Measuring the borders of the active area on silicon strip sensors

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Introduction

The High-Luminosity Large Hadron Collider will deliver an instantaneous luminosity of $5x10^{34}$ cm^{-2} s^{-1} and around 200 proton-proton collisions per bunch crossing. ATLAS detector upgrade will feature silicon strip sensors designed to enable reliable particle detection in this challenging environment.

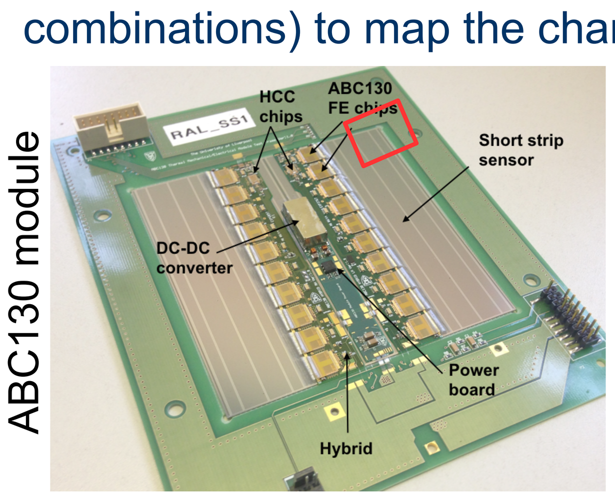
The sensor design comprises of an active area to collect the deposited charge and an inactive area which acts as a buffer between the dicing edges and the active area. An important design criterion is to minimize the inactive areas as they introduce inefficiencies in particle detection inside the detector. The active sensor area is surrounded by three rings: bias ring (ensures all strips have homogeneous potential), guard ring (shapes the field in active sensor area and minimizes edge effect, also allows correct positioning of the sensor) and edge implant (prevents the diced sensor edges from developing a high electric field). Previous measurements[1] demonstrated that the charge collecting area of the individual strip implants agree well with strip pitch and length.

The study presented here investigates the extent of charge collecting area of the strip implants adjacent to the sensor bias ring towards the charge collecting area. This information is relevant for accurate hermeticity estimates and position resolution for particles detected at the sensor edge.

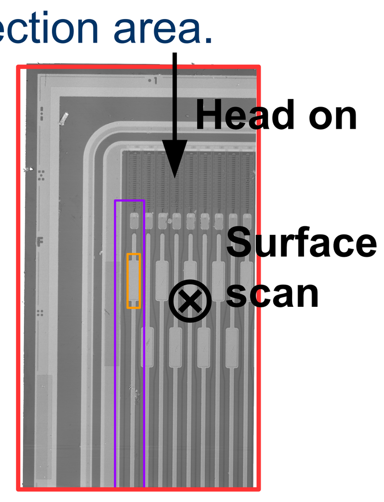
Experimental setup

A micro-focused (σ_x x σ_y = 2.6 x 1.3 µm) 15 keV X-ray beam was incident on the corner of an ITk strips module (used two generation of modules: ATLAS12SS-ABC130[2] and ATLAS17LS-ABCstar sensor-ASIC combinations) to map the charge collection area.

ABC130 module



ATLAS12SS-sensor



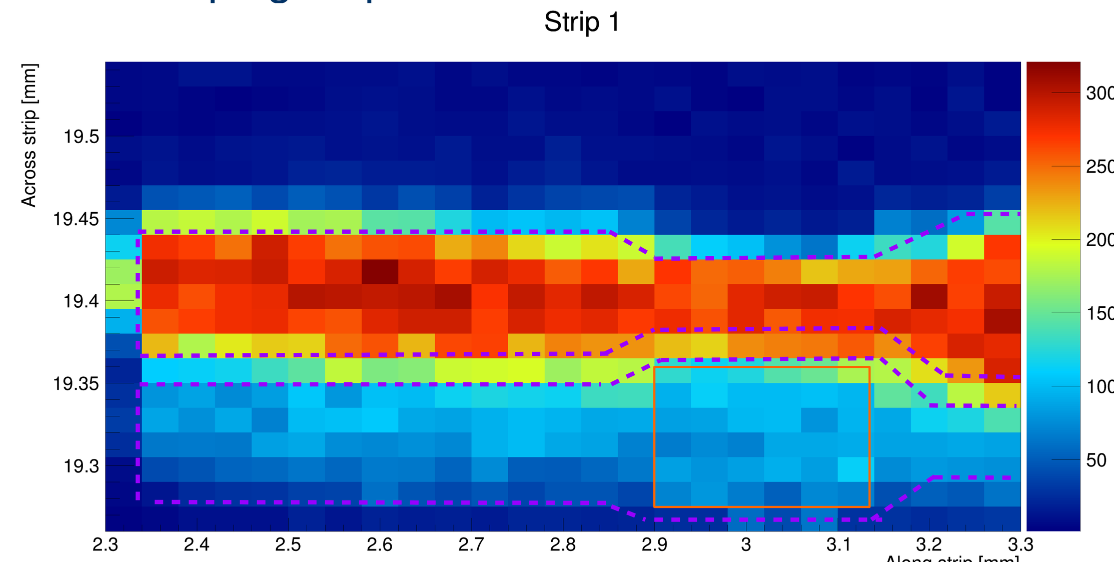
The X-ray beam was incident on the module from two different directions: one from the top to scan the charge collection along the strip length and across the strip length, and the other perpendicular to the module to scan the bulk effect when the module is fully depleted. Given the beam was much narrower compared than strip pitch, the beam was incident on three corner strips, one at a time and charge collection or hits around each strip was recorded. The input charge from 1 15keV is equivalent to 1/5 of the charge from 1 MIP. Readout thresholds were chosen based on the signal-to-noise ratio of each module to provide comparable working points.

ATLAS12SS-ABC130 module: The module was kept at temperature of 15°C and step size for perpendicular scan was 15 µm across the strip and 40 µm along the strip while the step size for head on scan was 15 µm across the strip and 15µm along sensor depth.

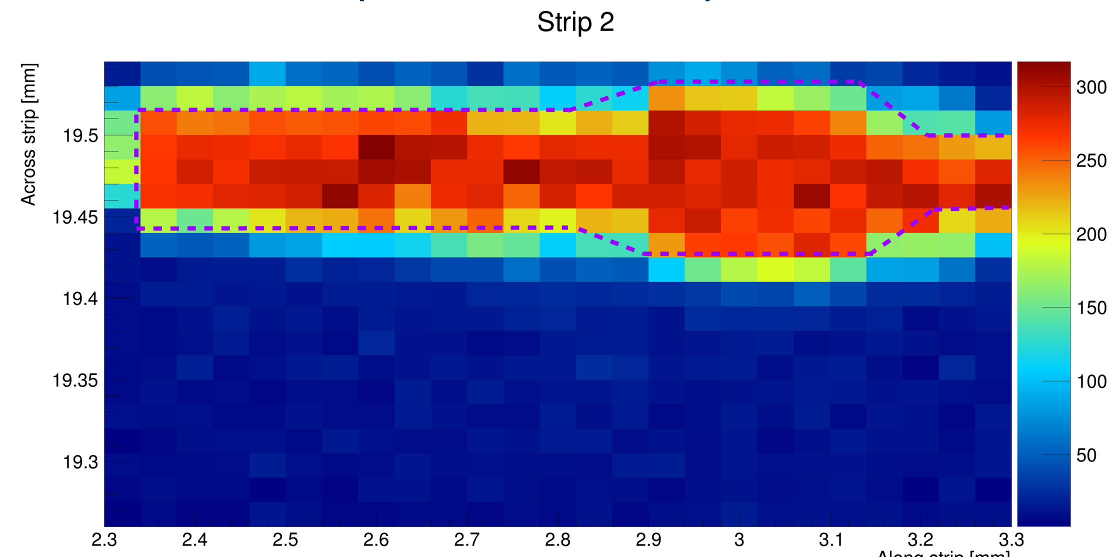
ATLAS17LS-ABCStar module: The temperature was maintained at 8°C and the step size was 9.8 µm across the strip and 15 µm along the strip.

Results from surface scan

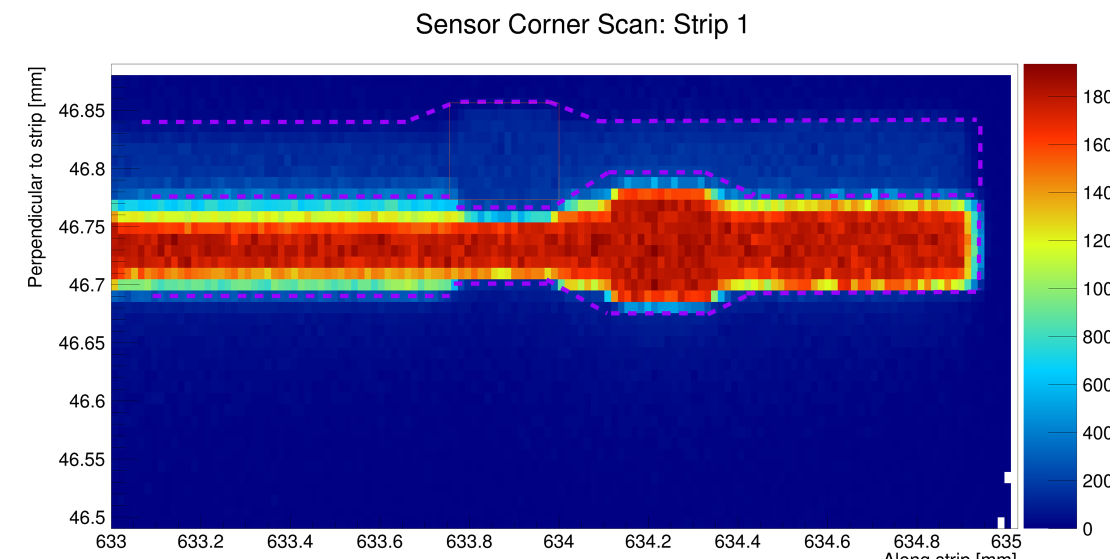
ATLAS12SS-ABC130 module: The charge collection pattern on strip adjacent to the sensor bias ring (Strip 1) clearly shows the charge bleeding into the field shaping strip (Strip 0). The lead hypothesis for this effect is that we have a capacitive charge division for the signal coming from the edge strip. The shape of the charge collection in Strip 0 agrees well with the shape of a strip confirming that it corresponds to the field shaping strip.

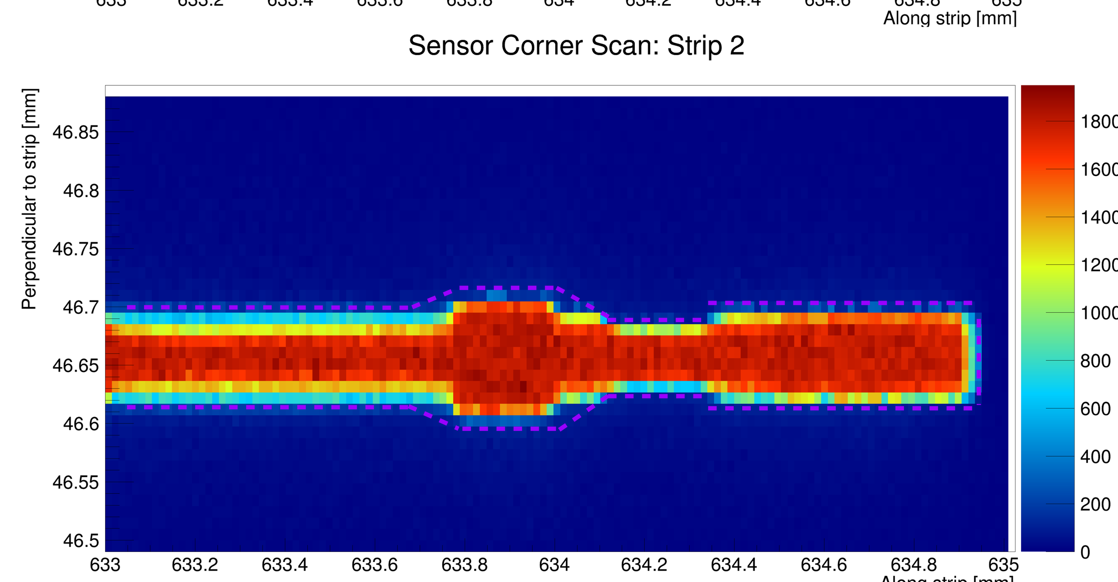


The charge collection pattern in the next strip (Strip 2) is shown below for reference of a nominal charge collection we expect around a strip.



ATLAS17LS-ABCstar module: For this module, the data was recorded with finer granularity which resulted in a sharper charge collection boundary. The results from Strip 1 confirm the charge collection pattern seen in earlier data. Due to higher granularity of the scan, the shape of the AC pad of the field shaping strip is clearly outlined and is consistent with the expected position for ATLAS17LS sensor.

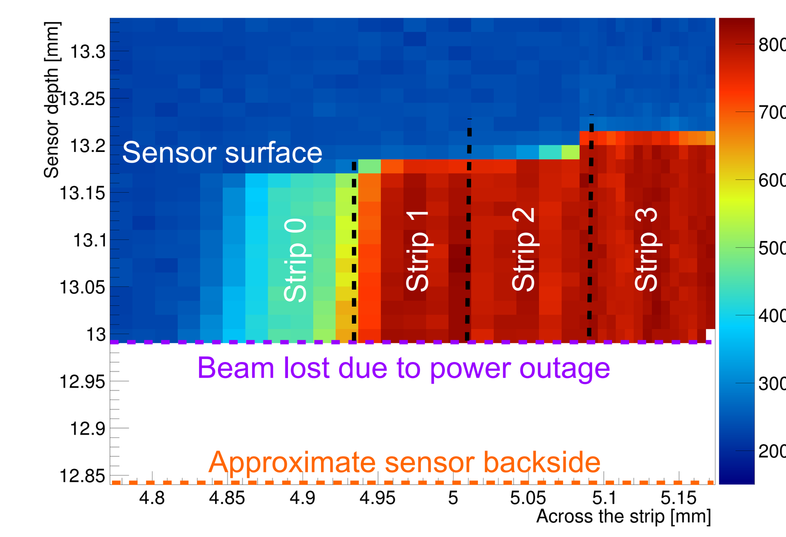




Note that the AC pad of the field shaping strip (Strip 0) was not grounded for this measurement.

Volume effect

ATLAS12SS-ABC130 module: The X-ray beam was incident from the side on to the fully depleted sensor to record charge collection in the bulk.



This indicates that the charge leakage into the field shaping strip is not just limited to the surface of the sensor, we see it in sensor bulk as well. Note that the sensor plane was tilted with respect to the incident beam resulting in charge collection at different sensor depths for different strips for this measurement. This result also demonstrates the uniformity of charge collection across strips in the bulk.

Summary

This study measured the extent of charge collection in the edge strips of silicon strip sensors to be used in ATLAS detector upgrade. The charge collection is consistent between two different generations of ATLAS silicon strip modules.

Results from the perpendicular scan clearly demonstrate the charge collection in the field shaping strip and the side scan shows the bulk effect.

The plan for next year's test beam is to measure the charge collection in a module with and without grounding the AC pads of the field shaping strip for comparison.

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References

[1] Investigations into the impact of locally modified sensor architectures on the detection efficeincy of silicon micro-strip sensors. L. Poley *et al* 2017 *JINST* **12** P07006

[2] Technical Design Report for the ATLAS Inner Tracker Strip Detector, ATLAS Collaboration, CERN-LHCC-2017-005