Investigation of velocity profile and charge collection in heavily irradiated detectors by Edge-TCT

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Edge-TCT

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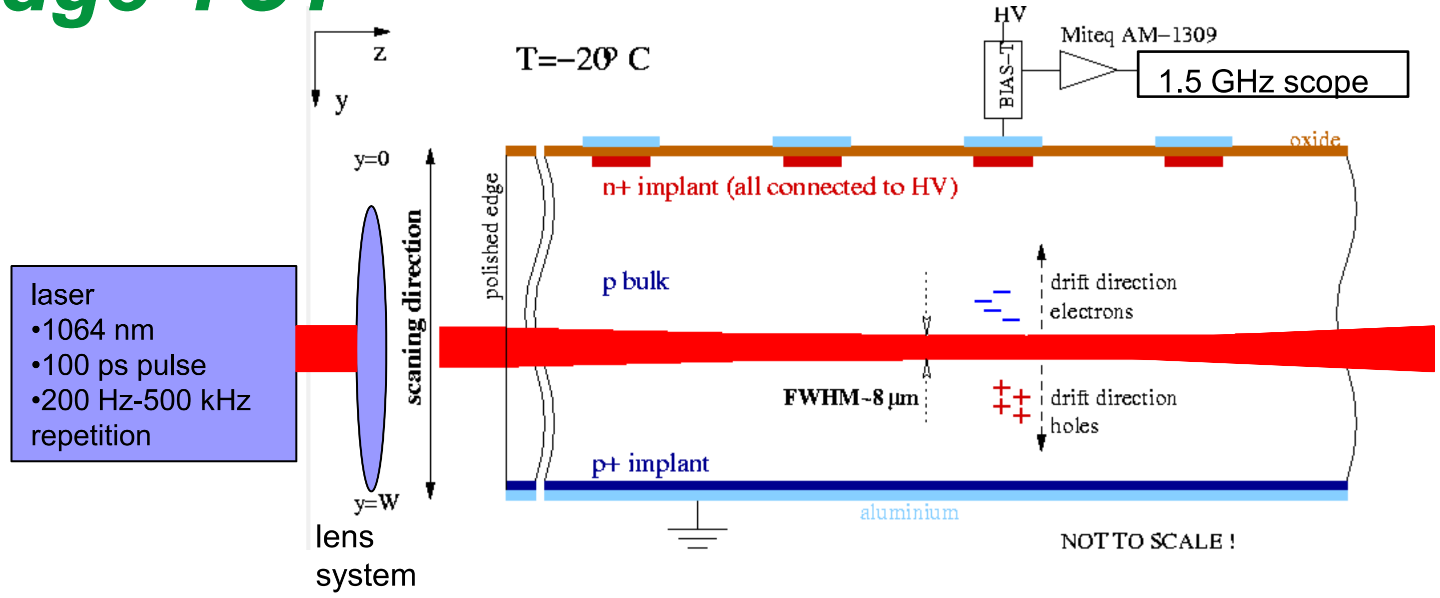


laser
- 1064 nm
- 100 ps pulse
- 200 Hz-500 kHz repetition

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

Advantages (compared to pixel test beam – grazing technique):

- Position of e-h generation can be controlled by 3 sub-micron moving tables (x,y,z)
- The amount of injected e-h pairs can be controlled by tuning the laser power
- Easier mounting and handling
- Not only charge but also induced current is measured – **a lot more information**

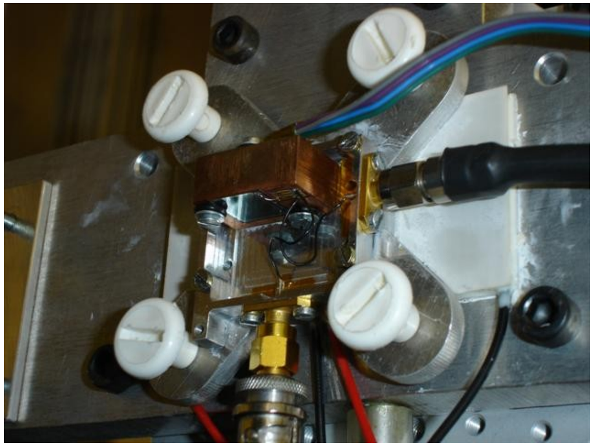
Drawbacks:

- Light injection side has to be polished to sub-micron level to have a good focus – depth resolution
- It is not possible to study charge sharing due to illumination of all strips
- Absolute charge measurements are very difficult

Samples

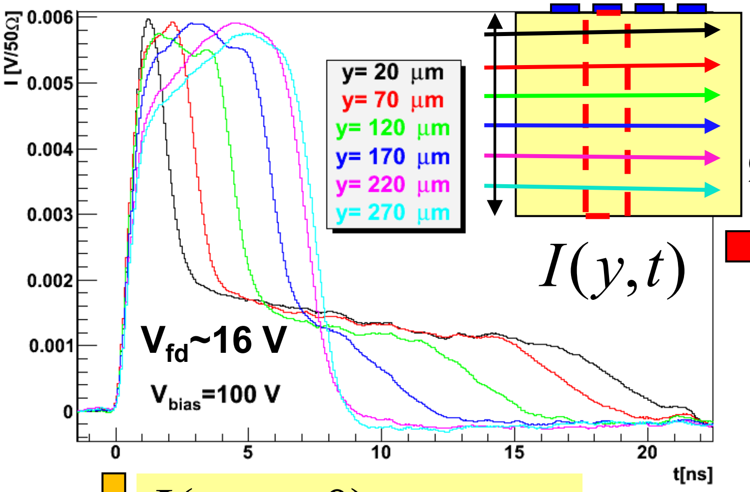
Samples	Fluences	Annealing
Micron (RD-50 run) 1x1 cm^2, 300 μm thick, 80 μm pitch p-type isolation: p-spray isolation initial V_{fd}~16 V	non-irradiated $5\cdot10^{14}$ cm^{-2}	80 min @ 60ºC
HPK (ATLAS-07 run) 1x1 cm^2, 320±20 μm thick, p-type isolation: p-stop initial V_{fd}~190 V	non-irradiated (100 μm pitch) $1\cdot10^{15}$ cm^{-2} (100 μm) 1,2,5,$10\cdot10^{15}$ cm^{-2} (75 μm)	sequential steps at 60ºC up to 80 min (0,10,20,40 min)

✓Neutron irradiated samples
✓Measurements done at -20ºC
✓Annealing done with samples mounted in the setup to ensure that the same spot in the detector is illuminated at different annealing times



G. Kramberger, "Investigation of electric field in heavily irradiated detectors by Edge-TCT", 6th Trento workshop on advanced silicon radiation detectors, 2-4.3.2011, Trento, Italy

Charge collection and velocity profiles



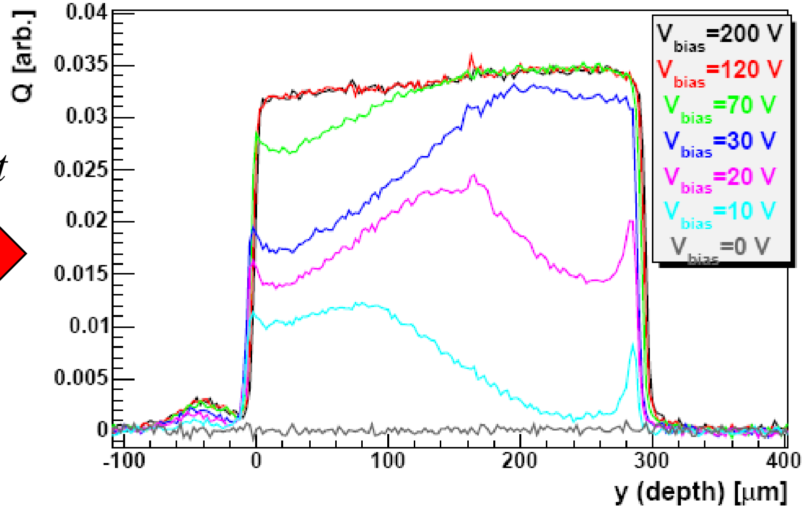
$I(y,t)$

V_{fd}~16 V

V_{bias}=100 V

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

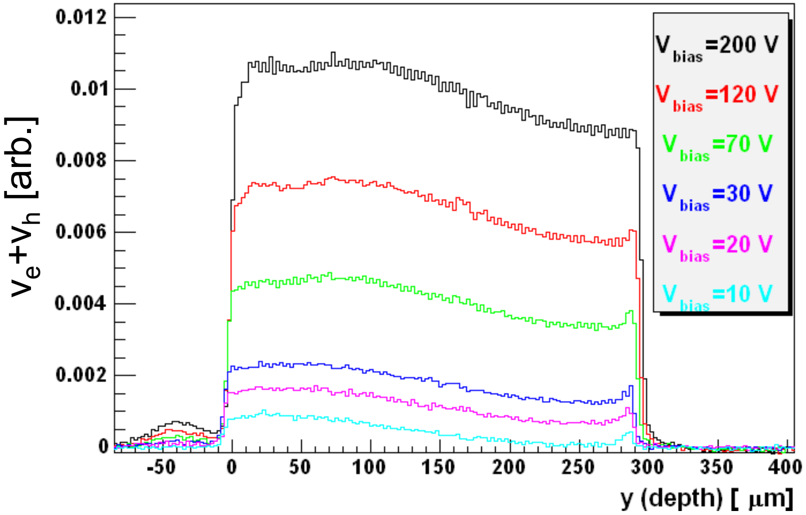
CHARGE COLLECTION PROFILE

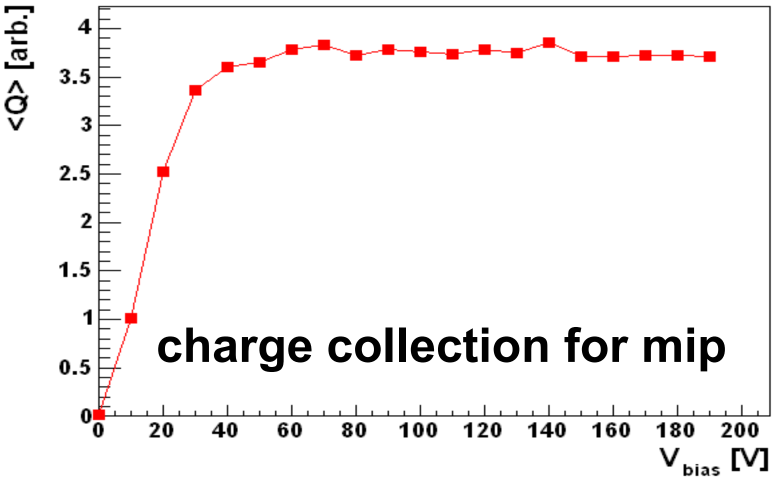


$$I(y,t\sim 0)\propto v_e+v_h$$

$$Q_{mip}\propto \langle Q\rangle=\int_0^W Q(y)\,dy$$

VELOCITY PROFILE





charge collection for mip

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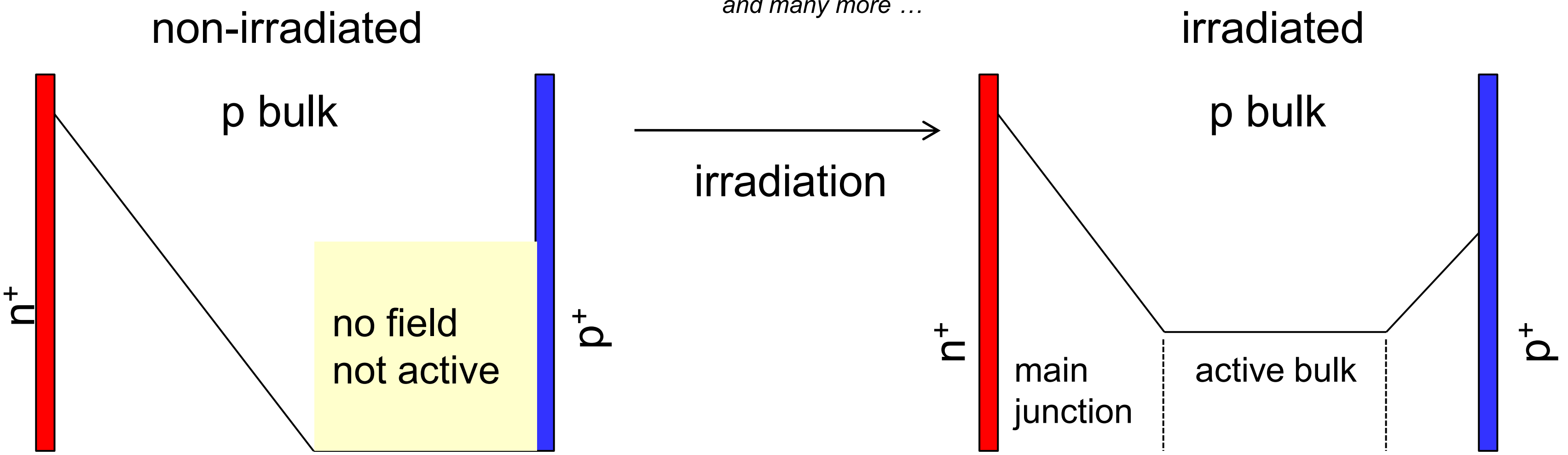
Electric field profile

V. Eremin et al., NIM A360 (2004) 458, NIM A535 (2004) 622.
D. Menichelli et al., NIM A426 (1999) 135., I. Mandic et al., NIM A512 (2004) 343
and many more …



non-irradiated

irradiated

irradiation

p bulk

n^+

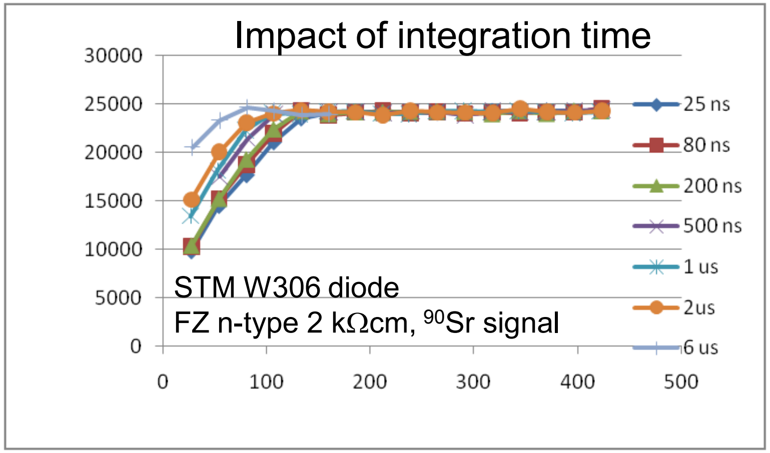
p^+

no field
not active

main
junction

active bulk

- •active region is only the depleted part (providing the integration time is short LHC like)
- •weighting field determined by the border of the depleted region (depends on resistivity)

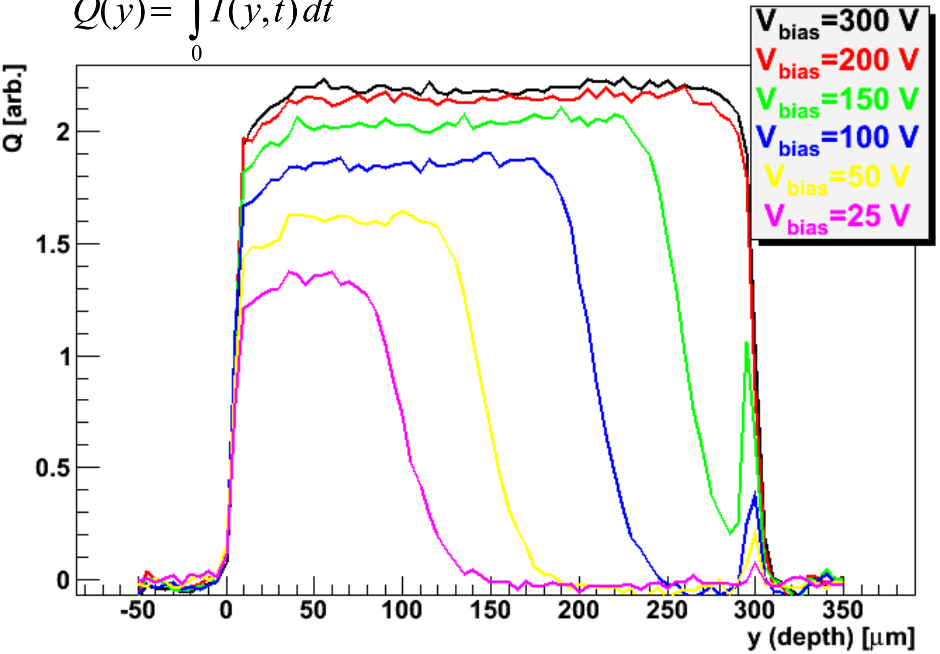


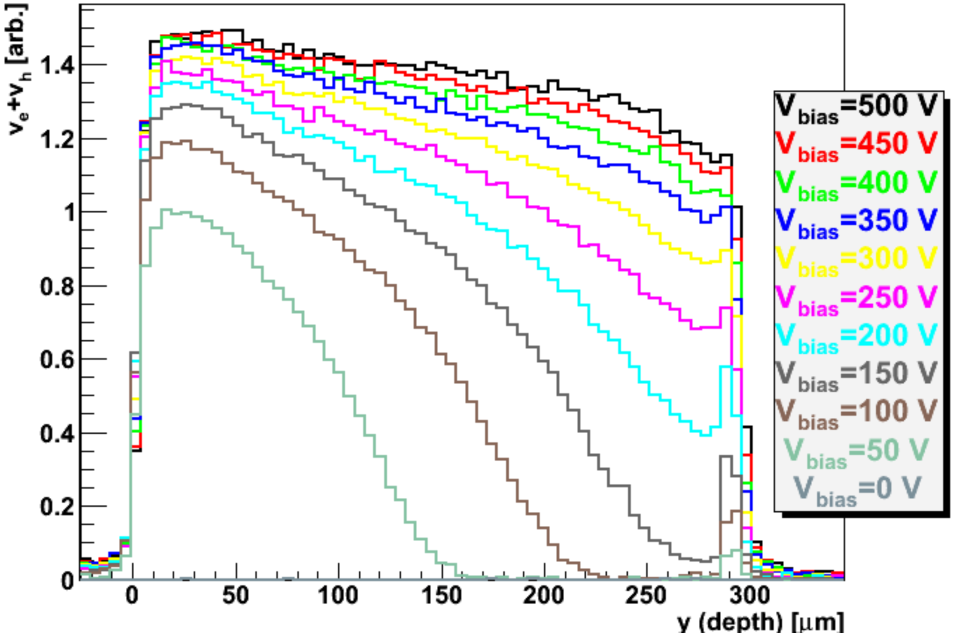
- •main junction determined by negative space charge
- •the field is present in active bulk - due to high resistivity (irradiation increases the resistivity of silicon)
- •the second peak at p^+ contact is due to positive space charge (leakage current/diffusion of majority carriers-holes to bulk)
- •weighting field determined by electrodes!

G. Kramberger, "Investigation of electric field in heavily irradiated detectors by Edge-TCT", 6th Trento workshop on advanced silicon radiation detectors, 2-4.3.2011, Trento, Italy

Non-irradiated p-type sensor (HPK, 100 μm)

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





- V_{fd} from CV and CCE profile agree well
- For $V<V_{fd}$ there is a region with E field at the back (p-p$^+$ contact), due to large difference in free hole concentration.
- Close to the V_{fd} the $Q\neq0$ for non-depleted part, due to diffusion of the carriers
- It seems that un-depleted bulk is resistive enough so that under-depleted detector can not be seen as detector with thickness determined by depletion depth Q(50 μm) ≠const.

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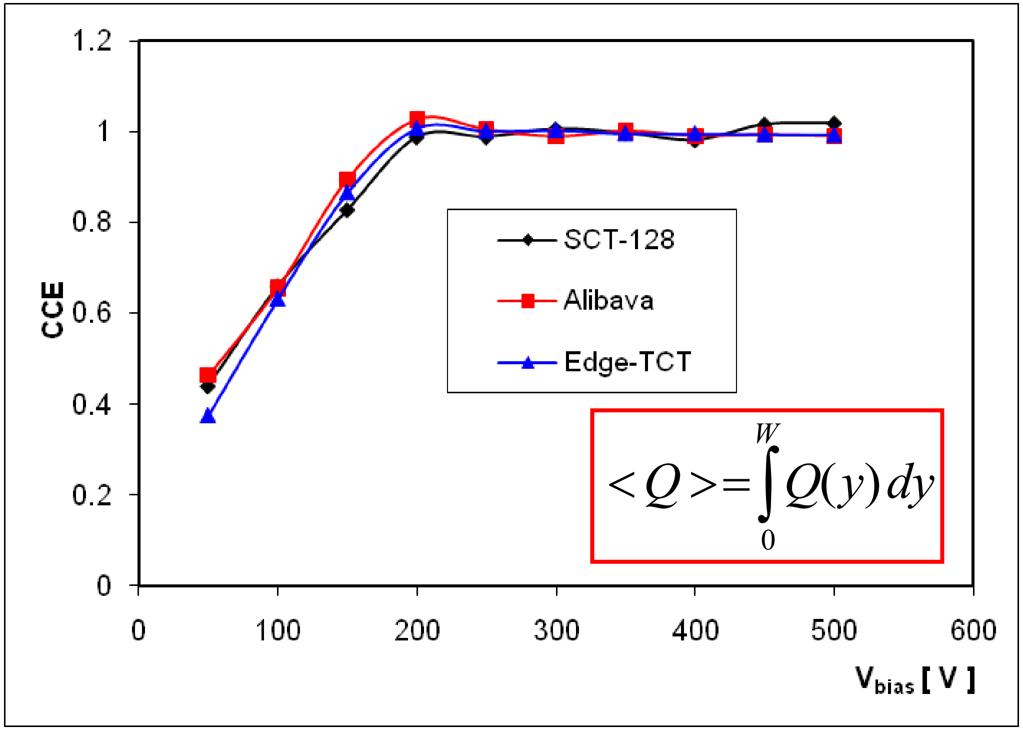
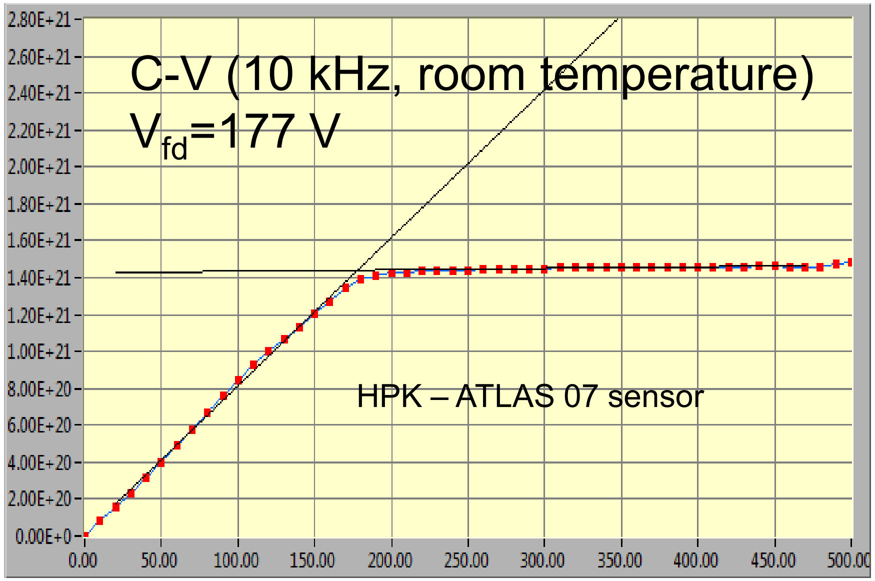
The <Q> from Edge-TCT was compared with same type detectors with the ^{90}Sr measurements (Alibava and SCT128A) and C-V

A very good agreement was observed for all three measurements.





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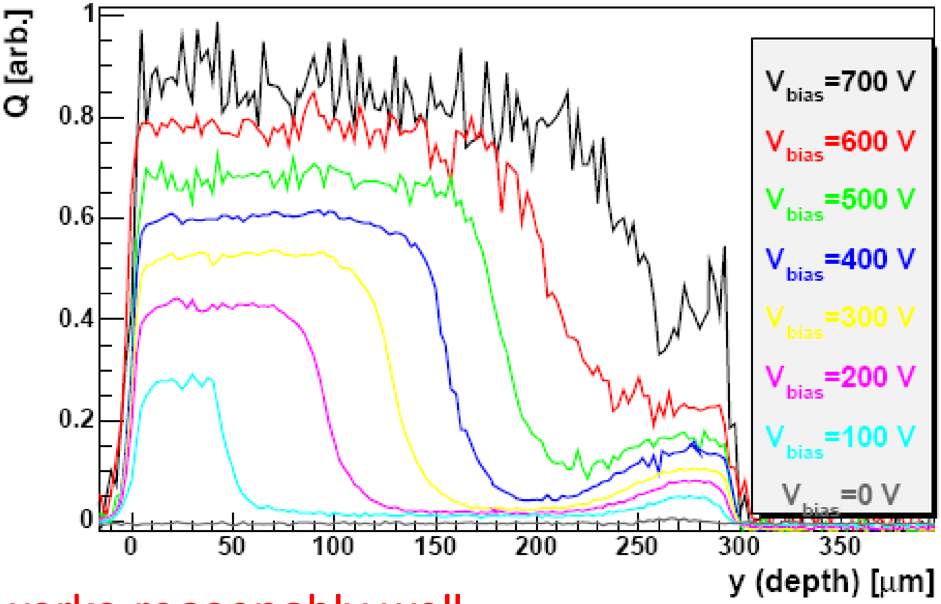
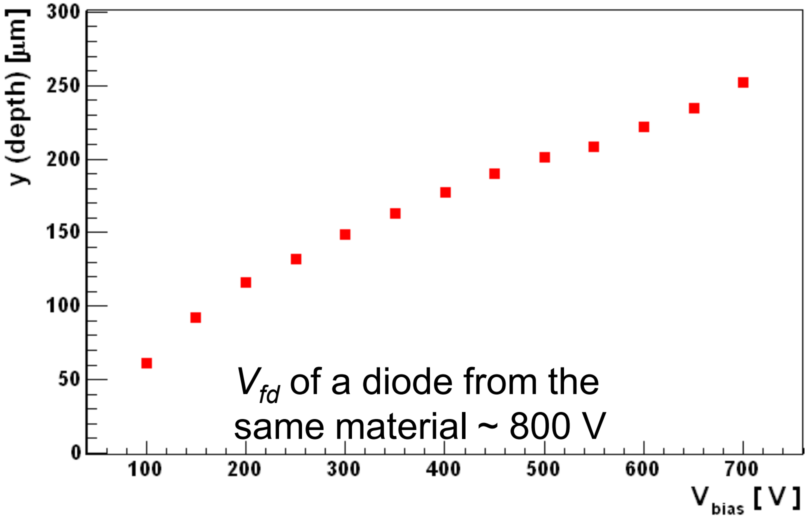
Micron ($\Phi_{eq}=5\cdot10^{14}$ cm^{-2})

80 min @ 60ºC, T=-5ºC

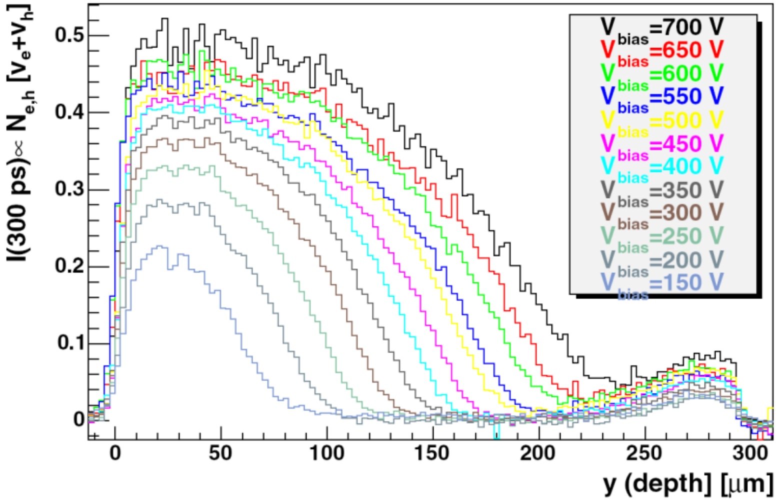
- The un-depleted bulk is almost non-active, except at higher bias voltage
- The active region grows with bias voltage almost as predicted – typical for p-type device
- The device is FZ irradiated with neutrons – small DJ effect
- Electric field at the p$^+$-p side is smaller and extends at most few 10 μm inside



The device model assuming constant N_{eff} works reasonably well.

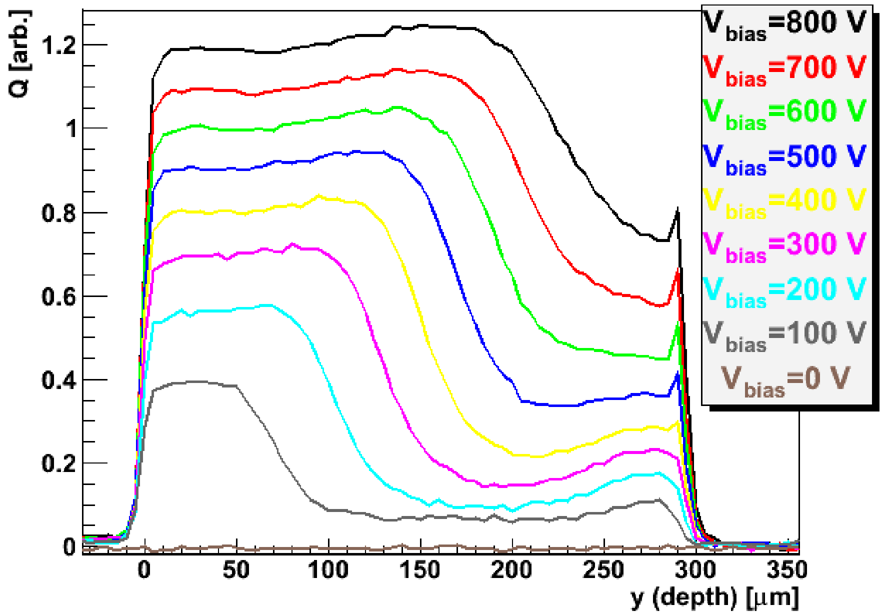


V_{fd} of a diode from the same material ~ 800 V

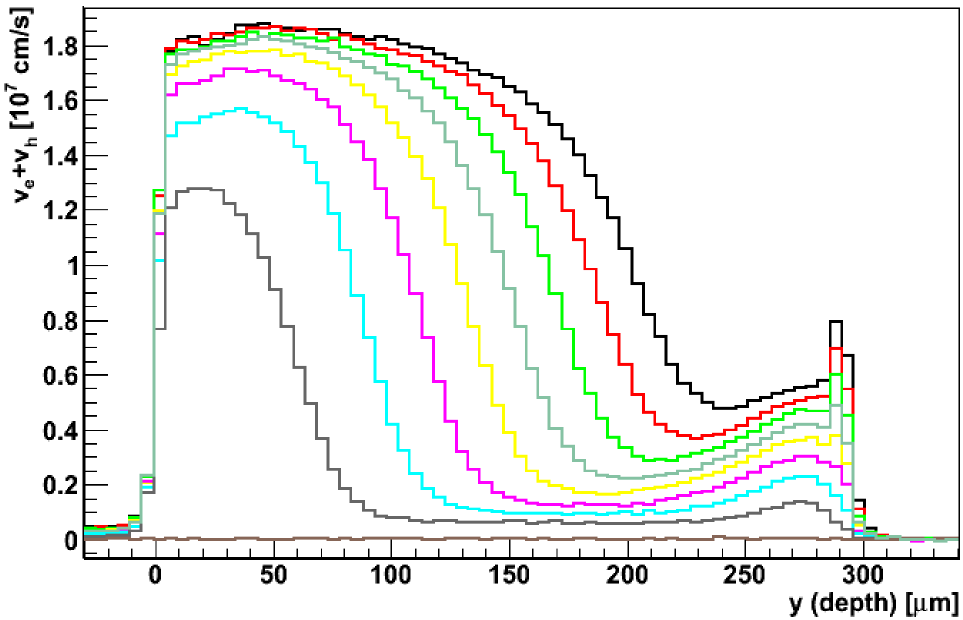


HPK ($\Phi_{eq}=10^{15}$ cm^{-2} , 100 μm)

80 min @ 60ºC, T=-20ºC



- Charge collection profile Q(y)
  - Collected charge in active bulk becomes important
  - Transition between both regions becomes less evident at high bias voltage
  - Once the charge is injected in the region with electric field the Q($y<y_{act}$) is almost constant – some increase in the middle due to smaller trapping of electrons than holes



- Velocity profile
  - At high bias voltages and small y the drift velocity saturates - **calibration of the scale**
  - "double peak profile" seen but not very large – the field at the back is small – although it clearly shows positive space charge
  - NOTE that minimum velocity in the detector $v_e+v_h>3\cdot10^6$ cm/s at 500 V.

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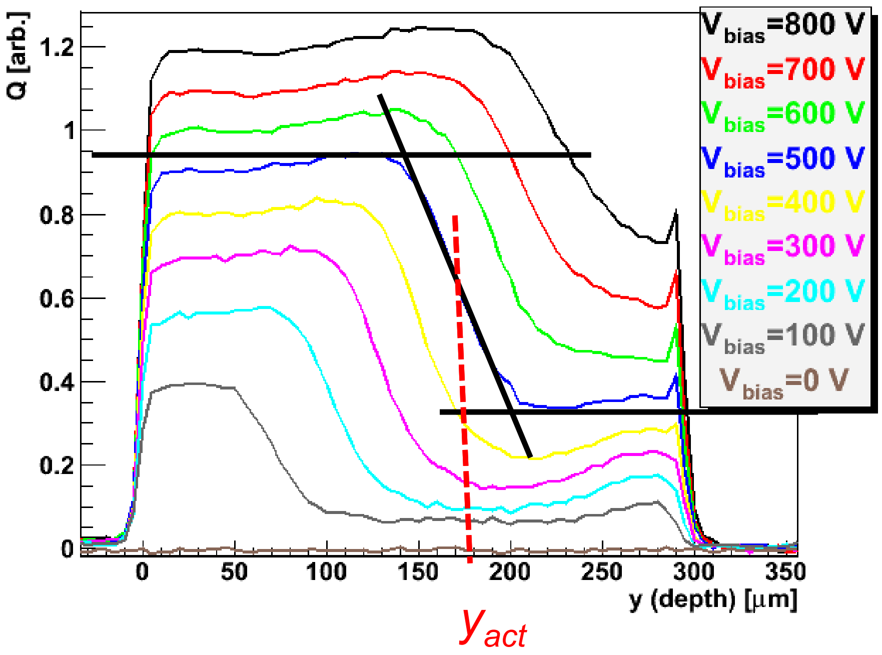
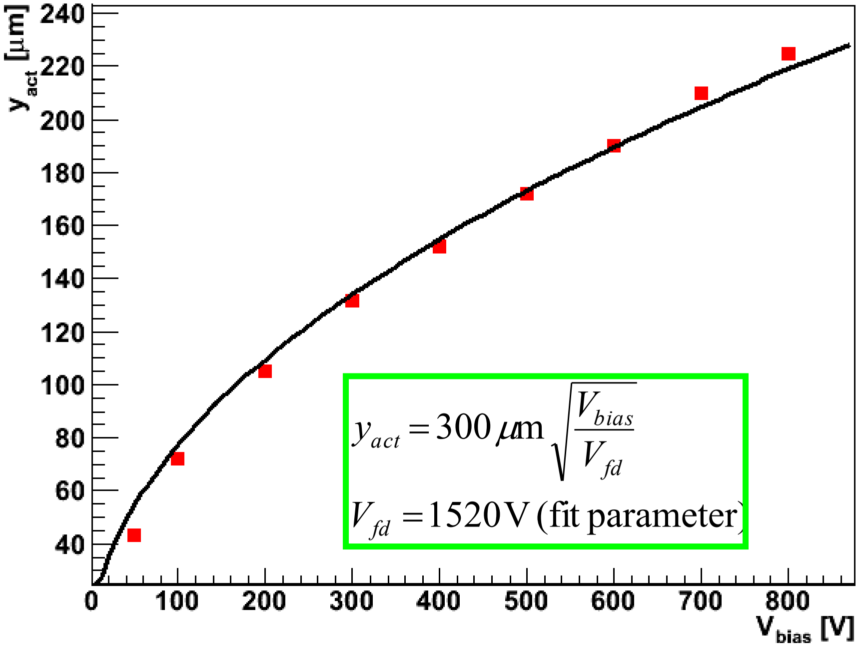
HPK (Φ_{eq}=10^{15} cm^{-2}, 100 μm) – active region





$$N_{eff} \approx g_c \cdot \Phi_{eq} + N_{eff0} \quad , \quad g_c = 2 \cdot 10^{-2}\ \mathrm{cm}^{-2}$$

$$V_{fd} = \frac{e_0 N_{eff} W^2}{2\varepsilon\varepsilon_0}$$

$$V_{fd}(80\,\mathrm{min\ at}\ 60^{\circ}C) \approx 1580\mathrm{V}$$

- The border of the "depleted-active region" and "active bulk" determined from intersection of the two lines

- y_{act} corresponds constant space charge (calculated and measured V_{fd} are almost identical)

V_{fd} still retains its validity as a parameter influencing CCE, but charge (<Q>,Q_{mip}) would be larger than estimated from V_{fd} , that is steeper Q-V plot.

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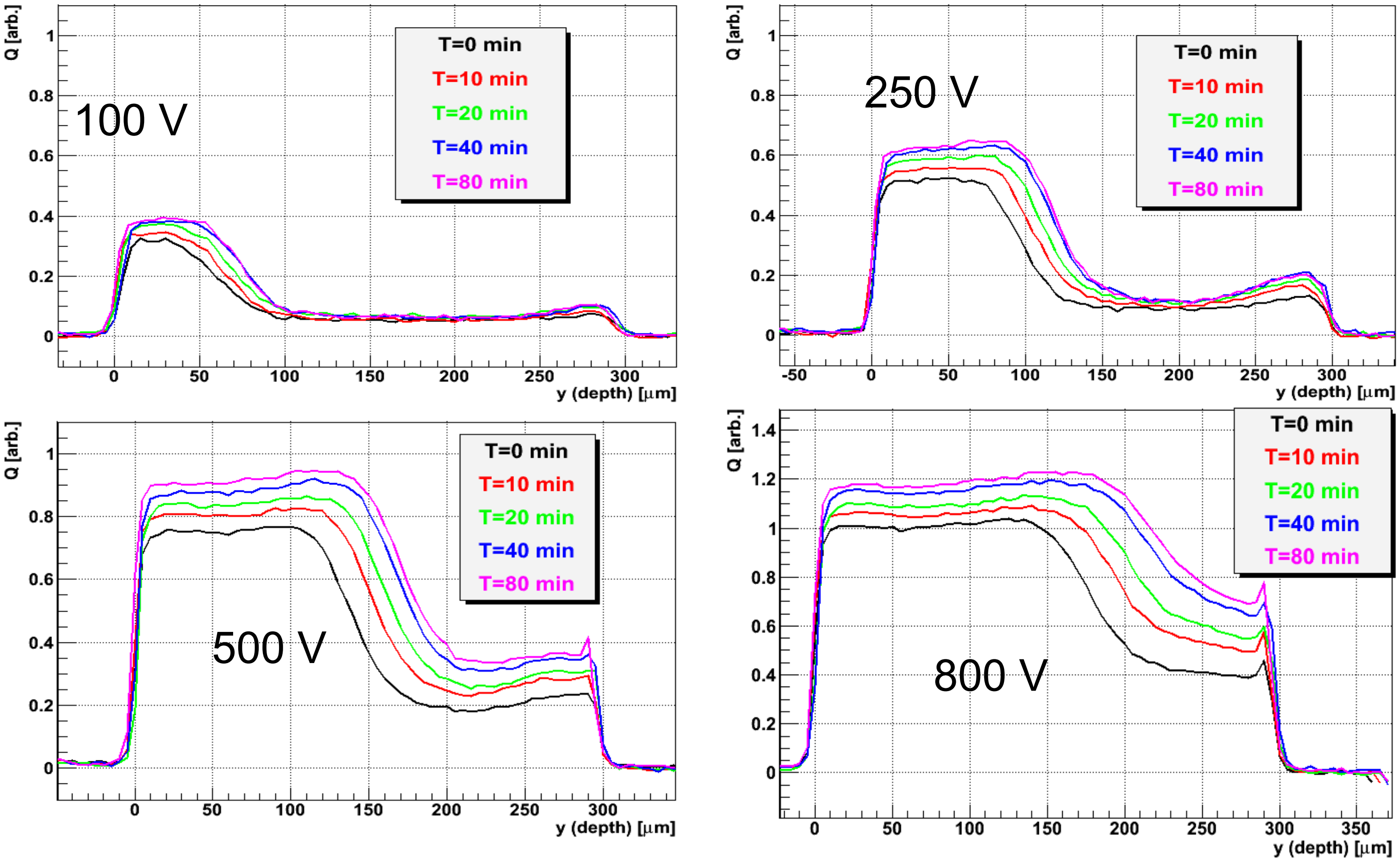
HPK ($\Phi_{eq}=10^{15}$ cm^{-2} ,100 μm) – short term annealing I



Annealing influences the “active bulk” at larger bias voltages – it seem as the proximity of the active/depleted region is important

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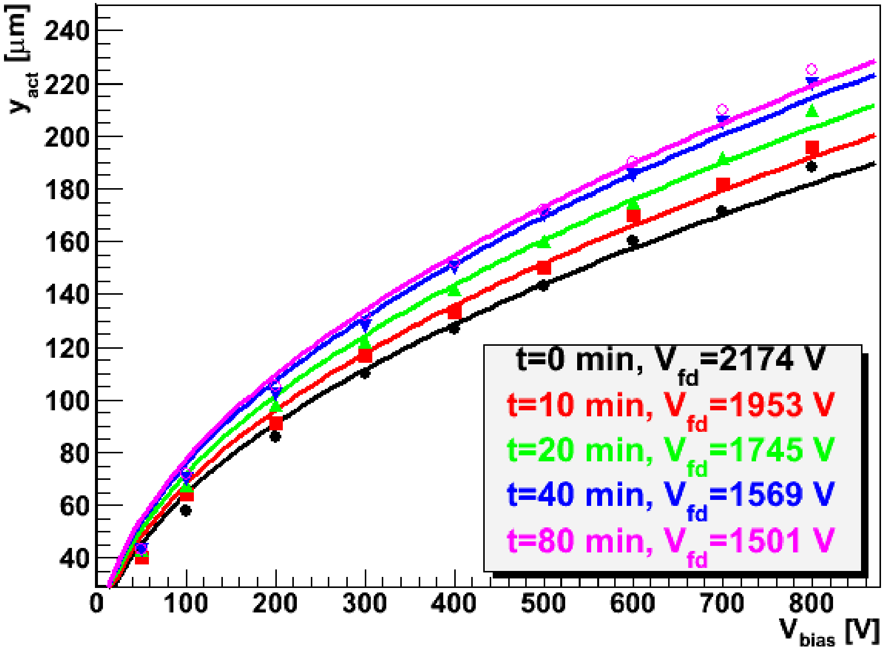
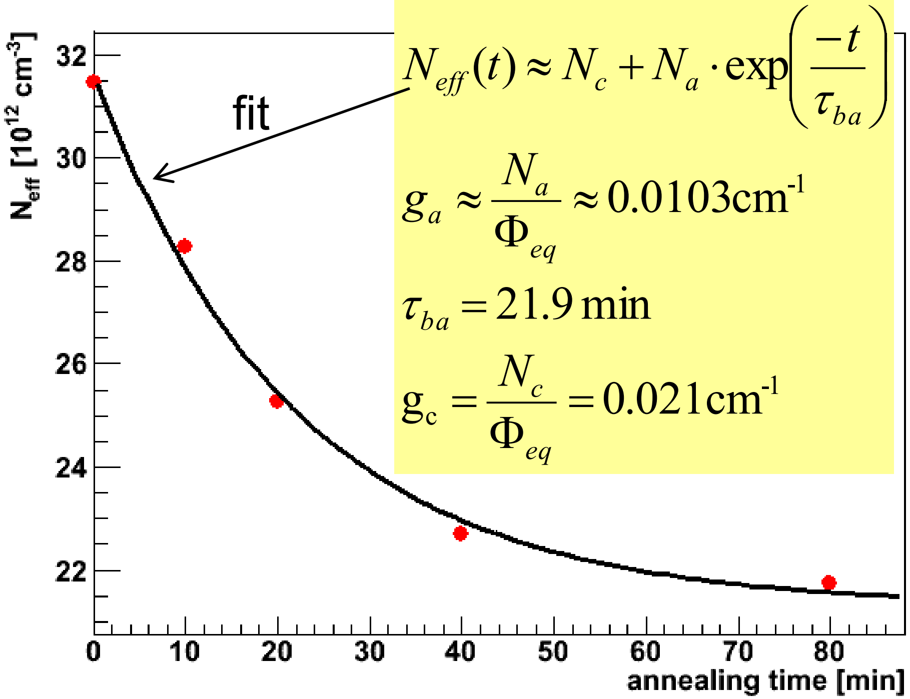
HPK ($\Phi_{eq}=10^{15}$ cm^{-2}) – short term annealing II





$$N_{eff}(t) \approx N_c + N_a \cdot \exp\left(\frac{-t}{\tau_{ba}}\right)$$

$$g_a \approx \frac{N_a}{\Phi_{eq}} \approx 0.0103\,\mathrm{cm^{-1}}$$

$$\tau_{ba} = 21.9\,\mathrm{min}$$

$$g_c = \frac{N_c}{\Phi_{eq}} = 0.021\,\mathrm{cm^{-1}}$$

- Active region grows as expected for constant space charge also during annealing
- The results from fit to the annealing data agree very well with RD48/50 data (*NIM A 466 (2001) 308.*)
- The electric field (voltage drop) in active bulk is small enough to obtain results comparable with those at lower fluences.

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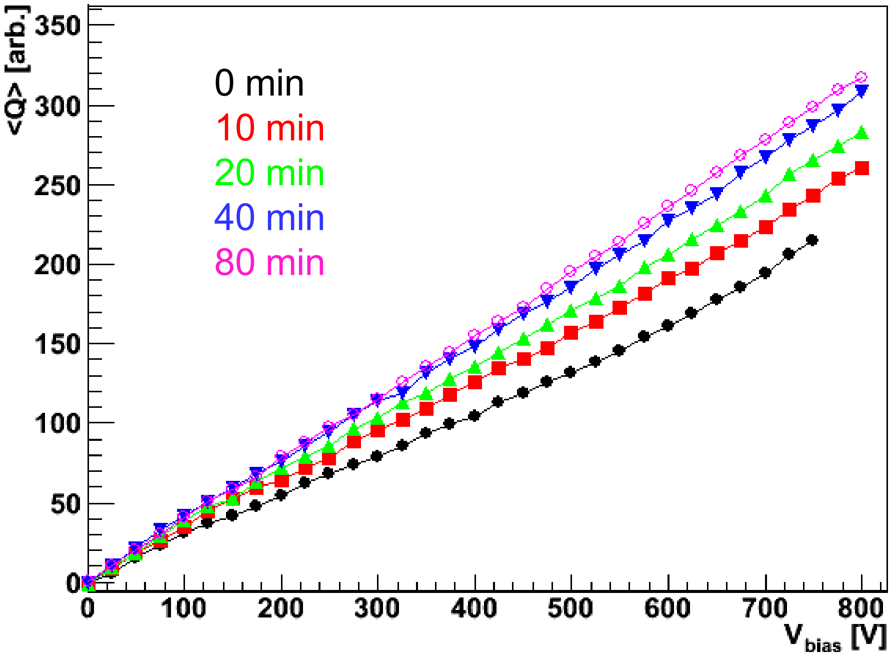
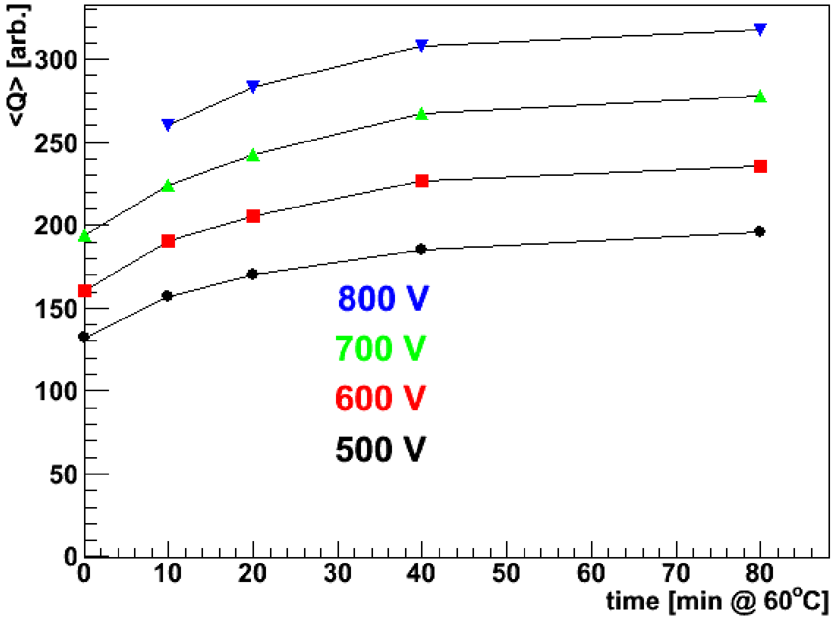
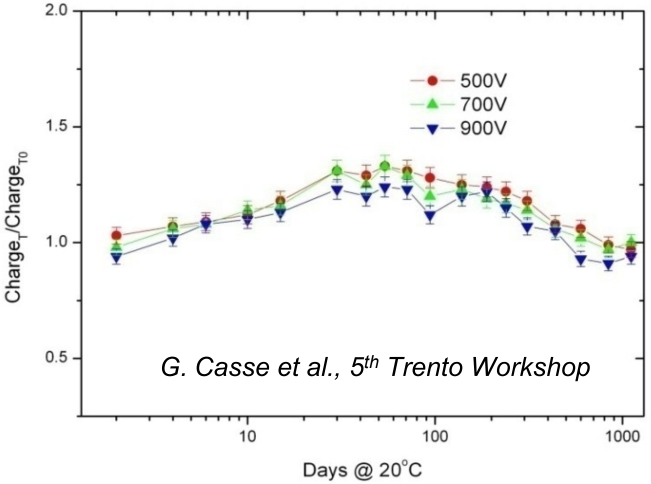
HPK (Φ_{eq}=10^{15} cm^{-2}) – short term annealing III





- Short term annealing improves the signal of m.i.p for 20-30% (in agreement with L'pool results)
- The dependence of <Q> on voltage is linear and shows no saturation
- Q_{mip} dependence measured with SCT128A on a detector of the same type shows the same behavior



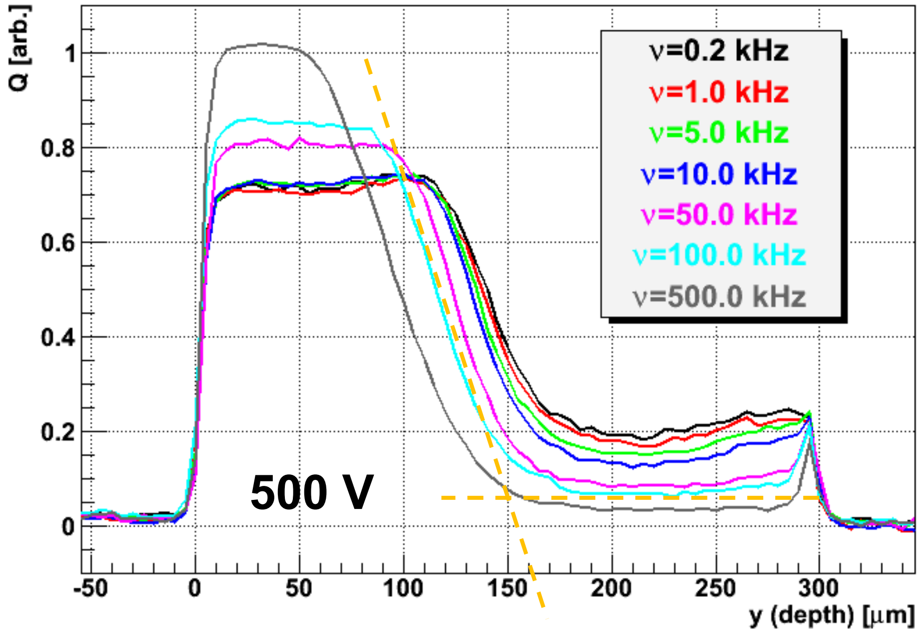
G. Casse et al., 5th Trento Workshop

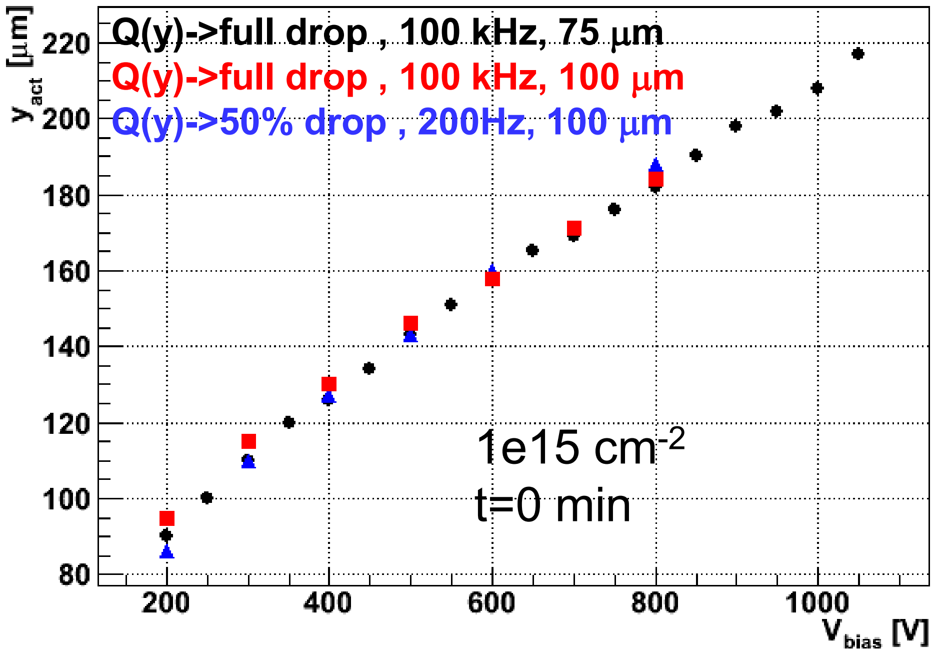
G. Kramberger, "Investigation of electric field in heavily irradiated detectors by Edge-TCT", 6th Trento workshop on advanced silicon radiation detectors, 2-4.3.2011, Trento, Italy

Impact of pulse frequency

The signal depends on the pulse frequency (studies triggered by accident ☺) – trapping/de-trapping effects

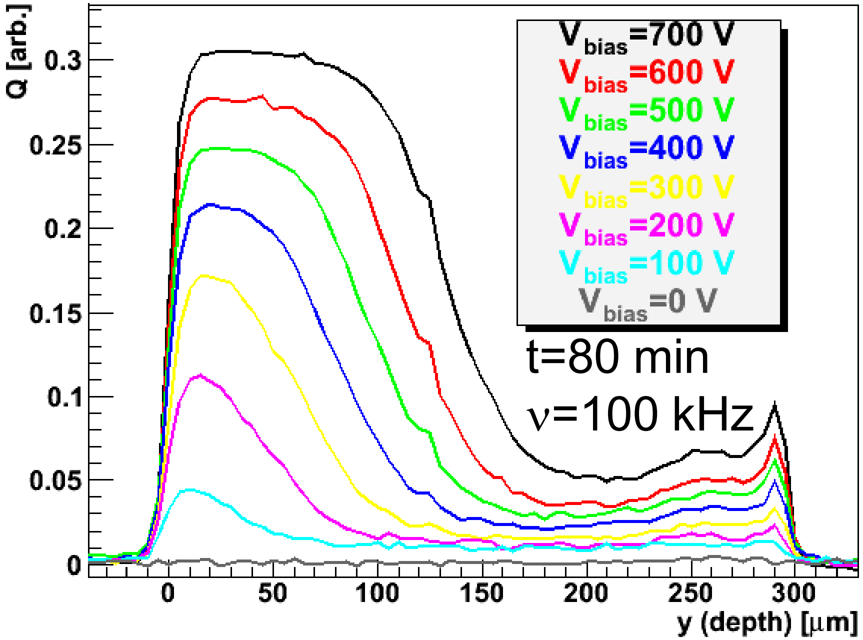
Currently the modeling is ongoing to extract some trap parameters …

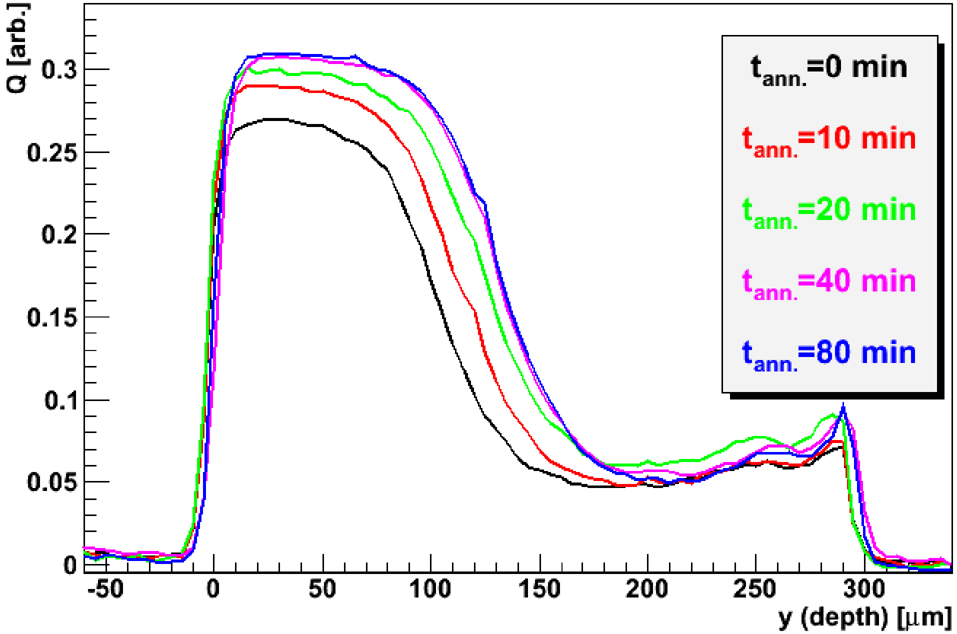




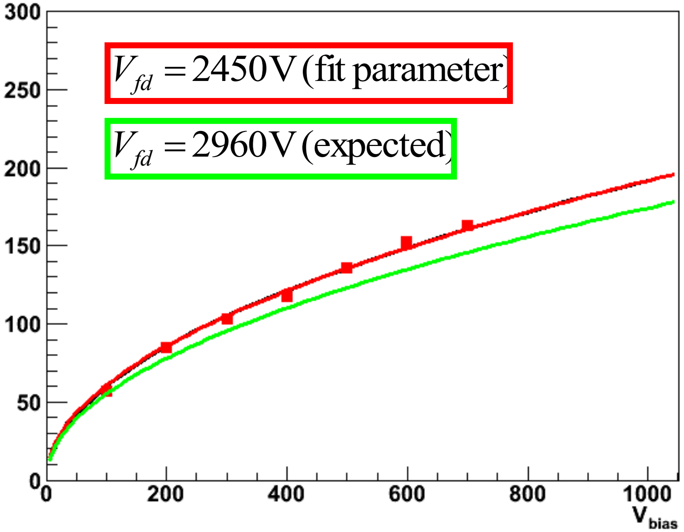
- Alternative definition of y_{act} at 100 kHz – the validity at high fluences is of course questionable
- For measurements at 100 kHz and 200 Hz the points (y_{act}) coincide

HPK (Φ_{eq}=2·10^{15} cm^{-2} , 75 μm)





- The “active region” is reduced with respect to lower fluence - as expected
- charge collection in “non-active” region becomes significant (note 100 kHz, presumably higher at ν->0)
- The active region becomes larger than expected – the low fluence extrapolation starts breaking down
- Effect of short term annealing is beneficial



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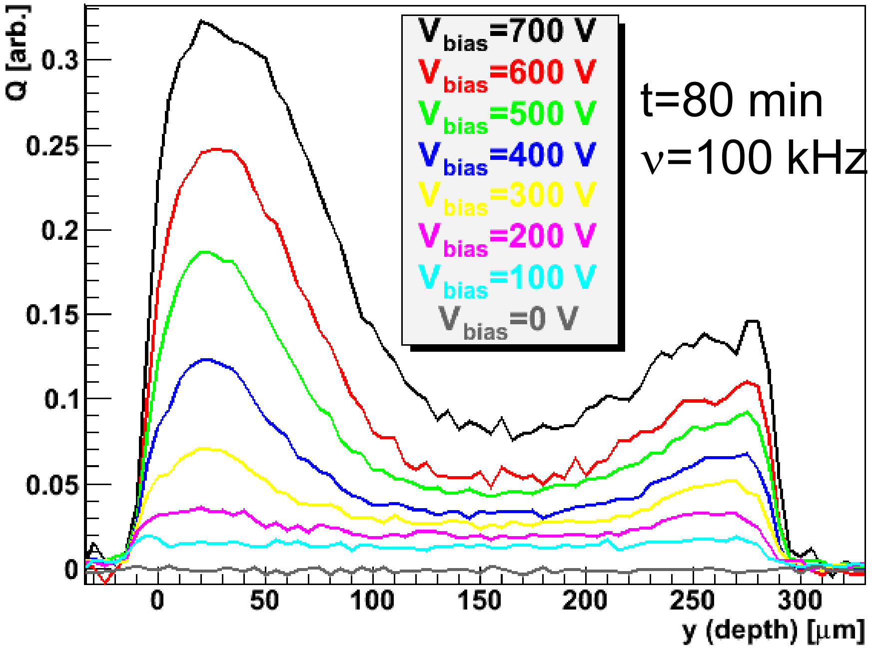
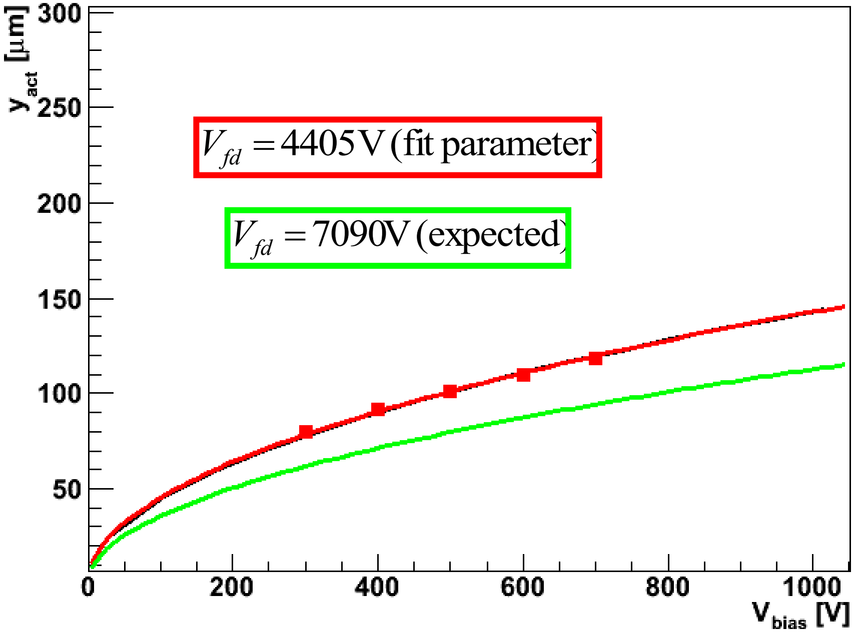
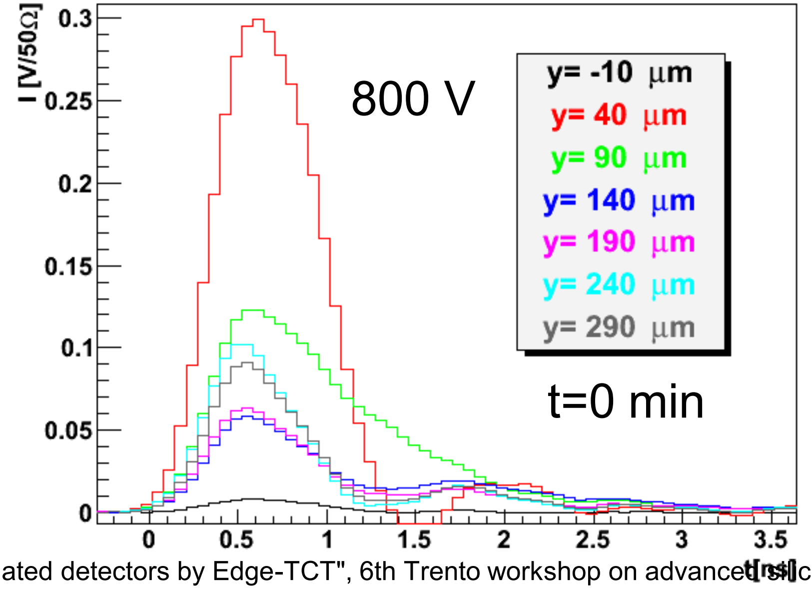
HPK (Φ_{eq}=5·10^{15} cm^{-2} , 75 μm)







- Effect of short term annealing is small (not shown) – as most of the damage is annealed out (annealing in previous steps + self annealing)
- y_{act} deviates from model prediction
- **No amplification is seen in the signal – seen in Micron detectors at that fluence (see talk at 5th Trento workshop). Reasons:**
  - **voltage is low**
  - **laser frequency can have an impact**

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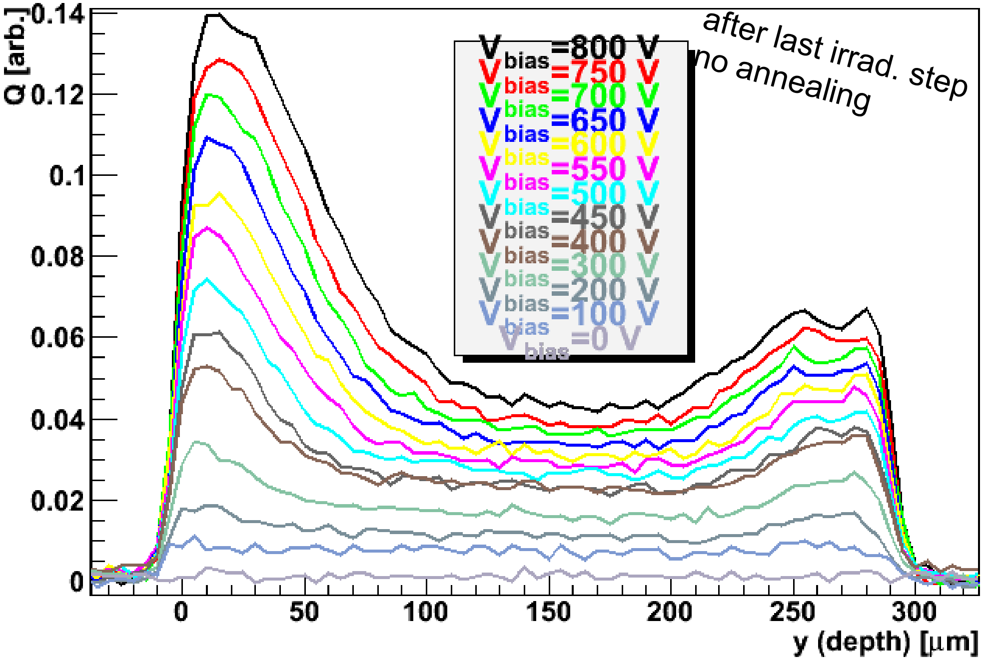
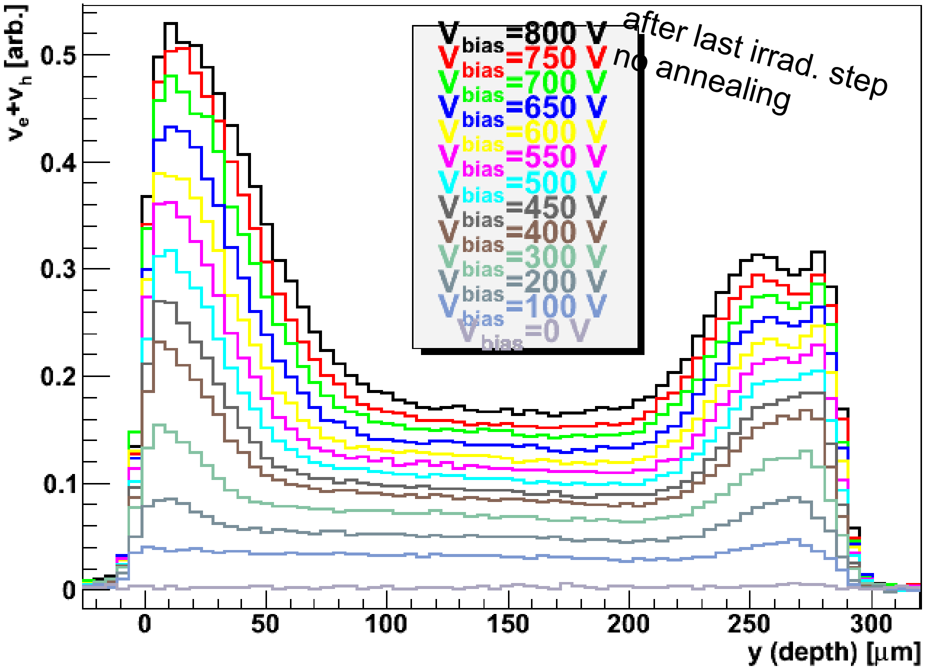
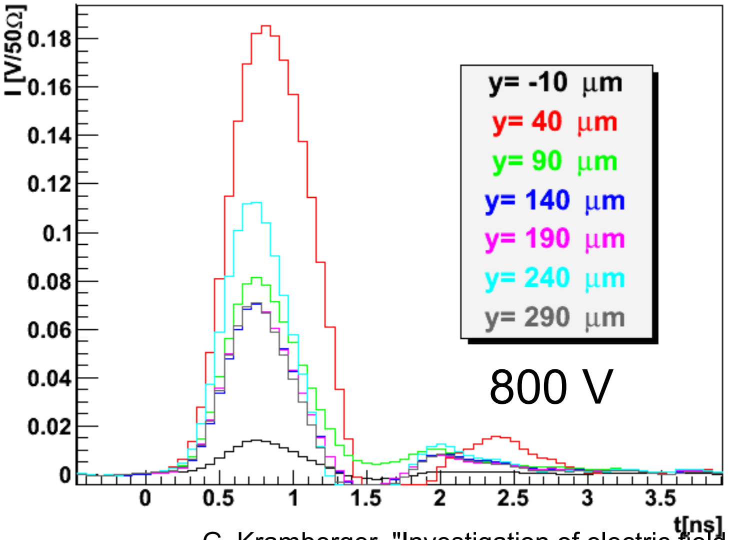
HPK ($\Phi_{eq}=10^{16}$ cm^{-2} , 75 μm)





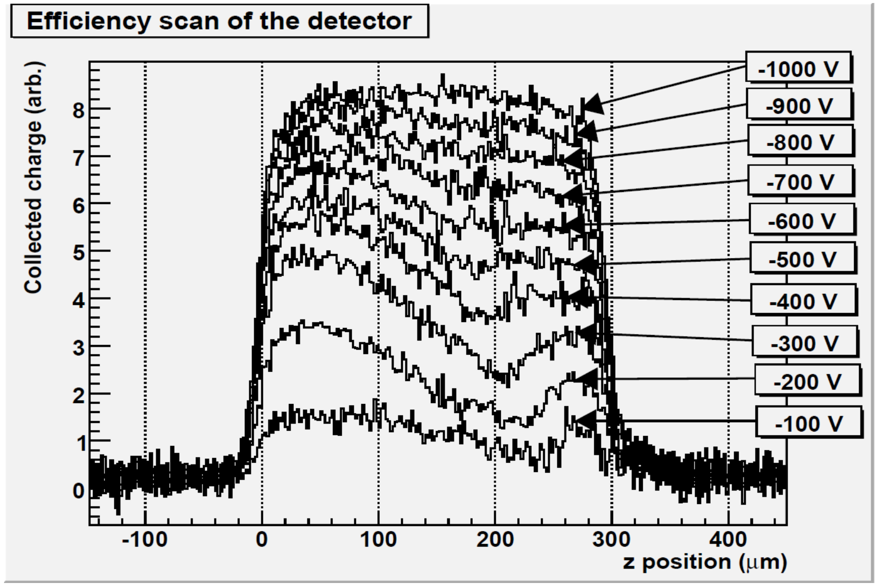


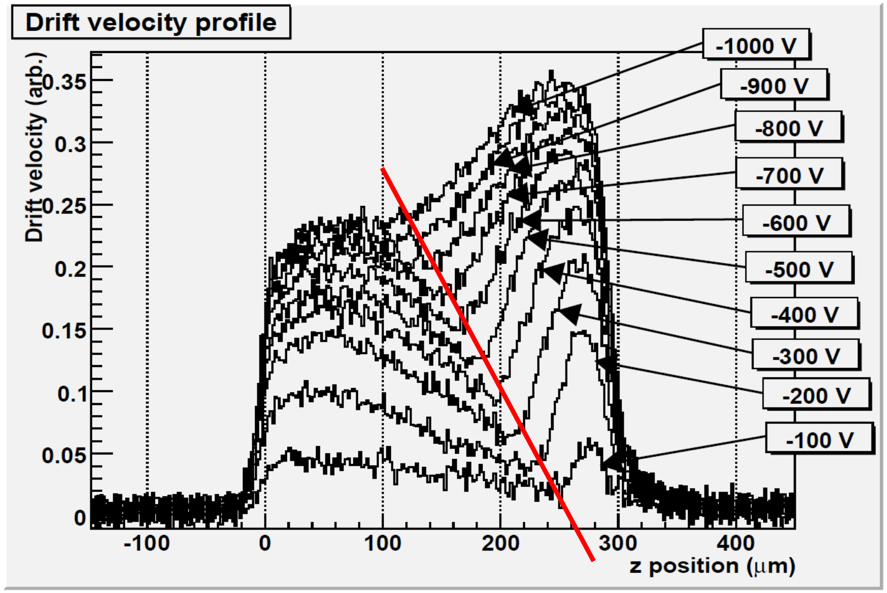
- Electric field is established in the whole detector – almost uniform at low V_{bias} or even larger at the back
- The velocity and charge collection profiles are very similar - large trapping and consequently short drift distance
- Electric field in the saddle should be E>0.3 V/cm

G. Kramberger, "Investigation of electric field in heavily irradiated detectors by Edge-TCT", 6th Trento workshop on advanced silicon radiation detectors, 2-4.3.2011, Trento, Italy

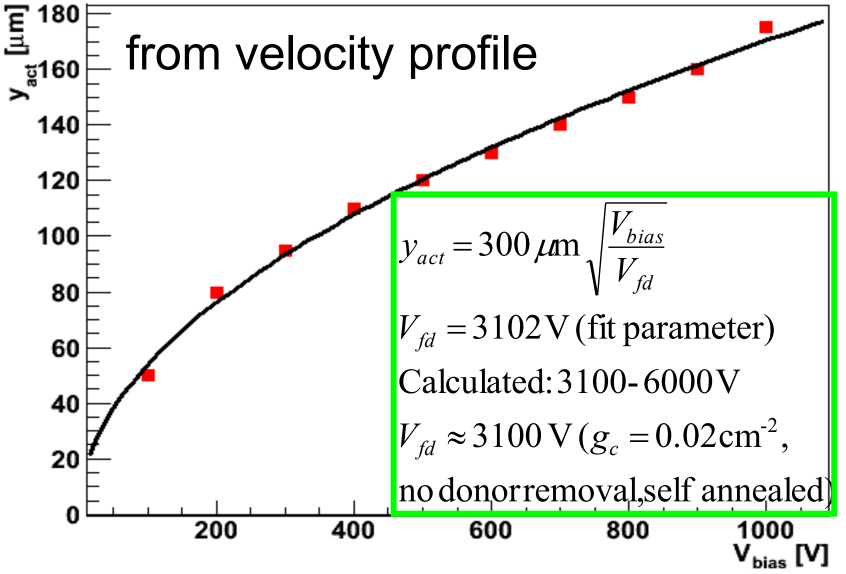
MCz p-n (Φ_{eq}=3·10^{15} cm^{-2})

N. Pacifico et al., presented at RESMDD 10





- MCz; p-n-n+ sensor, 280 Ωcm
- irradiated with neutrons to 31015cm-2
- no intentional annealing
- at 1000 V the sensor is equally efficient in the whole volume, even though the field at the back is stronger – larger hole trapping
- y_{act} is larger than assumed from the extrapolation at lower fluences



$$y_{act} = 300\,\mu\mathrm{m}\sqrt{\frac{V_{bias}}{V_{fd}}}$$

$V_{fd} = 3102\,\mathrm{V}$ (fit parameter)

Calculated: 3100-6000 V

$V_{fd} \approx 3100\,\mathrm{V}$ ($g_c = 0.02\,\mathrm{cm}^{-2}$, no donor removal, self annealed)

Conclusions

- V_{fd} retains the validity as the parameter determining active region (high CCE region) up to 1-2·10^{15} cm^{-2} for neutron irradiated HPK sensors
  - The charge collection profile shows significant contribution from active bulk – larger charge at given bias voltage than expected from V_{fd}
  - The expected active region properties agree well with predictions from RD48/50 measurements (space charge, annealing)
- Substantial electric field is present in whole detector at high fluences already for moderate voltages
  - The difference between efficiency of different regions in the detector is reduced with fluence
  - No clear indication of multiplication was seen in the signals (low voltage, high frequency?)
  - The field in the middle of detector at 10^{16} cm^{-2} is of order 0.5 V/μm at 700 V
  - Trapping is severe – TCT pulses become of 1 ns order

G. Kramberger, "Investigation of electric field in heavily irradiated detectors by Edge-TCT", 6th Trento workshop on advanced silicon radiation detectors, 2-4.3.2011, Trento, Italy