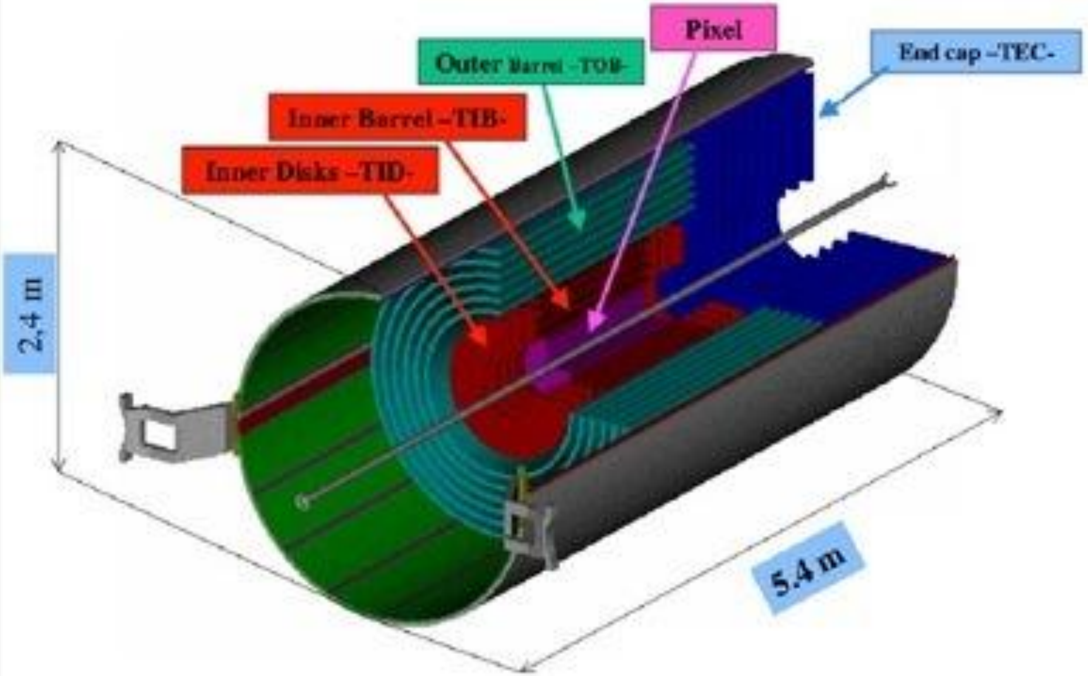
Radiation Damage in the CMS Strips Tracker

Christian Barth on behalf of the CMS Tracker Collaboration

The CMS Strips Tracker

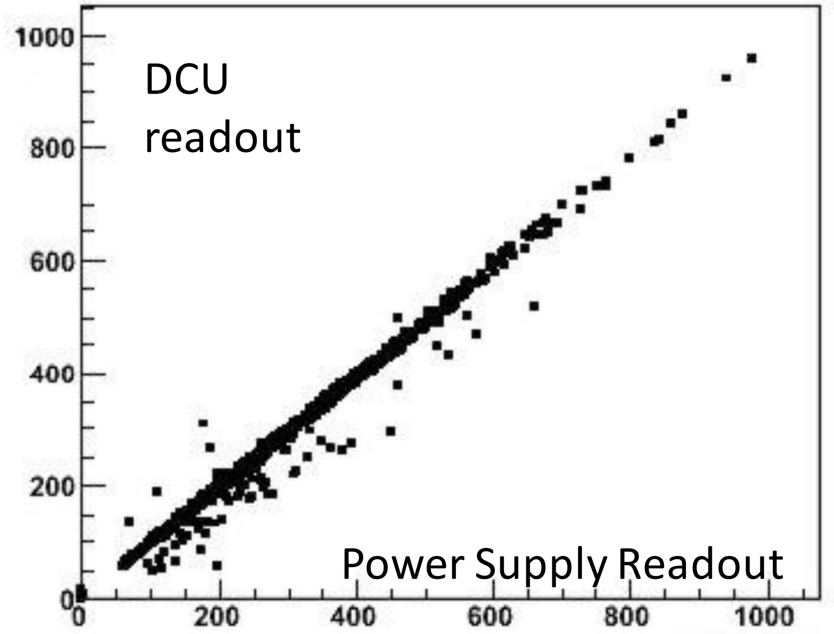
- 200 m^2 active silicon sensor area (p-on-n)
- About 6000 sensors of 300µm

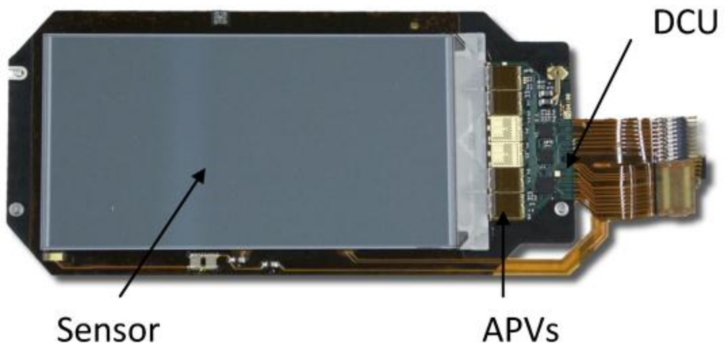
  20000 sensors of 500µm
- Currently operated at 300V bias voltage
- Expected fluence exposure: up to 2x10^{14} 1MeV neutron equivalent



DCU

DCU readout of the leakage current vs. the corresponding power supply measurements after 4.7fb^{-1}.



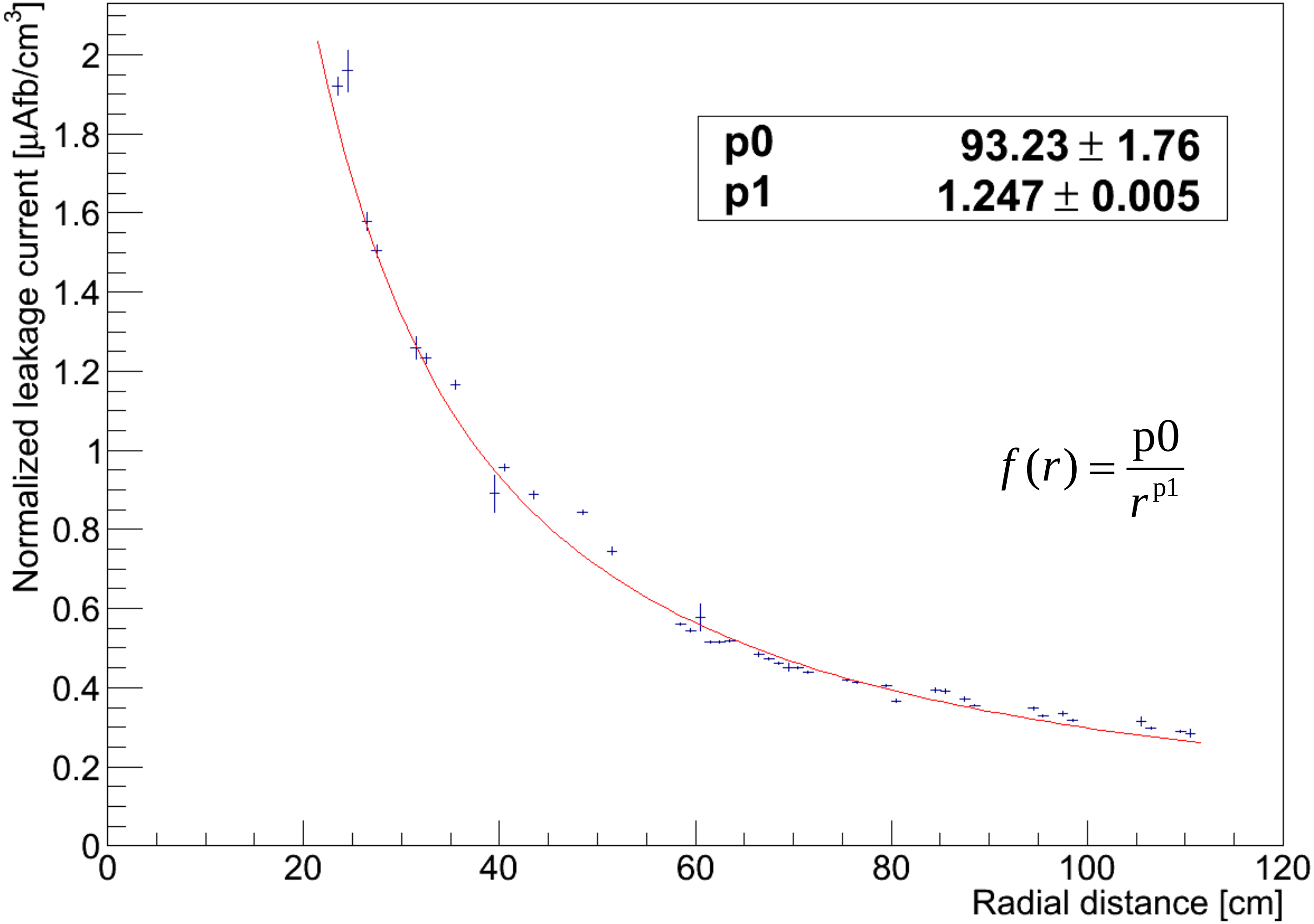


The detector control unit is a ASIC sitting on each of the tracker modules, with the ability to measure the temperature at different positions of the module as well as the leakage current and LV voltages applied.

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.

Radial Dependency of Leakage Current Measurements

Slope of leakage current increase per fb-1 after 4.7 fb-1 normalized to 1cm^3 and 0°C

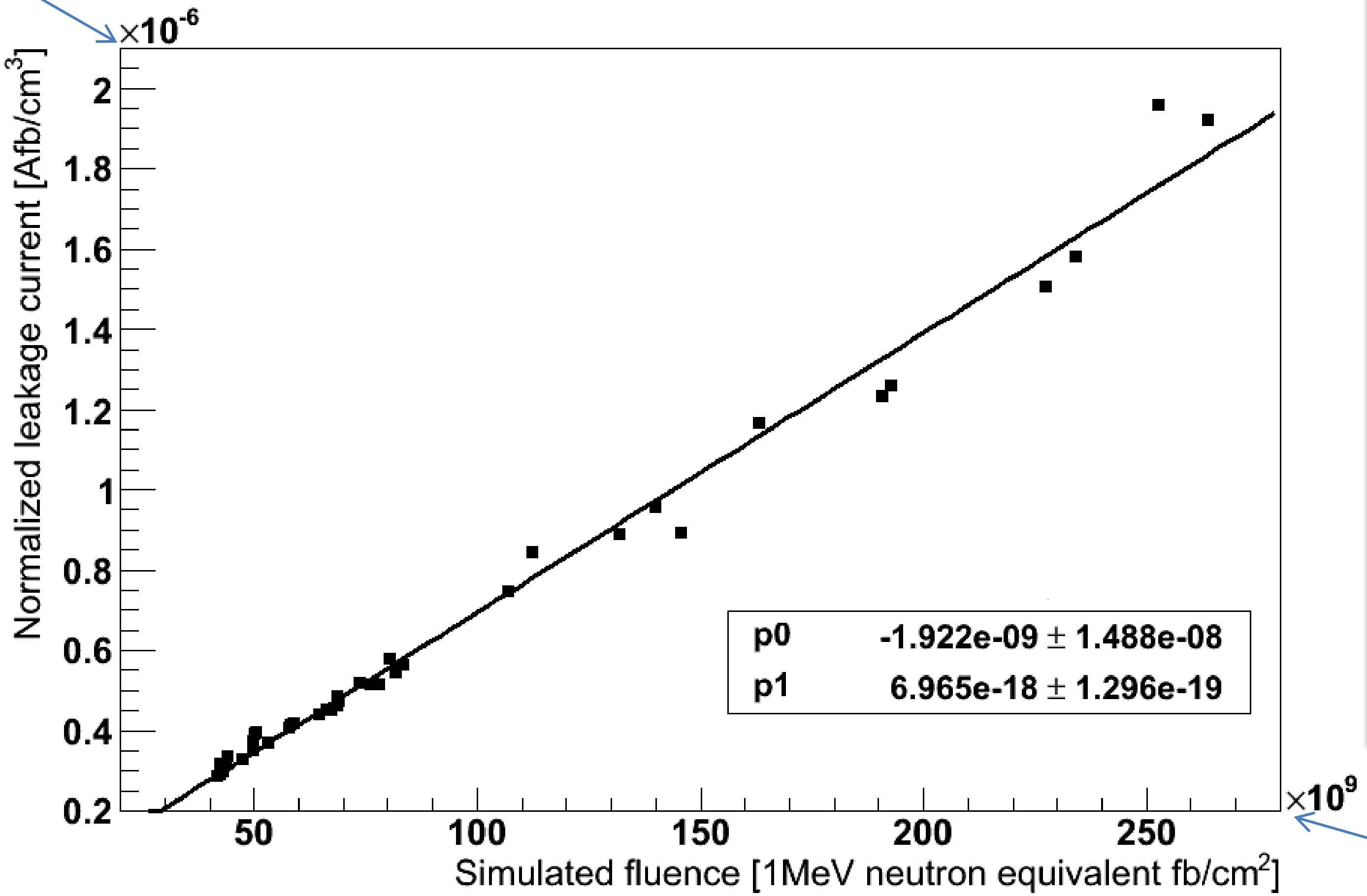


$$f(r) = \frac{\text{p0}}{r^{\text{p1}}}$$

The normalized leakage current is averaged within each bin of a given radial distance r

Normalized Leakage Current Measurements vs. Fluence Simulation

Slope of leakage current increase per fb-1 after 4.7 fb-1 normalized to 1cm³ and 0°C

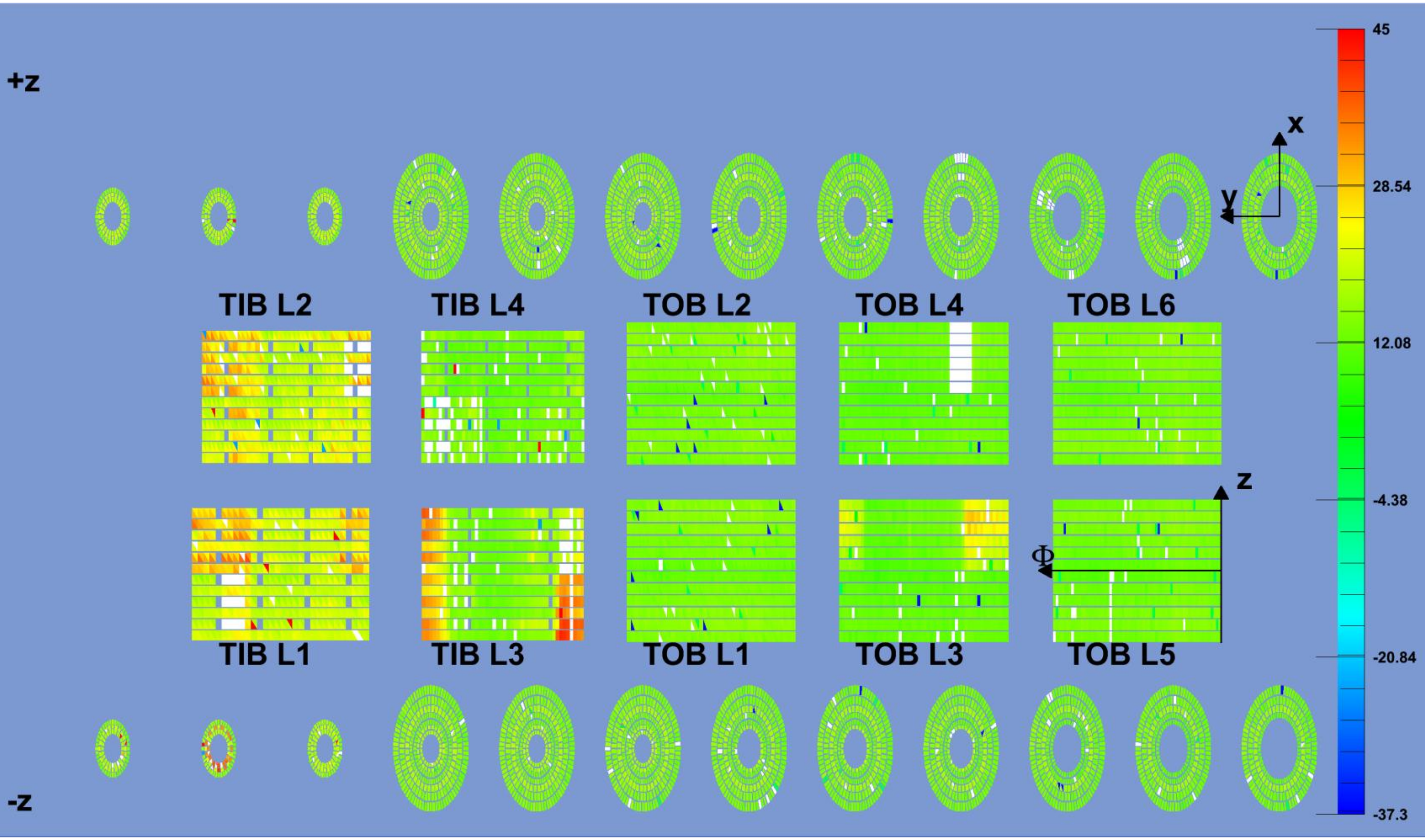


The slope of the fit is a measure of the effective alpha factor (scaled to 0C).

Rescaled to 20°C this leads to 4.66 e-17 A/cm

Fluence derived from 7TeV FLUKA simulation scored to 1MeV neutron equivalent.

Real Temperature Distribution within the Tracker



Quite high temperature spread within the tracker (some elements un-cooled)

→ Current normalization is needed to allow comparison

→ Simulate the leakage current on module granularity

→ Radiation damage and annealing processes are simultaneously present

→ <u>develop a tool on module granularity and work on a day by day basis in an integral way</u>

Simulation

Inputs:

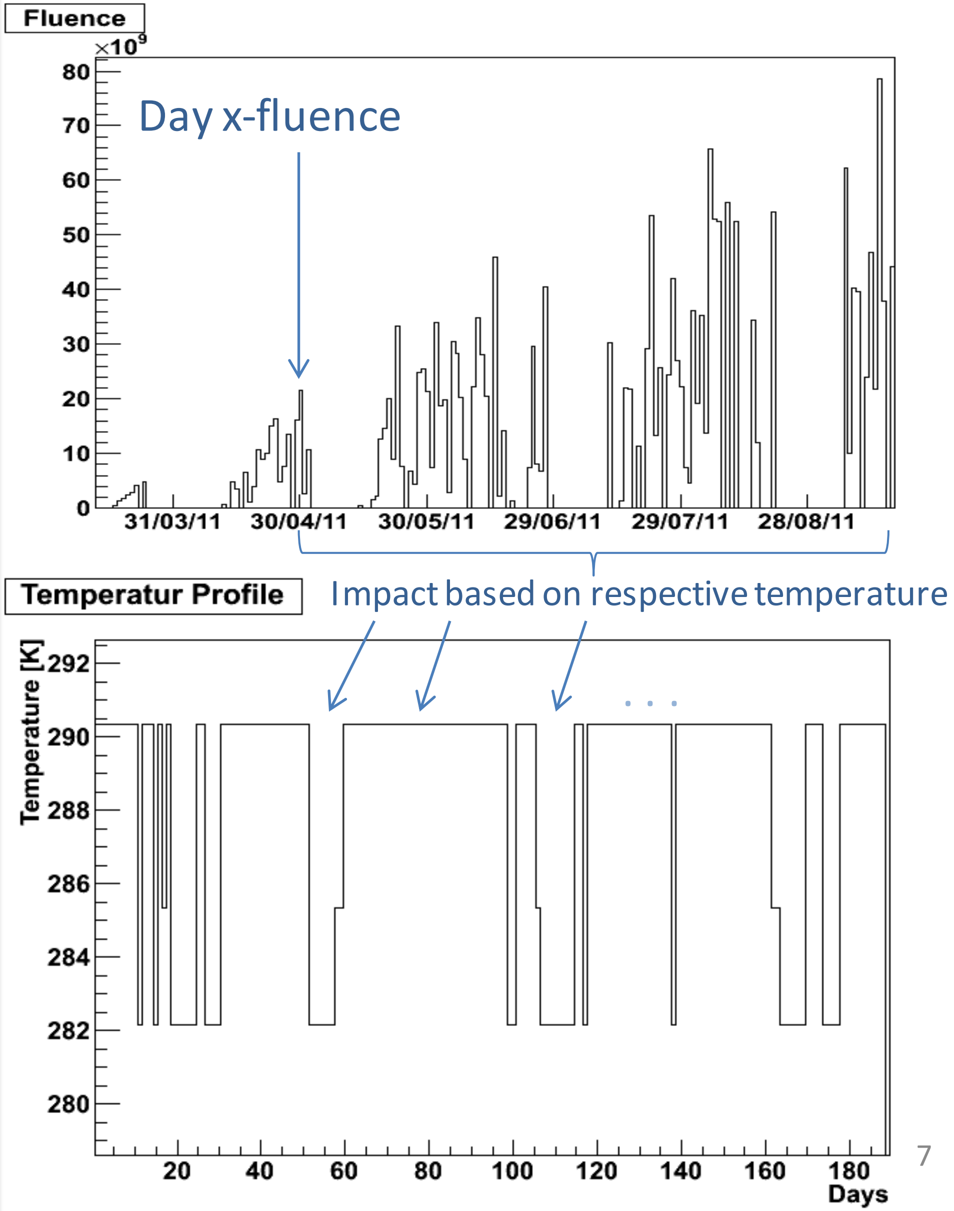
- Fluence at the module position
  - Linear interpolation of Fluka grid values (& integrated luminosity)
- Temperature of the modules
  - Measured by DCU

Method/Tools:

- Histograms filled with one bin per day for the temperatures and fluences
- Afterwards the impact of each day's fluence to all consecutive days is computed with the annealing time constants based on the given temperature at the respective day.
- The integrated sum over all days gives the result

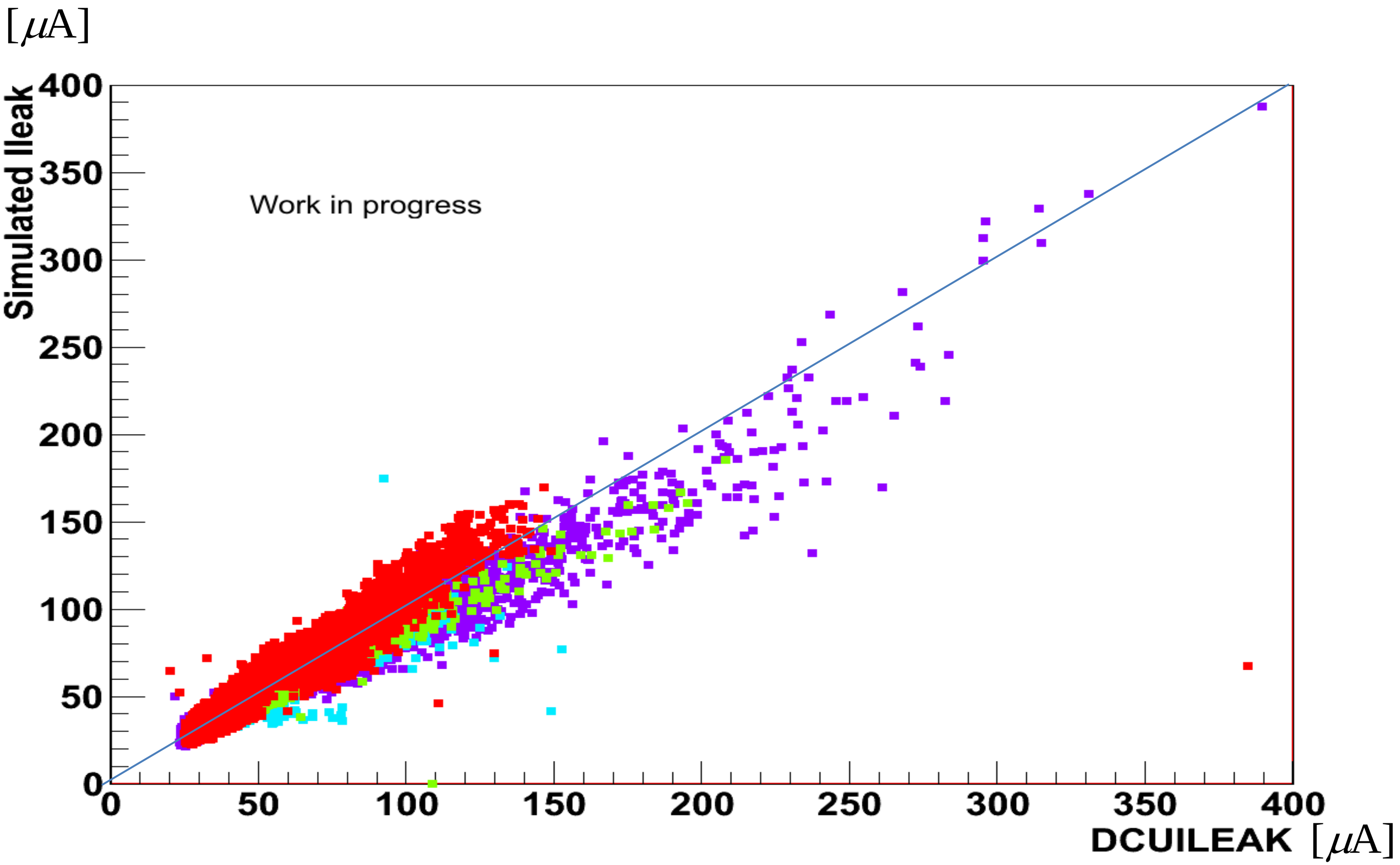
Output

- leakage current
  - Leakage current of modules for comparison
    - Measured by DCU, cross checked by PS values
- Depletion voltage
  - Tools to determine Vdep in-situ exists
    - Changes are still within measurement precision


Day x-fluence

Impact based on respective temperature

Cross Check the Simulations



The correlation plot shows in total a good agreement between simulation and measurement after 5fb^{-1} (red=TEC, green=TOB, teal=TID, purple=TIB)

Depletionvoltage Measurements

CMS currently uses two different measurement types:

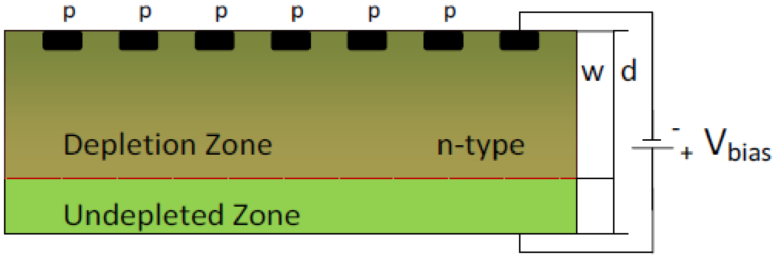
The Noise Scan

- performed during interfill periods

The Signal Scan

- monthly performed for 5 power groups (37 modules out of 15000)
- twice a year for the whole tracker

Principles of the Noise Method



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

$$\begin{aligned} C &= C_0\sqrt{\frac{V_{depl}}{V}} \quad \text{for } V < V_{depl} \\ C &= C_0 \quad \text{for } V \geq V_{depl} \end{aligned}$$

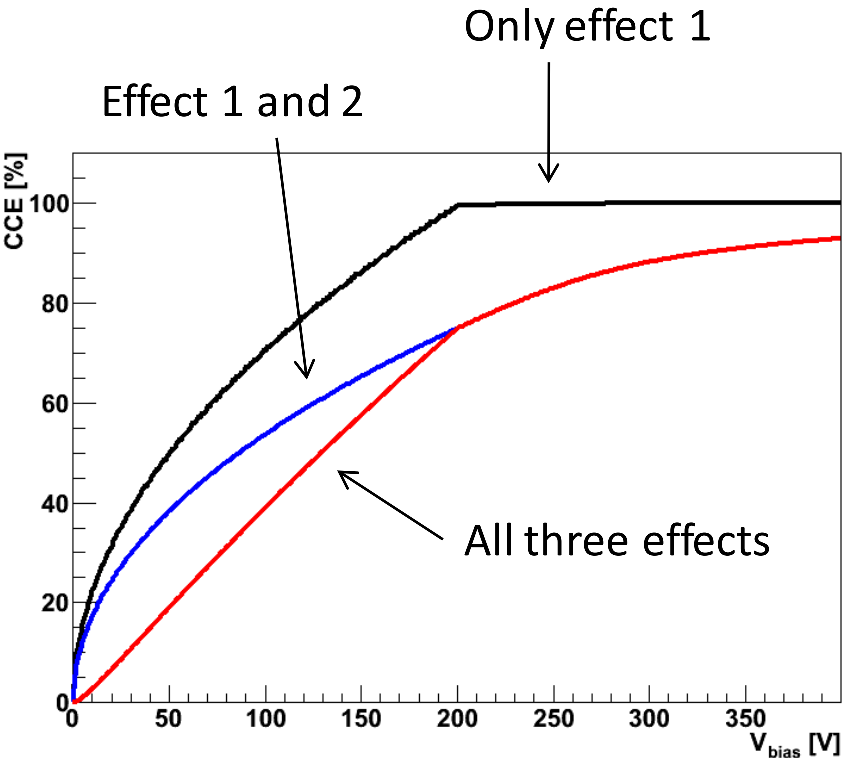
this leads with the readout electronic specific parameters A and B to

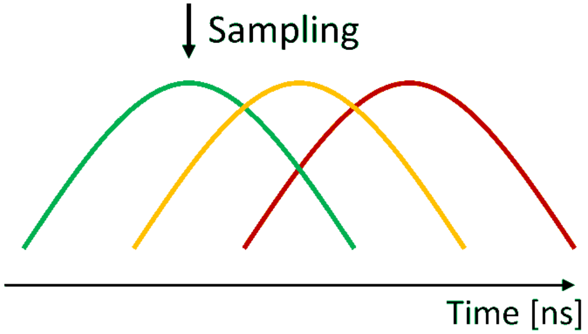
$$n = \sqrt{(A + B \cdot \sqrt{\frac{V_{depl}}{V}})^2 + others^2} \ \text{for } V < V_{depl} \quad ; \quad n = n_0 \quad else$$

The Signal Method

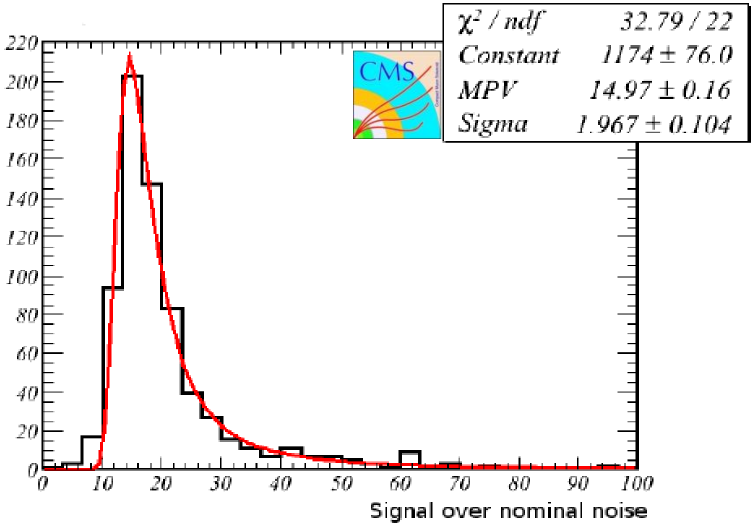
Three effects are taken into account with our model:

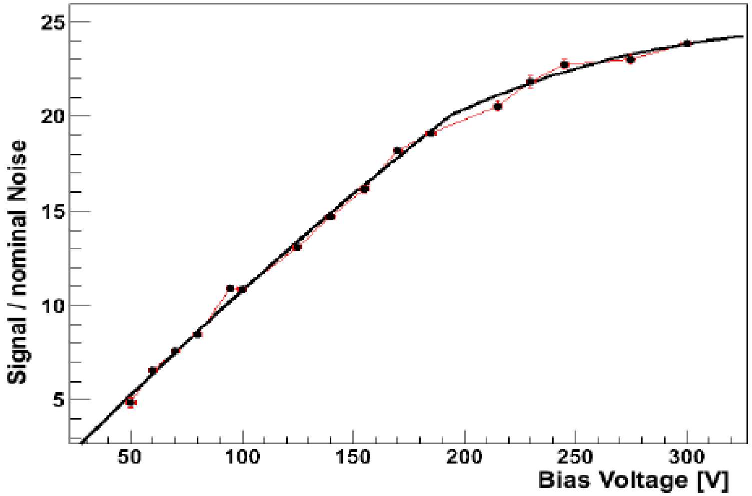
1. Variation of depletion zone width
2. Change in the mobility of charge carriers
3. Change in the load capacitance of the APV leading to a suboptimal sampling





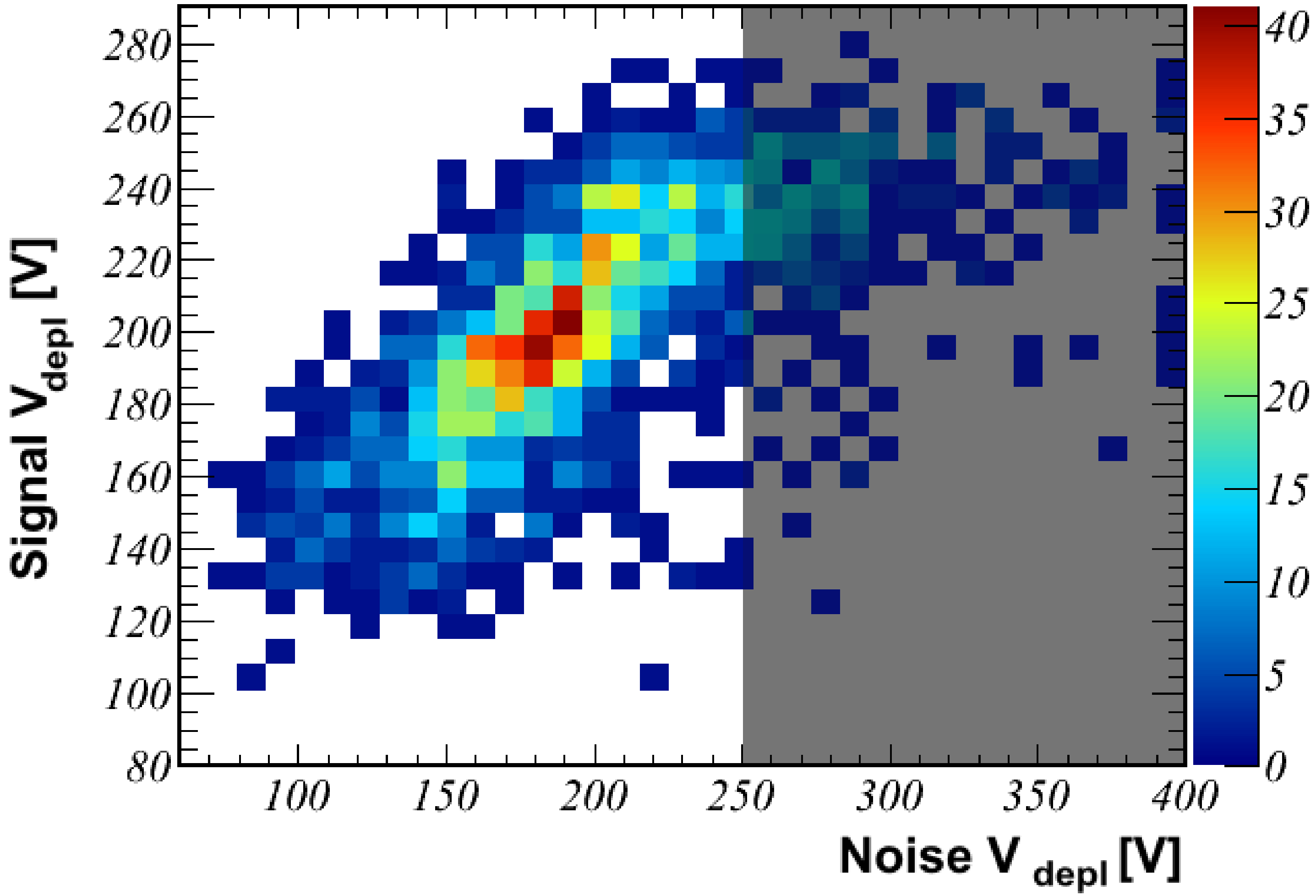
Approach of the Signal Method





- 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

Method Compatibility



Correlation plot between the results of the signal method vs the noise method in the tracker outer barrel partition.

The comparison between noise derived values or signal derived values also match quite well with the original lab (CV) measurements

Depletion Voltage Changes

So far there is no change in depletion voltage visible exceeding the accuracy of the measurement.

From simulation we expect a change up to 5V for the $5 fb^{-1}$ delivered so far.

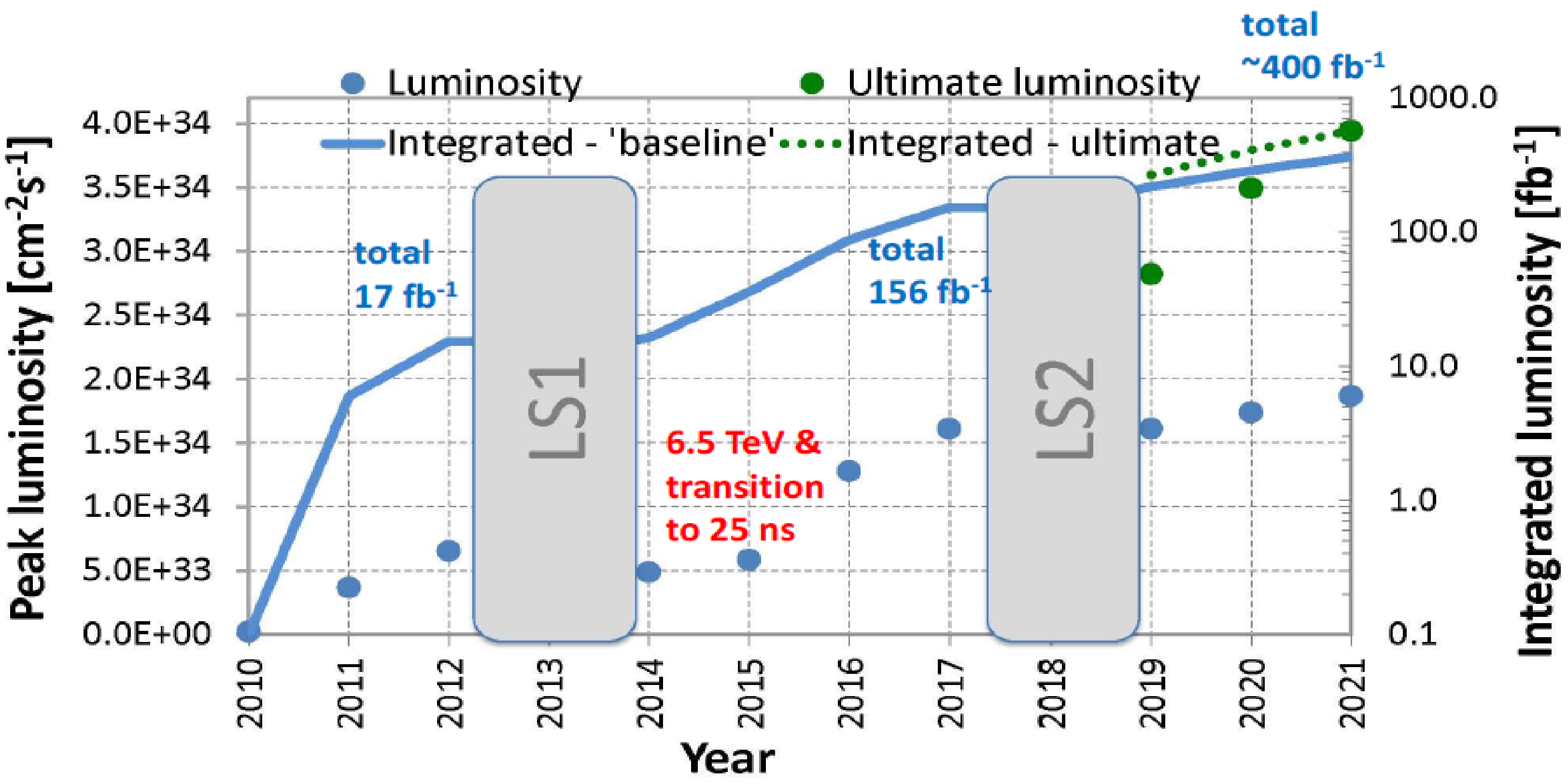
Thus for strips we cannot yet validate the simulation with data.

Assumed Luminosity Profile

Agreed Scenario within the inter-experiment working group

L. Rossi, 16 November 2011

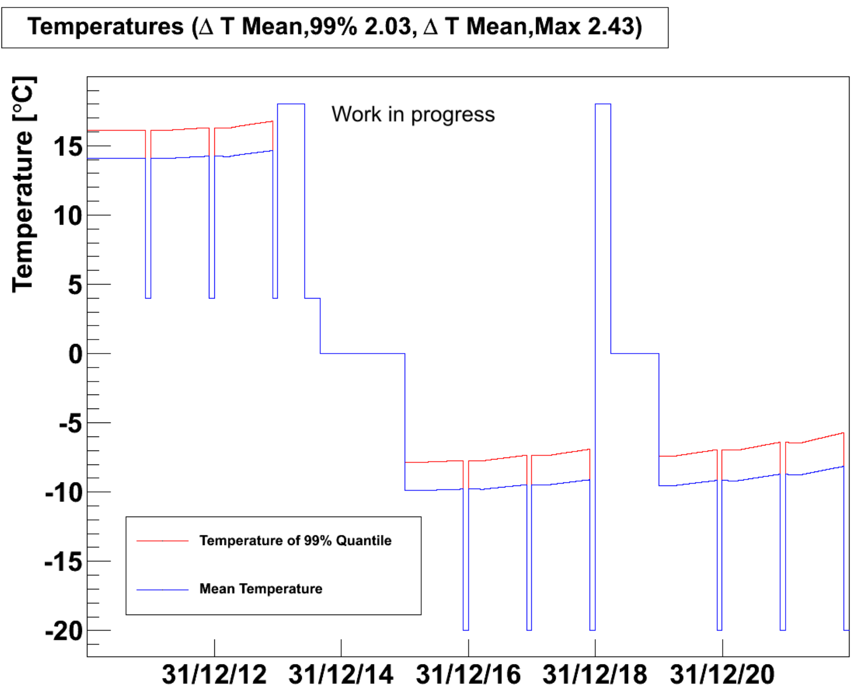
https://indico.cern.ch/getFile.py/access?contribId=1&sessionId=0&resId=1&materialId=slides&confId=150474



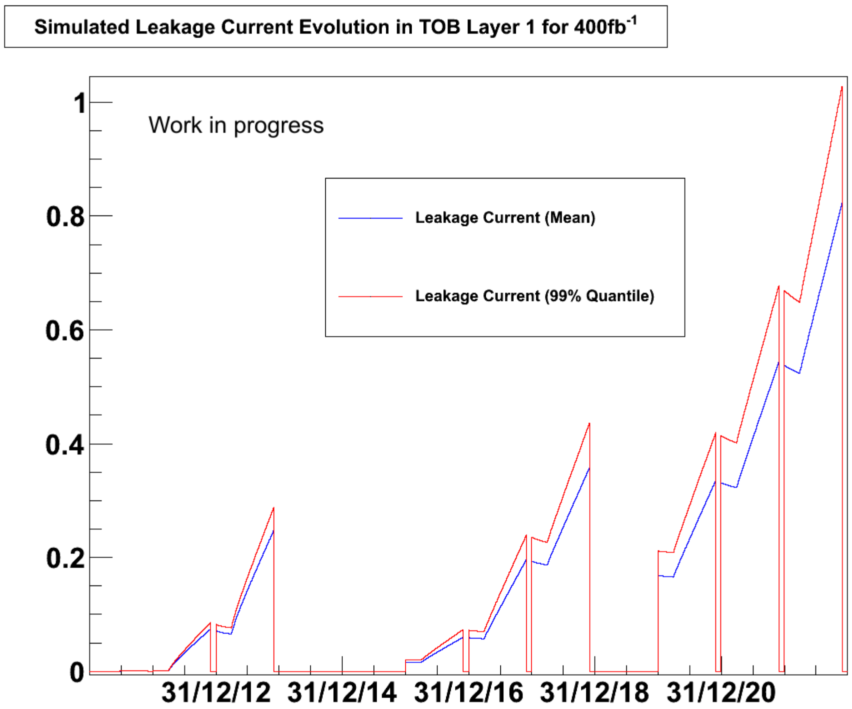
10-year luminosity forecast

modified from O. Brüning, M. Lamont, L. Rossi

Tool to evaluate
Future Evolution of Leakage Currents



Temperatures (Δ T Mean,99% 2.03, Δ T Mean,Max 2.43)

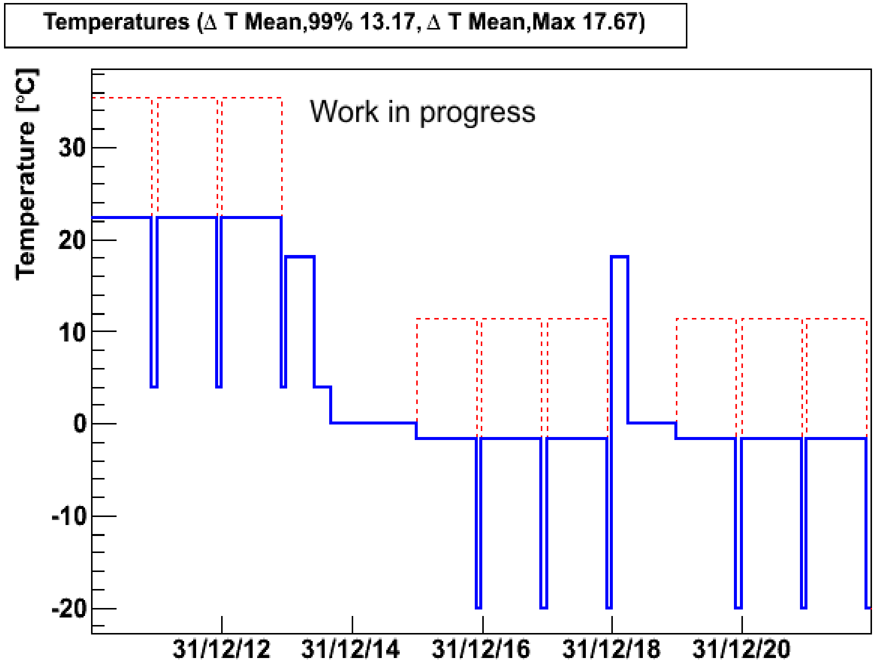


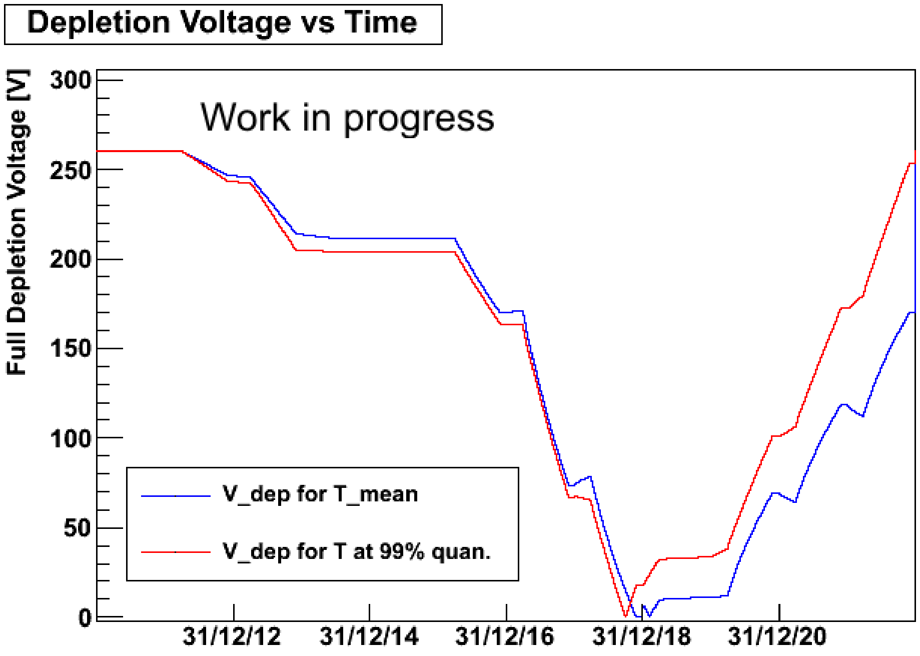
Simulated Leakage Current Evolution in TOB Layer 1 for 400fb^{-1}

We developed a tool to evaluate different temperature scenarios throughout the lifetime of the CMS – understand shut down periods

- The tool example shows the leakage Simulation for Tracker *Outer* Barrel Layer 1 (at around r=58.5cm):
  - One can see the average (blue) and the 99% quantile cases (red)
  - Current is shown for a two sensor module (Si volume: 18.6x9.36x0.05 cm^3)
- The tool also takes the radiation, annealing and also self-heating into account
- We validated the tool with the 5fb^{-1} collected so far -> see slide 8

Tool to evaluate Future Evolution of Depletion Voltage


Temperatures (Δ T Mean,99% 13.17, Δ T Mean,Max 17.67)


Depletion Voltage vs Time

We developed a tool to evaluate different temperature scenarios throughout the lifetime of the CMS – understand shut down periods

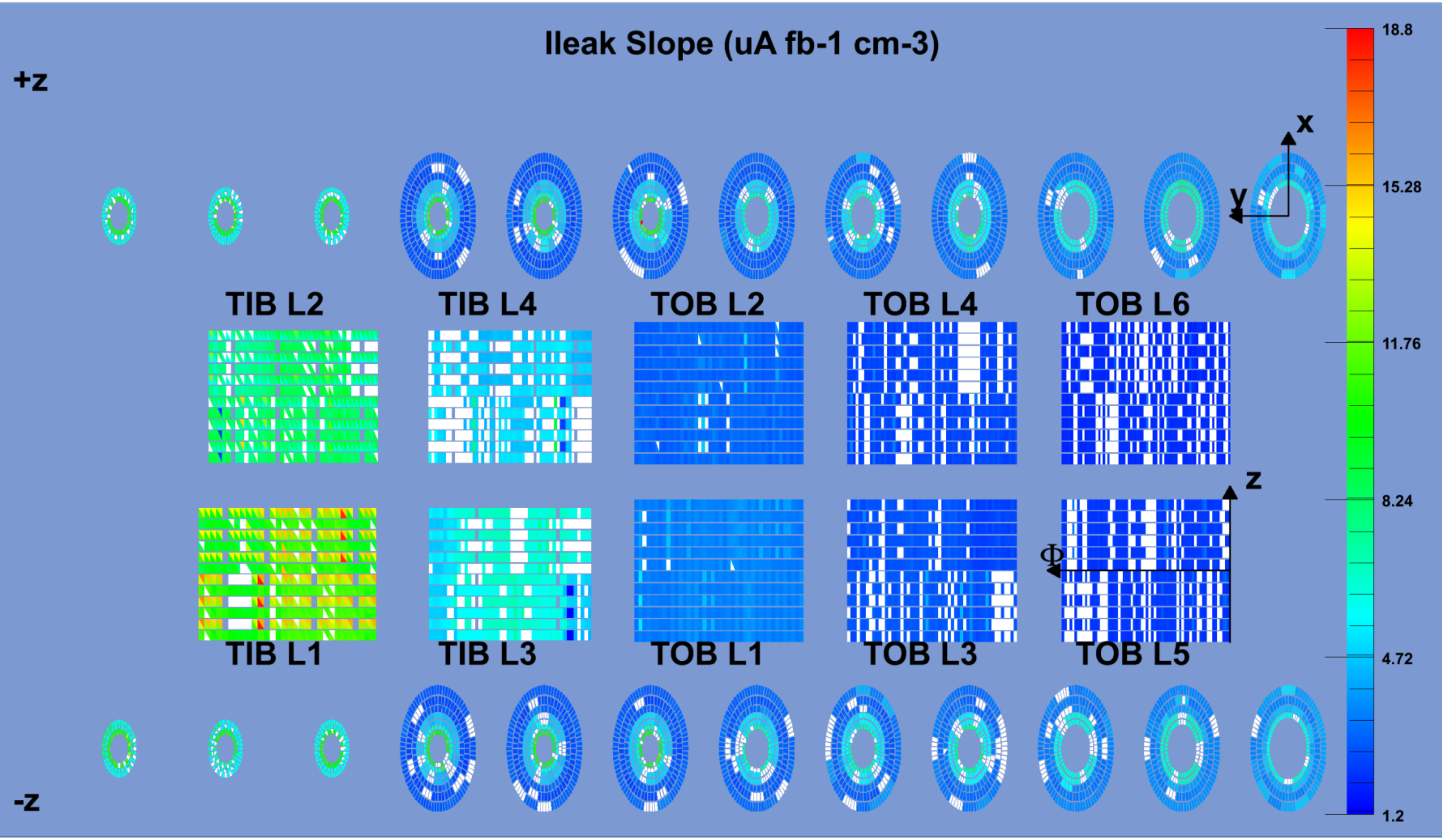
- The tool example shows the Simulation of depletion voltages for Tracker *Inner* Barrel Layer 1 (closest to the interaction at around r=24cm) for the aforementioned scenario:
  - One can see the average (blue) and the 99% quantile cases (red) which lost cooling
- We use CMS specific parameters, derived 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

Summary

- Tools have been developed to simulate leakage current and depletion voltage
  - Radiation damage, annealing, self-heating are taken into account
  - Tool uses historic daily information and the "integrates" on a day-by-day basis
- We validated the tool against the measured leakage currents at 5fb^{-1}
- Work is on-going to validate also with the help of our LHC colleagues – see inter-experiment working group
- We developed tools to determine the depletion voltages in-situ
  - Interfill – Noise vs. bias
  - Stable Beam – Signal vs. bias
  - No comparison with data possible yet

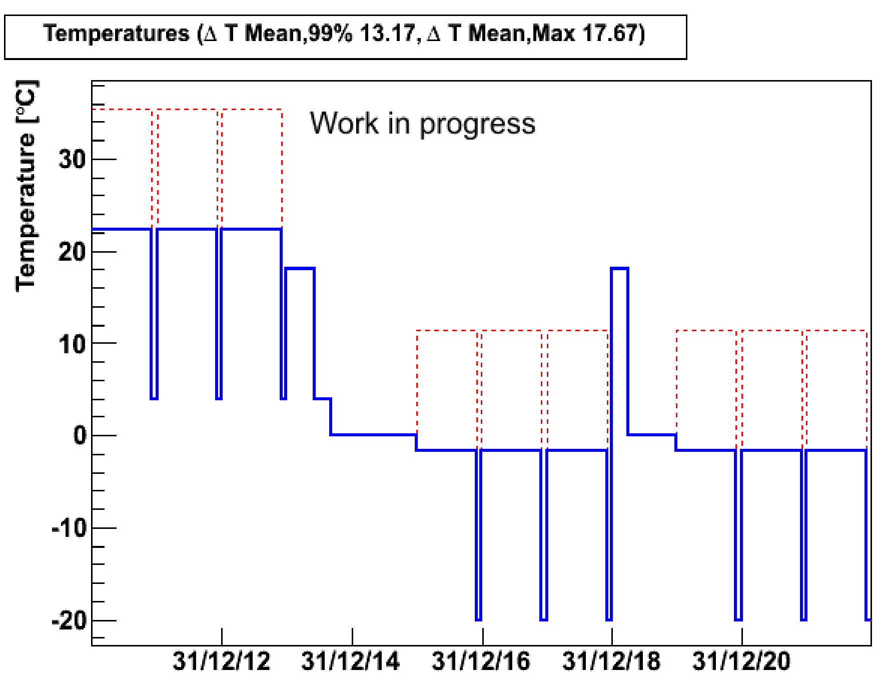
BACKUP

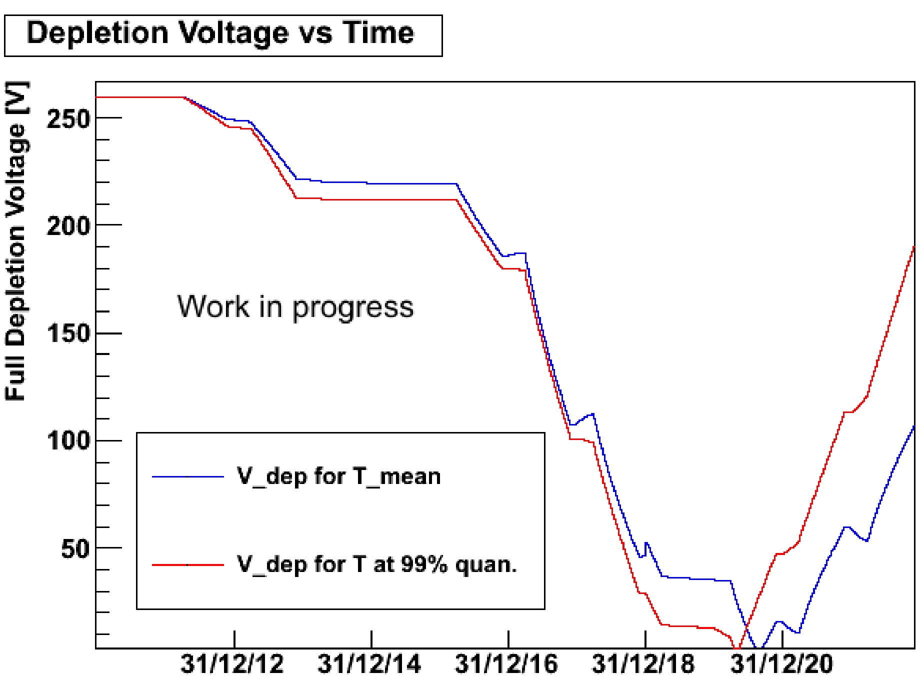
Radial Dependency Tracker Map



Tracker map of the leakage current change per fb^{-1} normalized to 1cm^{3} and to 20°C.
We can clearly see the radial dependency over the different layers.

Future Evolution of Vdepletion


Temperatures (Δ T Mean,99% 13.17, Δ T Mean,Max 17.67)


Depletion Voltage vs Time

Simulation for Tracker Inner Barrel Layer 1 with:

-**High temperatures**

-**High fluence exposure** (nearest to IP at r=24cm)

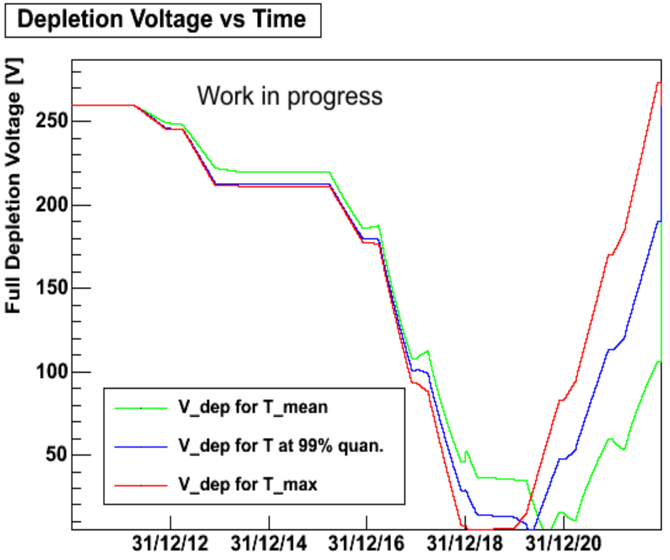
Using the aforementioned scenario with a total luminosity of 400fb^{-1}

Using the model & constants proposed in M. Moll's Ph.D. Thesis chap. 5 (**DESY-THESIS-1999-040**, December 1999, ISSN 1435-8085)

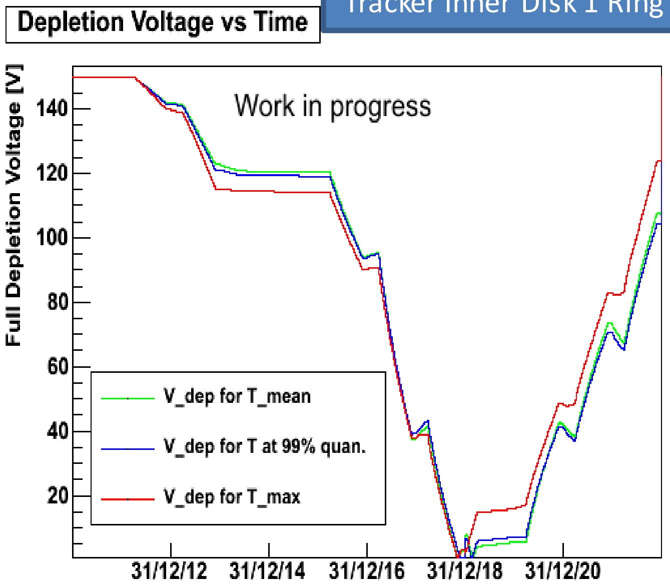
The tracker specific constants used in the plot on slide 16 is presented in A. Dierlamm's Ph.D. Thesis chap. 3 (IEKP-KA/03-23)

Future Evolution of Vdepletion

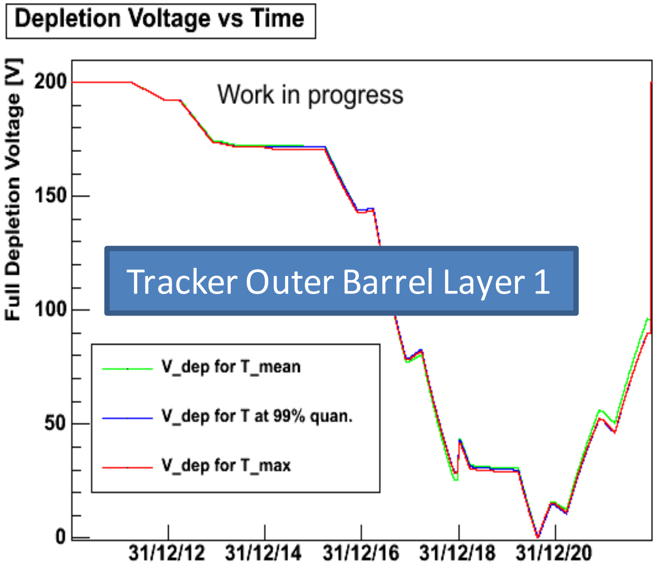
Tracker Inner Barrel Layer 2



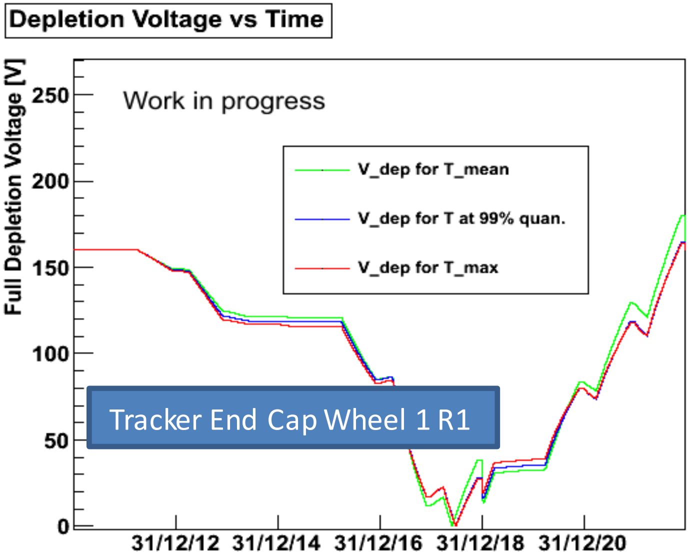
Tracker Inner Disk 1 Ring 1



Tracker Outer Barrel Layer 1

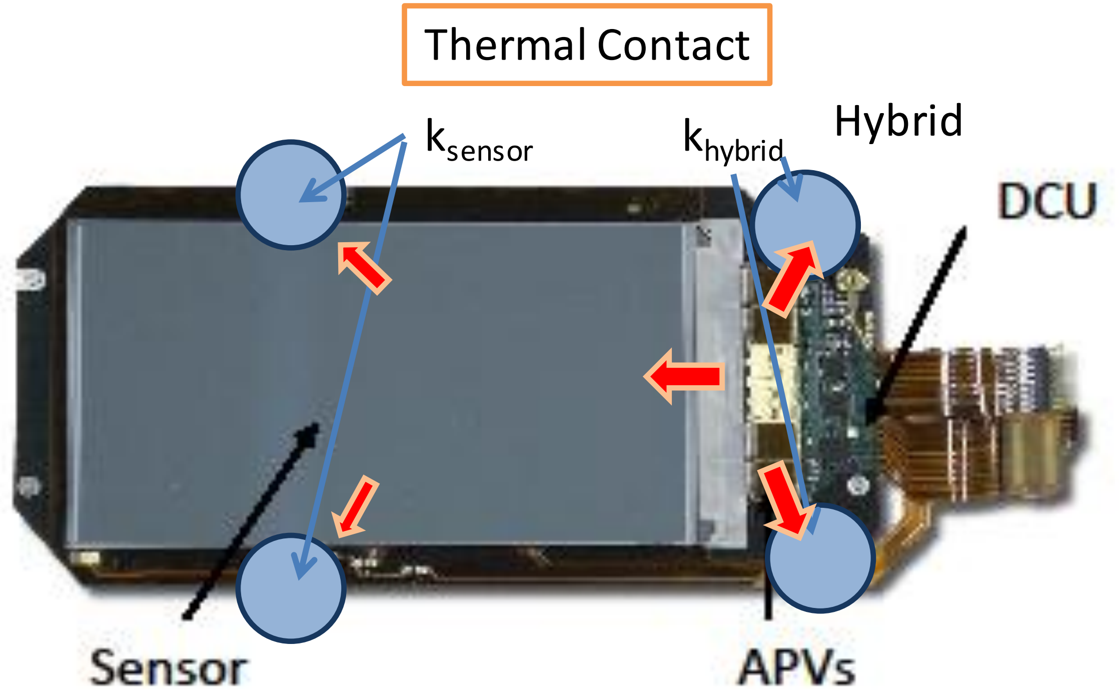


Tracker End Cap Wheel 1 R1



Exemplary selection of full depletion voltage evolutions at different location within the tracker. Computed with the corresponding temperature distributions (not shown here).

Power Scan



TDR

End-cap

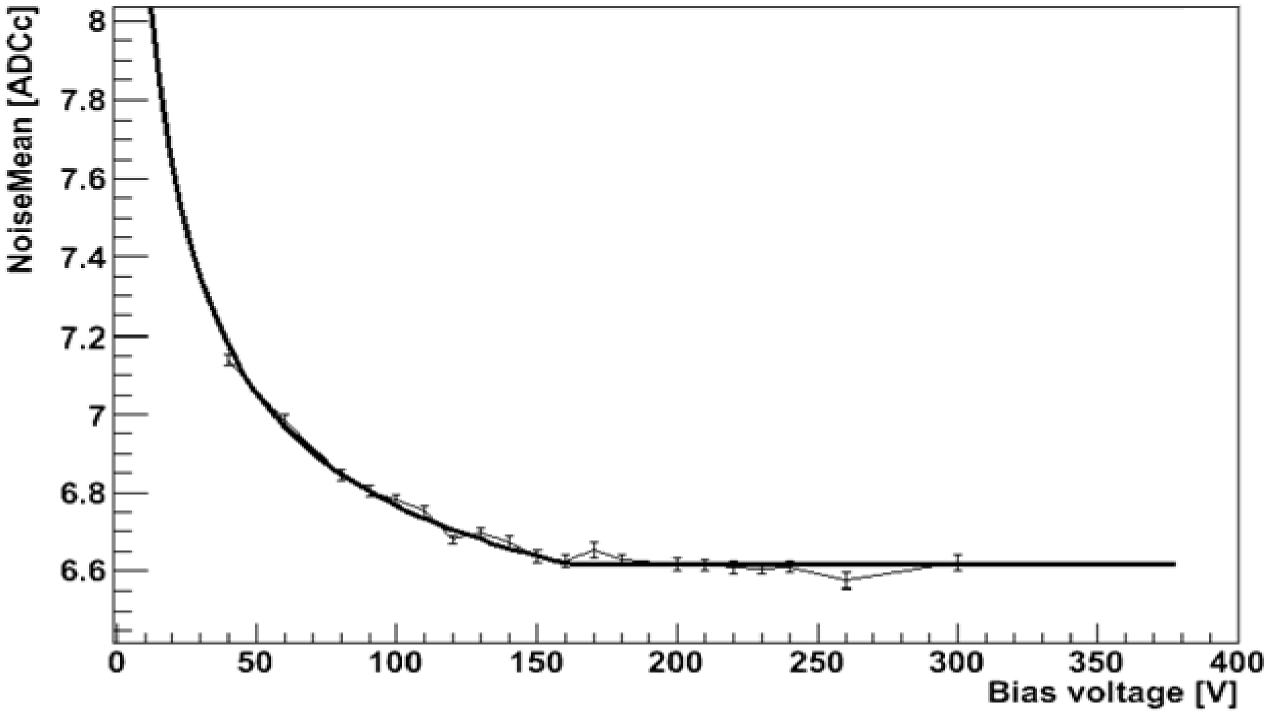
$$T_{Si} = 5.5\,\frac{\mathrm{K}}{\mathrm{W}} \cdot P_{Si} + 2.5\,\frac{\mathrm{K}}{\mathrm{W}} \cdot P_{Hyb} + T_{coolant}.$$

Barrel

$$T_{Si} = 5.7\,\frac{\mathrm{K}}{\mathrm{W}} \cdot P_{Si} + 2.2\,\frac{\mathrm{K}}{\mathrm{W}} \cdot P_{Hyb} + T_{coolant},$$

- Changing the power on the hybrid via VPSP results in a Temperature change on the hybrid
- This dT/dP is taken as an approximation for the dT/dP of the sensor
- FEA is planed to improve the approximation taking also the Tsil into account

Fitting Noise Data



The noise value is fitted with

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

Depletion Voltage Measurements vs Production Measurements