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Nuclear Instruments and Methods in Physics Research A 426 (1999) 34–37

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Performance of irradiated silicon microstrip detectors

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Abstract

Silicon microstrip devices to be installed in Large Hadron Collider (LHC) tracking detectors will have to operate in a high radiation environment. We report on performance studies of silicon microstrip detectors irradiated with neutrons or protons, up to fluences comparable to the first ten years of running at LHC. Obtained results show that irradiated detectors can still be operated with satisfactory signal-to-noise ratio,and in the case of inhomogeneously type inverted detector a very good position resolution is achieved regardless of the zone crossed by the particle.

1. Introduction

Studying the performances of irradiated silicon microstrip detectors is of fundamental importance for tracking devices to be installed in Large Hadron Collider (LHC) experiments, where a hostile radiation environment is envisaged. During the first years of LHC the detectors will be unhomogeneously irradiated, especially in the forward–backward trackers due to their position with respect to the beam line, and as a consequence they will undergo only partial bulk type inversion.After that period almost all detectors will be fully inverted and will have increasing depletion voltage and a worse signal-to-noise ratio; in order to understand their behaviour in such conditions, we decided to irradiate two prototype detectors. The detectors we tested are wedge shaped, double sided, built from N-type silicon wafers, 300 μm thick, 5 kΩ cm resistivity [1], with integrated AC coupling capacitors and polysilicon biasing resistors on both p and n sides. They are made by CSEM, Switzerland. The relevant design parameters are reported in Table 1. One of the detectors under test was uniformly irradiated at PSAIF, CERN, to a fluence of 8×10^{13} neutrons/cm^2 of 1 MeV equivalent neutron [2]; the other one to a fluence of 5×10^{13} protons/cm^2, 24 GeV equivalent proton,not uniformly irradiated at Karlsruhe, Germany. Both these fluences are enough to obtain type inversion of the silicon bulk. The proton beam used to irradiate the second detector illuminated only an area of 1 cm^2 near the smaller base of the trapezoid, so we had type inversion only in a fraction of the whole detector, underlying a surface of about 6×7 mm^2. The detector characteristics were measured on a probe station before and after irradiation, then they were exposed to a muon

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0168-9002/99/$ - see front matter
PII: S0168-9002(98)01466-1

Table 1
Characteristics of the detectors under test

Det	Batch		N	L (mm)	W (μm)	P_i (μm)	RB (MΩ)	D_{ph} (mm^2)
W/ORT	CREST	p	128	62.5	14–24	38–50	18	5.6 × 62.5
	DS	n	495	4.8–6.3	60	125	22	

N is the number of implanted strips on the junction or ohmic side, L strip length, W strip width, P_i implant pitch, RB bias resistor value, D_{ph} active area of the detector.

beam at CERN to test the response to minimum ionizing particles. The detectors were equipped with fast front end electronics (PreMux128, 45 ns shaping time [3]) and were installed in a climatic chamber capable of controlling the temperature within 0.2°C in a range between −30°C and +20°C. The DAQ system was built in Florence and is described in Refs. [4,5]. All test beam results reported here refer to p-side readout.

2. Results on neutron irradiated detector

The full depletion voltage, as measured from an I–V curve, shifted from 35 V to about 95 V after irradiation [6], while the beginning of the plateau in the charge collection vs.bias voltage distribution moved from 60 V to 150 V, with a 5% increase in collected charge due to temperature variation in the range −5°C to −15°C (see Fig. 1). The total noise seen in the detector, including the front end chip, showed a slow decrease as a function of the applied bias voltage down to a minimum corresponding to the beginning of the aforementioned charge plateau, and then an increase related to the leakage current of the detector, which in its turn is heavily dependant on the temperature (Fig. 2). From the practical point of view the most important parameter is anyhow the signal-to-noise ratio [7], since this is the quantity that will affect the efficiency for track finding and the position resolution when the detector will be irradiated; in Figs. 3 and 4 we report the S/N for the same type of detector before and after irradiation. These results make us confident that we can operate a heavily damaged detector of this type at bias voltage around 180 V and $T = -15$°C, with a signal-to-noise ratio slightly better than 20–1.

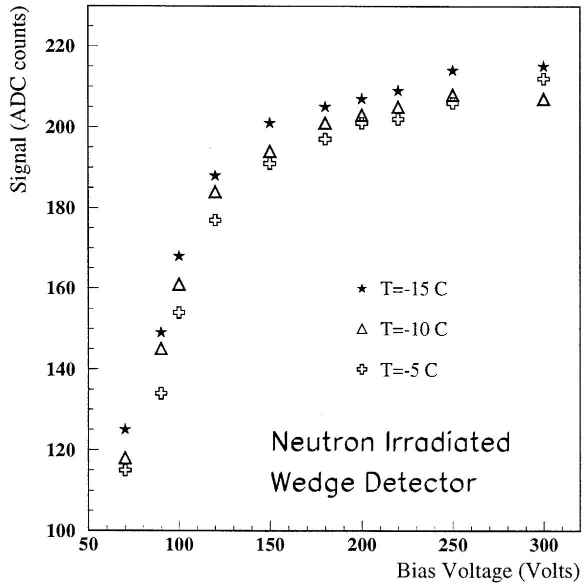

Fig. 1. Most probable value of collected charge (from Landau curve fit to the data) vs. bias voltage, at $T = -5$°C, −10°C, −15°C.

3. Results on proton irradiated detector

In the proton irradiated detector we can distinguish three regions (non-inverted, "gray" and inverted) with different bulk silicon characteristics, by measuring the value of the bias resistance for different strips on the N-side as a function of bias voltage (Fig. 5): the behaviour of the three curves reflects the different locations of p–n junction along the detector. This particular configuration of the bulk silicon will be reached if the detectors will be installed orthogonally to the beam line of LHC, in a forward tracker, during the first period of collider operation; this situation could eventually cause

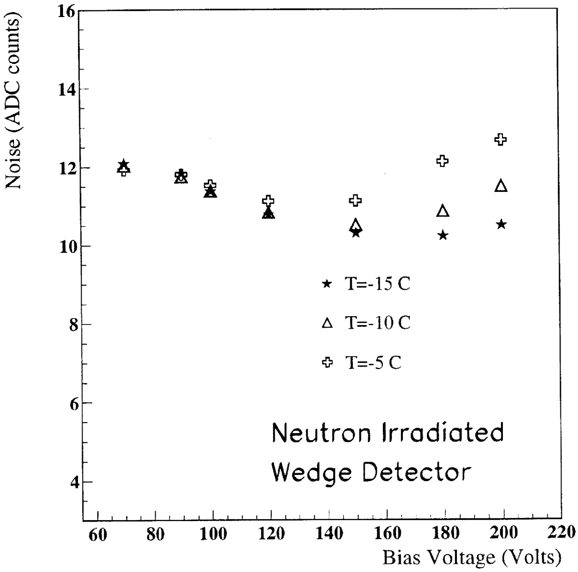

Fig. 2. Mean value of cluster noise vs. bias voltage, at $T = -5°C, -10°C, -15°C$.

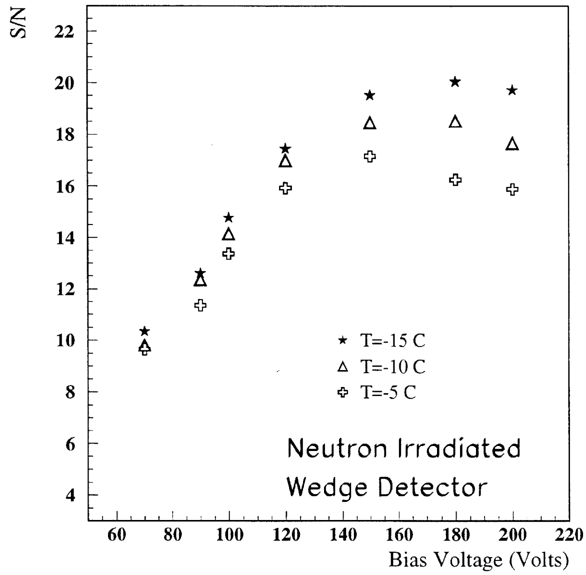

Fig. 4. Signal-to-noise ratio vs. bias voltage after neutron irradiation at $T = -5°C, -10°C, -15°C$.

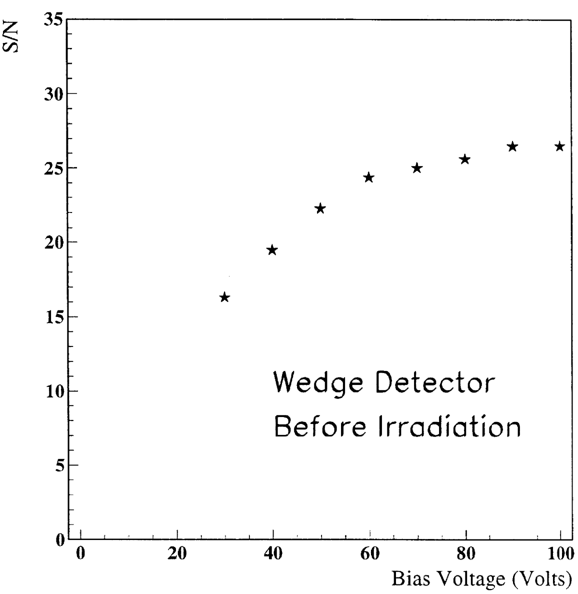

Fig. 3. Signal-to-noise ratio vs. bias voltage before neutron irradiation at $T = 20°C$.

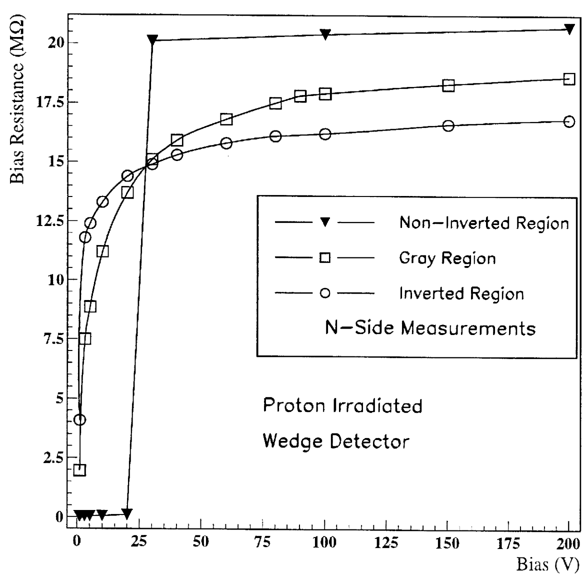

Fig. 5. Bias resistance vs. bias voltage in three different regions along the detector.

inefficiency and/or worsening in position resolution. We consequently checked for efficiency, and we found all the three regions are fully efficient for hit finding in a given fiducial area, even at bias voltage as low as 50 V. Concerning the signal-to-noise ratio we have seen a temperature dependence effect as an overall 10% increase going from + 5°C to − 20°C; we report in Fig. 6 S/N vs. bias voltage

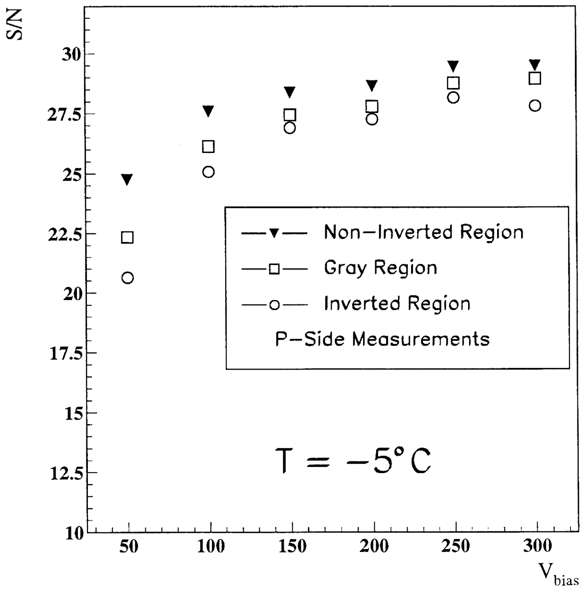

Fig. 6. Signal-to-noise ratio vs. bias voltage in three different regions along the proton irradiated detector.

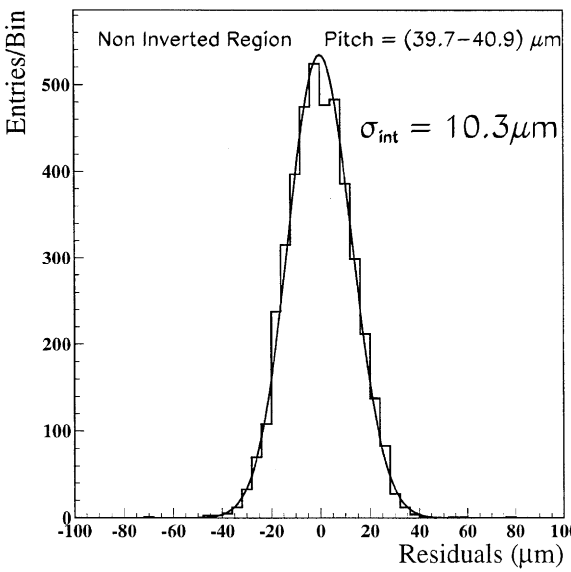

Fig. 7. Gaussian fit to the distribution of residuals and the intrinsic resolution for non inverted region.

for $T = -5°C$: this temperature is a sort of "upper limit" for the operating temperature of a silicon tracker at LHC, which should be below $-10°C$. The charge loss in the gray and inverted regions is

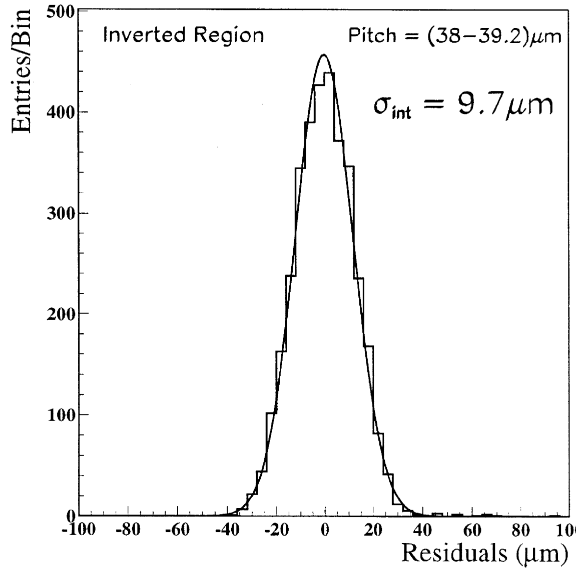

Fig. 8. Same as Fig. 7, but for inverted region.

evident but very limited. We measured also the position resolution, making a detailed study as a function of temperature (between $-20°C$ and $+5°C$) and bias voltage (between 50 and 300 V): all results are compatible for the three regions without any temperature or bias voltage dependent effect. Given this compatibility, we show in Figs. 7 and 8 the global fit to the residual distribution for the non-inverted and inverted regions: the intrinsic resolution of about 10 μm stays unchanged all along the different regions of the detector.

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