





6th Evian Workshop
15-17 December 2015

~~QPS operational experience in Run2~~ The eternal Quest for Peace and Serenity

Mirko Pojer

With many kind inputs by several people, in particular R. Denz, J. Steckert, G.J. Coelingh, J. Arroyo Garcia, Z. Charifoulline, P. Bozhidar, M. Zerlauth, I. Romera

Outline

- QPS
 - QPS in numbers
 - Changes during LS1
- System (un)availability after LS1
 - CSCM and SEU
 - Post-TS2 operation
 - Communication issues
 - Switches
- Software tools and interfaces
 - Macros
 - Sanity check
 - LHC Circuit Supervision
- Data quality
- Bonus

The QPS in numbers

- The Quench Protection System is 'one' of the most complex and extended systems in the LHC
- Reliability, availability and maintainability are a **major challenge and concern**

Circuit type	#
Main bends and quads	24
Inner triplets	8
Insertion region magnets	94
Corrector circuits 600 A	418
Total	544

Protection system type	Quantity
Quench detection systems	7568
Quench heater discharge power supplies	6076
Energy extraction systems 13 kA	32
Energy extraction systems 600 A	202
Data acquisition systems	2516 (~71 TB/year)
System interlocks (hardwired)	13722
Signals (analog)	31924
Signals (flags, status)	77792

90 standard racks in the LHC underground areas and alcoves

1670 special protection racks in the LHC tunnel

2298 protection crates

Thousands of control cables & connectors

88 fieldbus segments (44 gateways)

Courtesy of R. Denz

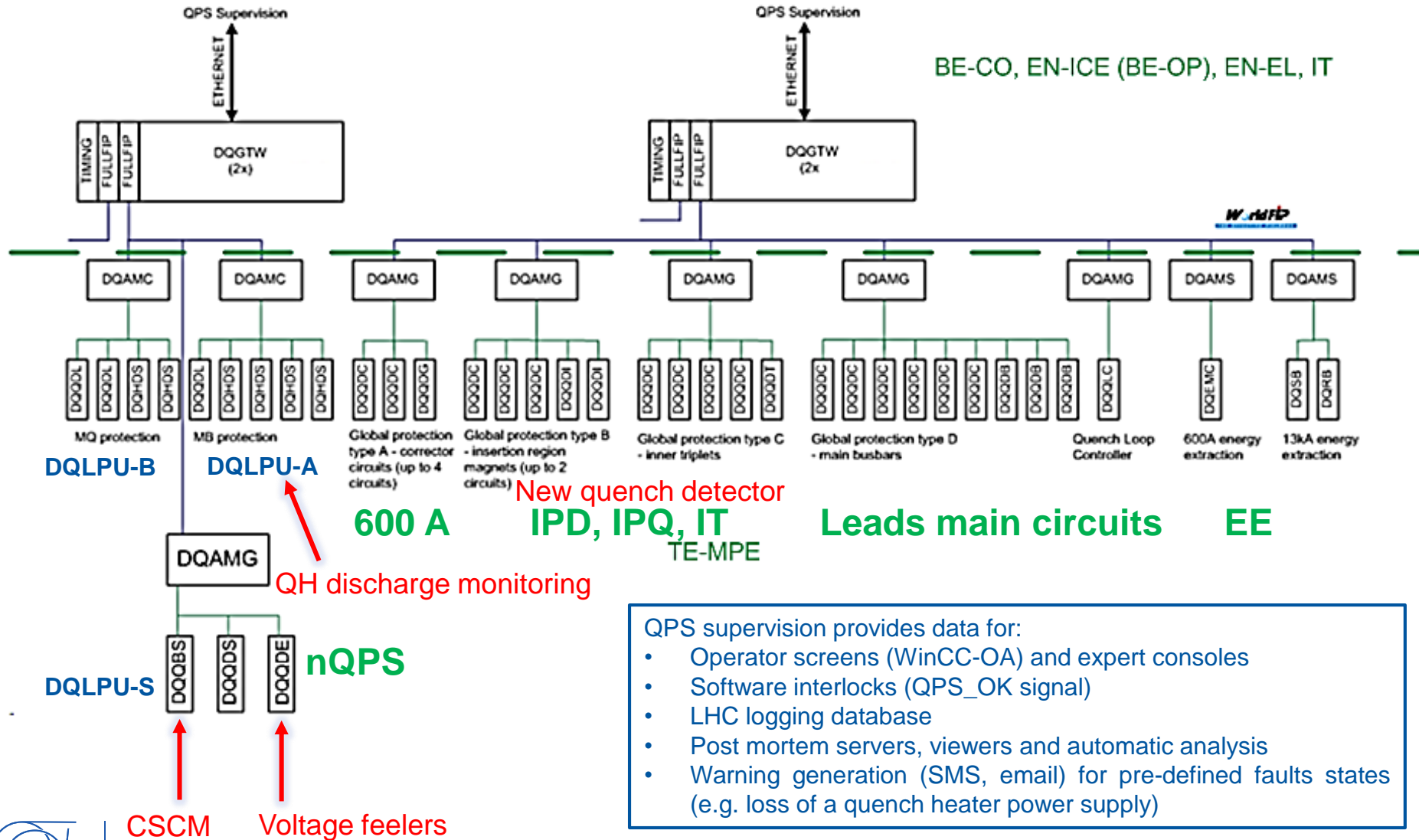
LS1 changes

- Major revision of main dipole protection systems
 - Upgrade of the DAQ systems, especially for the enhanced supervision of the main dipole quench heater circuits (FPGA based)
 - Change of field-bus configuration to double transmission capacity
 - Enhanced remote control options
 - Full adaption to redundant UPS powering
- IR magnets and ITs
 - Most of the detection systems were upgraded to radiation tolerant FPGA based systems; the IT systems were re-located to radiation free areas (UL14, UL16 and UL557)
 - Equipped as well with a bus-bar splice monitoring system (non-interlocking)
 - Warm instrumentation cables for some magnets re-routed to improve the immunity in case of perturbations of the electrical networks
- Energy extraction systems:
 - During LS1, the 13kA EE systems went through several interventions of upgrade, maintenance and measurement (IST)
 - For the 600A EE systems, the interventions aimed at improving circuit-breakers availability/reliability

QPS supervision—'basic' architecture

Modifications in LS1 + overall firmware upgrade

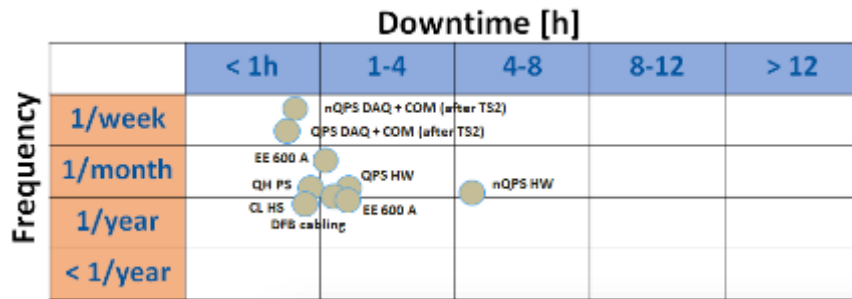
Courtesy of R. Denz



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The QPS after LS1



QPS HEATING & COOLING

24 HOUR EMERGENCY SERVICE

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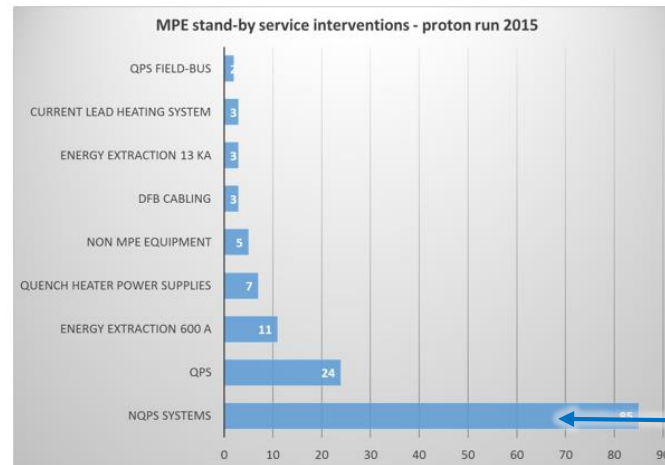
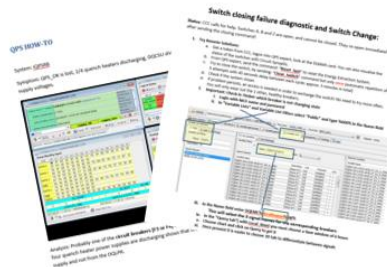
Got a breakdown?

Never miss a QPS Promotion! Join our QPS VIP List for instant notification!

TE Achievements (selection) – MPE Group

Standby Service Team 2015

- Yan Bastian
 - Gert-Jan Coelingh
 - Giorgio D'Angelo
 - Mathieu Favre
 - Vincent Froidbise
 - Spyridon Georgakakis
 - Richard Mompou
 - Joaquim Mourao
 - Stephen Pemberton
 - Grzegorz Seweryn
- 143 interventions; 0.49/day, 1.12 h/intervention (2012: 114)
 - 71% of all problems could be solved remotely (2012: 48%)
 - 1 machine access every 7.2 days (2012: 5.2 days)
 - Post LS1 teething problems dominating statistics



mQPS for CSCM!

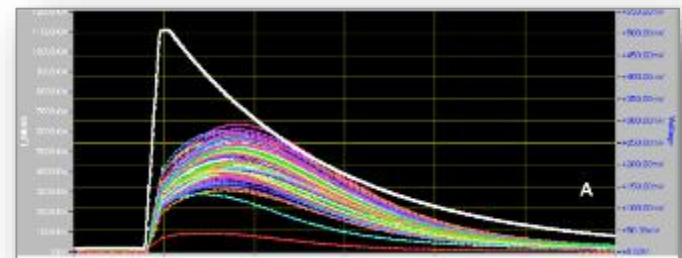
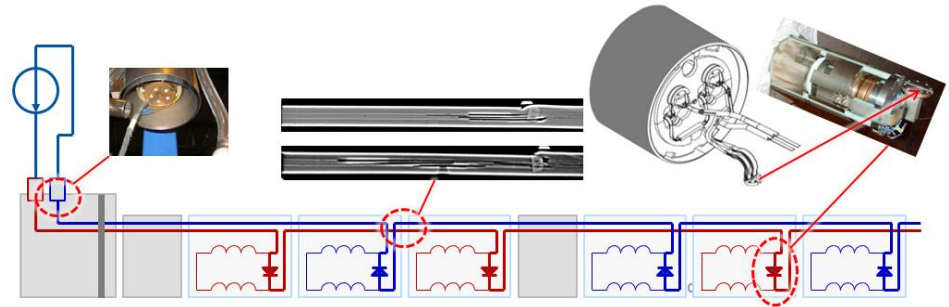
CSCM and mQPS

CSCM=Copper Stabilizer Continuity Measurement

- Extremely important and reliable **validation of the integrity of the splices, the diodes and the diodes busbars**

- A major effort by several teams and a big impact on the planning

- Test done at 20 K → high voltages to be detected + new dV/dt detection
--> **new boards (mDQQBS) developed to cope with these conditions**



*Voltages on bus bar segments of a sector
(spread due to RRR and segment length diff)*

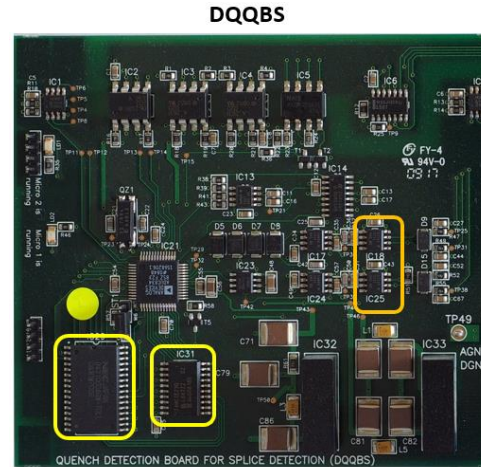
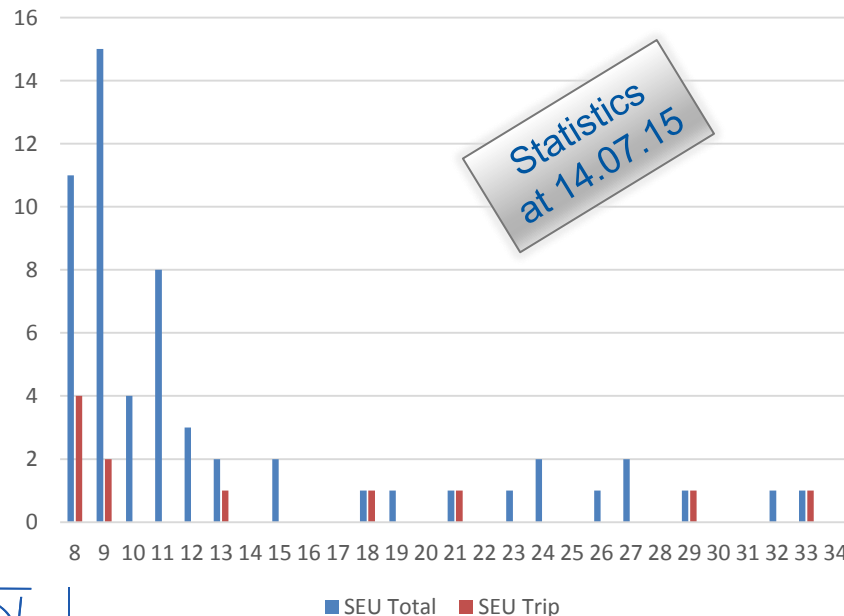
Should have to decide whether we keep on the baseline for any LS (suffered from the late decision on the global execution)

SEU on mDQQBS

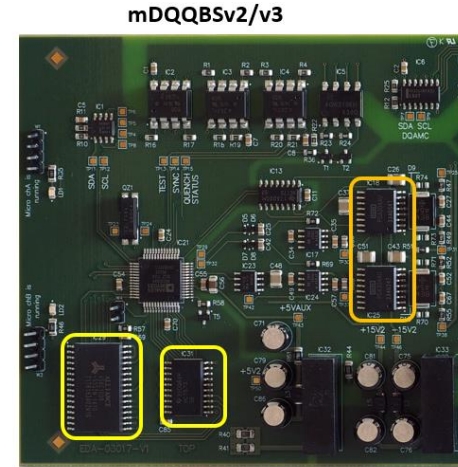
A. Siemko at LMC#226

- ✓ Changed input stage to a PGA to be able to perform CSCM
- ✓ Polyvalent Firmware (CSCM and normal mode)
- ✓ Some components had been changed to functionally equivalent replacement due to availability

SEU vs Half cell



SRAM: NEC D431000AGW-70LL
D-Latch: NXP 74HCT573
Amplifier: INA141
Passives



SRAM: Alliance AS6C1008-55SIN
D-Latch: TI 74HCT573
Amplifier: PGA204
Passives

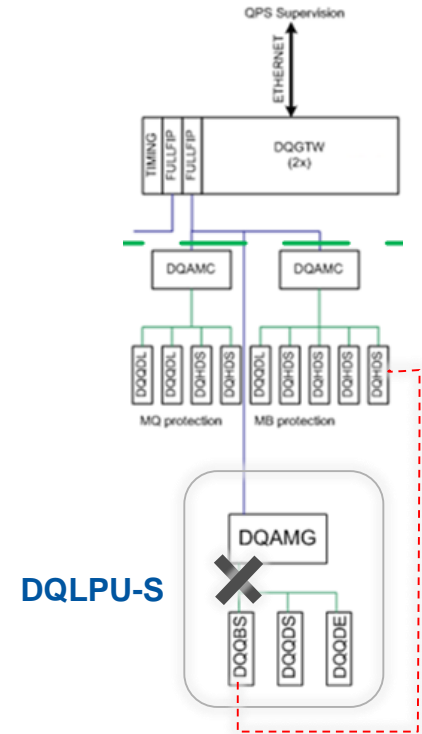
- **57 SEU in mDQQBS boards detected**
- 11 Triggers of mDQQBS (opening of interlock loop)

- Firmware update was first tried
- Complete replacement of all boards was necessary in TS#2

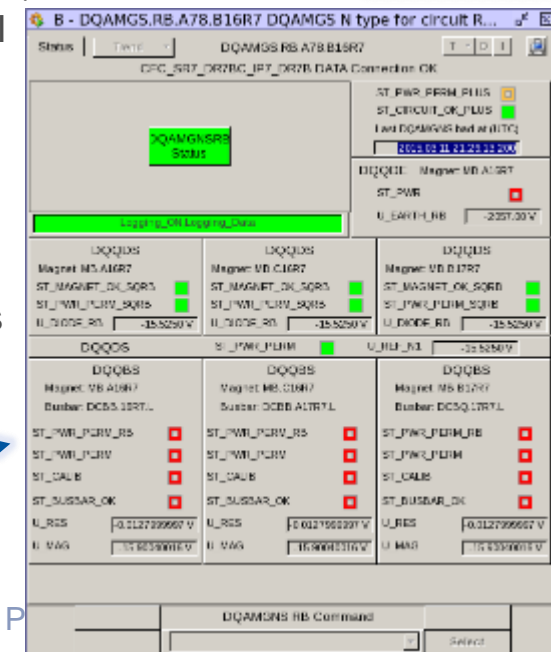
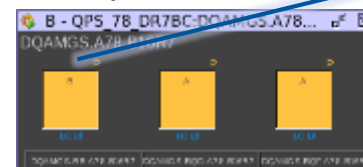
Net improvement in availability!

Post TS#2 QPS behaviour

- SEU almost absent; over the whole year (mQPS faults not counted)
 - DAQ systems: **139 transparent-mitigated- errors recorded** (about 30 with ions), **no fault, no downtime, no dump**, no blocked uFIP (automatic recovery is active for 1232 devices so far)
 - 600 A detection systems: **2 cases causing beam dumps** recorded (RR13 17/10/2015, RR57 31/10/2015). This is less than expected, as the devices have not been updated yet to a radiation tolerant version. **The update for RR13, 17, 53, 57, 73 and 77 will take place during the YETS.**
 - Any other detection system including standard DQQBS boards re-installed during TS#2: once during ion run, at hot spot**
 - No R2E problems for any re-located equipment in (UL14, 16, 557)
 - No R2E problems for upgraded detection systems type nDQQDI (ProASIC3E)

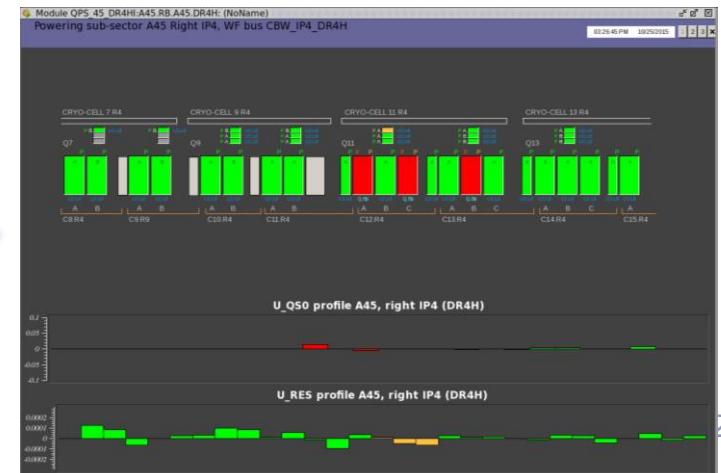
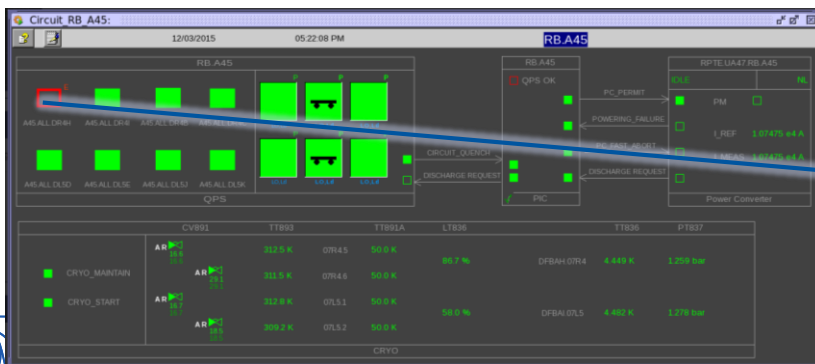
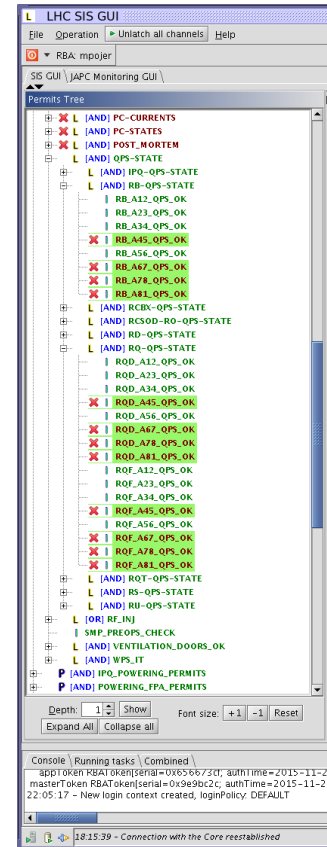


- After installation of the old nQPS boards, an already known communication problem appeared
 - Affecting the DQLPU type S (sitting below the B dipole)
 - Has the consequence of losing comm with the various detectors
 - Appeared in the initial commissioning, then disappeared
 - Not reproducible in the lab
 - The protection functionalities are not compromised



Comm lost issue

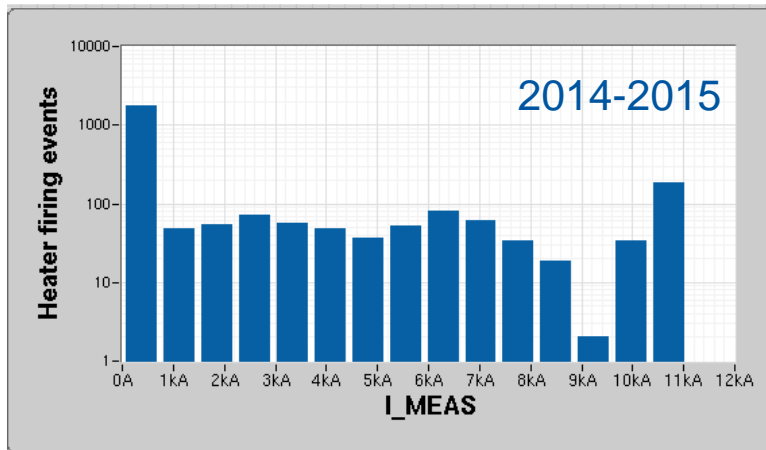
- Even if not safety critical, a faulty communication is nevertheless twofold problematic:
 - By removing the QPS_OK, it **interlocks the injection** through the SIS, even if it does not prevent operation (i.e., ramping)
 - A mask is needed to continue injecting – per se no safety issue but it **degrades the interlock redundancy**: we could miss a stalled board or ramp to high energy with two QHPS off (1 h delay before removal of PP)
 - It **prevents re-powering** a main circuit if the converter was set off (trip, access, loss of cryogenic conditions), as PIC does not grant PC permit in the absence of the QPS-OK
- To re-activate the communication, a power reset procedure was set, which was initially not optimized
 - If not done properly, quench heaters were discharged in the attempt of re-establishing the communication



Comm lost issue_cont.

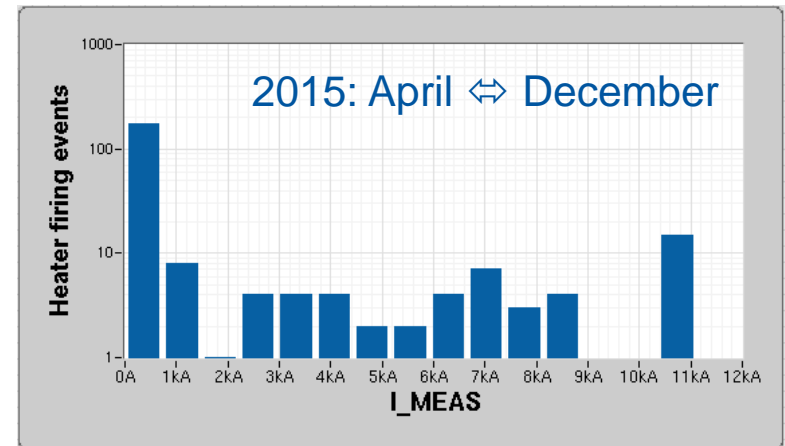
■ Statistics on QHDS firing

Courtesy of Z. Charifoulline



Since October 2014 (QPS-IST included):

- ✓ About 2525 full charge firings in total
- ✓ About 1650 firings at zero current



Since April 2015 (1st beam in the machine):

- ✓ About 234 full charge firings in total
- ✓ About 170 firings at zero current

- A firmware upgrade has been developed and will be deployed during the YETS on all 436 units affected by the communication bug
 - Will be carefully tested at the end of YETS
 - Should be transparent for re-commissioning

600 A EE issues

Courtesy of G.-J. Coelingh

- 600A EE switches - few changed this year:
 - ‘Normal’ replacement of failing components
 - **13 interventions in total on 600A-EE (202 systems):**
 - 2 interventions due to missing comm.
 - 2 low voltage power supply replacement
 - 1 cases of loose wires (post-LS1 effect?)
 - 5 breakers changed (4 old one plus 1 replaced again due to closing failure)
 - 2 cases of the main acting part which got lose (1 per year on average)
 - 1 micro-switch problem
 - 1 holding coil
 - 1 unknown
 - 3 remote interventions: could be reset remotely but 2 were leading to interventions later so part of tunnel interventions
- Future development:
 - A **pre-warning tool** is under development, to pre-trigger an alarm
 - Reiner is working on a pre-cycle monitoring tool
 - No new hardware needed, only software
 - Should provide the internal resistance of the breakers
 - An expert tool to draw “own” statistics
 - Counter for openings being developed (A. Gorzawski?)
 - Automatic analysis of failures is well advanced
 - Logbook entries



13 kA EE issues

- Two failures concerned the 13kA EE systems in the current year
 - On 22nd of July --> Unable to close switches of RB.A34-odd side. The intervention on the spot revealed a broken diode bridge rectifier of a holding coil auxiliary circuit.
 - As a result, four out of eight switches could not get closed.
 - On 3rd of November --> Unable to close switches of RQD.A34. The stator coil of one cooling fan was burned and tripped the local circuit breaker.
 - This led to a constant presence of an interlock "over temperature" and all switches of the system could not get closed.

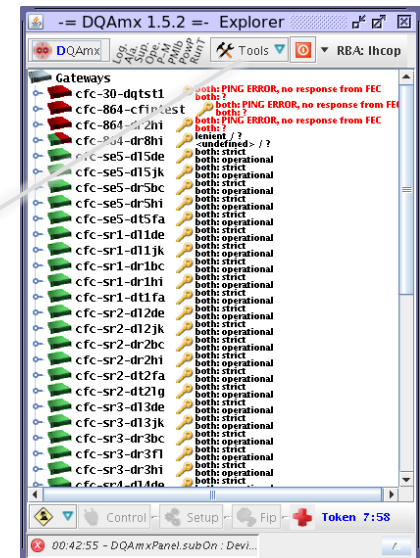
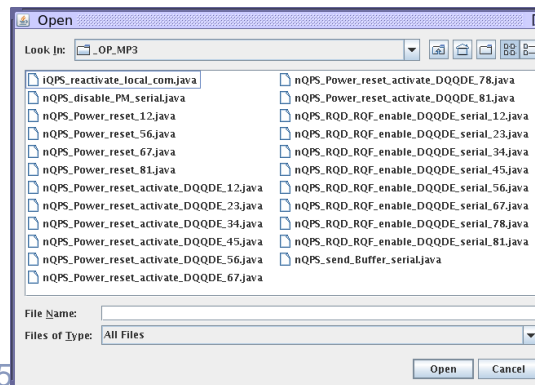
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QPS Macros

- Part of the diagnostics and operation of the main circuits is, at present, based on a series of macros, accessible from the QPS_expert_tool, to
 - Reactivate the local communication of a QPS board (no DQAMGS!)
 - Power reset the nQPS after a trip
 - Activate the voltage feelers after their triggering
 - Send/disable the PM data from nQPS
- These macros were of great importance during the training campaign, but
 - They require a series of operations and specific knowledge
 - Need to be run at every circuit trip (quench, FPA)
 - **Not systematically launched**
 - **Not protected by password** (lhcop has full rights)
 - **They are error prone**

The expert tool will be RBAC protected, with a timeout if no use (no user action on GUI) during more than 1 hour, then, application is locked for future actions!

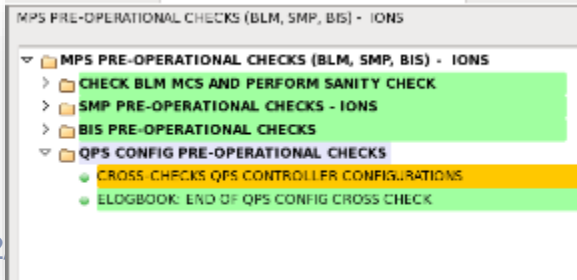
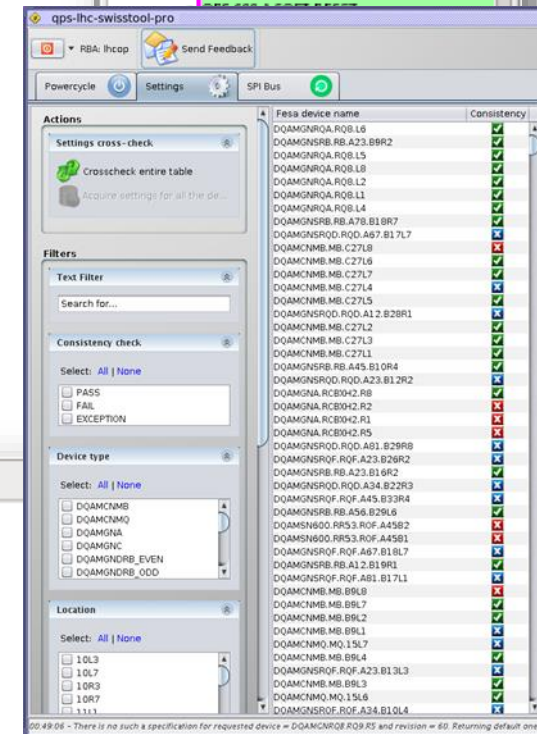
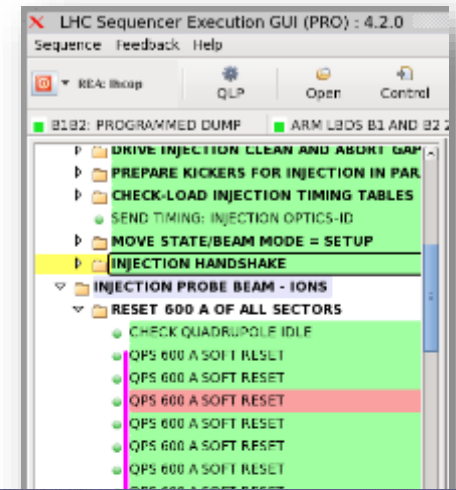


QPS Macros_cont

- Present status and future improvements:
 - In case of triggering of the nQPS a PM file is generated but not sent
 - The process blocks the generation of additional PM files, to avoid losing data in case of secondary events
 - A manual triggering of PM sending is presently required
 - A different solution will be deployed during YETS, which foresees the **automatic sending of the PM files, but with a (programmable) delay of 10 min**
 - This will as well prevent losing data for the 600 A circuits, where the controller is shared by 4 circuits at a time!
 - Without running the two macros of power reset and voltage feelers activation, the VF's are not activated → we were sometimes running without VF in some sectors
 - **As from YETS, the VF's will be automatically activated when resetting the nQPS**
 - **Ideally, this reset could be integrated in the sequence of preparation of a sector → BE/ICS will work on a macro for the sequencer!**
- As discussed and requested by LMC, the present voltage feelers sampling rate will be pushed from the present 1.25 Hz to **10 Hz after YETS**
 - Improve diagnostics in case of short-to-ground on the main circuits
 - Need to assess the compatibility and limits imposed by the tunnel infrastructure (presently 10 Hz, as stated by E.Hatziangeli)

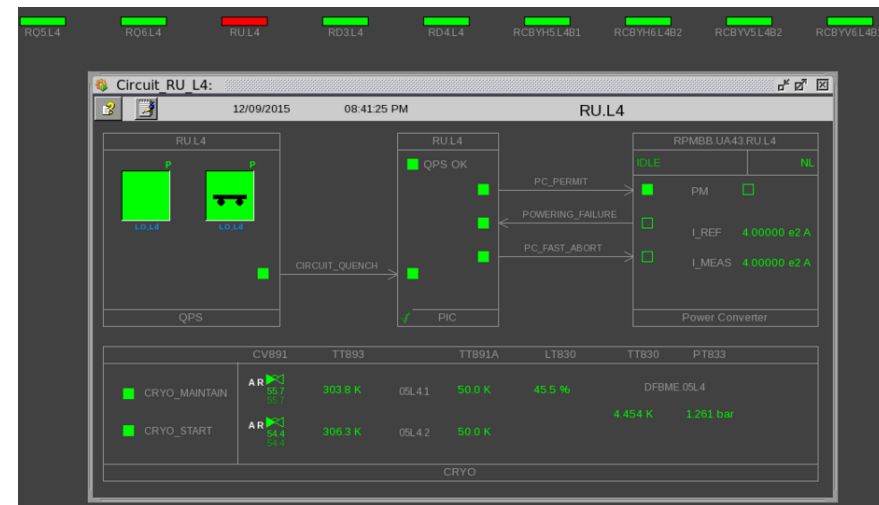
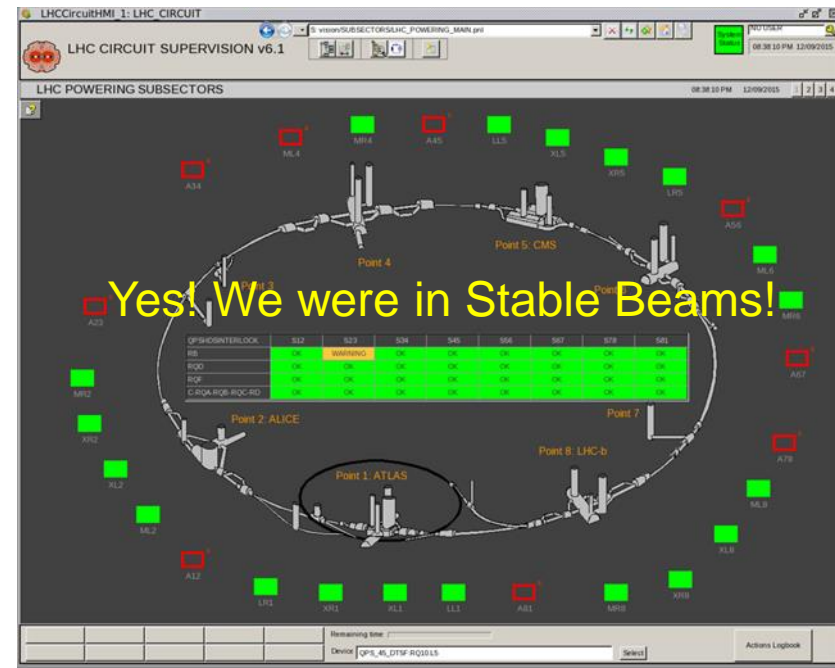
QPS sanity check

- Some checks have been progressively imported into the operational sequencer
 - The soft reset of the 600 A controller, to reset and check that the controller is live
 - For S34 it is systematically failing since the beginning due to the missing RSS.A34B1
 - **BE/ICS should implement a check in the existing macro to exclude this circuit from the evaluation**
 - The QPS configuration management check has been recently introduced (part of the Swiss tool)
 - It triggers a reading of the configuration from each of the FESA devices, and cross-check against the reference stored in LSA.
- QPS experts have also a maintenance tool which is running constantly, checking “all” values from logging every 10 min



PVSS

- EN/ICE (BE/ICS) has been working hard in the last months to consolidate the knowledge of the QPS supervision
 - Trying to get rid of erroneous visualization (persistency of signals)
 - Not easy to implement a new logic for the visualization of 'super-locked' circuits (RSS.A34B1 above); this would require a full commissioning of the PIC
 - **A test platform is under development, where modules from all users could be integrated/tested, before final release**



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Data quality

From MP3 review

- The data of the QPS Post Mortem files still contain many timing errors, saturated points, spikes, which make a dependable analysis and automation very difficult, if not impossible.
 - Non-logical signal and crate naming, signal swaps, polarity issues, and incorrect documentation further complicated the analysis.
 - The QPS team should provide PM-correctors so that the users can use corrected/filtered data (without changing the raw data files).
 - Automate the quench (heater) analysis at all levels and for all circuits
 - Automate monitoring of protection related signals, earth current and voltage to ground
 - Set up a realistic **test bed of all the soft and hardware** of the various types of circuits, in order to properly prepare for a following HWC campaign. This would significantly reduce the software debugging time during the HWC.
 - A strategy should be proposed by the automation team, with input from MP3, to store analysis results in a database.
- From QPS:
- corrupted files;
 - post-processing on raw data is needed; missing resources in EN-ICE and TE/MPE

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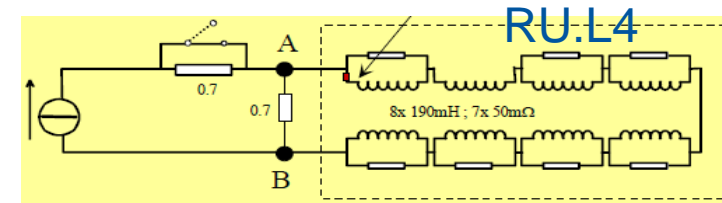
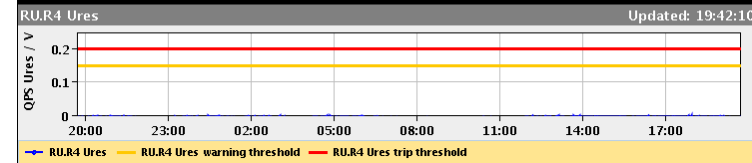
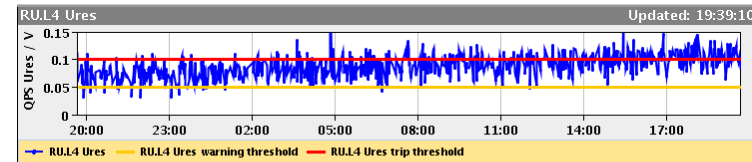
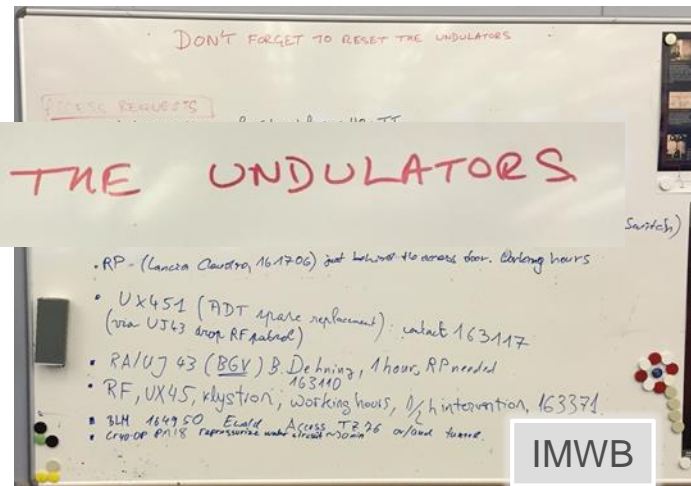
Undulator

- 2 dumps this year (and more in the past...)
- Problems

- Detection boards suffer from meas. drift
- Very noisy signal due to high inductance and LEM hall probe sensor
- Moving average filter to reduce noise
 - → keep acceleration low
- One has missing parallel resistor

- Actions for YETS

- LEM hall probe sensors will be replaced by DCCTs (10 times less noise)
- New detection boards being developed
 - Radiation tolerant implementation using Flash based PGA
 - Replaces complex auto-ranging analogue input stage by high resolution ADCs
 - Should not suffer from drift problem of previous generation



Concluding remarks

- More than 200 primary quenches were detected and actively protected by QPS in 2015
 - The QPS remains a fundamental system for the LHC
- The reliability has grown during the year, above all after the mQPS boards replacement
 - After initial problems, the performance has drastically improved
- On the software side, many things could be automatized
 - Working in that direction
 - Very few manual actions will be left to the operators

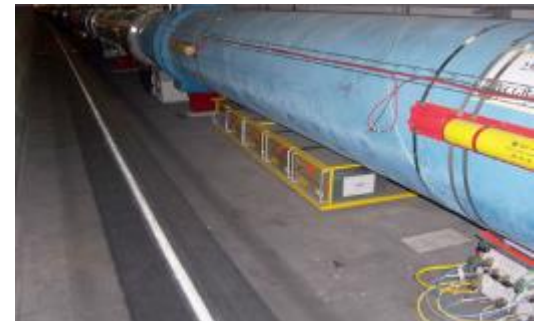
Many thanks for the attention!
Questions?



www.cern.ch

Protection of main circuits

- Basic protection systems are installed underneath the main dipole magnets integrating the quench heater power supplies, quench detection and DAQ systems
- Energy extraction systems, HTS lead protection and interlock controllers are installed in the respective underground areas on both end of an arc
- Huge amount of individual components
 - 4032 analog quench detection systems
 - 1632 digital quench detection systems
 - 2068 splice protection systems
 - 5712 quench heater power supplies
 - 32 13 kA energy extraction systems
 - 64 HTS high current lead protection systems
 - 16 QPS internal interlock controllers
 - 2060 DAQ systems



Protection of IR magnets and ITs

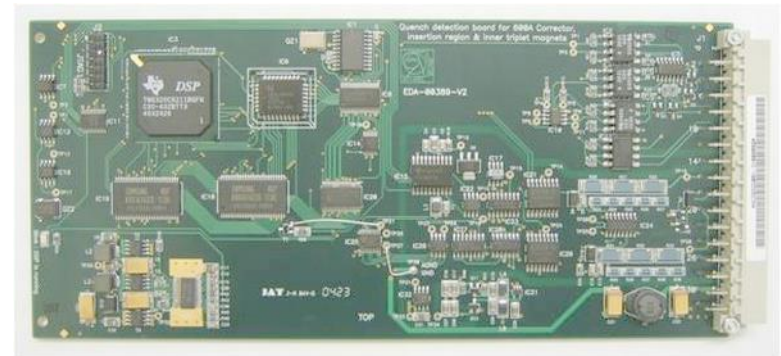
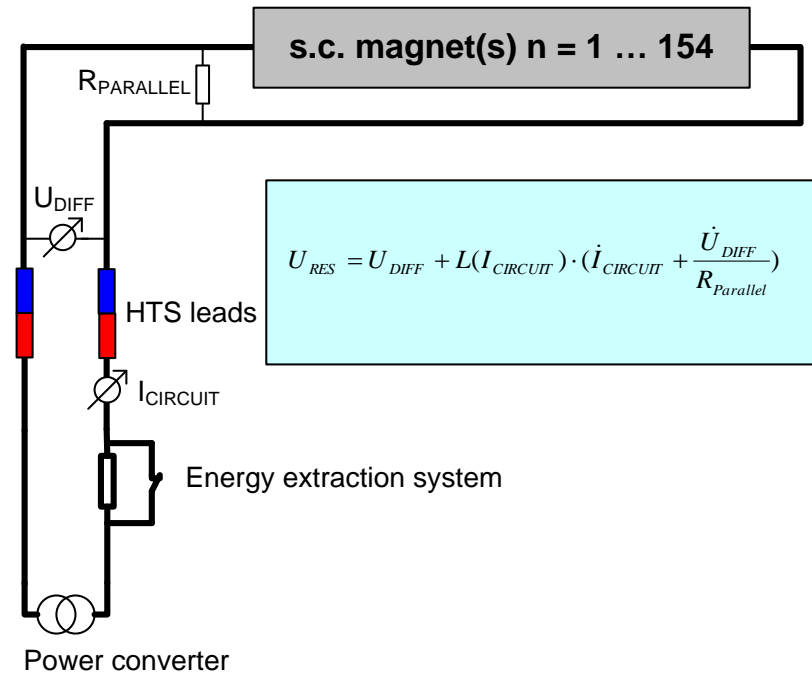
- One (separation dipoles), two (insertion region quads) or three (inner triplets) digital quench detection systems using a numerical bridge including bus-bar and two, three or four dedicated protection systems for the HTS leads
 - Thresholds are $U_{TH} = 100$ mV with $t_{DIS} = 20$ ms and $U_{TH} = 5(7)$ V for the overall voltage (symmetric quench protection)
- In case of any trigger the up to eight quench heater power supplies per circuit will be fired
 - Circuit will de-energize rapidly (~ 1 s) allowing the integration of the bus-bar protection in the magnet protection
- The protection of the circuit depends entirely on the quench heater circuits
 - No other possibility to extract energy fast enough to prevent damage
 - Quench heater power supplies connected to two different UPS
 - Detection systems powered by two different UPS

Protection of corrector magnets I

- Concerns all superconducting circuits with $120\text{ A} < I_{\text{NOM}} \leq 600\text{ A}$
 - Plus octupole spool pieces, $I_{\text{NOM}} = 100\text{ A}$ but 77 magnets in circuit
- Energy extraction systems needed for 202 circuits
- Circuit protection comprises one detection system for the magnet and the bus-bar and two separate systems for the HTS leads
- Digital quench detection system type DQQDG
 - Measures U_{DIFF} , I_{CIRCUIT} and dI_{CIRCUIT}
 - Calculates resistive voltage drop U_{RES}
 - Nominal threshold is $U_{\text{TH}} = 100\text{ mV}$ with $t_{\text{DIS}} = 20\text{ ms}$ ($I_{\text{CIRCUIT}} > 50\text{ A}$)
 - Circuit parameters including inductance table stored in detector memory
 - Pre-loaded inductance tables based on measurements performed on magnet test benches and during LHC hardware commissioning
 - Three stage digital filter system
- An upgrade of these systems aiming for better radiation tolerance and performance will be deployed during the EYET 2015/2016

Protection of corrector magnets II

- The big advantage of the concept is that it only requires the lead instrumentation
 - Only reasonable solution for circuits with large family size; to be avoided for single magnets
- Most complex detection system used by QPS
 - Very tedious commissioning; still some open issues e.g. tune feedback compatibility at higher energy
- Algorithm is currently ported to an FPGA in the framework of a radiation tolerant design → not so easy piece of work



LS1 changes_cont.

- During LS1, the 13kA EE systems went through several interventions of upgrade, maintenance and measurement (IST)
 - Particularly the maintenance: it was mainly related to extraction switches, which require certain maintenance to keep their reliable operation. During LS1 each switch faced:
 - An examination and inspection of all mechanical and electrical parts
 - Cleaning and alignment of the main and arcing contacts
 - Main contacts mechanical pressure verification
 - Tuning/adjustment
 - Check visually the main armature – clean and grease if necessary
 - Check status of micro-switches and their performance
 - Verification and re-tightening of flexible BB connections
 - Adding lubricant on the rotating axes

- For the 600A EE systems, the interventions aimed at improving circuit-breakers availability/reliability
 - New Voltage divider board and voltage measurement wires + Vtap
 - Thermostats on equalizing Resistors + new connection PCB + wiring to SK24
 - Replacement of A and Z imbus to hexag. Screws (> 27.000 checked)
 - Breaker maintenance general and breaker plate gluing
 - Visual inspection main axle
 - Interlock PCB resistor change
 - Interface card firmware upgrade (IST)
 - Acquisition and Monitoring board upgrade (IST)
 - New measurement PCB (IST)
 - Replacement of transformer (- overheated zener)
 - Dump Resistor modification RQTL9

Undulators

RU.L4	RU.R4
0.2 A/s	0.08 A/s
Ures includes inductive compensation	No compensation (problem with drift)
100 mV, 10 ms	200 mV, 10 ms
$V_{\text{inductive}} \sim 300 \text{ mV}$	$V_{\text{inductive}} \sim 150 \text{ mV}$
Effective threshold $\sim 100 \text{ mV}$	Effective threshold Ramp up $\sim 50 \text{ mV}$ Ramp down $\sim 350 \text{ mV}$
Ramp time $\sim 33 \text{ min}$	Ramp time $\sim 1\text{h}23$

Too high ramp time