CERN

RF and ADT hardware performance

A. Butterworth BE/RF

O. Brunner, Ph. Baudrenghien, H. Timko, G. Kotzian, D. Valuch, W. Hofle, P. Maesen, K. Turai, M. Karppinen

Outline

RF

- Summary of Run 1 HW issues and LS1
- Replacement of cavity module
- HW availability and issues in 2015
- Mitigation & improvements for 2016

ADT

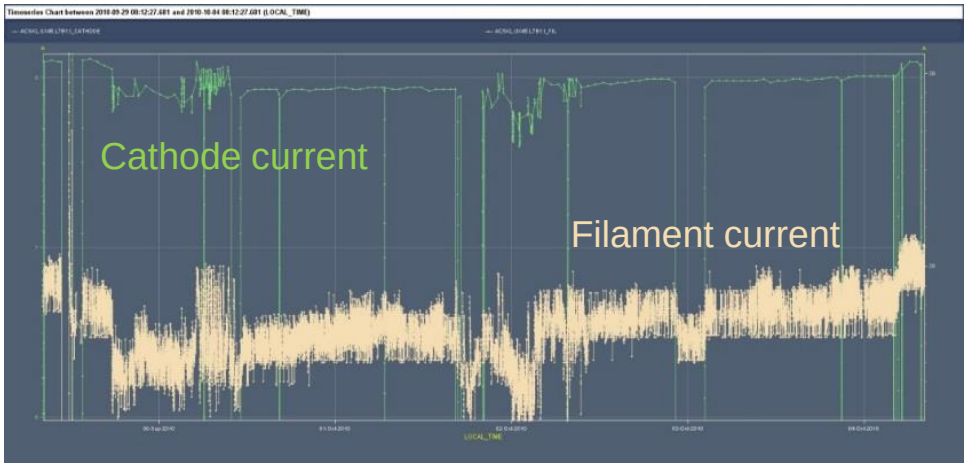
- Upgrades in LS1
- Performance and operational issues in 2015
- Mitigation & improvements for 2016

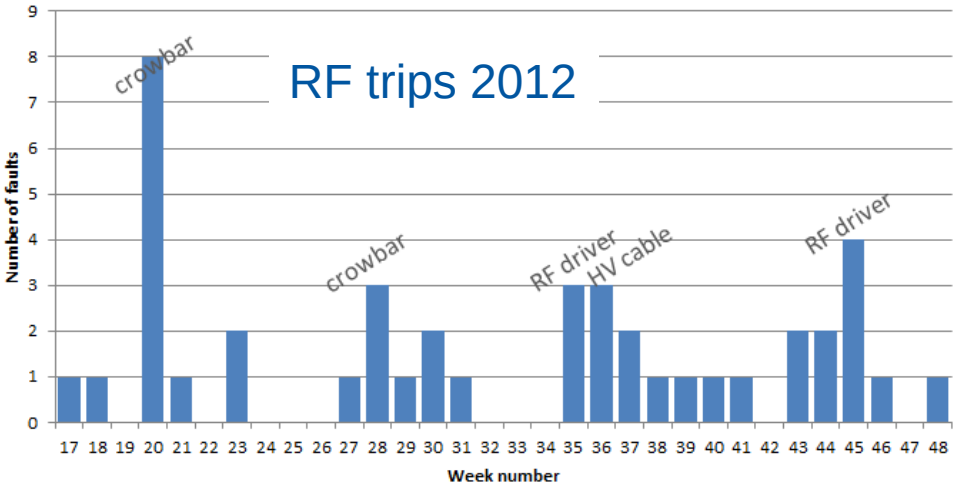
RF

Run 1 HV faults

RF fault statistics dominated by:

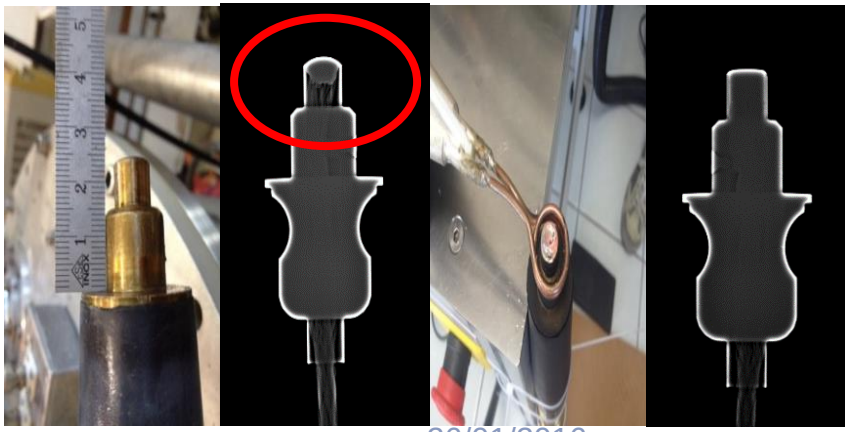
- Spurious crowbar trips
  - Thyratrons prone to spontaneous firing
- Klystron filament current glitches
  - High voltage interlock





LS1 HV & Power consolidation

- All klystron HV connectors were found defective => repair campaign
- Crowbars: Thyratrons replaced by Solid State devices (better performance & reliability)
- 8/16 klystrons replaced – age profile



No more klystron filament glitches
No more spurious crowbar trips

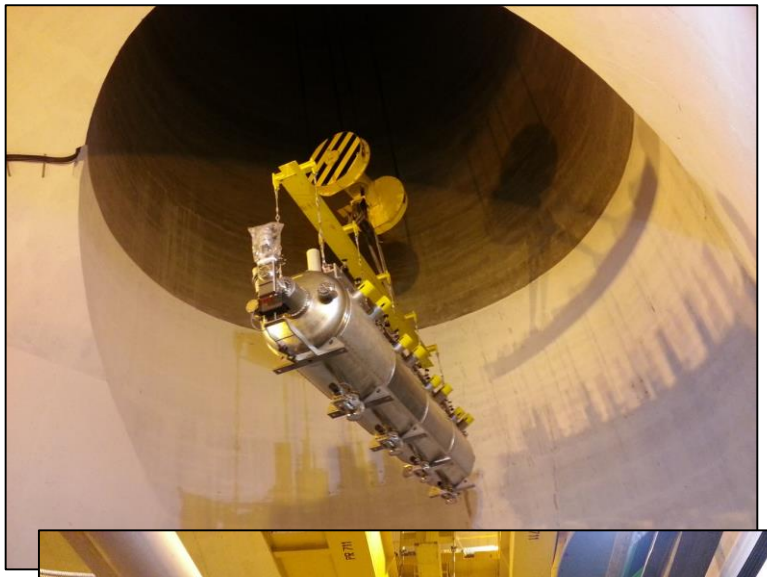
Replacement of cavity module

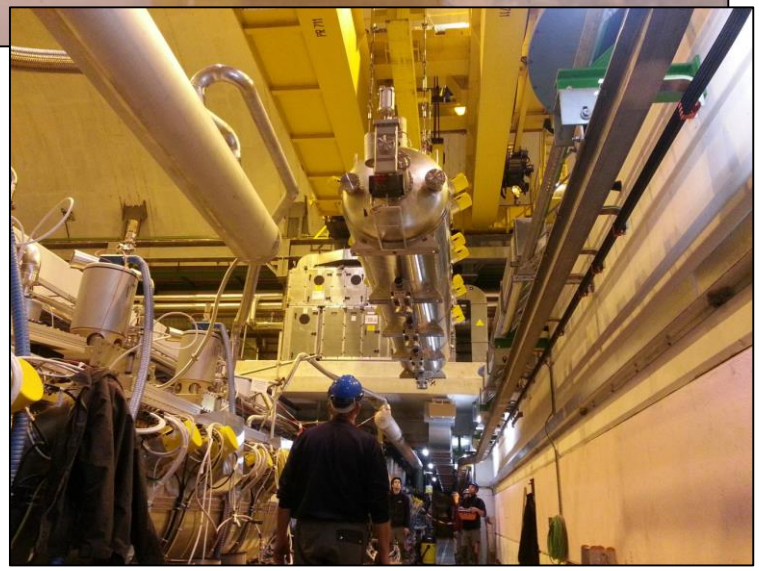
- From 2009, Cavity 3 Beam 2 was quenching after a few minutes at 2 MV CW nominal
  - Evidence of high X ray emission and cryo consumption
- Eventually clamped at 1.2 MV for the rest of Run 1
  - Missing voltage distributed to the other seven Beam 2 cavities
- Despite careful conditioning after each technical stop, no change of behaviour.

Replacement of cavity module

- Decided to replace the 4-cavity cryomodule containing the faulty cavity
- LHC ACS module M1.B2 *America* was replaced by the spare module *Europa* during LS1.
- *America* was stored under vacuum in SM18 awaiting repair
- Recovery options:
  1. Conditioning
  2. He processing
  3. Dismantling and cavity replacement

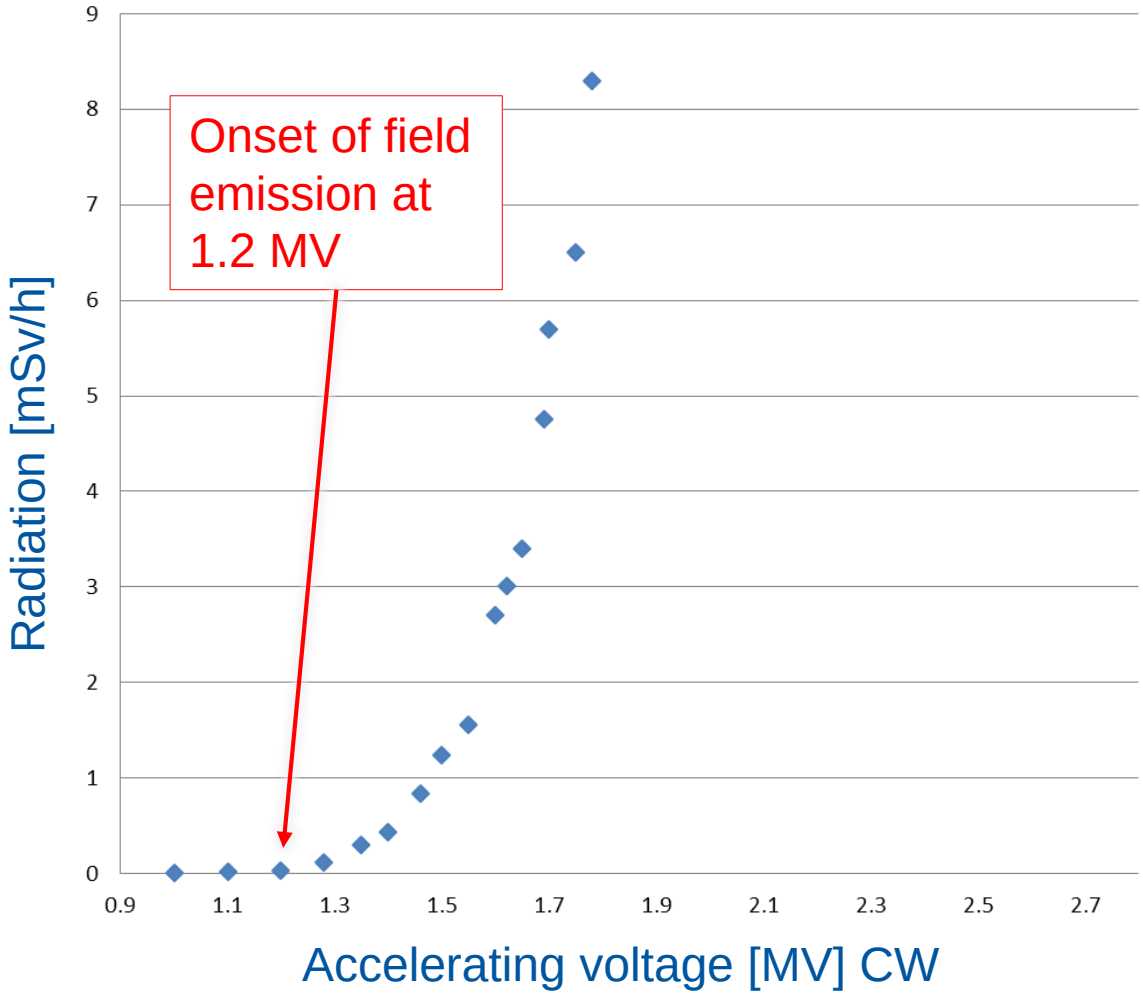
Don’t touch it until the 4 modules in LHC work properly with the full beam at 6.5 TeV !





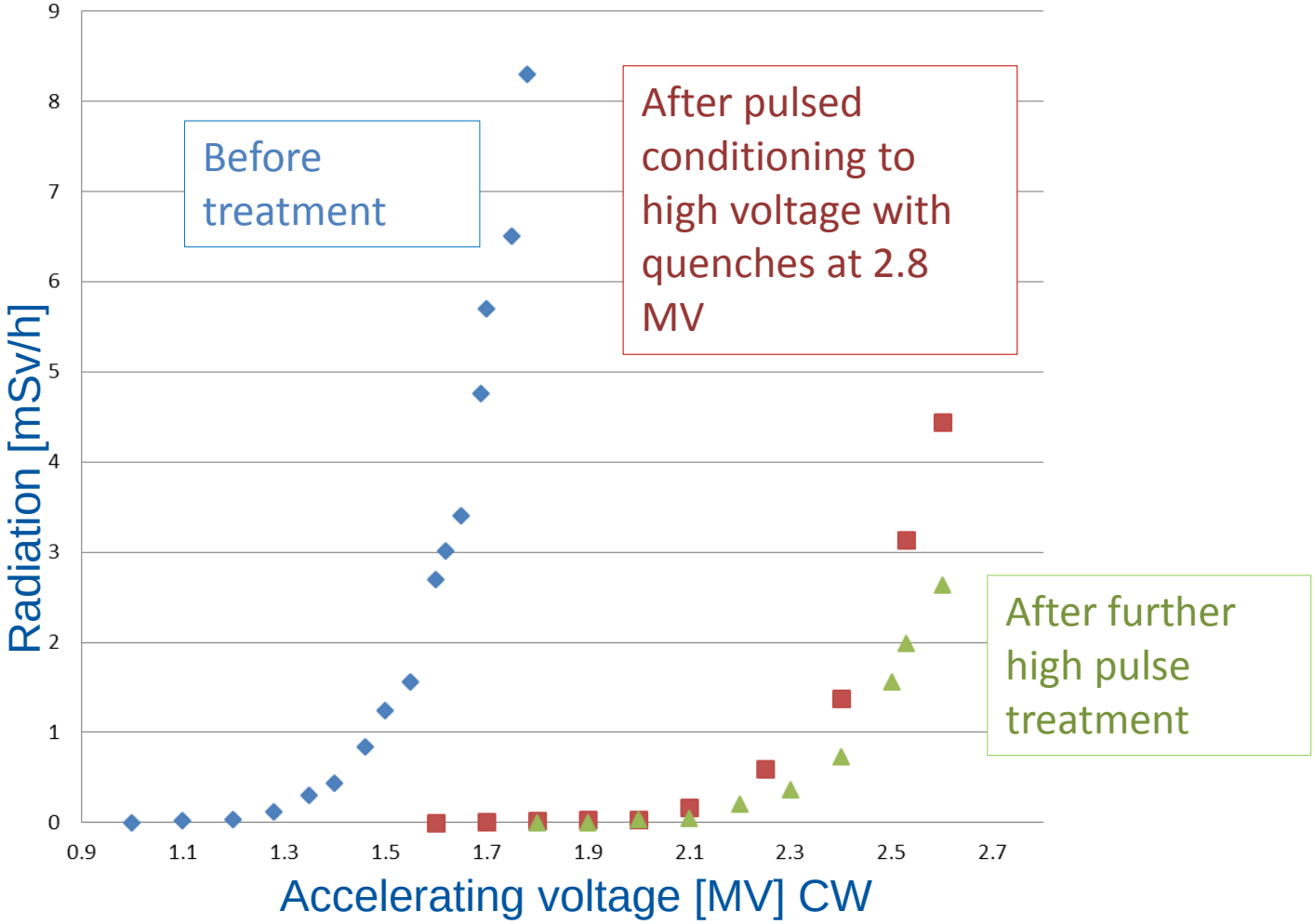
America measured in SM18

X Rays at 2 meters from Cavity B



America performance recovery

X Rays at 2 meters from Cavity B



America performance recovery

- Conditioning in pulsed mode to burn emitters was successful
- Nominal performance (>2MV) regained
- He processing was not necessary
- Not necessary to open the module
- Full power revalidation was successful on all 4 cavities
- *America* now a valid spare module

LHC Cryomodule project

- Produce stock of fully conforming spare units
- Re-establish Cu-Nb cavity technology at CERN
- Deliverables:
  - Cavity #19 to validate/re-process
  - Practice cavities (spinning) x 2 (in progress)
  - Model cavities (electro-hydraulic forming) x 2
  - Dressed cavities x 4
  - New spare cavity units x 10
  - As-built design folder
  - Inventory of CM parts & tooling
  - Cryomodule CM6-7 integration (TBC)

Dressed cavity #19: status

- Measured stiffness 16.3 kN/mm
- Warm RF test done
- LPWR (max 7 bar) in SM-18 in Jan
- Vertical test in SM18 Mid-Feb
- If not successful:
  - Strip, clean, and redo Nb-sputtering
  - Optical inspection
  - Warm and cold testing

RF availability 2015

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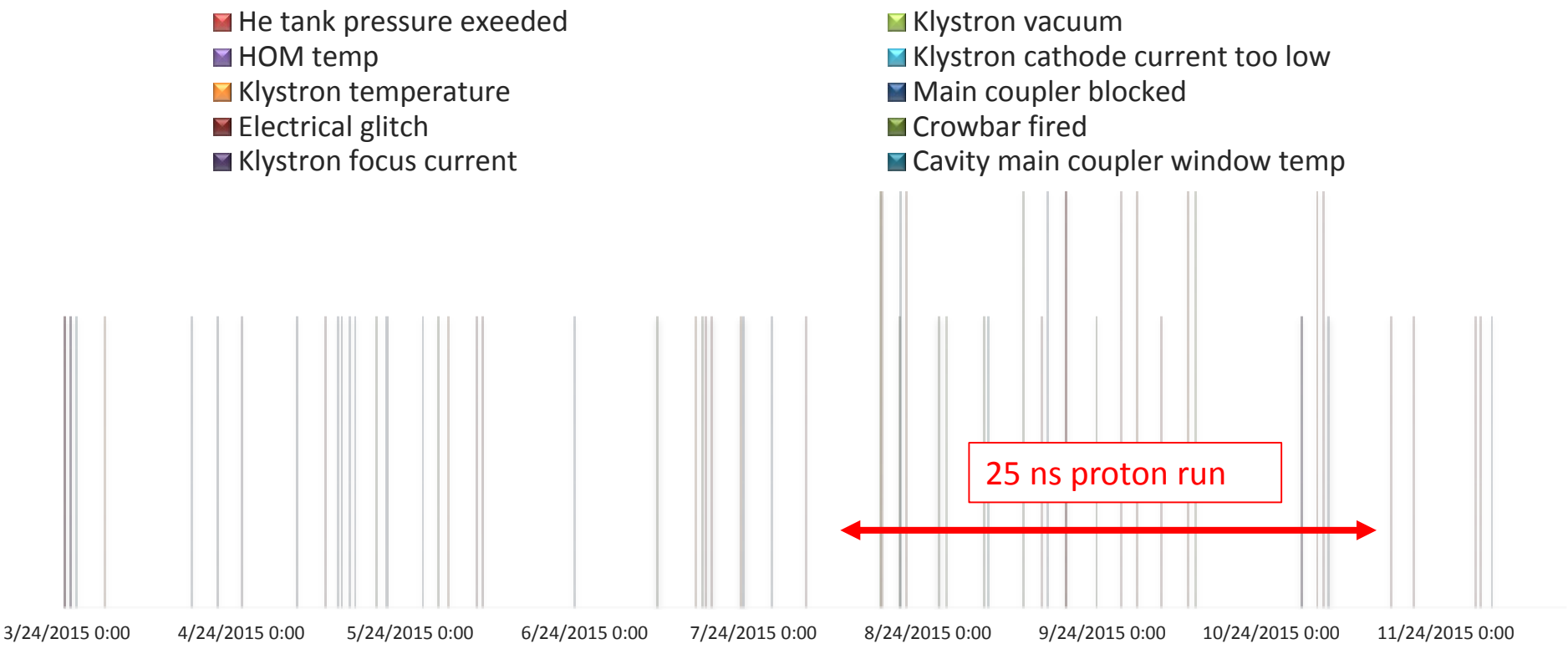
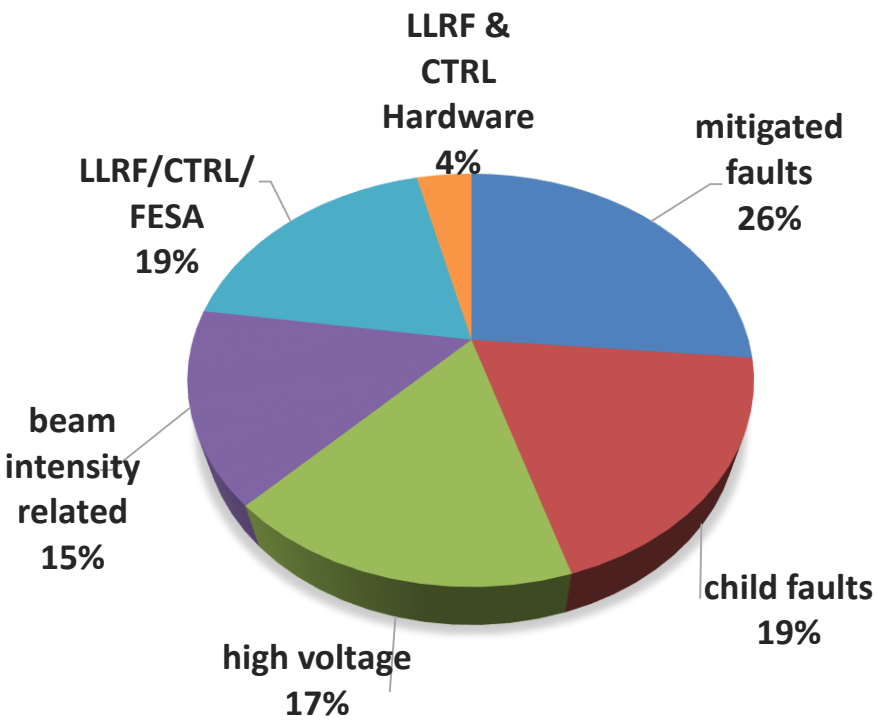
- 57 RF and HV trips recorded, 76 hours downtime in AFT
- 13 beam dumps (higher bars) – all during 25 ns run
- 15 categories

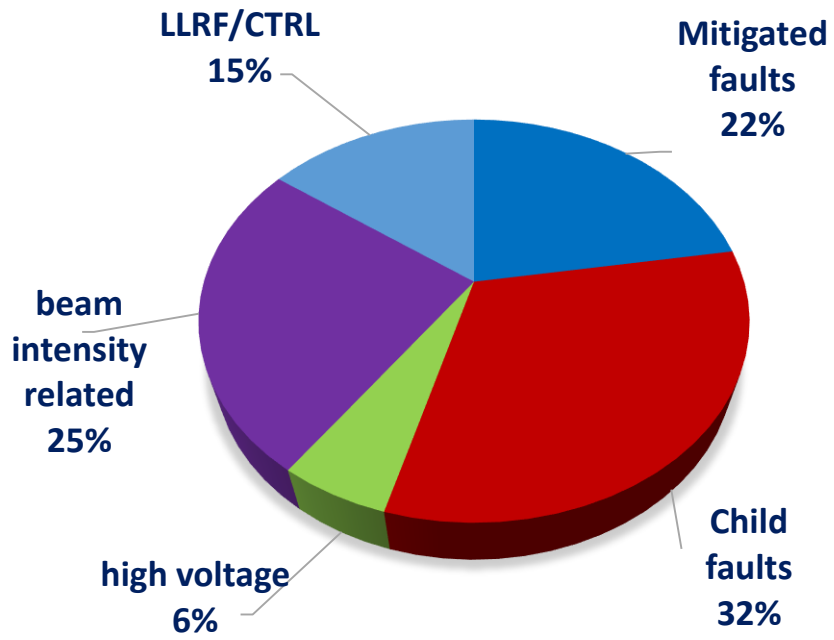


RF faults 2015

Number of faults



Downtime



RF faults 2015

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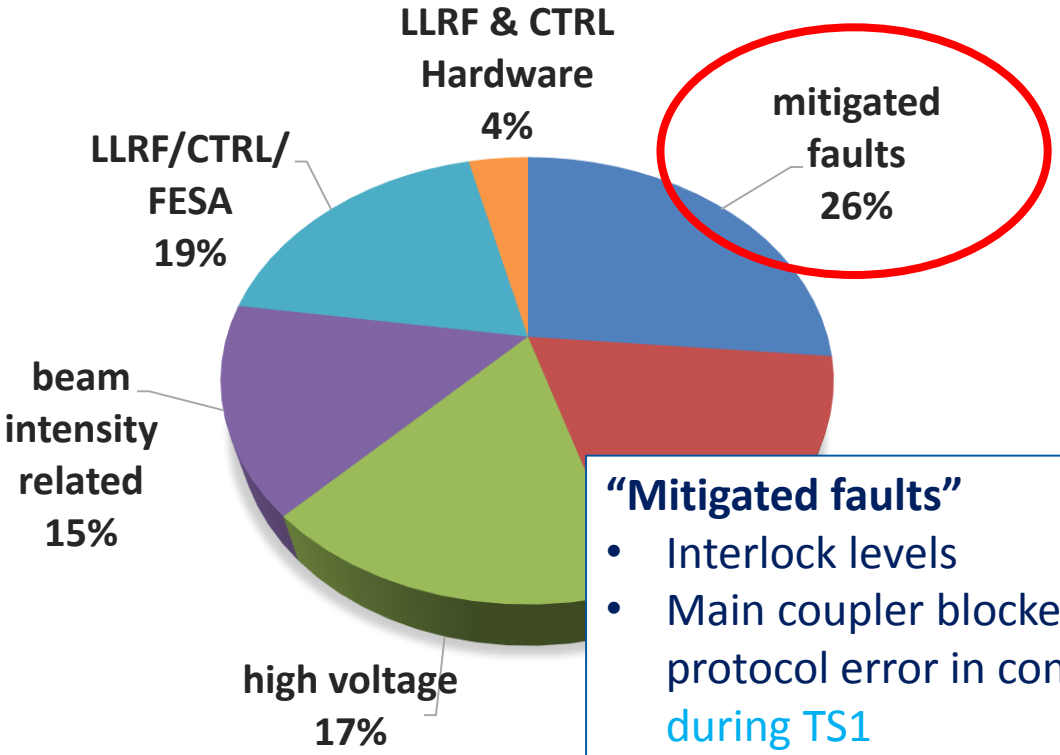

"Mitigated faults"

- Interlock levels
- Main coupler blocked: communication protocol error in control card. Solved during TS1
- Temperature glitches: Solved during TS2
- No trips since mid-September

RF faults 2015

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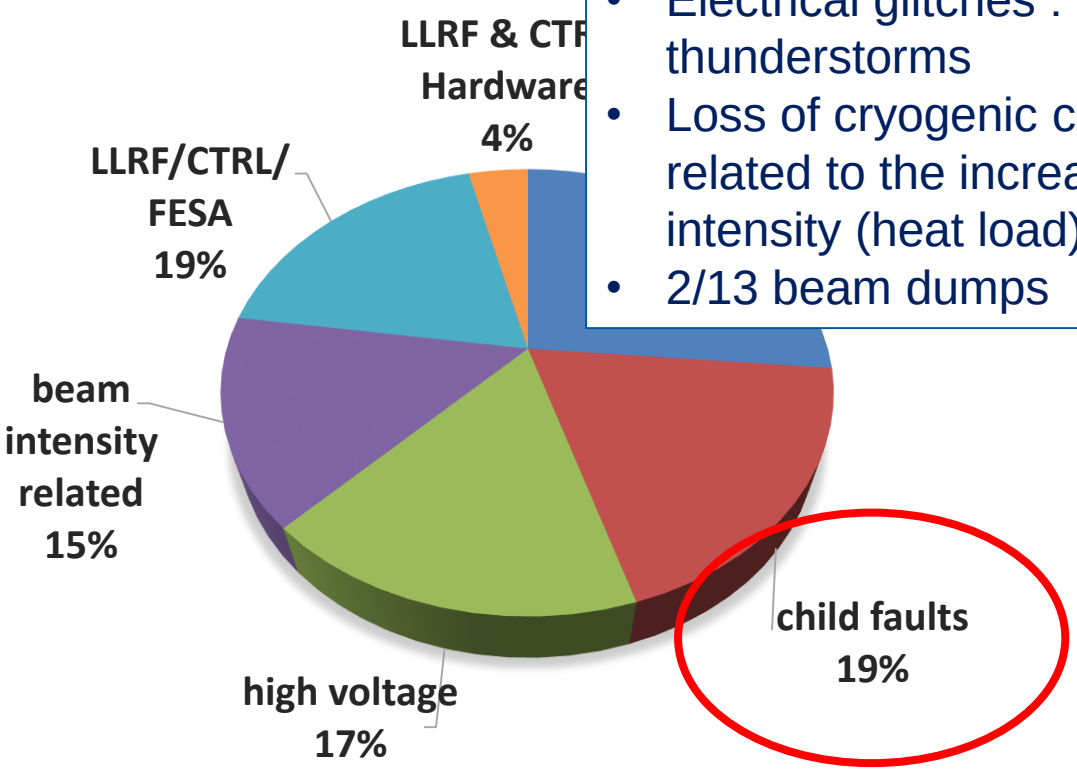

"Child faults"

- Electrical glitches : e.g. thunderstorms
- Loss of cryogenic conditions: related to the increase of beam intensity (heat load)
- 2/13 beam dumps

RF faults 2015

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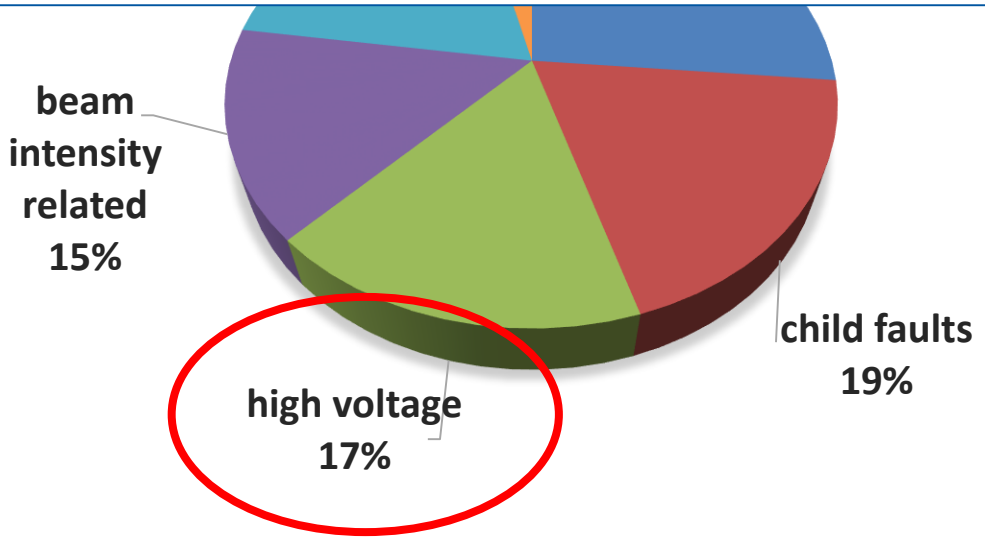
HV system crowbars

- Spurious crowbars were a major cause of trips during Run1
- In 2015 all “real” crowbars (klystron vacuum activity)
- All (except 1) soon after restarting the RF system (in particular after long periods at 10kV)
- 1 beam dump



RF faults 2015

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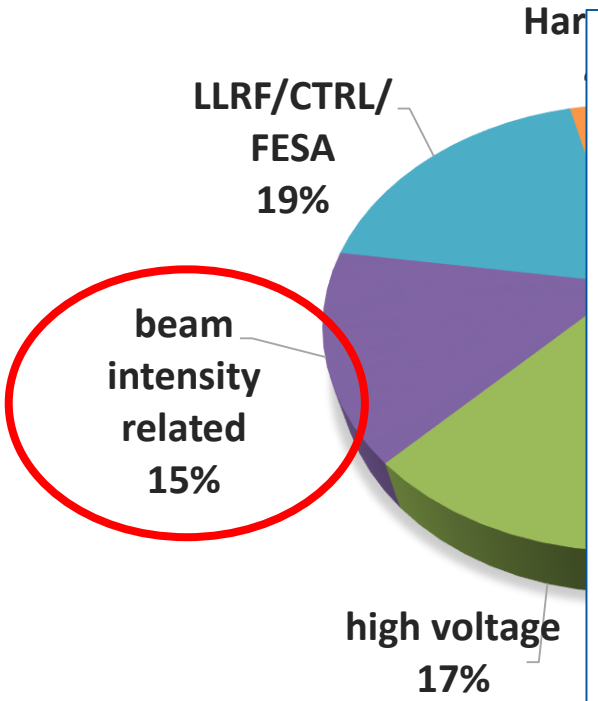
Beam intensity increase

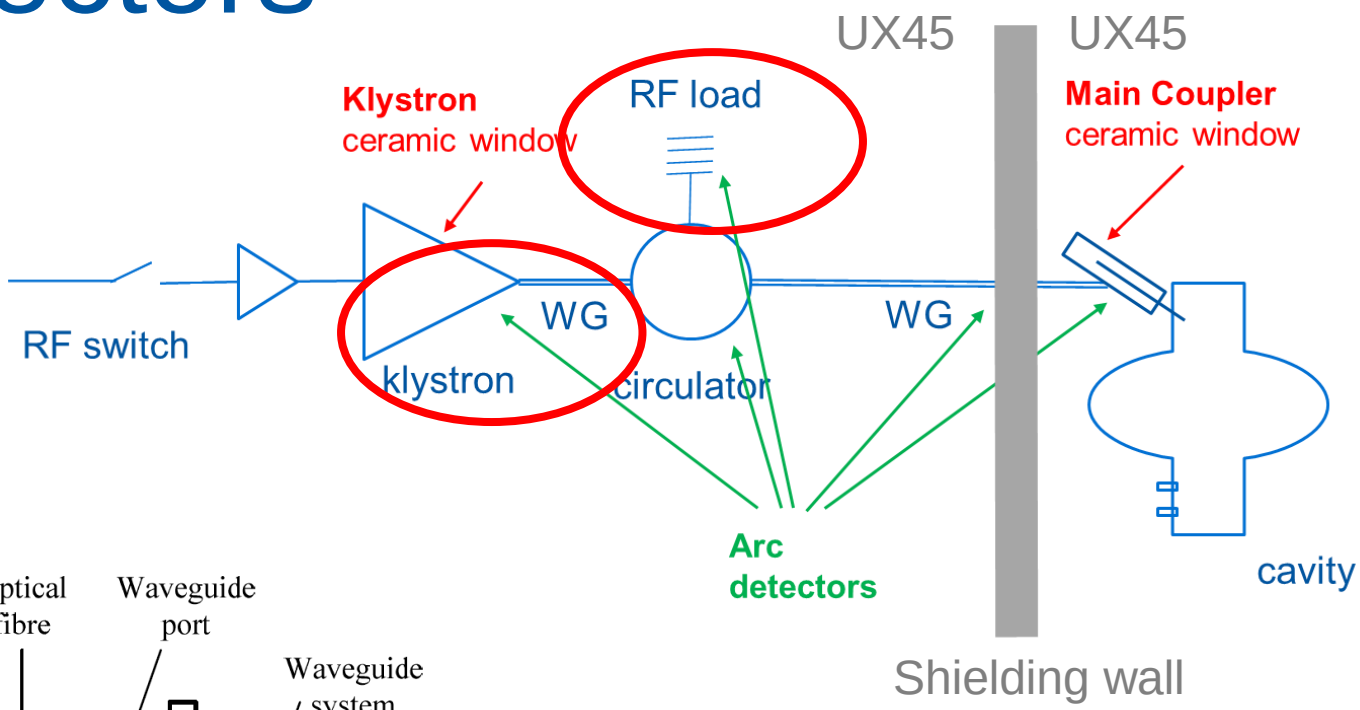
- **2015**: nominal intensity : 1.15e11 p/bunch, 25ns, 10MV
- => RF feedback power transients reaching limit (250 – 280 kW)

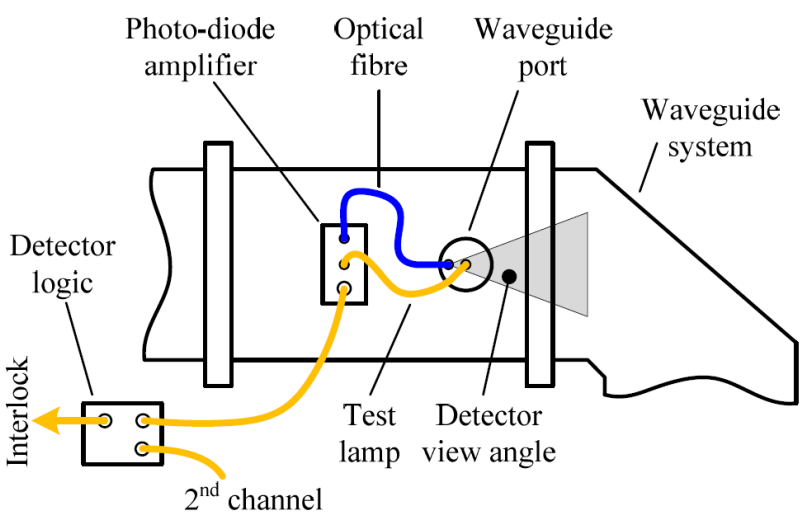


Faults related to beam intensity increase

- 7 beam dumps (50%)
- Klystron vacuum: Klystron oversaturated => fine adjustment of half detuning
- Cavity main coupler window overheated => better cooling system under study
- Arc detectors: no evidence of real arcs! Maybe radiation induced? =>YETS: modification + diagnostic system
- **2016**: klystrons, MC couplers & cavities will be conditioned to nominal 300 kW

Arc detectors

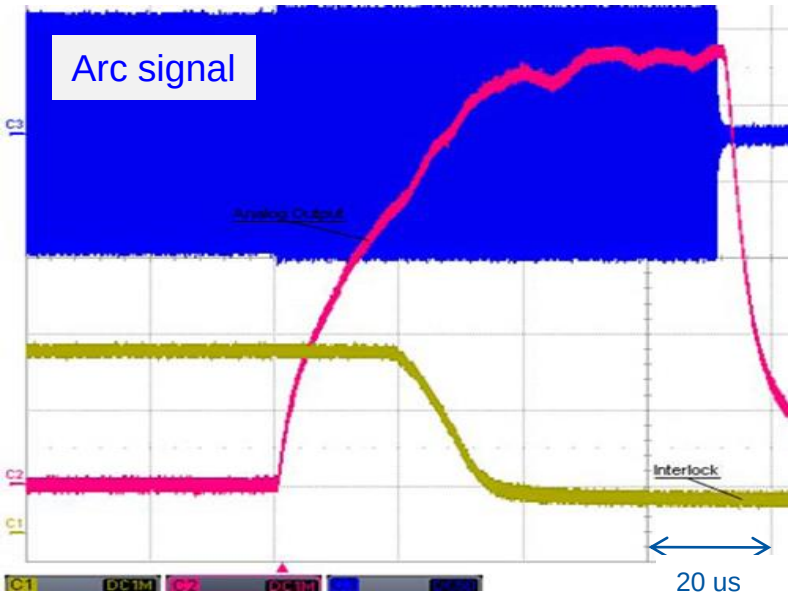


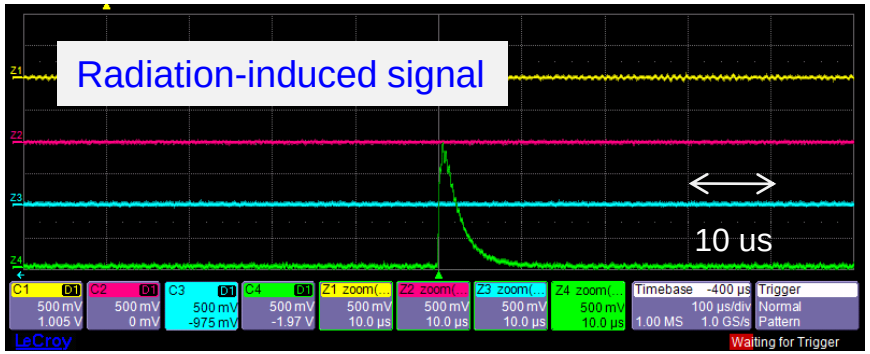


Trips on klystron window and circulator/load

Arc detector diagnostics

- 16 oscilloscopes installed in UX45
  - Record output waveforms of arc detectors
  - Distinguish between signature of arc or radiation-induced spike





RF faults 2015

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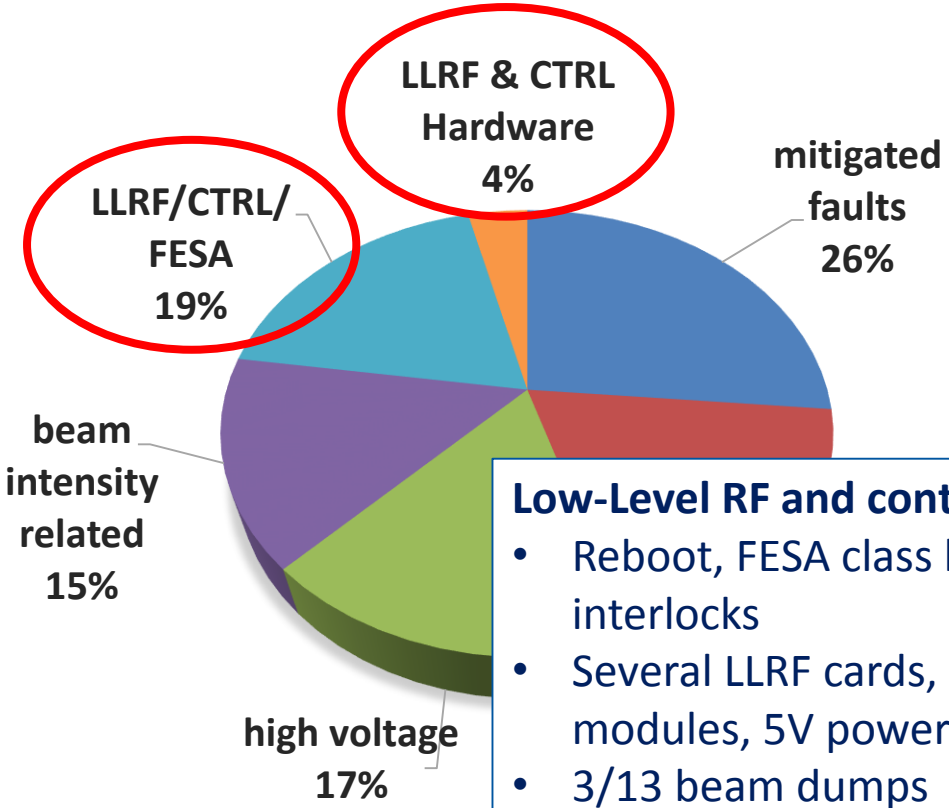


Low-Level RF and controls

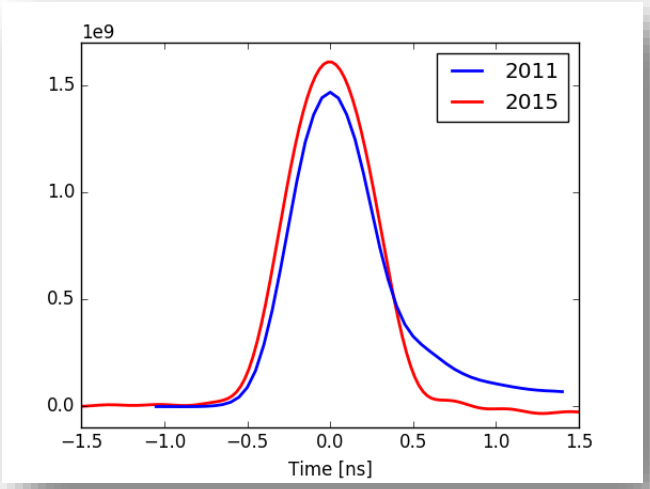
- Reboot, FESA class hiccups, RF frequency interlocks
- Several LLRF cards, PLC/CTRL IO modules, 5V power supplies replaced
- 3/13 beam dumps

LLRF & controls availability

- Few false alarms from RF frequency interlock
  - Single spike filtering of beam energy signal and diagnostics implemented; if recurrent, data to be analysed
- Two LLRF VME modules and a 5V power supply failed
  - First electronics failure since LHC start-up in 2008
  - More spares needed to keep system operational
- Long recovery time after power cut on VME crates in the Faraday cage
  - Took > 6 hours in one case
  - Problem with reloading FESA persistent data understood, fixed in 2016
- Spurious dump due to PLC receiving an RF off command
  - Source of command unidentified, occurred only once

Diagnostics (1)

- High-resolution beam profiles at 40 Gs/s
  - Fast scopes (1/beam) installed in ex-klystron galleries
    - Expert only at the moment; user interface planned
- Beam spectrum logged in MeasDB
  - Now a fixed display is available
    - Frequent problems with interface to spectrum analyser, to be made more robust. Source of problems under investigation
- Improved peak-detected Schottky spectra
  - Faster rise time for better resolution of bunch centre
    - Available only for one beam; further modules needed
- Beam profile screens in CCC (using 1 GHz scopes in SR4)
  - New hardware for streaming to make it more robust (Ph. Nouchi, U. Wehrle)
  - Software upgrade planned for 2016



2011: using scope in SR4

2015: using scope in UA43, corrected for transfer function of shorter cables

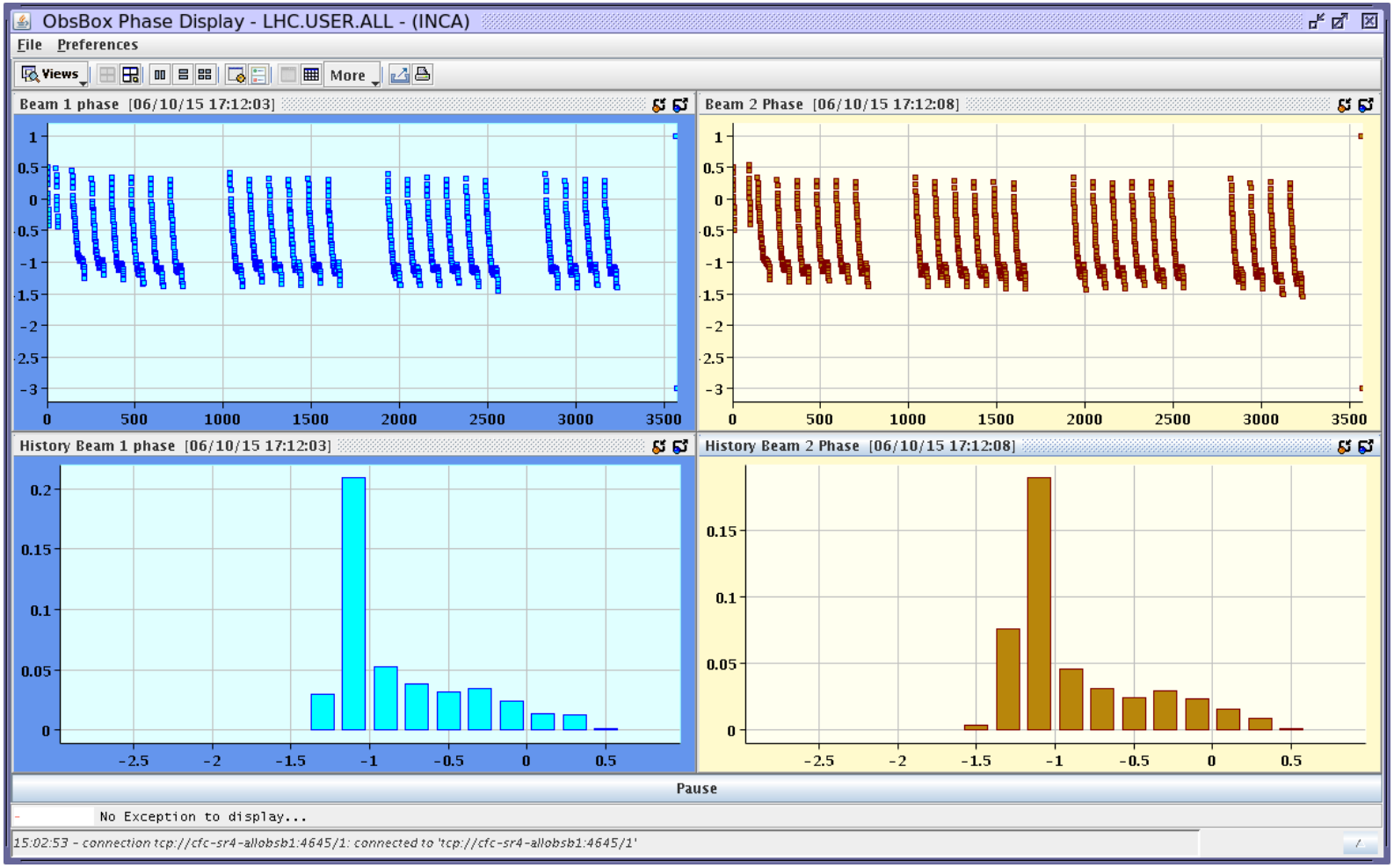
Observation Box

- LLRF and Transverse Damper (ADT) acquire bunch-by-bunch phase and position
- Short memory buffers on-board for HW diagnostics (~70 turns)
  - Not intended for beam observation!
- Boards have fiber/copper Gbit serial links for interconnect
  - Use these to stream data to an external computer with lots of memory
  - Make it available to whoever wants it via FESA
- Rack-mount server with 128 Gbyte of RAM (expandable)
  - 6 minutes of data at full 40 Msps on 4 channels
  - Improved FESA interface for 2016: huge buffer wilL disappear, replaced by multiple triggerable buffers, logging
- Install 4 boxes in ADT, 2 in LLRF

SuperMicro SuperServer 6028U-TR4+

Simple PCIe FMC carrier (SPEC)
RF specific firmware (T. Levens)

ObsBox beam phase display



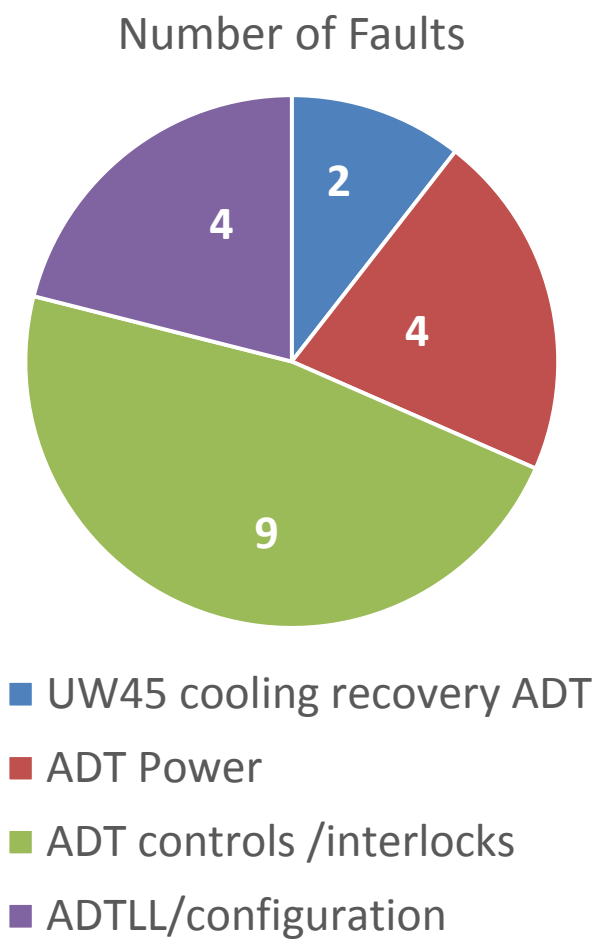
J-E Muller, G-H Hemelsoet

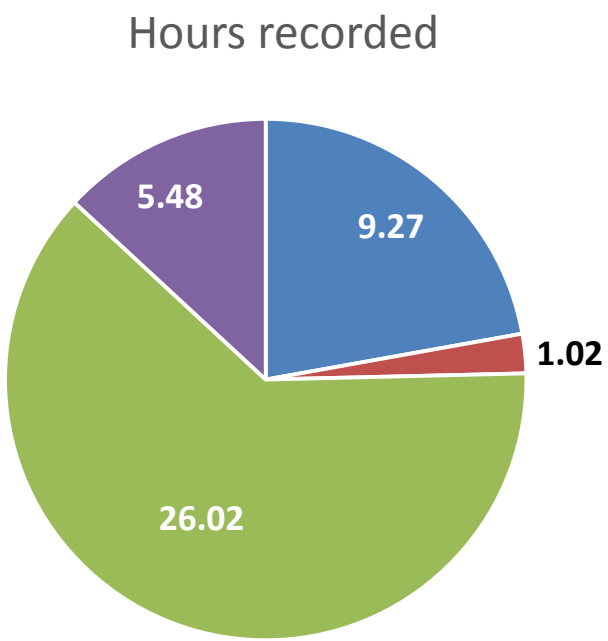
ObsBox in ADT

ADT

Availability in 2015

18 ADT Faults in 2015





Three largest faults → 82 % of fault time

- UX45 interlock chassis (22.05 h), → **3 interventions**
- CV water cooling UW45 recovery (9.27 h), → **2 interventions**
- Gbit Link ADTLL (3.16 h), → **3 interventions**

Major upgrades during LS1

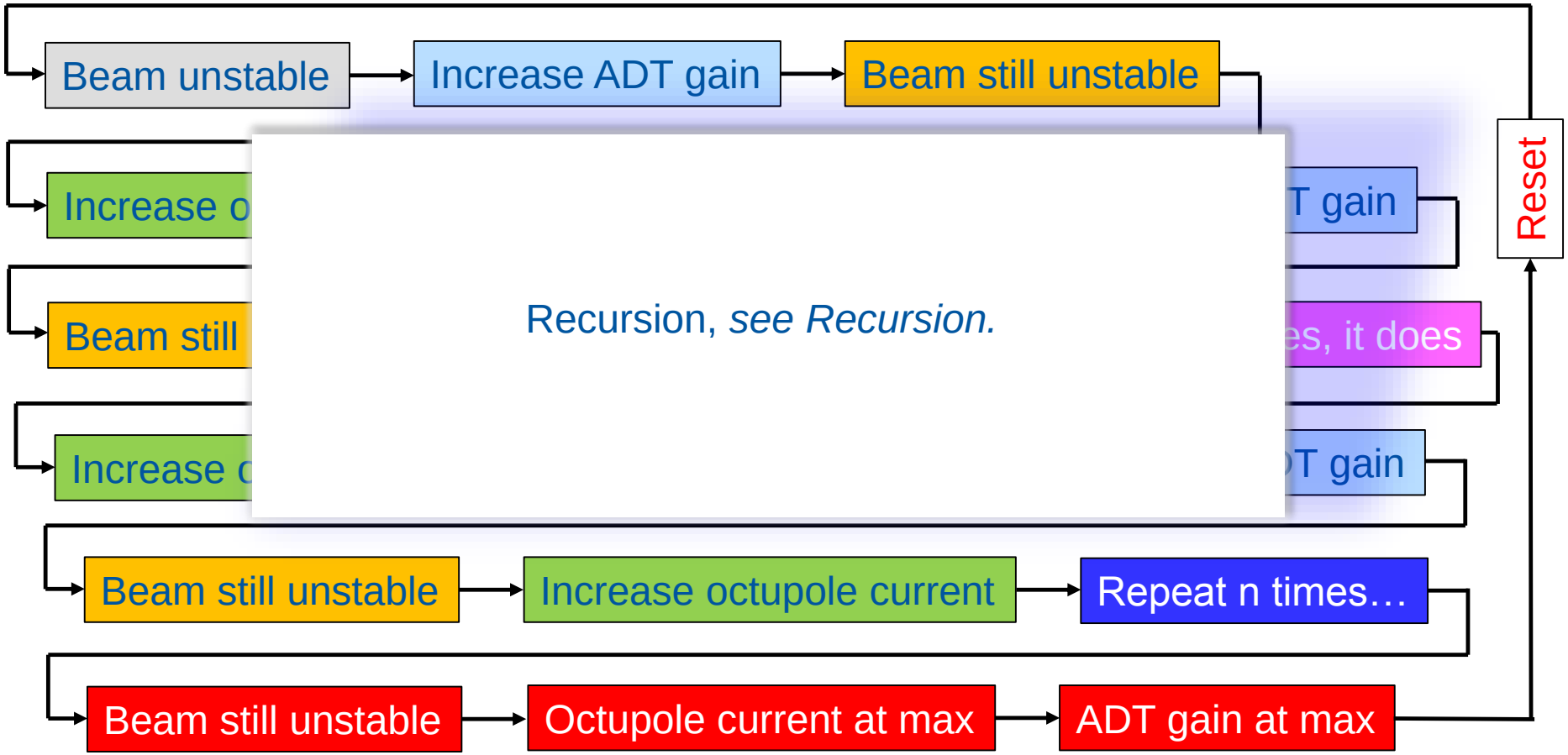
- New, much more performant signal processing hardware
- Properly integrated all the new functionality added during Run 1:
  - Fully independent feedbacks for main loop and witness bunches
  - Abort gap and injection gap cleaning
  - Blowup
  - Excitation functionality to perform controlled kicks through the whole cycle

Operational issues in 2015

- Answer to the question: is the damper working?
- Confusion between operational and special settings (cleaning, blowup…)

Is the damper working?

- Typical cycle observed every year since 2010:

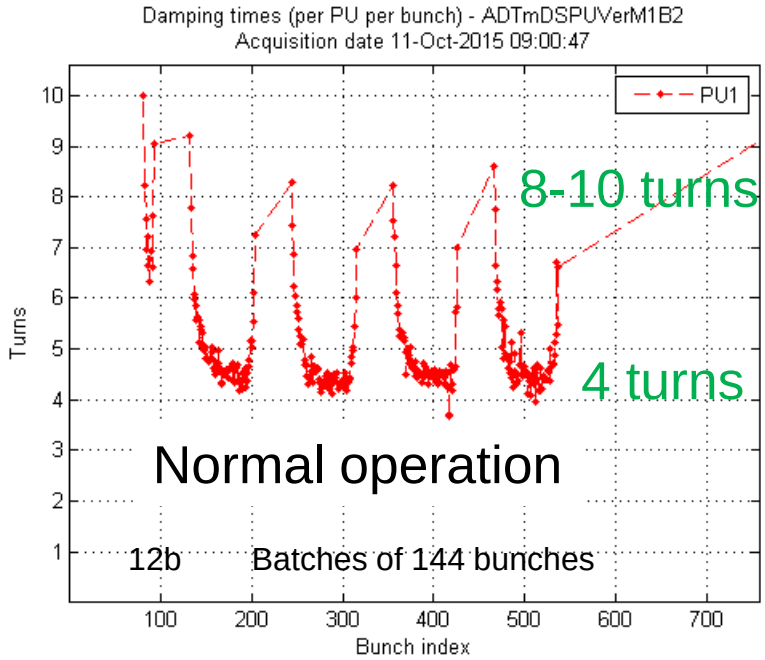


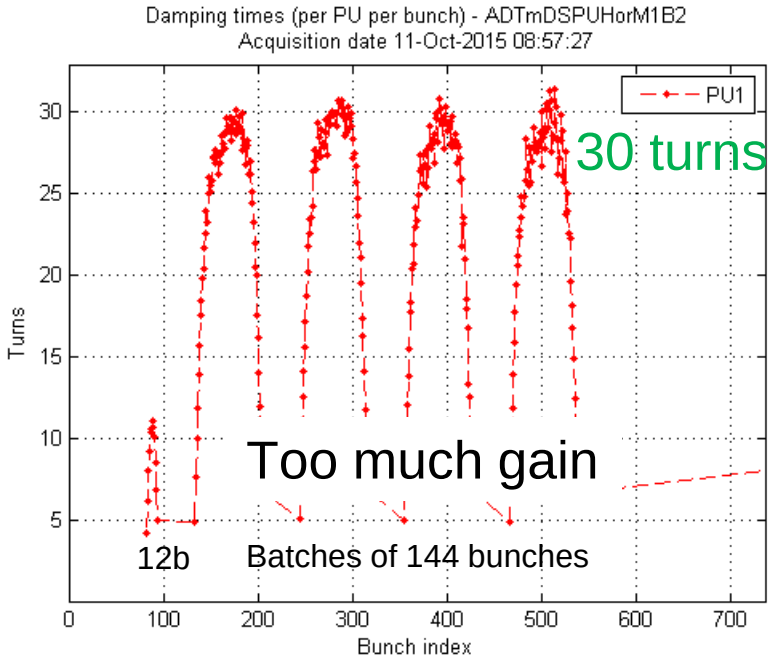
Is the damper working?

- Basic hardware check in IQC:
  - All signal processing modules are receiving correct data and able to function correctly
- Online monitoring of the damper performance with beam at injection and through the cycle
  - Injection oscillation analysis: damping times, per-bunch tune, phase advances between pickups (and many more)
  - Same thing through the cycle by on-demand active excitation
  - All data will be made available via logging and display/application in CCC

Is the damper working?

An example: damping time extraction





- Need to extract many more beam parameters important for proper functioning of ADT
- Injection analysis and damper performance: BE-RF + BE-OP
- Instability analysis: BE-ABP

Settings confusion

- The cleaning and the blow-up functionality will be completely decoupled
  - Sacrifice last free channel foreseen for future special manipulations
- Intensity settings of beam position measurement front-ends now available from a CCC application (pilot, nominal, high intensity)
  - Already since autumn 2015

Summary: RF

- Major Run 1 hardware issues with HV & klystrons fully mitigated during LS1
- Cavity module successfully replaced & recovered
- Many faults mitigated during TS1 and TS2
- Beam intensity related issues with peak klystron power: condition to nominal 300kW for 2016
- Arc detector trips not understood: diagnostics installed
- LLRF spares start to become important
- Some controls issues to mitigate for 2016
- New powerful diagnostics based on ObsBox

Summary: ADT

- Hardware availability is good
  - Few minor isolated issues
- Operational issues identified
  - Monitoring of performance with beam
  - Settings management
  - Will both be addressed for the startup

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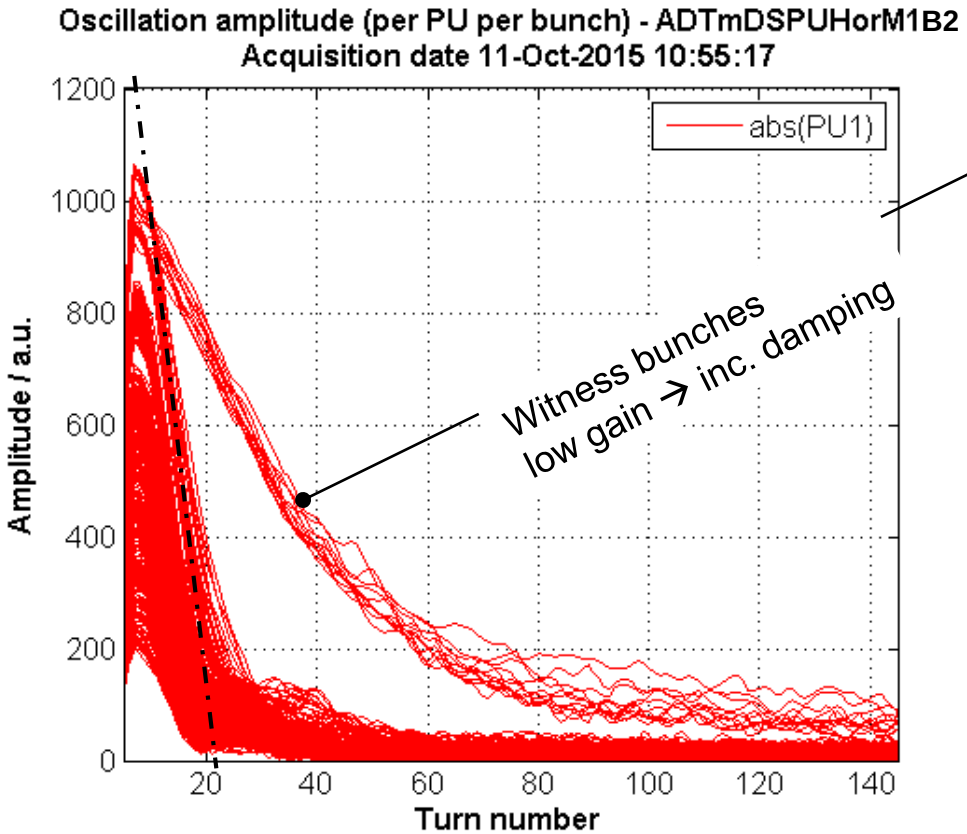
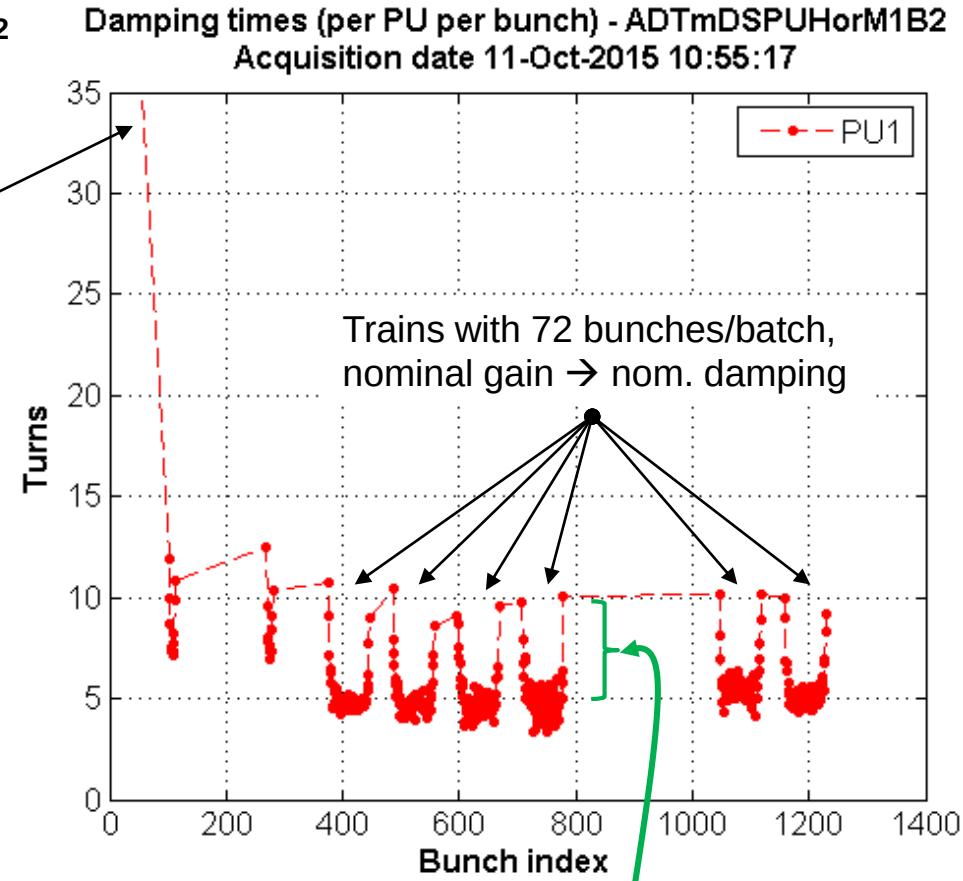
Damping Times per bunch





All bunches excited coherently during one turn.

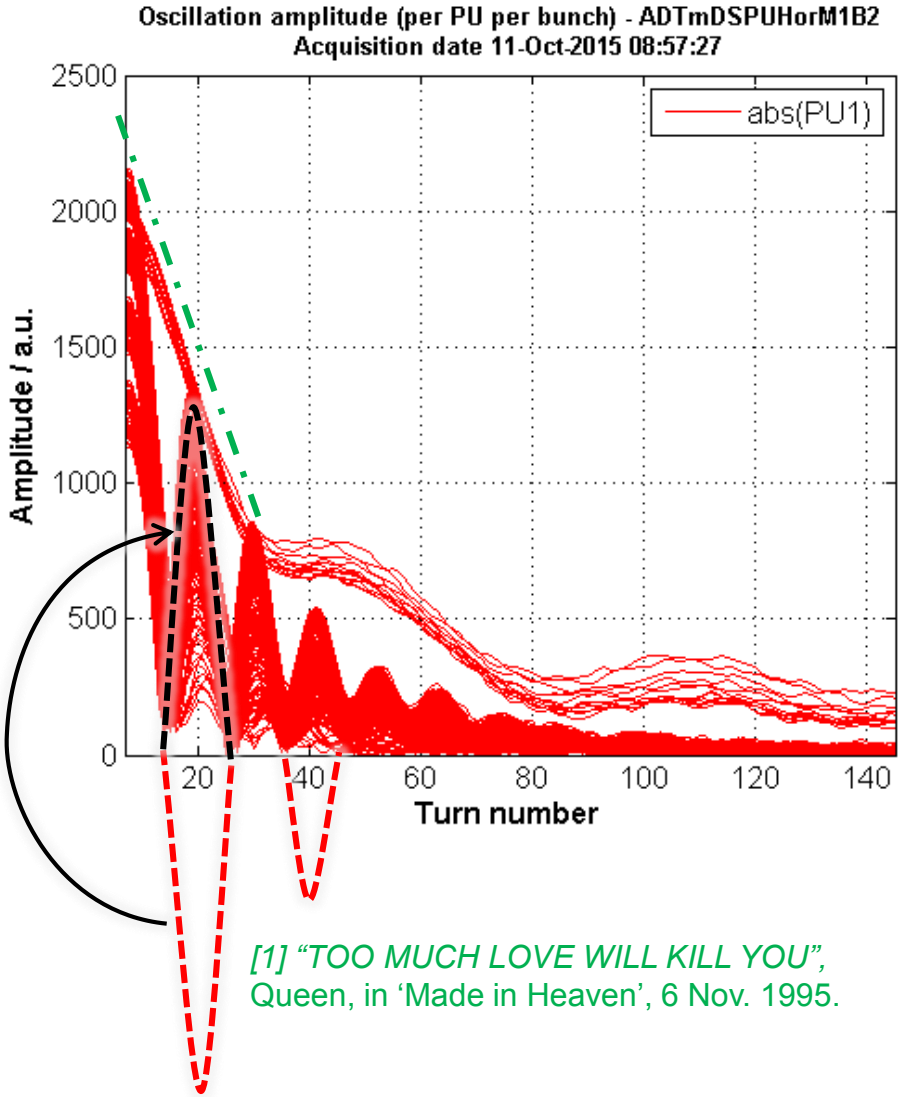
Transverse deflection by ADT << 1 mm.

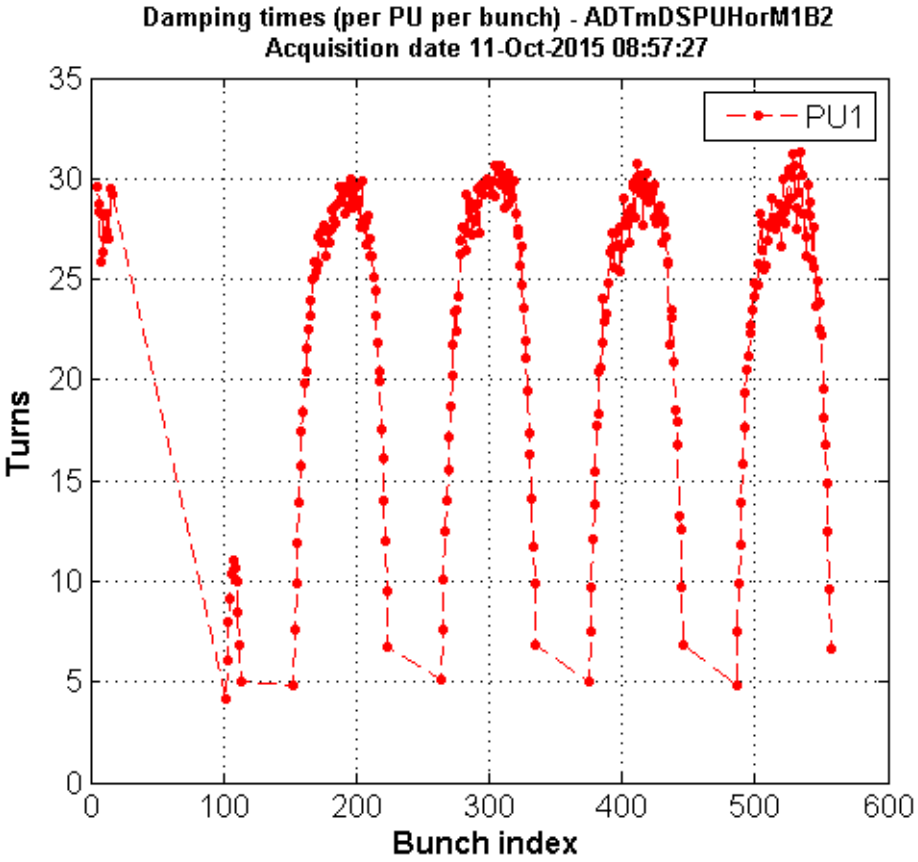
➔ expected blow-up less than 1 %.

Factor 2 between bunches in the centre an the edge of trains > 12 bunches

Damper was originally designed to counteract maximum injection errors of 3.3sigma corresponding to 4 mm at beta=185m, with an estimated emittance blow-up better than 2% [1]

Pathological Case: Over-Damping





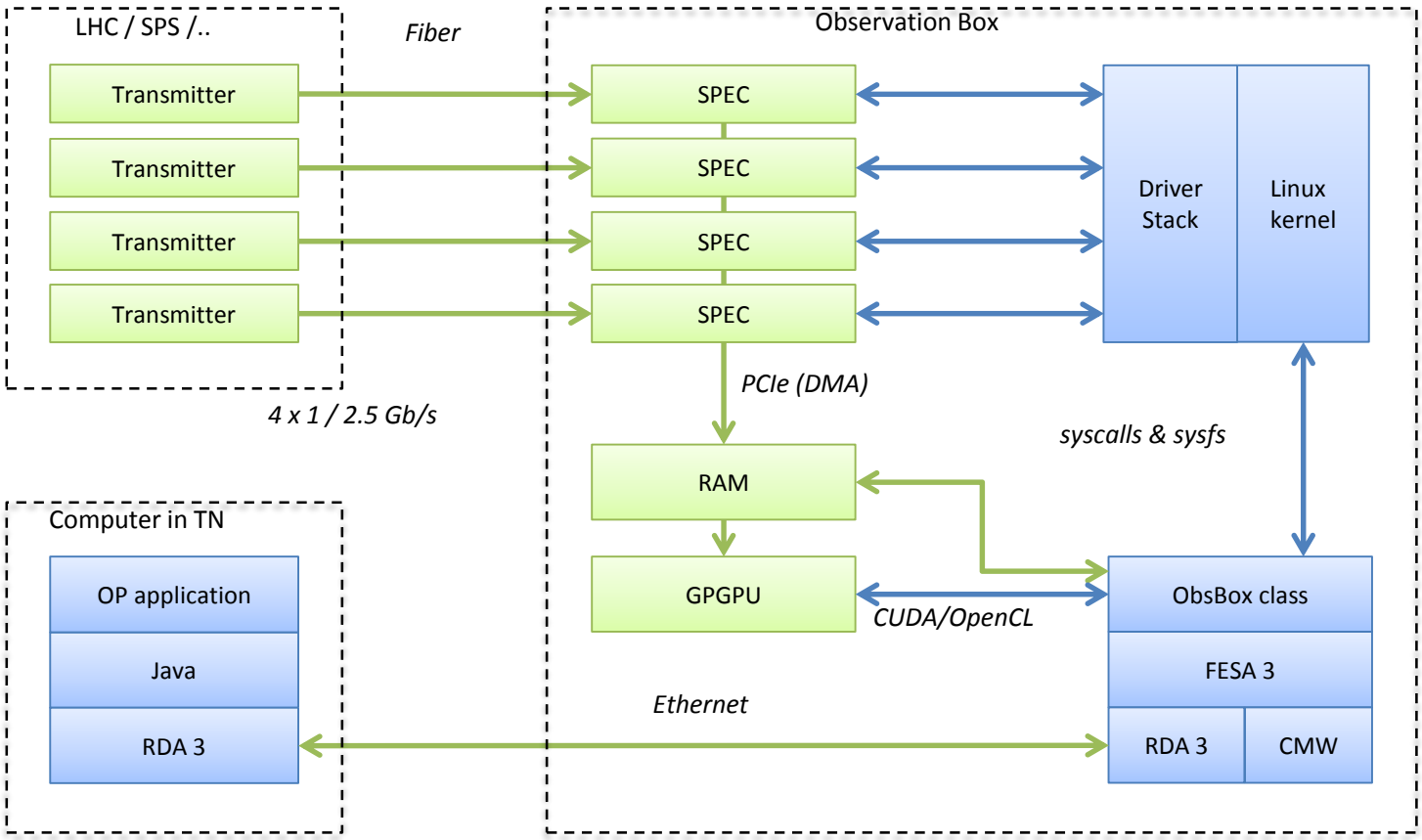
[1] "TOO MUCH LOVE WILL KILL YOU",
Queen, in 'Made in Heaven', 6 Nov. 1995.

See also: *"MARGINS TO INCREASE ADT GAIN AT INJECTION",* W. Hofle, LBOC 49, 6 Oct. 2015

https://indico.cern.ch/event/451051/

ObsBox

VME modules with integrated Transmitters



Faults summary in 2012

- Total downtime 18 hours in 2012

Tetrode exchange	Amplifier faults	HV Power supply faults	PLC & Server faults	Kicker Faults	Low-level RF
#9 #12 #16	#3 PT100 (exchange amplifier)	#15-16 HV cables burnt	#11-12 FESA server crashed	RB46 TPG 300 exchange	40MHz clock havoc after TS
#3 #15 #6	#8 PT100 (exchange amplifier)	#9-10 Gate control failure	#9-10 FESA server crashed		Gigabit link connector bad soldering
#14 #1 #4 #2	#2 attenuator (exchange amplifier)		#11-12 Beckhoff module exchange		
Total 20 tetrodes out of 32 replaced	#9 HV load (exchange amplifier)				
	#10 water flow meter				