New Operation Scenarios for Severely Irradiated Silicon Detectors

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OUTLINE:

Very high hadron fluences will need careful planning for successfully operating the silicon Vertex and Tracker detectors. It has been shown that planar technology with adequate choice of readout side (n-side) can satisfy the radiation tolerance for most, possibly all the anticipated layers of the upgraded experiments. Nonetheless, stringent requirements on bias voltage, and temperature (during and between operations) have to be implemented to exploit the full capacity of the silicon sensors.

RADIATION TOLERANCE: changes of the signal with n_{eq} fluence.

Expected signal from charge trapping

Effect of trapping on the Charge Collection Distance

After heavy irradiation it seems that the V_{FD} is lower than expected from extrapolation from lower doses. This could yield a larger signal. But, is depletion the limiting factor after heavy irradiation?

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

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

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

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

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

In fact, the charge trapping at radiation induced defect centres has a larger effect on the signal.

The collection distance at saturation velocity:

λ_{av} after $1x10^{15}$ n_{eq} cm^{-2}: 240µm (expected charge ~19ke).

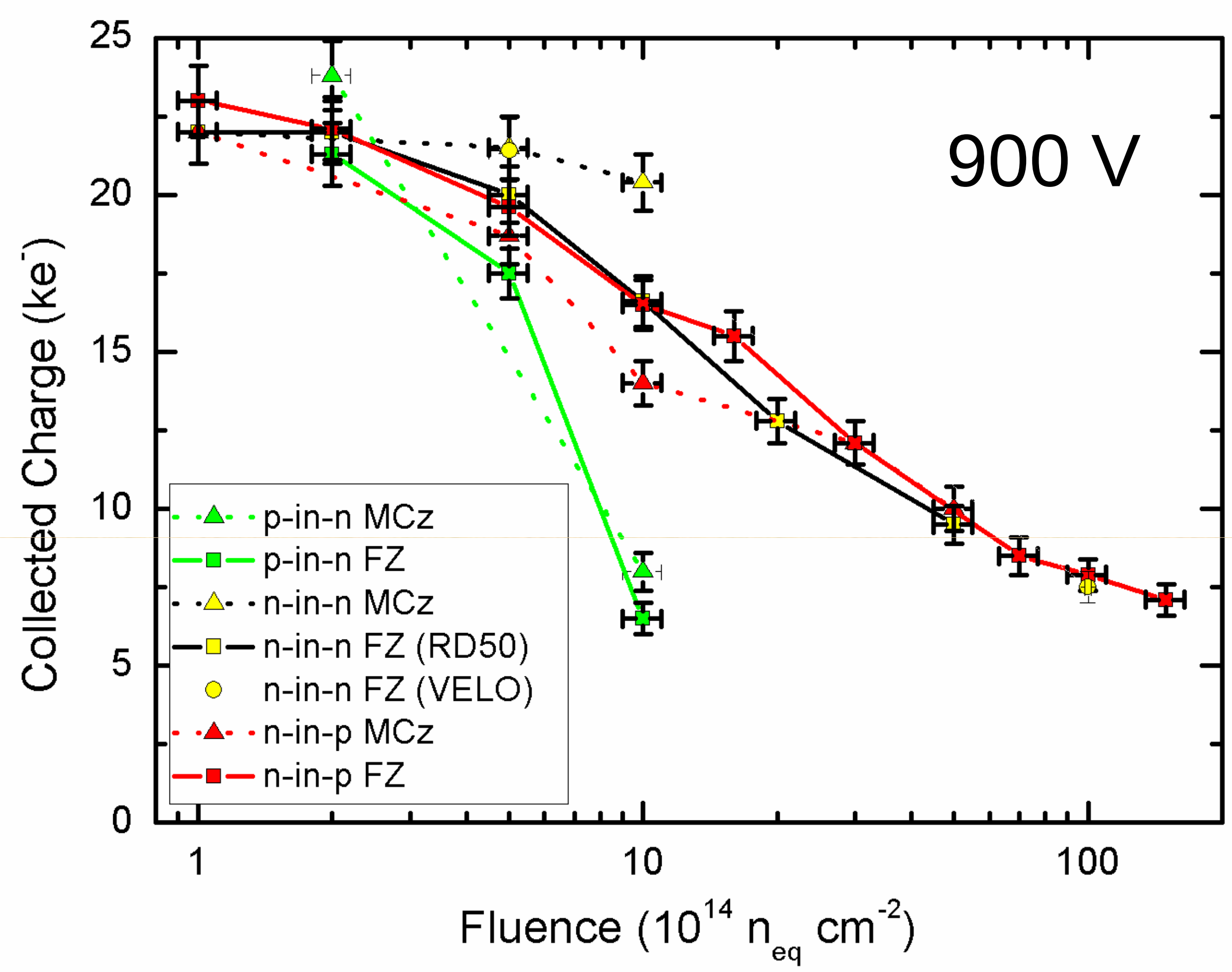
λ_{av} after $5x10^{15}$ n_{eq} cm^{-2}: 50µm (expected charge <4ke).

λ_{av} after $1x10^{16}$ n_{eq} cm^{-2}: 25µm (expected charge <1.3ke).

λ_{av} after $2x10^{16}$ n_{eq} cm^{-2}: 12µm (expected charge <1ke).

Neutron Comparison

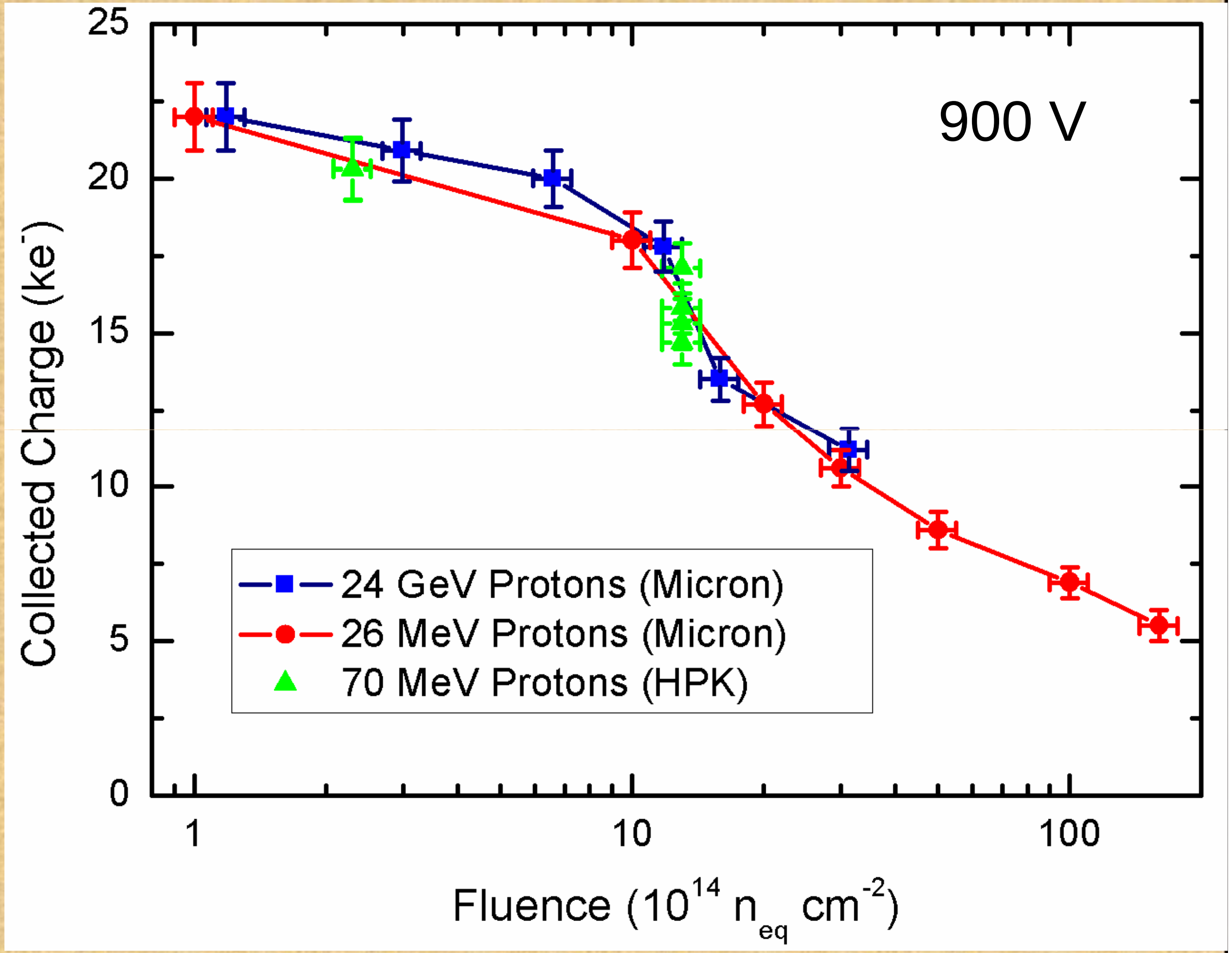
- After ~5×10^{14} n cm^{-2}, n-in-n FZ, n-in-p FZ, n-in-p MCz very similar
- At higher voltage n-in-n MCz superior up to maximum fluence (10^{15} n cm^{-2})
  - Need higher fluence data to determine if this continues
- p-in-n shows inferior performance as expected



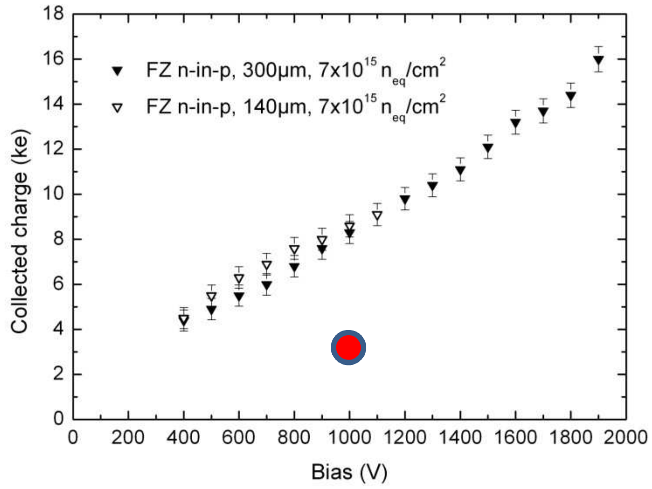
Appears once trapping dominates, all n-strip readout choices studied are the same after neutron irradiation

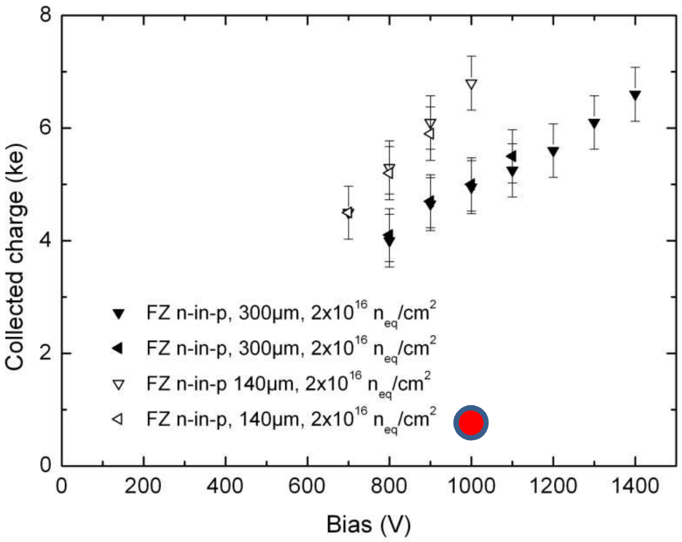
n-in-p FZ Proton Comparisons

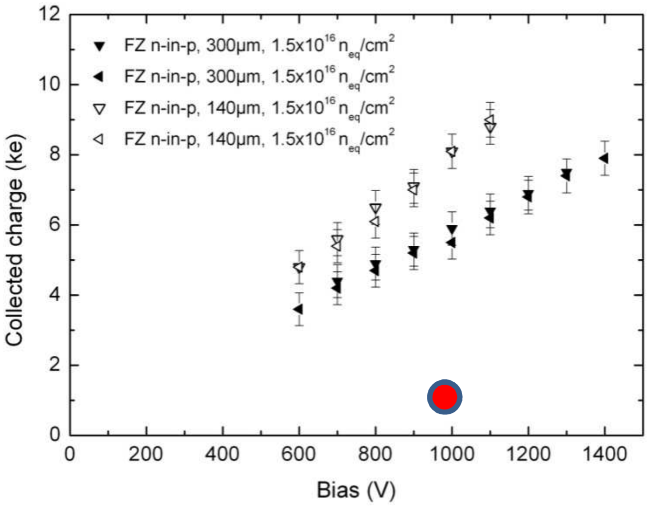
- For n-in-p FZ devices, CCE from all 3 proton sources looks compatible



Very good signal after extreme neutron fluences.



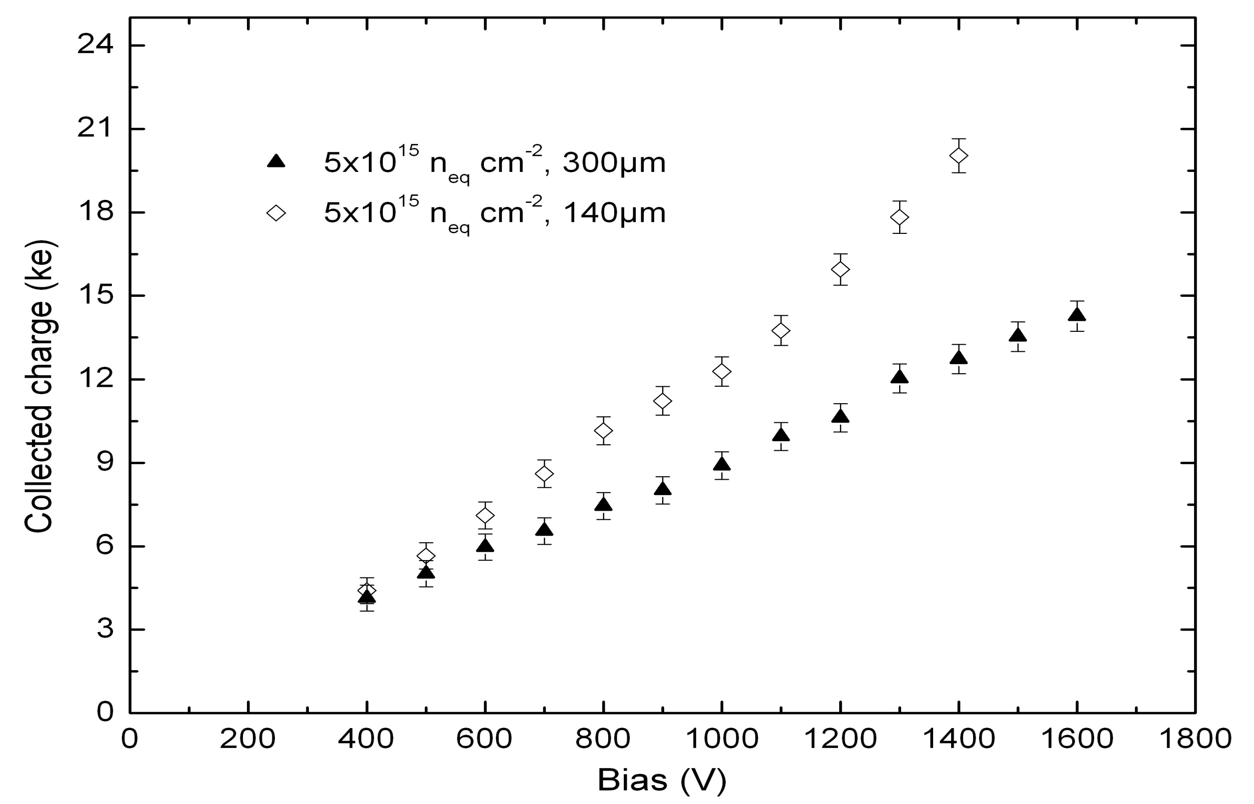




Moreover there is clear indication of a charge multiplication mechanism after irradiation.

Not only the whole charge is recovered, but increased by f = 1.75

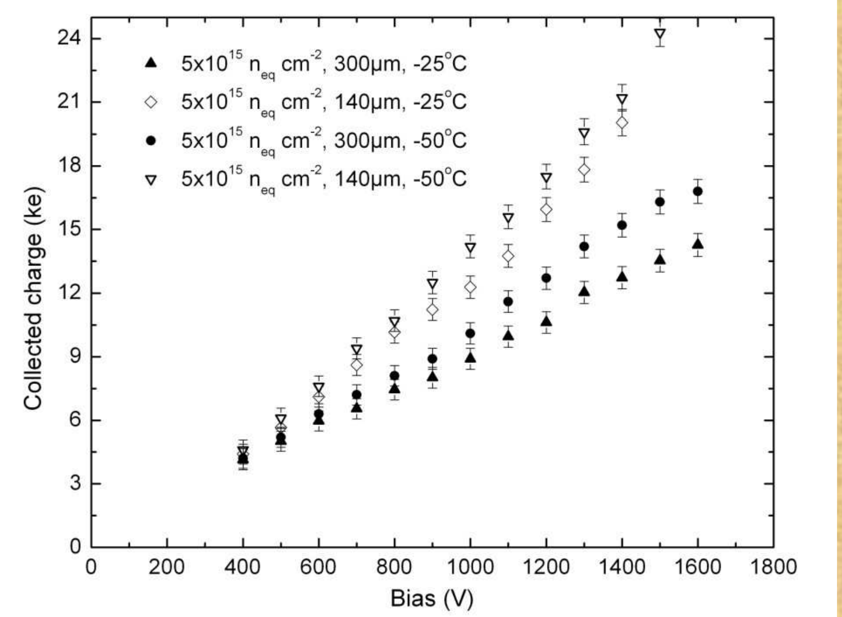
140 and 300 μm n-in-p Micron sensors after 5×10^{15} n_{eq} 26MeV p



Moreover there is clear indication of a charge multiplication mechanism after irradiation.

A slight improvement of the CCE with extremely high irradiated sensors is found by going from -25°C to -50°C. Nonetheless, is not such to justify the aggravation related with maintaining a lover operation T.

140 and 300 μm n-in-p Micron sensors after $5x10^{15}$ n_{eq} 26MeV p



It is clear that the signal is improving linearly (and even over-linearly, in the CM regime) with the applied bias voltage. The capability of severely irradiated sensor to withstand V_{bias} well in excess of 1000V, with safe operation, would encourage to break this 1000V “barrier” in the experimental regions (inner layers of the sLHC) where the most extreme radiation damage considerably reduces the signal. These areas are relatively small in volume, and the re-routing (or a different use) of the bias voltage services could be envisaged.

RADIATION TOLERANCE: changes of the reverse current with n_{eq} fluence.

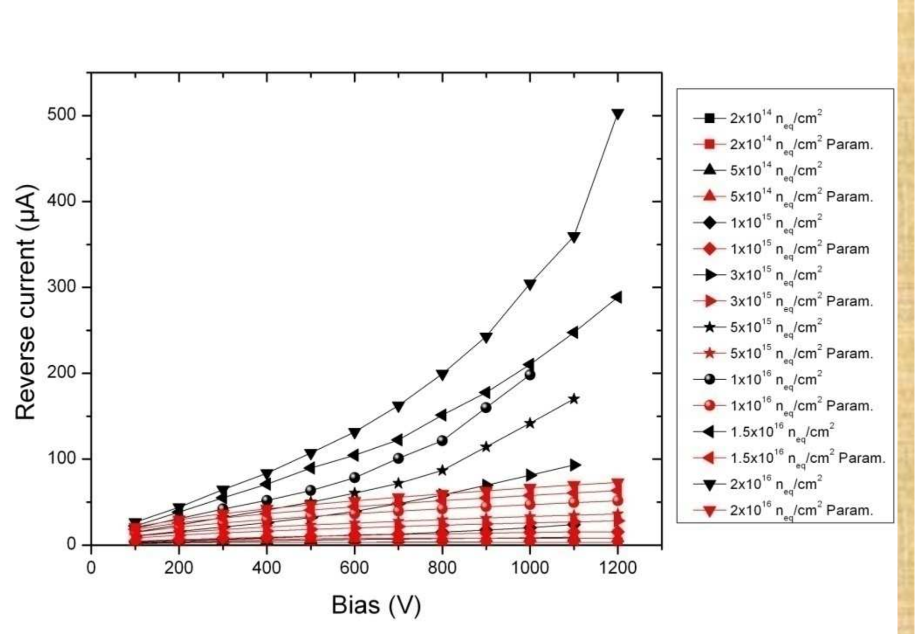
Reverse current after various doses: expectations and measurements

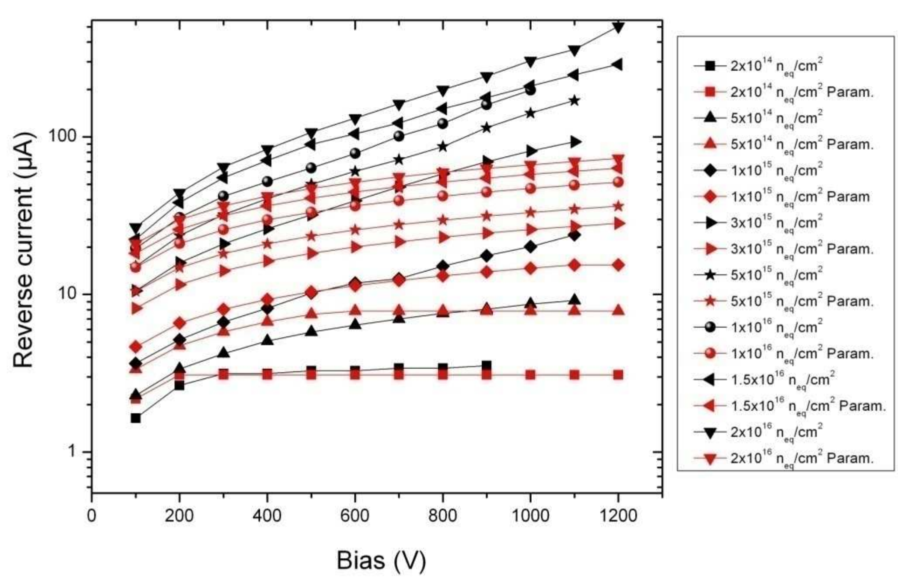
Expectations: bulk generated current, proportional to ϕ, the generation volume defined as the fully depleted fraction of the sensor.

$$I_R = \alpha \times \phi \times V$$

V_{FD}:

$5E^{14}$ n_{eq} cm^{-2} ~ 500V
$1E^{15}$ n_{eq} cm^{-2} ~ 1000V
$5E^{15}$ n_{eq} cm^{-2} ~ 5000V
$1E^{16}$ n_{eq} cm^{-2} ~ 10000V
$2E^{16}$ n_{eq} cm^{-2} ~ 20000V





Although the reverse current increases considerably with irradiation, the 1cm^2 microstrip detectors could be stably operated with >1000V bias with efficient cooling to a T=-20/25^{o}C.

We have discussed the required bias voltage and operation temperature for efficiently running the sensors after doses well compatible with the highest anticipated for the sLHC (B-layers).

But the detectors will spend a significant part of the year not operated (shut down and maintenance periods).

What is the T at which they should be ideally kept? The silicon will undergo a different amount of annealing for different T scenarios. The reverse current would significantly reduce (good), but the fill depletion voltage (V_{fd}) would increase (bad). But what happens to the CCE?

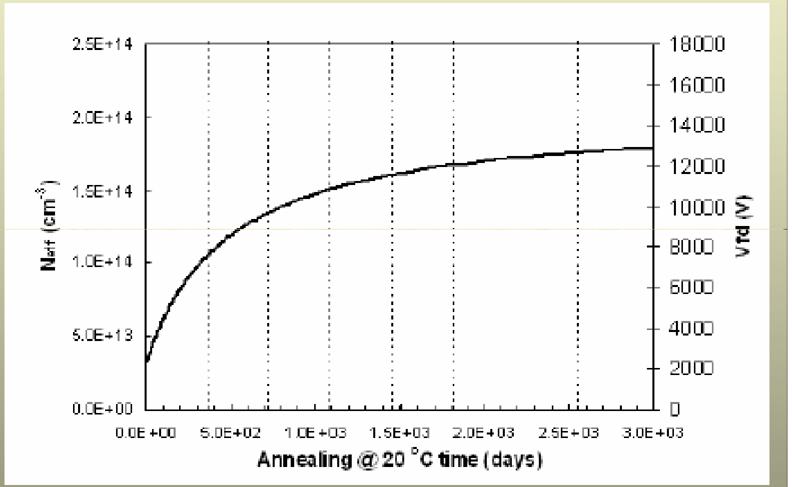
“Old” assumption:

Avoid to warming irradiated detectors above 0°C, even during beam down and reduce maintenance at room temperature to minimum.

V_{FD} undergoes reverse annealing and

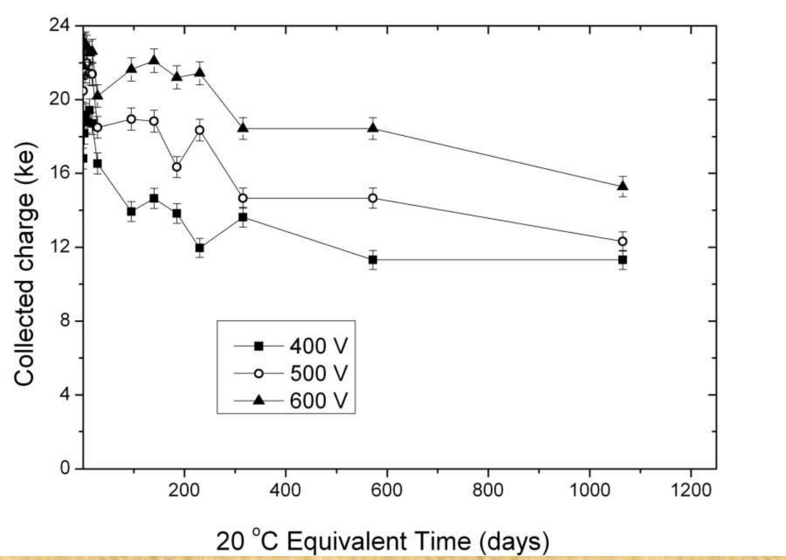
becomes progressively higher if the detectors are kept above 0°C.

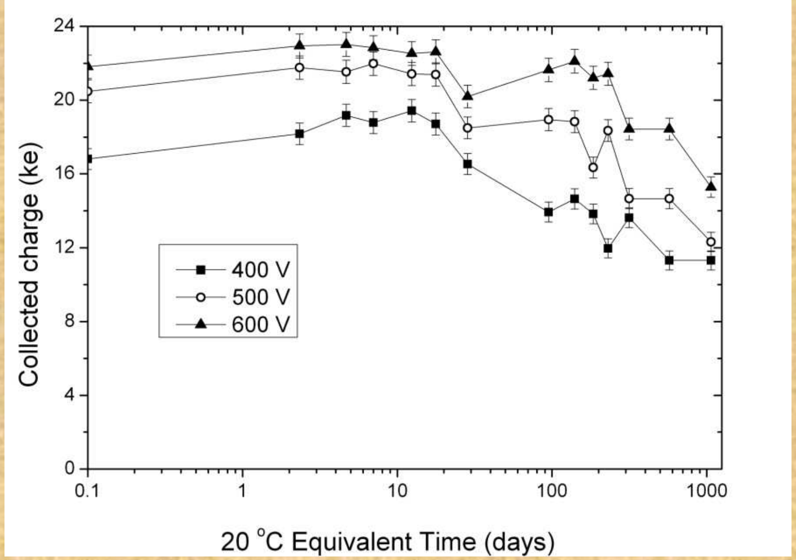
Initial V_{FD} ~ 2800V

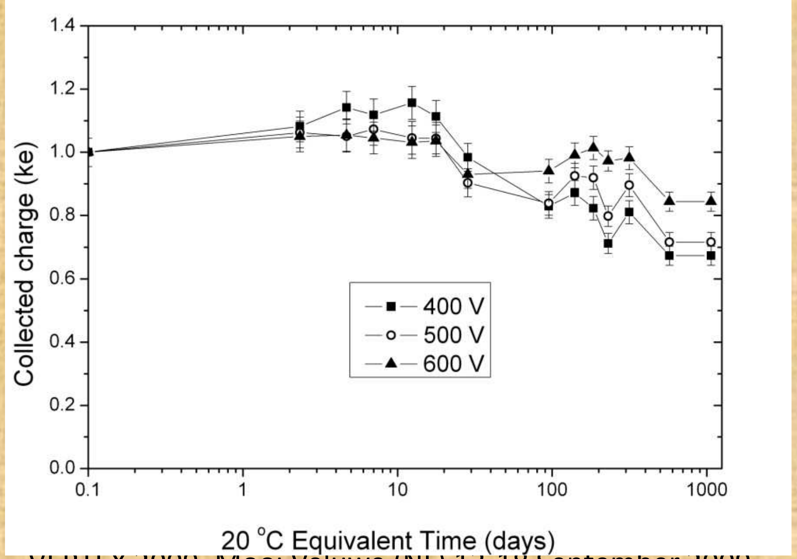


Predictions from RD48 parameters for Oxygen enriched devices (best scenario: after 7 RT annealing years the V_{fd} goes from ~2800V to ~12000 V!

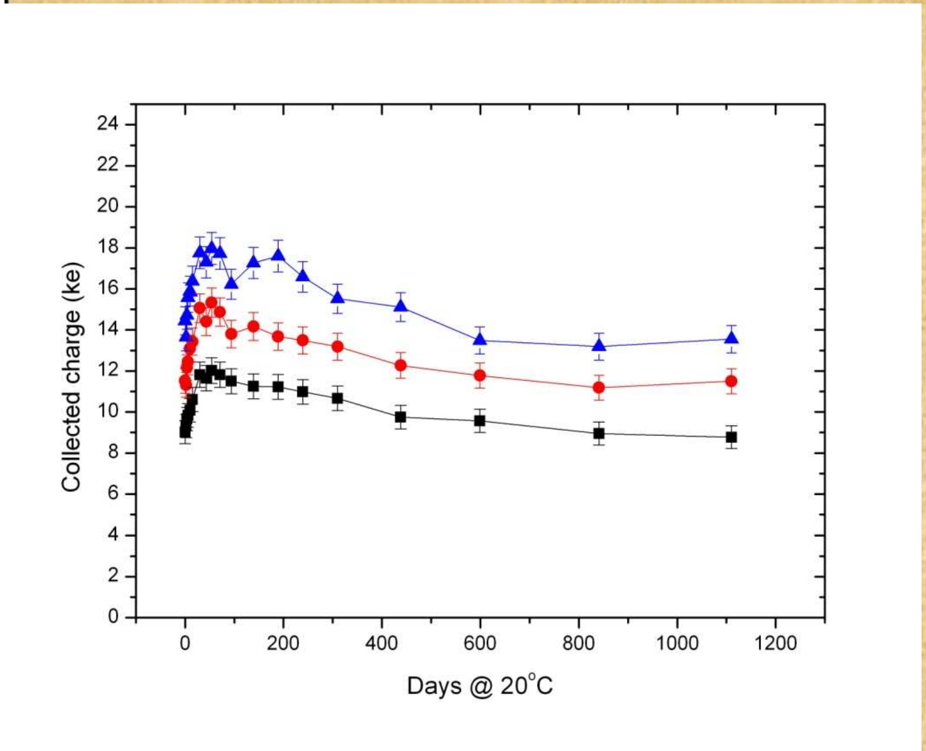
Changes of the CCE in p-in-n

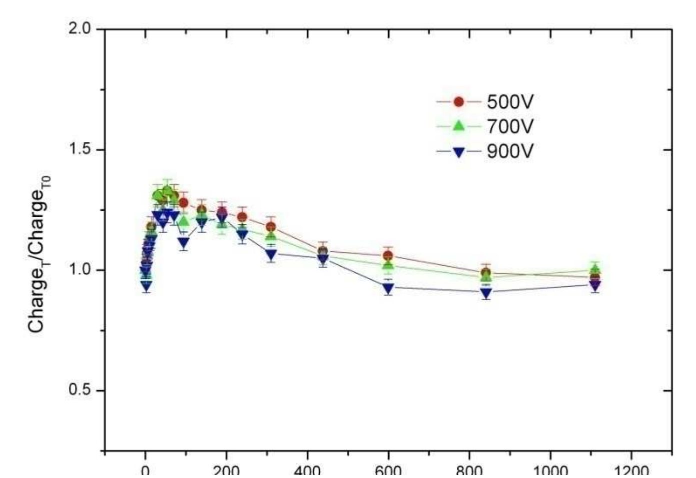


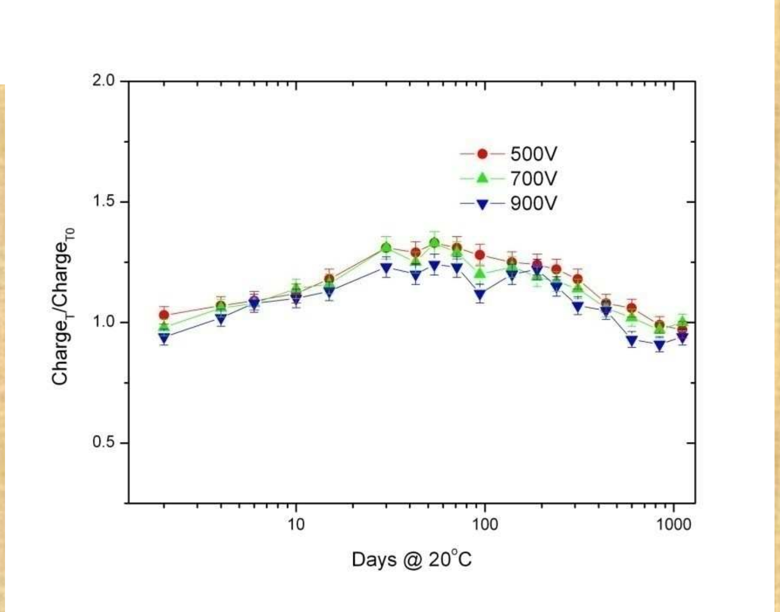




“Fine step” Annealing of the colleted charge, HPK FZ n-in-p, 1E15 n cm^{-2}

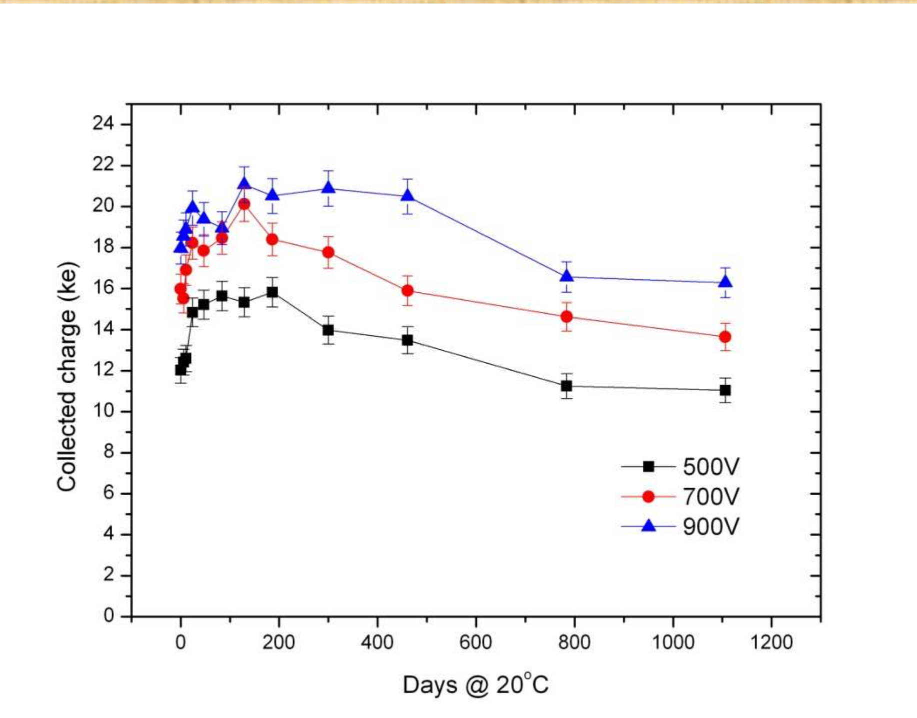


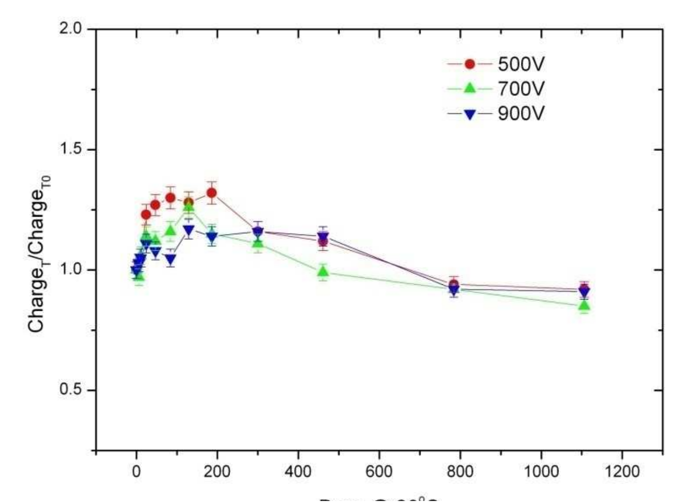


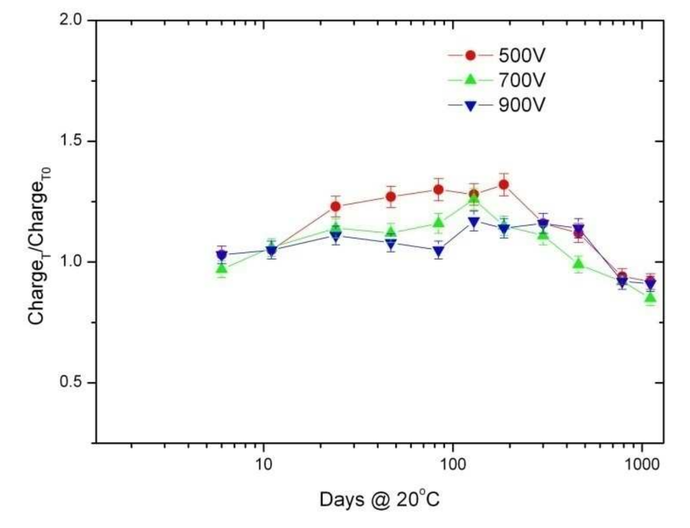


Neutron irradiations in Ljubljana, neutrons are dominating the radiation damage > 25 cm radius.

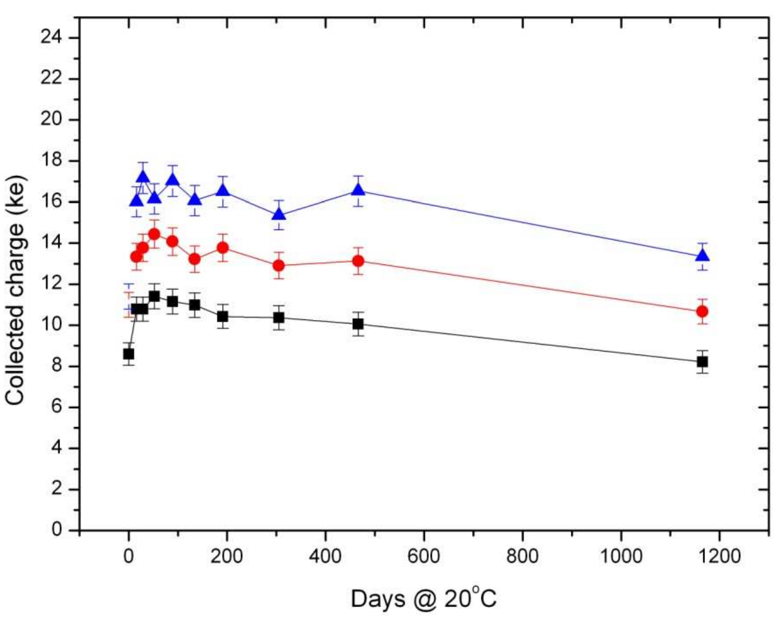
“Fine step” Annealing of the colleted charge, Micron FZ n-in-p, 1E15 n cm^{-2} (26MeV p irradiation)

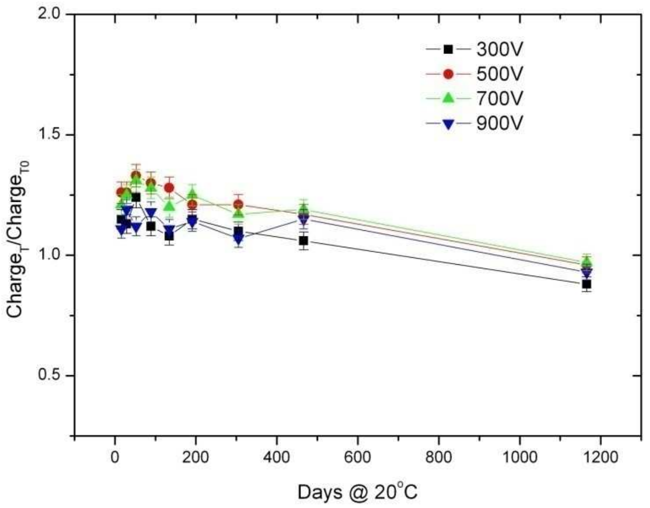


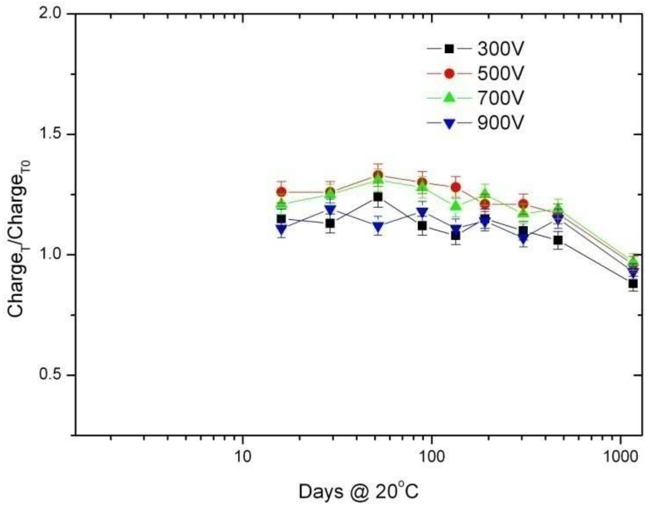




"Fine step" Annealing of the colleted charge, Micron FZ n-in-n, 1.5E15 n cm^{-2}

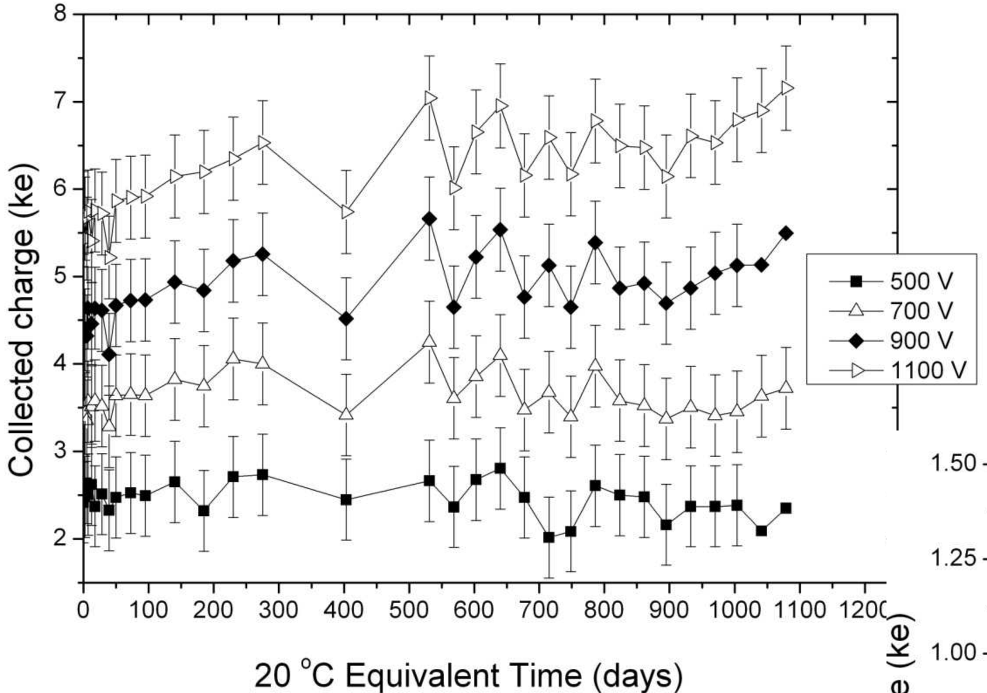


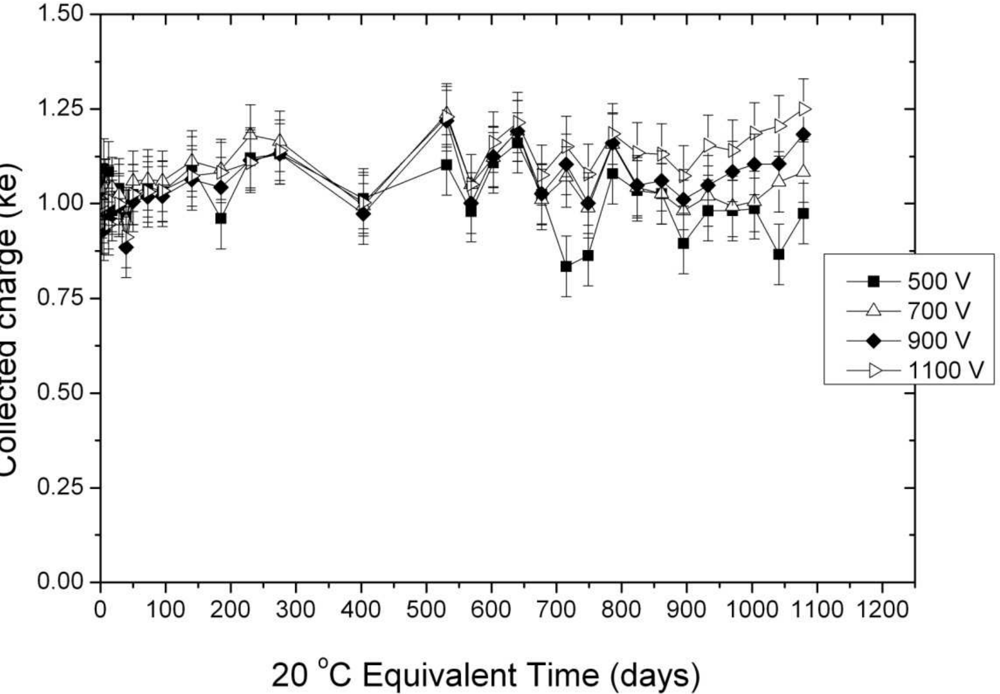




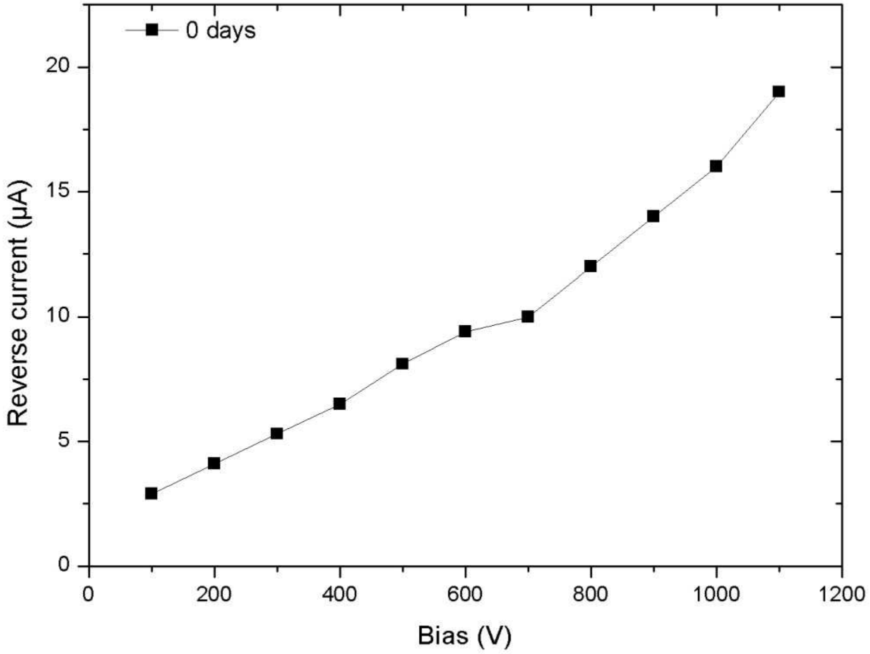
“Fine step” CCE Annealing 1.5E16 n cm^{-2}

Irradiated with 26MeV protons (Karlsruhe).





“Fine step” Annealing of the reverse current, HPK FZ n-in-p, 1E15 n cm^{-2}



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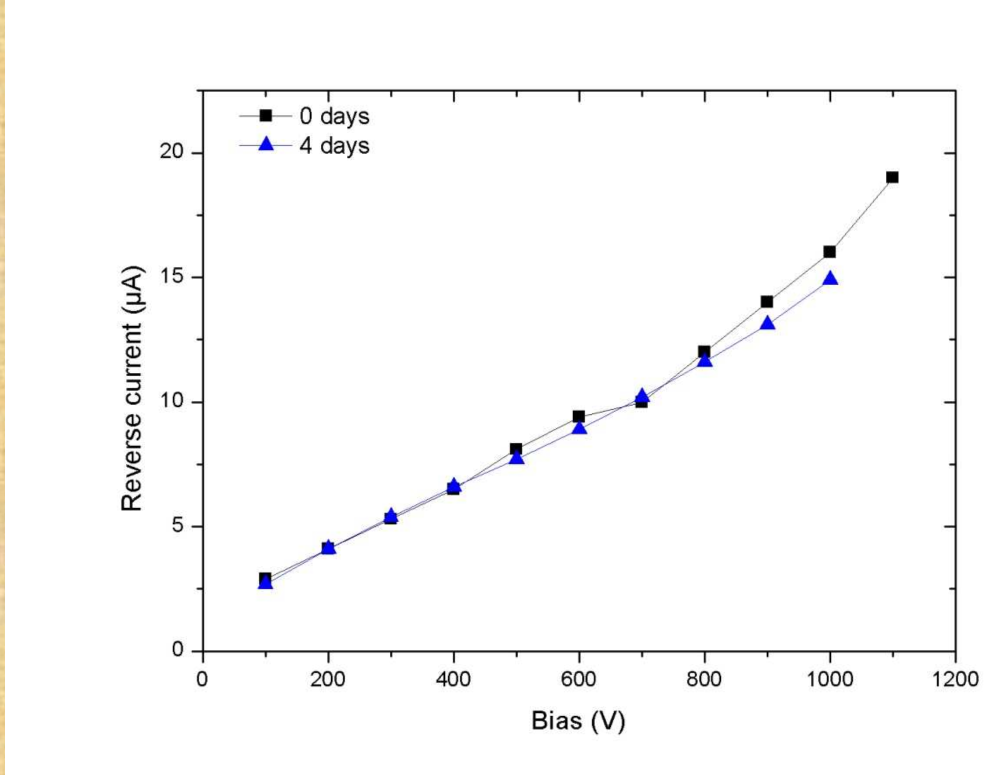

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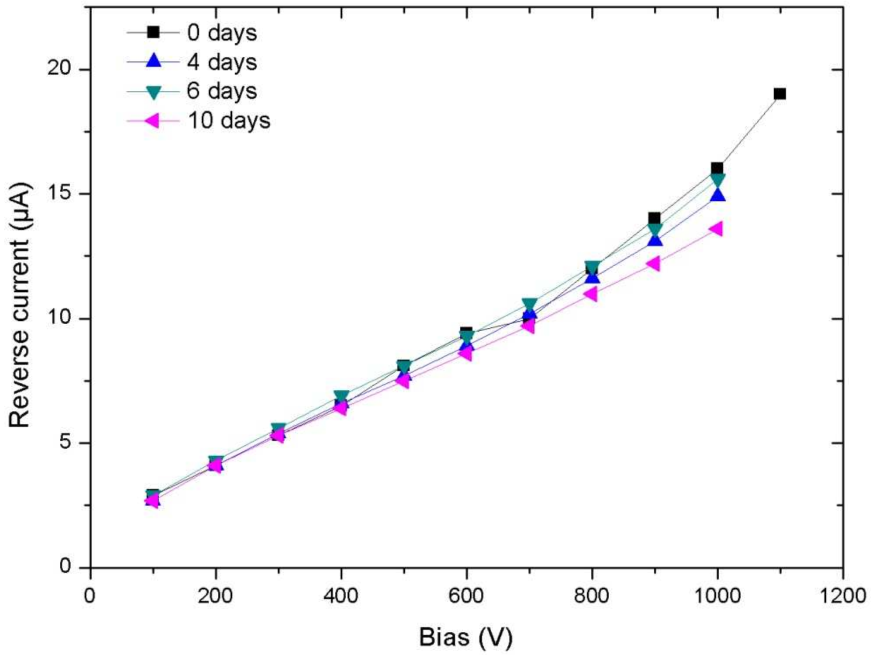

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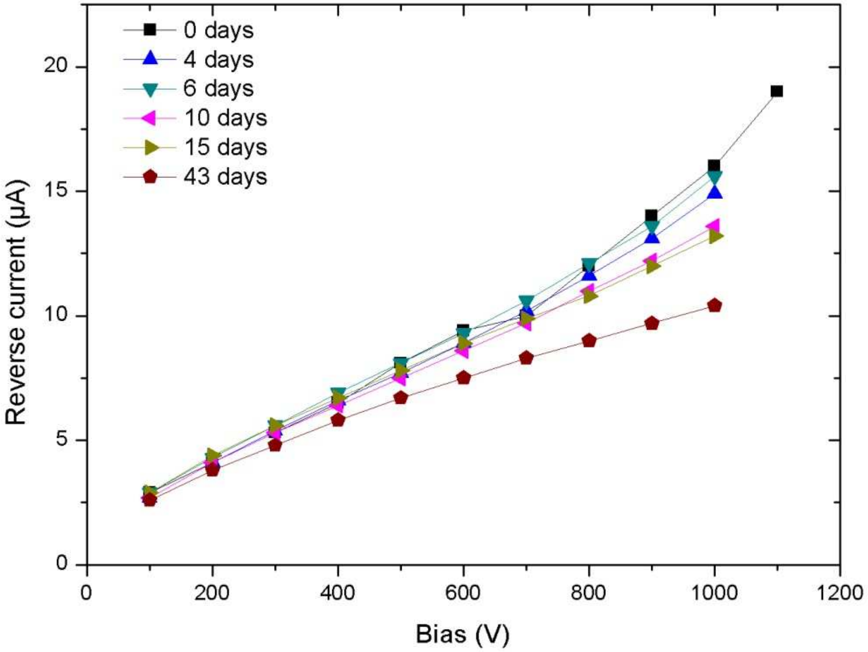

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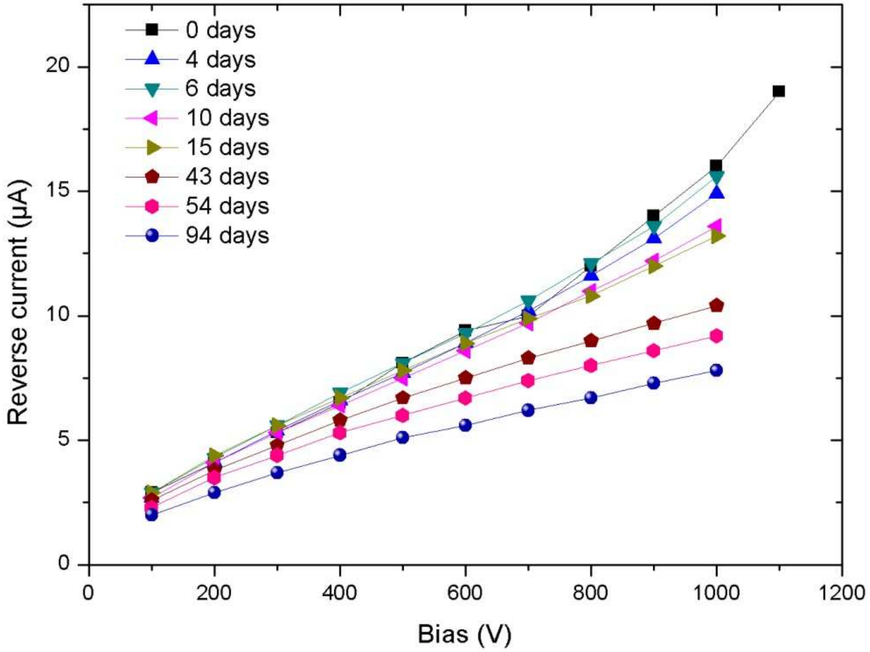

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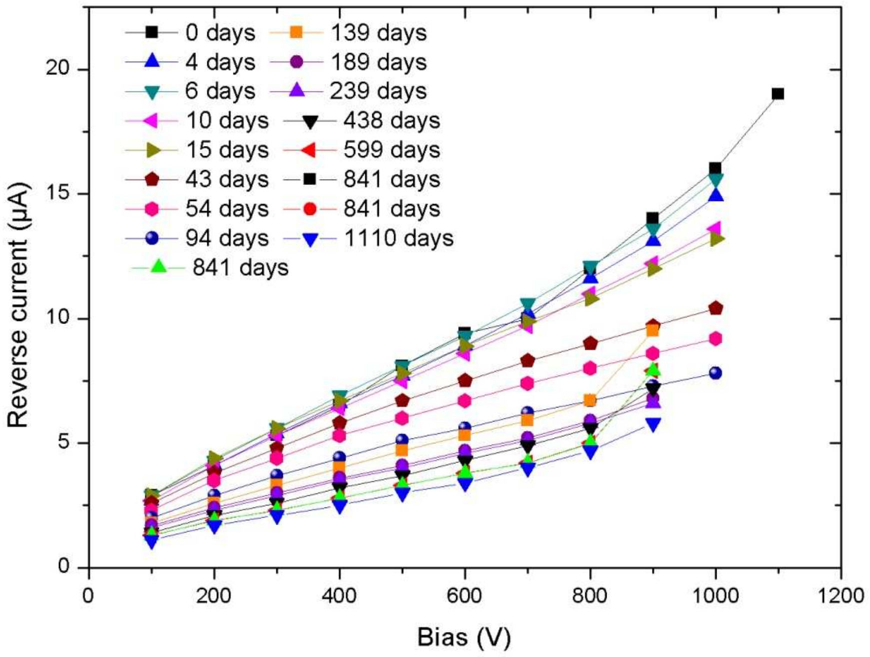
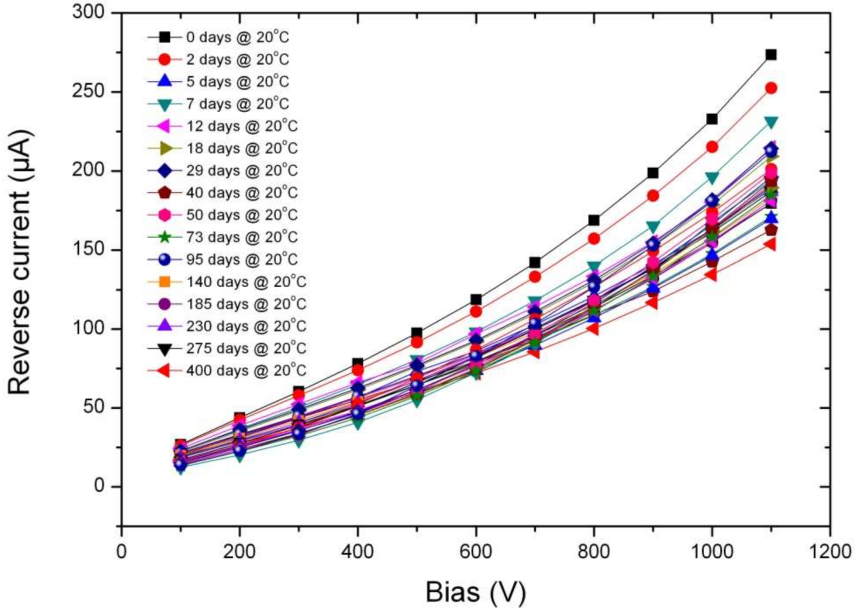
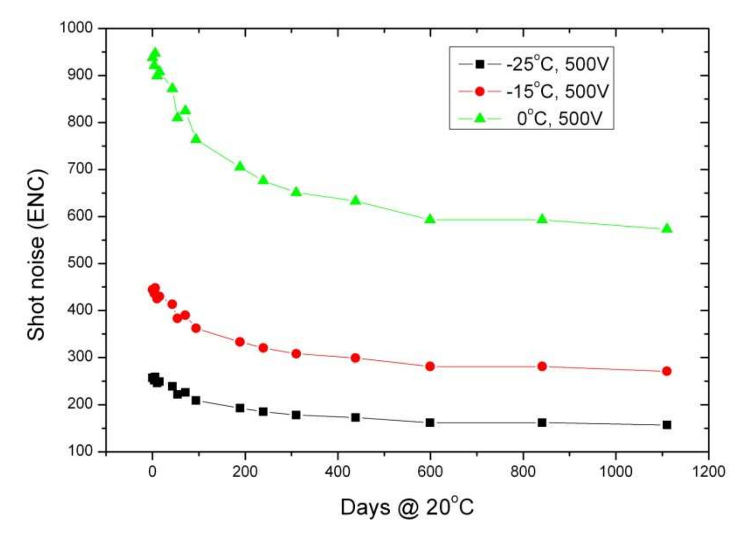


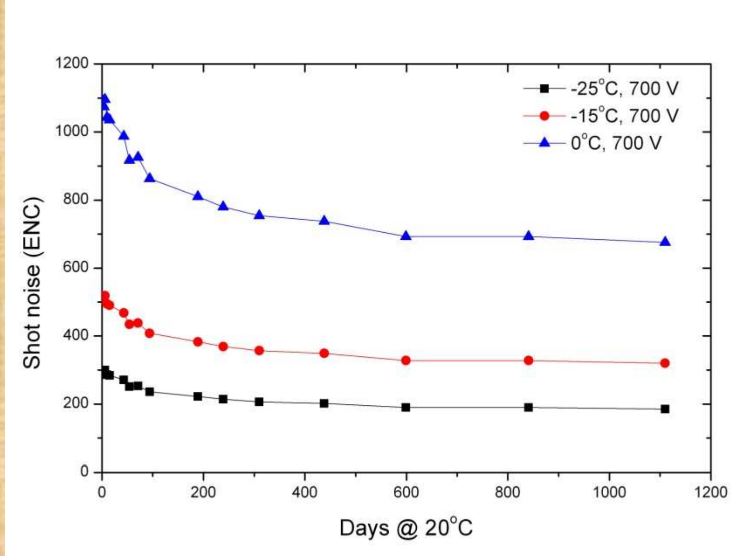
nnealing of the reverse current, Micron n-in-p, after 1.5E16 n_{eq} cm^{-2} (26 MeV p irradiation)

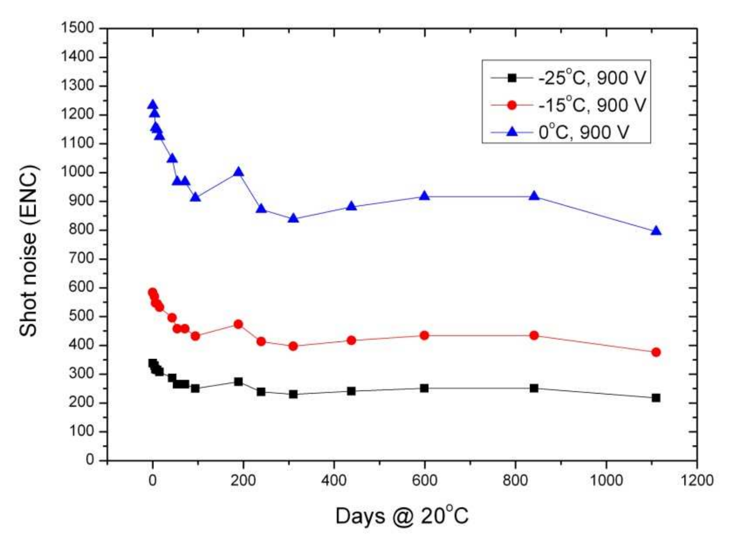


Shot noise

The reduction of the reverse current means a corresponding reduction of the power consumption of the detectors. But it also has a significant impact on the shot noise!

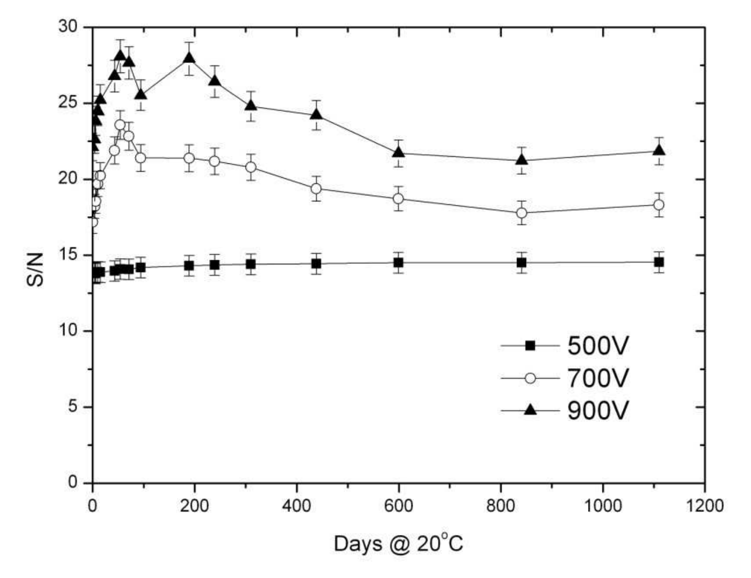


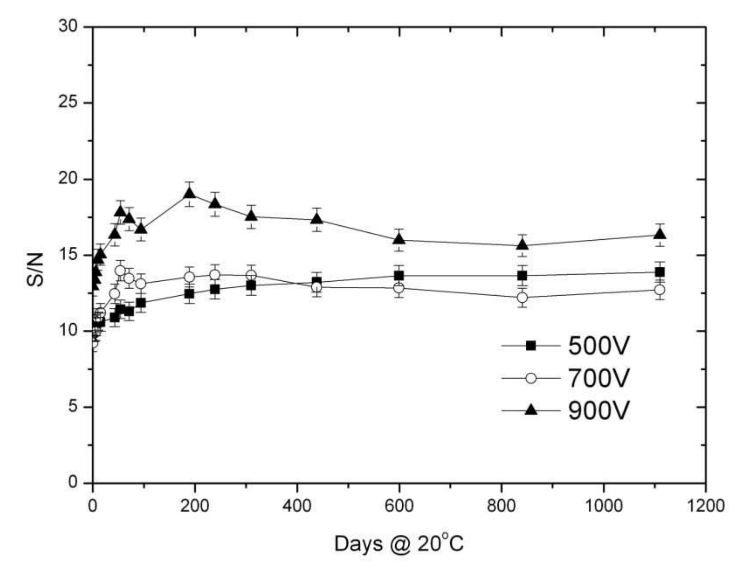




Annealing of S/N, 1E15 n cm^{-2}

Noise is the sum in quadrature of shot noise and parallel noise (taken from the Beetle chip specs, and estimated as 600ENC)





0°C

-25°C

CONCLUSIONS

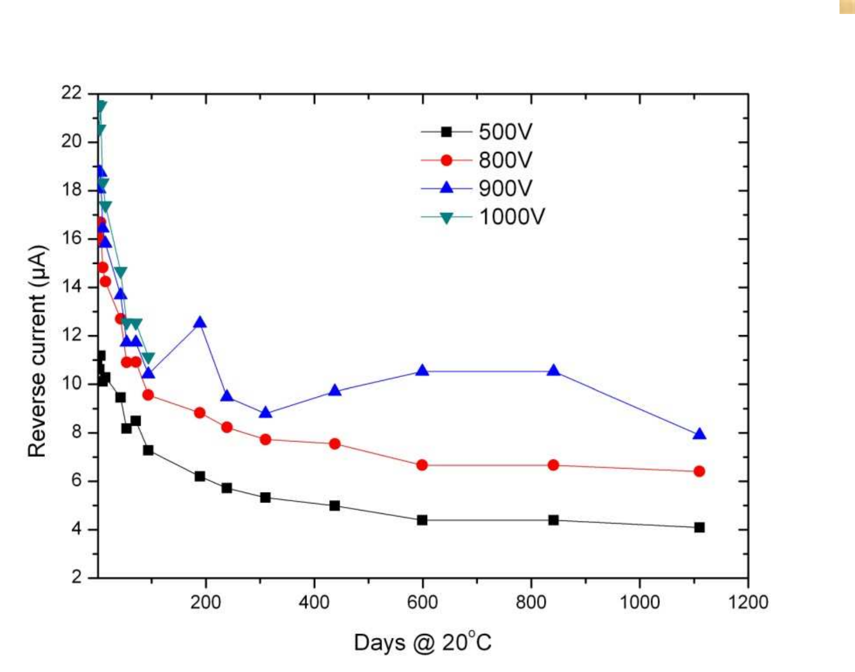
Microstrip and pixel sensors can instrument every layer of the upgraded sLHC experiments (with a S/N>10), provided that adequate voltage can be routed to the detectors. Adequate means 500V for the sensors at radii >30 cm, and 1000-1200V for the innermost (<4 cm) layers.

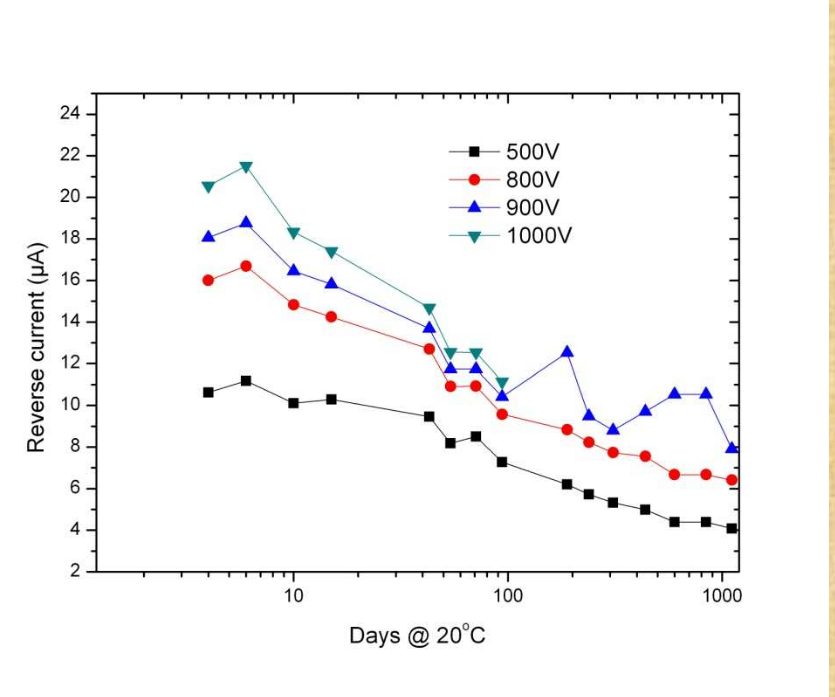
Together with the high voltage, adequate cooling must be provided. A -20/25 ^{o}C would be required to the innermost sensors, but also recommended to the outer strips, for controlling the shot noise.

It should be noticed that the experiments will probably require a rather homogeneous T in the all tracker, for practical reasons.

Controlled annealing (at 20^{0}C) is a very useful tool to reduce power dissipation and recover fraction of S/N in heavily irradiated silicon detectors. Optimum annealing time is between 100-300 days for CCE (while no restriction is found with reverse current recovery).

“Fine step” Annealing of the reverse current, HPK FZ n-in-p, 1E15 n cm^{-2}





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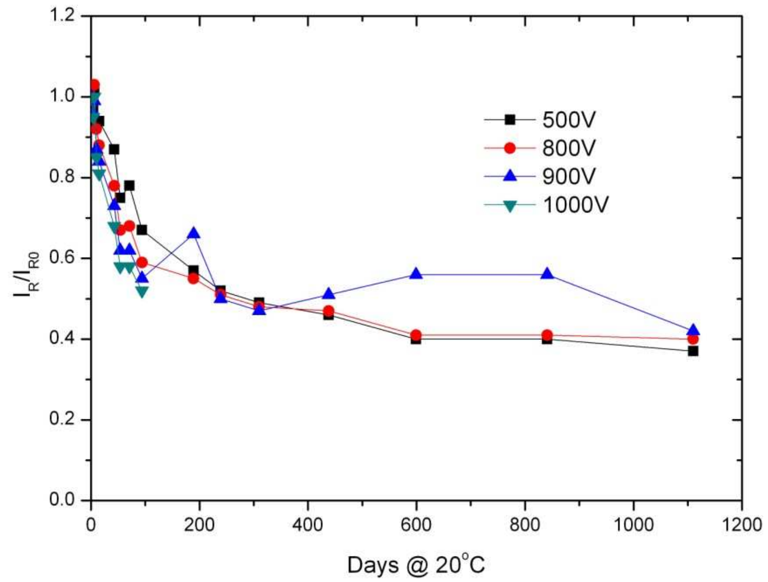
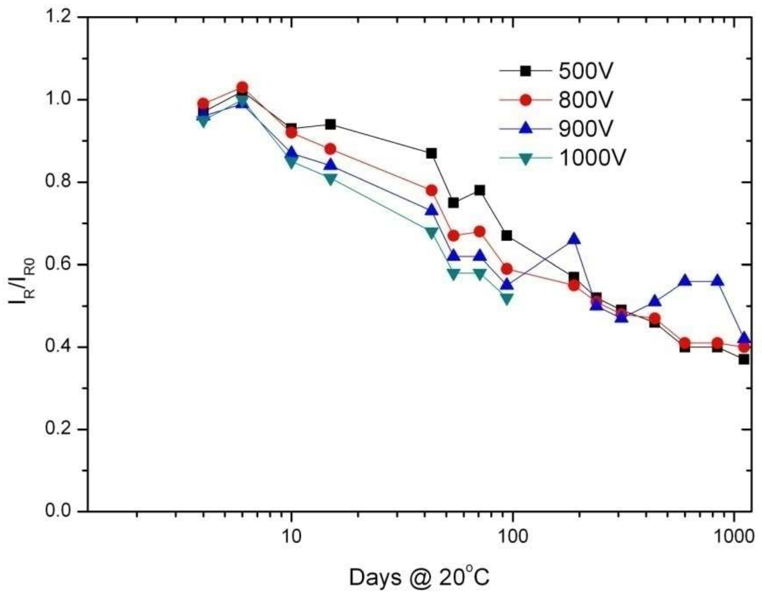
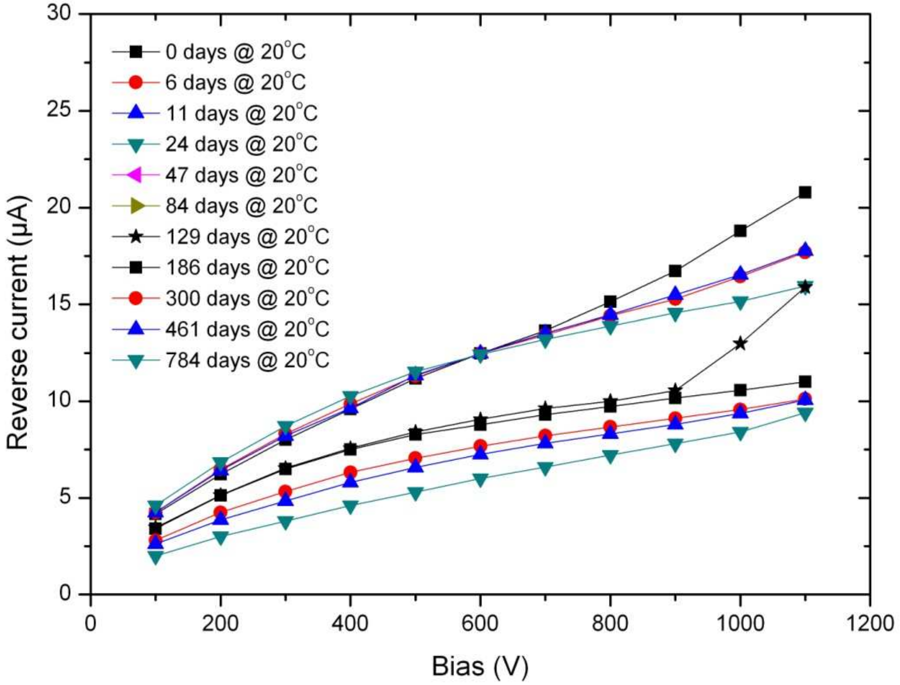




This translates directely in reduction of power consuption!

"Fine step" Annealing of the reverse current, Micron FZ n-in-p, 1E15 n cm^{-2} (26MeV p irradiation)



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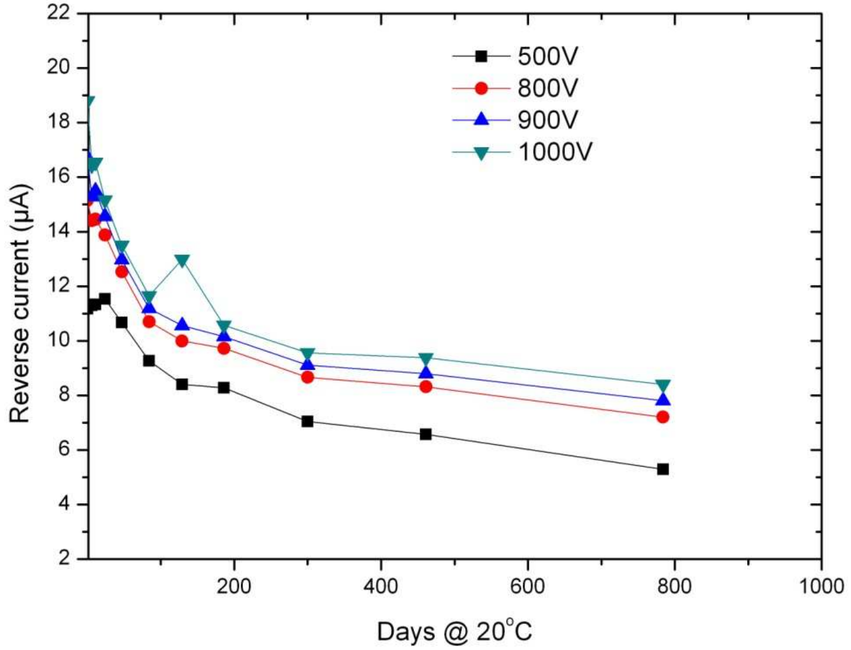
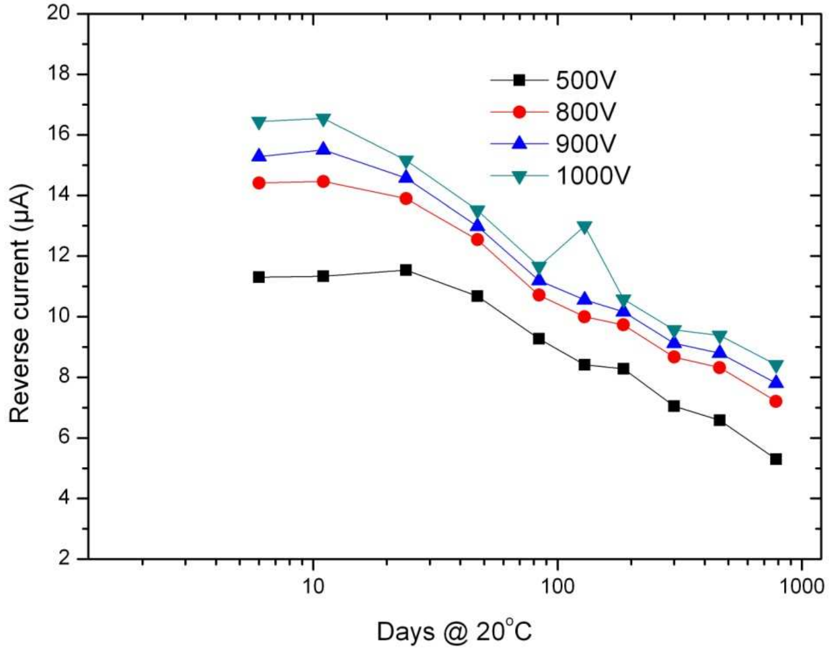
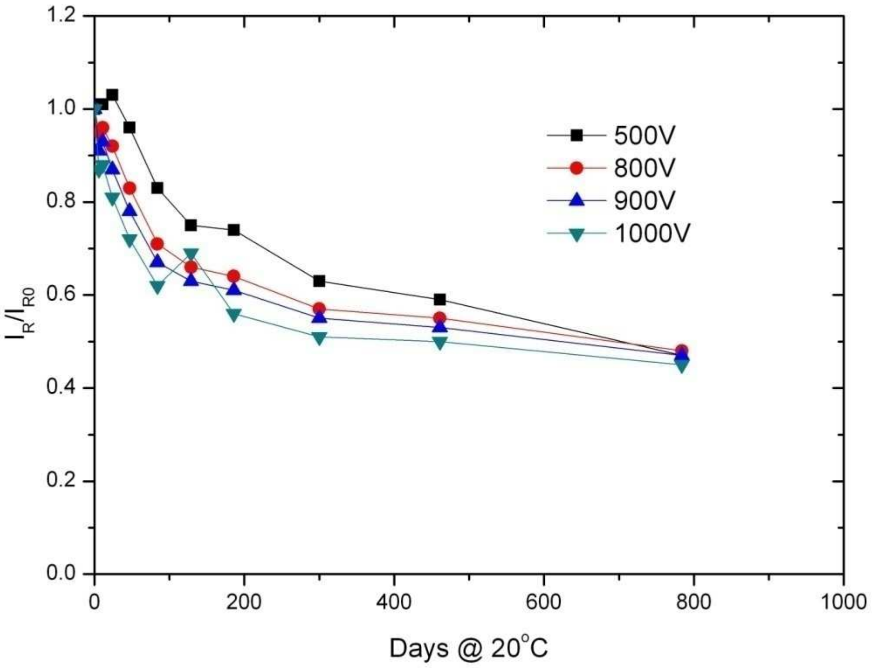
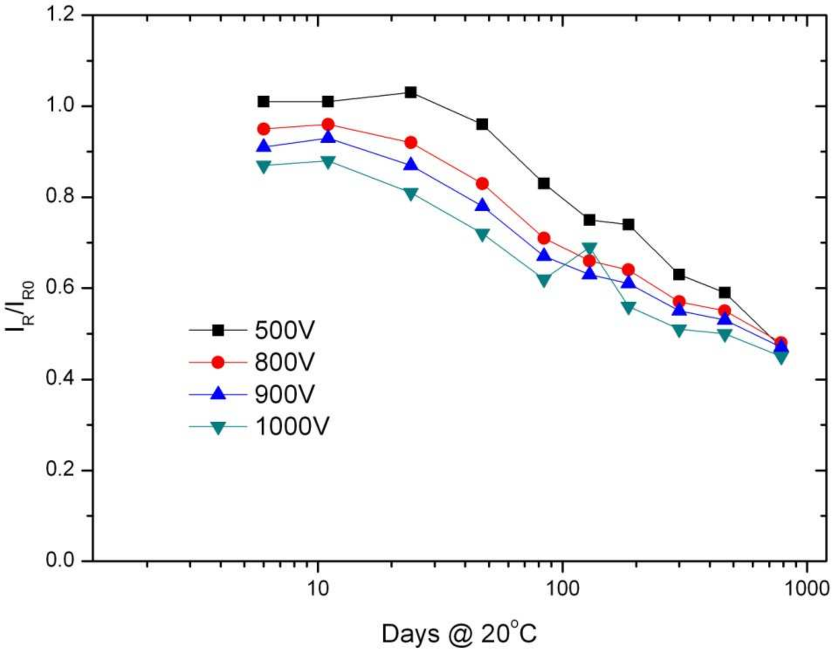




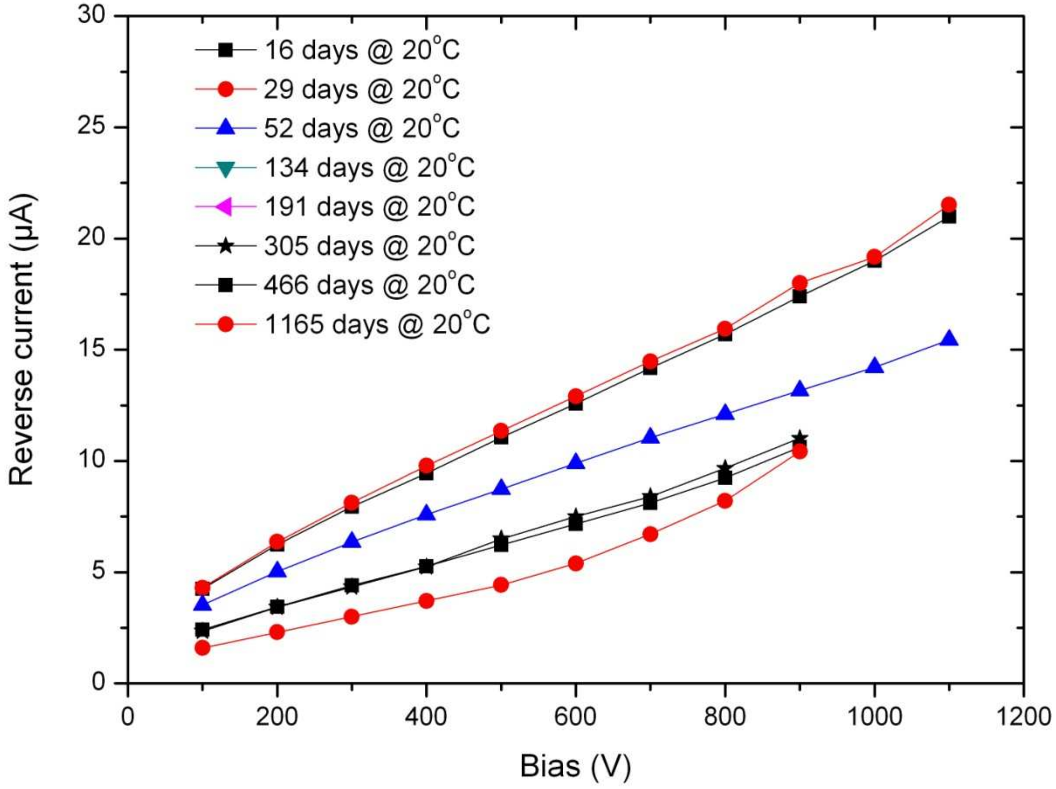
“Fine step” Annealing of the reverse current, Micron FZ n-in-p, 1E15 n cm^{-2} (26MeV p irradiation)



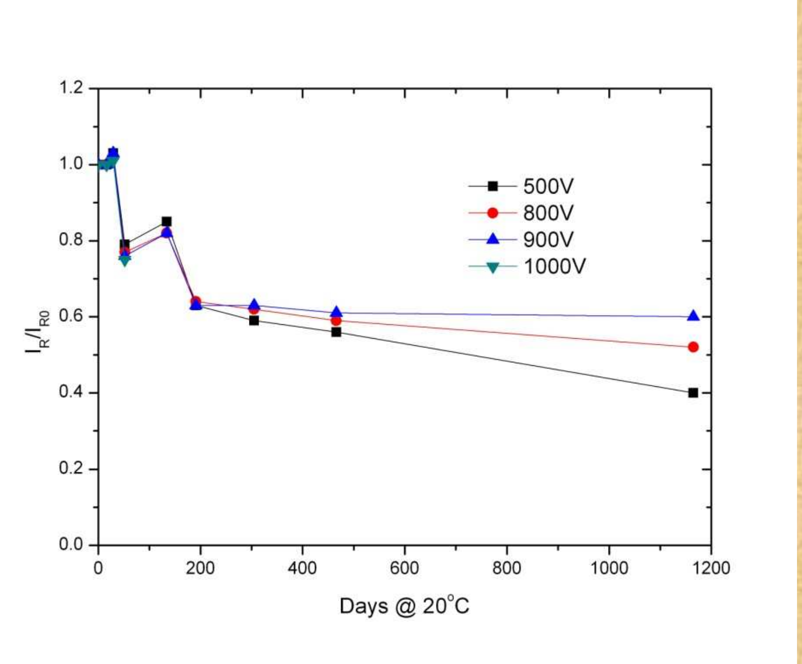


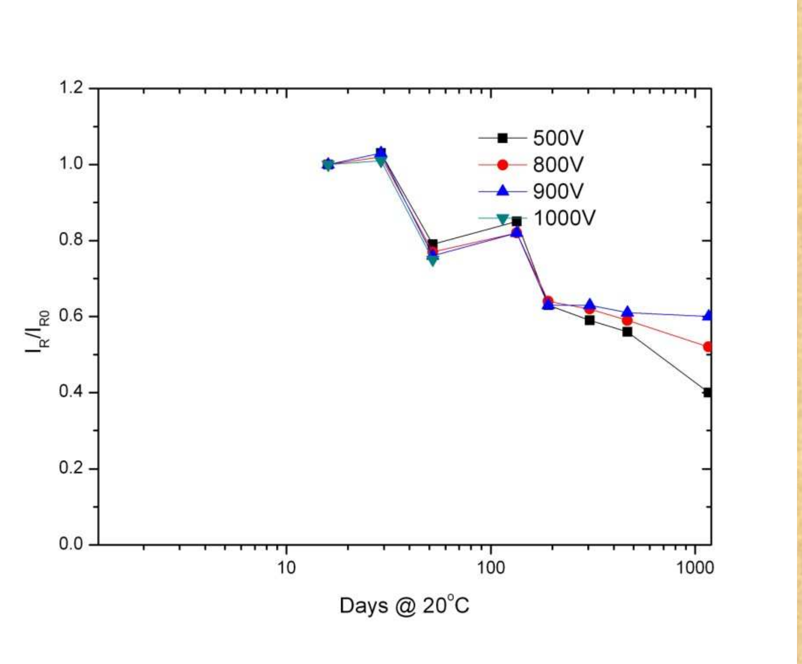
This translates directely in reduction of power consuption!

“Fine step” Annealing of the reverse current, Micron FZ n-in-n, 1.5E15 n cm^{-2}



"Fine step" Annealing of the reverse current, Micron FZ n-in-n, 1.5E15 n cm^{-2}





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