# Advanced Monte Carlo simulations and benchmark of residual dose rate assessments in the ATLAS detector at CERN LHC

Tommaso Lorenzon[a,*], Daniel Björkman[b], Davide Bozzato[a], Anna Cimmino[c], Robert Froeschl[a], Vasiliki Kouskoura[a]

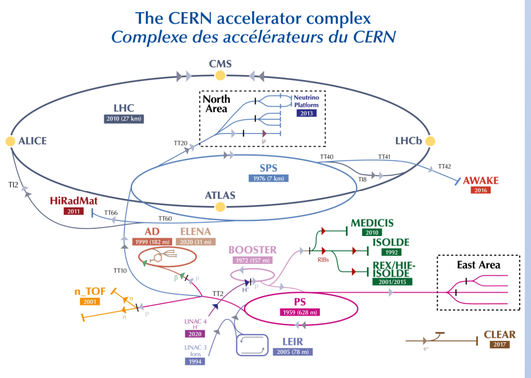
[a] European Organization for Nuclear Research (CERN), [b] Paul Scherrer Institute (PSI), [c] The Extreme Light Infrastructure ERIC, ELI Beamlines Facility

## Abstract – key points


- The prediction of residual dose rates in the *Large Hadron Collider* (LHC) experimental caverns requires advanced Monte Carlo simulation techniques, primarily to pursue a detailed description of the detectors' configuration changes between run and stop periods
- The integration of any change in the facility geometric description is seamlessly achieved with a Monte Carlo two-steps method and set of coded utilities
- The method is introduced and applied to the ATLAS[1] detector at LHC; a comparison with experimental measurements is presented.


## Introduction

- The European Organization for Nuclear Research (CERN) hosts the LHC, the longest circular accelerator in the world (13.6 TeV c.o.m. record energy for p-p collisions)



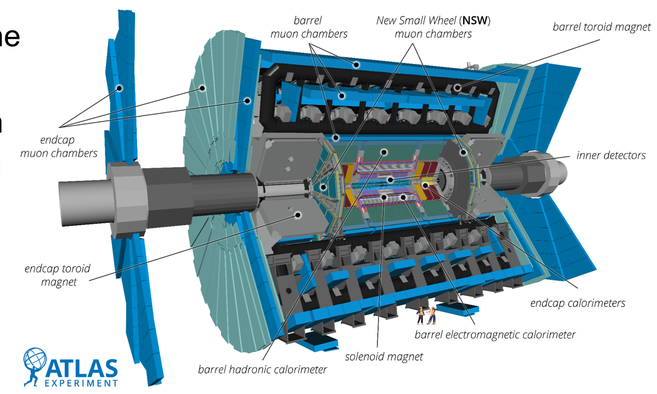

- The Radiation Protection team assesses residual dose rates for planned exposure situations (shutdown maintenance and upgrades)
- The ATLAS detector will undergo major upgrades during the next Long Shutdown (LS) 3, including the complete substitution of the inner detectors
- The detailed description of the LHC detectors configuration changes (run vs. stop periods) for dose computations requires advanced Monte Carlo simulation techniques.

## Approach

- Residual dose rates are calculated with:
  1. The FLUKA code
  2. SESAME[2,3,4]: a set of coded utilities that allow a seamless integration of any changes in the facility geometry.
- LS 2: comparison to experimental data collected in ATLAS cavern
- LS 3: prediction of LHC performance for years 2024-2026

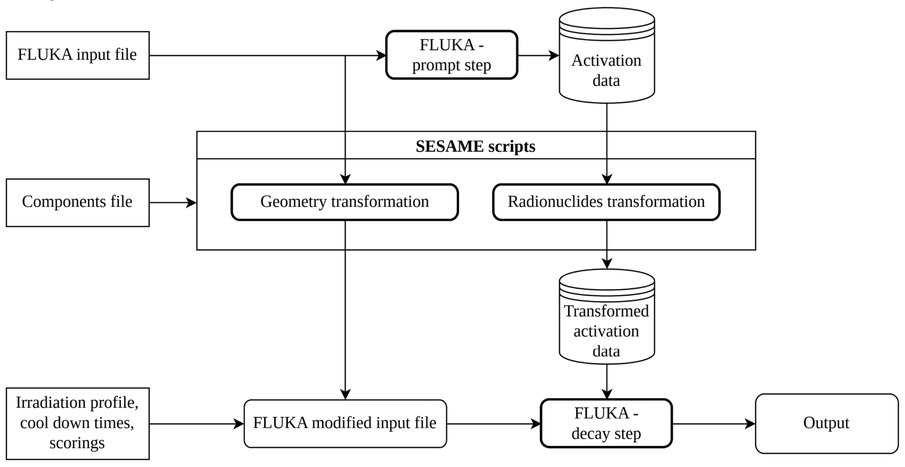
## The ATLAS detector

- General-purpose detector at the LHC
- Key numbers: 46 m long, 25 m high and 25 m wide, ~7E+6 kg weight
- *Opening* procedure is in steps (around 10 configurations)

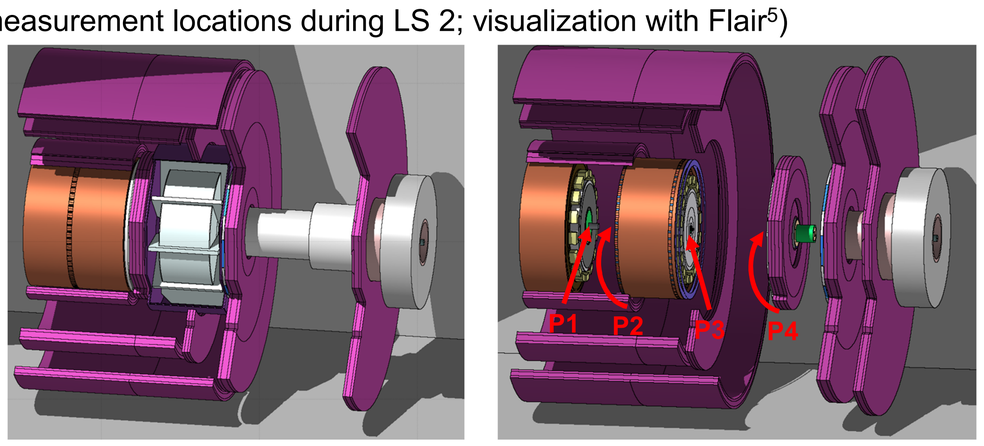



## Monte Carlo simulations (F)

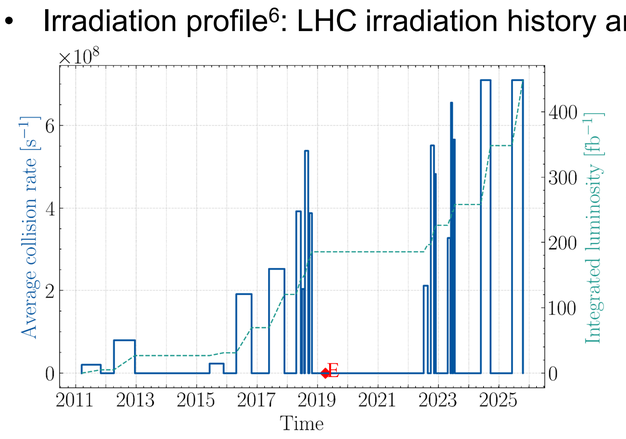
- Two-step method: FLUKA simulations and SESAME utilities




- Geometry transformation for ATLAS *standard opening* configuration (in red, measurement locations during LS 2; visualization with Flair[5])




- Irradiation profile[6]: LHC irradiation history and performance forecast until LS 3




  - FLUKA versions: 2011.3[7,8] (LS 2) and 4-3.3[9,10,11] (LS 3)
  - DPMJET-III[12,13] event generator
  - Beam energy: 6.5 TeV (LS 2), 7 TeV (LS 3) per proton beam

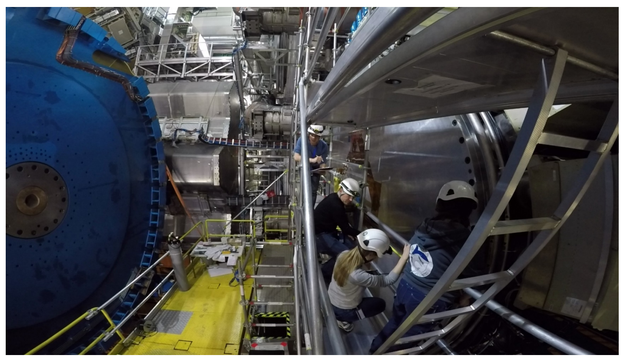
## Results

- *Standard opening* configuration; simulations (F) vs. experimental data (E)




## Measurement campaign (E)

- ATLAS cavern, Side A, on April 4, 2019
- Residual dose rate measurements in the *standard opening* configuration:
  - Four locations, see ATLAS geometry
  - Various radial distances
  - Measure at contact and at 40 cm distance (along Z-axis)
- Overall, 42 data points recorded in total
- Instrumentation: Automess AD6 (and teledetector)

## Conclusions and outlook

- Estimating residual ambient dose rate in LHC requires detector configurations workplan, LHC parameters, model of the detector geometry, specific software (FLUKA + SESAME), computing power
- LS 2: measurements and simulated data agree better than a factor of 2; this constitutes a relevant validation of the simulation approach presented
- LS 3: the study gives a valuable input for the preparation and optimization of complex interventions in radiation areas
- Further benchmarks are foreseen to validate simulations for different configurations; further investigation on detector response function and particle contributions could strengthen the benchmark

## References


1. The ATLAS collaboration (2008) "The ATLAS Experiment at the CERN Large Hadron Collider". Journal of Instrumentation, Volume 3, S08003
2. Cooijmans, T. and Guthoff, M. (2015) "SESAME Documentation". CERN internal document.
3. Froeschl, R. (2020) "The SESAME and DORIAN codes for residual dose rate calculations". CERN internal document, EDMS Document N. 2378246
4. Bozzato, D. et al. (2024) "Advanced simulation techniques for Radiation Protection studies at the Large Hadron Collider". Radiation Physics and Chemistry, 111573
5. Vlachoudis, V. (2009) "FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA". Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009)
6. Bozzato, D. et al. (2022) "LHC and HL-LHC luminosity and irradiation profiles for Radiation Protection studies". CERN internal document, EDMS Document N. 2641646
7. Fassò, A. et al. (2005) "Fluka: a multi-particle transport code". CERN-2005-10, INFN TC_05 11, SLAC-R-773.
8. Ferrari, A. et al. (2014) "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications", Nuclear Data Sheets 120, 211-214
9. Ahdida, C. et al. (2022) "New Capabilities of the FLUKA Multi-Purpose Code". Frontiers in Physics, Volume 9, 788253
10. Battistoni, G. et al. (2015) "Overview of the FLUKA code", Annals of Nuclear Energy 82, 10-18
11. FLUKA.CERN, FLUKA web site, viewed 29 February 2024, https://fluka.cern
12. Roesler, S. et al. (2000) "The Monte Carlo Event Generator DPMJET-III" in Proceedings of the Monte Carlo 2000 Conference
13. Fedynitch, A. PhD Thesis, https://cds.cern.ch/record/2231593/files/CERN-THESIS-2015-371.pdf


## Contacts


- * Email: tommaso.lorenzon@cern.ch