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Measurements of the performance of a beam condition monitor prototype in a 5 GeV electron beam

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ABSTRACT

The Fast Beam Conditions Monitor, BCM1F, in the Compact Muon Solenoid, CMS, experiment was operated since 2008 and delivered invaluable information on the machine induced background in the inner part of the CMS detector supporting a safe operation of the inner tracker and high quality data. Due to the shortening of the time between two bunch crossings from 50 ns to 25 ns and higher expected luminosity at the Large Hadron Collider, LHC, in 2015, BCM1F needed an upgrade to higher bandwidth. In addition, BCM1F is used as an on-line luminometer operated independently of CMS. To match these requirements, the number of single crystal diamond sensors was enhanced from 8 to 24. Each sensor is subdivided into two pads, leading to 48 readout channels. Dedicated fast front-end ASICs were developed in 130 nm technology, and the back-end electronics is completely upgraded. An assembled prototype BCM1F detector comprising sensors, a fast front-end ASIC and optical analog readout was studied in a 5 GeV electron beam at the DESY-II accelerator. Results on the performance are given.

1. Introduction

The fast beam conditions monitor, BCM1F [1], delivers data about the machine induced background to the CMS and LHC control rooms, ensures a safe operation of the inner tracking detectors, and contributes for high quality data taking. The excellent time resolution of BCM1F of about 1 ns allows to discriminate between machine induced background particles and collision products.

BCM1F was successfully operated during the first running period up to 2012. It was composed of 8 diamond sensors positioned at a radius of about 4.5 cm around the beam pipe in two planes perpendicular to the beam on both ends and 1.8 m away from the interaction point. The sensors were equipped with fast and radiation hard front-end, FE-, ASICs with a peaking time of 25 ns and an analog optical readout chain.

At the back-end the signals were split and fed into sampling Analog-to-Digital Converters, ADCs, for the performance monitoring of the device as well as to discriminators. The discriminator output signals were mapped to a time window corresponding to a full turn of relativistic particles around LHC. This allows us to assign the counted particles to individual bunches. Gated counting was used to separate machine induced background from collision products. The rate of collision products was used for on-line luminosity measurement, independent from the central CMS data acquisition.

In 2015, the energy of the LHC has to be enhanced by a factor of almost 2 and, in addition, the time between two bunch crossings is reduced from 50 ns to 25 ns. Therefore, an upgrade of the beam condition monitors is required [2,3]. To tackle the higher rates the sensors were subdivided in two pads being read-out individually.

Also a dedicated FE-ASIC with 7 ns peaking time and a signal width of 9 ns at half maximum was developed. The back-end electronics was redesigned and replaced by a dead-timeless histogramming unit with 6.25 ns binning and a 1.25 Gs/s real time

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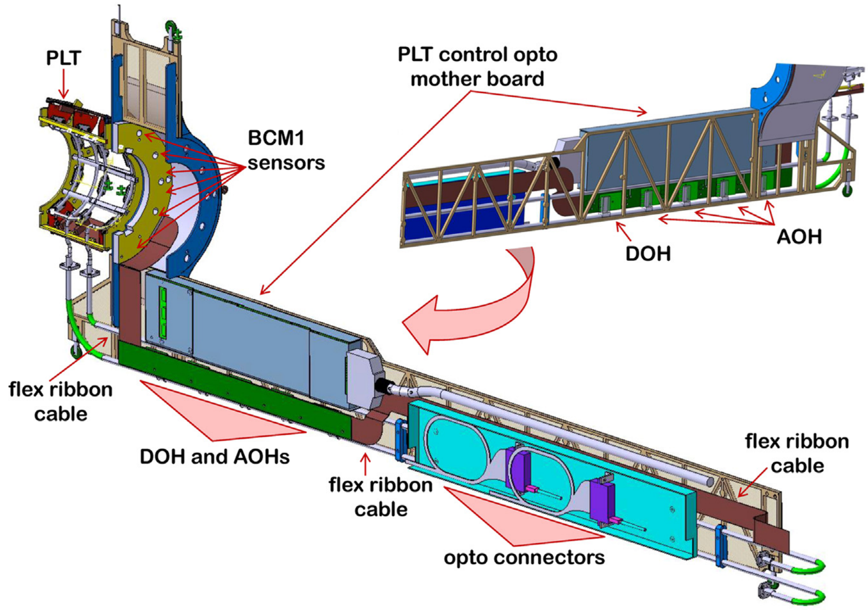

Fig. 1. The layout of a quarter of the very forward instrumentation inside CMS. The C-shaped PCB of BCM1F, mounted together with the PLT on a titanium frame, carries diamond sensors and FE-ASICs. The AOH boards transform electrical into optical signals.

Fig. 2. A photograph of a metallized diamond sensor (left) and a zoom of the gap between the two pads (right).

digitizer is in development. Again sampling ADCs are used for performance monitoring.

2. Layout of the upgraded BCM1F

A sketch of a quarter of the BCM1F detector and the Pixel Luminosity Telescope, PLT, is shown in Fig. 1.

Seen from the Interaction Point (IP) the three planes of the PLT are followed by BCM1F. Shown is a half-ring, made of an eight layer rigid C-shaped PCB continued by a flexible part of 1.9 m length. The half-ring carries sensors, FE-ASICs and passive components. The six sensors are positioned in azimuthal angle steps of 30°. Each sensor is metallized with two pads, resulting in 12 readout channels.

The whole BCM1F detector consists of four such half rings, positioned at 1.8 m distance at each end of the IP, with the sensors at a radius of 6.94 cm from the beam axis. The signals are transferred via the flexible PCB to custom-designed laser driver ASICs [4,5], which modulate the current of the edge-emitting laser diodes. The analog optical signals are transferred to the back-end electronics via single mode fibers.

At the back-end side the signals are converted to electrical signals using an opto-receiver module. They are distributed to discriminators with a double pulse resolution of 7 ns and to two independent digitizer systems in VME and Micro Telecommunications Computing Architecture, μTCA, standard.

The fast digitizer in μTCA standard with 1.25 Gs/s [6] will be used to replace the sampling ADC for performance monitoring, and when fully commissioned, for a more precise sampling of the time.

The discriminator output signals are fed in a look-up table to form coincidence between certain channels. They are also sent to a dead-time free histogramming unit [7] which maps the arrival time of the signals to a time interval of one LHC turn (89 μs). A binning of 6.25 ns is used.

2.1. Diamond sensors

Single crystal scCVD diamond sensors, produced by chemical vapor deposition by element6 [8], are used. The sensor area is roughly $5 \times 5\ \mathrm{mm}^2$ and the thickness is about 0.5 mm. The sensor surfaces are evened by reactive ion etching and metallized with a tungsten-titanium alloy (90:10 weight ratio) of 100 nm thickness.