Preliminary results from a partially irradiated LHCb r detector.

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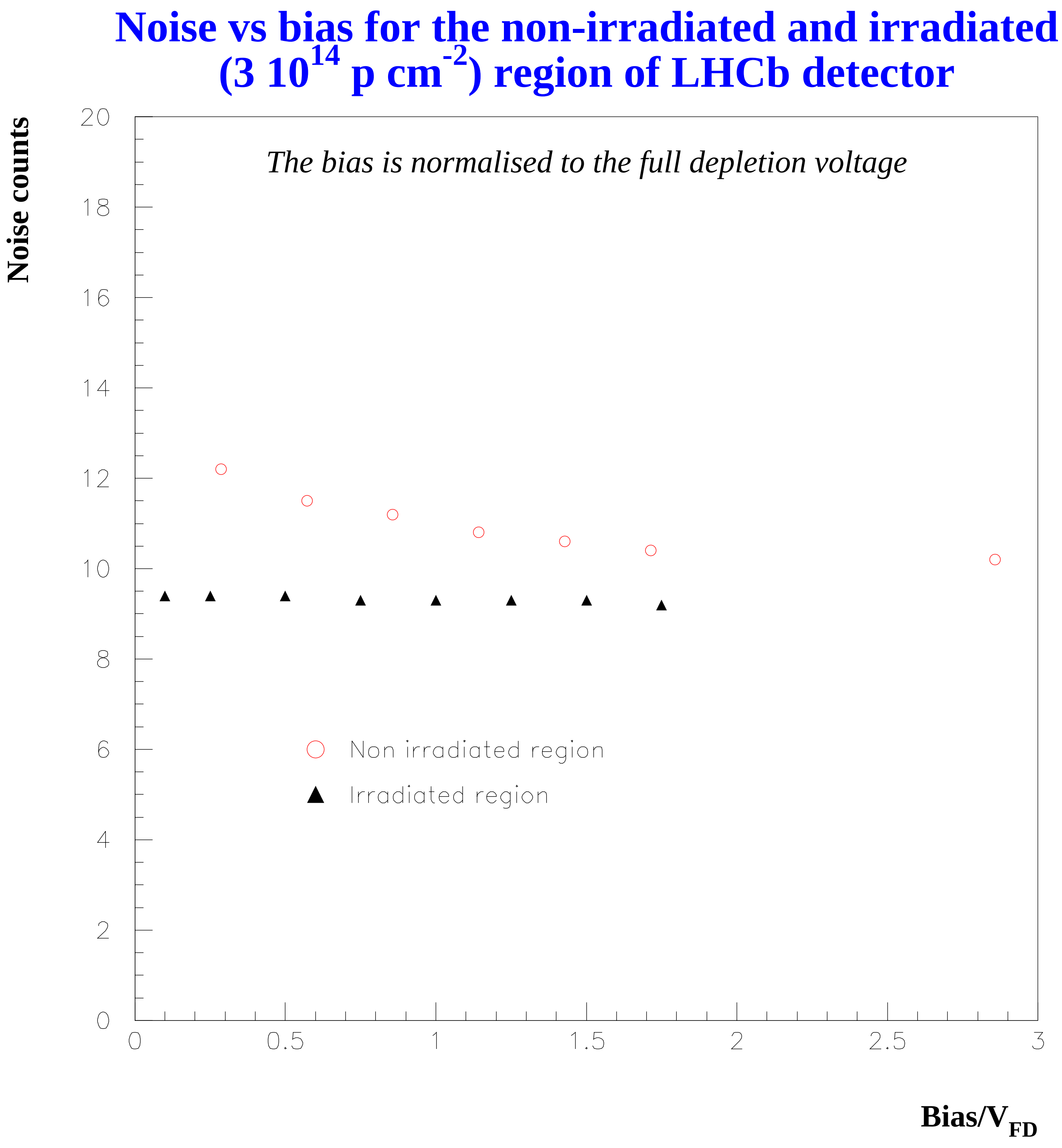
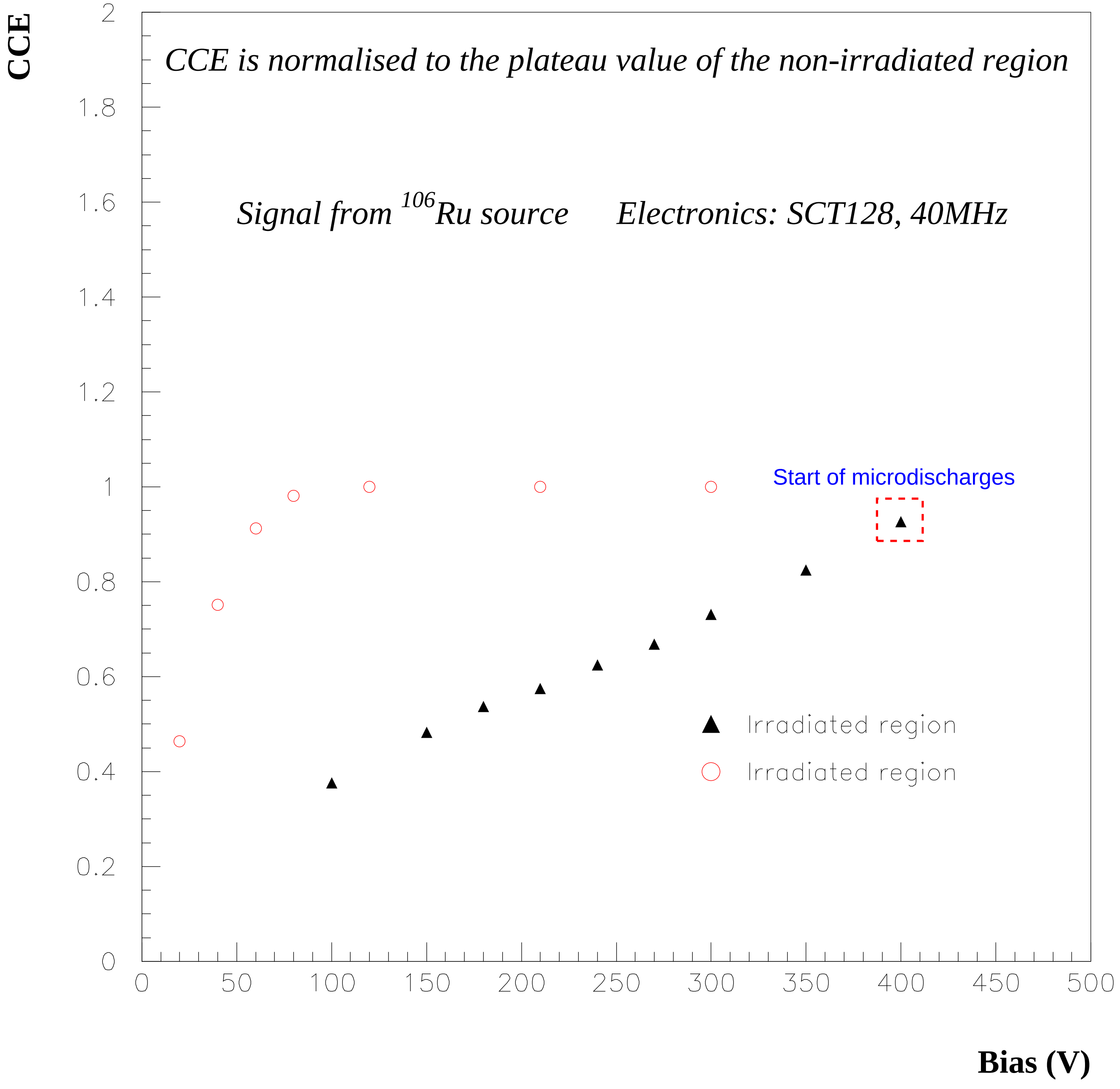
OUTLINE:

- Results in term of noise
- Results in term of charge collection efficiency (CCE)
- Discussion of possible benefit from oxygenated devices:
  - Oxygenation technique of silicon wafers by High Temperature Diffusion from a SiO_2 layer
  - Results of N_{eff} (V_{FD}) vs fluence for control and oxygenated diodes.
  - Results in term of CCE for control and oxygenated diodes.



Noise vs bias for the non-irradiated and irradiated ($3\ 10^{14}$ p cm^{-2}) region of LHCb detector

Charge collection efficiency for the non-irradiated and irradiated ($3\ 10^{14}$ p cm^{-2}) region of LHCb detector



Cluster size for partially irradiated LHCb r-detector

Non-irradiated region			
Bias [V]	**1 strip clusters [%]**	**2 strips clusters [%]**	**3 strips clusters [%]**
40	68	30	2
60	65	33	2
80	66	33	1
120	64	34	2
210	64	34	2
300	66	32	2

Irradiated ($3\cdot10^{14}$ p cm^{-2}) region			
Bias [V]	**1 strip clusters [%]**	**2 strips clusters [%]**	**3 strips clusters [%]**
180	71	28	1
210	66	33	1
240	61	38	1
270	58	40	2
300	56	42	2
350	51	46	3

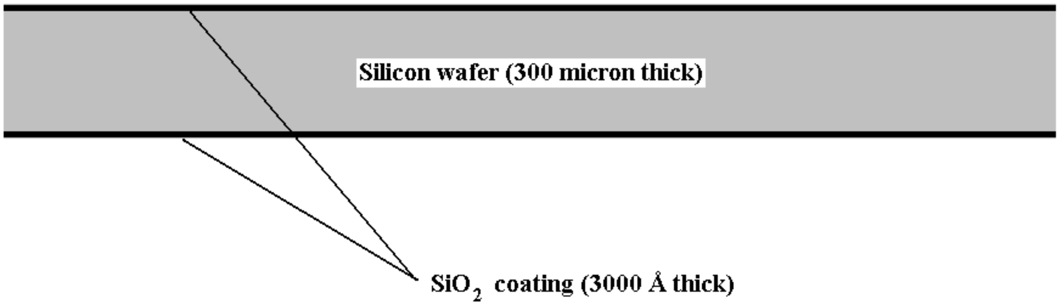
Oxygenation technique of silicon wafers by High Temperature Diffusion from a SiO_2 surface layer.

The isotropic diffusion process is described in term of diffusion coefficient *D*, as defined by the first Fick's law: $\bar{j} = -D\nabla N$

where *N* is the impurity concentration. The silicon devices are plane and parallel structures, therefore the analysis can be limited to the simple one dimensional case. $\frac{\partial N}{\partial T} = D\frac{\partial^2 N}{\partial x^2}$

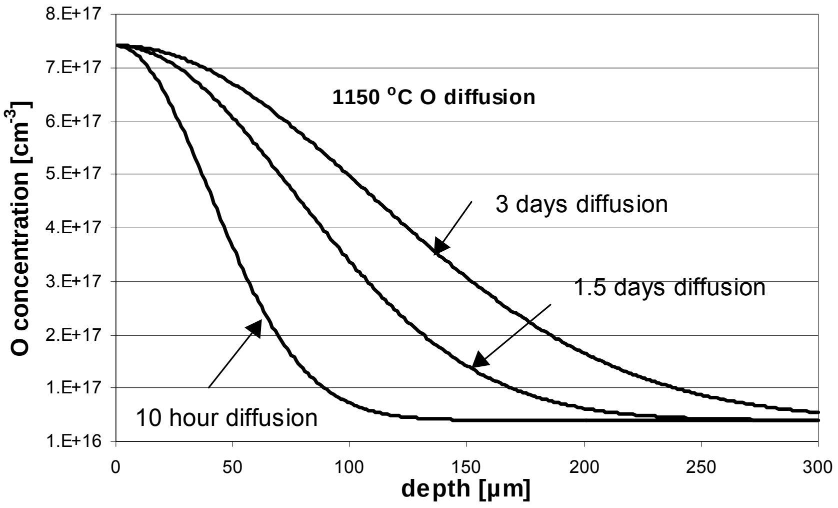
Solution in the case of diffusion from a surface layer of Oxygen acting as an infinite source: $N(x,t) = \frac{N_0}{2}\left[erfc\left(\frac{x-h}{2\sqrt{Dt}} \right) - erfc\left(\frac{x+h}{2\sqrt{Dt}} \right) \right]$.

where *h* is the depth of the initial impurity distribution.



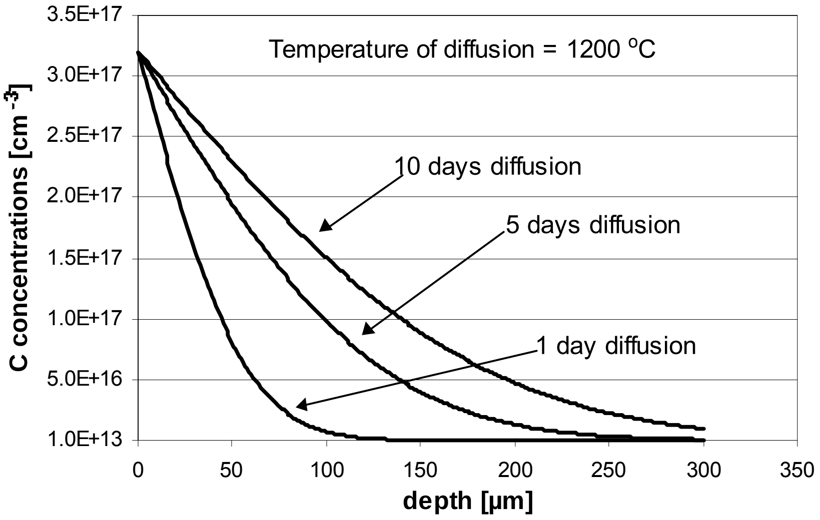
Diffusion atmosphere: N_2 or O_2 (no advantages using O_2)

Calculated oxygen diffusion profile @ 1150 ^{o}C using the diffusion coefficient: $2.25 \cdot 10^{-10}$ cm^{2} s^{-1} (obtained from fit on SIMS profile, Ref. G. Casse, 1998).



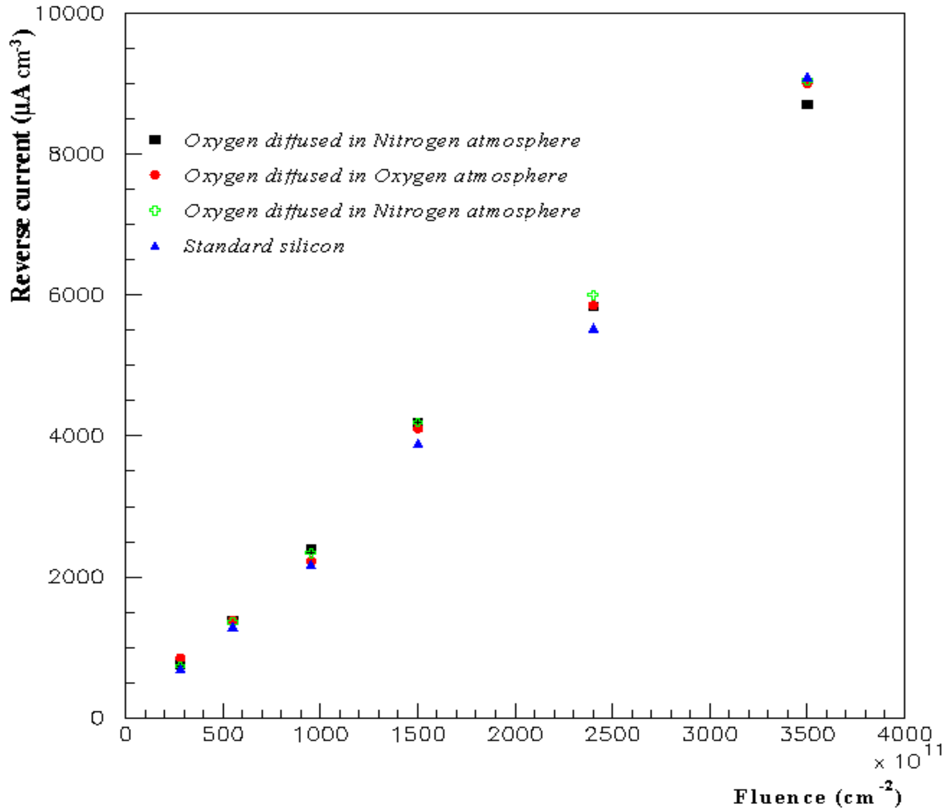
CARBON diffusion

Carbon is in competition with oxygen in term of beneficial effects on radiation hardness of silicon detectors.
The diffusion of carbon is ~ 10 times slower than oxygen (carbon diffusion coefficient is $3.38 \cdot 10^{-11}$ cm^2 s^{-1} (from Properties of silicon, INSPEC, The Institution of electrical Engineers, London and New York, 1998. The same source compiles oxygen diffusion coefficients ranging from $1.60 \cdot 10^{-10}$ to $5.60 \cdot 10^{-10}$ cm^2 s^{-1})



Leakage current versus fluence for oxygenated and un-oxygenated silicon diodes.

The increase of the leakage current is a linear function of the fluence. The current is proportional to the concentration of radiation induced defects. The reverse volume current is measured using irradiated diodes biased above full depletion. Silicon materials with different (deliberately introduced) impurity concentrations do not show differences in the slope of the volume current with fluence. In the LHC experiments, these high currents will be reduced by cooling the detectors.



Normalised to 20 °C

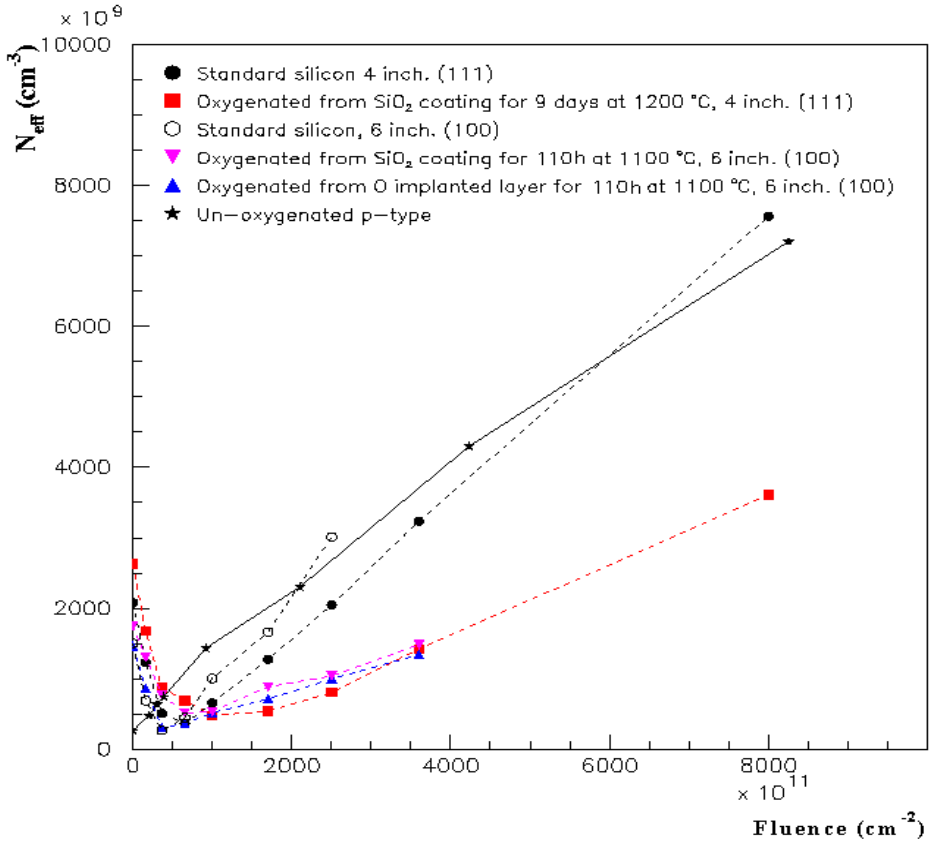
The introduction of high oxygen concentrations in the silicon bulk does not affect the increase of the leakage current with fluence

The effective doping concentration (N_{eff}) versus fluence for oxygenated and un-oxygenated silicon diodes.

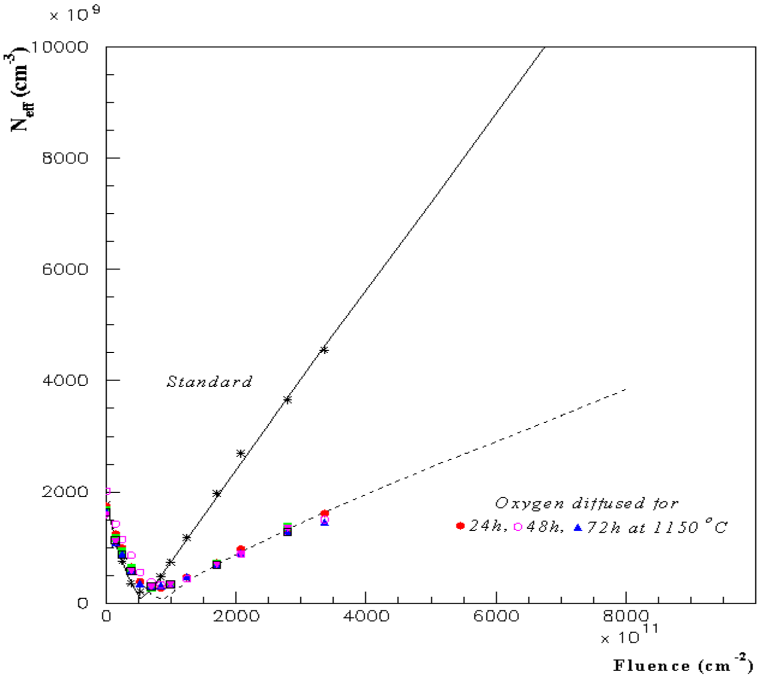
p-in-n detectors must be operated above full depletion to allow good signal/noise ratio. The full depletion voltage of silicon detectors is proportional to the effective doping concentration, which becomes more p-type as a consequence of the hadron irradiation. After heavy doses, N_{eff} is dominated by the concentration of the radiation induced p-type defects.

A high oxygen concentration (>10^{17} cm^{-3}) in the silicon bulk reduces the effective introduction rate of acceptor-like defects and therefore the required detector bias after high doses.

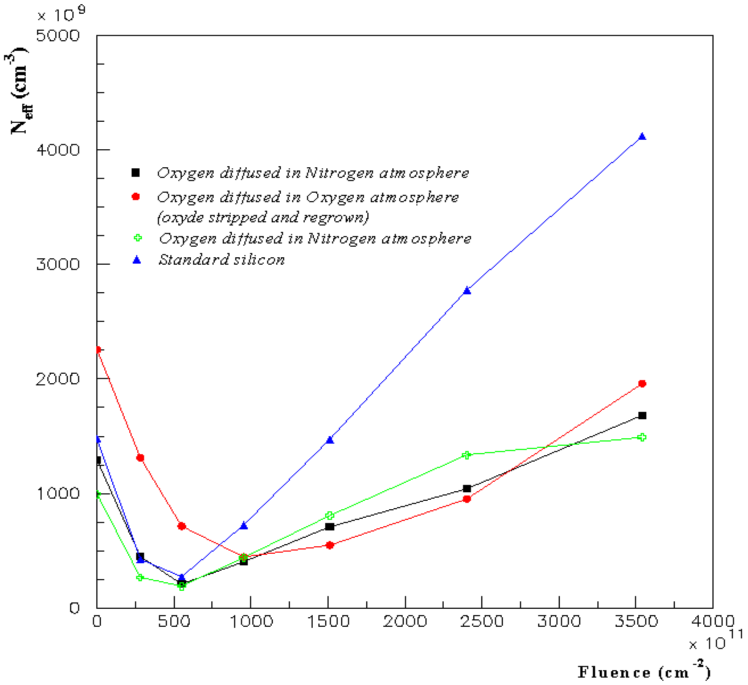
In all the following figures the diodes have been annealed at 80 °C for 4 minutes to just complete the beneficial annealing phase.



At high doses, N_{eff} is similar for un-oxygenated p-type or n-type starting materials, being dominated by the radiation induced defects. The oxygenated n-type silicon diodes show a substantially lower N_{eff} after high doses.

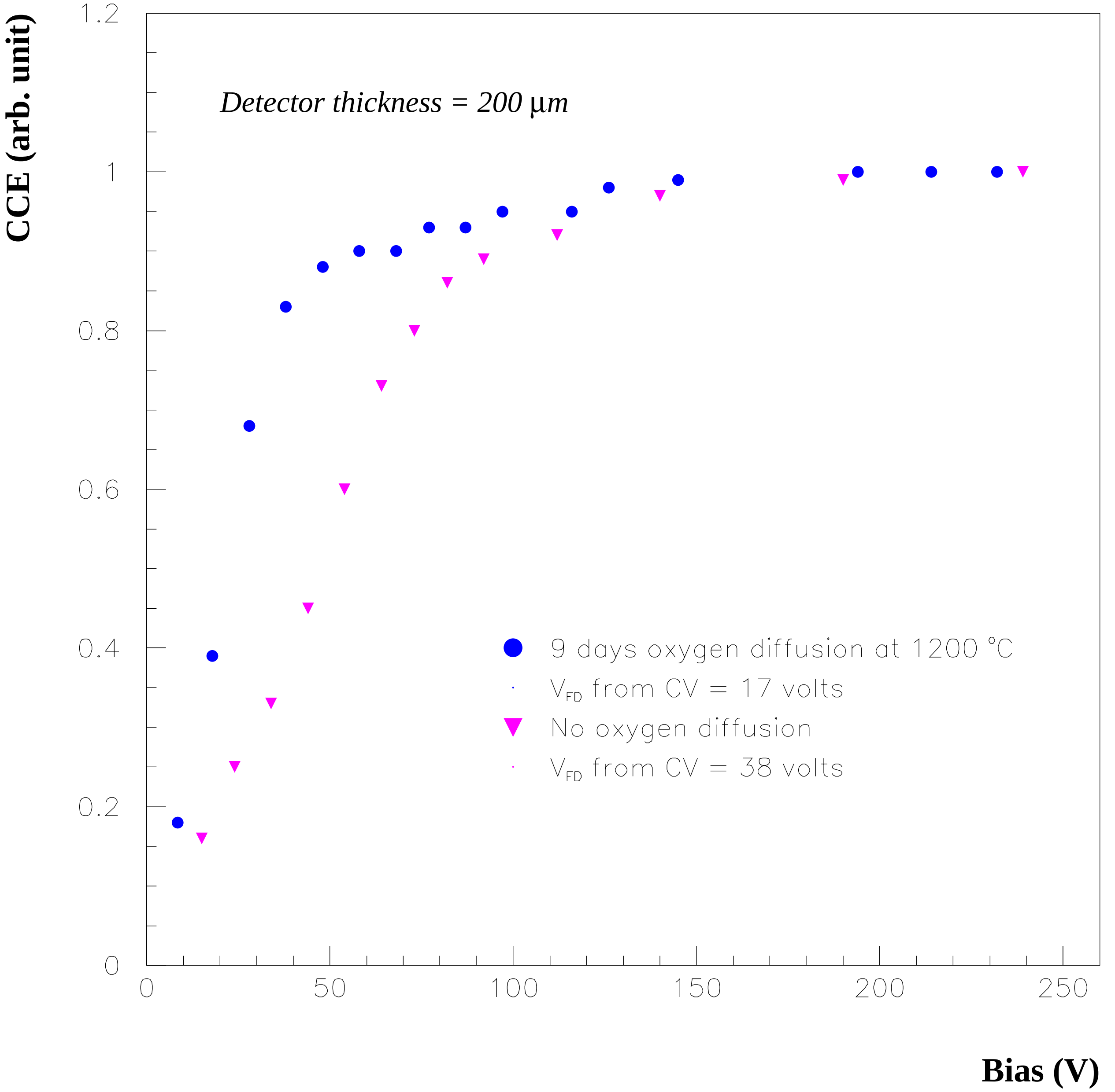


Diodes produced with silicon wafers submitted to high temperature oxygen diffusion for different times show very similar behaviours. They are here compared with diodes made from an un-oxygenated silicon wafer from the same ingot.



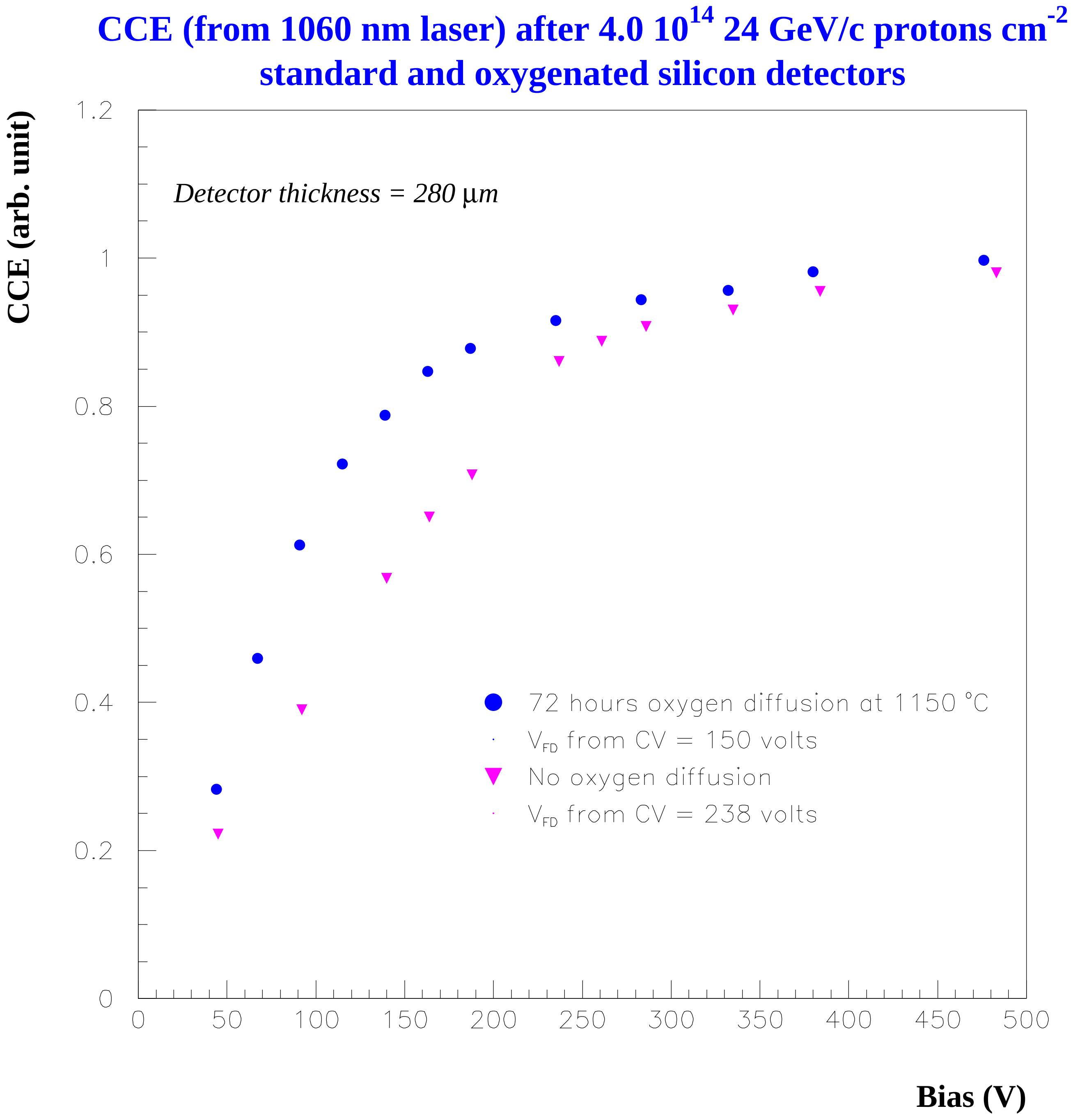
N_{eff} as a function of fluence for un-oxygenated and oxygenated n-type diodes with oxygen diffusion in different atmospheres.

BNL diodes. CCE normalised to the value @ 250 V.

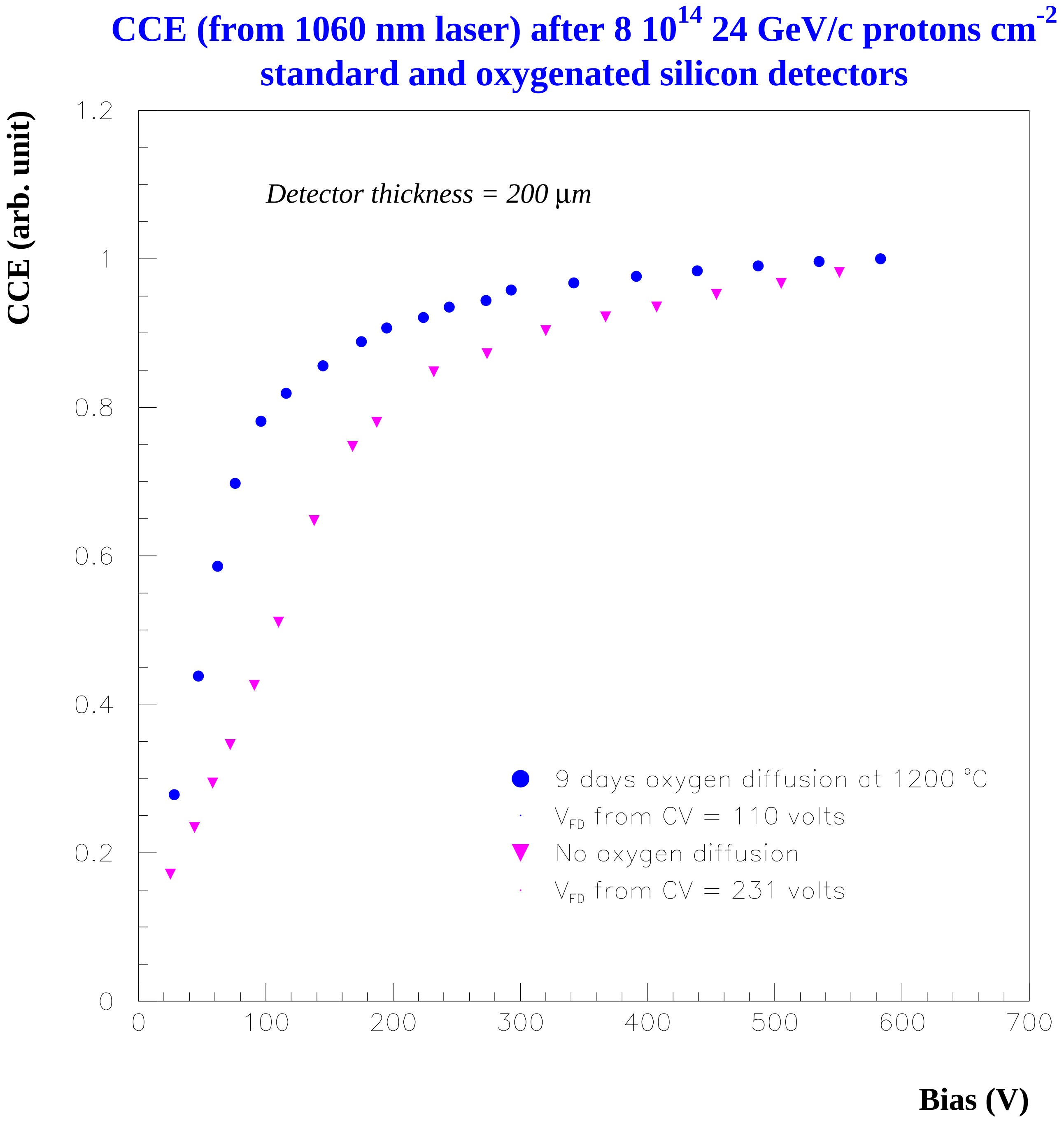


CCE (from 1060 nm laser) after 1.7 10^{14} 24 GeV/c protons cm^{-2}
standard and oxygenated silicon detectors

ITME diodes. CCE normalised to the value @ 500V.


CCE (from 1060 nm laser) after 4.0 10^{14} 24 GeV/c protons cm^{-2}
standard and oxygenated silicon detectors

BNL diodes. CCE normalised to the value @ 600 V



Bias voltage required to collect given fraction of the maximum charge for various doses of 24 GeV/c protons.

<table>
<tr><th colspan="4">Diodes (200 µm thick) irradiated to $1.7\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 36</td><td>~ 70</td><td>250</td></tr>
<tr><td>Control</td><td>~ 55</td><td>~ 105</td><td>250</td></tr>
<tr><th colspan="4">Diodes (280 µm thick) irradiated to $4\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 140</td><td>~ 210</td><td>500</td></tr>
<tr><td>Control</td><td>~ 220</td><td>~ 270</td><td>500</td></tr>
<tr><th colspan="4">Diodes (200 µm thick) irradiated to $8\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 105</td><td>~ 200</td><td>500</td></tr>
<tr><td>Control</td><td>~ 210</td><td>~ 315</td><td>500</td></tr>
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<tr><th colspan="4">Estimation for 300 µm equivalent diodes irradiated to $1.7\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 81</td><td>~ 124</td><td>560</td></tr>
<tr><td>Control</td><td>~ 180</td><td>~ 236</td><td>560</td></tr>
<tr><th colspan="4">Estimation for 300 µm equivalent diodes irradiated to $4\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 160</td><td>~ 252</td><td>575</td></tr>
<tr><td>Control</td><td>~ 241</td><td>~ 362</td><td>575</td></tr>
<tr><th colspan="4">Estimation for 300 µm equivalent diodes irradiated to $8\cdot10^{14}$ protons cm^{-2}.</th></tr>
<tr><th>Bias to collect a given fraction of the charge</th><th>80% [V]</th><th>90% [V]</th><th>Norm. voltage [V]</th></tr>
<tr><td>Oxy.</td><td>~ 236</td><td>~ 450</td><td>1120</td></tr>
<tr><td>Control</td><td>~ 405</td><td>~ 531</td><td>1120</td></tr>
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