Performance study of ATLAS ITk strip endcap modules using charged particle beams

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Abstract

The current Inner Detector of the ATLAS experiment is to be replaced with the all-silicon Inner Tracker (ITk), built from pixel and strip modules, to cope with high pile-up and harsh radiation environment expected during the operation of the High-Luminosity Large Hadron Collider (HL-LHC). During prototyping and early production phases of the ITk project, the performance of all types of ITk strip modules has been extensively evaluated using high-energy electron or hadron beams available at the DESY II and CERN SPS test beam facilities. Complementary to test beam measurements, full computer simulations of the experimental setup have been carried out using the Allpix-Squared framework, which has recently been extended to enable simulations of ITk strip endcap modules featuring a complex, radial strip geometry. This contribution focuses on results obtained by reconstruction and analysis of test beam measurements with an R2 ITk strip endcap module at the DESY II test beam facility. Comparisons of experimental results with computer simulations for key performance metrics are presented. Additionally, the effects of the particle beam impacting the tested module at non-perpendicular angles are explored and discussed.

1 Introduction

The upcoming High-Luminosity LHC accelerator will deliver 5–7.5 times higher instantaneous luminosity when compared with the LHC nominal value, with up to 200 inelastic proton-proton collisions per bunch crossing [1]. To ensure a sufficient tracking performance level of the ATLAS experiment, a new tracker with increased accuracy, granularity and radiation tolerance is being built. The ATLAS Inner Tracker (ITk) will consist of silicon pixel and strip detectors, with its layout separated into a central barrel section and endcap sections in the forward regions. A total of eight types of strip modules will be installed in the ITk, barrel modules with a rectangular sensor and parallel strips, and endcap modules featuring a trapezoidal sensor with radial strip geometry.

During the pre-production and production phases of the ITk project, strip modules are tested using charged particle beams to ensure their full functionality and sufficient performance level. Two performance criteria must be satisfied for a range of charge thresholds on any given module and at any point of its lifetime: detection efficiency above 99 % and noise occupancy below 0.1 %. These requirements are equivalent to establishing a signal-to-noise ratio of at least 10 [1].

2 Experimental setup

The presented measurements were performed at the DESY II test beam facility [2] using a 5 GeV electron beam and the EUDET-type [3] DURANTA telescope equipped with six Mimosa26 pixel detectors [4]. An FE-I4 pixel detector [5] served as an additional timing reference, enabling a precise evaluation of detection efficiency of the device-under-test (DUT).

The DUT was placed in a cooling box which was mounted on a moving stage, allowing for precise positioning and rotation of the DUT with respect to the electron beam. The telescope, the cooling box and the DUT are shown in Figure 1.

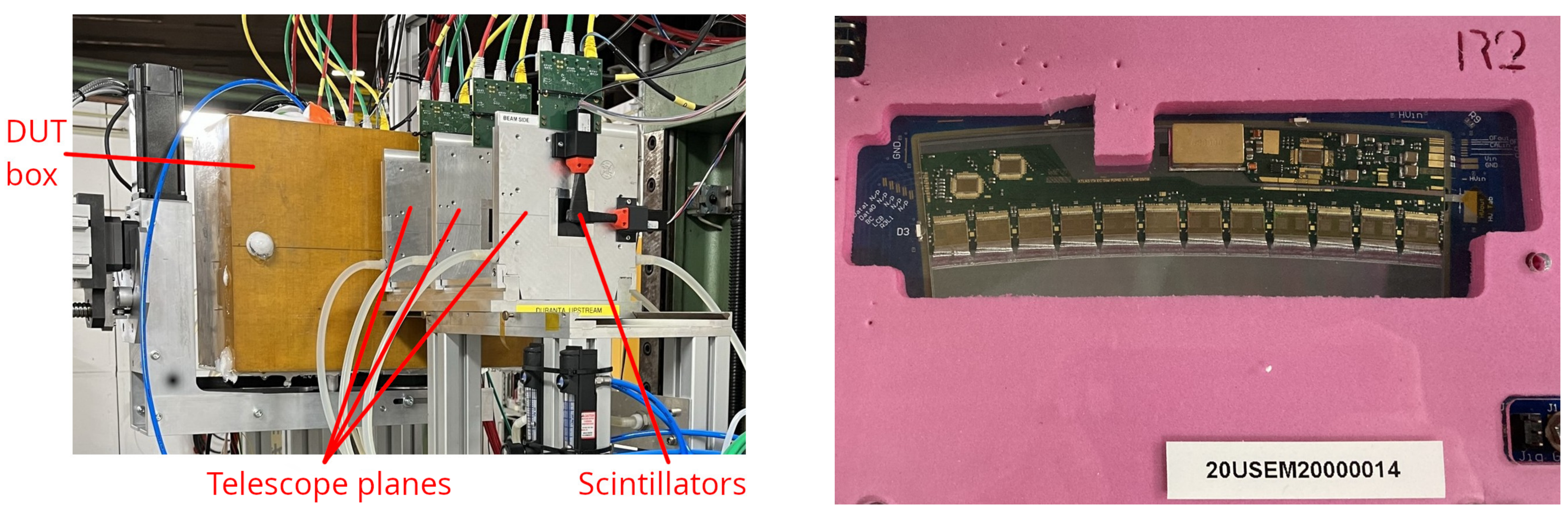

Figure 1: **Left:** The DESY DURANTA telescope, the DUT cooling box and the trigger scintillators. **Right:** The studied R2 module, partially covered by a protective material.

3 Datasets

The analysis was performed on threshold scans taken with an unirradiated ITk R2 endcap strip module. Each threshold scan includes several tens of measurements with a progressively increasing charge threshold above which a hit is registered in the DUT. The DUT was operated at 500 V of reverse-bias voltage with a fully depleted sensor.

Several threshold scans were taken with the electron beam impacting the module perpendicularly. In further scans, the module was rotated by 5° to 25° around the vertical axis parallel with the central strip direction, to explore the effect of angled beam incidence.

The measurements were complemented with simulations performed in the Allpix-Squared framework [6], where the entire experimental setup was accurately reproduced.

4 Data reconstruction

Reconstruction and analysis of the collected data was performed in the Corryvreckan framework [7]. Simulation data were analyzed identically to test beam data.

Particle tracks were reconstructed based on hit clusters in the telescope detectors and the FE-I4 only. The tracks were then used to align the telescope detectors and the FE-I4 by minimizing the track-fit χ^2. The subsequent DUT alignment was performed using the reconstructed particle tracks by minimizing the unbiased residuals.

The detection efficiency for a given charge threshold was defined as the fraction of tracks with an associated hit in the DUT to all tracks. The charge threshold, for which exactly half of the tracks exhibit a hit in the DUT, corresponds to the median of the collected charge distribution [8].

5 Results

Analysis of the taken data shows that the detection efficiency of the studied module starts decreasing at lower charge thresholds for larger module rotation angles due to increased charge sharing among the strips, as is shown on the left panel of Figure 2. Efficiency curves obtained from the test beam results and Allpix-Squared simulations match reasonably well for the respective module rotation angles.

The module rotation resulted in a decrease of the median charge from (3.814 ± 0.005) fC for the perpendicular incidence to (2.343 ± 0.003) fC for the 25° module rotation, a decrease to 61.4 %. The signal-to-noise ratio likewise decreased from 35.9 ± 0.2 to 22.5 ± 0.1, a decrease to 62.7 %. The median charge, input noise and signal-to-noise ratios for all module rotations are listed in Table 1.

The increased charge sharing for larger module rotations leads to larger mean associated cluster sizes, i.e. the mean number of adjacent strips forming a hit cluster associated to a track, as shown on the right panel of Figure 2.

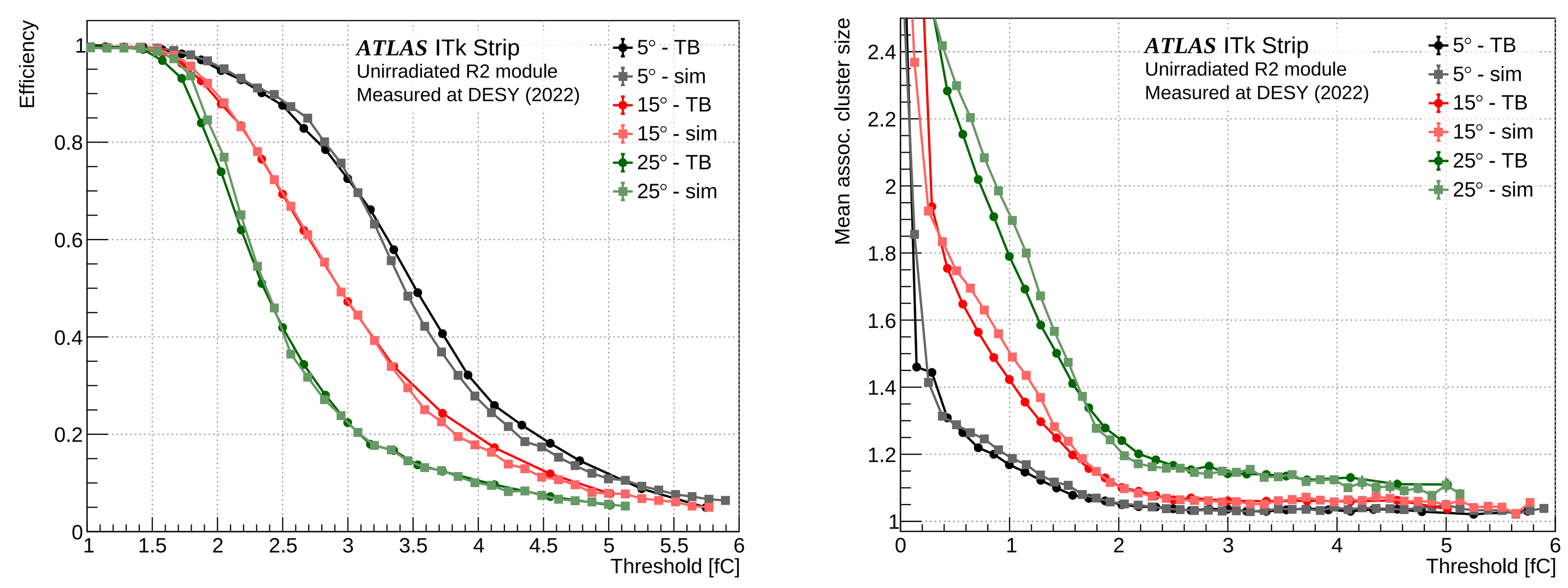

Figure 2: Detection efficiency (left) and mean associated cluster size (right) as a function of the charge threshold for 5°, 15° and 25° beam incidence angles, obtained from test beam measurements (labeled as TB) and Allpix-Squared simulations (labeled as sim).

Module rotation [°]	Median charge [fC]	Input noise [fC]	S/N
0	3.814 ± 0.005	0.1064 ± 0.0007	35.9 ± 0.2
5	3.520 ± 0.005	0.1046 ± 0.0006	33.7 ± 0.2
10	3.248 ± 0.006	0.1046 ± 0.0006	31.5 ± 0.2
15	2.882 ± 0.005	0.1046 ± 0.0006	27.9 ± 0.2
20	2.598 ± 0.004	0.1046 ± 0.0006	25.1 ± 0.2
25	2.343 ± 0.003	0.1046 ± 0.0006	22.5 ± 0.1

Table 1: Performance parameters of the studied R2 module obtained for perpendicular and non-perpendicular beam incidence.

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