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ATLAS radiation simulations overview

Paul S Miyagawa
for ATLAS Radiation Simulation Working Group

Contents

Introduction

- Radiation background simulations 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 impact procedures for cavern access scenarios for detector installation and maintenance
- Simulations of current LHC detector systems are being 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
- ATLAS using Pythia8 tuned with minbias data
  - A2 tune based on Run-1 data; A3 based on Run-2
  - DPMJET used by CERN Radiation Protection

Particle transport codes

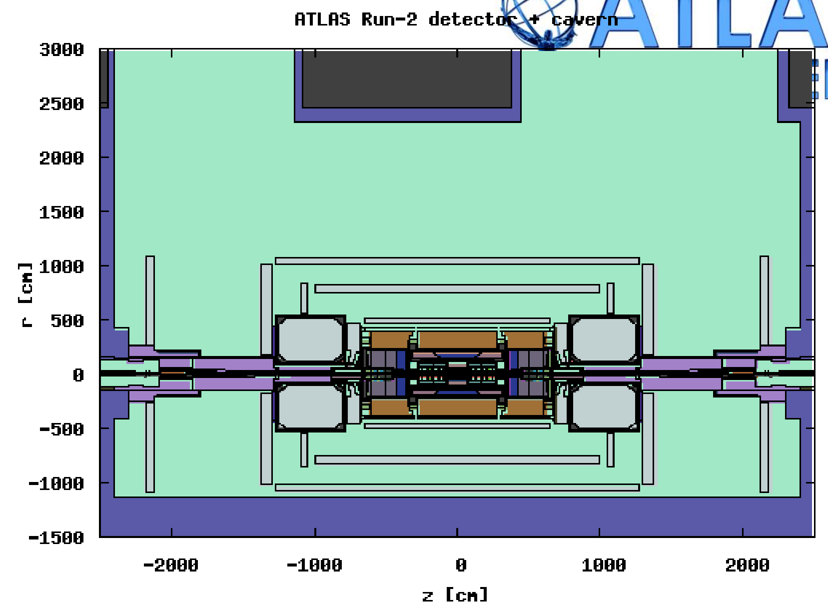
- Several particle transport codes are used on ATLAS for performing radiation background simulations
  - FLUKA, GCALOR, FLUGG, Geant4 (see talk by S. Menke)
- Extensive use of FLUKA by LHC experiments
  - Fully integrated physics Monte Carlo simulation package
  - Historically, favoured by CERN Radiation Protection
- 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

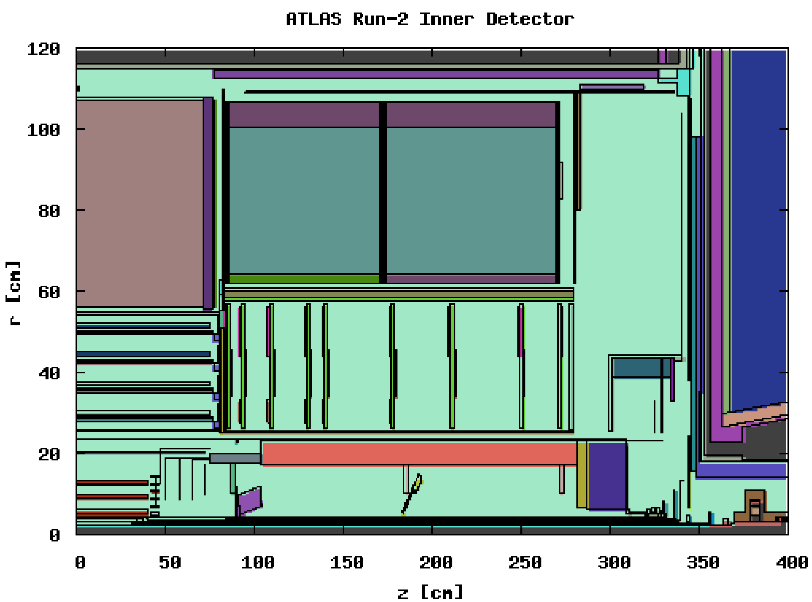
FLUKA geometry

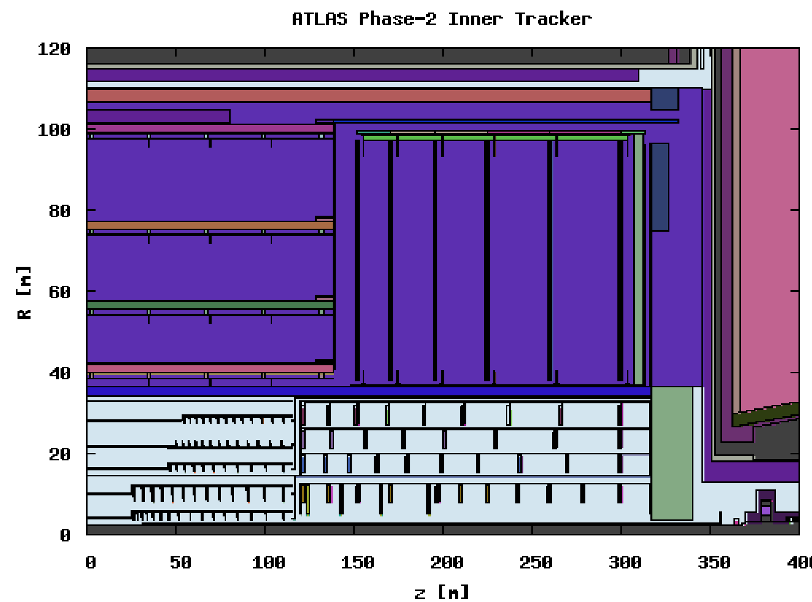
- Three FLUKA geometry developments
  1. Run-1 geometry for LHC start-up
  2. Run-2 (current) geometry with Insertable B-Layer (IBL)
  3. Phase-2 Upgrade for High Luminosity LHC: all-silicon Inner Tracker (ITk) + High Granularity Timing Detector (HGTD)
- Geometry + material description is simplified and mostly phi-symmetric
- SVN repository to share FLUKA geometry developments between ATLAS sub-groups + HSE/RP

- Explored GDML common geometry for sharing geometry details between different simulation codes (T. Koi, SLAC)

FLUKA geometry

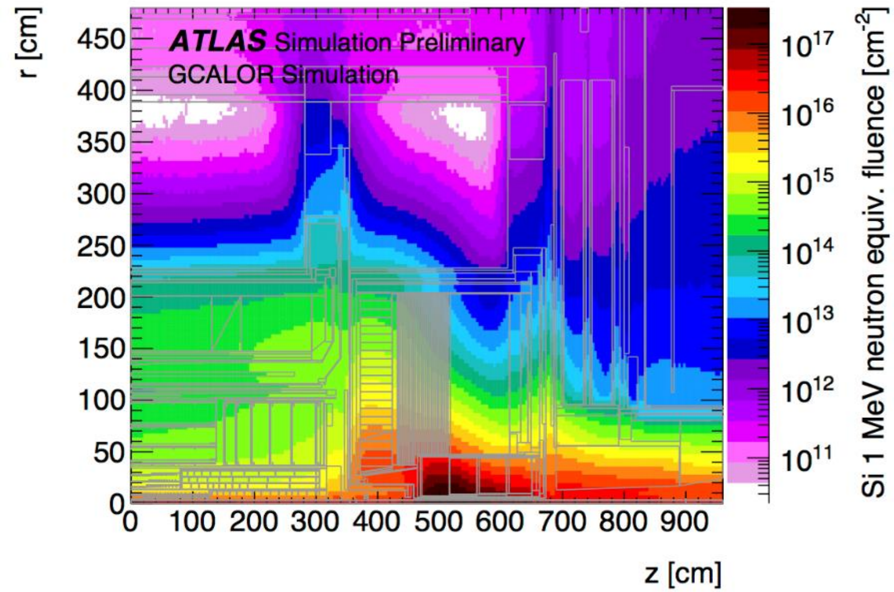






GCALOR simulations

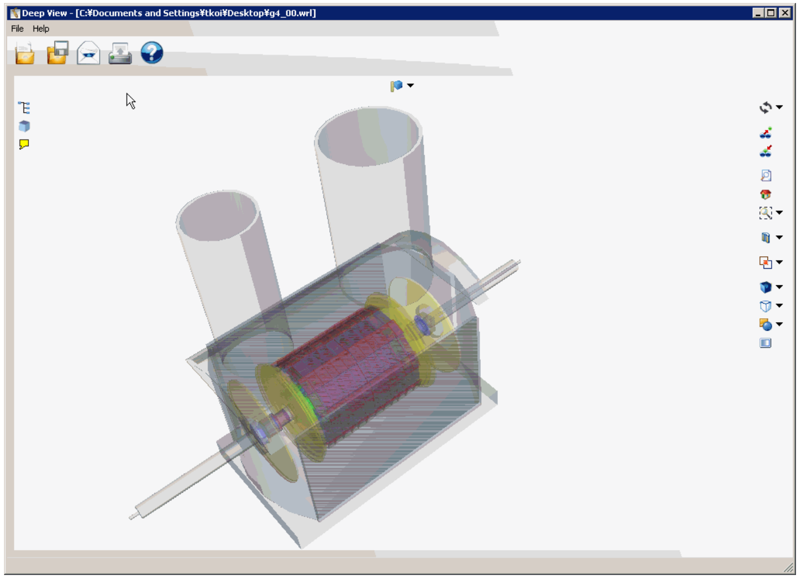
- GCALOR simulation developed initially for Forward Calorimeter (FCAL) proposal (M. Shupe, Arizona)
  - Based on Geant3 + CALOR neutron transport package
- Used in tandem with FLUKA as mutual cross-check + for understanding of uncertainties

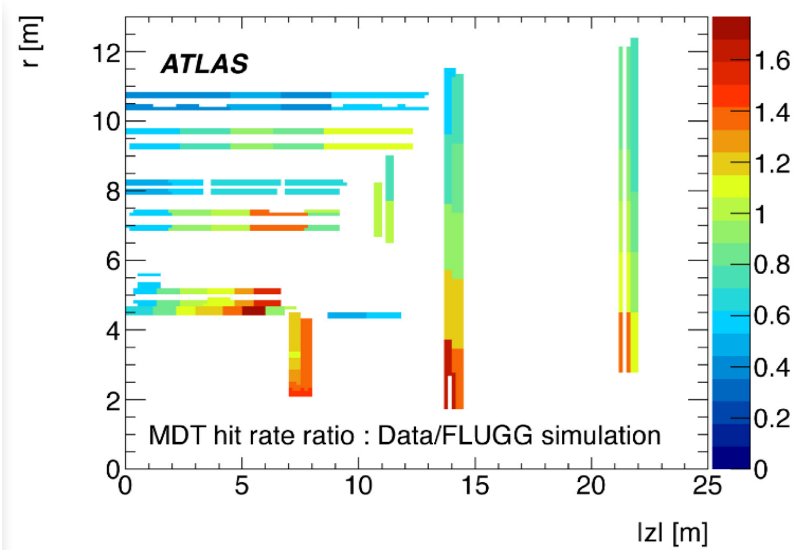


- Major contribution to ATLAS Radiation Background Task Force
  - ATL-GEN-2005-001
- Current emphasis on studies in calorimeter regions (E. Varnes, Arizona)

FLUGG simulations

- FLUGG simulation developed for cavern background studies (T. Koi, SLAC)
  - Geant4 for geometry definition
  - FLUKA for physics modelling
- Predictions benchmarked with Run-1 measurements
  - Results reported in ATLAS Radiation Estimate Task Force
- Major contribution to design of Muon Upgrade New Small Wheel detector
  - [ATLAS-TDR-020]





Simulation settings

- Magnetic field imported from ATLAS offline software
- Energy cut-offs for particle transport in FLUKA:
  - Hadrons + muons 100 keV, neutrons 10^{-5} eV (thermal), photons 30 keV, electrons 100 keV
  - No biasing applied
  - Photons and electrons have significantly higher cut-offs in some regions (collimators, forward shielding) to reduce simulation time

- Typical output is an R-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
  - Phi-dependence
  - Particle energy and angular distributions
  - Event-by-event output of full particle information (position, momentum, arrival time at specific boundaries)

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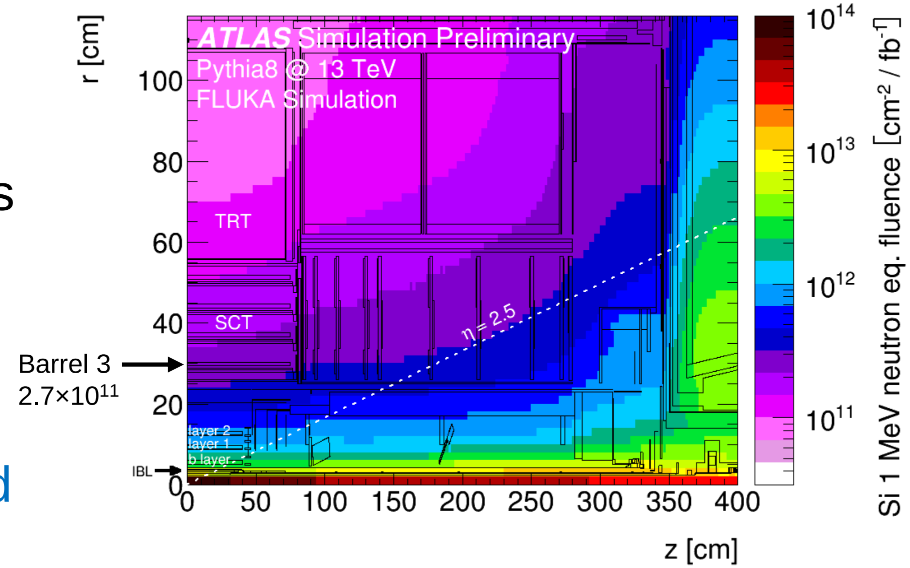
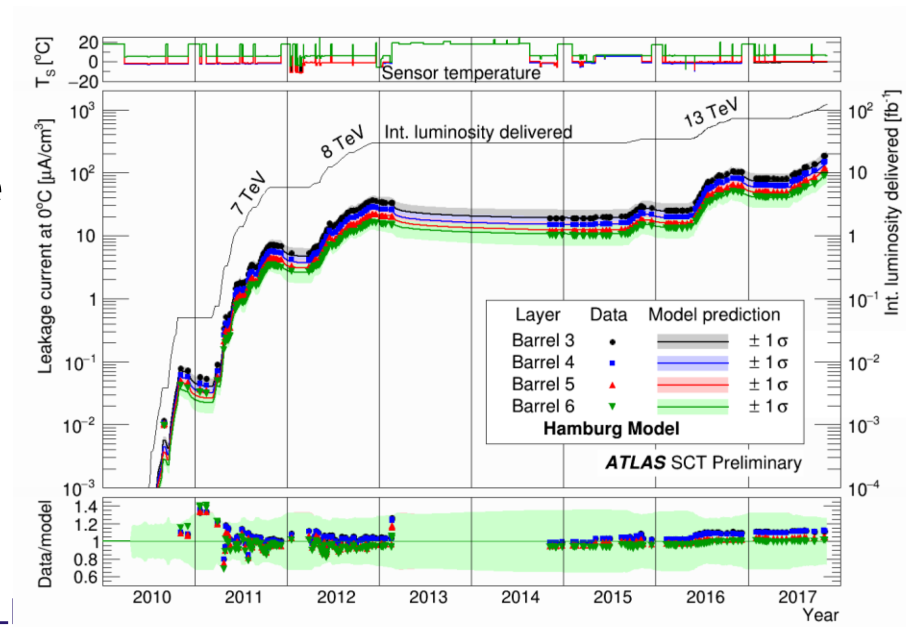
Validation with Run-2 measurements

- 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 (see yesterday's talk by T. Kondo)
    - Comparison with pixel leakage current measurements underway (see talk by A. Grummer)
- Comparisons of total ionising dose (TID) predictions with RadMon measurements also gives good agreement (see talk by I. Mandić)
- All of these benchmarking comparisons feed into uncertainty + safety factor discussions for Upgrade

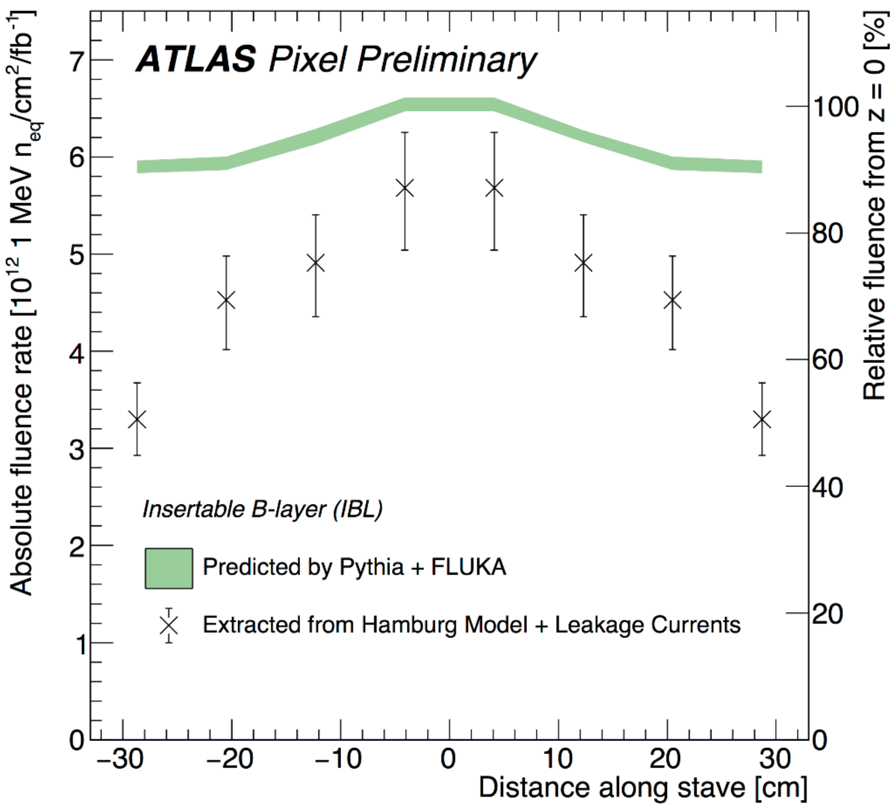




Comparison with Insertable B-Layer (IBL) leakage currents

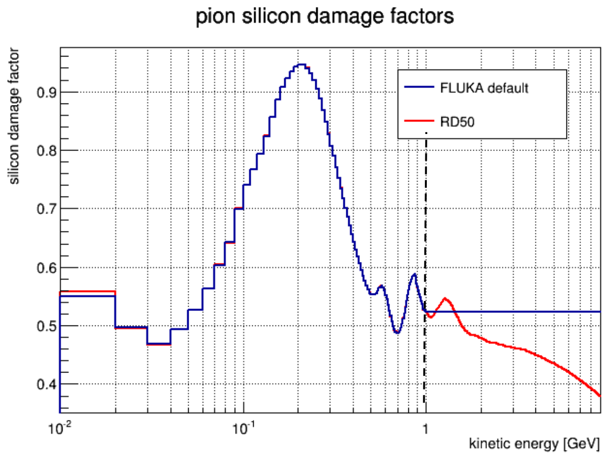
- Discrepancies observed between fluence predictions and IBL leakage current measurements
  - See talk by N. Dann, 31st RD50 workshop
  - FLUKA simulation overestimates absolute scale by 15-40%, underestimates *z*-dependence
  - NB: FLUKA prediction uses full silicon damage factors (see next slide)
- Additional studies to understand causes of discrepancies
  - Impact of silicon damage factors on *z*-dependence
  - Minimum bias tunes on absolute scale

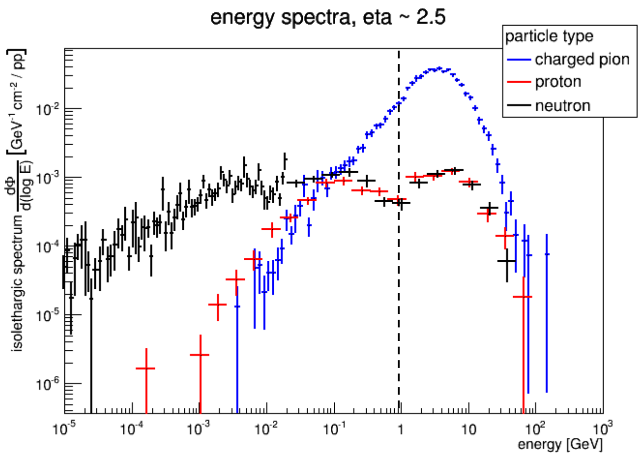
31st RD50 workshop, Nov 2017



Silicon 1 MeV neutron equivalent damage factors

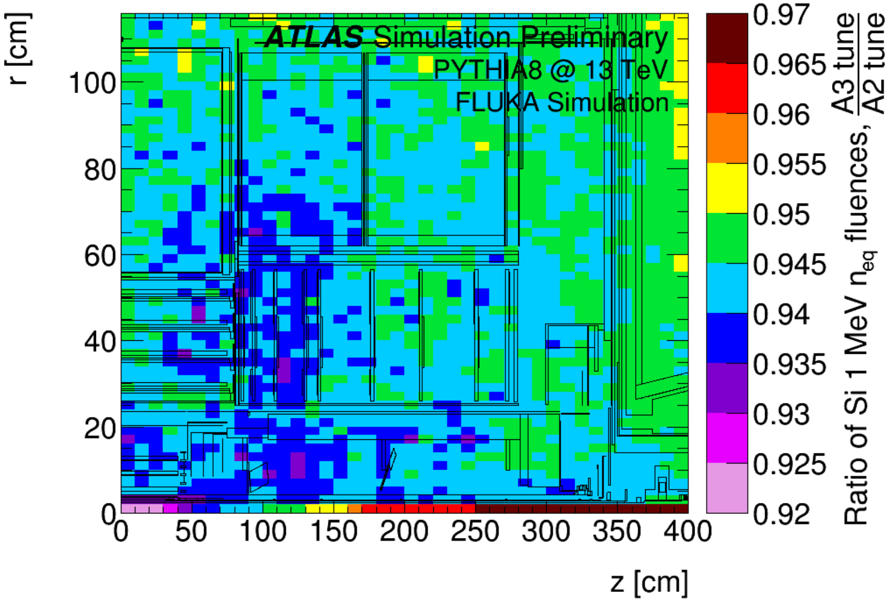
- FLUKA has implemented silicon damage weighting functions for pions, neutrons, protons and electrons
  - Taken from RD50 compilations
  - However, pions + neutrons above 1 GeV treated as constant; reasonable for most applications
- At LHC energies, energy spectra show a significant fraction of particles with KE > 1 GeV, particularly at high eta
  - Fraction of particles with KE > 1 GeV increases with eta
- Implemented new user routine to read in the silicon damage factors up to 9 GeV
  - *z*-dependence increases to 12% (from 5% using FLUKA default)





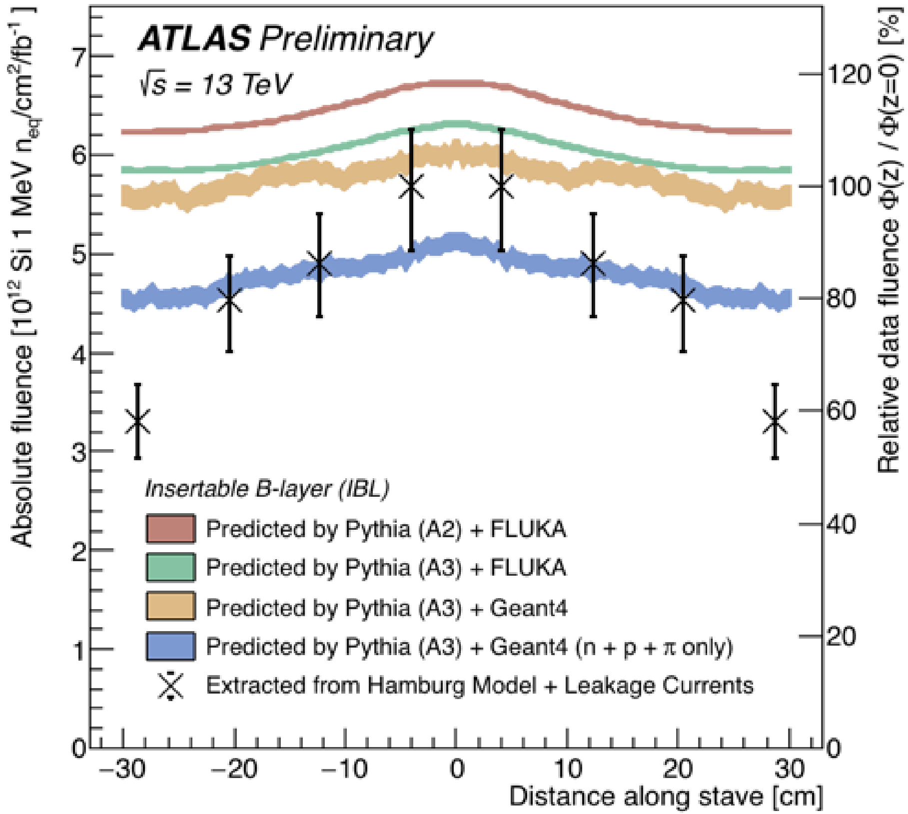
Pythia8 A3 minbias tune

- ATLAS generated Pythia8 events with new A3 tune using 13 TeV minbias data
  - ATL-PHYS-PUB-2016-017
- Fiducial cross-section for A3 tune (69.9 mb) decreases compared to A2 tune (74.4 mb)
  - A3 agrees with value measured from ATLAS data (68.1±1.4 mb)
- 1 MeV neq fluences show corresponding decrease of 5-7% compared to A2 tune



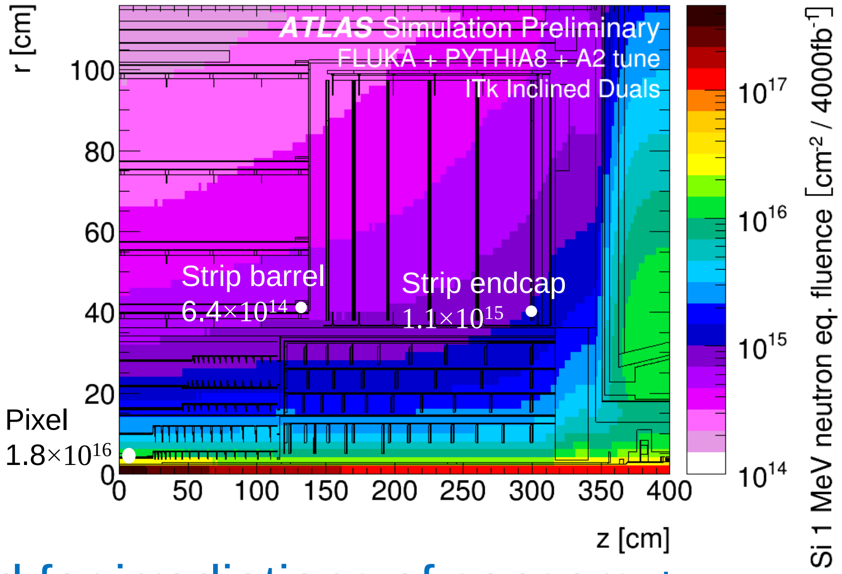
Comparison with IBL leakage currents

- NB: all simulation predictions use full silicon damage factors
- Predictions show sensitivity to the minbias tunes
  - Improved agreement with absolute scale of IBL leakage current data?
  - *z*-dependence not reproduced – still to be understood
- Geant4 prediction with A3 tune shows similar scale + shape to FLUKA (as expected)
  - First benchmarking with leakage current data for Geant4 simulation
- Also shown is Geant4 prediction considering only neutrons + protons + pions
  - Impact of kaons (+ others) significant
- Further studies to investigate impact of damage functions on shape



Upgrade Inner Tracker (ITk) simulations

- Benchmarking studies with current detector give confidence to recommend safety factor 1.5 for future predictions of fluence and dose
- Predictions made for Phase-2 upgrade geometries
  - As ITk layout evolves, these predictions are updated

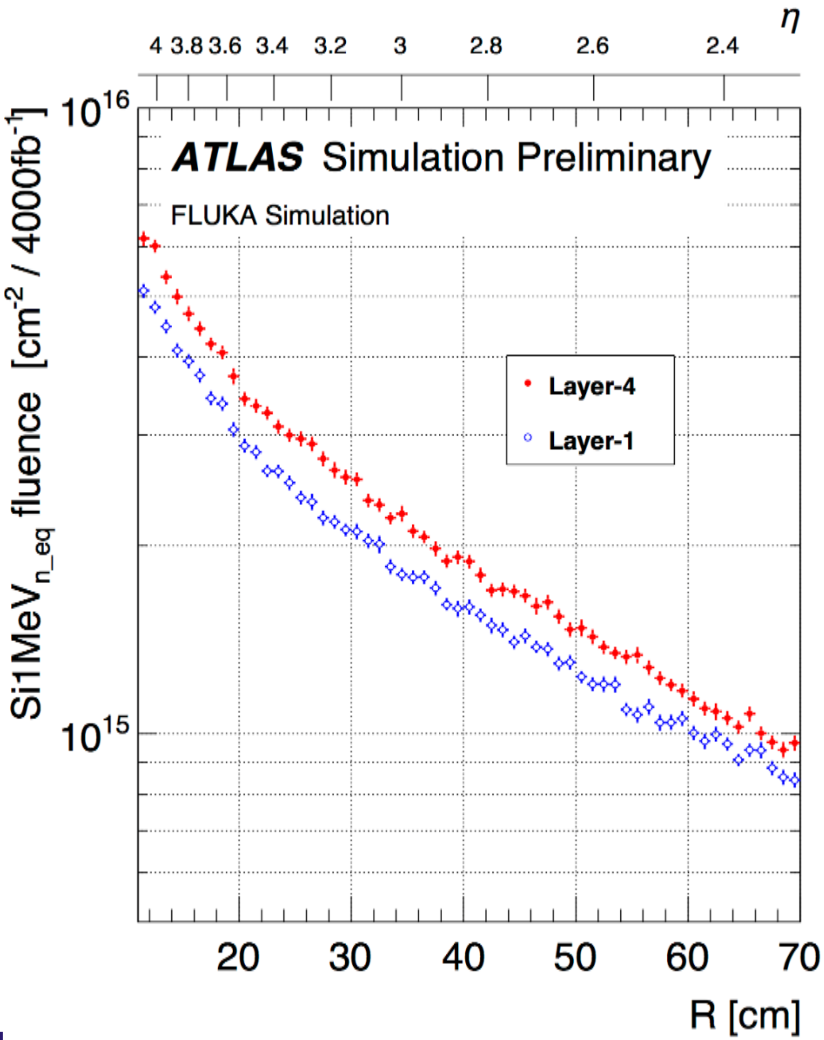


- Maximum values in ITk regions used for irradiations of sensors + chips after applying appropriate safety factors

- 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 regularly to ITk simulation & performance group

High Granularity Timing Detector (HGTD) studies

- Proposal to install High Granularity Timing Detector (HGTD) between ITk and FCAL
  - Mitigate effects of pile-up using high-precision timing information
- FLUKA studies provided vital input for HGTD design (A. Manousos + M. Huhtinen, CERN)
  - Also major contribution to design of neutron moderator around HGTD



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
- Dedicated simulations for other information on request
- New web tool developed to allow ATLAS members to extract & compare radiation levels over user-specified region

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Web tool for extracting radiation levels

- Web tool developed (E. Varnes, Arizona) to allow ATLAS members to access radiation levels from all 4 simulation codes (FLUKA, FLUGG, GCALOR, Geant4)
  - Results from all simulation codes saved with the same binning
- User specifies the desired region + integrated luminosity
- Web tool extracts & plots data for the specified region, calculates summary statistics

ATLAS radiation simulation results

This interface allows you to access the results of three different simulations of the ATLAS radiation background in Phase 2 (based on FLUGG, FLUKA, GCALOR, and GEANT4).

Note on geometries in the simulations: FLUGG, FLUKA, GCALOR, and GEANT4 all use a model of the Phase 2 geometry with the ITk.

Step 1: Choose the quantity you're interested in:

Total Ionizing Dose (Gy)

Step 2: Input the region of interest

388 $\leq r \leq$ 424 cm

616 $\leq |z| \leq$ 652 cm

Step 3 (optional): Set the integrated luminosity

Integrated luminosity : 4000 fb^{-1}

Submit

Summary

- Radiation background simulations are an important input in the design of detectors
  - Benchmarking simulations with measurements important for giving confidence in predictions for future running
- Several particle transport codes used on ATLAS for performing radiation background simulations
  - FLUKA, GCALOR, FLUGG, Geant4
  - Important to model details of full detector (including services) with correct mass and material composition
  - Event generators for pp collisions are crucial input into the radiation simulations; subject for further study
- Mostly good agreement in comparison of 1 MeV fluences with leakage current measurements
  - Discrepancy with IBL data has prompted further studies
- Radiation damage effects accentuated at high eta
  - This provides additional challenges for future detectors