University of Liverpool

Overview of n-side read-out microstrip devices

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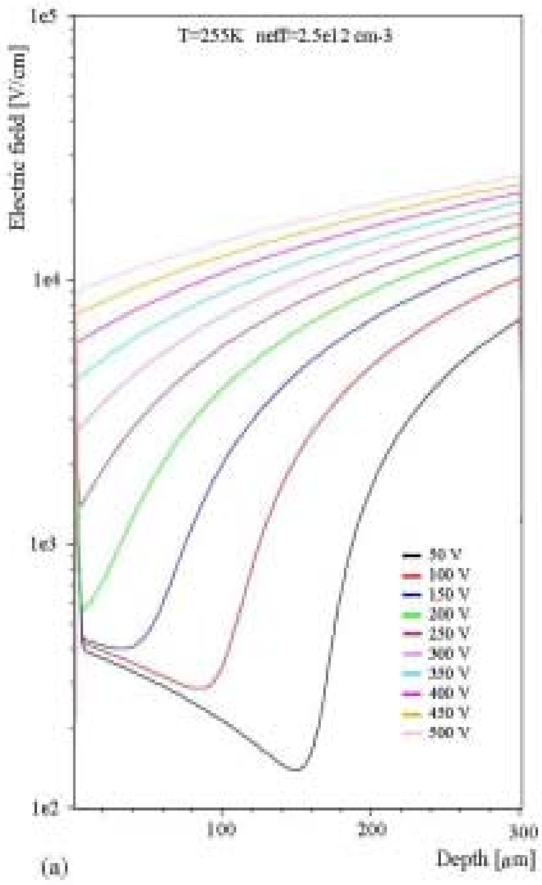
N side read-out for high radiation environments was proposed already for the Atlas SCT detectors. It takes advantage of the presence of the high electric field on the read-out side after irradiation.

The irradiation studies gave evidence of a sensitive improvement in the CCE performances.

P-side **N-side**



The devices where characterised in term of CCE, reverse current and noise. The increase of the CCE curves with V is fitted with a $V^{1/2}$ dependence.

P.P. Allport et al./Nucl. Instr. and Meth. in Phys. Res. A 418 (1998) 110–119

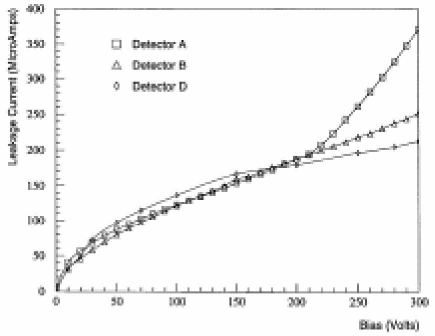


Fig. 4. *IV* curves of different manufacturer detectors after 2×10^{14} p/cm² at − 15°C.

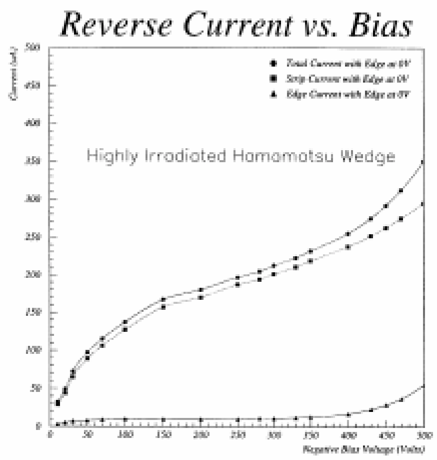


Fig. 5. Hamamatsu wedge irradiated detector, edge and total currents at − 15°C.

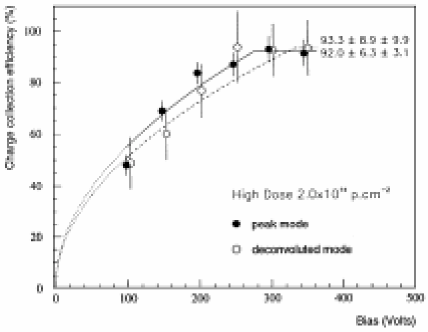


Fig. 6. Hamamatsu wedge irradiated detector charge collection efficiency (6 cm).

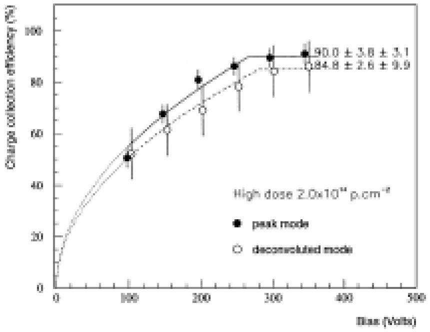
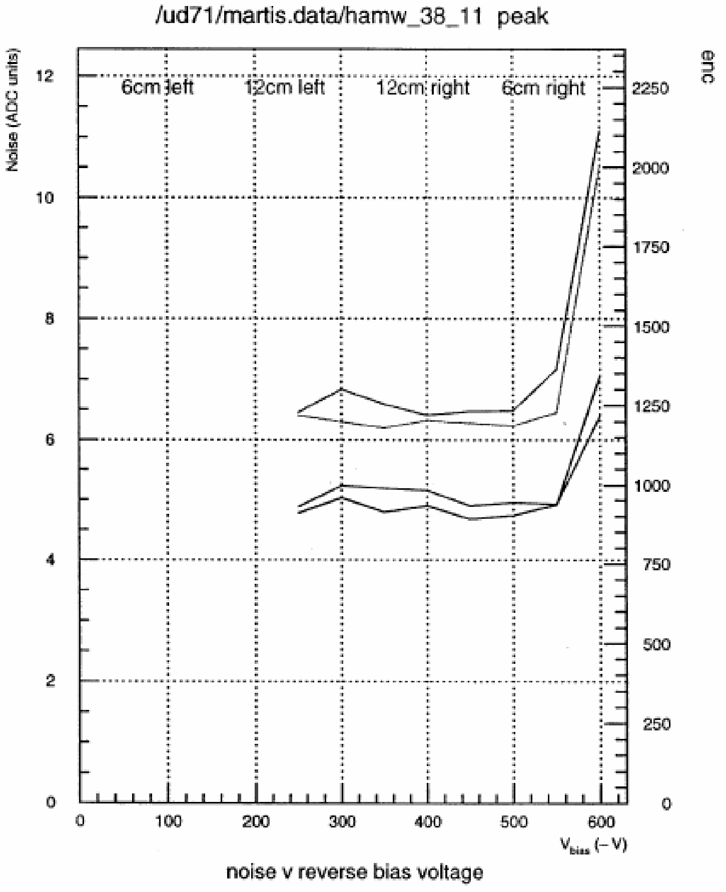
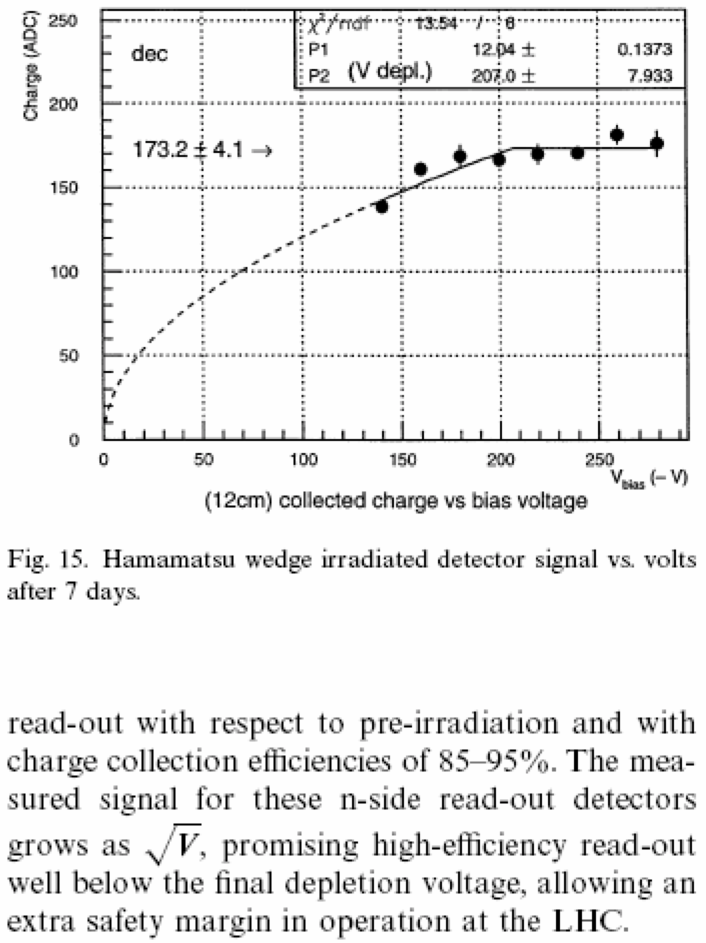


Fig. 7. Hamamatsu wedge irradiated detector charge collection efficiency (12 cm).

[2] and anyway, operationally, the voltage of interest is that where the charge collection saturates. In the quoted charge collection efficiencies shown in



The increasing of the CCE, that goes more like a SQRT(V) dependence, indicates that the collected charge is proportional to the depleted volume of the detector also for partially depleted operations. This is in contrast with what happens in simple diodes or in p-in-n detectors.



(12cm) collected charge vs bias voltage

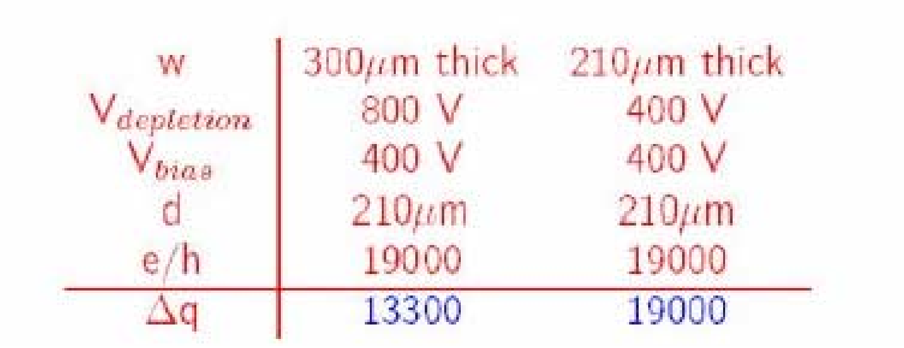
Fig. 15. Hamamatsu wedge irradiated detector signal vs. volts after 7 days.

read-out with respect to pre-irradiation and with charge collection efficiencies of 85–95%. The measured signal for these n-side read-out detectors grows as $\sqrt{V}$, promising high-efficiency read-out well below the final depletion voltage, allowing an extra safety margin in operation at the LHC.

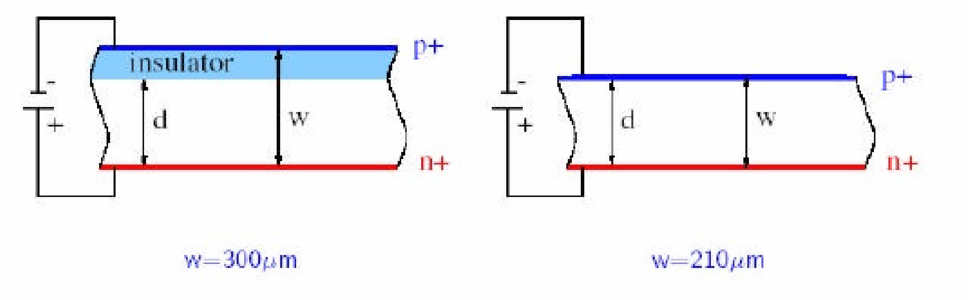
In pad diodes and p-side read-out detectors the collected charge is not proportional to the depleted depth *d* *(or $V^{1/2}$)*, but it is reduced by the ratio of *d* to the detector thickness *w*:

$Q=Q_0\, d/w$

So, for example:



w	300μm thick	210μm thick
$V_{depletion}$	800 V	400 V
V_{bias}	400 V	400 V
d	210μm	210μm
e/h	19000	19000
Δq	13300	19000



In the case of diodes the thick device depleted at the same depth as the thin detector collects less charge with a factor *d*/*w*. In the case of highly segmented detectors with n-side read-out, the charge collected is about proportional to the depleted thickness. This effect allows the underdepleted operation of relatively thick devices after irradiation.

The n-in-n geometry requires strips isolation to preserve the segmentation. The strip isolation can be achieved by the implantation of individual p-stops around the n-strips (technique used e.g. in the Atlas-SCT prototypes), or the more modern technique of p-spray (relatively low dose p-implantation on the entire wafer).

Drawbacks for the p-stops technique:

- requires a minimum strip pitch depending on the design rules of the manufacturer
- ‘Leaky channels’ can severely reduce the yield, hence the necessity of a minimum width of the p-stop implant
- It has shown problems of micro-discharge noise

Drawbacks for the p-spray technique:

- The tuning of the implant dose is critical (it needs to be sufficient to compensate for the radiation induced fixed oxide positive charge)
- The surface damage usually leads to higher leakage currents before irradiation

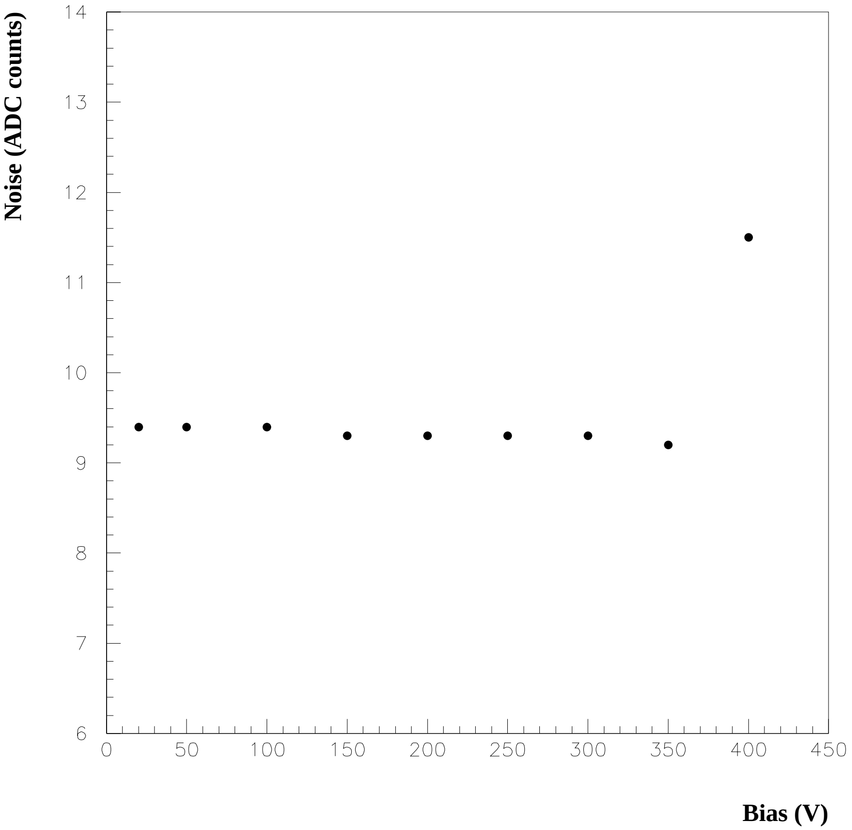
What type of interstrip isolation is preferable?

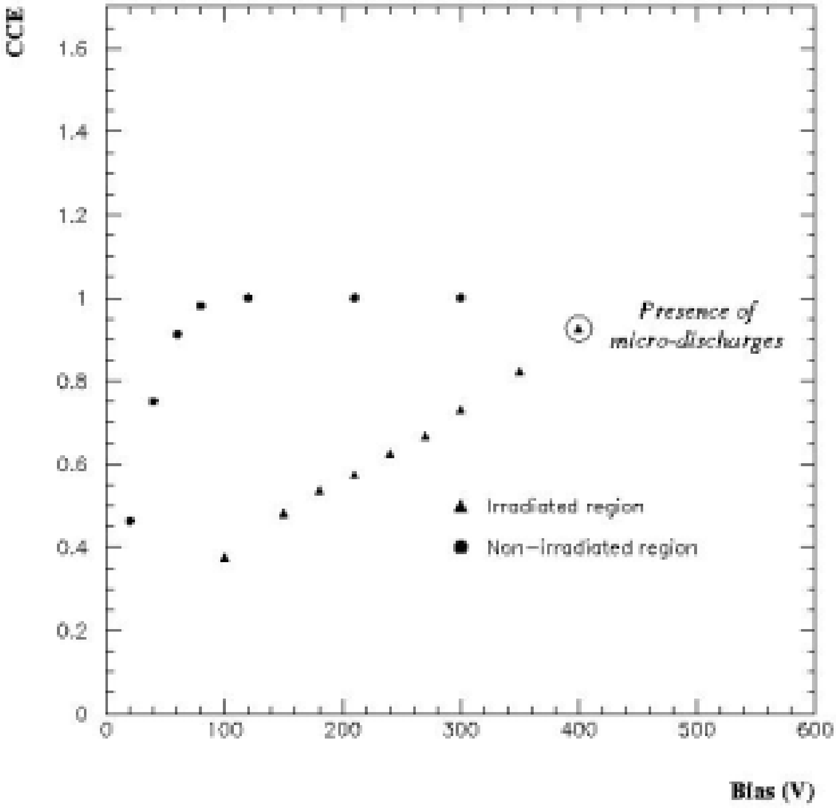
The results shown in the previous slides are obtained with individual p-stop isolation. Further results after irradiation of both type of devices are here reported, and, in my opinion, represent a quite clear indication of what processing technique delivers better performances after heavy irradiation.

Individual p-stops

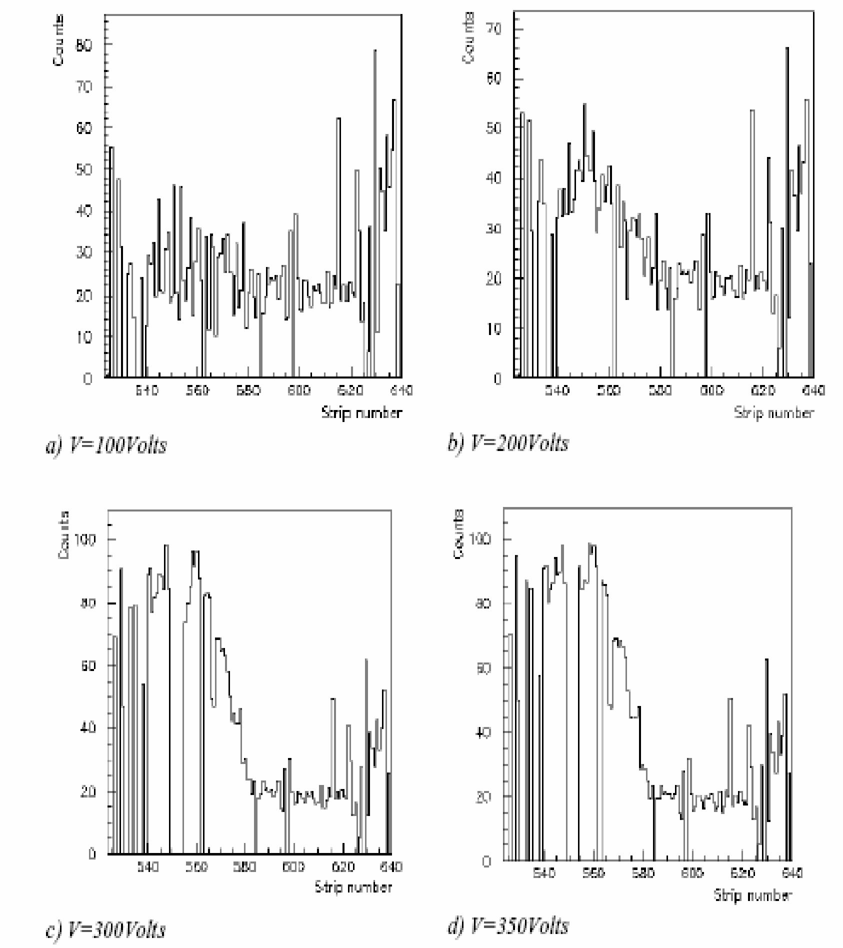
Here the performances in term of CCE of a Hamamatsu prototype n-in-n device with individual p-stops for the LHCb VELO are illustrated.

Even with the precaution included by the manufacturer in the design (field plates), the micro-discharge noise kicks in above 350V, after a relatively moderate irradiation dose (3. 10^{14} p cm^{-2}).





Examples of micro-discharges (here in p-in-n detectors)



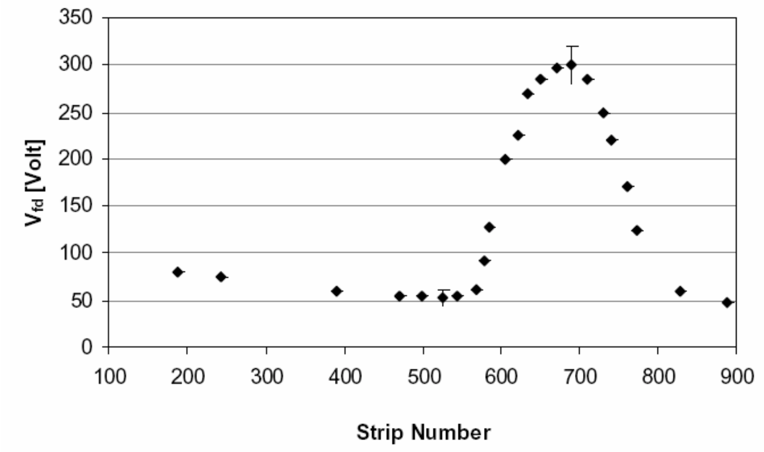
a) V=100Volts

b) V=200Volts

c) V=300Volts

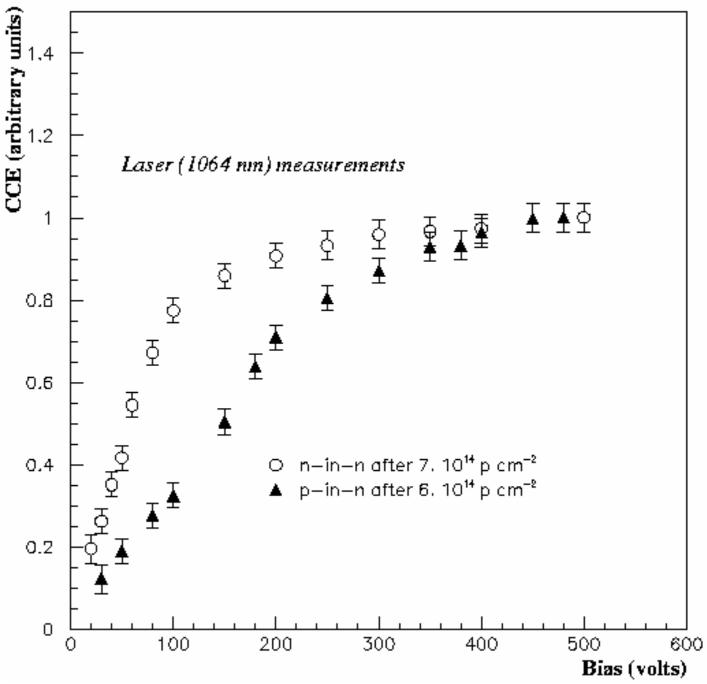
d) V=350Volts

Micro-discharges can represent the earliest mechanism of failure for micro-strip detectors when operated at high voltage, when high peak electric field are found. Here it is shown the development of micro-discharge noise in a partially irradiated p-in-n detector: the non-irradiated area has a higher electric field for the same applied voltage and the noise is clearly anti-correlated to the irradiation profile.



P-spray isolation

The p-sprayed devices show the same advantage in term of CCE as the p-stop ones……



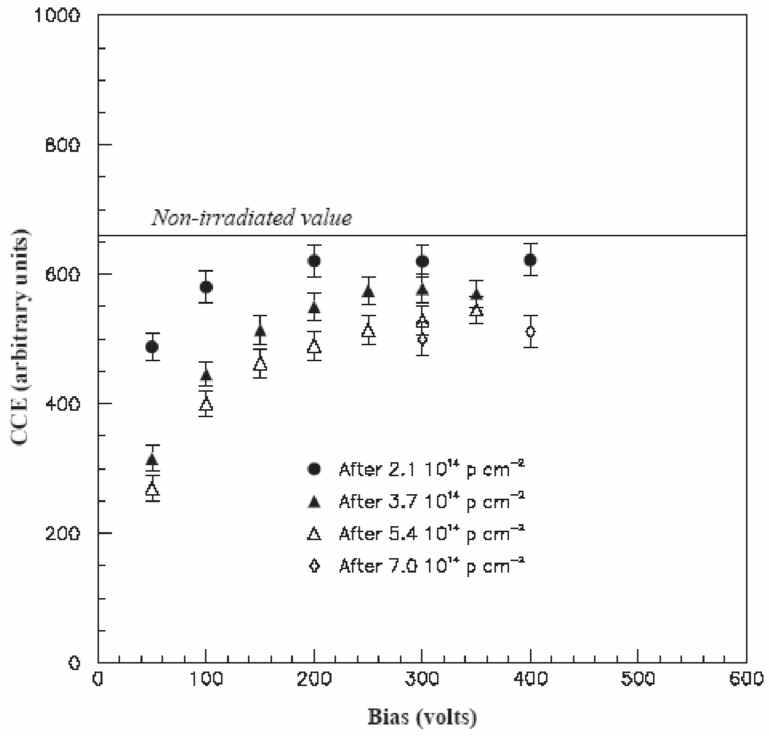
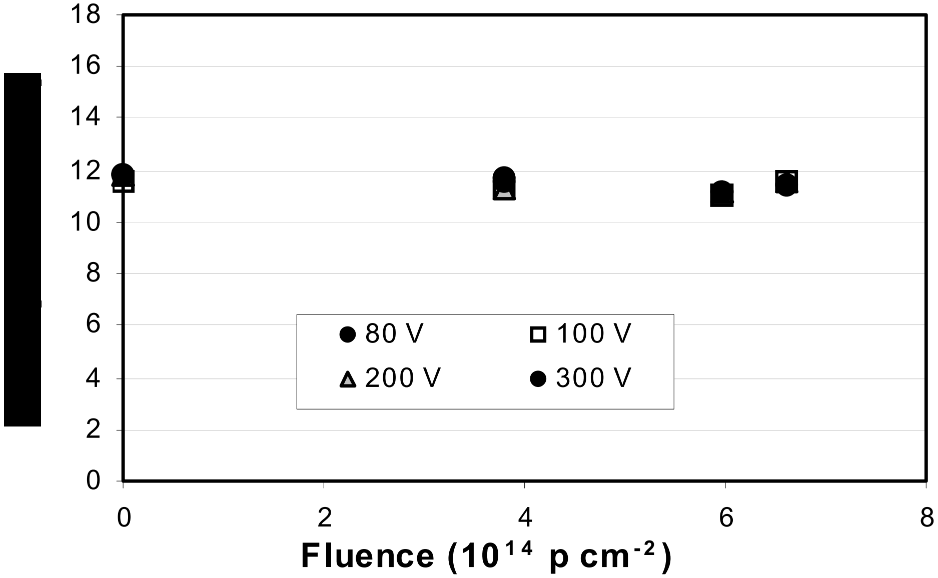


Fig. 5. ^{106}Ru β-source CCE(V) for different dose regions of the LHCb prototype n-in-n micro-strip detector.

P-spray isolation

…….and they also show an impressive robustness against micro-discharge noise, even without particular attention in the design of the electrodes and AC-coupled metal strips (metal or polysilicon field plates).

The device was a LHCb-VELO n-in-n prototype 200µm thick, and was biased to > 400V with no evidence of micro-discharges. Similar devices 300µm thick were biased to 800V after irradiation with identical results.


[redacted]

P-spray vs p-stops

The irradiation results clearly go to the directions of the p-spray isolation technique: the charge collection efficiency appears to be equally enhanced (compared to the traditional p-in-n) in both cases, but the noise performances appear to be much more robust for the p-spray. Concerning the pre-irradiation performances, although significant statistical comparison of both methods with similar production quality procedure (e.g. with the same manufacturer) are still missing, possible worse I-V performances before irradiation could be expected due to the implantation process and the relative damage to the silicon surface and Si-Oxide interface. These currents are though not important for devices that will be used in a harsh radiation environment. On the other hand, the elimination of the micro-discharge noise achieved by p-sprayed devices is a huge benefit in view of high voltage operations.

As a consequence, the specified QA procedures for individual sensors might keep into account the worsening of the pre-irradiation currents. It is possible that in the future requirements like: “The detector displays a characteristic at 20^{o}C which is below 6uA/cm^{3} at 150V and below 20uA/cm^{3} at 350V, and agrees with the manufacturer's data within the agreed tolerance.” could be relaxed. Cohort statistics of this type of devices will inform the QA requirements suitable for p-sprayed sensors.

State of the art rad-hard devices.

The advantages of these devices are now well accepted among the HEP detector community.

The devices that will be used in the highest radiation environments in ATLAS (pixels), CMS (pixels) and LHCb-VELO (microstrips) all use the n-side read out on oxygen enriched silicon with excellent radiation tolerance performances.

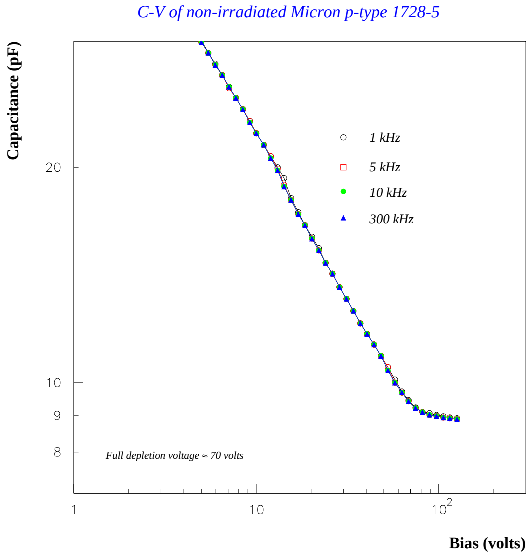
This detectors represent the small volume of sensors to be installed very close to the interaction region.

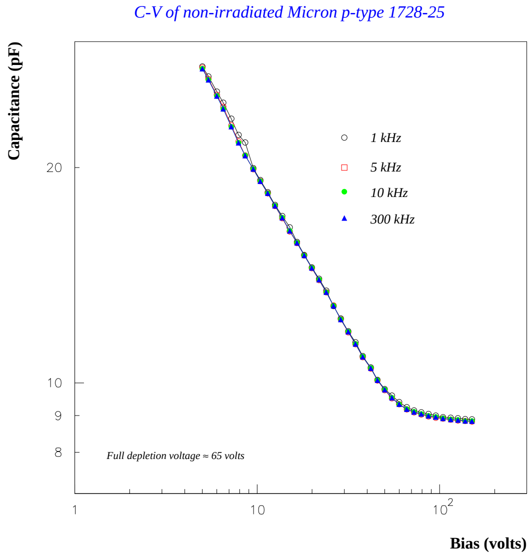
But what are the inconvenient of this geometry? The need of double sided lithography to implant guard ring structures on the pre-irradiation junction side (the backplane p-n junction) and the fact that the active volume develops, before irradiation, from the backside p-n diode junction. The first severely impact on the cost of the device (close to 50%) and the second requires overdepletion operation before type inversion.

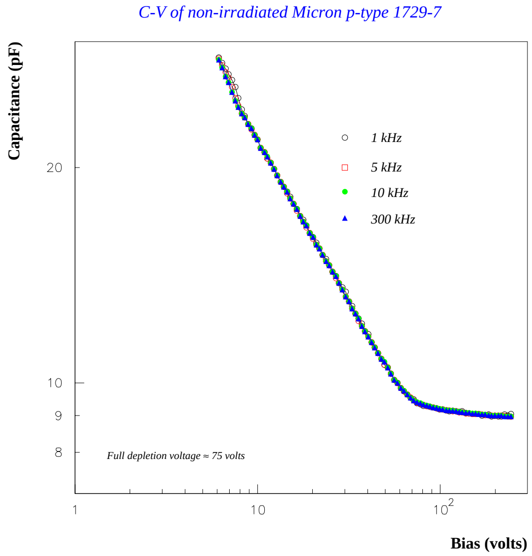
Both these disadvantages can be avoided with the **n-in-p diode geometry**.

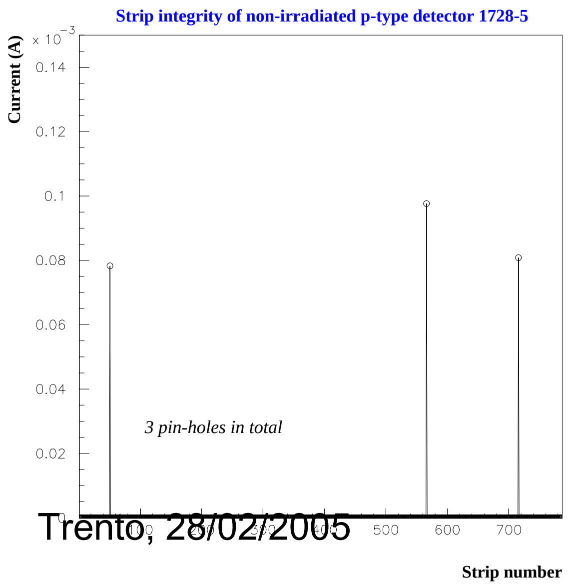
A development of n-in-p microstrip detectors with the typical ATLAS-SCT geometry was performed in Liverpool (see e.g. M. Hanlon PhD thesis, in collaboration with Micron). The results with the full size 6x6 cm^2 prototypes with individual p-stop isolation were very encouraging.

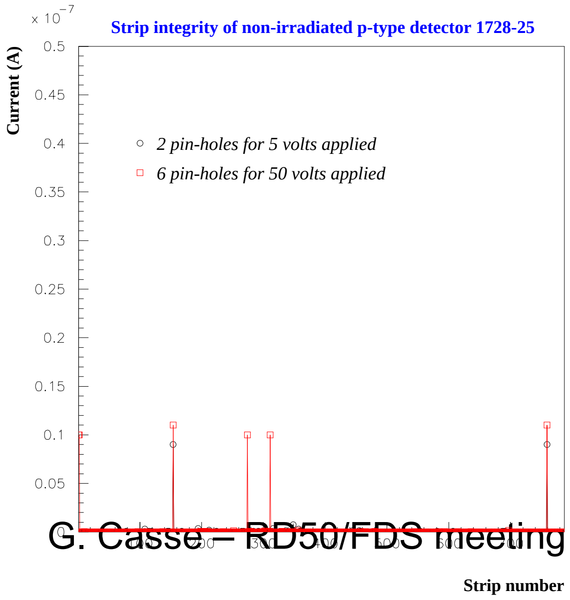
P-type detectors with individual p-stops processed by Micron on Liverpool masks (ATLAS SCT full size devices). Pre-irradiation characterisations

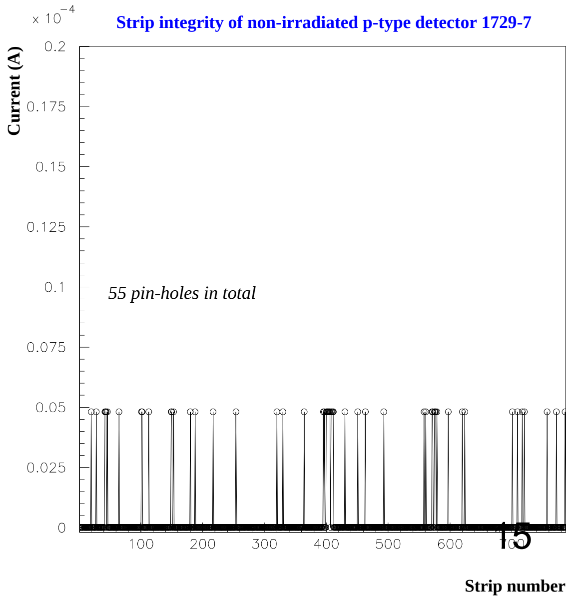

C-V of non-irradiated Micron p-type 1728-5


C-V of non-irradiated Micron p-type 1728-25

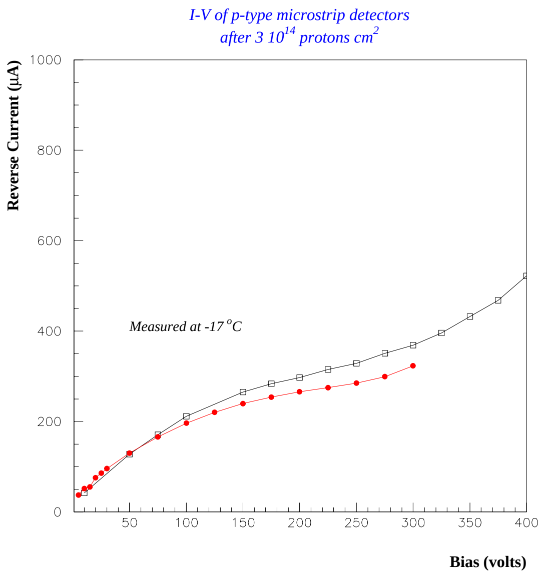

C-V of non-irradiated Micron p-type 1729-7


Strip integrity of non-irradiated p-type detector 1728-5

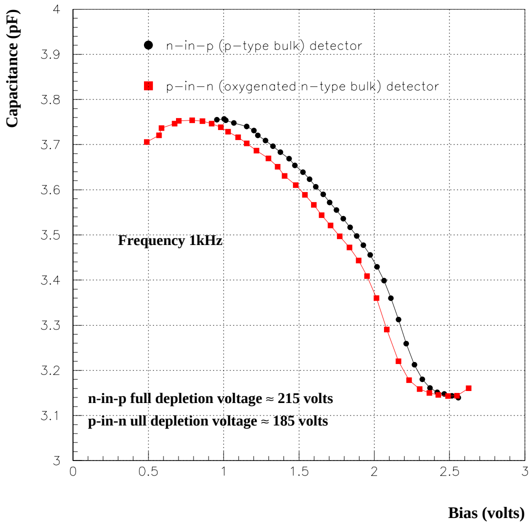

Strip integrity of non-irradiated p-type detector 1728-25


Strip integrity of non-irradiated p-type detector 1729-7

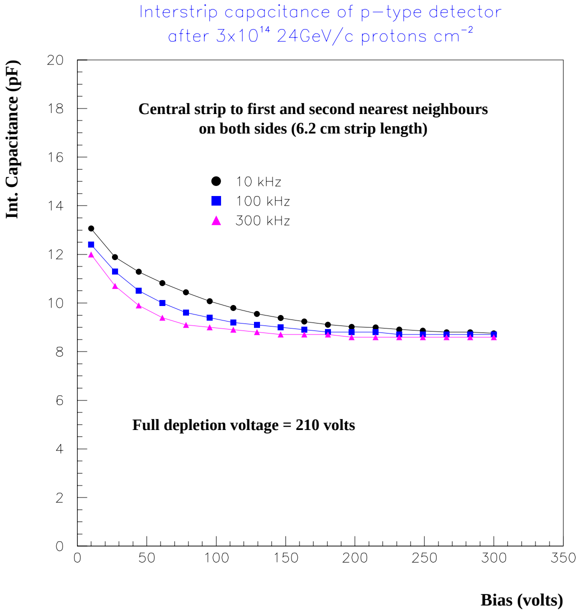
P-type detectors with individual p-stops processed by Micron on Liverpool masks (ATLAS SCT full size devices) after 3.10^{14} cm^{-2}


I-V of p-type microstrip detectors
after 3 10^{14} protons cm^{2}

Measured at -17 °C

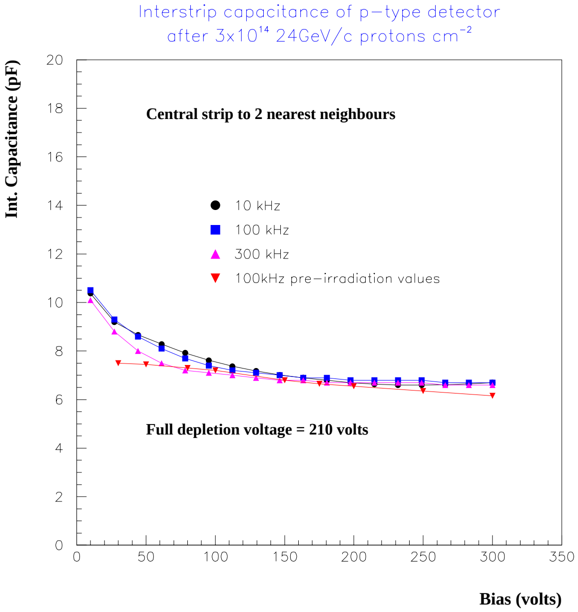

Frequency 1kHz

n-in-p full depletion voltage ≈ 215 volts
p-in-n ull depletion voltage ≈ 185 volts


Interstrip capacitance of p−type detector
after 3x10^{14} 24GeV/c protons cm^{-2}

Central strip to first and second nearest neighbours on both sides (6.2 cm strip length)

Full depletion voltage = 210 volts

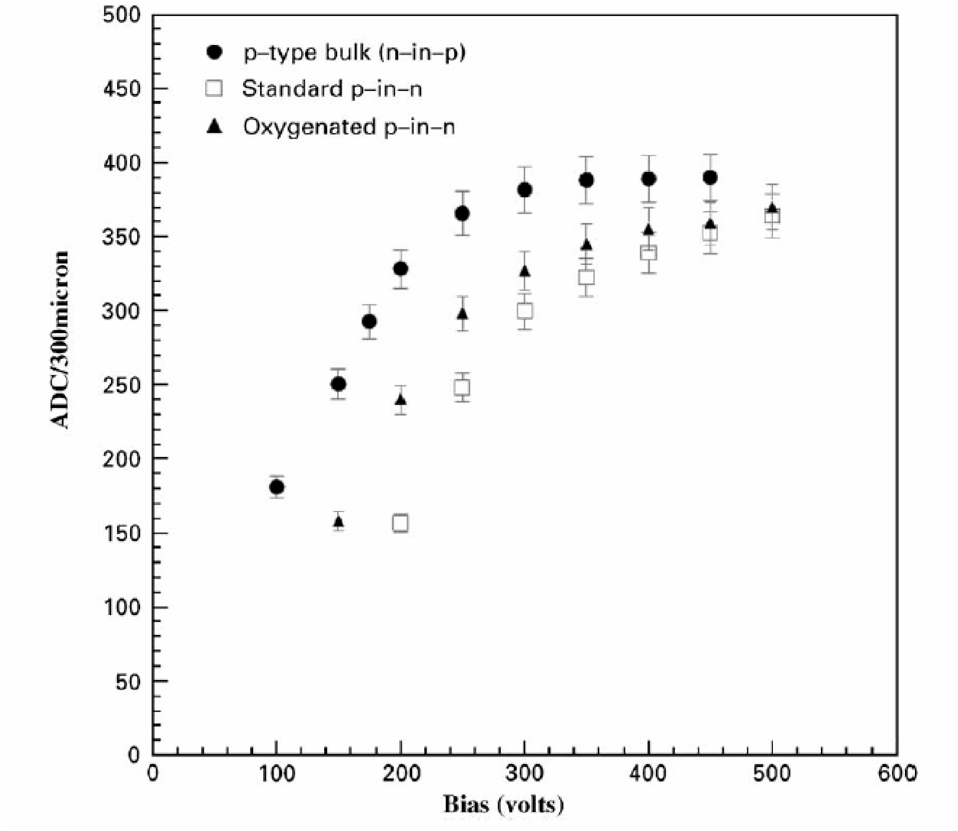

Interstrip capacitance of p−type detector
after 3x10^{14} 24GeV/c protons cm^{-2}

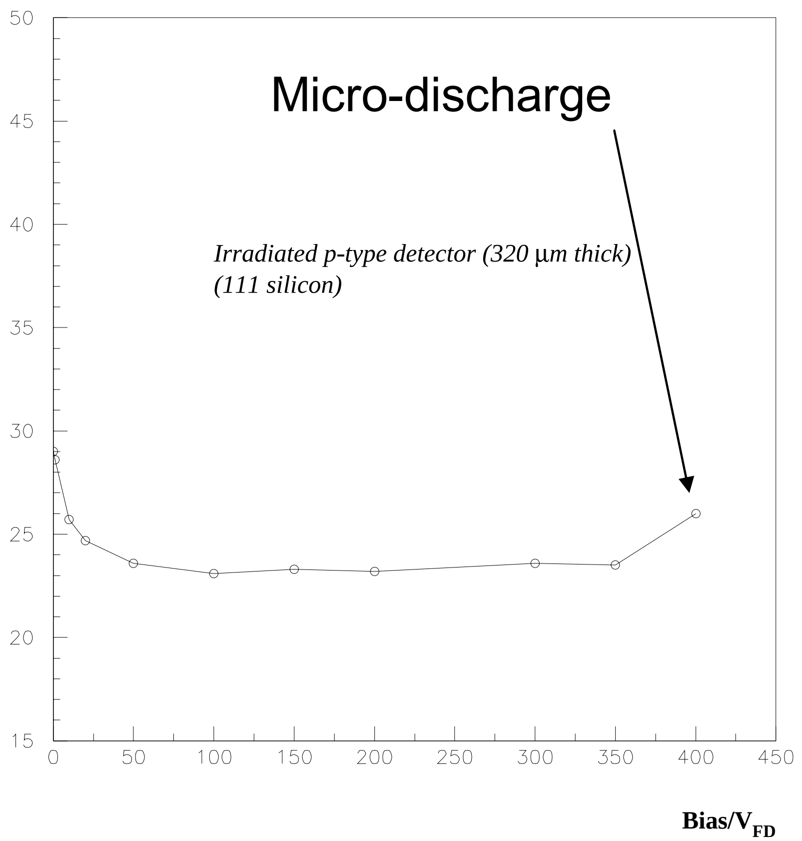
Central strip to 2 nearest neighbours

Full depletion voltage = 210 volts

Signal and noise performances of op-type detectors with individual p-stops processed by Micron on Liverpool masks (ATLAS SCT full size devices) after 3.10^{14} cm^{-2}

Signal vs V of p-type, std and oxy. n-type





Micro-discharge

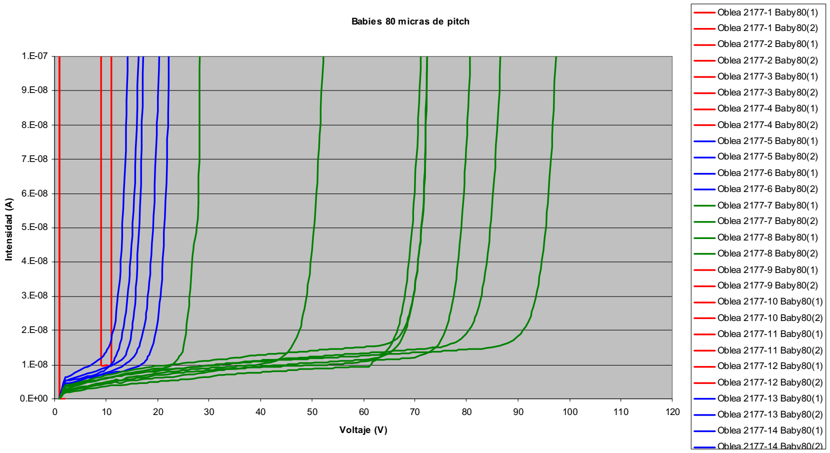
Irradiated p-type detector (320 μm thick)
(111 silicon)

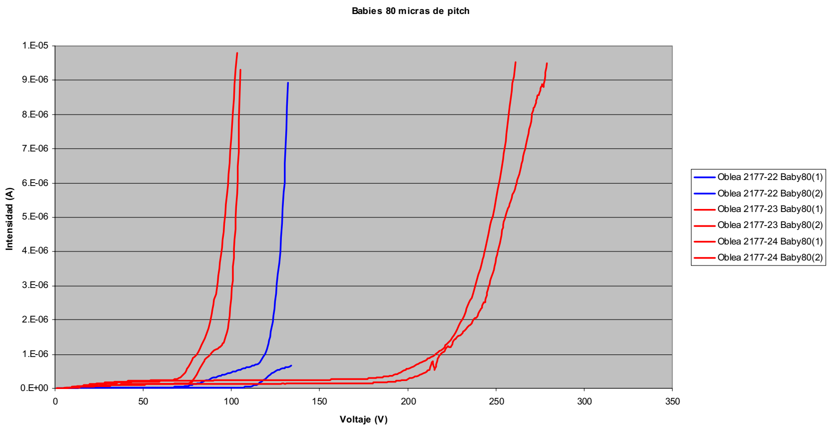
Very satisfactory results where obtained with this full size Atlas detector type, made on std. p-type silicon. But the experience from the n-in devices suggested to try the more performing p-spray isolation technique and also oxygen enriched p-wafers.

Than a collaboration between Liverpool and CNM-Barcelona lead to the production of a few wafers including full size ATLAS-SCT like devices and a few test structures (miniature 1x1 cm^2 microstrip detectors).

P-type miniature detectors

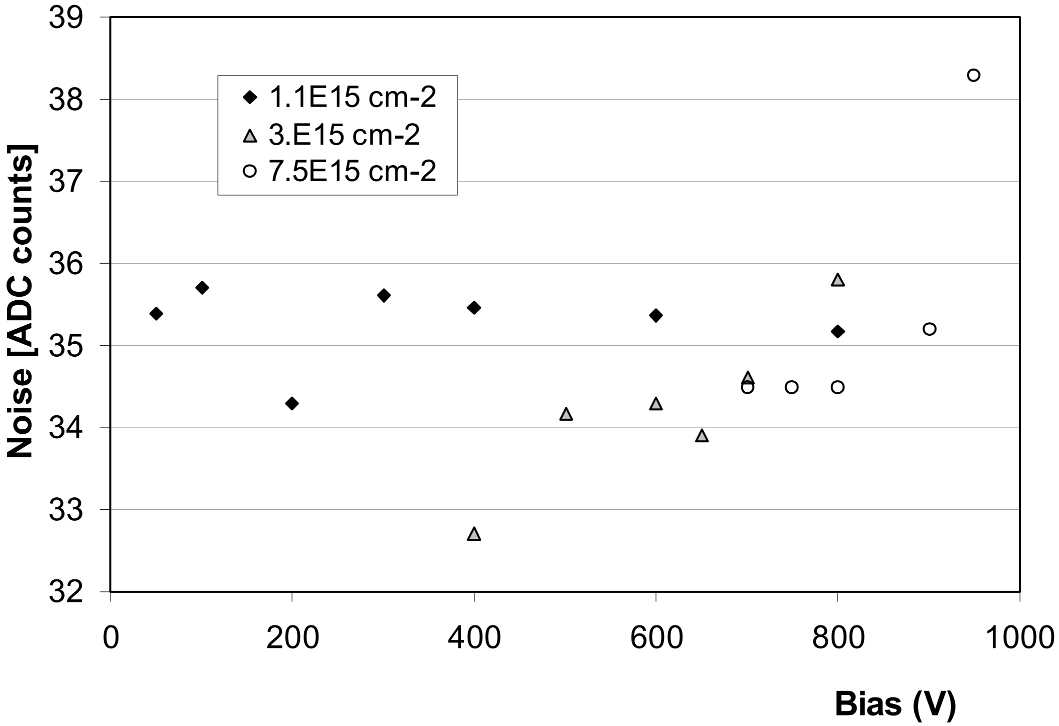
The first results after processing of miniature detectors were not particular encouraging, due to very low breakdown voltage.





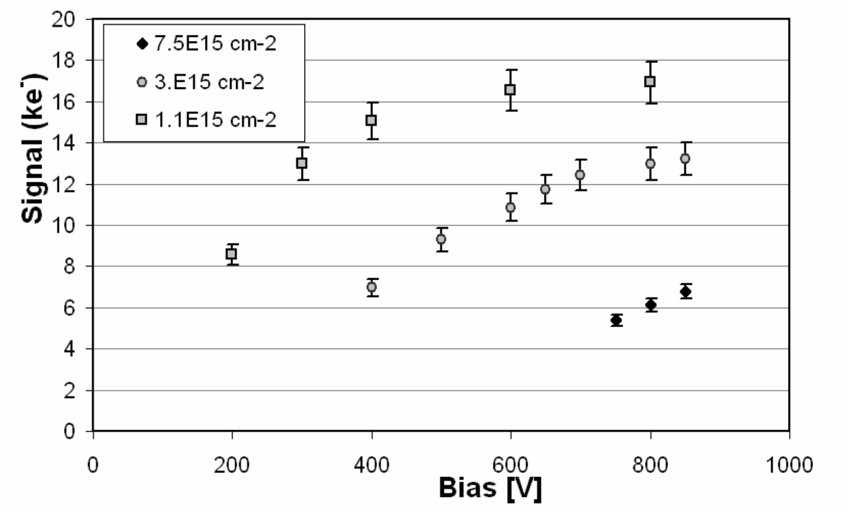
P-type miniature detectors

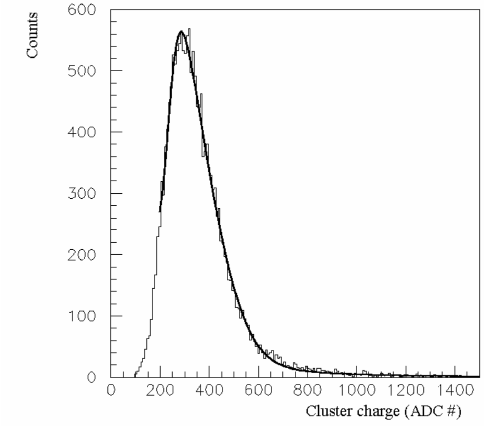
Nonetheless the devices (~300µm thick) show a remarkable robustness after irradiation, both in term of breakdown voltage and noise. Nevertheless the temperature should be kept low (in this case at -22°C) to control the reverse current and avoid thermal run-away after heavy doses.



P-type miniature detectors

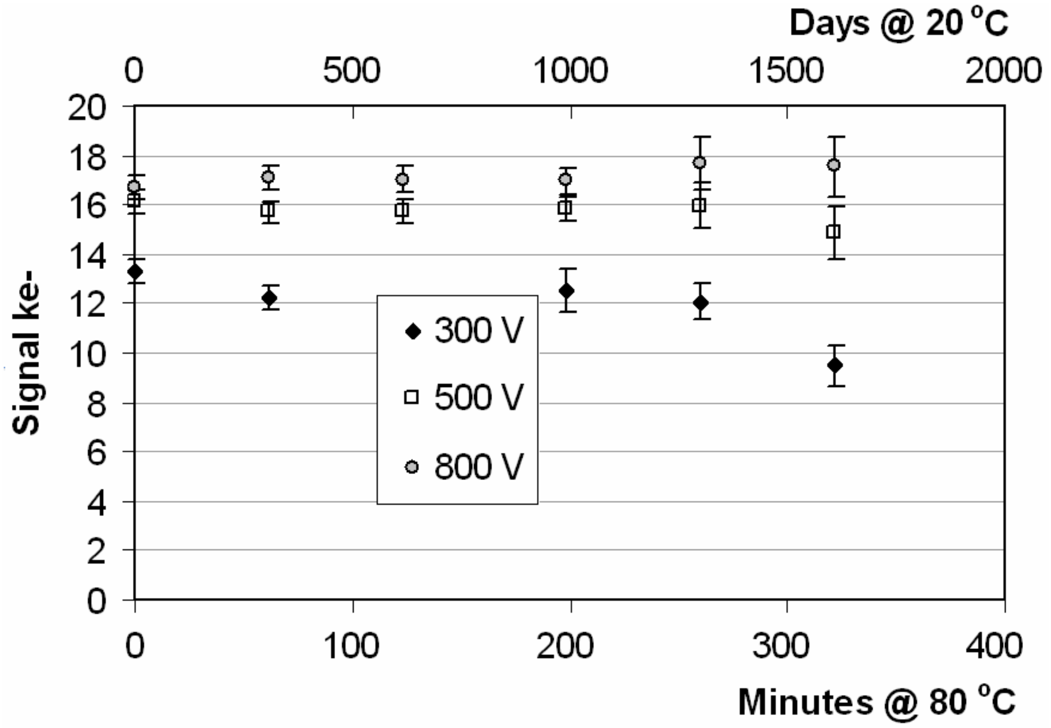
Extremely good performances have been measured both in term of charge collection and stability against accelerated annealing after irradiation. Here a few results after different doses (1., 3.5., and 7.5 10^{15} p cm^{-2}) are shown.





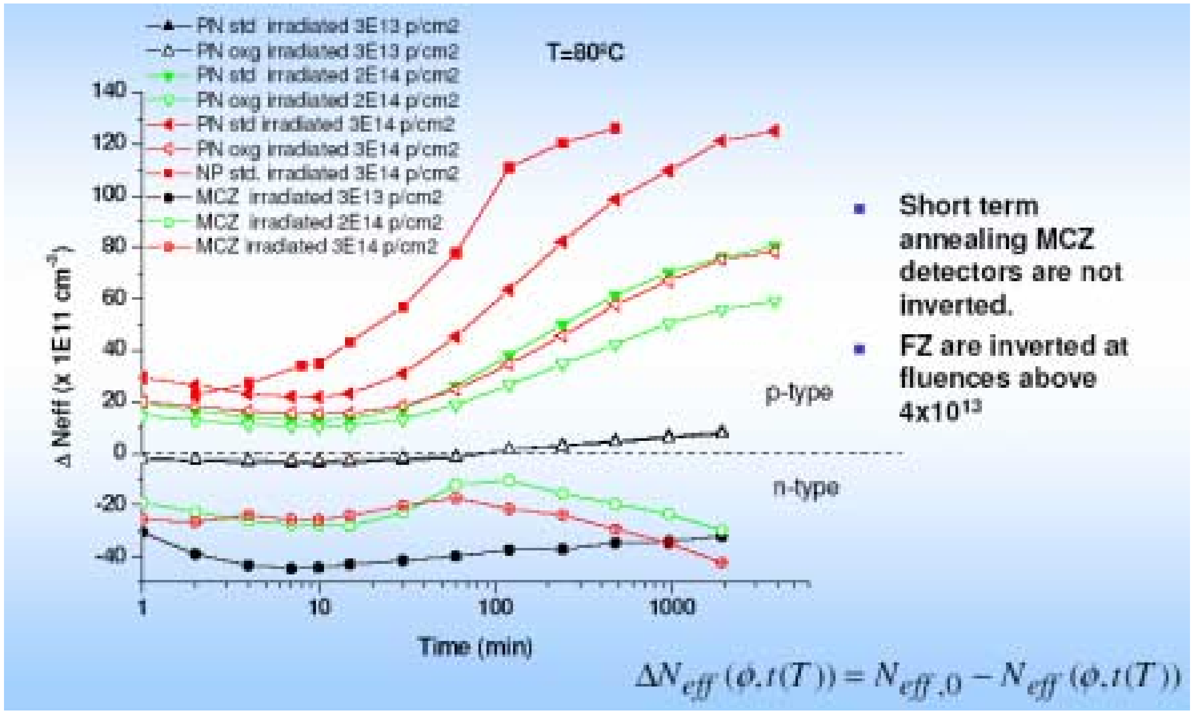
P-type miniature detectors

Annealing (@80 °C) behaviors of the collected charge after proton irradiation to 3.5. 10^{15} cm^{-2}. At high voltage the collected charge appears to be stable. It is known that the *full depletion voltage* as determined by CV measurements appears to follow the expected evolution.



P-type miniature detectors

behaviors of the collected charge after proton irradiation to 3.5. 10^{15} cm^{-2}. Evolution *effective doping concentration (proportional to full depletion voltage)* with annealing @80 ^{o}C as determined by CV measurements.



- Short term annealing MCZ detectors are not inverted.
- FZ are inverted at fluences above $4x10^{13}$

$$\Delta N_{eff}(\phi, t(T)) = N_{eff,0} - N_{eff}(\phi, t(T))$$

CONCLUSIONS

The n-side read-out has been tested at length and shows sensitively superior radiation performances, both on n-type and p-type silicon. The state of the art rad-hard devices for the innermost areas of LHC detectors are n-side read-out on oxygenated silicon.

P-type silicon has a much cheaper (close to 50%) processing and we have proven it stable both on miniature and large area devices.

The n-side read-out is also less sensitive to charge deficit due to under-depleted operations. This could imply that the detector thinning is not necessary with this diode configuration in highly segmented detectors.

It is anyhow clear that high voltage operations are necessary after severe doses. Both p-side read out and n-side read-out devices with p-stop isolation develop micro-discharges at intermediate voltages (400V after $4.10^{14}cm^{-2}$). A spectacular improvement is shown in p-sprayed devices (flat noise up to 900V). This indicates this technique as the choice for sLHC devices. The price to pay is higher pre-irradiation currents, which are though irrelevant for operation in a high radiation field. A statistical study of the correlation of the break-down performances before and after irradiation would give confidence for the modified quality assessment criteria that have to be used with p-sprayed devices.