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# Signal-to-Noise Measurements on Irradiated CMS Tracker Detector Modules in an Electron Testbeam

M. Bleyl, P. Schleper, G. Steinbrück, M. Stoye

*Institute of Experimental Physics, Hamburg University, Germany*

M. Dragicevic[a)], J. Hrubec, M. Krammer

*Institute of High Energy Physics, Austrian Academy of Sciences, Vienna, Austria*

M. Frey, F. Hartmann, T. Weiler

*Institute of Experimental Nuclear Physics, Karlsruhe University (TH), Germany*

B. Hegner

*Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany*

**Abstract**

The CMS experiment at the Large Hadron Collider at CERN is in the last phase of its construction. The harsh radiation environment at LHC will put strong demands in radiation hardness to the innermost parts of the detector.

To assess the performance of irradiated microstrip detector modules, a testbeam was conducted at the Testbeam 22 facility of the DESY research center. The primary objective was the signal-to-noise measurement of irradiated CMS Tracker modules to ensure their functionality up to 10 years of LHC operation.

The paper briefly summarises the basic setup at the facility and the hardware and software used to collect and analyse the data. Some interesting subsidiary results are shown, which confirm the expected behaviour of the detector with respect to the signal-to-noise performance over the active detector area and for different electron energies. The main focus of the paper are the results of the signal-to-noise measurements for CMS Tracker Modules which were exposed to different radiation doses.

[a)] Corresponding author.

# 1 Introduction

The testbeam was carried out at the *Deutsches Elektronen SYnchrotron* (DESY) in Hamburg, Germany. The beam provided electrons with energies between 1 to 6 GeV [1].

We studied two types of modules which were designed for the CMS Tracker Outer Barrel (TOB). One type was equipped with so called OB1 silicon strip sensors for the inner layers and the other with OB2 sensors for the outer layers of TOB.

Both sensor types are manufactured by Hamamatsu Photonics. The active area is 93.696 × 91.514 mm$^2$ and the thickness is 500 µm. OB1 sensors provide 768 strips with a pitch of 122 µm while OB2 have 512 strips with a pitch of 183 µm. A more detailed explanation of the sensors can be found in [2].

# 2 Irradiation of Detector Modules

During the operation of the CMS experiment at LHC, the effective doping concentration of a silicon sensor will change with fluence. Therefore, the full depletion voltage will change with the irradiation dose the sensor has already integrated. The p-on-n type detectors used in the CMS Tracker will even experience a type inversion, where the n-type bulk material will change to p-type as illustrated in fig. 1. The figure should only illustrate the basic behaviour while the absolute values are not applicable to the sensors used in the testbeam.

Nevertheless, the detector will be able to work in the inverted configuration as well, but the depletion zone will grow from the backside, which makes it necessary to fully deplete the sensor to read the signal.

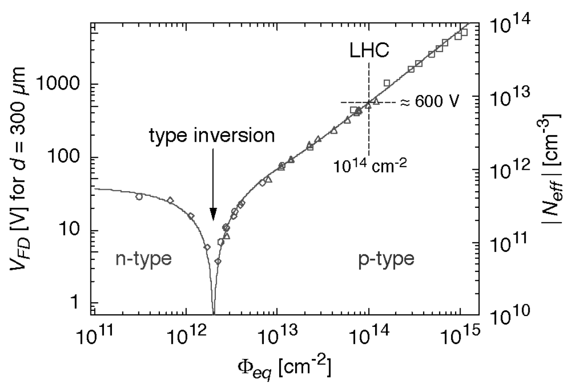



Figure 1: Full depletion voltage ($V_{FD}$) of a silicon p-on-n type sensor (300 µm bulk thickness) as a function of fluence ($\Phi_{eq}$) [3]. The absolute values for $V_{FD}$ and $\Phi_{eq}$ are not applicable to the material used in the tested sensors.

The fluences to which the testbeam modules were exposed, reflect three important stages in the lifetime of the silicon detectors in the CMS experiment (fluences normalised to 1 MeV neutrons per cm$^2$):

- Just before inversion of the sensor ($< 0.2 \times 10^{14}$)
- Shortly after inversion of the sensor ($> 0.2 \times 10^{14}$)
- After 10 years of LHC operation ($\approx 0.65 \times 10^{14}$)

According to [4] the expected irradiation after 10 years of LHC operation is $0.35 \times 10^{14}$ 1 MeV neutrons per cm$^2$ for the Outer Barrel. Keeping in mind a safety factor of at least 1.5, the maximum irradiation applied to the tested modules is comparable to at least 10 years of LHC environment in the TOB.

The modules were irradiated with protons at the Forschungszentrum Karlsruhe. After irradiation the sensors were annealed for 80 min. at 60°C and then stored in a freezer to avoid reverse annealing. As a reference point, unirradiated modules are also included in the plots.

# 3 The Setup

A small box was manufactured to keep the module at the desired humidity and temperature during data taking in the testbeam. The module was mounted inside the box on a copper plate, which was equipped with a cooling pipe.

A commercial cooling plant with temperature control supplied the cooling liquid.

The inside of the box was flushed with nitrogen to keep the relative humidity always well below 30%. Humidity and temperature were monitored by a seperate system.

The box was mounted on a motorised stand, providing X-Y movement on the plane perpendicular to the beam. A scintillator was placed into the beam before and after the module to provide trigger information.

The readout was done with the ARC system, which is primarily a test system for the CMS Tracker detector modules [5]. With some slight modifications to accept external triggers, the ARC Software was capable of writing the raw digitised signals into an ASCII file. Due to restrictions of the system, the trigger rate was very low at about 10 Hz.

A predefined set of parameters for cold operation was loaded into the APV25 readout chip. A dedicated timing run was done for each module to set the appropriate latency and measure at the peak of the signal.

# 4 Analysis Software

The analysis software was specifically written for this testbeam. It was implemented within the ROOT framework [6].

The software is providing a comprehensive output for each single run. The algorithms and cuts used in the software are all well established. We have directly extracted them from the CMS analysis code which was existent at the time of writing the software (beginning of 2005).

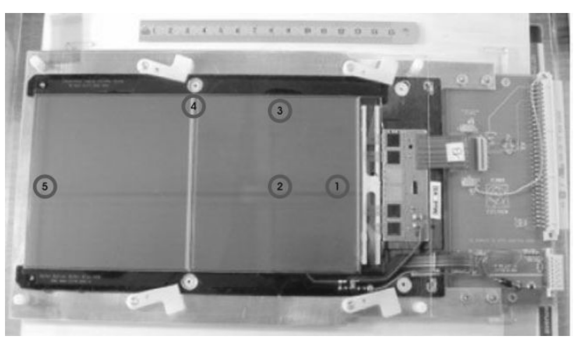
We divided the analysis in three phases. In the first phase, we extracted the pedestals and the raw noise for each channel from the raw data by applying a gaussian fit. We did not use dedicated pedestal runs, but calculated the pedestals directly from the data of the complete run. The parameters determined by the fit are not sensitive to the occasional hit strips. The Common Mode (CM) is calculated for groups of 32 channels. Pedestals and CM are subtracted from the raw signal, before the results are passed to the second phase, the cluster finding.

The cluster finding algorithm can be considered the most crucial part of the software. To accept a valid hit, a seed strip has to accumulate a minimum charge of 3 times the $\sigma$ of the strip noise. The neighbouring strip has to be above 2 times $\sigma$ and the accumulated charge for the whole cluster must be above 5 times $\sigma$. In short, the cuts for Seed/Neighbour/Cluster charge are 3/2/5.

In the final phase, the signal of each cluster is divided by the sum of the common mode subtracted noise of the hit strips. These values are filled into a histogram. The signal-to-noise (S/N) is then extracted from a convoluted Landau and gaussian fit of the histogram. The Most Probable Value (MPV) of the fit is considered to be the Signal-to-Noise (S/N).

# 5 Additional Results

We include two interesting additional results which confirm the expected behaviour of the detectors. Both measurements were performed at -15°C with the APV25 readout chip in deconvolution mode.




| Location | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| S/N | 21 | 21.6 | 21.3 | 20 | 19 |

Figure 2: The table shows the S/N at different locations on the module. (Module 05207, type OB1, measured 450V bias voltage, irradiation: $0.65 \times 10^{14}$ 1 MeV neutron equivalent per cm$^2$).

Changing the position of the beam impact we tested the uniformity of the sensor response as a function of the impact point of the track. In fig. 2 the S/N measured at several different positions on the module is shown. The individual locations are indicated in the picture. The S/N behaviour should be uniform over the active sensor area. Our measurements confirm the expectations, the deviations are negligible due to the intrinsic uncertainties of the readout.

Fig. 3 shows the S/N of modules with different irradiation doses which are exposed to electrons of different energies. The signal created in the silicon sensors should be proportional to the energy loss of the particles. Our measurements confirm the flat response to electrons with energies between 1 and 6 GeV.

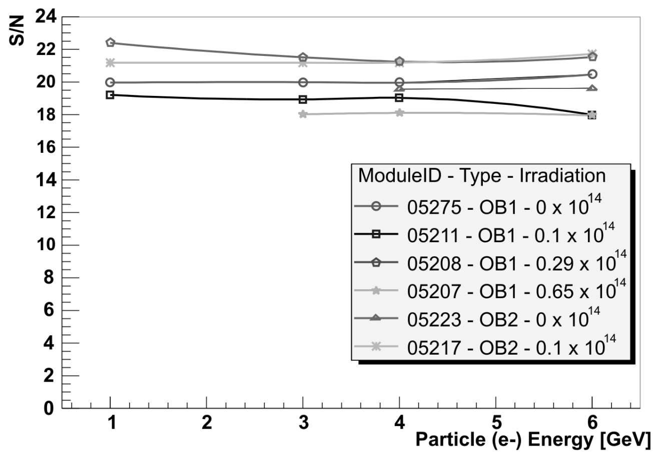



Figure 3: S/N for electrons of different energies measured on modules with OB1 and OB2 sensors. The modules were irradiated with different doses (measured at 450V bias voltage).

# 6 Results

The careful analysis of the testbeam data was lead by the demand to show, that the performance requirements for the silicon detector modules are met even after experiencing 10 years of LHC environment. During this time period, the modules are exposed to radiation and therefore will gather a significant amount of defects in the silicon. The strategies to ensure the radiation hard quality of the sensors were first summarised in [7], while a more elaborate description is found in [2].

To investigate the success of the CMS Tracker community to build radiation hard silicon detectors, we have plotted the S/N over reverse bias voltage for two groups of modules with the same sensor design (OB1 - see fig. 4 and OB2 - see fig. 5). The modules in each of the groups were irradiated with different fluences as described in section 2.

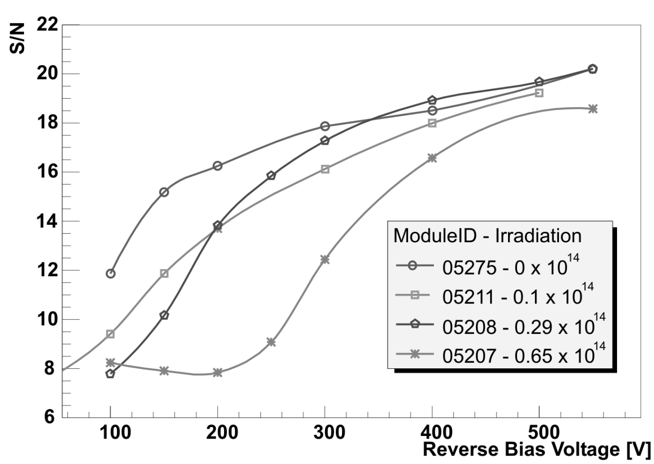



Figure 4: S/N over reverse bias voltage for 4 modules of different irradiation levels with OB1 sensors. The legend shows the module IDs and the integrated fluence in $10^{14}$ 1 MeV neutron equivalents per $cm^2$.

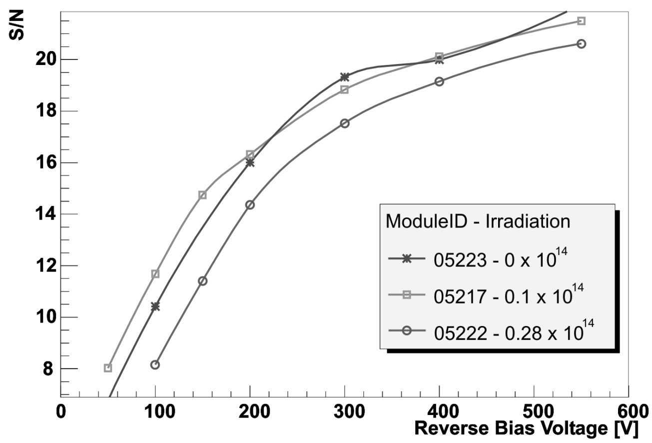



Figure 5: S/N over reverse bias voltage for 3 modules of different irradiation levels with OB2 sensors. The legend shows the module IDs and the integrated fluence in $10^{14}$ 1 MeV neutron equivalents per cm$^2$.

# 7 Conclusion

The detector modules in the TOB are expected to provide a S/N of at least 12 towards the end of the lifetime of the CMS experiment. The measurements presented in this paper show, that the modules measured in the DESY testbeam achieved a S/N above 16 when the reverse bias voltage is set to at least 400 V. This result is well above the design goal for silicon sensors in the Outer Barrel.

# References


[1] Additional information on the Testbeam 22 installation can be found at http://adweb.desy.de/˜testbeam/.

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