Radiation Environment of the LHC Experiments.

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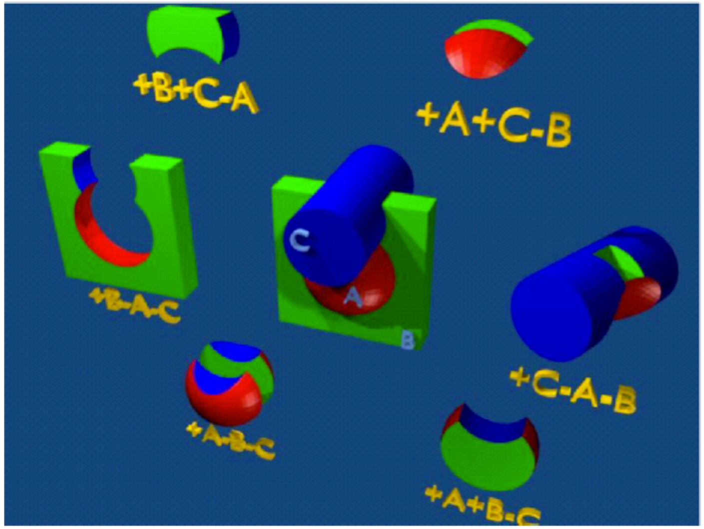
Overview

- Introduction to FLUKA.
- FLUKA simulations in CMS.
- Prediction of leakage current of Si-Detectors in CMS and comparison with data.
- Results from ATLAS Si Pixel and Tracker.

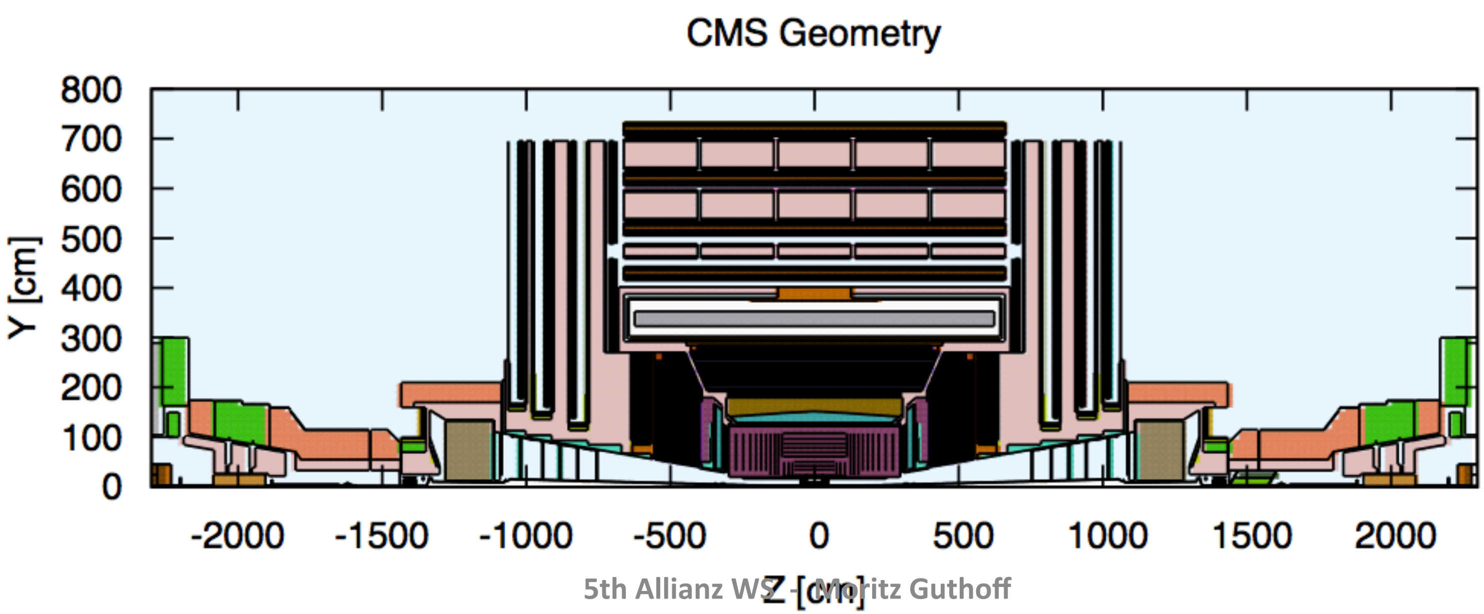
FLUKA

- FLUKA: Fully integrated particle physics MonteCarlo simulation package. [1]
- Events generated by DPMJET-3.
- No tracking of particles.
- Many different predefined scorings
  - Flux of different particles types
  - Energy spectra
  - Dose
  - Radiation damage
  - Activation
  - Etc.
- Geometry described with mathematical combination of geometric elements.
  - Import of mechanical drawings not possible



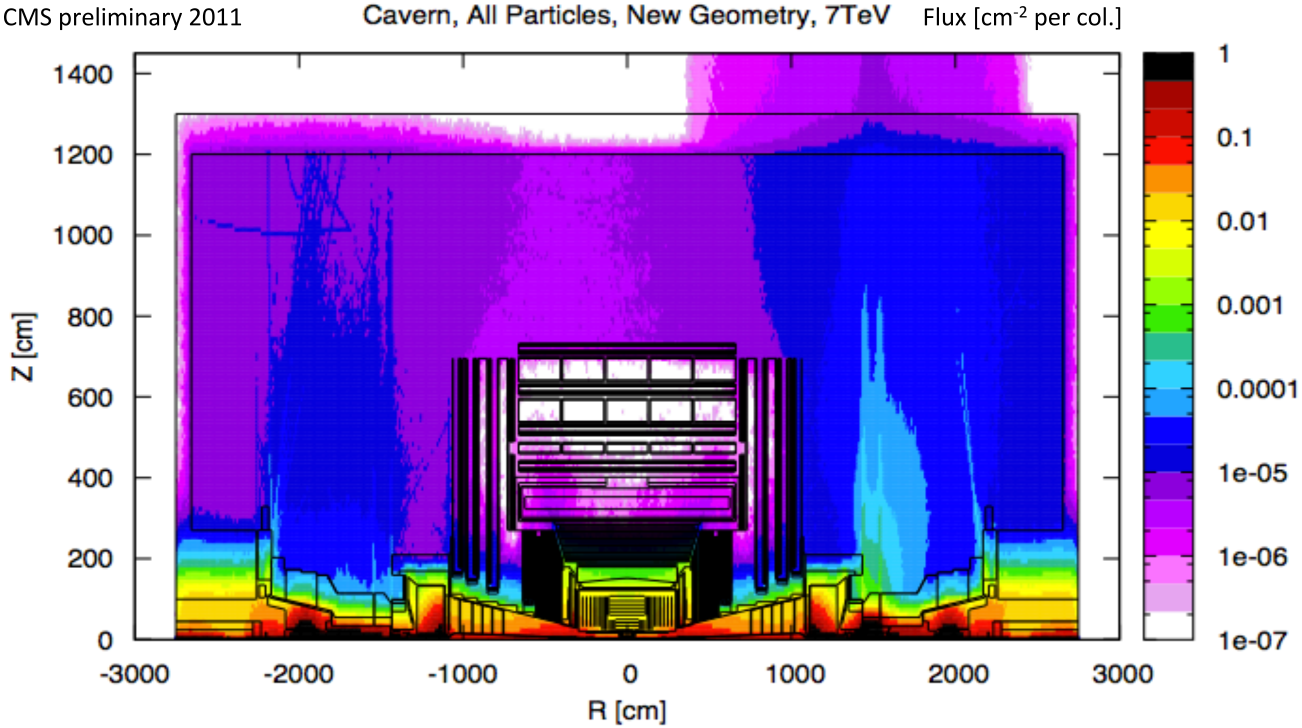
CMS in FLUKA

- My work for CMS builds on studies done by Steffen Müller. [2]
- CMS is fully implemented with a simplified Geometry (phi symmetric).
- Simulation of proton-proton or heavy ion collisions.
- Simulation of Machine Induced Background.
- Results are used to understand:
  - Rates in various subdetectors.
  - Radiation damage to Silicon pixel, strip trackers and preshowers as well as diamond based beam monitors.
  - Simulations related to activation are done by Radiation Protection.



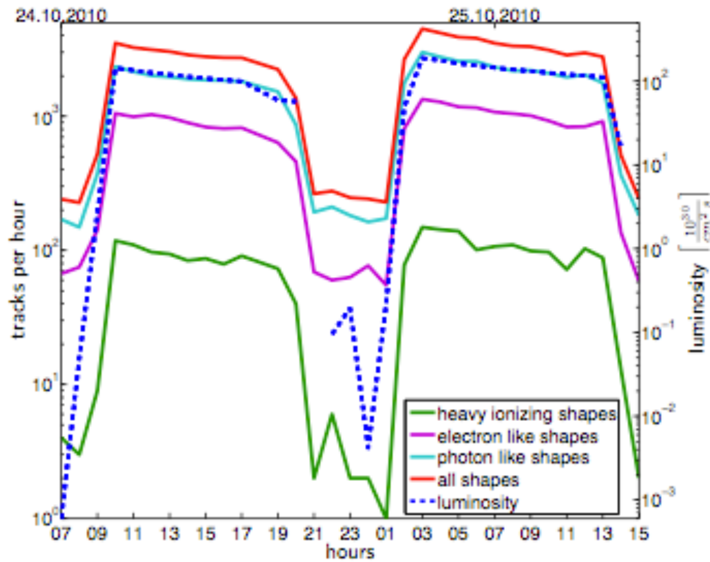
Cavern Flux maps

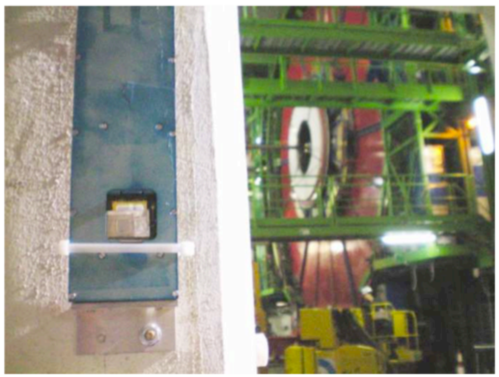
- Simulated data for the whole of CMS with a 7TeV collision energy.
- Many different scoring of various particle types and groups available.
- Flux maps are normalised per cm^2 per primary collision.

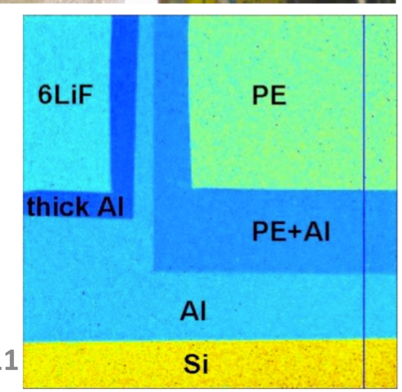


Particle rates in the Cavern

- A medipix detector is placed in the cavern with a special detection layer for neutron detection. [3]
- Particles of different types leave distinct signatures that can be identified via pattern recognition.
- Particle rates scale with luminosity.
- Good agreement with rates from FLUKA simulations.



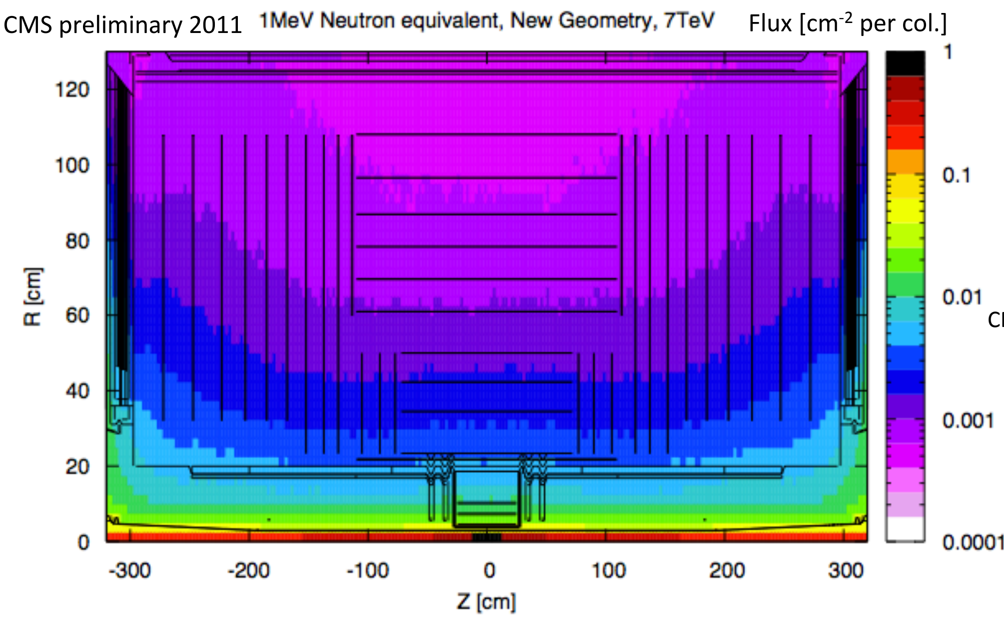




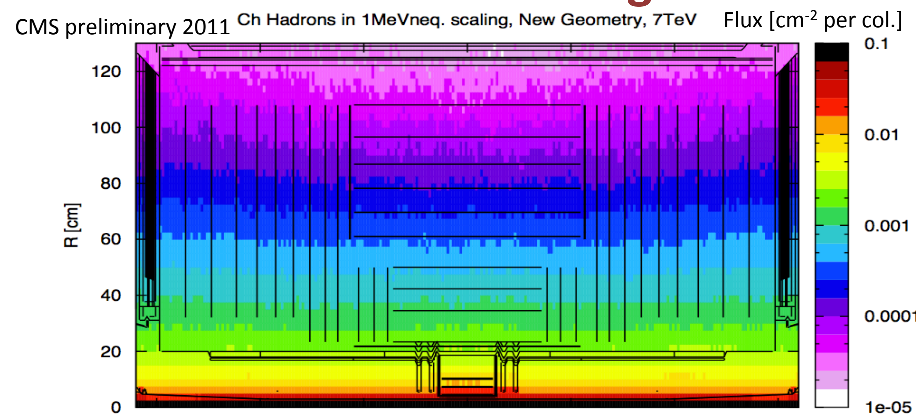
Particle	Measured Flux $\left[\frac{particles}{cm^2\ s} / \frac{10^{30}}{cm^2\ s}\right]$	Simulated Flux (7 TeV) $\left[\frac{particles}{cm^2\ s} / \frac{10^{30}}{cm^2\ s}\right]$	$\frac{\text{Measured Flux}}{\text{Simulated Flux}}$ [%]
neutrons (< 100 keV)	0.11	0.1017(14)	108
neutrons (100 keV - 20 MeV)	0.068	0.0659(07)	103
neutrons (> 20 MeV)	-	0.0181(03)	-
neutrons (all without neutrons > 20 MeV)	0.178	0.1858(12)	96
charged hadrons	-	0.000378(44)	-
electron	0.0021	0.0023(01)	91
photon	0.14	0.1354(19)	103
all (without neutrons > 20 MeV)	0.32	0.3240(23)	99

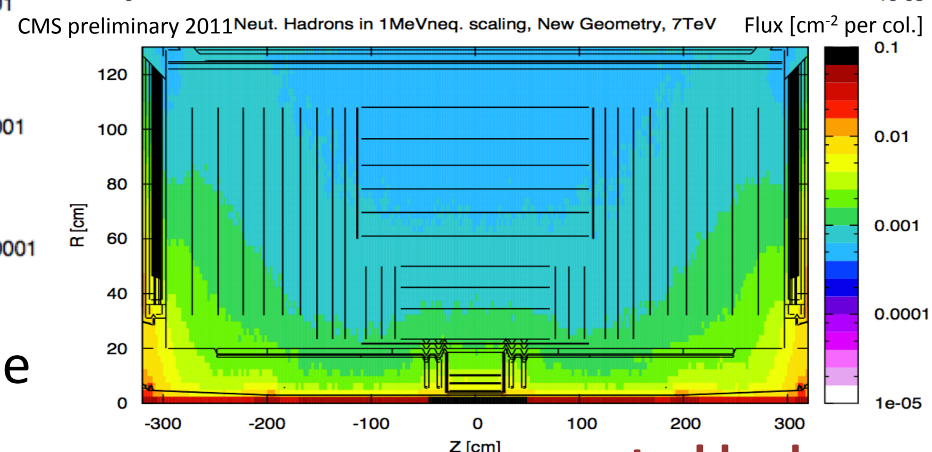
Flux in tracker region

Total 1MeV neutron equivalent



charged hadrons





neutral hadrons

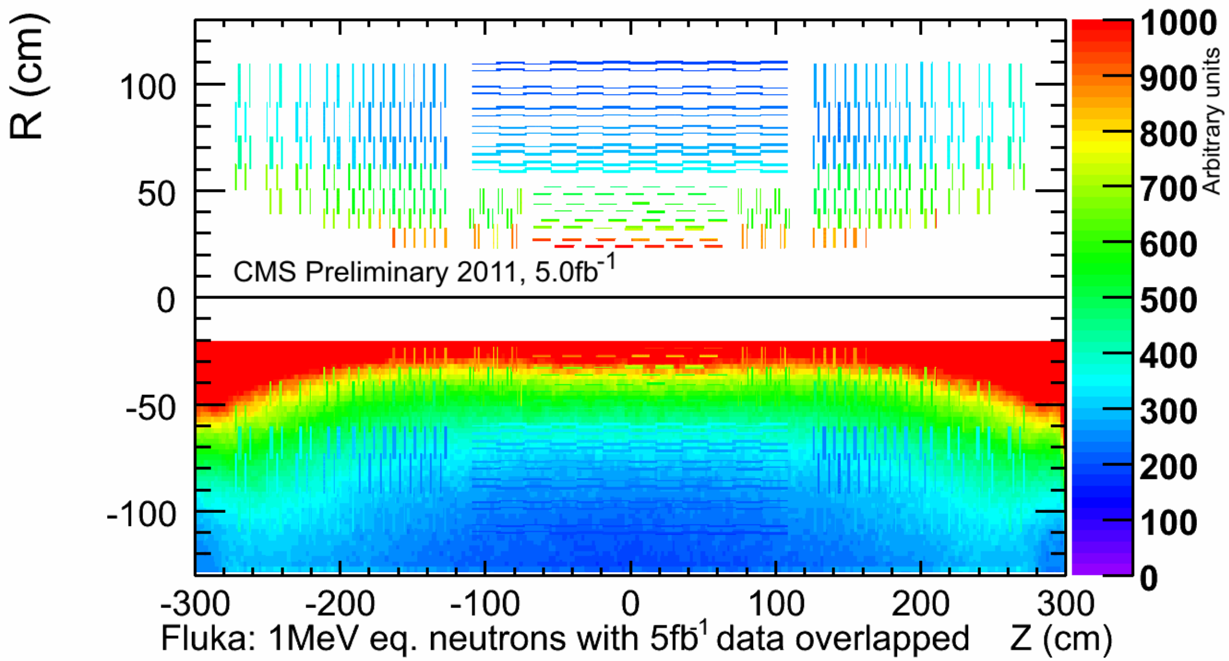
- For analysis of radiation damage the 1MeV neutron equivalent (n-eq.) scaling is most important.
- The left plot shows the total 1MeV n-eq. flux, the right plots show the contributions from charged hadrons and neutrons.

Fluka results in numbers

Detector	R [cm]	Fluence [cm^{-2}] after 100 fb-1	Fluence [cm^{-2}] after 3000 fb-1
BPix L1	4.1	2.58E+14	7.73E+15
BPix L2	7.2	1.30E+14	3.91E+15
Bpix L3	11.1	7.71E+13	2.31E+15
TIB L1	23.4	3.12E+13	9.37E+14
TIB L4	50	1.24E+13	3.73E+14
TOB L1	61	9.78E+12	2.93E+14
TOB L6	108	4.89E+12	1.47E+14

- Fluences at Z=0cm in selected pixel and tracker layers for $100fb^{-1}$ and $3000fb^{-1}$ at 14TeV.
- Scoring bins are 2.5cm in R. Values in between are interpolated.

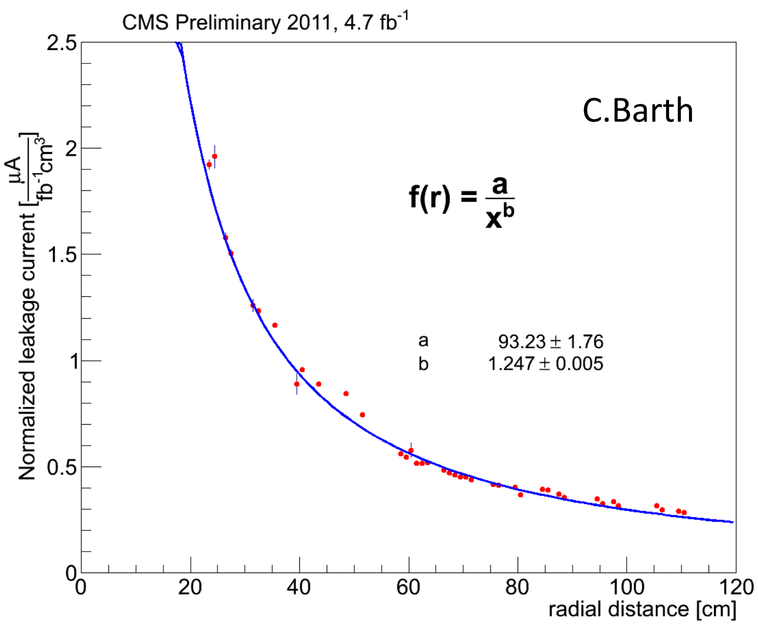
1MeV neutron-eq. compared to tracker leakage current.



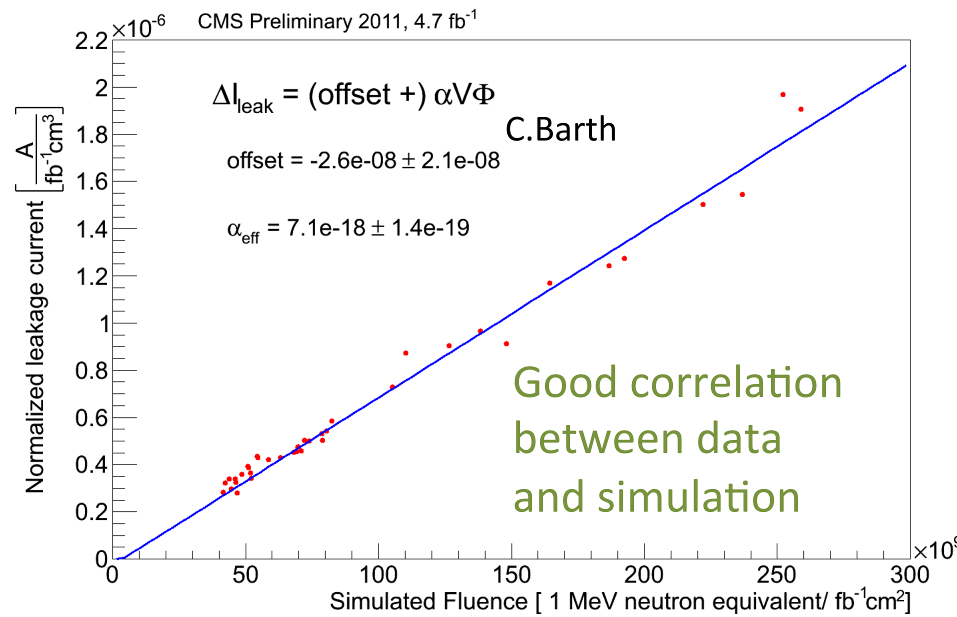
- Qualitatively the measurement of leakage current is consistent with the flux map.

Leakage current of Tracker barrel

Leakage current as function of radius after 4.7 fb^{-1}

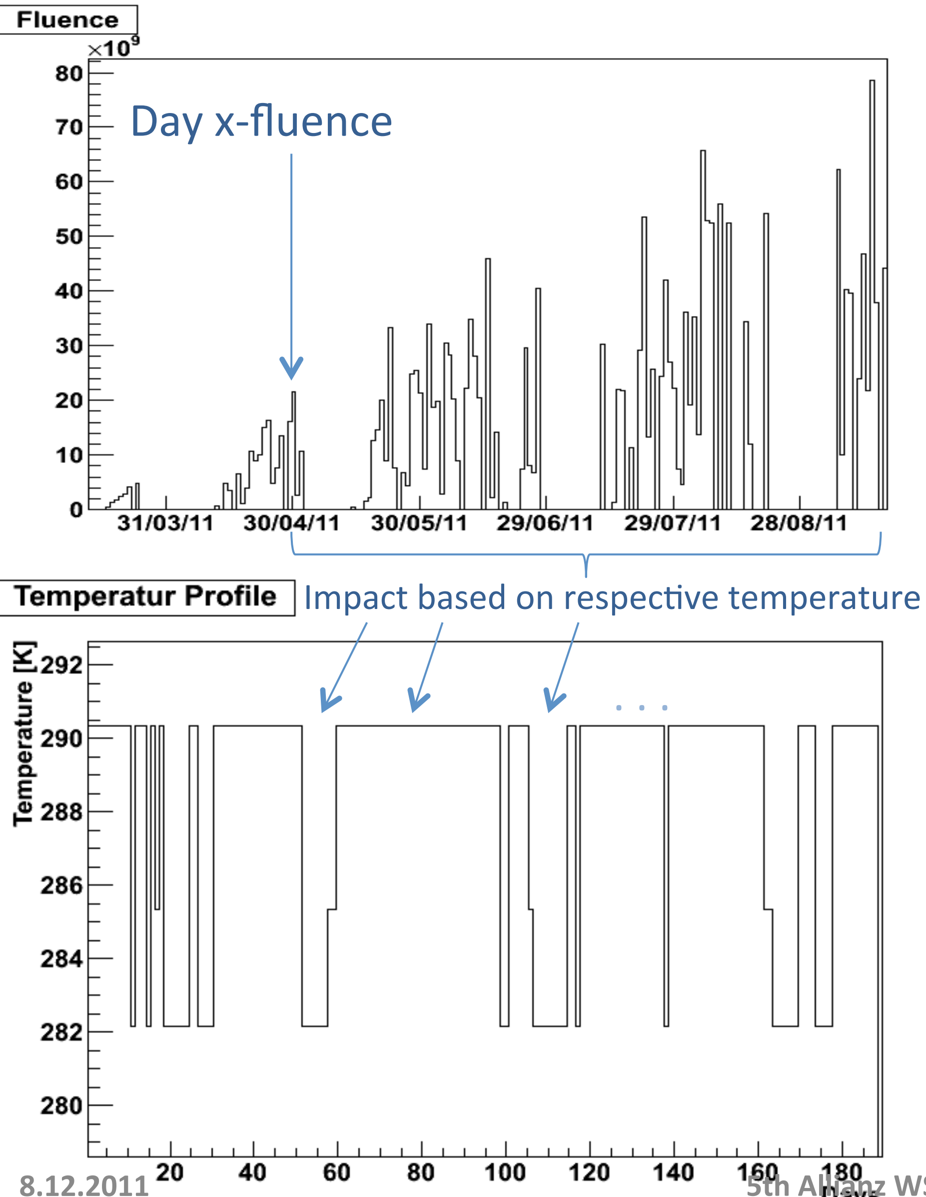


Leakage current as function of simulated fluence after 4.7 fb^{-1}



- Measured leakage current drops with radius: $I_{leak} \sim r^{-1.25}$
- When expressed as function of simulated fluence a good correlation between simulations is visible.

Prediction of Radiation damage to Si-Tracker



- If the expected leakage current is to be calculated the full history needs to be taken into account.
- A simulation tool was developed by Christian Barth to predict leakage current and depletion voltage.
- Based on established models describing radiation damage and annealing.

Inputs:

- Fluence at the module position (FLUKA)
- Temperature of the modules (measured)

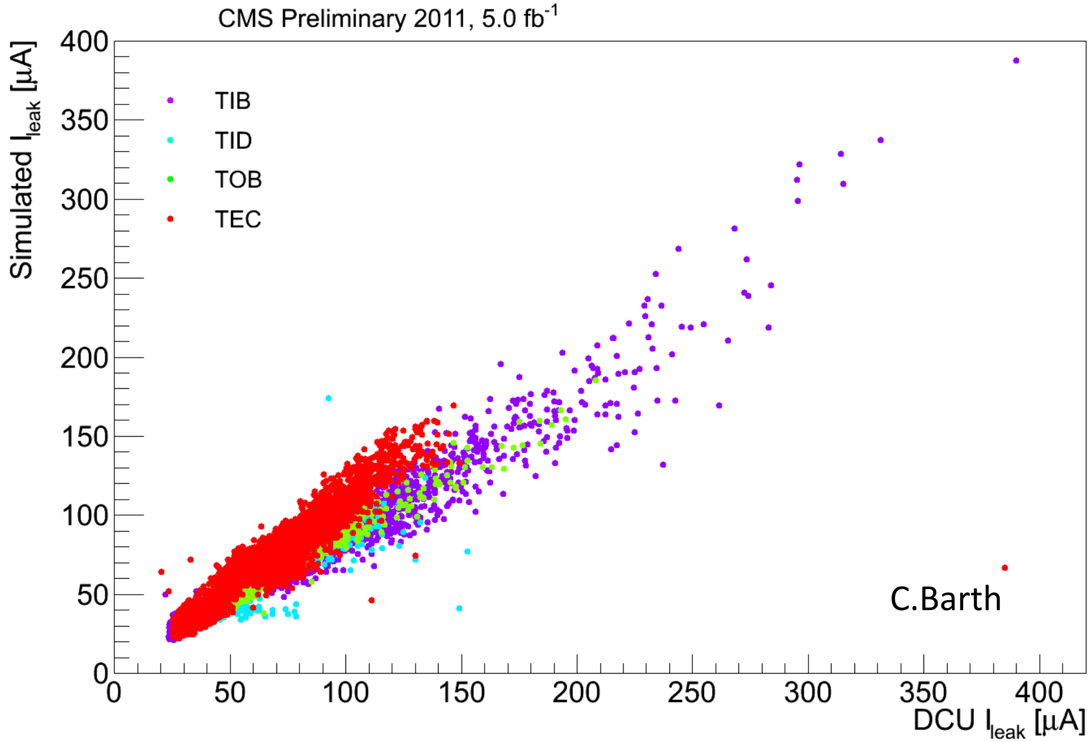
Method/Tools:

- One fluence and temperature value per day.
- The fluence of each day and the resulting annealing is calculated for all days iteratively.

Output

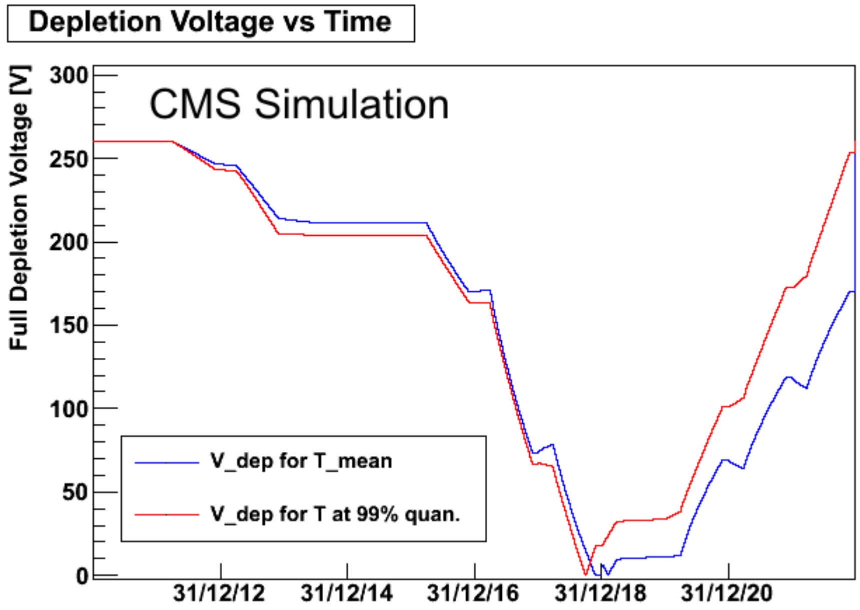
- Leakage current
- Depletion voltage

Simulated and measured leakage current

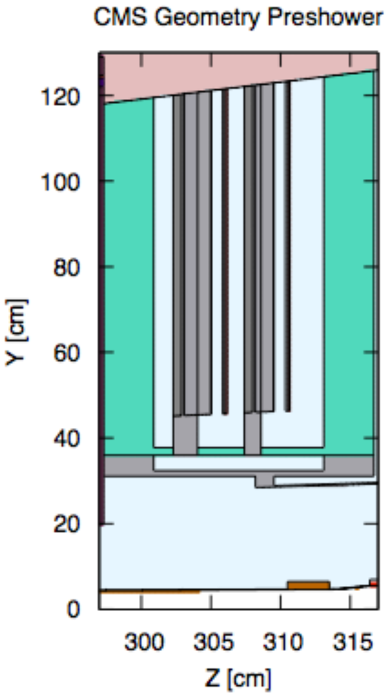


- Leakage current was simulated with the parameter of the running so far.
- Measured after 5fb^{-1}.
- Good correlation between simulated and measured leakage current and hence expected to provide reliable predictions.
- Method allows prediction of leakage current and therefore lifetime of the detector.

Prediction of depletion voltage

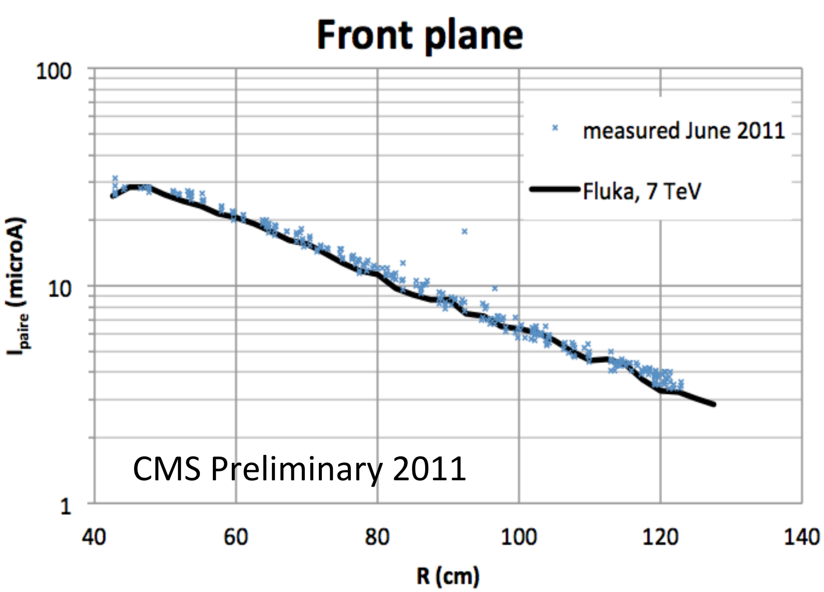


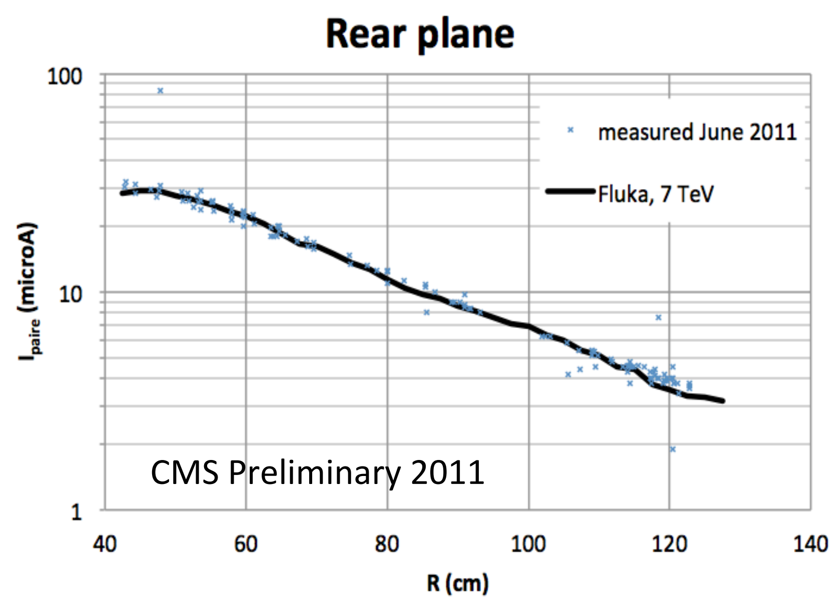
- Plot shows development of the depletion voltage of the inner most layer over the next years using actual prognosis on luminosity.
  - Up to 400fb^{-1}.
  - Certain development of the cooling plant set temperature.
  - Calculated for two representative temperatures based on temperature distribution in this layer.
- This allows to study the impact of various temperature scenarios of the cooling plant or during shutdown period.



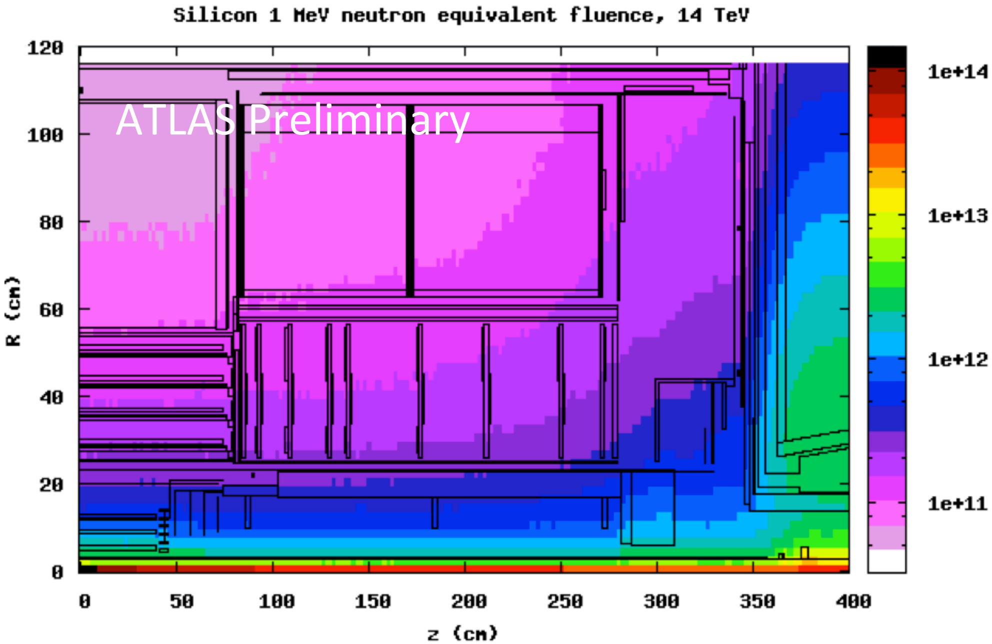
Preshower detector

- Leakage current of the Si sensors in the Preshower detector in comparison with simulated flux in 1MeV neutron equivalent.
- Simulation arbitrarily scaled to fit the data.
- Relative behavior well correlated.
- Work on the absolute comparison ongoing.





ATLAS simulations

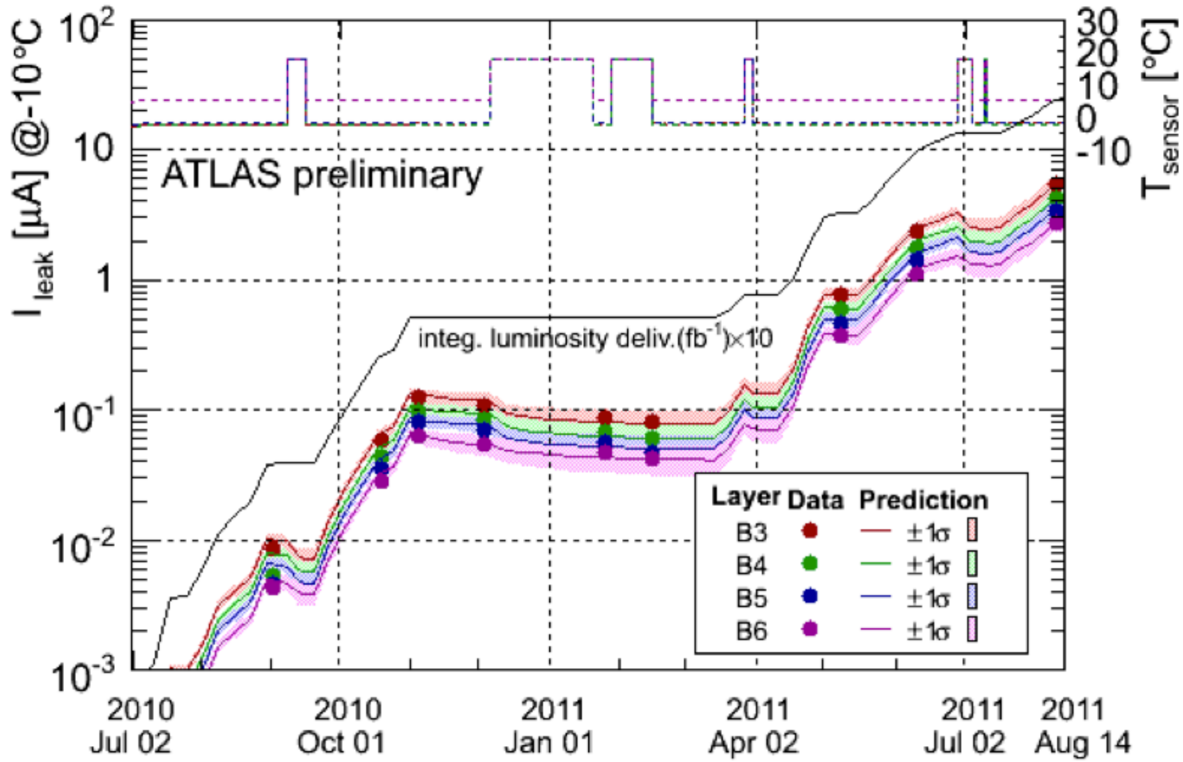


layer	R (cm)	Z(cm)	n_{eq} fluences (cm^{-2})/$100fb^{-1}$
Pixel B-layer	4.2	0-40.7	$267*10^{12}$
Pixel B2	12.7	0-40.7	$46*10^{12}$
SCT B3	30	0-75	$16*10^{12}$
SCT B6	52	0-75	$8.9*10^{12}$
SCT D9	44-56	272	$14*10^{12}$

- Plots and data show by Steve McMahon at the last RD50 meeting.
- For ATLAS Fluka simulations are also available.
- Shown is the particle fluence in 1MeV neutron equivalent scaling for 14 TeV collisions.

Predicted I_{leak} compared to measurements of tracker barrel

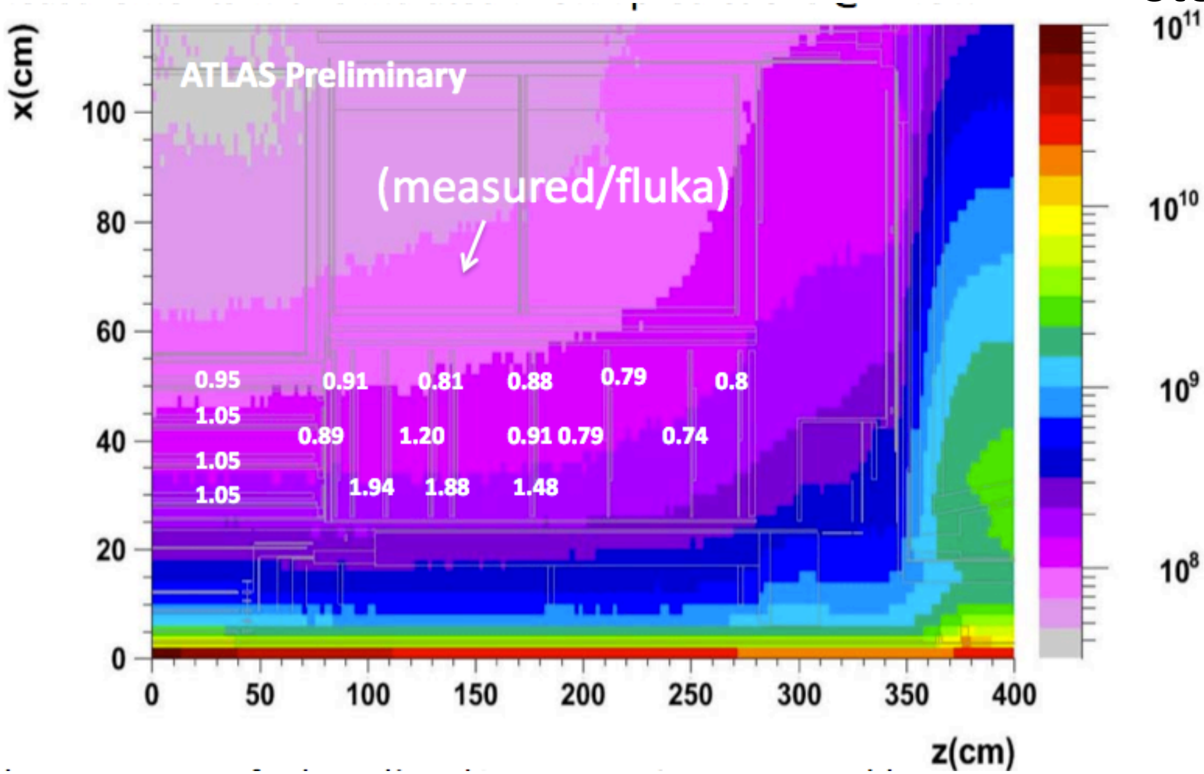
Steve McMahon



- Prediction of leakage current of the tracker barrel well correlated with measurements.

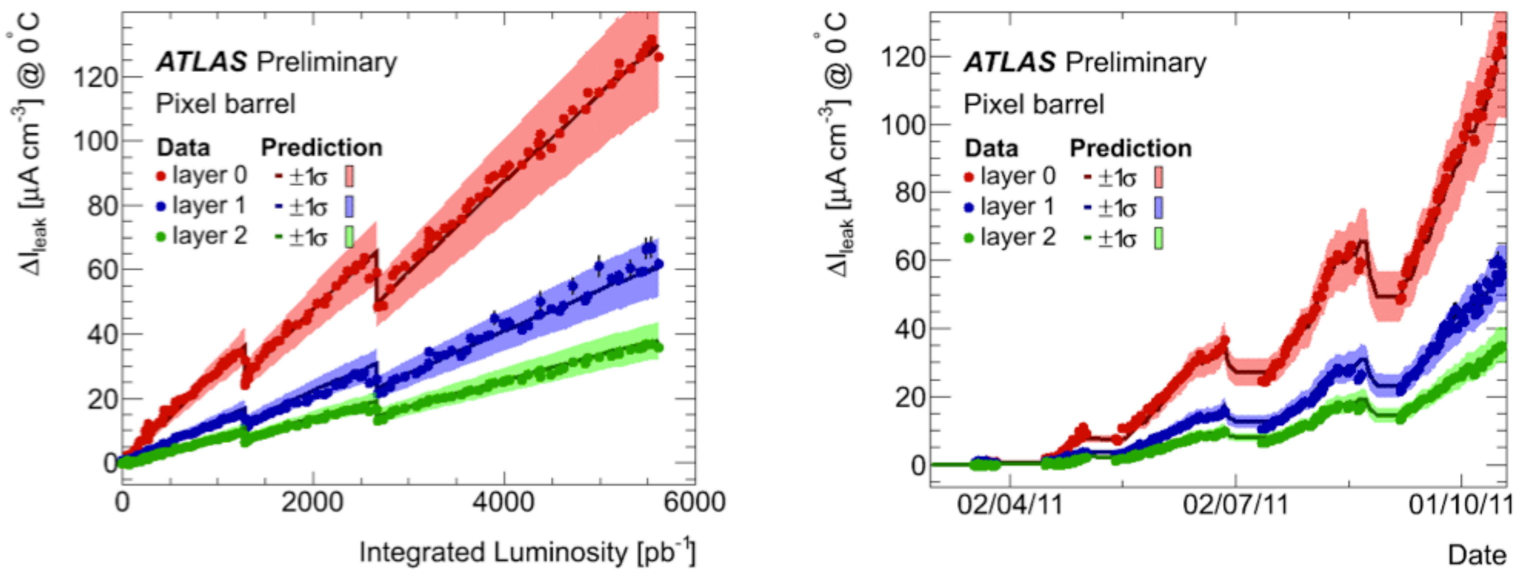
1MeV neutron equivalent compared to measured leakage current

Steve McMahon



- Good agreement with barrel region (within 5%).
- End caps within reasonable values (within factor 2).

Leakage current in ATLAS Pixel



- Shown by Markus Keil at the last RD50 meeting.
- Leakage current follows the integrated luminosity.
- Predictions are scaled up for Layer 1 by 15% and Layer 2&3 by 30%.

Summary and Outlook

- FLUKA simulations of particle rates inside CMS and in the cavern correlate well with various measurement.
- Precise understanding of the radiation levels important for Si detector community.
- Simulations correlate well with leakage current measurements of the Si Tracker in both ATLAS and CMS.

- TLDs placed inside CMS will be taken out during Long Shutdown 1.
- FLUKA simulations will further improve.
  - Scorings better suitable for analysis.
    - Region scoring on detector layers.
    - Particle energy spectra in various places.
  - Geometry improvements: Fitting better the material budget in the tracker.
  - Gain statistics.

Thank you

- References:

1. A. Fasso, A. Ferrari, J. Ranft, P.R. Sala: FLUKA: a multiparticle transport code, CERN-2005-10
2. S. Müller: The Beam Condition Monitor 2 and the Radiation Environment of the CMS Detector at the LHC, CERN-THESIS-2011-085
3. D.Pfeiffer et al.: "Design, Implementation and First Measurements with the Medipix Neutron Camera in CMS", arXiv:1105.1336v1, 2011