TCT measurements on Magnetic-Cz and Fz material

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Motivation:

Is Okmetic-Cz material inverted after proton irradiation?

- how to determine space charge sign in irradiated silicon
- how to interpret the measurements

Helsinki samples from Jakko Haerkoenen

- Fz – 1.2 kΩcm (V_{FD}=260 V), 300 μm
- Okmetic(magnetic) Cz - 1.1 kΩcm (V_{FD}=300 V), 300 μm

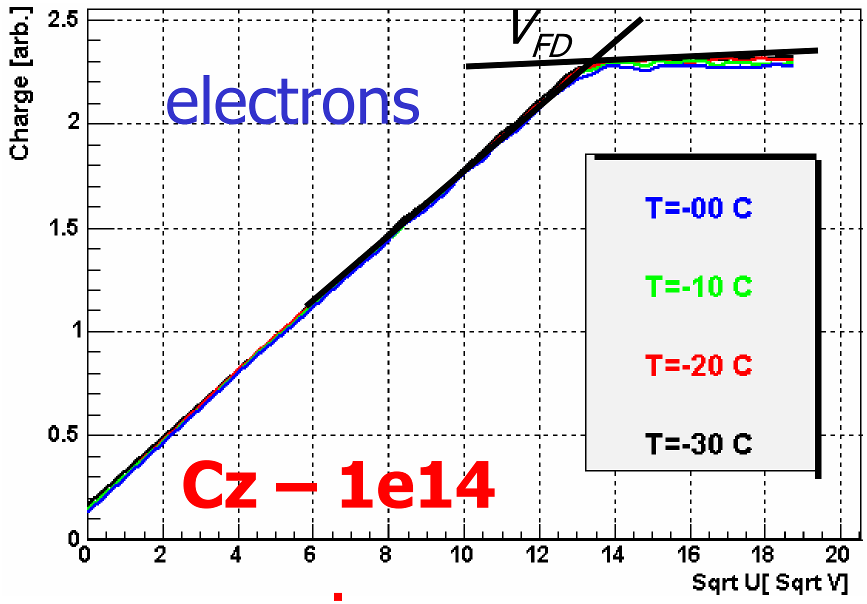
Irradiation:

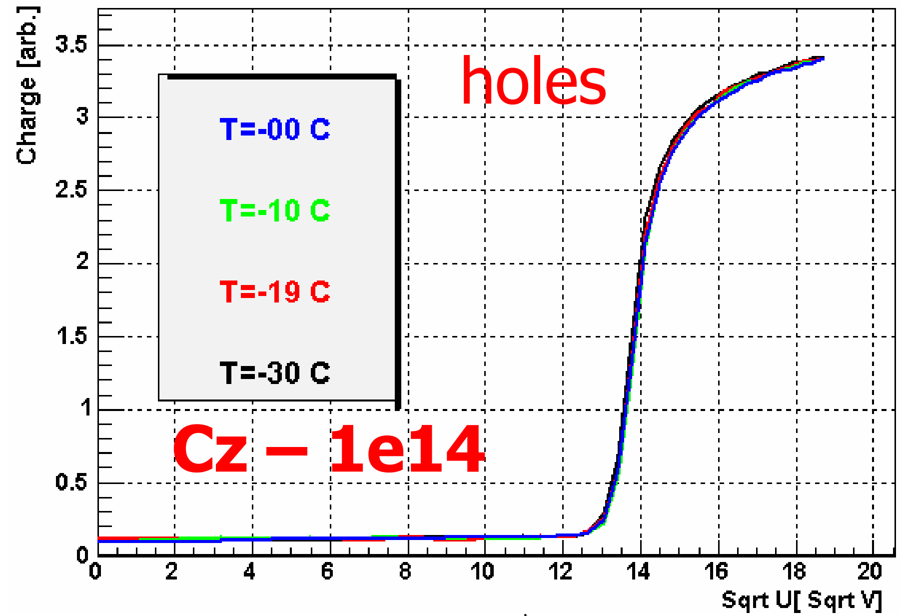
- fluence: 1×10^{14} p/cm^2 (Fz,Cz)
- fluence: 5×10^{14} p/cm^2 (Fz,Cz)

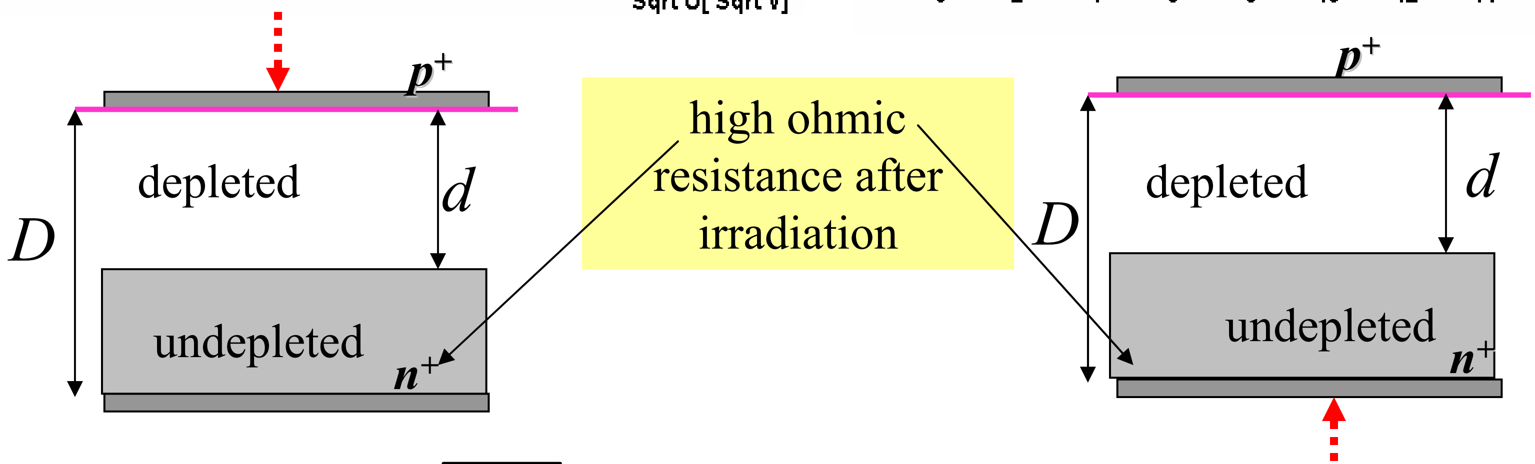
History: samples were annealed 2 weeks at RT

Measurements: TCT using the red laser

How to interpret Q(U) curves - diodes irradiated to “low” fluence?





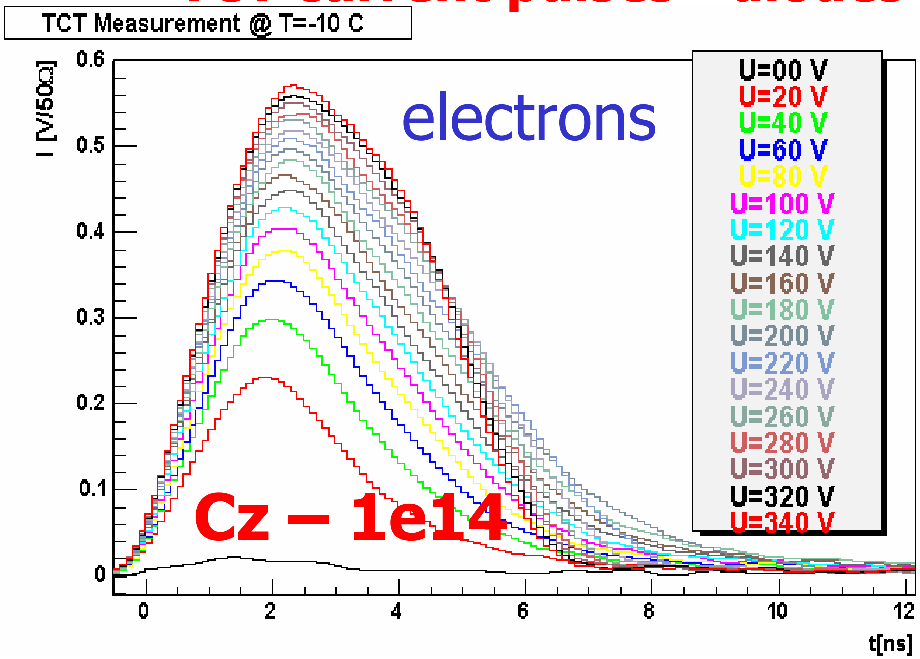


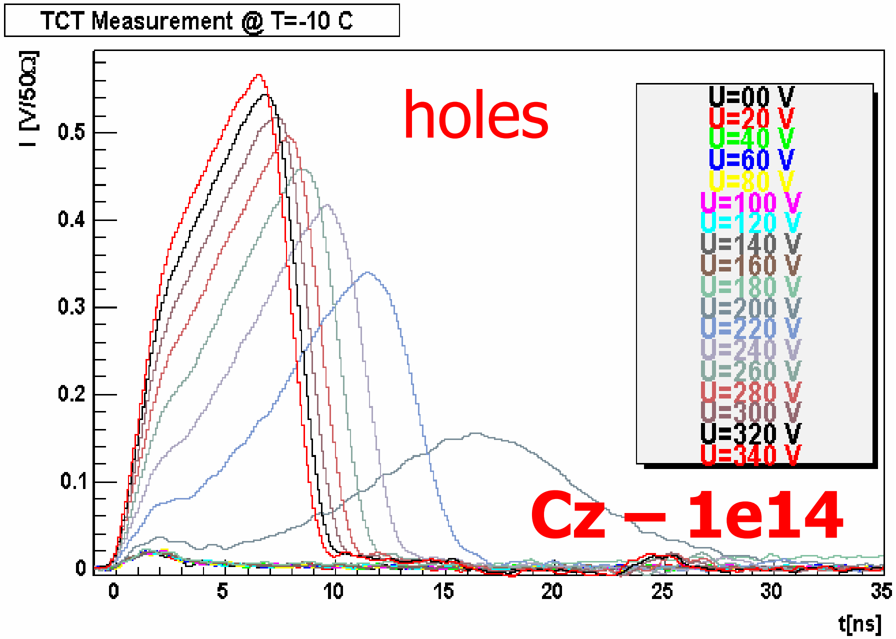
Steep transition at $U \sim V_{FD}$

$$Q \propto \frac{d}{D} \Rightarrow Q \propto \sqrt{\frac{U}{V_{FD}}} \rightarrow N_{eff} = const.$$

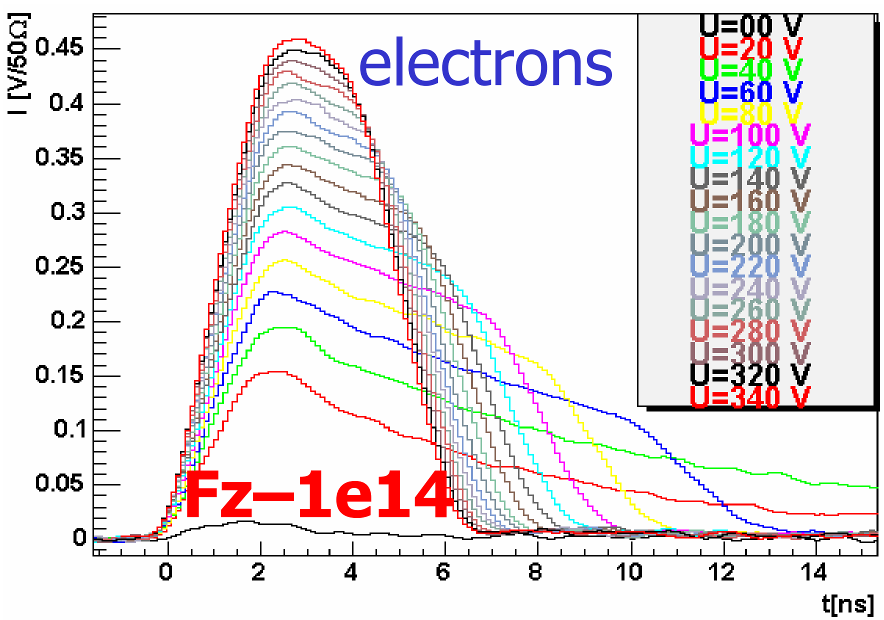
If the diode is inverted the picture is reversed!

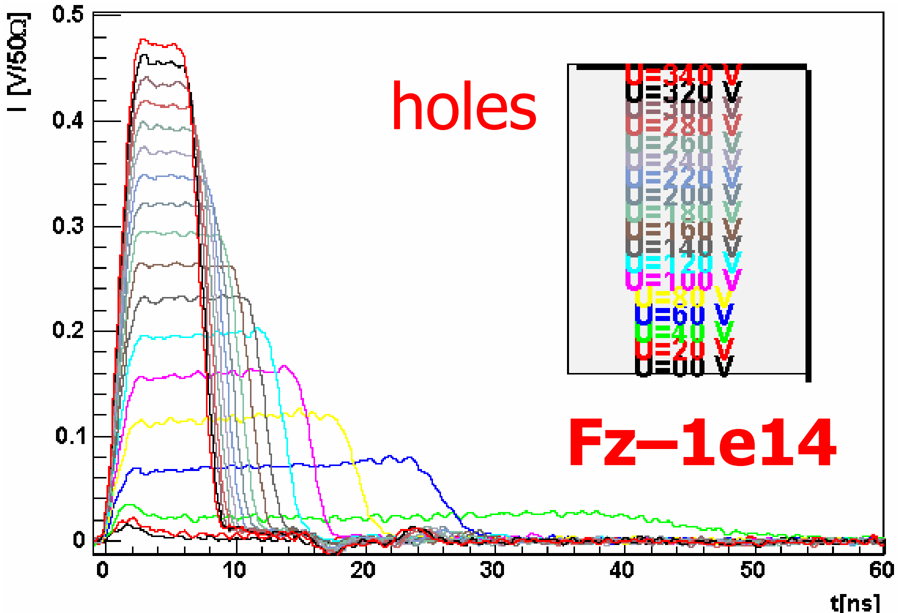
TCT current pulses - diodes irradiated to "low" fluence?



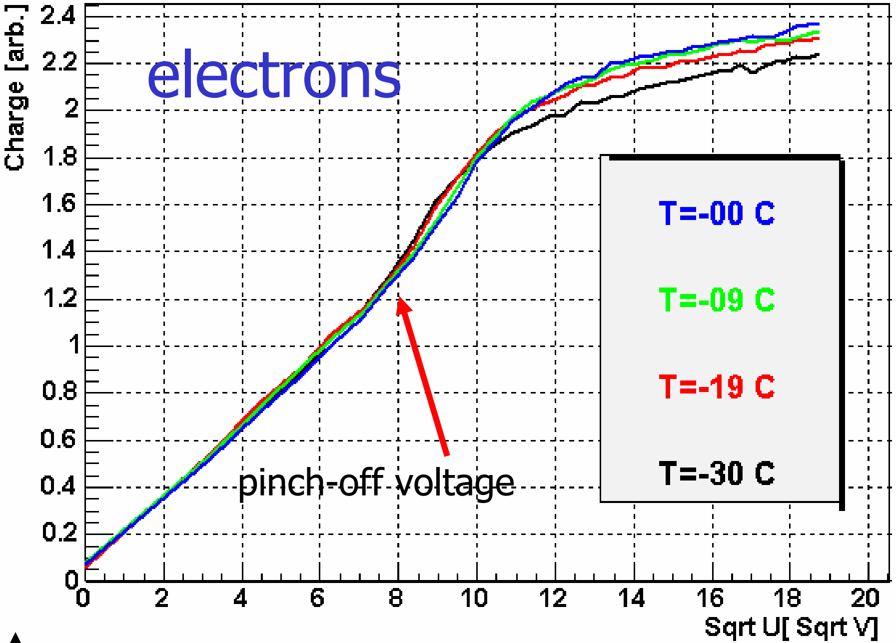


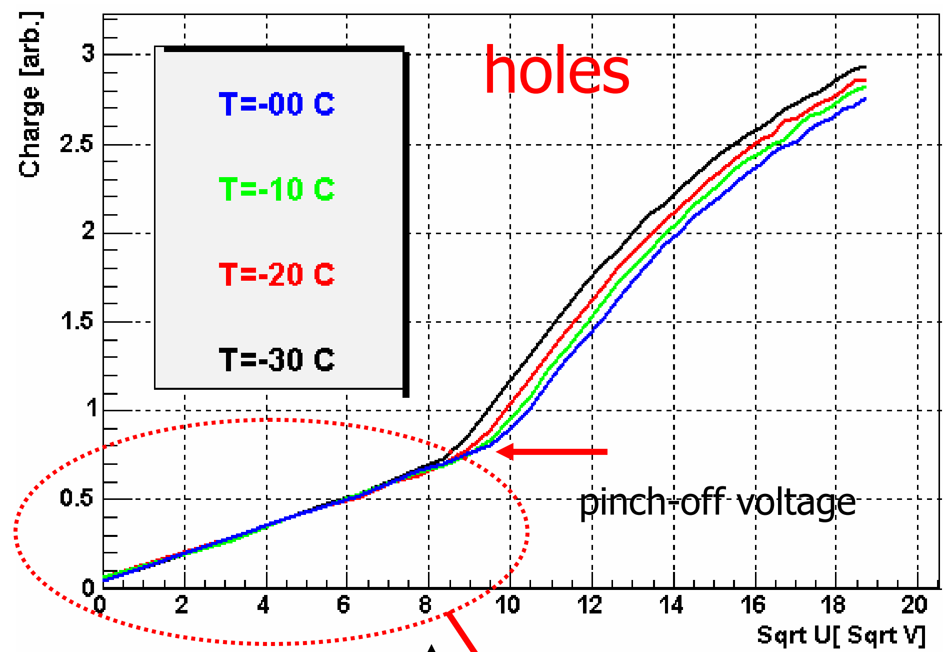
The TCT signals confirms the reasoning – <u>constant slope at higher voltages!</u>

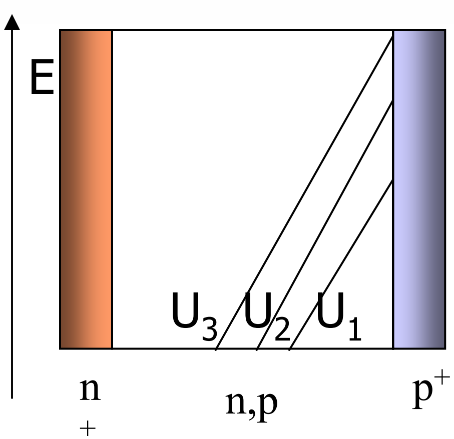




Cz – Irradiated to 5e14

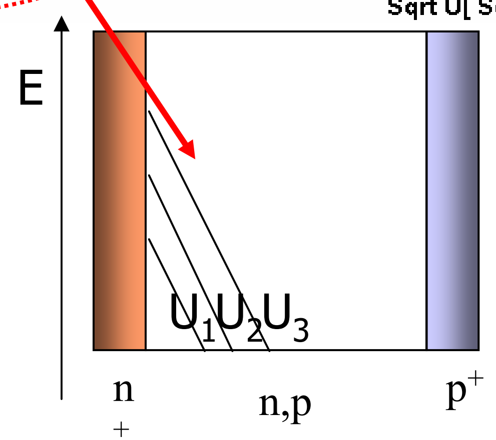






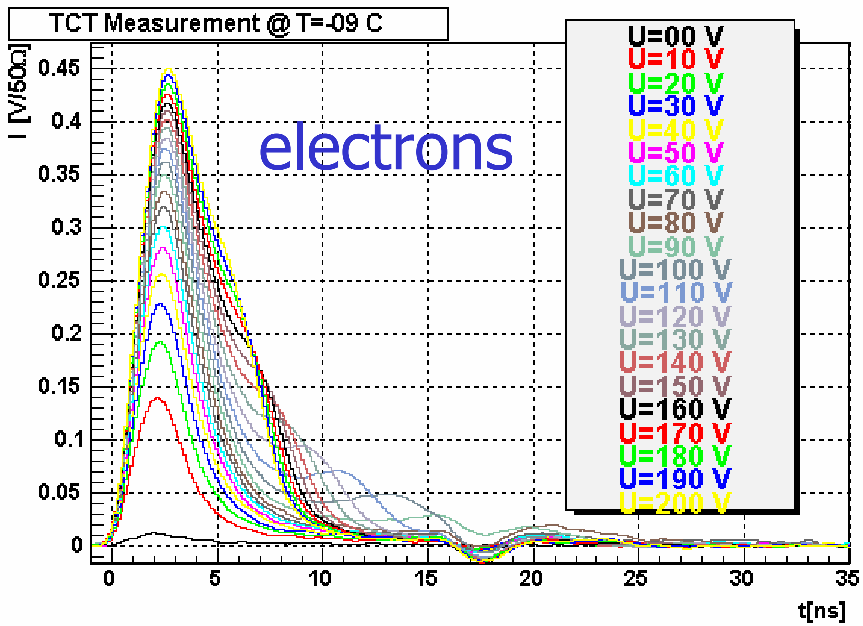
rough estimation:

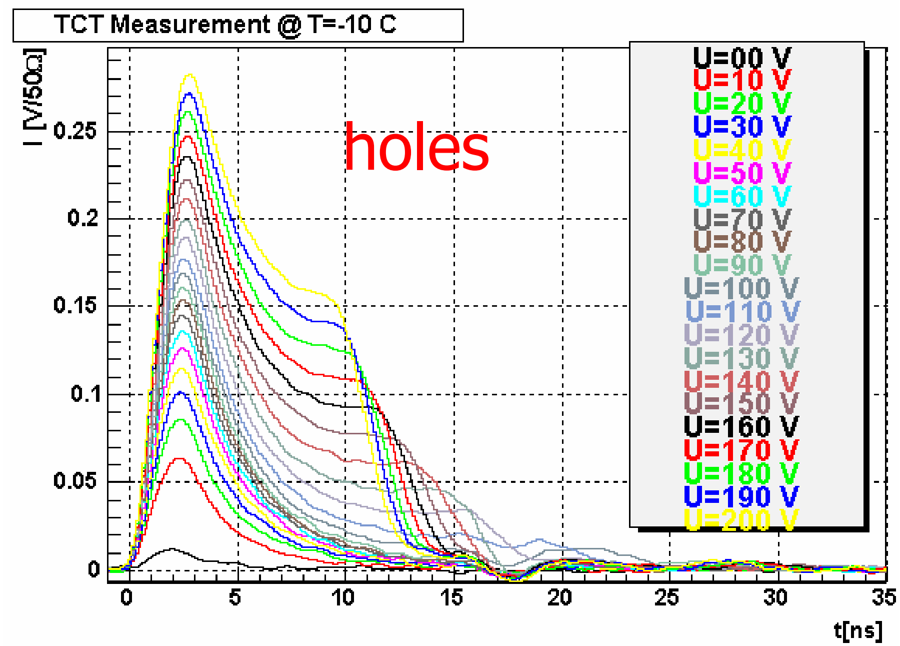
$$x_{pinch-off} \approx D \cdot \frac{Q_{pinch-off}}{Q_{V_{FD}}}$$



Charge plot for electrons/holes show that N_{eff} is not constant

Large hole signal (charge) already at low voltages – injection in electric field region



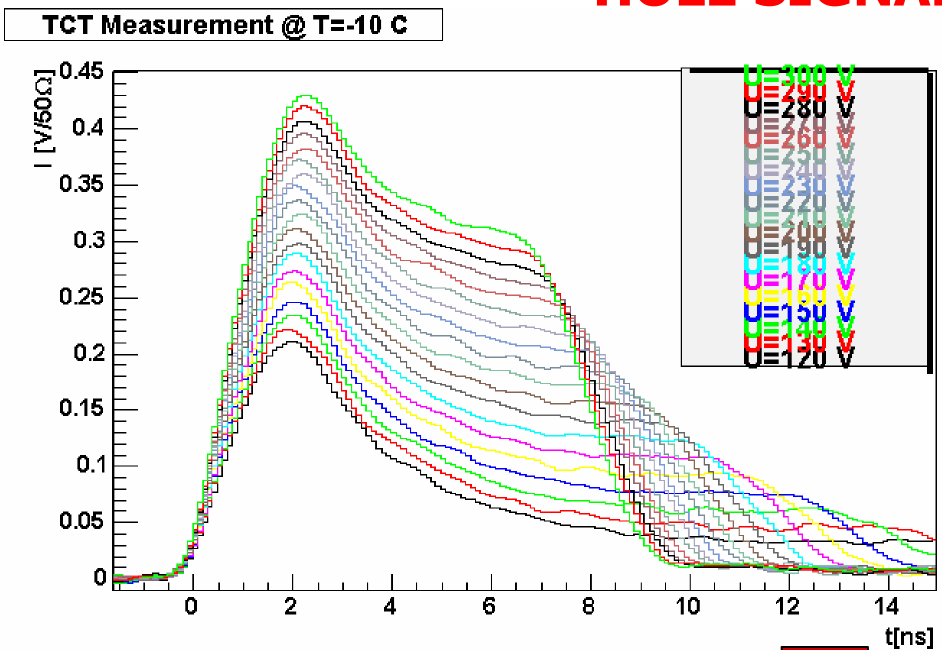


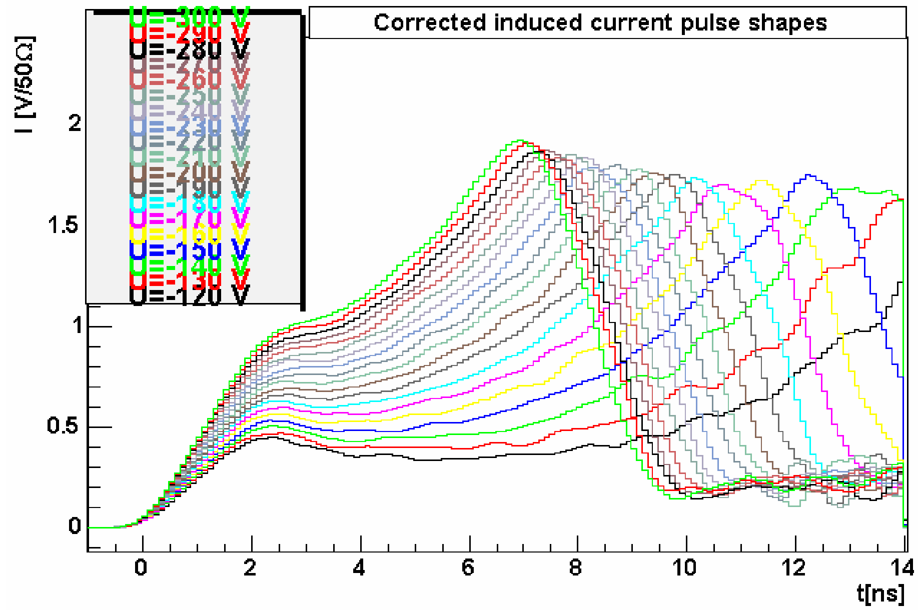
Both electron and hole seems to be injected in high field region, but…
what we measure/see is damped by trapping of the drifting charge

$$I_{e,h}(t) = N_0 \exp\left(\frac{-t}{\tau_{eff_{e,h}}}\right)\frac{1}{D}\ v_{e,h}(t)$$

To derive the electric field profile/space charge sign you must take trapping into account!

HOLE SIGNALS – Cz detector





trapping correction

τ=4.2 ns

<u>After full depletion</u> the slope of *I(t)* does not change sign

N_{eff} is of the same sign – not inverted !

larger U –> larger slope -> change in Neff

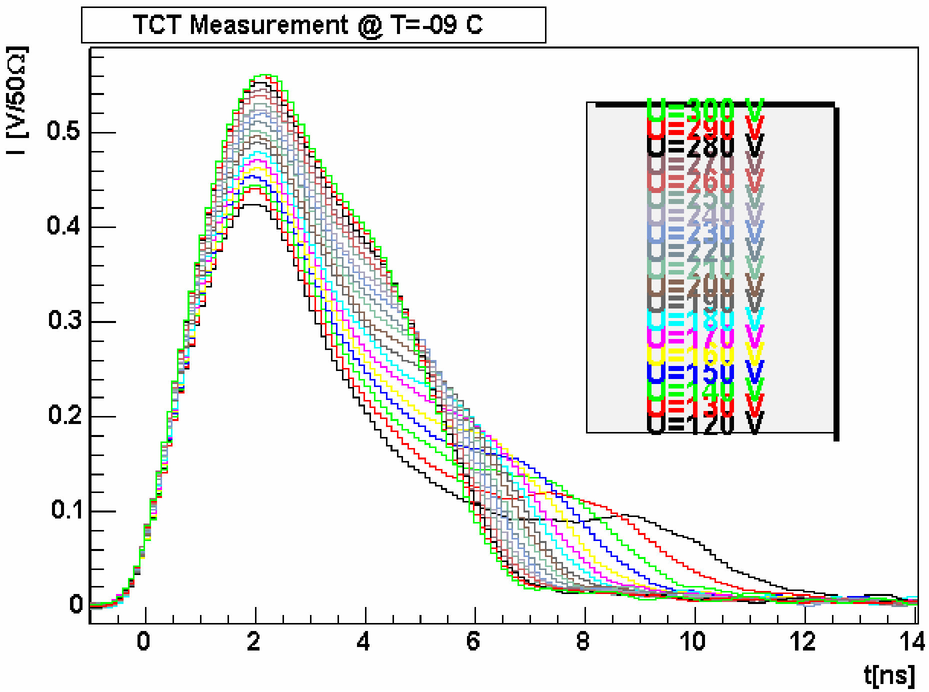
<u>rough explanation:</u>

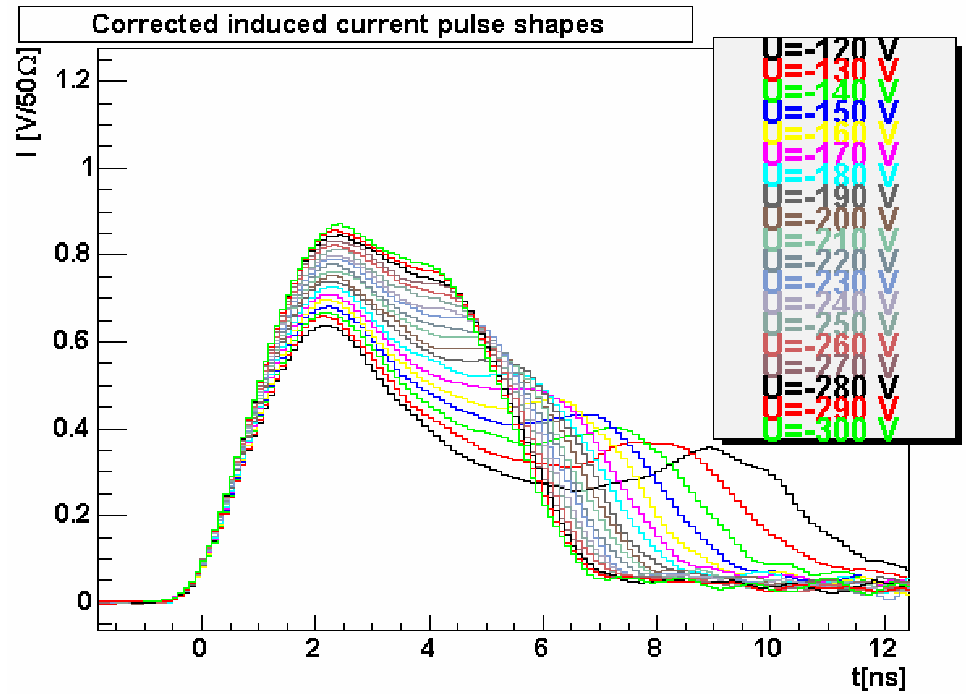
trapping of the free carriers (leakage current) is responsible for change in N_{eff}

$$I_e = -e_0 \cdot n \cdot v_e$$
$$I_h = e_0 \cdot p \cdot v_h$$

→ *n,p* depend on *U*,
hence occupation probability and N_{eff} as well

ELECTRON SIGNALS – Cz detector

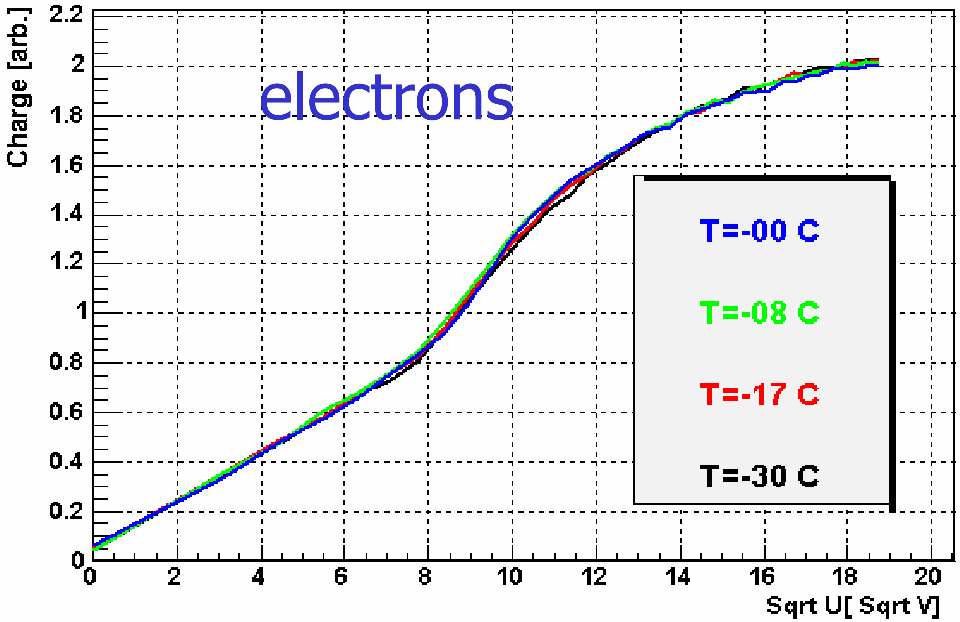


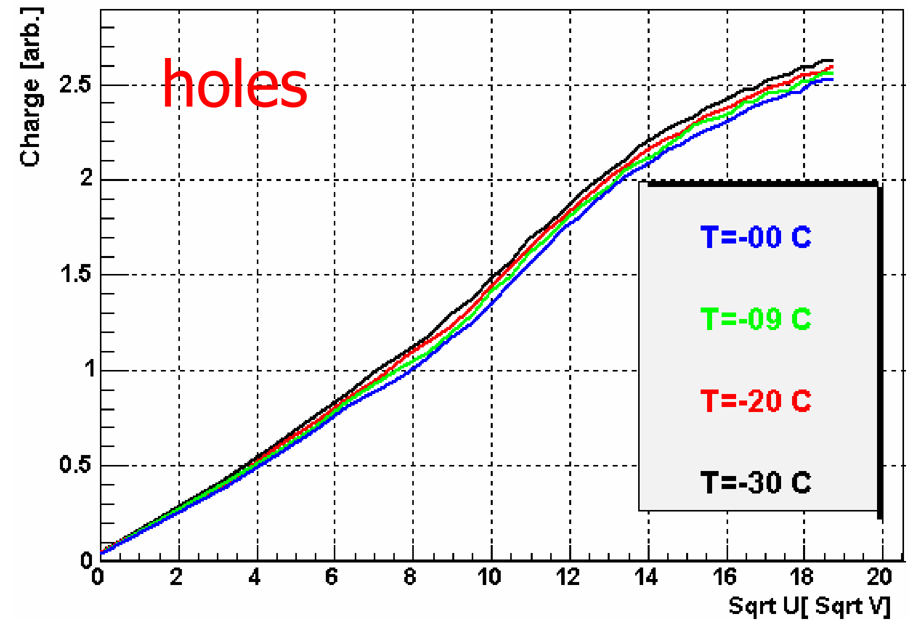


trapping correction τ=7.5 ns

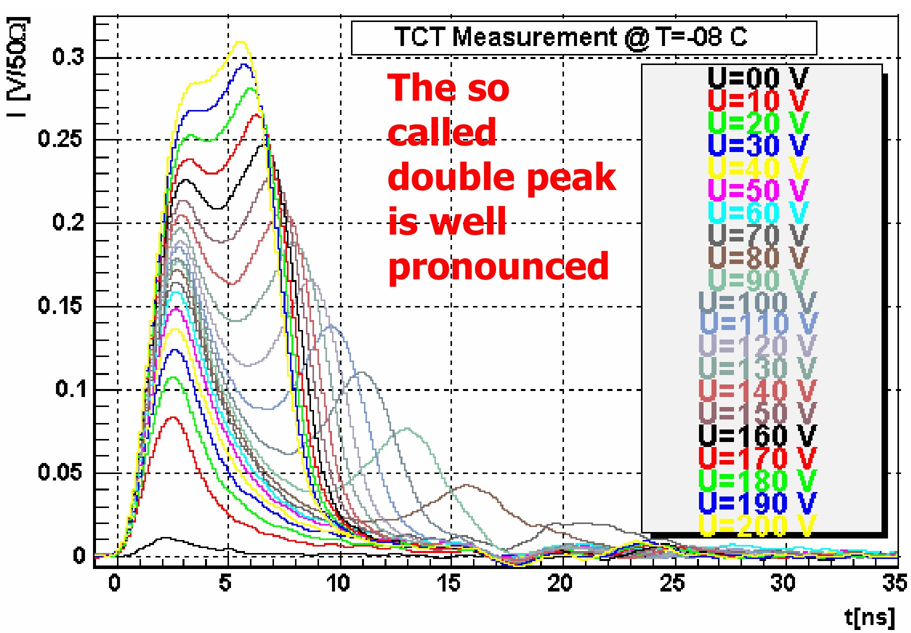
Same conclusions can be drawn as from the hole signal!

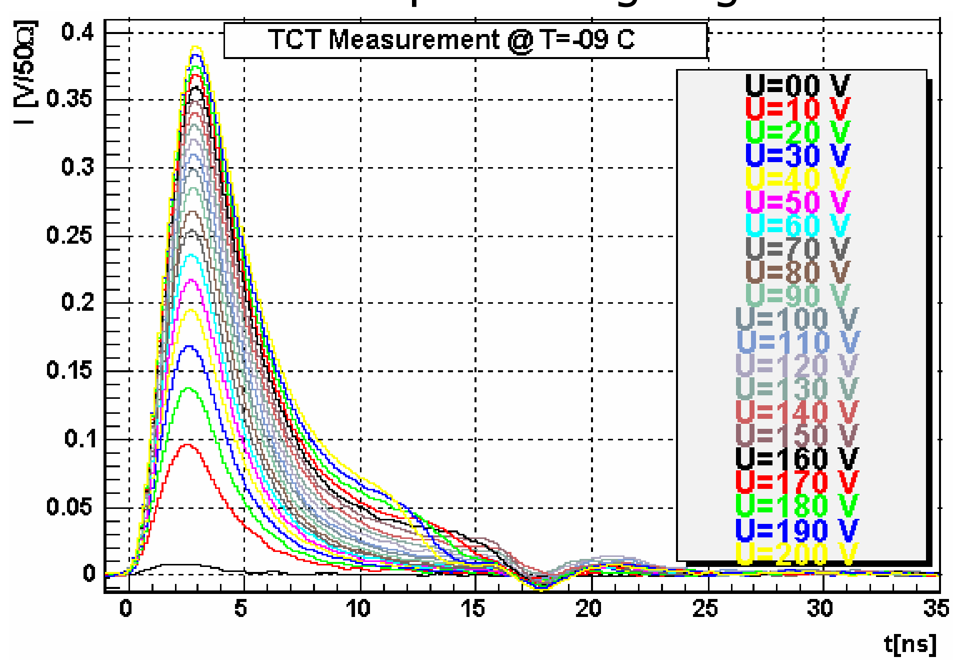
Fz – Irradiated to 5e14

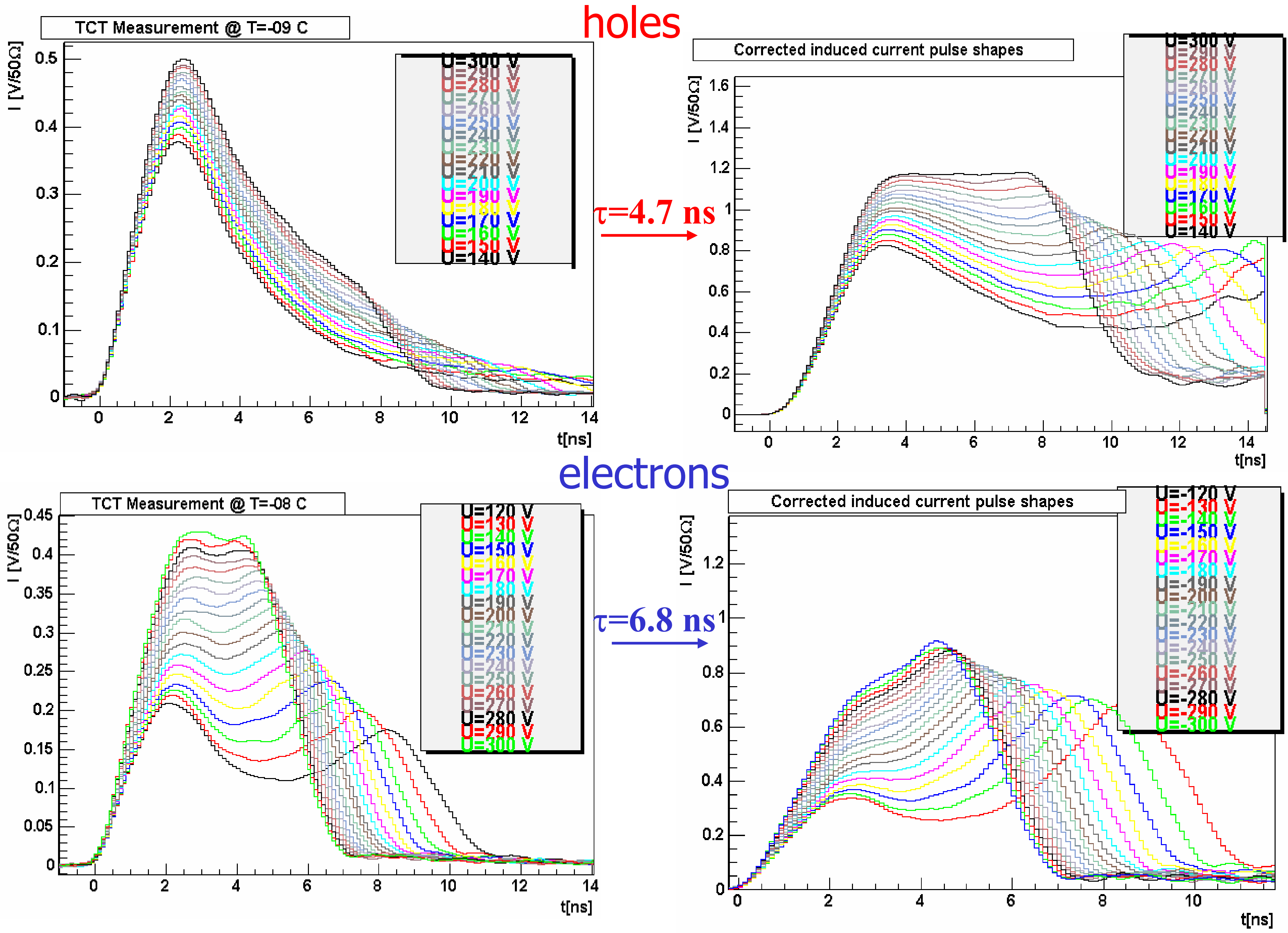




For FZ material it is impossible to determine the space charge sign!



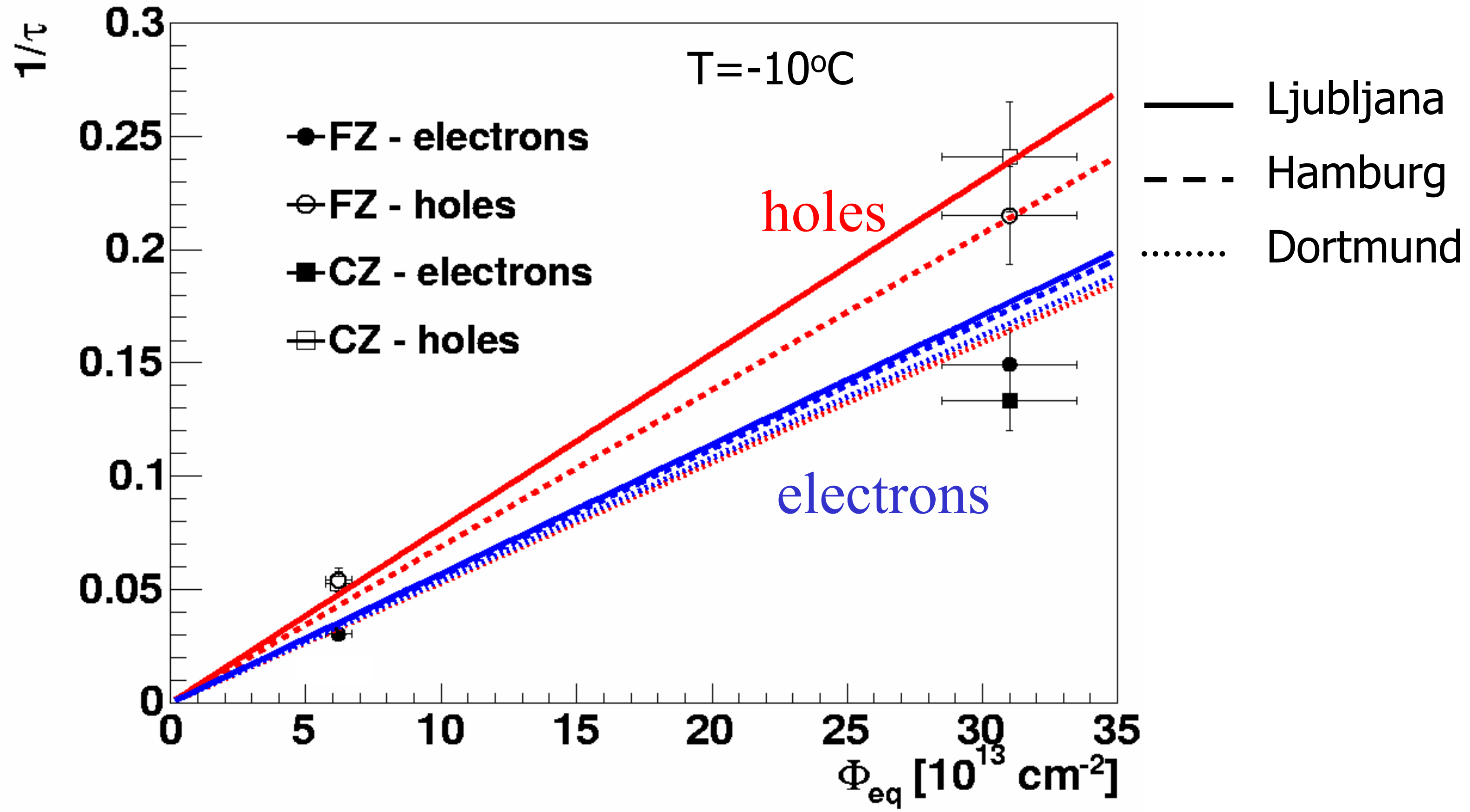




holes
TCT Measurement @ T=-09 C
I [V/50Ω]
t[ns]
U=300 V
U=290 V
U=280 V
U=270 V
U=260 V
U=250 V
U=240 V
U=230 V
U=220 V
U=210 V
U=200 V
U=190 V
U=180 V
U=170 V
U=160 V
U=150 V
U=140 V
τ=4.7 ns
Corrected induced current pulse shapes
I [V/50Ω]
t[ns]
U=300 V
U=290 V
U=280 V
U=270 V
U=260 V
U=250 V
U=240 V
U=230 V
U=220 V
U=210 V
U=200 V
U=190 V
U=180 V
U=170 V
U=160 V
U=150 V
U=140 V
electrons
TCT Measurement @ T=-08 C
I [V/50Ω]
t[ns]
U=120 V
U=130 V
U=140 V
U=150 V
U=160 V
U=170 V
U=180 V
U=190 V
U=200 V
U=210 V
U=220 V
U=230 V
U=240 V
U=250 V
U=260 V
U=270 V
U=280 V
U=290 V
U=300 V
τ=6.8 ns
Corrected induced current pulse shapes
I [V/50Ω]
t[ns]
U=-120 V
U=-130 V
U=-140 V
U=-150 V
U=-160 V
U=-170 V
U=-180 V
U=-190 V
U=-200 V
U=-210 V
U=-220 V
U=-230 V
U=-240 V
U=-250 V
U=-260 V
U=-270 V
U=-280 V
U=-290 V
U=-300 V

Determination of trapping times

Using CCM/ECC the trapping times were derived. For both materials they are compatible with previous measurements!
no dependence of trapping times on material type



Conclusions

2 Fz and 2 Magnetic-Cz diodes irradiated to 10^{14} cm^{-2} and 5x10^{14} cm^{-2} were studied!

Cz material is found not-inverted at voltages above V_{FD} for both fluences (below full depletion voltages sign of the space charge is not well defined) ,
while Fz material is inverted at larger fluence !

In order to determine sign of the space charge from TCT signals one must take trapping into account!

In many cases space charge sign can be deduced also from Q(V) plot!

Electric field profile in the detector (diode)

induced current pulse shape (measured) ✓
weighting field (pad detector-1/D) ✓
mobility parameterization (literature) ✓
effective trapping times of e,h ✓

→ extract $\boldsymbol{E(x)}$ $(E(x(t)), x(t))$

↓ determine $N_{eff}(x)$

$$I_{e,h}(t) = N_0 \exp\left(\frac{-t}{\tau'_{eff_{e,h}}}\right)\frac{1}{D}\, v_{e,h}(t)$$

$$x_{e,h}(t) = \int_{t_0}^{t} I_{e,h}(t')\,\frac{D}{N_0}\exp\left(\frac{t'}{\tau'_{eff_{e,h}}}\right) dt' \quad \Rightarrow \quad D = x_{e,h}(t_t)$$

$$v_{e,h}(t) = \mu_{e,h}(E(t))\,E(t) = I_{e,h}(t)\,\frac{D}{N_0}\exp\left(\frac{t}{\tau'_{eff_{e,h}}}\right)$$

(green circle) input-meas. parameters

(red circle) unknown parameters

More reliable determination from holes signals
(longer signal, less influence of laser width)!

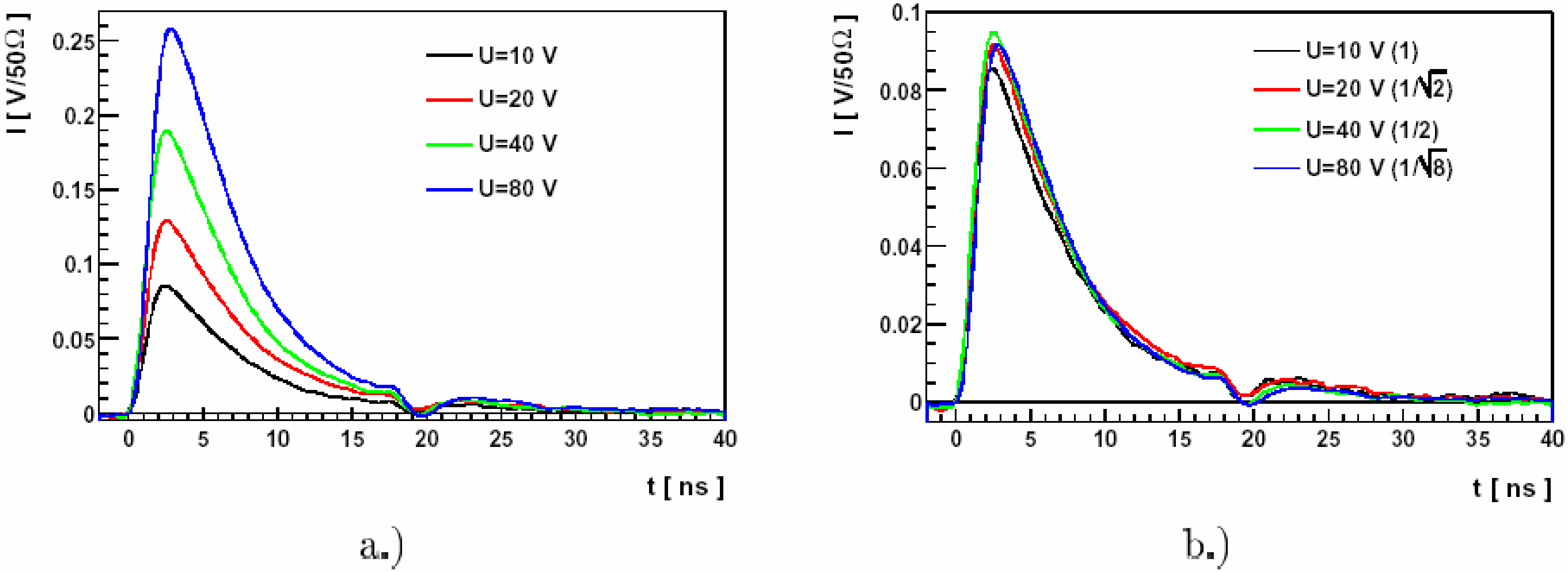
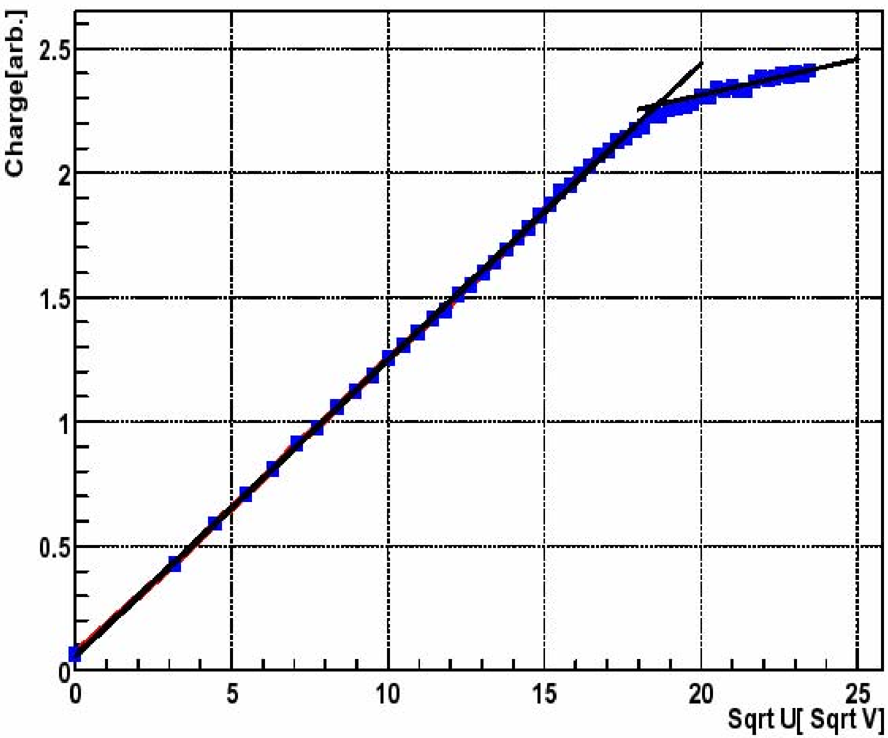


Figure 5.15 : a.) Induced current after hole injection for sample W317 irradiated with neutrons to $\Phi_{eq} = 7.5 \cdot 10^{13}$ cm^{-1} ($V_{FD} = 103$ V). Measurements were performed at $T = 10°$C. b.) The induced currents from a.) are scaled with $\sqrt{10\ \mathrm{V}/U}$. The scaling factor is given in brackets.

$$t_c = \frac{w}{v_{dr_h}} = \frac{w^2}{\mu_{0_h} U} \propto \frac{1}{\mu_{0_h}} \quad , \quad w^2 \propto U.$$

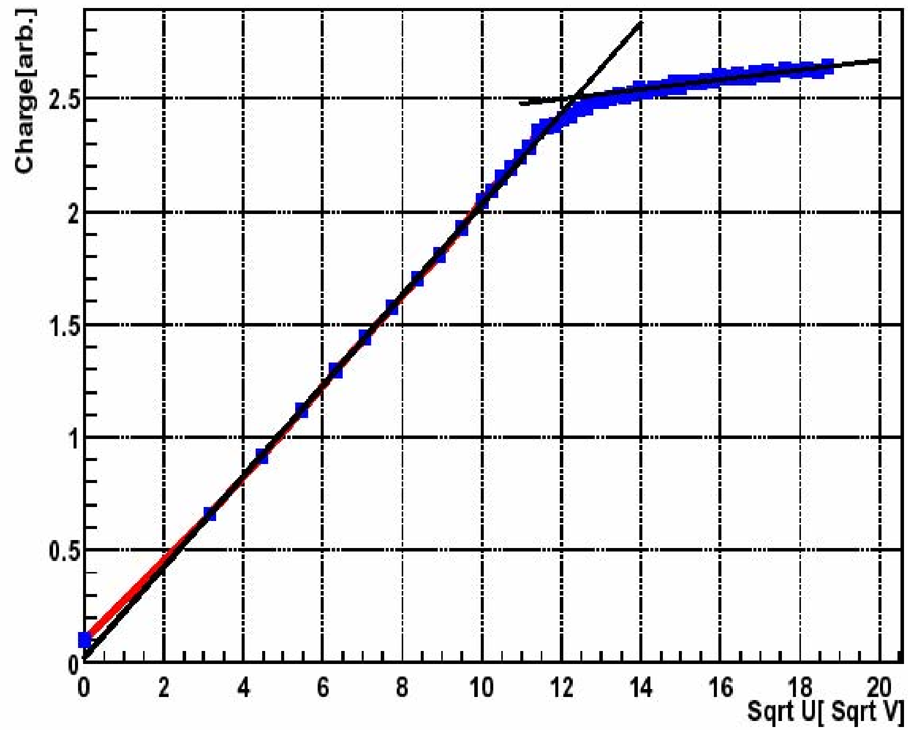
Standard material irradiated with neutrons:



$\Phi_{eq}=2x10^{14}\ cm^{-2},\ V_{FD}=295\ V$

$N_{eff} \approx const.$

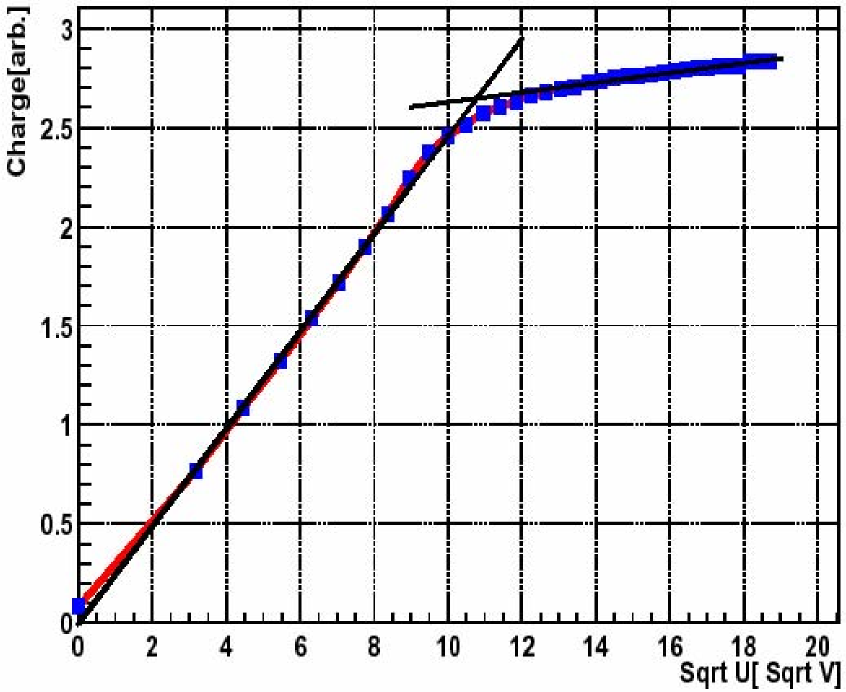
Oxygenated material irradiated with neutrons:



$\Phi_{eq}=7.5x10^{13}\ cm^{-2},\ V_{FD}=105\ V$

$N_{eff} \approx const.$

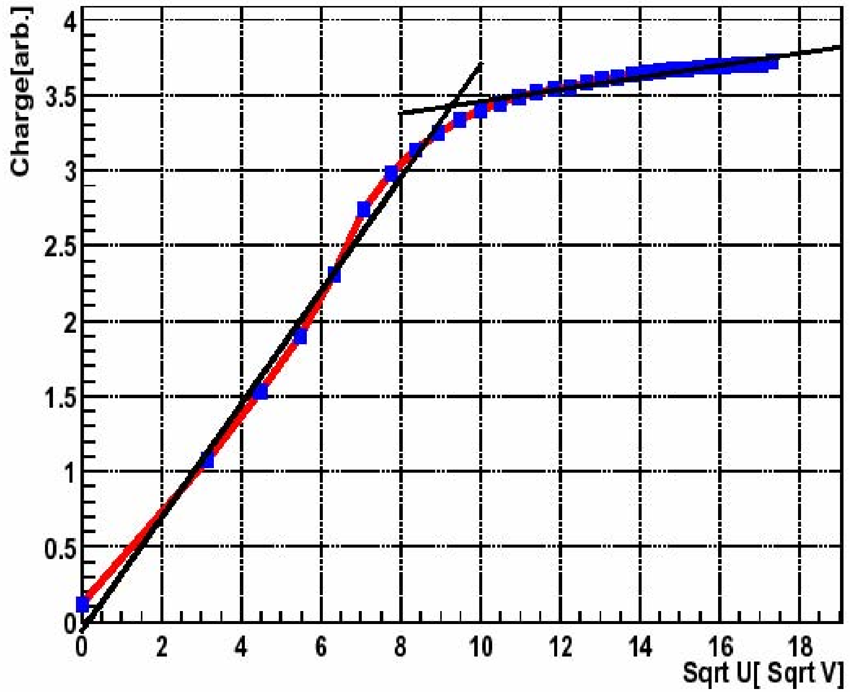
Standard material irradiated with protons:



Φ_{eq}=5x10^{13} cm^{-2}, V_{FD}=70 V

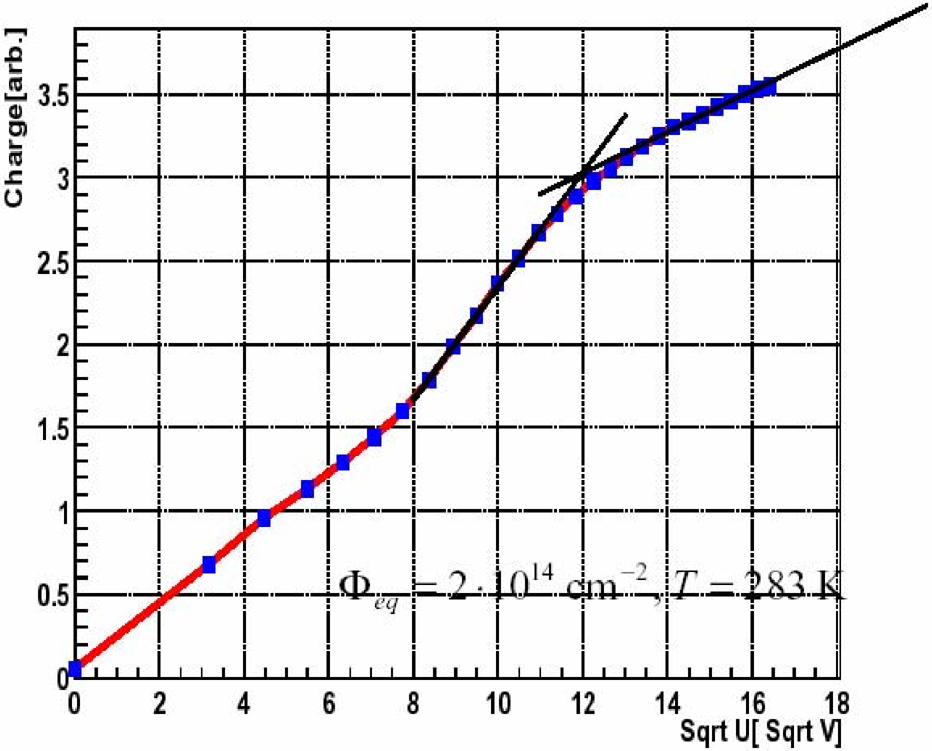
$N_{eff} \approx const.$

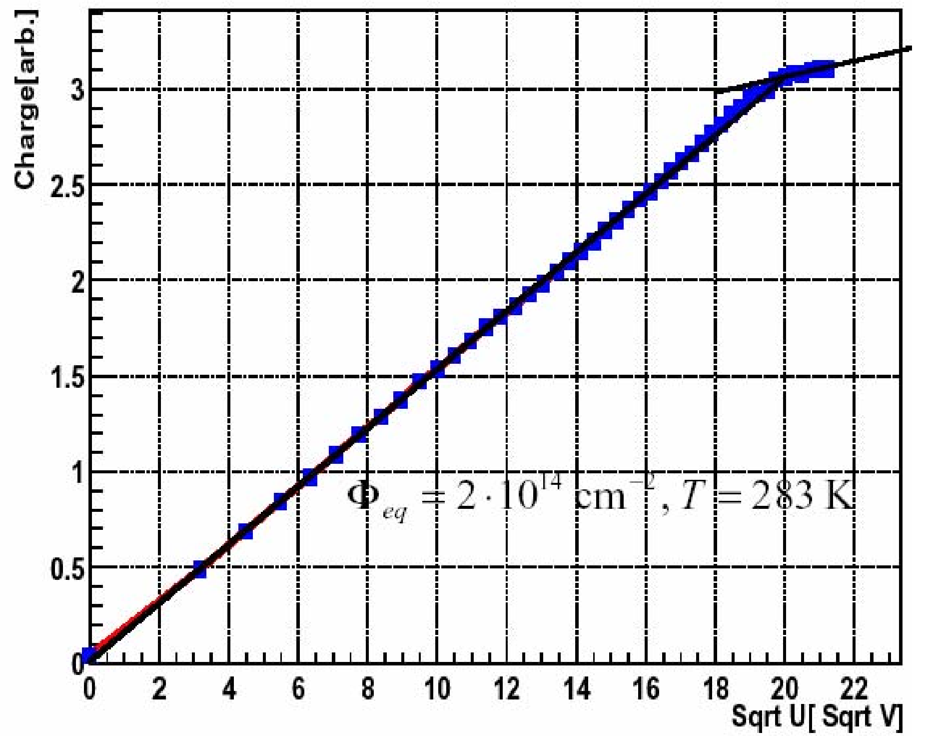
Oxygenated material irradiated with protons:



Φ_{eq}=5.4x10^{13} cm^{-2}, V_{FD}=65 V

$N_{eff} \neq const.$





Oxygenated material irradiated with <u>protons</u> to high fluence

Standard material irradiated with <u>protons</u> to high fluence

In oxygenated material electric field is more uniform (lower V_{FD}) after irradiation with charged hadrons compared to standard material!

Less overdepletion is needed for the same CCE, but at high voltages there should not be any difference!