Edge-TCT studies of heavily irradiated strip detectors

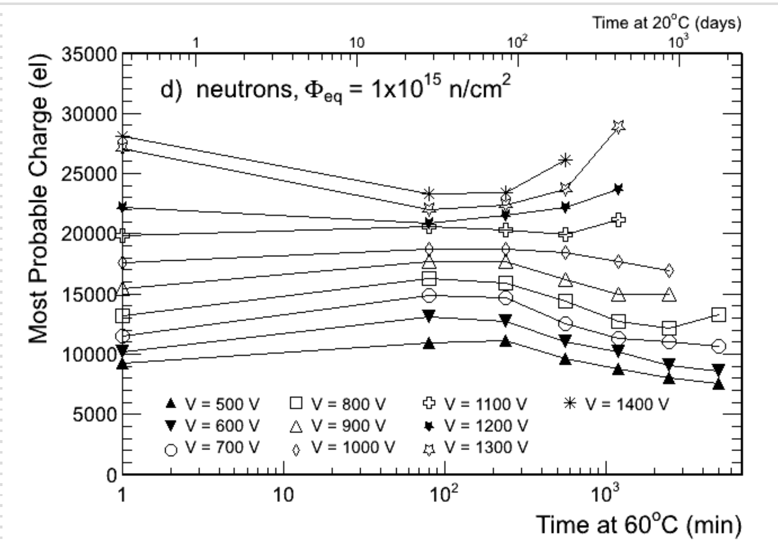
V. Cindro[1], G. Kramberger[1], A. Macchiolo[3], I. Mandić[1], M. Mikuž[1,2], M. Milovanović[1], P. Weigell[3], M. Zavrtanik[1]

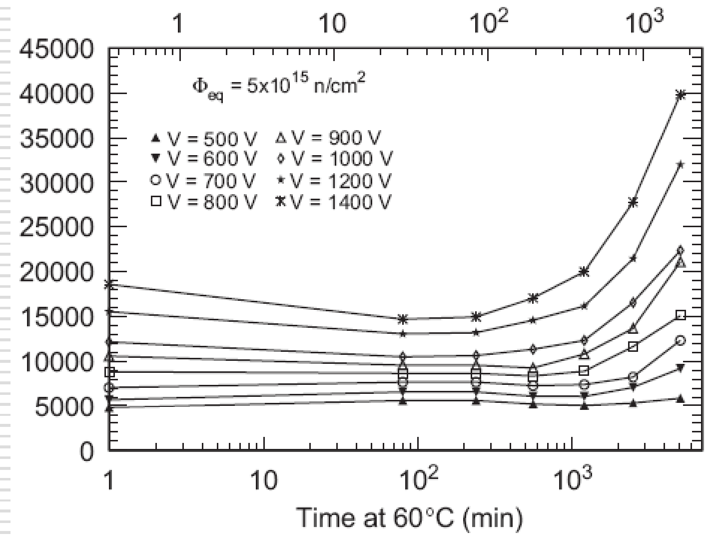
[1]Jožef Stefan Institute, Ljubljana, Slovenia
[2]Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
[3]Max Planck Institute for Physics, Munich, Germany

Outline

- Motivation
- Samples, irradiations, annealing procedure
- Experimental setup, extraction of charge collection and velocity profiles
- Results - evaluation of induced signals, CC, velocity and I-V profiles, influence of annealing
- Conclusions

Motivation





Taken from: I. Mandić et.al., NIM A 629 (2011) 101-105

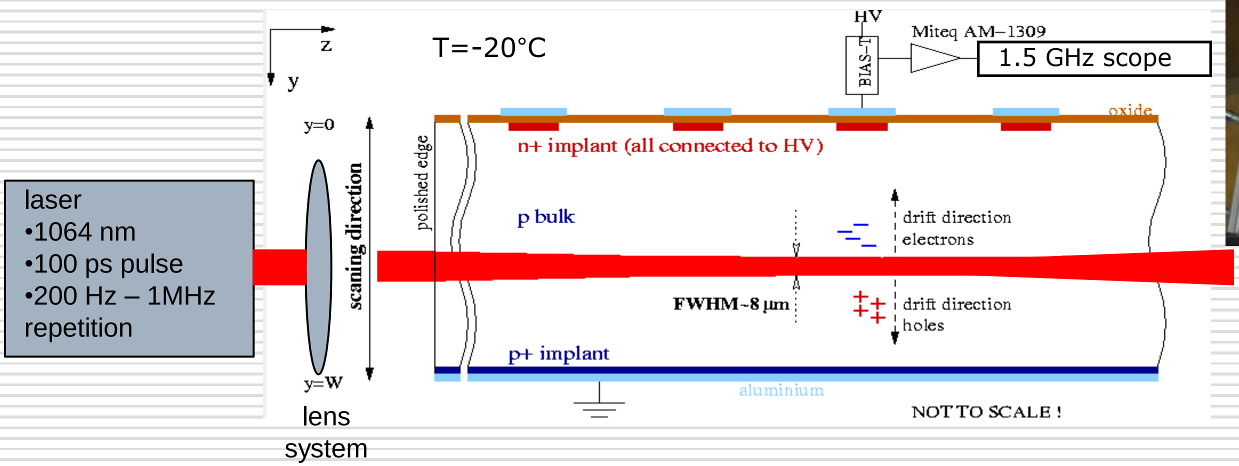
- Charge multiplication effects are observed in highly irradiated FZ p-type strip detectors after long annealing times. [*Liverpool, Freiburg, IJS*]
- The idea is to examine where/when impact ionization takes place inside the detector and how multiplication affects the total charge collected.

Samples, irradiation and the annealing procedure

Sample	Fluence	Annealing
1) HPK (ATLAS-07 run) 1x1 cm^2, **300 μm** thick Material/type: FZ, p-type initial V_{fd}~190 V	$\Phi_{eq}=1\cdot10^{16}$ cm^{-2} (Fluence history: 1,2,5 $\cdot10^{15} cm^{-2}$ with annealing up to 80min.)	Sequential steps (0,10,20,40,80,160,320, 640,1280,2560,5120 min) at 60ºC up to a cumulative time of 10240 min.
2) MPP/HLL (provided by MPI) 1x1.2 cm^2, **150 μm** thick, bonded on low resistivity handle wafer Material/type: FZ, p-type initial V_{fd}~82 V	$\Phi_{eq}=5\cdot10^{15}$ cm^{-2}	Sequential steps at 60ºC up to a cumulative time of 20480 min

- Irradiations performed with 1MeV reactor neutrons at TRIGA (JSI, Ljubljana)
- At each annealing step, measurements of collected charge and leakage current performed at bias voltages of up to 1000V.
- Annealing performed with the sample mounted inside the setup
  - Stable position/laser (the same spot illuminated each time)
  - Sample temperature stabilized to less than 1°C

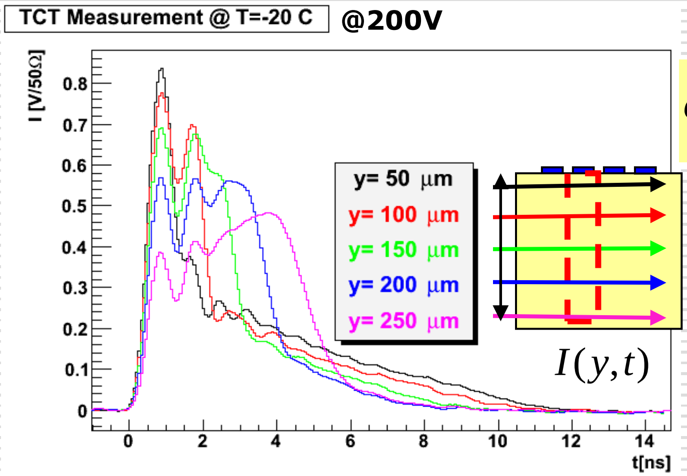
Edge-TCT setup



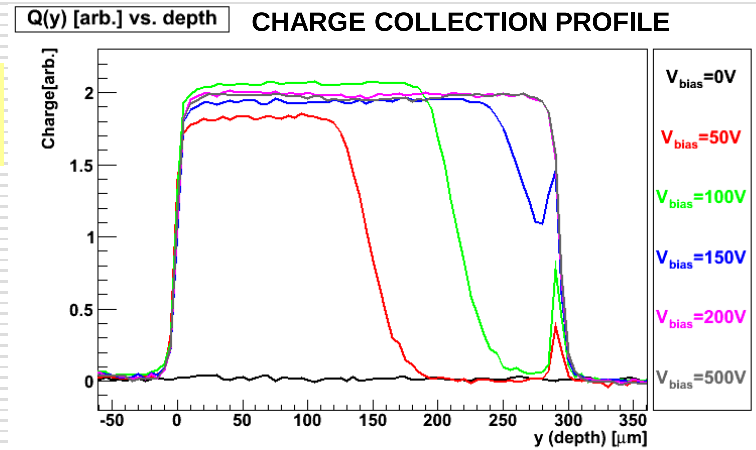
detectors on a Peltier cooled support in dry air atmosphere (down to -20°C)

- Position of e-h generation controlled by 3 sub-micron moving tables (x,y,z)
- The amount of injected charge and frequency can be controlled (laser tune and frequency=200Hz kept constant during these measurements)
- Absolute charge measurements are very difficult to achieve, therefore arbitrary units used for collected charge.

Charge collection and velocity profiles
HPK, non-irradiated



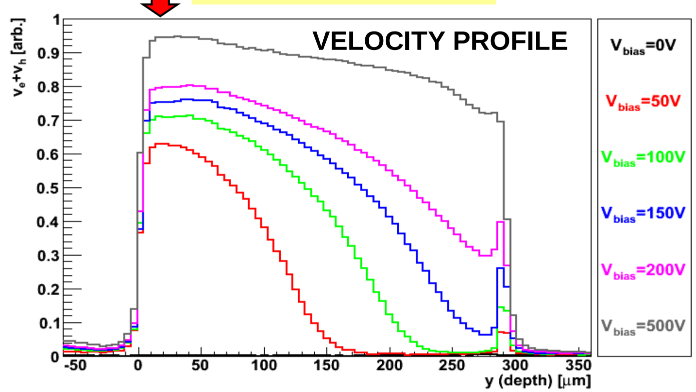
$$Q(y)=\int_0^{25ns} I(y,t)\,dt$$

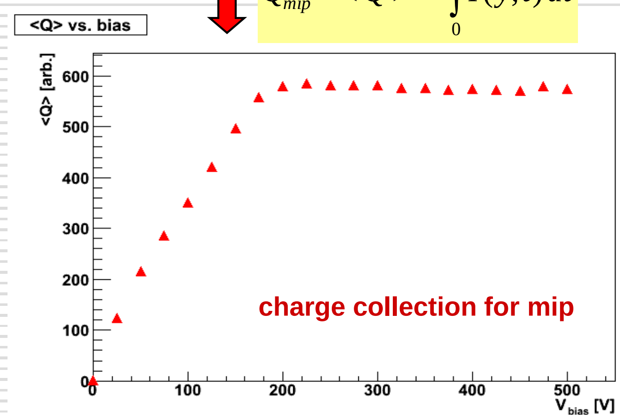


$$I(y,t\sim 0)\propto v_e+v_h$$

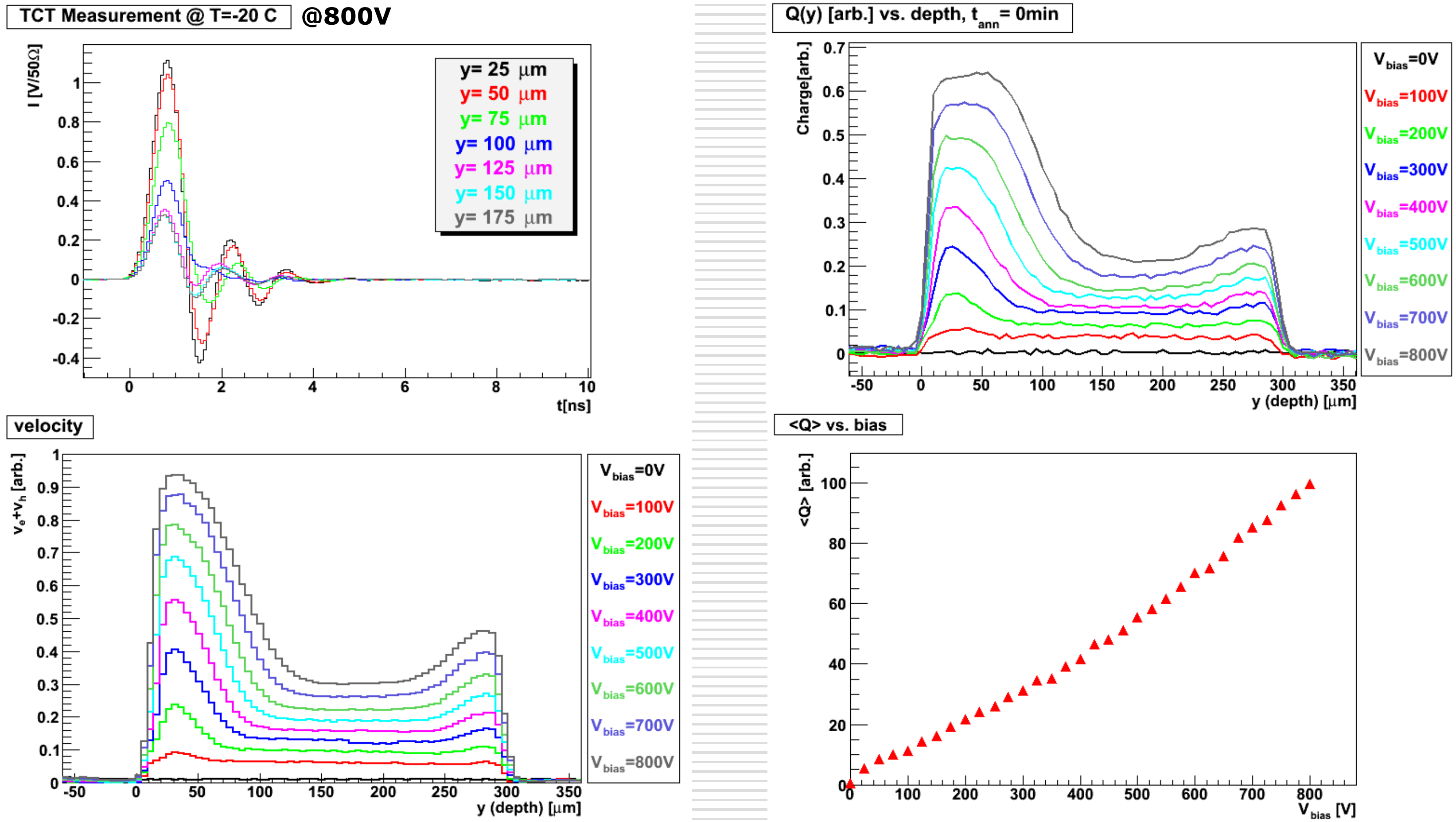
V_{fd}~190V

$$Q_{mip}\propto\ <Q>=\int_0^{25ns} I(y,t)\,dt$$

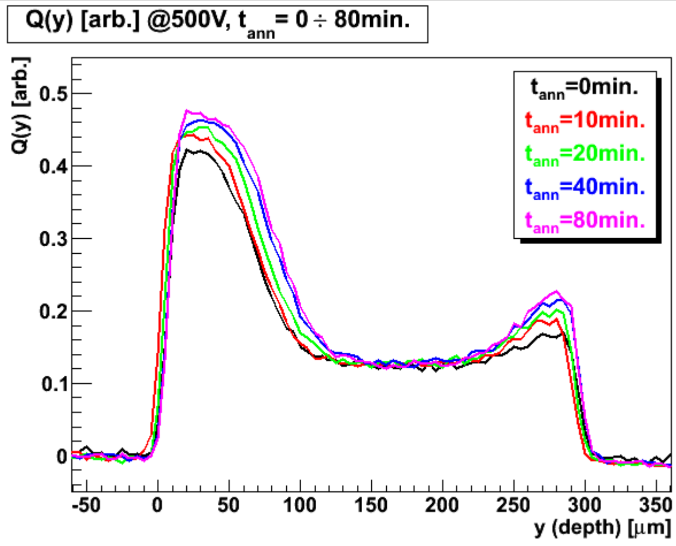


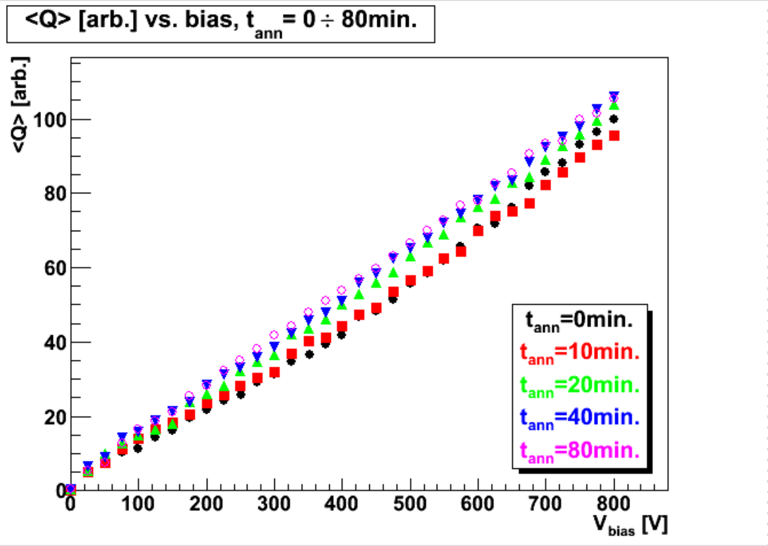


HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, no annealing



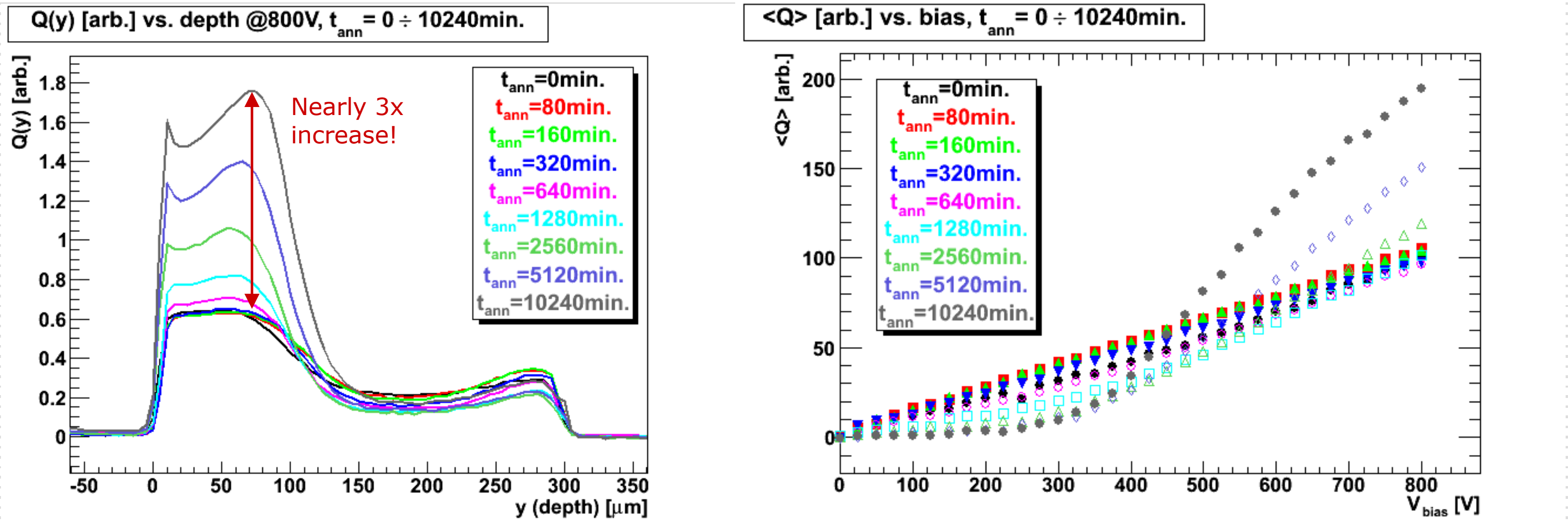
HPK – $\Phi_{eq}=1\cdot10^{16}\ n/cm^2$, $t_{ann}=0 \div 80$ min





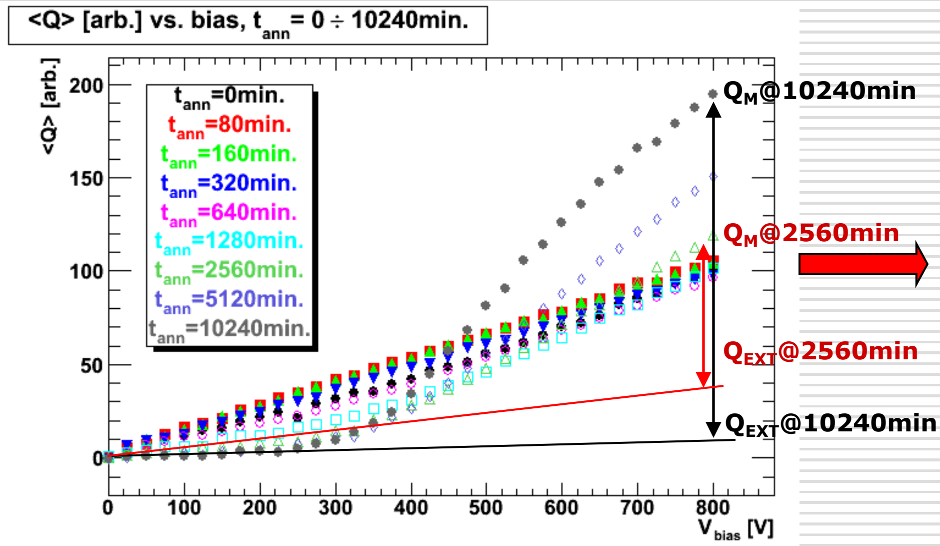
- Beneficial annealing (after 80 min at 60°C) of space charge and trapping times of electrons observed and found for both junctions.
- The annealing effect is not very significant, though it should be noted that annealing was already taking place during previous irradiation steps.

HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, $t_{ann}=0 \div 10240$ min

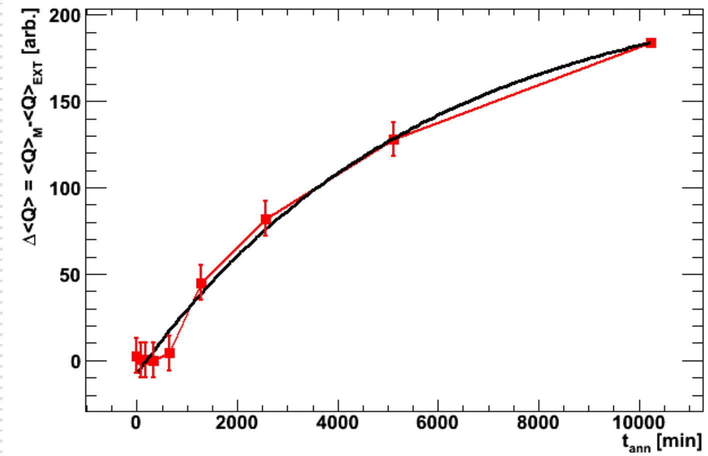


- During long-term annealing, up to a total of 10240 min. at 60ºC, a nearly threefold increase in CC in the region near the strips (highest *E*).
- Increase due to space charge concentration rising near the n$^+$-p junction with the annealing, leading to a substantial increase of *E* (*E*>~12V/µm) where the impact ionization takes place (between 320 and 640 min).
- If the voltage and thus *E* is not large enough to start impact ionization, CC decreases due to long-term (reverse) annealing.

HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, $t_{ann}=0 \div 10240$min.

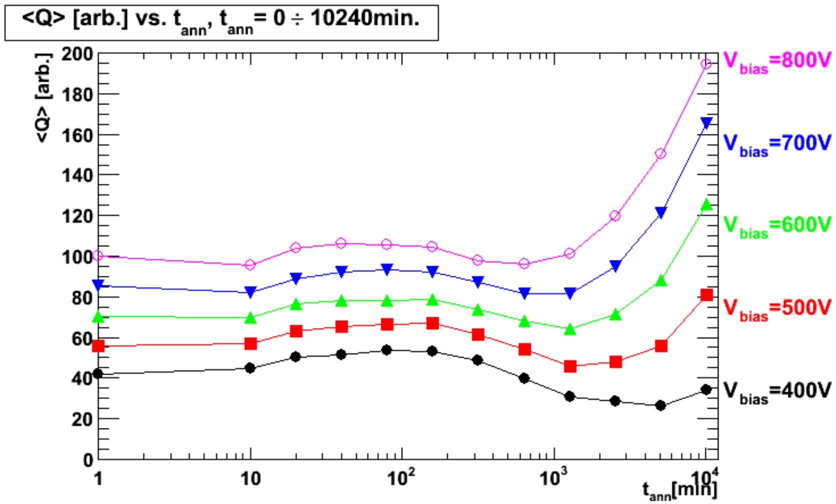


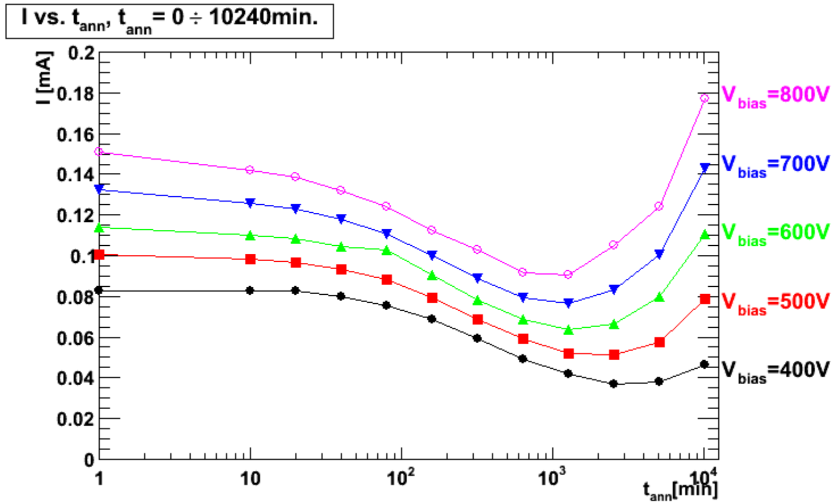
Only an approximate method!



- The contribution of charge multiplication to CC/<Q> was estimated by subtracting the measured values of CC at 800V with extrapolated values from the lower voltage CC curves linear fit to 800V ($\langle Q\rangle_M - \langle Q\rangle_{EXT}$) .
- By plotting the dependence of CC contribution on annealing time and fitting the values with $1-\exp(-t/\tau_Y)$, a time constant of 3000÷5000 min is obtained.
- Time constants for ΔN_{eff} and $\Delta\langle Q\rangle$ are the same order of magnitude, supporting the assumption that N_{eff} increase causes greater impact ionization.

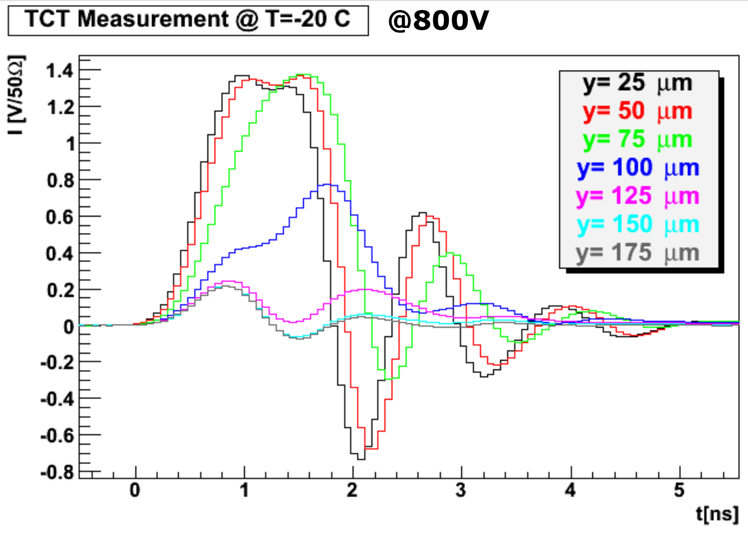
HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, $t_{ann}=0 \div 10240$min.

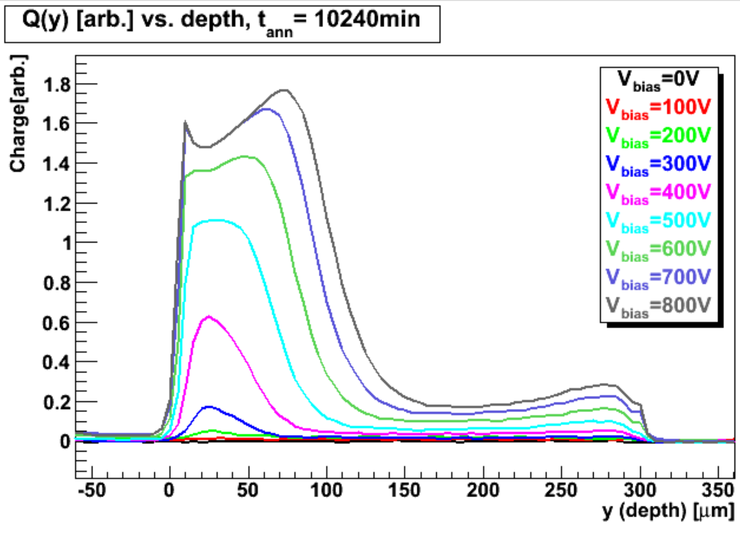




- The initial beneficial effect of annealing clearly noticed up to ~100min, later drop due to long term annealing effects, until the onset of multiplication.
- Charge multiplication noticed even at 400V after the final annealing step!
- Strong correlation with the leakage current – beneficial effect until the onset of multiplication at 1000min, following the pattern of increasing CC.
- Charge multiplication is also clearly recognized in the induced current pulse shapes measured at different depths.

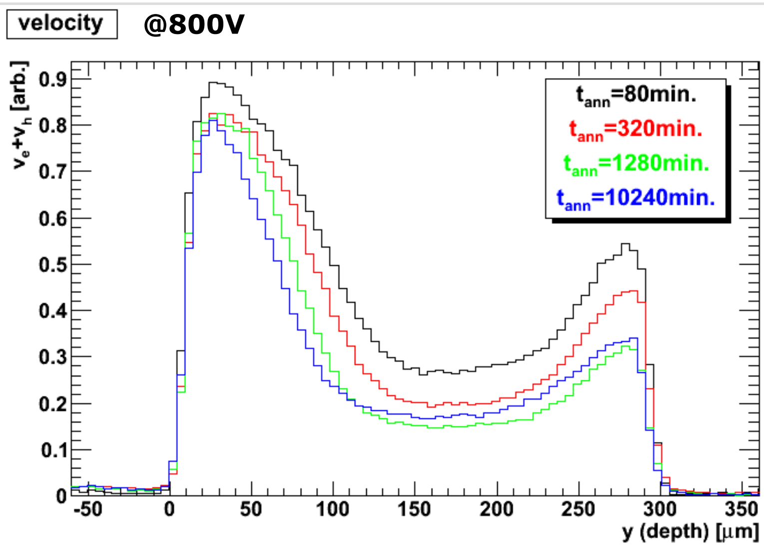
HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, $t_{ann}=0 \div 10240$min.

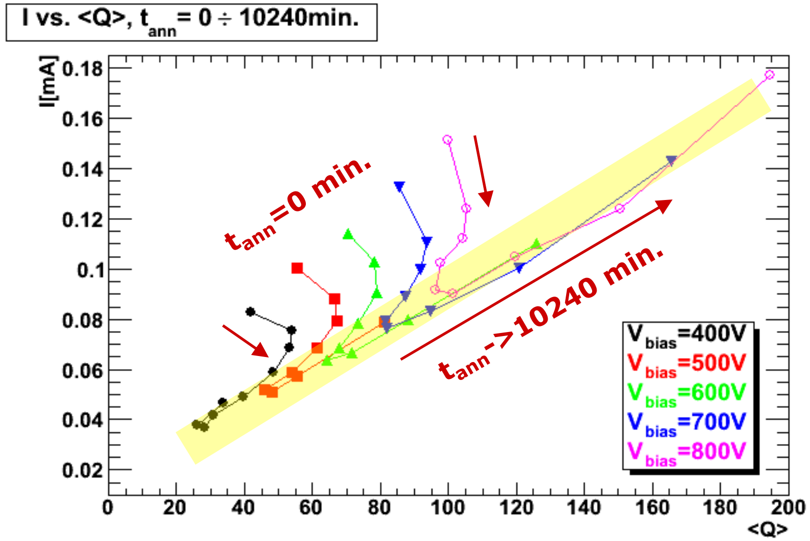




- The first peak, associated with the initial drift of primarily generated carriers (from the laser) widens up to a point where the second peak, coming from the multiplied carriers, becomes more apparent and the dominant one.
- This can also be observed in CC profiles for different bias voltages: as the bias increases, *E* becomes large enough to invoke multiplication over a larger area inside the detector.

HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2, $t_{ann}=0 \div 10240$min.



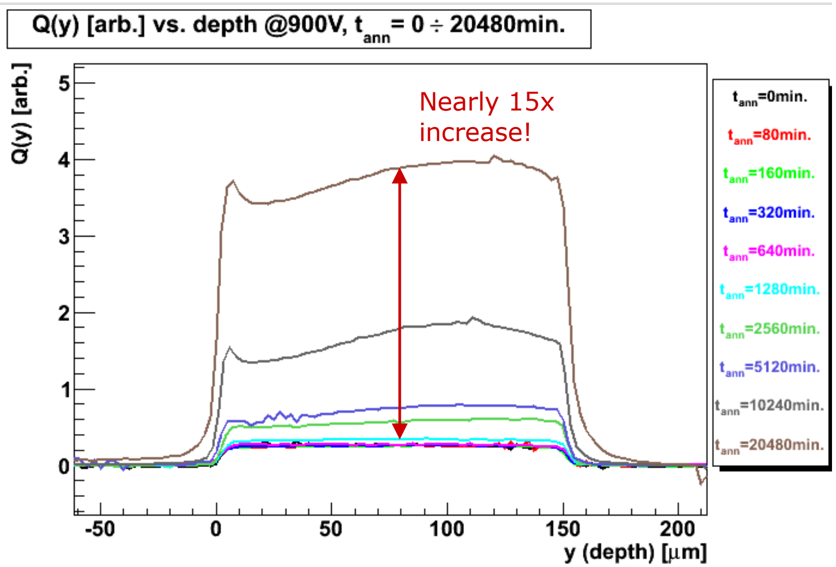


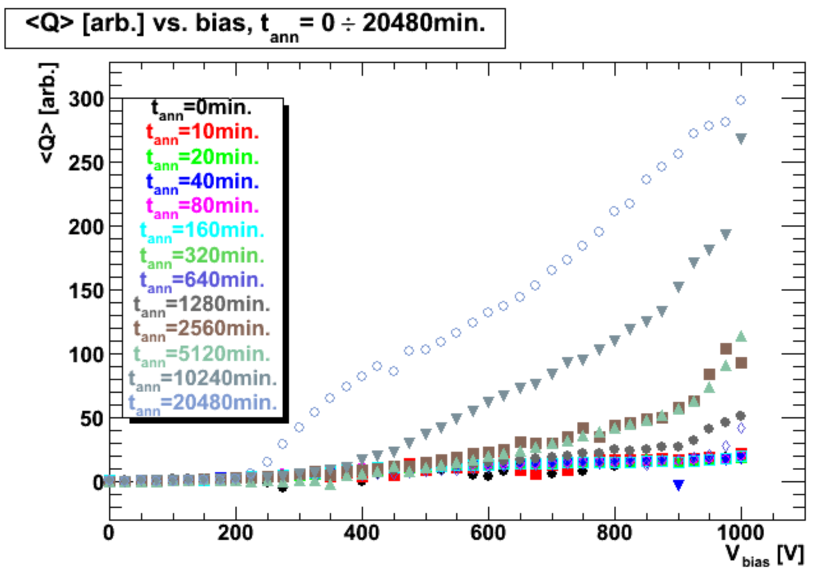
- The velocity profile points to the reduction of the high *E* region in the detector with annealing time. The drift velocity close to the strips is almost saturated, while in the rest of the detector is smaller for longer annealing times, implying that *E* close to the strips must increase.
- Confirmation of assumed space charge development with LT annealing.
- The correlation between the current and CC is near linear => thermally generated carriers undergo the same effect.

MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, $t_{ann}=0 \div 20480$min

(150 μm)

Thanks to: Philipp Weigell and A. Macchiolo, MPI

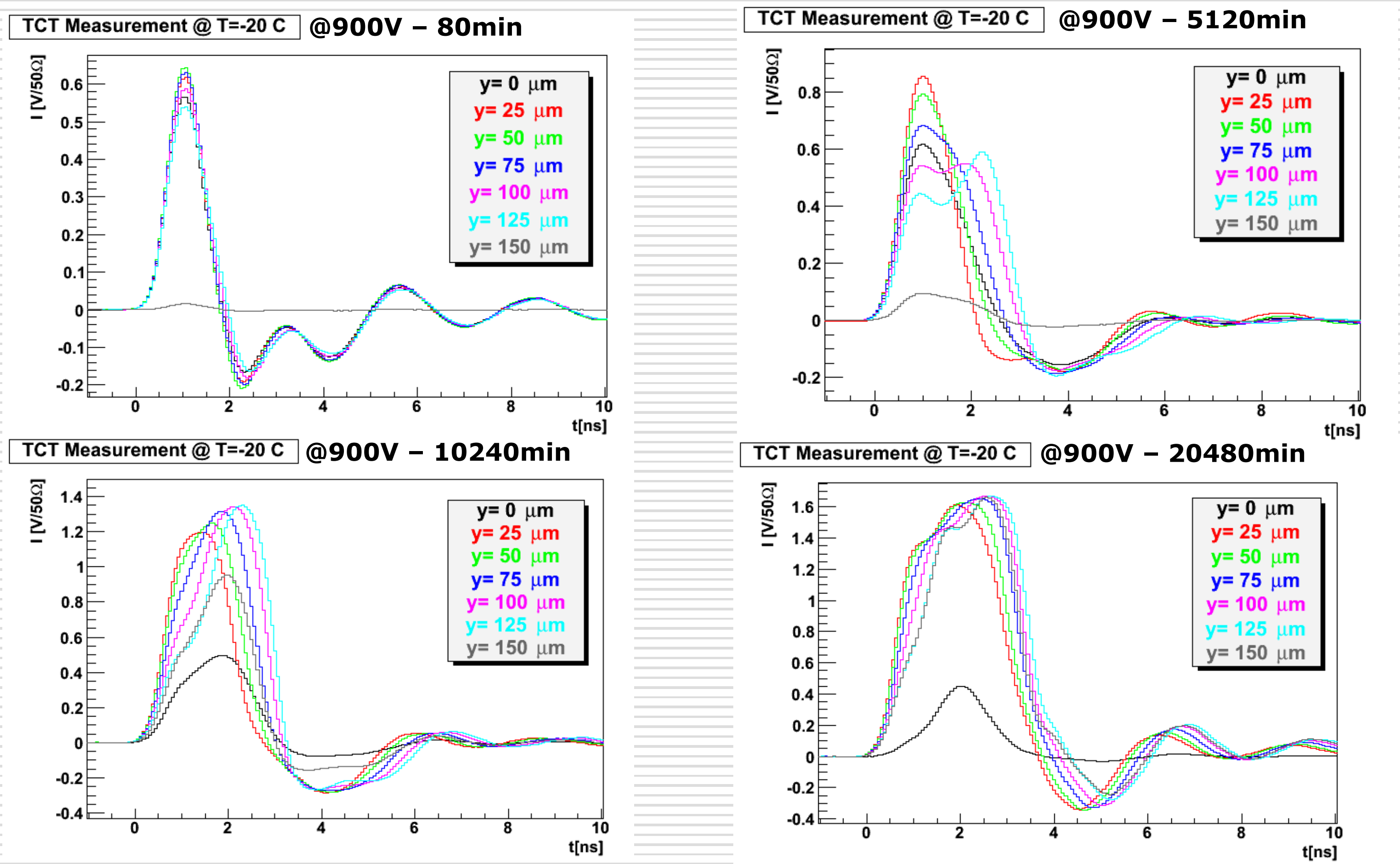




- Initial $V_{fd}\approx$82V.
- Estimated V_{fd} after irradiation and 80min of annealing: ~1500V.
- Charge multiplication contribution to CC ~15x after 20480min! (the detector still under study – currently annealing to 40960min!)
- Charge multiplication noticed even at 250V after the final annealing step!

MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, $t_{ann}=0 \div 20480$min (150 µm)

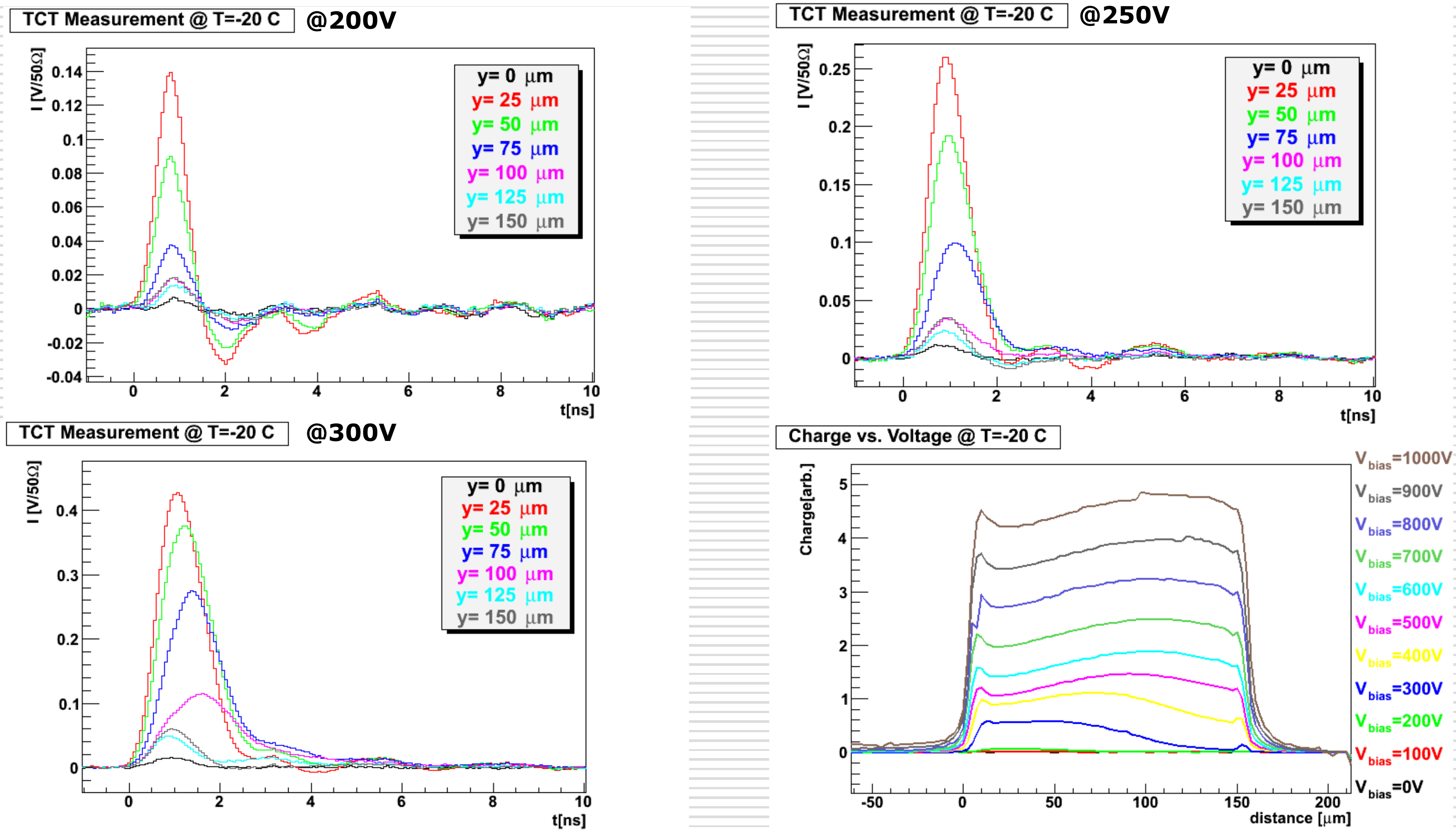
Thanks to: Philipp Weigell and A. Macchiolo, MPI



MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, t_{ann} = 20480 min

(150 µm)

Thanks to: Philipp Weigell and A. Macchiolo, MPI



MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, $t_{ann}=0 \div 20480$min

(150 µm)

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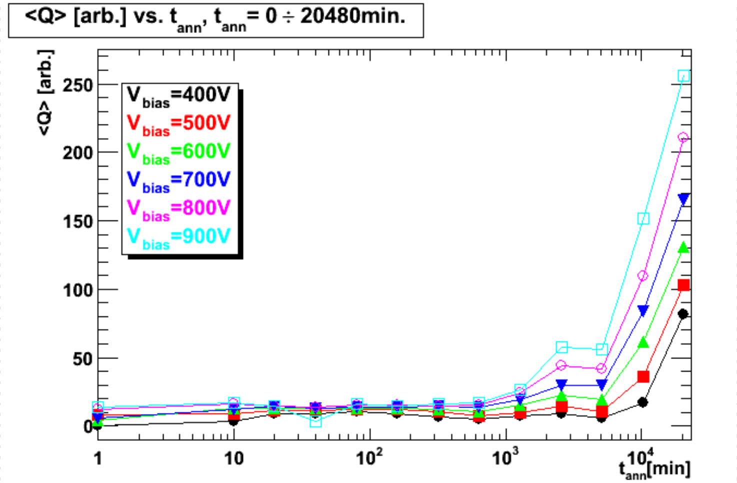
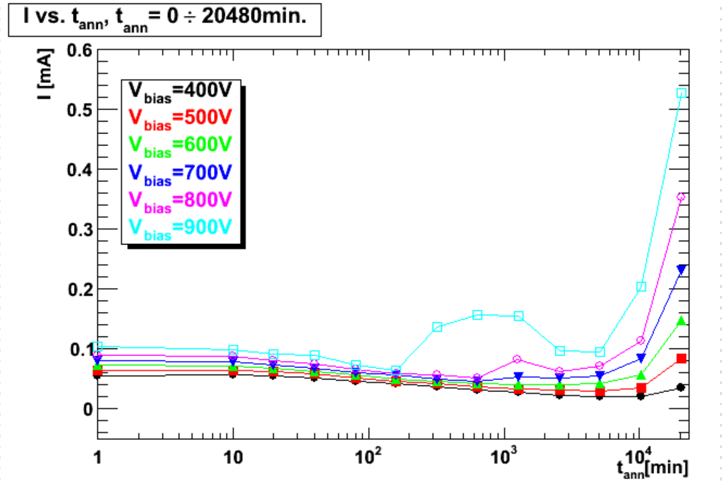
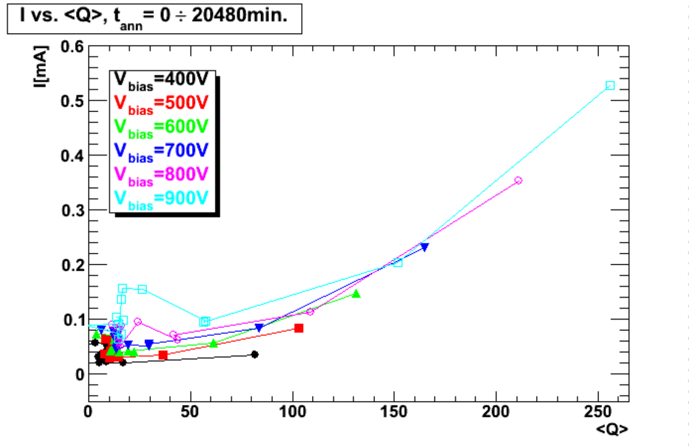
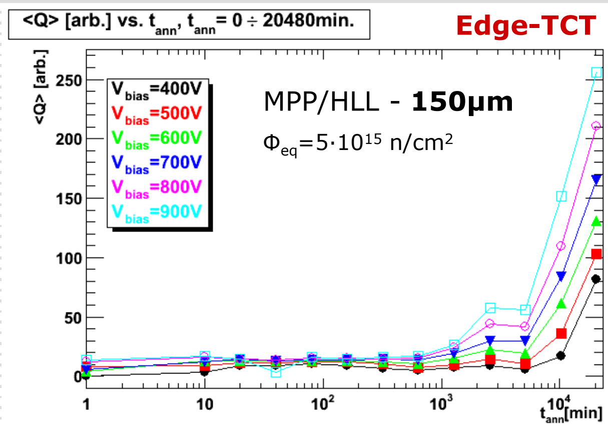
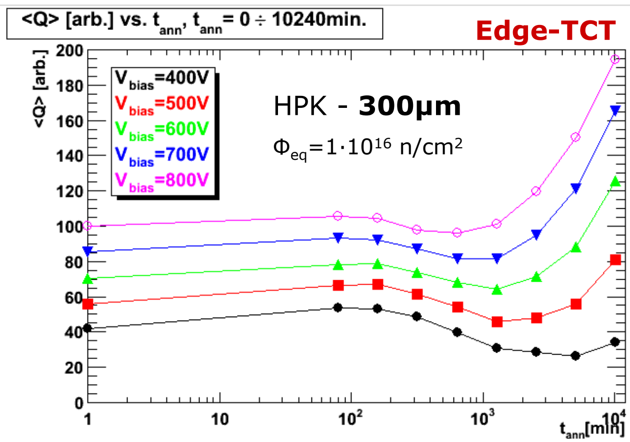


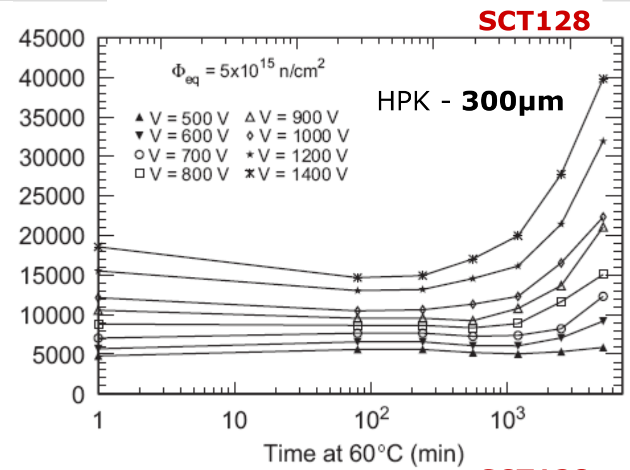


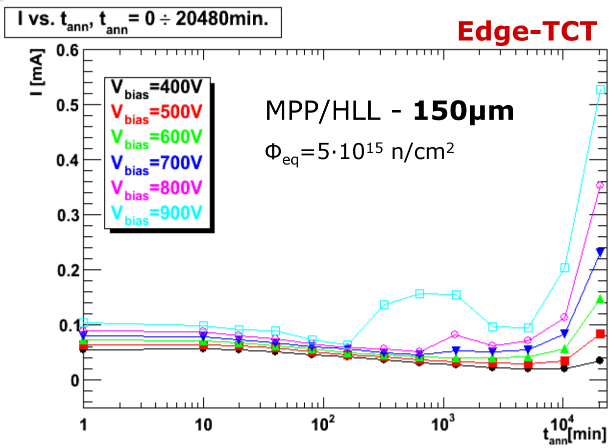


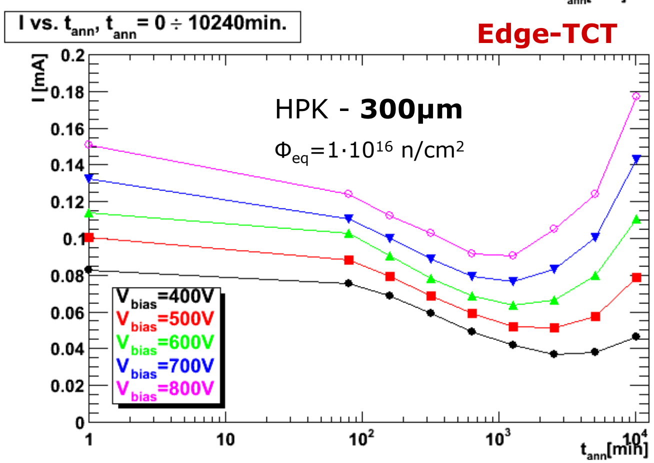
MPP/HLL - $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, HPK – $\Phi_{eq}=1\cdot10^{16}$ n/cm^2 - Comparison with HPK - $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, measured with SCT128 by I. Mandic -

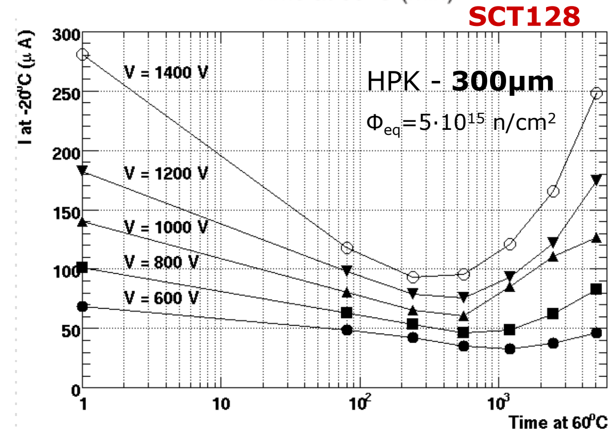








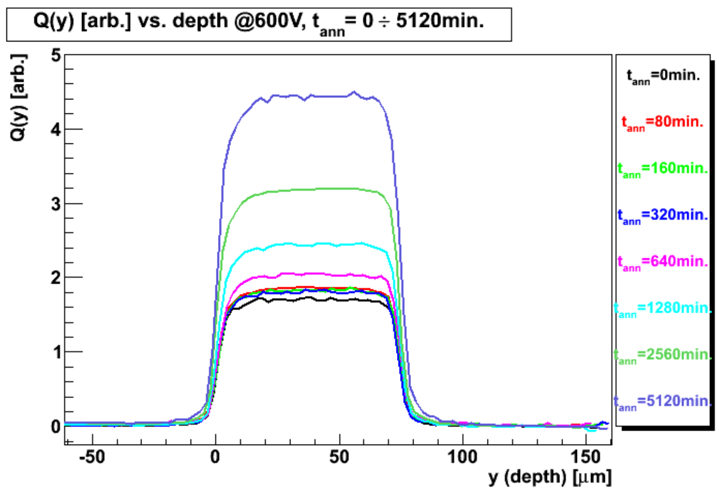


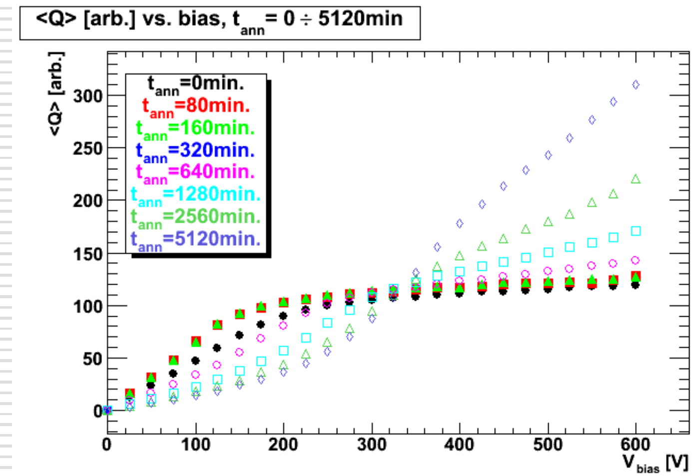


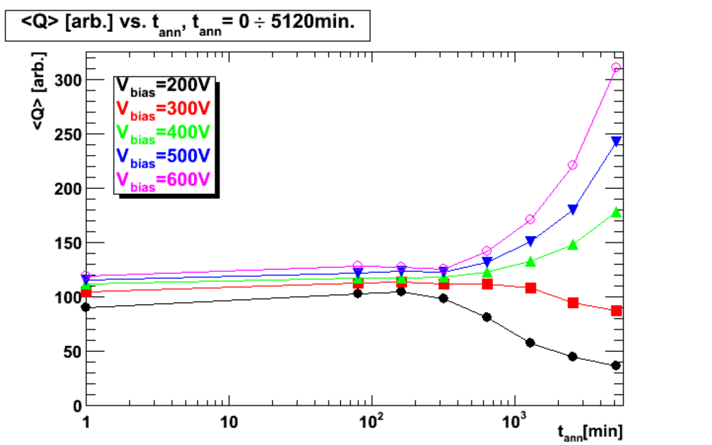
MPP/HLL – $\Phi_{eq}=5\cdot10^{15}$ n/cm^2, $t_{ann}=0 \div 20480$min

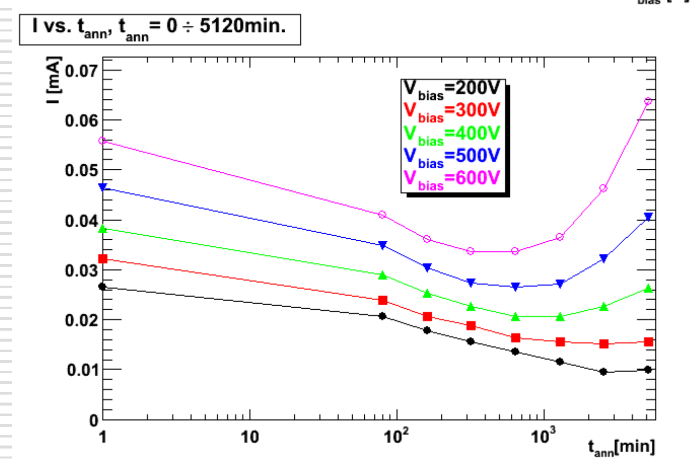
(75 μm)

Thanks to: Philipp Weigell and A. Macchiolo, MPI









Conclusions

- Charge collection efficiency increases with long-term annealing for highly irradiated ($\Phi_{eq} \geq 5 \cdot 10^{15}$ n/cm^2) p-type strip detectors due to increased space-charge concentration, hence the electric field in the strip region, consequently leading to the effect of multiplication even at voltages as low as a few hundred volts.
- Long term annealing shifts the multiplication mode of operation towards lower bias voltages, because it increases the space charge concentration near the n^+-p junction.
- Even at high fluences, the detector remains active throughout the whole volume.
- The leakage current shows strong, near linear correlation with the charge multiplication.
- Measurements of Edge-TCT and SCT128 are compared and validated.

Thank you for your attention!