Overview of Radiation Damage Effects Measured by the LHC Experiments

Summary from the Inter-Experiment Workshop from April 2018

Aidan Grummer

(University of New Mexico)

On Behalf of the ATLAS/CMS/LHCb/ALICE/RD50 Participants at the April Workshop

32nd RD50 Meeting

DESY, Hamburg, Germany

5 June 2018

Introduction

- A lot of great work was shown at the LHC Radiation Damage Workshop in April 2018

- I will summarize the sensor measurements session from that meeting

- The following detectors reported results:
  - The ATLAS Pixel Detector and Semiconductor Tracker (Aidan Grummer, Julien Beyer, Taka Kondo)
  - The CMS Pixel Tracker and Strip Tracker (Julia Hunt)
  - The LHCb Vertex Locator and Strip Tracker (Vinícius Franco Lima, William Barter)

*Radiation effects at the LHC experiments and impact on operation and performance, https://indico.cern.ch/event/695271/overview

ATLAS Detector

- The ATLAS Pixel detector is made up of 4 barrel layers and 3 endcap disks on each side

- The Semiconductor Tracker surrounds the Pixel detector and is made up of 4 barrel layers and 18 endcap disks
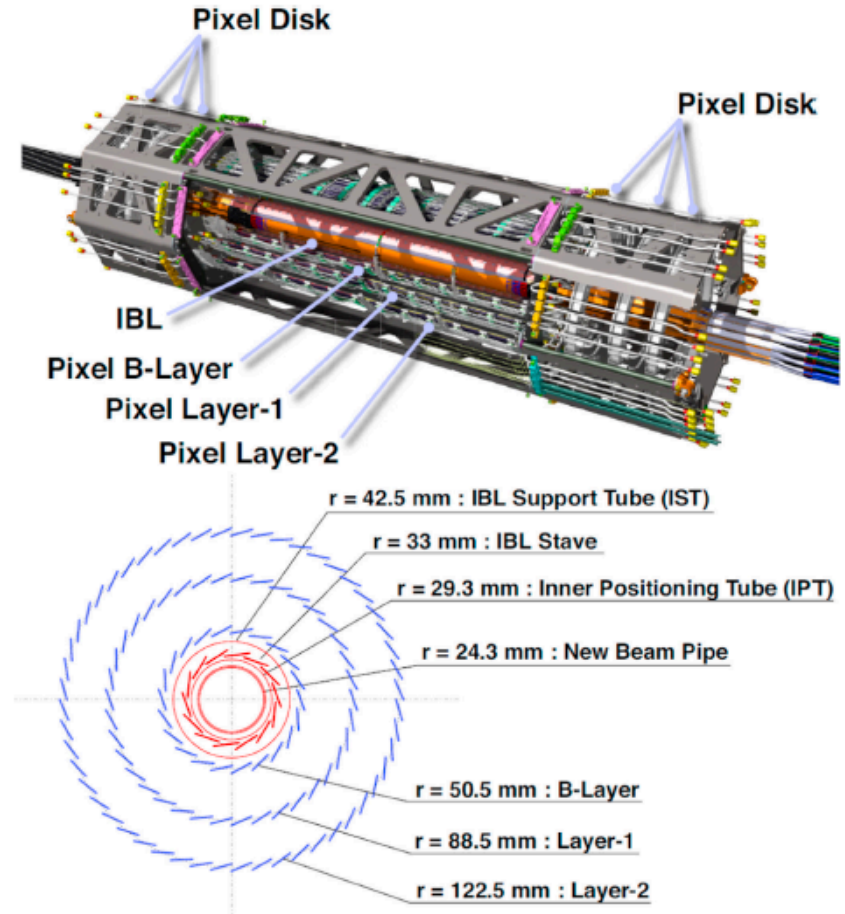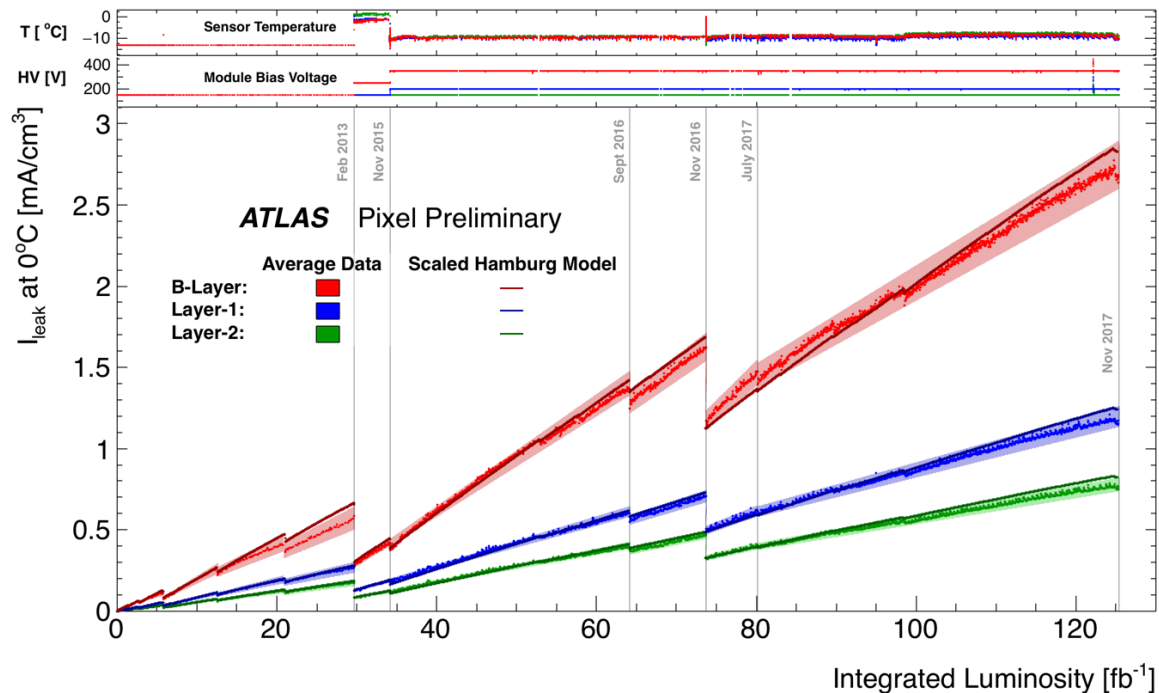

Diagram of the Pixel Detector

Leakage Current in the ATLAS Pixel Detector

- Average leakage current data compared to the average scaled Hamburg Model predictions for each barrel layer through 2017

- The Hamburg Model predictions have been scaled to match the measured leakage current data


- Measurements on each layer are averaged over a representative sample of modules in η and ϕ.

- The measurements are consistent with expected higher levels of radiation for sensors closer to the beam line.

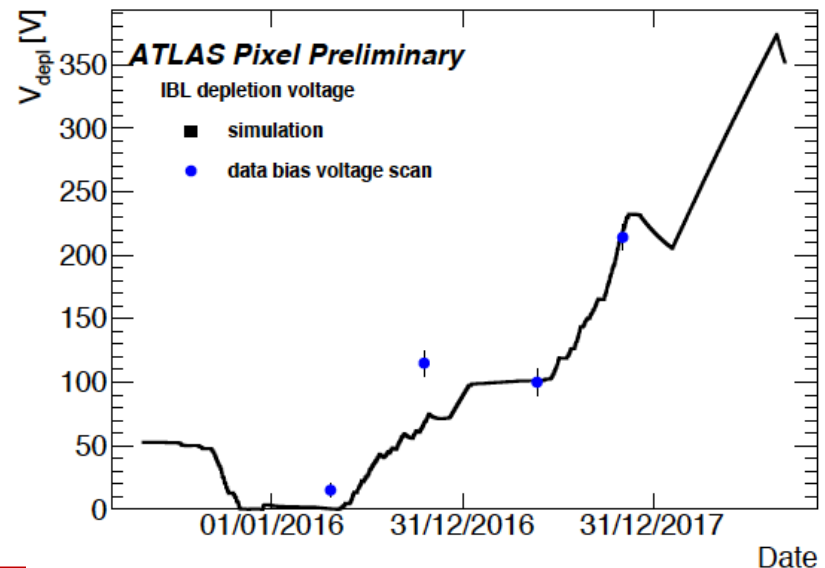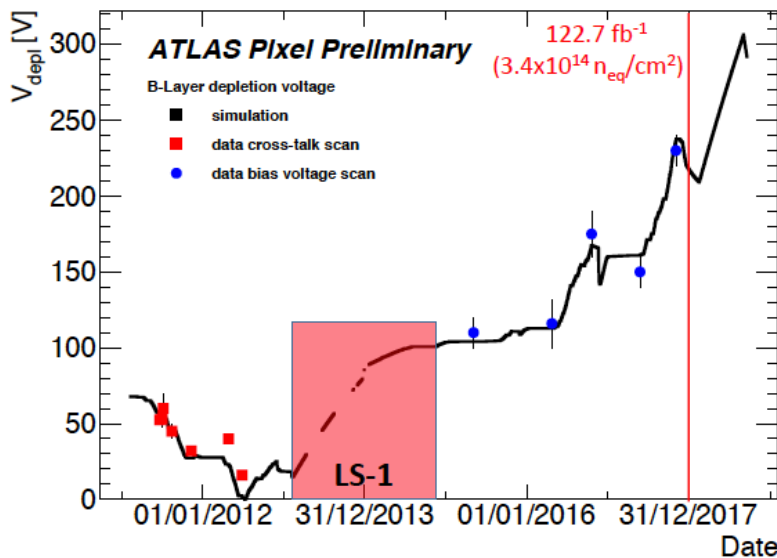- The Hamburg Model* fit is qualitatively good over the entire range

Fluence Comparisons

- Fluence predictions made with Pythia 8 + FLUKA and Pythia 8 + Geant 4 are compared to the fluence determined with the leakage current data and Hamburg Model, for the **IBL**

- Comparison of fluence predictions by Pythia 8 + FLUKA to the fluence determined from leakage current data combined with the Hamburg Model, for the **B-Layer**

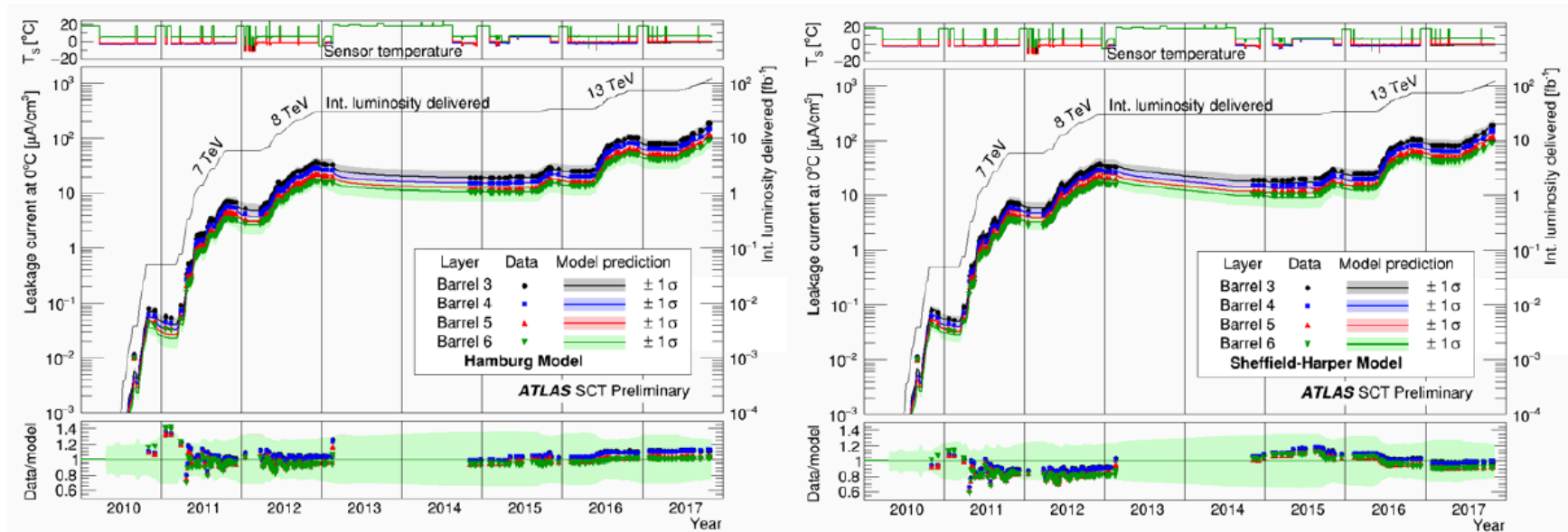- Clear |z|-dependence differences are seen between simulation and data
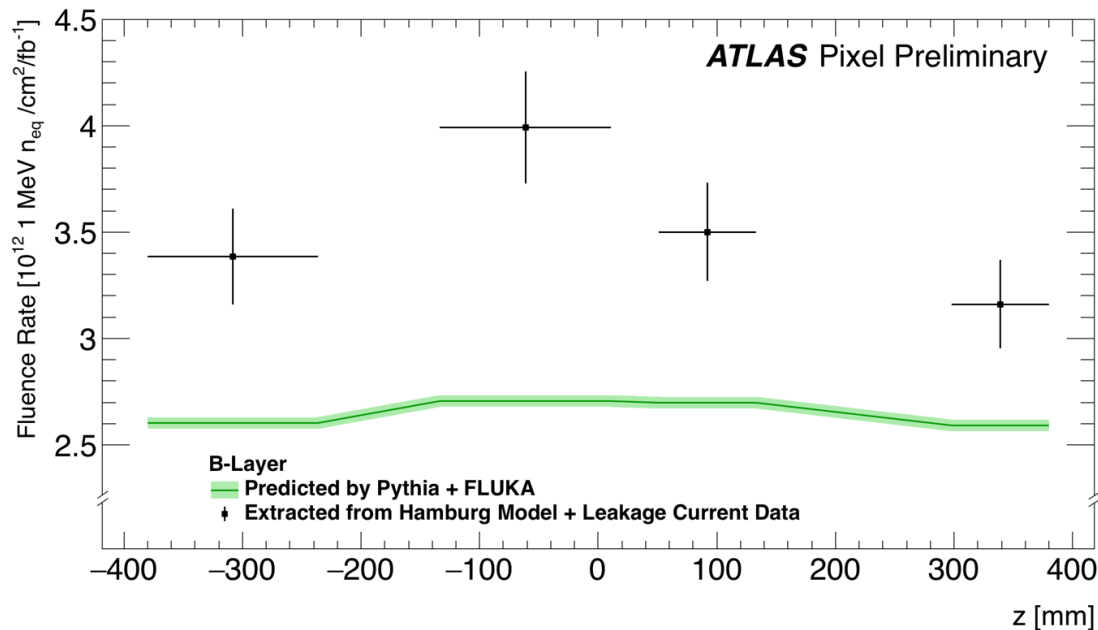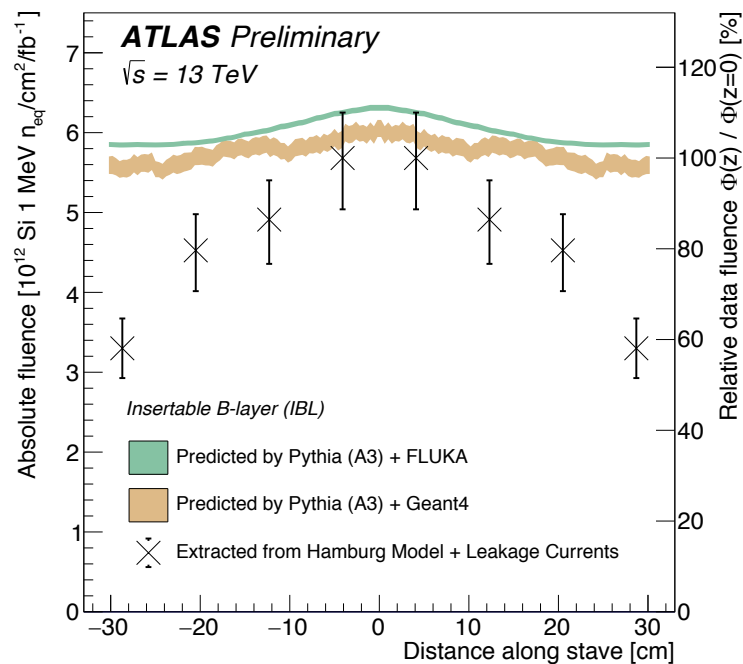
ATLAS Pixel Depletion Voltage

- Simulations of depletion voltage in the B-layer and IBL are shown below
- Decreasing depletion voltage before type-inversion is apparent
- We see strong reverse annealing during Long Shutdown-1 (LS-1) for the B-Layer
- It is difficult to accommodate all data points with Hamburg Model, but scan points are limited
- Finally, predictions through 2018 are also shown

Julien Beyer, https://indico.cern.ch/event/695271/contributions/2958674/attachments/1637640/2613544/beyer_depl_volt_ATLAS.pdf

# ATLAS Semiconductor Tracker Leakage Current

- Average measurements of the leakage current for each of the 4 barrel layers on the ATLAS Semiconductor Tracker with greater than 100 fb^{-1} delivered luminosity were presented

- These measurements were found to agree well with both the Sheffield-Harper Model* and Hamburg Model

Taka Kondo, https://indico.cern.ch/event/695271/contributions/2964668/attachments/1637686/2613628/RadDamageWksp_20180423_Taka.pdf
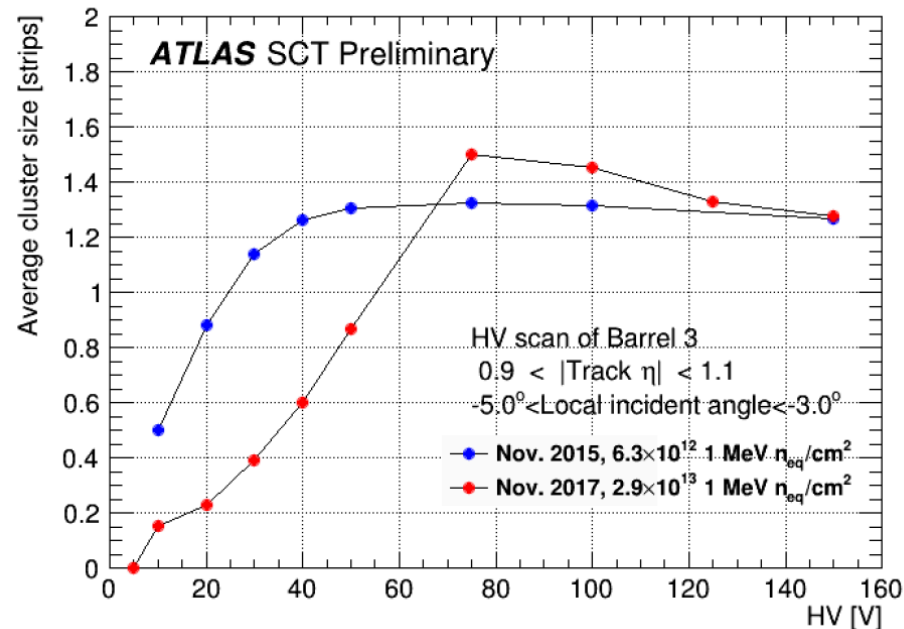* R. Harper, Thesis, Sheffield University (2001)

# ATLAS Semiconductor Tracker Depletion Voltage
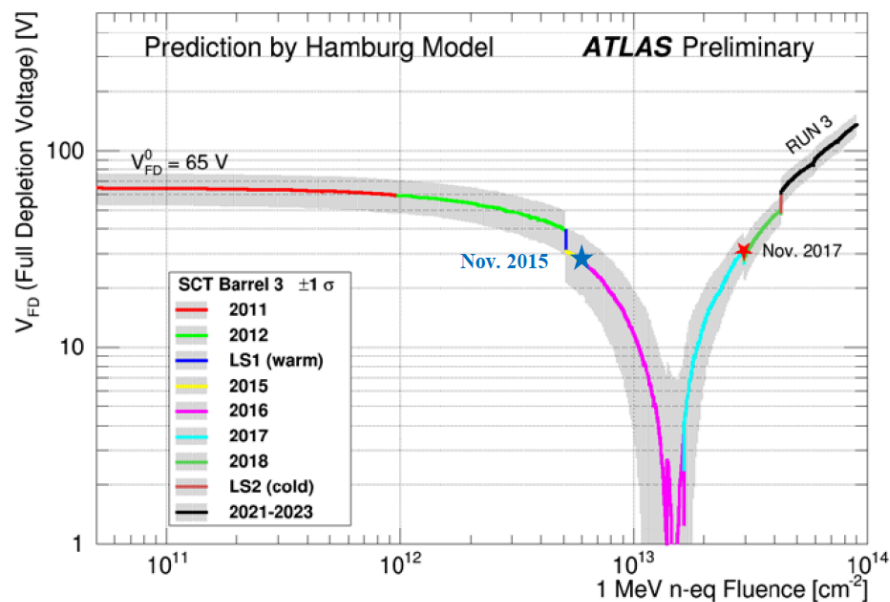
- Predictions of the full depletion voltage made with the Hamburg Model are shown here

- Average cluster sizes in Barrel 3 as a function of HV on Nov. 2015 and Nov. 2017 are also shown, corresponding to full depletion voltage of 30 V (n-type) and 30 V (p-type), respectively, before and after type inversion.

CMS Detector

- Results presented for the 3 barrel layer CMS Pixel Tracker
- As well as for the surrounding Inner Barrel, Outer Barrel and Endcaps of the Strip Tracker
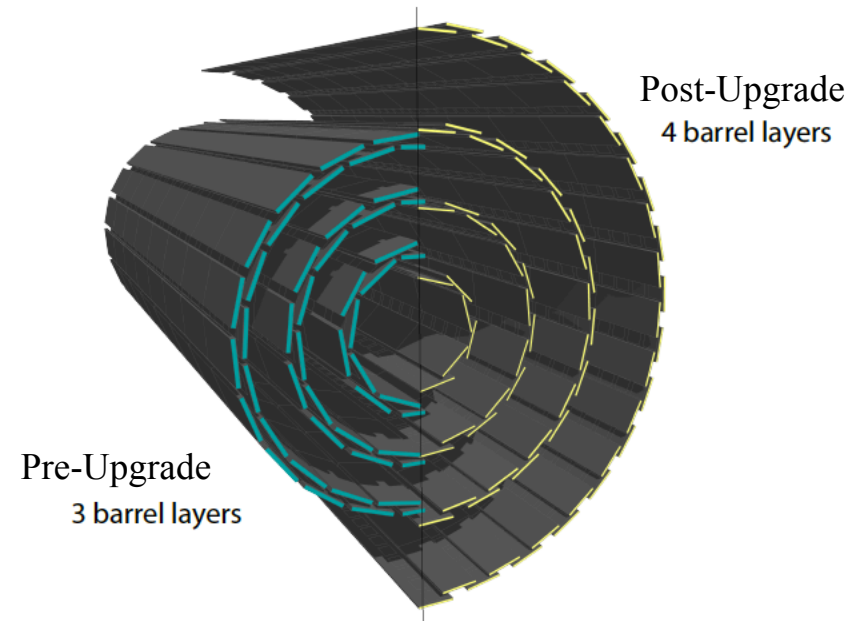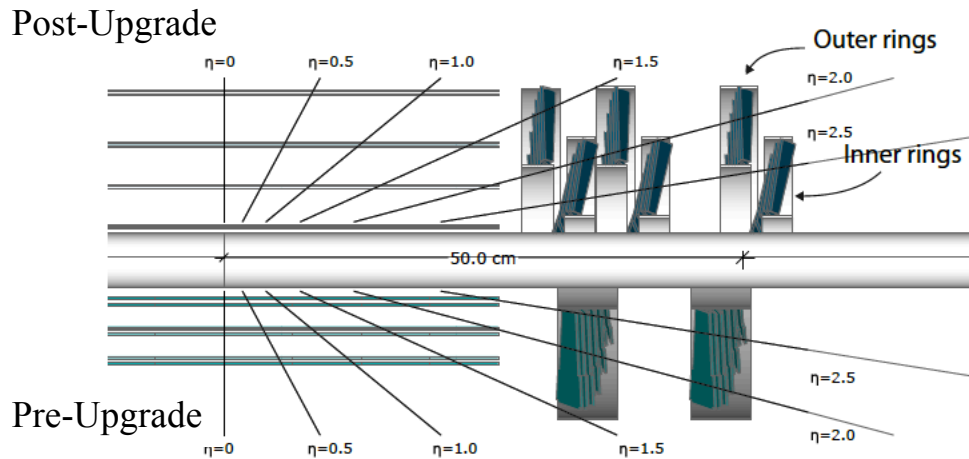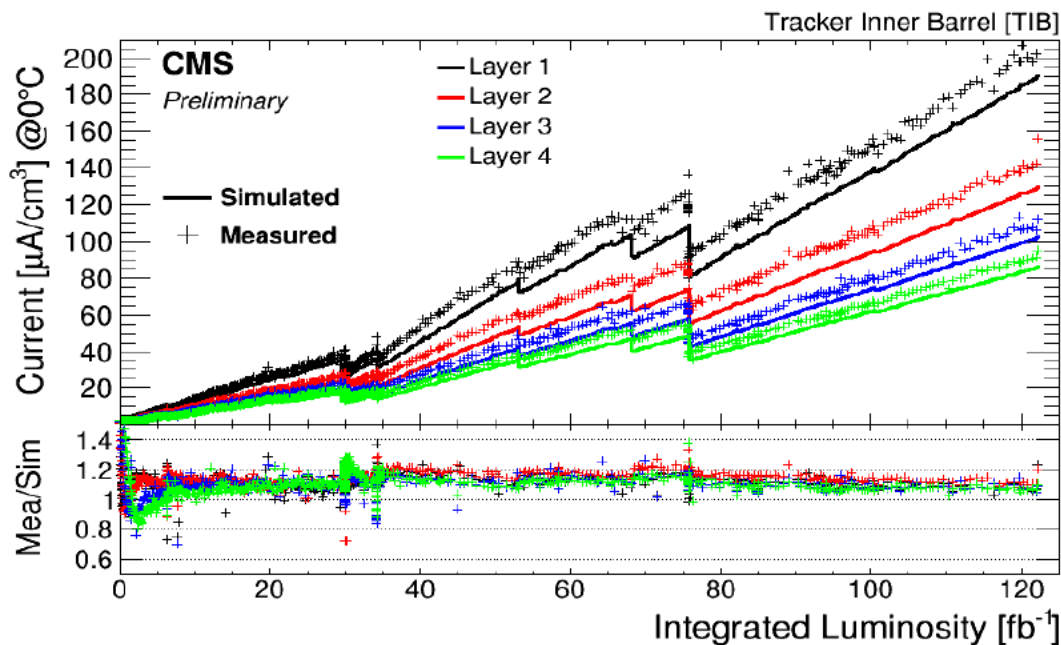
CMS Pixel Tracker

- Simulation of the full depletion voltage for the three Pixel Tracker layers as a function of time is presented

- The simulations are based on the Hamburg Model

- Plateaus in the simulation reflect the long shutdown 1 and other LHC technical stops

- Data from high voltage scans are also shown
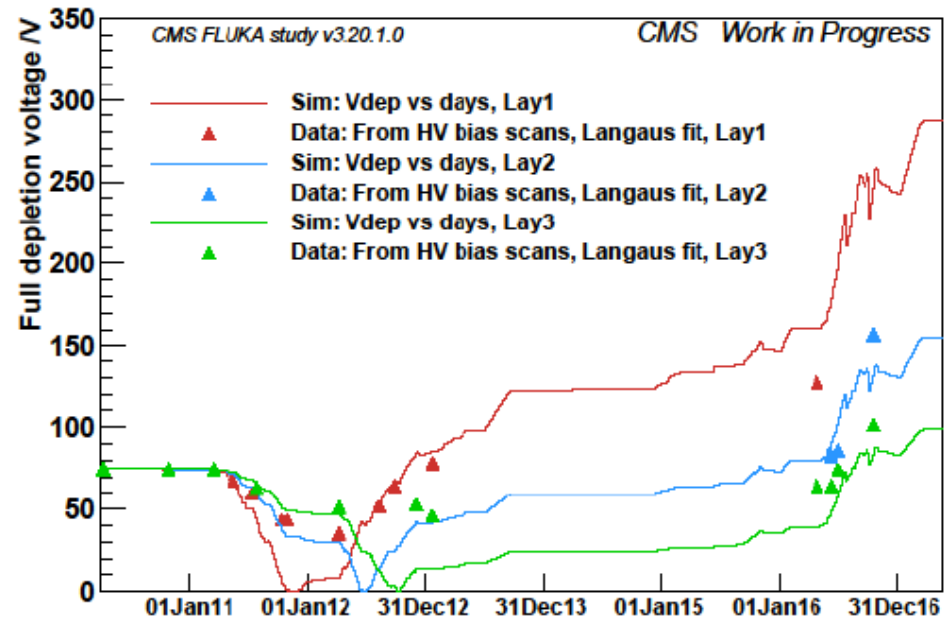
CMS Strip Tracker Inner Barrel Leakage Current

- Leakage current data of the four Tracker Inner Barrel layers versus delivered luminosity (greater than 120 fb^{-1}) is shown in the figure

- The data are compared to simulation from the Hamburg Model

- There is approximately 20% underestimation of leakage current by the Hamburg Model

CMS Strip Tracker Inner Barrel Depletion Voltage
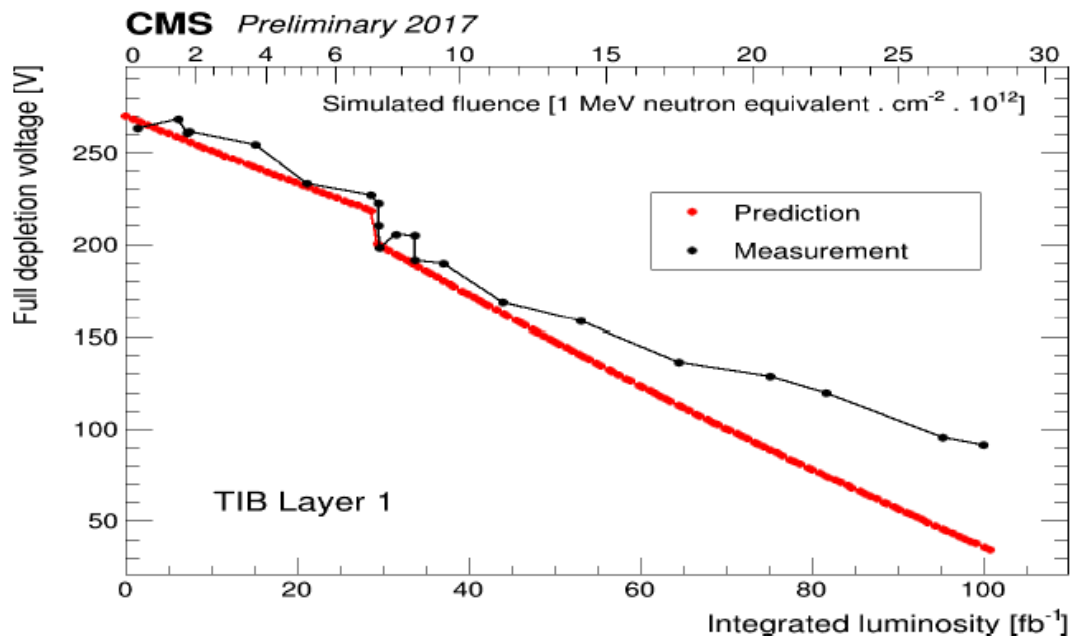
- Prediction of the full depletion voltage on Layer 1 of the Tracker Inner Barrel is made and compared to measurement for one example module.

- Full depletion voltage simulations agree well in the beginning, and start to deviate when approaching the inversion point.

CMS Strip Tracker

- Extrapolation of the expected full depletion voltage after delivered luminosity of 400 fb^{-1} during LHC Run 3 on a per module basis is shown in the figure here


Expected full depletion voltage after 400fb^{-1} running at -20°C during run 3
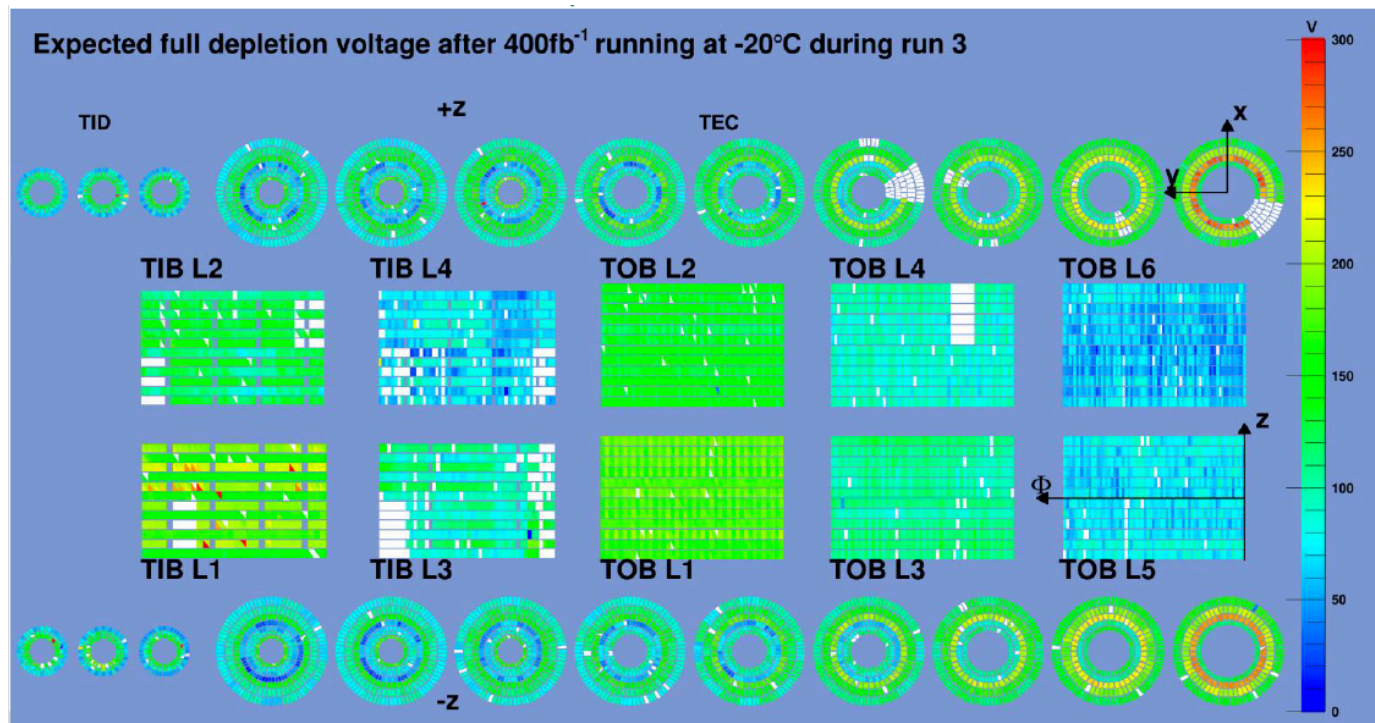
LHCb Detector

• Studies of the leakage current and depletion voltage for the Vertex Locator (VELO) and the Silicon Tracker were presented

Vertex Locator (VELO)

Silicon Tracker
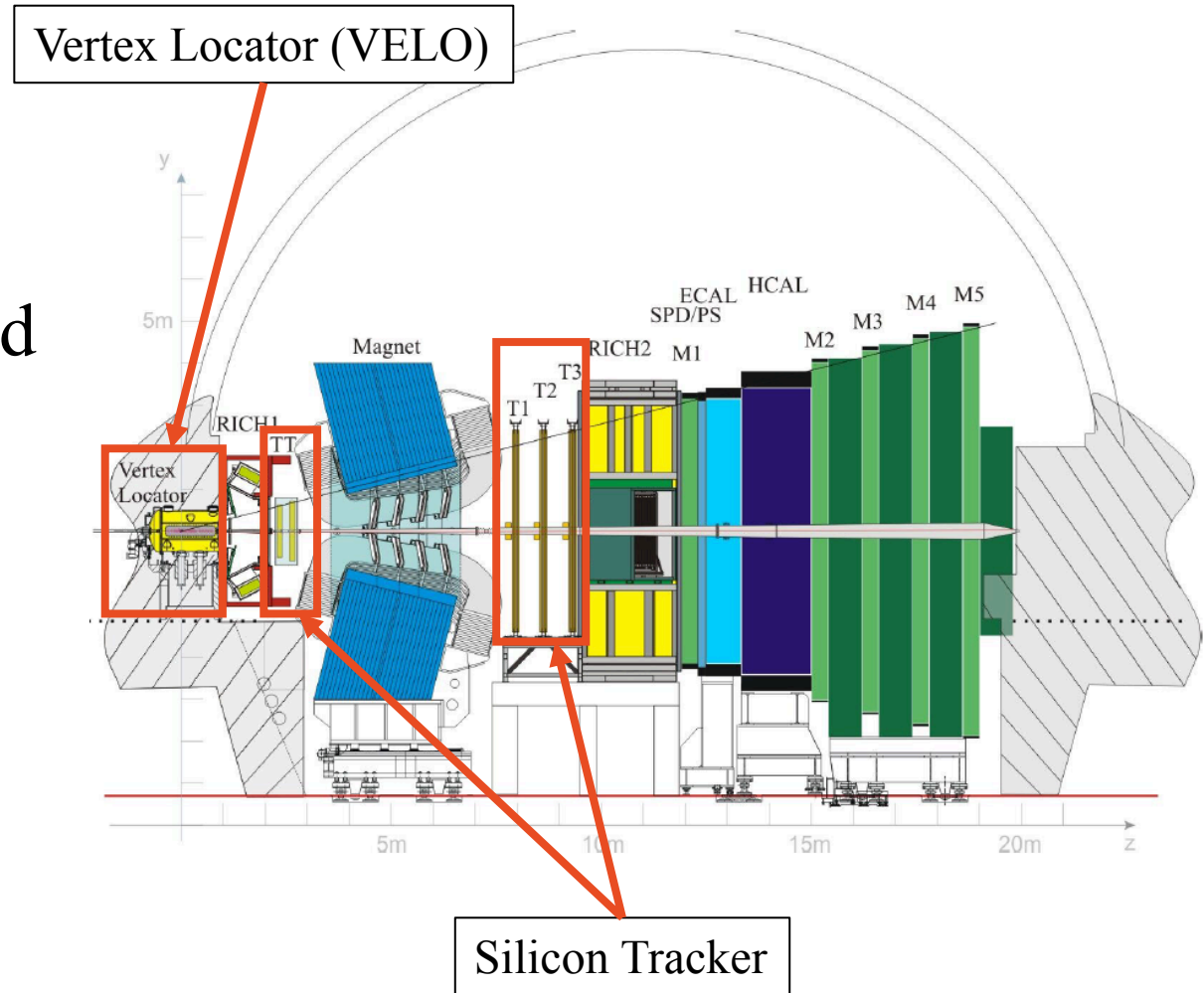
LHCb Vertex Locator Leakage Current

- Average measurement of the leakage current versus date for the Vertex Locator is shown in the figure

- The delivered luminosity is greater than 7 fb^{-1}
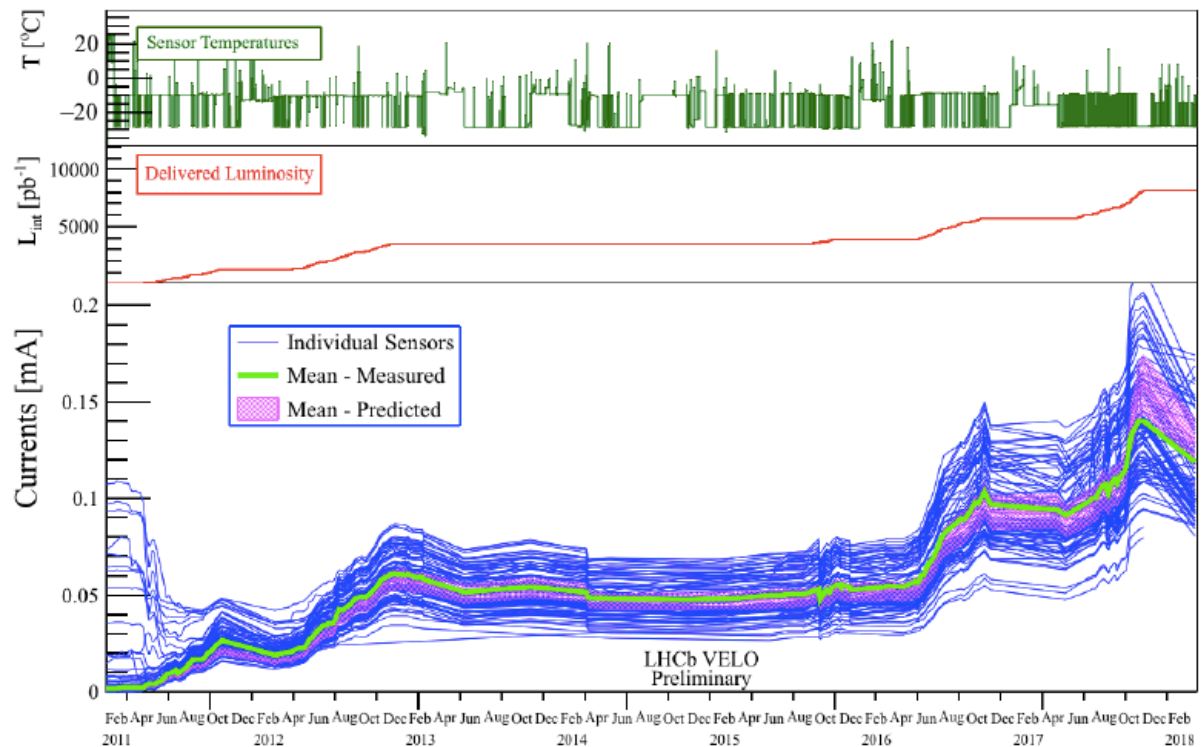
LHCb VELO Depletion Voltage

- Depletion voltage scan from Nov. 2017 compared to the Hamburg Model prediction is shown on the left
- Predictions of the depletion voltage for individual sensors is shown on the right and predictions are made into 2018
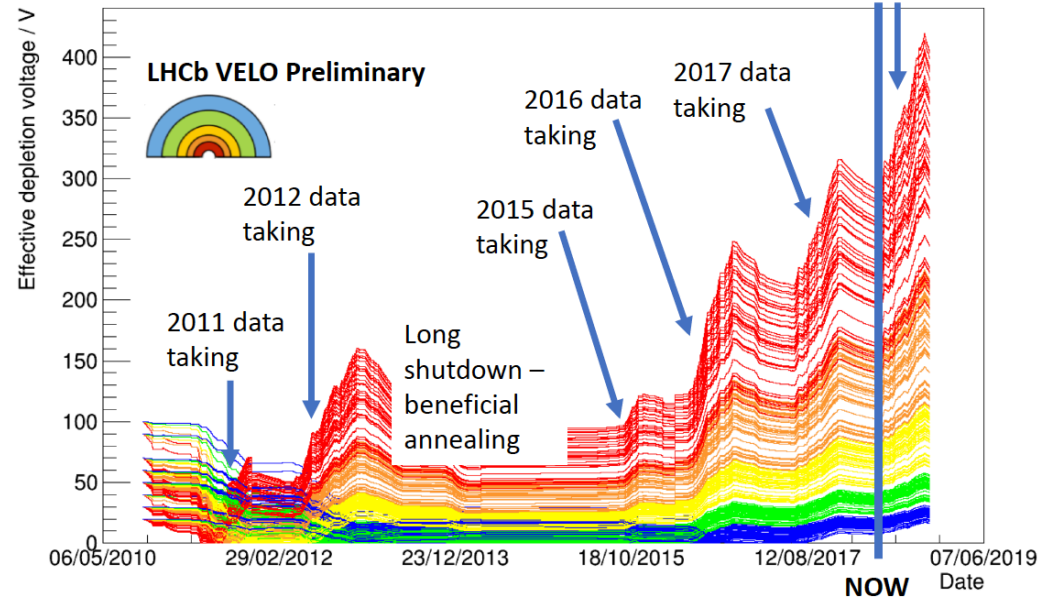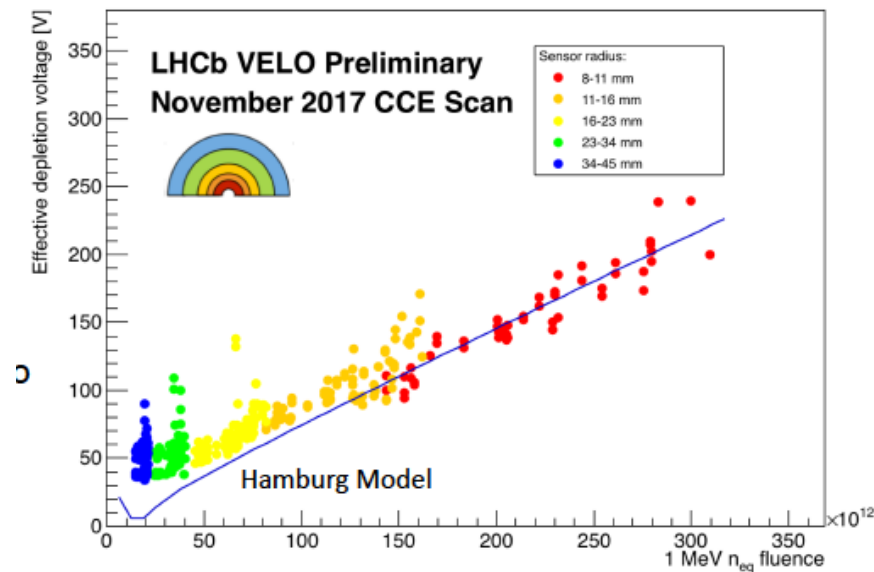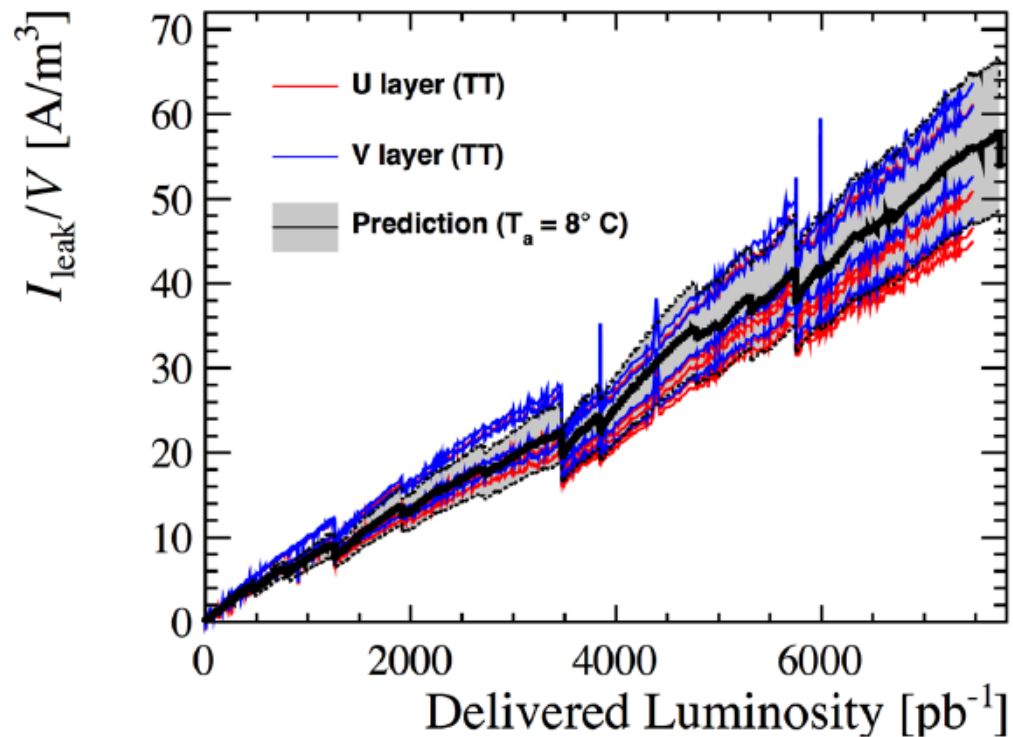

- Possible warming of VELO to eg. 20°C for 5 days in September Technical Stop to allow beneficial annealing and further study of Hamburg Model.

LHCb Silicon Detector Leakage Current

- Measurement of leakage current in the LHCb silicon detector sensors is shown

- The prediction is made with the Hamburg Model and agrees well with the data

LHCb Silicon Detector Depletion Voltage

- Measurements of the depletion voltage versus fluence and versus date in the Silicon Detector are compared to the Hamburg Model
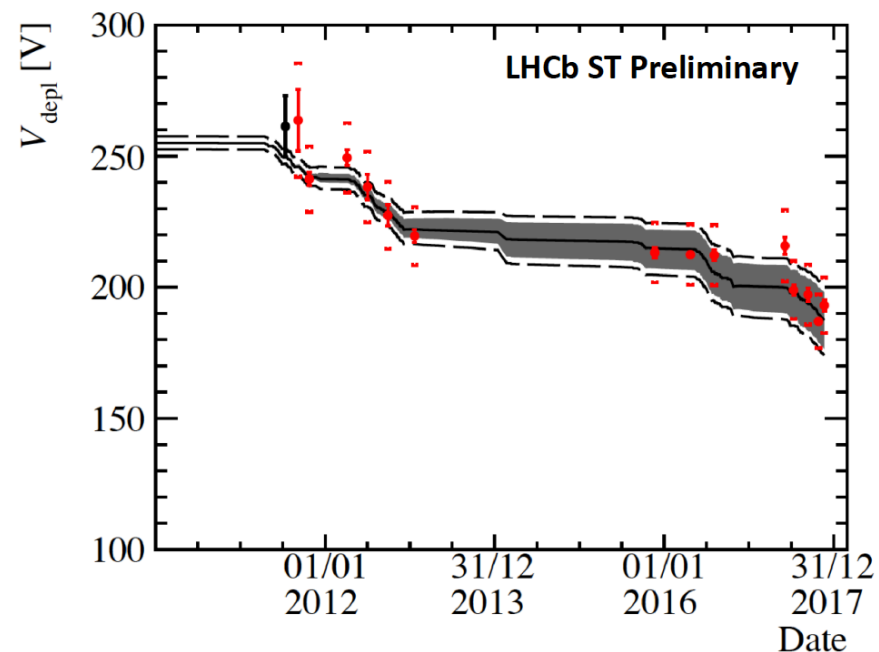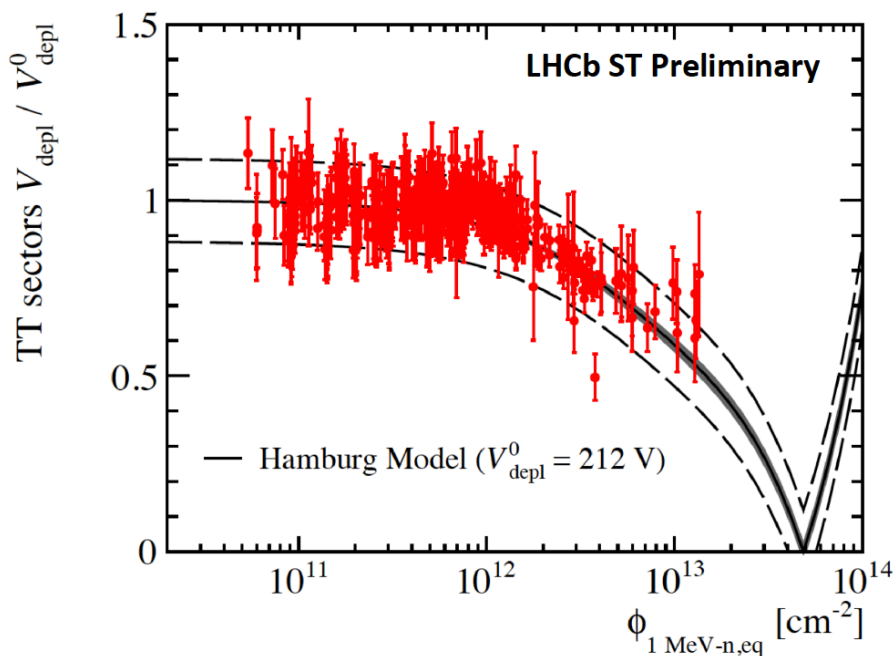
Final Comments

- This has been an overview of sensor measurements discussed at the LHC inter-experiment radiation workshop

- A lot of important work has been accomplished and presented at that meeting

- Some discrepancies between data and simulation will motivate further analysis
  - An open question from the LHC Radiation Workshop: How much does the choice of bias voltage affect the leakage current level and can this be accounted for in the Hamburg Model?
  - We have seen some puzzling comparisons with the predicted fluences from simulation (Pythia8 + FLUKA/G4)
    - Currently studying alternative min-bias p-p event generators such as DPMJET3 to investigate the |z|-dependence