Aspects of CCE in irradiated silicon detectors and advantages using p-type silicon substrates

- Evaluation of trapping effects
- The influence of ballistic deficit
- Fits to the Charge Collection Efficiency
- Feasibility of p-type substrate microstrip detectors
- Results of CCE of p-type detectors
- Conclusions

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1st Workshop on Radiation hard semiconductor devices for very high luminosity colliders

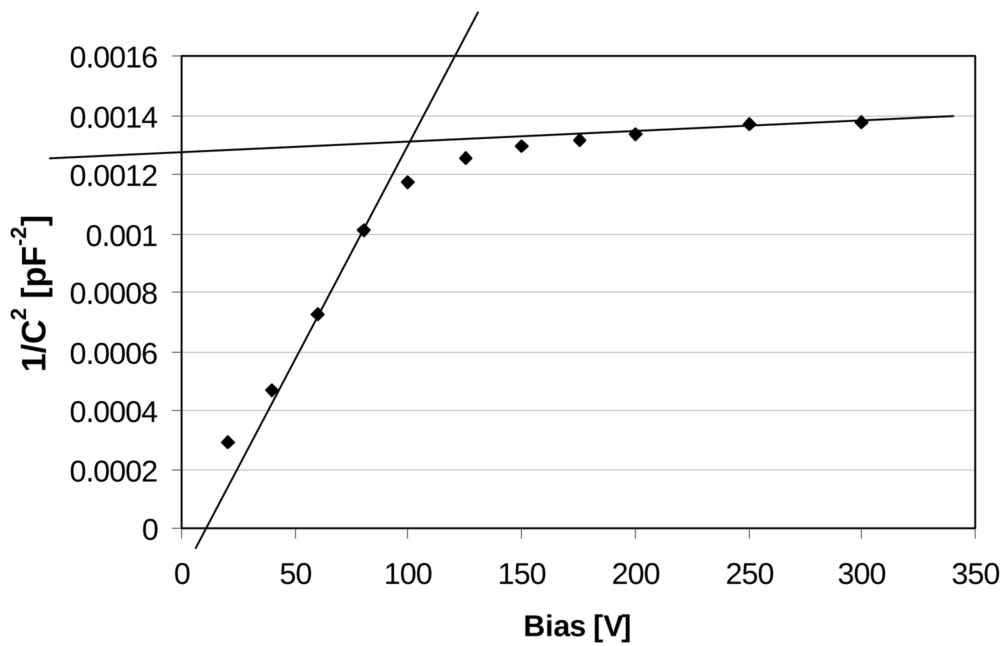
Evaluation of Trapping Effects

- **Radiation damage to silicon detectors**
  increases reverse currents,
  creates interface trapped charge,
  introduces traps reducing charge collection efficiencies
  changes the effective doping concentrations
- **Studies of the latter effect have shown significant improvements under charge hadron irradiation when high concentrations of interstitial oxygen are introduced**
- **However, unlike in the case of n-side read-out detectors, the charge collection efficiencies for p-side read-out detectors do not plateau with voltage until well above the depletion voltage**

⇨ **This is usually assigned to the effect of trapping**

Evaluation of Trapping Effects

- **Capacitance – Voltage Derived Depletion Voltage**



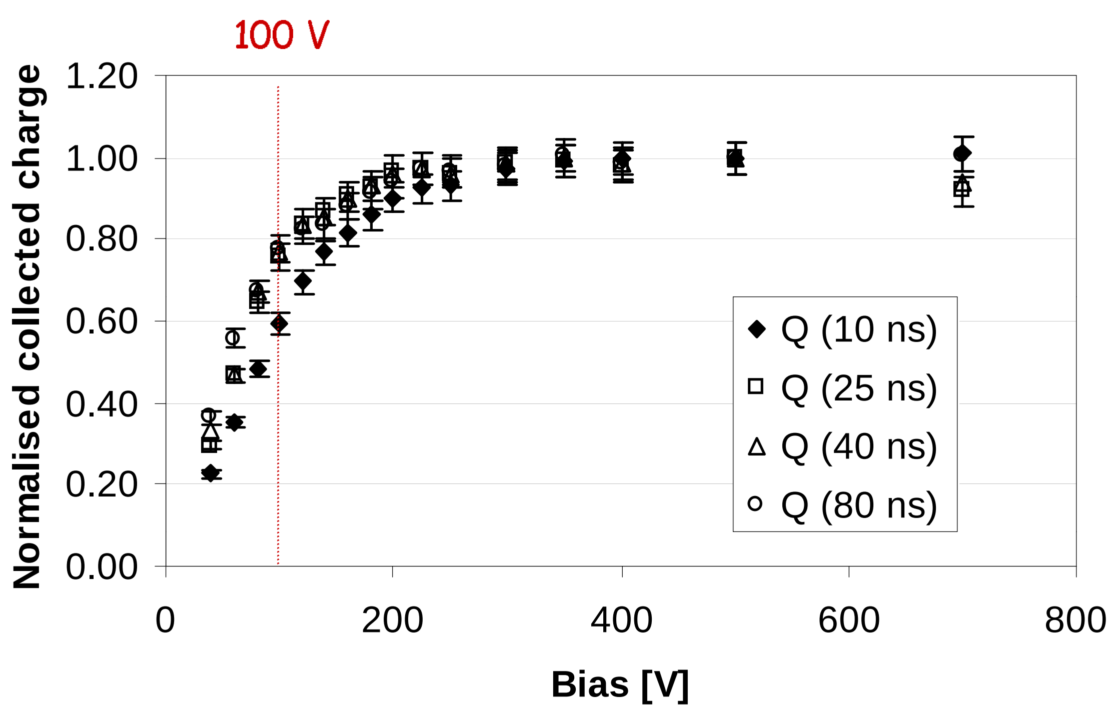
$1.9 \pm 0.1 \times 10^{14}$ p/cm^2

Oxygenated Miniature Micro-strip Detector

$V_{FD} = 100 \pm 7$ V

Evaluation of Trapping Effects

- **Corresponding Charge Collection Efficiency vs Voltage**



Evaluation of Trapping Effects

- The effects of trapping can be parameterized in terms of effective trapping time (*Kramberger et al*) or, equivalently, velocity dependent attenuation length (*Marti i Garcia et al*)
- In both cases, trapping is highest where the field is lowest
- These parameterizations assume timescales such that the total untrapped charge is collected, integrating over transient effects.

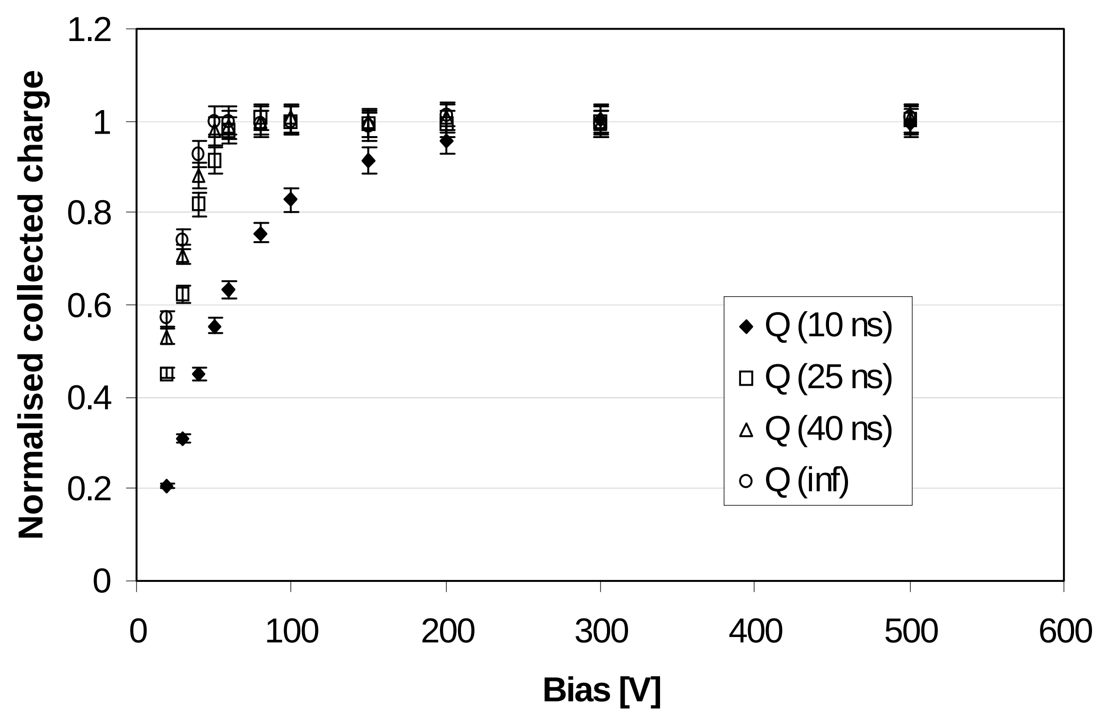
→ **No influence of ballistic deficit is taken into account**

- Nevertheless, both analyses give values of β (averaged over *e* and *h*) that agree. $\beta_{e,h} \times \Phi_{eq} = 1/\tau_{\mathrm{eff}\ e,h}$ (trapping $\propto$ flux)

Influence of Ballistic Deficit

- **Since at the LHC electronics response times are close to charge collection times, signal loss due to incomplete charge integration must also be considered, which will also depend on the field within the detector.**

Non-irradiated p-strip Detector



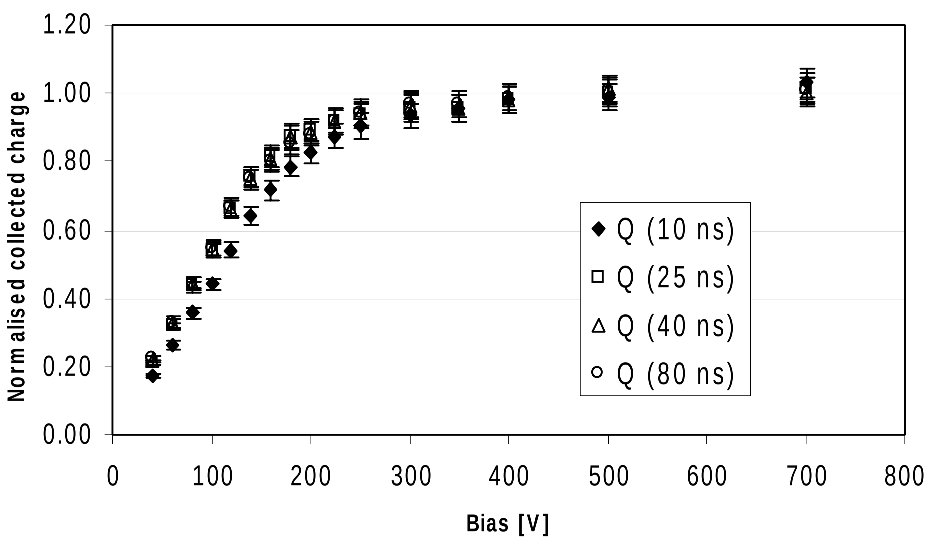
Influence of Ballistic Deficit

Several miniature detectors have been studied after irradiation and annealing.

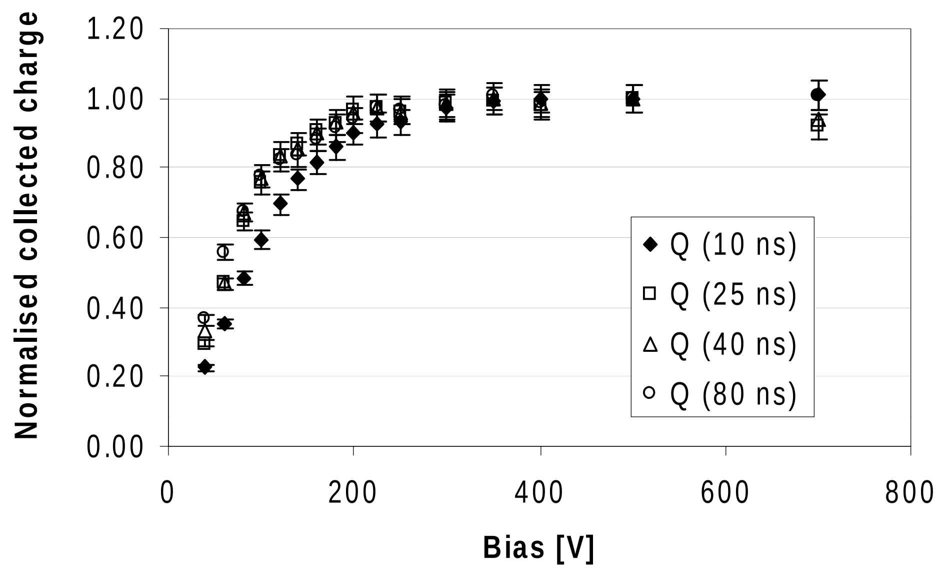
Detector label	Fluence [p cm^{-2}]	Oxygenation[$\sim 2 \cdot 10^{17}$ at. Cm^{-3}]
NI	Non irradiated	No
SO1	$1.9 \pm 0.1 \cdot 10^{14}$	Yes
SN1	$1.9 \pm 0.1 \cdot 10^{14}$	No
SO2	$2.9 \pm 0.2 \cdot 10^{14}$	Yes
SN2	$2.9 \pm 0.2 \cdot 10^{14}$	No
SO3	$5.1 \pm 0.4 \cdot 10^{14}$	Yes
SN3	$5.1 \pm 0.4 \cdot 10^{14}$	No

Influence of Ballistic Deficit

Miniature detectors irradiated to 1.9×10^{14}p/cm^2



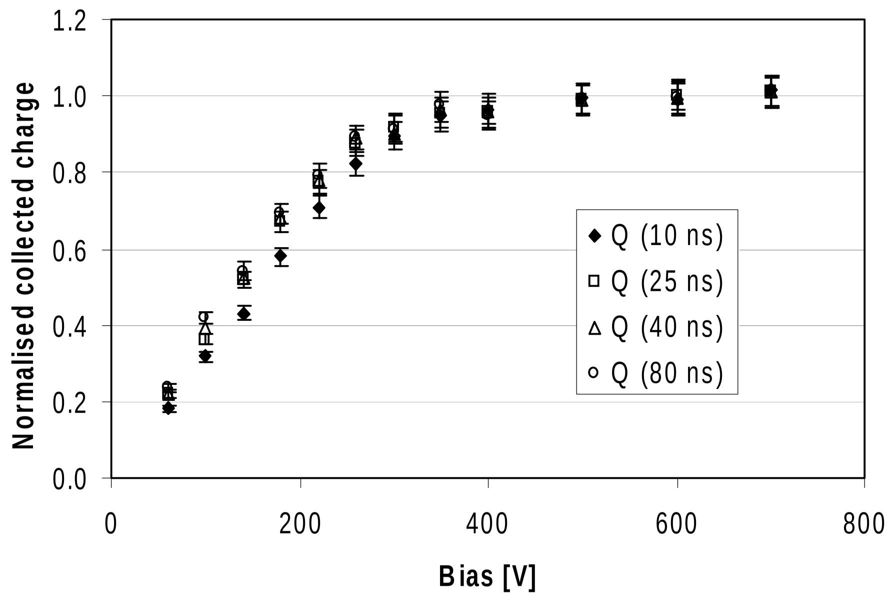
Non-Oxygenated



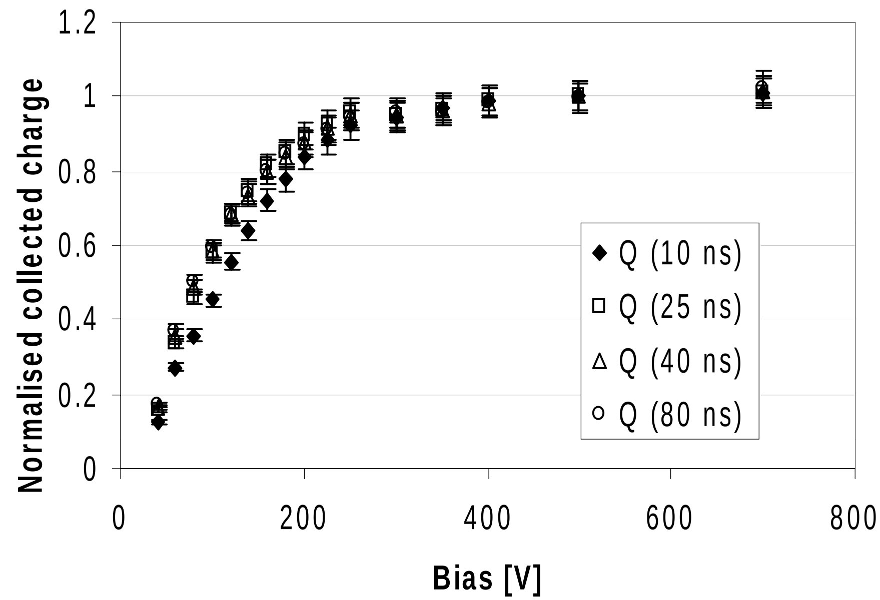
Oxygenated

Influence of Ballistic Deficit

Miniature detectors irradiated to 2.9×10^{14}p/cm^2



Non-Oxygenated



Oxygenated

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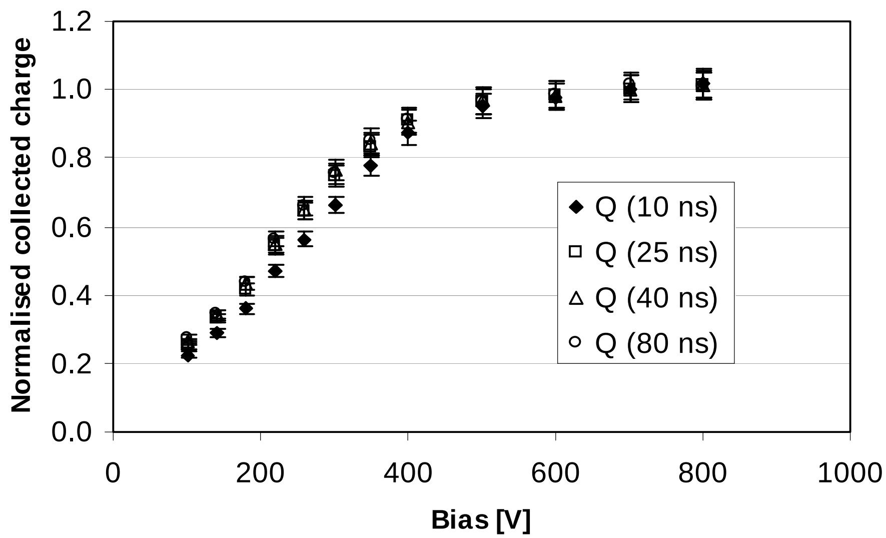
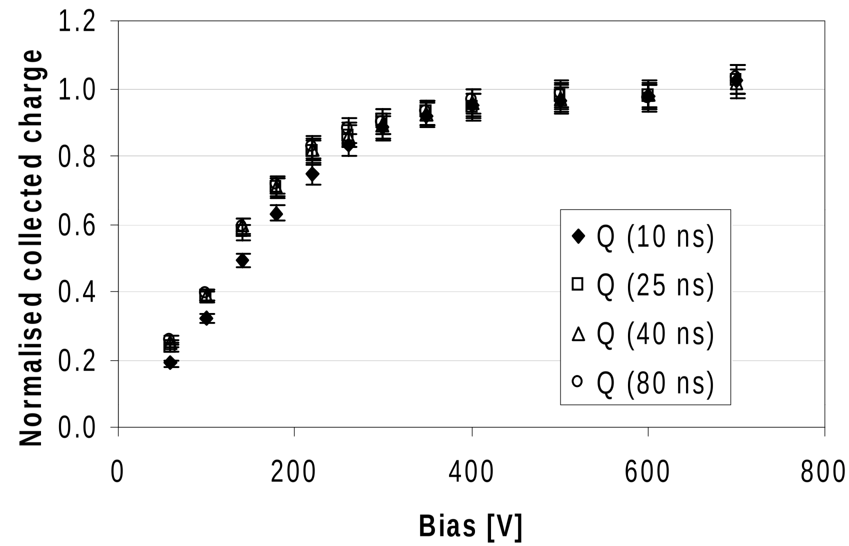
Influence of Ballistic Deficit

Miniature detectors irradiated to 5.1×10^{14}p/cm^2

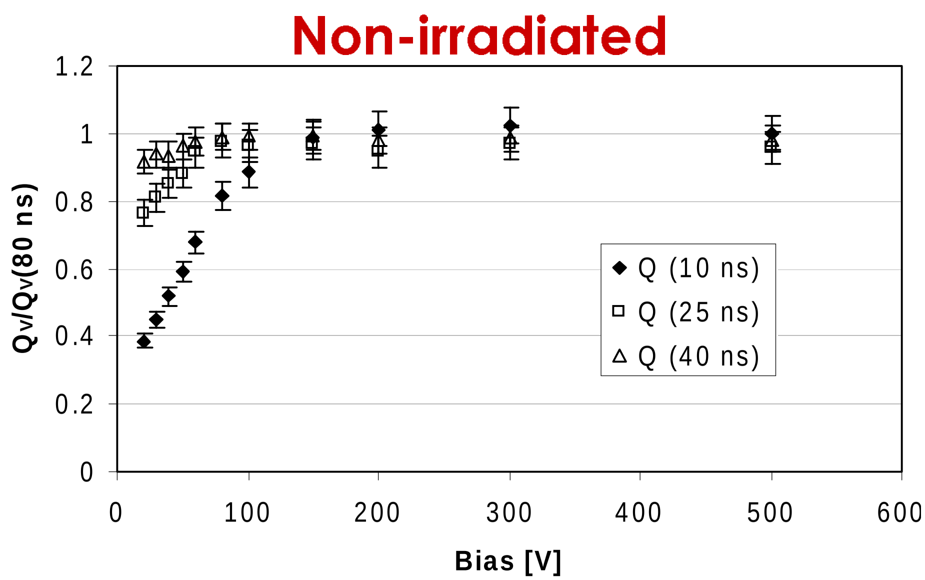


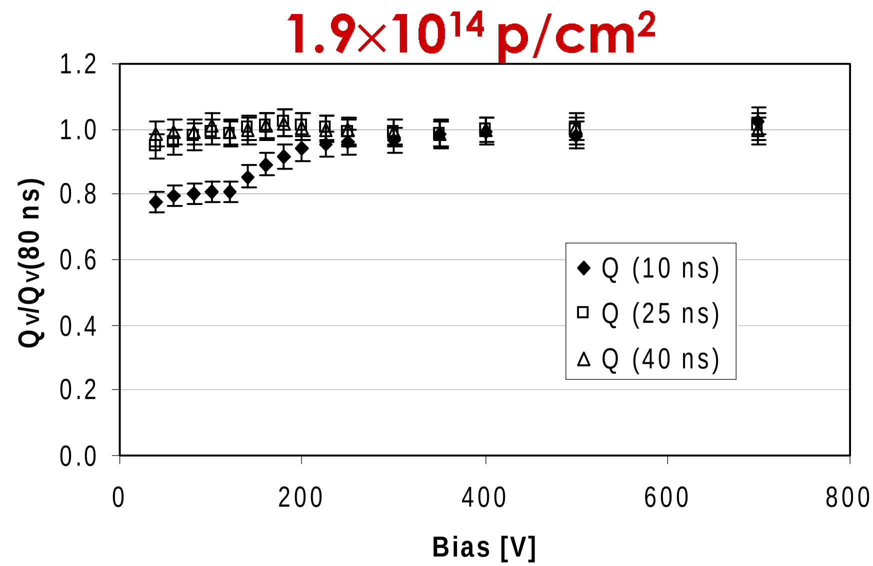
Non-Oxygenated

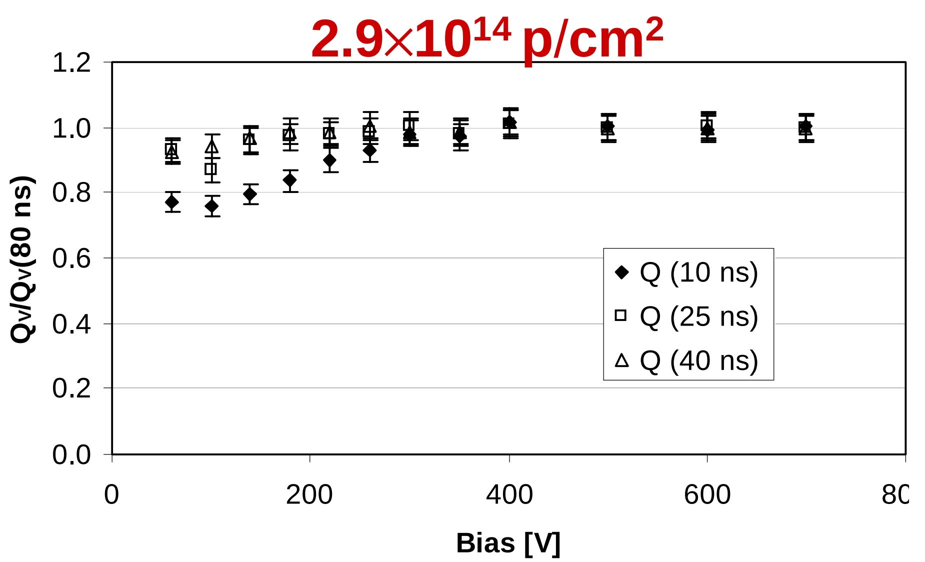


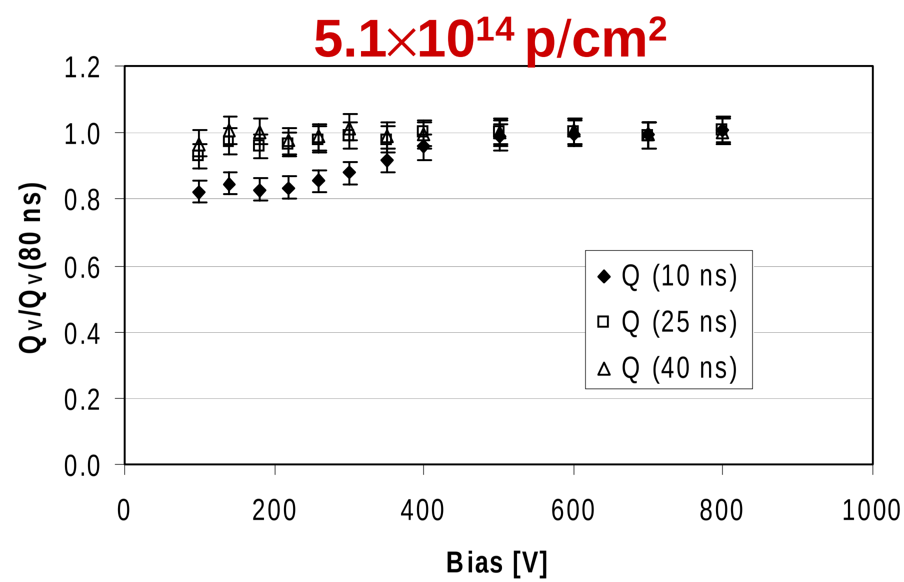
Oxygenated

Non-Oxygenated Detectors: Relative Ballistic Deficit



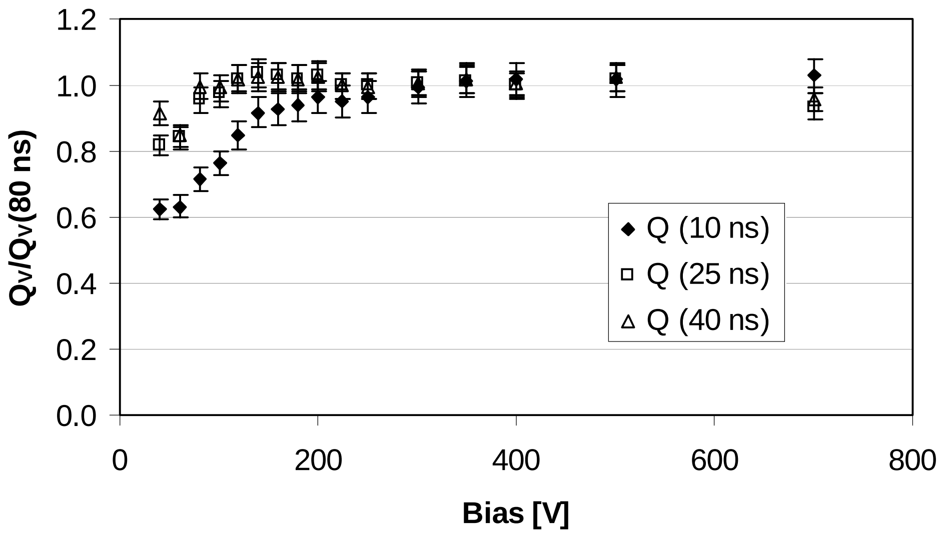




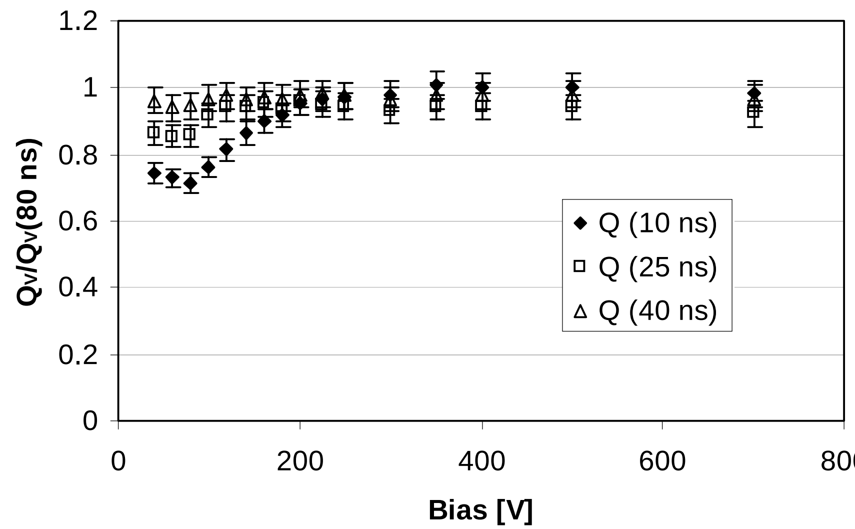


Oxygenated Detectors: Relative Ballistic Deficit

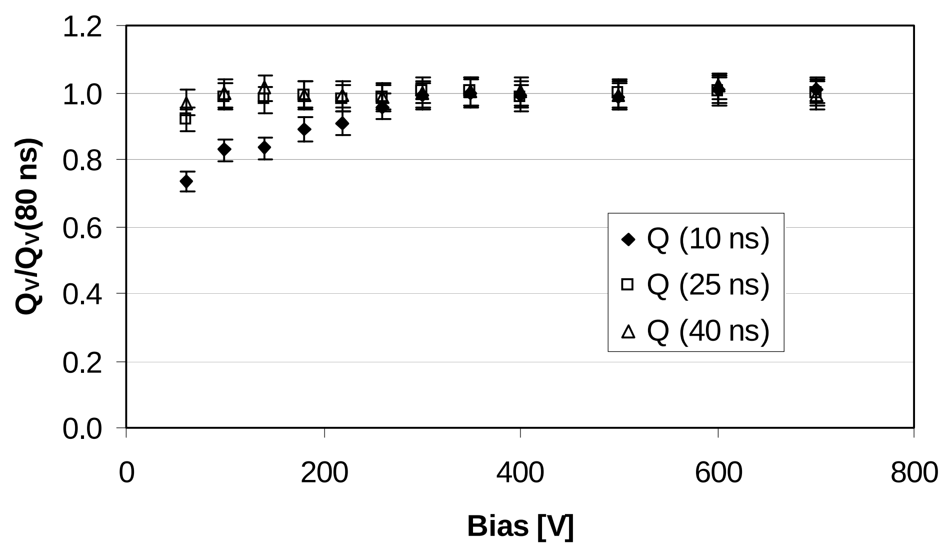
1.9×10^{14} p/cm^2



2.9×10^{14} p/cm^2



5.1×10^{14} p/cm^2



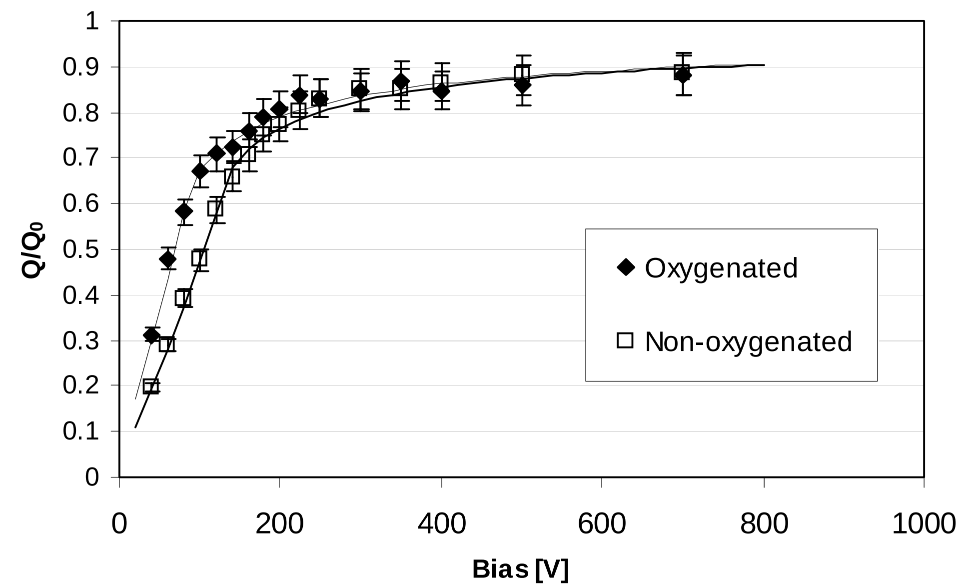
Fits to the Charge Collection Efficiency

The above results suggest that, particularly at high doses, the ballistic deficit is not a major factor

In the following fits, only charge loss due to trapping is assumed

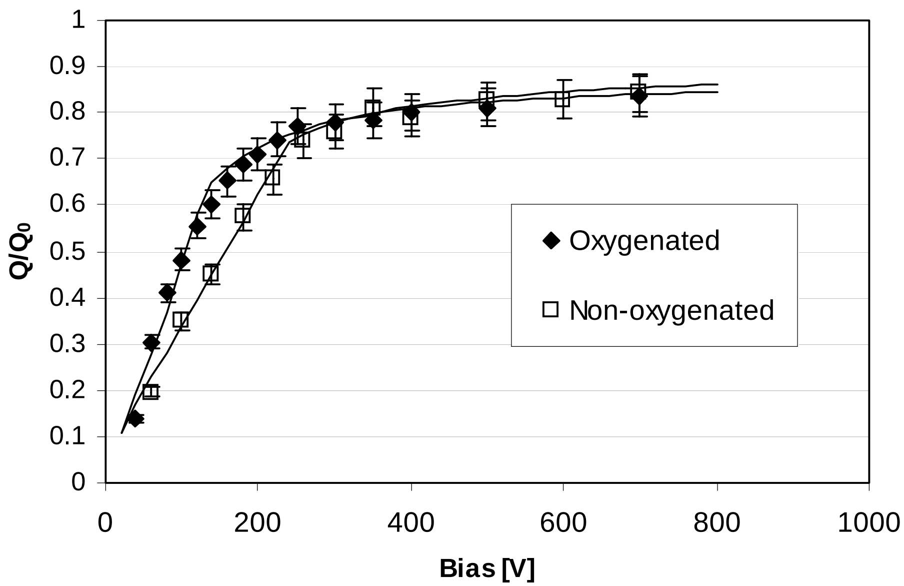
Free parameters:

attenuation length λ,
depletion voltage V_{FD}
total generated charge Q_0

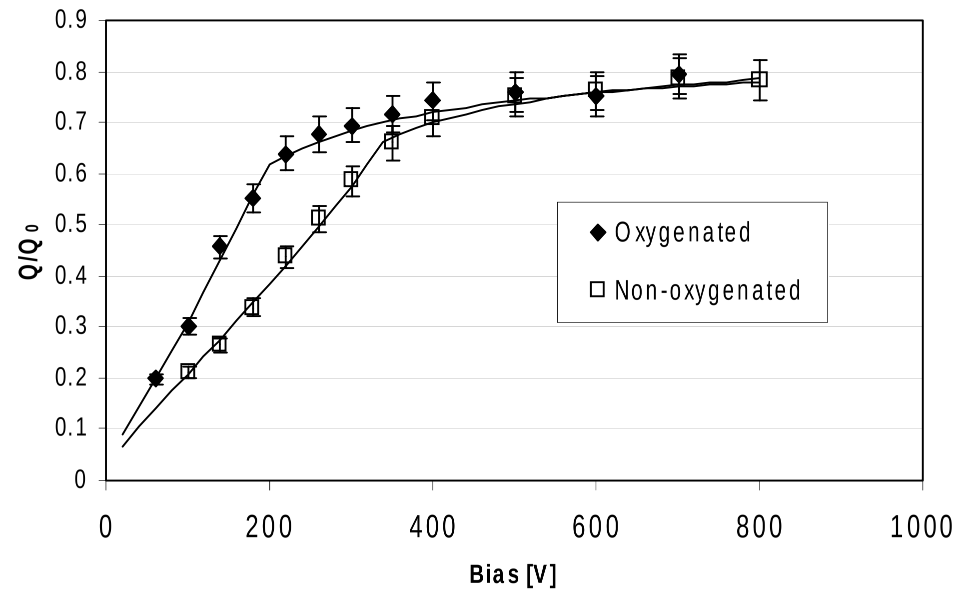


1.9×10^{14} p/cm^2

Fits to the Charge Collection Efficiency



2.9×10^{14} p/cm^2



5.1×10^{14} p/cm^2

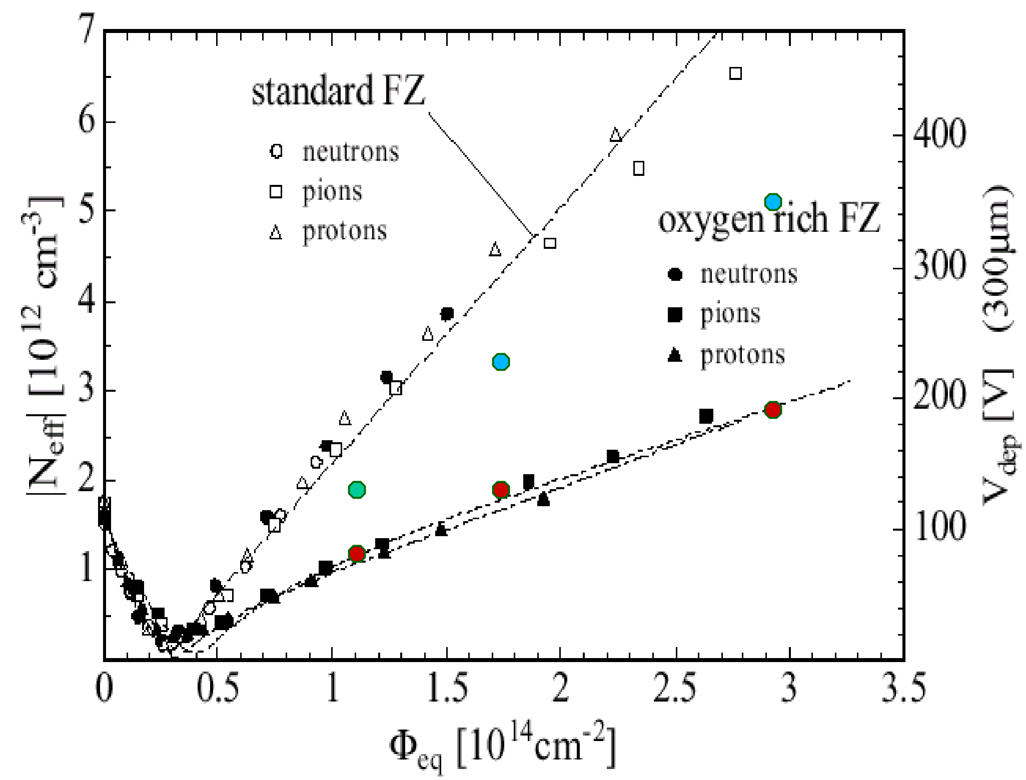
Fits to the Charge Collection Efficiency

Detector label	Fluence [p cm^{-2}]	Oxygen enrichment	V_{FD} [V] (From C-V)	V_{FD} [V] (From CCE)	λ [ns^{-1} cm^2]
NI	Non irr.	No	49 ± 2	50 ± 2	
SO1	$1.9 \pm 0.1 \cdot 10^{14}$	Yes	100 ± 7	90 ± 2	1338 ± 15
SN1	$1.9 \pm 0.1 \cdot 10^{14}$	No	150 ± 8	137 ± 2	1407 ± 220
SO2	$2.9 \pm 0.2 \cdot 10^{14}$	Yes	121 ± 7	130 ± 2	1224 ± 138
SN2	$2.9 \pm 0.2 \cdot 10^{14}$	No	218 ± 15	214 ± 4	1313 ± 122
SO3	$5.1 \pm 0.4 \cdot 10^{14}$	Yes	181 ± 15	196 ± 3	731 ± 84
SN3	$5.1 \pm 0.4 \cdot 10^{14}$	No	320 ± 20	348 ± 7	781 ± 55

Fits to the Charge Collection Efficiency

The fitted values of V_{FD} agree with each other and with oxygenated data from RD48 (CERN LHCC 2000-009) taking account of the proton damage factor

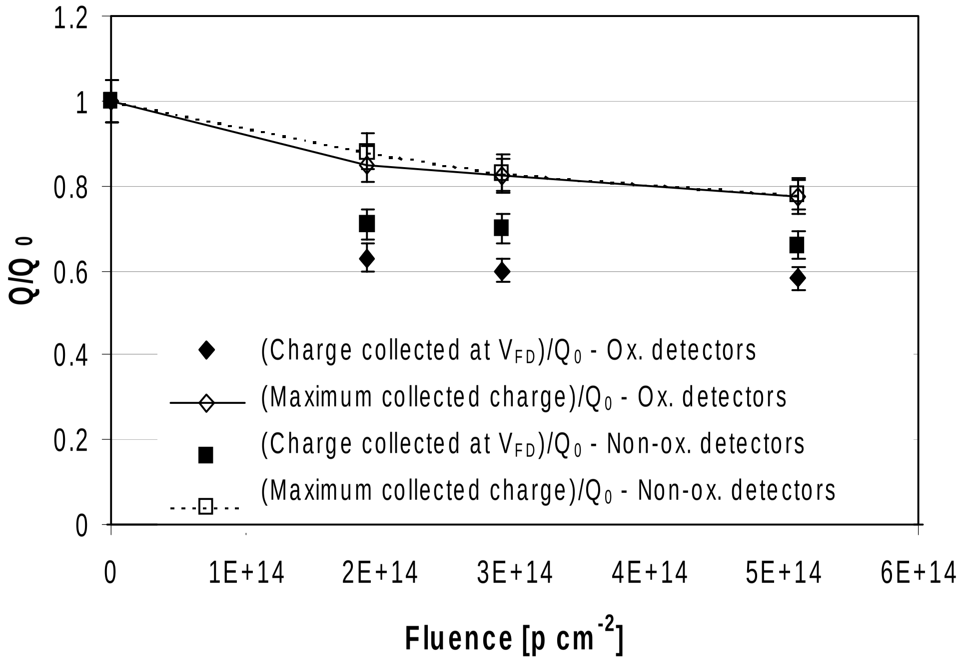
The fitted values of Q_0: **18.1±0.3, 18.2±0.3, 17.7±0.3, 18.1±0.6, 18.2±0.4** and **18.3±0.4** are all consistent and agree with the pre-irradiation value **17.7±0.3**

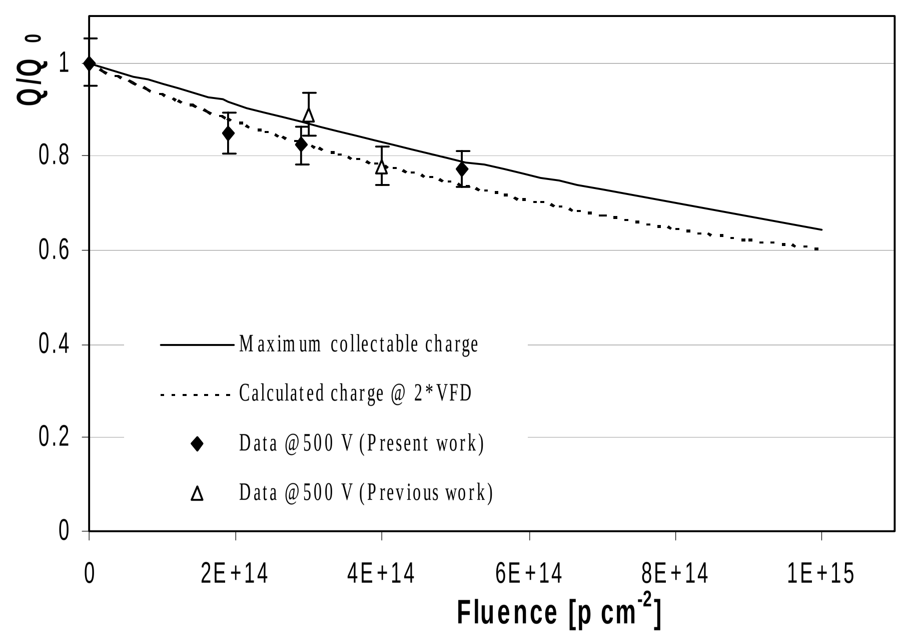


Fits to the Charge Collection Efficiency

The dependence of Q/Q_0 and therefore λ on Φ leads to a value of $\beta = 5.6 \pm 0.6 \times 10^{-16} cm^2/ns$

Assuming this value allows extrapolation of CCE to high Φ





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Discussion and Conclusions

Because for p-strip read-out, the trapping significantly affects the CCE(V), the improvements in V_{FD} due to oxygenation do not give correspondingly large effects in terms of CCE

The trapping dependence on the field leads to CCE(V_{FD}) being higher for non-oxygenated than oxygenated detectors by ~5%

Read-out from the high-field n-side gives less dependence on trapping leading to the $CCE(V) \propto \sqrt{V}$ behaviour below V_{FD}

This would imply that for high doses, n-side readout should benefit more from oxygenation of the substrate

Discussion and Conclusions

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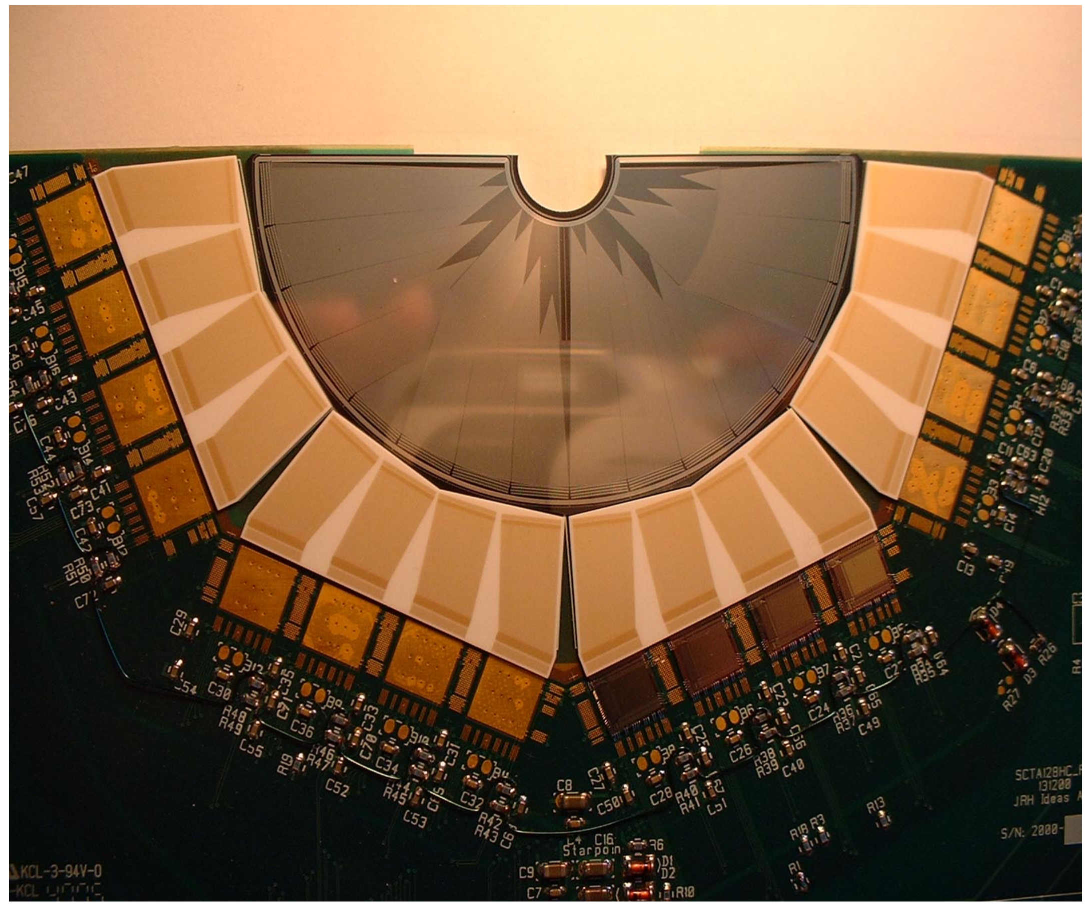
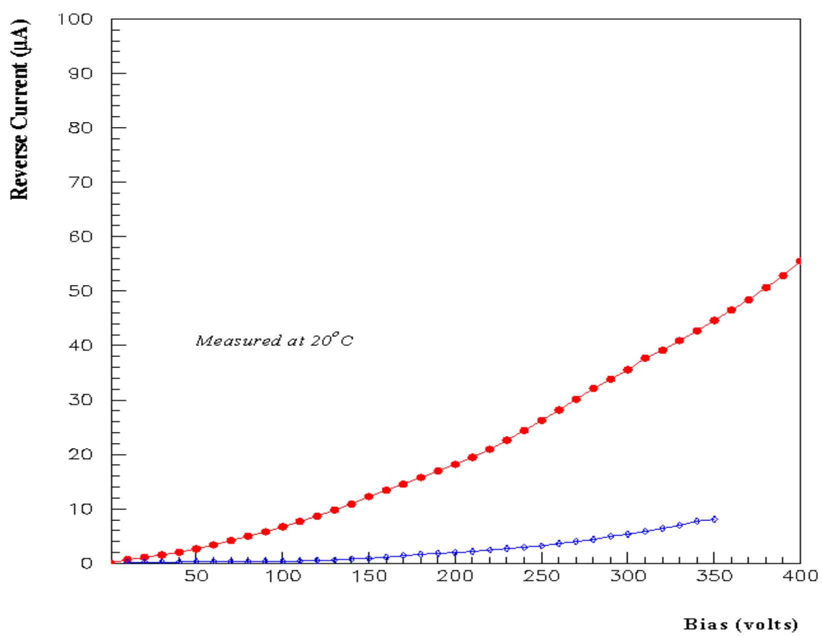
LHC-b and the pixel systems of ATLAS and CMS need to maximise their survival; n-side readout oxygenated detectors look to offer the best possibilities

Super-LHC with factor of 10 increased luminosity could also need such technology

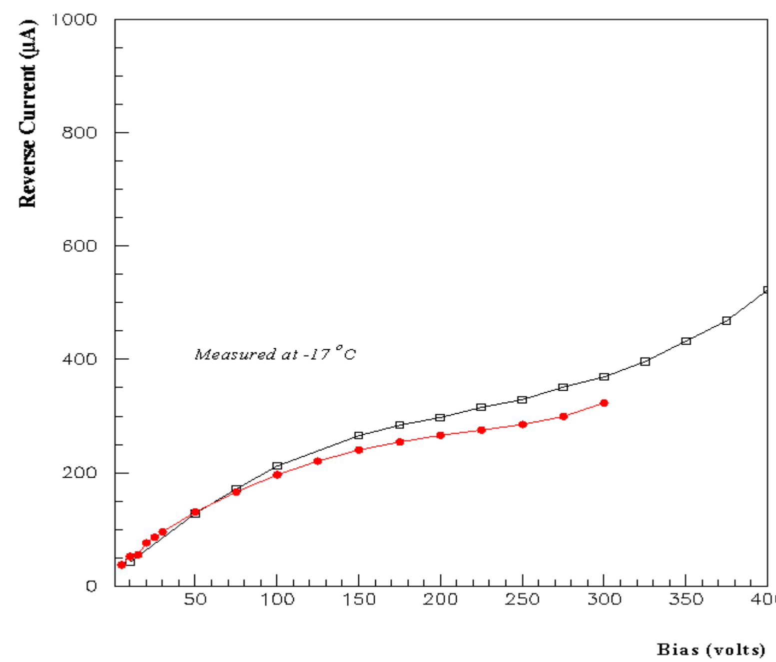


First results with p-type substrate microstrip detectors

Pre-irradiation I-V (Vfd = 65 volts)

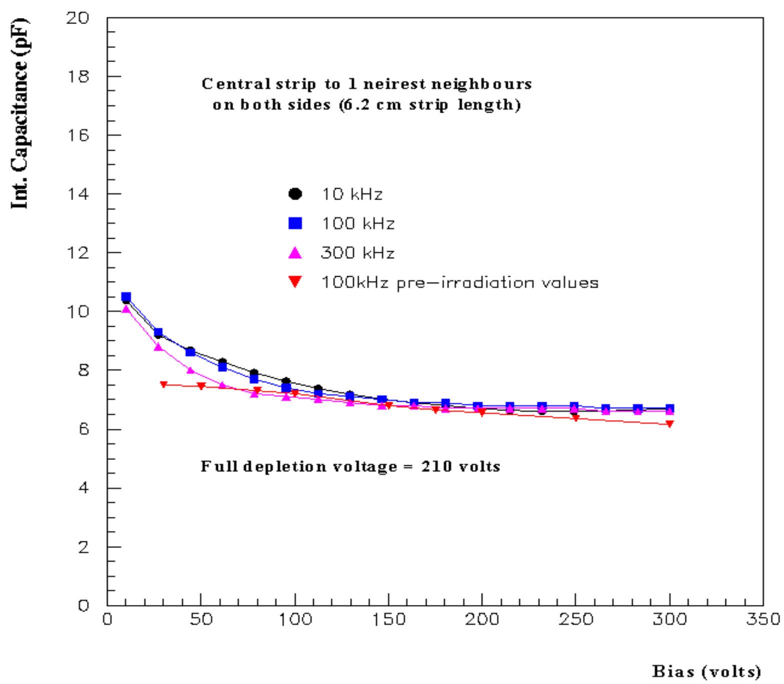


I-V after 3 10^{14} p cm^{-2} (Vfd = 210 volts)

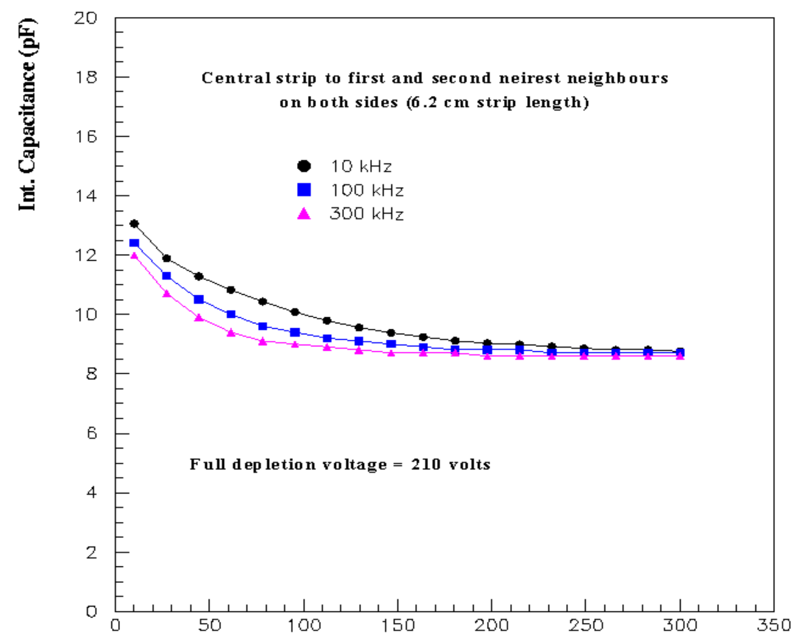


Interstrip capacitance before and after irradiation

Capacitance of central strip to first neighbours each side. The values after irradiation are similar to the pre-irradiation value.



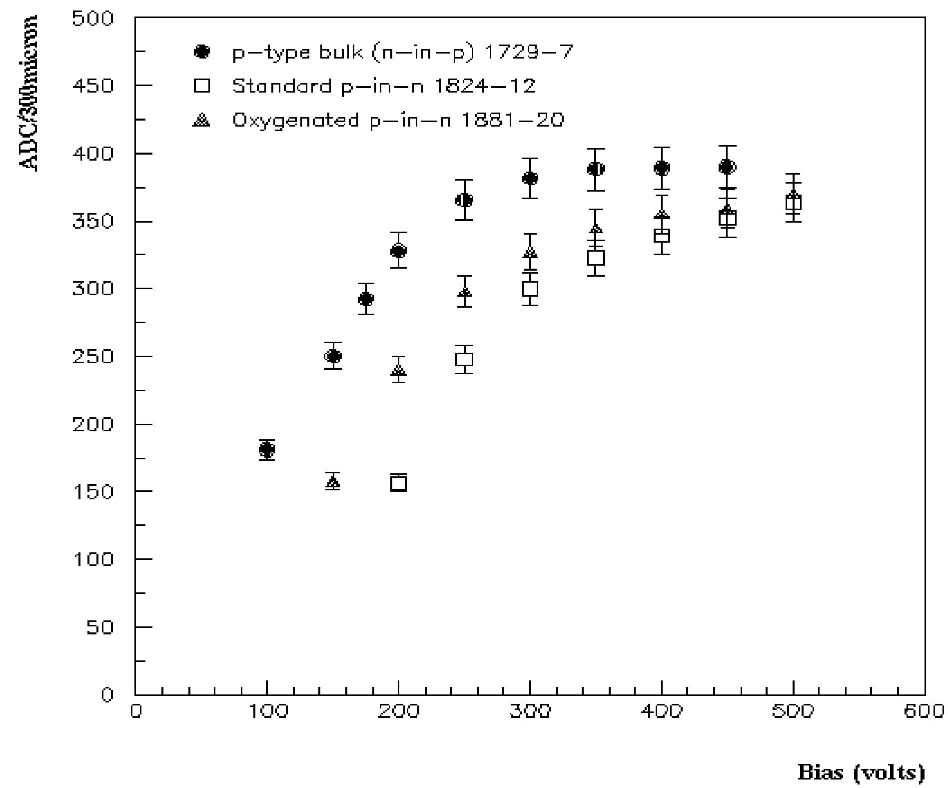
Capacitance of central strip to two first neighbours each side in a p-type detector after $3 \cdot 10^{14}$ protons cm^{-2}.



Discussion and Conclusions

Detectors produced with n-side read-out do suffer from the disadvantage of requiring potentially expensive double-sided processing

Use of p-type substrates does provide a viable alternative where cost is of paramount importance



Comparison of p-type and n-type detectors after 3×10^{14} p/cm^2