Single Event Effect measurements on the Resistive Plate Chambers Front-End Chips for the CMS experiment

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Abstract

Measurements of irradiation damaging on the analog front-end electronics of the RPC detector for the CMS experiment have been made. They were performed according to the estimated neutron and gamma total dose foreseen in the muon barrel and end-cap region of the apparatus in the 10 years of LHC operation. Test results are shown, considering all the possible irradiation effects on the custom RPC front-end chip, developed in the 0.8 μm Bi-CMOS technology from AMS.

I. Introduction

We report on the results of some irradiation tests made at different sites (Bari University, Pavia Neutron Reactor, CERN-GIF area, UCL Louvain-la-Neuve Cyclone) during the last two years, on the RPC front-end electronics. The goal was to collect data, in different experimental conditions which took into account as closest as possible, the hostile working environment into which the RPC front-end electronics will be operate in CMS experiment.

II. The RPC front-end electronics

An analog full custom ASIC in the 0.8 μm BiCMOS technology from AMS has been developed to amplify and discriminate RPC signals for timing purposes and LHC bunch crossings identification. The features and performances of the RPC front-end chip have been extensively described elsewhere [1,2]. In the following, some of them are summarized.

The chip contains 8 channels over a total silicon area of 10 mm^2; it has a power consumption of 50 mW/channel using a +5 V powering and is encapsulated into a PQFP 80 pin package. Each channel contains a cascoded common emitter transimpedance preamplifier stage with input impedance of 15 Ω at the signal frequency (100÷200 MHz). It is followed by a gain stage, giving a non-saturated response on the signal dynamic range, in order to fully exploit the zero-crossing timing. The amplifier overall charge sensitivity is of about 2mV/fC for input charges smaller than 100 fC and the total ENC < 2 fC. The output signal amplitude walk is reduced down to 0.7 ns and the threshold uniformity is 1.5 fC rms over an input threshold value ranging between 10 fC to 500 fC.

The front-end boards used in these tests, are equipped with two front-end chips and the control electronics is designed using the following off-the shelf components:

- one 10 bit DAC (AD5311) for threshold setting;
- one 10 bit ADC including temperature sensor (AD7417) for threshold read back and temperature monitoring;
- one LVDS receiver (National Semiconductor DS90C032);
- two voltage regulators (MIC29201).

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The performed tests were aimed also to verify the performance of such components during and after the irradiation.

III. Bari University gamma irradiation measurements

Since 1998, a Gamma Irradiation facility (GIF) was built at the Bari University to expose both RPC and its related electronics to a high gamma dose. The irradiation area, built inside a telescope detector made by 8 RPCs and operated in streamer mode for tracking purposes, was equipped with three ^{60}Co sources, located inside a cylindrical lead collimator, which could be remotely closed and opened. The ^{60}Co isotope emitted two photons at an energy E_γ of 1.17 and 1.33 MeV respectively in 100% of the decays with a half-life of 5.27 years.

A RPC equipped with the front-end electronics was placed at 1 meter from the γ sources. In order to evaluate the accumulated dose, a detailed simulation of the source, the collimator and the shielding geometry, was performed using the MCNP-4b Monte Carlo code [3]. The sources activity was equal to $4.4\text{x}10^8$ Bq corresponding to an estimated gamma fluxes of $\varphi_{sim} = 1.5\text{x}10^5$ cm^{-2}s^{-1} at the test location and equivalent to a dose rate of 1.5 μ Gy/s.

To spot possibly damaging effects, the performance of the front-end boards has been checked after an irradiation equivalent to 1.3 Gy and the entire functionality of the electronics was preserved.

IV. CERN gamma irradiation measurements

Another front-end board has been mounted and irradiated on the first full size prototype of the RB2 type RPC chamber for CMS, at the CERN Gamma Irradiation Facility (GIF) during the 1999 test beam. The GIF is located downstream the final dump of the X5 beam line at CERN. Inside the zone a 740 GBq ^{137}Cs gamma source creates background conditions similar to those expected during the LHC operation. The ^{137}Cs isotope emits 661 KeV photons; a system of lead filters, which can be moved in front of the source, allows reducing the flux up to a factor 10000. The tests were performed with absorption 1 (i.e. source open and no filters), absorption 5 (i.e. a factor 5 less the nominal absorption 1) and with source off. For this test a discrimination threshold of 80 fC was used.

The MCNP-4b Monte Carlo code has been used to estimate a gamma flux of $\varphi_{sim} = 5.9 \text{ x } 10^5 \pm 0.5$ % cm^{-2}s^{-1} at a distance of 155 cm from the source, where the RPC and its associated electronics was placed during the test. An integrated dose of 1.7 Gy has been accumulated over the total exposition time period. Also in this case the full functionality of the front-end boards after the irradiation has been preserved.

V. Pavia-LENA Reactor irradiation measurements

More extensive tests using neutrons was started at the Pavia-LENA reactor, to study the effect of those particles on the front-end electronics. Two printed circuit boards having four RPCs FE chips for a total of 32 channels have been exposed to neutrons at the Pavia Triga Mark II 250 kW reactor. The test was aimed to measure the Single Event Upset (SEU) rate using slow and fast neutrons (from some hundredth of eV up to 10 MeV) and to identify some damaging for *displacement effects* or for *accumulation dose*.

The FE boards were put in the Thermal Column of the Reactor at a distance of 15 cm behind a boral window (used to deplete thermal component) and two sets of measurements were performed, with and without the boral window. This allowed taking into accounts both slow and fast neutron effects. However the insertion of the boral window gave a high gamma contamination, the ratio of the gamma dose to the neutron one being about 100. Considering neutron in the energy range between 0.4 eV and 10 MeV, we estimated a flux of $6\text{x}10^5$ n/cm^{2}s impinging our electronics. This calculation was confirmed a posteriori measuring the neutron flux with activated Au target.

Fig. 1 shows the effect of the insertion of the boral window. In the empty curve the first bin shows the big contribution ($2x10^9$ n/cm^2s) coming from the thermal component of the total neutron spectrum, while in the dashed curve only the fast part of the spectrum is retained.

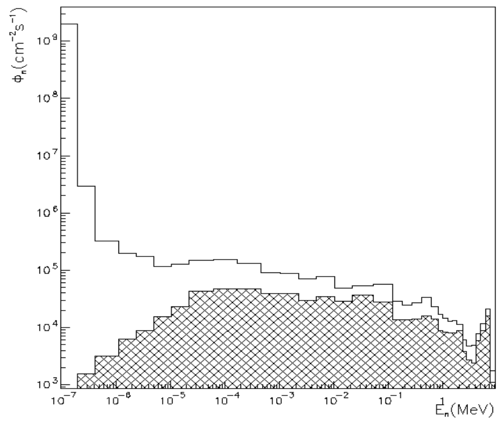

Fig. 1: Neutron fluxes before (empty curve) and after (shadowed curve) the Boral window.

In Fig. 2 a comparison between the available fluxes at LENA (with Boral window in) and those ones expected in CMS detector in the MB1 barrel region, is shown.

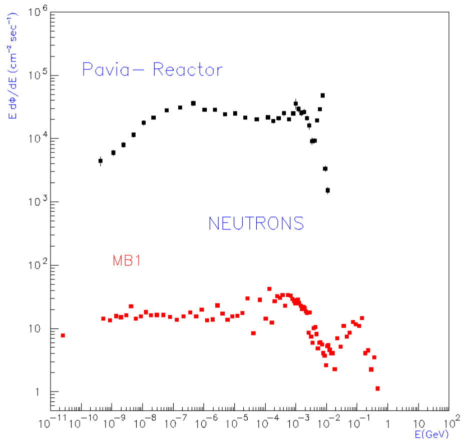

Fig.2: LENA and CMS neutron fluxes vs energy

Fig. 3 shows the Single Event Upset (SEU) rate induced by Fast Neutrons (0.4 eV -10 MeV) on the four FE chips. Due to the very low noise inside the test location we were able to lower the front-end threshold to 25 fC. The resulting rate per channel was in average 2.5 10^{-3} Hz and constant as a function of the fluence up to a value of about 1.6 x 10^{11} cm^{-2}. This rate is about 8 orders of magnitude lower than the maximum rate expected per channel in the experiment.

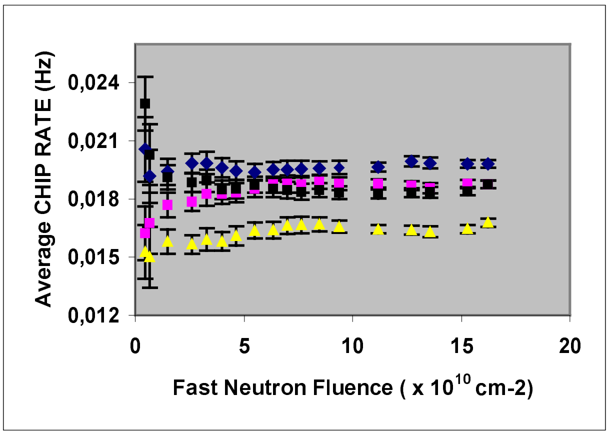

Fig. 3: SEU rate measured on the four chips at LENA reactor for a threshold of 50 mV.

VI. UCL-Cyclotron measurements

Other measurements have been performed at the UCL (Louvain-la-Neuve) cyclotron facility (Cyclone), where more energetic neutrons are produced bombarding a 17 mm thick beryllium target with a 65 MeV proton beam [5, 6].

The target is backed with an 8.5-mm thick carbon shield to lower the γ-component and to reduce the low-energy component in the neutron spectra. The neutron beam was furthermore filtered with hydrogenous materials to eliminate these low-energy components. According to different filter set-ups and different displacements from the beam axis, different neutron fluence spectra were obtained as shown in Fig. 4. Our measurements were performed in the conditions shown by curve 3 in the figure.

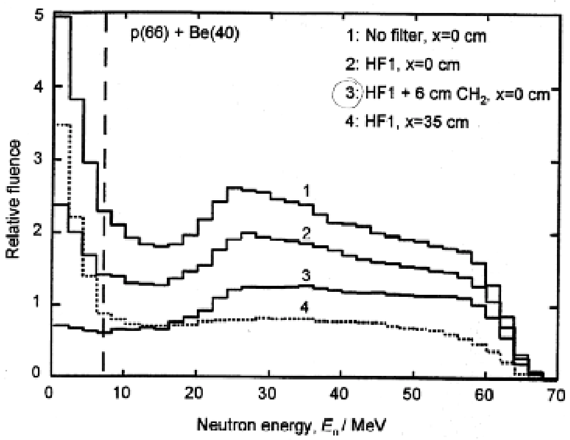

Fig.4: UCL neutron spectra for p(65) on Be(40)

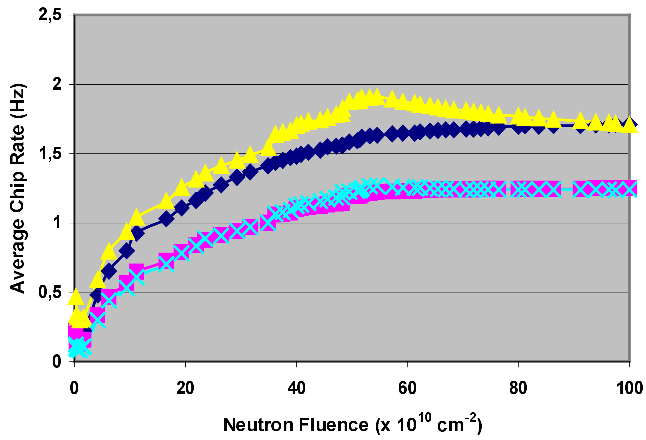

Fig.5: SEU rate vs neutron fluence at Louvain

The maximum irradiation area outside the collimator was 25x25 cm^2 at about 180 cm from the target. Two front-boards were put just in that area and therefore uniformly illuminated. In that position a neutron yield of $3.3x10^7$ $n/cm^2/s$, was obtained. A total fluence of 10^{12} n/cm^2 was accumulated; this is similar to what will be expected in ME1/1 region of CMS during 10 years. A corresponding dose of 70 Gy was so accumulated during 8 hours of exposition.

The collected data are shown in Fig. 5 where the SEU rate, for a threshold of 60 fC, is shown versus neutron fluence. The plotted data show a rather flatness behaviour after a fluence value of $0.5x10^{11}$, where the neutron current value was raised from the initial value of 0.82 μA to the final value of 14.5 μA corresponding to the nominal value of $3.3x10^7$ $n/cm^2/s$.

The mean SEU rate value is in this case about 0.25 Hz/channel, which is 5-6 orders of magnitude lower than the maximum rate expected in the experiment.

The front-end boards contain also a circuit to mitigate the effects of some undesired over-currents, which could be induced by latch-up events. If this occurs the power supply is disconnected for about 100 ms; if the failure persists a resettable fuse intervenes. During the entire test the above-mentioned circuit never intervened giving the indication that no latch-up events occurred.

Moreover, every 30 s the analog output of both DACs and their pre-set digital code were monitored showing that neither degradation on the analog behaviour nor single events with data corruption occurred.

After the irradiation test the charge sensitivity and power consumption of the four irradiated chips was measured and no degradation were observed.

The difference between the propagation time of the 32 channels before and after the irradiation, injecting a charge of 800 fC and using a threshold of 100 fC, has been plotted in Fig. 6.

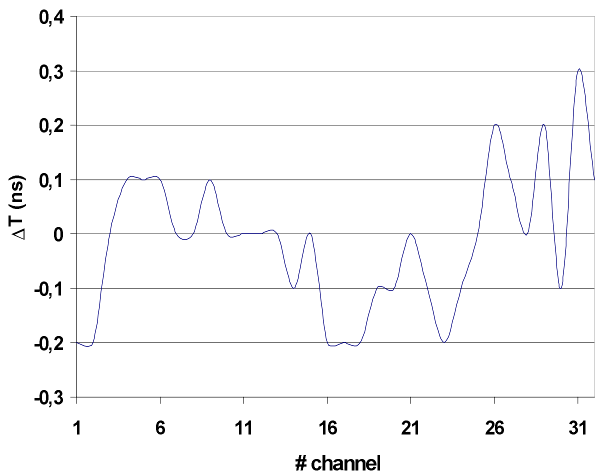

Fig.6: Difference between delay time measured before and after the irradiation

VII. Conclusions

We have made an extensive study of the possible radiation damaging effects which could be experienced by the analog ASIC designed for the RPC front-end in the 0.8μm BiCMOS technology by AMS. The various tests have been made using gamma and neutron particles reaching the estimated fluence values expected in CMS in the muon barrel and in the end-cap regions. We have measured the SEU rate expected and it resulted to be 5 orders of magnitude lower than the expected rate in CMS, in the worst case. Moreover no evidence of any possible destructive events has been found, demonstrating the reliability of the front-end chip and the related control electronics, under the CMS expected radiation environment.

References

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