Results of Radiation Tests of the Anode Front-End Boards for the CMS Endcap Muon Cathode Strip Chambers

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Abstract

We report the results of several radiation tests on pre-production samples of the anode front-end boards for the CMS endcap muon system. The crucial components tested were the 16-channel amplifier-shaper-discriminator ASIC (CMP16) and the voltage regulator TK112B. The boards were exposed to doses up to 80 kRad in a 63 MeV proton beam, and to a neutron fluence up to $2x10^{12}$ n/cm^2 from a nuclear reactor. The static and dynamic characteristics were measured versus the radiation dose. The boards were found operational up to a total ionizing dose (TID) of 60 kRad.

I. Introduction

The Anode Front-End Boards (AFEB) [1] are designed for the Cathode Strip Chambers (CSC) [2] of the CMS Endcap Muon System [3]. The AFEB amplifies and discriminates signals from the CSC anode wires which are grouped in bunches from 5 to 16. Their main purposes are to acquire precise muon timing information for bunch crossing number identification at the Level-1 trigger and to provide a coarse radial position of the muon track for the offline analysis. Radiation tolerance and reliability are important issues for the CMS electronics, including the endcap muon CSC anode front-end electronics. The peak luminosity of LHC, 10^{34} cm^{-2}s^{-1}, combined with the 7 TeV beam energy, will create a very hostile radiation environment in the detector experimental hall. The most severe conditions in the CMS muon endcap region are in the vicinity of the ME1/1 CSC chambers. Here, the neutron fluence and the total ionizing dose (TID) accumulated during 10 years of LHC operation ($5x10^7$ s) are expected to be about $6\text{-}7x10^{11}$ n/cm^2 (at En>100 keV) and 1.8-2 kRad, respectively [4-5]. For locations other than the ME1/1 chambers the doses are at least 10 times lower.

As BiCMOS devices, the AFEB's ASIC chip and voltage regulator TK112B are affected by exposure to both ionizing radiation (TID) and to neutrons (Displacement damage), yielding degraded performance and even failure if the doses are sufficiently high. The corresponding effects are cumulative. The other major category is the Single Event Effects (SEE) which are caused by the nuclear reactions of charged hadrons and neutrons. From these, the relevant effect is Single Event Latch-up (SEL) which results in a destructively large current draw.

The plan of our measurements [6-7] was to test the performance of the anode front-end boards, with pre-production chips, CMP16F (1.5 micron BiCMOS AMI technology), on them, up to a level of 3 times the doses mentioned above, and to observe the presence of single-event effects such as latch-up, at higher doses. The boards were irradiated with a 63 MeV proton beam at the University of California, Davis in June, 2000 to test them for TID and SEL effects. The results are presented in Section II. The purpose of the test with 1 MeV neutrons from a reactor at the Ohio State University was to expose the boards to possible displacement damage (Section III). The radiation test results are summarized in Section IV.

II. Tests with 63 MeV protons

The description of the 63 MeV proton beam test facility can be found in [8]. The beam current can be regulated from 2 pA up to 100 nA, with a profile almost flat over a radius of 35 mm. Four powered anode front-end 16-channel boards with CMP16F chips on them were tested at an incident beam angle of 0 degrees with respect to the normal to the board. The beam covered all elements of the board including the ASIC chip itself, the input protection diodes, the voltage regulator and passive elements. Boards #8 and #9 received 7 successive exposures for approximately 1 min each, for a total TID of 14 kRad. Two other boards (#5 and #7) received correspondingly 7 (10) successive exposures for a total TID of 80 kRad (74 kRad) for approximately 1-2 minutes per exposure. One more board was placed out of the beam and tested in parallel with the irradiated boards to provide monitoring of the test conditions.

The static parameters (voltages on the amplifier and discriminator of the ASIC and on the regulator TK112B) were measured during each exposure. The measurements of the threshold, noise, gain, discriminator offset, resolution time and slewing time were done during 10-20 minutes after each exposure with the use of the ASIC test stand [9]. For each chip the results were averaged over all channels and normalized to their initial values obtained before the first exposure.

No latch-ups or spikes or any changes in the static parameters were observed. However, the dynamic parameters such as gain, offset, threshold and slewing time were slightly sensitive to the radiation. The observed threshold Q_{thr} measured in terms of input charge decreased with the TID (Figure 1) due to changes in the amplifier gain (Figure 2) and the discriminator offset[1] (Figure 3). The overall effect for Q_{thr} is rather small, about 15% for a TID of 60 kRad. The noise increased by less than 10% from its initial value of about 1.7 fC. The resolution time of 1 ns was not affected. The slewing time ST showed a maximum increase of 40% at a TID of 60 kRad (Figure 4). At the required 3 times level of TID (5-6 kRad), all changes were practically negligible. However, at a TID of 65-70 kRad, two boards failed (no output signal) showing large changes in the amplitude and the shape of the pulse after the shaper. About a month later, though, these boards had become operational again.

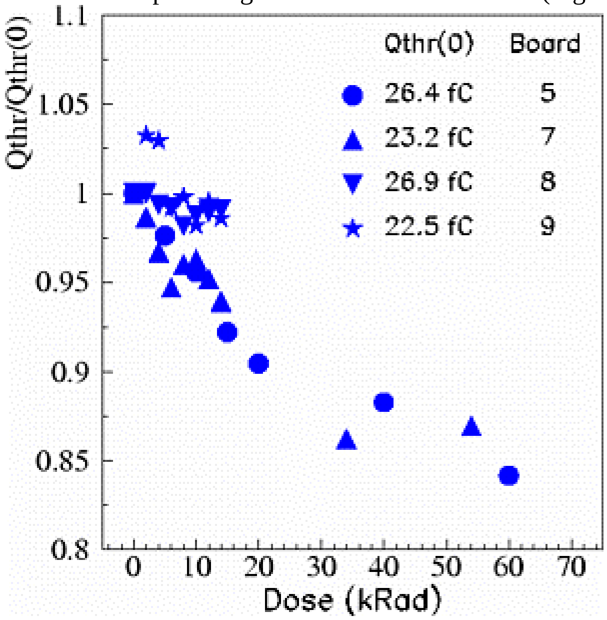

Figure 1: Normalized threshold versus dose.

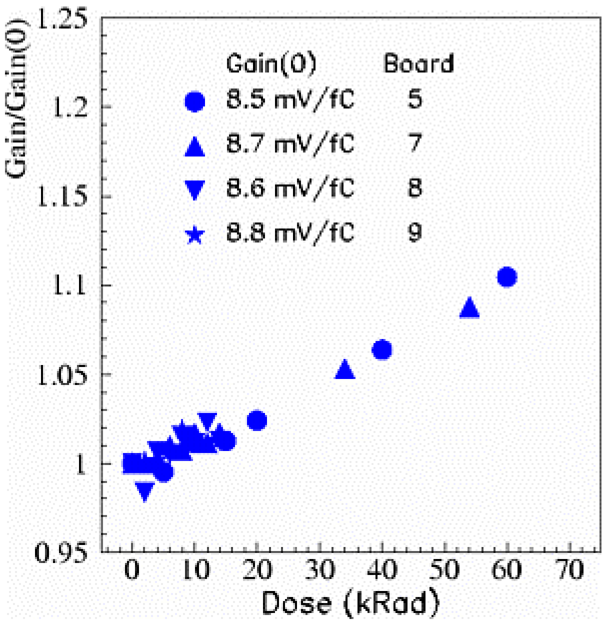

Figure 2: Normalized gain versus dose.

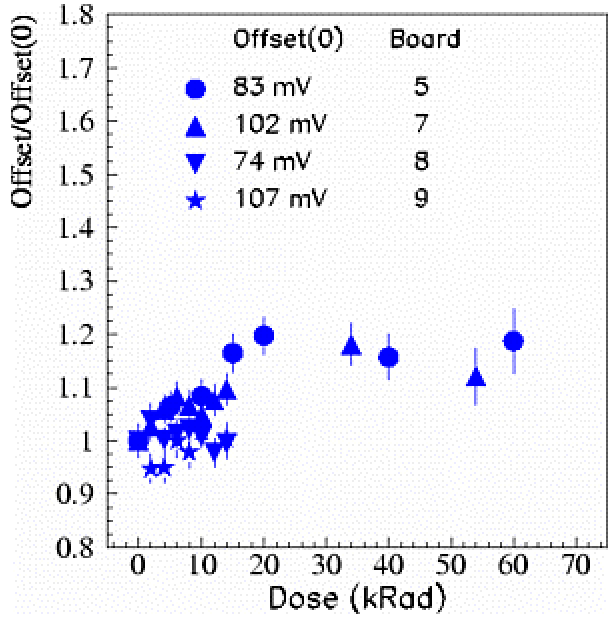

Figure 3: Normalized discriminator offset versus dose.

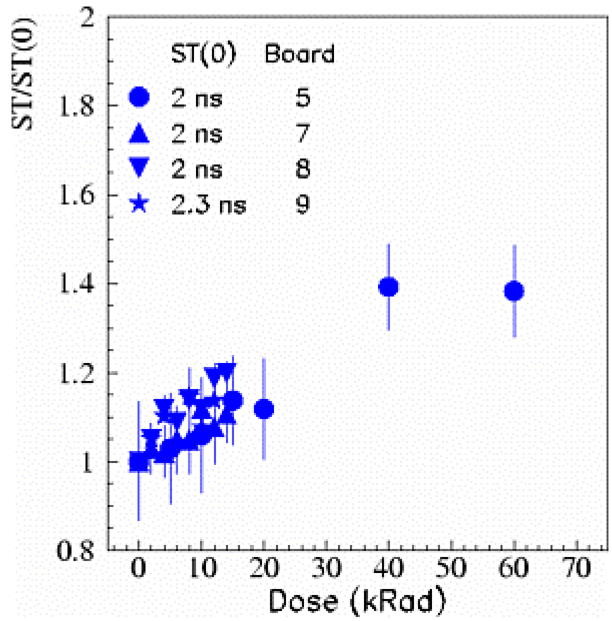

Figure 4: Normalized slewing time versus dose.

III. NEUTRON IRRADIATION OF THE ANODE BOARDS

Six boards with CMP16F chips on them were exposed in October, 2000 to a reactor neutron fluence up to 2×10^{12} n/cm^2 at a neutron energy of around 1 MeV. The exposure was 14 min long. The boards also received a TID of about 50-60 kRad from γ's [10] which accompanied the reactor neutrons. Prior to the test with neutrons, in August 2000, the same boards have been irradiated in the 63 MeV proton beam at the UC Davis with a total ionizing dose of 5 kRad delivered during 2.5 min. The boards were powered in both exposures. The static parameters of the boards were monitored during the irradiation tests. No changes of static parameters were recorded in the 63 MeV proton beam. In the neutron irradiation, the board regulator output voltage and the voltages of the preamplifier and discriminator increased by only 2-5% at the end of the exposure.

The dynamic characteristics of the boards were measured on the ASIC test stand at Fermilab [9] prior to the test in the proton beam, and before and after the neutron irradiation. The set of data obtained after the neutron irradiation includes five measurements made at intervals of one to two weeks, with the first measurement taken about 40 days after the neutron irradiation. The last three tests included two periods of one week each and one period of four weeks of heating the boards in an oven at 110^O C. The corresponding changes, averaged over 16 channels, of Q_{thr} , gain and discriminator offset relative to their initial values for the six boards are presented in Figures 5 – 7. The initial values of Q_{thr}, gain and offset were in the ranges of 12 – 22 fC, 9 – 10 mV/fC and 10 – 80 mV respectively. The noise increased by less than 10% from its initial value of 2 fC.

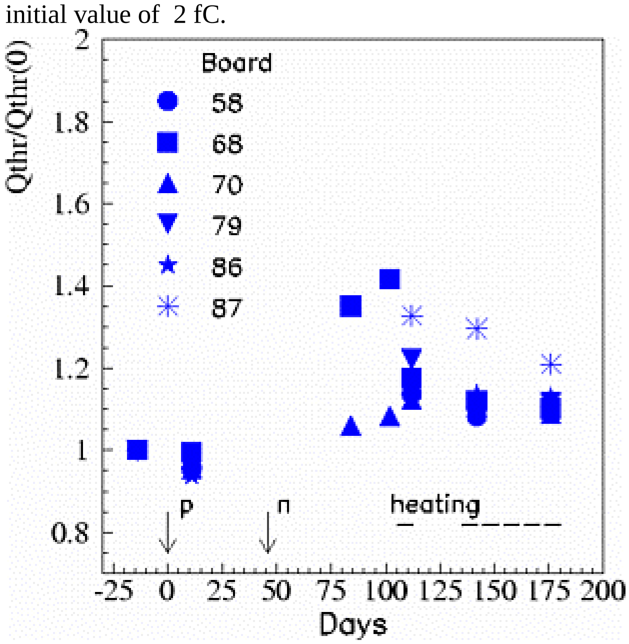

Figure 5. Normalized Q_{thr} versus time. The arrows show the days of proton and neutron irradiations. The dash line presents the days of heating.

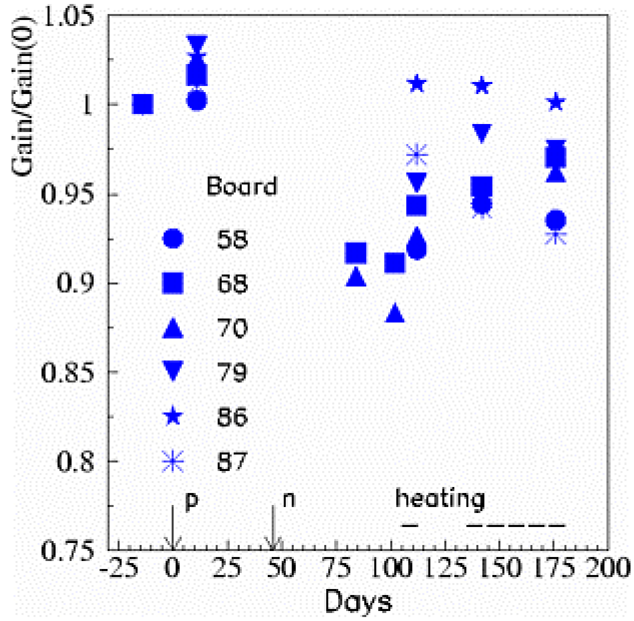

Figure 6. Normalized gain versus time.

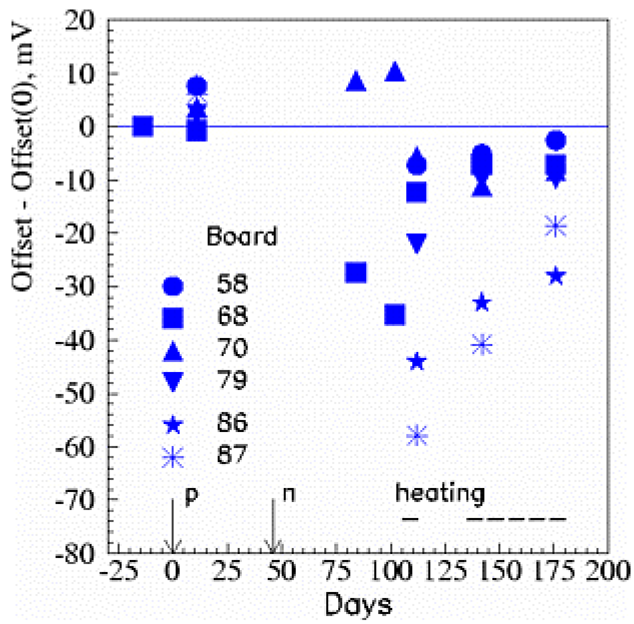

Figure 7. The discriminator offset changes versus time.

All boards survived unchanged after the irradiation by the 63 MeV proton beam. This confirms the results obtained earlier in the proton beam. However, only two boards (68,70) from the six were working in the first test taken 40 days after the neutron irradiation. The rest came to life after one week of heating in the oven at 110^O C. All boards showed moderate changes in their dynamic characteristics after irradiation by neutrons. Note that these changes are opposite to the effects observed during proton irradiation (Section II). Five more weeks of heating brought the parameters of the boards closer to their values measured before the proton test.

IV. CONCLUSIONS

The radiation tests of the anode front-end boards performed in a 63 MeV proton beam show that the boards are operational up to TID of 60 kRad. At the required 3 times level of TID (5-6 kRad) the dynamic characteristics of the boards remain unchanged.

The measurements with the neutrons were complicated by the presence of a significant γ flux. In addition to the nominal neutron fluence up to $2x10^{12}$ n/cm^2 , the boards received a TID of 50 – 60 kRad. Only two boards from the six were working in the test taken 40 days after the neutron irradiation[2]. The rest become operational after one week of heating in the oven at 110^{O} C. From our results, we can roughly estimate that for the test doses given above the annealing time is about a few months at room temperature. Since the LHC rate of real radiation exposure is much slower than this, and assuming that the observed effects were cumulative, we can conclude that the anode front-end boards should not show any significant radiation damage during the 10 years of normal LHC operation.

V. ACKNOWLEDGEMENTS

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VII. FOOTNOTES

1. The gain and offset were calculated from the following equation: Gain x Q_{thr} + Offset = U_d , where U_d is the discriminator setting.
2. Two other boards with CMP16F chips were found working after neutron irradiation up to $1.2x10^{12}$ n/cm^2 and $1.8x10^{12} n/cm^2$ in a preliminary test made in July 2000.