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Performance of the CMS 2S p_T module prototype using CBC2 readout at beam tests

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Abstract

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Abstract. As the LHC will enter into its high luminosity phase (HL-LHC), operating at a luminosity of $5\text{--}7.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$, the CMS experiment will replace the Run 2 tracker with a new one which will be able to sustain the increased number of collisions per bunch crossing, which can be as high as 200. The tracker information will be used in the Level-1 trigger to reject low p_T tracks. In this paper, the performance of the modules of the proposed outer tracker in test beams is reported.

Keywords: CMS, upgrade, stub, beam test, p_T module

1 Introduction

Beyond 2026, the planned upgrade of the LHC to the HL-LHC will result in an increase in instantaneous luminosity in proton-proton collisions reaching values up to $5\text{--}7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$, leading to an average number of collisions per bunch crossing between 140 and 200. The current CMS tracker will be damaged by the radiation received during the Run 1 and Run 2 operations of the LHC and will not be able to run efficiently under the HL-LHC conditions. The current Level-1 trigger system in the CMS experiment [1] using information from the calorimeters and the muon systems will not be able to efficiently select important events. The CMS collaboration foresees to install a new tracker which will be able to provide tracking information to the L1 trigger system to keep the Level-1 trigger rates within sustainable limits. Besides that, new tracker should be radiation hard to operate over the planned HL-LHC period corresponding to an integrated luminosity of about 3000 fb^{-1} .

2 Future tracker and the concept of the p_T module

The sketch of one quarter of the proposed CMS tracker is shown in Figure 1a. The radial region below 200 mm will be instrumented with pixel modules providing excellent vertex resolution. The outer tracker will be equipped with p_T modules where each module will be made out of two silicon sensors separated by some distance. The distance between the two sensors of the modules will vary between 1.6 mm and 4 mm. In the outer tracker, the radial region between 200 and 600 mm will be equipped with modules with a macro-pixel sensor on one side and a strip sensor on the other side (**PS** p_T module) while the region above 600 mm will be populated with modules having strip sensors on both sides (**2S** p_T module).

Fig. 1: The proposed CMS tracker layout in r - z view (a). The green and yellow lines correspond to inner pixel modules. The blue lines correspond to PS modules, while red lines correspond to 2S modules. Concept of a p_T module (b).

2.1 The p_T module

In the presence of a magnetic field of 3.8 T the final state charged particles bend in a plane transverse to the direction of the beam. The radius of curvature of the track of a particle depends on the p_T , the component of the momentum transverse to the beam line, of the particle. The p_T discrimination principle of a module is shown in Figure 1b. As a charged particle passes through the module, it creates hits in the bottom and top sensors within the module. A hit in the bottom sensor is matched to coincident hits in the top sensor and if they are within a predefined window the two hits are combined to form a short track segment, a **stub**. The stubs are sent to the Level-1 trigger at bunch crossing frequency.

The front end readout chips of the modules, capable of reading out both the bottom and top sensors, will provide the logic to discriminate between high and low p_T tracks. The window for hit matching can be set within the readout chip according to the p_T threshold to be used. Stubs of tracks with p_T greater than 2 GeV will be used for the Level-1 tracking. For the 2S p_T module, the readout chip will be the CMS Binary Chip (CBC) [2, 3]. In this work the performance of modules with version 2 of the CBC chips will be discussed.

3 Test beam setup

Two prototype mini 2S-modules were tested using a pion beam in the test beam facility at CERN. A 2S mini-module consists of two strip sensors, each sensor comprising 254 strips of 5 cm length. The module is read out by two CBC2 chips. One of the modules with a sensor spacing of 3.05 mm was irradiated to a fluence of $6 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$. The expected fluence for the 2S modules during the high luminosity phase operations corresponding to an integrated luminosity of 3000 fb^{-1} is $4 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$. The non-irradiated module has a sensor spacing of 2.75 mm. The schematic of the beam test setup is shown in Figure 2. The detector under test (DUT) was placed within a telescope system [4] consisting of six layers of pixel detectors. The telescope was used for reconstructing the path

Fig. 2: Schematic drawing of the test beam setup; p0 to p6 refers to the telescope planes, DUT is the 2S prototype module under test.

of the incident particles and matching the incident particle to a hit in the DUT. Additionally, another pixel detector layer (FE-I4) was used for timing.

4 Event reconstruction and results

The readout of the modules is binary and zero-suppressed. Only the number of fired strips having collected charge above a threshold is stored. The offline analysis of the data involves reconstruction of clusters (consecutive fired strips joined together) and stubs from the recorded hits in the event.

To emulate the effect of the track bending inside a magnetic field, the DUT was rotated with respect to the incident beam. The variation of the mean cluster width (number of strips in a cluster) with the beam incident angle for the non-irradiated module is shown in Figure 3. As the incident angle of the particles increases, the charge deposited is shared by multiple strips and hence the cluster width increases. For the CMS field strength of $B = 3.8\text{ T}$, the relation-

Fig. 3: Cluster width as a function of beam incident angle.

ship between the beam incident angle (α) and the transverse momentum (p_T) of the traversing particle for a radial position of the module (R) is given by $p_T [\text{GeV}] \approx \frac{0.57 \cdot R [\text{m}]}{\sin(\alpha)}$. The stub efficiency, defined as the ratio of the number of events with stubs matched to a track to the number of events with a track, was

measured for each incident angle. The stub efficiency as a function of p_T is shown in Figure 4. This turn-on curve is different for the two modules owing to different sensor spacing. The plot shows that the modules are efficient in selecting particle tracks above a $p_T \approx 2$ GeV with a resolution of 5.3%.

Fig. 4: Stub efficiency for the irradiated (blue) and non-irradiated (red) module as a function of the particle p_T . A radius of 60 cm was used for the calculation of the p_T from the beam incident angle (Sect. 4).

5 Summary

The performance of prototype 2S modules (irradiated and non-irradiated) with the CBC2 readout chip has been studied. The cluster width increases with the incident angle as expected. The concept of p_T discrimination has been demonstrated with a p_T threshold of 2 GeV for both the irradiated and non-irradiated module. The efficiency above the p_T threshold is maintained at 95% even for the irradiated module under the beam test conditions.

References

1. S. Chatrchyan et al., "The CMS experiment at the CERN LHC", JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004
2. M. Raymond, D. Braga et al., "The CMS binary chip for microstrip tracker readout at the SLHC", JINST 7 (2012) C01033, doi:10.1088/1748-0221/7/01/C01033
3. W. Ferguson, D. Braga et al., "The CBC microstrip readout chip for CMS at the high luminosity LHC", JINST 7 (2012) C08006, doi:10.1088/1748-0221/7/08/C08006
4. I. Rubinskiy, "An EUDET/AIDA Pixel Beam Telescope for Detector Development", Physics Procedia 37 (2012) 923, doi:10.1016/j.phpro.2012.02.434