



Update on Protection Systems and Beam Failure Cases for HL-LHC

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Acknowledgments: A. Apollonio, M. Bednarek, T. Cartier-Michaud, D. Carrillo, G. D'Angelo, R. Denz, J. Guasch Martinez, C. Hernalsteens, C. Lannoy, B. Lindstrom, B. Panev, T. Podzorny, M. Pojer, E. Ravaioli, F. Rodriguez Mateos, J. Spasic, J. Steckert, J. Uythoven, A. Verweij, M. Villen Basco

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Outline

- 11T (MBH) protection equipment
- CLIQ & Quench Heater Power Supplies
- Energy Extraction Systems
- Quench Detection Systems, Data Acquisition Systems, Protection Device Supervision Units
- Instrumentation Feed Boxes & Cold Diodes & EIQA rack
- Beam Interlock System & Powering Interlock Controller
- Reliability & Availability studies
- Circuit modelling and protection
- Fast failure & Damage studies
- Conclusion

11T (MBH) protection equipment

- Finished production of 11T (MBH) protection equipment:
 - Quench detection systems (QDS)
 - Data acquisition systems (DAC)
 - Protection device supervision units (PDSU)
 - Quench heater power supplies (DQHDS)



UQDS

PDSU for 11 T (MBH)



DQHDS for 11T (MBH)

CLIQ & Quench Heater Power Supplies

- [CLIQ & DQHDS – design & status, D. Carrillo, WP3/WP7, THU AM](#)
- [Summary of capacitor qualification campaign for DQHDS & CLIQ, D. Carrillo, J. Guasch Martinez, WP7, THU AM](#)

Capacitors:

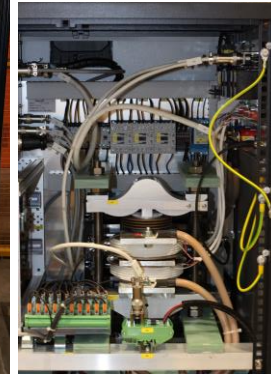
- Lifetime studies and qualification tests performed
- Capacitor candidates identified
- Contract signed for CLIQ capacitors (String and Series)
- Capacitors for DQHDS String units received from KEK (in-kind)

Quench Heater Power supplies:

- Specification, design and prototyping finished
- CE marking tests finished
- String production in-house
- Series production likely as in-kind contribution from Japan

CLIQv3:

- Specifications and design finished
- CERN prototype built and qualified
- Contract signed for String and Series production

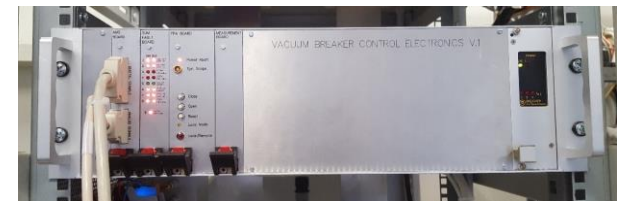


Capacitor aging test bench



Energy Extraction systems

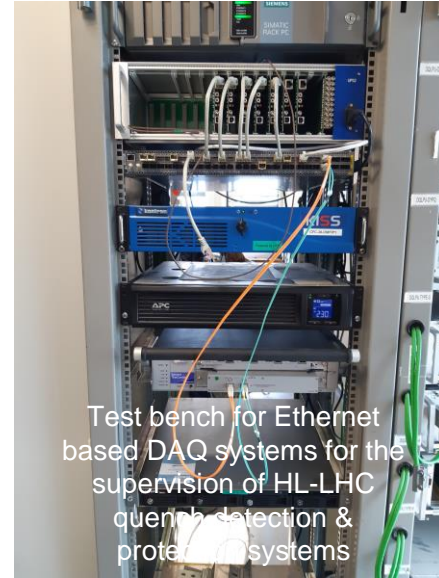
- The layout of the new 600 A and 2 kA Energy Extraction systems is well defined.
- Redundancy implemented in the electronics and extensively tested in the lab.
- Specifications and designs are finished
- Market survey and tender for String units (7 x 2kA, 2x 600A) finished
- Signing of contract for String units imminent
- Optimization of the control electronics currently under study:
 - Separation of controls and power electronics.
 - Possible implementation to be adopted for the series, with later modification of the String units.



[Energy Extraction Systems - design and status, B. Panev, WP3/WP7, THU AM](#)

Quench Detection Systems, Data Acquisition Systems & Protection Device Supervision Units

- Specifications well advanced (final validation with full size MQXF test)
- Design and prototyping for Universal Quench Detection System finished; deployment on various testbenches ongoing
- Design for Protection Device Supervision Unit advancing well, prototyping phase starting soon
- Ordering & delivery of components for String series well advanced
 - This task is non-trivial due to a worldwide shortage of electronic components caused by the COVID-19 crisis
- Unit assembly for the String has started
- The development of Ethernet based Data Acquisition Systems for the supervision of HL-LHC quench detection & protection systems is advancing well and has reached the type testing phase
- Integration of new HL-LHC protection devices into CERN's control infrastructure ongoing



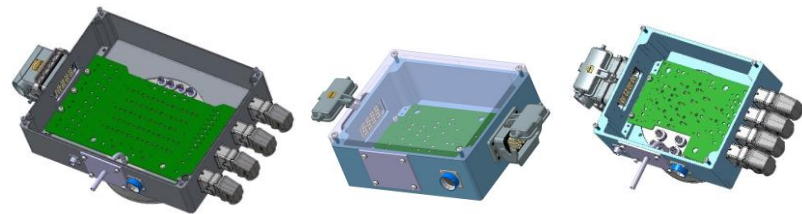
Latest version of the UQDS HL-LHC quench detection system

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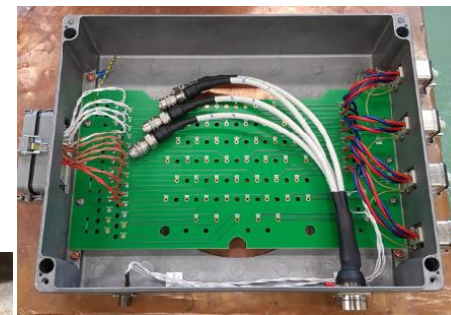
- [DAQ systems and new ethernet based communication board – design and status, T. Podzorny, WP7 THU AM](#)
- [Protection device supervision units – design and status, J. Spasic, WP7 THU AM](#)
- [Radiation hard electronics for the Quench Detection System in HL-LHC: ongoing developments and challenges, J. Steckert, WP6B/WP7/WP10/WP13/WP18, THU PM](#)

Instrumentation Feed Boxes & Cold Diodes & EIQA rack

- Instrumentation Feed Boxes (IFS):
 - Instrumentation interfaces to HL magnets defined
 - Design finished
 - Six IFS boxes type L for Q1/Q3 have been produced and four shipped to the US, two more to be shipped in the coming weeks
- Cold diode press packs:
 - 60 oo 60 diode press-packs received from supplier and validated
 - Supply for HL lifetime at CERN
- Diode stacks:
 - Design of diode stack well advanced
 - First prototype has been built
 - Minor modifications to the prototype are ongoing, reassembly is imminent, which will be followed by electrical testing
 - After full testing, prototype is expected to be ready for String installation
- Requirements defined for an EIQA rack to allow easy measurement access to the locally powered 120 and 200A corrector circuits of the HL triplets in non-radiative area.



IFS: 3D models: Size L, M and S



[Auxiliary systems for protection by M. Bednarek, WP3/WP7, THU AM](#)

[Diode stack for DCM, G. D'Angelo, WP3/WP7, THU AM](#)

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Beam Interlock System & Powering Interlock Controller

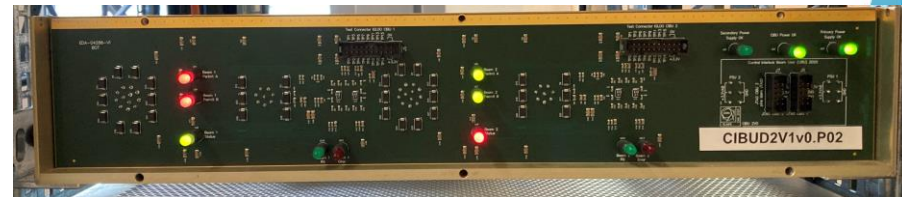
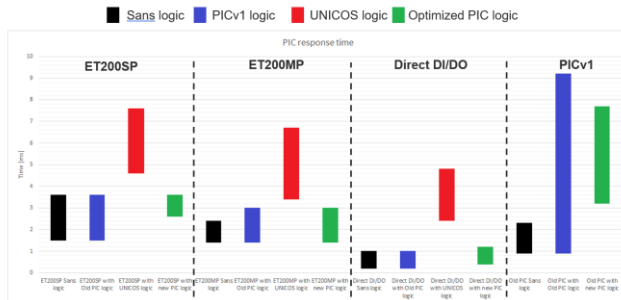
PICv2 and BISv2 for HL-LHC – design and status, J. Uythoven, WP7 THU AM

- **BISv2:**
 - Several prototype cards for the new BIS have been designed, built, tested and programmed
 - Beam permit loop has been closed in the lab with the new components
- **PICv2:**
 - First results from prototype delay tests



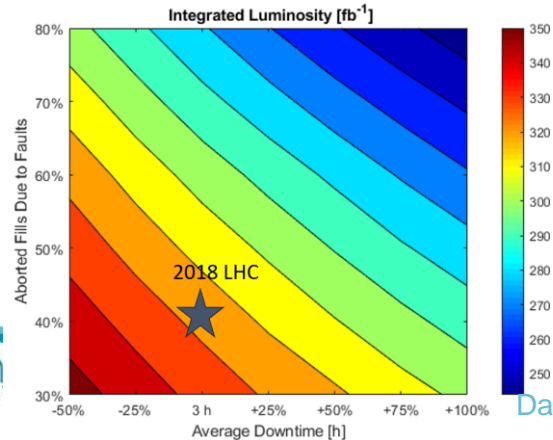
CIBM2v0

PICv2 Industrial Solution – Response Time Results



Reliability & Availability studies

- Reliability studies for new Energy Extraction Systems finished
 - Calculated probability of failure on demand: 1.6×10^{-6}
- Reliability run with CLIQ v2 finished (8800 discharges, no failures observed)
 - Calculated probability of failure on demand: 8.7×10^{-5}
- Reliability studies for BISv2 ongoing in parallel to BISv2 design and prototyping
- Failure mode analysis for PICv2 ongoing

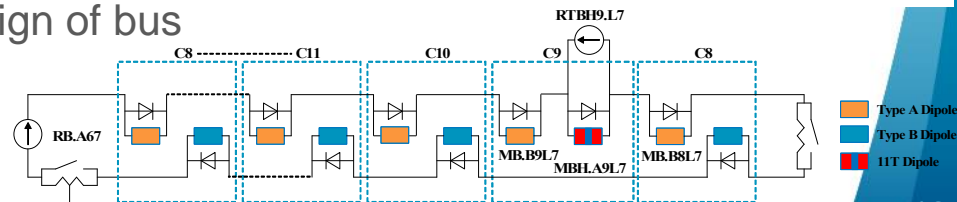
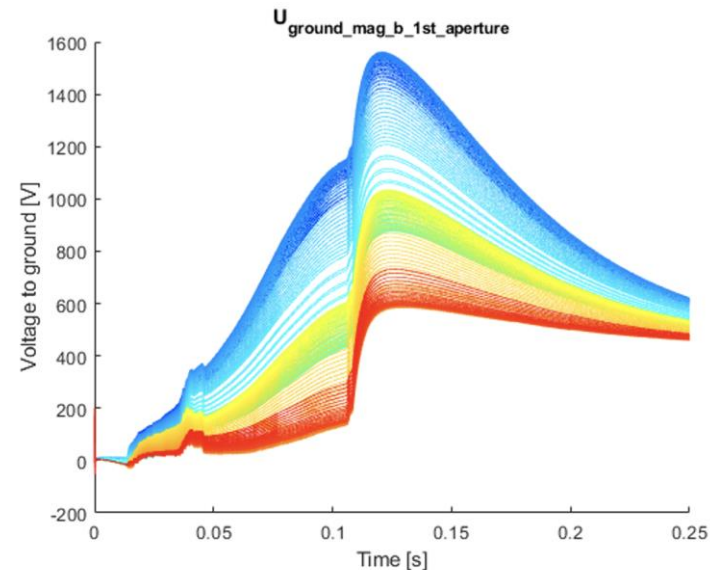


- First release of AvailSim4, the Monte Carlo tool developed at CERN for availability & reliability calculations
- Availability predictions for HL-LHC based on observed LHC availability

Circuit modelling and protection

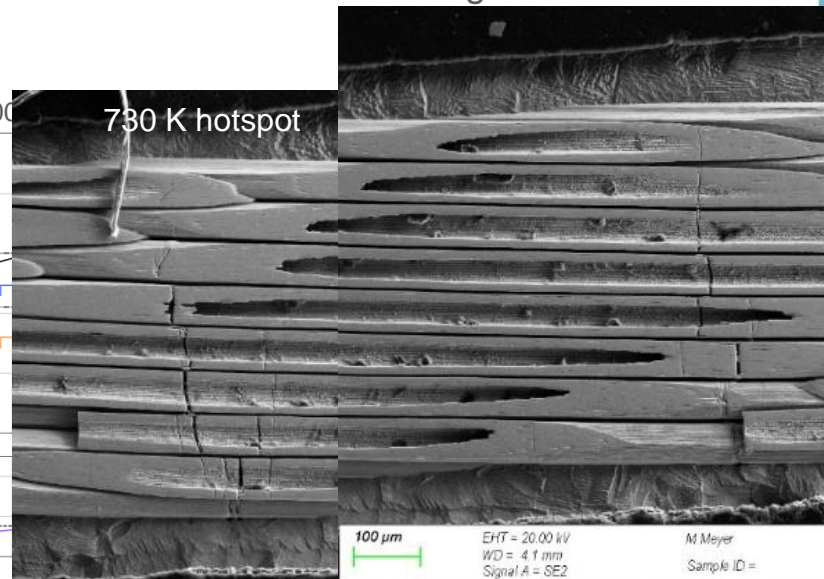
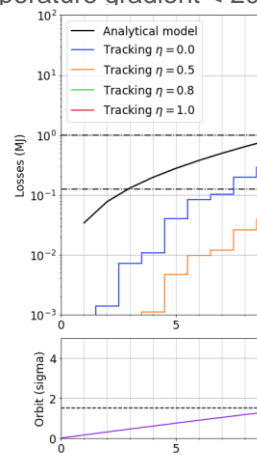
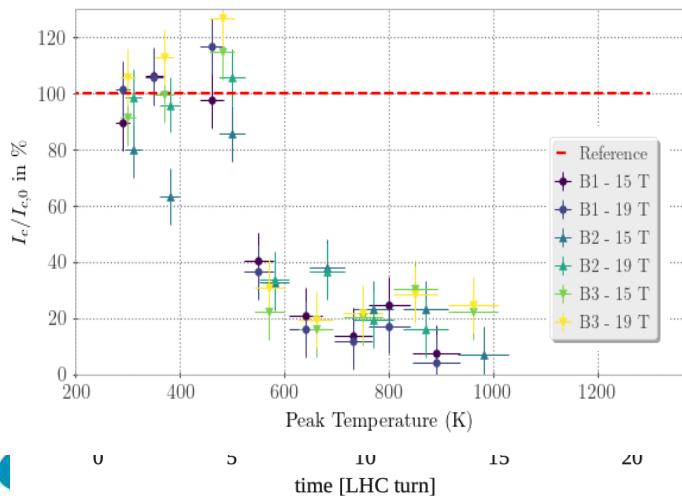
[Confirmation of the Inner Triplet circuit protection design, E. Ravaioli and S. Izquierdo Bermudez, WP3/WP7, THU AM](#)

- Protection studies of HL-LHC circuits (magnets, bus-bars, sc. link) performed for:
 - Triplet circuit with protection by quench heaters and CLIQ
 - 11 T dipole with trim (MHB) protection in dipole circuit
 - Protection on D2 correctors
 - Hollow e-lens circuits
- Magnet models for all HL magnets have been developed
- Circuit models have been developed for the RB+MBH and the HL-LHC triplet
- Validation of models is based on measurement data from short model and prototype magnets
- Validated the protection of bus-bars and splices
- Modelling provided important input for design of bus bars and definition of instrumentation.



Fast failure & Damage studies

- Fast failures in HL-LHC identified due to firing of CLIQ and quench heaters:
 - Adjusted connection schemes for CLIQ and quench heaters
 - Dedicated interlocking of CLIQ and quench heater discharges implemented in baseline
- Studies of the effect of a partially depleted halo on failure detection and interlocking delays (hollow e-lens) are well advanced → first results confirm the protectability with the current interlocking strategy
- Analysis of Nb₃Sn strands impacted by beam at 4.5 K in HiRadMat finished and damage mechanisms identified
 - filament cracking & residual strain in the copper matrix
 - Safe conditions identified (hotspot < 460 K, and temperature gradient < 200 K)



Conclusions

- R&D, design, reliability studies and specification finished for major parts of the protection equipment of the HL-LHC magnets and circuits
- Protection equipment for the String in production
- Simulation models available for all HL magnets and the most critical circuits → validation closely following testing of prototypes
- Fast failure cases due to beam identified and mitigation implemented
- Effect of hollow e-lens on protectability of known failure cases under study
- AvailSim4 - becoming the workhorse for availability and reliability studies
- R&D and prototyping for the new Beam Interlock System and Powering Interlock Controllers advancing well

Related talks in parallel session in the coming days

- *Criticality of fast failures in the HL-LHC with depleted halo*, C. Hernalsteens, WP5/WP7/WP14/WP13, Wed PM
- *Impact of high intensity protons on Nb₃Sn and Nb-Ti superconductors- damage limits and mechanisms*, C. Hernalsteens, WP5/WP7/WP14/WP13, Wed PM
- *Confirmation of the Inner Triplet circuit protection design*, E. Ravaioli and S. Izquierdo Bermudez, WP3/WP7, THU AM
- *Auxiliary systems for protection* by M. Bednarek, WP3/WP7, THU AM
- *Diode stack for DCM*, G. D'Angelo, WP3/WP7, THU AM
- *CLIQ & DQHDS – design & status*, D. Carrillo, WP3/WP7, THU AM
- *Energy Extraction Systems - design and status*, B. Panev, WP3/WP7, THU AM
- *DAQ systems and new ethernet based communication board – design and status*, T. Podzorny, WP7 THU AM
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- *Summary of capacitor qualification campaign for DQHDS*, J. Guasch Martinez, WP7, THU AM
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- *Radiation hard electronics for the Quench Detection System in HL-LHC: ongoing developments and challenges*, J. Steckert, WP6B/WP7/WP10/WP13/WP18, THU PM
- *Quench detection and DAQ systems for WP6a*, J. Steckert, WP6a/WP7, FRI AM