

Quench Detection System for the FCC Era

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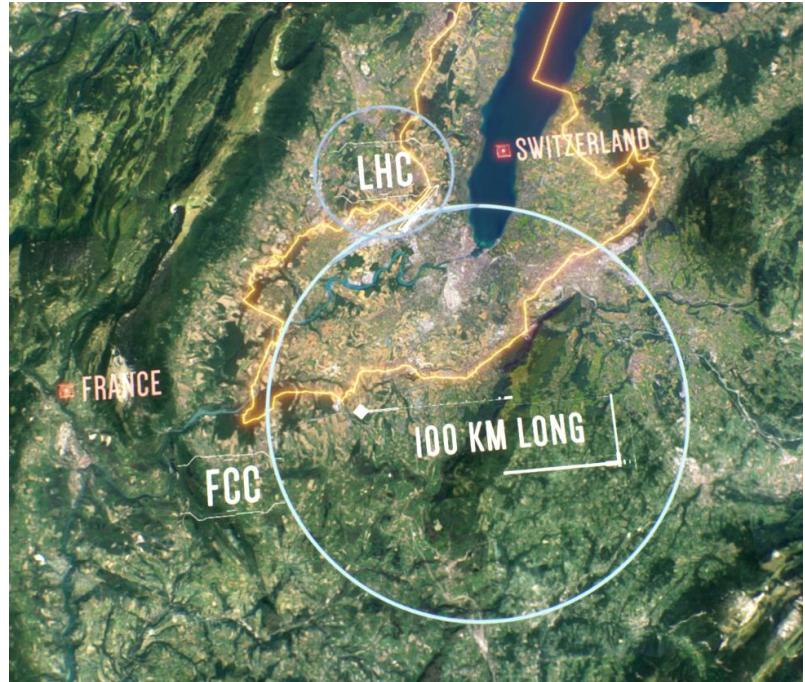
Agenda

- Introduction
 - Motivation
- Overview of the Quench Protection System
 - Quench Detection System
 - Maintainability
- Summary



FCC

- **100 km tunnel**
- Beam
 - FCC-ee
 - FCC-eh
 - FCC-hh – **100 TeV**
- Increased radiation
- Availability expectations



FCC superconducting dipoles

- **4664 magnets**
- **16 T Nb₃Sn**
- **20x more stored energy**
- **Compact** design
 - Large stored energy density
- Hot spot temp **350 K at 40 ms** time budget
 - Including 20 ms for the quench detection

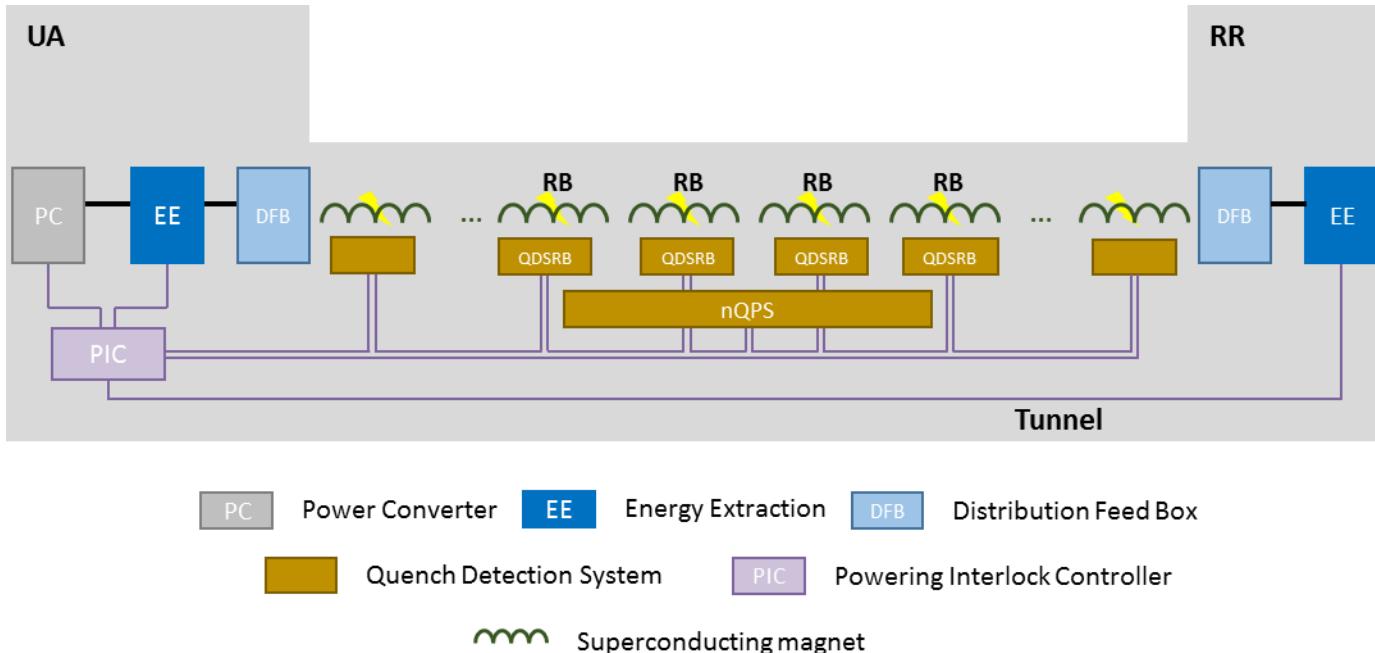


FCC superconducting magnets

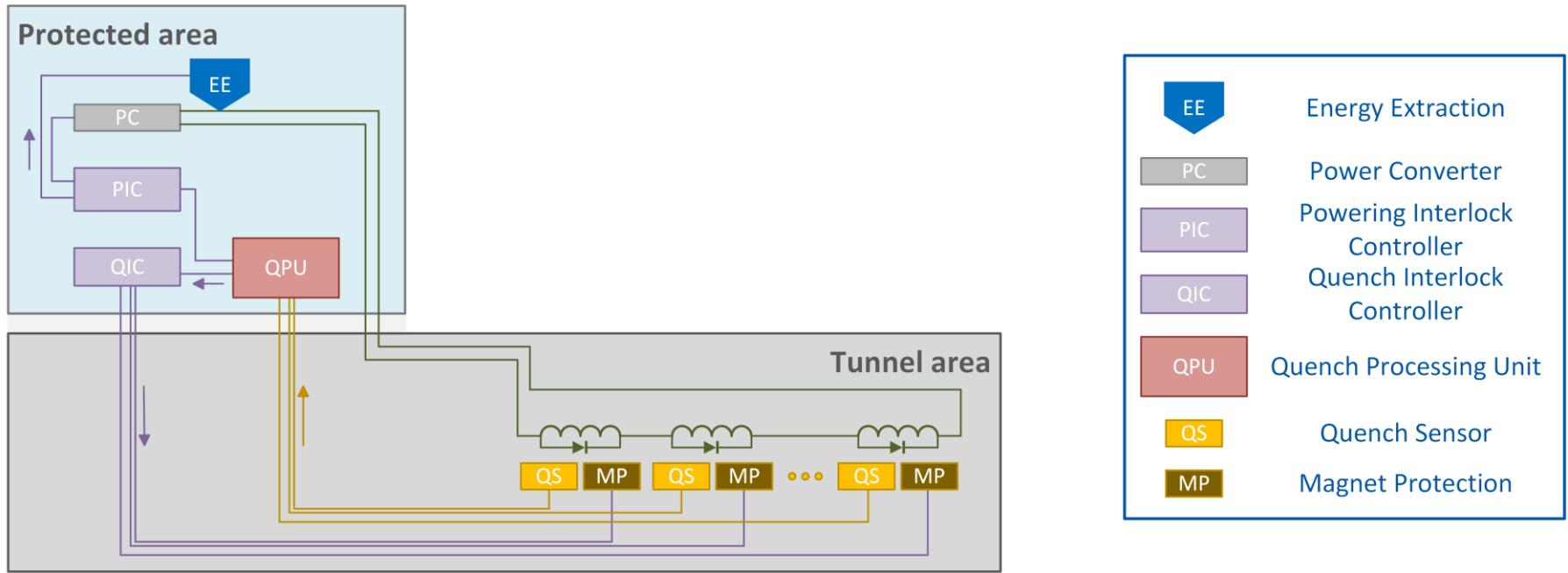
- Beam optics requirements
 - Proportional magnet number increase
- Superconductors:
 - **NbTi**
 - General corrector magnets
 - **Nb₃Sn**
 - Main magnets
 - **HTS**
 - Quench propagation speed is very low
 - Development of alternative detection techniques



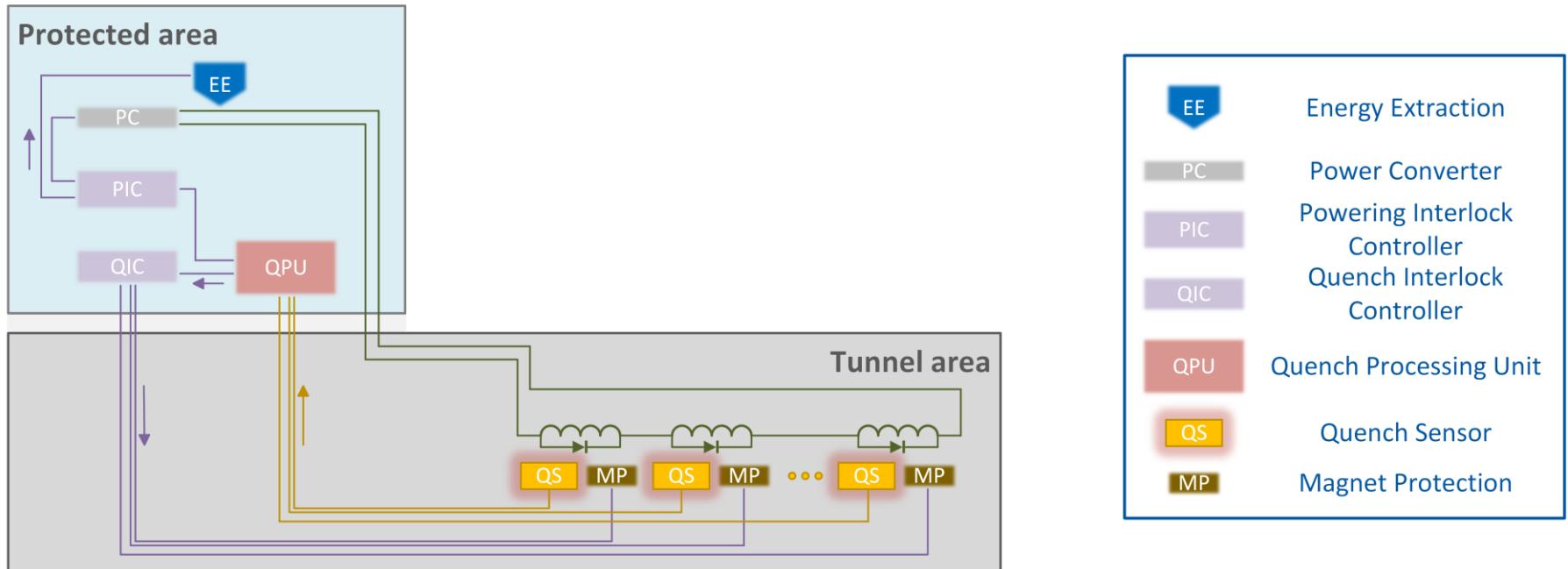
LHC protection scheme



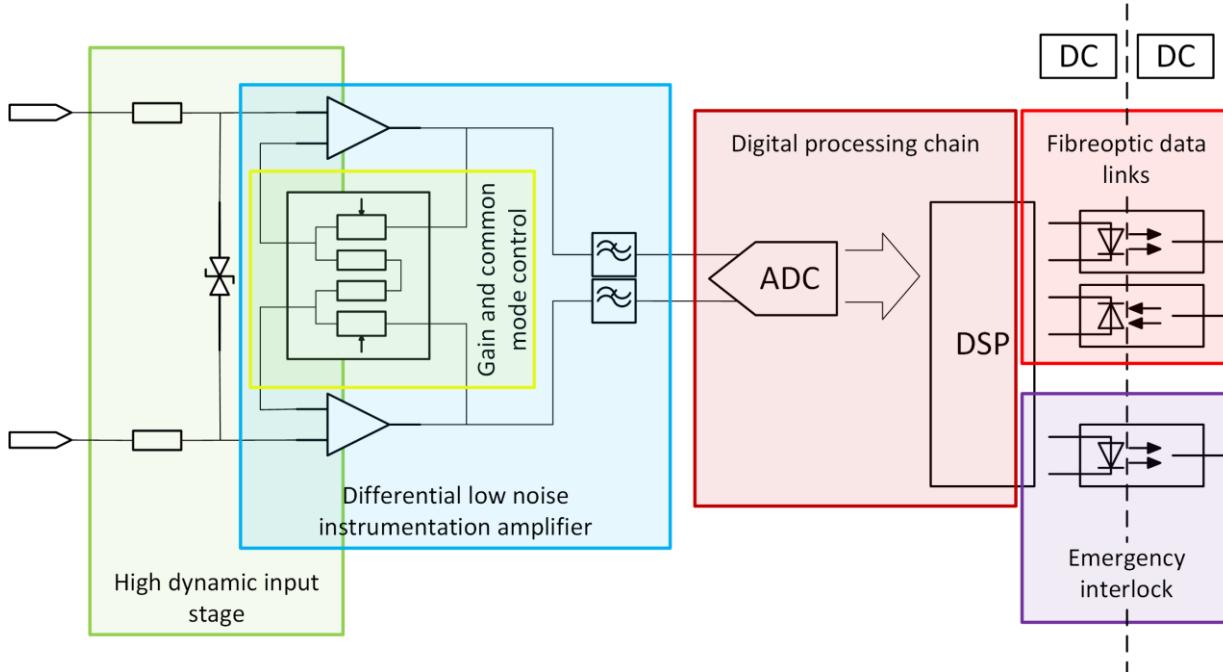
FCC era protection concept



Distributed instrumentation



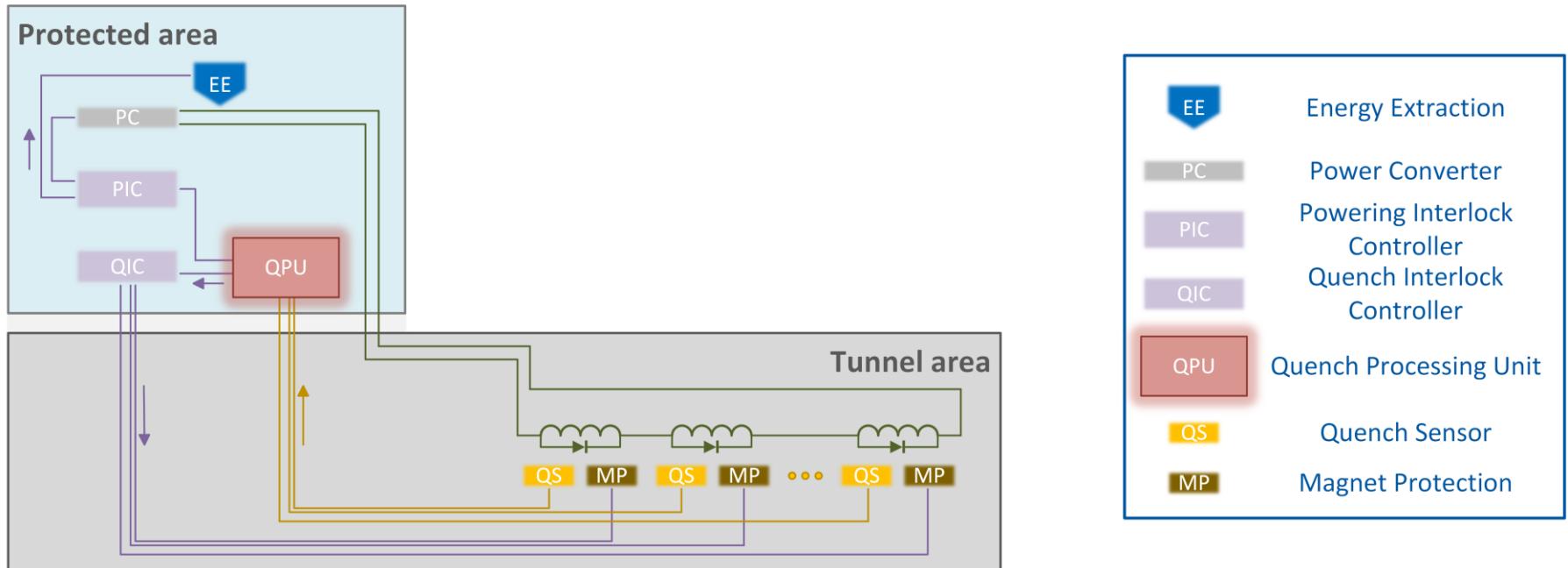
Magnet instrumentation



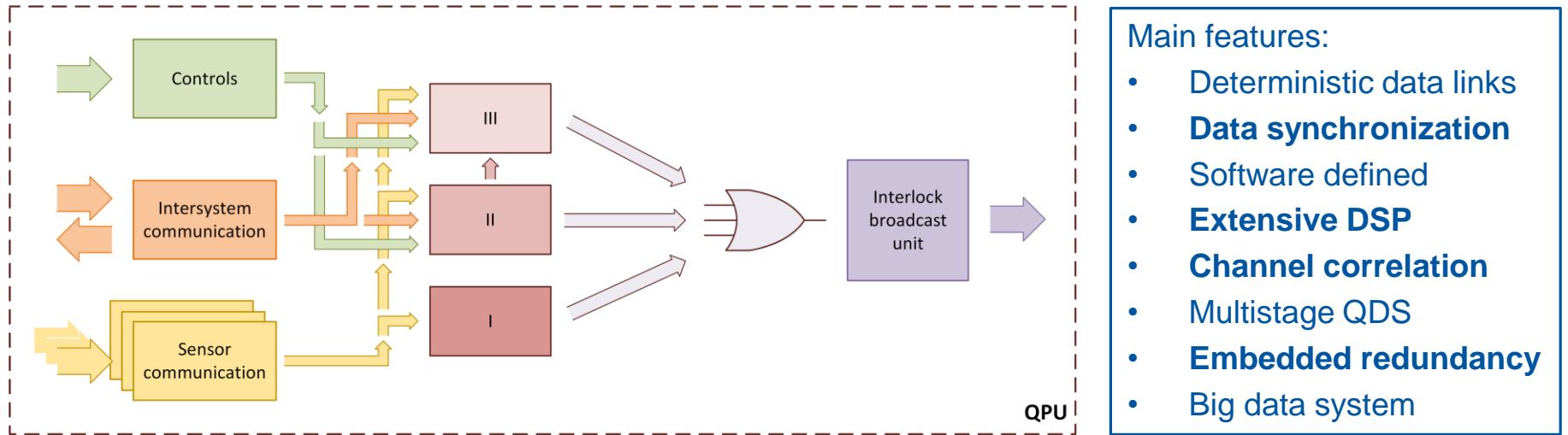
Main features:

- **Isolation**
- **Resolution**
- High bandwidth
- Re-configurability
- **Timing accuracy**
- **Radiation tolerance**

Centralized quench detection



Quench Processing Unit



Quench detection techniques

Proven techniques:

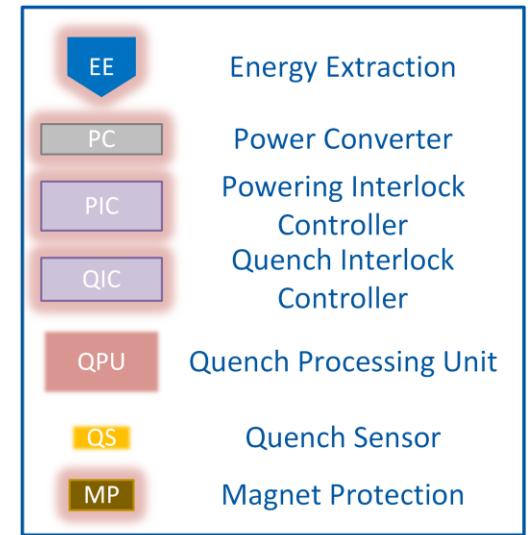
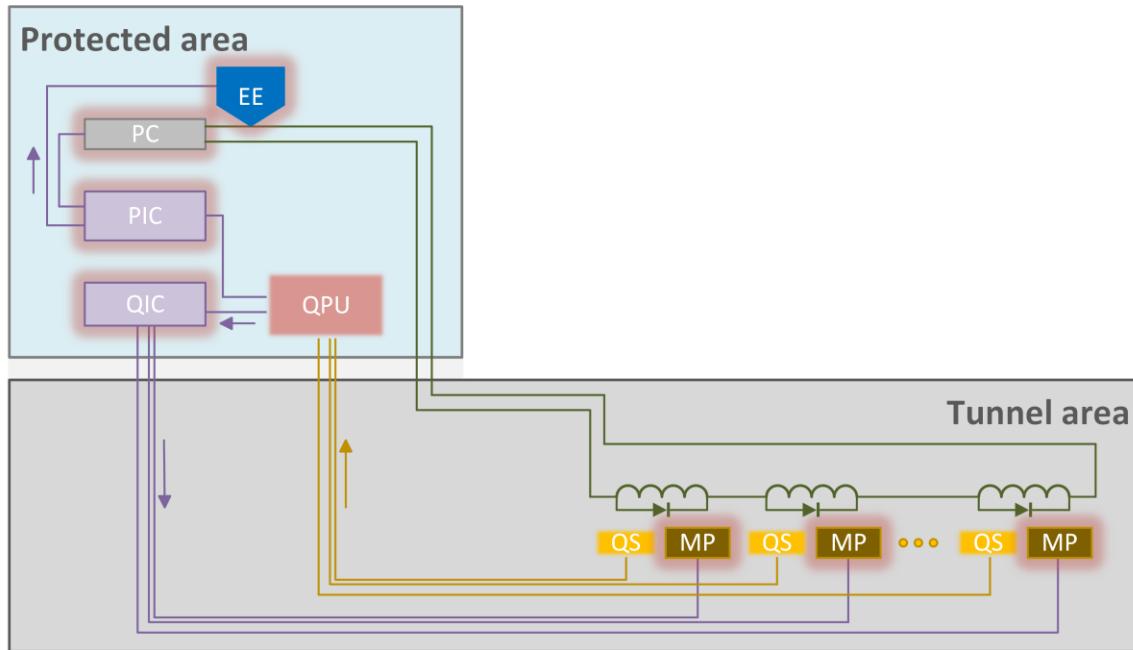
- **DC voltage measurement**
 - Enhanced by extensive digital signal processing
- dI/dt sensors

Emerging techniques:

- AC voltage measurement
 - Digital lock-in amplifier
- Embedded sensors
 - Acoustic techniques
 - Capacitive techniques
 - Photonic-crystal fiber sensors



Quench protection

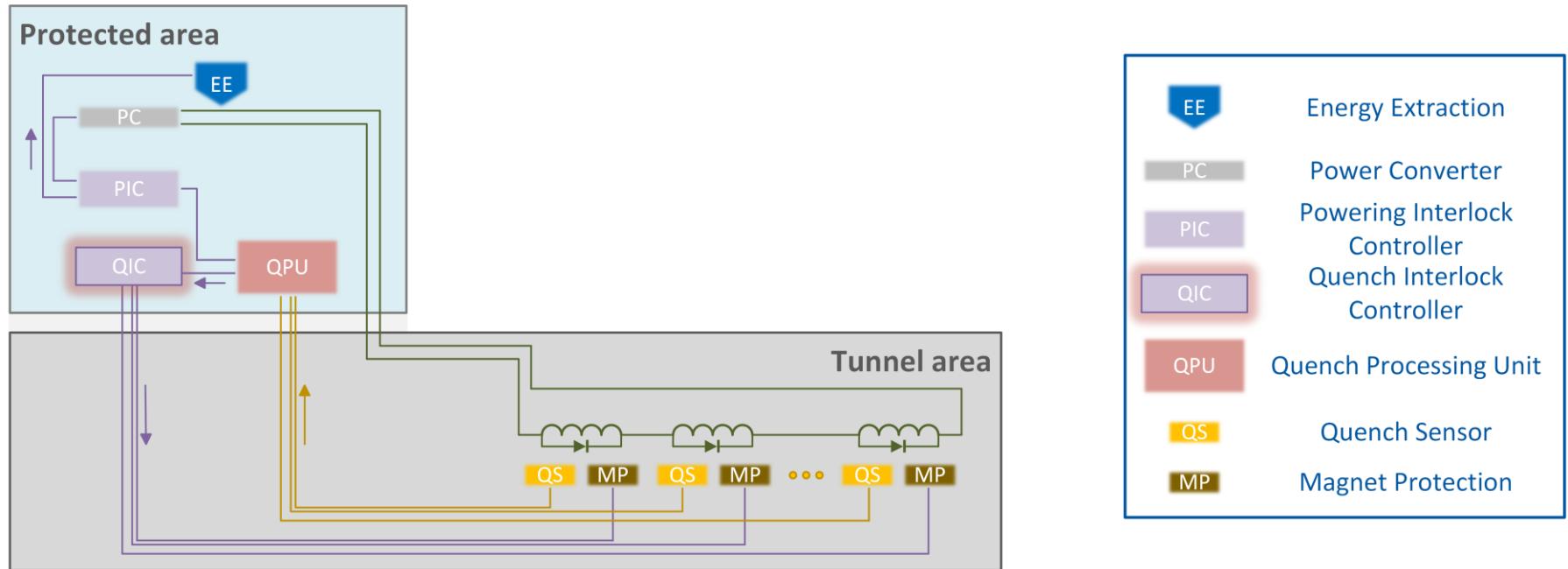


Quench protection strategy

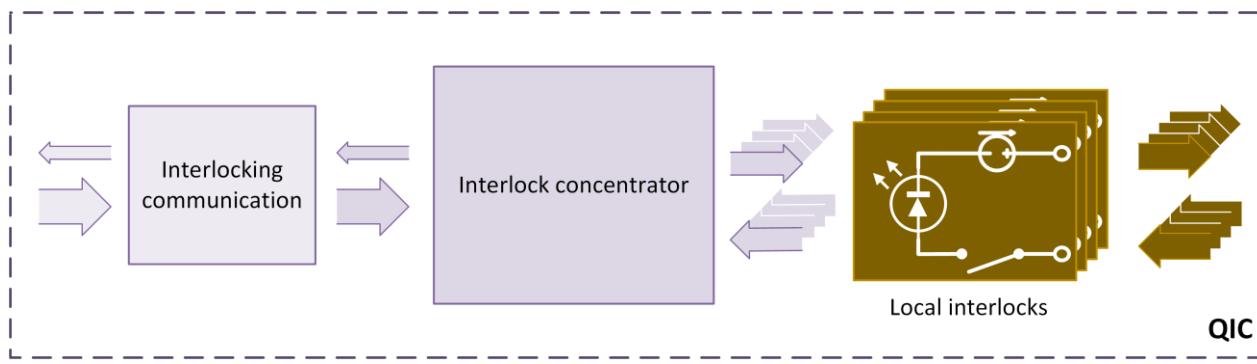
- Powering Interlock Controller:
 - Power Converter
 - Energy Extraction
- Magnet protection – QIC → MP:
 - Quench Heaters (QH)
 - Coupling Loss Induced Quench (CLIQ)



Distributed quench signaling



Quench Interlock Controller



Main features:

- **Very reliable signaling**
- **Low latency**
- Timing accuracy
- Link quality monitoring
- **Addressability**
- Simple local interface

Maintainability of the system

- Unification of the equipment in the tunnel
 - Modular and software defined QPU architecture
 - Fully redundant and fault tolerant equipment
-
- **Deep learning neural networks**
 - Sophisticated system verification
 - Detailed assessment of the state of the system
 - Fault prediction
 - **Autonomous maintenance – robotics**



Summary

- The new architecture of the quench detection and magnet protection system for the FCC era is proposed.
- The development is oriented on the state of the art technologies available in the industry.
- Availability, reliability and maintainability are crucial requirements in the design process.
- Proposed distributed and modular approach enables a continuous adaptation to the evolution of the machine.



Thank you for the attention



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