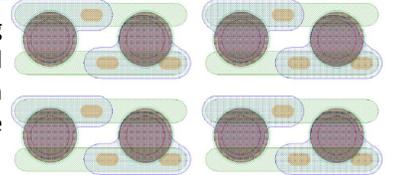


Abstract

The CMS and ATLAS detectors will face challenging conditions after the upgrade of the LHC to the High Luminosity LHC. In particular, the granularity of the pixel detectors should increase to mitigate the effect of pile-up. Two possible sensor geometries are being investigated, 50x50 μm^2 and 25x100 μm^2 , to handle these conditions. One of the main factors in choosing the pixel geometry is cross-talk, defined as the ratio of charge induced in neighboring pixels relative to the total charge. This charge induction will affect the data rates, position resolution, and track reconstruction efficiencies, and therefore should be investigated carefully. The effect of cross-talk is expected to depend on the chosen pixel geometry, threshold of the signal, and readout front-end. The readout chip in this study is RD53A, developed by the RD53 Collaboration, which is a prototype investigated by both CMS and ATLAS collaborations implementing three different analog front-end designs. Cross-talk effects are larger for the 25x100 μm^2 geometry, given the larger sensor capacitance. They have been studied both in the lab, through direct charge injection, and also at DESY test beam facility, by charge deposition of 5.6 GeV electrons in 150- μm thick silicon pixels. The effect of front-end, threshold, and impinging position of electrons on the cross-talk will be presented.

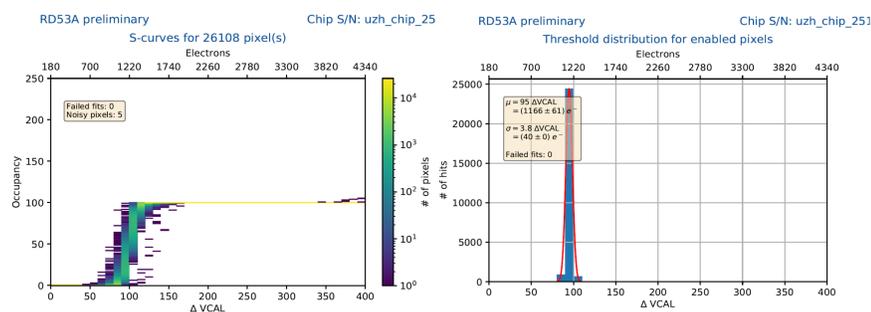
Introduction

In the geometry with a 25x100 μm^2 cell size, the layout of the aluminum pad for the Under Bump Metallization (UBM) of one cell, overlaying the neighboring implant, can cause cross-talk between the pixels paired by these pads (see picture). The cross-talk effect is more pronounced between these pairs, but a small amount of charge can also be induced in other neighboring channels. Cross-talk causes two main complications. It increases the number of pixels with an over-threshold charge, which leads to higher data-rates, and it also increases the error on cluster position reconstruction, and subsequently track reconstruction.



Measurements by Direct Charge Injection

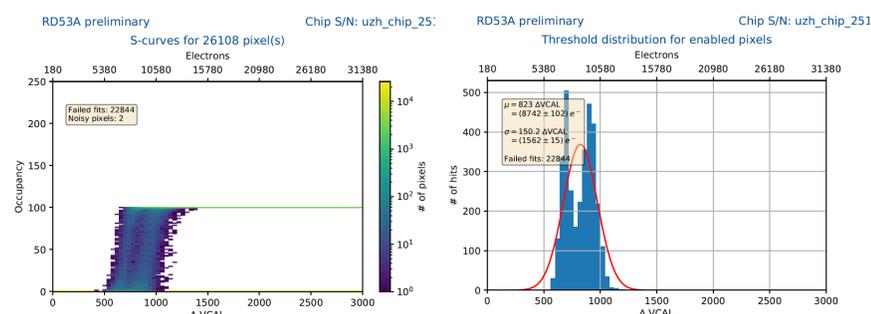
Cross-talk can be studied by direct charge injection in specific channels of the RD53A chip utilizing the BDAQ53 software[1] and a corresponding firmware programmed on a KC705 FPGA. A global threshold can be set per front-end and on top of it, the threshold can be fine-tuned per pixel for linear and differential front-ends, with a 4 and 5 DAC bit values, respectively. Increasing charges can be injected in one RD53A channel and the mean occupancy is calculated for each charge being injected 100 times per pixel. The obtained data is fitted with an error function (S-curve) from which the point corresponding to 50% occupancy is taken as the channel threshold. Below, a superposition of S-curves of all the pixels of the differential front-end for an RD53A module with non-irradiated 100 μm thick MPG-HLL sensors[2] of 25x100 μm^2 pitch is shown.



If instead, we inject charge into a channel but count the occupancy of its paired channel, the injected charge multiplied by the cross-talk value (induced charge) should be above the threshold of the paired channel to be recorded. The injected charge corresponding to 50% occupancy when reading only the paired channel is defined as cross-talk threshold.

$$\text{cross-talk} = \frac{\text{induced charge}}{\text{total charge}} = \frac{\text{S-curve thr of injected channel}}{\text{S-curve thr of paired channel}}$$

The S-curve obtained by injecting in one channel and reading the occupancy in the paired one is shown in the figure below.



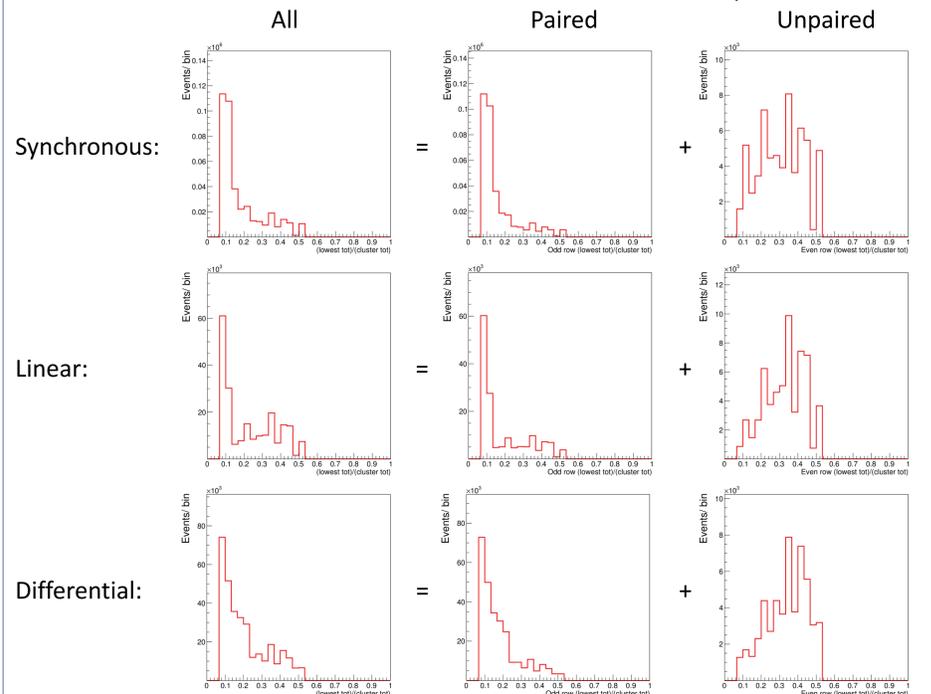
These measurements were also performed on an RD53A module with 150 μm thick MPG-HLL sensors of 25x100 μm^2 pitch, irradiated by CERN PS 24 GeV proton beam at 5x10¹⁵ neq/cm² fluence. The measured cross-talk values through direct charge injection are presented below.

Cross-talk	Linear	Differential
Non-irradiated	14% (11-21%)*	13.3% (11-18%)*
Irradiated	18.5% (17-20%)*	12.5% (11.5-14.5%)*

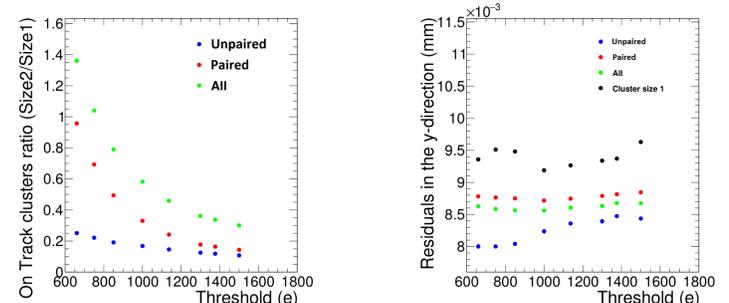
*Numbers in parenthesis show the range of measured cross-talk

Measurements with Electron Beam

RD53A modules with HLL sensors of 100 and 150 μm thickness and 25x100 μm^2 pitch were investigated by a 5.6 GeV electron beam to look for possible cross-talk effects. Synchronous, linear, and differential front-ends were studied. To measure the value of cross-talk, only the clusters with two pixels were studied. Charge sharing between these two pixels is in principle a combination of two effects. The impinging particle can deposit charge in both pixels with a ratio depending on the impinging point. Also, if the two pixels have cross-talk, even if there is no normal charge sharing, a fraction of deposited charge would be induced in the paired channel. Therefore, if the ratio of the charge in the pixel with lower charge to the total charge is taken, a rather flat distribution due to normal charge sharing is expected with a relatively sharp peak on top of it at a certain value, which indicates the cross-talk value. When the two pixels are unpaired, this sharp peak is expected to vanish. The distributions for paired, unpaired, and all clusters with two pixels for three front-ends are shown below. Results are similar for the module with 100 μm thick sensors.



As an illustrative example, the results of study on the linear front-end of the module with 150 μm thick sensors are shown. The cross-talk effect is mitigated for higher thresholds (left). The uncertainty on the cluster position resolution, measured from the residual distribution is higher for paired channels than unpaired ones (right).



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References:

- [1] BDAQ Software and Hardware, URL <https://gitlab.cern.ch/silab/bdaq53>
- [2] J. Beyer "Optimization of pixel modules for the ATLAS inner tracker at the high-luminosity LHC", Ph.D. Thesis, LMU Munich. <https://edoc.ub.uni-muenchen.de/23939/>

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