Fast polycrystalline CdTe detectors for Bunch-by-bunch luminosity monitoring in the LHC

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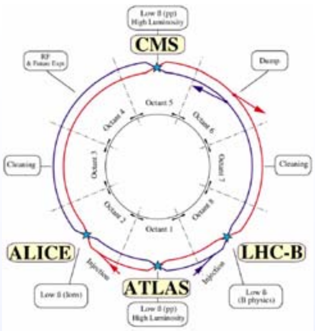
Abstract :

The luminosity at the four interaction points of the Large Hadron Collider must be continuously monitored in order to provide an adequate tool for the control and optimisation of the beam parameters. Polycrystalline CdTe detectors have previously been tested showing their high potential to fulfil the requirements of luminosity measurement in the severe environment of the LHC interaction regions. Further the large signal yield and the fast response time should allow bunch by bunch measurement of the luminosity at 40 MHz with high accuracy.
Four luminosity monitors with two rows of five polycrystalline CdTe detectors each have been fabricated and will be installed at both sides of the low luminosity interaction points ALICE and LHC-b. A detector housing was specially designed to meet the mechanical constraints in the LHC. A series of elementary CdTe detectors were fabricated and tested of which 40 were selected for the luminosity monitors. A sensitivity of 10^4 electrons/MIP and a pulse width better than 5 ns FWHM are currently achieved.

Luminosity monitoring at LHC

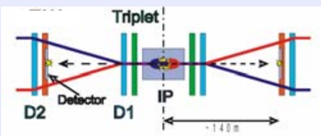


In LHC the two counter-rotating proton (or heavy ion) beams will collide in four interaction points (IP). At each of these locations dedicated experimental detectors will be installed. Two of them, ATLAS and CMS, are general purpose detectors and will profit from the highest possible luminosity (10^{34} cm^{-2}s^{-1}) provided by LHC. The other two have been developed for specific studies and will never be exposed to the full luminosity (L_{max} of 10^{30} for ALICE and 10^{32} for LHC-b).

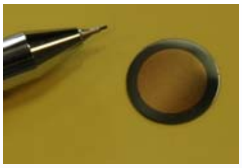
The luminosity is defined as the the ratio between the proton-proton collision rate and beam cross-section:

$$\mathcal{L} = \frac{\dot{N}_x}{\sigma_x}$$

The relative luminosity will be measured by detecting the neutral particles that are produced by the p-p collision in the IP. The luminosity monitors will be installed at both side of the IP behind a 15 cm copper absorber to measure the electromagnetic and hadronic showers caused by the neutral particles.



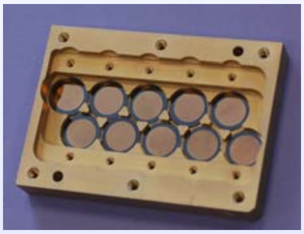
CdTe detectors

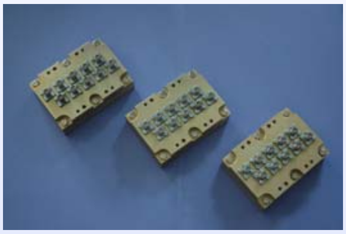


Cadmium Telluride (CdTe) is a high density semiconductor often chosen for X and γ-rays detections. In our case polycrystalline CdTe has been chosen for specific properties :

→ The fast response time (< 5 ns FWHM) enables the luminosity measurement at the LHC collision rate of 40 MHz.

→ The resistance to radiation up to 10^{16} neutrons/cm² (1), at least one order of magnitude higher than other semiconductor materials, is sufficient to withstand the high environmental doses of ALICE and LHC-b without human intervention for maintenance or repair.



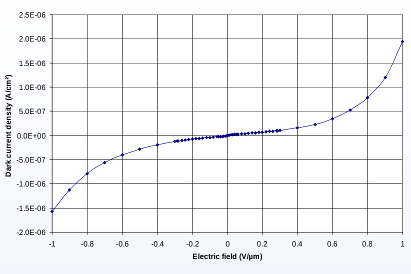


The 4 luminosity detectors are based on 2x5 polycrystalline CdTe detectors each. Each detector is 350 µm thick, the diameter is d=16mm with gold electrodes of d=12mm. The housing has been designed to meet the mechanical constraints of the LHC.

(1) Fast Polycrystalline CdTe Detectors for LHC Luminosity Measurements

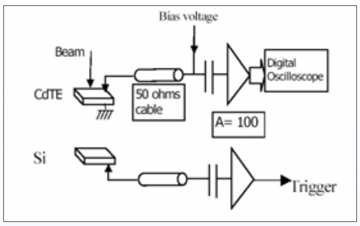
Results

Dark current characteristics



Typical Current – Voltage characteristic of a polycrystalline CdTe detector. At high Electric field (above 0.5 V/µm), the current is dominated by charge injection and increases with V². For this reason, the nominal bias voltage for the detectors was fixed to 350 V (~1 V/µm) in order to limit the dark current density below 10 µA/cm².

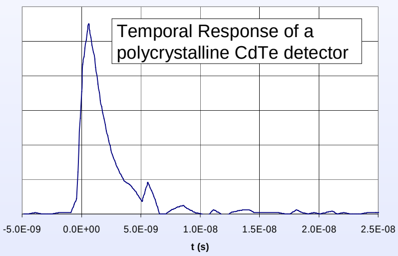
Response to Minimum Ionizing Particles (MIP)

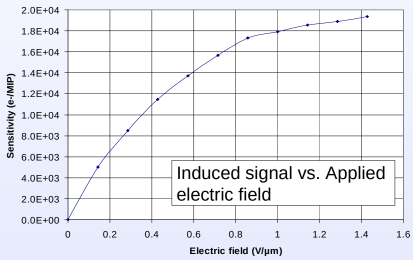


Experimental set-up for the measurement of the response to MIP

The response to MIP was measured with a 2.2 MeV ^{90}Sr Beta source. The polycrystalline detector is connected to a 3 MHz – 2.3 GHz amplifier and to a digital oscilloscope. The signal of the detector is triggered by a silicon PIN diode in order to reject low energy beta particles.

A sensitivity of 10^4 electrons/MIP is currently obtained while in some samples it reaches 2 10^4 with pulse duration well below 25 ns (40 MHz). The deposited charge for a single MIP is 6 10^4 e-/h pair leading to a Charge Induced Efficiency up to 30%. Considering that holes do not induce any signal at this time scale due to their low mobility the signal is mainly due to electrons with very low collection losses. This result is obtained thanks to the good transport properties of the sample together with high electric field and the low detector thickness (350 µm)





Conclusion and Perspectives

40 polycrystalline CdTe detectors were fabricated and selected to meet the required performances in terms of time response, sensitivity and dark current density :

→ Sensitivity > 9000 e- per Minimum Ionizing Particles (MIP)
→ Decay time < 9 ns (90 % to 10% level)
→ Dark current < 10 µA/cm² at 25°C

They were integrated in dedicated detector housing and were delivered to CERN. The 4 luminosity monitors will be tested in July 2007 for exact sensitivity calibration and mounted before the LHC start up.