Performance of 2S Modules of CMS-Phase2 Tracker in a Test Beam Environment

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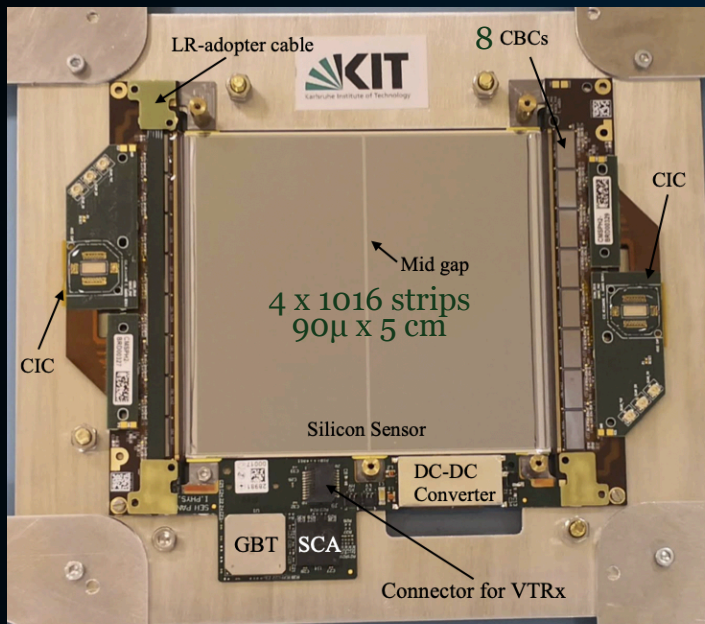On behalf of CMS Tracker collaboration

Introduction

CMS Tracker Upgrade for HL-LHC

The Large Hadron Collider (LHC) will be upgraded before 2027 to allow for the delivery of an instantaneous luminosity up to 7.5×10^{34} cm^{-2}s^{-1} at HL-LHC period. CMS will install a new silicon tracking detector with some major requirements i.e. radiation hardness, high granularity, compatible with high data rates etc. The Outer Tracker (OT) will supply tracking information to the CMS Level-1 trigger system for event selection. To achieve this, the OT modules will consist of two closely spaced silicon sensors read out by common Front End (FE) chips. These FE chips will be programmed to discriminate tracks based on their transverse momentum (p_T).

2S p_T Module

LR-adapter cable — KIT — 8 CBCs — CIC — Mid gap — 4 x 1016 strips 90μ x 5 cm — CIC — Silicon Sensor — DC-DC Converter — GBT — SCA — Connector for VTRx

2S p_T Modules with CMS Binary Chips (CBCs) v3 : p_T Discrimination

- A 2S module consists of 2 closely spaced (1.6 to 4.0 mm) silicon sensors with total 4 x 1016 strip detectors of dimension 90μ x 5cm.
- At each side 8 CBCs, the FE readout chips, readout 127 strips of each sensor.
- The bending radius of a particle trajectory depends on its p_T.
- The combination of a hit on the bottom sensor and a hit on the top sensor within a predefined window will form a stub.
- This window (± n-Strips) is chosen to set a lower cutoff on p_T.
- This stub will be used for Level-1 tracking.

pass — fail — programmable search window — stub — B
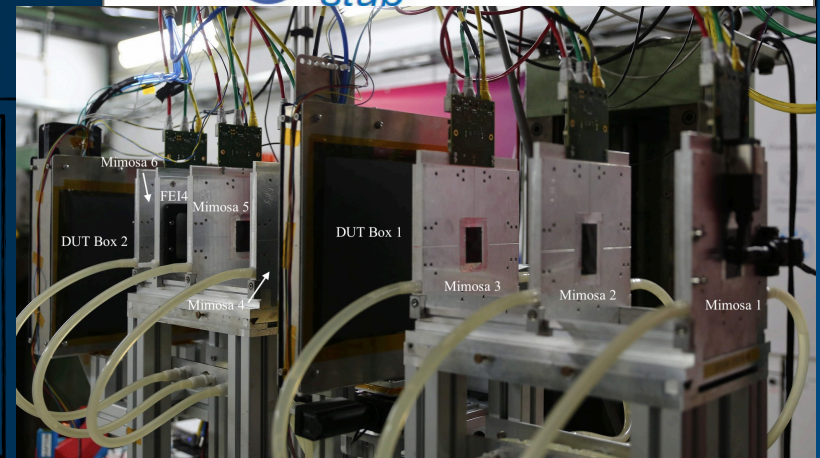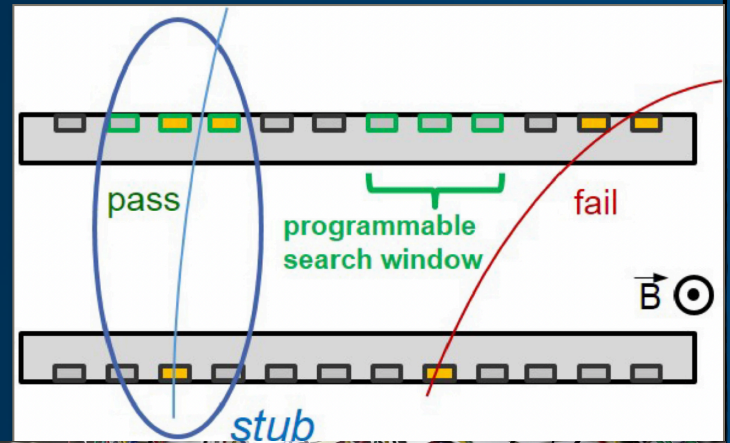
Test-Beam Setup

- **Electron beam** : 4 GeV.
- **Telescope System**: Six MIMOSA26 active pixel devices were used as beam telescope for tracking the beam particles with high precision. This is used for track reconstruction.
- Detector Under Test (DUT) : 4 **DUT**s (2S p_T modules) were used here. DUT-Box1, contains one DUT placed in the middle, can be rotated in order to emulate track bending in magnetic field. DUT-Box2 contains three modules .
- Timing Detector : An **FeI4** timing layer was used as a trigger system placed in between 5th and 6th telescope layers .
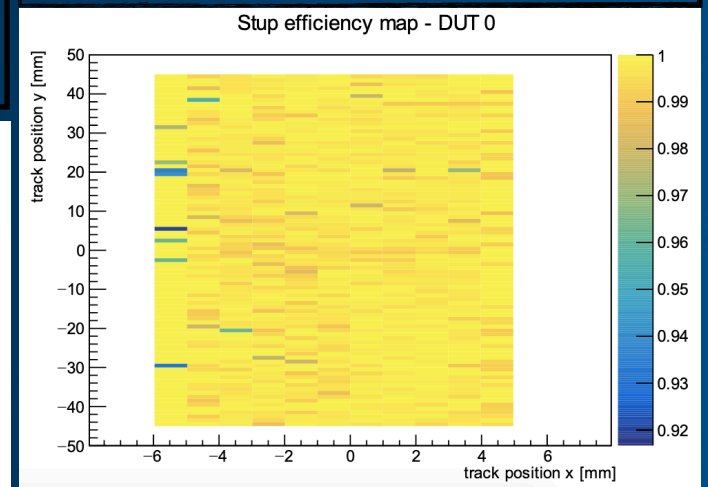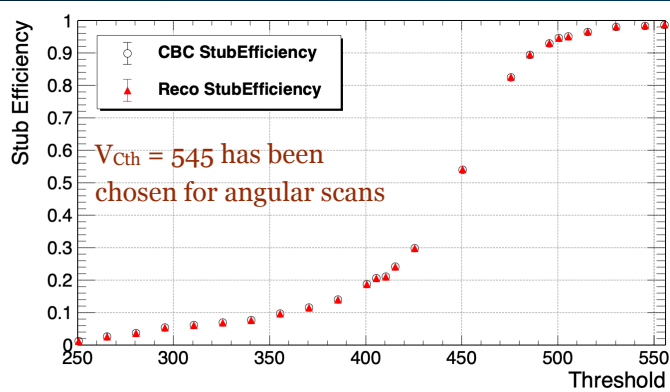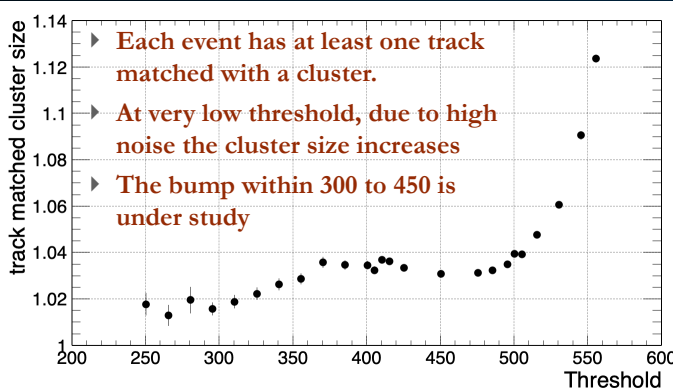

Results

Cluster & Stub Reconstruction:

- Consecutive hits on the sensors form a cluster.
- If a cluster (max size 3) on the bottom sensor matched another cluster on the top sensor within a predefined window (± nStrips), it would form a stub.

Stub Efficiency:

$$\frac{\text{Number of tracks matched with stubs}}{\text{Total number of tracks}}$$

Tracks are reconstructed from the hits on the telescope system and the FeI4 plane and then matched with a hit on DUT.

- Each event has at least one track matched with a cluster.
- At very low threshold, due to high noise the cluster size increases
- The bump within 300 to 450 is under study

V_{Cth} = 545 has been chosen for angular scans

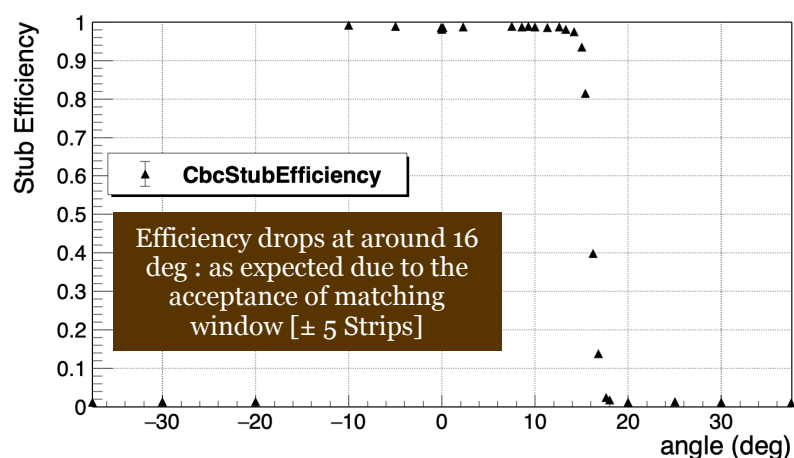Stub efficiency map - DUT 0

Threshold Scan

- Electrons are collected as signal and the Threshold or V_{Cth} (Threshold Comparator Voltage) is proportional to number of electrons collected. So, high V_{Cth} value corresponds to low threshold.
- To choose the optimal threshold point to increase the S/N ratio.
- The plateau region at low threshold corresponds to a dip in differential plot of Stub Efficiency Vs. Threshold. That dip separates the signal from the pedestal.

Stub Efficiency Map

For this study, the beam was focussed at different y positions of the strips [along the strips]. The beam profile is along the x axis.
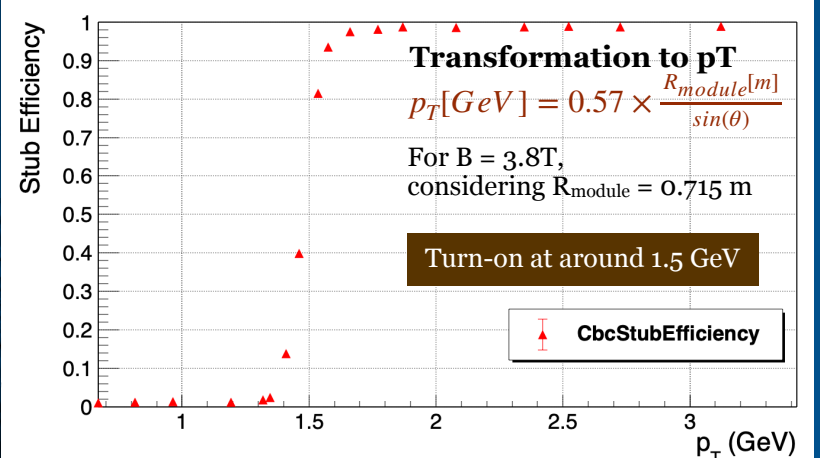
Stub efficiency mostly at about 99%, exceptions especially in beam boundary areas.

- Efficiency drops at around 16 deg : as expected due to the acceptance of matching window [± 5 Strips]

Angular Scan

The DUT has been rotated to emulate the bending of charge particle in a magnetic field

The stub efficiency is measured as a function of the angle between the beam and the module and then transformed to p_T to verify the p_T discrimination logic of CBC

Transformation to pT

$$p_T[GeV] = 0.57 \times \frac{R_{module}[m]}{sin(\theta)}$$

For B = 3.8T, considering R_{module} = 0.715 m

Turn-on at around 1.5 GeV

Conclusion

- The performance of 2S prototype modules with CBC3 has been evaluated in a test beam environment.
- Cluster and stub properties have been studied.
- p_T discrimination logic has been verified through angular scan.

Reference

- CMS Collaboration. The Phase-2 Upgrade of the CMS Tracker. Technical report CERN- LHCC-2017-009. CMS-TDR-014.
- W. Adam et al 2020 JINST15 P03014