Investigation of accelerated and room temperature annealing of irradiated silicon sensors with CC(V)

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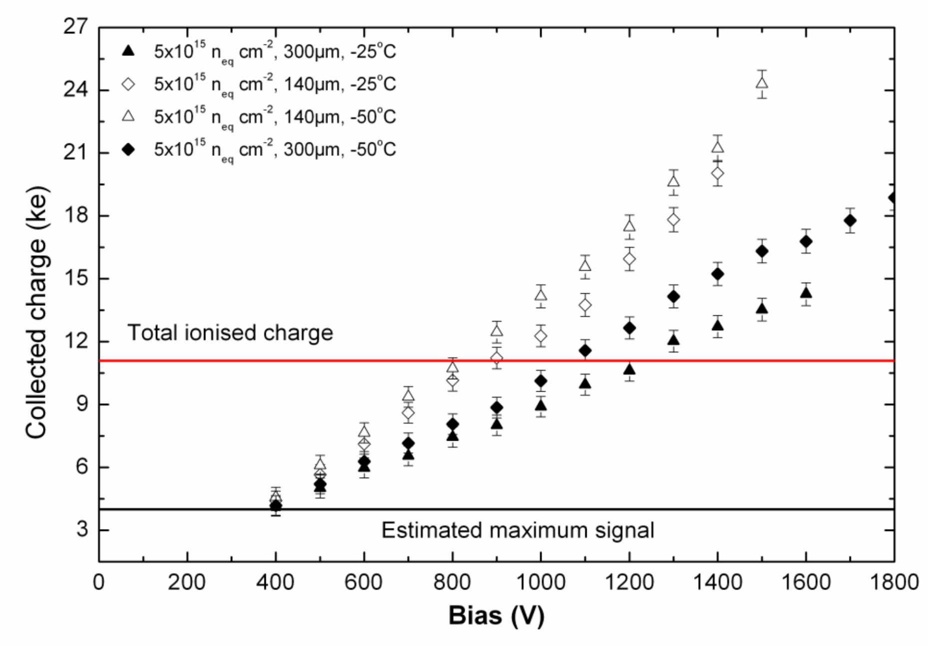
CONTEXT:

Two rather recent results from studies performed for preparing high resolution sensors for the future supercolliders (sLHC at CERN) have proven that silicon detectors can be used for tracking minimum ionising particles (mip's) after doses above 2×10^{16} n_{eq} cm^{-2}. These are the discovery of the charge multiplication mechanism taking place in irradiated **n-in-p** silicon detectors and the *suppression* of the reverse annealing. A discussion of this last feature is here presented.

140 and 300 μm n-in-p Micron microstrip 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 = 1.75/2.1



Annealing Parameterisation

The Hamburg parameterisation is believed to best fit the available data to predict V_{DEP}.

However, large differences observed between the predictions of the TDR model and the Hamburg model.

Origin is in **reverse annealing** contribution ΔN_Y to the predicted change in effective doping concentration ΔN_{EFF}:

$$\Delta N_{EFF}(\Phi,T,t) = \Delta N_C(\Phi) + \Delta N_A(\Phi,T,t) + \Delta N_Y(\Phi,T,t) \qquad V_{DEP} = \frac{ed^2|N_{EFF}|}{2\varepsilon}$$

TDR model parameterised reverse annealing as a **second order process**

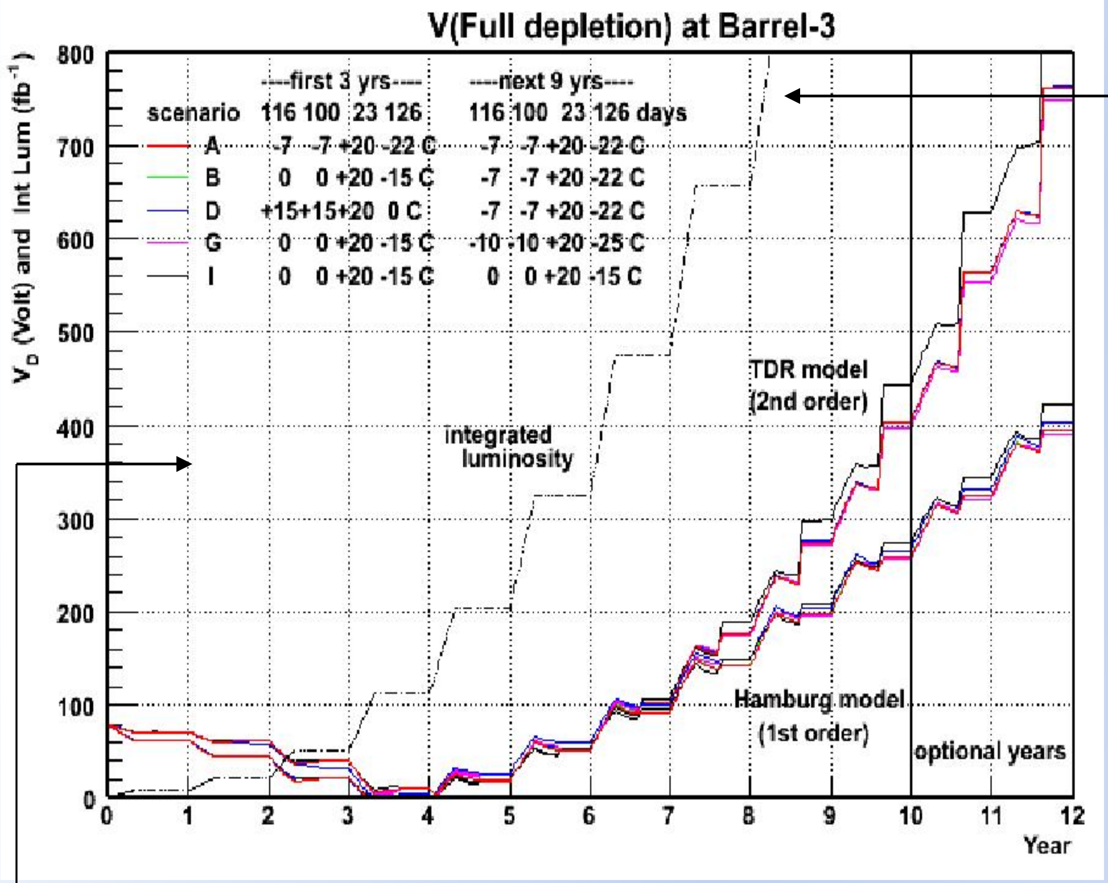
$$\mathbf{(dN_Y=-k\cdot dN_X^2\cdot dt) \quad N_Y(t)=N_{X,0}(1-(1+k\cdot N_{X,0}\cdot t)^{-1})}.$$

Hamburg model parameterises reverse annealing as a **modified first order process**.

$$\mathbf{(dN_Y=-1/\tau\cdot dN_X\cdot dt) \quad N_Y(t)=N_{X,0}(1-\exp(-t/\tau))}$$

Need high fluence + long annealing data to compare to predictions of both models.

Re-Evaluating the Evolution of V_{DEP} and I_{LEAK} in the SCT



An updated LHC luminosity profile now exists.

Maintenance/shutdown time and cooling temperatures reviewed in line with:

Achievable coolant temperatures.

Insertable B-Layer installation.

Possibly longer maintenance.

V_{DEP} predictions suggest 450 V (max for SCT) is sufficient for at least 10 years operation.

Paul Dervan, Joost Vossebeld, Tim Jones (Liverpool), Taka Kondo (KEK), Graham Beck (QMUL), Georg Viehhauser (Oxford), Steve McMahon (RAL), Koichi Nagai (Brookhaven), Kirill Egorov (Indiana), Richard Bates, Alexander Bitadze (Glasgow).

Annealing can be accelerated with “*known*” factors by mean of rising the temperature, e.g.:

40 ^{o}C f = 30

60 ^{o}C f = 510

80 ^{o}C f = 6700

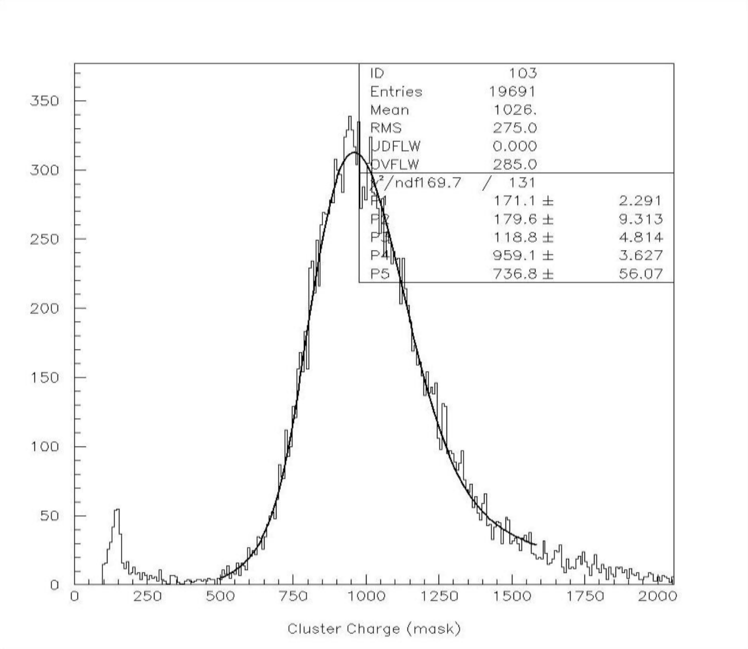
(relative to room temperature RT = 20^{o}C).

Real issues about annealing

For sLHC doses: forget about V_{FD}, consider only:

CC(V)
Reverse current (mainly power dissipation, a bit of noise contribution).
Noise

Experimental Setup and Analysis Procedure



Charge Collection Measurements

^{90}Sr fast electron source used to generate signal.
Readout triggered by scintillator.

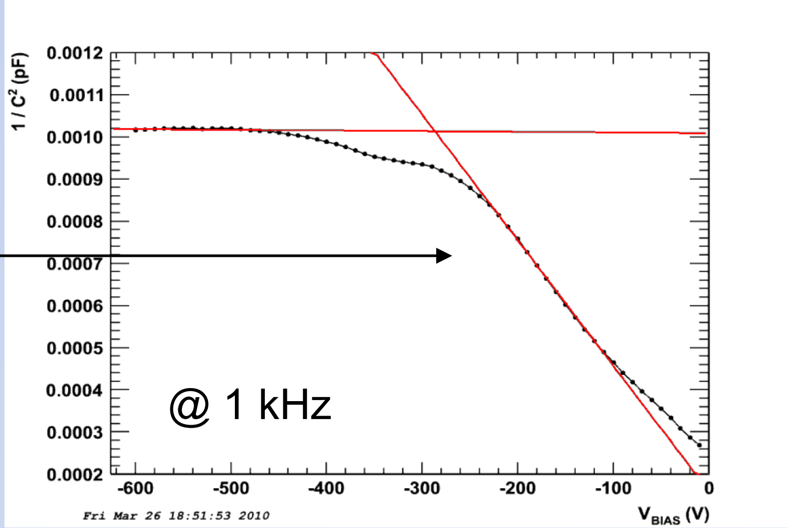
Charge collection measured using analogue electronics chip (SCT128A or Beetle) clocked at LHC speed (40 MHz clock, 25 ns shaping time).

System calibrated to most probable value of MIP energy loss in non-irradiated 300 μm thick sensor (~ 23000 e).

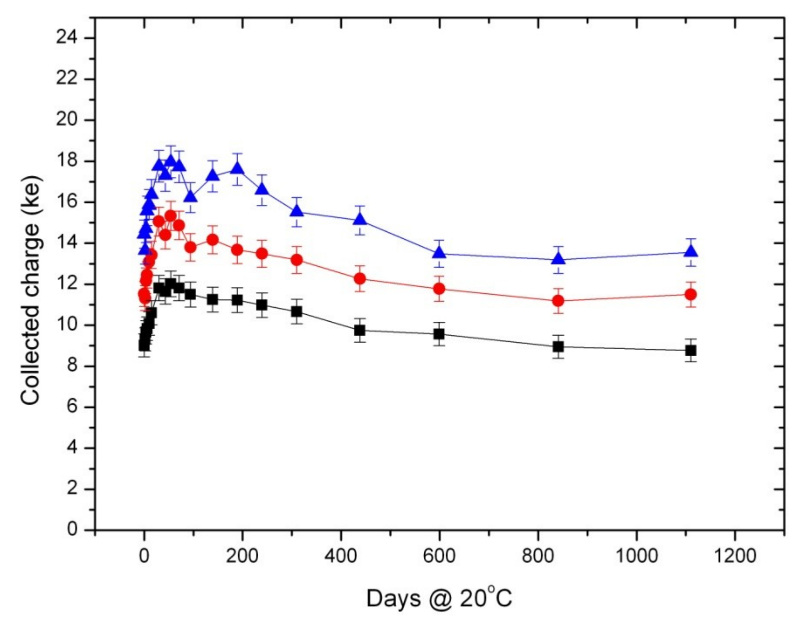
Depletion Voltage Measurements

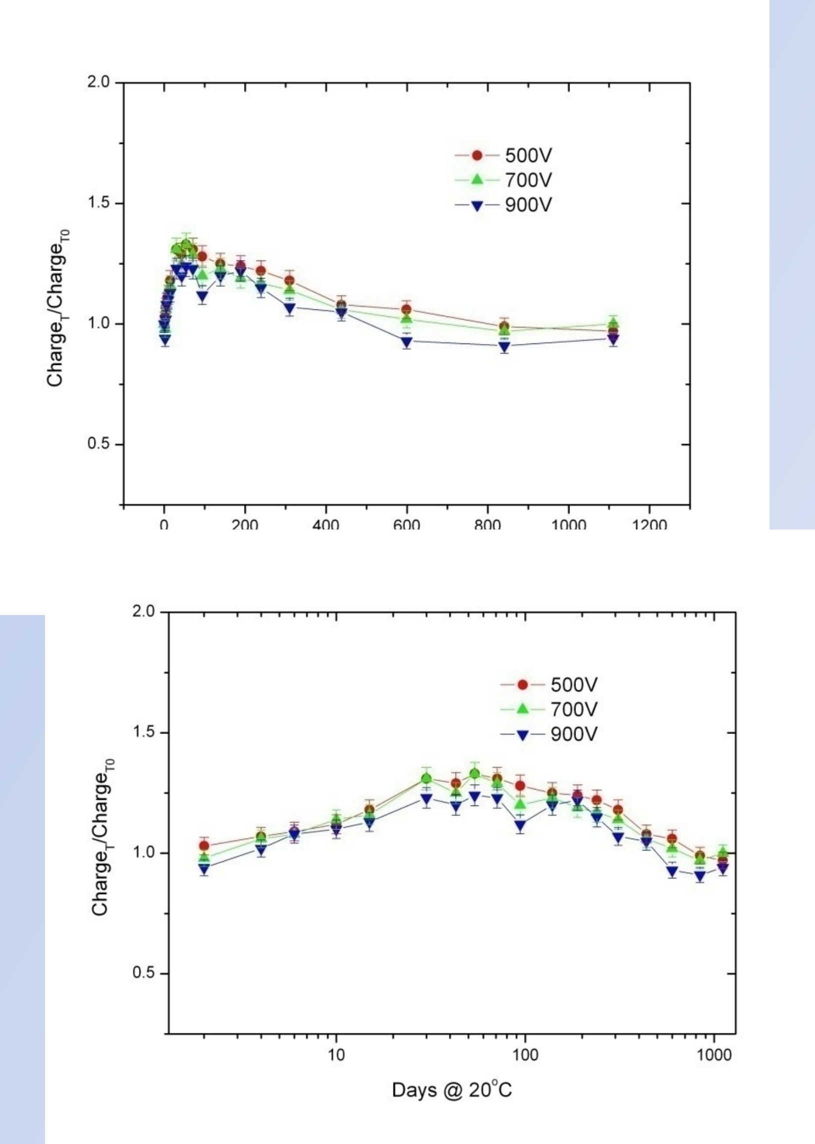
V_{DEP} Determined by standard method of measuring the V_{BIAS} at which $1/C^2$ saturates.

Both sets of measurements performed in freezer at temperature of ~-25 ^{o}C with N^2 flush.



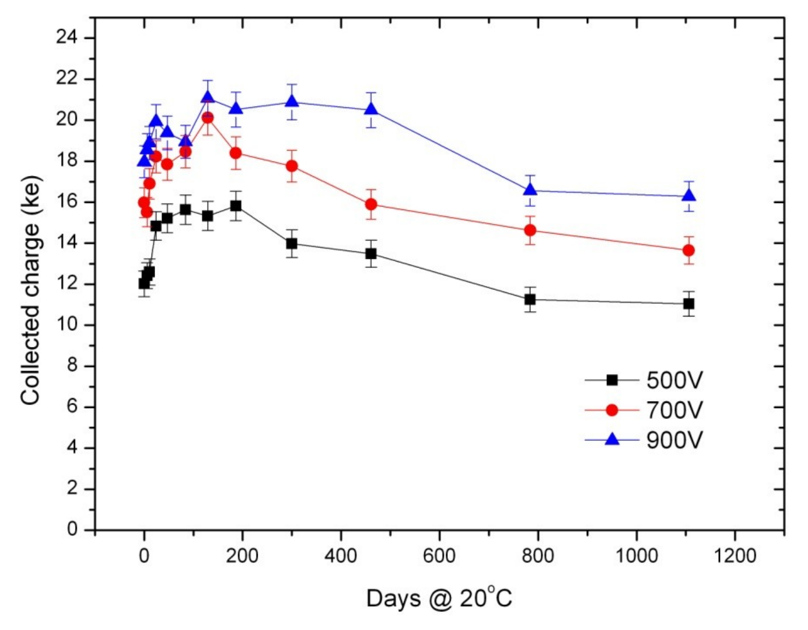
Accelerated Annealing of the collected charge, case of n-in-p sensors. HPK FZ n-in-p, 1E15 n_{eq} cm^{-2}

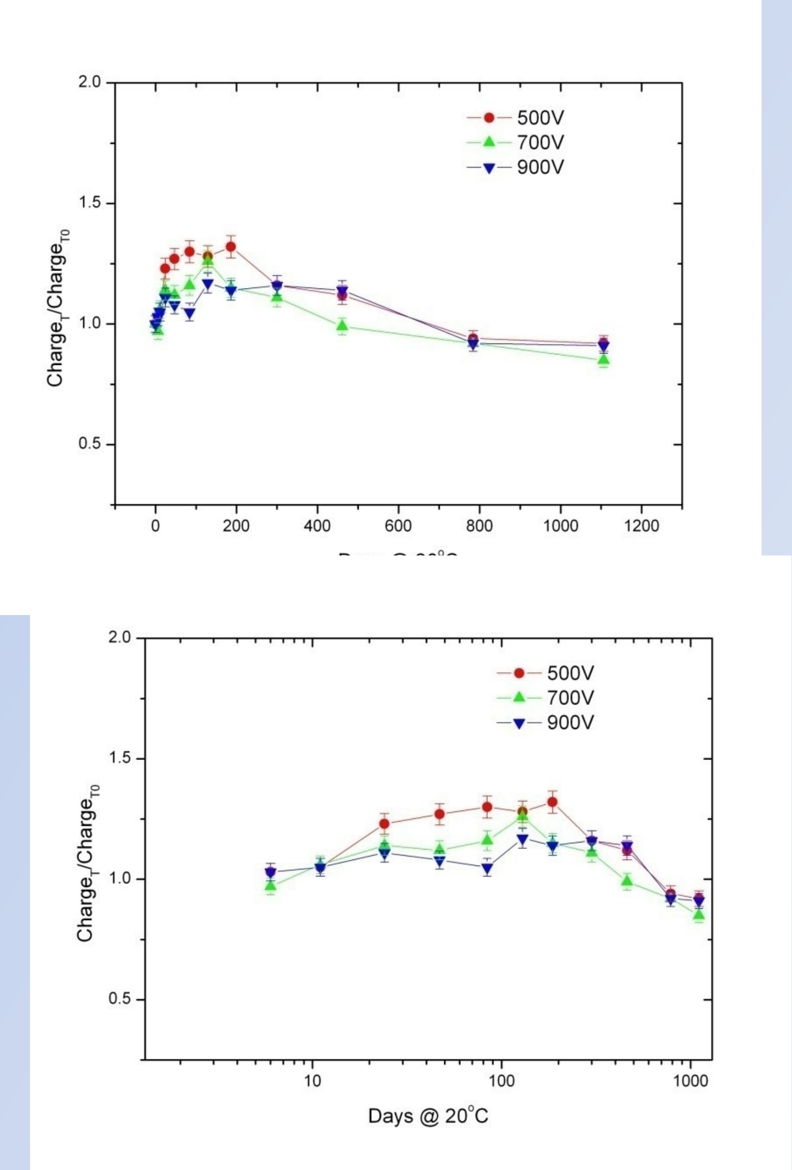




Neutron irradiations in Ljubljana, neutrons are dominating the radiation damage > 25 cm radius.

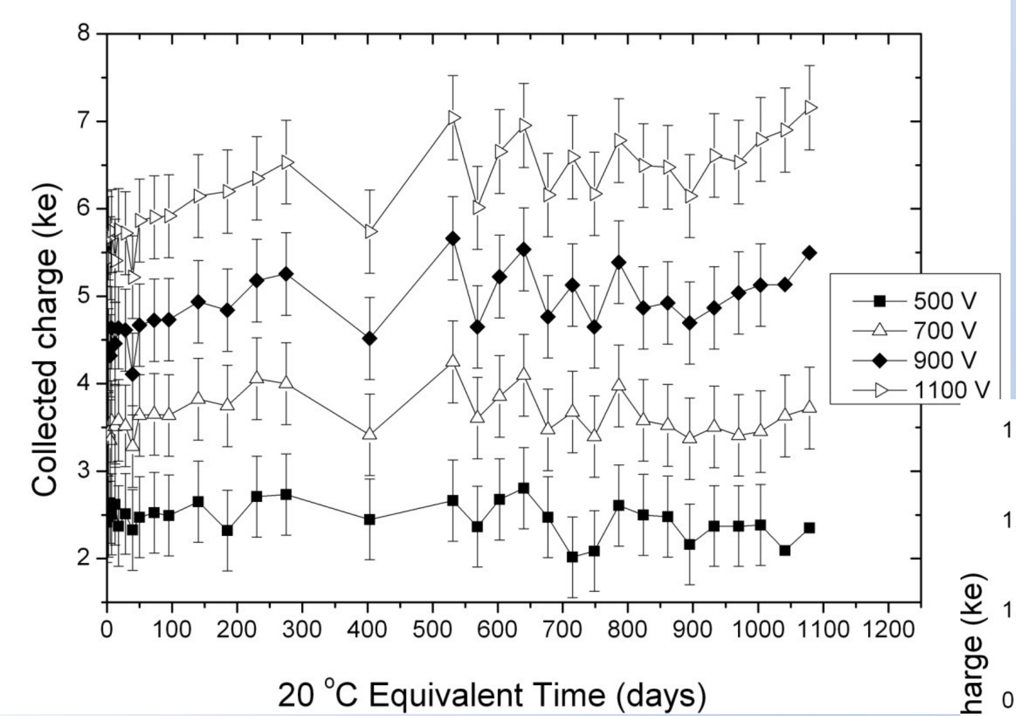
Accelerated annealing of the colleted charge, Micron FZ n-in-p, 1E15 n cm^{-2} (26MeV p irradiation)

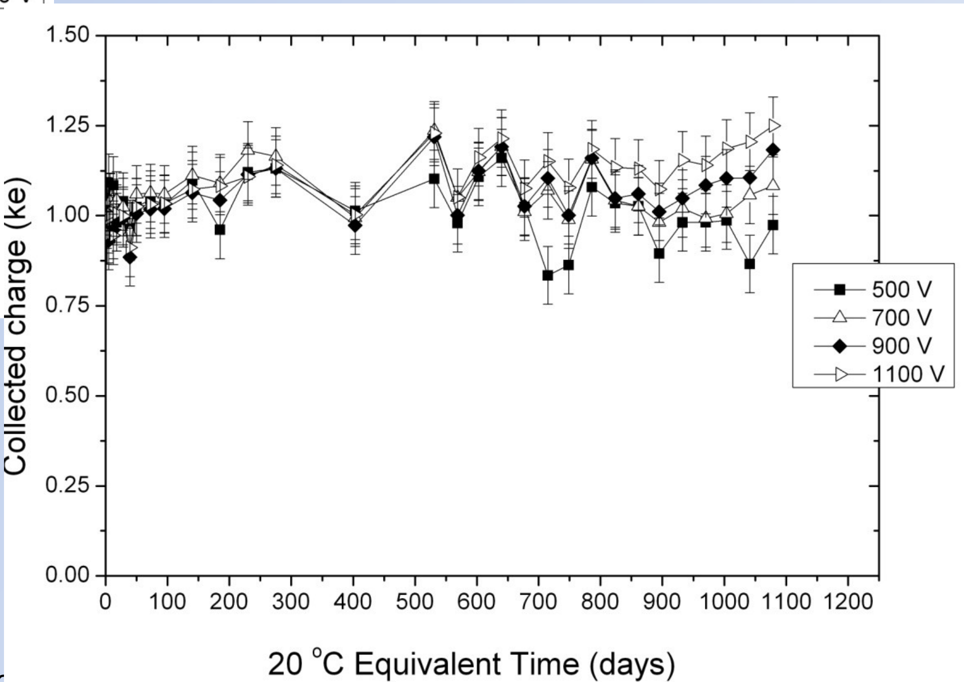




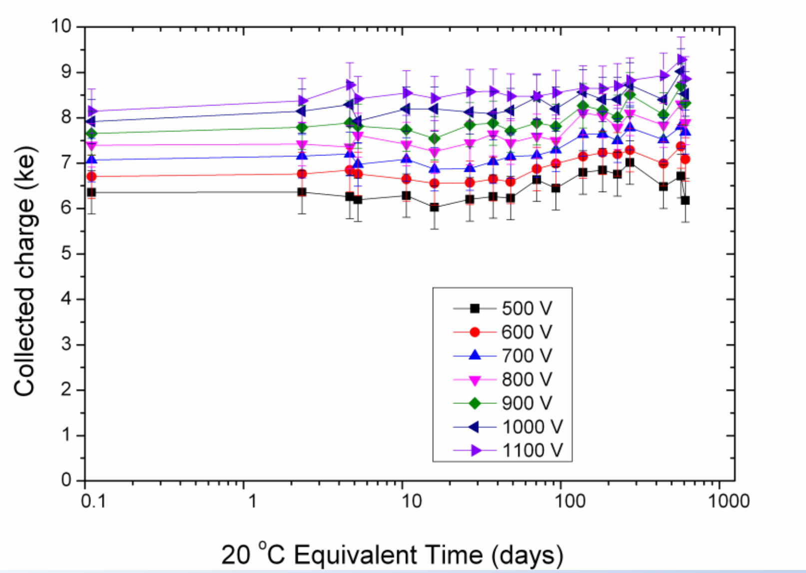
Accelerated CCE Annealing 1.5E16 n_{eq} cm^{-2} (Micron sensors)

Irradiated with 26MeV protons (Karlsruhe).





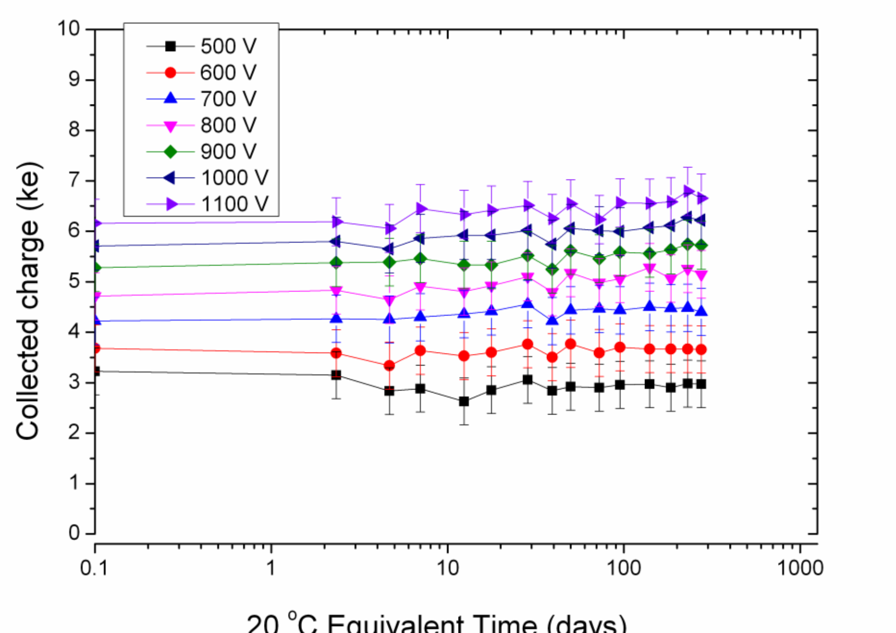
Accelerated CCE Annealing 5 and 1.5E16 n cm^{-2}



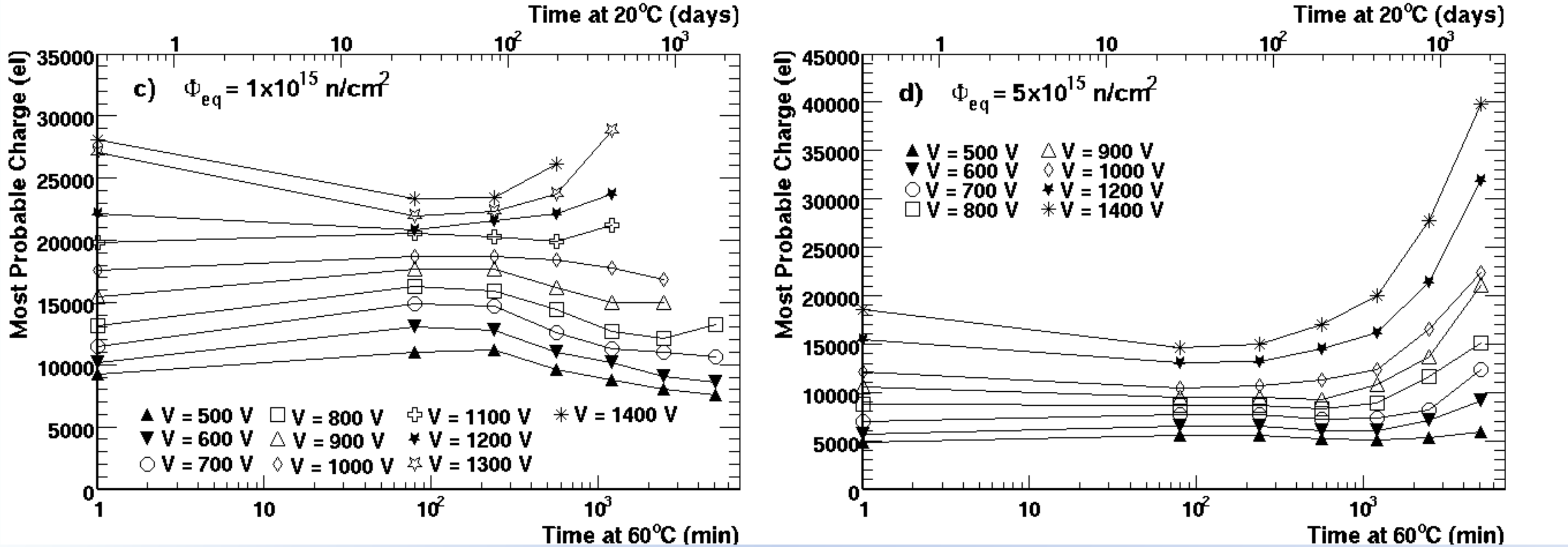
5x10^{15} n$_{eq}$ cm^{-2} Irradiated with 26MeV protons (Karlsruhe).

1.5x10^{16} n$_{eq}$ cm^{-2} Irradiated with 26MeV protons (Karlsruhe).

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



Annealing of collected charge



High fluences, high voltages:

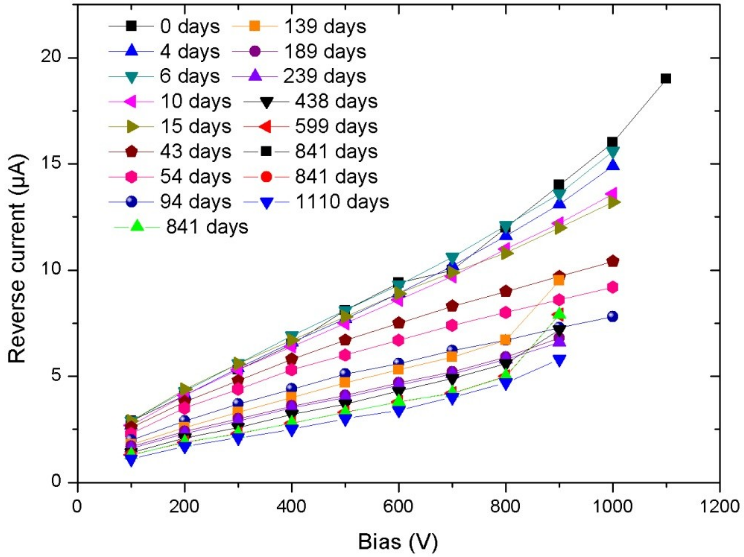
- Most probable charge drops due to short term annealing:
  ➔N_{eff} drops → smaller peak electric field → less multiplication

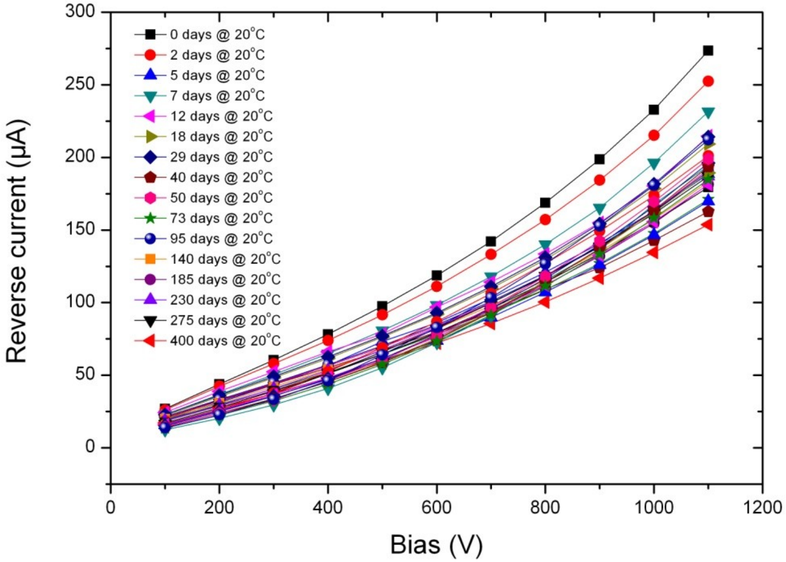
- Most probable charge rises due to long term annealing:
  ➔ N_{eff} rises → larger peak electric field → more multiplication

I. Mandić, 17th RD50 Workshop, CERN, 17 – 18 November 2010

- Breakdown voltage is lower at 5·10^{14} and 1·10^{15} than at 2·10^{14} and 5·10^{15}
  ➔ for detectors irradiated to 5·10^{14} and 1·10^{15}
  breakdown voltage decreases with reverse annealing

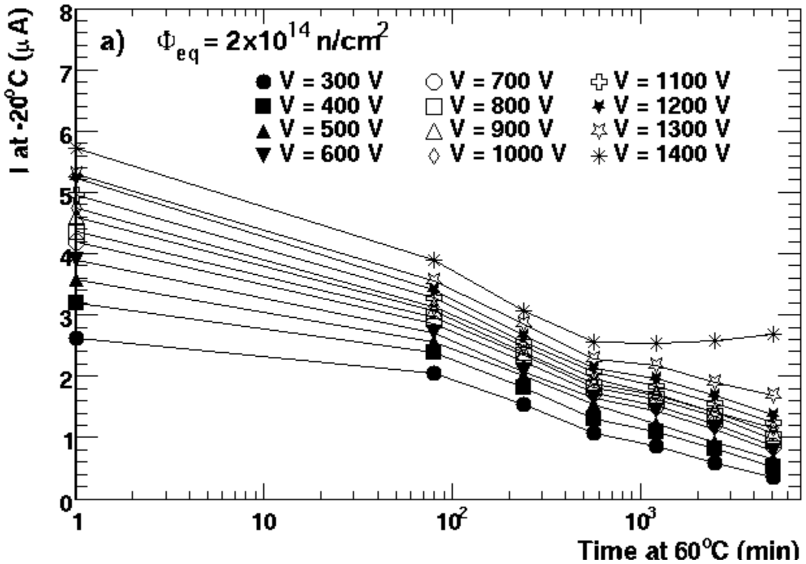
Accelerated Annealing of the reverse current, n-in-p sensors, 1E15 and 1.5E16 n cm^{-2}

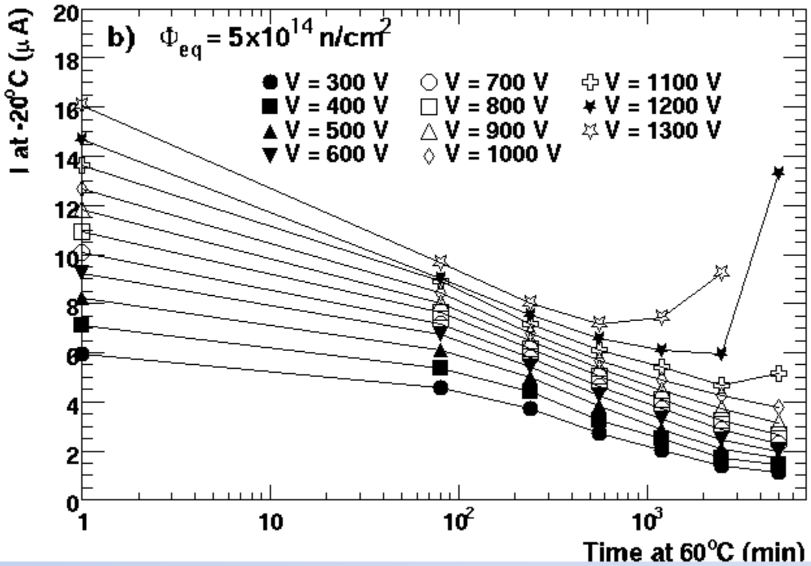


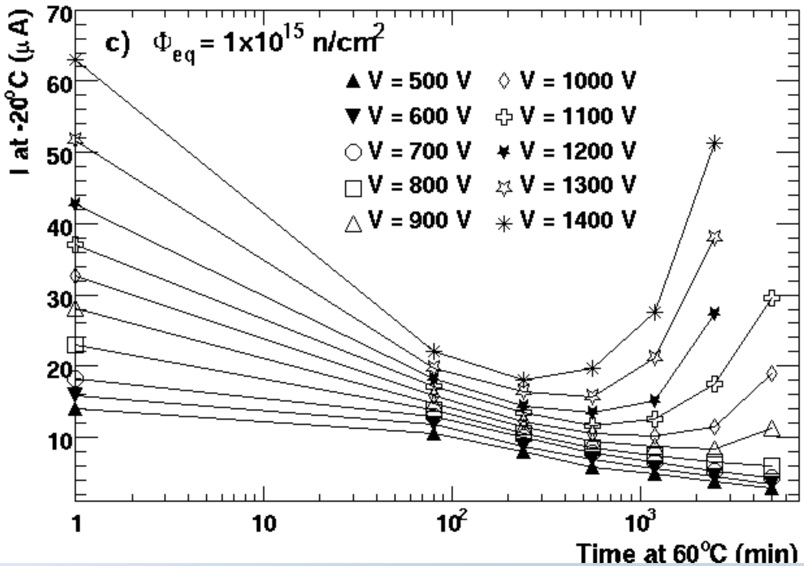


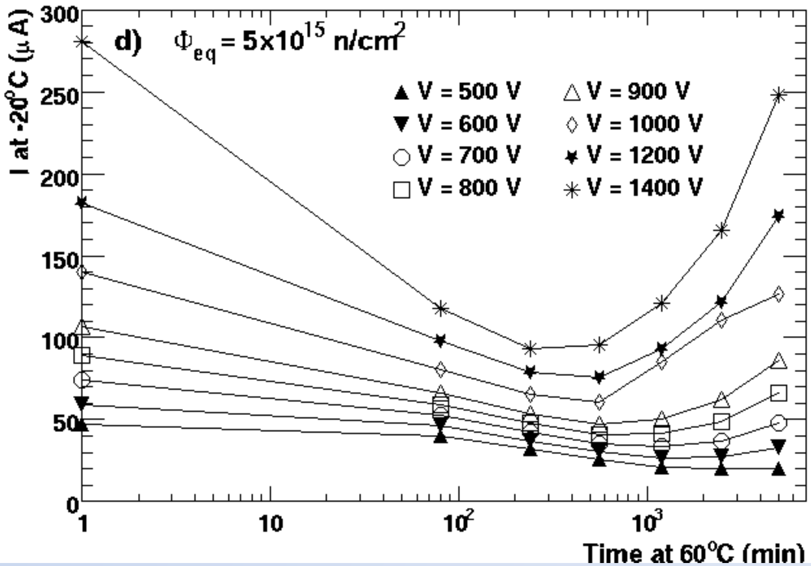
Leakage current

- guard rings not bonded



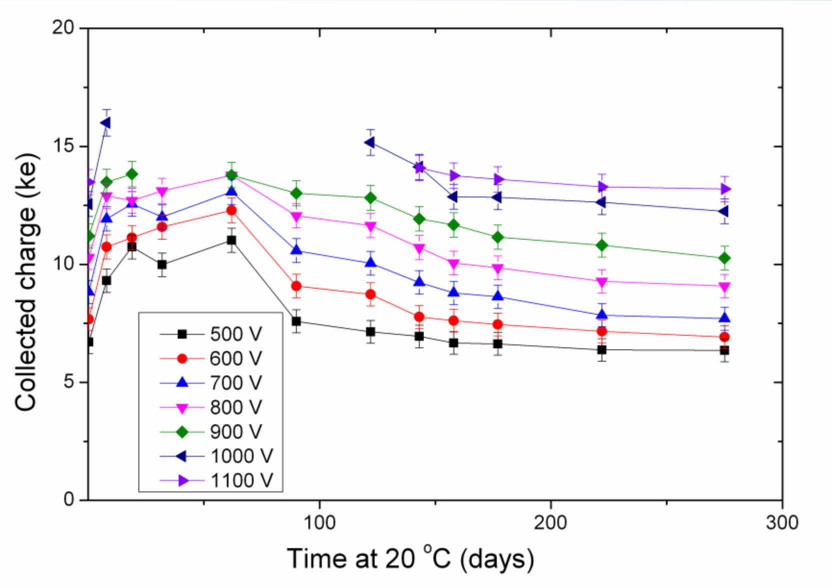




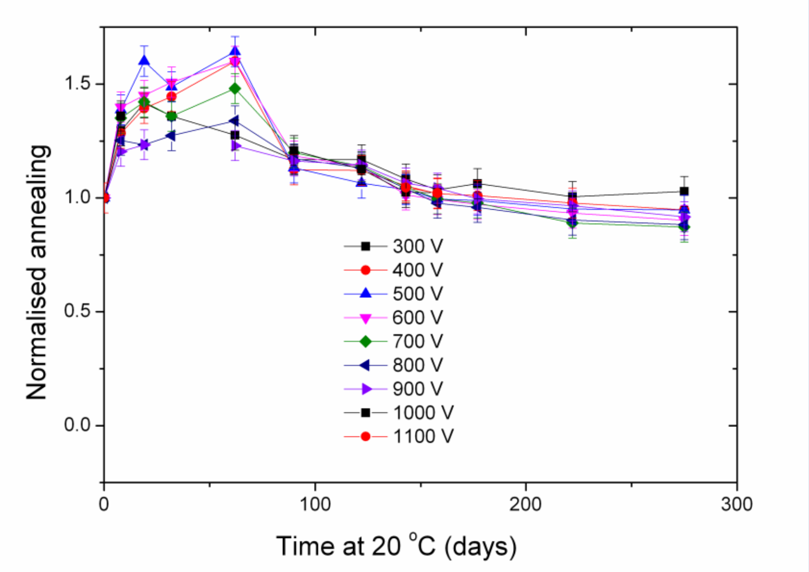


- Increase of leakage current with annealing ➔ multiplication

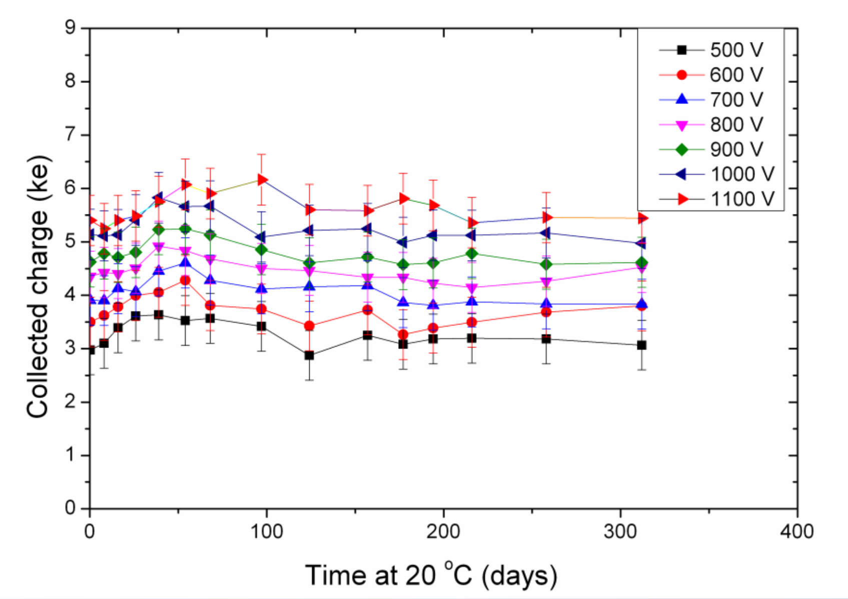
Room Temperature Annealing of the collected charge, HPK FZ n-in-p, 2E15 n cm^{-2} (26MeV p irradiation)



We make large use of accelerating annealing: is this a safe and correct approach?



Room Temperature Annealing of the collected charge, HPK FZ n-in-p, 1E16 n cm^{-2} (26MeV p irradiation)



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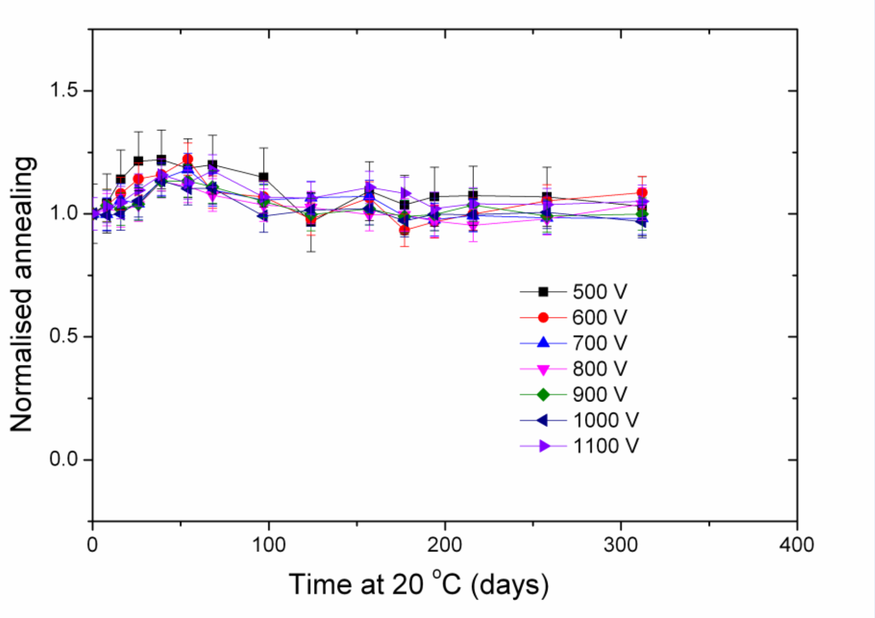
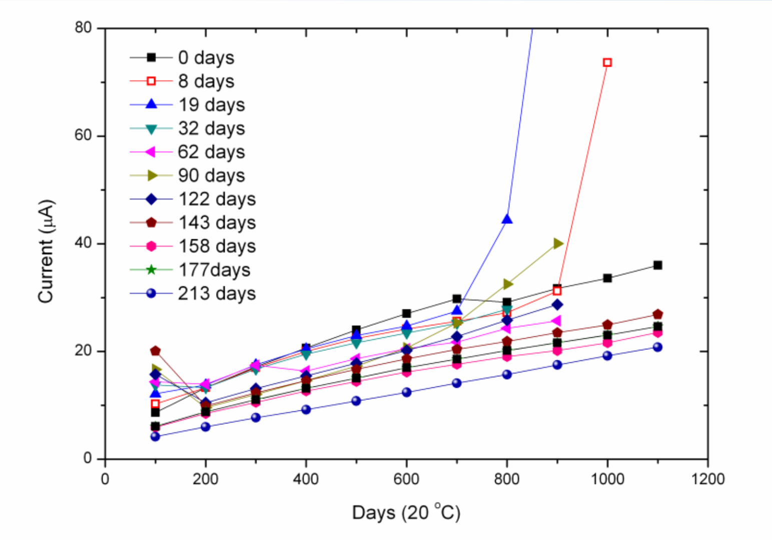
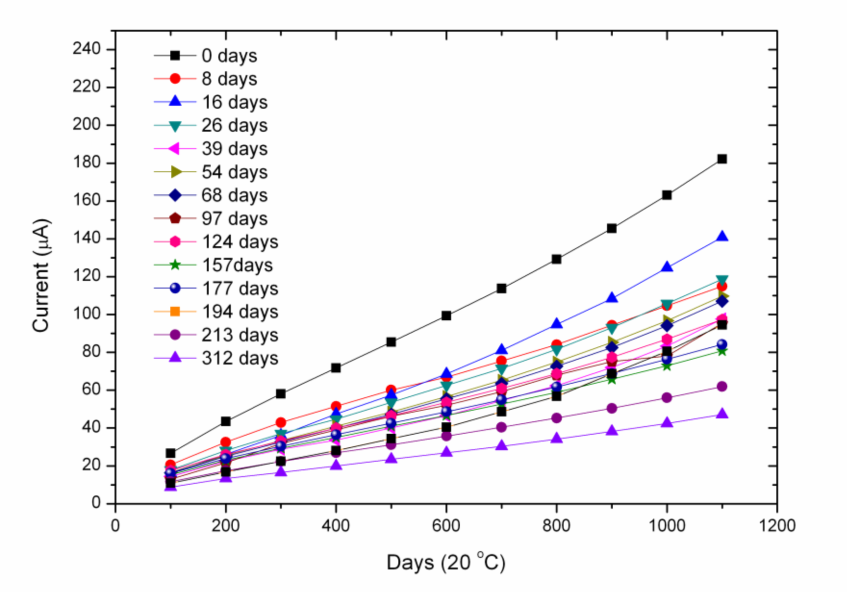
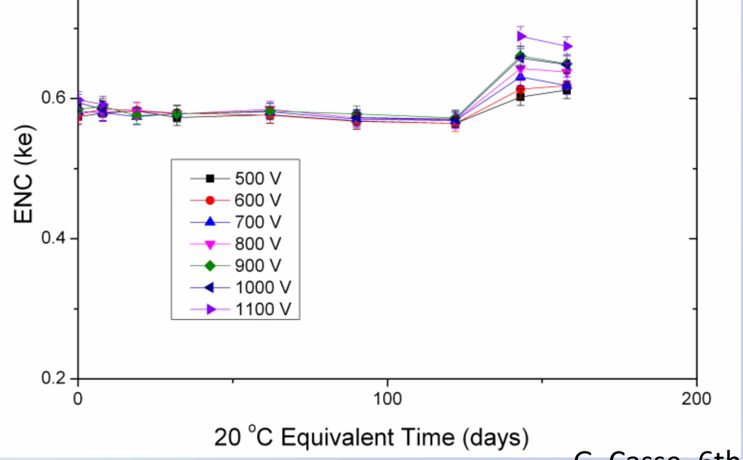


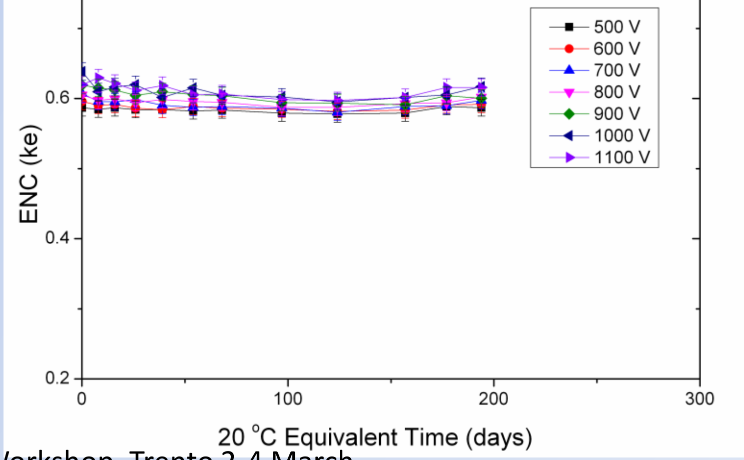
Room Temperature Annealing of the reverse current, n-in-p sensors, 0.2 and 1E16 n cm^{-2} (26MeV p irradiation)



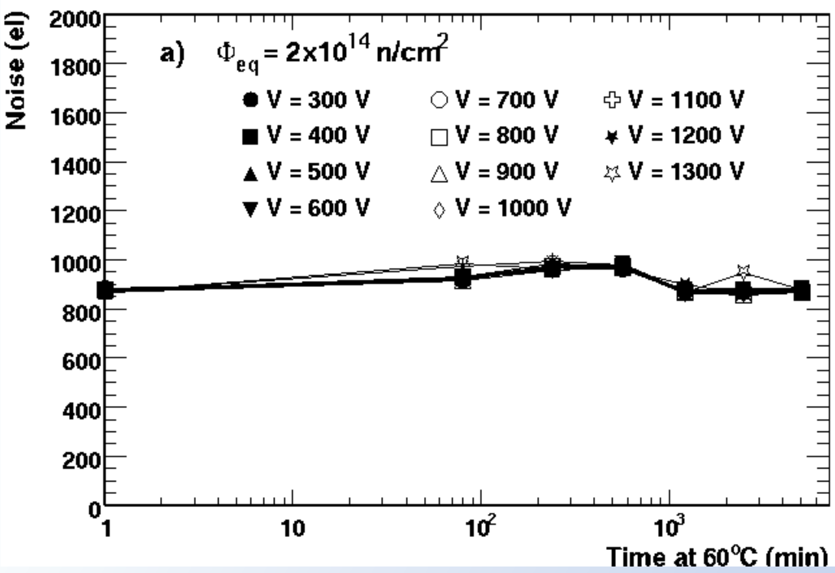


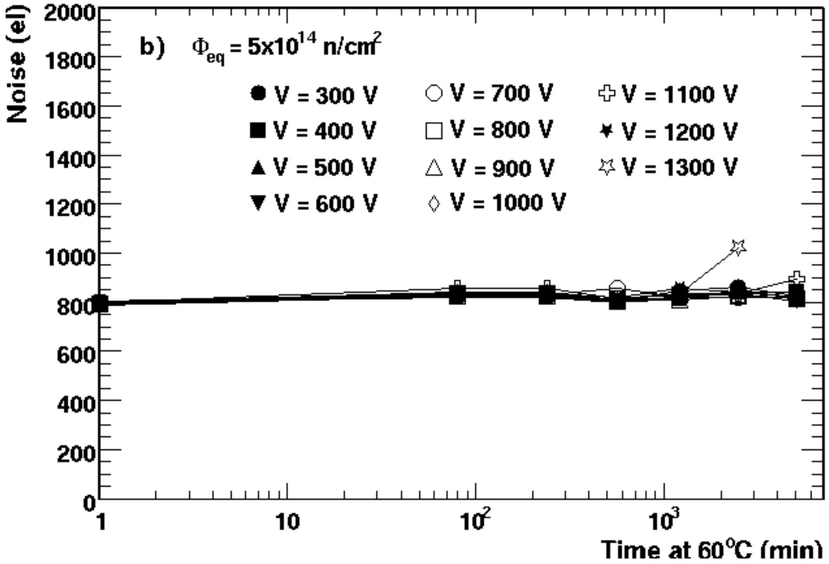
NOISE

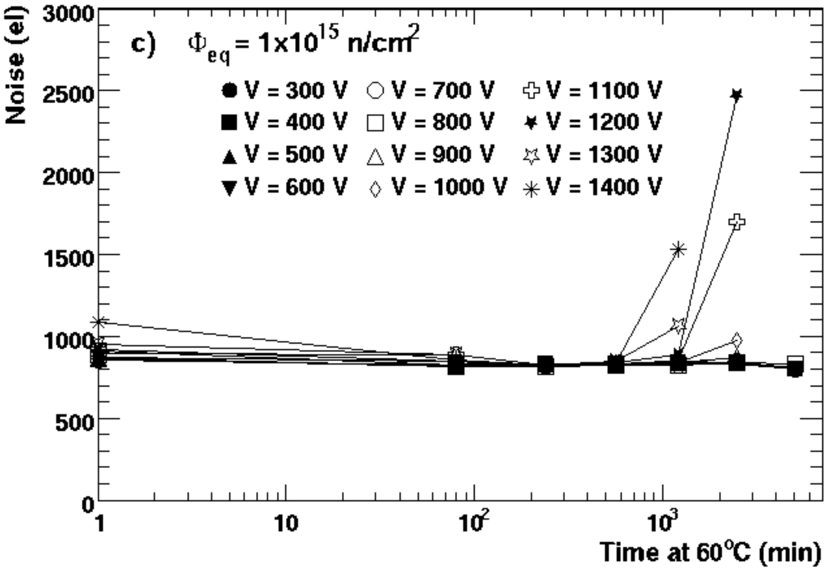


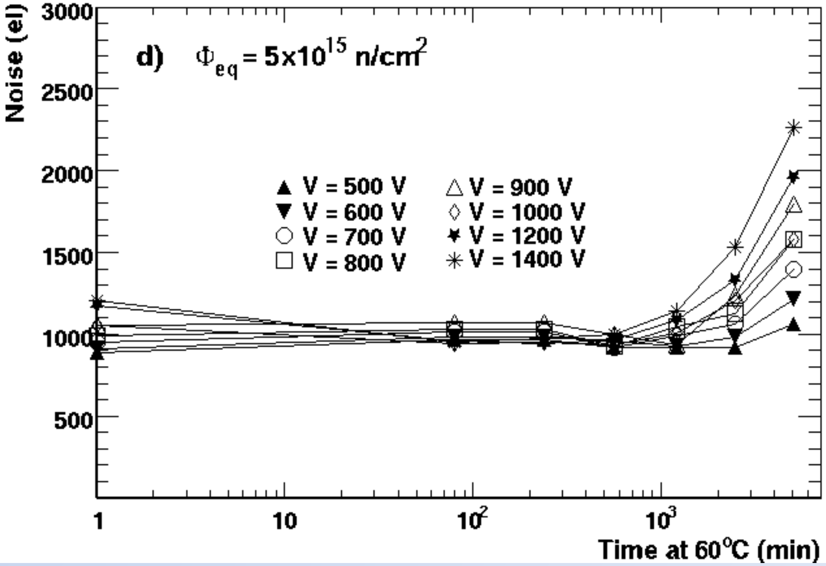


Noise









- Noise increases when multiplication large

CONCLUSIONS

The annealing of the CC(V) shows discrepancies from the accepted rescaling of the time axis with temperature. The discrepancy is evident for the measurements with sensors irradiated up to 1-2E15 n_{eq} cm^{-2} (need more dense data as a function of fluence to clarify this point). At higher doses the difference seems smaller? The reverse current has qualitatively a similar reduction (accelerated and RT). A more accurate measurement, making use of a better heat sink (possibly using pad sensor in thermal contact with a big mass) can give a more accurate insight.

The noise can be controlled, it increases with higher rate than shot-noise for very high biases.

Controlled annealing (at 20^0C) is still a very useful tool to reduce power dissipation and recover fraction of S/N in heavily irradiated silicon detectors. The discrepancies between the accelerated and RT annealing need to be studied to base the prediction for the changes of CCE with time according to the real operation and maintenance temperatures in the experiments.