Benchmark of Run 2 Radiation Monitor Data with FLUKA in IP1/5 of LHC

Daniel Prelipcean, Giuseppe Lerner

with input from
the MCWG: Kacper Bilko, Diego Di Francesca, Rubén García Alía
and FLUKA: Marta Sabate Gilarte, Francesco Cerutti

teams

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https://indico.cern.ch/event/971222/
Summary

1. Introduction

2. Radiation Monitor Tools

3. Results

4. Conclusions
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2. Radiation Monitor Tools
3. Results
4. Conclusions
Introduction (1/2)

- The radiation environment in IP1-IP5 of the LHC, hosting the high-luminosity experiments (ATLAS and CMS), is driven by inelastic collisions, implying that the radiation levels are proportional to integrated luminosity.

- The Monitoring and Calculation Working Group (MCWG) in the R2E context characterizes the radiation environment by means of FLUKA simulations and data from different radiation monitors. Those relevant in this work are:
  - Beam Loss Monitors (BLM) Total Ionizing Dose (TID) -> in the LHC tunnel,
  - RadMon High Energy Hadron (HEH) fluence -> in the LHC tunnel and shielded alcoves,
  - Optical Fiber (OF) TID -> in the LHC DS tunnel of IP1.

- This work consists in benchmarking the radiation levels simulated in the LSS and DS of IP1 and IP5 with measured data in specific periods of Run 2 with constant operational settings.

- Important for quantifying the accuracy of the FLUKA predictions in regions where radiation monitoring detectors are not available.
Introduction (2/2)

- Previous/similar work has been carried out in the past:
  - for Beam Loss Monitors (BLMs), but only compared to data from individual fills; see talks by Andrea Tsinganis:
    - [https://indico.cern.ch/event/629210/](https://indico.cern.ch/event/629210/)
    - [https://indico.cern.ch/event/677406/](https://indico.cern.ch/event/677406/)
  - for RadMons:
    - [http://www.aesj.or.jp/publication/pnst002/data/948-954.pdf](http://www.aesj.or.jp/publication/pnst002/data/948-954.pdf) (tables 1, 2, 3)
- The goal of this broader benchmark study is to:
  - select the most representative measured data set per LHC configuration,
  - extend to larger statistics (from individual fill of at most 0.7 fb\(^{-1}\) to even 33 fb\(^{-1}\)),
  - use comprehensive (i.e. all available) sets of radiation monitors and quantities.

- Partly presented at the MCWG meetings:
  - BLM and RadMON benchmark in IP1 LSS -> [https://indico.cern.ch/event/956446/](https://indico.cern.ch/event/956446/)
  - Optical Fibre Dosimeters in the LHC complex -> [https://indico.cern.ch/event/978953/](https://indico.cern.ch/event/978953/)
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Radiation Monitors for R2E purposes (in FLUKA)

Beam Loss Monitors (BLM)
- explicitly modelled in FLUKA
- TID deposited in their active volume

Optical Fibre
- Actual fibre is 150 um in diameter -> too small for identical modelling.
- Different OF sizes are studied to find a balance with computational time

RadMON
- Not explicitly modelled due to their small sensitive volume (order of mm³)
- Replaced by a cube of AIR with side length 20/50/100 cm (depending on statistics)
Comparison of BLM TIDs for different time periods with identical operational settings

- Time-integrated BLM signal (as from the MCWG analysis) in different sub-periods within a standard LHC fill, but sharing the same operational settings.
- Luminosity scaling works as normalization factor for time periods of constant operational settings.

\[ \text{number of events of interest} = \mathcal{L}_{\text{int}} \cdot \sigma_p \]

- The comparison of measured TID per unit integrated luminosity for different periods of operation with the same configuration is showing a very stable profile.
- We can merge the full datasets corresponding to periods with stable operational conditions, yielding:
  - 33 fb\(^{-1}\) (2016), 8 fb\(^{-1}\) (2017), 20 fb\(^{-1}\) (2018)

- Symmetry around the Interaction point -> Reduce analysis and Simulation just to the Right Side of IP
Impact of TCL5&6 changes on radiation profile

Physics debris collimator absorbers = TCL’s (Target Collimator Long) are required around LHC high luminosity experiments in the IP1/5 to protect the cold magnets from products of proton-proton collisions.

The levels are fully proportional to the integrated luminosity up to the TAN
Different local radiation levels due to the change in the collimator settings
The TCL changes do not affect the DS radiation profile after 400m.
Impact of Roman Pot changes on radiation profile

Roman Pots are an important tool to measure the total cross section of two particle beams in a collider. Can be either used (IN) or not (OUT).
### Characteristic Operational Settings

This table provides the key operational parameters of the LHC that affect the radiation levels in IP1-IP5, providing their typical values in each year of RUN 2 and the associated amount of luminosity delivered to them.

<table>
<thead>
<tr>
<th>year</th>
<th>Crossing Angle [micro-rad]</th>
<th>beta* [cm]</th>
<th>TCL5 [sigmas (state)]</th>
<th>TCL6 [sigmas (state)]</th>
<th>Roman Pots</th>
<th>Extracted Lumi per setting (Approx)</th>
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<tr>
<td>2016</td>
<td>-185</td>
<td>40</td>
<td>15 (closed)</td>
<td>open</td>
<td>OUT</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>35 (open)</td>
<td>20 (closed)</td>
<td>IN</td>
<td>0.04</td>
</tr>
<tr>
<td>2017</td>
<td>150</td>
<td>40</td>
<td>15 (closed)</td>
<td>open</td>
<td>OUT</td>
<td>1.0</td>
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<td></td>
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<td>20 (closed)</td>
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<td></td>
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<td>30</td>
<td>15 (closed)</td>
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<td>20 (closed)</td>
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<tr>
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<td>30</td>
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<td></td>
<td>38.2 (open)</td>
<td>open</td>
<td>IN</td>
<td>20</td>
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<td>open</td>
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<td>IN</td>
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<td></td>
<td>25</td>
<td>15.0 (closed)</td>
<td>open</td>
<td>OUT</td>
<td>0.05</td>
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<td></td>
<td>35.0 (open)</td>
<td>open</td>
<td>IN</td>
<td>0.81</td>
</tr>
</tbody>
</table>

*not entirely representative since levelling took place*
Without loss of generality, only the 2018 configuration is presented.

Full results in backup.
BLM TID IP1 Long Straight Section (LSS)

Good agreement for the Inner Triplet (within errorbars)

Good Agreement on the TAN BLM

A local overestimation is usually followed by an underestimation (and vice-versa).

The further away, the larger the simulated error due to poorer statistics.

Generally, good agreement within a factor 2.

Investigated reasons for the prominent outliers: e.g. this BLM is shifted in the simulation with 1m, placing it into the peak of a radiation shower.
IP1 Dispersion Suppressor (DS) + ARC (Cells 14, 15, 16)

Reasonable agreement for high TID BLMs.

Large discrepancies in Cell 13 (present in IR5 benchmark as well) -> To be investigated

For ARC BLMs, the Interaction Point is no longer the main source of radiation. In this region, we are dominated by residual beam gas interactions, of order $10^{-4}$ Gy/fb$^{-1}$

Simulation error larger than the 20% MC threshold required for the reliability of the results.
Measured and Simulated Data for 2018 with TCL456 settings: 15s_35s_park, Roman Pots: IN

Measured data from time periods with congregated delivered luminosity of 20.27 fb⁻¹
FLUKA simulation ran with 205 800 + 260 700 primaries

General good agreement

Outliers: to be investigated

FLUKA overestimation for the RadMONs in Cell 4 (present in IR5 benchmark as well)
RADMON HEH Fluence IP1 - shielded alcoves

<table>
<thead>
<tr>
<th>RadMon name</th>
<th>Measured [cm⁻²/fb¹]</th>
<th>Total Error (Sys. + Stat.) [%]</th>
<th>Simulated [cm⁻²/fb¹]</th>
<th>Simulation Error [%]</th>
<th>Measured/Simulated</th>
<th>Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMA.UL16.1RM01S</td>
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<td>1.73E+05</td>
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<td>0.63</td>
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<tr>
<td>SIMA.UJ16.1RM02S</td>
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<td>7</td>
<td>0.39</td>
<td>52</td>
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</table>

<table>
<thead>
<tr>
<th>RadMon name</th>
<th>Measured [cm⁻²/fb¹]</th>
<th>Total Error (Sys. + Stat.) [%]</th>
<th>Simulated [cm⁻²/fb¹]</th>
<th>Simulation Error [%]</th>
<th>Measured/Simulated</th>
<th>Error [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMA.RR17.1RM11S</td>
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<td>50</td>
<td>4.00E+07</td>
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<td>SIMA.RR17.1RM12S</td>
<td>2.11E+06</td>
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<td>5.18E+06</td>
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<tr>
<td>SIMA.RR17.1RM13S</td>
<td>4.01E+06</td>
<td>50</td>
<td>6.29E+06</td>
<td>36</td>
<td>0.64</td>
<td>62</td>
</tr>
</tbody>
</table>

Measured Systematic Error of 50% considering the mixed field radiation in the LHC (also supported by the ongoing CHARM benchmark studies)

Good Agreement within factor 2
Optical Fibre DS IP1

Large Overestimation near the Interconnects.

Good agreement in regions “shielded” by dipoles.

How does the radiation shower differ from one region to another, and does this affect the deposited TID?

The shower at the Interconnects contains more EM radiation (electrons, photons), possibly leading to a different TID deposition pattern amplified by the simulated larger OF diameter.
Summary

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4. Conclusion
Conclusion

Benchmarked the radiation levels simulated in the LSS+DS of IR1 and IR5 for time periods of Run 2 with constant operational settings using a comprehensive set of radiation monitors and quantities:

- Beam Loss Monitors Total Ionizing Dose (TID) in the tunnel
- RadMon High Energy Hadron (HEH) fluence in the tunnel and shielded alcoves
- Optical Fiber TID in DS tunnel of IR1

Future work

- Investigate outliers for possible inconsistencies coming from:
  - measurements: radiation monitor not functioning properly, error in data analysis, etc.
  - simulations: position inaccuracy, simulation mismodeling, etc.
- Solve them, thereby increasing the reliability of both measurements/simulations over time.
- Quantify the systematic uncertainties via a similar benchmark in the CHARM facility.
Thank you for your attention!

Questions?

daniel.prelipcean@cern.ch
Measured and Simulated Data for 2016 with TCL456 settings: 15s_15s_park, Roman Pots: OUT

- Measured data from time periods with congregated delivered luminosity of 32.04 fb$^{-1}$
- FLUKA simulation ran with 136 000 primaries

- FLUKA Simulated ±2σ
- FLUKA Simulated ±1σ

Distance from IP1 [m]
BLM Profile IR1 2017

Measured and Simulated Data for 2017 with TCL456 settings: 15s_35s_20s, Roman Pots: IN

- Measured data from time periods with congregated delivered luminosity of 7.93 fb⁻¹
- FLUKA simulation ran with 187,000 primaries

- FLUKA Simulated ±2σ
- FLUKA Simulated ±1σ

Distance from IP1 [m]

DATA/FLUKA

Dose [GeV/μb⁻¹]

Magnet Layout:
- Solenoid
- Collimator
- Quadrupole
- Dipole

Half-cell
BLM Profile IR5 2018

Measured and Simulated Data for 2018 with TCL456 settings: 15s_35s_park, Roman Pots: IN

- Measured data from time periods with congregated delivered luminosity of $\mathcal{L}_{\text{int}} = 28.98 \text{ fb}^{-1}$ at $\sqrt{s} = 13 \text{ TeV}$
- FLUKA simulation ran with 114,900 + 235,810 primaries

![Graph showing dose vs. distance from IP5 in units of [m].](image-url)

- Yellow: FLUKA Simulated $\pm 2\sigma$
- Green: FLUKA Simulated $\pm 1\sigma$

**Magnet Layout**
- Coliminator
- Quadrupole
- Dipole

![Magnet layout diagram](image-url)
### RADMOM HEH Fluence IP1 2018 - floor level

<table>
<thead>
<tr>
<th>RadMon name</th>
<th>DCUM [m]</th>
<th>Measured [cm⁻²/fb¹]</th>
<th>Total Error [%]</th>
<th>Systematic [%]</th>
<th>Statistical from counting SEU [%]</th>
<th>Simulated [cm⁻²/fb¹]</th>
<th>Simulation Error [%]</th>
<th>Measured/Simulated</th>
<th>Error [%]</th>
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<tbody>
<tr>
<td>SIMA.4R1.1RM19S</td>
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<td>6.54E+09</td>
<td>50</td>
<td>50</td>
<td>0.08</td>
<td>2.90E+10</td>
<td>1.92</td>
<td>0.23</td>
<td>50.12</td>
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<tr>
<td>SIMA.4R1.1RM08S</td>
<td>163</td>
<td>6.47E+08</td>
<td>50</td>
<td>50</td>
<td>0.27</td>
<td>1.99E+09</td>
<td>3.42</td>
<td>0.33</td>
<td>50.38</td>
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<td>50</td>
<td>0.93</td>
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<td>14.12</td>
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<td>3.29E+08</td>
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<td>50</td>
<td>0.37</td>
<td>2.75E+08</td>
<td>10.42</td>
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<td>51.44</td>
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<tr>
<td>SIMA.7R1.1RM14S</td>
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<td>50</td>
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<td>SIMA.13R1.1RM21S</td>
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<td>9.90</td>
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<td>65.07</td>
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</table>
RADMON HEH Fluence IP1 2016 - floor level

Measured and Simulated Data for 2016 with TCL456 settings: 15s_15s_park, Roman Pots: OUT

- Measured data from time periods with congested delivered luminosity of 32.04 fb\(^{-1}\)
- FLUKA simulation ran with 136 000 primaries

Graph showing measured and simulated HEH fluence with distance from IP1 in meters. The graph includes data points with error bars and different colored areas representing different simulations and measurements.
## RADMON HEH Fluence IP1 2016 - RadMONs

<table>
<thead>
<tr>
<th>RadMon name</th>
<th>Measured [cm$^{-2}$/fb$^1$]</th>
<th>Total Error [%]</th>
<th>Systematic [%]</th>
<th>Statistical from counting SEU [%]</th>
<th>Simulated [cm$^{-2}$/fb$^1$]</th>
<th>Simulation Error [%]</th>
<th>Measured/Simulated</th>
<th>Error [%]</th>
</tr>
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<tbody>
<tr>
<td>SIMA.4R1.1RM19S</td>
<td>2.92E+10</td>
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<td>SIMA.4R1.1RM08S</td>
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<td>50</td>
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<td>2.39E+06</td>
<td>59</td>
<td>1.22</td>
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RADMON HEH Fluence IP1 2017 - floor level

Measured and Simulated Data for 2017 with TCL456 settings: 15s_35s_20s. Roman Pots: IN

- Measured data from time periods with congregated delivered luminosity of 7.93 fb⁻¹
- FLUKA simulation ran with 187 000 primaries

![Graph showing HEH fluence vs. distance from IP1 (m)]

- FLUKA Simulated ±2σ
- FLUKA Simulated ±1σ

Distance from IP1 [m]

Solenoid
Collimator
Quadrupole
Dipole
<table>
<thead>
<tr>
<th>RadMon name</th>
<th>Measured [cm$^{-2}$/fb$^1$]</th>
<th>Total Error [%]</th>
<th>Systematic [%]</th>
<th>Statistical from counting SEU [%]</th>
<th>Simulated [cm$^{-2}$/fb$^1$]</th>
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<td>9.15E+08</td>
<td>53</td>
<td>50</td>
<td>3</td>
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Measured and Simulated Data for 2018 with TCL456 settings: 15s_35s_park, Roman Pots: IN

- Measured data from time periods with congregated delivered luminosity of 29.27 fb⁻¹
- FLUKA simulation ran with 114 900 + 235 810 primaries

![Graph showing data and FLUKA simulation comparison](image_url)
Even within single fills the operational parameters are not constant -> a known procedure is to open TCL5/close TCL6 after approx. 30 min of stable beam.

Example of a TCL collimator aperture change: a 2016 fill/run

- TCL5: closed
- TCL6: open

- TCL5: open
- TCL6: closed

start of stable beam

end of stable beam