Charge collection with binary readout

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Abstract

Some aspects of charge collection in the binary readout scheme are discussed in the light of beam test results of recent SCT prototypes.

1 Introduction

On its passage through the Silicon a minimum ionizing particle deposits charge. To first order, the distribution of deposited charge is described by a Landau distribution, see figure 5. The most probable charge for 180 GeV pions perpendicularly incident on a 285 micron Silicon wafer is approximately 3.5 fC [1] . The corresponding median charge is ~ 3.8 fC. This theoretical picture is distorted by charge deposition effects like delta electrons, but also by the details of the charge collection in the detector and Front-End electronics.

Beam tests of prototype modules have yielded a wealth of information in recent years, written up in [1–6] and the barrel and forward module Technical Design Reports. Measurements on non-irradiated barrel and forward modules yield a median collected charge 0f 3.4 ± 0.1 fC. This note discusses a few possible causes for the 0.4 fC that is apparently not collected.

We try to summarize what we think we know and to identify what we do not know with regards to charge collection with binary readout.

[1] The calculation of this number is actually rather simplified. It only takes into account ionization and assumes all holes are collected.

2 Charge sharing

Cross talk between channels is thought to be dominated by capacitive coupling between adjacent strips in the detector. The inter-strip and strip-to-backplane capacitance have been measured, finding values of $\sim$ 1 pF/cm and 1.3/768 nF, respectively. The design value of the coupling capacitor to the Front End electronics is larger than 20 pF/cm. From figure 1 one can estimate the fraction

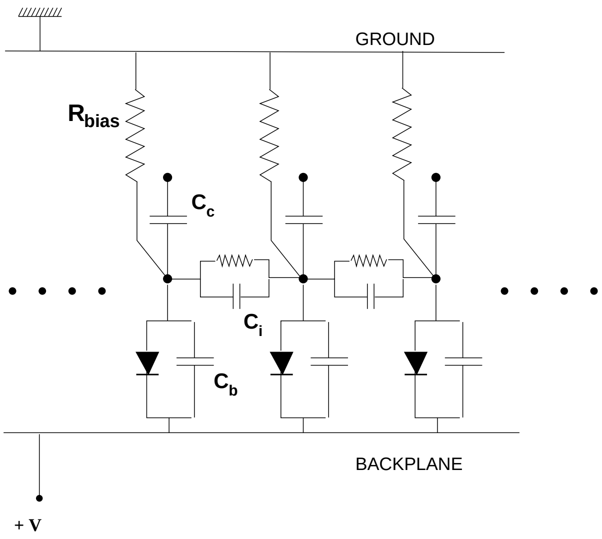


Fig. 1. Equivalent diagram of three strips with their capacitive connections to the Front-End electronics, the neighbouring strips and the backplane.

of the signal that is amplified. Ignoring the impedance of the amplifier and assuming the capacitor on the hybrid that joins the detector backplane and HV ground is sufficiently large we obtain

$$I_{amp} = \frac{I_s C_c}{C_c + C_i + C_b} \tag{1}$$

Using values for the coupling, interstrip and strip-to-backplane capacitances of $C_c = 120$ pF, $C_i = 6$ pF and $C_b = 1.7$ pF we find the charge loss due to cross talk is of the order of 6%.

The effects of charge sharing have been studied in some detail in beam test of prototype modules, see for example [1,**?**]. For perpendicularly incident particles, its effect is limited to a rather small region exactly between two readout strips. Only when particles are incident at an angle this effect becomes important over a larger region.

The amount of leakage of charge to adjacent strips is best characterised by the average size of signal clusters. Clusters with signal over threshold in more than one channels are rather rare (of the order of 5 %) at the operating threshold (1 fC), but the fraction of course grows strongly when the threshold is lowered. Measurements of cluster sizes in the beam test have been reported routinely.

The fact that the charge sharing is limited spatially can be used to try to disentangle its effect from the cross talk. In the test beam, tracks are reconstructed using a beam telescope made up of Silicon strip detectors with analog readout. The tracks can be projected on the DUT with high precision (better than 5 micron). The table below lists the signal cluster sizes and median charges for two cases:

- in the first analysis all tracks are accepted, ie the position of the track with respect to the two nearest strips is uniformly distributed
- the second analysis only accepts those tracks that project onto a region of $\pm$ 20 microns around the strip. The effect of charge sharing is expected to be small in the remaining events.

	All tracks		On-strip tracks	
	median charge	cluster size	median charge	cluster size
Forward	3.30	1.17	3.43	1.05
Irrad. Forward	2.43	1.12	2.59	1.07
Barrel	3.29	1.08	3.42	1.03
Irrad. Barrel	3.13	1.12	3.29	1.05

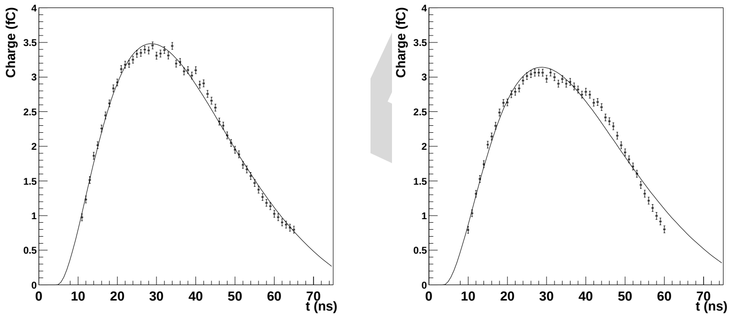
Table 1
The median charge and cluster size at 1 fC measured on non-irradiated and irradiated modules of barrel and outer forward geometry. Of each type, one or two modules were present. The detector bias voltage is 150 Volts for the non-irradiated modules and $\sim$ 330 Volts for the irradiated modules. Perpendicular incidence.

The cluster sizes are reduced rather effectively by the cut on the track position. Some two-strip clusters remain after excluding the charge sharing region, these are probably due to cross-talk. On the total collected charge, however, the cut has only a very small effect. For all module types, the charge difference is 0.13-0.16 fC. Data at different bias voltages show the expected decrease of the difference with increasing detector bias.

3 Timing effects

The Front End of the SCT modules is very fast in order to cope with the high bunch crossing rate in the LHC. This brings about the necessity to control the timing of the readout at the level of nanoseconds. In the beam test this is achieved by measuring the delay between the scintillator trigger and the next rising edge of the clock. Offline, the optimum time window is selected for each module. The width of this window is set to 10 ns, balancing the loss of statistics and the error introduced by the smearing of the timing.

An alternative approach uses the full time and hit information to explicitly reconstruct the charge vs time dependence. Figure 2 shows an example of the pulse shape thus reconstructed for a non-irradiated and irradiated barrel module. The data points are fit with the design transfer function of the ABCD chips [1].



(a) (b)

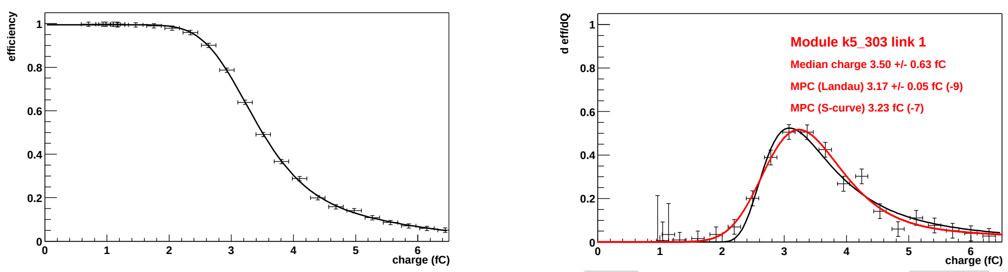
Fig. 2. Reconstructed pulse shape for a non-irradiated *(a)* and irradiatead *(b)* barrel module

The charge measured in the beam test corresponds to the average over the pulse shape in a 10 ns interval around the peak. The error introduced by this procedure is estimated to be less than 0.1 fC. This estimate is confirmed by charge measurements in a beam with an LHC-like time structure [2].

4 Median versus Most Probable charge

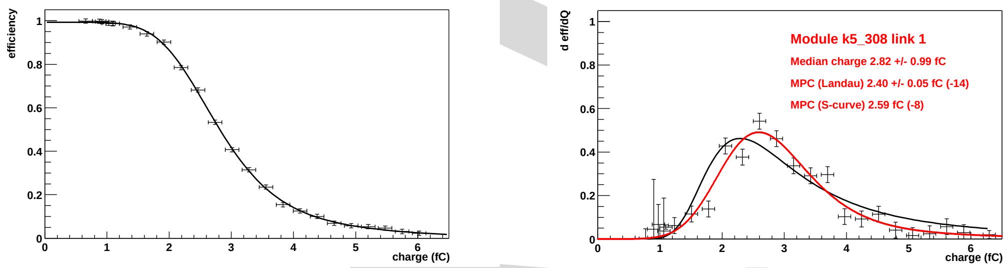
With binary readout the charge that is most easily measured is the median of the distribution, whereas with analog electronics the most probable charge is a more natural choice. The relation between both charges depends on the details of the distribution, which is affected by charge losses to adjacent strips.

Figures 3(a) and 4(a) show the S-curve - efficiency versus discriminating threshold - for a non-irradiated and irradiated module. The points with error bars represent the efficiency measurements at different threshold in the beam test. The continuous line is a fit with a skewed error function. The derivatives of the S-curves in figures 3(b) and 4(b) give an idea of the charge distribution in both types of modules. The points with error bars correspond to the difference of two consecutive measured data points divided by their charge



(a) (b)

Fig. 3. S-curve for a non-irradiated K5 module *(a)* and the numerical derivative *(b)*



(a) (b)

Fig. 4. S-curve for a non-irradiated K5 module *(a)* and the numerical derivative *(b)*

distance. Two curves are drawn in the same figure: the red curve is the numerical derivative of the skewed error function, the black curve is a fit of a Landau distribution to the data points. The most probable charge, found as the peak of the Landau fit, is smaller than the median charge, from the fit to the S-curve, by 8-15 %.

For the purpose of comparison the charge distribution of one of the telescope modules in the test beam is shown in figure 5. The fit with a Landau distribution fits rather nicely in this case.

5 Absolute calibration

The absolute calibration is a long-standing issue in the interpretation of the beam test results. The calibration circuit produces a voltage step that is applied to a capacitor at the input of the amplifier. The calibration capacitors vary slightly depending on the processing of the batch of chips. Therefore, on each wafer test structures of oxide layers are measured. The calibration of the chips corresponding to that wafer is corrected according to the results of these

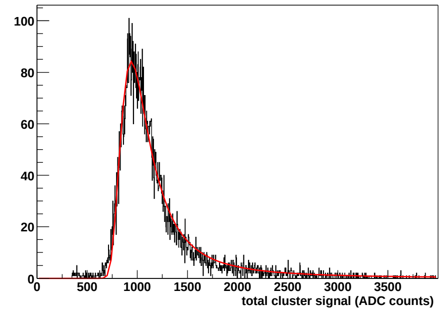


Fig. 5. Measured charge distribution of a 50 μm pitch microstrip detector with analog readout. The signal on adjacent strips has been recovered using a rudimentary clustering algorithm.

measurements.

Measurements of the stability of the calibration DACs under temperature variations were presented in reference [7]. Small variations with temperature were found. More importantly, after irradiation the spread in the observed DAC steps between chips is double that before irradiation.

The variation of the calibration from one chip to the next was evaluated in the May and July beam test by pointing the beam to areas of the detector read out by different chips and measuring the median charge of each chip separately. For non-irradiated modules the spread was measured to be of the order of 0.1 fC (around 4%). After irradiation the spread increased to about 0.2 fC, corresponding to nearly 10%. Correcting the charges by the DAC step measurements mentioned before improves the uniformity, suggesting that the spread in median charges is due to variations in the components of the calibration circuit. In practice, the signal-to-noise ratio, dividing the median charge by the equivalent noise charge, is used.

6 Conclusions

A number of effects have been discussed that are related to the “gap” that is observed between the predicted median charge and the measurements in the test beam. A number of them have been found to cause a very small loss. Examples of these are timing effects and charge sharing, both responsible for a loss of the order of 0.1-0.2 fC.

Cross talk due to the inter-strip capacitance is expected to be responsable for a charge loss of the order of 6 % (0.23 fC). Two-strip clusters that cannot (easily) be attributed to charge sharing in the silicon have been observed.

The absolute calibration remains a source of uncertainty.

References

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