Study of charge collection properties of silicon microstrip detectors with different read out geometries after high doses of proton irradiation

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Outline:

- Introduction
- ISE simulation of non-irradiated and irradiated devices
- Non-homogeneous irradiation of large area microstrip detectors
- Study of the non-homogenously irradiated detector - CCE(V) and charge sharing -
- Signal/noise as a function of the irradiation
- Conclusions

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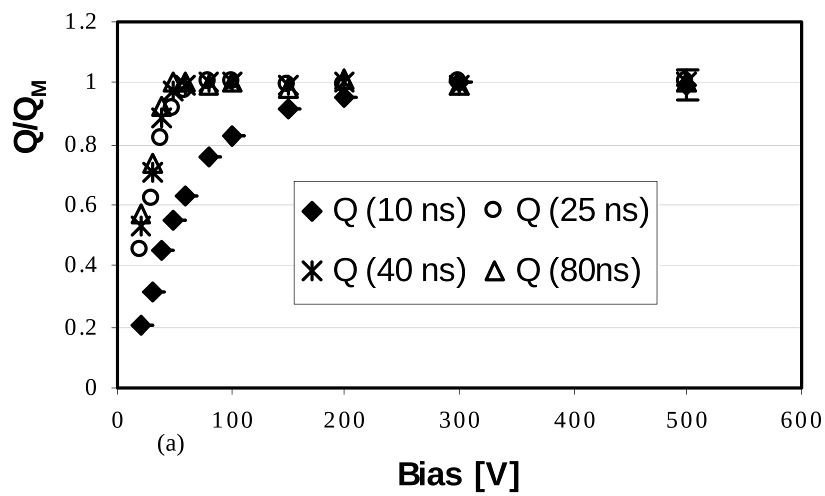
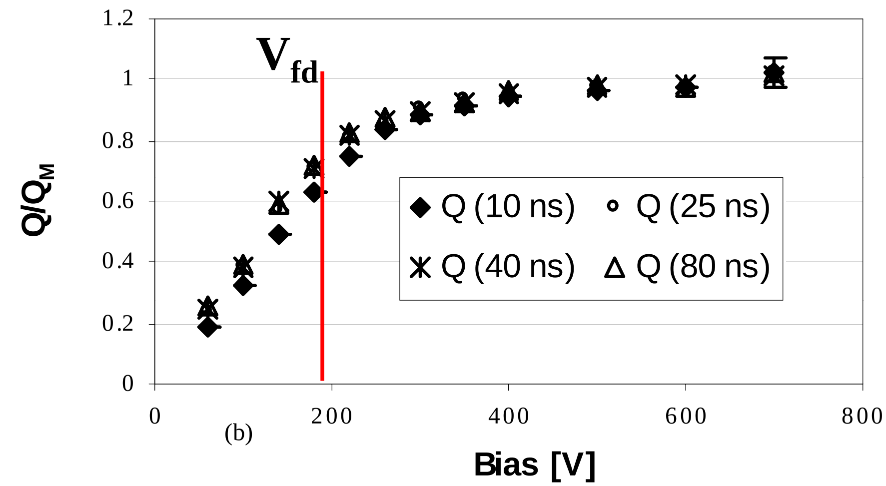
CCE in silicon diodes before and after irradiation (4 10^{14} cm^{-2})



(a)



(b)

The radiation damage introduces charge trapping and changes in V_{FD}, electric field profile, dielectric properties of non-depleted bulk

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We use ISE-TCAD to simulate non-irradiated and irradiated silicon detectors.

The radiation effects have been introduced by electron and hole traps in the silicon band-gap. The trap density below corresponds to a fluence of 1×10^{15} 1MeV neutron equivalent cm^{-2}.

Trap type	Trap density [cm^{-3}]	Energy from mid band gap [V]	El. capture cross section [cm^{-2}]	Hole capture cross section [cm^{-2}]
*Electron	$1.50\ 10^{15}$	0.39	$1.00\ 10^{-14}$	$5.50\ 10^{-13}$
*Electron	$2.20\ 10^{15}$	0.13	$2.00\ 10^{-15}$	$1.20\ 10^{-14}$
Electron	$3.60\ 10^{14}$	0.035	$1.20\ 10^{-15}$	$1.20\ 10^{-14}$
Hole	$3.24\ 10^{14}$	-0.045	$1.20\ 10^{-14}$	$1.20\ 10^{-15}$
*Hole	$1.50\ 10^{15}$	-0.20	$1.50\ 10^{-14}$	$2.00\ 10^{-15}$

* Hallen et al. J. Appl. Phys. 79(1996) 3906

ISE simulation of the electric field profile in a n-bulk silicon diode before and after irradiation (4 10^{14} p cm^{-2})

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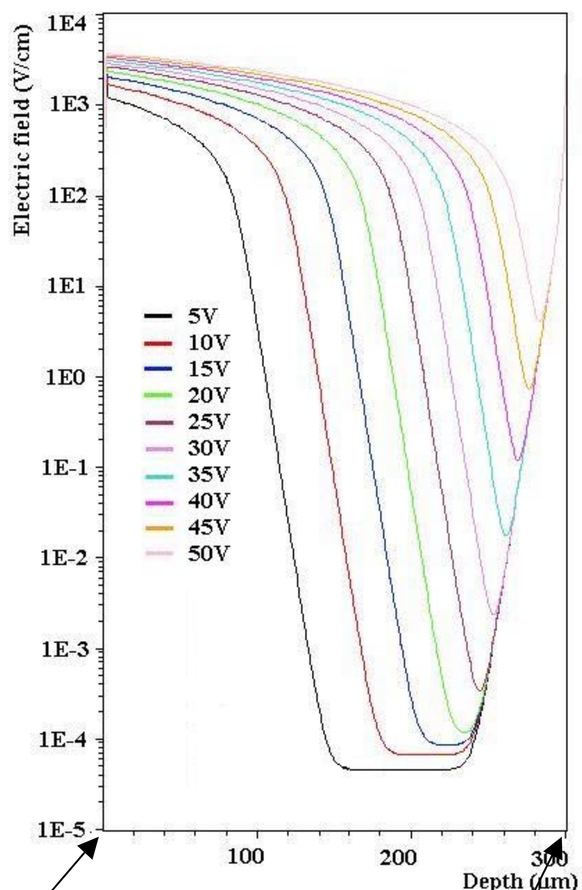
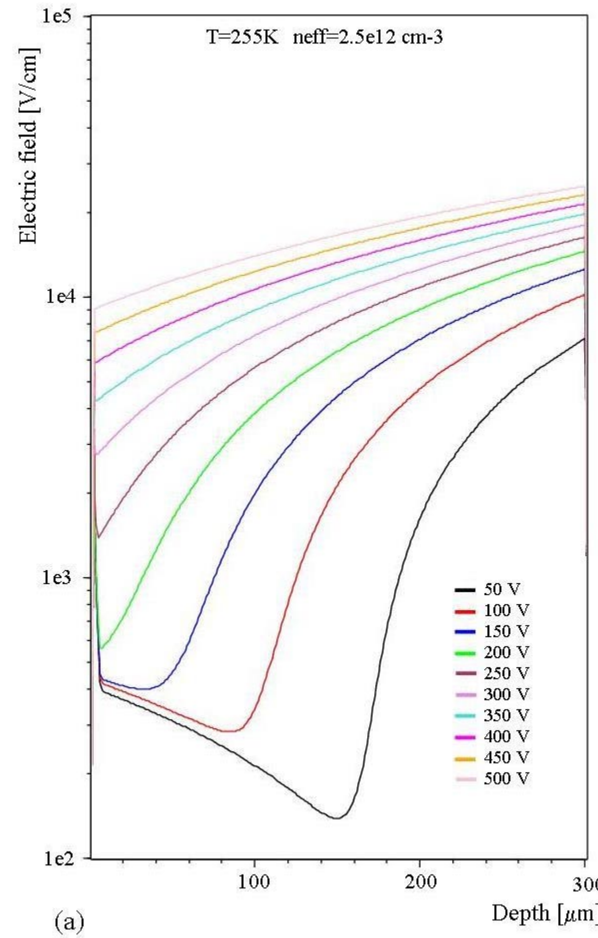


p+-implant

n+-implant



(a)

Note the presence of an electric field in the '*non-depleted*' bulk at low biases and the '*double-junction*'

ISE simulation of the majority carrier concentration in a silicon diode before and after irradiation (4 10^{14} p cm^{-2})

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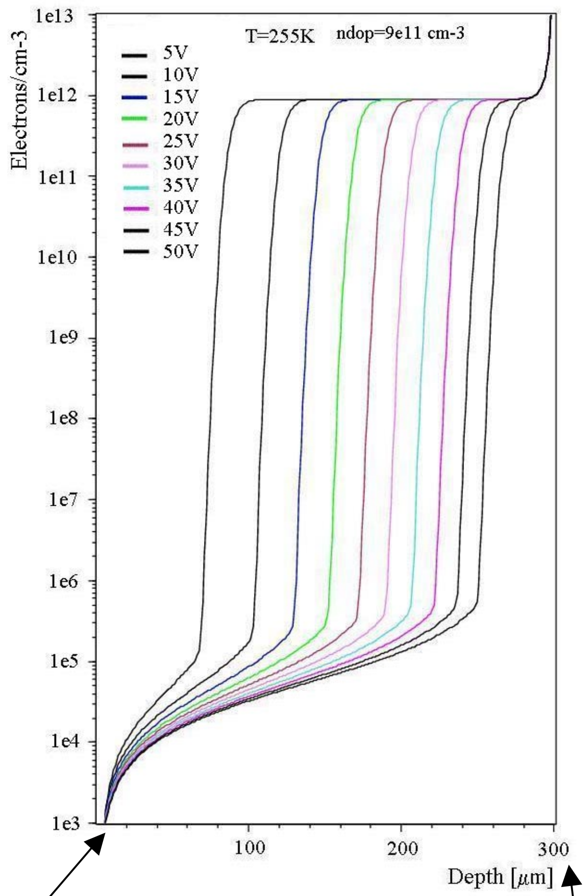

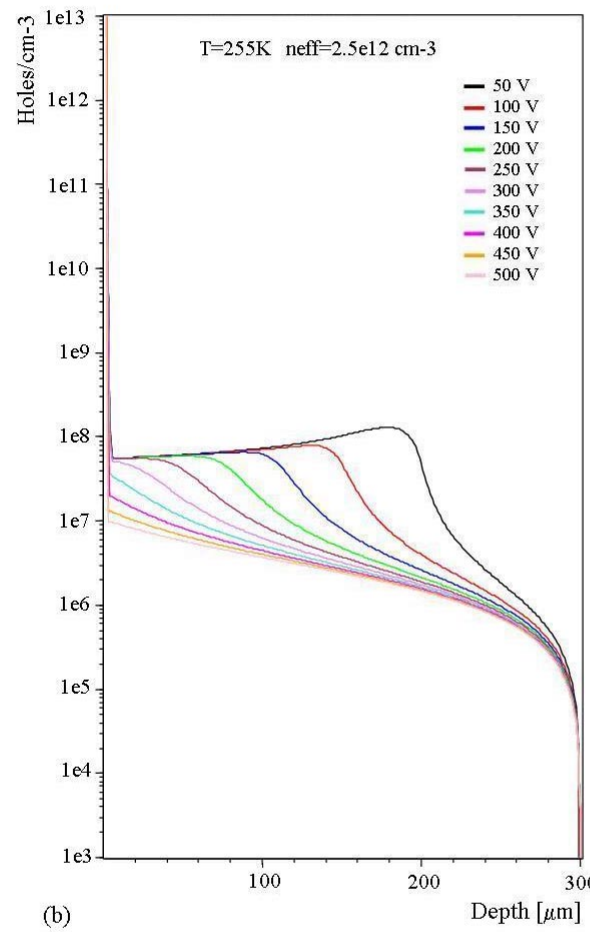

p^+-implant

n^+-implant

Non-homogenous irradiation of large area LHCb VELO phi-type prototype detectors

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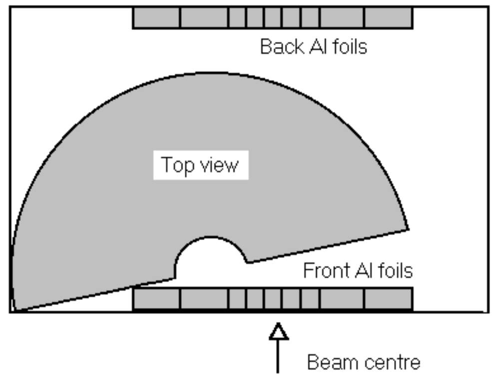
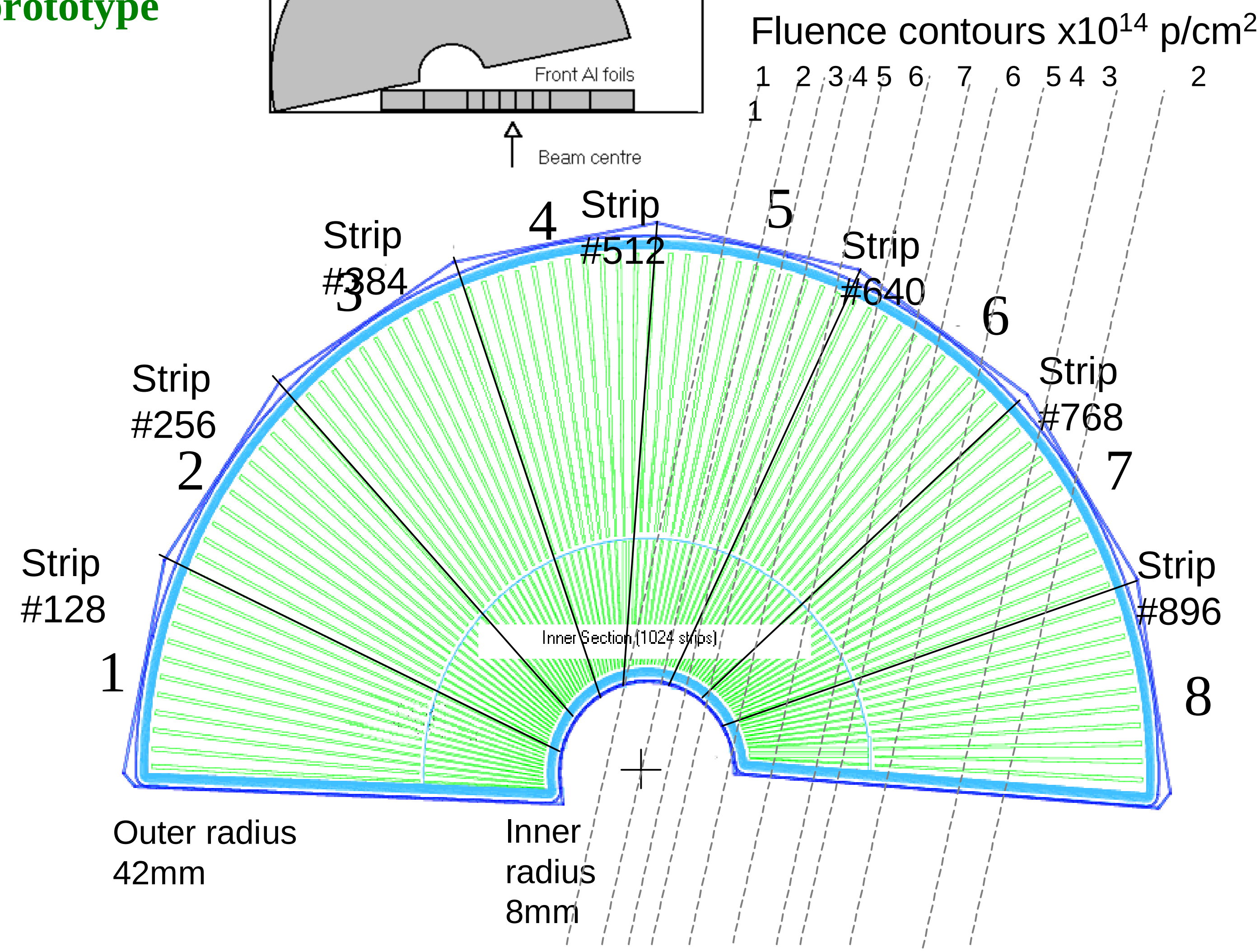
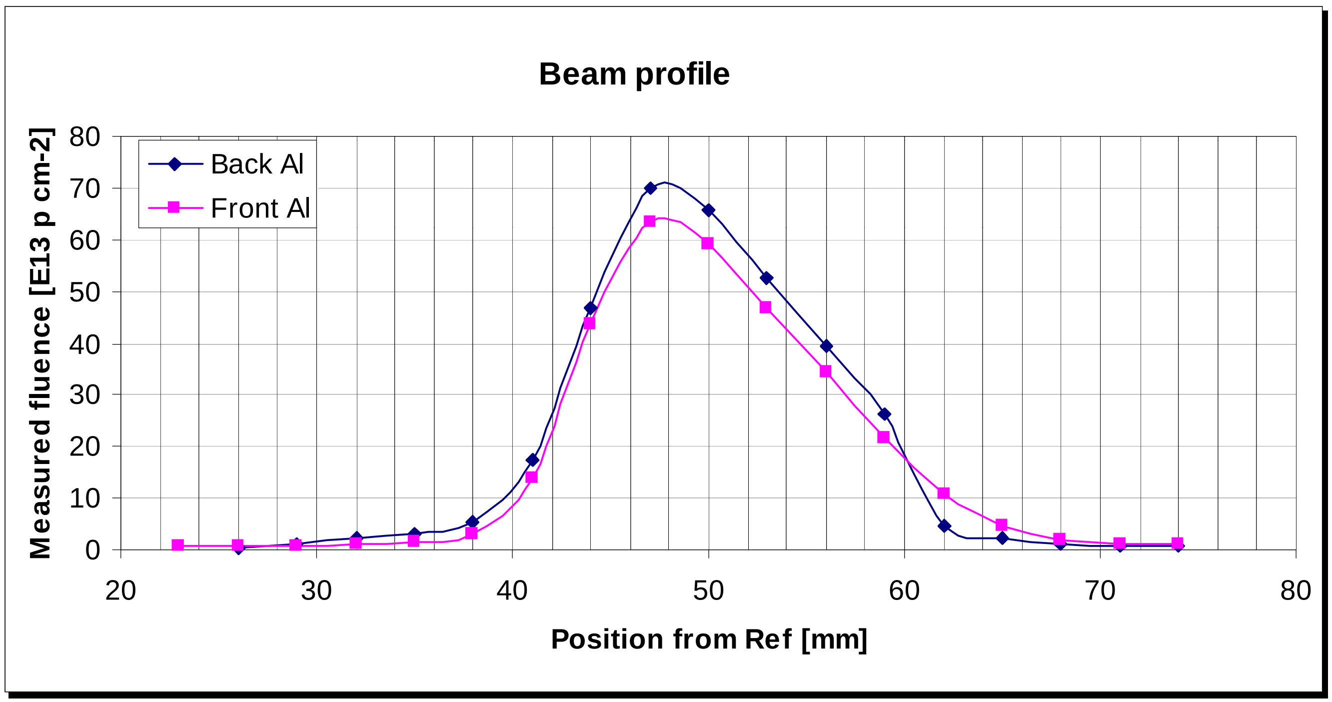




Irradiated devices :

200 μm n-in-n
200 μm p-in-n } **Irradiated together, maximum fluence ~ 7 10^{14} p cm^{-2}**

300 μm p-in-n **Maximum fluence ~ 4.6 10^{14} p cm^{-2}**



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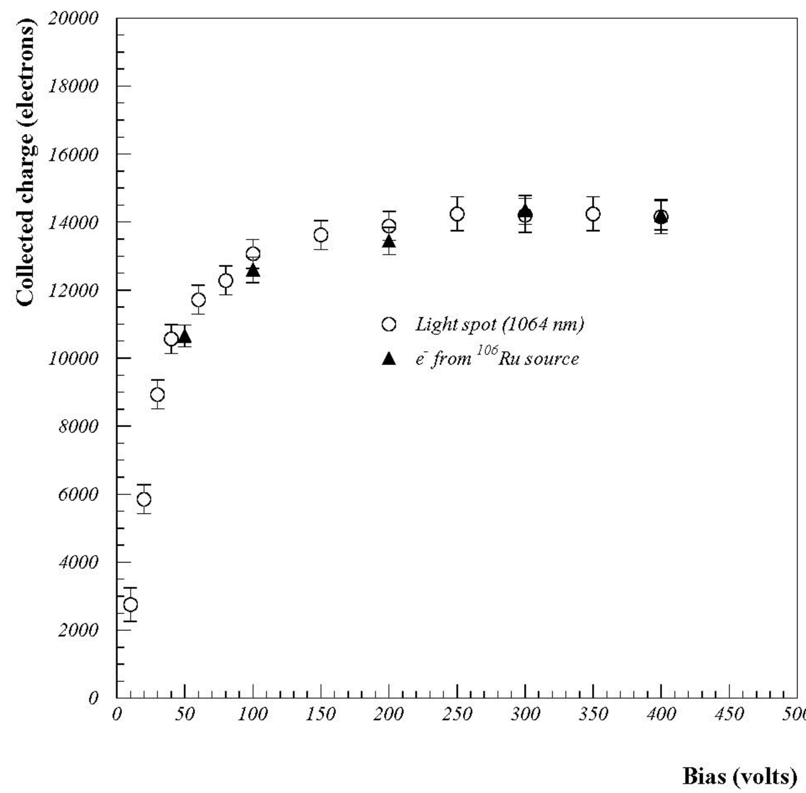
Tools for studying the non-homogeneously irradiated detector: comparison between CCE with infrared (1060 nm) laser and ^{106}Ru ß–source. All measurements with SCT128-VG (LHC speed electronics)

CCE(*V*) for irradiated, 200μm thick, detector with laser data (normalised to value at 400V) superimposed



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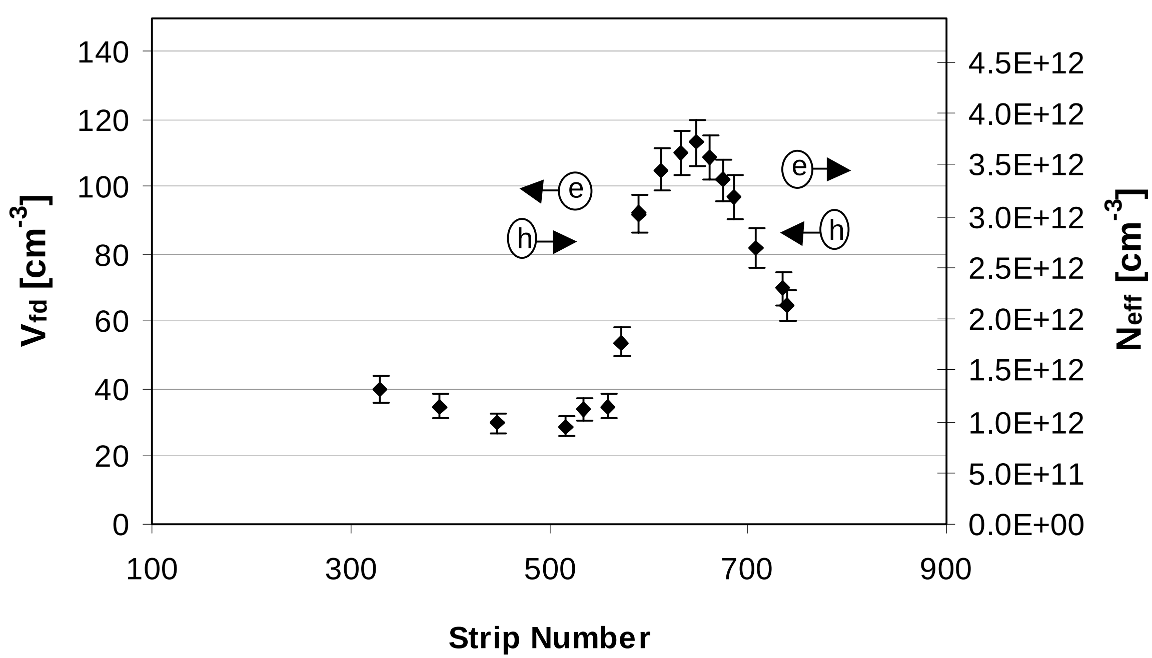
From fits to the CCE(*V*), the depletion voltages for the different regions of the detector can be extracted.

The V_{fd} (N_{eff}) profile corresponds to the irradiation profile and allows to study the properties of the detector with a steep gradient of $V_{fd}(N_{eff})$.



Gradient of N_{eff} can introduces a 'transverse' component of the electric field and a distortion in the reconstructed cluster position. Distortions are expected to have opposite sign for opposite sign of the gradient of N_{eff}.

N-in-n 200 μm detector

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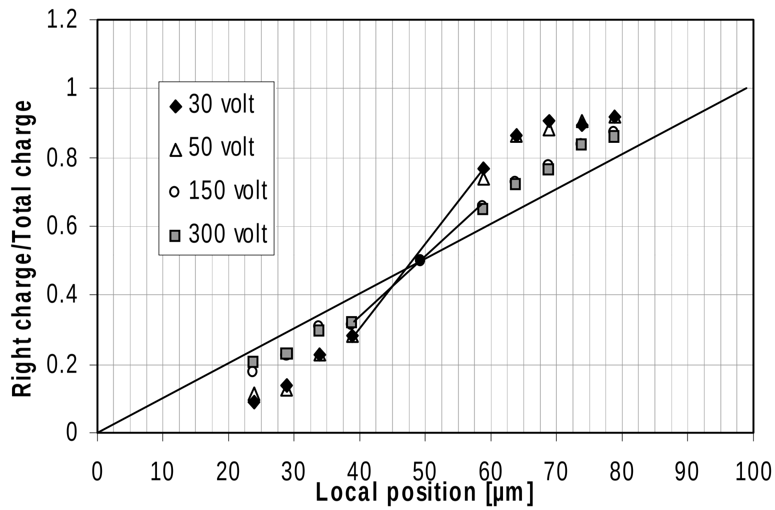
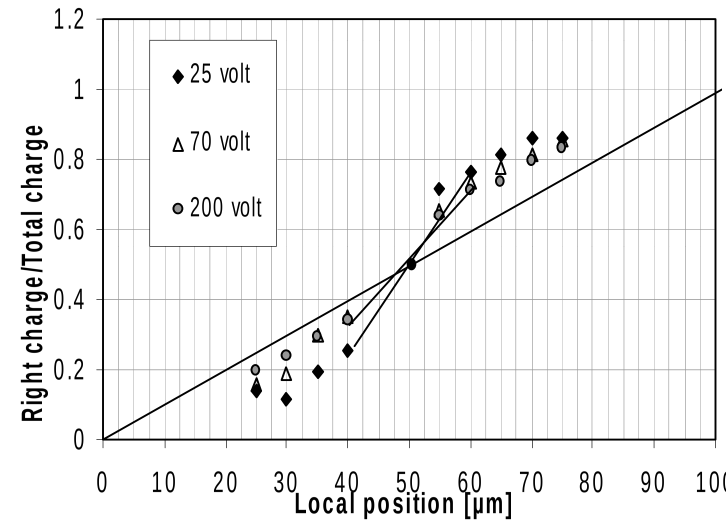
$$\eta = Q_R/(Q_R+Q_L)$$

Strip 517-518
Vfd=29 V



Strip 534-535
Vfd=34 V



N-in-n 200 μm detector $\eta = Q_R/(Q_R+Q_L)$

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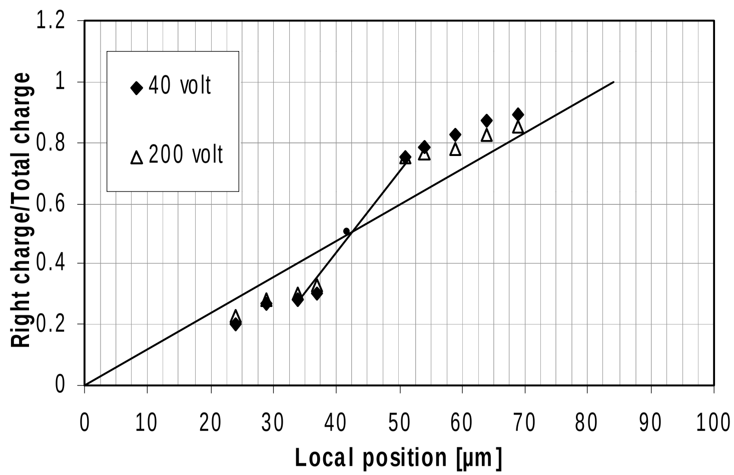
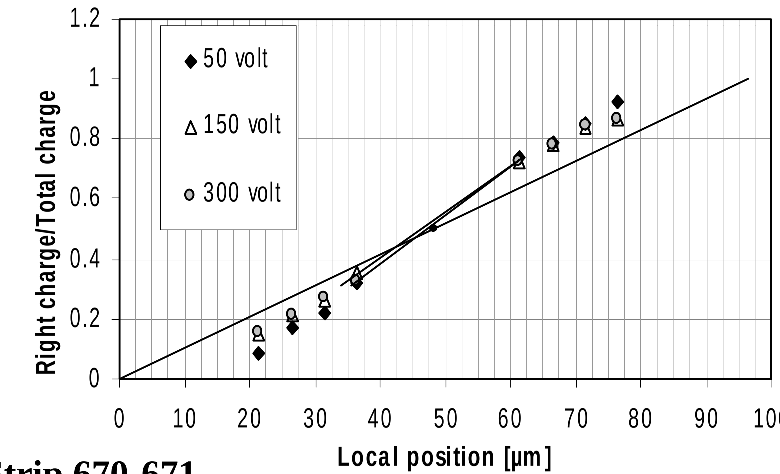
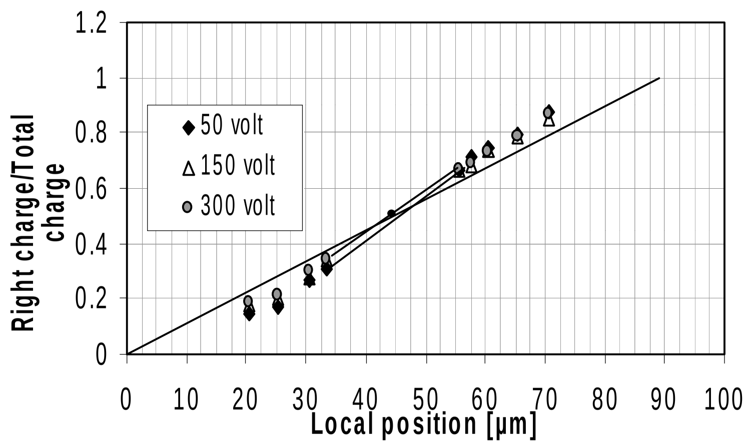
Strip 582-583
Vfd=90V



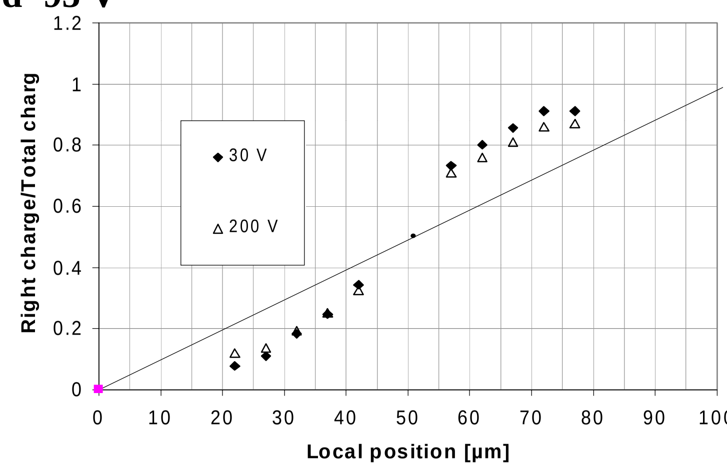
Strip 612-613
Vfd=105V



Strp 632-633
Vfd=110V



Strip 670-671
Vfd=95 V



P-in-n 300 μm detector $\eta = Q_R/(Q_R+Q_L)$

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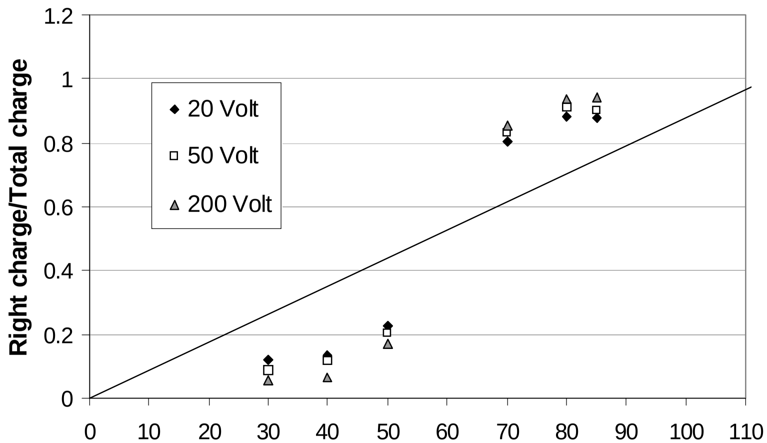
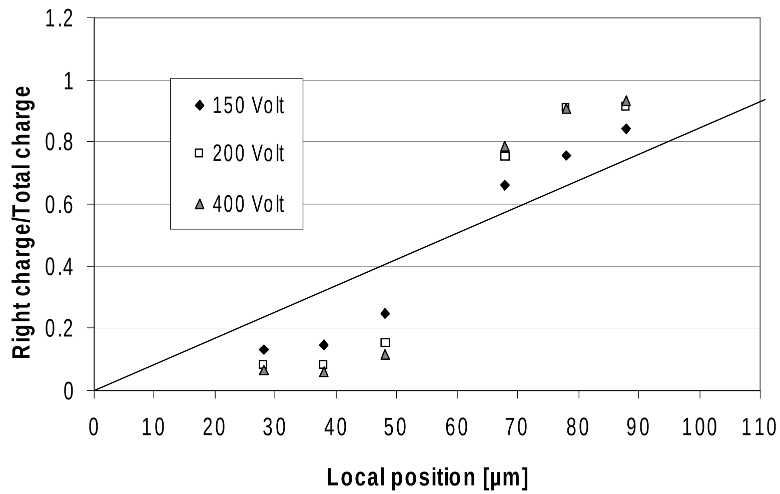
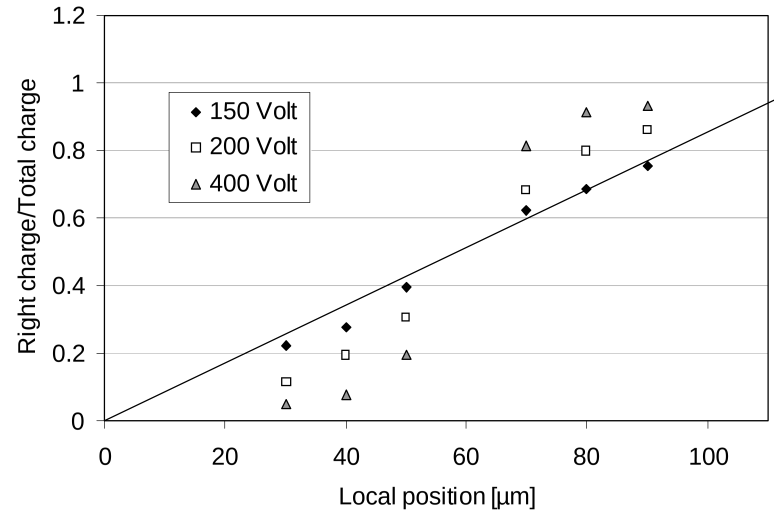
Low radiation region Vfd=75V





Irradiated region with positive gradient of $|N_{eff}|$ as a function of the strip number (Vfd 230 V)



Irradiated region with negative gradient of $|N_{eff}|$ as a function of the strip number (Vfd 230 V)

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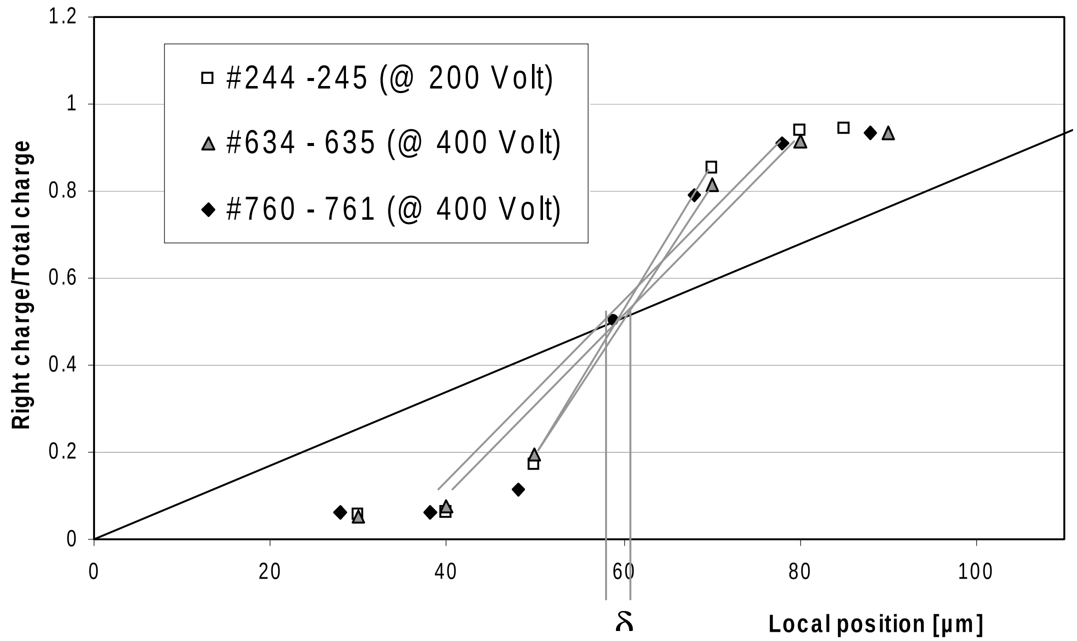

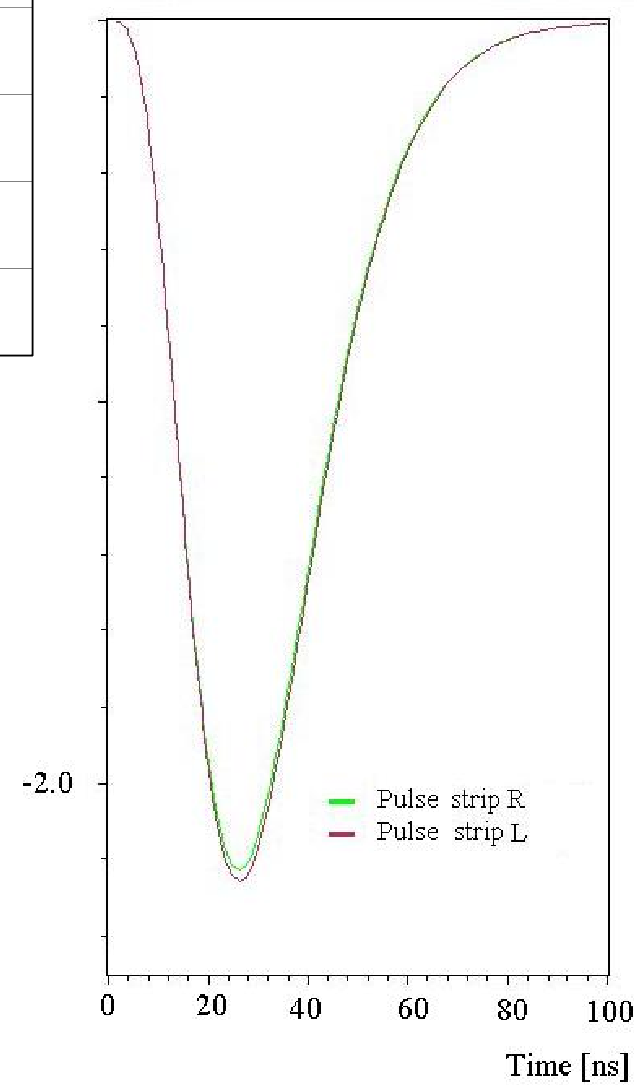

No evidence of distortion (spread observed (δ) is approximately ±2µm) in the reconstructed cluster position due to the high gradient of Neff in the detector. The experimental results are also supported by ISE simulations

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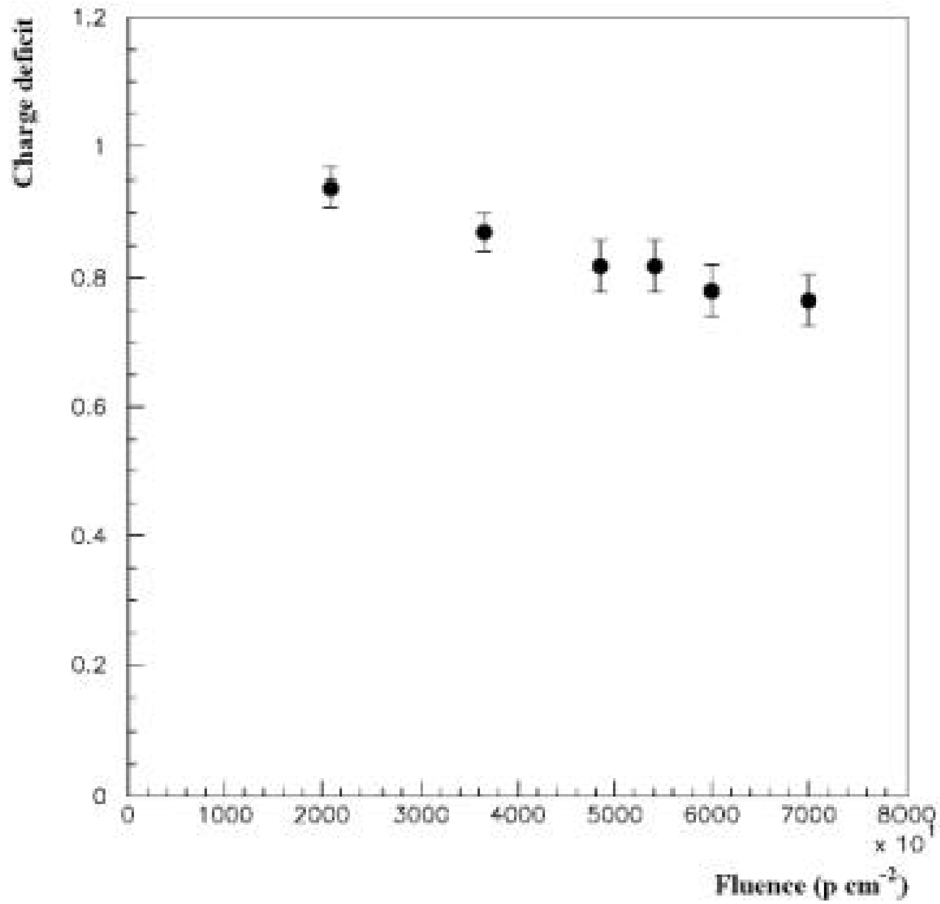

Signal (^{106}Ru ß–source) degradation as a function of fluence in the non-homogeneous irradiated detector (n-in-n).

Noise as a function of the applied bias: dose varying from 2. 10^{14} to 7. 10^{14} p cm^{-2}

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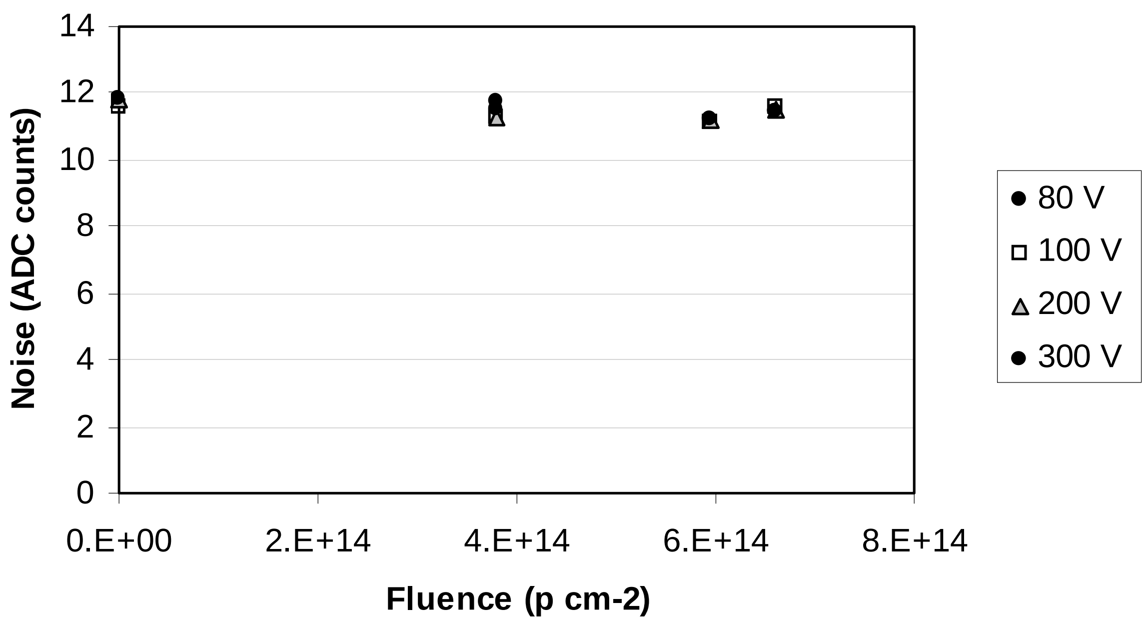

The noise doesn't change with irradiation and bias (when the total reverse current is kept low, below 1mA)

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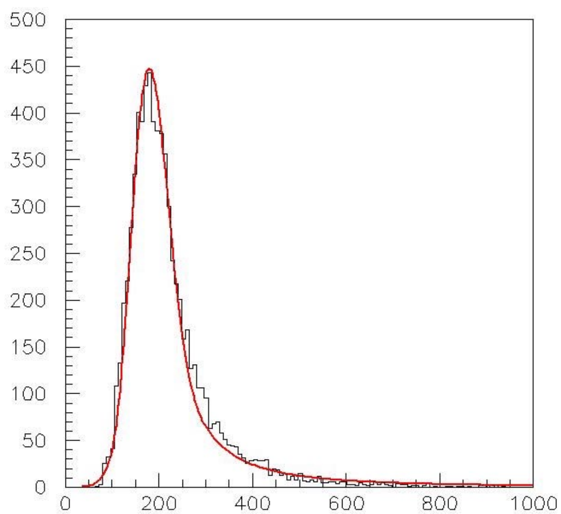
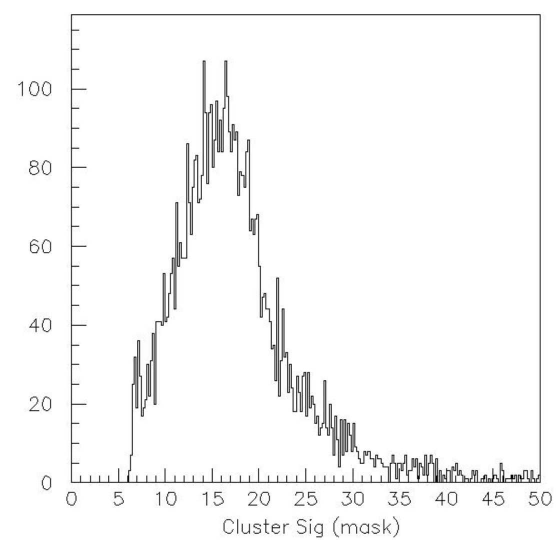
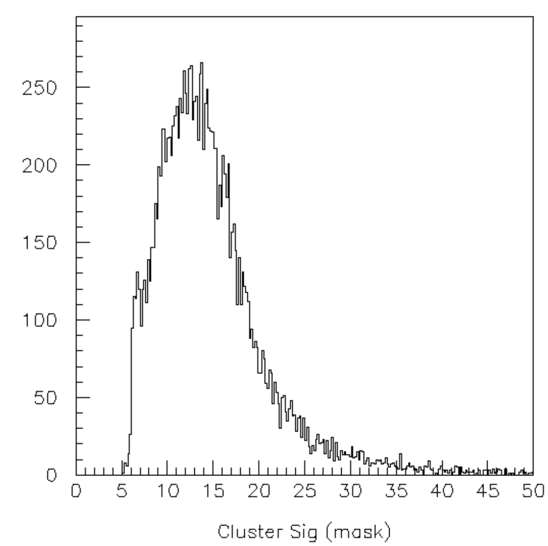
The signal/noise measured with this 200 μm thick detector with about 7.5 pF input capacitance is about 16 and 12.5 in the non-irradiated and in the most irradiated areas respectively, as measured with the SCT128-VG analogue electronics



Signal of fast electrons from ^{106}Ru source (non-irr. area)

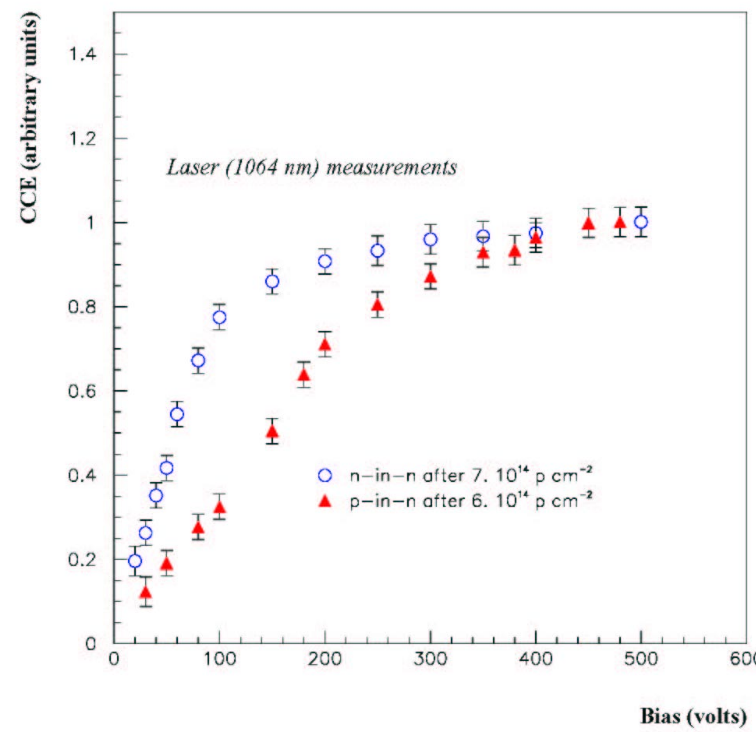


Cluster significance (non-irr. area)



Cluster significance (irr. area)

- For simple one dimensional structures *eg* large area diodes little difference is expected between the signals seen on the n-side or the p-side.
- Direct comparisons of n-side and p-side detectors with the same masks fabricated on the same material confirm the superiority of n-side read-out after irradiation.



Laser (1060 nm) CCE(V) in the highest irradiated areas for a n-in-n (7. 10^{14} p cm^{-2}) and p-in-n (6. 10^{14} p cm^{-2}) 200 μm thick microstrip detectors

Conclusions:

- ISE simulations describe well the device properties also after irradiation and successfully predict charge collection properties and are being used for updating designs.
- The effect of non-uniform irradiations (with resulting high gradient - $2.6 \, 10^{12} \, cm^{-4}$ - of N_{eff} across the detector and perpendicular to the strip) has been studied and small limit to the distortion of the reconstructed cluster position have been placed.
- The charge collected at a given voltage is reduced both by the trapping and by the changes to the effective doping concentration.
- The former is addressed by n-side read-out while the latter can be helped by using an oxygen enhanced substrate.
- Combining the techniques of n-side read-out (to reduce the influence of trapping) and enhanced interstitial oxygen should yield tracking detectors good to $10^{15} p/cm^2$ at least.