Update on Annealing Studies for Severely Irradiated Silicon Detectors

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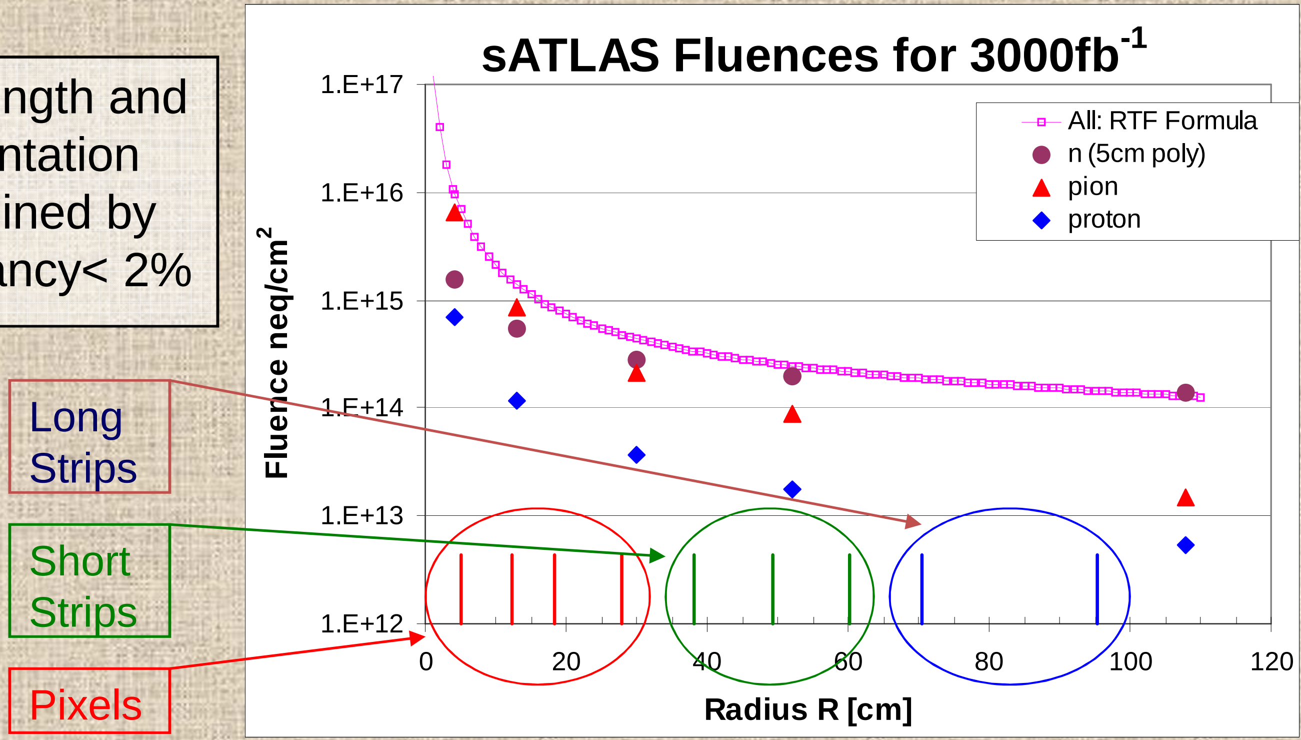
MOTIVATION and OUTLINE:

Although several of these results have been published since 2006, I have learned (e.g. in a recent ATLAS-IBL meeting) that the performance of irradiated planar silicon detectors with time after irradiation (annealing) are often interpreted in the light of early results obtained with CV measurements. These results have been used for planning the running scenario of the present LHC sensors, but things have evolved since. It is true that operating the silicon Vertex and Tracker detectors at the sLHC (or also the IBL) will need even more careful planning, due to the unprecedented level of radiation.

The results of charge collection and reverse current measurements of variously irradiated sensors are here shown.

Expected Fluence in sATLAS Tracker

Strip length and segmentation determined by occupancy< 2%



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

Mix of neutrons, protons, pions depending on radius R

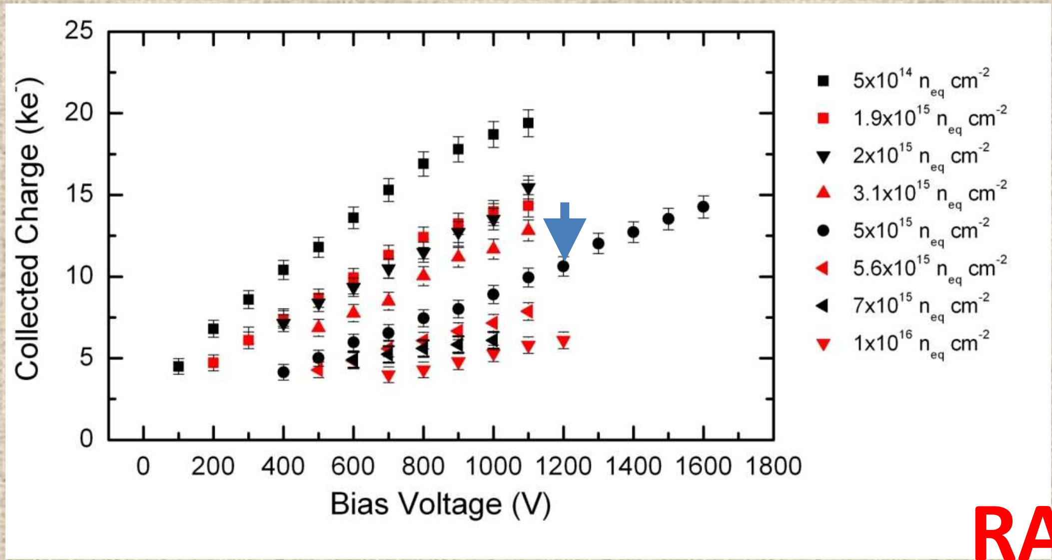
Long and short strips damage largely due to neutrons

Pixels damage due to neutrons and pions

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

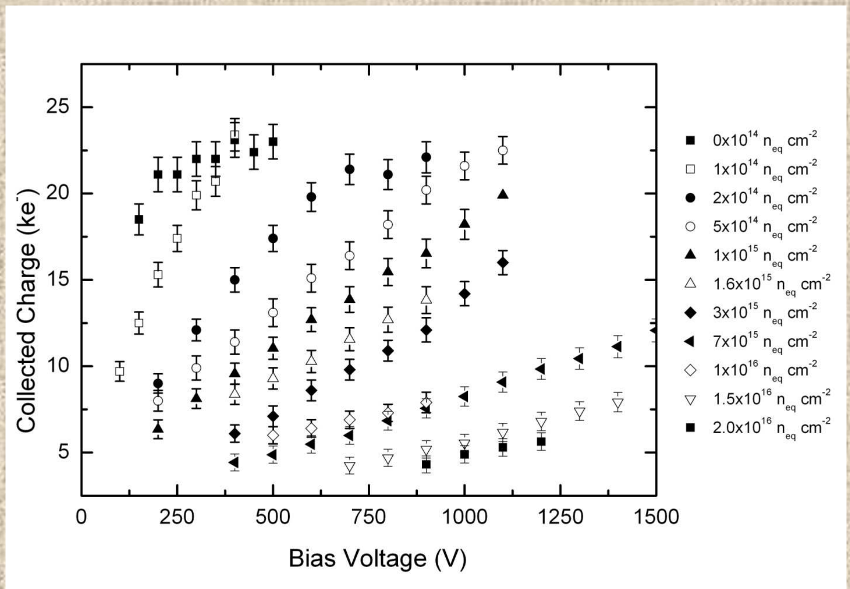
Innermost Pixel Layer:	1-1.6*10^{16} n_{eq}/cm^2 = 500 Mrad
Outer Pixel Layers:	3*10^{15} n_{eq}/cm^2 = 150 Mrad
Short strips:	1*10^{15} n_{eq}/cm^2 = 50 Mrad
Long strips:	4*10^{14} n_{eq}/cm^2 =20 Mrad

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

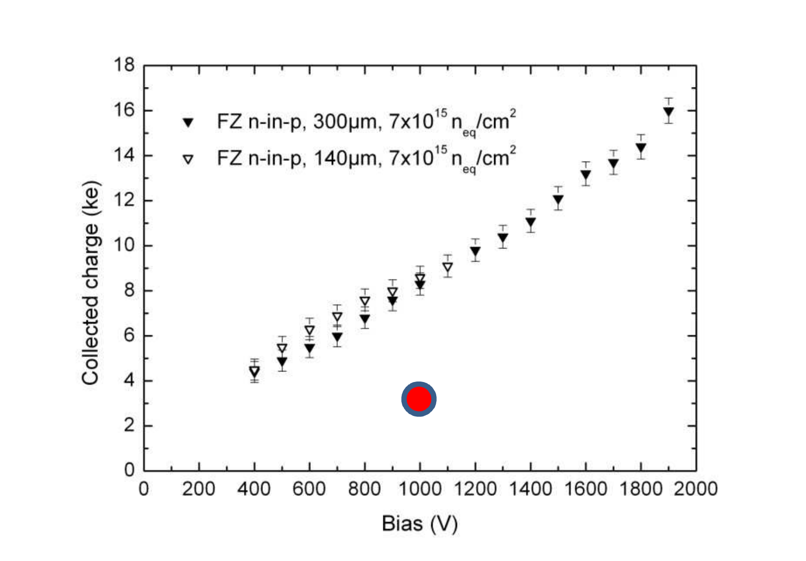


Proton irradiation (24GeV/c CERN-PS and 26MeV Karlsruhe)

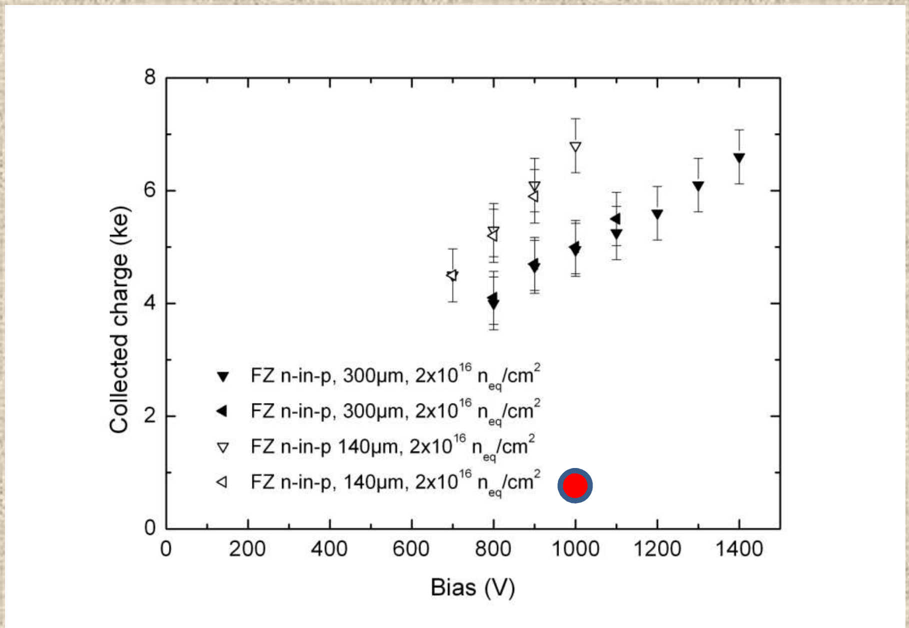
RADIATION TOLERANCE: changes of the signal with n_{eq} fluence.

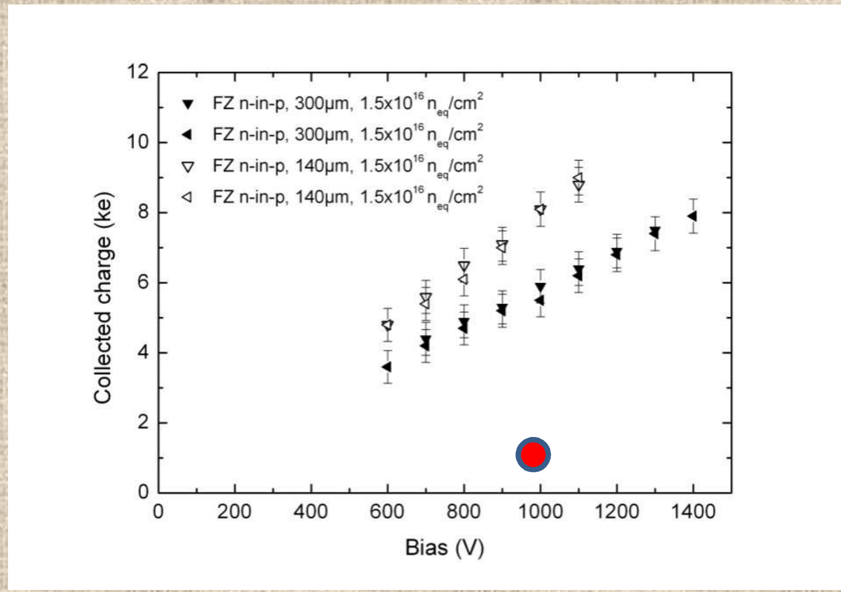


Neutron irradiation (Triga reactor, Ljubljana)



Enhanced signal after extreme fluences (charge multiplication).

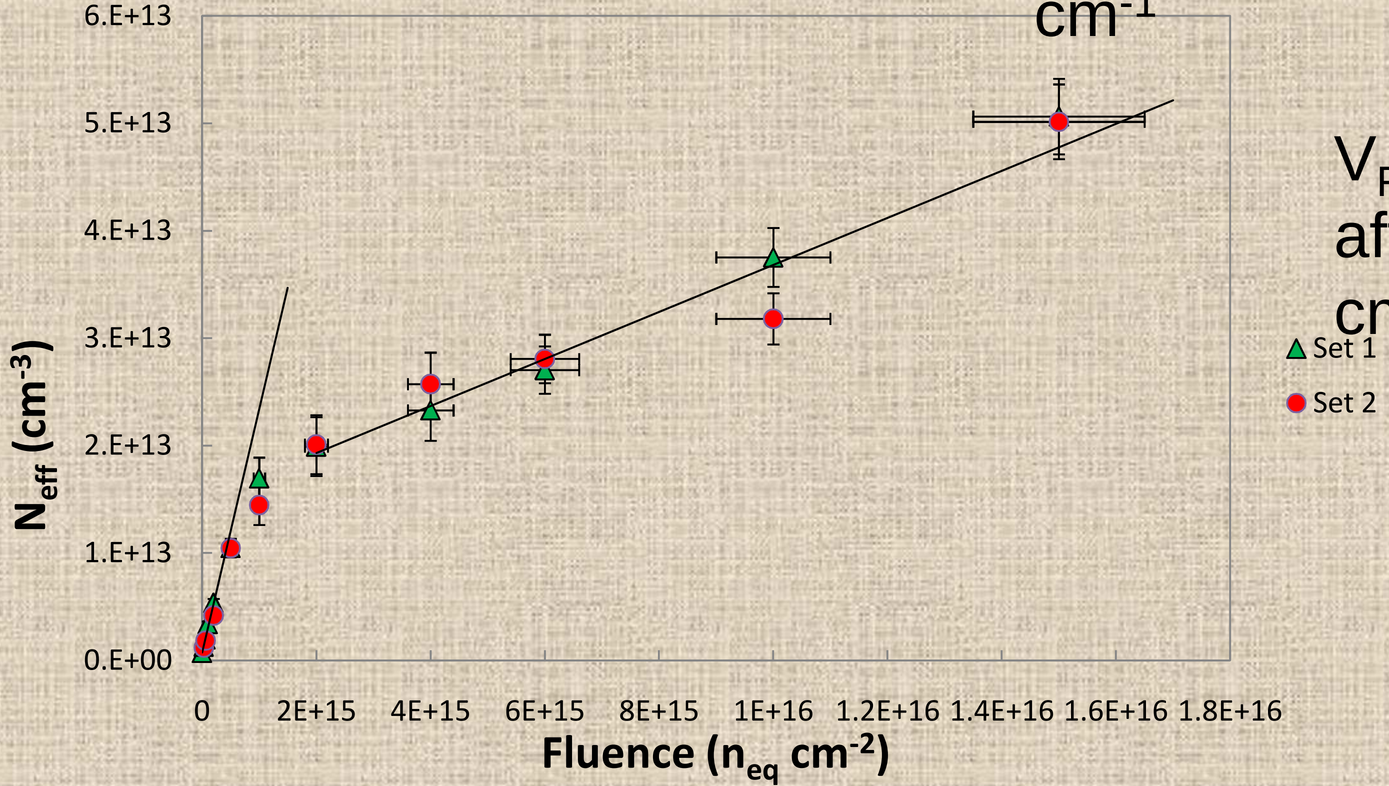




N_{eff} vs ϕ measured with the CV characteristic of 140 μm n-in-p Micron sensors after 80 min 60ºC annealing time

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}



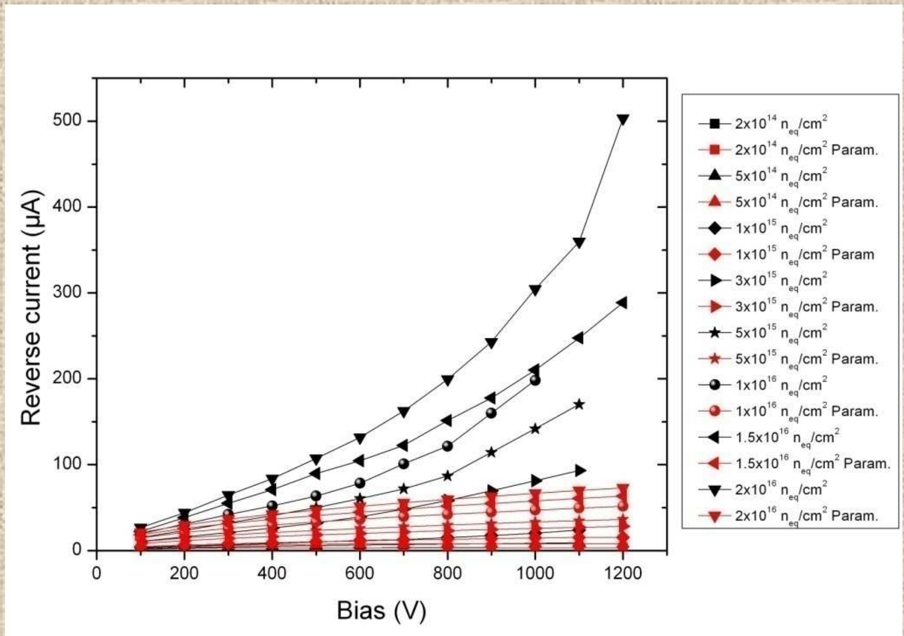
$V_{FD} \cong 890V$ after 1.5×10^{16} cm^{-2}

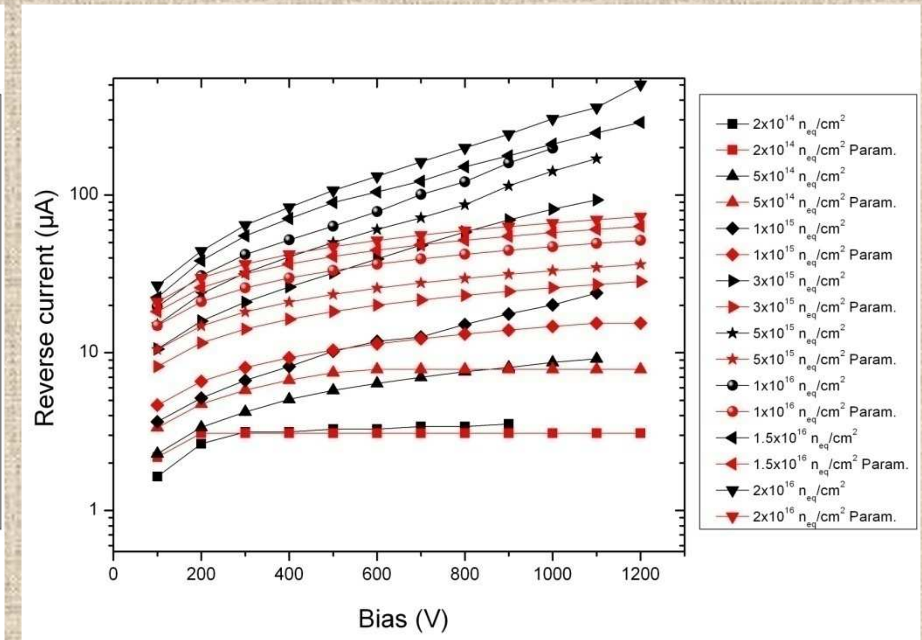
Reverse current after various doses: expectations and measurements

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

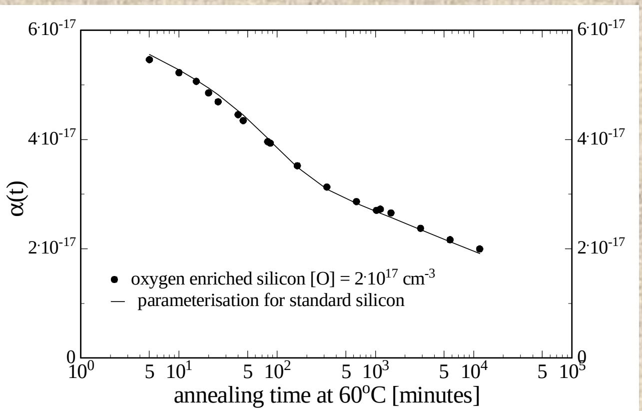




Annealing: “Old” assumption:

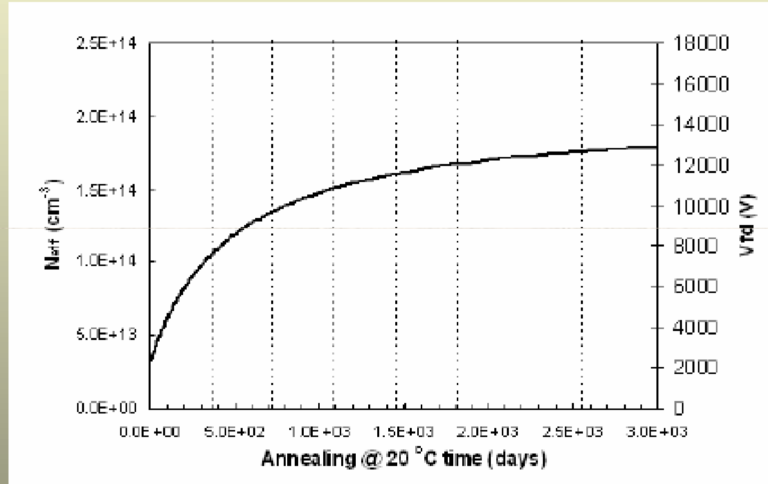
Avoid to warming irradiated detectors above 0°C, even during beam down and reduce maintenance at room temperature to minimum.

V_{FD} undergoes reverse annealing and becomes progressively higher if the detectors are kept above 0°C. To prevent the rise of V_{FD}, one looses the advantage given by the annealing behaviour of the reverse current.



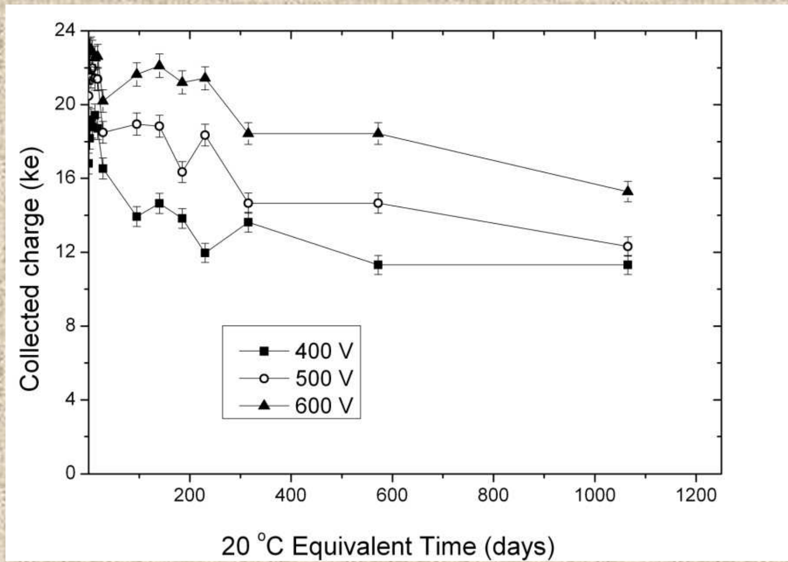
M. Moll PhD thesis

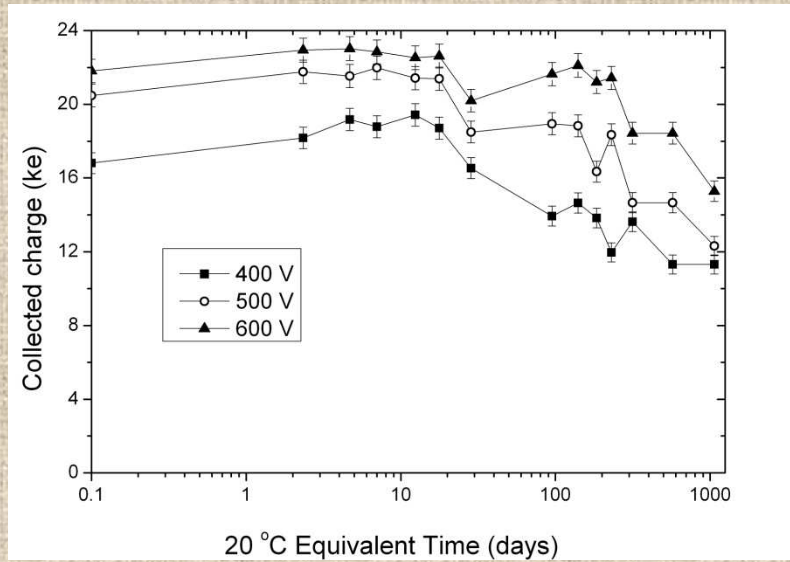
Initial V_{FD} ~ 2800V



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

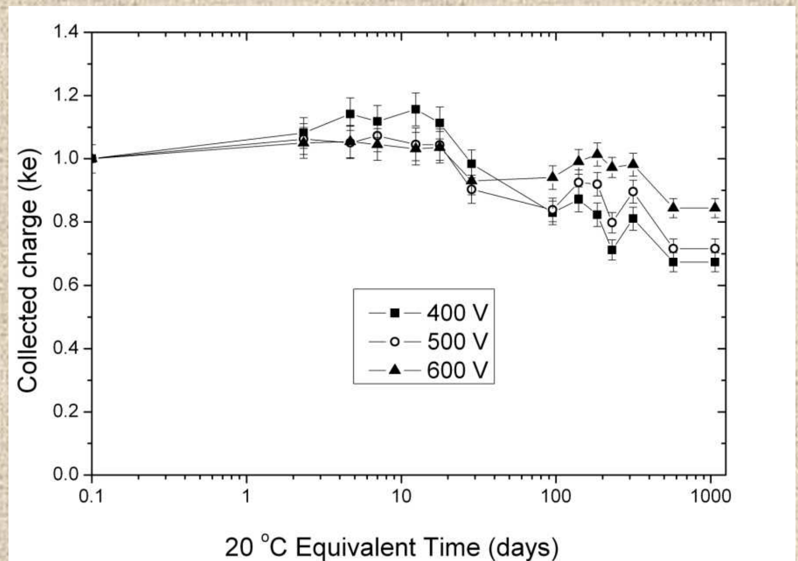
Changes of the CCE in p-in-n



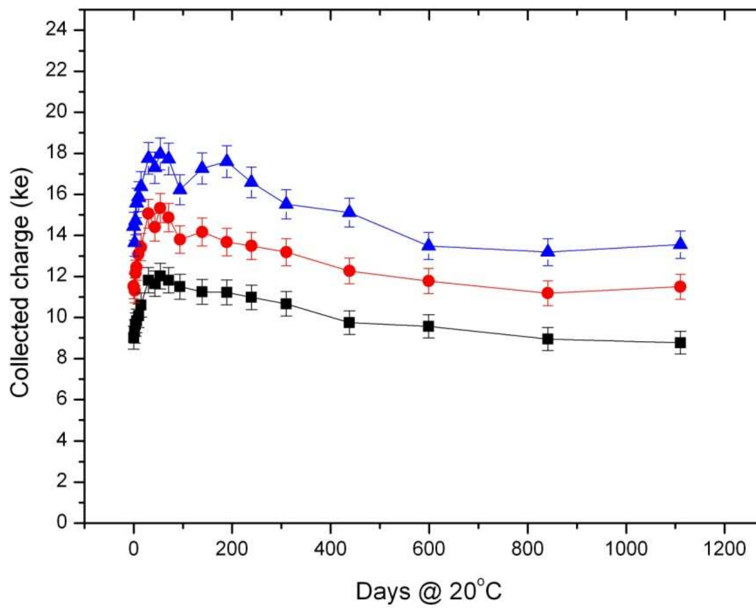


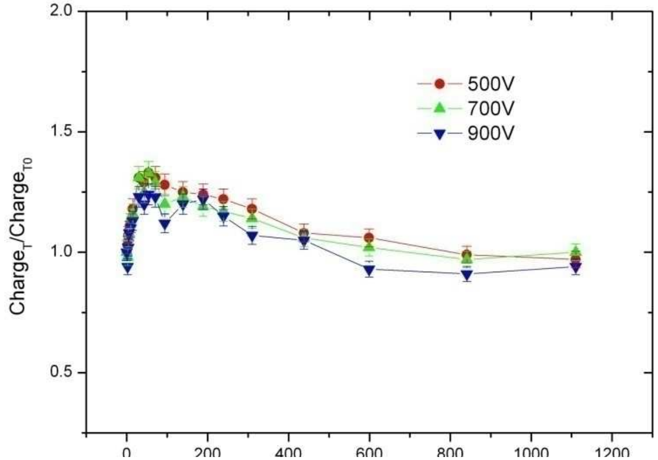
After $2x10^{14}$ n_{eq} cm^{-2}.

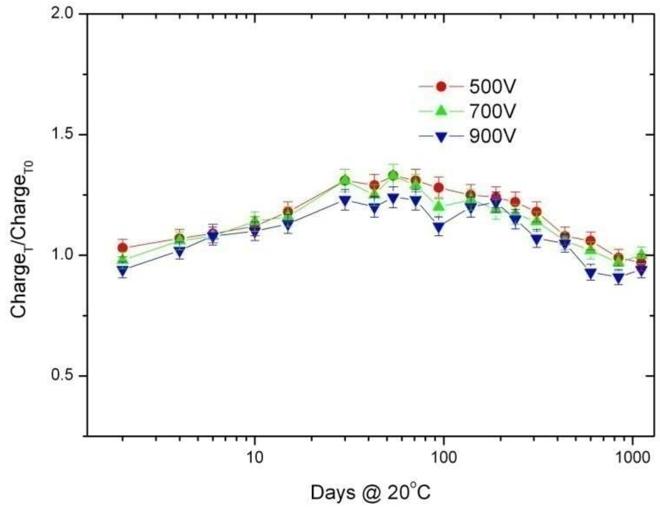
Accelerated annealing at 40, 60 and 80°C. DAQ based on SCT128A chip



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



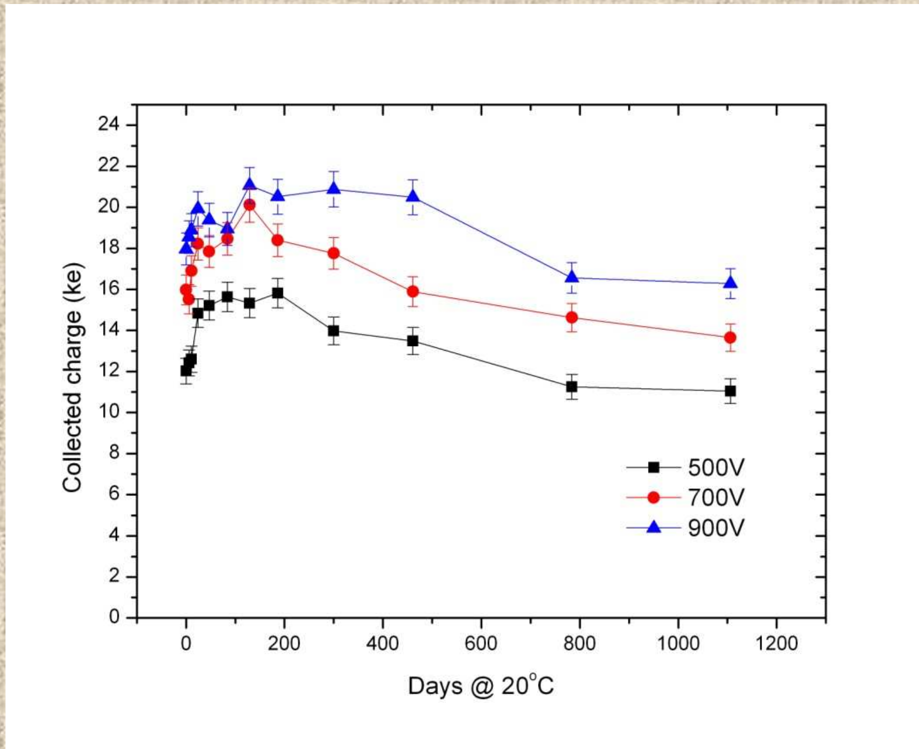


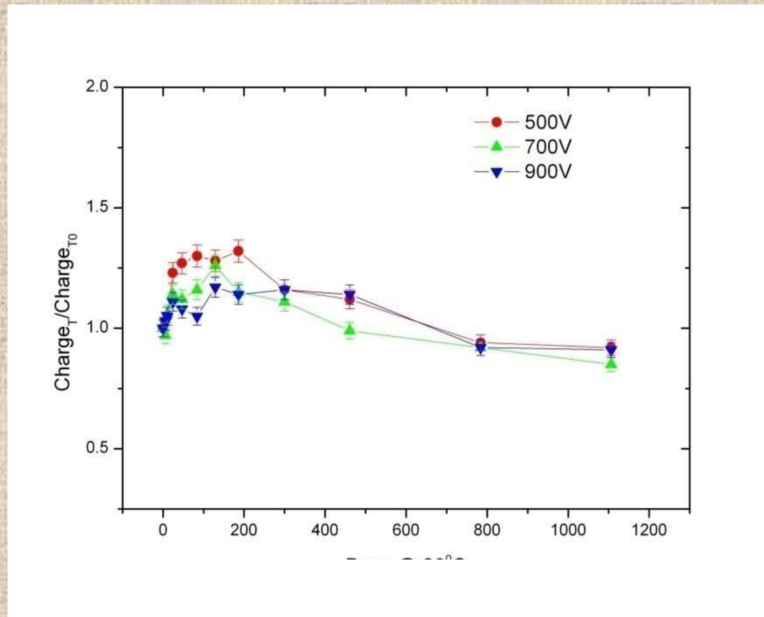


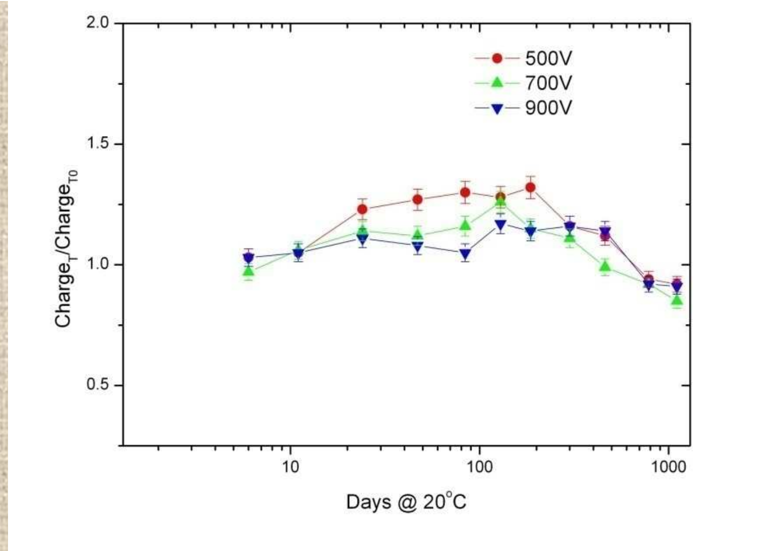
Neutron irradiations in Ljubljana, neutrons are dominating the radiation damage > 25 cm radius.

Accelerated annealing at 40, 60 and 80^{o}C. DAQ based on SCT128A chip

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

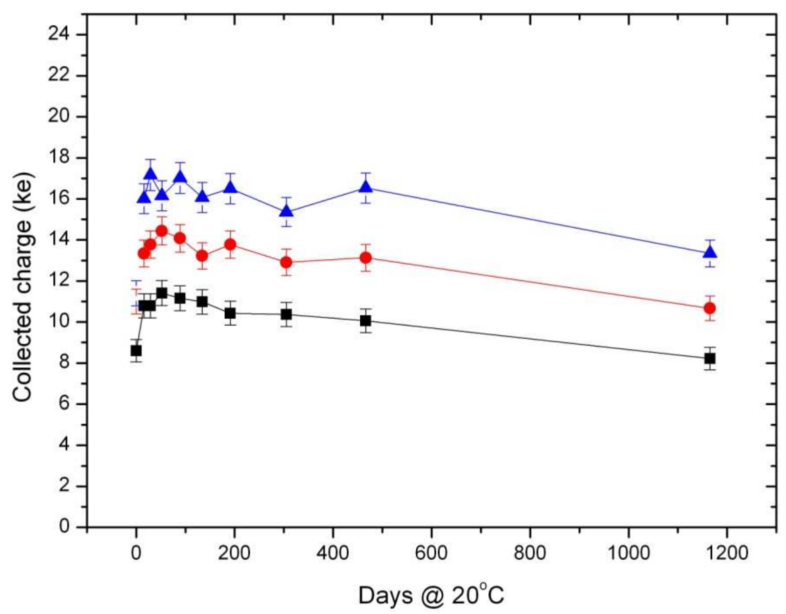


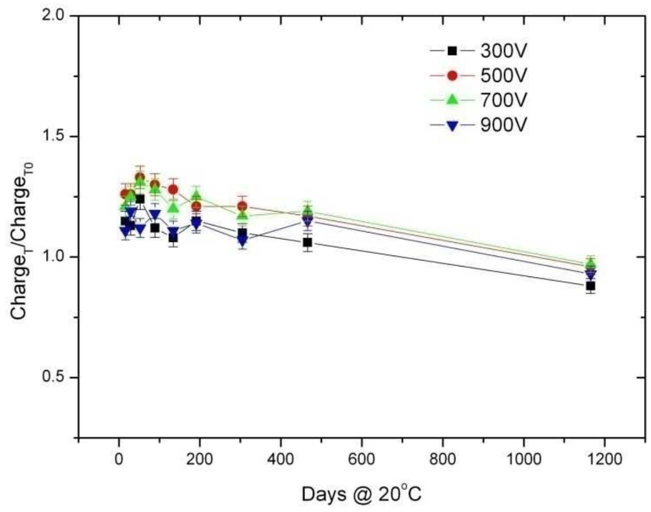


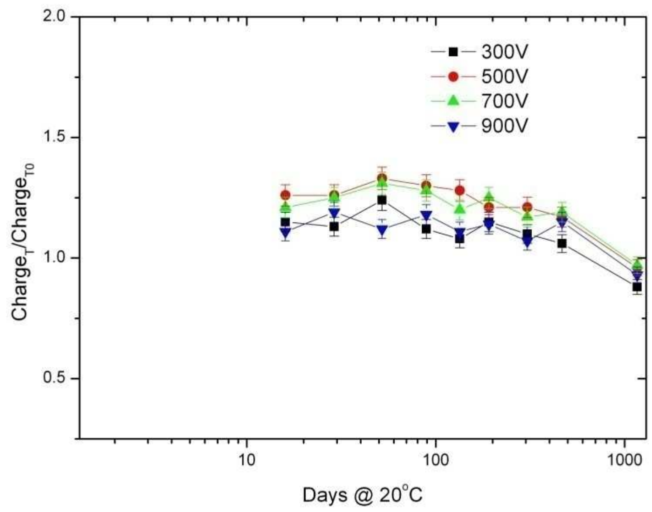


Accelerated annealing at 40, 60 and 80°C. DAQ based on SCT128A chip

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

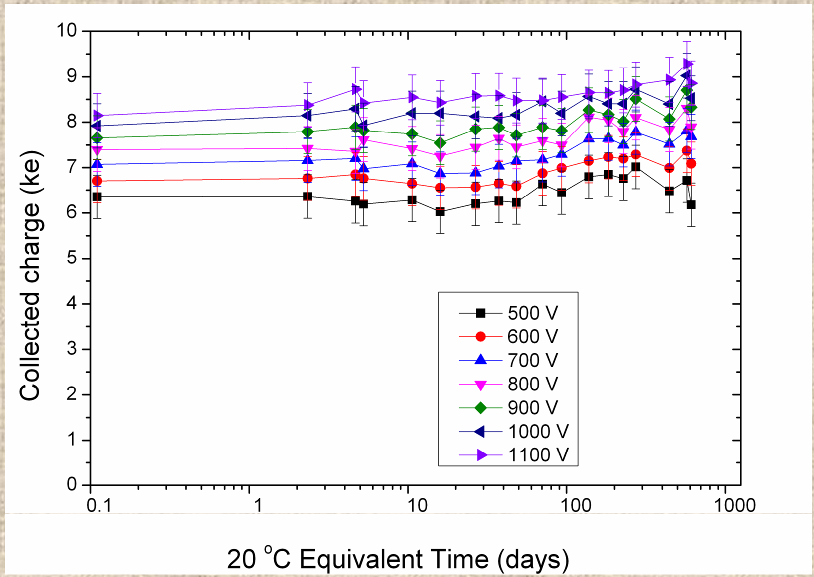






Accelerated annealing at 40, 60 and 80°C. DAQ based on SCT128A chip

CCE Annealing 1.5E16 n cm^{-2}



5x10^{16} n$_{eq}$ cm^{-2}
Irradiated with
26MeV protons
(Karlsruhe).

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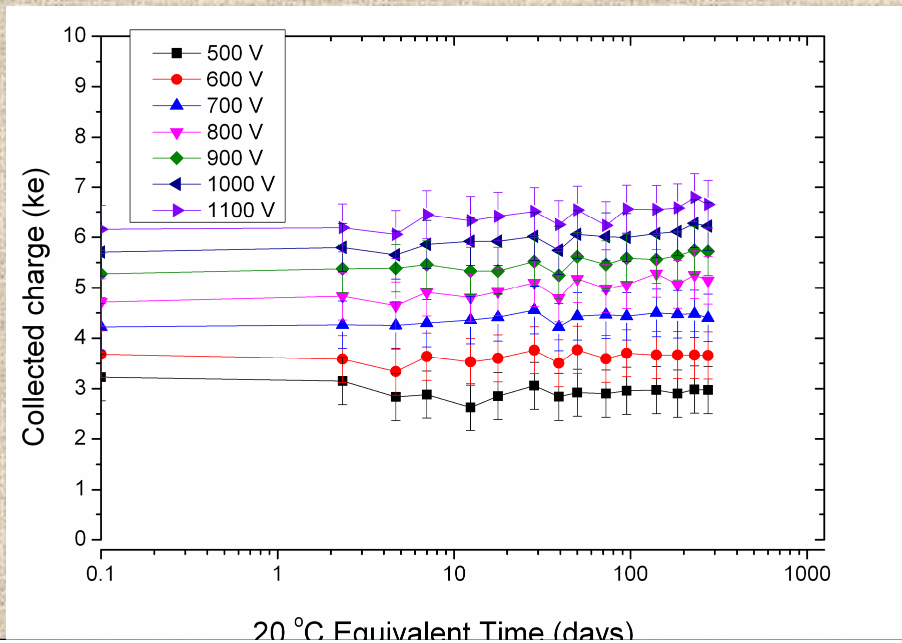
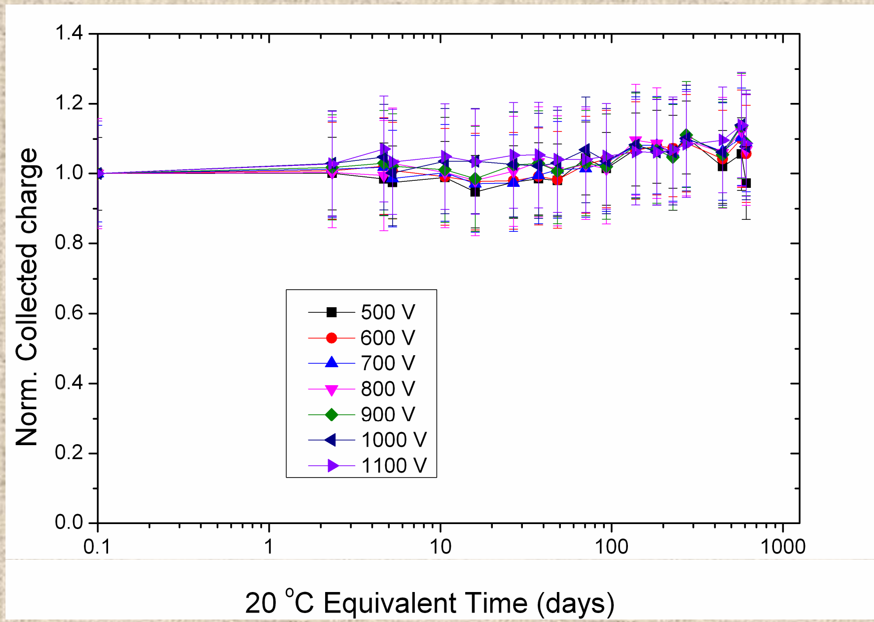
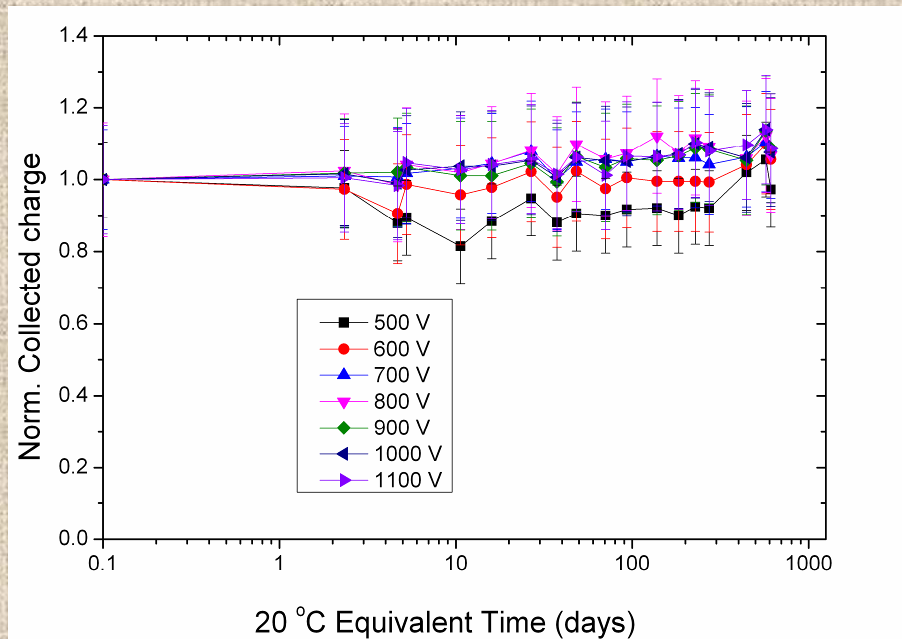
Accelerated annealing at 40, 60 and 80^{o}C. Alibava DAQ based on Beetle chip.



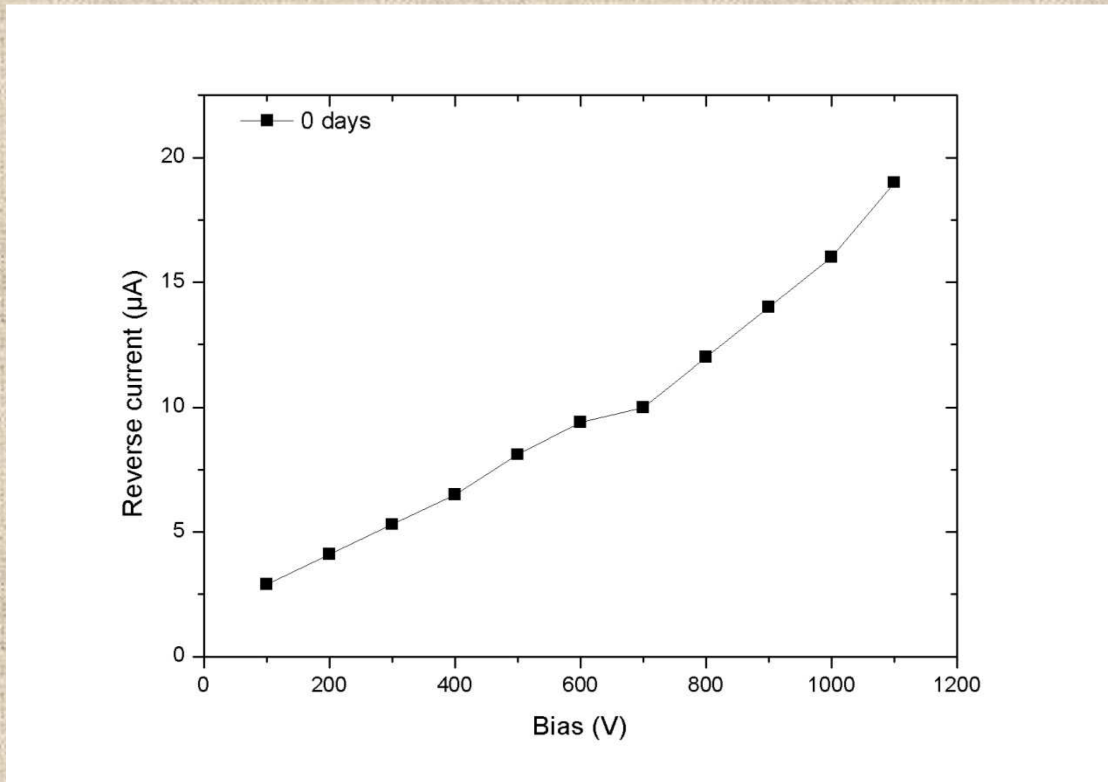
CCE Annealing 1.5E16 n cm^{-2}



Accelerated annealing at 40, 60 and 80°C. DAQ based on SCT128A chip



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



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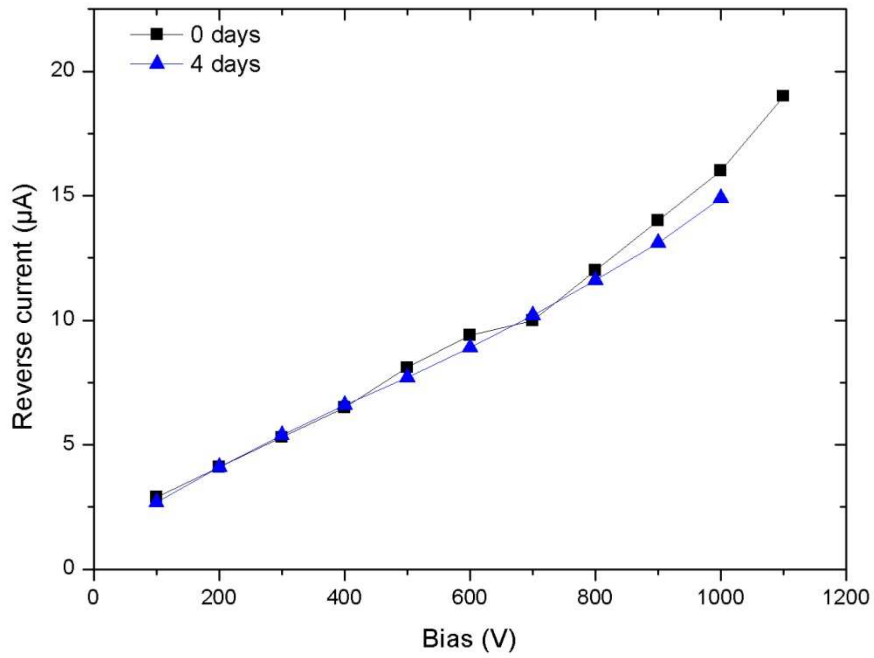

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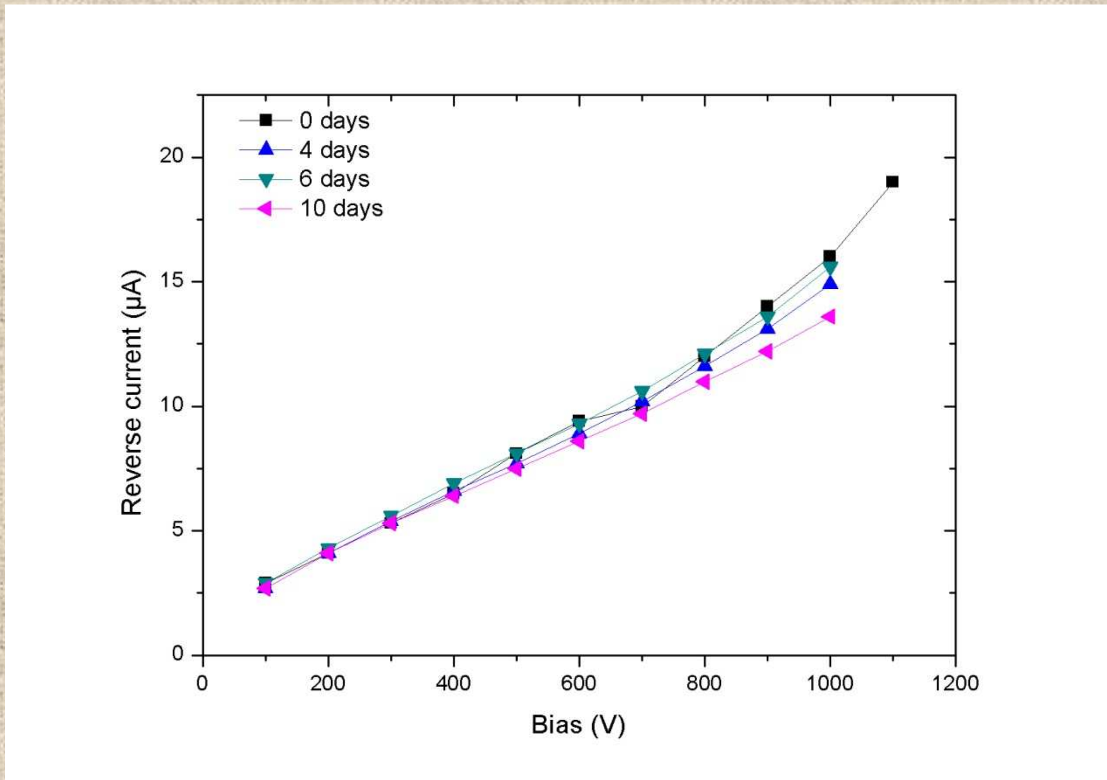

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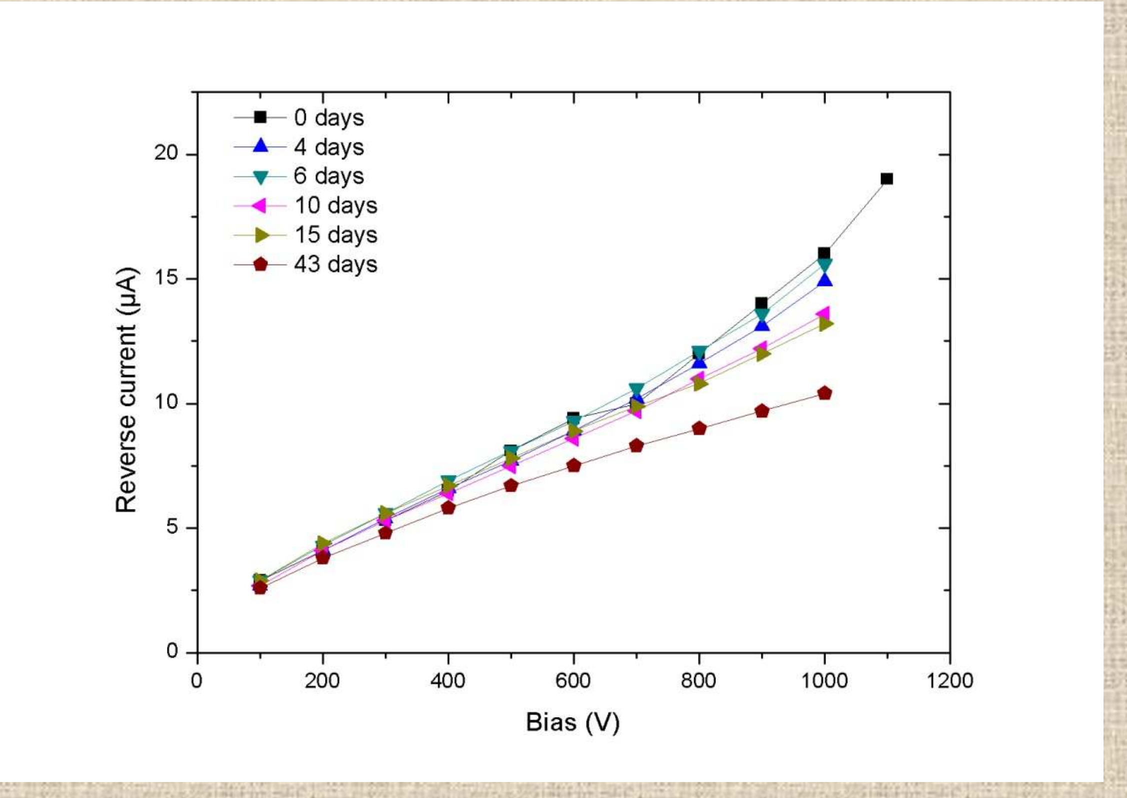

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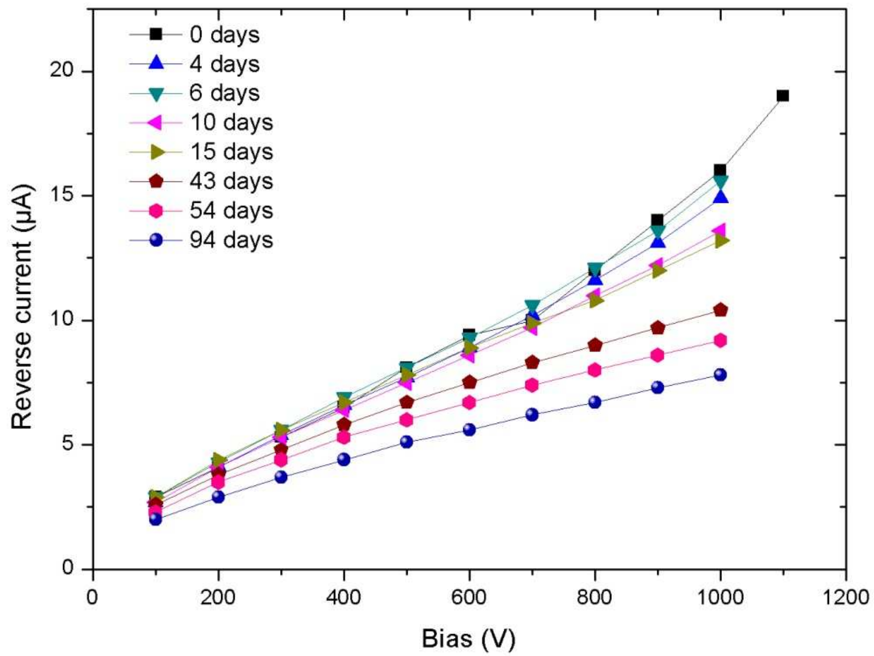
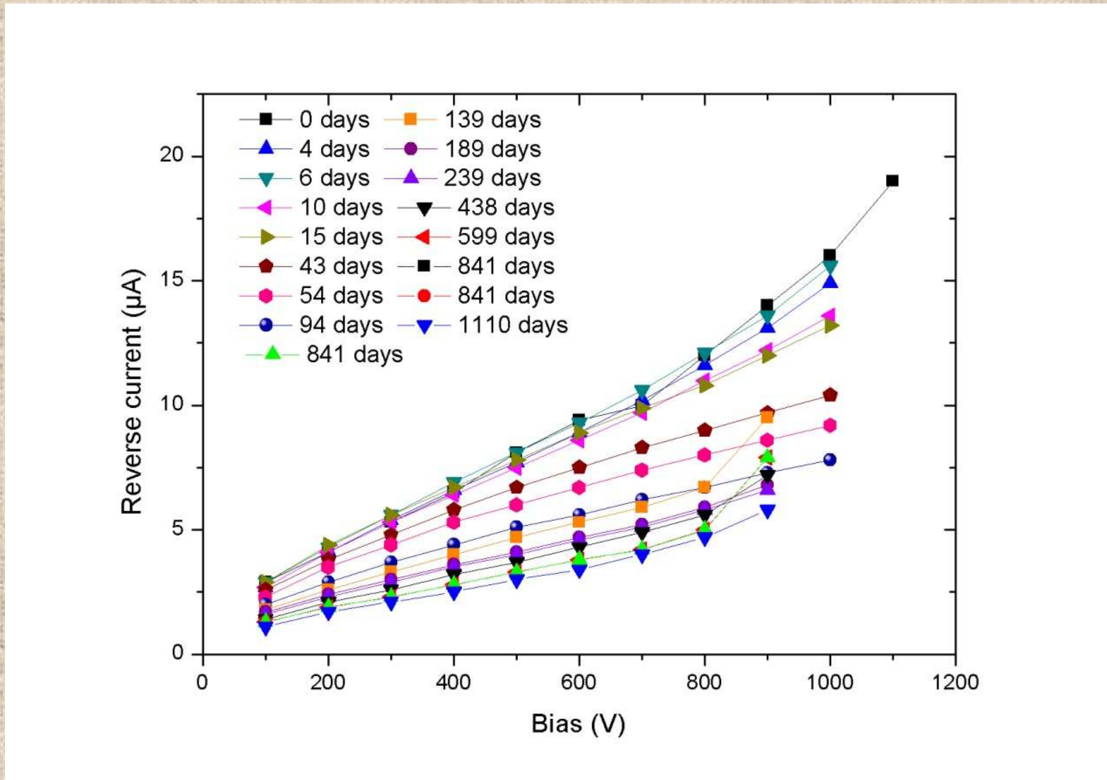
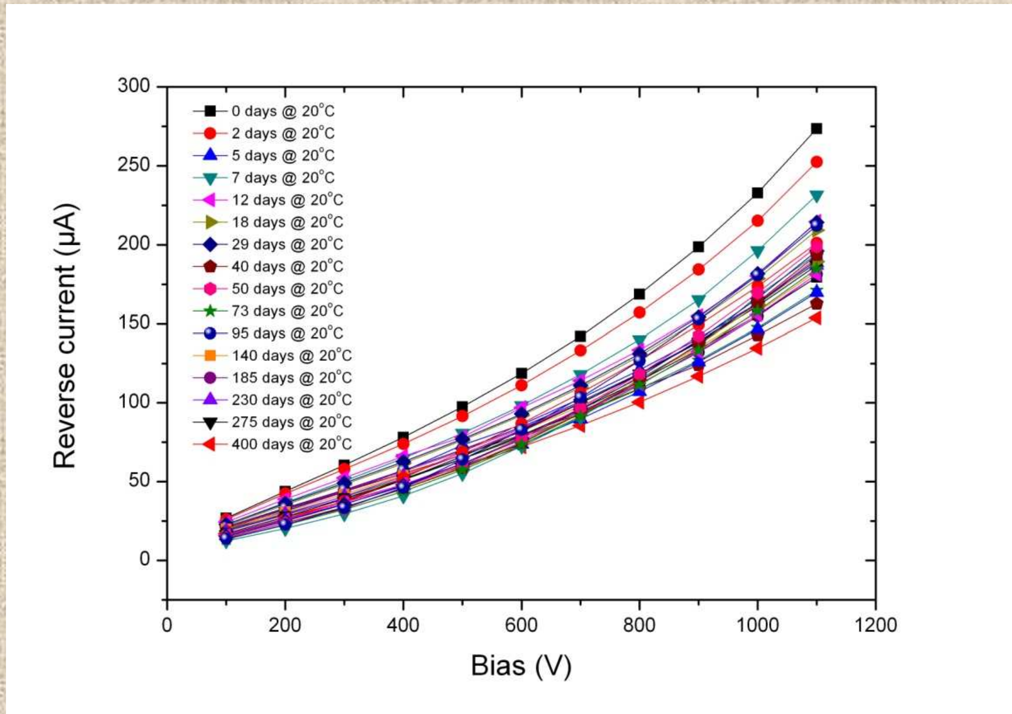


"Fine step" Annealing of the reverse current, HPK FZ n-in-p, 1E15 n cm^{-2}

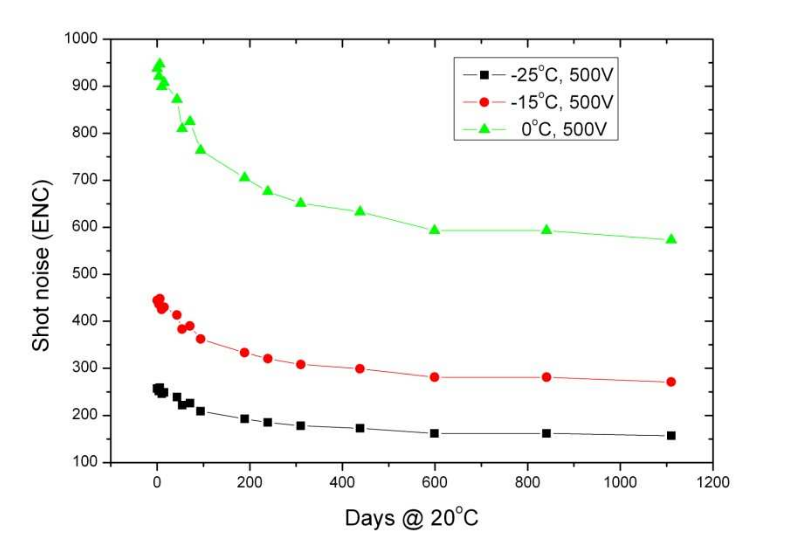


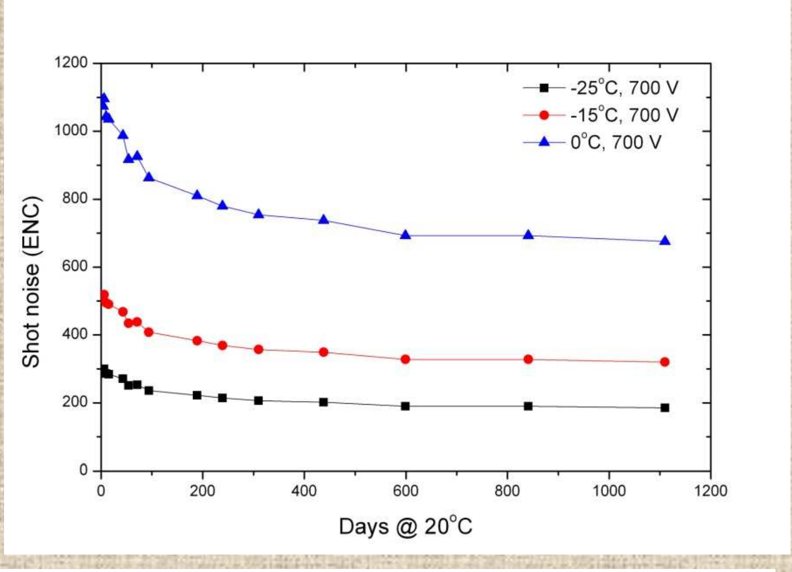
nnealing of the reverse current, Micron n-in-p, after 1.5E16 n_{eq} cm^{-2} (26 MeV p irradiation)

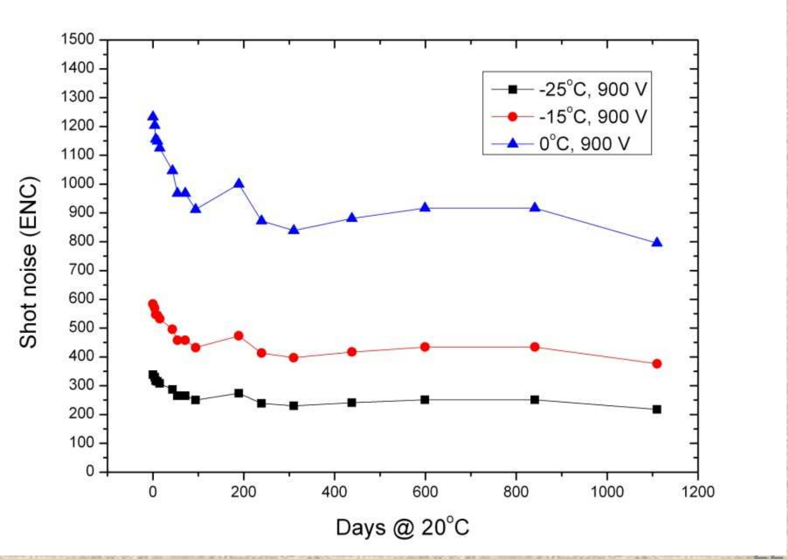


Shot noise

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!

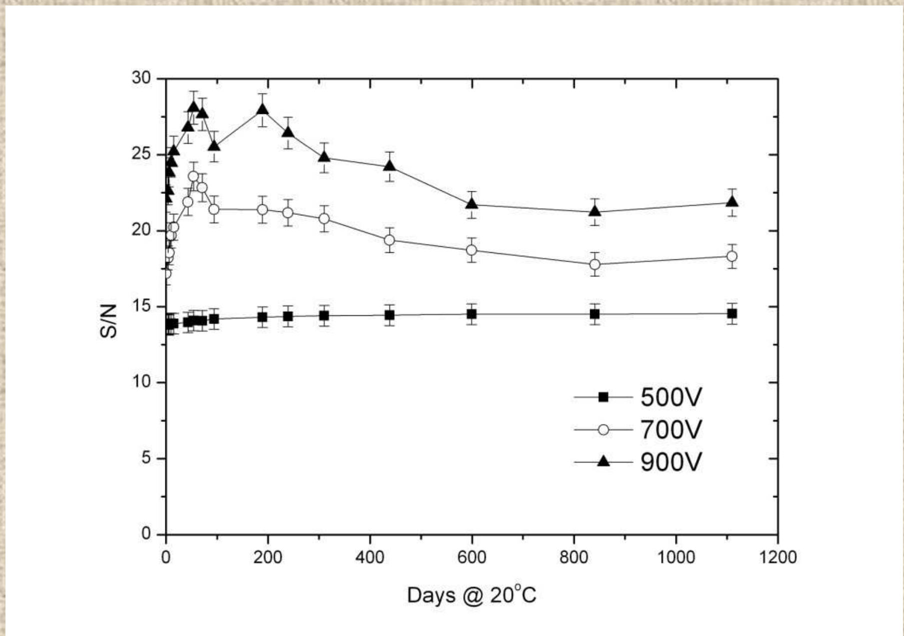




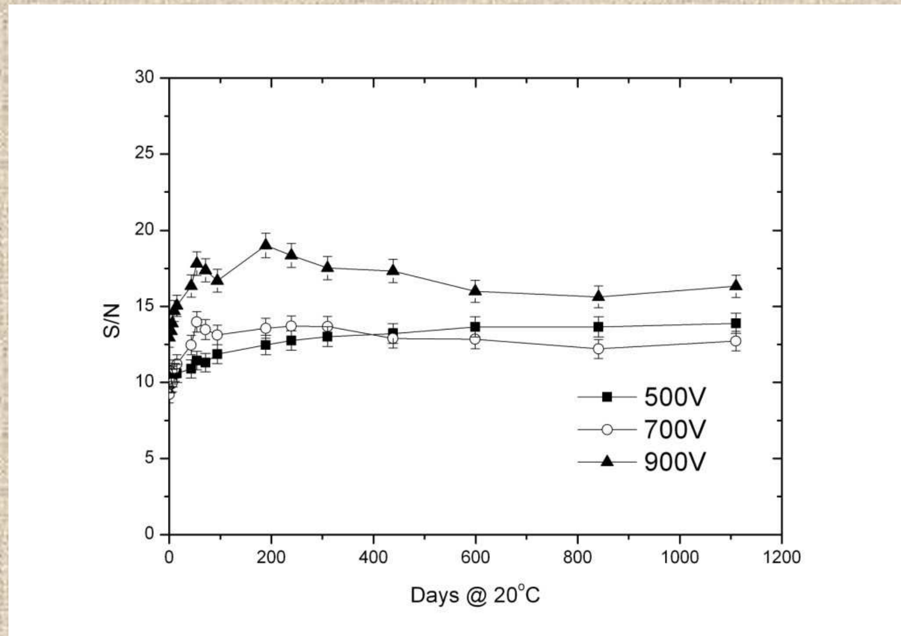


Annealing of S/N, 1E15 n cm^{-2}

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



-25°C



0°C

CONCLUSIONS

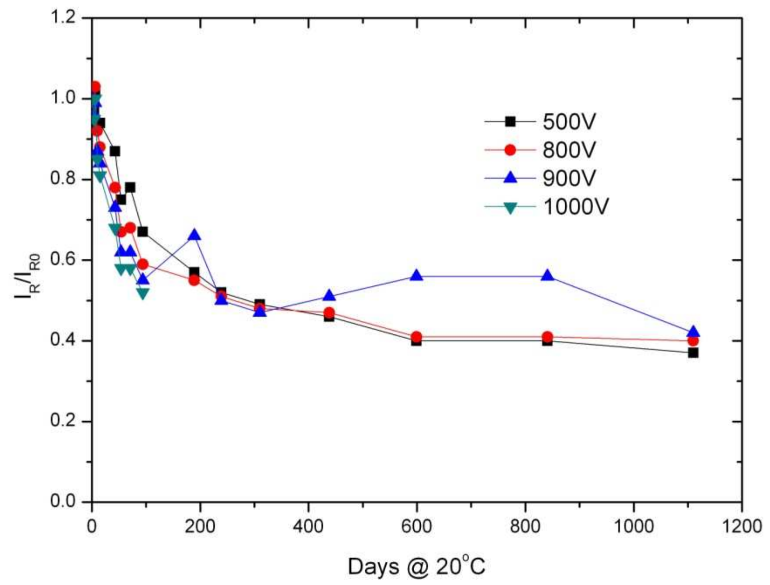
Microstrip and pixel sensors can instrument every layer of the upgraded sLHC experiments (with a S/N>10), provided that adequate voltage can be routed to the detectors. Adequate means 500V for the sensors at radii >30 cm, and 1000-1200V for the innermost (<4 cm) layers.

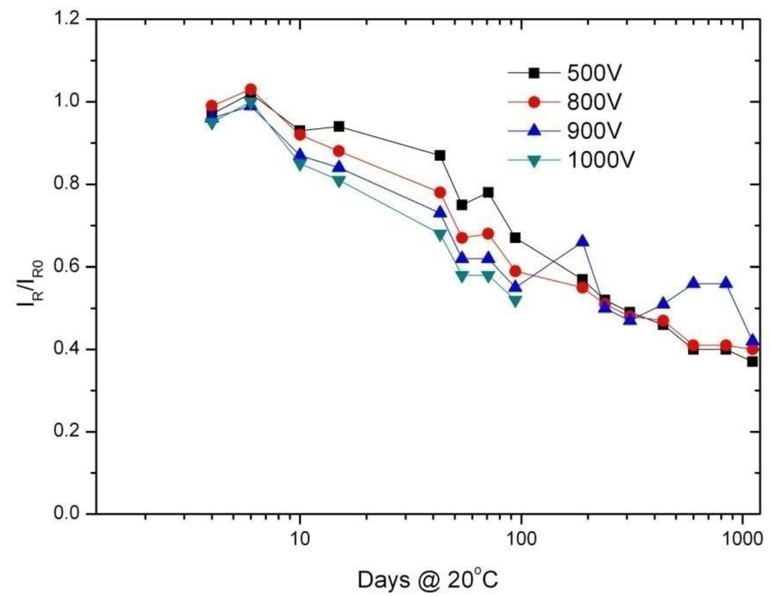
Together with the high voltage, adequate cooling must be provided. A -20/25 ^{o}C would be required to the innermost sensors, but also recommended to the outer strips, for controlling the shot noise.

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}





This translates directely in reduction of power consuption!