EXPERIMENTAL RESULTS FROM THE CHARACTERIZATION OF DIAMOND PARTICLE DETECTORS WITH A HIGH INTENSITY ELECTRON BEAM *

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Abstract

Understanding the sources of ultra-fast failures, with durations of less than 3 LHC turns, is important for a safe operation of the LHC, as only passive protection is possible in these time scales.

Diamond particle detectors with bunch-by-bunch resolution and high dynamic range have been successfully used to improve the understanding of some new ultra-fast loss mechanisms discovered in the LHC.

To fully exploit their potential, diamond detectors were characterized with a high-intensity electron beam (1E5 to 1E10 electrons per shot). For the first time their efficiency and linearity has been measured in such a wide range of intensities. In this paper the experimental setup will be described and the signals of the different detectors will be discussed.

Finally, future applications of these detectors in high-radiation applications will be discussed.

DIAMOND BASED PARTICLE DETECTOR

The detector characterization tests were conducted with primary electron beam at the Beam Test Facility (BTF) at INFN Frascati, Italy. For these experiments three diamond particle detectors (dBLMs) specially designed for high-fluence experiments in collaboration with CIVIDEC (Vienna, Austria) were used. They consist of a pCVD diamond with a diameter of 5 mm, a thickness of 100 μm and gold electrode with a diameter of 4 mm. The bias voltage was choosen between 70 - 230 V, which corresponds to an electric field strength of 0.7 - 2.3 V/μm across the diamond crystal. The detector was connected to a 50 Ohm terminated measurement system with an oscilloscope (see Fig. 1). [1] [2].

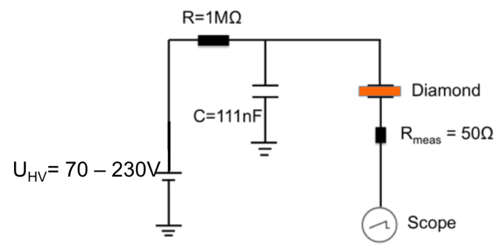

Figure 1: Circuit diagram of a diamond detector. The bias voltage was 70-230V, the diamond was connected to a 50 Ohm terminated read-out system.

EXPERIMENTAL SETUP

Figure 2 and 3 show the experimental setup. The setup was installed 50 cm downstream of the 0.1 mm thick beryllium beam window, which seals off the beam line. The detector PCB with the active polycrystalline diamond was fixed on the front plate of a hollow copper cylinder (20 cm length, 5 cm diameter). To increase the angular acceptance the diameter of the hole in the cylinder had a diameter of 6 mm, i.e. 1 mm larger than the active detector material. Furthermore the hole's diameter in the copper cylinder was increased stepwise by 1 mm every 5 cm, leading to an angular acceptance of 10 mrad. To minimize the bremsstrahlung a 6 cm long hollow lead cylinder with a 16 mm hole diameter was added after the copper cylinder. The movable support allowed an on-axis alignment of the detector setup with a incremental transverse adjustment of 0.5 mm. The angular deviation was small (δ horiz. plane 0.5 mrad, δ vert. plane 0.5 mrad) in respect to the angular acceptance of the setup. As a reference detector a standard LHC ionization chamber (icBLM) was used which was installed 10 cm behind the collimator on a fixed table. To minimize the radiation in the experimental hall, the whole setup was surrounded by 5 cm thick lead shielding. By using scrapers the particle intensity of the 10 ns long bunches could be decreased from 10E9 down to 4E5 electrons. Intensity measurements were conducted with the Wall-Current-Monitor (WCM) which was installed downstream of the scrapers. The WCM had a sensitivity limit of 1E7 electrons per bunch.

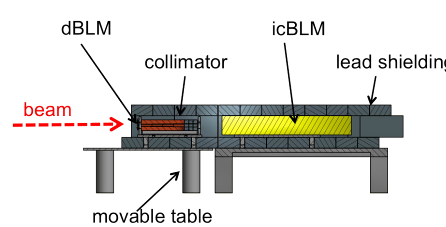

Figure 2: Cut-drawing of the experimental setup on the beam axis. End of the beam pipe with beam window on the left, two tables with Diamond Detector, copper (red) and lead (grey) Collimator and the icBLM (yellow), shielded with lead bricks.

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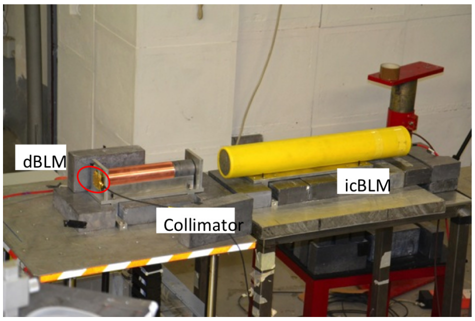

Figure 3: Picture of the setup installed in the experimental hall. The beam is coming from the left side. The diamond detector is marked with a red circle. Downstream of the dBLM the collimator and the icBLM reference detector can be found.

FIRST SIGNALS

The measurements were performed with bunch intensities between 8E4 and 5E4 as well as 1E8 and 4E9 electrons. Voltage scans to evaluate the efficiency of the detector at fixed intensity were conducted. During these scans the bias voltage was increased with a stepsize of 10 V (increase of 0.1 V/μm field strength across the diamond crystal). In total $\sim$ 25000 measurements were recorded. Figure 4 shows the signals of the different particle detectors for a bunch intensity of 3E8 electrons with an electric field strength of 1.0 V per μm in the diamond. The signal of the WCM is multiplied by 5000 for a better visibility. Due to the resolution of the oscilloscope only the electron-signal of the icBLM was recorded. Therefore the icBLM signal has been corrected by a factor 1.3. This correction factor was calculated from experiments with WCM and icBLM and verified by previous tests in the PS-Booster [5]. The analysis shows that the WCM has the lowest signal-to-noise ratio (SNR). Table 1 lists the average SNR for the three detectors at an intensity between 2E8 and 5E8.

Table 1: Mean SNR for the WCM, icBLM and dBLM in an intensity regime between 2E8 and 5E8 electrons per bunch.

	WCM	icBLM	dBLM
SNR	6.5	1670	4238

The total dose measured with the WCM on the three diamond detectors was 0.6E12, 1.6E12 and 3.8E12 electrons, respectively.

EXPERIMENTAL RESULTS

Figure 5 and 7 show the measured signals in the two intensity ranges recorded during the voltage scans. The signal of the dBLM is plotted vs. intensity measured by icBLM, the colour indicates the different electric fields across the diamond. The signal for a given intensity increases by a factor 2.2 for field strengths between 0.7 and 2.3 V/μm. Figure 5 shows the response of one diamond detector in the lower intensity range. All measurement points show a linear behaviour with a slight variation of the gradient. The gradient indicates the conversion factor from diamond detector signal in Coulomb to the number of particles. The conversion factors for different field strengths in the lower intensity range are shown in figure 6.

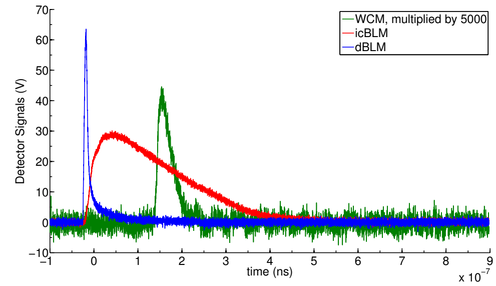

Figure 4: Signals of the three detectors. The dBLM signal is marked in blue, icBLM in red and the signal of the WCM in green. The signal of the WCM is multiplied by 5000 for a better visibility.

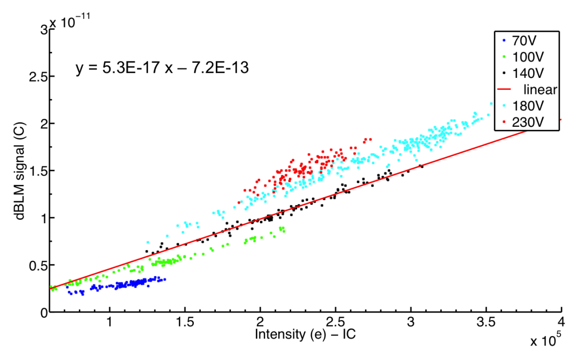

Figure 5: Measured dBLM signal vs. measured intensity from the icBLM in the intensity range between 8E4 and 4E5 electrons per bunch. Colour indicates the different bias voltages. The red lines shows the linear fit of the measurements at a field strength of 1.4 V/μm.

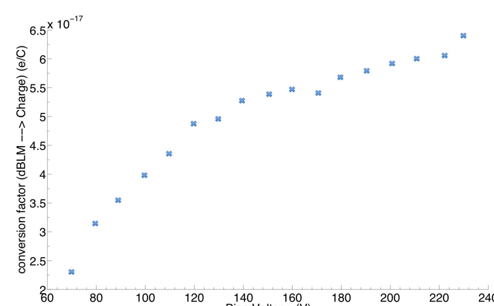

Figure 6: Factors (e/C) to convert dBLM signal in Coulomb to the numbers of particles for different bias voltages.

Figure 7 show the response of the diamond detectors in the higher intensity range. The response is non-linear. Due to fact that the intensity range was too small to find the transition between linear and saturation behaviour of the measurement points for the different electric field strengths.

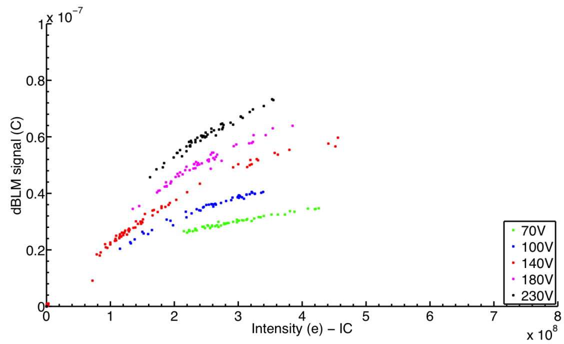

Figure 7: Measured dBLM signal vs. measured intensity from the icBLM in the intensity range between 1E8 and 5E8 electrons per bunch.The colour indicates the used bias voltage.

Figure 8 shows a comparison of measured and expected signal at 100 V bias voltage. The expected signal are calculated by using a detector current of 0.01 μA per minimum ionizing particle (MIP) [3]. The measured detector current is a factor 0.68 lower then expected. This is caused by a lower charge collection efficiency of the detector, probably caused by radiation damage [4]. The detailed analysis of the results from the other detectors is still ongoing.

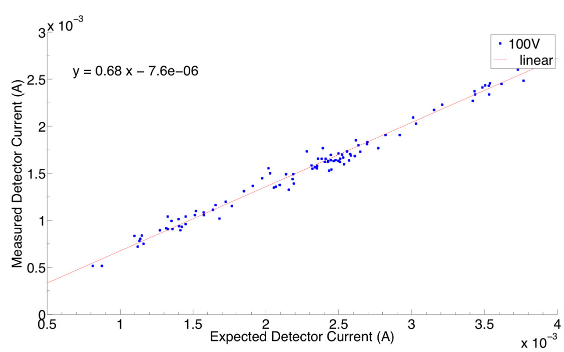

Figure 8: Comparison of measured and expected signal at a bias voltage of 100 V, i.e. 1V/μm electric field strength. A factor 0.68 between measured and expected signal was found.

LIMITATIONS

The measurements showed that the 50 Ohm impedance of the read-out electronics limited the dynamic range of the diamond detector. When the amplitude of the signal reached $\sim$ 60 percent of the bias voltage the signal went into saturation and only the FWHM increased further. Figure 9 shows the FWHM vs. peak amplitude for different bias voltages in an intensity regime between 1E8 and 5E8. The increase of the FWHM leads to an increasing number of electron-hole pairs which will recombine and therefore a part of the signal was lost. For a bias voltage of 70 V, this dBLM was already in saturation at the beginning of the plotted intensity range. To overcome this problem the bias voltage should be increased as much as possible or the impedance of the read-out should be reduced from 50 Ohm to 1 Ohm. This should increase the dynamic range by a factor 50. A 1 Ohm shunt was built by CIVIDEC and will be used for future diamond detector experiments at high intensities (above 1E6 electrons per pulse).

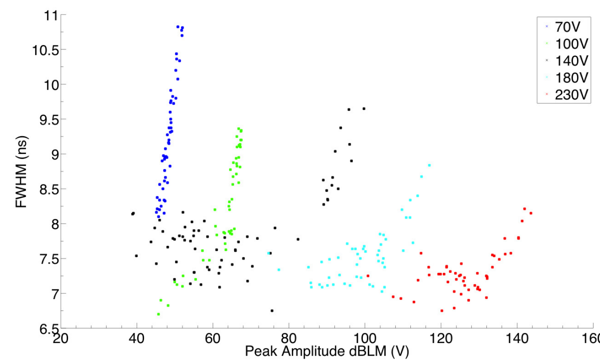

Figure 9: FWHM vs. peak amplitude of the dBLM signal.

CONCLUSION

For the first time diamond particle detectors with 100 μm thick diamonds were tested with a high intensity electron beam. Signals were measured over four orders of magnitude of bunch intensities. The experimental setup with collimator and icBLM as reference detector worked well and can be used in future experiments. The beam parameters, the beam quality and the availability of the BTF showed that detector tests in this facility are feasible. The diamond detector shows a linear behaviour in the intensity regime between 8E4 and 4E5 electrons per bunch. The SNR of the diamond detector was a factor 2.5 higher than the icBLM and a factor 652 higher than the WCM. The 50 Ohm impedance of the read-out electronics limited the dynamic range of the detector. At high intensities the diamond detectors were therefore showing a saturation. This problem could be solved by using a 1 Ohm shunt system.

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