Radiation Tolerance of Oxygenated n-strip Read-out Silicon Detectors

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1st RD50 Workshop, 2-4 Oct. 2002

Introduction

- 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 effective doping changes have shown reduced susceptibility to charged hadron irradiation when high concentrations of interstitial oxygen are introduced (RD48)
- However, the other effects, in particular the trapping, do not seem to show corresponding improvements in radiation tolerance

Introduction

- Effective doping concentration, N_{eff} , for a diode of thickness, w , is derived from the voltage needed to fully deplete the diode, V_{fd} (>> V_{bi}), through the equation:

$$V_{fd} = \tfrac{1}{2}\, e\, w^{2}\, N_{eff} / \varepsilon_{Si}$$

- Since $C \propto 1/w$, $V \propto 1/C^2$ for $V << V_{fd}$ allowing N_{eff} to be extracted from $C(V)$

- Because of the effects of trapping, the charge collection efficiency (CCE) as a function of voltage does not saturate at V_{fd} and for segmented detectors read out from the p-side, CCE(V) continues to rise, well above V_{fd}

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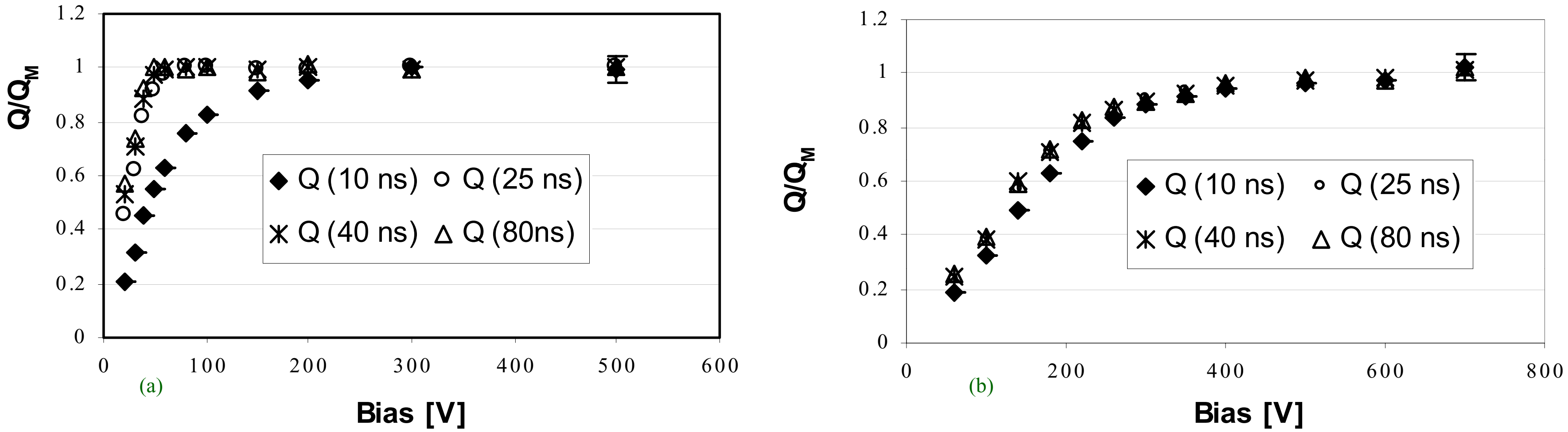
Evaluation of Trapping Effects

- **Corresponding Charge Collection Efficiency vs Voltage**



Normalised (to Q_M) charge collection for (a) non-irradiated and (b) oxygen-enriched detector after **$5.1\cdot10^{14}$ p cm^{-2}**

Evaluation of Trapping Effects

- **The effects of trapping can be parameterised 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 parameterisations assume timescales such that the total untrapped charge is collected, integrating over transient effects.**
- **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)**

  $(\beta_{e,h} \sim 5 \times 10^{-16}\ \mathrm{cm}^2/\mathrm{ns})$

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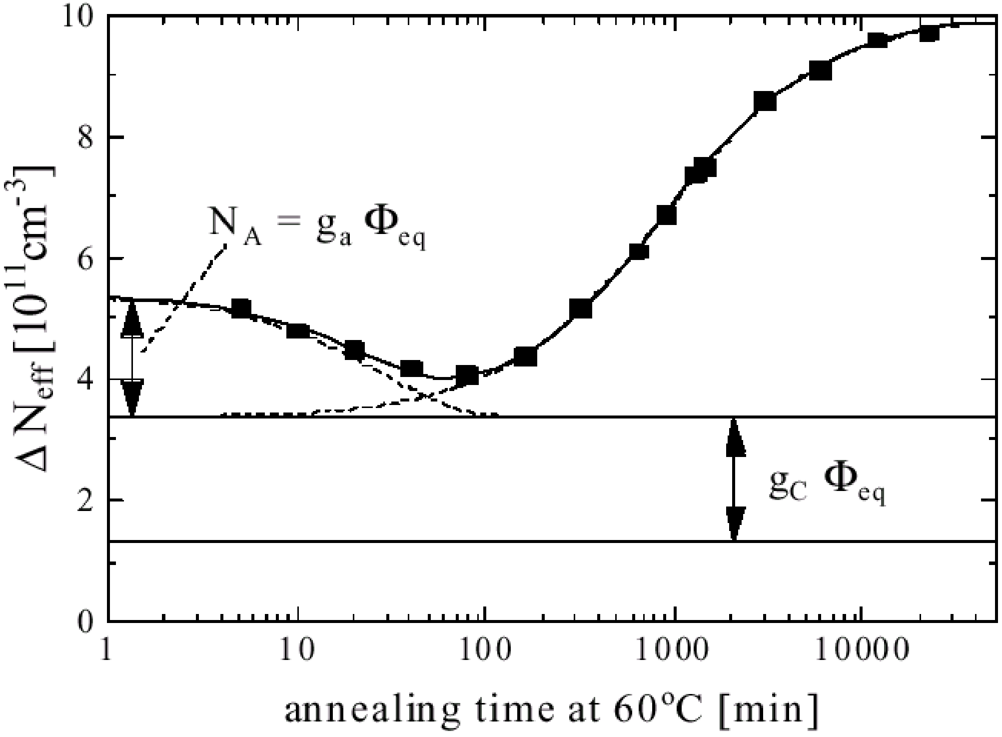
Annealing of Irradiated Detectors

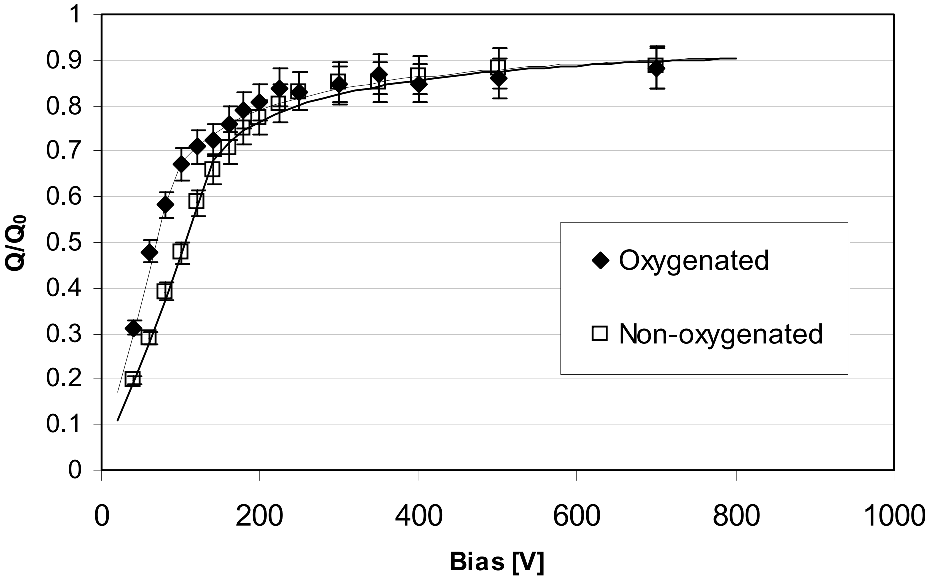
- Oxygenated and non-oxygenated detectors with both p-side and n-side read-out have been studied

- These have been irradiated in the CERN-PS and annealed to the minimum of the N_{eff} vs time annealing curve



Charge Collection Efficiency Studies

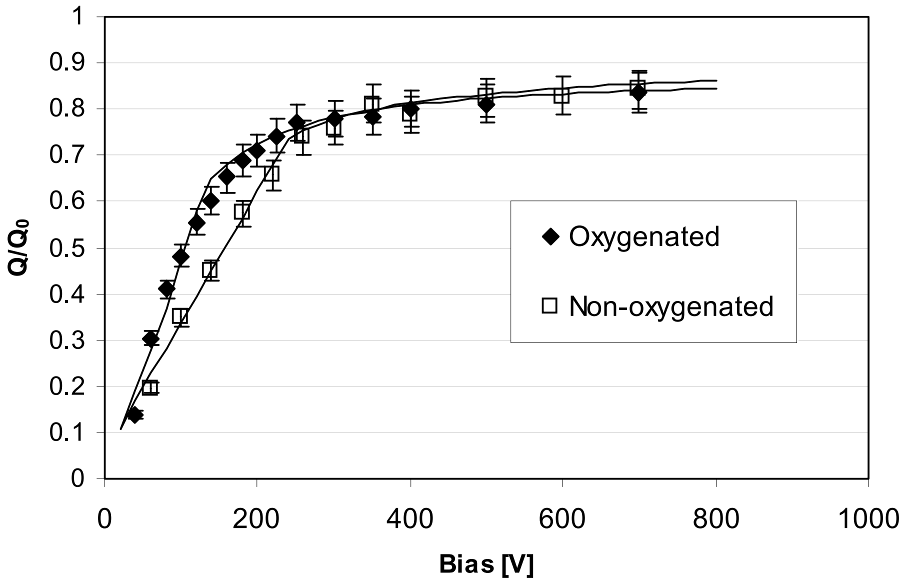
- We have previously reported excellent fits to the CCE(V) for irradiated detectors based on the parameterisation of Marti i Garcia *et al* using attenuation length $\propto v_{\text{drift}}$ up to $v_{\text{saturation}}$



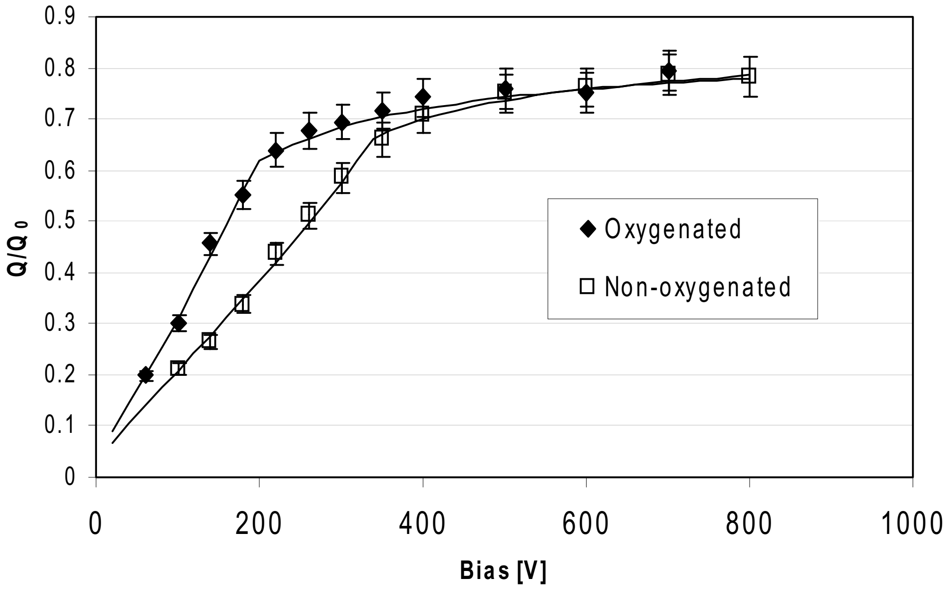
1.9×10^{14} p/cm^2

- Free parameters:
  - attenuation length λ,
  - depletion voltage V_{FD}
  - total generated charge Q_0

Charge Collection Efficiency Studies



2.9×10^{14} p/cm^2



5.1×10^{14} p/cm^2

Charge Collection Efficiency Studies

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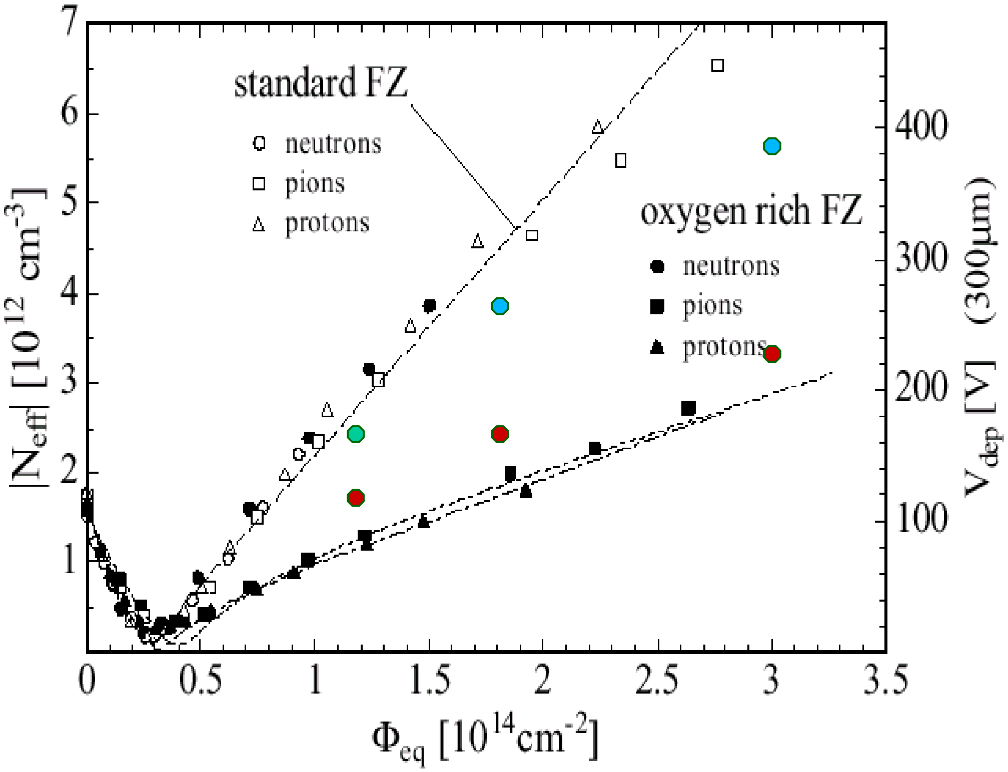
Detector label	Fluence [p cm^{-2}]	Oxygen enrichment	V_{FD} [V] (From C-V)	V_{FD} [V] (From CCE)	λ [μm]
NI	Non irr.	No	49 ± 2	50 ± 2	
SO1	1.9±0.1 · 10^{14}	Yes	100 ± 7	90 ± 2	1338 ± 15
SN1	1.9±0.1 · 10^{14}	No	150 ± 8	137 ± 2	1407 ± 220
SO2	2.9±0.2 · 10^{14}	Yes	121 ± 7	130 ± 2	1224 ± 138
SN2	2.9±0.2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

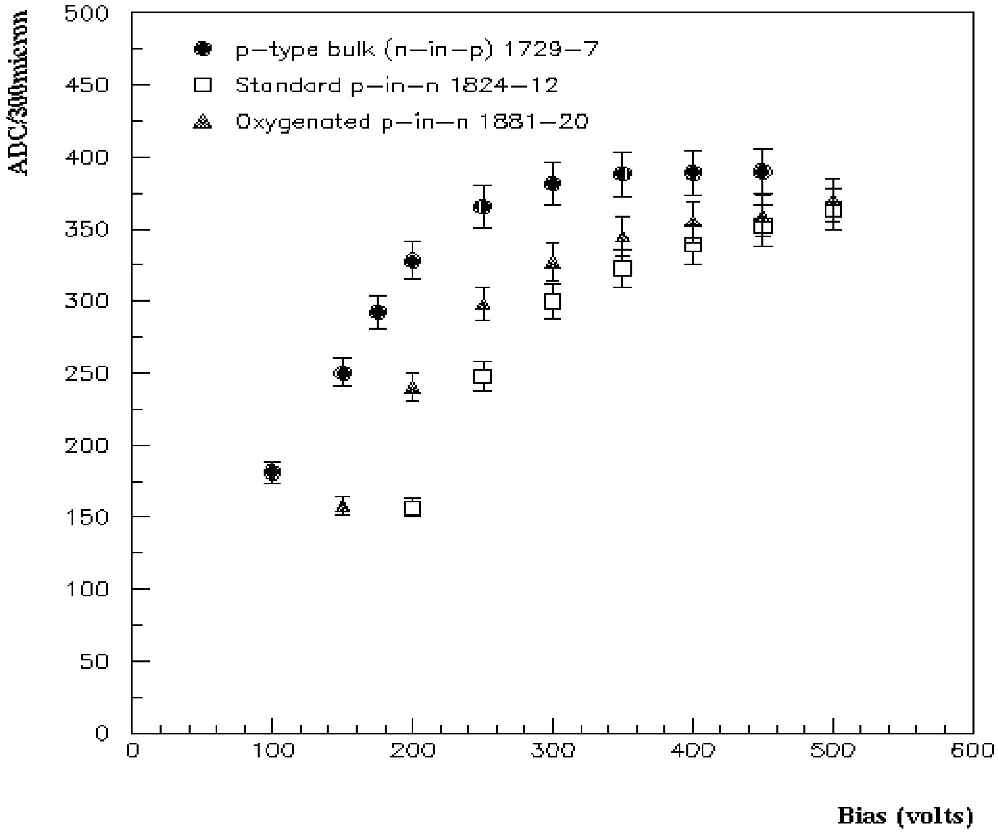
Charge Collection Efficiency Studies

- **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 17.9±0.3**



Charge Collection Efficiency Studies

- **Because high resistivity n-type bulk detectors become effectively p-type after heavy hadron irradiation, read-out using segmentation of the n-implants allows charge to be collected on the high field side, giving higher CCE at lower *V*.**

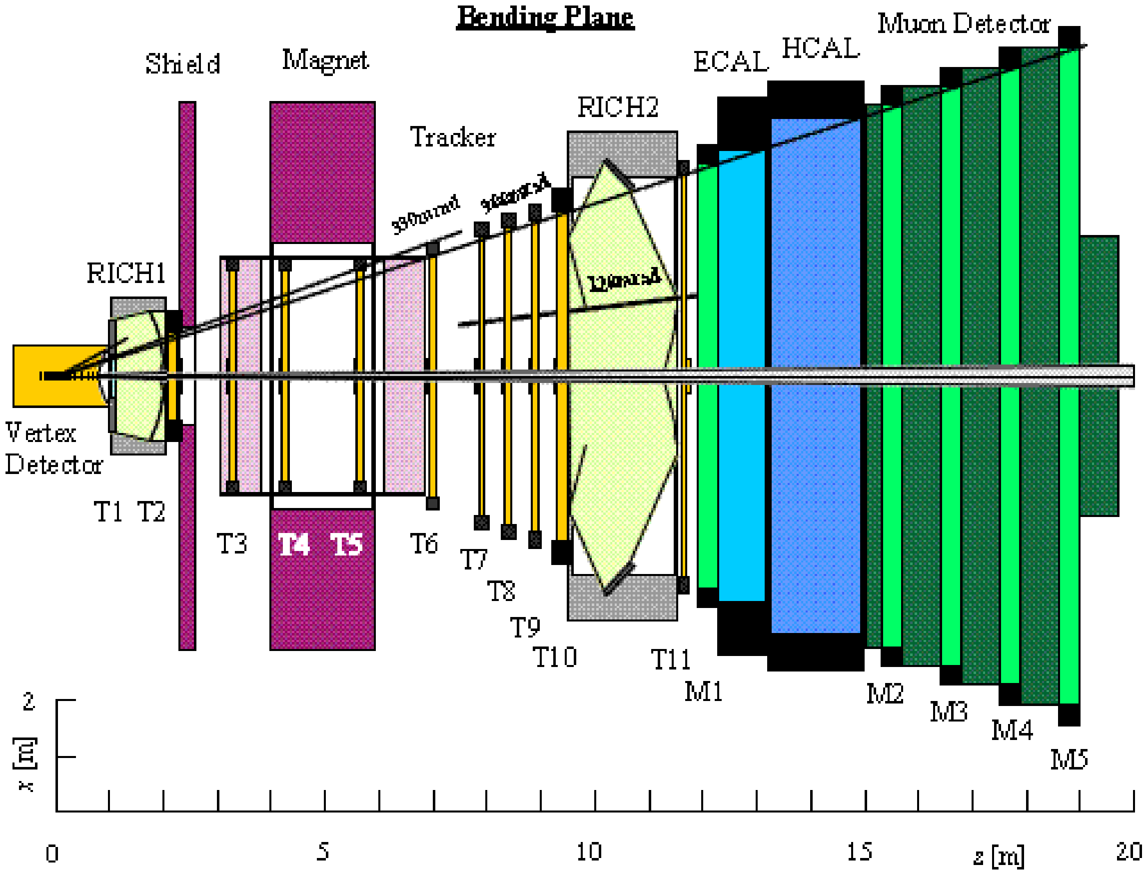


Comparison of p-type and n-type detectors using ^{106}Ru β-source after 3×10^{14} p/cm^2 (SCT-128A read-out)

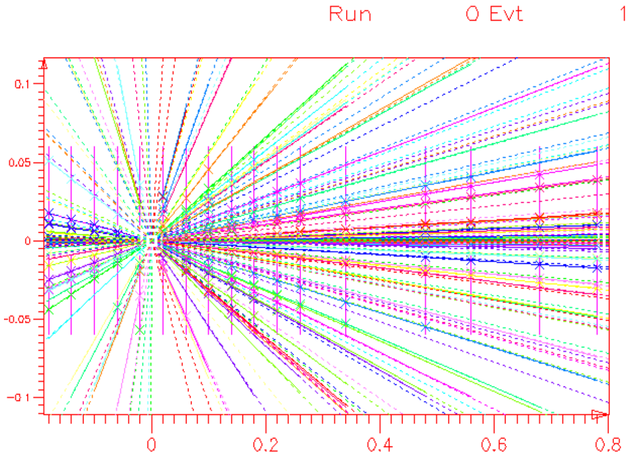
Detectors for the LHC-b Experiment

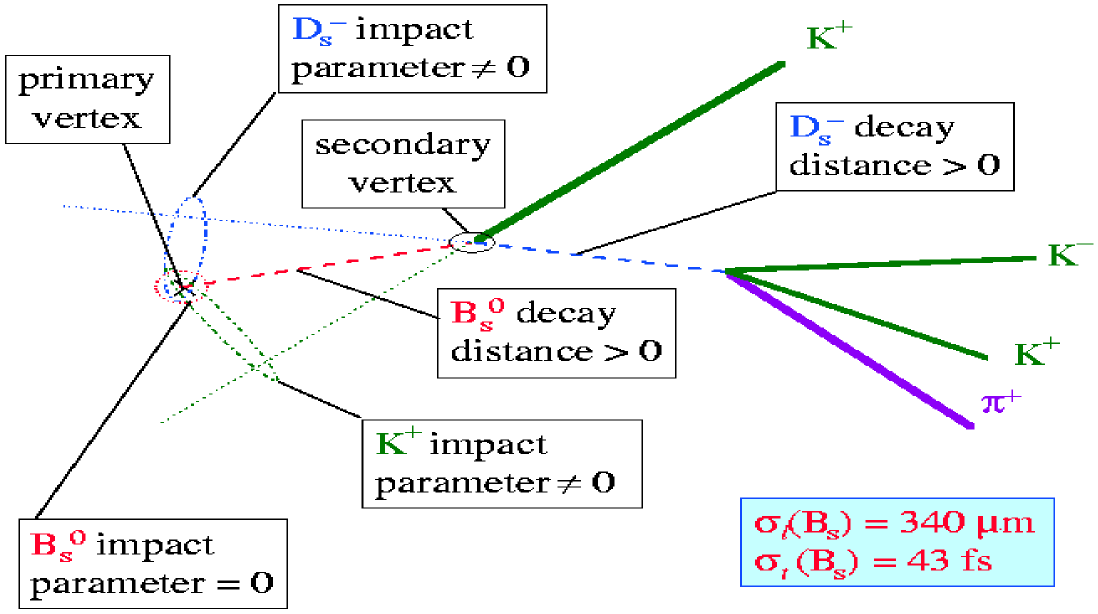
- The **LHC-b** vertex locator **VeLo** uses oxygenated 200µm thick detectors.

- Prototypes have been fabricated using both p-strip and n-strip read-out and irradiated at the CERN PS.



Detectors for the LHC-b Experiment





primary vertex

D_s^- impact parameter $\neq 0$

secondary vertex

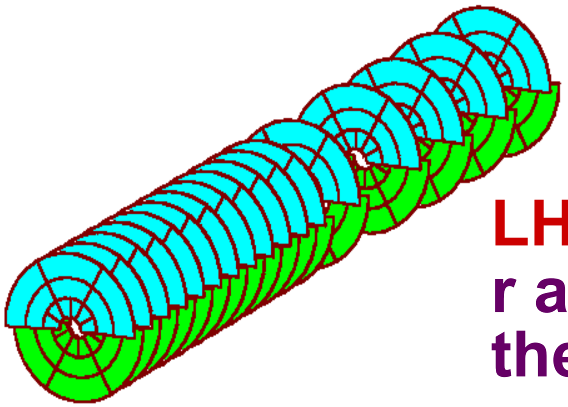
D_s^- decay distance > 0

B_s^0 decay distance > 0

K^+ impact parameter $\neq 0$

B_s^0 impact parameter $= 0$

$\sigma_l(B_s) = 340\ \mu m$
$\sigma_t(B_s) = 43$ fs



LHC-b uses back-to-back half disks for r and φ plus double-metal routing to the electronics mounted at the rim

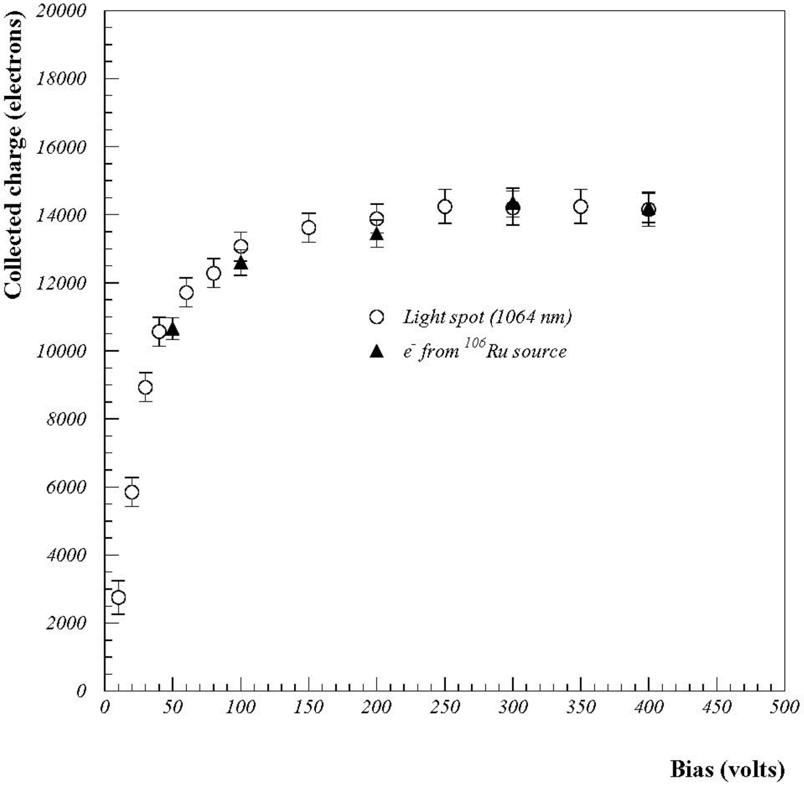
Detectors for the LHC-b Experiment

- LHC-b and the pixel systems of ATLAS and CMS need to maximise their survival, given expected maximum doses approaching 10^{15} p/cm^2 and 10s of Mrad.

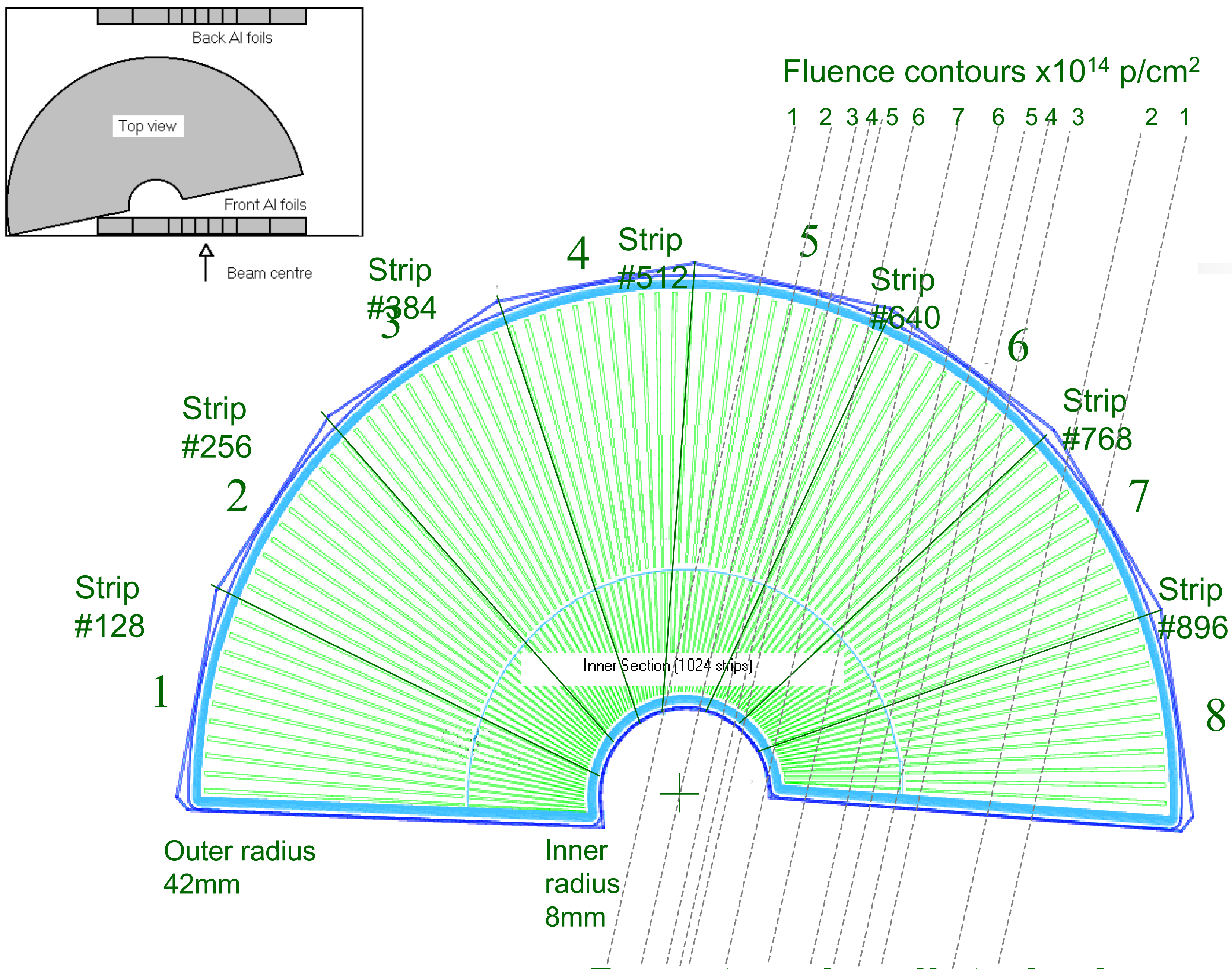
- Super-LHC is proposed with a factor of 10 increased luminosity.

Detectors Studied

- Studies have been carried out with full-sized LHC-b prototypes using SCT-128 analogue read-out and miniature (cm×cm) micro-strip detectors using SCT-128 or wide bandwidth (Phillips 6954) current amplifier.
- CCE(*V*) has been studied using a ^{106}Ru β-source and a 1064nm light spot (where the latter is tuned to give an energy deposit about 3 times that of a minimum ionising particle)
- All give comparable results.



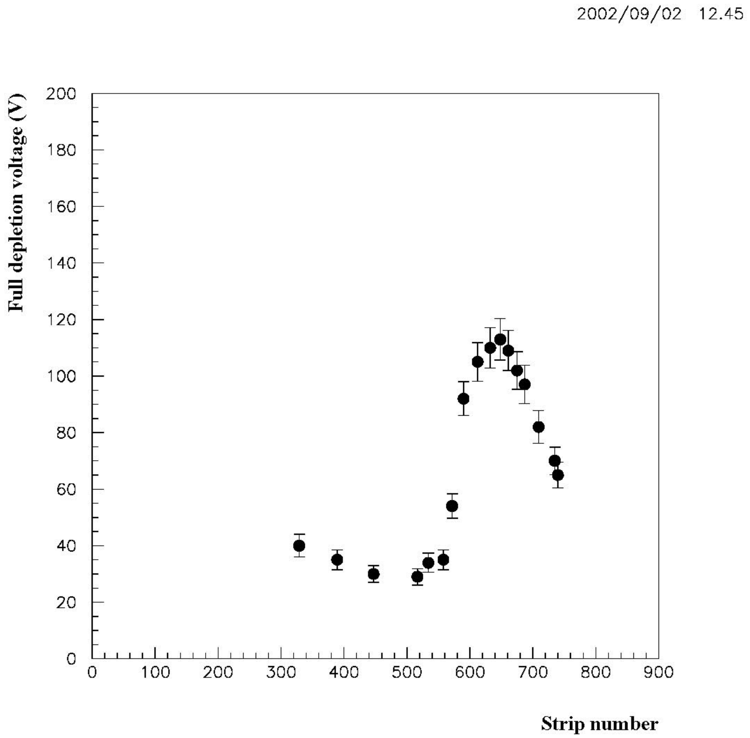
CCE(*V*) for irradiated, 200μm thick, LHC-b n-in-n full-size prototype detector with laser data (normalised to value at 400V) superimposed



Detectors irradiated edge-on

LHC-b Prototype CCE(*V*) Results

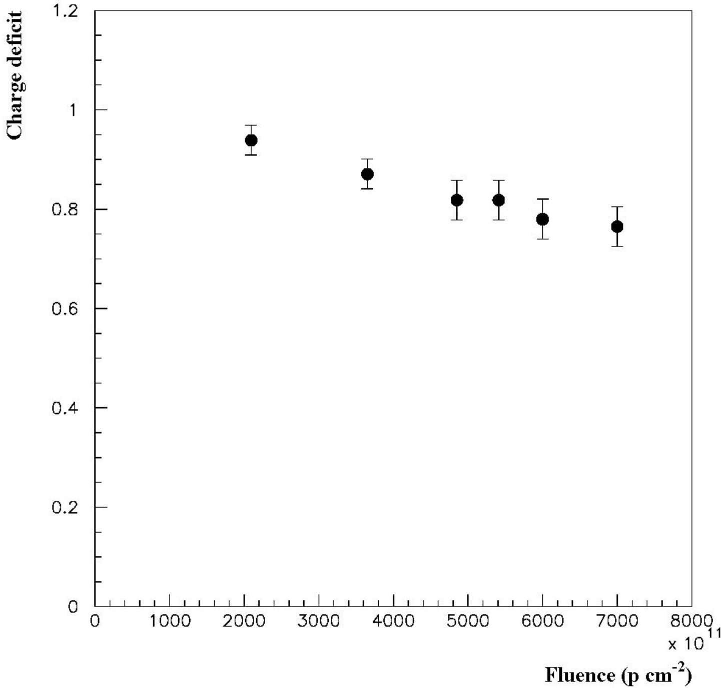
- From fits to the CCE(*V*), the depletion voltages for the different regions of the detector can be extracted.
- These detectors were processed by Micron Semiconductor Ltd to Liverpool designs on oxygenated (> 10^{17} cm^{-3}) FZ 200μm thick 6” wafers.
- Given the thickness, the depletion voltages agree well with previous proton irradiation measurements, corroborating the dose estimates.



CCE(*V*) extracted depletion voltages vs strip number for non-uniformly irradiated n-strip LHC-b ‘φ-detector’

LHC-b Prototype CCE(*V*) Results

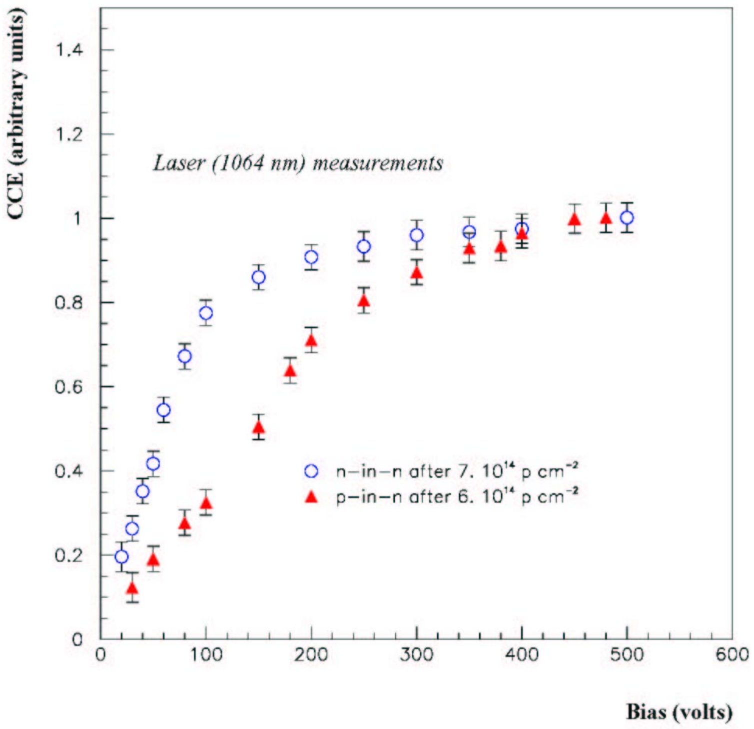
- The CCE(*V*) values at high voltage for n-side read-out with respect to the non-irradiated value show limited signal loss even after 7.10^{14}p/cm^2.
- The tracking parts of ATLAS and CMS are designed for an integrated dose after 10 years equivalent to 3.10^{14}p/cm^2 although their pixel vertex detectors and the LHC-b VeLo have to survive much more.
- Should Super-LHC go ahead, the ATLAS and CMS trackers will need to be affordably upgraded



^{106}Ru β-source CCE at high voltage *vs* dose for the LHC-b n-in-n prototype

n-side vs p-side read-out

- **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.**
- **However, for segmented detectors as designed for experiments, the key issue is the operating voltage for a given CCE after heavy irradiation.**
- **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.**



1060nm laser CCE(*V*) for the highest dose regions of an n-in-n (7.10^{14}p/cm^2) and p-in-n (6.10^{14}p/cm^2) irradiated LHC-b full-size prototype detector.

Conclusions

- Operationally, for position resolution and tracking efficiency the key parameter is the signal/noise.
- After irradiation, at the LHC, although other effects may raise the noise, the key deterioration as a position sensitive detector is in terms of the collected charge.
- 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.