



Radiation Damage of the CMS Pixel and Strips Tracker 20th RD50 Workshop Bari

Christian Barth, Seth Zenz on behalf of the CMS Tracker Collaboration

INSTITUT FÜR EXPERIMENTELLE KERNPHYSIK





Leakage Current

- Leakage current measurements and evolutions
- Temperature dependency of Ileak
- Simulation of leakage current



lleak vs. Pixel Detector Phi



- LHC Beam Spot is not at center of Pixel Detector!
- Known to be at (x,y) = (-2.4mm, 3.9mm) $\rightarrow \phi \sim 2.12$
- 30% effect on potential Layer 1 lifetime!
- Can also see impact of staggered geometry



Measured Leakage Current within the Barrel Region of the Strips Tracker vs. Fluence





Measured Leakage Current within the Barrel Region of the Strips Tracker vs. Fluence





Measured Leakage Current within the Barrel Region of the Strips Tracker vs. Radius

- Blue curve fit of measurement
- Red curve FLUKA simulations (with alpha value from fit see slide 4)

Pixel Leakage Current vs. Fluence

Pixel lleak Temperature Scaling

- Pixels: Investigated Temp. scaling of Ileak by fitting scans
- Let effective band gap Eg vary (should be 1.21 eV)
- Tried allowing Temperature independent surface term
- Should correspond to ohmic behavior in IV curve after saturation
- Conclusion: not justified
- Long extrapolation (17.2 C operation temperature to $0 \text{ C} \rightarrow$ significant impact

Pixel Temperature Scaling 2012

- Pixel operating temperature: 17.2 C \rightarrow 9.8 C
- Wider range for temp scans
- Good agreement with 2011 fits, implying extrapolation to 0 would be improved by using fit Eg values

Karlsruhe Institute of Technology

Modeling the Evolution

- Inputs
 - Fluence (FLUKA)
 - Temperature
- Output
 - Leakage current
 - Depletion voltage
- Calculates the impact of each day's fluence to all later days, based on each day's temperature
- Equations from models in literature – constants can be material dependent
- Vdep parameters measured for strips only

Example Comparison Between Ileak Model and Measurent

Simulation seems to overestimate annealing slightly with respect to measurement

Model – Data Comparison Pixel Channel-by-Channel

Pixel: model systematically low

Model – Data Comparison Strips Module-by-Module

Strips has good agreement during 2011 pp collisions

Agreement becomes worse after HI perdiode (pure annealing)

Relative Deviation Between Model and Measurement (Strips)

14 30.05.2012

C. Barth Institut für Experimentelle Kernphysik

Relative Deviation vs. Temperature (after HI)

- Deviation is temperature dependent
 - Uncertainty in Temperature Measurement (bad dynamic range of DCU)?
 - Modelparameters for annealing?

lleak over 2011 (Pixel)

Fair agreement between model and measurement, when a "cheating factor" of 1.7 is applied

I V Curves Pixel 2012

Prediction for lleak for 2012 (Pixel)

Final predicted lleak for end of 2012 (Strips)

Full Depletion Voltage

- Full depletion voltage measurements and evolutions
- Simulation of full depletion voltage

Full Depletion Voltage Measurements

Two methods for Strips:

- Noise Scan (interfill periods)
- Signal Scan (during operation)
 - Monthly for 5 power groups, twice annually for entire detector
 - Fit cluster charge vs. voltage
- No change detected within measurement uncertainty

Pixels:

- Hit efficiency vs. voltage (during operation)
- Work in progress: cluster charge vs. voltage

Pixel HV Scan for 1 HV Group in Layer 1

Fitting function for efficiency plot: [0]+[1]/(1+exp(([2]-x)/[3]))

Pixel Turnon Voltage Evolution

Turnon voltage evolution for all pixel layers

Full Depletion Voltage Example Projection

- The developed tool is used to evaluate different temperature scenarios throughout the lifetime of the CMS – understand shut down periods
- The tool example shows the Simulation of depletion voltages for Tracker Inner Barrel Layer 1 (closest to the interaction at around r=24cm) for the aforementioned scenario:
 - One can see the average (blue) and the 99% quantile cases (red) which lost cooling
- We use CMS specific parameters, derived during the QA of construction
 - The tool takes radiation and annealing effects into account
 - Tool also gives beneficial, reverse annealing and stable damage part separately

Conclusion

- Models give fair agreement
- Evolution in 2012 will provide a good opportunity to test/tune
 - M. Moll provided us with parameters for oxygenated silicon good opportunity to validate pixel Vdep evolution
 - Cross validate FLUKA predictions
- Many small improvements to be studied
 - Strips bias voltage scan accuracy
 - Model parameters
 - Comparisons of FLUKA to charged particle density
 - Better understanding of temperature extrapolation
- Projections for LS1 and the more distant future will improve over the course of this year

BACKUP

DCU readout of the leakage current vs. the corresponding power supply measurements after 4.7fb⁻¹.

Each high voltage line of our power supply system is connected to 3-12 modules, to achieve higher granularity we need to use the DCU information.

Comparison between Model and Measurement for Vdep (Pixel Layer 1)

- Compared to calculations with same model as Ileak comparison
- Good agreement up to the last part of the year
- Disagreement at low voltage different behaviour expected, simulation not for oxygenated silicon
 - Slope of oxygenated silicon is expected to be lower

Arlsruhe Institute of Technology Principles of the Noise Method

Karlsruhe Institute of Technology

The width of the depletion zone is $w = \sqrt{\frac{2\epsilon_{Si}V}{q|N_{eff}|}} = d\sqrt{\frac{V}{V_{depl}}}$ this leads to

$$C = C_0 \sqrt{rac{V_{depl}}{V}}$$
 for $V < V_{depl}$
 $C = C_0$ for $V \ge V_{depl}$

this leads with the readout electronic specific parameters A and B to

$$n = \sqrt{(A + B \cdot \sqrt{rac{V_{depl}}{V}})^2 + others^2}$$
 for $V < V_{depl}$; $n = n_0$ else

Karlsruhe Institute of Technology The Signal Method

Three effects are taken into account with our model:

- 1. Variation of depletion zone width
- 2. Change in the mobility of charge carriers
- Change in the load capacitance of the APV leading to a suboptimal sampling

Approach of the Signal Method

Karlsruhe Institute of Technology

- For each given bias voltage the distribution of the collected charge per hit is analyzed
- This distribution is fitted with a Landau, resulting in a peak and an error
- We use only hits from good tracks ($\chi^2 < 5$) as well as MPVs with an error smaller than 5
- The graph is fitted with the corresponding curve obtained through simulation

Strips Full Depletion Voltage april 2012 - few examples

Pixel Hit Efficiency Definition

- Tracks from primary vertex
- Transverse momentum > 1GeV
- Minimum number of hits: 11
- Hit in both other pixel layers required
- Impact parameter selected to reduce secondaries
- Trajectories near edges of sensors excluded
- Only tracks with no additional trajectory within 5mm used
 - Efficiency is fraction of traversing tracks for which either a hit is used in the reconstruction or a hit is found within 500µm

Depends on:

- Luminosity
- Trigger rate