Status and evolution of radiation dose on 60A power converters

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HL-LHC WP10

Outline

- Introduction
- Monitoring and calculation of LHC radiation levels
- HEH fluences and their evolution
- TID BLM values
- Conclusions & Outlook

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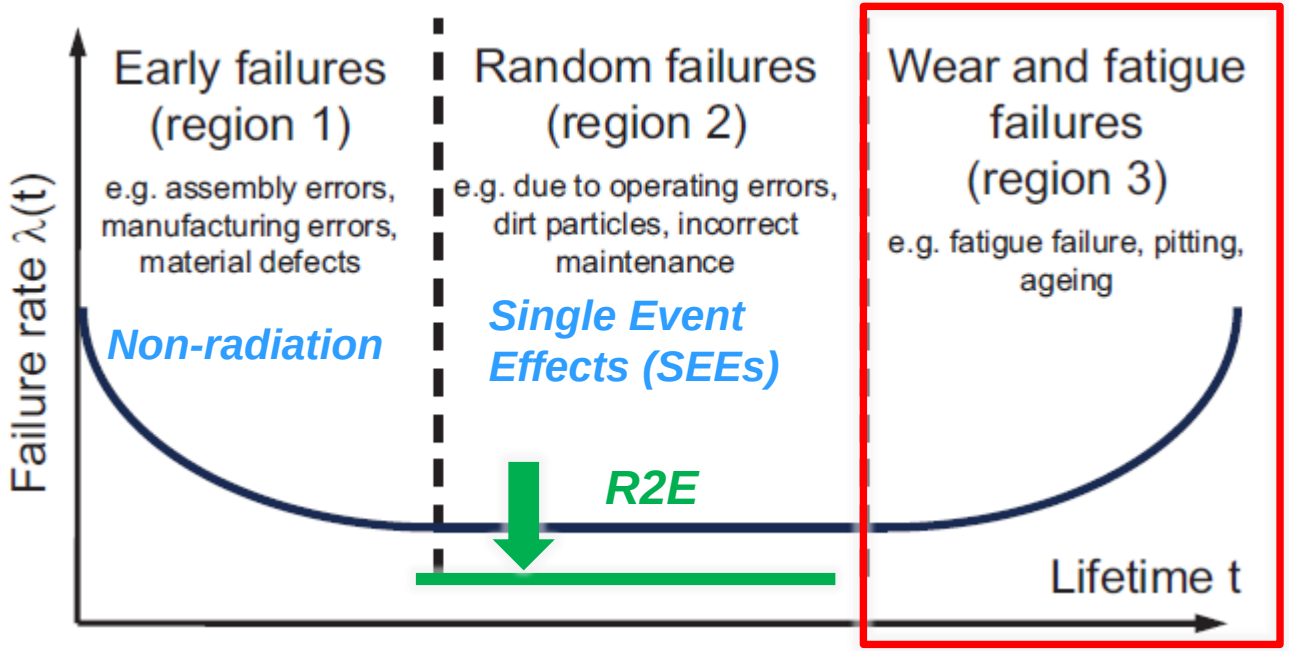
Setting the scene

- 752 60A correctors installed in the LHC ARC; in even cells from 12-34
- Possible upgrade of LHC60A-08V correctors for ensuring radiation tolerance, also compatible with HL-LHC high-availability; ready for operation as of LS3
- Present system: most reliable converter in LHC, with MTBF of ~1M hours, and therefore compliant with HL-LHC availability requirements
- New design would need to be redundant (i.e. 2x 60A-10V power bricks) in order to ensure availability requirements
- New design to be based on components qualified for 600A and 4-6-8 kA, and to also serve as building block for 120A (i.e. 3x 60A-10V)
- Radiation lifetime of present converter estimated to be 30-50 Gy based on two tested units, therefore initially thought to be only compliant with LHC lifetime (i.e. not beyond LS3)
- Purpose of the study presented here: to **re-evaluate the need of a new 60A design due to radiation lifetime requirements** and based on estimated lifetime and HL-LHC radiation levels

Equipment location

- 60A correctors + FGClite
- RYLA racks, under MBB magnets in even half-cells, from 12 to 34 (both included)
- 752 units in LHC ARC

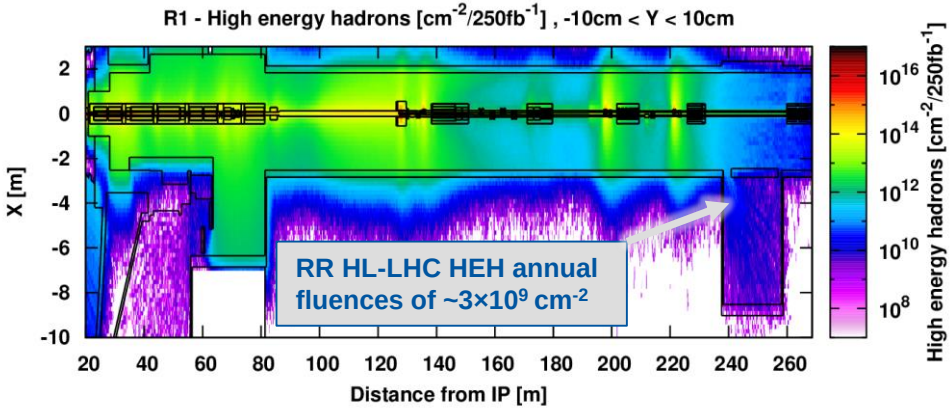
Bathtub curve – stochastic versus end-of-life



- ***Cumulative Radiation Damage***
  - *Total Ionizing Dose (TID)*
  - *Displacement Damage (DD)*
- *Can impact availability of accelerator*
- *Risk of lifetime issues arriving nearly at the same time*
- *Estimation for 60A correctors: 30-50 Gy*

Before moving into the ARC

- R2E failures (i.e. leading to dump) in present LHC machine (~5-10/year) are dominated by power converters in RRs of IP1 and IP5
- Reasonably transparent for operation, however if scaled with radiation levels for HL-LHC (factor ~10 due to luminosity and TCL impact) can become an availability limitation
- R2E/EPC development & qualification of 600A, 4-6-8 kA and FGClite for HL-LHC lifetime and failure limits, requiring 2-3 weeks of test of 2-3 systems in parallel



"Update on expected HL-LHC radiation levels with a focus on Point 7, Point 1 and Point 5", R. G. Alia, HL-LHC week 2017
"Recent result on qualification of PC for HL radiation levels" R. V. Herrero, HL-LHC week 2017

FGClite development, qualification & operation

- System based on modular design (7 boards) and broad range of micro-electronic components
- Qualification against radiation at component and system level
- TID lifetime of **>200 Gy**, SEE cross section upper limit of **10^{-12} cm^2/unit**, compliant with HL-LHC lifetime and SEE failure requirements
- LHC ARC deployment for 60A correctors in EYETS 16-17, excellent performance in 2017
- Deployment in RRs planned for LS2 (along with the 600A and 4-6-8 kA power converters)

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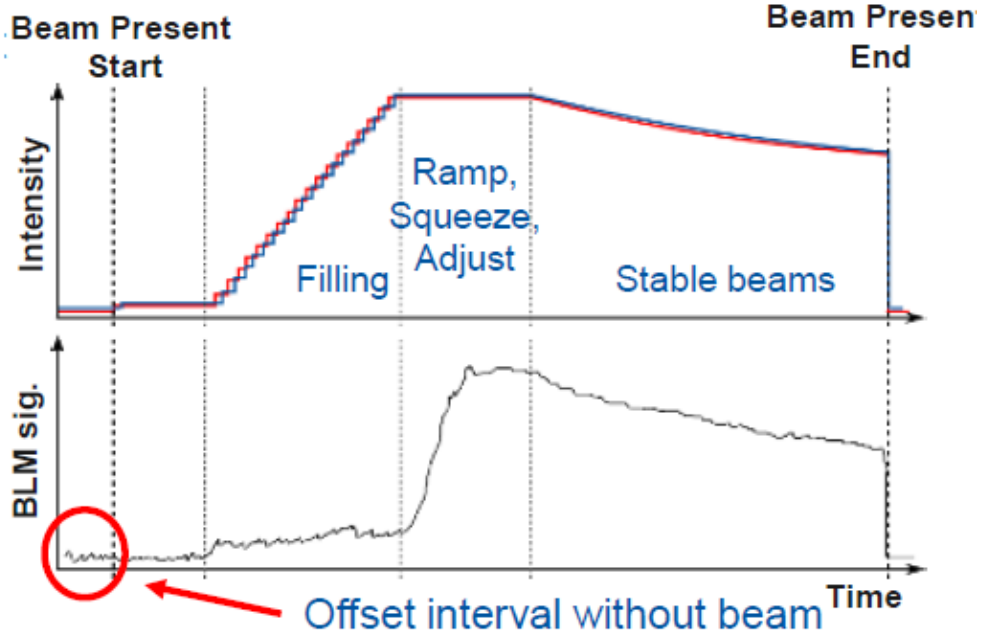
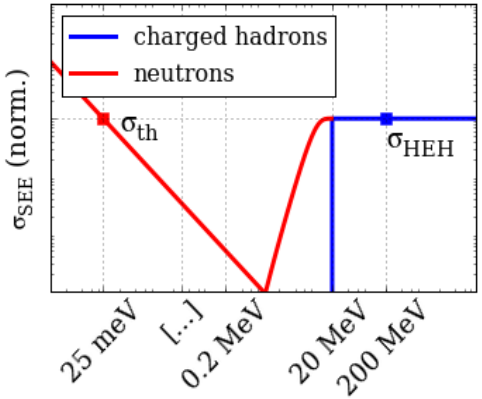
BLM and intensity calculations



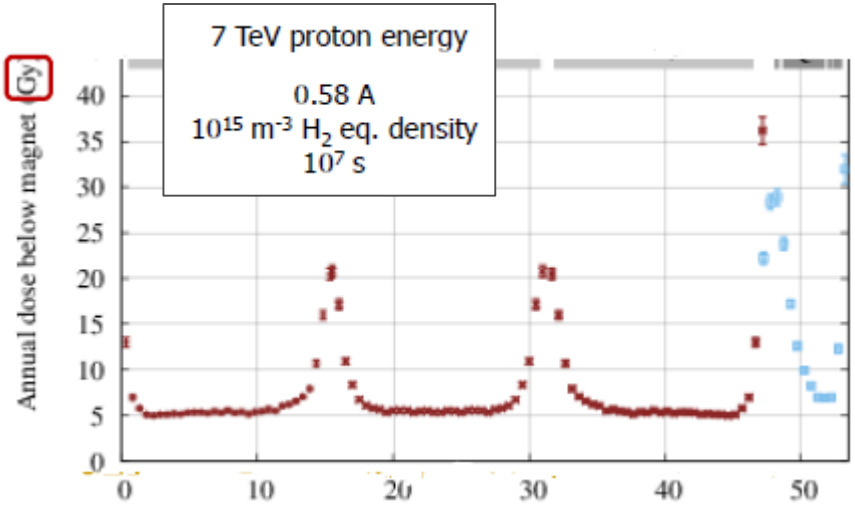
- Contributors: Oliver Stein and Kacper Bilko (MCWG), with support from BLM team
- Dedicated Python workflow for data retrieval and analysis
- Main objective of calculating TID levels along the LHC and normalizing with integrated luminosity/intensity
- BLM offset subtraction, losses per beam mode/operational conditions (on-going), implications on equipment damage (R2E), etc.

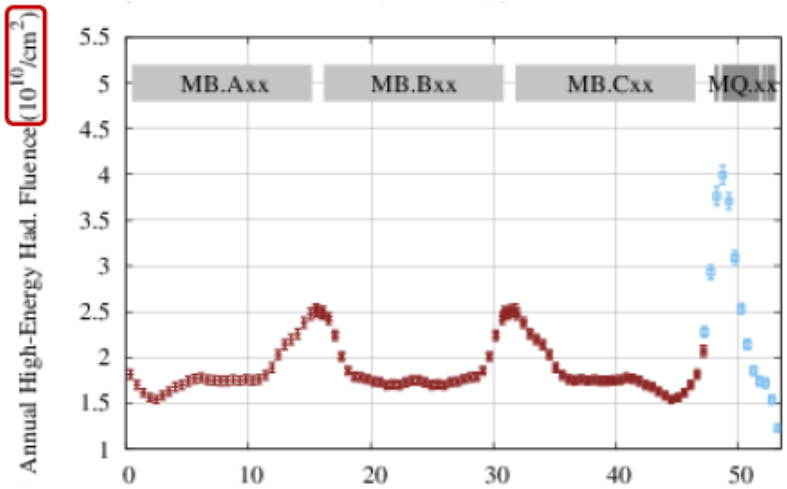
RadMON high-energy hadron fluence measurement

- Capable of measuring quantities relevant to all types of radiation damage: total ionizing dose, 1 MeV neutron equivalent fluence (displacement damage) and high-energy hadron fluence (Single Event Effects)
- Placed 70 cm below the beam (i.e. at rack equipment height) but typically in the interconnects; located in cells 12-20 of LHC ARC, one RadMON per cell; on-line measurements
- RadMON values reported in this presentation correspond to annual HEH fluences
- In the LHC ARC, most 2016/17 measured annual values are ~5×10^7 HEH/cm^2, considered as baseline value



FLUKA calculations for LHC ARC





- Absolute values are factor ~200 larger than measured values due to assumed residual gas density of 10^{15} m^{-3} (actual situation 2-3 orders of magnitude lower)
- Fluence-to-dose ratio in peaks: ~$1 \cdot 10^9$ HEH/cm^2/Gy
- RadMON values of ~$5 \cdot 10^7$ HEH/cm^2 correspond to ~50 mGy

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RadMON HEH fluences during 2016

- 2016 RadMON levels in the ARC:
  - Baseline annual values of ~5×10^7 HEH/cm^2 (corresponding to ~150 mGy on BLM)
  - Table shows **peak values**, defined as 10 times above baseline (in red, more than 100 times larger)
  - Peaks of ~10^{10} HEH/cm^2 correspond to **~10 Gy**
  - RadMONs located in interconnects – at equipment locations below the magnets, we expect ~3 times lower value

Cell	IP1	IP5	IP7	IP8
12	5.2×10^9			
13	*2.7×10^9*	1.3×10^{10} *9.8×10^9*		*9.3×10^8*
14				*1.2×10^{10}*
15	2.2×10^9 *9.2×10^9*	*2.5×10^9*		3.0×10^9
16			6.1×10^8 *4.6×10^8*	9.8×10^8 *1.2×10^9*
17	6.7×10^8 *2.0×10^9*			*8.3×10^8*
18			1.8×10^9	
20				*7.1×10^8*

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RadMON HEH fluences during 2017

- 2017 RadMON levels in the ARC (*):
  - Baseline annual values of ~5×10^7 HEH/cm^2 (corresponding to ~150 mGy on BLM)
  - Table shows **peak values**, defined as 10 times above baseline (in red, more than 100 times larger)
  - Peaks of ~10^{10} HEH/cm^2 correspond to **~10 Gy**
  - RadMONs located in interconnects – at equipment locations below the magnets, we expect ~3 times lower value

Cell	IP1	IP5	IP2	IP8
12	7.3×10^9			
13	*3.1×10^9*	1.6×10^{10} *1.0×10^{10}*		
14				*7.4×10^9*
15	*3.6×10^9*			9.0×10^8
16			*1.1×10^9*	*5.1×10^9*
17	5.0×10^8 *4.0×10^9*			
18				
19			*4.3×10^9*	

(*) IP3 and IP7 data not included

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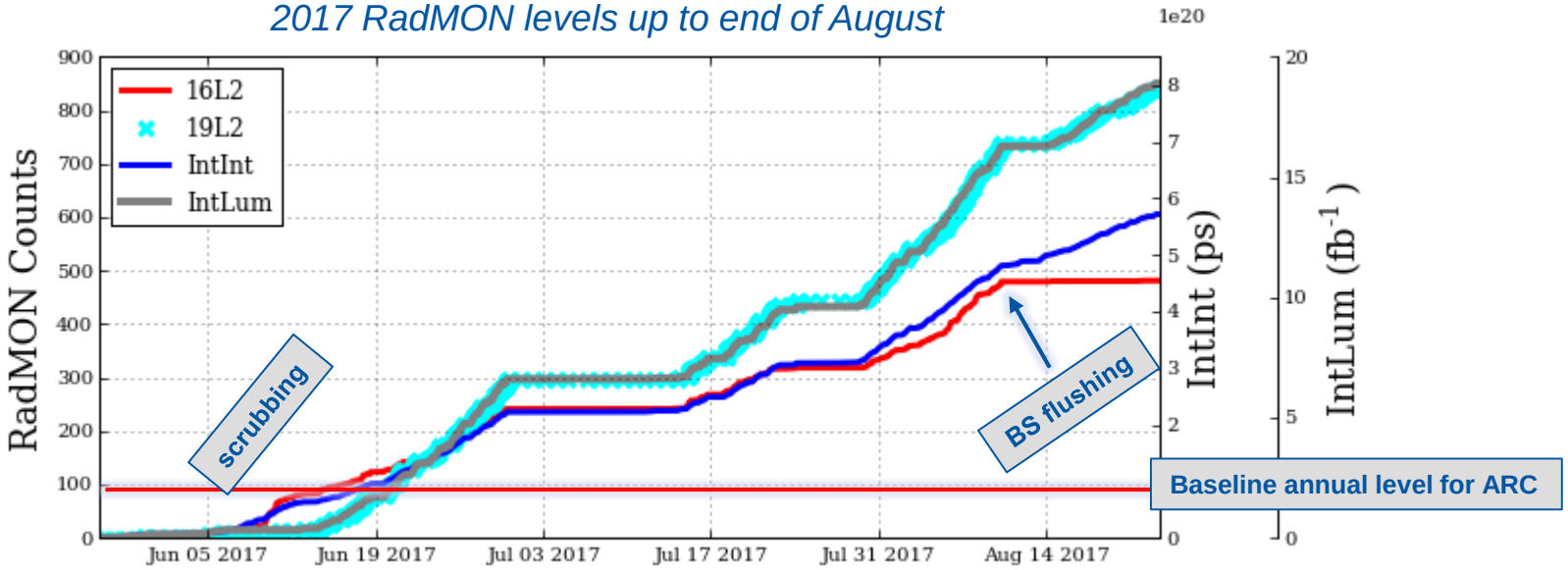
LHC ARC: 16L2 and 19L2

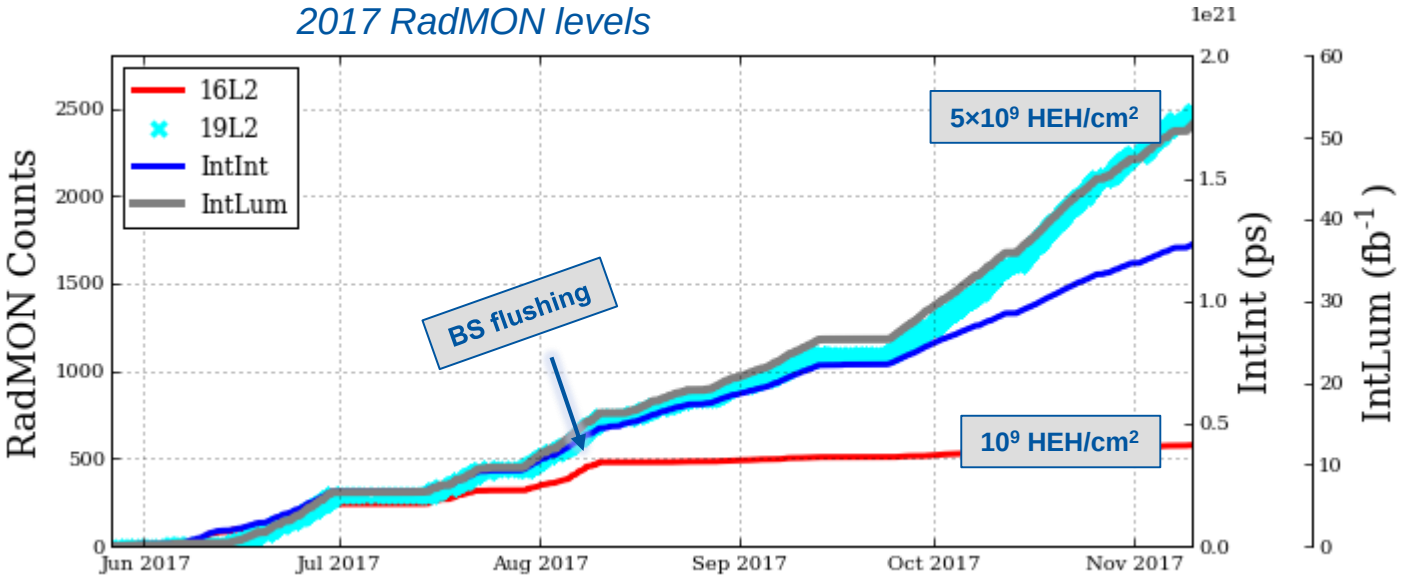
2017 RadMON levels up to end of August



- *Two examples of ARC radiation level peaks: 16L2 (intensity driven) and 19L2 (luminosity driven)*
- *16L2 losses already significant during scrubbing; steady-state losses disappeared (i.e. compatible with baseline level) after BS flushing (compatible with BLM observation)*

LHC ARC: 16L2 and 19L2

2017 RadMON levels



- *Radiation levels in 16L2 (19L2) in 2017 were a factor 20 (100) larger than baseline value*
- *Just two examples of arc peaks → currently under further investigation with focus on equipment impact*
- ***Main message: luminosity-driven annual dose peaks of ~10 Gy can appear even deep in the arc***

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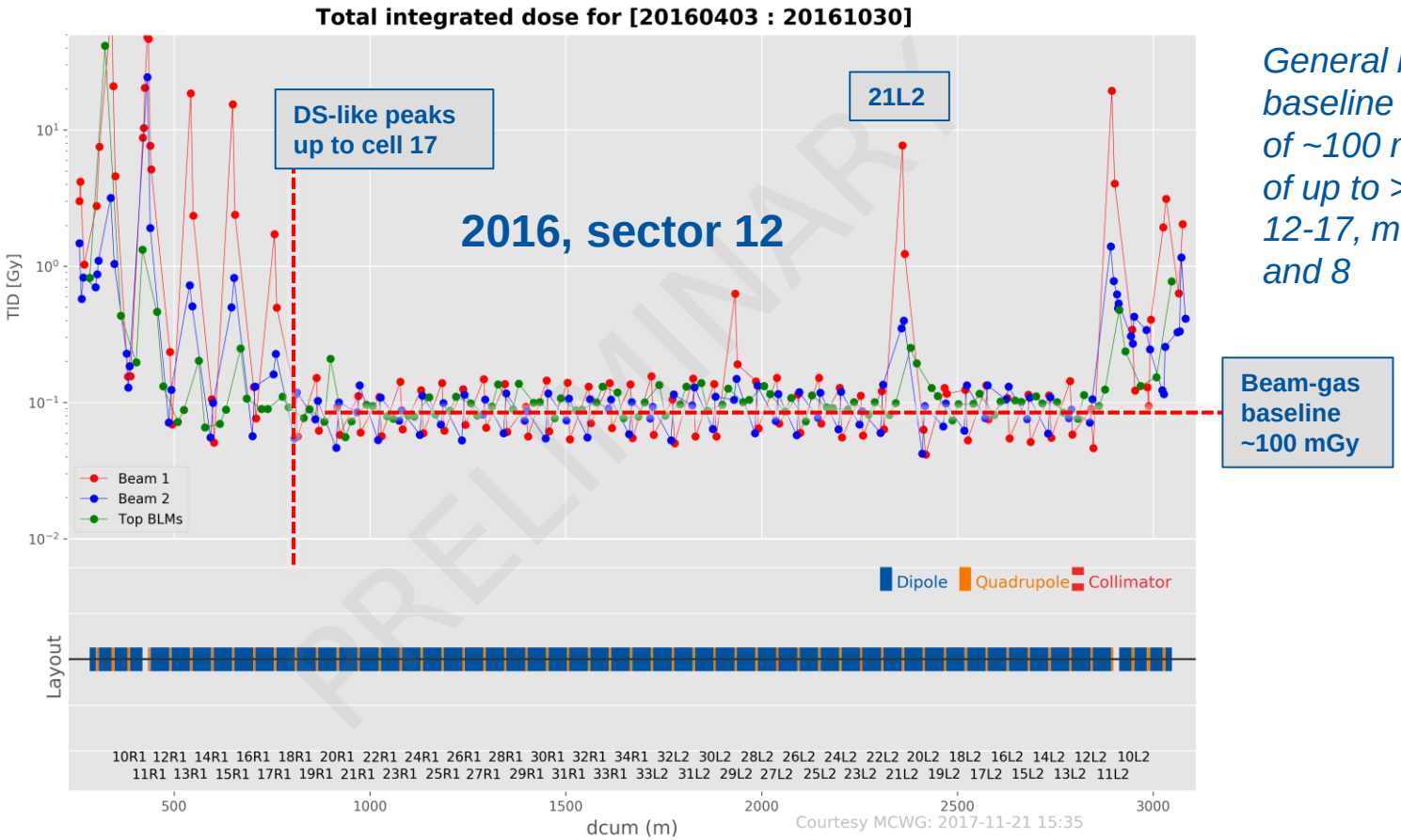
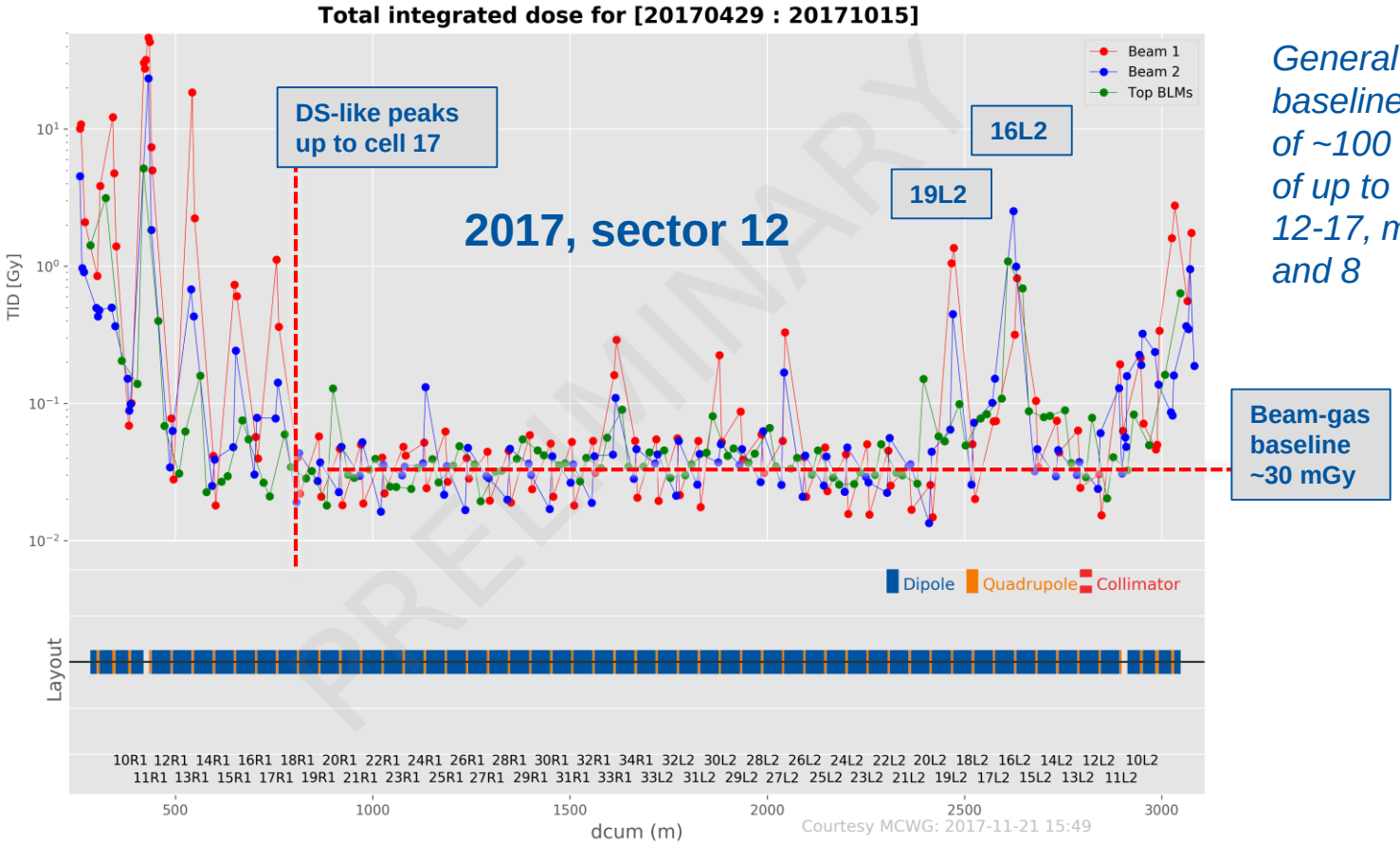


General behaviour: baseline annual values of ~100 mGy, plus peaks of up to >10 Gy in cells 12-17, mainly in IP1, 5 and 8



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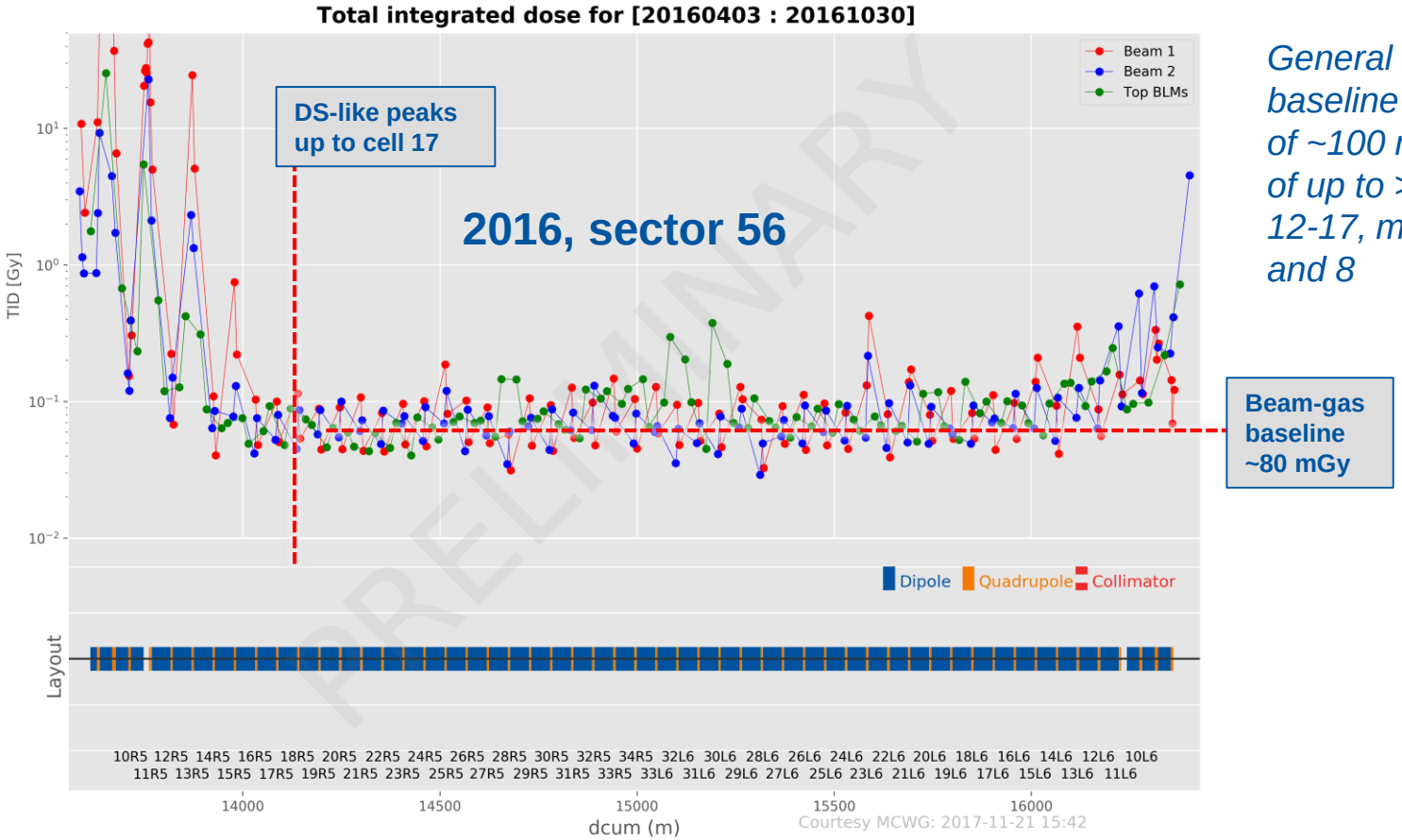

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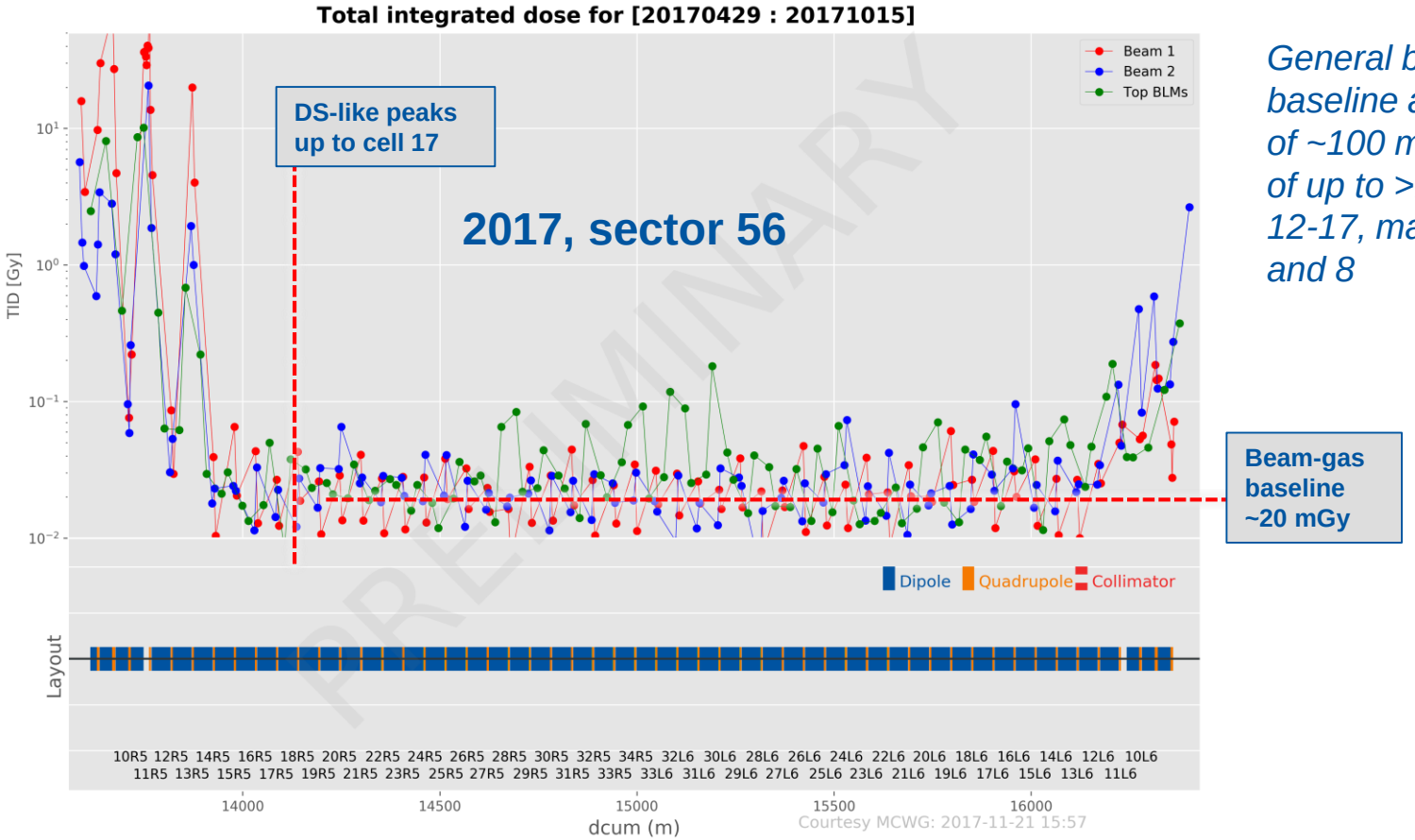

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Expected radiation level evolution for HL-LHC

- Beam-gas baseline levels expected to scale with integrated intensity (factor ~4 larger HL-LHC annual value with respect to 2016/17) and residual gas pressure
- Considering baseline of worst-case sectors for 2016/17 and scaling with intensity and a safety margin of 10 related to residual beam gas leads to HL-LHC annual values of **~1 Gy/year** on equipment → **OK for present 60A lifetime**
- However, peaks of **>10 Gy/year**, mainly in (but not limited to) IP1, 5 and 8 and cells 12-17, and potentially scaling with luminosity, are certainly a **TID lifetime threat** (not only for 60A equipment)

Conclusions & Outlook

- Possible R2E/EPC approach for HL-LHC 60A converters:
  - development of 60A power brick based (when possible) on qualified components; qualification at system level, and to serve also as building block for 120A
  - production of 60A redundant converters for cells 12-17; LS3 deployment and use of removed units as spares
  - active monitoring of radiation levels on 60A converters and preventive rotation/substitution (challenging coverage due to distributed nature of system)
- Present lifetime estimation based on two measurements could be significantly improved by testing several (i.e. at least 3) systems in the CHARM mixed-field facility
- New 60A design could require new Bri/Tri volt PSU for FGC, thus also potentially needing a rad-tol development
- Important to consider aspects not directly related to radiation, e.g. part obsolescence, other type of degradation/lifetime constraints, availability of spares