ALICE/ITS 2000-24
Internal Note-ITS
19 September 2000

IRRADIATION MEASUREMENTS ON THE 0.25 μm CMOS PIXEL READOUT TEST CHIP BY A 14 MEV NEUTRON FACILITY

A. Badalà, R. Barbera, F.Librizzi, A. Palmeri, G. S. Pappalardo, F. Riggi

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

S. Di Liberto, F.Meddi, S.Sestito and D.Loi

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

M.Angelone and M.Pillon

Associazione Euratom-ENEA sulla Fusione, ENEA C.R. Frascati,
P.O. 65, 00044 Frascati, Italy

Abstract

A test facility station with 14 MeV neutrons was arranged at the FNG-ENEA Laboratory in Frascati (Italy) for the characterization with respect to radiation tolerance of the prototype pixel readout test chips in 0.25 μm IBM technology on edgeless design. This facility could allow to test both the readout chips and the pilot chips for the pixel readout system. In fact both ASIC's will have to survive at the same radiation level foreseen for the innermost layer (r = 4 cm) of the Inner Tracker System (ITS) in the LHC-ALICE experiment. Two test chips were exposed to an overall flux of 1.3×10^{12} 14 MeV neutrons/cm^2, which is larger than the expected neutron flux in ALICE during 10 years data taking. No measurable variation in the parameters defining the chip functionality (analog and digital currents, linearity, shapes of the signal, efficiency) was observed.

1 Introduction

One of the experimental problems to be faced in the design of the Inner-Tracking-System (ITS) [1] of the ALICE experiment is the implementation of radiation tolerant technologies for the electronics located close to the interaction region. This problem is of special concern for the pixel readout electronics, which stays on the first two layers of the ITS at r= 4 cm and r =7 cm respectively. For such layers the expected overall dose is in the order of 150-200 krad [2, 3], while the energy-integrated equivalent neutron flux has been estimated as 3×10^{11} n/cm^2 [4]. All these quantities refer to the commonly used scenario of ten years data taking for the ALICE experiment, with a proper sharing of Pb, Ca and proton beams.

The electronics to be used for pixel detectors include the readout chip and the pilot chip, which will control the data flow from the pixel ladder to the DAQ. While the latter is under design, significant progress has been achieved in the design of the final readout chip, which has been submitted to IBM and is expected back in October 2000. The tests reported here refer to the last prototype available, which was fabricated in 0.25 μm CMOS technology by IBM with the layout designed by the CERN Microelectronics Group in order to be radiation tolerant [5]. The main layout modifications with respect to the standard CMOS design rules were the use of the gate all around the drain, instead of simply linear, and the use of a guard ring around the transistors. The penalty for such layout modifications is a reduced integration capability with respect to a standard design in 0.25 μm.

This investigation aimed at two different goals. The first was to study the peculiar experimental problems that are to be solved in order to perform a neutron irradiation, also in view of possible irradiation investigations on the final chip. The second goal was to extend previous measurements carried out on this chip with γ-rays and protons [1], by using 14 MeV neutrons as well.

2 Experimental conditions

The facility used is the 14 MeV Frascati Neutron Generator (ENEA-FNG) based on the T(d,n)^{4}He fusion reaction [6]. The FNG produces a nearly isotropic source of 14 MeV neutrons. A beam of deuterons is accelerated up to 300 keV onto a titanium-tritiated target, which is located a few meters above the floor in order to minimize background due to neutrons scattered from the walls. The neutron source strength is measured using the associated α-particle measurement performed by a solid state silicon counter located inside the vacuum beam tube at an angle of about 180 degrees. This information is treated together with the calculation obtained with a Monte-Carlo program realized and optimized by the FNG service in order to know the neutron differential energy spectrum in the position where the device to be irradiated is located.

In addition to this standard procedure, we profited also of a complementary information obtained by an activation measurement on a Niobium foil placed just behind the chip during the irradiation, whose activity was measured for a few hours after the end of the irradiation with a Ge counter. For such measurement a Nb foil with 12 mm diameter was used. The ^{93}Nb(n,2n)^{92}Nb reaction gives a metastable Nb isotope with half life equal to 10.15 days, which emits 934.5 KeV γ-rays (99 %). The activity was then measured by a HPGe detector which was previously calibrated by the absolute activity of sealed radioactive sources produced at CEA, France. Cross sections to deduce the absolute neutron flux were taken from [7].

Two test chips in 0.25 μm technology (z3, z4 in the following) were exposed. This kind of prototype chip is a matrix with 65 rows and 2 columns, with a total active area of 0.1 cm^2. The chip is packaged to allow the mounting in a simple board for an easier manipulation during the tests. No active device is present in such small board, which contains only a few resistors and capacitors. The chip was placed at zero degrees with respect to the deuteron beam and at a distance of 21.1 mm from the interaction plane, i.e. from the neutron source (see fig.1). During the irradiation the electronic chip was powered, and long cables (20 m) were used in order to maintain at a safe distance the rest of the electronic chain needed for the readout. Consequently it was not possible to perform the standard and complete characterization of the chip in place during the irradiation with such long cables and only the monitoring of the currents was possible, both for the analog and digital parts of the chip. To characterize the chip in terms of its functionality we moved the chip outside the irradiation hall and used conventional short connections. The characterization was carried out for both the digital and the analogue part. For the analogue part we measured the linearity response of both the preamplifier and the shaper, injecting a step pulse with different amplitudes through a coupling capacitor. The shape of the signal response at specific pulse amplitudes was also recorded by a digital oscilloscope. For the digital part the efficiency response and the dispersion of the response parameters were studied.

3 Irradiation conditions

The results discussed here refer to the chip z4, for which we collected all the information foreseen and described at the end of the previous section. For the other chip (z3), which received a slightly smaller neutron flux, only the monitoring of the digital and analog currents was carried out during the irradiation, while no information is available concerning the complete characterization of the chip, due to an electrical discharge, which caused severe damage to the chip, probably due to grounding problems.

The flux of neutrons on the chip was kept almost constant during the irradiation time of about 80' (see fig. 2), with a slightly lower rate during the first 30'. The neutron fluence per unit of energy on the chip in the irradiation position is shown in fig.3. The energy-integrated overall flence was 1.34×10^{12} n/cm^2 with a mean energy of 14.32 MeV. Such a spectrum was evaluated by taking into account the experimental effects due to the finite geometry of the device, the energy and angle distribution of neutrons due to the kinematics of the $T(d,n)^4He$ reaction and the material distribution close to the irradiated chip. In addition to the neutrons, also a photon flux is present. The associated fluence per unit of energy in the position of the chip is shown in fig.4. The total γ-fluence was 1.69×10^{11} γ/cm^2 with a mean energy of 2.33 MeV.

It is common practice to refer the neutron fluence to that of 1 MeV neutrons to evaluate the relative damage in silicon. Several models have tried to parametrize the relative displacement damage in silicon by fast neutrons, as a function of the neutron energy [8, 9], in order to evaluate the hardness factor for a specific energy spectrum. The equivalent 1 MeV neutron fluence received by our chip was estimated to be 2.33 $\times$ 10^{12} n/cm^2 assuming 1.74 as hardness parameter for our neutron spectrum. The estimated error on the measured 14 MeV neutron fluence is 5 %. Simulations show that the cumulated dose due to a total fluence of 2.33×10^{12} n/cm^2 of 1 MeV is of the order of 80 rad. The contribution to the cumulated dose by 1.69×10^{11} γ/cm^2 with a mean energy of 2.33 MeV is of the order of 130 rad in the hypothesis of charged particle equilibrium. It should be observed that recent FLUKA simulations [4] of the secondary neutron flux on the pixel layers predict a spectrum with a maximum yield in the energy range 100 keV-1 MeV, so that the normalization to 1 MeV-equivalent neutron fluence is a realistic choice.

4 Experimental results

The behaviour of the currents for the digital (open squares) and for the analogue (black dots) part of the chip (z4) as a function of the neutron fluence is shown in fig.5. Each current is normalized to the value assumed before the start of the exposure: the maximum variation is less than 0.5 %. Similar values were also obtained for the chip z3.

No effect was noticeable comparing prior and after the irradiation the shape of the signals obtained from the preamplifier and from the shaper using pulses sent to the analogue input via the coupling capacitor. No degradation effect is visible in the linearity study done prior and after irradiation. In fact the relative errors in the linear gain remain in the order of a few percent both for the preamplifier and for the shaper outputs (figs. 6-9).

The efficiency response was found to be the same comparing the results before and after the irradiation. This is evident looking at the plots shown in figs.10-13, which show the behaviour of the same group of ten pixel cells, before and after the irradiation. The analysis was done separately for the two groups of pixels with static and dynamic flip-flop respectively.

The efficiency measurements shown in figs. 10-13 were fitted by a sigmoid shape $f(V)=A/[1+\exp-(V-B)/C]$, where V stands for the amplitude of the step analog pulse injected through the coupling capacitor to the input of each cell, A is a nor-

Table 1: Results of the fit carried out on the efficiency measurements, for the static flip-flop (see text)

	B (mV)	C (mV)
Before irrad.	95.76 ± 0.97	2.145 ± 0.088
After irrad.	97.88 ± 0.93	2.006 ± 0.034

Table 2: Results of the fit carried out on the efficiency measurements, for the dynamic flip-flop (see text)

	B (mV)	C (mV)
Before irrad.	94.96 ± 0.83	1.925 ± 0.069
After irrad.	96.40 ± 0.80	1.928 ± 0.028

malization factor, B is the threshold value measured at 50 % efficiency, and C is a slope parameter, related to the noise width σ. The values of the parameters B and C extracted from the fit are reported in Tables 1 and 2.

By a comparison of the values before and after the irradiation, we observed a variation in the threshold value of 2.12 mV (about $210e^-$) for the static flip-flop and 1.44 mV (about $140e^-$) for the dynamic ones. These values are smaller than the noise width σ which can be extracted from the C parameters in the fitted curves, which correspond to $(417 \pm 17)e^-$ and $(375 \pm 13)e^-$ for the static and dynamic cases, before the irradiation.

5 Conclusions

Two prototypes of the pixel readout chip were exposed to a fluence of 14 MeV neutrons of about 1.3×10^{12} n/cm^2, largely above the expected value on the inner layers of the ITS, according to the simulations. A neutron generator based on the T(d,n)^{4}He reaction was used at the ENEA Laboratory in Frascati. The results demonstrate that all the relevant parameters of the chip have not been altered by such a fluence. Both the analog and digital part of the chip were investigated. The shape of the signals, both from the preamplifier and from the shaper, were recorded before and after irradiation, showing no variation. The variation in the digital and analog currents of the chip was seen to be in the order of 0.5 %. Also the linearity gain and the efficiency response did not show any sensible effect due to neutron irradiation.

While such results, together with those obtained with γ-rays and protons [1], up to a cumulated dose of several Mrad, show that the chip functionality is preserved as far as the total dose is concerned, single event effects (SEE), such as latchup or other effects, could still be important and need a detailed and dedicated investigation. This will require a special set-up in order to control the full response of the chip during the irradiation, thus monitoring SEE along the time.

References

[1] ITS Technical Design Report, CERN/LHCC 99-12(1999).

[2] F.Meddi and M.Morando, Nucl. Instr. and Methods A395(1997)416.

[3] A.Badalà et al., Internal Note ALICE-99/01.

[4] A.Morsch, FLUKA calculations; see http://AliSoft.cern.ch/offline/ and private communication.

[5] W.Snoeys et al., 8th European Symposium on Semiconductor Detectors, Schloss Elmau, Germany, 1998; NIM A439(2000)282.

[6] M.Martone, M.Angelone and M.Pillon, Report ENEA RT/ERG/FUS/93/65.

[7] N.P.Kocherov, P.K.Mc Laughlin, The International Reactor Dosimetry File, IAEA-NDS, Rev.2, Wien, 1993). Data were taken from file IRDF-90 v.2

[8] V.A.J.van Lint et al., Mechanisms of radiation Effects in Electronic Materials, vol.1 (Wiley, New York 1980).

[9] G.Lindstrom, M.Moll and E.Fretwurst, NIM A426(1999)1, and references therein.

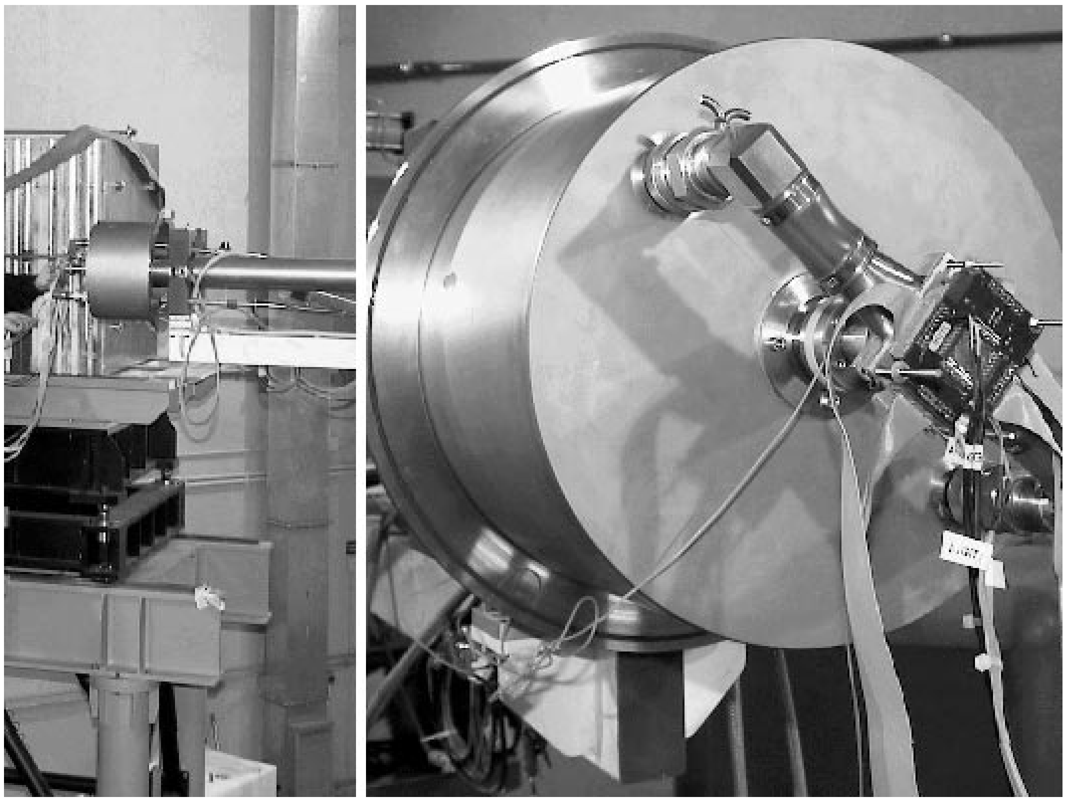

Figure 1: The beam line transport for the deuteron (on the left) and a detail of the board with the chip mounted close to the neutron source (on the right).

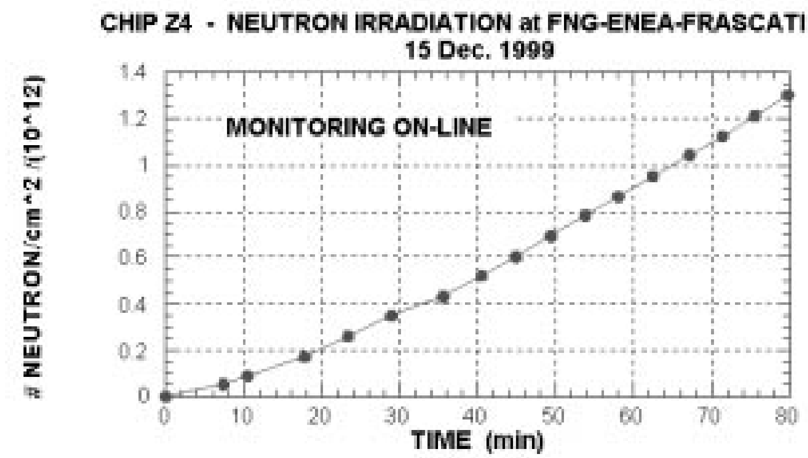

Figure 2: The reconstructed neutron fluence during the exposure of the chip z4 as a function of the irradiation time, as obtained by the monitoring of the associated alphas from the T(d,n)^{4}He and the Monte Carlo program by the FNG service.

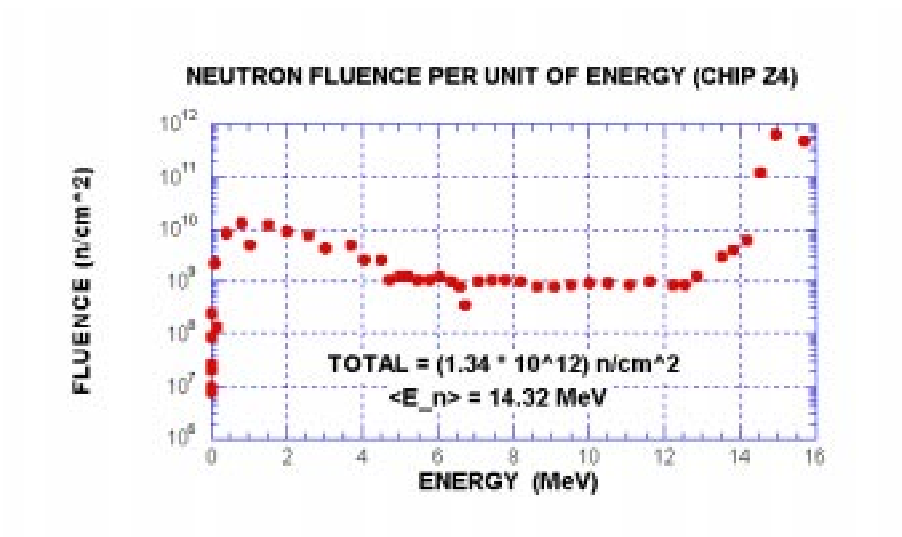

Figure 3: Energy distribution of the neutron fluence on the chip.

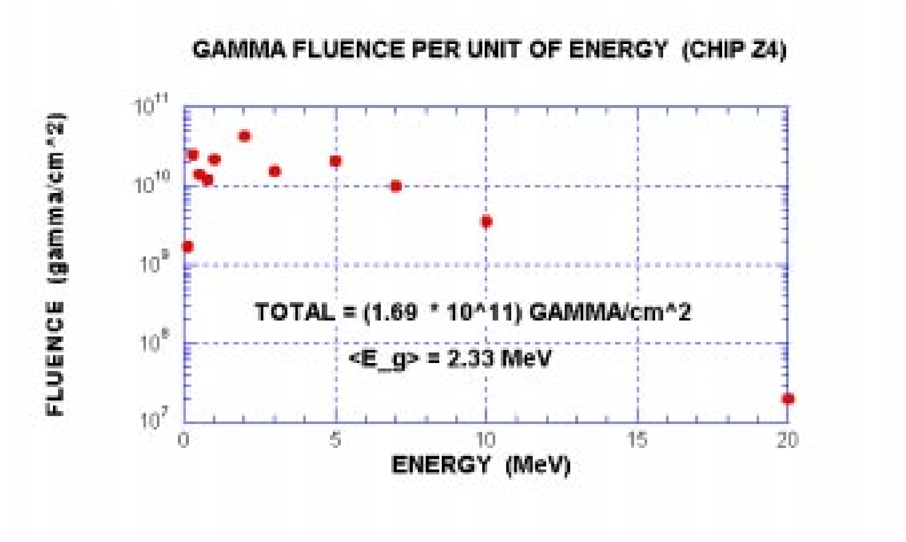

Figure 4: Energy distribution of gammas impinging on the chip during the irradiation.

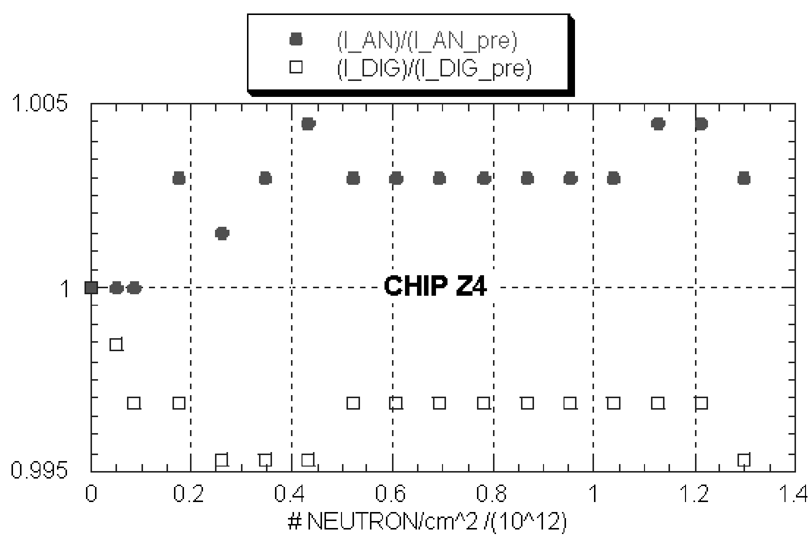

Figure 5: Ratio between the values of the digital (open squares) and the analog (black dots) currents as compared to the corresponding values before the irradiation, as a function of the neutron fluence.

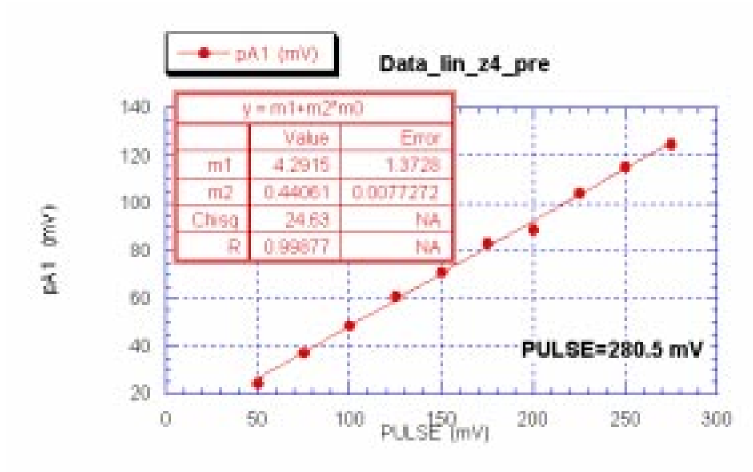

Figure 6: Results of the linearity study carried out before irradiation, on the preamplifier output.

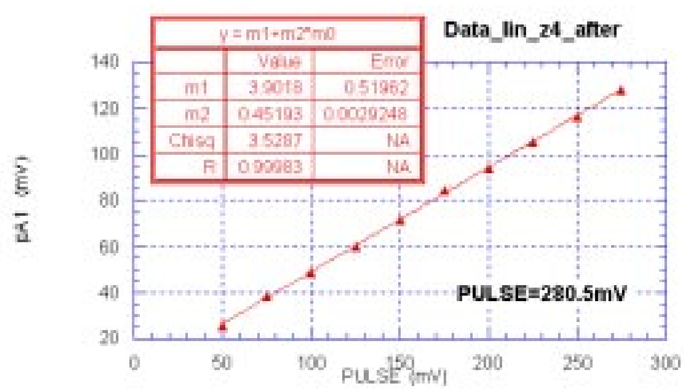

Figure 7: Results of the linearity study carried out after irradiation, on the preamplifier output.

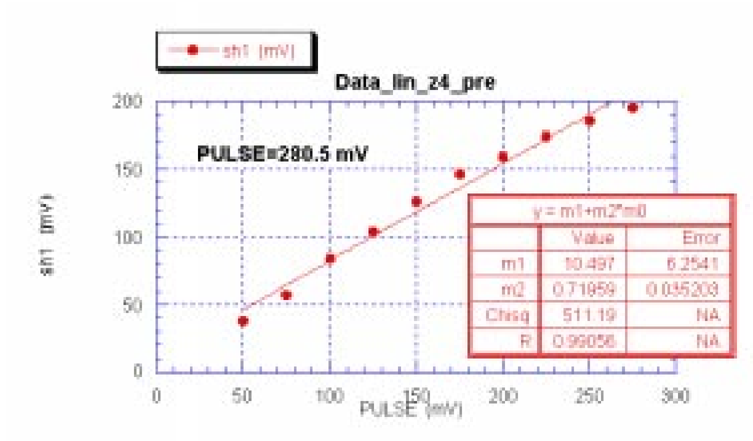

Figure 8: Results of the linearity study carried out before irradiation, on the shaper output.

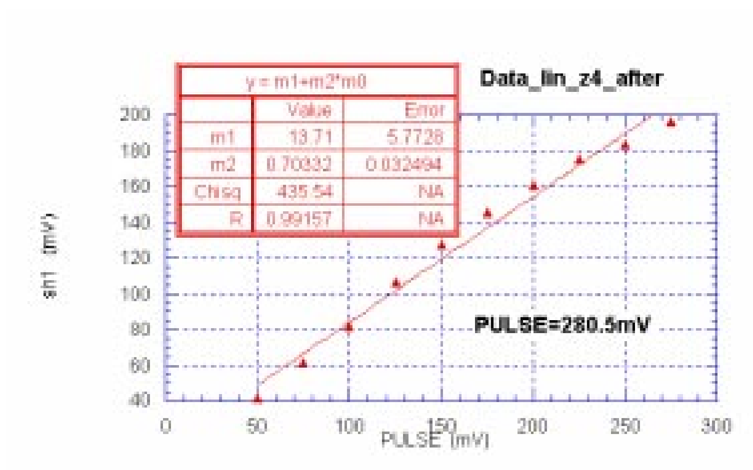

Figure 9: Results of the linearity study carried out after irradiation, on the shaper output.

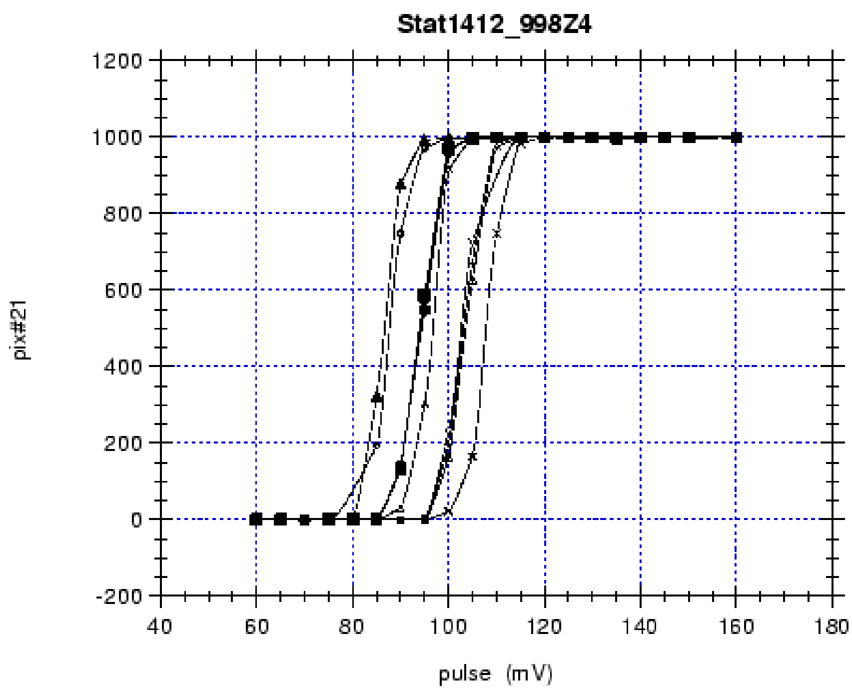

Figure 10: Efficiency response for a group of ten pixel cells, measured on the static flip-flop, before the irradiation.

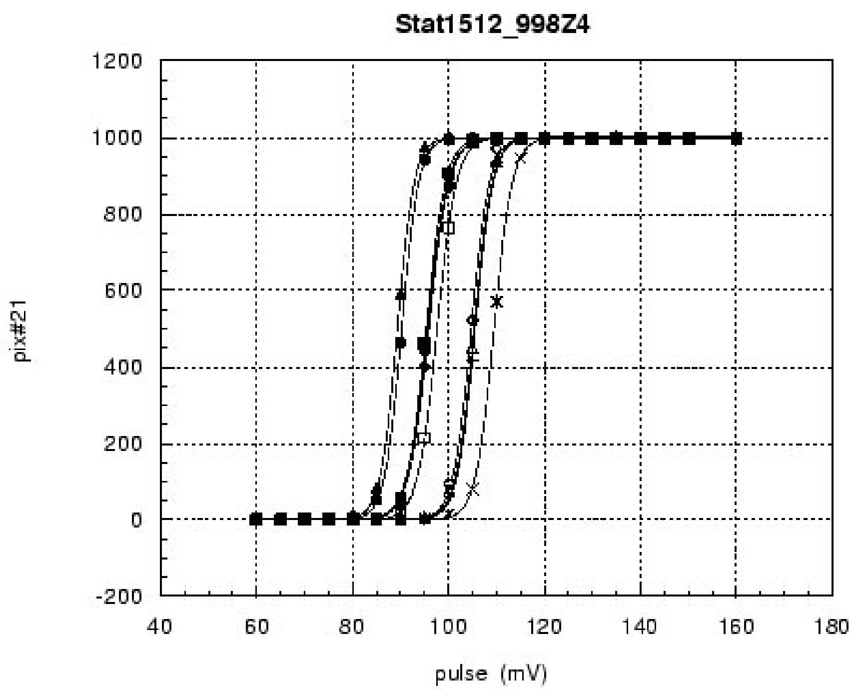

Figure 11: Same as fig. 10, measured just at the end of the irradiation.

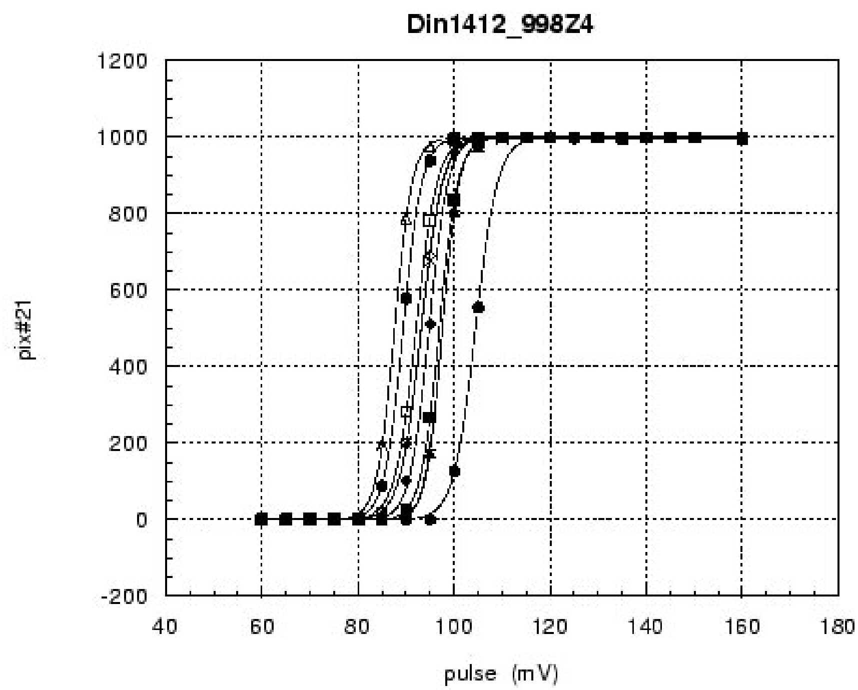

Figure 12: Efficiency response for a group of ten pixel cells, measured on the dynamic flip flop, before the irradiation.

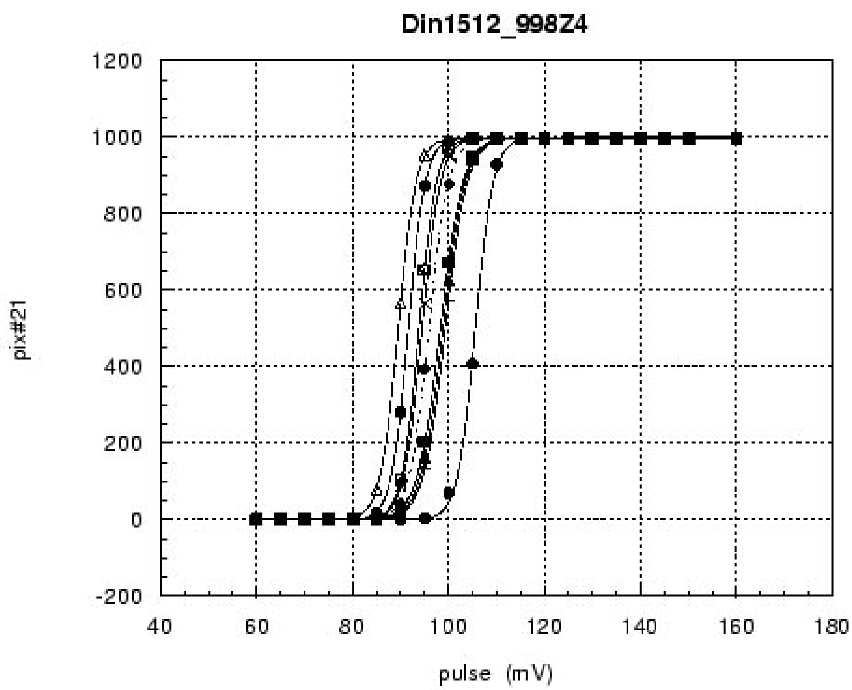

Figure 13: Same as fig.12, just at the end of the irradiation.