Available on CMS information server

CMS DP -2021/019

The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

25 May 2021

Measurement and modelling of the depletion voltage in Layer-1 for the Phase-1 Pixel

CMS Collaboration

Abstract

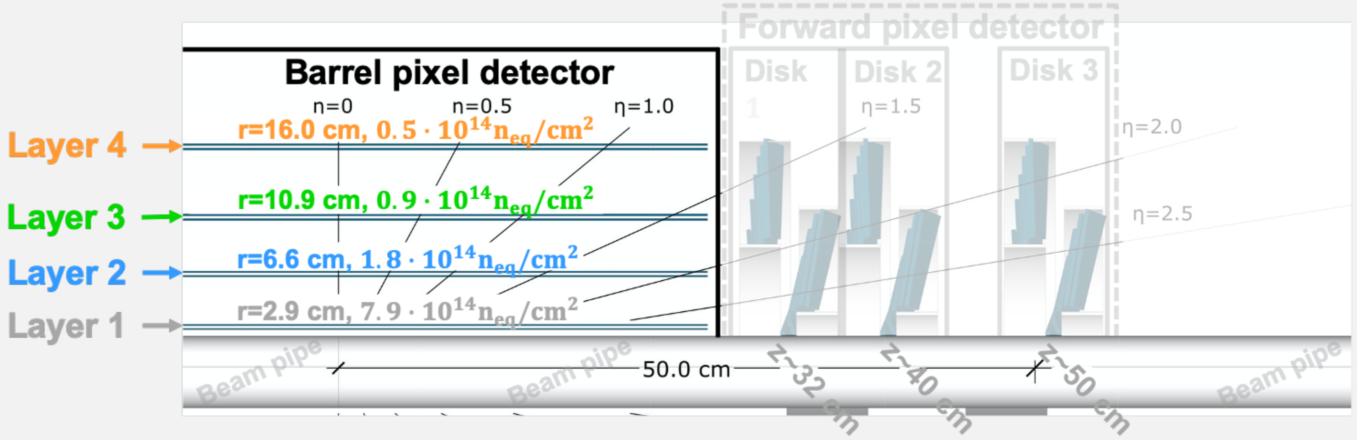
This Detector Performance Summary shows a comparison between the modelling and measurement of the depletion voltage in Layer-1 for the Phase-1 Barrel Pixel.

DEPLETION VOLTAGE FOR BARREL PIXEL LAYER 1

cms-tracker-runcoord@cern.ch

INTRODUCTION

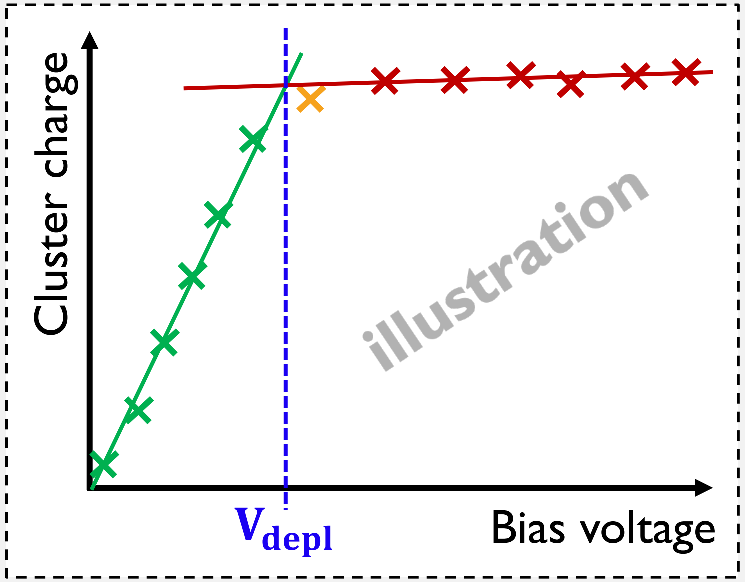
- The pixel detector is the innermost part of the CMS
- Two parts: barrel and forward
- The barrel pixel detector is divided by layers (picture below), which are sets of modules –n+-in-n sensors with dimensions 6.42x1.68x0.0285 cm^3
- Since the pixel detector is the innermost part of the detector, the monitoring of the radiation damage in it is important.
- Macroscopic physics effect of the radiation damage is change in the leakage current and the full depletion voltage.

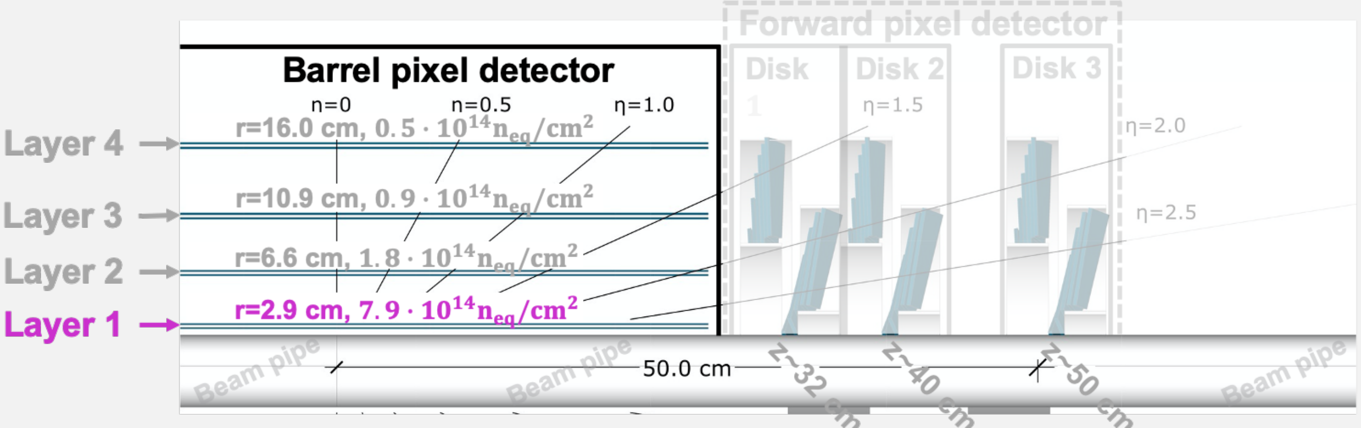


Fluence information comes from FLUKA simulation

DEPLETION VOLTAGE FOR LAYER 1

- Temperature is measured from probes placed close to cooling pipes and not directly on silicon sensors. Layer 1 temperature is assumed to be equal to the average of temperature readings plus 3℃ to account for the fact that temperature on sensors is expected to be higher as from studies performed on a mock-up system.
- Fluence values used to simulate the depletion voltage for Layer 1 is taken as the sum of maximum fluence of each module divided by the number of modules.
- Depletion voltage data is determined from the cluster charge vs bias voltage data.
  - Depletion voltage is defined as the bias voltage at which the cluster charge reaches the plateau, i.e. the point at which the curve kinks. This point is calculated as the intercept of two linear functions, that are used to fit two different regions of the average normalized on-track cluster charge.
  - Uncertainty is the sum in quadrature of the fit uncertainty and systematic uncertainty. We assume the latter to have the value of 10 Volts.





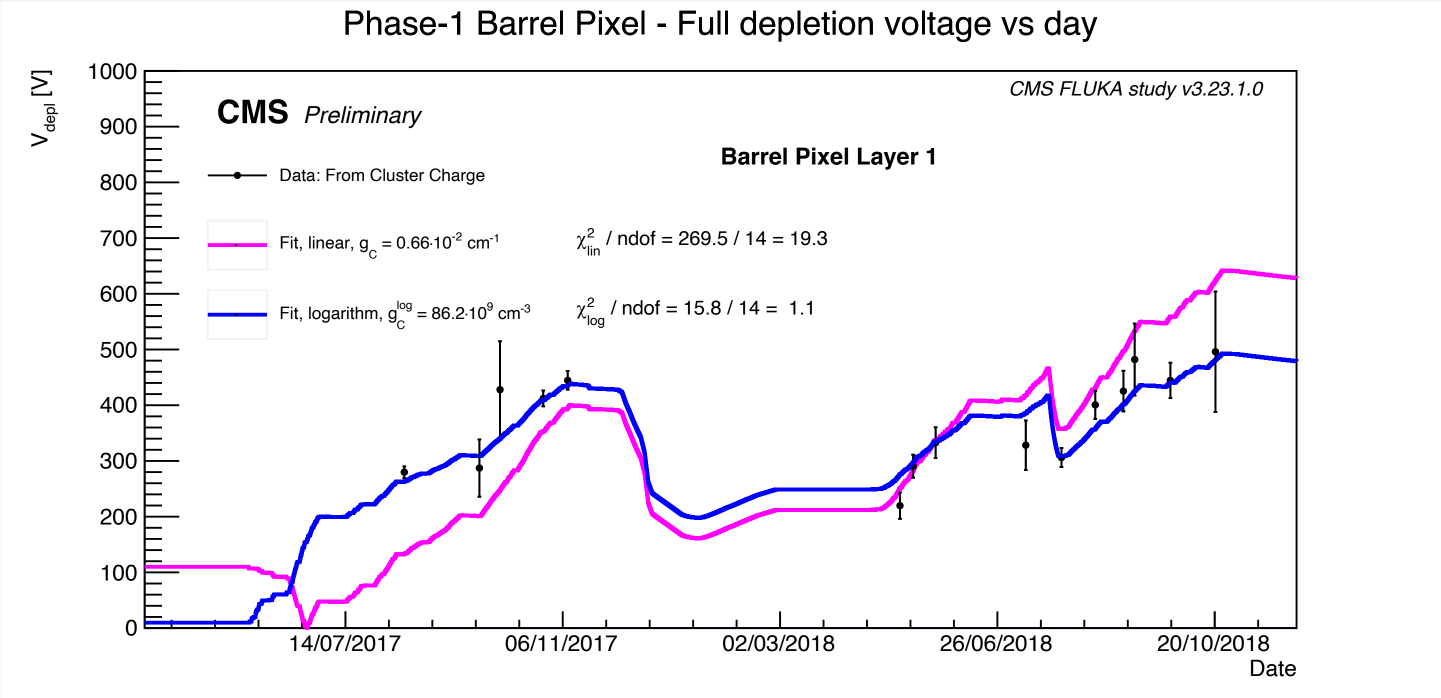
DEPLETION VOLTAGE: SIMULATION

- $V_{depl} = \frac{e \cdot d^2}{2\epsilon_r \epsilon_0} \left| N_{eff}\left(t, T; \frac{1}{n_{modules}} \sum_{modules} \phi_{eq,max,module}\right) \right|$ - depletion voltage as a function of effective doping concentration. $\phi_{eq,max,module}$ **is a maximum fluence/time** for a **BPix module**, $n_{modules}$ is the number of modules in Layer 1.
- $N_{eff}(t, T; \phi_{eq}) = N_c^{dr}(t; \phi_{eq}) + N_c^a(t; \phi_{eq}) + N_r^{a,1}(t, T; \phi_{eq}) + N_r^{a,2}(t, T; \phi_{eq})$ - number of effective doping concentration (Hamburg model):
  - **Dopant removal**: $N_c^{dr}(t; \phi_{eq}) = N_{eff}^{0,nr} + N_{c,0} \cdot \left(1 - e^{-c\phi_{eq}(t)t}\right)$
  - **Constant damage**: $N_c^a(t; \phi_{eq}) = g_C \phi_{eq}(t)t$ or $N_c^a(t; \phi_{eq}) = g_C \ln(\phi_{eq}(t)t)$
  - **Beneficial annealing**: $N_r^{a,1}(t, T; \phi_{eq}) = \frac{g_A \phi_{eq}}{k_A}\left(1 - e^{-k_A t}\right) + N_0^{a,1} \cdot e^{-k_A t}$
  - **Reverse annealing:** $N_r^{a,2}(t, T; \phi_{eq}) = g_Y \frac{\phi_{eq}}{k_Y}\left(k_Y t + e^{-k_Y t} - 1\right) + N_0^{nd}\left(1 - e^{-k_Y t}\right)$
- We can **express N_{eff}** as a function of **g parameters and fit g_C parameter**, with $g_Y = 6.7 \cdot 10^{-2}\ cm^{-1}$, $g_A = 1.4 \cdot 10^{-2}\ cm^{-1}$ fixed.

- **The depletion voltage fit is performed using two models for the constant damage:**
  - **Linear:** $N_c^a(t; \phi_{eq}) = g_C \phi_{eq}(t)t$
  - **Logarithmic:** $N_c^a(t; \phi_{eq}) = g_C \ln(\phi_{eq}(t)t)$

M. Moll, Radiation damage in silicon particle detectors: Microscopic defects and macroscopic properties, Ph.D. thesis, Hamburg U. (1999)

DEPLETION VOLTAGE. LAYER 1



Based on the full temperature and irradiation history the expected full depletion voltages of the barrel pixel tracker, layer 1 are simulated using the Hamburg model (M. Moll, Radiation Damage in Silicon Particle Detectors, Universität Hamburg, DESY-THESIS-1999-040, 1999) for radiation damage. Warm periods during various technical stops lead to a change of depletion voltage due to annealing. Simulation input: FLUKA fluence simulation (v3.23.1.0) with high granular resolution and detector geometry where the different impact of charged and neutral particles on oxygenated silicon are taken into account. The Hamburg model is fitted to 2017-2018 data leaving the g_C parameter as a free parameter. The g_Y parameter is fixed to 6.7×10^{-2} cm^{-1} and g_A to 1.4×10^{-2} cm^{-1}. Data points are taken from bias voltage scans and are defined to be the point of saturation of the charge collection. The integrated luminosity for 2017 is 50 fb^{-1} and for 2018 is 70 fb^{-1}. Logarithmic model does not predict well the depletion voltage in the region before type inversion.

FUNCTIONS AND CONSTANTS

Function, relation or constant	Expression
Arrhenius relation	$k_X = k_{0X} \cdot \exp\left(-\frac{E_X^a}{k_B T}\right)$
k_{0A}	$2.4 \cdot 10^{13}\ s^{-1}$
k_{0Y}	$7.4 \cdot 10^{14}\ s^{-1}$
E_A^a	$1.09\ eV$
E_Y^a	$1.325\ eV$