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Irradiation of the CLARO-CMOS chip, a fast ASIC for single-photon counting

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ABSTRACT

The CLARO-CMOS is a prototype ASIC that allows fast photon counting with low power consumption, built in AMS 0.35 μm CMOS technology. It is intended to be used as a front-end readout for the upgraded LHCb RICH detectors. In this environment, assuming 10 years of operation at the nominal luminosity expected after the upgrade, the ASIC must withstand a total fluence of about 6×10^{12} 1 MeV n_{eq}/cm^2 and a total ionising dose of 400 krad. Long term stability of the electronics front-end is essential and the effects of radiation damage on the CLARO-CMOS performance must be carefully studied. This paper describes results of multi-step irradiation tests with protons up to the dose of ~8 Mrad, including measurement of single event effects during irradiation and chip performance evaluation before and after each irradiation step.

1. Introduction

The CLARO-CMOS chip is a custom designed ASIC composed of a charge sensitive amplifier and a discriminator [1]. An important upgrade of the whole LHCb detector is foreseen in 2018 in order to make it able to run at higher luminosity and sustain a readout rate of 40 MHz [2,3]. The CLARO-CMOS has been chosen as the baseline front-end chip for the upgrade of the LHCb RICH detectors.

In order to ensure stable operation of the upgraded RICH detector over 10 years in the upgraded LHCb environment, irradiation tests of the CLARO-CMOS chips have been done using neutrons, X-rays and protons. According to the FLUKA simulations of the experiment the radiation levels expected for the upgraded RICH are 6.1×10^{11} 1 MeV n_{eq}/cm^2 for the neutron fluence and 40 krad for total ionising dose, accumulated in 1 year.

In a very conservative approach, several CLAROs were irradiated up to a level 10 times larger than the radiation levels expected in 10 years of LHCb. Irradiation with neutrons and X-rays has been described in Ref. [4]. This paper focuses on proton irradiation tests.

2. Irradiation with protons

In order to test the CLARO-CMOS chip tolerance to total ionising dose, an irradiation with protons has been performed at the Institute of Nuclear Physics, Polish Academy of Sciences in Krakow, Poland. Protons with an energy of 60 MeV were delivered by the Cyclotron AIC-144 and irradiation tests have been conducted in the eye therapy room (low dose) and in the so-called experimental room (high dose). A precise dosimetric system based on ionising chambers, plus alanine foils and thermoluminescent detectors, allowed for a few percent precision on the dose delivered to the samples.

The irradiation was done on 3 chips, and was performed in steps: 3 irradiation steps (Steps 1–3) for one chip and an additional one (Step 4) for the other 2 ASICs (Step 0 is defined as pre-irradiation). The different steps are defined as follows:

- Step 1: 40 krad (1 LHCb-equivalent year).
- Step 2: 400 krad (10 LHCb-equivalent years).
- Step 3: 4 Mrad (100 LHCb-equivalent years).
- Step 4: 7.6 Mrad (190 LHCb-equivalent years).

The CLARO chips were irradiated one at a time, with the package lid removed. The chip under test was powered and configured, with threshold set to a reference value. Threshold voltage and supply currents were monitored online every 5 s. Before and after each irradiation, a measurement of linearity curves was done, by varying the threshold DAC setting and measuring the corresponding threshold voltage at test-point. In addition a measurement of S-curves was done, by sending bursts of 1000 pulses to all CLARO inputs simultaneously, and measuring the number of discriminated output signals as a function of input signal amplitudes.

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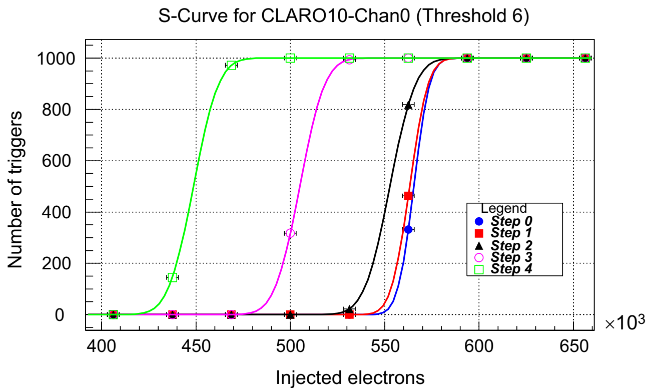

Fig. 1. S-curves for one channel acquired during proton irradiation.

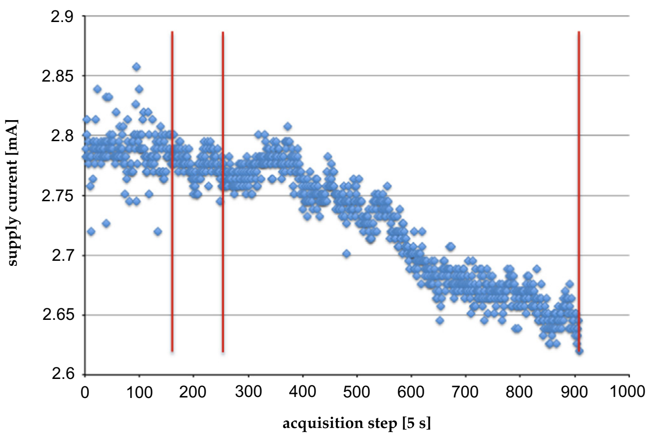

Fig. 2. Monitoring of the supply current values for one chip during irradiation.

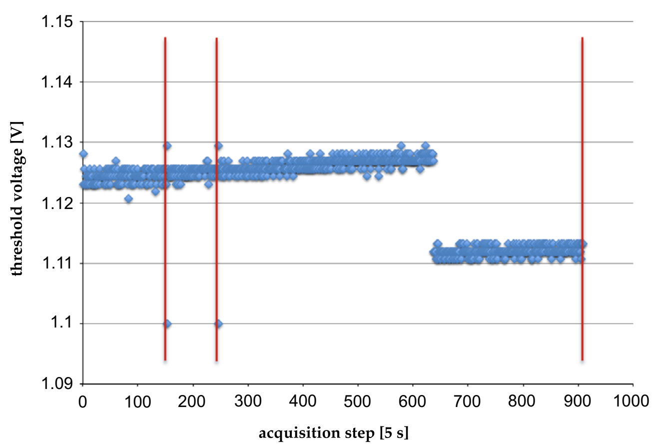

Fig. 3. Threshold voltage monitoring values for one chip during irradiation. A single event upset is clearly visible after the acquisition step 600.

S-curves for one channel of a CLARO-CMOS chip can be seen in Fig. 1: the position of 50% transition point of the curve allows us to evaluate any variation in the threshold level, while an increase of the noise would result in a smoother transition. No significant increase of the noise was observed, while the threshold level is moving systematically to lower values as the irradiation proceeds.

The chip bias current was measured every 5 s and an additional circuit provided protection against single event latchup (SEL). No SEL occurred during the irradiation of the three chips, while the supply current decreased by a factor ~10%, as can be appreciated from Fig. 2.

Also the chip threshold voltage was measured every 5 s in order to detect possible single event upsets (SEUs). As can be seen in Fig. 3 a SEU occurred which made the DAC output move abruptly from 1.13 V to 1.1 V (corresponding to thresholds 6 and 7, respectively). Our team will equip the new version of the ASIC with a register protected with triple modular redundancy and a SEU internal counter in order to monitor and correct such events.

3. Conclusions

Irradiation with protons of the CLARO-CMOS chip has been described. The main features of the chip are the capability to sustain high photon counting rate with a low power consumption, and for that it was chosen as the baseline front-end for the upgraded RICH detectors of the LHCb experiment. The CLARO-CMOS chip has demonstrated to be tolerant to protons, in addition to neutrons and X-rays, up to levels 10 times larger than those expected in 10 years of LHCb operation after the upgrade. For proton irradiation in particular, a threshold variation in the order of ~20% was measured, while the noise did not change significantly. Single event upset protection will be implemented in the next version of the chip.

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