Expected radiation level evolution in the LHCb insertion

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Energy deposition & R2E

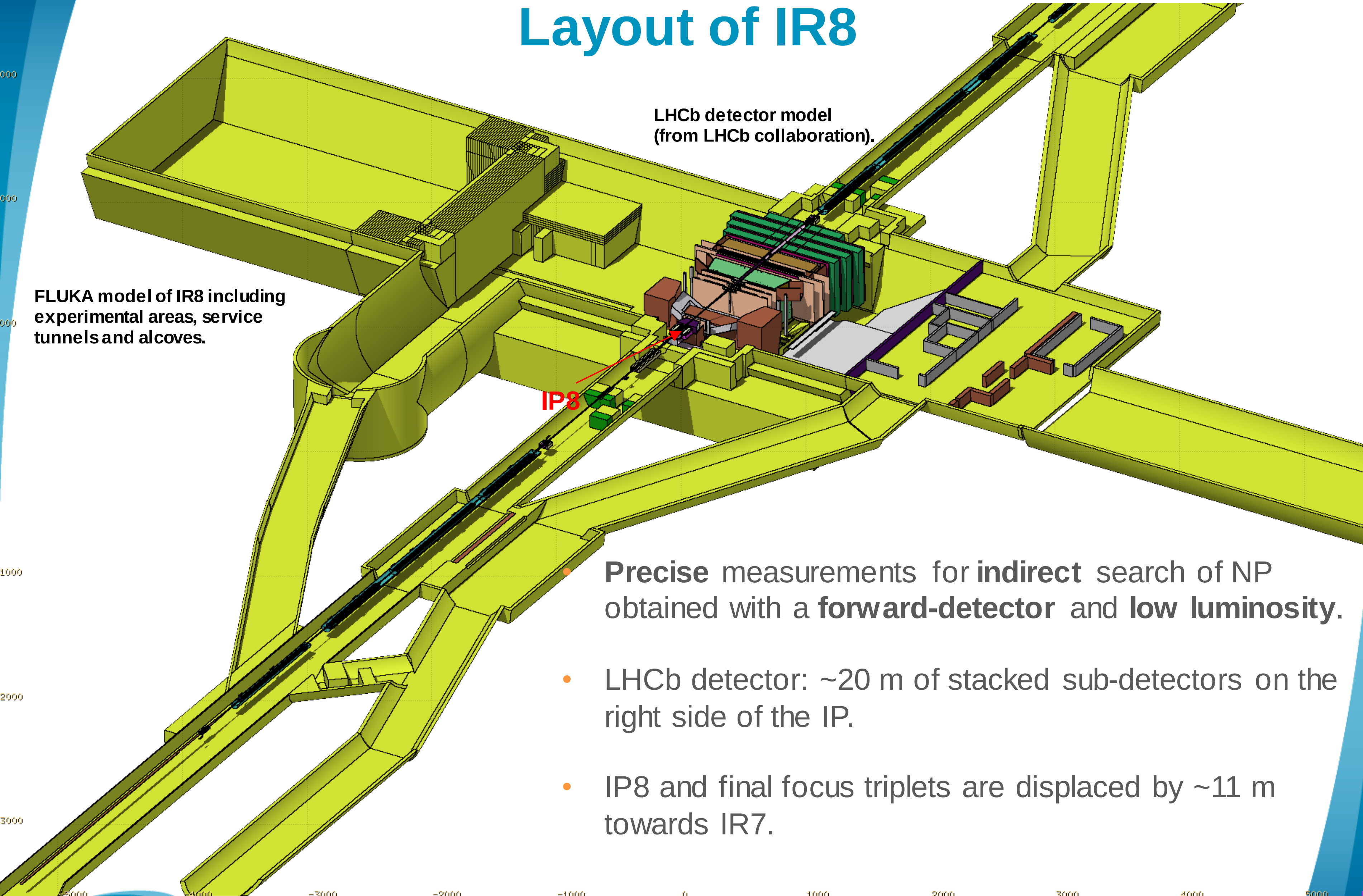
WP10

11th HL-LHC Collaboration Meeting **21 October 2021**

Overview

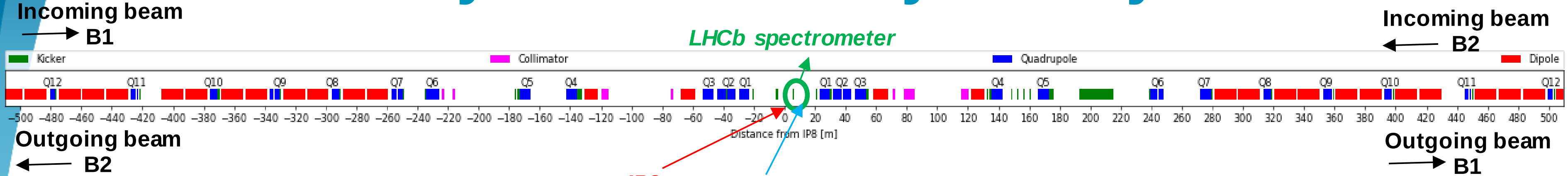
- Specificity of IR8.
- Validation of FLUKA model.
- Expected impact of Upgrade I of LHCb on radiation levels (HL-LHC baseline).
- Outlook and conclusions.

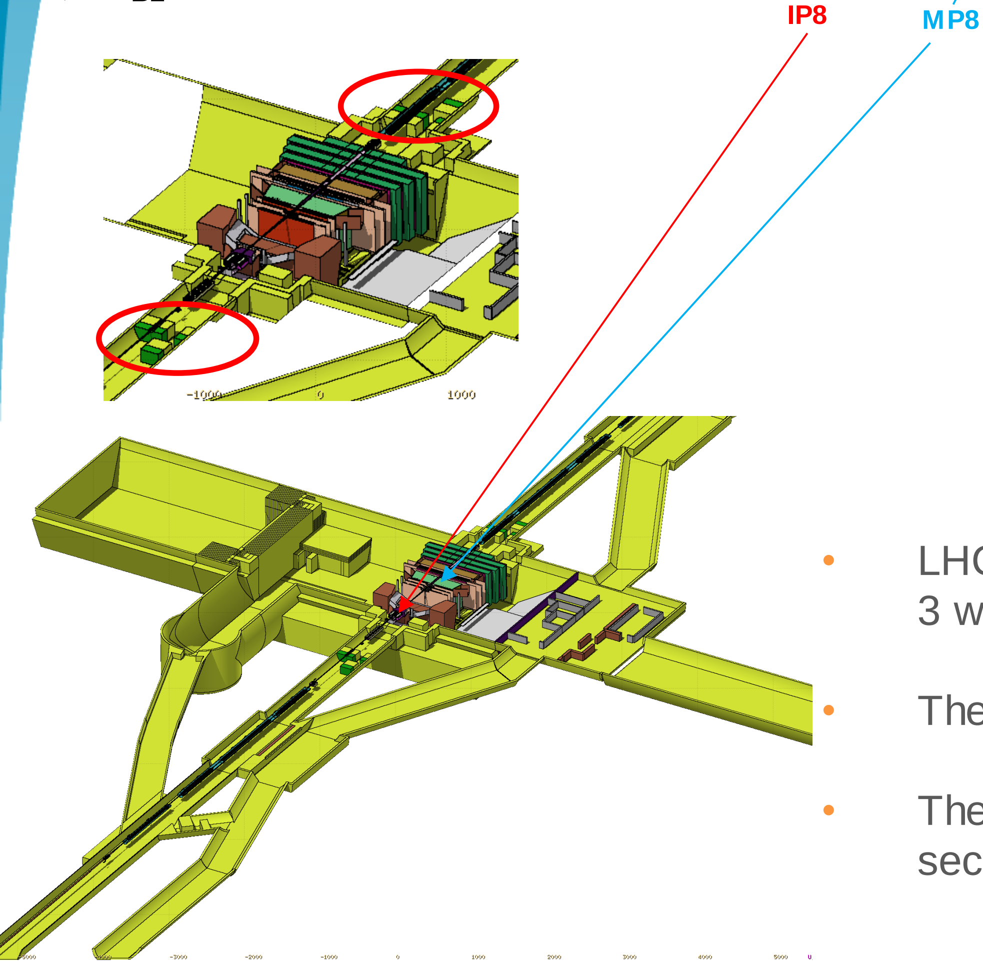
Layout of IR8

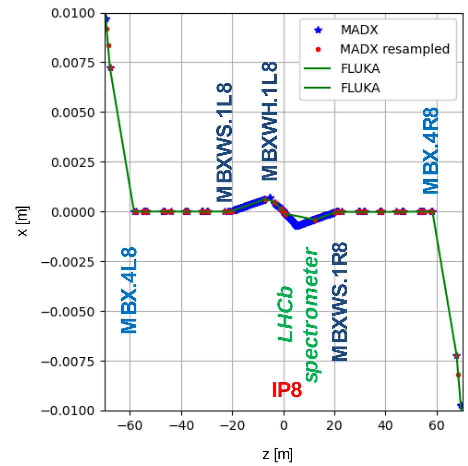


- **Precise** measurements for **indirect** search of NP obtained with a **forward-detector** and **low luminosity**.
- LHCb detector: ~20 m of stacked sub-detectors on the right side of the IP.
- IP8 and final focus triplets are displaced by ~11 m towards IR7.

Layout of IR8 - asymmetry





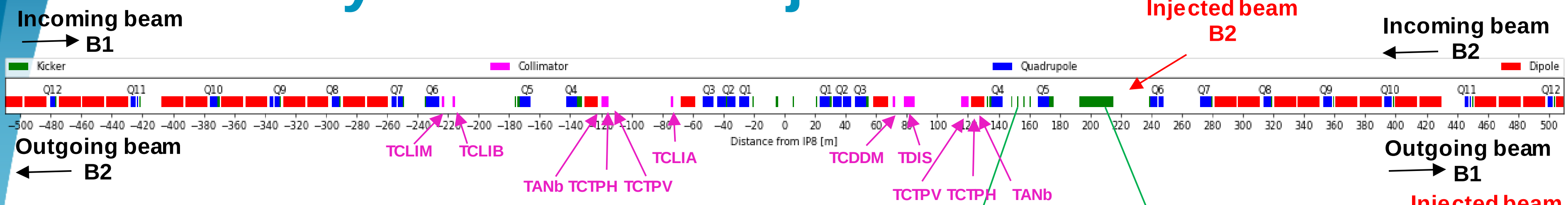


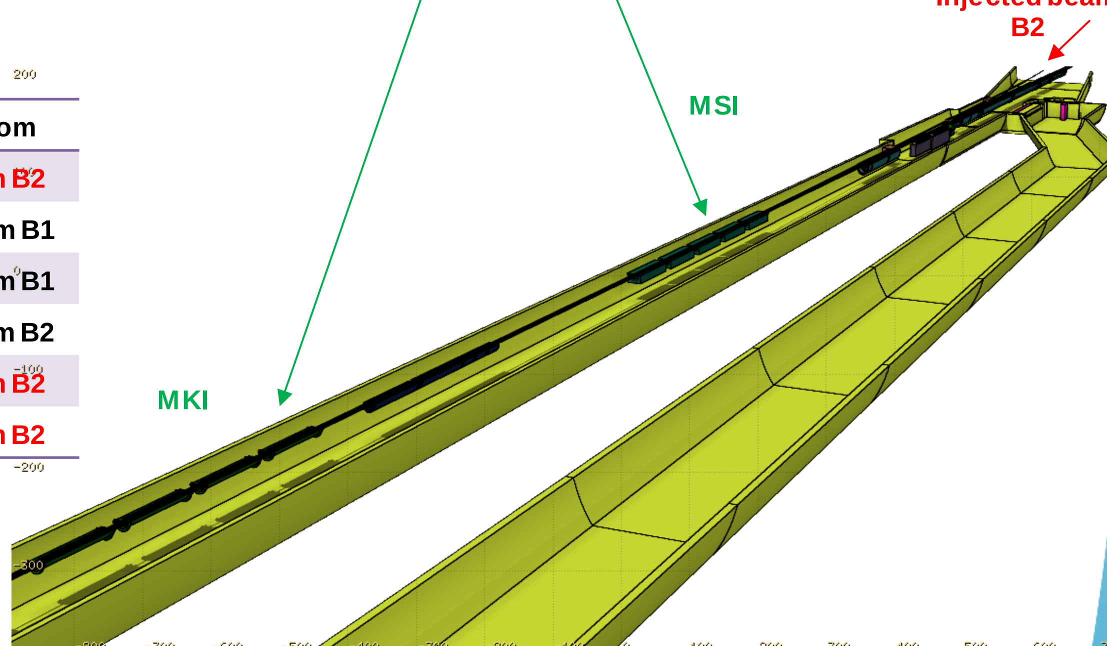
Beam 1 trajectory calculated with FLUKA in agreement with MADX within few μm on the horizontal plane.

LHCb dipole downward polarity

- LHCb spectrometer compensated by a system of 3 warm dipole magnets just upstream of the Q1.
- The shift of the IP is recuperated before the DS.
- The infrastructure and layout of the matching section are asymmetric with respect to the IP8.

Layout of IR8 – injection elements





Collimators	Distance from IP8 [m]	Protection from
TCLIA.4L8	-73	**Injected beam B2**
TCTPV.4L8	-115	**Incoming beam B1**
TCTPH.4L8	-117	**Incoming beam B1**
TANB.4L8	-120	**Outgoing beam B2**
TCLIB.6L8	-217	**Injected beam B2**
TCLIM.6L8	-223	**Injected beam B2**

- Injection elements for B2 on the right side

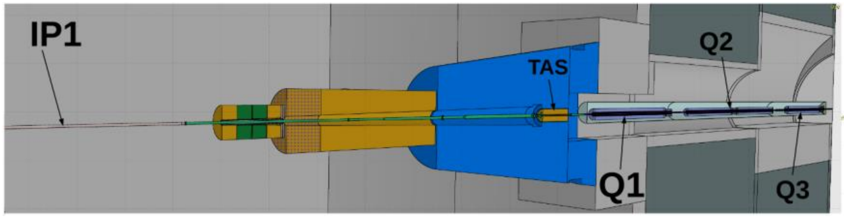
Collimators	Distance from IP8 [m]	Protection from
TCDDM.4R8	71	**Injected beam B2**
TDIS.4R8.	84	**Injected beam B2**
TCTPH.4R8	117	**Incoming beam B2**
TCTPV.4R8	115	**Incoming beam B2**
TANB.4R8	120	**Outgoing beam B1**

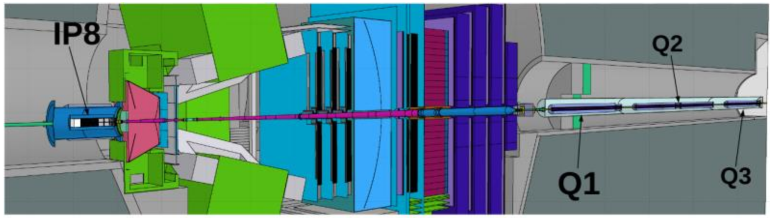
Layout of IR8 – target luminosity

Luminosity delivered for proton operations	Peak instantaneous Luminosity [$cm^{-2}s^{-1}$]		Integrated Luminosity [fb^{-1}]	
Experiment	HL-LHC	LHC	Max. annual HL-LHC	LHC (2018)
ATLAS	5×10^{34}	2×10^{34}	360	65.2
CMS	5×10^{34}	2×10^{34}	360	66.9
ALICE	1×10^{31}	1×10^{31}	0.1	0.03
LHCb	Upgrade I of LHCb **2×10^{33}**	**4×10^{32}**	Upgrade I of LHCb **15**	**2.46**

https://cds.cern.ch/record/1972604/files/CERN-ACC-2014-0300.pdf
https://edms.cern.ch/document/2302154/1.0

- Unlike IR1 and IR5, the TAS and TAN absorbers and TCL collimators were not necessary in IR8 for Run1 and Run2





https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.071003

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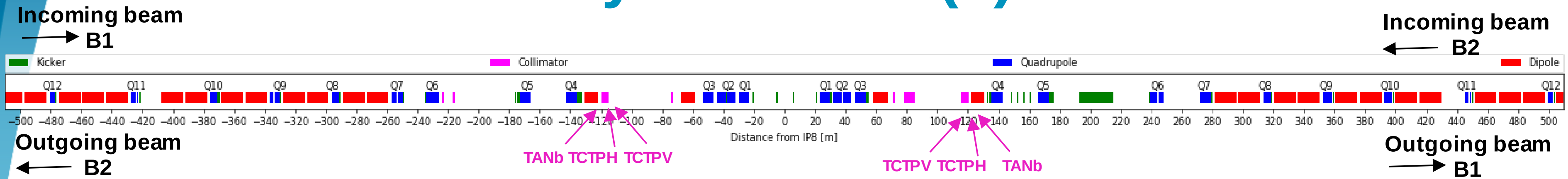
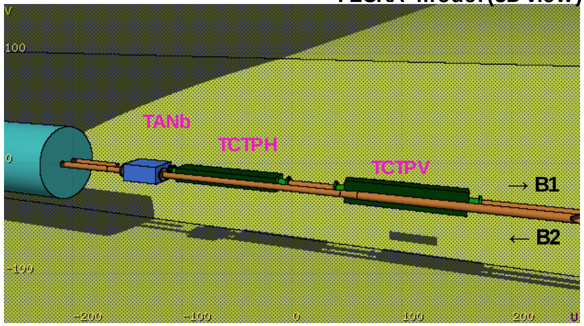
Layout of IR8 (3)



- A **TANb** absorber installed during LS2 allows to operate at the foreseen increase of luminosity operation during Run3.
  EDMS 1961576
  EDMS 1960537

CERN Layout database

FLUKA model (3D view)



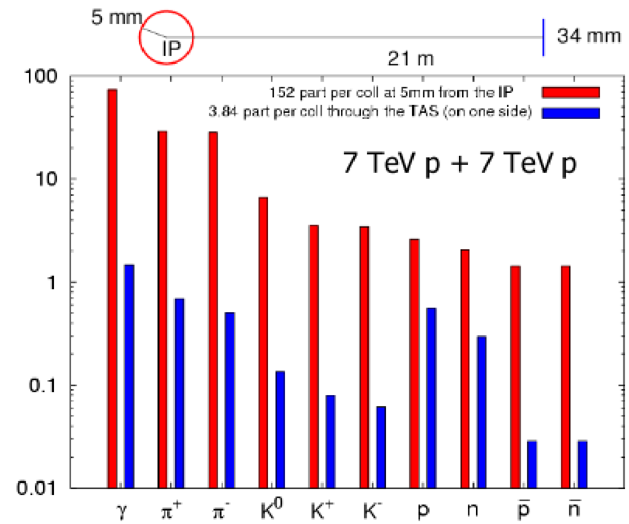
- The TAS and TCL collimators are still not required in IR8 for the expected luminosity operation up to 2×10^{33} $cm^{-2}s^{-1}$ and 50 fb^{-1}.

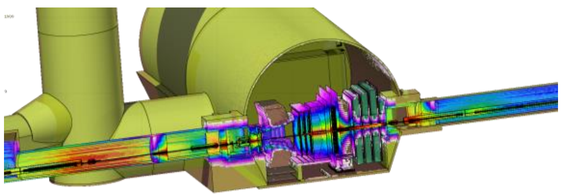
- The proposed Upgrade II of LHCb aims to approach 1.5×10^{34} $cm^{-2}s^{-1}$ and 50 fb^{-1}/y, requiring to evaluate possible mitigation options.

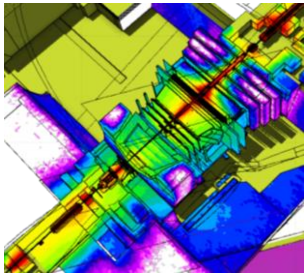
Simulation settings

	Run2	HL-LHC LHCb Upgrade I
p-p collisions	beam energy of 6.5 TeV	beam energy of 7 TeV
External crossing angle	250 μrad on the **horizontal** plane	200 μrad on the **vertical** plane
Integrated luminosity	6.6 fb^{-1}	Annual 15 fb^{-1*} Annual 10 fb^{-1} (Run3)
Instantaneous luminosity	$4 \cdot 10^{32} cm^{-2} s^{-1}$	$2 \cdot 10^{33} cm^{-2} s^{-1}$
*Annual HL-LHC performance parameters for the R2E radiation level specification document link		

Collision debris





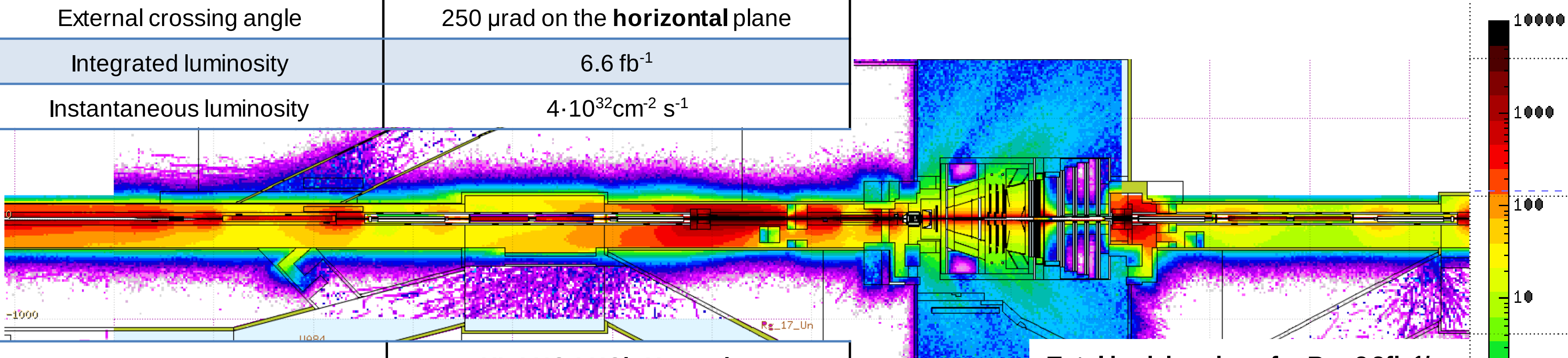


- Radiation shower in IR8 dominated by inelastic nuclear interactions: Cross section $\sigma_{inel} = 80\ mb$
- The most energetic debris is scattered at small angle and propagates along the beam line.
- This debris impacts on the machine elements (on warm compensators, superconducting magnets of the triplet and D1, MS, DS), determining radiation levels in the nearby locations (and on electronics equipment).

Simulation scenarios

	Run2
p-p collisions	beam energy of 6.5 TeV
External crossing angle	250 μrad on the **horizontal** plane
Integrated luminosity	6.6 fb^{-1}
Instantaneous luminosity	$4 \cdot 10^{32} cm^{-2}\ s^{-1}$

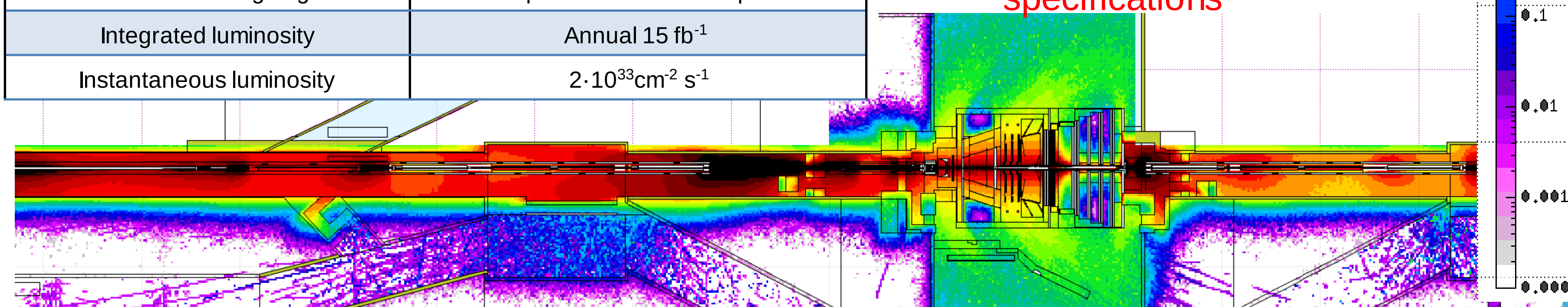
Benchmark and validation of the FLUKA model



Total ionizing dose for Run2 2fb^{-1}/y

	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	$2 \cdot 10^{33} cm^{-2}\ s^{-1}$

Radiation level specifications



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

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Validation studies for BLM

Validation of energy deposition simulations for proton and heavy ion losses in the CERN Large Hadron Collider

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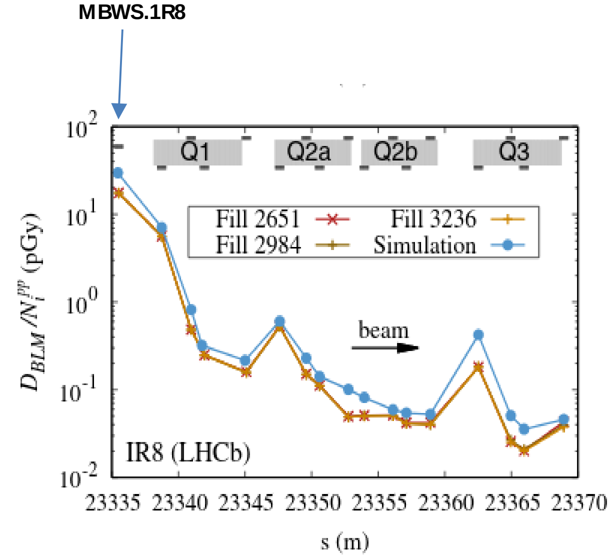
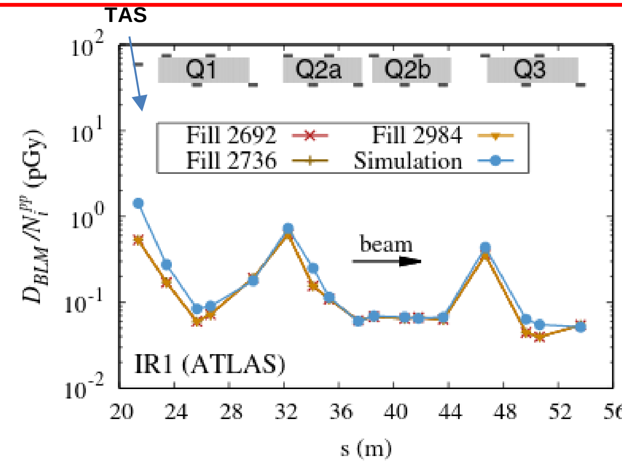
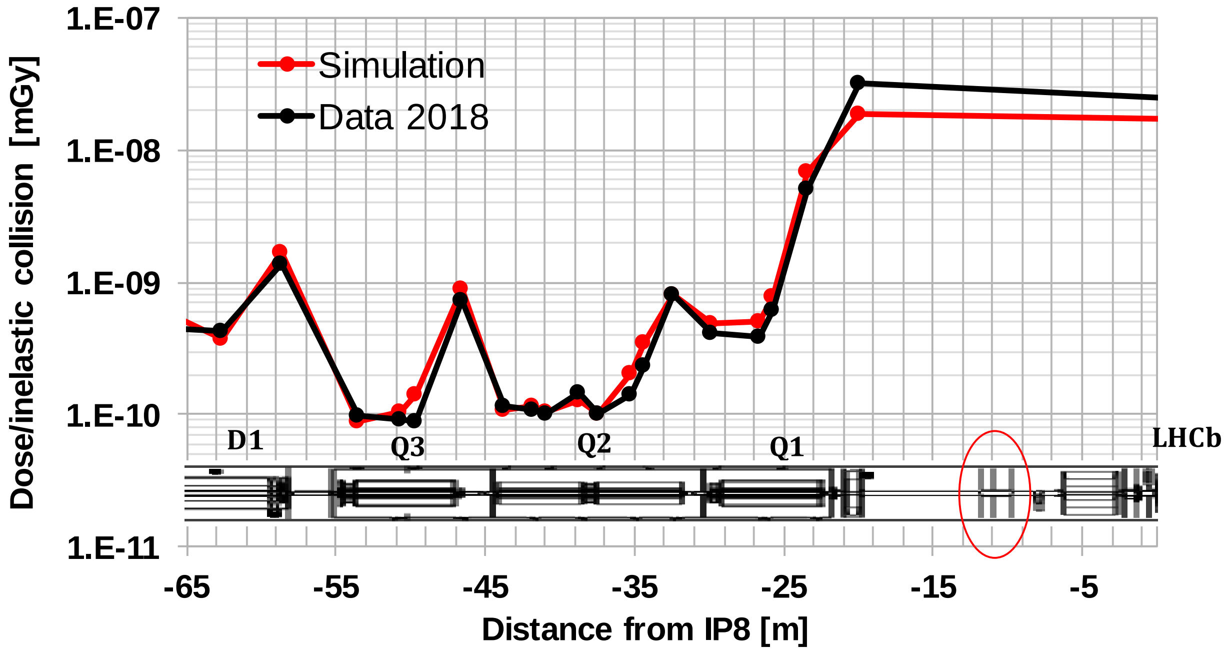


- A benchmark study has already been published for **Run1** including both IR1 and IR8. On average, simulated signals ~20% higher than measured one in IR1 and 50% in IR8.
- Overestimation of measured values due to secondary particles generated upstream of the Q1 which travel outside of the magnets.
- If the contribution of these secondary particles is neglected, most FLUKA-predicted BLM signals would be lower than the measurements.

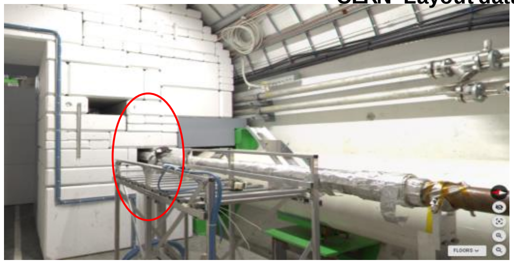


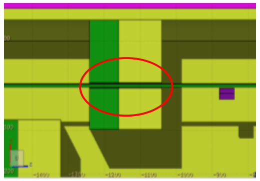
https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.22.071003

Run2: Validation studies based on BLM

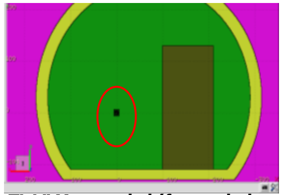


CERN Layout database





FLUKA model (top view)



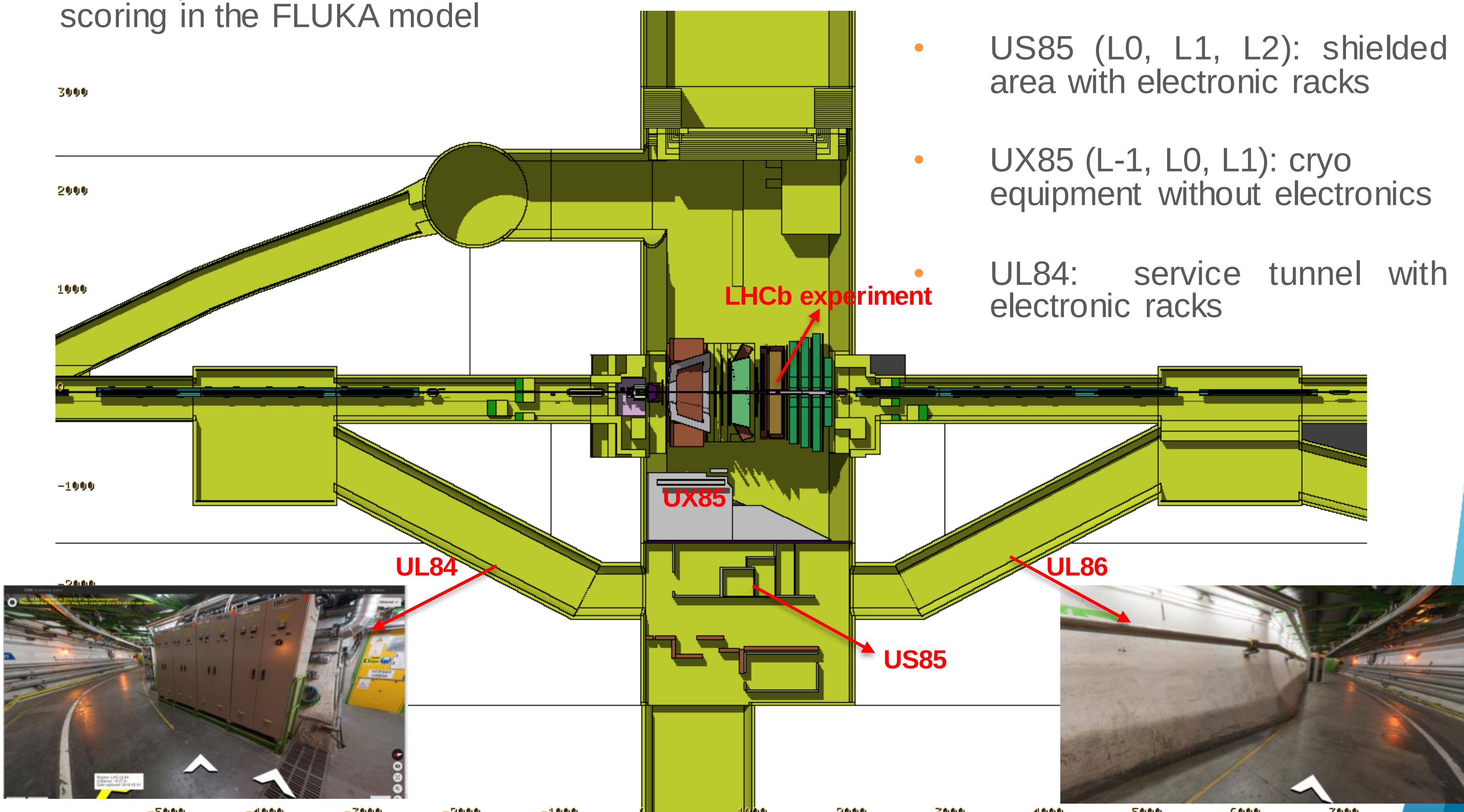
FLUKA model (frontal view)

- The FLUKA model has been refined on the left side where the discrepacy between simulated and measured data in Run 2 was more evident.
- Most BLM signals at the triplet are in agreement with the measurements after improving the FLUKA model of the shielding wall between MBWLH and MBLWS.
- On average, simulated signals are ~20% higher than measured ones in IR8 left side.
- Moreover, a reasonable agreement is found between HEH fluence simulation and Radmon measurements (EDMS 2424228).

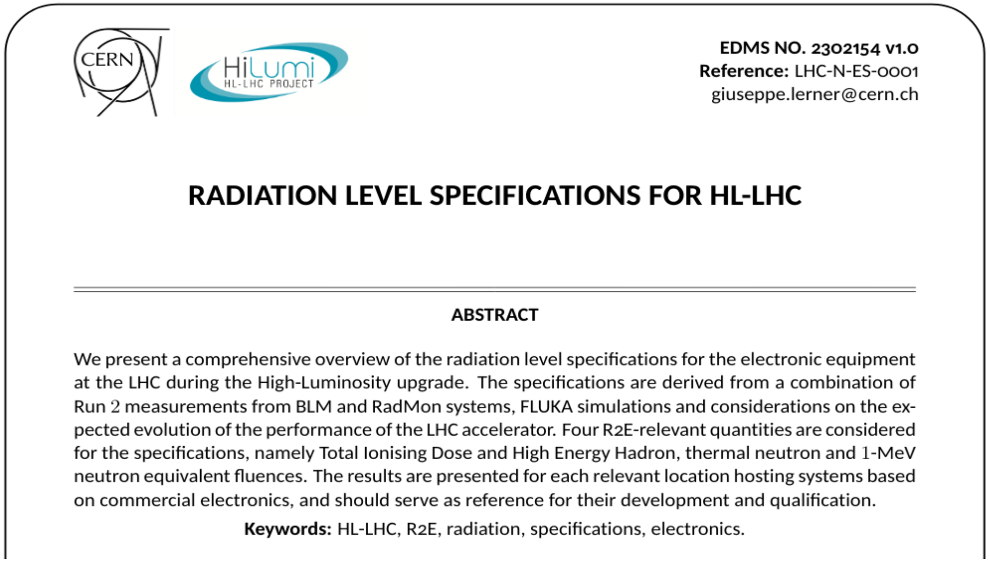
Run2: radiation studies in the LHCb experimental area

- HEH equivant fluence from 3D scoring in the FLUKA model

- Radmon placed in:
  - US85 (L0, L1, L2): shielded area with electronic racks
  - UX85 (L-1, L0, L1): cryo equipment without electronics
  - UL84: service tunnel with electronic racks



HL-LHC Radiation level specification document


EDMS NO. 2302154 v1.0
Reference: LHC-N-ES-0001
giuseppe.lerner@cern.ch

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.

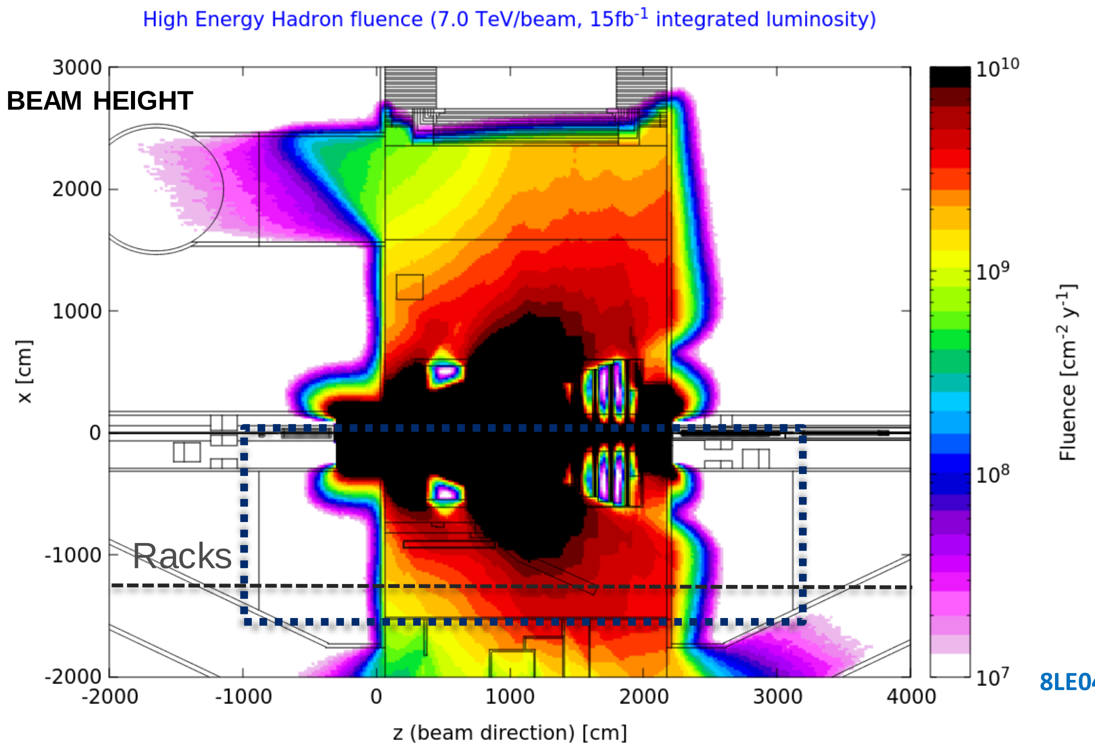
Keywords: HL-LHC, R2E, radiation, specifications, electronics.

EDMS 2302154

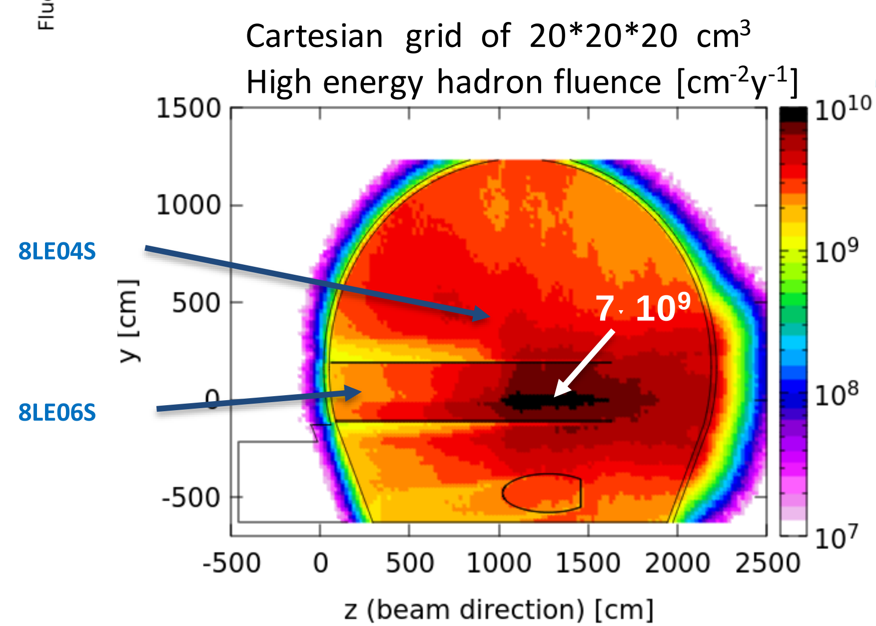
- Radiation levels are based on Radmon and BLM measurements for IR8
- The HEH fluence specifications in the shielded alcoves are derived from rescaled RadMon measurements without any safety margin.
- An extra safety margin of a factor 2 is applied to the associated specifications of TID, thermal neutron fluence and 1-MeV neutron equivalent fluence, obtained by applying standard conversion coefficients:

$$1Gy \sim 1 \cdot 10^{9} HEH\ cm^{-2} \sim 1 \cdot 10^{10} 1MeVn\text{–}eq\ cm^{-2} \sim 1 \cdot 10^{10} th\text{–}n\ cm^{-2}$$

HEH fluence - 15fb^{-1} in UX85



RadMon	FLUKA HEH [cm^{-2}] [15 fb^{-1}]
8LE04S UX85 L1	$4.2 \cdot 10^{9}$
8LE06S UX85 L0	$2.2 \cdot 10^{9}$
8LE07S UX85 L-1	$5.6 \cdot 10^{9}$



	RadMon	2018 HEH (cm^{-2})	Annual HL-LHC HEH (cm^{-2})
UX85 (max. RadMon)	SIMA.UX85.8LE07S	$6.0 \cdot 10^{8}$	$4 \cdot 10^{9}$
UL84	SIMA.UL84.8LE03S	$1.5 \cdot 10^{7}$	$1 \cdot 10^{8}$
US85 (L0)	SIMA.US85.8LE11S	$4.3 \cdot 10^{7}$	$3 \cdot 10^{8}$
US85 (L1)	SIMA.US85.8LE01S	$1.8 \cdot 10^{7}$ (*)	$1 \cdot 10^{8}$
US85 (L2)	SIMA.US85.8LE05S	$1.4 \cdot 10^{8}$	$9 \cdot 10^{8}$

Measured

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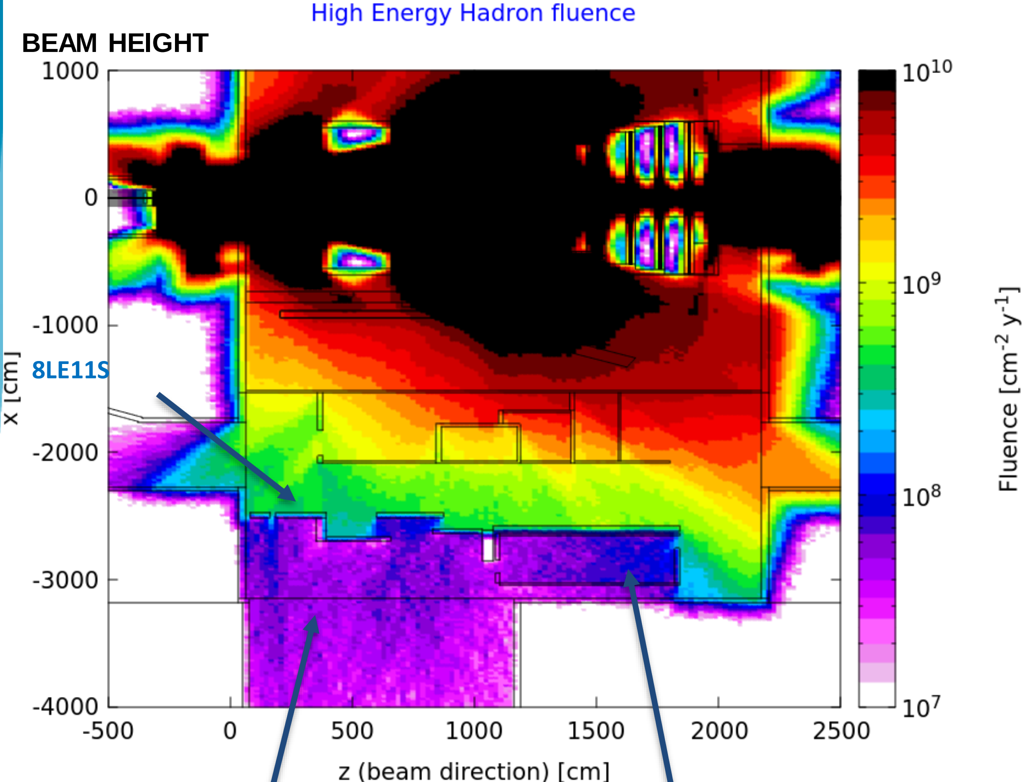
HEH fluence - 15fb^{-1} in US85



UW85
≲ 4·10^{7} HEH [cm^{-2}]
New RadMon installed for Run3

SAFE ROOM
< 1· 10^{8} HEH [cm^{-2}]
New RadMon installed for Run3

Cartesian grid of 20*20*20 cm^3
High energy hadron fluence [cm^{-2}y^{-1}]

RadMon	FLUKA HEH [cm^{-2}] [15 fb^{-1}]
8LE011S US85 L0	4.4·10^{8}
8LE01S US85 L1	4.7·10^{8}
8LE05S US85 L2	2.0·10^{9}

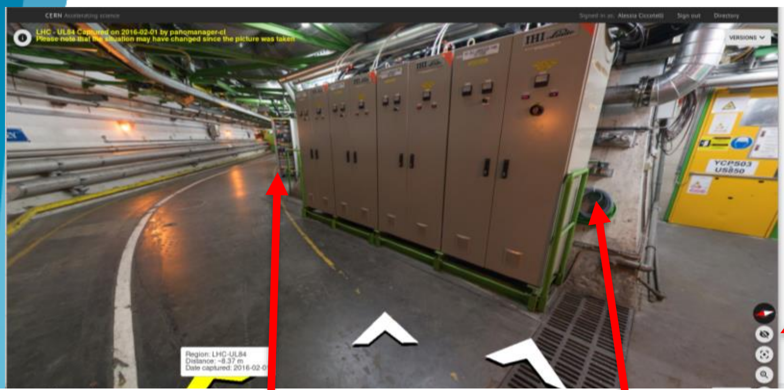
	RadMon	2018 HEH (cm^{-2})	Annual HL-LHC HEH (cm^{-2})
UX85 (max. RadMon)	SIMA.UX85.8LE07S	$6.0 \cdot 10^8$	$4 \cdot 10^9$
UL84	SIMA.UL84.8LE03S	$1.5 \cdot 10^8$	$1 \cdot 10^8$
US85 (L0)	SIMA.US85.8LE11S	$4.3 \cdot 10^7$	$3 \cdot 10^8$
US85 (L1)	SIMA.US85.8LE01S	$1.6 \cdot 10^7$ (*)	$1 \cdot 10^8$
US85 (L2)	SIMA.US85.8LE05S	$1.4 \cdot 10^8$	$9 \cdot 10^8$

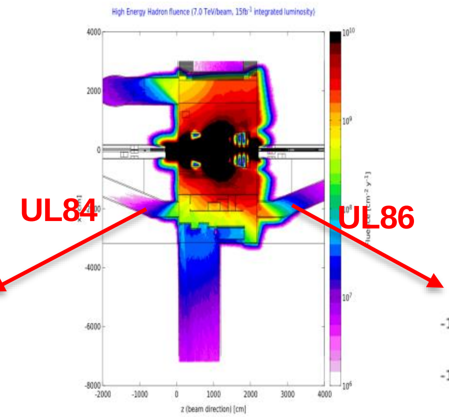
Measured

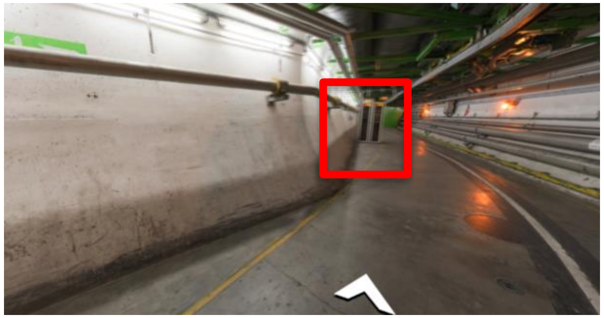
The * label indicates that for the 8LE01S RadMon the 2017 data set was used

EDMS 2302154

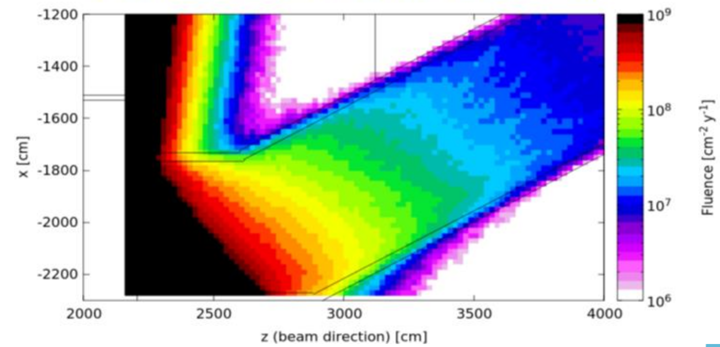
UL84 and UL86



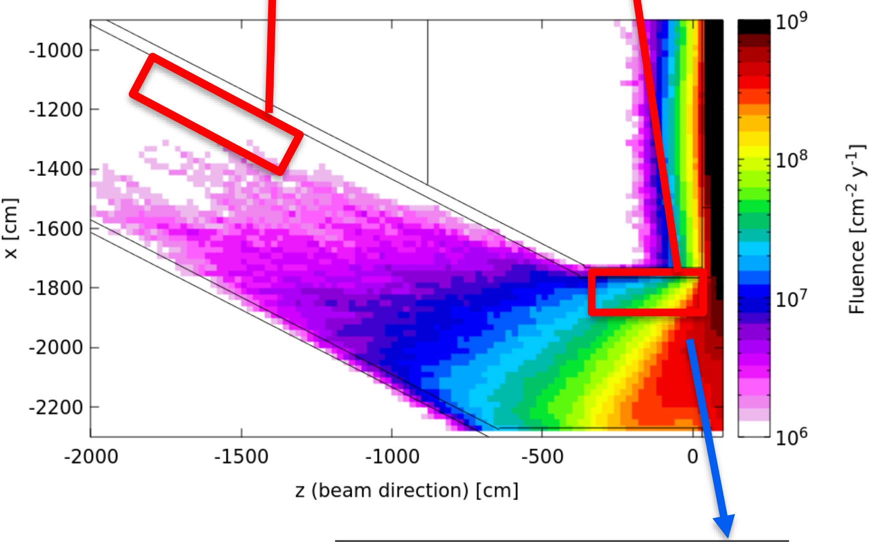




High Energy Hadron fluence (7.0 TeV/beam, 15fb^{-1} integrated luminosity)



High Energy Hadron fluence (7.0 TeV/beam, 15fb^{-1} integrated luminosity)



- High gradient regions in which racks for electronics are placed
- UL86 more exposed than UL84
- New RadMons installed for Run3

RadMon	FLUKA HEH [cm^{-2}] [15 fb^{-1}]
8LE03S UL84	1.1·10^8

	RadMon	2018 HEH (cm^{-2})	Annual HL-LHC HEH (cm^{-2})
UX85 (max. RadMon)	SIMA.UX85.8LE07S	$6.0 \cdot 10^8$	$4 \cdot 10^9$
UL84	SIMA.UL84.8LE03S	$1.5 \cdot 10^7$	$1 \cdot 10^8$
US85 (L0)	SIMA.US85.8LE11S	$4.3 \cdot 10^7$	$3 \cdot 10^8$
US85 (L1)	SIMA.US85.8LE01S	$1.6 \cdot 10^7$ (*)	$1 \cdot 10^8$
US85 (L2)	SIMA.US85.8LE05S	$1.4 \cdot 10^8$	$9 \cdot 10^8$

Measured

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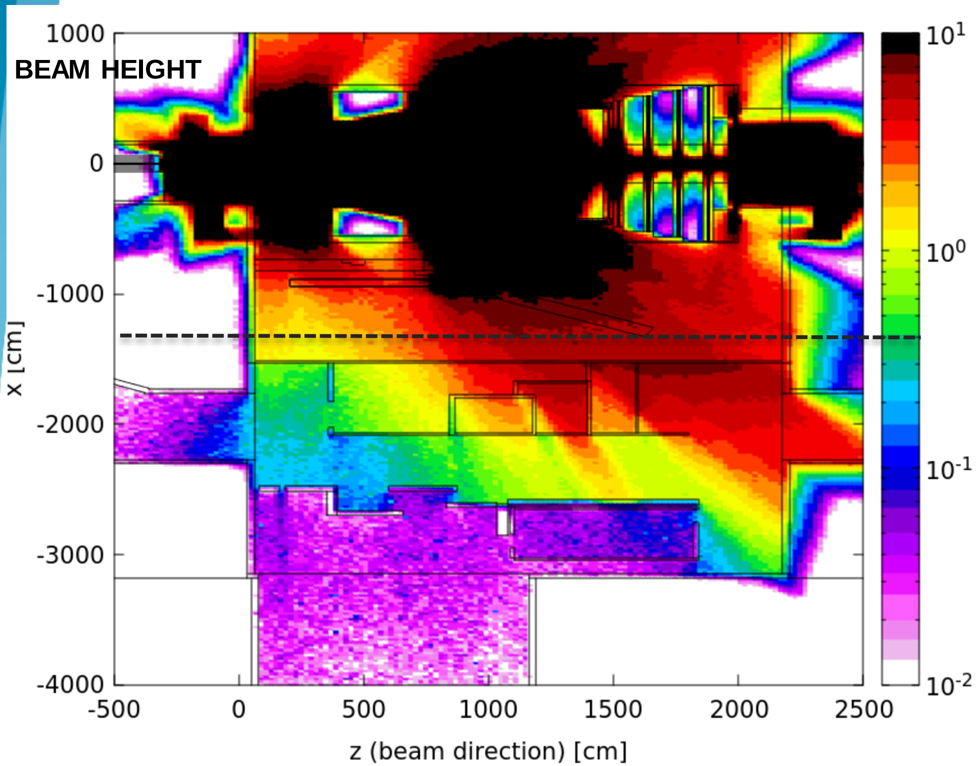
TID in UX85 and US85



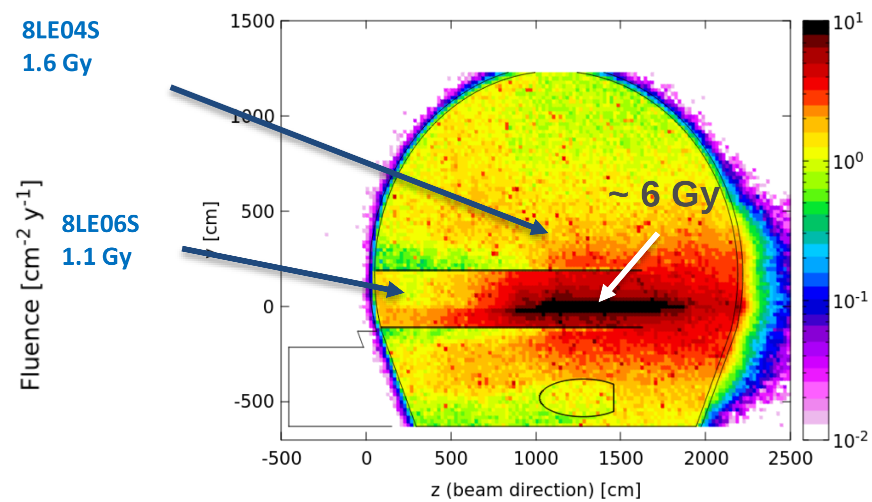


Table 2.12: Annual HL-LHC specifications of TID, HEH fluence, 1-MeV neutron equivalent fluence and thermal neutron fluence in the shielded alcoves of IR8 normalised to an integrated luminosity of 15 fb^{-1}. The HEH fluence specifications are obtained from rescaled RadMon measurements as illustrated in Table 2.11, while the others are derived by applying the same standard conversion coefficients used for the definitions of radiation level categories in the DS (1 Gy $\sim 1 \cdot 10^9$ HEH/cm^2 $\sim 1 \cdot 10^{10}$ 1MeVn-eq/cm^2 $\sim 1 \cdot 10^{10}$ thn/cm^2, as first introduced in Section 2.2.2) with an extra safety margin of a factor 2 and with result rounded by excess.

	HL-LHC TID (Gy)	HL-LHC HEH (cm^{-2})	HL-LHC 1MeVn-eq (cm^{-2})	HL-LHC th.n. (cm^{-2})
UX85	8	$4 \cdot 10^9$	$8 \cdot 10^{10}$	$8 \cdot 10^{10}$
UL84	0.2	$1 \cdot 10^8$	$2 \cdot 10^9$	$2 \cdot 10^9$
US85 (L0)	0.6	$3 \cdot 10^8$	$6 \cdot 10^9$	$6 \cdot 10^9$
US85 (L1)	0.2	$1 \cdot 10^8$	$2 \cdot 10^9$	$2 \cdot 10^9$
US85 (L2)	2	$9 \cdot 10^8$	$2 \cdot 10^{10}$	$2 \cdot 10^{10}$

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- Direct prediction of relevant R2E physical quantities (TID and 1MeVn-eq, HEH and thermal neutron fluences)

RadMon	FLUKA Dose [Gy] [15 fb^{-1}]
8LE07S UX85 L-1	2.8

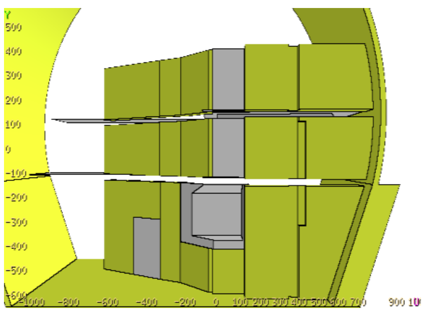
Future scenario: Upgrade II of LHCb

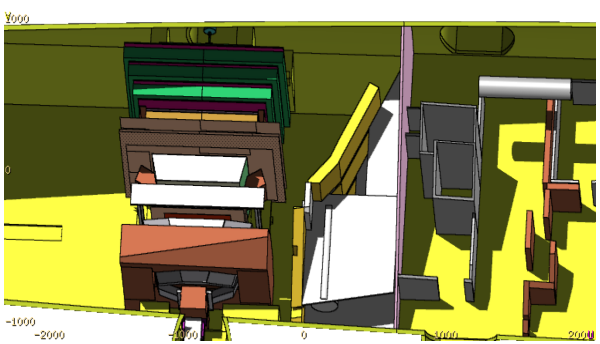
	Run2	HL-LHC LHCb Upgrade I
p-p collisions	beam energy of 6.5 TeV	beam energy of 7 TeV
External crossing angle	250 μrad on the **horizontal** plane	200 μrad on the **vertical** plane
Integrated luminosity	6.6 fb^{-1}	Annual 15 fb^{-1}
Instantaneous luminosity	$4 \cdot 10^{32} cm^{-2} s^{-1}$	$2 \cdot 10^{33} cm^{-2} s^{-1}$

HL-LHC
LHCb Upgrade II

Annual 50 fb^{-1}

$1.5 \cdot 10^{34} cm^{-2} s^{-1}$





- Impact on the cryogenic and electronic equipment near the LHCb experimental cavern: additional 80 cm concrete or 40 cm iron shielding wall in UX85 protecting LHC machine electronics is required EDMS 2424228
- Accelerator element protection:
  - The TAS-like absorber will be needed to avoid Q1 quench.
  - D1 inner shielding to prevent quench risk.
  - Possible TANb optimization to decrease the overall power on the D2, which is well protected against the quench risk and lifetime degradation.
  - TCL physics debris scheme to be investigated to decrease the dose value at the MCBC correctors below their lifetime limit and protect the matching section magnets.

HiLumi HL-LHC PROJECT

Summary

- The FLUKA model of IR8 has been significantly improved and extended providing the basis for radiation calculations in the insertion.

- **Expected values of R2E-related quantities are available for updating the Radiation level specifications for HL-LHC (TID and 1MeVn-eq, HEH and thermal neutron fluences).**

- New benchmark between simulation and measurements is planned for Run3 as well as machine-induced background study.

- The investigation on the implications of the Upgrade II of LHCb is behind the corner in order to ensure the safe operation of magnets and electronics, define the cryogenics requirements and identify the necessary protection measures from the machine point of view.

Thank you for your attention!