Study on the crosstalk sources of the Hermes Silicon Recoil Detector at DESY

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In summer of 2005 the Hermes *collaboration will install the Recoil Detector in the* Hera *ring with the aim of improving the detection of low momentum protons from hard exclusive reactions. Some studies are currently being conducted in order to test the silicon modules for the Silicon Detector. Since the presence of crosstalk in the measurements is a known fact, a detailed study of its sources is presented here. Some results for the existent crosstalk in all the sensors of one module are given, as well as an explanation of its possible causes.*

1 Introduction

1.1 The Hermes *experiment at DESY*

Since 1995, the Hermes experiment has been in operation, its main goal being the experimental investigation of the spin structure of the nucleon by polarised deep-inelastic scattering. For this purpose, the 27.5 GeV electron-positron beam of the Hera accelarator is used, in combination with polarised gas targets of hydrogen, deuterium or helium. Hermes also has a programme of measurements in unpolarised targets.

With the Hermes Spectrometer important contributions to the study of the nucleon spin structure through semi-inclusive measurements have been made. The next challenge, however, is the study of Generalized Parton Distributions (GPD's) in hard exclusive reactions, such as the Deeply Virtual Compton Scattering (DVCS). In order to detect the recoiling protons from DVCS and other exclusive reactions, a recoil detector is required, surrounding the target cell. Measurements from the new recoil detector will reduce the non-exclusive background while improving the transverse momentum resolution [1]. The commissioning of the Hermes recoil detector is foreseen for 2005.

1.2 The Recoil Detector

The Hermes Recoil Detector, schematically shown in figure 1, will consist of three parts: a silicon detector, a scintillating fibre tracker in a magnetic field of about 1 Tesla and a photon detector consisting of three layers of tungsten radiators and scintillators. The electron beam enters through the collimator. The detector will allow the identification of the recoiling particles, as well as their momentum determination. This paper concentrates solely on the silicon detector.

The innermost layer of this system is the silicon detector, which will be set up inside the Hera vacuum to enable the detection of low momentum protons from exclusive reactions at large laboratory angles. Recoiling protons are expected with momenta from 1400 MeV/c down to 135 MeV/c, covering an angular range of $0.4 < \theta < 1.35$ rad. The momentum of fast particles will be determined by their bending in the magnetic field, while the photon detector will be used for particle identification of high momentum particles and for background rejection of neutral particles [2].

The silicon detector is shown in detail in figure 2. The target containing the polarised gas cell is visible in the centre, surrounded by the eight double-sided silicon strip modules. They are placed in two layers around the target, in a diamond shaped configuration with an azimuthal coverage of about 76% [3].

The readout electronics are placed on an aluminium heat-sink close to the entrance of the electron beam. These hybrid devices will be operating in the beampipe vacuum, close beside the Tigre sensors, and thus need to be connected to the water cooling pipes. As it is shown

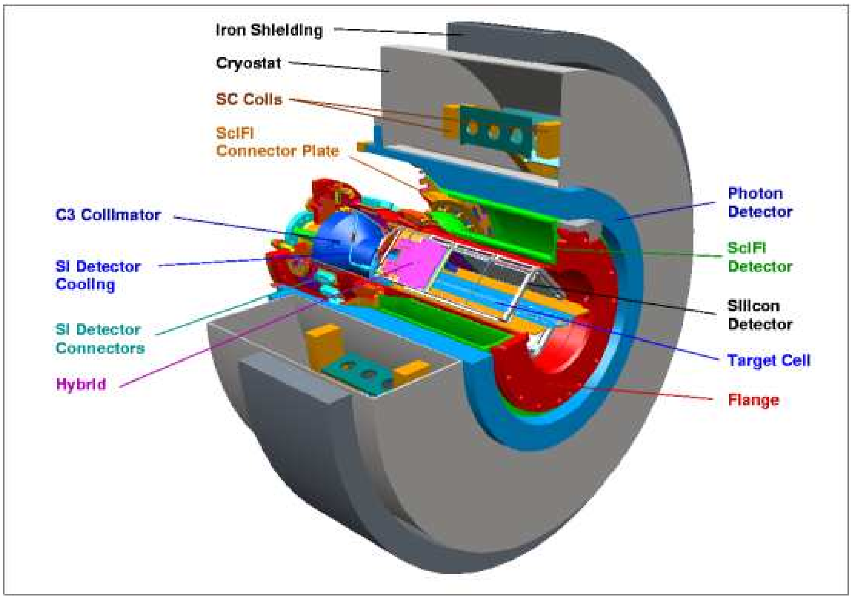

Fig. 1: *The* HERMES *Recoil Detector. The electron beam enters from the collimator. In the center the target cell is surrounded by the Silicon Detector, inside the* HERA *vacuum. The outer layers show the SciFi and the photon detector.*

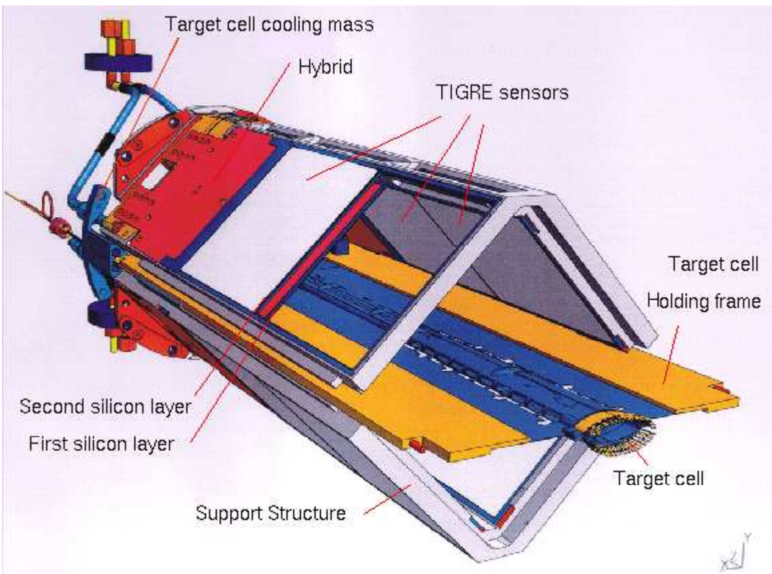

Fig. 2: *The Silicon Detector. The eight silicon modules are placed in a diamond shaped configuration around the target cell, inside the* HERA *vacuum. The gas target cell can be seen in the centre.*

in figure 2, the total length of the silicon detector is aproximately the same as that of a silicon module, this is around 30 cm long.

Every silicon strip module (SSD) (Fig. 3) consists of two double-sided TIGRE silicon strip sensors covering an active area of $99 \times 99 mm^2$ each. They feature 128 strips on each side with a pitch of 758 μm. P and n strips are perpendicular to each other, which allows the reconstruction of the impact point. Proton momenta measurements are possible due to the energy deposition in the two silicon layers, parametrised by the Bethe-Bloch formula [5].

The sensor naming convention followed in this paper is also shown in figure 3: for both p and n sides, the closest sensor to the hybrid is labelled '1' while the farthest one is labelled '0'. Note that in some recent papers, e. g. [7], the labelling '0' has been substituted by '2'.

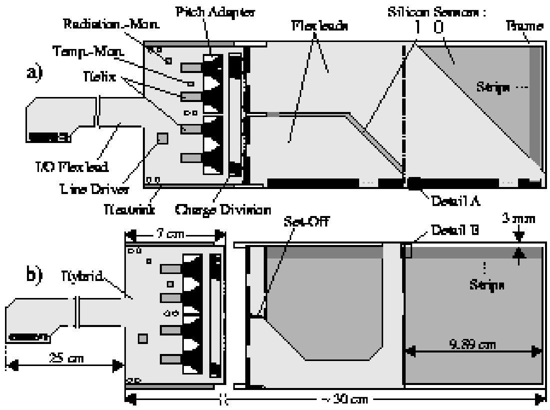

Fig. 3: *n-side (a) and p-side (b) of a SSD module. Each module consists of two doubled-sided silicon sensors (right) and one hybrid containig the readout electronics (left).*

2 Electronics

The HELIX128 3.0 chip (Fig. 4) was chosen as the analog readout chip [6]. It will be operated at the 10.4 MHz HERA bunch crossing frequency. The HELIX128 3.0 is a design by the ASIC laboratory of the Heidelberg University, manufactured in the 0.8 μm CMOS process by AMS. The chip consists of 128 channels, each of them containing a charge sensitive preamplifier and a shaper whose output is sampled into an analog pipeline with 128 memory cells to store the charge until the trigger signal arrives.

The dynamical response of these chips ranges over 40 fC, while an estimated range of 280 fC is needed. Therefore, to cover the larger dynamical range of the expected signals, the TIGRE sensors are connected to the readout electronics via charge divider capacitors. The final value chosen for the capacitance after charge injection testing is 10 pF. By this, the signal is split into high and low gain, which enables a total dynamical range from 4 fC up to 270 fC. Each of the 128 strips per sensor is connected to one input of two differents HELIX IC's.

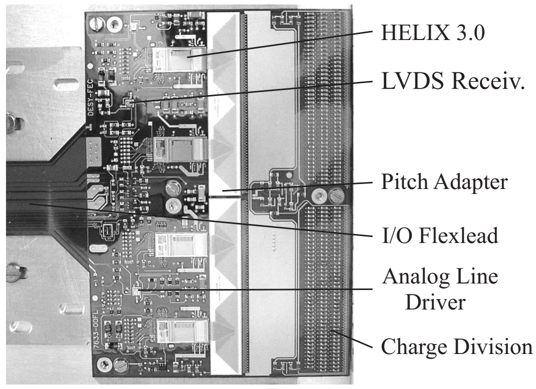

Fig. 4: *Assembled hybrid with the readout electronics. The hybrid contains the charge divider coupling capacitors, a pitch adaptator and four* HELIX128 *chips.*

3 Crosstalk

The term crosstalk is used refering to any phenomenon by which a signal transmitted on one channel of a communications system creates an undesired effect on another one, due to the electromagnetic (inductive) or electrostatic (capacitive) coupling between the conductors carrying the signals. In the context of the silicon detector, the term crosstalk is applied to the response measured in the neighbouring readout channels when a certain strip in the silicon is hit by a particle. When refering to asymmetric crosstalk what is meant is the response in the right neighbour minus the response in the left one. Note that this so defined quantity will be negative if the left neighbour response is greater than the right one.

The accurate knowledge of the crosstalk that affects the silicon detector readout is of first importance in order to obtain precise measurements of the particle tracks. Hence, it is the aim of this paper to study the crosstalk in order that its origins and relative importance are established.

3.1 Strips

The first source of crosstalk arises from the silicon strips in the sensors. The 128 strips per side have a pitch of 758 μm, while the strip separation of the sensors comes to 56 μm. On the n-side the strips are separated by p-stop implantations, as can be seen in figure 5. Due to the coupling between the large detector strips, an estimated strip and inter-strip capacitance for the n-side of the silicon sensor of 54 pF and 7 pF respectively has been reported. For the p-side, strip and inter-strip capacitance come to 34 pF and 9 pF respectively [7].

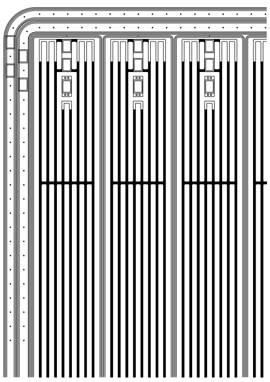

Fig. 5: *Surface of the* TIGRE *'s n-side. Three strips are depicted, the aluminium readout paths and the p stops are visible.*

Since the design of the strips in the silicon sensors follows a symmetrical pattern with perfect alternance between silicon strips and aluminium wires (see fig. 5), it is reasonable to expect that the crosstalk due to them is also symmetric, meaning that it should affect both the neigbouring strips in the same way, left and right.

3.2 Flexleads

The electrical connection from the silicon sensors to the hybrid is realized by 50 μm thick Kapton flexleads with traces consisting of 5 μm copper, 5 μm nickel and 0.1 μm gold. First of all, the sensors are glued into a support frame, afterwards the flexleads are glued to the frame. The connection between sensors and flexleads is done by ultrasonic bonding with 17.5 μm thick aluminium wires. Due to the fact that the tracks on the flexleads are very close to each other, there is a capacitive coupling between them, which results in the existence of parasitic capacitances that can cause crosstalk (and also signal attenuation). For the flexleads, an average inter-strip capacitance of up to 6 pF has been calculated (see fig. 6).

As well as this average capacitance, affecting in the same way every sensor, it is noticeable that the different configuration of the flexleads for the four sensors in a module (see fig. 3) can lead to an observable effect in the crosstalk. Hence, certain differences in the crosstalk behaviour are expected between sensors p-0, p-1, n-0 and n-1 for every module. Moreover, since the length and arrangement of the flexleads varies as well with the strips, a certain crosstalk depencence on the position of every strip within a sensor, namely a dependence on the strip numbering, is also expected.

It is important to point out that the crosstalk coming from the flexleads has to be symmetric in the same way that the crosstalk caused by the strips is symmetric. This is due to the fact that both are caused by the same physical phenomenon: the existence of coupling between two parallel conductors when carrying an electrical signal. An estimation of the total symmetric crosstalk expected from all the symmetric sources is depicted in figure 6, as a function of the interchannel capacitance.

3.3 Chips

It has been reported by other groups that the HELIX exhibits an asymmetric crosstalk behaviour [8],[9]. Thus, when charge is injected into HELIX channel *n*, not all that charge goes into the injected channel, but a non-negligible fraction of it is measured in the neighbouring channels (*n-1*) and (*n+1*), and it is known that this fraction is dependent on whether the injected channel *n* is odd or even [10]. It is necessary to point out that 'odd' and 'even' here only refer to a certain numbering convention.

The asymmetric behaviour of the HELIX128 is due to an intrinsic asymmetry in the pipecell layout, schematically shown in figure 7. A pipeline cell consists of a storage capacitor connected by a switch to a 'read' and a 'write' line. The internal configuration of the HELIX128 chips is such that 'read' and 'write' lines are placed alternately between odd and even channels. It is assumed that it is the coupling between the 'write' lines that causes the extra asymmetric crosstalk [11].

It is also important to note that, apart from

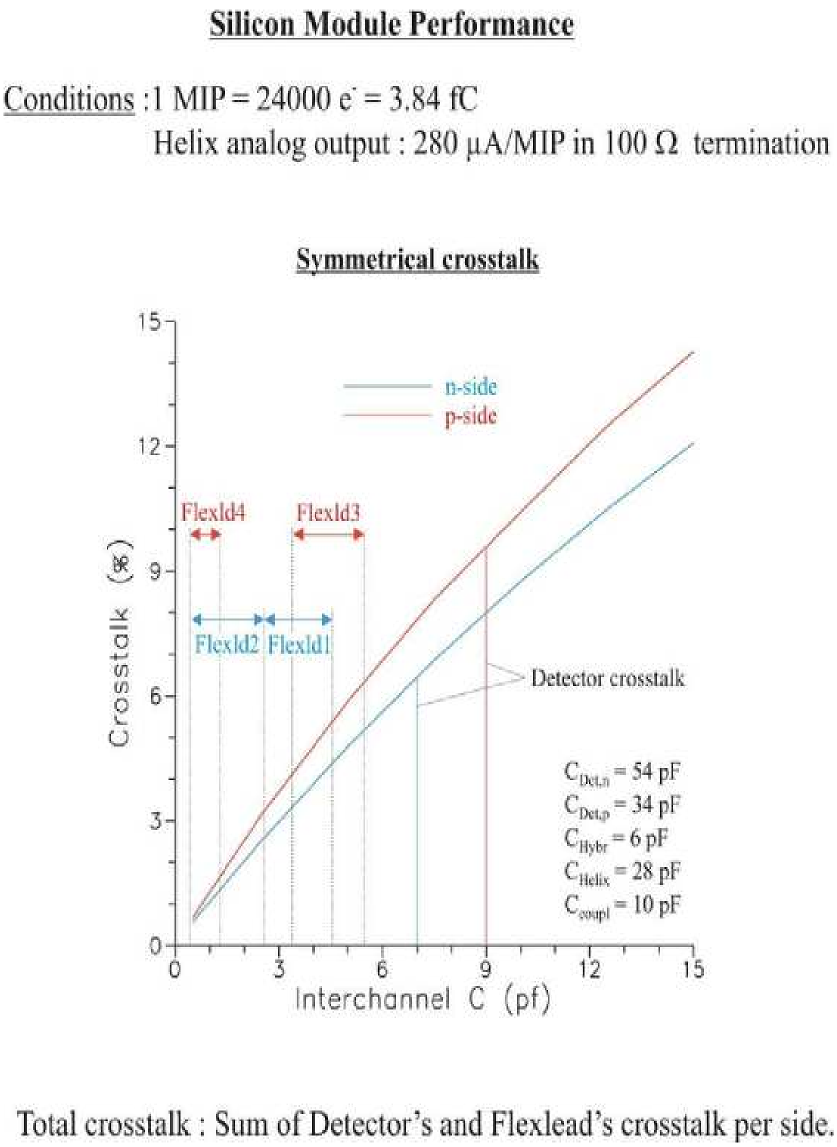

Fig. 6: *Estimation of the percentage of total symmetric crosstalk expected as a function of the coupling interchannel capacitance between strips.*

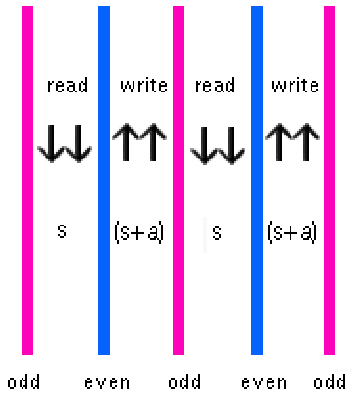

Fig. 7: *Asymmetry in the pipeline layout. 'Read' and 'write' strips are alternatively placed between odd and even channels. Crosstalk between channels is due mainly to the 'write' strips.*

the purely asymmetric crosstalk present in the chips, a certain value of symmetric crosstalk could also exist. A simple way to disentangle the two contributions could be just to substract the responses from the two neighbours, and the value left is the symmetric contribution. What is finally expected from the measurements is a certain dependence of the crosstalk on the channel numbering parity.

4 Crosstalk Measurements

Two kinds of measurement testing have been carried out in DESY Zeuthen in order to test both the silicon sensors and the hybrids: the charge injection measurement with the hybrid and the laser test-stand for the silicon modules. As well as providing data about the response in the strips/channels under study, information about the crosstalk can also be obtained due to these test-stands. Therefore, a brief description of both is given.

4.1 Charge Injection system

The characteristics of the readout electronics have been tested by injecting a predefined amount of charge into one analog input channel of the hybrid. The input charges divides up between the high- and low-gain HELIX inputs, depending on the charge divider capacitor. A parasitic capacitance in each channel of the hybrid of 6 pF and an effective input capacitance of the HELIX of 30 pF is assumed. A more in-depth description can be found in [6] and [7].

4.2 Laser test-stand

A laser test-stand has been proven to be an useful tool for testing the properties of silicon detectors [12], [13], [14]. Studies can be made without an accelerator facility and large data samples can be achieved in a shorter time. The setup for the laser stand in DESY Zeuthen was made as similar as possible to the final SRD setup in HERMES . The silicon module is screwed to a translating table, controlled via a stepping motor. By moving the table, laser light can be fed into different areas of the detector. A more detailed description can be found in [10].

5 Results

5.1 Charge Injection system

The plots depicted in figure 8 exhibit clearly the behaviour expected for the HELIX128 chips: while odd channels show bigger crosstalk in the previous (left) neighbouring channel than in the following (right) one, for even channels is the opposite. These results are closely related to the assymetry present in the pipecell layout shown in figure 7.

Quantitatively speaking, the value of the asymmetric crosstalk from the charge injection measurements can be obtained by substracting the values for right and left neigbours (with the sign convention introduced in section 3). Hence, an approximate value of -5.5% for odd and 5% for even strips can be given, in perfect agreement with other studies done for asymmetric crosstalk [10]. Note the change of sign between odd and even strips predicted.

5.2 Laser test-stand

In order to analyse the data from the laser test-stand, the files containing mean values for the responses in left, central and right strips have been studied, for every module under test. It is remarkable that the general behaviour of all the modules has been proven to be roughly homogeneous. Therefore, results from only one module, number 5, will be shown in this paper, as it presents a small number of faulty strips.

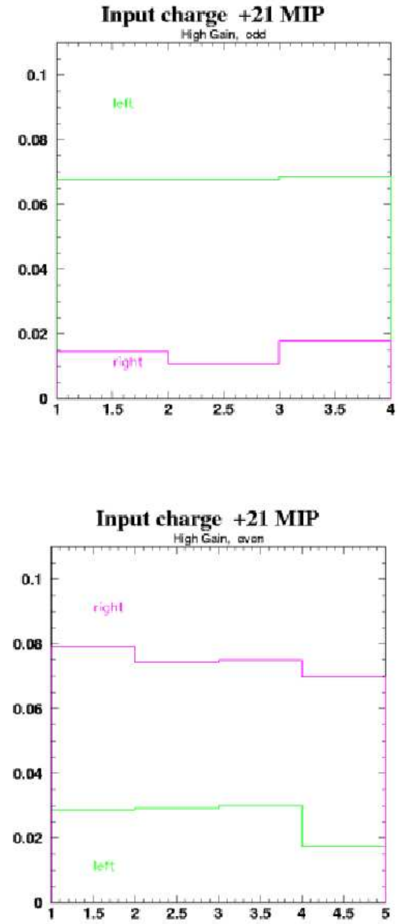

Fig. 8: *Assymetric results from the charge injection system. While odd channels show bigger crosstalk in the previous (left) neighbouring channel, the behaviour for even ones is the opposite.*

In figure 9 asymmetric crosstalk for p side, sensor 0 of module 5 is plotted. The usual convention (right-left) has been followed. The oscillations between odd and even channels are evident, as expected. However, it is notable that all depicted values are positive, meaning that the response of the right neigbour is always greater than the left neighbour. This kind of asymmetric behaviour is not exactly the same as the one exhibited by the charge injection system, where the predicted change of sign ocurred. Thus, this new behaviour can only be explained if it is assumed that other sources of crosstalk are affecting the laser test-stand.

A more detailed examination of the results

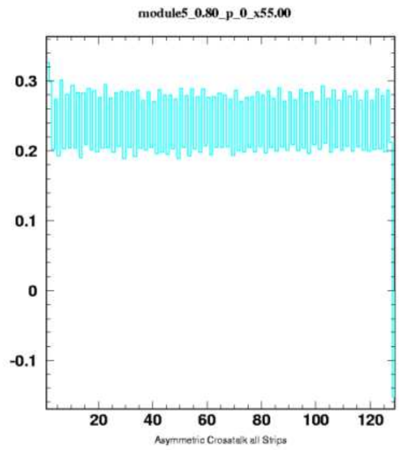

Fig. 9: *Assymetric crosstalk from the laser test-stand for p side, sensor 0 of module 5. The oscillations between odd and even channels are evident. The values depicted follow the usual convention (right-left).*

for p side, sensor 0 of module 5 can be found in figure 10. The two upper graphics show the responses of right (in red) and left (in blue) neighbours for odd (upper left) and even (upper right) hit strips. The x axis represents the strip number but divided by two, since the strips were separated in two groups, odd and even. In the y axis the neighbours responses are shown as ratios with respect to its central strip.

A certain dependence of the neighbouring strips responses on the strip number is clearly visible. This is due to the fact that the flexleads are longer for higher strip numbers, and that means also a higher coupling capacitance and hence a bigger crosstalk.

The two lower plots show the difference between right and left neighbours, again for odd (lower left) and even (lower right) hit strips. The dependence on the strip number shown above has now disappeared, cancelled due to the very similar of the slopes for right and left neighbours.

The quantitative value for the asymmetric crosstalk is also depicted in the two lower plots of figure 10. It is clear that for both odd and even strips a positive value is obtained. It is also to be noticed, however, that for even channels the above mentioned value is always bigger than for odd ones. This is probably because the even channels were the ones with positive asymmetric crosstalk in the charge injection system.

In figure 11 we can see the results obtained

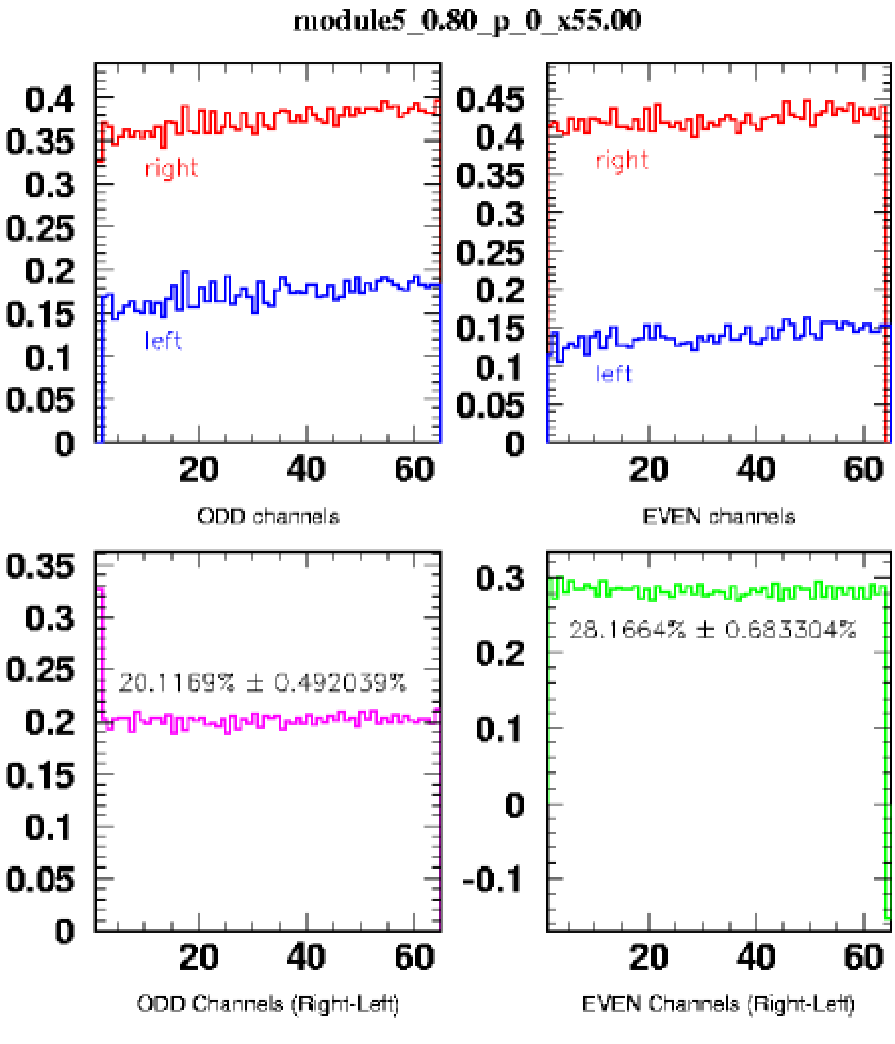

Fig. 10: *Detailed results for p side, sensor 0 of module 5. The two upper plots show the response in the neighbouring channels for odd and even hit strips (in percentage). The strip numbering dependence can be seen. In the two lower plots the difference (right-left) is depicted, and its mean value calculated.*

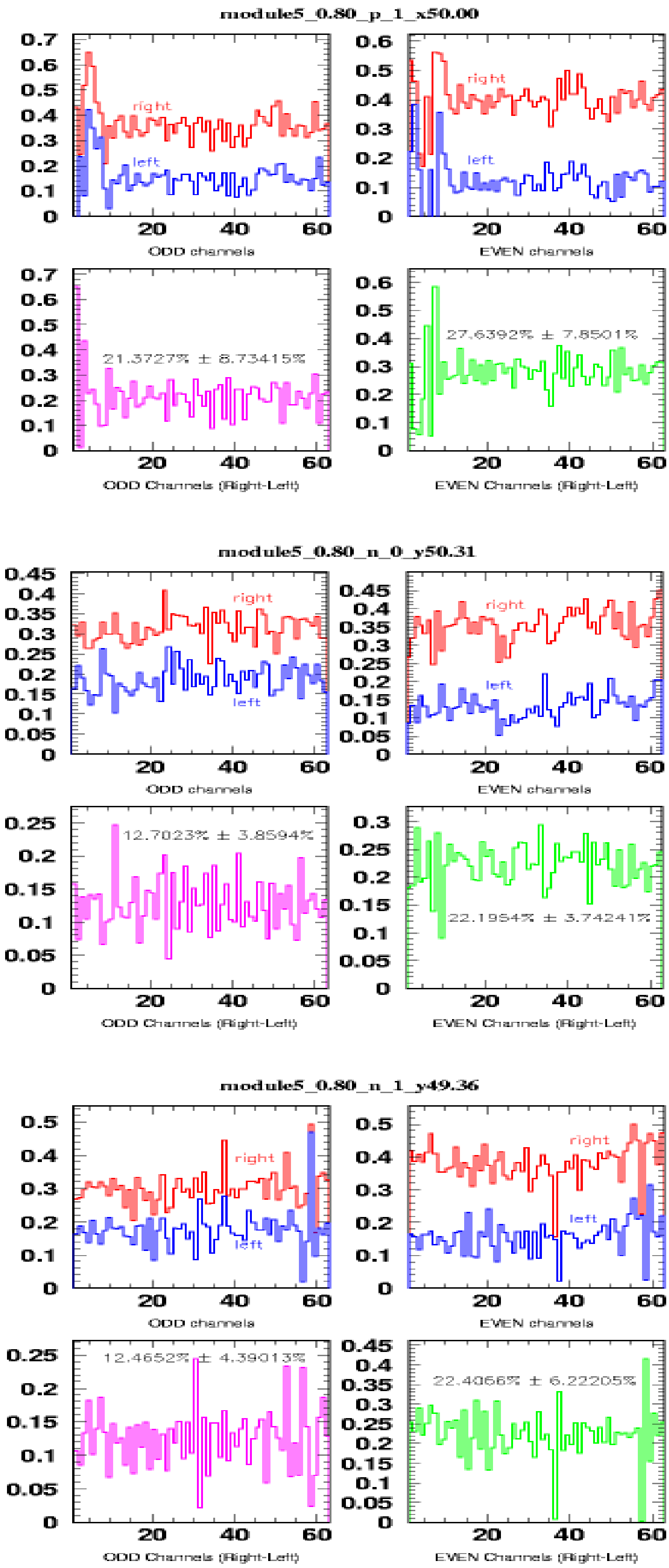

Fig. 11: *Results for the rest or sensors in module 5. The four upper plots belong to p side, sensor 1 (note the effect of the flexleads in the first 20 strips). The 4 plots in the centre belong to n side, sensor 0, and the lower 4 to n side, sensor 1 (the effect of the flexleads is less visible).*

for the rest of the sensors in module 5. At first, it appears that their behaviour is not as smooth as that of the p-0 sensor. The four upper plots in figure 11 belong to the other sensor in p side, sensor 1, which is the closest to the hybrid. Note that the first 22 strips (first 11 odd and first 11 even) show a very irregular behaviour, because they are completely covered by the flexfoils (see fig. 3), with the result of greater signal loss, since the laser light is reflected. It is important to note that there is no dependence on strip number. This is because all the connections to the hybrid for this sensor have roughly the same length.

The quantitative values of the asymmetric crosstalk exhibited by the p sides of all the modules, that is to say, sensors 0 and 1, are in agreement with the results shown here for module 5, namely around 20% for odd channels and slightly below 30% for even channels.

With respect to sensors 0 and 1 of the n side, it can again be seen that the crosstalk is very irregular throughout the strips, and does not seem to show a clear dependence on the strip number. However, it is interesting to point out that the numerical values for the asymmetric crosstalk in n side are roughly around 8-10% smaller than those found for p side. This result is in agreement with the predictions of bigger interstrip capacitance for the p sides explained in section 3.1. Typically, we have 12% of asymmetric crosstalk for odd channels and 22% for even channels, with little variations within all the tested modules. It has not to be forgotten, however, that the laser test data for the n sides are less reliable than for the p sides, because the laser light only creates electron-hole pairs near the p surface. Hence, the current measured in the n side can be affected by recombination processes within the silicon.

6 Summary and Outlook

A brief description of the procedures carried out in DESY Zeuthen to test the silicon modules, namely charge injection system and laser test-stand, has been given. It has been proven that the Helix128 chips exhibit an asymmetric behaviour between odd and even channels which leads to the crosstalk depending on the parity of the channels. By analysing the data from the laser test, the results show that the crosstalk behaviour changes, and the change of sign disappears, with the consequence that the response in right neighbours is always bigger than in left neighbours. The difference between odd and even channels, however, still remains in the numerical values.

Certain differences between the four sensors of a module also appear. It seems to be that the crosstalk behaviour is smooth only for p-0 sensor, while the other three sensors behave much more irregularly. Nevertheless, it has also been seen that in general the asymmetric crosstalk is bigger for p side than for n side. Approximate mean values are 20% for odd-28% for even channels in the p side and 12% for odd-22% for even channels in the n side.

In order to understand properly these results, a more detailed study on the sources of the crosstalk is required. The divergences found for the two test-stands (charge injection and laser) suggest a certain kind of dependence of the crosstalk also on the laser test-stand itself. It is important to remark that predicted values for the symmetric crosstalk in the flexleads and detector come up to 16%, while for the asymmetric contribution in the Helix128 an additional 8% should be added. Hence, a value for the total crosstalk around 25% could be understood. The greater values shown here need to be explained. A better understanding of this point could come from a specific study with the testbeam in Erlangen. If new results found significant differences between laser test and testbeam, the real value of the crosstalk, once the detector is working inside the Hera ring, could be smaller and closer to the expected results.

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