Radiation tolerant developments: Power Converters
Review of R2E-related projects

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Outline

- Finished & qualified products
- On-going developments towards HL-LHC
- Future developments
- Impact of RR converters on LHC operation
- Conclusions

Finished & qualified products

EPC Item / type	Status	TID [Gy]	SEE XS [cm²]	DD [/cm2]	Available	Deployed
FGClite 	In operation	200 *qualified*	$<10^{-13}$ *qualified*	$>10^{12}$ *qualified*	2016	**ARC:** EYETS **RR1/5/7:** LS2
RadDIM 	In operation	200 *qualified*	$<10^{-13}$ *qualified*	$>10^{12}$ *qualified*	2016	**ARC:** EYETS **RR1/5/7:** LS2
R2E-LHC 600A-10V 	Production	300 *qualified*	$<10^{-12}$ *qualified*	$>10^{12}$ *qualified*	2019	**RR1/5/7:** LS2
R2E-LHC 4-6-8kA-08V 	Production	60 *qualified*	$<10^{-12}$ *qualified*	$>10^{12}$ *qualified*	2020	**RR1/5/7:** LS2

FGClite

- Rad-tol & High-Rel replacement of the FGC2
  - Distributed regulation to avoid using MCU/DSP in rad-area
  - Plug-in compatible with the FGC2
- Fully compliant with R2E RHA design flow: EDMS 2046131
  - Component selection: type rad-tests
  - Production lot rad-tests
  - System validation at CHARM
  - **~50** components, **~10** facilities, **>1000h** of beam time
- Reliability modeled & confirmed post-deployment
  - Proven **>1Mh of MTTF, >12M dev*h** in OP with 1 HW failure, 3 HW replacements

1600x

1600x	3.4 MCHF	2012-2017
Production	Budget	Time Frame

RadDIM

- Rad-tol & High-Rel replacement of the DIM-550
  - Projects shares the BoM and part qualification with the FGClite
- Fully compliant with R2E RHA design flow: EDMS 2046131
  - Component selection: type rad-tests
  - Production lot rad-tests
  - System validation at CHARM
- Second production batch needed funded by HL-LHC
  - Assembly & test in 2019
  - Needed for the HL-LHC(60-120)A-10V

3900x + 2000x

3900+2000x	0.45 + 0.2 MCHF	2012-2016
Production	Budget	Time Frame

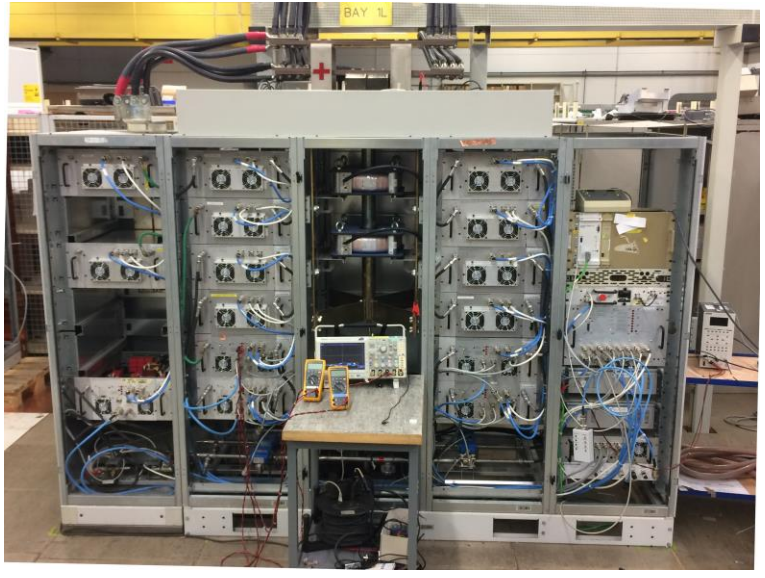
R2E-LHC600A-10V

- Rad-tol replacement of the LHC600A-10V
  - Rad-tol, fully redundant design overcoming electrical limitations
- System rad-validation done at CHARM
  - Production lot rad-tests with dedicated testers in 2017
  - System rad-tests at CHARM done
- Pre-series fully validated at CERN
  - Project currently in full production phase
- Project on time to be deployed during LS2

133x	4.8 MCHF	2014-2020
Production	Budget	Time Frame

R2E-LHC4-6-8kA-08V

- Rad-tol replacement of the LHC4-6-8kA-08V
  - Rad-tol, fully redundant design
- System rad-validation done at CHARM
  - Production lot rad-tests with dedicated testers
  - System rad-tests at CHARM
- Pre-series fully validated at CERN
  - Project in full production phase
- Project on time to be deployed during LS2:
  - Production on schedule
  - Budget has been reduced to 6.00MCHF
  - 6.35MCHF was requested and is needed



60x	6.3 MCHF	2015-2020
Production	Budget	Time Frame

On-going / scheduled developments

EPC Item / type	Status	TID [Gy]	SEE XS [cm²]	DD [/cm2]	Budget	Design/ Production
Tri-Volt Bi-Volt 	*R2E-funded (design)* *Production not funded* *740x*/490x**	200 *Spec*	$<10^{-12}$ *Spec*	$>10^{12}$ *Spec*	*1.1 MCHF**	**2019-2020** *Deployment Post LS2*
R2E-HL-LHC60A-10V	*HL-Funded (design + prod)* *R&D >LS2*	70-200 *Spec*	$<10^{-12}$ *Spec*	$>10^{-12}$ *Spec*	*7.8 MCHF*	*2022+ Deployment LS3*
R2E-HL-LHC120A-10V	*HL-Funded (design + prod)* *R&D >LS2*	70-200 *Spec*	$<10^{-12}$ *Spec*	$>10^{-12}$ *Spec*	*4.4 MCHF*	*2022+ Deployment LS3*

** Numbers not accounting for units for HL-LHC120A and HL-LHC60A*
Price estimation based on production of 25 units

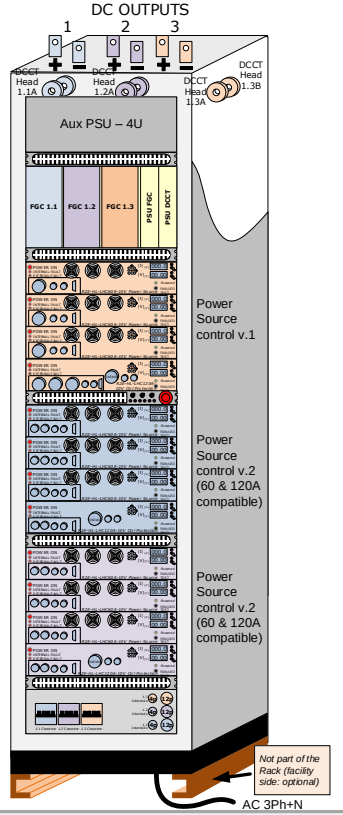
Tri- & Bi-Volt

- 100W Rad-tol replacement of the current Tri- & Bi-Volt design
  - DC-DC module tested at CNGS in 2009: EDMS 1053817
  - Bi-Volt/Tri-Volt PSUs tested at CHARM in 2017: EDMS 1933100
- Work on-going on DC-DC brick with external companies:
  - **TRACO:** NDA signed and components Rad-tested at CHARM
  - **ASP:** dedicated rad-tol design for CERN
  - **BE-CO** convergences
- DC-DC brick & system rad-validation at CHARM
  - COTS DC-DC component screening via EN-STI
  - Prototype design tests as well as lot qualification needed
- Potentially needed During **Run3** (replacement) & during **LS3** (full deployment)

Name	DUT	CHARM min TID	CHARM avg TID	CNGS TID
+5V Tri	DC-DC 5V 50W	**25.9**	47.8	40.0
+/-15V Tri	DC-DC 15V 16W	108.0	141.6	**100.0**
+15V Bi	DC-DC 15V 51W	**53.2**	64.6	80.0

R2E-HL-LHC(60-120)A-10V

- Redundant Rad-tol replacement of the current designs (**R2E CSR** Indico 666689)
  - Based on the same 60A-10V brick design
  - R2E-HL-LHC60A-10V **2x** 60A-10V 420 units
  - R2E-HL-LHC120A-10V **3x** 60A-10V 150 units
- Initially both projects were R2E but changed to R2E-HL.
  - Numbers & locations still to be confirmed (UJ/UR)
- Projects will start after LS2.



420x + 150x	12.2 MCHF	2022-2025
Production	Budget	Time Frame

Control Chassis not studied in detail, estimated:
- 3x FGClite with 1x Tri- & 1x Bi-Volt
- Tri-Volt: 3x FGClites
- BiVolt: 6x DCCTs

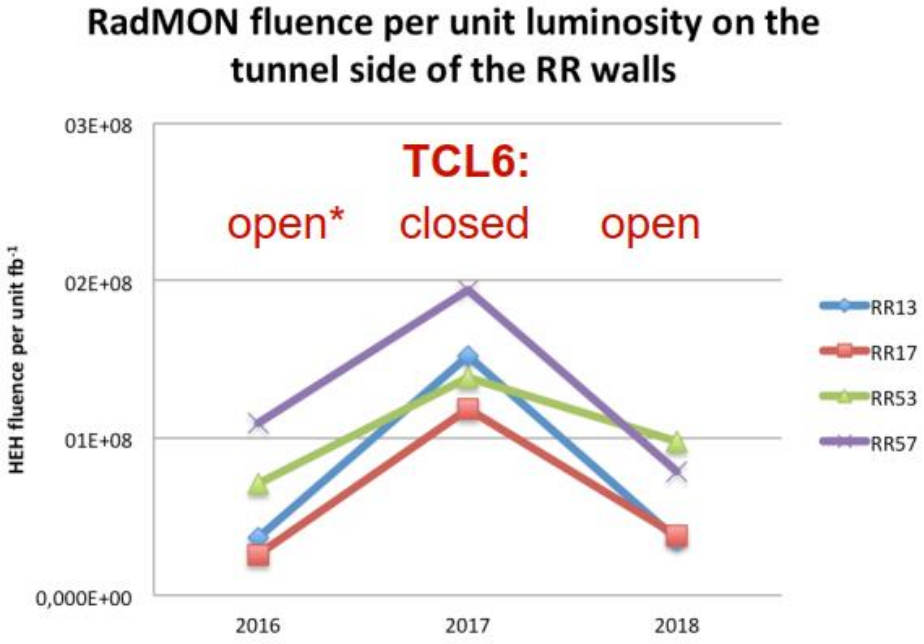
New developments

EPC Item / type	Status	TID [Gy]	SEE XS [cm²]	DD [/cm2]	Cost [/unit]	Design/ Production
Fan-Tray 	***Not funded*** ***200x***	200	<1E-12	>1E12	?	**On-hold** ***Needed for LS3?***

- Provide a cool air to controls crate in power converter
  - Initially dismissed, but is now needed due to mechanical integration
- Based on fans selected for power bricks: 60/200A-10V and temperature control mostly re-using the FGClite BoM
  - Production would be needed for the **LS3?**
- As for the Bi-/Tri-Volt Proposal to fun the **R&D studies** from the **R2E** budget and **production** from the **HL-LHC**

Radiation Levels in RR dependency on TCL settings

- TCL6 settings have a strong impact on radiation levels in the RR1/5
- 2018 open settings for TCL6 allowed a RR rad-levels reduction
  - **~4x** for IP1 &
  - **~2x** for IP5
  - increase in IP7 due to betatron collimator losses
- The ARC rad-levels increased due to open TCL6 impacting MPE equipment in DS locations



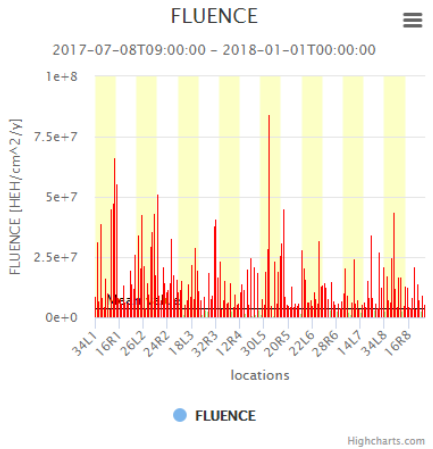
Impact of RR converters on LHC operation

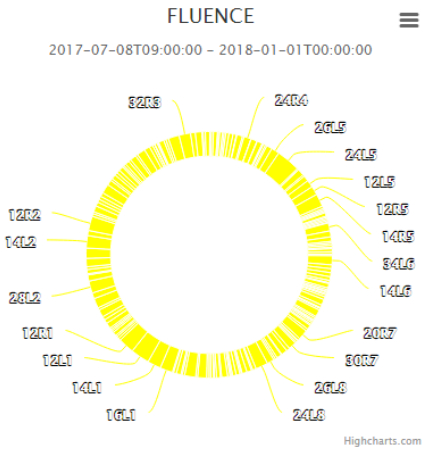
- Sensitive systems and assumed SEE cross sections in RRs :
  - FGC2: 120A (x56), 600A (x76) and 4-6-8 kA (x30): **$1.5 \cdot 10^{-10}$ cm2/unit**
  - Power: 600A (x76): **$3.0 \cdot 10^{-10}$ cm2/unit**
- Expected RR1X-RR5X EPC failures:
  - 2017: 16 events
  - 2018 [up to TS2]: 11 events
- All rad-related failures in operation in 2018 :

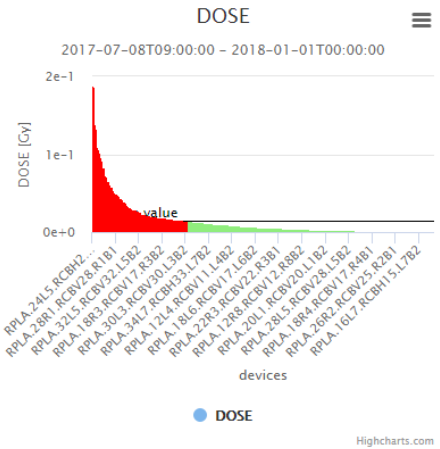
Converter	Power	Controls
LHC600A-10V	6x	2x
LHC120A-10V	0x	3x

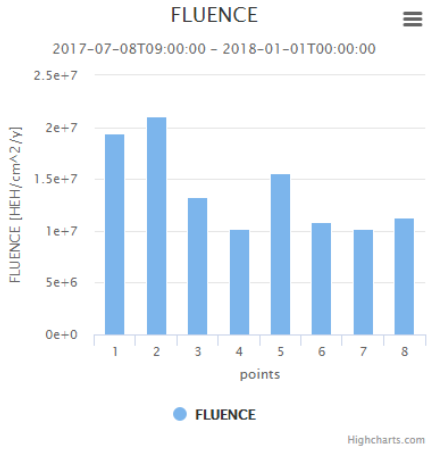
- Both controls and converter failures will be mitigated thanks to the **FGClite** (R2E) and **R2E-LHC600A-10V** deployment during **LS2.**

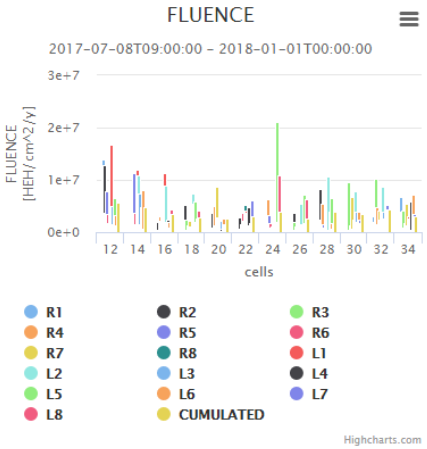
FGClite-Rad-Mon http://fgclite-rad-mon.cern.ch/

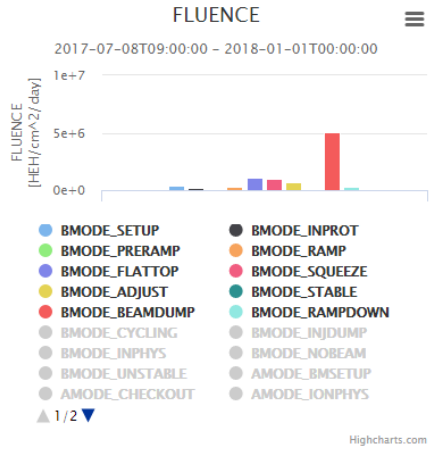












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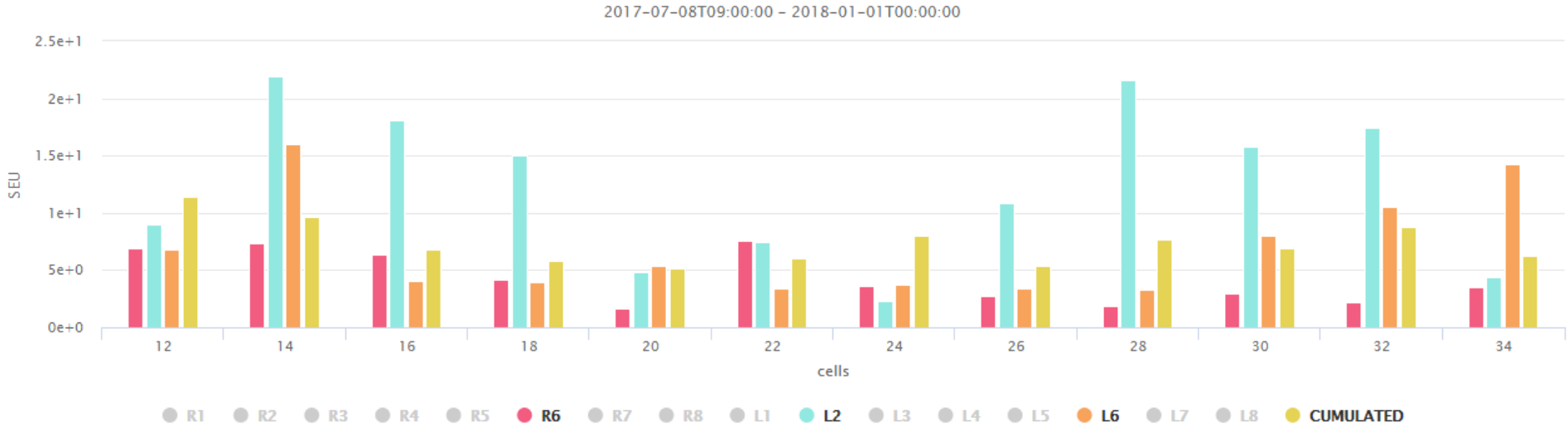

- **758x FGClites** in the **ARCs: g**reat spatial coverage: Cell12-34
  - Low statistics as of now due to low radiation levels in the equipment position
- After LS2: **256x FGClites** in the **RRs** (1/5/7)
  - Great mapping of rad-level gradients

Conclusions

- FGClite & RadDIM are deployed & fully operational:
  - FGClite Phase 2 will finish that project
  - Qualified **rad-tolerance** at component- & system-level at CHARM
  - Proven a very **high-reliability** exceeding the specification of **1Mh** of **MTTF**
- R2E-LHC600A-10V & R2E-LHC4-6-8kA-08V are in production:
  - Qualified at CHARM and satisfying their rad-tol specification
  - To be deployed during the LS2
- Bi-/Tri-Volt PSUs are in R&D phase
  - R&D costs covered by R2E but production is not funded yet
- R2E-HL-LHC(60-120)A-10V
  - Project is funded from the HL-LHC budget to be launched after LS2
- Fan-Tray project is not funded and likely needed for Run 3.


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