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The Compact Muon Solenoid Experiment

Conference Report

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The new Fast Beam Condition Monitor using diamond and silicon sensors for luminosity measurement at CMS

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Abstract

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The new Fast Beam Condition Monitor using poly-crystalline diamond sensors for luminosity measurement at CMS

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Abstract

The Fast Beam Condition Monitor (BCM1F) is used in CMS to measure beam induced background and precision luminosity. The system in its current implementation was first installed in 2014, equipped with single-crystalline (sCVD) diamond sensors. After some radiation damage, erratic occurrence of HV instabilities required lowering of the operational HV and the system became inefficient, resulting in unstable measurements. The system was replaced in 2017 with poly-crystalline (pCVD) diamond sensors and silicon (Si) sensors. Both new sensor types show significantly better operational stability. The luminosity performance of pCVD and Si based luminosity measurement is discussed.

Keywords: Solid State detectors, Diamond, Luminosity measurement, CMS, BCM1F

1. Introduction

The BCM1F detector is a dedicated beam monitoring device operated by the BRIL group of the CMS experiment [1]. It is used to measure luminosity and beam-induced-background rates. To achieve this a fast front-end amplifier [2] is used, which provides fast recovery to baseline. The system in its current form was first installed in 2014 and was in operation during 2015/16, where 500 μm thick single-crystalline diamond (sCVD) sensors were used. In operation, after a small amount of radiation damage, the sensors showed erratic break through behavior, causing the HV to trip after many hours of operation. This instability could only be solved by reducing the operational HV. Operating at HV as low as 100 V (E ~ 0.2 V/μm) resulted in significantly reduced charge collection and minimal ionizing particles could not be discriminated any more. A replacement using the same electronics with poly-crystalline diamond sensors (pCVD) was built in 2016 and operated since 2017.

2. Expected detector performance

To prevent non-linear behavior of the measured luminosity and achieve good stability, the pulse heights from minimal ionizing particles (MIP) should be well separated from the peak detection threshold. pCVD diamonds promise good instrinsic stability [3]. Due to the heterogeneous nature of pCVD diamonds, particle hits can create relatively low amount of charge, leading to small pulse heights. A test beam study with pCVD diamonds in the BCM1F readout showed that the MIP peak can be separated from noise, promising sufficiently efficient operation, however the pulse height spectrum (fig. 1) does not reach

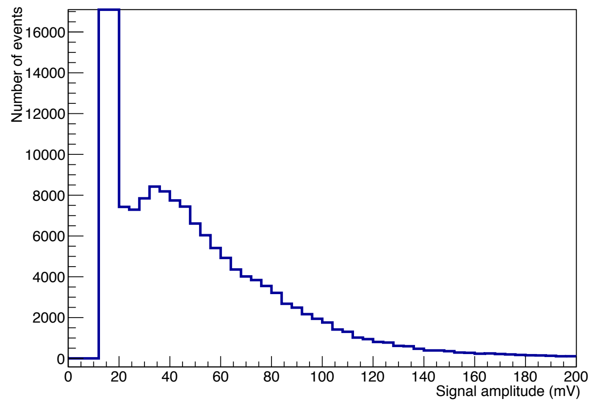

Figure 1: Pulse height spectrum of a pCVD diamond at 1000V in the BCM1F readout as measured in a test beam.

zero below the MIP peak. Even if the peak detection threshold is placed in this minimum, small changes in efficiency of the sensor or the electronics translate directly to a change in the measured hit rate.

3. Luminosity performance in 2017

To maintain the detector efficiency, the sensors have to be operated at maximum HV, which is limited by erratic currents occurring at higher HV. In operation a HV between 400 V and 750 V was possible. The sensors maintained a pulse height spectrum similar to figure 1. The key quality parameter for a luminosity measurement is a linear response of the measurement from low rate calibration measurement to high rate nominal operation. To measure the long term stability and the nonlinearity, quick calibration scans are performed in nominal operation at the start and the end of every LHC fill to obtain the

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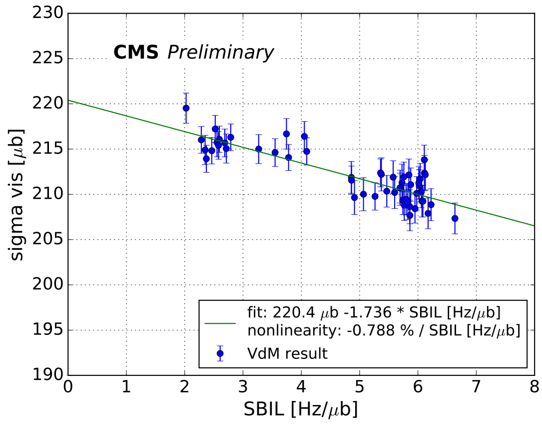

Figure 2: σ_{vis} as function of single bunch instantaneous luminosity for pCVD diamond based luminosity.

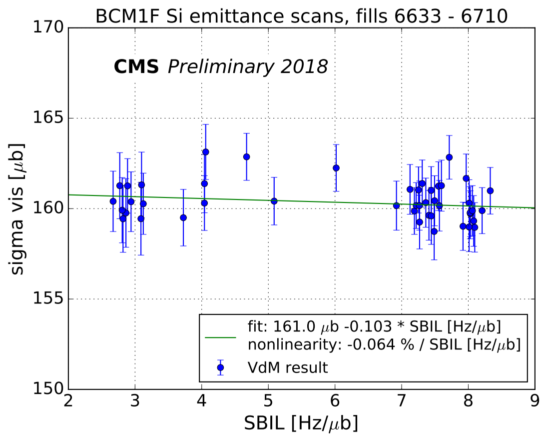

Figure 3: σ_{vis} as function of single bunch instantaneous luminosity for silicon diode based luminosity.

calibration constant σ_{vis} [4]. Figure 2 shows the σ_{vis} as function of single bunch instantaneous luminosity (SBIL), showing a slightly decreased peak detection efficiency at high luminosity. The change in performance may be a result of changes in the sensor, the analog optical pulse transmission or the backend electronics. The linear fit to the calibration as function of luminosity is used to calculate the correction factors for the nonlinearity to obtain a very linear measurement of the instantaneous luminosity.

4. Silicon sensor alternative

Compared to diamond, silicon sensors have a higher capacitance and therefore more front end noise, however more charge is generated. A separation of MIP peak and noise promises good measurement stability. The σ_{vis} as function of instantaneous luminosity is shown in figure 3. No rate-dependency is observed. With irradiation, the leakage current of the silicon sensors increases. The front end electronics is very sensitive to DC currents and saturated from leakage current after a delivered luminosity of about 80 fb^{-1}. To improve the longevity of silicon diodes in this system, we propose that a future upgrade uses A/C-coupled diodes to prevent leakage current in the front end ASIC.

5. Conclusion

The operational experience with the BCM1F replacement system shows much better reliability of pCVD diamond sensors over sCVD diamond sensors in a high rate environment. The disadvantage of low charge collection did not show to be problematic. A slight non-linearity is observed with an about 2-3 % reduced efficiency at peak luminosity compared to the late part of a typical LHC fill. The prototype silicon diode sensors show excellent linearity.

Acknowledgments

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