# *Edge-TCT measurements of heavily irradiated HPK p-type sensors*

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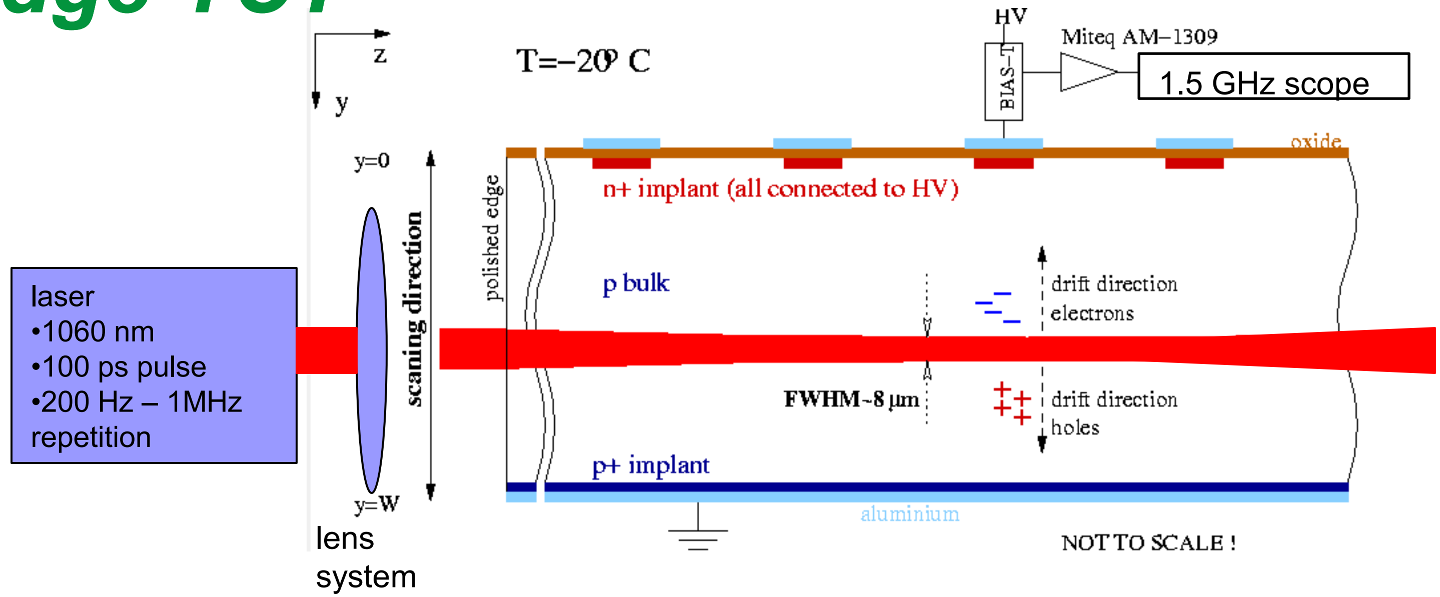
# Edge-TCT




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

**<u>Advantages (compared to pixel test beam – grazing technique):</u>**

- 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**

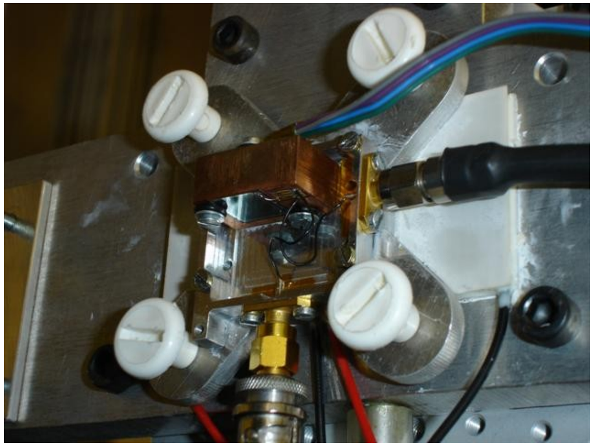
**<u>Drawbacks:</u>**

- 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

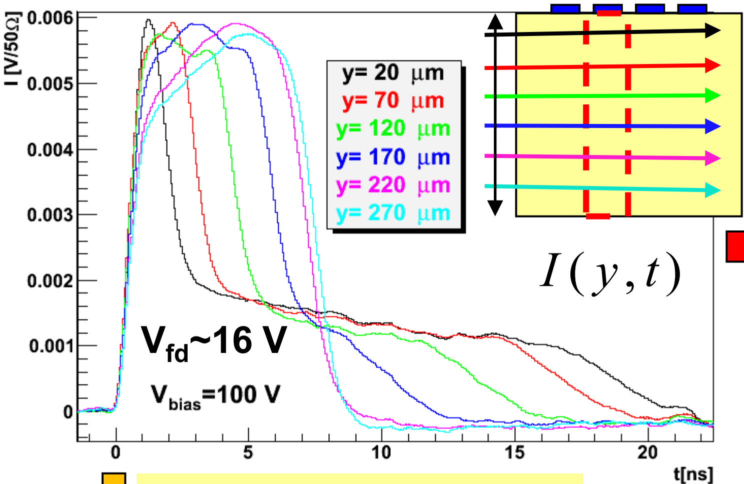
| Samples | Fluences | Annealing |
|---|---|---|
| HPK (ATLAS-07 run)<br>1x1 cm2, 300 μm thick, 80 μm pitch<br>p-type<br>isolation: p-stop + p-spray<br>initial $V_{fd}$~190 V | non-irradiated<br>1,2,5,10·$10^{15}$ $cm^{-2}$<br>irradiated in steps | sequential steps at 60ºC up to 80 min (0,10,20,40 min) at each fluence |

✓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



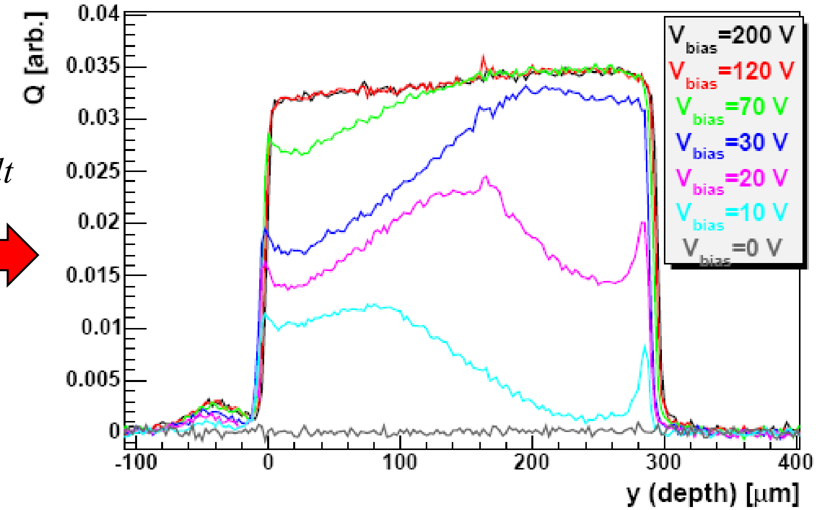
# Charge collection and velocity profiles

**RD50 Micron p-type sensor**



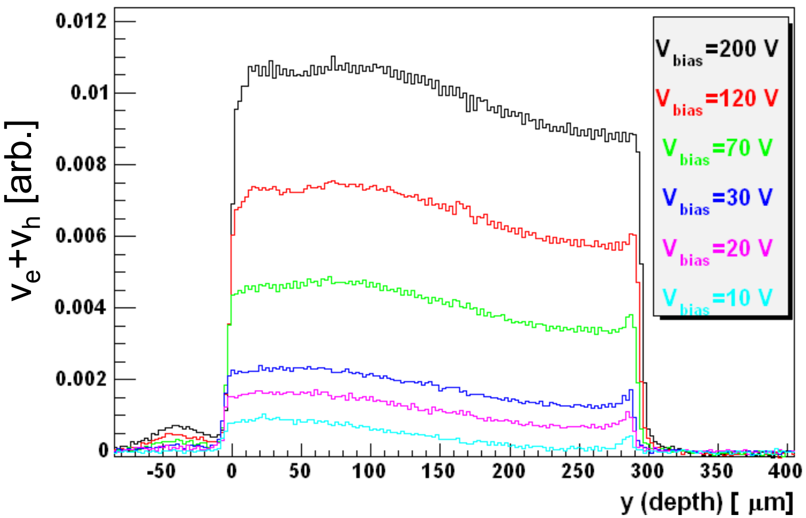

$$Q(y) = \int_0^{25\,ns} I(y,t)\,dt$$

**CHARGE COLLECTION PROFILE**

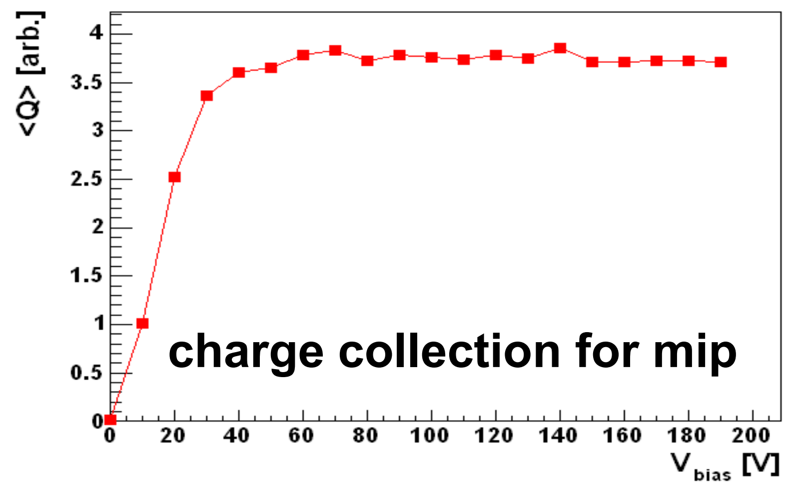



$$I(y, t \sim 0) \propto v_e + v_h$$

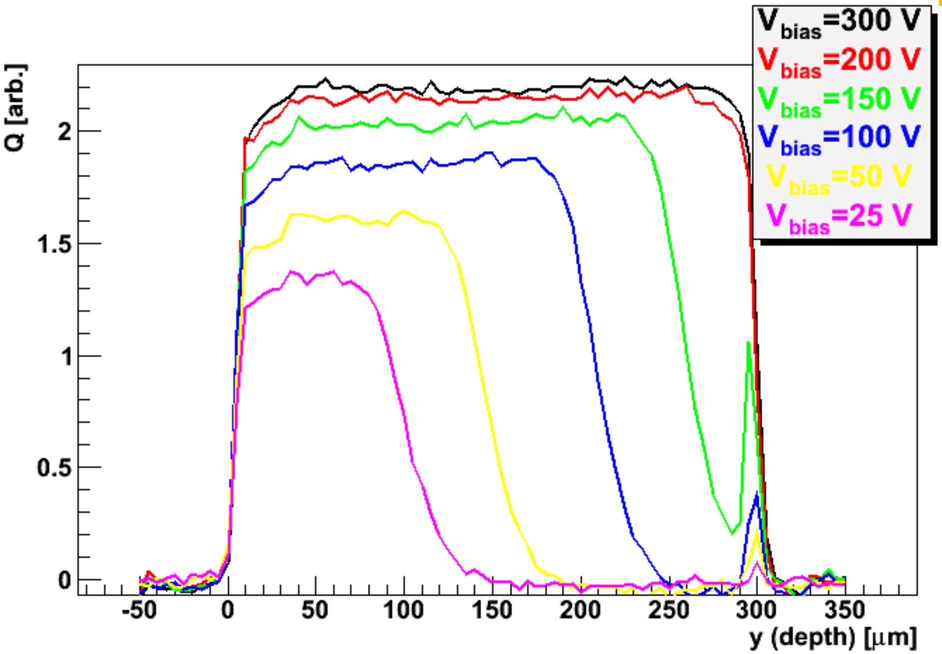
**VELOCITY PROFILE**

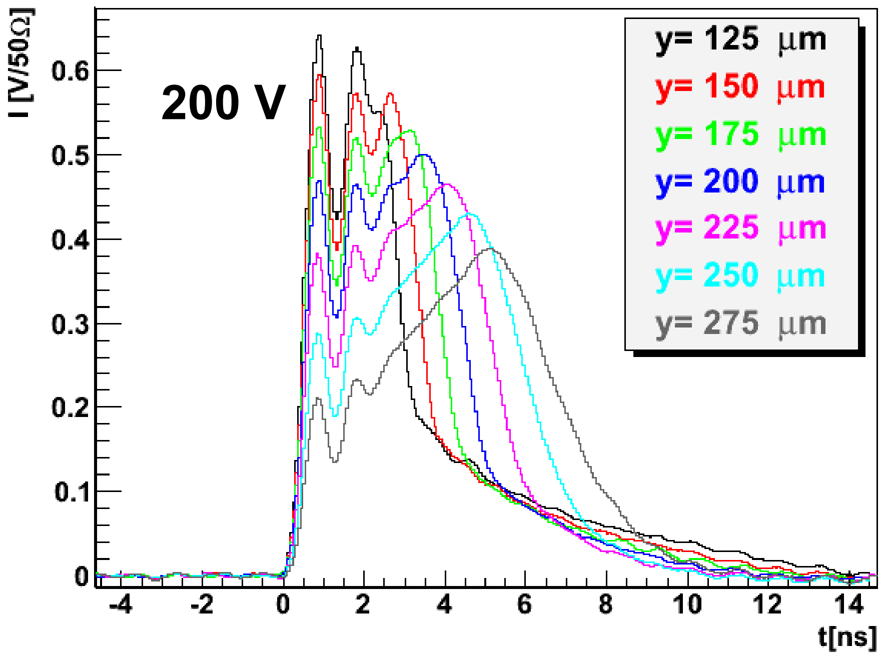



$$Q_{mip} \propto \langle Q \rangle = \int_0^{25\,ns} I(y,t)\,dt$$



# HPK (non-irradiated)



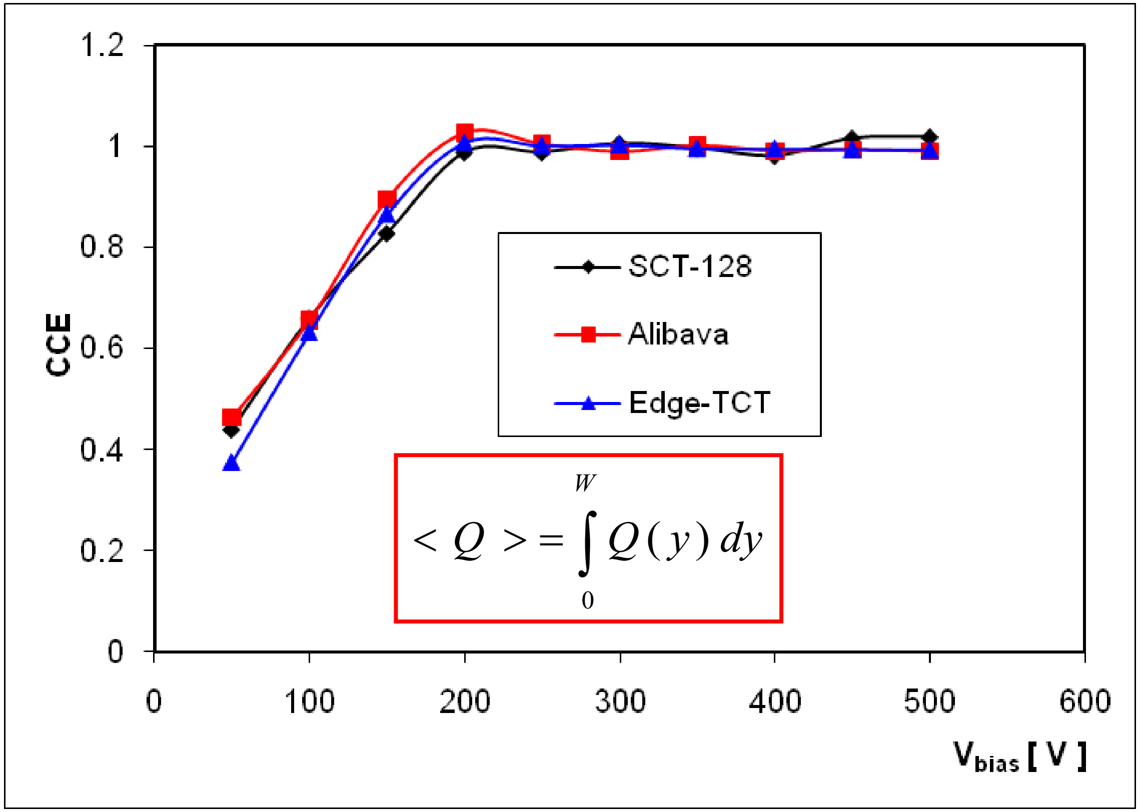




- $V_{fd}$=180 V from CV (10 kHz, RT), at 200 V the detector is fully efficient
- For V<Vfd there is a region with E field at the back (p-p+ contact).
- growth of "active region ($y_{act}$)" with bias voltage can be observed (agrees with homogenous $N_{eff}$)

The current pulses show expected behavior:

- the reflections with HPK are larger than with Micron (impendence issue?)
- Long tail from drift of holes
- Increase of signal from drift of electrons

# HPK (non-irradiated)




$$< Q > = \int_{0}^{W} Q(y)\, dy$$

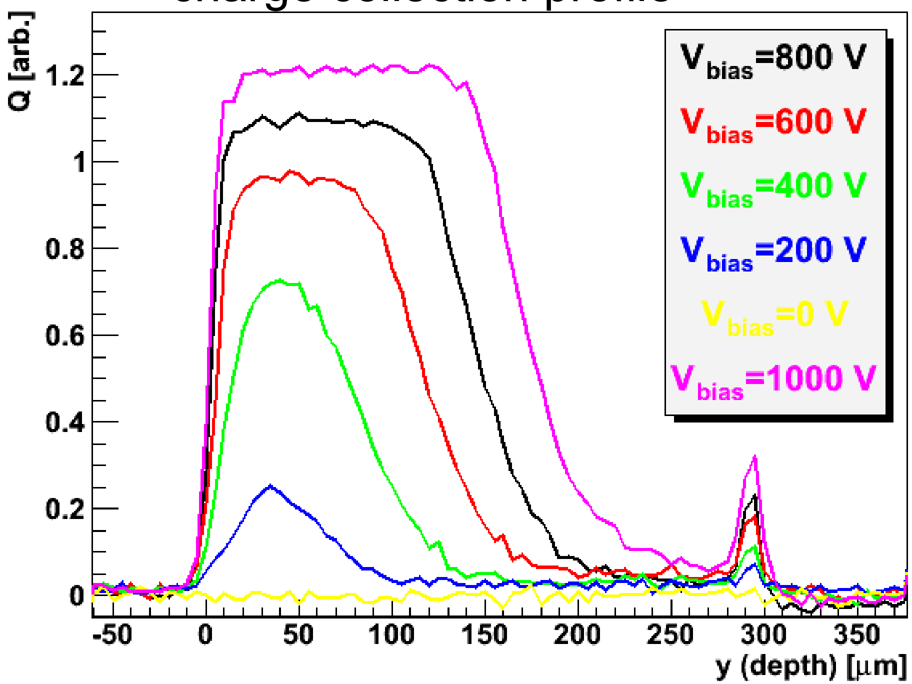
The <Q> from Edge-TCT was compared with $^{90}$Sr setups using Alibava and SCT128A !

**A very good agreement was observed for all three measurements – validation of the <Q> technique**

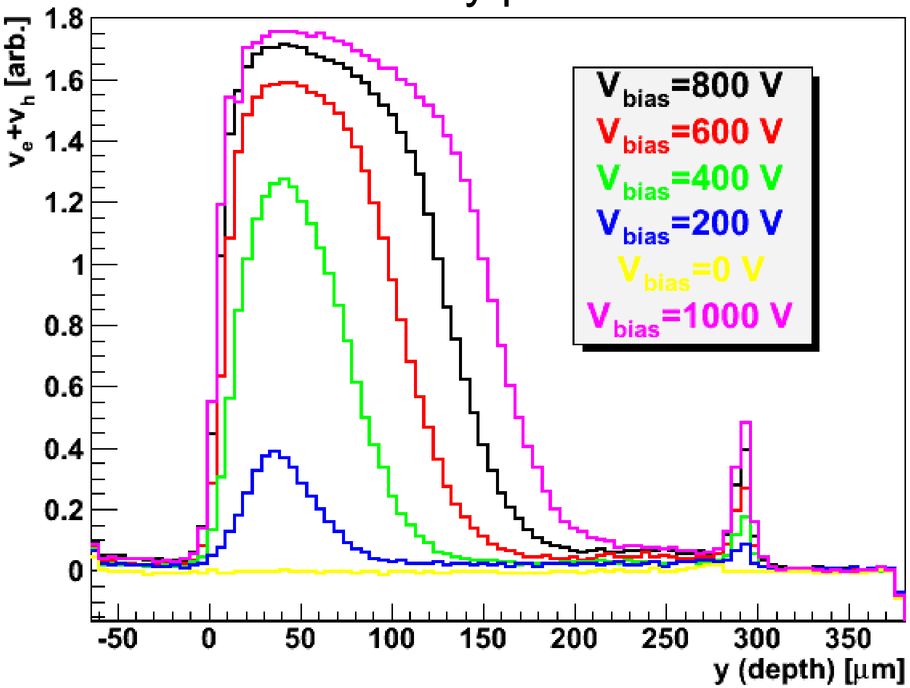
# HPK ($\Phi_{eq}$=10$^{15}$ cm$^{-2}$ )

as irradiated/no annealing

charge collection profile




velocity profile



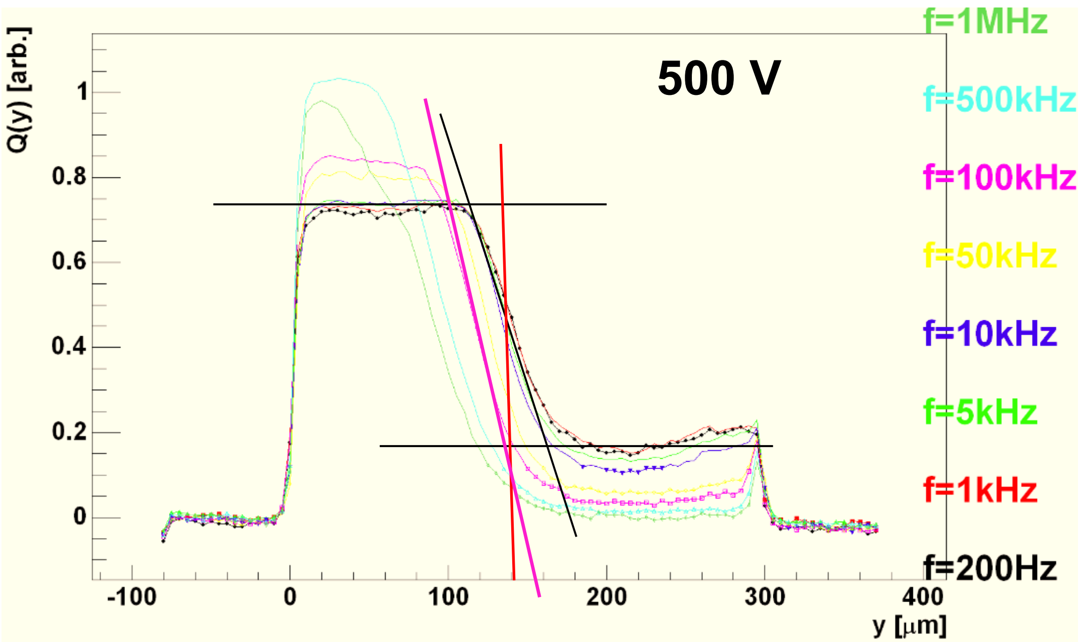

- Shape of Q(y) is not much different from that of a non-irradiated detector -> the device model is the same as for non-irradiated detector
  - Electric field at the back is much smaller than at front **- "double junction effect" is small** due to oxygen lean detectors and neutron irradiations
  - Once the charge is injected in the region with electric field the $Q(y<y_{act})$ is constant
- The velocity profile confirms the Q(y)

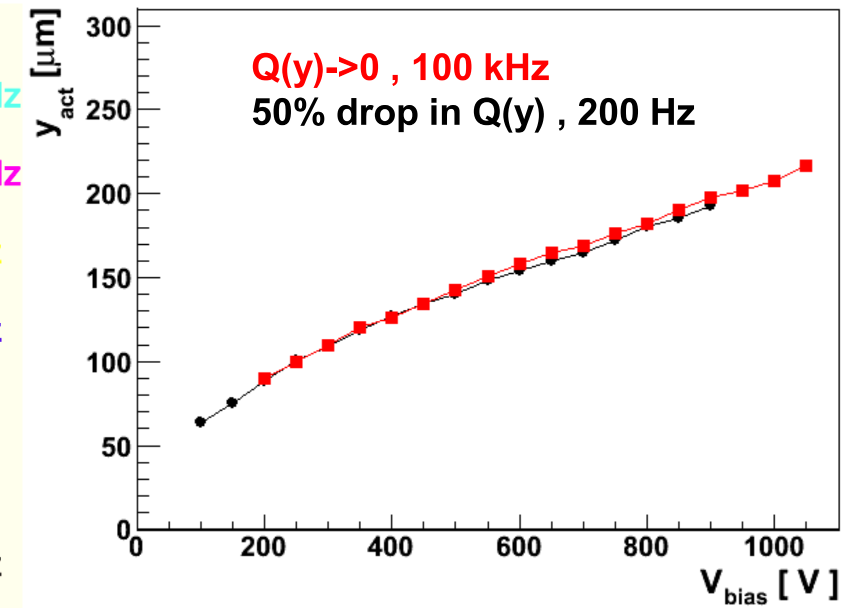
# Impact of pulse frequency and amplitude

The signal from "non-active" region depends on the pulse frequency (studies triggered by accident ☺)

- low for high frequency
- high for low frequency

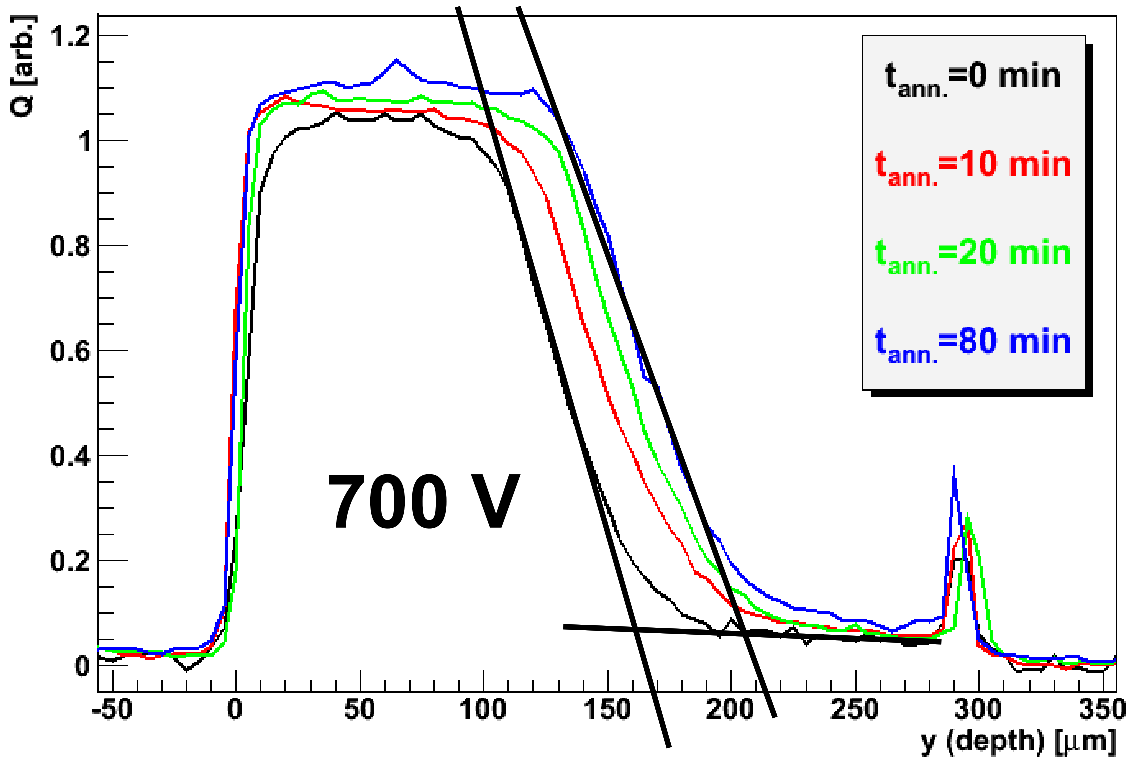
Simplistic explanation: more electrons get trapped leading to increase of $N_{eff}$ and less voltage is dropped in the non-active region




- The active region is defined as a point where Q(y) drops to 50% from the peak-plateau – see figure
- There is 30 μm difference between 100 kHz and >1 kHz
- For measurements at 100 kHz this point coincides with Q(y)->0
- $v_e+v_h$->0 coincides with $y_{act}$ measured at 200 Hz

# HPK ($\Phi_{eq}$=$10^{15}$ cm$^{-2}$ ) – beneficial annealing




$$N_{eff} \approx g_c \cdot \Phi_{eq} + N_{eff\,0} \quad , \quad g_c = 2 \cdot 10^{-2}\ \mathrm{cm}^{-2}$$

$$V_{fd}\,(80\ \mathrm{min\ at}\ 60^{\circ}C) \approx 1600\ \mathrm{V}$$

$$\Downarrow$$

$$\text{predicted} \quad : y_{act}\,(700\ \mathrm{V}) \approx 200\ \mu\mathrm{m}$$

$$\text{measured} \quad : y_{act}\,(700\ \mathrm{V}) = 205\ \mu\mathrm{m}$$

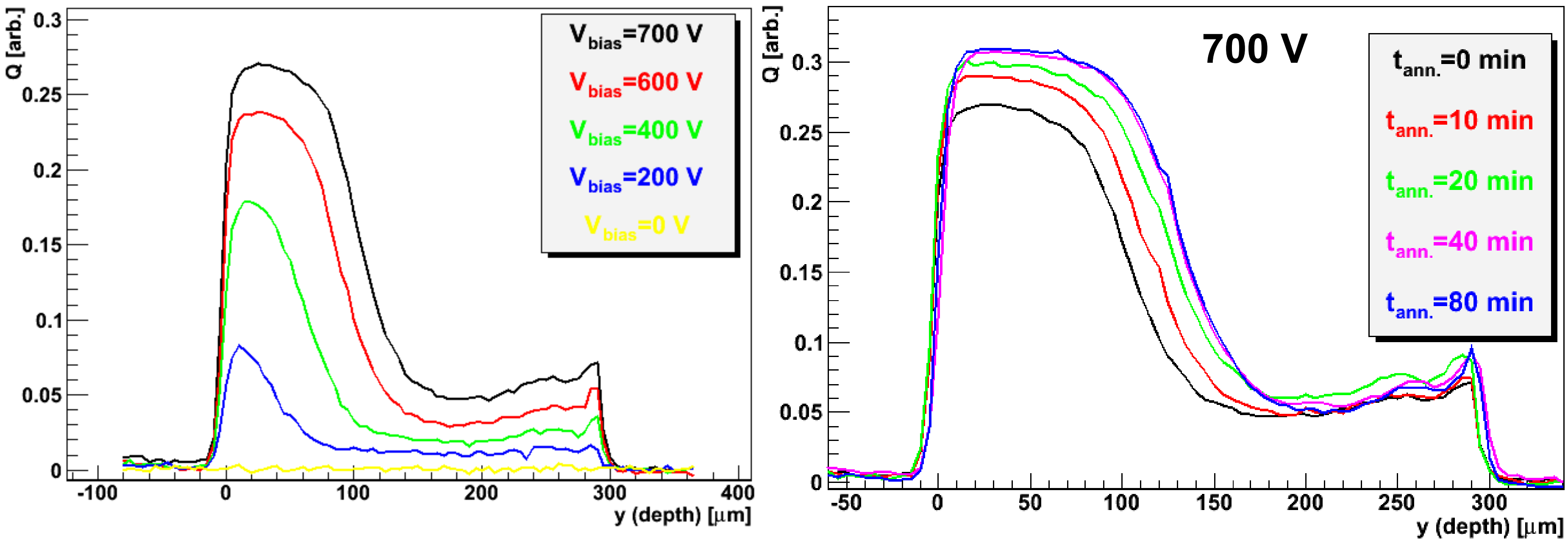
$$\Delta N_{eff} \approx N_{eff} \cdot \left[ \frac{y_{act}\,(0\mathrm{min})}{y_{act}\,(80\mathrm{min})} \right]^2$$

$$g_a \approx \frac{\Delta N_{eff}}{\Phi_{eq}} \approx 0.008\ \mathrm{cm}^{-1}$$

- beneficial annealing is close to that at lower fluences – the method gives a possibility to measure it also at such high fluences
- The improvement in <Q> is around 30% at 700 V
- the predicted active region ($N_{eff}$=const.) is very close to the measured

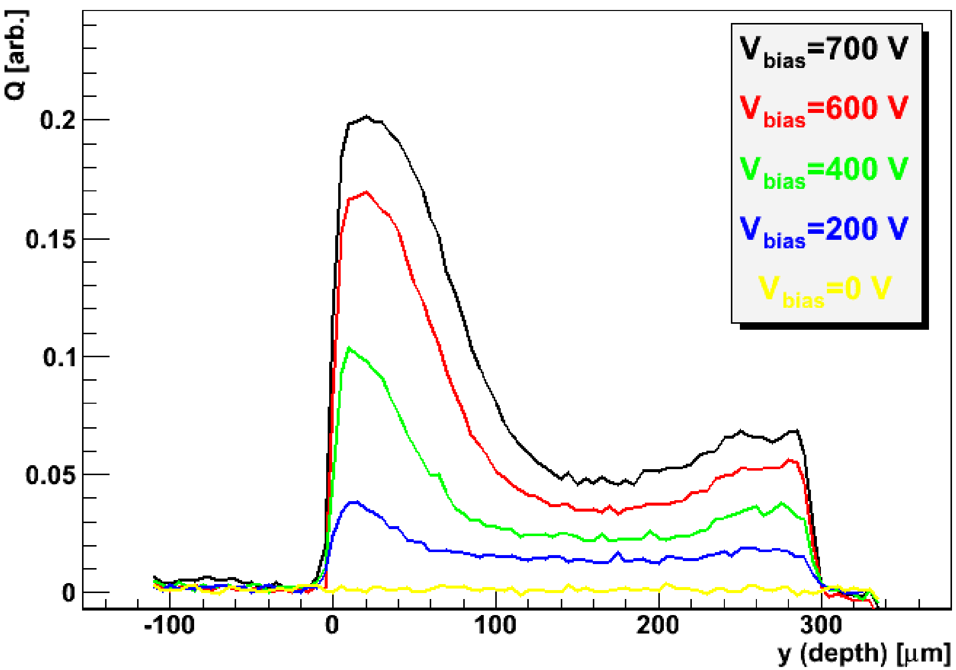
***In agreement with expectations based on RD48 and RD50 data – up to $10^{15}$ cm$^{-2}$ the device behaves in accordance with expectations derived at lower fluences.***

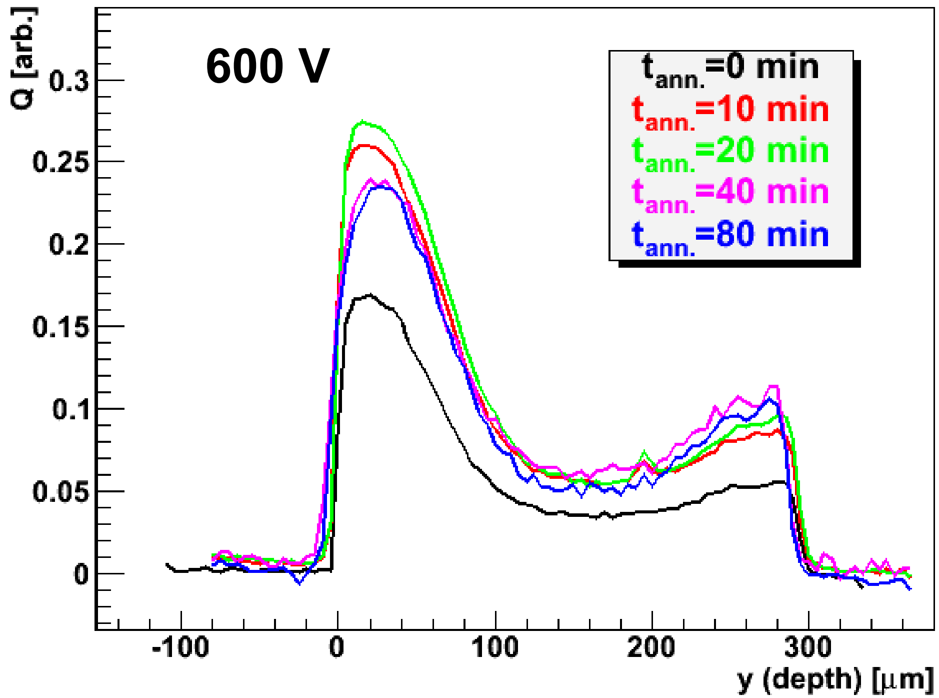
# HPK ($\Phi_{eq}$=2·10$^{15}$ cm$^{-2}$ )




- The "active region" is reduced with respect to lower fluence - as expected
- charge collection in "non-active" region becomes significant – should be even more at lower frequencies!
- Q(y<<$y_{act}$) is not flat - two possible reasons
  - charge multiplication
  - less effective trapping in high fields

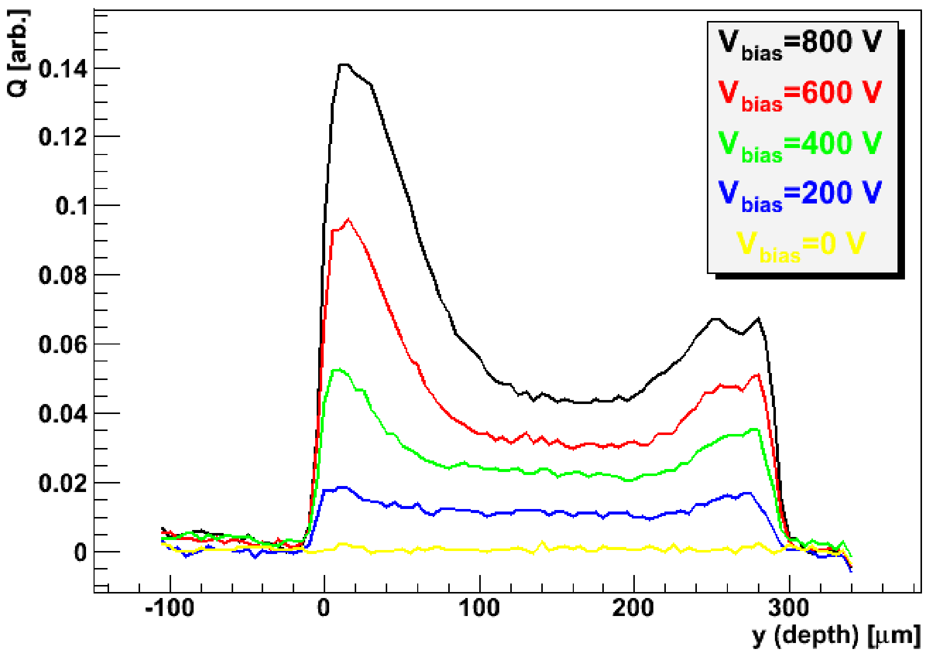
# HPK ($\Phi_{eq}$=5·10$^{15}$ cm$^{-2}$ )

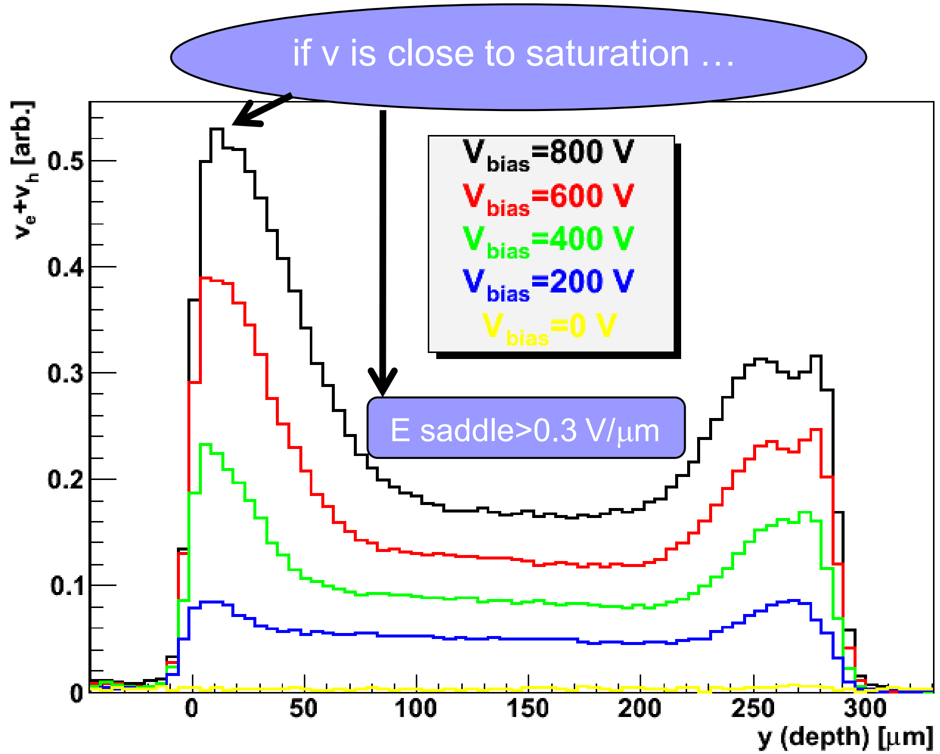



- Important contribution for $y>y_{act}$
- Reduction of $y_{act}(\Phi_{eq})$
- Annealing (note “CERN scenario”) influences mainly trapping – the shape of the $Q(y)$ remains the same
- At low voltages E is almost homogenous in the entire detector

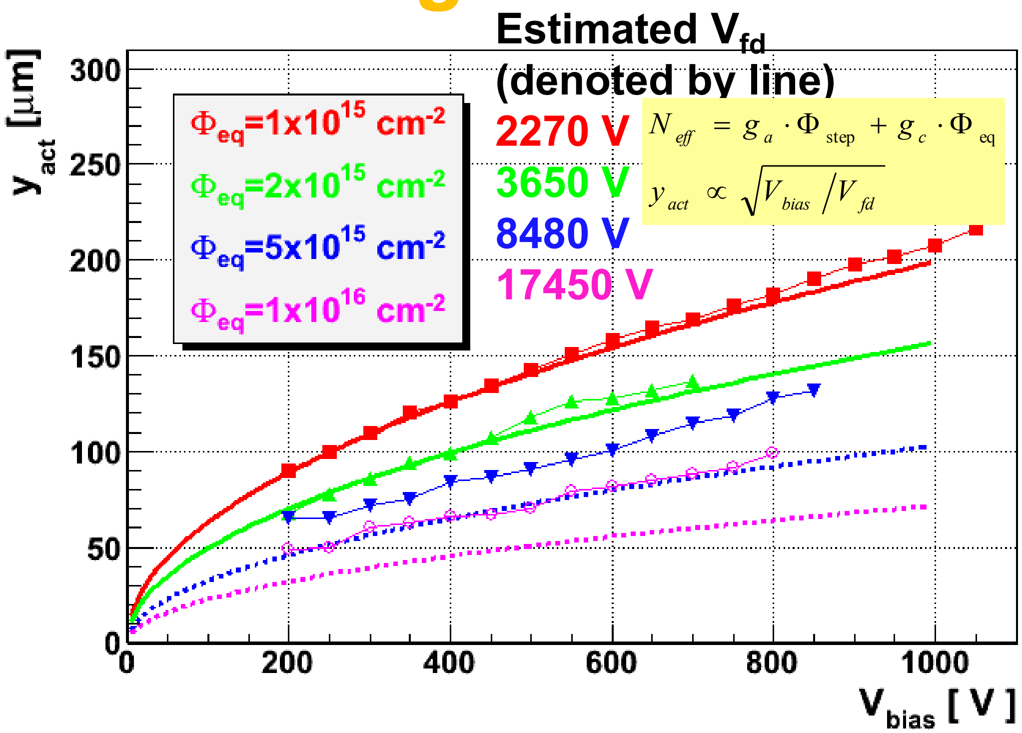
# HPK ($\Phi_{eq}=10^{16}$ cm$^{-2}$ )

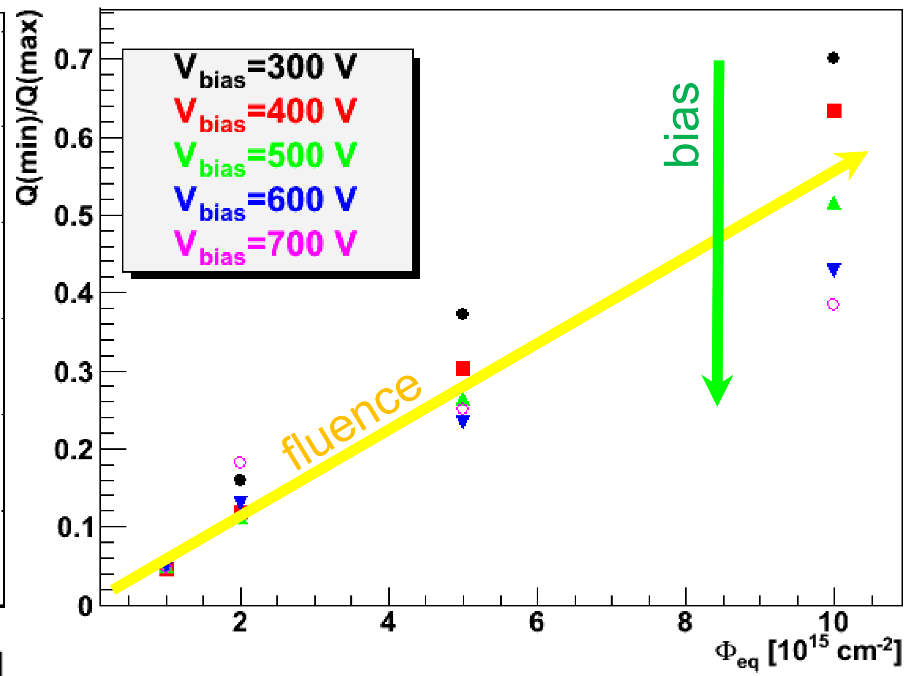



- Only the measurement after irradiation was possible – break down after first annealing step destroyed the detector
- Electric field is established in the whole detector – more pronounced double junction profile
- The electric field in the saddle should be more than E>0.3 V/μm
- At lower voltages electric field is uniform or even larger at the back

# Active region




- Active region decreases with fluence
  - as predicted at low fluences
  - less than predicted at high fluences
- The difference between highest and lowest efficient region decreases with fluence and increases with bias

**Conclusions:**

**•$V_{fd}$ predicts the $y_{act}$ up to $2 \cdot 10^{15}$ cm$^{-2}$**

**•Substantial E is established in whole detector for $\Phi_{eq} > 2 \cdot 10^{15}$ cm$^{-2}$**

**•The non-active region $y > y_{act}$ becomes more important – $y_{act}$ loses importance**

**•Charge multiplication close to the strips only adds to this beneficial effects**

# Conclusions

- $V_{fd}$ retains the validity as the parameter determining active region (high CCE region) up to $1\text{-}2\cdot10^{15}$ $cm^{-2}$ for neutron irradiated HPK sensors
  - The charge collection profile shows no significant deviation from $N_{eff}$=const.
  - The expected active region agrees well with predicted from RD48/50 measurements
- 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
  - Large injection rate reduces the charge collection from “non-active” region (i.e. active bulk)
  - The field in the middle of detector at $10^{16}$ $cm^{-2}$ is of order 0.5 V/$\mu$m at 700 V
- Annealing impacts the performance in positive way
  - before significant contribution from amplification the beneficial annealing is similar to the predicted from low fluence data
- Future plans
  - repeating the measurements with HPK sensors
  - studies on pion irradiated sensors
  - Edge-TCT parallel with strips (charge sharing, weighting field impact)