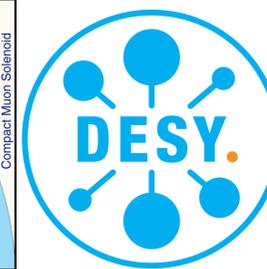
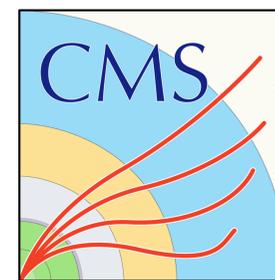


The new Fast Beam Condition Monitor using diamond sensors for luminosity measurement at CMS.

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on behalf of the CMS collaboration

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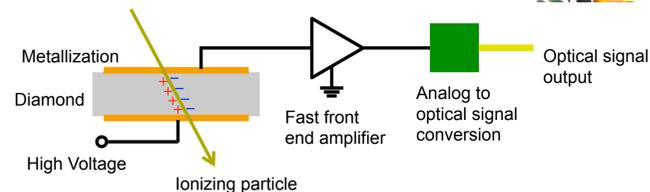
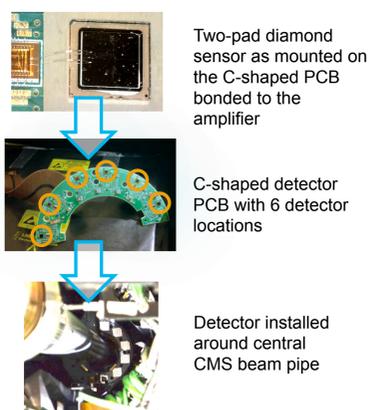
Introduction

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 after a particle hit. An analog optical pulse transmission allows the readout to be placed ~ 100 m away from the detector. A discriminator is used to find pulses, which are counted by the dedicated Realtime Histogramming Unit (RHU), which histograms hits as a function of position in the LHC orbit with 6.25 ns time resolution (4 bins per LHC bunch crossing).

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 ($E \sim 0.2$ V/ μm) resulted in significantly reduced charge collection and minimal ionizing particles could not be discriminated any more. A replacement using the same electronics was built in 2016 and operated since 2017. Poly-crystalline diamond sensors (pCVD) are used instead. Some sCVD and silicon sensors are also installed for testing and comparison purposes. While pCVD sensors offer less charge collection than un-irradiated sCVD sensors, they provide much better stability at high particle rates and with increasing radiation damage.

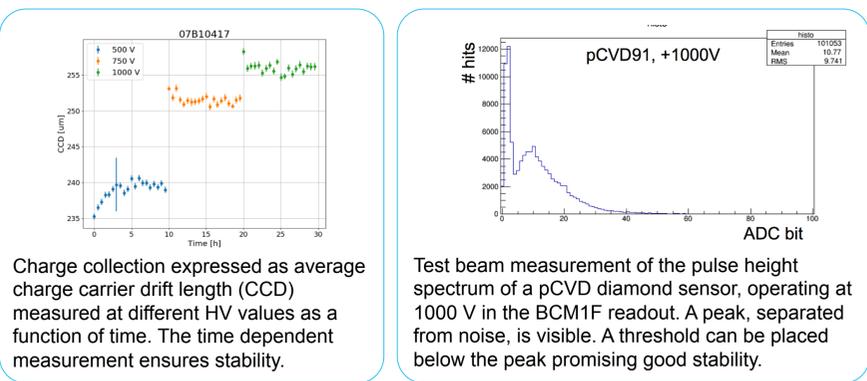
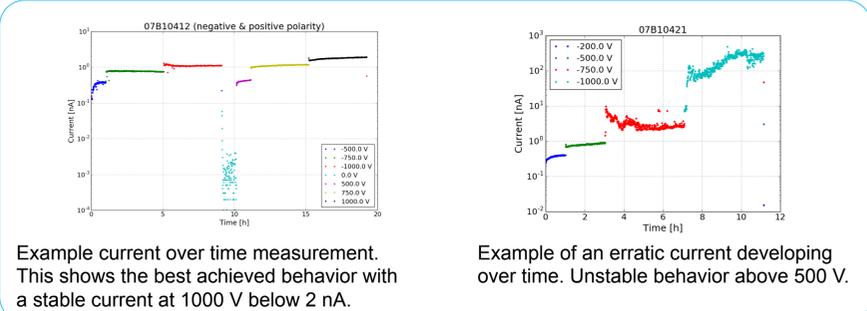
Detector concept

- Single particle detection using 10 poly-crystalline diamond sensors (pCVD), placed around the LHC beam pipe.
- Diamond is used as a solid state ionization chamber. Electron-hole pairs, created by ionizing particles, drift along the electric field induced by the HV and create a current pulse.
- Fast charge sensitive pre-amplifier.
 - 50 mV/fC
 - 7 ns rise time, 10 ns FWHM
 - Pulse recovery within 25 ns
- An analog-to-optical conversion for long distance pulse transmission is used.



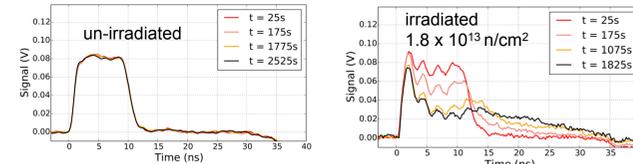
Qualification of diamond sensors

- Various types of defects can be present in diamond, resulting in both deep and shallow traps.
- When sensors are irradiated, charge carriers fill the traps. This process is called pumping.
- Measurements are performed using high rate Sr-90 source to ensure sensors are fully stabilized when taking data.
- Erratic current can occur after many hours. Long exposure time at high particle rate is necessary to predict diamond behavior in operation.
- Charge collection and test beam measurements predict sufficient signal amplitude.

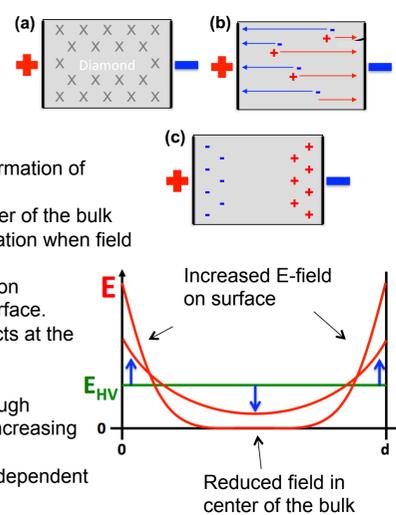


Radiation damage induced polarization

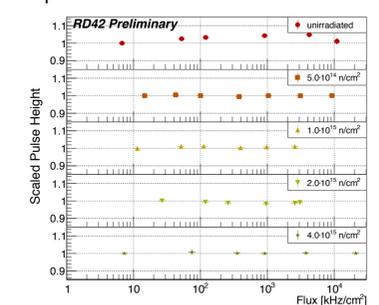
Measurement of the electric field in sCVD diamond using Transient Current Technique (TCT). Un-irradiated sensors show a constant E-field. Irradiated sensors have a constant E-field at the start of measurement, but as charge builds up in the bulk, the E-field deforms. [3]



- Radiation damage creates defects in the diamond bulk.
 - These defects are typically neutral vacancies.
- When free charge carriers are trapped at defects they form a fixed space charge.
- Space charge results in a deformation of electrical field
 - Field is reduced in the center of the bulk
 - charge carrier recombination when field is very low.
 - Reduced charge collection
 - Field is increased at the surface.
 - Charge generating defects at the diamond/metal interface become active.
 - HV at which a breakthrough occurs is reduced with increasing polarization.
- Shallow defects lead to a rate dependent polarization.
 - HV trips occur at high rates only

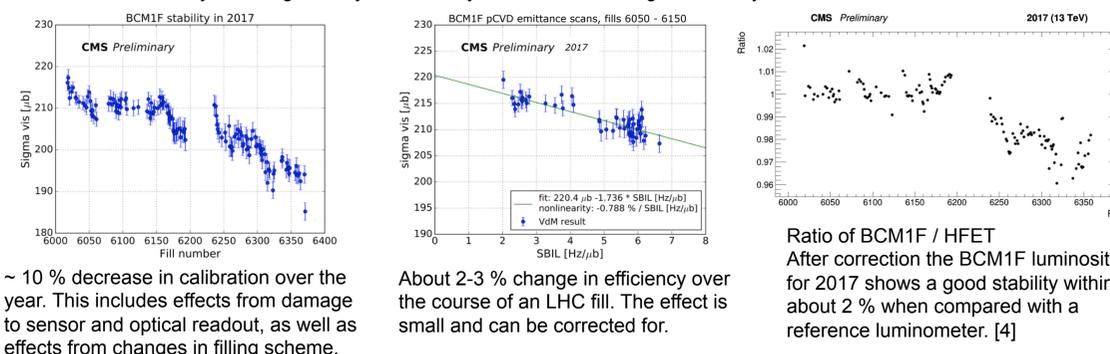


pCVD diamond suffers significantly less from radiation damage induced polarization compared to sCVD sensors. A much better stability with irradiation is expected.



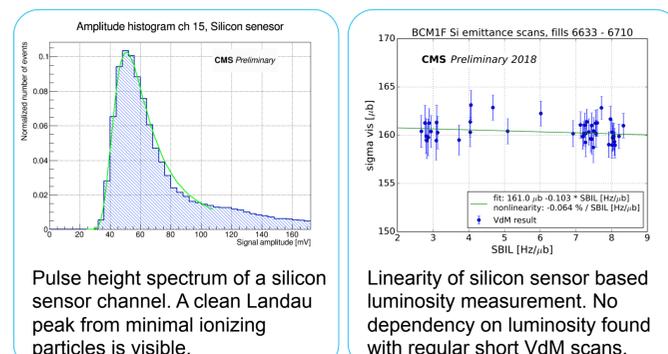
Luminosity performance in 2017

- Calibration of luminosity detectors done with Van der Meer scans. [4]
 - Absolute calibration obtained from yearly dedicated VdM fill.
- Regular short VdM scans in every LHC fill to obtain approximate calibration (so called emittance scans). [5]
 - Measurement of long term stability and linearity (luminosity dependent calibration).
- Offline luminosity including stability and linearity corrections shows good stability.



Silicon sensor alternative

- Prototype silicon sensors are installed instead of diamond.
- Excellent performance
 - Separation of signal and noise.
 - Excellent linearity of luminosity
- Expect life time of about 100 fb⁻¹ due to increased leakage current.
 - Future upgrade will use A/C-coupled sensors to mitigate leakage current issues.



Summary

- Modification to use pCVD instead of sCVD sensors in BCM1F provides much better operational stability.
 - Failure of sCVD is consistent with radiation damage induced rate dependent polarization.
 - New pCVD are able to operate at significantly higher HV.
 - Rate dependent polarization was shown by TCT measurements in combination with TCAD simulations.
 - Small efficiency drifts as function of time and total rate can be compensated for by using CMS emittance scan analysis.
 - BCM1F is now successfully used as one of the CMS online luminometers. Luminosity performance will be improved further by further studying the linearity and correction model.
- Acknowledgements**
- We thank the RD42 collaboration for the help in purchasing the pCVD diamonds, as well as the preparing of the diamonds and metallization.

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