Impact of radiation damage on performances of finely segmented Si detector for tracking applications

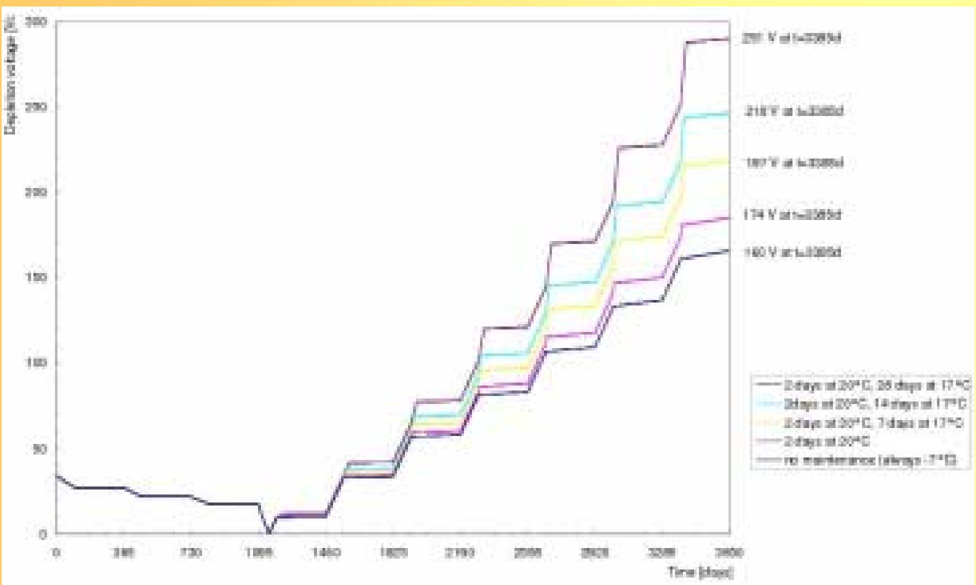
G. Casse – University of Liverpool

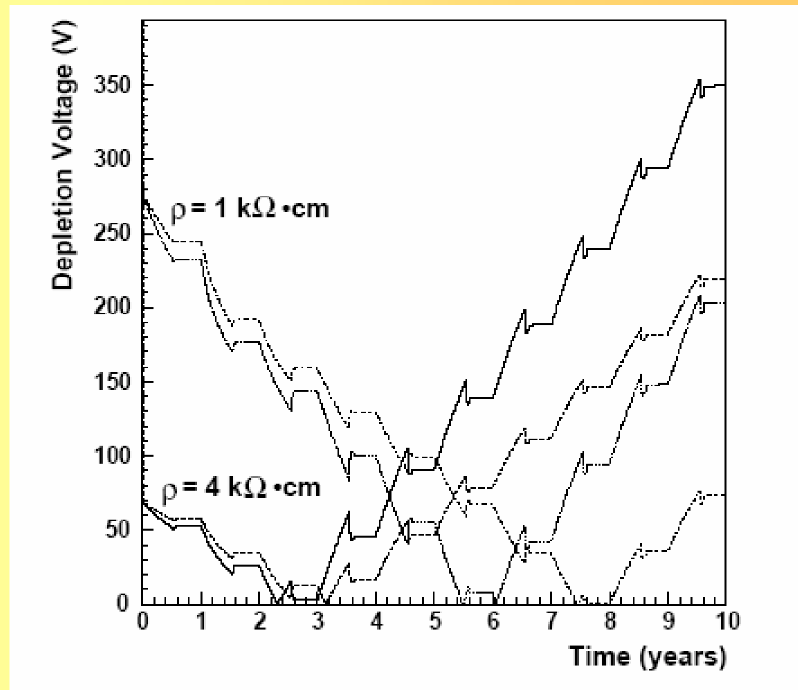
OUTLINE

- **Mechanism of radiation damage**
- **Full depletion voltage (V_{FD}) vs Charge Collection Efficiency (CCE)**
- **Optimisation of the CCE**
- **Radiation damage and resolution:**
  - **Effect of in-homogeneous irradiation**
  - **Effect on charge sharing of angled track**
- **Summary**

The failure mode for the tracking silicon detectors is usually computed by guessing the required voltage to achieve a sufficient S/N. For the LHC detectors (mainly p-in-n devices for the ATLAS and CMS SiTrackers), this estimate has been performed by using the concept of full depletion (V_{FD}). V_{FD} + some overdepletion (50%) is considered adequate for detector operation. When this value matches the maximum bias voltage allowed by the system, the detector fails. This approach takes into account the variation of V_{FD} with fluence and annealing time. It can be shown that the operations of the segmented detectors after irradiation are though better described by considering the degradation of the charge collection efficiency with fluence and time, and this doesn't always intuitively compare with the V_{FD} description. The failure mode of tracker devices is better described by the concept of 'electronic threshold', in term of multiple of the noise, above which the signal guarantees a sufficient tracking efficiency with negligible noise occupancy. Moreover other mechanisms should be considered, namely the failure to deliver the resolution required by the physics performances. In fact, detector thickness effects and track angles can play a role. Those effects can be measured and simulated in order to establish if offline corrections have to be implemented to recover the required resolution.

Simulated scenario of the changes of V_{FD} with cumulated LHC fluence and time for the ATLAS and CMS inner trackers. There is a different approach concerning the effect of the initial resistivity.

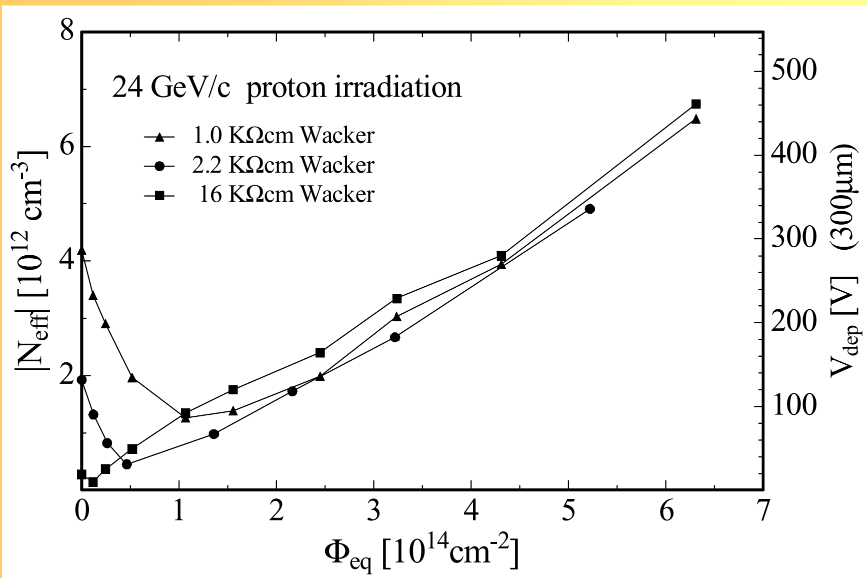




The initial resistivity has an effect only for irradiation with neutrons, while no benefit is seen with proton irradiation.

3[RD] RD48 STATUS REPORT

CERN/LHCC 2000-009
LEB Status Report/RD48
31 December 1999



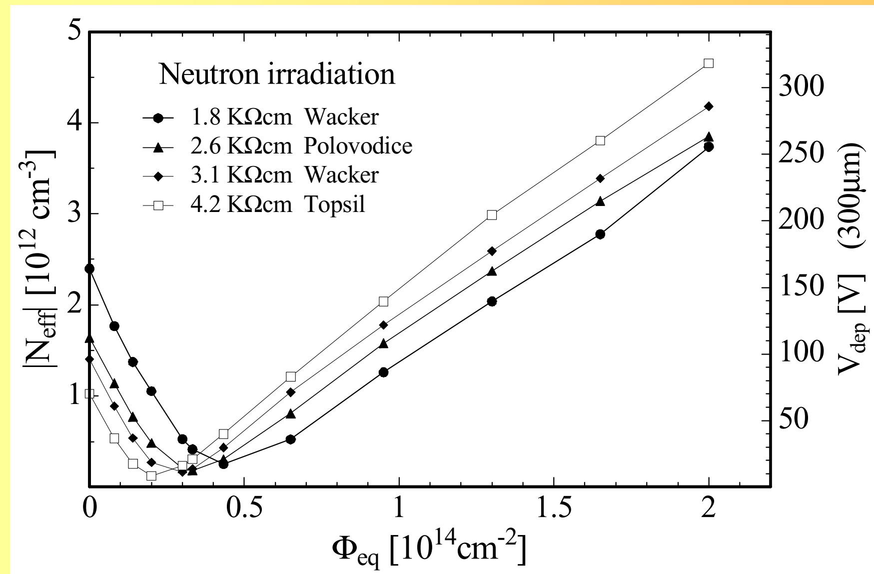
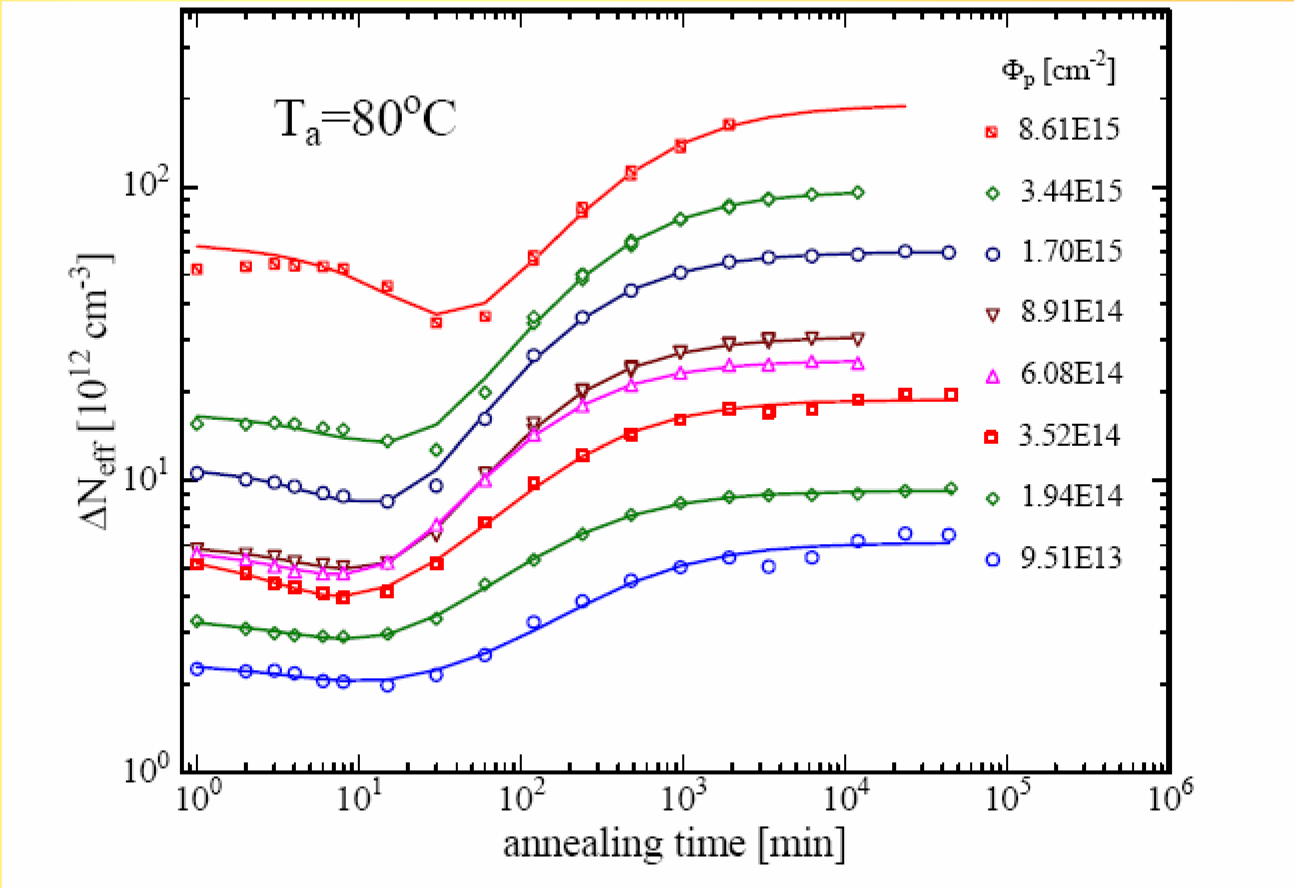


Fig. 11.: 24 GeV/c proton irradiation of O-rich diodes with different resistivity.

Fig.12: Reactor neutron irradiation of O-rich diodes with different resistivity.

The LHC scenario always includes the well known evolution of V_{FD} with maintenance time at temperature above operation temperature (17 – 20 ^{o}C).

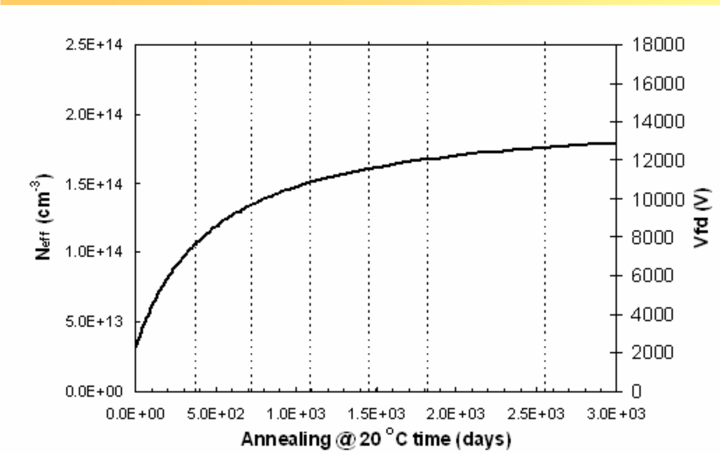
Presented by E. Fretwurst at the 4th RD50 workshop, CERN 5th-7th May 2004.

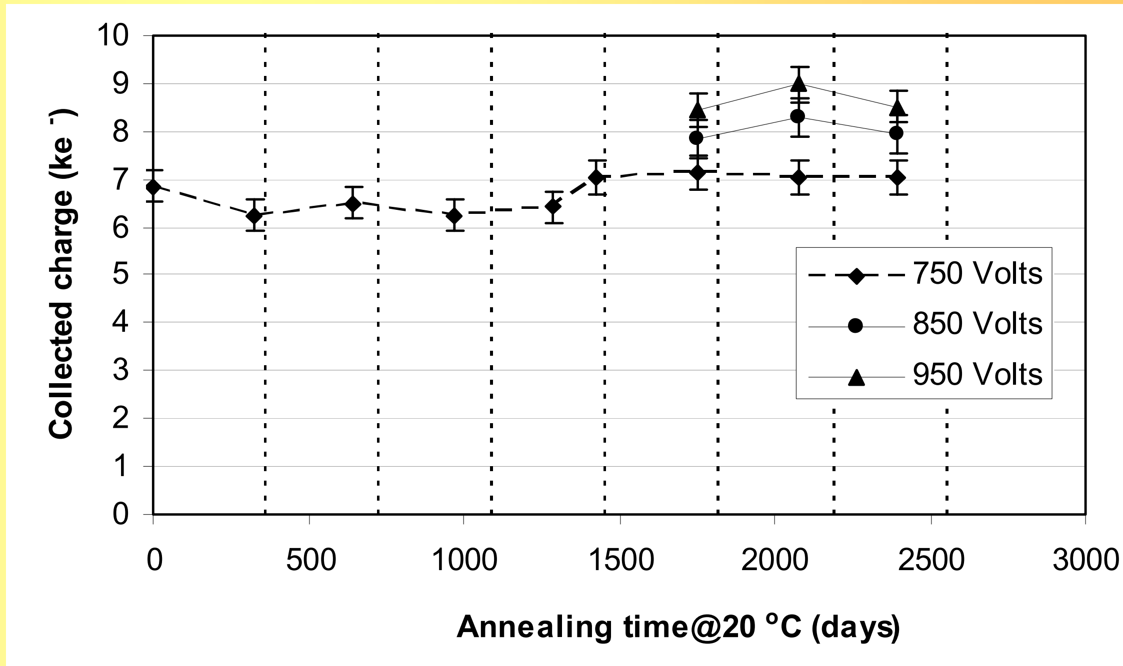


How does actually change the relevant parameter (CCE)?

P-type detector irradiated to 7.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 2800V



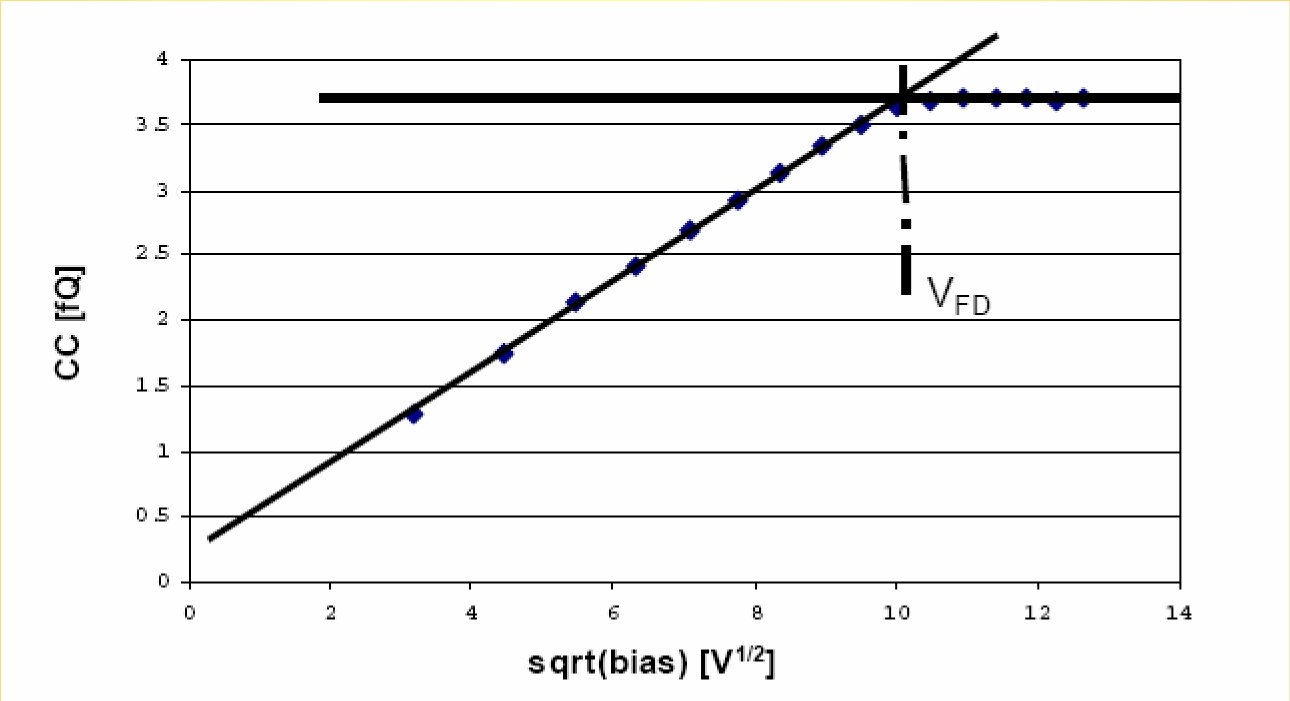


Predictions from RD48 parameters for Oxygen enriched devices (best scenario: after 7 RT annealing years the V_{fd} goes from ~2800V to ~12000 V!

It has been reported (e.g. G. Casse, 6th RD50 workshop, Helsinki) that after three different fluences, and at different voltages (from 1.1 10^{15} p cm^{-2} to 7.5 10^{15} p cm^{-2}), the collected charge doesn't decrease sensitively up to several years at R.T. A small decrease of the CCE is observed only for the lower voltages after a few years at R.T. If high voltage operations of silicon microstrip detectors are maintained, the annealing effects could be neglected. It must be stressed that the detector cooling during operation is necessary (the detectors must be kept at temperature safely below the thermal run-away limit) to be able to apply the required high voltage.

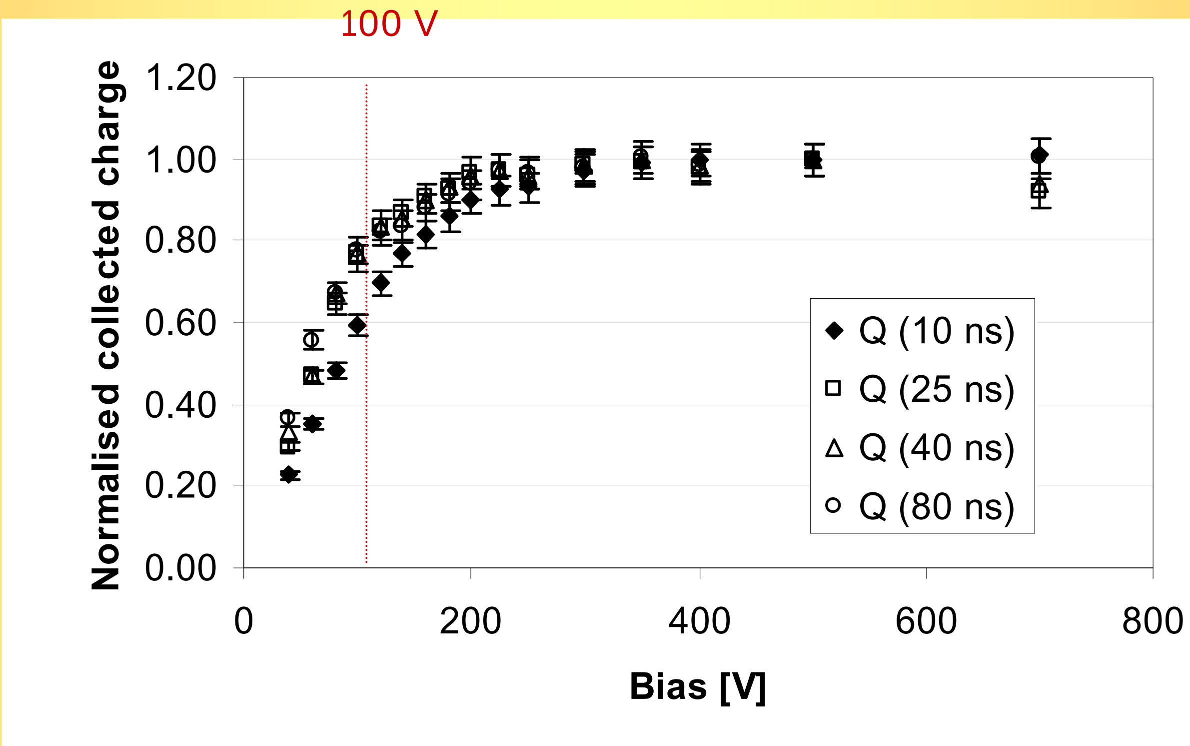
The information carried by V_{FD} is proven not adequate to the description of the detector operation. How the can be linked to the most relevant parameter (CCE)? No info's about trapping???

Charge collection as a function of bias for a non-irradiated silicon diode. The collected charge clearly saturates at V_{FD}.



Evaluation of Trapping Effects

- Corresponding Charge Collection Efficiency vs Voltage for diodes irradiated to ~2.10^{14} p cm^{-2}. At V_{FD} < 80% of the plateau charge is collected.



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, it accounts for highest trapping where 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, but the measurements show that this is not influent for integration times of 25ns.

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

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

$$1/\tau_{eff} = \beta \Phi$$

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

$$v(x) = \mu(x)\varepsilon(x)$$

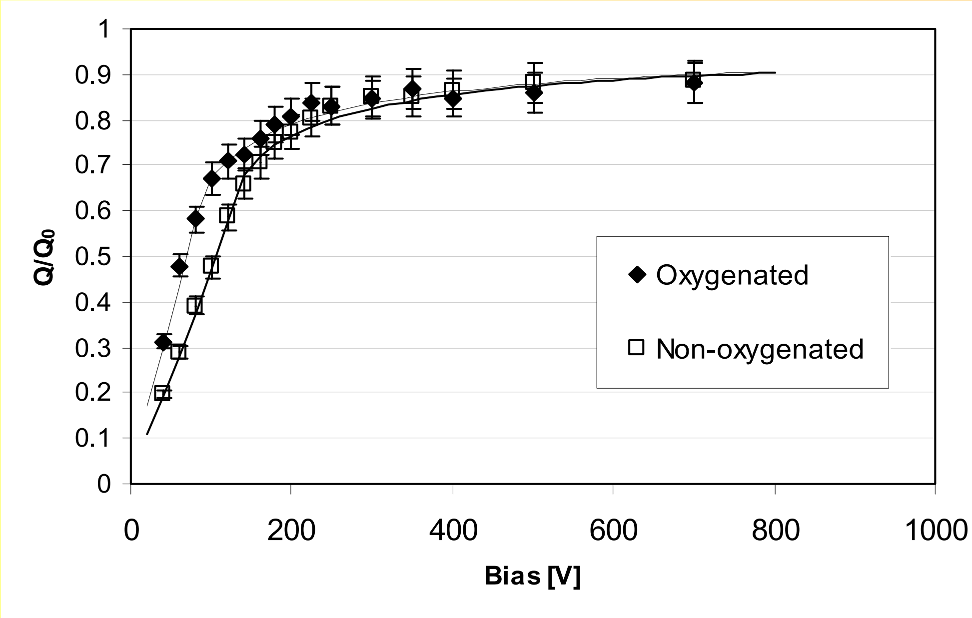
$$\mu(x) = \frac{\mu_0}{1 + \mu_0 \varepsilon(x)/v_s}$$

$$\varepsilon(x) = \frac{2V_{fd}}{w_0^2}(w(V) - x).$$

Fits to the Charge Collection Efficiency

V_{FD} oxy. 50V

V_{FD} std. 100V



1.9×10^{14} p/cm^2

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

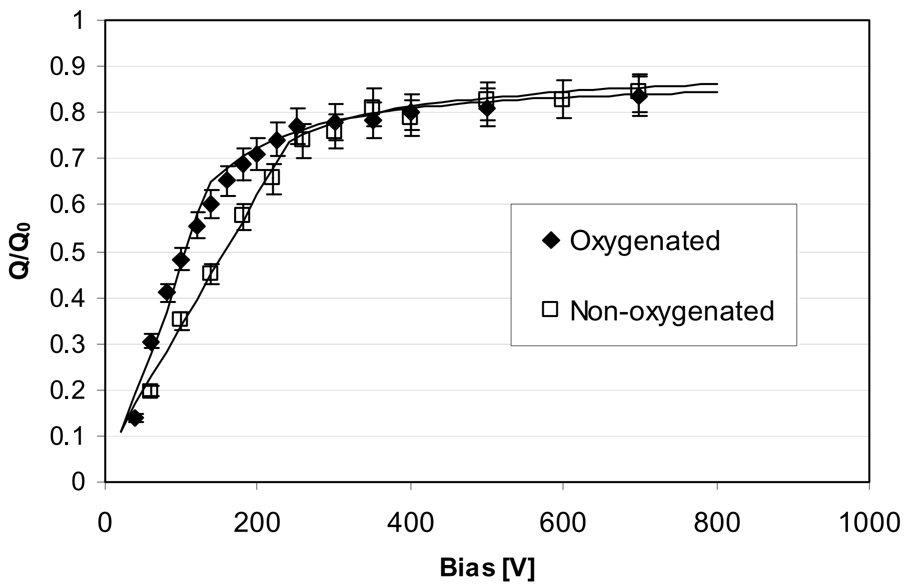
Fits to the Charge Collection Efficiency

V_{FD} oxy. 121V

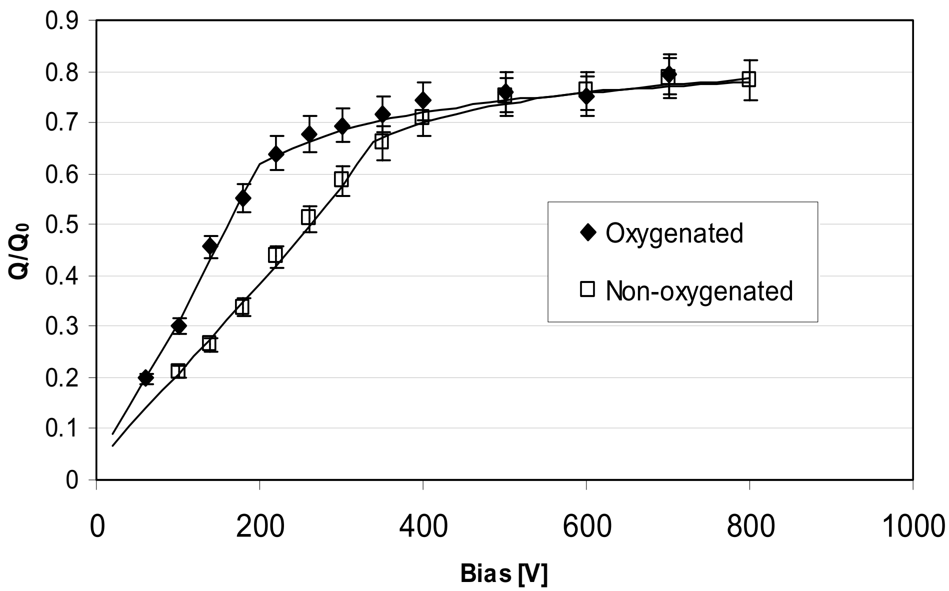
V_{FD} std. 218V

V_{FD} oxy. 181V

V_{FD} std. 320V



2.9×10^{14} p/cm^2



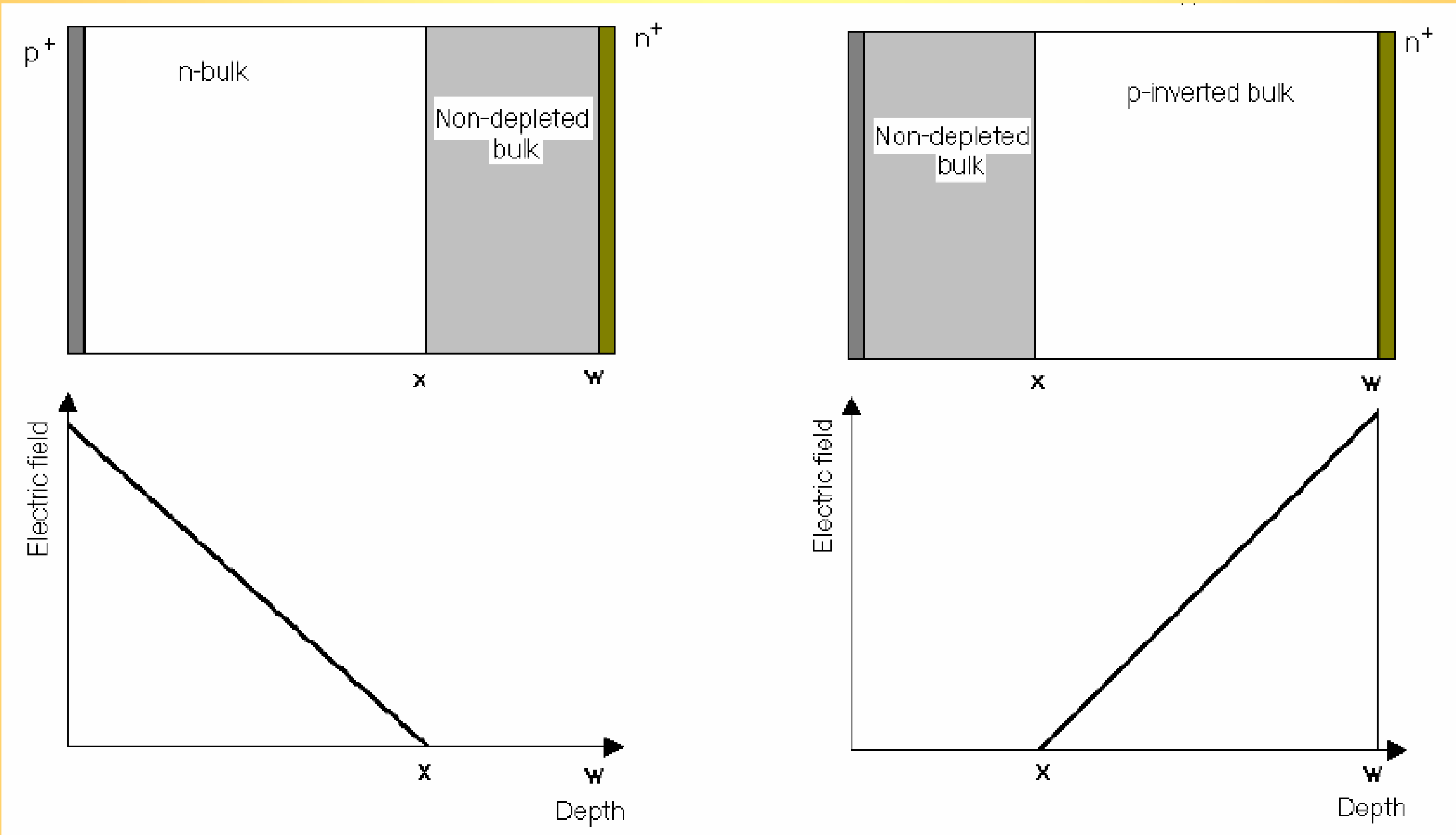
5.1×10^{14} p/cm^2

Fits to the Charge Collection Efficiency

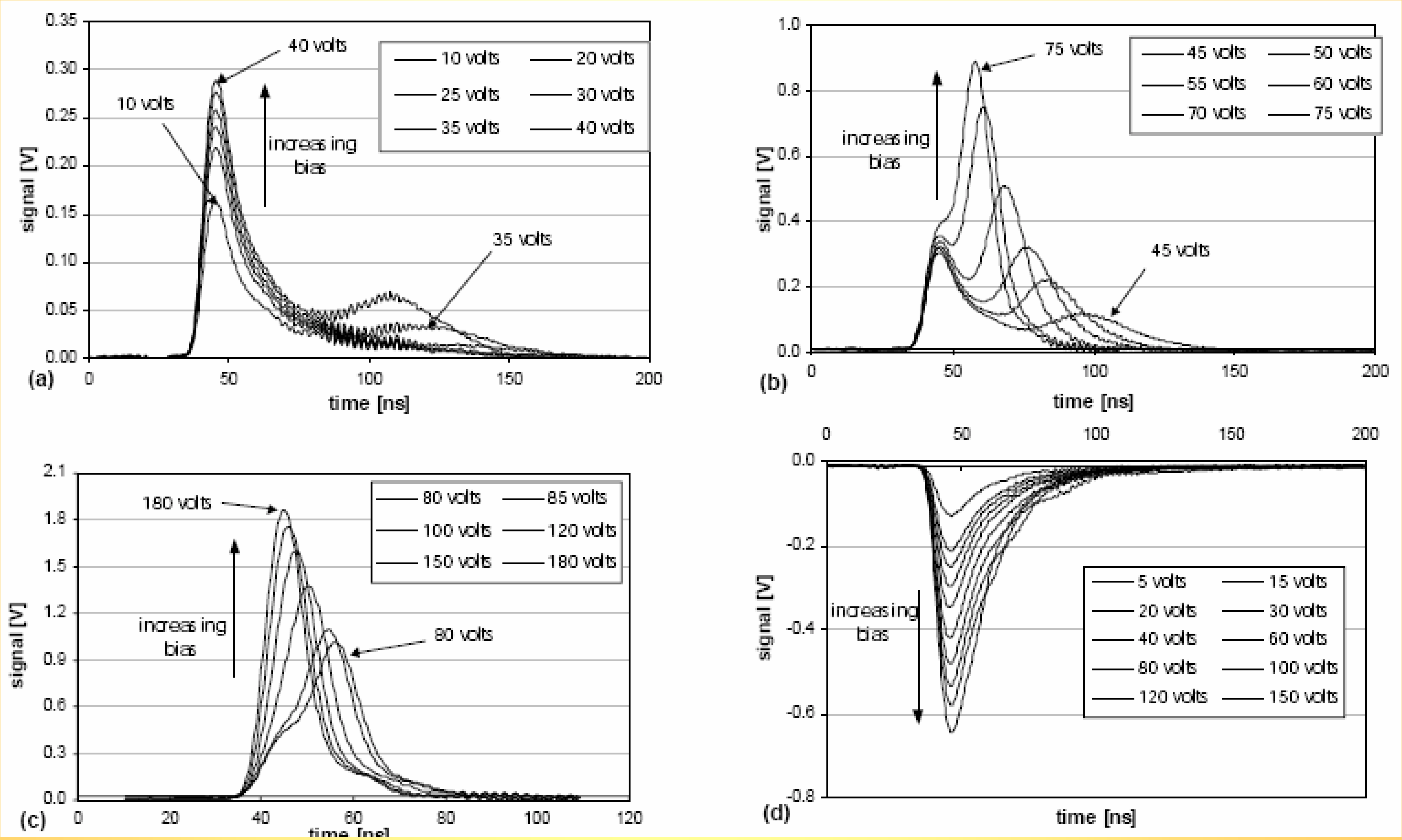
Detector label	Fluence [p cm^{-2}]	Oxygen enrichment	V_{FD} [V] (From C-V)	V_{FD} [V] (From CCE)	λ [ns^{-1} cm^2]
N I	Non irr.	No	49 ± 2	50 ± 2	
SO1	$1.9 \pm 0.1 \cdot 10^{14}$	Yes	100 ± 7	90 ± 2	1338 ± 15
SN1	$1.9 \pm 0.1 \cdot 10^{14}$	No	150 ± 8	137 ± 2	1407 ± 220
SO2	$2.9 \pm 0.2 \cdot 10^{14}$	Yes	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

The trapping significantly affects the CCE(V) to the point that about 70% of the plateau charge is collected at V_{FD} for diodes irradiated to LHC level doses.
The signal formation in the case of diodes is due to both charge carriers (*e-h*). In the case of finely segmented devices, the charge collection mechanism changes and the signal is mainly due to one type of charge carrier, namely h in the case of p-side read-out and e in the case of n-side read-out. The fraction of charge loss due to trapping is sensitively different in those two cases.
The above description of the CCE(V) properties suggest that trapping is inversely proportional to the collection time, therefore in the case of segmented detectors reading-out from the high-field n-side (after type inversion) leads to better CCE(V) behaviour.

Simplistic representation of the electric field before and after irradiation

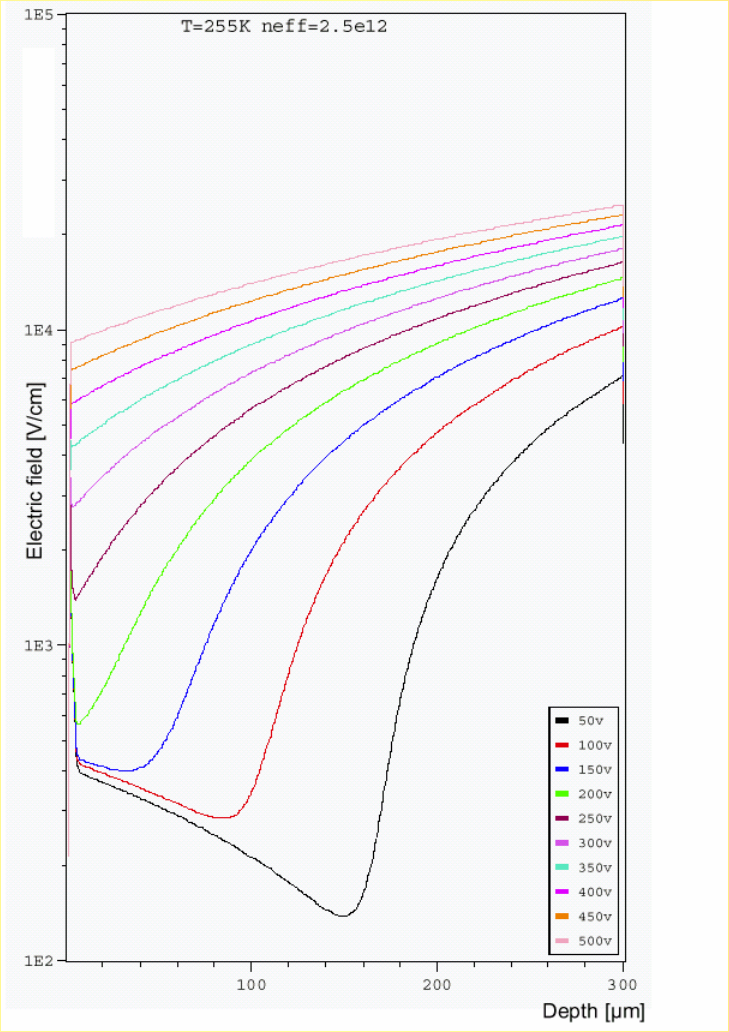


Can't account for several features of irradiated devices, e.g. the "double junction"



More realistic simulation (ISE-TCAD) of the electric after irradiation

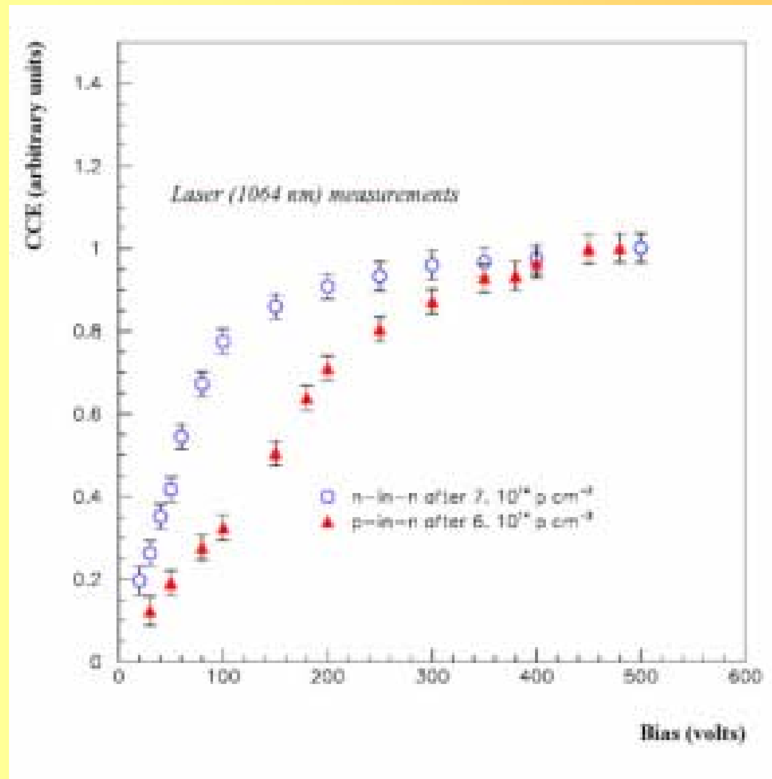
Irradiation fluence
$6.\ 10^{14}\ p\ cm^{-2}$



Motivation for using n-side read out

It is now well accepted that the best results of segmented detector in term of mip detection performances after heavy irradiations are obtained by reading out the segmented n-side. This is due to the signal being formed mainly by electron carriers being collected on the high electric field side. The reduced charge collection time results in less trapping and higher signals. Example: comparison between a traditional p-in-n geometry (with high electric field on the backplane after type inversion) and n-in-n geometry (high electric field on the read-out side after type inversion) (LHCb detectors).

n-side read-out of a n-type (n^+-n) detector after 7.10^{14} p cm^{-2}, compared with a standard p^+-n after 6.10^{14} p cm^{-2} (LHCb VELO prototypes).

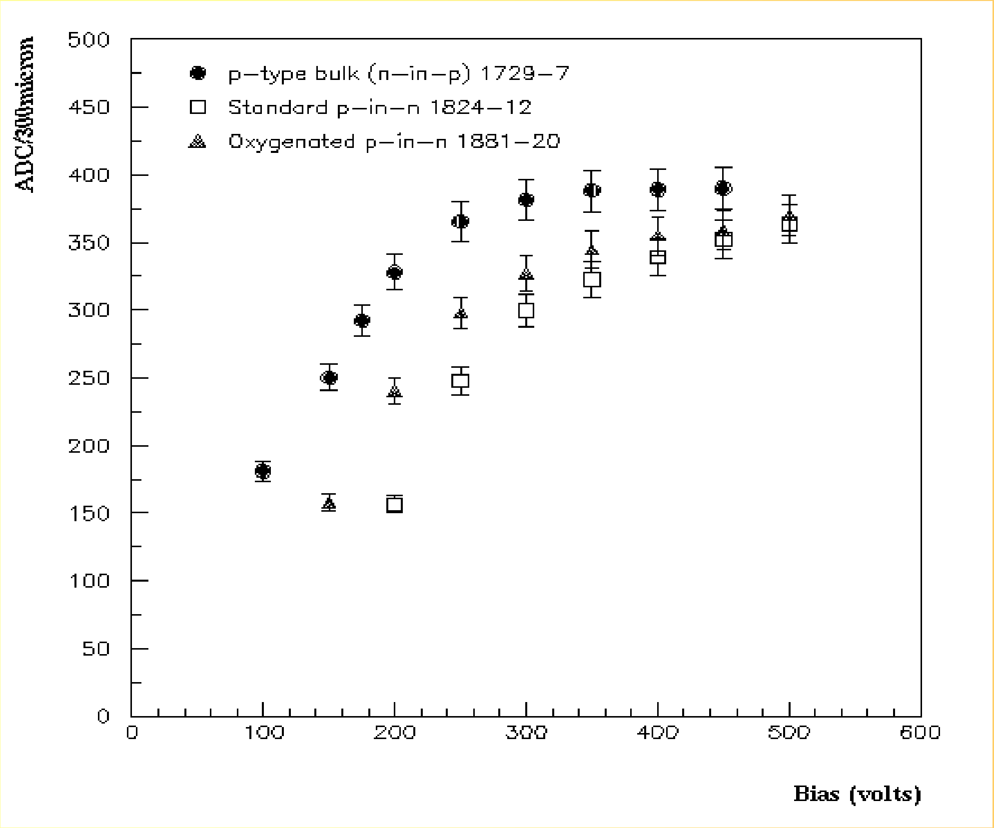


Motivation for using p-type silicon

The n-side read-out can be equally well implemented on a p-type substrate and keep the same advantages for CCE after irradiation and exhibiting two additional advantages compared to the n-type bulk.

• The p-type bulk doesn't invert, so the junction side will always be on the same side before and after irradiation

•The p-type substrate devices don't required backplane processing, which turns out being cheaper than the n-type. This argument can be of capital importance for large area coverage (sLHC trackers).



N-in-p full size segmented (microstrip) detectors have been made and successfully tested on standard p-type substrate

The n-side read-out segmented Si-detectors are the state-of-the-art rad hard devices for tracking in hep experiments. What is it the maximum survival dose?

Noise, Threshold setting

Signal-to-noise ratio S/N is essential for performance of the tracking system.

RMS noise σ [electrons]

depends on shaping time and size (i.g. C, i) of the detector channel

Threshold Thr

need to suppress false hits Thr = n* σ + threshold dispersion δThr

SCT: $\sigma \approx 600 + C*40 \approx 1500e^-$, n = 4 —> Thr ≈ 6,000$e^-$

Pixels: $\sigma = 260e^-$, δThr = 40 e^- n = 5 —> Thr ≈ 1,300e^-

BUT Pixel Threshold ≈ 2500 – 3000 e^- —> Mixed signal system issue, S/N!

Single-bucket timing is needed, use short shaping times (τ_R= 15ns for sLHC?).
yet there is still a problem with time walk: signal is in time
only if it exceeds the threshold by large amount ("overdrive")
Or: measure pulse height (ToT) and correct timing for pulse height.

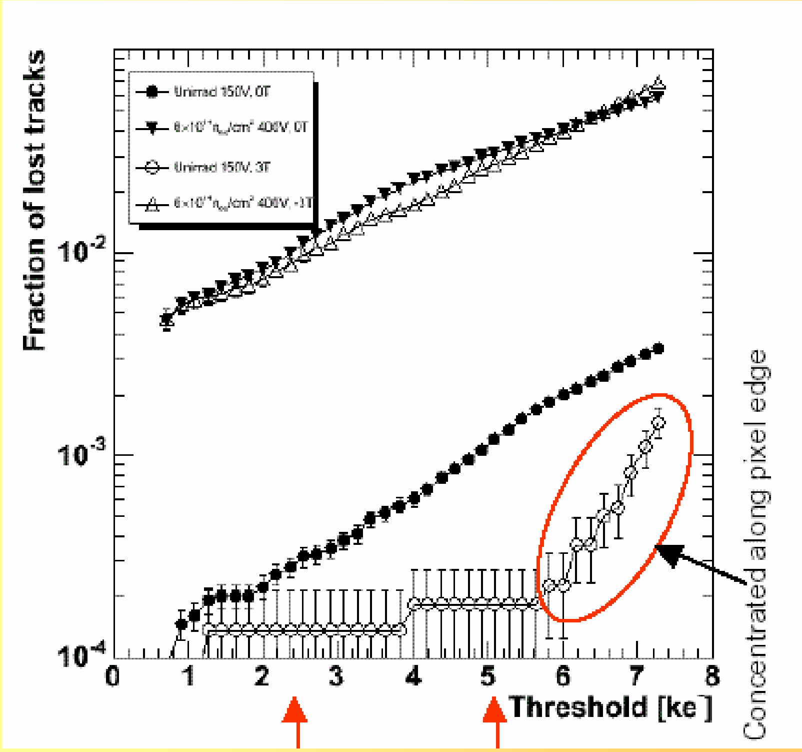
Signal / Threshold S/T : Expected Performance

Efficiency in CMS Pixels

(T. Rohe, RESMDD04)

After radiation damage from a fluence of $6*10^{14}$ n_{eq}/cm^{-2}, inefficiency vs. the signal-to-threshold ratio S/T:

S/T	Inefficiency [%]
6	1
4	2
3	3
2	9



Efficiency in Pixels
(depends on B-field, pixel size etc, but serves as a guide even for larger fluences):

Need S/T > 4 - 5

sATLAS Tracker Regions: Predicted Threshold

Integrated Luminosity
(radiation damage) dictates the detector technology

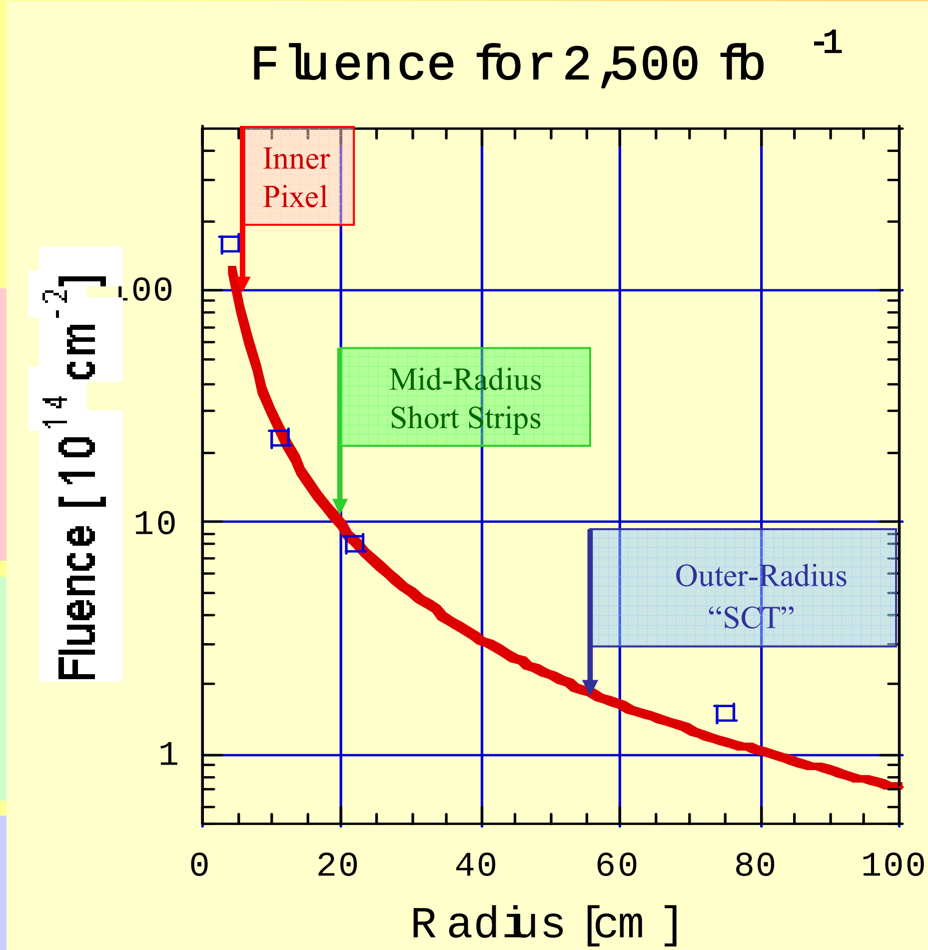
Instantaneous rate
(particle flux) dictates the detector geometry

Straw-man layout:

Inner: 6 cm r 12 cm
pixels style readout
Threshold = 2.5 ke$^-$ > 2.0ke$^-$?

Middle: 20 cm r 55 cm
short strips
Threshold = 4400 e$^-$ (0.7 fC)

Outer: 55 cm r 1 m
“long strips”
Threshold = 6250 e$^-$ (1.0 fC)



Detailed sCMS Pixels (R. Horisberger)

Summary

- Propose 3 Pixel Systems that are adapted to fluence/rate and cost levels

- **Pixel #1** max. fluence system ~400 SFr/cm^2
  100 μ * 150 μ

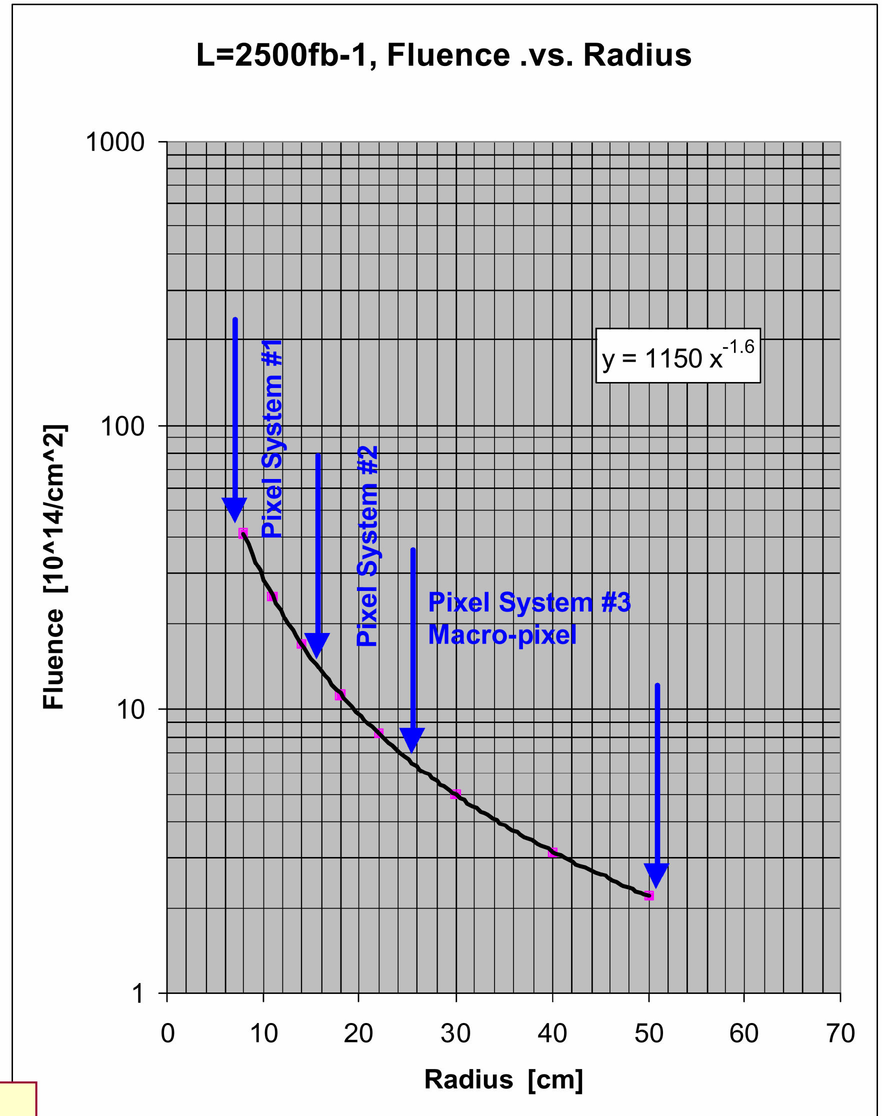
- **Pixel #2** large pixel system ~100 SFr/cm^2
  160 μ * 650μ

- **Pixel #3** large area system
  Macro-pixel ~40 SFr/cm^2
  200 μ * 5000 μ

- 8 Layer pixel system can eventually deal with 1200 tracks per unit pseudo – rapidity

- Use cost control and cheap design considerations from very beginning.

- Can this be done for 2012/13 ????

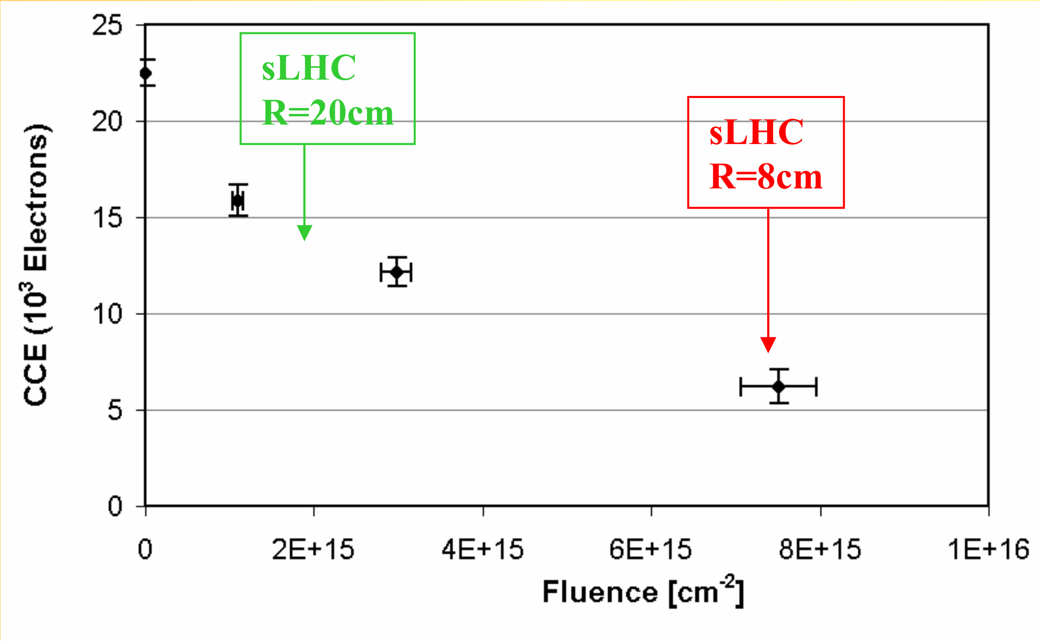


CMS: Inside out: "Fat" pixels, strips
ATLAS Outside in: "Skinny" strips, pixels

Charged Trapping in Si: the Good News

Efficiency of Charge Collection in 280 um thick p-type SSD

G. Casse et al., (RD50): After 7.5 $*10^{15}$ p/cm^2, charge collected is > 6,500 e^-



Trapping Time is factor 2 longer than extrapolated from previous measurements (Krasel et al.)

No adverse effects of anti- annealing observed! (P.P. Allport, 2004 IEEE)

Charge collection in Planar Silicon Detectors might be sufficient for all but inner-most Pixel layer?

For 3-D after 1 $*10^{16}$ n/cm^2, predicted charge collected is 11,000 e^-

Signal / Threshold S/T : Expected Performance

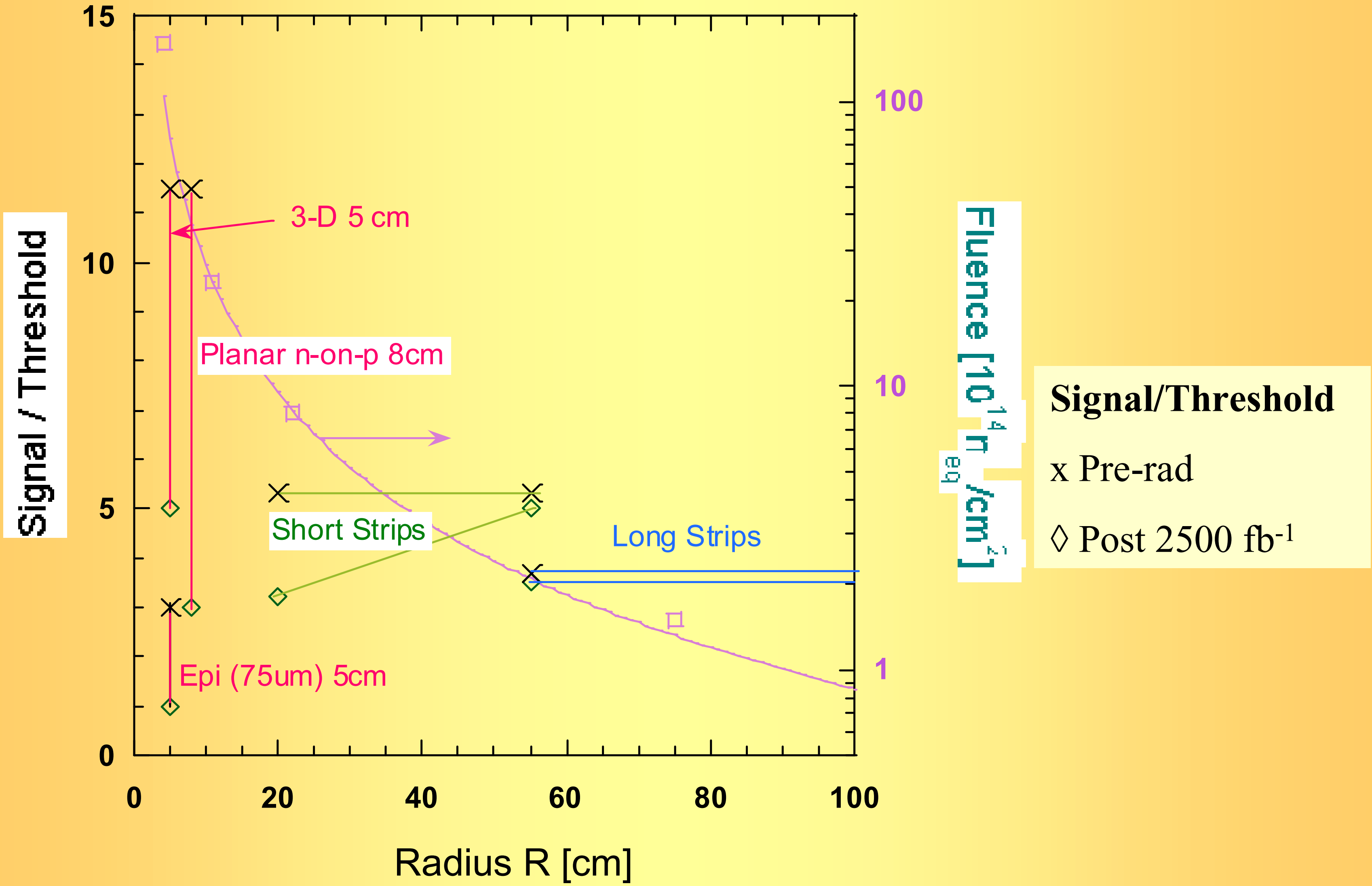
Efficiency in CMS Pixels (T. Rohe, RESMDD04)

Need S/T > 4 - 5

S/T	Inefficiency [%]
6	1
4	2
3	3
2	9

Radius [cm]	Detector	Threshold [e^-]	Signal / Threshold			Comment
			Pre-Rad	After 1250 fb^{-1}	After 2500 fb^{-1}	
> 55	Long strips	6250	3.7	3.7	3.7	~ SCT n-on-p
20 - 55	Short strips	4400	5.3	3.9	3.2	n-on-p
8 cm	Thick Pixel	2000	11.5	5.5	3.0	n-on-p
5 cm	Thin Pixel	2000	3.0	1.5	1.0	Epi 75 μm
5 cm	3-D	2000	11.5	7.5	5.0	100 μm cells

Signal / Threshold : Expected Performance



2nd CMS Workshop on Upgrades for SLHC (P. Sharp)

Conclusions from the 1rst SLHC Workshop

- CMS Electronics is very Robust, Handles increased rates well
- Pixel and Tracker Upgrades – (RH and GH)
- 8 cms – 15 cms Pixels 1 100 μ * 150 μ (Present System at 8, 11, 14 cms)
- 15 cms – 25 cms Pixels 2 160 μ * 650μ (C4 Bonding, at 18, 22 cms)
- 25 cms – 50 cms Pixels 3 200 μ * 5000 μ (at 30. 40, 50 cms)
- 50 cms - Silicon Strips (Rationalize Module Types)
- R&D E1: Review Electronics Systems for Level 1 trigger
- How will Tracker interface to: Calorimeters and μ Systems ?

2nd CMS Workshop on Upgrades for SLHC (P.Sharp)

Conclusions from the 1rst SLHC Workshop

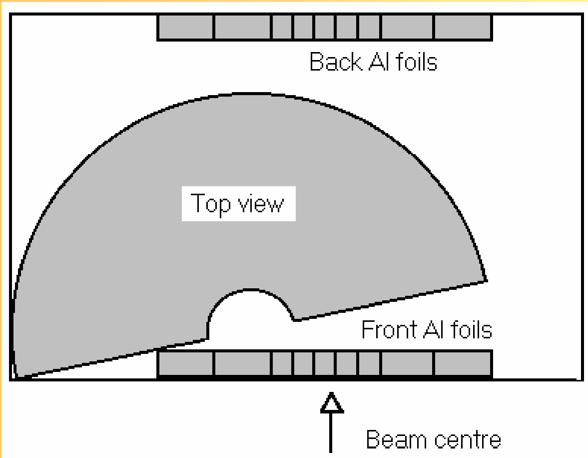
- The Tracker upgrade will require access to DSM Electronics
- Will need to Characterize the 130 nm Processes
- Will need to Characterize < 130 nm Processes (Propose 65 nm)

- R&D E2: Continue to Develop Relationship with DSM Vendors and obtain access to Design Tools to continue to optimize the use of DSM processes in Particle Physics
- Cost : Must get design right in < 2 Iterations
  Must use > 100,000 chips / Design
  Then Cost / Chip is no worse than 250 nm

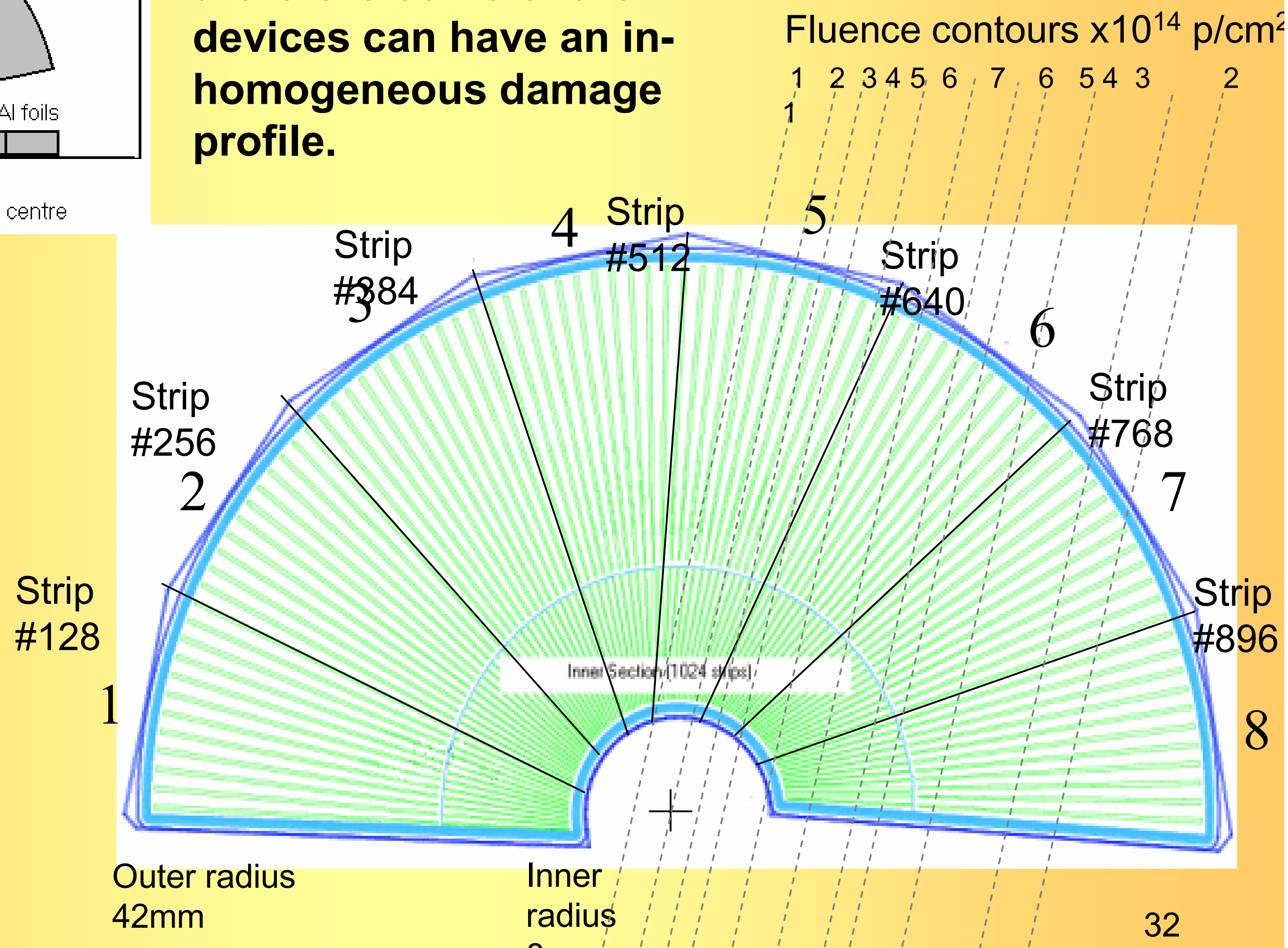
F.E.E. Technologies for sLHC:

Sub-μ CMOS	"accidentally" rad-hard, low power, used for pixels,CMS, also in sCMS
Bipolar BiCMOS	power-noise advantages for large capacitances and fast shaping, also excellent matching technologies used in ATLAS SCT are not sufficiently rad-hard beyond the LHC because of current gain β degrading from about 100 to about 40 at 10^{14}cm^{-2}, limited availability
SiGe BiCMOS	very fast (f_T > 50GHz and β > 300), used in cell phones, backend: DSM CMOS "du jour", available IBM–MOSIS rad hardness has been measured to 10^{14}cm^{-2} we have now measured test structures in the CERN beam! Survive 10^{16}cm^{-2} , β useful above 10^{15}cm^{-2}
SiGefor sLHC?	Expect that largest area of sLHC tracker will be made of strips, so SiGe could give an advantage, specially for short shaping times (noise, overdrive). (Power (SiGe) < Power (0.25 μm CMOS) for "long" strips).

Effect of non-homogeneous irradiation



In the LHC tracker the radiation field goes ~ $1/R^{1.99}$, therefore some of the devices can have an in-homogeneous damage profile.



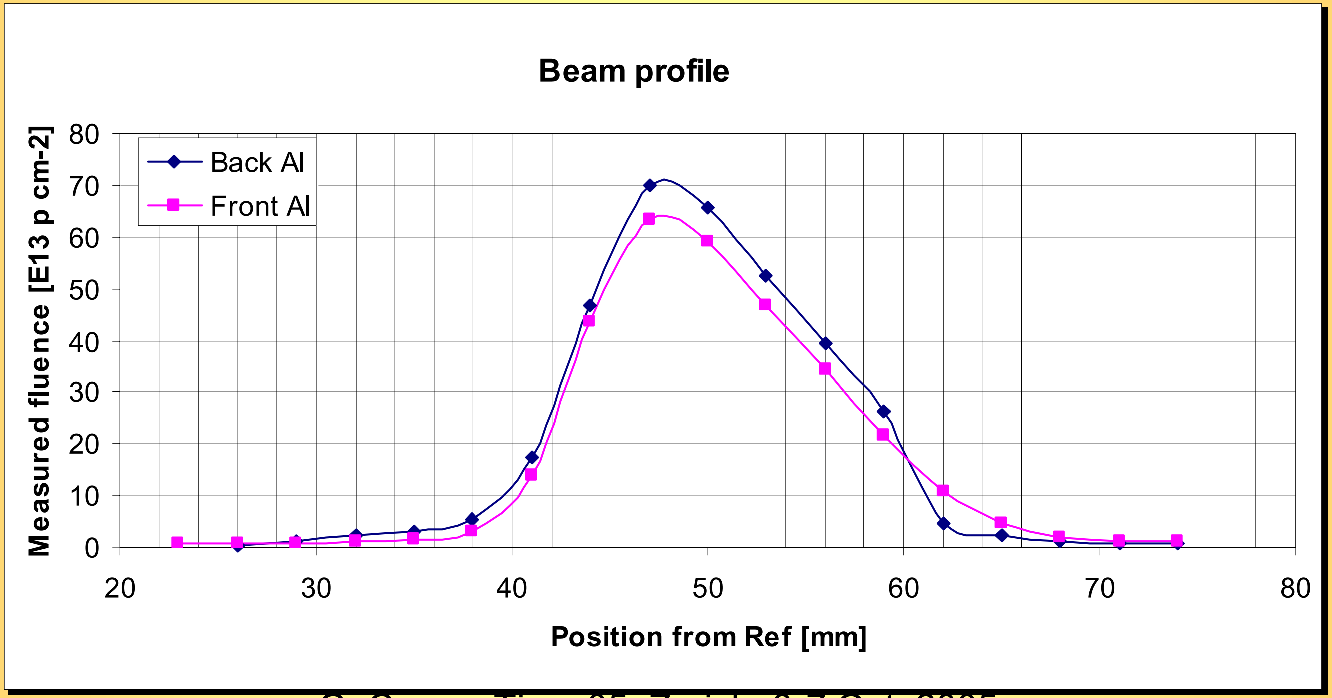
Effect of non-homogeneous irradiation

Irradiated devices :

200 μm n-in-n

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

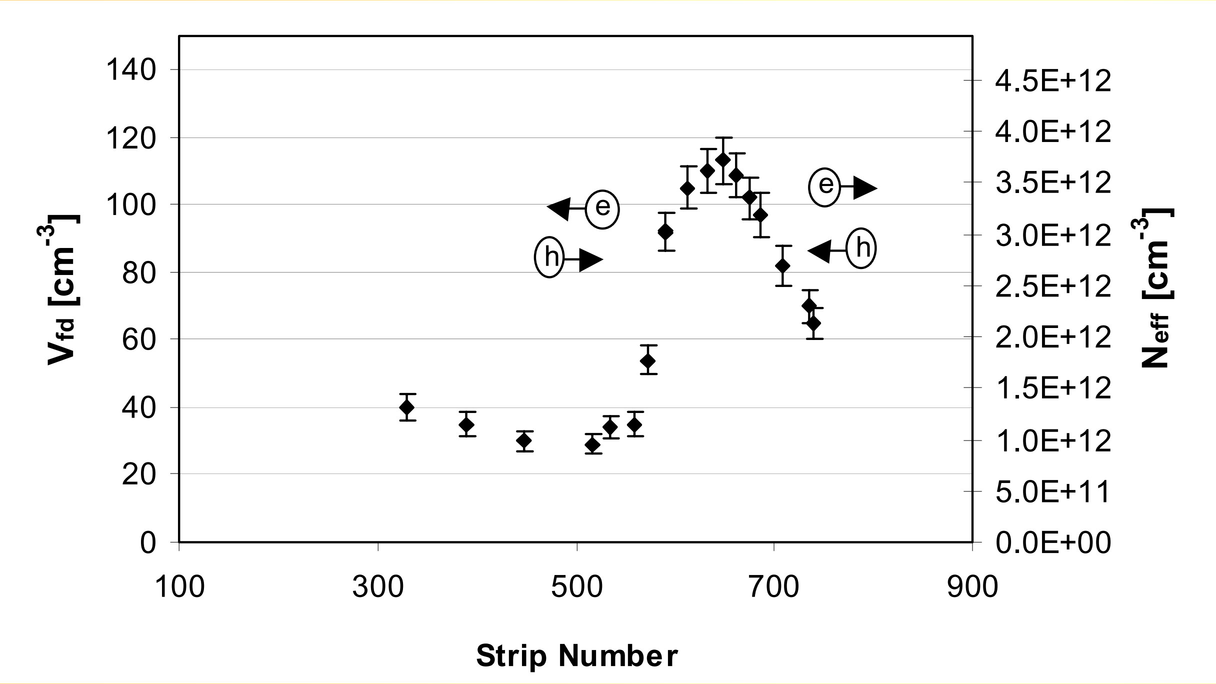
Maximum fluence ~ 4.6 10^{14} p cm^{-2}



Effect of non-homogeneous irradiation

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}).



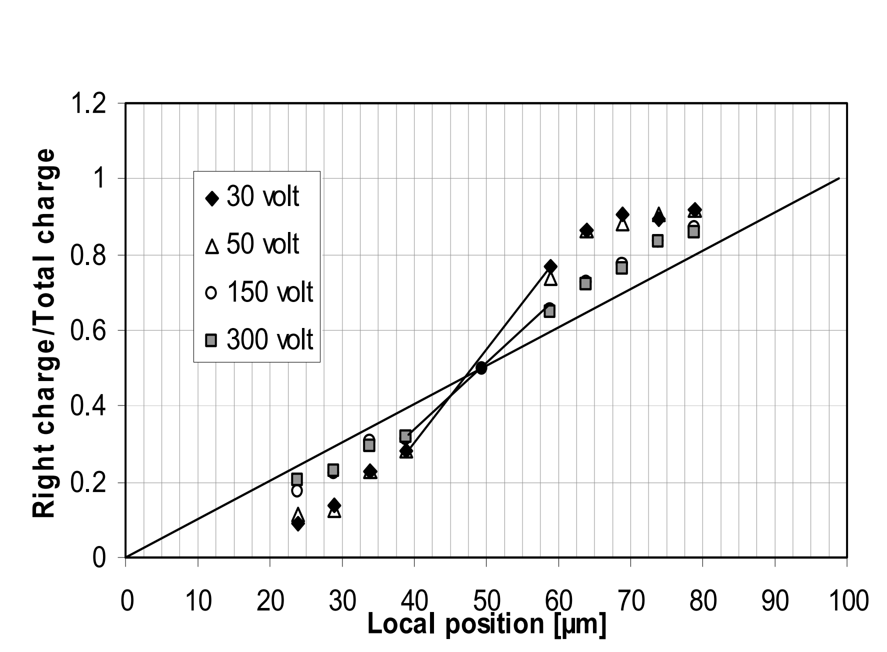
Gradient of N_{eff} can introduces a 'transverse' component of the electric field and a distortion in the reconstructed cluster position. Distortions are expected to have opposite sign for opposite sign of the gradient of N_{eff}.

Effect of non-homogeneous irradiation

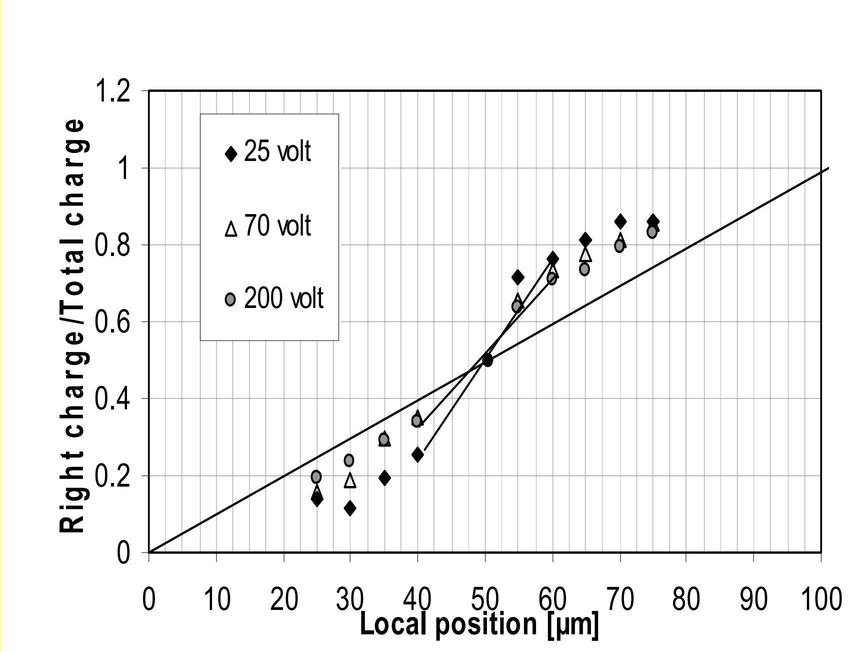
N-in-n 200 μm detector

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

Strip 517-518
Vfd=29 V



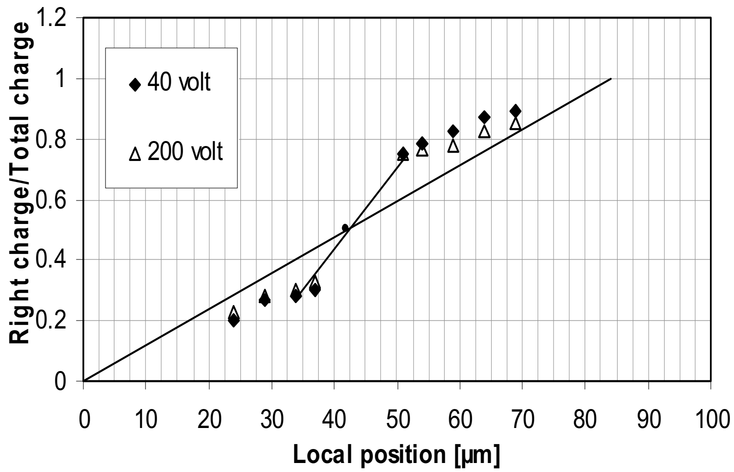
Strip 534-535
Vfd=34 V



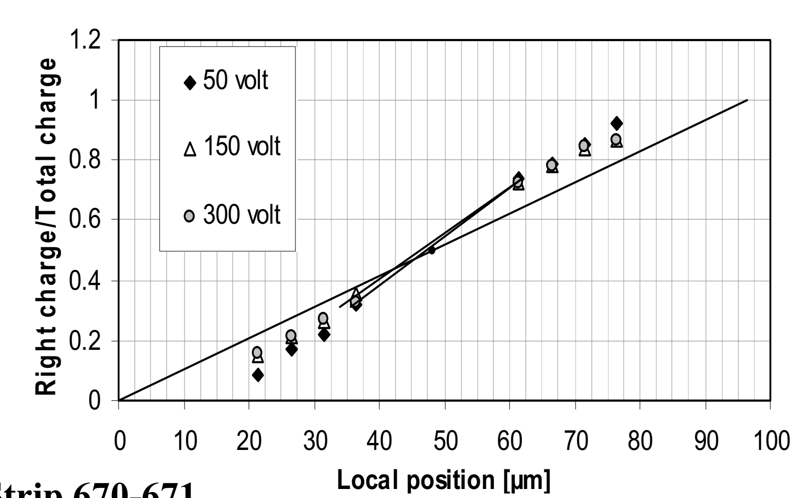
Effect of non-homogeneous irradiation

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

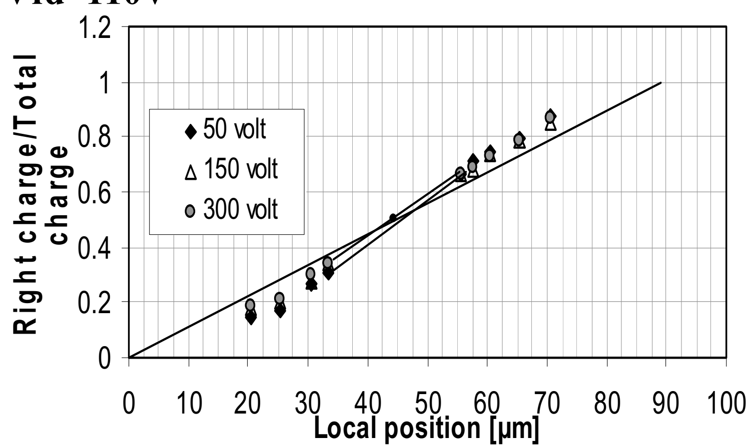
Strip 582-583
Vfd=90V



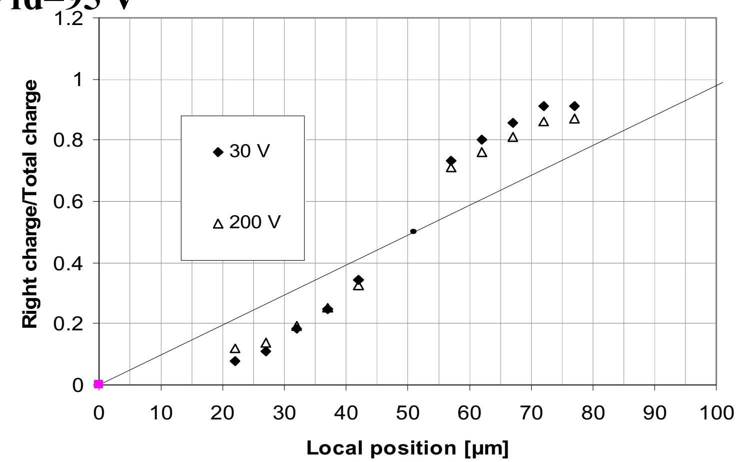
Strip 612-613
Vfd=105V



Strp 632-633
Vfd=110V



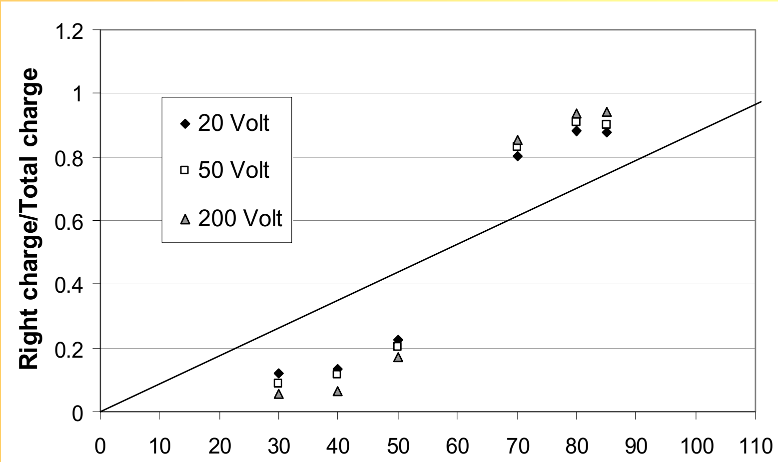
Strip 670-671
Vfd=95 V



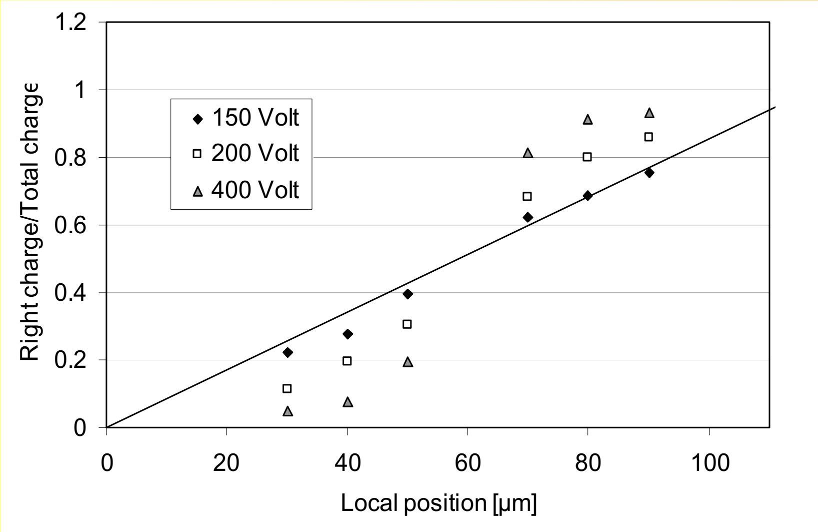
Effect of non-homogeneous irradiation

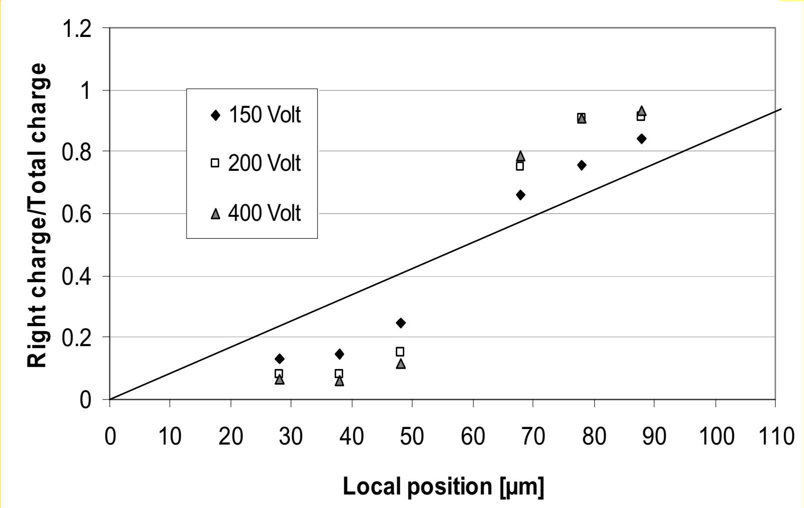
P-in-n 300 µm detector $\eta = Q_R/(Q_R+Q_L)$

Low radiation region Vfd=75V



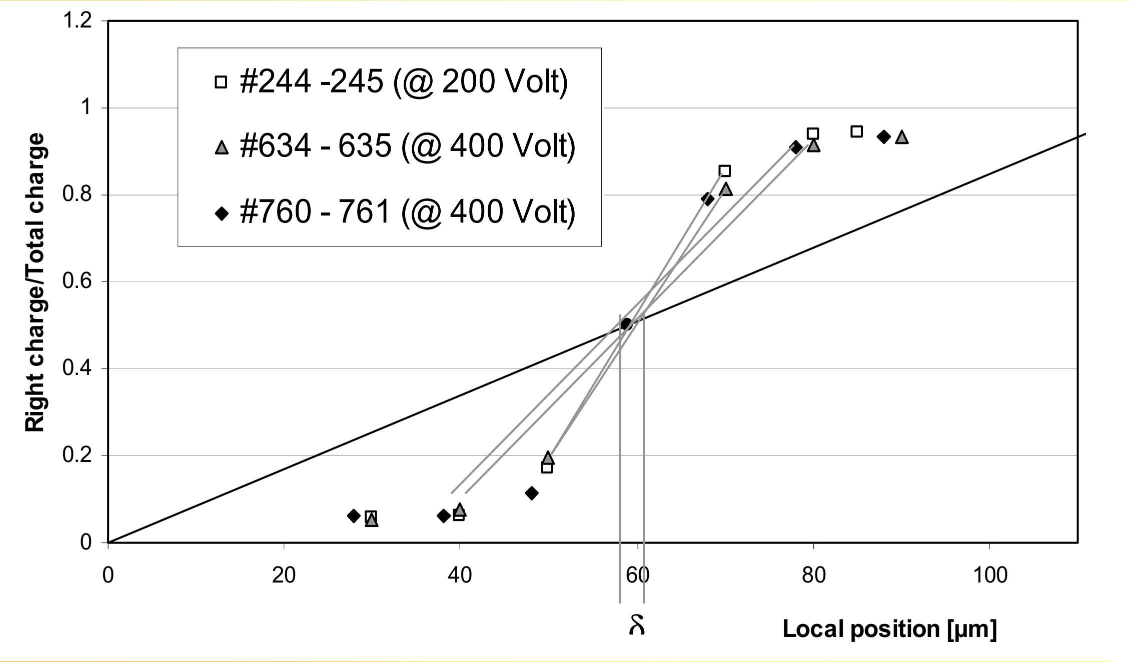
Irradiated region with positive gradient of $|N_{eff}|$ as a function of the strip number (Vfd 230 V)

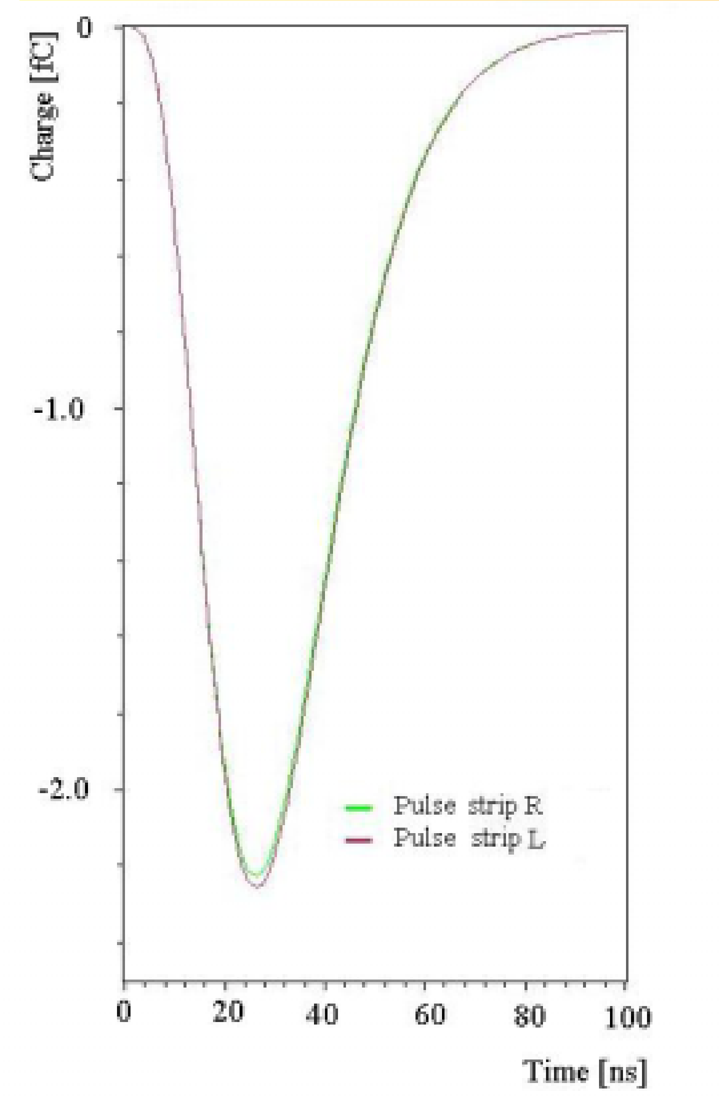




Irradiated region with negative gradient of $|N_{eff}|$ as a function of the strip number (Vfd 230 V)

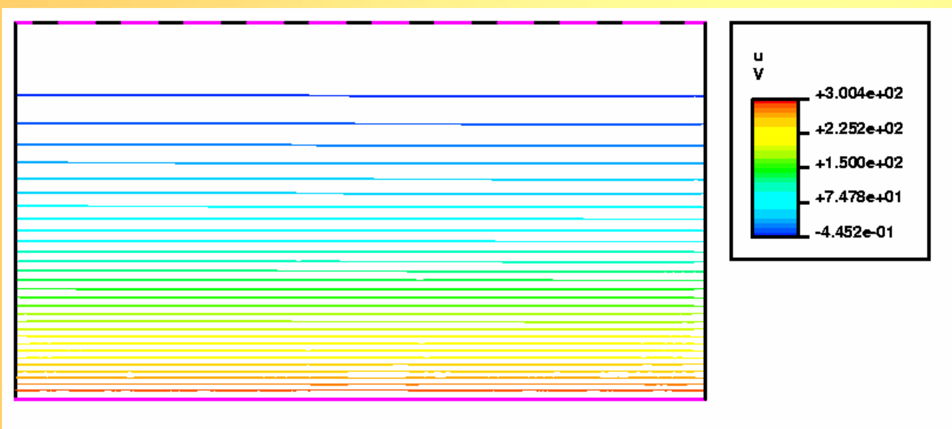
Effect of non-homogeneous irradiation

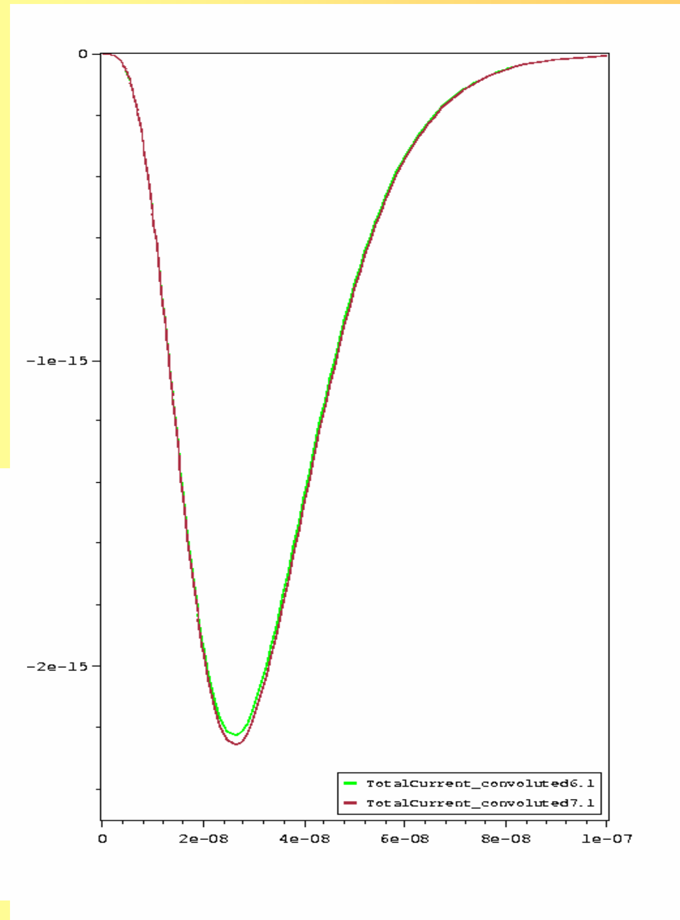




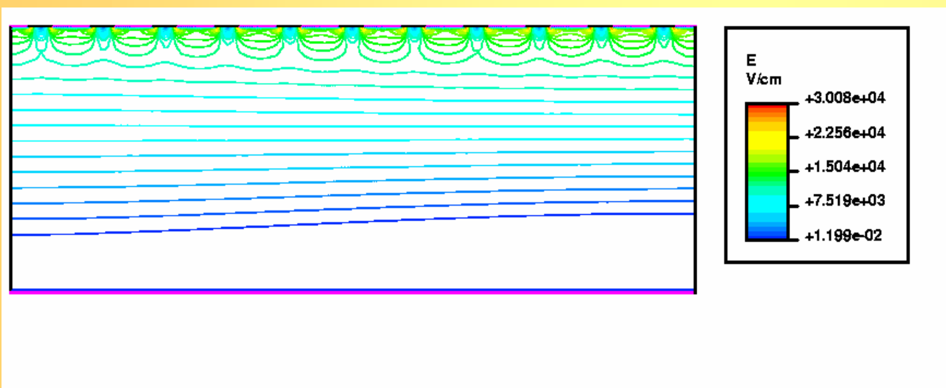
No evidence of distortion (spread observed (δ) is approximately ±2µm) in the reconstructed cluster position due to the high gradient of N_{eff} in the detector. The experimental results are also supported by ISE simulations

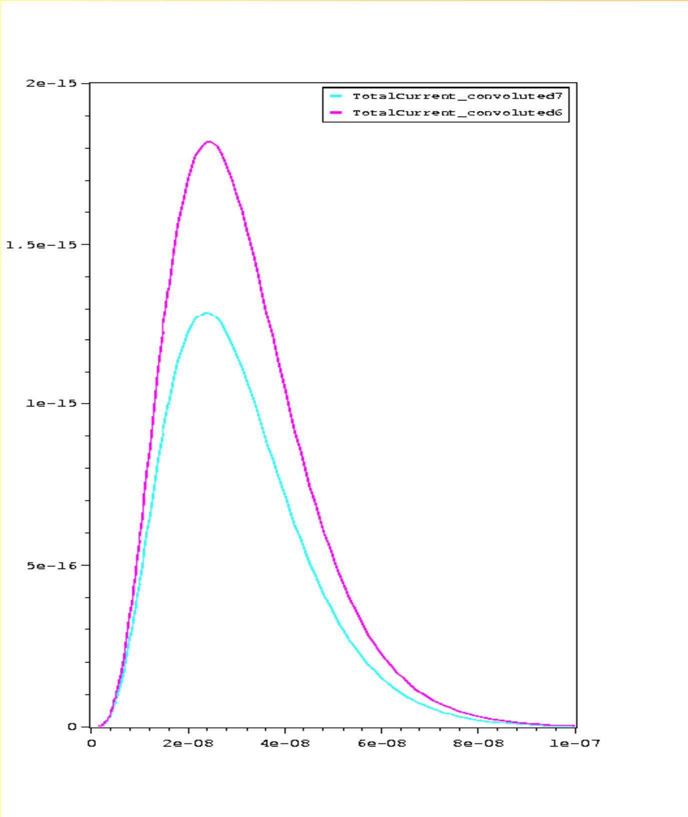
ISE simulation of the electric field (300 V applied bias) in the high gradient area of an irradiated (>4.10^{14} cm^{-2}) p-in-n silicon detector and signal of two neighbour strips generated by a MIP crossing mid way of the two strips



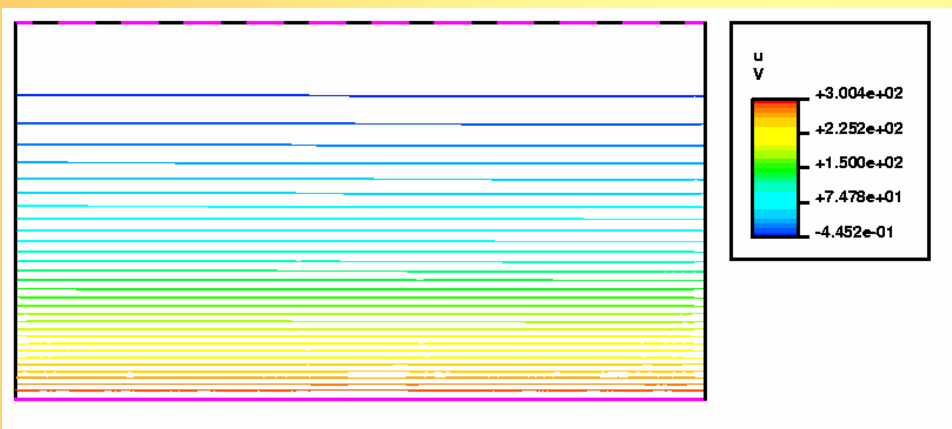


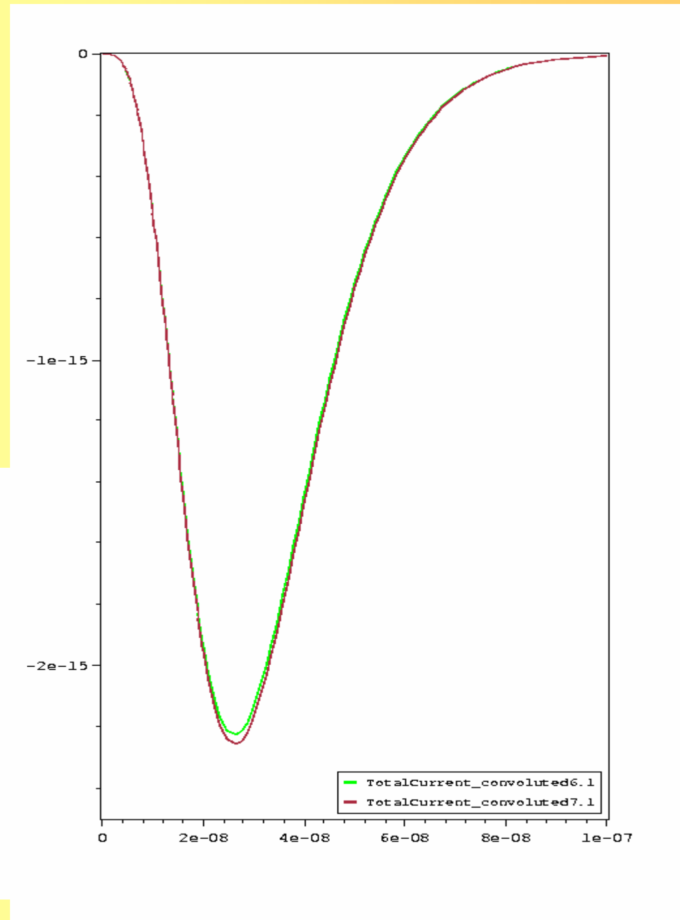
ISE simulation of the electric field (120 V applied bias) in the high gradient area of an irradiated (>6.10^{14} cm^{-2}) n-in-n silicon detector and signal of two neighbour strips generated by a MIP crossing mid way of the two strips. The difference in signal height corresponds to the one obtained by moving the impact point of the MIP off centre by half a micron.



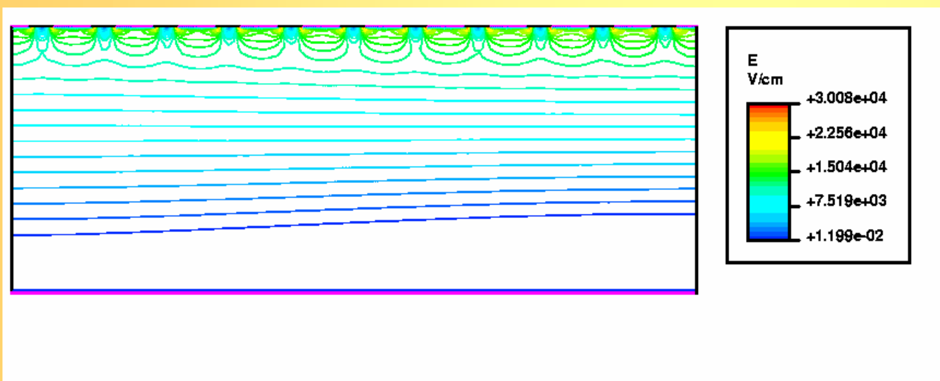


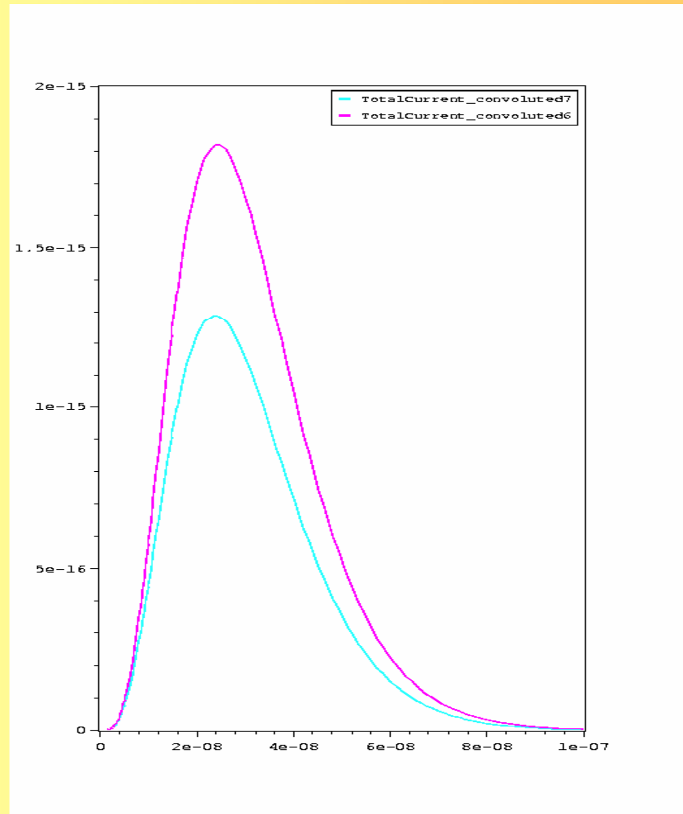
ISE simulation of the electric field (300 V applied bias) in the high gradient area of an irradiated (>4.10^{14} cm^{-2}) p-in-n silicon detector and signal of two neighbour strips generated by a MIP crossing mid way of the two strips





ISE simulation of the electric field (120 V applied bias) in the high gradient area of an irradiated (>6.10^{14} cm^{-2}) n-in-n silicon detector and signal of two neighbour strips generated by a MIP crossing mid way of the two strips. The difference in signal height corresponds to the one obtained by moving the impact point of the MIP off centre by half a micron.

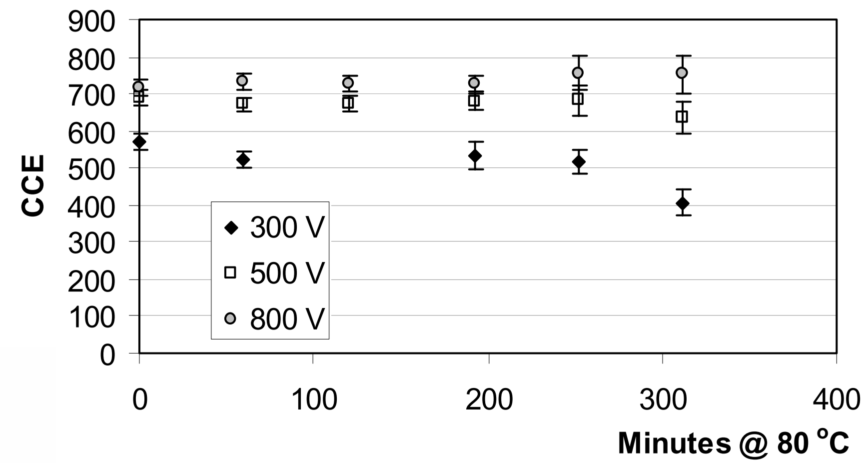


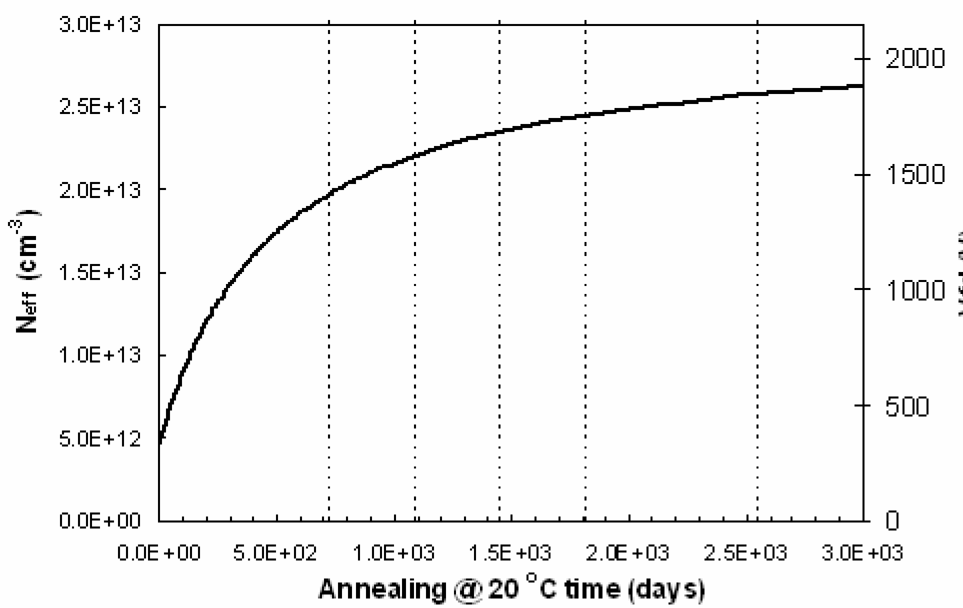


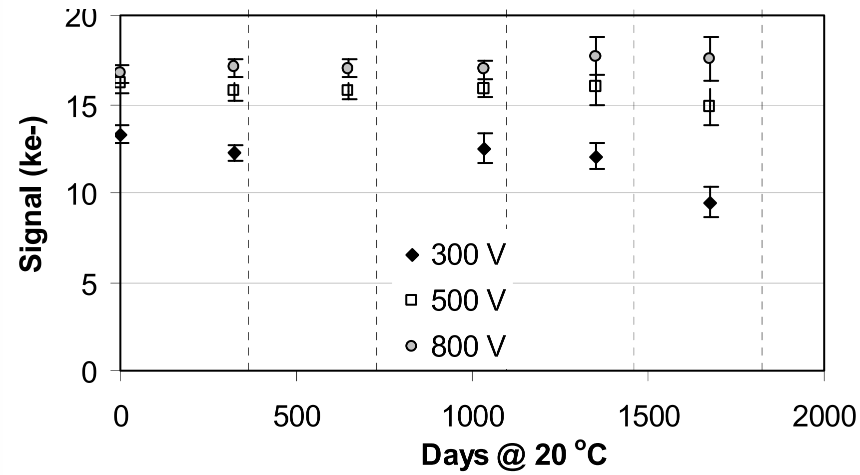
CCE annealing studies of p-type detector irradiated to 1.1 10^{15} p cm^{-2}

Initial V_{FD} ~ 420V

Final V_{FD} ~ 1900V



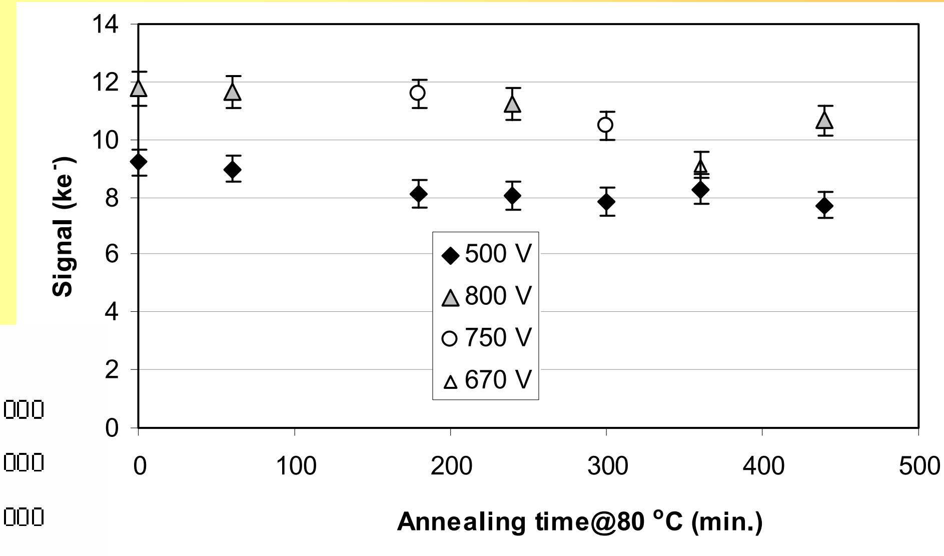


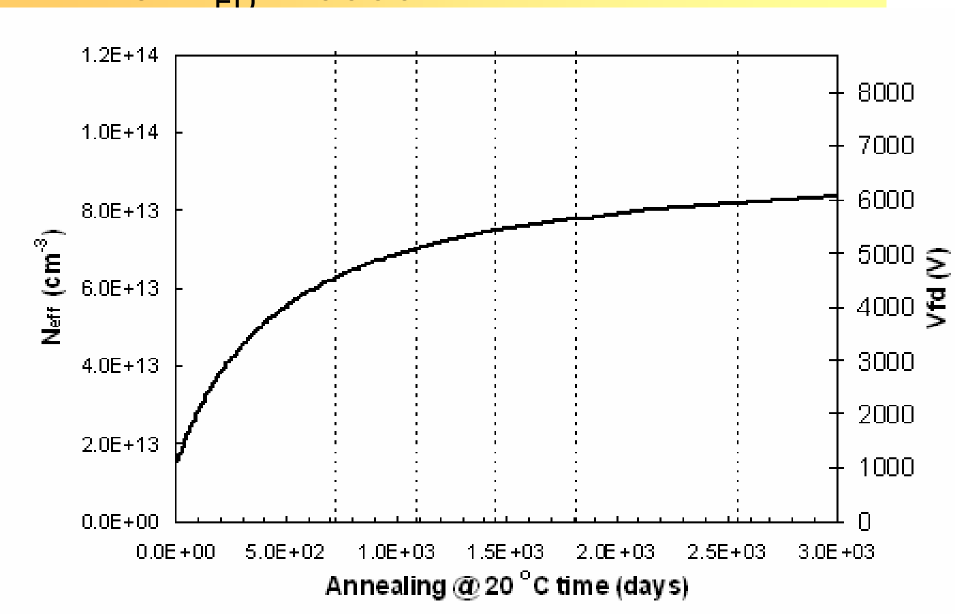


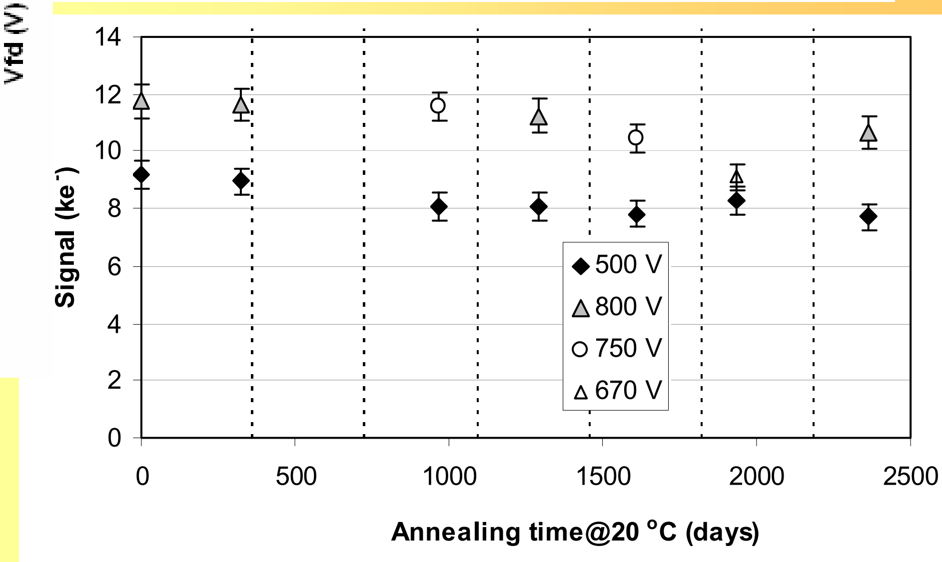
P-type detector irradiated to 3.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 1300V

Final V_{FD} ~ 6000V



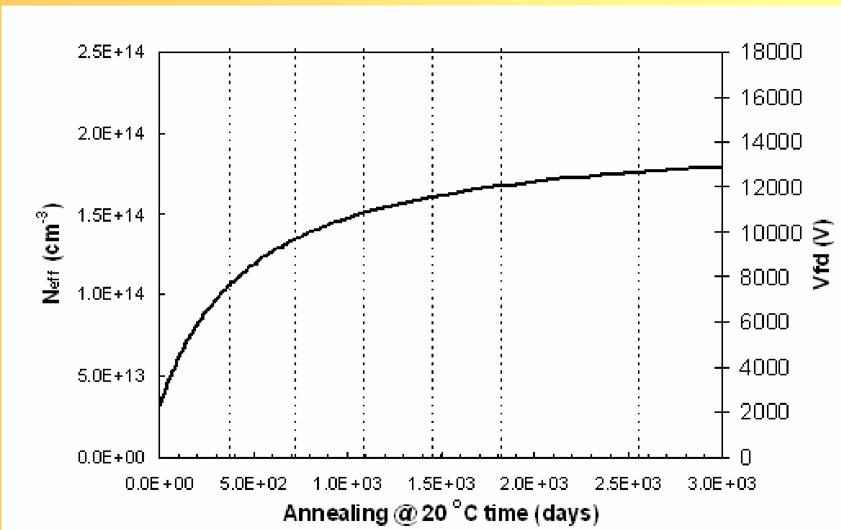


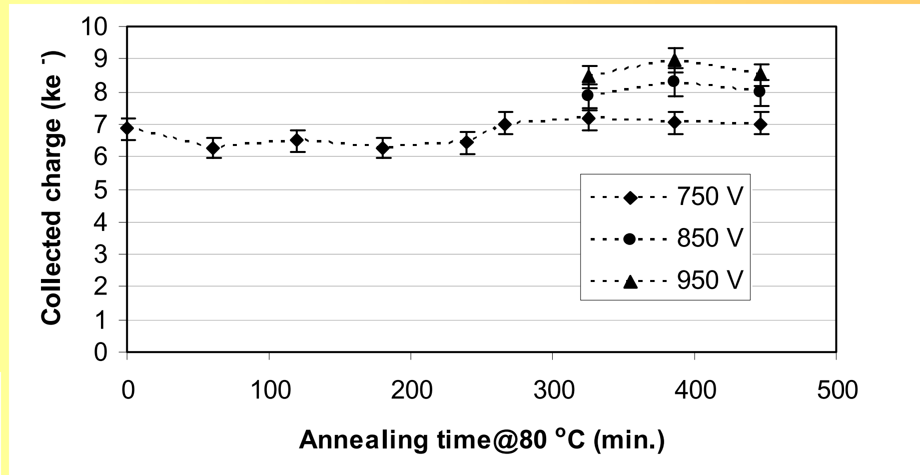


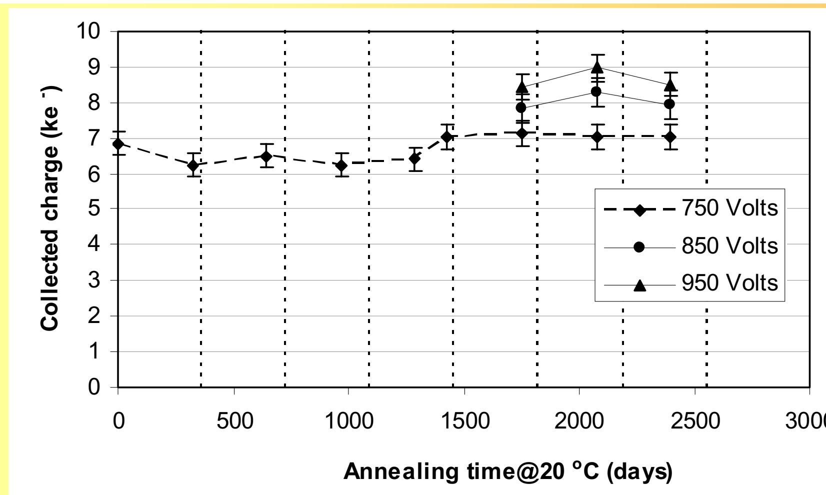
P-type detector irradiated to 7.5 10^{15} p cm^{-2}

Initial V_{FD} ~ 2800V

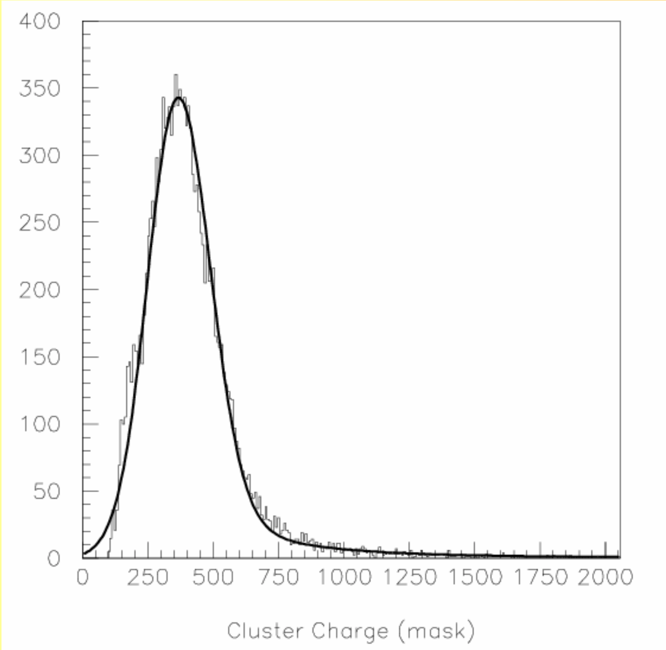
Final ~12000 V!







The measured signal loss after long term annealing doesn't correspond to the changes in the depletion voltage. Even after 6 equivalent y at 20 °C the measured signal (after a fluence of 7.5 10^{15}cm^{-2}) exceeds 8 times the noise (that remains unchanged with annealing, as expected), and in no case the degradation of the signal follows the changes of the V_{FD}.



Ratio of the signal measured after various annealing times at room temperature to the pre-annealed value

After 1.1 10^{15} p cm^{-2}

Bias	~1 y	~ 3 y	~ 4.5y
300 V	0.9	0.93	0.72
500 V	1.02	1.0	1.07
800 V	0.98	0.98	0.93

After 3.5 10^{15} p cm^{-2}

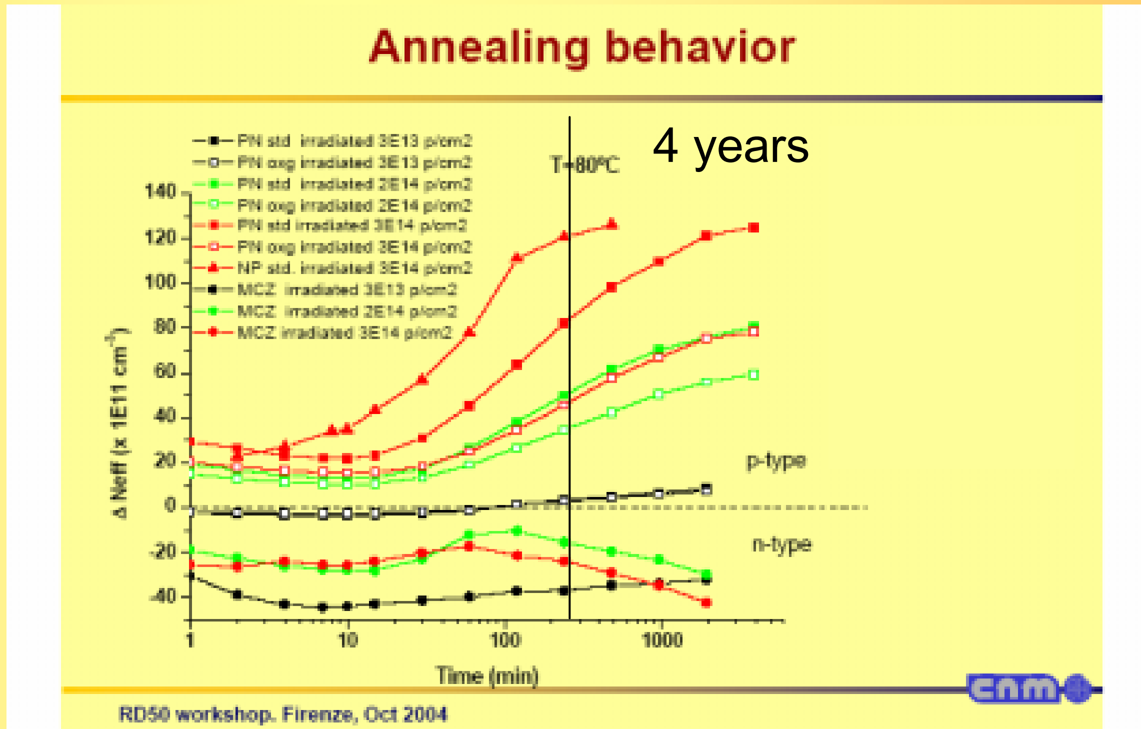
Bias	~1 y	~ 2.5 y	~ 6.5y
500 V	0.98	0.9	0.87
800 V	0.98	0.94	0.88

After 7.5 10^{15} p cm^{-2}

Bias	~1 y	~ 2.5 y	~ 6.7y
750 V	0.93	0.93	1.01

From the CCE measurements the reverse annealing seems suppressed (at least at very high voltages). Is it a real suppression of the reverse annealing in p-type silicon, or rather a feature of the measurement?

There are no available CV measurements of the p-type material annealing at those high doses. The only available measurements are on pad diodes made of same material as the miniature detectors. They were irradiated to 3 10^{14} p cm^{-2}, and show a six times increase of V_{fd}, after 4 years of annealing time @ 20°C.



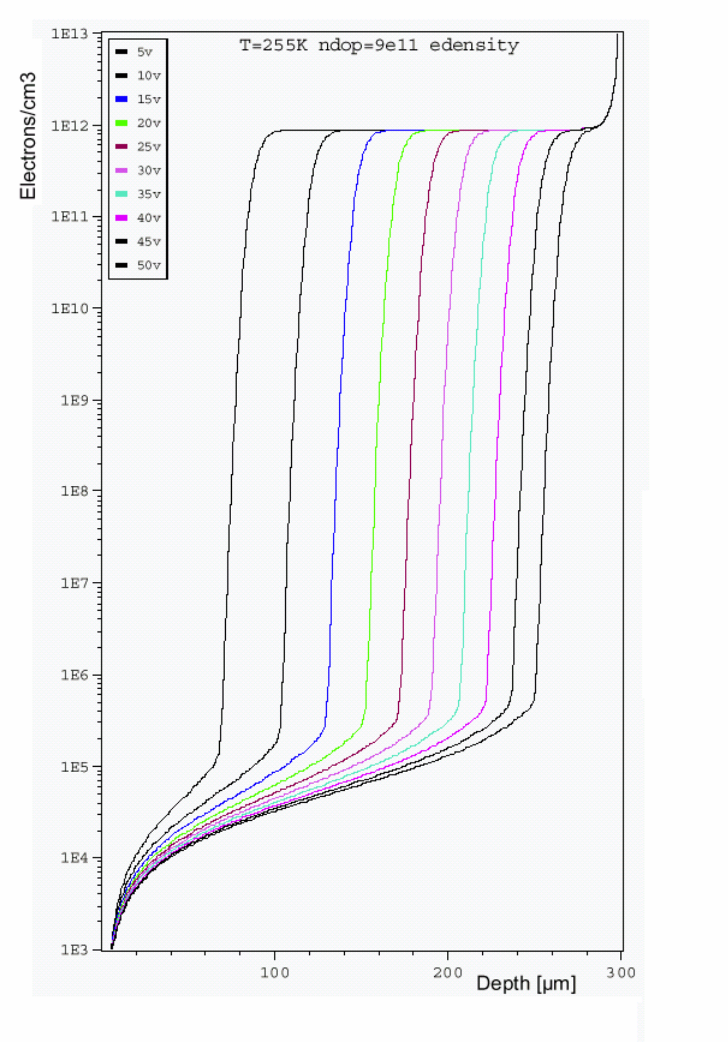
The annealing of the p-type substrate shows the same (possibly worse) changes of the n-type substrate. The differences between the CCE and CV results must be related to the measurement.

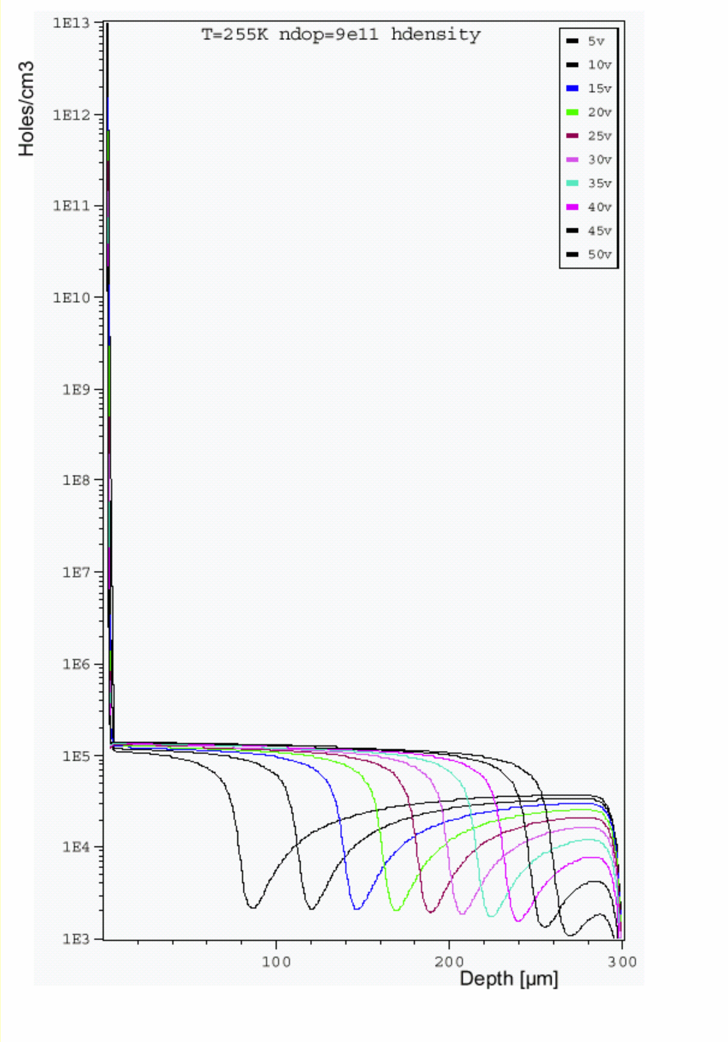
From the information available on CV-measurements of p-type detectors irradiated to lower doses, the reverse annealing seems to take place in a way similar to the n-type devices. If we assumed that the predictions on the V_{FD} changes of n-type silicon with time after irradiation are valid for the p-type, the CCE measurements are in a sharp disagreement with the CV measurements. It is noticeable that for the three different fluences, and at all voltages (even at the lowest voltage measured, namely 300 V after 1.1 10^{15} cm^{-2}, and 500 V after 3.5 and 7.5 10^{15} cm^{-2}), the collected charge doesn't decrease sensitively up to 3 years at R.T. For the higher voltages the **CCE remains flat** after several year of equivalent R.T. annealing, while the V_{FD} changes by **more than a factor of 4!** This shows that the description of the relevant detector properties (CCE with mip signals) extrapolated from the measurements of the V_{FD} with CV methods is not complete and can lead to erroneous predictions. For very high level of irradiation, an accurate measurement of the electric field profile in the detector would be preferable (essential) for the description of the detector performances.

Conclusions

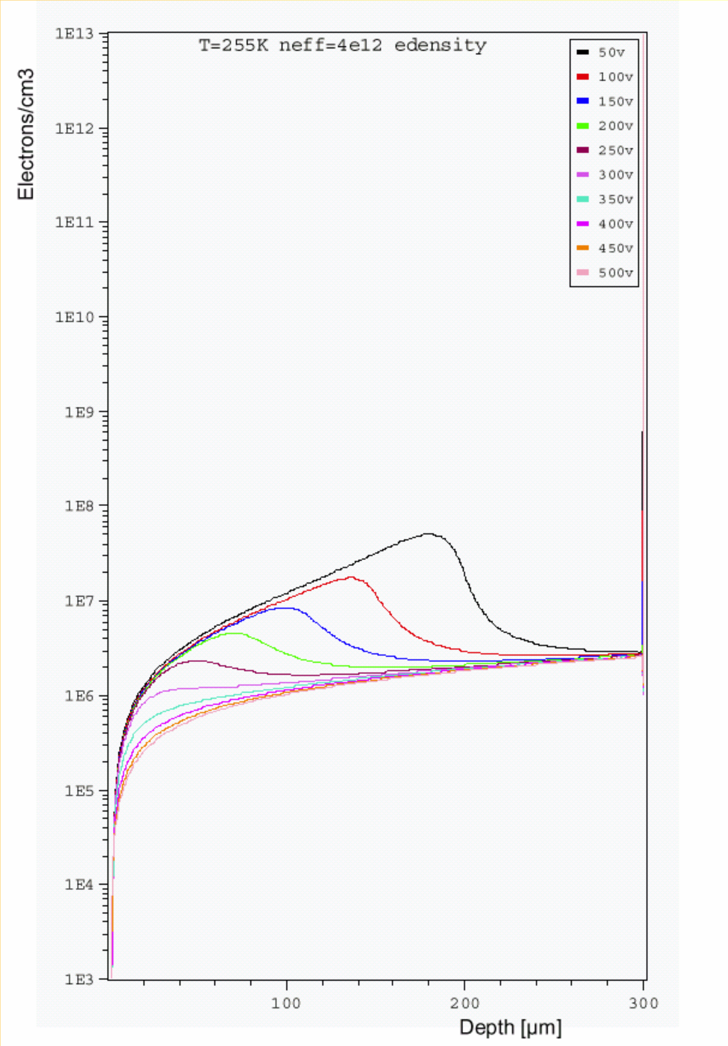
We have shown that the annealing of the CCE after severe irradiation remains flat at very high voltages. Also the noise of the detector remains unchanged during the annealing, so it is actually the S/N that remains almost constant for several years at RT. After this results, the necessity of keeping the tracker detectors in the experiments (assuming they are n-side read-out) at room temperature for any length of time (e.g. for maintenance purposes) is not a problematic issue as it has always been assumed. We want to stress out that the cooling of the detectors during operation is not only related to the control of the reverse annealing, but it is essential to keep the reverse current below the limit of thermal run-away. The operation temperature of the detectors is therefore not affected by the results concerning the reverse annealing.

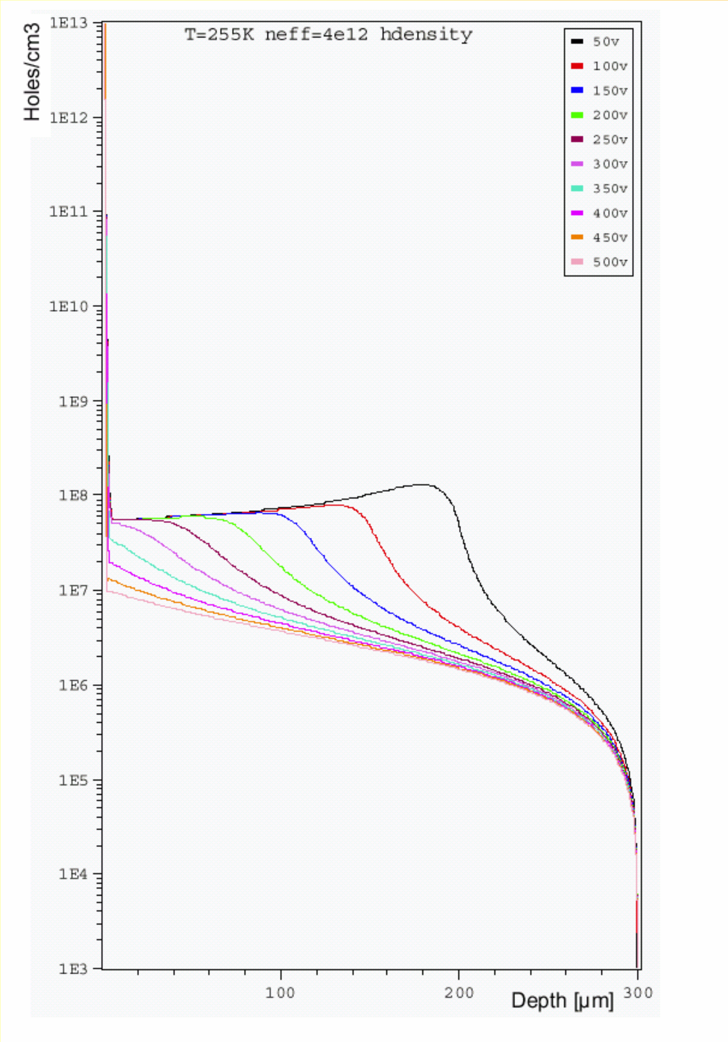
Non irradiated device





Irradiation fluence 6. 10^{14} p cm^{-2}



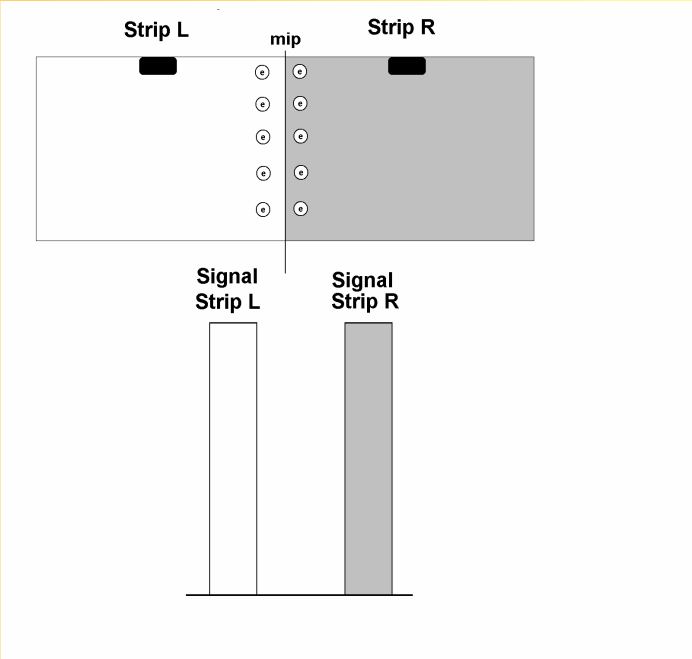


Purpose

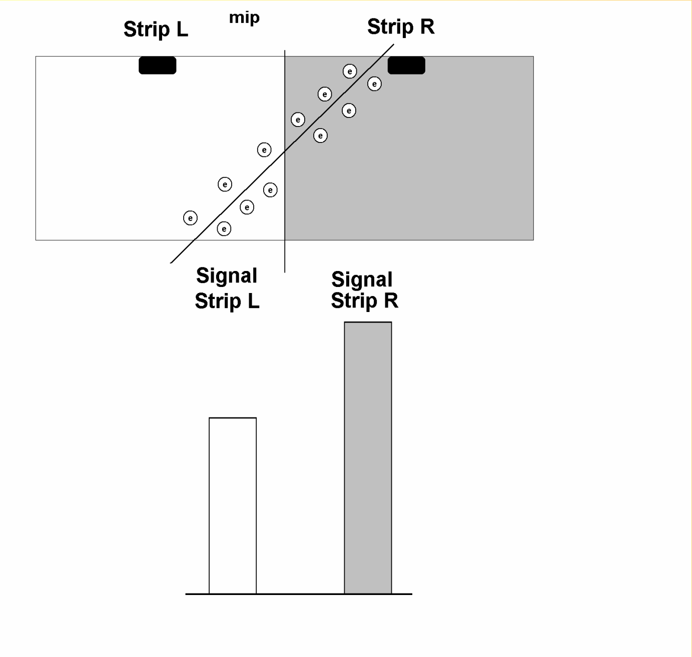
- Estimation of the shift in the reconstructed position for angular tracks in a typical LHCb VELO detector geometry

Why do we expect distortion of the resolution?

Case of normal impact in the midpoint between two strips: equal signal on both strips irrespectively of irradiation



Case of angular incidence where the mid-plane between the two strips is crossed at half the detector thickness: expected equal signal on both strips, but the collection time of the charge drifting towards strip L is larger due to distance and lower field. This introduces a distortion which varies with irradiation.



Programme

- ISE TCAD
  - DESSIS V7.5
  - Complete model of geometry (2D)
  - Complete model of processing
  - All semiconductor effects taken into account
  - Radiation effects parameterized by 4 Energy levels in band gap
  - Each iteration takes 16hours

Model Parameters

- Sensors
  - PR-03 at 295µm
    - Pitch 32.5 and 70µm
    - PR-03 geometry
  - PR-04 at 295µm
    - Pitch 50 µm
    - PR-04 geometry
- Track angles
  - 0 and 9°
- Bias Voltages
  - 70,140,300,400V
- Radiation
  - 0, 3×10^{14}, 3×10^{14}p/cm^2

Investigate

- Charge sharing
- Peak sampling time

Cluster Profile Example

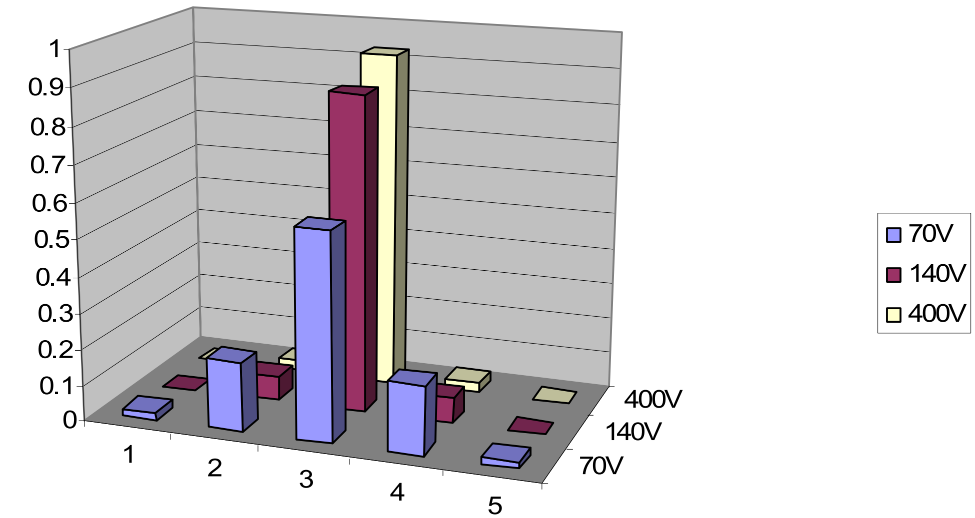
PR-03 32.5µm 0deg

Unirradiated

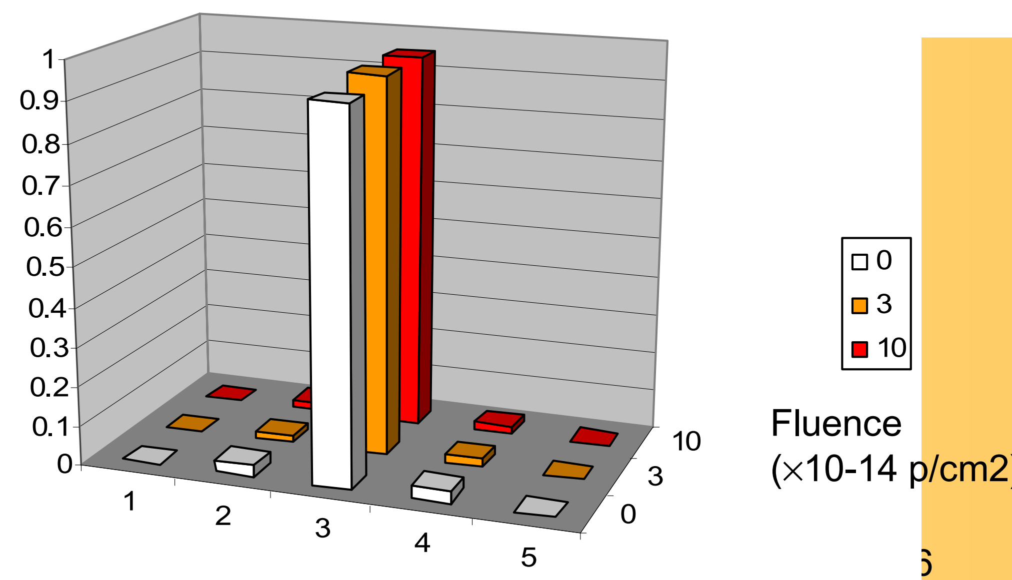
Normal incidence over middle

Strip

Cluster Shape v Voltage



PR-03 32.5µm 0deg
Normal incidence over middle
Strip at 400V
Cluster Shape v Fluence



Cluster Profile Example

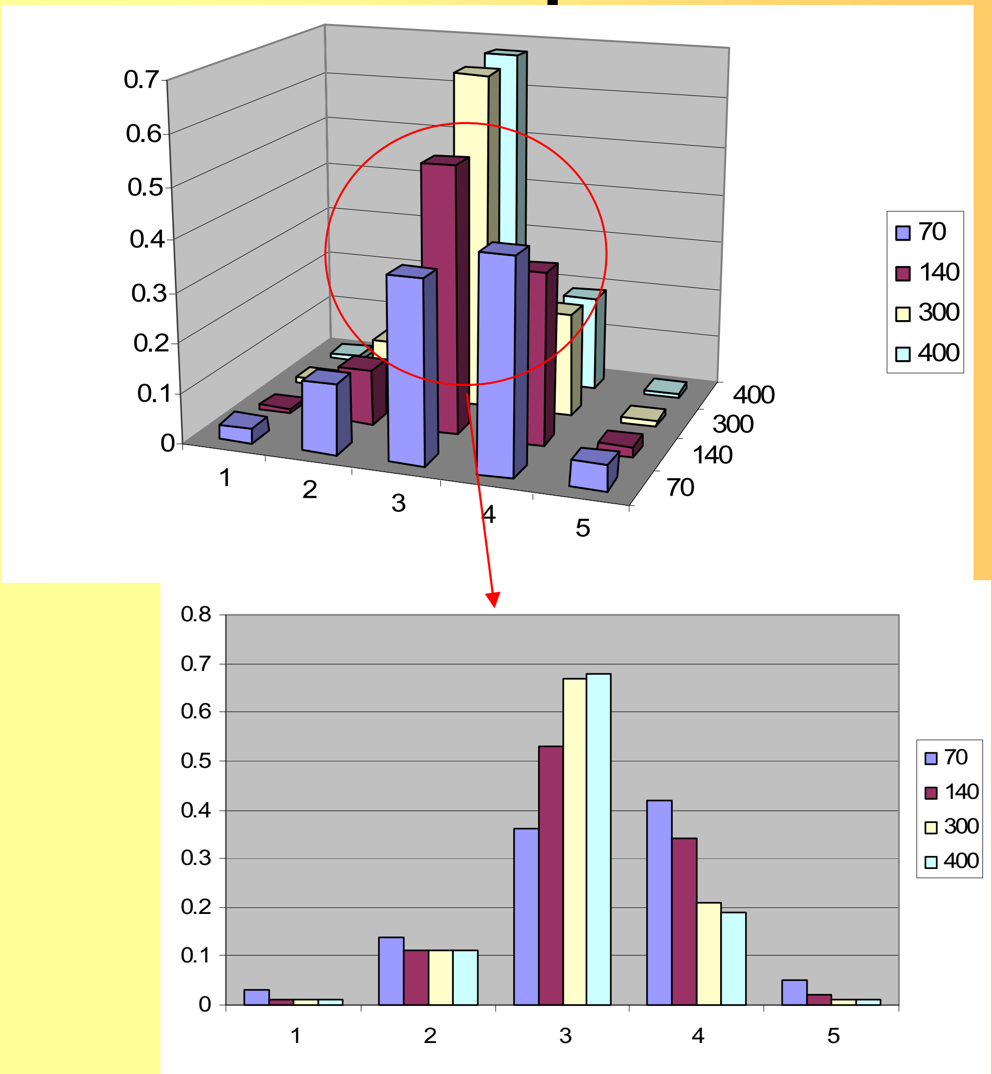
PR-03 32.5µm 0deg

Unirradiated

9° incidence over middle

Strip

Cluster Shape v Voltage



Note change of cluster "mode" strip

Cluster Profile Example

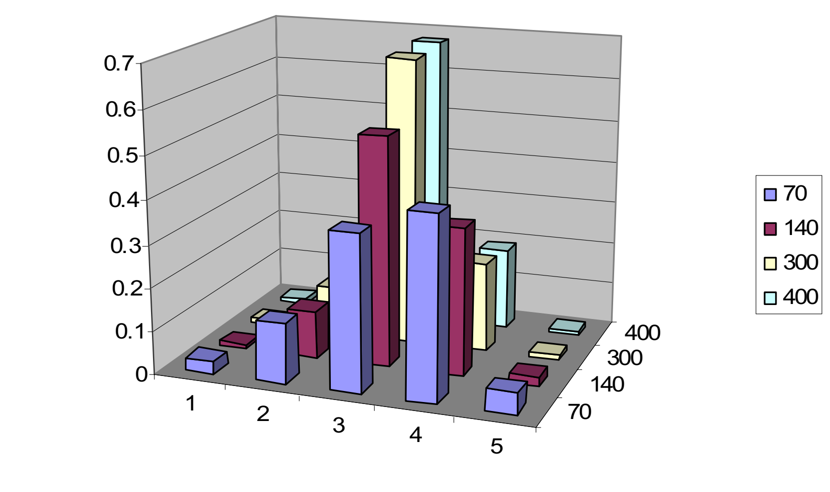
PR-03 32.5µm

Unirradiated

9° incidence over middle

Strip

Cluster Shape v Voltage



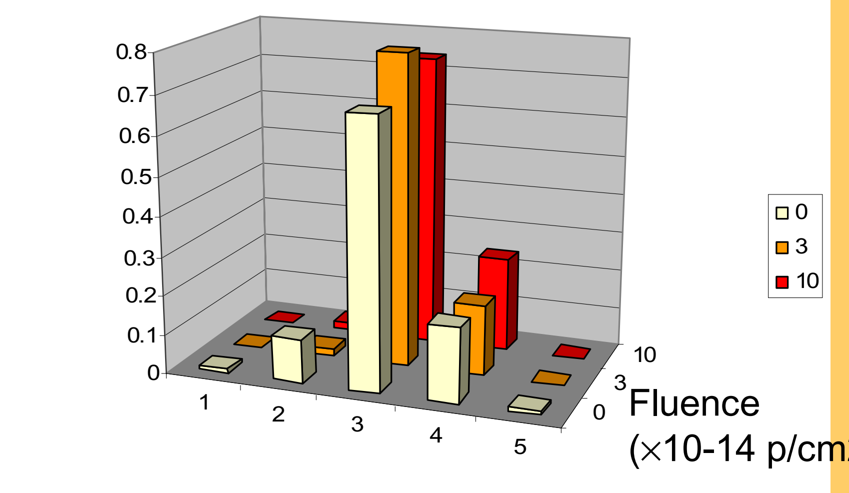
PR-03 32.5µm

Irradiated 400V

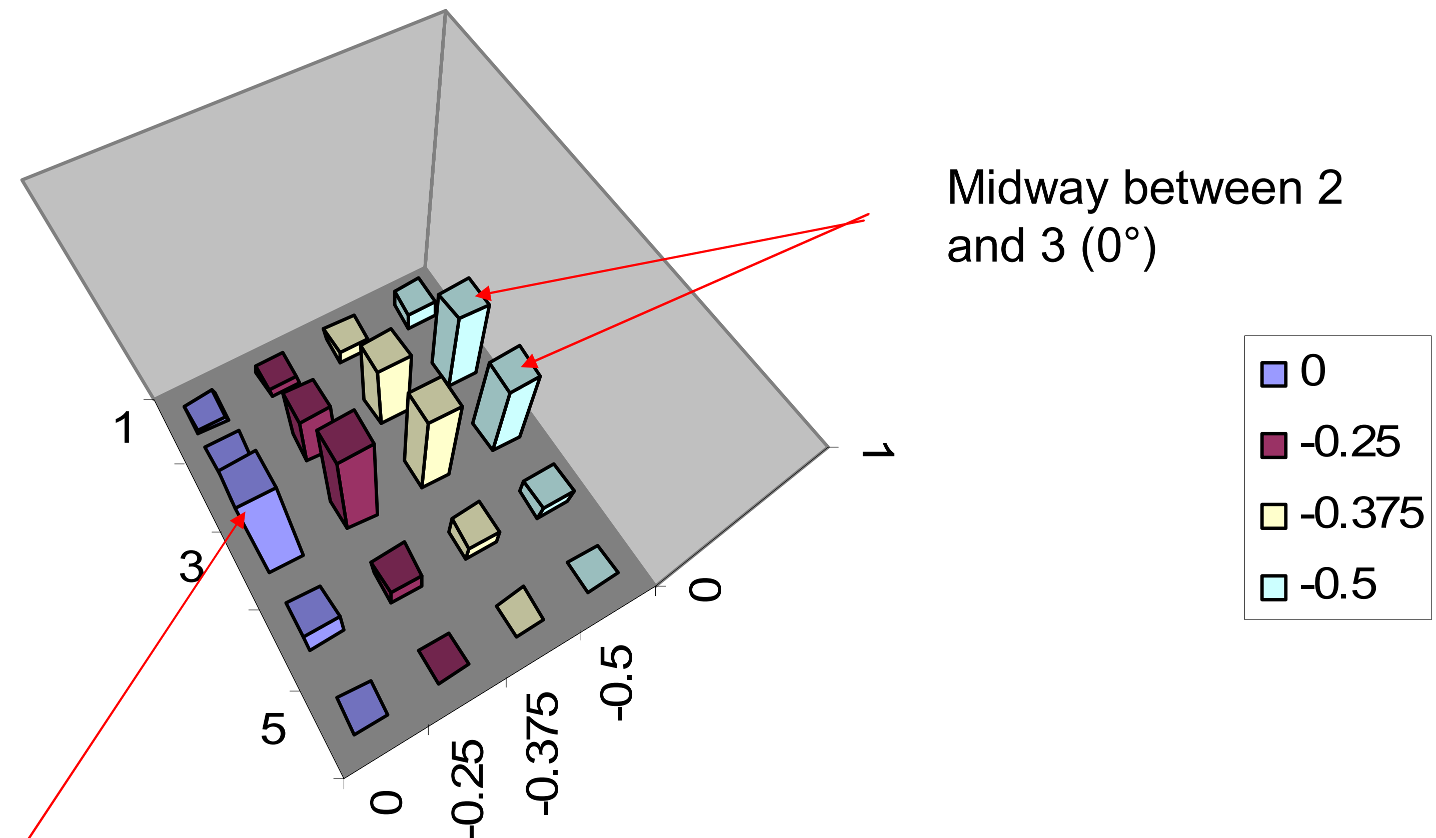
9° incidence over middle

Strip

Cluster Shape v Fluence



Cluster Profiles Example



Midway between 2 and 3 (0°)

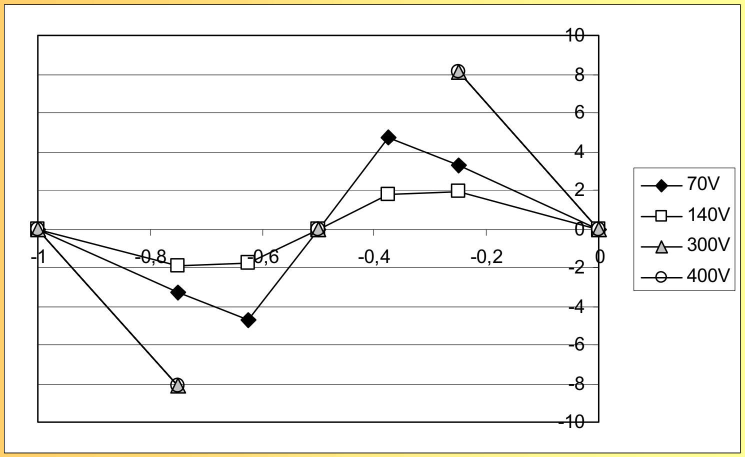
Centred on strip 3 (0°)

Cluster Profiles

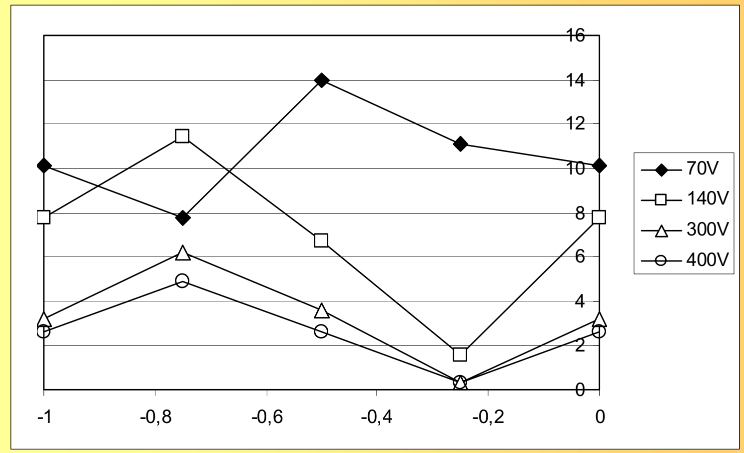
- Lot of information
  - PR-03 32.5: 0°,9°
  - PR-03 70.0: 0°,9°
  - PR-04 50.0: 9°
- Function of Voltage and Fluence!

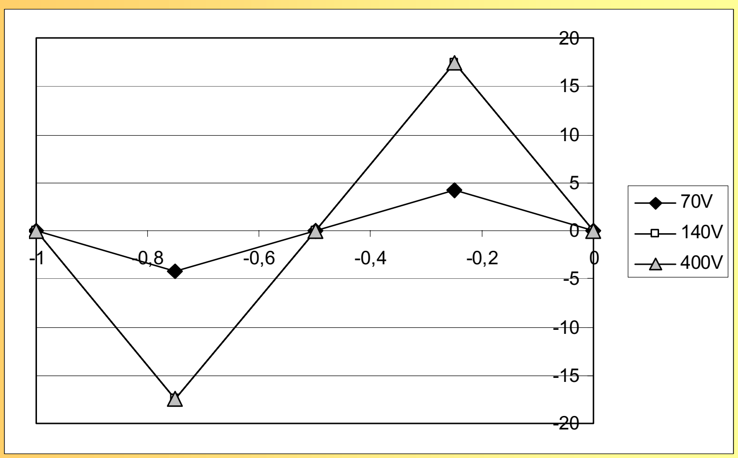
“Shift Errors”

32.5 pitch, 0° Incidence

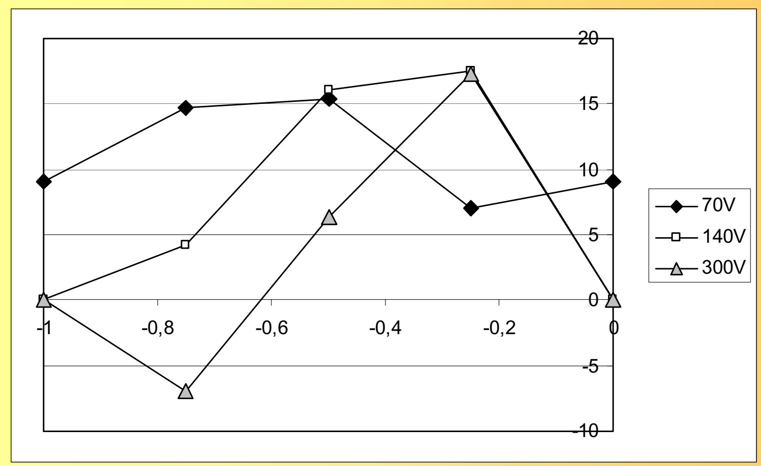


32.5 pitch, 9° Incidence





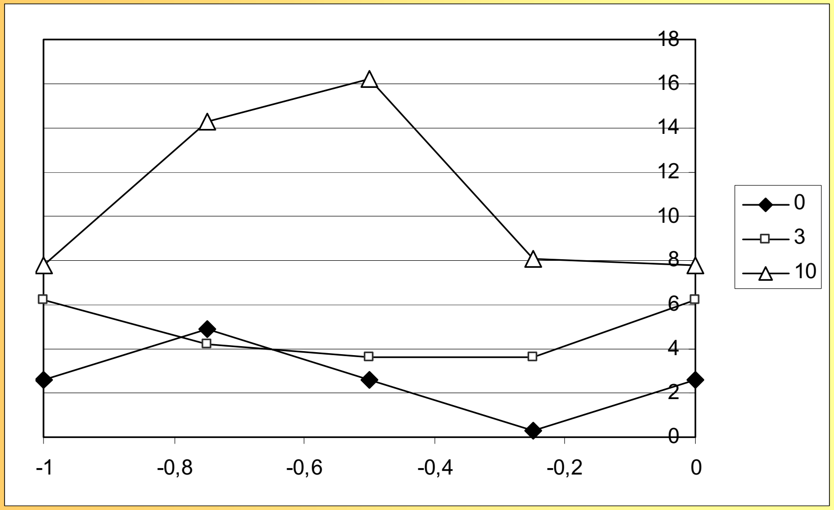
70.0 pitch, 0° Incidence



70.0 pitch, 9° Incidence

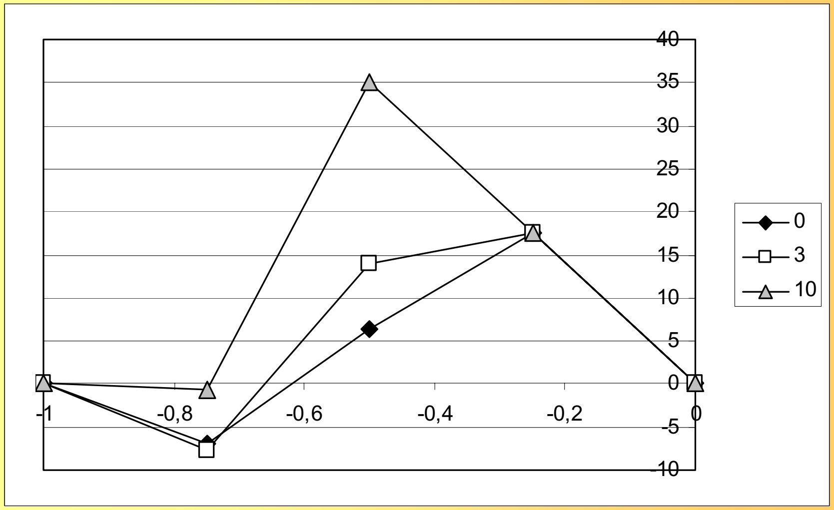
Shift Error with Radiation

32.5 pitch, 9° Incidence



Fluence
(×10-14 p/cm2)

70 pitch, 9° Incidence



Fluence
(×10-14 p/cm2)

Inclined tracks have more problems

As detector degrades effects appear to get larger

Summary

- Low voltages (even if above depletion, up to 140V): diffusion gives some charge sharing
- AT high voltage (300, 400V) there is almost no diffusion: the η function is determined by geometric overlap
- Asymmetric charge sharing is found for hits at angles different from 0^{o}
- The asymmetry depends on radiation: large at high doses and low electric field (low bias)
- At high fields asymmetry is small and almost radiation independent
- The charge at high fields is though contained to 1 strip for larger pitches (worsening resolution). The number of 1 strip hits is reduced with thicker detector (300 μm) (geometric overlap)