Studies on Charge Collection Efficiencies for Planar Silicon Detectors after Doses up to 10^{16} n_{eq}/cm^2 and the Effect of Varying Substrate Thickness

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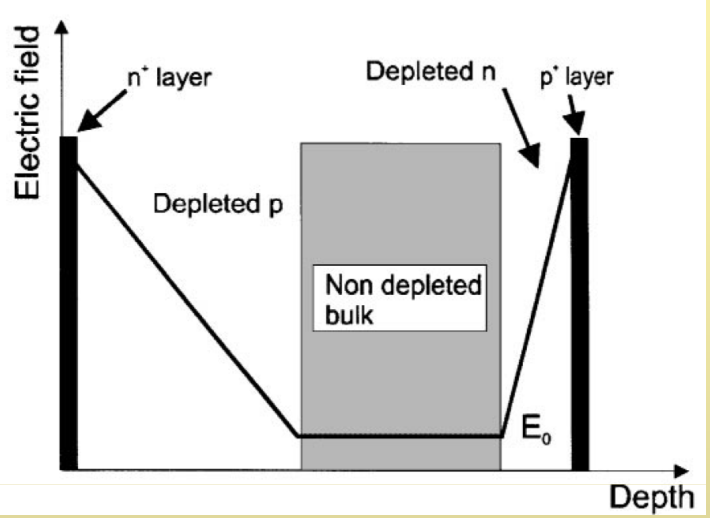
IEEE NSS, Dresden 19 - 25 Oct. 2008

N-side read-out for tracking in high (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

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

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

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

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

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.

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

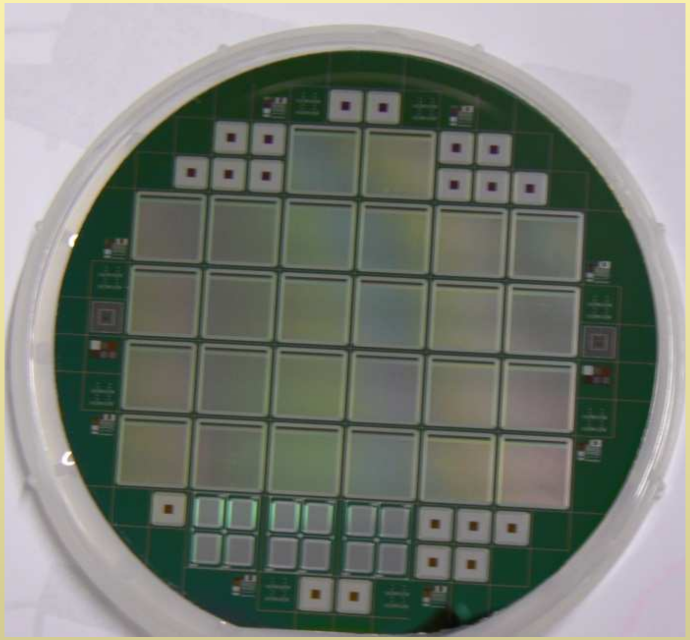
$\lambda_{av}\ (\Phi=1e16) \cong 24\mu m$

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)?

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:

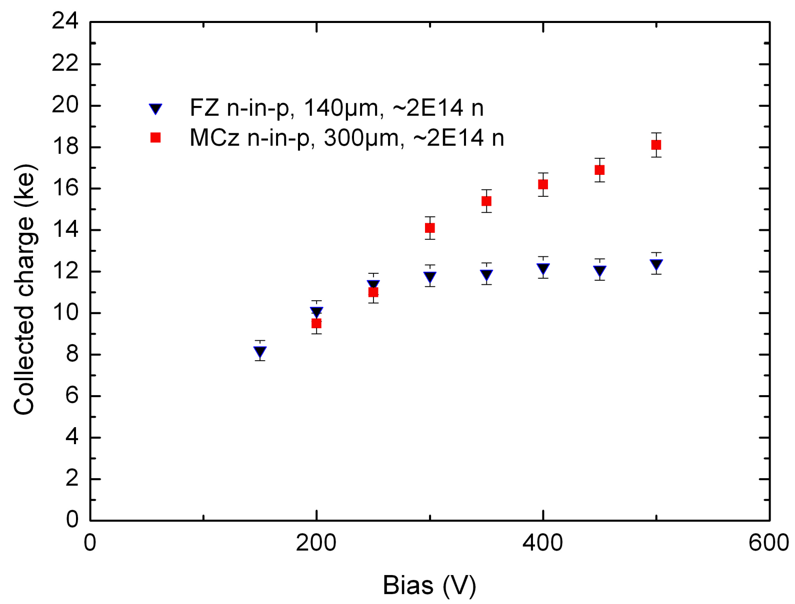
Neutron:
TRIGA Mark II research reactor
Reactor Centre of the
Jozef Stefan Institute, Ljubljana,
Slovenia

24GeV protons:
CERN-PS Irrad1 (M. Glaser)

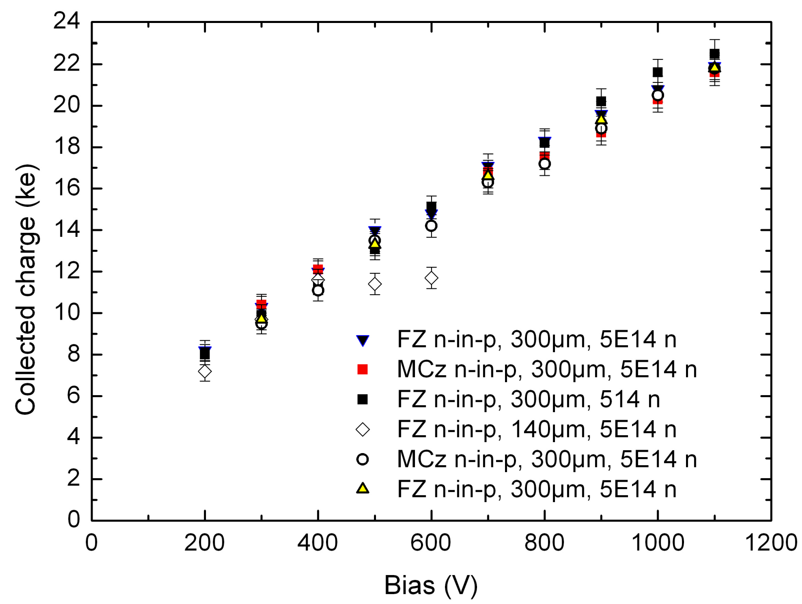
26 MeV protons:
Compact Cyclotron of the University of
Karlsruhe (W. de Boer)

Changes of the CCD: comparison of thin and thick detectors after 2 and $5x10^{14}$ n cm^{-2}.

After $2x10^{14}$ n cm^{-2}, same CCE at low voltages and than saturation for the thin sensor (~250V).

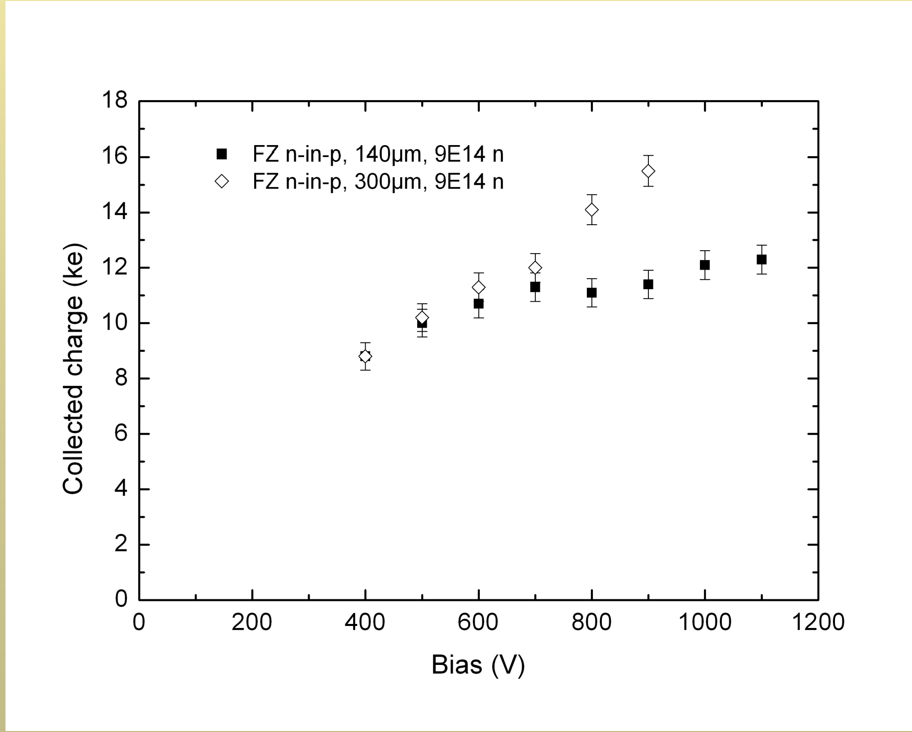


After $5x10^{14}$ n cm^{-2}, same CCE at low voltages and than saturation for the thin sensor (~400V).



Changes of the CCD: comparison of thin and thick detectors after $1x10^{15}$ n cm^{-2}.

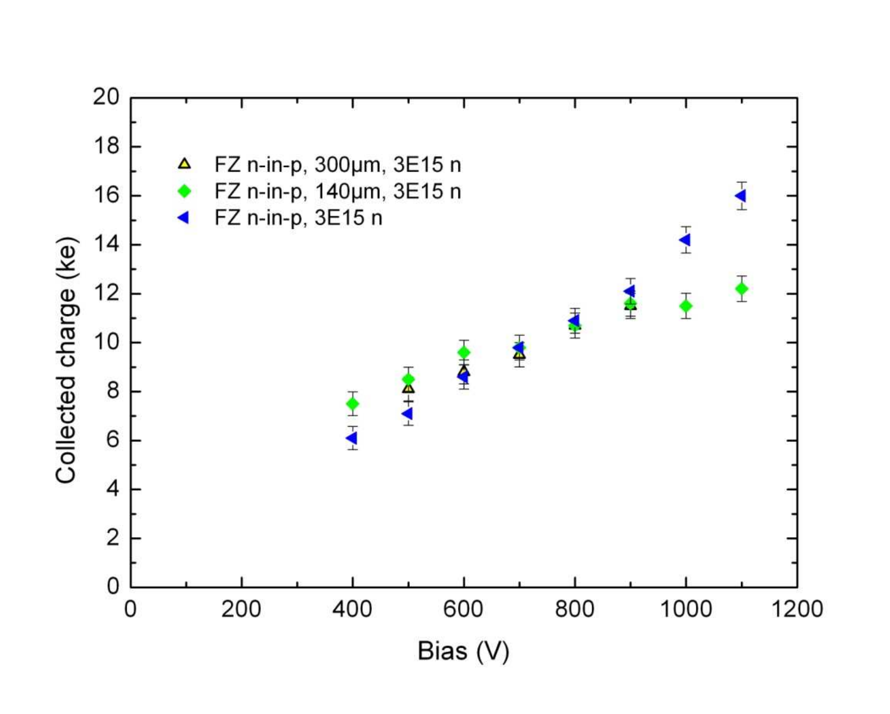
After $1x10^{15}$ n cm^{-2}, saturation for the thin sensor (~600V).

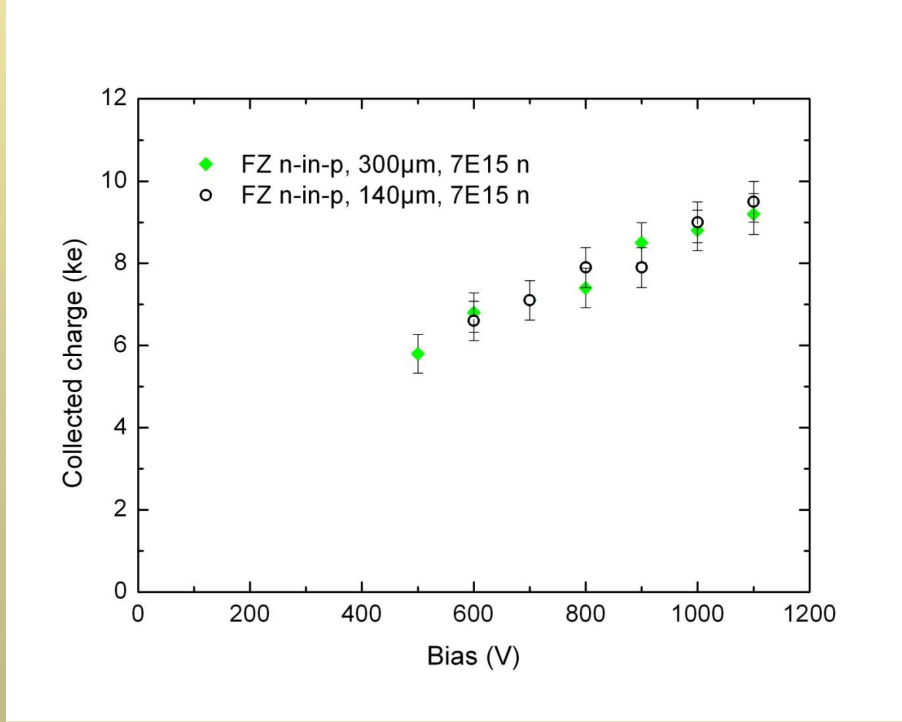


Changes of the CCD: comparison of thin and thick detectors after 3 and 7.5x10^{15} n cm^{-2}.

After 3x10^{15} n cm^{-2} the CCE of the 300µm thick devices becomes higher above 900V.

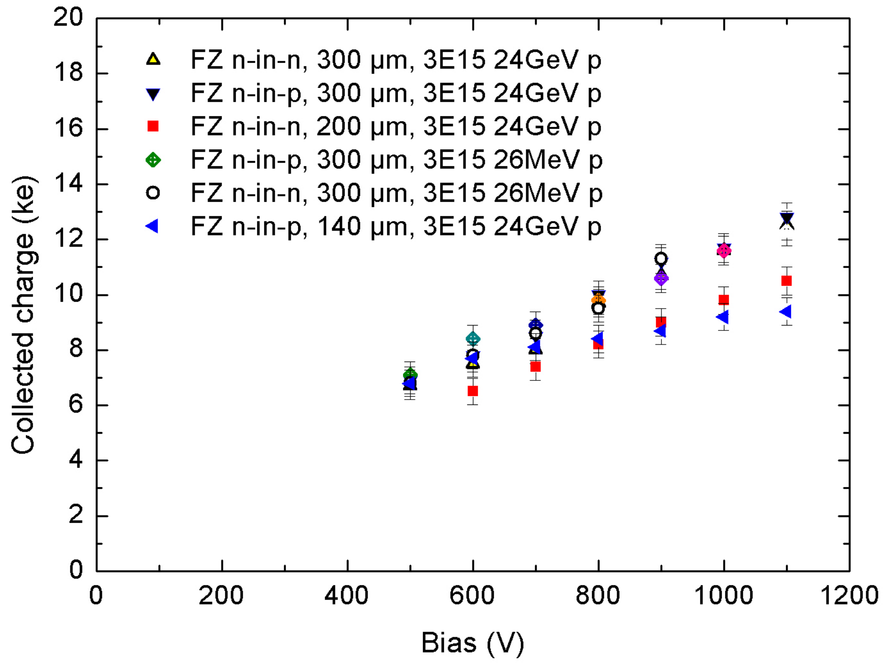
After 7.5x10^{15} n cm^{-2} the CCE of thin and thick sensors is the same up to 1100V.





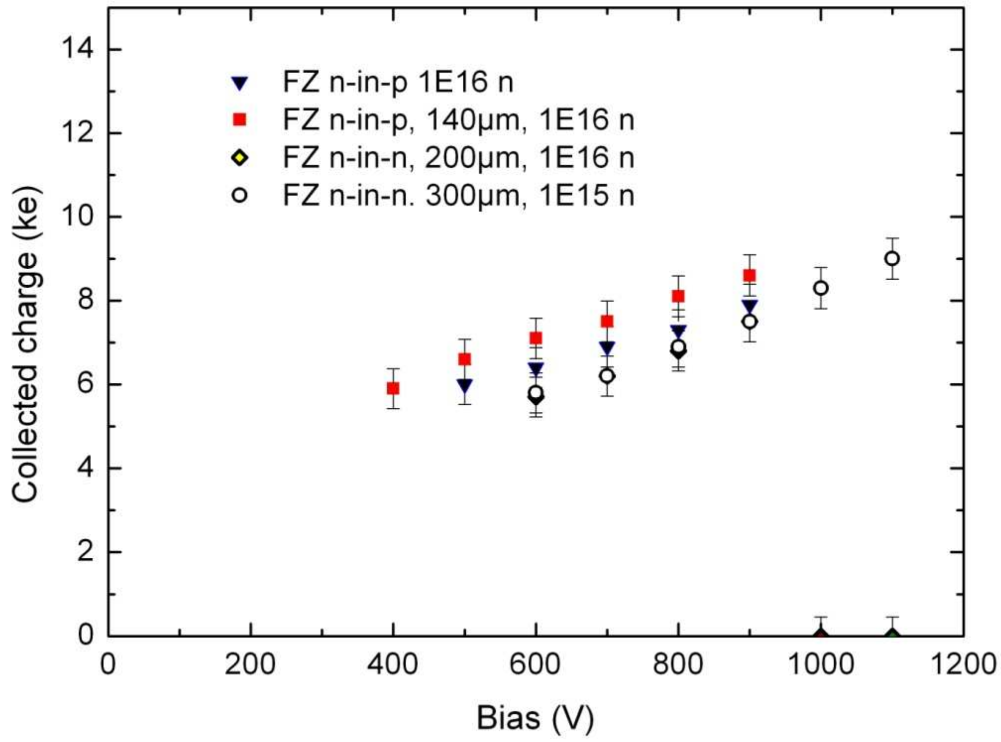
Changes of the CCD: comparison of thin and thick detectors after $3x10^{15}$ 26MeV and 24GeV p cm^{-2}.

After $3x10^{15}$ n_{eq} cm^{-2} the CCE of the 300µm thick devices becomes higher above 700V.



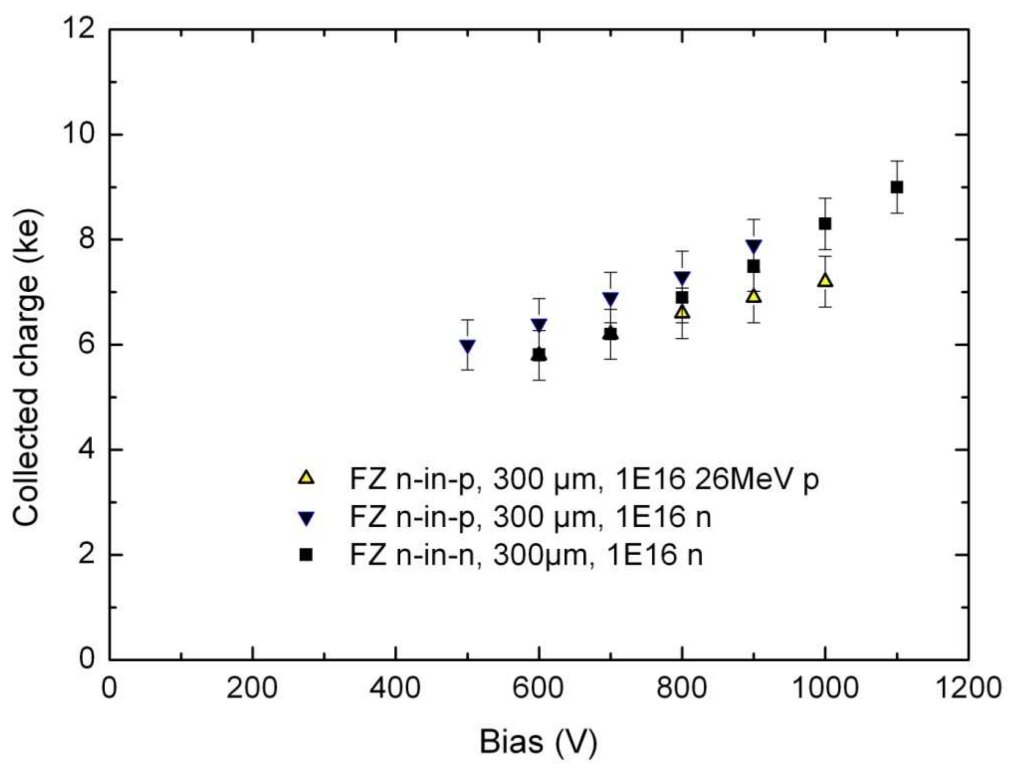
140, 200 and 300 μm thick detectors after ~$1x10^{16}$ n cm^{-2}!

About 10% higher CCE for the 140μm thick sensors (irradiated in the same session as the 300 μm thick one).



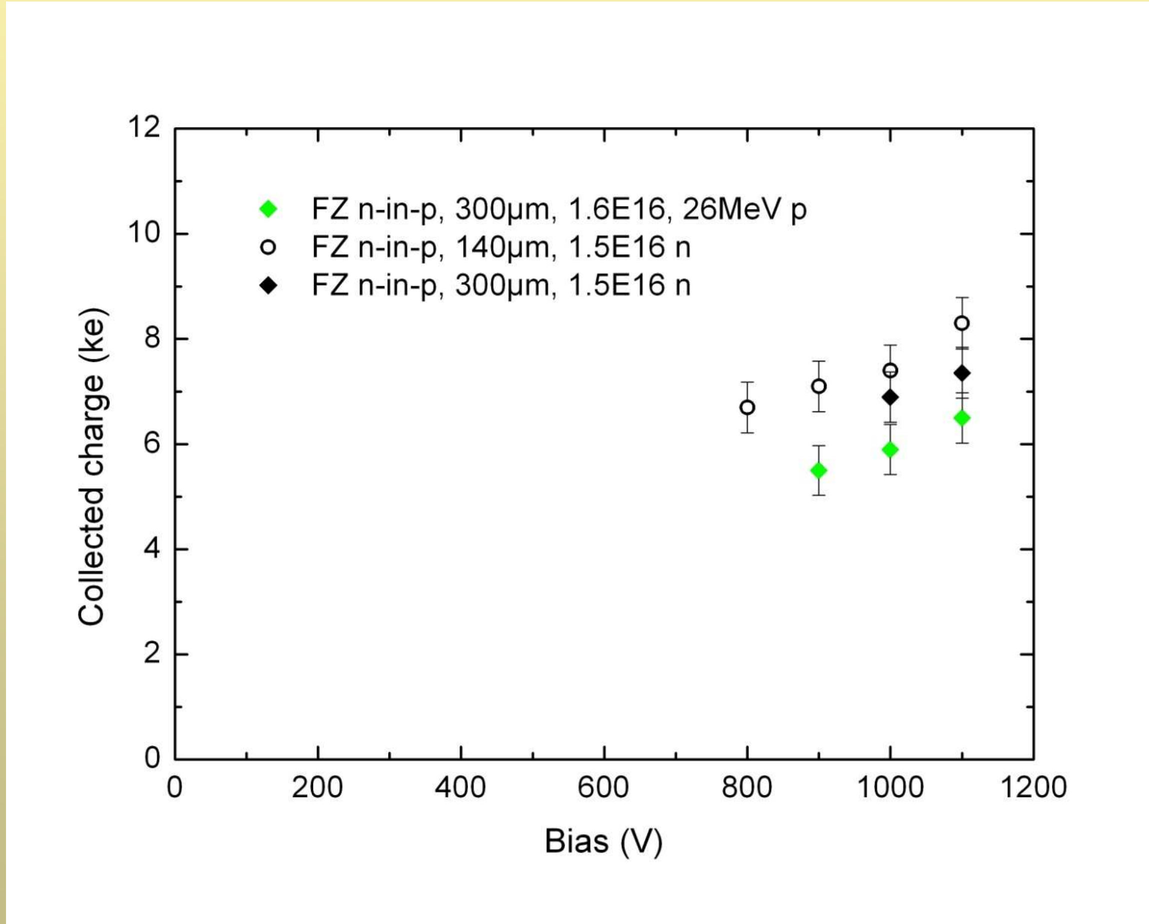
300 μm thick n-in-n and n-in-p detectors after ~1x10^{16} n and 26MeV p cm^{-2}!

Indication that proton introduces more charge trapping than neutron irradiation for equivalent NIEL doses. Similar CCE vs Bias(V) for n-side read out n and p FZ substrates.

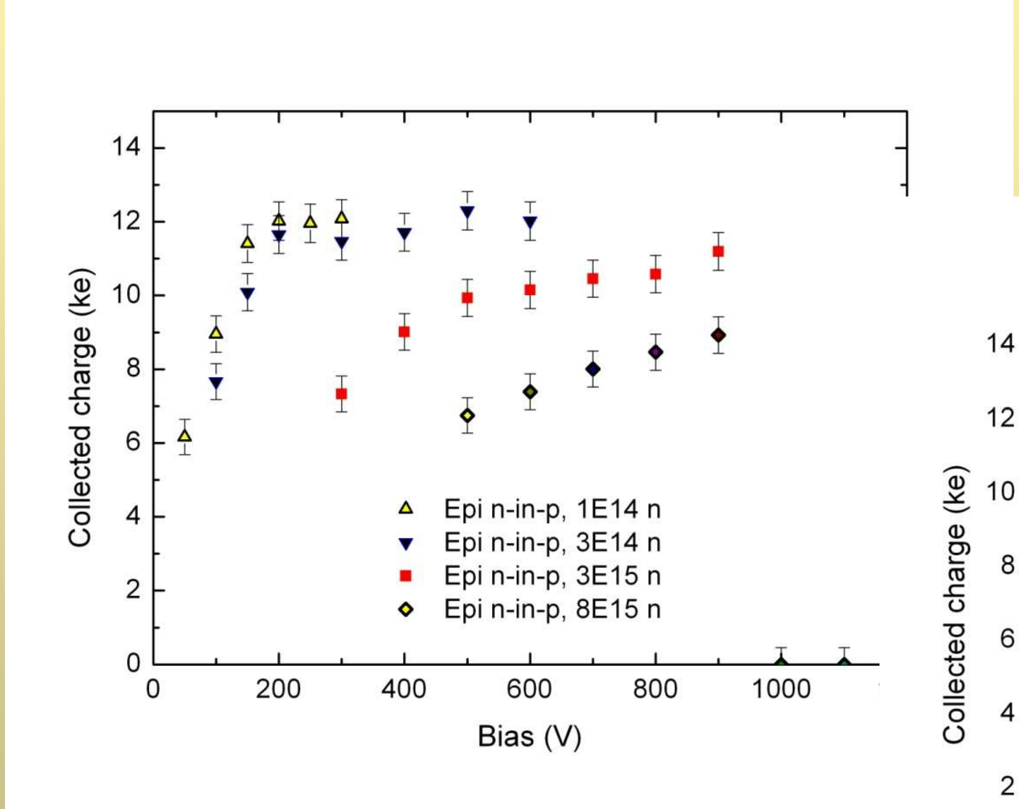


140 and 300 μm thick detectors after ~1.5x10^{16} n and 26MeV p cm^{-2}!

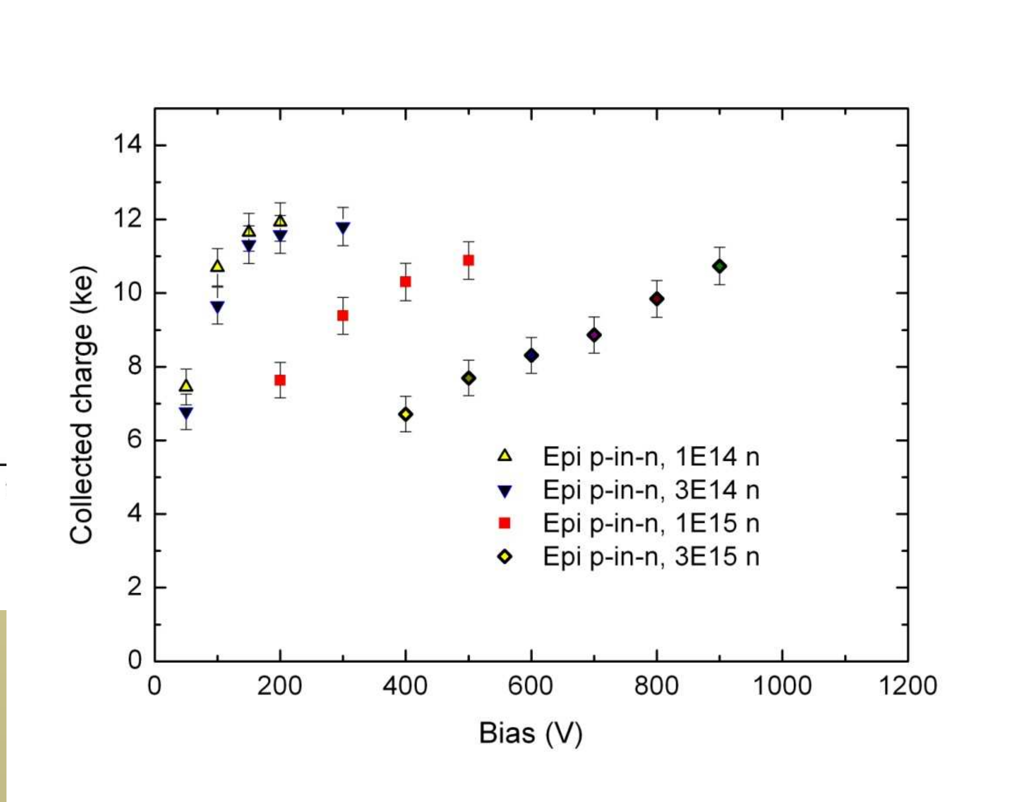
Evidence that proton introduces more charge trapping than neutron irradiation for equivalent NIEL doses.



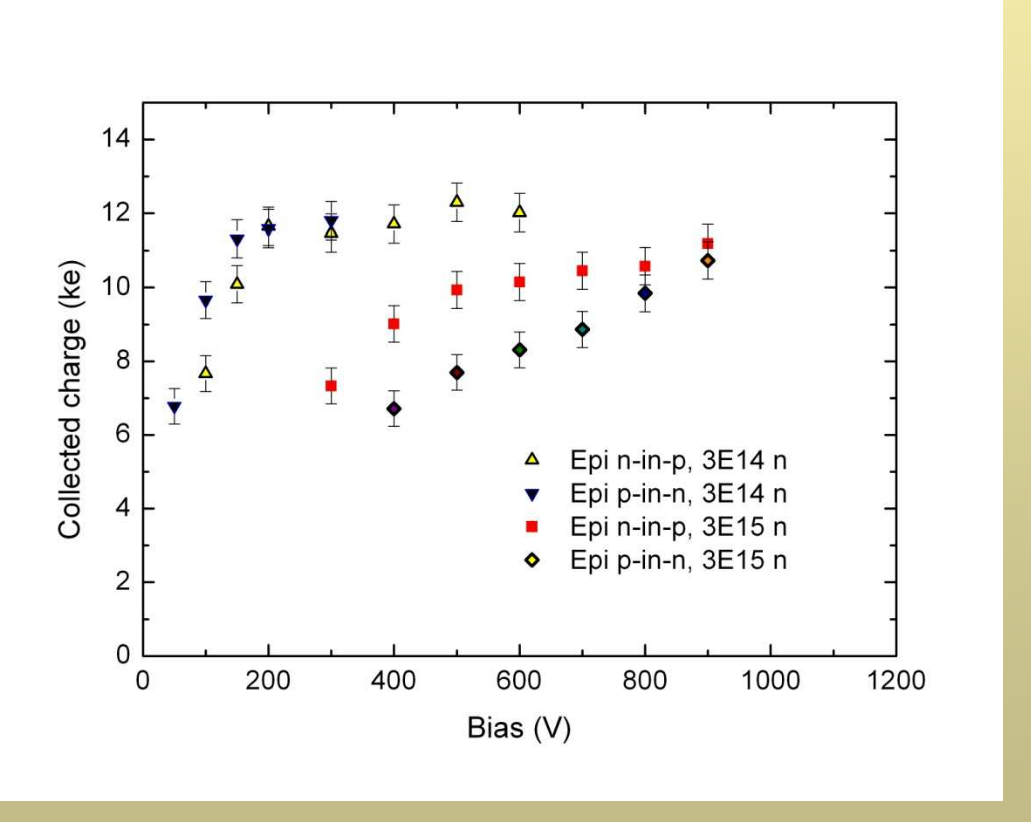
Material comparison: EPI n and p (150μm) reactor neutrons



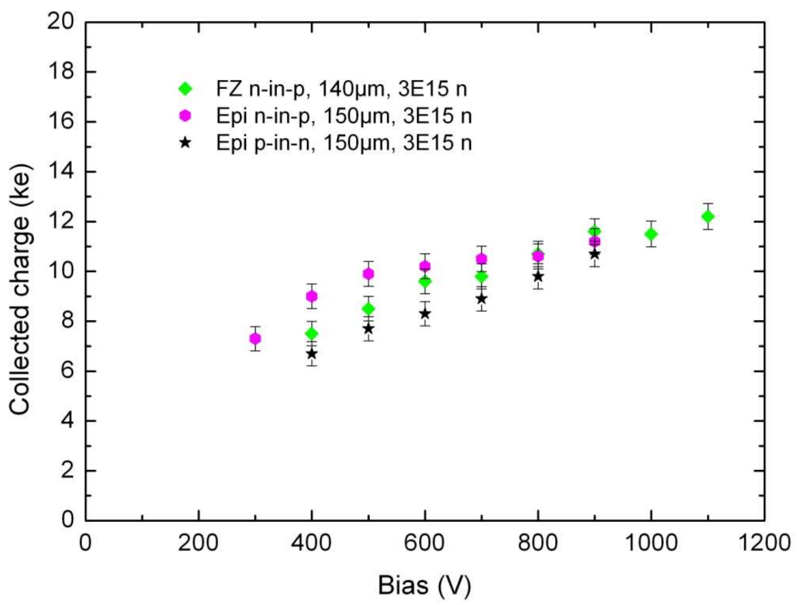
Produced by CNM Barcelona

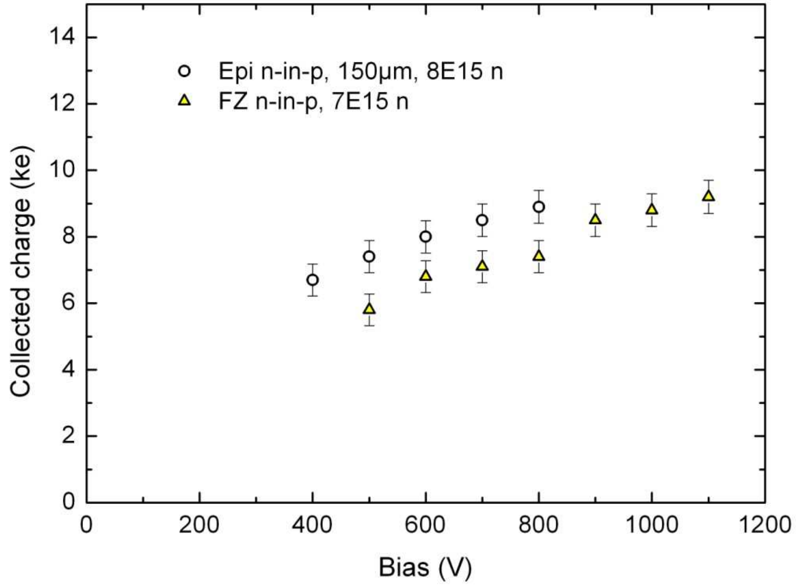


Material comparison: EPI n vs p, reactor neutrons



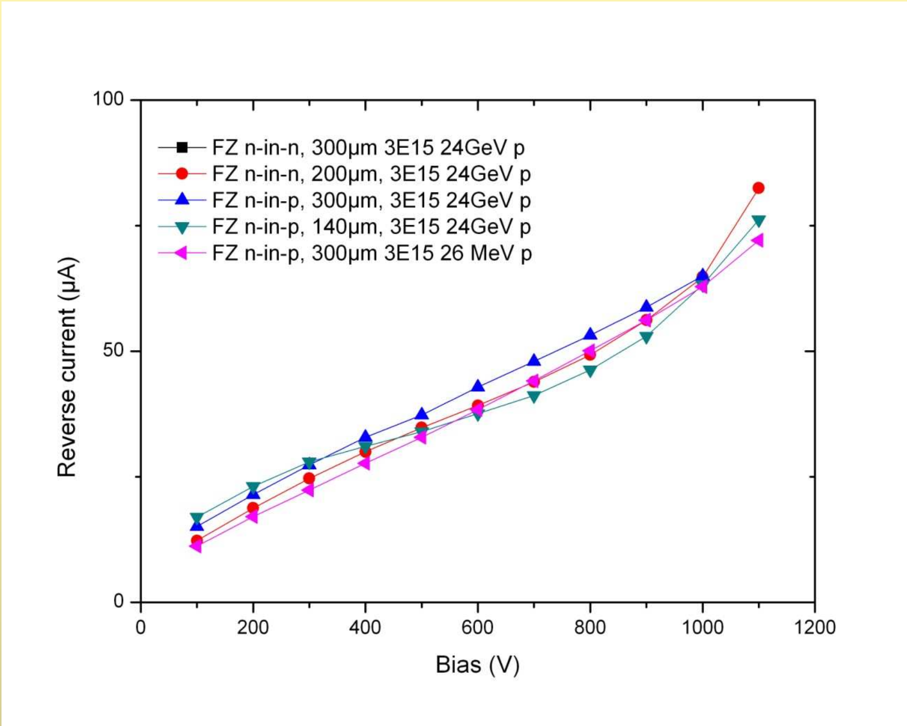
Material comparison: EPI vs FZ, reactor neutrons

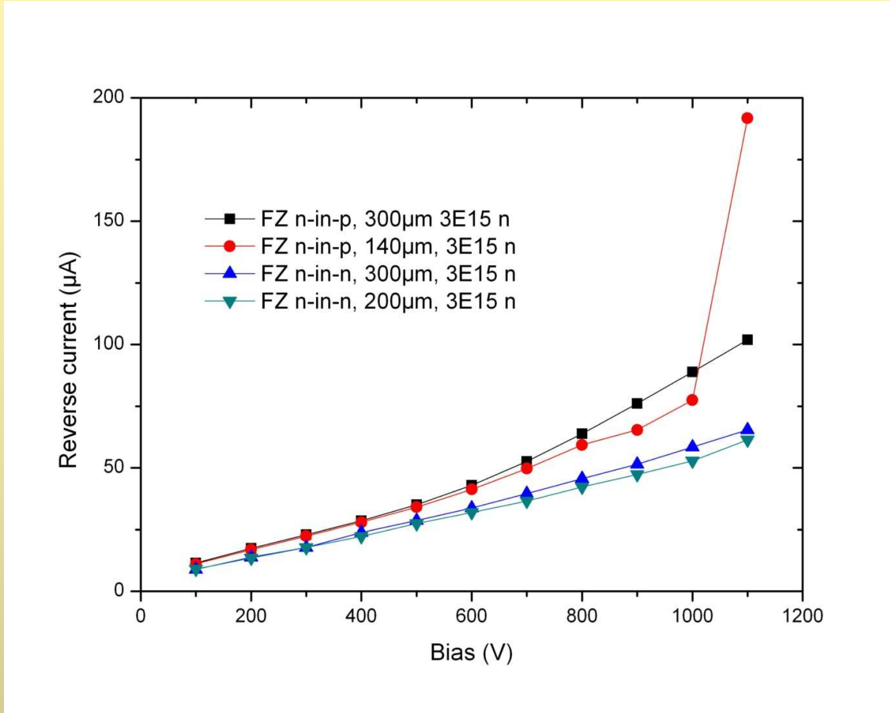




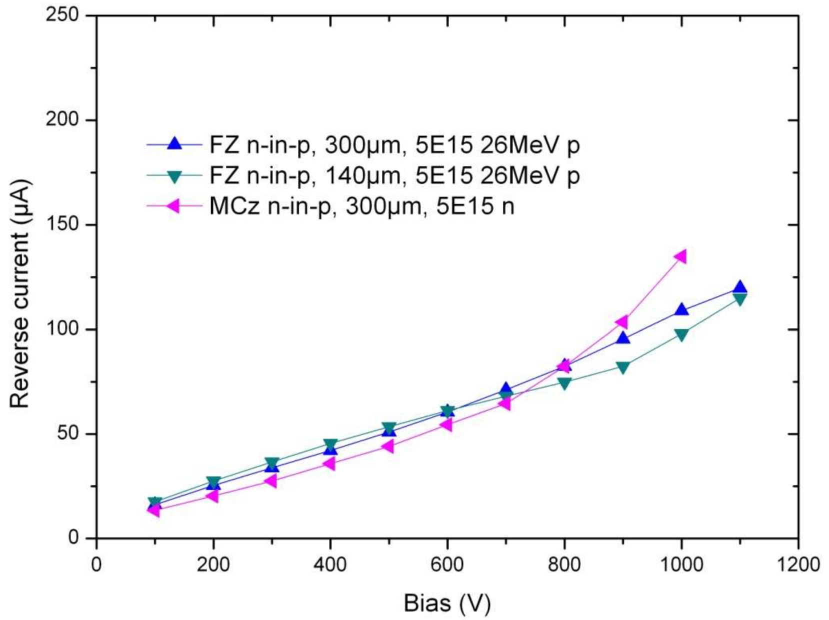
Good CCE results with Epi! Drawbacks: difficult to process, expensive, limited sources of thick Epi (150µm), possible variability of performances!

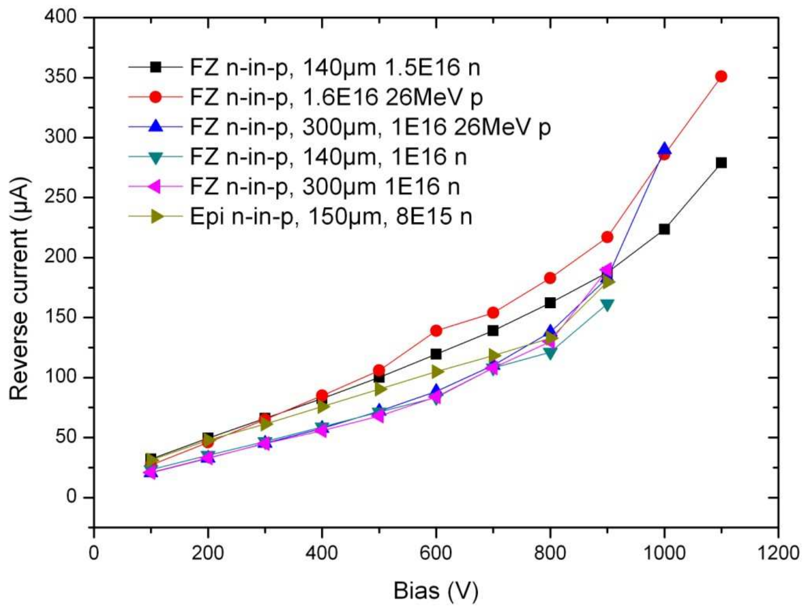
IV thin vs standard, various irradiation





IV thin vs standard, various irradiation





CONCLUSIONS:

The comparison of 140 and 300μm thick Si sensors shows that after hadron irradiation doses between 3 and 7×10^{15} n cm^{-2} the CCD in silicon becomes smaller than 140μm, at least up to bias voltages up to 1100V. Thin and thick detectors show essentially the same CCE (with a possible 10% higher CCE for the thin ones after doses >10^{16} cm^{-2}).

Evidence of more charge carrier trapping introduced by proton with respect to neutron irradiation is found with CCE measurements at high doses. Comparison of thin and thick devices with charged particle irradiation will tell if a more consistent advantage is found with thin devices in this case.

After heavy neutron irradiations the CCE of thin and thick detectors becomes similar. The choice of optimal thickness can be dictated by the need of reducing the detector mass rather than increase of the signal after irradiation (at least up the remarkable dose of 1×10^{16} n cm^{-2}!!).