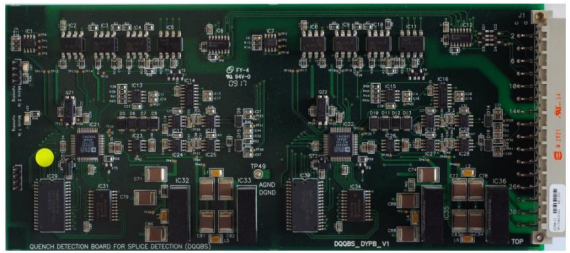
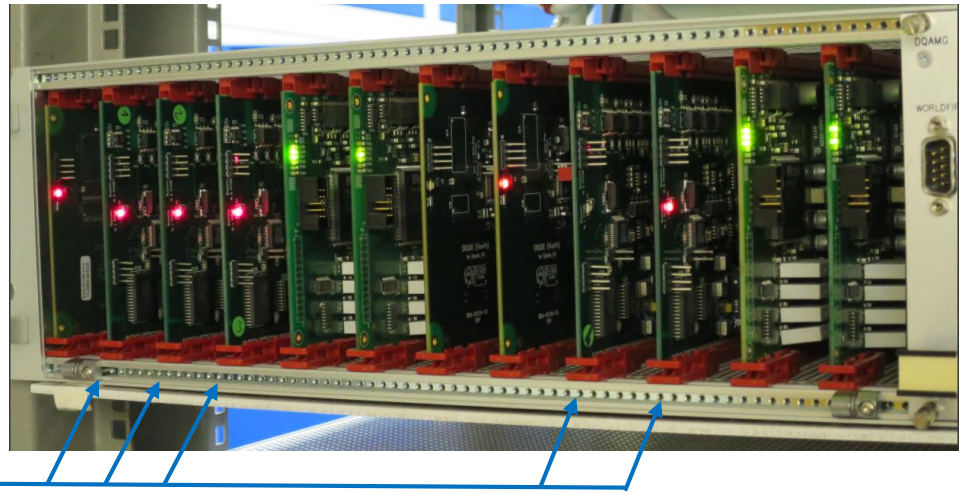
Radiation tolerant bus-bar splice protection system for the HL-LHC era

J. Spasic, TE-MPE-EP

Introduction

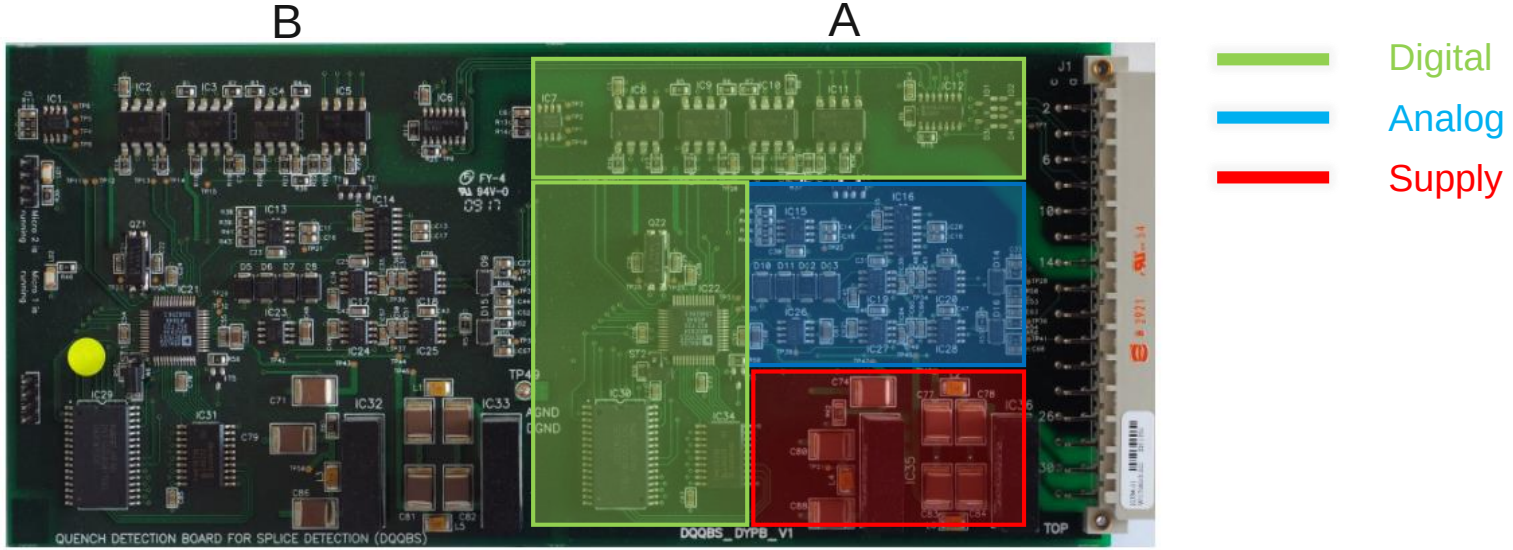
- DQQBS = Bus-bar Splice Quench Detector
- Up to 5 DQQBS integrated in DQLPU-S crates
  → 2048 DQQBS all around LHC tunnel → 4096 means to stop LHC





Introduction

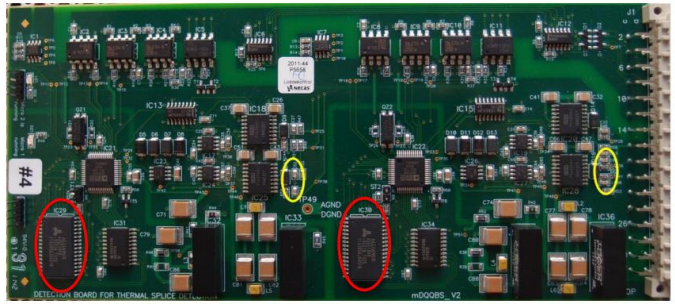
- DQQBS = Bus-bar Splice Quench Detector
  - Resistance in pOhm range measured through a redundant (A/B) voltage measurement over a bus-bar splice (inductive compensation applied)
  - In case of quench fast power abort activated through interlock loop opening



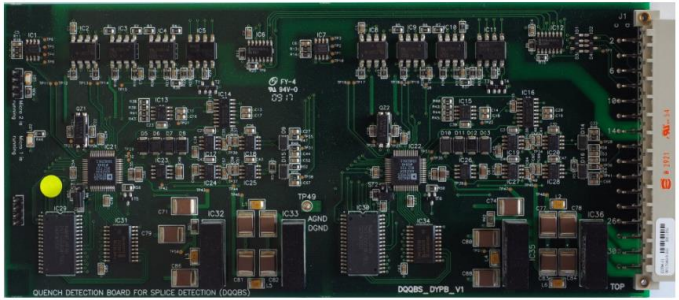
Introduction

- DQQBS = Bus-bar Splice Quench Detector
  - Although looks like, this is not a board mentioned yesterday in Ruben's talk
  - But it is a radiation tolerant version, designed and worked well for the LHC radiation environment
  - However, HL-LHC is beyond its capabilities

R2E challenges: COTS component SEE sensitivity



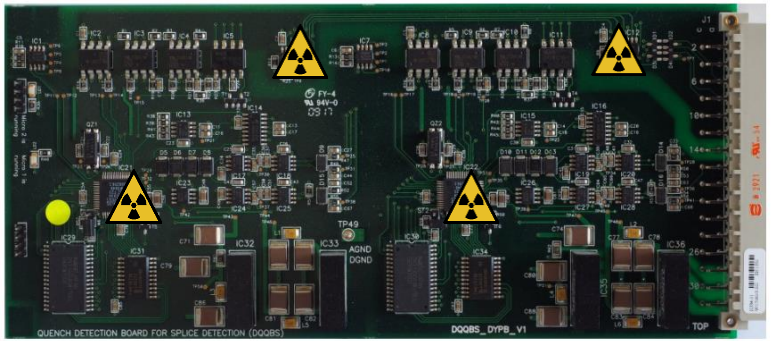
≠



- SEL sensitive SRAM performing critical function in critical system (in red)

Development motivation

- DQQBS boards in half-cell 8 to11 around P1 and P5 were affected by radiation in Run2
  - Strong location dependence correlated to the changed TCL settings in 2018
    → Very good exercise for the HL-LHC era
- Vulnerable components: PhotoMOS and ADuC834 Flash – 8 faults in 2018
  - Opening interlock loop when no quench and causing beam dumps
  - Configuration corrupted
  - Flash corrupted → false positives of quench detection → beam dump
- Some of the affected boards were exchanged by a temporary solution
  - Patches replacing the PhotoMOS by electro-mechanical relays
  - Successful but do not solve all problems



Solution strategy

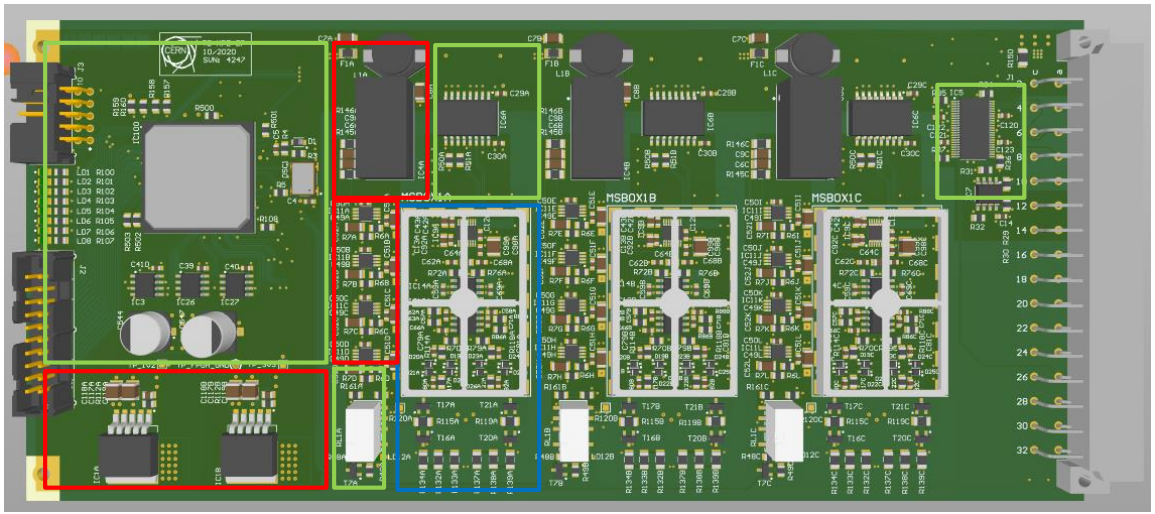
- Develop a new circuit board based on the IGLOO2 FPGA and electro-mechanical relays with a goal of surviving 400 Gy TID
- Reuse proven designs and components
- Apply SEU mitigation techniques in FPGA
- Perform board deployment in multiple deployment campaigns based on criticality in terms of radiation levels
- According to estimated radiation levels in DS areas of 10 Gy/year and 100 Gy/year[1]
  - → Lifetime TID would be 250 Gy and 2500 Gy → anticipate board exchange
  - → Board replacement planned in 8 to 12 half-cells of P1, P5, (P7), P2 and P8
  - → 190 DQQBS to be changed (2021 – 2023)

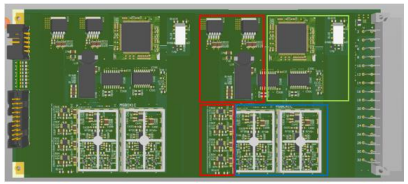
[1]https://edms.cern.ch/ui/file/2302154/1.0/HLLHC_Specification_Document_v1.0.pdf

Development timeline

1/2

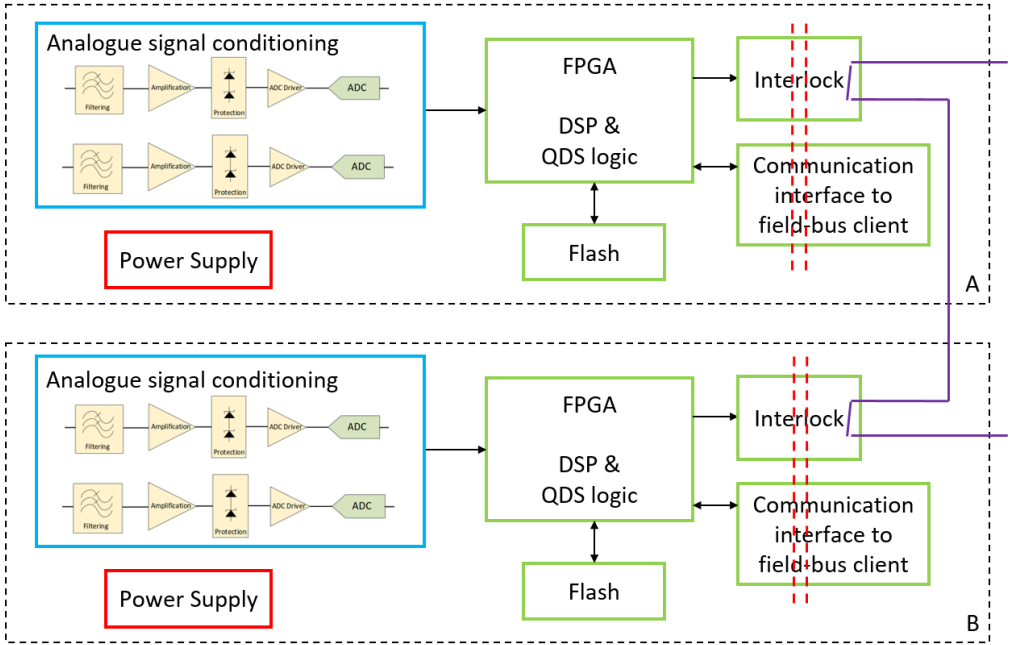
- Development has started recently
- Design based on our recent designs → most components qualified

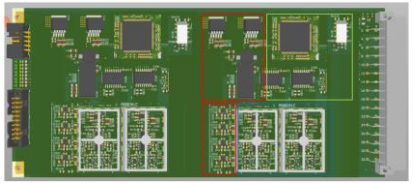




Development timeline 2/2

- IGLOO2 FPGA used for digital signal processing and quench detection logic
- 20-bit SAR ADC with oversampling and filtering to replace 24-bit sigma-delta ADC





Component-level R2E considerations 1/2

- Majority of the components have been tested for DQLPUB upgrade and UQDS development, rest to be tested

Component	Component class	Status	Results
P82B96TD	Bus buffer	Used in QPS in the tunnel	
SN74LVTH16245ADGGR	Bus transceiver	Tested by R2E	Works fine up to 500 Gy
MEJ2D0515SC	DCDC converter	Tested by TE-MPE-EP	Works fine up to 500 Gy
THS4521ID	Differential amplifier	Tested by R2E	Works fine up to 500 Gy
ADUM263N1BRIZ	Digital isolator	Tested by TE-MPE-EP	Works fine up to 500 Gy
1N4148WS	Diode	Not tested yet	
AT25DN512C-SSHF-B	Flash memory	Tested by R2E	Works fine up to 500 Gy
M2GL010-TQ144	IGLOO2 FPGA	Family tested by R2E	Works fine up to 450 Gy
TPS7A3001DGNT	Linear regulator	Tested by R2E	Works fine up to 500 Gy
LT3083EQ#PBF	Linear regulator	Tested by R2E	Works fine up to 1000 Gy
TPS7A4901DGNT	Linear regulator	Tested by R2E	Works fine up to 500 Gy
OPA2192ID	Operational amplifier	Tested by R2E	Works fine up to 500 Gy
OPA192ID	Operational amplifier	Tested by R2E	Works fine up to 500 Gy
LFSPXO018077	Quartz oscillator	Tested by R2E	Works fine up to 500 Gy
MDC3105LT1G	Relay driver	Tested by R2E	Works fine up to 500 Gy
LTC2378IMS-20#PBF	SAR ADC	Tested by TE-MPE-EP	Works fine up to 500 Gy
PMEG4002EJ	Shottky diode	CHARM test by TE-MPE-EP	Survived 130 Gy
CDSOD323-T12C-DSL	TVS diode	Tested by R2E	Works fine up to 500 Gy
ADR435-EP	Voltage reference	Tested by R2E	Works fine up to 400 Gy

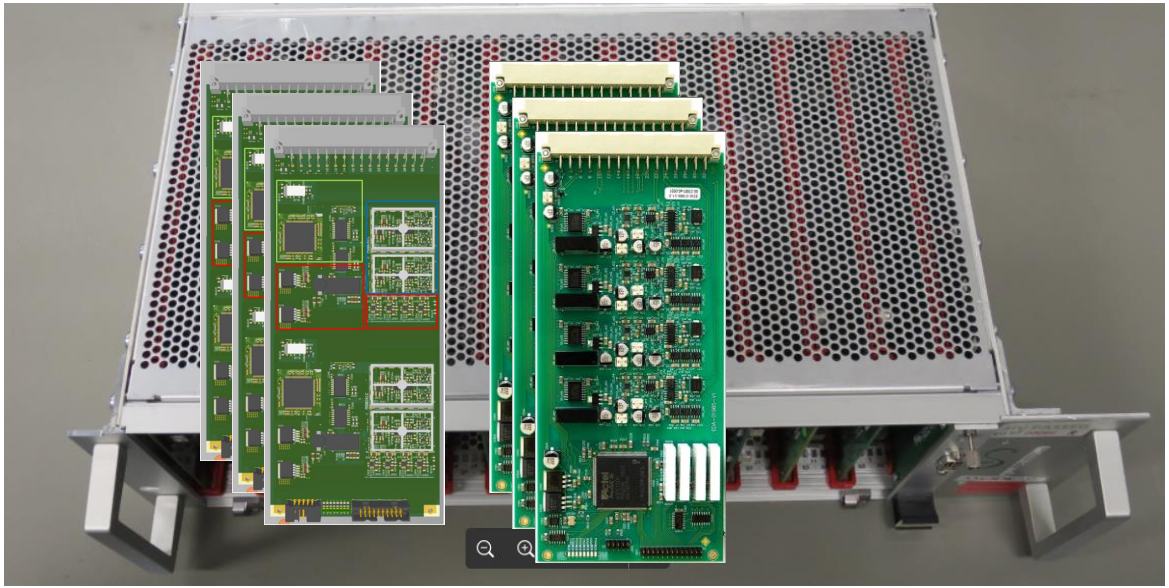
Component-level R2E considerations 2/2

- P82B96TD to be tested in PSI
- Diodes could be tested with Co60
- M2GL010 not tested, but family tested

- Design of the first prototype is ongoing → list might change!

System-level R2E considerations

- If schedule allows, system-level test should be done in CHARM up to 500 Gy for a modified DQLPU-S crate that hosts new DQQBS boards and symmetric quench detectors for main magnets (DQQDS)



Summary

- Design of the first prototype of a new radiation tolerant quench detector for bus-bar splices based on IGLOO2 FPGA and electro-mechanical relays is ongoing
- The first prototype will be sent for production in coming weeks
- As system parts have been evaluated due to synergies with other consolidation measures, the design is expected to be ready for production in Q3 2021
- Few components (so far) left to be qualified in radiation
- Testing the DQLPU-S crate hosting new bus-bar detection board together with the current quench detectors for main LHC magnets would be beneficial
- Board exchange campaign planned to be performed in staggered arrangement from 2021 to 2023

Thank you for your attention!

Questions?