DIAMOND DETECTORS AS BEAM MONITORS

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Abstract

CVD diamond particle detectors are already in use in the CERN experiments ATLAS, CMS, LHCb and ALICE and at various particle accelerator laboratories in USA and Japan. This is a proven technology with high radiation tolerance and very fast signal read-out [1]. It can be used for measuring single-particles as well as for high-intensity particle cascades, for timing measurements on the nanosecond scale and for beam protection systems. The radiation tolerance is specified with 10 MGy.

INTRODUCTION

The diamond beam monitor is a solid-state ionization chamber that stands out due to its fast and efficient charge collection and its high radiation tolerance. The diamond technology gives a charge collection time of less than 1 ns and lifetime studies made at CERN showed a 50% decrease in signal ampltude at 10 MGy [2], which make this device particularly well adapted to applications in particle accelerators.

Poly-crystalline CVD diamond beam monitors have been evaluated at the CERN SPS and at LHC accelerators. The read-out was made through 250 m long coaxial cable. Tests were made on the signal-to-noise ratio, the timing resolution and the dynamic range.

A single-crystalline CVD diamond beam monitor was tested for ISOLDE at CERN for the HIE-REX upgrade. This device was used to measure the beam intensity by particle counting and for measuring the beam energy spectrum for carbon ions.

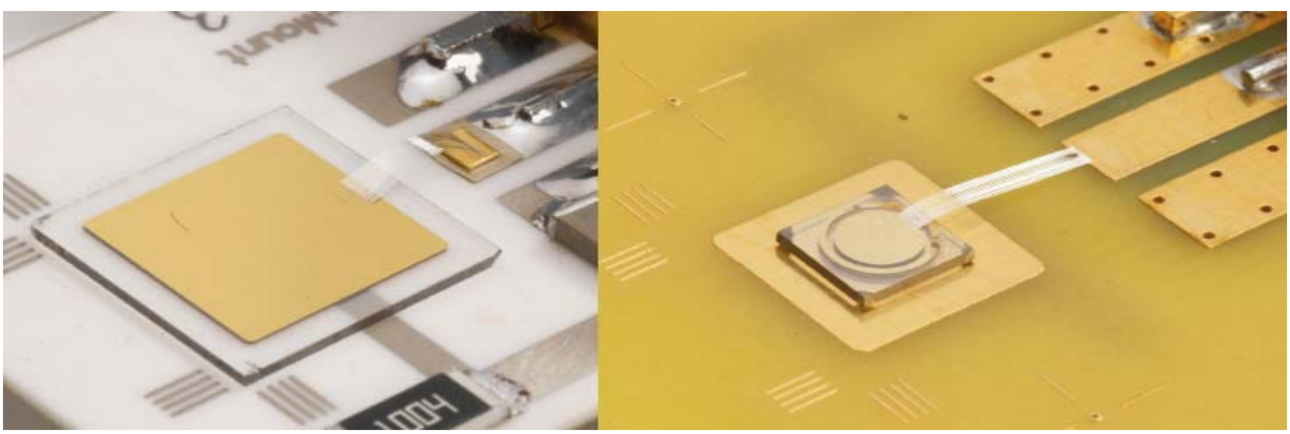

Figure 1: Single-crystalline and poly-crystalline diamond substrates, metalized with gold, are mounted on a ceramics board and a FR72 board, respectively.

TESTS AT ISOLDE

A novel beam instrumentation device for the HIE-REX (High Intensity and Energy REX) upgrade has been developed and tested at the On-Line Isotope Mass Separator ISOLDE, located at the European Laboratory for Particle Physics (CERN) in cooperation with Bergoz Instrumentation [3].

This device is based on a single-crystal CVD diamond detector (Figure 1, right picture) and is used for measuring the beam intensity, particle counting and measuring the energy spectrum of the beam. The detector is located inside the beam pipe in vacuum.

The carbon ions are completely absorbed by the diamond and the deposited energy is converted into ionization charges, which are read out via a fast preamplifier.

In Figure 2 the time response of the detector is shown on a time scale of 10 ns/div. The persistence plot shows the detector response to single ions. The 100 MHz RF beam-bunch structure of the carbon ions is clearly resolved. The average amplitude is 100 mV and represents the ion energy of 22.8 MeV.

Test results

The energy resolution of 0.6% was measured at a carbon ion energy of 22.8 MeV, which corresponds to an energy spread of ±140 keV.

The intrinsic time resolution for a signal-to-noise ratio of 100 and an average rise time of 3 ns, is 30 ps.

TESTS AT THE SPS

In preparation for tests at the LHC accelerator, a pCVD diamond detector (Figure 1, left picture) has been evaluated as a beam loss monitor using beam halo particles. The test monitor was mounted in the SPS BA5 downstream of a LHC collimator during the LHC beam set-up [4].

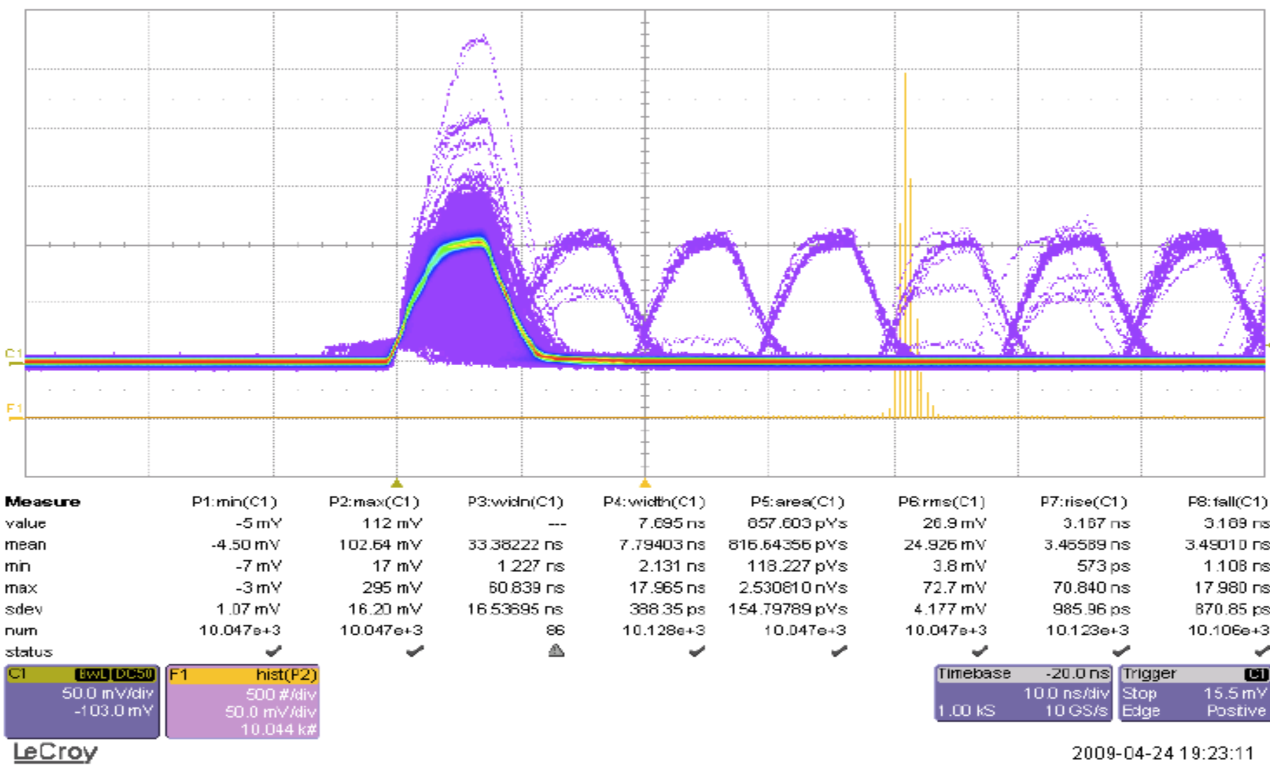

Figure 2: Time response of the diamond detector to single particles, which arrive at the RF frequency of 100 MHz.

Despite the read-out being made through 250 m of CK50 cable, the tests have shown a signal-to-noise ratio of 7, an excellent timing performance with a rise time of 2 ns, a pulse width of 5 ns and a fall time of 10 ns for single-particle detection. The dynamic range of the detector is only limited by the electronics to 1:350.

Test results

Four different types of beam loss were measured, i.e. single-particles, multi-particles, shower cascades and high-intensity beam losses as shown in Figure 3. The detector has proven its sensitivity for single particles as well as its robustness for high-intensity beam losses that saturated the electronics, which required up to 10 us for recovery.

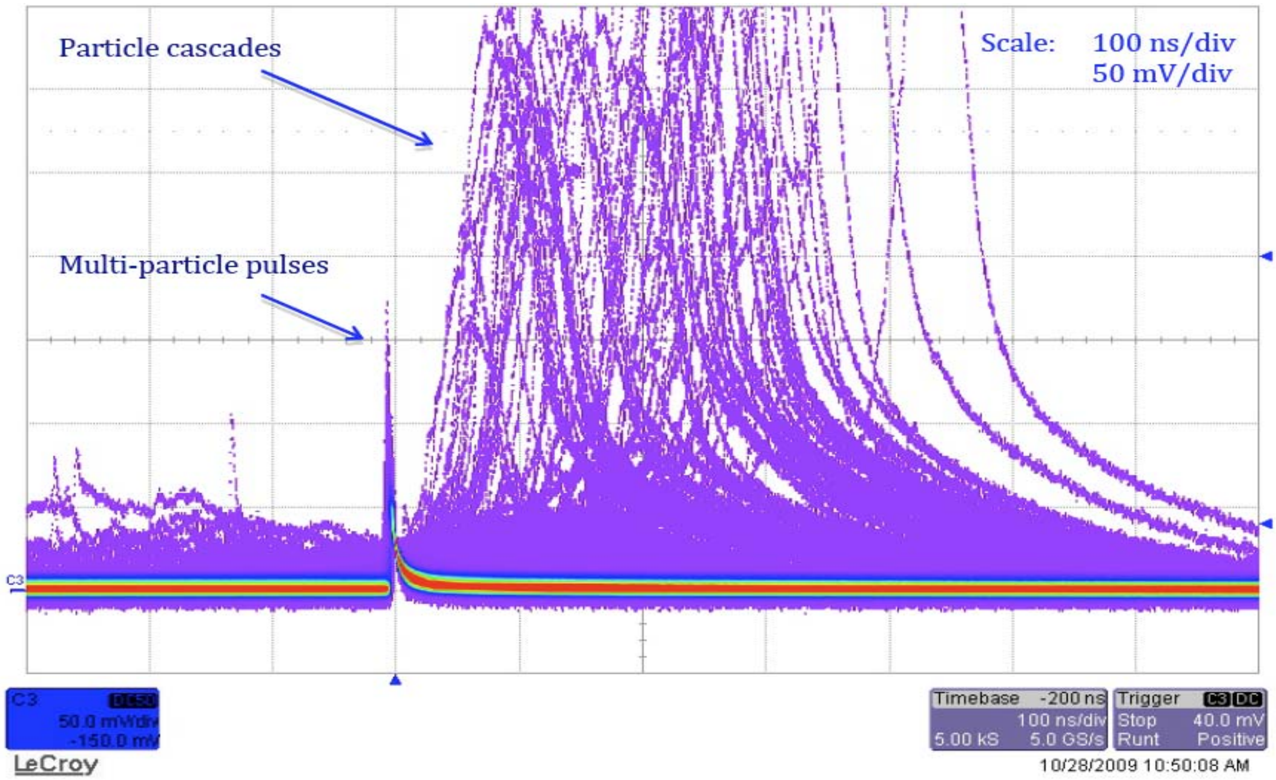

Figure 3: Time structure of beam losses in the SPS showing multi-particle pulses peaking at 200 mV (corresponding to 50 MIP particles simultaneously hitting the detector) and time extended particle cascades with amplitudes up to 1 V.

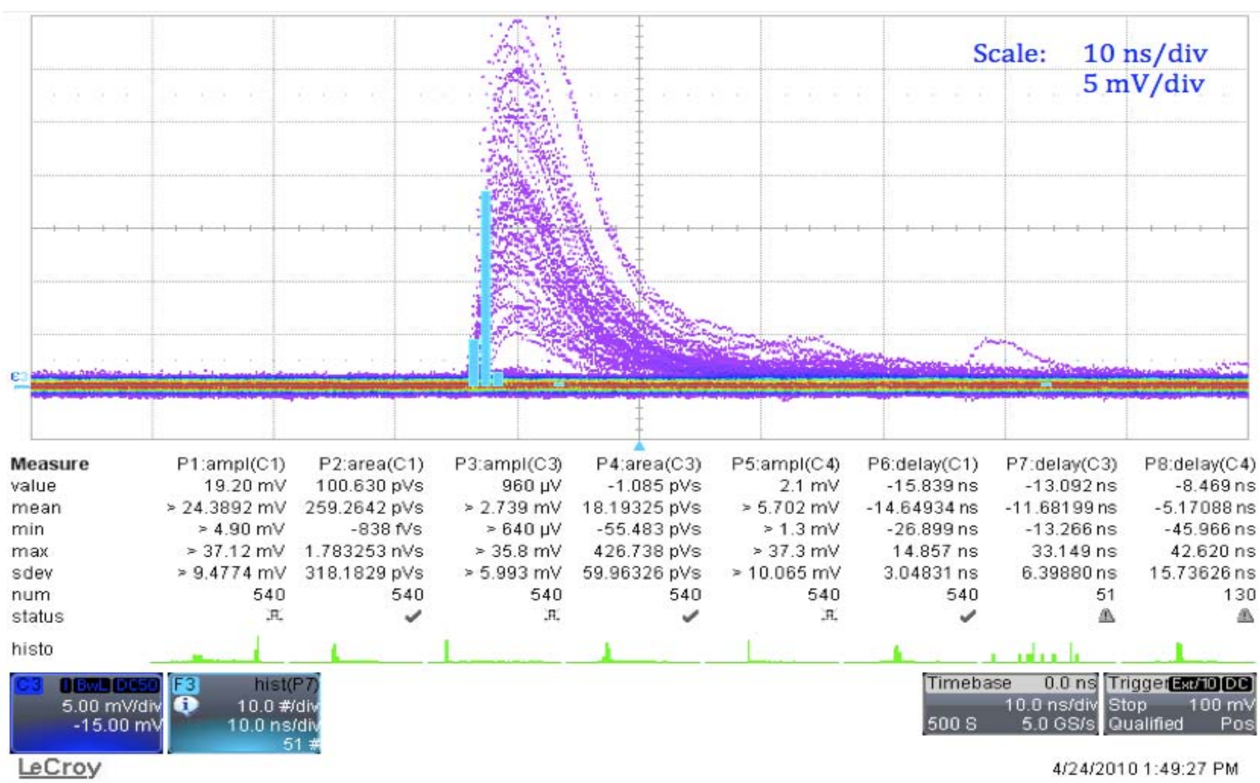

Figure 4: Time structure of beam losses (10 ns/div) and the corresponding phase histogram (1 ns per bin). Four 25 ns slots of the LHC accelerator are shown.

TEST AT THE LHC

As a result of the short single-particle resolution time, a beam-loss diagnostics instrument with 2.5 ns time resolution was built and is under test at the LHC accelerator. The diamond detector is built to resolve individual particle bunches of the 400 MHz RF buckets of LHC.

In addition, various parts of the beam can be measured, e.g. bunched beam, coasting beam, and in particular halo diagnostics with single-particle resolution can be performed. Machine protection with a reaction time < 20 ns is feasible in case of fast abnormal losses at a primary collimator.

Figure 4 shows the time structure of individual bunch losses. The rise time of 2 ns and sufficient amplitude allows a precise measurement of the arrival time. The timing histogram in Figure 4 has a bin width of 1 ns and demonstrates that the beam is well aligned with respect to the 2.5 ns long RF buckets.

Test results

Tests are still going on. Results of the tests will be published later.

SUMMARY

CDV diamond detectors where tested at three different accelerators at CERN, REX-Isolde, SPS and LHC. The tests have proven that CVD-diamond based beam instrumentation devices are feasible for a wide variety of beam instrumentation, such as particle counters, phase monitors, beam-loss monitors and spectrometers.

The high sensitivity of the detector allows single-particle detection, which is crucial for a particle counter. The dynamic range of the detector material is over many orders of magnitude [5] and mainly limited by the lifetime and by thermal parameters, which makes diamond of special interest for beam-loss and beam-intensity applications.

The rapid response of CVD diamond detectors is used for fast readout of the signals in the range of nanoseconds which is the key for single-particle counting in the range of GHz. The excellent time resolution of 30 ps can be used for time-of-flight applications. The low-noise properties of diamond can be used for energy spectrometers with energy resolutions of less than 1%.

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