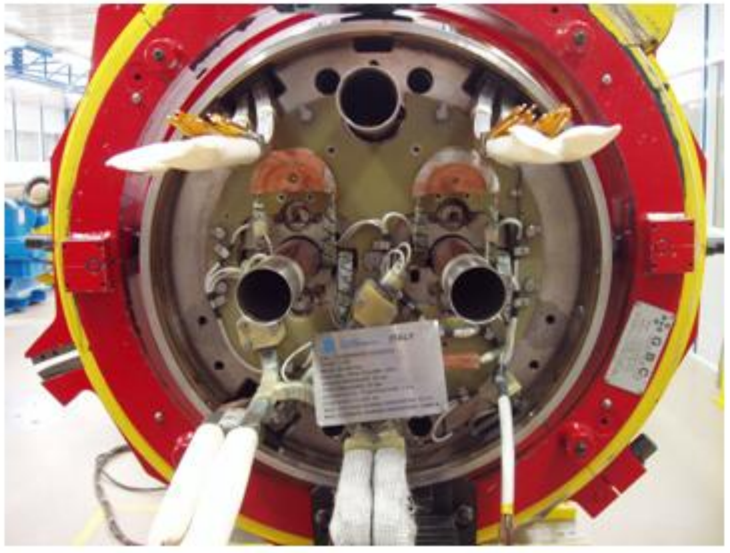
Sector A12: A15R1 – C19R1: Dipole Measurements made on 03.11.08

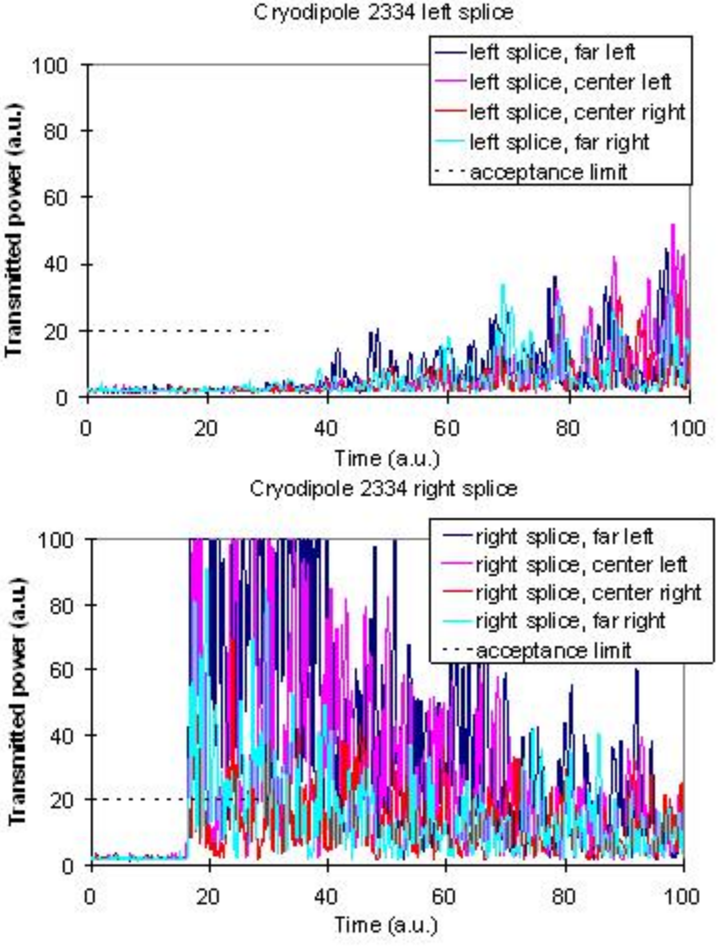


Improved quality control

Ultrasound splices

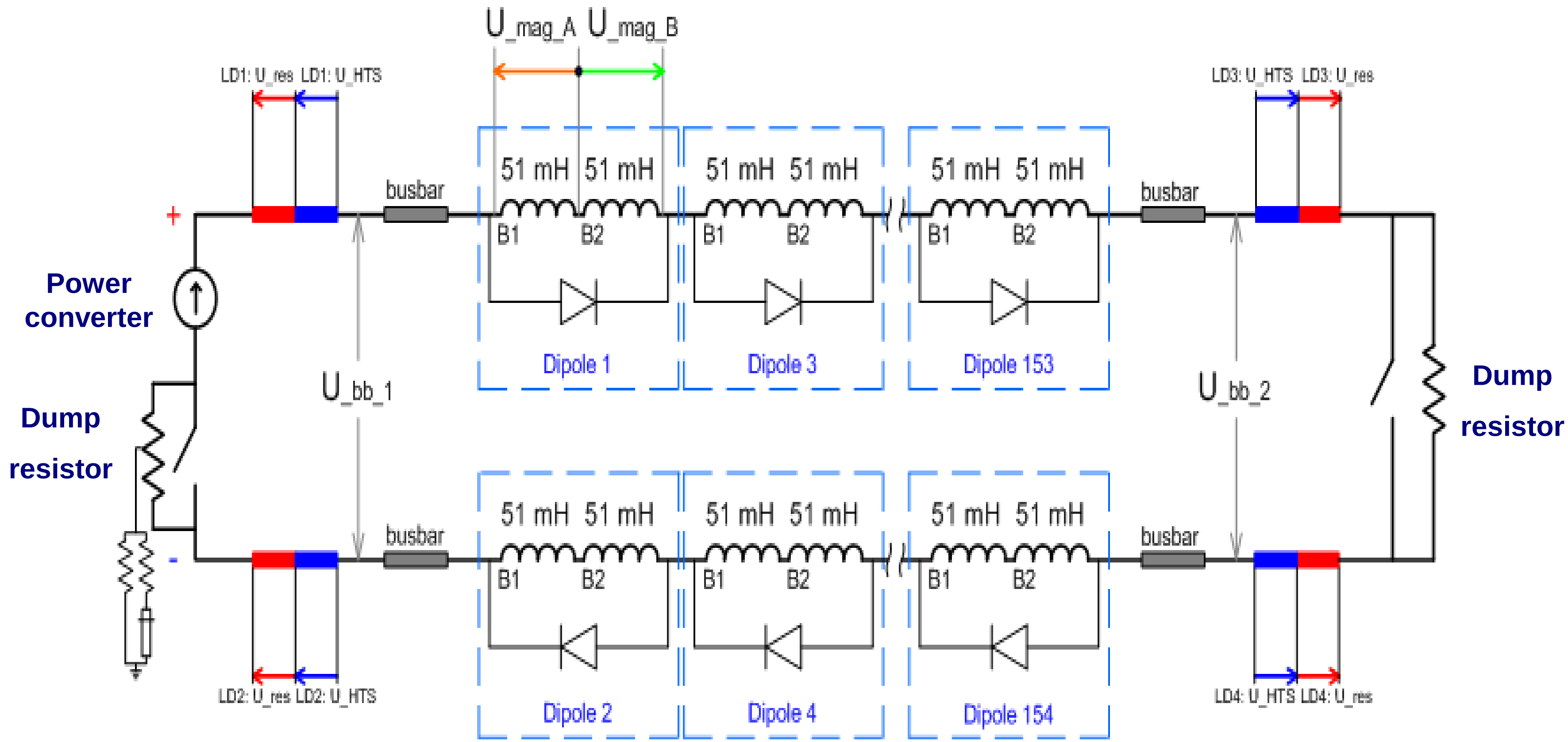
US inspection of defective inter-pole splice in MB 2334 has confirmed the US test to be a very useful QC tool.





Courtesy C. Scheurlein

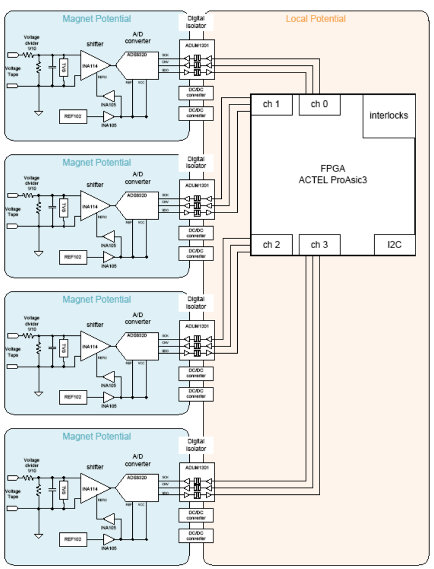
Quench Detection



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)

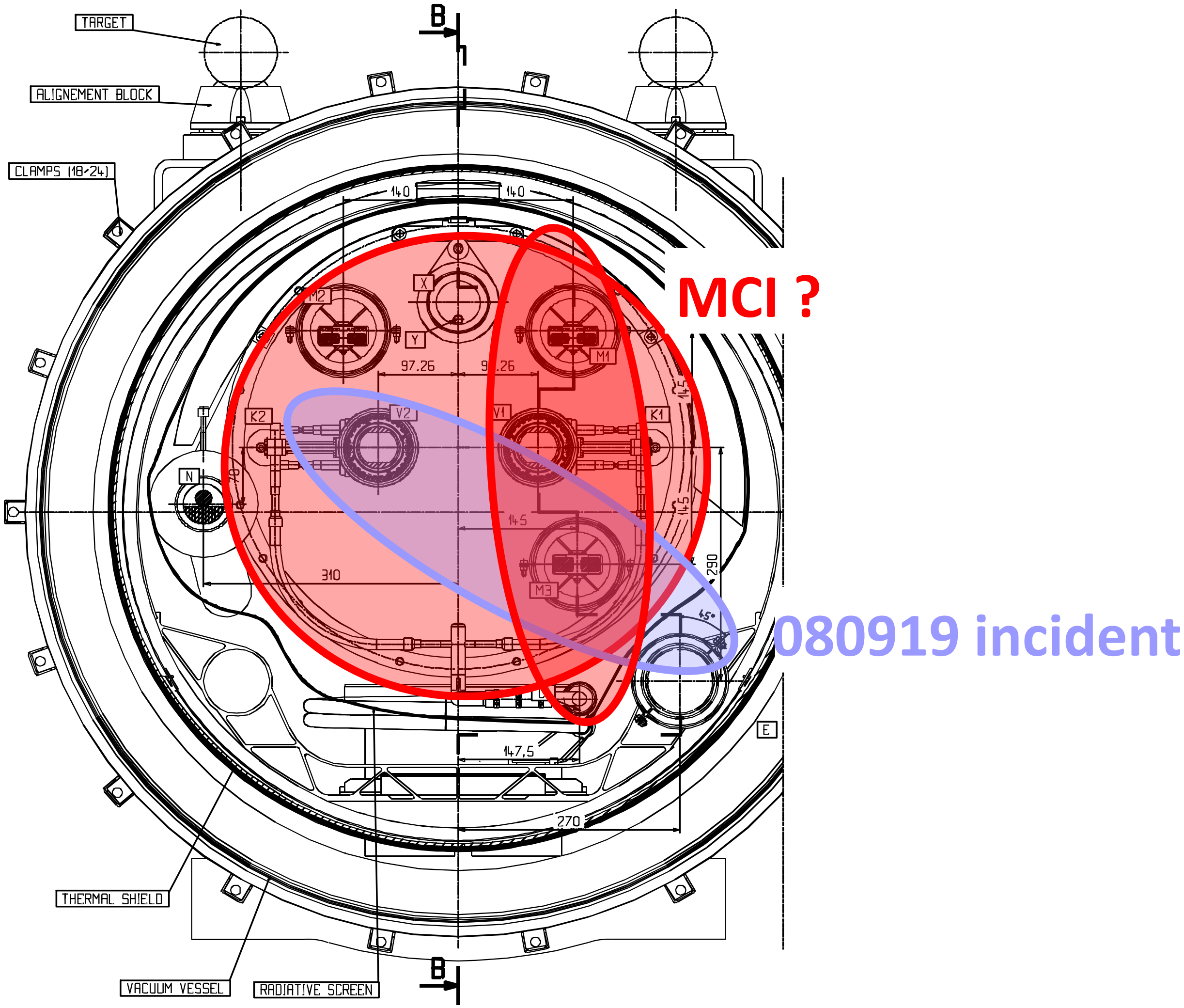
4400 individual cables

7800 connectors

0 errors permitted

Maximum Credible Incident

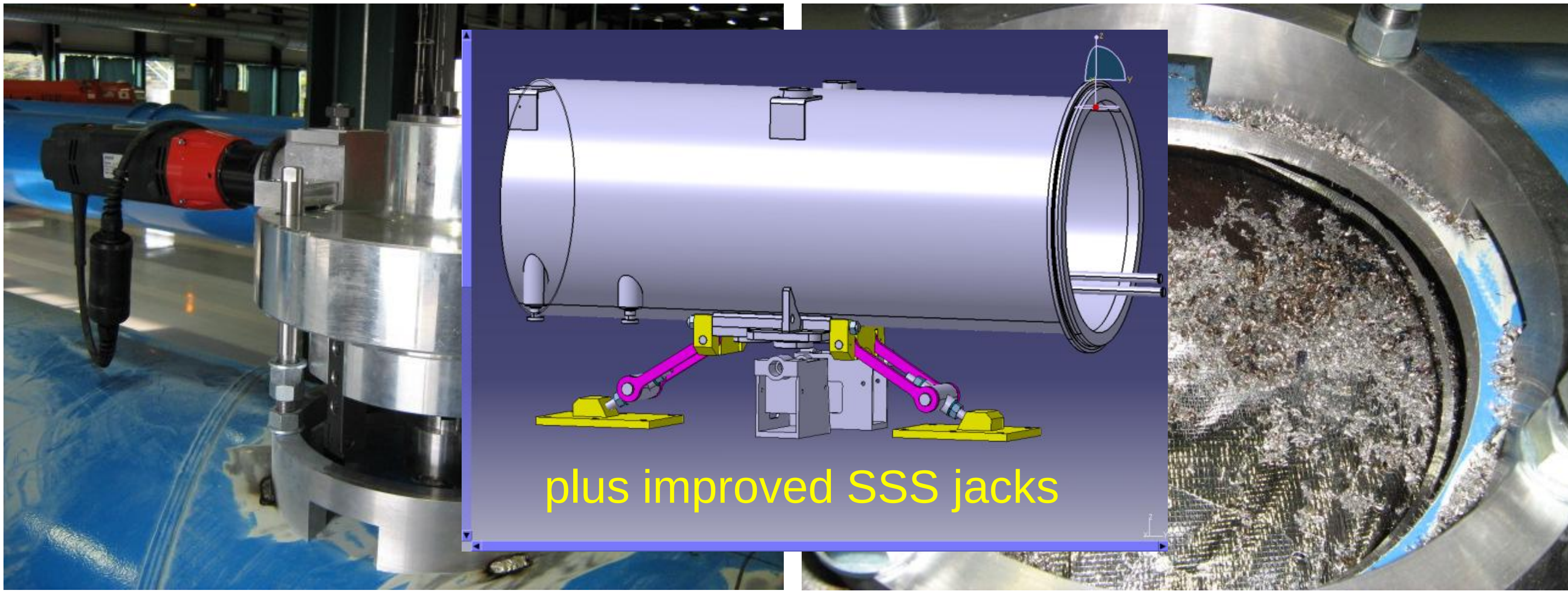
Alleviate knock-on effects - try and cater for the worse



L. Tavian

Improved pressure relief

Additional relief valves on dipole vacuum enclosure



- **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

F. Bertinelli

4. Schedule until beam

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

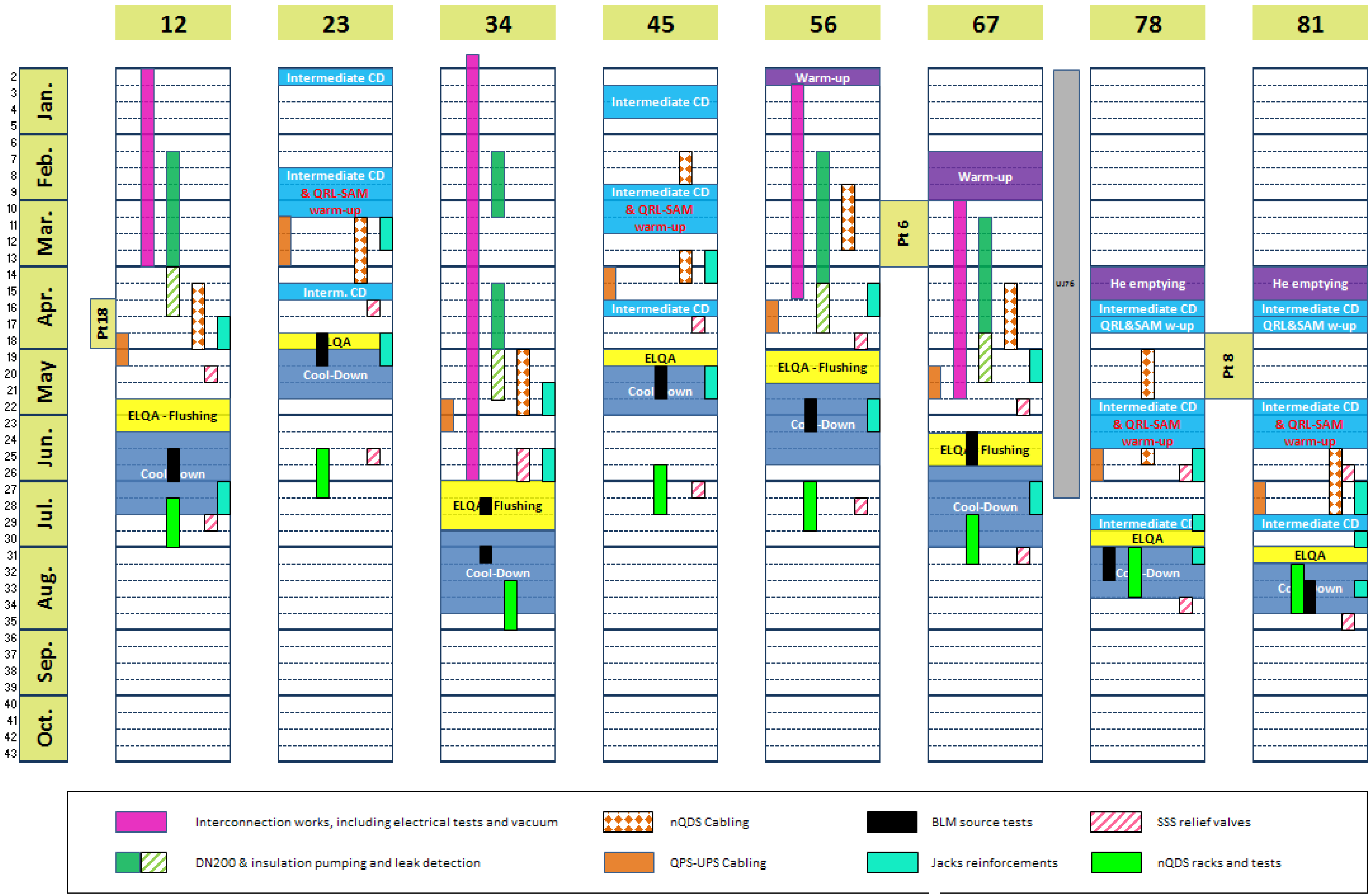
- repair
- consolidation

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.

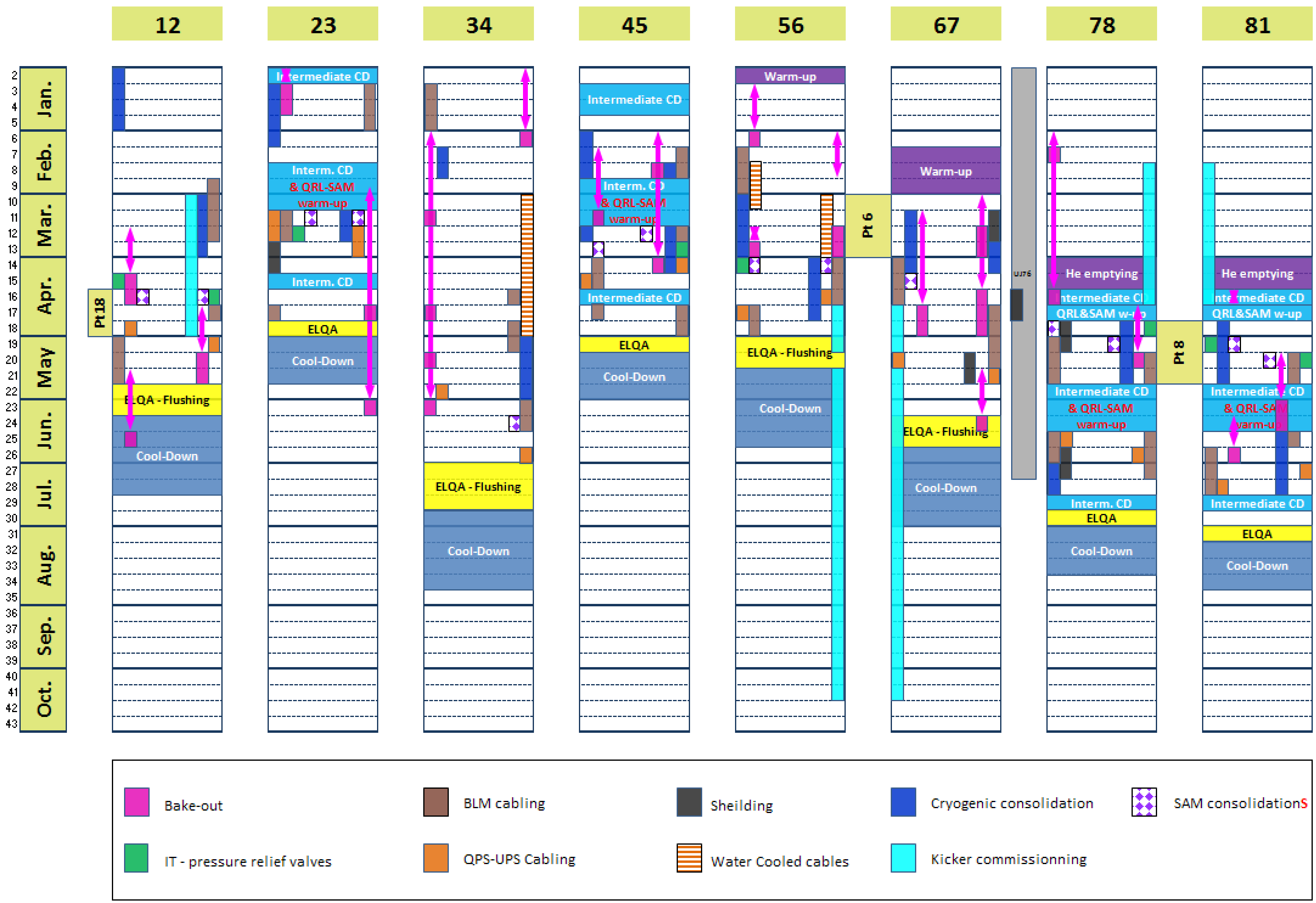
Arcs

Katy Foraz



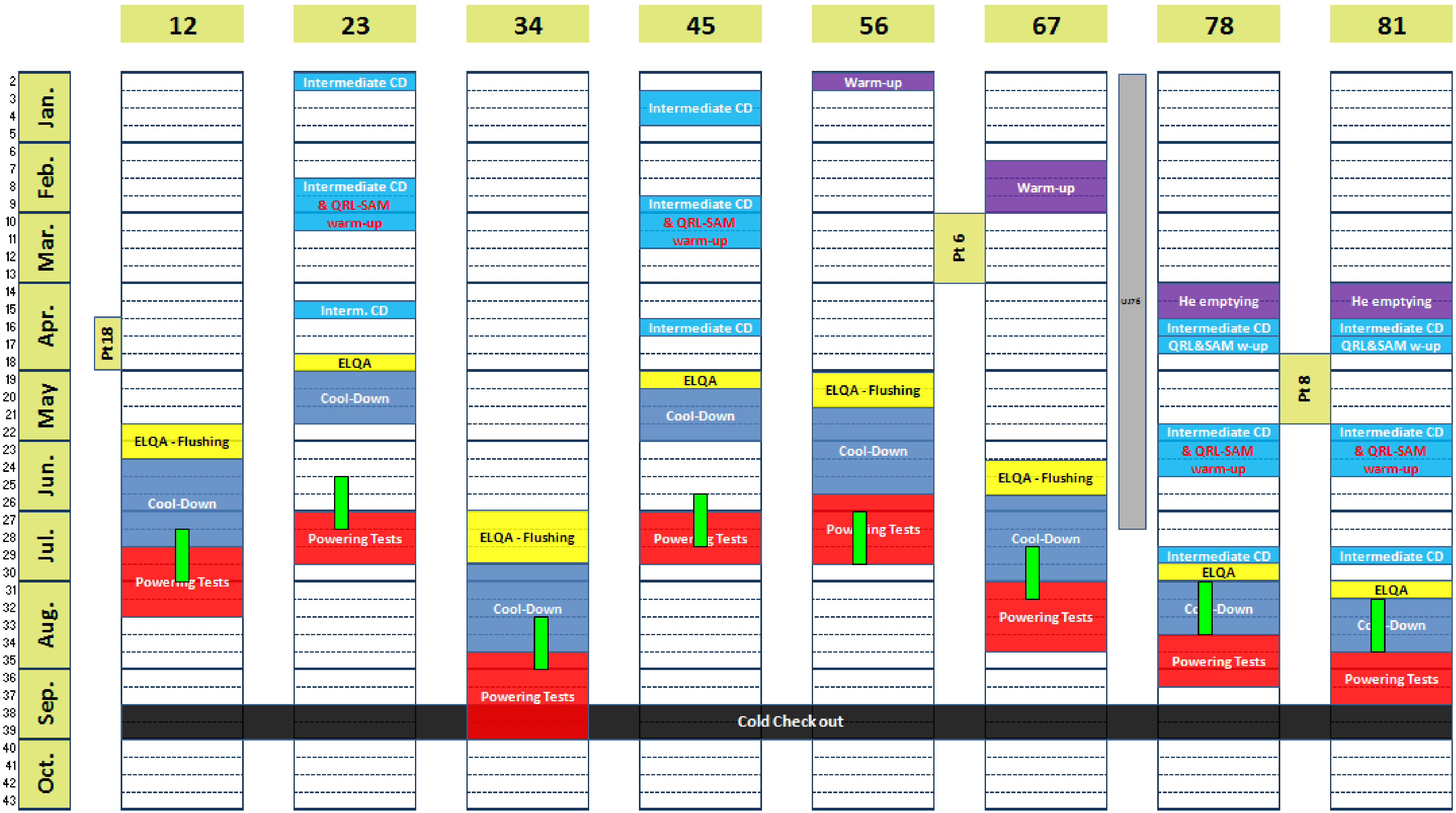
Long Straight Sections

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 '	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	SH
	44 weeks physics possible																									
Delay (4W)	SH	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
Delay (8W)	SH	SH	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH

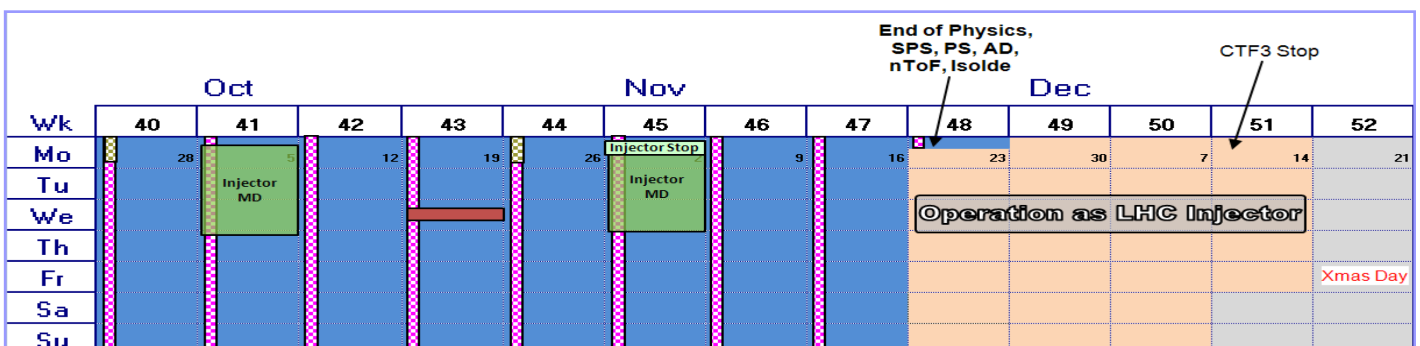
Gain 20 weeks of physics in 2010 by running during winter months

HIGH price Electricity

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.

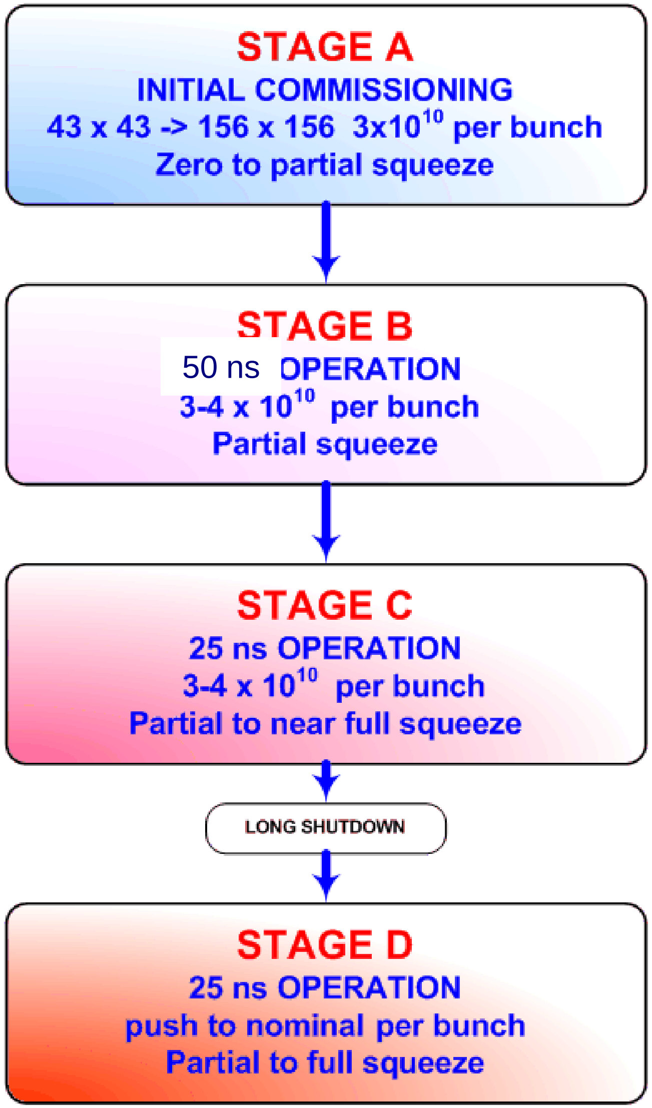


5. Beam Commissioning

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.. ≈100pb-1
  - during next 100 days of operation.. ≈ 200 – 300 pb-1
- End of 2010 run – one month ions

Commissioning stages



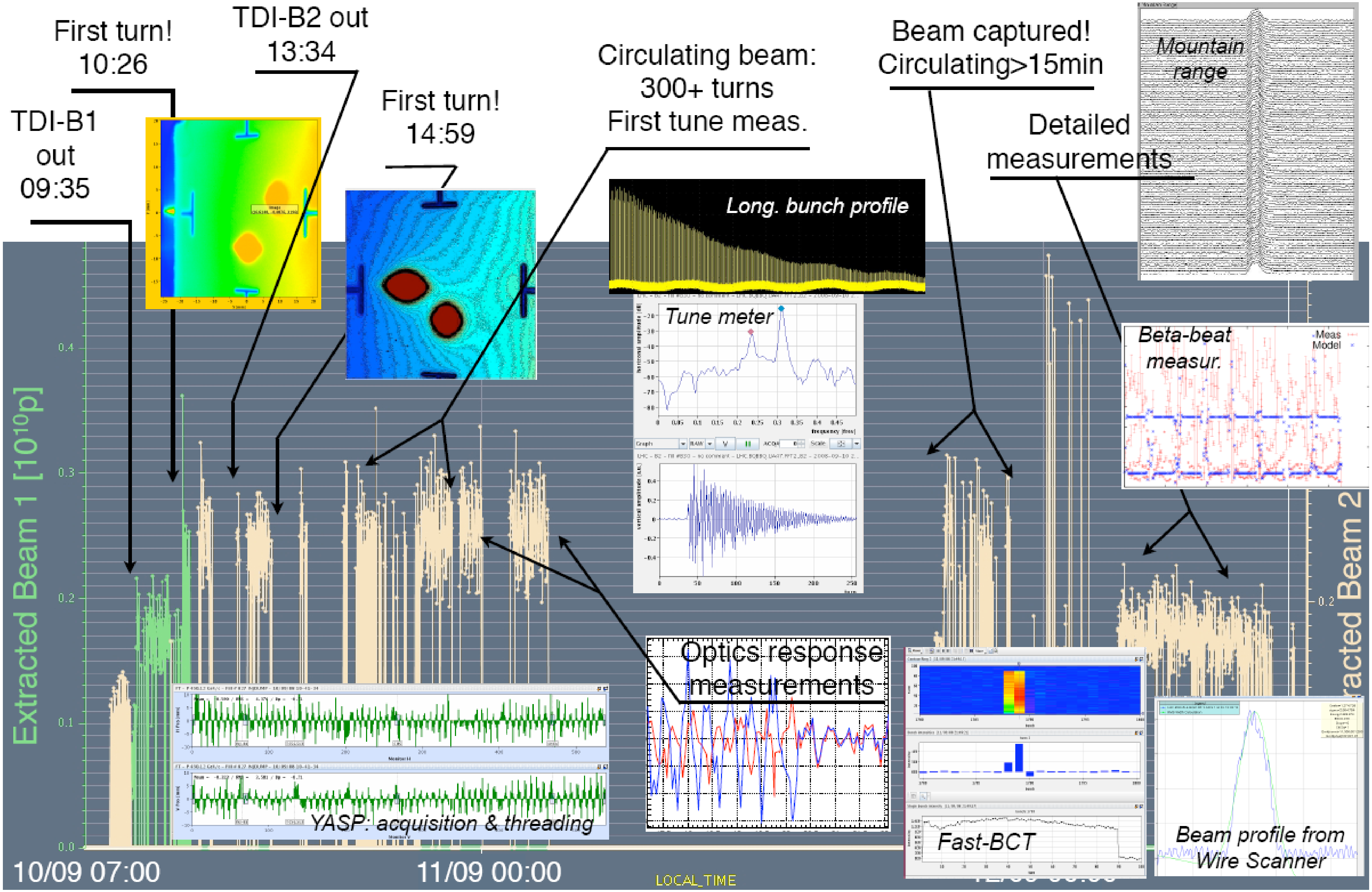
Safely establish colliding beams as quickly as possible

- Initial optics:
  - β*= 11 m in IR 1 & 5
  - β*= 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

RHIC 2000:
- First beam April 3rd
- First successful ramp: June 1st
- First collisions June 12th

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	Ions					
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?

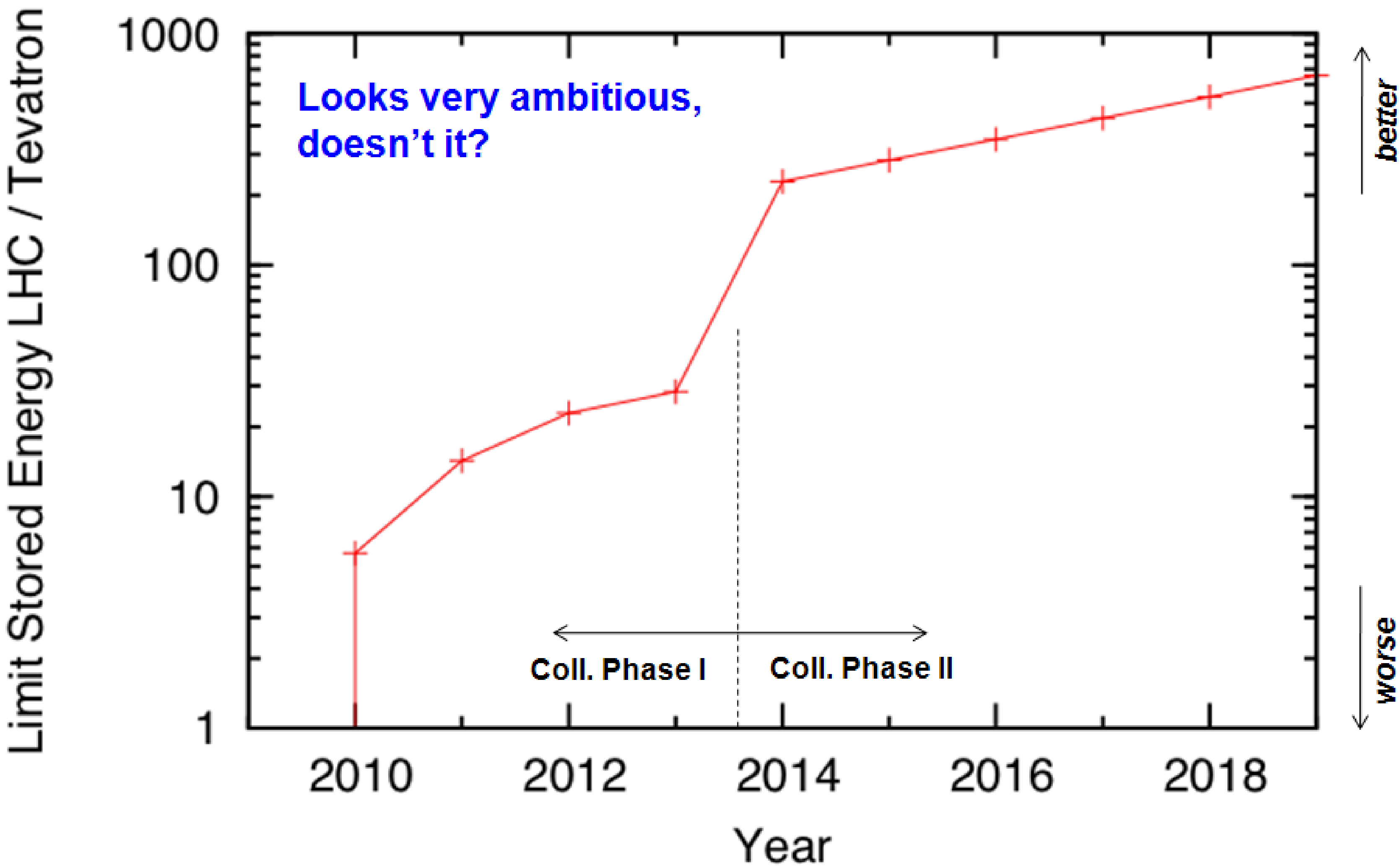
Ralph Assmann

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 x10^{10} 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