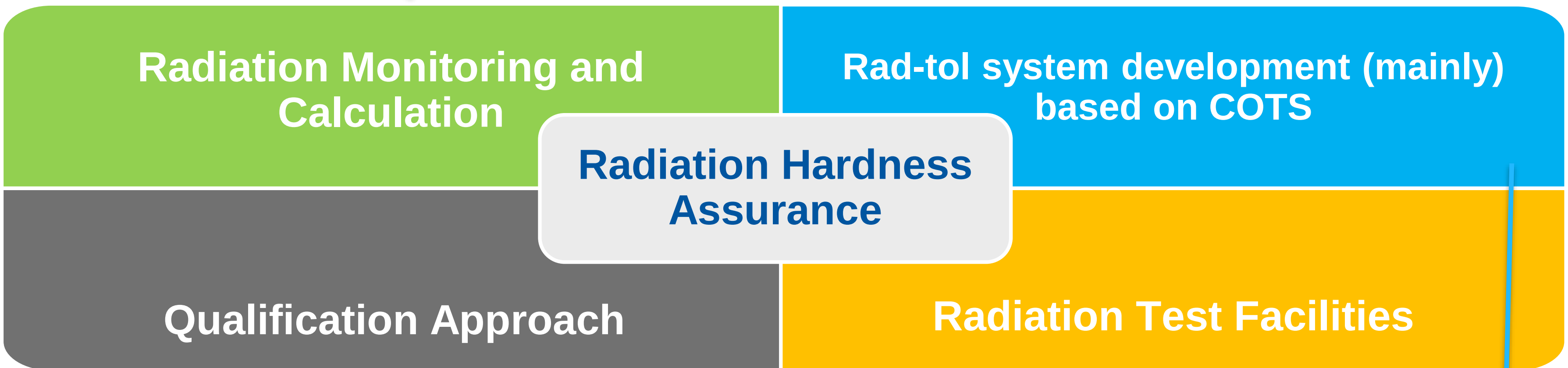
Status of the HL-LHC LS2 radiation qualifications and LS3 radiation-tolerant designs

Rubén García Alía, Salvatore Danzeca, Simone Gilardoni

8th HL-LHC Collaboration Meeting at CERN – 18/10/2018

Radiation Hardness Assurance for HL-LHC

Already covered in "Update of the expected radiation levels for HL-LHC", Giuseppe Lerner



- **Presentation outline:**
  - **Overview and Implementation of R2E Radiation Hardness Assurance**
  - **Status of LS2/LS3 HL-LHC radiation tolerant developments**

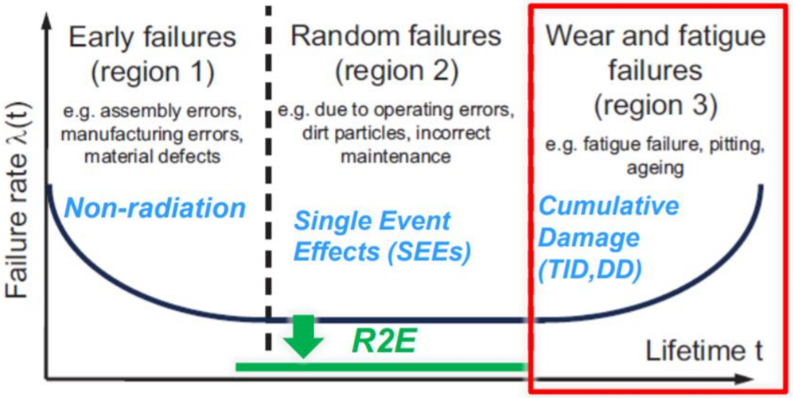
Outline

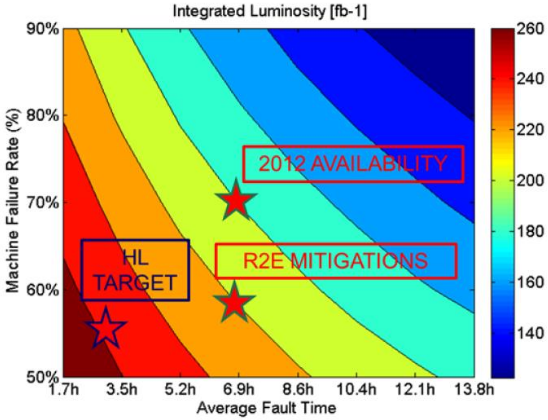
- **Overview and Implementation of R2E Radiation Hardness Assurance**
- Status of LS2/LS3 HL-LHC radiation tolerant developments

R2E status and future challenges/risks

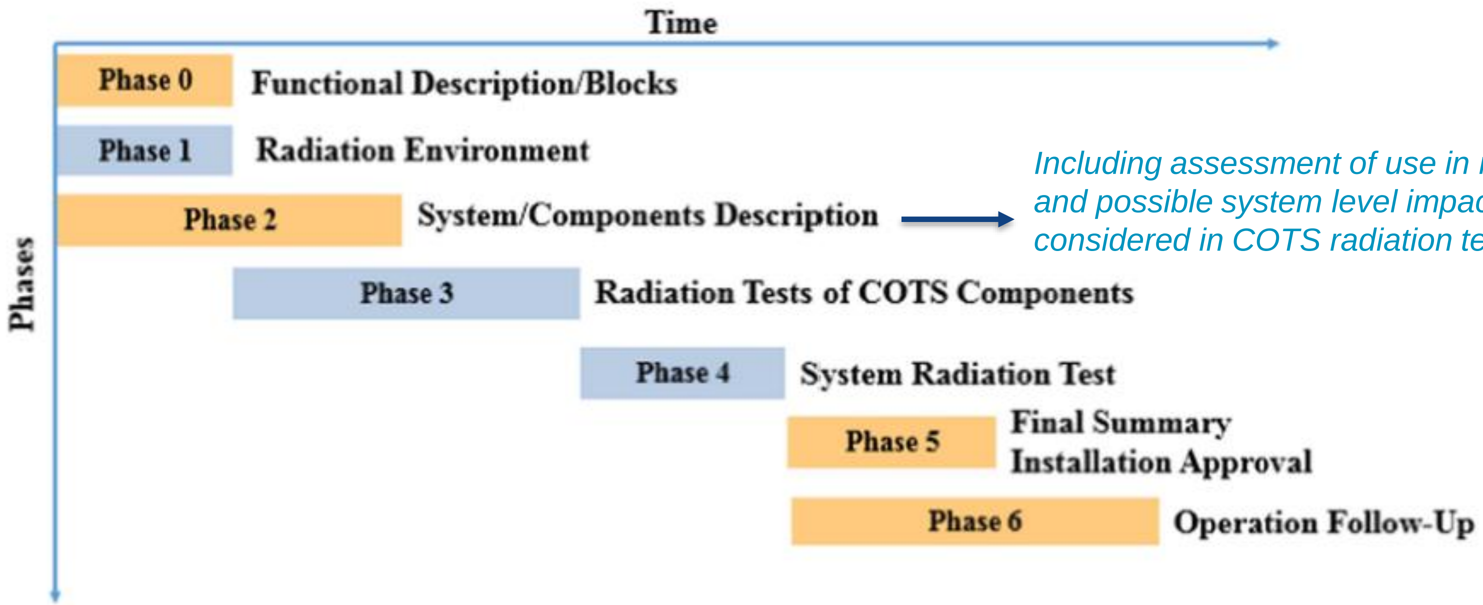
- Presently (Run 2), R2E failures in the LHC remain in the shadow for operation (i.e. relatively small impact on availability & performance*)
- However [R2E Cost & Schedule Review 2017]:
  - **R2E Lifetime failures** are not constant in time (fluence) and could appear at a similar stage for many different distributed system units (e.g. nQPS, 60A converters…)
  - **R2E SEE failures** that are acceptable in terms of premature dumps (1-10 dumps/system/year) for present operation might not be acceptable for HL-LHC (tighter availability constraints, increased radiation levels)
  - The **injector availability** is critical for LHC operation; so far, no systematic R2E approach has been applied, and post-LIU operation will involve new equipment and different (typically more severe) radiation level distribution (e.g. SPS LSS5 dump area)

(*) LHC availability report, 2017





RHA guidelines for COTS-based systems

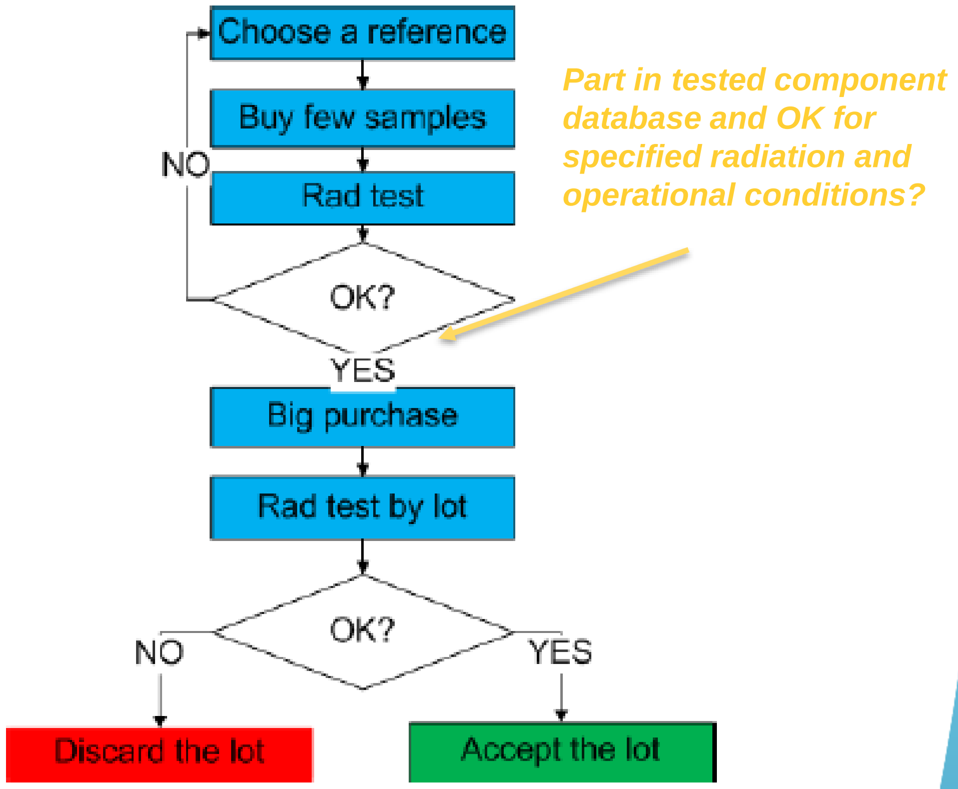


Including assessment of use in radiation and possible system level impact, to be considered in COTS radiation test

- *Considering radiation tolerance constraints at* ***very early (initial) stage of design***
- *Validation of* ***radiation tolerance at system level*** *before final production*

Lot screening and acceptance

- Components purchased through vendors which obtain them from different foundries
- Dedicated production follow-up (i.e. full traceability) is expensive
- We rely on the assumption that COTS samples belong to same lot when they have same date code
- **Common COTS procurement, storage and up-screening** (electrical + radiation) **strategy is crucial for on-going/future (e.g. LS3) developments**



R2E RHA documents

- **RHAPS: Process Structure** → Pure RHA guideline which gives information about the process and guides the user through the design and qualification methodology
- **RHAPV: Project Validation** (new project) → report of the project information, radiation environment, radiation tests [linked to Engineering Change Request]
- **RHACD: Check document** (existing equipment) → report the cards changed and if they are conform with the RHAPS

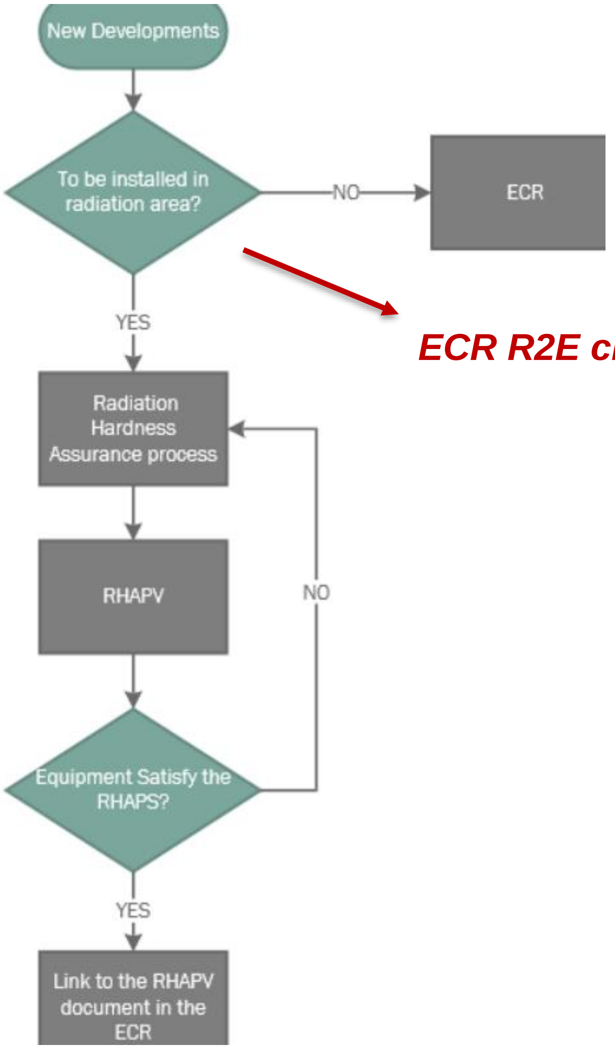
New Developments

- Have to follow a radiation assurance procedure RHA
- The criticality needs to be assessed
- The system has to be tested in a representative radiation environment

System already installed

- Their fault rate should be assessed
- The relocation should be notified
- The integration document will have a field pointing at the RHA document
- Any system change should be notified

RHAPV – Process Structure



ECR R2E check-box

- Endorsed during 2017 R2E Cost & Schedule review
- Linked to LHC Engineering Change Request (ECR) as final validation
  - **Check-box in ECR template** for electronics installed in possible radiation areas
- Contains the RHA Project Validation document as cornerstone for equipment exposed to radiation
- RHAPV and ECR provide final validation, but **actual R2E work starts at very early stage of system design**

RHAPV – Project Validation

- Example: GEFE BPM FE system

CERN CH-1211 Geneva 23 Switzerland

EDMS NO.	REV.	VALIDITY
0000000	0.0	DRAFT

REFERENCE
XXXX

CERN EN Engineering Department

To be sent to: ecr.ENDEPT@cern.ch Date: 201x-xx-xx

Radiation Hardness Assurance Protocol Document

GBT-based Expandable Front-End (GEFE)

Brief description of the project(s):

EQUIPMENT CONCERNED:	DRAWINGS CONCERNED:	DOCUMENTS CONCERNED:

PE IN CHARGE OF THE ITEM:	PROJECT LEADER:
< Name >	< Name >
DECISION OF THE PROJECT ENGINEER: ☐ Rejected. ☐ Accepted by the Project Engineer, no impact on other items. *Actions identified by the Project Engineer.* ☐ Accepted by the Project Engineer, but impact on other items. *Comments from other Project Engineers required.* *Final decision and actions by the Project Management.*	DECISION OF THE PROJECT LEADER: ☐ Rejected. ☐ Accepted by the Project Leader
DATE OF APPROVAL:	DATE OF APPROVAL:

ACTIONS TO BE UNDERTAKEN:

< ACTIONS >

DATE OF IMPLEMENTATION: < DATE >

EN Engineering Department — REFERENCE XXXX — EDMS NO. 0000000 — REV. 0.0 — VALIDITY DRAFT

Page 2 of 14

1. PROJECT DESCRIPTION 1.1.1 TECHNICAL REQUIREMENTS AND MAIN SPECIFICAITONS 1.1.2 ARCHITECTURE 1.2 CRITICALITY	Equipment group
2. RADIATION ENVIRONMENT	MCWG chair
3. RADIATION TESTING 3.1 COMPONENTS LIST AND CRITICALITY 3.2 RADIATION TEST AT COMPONENT LEVEL	Radiation test service
4. RADIATION TEST AT SYSTEM LEVEL	Equipment group + Radiation test service
5. FINAL SUMMARY 6. COMMENTS	R2E project leader

Document template available on EDMS (2028777)

CHARM R2E facility for system level testing

- Unique facility for radiation testing at component, board and **system level** in **high-energy accelerator environment**
- Facility makes use of available beam (PS East Area) while being specifically tailored for accelerator electronics qualification
- Similar approaches outside CERN at **board level**: neutron spallation (e.g. LANSCE, ChipIr), proton cyclotrons (e.g. PSI, KVI, TRIUMF), very-high energy heavy ions (GSI, NSRL)
- TID board/system level qualification possible also during LS2 in **CERN cobalt-60 facility (CC60)**



RHA LMC approval & recommendations

Summary of the 362nd LMC Meeting held on 26th September 2018

DECISION: the LMC endorses the proposal to formalize the Radiation Hardness Assurance (RHA) validation in the LHC.

RECOMMENDATION (for IEFC): the LMC recommends to follow the same RHA validation practices and formalization process in the LHC injectors.

ACTION (for EN-ACE and equipment groups): review the ECR template to include the R2E checkbox and update all ECRs for LS2 in order to ensure a good traceability.

Outline

- Overview and Implementation of R2E Radiation Hardness Assurance
- **Status of LS2/LS3 HL-LHC radiation tolerant developments**

R2E support & common building block activities

- **MCWG** (chair: Yacine Kadi)
  - In charge of radiation level calculation & monitoring
  - For calculations, strong link with Monte Carlo/FLUKA activities in EN/STI-BMI
  - Dedicated HL-LHC fellow: Giuseppe Lerner
- **RADWG** (chair: Salvatore Danzeca):
  - Support for rad-tol design and COTS component selection
  - Continuous radiation qualification of equipment group components at PSI
- R2E **CERN facilities** [CHARM, Cobalt-60] (WP leader: Salvatore Danzeca)
  - Facility operation, including dosimetry
  - Interface with users
  - Continuous upgrades (e.g. cryo-cooler integration in CHARM, cobalt-60 source activity increase)
- R2E **external facilities** for high-level TID testing (WP leader: Marco Calviani, activity technical responsible: Elisa Guillermain)
  - Mainly for passive TID testing (e.g. materials) up to MGy level
- R2E **common building blocks** (WP leaders: Salvatore Danzeca, Rubén García Alía)
  - In implementation: common purchase, screening, qualification & storage of COTS parts
  - FPGA-based modules: SmartFusion2, NanoExplore

R2M work-package in R2E

- Coordinating **high-dose (~MGy) irradiation activities** on electronics and (mainly) **materials** in external facilities (see table below)
- Key added value in optimizing resources by combining different users
- Examples of recent/on-going HL-LHC material irradiation campaigns:
  - Precision components for HL-LHC alignment systems **[WP15.4]**
  - Roller screws for adjustment of collimator jaws (TCPPM, TCSPM, TCLD…) **[WP5]**
  - Several irradiations for EP/DT HL-LHC detectors

Facility	Radiation	Min	Max	Active ?	Location
Fraunhofer TK100	Gamma	2 Gy/h	300 Gy/h	Yes	Germany
Fraunhofer TK1000	Gamma	1 Gy/h	10 kGy/h	Yes	Germany
BGS (Fraunhofer)	Gamma	700 Gy/h	30 kGy/h (70 kGy/h)	No	Germany
Ionisos	Gamma	20 Gy/h in static	2.5 kGy/h in conveyor	No (Powering possible)	Near Lyon

With input from Elisa Guillermain and Marco Calviani

R2E activities linked to HL-LHC WP6B

Overview of converters in HL-LHC radiation areas

Location	Converters
ARC	376x LHC60A-08V 376x R2E-HL-LHC60A-10V
RR13/17	36x R2E-HL-LHC120A-10V 28x R2E-LHC600A-10V 30x R2E-LHC4-6-8kA-08V
RR53/57	36x R2E-HL-LHC120A-10V 28x R2E-LHC600A-10V 30x R2E-LHC4-6-8kA-08V
RR73/77	20x R2E-HL-LHC120A-10V 48x R2E-LHC600A-10V 2x R2E-HL-LHC600A-10V (*)

Operating in present LHC machine

System radiation tolerance validated in CHARM; LS2 installation

Architecture/component selection; LS3 installation

(*) 11T trims, equipment code HCRPMBE
Note: possibility of having 200A converters (equipment code HCRPMBG) in UL14/16 if warm powering is moved from UR (same applies to 120A [HCRPLBC] which are already foreseen to be radiation tolerant

With input from Yves Thurel and Michele Martino

R2E activities linked to HL-LHC WP6B

FGClite & 600A/4-6-8 kA

- Essential systems for HL-LHC availability & performance
- Followed the R2E development & qualification procedure, including CHARM system level validation
- Machine deployment:
  - **FGClite:**
    - EYETS 16-17 in LHC ARC (752 units), excellent availability in 2017 & 2018 runs
    - RRs 1/5/7: during LS2
  - **600A & 4/6/8 kA:**
    - RRs 1/5/7: during LS2

System	TID	SEE XC [cm^2]	DD [cm^{-2}]
FGClite	>200	<10^{-13}	>10^{12}
600A & 4/6/8 kA	>70 (*)	<10^{-12}	>10^{12}

(*) including factor 3 safety margin for ELDRS

FGClite

R2E-LHC4-6-8kA-8V

With input from Yves Thurel and Slawosz Uznanski

R2E activities linked to HL-LHC WP6B

60A & 120A

- 120A:
  - Timeline: to be installed during LS3
  - Locations:
    - RR1/5/7
    - open option of relocating UR 200A and 120A converters to UL14, UL16, UL557 & UCS55
- 60A:
  - Timeline: to be installed during LS3
  - Baseline: production of ~half the 752 units as rad-tol, redundant
- Design considerations:
  - Based on 600A, 4Q design
  - 60A and 120A to be based on same basic unit [60A-10V power brick], with n+1 redundancy (2x 60A, 3x 120A)
- R2E considerations:
  - FGClite and 4/6/8 kA component references to be re-used whenever possible; batch acceptance of such parts to be carried out at part/system level in CHARM (Run 3)
  - New critical references to be tested at component level (LS2, start of Run 3)

LHC60A-08V

With input from Yves Thurel and Michele Martino

R2E activities linked to HL-LHC WP6B

Bi-Volt/Tri-Volt PSU

- Aims at providing 1400 bi-volt [DCCT] and 1000 tri-volt [FGC] radiation tolerant units (*)
- Estimated radiation lifetime for presently installed units (mainly RRs): 25-50 Gy, as confirmed in CHARM tests (EDMS 1933100)
  - Limiting factor: DCDC converter module
- R2E project for development & qualification of radiation tolerant bi-volt/tri-volt PSU
  - Critical element: DCDC converter; main action paths:
    - Test of commercially available DCDC converter modules** (RADWG, Salvatore Danzeca)
    - Collaboration with industry for COTS selection (e.g. power MOSFET, optocoupler) in existing DCDC design
    - In-house COTS DCDC converter design

***600A fan tray:** possible need of rad-tol design, as opposed to initially expected*

(*) final number of units will depend on HL-LHC 60A architecture and possible need of separate FGClite power supply
(**) for COTS modules, Bill-Of-Material and traceability of COTS components is essential to mitigate radiation failure risk

With input from Slawosz Uznanski and Ben Todd

R2E activities linked to HL-LHC WP7

11T uQDS

- QDS function defined by FPGA configuration (Microsemi IGLOO2)
- ADC: 20bits/1Msps
- Quench heaters located as close as possible to magnet, monitoring in RR area (~75m away from magnet)
- Radiation tolerant up to RR73/RR77 environment
- CHARM 2018 test: one week
- Further component tests foreseen at PSI (ADC, DC-DC…)

“Status of Hardware for quench detection and circuit monitoring for HL-LHC”, Jens Steckert, 7th HiLumi Collaboration Meeting, Madrid, 13-16 Nov. 2017

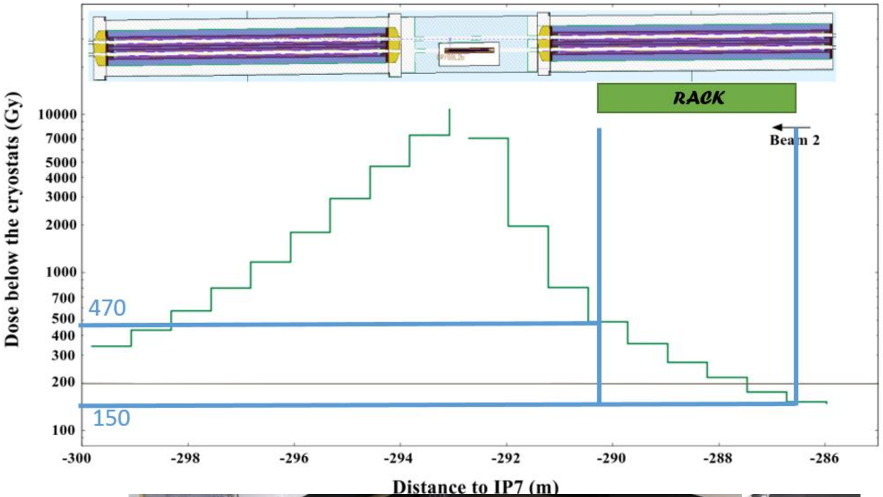
With input from Jens Steckert

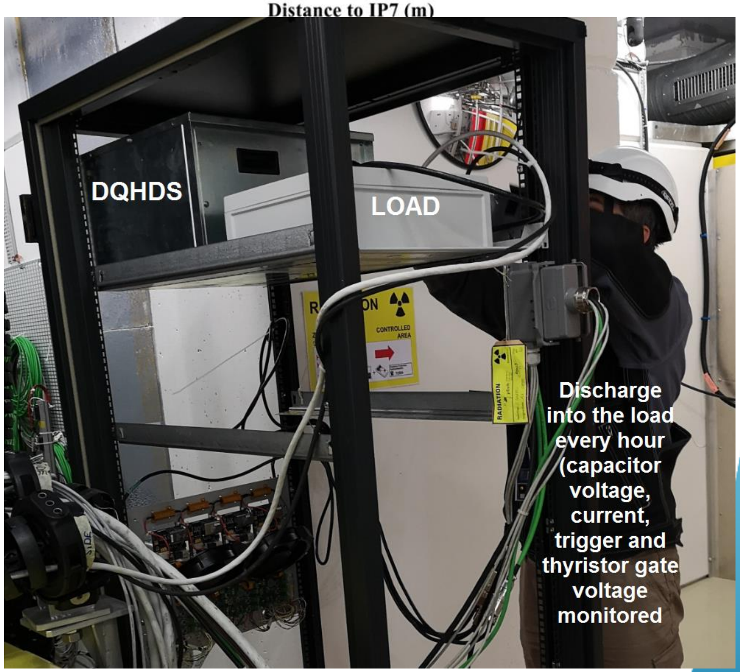
R2E activities linked to HL-LHC WP7

MPE-EE 11T quench heater power supply (DQHDS)

- Partial side of the rack will be exposed to a radiation up to 400-500 Gy
- Component level tests in PSI up to 500 Gy
  - Optocouplers to replace triggering relay (will not be used in the end) (EDMS reports: 2002397, 2002401, 2002403)
  - Regulator/transistors (EDMS reports: 2011367, 2029282)
  - Thyristors to be tested
- System level test in CHARM up to 500 Gy
  - Two DQHDS units tested had detectable failure at ~420 Gy and ~470 Gy
  - "Safe" failure mode, as it is detectable before quench
  - Cause of failure under investigation
- A strategy of replacement or exchange might be put in place during HL-LHC

With input from David Carrillo and Jelena Spasic





R2E activities linked to HL-LHC WP7

Cold by-pass diode

- WP10 definition of HL-LHC radiation levels for:
  - Cold diodes presently installed in the machine
  - Cold diodes to be possibly installed in IP1 & IP5 inner triplet (DFX location)
- Integration of cryo-cooler setup in CHARM facility
- Related dosimetry during tests
  - Expected radiation levels for full CHARM run at cryo-cooler of ~10 kGy and ~2×10^{14} n/cm^2
- Evaluation of possible further tests (pure gamma field, CHARM during Run 3…)
- Dedicated presentations during 2018 HL-LHC week

"Update on Cold Diodes Project for HL-LHC", Giorgio D'Angelo
HL-LHC TCC #55, August 2018

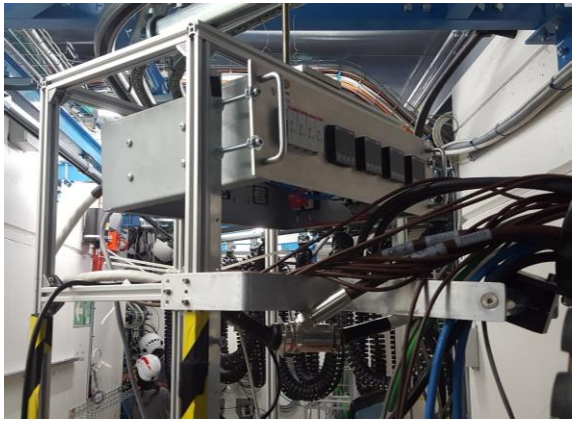
With input from Giorgio D'Angelo

R2E activities linked to HL-LHC WP7

Temperature controller + solid-state relay (current leads)

- Installed in RRs of IP1, 5 & 7 (364 controllers in total)
- Temperature controllers tested in CHARM in 2018:
  - Failure due to power board (potentially linked to power MOSFET SEB)
  - Failure rate acceptable for Run 3, radiation reliability to be improved for HL-LHC
- COTS system:
  - Importance of access to schematics and bill-of-material (BOM)
  - Traceability of references/lots is crucial

With input from Giorgio D'Angelo



R2E activities linked to HL-LHC WP12

Radiation-tolerant conditioning electronics for pressure sensors

- To be installed in DS (LS2) and ARC (LS3)
- Upgrade from present system: 4-20mA transmission (as opposed to 0-10V) resulting in reduced signal loss and noise coupling
- Radiation qualification:
  - At component level: 18 COTS references tested at PSI up to 500Gy, 15 accepted → batch procurement of accepted parts
  - At system level: in CHARM, two weeks of irradiation for each sub-system

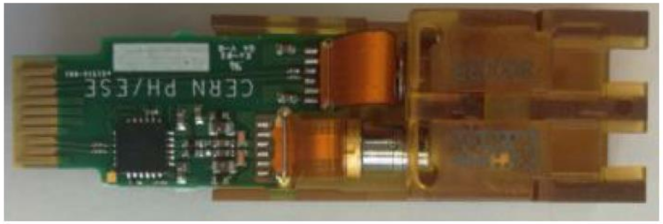
With input from Nikolaos Chatzigeorgiou and Gregory Pigny

R2E activities linked to HL-LHC WP13

LHC BPM system

LHC-CONS, with HL-LHC radiation level & availability requirements

- Complete consolidation: 1100 devices, aiming at LS3 (LS4 possible, but components would need to be ready after LS3 as back-up)
  - R2E sub-activity: rad-hard optical transceiver for mono-mode fiber transmission



LHC BLM system

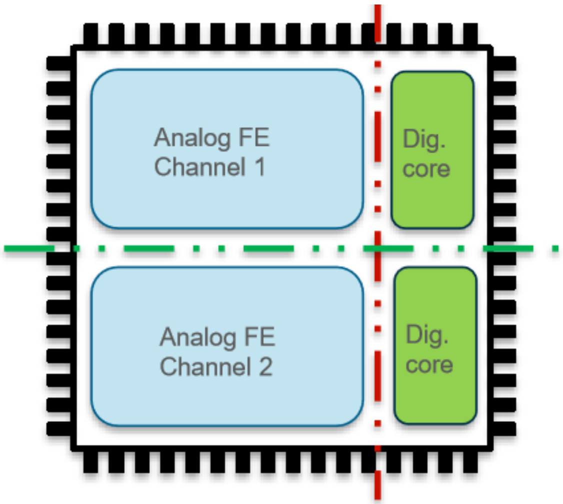
- Surface electronics by LS3, tunnel electronics by LS4
- Aiming at same system as SPS ring BLM (re-using LpGBTx and VTRx+)

With input from Thibaut Lefevre and Rhodri Jones

R2E activities linked to HL-LHC WP13

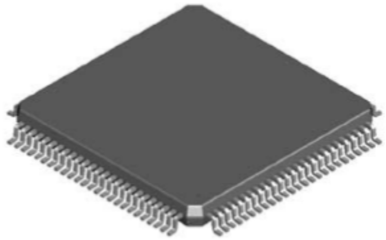
Rad-hard FE for LHC BLM in IP1, 3, 5 and 7

- Development of radiation hard ASIC BLM to increase margin between quench threshold & noise level
- Target radiation tolerance: 1 MGy
  - 2018: design & production
  - 2019: radiation testing



Other R&D activities

- HL-LHC BE/BI activities (LS3):
  - LHC new luminosity detectors
  - Beam-gas vertex detectors
- Rad-Hard camera to replace vidicon tube (LS3):
  - Option 1: rad-hard CMOS development
  - Option 2: optical fibre bundle to move imaging sensor to radiation safe area

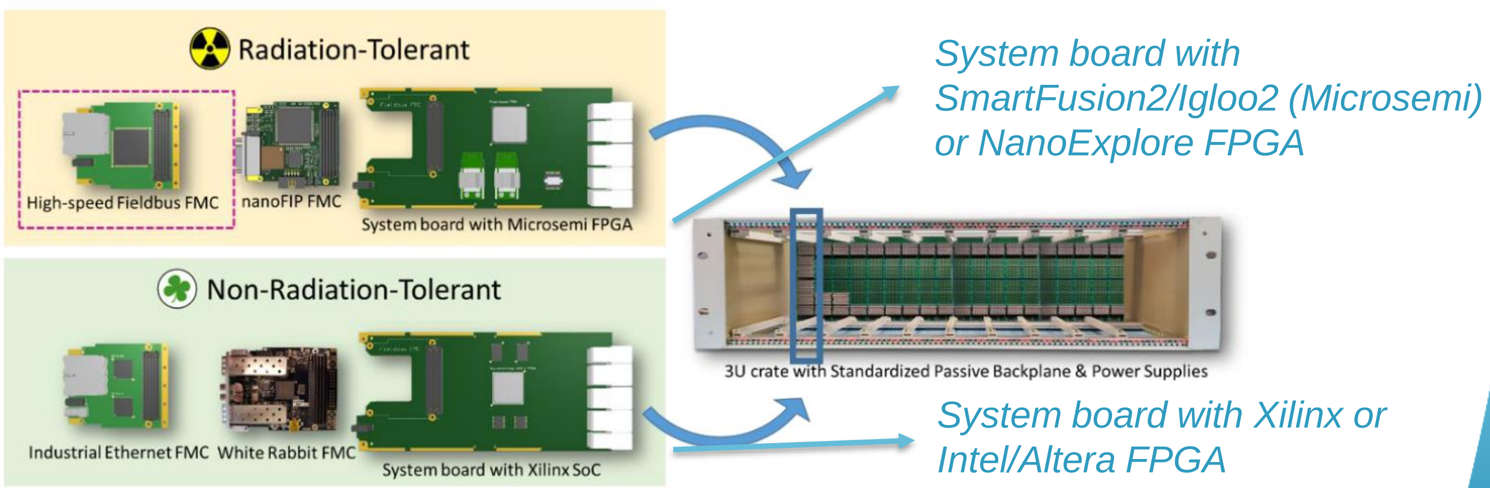


With input from Thibaut Lefevre, Rhodri Jones and Luca Giangrande

R2E activities linked to HL-LHC WP18

Distributed I/O Tier project

- Development of generic **radiation-tolerant power supply** for distributed I/O Tier project
  - Architecture design and part/module selection (critical building block: DCDC converter)
- Radiation tolerant high-speed fieldbus slave (industrial Ethernet protocol **POWERLINK**)
  - 2018 tests in CHARM (runs & analysis on-going):
    - running on hard ARM core of SmartFusion2
    - RISC-V soft-core (TRM protected) with ECC ram



With input from Javier Serrano and Mattia Rizzi

Conclusions & Outlook

- Formalization of **Radiation Hardness Assurance procedure** will contribute to increase R2E quality assurance for accelerator equipment
  - Implemented as ECR check, but this is only the final step (i.e. R2E constraints to be considered at initial project stage)
  - Main HL-LHC challenges:
    - Radiation lifetime issues in (installed) distributed equipment, not visible now but which could impact many systems at similar time
    - SEEs in sensitive equipment in areas with enhanced radiation levels e.g. PLCs in ULs)
    - R2E reliably in injector chain (enhanced radiation levels, LIU equipment)
- Status of **LS2 radiation tolerant equipment**:
  - Radiation qualification completed at system level (CHARM) for critical distributed equipment
  - Formalization of followed RHA procedure in dedicated document, to be linked to ECRs
- Status of **LS3 radiation tolerant developments**:
  - System architecture design, considering radiation environment constraints
  - Identification & qualification of critical components
  - Importance of common component qualification & purchase
  - Common module/sub-system developments (power units, analogue signal conversion & processing, etc.)

HL-LHC 2018 annual meeting references

- **[WP13]** “Status of the beam gas vertex profile monitor development for HL-LHC”, Robert Kieffer (Tuesday PM)
- **[WP7]** “Impact of HL-LHC radiation levels on cold diodes and first results from radiation tests” Giorgio D’Angelo (Wednesday – plenary session)
- **[WP10]** “Update of the expected radiation levels for HL-LHC”, Giuseppe Lerner (Wednesday AM)
- **[WP7]** “Long term strategy for LHC DS cold diodes”, Giorgio D'Angelo (Wednesday AM)
- **[WP7]** “Diode radiation tests, setup and first results”, Arnaud Monteuuis (Wednesday AM)
- **[WP13] “**Status of luminosity monitor design for HL-LHC”, Marcus Palm (Wednesday AM)
- **[WP13]** “Design options for the BLM ASIC”, Luca Giangrande (Wednesday AM)
- **[WP7]** “Status of detection electronics for 11T protection including trim protection”, Jens Steckert (Wednesday PM)
- **[WP7]** “11T protection racks”, David Carrillo (Wednesday PM)
- **[WP7]** “HL-LHC operation impacting existing LHC protection systems”, Reiner Denz (Thursday PM)
- **[WP7]** “Results of radiation tests with HL-LHC detection electronics and quench heater power supplies”, Jelena Spasic (Thursday PM)
- **[WP13] “**Measuring beam size with the BGV - results from the demonstrator in run 2”, Benedikt Wurkner (Thursday PM)
- **[WP13] “**Specifications for the HL-LHC BPM system”, Manfred Wendt (Thursday PM)