CERN

FLUKA STUDIES OF DOSE RATES IN THE ATLAS STANDARD OPENING SCENARIO

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Occupational Health & Safety
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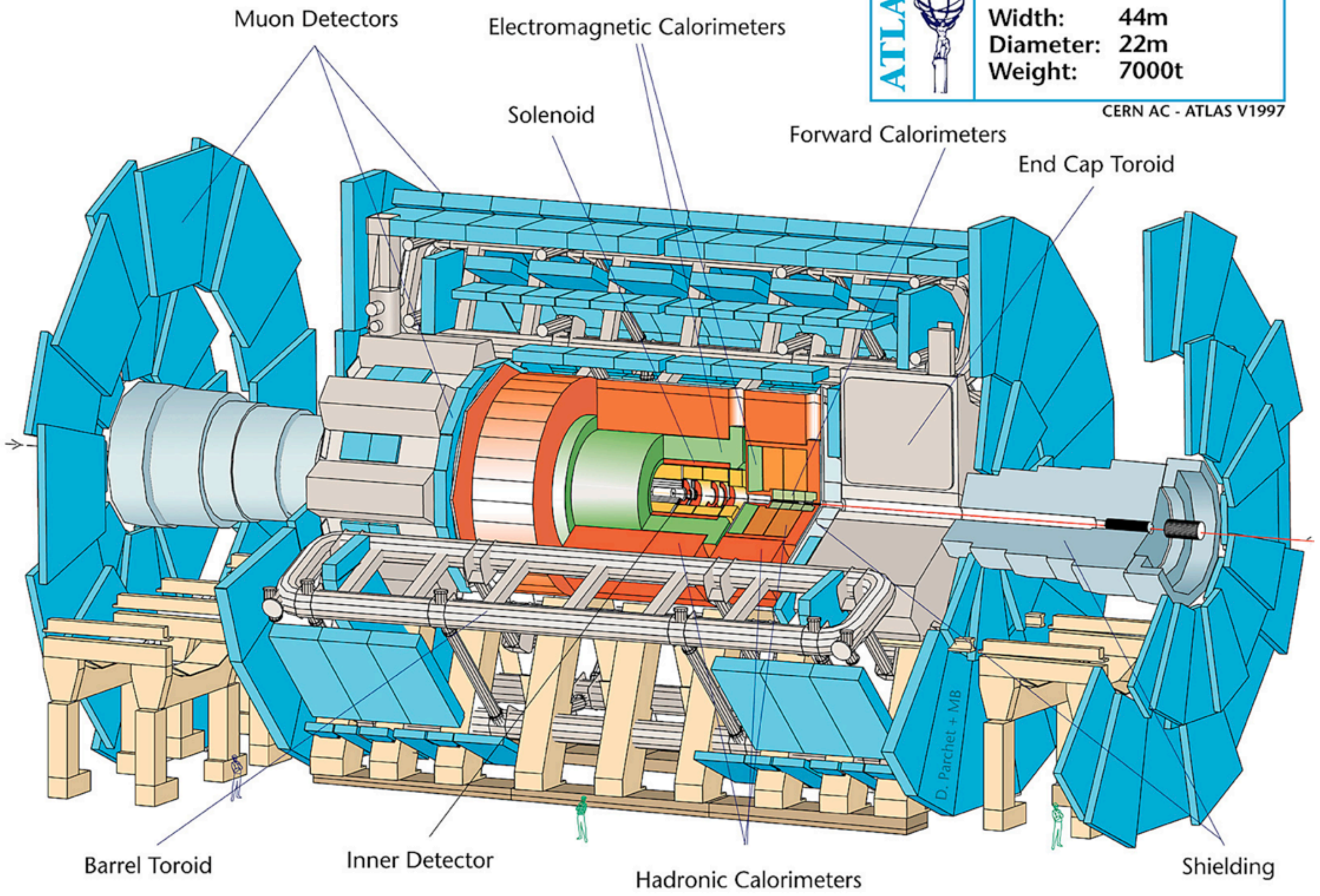
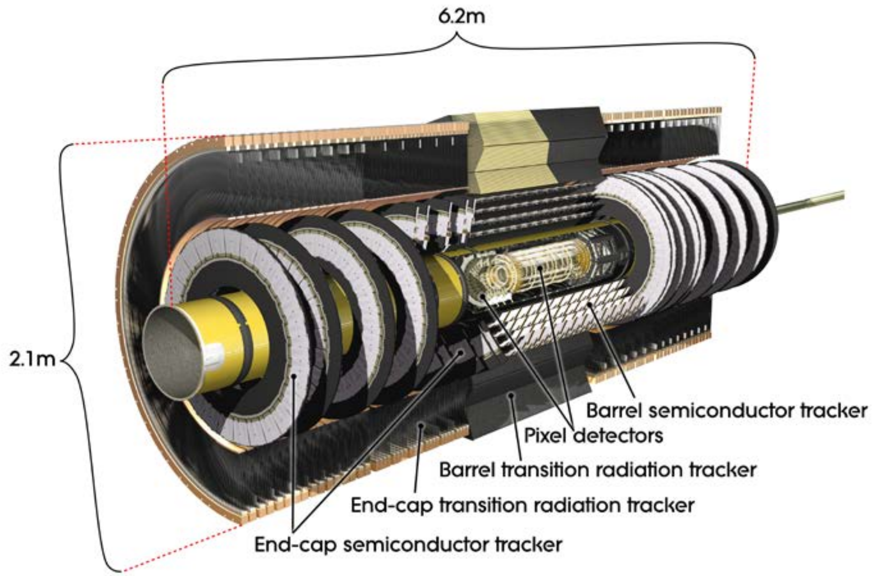
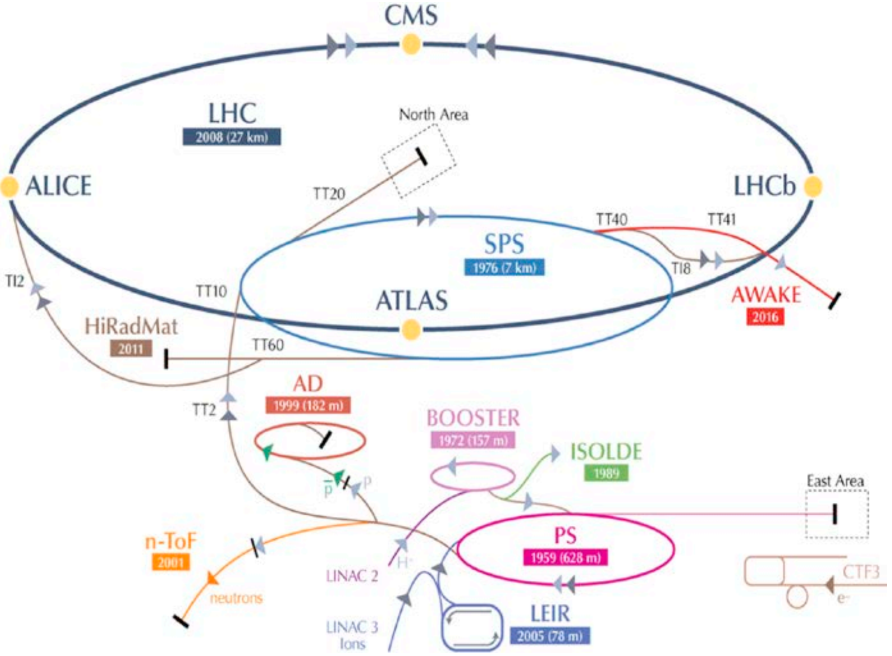
ATLAS Detector

ATLAS (A Toroidal LHC Apparatus)







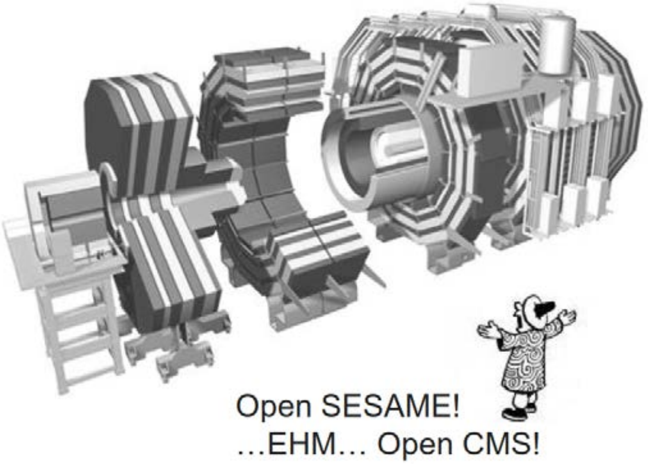
Motivation

- An extended period without beams in the Large Hadron Collider (LHC) at CERN is scheduled for 2024-2025. This stop in operations, known as Long Shutdown 3 (LS3), is required for the experiments, as well as the accelerator, to perform crucial consolidation and upgrade tasks.
- In particular, the ATLAS Inner Detector (ID) will be decommissioned and replaced by a new tracking system (ITk), allowing the experiment to collect 4000/fb.
- Given the location of the inner detector with respect to the beam pipe and the expected integrated luminosity up to LS3 of 300/fb, a detailed radiological assessment of the scheduled work is needed.

Aim

1 μSv = 0.1 mrem

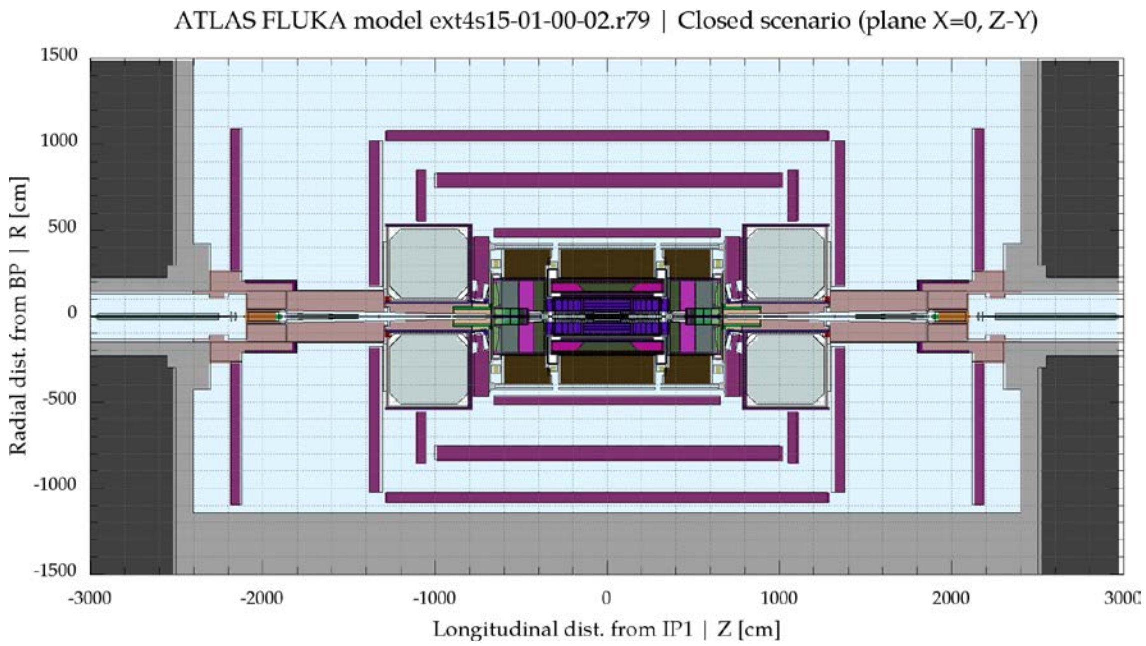
- Study using the Monte-Carlo particle transport code FLUKA version 2011.2c.5 and DPMJET-III:
    - The ambient dose equivalent rates in the ATLAS experimental cavern during future LS.
    - Estimate the expected radiation levels at the ITk during the High Luminosity LHC shutdown periods.

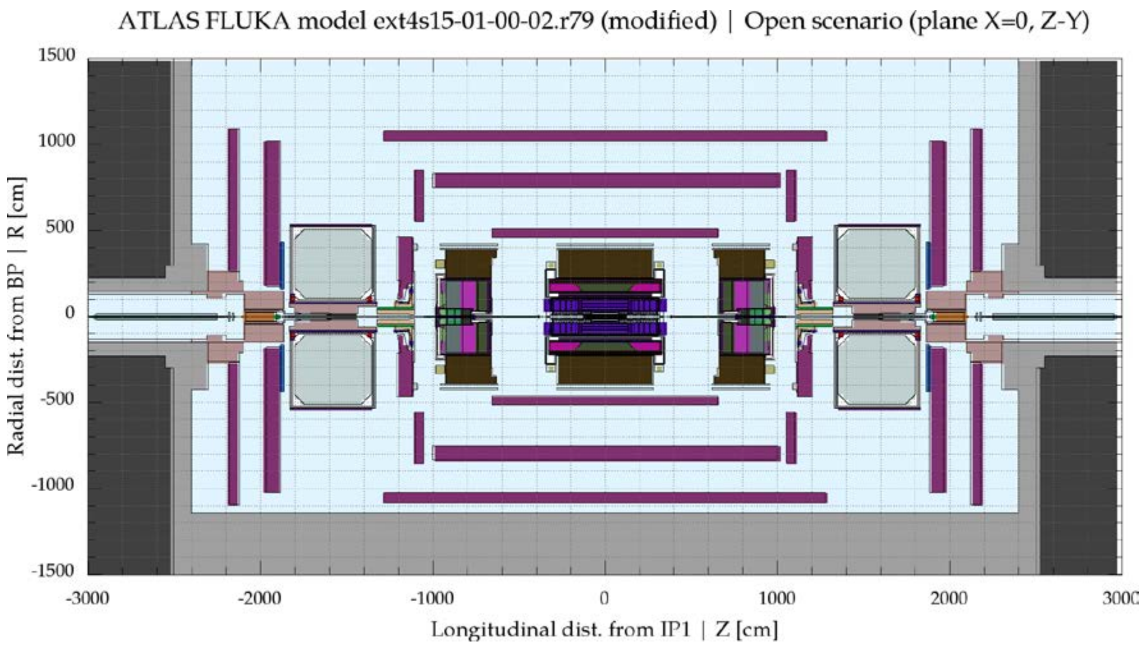


- Consider the detector configuration changes with the toolkit SESAME:
    - Various detector elements will be removed or displaced during LS, YETS or EYETS (Extended Year End Technical Stop) to facilitate the interventions.
    - This variation of detector geometry strongly influences the results of the simulation and needs to be taken into account.

Method: SESAME

- Simulating prompt radiation in the closed geometry, storing the nuclides produced on a file.
- Letting these nuclides decay in the open geometry after some transformations/displacements.





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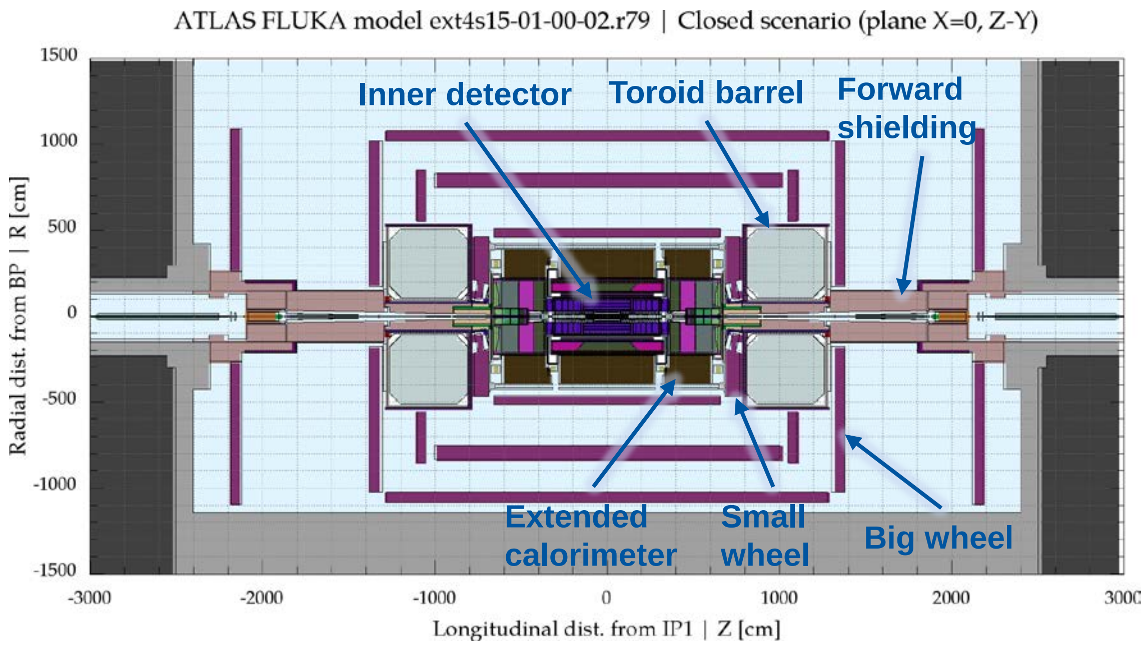

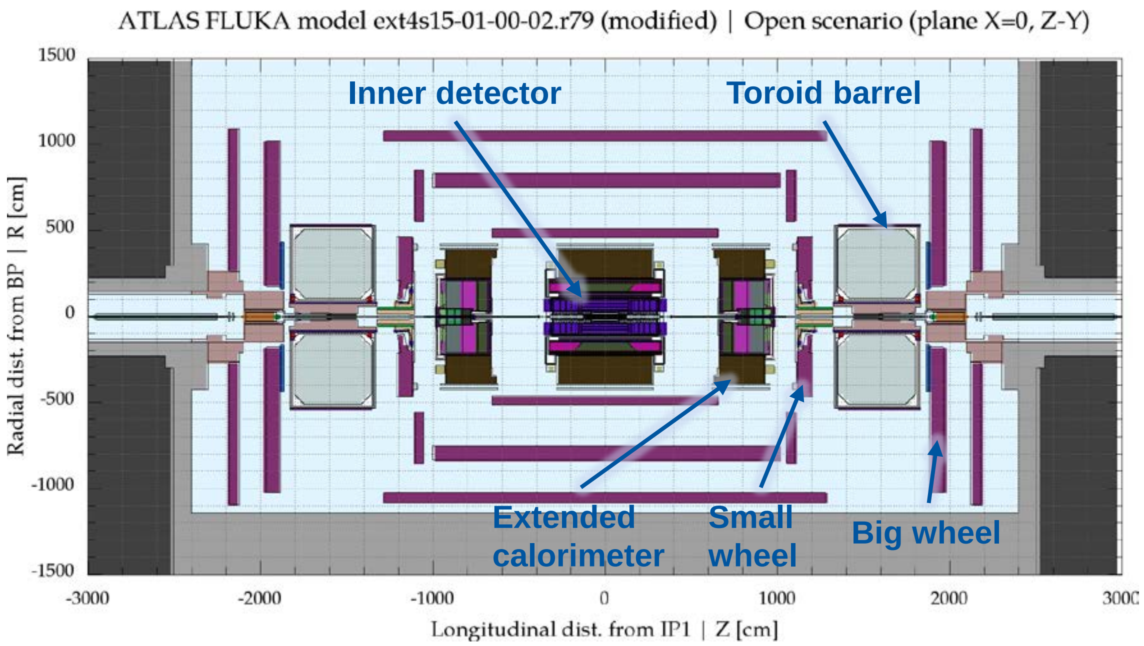

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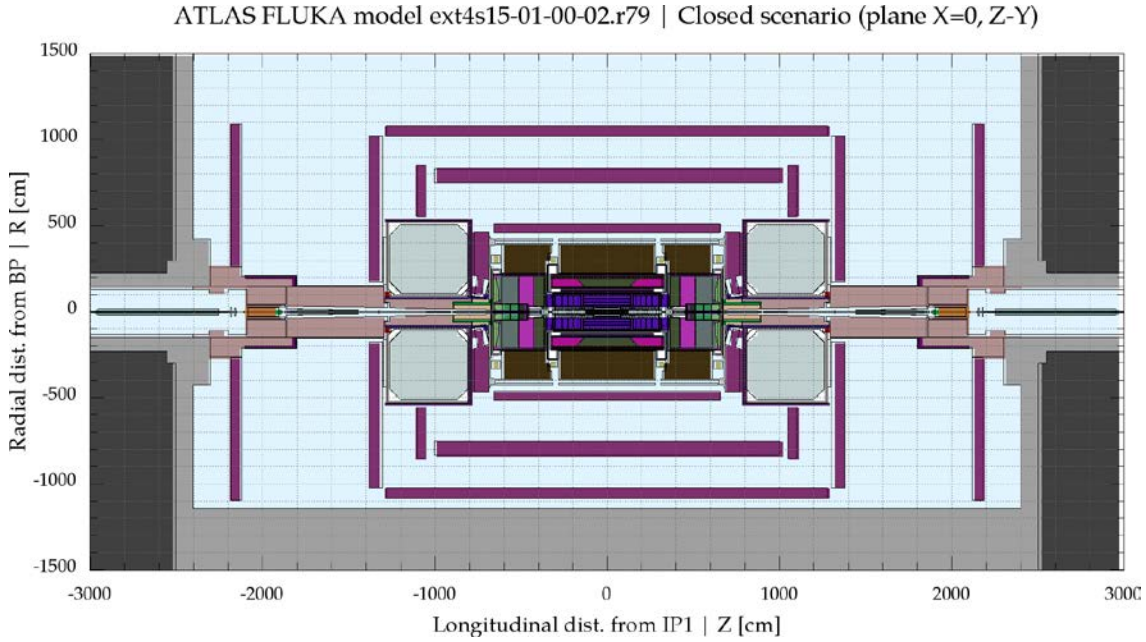
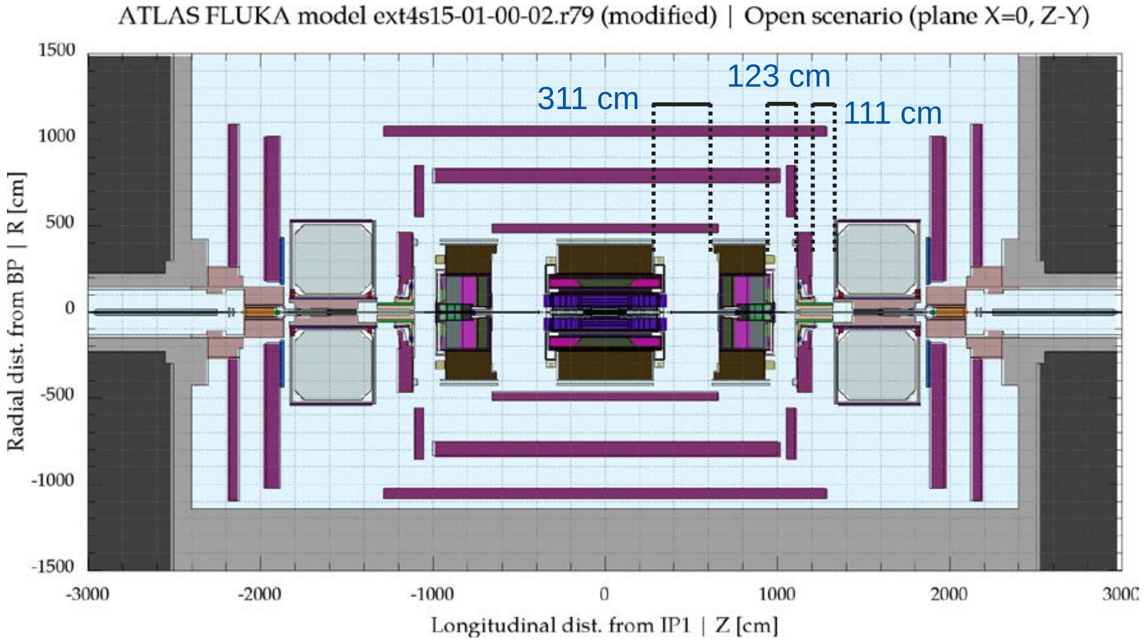




SESAME prompt step

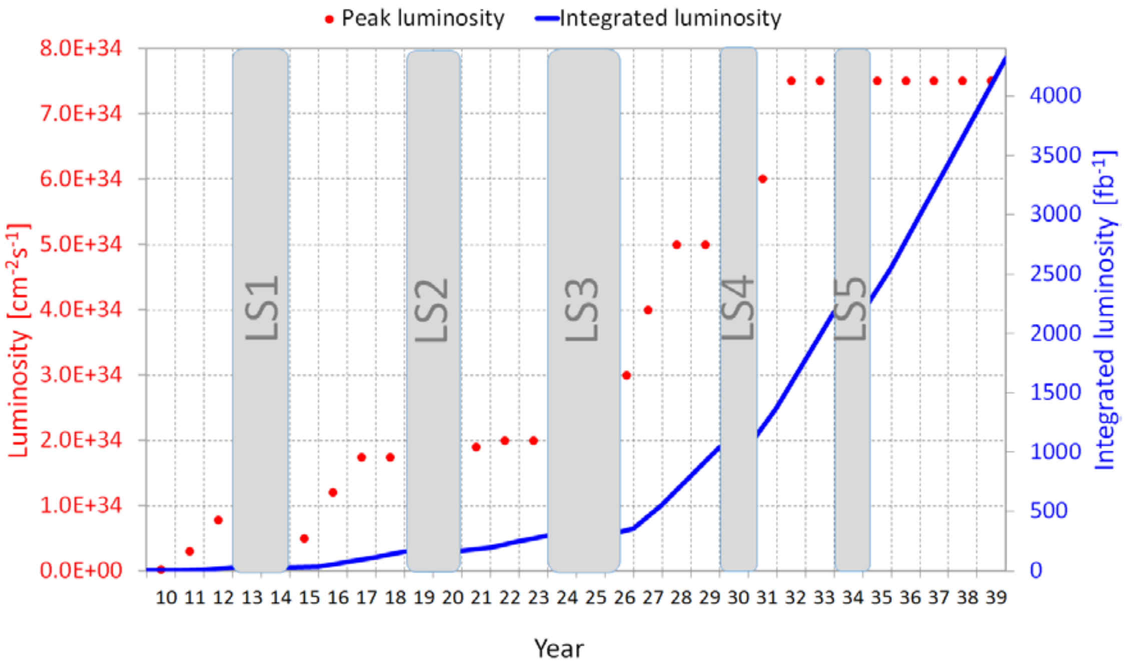
- The geometry corresponds to the operational closed scenario.
- The source is a 2×7 TeV colliding proton beam (half-crossing angle of 142.5 µrad). The total number of simulated proton collisions is 187 000.
- The magnetic field is switched on.
- The FLUKA physics parameters are the standard for activation studies:
  - The EM shower is off cause it is not particularly relevant for creation of isotopes and it is very time consuming.
- The information of the nuclides is stored with the SESAME routines in a binary file.

SESAME decay step

- The geometry is remodelled to match the standard opening scenario.
- The source consists of loading the information from the modified binary file with the nuclide information, where:
    - The nuclides belonging to regions that are transformed, change their position accordingly.
    - The nuclides from regions that are removed, are also removed.
    - The nuclides created in air, are discarded as the air is continuously flushed with fresh air during shutdown periods.
- The magnetic field is turned off.
- The EM shower is now on.
- Usual particle thresholds:
    - All particles thresholds set to 100 keV.
    - Low energy neutrons in 260 groups from 0.01 meV to 20 MeV.
    - EM shower cuts for transport and production of electrons: 50 keV, and gammas: 10 keV.

SESAME decay step

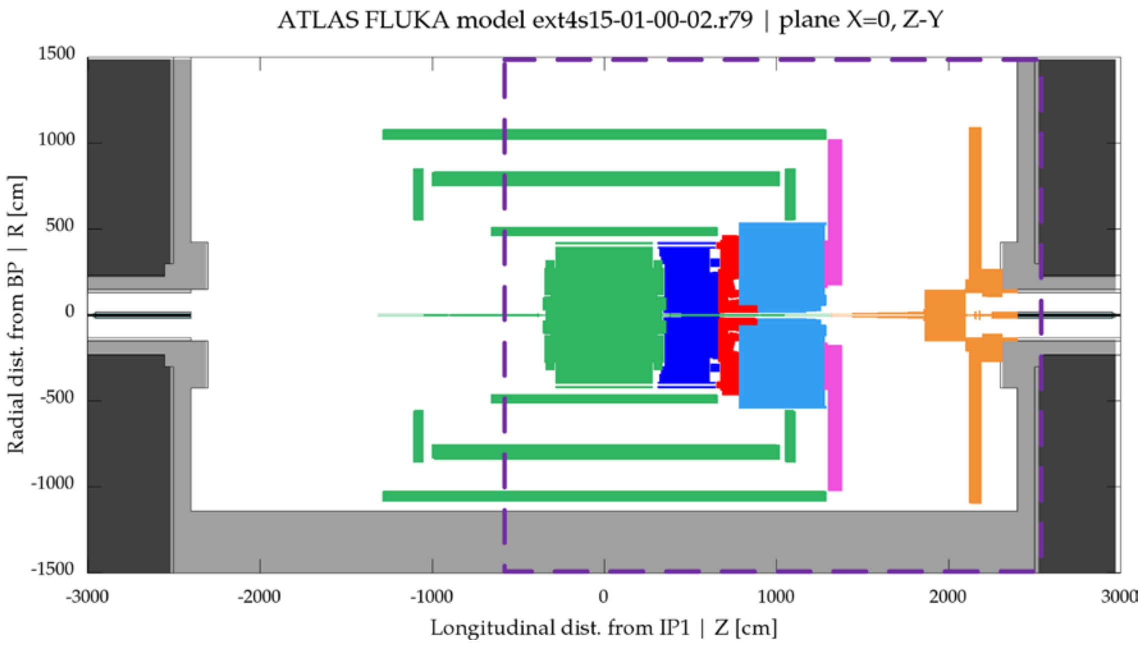
- The decay of the nuclides is scaled according to the irradiation profile provided by the Technical Coordinator of ATLAS (ultimate scenario estimates, August 2016).
  - Ion runs can be judged as cooling times due to their small impact in the activation.
  - A 75% of peak luminosity levelling is considered up to LS3.

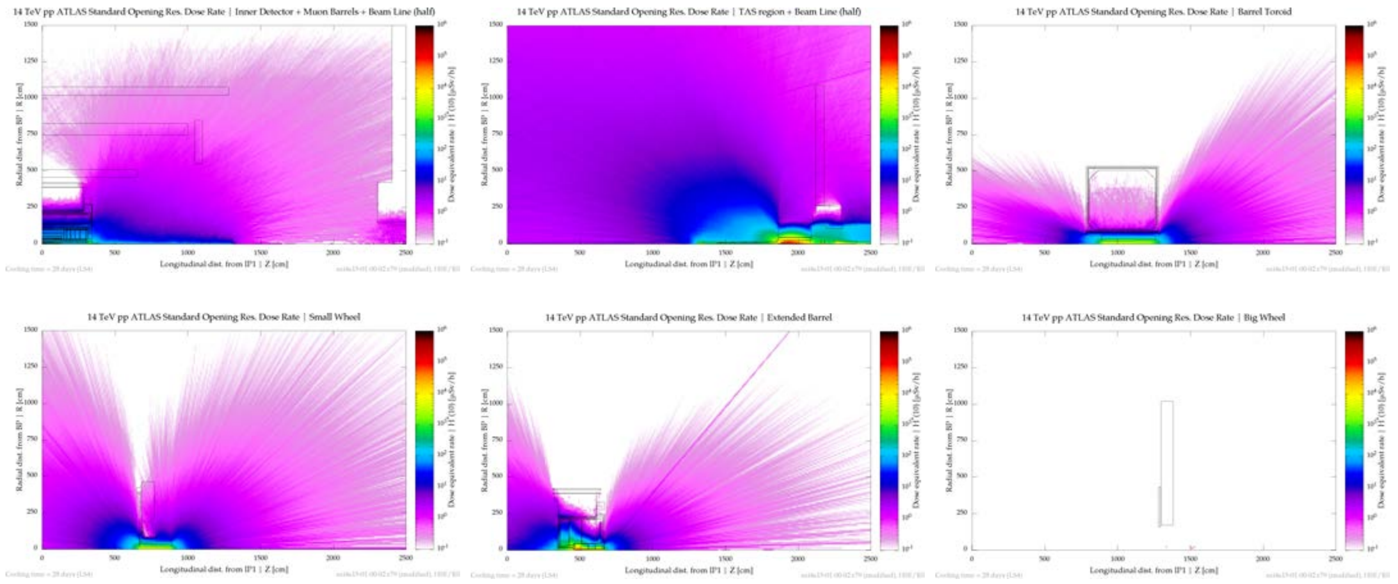


  - The proton-proton inelastic total cross section is of 75 mb up to LS1 and 80 mb afterwards.
  - The irradiation is supposed to be delivered at the end of the proton run schedule, at the maximum luminosity (conservative scenario).
- The ambient dose equivalent is scored in the region of interest:
  - $0 \leq R \leq 1500$ (150 bins).
  - $0 \leq \varphi \leq 2\pi$ (1 bin).
  - $0 \leq Z \leq 2500$ (250 bins).

FLUKA 1-step

- Some regions materials are set to vacuum for decay purposes, to simulate different contributions from the components that are displaced.
- Multiple runs: Sum up the scorings (after displacement).

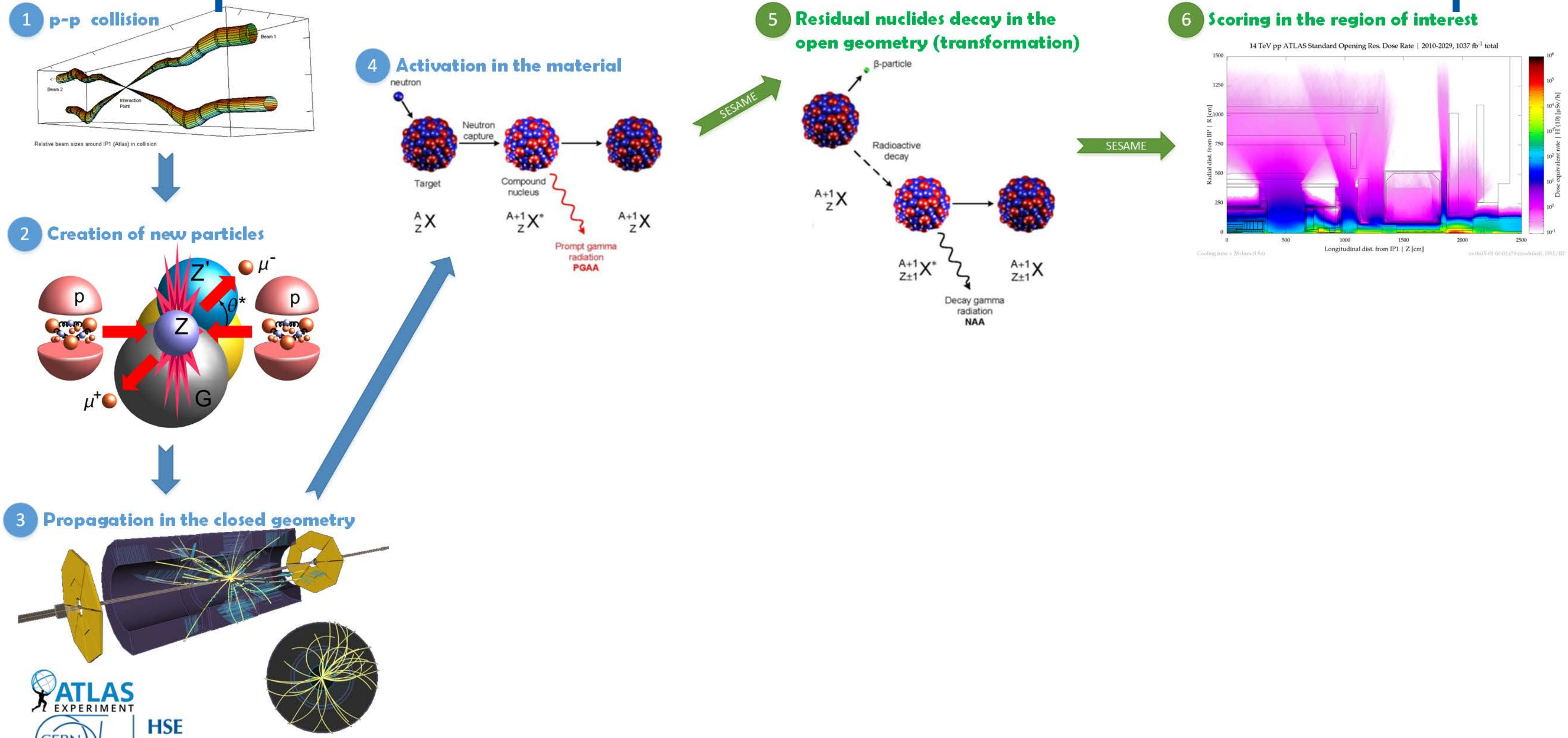




FLUKA 1-step

- There is only one geometry: the closed scenario.
- The source is a 2×7 TeV colliding proton beam (half-crossing angle of 142.5 μrad). The total number of simulated proton collisions is 25 000 (6 times).
- One run per component (prompt and decay in a single step).
- The magnetic field is turned on in the prompt and off in the decay.
- The same physics cards than in the prompt step in the SESAME approach, but the EM shower is now on.
- Usual particle thresholds as from the decay step in the SESAME approach.
- The region of interest is extended to avoid artefacts in the superposition afterwards.

Comparison: SESAME vs. FLUKA 1-step



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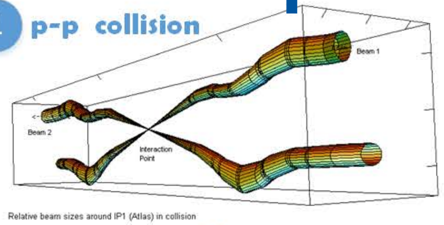
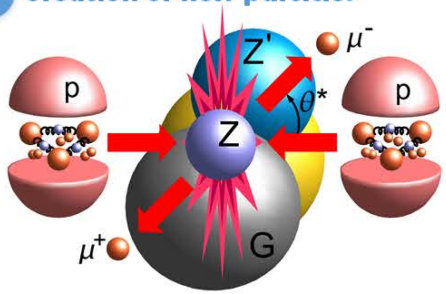
Comparison: SESAME vs. FLUKA 1-step

1 **p-p collision**

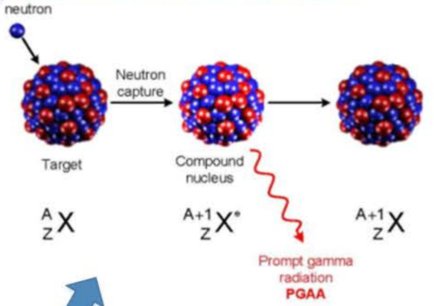


2 **Creation of new particles**

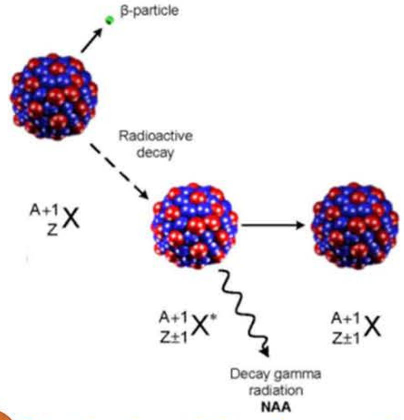


3 **Propagation in the closed geometry**

4 **Activation in the material**



FLUKA 1-STEP



5 **Residual nuclides decay with some materials set to vacuum in the closed scenario**

FLUKA 1-STEP

6 **Post-process contributions in an extended region of interest (transformation)**

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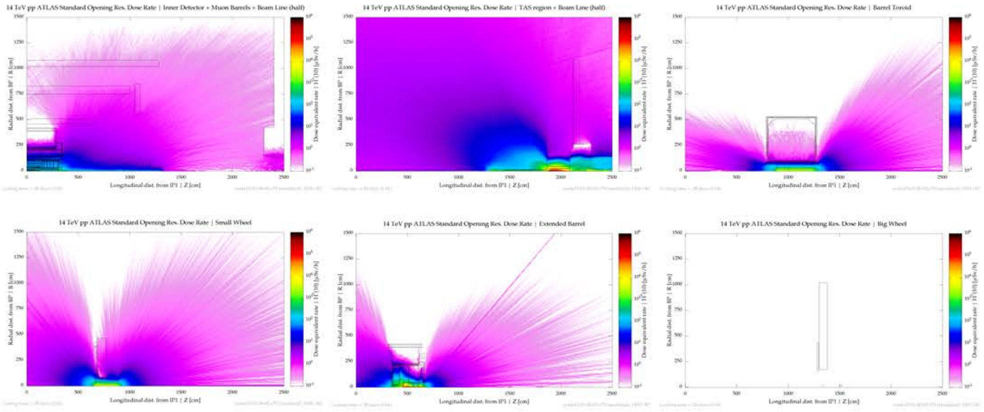

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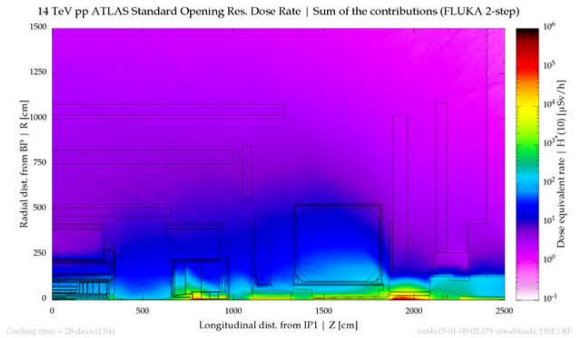

ATLAS EXPERIMENT

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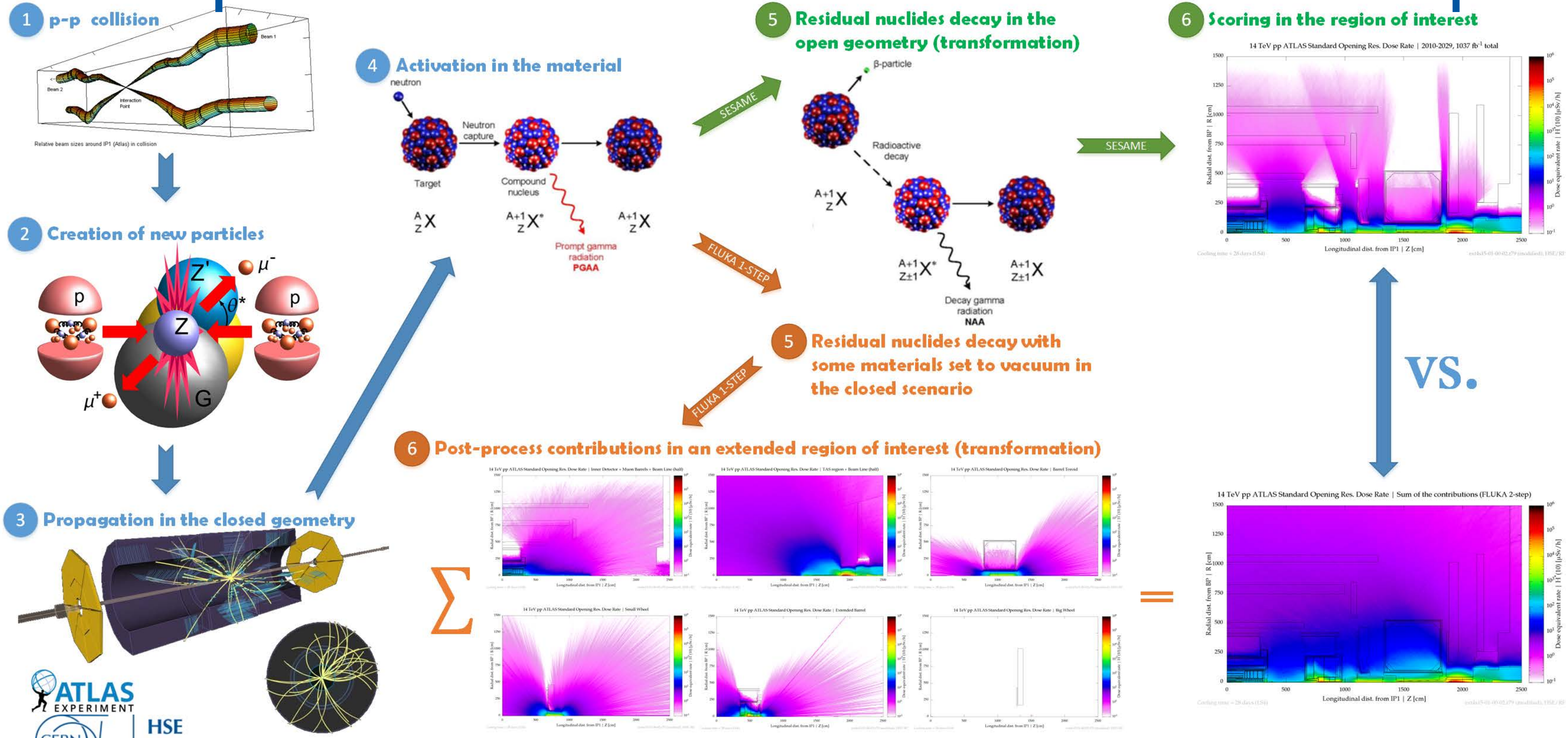
Comparison: SESAME vs. FLUKA 1-step



ATLAS EXPERIMENT

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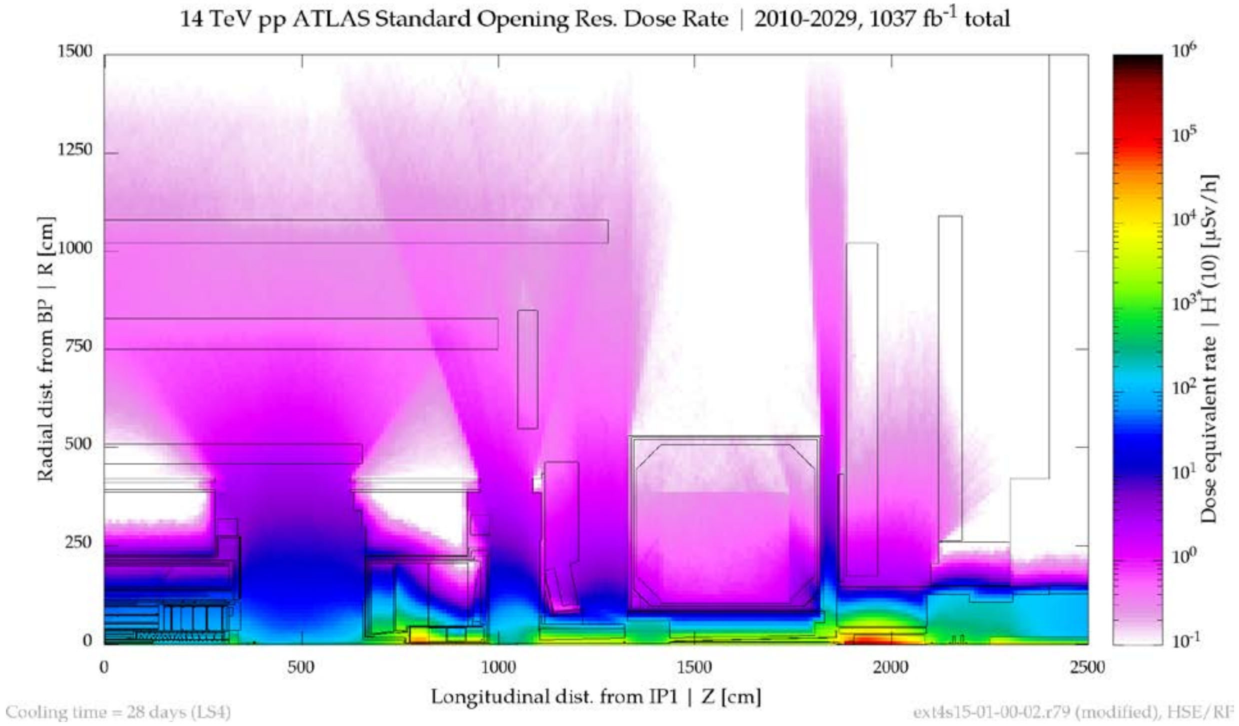
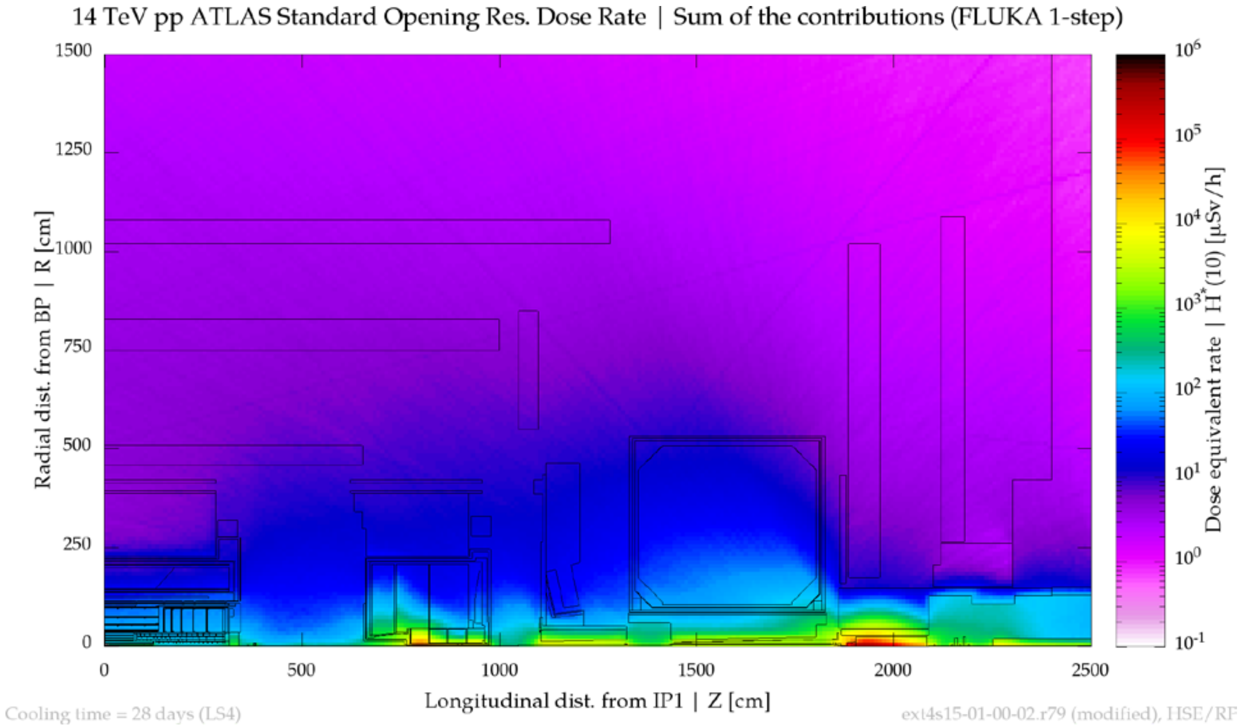


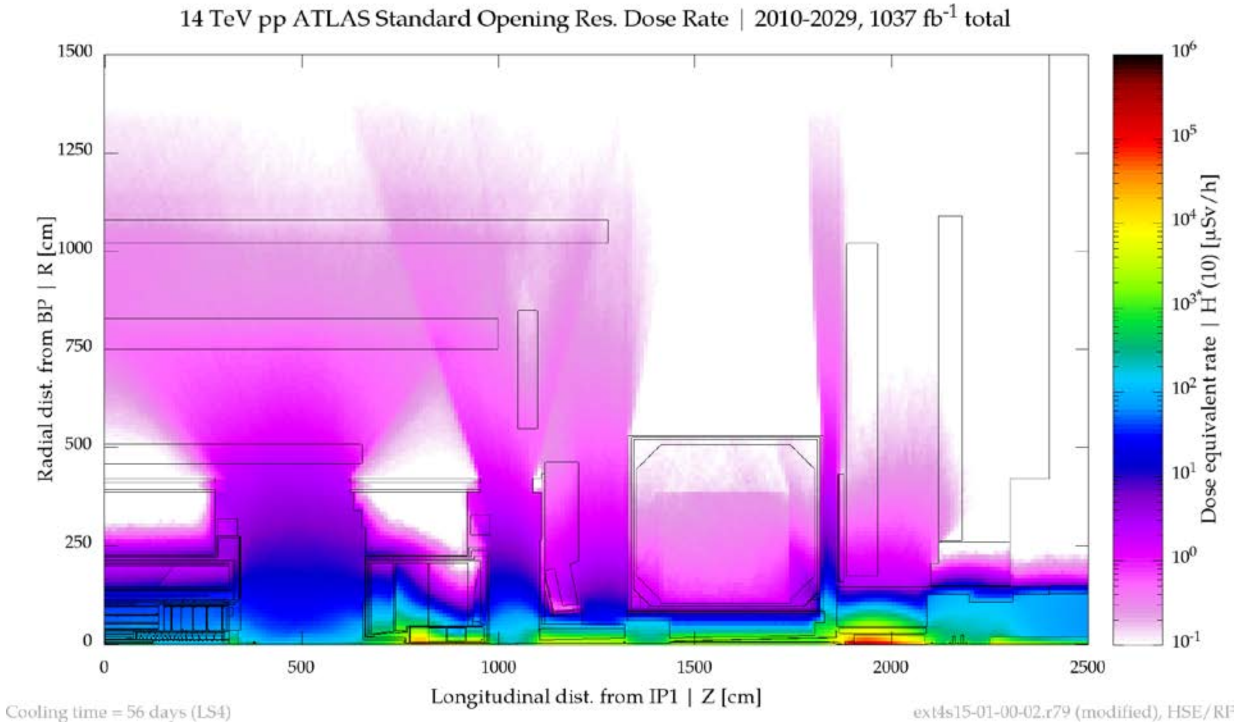
- General overestimation in FLUKA 1-step method for open geometries.



- Shielding effect in SESAME scheme for open geometries.

LS4 (28 days)

Comparison: SESAME vs. FLUKA 1-step



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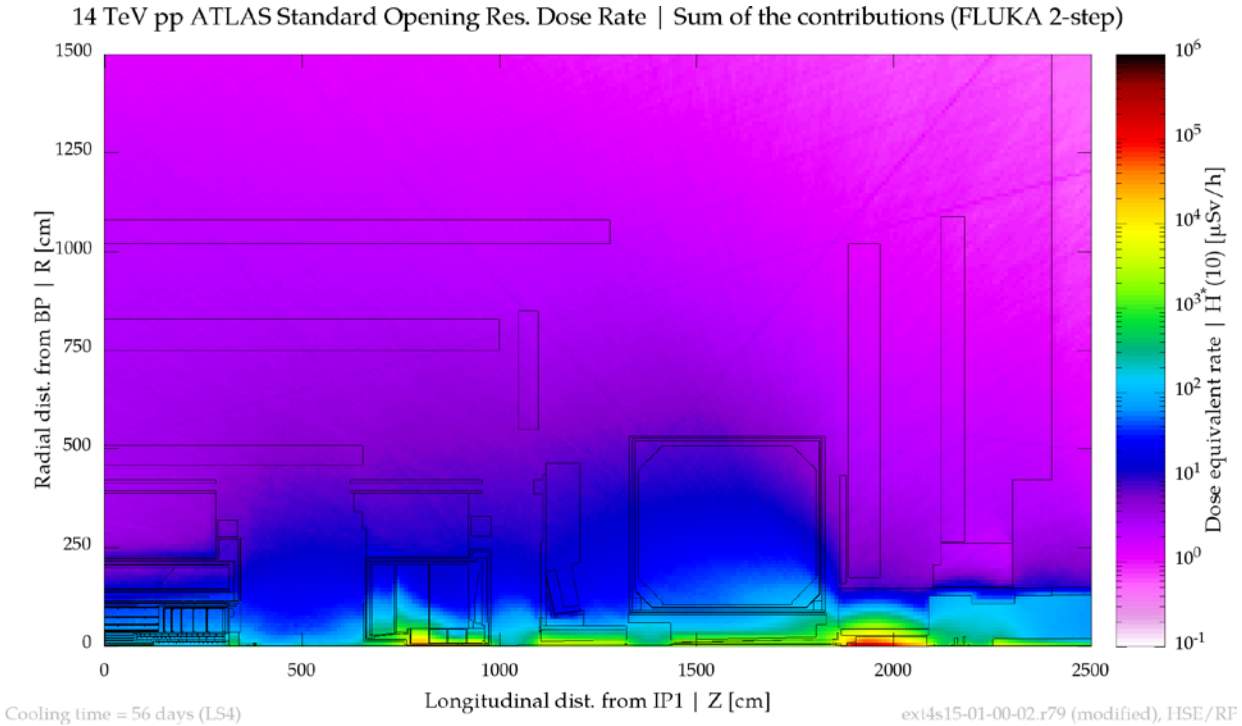
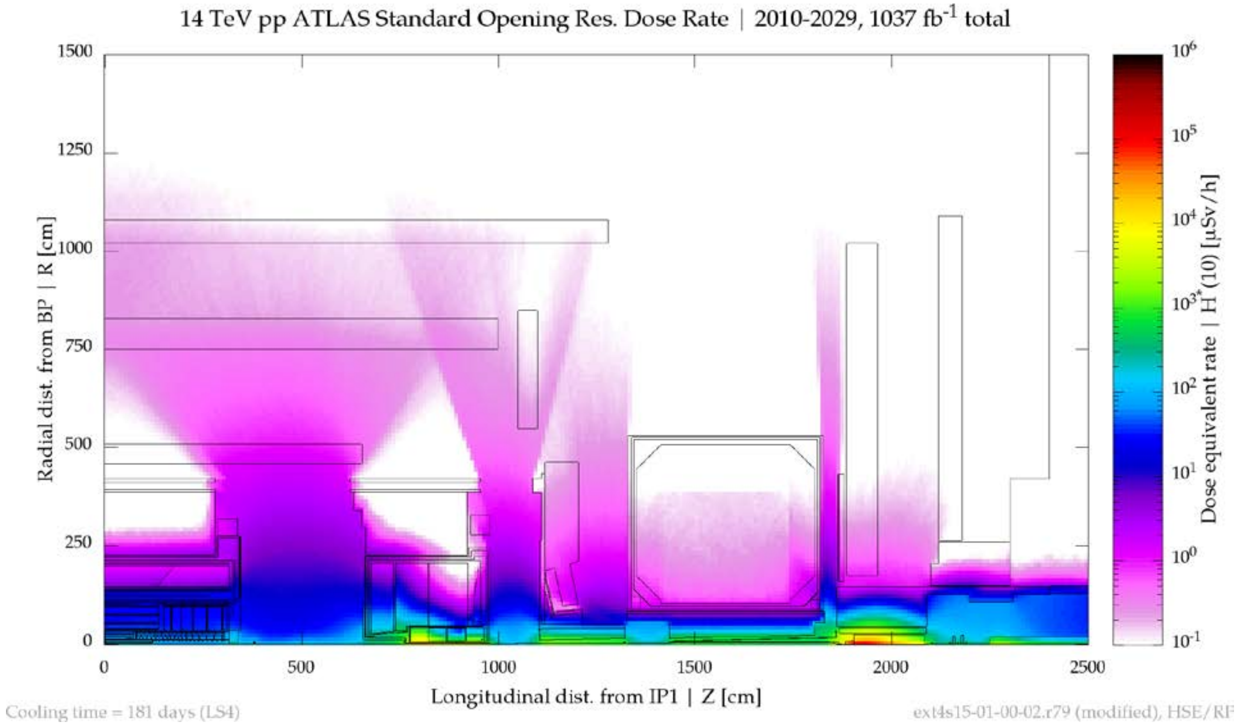


- Shielding effect in SESAME scheme for open geometries.

LS4 (56 days)

Comparison: SESAME vs. FLUKA 1-step



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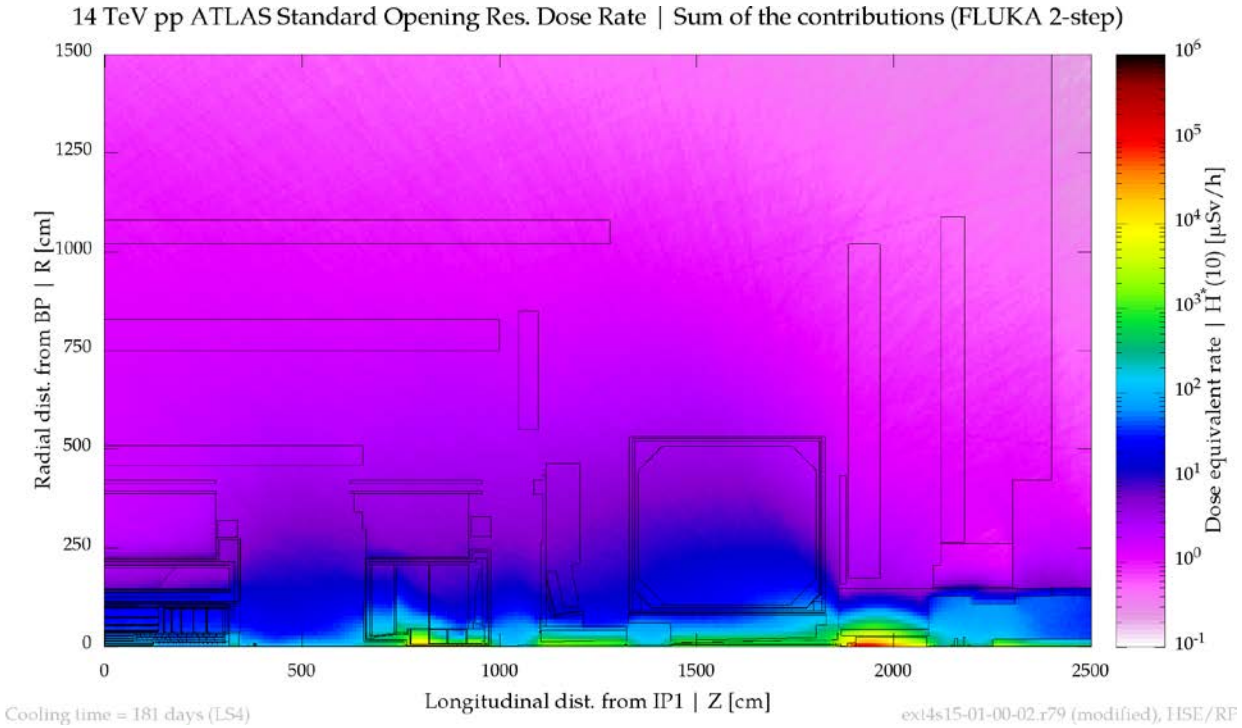
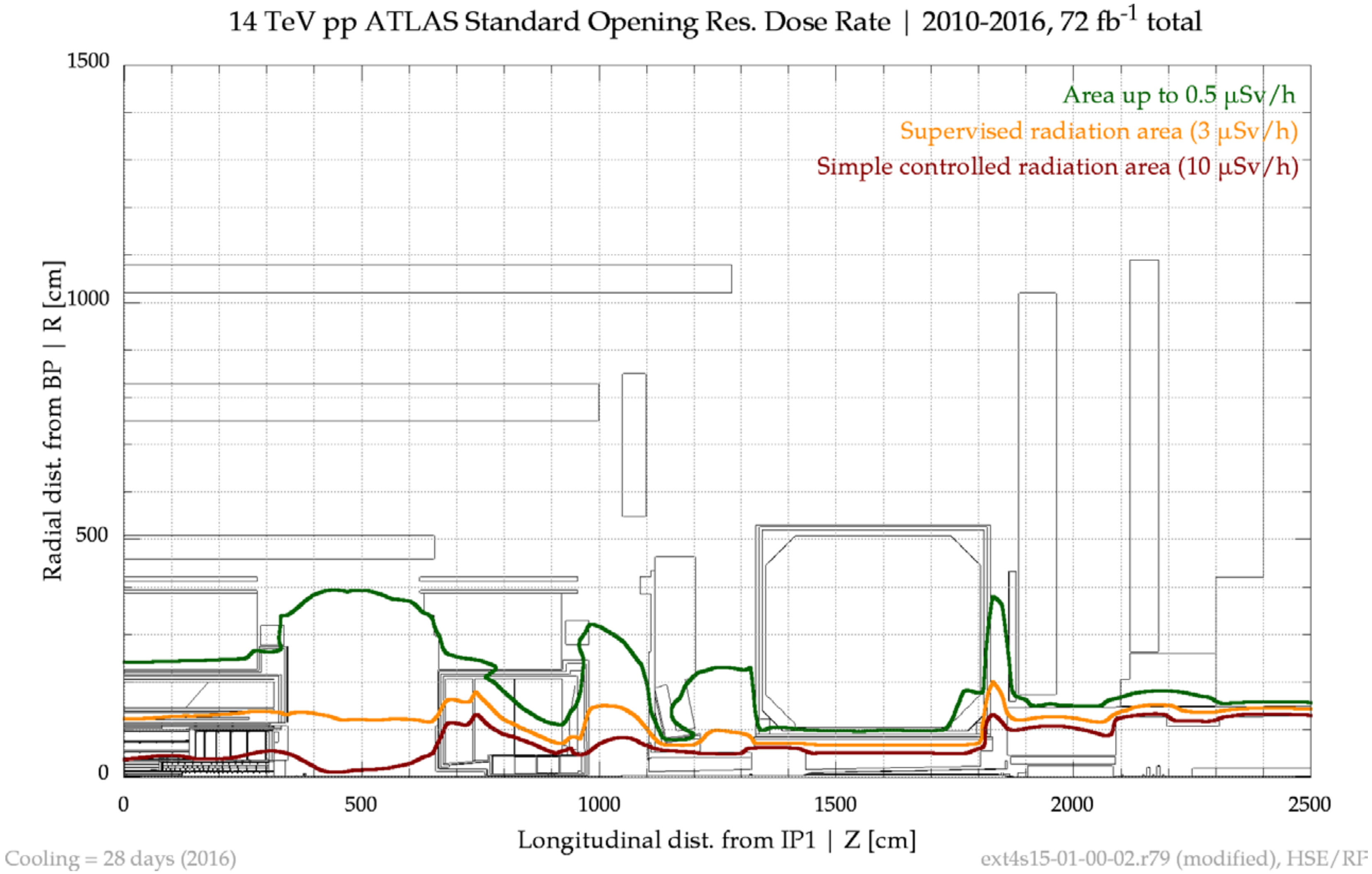


- Shielding effect in SESAME scheme for open geometries.

LS4 (181 days)

Results

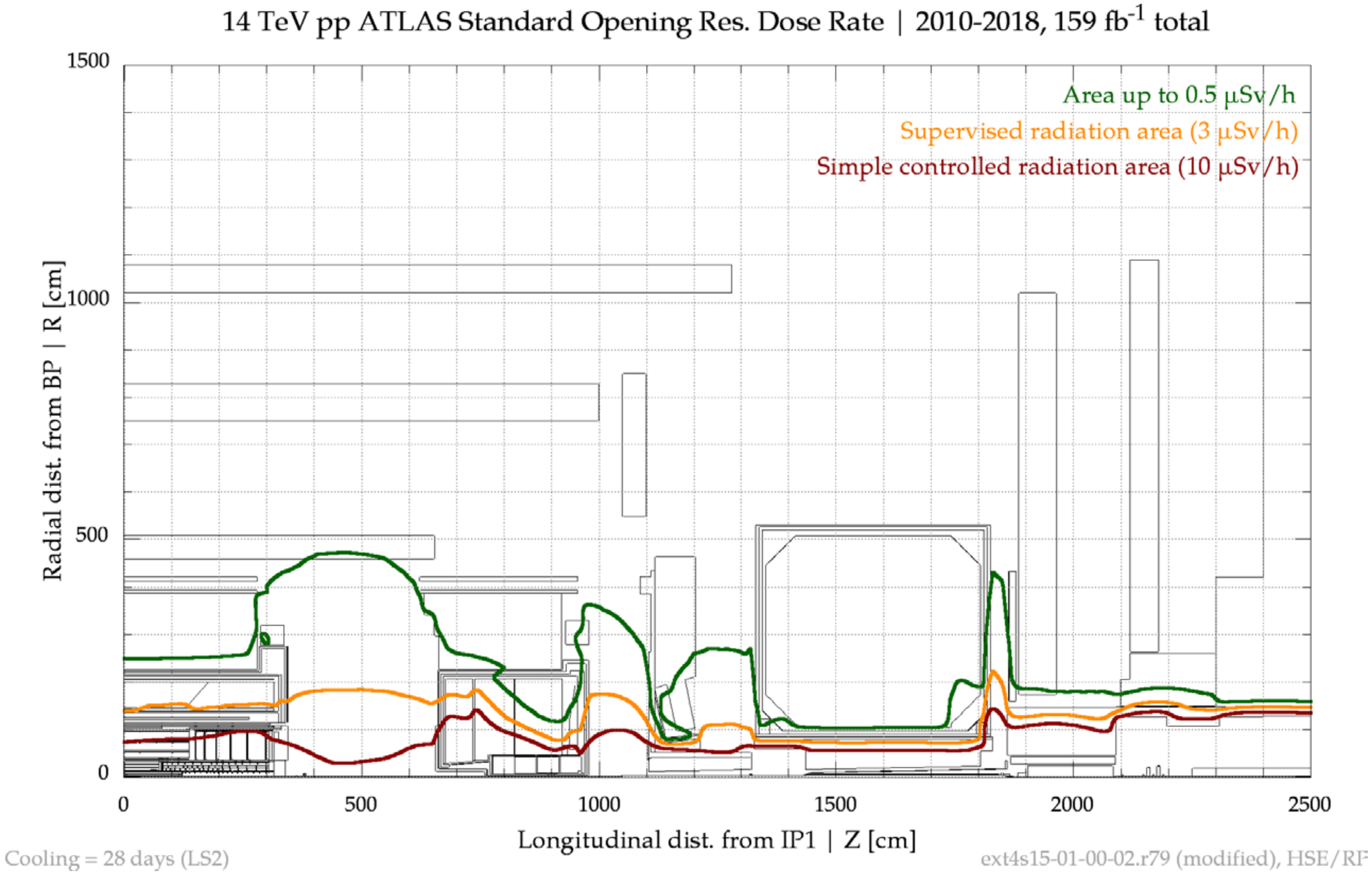
2016 (28 days)



- 28 days of cooling time after the proton run:
  - At a radial distance of around 1-2 m from the beam line, it can be considered as controlled radiation area.
  - The remaining cavern is considered as supervised radiation area.
  - In order to mitigate the radioactive risk, and also to address any operational problems encountered near the beam pipe, a temporary shielding can also be placed.

Results

LS2 (28 days)



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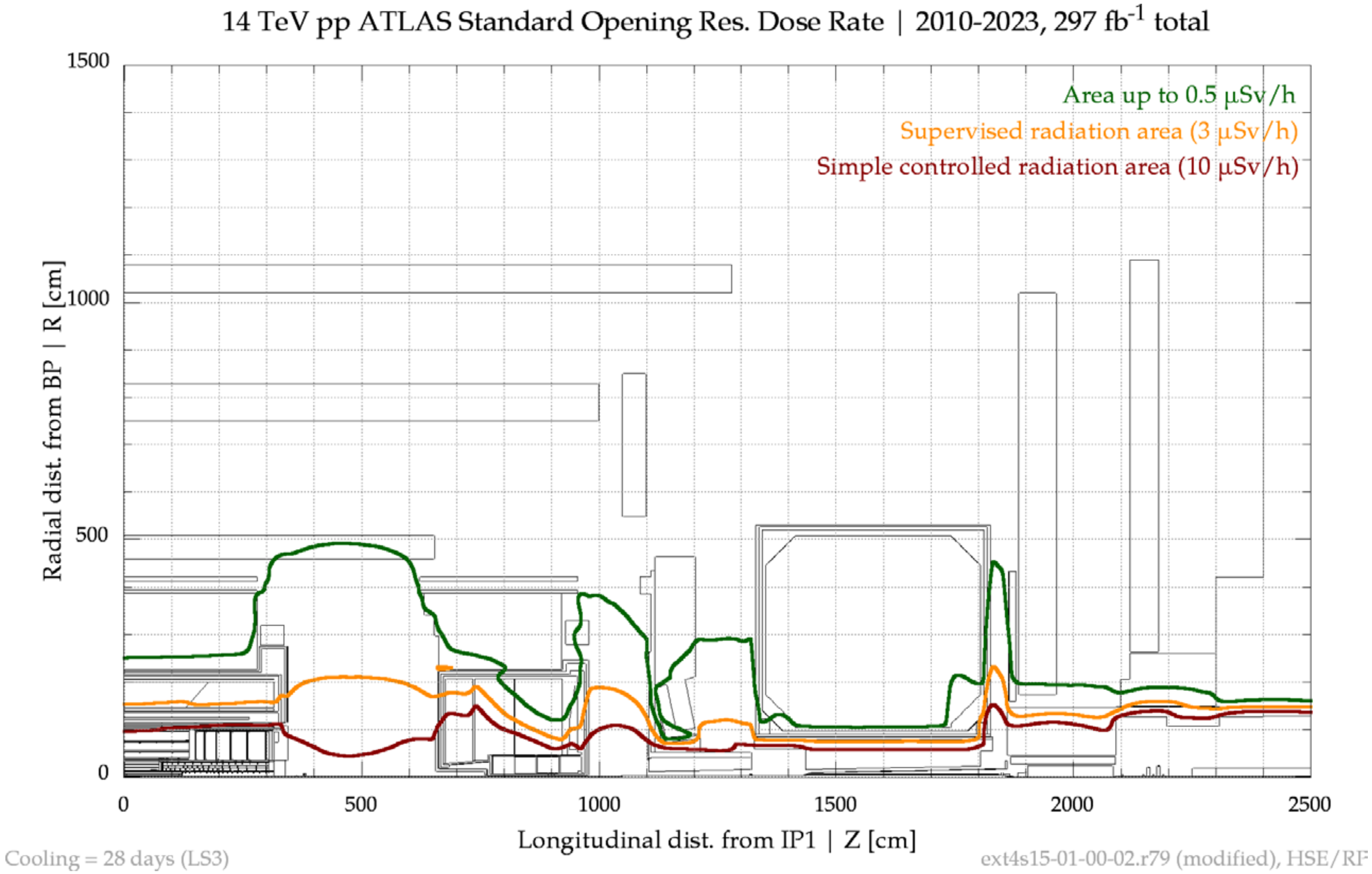
Results

LS3 (28 days)



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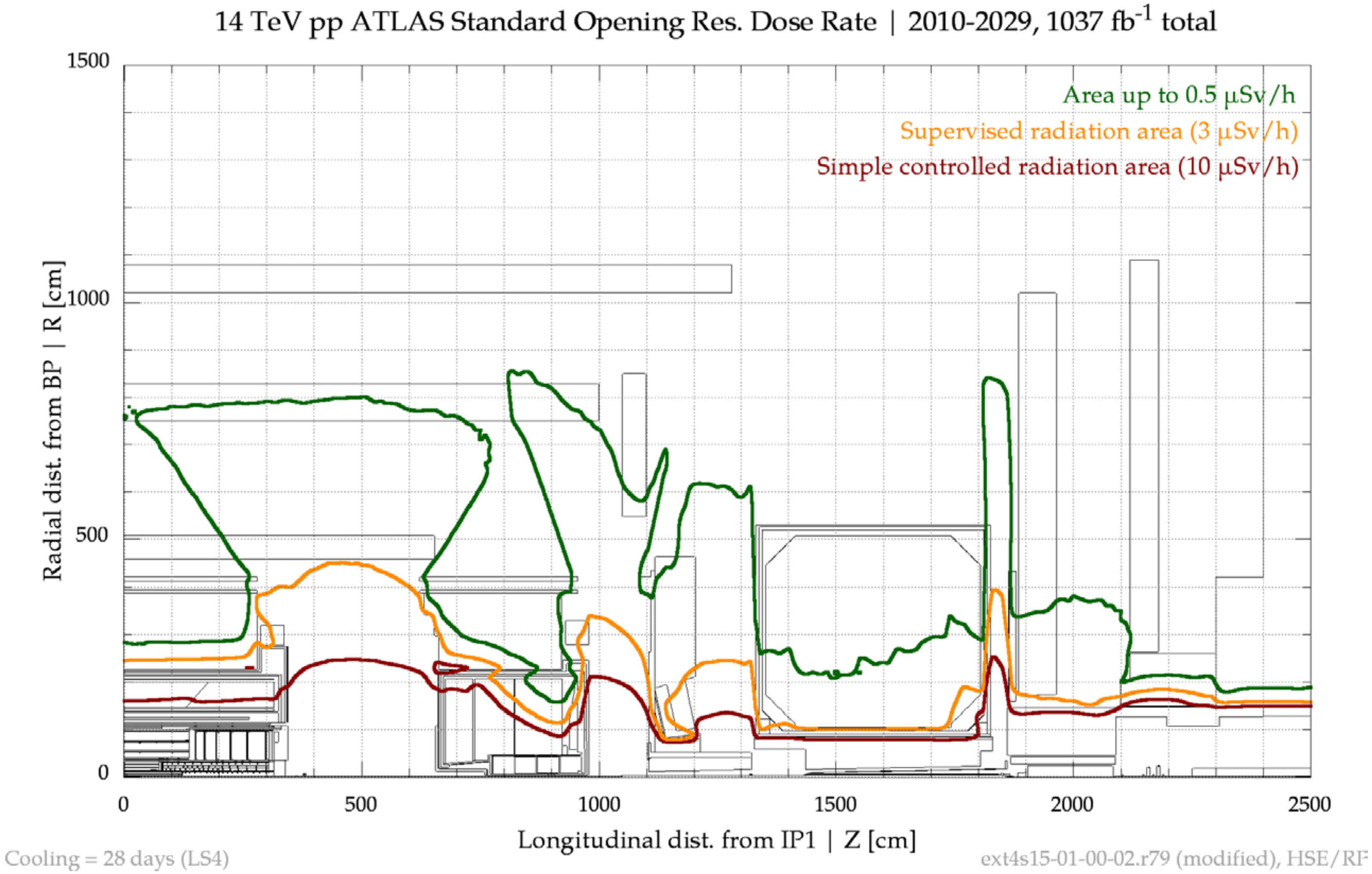
Results

LS4 (28 days)



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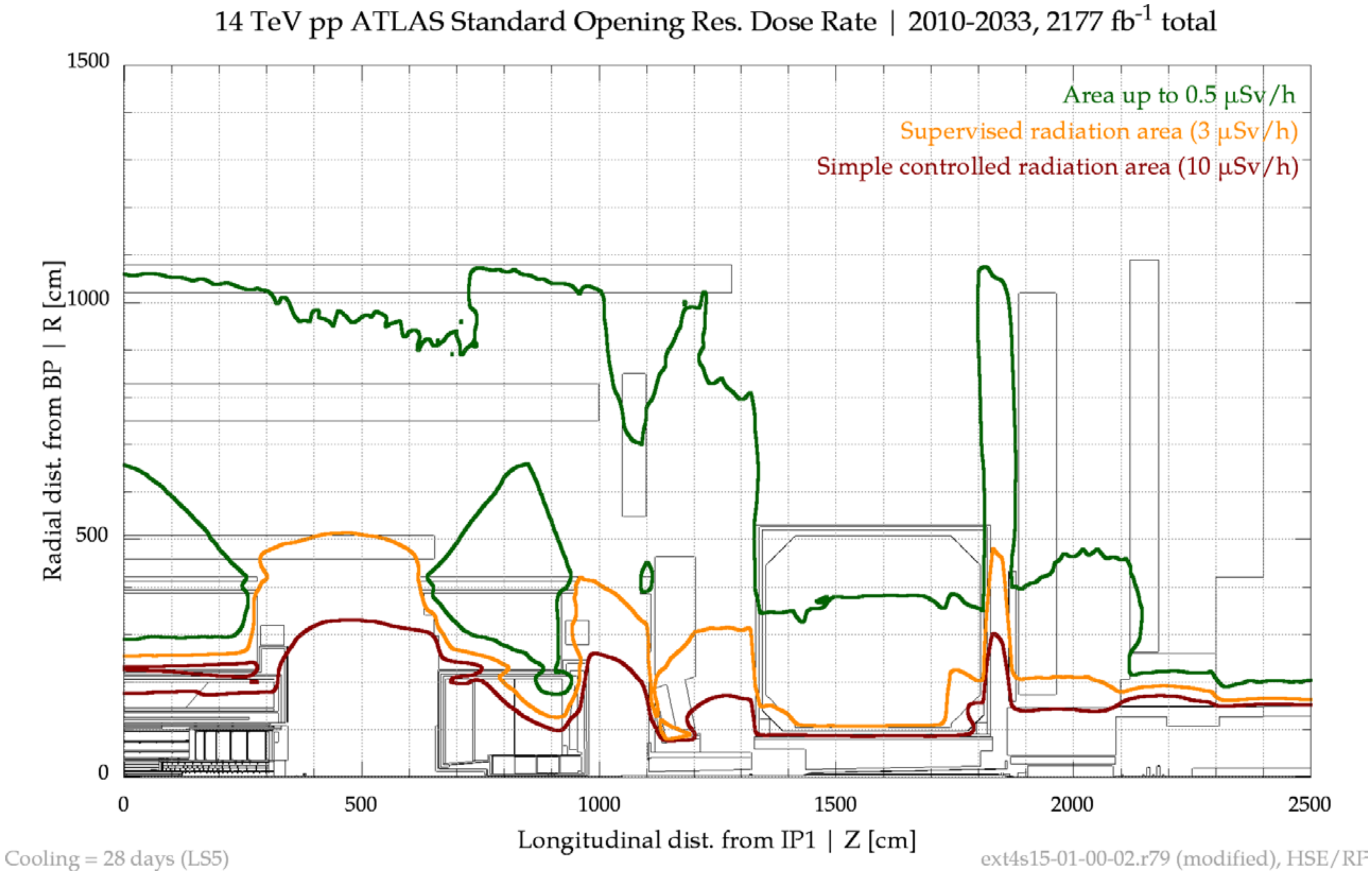
Results

LS5 (28 days)



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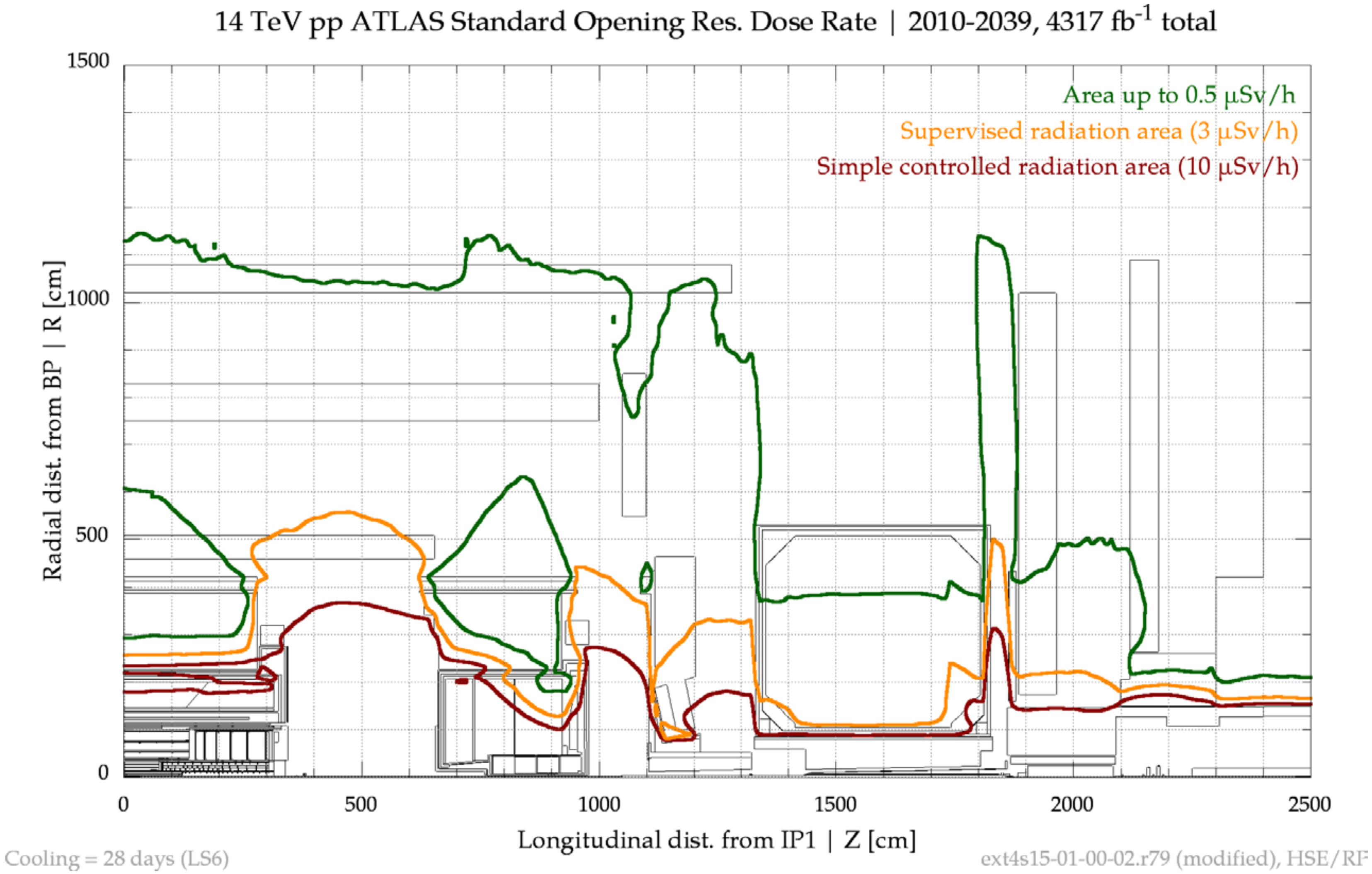
Results

LS6 (28 days)



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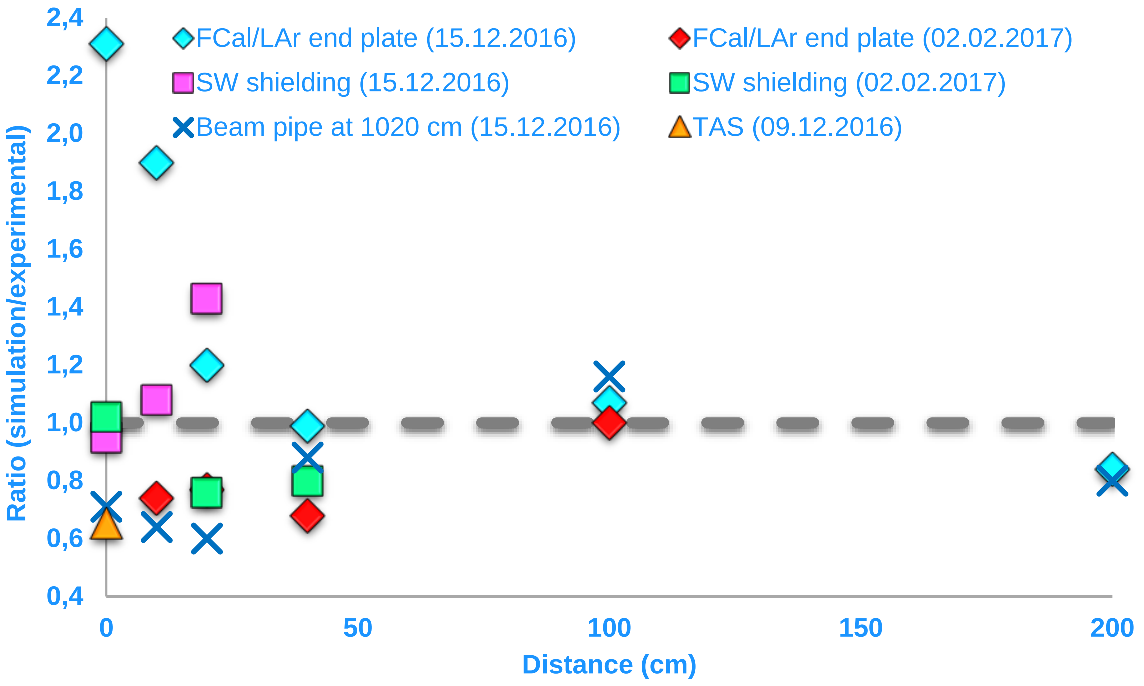
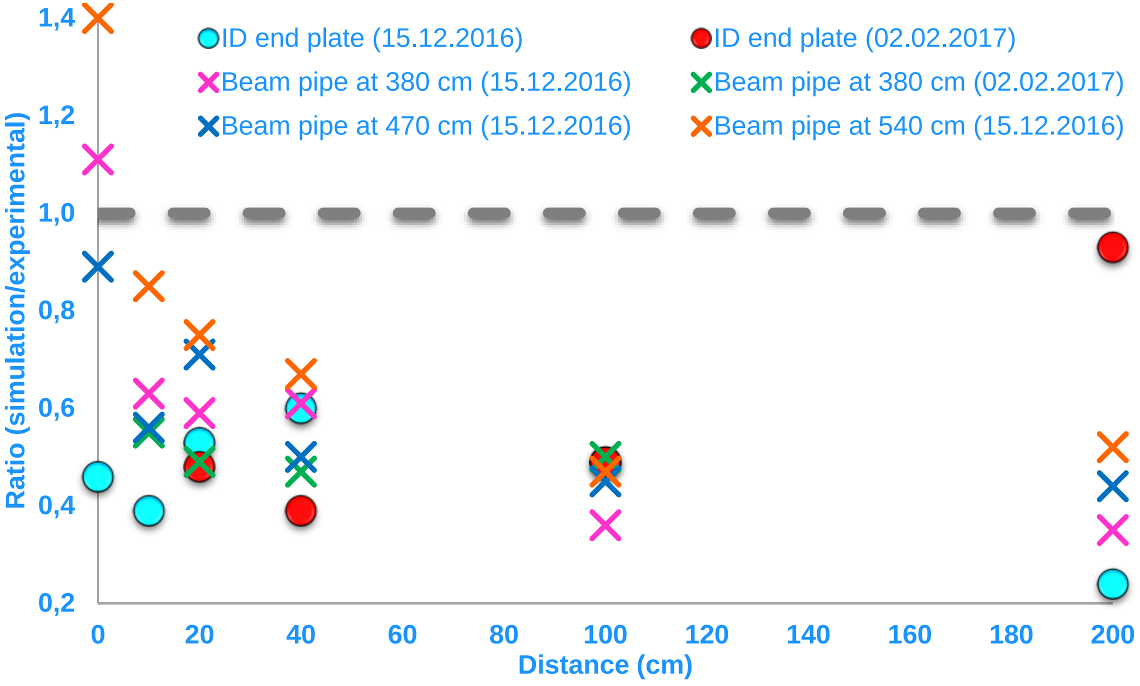
Benchmark

- Comparison of measurements taken in 2016 YETS.
- Good agreement but the underestimation might be due to some material missing in the FLUKA geometry description (ID and flanges).





Conclusions

- The SESAME approach is better as:
  - It still relies on FLUKA, it only provides tools to run the simulation.
  - It is not straightforward to transform and combine the scorings in case of rotations in the FLUKA 1-step, and also precision error can arise because of the displacements and the bin width mismatch.
  - It avoids the repetition of the nuclide production, that has to be done only once per closed geometry, and is very time consuming.
  - The results are validated according to some measurements taken in 2016 YETS.
  - The radiation field is more realistically described in the open scenario. Shielding regions can easily be added and the replacement of components can be considered faster.

Acknowledgements

I would like to thank:

- Tim Cooijmans and Moritz Guthoff, for their brilliant idea of developing SESAME.
- Ida Bergström for critical feedback and testing, and Chris Theis for hints on interfacing C++ with FORTRAN77.
- The CMS Beam and Radiation Instrumentation and Luminosity (BRIL) working group, for granting Radiation Protection access to the code and letting us implement some new features.

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