

# RESPONSE OF POLYCRYSTALLINE DIAMOND PARTICLE DETECTORS MEASURED WITH A HIGH INTENSITY ELECTRON BEAM <sup>\*,†</sup>

O. Stein, CERN, Geneva, Switzerland and University of Hamburg, Germany <sup>‡</sup>

F. Burkart, B. Dehning, R. Schmidt, C. Buhl Sørensen, D. Wollmann, CERN, Geneva, Switzerland

E. Griesmayer, CIVIDEC Instrumentation, Vienna, Austria

## Abstract

Comprehensive understanding of beam losses in the CERN-LHC is required to ensure full machine protection and efficient operation. The existing BLM system using ionisation chambers is not adequate to resolve losses with a time resolution below some 10  $\mu$ s. Ionisation chambers are also not adequate to measure very large transient losses, e.g. beam impacting on collimators. Diamond particle detectors with bunch-by-bunch resolution have therefore been used in LHC to measure fast particle losses with a time resolution down to a level of single bunches. Diamond detectors have also successfully been used for material damage studies in other facilities, e.g. HiRadMat at the CERN-SPS. To fully understand their potential, such detectors were characterised with an electron beam at the beam test facility in Frascati with bunch intensities from  $10^3$  to  $10^9$  electrons. The detector response and efficiency has been measured with a 50  $\Omega$  and a 1  $\Omega$  read-out system. This paper describes the experimental setup and the results of the experiment. In particular, the responses of three samples of 100  $\mu$ m polycrystalline diamond detectors and two samples of 500  $\mu$ m polycrystalline diamond detectors are presented.

## DIAMOND BASED PARTICLE DETECTORS

During the experiments at the Beam Test Facility (BTF) in Frascati, Italy, the response function and the efficiencies of two diamond detectors (dBLM) types were measured. The first type (H-type) is a special detector which was developed for high intensity ranges. This detector type was used in the damage experiment in the HiRadMat facility at CERN in 2012 [2]. The second type (L-type) is used at the LHC for monitoring fast beam losses [3]. These two detectors types consist of polycrystalline diamond (pCVD) which differs in the size and quality of the active material, see tab.1.

During the experiments at the BTF, three H-type dBLMs (H1, H2, H3) and two L-type detectors (L1 and L2) were measured.

Table 1: Characteristics of the dBLMs used at the BTF experiments [4].

	H-type	L-type
Material	pCVD	pCVD
Area	round $r = 2.5$ mm	square $10 \times 10$ mm <sup>2</sup>
Thickness	100 $\mu$ m	500 $\mu$ m
Nominal bias voltage	100 V	500 V
Company	Cividec	Cividec

## BEAM PARAMETERS AND MEASUREMENT SETUP

### The Beam Test Facility

The BTF is a beam line at the Daphne accelerator complex. In the used mode, a bunch of the primary electron beam of 500 MeV and an intensity of  $\approx 10^9 e^-$  was delivered into the experimental hall with a repetition rate of 1 – 2 Hz. The bunch length was in the order of 10 ns. The beam intensity was reduced by using scrapers in the beam line [1].

### Experimental Setup

In the setup the dBLM detector was placed in front of a reference detector. Both detectors were aligned on the beam axis. A collimator was placed between the two detectors to ensure that only electrons that passed through the dBLM are detected in the reference detector, see Fig.1.

The collimator consists of a 20 cm long hollow copper cylinder with an opening of the size of the active diamond crystal in the dBLM. The copper cylinder was followed by a lead cylinder for shielding Bremsstrahlung. The whole setup was shielded with lead to minimise the radiation levels in the experimental hall.

The signals of the dBLM and the icBLM were fed through 30 m long BNC-cables into a 50  $\Omega$  read-out system (scope, Agilent DSO 9254A).

### The Reference Detector

For the measurements a standard LHC type ionisation chamber beam loss monitor (icBLM) was used as a reference detector. During the experiments the electron peak of the icBLM was measured which contains about 50 % of the whole charge. By applying a conversion factor to the

\* Work sponsored by the Wolfgang Gentner Programme of the Federal Ministry of Education and Research, Germany

† Research supported by the High Luminosity LHC project

‡ oliver.stein@cern.ch

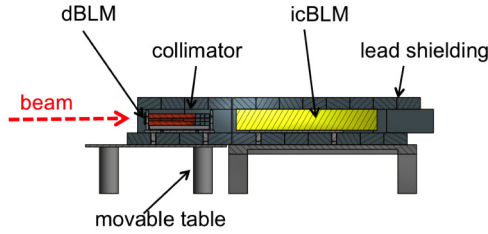


Figure 1: Cut of the 3d drawing of the experimental setup.

integrated signal the particle intensity can be calculated. The error of this detector is assumed to be about 10% [5].

### Measurement Routines

The experiments were performed as shot-by-shot measurements. To cover a large intensity range, different attenuators (-20 dB and -40 dB) were used. They were installed between the BNC-cable and the scope. To avoid limitations due to the 50 Ω read-out system at high intensities a 1 Ω shunt (built by CIVIDEC [4]) was installed between the dBLM and the BNC-cable to the scope. With one attenuator-shunt configuration an intensity range of about two orders of magnitude was covered. The measurements with different attenuators respectively shunt were performed with an overlap to allow a comparison of the different configurations. The dBLMs, see tab. 1 and the icBLM ( $U_{bias} = 1500V$ ) were operated at their nominal bias voltages.

## RESULTS

### Data Analysis

For the analysis automated scripts were developed which allowed a first check during the experiments. For the follow-up analysis these scripts were refined. To minimise the effects of dark currents the offset of the signal was corrected. Signal losses due to damping effects of fast signals ( $dBLM_{FWHM} \approx 10$  ns) were compensated by applying a correction factor ( $c_f = 1.23$ ) which was measured at CERN. With an energy of 500 MeV the electrons are assumed to be minimum ionising particles (MIP).

### Covered Intensity Range and Detector Response

One of the major goals was to measure the response function of the diamond detectors over a wide range of intensities. In Fig. 2 the measurements of all detectors are shown. The lower intensity limit is given by the resolution limit of the DAQ which is  $3 \times 10^4$  for the H-type detectors and  $9 \times 10^3$  electrons for the L-type detectors. The upper limit for the H-type detectors at  $1 \times 10^9$  is given by the radiation protection system of the BTF when radiation thresholds were exceeded. The upper limit of  $5 \times 10^7$  electrons per shot for the L-type detectors was chosen to avoid hardware damage in the dBLMs. The ranges are covered almost completely and without major gaps. For every detector more than 4000 measurements were performed,

in case of the H3 detector more than 10000. For better readability presentation only every 10th data point is plotted.

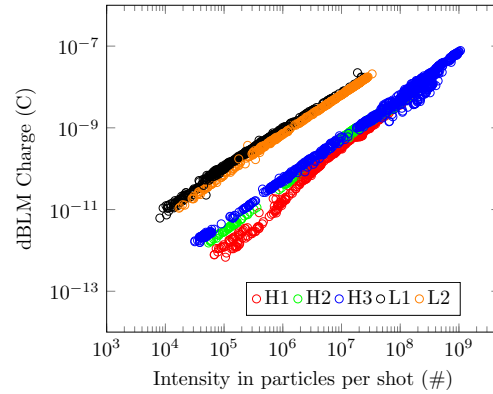


Figure 2: Response of all tested detectors.

### Efficiency

The efficiency (*eff*) of the detectors are calculated from the charge generated in the dBLM ( $Q_{dBLM}$ ), the particles per bunch ( $ppb_{icBLM}$ ), the thickness of the active detector material ( $d$ ) in  $\mu m$ , the elementary charge ( $q_e$ ) and the number of charges created by a MIP passing  $1 \mu m$  of diamond material ( $n_q = 36$ ).

$$eff = \frac{Q_{dBLM} 100}{ppb_{icBLM} q_e d n_q} \quad (1)$$

To ease the readability the data was binned in ten bins per order of magnitude (Fig.3 to Fig.7). The efficiency error-bars represent the standard deviation of the data in the corresponding bin.

The detectors H1 and H2 show a change of the efficiency over four orders of magnitude of absolute 5%. The trend of the change is comparable for both detectors. The efficiency change is present at different attenuator/shunt configurations. This trend is not observable in data of the H3 detector. The efficiency change might be caused by scraping the electron beam. Not only the beam intensity but also the beam size is influenced by the scraper positions. For the low intensity measurements the scraper opening was about  $100 \mu m$ . Due to the polycrystalline character of the diamond, the local efficiencies might differ. With small beam sizes it is possible that an area with lower efficiency was irradiated. All three H-type detectors have an efficiency in the range of 5% to 11%, see tab. 2.

In the H3 data an efficiency decrease for the measurements with the -40 dB attenuator can be observed. This is most probably due to the quenching of the bias voltage while using the 50 Ω read-out system. This effect does not appear in the data when the shunt was used.

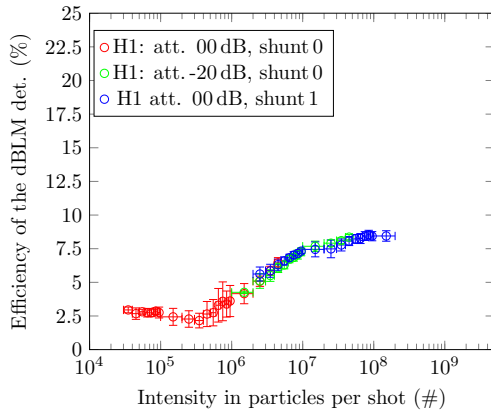


Figure 3: Efficiency of the H1 detector.

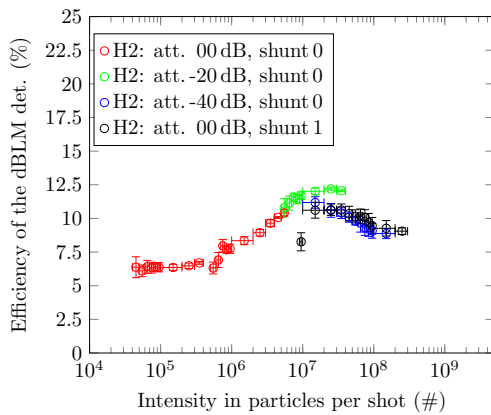


Figure 4: Efficiency of the H2 detector.

The absolute detector efficiencies of the L-type detectors are above 25%, see Fig. 6 and Fig. 7. The efficiency of the L2 detector is relatively constant. Nevertheless an efficiency decrease at intensities higher than  $10^6 e^-$  can be observed. This decrease is much more obvious in the L1 data. In this case the decrease is more than absolute 10% of efficiency.

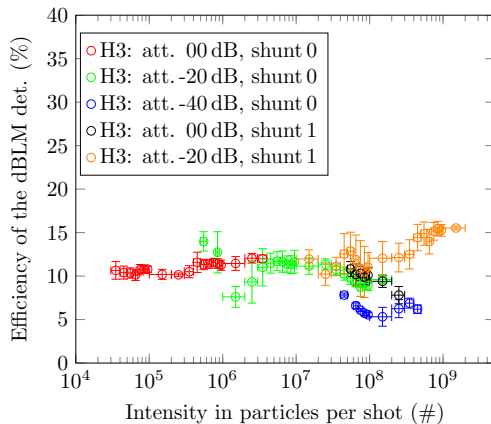


Figure 5: Efficiency of the H3 detector.

This might indicate a saturation effect which appears at these intensities for L-type detectors. The wide spread in the L1 data with the  $-20$  dB shunt configuration can be explained by the resolution limit of the DAQ. This spread does not occur in the measurements without the attenuator, see Fig. 6.

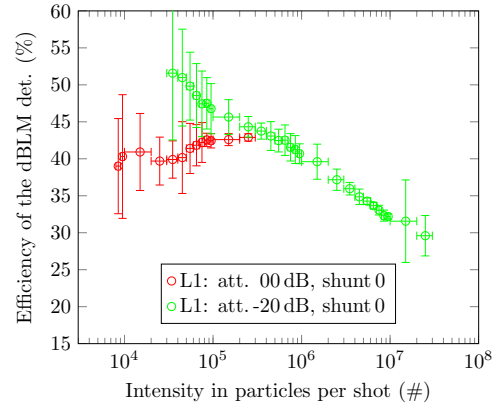


Figure 6: Efficiency of the L1 detector.

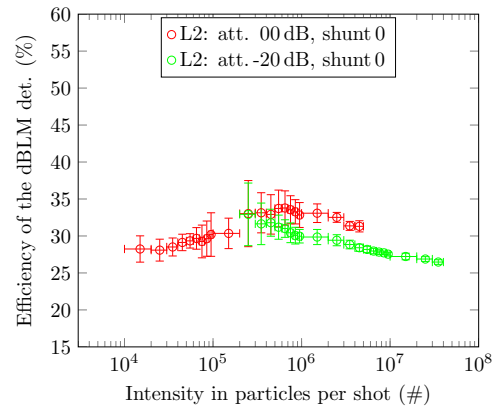


Figure 7: Efficiency of the L2 detector.

Table 2: Mean and standard deviations of the detector efficiencies.

dB LM	Mean of Eff. (abs. %)	STD of Eff. (abs. %)
H1	5.65	2.17
H2	9.21	1.84
H3	10.68	2.31
L1	40.95	5.43
L2	30.29	2.14

## REFERENCES

- [1] BTF website: <http://www.lnf.infn.it/acceleratori/btf/>
- [2] F. Burkart et al., Diamond particle detector properties during high fluence material damage tests and their future applications for machine protection in the LHC, in proceedings of IPAC 2013, Shanghai, China.
- [3] Erich Griesmayer et al., 'Diamond Detectors for LHC', Conference, Tsukuba, Japan, 2012.
- [4] Cividec website: <http://www.cividec.at/>
- [5] Communications with Bernd Dehning Beam Instrumentation group CERN, Switzerland.