Status report on the LHC accelerator complex

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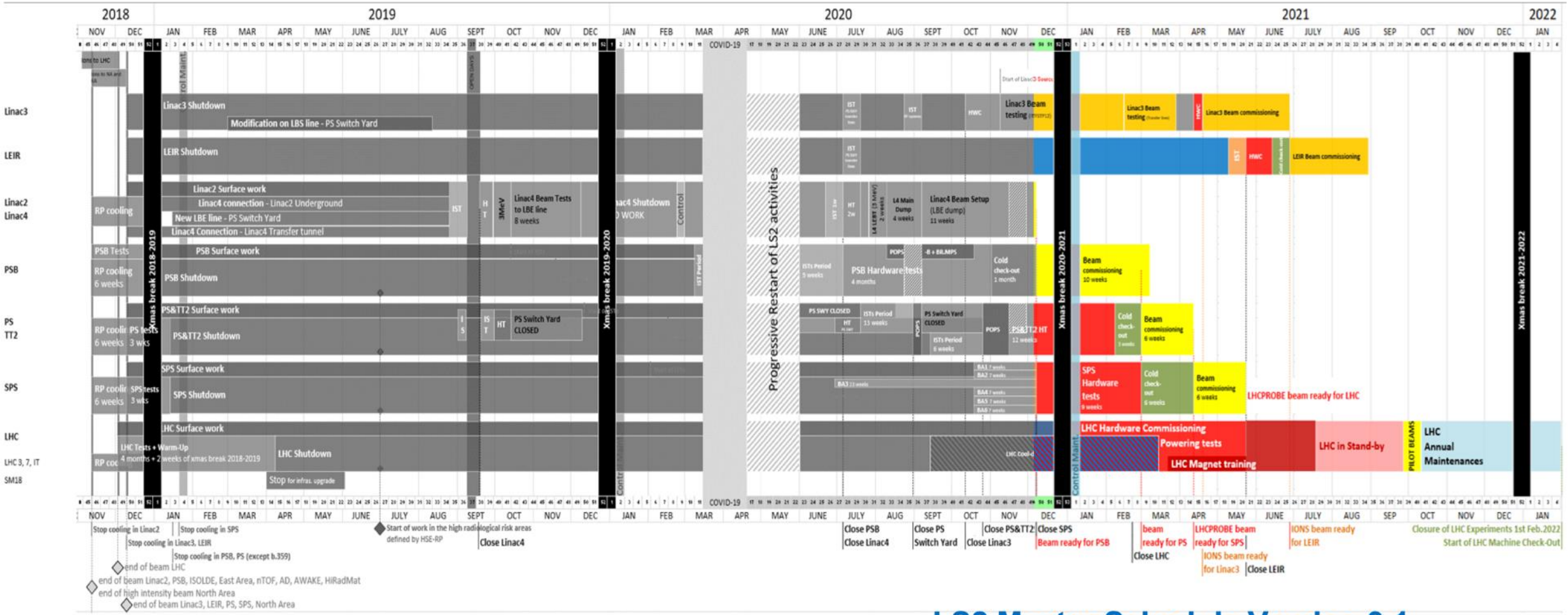
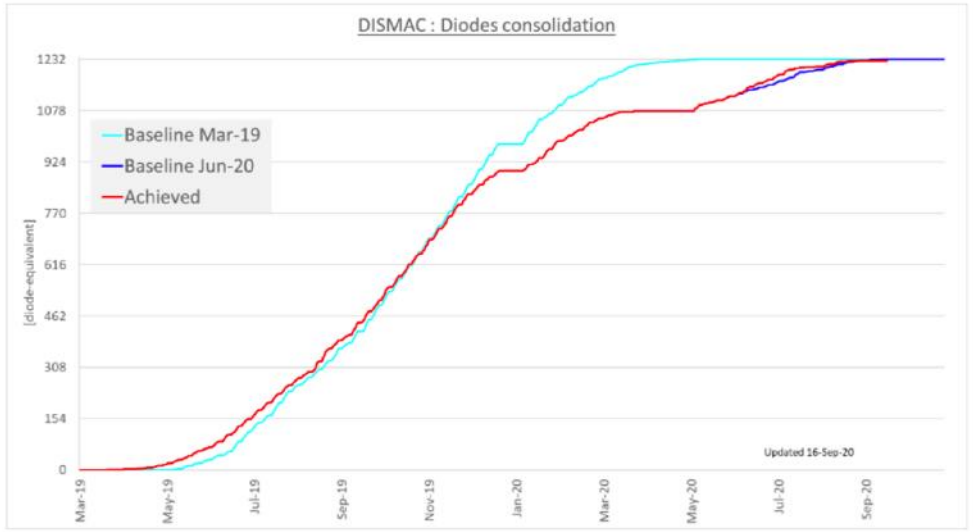
LS2 a great success in spite of COVID

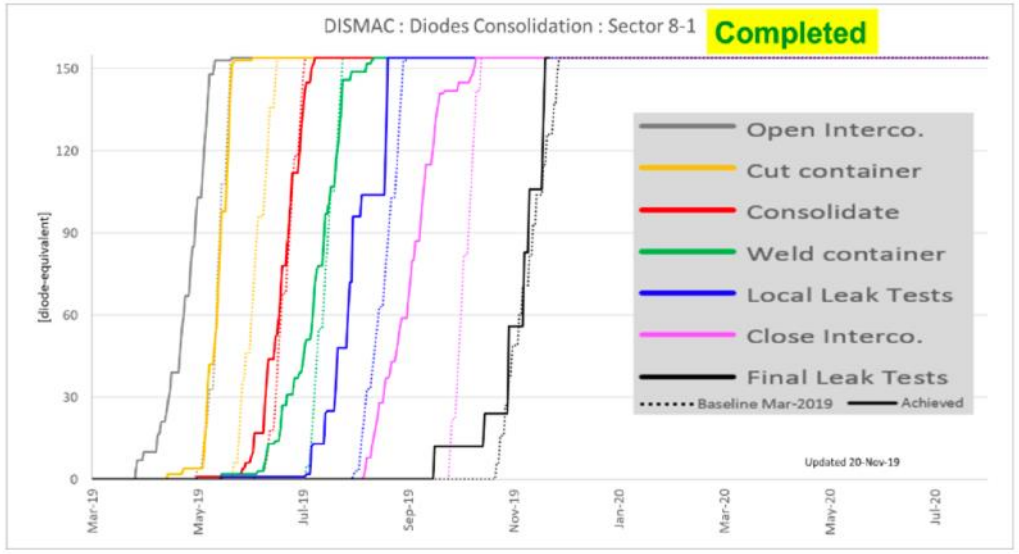


LS2 Master Schedule Version 3.1

DISMAC project status: diode consolidation

Diodes Insulation and Super-conducting MAgnets Consolidation





1st March 2019:
First Interconnection opening
QBBI.A30L8 sector 78

Participation of several teams (OPCLIC [TE-MSC], BLM [BE-BI], CRIM [TE-CRG], PO [BE-OP]) including collaborators from NTUA (National Technical University of Athens) and WUST (Wroclaw University of Science and Technology)

3rd August 2020:
Last Interconnection Closure
QBBI.8L8 sector 78

LS2 Report: All interconnections in the LHC have been closed

The DISMAC project is coming to an end: the last of the 1232 interconnections was closed in August and the cool-down of the machine will now begin

16 SEPTEMBER, 2020 | By Anaïs Schaeffer

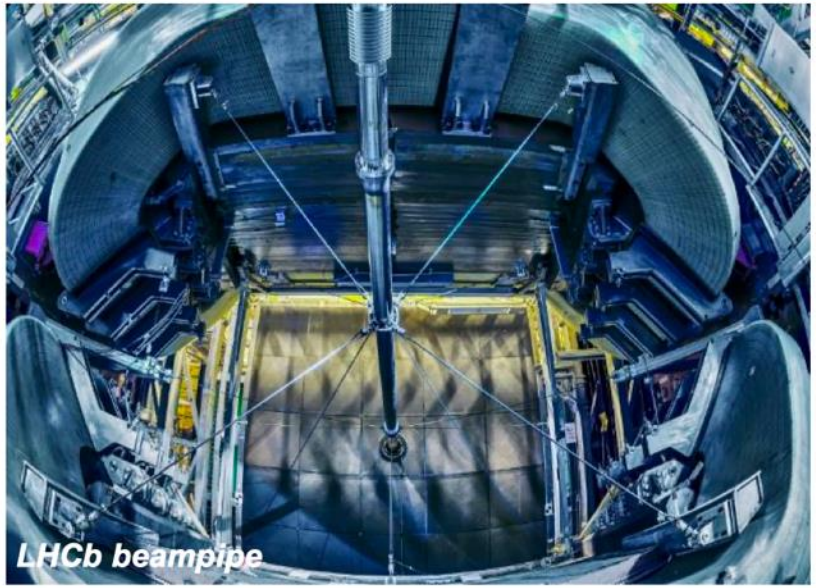
Wroclaw University of Science and Technology

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

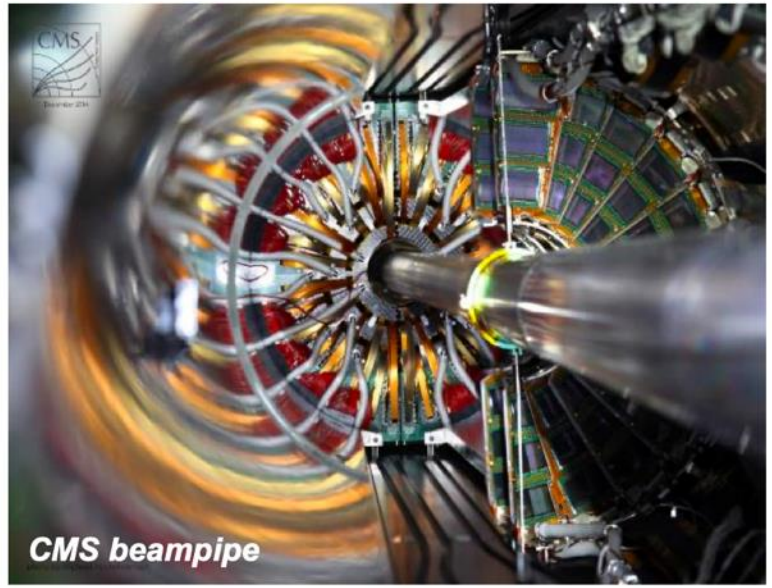
Henryk Niedwodiczanski Institute for Nuclear Physics

Pakistan Atomic Energy Commission

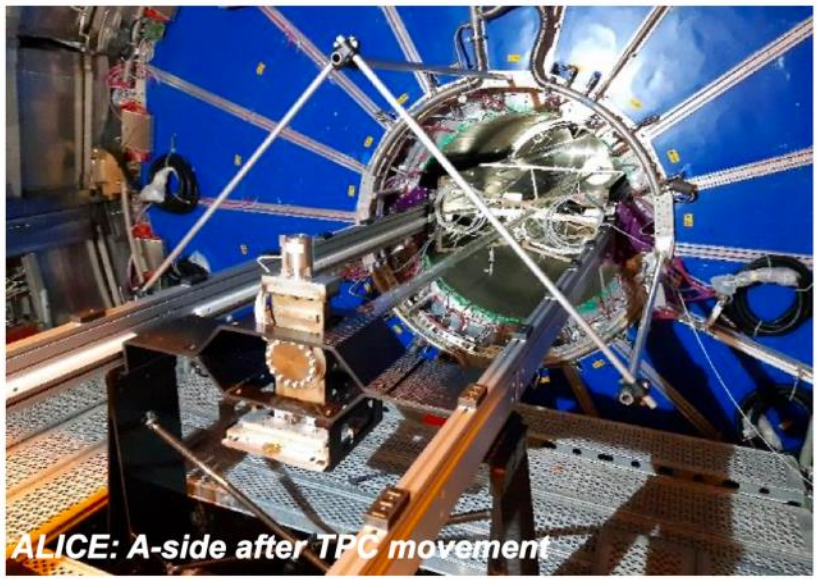
Consolidation and upgrade of LHC experiments' vacuum

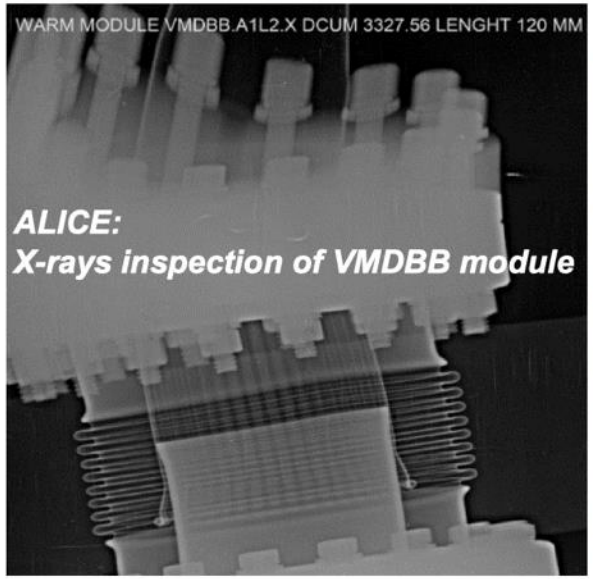

LHCb beampipe


LHCb beampipe



CMS beampipe


ALICE: A-side after TPC movement



ALICE:
X-rays inspection of VMDBB module

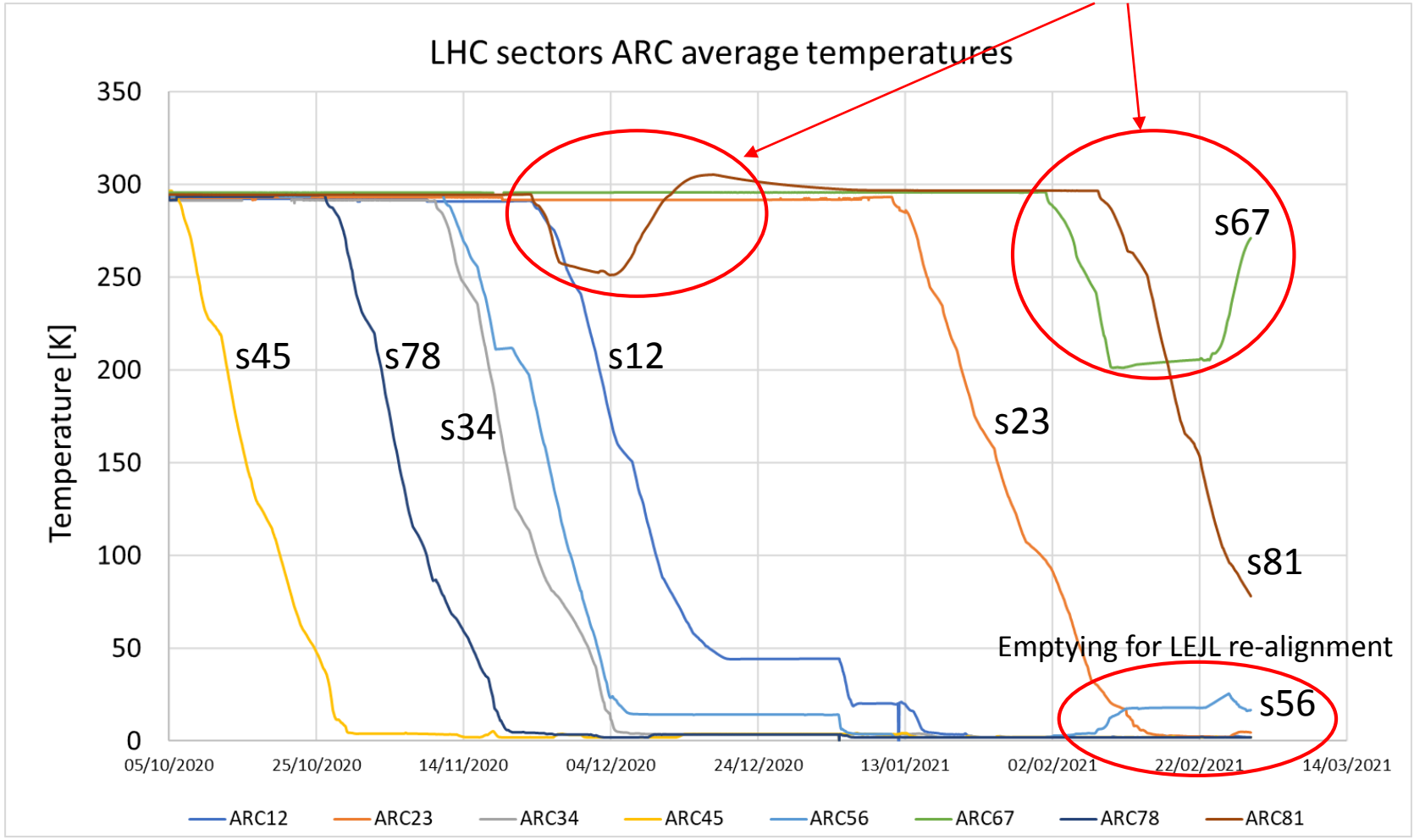

ATLAS beampipe dismounting

LS2 is drawing to a close

- Injectors back in the hands of the Operations group
  - Beam in L4 and Booster, PS this week, and SPS preparing for beam
  - Booster commissioning: H^- charge exchange injection at 160 MeV from Linac4, beam to 2 GeV and extracted…
- In the LHC the bulk of LS2 activities have been completed
  - DSO tests for powering performed
  - Electrical QA: all 8 sectors qualified at warm, after DISMAC
  - Final alignments ongoing by survey team
- The key is planned to be handed over to OP on 15 March

Cool down process

- 5 sectors are running at required conditions
- 3 sectors are in transients



MB.C22R8 activity

On 27 Nov. 20, a short to ground was detected on RB circuit and localised on the lyra of the magnet C22R8 → LMC 20/1/20

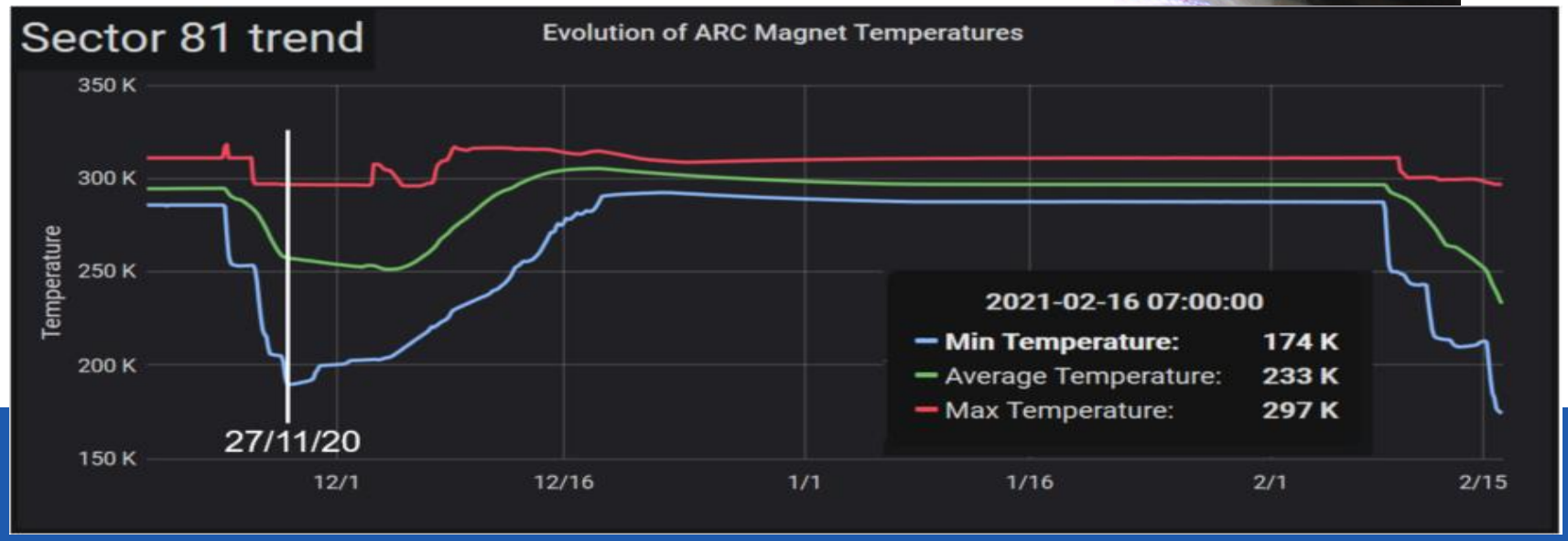
On 6 Jan. 21, the lyra insulation was reinforced Procedure 1430405.

On 13 Jan. 21, closure of QBQI.22R8 W bellow

On 19 Jan. 21, ElQA test at warm passed

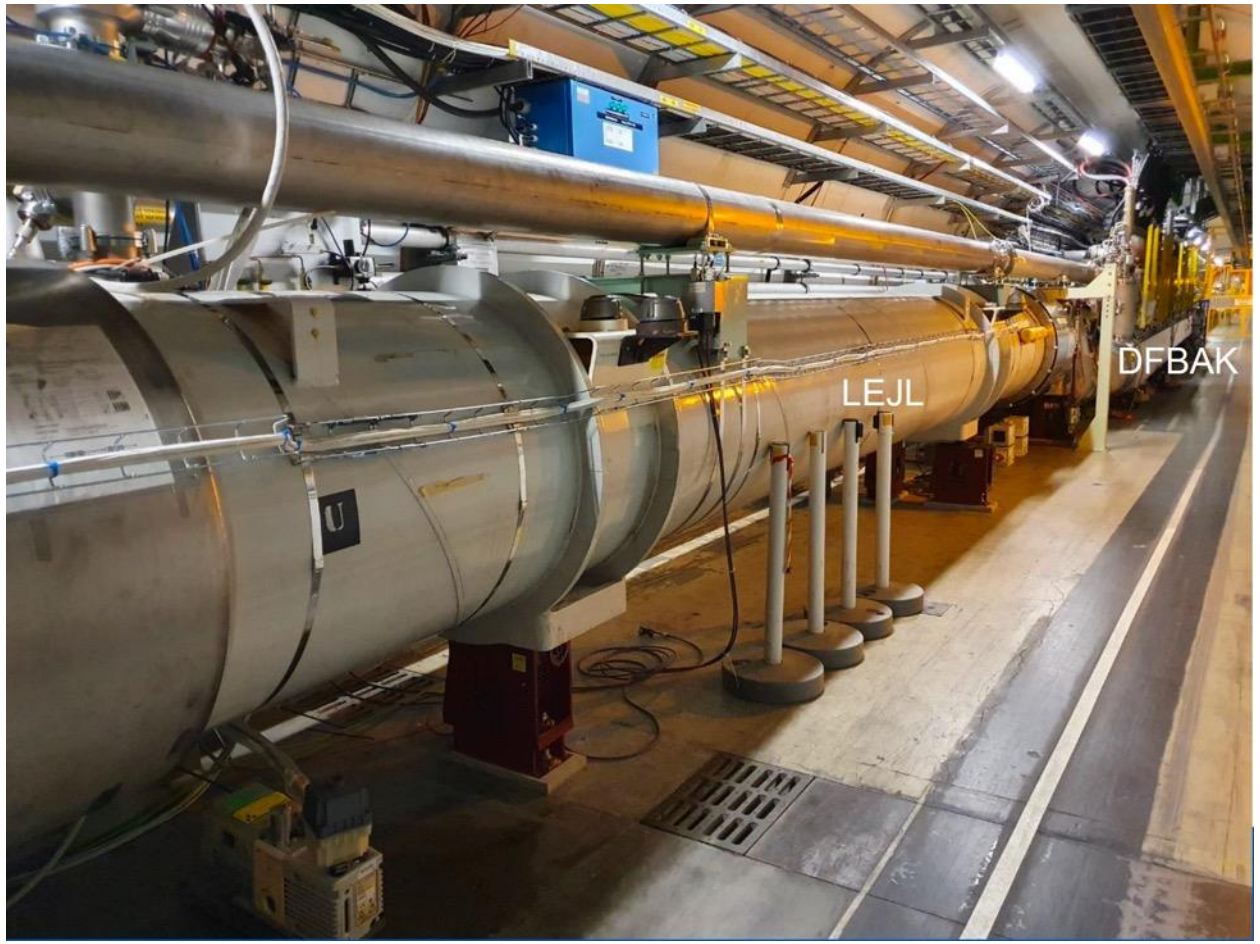
On 25 Jan. 21, pressurisation test at 18 bars, validated with the global leak test HSE-OHS- 2458898

On 8 Feb. 21, start of cool down



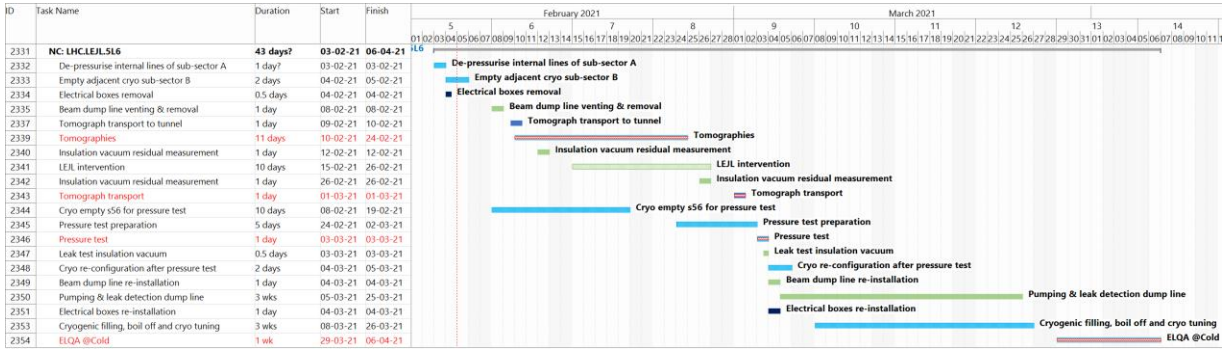
Vertical offset of LEJL.5L6

LEJL is a connection cryostat located between MB.A8L6 and the DFBAK (no Q7.L6). The dump line stands on top of it



A significant vertical misalignment has just been found. Realignment is imperative.

Will keep the cryogenic sub-sectors concerned at 20 K and realign very carefully at cold.



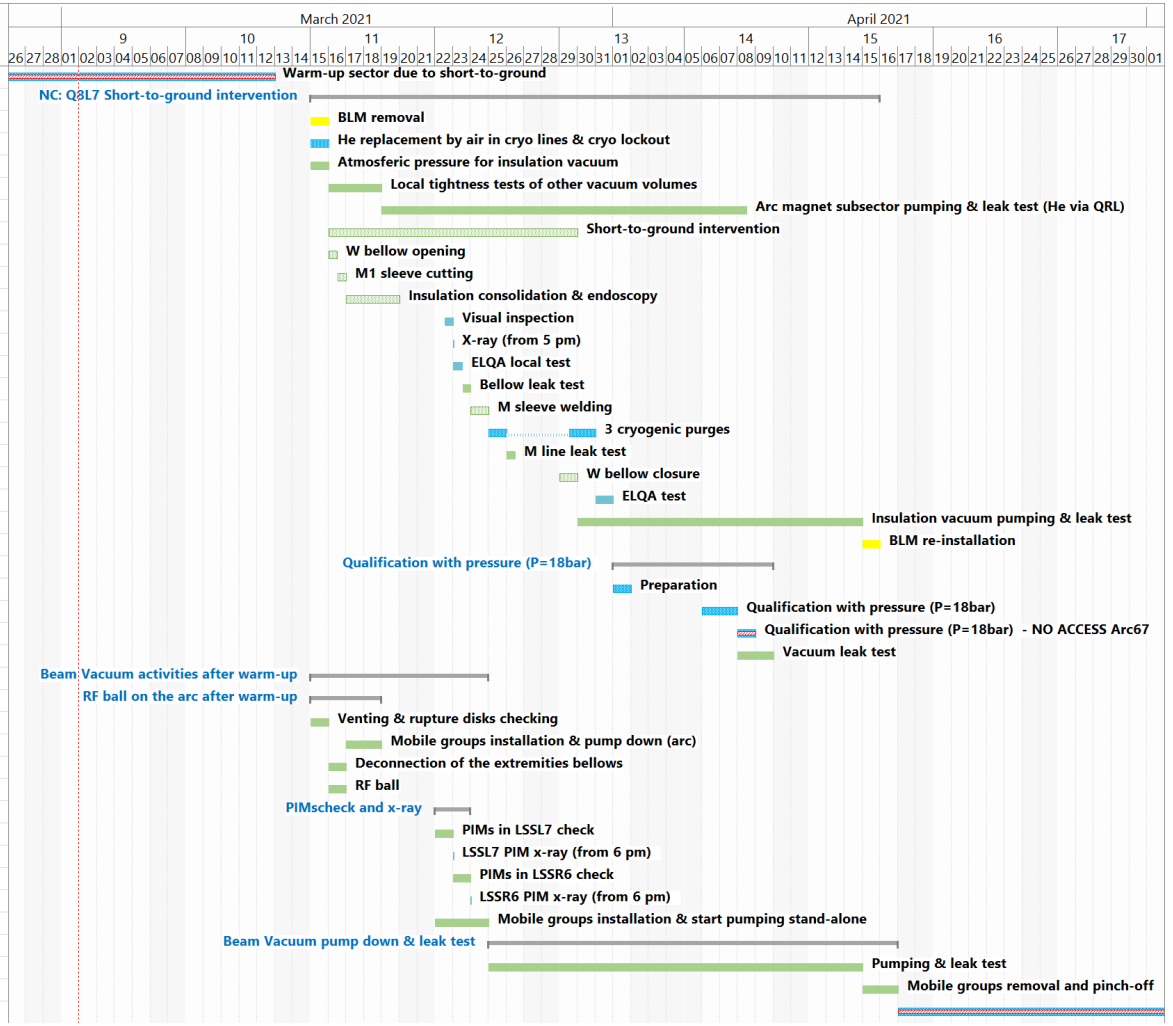
ID	Task Name	Duration	Start	Finish
2331	NC: LHC.LEJL.5L6	43 days?	03-02-21	06-04-21
2332	De-pressurise internal lines of sub-sector A	1 day?	03-02-21	03-02-21
2333	Empty adjacent cryo sub-sector B	2 days	04-02-21	05-02-21
2334	Electrical boxes removal	0.5 days	04-02-21	04-02-21
2335	Beam dump line venting & removal	1 day	08-02-21	08-02-21
2337	Tomograph transport to tunnel	1 day	09-02-21	10-02-21
2339	Tomographies	11 days	10-02-21	24-02-21
2340	Insulation vacuum residual measurement	1 day	12-02-21	12-02-21
2341	LEJL intervention	10 days	15-02-21	26-02-21
2342	Insulation vacuum residual measurement	1 day	26-02-21	26-02-21
2343	Tomograph transport	1 day	01-03-21	01-03-21
2344	Cryo empty s56 for pressure test	10 days	08-02-21	19-02-21
2345	Pressure test preparation	5 days	24-02-21	02-03-21
2346	Pressure test	1 day	03-03-21	03-03-21
2347	Leak test insulation vacuum	0.5 days	03-03-21	03-03-21
2348	Cryo re-configuration after pressure test	2 days	04-03-21	05-03-21
2349	Beam dump line re-installation	1 day	04-03-21	04-03-21
2350	Pumping & leak detection dump line	3 wks	05-03-21	25-03-21
2351	Electrical boxes re-installation	1 day	04-03-21	04-03-21
2353	Cryogenic filling, boil off and cryo tuning	3 wks	08-03-21	26-03-21
2354	ELQA @Cold	1 wk	29-03-21	06-04-21

There will a knock-on to the planning in sector 56 but we have time.

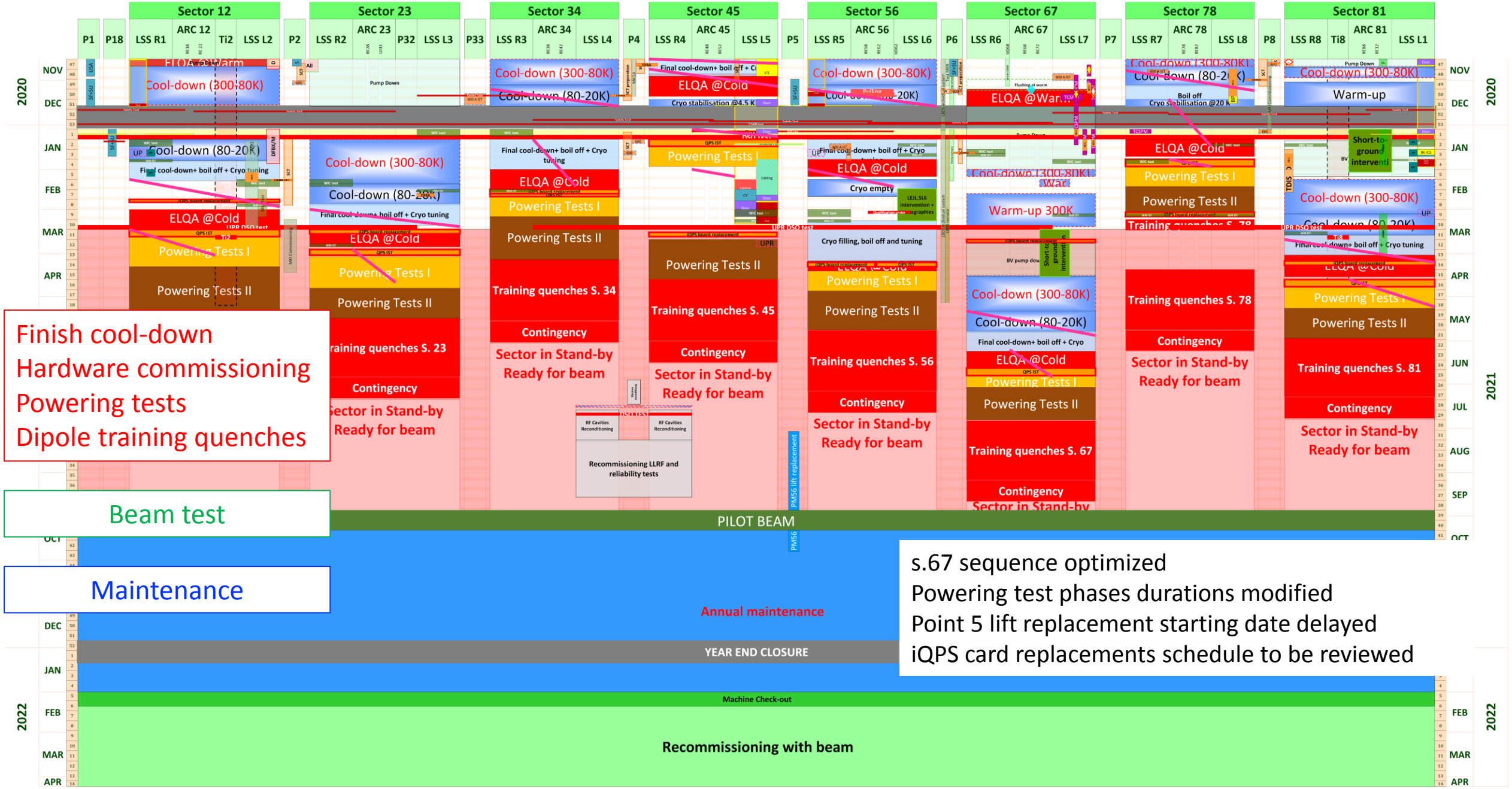
S67 intervention sequence

Q8L7 Earth-Fault

ID	Task Name	Duration	Start	Finish
3052	Warm-up sector due to short-to-ground	3.4 wks	18-02-21	12-03-21
3053	**NC: Q8L7 Short-to-ground intervention**	**22 days**	**15-03-21**	**15-04-21**
3054	BLM removal	1 day	15-03-21	15-03-21
3055	He replacement by air in cryo lines & cryo lockou	1 day	15-03-21	15-03-21
3056	Atmosferic pressure for insulation vacuum	1 day	15-03-21	15-03-21
3057	Local tightness tests of other vacuum volumes	3 days	16-03-21	18-03-21
3058	Arc magnet subsector pumping & leak test (He v	2.5 wks	19-03-21	08-04-21
3059	Short-to-ground intervention	10 days	16-03-21	29-03-21
3060	W bellow opening	0.5 days	16-03-21	16-03-21
3061	M1 sleeve cutting	0.5 days	16-03-21	16-03-21
3062	Insulation consolidation & endoscopy	3 days	17-03-21	19-03-21
3063	Visual inspection	0.5 days	22-03-21	22-03-21
3064	X-ray (from 5 pm)	0.5 edays	22-03-21	23-03-21
3065	ELQA local test	0.5 days	23-03-21	23-03-21
3066	Bellow leak test	0.5 days	23-03-21	23-03-21
3067	M sleeve welding	1 day	24-03-21	24-03-21
3068	3 cryogenic purges	4 days	25-03-21	30-03-21
3069	M line leak test	0.5 days	26-03-21	26-03-21
3070	W bellow closure	1 day	29-03-21	29-03-21
3071	ELQA test	1 day	31-03-21	31-03-21
3072	Insulation vacuum pumping & leak test	2 wks	30-03-21	14-04-21
3073	BLM re-installation	1 day	15-04-21	15-04-21
3074	**Qualification with pressure (P=18bar)**	**5 days**	**01-04-21**	**09-04-21**
3075	Preparation	1 day	01-04-21	01-04-21
3076	Qualification with pressure (P=18bar)	2 days	06-04-21	07-04-21
3077	Qualification with pressure (P=18bar) - NO ACC	1 day	08-04-21	08-04-21
3078	Vacuum leak test	2 days	08-04-21	09-04-21
3079	**Beam Vacuum activities after warm-up**	**8 days**	**15-03-21**	**24-03-21**
3080	**RF ball on the arc after warm-up**	**4 days**	**15-03-21**	**18-03-21**
3081	Venting & rupture disks checking	1 day	15-03-21	15-03-21
3082	Mobile groups installation & pump down (arc	2 days	17-03-21	18-03-21
3083	Deconnection of the extremities bellows	1 day	16-03-21	16-03-21
3084	RF ball	1 day	16-03-21	16-03-21
3085	**PIMscheck and x-ray**	**2 days**	**22-03-21**	**24-03-21**
3086	PIMs in LSSL7 check	1 day	22-03-21	22-03-21
3087	LSSL7 PIM x-ray (from 6 pm)	0.5 edays	22-03-21	23-03-21
3088	PIMs in LSSR6 check	1 day	23-03-21	23-03-21
3089	LSSR6 PIM x-ray (from 6 pm)	0.5 edays	23-03-21	24-03-21
3092	Mobile groups installation & start pumping stan	3 days	22-03-21	24-03-21
3093	**Beam Vacuum pump down & leak test**	**15 days**	**25-03-21**	**16-04-21**
3094	Pumping & leak test	2.6 wks	25-03-21	14-04-21
3095	Mobile groups removal and pinch-off	2 days	15-04-21	16-04-21
3096	Cool-down (300-80K)	3.5 ewks	16-04-21	11-05-21



Baseline 4.2 – IN WORK (optimized)



Finish cool-down
Hardware commissioning
Powering tests
Dipole training quenches

Beam test

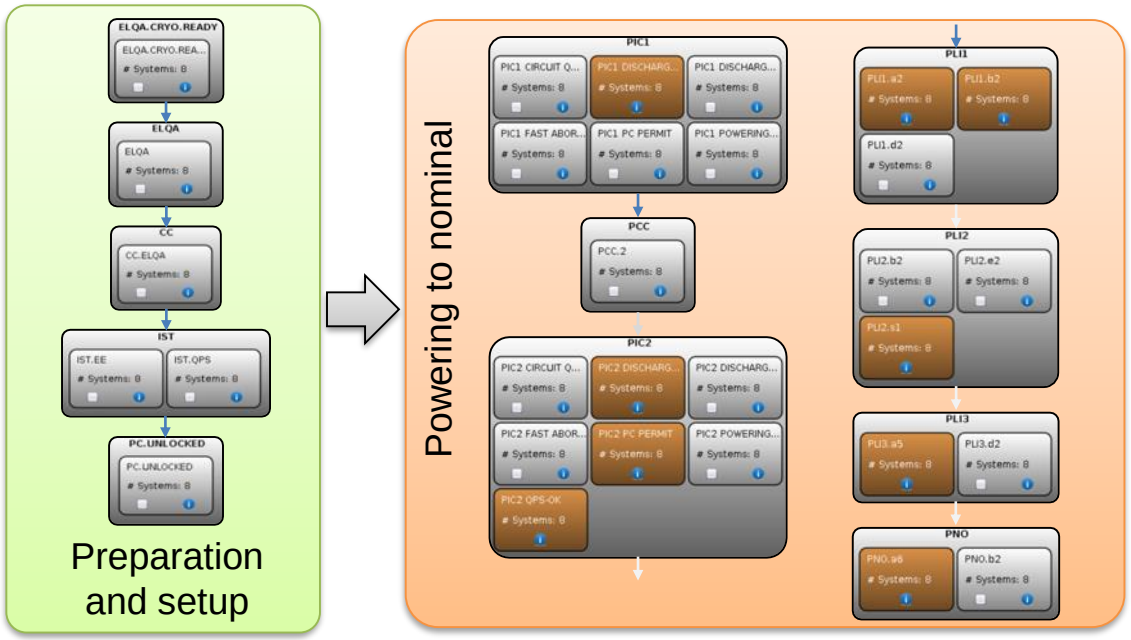
Maintenance

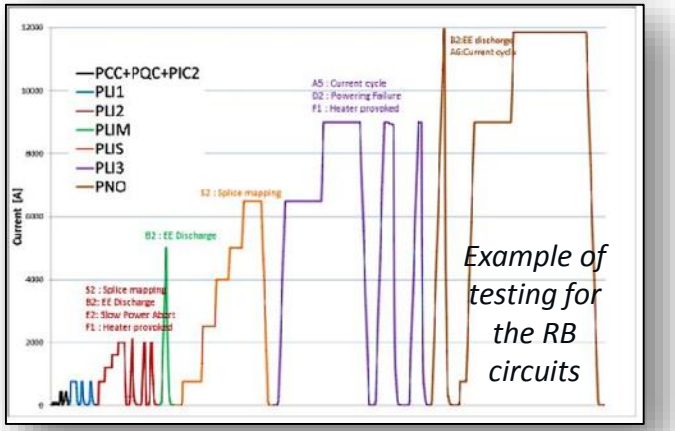
s.67 sequence optimized
Powering test phases durations modified
Point 5 lift replacement starting date delayed
iQPS card replacements schedule to be reviewed

Powering tests of magnet circuits

Following Electrical Quality Assurance (ElQA) a series of current cycles has to be performed to test:

- Magnet performance
- Powering interlocks
- Full powering chain
- Protection functionalities





Powering tests after LS1

- In total, **16249 powering tests** were executed (including repeated and failed) on the **1572 superconducting circuits**
- Essentially the **same amount** of tests has to be carried out

Powering tests: Phases 1 & 2

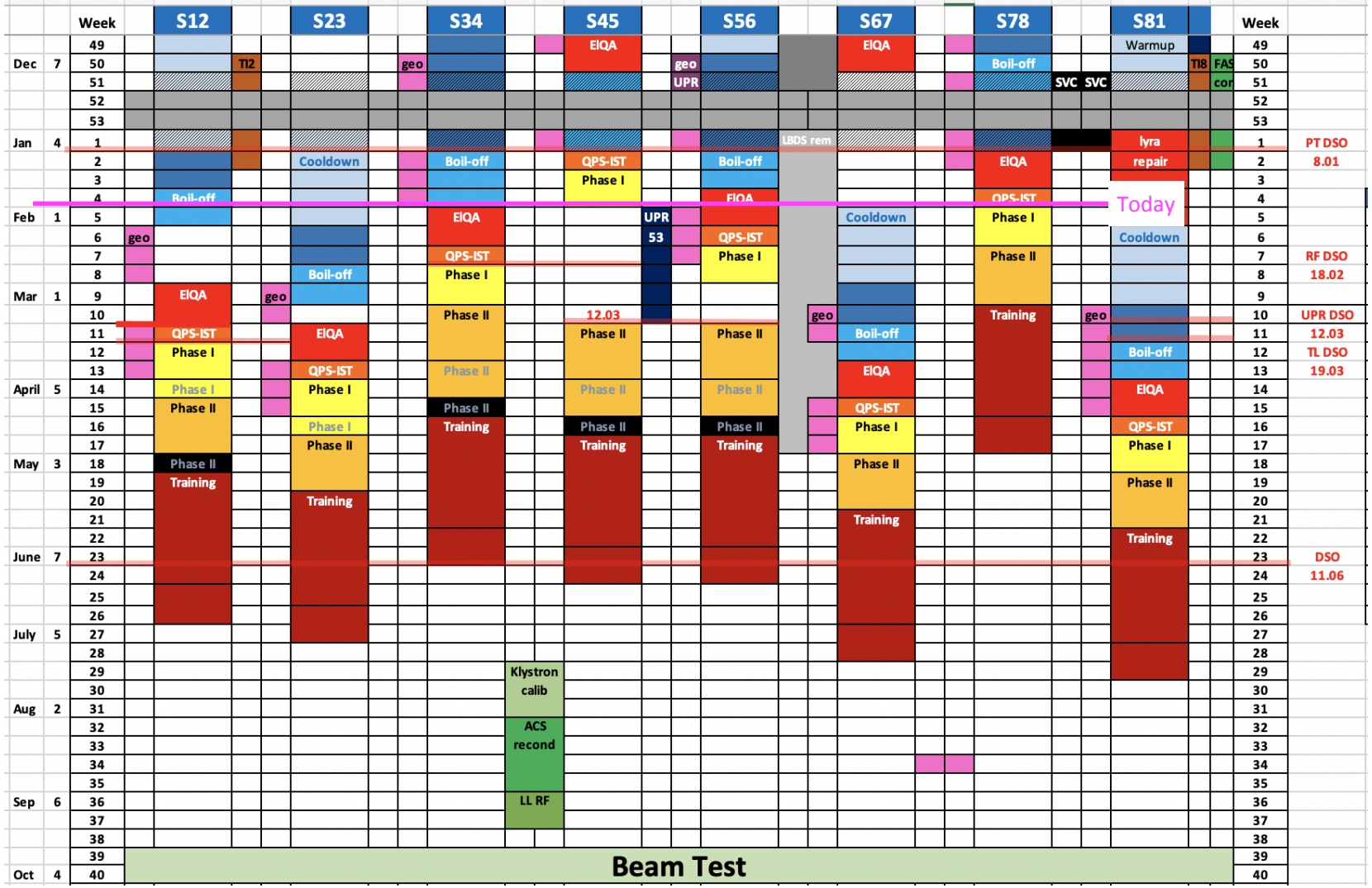
	Powering	He Spill	Access
Powering Test Phase I a	Up to 30 kJ per circuit	320g/s	Expert access only Restrict other personnel access to avoid the risk related to co-activities while powering the magnet circuits.
Powering Test Phase I b	Up to 100 KJ per circuit	1 kg/s	No access to the area under powering tests
Powering Test Phase II	No limit	40 Kg/s	No access to large parts of the tunnel

References:

[Ref.1] EDMS 1029391 - LHC machine Maximum Credible Incident Pressure build up inside LHC tunnel – Summary, P. Azevedo, B. Delille (2009)

[Ref. 2] EDMS 1410247 - Helium Spill Working Group Recommendations, J. Jiménez, J. Bremer, B. Delille (2014, rev. 2018)

LHC Powering Test Planning



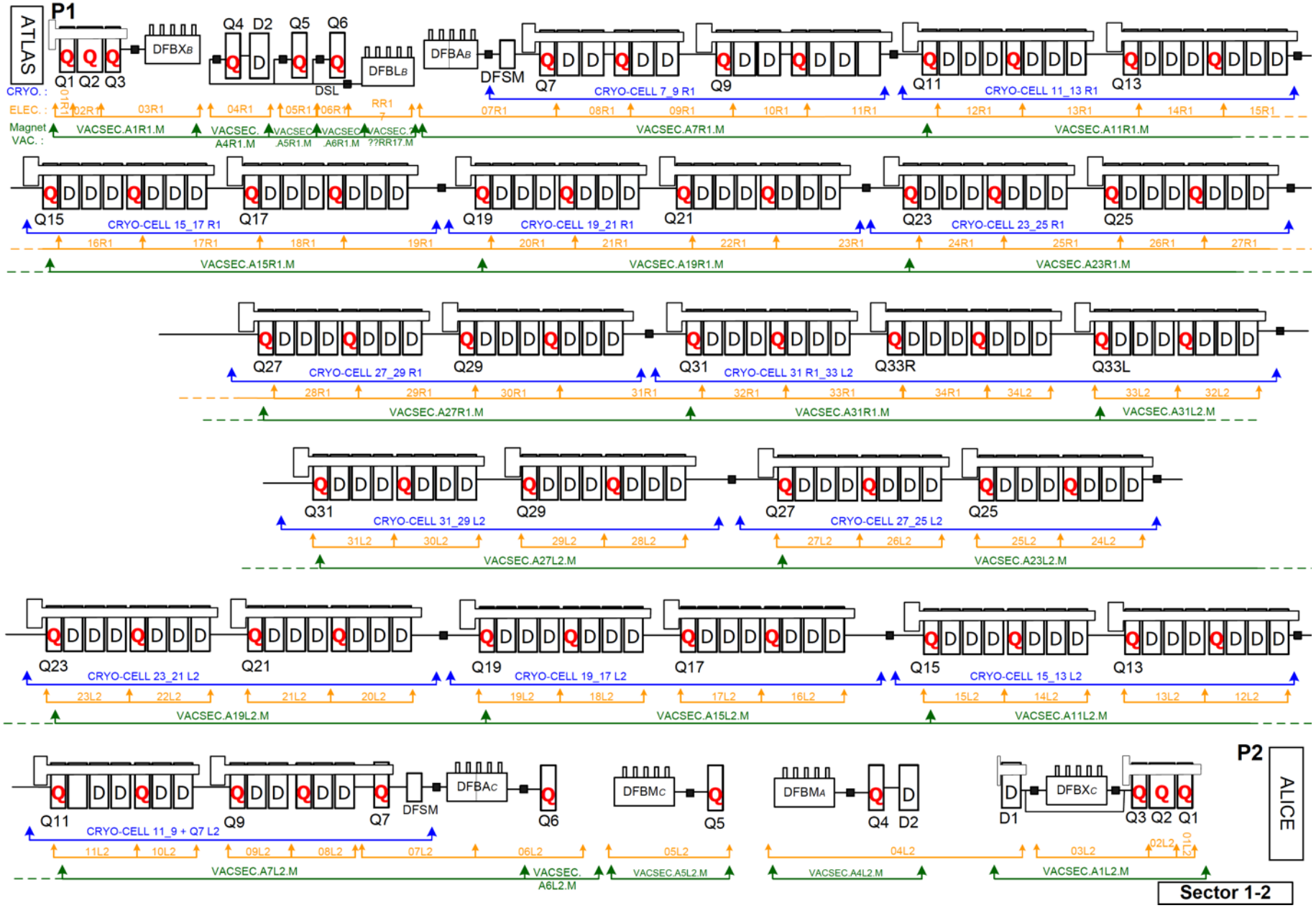
Courtesy of M. Solfaroli & A. Apollonio

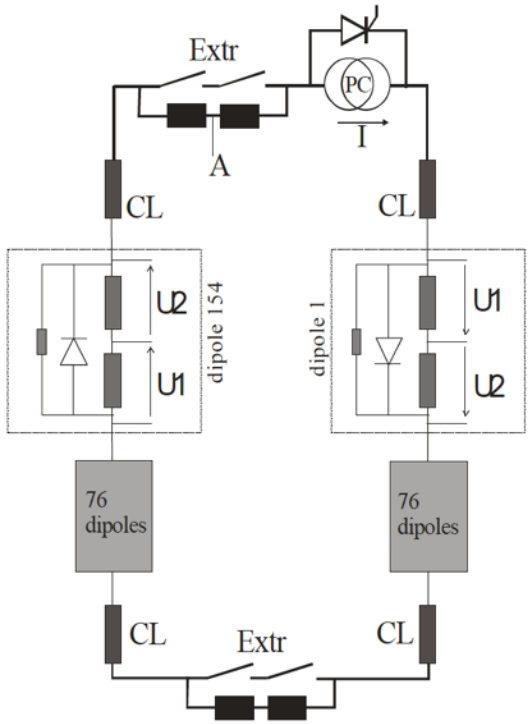
Only Phase 1 at present

Powering tests:

- Phase 1: 2 wks/sector
- Phase 2: 3 wks/sector

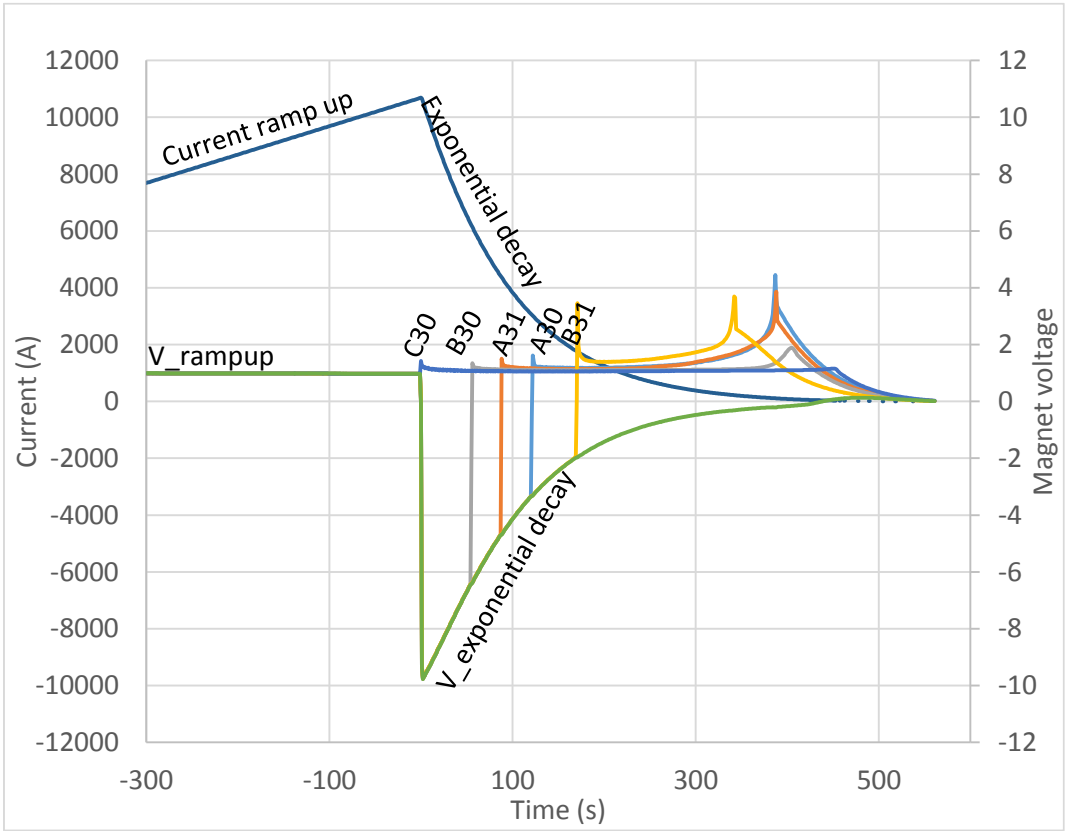
Sector 1-2


ATLAS
P1
Q1 Q2 Q3
DFBXB
Q4 D2 Q5 Q6
DSL
DFBLB
DFBAB
DFSM
Q7
CRYO-CELL 7_9 R1
Q9
Q11
CRYO-CELL 11_13 R1
Q13
CRYO. :
ELEC. :
Magnet
VAC. :
VACSEC.A1R1.M
VACSEC. A4R1.M
VACSEC.A7R1.M
VACSEC.A11R1.M
Q15
CRYO-CELL 15_17 R1
Q17
Q19
CRYO-CELL 19_21 R1
Q21
Q23
CRYO-CELL 23_25 R1
Q25
VACSEC.A15R1.M
VACSEC.A19R1.M
VACSEC.A23R1.M
Q27
CRYO-CELL 27_29 R1
Q29
Q31
CRYO-CELL 31 R1_33 L2
Q33R
Q33L
VACSEC.A27R1.M
VACSEC.A31R1.M
VACSEC.A31L2.M
Q31
CRYO-CELL 31_29 L2
Q29
Q27
CRYO-CELL 27_25 L2
Q25
VACSEC.A27L2.M
VACSEC.A23L2.M
Q23
CRYO-CELL 23_21 L2
Q21
Q19
CRYO-CELL 19_17 L2
Q17
Q15
CRYO-CELL 15_13 L2
Q13
VACSEC.A19L2.M
VACSEC.A15L2.M
VACSEC.A11L2.M
Q11
CRYO-CELL 11_9 + Q7 L2
Q9
Q7
DFSM
DFBAC
Q6
DFBMC
Q5
DFBMA
Q4 D2
D1
DFBXC
Q3 Q2 Q1
P2
ALICE
VACSEC.A7L2.M
VACSEC. A6L2.M
VACSEC.A5L2.M
VACSEC.A4L2.M
VACSEC.A1L2.M
Sector 1-2


Extr
PC
I
A
CL
CL
U2
U1
dipole 154
dipole 1
U1
U2
76 dipoles
76 dipoles
CL
Extr
CL

Quench event during HWC in the LHC

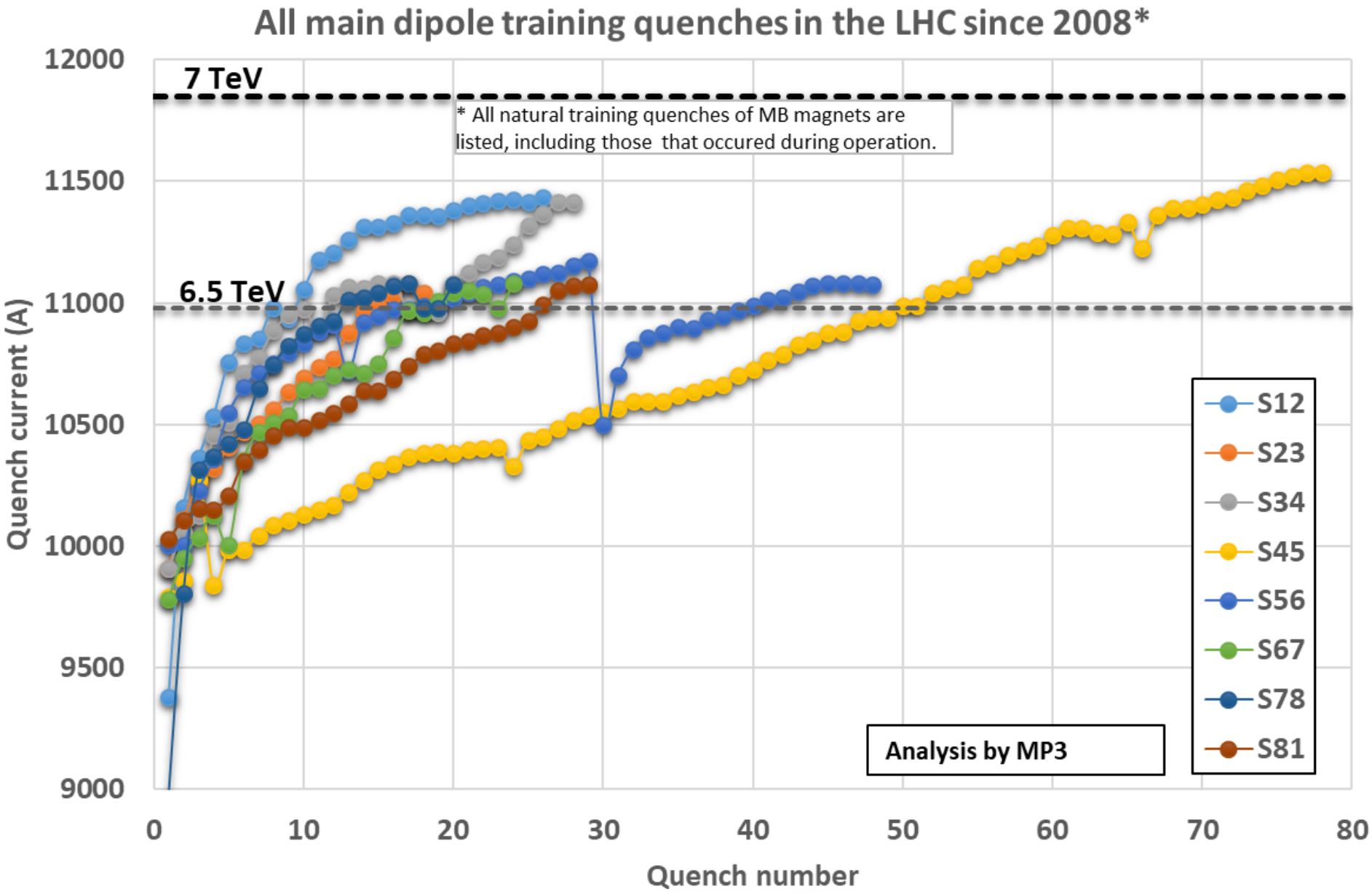
Example of a quench event in the magnet in position C30



- 154 magnets in series
- Quench in a magnet triggers energy extraction opening. Current in the circuit decays exponentially with τ = 100 s.
- Negative inductive voltage across each superconducting magnet.
- Positive voltage across quenched magnet when current goes through bypass diode.

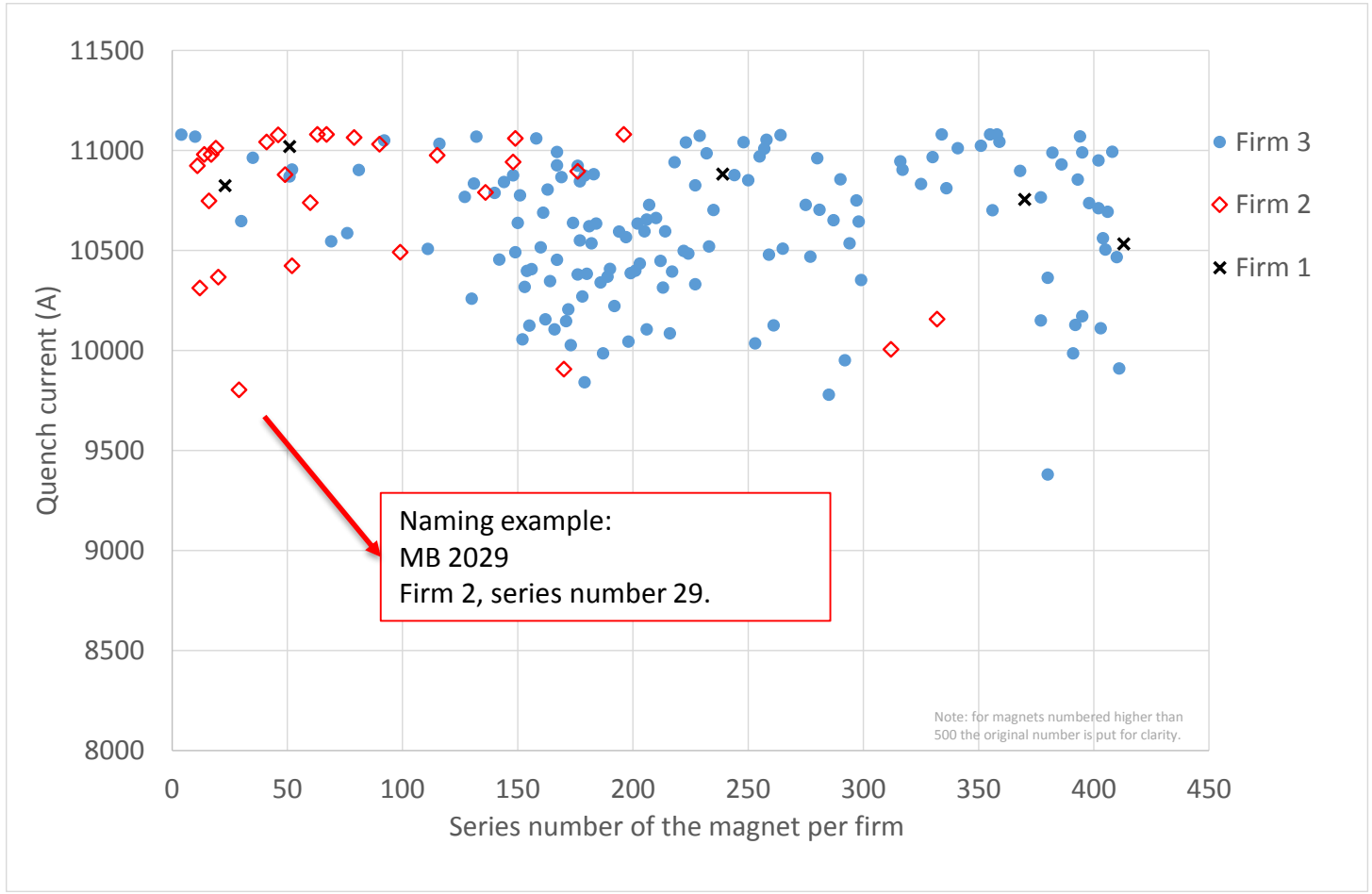
Typically a training quench is followed by secondary quenches through heat propagation.

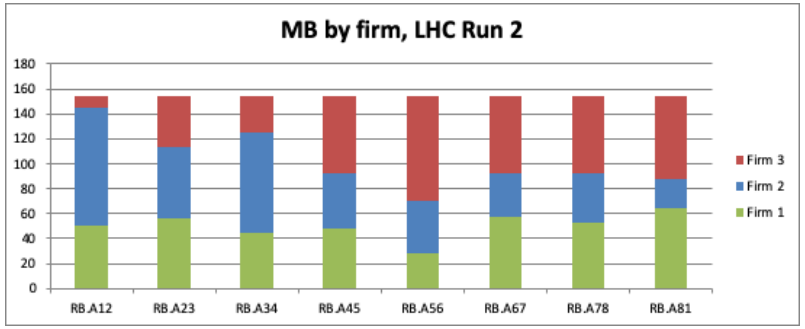
Each quench implies a certain risk (heater failure, inter-turn short, short-to-ground, pressure-related damage, etc)



https://twiki.cern.ch/twiki/bin/viewauth/MP3/WebHome

HWC 2015 – all 2015 quenches in one figure.





Main dipole training

- Originally allocated time for training in each sector was calculated using the number of predicted quenches.
- This foresaw 108 quenches for the “slowest” sector (S45), meaning **8 weeks with rate of 2 quenches/day**.
- Present schedule allocates **6+2 weeks, for each sector**.
- High level of parallelism foreseen

- Quite some margin in the majority of the cases - **2 quenches/day/sector assumption is optimistic**:
  - with increased energy and parallel recovery, **recovery time increases to ~15h**
  - due to tunnel activities and resources limitations, some delays may occur before launching quenches
- S67 is on the critical path, S45 is the “slowest” sector - **training has to be completed before RF commissioning** (8 weeks) required for the beam test in week 39-40.

The target is 7 TeV (~600 training quenches expected for main dipoles)

HWC of other systems (beam dump, injection, collimation, BI etc.) in the shadow of power tests & training

Beam test and checkout

- **Current test planning in weeks 39 and 40 :**
  - **3 days of machine checkout**,
  - **7 days of beam test.**

- Preparation: period May – September for system commissioning, IST, dry runs etc.
  - Minimize work during checkout period.

- **Machine checkout period** – **conditions** :
  - Ring closed (also experiments!) – no access anywhere.
  - All vacuum valves opened, including those around the experiments.

- **Machine checkout period** – **activities** :
  - Operation of the beam interlock (BIS) and dump (LBDS) systems in nominal conditions.
  - Critical machine protection tests of BIS and LBDS.
  - Final dry tests of the machine under nominal conditions.
  - Beam in the TI2 and TI8 transfer lines, final check.
    - Expect the first TI2/8 beam tests to be scheduled a few weeks earlier, dates to be defined.

Injection beam test program

- A **minimum beam test program at 450 GeV** should include:
  - Inject, circulate and capture bunches, good closed orbit,
  - Measure and correct optics,
  - Measure aperture – global, local in IR1/2/5/8

  } **probe bunch**

- A **minimum pedestal** of **system commissioning activities** have to be scheduled to achieve this program :
  - Beam interlock system (and key clients), LBDS, Post-mortem,
  - RF system for capture, cavity phasing,
  - Minimal collimation setup for aperture protection,
  - Injection system test,
  - BPM, BLM and tune measurements, RF modulation,
  - AC dipole for optics measurements, ADT for excitation,
  - FIDEL corrections.

Ramp to 7 TeV

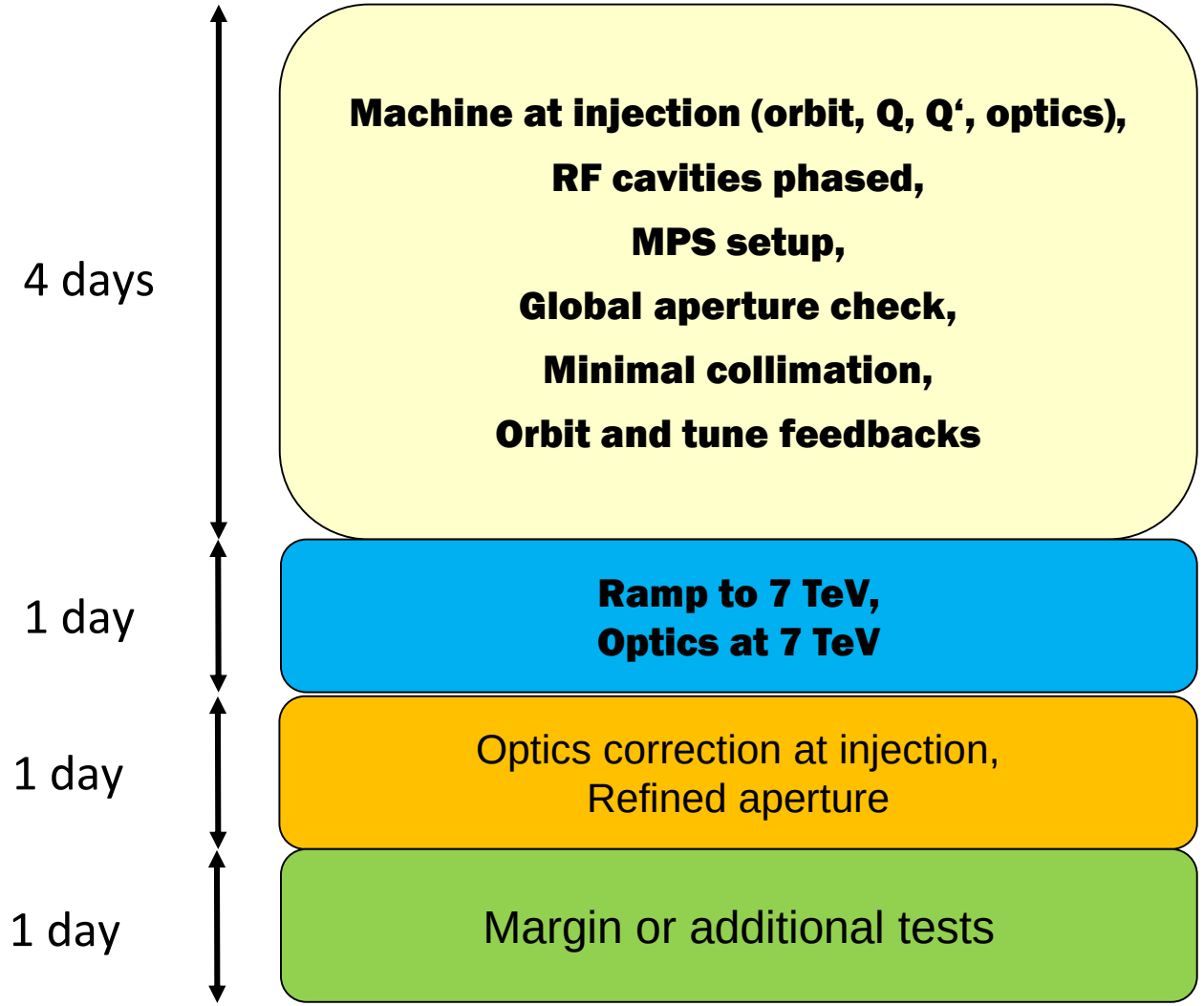
- A **ramp to 7 TeV** requires a **small squeeze in IR2/8** (even at constant β^*).
  - Injection optics is **not** scalable to 7 TeV.
- Ramp preparation – for a probe bunch:
  - Machine in reasonable state at injection (orbit, Q, Q‘, optics),
  - RF cavities phased,
  - MPS setup & checks (BLM triggers, AGK…),
  - Global aperture checked, minimal collimation for probes, loss maps (ADT or 1/3),
  - Orbit and tune feedbacks in simple configuration (constant orbit and tunes).
- Ramp preparation activities will require **~ 4 days.**
  - ~75% of the preparations are also required for the 450 GeV test program.
- If the **ramp can be completed after 5 days**, including optics measurements at 7 TeV, this could leave **2 days of margin** for:
  - Optics corrections at injection – 1 shift,
  - Aperture measurements at injection : global, local IR – 2-3 shifts,
  - A few extra activities (to be defined) – 2-3 shifts.

Nominal bunch and collisions

- Most experiments have indicated interest to profit from potential 450 GeV collisions (except ATLAS for radiation protection reasons)
- Preparing the machine safely for a nominal bunch and for collisions **does not look feasible** within a week **if a ramp to 7 TeV has to be performed**.
  - The beam test would have to be extended by a few days.

Possible beam test outline

Availability of >= 80% required !



Conclusions

- LS2 in the LHC
  - fabulous job by all teams under difficult circumstances
  - activities drawing to a close
- Cool-down well advanced, magnet circuit powering tests started
- Major dipole training programme planned
  - Experienced teams in place
  - The target is 7 TeV but we really need to see how things evolve
- The beam test will be a useful exercise in preparation for 2022

Baseline 4.2 – IN WORK (optimized)