Update on HL-LHC radiation levels

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12th HL-LHC Collaboration Meeting, Uppsala (Sweden), 21st September 2022
https://indico.cern.ch/event/1161569/contributions/4921523/

WP10
Energy Deposition & R2E

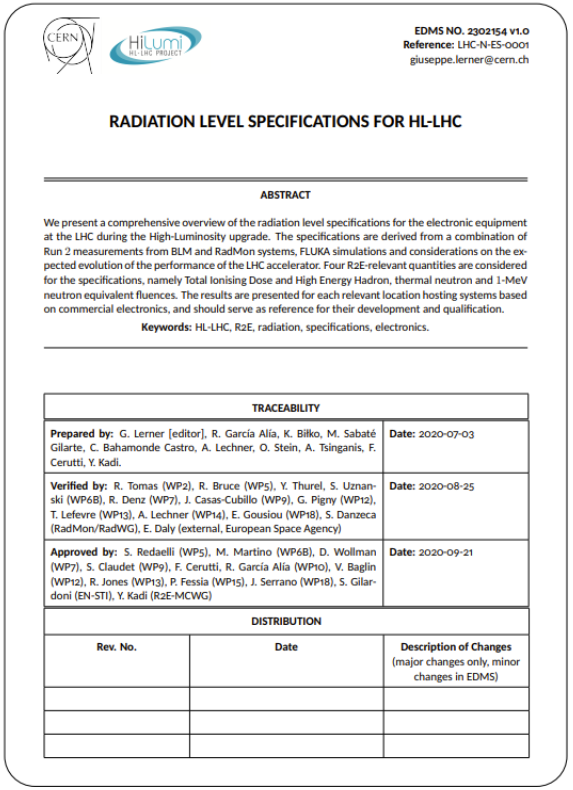
Introduction

- Review of WP10 activity aimed at providing HL-LHC radiation level specifications for R2E:
  1. Short recap of the baseline set of specifications for electronics, as included in EDMS 2302154
  2. New studies carried out over the last ~year:
     a. **IR1-IR5**: radiation level specifications on cables, TID in the UPRs and on the ODH detectors
     b. **IR4**: radiation levels from beam-gas detectors
     c. **IR7**: radiation levels on the top floor of UJ76
     d. **IR8**: FLUKA radiation levels in the LHC tunnel and shielded alcoves

HL-LHC radiation level specification document

- Radiation level specifications for electronics: EDMS 2302154 (09/2020)
- Covered in EDMS 2302154:
  - LHC DS and arcs, at the reference position of electronic racks (i.e., below the beamline)
  - Shielded alcoves (with few exceptions)
- Not covered in EDMS 2302154:
  - LSS areas (typically not hosting electronics)
  - Radiation levels on equipment on (or close to) the beamline

→ object of dedicated studies described in this talk



EDMS NO. 2302154 v1.0
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:** 2020-08-25
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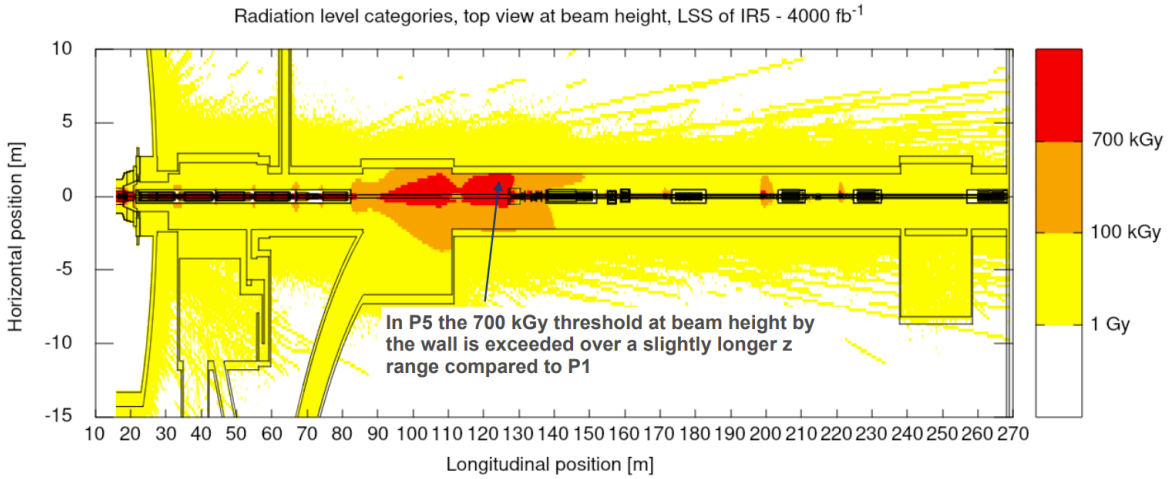
DISTRIBUTION		
Rev. No.	**Date**	**Description of Changes** (major changes only, minor changes in EDMS)

Radiation level specifications on cables

- **HL-LHC cable categories** defined based on FLUKA simulations in IR1-IR5 by M. Sabaté Gilarte, with a safety factor of 5 due to dose rate effects



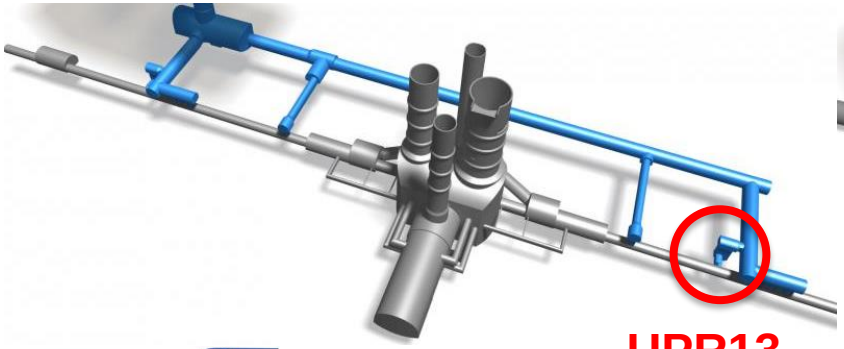
- **Standard cables**, qualified up to 500 kGy (to be used up to 100 kGy)
- **Intermediate cables**, ideally qualified at least up to 3.5 MGy (i.e. ok up to 700 kGy in operation)
- **Rad-hard cables**, qualified up to 10 MGy (ok up to 2 MGy)

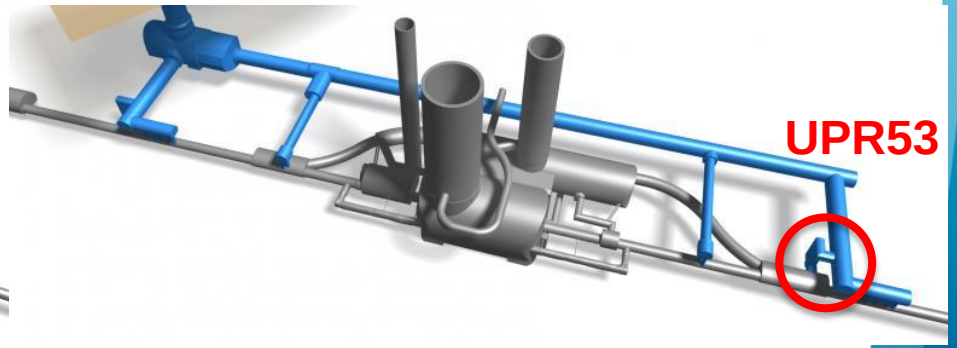
G. Lerner, WP15 meeting 09/2021

More on this in the talk by J. Gascon

IP1-IP5: TID in the UPRs

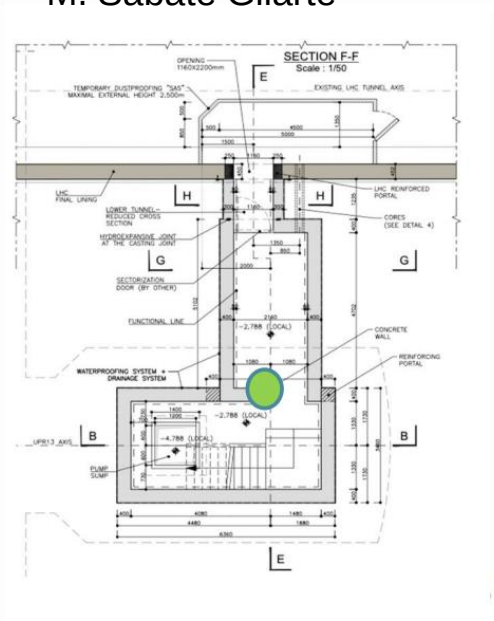
- New **FLUKA simulations of Total Ionizing Dose (TID) at the ground floor of the UPRs** (M. Sabate Gilarte)
- Requested by EN-CV for fire damper equipment (EDMS 2599444)
- Focus on **UPRs 13-53** (left of P1-P5, closer to the IP center compared to UPRs 17-57):

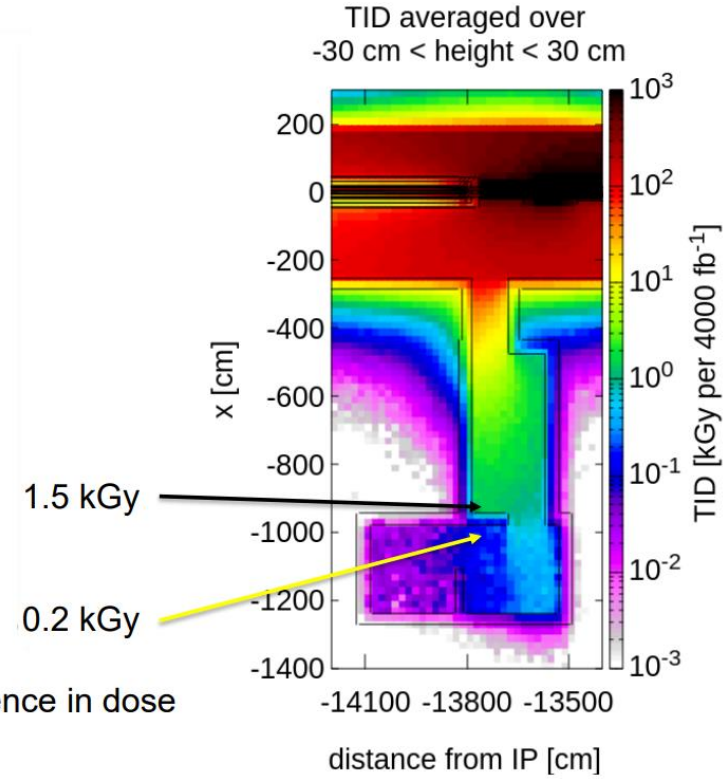




UPR13 FLUKA results – EDMS 2599444

M. Sabaté Gilarte





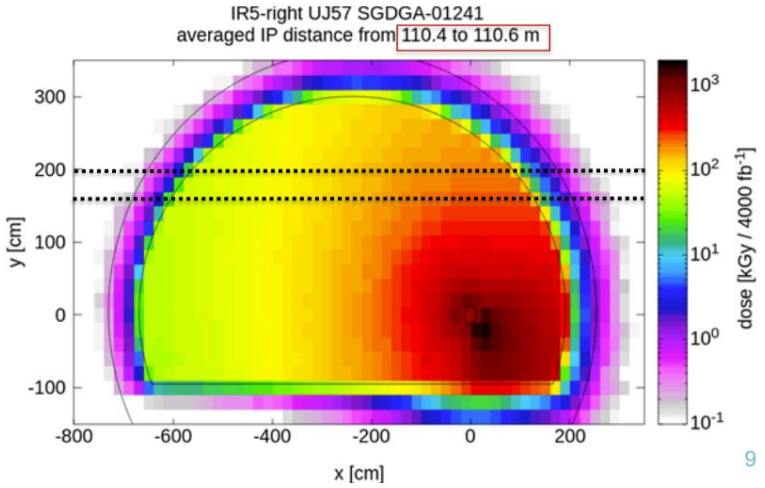
There is an important difference in dose level in front/back the wall.

- Significant TID in UPR13, with highest levels close to the LHC tunnel
- The TID in UPR17 is much lower, due to the larger distance from IP1
- If possible, we recommend installing the equipment behind the wall indicated in the figure

Similar situation in UPR53 (see backup)

IR1-IR5 (and more): TID on ODH sensors and flashing lights

- TID specifications for ODH detectors and flashing lights, requested by EN-AA (EDMS 2718033-2636143)
- Highest TID in IR1-IR5, reaching up to 250 kGy / 4000 fb^{-1} near UJ53-57, much lower TID in other locations



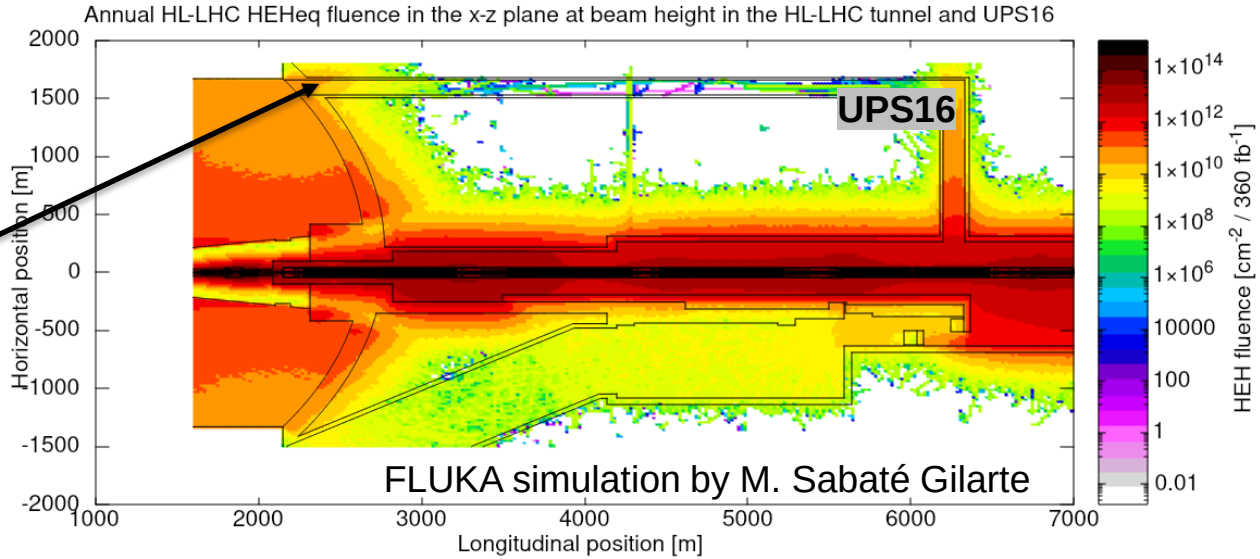
M. Sabaté Gilarte, M. Cecchetto

	Detector name	Dose [kGy] at 1.6 m*	Dose [kGy] at 2 m*
IR5 – left	SGDGA-01045	75	75
UJ53	**SGDGA-01044**	**220**	63
IR5 – left	SGDGA-01047	21	--
RZ54	SGDGA-01046	16	15
IR5 – right	SGDGA-01239	47	27
UJ56	SGDGA-01240	31	23
IR5 - right	SGDGA-01242	17	--
UJ57	**SGDGA-01241**	**231**	190

IR1: UPS16 radiation levels

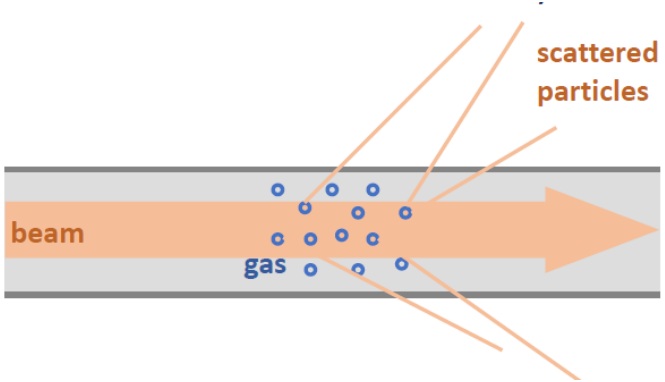
- UPS16 is foreseen to host FRAS equipment (DIOT, electronics)
- The FLUKA simulations can model the leakage of radiation from the tunnel, but the leakage from the ATLAS cavern is inaccurate (as the ATLAS detector is not included in the geometry

→ BatMon deployed in 2022 on the ATLAS side of UPS16 (waiting for data)



IR4: beam-gas detectors as a radiation source

- FLUKA simulations have been carried out to analyze the radiation levels generated by the beam-gas detectors in IP4
- Presentation at 150th TCC (February 2022) by D. Prelipcean
- Radiation levels proportional to the beam intensity and to the integral of the pressure profile along z:



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

BGV operation

(HL-)LHC operation

Injected gas density profile

Interaction cross section - Gas species (Neon)

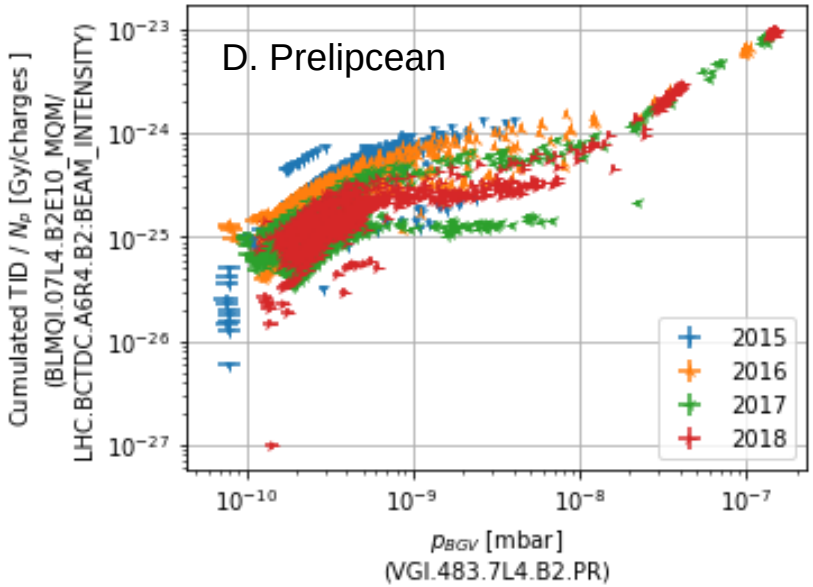
Beam intensity

LHC revolution frequency (constant)

Beam energy

IR4: Run 2 BLM TID near the BGV

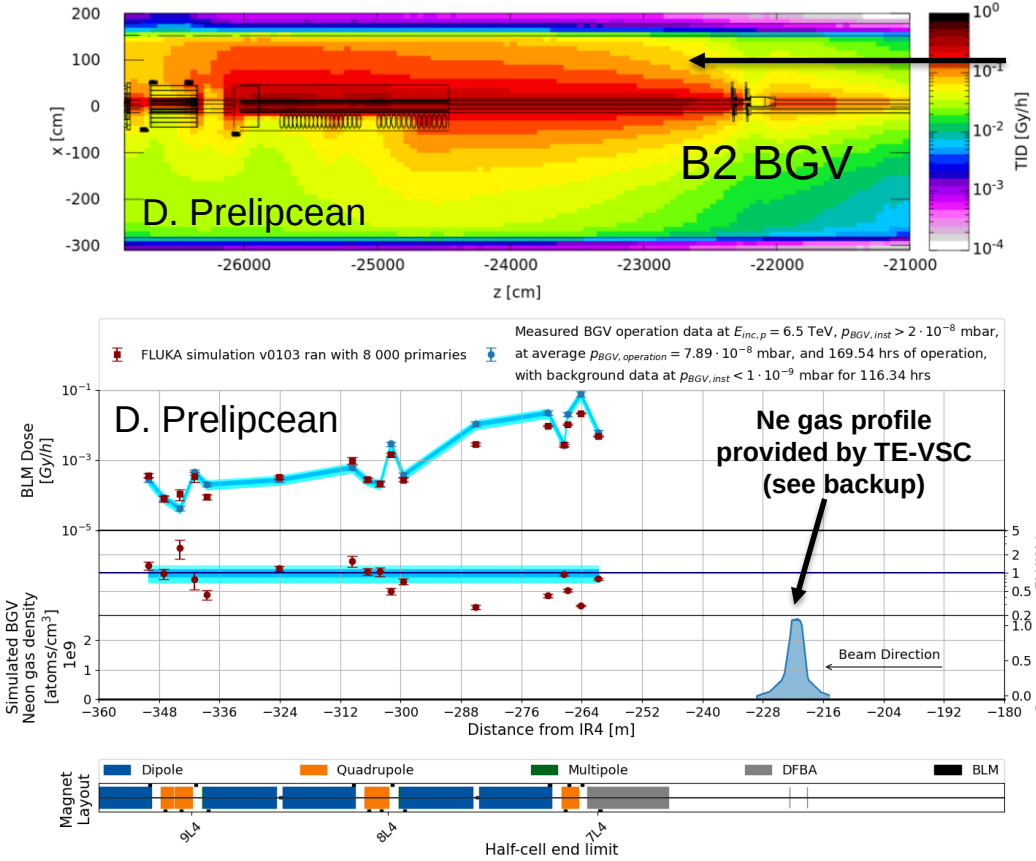
- Clear correlation between BLM TID data downstream of the BGV prototype and the BGV gas pressure in Run 2 → proof that the BGV is the main source of radiation in its proximity



- Similar analysis to be carried out with BGC data in Run 3, as soon as they become fully available

IR4: Run 2 FLUKA-data comparison for BLMs

- Run 2 FLUKA simulation of B2 BGV, with radiation shower towards the DS
- Improved agreement with Run 2 BLM data compared to the results shown at the TCC, but more investigations ongoing
- Peak measured BLM dose around 0.1 Gy/h (underestimated by FLUKA)
  → **~20 Gy for ~200h of BGV operation per year**

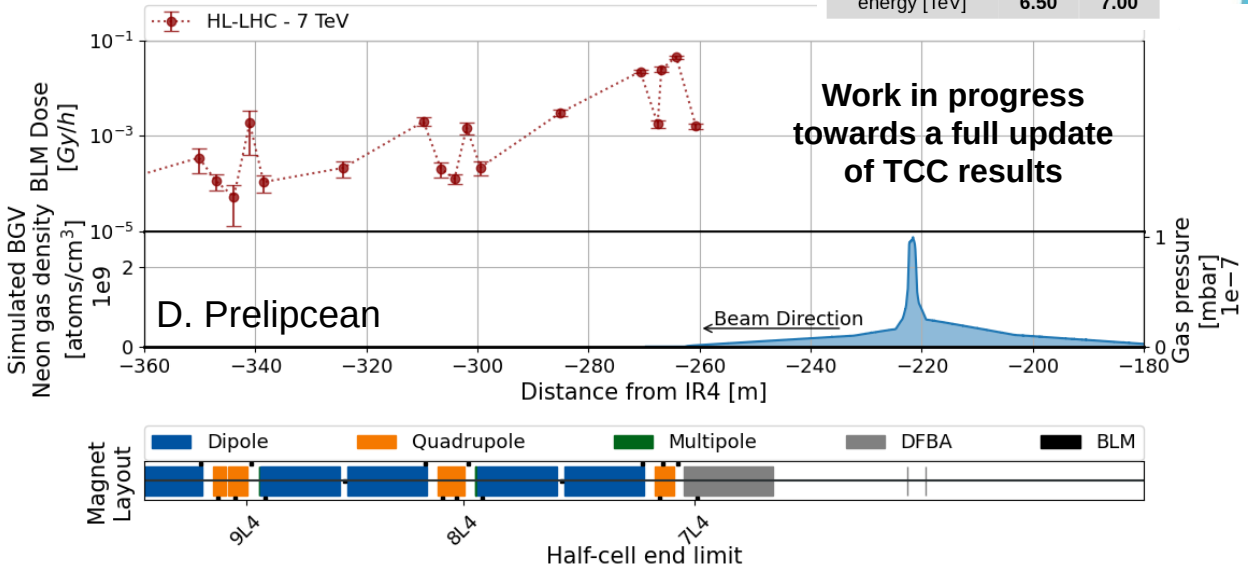


IR4: HL-LHC projections (preliminary)

- HL-LHC FLUKA simulation of BLM TID per hour, using an updated gas profile
- Peak BLM TID below 0.1 Gy/h, but the underestimation in Run 2 data signals that higher levels may be reached (investigation in progress)

	LHC Run 2	HL-LHC
pressure [1e-7 mbar]	0.77	1
operational time [hrs]	169.80	400

	LHC Run 2	HL-LHC
revolution frequency [Hz]	11245	
number of bunches	2500	2760
protons per bunch [1e11]	1.20	2.30
total_charges [1e14]	**3.00**	**6.35**
charge/s [1e18]	3.37	7.14
energy [TeV]	**6.50**	**7.00**



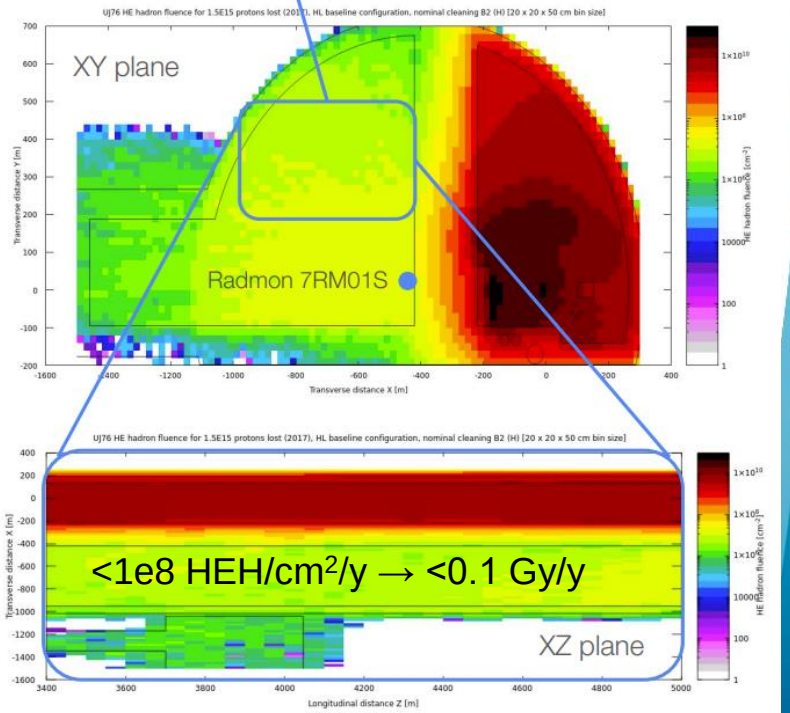
IR7: radiation levels in UJ76 at L1

A. Waets

- Request by SY-BI for DOROS equipment in UJ76 L1 (EDMS 2715794)
- FLUKA simulations by A. Waets combined with projections of integrated beam losses in IR7 lead us to set a conservative upper limit of 12 Gy over the full HL-LHC lifetime
- A BatMon measurement this year (by BE-CEM) confirmed that this is a low-radiation area (<10^7 HEH/cm^2, <10mGy in around 1 month of operation)

Location of electronics racks on top floor of UJ76

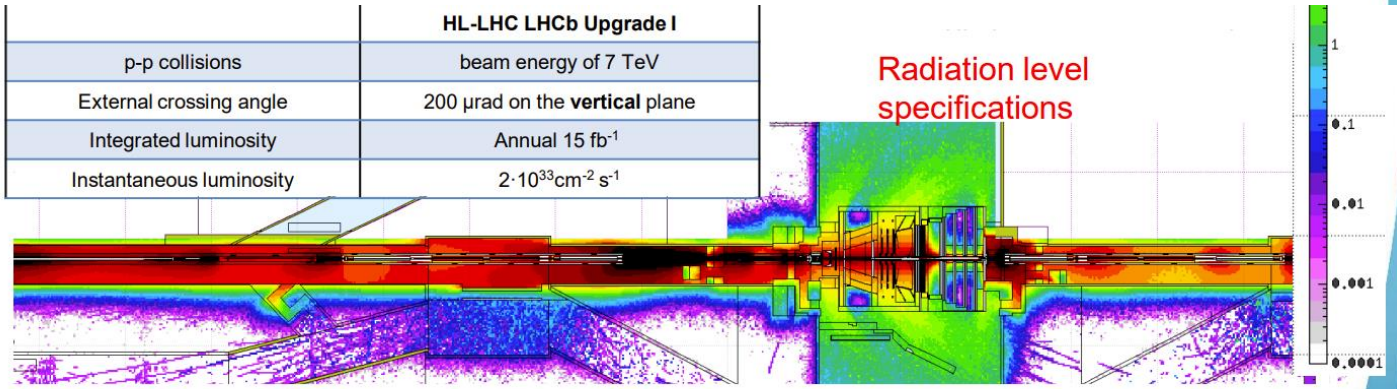
HEH-eq fluence in UJ76 for 1.5e15 lost protons in IR7



IR8: previous work

- A comprehensive FLUKA study covering the radiation levels in IR8 (LHCb) has been presented at the 11th HL-LHC Collaboration meeting by A. Ciccotelli (2021 - link)
- This included updated radiation level specifications with respect to EDMS 2302154
- More has been done in the last year (see next slides)

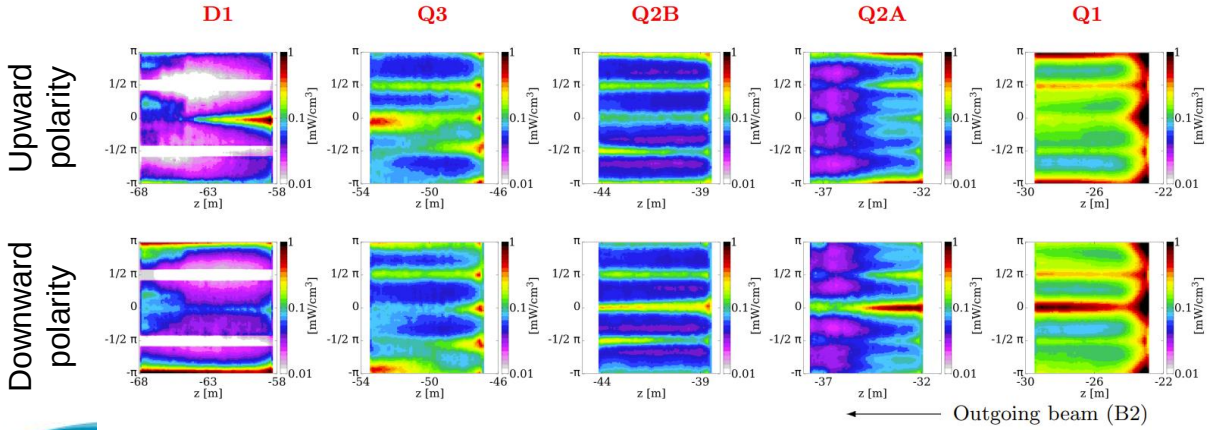
	HL-LHC LHCb Upgrade I
p-p collisions	beam energy of 7 TeV
External crossing angle	200 μrad on the **vertical** plane
Integrated luminosity	Annual 15 fb^{-1}
Instantaneous luminosity	$2 \cdot 10^{33} cm^{-2} s^{-1}$



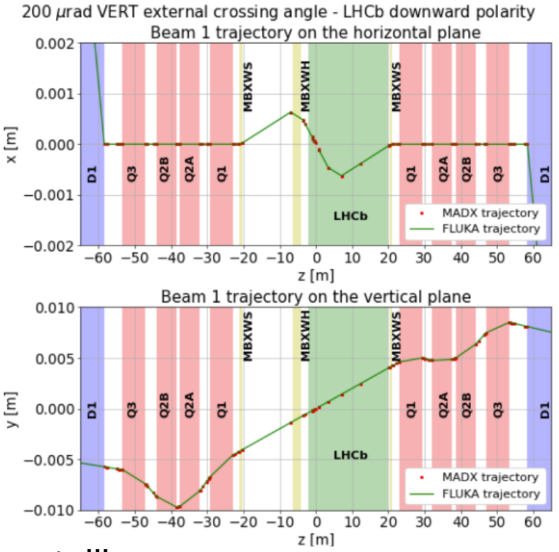
Total ionizing dose for Run3-4 15fb^{-1}/y

IR8 energy deposition studies

- Recent paper (CDS 2813955) on energy deposition in IR8
- Important result: crossing angle and LHCb spectrometer polarity affect the radiation levels in the tunnel and in nearby alcoves (e.g., the UAs)
  → important for the specifications!



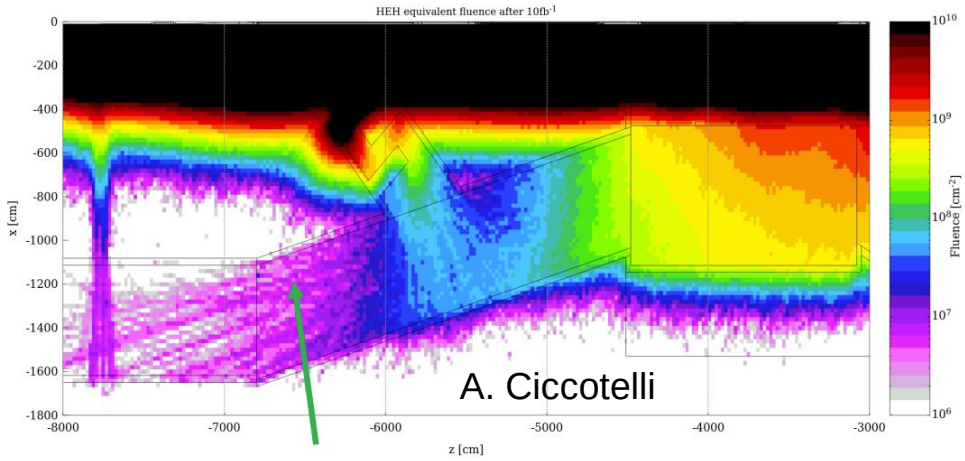
Vertical crossing



A. Ciccotelli

IR8: radiation level specifications in the UAs

- Radiation level request by SY-BI for BPM electronics (EDMS 2663182) covering rack position BY01 in UA23-27 (IR2, low radiation levels) and US83-87 (IR8)



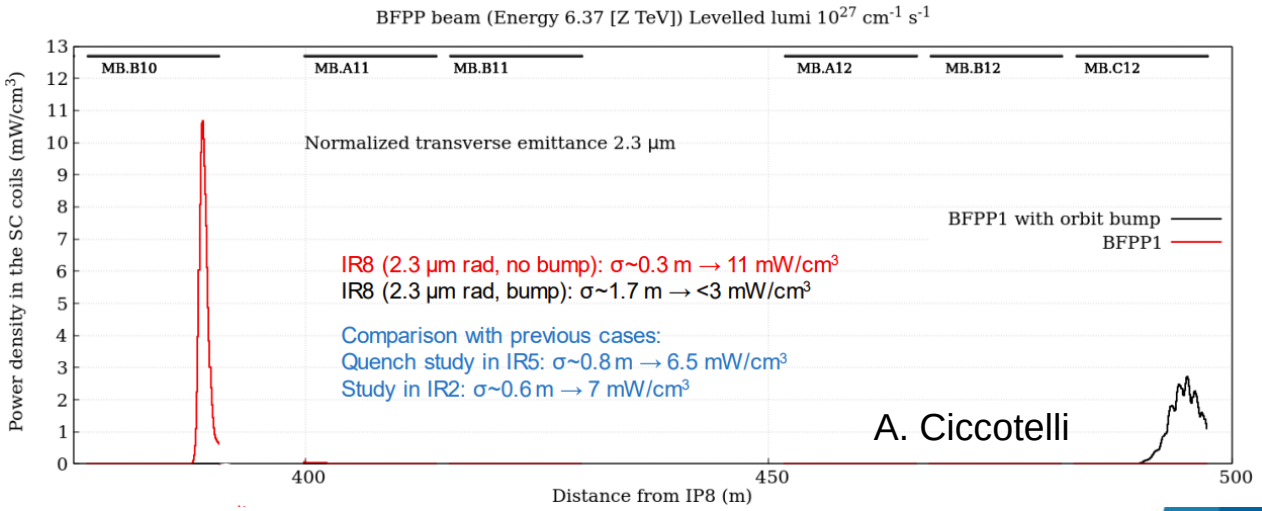
8·10⁶ HEH/cm²/y at BY01 rack position

- High radiation gradient in the UAs, with relatively higher HEH-eq fluence at the entrance (and near cable ducts)
- Caveat: results obtained for downward polarity, while full specifications require averaging with the upward case (to be done)

IP8 Pb-Pb operation with orbit bumps

- FLUKA simulations of BFPP peak during Pb-Pb operation in good agreement with Run 2 BLM data (see talk by A. Ciccotelli)
- Orbit bumps to be used in HL-LHC, reducing the peak power density in the magnet coils by ~3x

- A reduction of the peak TID in the DS is expected as a result, but different equipment will be exposed

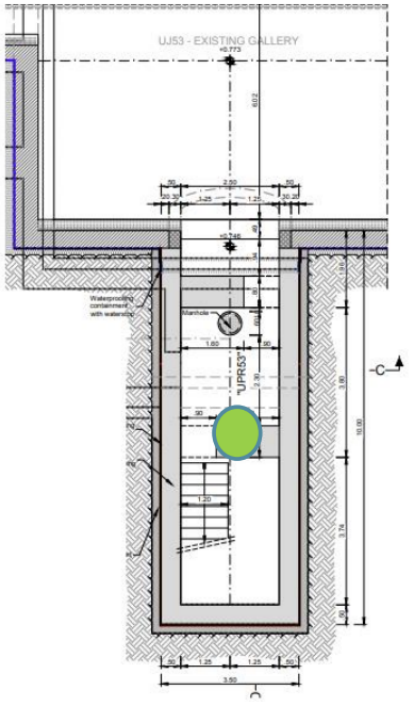


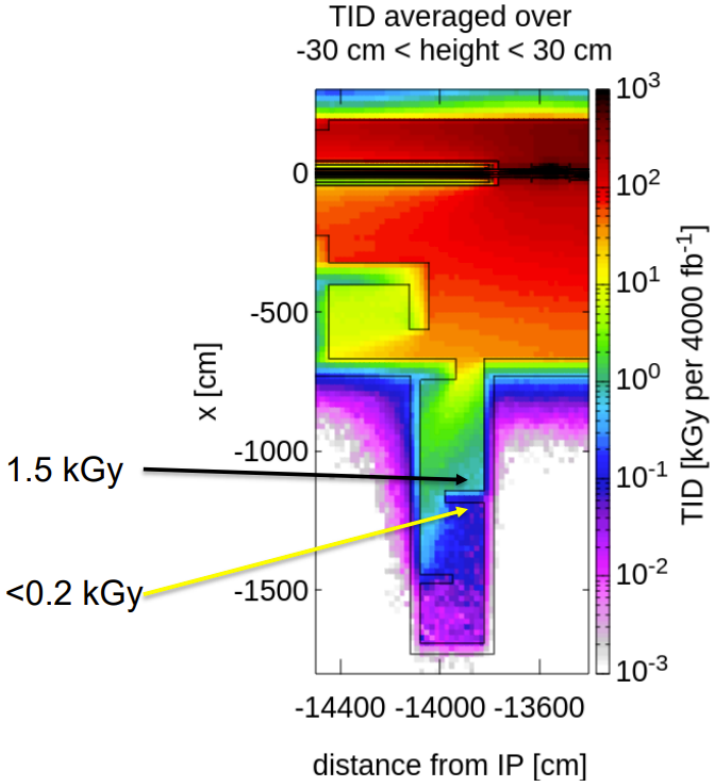
Summary

- Even after the release of the specification document in 2020 (EDMS 2302154) WP10 has continued to perform multiple analyses with different purposes:
  - Targeting areas/devices not covered in the specification document (e.g., cables and LSS equipment in IR1-IR5)
  - Performing new analyses not available at the time (e.g., IR4, IR8)
  - Addressing specific needs/requests (e.g., UJ76 in IR7)
- The work will continue over the next years, with special attention devoted to the validation of HL-LHC specifications using Run 3 data
- We also plan to update the specification document with new locations (e.g., IR4, IR8) once the related studies are completed

BACKUP

UPR53 FLUKA results – EDMS 2599444





- Similar situation in IR5 (UPR53 ground floor)
- The TID in UPR57 is much lower due to the larger distance from the IP5
- The best position for the equipment is behind the wall shown in the figure

IR4: BGV gas profiles for Run 2 and HL-LHC

- BGV gas profile provided by TE-VSC for:
  - BGV demonstrator (Run 2)
  - HL-LHC BGV only
  - HL-LHC BGV plus baseline residual gas in the beam pipe