UNIVERSITY OF LIVERPOOL

Enhanced efficiency of segmented silicon detectors of various thicknesses after hadron irradiations up to 2×10^{16} n_{eq} cm^2.

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OUTLINE

- Comparison of thin and thick sensors after neutron and proton irradiation
- Studies at low temperature (-50^{o}C)
- Non-linearity of N_{eff} vs Φ
- Conclusions

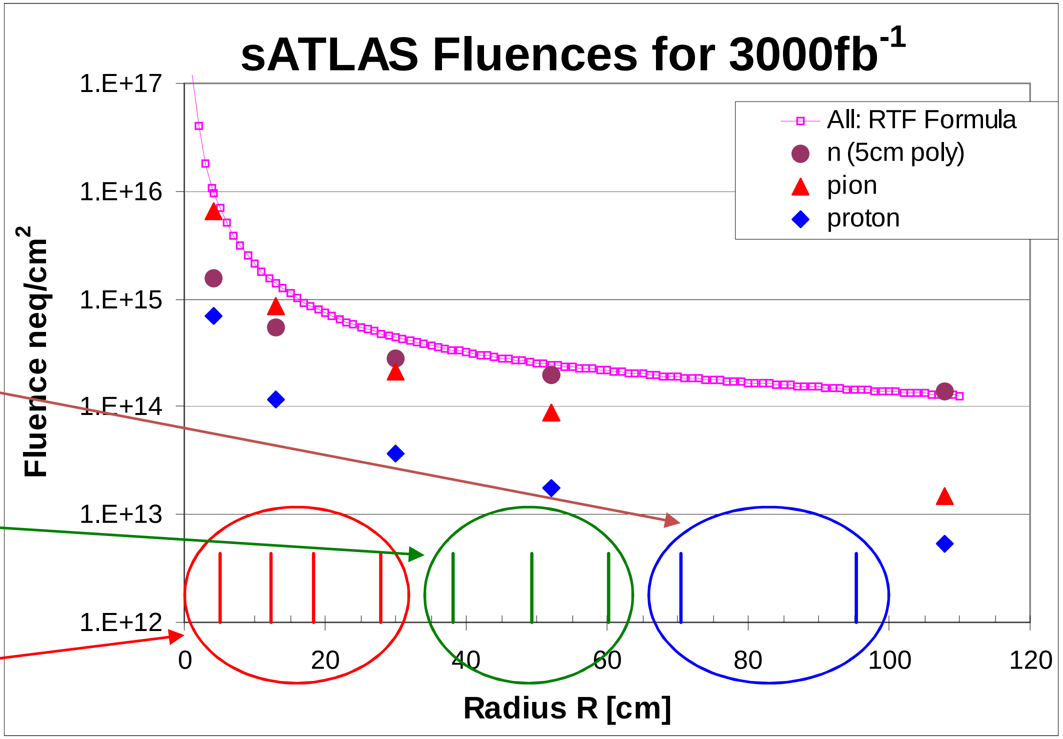
Fluence in Proposed sATLAS Tracker

Strip length and segmentation determined by occupancy< 2%

LongStrips

ShortStrips

Pixels



ATLAS Radiation Taskforce http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RADIATION/RadiationTF_document.html

Mix of neutrons, protons, pions depending on radius R

Long and short strips damage largely due to neutrons

Pixels damage due to neutrons and pions

Design fluences for sensors (includes 2x safety factor) **:**

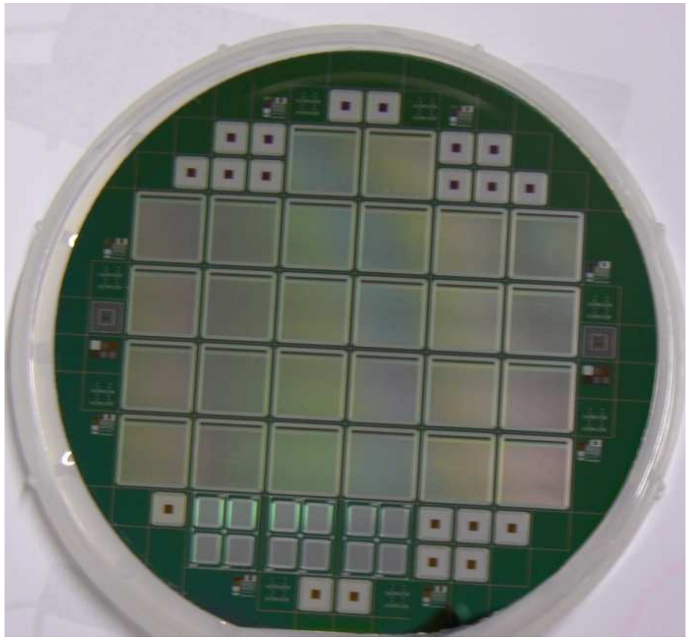
Innermost Pixel Layer:	$1\text{-}1.6*10^{16}\ n_{eq}/cm^2 = 500$ Mrad
Outer Pixel Layers:	$3*10^{15}\ n_{eq}/cm^2 = 150$ Mrad
Short strips:	$1*10^{15}\ n_{eq}/cm^2 = 50$ Mrad
Long strips:	$4*10^{14}\ n_{eq}/cm^2 = 20$ Mrad

Need to study response to both neutral (neutrons) and charged (proton) particle irradiations

Silicon miniature microstrip detectors and irradiation

RD50 mask set (see: http://rd50.web.cern.ch/rd50/)

Miniature sensors, ~1x1 cm^2, 128 strips, 80 µm pitch, designed by Liverpool and produced by Micron on 300µm and 140µm thick wafers.



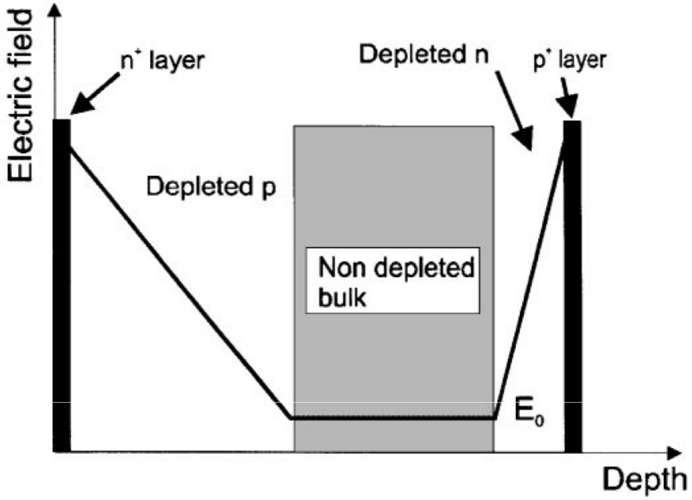
Irradiation and dosimetry:

Neutron:
TRIGA Mark II research reactor
Reactor Centre of the
Jozef Stefan Institute, Ljubljana, Slovenia, thanks to V. Cindro

24GeV protons:
CERN-PS Irrad1, irradiated at area temperature (~30°C) and cold (<5°C). thanks to M. Glaser.
26 MeV protons:
Compact Cyclotron of the University of Karlsruhe, thanks to A. Dierlamm and W. de Boer.

N-side read-out can make planar segmented Si detectors suitable for tracking in extreme (SLHC levels: 1-2x10^{16} cm^{-2}) radiation environments.

Schematic changes of Electric field after irradiation



Effect of trapping on the Charge Collection Efficiency (CCE)

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

Collecting electrons provide a sensitive advantage with respect to holes due to a much shorter t_c. P-type detectors are the most natural solution for *e* collection on the segmented side.

N-side read out to keep lower t_c

Effect of trapping on the Charge Collection Distance

$$Q_{tc} \cong Q_0 \exp(-t_c/\tau_{tr}),\ 1/\tau_{tr} = \beta\Phi.$$

$$v_{sat,e} \times \tau_{tr} = \lambda_{av}$$

$\beta_e = 4.2\mathrm{E}{-}16\ \mathrm{cm}^{-2}/\mathrm{ns}$

$\beta_h = 6.1\mathrm{E}{-}16\ \mathrm{cm}^{-2}/\mathrm{ns}$

G. Kramberger et al., NIMA 476(2002), 645-651.

After heavy irradiation the charge collection distance (CCD) of thin detectors should have a similar (better?) charge collection efficiency (CCE) as thicker ones.

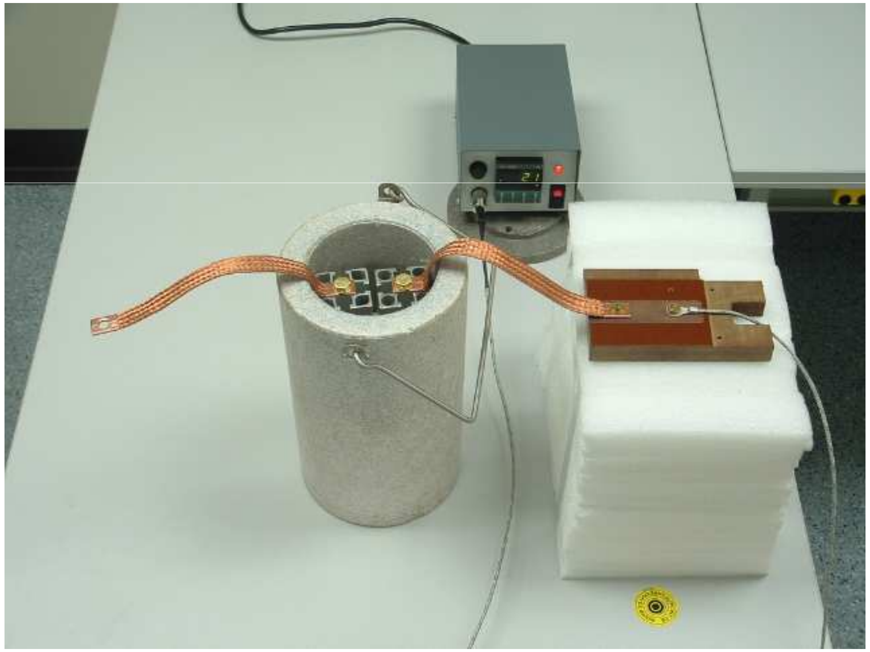
$$\lambda_{av}\ (\Phi=1e14) \cong 2400\mu m$$

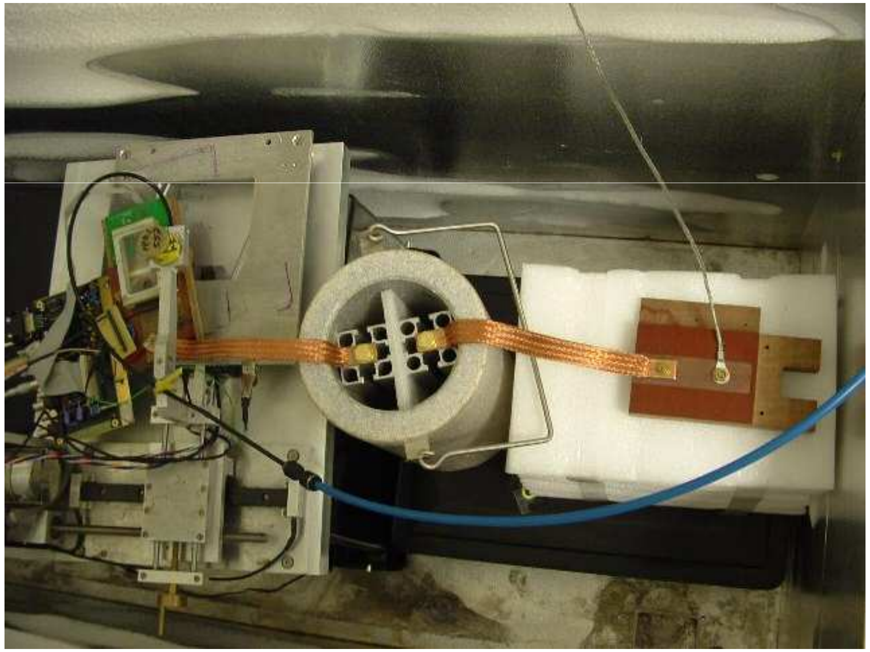
$$\lambda_{av}\ (\Phi=1e16) \cong 24\mu m$$

The reverse current is proportional to the depleted volume in irradiated detectors. Do thin sensors offer an advantage in term of reduced reverse current compared to thicker ones (this aspect is particularly important for the inner layer detectors of SLHC, where significant contribution to power consuption is expected from the sensors themselves)?

MEASUREMENTS: at -25 and -45/50 ^{o}C.

Cooling: “cold finger” system in liquid nitrogen bath. 40MHz analogue readout. ^{90}Sr with plastic scintillator trigger, with plastic filter to remove the lower energy electrons (mip’s). MP value is measured, calibration with a 300μm non irradiated sensor.

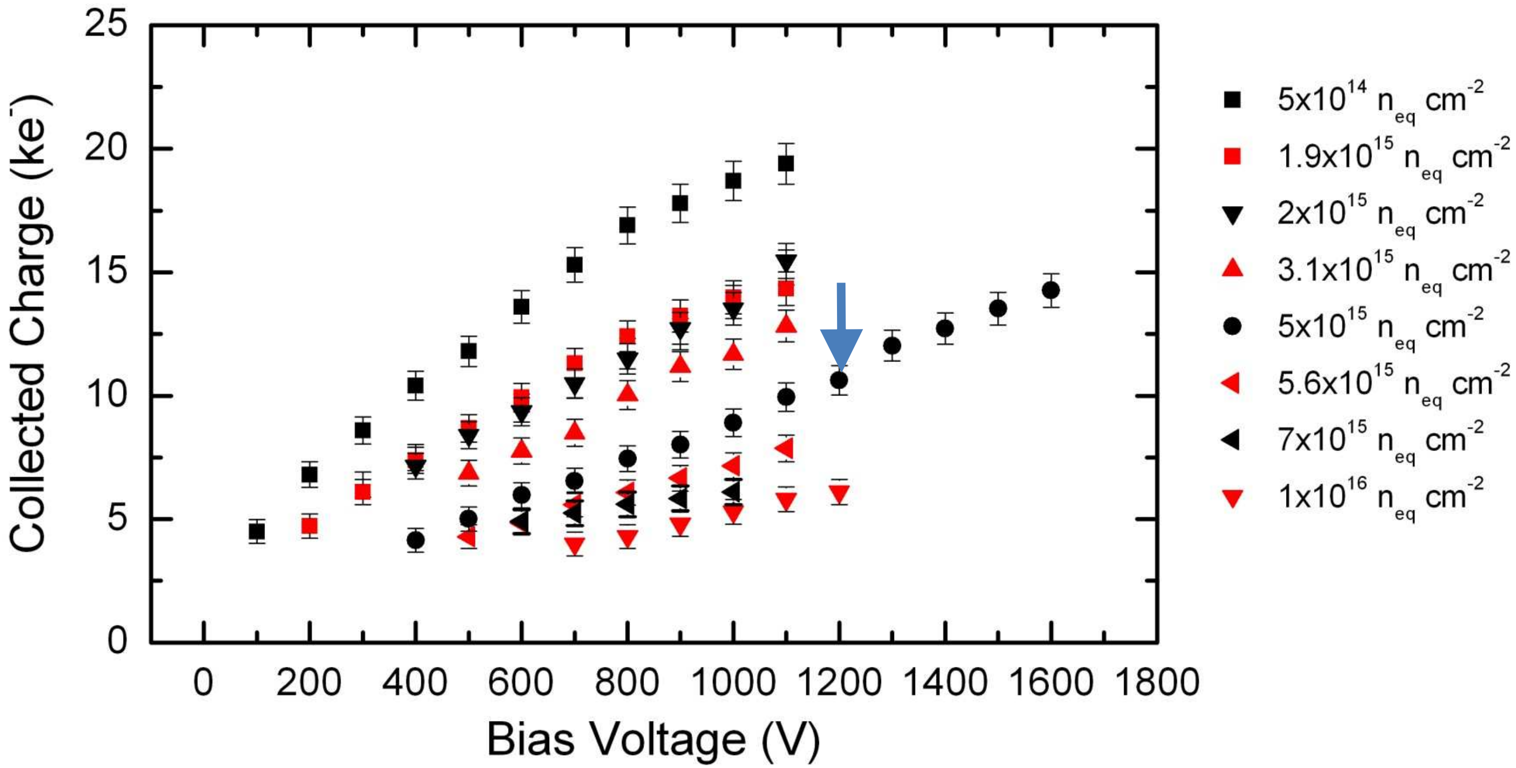




Results with proton irradiated 300 μm n-in-p Micron sensors (up to 1x10^{16} n$_{eq}$ cm^{-2})

RED: irradiated with
24GeV/c protons
Other: 26MeV protons

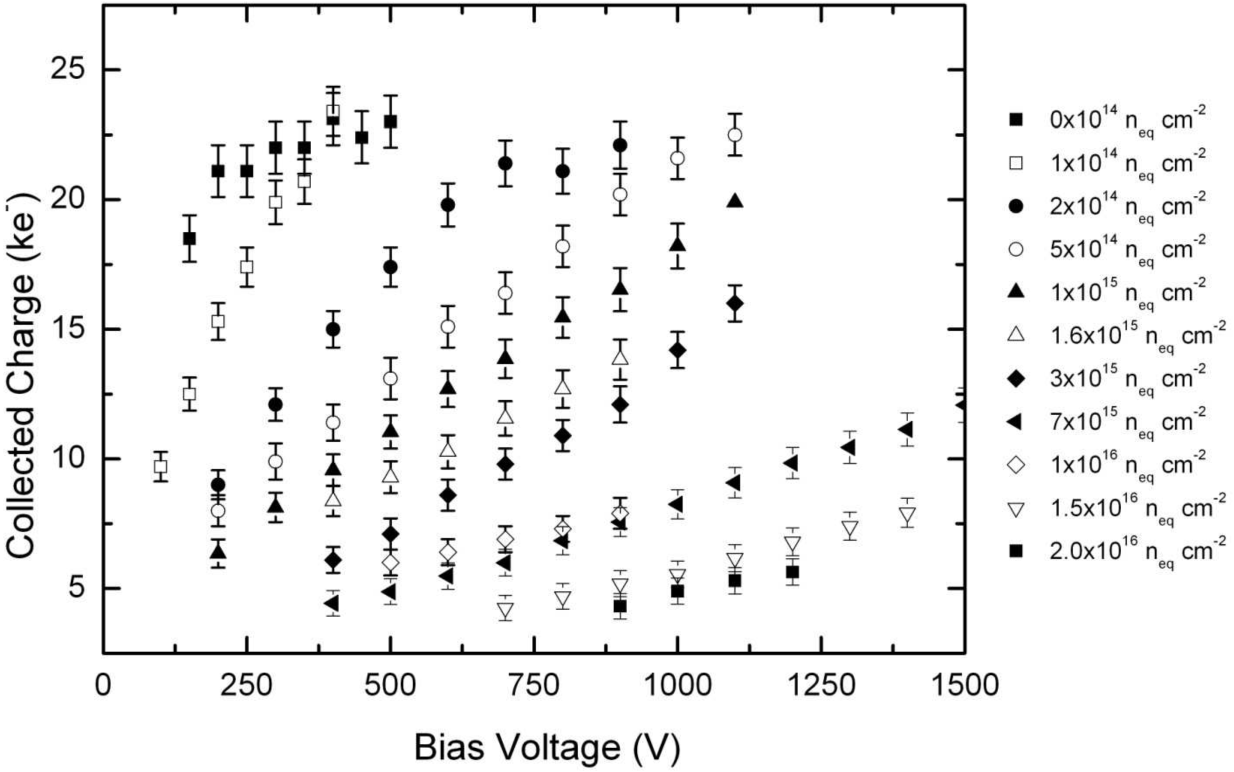
24GeV/c protons irradiated COLD,
all but the 3.1E15 cm^{-2} series,
which had ~ 10 days @ 33°C



Results with neutron irradiated 300 μm n-in-p Micron sensors (up to $2x10^{16}$ n_{eq} cm^{-2})

Short irradiation time, practically no annealing

After both p and n irradiations, the collected charge is much higher than expected from charge trapping measurements (<2000e after $1x10^{16}$ cm^{-2}).

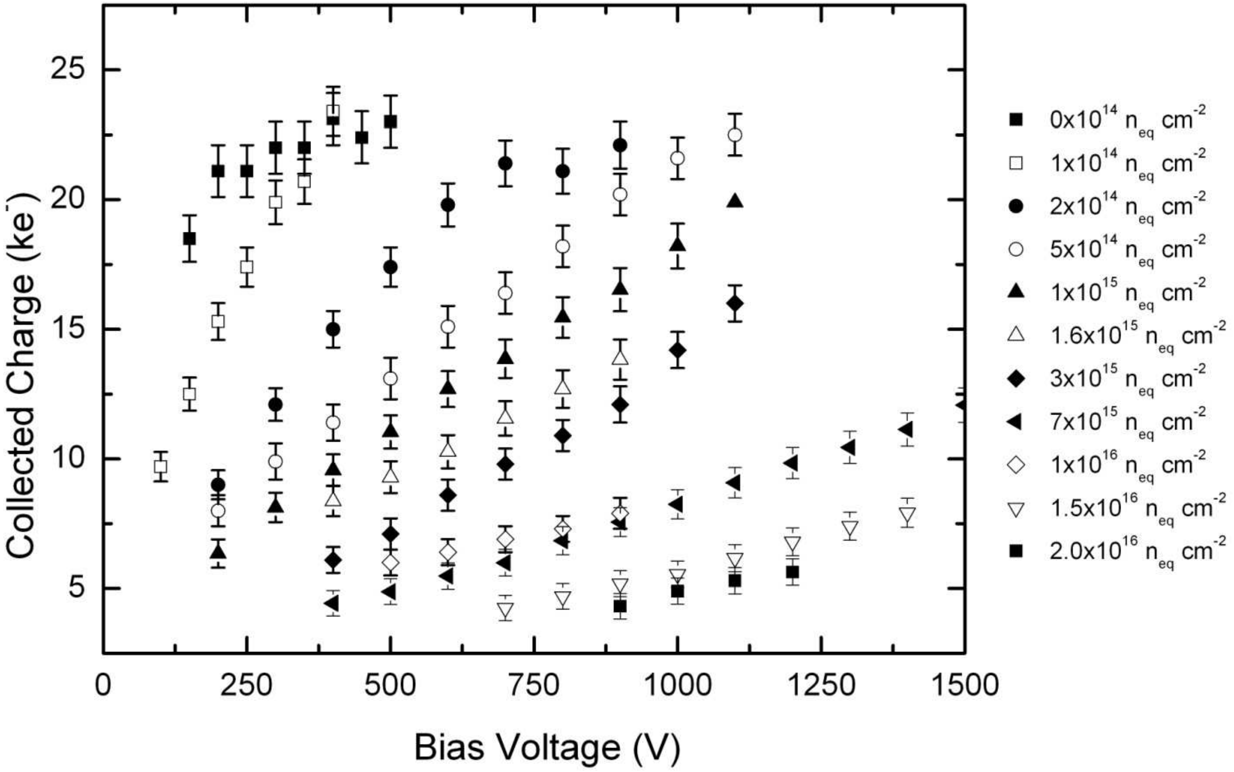


G. Casse, 11th ESSD, Wildbat Kreuth, 7-11 June 2009.

Results with neutron irradiated 300 μm n-in-p Micron sensors (up to 2×10^{16} n_{eq} cm^{-2})

Short irradiation time, practically no annealing

Is there a mechanism to explain this enhanced signal, at high bias voltages and after heavy irradiation?

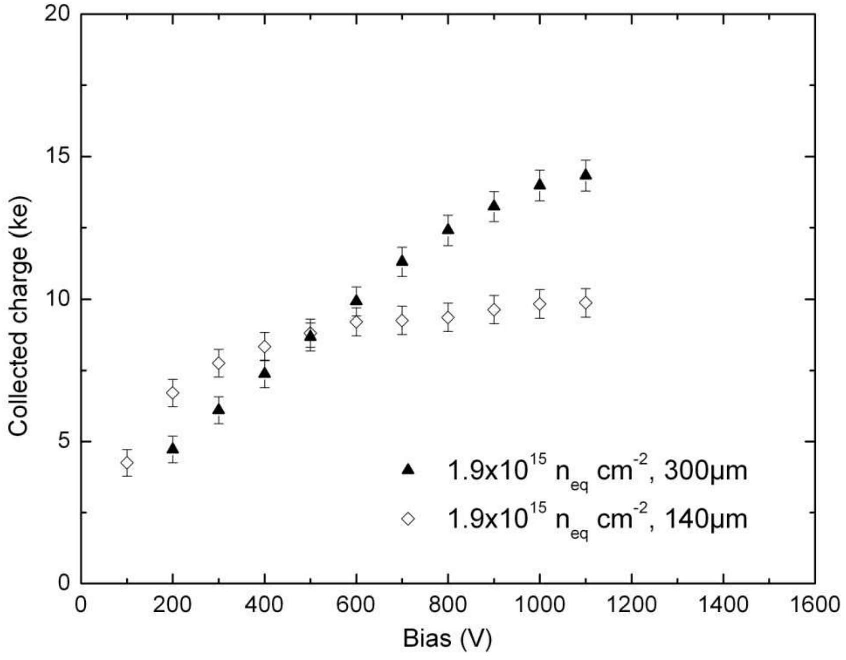


G. Casse, 11th ESSD, Wildbat Kreuth, 7-11 June 2009.

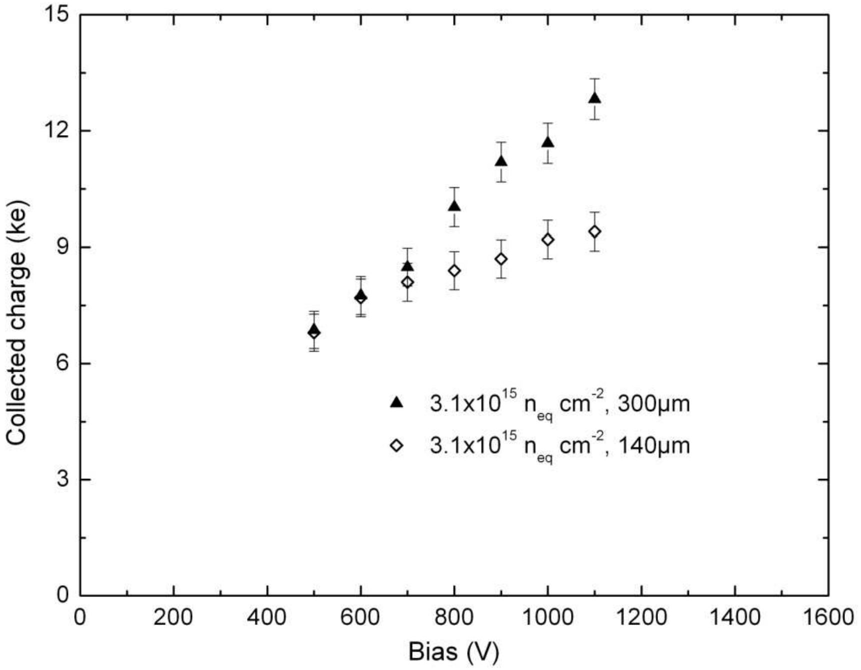
This was achieved with 300μm thick sensors (High Energy Physics standard). The collected charge after extreme doses is much higher than expected from the dependence of τ_{tr} with fluence. Moreover, can thin devices be even better?

140 and 300 μm n-in-p Micron sensors after 1.9 and 3.1×10^{15} n_{eq} 24GeV/c p

Cold(0-5 °C) irradiation

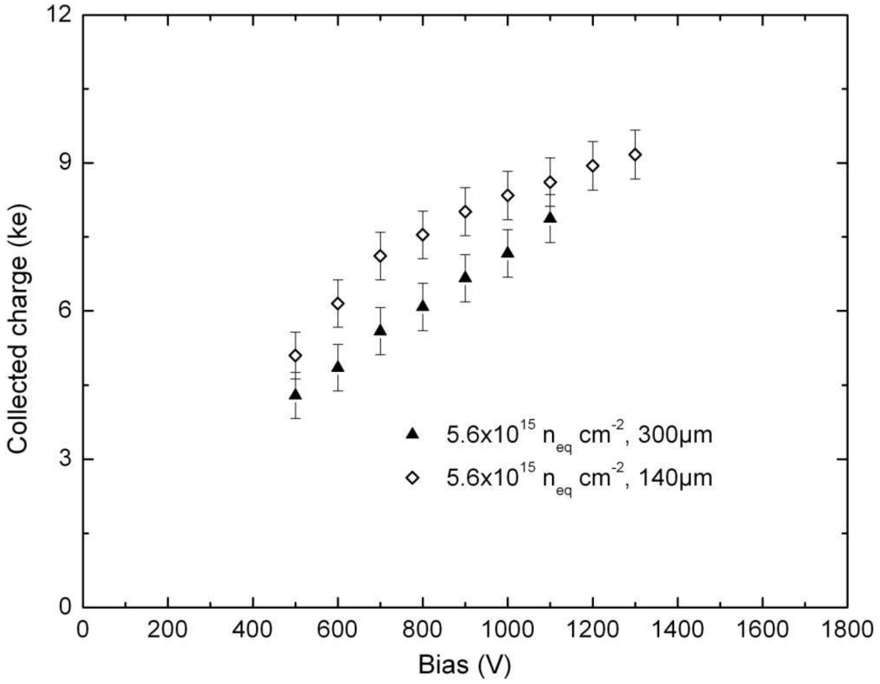


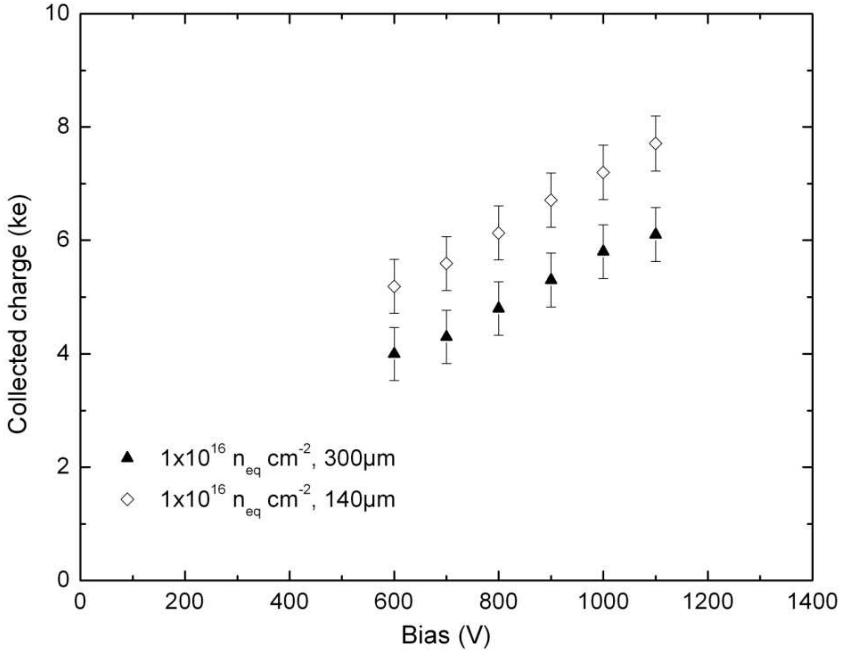
Room T (29-31 °C) irradiation



140 and 300 μm n-in-p Micron sensors after 5.6 and $1x10^{16}$ n_{eq} 24GeV/c p

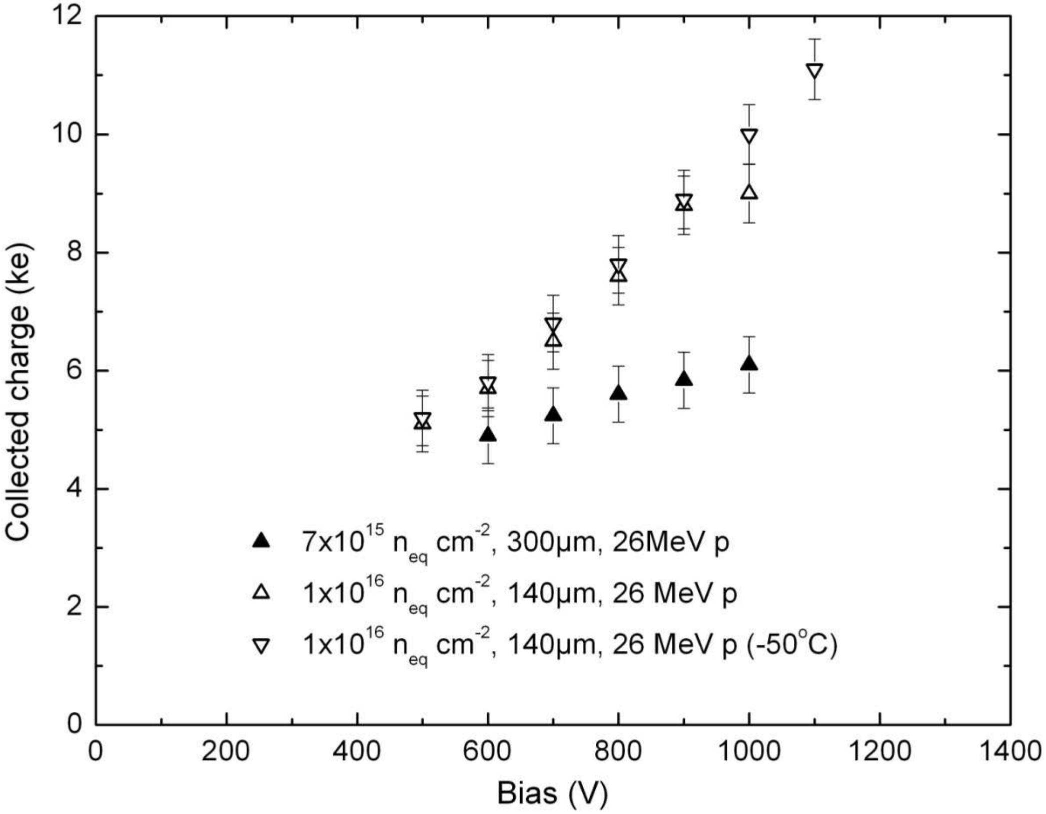
Cold(0-5 °C) irradiation





140 and 300 μm n-in-p Micron sensors after 1x10^{16} n$_{eq}$ 26MeV p

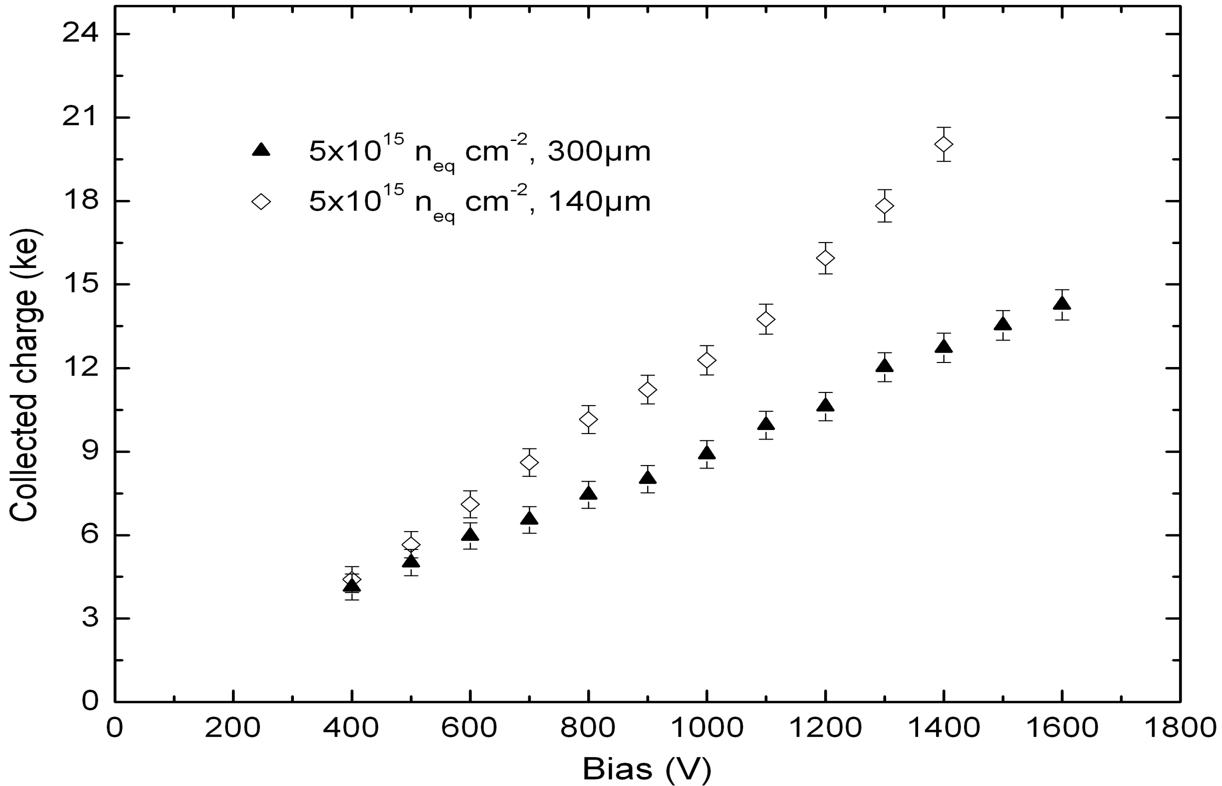
Even after heavy irradiation it is possible to recover the whole ionised charge (the 140μm thick sensors collects here ~12000e).



G. Casse, 11th ESSD, Wildbat Kreuth, 7-11 June 2009.

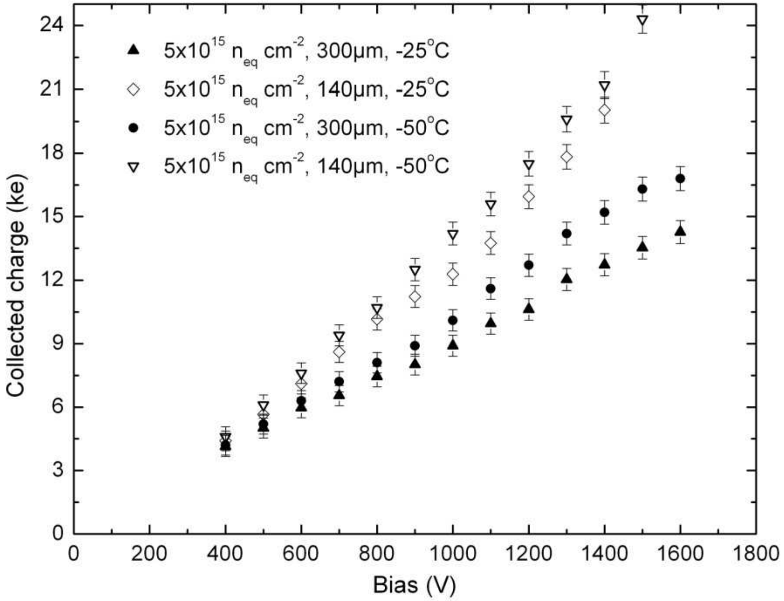
140 and 300 μm n-in-p Micron sensors after 5×10^{15} n_{eq} 26MeV p

Evidence of a charge multiplication effect: not only the whole charge is recovered, but increased by f = 1.75

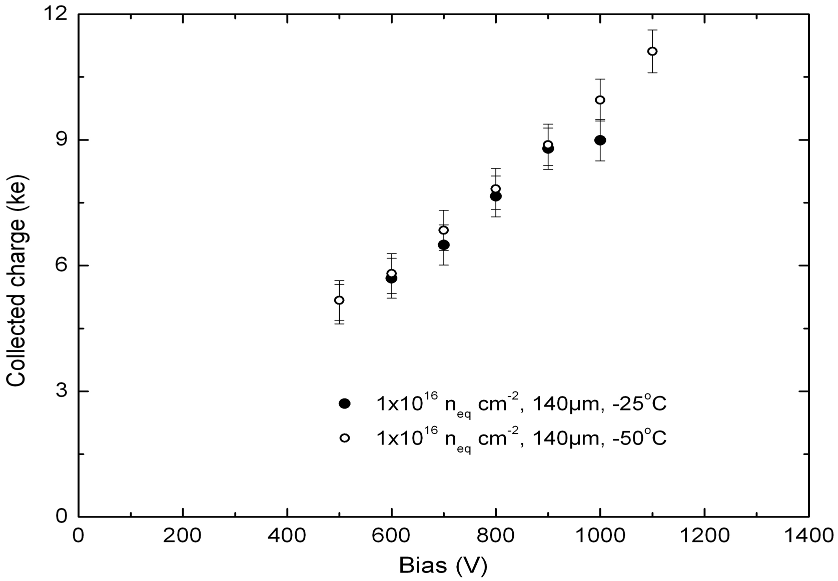


140 and 300 μm n-in-p Micron sensors after 5 (26MeV p) and 10x10^{15} n$_{eq}$ (24GeV/c p) at low (-50°C) T.

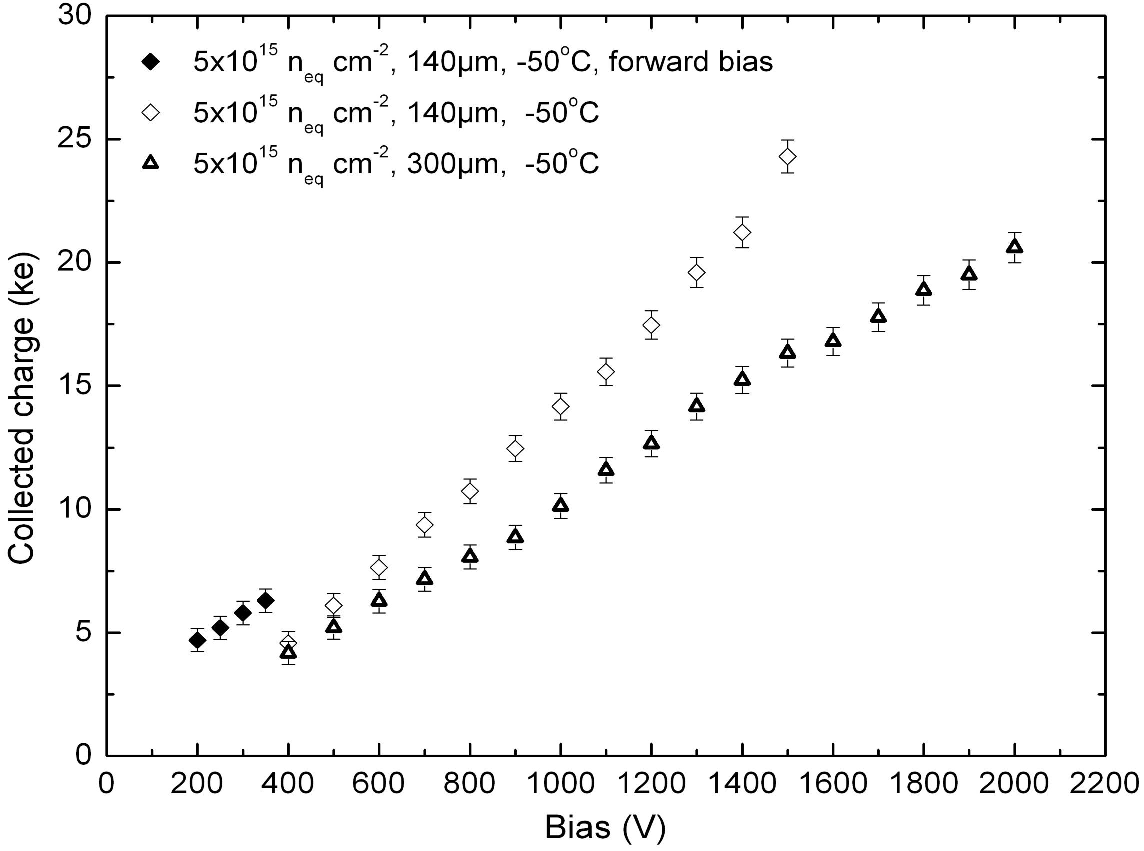
F = 2.1 at -50°C!



Pre-irradiation charge recovered after 1x10^{16} n$_{eq}$.

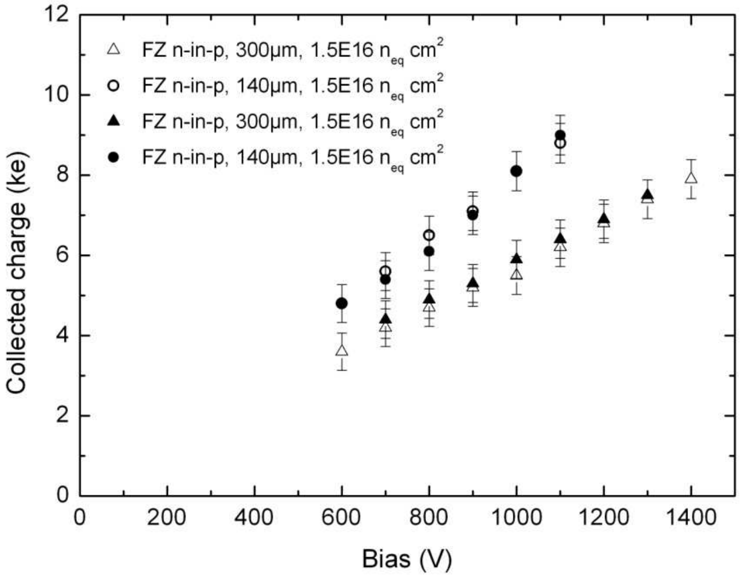


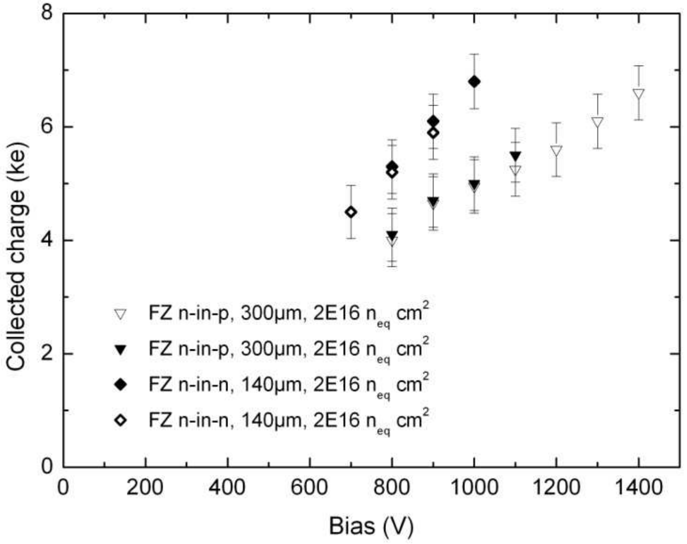
Special effects: forward bias

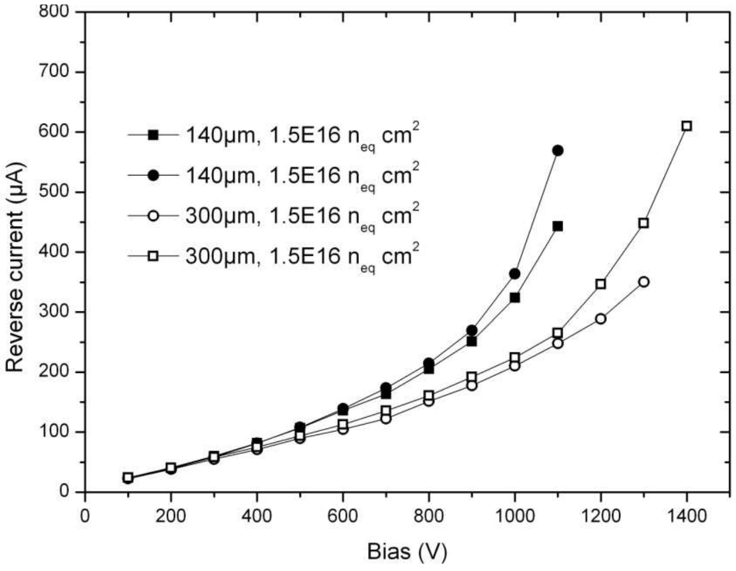


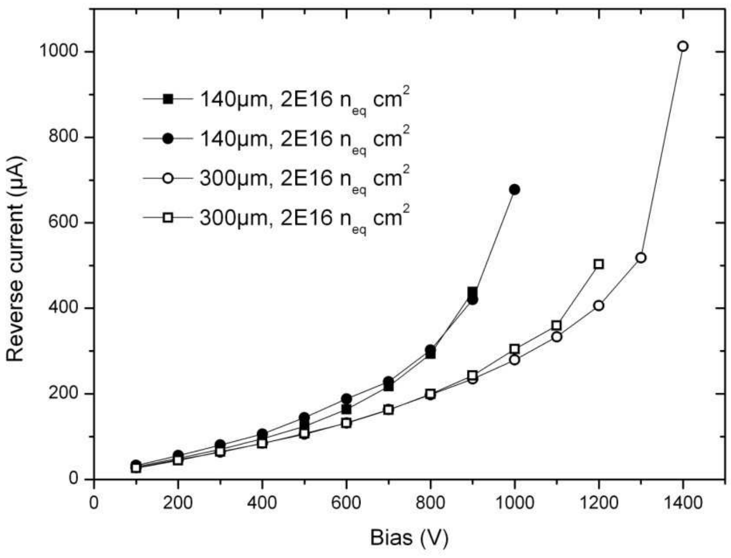
The 140µm detectors could also be operated in forward bias (unlike the thicker devices). The CCE was surprisingly higher than at the corresponding reverse bias voltage, up to the maximum applicable bias before thermal runaway.

CCE and currents after neutron irradiations after 1.5 and 2x10^{16} n_{eq} cm^{-2}









G. Casse, 14th RD50, Freiburg 5-7 June 2009.

CONCLUSIONS

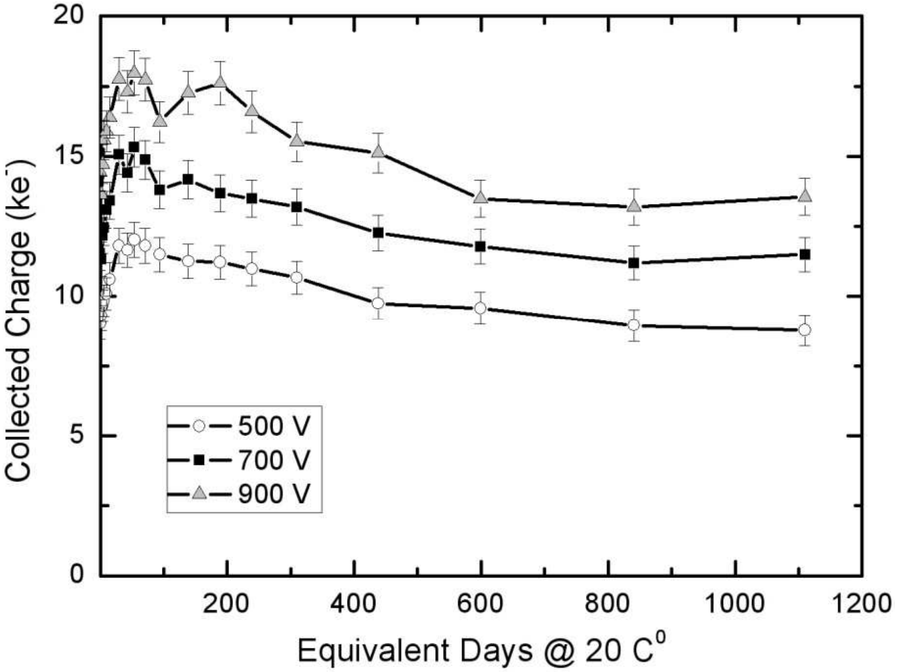
A much enhanced CCE is measured with proton and neutron irradiated diodes after extreme doses (equivalent to the anticipated doses for the innermost pixel layers of SLHC).

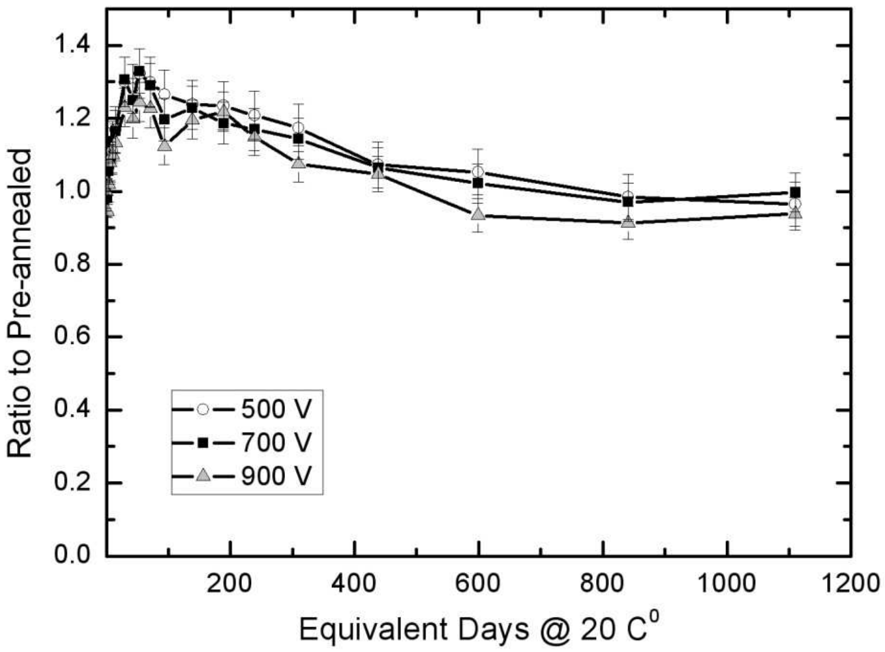
Even considering a non-linear dependence on fluence of the so called V_{FD}, and under the hypothesis of reduced trapping (non linear dependence on fluence? Field enhanced fast de-trapping?) the charge collected exceed the expectations. There is also evidence of collection of more charge than the ionised amount.

A controlled multiplication is taking place with heavily irradiated microstrip detectors. This opens the possibility of engineering the geometrical parameters of the detectors to increase the radiation tolerance of segmented detectors for applications where extreme hadron radiation damage is expected.

Spare slides

A word on the annealing of the CCE (Neutrons)

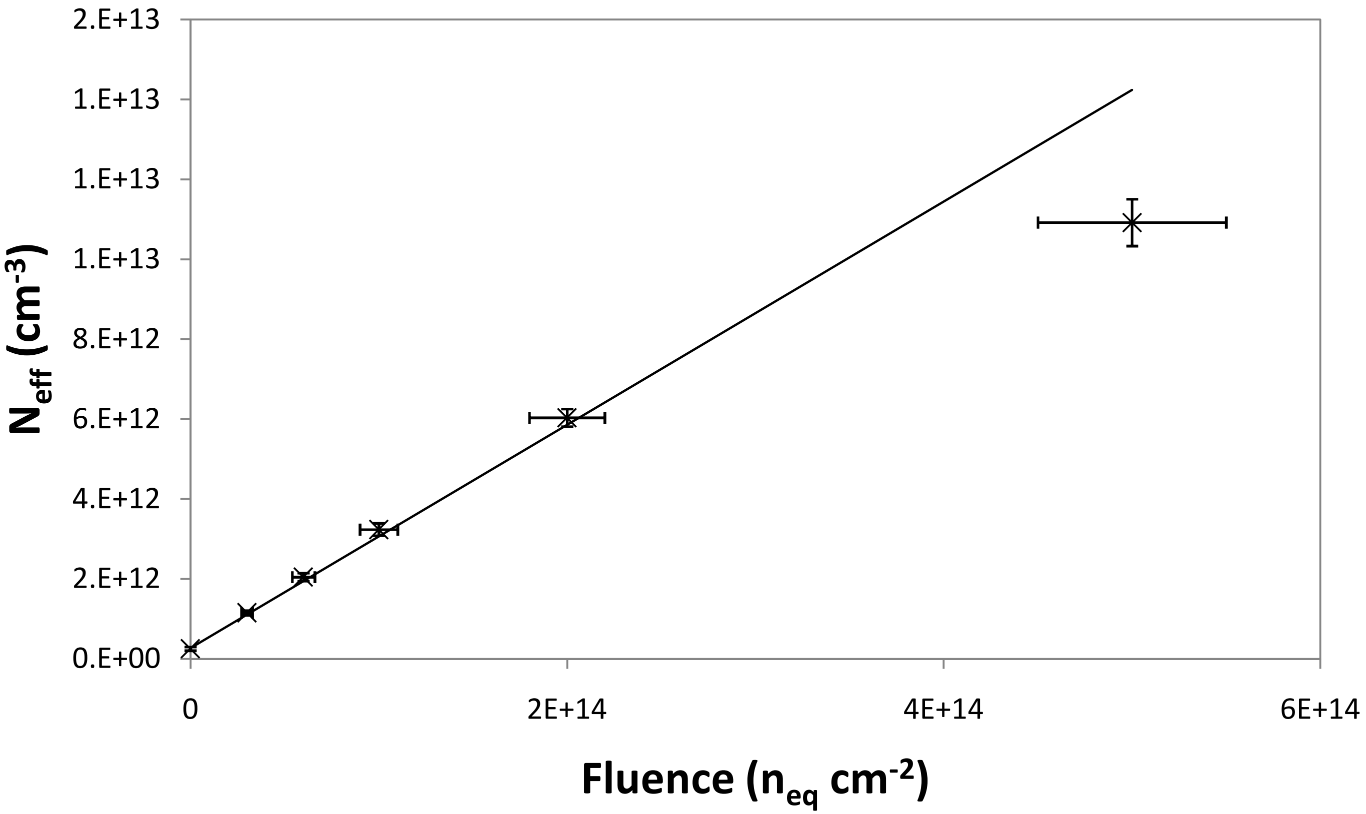




N_{eff} vs ϕ measured with the CV characteristic of 300 μm n-in-p Micron sensors after 80 min 60^{o}C annealing time

$N_{eff}=N_0(\exp(-c\phi)) - \beta\phi$

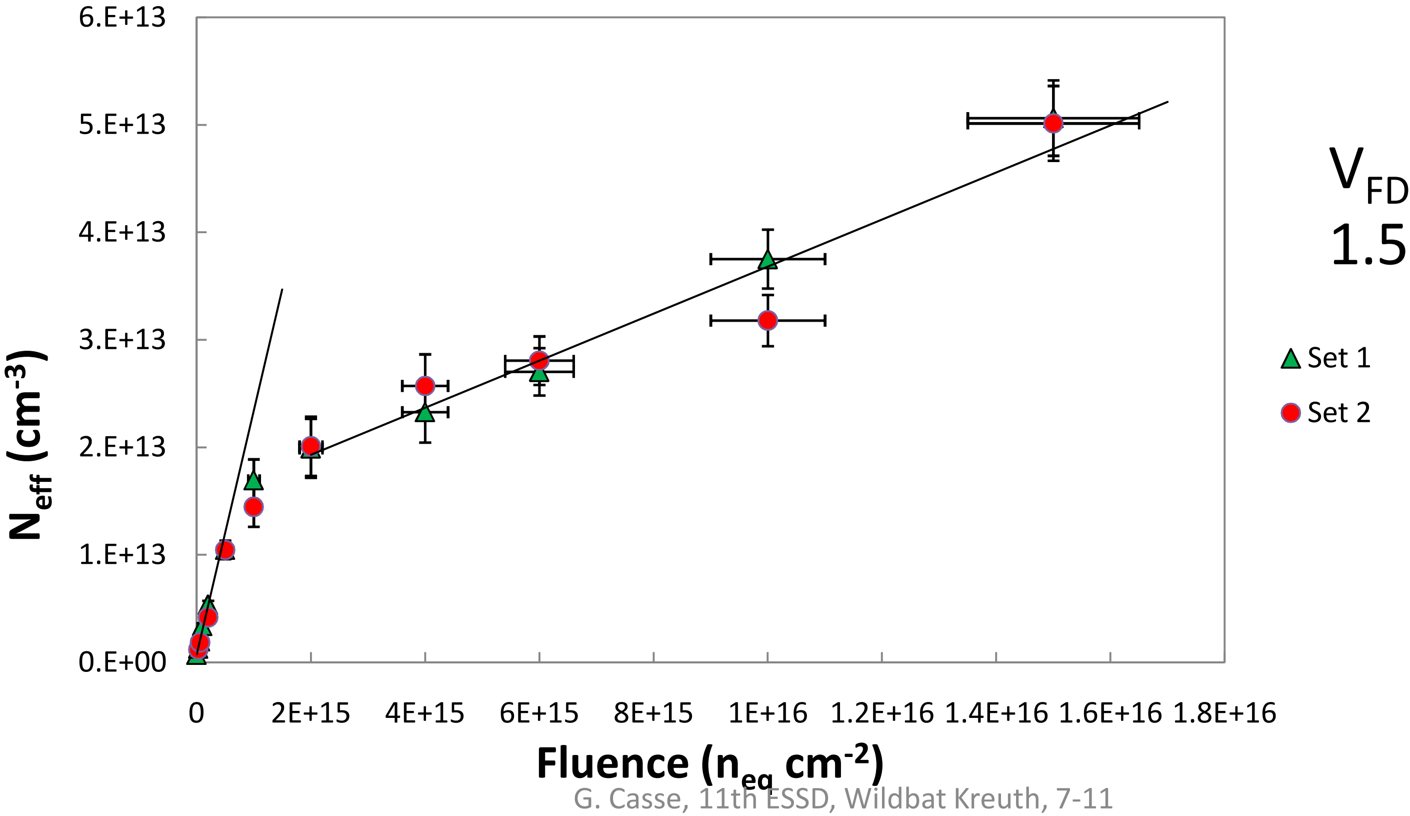
$\beta = 0.028 \pm 0.002$ cm^{-1}



N_{eff} vs ϕ measured with the CV characteristic of 140 μm n-in-p Micron sensors after 80 min 60°C annealing time

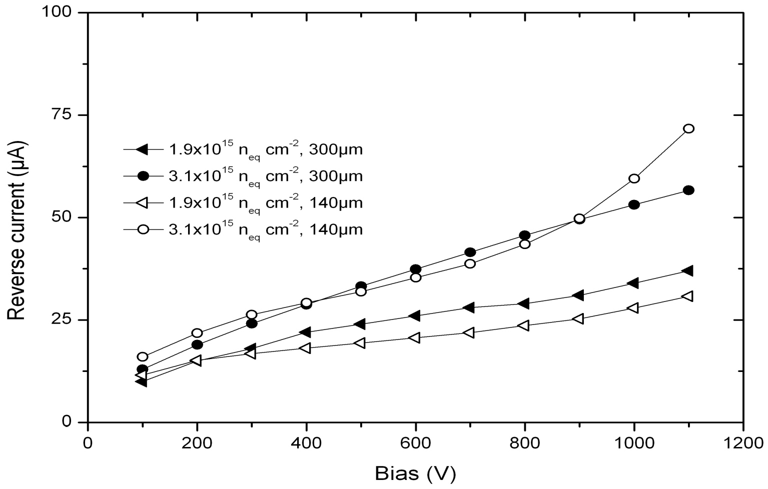
β calculated for dose up to 5×10^{14} n_{eq} cm^{-2}
$\beta = 0.023 \pm 0.002$ cm^{-1}

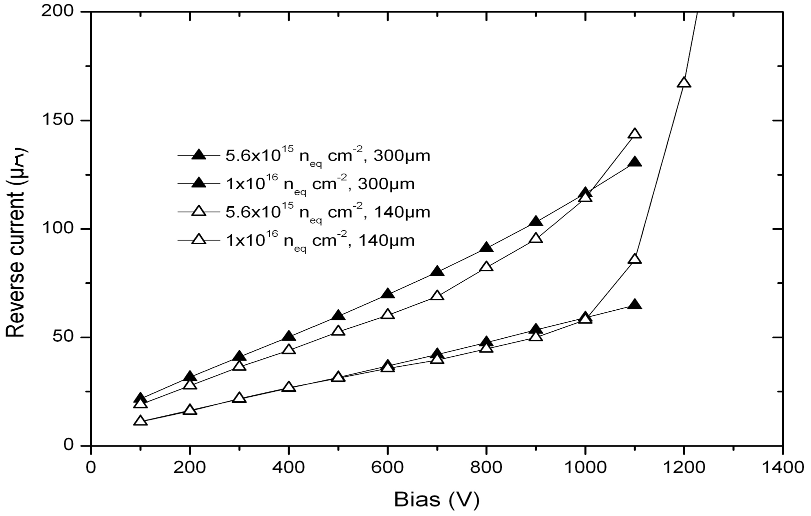
β calculated for dose up to 5×10^{14} n_{eq} cm^{-2}
$\beta = 0.0022 \pm 0.0003$ cm^{-1}

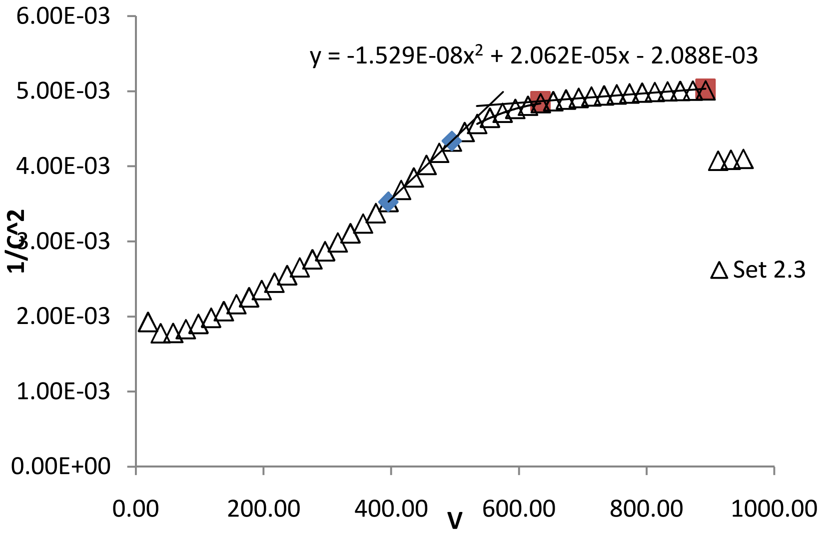


$V_{FD} \cong 890V$ after 1.5×10^{16} cm^{-2}

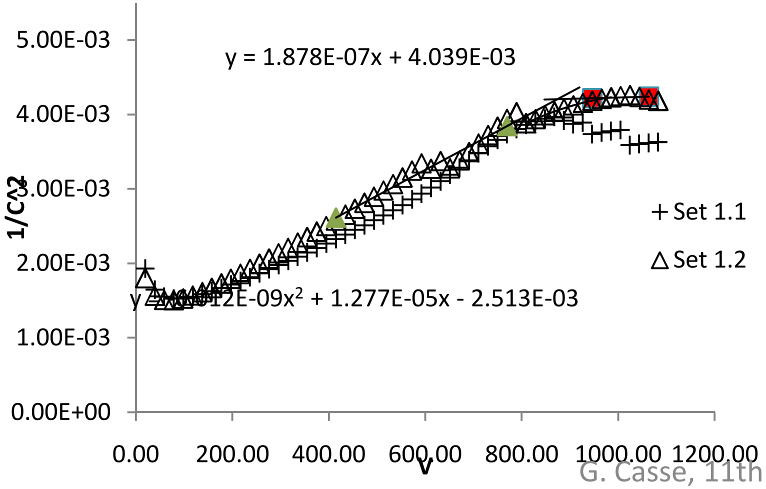
Reverse currents of 140 and 300 μm n-in-p Micron sensors after various proton doses



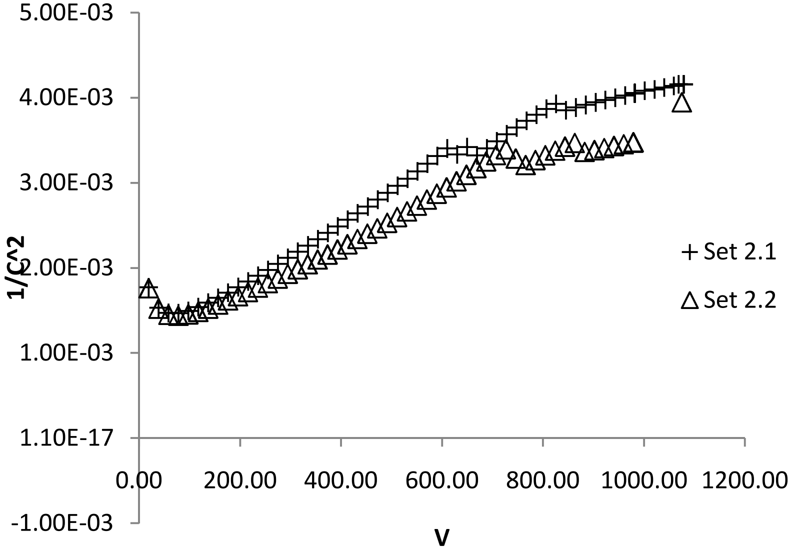




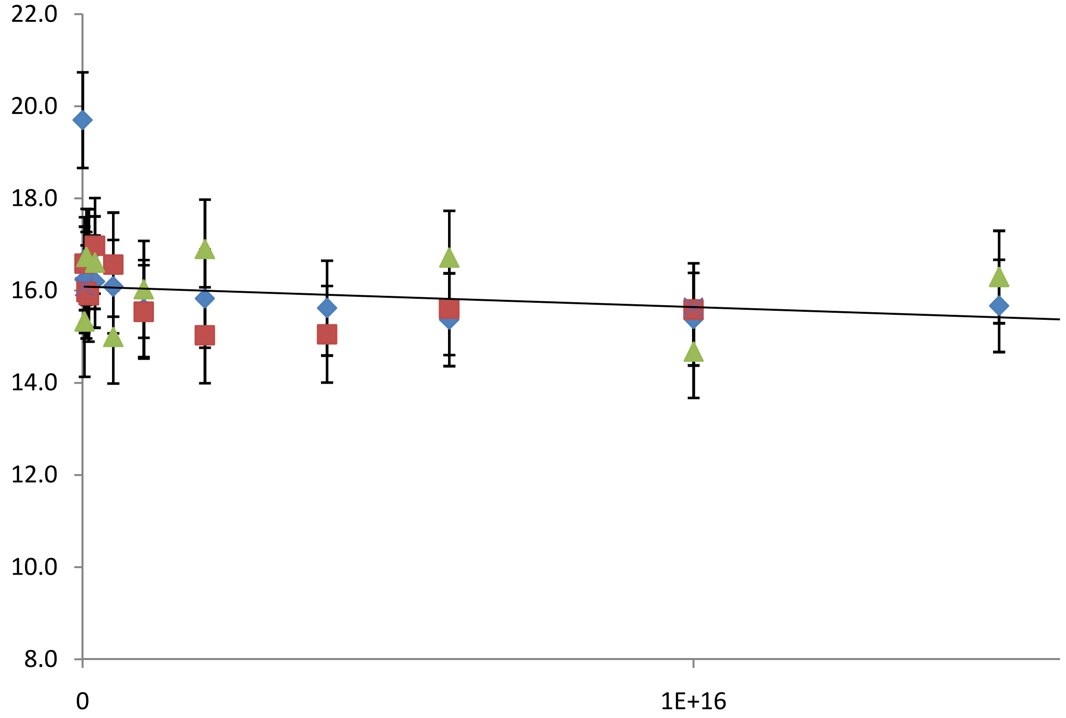
y = -1.529E-08x^2 + 2.062E-05x - 2.088E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
1/C^2
0.00
200.00
400.00
600.00
800.00
1000.00
V
△ Set 2.3



y = 1.878E-07x + 4.039E-03
y 12E-09x^2 + 1.277E-05x - 2.513E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
1/C^2
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
V
+ Set 1.1
△ Set 1.2



5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
1.10E-17
-1.00E-03
1/C^2
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
V
+ Set 2.1
△ Set 2.2


22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
0
1E+16

α (300μm thick) = 3.2×10^{-17} A cm^{-2}.
α (140μm thick) = 2.7×10^{-17} A cm^{-2}.