Charge collection inefficiency of p-in-n silicon microstrip detectors

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OUTLINE:

- Irradiation of silicon detectors
- Measurements of Charge Collection Efficiency (CCE)
- Comparison between *standard* to oxygen enriched substrates
- Discussion of the ballistic deficit
- Measured and expected charge deficit up to $1 \cdot 10^{15}$ p cm^{-2}
- Comparison between CV to CCE methods for determining the *full depletion voltage* (V_{fd})
- Brief discussion of the definition of V_{fd}

Irradiation with 24 GeV/c protons in CERN/PS IRRAD facility.

Detector label	Fluence [p cm^{-2}]	Oxygenation [~2 10^{17} at. Cm^{-3}]
NI	Non irradiated	No
SO1	1.9 $10^{14} \pm 7\%$	Yes
SN1	1.9 $10^{14} \pm 7\%$	No
SO2	2.9 $10^{14} \pm 7\%$	Yes
SN2	2.9 $10^{14} \pm 7\%$	No
SO3	5.1 $10^{14} \pm 7\%$	Yes
SN3	5.1 $10^{14} \pm 7\%$	No

Pre-irradiation $V_{fd} \sim 50$ V
After irradiation the detectors have been annealed to the minimum of the characteristic annealing curve

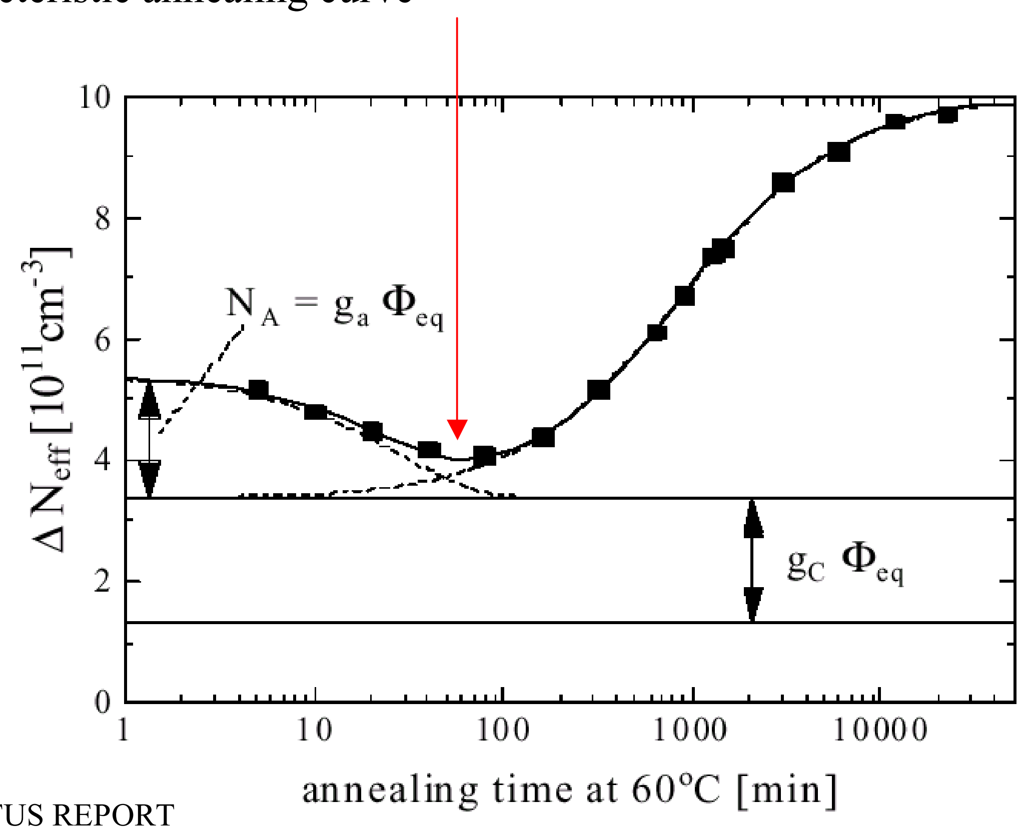

Figure from
3 rd RD48 STATUS REPORT
CERN LHCC 2000-009, LEB Status
Report/RD48, 31 December 1999

Behaviour of N_{eff} (V_{fd}) vs fluence for silicon detectors as measured with the CV method

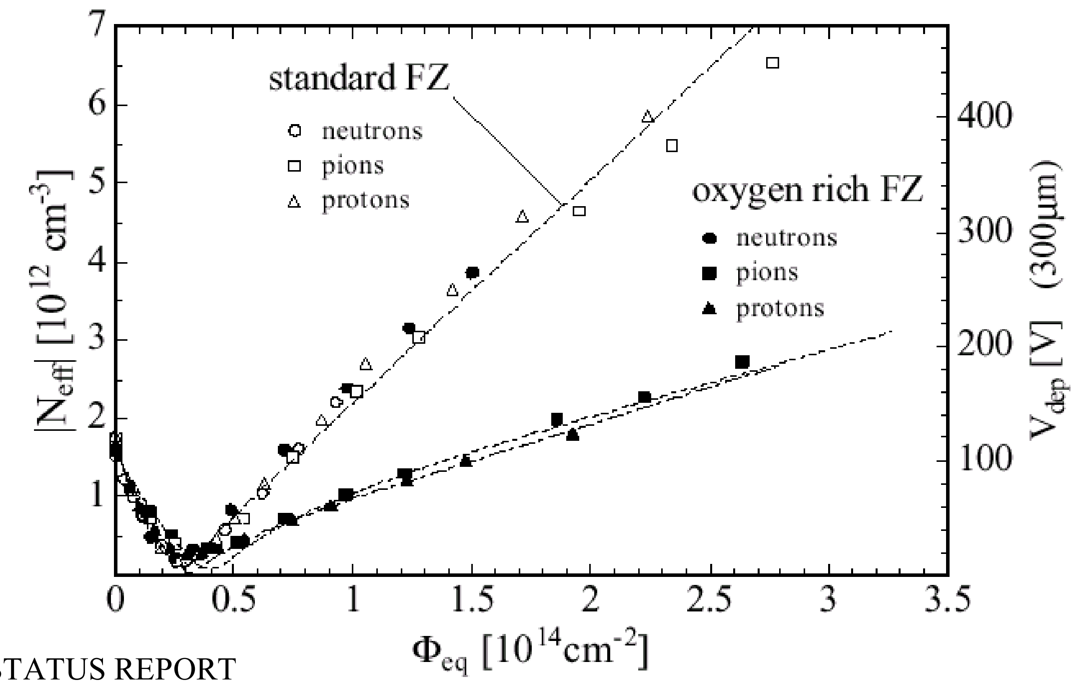

Figure from
3 rd RD48 STATUS REPORT
CERN LHCC 2000-009, LEB Status
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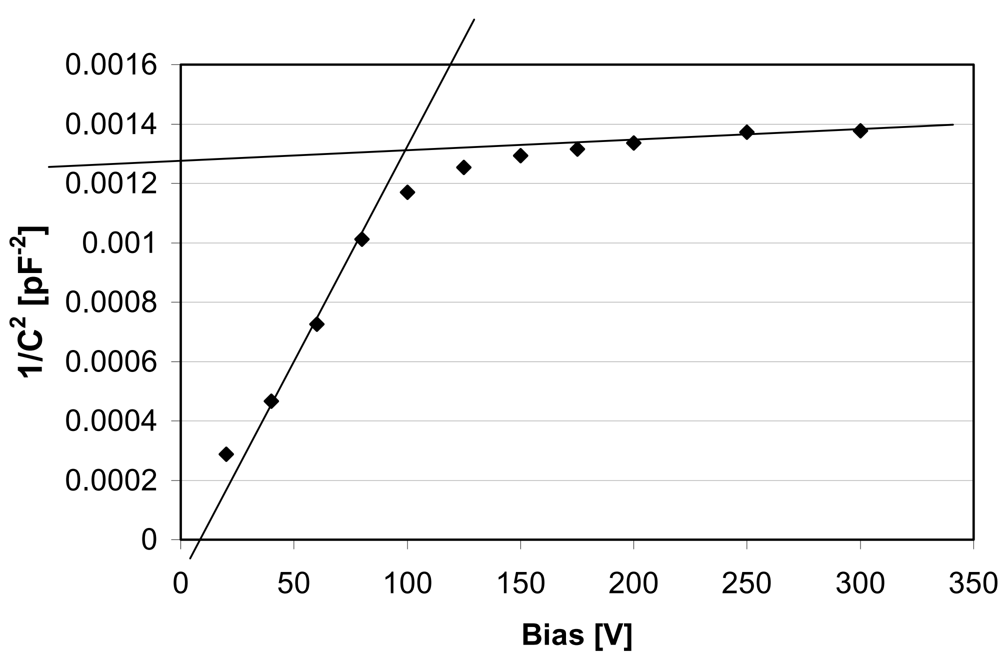
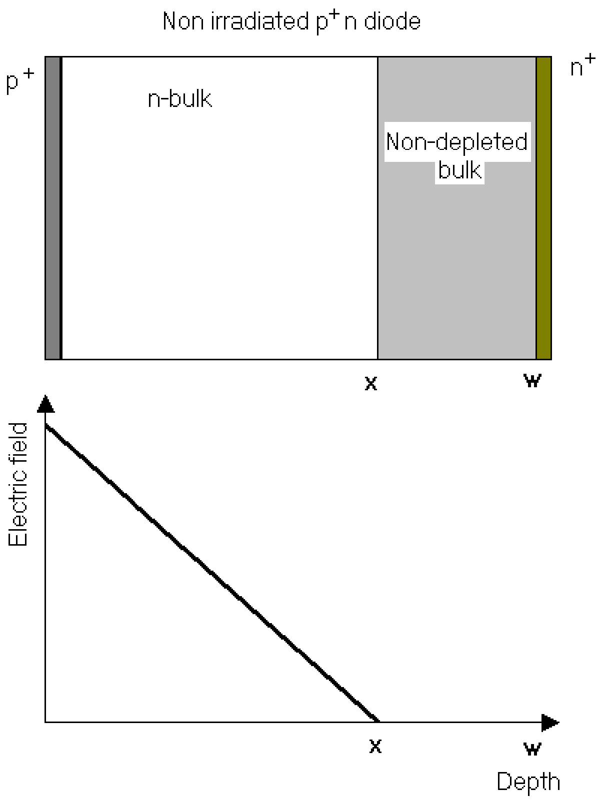
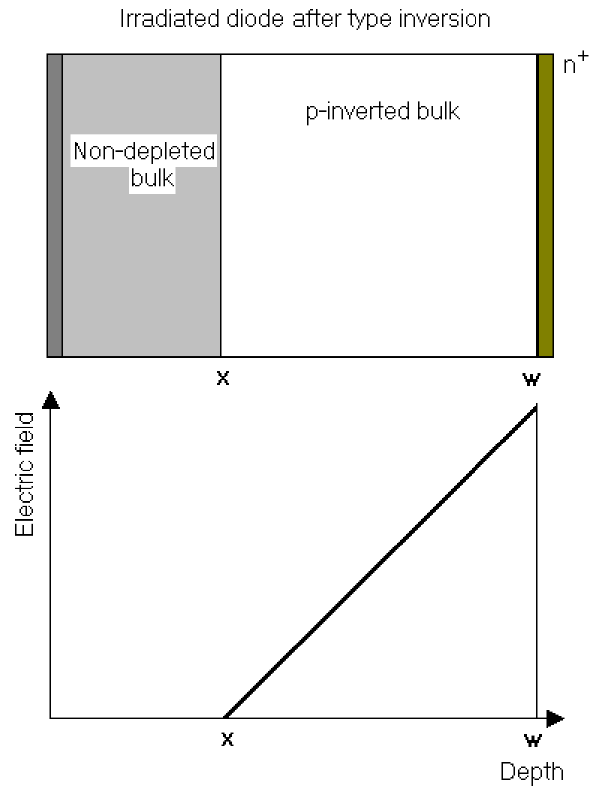
Example of CV method ($1/C^2$ vs Vbias)

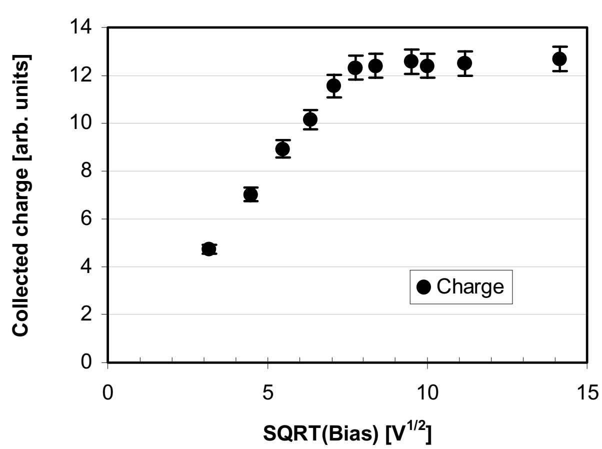


Schematic description of type inversion

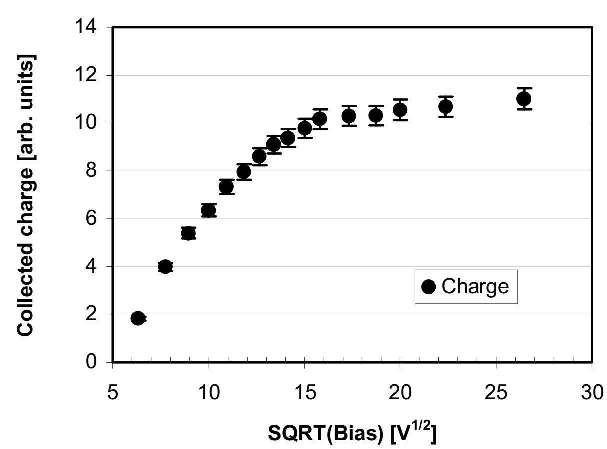


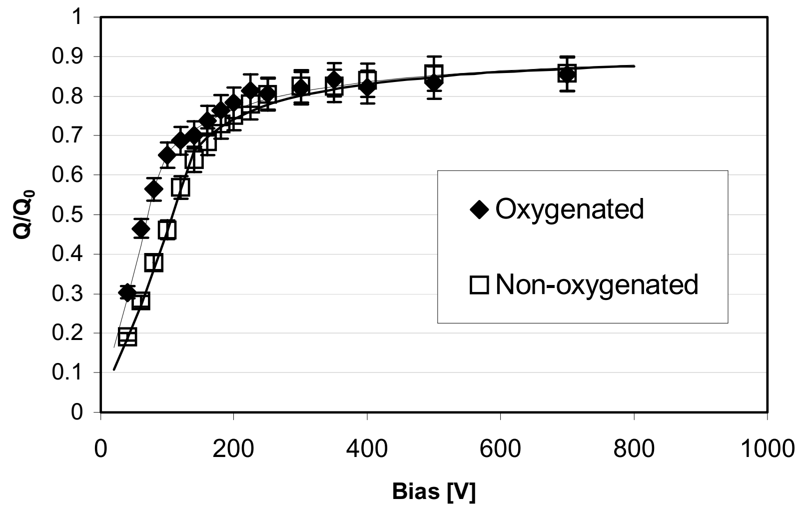


CC of non-irr. detector

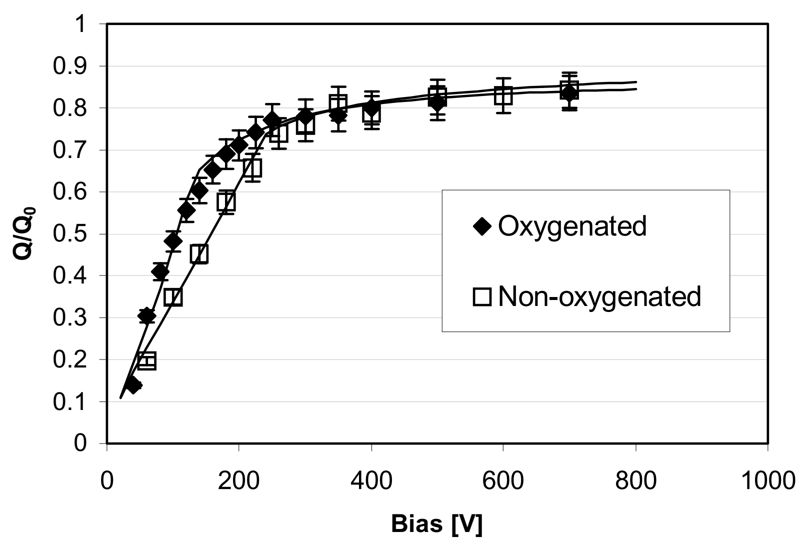


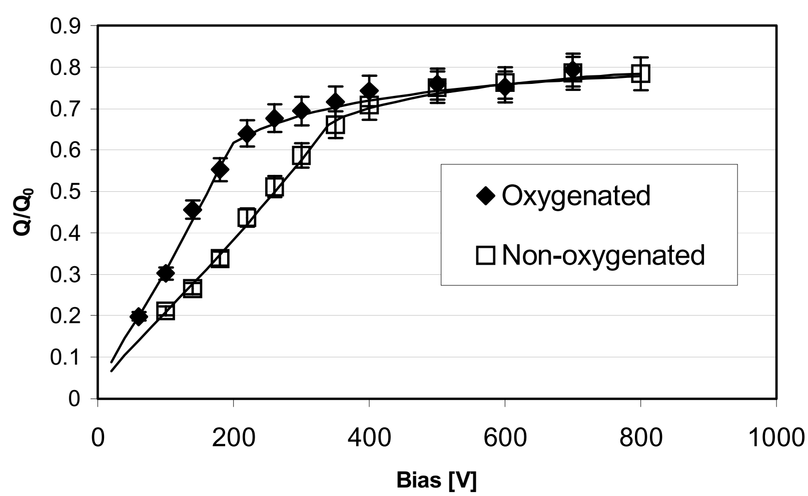
CC of irradiated detector





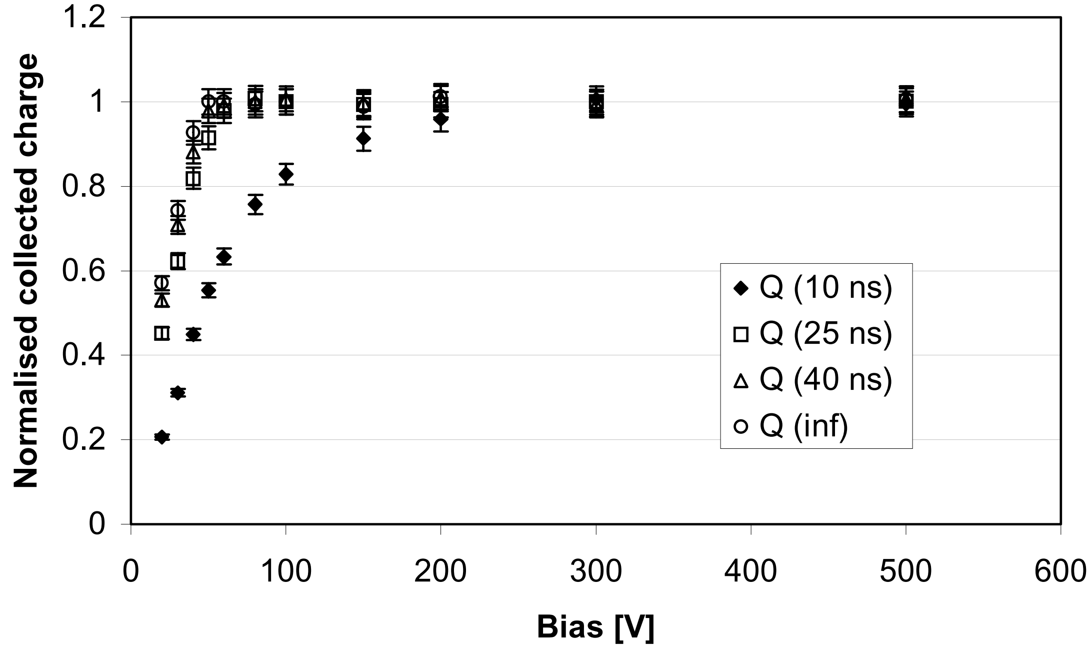
Comparison of CCE (normalised to the pre-irradiation value) for detector irradiated to 1.9, 2.9 and 5.1 10^{14} p cm^{-2} between standard and Oxygen enriched substrates



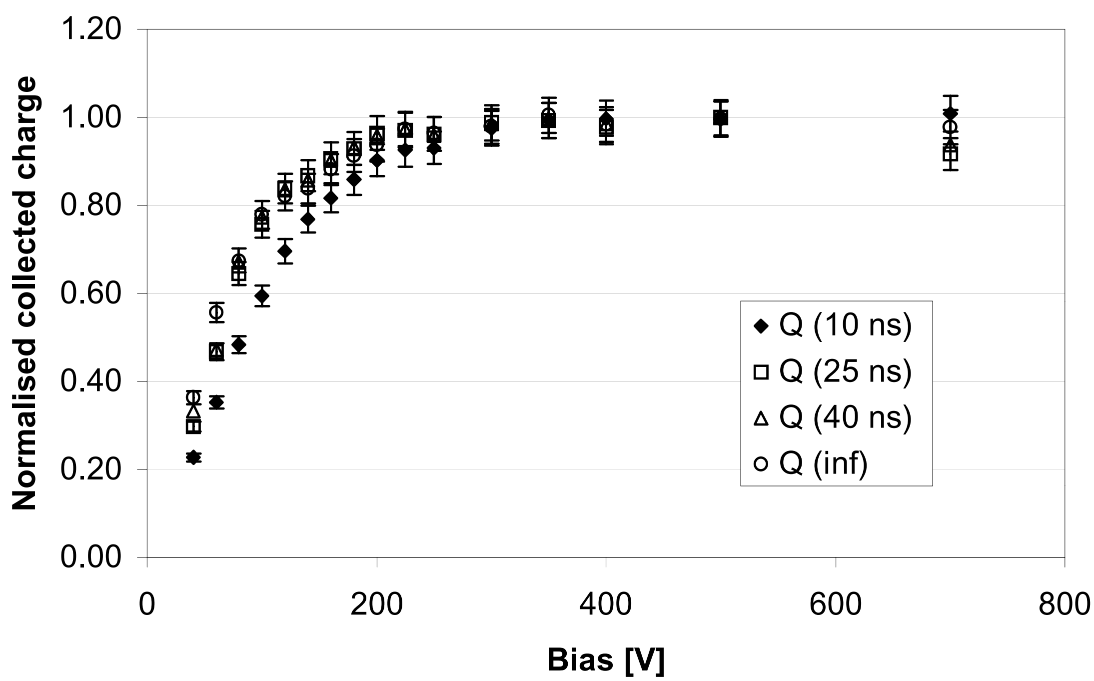


CCE at different integration times.

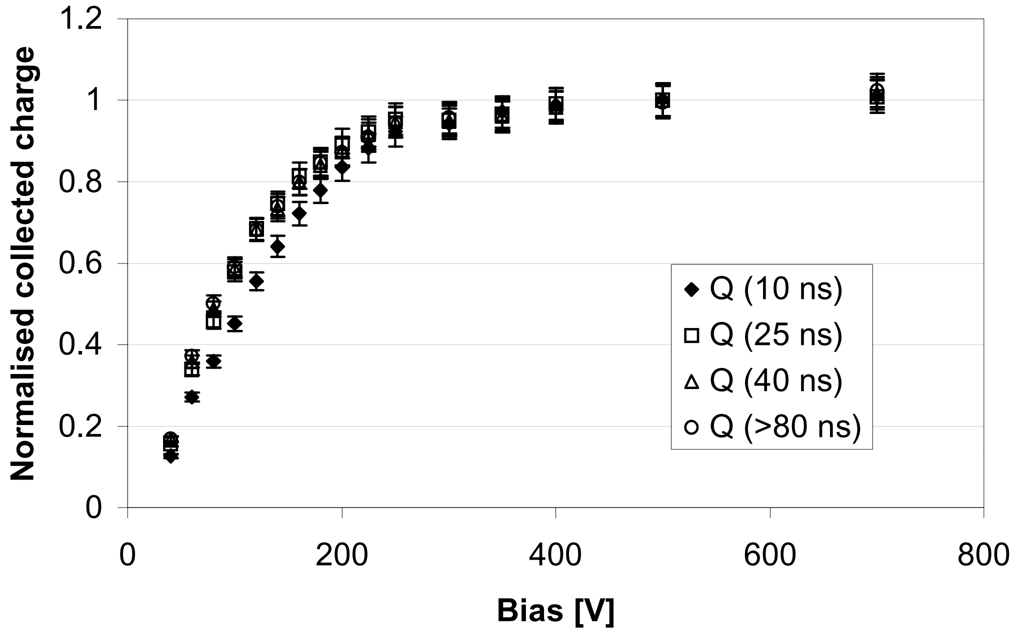
Non-irradiated detector



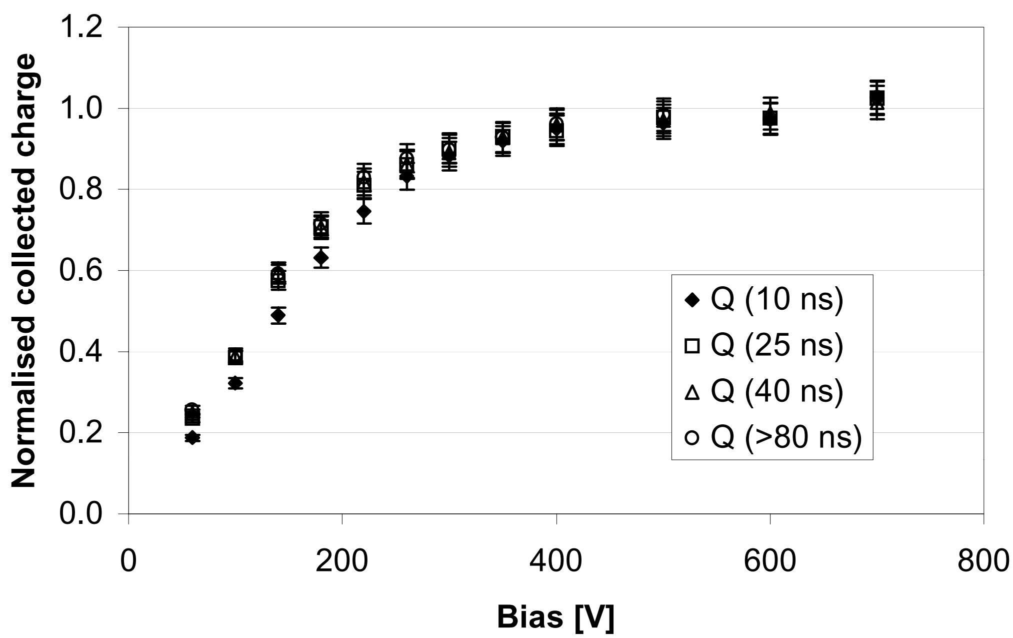
After 1.9 10^{14} p cm^{-2}



After 2.9 10^{14} p cm^{-2}

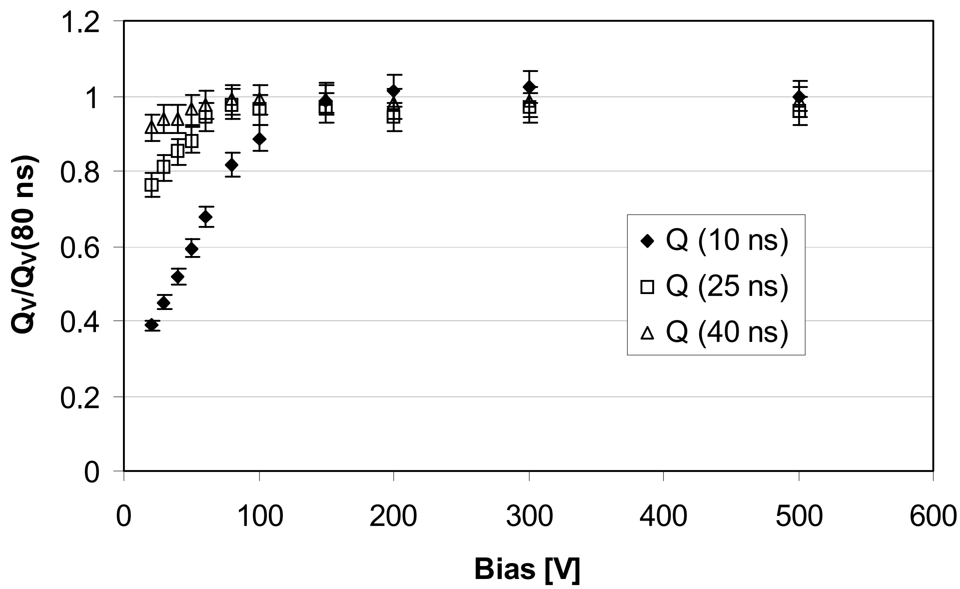


After 5.1 10^{14} p cm^{-2}

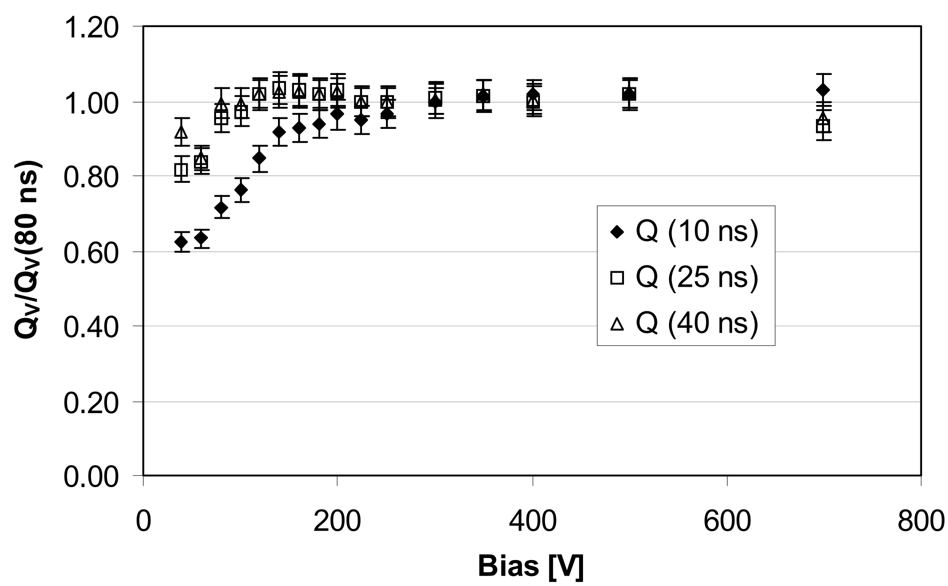


Estimate of the ballistic deficit

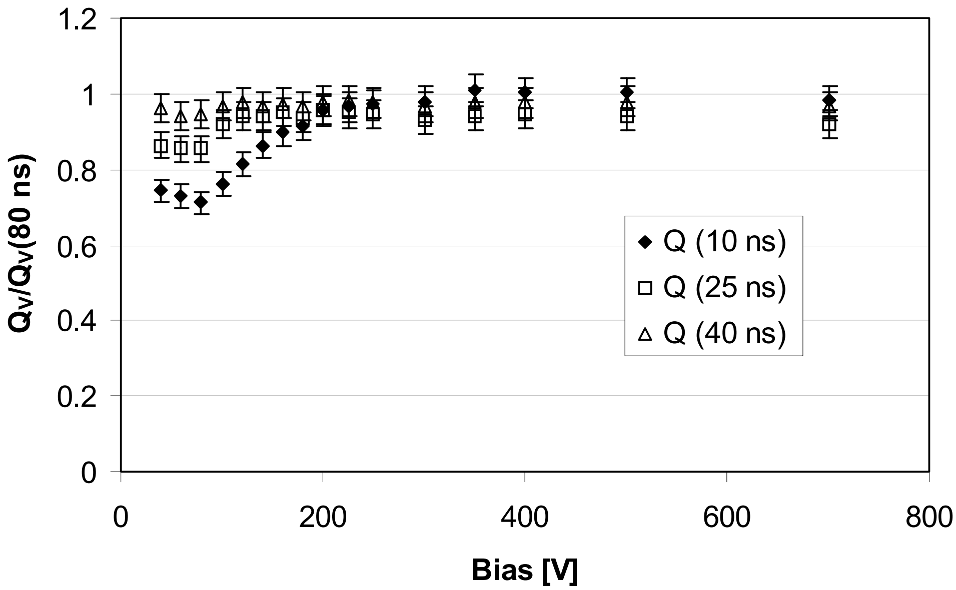
Non-irradiated detector



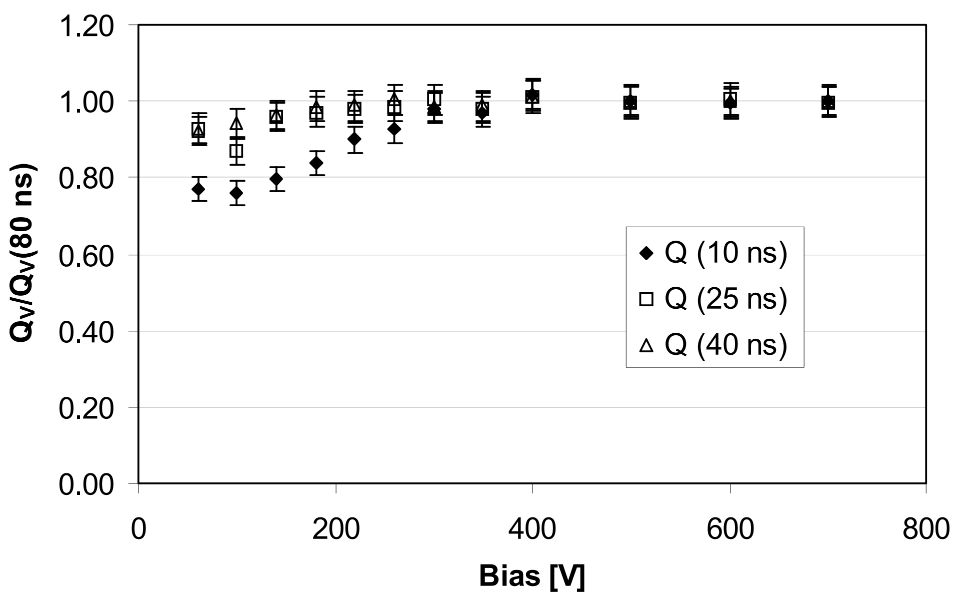
After 1.9 10^{14} p cm^{-2}



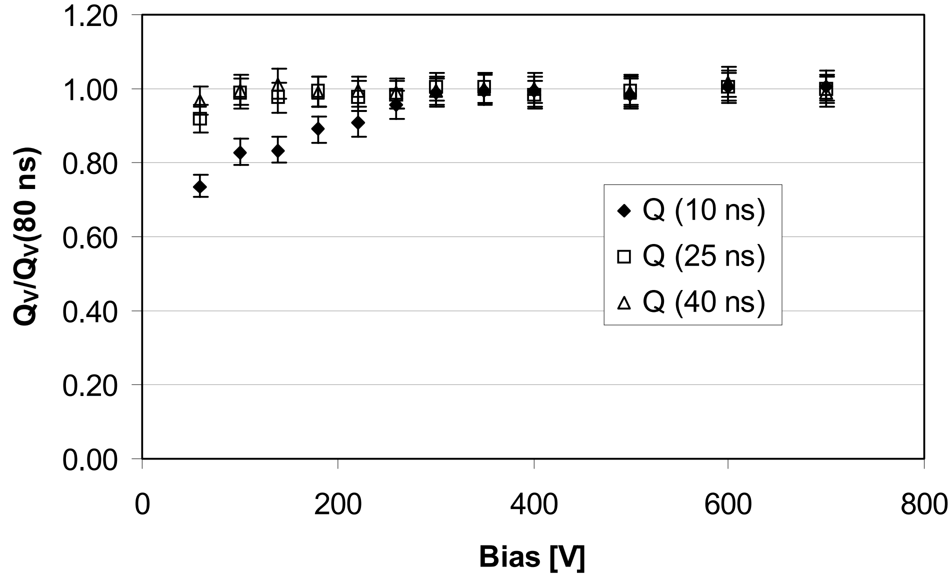
After 2.9 10^{14} p cm^{-2}, Oxyg. enriched



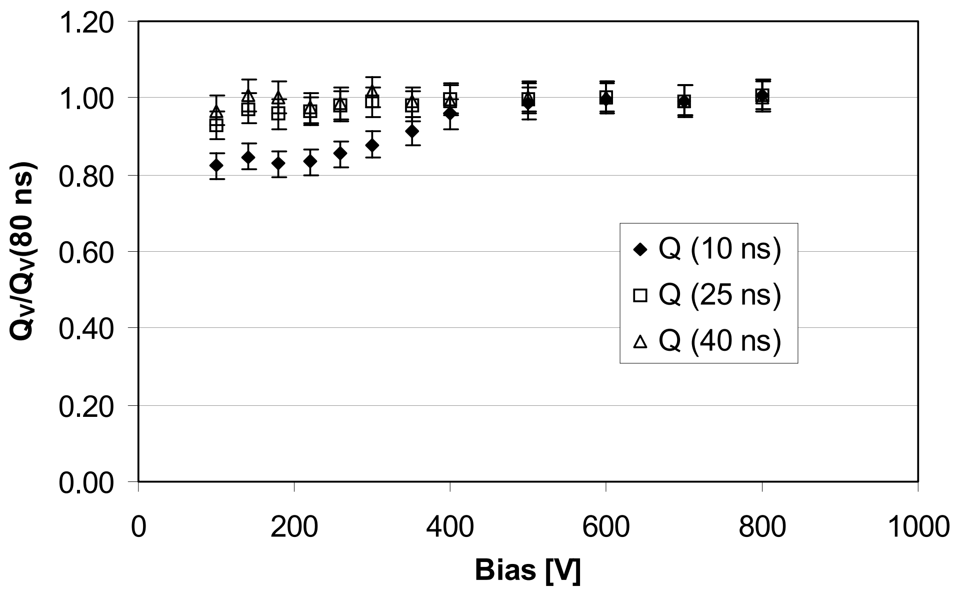
After 2.9 10^{14} p cm^{-2}, standard



After 5.1 10^{14} p cm^{-2}, Oxyg. enriched



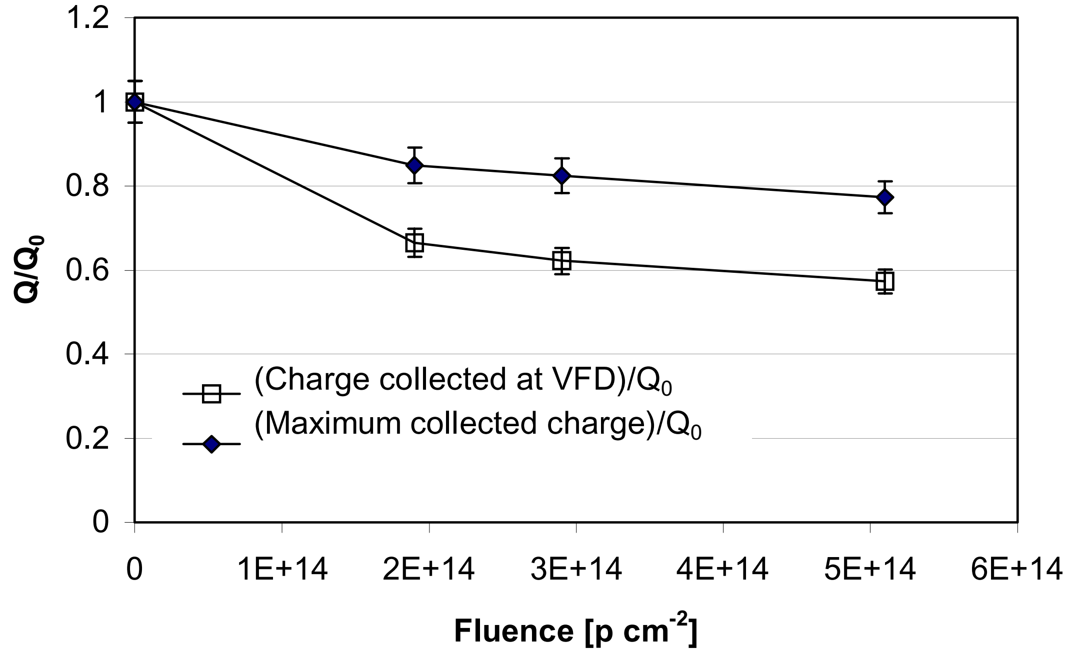
After 5.1 10^{14} p cm^{-2}, standard

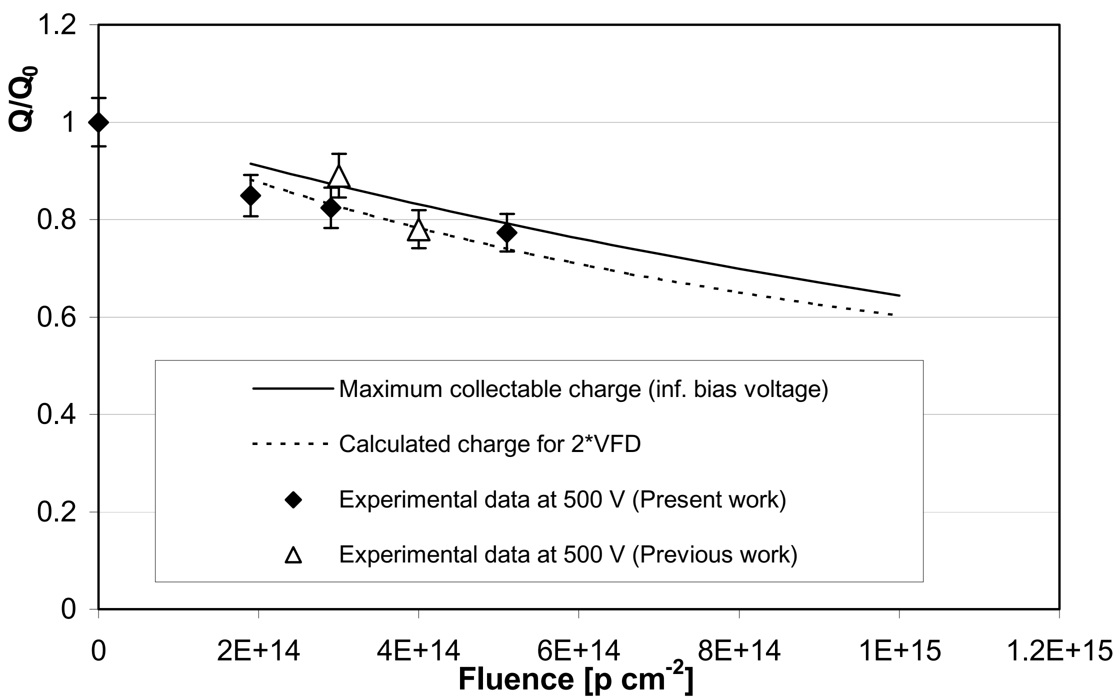


Relevant parameters from CCE curves and comparison with CV

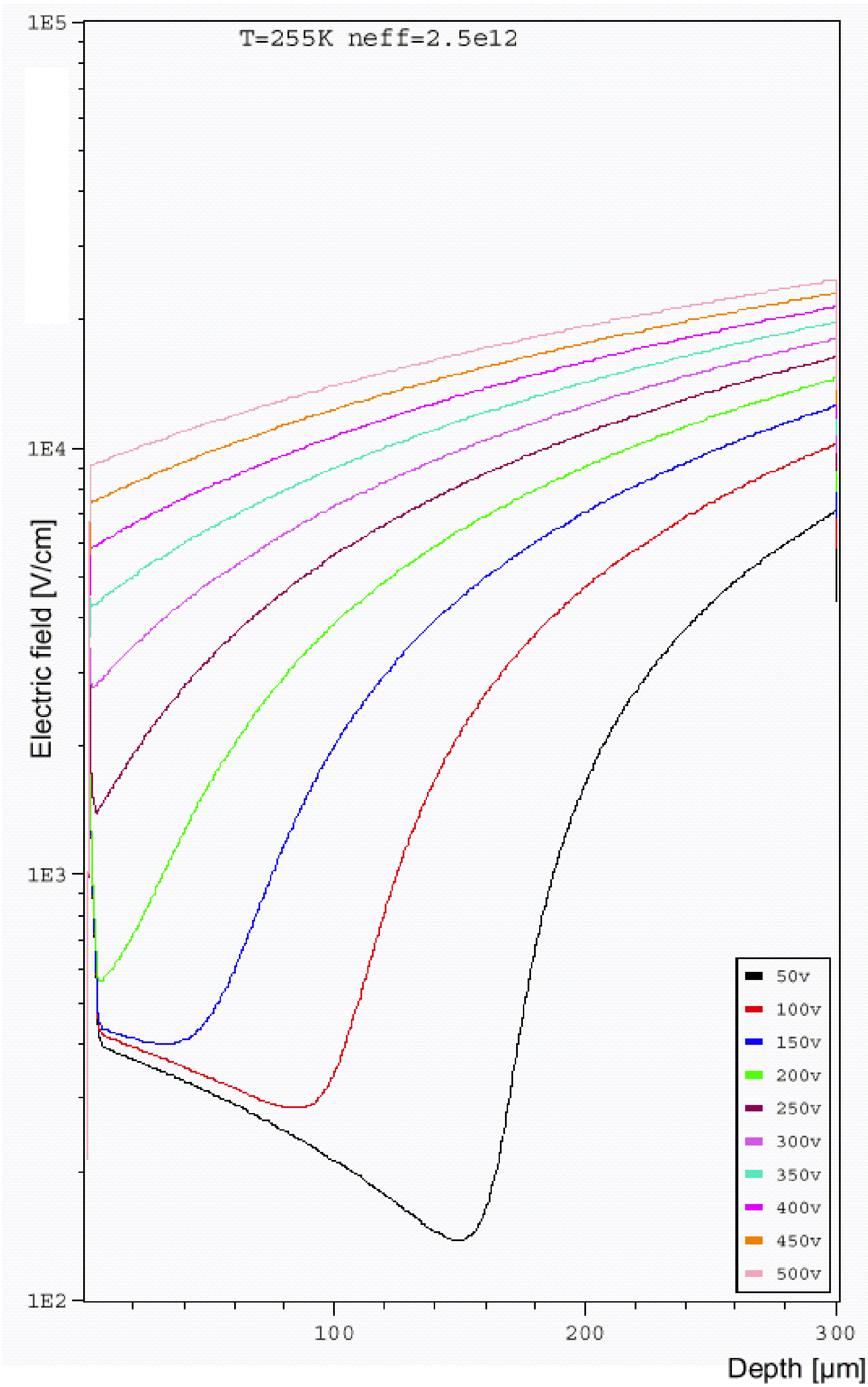
Detector label	**Fluence [p cm^{-2}]**	**Oxygen enrichment**	**V_{FD} [V] (From C-V)**	**V_{FD} [V] (From CCE)**	**λ [μm^{-1}]**
NI	Non irr.	No	49 ± 2	50 ± 2	
SO1	$1.9 \cdot 10^{14} \pm 7\%$	Yes	100 ± 7	90 ± 2	1338 ± 15
SN1	$1.9 \cdot 10^{14} \pm 7\%$	No	150 ± 8	137 ± 2	1407 ± 220
SO2	$2.9 \cdot 10^{14} \pm 7\%$	Yes	121 ± 7	130 ± 2	1224 ± 138
SN2	$2.9 \cdot 10^{14} \pm 7\%$	No	218 ± 15	235 ± 4	2076 ± 100
SO3	$5.1 \cdot 10^{14} \pm 7\%$	Yes	181 ± 15	196 ± 3	731 ± 84
SN3	$5.1 \cdot 10^{14} \pm 7\%$	No	320 ± 20	348 ± 7	781 ± 55

Charge deficit as a function of proton fluence

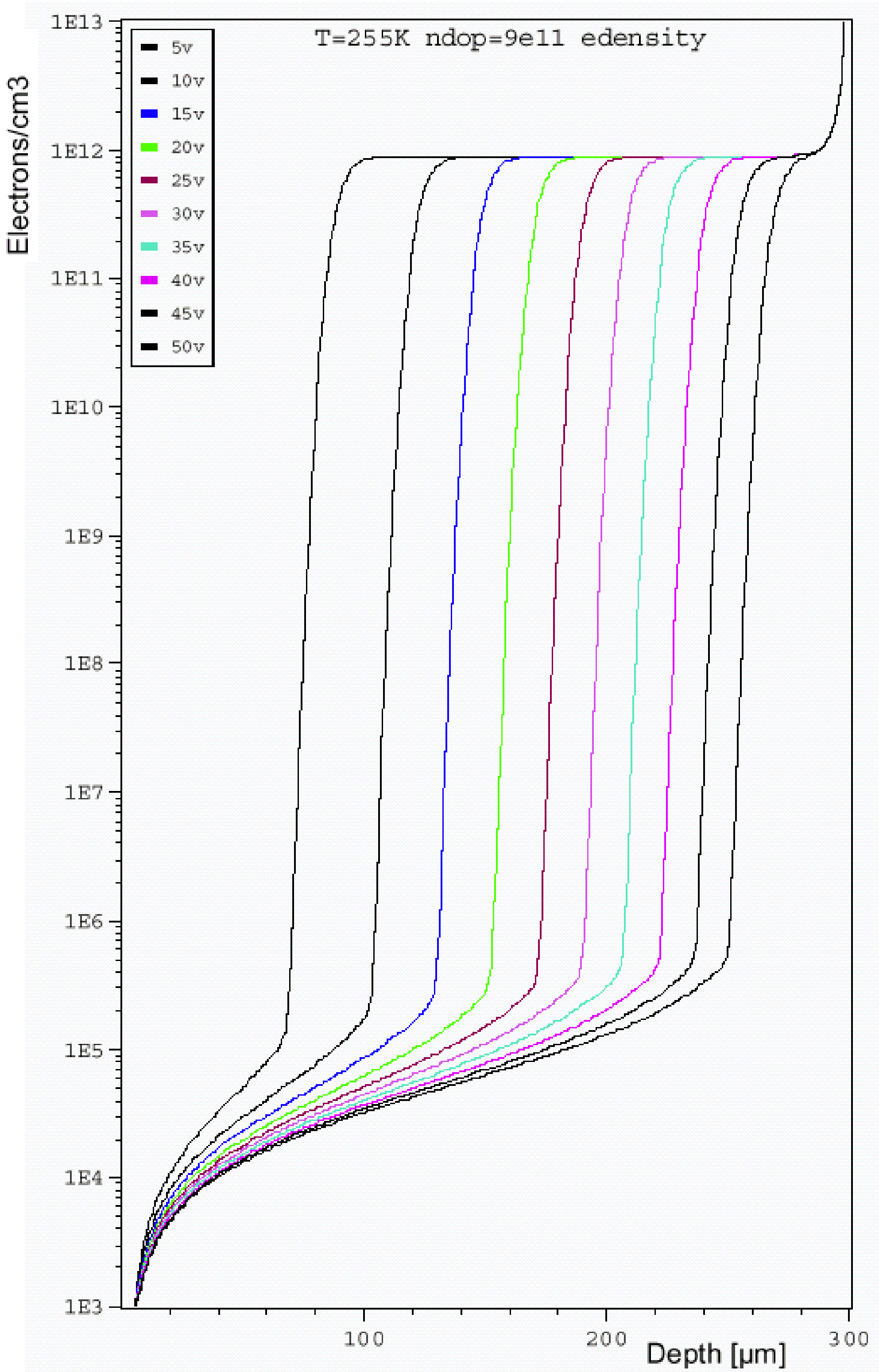




Electric field in irradiated detectors

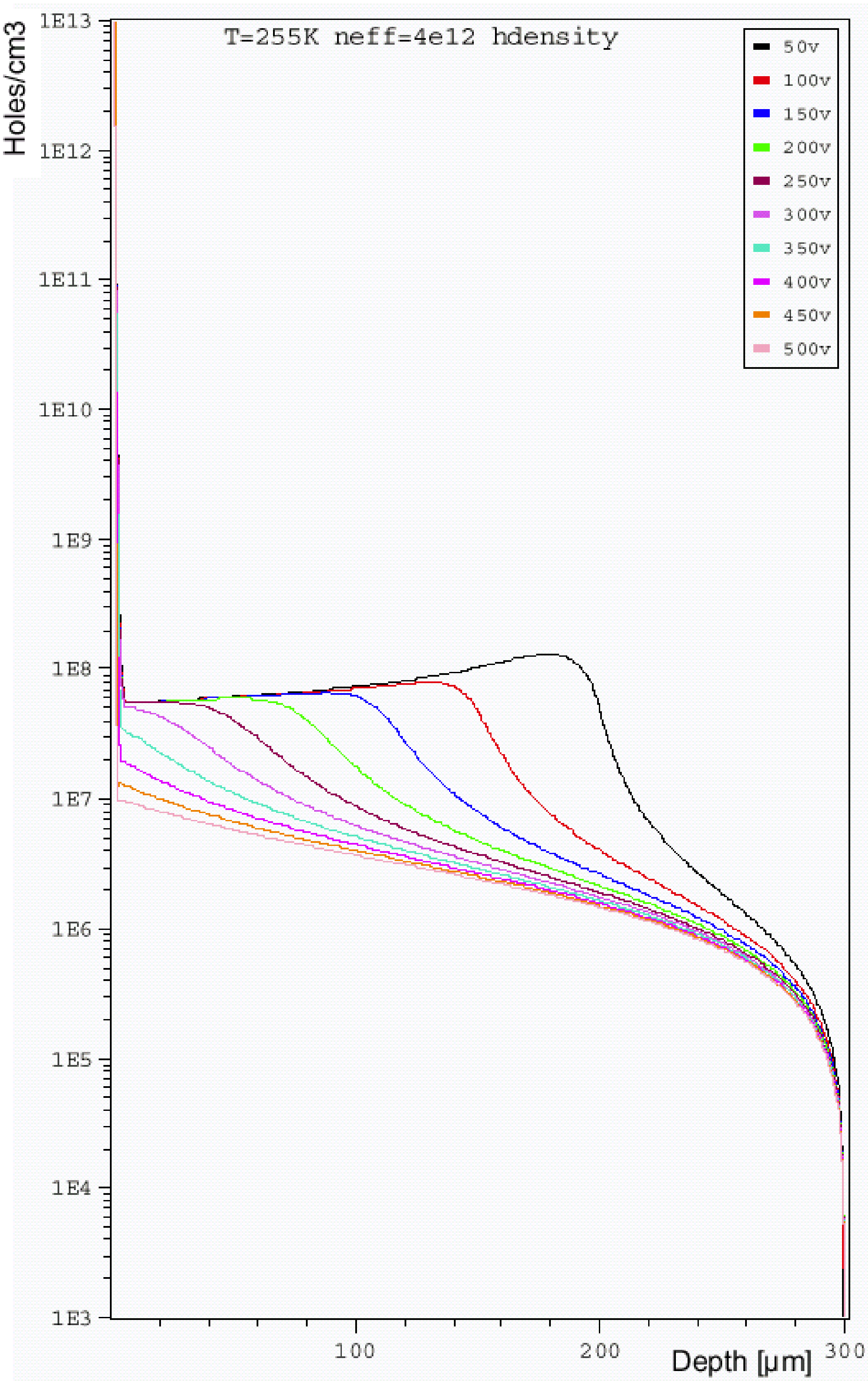


Majority carriers in non-irradiated detectors

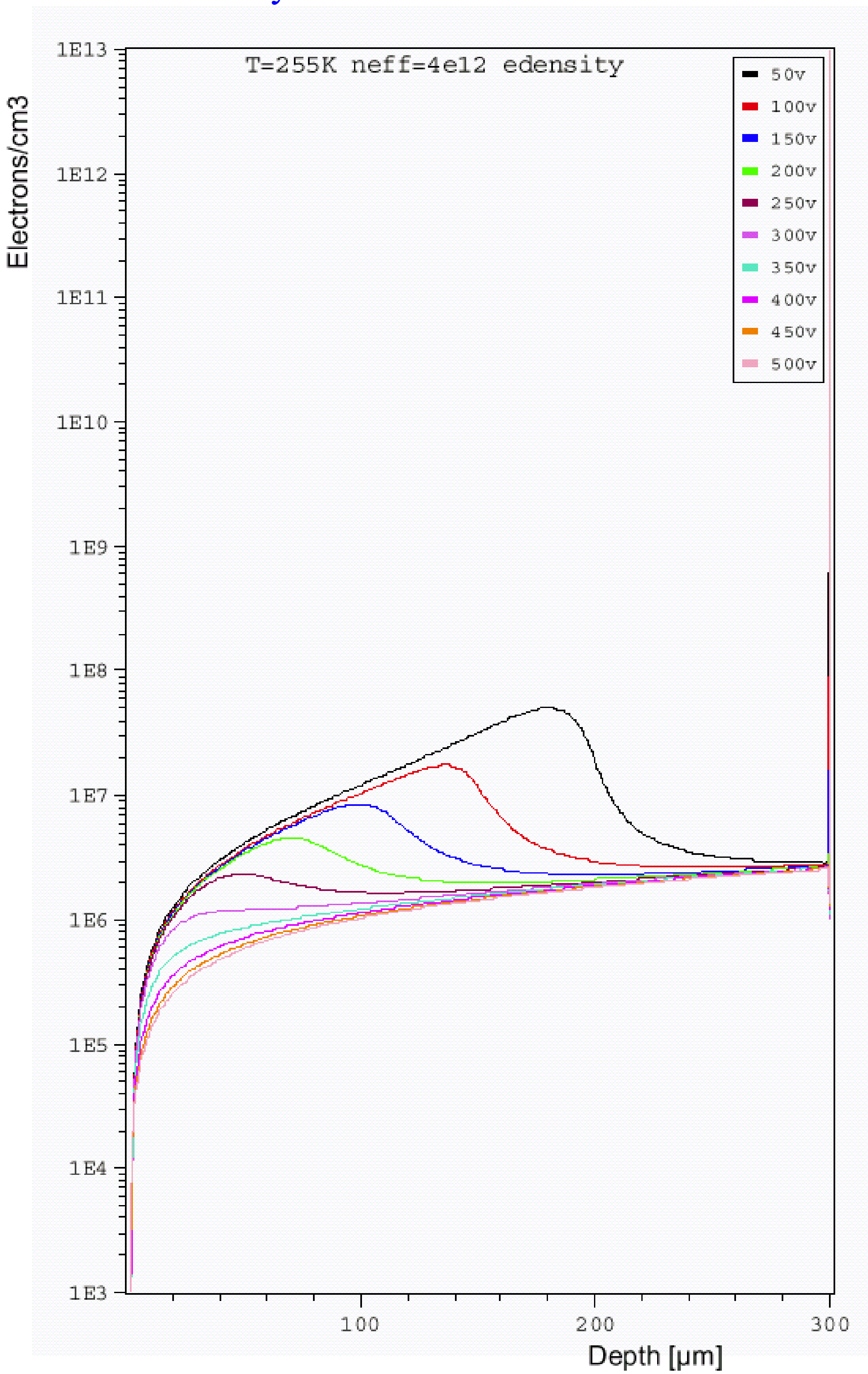


Minority carriers in non-irradiated detectors

Majority carriers in irradiated detectors



Minority carriers in irradiated detectors



SIMULATION PARAMETERS

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	$2.00\ 10^{-15}$	1.2010^{-14}
Electron	$3.60\ 10^{14}$	0.035	$1.20\ 10^{-15}$	$1.20\ 10^{-14}$
Hole	$3.24\ 10^{14}$	-0.045	$1.20\ 10^{-14}$	$1.20\ 10^{-14}$
Hole	$1.50\ 10^{15}$	-0.20	$1.50\ 10^{-14}$	$2.00\ 10^{-14}$

Charge collection efficiency fit

Taking into account the charge trapping:

$$q(V) = \frac{Q_0}{w_0} \int_0^{w(V)} \exp\left(- \int_x^{w_0} \frac{dx'}{\lambda(x')} \right) dx$$

where Q_0 is the charge released by the ionising particle, $w(V)$ is the depth of the depleted region as a function of the applied bias, w_0 is the thickness of the detector, λ is the signal attenuation length and x is the position of the moving charge. The relationship between the parameters of the equation is the following

$$w(V) = \begin{cases} w_0 \sqrt{V/V_{FD}} & if \quad V < V_{FD} \\ w_0 & if \quad V \geq V_{FD} \end{cases}$$

$$\lambda(x) = \lambda_0 + \lambda_1 \frac{v_x}{v_s}$$

$$v(x) = \frac{\mu_0}{1 + \mu_0 \varepsilon(x) / v_s}$$

$$\varepsilon(x) = \frac{2V_{FD}}{w_0^2 \left(w(V) - x \right)}$$

where μ_0 is the carrier mobility, ε the electric field and v (v_s) is the (saturation) velocity of the charge carrier.

The parameter λ correlates to the carrier lifetime time through the relationship

$$1/\tau = \beta\Phi, \quad \lambda = v\tau$$

where β defines the rate for the change of the trapping probability with dose.

CONCLUSIONS

The charge collection properties of miniature microstrip p^+n detectors have been studied up to the fluence of $5.1 \cdot 10^{14}$ protons cm^{-2}. The charge deficit has been measured as a function of the integration time and of the trapping at radiation induced charge trap centres. A prediction of the deficit has been shown up to 10^{15} p cm^{-2}. At this high fluence, corresponding approximately to the maximum dose expected after 10 years of operation of LHC at a radial distance of 1 cm, it is still possible to collect ~60% of the charge released by the ionising radiation by applying a bias voltage equal to $2*V_{FD}$, namely ~800 V (~1300 V) if an oxygenated (non-oxygenated) substrate is used.
A comparison between oxygen enriched and standard material has been carried out. Oxygen enhancement is known to reduce the increasing rate of V_{FD} with charged hadron irradiation, while the increase of the reverse current remains unaffected. This is confirmed from the charge collection studies, which also shows that the charge trapping is not affected by the oxygen concentration.