RF System: availability and general performance - Run II

Katarzyna Turaj

Luca Arnaudon, Philippe Baudrenghien, Andy Butterworth,
Olivier Brunner, Frank Gerigk, Elena Shaposhnikova,
Eric Montesinos, Helga Timko, Daniel Valuch

and the entire piquet team

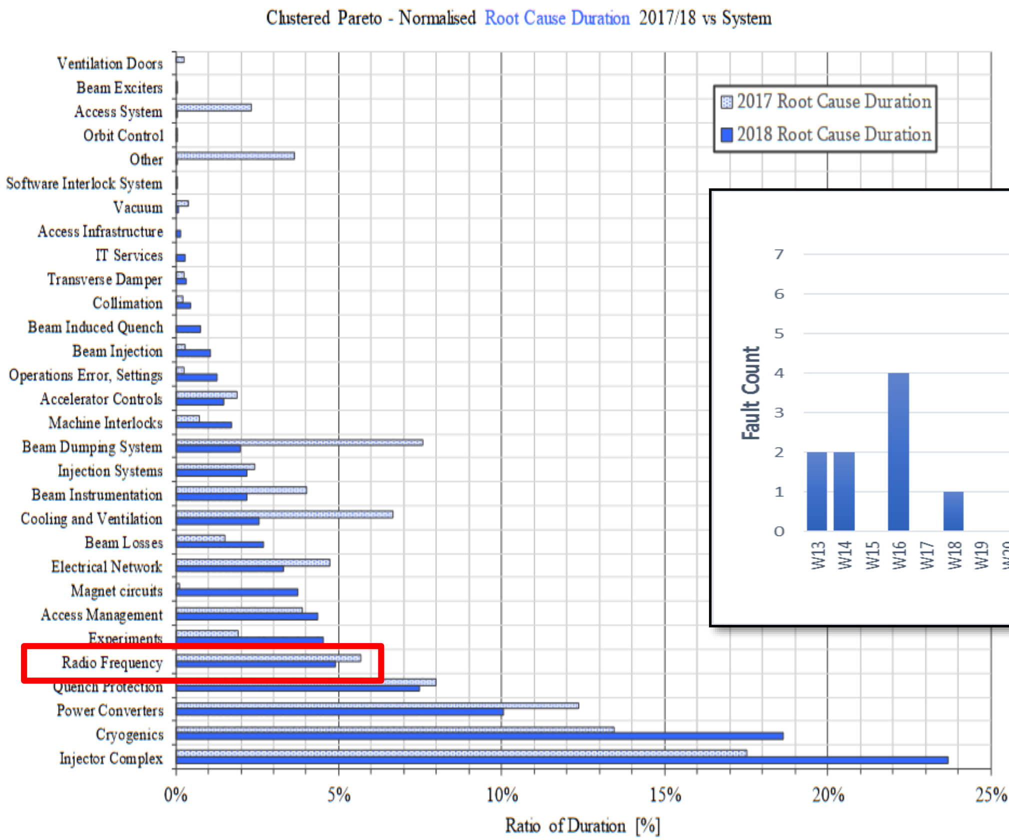
Content

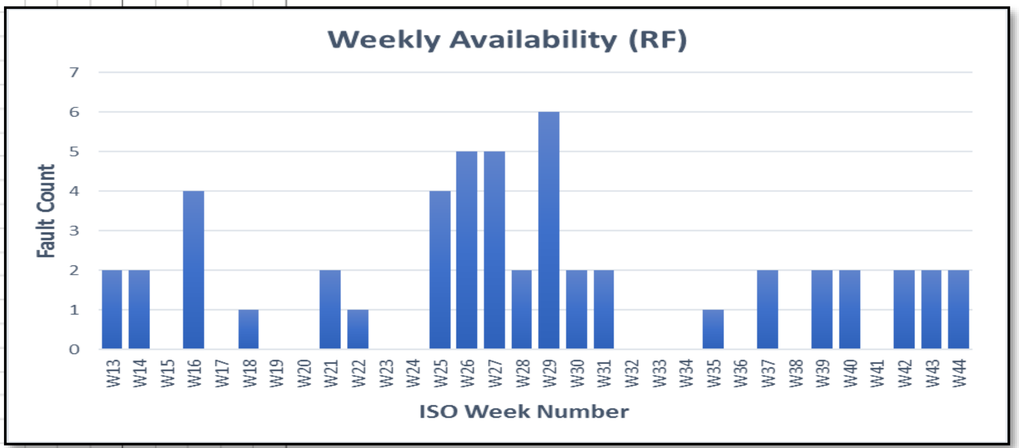
- RF system availability
- Software and diagnostics
- System limitations during run II
- Upcoming system limitations
- Forthcoming studies and improvements

RF system availability

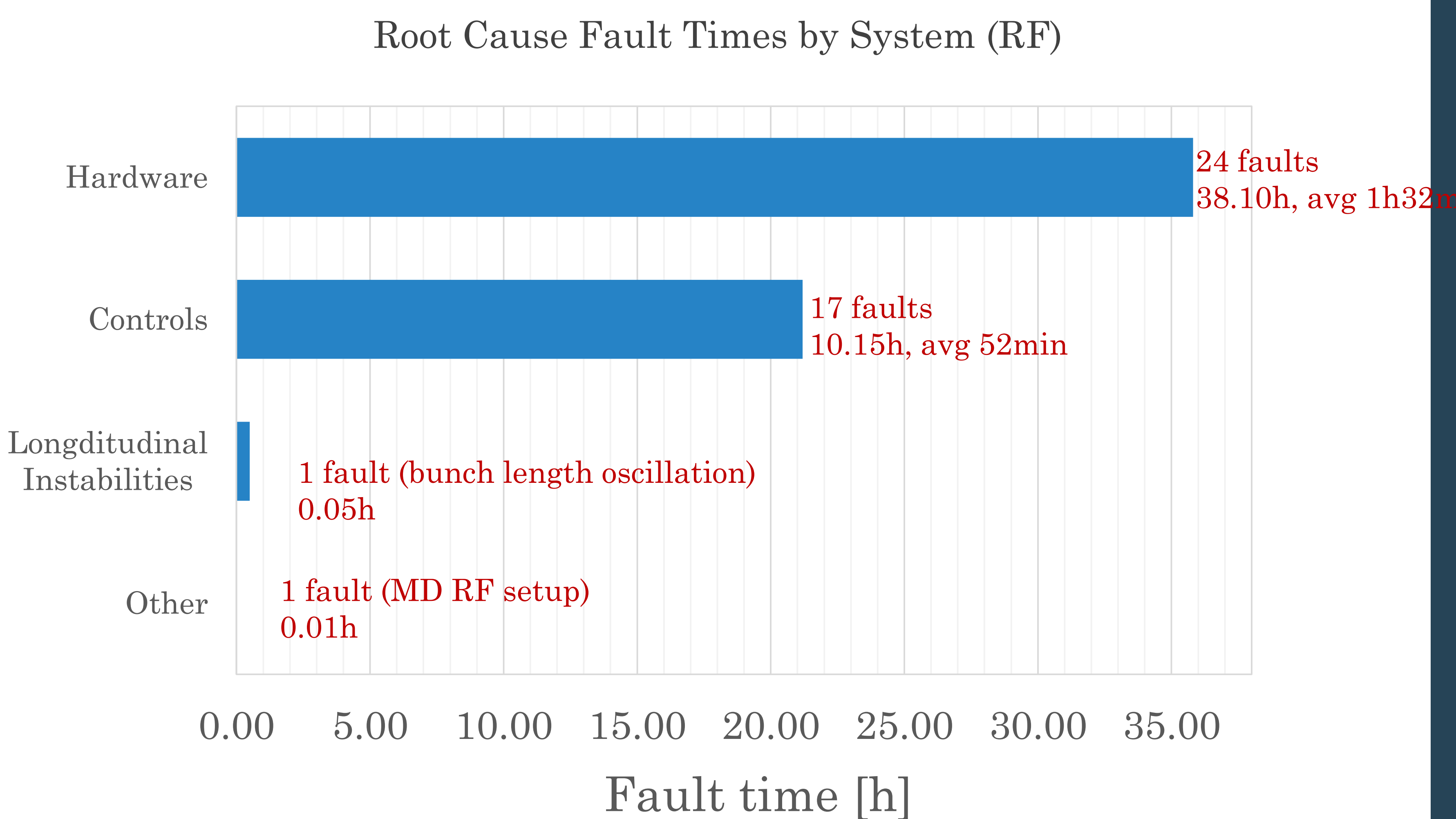
RF System Availability 2018

- Improved reliability over 2017
  - 2017 run (29 weeks): 32 faults, 45.5h → **5.7%** root caused duration
  - 2018 run (32 weeks): 59 faults, 49.2h → **4.9%** root caused duration
- Longest intervention: 2018 → 4h22min, 2017 → 14h
- Several weeks when no faults at all were recorded



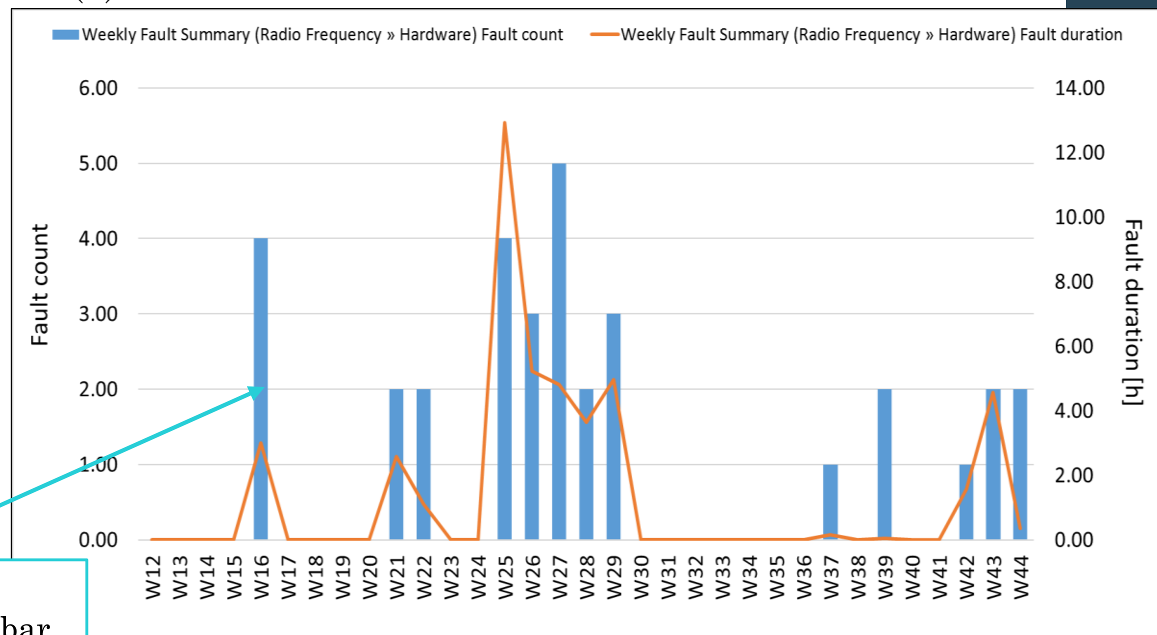


RF System faults summary 2018



Hardware faults

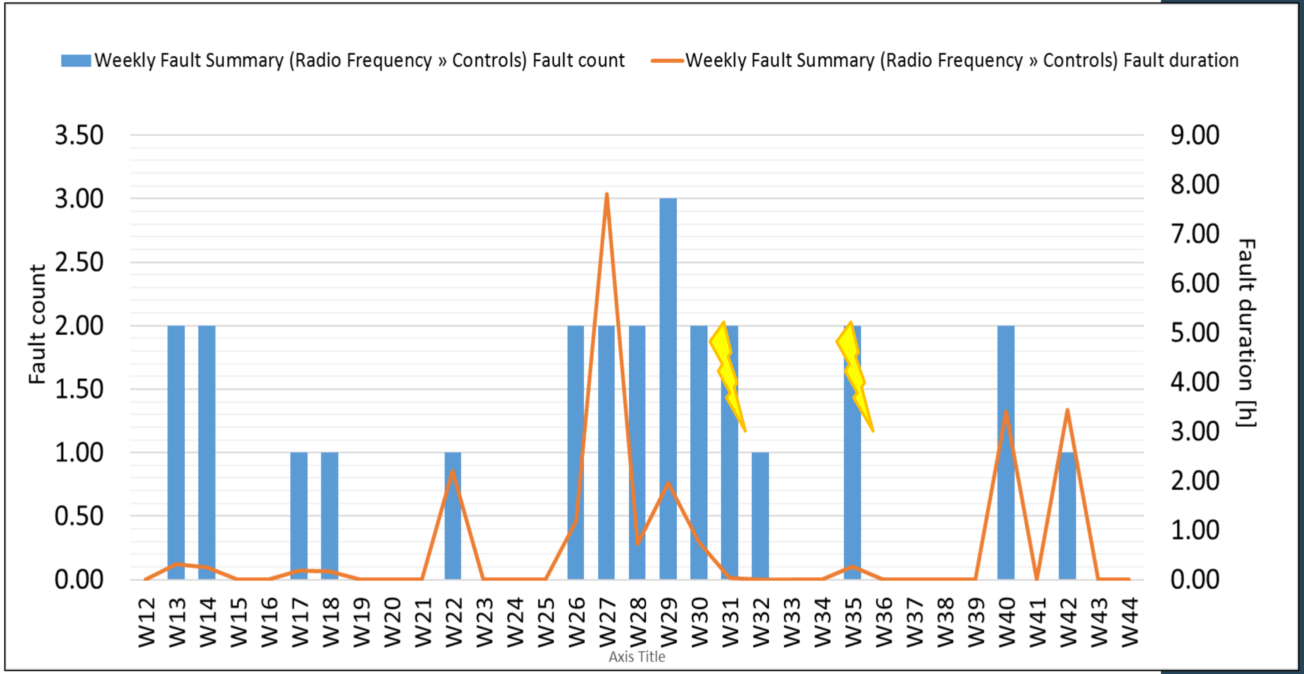
- Accumulation of faults in weeks 25 -29
  - Broken water flowmeter (1)
  - BIC intrlk → FESA class migration → control fault
  - New firmware for ALLSetPoint → cavity phasing → reflected power → arcs (5)
  - Electrical glitches
- Cavity trips during RF MD (6)
- LLRF crate down (1)
- LLRF module replacement (1)
- Crowbars (3)



4 faults:
klystron drive, crowbar and klystron vac intlk -> SWAP and FB off

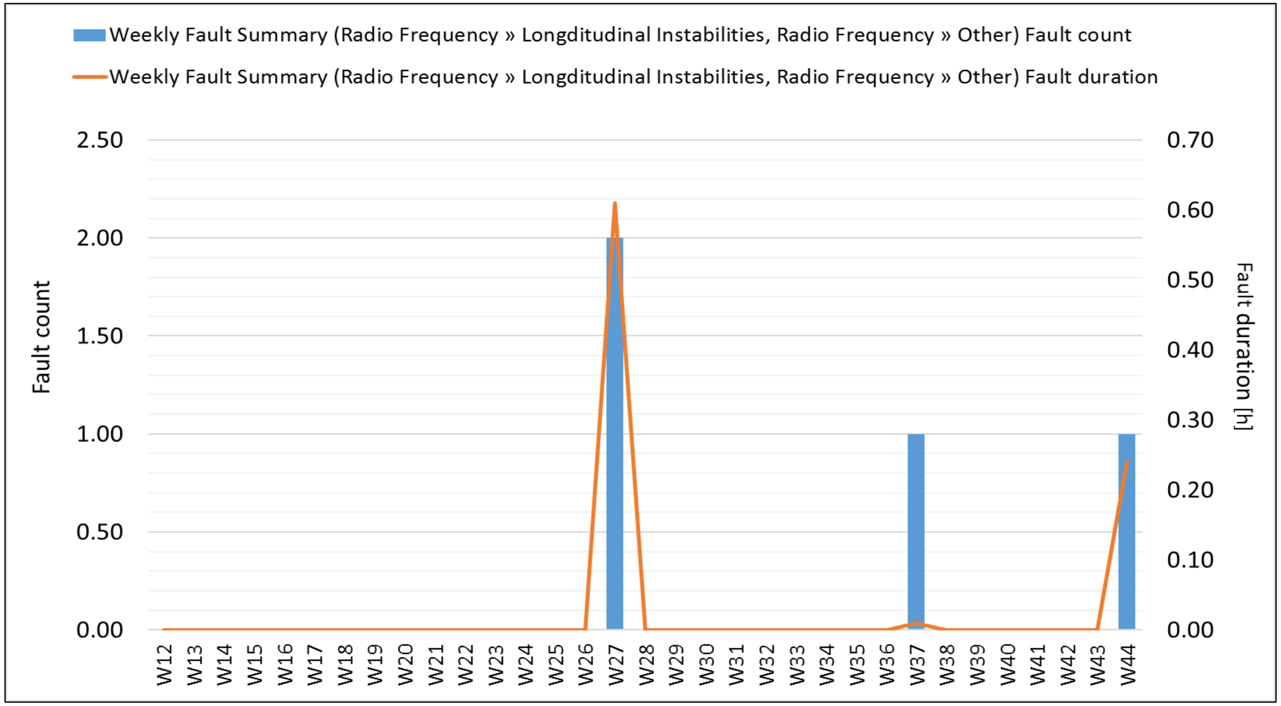
Controls faults

- Longitudinal blow-up (4)
- Lost communication (2)
- Accumulation of faults in weeks 25 -29
  - New firmware for ALLSetPoint → cavity phasing
- LLRF crate down (1)
- XPOC error (2)
- Power glitch (2)
- Server issue (1)
- Sequencer issue (1)
- Power Supply (HW) (1)



Other faults

- Longitudinal instabilities – bunch length oscillation (1)
- Caused by electrical glitch (2)
- During MD set-up (1)



Total faults duration less than 1h

Summary of faults and availability

- Hardware related faults were dominating and they are expected to be more frequent with ageing equipment
- Software constantly evolves or is migrated, leading to some faults → deployment of modifications often limited to TS
- LHC requests evolve with time as well, requiring new solutions → MDs
- Significant number of faults were diagnosed and fixed remotely → access only needed for hardware faults

Software and diagnostics

RF Expert tools

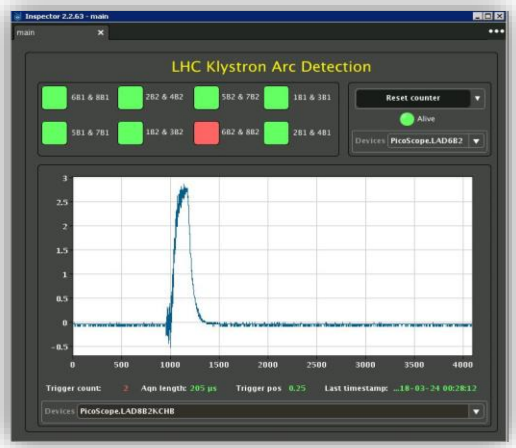
Yearly commissioning and lessons learned

RF Expert tools

Expert acquisition interfaces (previously LabVIEW, now Inspector)

LHC Control > LHC Equipment Control > RF > Expert

- Improvements to existing monitoring systems
  - Crowbar detection
  - Arc detection
- Additional diagnostics: power supplies, interlocks, temp., radiation …
- LHC RF OP Viewer → https://lhc-rf-op.web.cern.ch/lhc-rf-op/
  - Last 3h of data, archive, faults, SMS notification



Cavity conditioning tools

Cavity and coupler conditioning (better control and set-up of conditioning process):

- Automatized set-up of conditioning process
- Detailed procedures

Pulsed FM RF power is applied to the cavity in a controlled way with vacuum FB

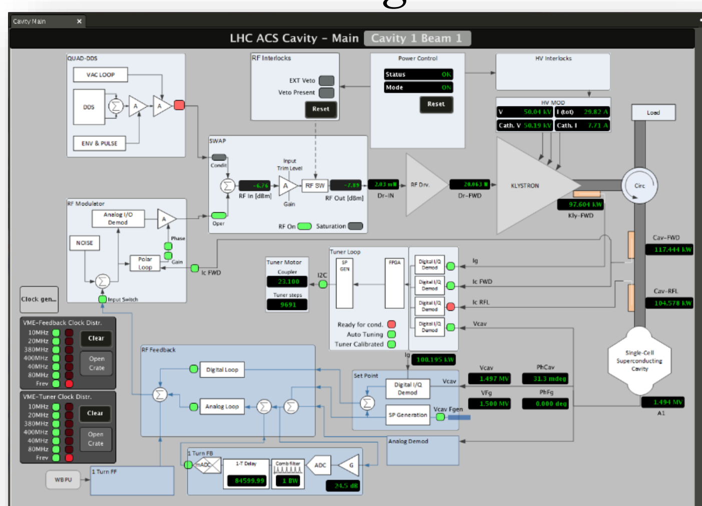
- Pulse length from 200us to CW
- Power from 10kW to 300kW
- Various coupler positions
  - Q_L = 20000, flat bottom → 1.5 MV/cavity (0.75 MV/cavity)
  - Q_L = 60000, flat top → up to 2.2 MV/cavity (1.5MV/ cavity)
  - Q_L = 40,000 (intermediate position)

Recommissioning scripts

LLRF Commissioning scripts were migrated from MATLAB to Python

- No MATLAB license needed
- PyJapc instead of JavaCoInterface
- Automatic backup/restore
- Improved data processing
- New algorithms added
- Step-by-step procedure and documentation

They were successfully used during recommissioning in 2018



Recommissioning timeline

STEP 1: Re-commissioning of the High Voltage (2 weeks)
- HV Bunkers: crowbars, modulator, cables… Interlocks and signals checks

STEP 2: Re-commissioning of the High Power (3 weeks)
- Klystron, Circulator, Loads, Power supplies, Power meters, Water Flowmeters – validation
- Klystron power calibration
  - Calibration of klystron DC power against collector thermal power
  - Circulator, arc detector, interlock levels, etc. adjustment

STEP 3: Re-commissioning of Cavities (4 weeks) + DSO test

STEP 4: Re-commissioning of LLRF (2 weeks)
- Calibration of offsets, delays, phases, gains, etc..

Plus software debugging

FIRST BEAM

STEP 5: First Pilot Capture and Beam Control Adjustment

STEP 6: First Nominal Bunches

STEP 7: Intensity RAMP-UP, Adjustment for The Beam Loading Compensation

STEP 8: Ion Setting up (in ion run)

Plus software debugging

Commissioning experience

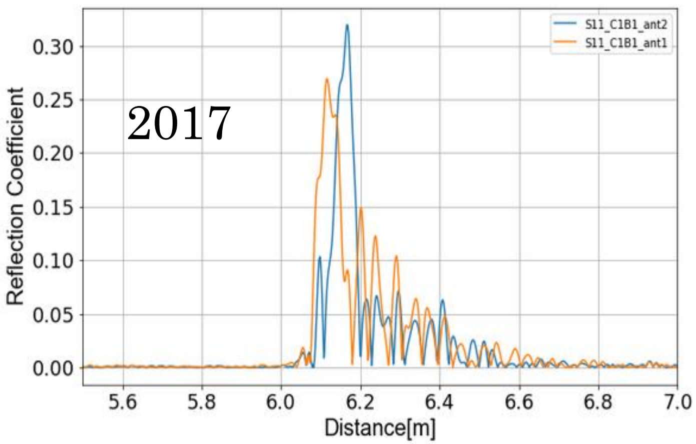
- Many things can be automatised, but still human intervention is necessary: a few lines will always show unexpected behaviour at some stage of the commissioning
- Many diagnostic tools and expert panels have been developed to ensure smooth operation, but trained people are still needed
- Technical stops are shortened to a minimum and often commissioning has to be performed with modified hardware & software
  - Many activities are carried out one after another and depending on the previous results, some in parallel
  - The LLRF commissioning is the last in the line and has to absorb potential delays in the schedule
  - Good coordination and communication

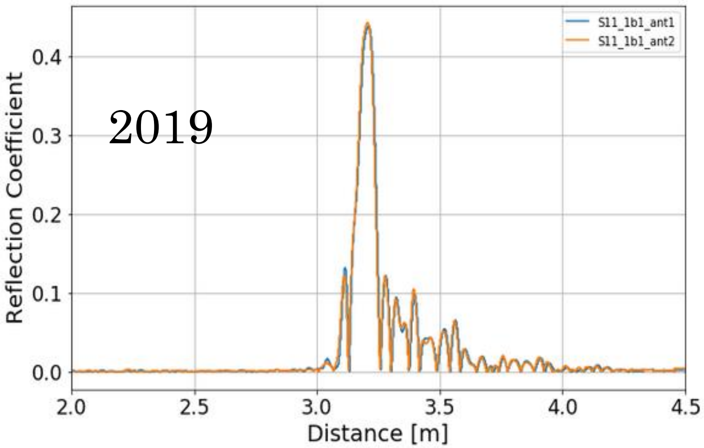
System limitations during Run II

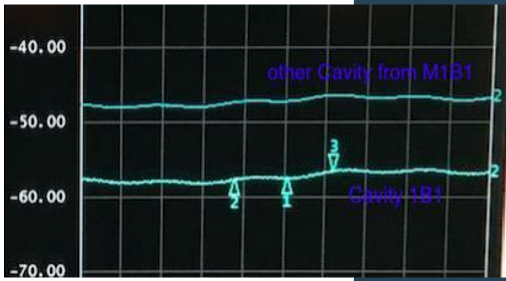
Antenna problem

C1B1 Antenna problem

- Detected during the cavity conditioning in 2017 → the field level ~10 dB less than expected (wrong tune and coupler position were ruled out)
- Measuring the transmission between operational and spare antenna showed indeed 10 dB less signal on C1B1 than on other cavities, TDR measurement has also been performed
- Since April 2017 the cavity is operated using the spare antenna



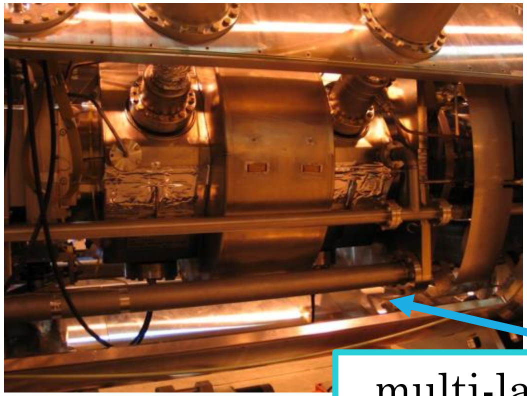




C1B1 Antenna problem

TDR measurements at cold and at warm have been performed annually

- All measurements very consistent → no significant impedance changes between different antennae were observed



multi-layer insulation is not shown

Actions to be taken:

- **Opening of the CM insulation vacuum** → an visual inspection of the connecting cables and the pick-up connectors, followed by a leak check on the pick-up and probably installation of a new cable → a detailed plan is discussed
- If replacing the antenna turns out to be necessary, this operation would almost certainly have to take place in a clean room and then **we may have to exchange this module.**

Upcoming system limitation

Anticipated limitations and actions taken

RF power limitation at injection

Initially the energy ramp and flat top were consider as a limitation for the HL-LHC (target intensity of 2.3×10^{11} ppb) → full-detuning beam loading compensation scheme since 2017

Available klystron power

Klystron HV	Cathode current	DC power	RF power(*)	Measured saturation
50 kV	7.8 A	390 kW	230 kW	190 – 220 kW
58 kV	8.6 A	500 kW	300 kW	250 – 280 kW

* assuming a klystron efficiency 60% (the expected ageing effect may reduce performance)

MD#3 and MD#4 on power consumption at injection (optimized loaded Q and cavity tune)

- MD#3 at 50kV, 1.15×10^{11} ppb
  - 9MV → all lines saturated
- MD#4 at 58kV, 1.3×10^{11} ppb (with circulating beam instead of injection transient)
  - 10MV → with the voltage partition

to be continued

see Helga's talk

Static heat load (?)

- Boil off test in SM18: flowmeter saturated at **10g/s**, much higher than expected
- Values measured for modules in LHC tunnel using a different method are lower:

(measuring needed time between closing of supply valve and start of TTmax raising in concerned module)

S34_B1: P=135.3kPa, empting time=88min→ heat load **131.1W**

S34_B2: P=135.5kPa, empting time=103min→ heat load **111.9W**

S45_B1: P=135.5kPa, empting time=93min→ heat load **123.9W**

(Courtesy of K. Brodziński)

- Meeting with TE-CRG colleagues: we think we understood the discrepancy.
- A 2nd measurement in SM18 in February, with the same settings as in the LHC
  - CM is already cold

Saturation of the mass flow meter at 10 g/s

Forthcoming actions

Maintenance and operational spares

Hardware

- Crowbar (Solid State): 4 units (LHC needs 4 units) → 3 to 5 additional units by the end of LS2
- Modulator MAC10 (tetrode) : 2 units + 3 units used on tests stand → tetrode replacement system is under development

Controls

- Replacement/maintenance of a large number of PLC processors, interlock cards, power supplies, etc..
- LLRF modules → spare production campaign ongoing
- Replacement of the power supplies (LLRF)

Software

- FESA2 → FESA3 migration (e.g. beam control classes → difficult to debug without a beam)

Maintenance and operational spares

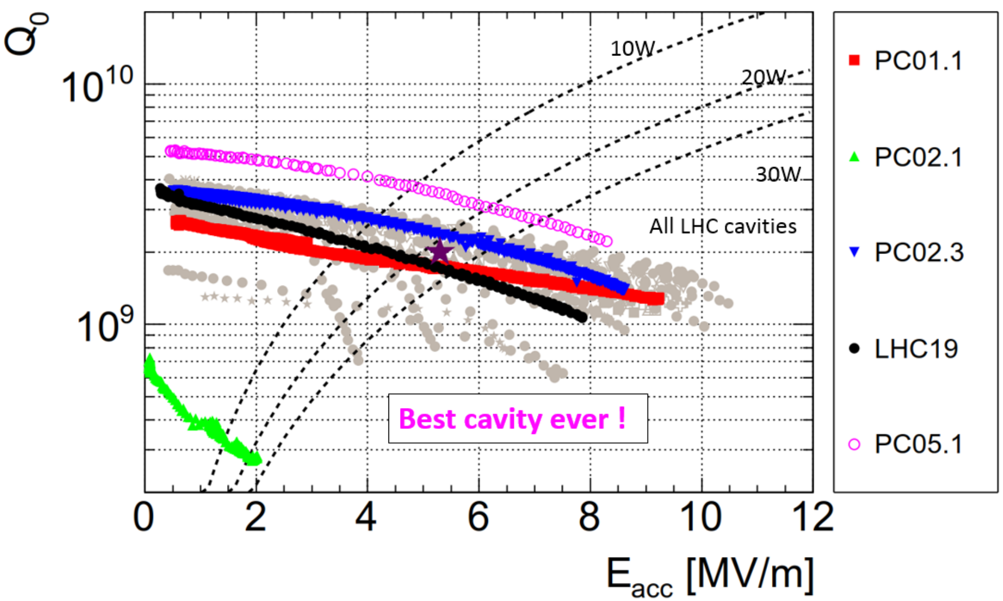
Test stand infrastructure

- ACS test stand in SM18 → partially done in 2018 but work should continue (controls upgrade)

ACS module and cavities

- 1 spare dressed cavity (90s production) → successfully tested in 2018
- 1 spare LHC ACS module (with new pumping crosses)
- 4 dressed spare cavities and 1/4 test CM will be available for Run3

and more see Helga's talk



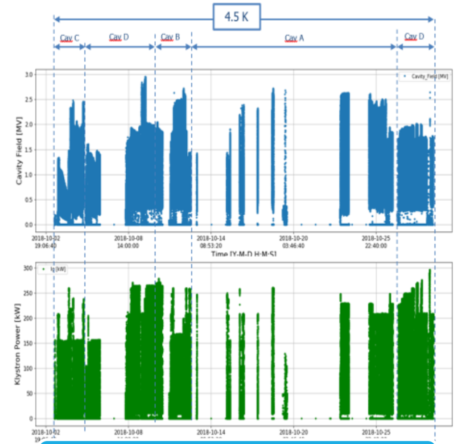
Successful test of the spare LHC ACS CM

Test of spare LHC ACS module with new pumping crosses in October 2018 (America, taken out in LS1)

- **2.5MV @ Qx=60k (flat top) and 1.5MV @ Qx=20k (injection position), all cavities were able to work stably for several hours**
- Additional studies and tests such as HOM measurement and TDR of field antenna have been performed
- The M9 horizontal test bench in SM18 was brought back in operation → **to be continued**
- A significant number of software updates and improvements have been introduced following the user interface adaptation → **to be continued**

Assembly of new pumping crosses

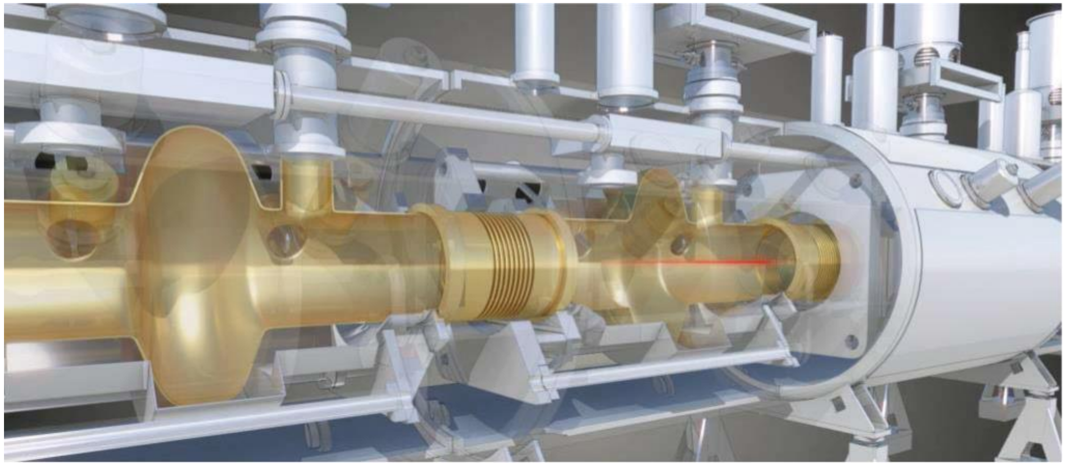
CM installation and RF Test



CM validation

Summary

- The LHC RF system is working reliably and successfully throughout the years
- Flexibility of the RF system has been proved: MD requirements, special runs
- Huge amount of work has been performed in 2018
- Preparation for post-LS2 operation under way



Acknowledgments

- RF stand-by teams:
  - **High Power** (A. Chauchet, D. Glenat, D. Landre, Ch. Nicou, G. Ravida, M. Therasse, K. Turaj)
  - **LLRF** (J. Betz, B. Bielawski, R. Borner, G. Hagmann, G. Kotzian, A. Spierer, H. Timko, D. Valuch)
- T. Argyropoulos
- J. Banjac
- Y. Brischetto
- A. Boucherie
- V. Costa
- M. Karppinen
- P. Martinez Yanez
- P. Maesen
- J. Molendijk
- F. Peauger
- N. Schwerg
- D. Smekens
- N. Stapley
- W. Venturini Delsolaro

Thank you very much

References:

H. Timko et al., 'Estimated LHC RF system performance reach at injection during Run III and beyond', to be published, (2019)

K. Turaj, F. Peauger, 'LHC HCACSGA000002 retest in SM18 – 2018', EDMS 2030664

K. Turaj, P. Maesen, 'LHC HCACSGA000002 retest in SM18 – 2015', EDMS 1809575