Update on the expected radiation levels for HL-LHC

WP10
Energy Deposition & R2E

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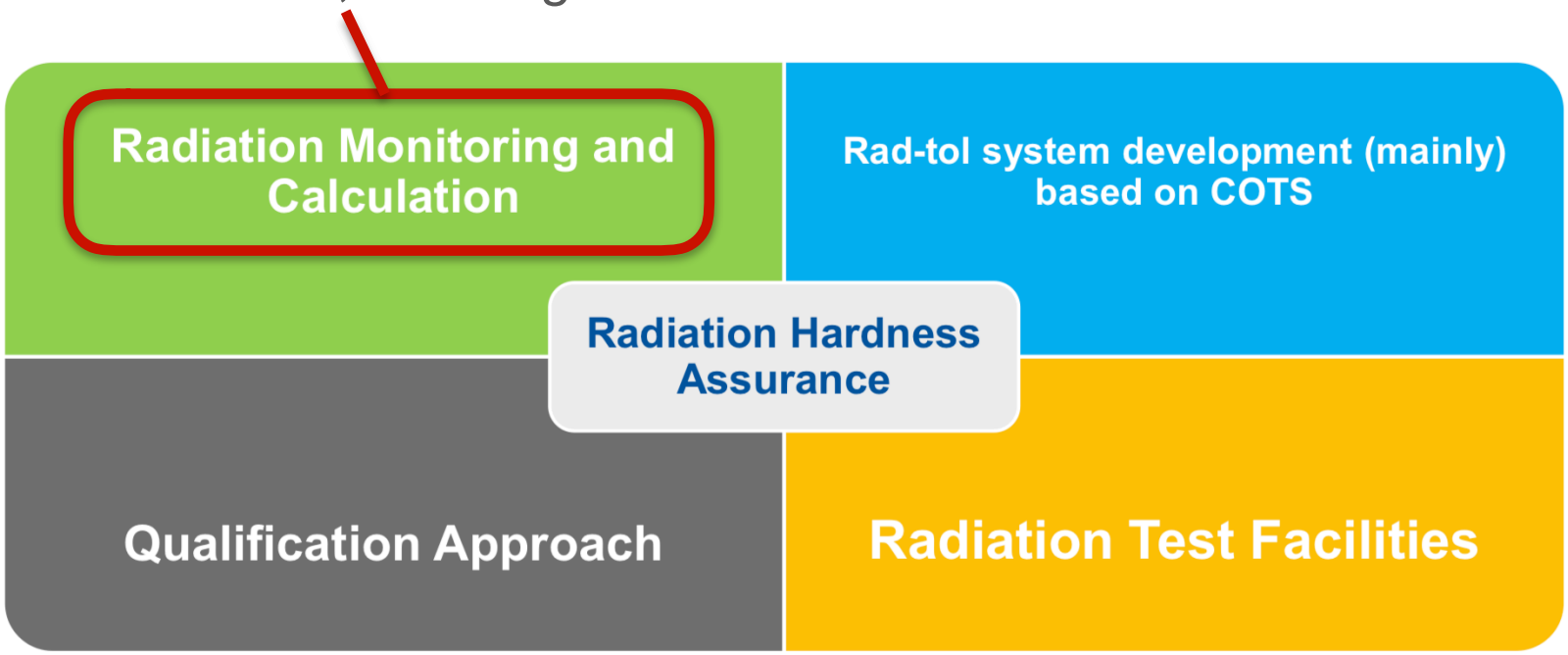
8th HL-LHC Collaboration Week, 17 October 2018

Outline

- Followup of the material presented in the 2017 HL-LHC Collaboration meeting by R.García (link1, link2).
- Content:
  - Monitoring and calculation of radiation levels in the context of the Radiation Hardness Assurance (RHA) procedure.
  - Levels in the IR1-IR5 DS in tunnel and RR areas, and impact of the collimator settings.
  - Impact of radiation on cold bypass diodes in IR1-IR5.
  - Levels during Pb-Pb operation in IR1-IR2-IR5.
  - Levels in IR3-IR7 and integrated beam intensity scaling.
  - ARC levels.
  - Conclusions and outlook.

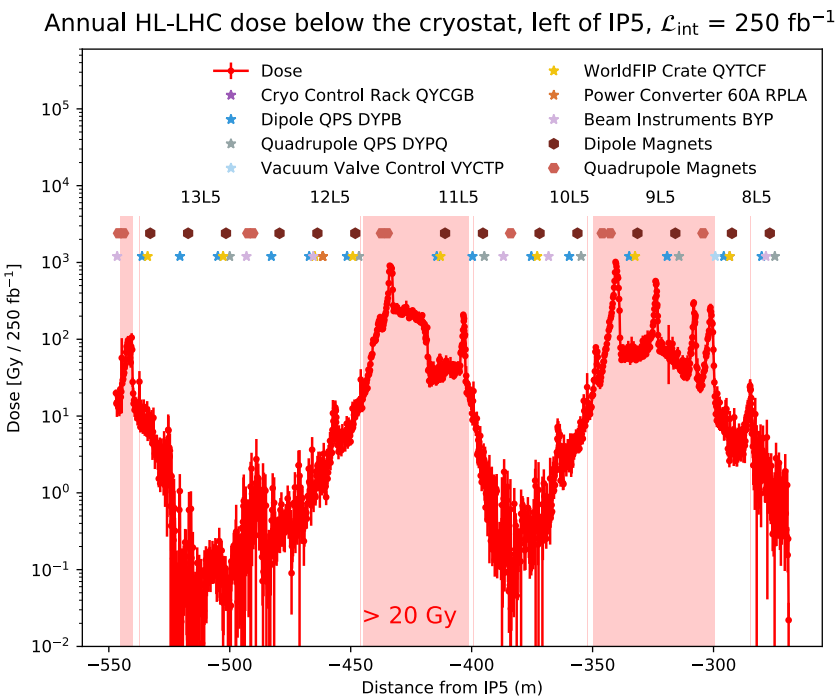
Radiation Hardness Assurance

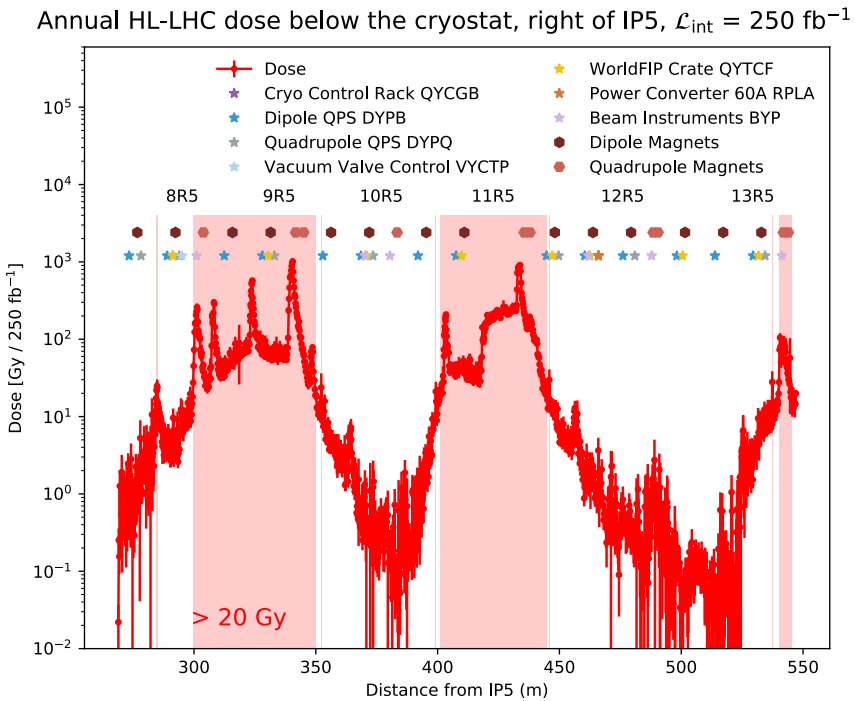
- A Radiation Hardness Assurance procedure has been defined in order to involve R2E from the initial design phase of the relevant electronic systems for HL-LHC.
- More on this in R.García's presentation tomorrow afternoon.
- This talk gives an overview of the expected HL-LHC radiation environment, focusing on the most critical locations for R2E.



HL-LHC simulations of IR1-IR5 DS levels

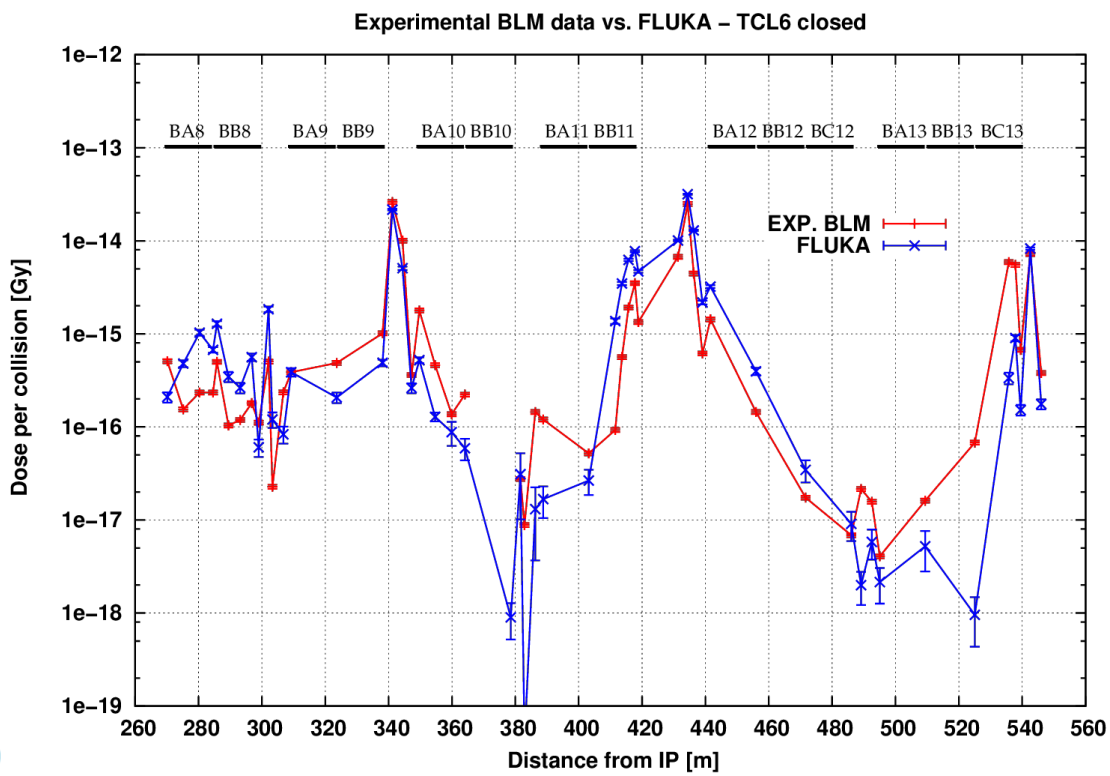
- Fluka simulation of HL-LHC annual (250 fb^{-1}) dose below the cryostats in the IR5 DS (IR1 in backup) and presently installed racks.
- Nominal HL-LHC config with TCLs 4-5-6 closed (all at 14σ). The profile can change if the settings are modified.
- Possible relocations/rotations of electronic racks to be discussed with equipment groups and WP15.





Impact of TCL settings on the IP1-5 DS levels

- In Run 2 the LHC operated both with TCL6 open and closed:
  - TCL6 open → More radiation in cell 8, less in the RRs.
  - TCL6 closed → Less radiation in cell 8, more in the RRs.
- More detail in MCWG talk. Similar effect expected in HL-LHC.
- Note that the Fluka simulations are robust, as verified for Run 2:

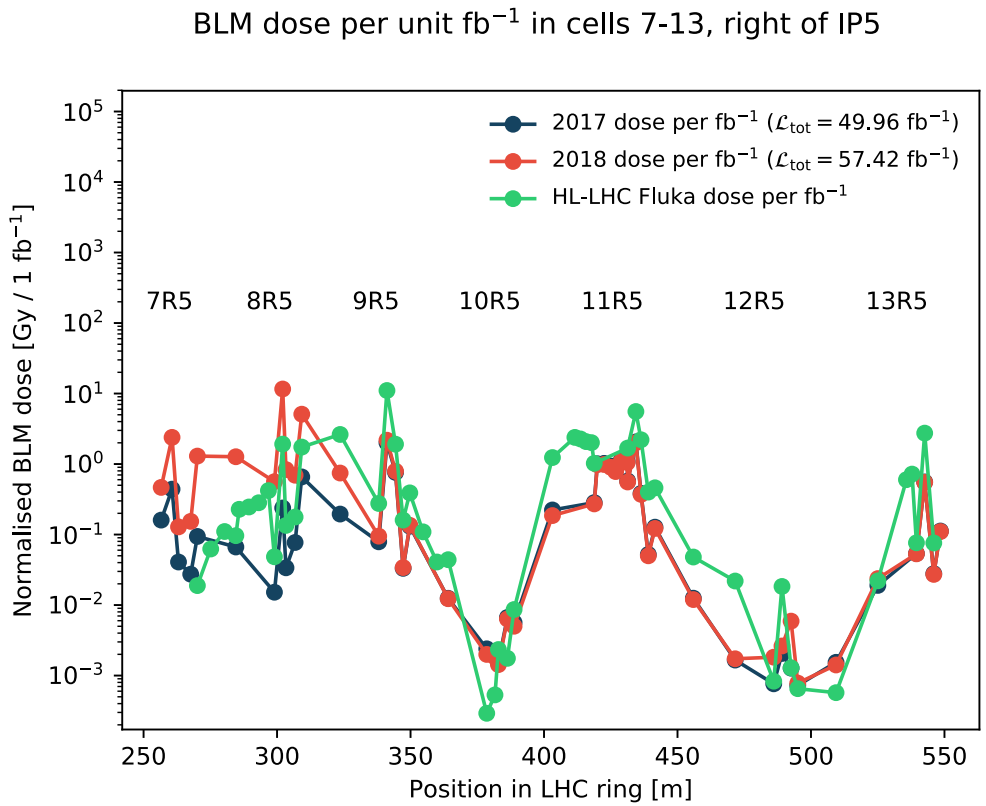


BLM data vs Fluka in IR5 for fill #5401 (October 2016) TCLs @ 15-35-20 σ

Plot extracted from IEEE publication: DOI 10.1109/TNS.2017.2776107

Impact of TCL settings on the IP1-5 DS levels

- The HL-LHC Fluka simulation (with TCL6 closed) can be compared to the 2017 (TCL6 closed) and 2018 (TCL6 open) BLM data, analysed with the MCWG framework (see backup).
- Main indication: higher dose per unit fb^{-1} in cell 8 in 2018.

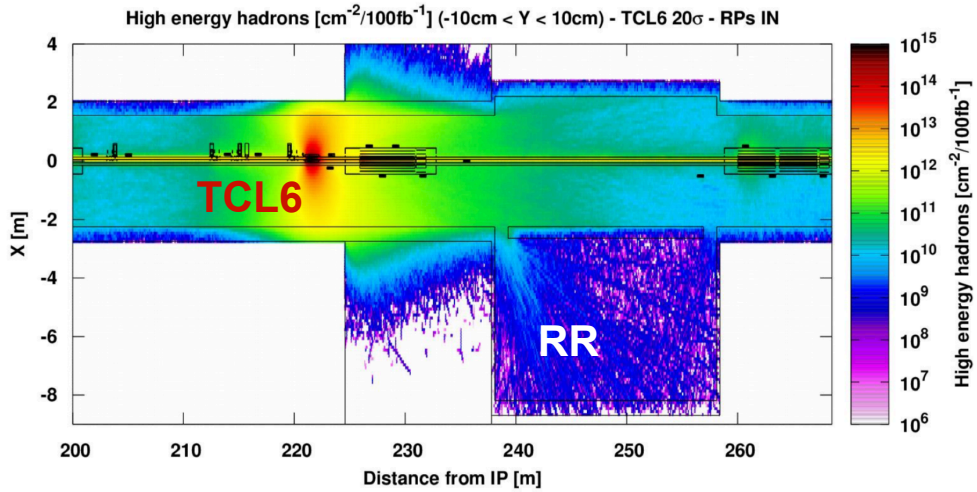


- 2018 can be seen as 'worst-case' scenario for the dose per unit fb^{-1} in cell 8.
- The total HL-LHC dose depends on the integrated luminosity (baseline: 250 fb^{-1} per year)

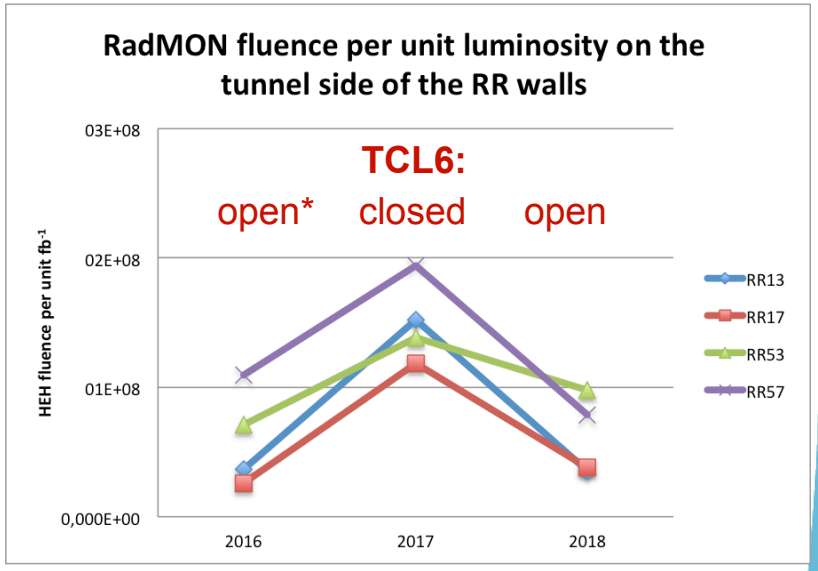
Radiation levels in the IP1 and IP5 RRs

- TCL6 “cleans” cell 8, but in parallel it increases the RR levels.

Roman pots in, TCL6@20σ



Plot by A.Tsinganis, see talk at 226th LHC Collimation WG

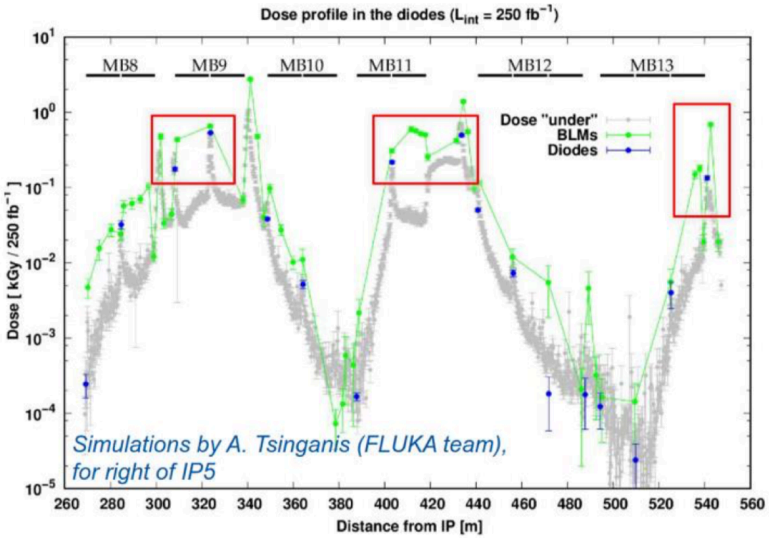


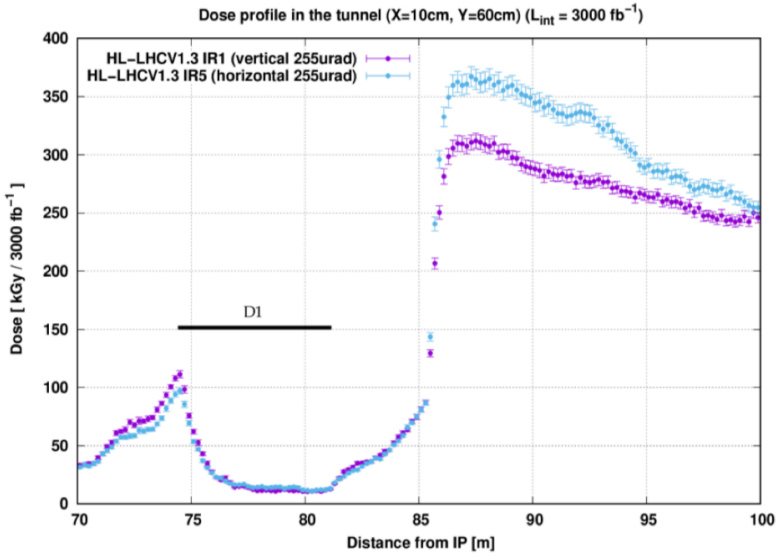
*closed for short periods in P5

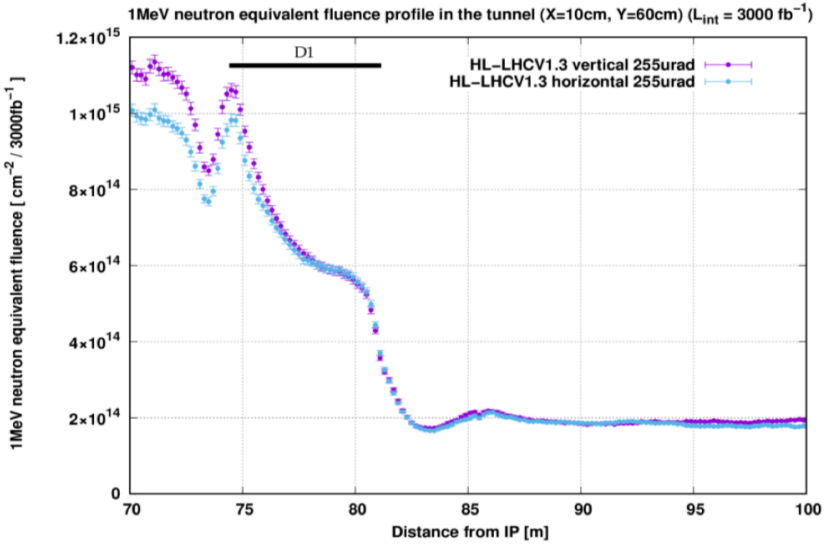
- TCL6 closed increases the levels on the external RR walls by a factor 1.5-5. Smaller increase inside the RR.
- Mitigation measures for HL-LHC to operate with TCL6 closed: extra shielding close to the TCL or at the RR entrance (under exam), rad-tolerant design of the equipment after LS2.

LHC cold diodes: present and new layout

- Cold bypass diodes for magnet quench protection. Existing ones in the DS: ok up to LS2, higher levels expected in HL-LHC.
- New diodes for inner triplets: levels strongly depend on z position (minimum at ~80-85m from IP).
- More in other talks (link1, link2).

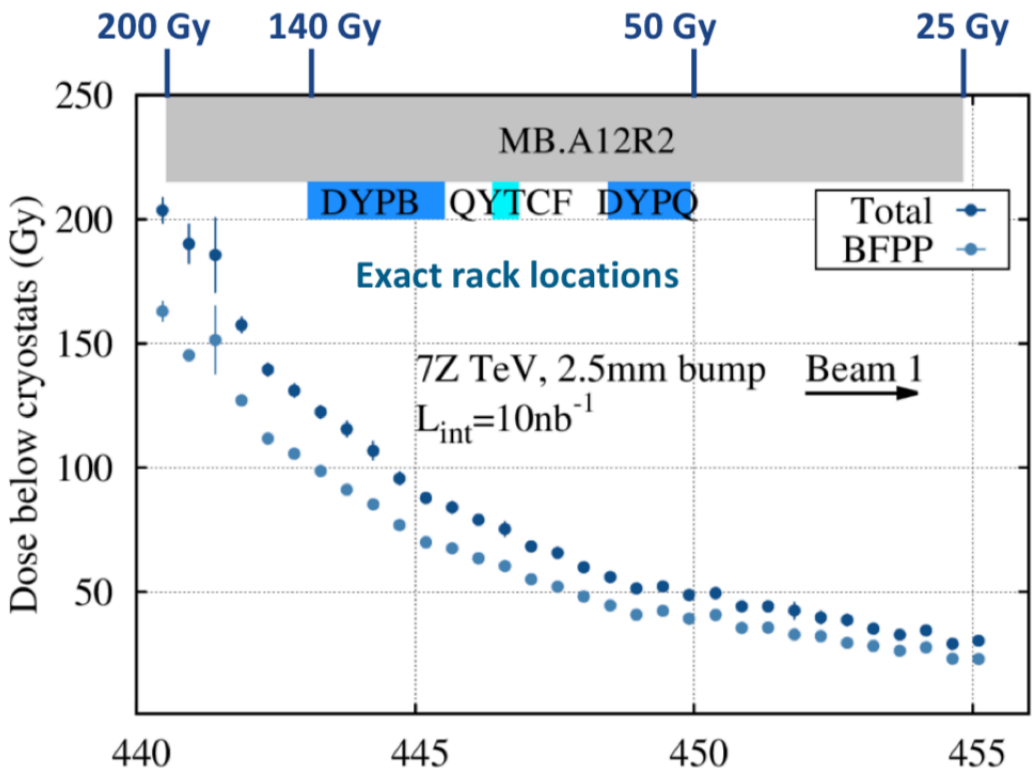






Ion operation in IR2

- Localised dose peak caused by Bound Free Pair Production (BFPP) and electromagnetic Dissociation (EMD) processes, requiring a new collimator to be installed during LS2 to protect the magnets from quench risks.
- The new collimator results in a dose peak in cell 12:



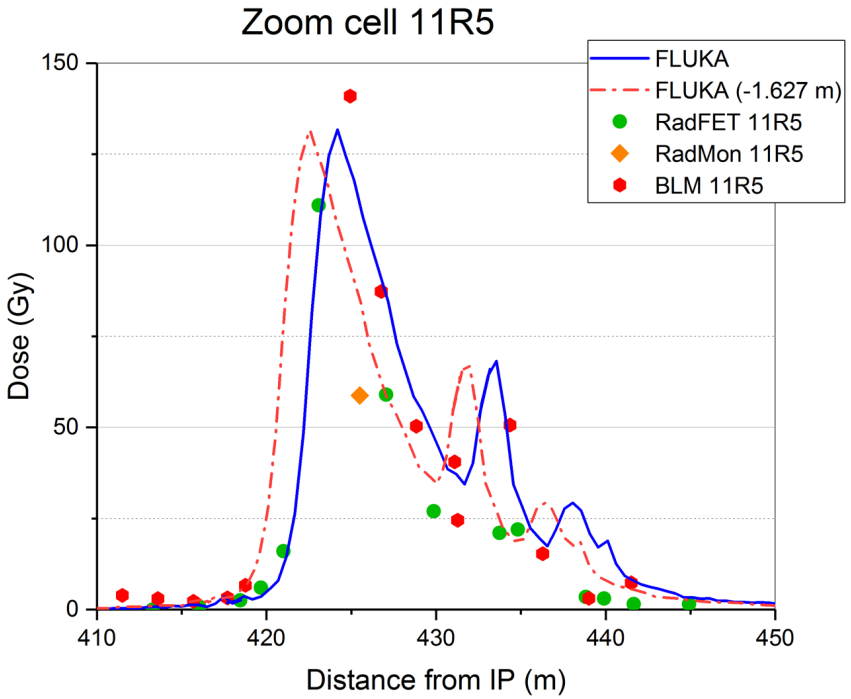
Fluka simulation of BFPP and total ion dose normalised to 10 nb^{-1} (full HL-LHC Pb-Pb dataset)

Plot by C.Bahamonde from presentation at 14th HL-LHC TCC meeting

Ion operation in IR1-IR5

- 10 nb^{-1} of Pb-Pb data are planned also in IP1-IP5 for after LS2, with similar impact of BFPP and EMD processes.
- No major machine changes → The 2015 Pb-Pb run (~0.7 nb^{-1}) can be used as benchmark for HL-LHC predictions.

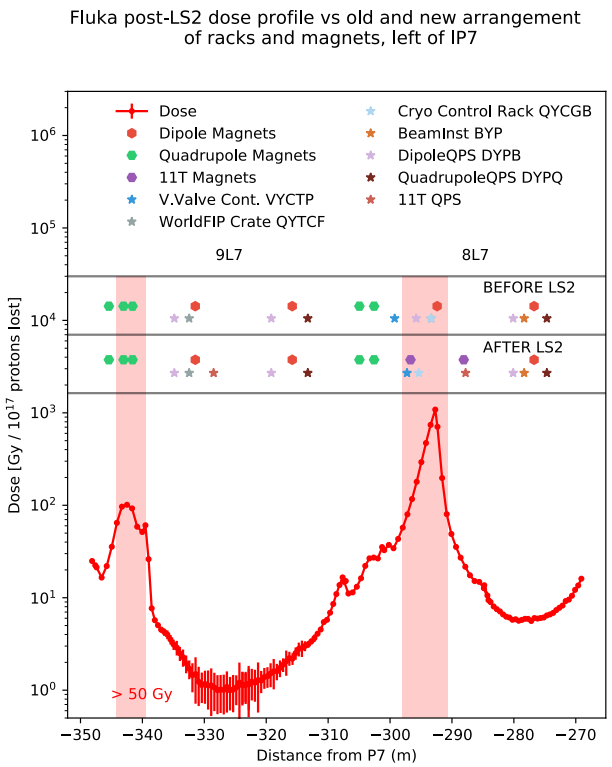
- Good agreement between data and Fluka simulations.
- Dose peak at ~425m from IP5 (similar in IP1), to be scaled up by a factor ~15 to obtain HL-LHC predictions.
- The upcoming Pb-Pb run (~1 nb^{-1}) will be used to further verify these results.

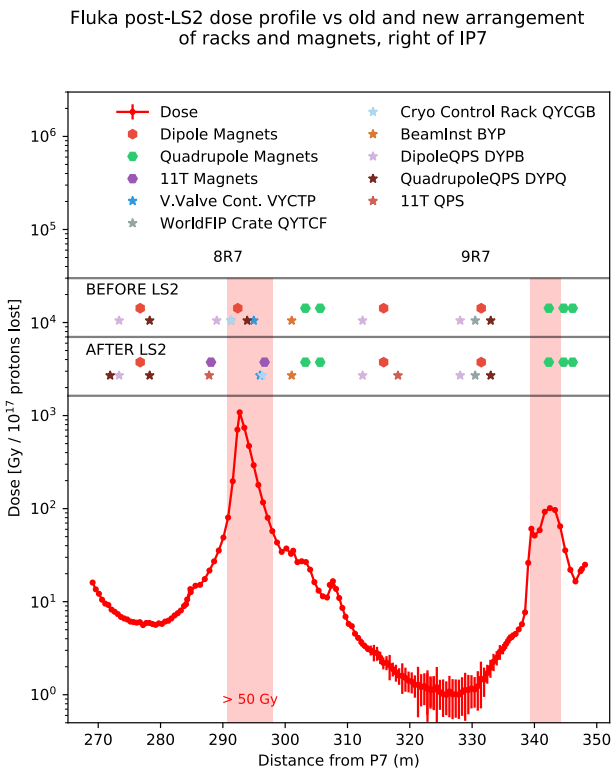


C.Martinella et al., "Radiation levels at the LHC during the 2015 Pb-Pb and 2016 p-Pb Runs and mitigation strategy for the electronic systems during HL-LHC operation", submitted as ATS note

Dose levels in IR7 after LS2

- Main source of radiation: losses in the primary IR7 collimators.
- Main layout upgrade: 11T magnets and TCLD collimators.
- Post-LS2 Fluka simulations normalised to 10^{17} lost protons (full HL-LHC lifetime). More on the normalisation in the next slides.

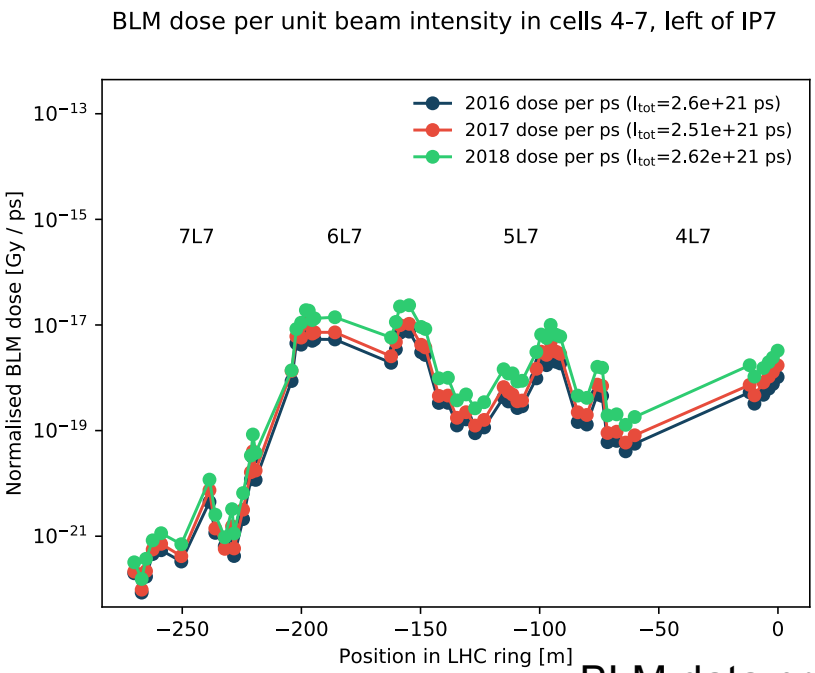


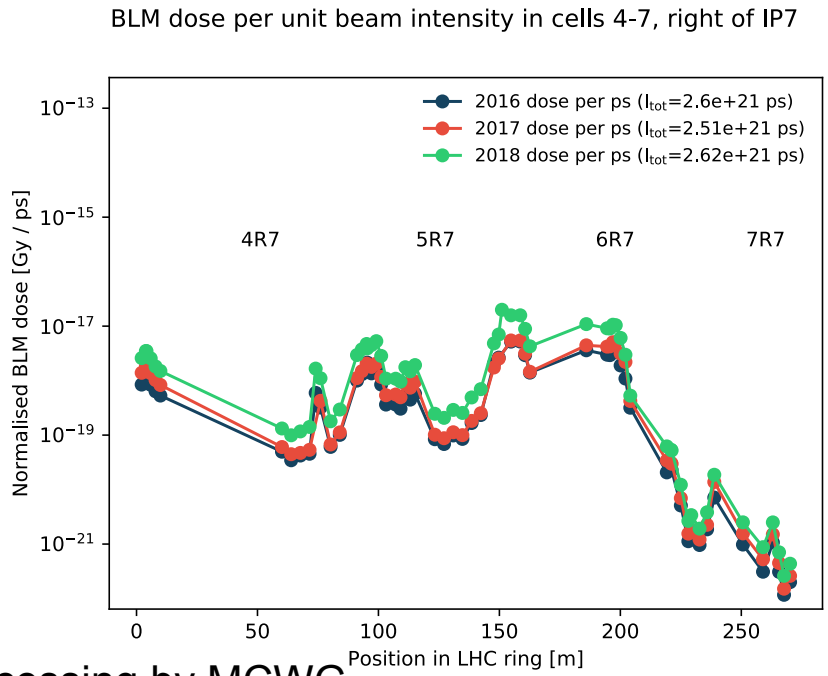


- Dose peak in cell 8 caused by the TCLD.
- Several hundreds Gys on the nearby racks (vacuum, cryo, 11T QPS): more detail in [11T installation report](#).

IR7 dose scaling in Run 2

- The estimate of 10^{17} lost protons in IR7 in HL-LHC is based on the assumption that the losses in the primary collimators scale with the integrated beam intensity (talk by R.García last year).
- However in 2018 the IR7 dose per unit integrated intensity increased by a factor ~3 (more detail here and here) → impact of different machine operating conditions to be examined.

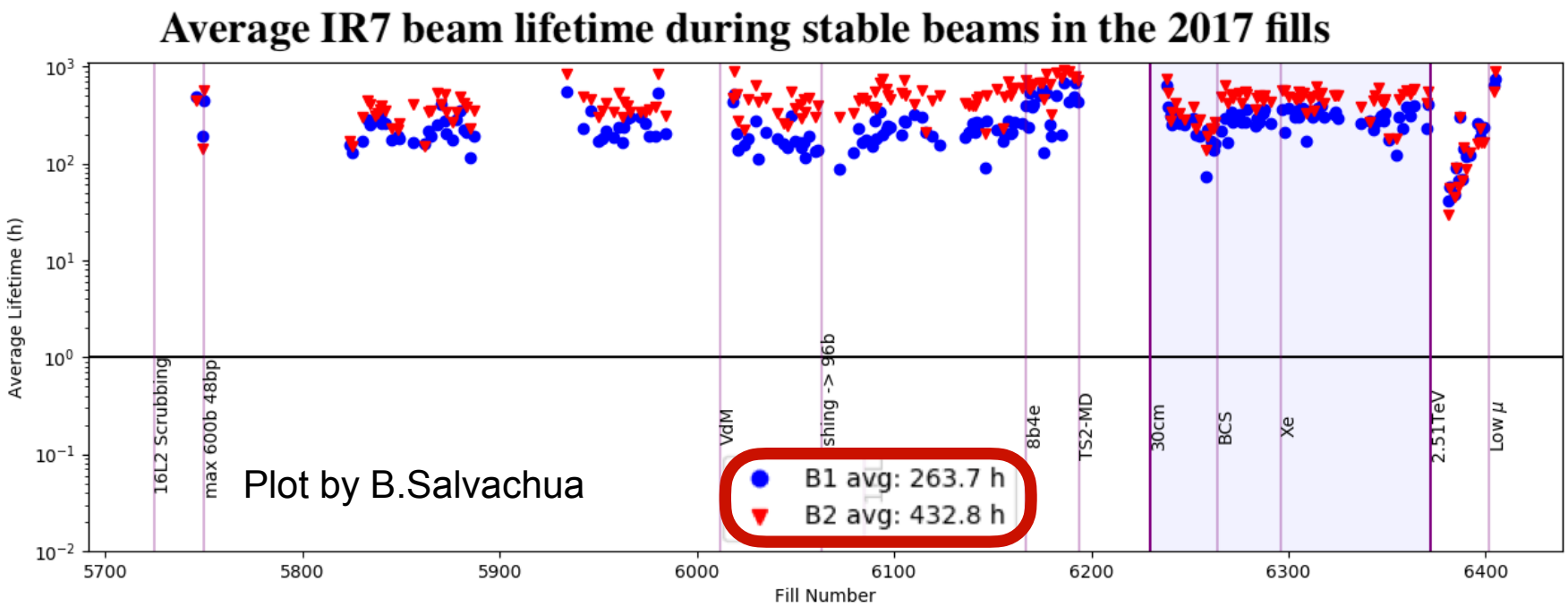




BLM data processing by MCWG

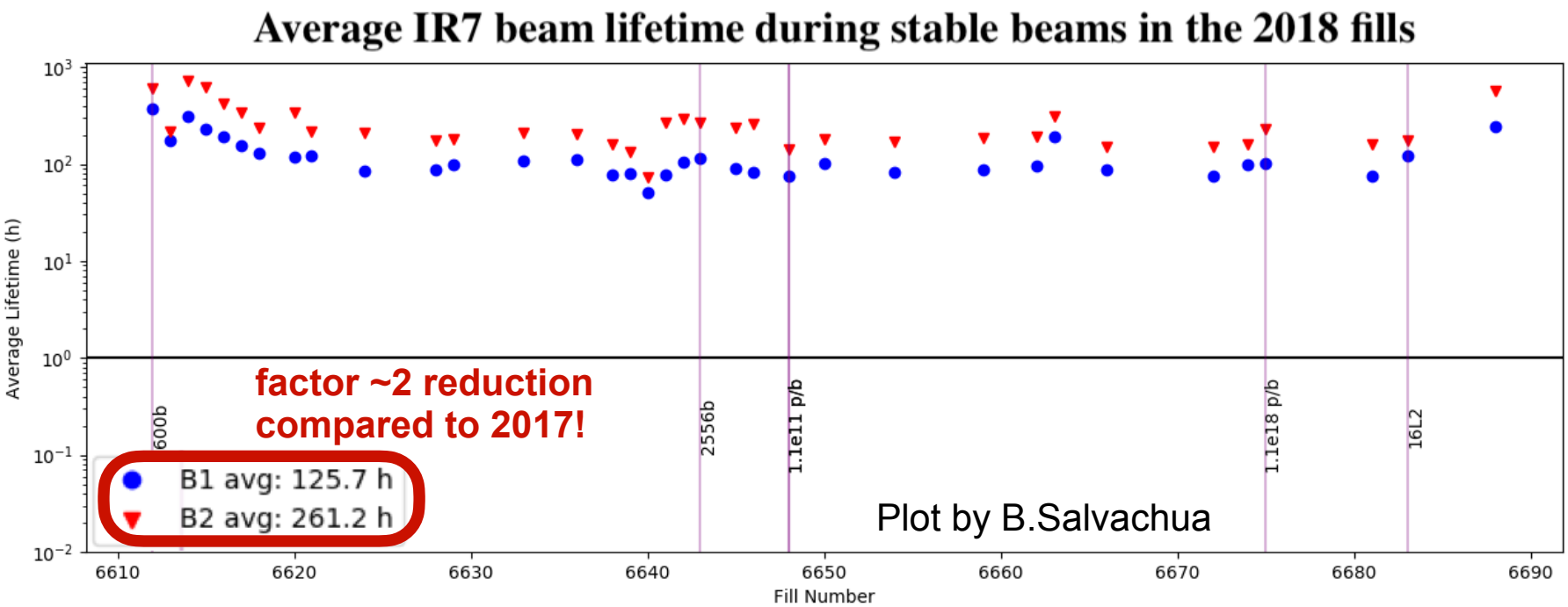
Dose levels in IR7 and beam lifetime

- The IR7 dose is proportional to the number of lost protons in the primary collimators, so it (anti) correlates with the beam lifetime.
- Indeed, the IR7 beam lifetime (lumi burn-off subtracted) can be measured with the BLMs by employing a dedicated calibration (see B.Salvachua's presentation). For 2017:



Dose levels in IR7 and beam lifetime in 2018

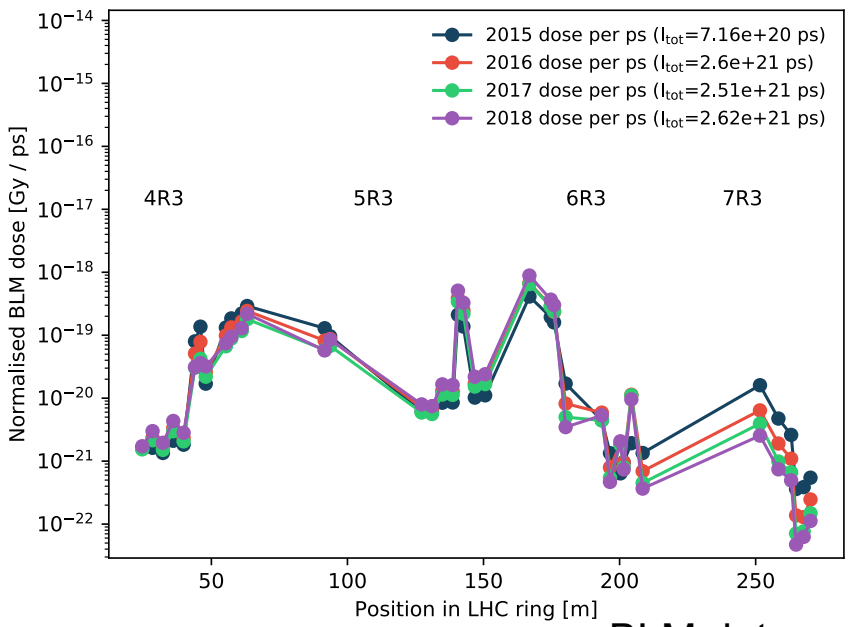
- Lower lifetime during stable beams in 2018, due to crossing angle levelling and smaller β^* (see also G.Iadarola's talk).
- The different lifetime 'spoils' the integrated intensity scaling.
- The 2018 conditions may be more representative of HL-LHC → IR7 scaling to be reassessed involving WP2-WP5.



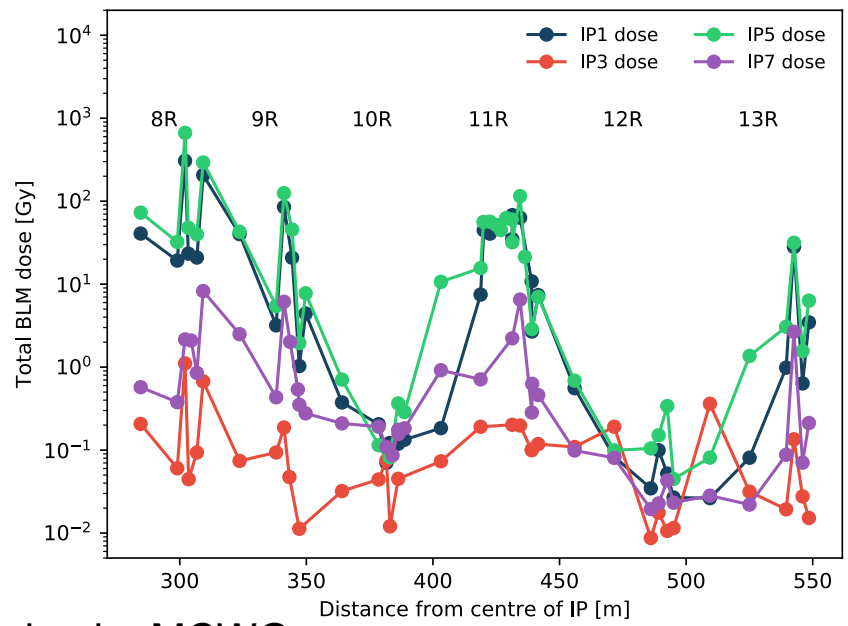
Dose levels in IR3

- The scaling with integrated beam intensity is instead robust in IR3 (bottom-left plot, showing the LSS section right of IP3).
- In addition to this, the annual DS levels in IR3 are significantly lower compared to the DS of IR1, IR5 and IR7 (bottom-right plot, 2018 data right of each IP).

BLM dose per unit beam intensity in cells 4-7, right of IP3



2018 BLM dose in cells 8-13, right of each IP

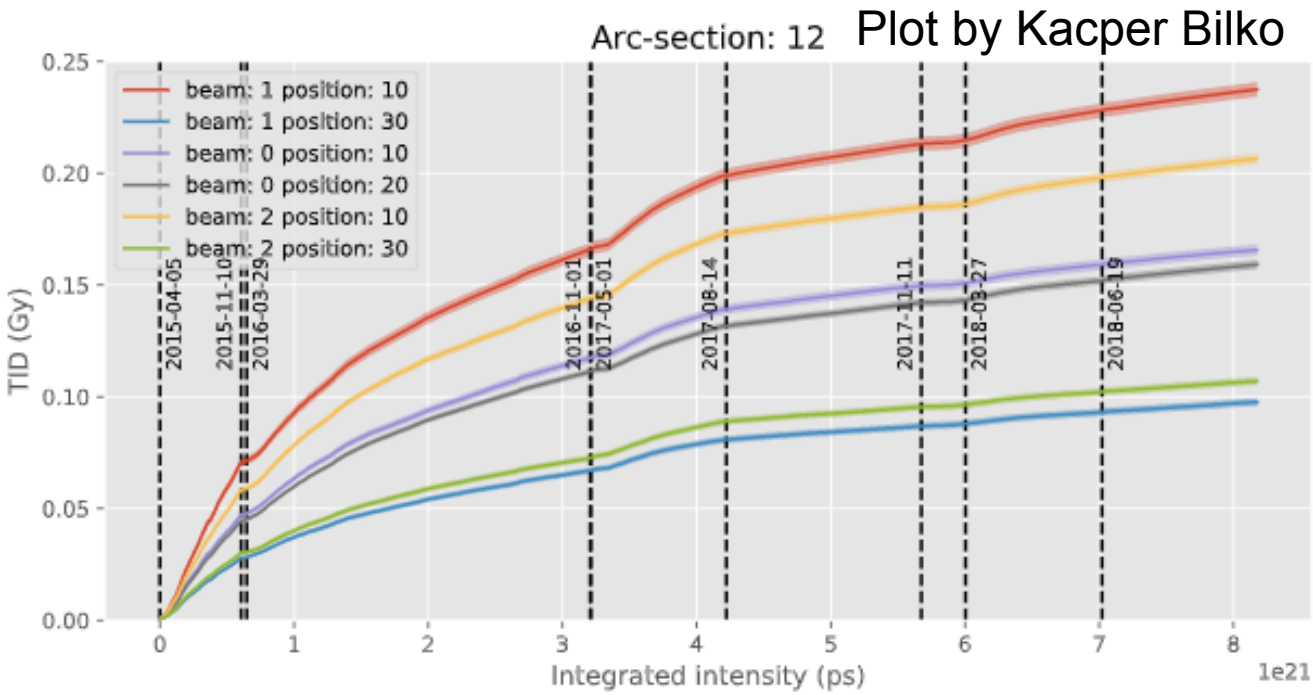


BLM data processing by MCWG

Dose levels in the ARCs

- The average dose in the ARCs (excluding peaks) is expected to be proportional to the integrated beam intensity, but it also depends on the beam-gas pressure.
- Indeed, during Run 2 the BLM dose per unit integrated beam intensity has decreased over the years.
- Average BLM dose in Run 2 below 0.25 Gy for all BLM types.

- The HL-LHC dose will depend on the evolution of the beam-gas pressure, but the absolute levels should remain low in terms of radiation damage to the electronics.



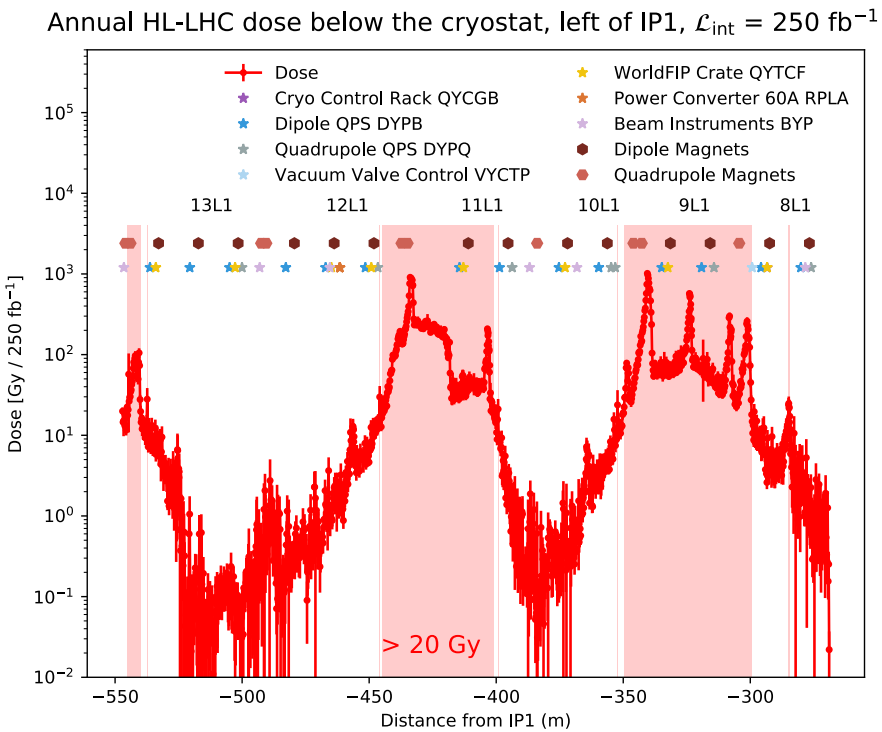
Summary and outlook

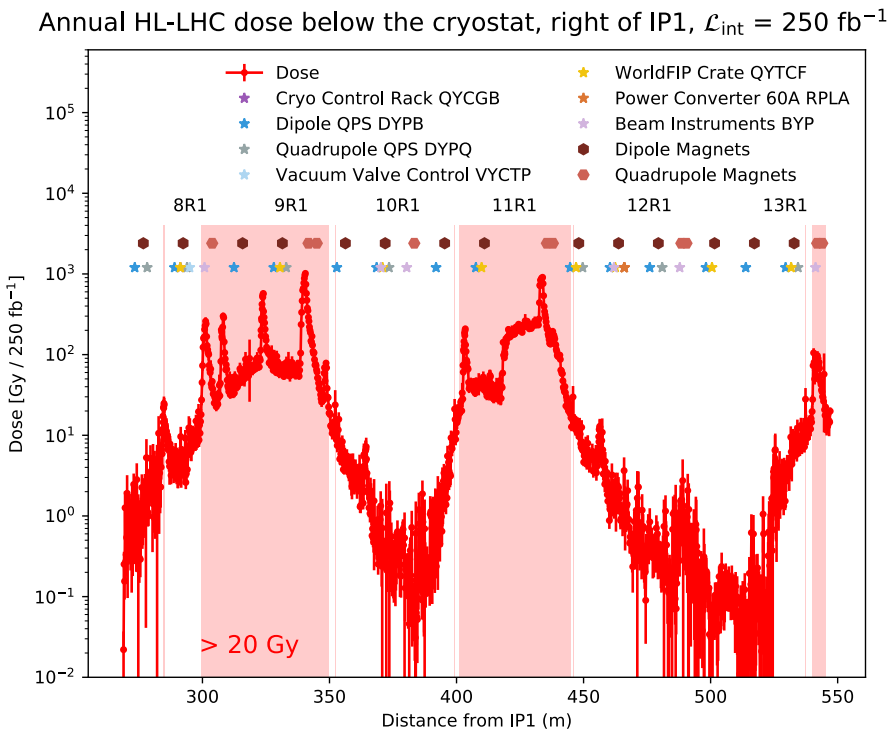
- I presented the expected HL-LHC radiation levels in the most critical locations for R2E:
  - IR1-IR5 during pp operation, discussing the impact of the TCL settings and the case of the cold diodes.
  - IR1-IR2-IR5 during Pb-Pb operation.
  - IR3-IR7 and dose scaling with integrated beam intensity.
  - ARCs.
- Uncovered locations:
  - Injection lines (TI2 and TI8) both inside the injection tunnels and at their end (UJ22-23 and UJ87-88).
  - IR8 (LHCb) - lower luminosity compared to IR1-IR5.
  - Other IRs (4,6) with significantly lower radiation levels.
- Lots of ongoing activities: stay tuned for more results to come!

BACKUP

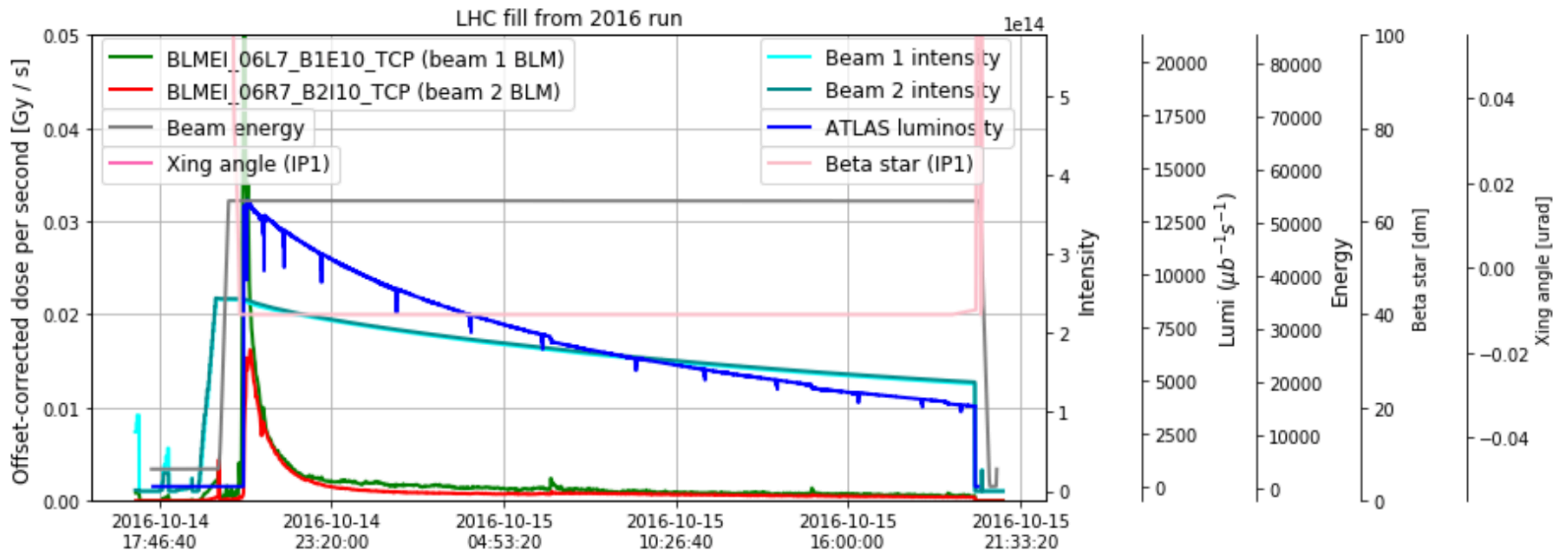
HL-LHC dose levels in IP 1

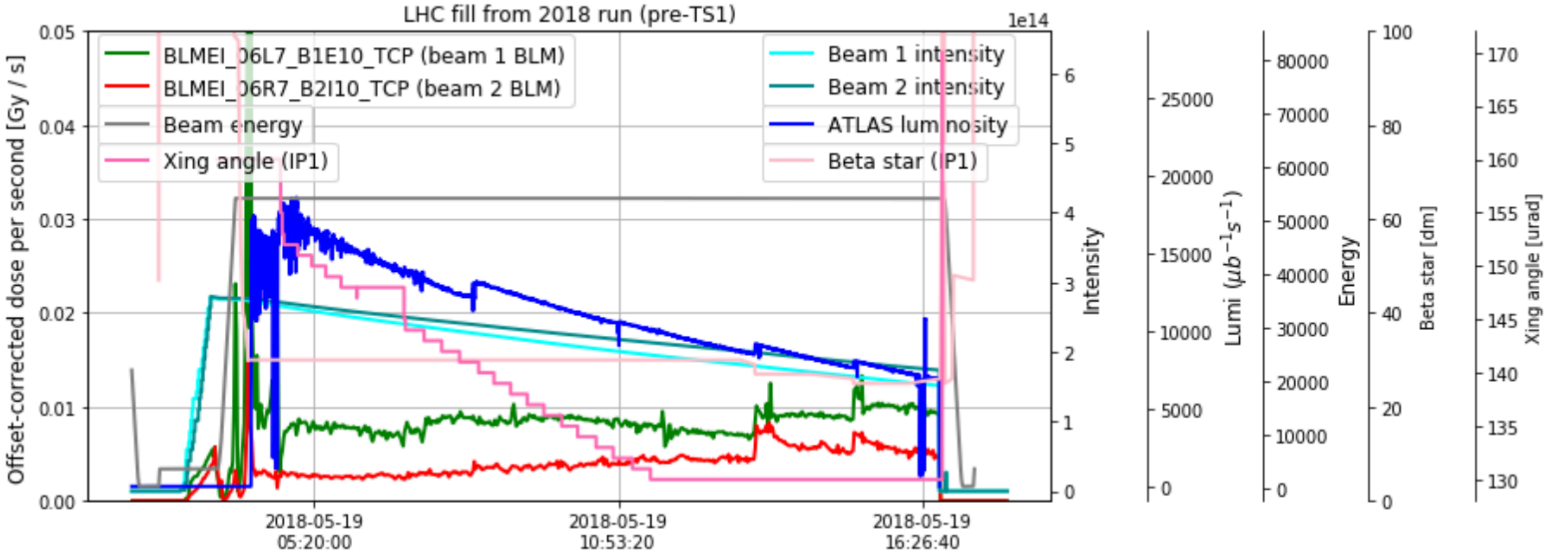
- Radiation profile in the DS and current IP1 rack locations.
- Note that the simulation is the same as the one used for IP5.





2016 vs 2018 fill comparison with IR7 BLM dose





HEH fluence in the RRs of P1, P5 and P7

- Total fluence measured in 2016, 2017 and 2018 (up to TS2) by the RadMONs on the tunnel side of the RR walls (OUT) and by the RadMONs inside the RRs (IN).

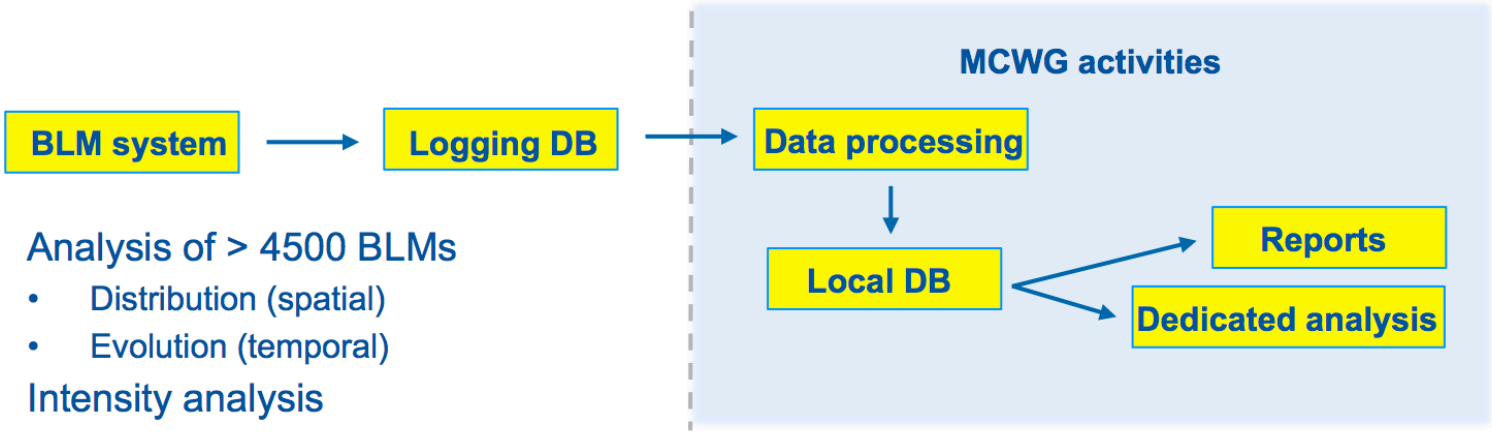
		HEH fluence in RadMONs (cm^{-2}/y)		
		2016	**2017**	**2018***
RR13	OUT	1,4E+09	7,7E+09	1,9E+09
	IN	4,2E+07	2,4E+08	1,3E+08
RR17	OUT	1,0E+09	6,0E+09	2,0E+09
	IN	5,4E+07	3,9E+08	1,3E+08
RR53	OUT	2,9E+09	6,9E+09	5,3E+09
	IN	1,2E+08	3,5E+08	3,0E+08
RR57	OUT	4,5E+09	9,7E+09	4,3E+09
	IN	1,6E+08	3,5E+08	2,7E+08
RR73	OUT	2,0E+09	2,5E+09	7,6E+09
	IN	1,6E+07	1,8E+07	7,2E+07
RR77	OUT	8,5E+08	9,3E+08	2,4E+09
	IN	1,2E+07	1,4E+07	2,8E+07

*up to LS2 (mid-September)

MCWG framework for BLM analysis

- Scheme extracted from K.Bilko's presentation at 34th MCWG meeting:

Goal: Using the BLM data for calculating the dose distributions along the LHC.



Analysis of > 4500 BLMs
- Distribution (spatial)
- Evolution (temporal)

Intensity analysis
- Max. intensities
- Lost intensities
- Integrated intensities etc.