Available on CMS information server

CMS DP -2012/029

The Compact Muon Solenoid Experiment

CMS Performance Note

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

23 November 2012

BCM Detector Performance Plots showing radiation damage to diamond sensors based on leakage current measurements and fluka simulations

On behalf of the CMS Collaboration

Abstract

The Beam Condition Monitor (BCM) of the CMS detector at the LHC is a protection device similar to the LHC Beam Loss Monitor system. While the electronics used is the same, poly-crystalline Chemical Vapor Deposition (pCVD) diamonds are used instead of ionization chambers as the BCM sensor material. The main purpose of the system is the protection of the silicon Pixel and Strip tracking detectors by inducing a beam dump, if the beam losses are too high in the CMS detector.

By comparing the detector current with the instantaneous luminosity, the BCM detector efficiency can be monitored. Over the LHC running period thus far, a reduction in signal strength has been observed. An explanation for this effect will be discussed in this paper, depending on the sensor type and location in CMS.

The number of radiation-induced defects in the bulk material, reduces the average drift length (CCD) of the charge, and hence lowers the signal. The number of these induced defects can be simulated using FLUKA monte-carlo. The cross section for creating defects increases with decreasing energies of the impinging particles. This explains, why diamond sensors mounted close to heavy calorimeters experience more radiation damage, owing to the high number of low energy neutrons produced in these regions. The signal decrease was stronger than expected from the number of simulated defects. Here polarization from trapped charge carriers in the defects is a likely candidate for explaining the difference, as suggested by Transient Current Technique (TCT) measurements. With increasing trap density charge carriers get more frequently trapped, forming a corresponding increase in local polarization effects. Mounted at the same location, the single-crystalline (sCVD) diamond sensor shows a faster relative signal decrease than the pCVD sensor. This is expected, since the relative increase in the number of defects is larger in sCVD than in pCVD sensors.

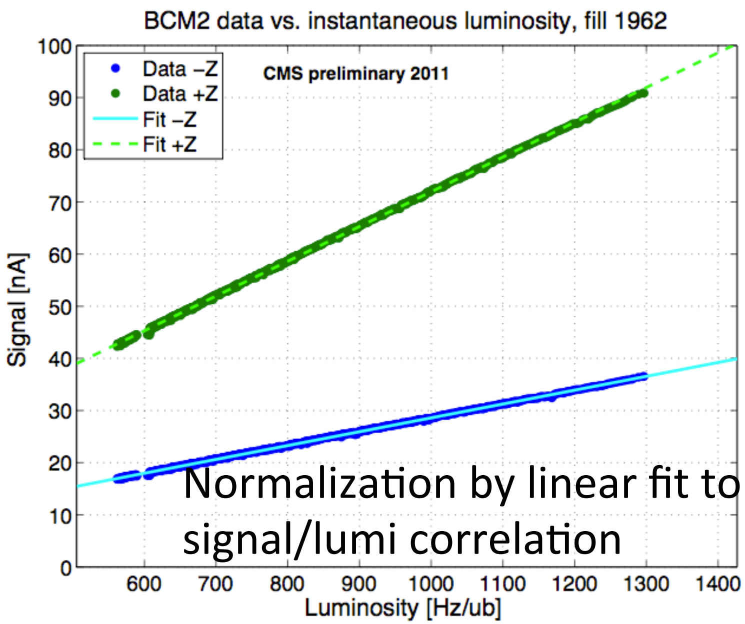
BCM Detector Performance Plots showing radiation damage to diamond sensors based on leakage current measurements and fluka simulations

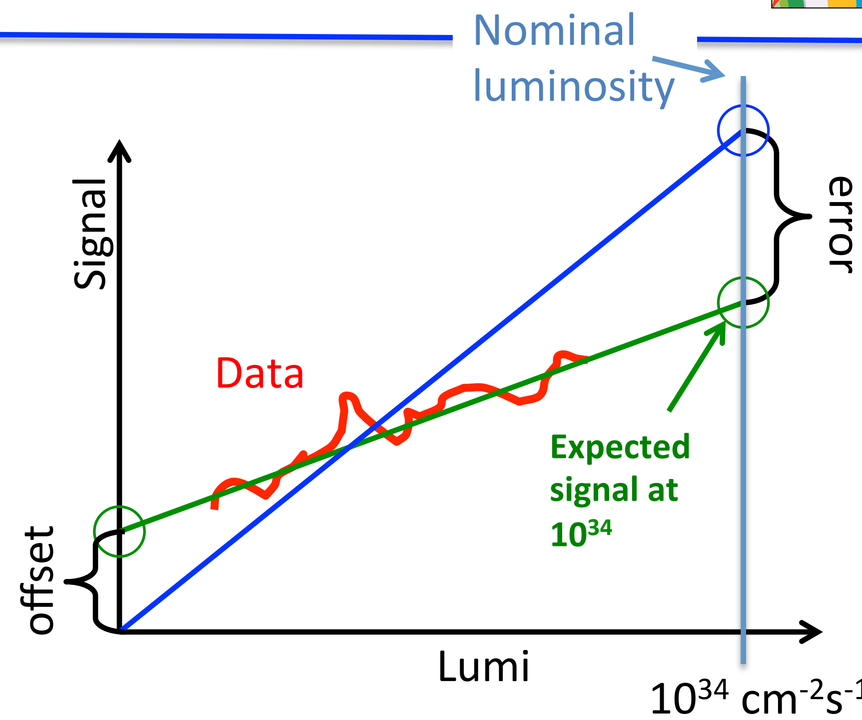
On behalf of the CMS Collaboration

BCM Detector Performance September 2012

- Plots for approval here were first approved for RESMDD2012 conference: http://www2.de.unifi.it/RESMDD12/
  - Title of talk: “Radiation damage in the diamond based beam condition monitors of the CMS experiment at the Large Hadron Collider (LHC) at CERN”, Moritz Guthoff
- Plots explain loss of detector efficiency as a function of exposure to radiation
  - Show decrease of signal efficiency of BCM detectors.
  - Compare with expectations based on FLUKA.
  - Present the lab tests that have been performed afterwards.
  - Give potential explanation of observed signal decrease

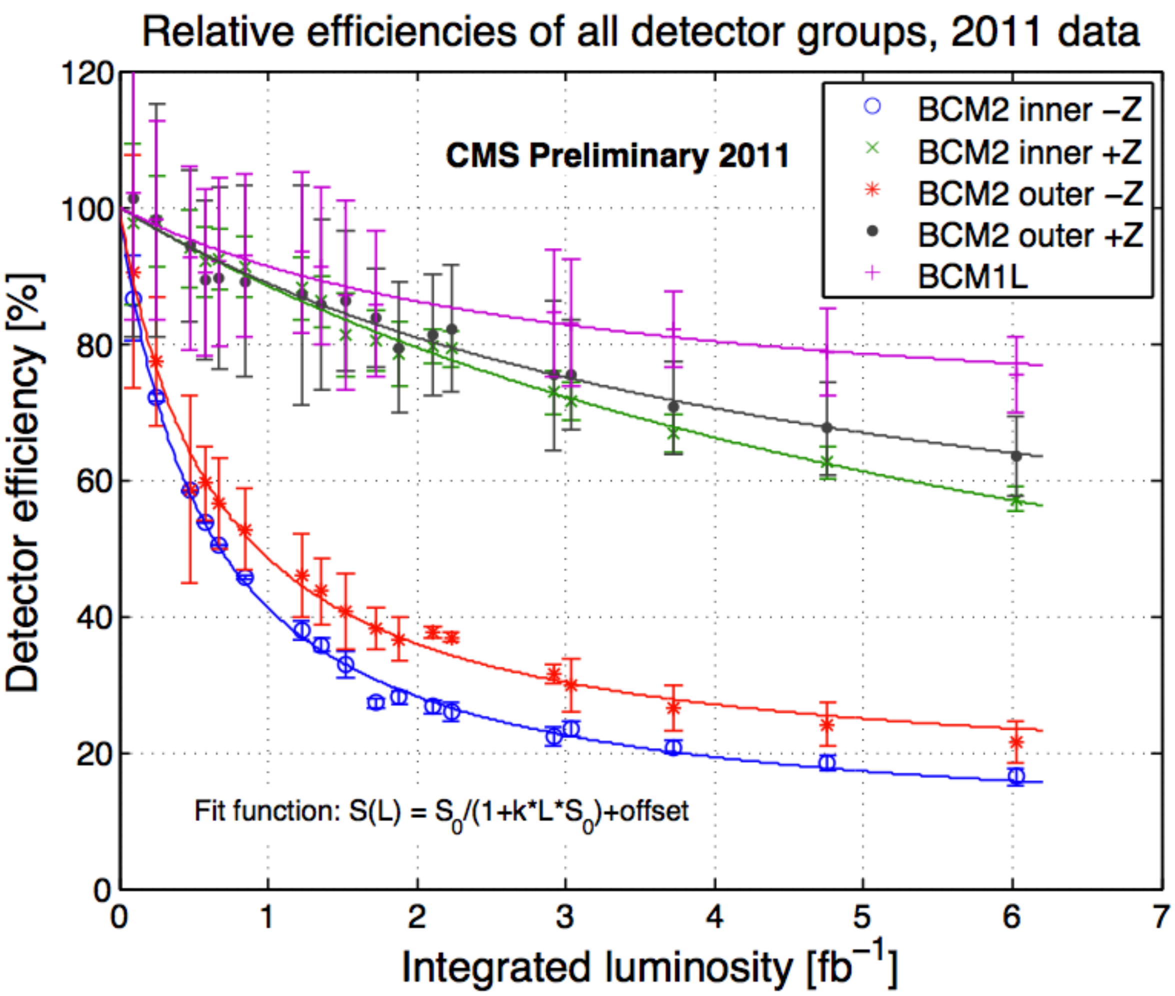
Normalization and error bars





- For every analyzed fill the data is plotted vs. the instantaneous luminosity and a linear fit is applied.
- This is used to extrapolate the signal to nominal luminosity, which is always assumed to be 10^{34} cm^{-2}s^{-1}.
- The errors on the results of the unconstrained linear fits are very small.
- Due to non-linearity of the system the fit has an offset greater than the error on the fit parameters. A linear fit constrained to a zero offset is used to define the error on this normalization method.

Signal efficiency as function of integrated luminosity

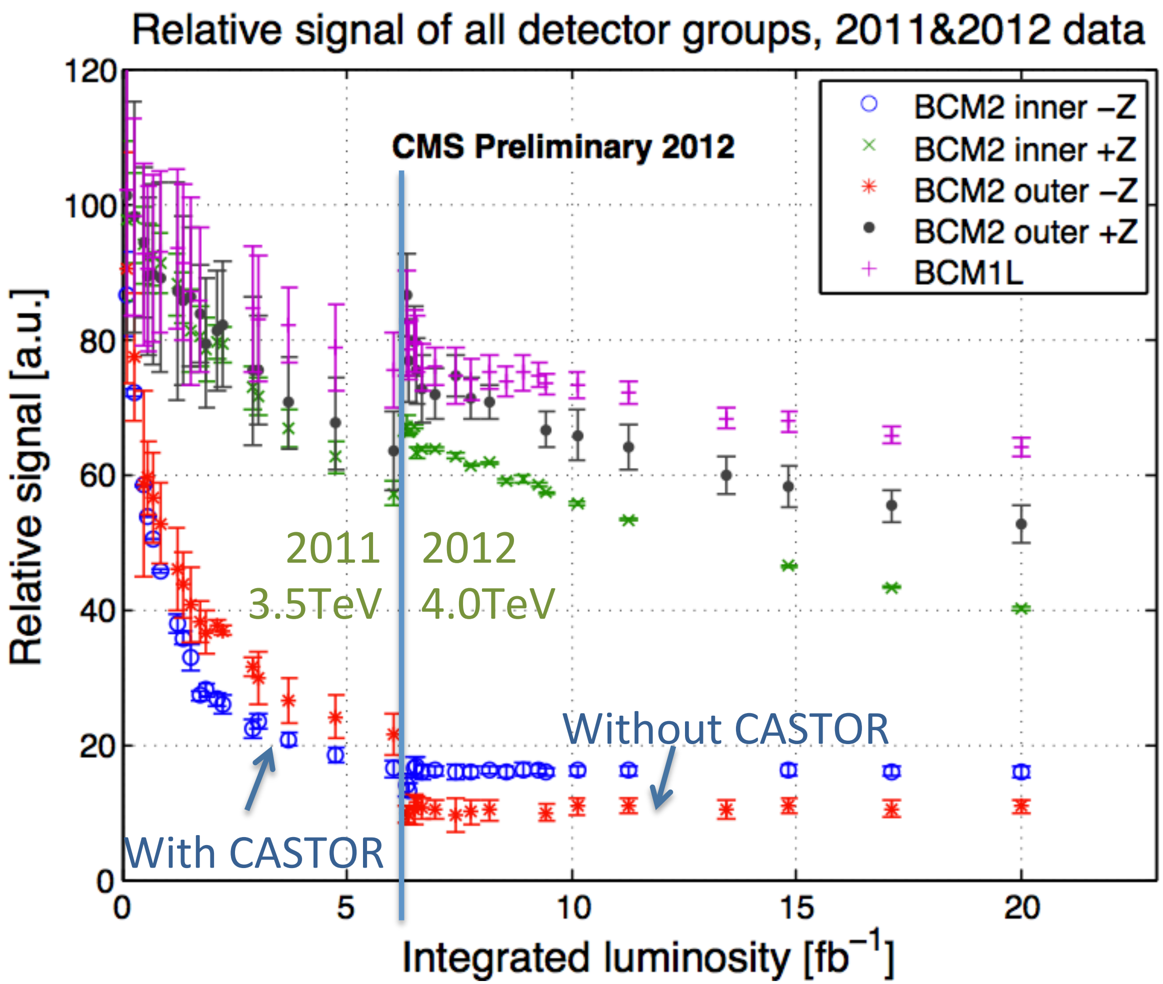


Signal efficiencies from 2011 data of the BCM detectors at the five different locations as a function of integrated luminosity. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used. The error bars are calculated by refitting the data using a linear fit constrained to zero. The total error is calculated by combining:

1. The statistical error on the fit parameters of the unconstrained linear fit.
2. The systematic component is calculated by constraining the fit to zero offset reflecting the non-linearity of the system.

The parametric function of a hyperbolic curve is used to fit the data. This is an updated plot of a previously approved one, where the online luminosity was used.

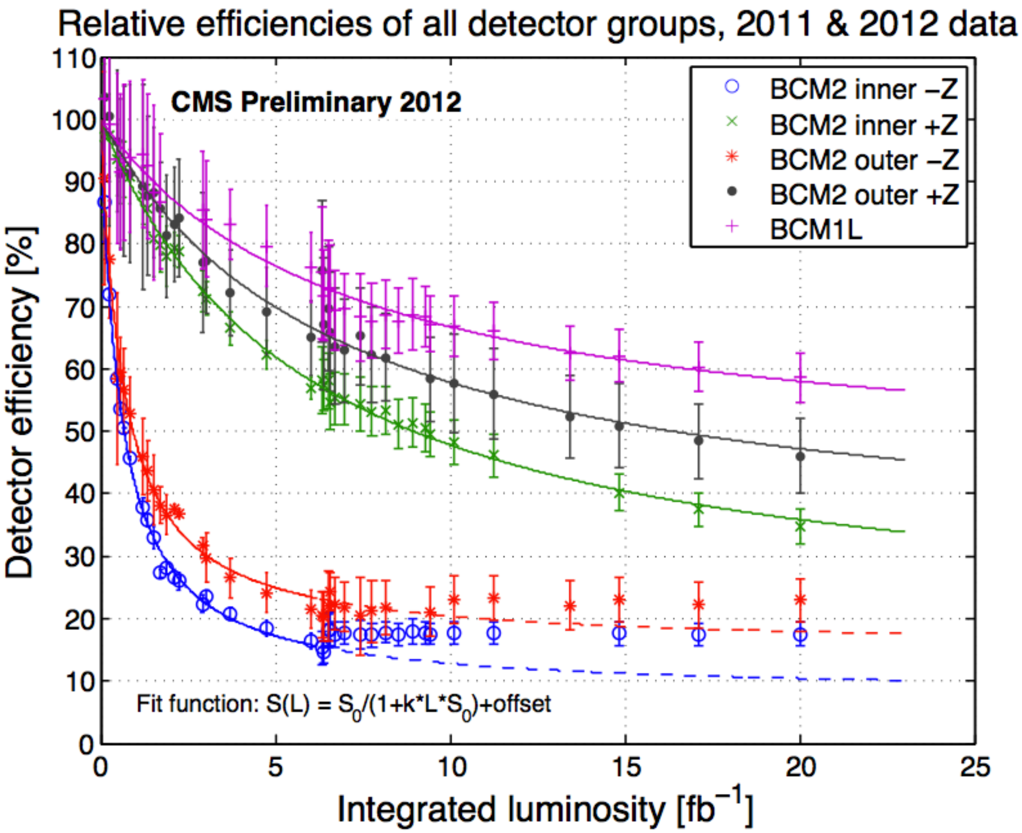
Relative signals during 2011 and 2012 running period



Relative signals from 2011 and 2012 data of the BCM detectors at the five different locations as a function of integrated luminosity. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used. The error bars are calculated by using the offset of the linear fit as benchmark.

Due to the different radiation environments during 2011 and 2012 the signal levels are different. An increase in signal level is visible on BCM2 +Z and BCM1L, which is a result of the higher collision energy. In addition CASTOR was removed changing the radiation field at BCM2 –Z inner and outer. The amount of backscattered neutrons at this location is extremely reduced after the CASTOR removal. Therefore the signal is rather constant for BCM2 –Z inner (beam energy effect, and CASTOR effect cancel out) and even steps down for BCM2 –Z outer (CASTOR effect dominant since collision products are very few at this location). Also the decay due to radiation damage stopped for BCM2 –Z, owing to the reduction in the neutron flux produced by CASTOR.

Signal efficiency as function of integrated luminosity



Signal efficiencies from 2011 and 2012 data of the BCM detectors at the five different locations as a function of integrated luminosity. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used. The 2012 signals are multiplied with a correction factor to take into account the different radiation environment due to higher beam energy and the removal of CASTOR on the –Z end. This correction factor was obtained from FLUKA simulations.

The total error is calculated by combining:

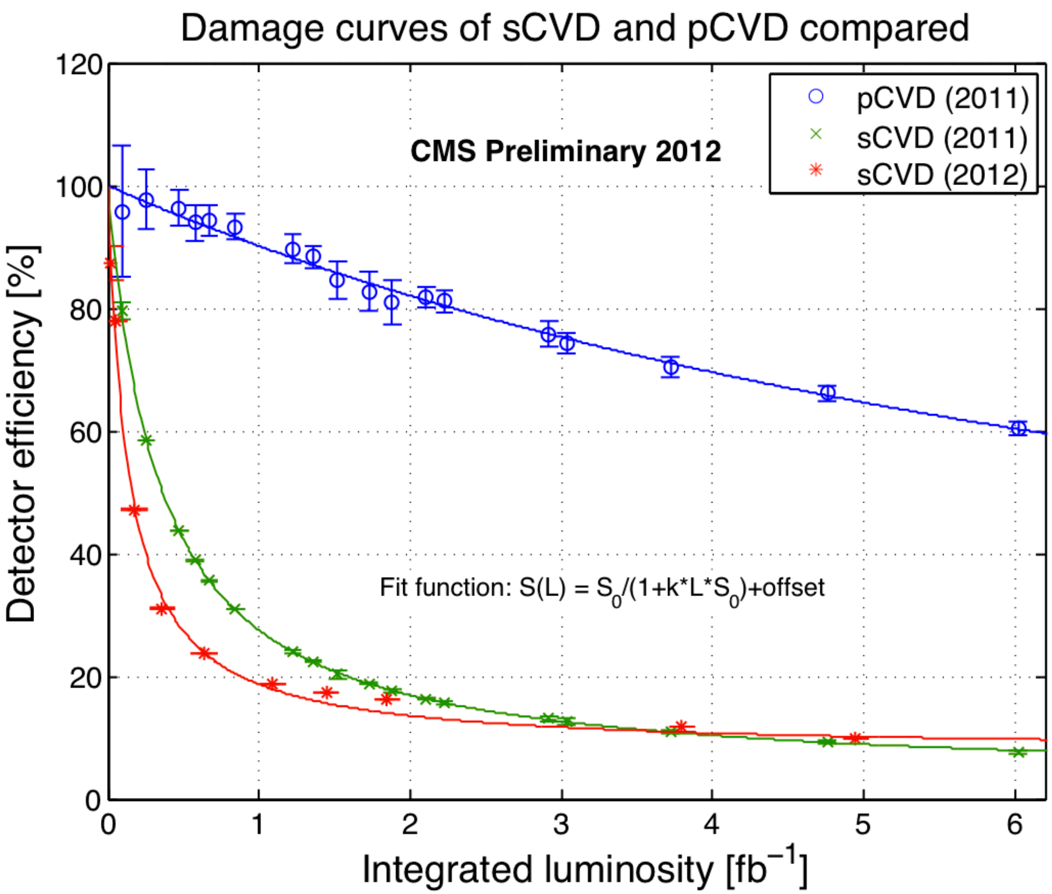
1. The statistical error on the fit parameters of the unconstrained linear fit.
2. The systematic component is calculated by constraining the fit to zero offset reflecting the non-linearity of the system.
3. For 2012 data the statistical error on the correction factor from FLUKA is added.

The parametric function of a hyperbolic curve is used to fit the data. For BCM2 the fit is only applied to 2011 data since the significantly reduced radiation environment stopped the signal decay. The error bars are used as weight for the fitting.

Since the CASTOR detector directly behind BCM2 –Z was removed the amount of low energy neutrons reduced drastically. The radiation environment is therefore much less harsh in 2012. This results in the diamond signal of BCM2 –Z seems to stabilize.

For BCM2 +Z and BCM1L the radiation environment is similar between 2011 and 2012 and therefore the decay of signal continues as expected.

Comparison of prototype singe-crystal and poly-crystalline diamonds installed at same locations



The signal efficiency of two prototype single-crystal diamonds (sCVD) located at BCM2 +Z inner near together with efficiency of the poly-crystalline diamond (pCVD) at the same location. One single-crystal was installed during 2011 and one during 2012 at the same location. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used.

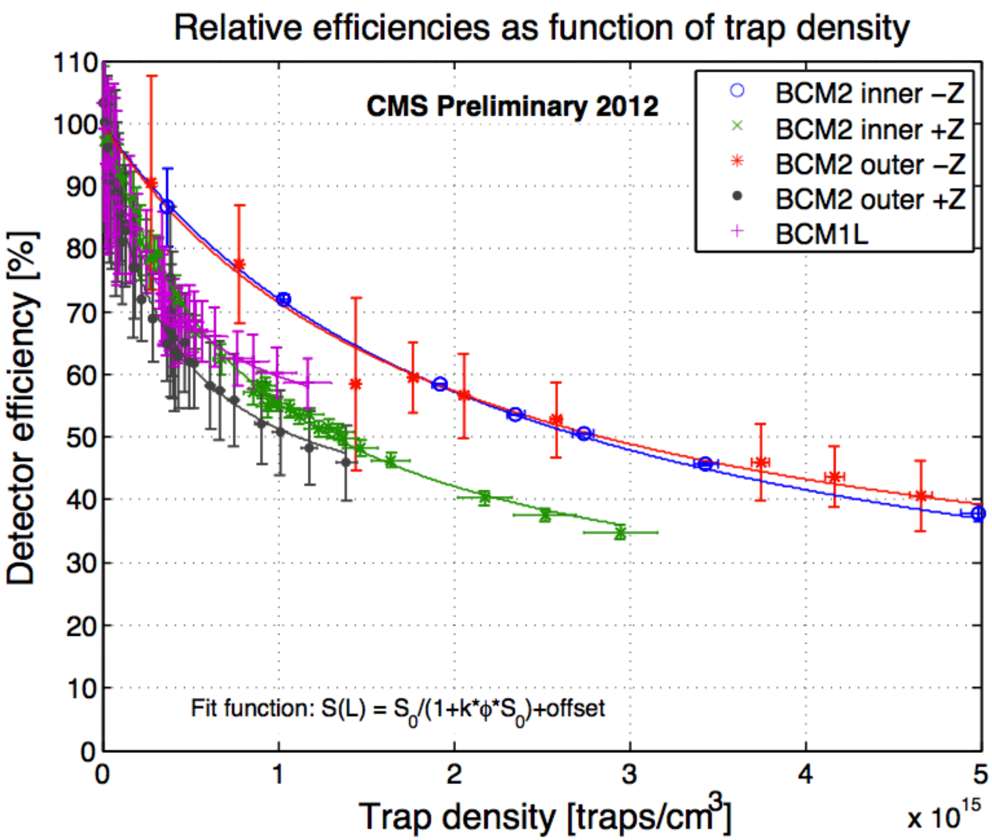
The total error is calculated by combining:

1. The statistical error on the fit parameters of the unconstrained linear fit.
2. The systematic component is calculated by constraining the fit to zero offset reflecting the non-linearity of the system.

A sCVD diamond decays faster than a pCVD (relative to its initial signal) as expected from the theoretical decay function. All diamonds are located at exactly the same position. Therefore they sit in the same radiation environment.

This is an updated version of a previously approved plot where the 2012 single-crystal was not present.

Detector efficiencies as function of trap density as simulated with FLUKA



Signal efficiencies from 2011 and 2012 data of the BCM detectors at the five different locations as a function of trap density. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used. The trap density was simulated by FLUKA using the displacement per atom scoring (DPA). The 2012 signals are multiplied with a correction factor to take into account the different radiation environment due to higher beam energy and the removal of CASTOR on the –Z end. This correction factor was obtained from FLUKA simulations.

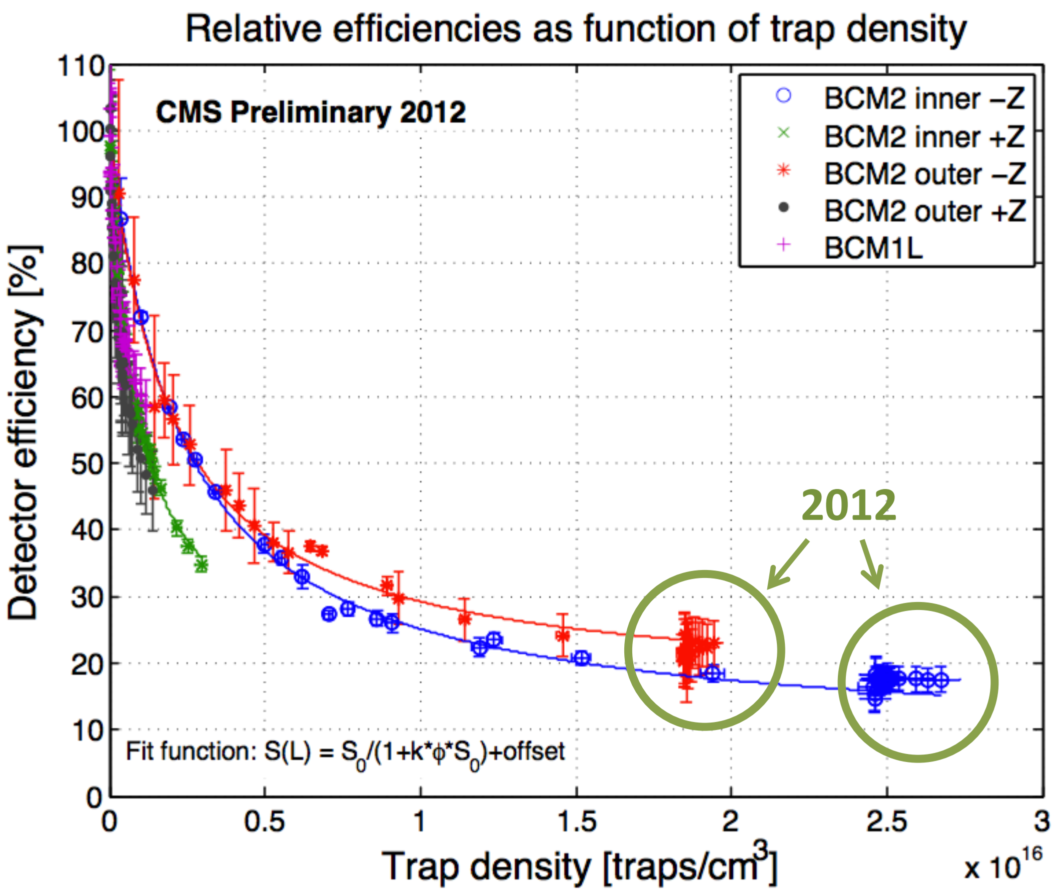
The total error is calculated by combining:

1. The statistical error on the fit parameters of the unconstrained linear fit.
2. The systematic component is calculated by constraining the fit to zero offset reflecting the non-linearity of the system.
3. For 2012 data the statistical error on the correction factor from FLUKA is added.
4. The horizontal errors are calculated from the errors of the DPA scoring.

The parametric function of a hyperbolic curve is used to fit the data. The error bars are used as weight for the fitting.

The discrepancy between the BCM2 –Z data and the other detectors is most likely due to approximations in the geometry of the FLUKA model. CASTOR might not be correctly modeled.

Detector efficiencies as function of trap density as simulated with FLUKA



Signal efficiencies from 2011 and 2012 data of the BCM detectors at the five different locations as a function of trap density. For normalization of the signal and for obtaining the integrated luminosity the HF offline luminosity was used. The trap density was simulated by FLUKA using the displacement per atom scoring (DPA). The 2012 signals are multiplied with a correction factor to take into account the different radiation environment due to higher beam energy and the removal of CASTOR on the –Z end. This correction factor was obtained from FLUKA simulations.

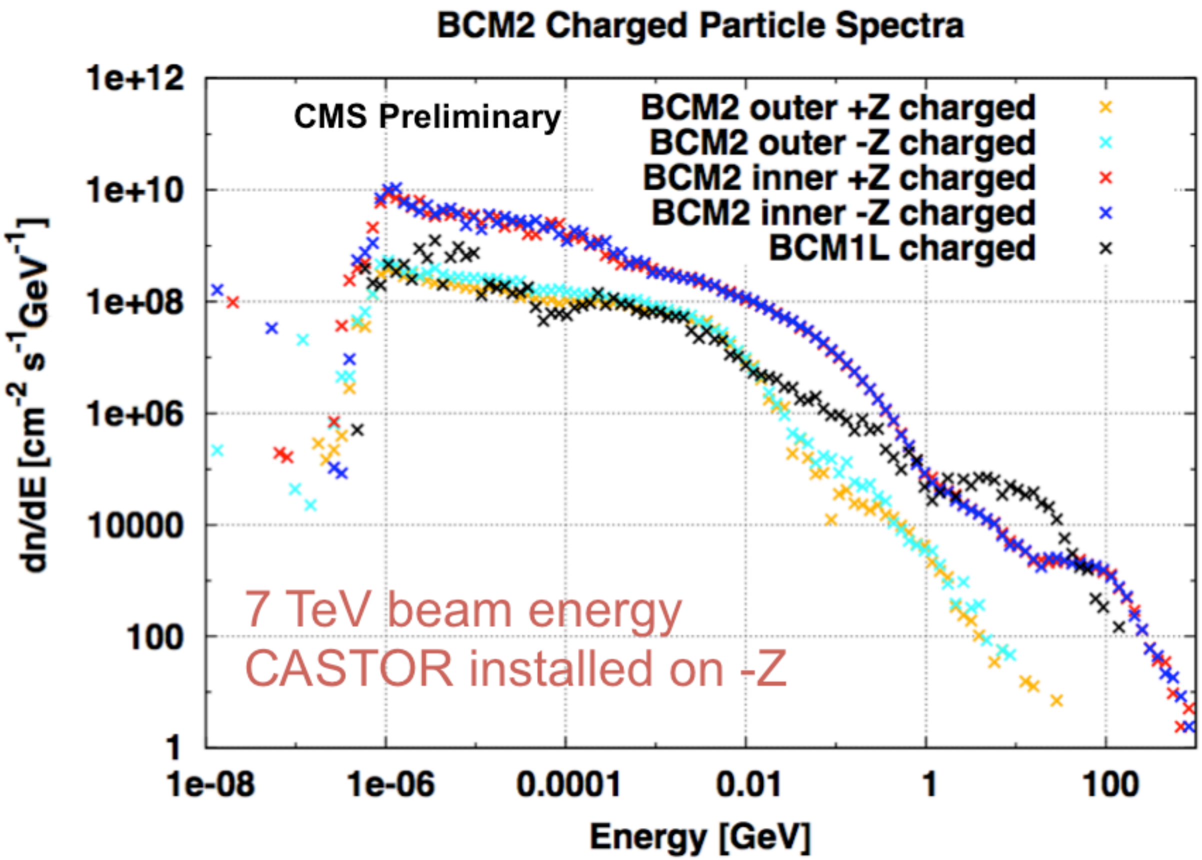
The total error is calculated by combining:

1. The statistical error on the fit parameters of the unconstrained linear fit.
2. The systematic component is calculated by constraining the fit to zero offset reflecting the non-linearity of the system.
3. For 2012 data the statistical error on the correction factor from FLUKA is added.
4. The horizontal errors are calculated from the errors of the DPA scoring.

The parametric function of a hyperbolic curve is used to fit the data. The error bars are used as weight for the fitting.

This plot shows the same data as the one before with the full range of trap density of BCM2 –Z. This shows that the damage in 2012 (the many points at the end of the curve) is very small compared to the damage from 2011 for this location, because of the removal of the CASTOR detector.

Particles Spectra of charged particles at BCM locations from FLUKA simulations

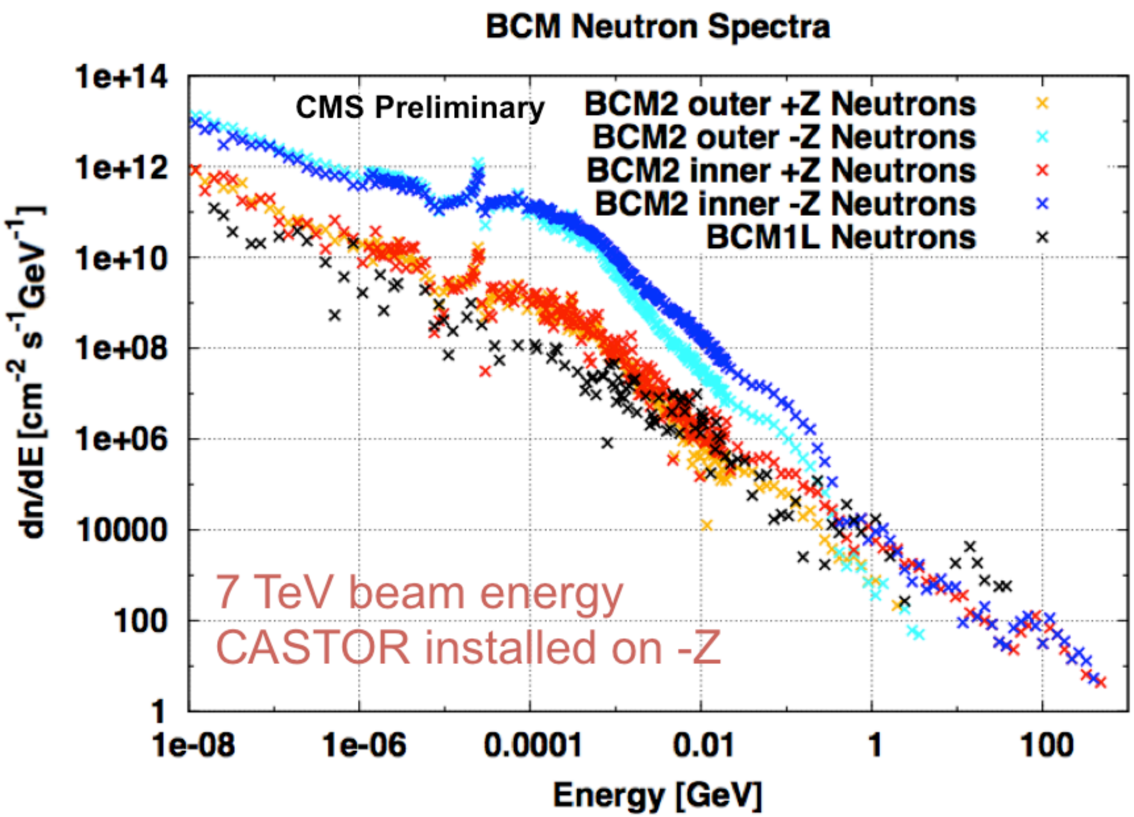


Particle energy spectra of charged particles at the location of the BCM detectors simulated with FLUKA.

The rates are normalized per cm^2 and per second for nominal luminosity. Beam energy is 7TeV.

For this simulation run CASTOR is included on the –Z end. However there is no difference in the radiation environment of charged particles comparing BCM2 +Z with –Z.

Particles Spectra of neutrons at BCM locations from FLUKA simulations



Particle energy spectra of neutrons at the location of the BCM detectors simulated with FLUKA.

The rates are normalized per cm^2 and per second for nominal luminosity.

For this simulation run CASTOR is included on the –Z end. This results in a increased neutron rate at BCM2 –Z compared to BCM2 +Z by a factor 100 below 100MeV.

The neutron environment at BCM1L is roughly a factor of 10 lower compared to BCM2 +Z for low energy neutrons.

This correlates well with the observed radiation damage showing that the observed radiation damage is inflicted by low energetic neutrons.