Possibly relevant new from RD50

G. Casse

UNIVERSITY OF LIVERPOOL

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Annealing: p-in-n, n-in-p (n)

Charge trapping

Multiplication

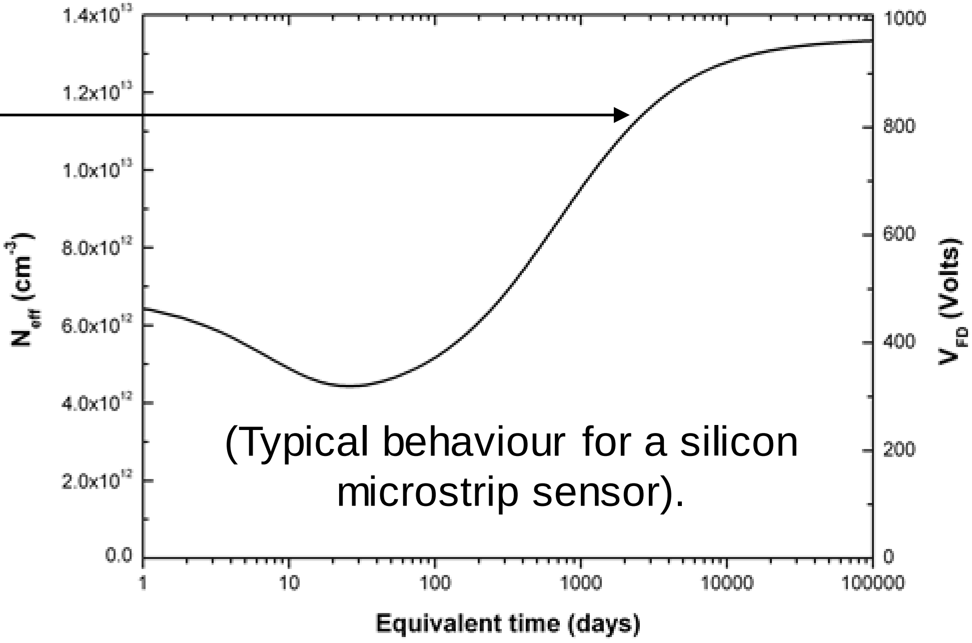
Evolution of Sensor Properties After Irradiation

Sensor **leakage current** (**I_{LEAK}**), **depletion voltage** (**V_{DEP}**) and **charge collection efficiency** (**CCE**) are all affected by irradiation.

Evolution of **V_{DEP}** shows dependence on both temperature and time spent after irradiation.

Require full depletion (and some) of sensor in order to optimise **CCE.**

I_{LEAK} Shows strong temperature.

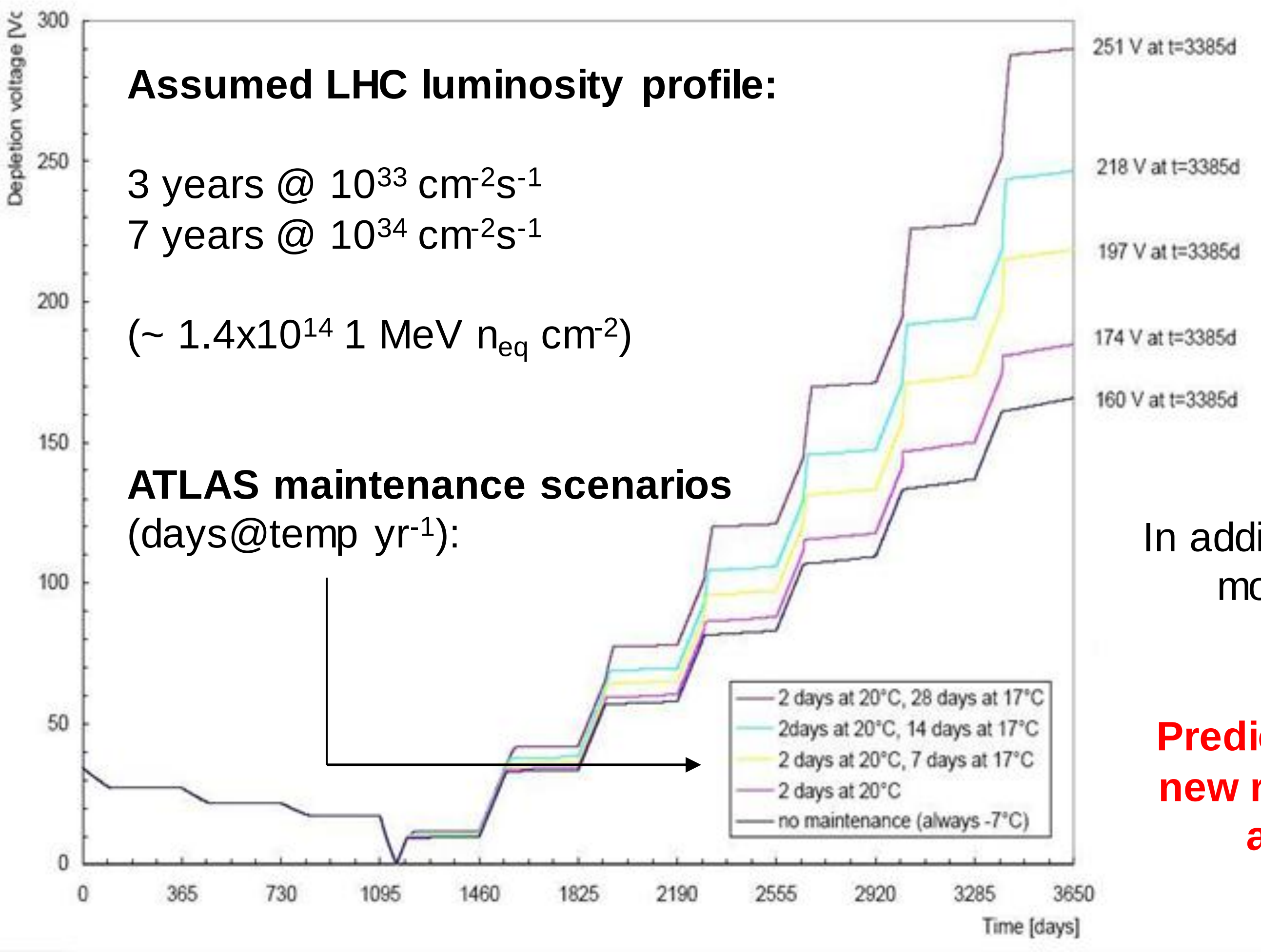


(Typical behaviour for a silicon microstrip sensor).

Need to avoid the sensors being warm (> 0 °C) for long periods of time!

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

In the ATLAS Inner Detector Technical Design Report (**1997**) $\mathbf{V_{DEP}}$ and $\mathbf{I_{LEAK}}$ were predicted for SCT sensors.



Assumed LHC luminosity profile:

3 years @ 10^{33} cm^{-2}s^{-1}
7 years @ 10^{34} cm^{-2}s^{-1}

(~ 1.4×10^{14} 1 MeV n_{eq} cm^{-2})

ATLAS maintenance scenarios
(days@temp yr^{-1}):

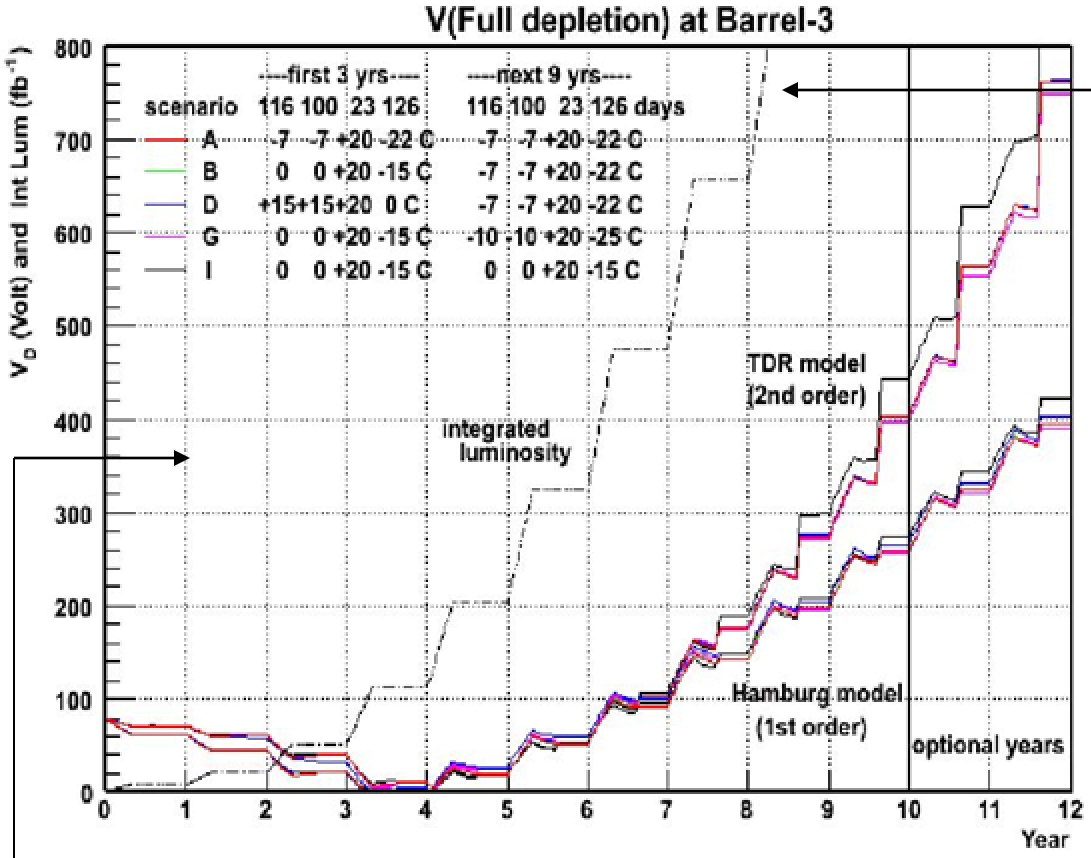
Standard Access Procedure (SAP)

Many of the inputs to these calculations have since changed.

In addition, the radiation damage model itself has evolved.

Predictions re-evaluated with new radiation damage model and updated inputs.

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).

Comparison of Hamburg Model and TDR Model

Hamburg model is now believed to be the best model available 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}:

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

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

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

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

Programme of Accelerated Annealing Measurements

Sensor performance traditionally studied by determining V_{DEP} from CV measurements.

In **Liverpool** the focus has been on **measuring the annealing of CCE**.
Much data available for n-side readout sensors. Less detailed information for p-in-n sensors.

New programme of accelerated annealing measurements on **ATLAS mini sensors**. →

Manufacturer	HPK
Wafer Tech.	FZ
Structure	p-in-n
Size	1 cm x 1 cm
Thickness	285 µm

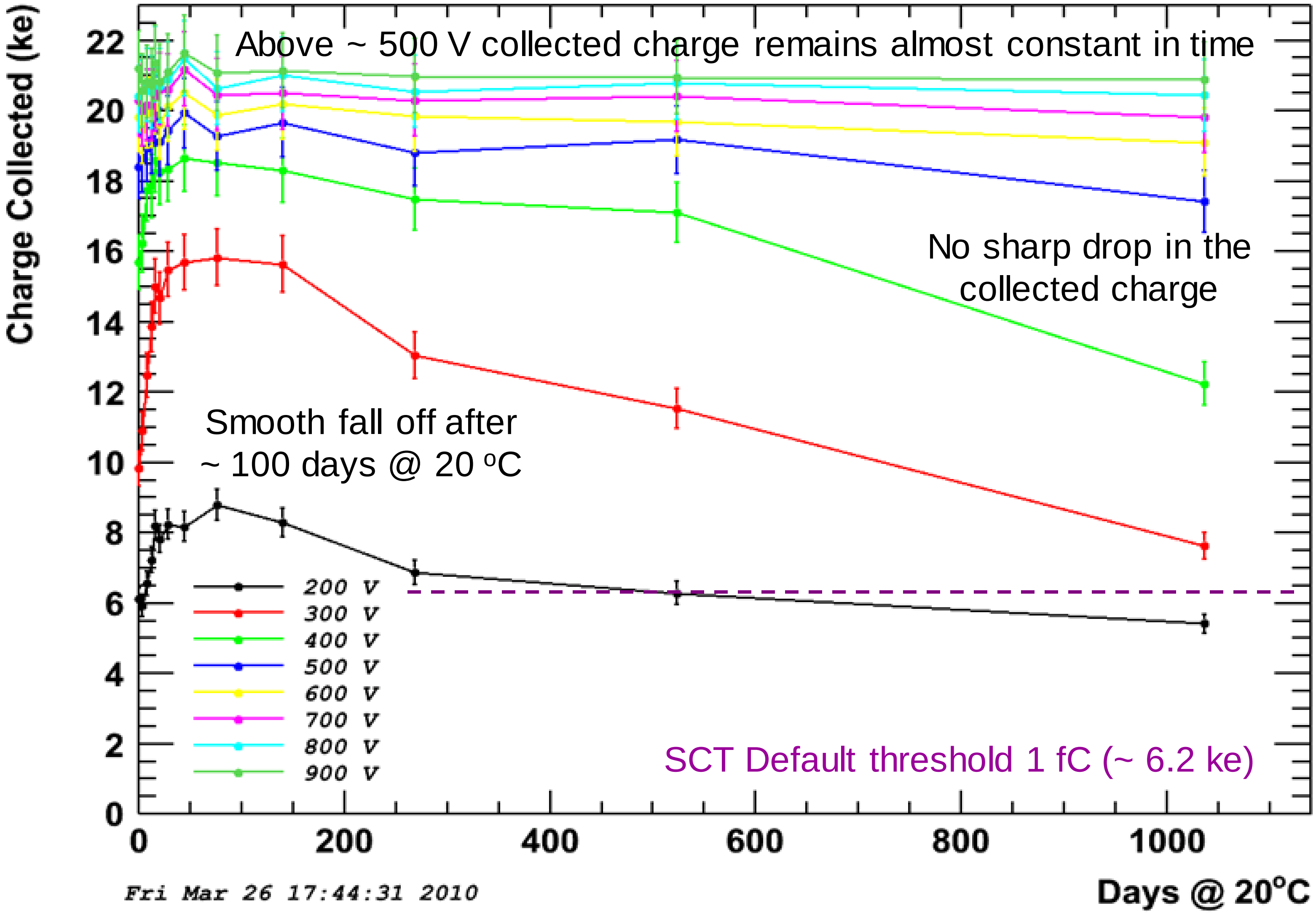
Pair of sensors irradiated with neutrons at Ljublijana (V. Cindro et al) to $\mathbf{2x10^{14}\ 1\ MeV\ n_{eq}\ cm^{-2}}$

(new prediction for SCT = $\mathbf{1.6x10^{14}\ 1\ MeV\ n_{eq}\ cm^{-2}}$).

One sensor used for **CCE** measurements and one sensor used for $\mathbf{V_{DEP}}$ measurements.
Both **sensors annealed together** at same temperature for same length of time.

All following plots by…. A. Affolder, H. Brown, G. Casse, P. Dervan, J. Vossebeld, C. Wiglesworth (Liverpool)

Results of Charge Collection Measurements



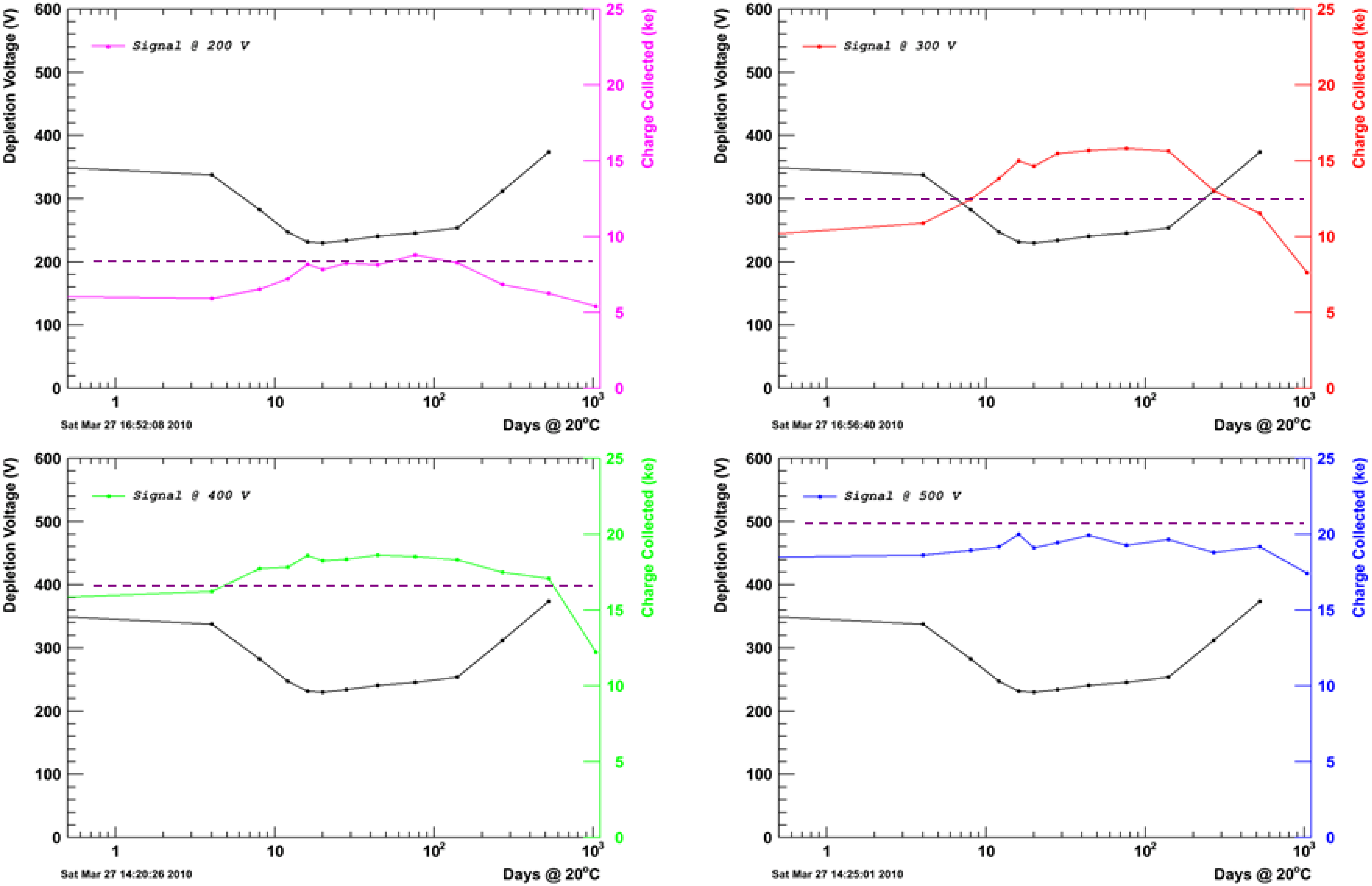
Above ~ 500 V collected charge remains almost constant in time

No sharp drop in the collected charge

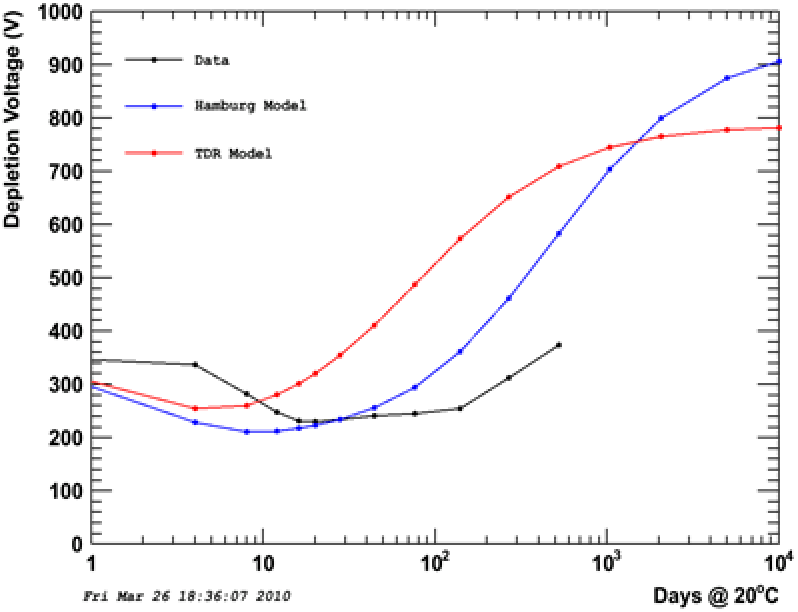
Smooth fall off after ~ 100 days @ 20 °C

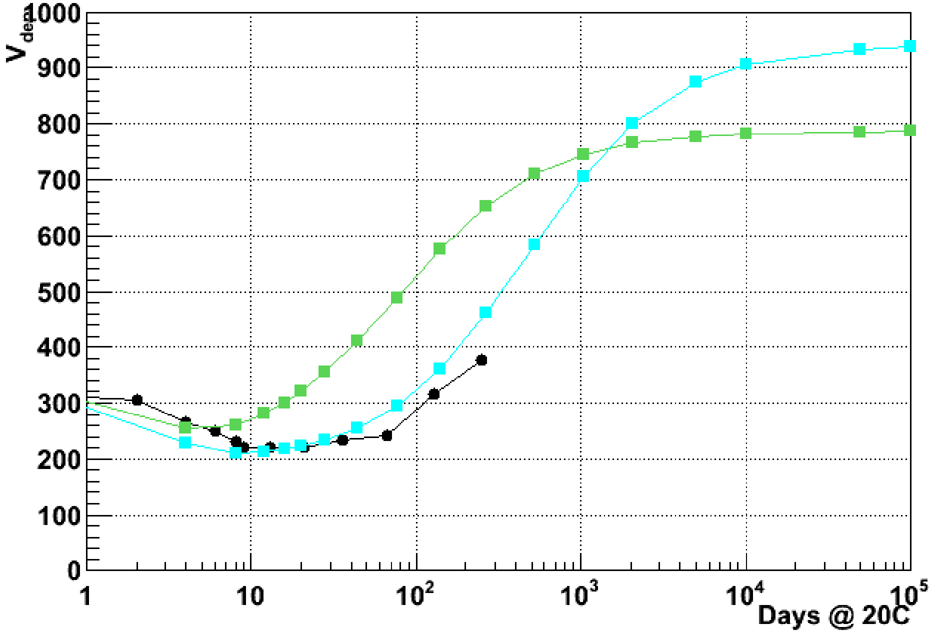
SCT Default threshold 1 fC (~ 6.2 ke)

Comparison of Measured V_{DEP} and Charge Collected



Comparison of Predicted V_{DEP} and Measured V_{DEP}

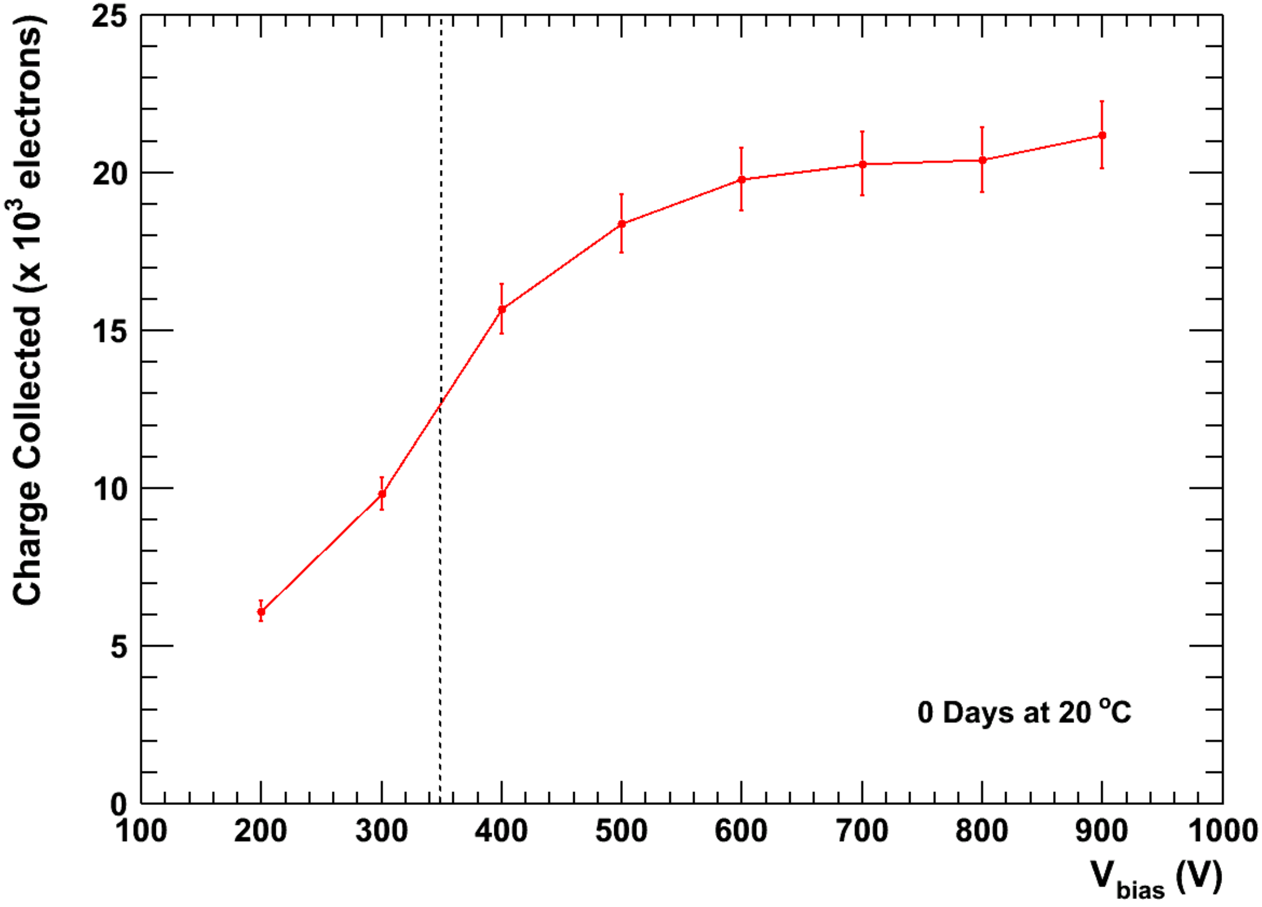




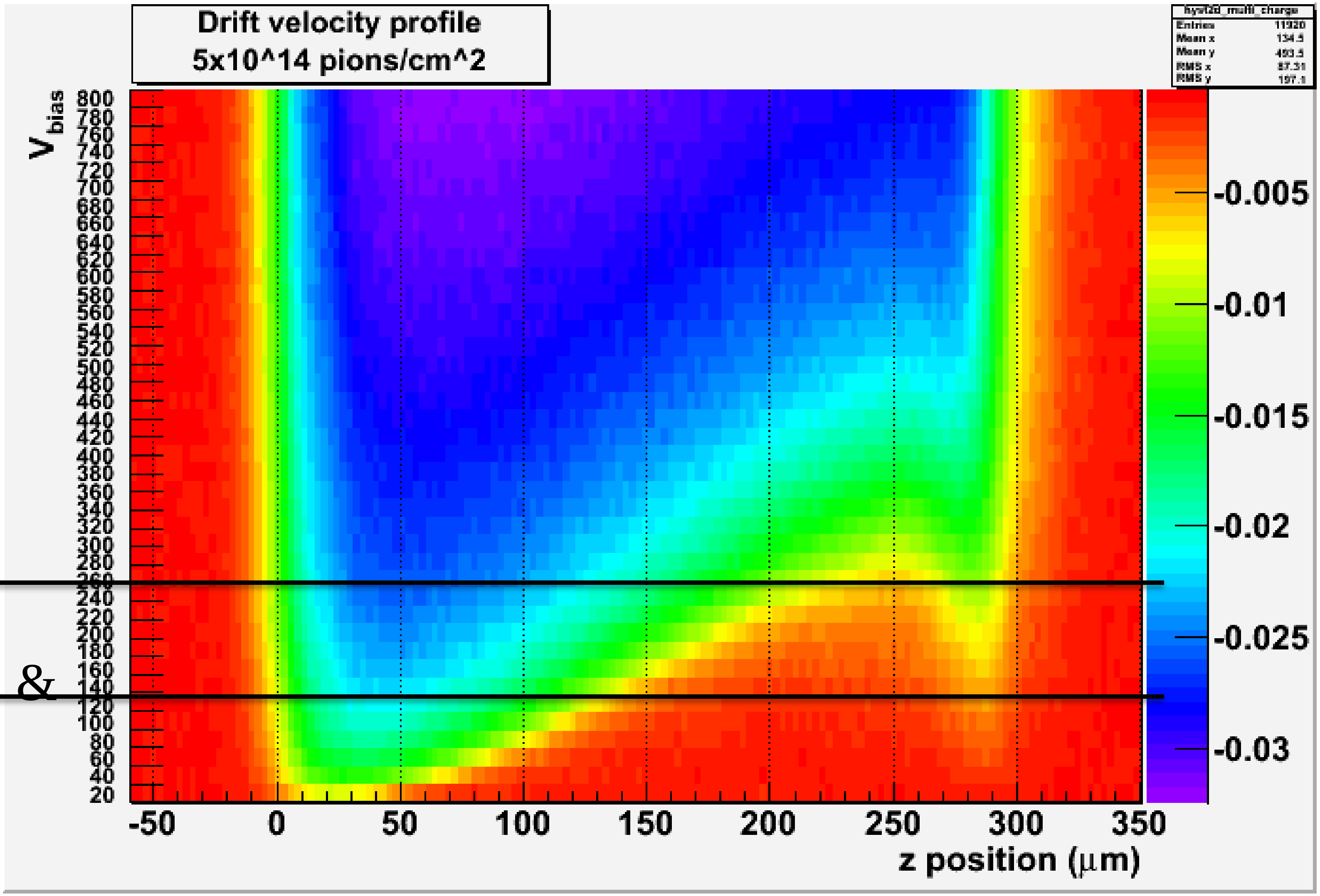
Data shows a slower annealing effect than the two models

Data looks closer to Hamburg model

A warning about Comparing V_{DEP} (CV) to signal collected



Drift velocity profile: 5x10^{14} π/cm^2 irradiated detector



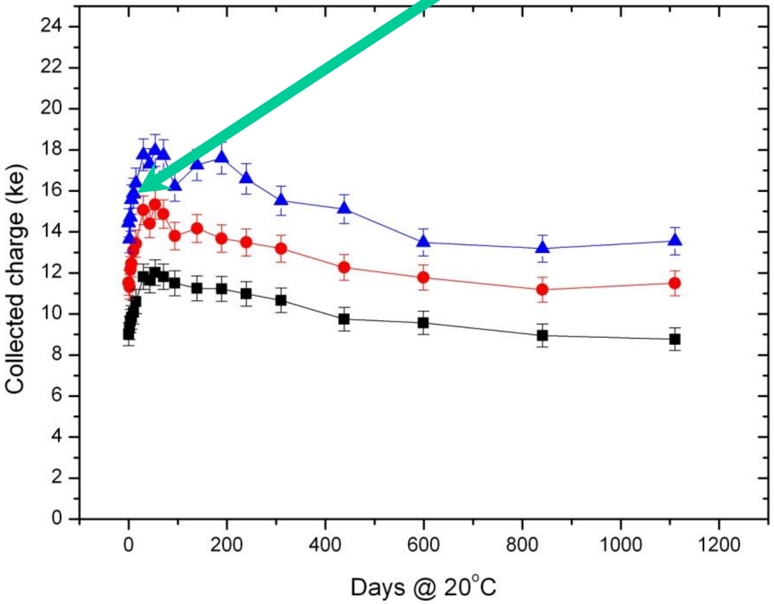
$V_{dep}(C)$

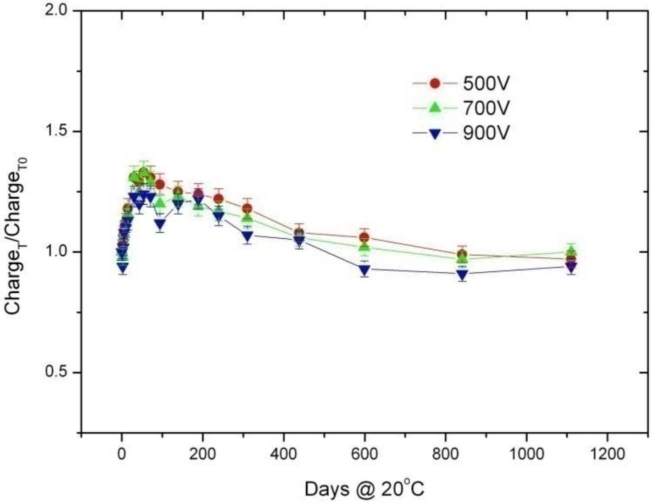
$V_{dep}(I_{leak})$ &
CV first
kink

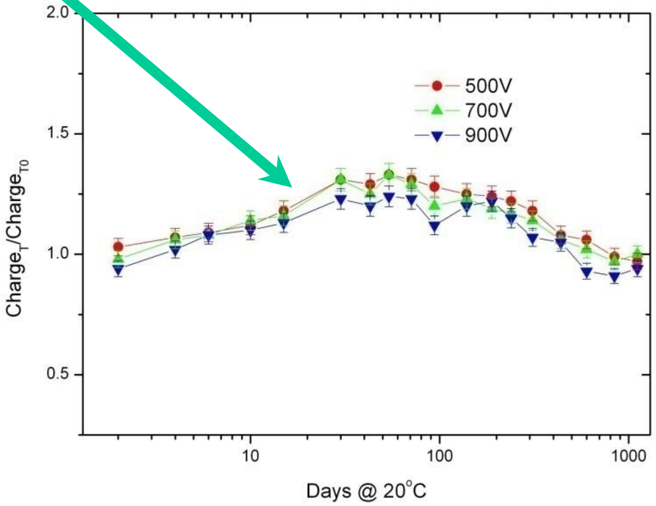
Using fixed annealing time for comparison of the electrical properties

HPK FZ n-in-p, 1E15 n_{eq} cm^{-2}

80 minutes at 60°C (30 days at RT).

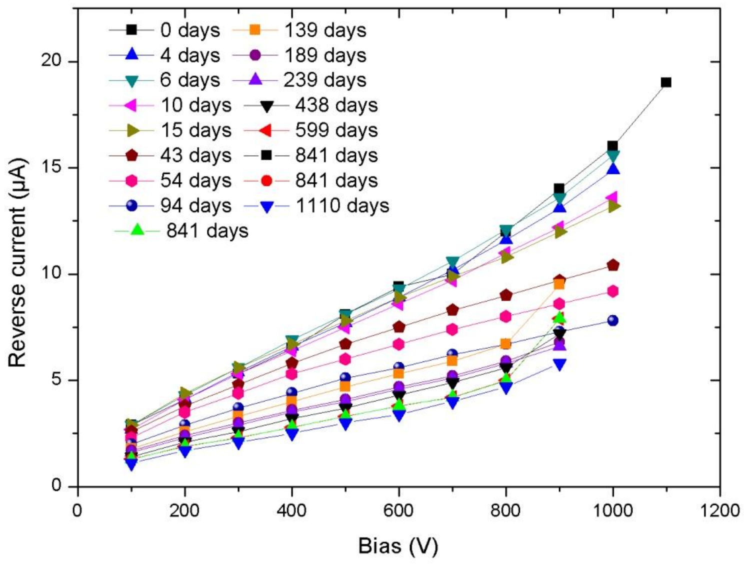


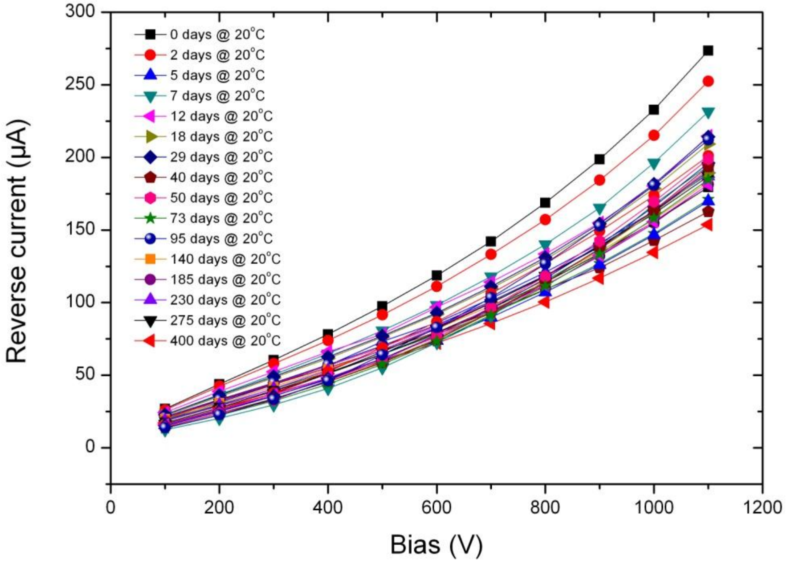




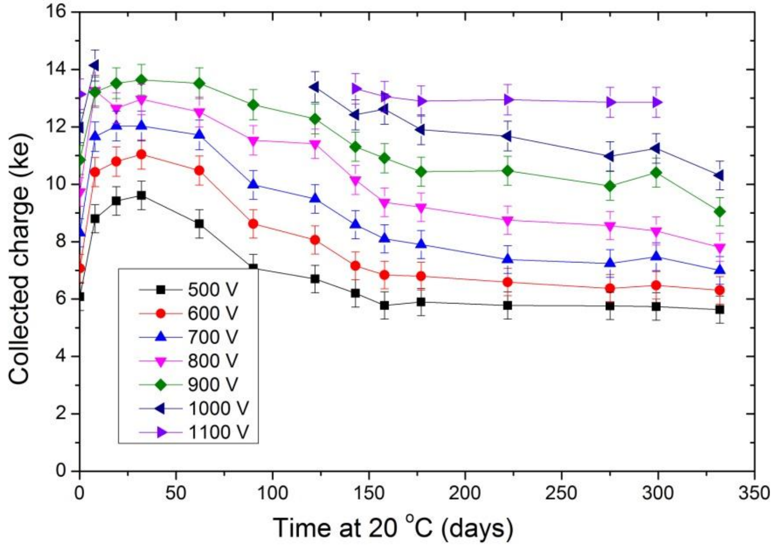
Neutron irradiations in Ljubljana.

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

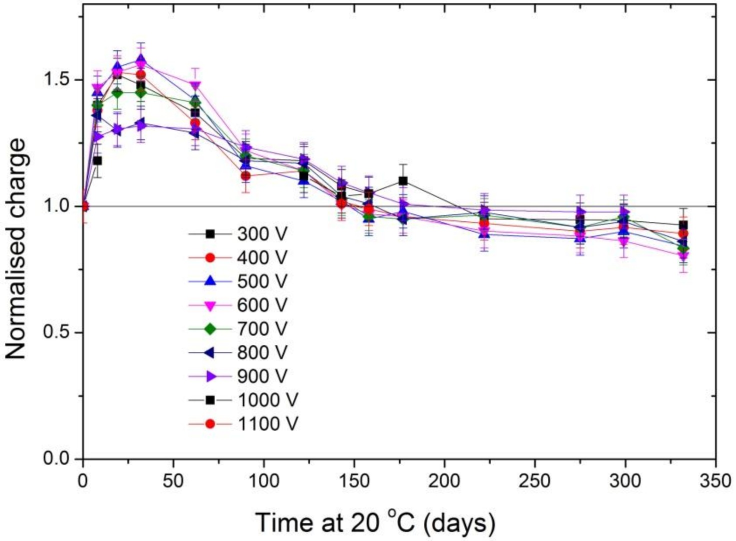




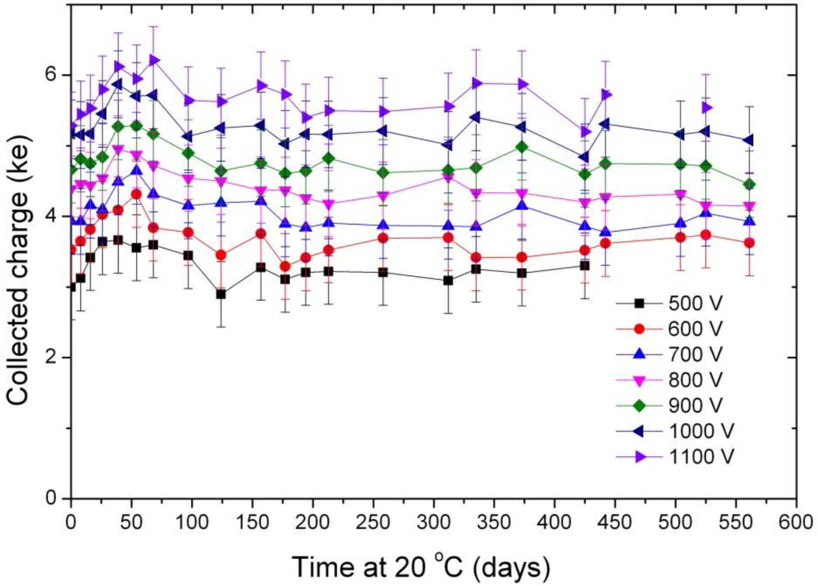
Room Temperature Annealing of the collected charge, HPK FZ n-in-p, 2E15 n cm^{-2} (26MeV p irradiation)

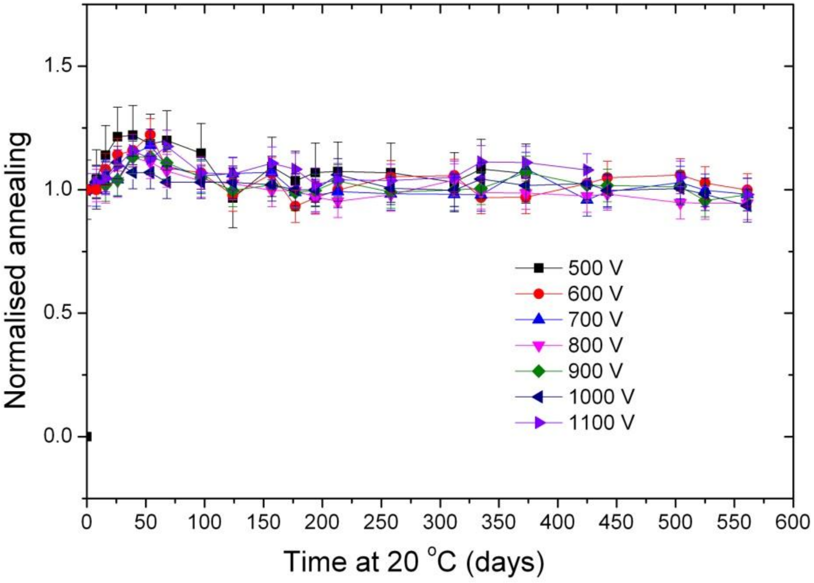


We make large use of accelerating annealing: is this a safe and correct approach?

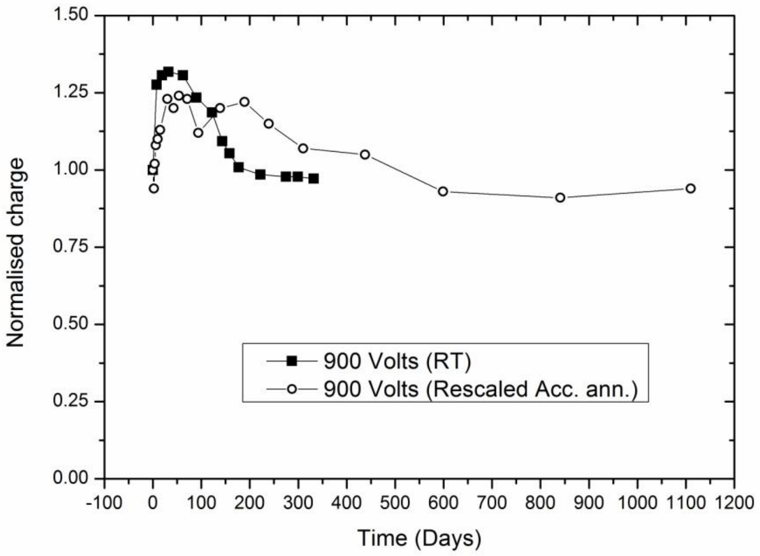


Room Temperature Annealing of the collected charge, HPK FZ n-in-p, 1E16 n cm^{-2} (26MeV p irradiation)

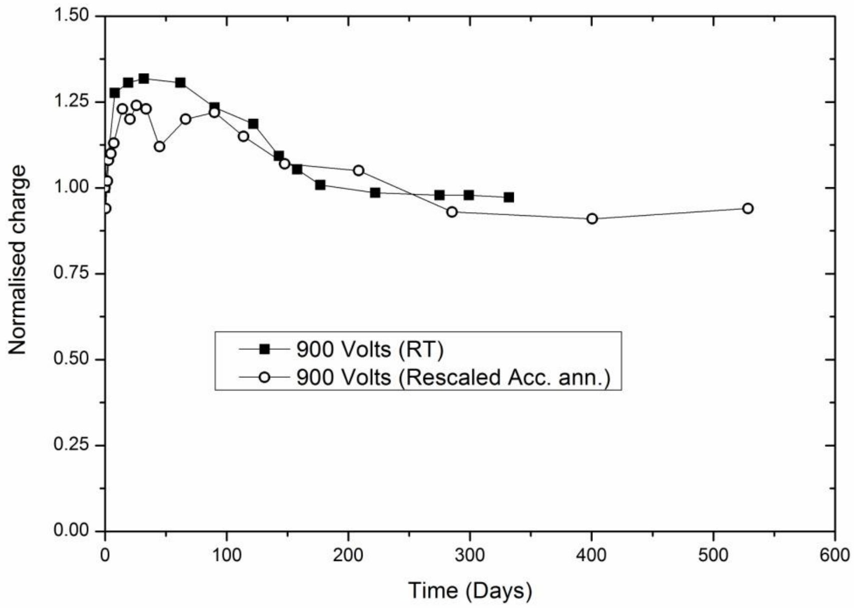




Comparison of Room Temperature and Accelerated Annealing of the collected charge, HPK FZ n-in-p, 1and 1.5E15 n cm^{-2} (26MeV p irradiation)



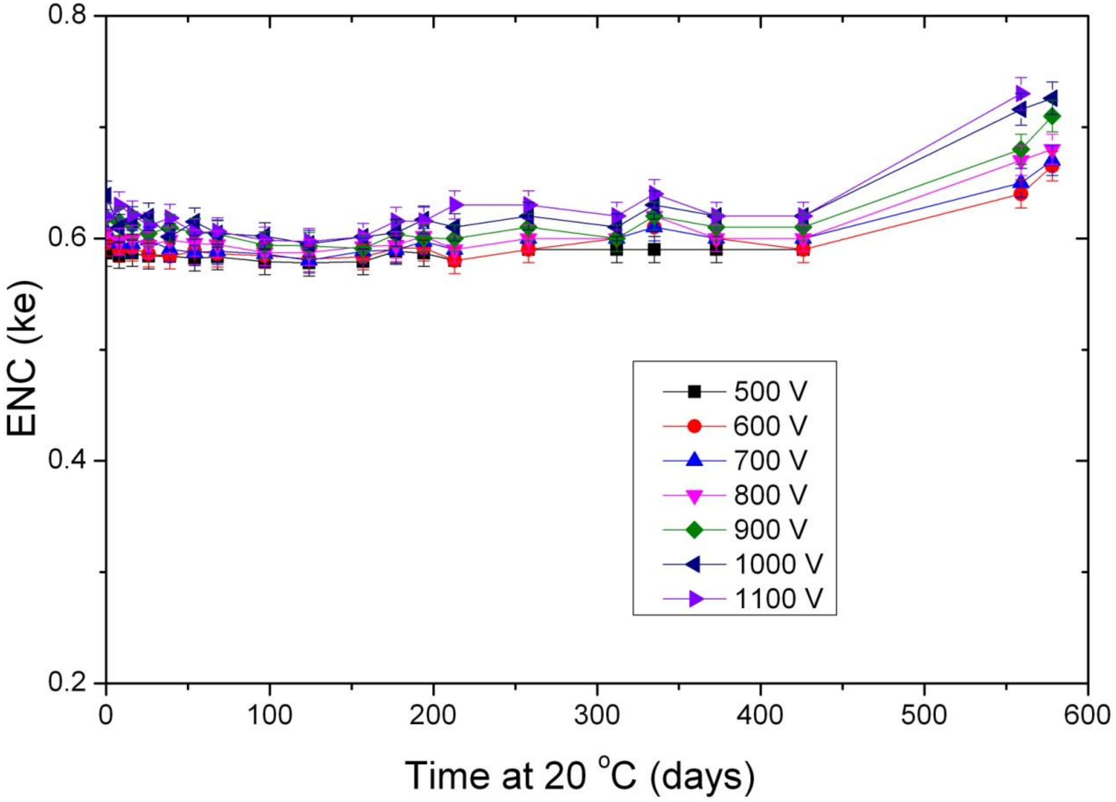
Accepted acceleration factor



Acceleration factor divided by 2.1

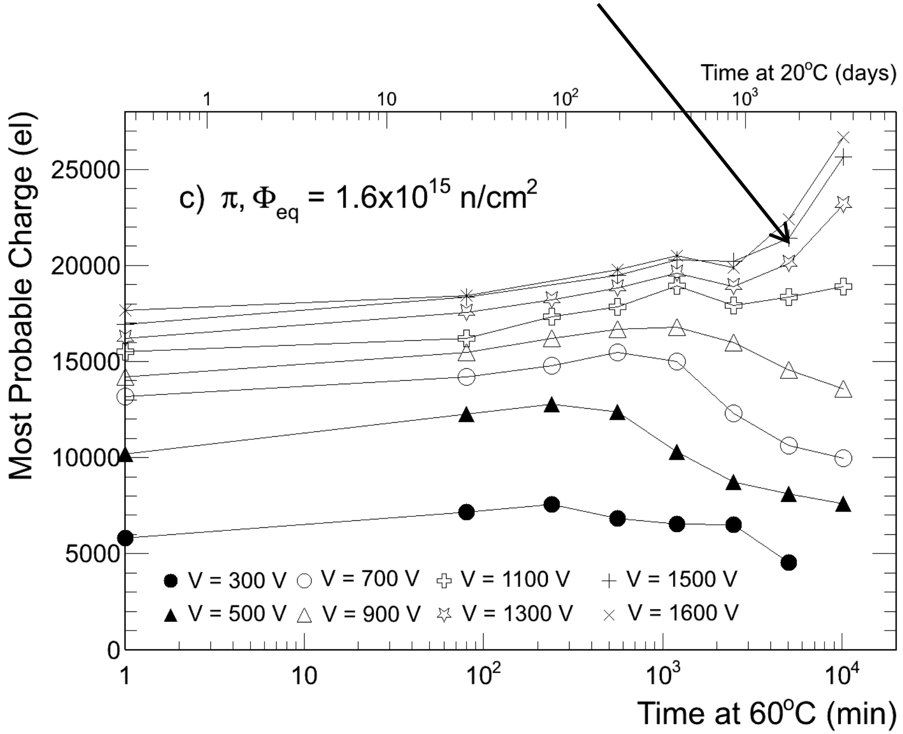
Suggestion for comparing results (awaiting for systematic studies): 120 minutes at 60^{o}C

Noise

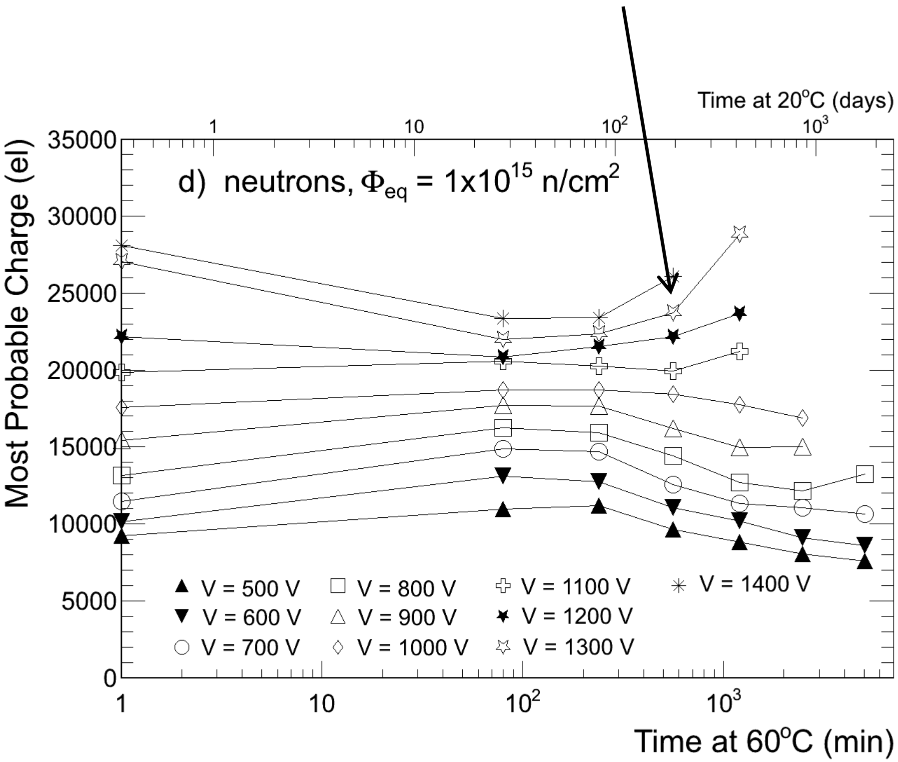


0.8
0.6
0.4
0.2
ENC (ke)
0
100
200
300
400
500
600
Time at 20 °C (days)
500 V
600 V
700 V
800 V
900 V
1000 V
1100 V

Pions: t ~ 5000 minutes, V ~ 1300 V



Neutrons: t ~ 500 minutes, V ~ 1300 V

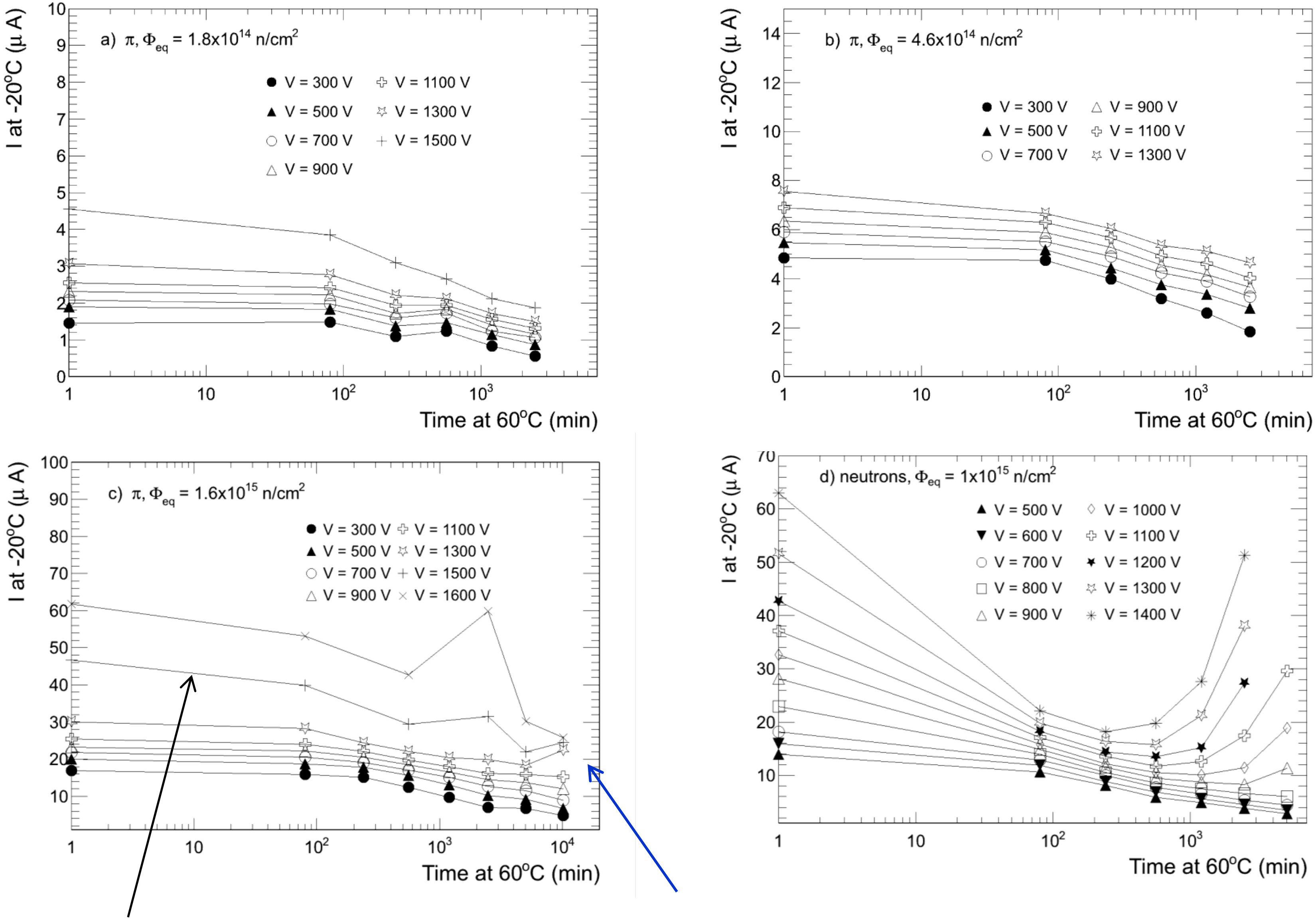


- multiplication obvious in detectors irradiated with pions after longer annealing times then after irradiation with neutrons:

➔ smaller introduction rates for pions ➔ takes longer to reach sufficient N_{eff} for high enough peak electric field

➔ N_{eff} ~ 4e13 cm^{-3} at annealing points where multiplication starts to be obvious

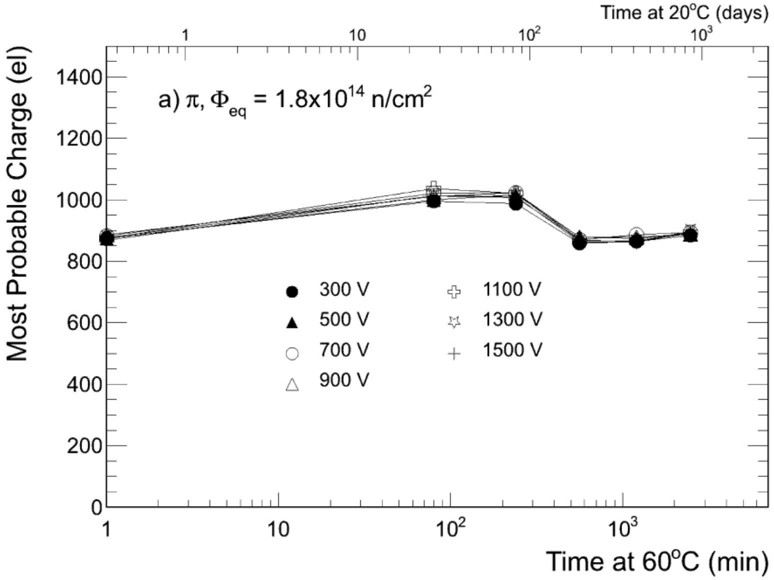
Detector current

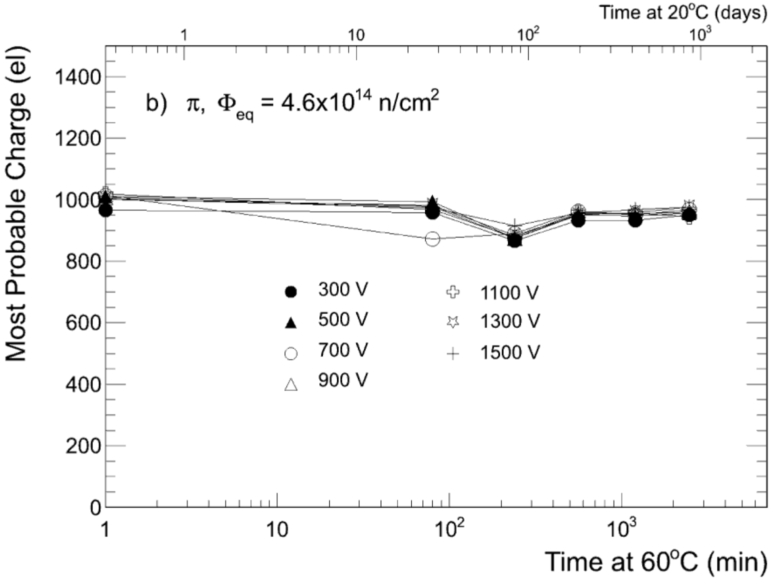


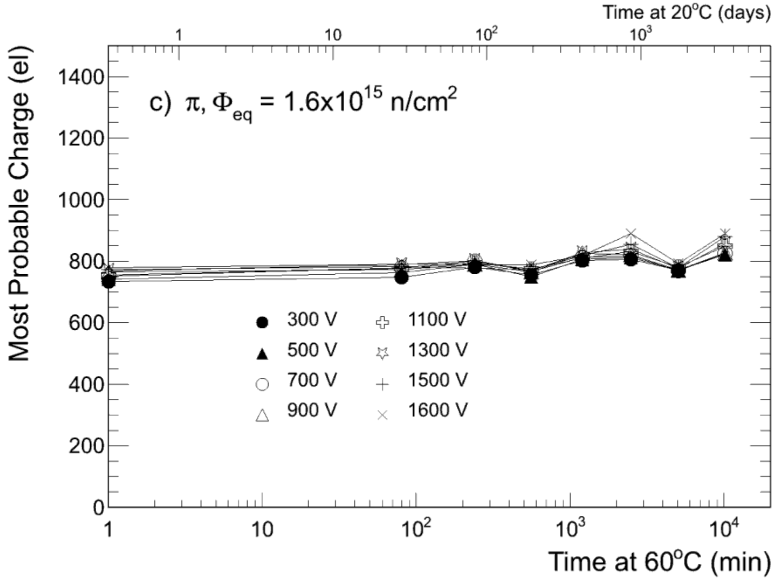
Near breakdown, unstable

Multiplication not as obvious for pions as for neutrons
→ higher N_{eff} (i.e. E_{max}) reached with neutrons

Noise



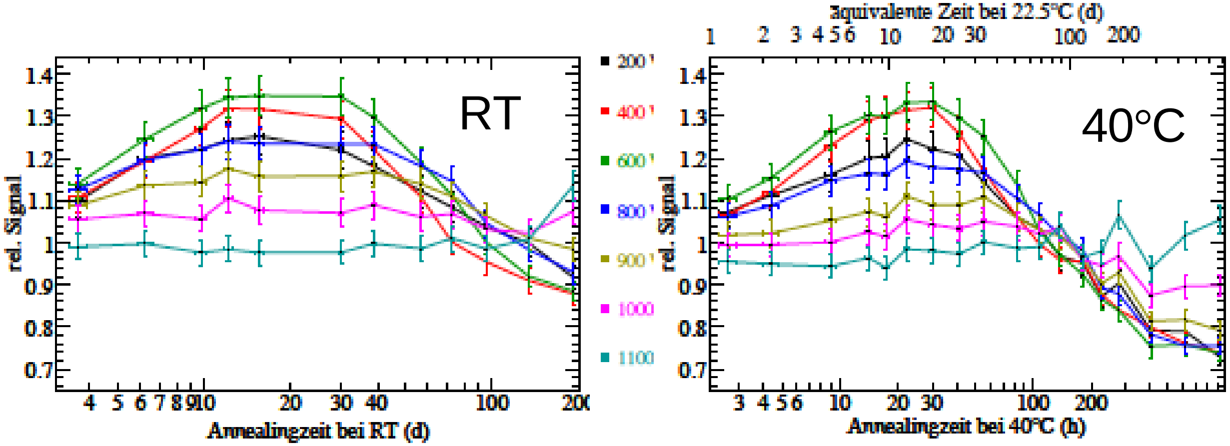


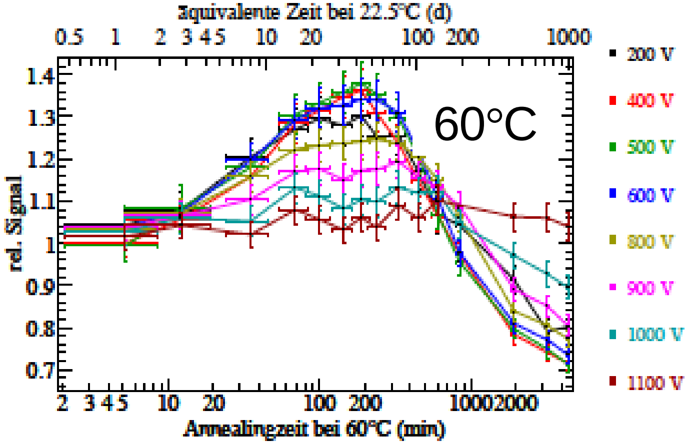


- no large multiplication
  ➔ no significant increase of noise

Relative signal

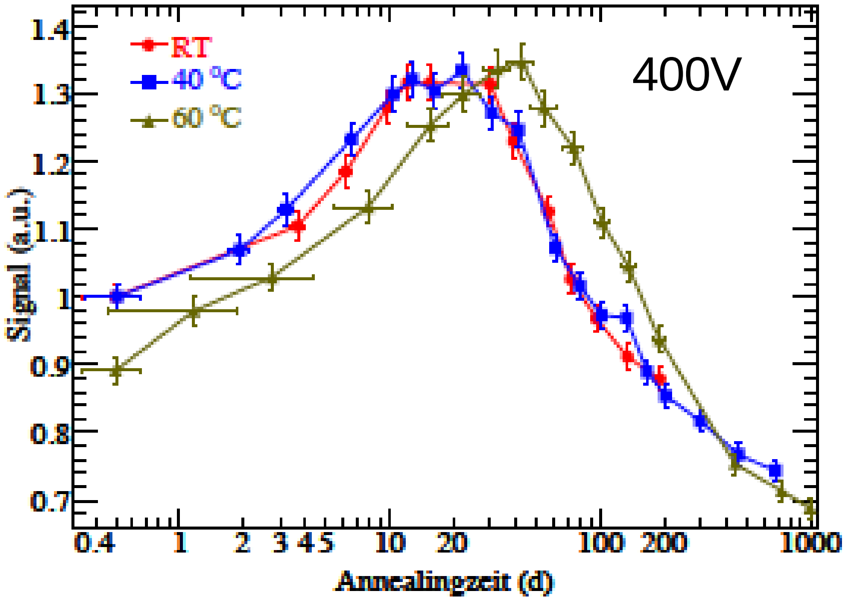
- Signal normalised to pre-annealing signal
  - N.B.: different time ranges in plots
- Beneficial and reverse annealing visible
- Higher bias voltages are less affected by annealing

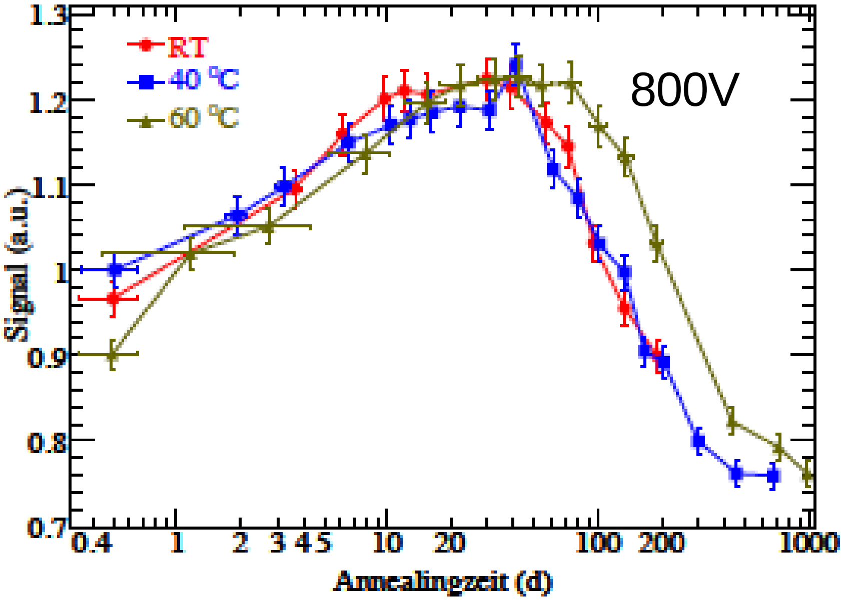




Scaling

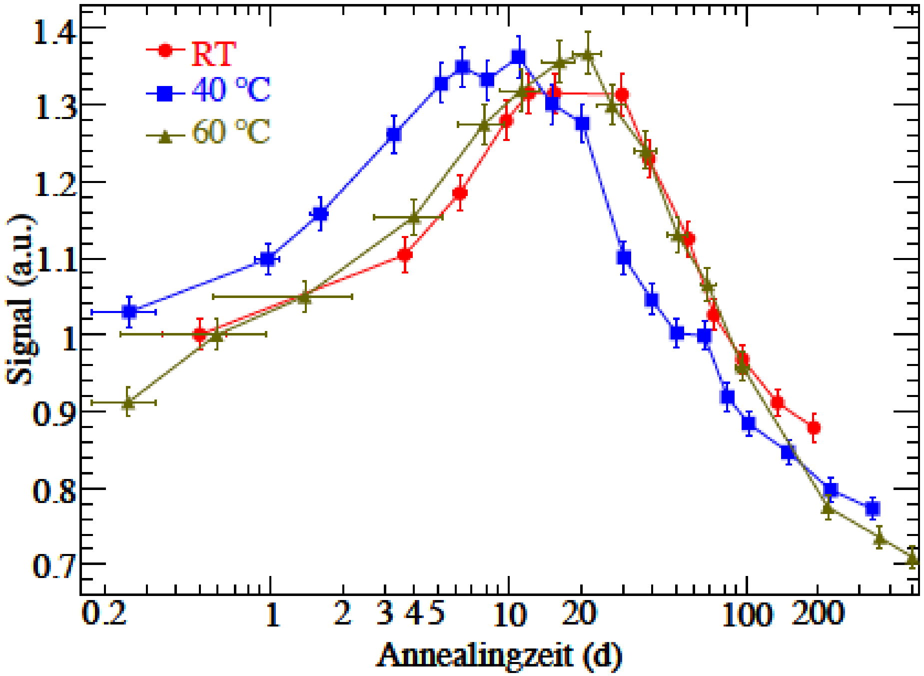
- **Comparison of signal evolution for RT, 40°, 60°**
- **RD48 Model does not scale 60° data correctly to RT**
- **Annealing at 60° appears “too slow”**
- **As observed by e.g. Gianluigi: scale factor appears too large**

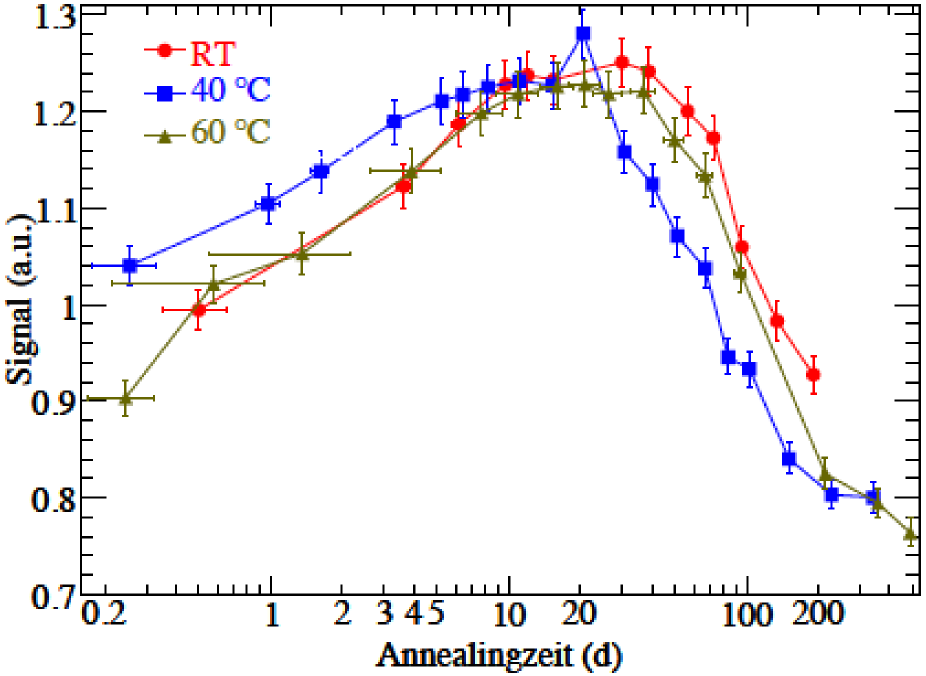




Scaling

- Signal comparison for RT, 40°, 60°
- As before, but scale factor reduced by ≈2
- Reasonable agreement between RT and 60° CCE data (as previously reported by G.C.)





Time Evolution

- Repeated measurement of signal spectra
  - Same sensor, same conditions, 7 days later
- Landau signal peak narrows with time (sensor stored cold)

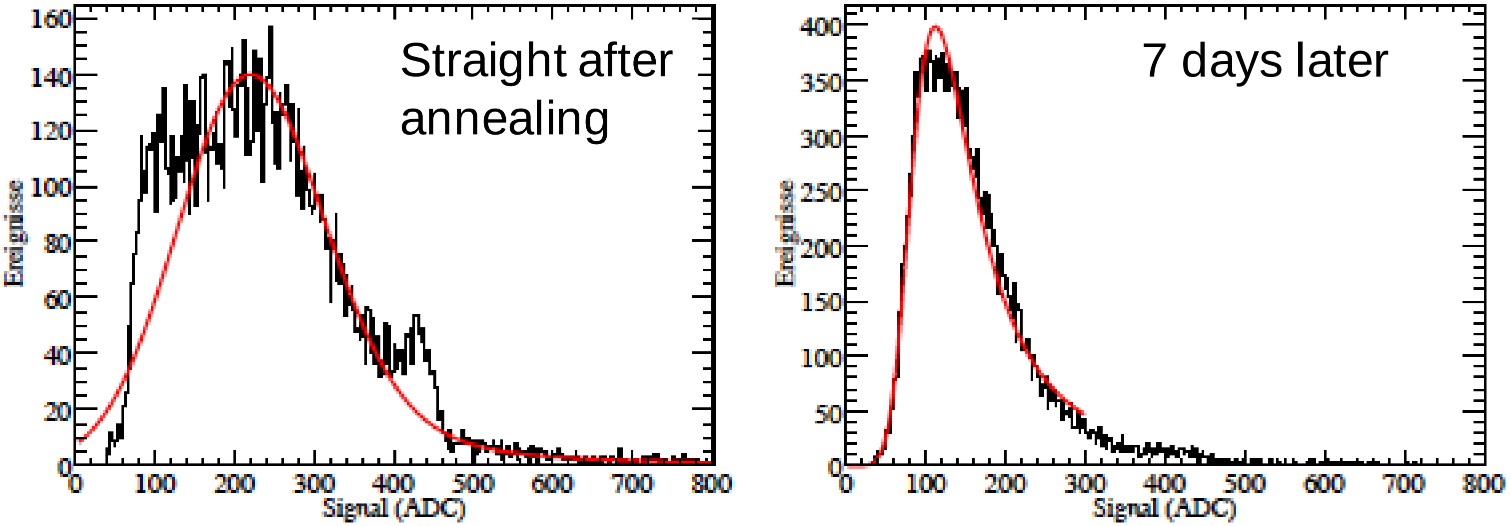


Abbildung 7.9: Signalspektrum von Messungen direkt nach der Wärmebehandlung (links) und 7 Tage später (rechts).

Charge trapping parameters

Was not parameterised at the TDR times.

G. Kramberger et al., NIMA, Volume 579, Issue 2, 1 September 2007, Pages 762-765

$$1/\tau_{eff\,\mathrm{e,h}}=\beta_{\mathrm{e,h}}(t,T)\Phi_{eq}$$

t_{min},		
Reactor neutrons	5.7±1	3.7±0.6
Fast charged hadrons	6.6±0.9	5.4±0.4

$$\beta_{\mathrm{e,h}}(t)=\beta_{0\mathrm{e,h}}\cdot \mathrm{e}^{-t/\tau}{}_{\mathrm{e,h}}+\beta_{\infty\mathrm{e,h}}\cdot(1-\mathrm{e}^{-t/\tau}{}_{\mathrm{e,h}})$$

	τ (min at)	$(\beta_0-\beta_\infty)/\beta_0$	E_{ta} (eV)
Electrons	650±250	0.35±0.15	1.06±0.1
Holes	530±250	-0.4±0.2	0.98±0.1

140 and 300 μm n-in-p Micron 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