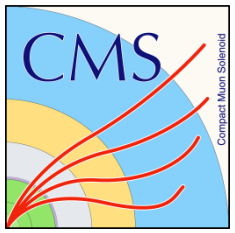

FLUKA radiation simulations

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Contents

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Introduction

- Radiation background simulation are an important input in the design of silicon tracker and vertex detector systems
  - **Silicon damage (1 MeV) fluences** used to model leakage currents and depletion voltages, which allow us to anticipate detector performance over its lifetime
  - **Ionising dose** measurements important for predicting damage in electronics
  - **Fluence of hadrons > 20 MeV** can be used to estimate rate of Single Event Effects (SEE) in electronics
  - **Radioactivation** estimates can dictate procedures for cavern access and detector installation and maintenance
- Simulations of current detectors benchmarked with measurements
  - Gives confidence in predictions for Phase-2 running
  - Feeds into discussions of safety factors and systematic errors

Event generation

- Minbias events for proton-proton collisions generated to serve as input to FLUKA
  - 7 + 8 TeV for Run 1
  - 13 TeV for Runs 2 + 3
  - 14 TeV for Run 4 and beyond
- CMS use DPMJET III (FLUKA built-in)
  - Investigating updated DPMJET to assess systematics
- ATLAS: Pythia8 tuned with minbias data
  - Previously used PHOJET

- Also generate heavy-ion collisions and machine-induced backgrounds (halo, beam gas, failures etc) for other studies

Particle transport codes

- Bulk of simulation work on ATLAS and CMS done with FLUKA
  - Historically, favoured by CERN for particle transport
  - Also used by CERN Radiation Protection
  - Alternative simulation using MARS (CMS) and FLUGG + GCALOR (ATLAS)
- FLUKA is a fully integrated physics Monte Carlo simulation package
- Necessary to implement details of full detector geometry and material (including shielding and beam line)
  - Important to have correct mass and material composition of each detector component
  - Trace elements important for activation simulations
- Event-by-event simulations, but output is typically averaged over all events
  - Minbias cross-section used to scale to expected rates

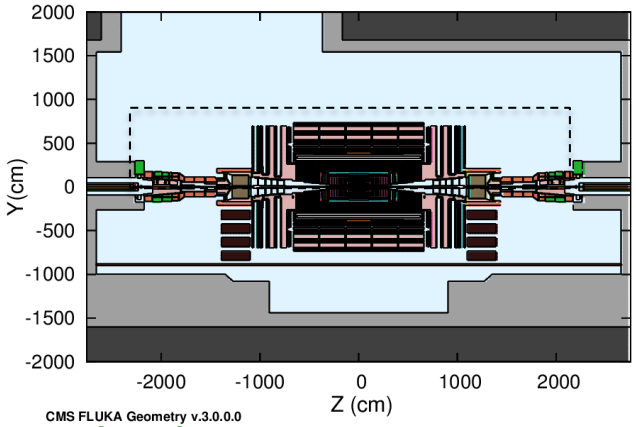
CMS FLUKA geometry

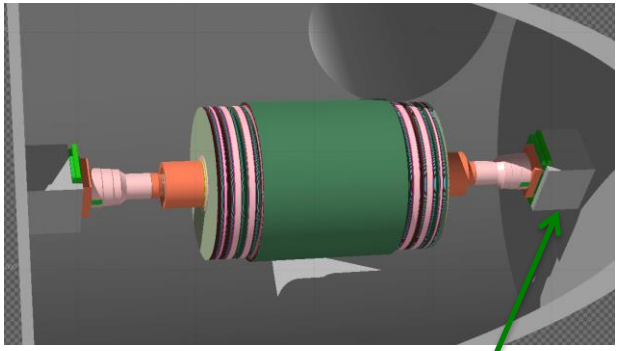
- Various FLUKA geometries are maintained by BRIL to reflect the LHC era
- The CMS FLUKA 'nominal' geometry model
  - defined as best available representation of Run-2 detector configuration
  - is continuously updated with **general improvements** and **actual upgrades**
- Maintain future geometry models for feasibility studies
- Aim to maintain historic detector configuration geometry models
  - (i.e. implement improvements but not upgrades) for better benchmark results,
  - although this is done much less frequently.
- The geometry (and simulation settings) is versioned with a tag

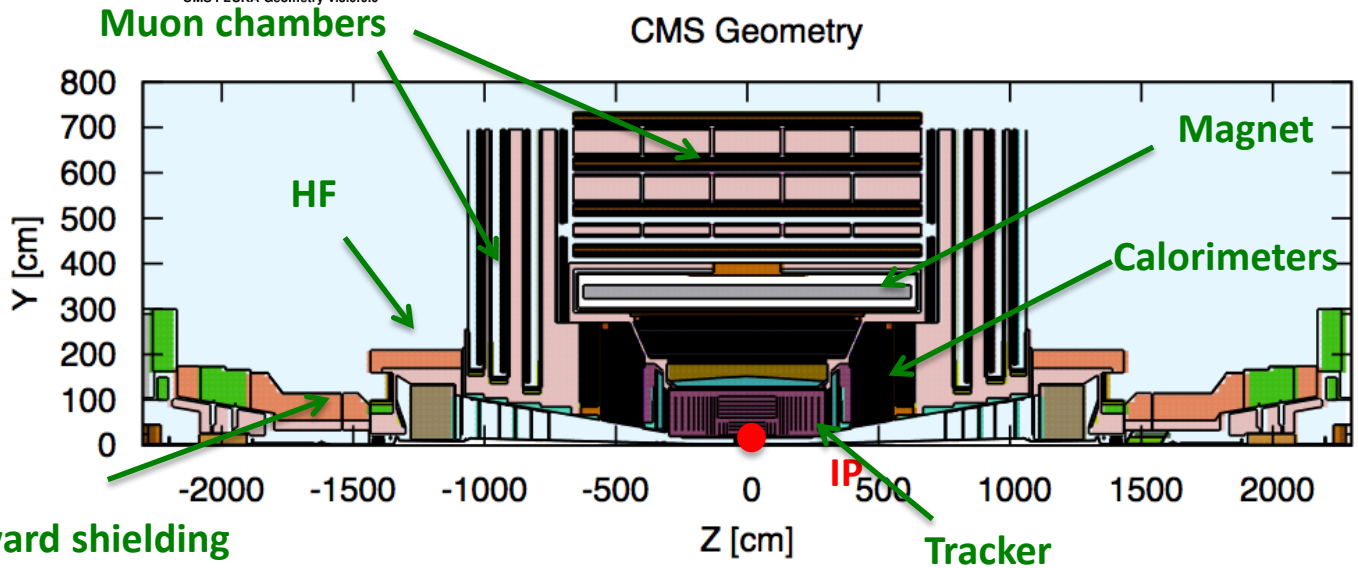
- **6.5 TeV and 7 TeV per beam results** available with **detailed version of Phase 1 tracker geometry** (Phase 0 pixel)
- **6.5 TeV run with 2017 geometry** (Phase 1 pixel) in progress
- **3.5 and 4 TeV per beam** (2011,2012) results still with former **simplified Phase 1 tracker geometry**

CMS FLUKA geometry

- Mostly cylindrical shapes apart from cavern elements







ATLAS FLUKA geometry

- Three FLUKA geometry developments
  1. Run-1 geometry for LHC start-up
  2. Run-2 (current) geometry with Insertable B-Layer (IBL)
  3. Phase-2 Upgrade to all-silicon Inner Tracker (ITk) for High Luminosity LHC
- SVN repository to share FLUKA geometry developments between ATLAS sub-groups

- Also developing GDML common geometry for sharing ITk geometry with sub-groups using alternative simulation codes

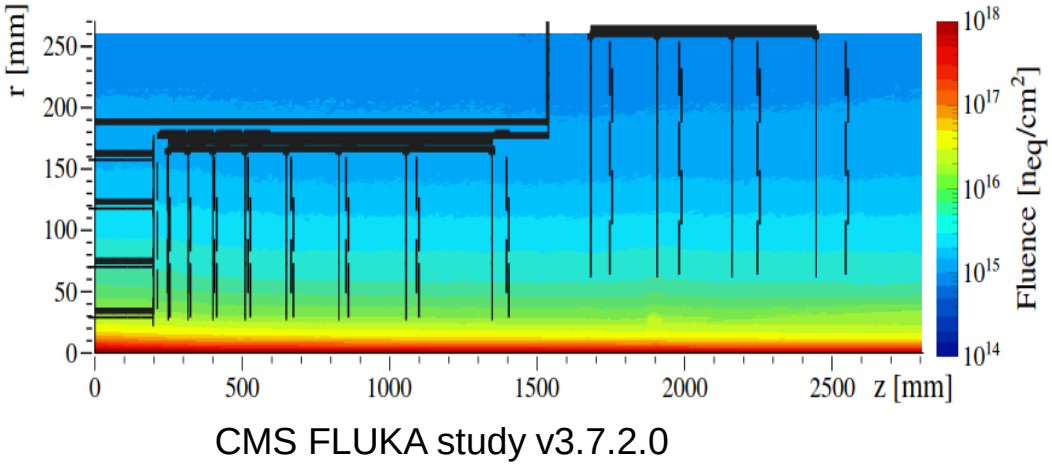
Simulation settings

- Magnetic field imported from CMS/ATLAS offline software
- Energy cut-offs for particle transport:
  - CMS: hadrons + muons 1 keV, neutrons 0.01 meV, photons 3 keV, electrons 30 keV
  - ATLAS uses similar
  - Photons and electrons have significantly higher cut-offs in some regions (collimators, forward shielding)

- Typical output is an R-phi-Z grid for various quantities
  - Flux/fluence: 1 MeV neutron equivalent, hadrons > 20 MeV, various particles types
  - Dose-like: ionising dose, NIEL
    These are dependent on the material details of the region scored
- Dedicated simulations for other quantities
  - Particle energy and angular distributions
  - Event-by-event output of full particle information (position, momentum, arrival time at specific boundaries)

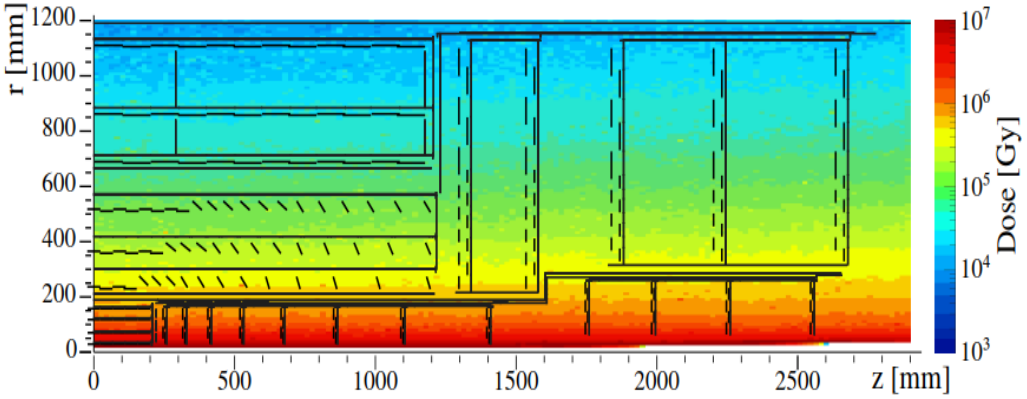
CMS FLUKA Results

- Radiation Levels in a phase 2 tracker model for a total integrated luminosity of 3000 fb^{-1}



1 MeV n eq. on Silicon

CMS FLUKA study v3.7.2.0

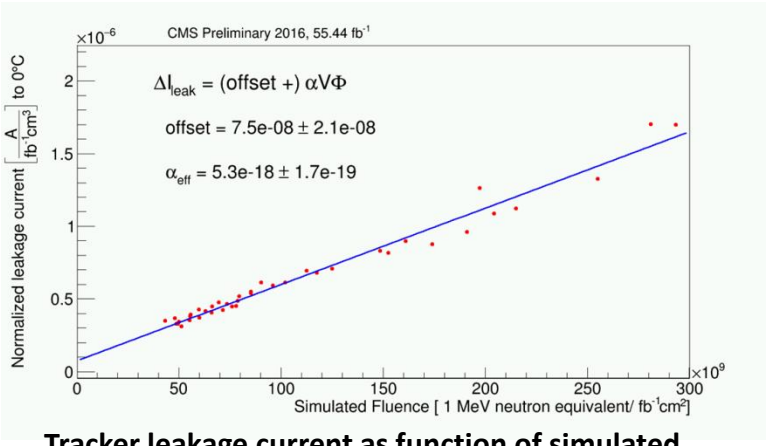


Absorbed dose (TID)

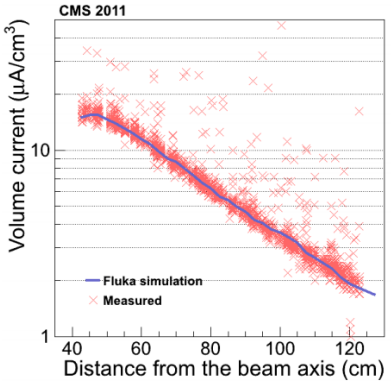
CMS FLUKA comparison with data

- Prediction of radiation damage to Pixel and Strip Tracker.

- Prediction of radiation damage to Preshower silicon sensors.



Tracker leakage current as function of simulated fluence after 55.44 fb^{-1}



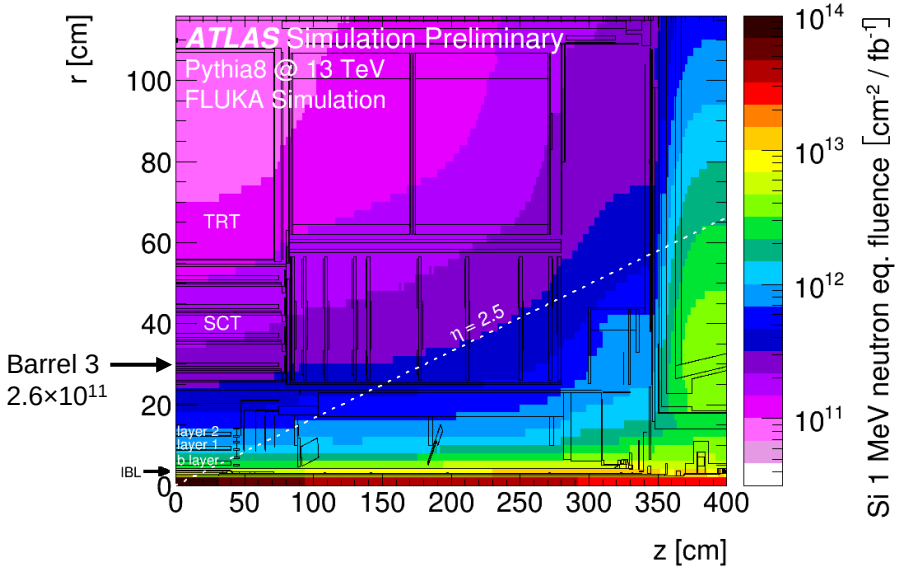
Preshower leakage current in comparison with prediction based on FLUKA results.
D.Barney et al. 2013 JINST 8 P02004

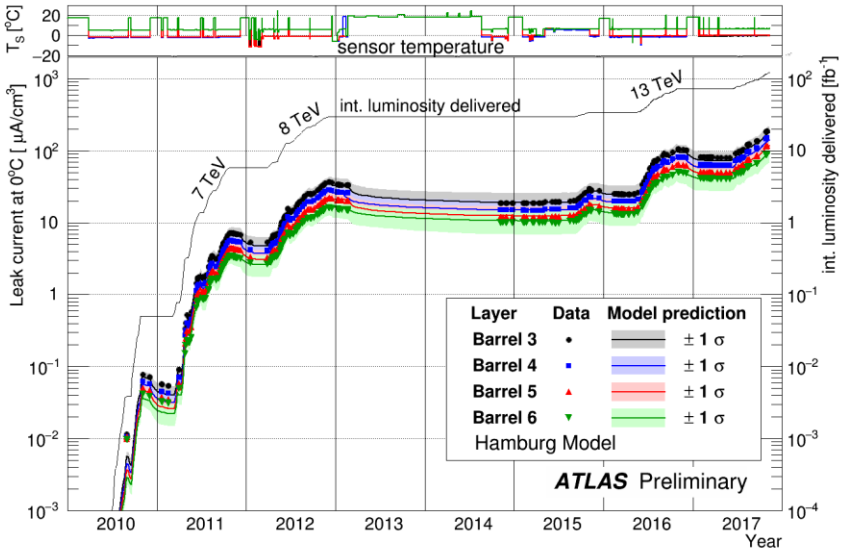
The University Of Sheffield.

ATLAS EXPERIMENT

ATLAS Run-2 results

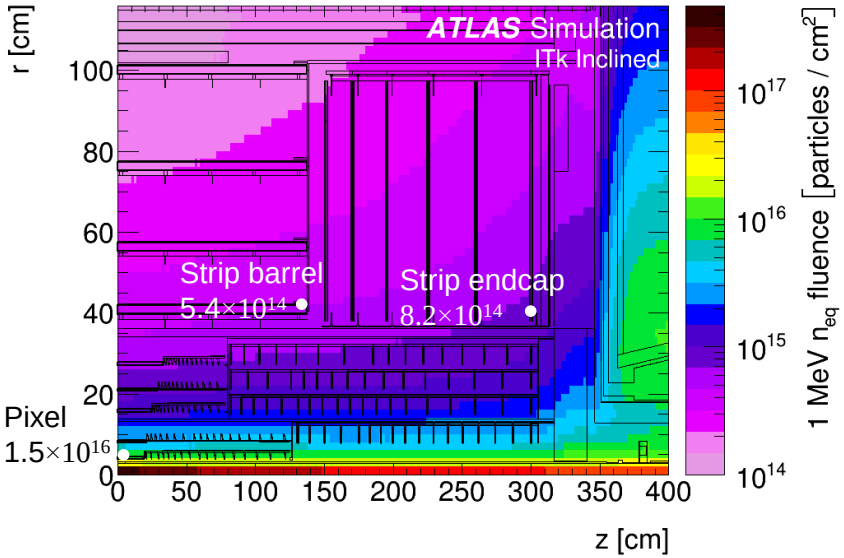
- Predictions of 1 MeV neq fluences made for Run-2 geometry
- These fluence predictions feed into the leakage current models, e.g., Hamburg/Dortmund
- Comparison with SCT leakage current measurements gives good agreement
  - Also good agreement with pixel leakage current measurements
  - Gives confidence to recommend safety factor 1.5 for future fluence + dose predictions





ATLAS Upgrade simulations

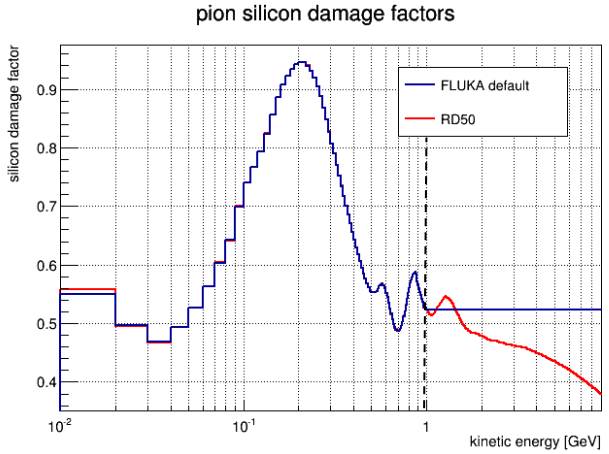
- Predictions of fluence and dose made for Phase-2 upgrade geometries
  - As ITk layout evolves, these predictions are updated
- Maximum values in ITk regions used for irradiations of sensors + chips after applying appropriate safety factors

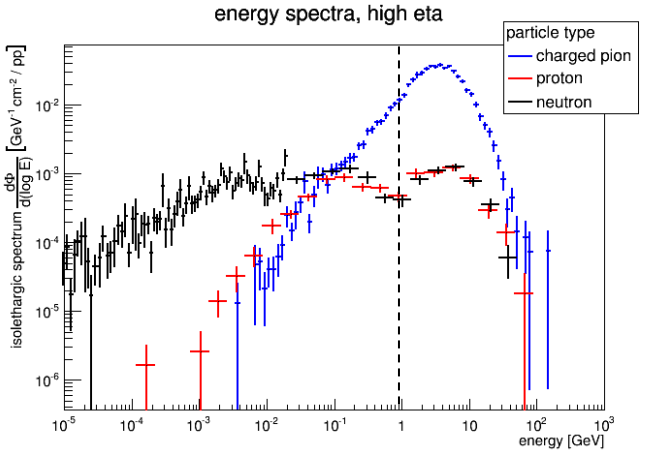


- Our studies indicate that placement of services has significant impact on ITk as well as downstream subdetectors
  - Radiation background simulations feed into detector layout design
  - Results reported to ATLAS ITk simulation & performance group

Silicon 1 MeV neutron equivalent damage factors

- FLUKA has implemented silicon damage weighting functions for pions, neutrons, protons and electrons
  - Taken from RD50 compilations
  - However, pions + neutrons above 1 GeV treated as constant; reasonable for most applications
- At LHC energies, energy spectra show a significant fraction of particles with KE > 1 GeV, particularly at high eta
- Implemented new user routine to read in the silicon damage factors up to 9 GeV
  - Can have up to 10% effect on predicted 1 MeV neq fluences
  - Will request that the FLUKA team have these implemented as default





CMS dissemination of results

- **In publications, TDRs and DPSs - Twiki used for CMS approved and published plots and captions**
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/BRILRadiationSimulation
- **Web-based 'radiation simulation plotting tool'** to enable CMS members to access to BRIL simulation data from qualified models and generate their own corresponding 2D 'flux maps', according to user-specified parameters: https://cern.ch/cms-fluxmap
- Specialist Studies not on webtool
  - Scorings e.g. energy spectra or data sets can be provided independently upon request (depending on priority)
  - Feasibility Studies (e.g. shielding study) results presented at relevant working group meetings, e.g BRIL Rad Sim Meeting or phase 2 Integration Meeting.
- FOCUS is a BRIL-designed tool that would allow non-FLUKA users to score their own information at a user-defined boundary in the CMS FLUKA model (can be used for timing information, spectra etc): https://cern.ch/bril/SitPages/FocusBril.aspx

ATLAS dissemination of results

- In publications and TDRs, public Twiki used for ATLAS approved plots and captions

  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RadiationSimulationPublicResults
- Internal Twiki used to share fluence colour maps and tables with detector systems
- Currently developing a web tool like CMS
- Dedicated simulations for other information on request

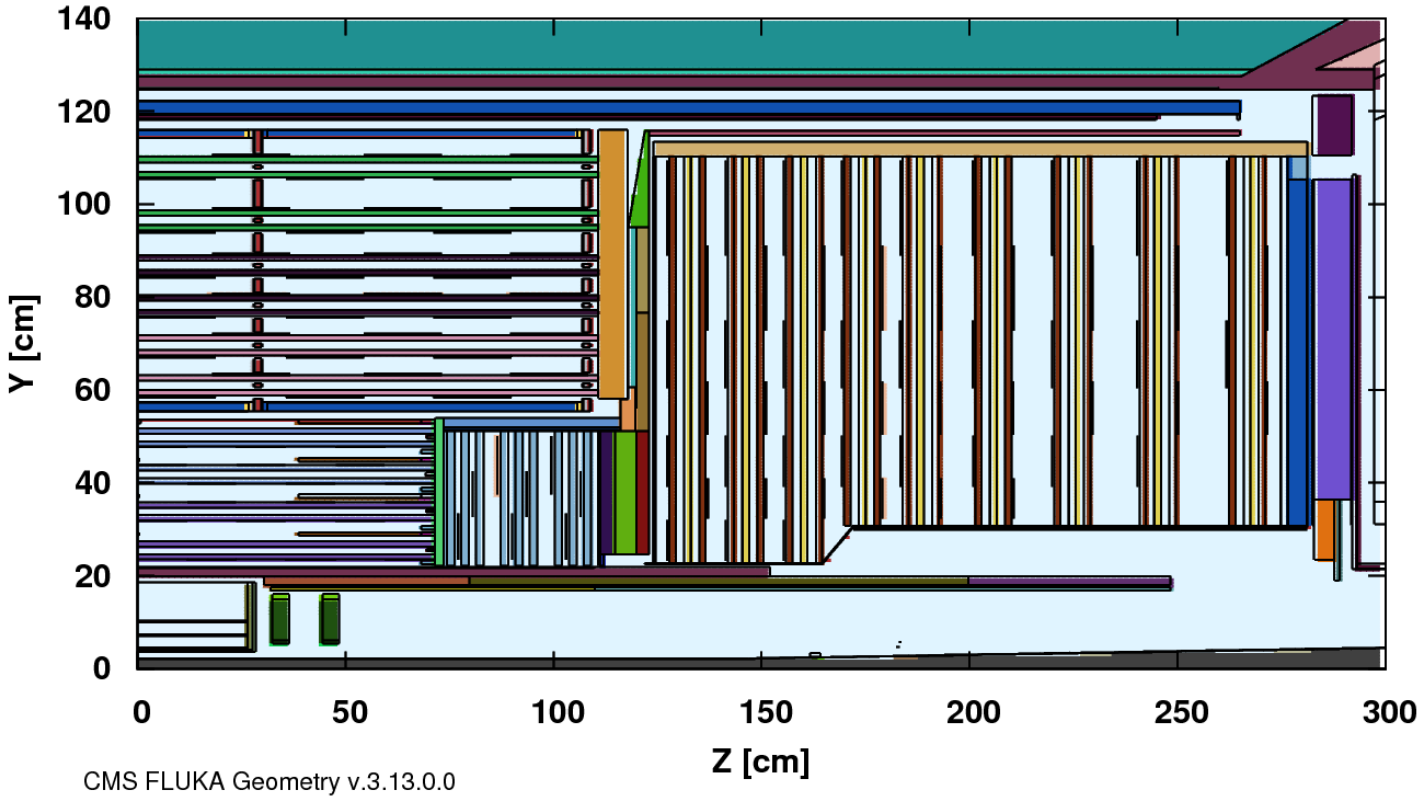
Summary

- Radiation background simulation are an important input in the design of silicon tracker and vertex detector systems
  - Benchmarking simulations with measurements important for giving confidence in predictions for future running
- FLUKA used by both CMS and ATLAS for radiation background simulations
  - Important to model details of full detector (including services) with correct mass and material composition
  - Event generators for pp collisions also important for understanding systematics
- CMS and ATLAS show good agreement in comparison of 1 MeV fluences with leakage current measurements
- Radiation damage effects accentuated at high eta
  - This provides additional challenges for future trackers

Additional material

CMS FLUKA Geometry: Tracker

- Simulation runs for Run2&3 tagged v.3.9.0.0 and beyond use detailed version of Phase1 Tracker with Material budget imported from CMS-SW



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ATLAS FLUKA geometry