

Quench Protection System

Insight into operational experience in Run 2

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On behalf of TE-MPE group

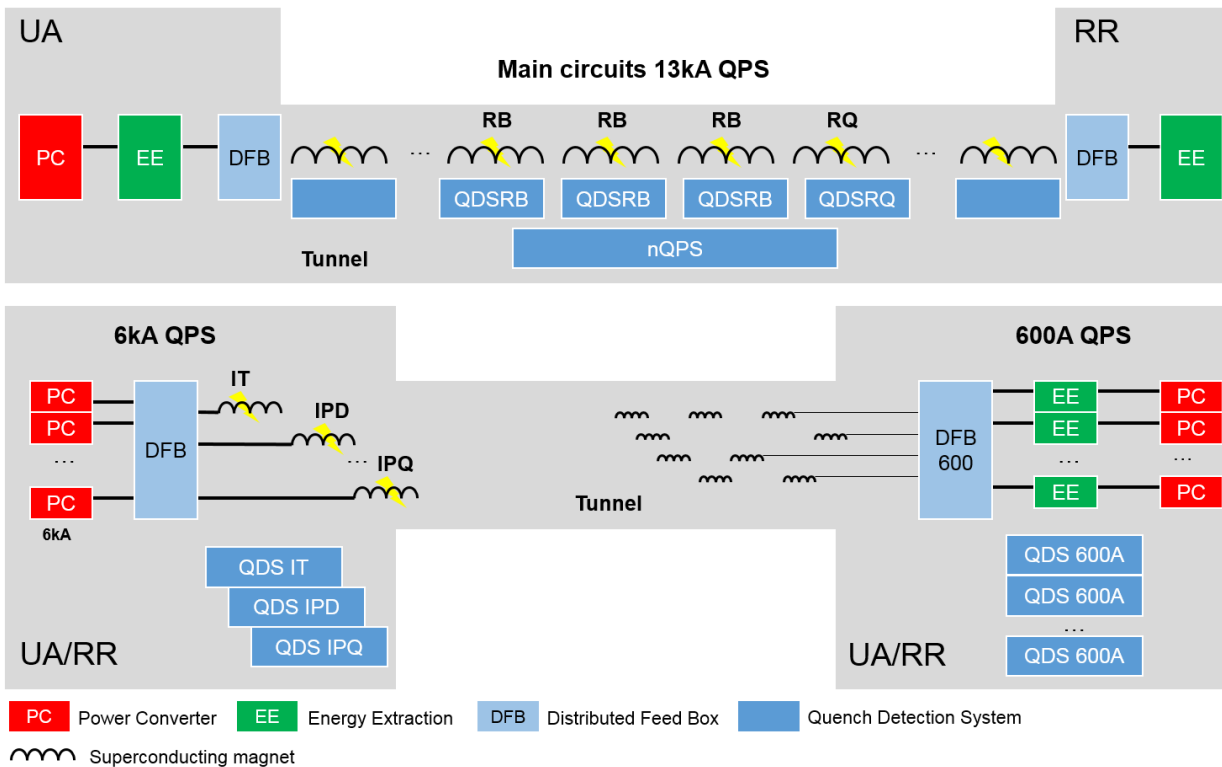
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13800 hardwired means to stop LHC

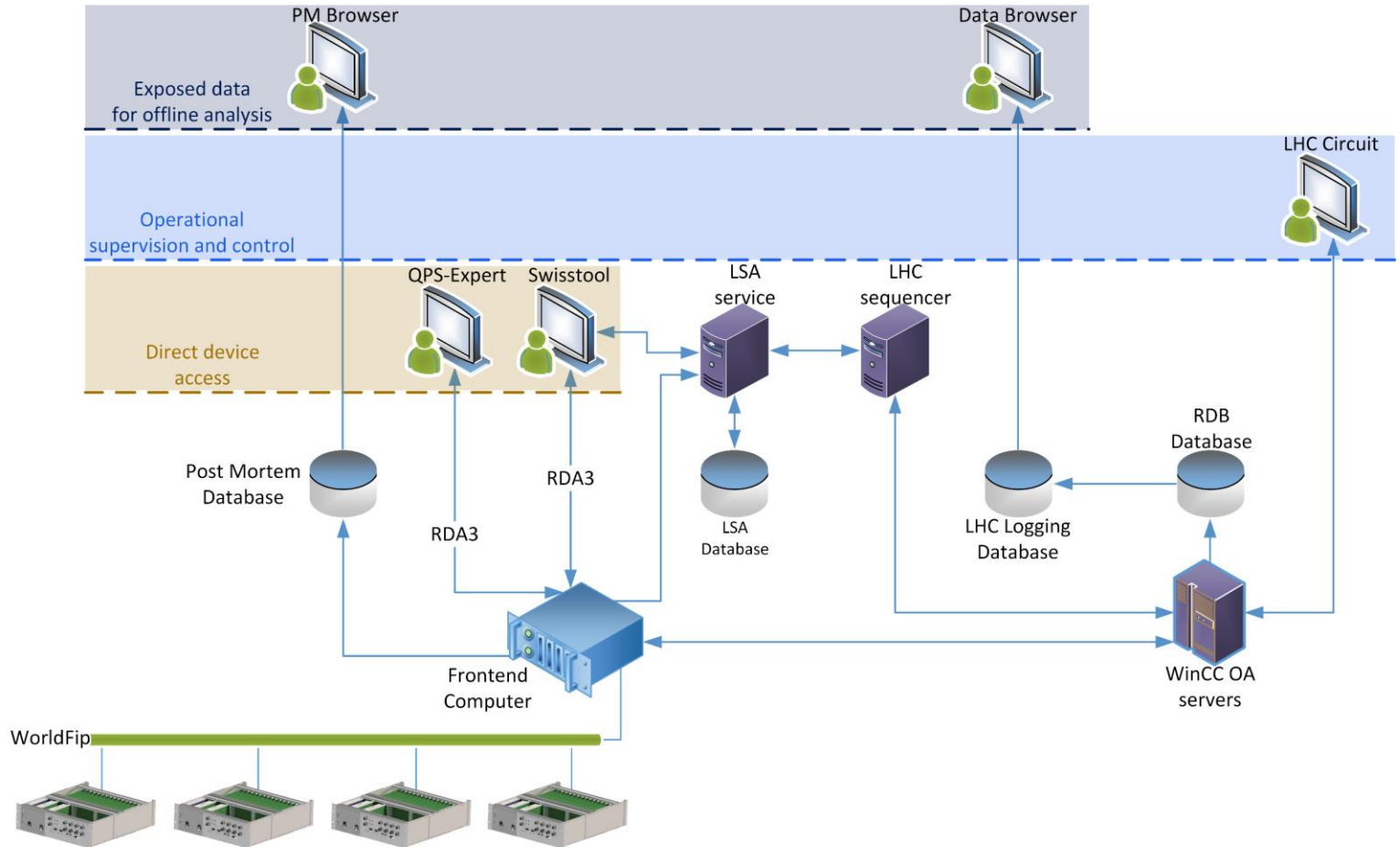
Introduction to QPS

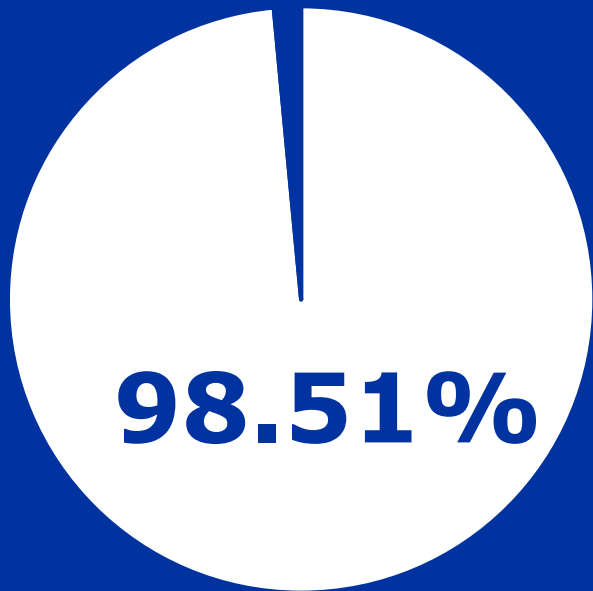
QPS Hardware



Item	Count
EE13kA	32
EE600	202
HDS	6084
QDSRB	1232
Magnet detector	2464
QDSRQ	392
Magnet detector	1568
nQPS	436
Magnet detector	1632
Bus-bar detector	4096
QDSIPX	76
IP magnet detector	360
IT magnet detector	48
Current lead detector	1124
QDS600	114
Magnet detector	624
Rad-tol magnet det.	212
Current lead detector	1672
Total	8568
Interlocking	13800

QPS supervision and control

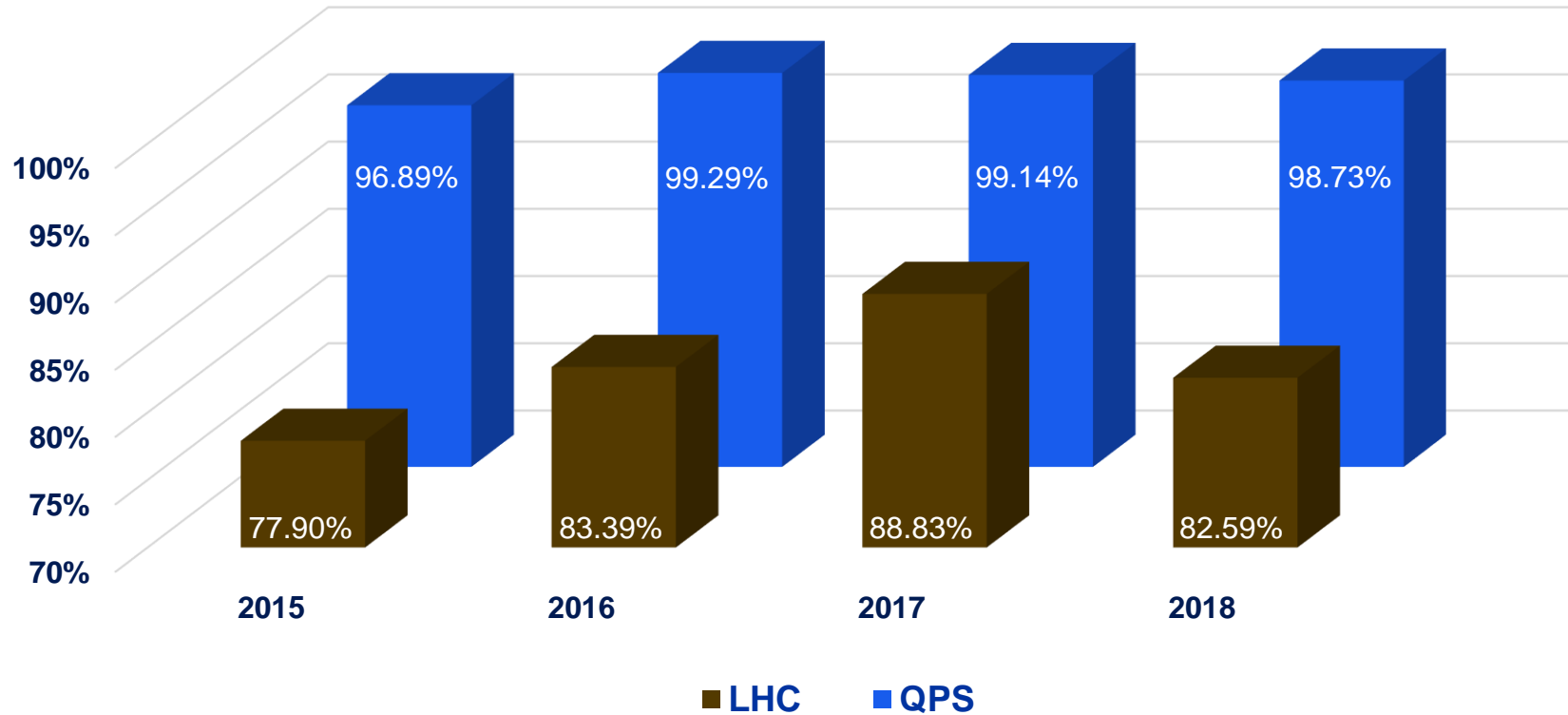




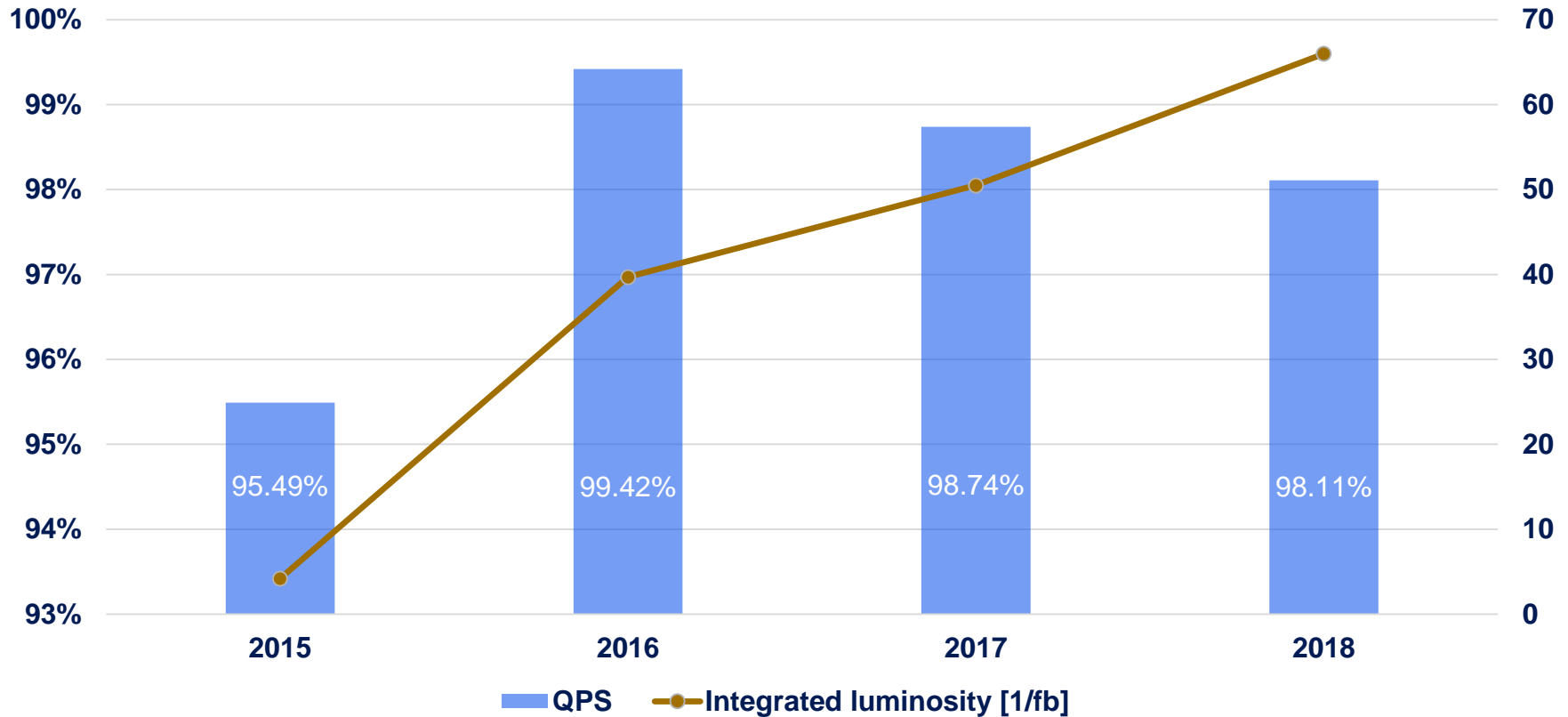
Availability in Run 2

Overview of operation

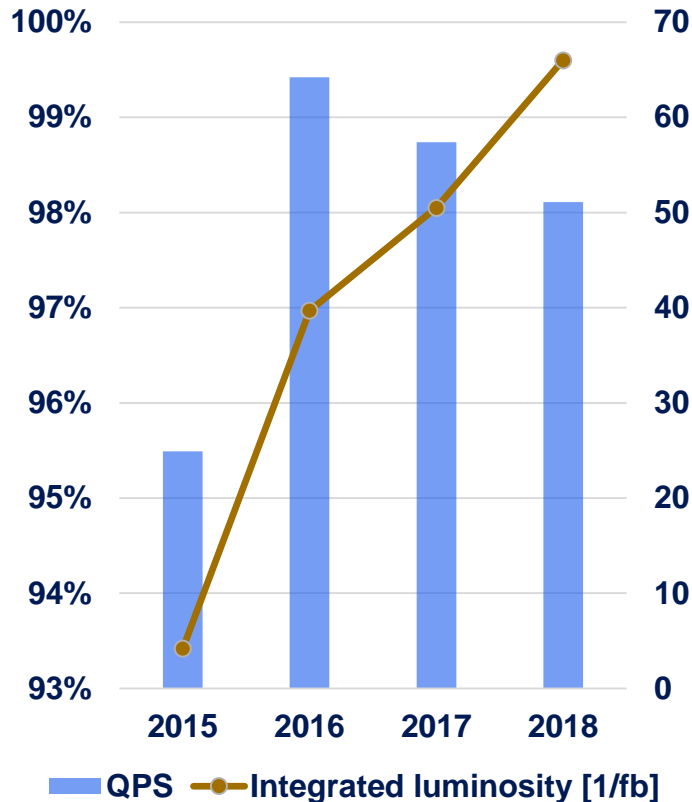
Overall availability



Closer look: proton run availability



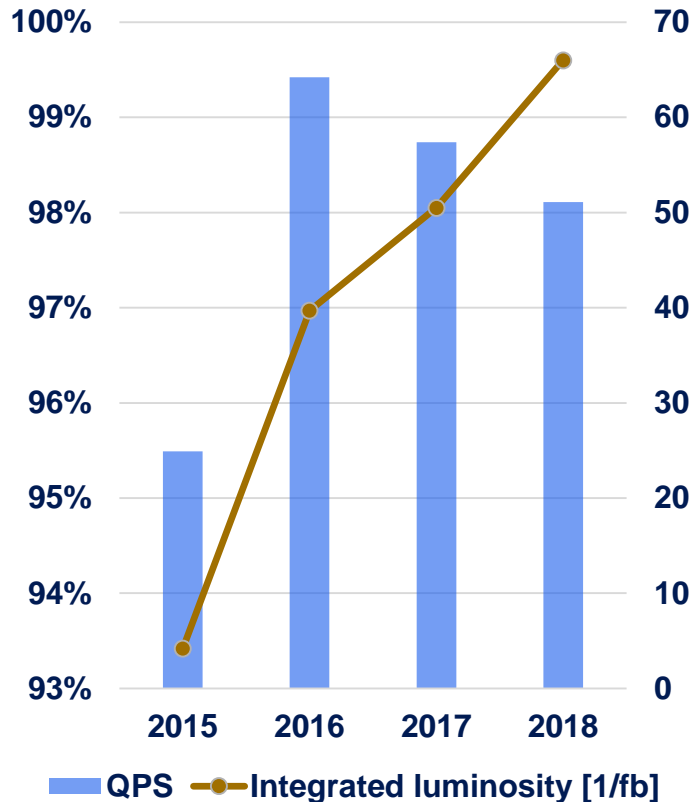
Closer look: corrective actions taken



Key period in 2015/16:

- Replacement of BS dipole protection boards in TS2 in 2015
 - No significant issues since
- FPGA based 600A detectors in rad exposed areas in YETS 15/16
 - No R2E since
- Maintenance of energy extraction systems in YETS 15/16
 - Integrity problem of 13kA switches
 - General maintenance of 600A system

Closer look: corrective actions taken

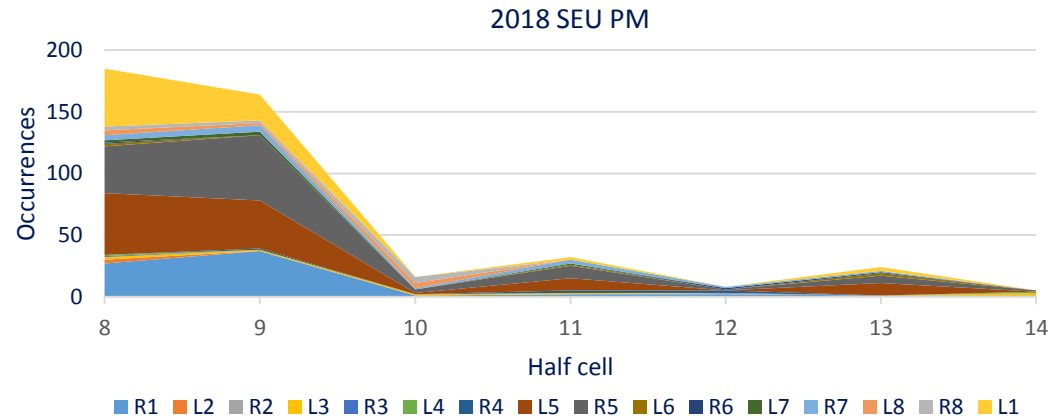
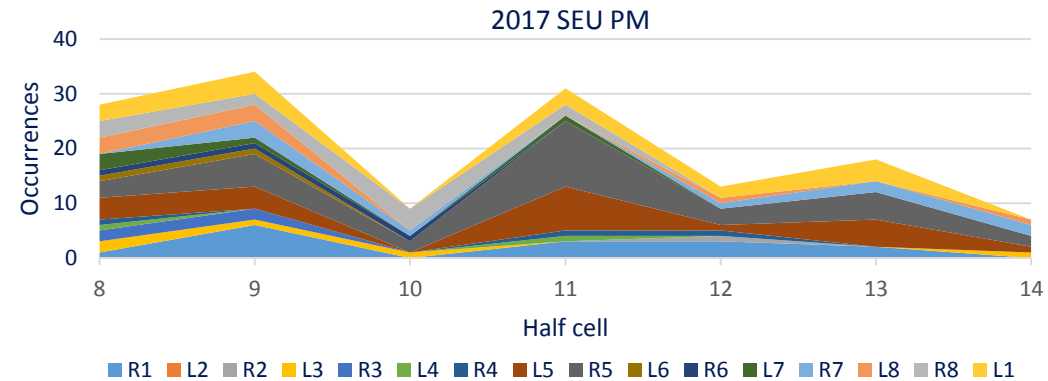


Maintenance since 2016:

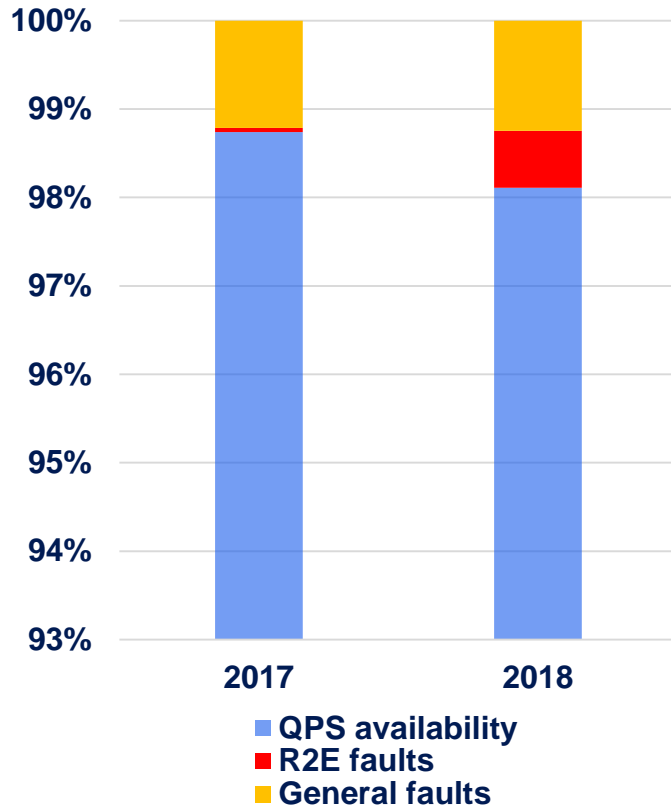
- Energy Extraction RQD.A12 UPS connectors
 - Significant contributor in 2017
 - Connectors reviewed in YETS
- Bus-bar protection boards in half-cell 8 around IP1 and IP5
 - Radiation vulnerable PHOTOMOS
 - Exchanged in TS2 in 2018
 - Exchange planned in DS of IP1, IP5, IP2, and IP8
 - Further exchanges possible

Radiation load increase in 2018

R2E effects	2017	2018
Spurious triggers	0	6
DAQ events with intervention	1	8
Other	0	2
Transparent DAQ events	59	341
R2E issues in RR	0	0
Effect		
Downtime	2.2h	31.5h
QPS downtime impact	3.8%	34.1%



Radiation load increase in 2018



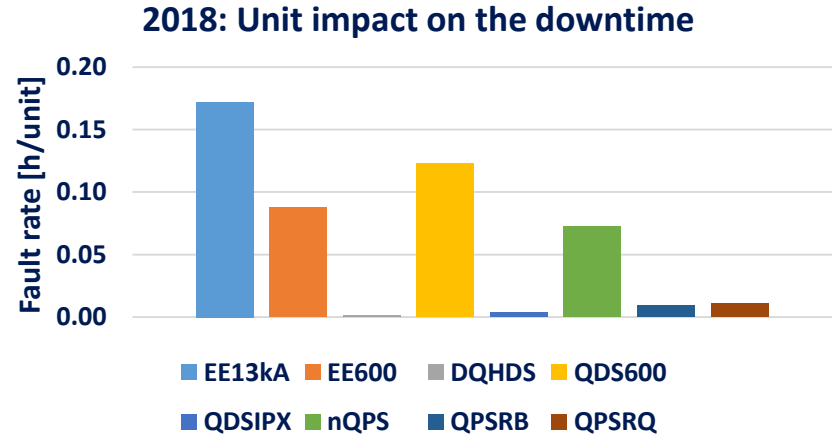
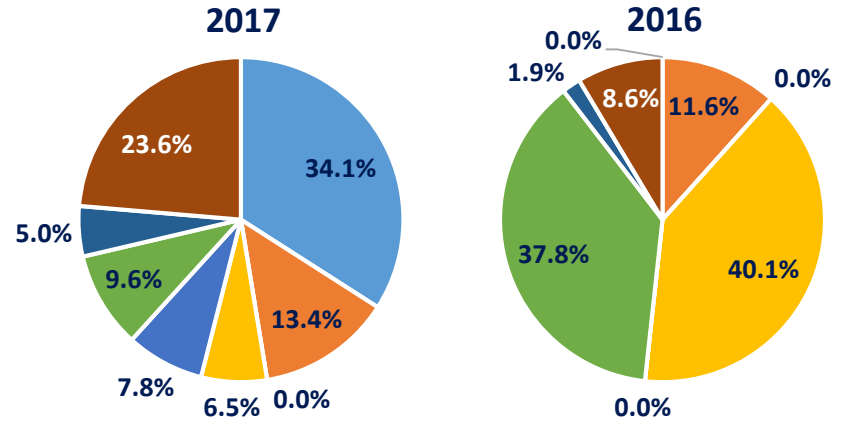
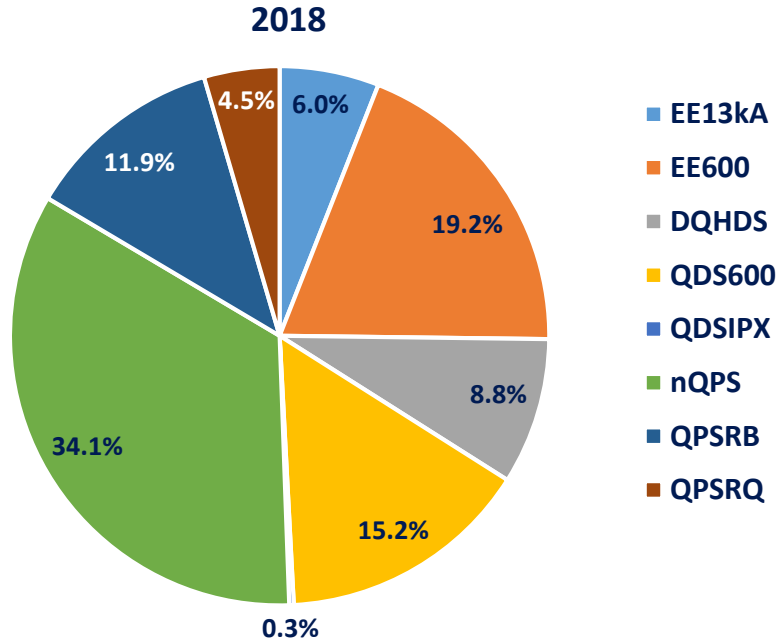
- **Intentional TCL collimators settings considerably affected radiation load seen by QPS in half-cells 8 and 9**
 - **Reducing load seen by power converter's FGCs in RRs**
 - Comparable to the HL-LHC radiation level baseline
- Protection was available
 - Increased number of false dumps
- Adaptation to radiation conditions proved difficult during operation
- It will be addressed for the most exposed areas



Downtime

Limitations remaining in 2018

Fault distribution in QPS



QDS: Dipole and Quadrupole magnets

Operational issues:

- Radiation vulnerability
 - QPS OK problems
 - SEU triggered PM
- MQ: limited HDS supervision
- MQ: no remote maintenance
- **Mostly inconveniences**

Actions to be taken:

- Replacement of MQ QDS
 - Remote maintenance
 - Fully simultaneous data
 - Improved timing
 - Radiation performance
- MB QDS improvements:
 - Radiation problem limited
 - SEU triggered PM can be resolved on a gateway level
 - Local bus problems resolution by gateway software features

QDS: 600A magnets

Operational issues:

- Random trips
 - EMI vulnerability of QPS current sensor
 - Zero crossing of Power Converters – correct QPS behaviour
- Ramp rate and acceleration limits for circuits
 - Powering tests showed margin
 - Threshold can be evaluated
 - Derivative (dI/dt) current sensor

Actions to be taken:

- General consolidation
- Reinforcement of shielding of current sensors
- Exchange of current sensors in sensitive areas
- Some of power converters control modules to be exchanged

QDS: miscellaneous

Operational issues:

- IPQ
 - Symmetric quenches – BLM
 - Sensitivity to thunderstorms
 - electrical power distribution

- nQPS
 - Local bus problems
 - Bus-bar protection vulnerable to radiation – limited number of units

Actions to be taken:

- IPQ
 - Derivative current sensor (dI/dt)
 - proof of principle deployment
 - Separation of magnet and bus-bar protection (work in progress)

- nQPS
 - Local bus problems do not impact protection and recovery can be simplified
 - Further exchanges of radiation affected boards

Energy Extraction: 13kA and 600A systems

EE 13kA

- Consolidation and maintenance of 256 circuit breakers
- Inspection and maintenance of dump resistors
- Consolidation of controls
- Anticipated remaining lifetime: 15 years
- **Transparent actions from operational perspective**

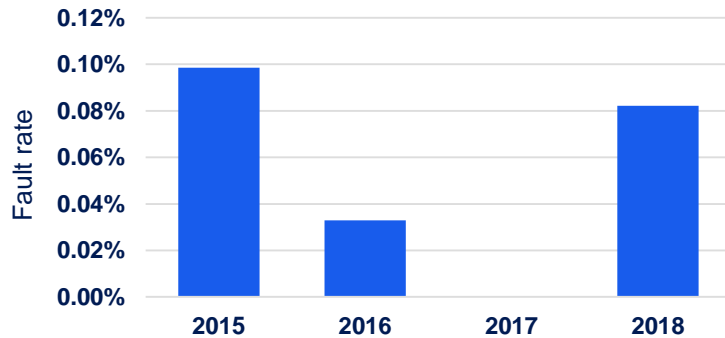
EE 600A

- General maintenance
 - Systems targeted according to closing failure rate
 - No new limitations discovered
 - 600A EE systems approaching useful life time
- Reduction of units in operation
 - Circuits with operational currents below 300 A to be by-passed
 - Decisions to be taken
 - Changes in firmware required
 - Interlock configuration affected
 - **Availability increase**
 - **Transparent for operation**

Other TE-MPE equipment

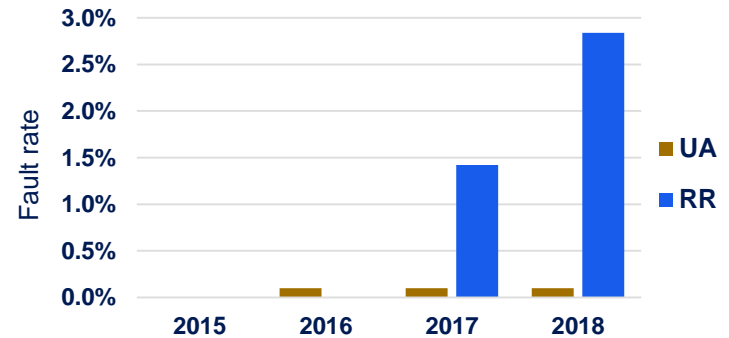
Quench heater power supplies

- 6084 power units installed
- Discharges regularly analysed
- End of useful life of 36000 capacitors evaluated at least until LS3
 - Accelerated life test ongoing
- **HDS fault rate is stable**



Current lead heaters

- **Interlocking**
- Located in UA and RR areas
- Number of failures increases
 - End of useful life time
- Units to be replaced in LS2
 - Radiation reinforced in RR
 - Regular units in UA



QPS: supervision and controls

Operational issues:

- QPS OK flickering after LS1
- Crate controllers vulnerable to radiation – limited area
 - Development ongoing
- QPS OK masking
 - Safe
 - Frequency to decrease
- DQAmx freezes
- Missing PM data
 - Mostly during Powering Tests and HW commissioning
 - Mainly 600A and IPQ devices

Actions to be taken:

- MasterFIP replaces WorldFip
- Major software stack update
- NXCALS logging
 - Cooperation with BE-ICS
- **Refactoring of real time application**
 - Data processing optimization
 - State machine controller
 - Automatic fault recovery
- Automatic analysis of state of health of the system
- **Swisstool extension**

New installations

Baseline for LS2

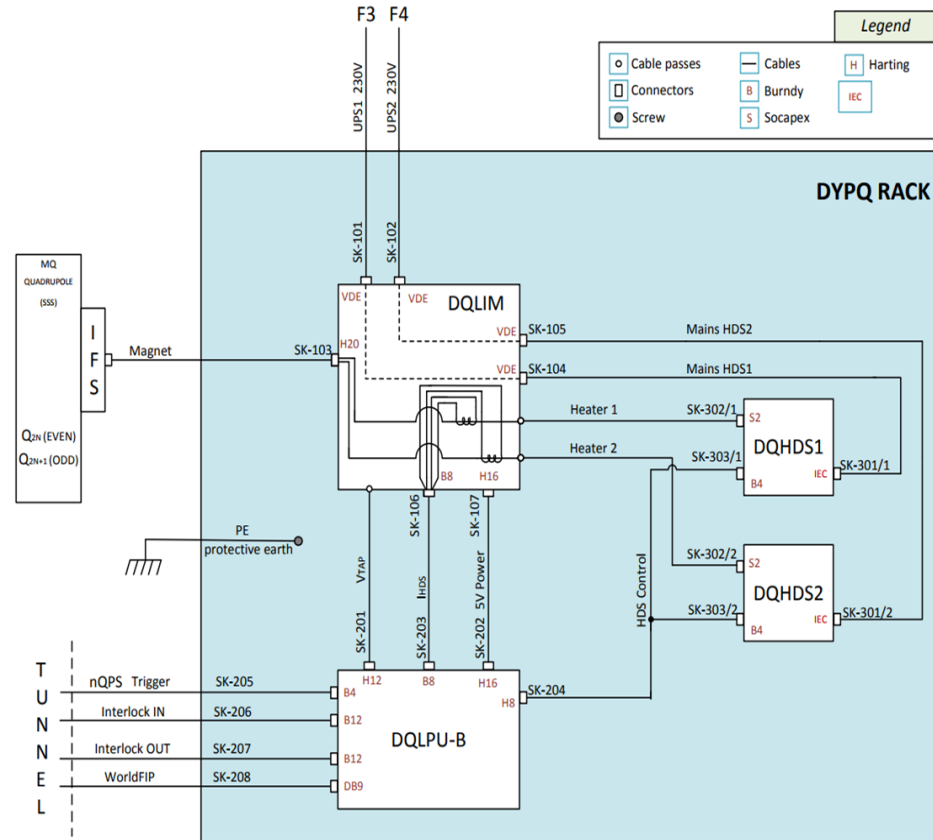
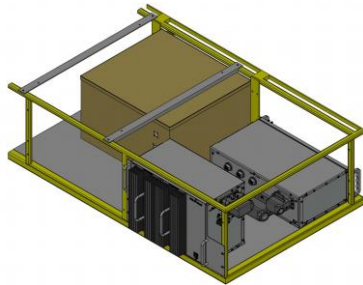
DYPQ consolidation (QDS for LHC quadrupoles)

Replacement of 392 racks:

- Lifecycle management driven
- Quench detectors DQLPUB
- Interface and power supply DQLIM
- Keep heater power supplies DQHDS

Impact on operation:

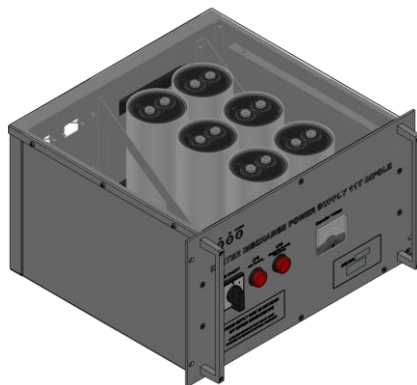
- Redundant powering
- Remote maintenance
- More accurate data acquisition
- Improved PM data timing



11T Dipole and Trim circuit

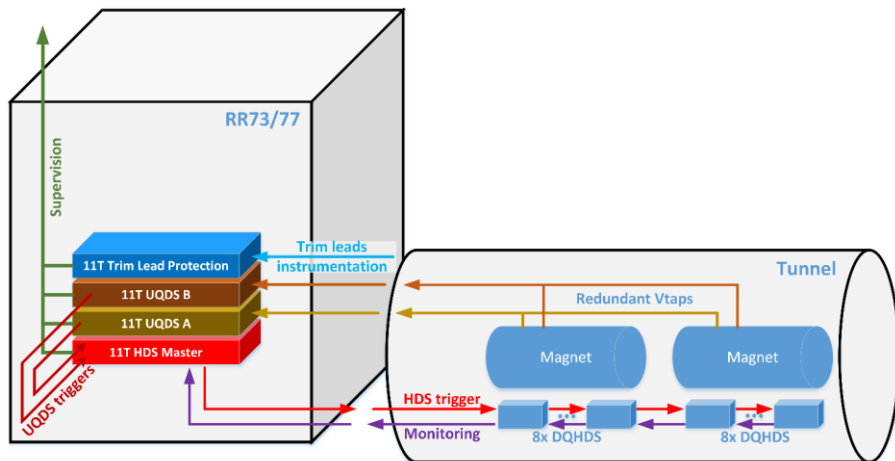


UQDS quench detector



11T Heater Power Supply

- Based on new generation of UQDS detectors
 - Symmetric and asymmetric quench detection
 - Bus-bar monitoring
 - Fast interlocks
- 11T HDS controller
- Trim lead protection unit
- 11T HDS units
 - Radiation qualified
- Full integration with supervision and controls
- High accuracy data acquisition



Summary

Conclusions

- System showed very good performance
- **TCL collimators settings significantly affected QPS downtime**
 - TCL settings to be taken into account for Run 3
- Consolidation of 600A QPS
- Significant changes in supervision
 - More remote procedures
 - Automatic recovery procedures
- Some teething problems to be expected
- **Goal: Keep availability level**

Thank you for your attention

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