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Test-beam studies of diamond sensors for SLHC

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Abstract:

Diamond sensors are studied as an alternative to silicon sensors to withstand the high radiation doses that are expected in future upgrades of the pixel detectors for the SLHC. Diamond pixel sensors are intrinsically radiation hard and are considered as a possible solution for the innermost tracker layers close to the interaction point where current silicon sensors cannot cope with the harsh radiation environment.
An effort to study possible candidates for the upgrades is undergoing using the Fermilab test-beam facility, FTBF, where diamonds and 3D silicon sensors have been studied. Using a CMS pixel-based telescope built and installed at the FTBF, we are studying charge collection efficiencies for un-irradiated and irradiated devices bump-bonded to the CMS PSI46 pixel readout chip. A description of the test-beam effort and preliminary results on diamond sensors will be presented.

Key words: Tracking detectors, Diamond detectors, Solid state detectors, Test-beam

1. Introduction*

The innermost tracking device of the CMS general purpose detector [1] at the Large Hadron Collider (LHC) at CERN, consists of three Barrel layers and four Forward disks whose basic building blocks are highly segmented silicon sensors (pixels) tightly coupled with their corresponding PSI46V2 [2] readout chips (ROC*s*). The high radiation doses that these devices will have to withstand after the future LHC upgrades is so high that the currently installed planar silicon sensors will be damaged too quickly to be a practical solution. In order to increase the radiation hardness of pixel detectors different strategies are being pursued and test-beam around the world are conducted to make sure that the performances of these sensors, after a heavy irradiation comparable to the doses that are envisioned at the SLHC, can still guarantee tracking capabilities to meet the physics goals. An effort to study possible candidates for the upgrades is undergoing at the Fermilab test-beam facility, FTBF, where diamonds and 3D silicon sensors are being studied. In this paper we'll focus our attention to the description of the test-beam architecture and to some preliminary results on diamond sensors.

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2. Experimental setup

The beam-tests were performed in 2012 at the FTBF with a 120 GeV/c protons beam incident on an 8 planes pixel-detector telescope. This telescope consists of 8 modules leftover from the CMS Forward pixel detector production [2]. They are based on the PSI46v2 Read Out Chip (ROC) [3] , with 150 µm × 100 µm pixel size, arranged in two sections, with two Detectors Under Test (DUTs) placed between the two telescope stations. Enhanced resolution is derived from charge sharing by tilting the telescope planes at 25º. The telescope resolution on the DUTs is as small as 6 µm both in X (150 µm) and Y (100 µm) coordinates.
The Data Acquisition (DAQ) hardware is based on the CAPTAN system [4] , developed at Fermilab, which uses a gigabit Ethernet link to transfer the data from the experimental area to the DAQ computer where data are stored. The software, also developed at Fermilab, runs on a Windows PC and is a suite of multithreaded applications written in C++. A Data Quality Monitor runs in parallel, while data are acquired to provide immediate feedback to spot any problem in real time.

3. Offline analysis

In order to achieve the necessary resolution on the DUTs to allow for detailed studies on resolution and charge sharing, careful attention needs to be given to the alignment of the telescope and DUTs detectors in the beam. A dedicated software, called Monicelli, has been developed at the University of Milano Bicocca which achieves a track resolution on the DUTs as small as 6 µm. Tracks are saved in ROOT format to be later analyzed by another program, called Chewie; the results of that analysis are discussed below.

We'll focus our attention on the preliminary results of efficiency and charge collection for two diamond detectors, both 500 µm thick but with different crystal structure: mono and poly crystalline.

4. Charge collection

The charge collected in the two detectors varies greatly due to the intrinsic nature of the two crystalline structures. The mono-crystal has a charge collection distance (CCD) greater than 500 µm and the charge collected is thus around 20000 e^- while the poly-crystal with its 172 µm CCD only collects about 3400 e^- as the Landau charge profiles show in Figure 1.

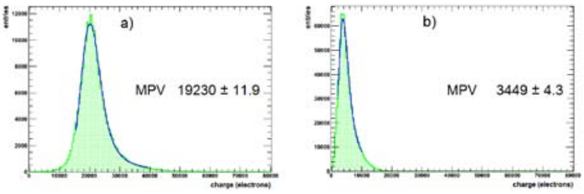

Figure 1: *a) Charge collected in the mono-crystal with most probable value (MPV) around 20000 e^- while b) is the charge collected in the poly-crystal with MPV value around 3400 e^-.*

In Figure 2 instead we show the charge distribution in the 150 µm × 100 µm pixel cell for the two detectors. In these sensors the charge drifts along the thickness of the detector allowing the charge cloud to diffuse across pixels. Figure 2 shows that significant charge sharing is observed at 20 µm where the charge collected by the pixel cell is lower than the charge collected at the center. This effect is more evident in Fig 3 where the charge collected at the corners of 4 pixel cells is plotted.

Both mono and poly crystals show similar diffusion properties with a cloud extending for 20-25 µm with a slightly greater diffusion cloud in the poly-crystal.

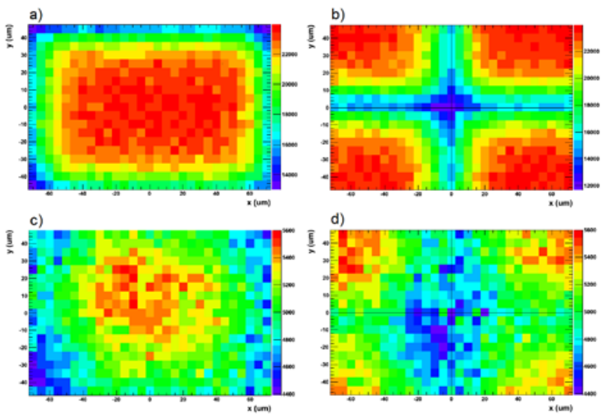

Figure 2: *Plots a) and c) show the mean charge collected as a function of the coordinates of the telescope predicted track impact point on a single pixel cell for the mono and poly crystals respectively. Plots b) and d) show the mean charge collected as a function of the coordinates of the track impact point centered at the corner between four adjacent pixels for the mono and poly crystals respectively.*

5. Efficiency

Efficiency measurements are strongly biased by the fact that the amount of charge collected in the poly-crystal is just above the minimum threshold of about 2400 e^- that we could apply to the ROC. Figure 3 shows the almost perfect efficiency for the mono-crystal that reaches 99.8% and, on the other hand, the low efficiency, due to threshold settings, of the poly-crystal that is only around 65%. The two types of data points refer to the sole efficiency of the pixel pointed by the track (green points) and the combined efficiency of the two adjacent pixels (blue points). While the combined efficiency, for the mono-crystal, is constant and does not show any appreciable degradation even in the region between pixels, for the poly-crystal instead there is a further decrease in efficiency due to the fact that the charge is split between two pixels thus increasing the probability to be under threshold.

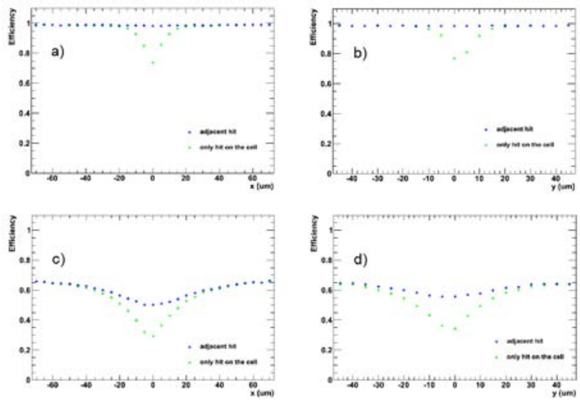

Figure 3: *The green points show the detection efficiency of the sole pixel pointed by the track as a function of the distance of the track impact point from the boundary of the two adjacent pixels while the blue points show the combined efficiency of the pixel pointed by the track and the adjacent one on the same column, histograms a) for the mono-crystal, and c) for the poly-crystal, or on the same row, histograms b) for the mono-crystal and d) for the poly-crystal.*

Conclusions

Preliminary results on two different, un-irradiated diamond sensors tested extensively in a beam-test at Fermilab have been shown in this paper. The purity of the mono-crystal detector allows for a much higher charge collection distance that results in the collection of a much higher quantity of charge and thus showing very high detection efficiency (99.8%). On the other hand, instead, the impurities in the poly-crystalline structure of the other diamond detector limit the amount of charge collected and thus results in poor efficiencies (65%) since the ROC cannot be set at a threshold far away from the Landau peak of this type of detector. Both diamonds show similar charge diffusion properties though.

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