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IRRADIATION TESTS OF THE OMEGA3 PIXEL READOUT CHIPS BY 15 MEV ELECTRONS

A. Badalà, R. Barbera, M. Gulino, F.Librizzi, G. Lo Re, A. Palmeri, G. S. Pappalardo, F. Riggi

INFN, Sezione di Catania, and Dipartimento di Fisica, Università di Catania, Italy

A. Grasso, O. Marilli and G. Scandurra

Acceleratore Lineare, Ospedale S.Luigi, Catania, Italy

F.Meddi

INFN, Sezione di Roma and Dipartimento di Fisica, Università La Sapienza, Roma, Italy

M.Morando

INFN, Sezione di Padova and Dipartimento di Fisica, Università di Padova, Italy

Abstract

Several Omega3 electronic chips for the readout of pixel detectors have been tested by irradiation with a 15 MeV electron beam. Several parameters concerning the functionality of the chip have been measured during and after irradiation up to 60 krad. Some annealing effect was also observed.

1 Introduction

Heavy-ion collision experiments at the Large Hadron Collider (LHC) at CERN will provide a unique opportunity to study strongly interacting matter at extreme energy densities, so as to probe the expected phase transition from hadronic matter to a plasma of deconfined quarks and gluons.

The heavy-ion detector ALICE (A Large Ion Collider Experiment) is a general purpose facility [1], which will be sensitive to most of the emitted products (hadrons, electrons, muons and photons). The ALICE collaboration will study collisions of heavy (Pb-Pb) and lower mass (e.g. Ca-Ca) systems, in addition to pp and p-nucleus collisions, which provide reference data.

At a c.m. energy around 6 TeV/nucleon, foreseen for the LHC experiments, a huge particle multiplicity is predicted by the current theoretical models. This may reach values slightly less than 10^5 for a central Pb-Pb collision. An efficient tracking system is then required to handle events with such a large multiplicity. To this aim, a Silicon Inner Tracking System (ITS) and a Time- Projection-Chamber (TPC) are planned. The ITS is made by six silicon layers surrounding the interaction point at distances between 3.8 cm and 45 cm. A large flux of charged particles is then expected to cross such detectors, which must be taken into account to estimate the radiation dose. Especially the available technology for the pixel readout electronics (which will be used for the two innermost layers) could be critical with respect to radiation hardness, due to the distance from the interaction point. Studies on how to improve this parameter are currently in progress [2].

Studies of the radiation hardness of the electronic chips are currently in progress within the ALICE Collaboration with the use of several probes (X-rays, gamma rays, protons). Here we report on some results of a study carried out by a 15 MeV electron beam. The use of electrons is particularly suited to this aim, since electrons are minimum ionizing particles at these energies, and thus they simulate well the bulk of the expected flux of charged particles through the ITS.

Section 2 recalls some results of the evaluation of the absorbed dose in the ITS, which were obtained by MonteCarlo simulations. Section 3 is devoted to a short description of the irradiation and testing set-up, while Section 4 reports on the obtained results. Some conclusion is drawn in Section 5.

2 Evaluation of the expected dose in the ITS

Evaluation of the radiation dose exposure have been reported in the Technical Proposal [1] and in recent studies [3, 4, 5].

Here we want to recall the overall result of a recent simulation [5], which was done by a full GALICE [6] simulation of the response of the ITS to the flux of

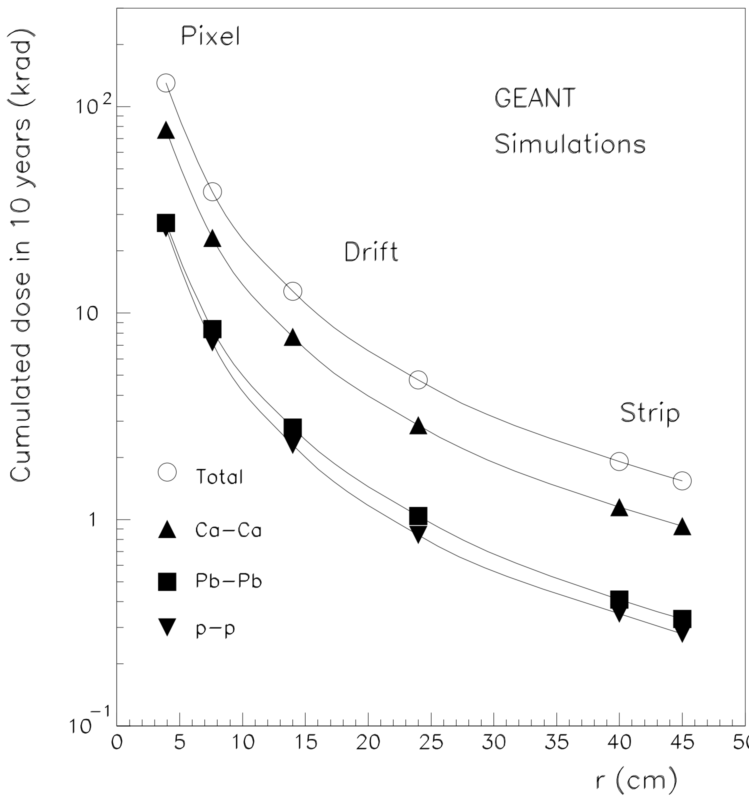

Figure 1: Expected overall dose in the ITS according to the ALICE scenario.

particles originating from realistic pp, CaCa and PbPb events description (according to the HIJING 1.35 event generator [7]) and incorporating all the relevant material distribution around the ITS. The results are summarized in fig.1, which shows the expected dose for each individual layer in the ITS (Pixel, Drift and Strip detectors) according to the planned scenario of beam use in ten years.

The radiation dose (i.e. the deposited energy per unit mass) expected for the innermost pixel layer is around 150 krad (1 krad = 10 Gy = 10 J/kg) over ten years, according to a reasonable running scenario for the ALICE experiment [1], in agreement with other calculations [3, 4].

3 Irradiation set-up

All the necessary electronics and data acquisition components to carry out the required tests are located within a clean-room situated in the Catania Physics Department.

The irradiations with electrons have been carried out at the LINAC facility of the Ospedale S.Luigi in Catania, which provides terapeutic beams of electrons and photons up to 21 MeV. The beam intensity was monitored by two different dosimeters and cross-checked against absolute normalization by the use of different ionization chambers. The value of the dose is known within 5%. The beam profile has a size of several centimeters, and it is uniform to a few percent at the center of the irradiation zone.

For this study, Omega3 readout chips were used. These chips are currently in use for other experiments running at CERN SPS, such as the NA57 experiment, and were a starting point in the design of the final eelectronic circuit for the ALICE experiment.

Each Omega3 chip was glued on a small card and bonded to the 42 relevant lines. This card is connected in turn to a second card which provides all the necessary bias voltages, which can be adjusted by setting the same working point as during the test performed in the clean-room. This system allows to bias the chip during all the irradiations and during the transport from the LINAC to the clean-room in the Physics Department. During the irradiations with electrons, similarly to what has been done with γ rays [8] the two currents I(+3.5 V) and I(+1.5 V) were monitored continuosly as a function of the time and of the absorbed dose. The following bias was applied to the chip: V_{comp} = 4000 mV, V_{bias} = 3500 mV, V_{dl} = 4000 mV, V_{dla} = 3000 mV.

Each irradiation procedure was carried out by using small cycles at the LINAC machine, each giving a dose of about 420 rad in Silicon, with only 2-3 seconds between a cycle and the next one. Fig.2 shows the absorbed dose for one of the irradiated chips as a function of time. This chip was irradiated in three different

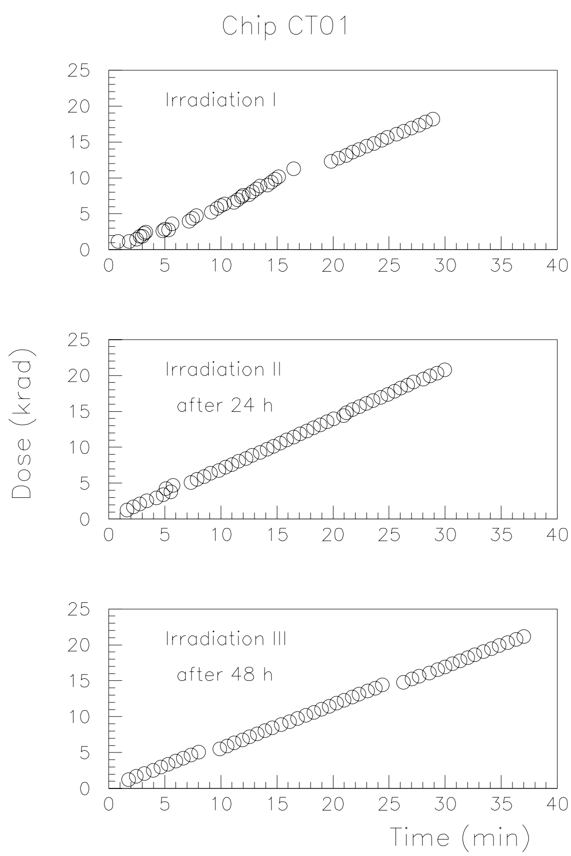

Figure 2: Absorbed dose as a function of time for one of the Omega3 chip.

steps, each giving approximately 20 krad with a shift of 24 h and 48 h. Apart from small fluctuations at the beginning of the procedure, the dose was linearly increasing with time. The mean dose rate during the irradiations was estimated to be around 610 rad/min, similar to that used with gammas from ^{60}Co source [8].

4 Results

During the irradiations the functionality of the chips was monitored by the measure of the *digital* and *analog* currents. Fig.3 shows a typical example of the trend which is usually observed [8] for the I(+3.5 V).

Up to a dose of 10 krad, there is practically no variation of the current, while a large increase is observed after 10-12 krad. At the end of the first irradiation period (about 30 minutes, giving a dose slightly less than 20 krad), the current was seen to raise approximately a factor of 2, from 40 mA to 80 mA. The time interval from the first to the second irradiation results in some annealing effect, which decreases the current back to about 50 mA. A further dose of 20 krad produces again a rapid increase of the current, up to 200 mA; a second annealing period of 48 hours decreases the current to 70 mA, and a somewhat limiting value around 200 mA is reached during the third irradiation. This trend, apart from small differences, is observed also with γ rays and with low energy protons [8]. The trend of the I(+1.5 V) current is shown in fig.4. As a result of the irradiation, this current decreases slightly during the first 20 krad, and after some recovery effect, a steep decrease is observed around 35-40 krad, where the current changed by more than three orders of magnitudes, down to about 1 mA after 50 krad. Also for the I(+1.5 V) current the behaviour as a function of the cumulated dose is similar to that seen with gammas and protons [8].

The variation of the currents as a consequence of the irradiation has important effects on the electric power which is dissipated and hence on the temperature, thus requiring a suitable cooling system. At the beginning, the dissipated power had a value of 0.16 W, corresponding to 78 μW/pixel, while this quantity increased to 340 μW/pixel after 60 krad.

Each pixel cell may have different behaviours concerning its functionality: *working pixel*, *noisy pixel* (output without any input) and *dead pixel* (no signal at all). Table 1 shows the results of a characterization carried out on one of the Omega3 chips, before irradiation and after 20, 40, 60 krad absorbed dose. After 20 krad

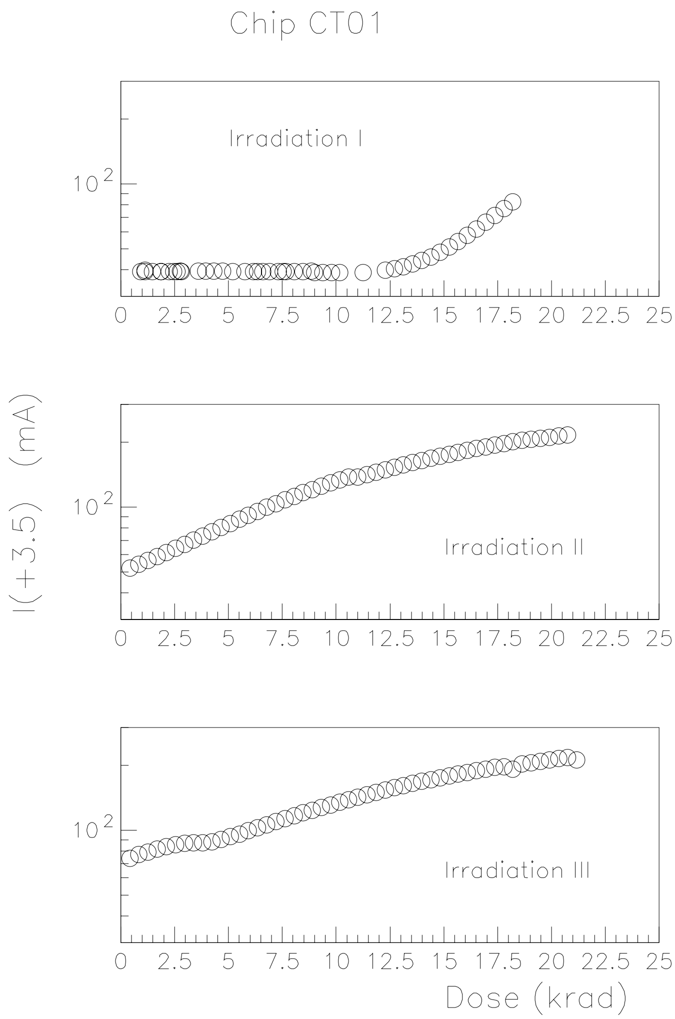

Figure 3: Trend of the I(+3.5 V) current in the Omega3 chip during irradiation. The three irradiations were consecutive with a pause of 24 h and 48 h respectively.

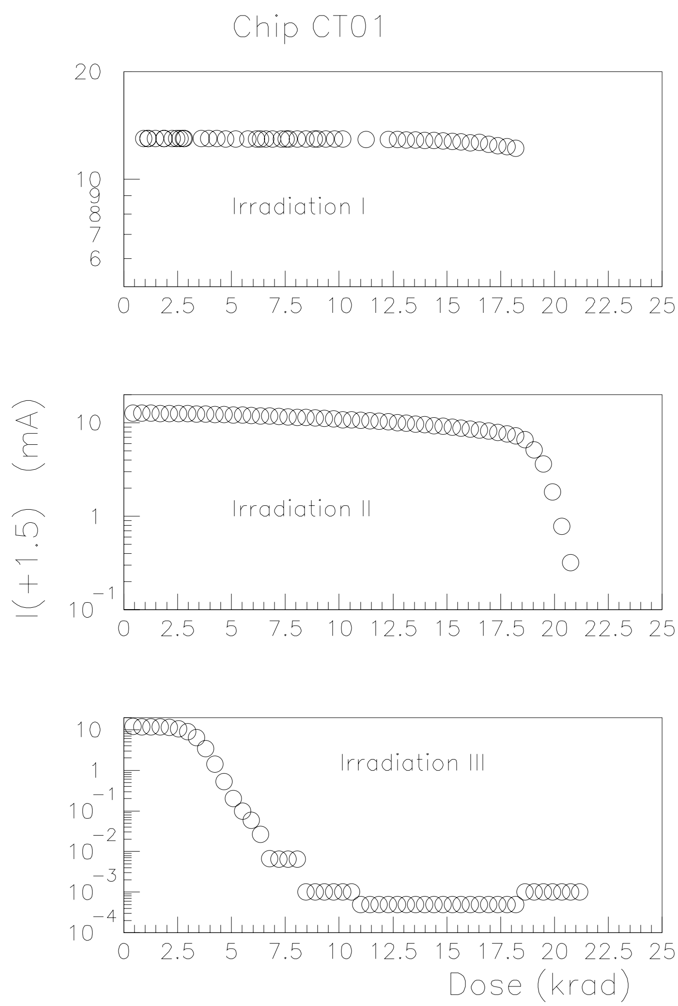

Figure 4: Trend of the I(+1.5 V) current in the Omega3 chip during irradiation. The three irradiations were consecutive with a pause of 24 h and 48 h respectively.

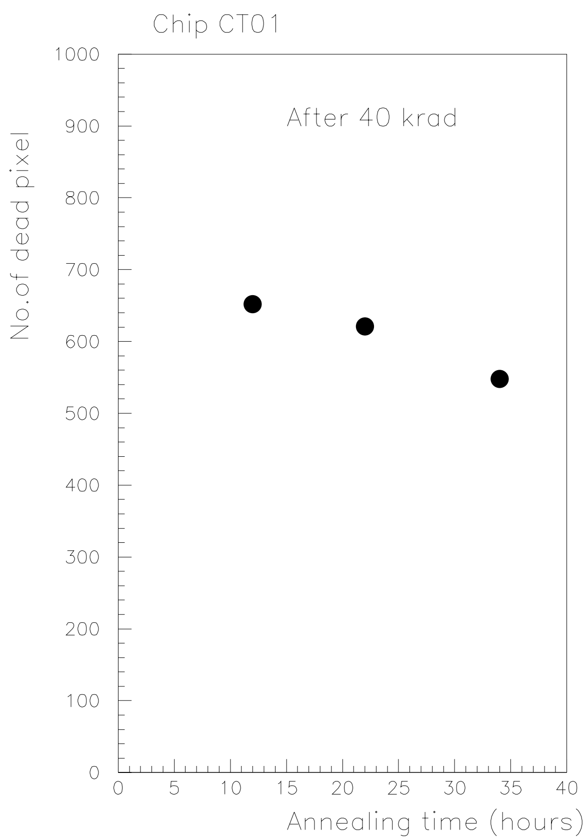

Figure 5: Number of dead pixels as a function of the annealing time, after a dose of 40 krad.

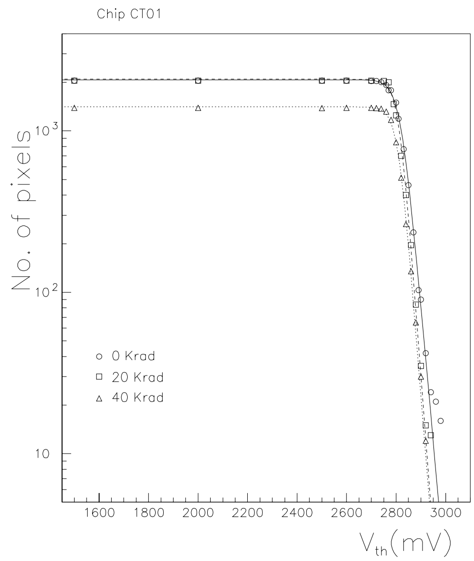

Figure 6: Number of working pixels in the chip as a function of the threshold, for different values of the absorbed dose.

	0 krad	20 krad	40 krad	60 krad
Working Pixel	2031	2033	1395 $\rightarrow$ 1499	0
Noisy Pixel	17	14	1 $\rightarrow$ 1	92
Dead Pixel	0	1	652 $\rightarrow$ 548	1956

Table 1: Functionality of the pixel cells before and after the irradiation. The arrows in the third column (40 krad) denote the effect of the annealing at room temperature (36 h).

the chip shows no change, in agreement with what was monitored by the electrical currents. A reduction of the number of working pixels has been observed for doses between 20 and 40 krad, with a loss around 30 % after 40 krad. After 60 krad all the pixel cells are noisy or dead.

Some annealing effect has been however observed after 40 krad. Fig.5 show the number of dead pixels after the chip received a dose of 40 krad, as a function of the annealing time (at room temperature). After approximately 36 hours, a partial recovery is observed, with more than one hundred cells coming back to their normal functionality.

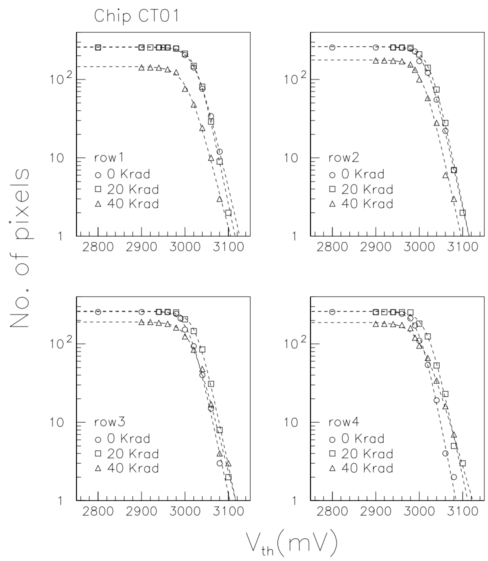

Figure 7: Number of working pixels in each particular region (256 cells) of the chip as a function of the threshold, prior to irradiation and after 20 and 40 krad.

	0 krad	20 krad	40 krad
$V_{th,0}$ (mV)	2819	2811	2809
W (mV)	25.36	21.18	22.21

Table 2: Parameters of the fit to the data in fig.6

The efficiency of the chip was investigated as a function of the electronic threshold, for a given input signal, before irradiation and after 20, 40 krad. Fig.6 shows the number of responding pixels versus threshold. The plateau below a given threshold shows no variation up to 20 krad, and a 30 % loss after 40 krad. The overall shape of this behaviour may be parametrized by the function

$$f(V_{th}) = C(1 - \frac{1}{1 + exp(\frac{-(V_{th} - V_{th,0})}{W})}) \quad (1)$$

where $V_{th,0}$ is the threshold at which 50 % of the pixel cells respond and W is a width parameter. The values of these two relevant parameters extracted from the fit for the data measured before and after the irradiations are shown in Table 2.

	0 krad	20 krad	40 krad
Region 1 $V_{th,0}$ (mV) W (mV)	 3024 18.38	 3026 16.09	 3006 19.89
Region 2 $V_{th,0}$ (mV) W (mV)	 3017 17.58	 3024 16.39	 3008 17.15
Region 3 $V_{th,0}$ (mV) W (mV)	 3010 16.75	 3025 16.36	 3015 19.36
Region 4 $V_{th,0}$ (mV) W (mV)	 2999 15.46	 3018 16.94	 3005 22.64
Region 5 $V_{th,0}$ (mV) W (mV)	 2989 15.41	 3017 16.84	 3009 22.75
Region 6 $V_{th,0}$ (mV) W (mV)	 2982 14.15	 3015 17.84	 3017 20.63
Region 7 $V_{th,0}$ (mV) W (mV)	 2967 17.74	 3015 18.29	 3014 22.12
Region 8 $V_{th,0}$ (mV) W (mV)	 2966 17.96	 3016 17.61	 3011 21.42

Table 3: Parameters of the fit to the data measured for the 8 subregions of the chip.

To study a possible dispersion in these parameters, the efficiency of the chip has been investigated as a function of the threshold for any selected subregion of the chip, by dividing each chip into eight regions, each including 256 cells, and by masking via software the other parts.

If the same analysis through eq.(1) is carried out on each of the eight regions, a dispersion of these two parameters may be observed. Fig.7 shows the behaviour of these curves for the regions 1-4 of the chip, before irradiation and after doses of 20 and 40 krad. The parameters $V_{th,0}$ and W fitted to the shape of each curve are reported in Table 3, and shown in fig.8.

What can be observed is an apparent narrowing of the data cloud after 20 krad, and a small spreading between 20 and 40 krad. This behaviour, somewhat strange, was observed also for a second chip after 20 krad, and further investigations could

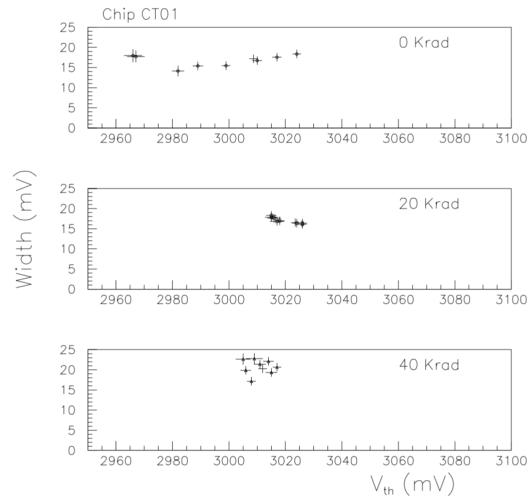

Figure 8: Dispersion of the threshold centroid and width among the eight regions of the chip before and after irradiation.

show whether it is due to a real effect.

We also looked at the efficiency of the chip as a function of the time delay with the strobe signal. Some shift of the order of a few tens of ns was observed after a dose of 40 krad, together with an overall spread of the curve. However it should be noted that the strobe width has usually a much larger value, so these effects should not be dramatic as far as a loss of efficiency is concerned.

5 Conclusions

A few Omega3 electronic chips were irradiated with 15 MeV electrons, up to a dose of 60 krad. The functionality of the chips was monitored during the irradiations by means of the *digital* and *analog* currents, and by a complete characterization before the irradiation and after a dose of 20, 40 and 60 krad. The results are in agreement with those already obtained with gamma rays from a ^{60}Co source and with low energy protons [8]. Small differences may be explained mainly in terms of differences in the behaviour of different chips, which can be relevant especially in case of commercial type CMOS circuits, not specifically designed to be radiation tolerant.

The overall irradiation procedures, carried out with different probes, allowed to study several aspects of the radiation damage of the Omega3 chips and to set-up a protocol which can be applied to the coming up final design ALICE readout chips.

References

[1] A Large Ion Collider Experiment (ALICE), Technical Proposal, CERN/LHCC 95-71 (1995).

[2] W.Snoeys, Proceedings of the International Pixel Detector Workshop (PIXEL98), Batavia, 7-9 May 1998.

[3] G.Chabratova, W.Klempt, L.Leistam and N.Slavin, ALICE Internal Note ALICE/95-41 (1995).

[4] F.Meddi and M.Morando, Nuclear Instruments and Methods A395(1997)416.

[5] A.Badalà et al., Internal Note ALICE/ITS 99-01(1999).

[6] See N.J.A.M. van Eijndhoven, ALICE Internal Note/1995-44 for the original version (1.05) of the package.
Updated versions of GALICE may be found at the Web address http://www.cern.ch/ALICE/Projects/offline/Simulation/galice/

[7] X.N.Wang and M.Gyulassy, Phys. Rev. D44(1991)3501; last version of the package may be obtained by anonimous ftp at nsdssd.lbl.gov

[8] S.Di Liberto et al., Internal Note ALICE/ITS/98-43