Determination of strip detector properties by using Edge-TCT

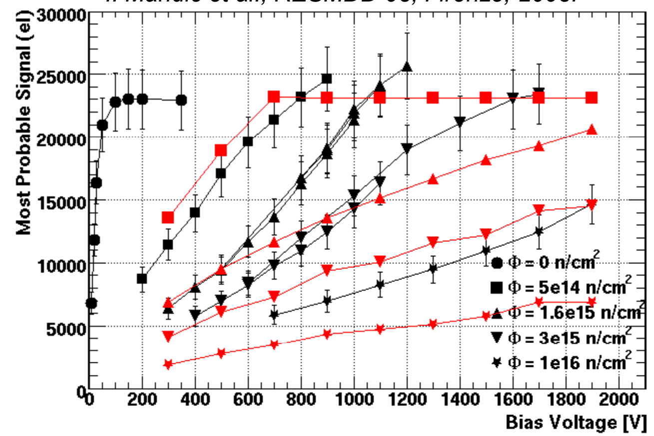
G. Kramberger, V.Cindro, I. Mandić, M. Mikuž, M. Zavrtanik
Jožef Stefan Institute, Ljubljana, Slovenia

Motivation

- High CCE measured from different groups with silicon strip detectors at high fluences and high bias voltages (L'pool, Ljubljana, SCIPP). Device modeling using extrapolated parameters from low fluence region fails, hence:
  - electric field must be different from that expected (even with DJ)
  - trapping times must to be longer

  or/and
  - possible charge multiplication takes place

I. Mandić et al., RESMDD 08, Firenze, 2008.

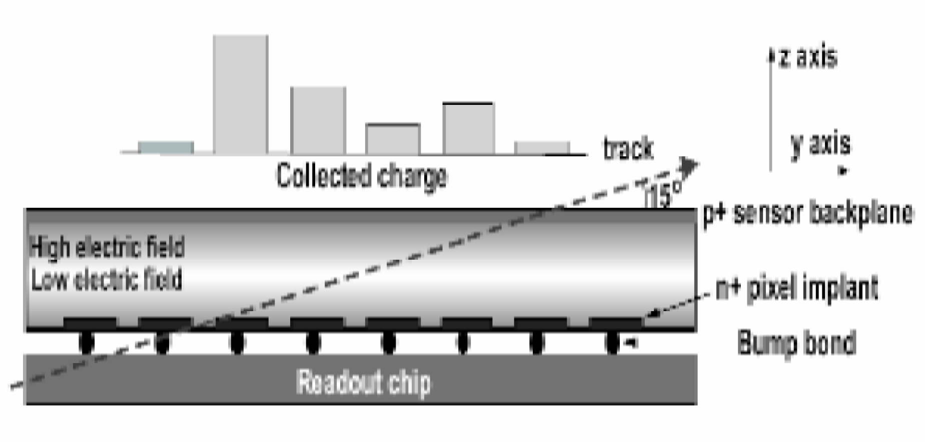


Looking for a tool to answer these questions!

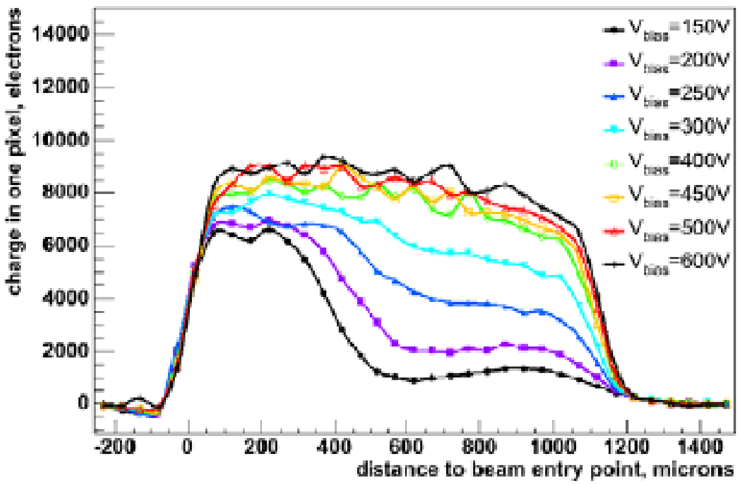
- **"Conventional red laser – TCT"** which can be successfully used at lower fluences becomes less powerful tool at high fluences
  - It is appropriate only for pad detectors
  - the devices can not be depleted – it is difficult to establish field profile
  - Trapping renders signal in such way that extraction of E and $\tau_{eff,e,h}$ from current evolution becomes very difficult – CCM with small $\tau_{eff,e,h}$ blows up any noise

Test beam of pixel detectors – a close to ideal tool

- So called "grazing technique" was found to be ideal tool to study electric field profile and trapping (went only to 10^{15} cm^{-2} and 600 V – PS limit)
- It is very difficult to perform such experiment routinely



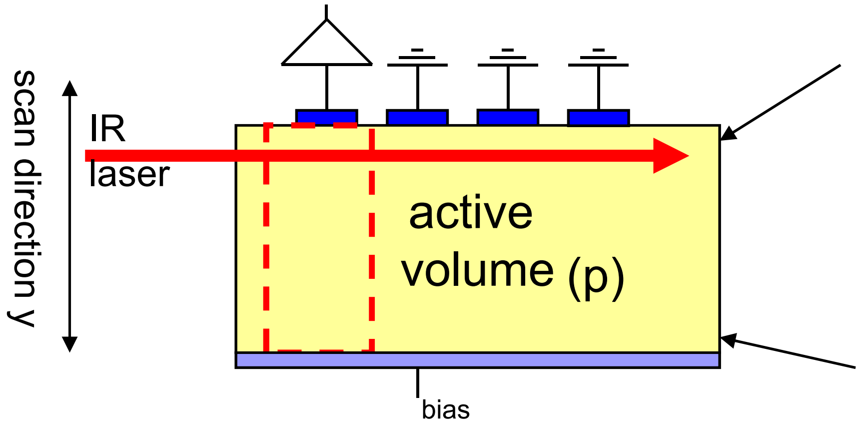
V. Chiochia et al., 8th RD50 Workshop, Prague, 2006



- "Grazing technique" on strip detectors would be the a logical step forward. A possible draw-back would be higher noise (capacitance & current) which spoils charge measurement (signal per strip ranges from 22500 e to 6000 e)
- Although "easier" than for pixels it is still a very difficult experiment!

"Edge-TCT" combines benefits of "grazing technique" with easier handling!

“Edge-TCT” a new way of using TCT



Illumination close to strips – hole injection

The same amount of charge injected for close to strip and close to backplane – change of e-h fraction

Illumination close to backplane – hole injection

The idea is to use focused IR laser to simulate grazing technique:

Advantages:

- Position of e-h generation can be controlled by moving tables
- 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 is obtained

Drawbacks:

- Applicable only for strip/pixel detectors if 1060 nm laser is used (light must penetrate guard ring region)
- Only the position perpendicular to strips can be used due to widening of the beam! Beam is “tuned” for a particular strip
- Absorption falls with temperature of the sensor – a relatively powerful laser is required for large signal and makes absolute measurements of the charge more difficult
- Light injection side has to be polished to have a good focus – depth resolution
- It is not possible to study charge sharing due to illumination of all strips

What information do we get – methods ?

•Direct determination of CCE(y) which identifies the “low/high CCE” regions in the detector.

•Since the number of injected e-h pairs are the same for electron (illumination close to strips) and for hole (illumination close to backplane) it is possible to study asymmetries in hole and electron trapping. The difference can be seen even for not fully depleted detector

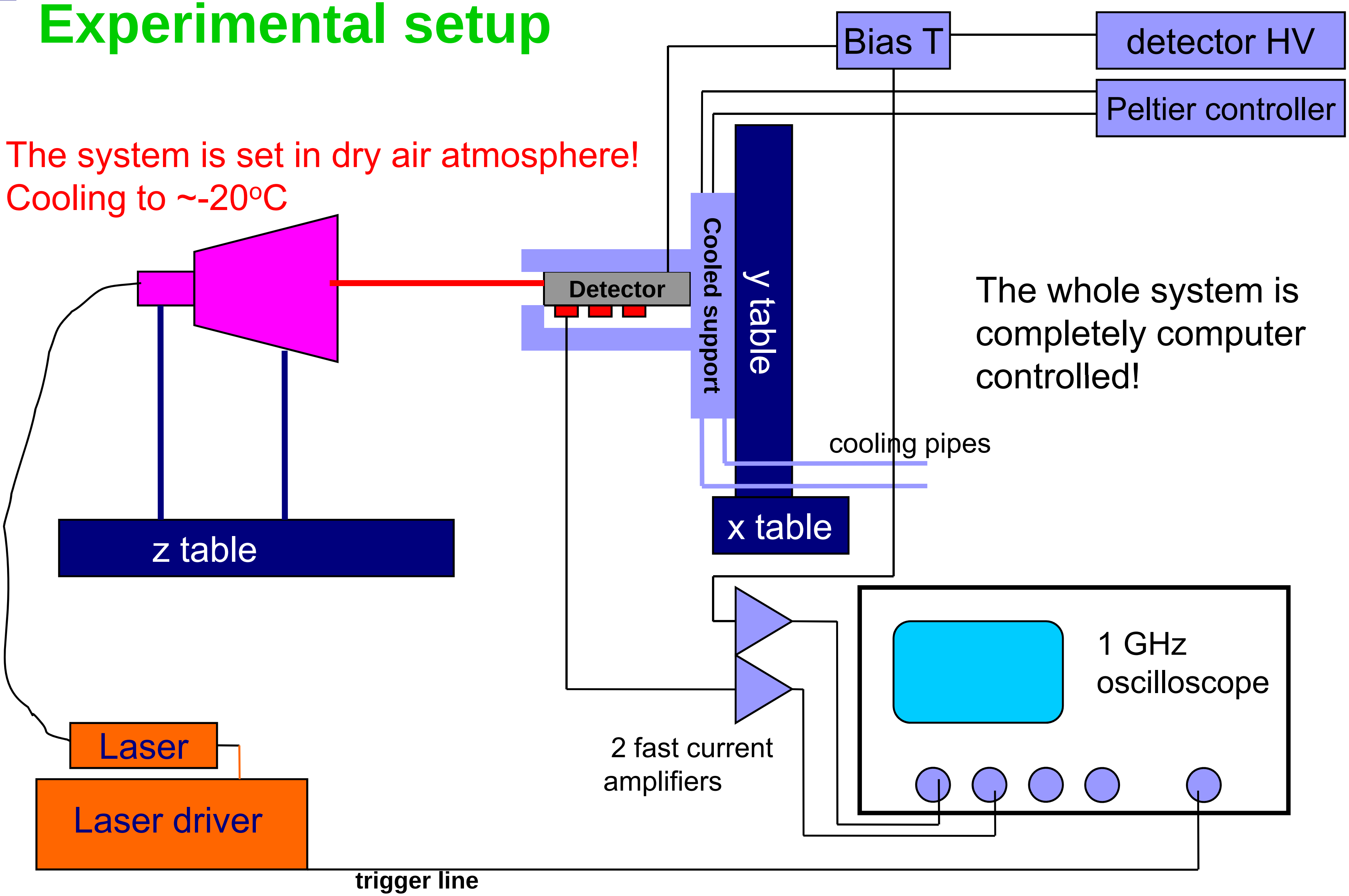
• The increase of induced current, due to possible charge multiplication, should be seen in the shape of the current and consequently in induced charge.

•Electric field can be extracted without relying on trapping parameters:
- •Delayed Peak Method
- •Prompt Current Method

•Other possible surprises …

Experimental setup

The system is set in dry air atmosphere!
Cooling to ~-20^{o}C



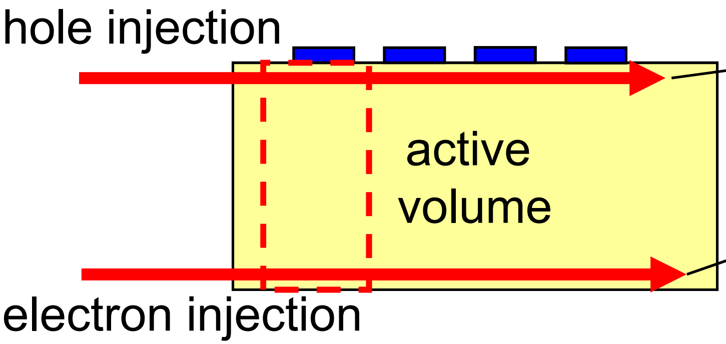
The whole system is completely computer controlled!

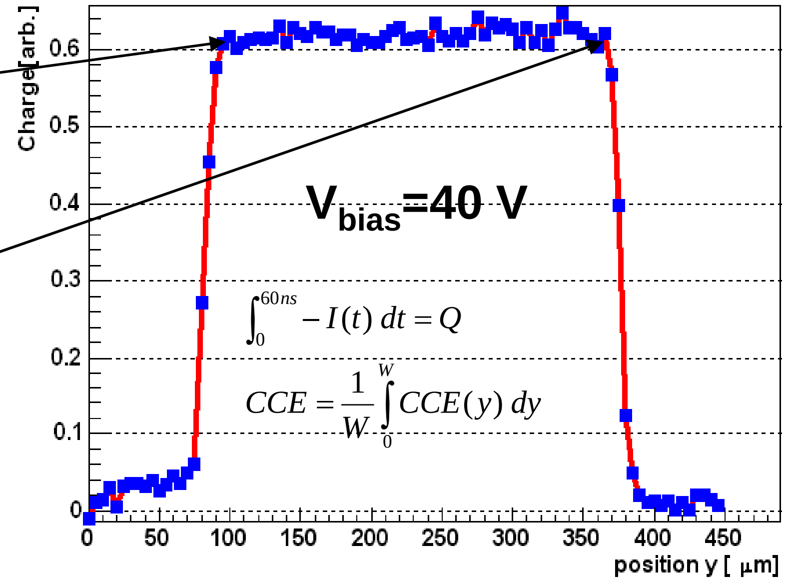
Samples

- n^+-p Micron SSD detector (1x1 cm^2) ATLAS geometry
  - 300 μm thick
  - 80 μm pitch
- Initial resistivity 20 kΩ cm – V_{fd} ~ *15* V
- 3 polished samples are available

Only the data on a non-irradiated detector will be shown due to the failure (fiber break) of the IR laser.

Identification of active areas in silicon detectors (I)

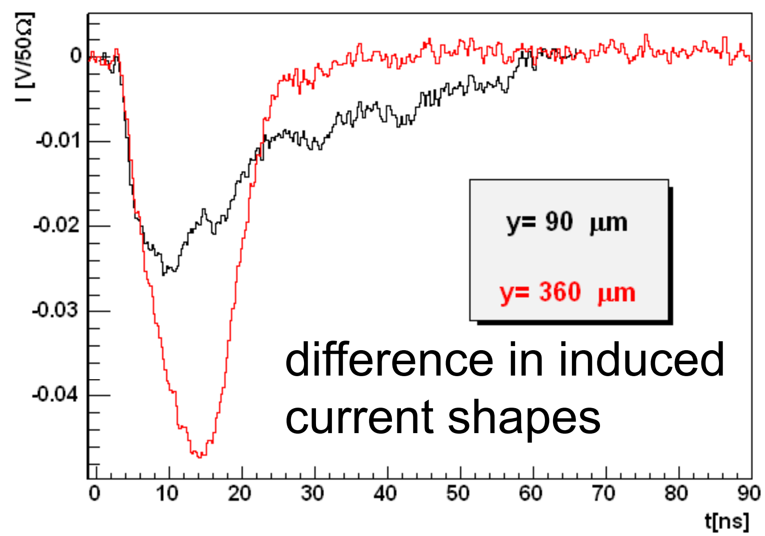




As expected CCE~100% at all depths

Observations proving understanding and quality of the setup:

- Beam diameter is smaller than 15 μm (σ=6 μm) – determines the position resolution!
- Measured detector thickness as FWHM of Q(y) gives 297 μm - in perfect agreement with expected 300 μm.
- In an un-irradiated detector the integral of the charge doesn't depend of the position where charge is generated!

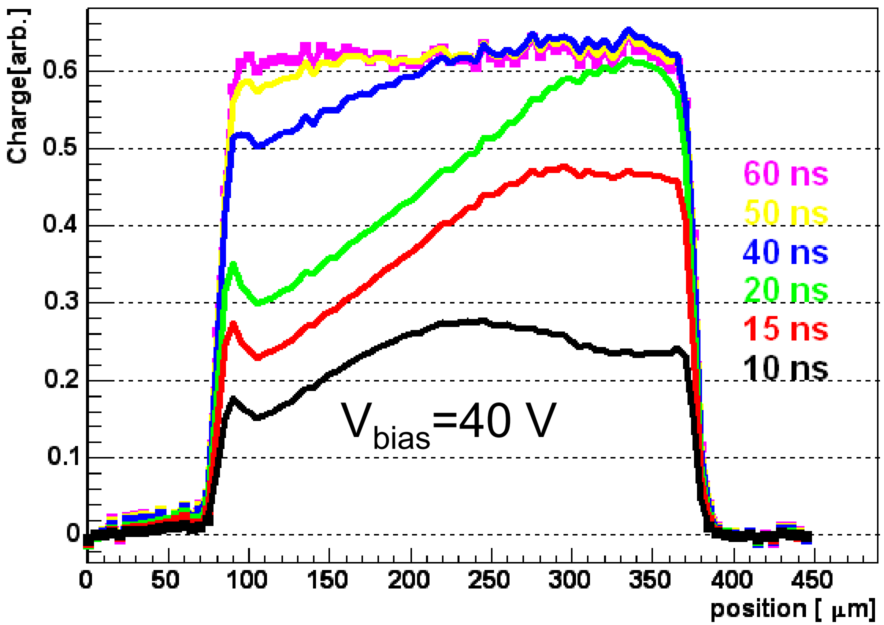


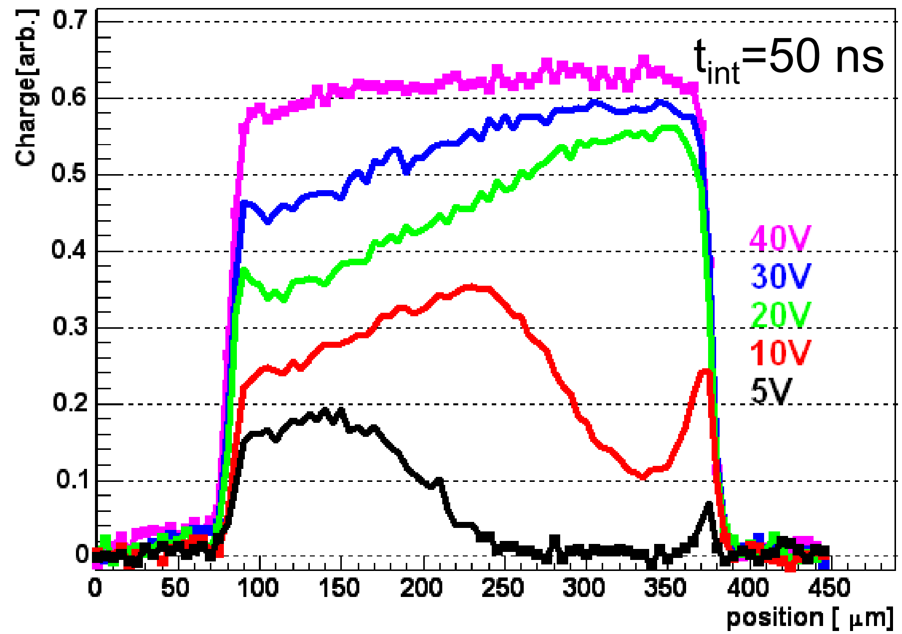
CCE of detector for mip:

$$CCE = \frac{1}{W}\int_0^W CCE(y)\,dy$$

G. Kramberger et al.,"Edge TCT, A new way of extracting electric field from irradiated silicon detectors", 13th RD50 Workshop, Freiburg, 3-5.6.2009

Identification of active areas in silicon detectors (II)
Dependence on integration time and bias voltage



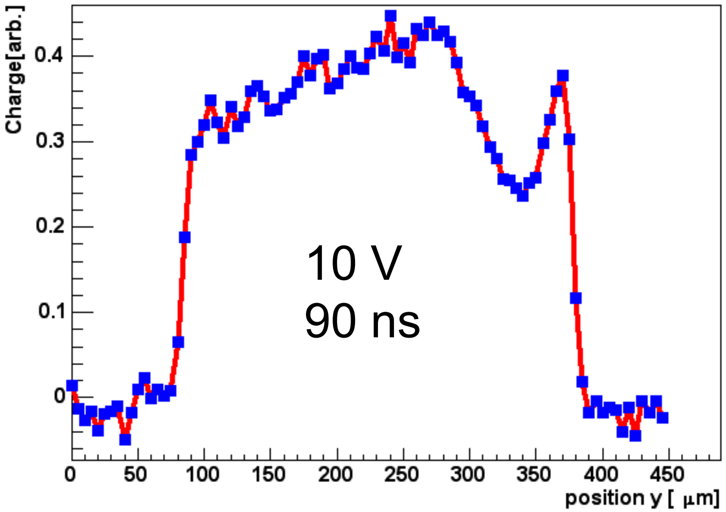


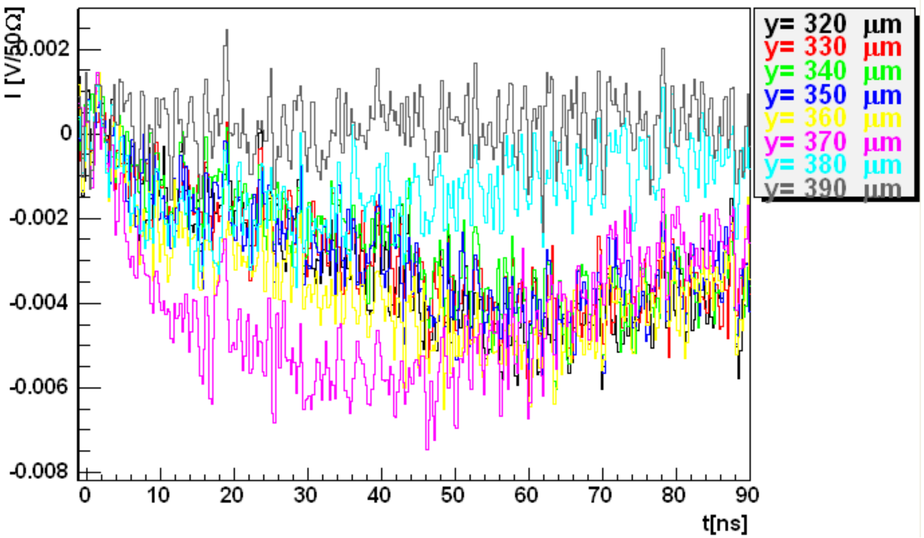
As V_{bias}-V_{fd}~20 V, ballistic deficit clearly seen:

- Induced charge in 20ns is larger for e-h pairs generated at the back of the detector
- If t_{int} is long enough the Q(y) is constant
- For very short integration times the most "effective" region is in the center of detector
- Collection close to the surface in the interstrip region seems to be slower than slightly away from the strips

- It seems that close to the back the electric field is also present?
- Lower/no contribution from un-depleted region can be observed.
- It seems that the carrier life time is so long that even some charge is obtained from the non-depleted region!
- The resistivity of the un-depleted bulk is such that the detector contact is not brought to the edge of the depleted region

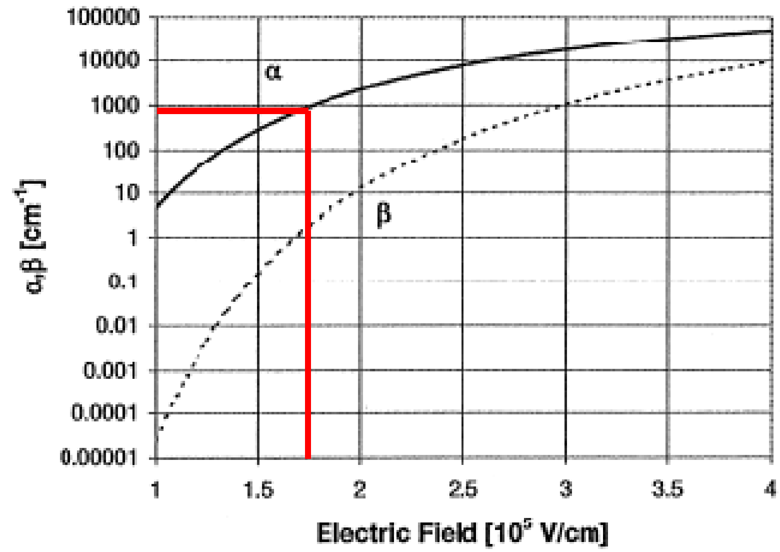
Identification of active areas in silicon detectors (III) Dependence on integration time and bias voltage





- It seems that the carrier life time is so long that even some charge is obtained from the non-depleted region!
- The resistivity of the un-depleted bulk is such that the detector contact is not brought to the edge of the depleted region

Possible identification of multiplication



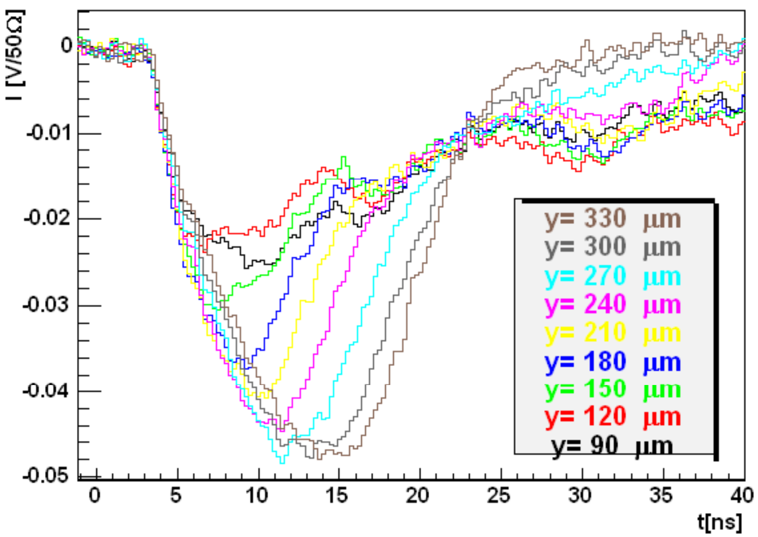
Multiplication starts at E~10 V/μm

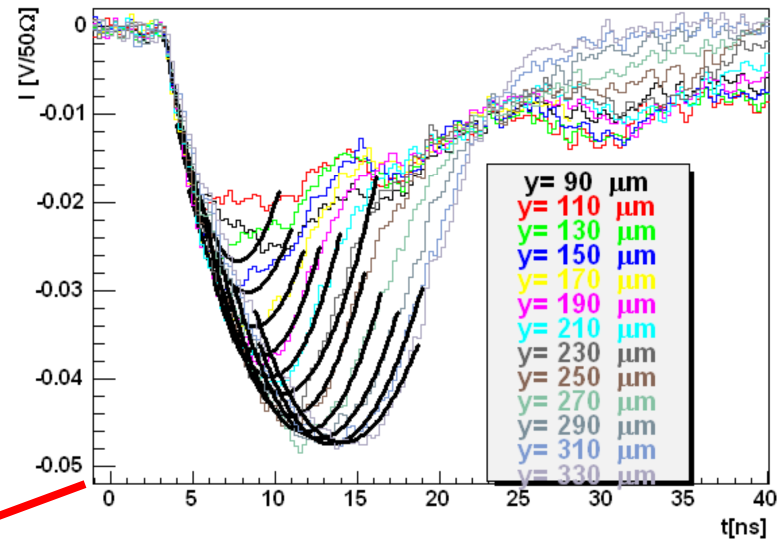
- very likely to be achieved in at least some part of detector if <E>~5 V/μm for under-depleted diode
- can happen in high field at n^+ electrodes in segmented detectors – even higher electric field due to implant edges – multiplied charge drifts in high weighting field *(see V. Eremin et al., 13th RD50 Workshop)*
- Higher N_{eff}-> higher E – avalanche more likely

Expected indications of the multiplications:

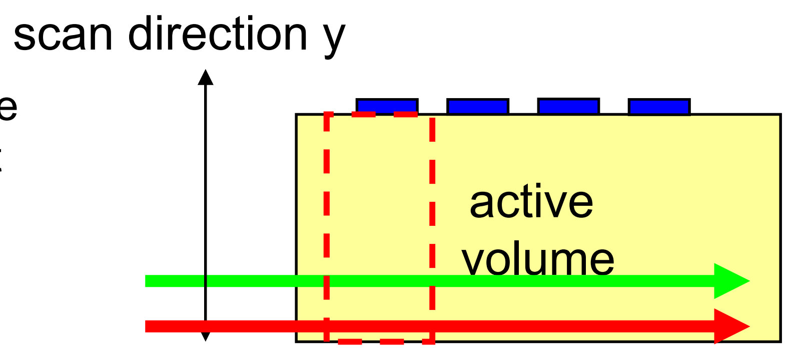
•Shape of the CCE(y,V_{bias})
close to the strips very high and much lower away from the strips (carriers are trapped)
•The induced current shape should get higher and brother at the same time:
•higher due to avalanche (time resolution probably too low to identify the location of the avalanche)
•after the maximum a tail should be brother due to hole drift away from the strips
•Any other surprises …

Extraction of electric field (Delayed Peak Method)



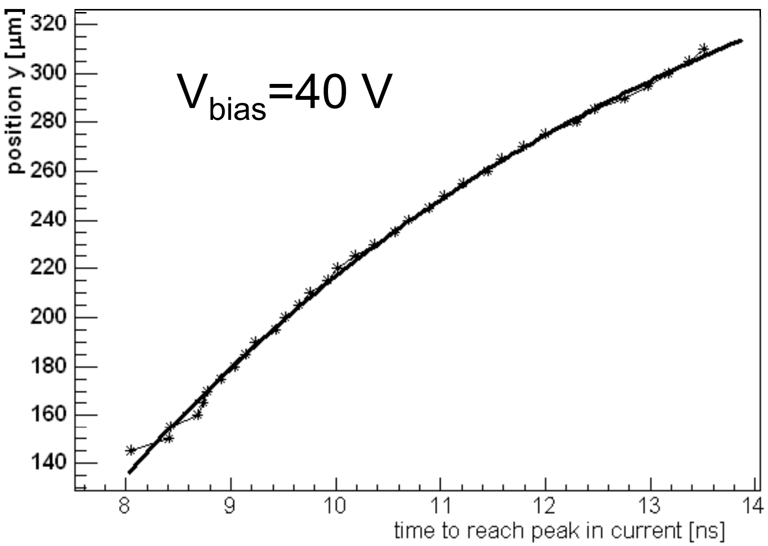


difference in beam position reflects in the time difference of the peak – electrons should drift over the additional distance to get to high electric field close to electrodes

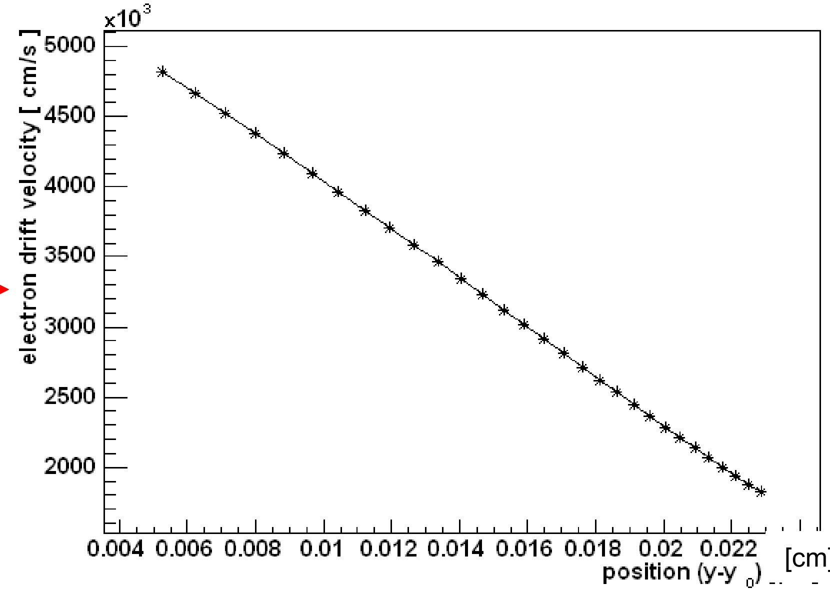


$$v_e(y)=\Delta y/\Delta t$$

Extraction of electric field (Delayed Peak Method)

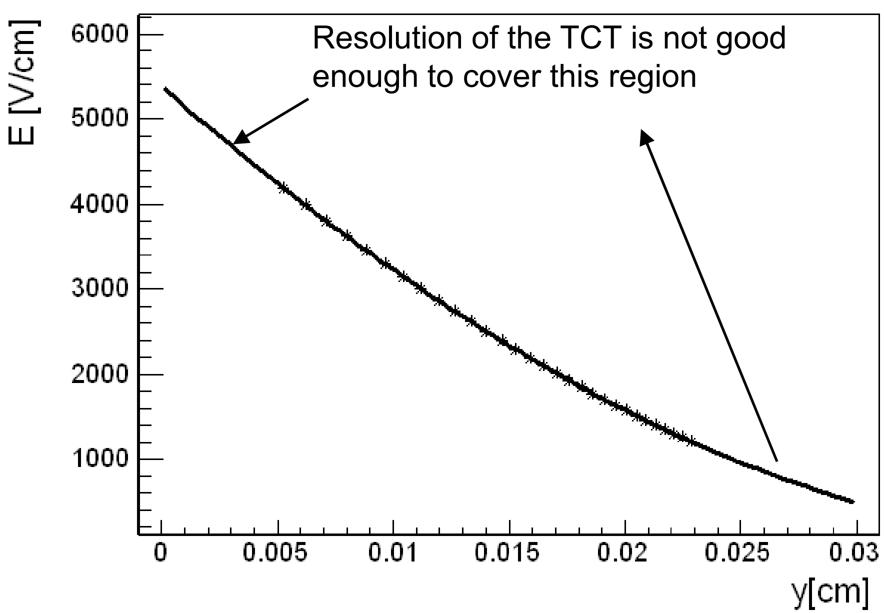


dy/dt



Solving the equation and using position instead of peak time

$$v_e = \mu_e(E)\,E$$



However the calculated voltage is some 20 V too high! Studies in progress ….

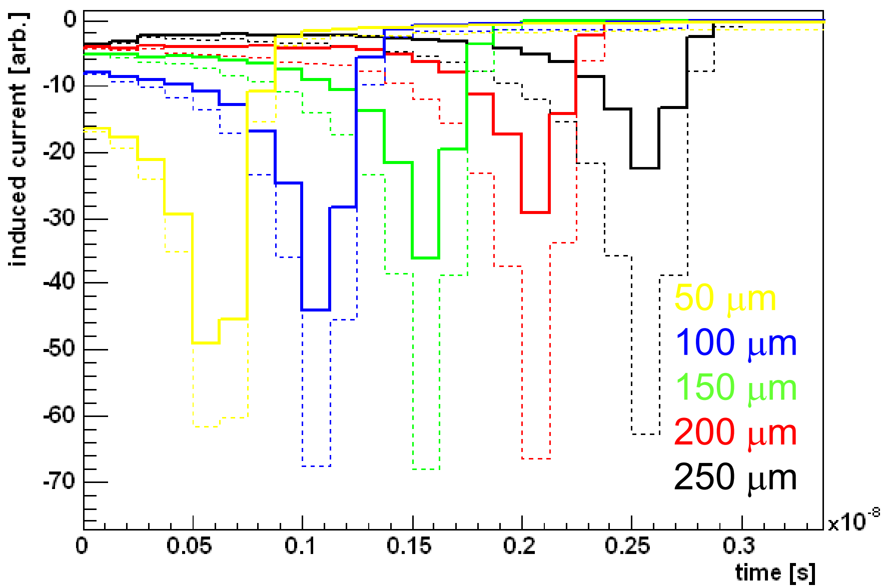
Extraction of electric field (Delayed Peak Method)

The validity of method could be limited:

- If trapping is so strong that electrons are trapped before reaching the high field region
- The difference in saturated drift velocity between holes and electrons is small the separation of peaks might be a problem

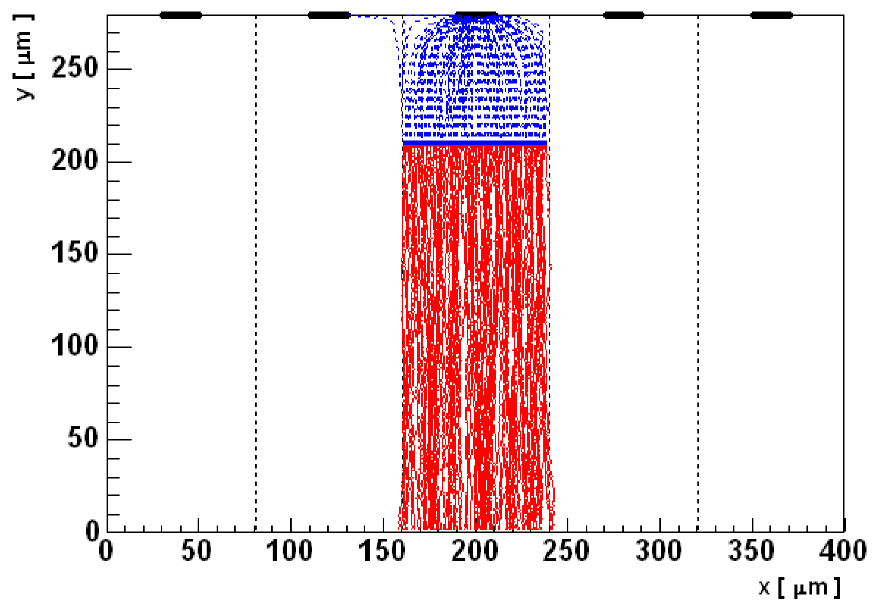
Simulation:

V_{bias}=1000V, p-type, N_{eff}=-7x10^{12} cm^{-3}, T=-20^{o}C, $\tau_{eff,e}$=2.5 ns, $\tau_{eff,h}$=2 ns, W=280 μm



Dashed - no trapping

Solid - trapping



Fairly large signal is required to be sensitive to small Δt (y)!

Extraction of electric field (Prompt Current Method)

Providing rise time is fast enough (current sensitive system on a scale of 200 ps) the electric field can be probed directly by observation of prompt current pulse

$$I(t=0) = q(\mu_e(E) + \mu_h(E))E \cdot E_w$$

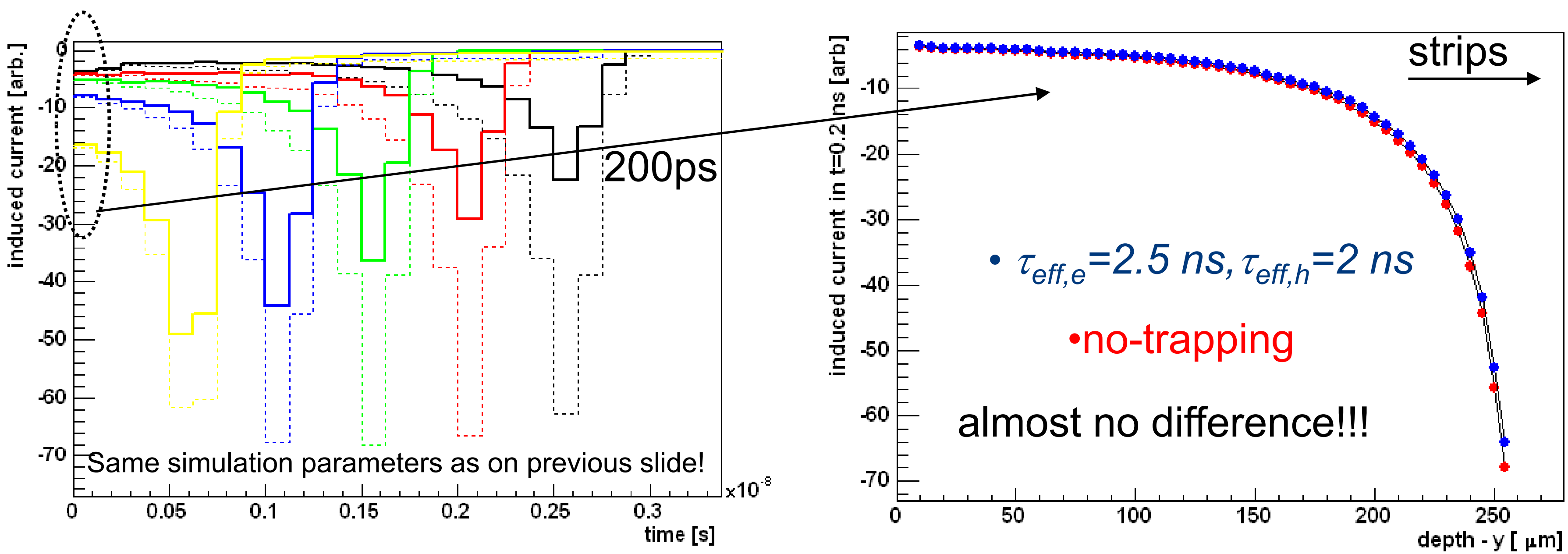
t~200 ps << $\tau_{eff,e,h}$ and trapping can be neglected

In order to account for somewhat larger noise after de-convolution for electronic transfer function (RC) the signal should be fairly large!

Requirements are

- Fast laser and powerful laser of width < 100 ps
- Amplifier with bandwidth few GHz
- Fast (~3 GHz) oscilloscope

We are currently upgrading our laser to meet these requirements!

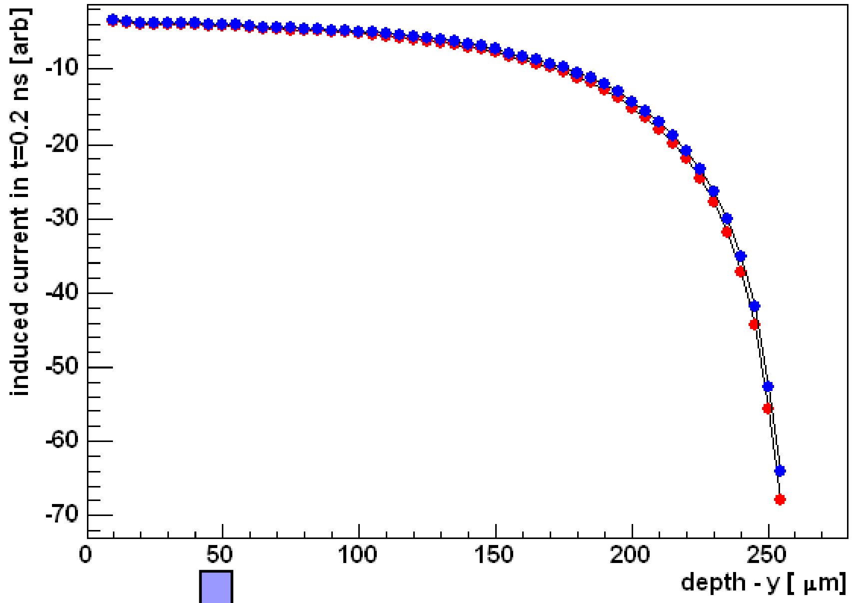


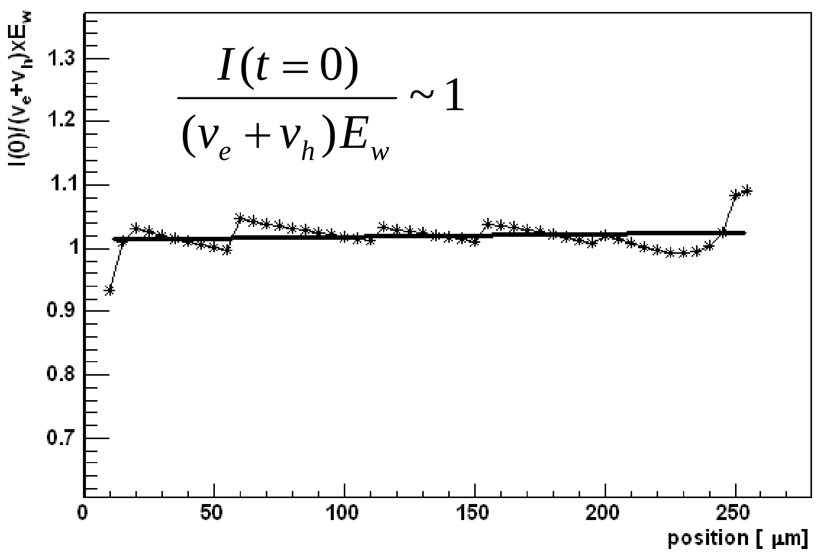
Extraction of electric field (Prompt Current Method)

Recipe to extract electric field:

1. Measure induced current at <200 ps
2. Calculate $<E_w>$ at given depth in the detector (perpendicular to the direction of the strip)
3. Solve equation for electric field E

$$\frac{I(t=0)}{<E_w>} \approx [\mu_e(E)+\mu_h(E)]\cdot E$$





using simulated I(t~0) simulated $v_{e,h}$ and E_w at location of the beam one can verify if the method works …

Conclusions and future work

- Edge-TCT is a tool which enables investigation of segmented detectors and offers many benefits:
  - Precise profile of Charge Collection Efficiency over the detector depth
  - Evaluation of electric field profile without relying on trapping parameters:
    - Delayed Peak Method (measuring the arrival time of electrons to the strips)
    - Prompt Current Method (measurement of the prompt current rise)
  - Search for anomalies in induced current shape, e.g. multiplication
- First tests on non-irradiated segmented detectors were successful and soon we will measure irradiated detectors.
- An upgrade of PS-TCT is underway at Ljubljana to make it fast enough for Prompt Current Method!