Annealing effects in n+p strip detectors irradiated with high neutron fluences

Igor Mandić[1], **Vladimir Cindro**[1], **Andrej Gorišek**[1], **Gregor Kramberger**[1], **Marko Milovanović**[1], **Marko Mikuž**[1,2], **Marko Zavrtanik**[1]

[1]Jožef Stefan Institute, Ljubljana, Slovenia
[2] Faculty of Mathematics and Physics, University of Ljubljana, Slovenia

Outline:

- final results of annealing studies with Hamamatsu detectors

➔ paper "*Annealing effects in n+p strip detectors irradiated with high neutron fluences*" accepted for publication in NIM-A
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Setup:

- SCTA128VG chip
- VME module SEQSI (for clock, commands...)
- Tektronix digital scope for data acquisition
- ^{90}Sr source, photomultiplier, scintillator,
  power supplies, coincidence circuit ......

- Most probable value (MPV) from fit of Landau + Gauss
  to distribution of measured signal cluster heights
  ➔ scale defined with signals from not irradiated detector

- measure collected charge and leakage current at different bias voltages,
  after 80, 240, 560, 1200 2480 and 5040 minutes at 60 C.

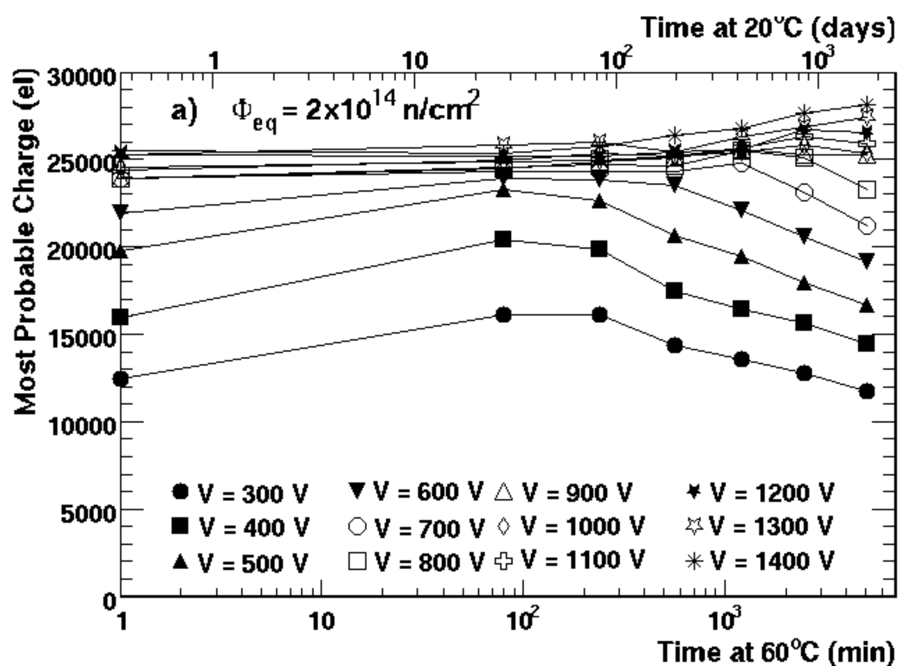
Detectors:

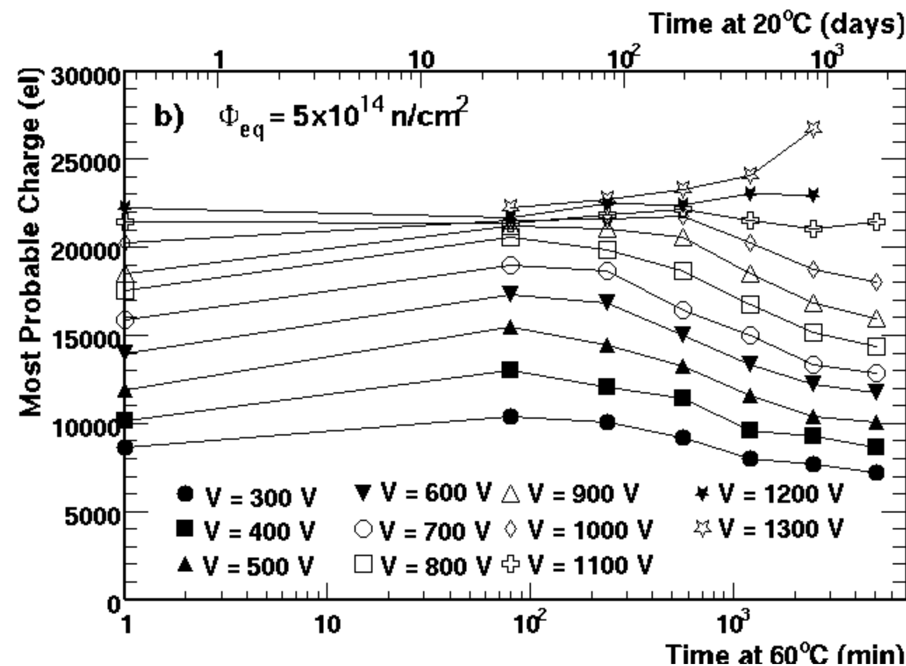
- p-type, FZ, 320 μm thick, 75 μm strip pitch, 1x1 cm^2 , produced by Hamamatsu

  1) ATLAS07-PSSSSD_Series I, W45, BZ3-P15: $\Phi = 2\cdot10^{14}$ n/cm^2
  2) ATLAS07-PSSSSD_Series I, W19, BZ3-P18: $\Phi = 5\cdot10^{14}$ n/cm^2
  3) ATLAS07-PSSSSD_Series I, W22, BZ3-P3: $\Phi = 1\cdot10^{15}$ n/cm^2
  4) ATLAS07-PSSSSD_Series I, W16, BZ3-P21: $\Phi = 5\cdot10^{15}$ n/cm^2

- detectors irradiated with neutrons in reactor in Ljubljana

Annealing of collected charge





Low voltages:

➔ standard behavior: beneficial annealing followed by reverse annealing

High voltages:

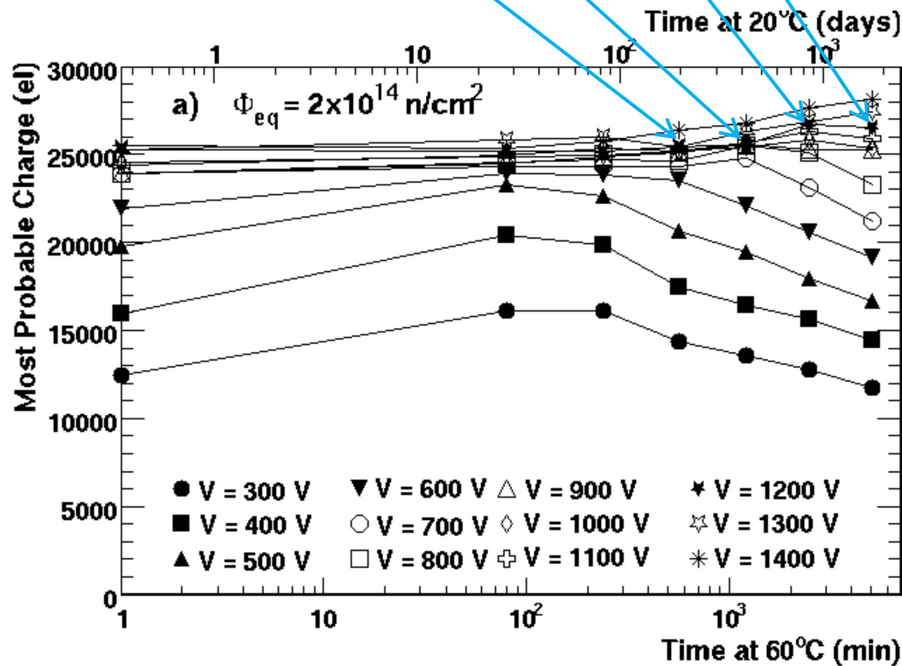
➔ rise of collected charge with reverse annealing

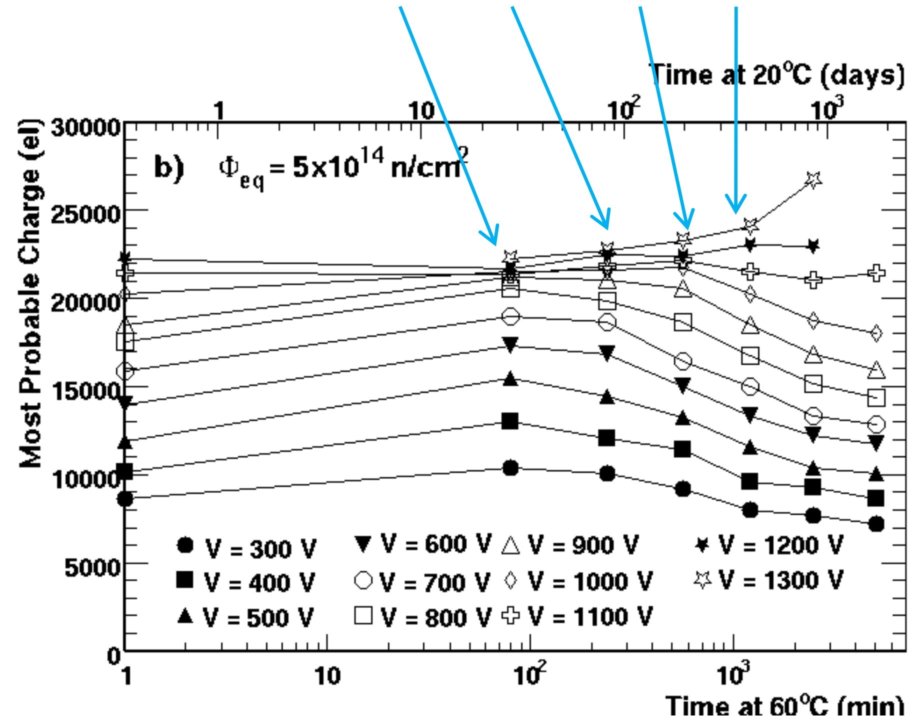
- top scale (days at 20°C) obtained by multiplying bottom scale with 500 – corresponds to activation energy E_a = 1.31 eV in Arrhenius relation for temperature dependence of reverse annealing of V_{fd} (from Cindro et al.)

Annealing of collected charge

V_{fd} from the kink: ~600 , ~700, ~800, ~900
V_{fd} calculated: 710, 860, 1000, 1100

V_{fd} from the kink: ~800, ~900, ~1000, ~1200
V_{fd} calculated: 980, 1200, 1500, 1900



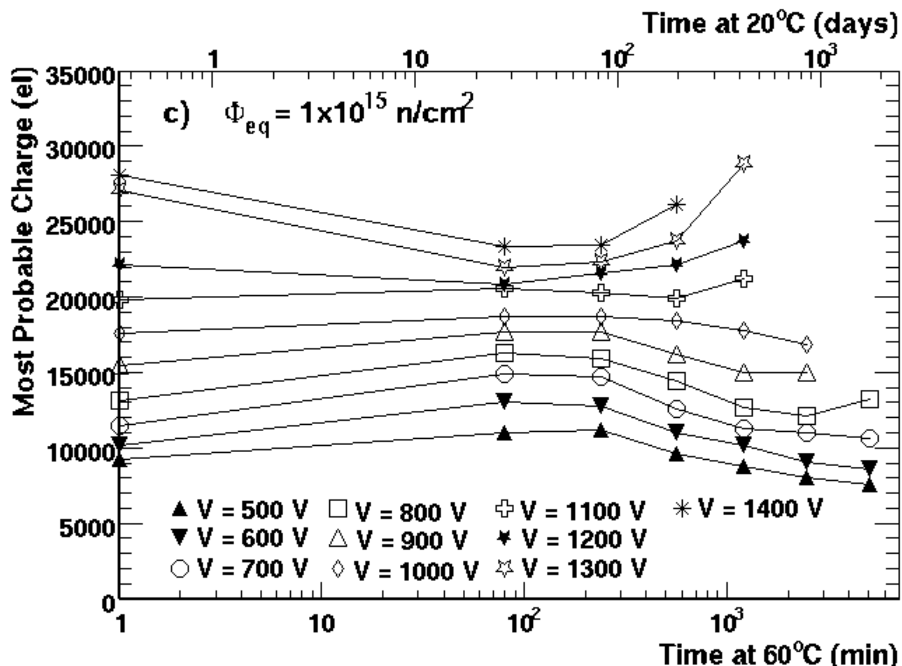


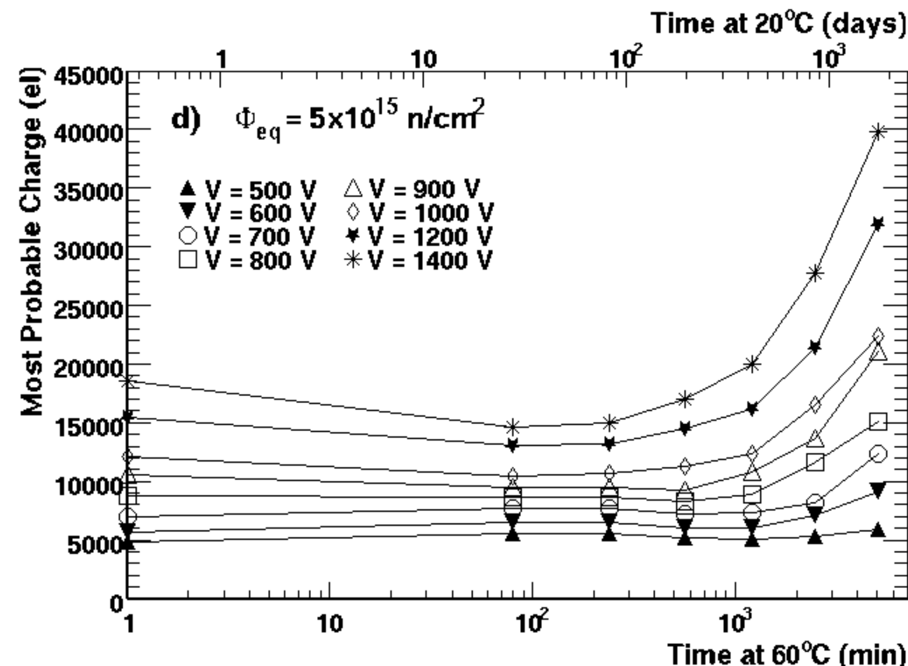
V_{fd} calculated using Hamburg model with following parameters:

Stable: g_c = 0.017 cm^{-1}, (V. Cindro et al. NIMA 599 (2009) p60)
Short term: g_a = 0.018 cm^{-1}, τ_a = 19 min, (G. Lindström et al. NIMA 466 (2001) p308)
Long term: g_Y = 0.053 cm^{-1}, τ_Y = 1100 min, (G. Kramberger et al. NIMA 612 (2010) p288)

➔V_{fd} estimated from the plot higher then expected from calculation: a sign of multiplication

Annealing of collected charge





High fluences, high voltages:

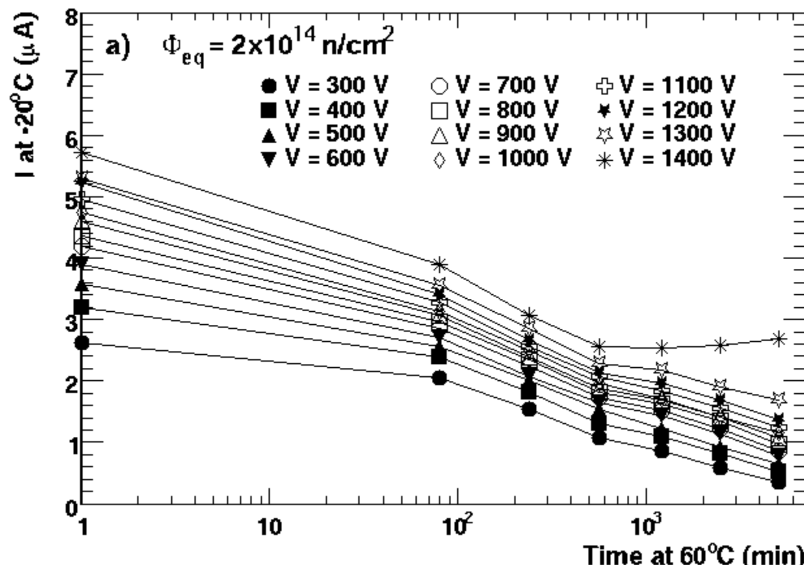
- Most probable charge drops due to short term annealing:
  ➔ N_{eff} drops → smaller peak electric field → less multiplication

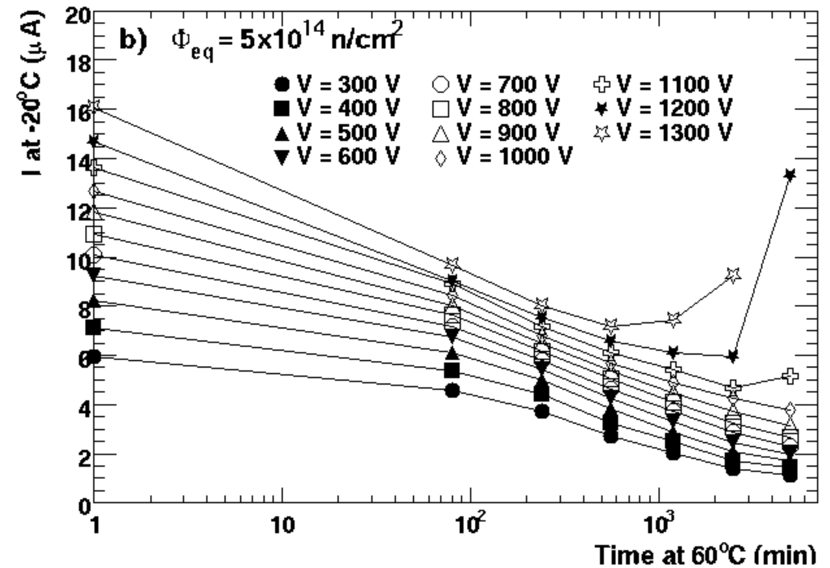
- Most probable charge rises due to long term annealing:
  ➔ N_{eff} rises → larger peak electric field → more multiplication

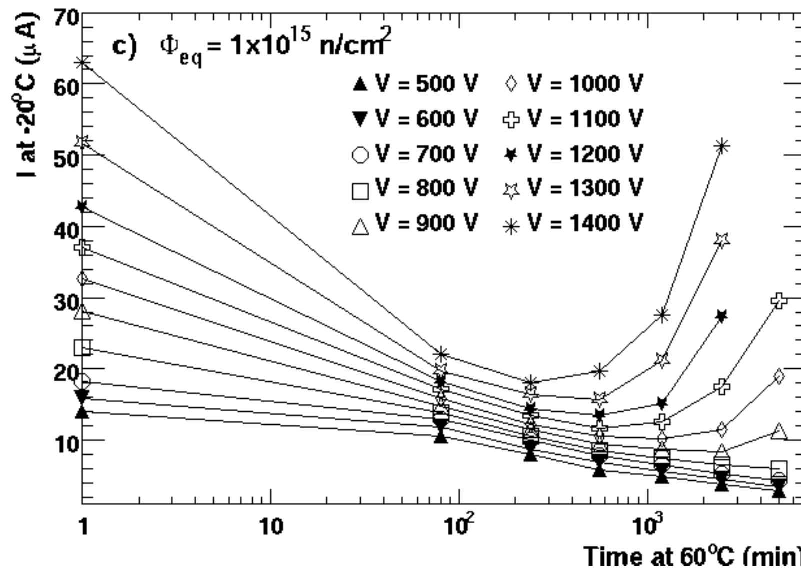
- Breakdown voltage is lower at $5 \cdot 10^{14}$ and $1 \cdot 10^{15}$ than at $2 \cdot 10^{14}$ and $5 \cdot 10^{15}$
  ➔ for detectors irradiated to $5 \cdot 10^{14}$ and $1 \cdot 10^{15}$
  breakdown voltage decreases with reverse annealing

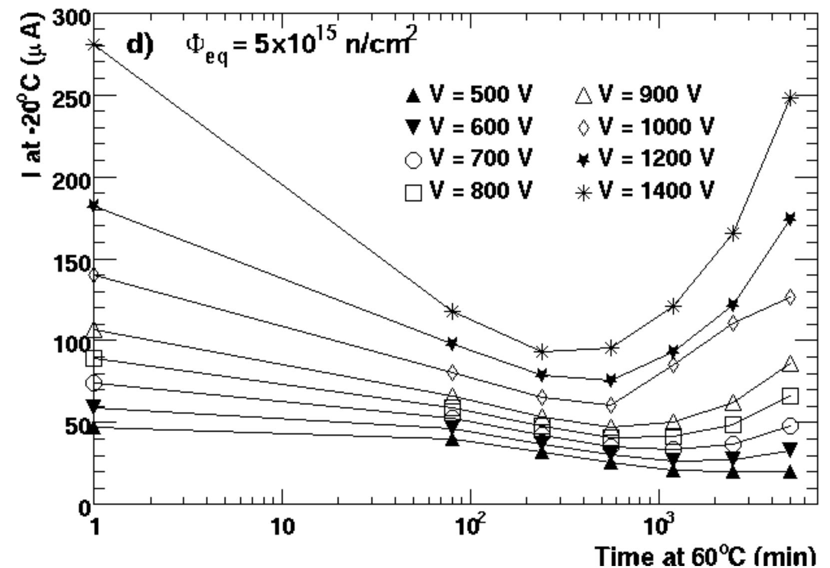
Leakage current

- guard rings not bonded



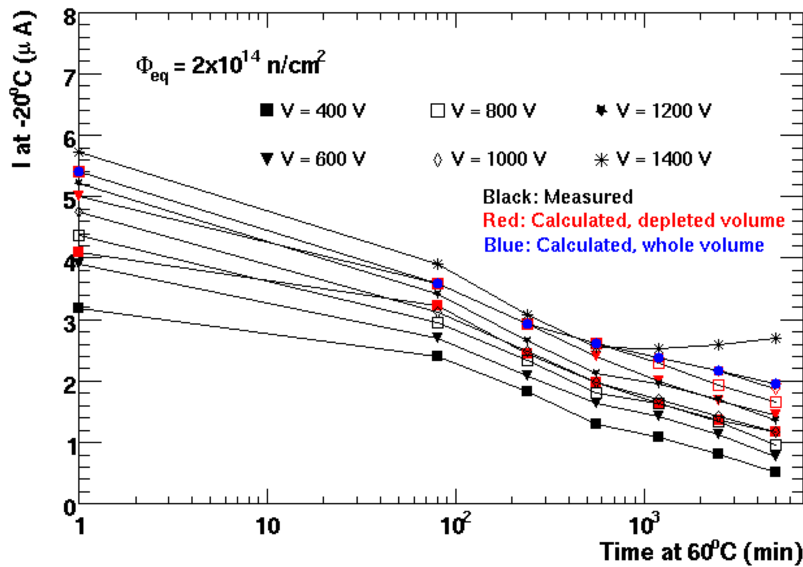


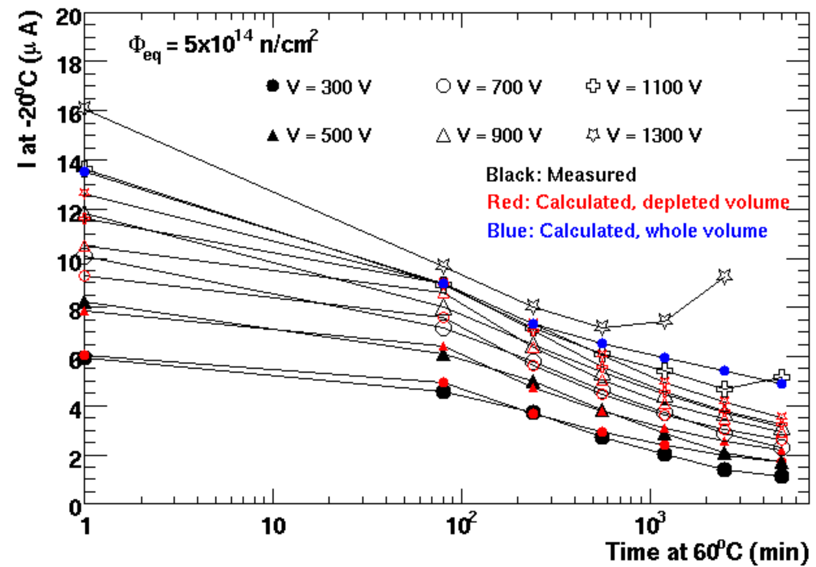


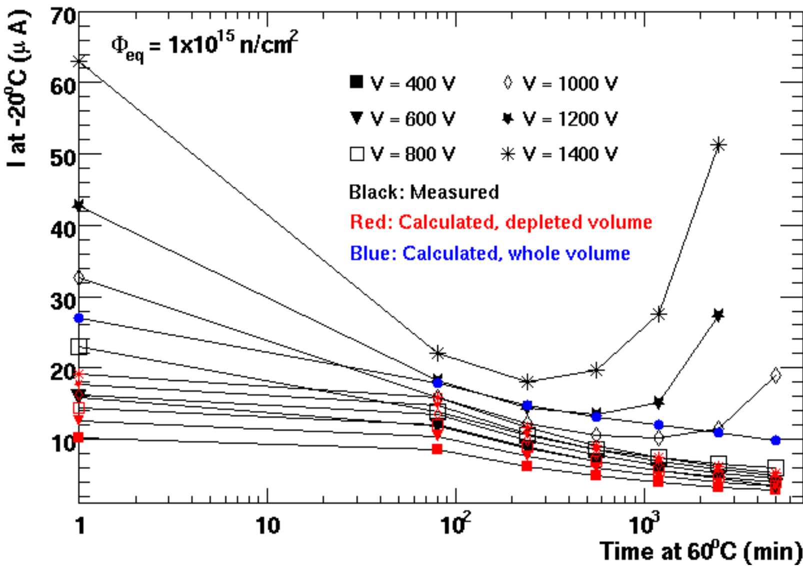


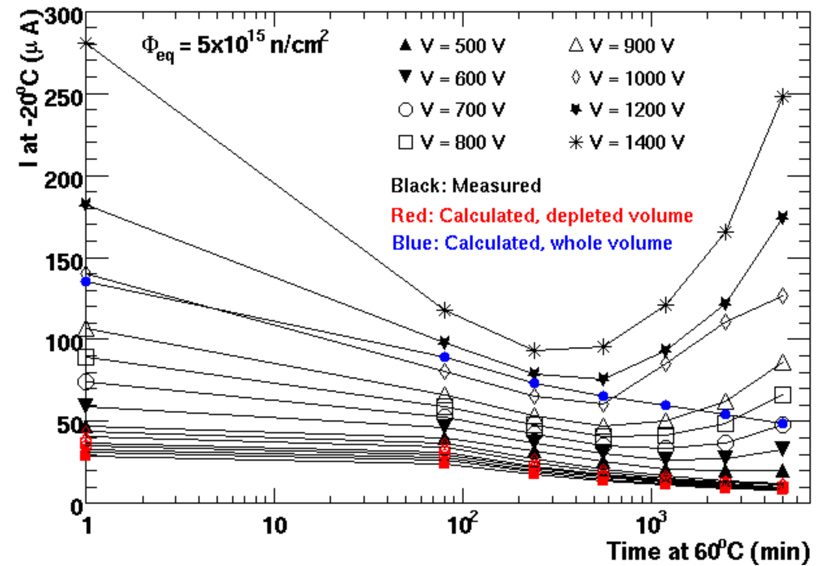
- Increase of leakage current with annealing ➔ multiplication

Compare with calculation (annealing parameters from M. Moll et al. NIMA 426(1999) p. 87)



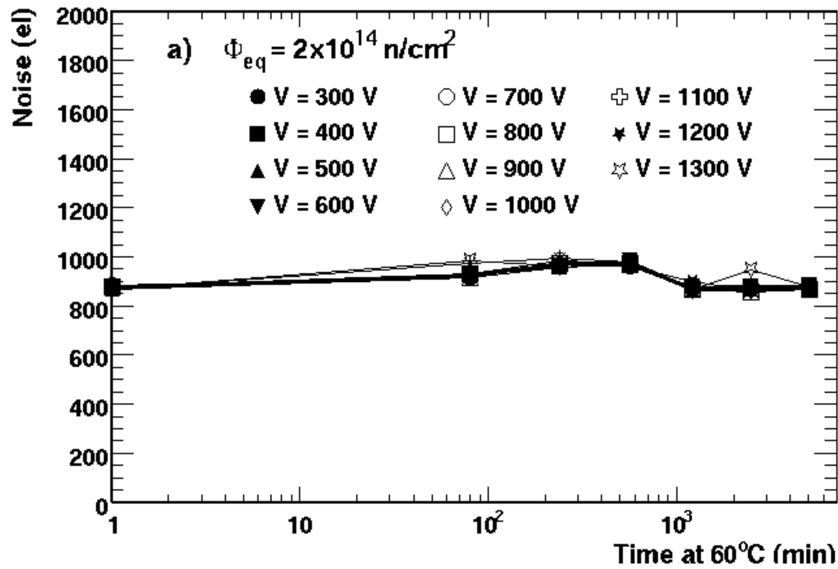


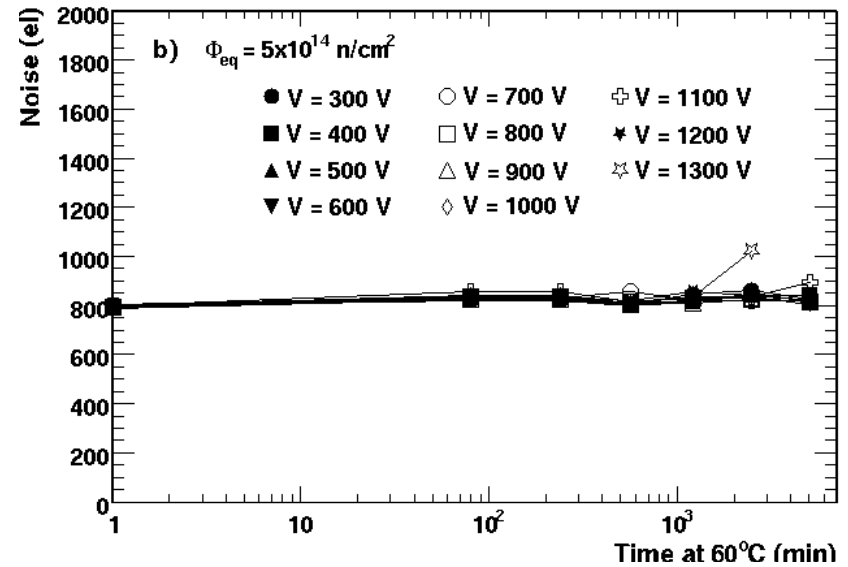


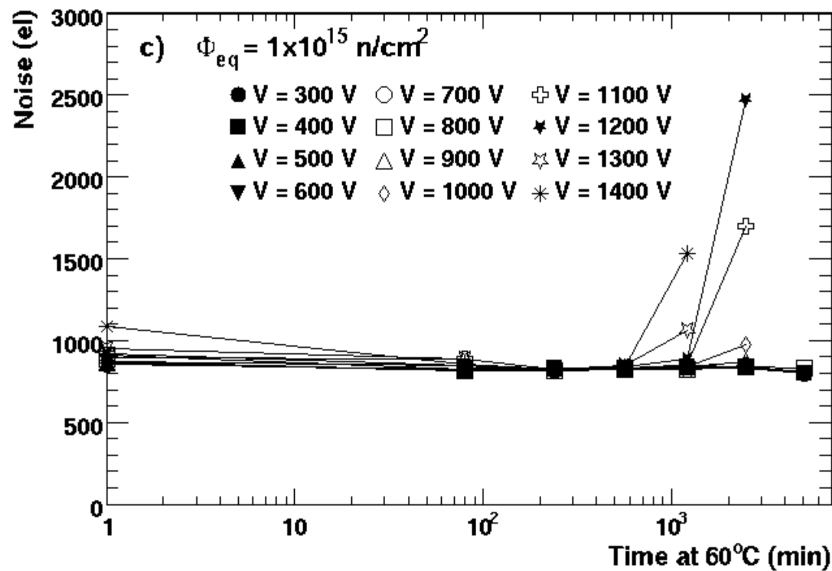


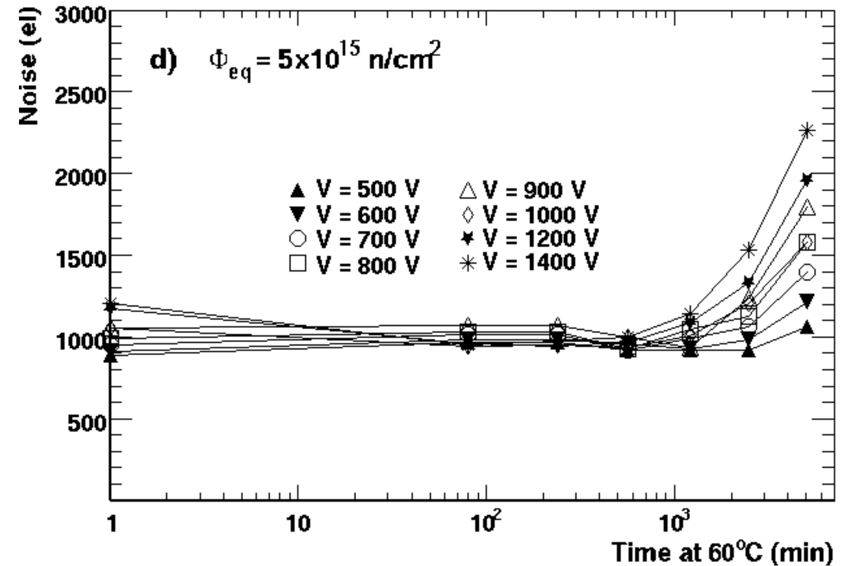
- high voltage: current higher then expected even if full depletion assumed

Noise



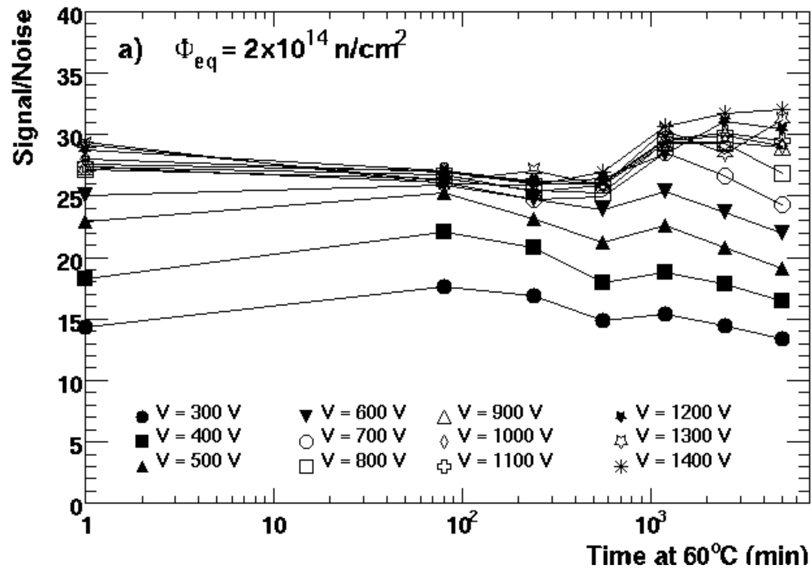


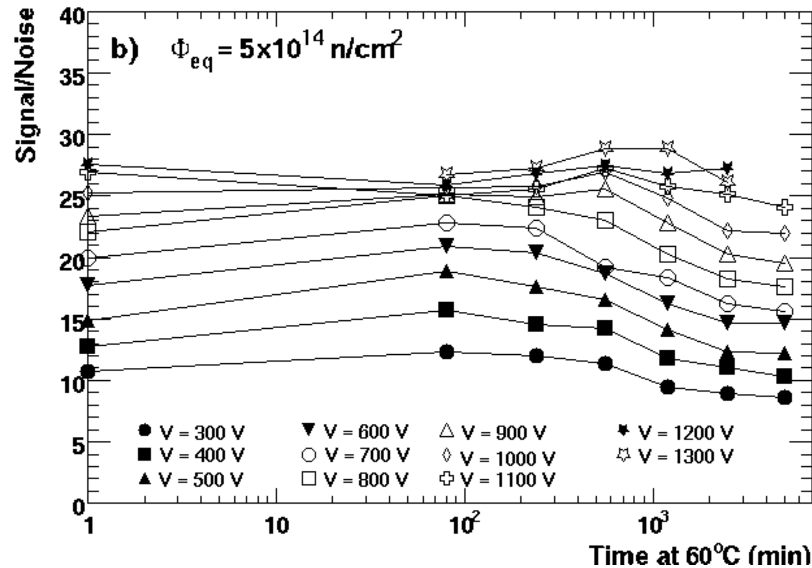


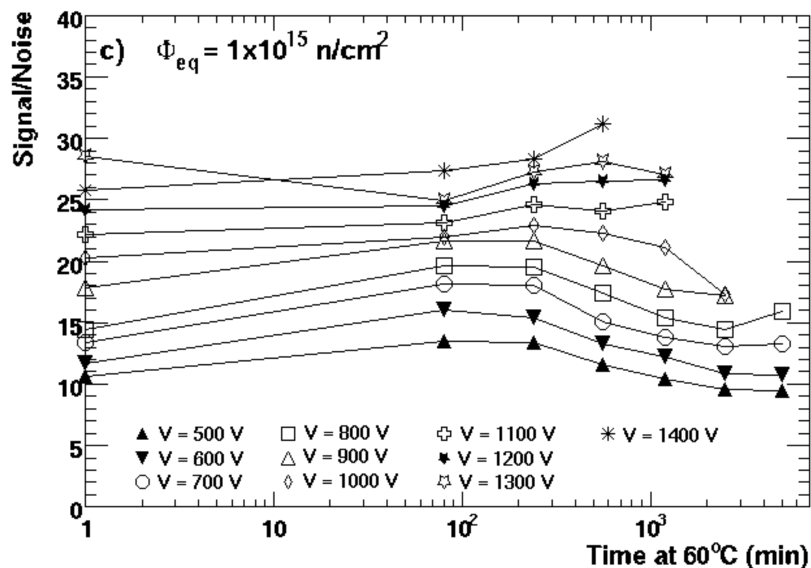


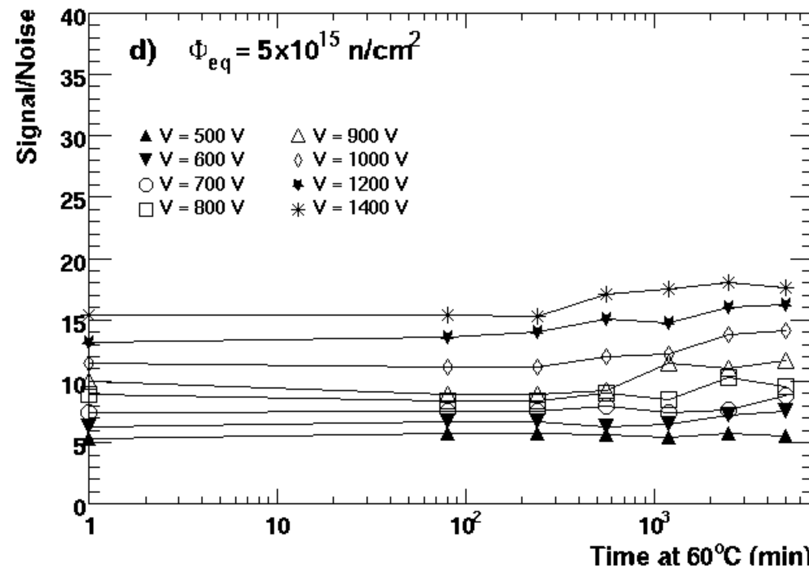
- Noise increases when multiplication large

Signal/Noise









- Signal/Noise ratio doesn't change significantly

Discussion about noise

(see also: - J. Lange et al. NIMA 622, 2010, p49,
- G. Kramberger et al. *Proceedings of Vertex 2010*)

- Noise can be written as:

$ENC^2 = ENC_s^2 + ENC_p^2$,

ENC_s : serial noise for SCT128 and this detector capacitance ~ *800 e*
ENC_p: dominated by shot noise proportional to square root of detector current $\sqrt{I}$

- If no multiplication: *ENC* ~ 900 e ➔ dominated by ENC_s (shot noise contribution small)

- Multiplication: $\sigma_I^2 \propto (\sqrt{F} \cdot M \cdot \sqrt{I_0})^2 = F \cdot M^2 \cdot I_0 = F \cdot M \cdot I$

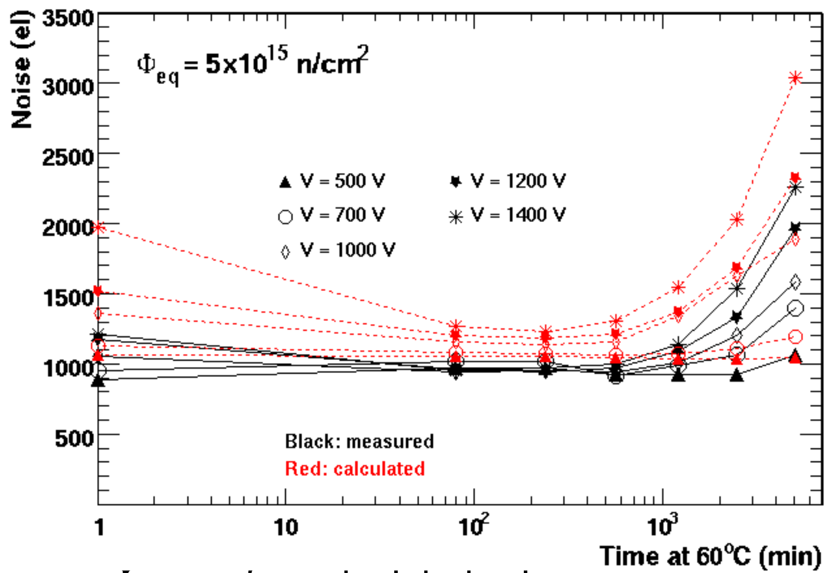
M : average multiplication factor
F : noise excess factor, $F \sim 2$ if only electrons get multiplied (our case)
I_0 : generated current (before multiplication)
$I = M \cdot I_0$: measured current

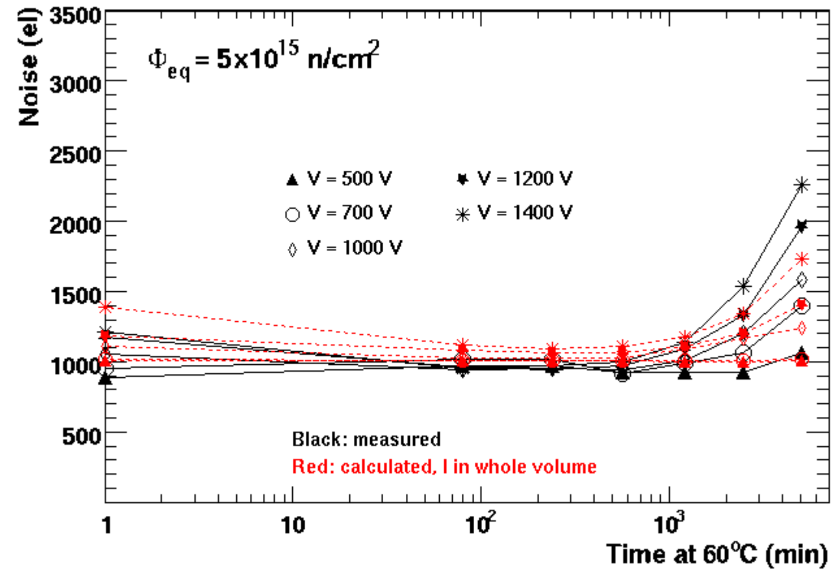
- Shot noise for SCT128 chip (triangular shaping):

$$ENC_I^2 = \frac{2}{3e} \cdot \tau_p \cdot \sigma_I^2 = \frac{2}{3e} \cdot \tau_p \cdot F \cdot M \cdot I$$

$\tau_p = 20\ ns$: peaking time
$e = 1.6 \cdot 10^{-19}$ As : elementary charge
$F = 2$

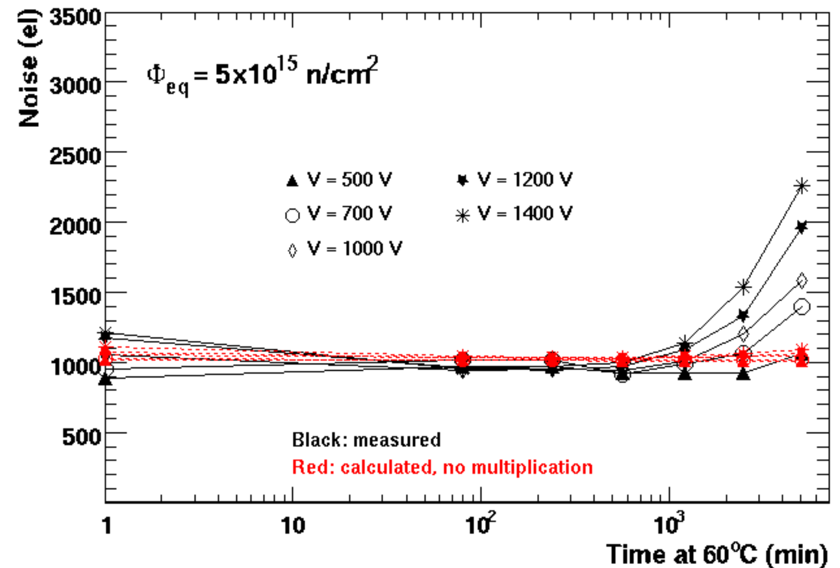
M can be estimated from: $M = \frac{I_{Measured}}{I_{Calculated}}$



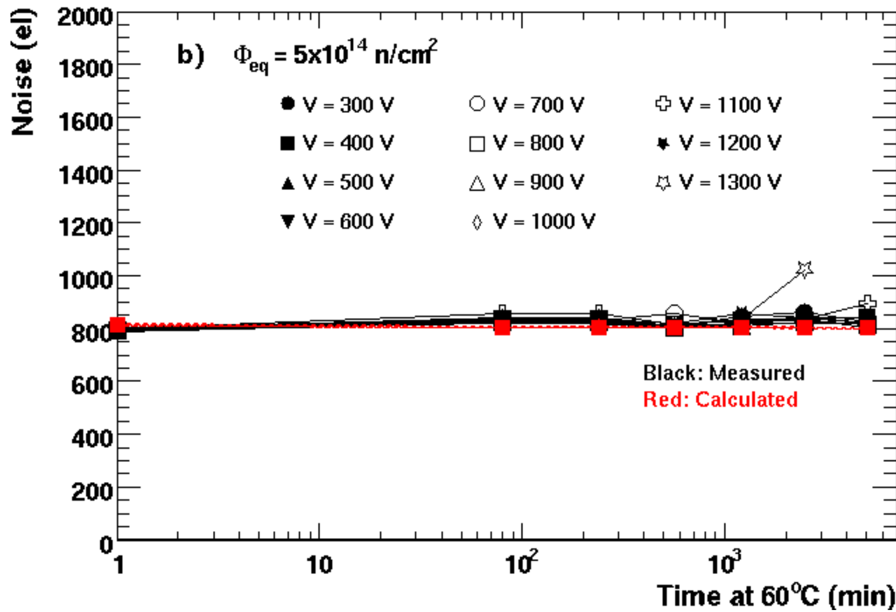


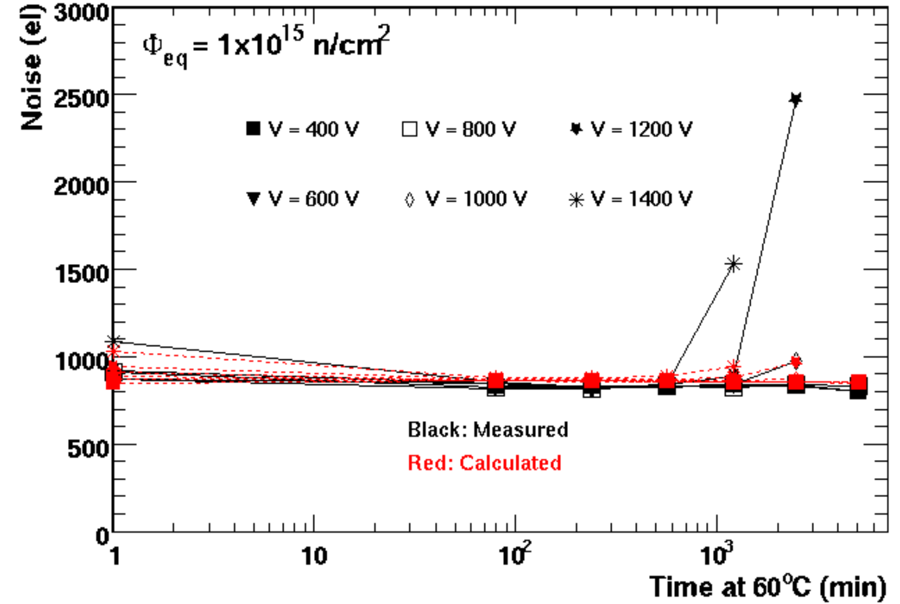
$I_{calculated}$ from depleted volume
(smaller $I_{calculated}$ => larger M)

$I_{calculated}$ from whole detector volume



Total noise increase due to shot noise
if there is no multiplication ($F = M = 1$) small:





- Noise increase larger than calculated
  ➔ disagreement in the last point before breakdown – micro-discharges?

Conclusions

- at high fluences and high bias voltages multiplication effects influence annealing behavior:

  ➔ multiplication increases with annealing time larger than ~ 500 minutes @ 60°C (~170 days @ 20°C)

  ➔ increase of space charge concentration ➔ higher electric fields ➔ more multiplication
  ✓ collected charge increases with reverse annealing
  ✓ leakage current increases with reverse annealing

  ➔ multiplication decreases with short term (beneficial) annealing
  ✓ collected charge decreases with reverse annealing

- noise increases because of multiplication

- signal/noise ratio doesn't change significantly