Update on the expected radiation levels for HL-LHC

WP10
Energy Deposition & R2E

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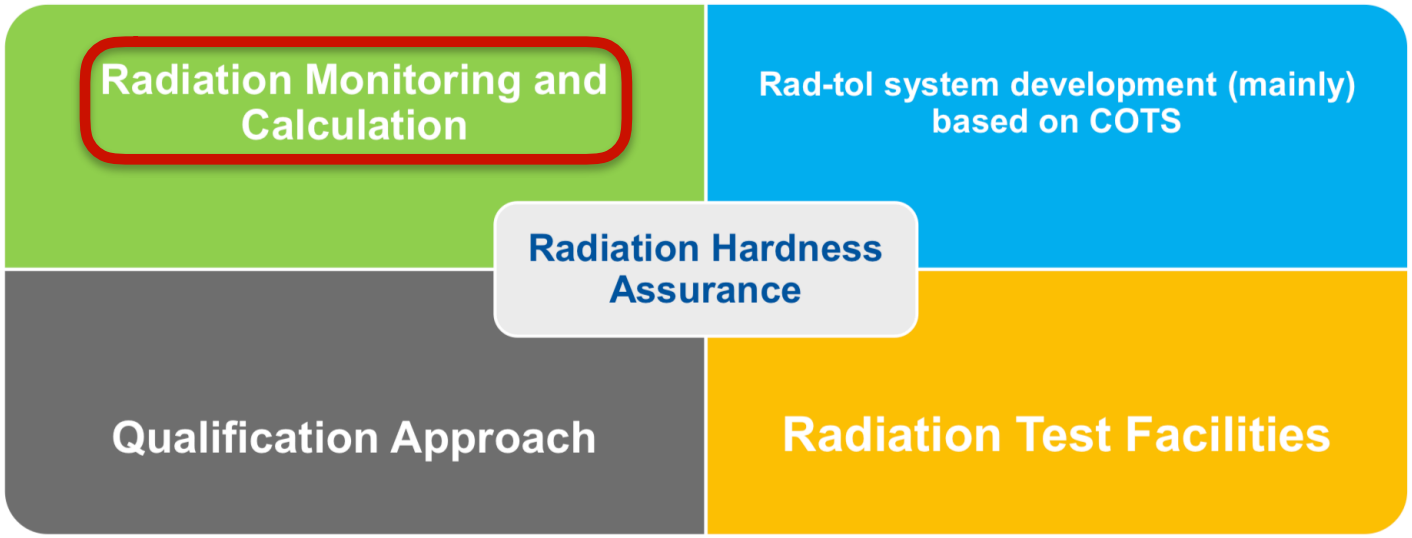
R2E Annual Meeting, 12 December 2018

Outline

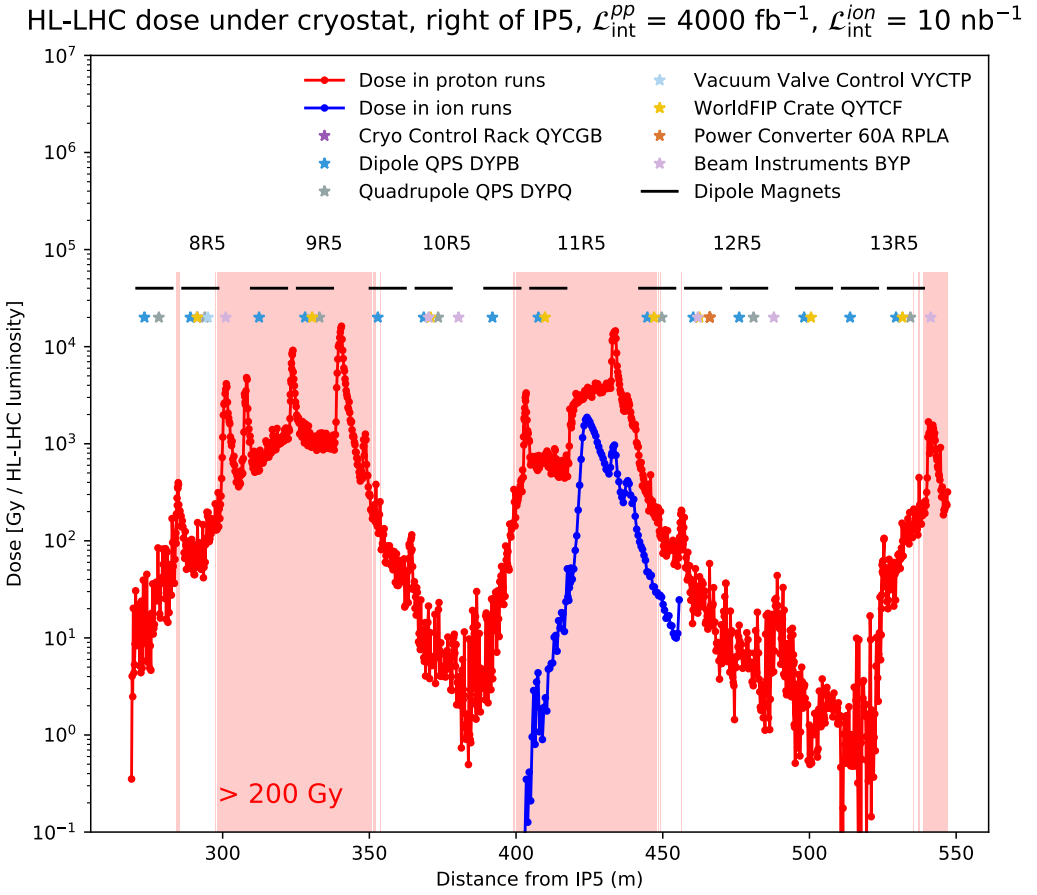
- The monitoring and calculation of radiation levels is a crucial step of the Radiation Hardness Assurance (RHA) procedure for the assessment of R2E-related issues in HL-LHC.



- This talk presents the expected HL-LHC radiation levels in the most critical locations of the machine for R2E:
  - IR1-IR5 DS and RRs, IR2 (for ion operation), IR3-IR7 (collimation IRs), IR8.

IR1-IR5 DS dose below the cryostat

- Red: Fluka simulation for proton operation with TCL4, TCL5, TCL6 closed @14σ, for the ultimate HL-LHC scenario (4000 fb^{-1}).
- Blue: Fluka simulation for ion operation (10 nb^{-1}), causing a Bound Free Pair Production (BFPP) peak in cell 11.
- Highlighted areas with total dose > 200 Gy.
- Note: large fraction of ion dose to be received in Run 3, while the proton dose is for the entire HL-LHC period.
- 1MeV neutron equivalent fluence also relevant for displacement damage (DD).

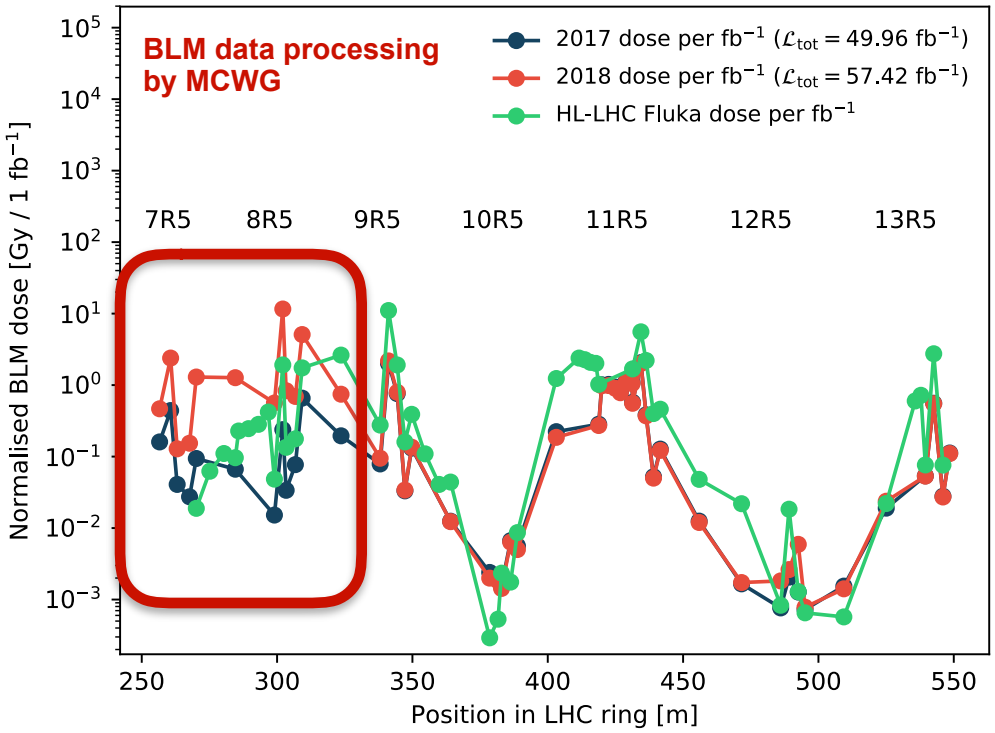


Impact of TCL settings on IR1-IR5 DS levels

- 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.

- Confirmed by comparing the dose per unit fb^{-1} for:
  - 2017 BLM data (TCL6 closed)
  - 2018 BLM data (TCL6 open)
  - HL-LHC Fluka simulations (HL-LHC baseline design with TCL6 closed).
- RR levels in next slide.

BLM dose per unit fb^{-1} in cells 7-13, right of IP5



IR1-IR5 RR levels and shielding

- HL-LHC annual levels inside the RRs from Fluka simulations (only RR wall shielding applied): $3 \cdot 10^9$ HEH/cm^2.
- The worst-case annual levels in Run 2 (2017) are ~10 times lower than the HL-LHC prediction due to the lower luminosity (~50 fb^{-1} vs ~250 fb^{-1}) and due to the presence of machine-level shielding.
- Note that the impact of the TCL6 settings is opposite to cell 8: the RR levels decrease from 2017 (TCL6 closed) to 2018 (TCL6 open).

HL-LHC annual levels in shielded areas

Location	HEH fluence (cm^{-2})	1 MeV n_{eq} (cm^{-2})	TID (Gy)
UJ	5×10^9	5×10^{10}	10
UL	10^8	10^9	0.2
RR	3×10^9	3×10^{10}	6
DS	5×10^{10}	5×10^{10}	100
ARC	10^9	10^9	2

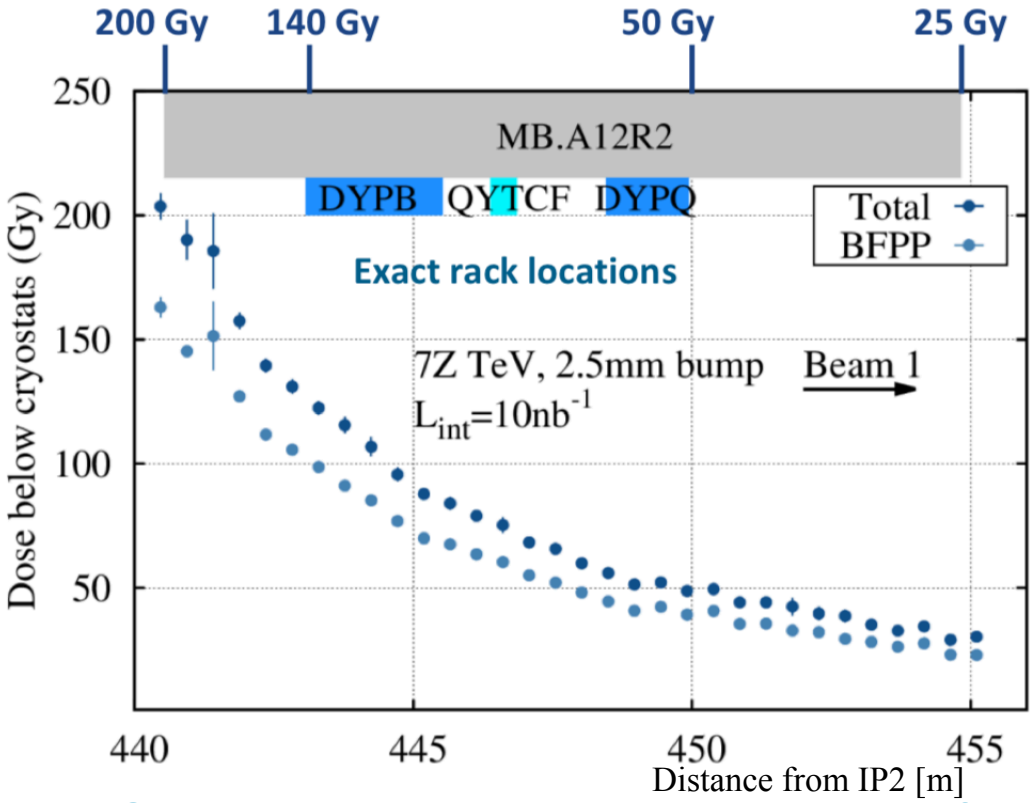
LHC annual RR levels in Run 2

		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)

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:

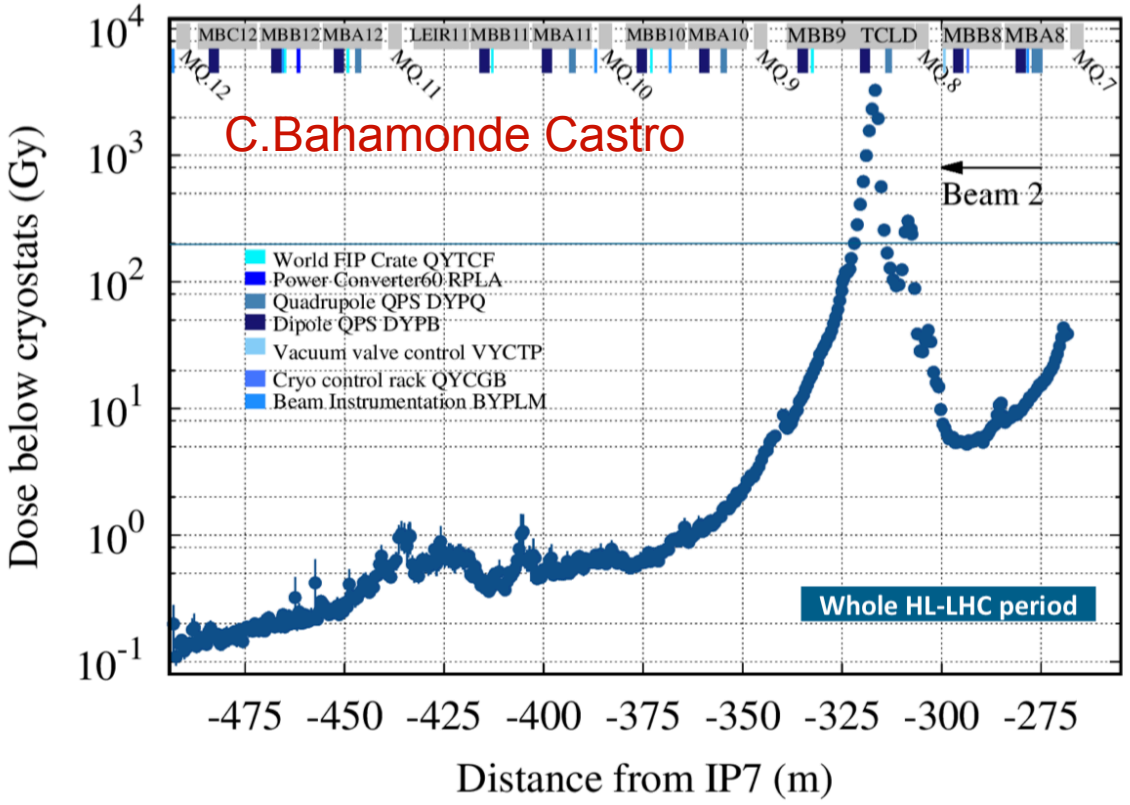


Fluka simulation of BFPP and total ion dose normalised to 10 nb^{-1} (full HL-LHC Pb-Pb dataset)

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

Dose levels in the DS of IR7 after LS2

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

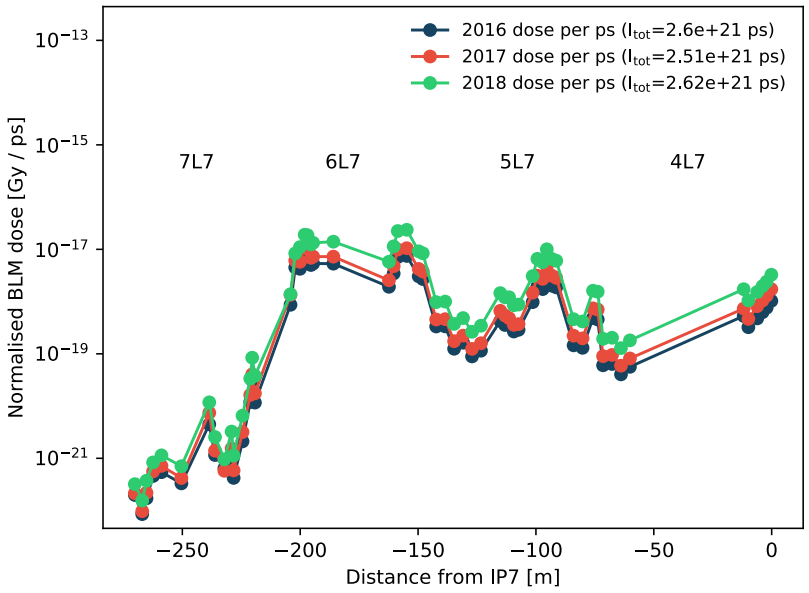


- New design with 11T installed in cell 9 (previous plan was cell 8).
- Significant dose peak in cell 9, but highly efficient cleaning of the downstream region.

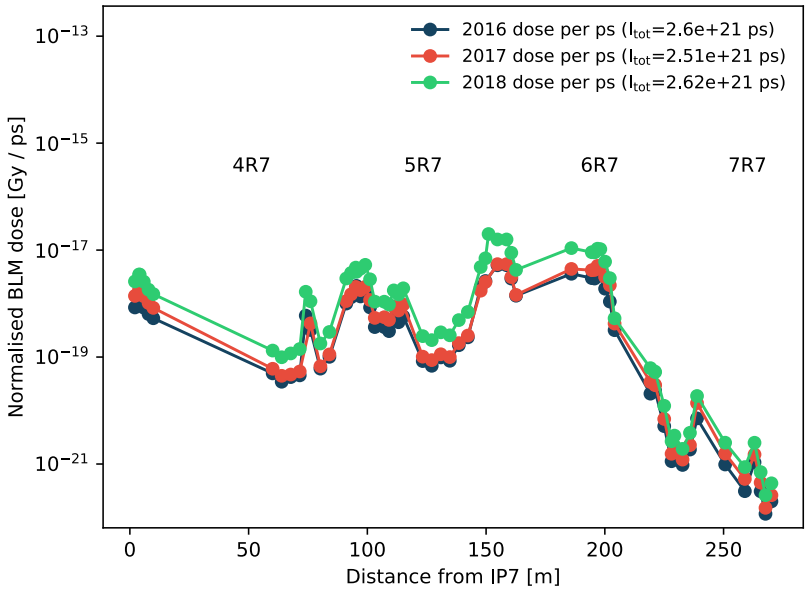
IR7 dose scaling in Run 2

- 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 (see talk by R.García).
- Interestingly, 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 dose per unit beam intensity in cells 4-7, left of IP7



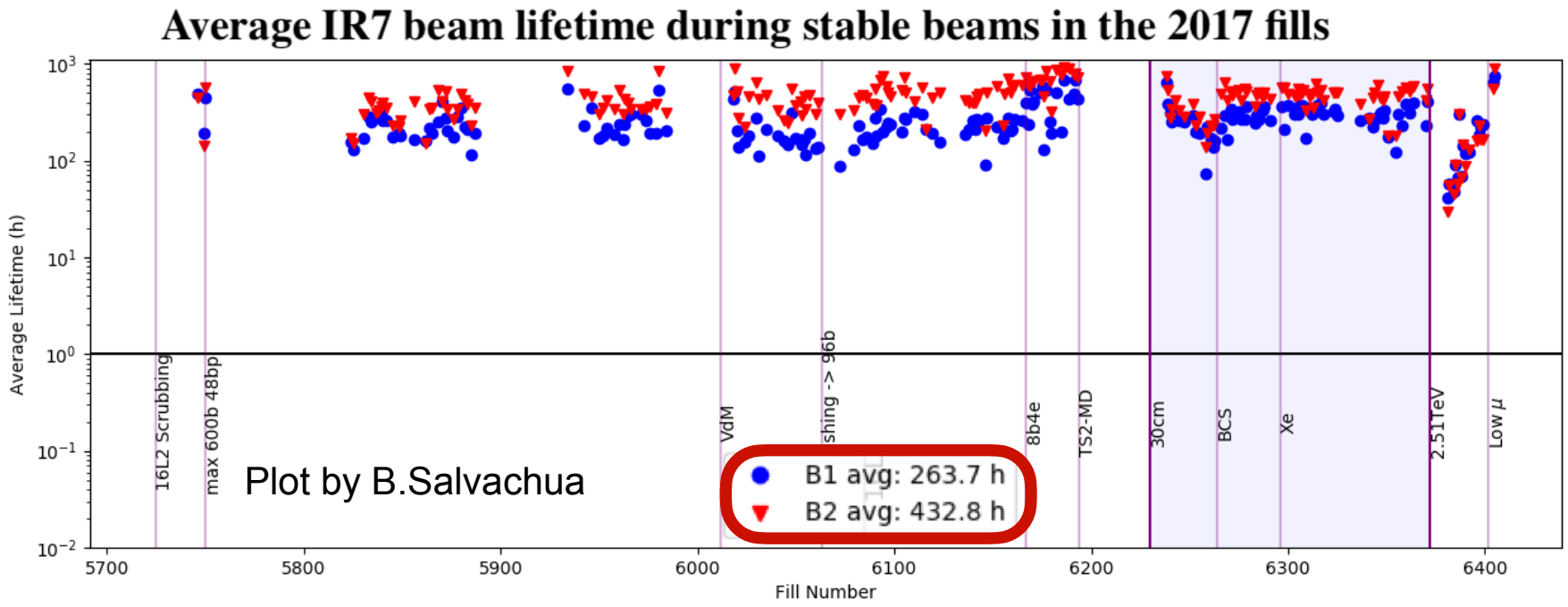
BLM dose per unit beam intensity in cells 4-7, right of IP7



BLM data processing by Monitoring and Calculation Working Group (MCWG)

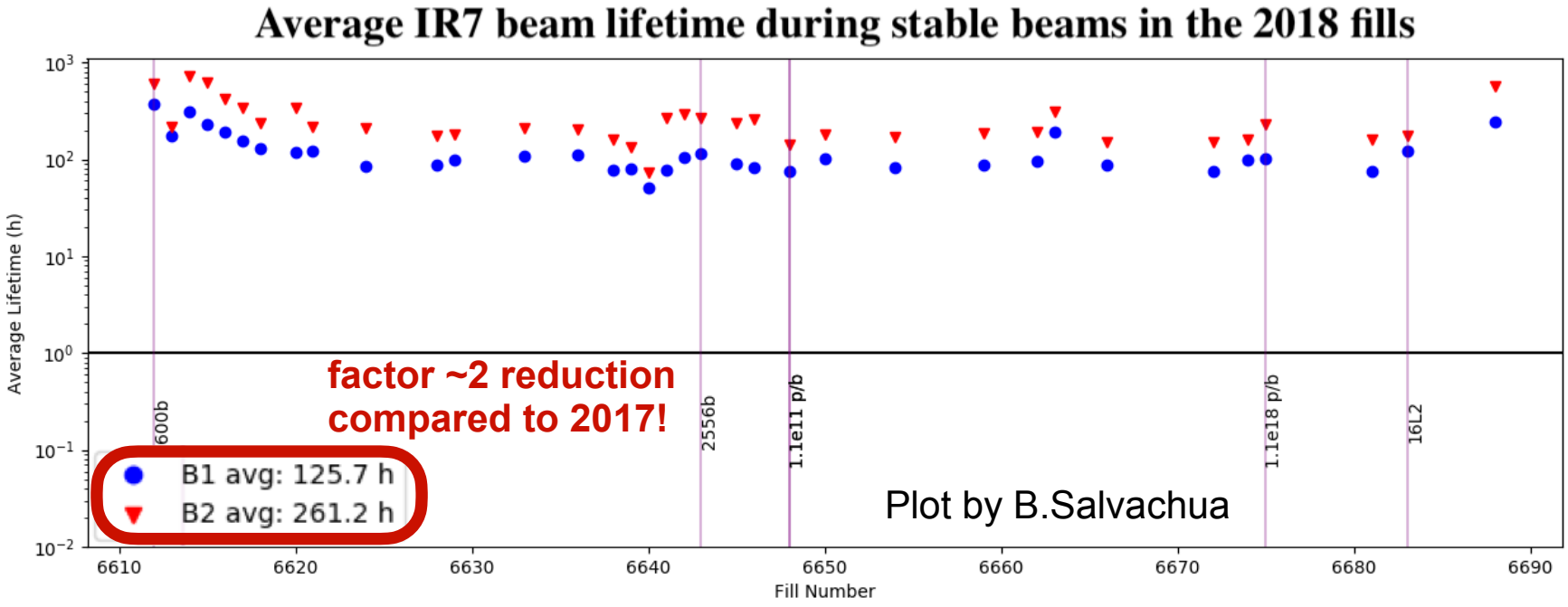
Dose levels in IR7 and beam lifetime

- 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 integrated intensity scaling is 'spoiled'.
- The 2018 to HL-LHC scaling is consistent with 10^{17} lost proton over the full HL-LHC lifetime, but things can change if the IR7 lifetime is further reduced → non-negligible uncertainty.



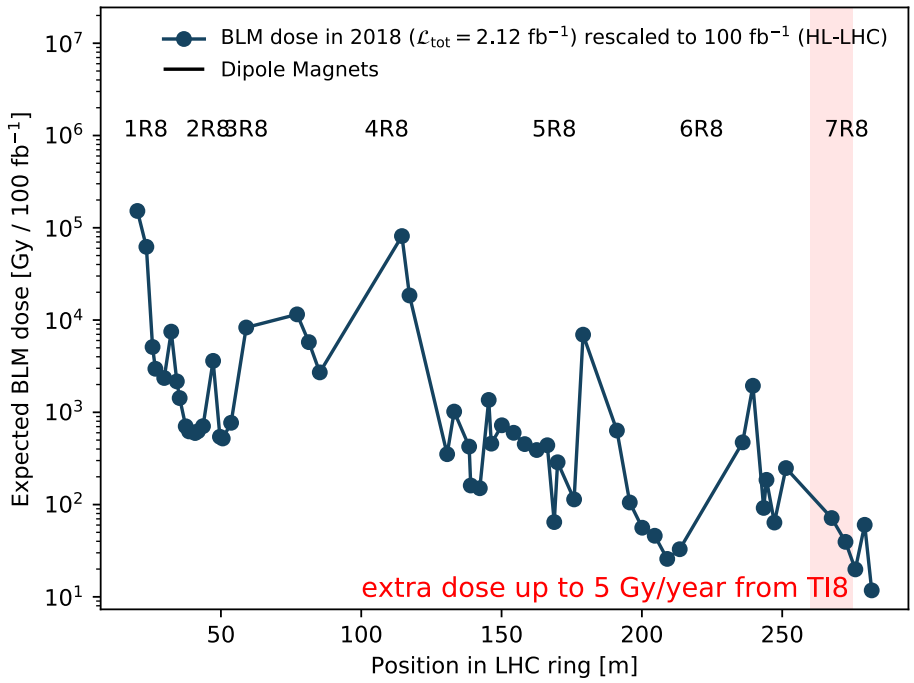
Radiation levels in IR8 (LHCb)

- Sources of radiation in IR8:
  - LHCb luminosity, with ~50 fb^{-1} expected up to LS4 and ~50 fb^{-1} more after LS4 if no further upgrade takes place. Total: 100 fb^{-1}.
  - TI8 injection line, merging into the LHC on the right of IP8 at the beginning of the DS (UJ87-UJ88).
- UJ87-88 losses driven by the number of lost protons in the main post-LIU collimators (TCDIH.87822, TCDIH.87939).
- Fluka simulations by A.Ciccotelli (link) allow to place conservative upper limits of 5 Gy per year next to the two collimators, with negligible losses elsewhere:
  - Between 260m and 275m from IP8 (TCDIH.87939).
  - Between 315 and 335m from IP8 (TCDIH.87822).

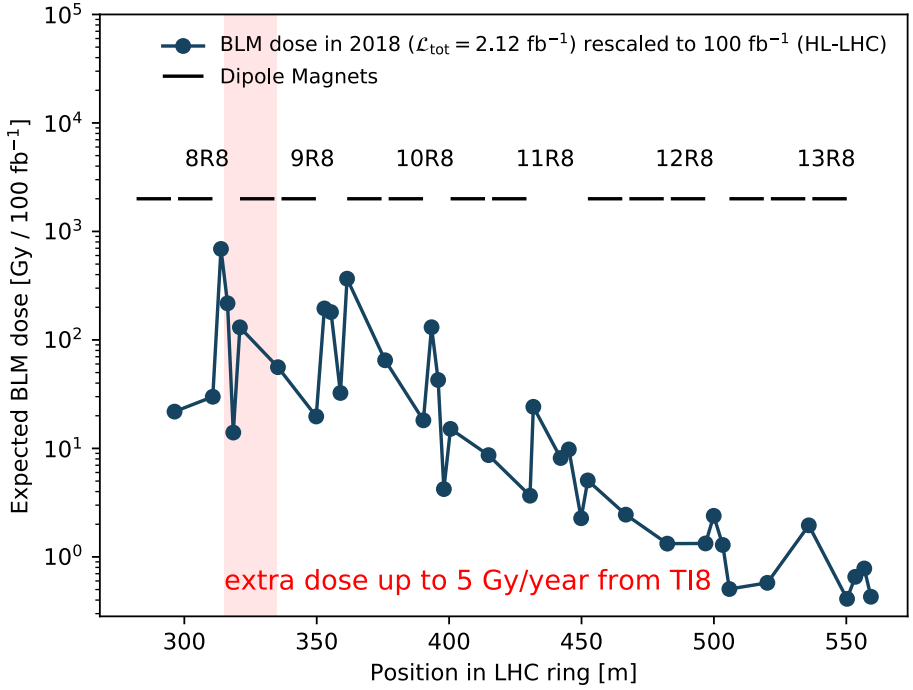
Dose levels on the right of IR8

- 2018 BLM dose rescaled to 100 fb^{-1} in LSS and DS of IR8.
- The dose is significantly lower compared to IR1-IR5, but the DS levels (in cell 8-9) reach few hundred Gys.
- Note: levels may be a factor 2-3 lower under the cryostats.

BLM dose for 100 fb^{-1} in cells 1-7, right of IP8



BLM dose for 100 fb^{-1} in cells 8-13, right of IP8



Summary and outlook

- I presented the expected HL-LHC radiation levels in the most critical locations for R2E.
- Additional material included in backup:
  - Radiation levels on the cold bypass diodes in IR1-IR5.
  - Levels in the IR7 RRs.
  - Levels in the DS of IR3 (much lower compared to IR7).
  - Levels in the ARCs (average full-Run 2 levels < 0.25 Gy).
- Other areas of the machine:
  - IR4-IR6, with significantly lower radiation levels.
- Lots of ongoing activities: stay tuned for more results to come!

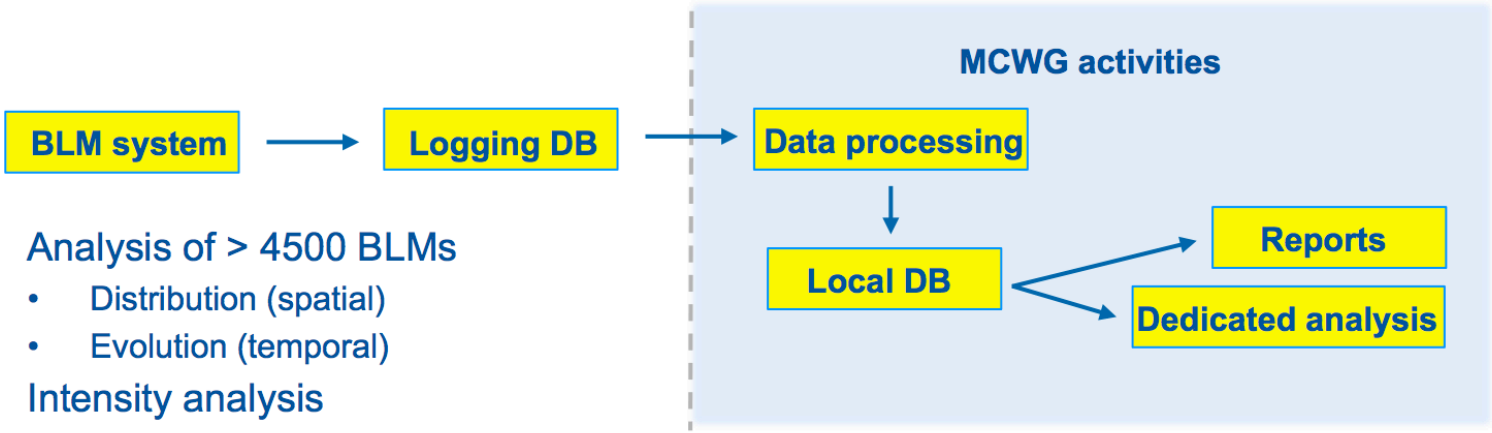
HiLumi
HL-LHC PROJECT

BACKUP

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.



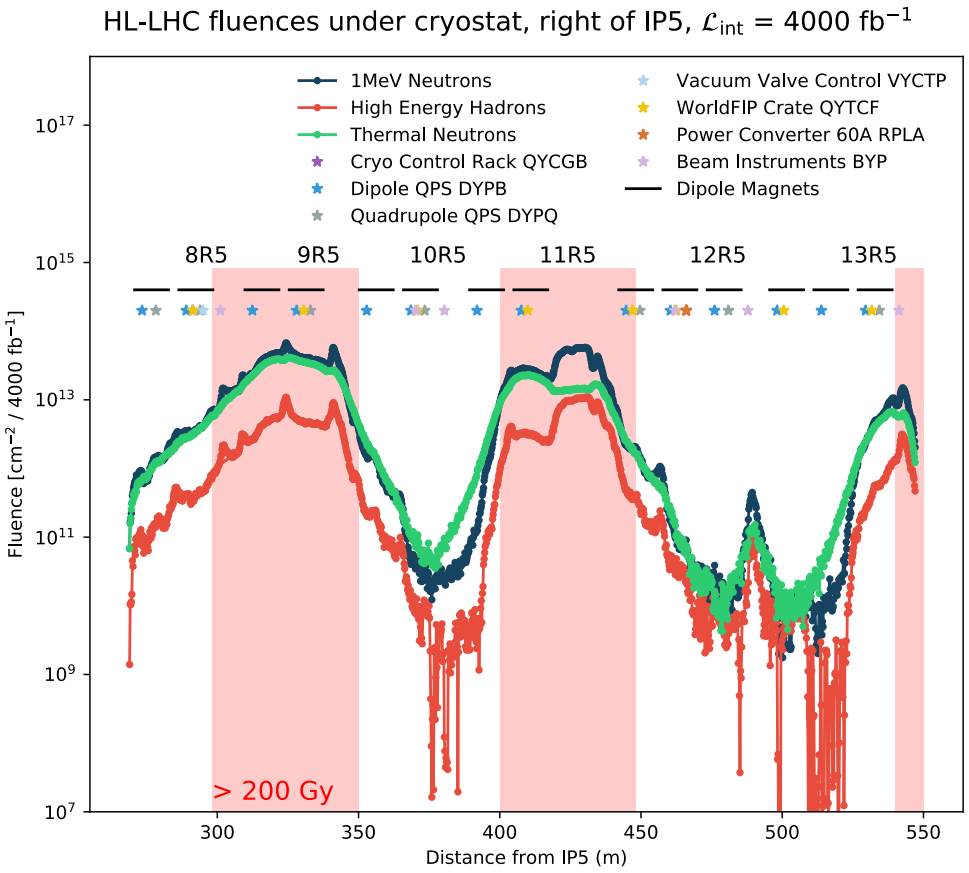
Analysis of > 4500 BLMs
- Distribution (spatial)
- Evolution (temporal)

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

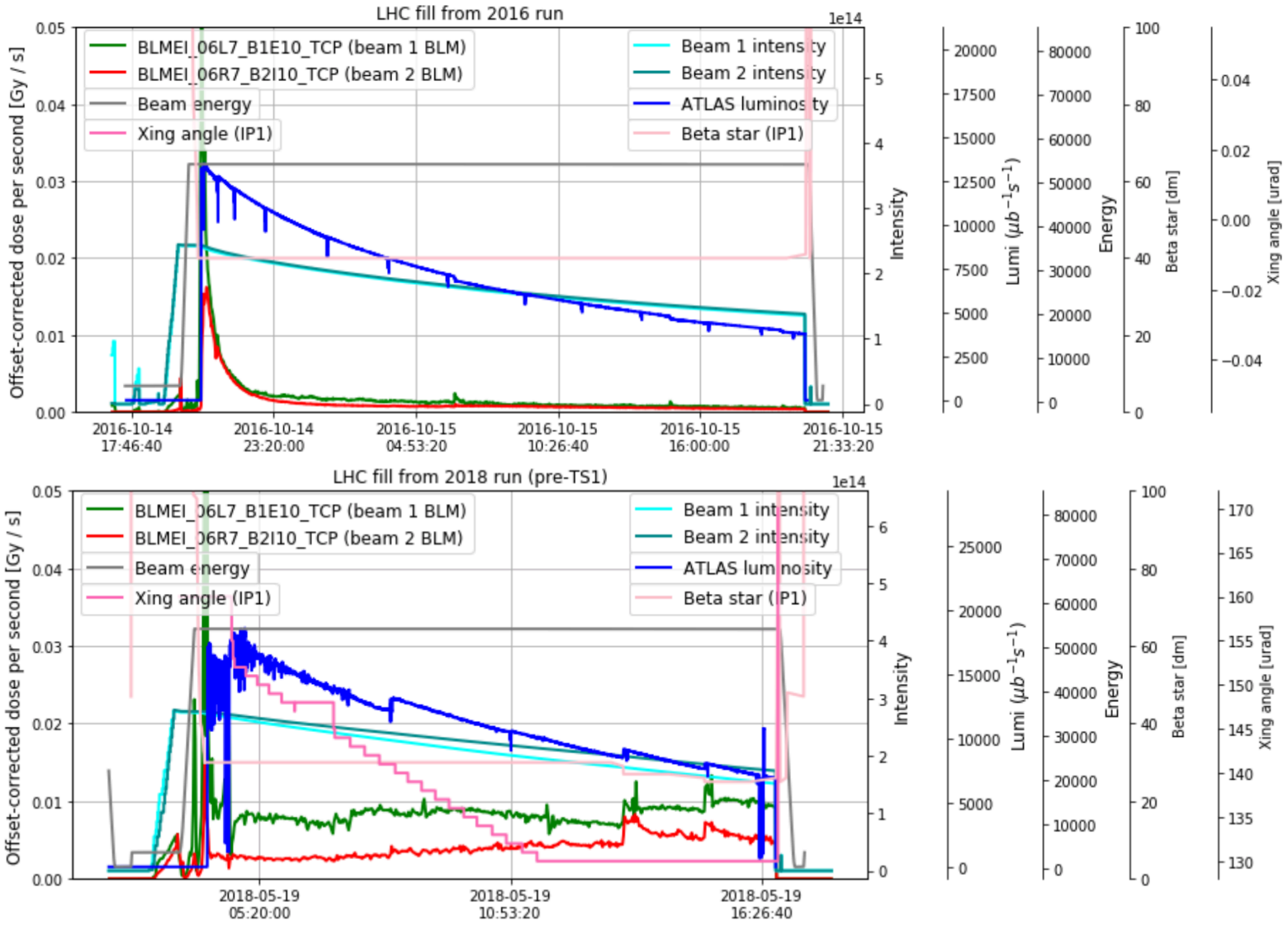
IR1-IR5 DS fluences

- IP1-IP5 DS profile of High Energy Hadron (HEH) fluence, 1 MeV neutron equivalent fluence and thermal neutron fluence for the ultimate HL-LHC scenario (4000 fb^{-1}).

- Only proton operation shown in the plot.
- Similar pattern as for the dose, with peaks in cells 9, 11, 13.
- The 1 MeV neutron equivalent fluence is relevant for equipment lifetimes. Typical qualification limit: $2 \cdot 10^{12}$ n/cm^2



2016 vs 2018 fill comparison with IR7 BLM dose



HEH fluence in the IR7 RRs

- An increase by a factor 2-3 was also observed in the RR fluence levels in 2018, as measured by RadMONs inside and outside the RR walls.
- The integrated beam intensities in 2016-2017-2018 are comparable, but the 2018 RR73 and RR77 fluences are systematically higher.

- Note that the IR7 RRs have a better IN/OUT ratio (~100) compared to the IR1-IR5 RRs (~10).
- This is likely to remain true in HL-LHC unless further shielding is added to the IR1-IR5 RRs.

		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
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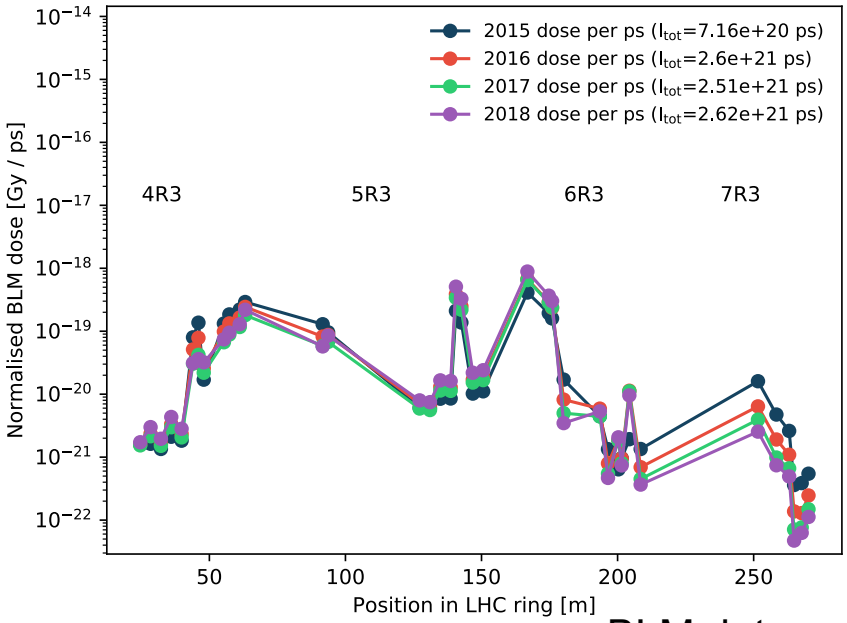
	IN	1,2E+08	3,5E+08	3,0E+08
RR57	OUT	4,5E+09	9,7E+09	4,3E+09
	IN	1,6E+08	3,5E+08	2,7E+08
RR73	OUT	2,0E+09	2,5E+09	7,6E+09
	IN	1,6E+07	1,8E+07	7,2E+07
RR77	OUT	8,5E+08	9,3E+08	2,4E+09
	IN	1,2E+07	1,4E+07	2,8E+07

*up to LS2 (mid-September)

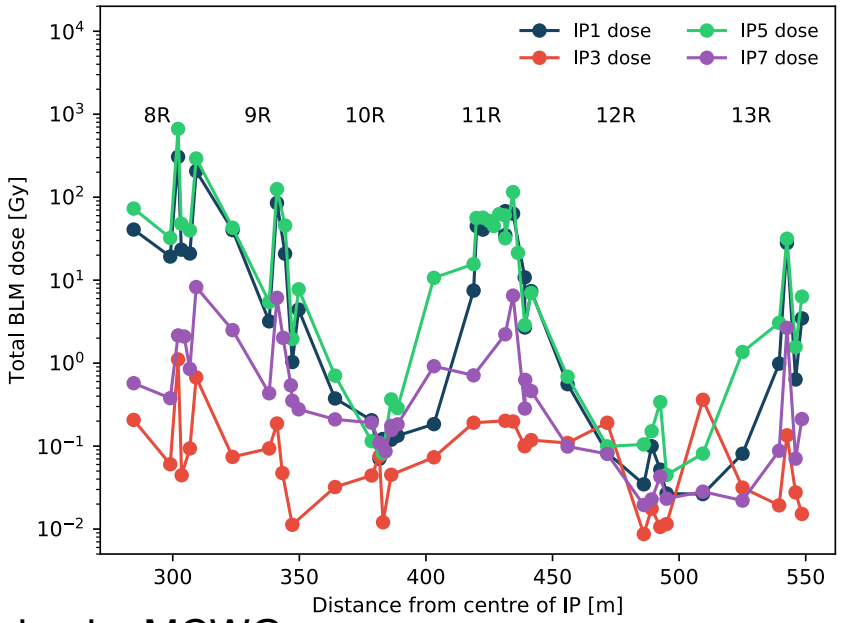
Dose levels in IR3

- The scaling with integrated beam intensity is 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



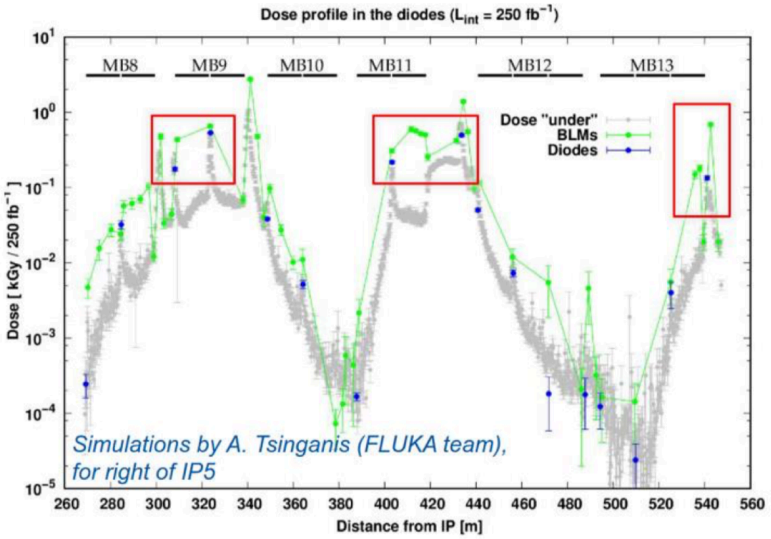
2018 BLM dose in cells 8-13, right of each IP

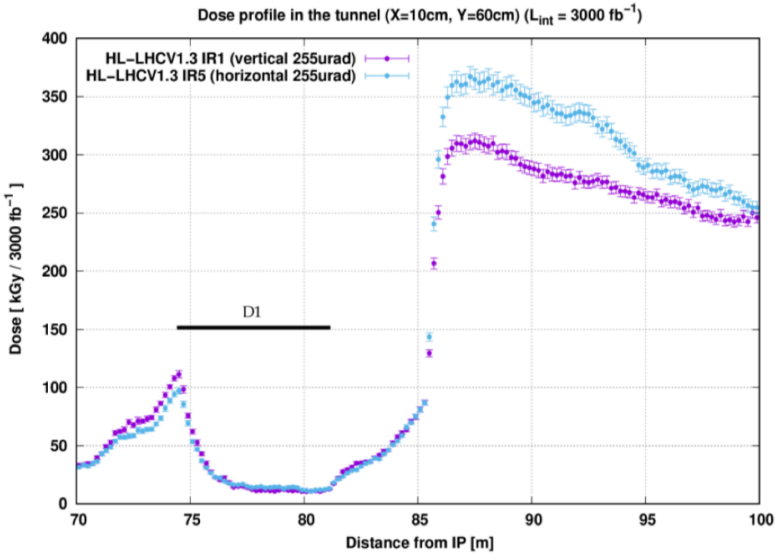


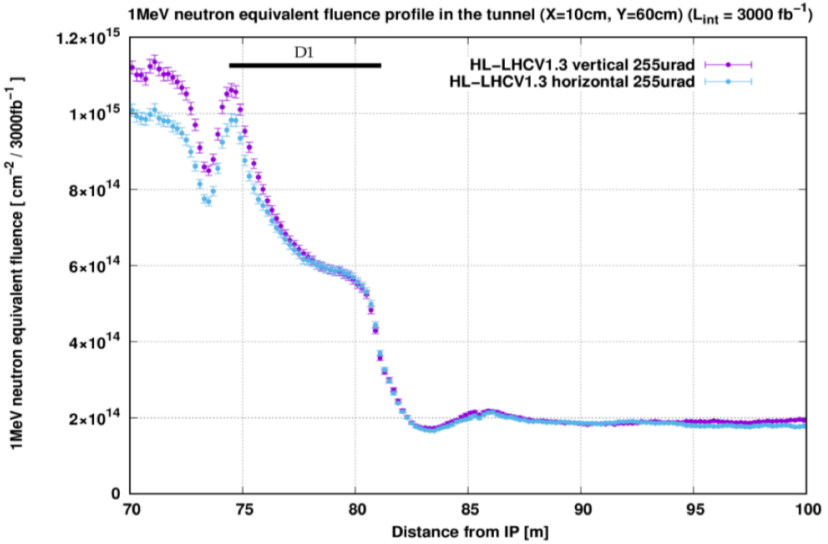
BLM data processing by MCWG

LHC cold diodes in IR1-IR5: 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 on this in link1 and link2.







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.