Determination of the electric field in highly-irradiated silicon sensors using edge-TCT measurements

R. Klanner[+], G. Kramberger[*], I. Mandić[*], M. Mikuž[*], M. Milovanović[*], J. Schwandt[+]

[*]Jožef Stefan Institute Ljubljana

[+]Univeristy of Hamburg

Motivation

- Modelling the electric field for heavily irradiated n^+-p sensors
  - input to simulations
  - understanding the radiation damage at high fluences
  - where does the “standard” device model break down?

- Conventional-TCT which was used to extract the electric field shape at low fluences from the time evolution of the induced currents is not possible – too much trapping. But Edge-TCT (*IEEE Trans. Nucl. Sci. Vol. 57(4), 2010, p. 2294*) can …

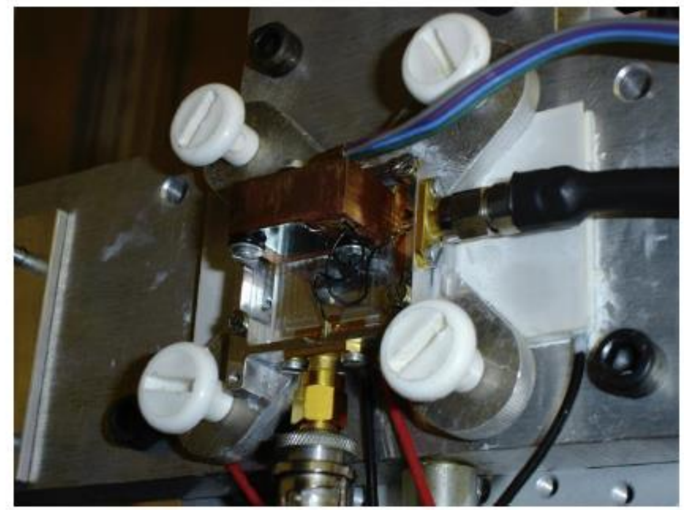
- It aims to develop a method allowing accurate extraction of measurements. It should be easily fed to the simulators and should serve to understand also the fundamental reasons for the change.

Samples and measurement technique

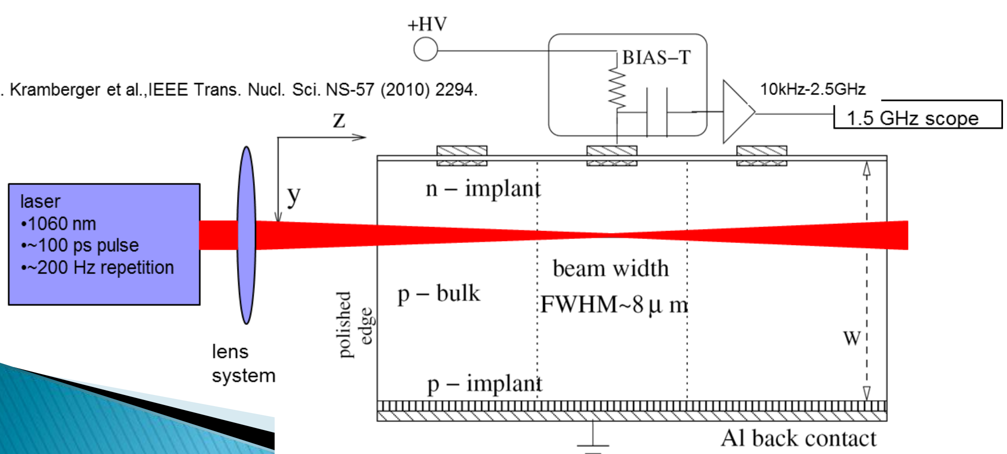
ATLAS 07 mini-strip sensors (single p-stop+p-spray isolation)

Thickness µm	Crystal orientation	pitch µm	n^+ width µm	Strip length cm	Area cm^2	B-doping cm^{-3}	U_{fd} V
300	⟨100⟩	100	20	0.8	0.62	2.8×10^{12}	180

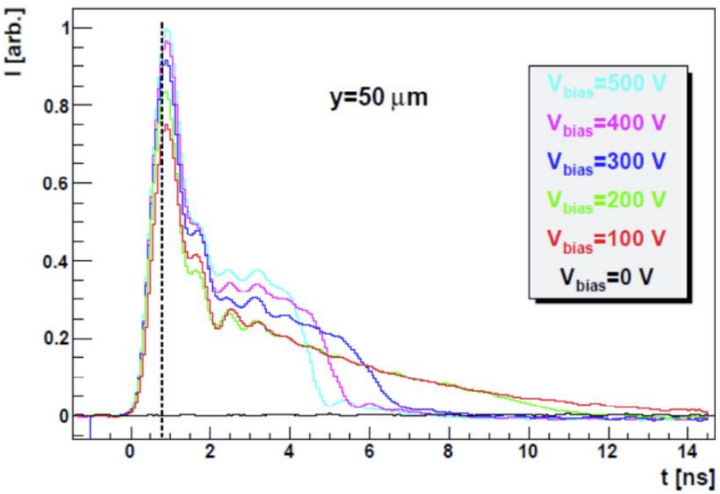
- Samples irradiated with reactor neutrons to 1,2,5,10e15 cm^{-2} and 200 MeV pions to 1.5e15 cm^{-2}
- Samples were irradiated for 80min @ 60ºC
- Samples were measured at -20ºC and measured in forward and reverse direction with Edge-TCT (neighbors at the same potential as the strips)



G. Kramberger et al.,IEEE Trans. Nucl. Sci. NS-57 (2010) 2294.



Measurement of velocity profiles



$$I(y,t\sim 0)\approx\frac{Ae_0N_{e,h}}{W}\left[\bar{v}_e(y)+\bar{v}_h(y)\right]\quad ,\quad t<<\tau_{eff,e,h}$$

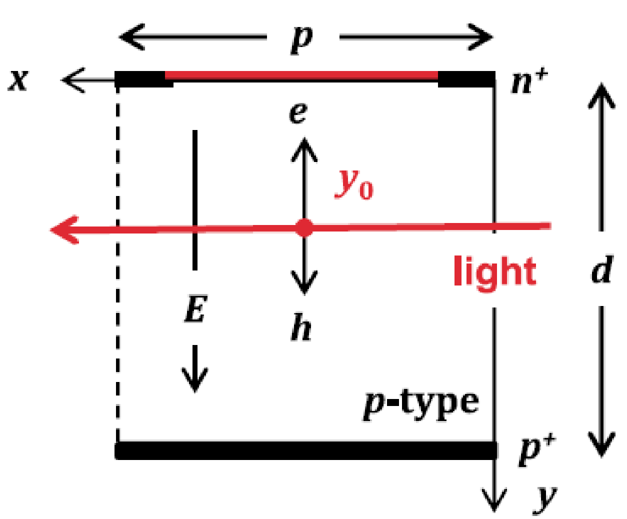
The trapping can be completely taken out of the equation!

(The major obstacle of extraction of physics parameters from time evolution in conventional/Top-TCT is severe trapping)

Different methods were tried in [200,t_{int}]

- integral
- value at different times
- slope of the current pulse rise

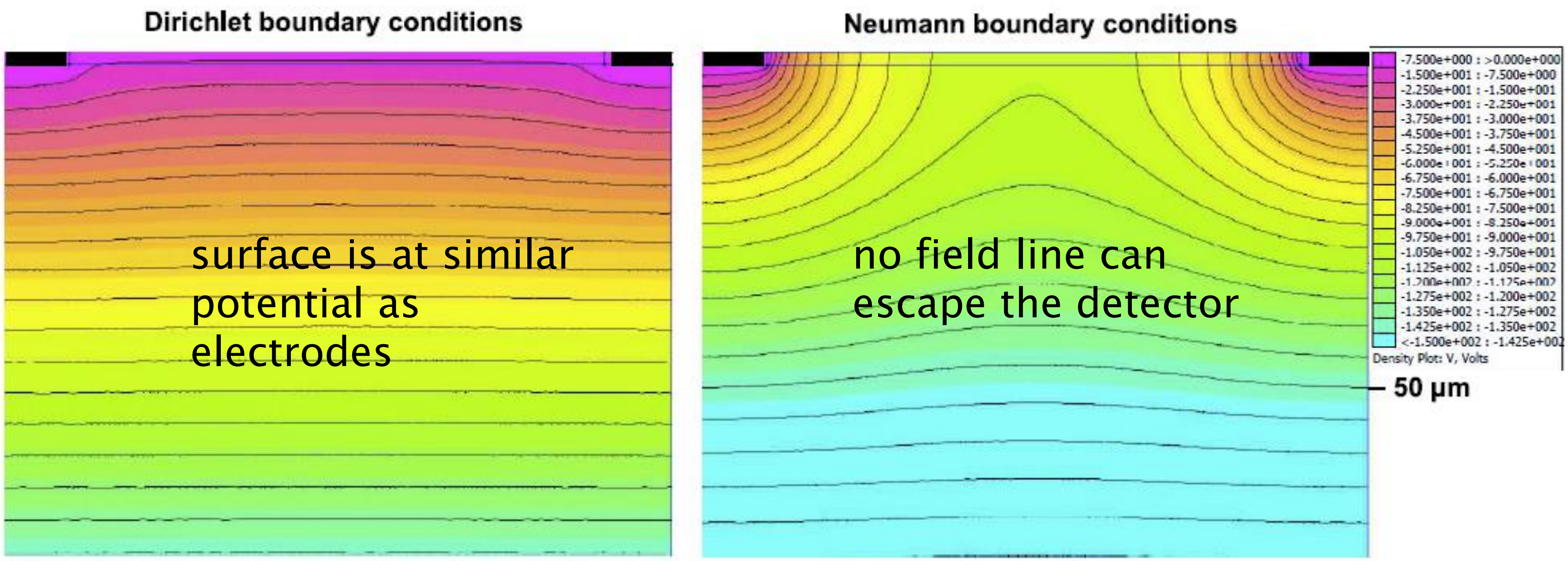
Comparable results for all – no big difference between them



Correctness of the above equation depends on several assumptions:

- attenuation of the laser should be small over the distance of several strips – effective weighting field
- implant width/strip pitch should be as close to 1 as possible – effecting the drift paths and effective weighting field
- trapping is much longer than the rise time

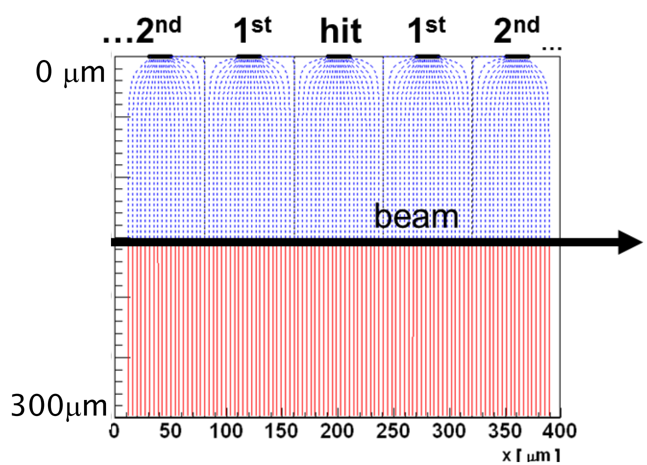
Effect of strip proximity/surface



- the surface condition (humidity/temperature, salts, impurities on the surface influence the electric field)
- assumption of electric field with only E_y component can be too simplistic
- as this conditions can change with time/temperature/humidity it is difficult to know them
- in the analysis of the data this effects can be probed/evaluated by changing the start of first (modeling)

Effect of finite attenuation length

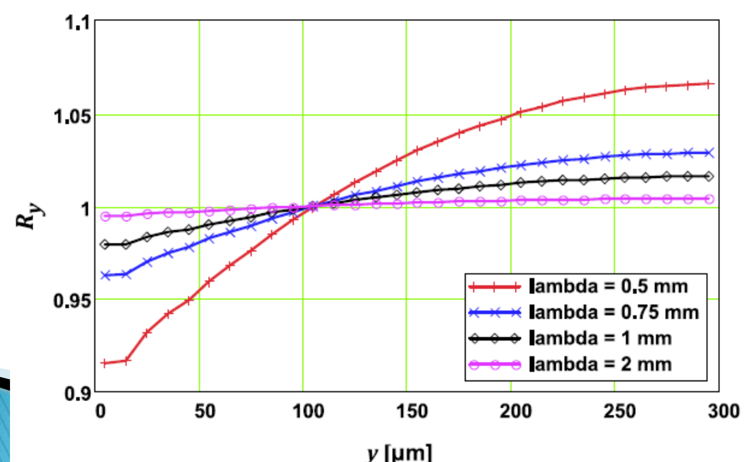
- Induction from the neighbors is affected by the attenuation (follows from symmetry)
- Simulation of 6 neighbors was used to check the influence on effective weighting field

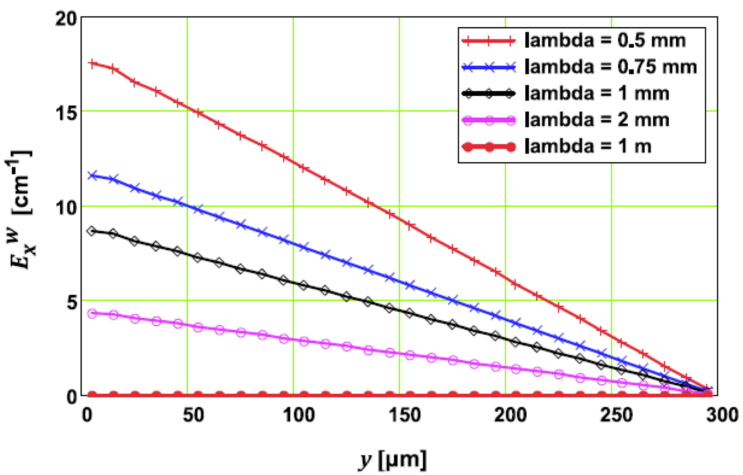


$$\overrightarrow{E_w} = \frac{1}{p}\int \overrightarrow{E_w}(\vec{r})\,\exp(-\lambda_{abs}\cdot x)\,dx$$

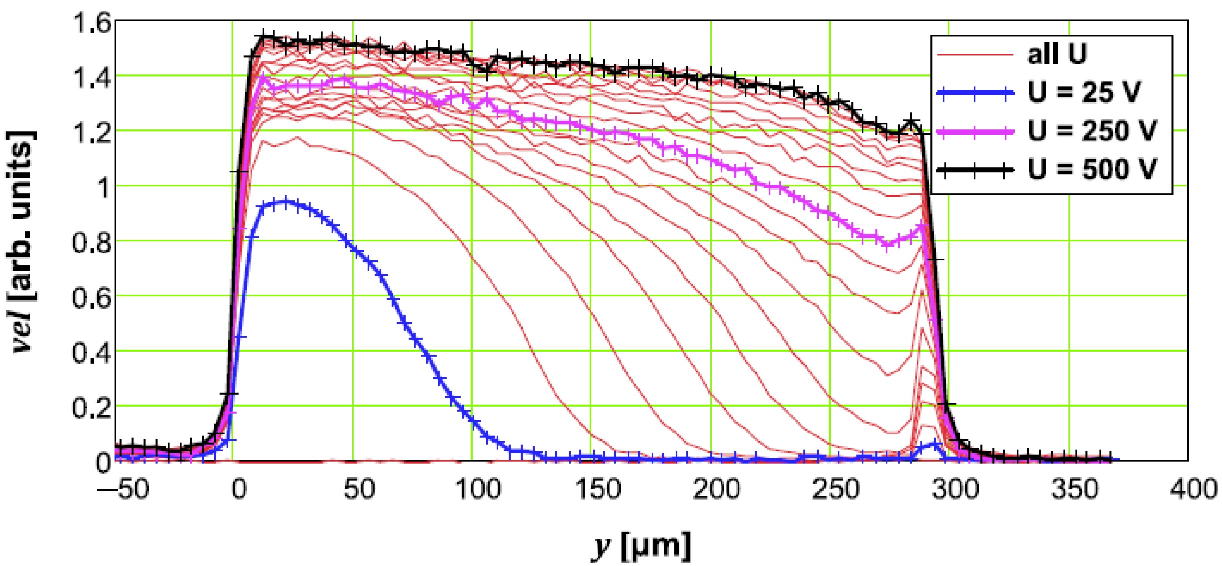
$$R_y = \frac{E_w(\lambda_{abs})}{E_w(\lambda_{abs}\to\infty)}$$

- For 6 strips the difference in Ew<10% (the more strips are bonded the better)
- Only for $\lambda_{abs} \to \infty$ the $E_w(\lambda_{abs})$ sums from all contributions yield effectively weighting field of the Ew=(0,1/W,0)
- Simulation of 6 neighbors (von Neuman boundary condition – worst case) was used to check the deviation from Ew=(0,1/W,0)





Modeling-extraction of the Efield



- Step in y was 5 μm defining N_E points in which field E_k is calculated (free parameters of the fit)

$$\chi^2 = \frac{1}{\sigma_{vel}^2} \sum_{k=1}^{n_k} \left(1 - \frac{vel_k}{vscale \cdot u_k}\right)^2 + w_{pen} \sum_{i=2}^{n_E - 1} \left(\frac{0.5 \cdot (E_{i-1} + E_{i+1}) - E_i}{E_i}\right)^2$$

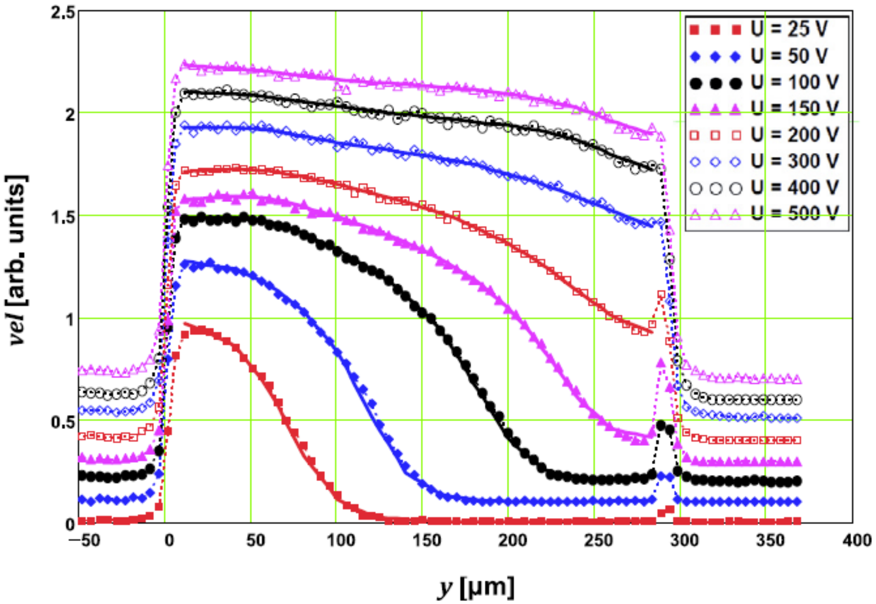
$$u_k = \left(\mu_h(E_k) + \mu_e(E_k)\right) \cdot E_k$$

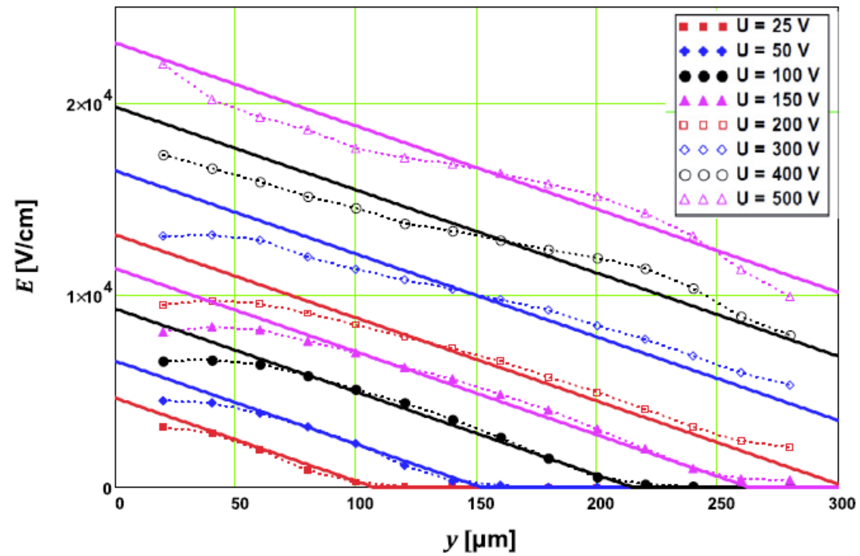
Constrain:

$$\int_0^d E(y)\, \mathrm{d}y = U$$

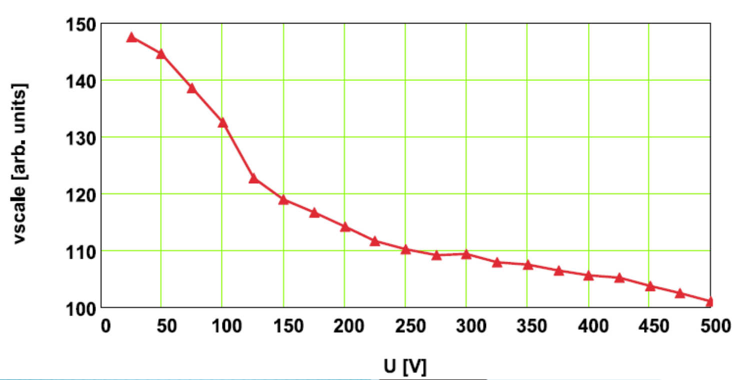
σ_{vel} – relative uncertainty of velocities ~ 2%
vel_k –measured velocity profiles
vscale – measured scale is relative
w_{pen} – dumps large fluctuations of the field

Electric field in non-irradiated detector





- very good agreement of the model (solid lines) with data points (shifted by 0.1for clearer view)
- extracted electric field is in reasonable agreement with the electric field in pad detector with uniform doping

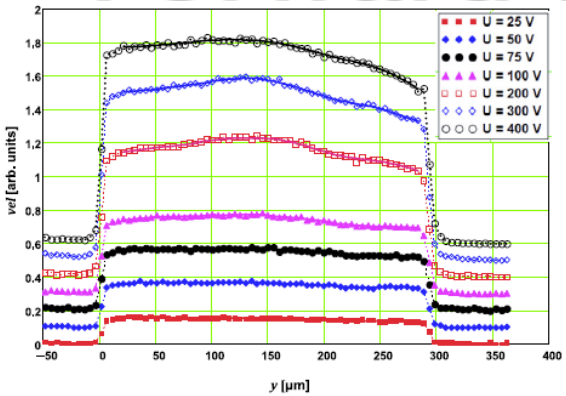


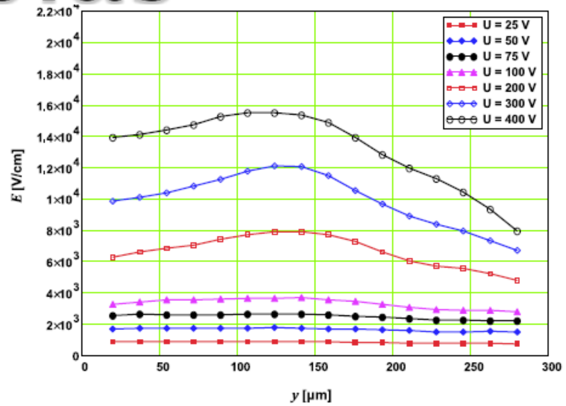
vscale parameter is a function of voltage, due to: finite rise time of intial current an

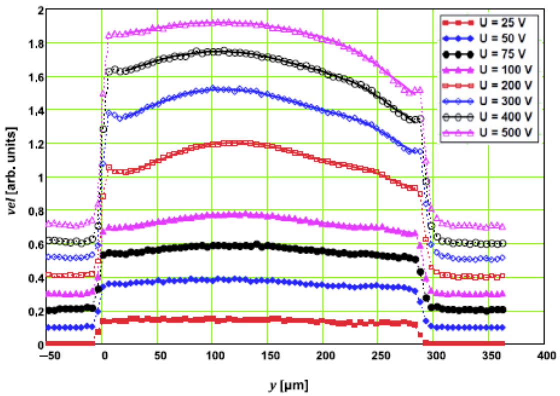
shows the voltage dependence of $vscale(U)$, with which the signal from the model calculation has to be multiplied in order to describe the velocity profiles. It has to be introduced, as the relation between the initial slope of the pulse, which is used to determine the velocity profiles, and the actual velocities of the charge carriers, is not known with sufficient accuracy. An increase of vscale with decreasing U is expected from the finite rise time, t_r, of the initial current transient

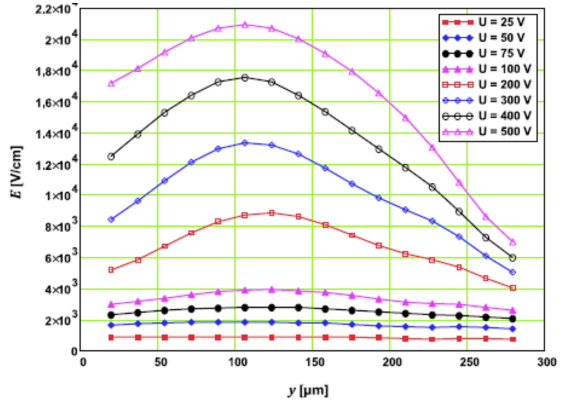
Influence of electronics and carrier lifetimes

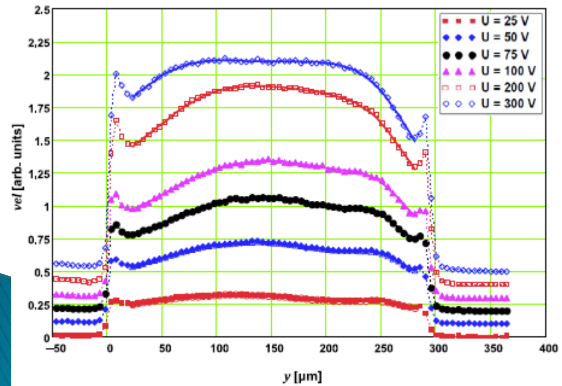
Forward bias

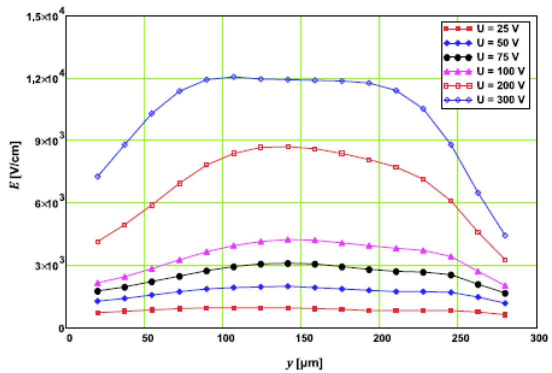




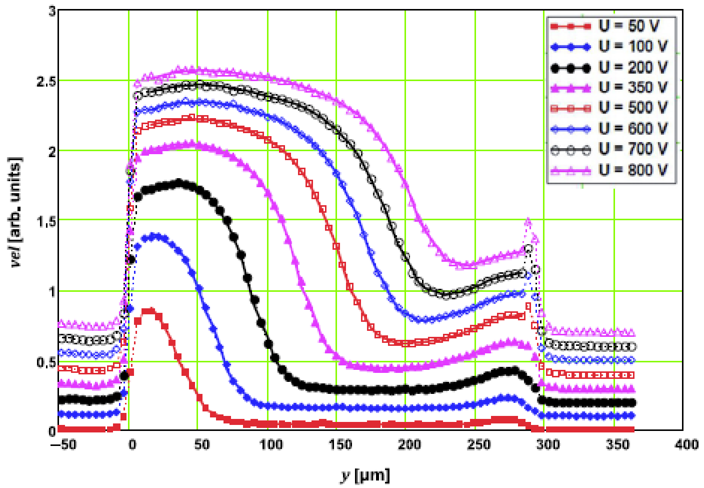


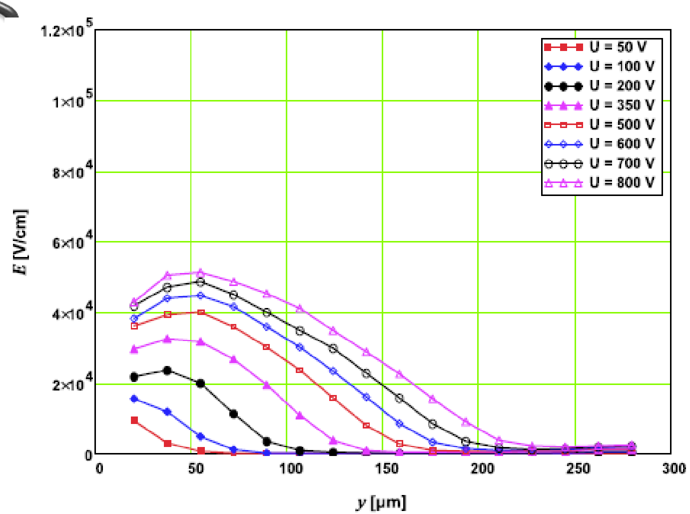


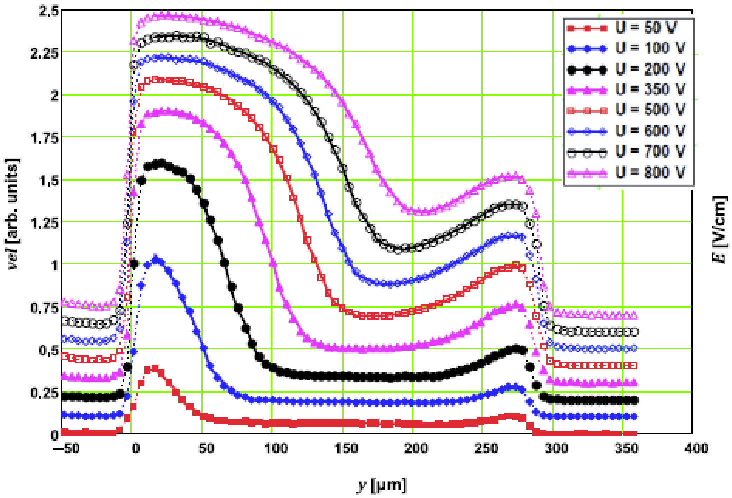


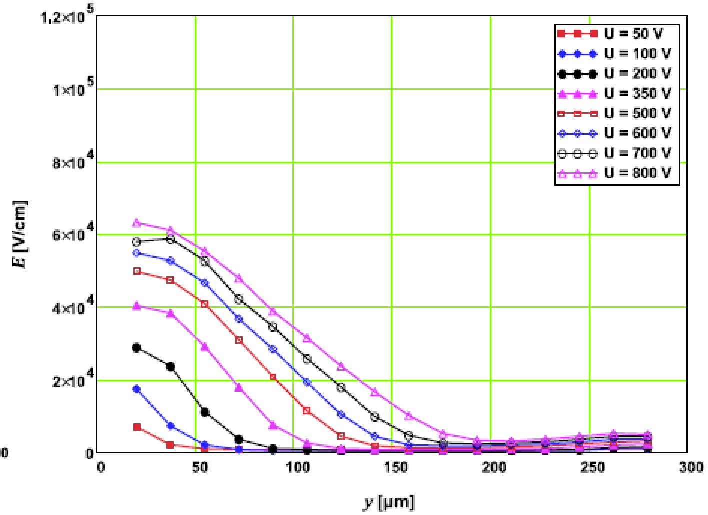


Reverse bias









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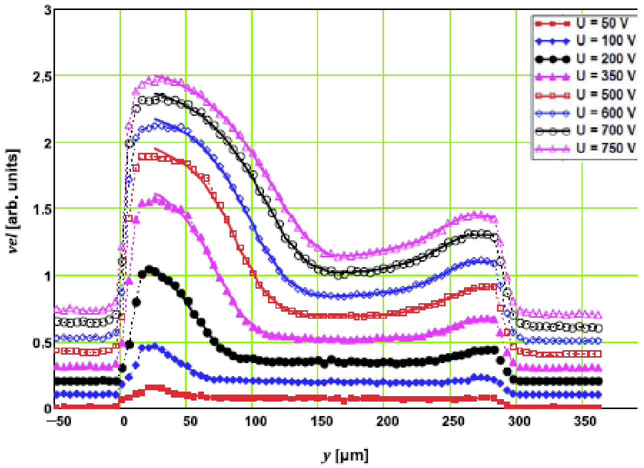
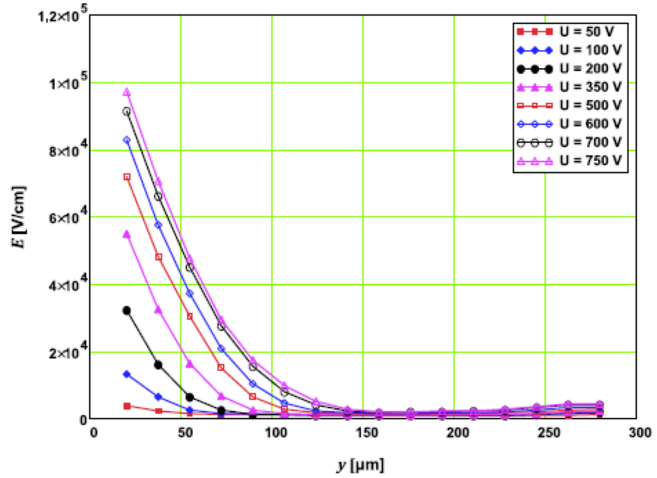
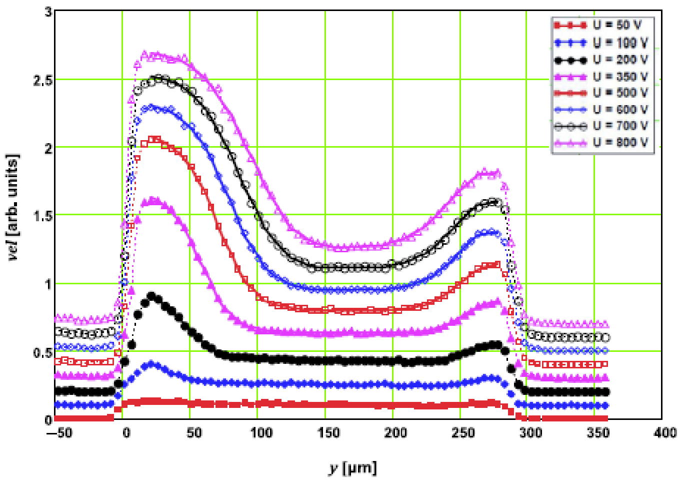
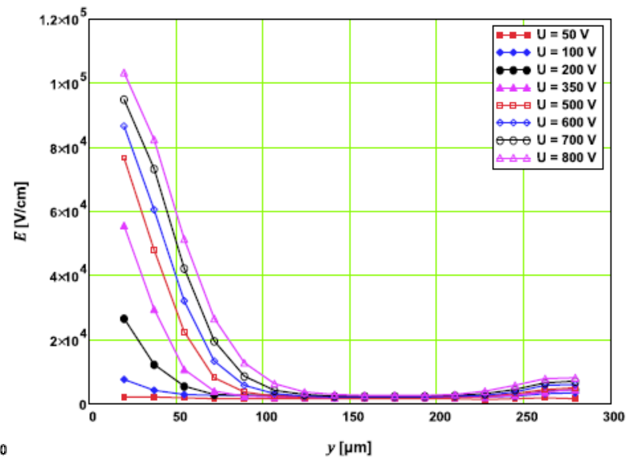
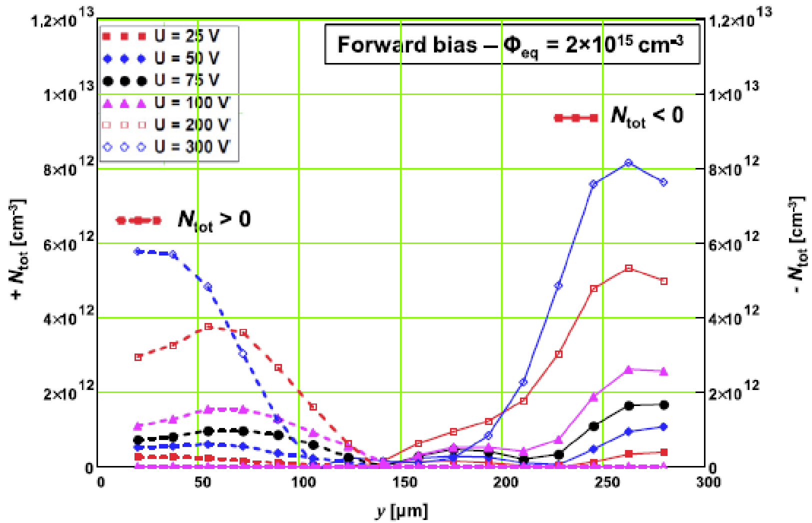


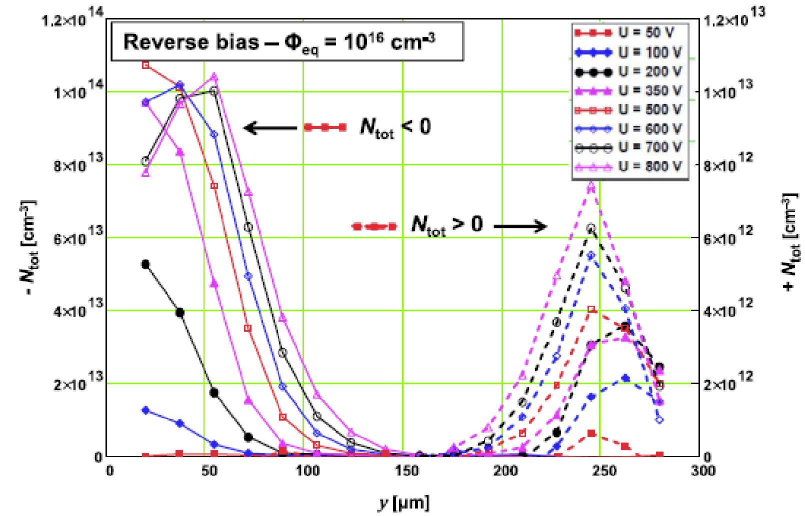






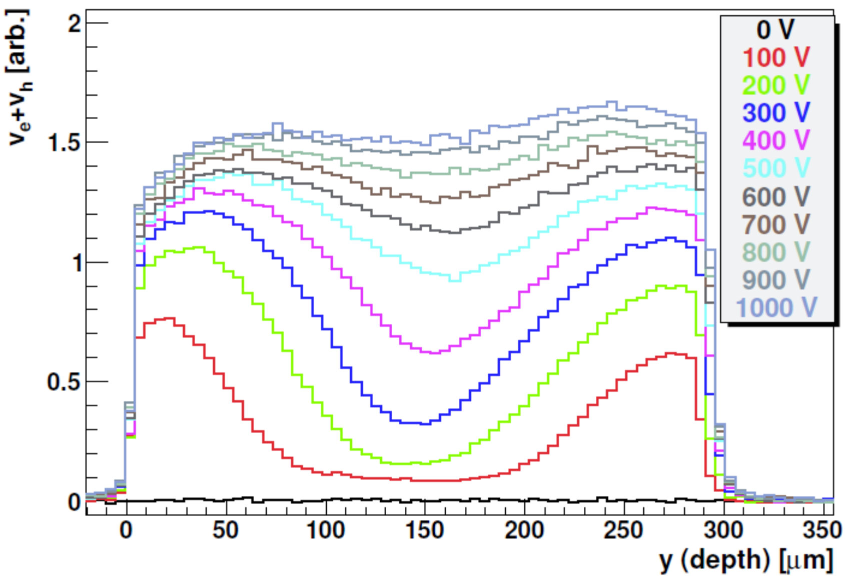
Effective doping concentration

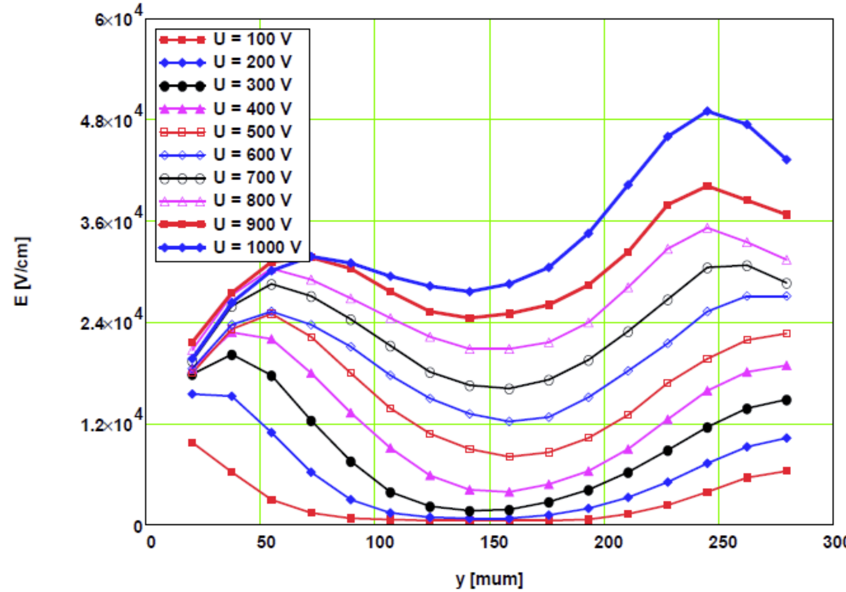




- Double junction with symetrical

Pion irradiated samples





Conclusions