HL-LHC radiation level studies and specification document

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14th HL-LHC Collaboration Meeting, 9th October 2024

WP10
Energy Deposition & R2E

1. Radiation level specification document v1.1: content and discussion of EDMS comments
2. WP10 status and work plan for the coming months

HL-LHC radiation level specification document

- New release of the HL-LHC radiation level specification document for electronics: EDMS 2302154 v1.1 (circulated on August 2nd)
- Providing values of **Total Ionizing Dose (TID)**, and High Energy Hadron equivalent (**HEH-eq**), thermal neutron equivalent (**thn-eq**), and Silicon 1-MeV neutron equivalent (**1MeVn-eq**) fluences
- Covered areas:
  - LHC DS and arcs, at the reference position of electronic racks (i.e., below the beamline)
  - Shielded alcoves
- Not covered:
  - LSS tunnel areas (typically not hosting electronics)
  - Radiation levels on equipment on (or close to) the beamline

EDMS NO. 2302154 v1.1
Reference: LHC-N-ES-0001
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RADIATION LEVEL SPECIFICATIONS FOR HL-LHC

ABSTRACT

We present a comprehensive overview of the radiation level specifications for the electronic equipment at the LHC during the High-Luminosity upgrade. The specifications are derived from a combination of Run 2 measurements from BLM and RadMon systems, FLUKA simulations and considerations on the expected evolution of the performance of the LHC accelerator. Four R2E-relevant quantities are considered for the specifications, namely Total Ionising Dose and High Energy Hadron, thermal neutron and 1-MeV neutron equivalent fluences. The results are presented for each relevant location hosting systems based on commercial electronics, and should serve as reference for their development and qualification.

Keywords: HL-LHC, R2E, radiation, specifications, electronics.

TRACEABILITY	
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Verified by: R. Tomas (WP2), R. Bruce (WP5), Y. Thurel, S. Uznanski (WP6B), R. Denz (WP7), J. Casas-Cubillo (WP9), G. Pigny (WP12), T. Lefevre (WP13), A. Lechner (WP14), E. Gousiou (WP18), S. Danzeca (RadMon/RadWG), E. Daly (external, European Space Agency)	**Date:** 2024-MM-DD
Approved by: S. Redaelli (WP5), M. Martino (WP6B), D. Wollman (WP7), S. Claudet (WP9), F. Cerutti, R. García Alía (WP10), V. Baglin (WP12), R. Jones (WP13), P. Fessia (WP15), J. Serrano (WP18), S. Gilardoni (EN-STI), Y. Kadi (R2E-MCWG)	**Date:** 2024-MM-DD

DISTRIBUTION

Rev. No.	Date	**Description of Changes** (major changes only, minor changes in EDMS)
v1.0	2020-09-21	First released version
v1.1	2024-07-30	Updated specifications in IR1-IR5 UPS (2.3.5), IR8 shielded alcoves (2.4.2), IR4 (2.8). The same reference performance parameters have been retained, with an explanatory note in 1.3. No other changes have been made compared to v1.0.

EDMS 2302154 v1.1: updates

- The bulk of the radiation level specifications in v1.1 remains unchanged with respect to v1.0, but three areas are expanded:
  - IR1-IR5 UPS galleries (UPS14-16, UPS54-56), based on Run 3 RadMon and BatMon measurements
  - IR8 shielded alcoves, based on a FLUKA simulation developed by A. Ciccotelli
  - IR4 tunnel and shielded alcoves, quantifying the impact of Beam Gas Vertex (BGV) and Beam Gas Curtain (BGC) monitors
- The material in EDMS 2302154 v1.1 has been presented at the TCC:
  - 193rd TCC (G. Lerner, D. Prelipcean): review of the main updates
  - 197th TCC (G. Lerner): A.O.B. on UPS radiation levels in IR5

EDMS 2302154 v1.1: note on reference performance parameters

- All radiation level specifications are given for a reference year of peak HL-LHC performance (reached towards the end of the ramp-up in the WP2 projections)
- Reference parameters endorsed at the 100th TCC (2020), no change now as this would affect all results in the document

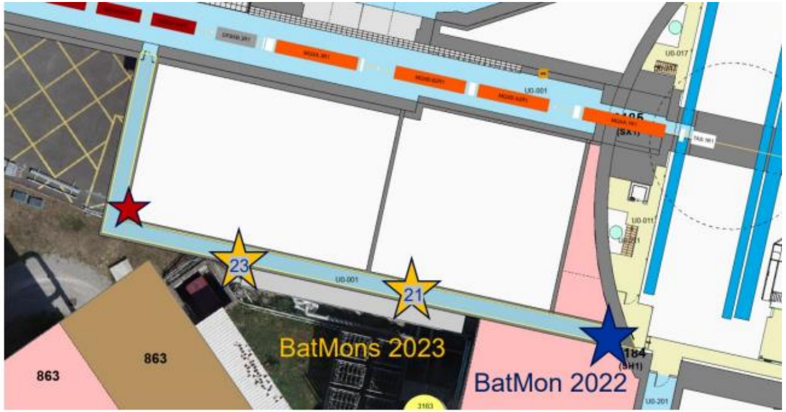
NOTE (v1.1): as detailed below, the reference performance parameters used in this document have been defined based on input from WP2 in 2020, and have been endorsed at the 100$^{\text{th}}$ HL-LHC TCC meeting on 16/04/2020. In recent operational scenarios, some modifications of these parameters have been introduced: for example, while this document considers an annual integrated luminosity of 360 fb^{-1} in ATLAS and CMS with 220 days of physics per year, the current estimates are lower by around $10-20\%$. While such changes are significant for operation, for the purpose of defining R2E specifications these differences can be regarded as small, and they go in the direction of adding extra margin. For this reason, it was decided to keep these parameters as defined in the original v1.0 document also in v1.1, without modifying any sections of the document aside from those that are interested by dedicated updates.

	2018		Annual HL-LHC reference	
	$\mathcal{L}_{pp}$ (fb^{-1})	$\mathcal{L}_{PbPb}$ (nb^{-1})	$\mathcal{L}_{pp}$ (fb^{-1})	$\mathcal{L}_{PbPb}$ (nb^{-1})
ATLAS	65.2	1.8	360	3.5
ALICE	0.03	0.9	0.1	3.5
CMS	66.9	1.8	360	3.5
LHCb	2.46	0.23	15	0.5

Quantity	Annual HL-LHC reference value	Description and notes
f^{T}_{TopEne}	0.5	Fraction of time at top energy
T_{tot}	200 days	Days of operation per year, to be converted to seconds
N_{b}	2760	Number of LHC bunches
$N^{\mathrm{p/b}}_{\mathrm{inj}}$	$2.3 \cdot 10^{11}$ p	Number of protons per bunch at injection
$N^{\mathrm{p/b}}_{\mathrm{dump}}$	$1.1 \cdot 10^{11}$ p	Number of protons per bunch at beam dump
$N_{\mathrm{fills/day}}$	2	Number of HL-LHC fills per day
I_{int}	$4.0 \cdot 10^{21}$ ps	Integrated beam intensity per beam per year
N_{inj}	$2.5 \cdot 10^{17}$ p	Number of injected protons per beam per year
N_{dump}	$1.2 \cdot 10^{17}$ p	Number of dumped protons per beam per year

EDMS 2302154 v1.1: IR1-IR5 UPS galleries

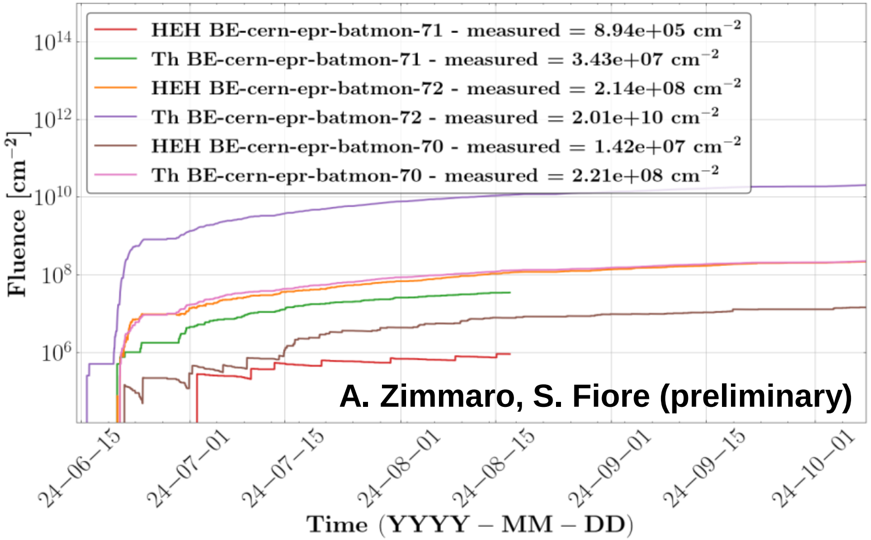
- Specifications in the core of UPS14 and UPS16 are set based on Run 3 BatMon measurements with luminosity scaling (360 fb^{-1}/y)
- UPS14 and UPS16 specs are equal (justified by Run 3 RadMons)
- UPS54 and UPS56 specs are set to **30x** the ones in UPS14-16, due to evidence of higher radiation levels (based on Run 2 RadMons)
- *Ongoing BatMon measurements in UPS54-56 to validate these specs (next slide)*



	Annual (360 fb^{-1}) HL-LHC radiation levels			
	TID [Gy]	HEH [cm^{-2}]	Th. neut. [cm^{-2}]	1MeVn-eq [cm^{-2}]
RR13-17-53-57 L0	15	$1 \cdot 10^{10}$ cm^{-2}	$9 \cdot 10^{10}$ cm^{-2}	$7 \cdot 10^{10}$ cm^{-2}
RR13-17-53-57 L1	25	$1.4 \cdot 10^{10}$ cm^{-2}	$1.2 \cdot 10^{11}$ cm^{-2}	$7 \cdot 10^{10}$ cm^{-2}
UJ14-UJ16 L0	6	$3 \cdot 10^{9}$ cm^{-2}	$3 \cdot 10^{11}$ cm^{-2}	$5 \cdot 10^{10}$ cm^{-2}
UL14-UL16 L0	< 1	$1.2 \cdot 10^{8}$ cm^{-2}	$2.5 \cdot 10^{10}$ cm^{-2}	$< 10^{10}$ cm^{-2}
UJ56 L0	3	$1.5 \cdot 10^{10}$ cm^{-2}	$1 \cdot 10^{10}$ cm^{-2}	$4 \cdot 10^{10}$ cm^{-2}
UJ56 L1	2	$1 \cdot 10^{10}$ cm^{-2}	$8 \cdot 10^{9}$ cm^{-2}	$2.5 \cdot 10^{10}$ cm^{-2}
UPS14-16 (core)	0.003	$7 \cdot 10^{6}$ cm^{-2}	$3 \cdot 10^{8}$ cm^{-2}	$7 \cdot 10^{7}$ cm^{-2}
UPS54-56 (core)	0.09	$2.1 \cdot 10^{8}$ cm^{-2}	$9 \cdot 10^{9}$ cm^{-2}	$2.1 \cdot 10^{9}$ cm^{-2}

EDMS 2302154 v1.1: IR5 BatMon measurement

- Ongoing BatMon measurements in UPS54-56 to validate the specifications
- BatMons 70-71 are in the core of UPS56, roughly (but not exactly) corresponding to BatMons 21-23 in UPS16, based on which the specifications have been set
- Consistent results when considering some differences in the exact positions (with the UPS16-based specifications being more conservative)

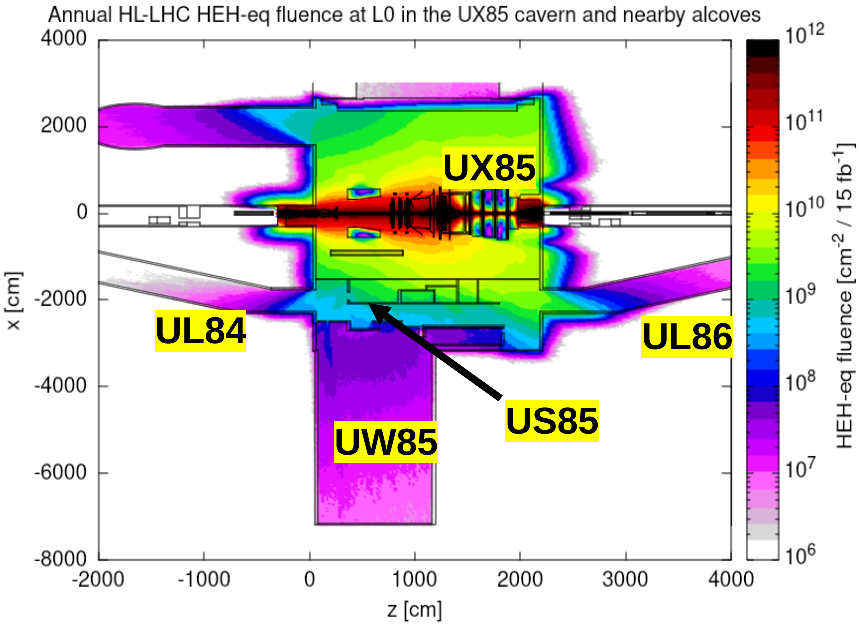


	BatMon70 [86.5 fb^{-1}]	BatMon70 [360 fb^{-1}]	BatMon71 [48.8 fb^{-1}]	BatMon71 [360 fb^{-1}]	Current specs [360 fb^{-1}]
HEH-eq	1.42e7 cm^{-2}	5.9e7 cm^{-2}	8.94e5 cm^{-2}	6.6e6 cm^{-2}	**2.1e8 cm^{-2}**
Thn-eq	2.21e8 cm^{-2}	9.2e8 cm^{-2}	3.43e7 cm^{-2}	2.5e8 cm^{-2}	**9e9 cm^{-2}**

EDMS 2302154 v1.1: IR8 specifications

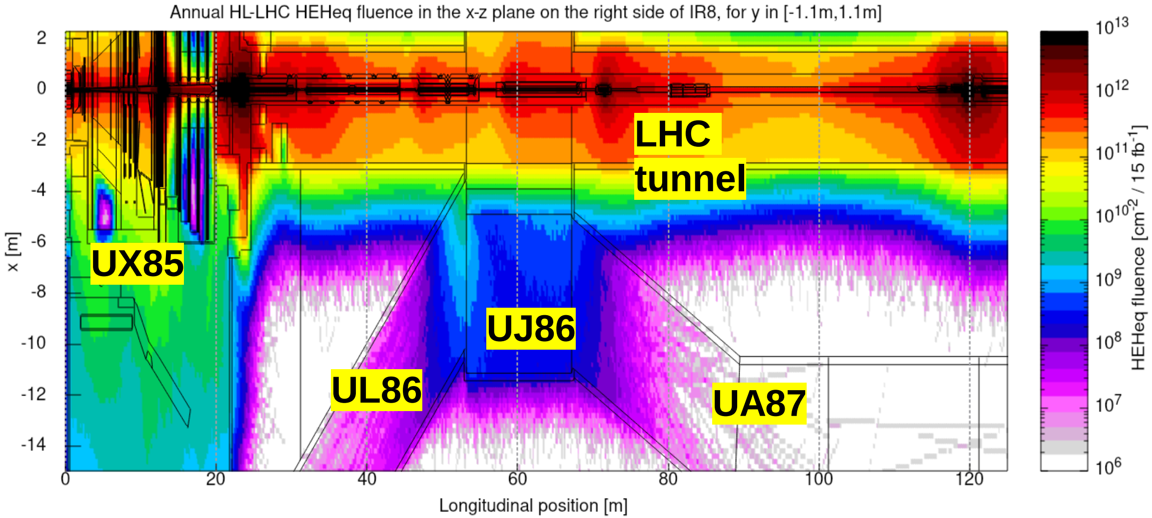
- **FLUKA simulations by A. Ciccotelli** of radiation levels in IR8 (LHCb) presented at the 11th and 12th HL-LHC collaboration meetings, now used to update the radiation level specifications in EDMS 2302154 v1.1 for an **annual luminosity of 15 fb^{-1}** (i.e., Upgrade II excluded)
- First set of specifications covering radiation that leaks from UX85 into the nearby shielded alcoves:

	TID (Gy)	HEH (cm^{-2})	1MeVn-eq (cm^{-2})	th.n. (cm^{-2})
UX85 L0 (x=7 m)	12	$2 \cdot 10^{10}$	$6 \cdot 10^{10}$	$4 \cdot 10^{10}$
UX85 L1 and L-1 (x=7 m)	5	$1 \cdot 10^{10}$	$5 \cdot 10^{10}$	$5 \cdot 10^{10}$
US85 L0 (safe area)	0.1	$1 \cdot 10^{8}$	$6 \cdot 10^{8}$	$5 \cdot 10^{9}$
US85 L1	0.4	$7 \cdot 10^{8}$	$3 \cdot 10^{9}$	$8 \cdot 10^{9}$
US85 L2	1	$3 \cdot 10^{9}$	$1 \cdot 10^{10}$	$2 \cdot 10^{10}$
UW85	0.05	$9 \cdot 10^{7}$	$5 \cdot 10^{8}$	$3 \cdot 10^{9}$
UL84 (US85 side, corner)	0.25	$7 \cdot 10^{8}$	$3 \cdot 10^{9}$	$9 \cdot 10^{9}$
UL84 (US85 side, after dogleg)	0.02	$6 \cdot 10^{6}$	$1 \cdot 10^{8}$	$2 \cdot 10^{9}$
UL86 (US85 side, after dogleg)	0.1	$6 \cdot 10^{7}$	$5 \cdot 10^{8}$	$2 \cdot 10^{9}$



EDMS 2302154 v1.1: IR8 specifications (2)

- The FLUKA simulations are also available in the tunnel, for different crossing angles and LHCb spectrometer polarities
- These results are used to set radiation level specifications in **UJ84-86, UA83-87**, and the UA sides of **UL84-86**
- Due to the radiation level gradients, the UA specifications are given separately for the core (R2E-safe) and UJ side

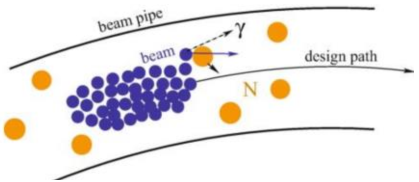


	TID (Gy)	HEH (cm^{-2})	1MeVn-eq (cm^{-2})	th.n. (cm^{-2})
UL84 (UJ84 side)	0.3	$4 \cdot 10^9$	$6 \cdot 10^9$	$2 \cdot 10^9$
UL86 (UJ86 side)	0.2	$2 \cdot 10^9$	$4 \cdot 10^9$	$2 \cdot 10^9$
UA83 (UJ84 side)	0.1	$6 \cdot 10^8$	$1 \cdot 10^9$	$8 \cdot 10^8$
UA87 (UJ86 side)	0.1	$5 \cdot 10^8$	$1 \cdot 10^9$	$4 \cdot 10^8$
UA83-87 (core, near ducts)	0.01	$9 \cdot 10^6$	$4 \cdot 10^7$	$7 \cdot 10^7$
UA83-87 (core, away from ducts)	R2E safe			

EDMS 2302154 v1.1: IR4 BGC-BGV studies

- The radiation showers from the operation of **BGV** (now descoped) and **BGC** monitors have been simulated by D. Prelipcean with FLUKA, benchmarking the predictions with Run 2 and Run 3 data from BLMs (and Timepix3)

Radiation source: beam-gas collisions

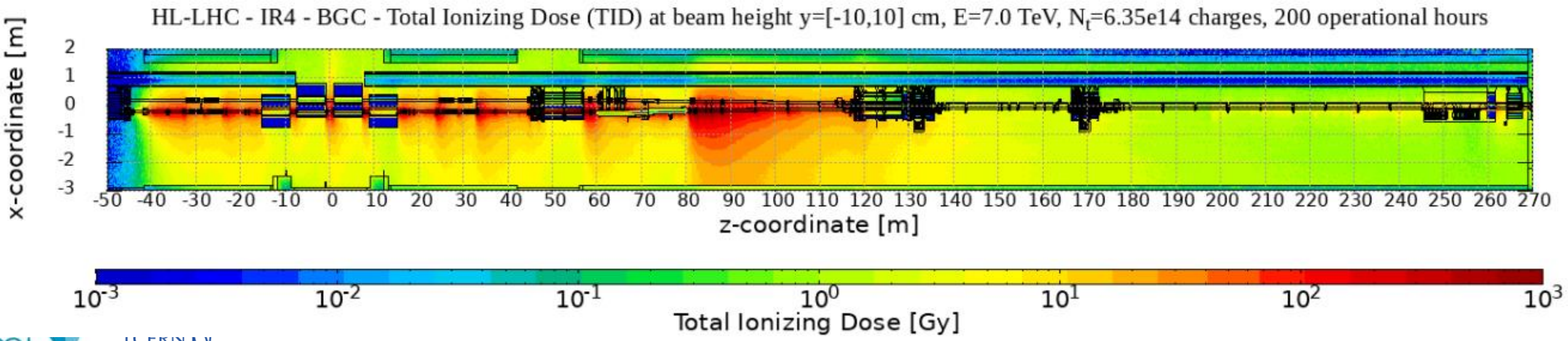


Radiation levels [rate of any quantity] →

BGC operation | (HL-)LHC operation

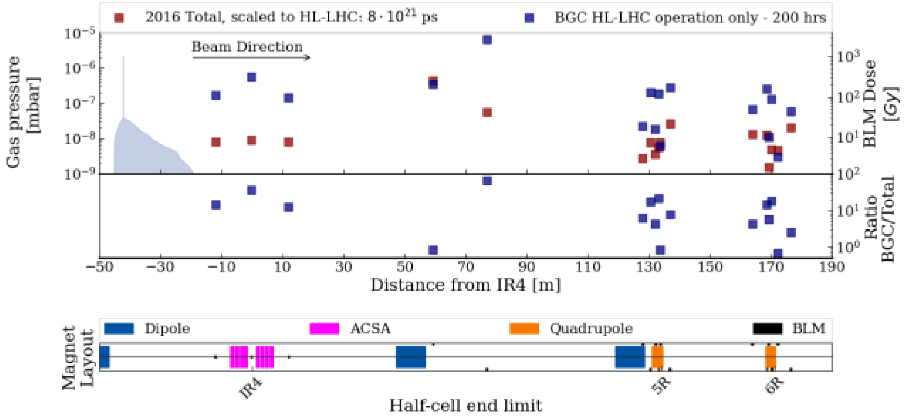
$$\frac{dN}{dt} \propto \Theta(t; s_a, s_b) \cdot \sigma_j(E) \cdot f \cdot I(t)$$

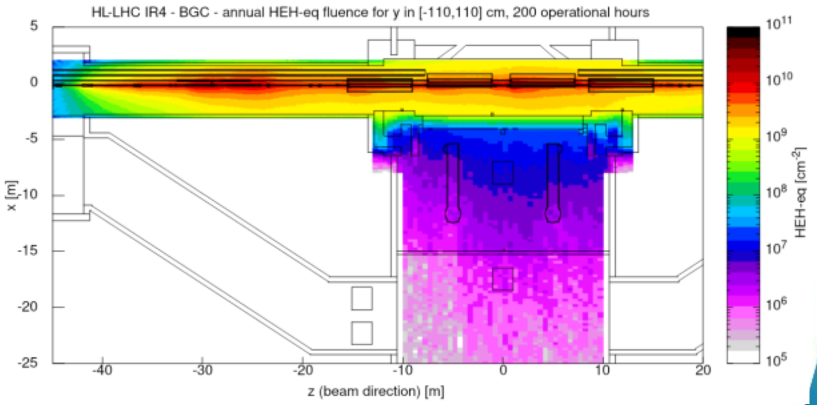
Injected gas density profile | Interaction cross section - Gas species (Neon) | Beam energy | LHC revolution frequency | Beam intensity



EDMS 2302154 v1.1: IR4 BGC specifications

- IR4 studies are included for the following instruments:
  - **BGV in 6L7**, showering towards the DS (now descoped → DS specs do not consider the BGV)
  - **BGC in 5L4**, showering towards the right side of IR4:
    → in the tunnel, the BGC causes a significant increase of radiation levels up to cell 5 included, but NOT up to the DS
    → in the shielded alcoves (e.g., US450) the impact of the BGC is significant





		HL-LHC TID (Gy)	HL-LHC HEH (cm^{-2})	HL-LHC 1MeVn-eq (cm^{-2})	HL-LHC th.n. (cm^{-2})
US450	BGC (FLUKA)	0.004	$3 \cdot 10^7$	$2 \cdot 10^8$	$8 \cdot 10^7$
	Scaled 2016 data	0.01	$8.0 \cdot 10^7$	$5 \cdot 10^8$	$2 \cdot 10^8$
	Total	0.014	$1.1 \cdot 10^8$	$7 \cdot 10^8$	$2.8 \cdot 10^8$

EDMS comments since circulation on August 2nd (1)

✔ **Accepted** by ZERLAUTH Markus (ATS-DO) — Created on 2024-08-05, 08:10

Many thanks for the update of this important document for the HL era. Main changes were discussed and approved in TCC #193 and TCC#197.

Seen by LEFEVRE Thibaut (SY-BI) — Created on 2024-08-23, 09:52

very useful, no comment

Seen by TOMAS GARCIA Rogelio (BE-ABP) — Last modified on 2024-08-25, 12:30 | Created on 2024-08-25, 12:28

-In Section 1.3 (red text) it would be useful to add a reference to the draft document of operational days: https://edms.cern.ch/document/2902691/0.9 ✔

-Table 1.3 displays 200 days for the reference year while in Section 1.3 220 days is mentioned:
"...this document considers an annual integrated luminosity of 360 fb-1 in ATLAS and CMS with 220 days of physics per year..."
220 days is indeed more consistent with 360 fb-1 and is more conservative.

-Number of fills per day is given as 2 in Table 1.3. We have seen in the LHC that during periods with faults this number can be larger. Also in the ultimate scenario this could be larger due to the shorter physics fill. I wonder if some margin should be taken here.

-On page 11 the outdated 11T dipoles are mentioned: "...among which the most relevant for R2E are the new TCLD collimators and 11T dipole magnets in half-cell 9 on each side of the IR"

-Since it is mentioned that the LHCb upgrade is not considered in this document, maybe it should also be mentioned that the ALICE upgrade is not considered. ✔

Seen by BRUCE Roderik (BE-ABP) — Created on 2024-09-09, 11:09

Very useful document!

Can anything be learned in particular from the radiation problems encountered in the 2023 Pb ion run? As far as I can see, only ions affected by BFPP are accounted for in terms of radiation from the ion collisions, although we likely had R2E problems in 2023 caused by other collision products, as these problems occurred significantly upstream of the BFPP impact location.

Seen by DENZ Reiner (TE-MPE) — Created on 2024-09-12, 15:13

Seen. Indeed, a very useful document!

Seen by GARCIA GAVELA Hector (ATS-DO) — Created on 2024-09-17, 15:54

Seen. Thanks for this updated version.

Seen by PRICA Gorana (ATS-DO) — Created on 2024-09-19, 15:07

Comments by E. Daly sent by email.

✔ **Accepted** by THUREL Yves (SY-EPC) — Created on 2024-09-25, 05:14

Many thanks for this important document.

> These are pertinent observations, but for v1.1 we did not redefine the reference performance parameters (which would require a full update of the document, rather than the individual additions that we made). We advise users to always consider the reference performance parameters when using the specifications.

> IR7 specifications are indeed still including the FLUKA calculations for the descoped 11T TCLDs. This study is obsolete, but we did not modify the related section in v1.1 of the document.

> Efforts in radiation level monitoring during Pb ion operation have been ongoing last year and will continue in 2024, taking into account all losses (dominated by, but not limited to, BFPP and EMD).

EDMS comments (2) – Eamonn Daly

section	comments
overall	A very good and carefully developed specification.
1.3	The added note, "*although annual integrated luminosity in ATLAS and CMS are expected to be 10−20% lower than in the v1.0 specification, the same reference performance parameters have been retained, providing additional margin*" is reasonable (although, generally, are margins catalogued?)
2.3.5	A reasonable approach, with the use of the above luminosity margin, and choice of largest measured values to scale with. It is said that: "*Since the electronic racks in UPS14 and UPS16* ***are expected to be placed in the core*** *part of the galleries, represented by the positions where the 2023 BatMons were deployed, we define the radiation level specifications by relying solely on the BatMon measurements*" OK, but how is this information transferred to the designers/constructors of the racks: as a warning/constraint/requirement?
2.4.2	The specification here relies solely on FLUKA simulations. As stated, the radiation levels vary greatly over short distances. However, no margins are applied to the calculations. (Indeed, the conclusion later says "*Safety margins are not explicitly included, but several conservative assumptions are made to mitigate the risk that the levels during regular HL-LHC operation will exceed the specifications.*") Apart from the luminosity, these assumptions are not described for IR8 alcoves. So what risks remain that levels could be higher than specified? (see comment below on table 2.27) At what stage will actual measurements be available to validate the specifications?
2.8	Here there is a good discussion of margins and because the specification is supported by measurement, one can perhaps have more confidence. Table 2.27 shows a significantly higher (scaled) measured level than predicted.

→ Yes: at the beginning of each paragraph presenting the specifications for given areas, we include a table with (among other things) information about the safety margin strategy

→ The installation of electronics in the core of UPS14-16 is already planned by the relevant stakeholders. Our radiation level studies confirm the importance of this choice of position.

→ The FLUKA model used to define the IR8 specifications has been benchmarked with the available RadMon measurements, and unlike the point-like RadMons, FLUKA allows to cover the full 3D geometry of the area. When FLUKA indicates that high radiation level gradients are present, the higher values within the areas of interest are used to set the specification, effectively providing a safety margin.

→ For US450 specifications, the rescaled 2016 data and the FLUKA simulation represent independent contributions to the radiation levels (i.e., non-BGC and BGC radiation). Note that also in this case, the FLUKA model is benchmarked with data from Run 3 BGC operation.

1. Radiation level specification document v1.1: content and discussion of EDMS comments
2. WP10 status and work plan for the coming months

WP10 status and planned studies

- In the coming months, the following activities with HL relevance are foreseen within SY-STI-BMI:
  - Calculate the Total Ionizing Dose near PPS2 in IR5, for the possible installation of Peltier Thermoelectric Coolers, updating a preliminary result shared in early 2024 (see next slide).
  - Run FLUKA simulations of Pb ion losses in IR2 with the new TCLD installation (and the related orbit bump), to be compared with the measured radiation levels in the 2023 and 2024 ion runs.
  - Perform IR1-IR5 FLUKA calculations with layout v1.8, updating the previous results obtained with v1.5.
- A new QUEST (Daniel Prelipcean) has been hired to work on HL-LHC WP10 studies, beyond the scope of the specification document update

RQF2489239: PPS2 cooling - Peltier

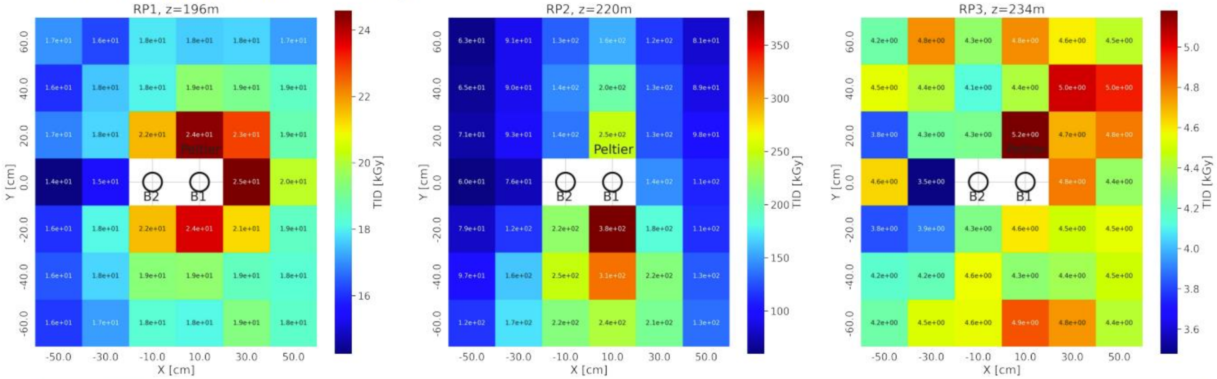
- Request received by the PPS2 team (Ksenia Shchelina et al.), handled as a ticket of the R2E Monitoring and Calculation Working Group (MCWG): radiation levels on Peltier Thermoelectric Coolers for PPS2.
- Preliminary results shared by A. Canesse based on FLUKA simulations by M. Sabaté Gilarte. More refined calculations are planned for this autumn with a more refined layout of the equipment.

Preliminary results (v1.5 layout)

TID for full HL-LHC (preliminary), cell above beampipe

- Z = 196m, max TID = 24 kGy
- Z = 220m, max TID = 250 kGy
- Z = 234m, max TID= 5.2 kGy

Note that the addition of the Roman Pots is expected to significantly change the TID at these locations



Auriane Canesse – SY-STI-BMI 3

Summary

- I covered the WP10 progress in the past year, focusing on the new release of the HL-LHC radiation level specification document (EDMS 2302154 v1.1)
- The document was circulated on August the 2nd, and the comments received so far have been addressed in this presentation
- The WP10 work in the coming months will focus on the implementation of FLUKA simulations for layout v1.8, IR2 studies of Pb ion radiation levels, and TID in the proximity of the PPS2 experiment in IR5

THANK YOU FOR YOUR ATTENTION

BACKUP

BatMon positions in UPS56