EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN — SL DIVISION

CERN-SL-2001-024 BI

New development of a Radiation-Hard Polycrystalline CdTe Detector for LHC Luminosity Monitoring

E. Rossa; H. Schmickler.

CERN, Geneva – CH

A. Brambilla; L. Verger; F. Mongellaz.

LETI, Grenoble, FR

Abstract

Detectors presently considered for monitoring and control of the LHC luminosity will sample the hadronic/electromagnetic showers produced by neutrons and photons in copper absorbers designed to protect the superconducting magnets from quenching. At this location the detectors will have to withstand extreme radiation levels and their long term operation will have to be assured without requiring human intervention. For this application we have successfully tested thick polycrystalline-CdTe detectors. The paper summarizes the results obtained on rise-times, sensitivity and resistance to neutron irradiation up to a dose of $10^{15}/cm^{2}$.

Presented at DIPAC 2001 – Grenoble– France

13 – 15 May 2001

Geneva, Switzerland

May 2001

NEW DEVELOPMENT OF A RADIATION-HARD POLYCRYSTALLINE CdTe DETECTOR FOR LHC LUMINOSITY MONITORING

E. Rossa, H. Schmickler, CERN, Geneva, Switzerland,
A. Brambilla, L. Verger, F. Mongellaz, LETI, Grenoble, France

Abstract

Detectors presently considered for monitoring and control of the LHC luminosity will sample the hadronic/electromagnetic showers produced by neutrons and photons in copper absorbers designed to protect the superconducting magnets from quenching. At this location the detectors will have to withstand extreme radiation levels and their long term operation will have to be assured without requiring human intervention. For this application we have successfully tested thick polycrystalline-CdTe detectors. The paper summarizes the results obtained on rise-times, sensitivity and resistance to neutron irradiation up to a dose of $10^{15}/cm^2$.

1 - INTRODUCTION

The requirements on the LHC luminosity monitors can be summarised as:

- Possible counting rate of 40 MHz, i.e. rise and fall times below 10 ns
- Resistance to radiation damage up to doses of 10^{18} neutrons/cm^2 and 10^{16} protons/cm^2
- Good signal to noise ratio even for single minimum ionisation particles, such that in the shower sample statistically multiple events per bunch crossing can be destinguished from single events.

Cadmium telluride (CdTe) photo-conductor material used for nuclear radiation detectors and opto-electronic devices. A single Minimum Ionising Particle (MIP) creates about 50 000 electron-hole pairs in a 300 μm thick CdTe layer. In comparison about 53 000 pairs will be created in GaAs, but only 32 200 in Si and 11 850 in diamond [1].

The CdTe samples used for our tests have been produced by LETI (part of CEA) in Grenoble. These prototype detectors consist of discs of polycrystalline-CdTe about 16-mm in diameter with gold electrodes of 7 by 7 mm on both sides.

An ionisation chamber is currently as well under study to meet the above requirements [2]. References on the luminosity project are given in [3] and some others applications of CdTe are in [4-5].

2 - SPEED TESTS

2.1 Tests with a picosecond laser

The speed tests of the polycrystalline-CdTe output signal were undertaken at the Laboratoire de Sciences et Ingénierie des surfaces at the Université Claude Bernard-Lyon 1, [7]. A laser pulse (35 ps FWHM, 1060 nm wavelength) was onto one of the gold plated electrodes. The electrodes are porous enough to allow photons to reach the main bulk of the photoconductor. The photon transmission through the 0.5 mm thick sample was close to 50% at 1060 nm. Such a pulse is a good simulation of the ionisation track produced by a high energy particle going through the detector parallel to the electric field.

The signal produced by the laser pulse was very large and easy to measure on a single shot, fast-sampling oscilloscope. The measured rise time was limited to a fraction of nanosecond by the oscilloscope bandwidth.

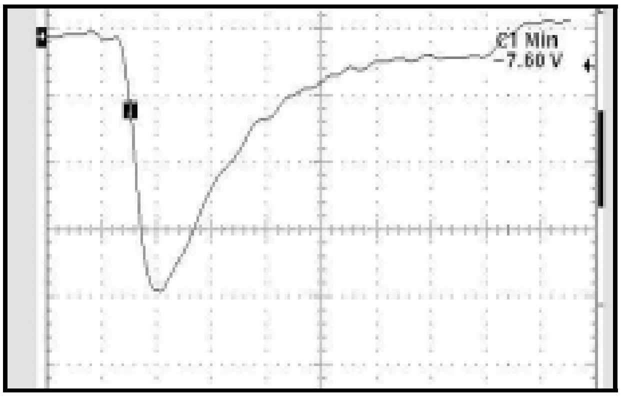

Figure 1: Example of a CdTe output signal terminated directly into 50Ω on the oscilloscope. The vertical scale is 2 Volts/division and the horizontal 2.5 ns/division. The applied bias voltage was 100 Volts.

3 - TESTS WITH MIP

The sensitivity was measured using a charge sensitive amplifier with a shaping time of 2 μs. The set-up used is described in reference [8]. The sample was irradiated by a radioactive source (^{90}Sr) and the particles traversing the sample were detected by a diode and triggered the acquisition of a digital oscilloscope. With a bias voltage of 200 Volts the collected charge reached 10000 electrons (see Fig.2)

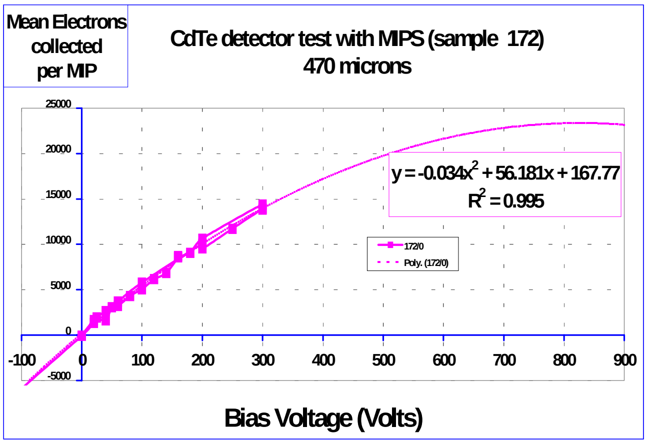

Figure 2: Average number of electrons per incident particle collected by the charge amplifier connected to the CdTe electrode

4 - IRRADIATION TESTS

The irradiation of the sample was carried out both at CERN and at a nuclear reactor in Valduc (France) where a high neutron flux was made available for our tests.

a) The set-up used at CERN is described in references [9,10]. After a total flux of 1.18 10^{14} n/cm^2 with neutron energies above 1 keV no significant change in the sample sensitivity was measured. The beam provided a flux in excess of 9 10^{13} n/cm^2 with energies above 100 keV.

b) In the Valduc reactor the samples were irradiated up to 10^{15} n/cm^2 at energies up to 1 MeV for about 2 weeks. No appreciable change in the sensitivity of the CdTe sample could be observed within the 5% precision of the measurement.

4.1-Time response measurement after neutron irradiation (laser stimulation of CdTe)

The speed test after neutron irradiation was carried out at CERN with a fast laser (1047 nm, 60 ps FWHM) using a similar technique as outlined in section 2.
Figure 3 shows the comparison of the time response measurement before and after irradiation to 10^{15} n/cm^2

4.2 Time response measurement after neutron irradiation (radioactive source stimulation of CdTe)

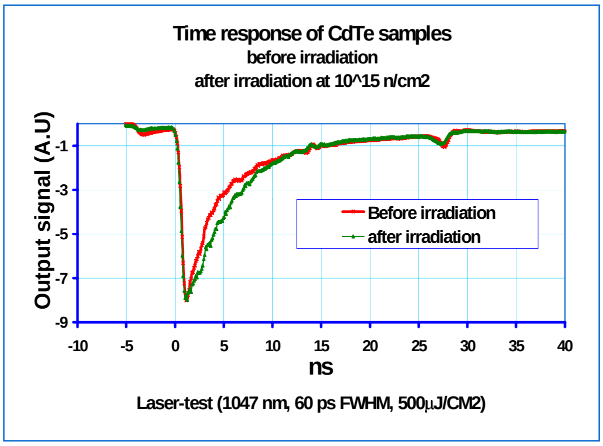

Figure 3: Time Response of CdTe detector before and after neutron irradiation

For this measurement the CdTe was exposed to the radiation of a ^{90}Sr source. The small signal produced by the minimum ionising radiation of the source had to be amplified before a signal spectrum could be measured. A digital oscilloscope Lecroy 9354 and a fast preamplifier(DBA) [11] developed in GSI (Germany) were chosen for the test. The amplified signal was analysed by using the facilities of the scope software.

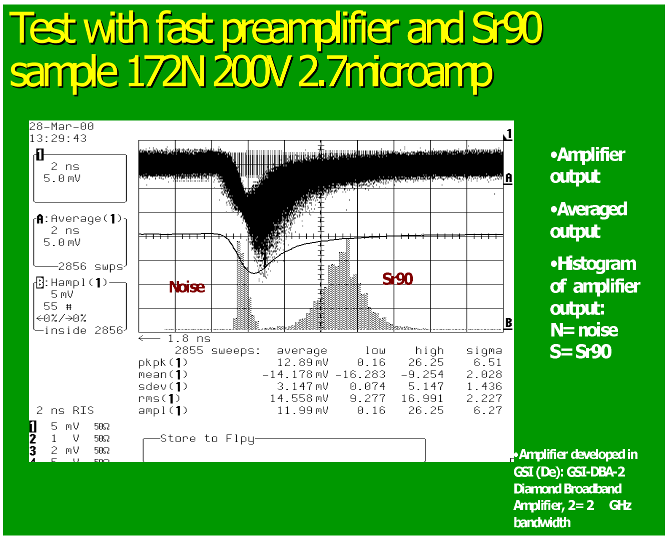

Figure 4: Real time analysis of the preamplified output signal using a Lecroy 9354 oscilloscope.

This preliminary result confirms the speed tests with the infrared laser.

6 - FUTURE PLANS

Irradiation tests at very high doses of up to 10^{18}n/cm2, during a reasonable exposure time of a few weeks are available at a research nuclear reactor facility in Ljubljana. These tests are scheduled to take place in autumn 2001 in order to fully qualify the detectors for the expected irradiation levels in the LHC.

One of the major problems with these tests is that the detector itself will become highly activated, such that later tests on its functionality in a laboratory are excluded.

We are planning to install a set of detectors connected via radiation resistant coaxial cables to the outside of the reactor core. A coincidence circuit of several detectors will be used to register online the pulse height spectrum of cosmic ray minimum ionising radiation.

7 - CONCLUSIONS

We have successfully tested thick polycrystalline-CdTe detectors for a potential use as LHC luminosity monitors. The following results were obtained:

- The signal response of the 300 µm thick detectors (16 mm diameter) is largely sufficient for a 40 MHz event rate measurement.
- The sensitivity is in excess of 10 000 electrons/MIP in combination with fast 50 ohms-preamplifier deliver a signal, which has an excellent signal to noise ratio and which allows statistically to distinguish single proton-proton interactions from multiple interactions.allows for a simple design.
- No significant loss in sensitivity or speed has been measured after irradiation tests up to 10^{15} n/cm^2.
- Beam tests confirmed the preliminary results obtained with a fast laser and a ^{90}SR source.
- New experiments after irradiation up to 10^{18} n/cm^2 are in preparation.

ACKNOWLEDGEMENT

The authors would like to thank A. Million, O. Peyret, G. Rumen from LETI, E. Berdermann, P. Moritz from GSI and P. Legros, S. Hutchins, G. Burtin and J-P. Bindi from CERN. The help of Karl Gill during the neutron irradiation tests is acknowledged as well as Rhodri Jones for his collaboration all along this development.

REFERENCES

[1] E. Rossa, C. Bovet, D. Meier, H. SchmicklerL. Verger, F. Mongellaz, G. Rumen, CdTe photoconductors for LHC luminosity monitoring, http://documents.cern.ch/archive/electronic/cern/preprints/sl/sl-2000-068.pdf

[2] W.C Turner, M.T. Burks, P.S. Datte, P.F. Manfredi, J.E. Millaud, N.V. Mokhov, M. Placidi, L. Ratti, V. Re, H Schmickler, V. Speziali, "Development of a detector for bunch by bunch measurement and optimization of luminosity in the LHC", LBNL-45774. CBP Note 337.

[3] H. Schmickler, "Summary Comments" in Proc. Of Tools for Luminosity Optimisation in LHC, 15-16 Apr. 1999, CERN, Geneva. Proceedings at http://www.cern.ch/CERN/Divisions/SL/groups/bi

[4] E. Rossa, " Picosecond diagnostics", in Opt. Eng. : 34 (1995) pp.2353-2360

[5] M.Placidi, E.Rossa, H.Schmickler, "A CdTe Detector for Muon Transverse Profile Measurements" http://documents.cern.ch/archive/electronic/cern/preprints/open/open-2001-034.pdf

[6] LETI (CEA-Technologies Avancées) -17 Rue des Martyrs-F38054 Grenoble Cedex 9- France

[7] With the help of Jean-Pierre Girardeau-Montaut and Bélà Kiraly at the Laboratoire de Sciences et Ingénierie des surfaces at the Université Claude Bernard-Lyon 1.

[8] Dirk Meier thesis: "CVD Diamond Sensors for Particle Detection and Tracking" Fig.3.27 page 92 http://atlasinfo.cern.ch/Atlas/documentation/thesis/thesis.html

[9 M. Glaser, RADEC99, 5th European Conference on Radiation and its Effects on Components and Systems. by Sharp, Richard ed. ; Publ. Ref.: IEEE Trans. Nucl. Sci. : 47 (2000) no.3, 13 - 17 Sep 1999

[10] M. Glaser, L. Durieu, F. Lemeilleur, M. Tavlet, C. Leroy, P. Roy," New irradiation zones at the CERN-PS " - ROSE Collaboration. In: Nucl. Instrum. Methods Phys. Res., A : 426 (1999) no.1, pp.72-77

[11] The DBA amplifier are developed by Peter Moritz in GSI (Germany) **email**: p.moritz@gsi.de