Calculating the electric field from eTCT measurements

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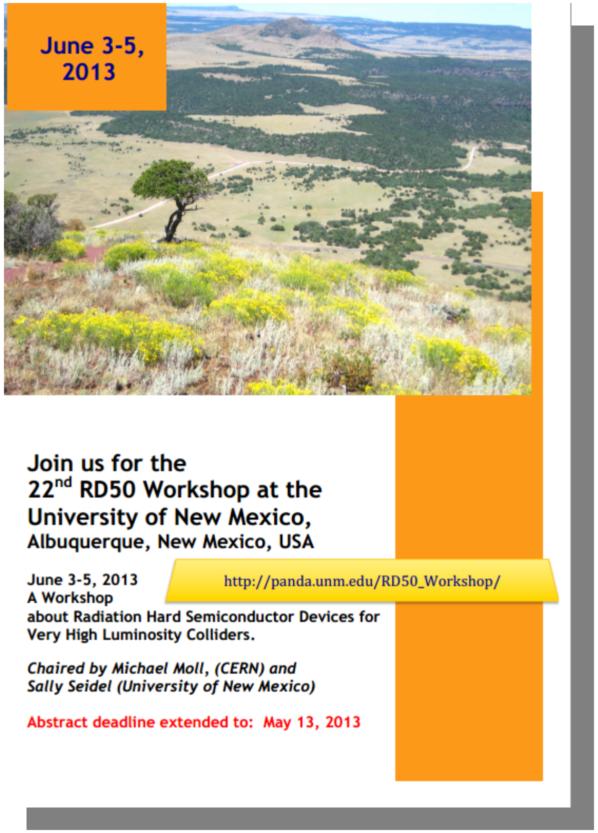
Work developed at the SSD lab at CERN



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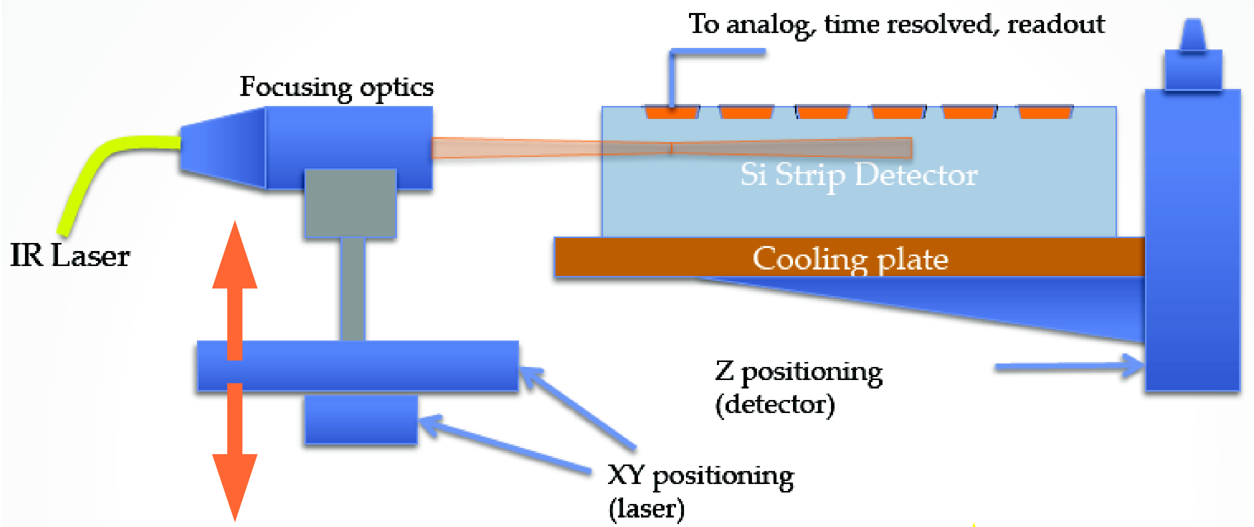
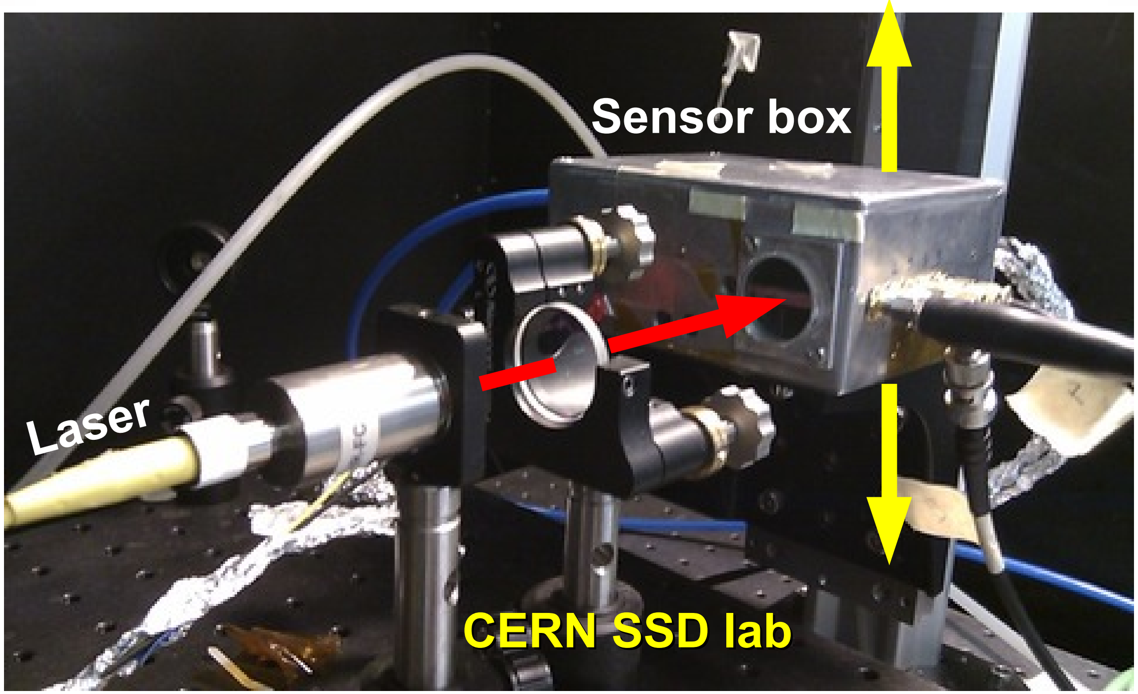




- Characterization technique developed by Ljubljana group. It allows to extract sensor properties (vdrift, efficiency, CCE) **as a function of depth.**

- Charge carriers created at **selected depth** in the bulk

- **Spatial resolution** given by laser width (vertical). Measurements averaged over strip width (horizontal).

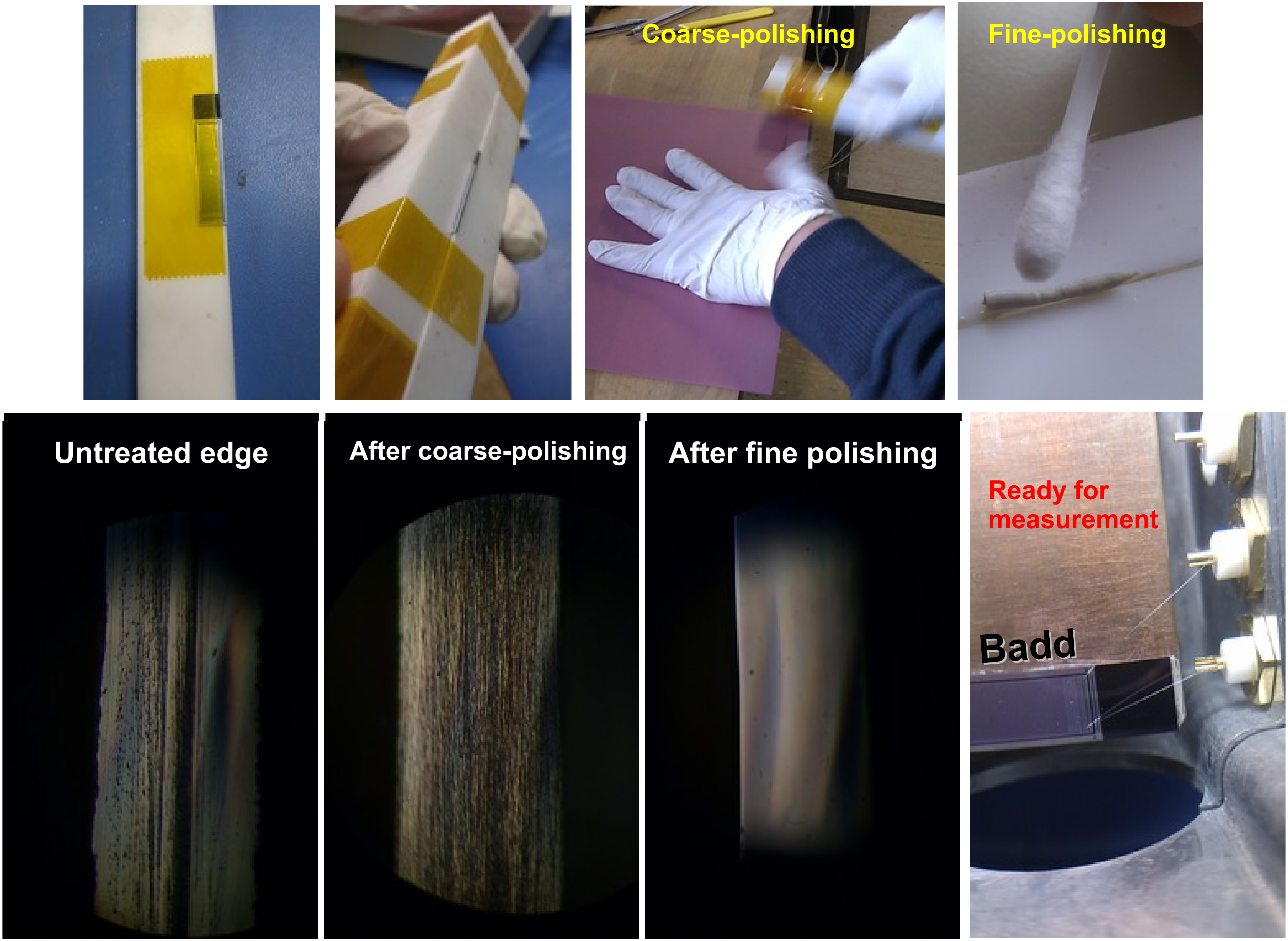
- **SSD setup: 5th strip** AC readout. Bias Ring grounded, Backside biased.

<u>Setup Featuring:</u>

→ 80 ps FWHM laser 1060 nm
→ XYZ motion
→ T controlled measurements
→ In-situ annealing

- DAQ by CERN SSD
(N. Pacifico, M. Gabrysch, I. Dolenc)

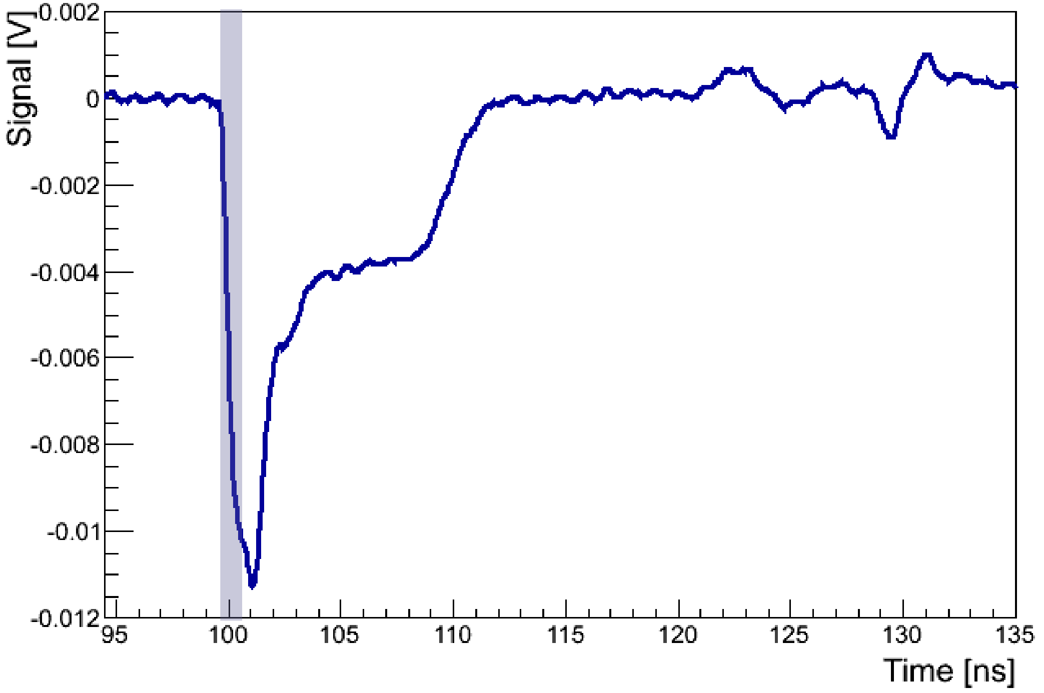
ETCT method: G. Kramberger et al., IEE TNS, VOL. 57, NO. 4, August 2010, p. 2294


Coarse-polishing
Fine-polishing
Untreated edge
After coarse-polishing
After fine polishing
Ready for measurement
Badd

Calculation of drift velocity:

- eTCT provides a **profile** of the instantaneous “trapping-free” drift velocity ve+vh

$$I_{e,h}(t,z)=Ae_0N_{e,h}\left[\exp\left(\frac{-t}{\tau_{e,h}}\right)\right]\frac{v_e(z,t)+v_h(z,t)}{d} \Rightarrow v_e(t\approx 0)+v_h(t\approx 0) = \frac{d\cdot I_{e,h}(t\approx 0;z)}{Ae_0N_{e,h}(z)}$$



Uncertainties on the measured drift velocity:

- eTCT provides a **profile** of the instantaneous “trapping-free” drift velocity v_e+v_h

$$I_{e,h}(t,z)=A e_0 N_{e,h}\left[\exp\left(\frac{-t}{\tau_{e,h}}\right)\right]\frac{v_e(z,t)+v_h(z,t)}{d} \quad\Longrightarrow\quad v_e(t\approx 0)+v_h(t\approx 0) = \frac{d\cdot I_{e,h}(t\approx 0;z)}{A e_0 N_{e,h}(z)}$$

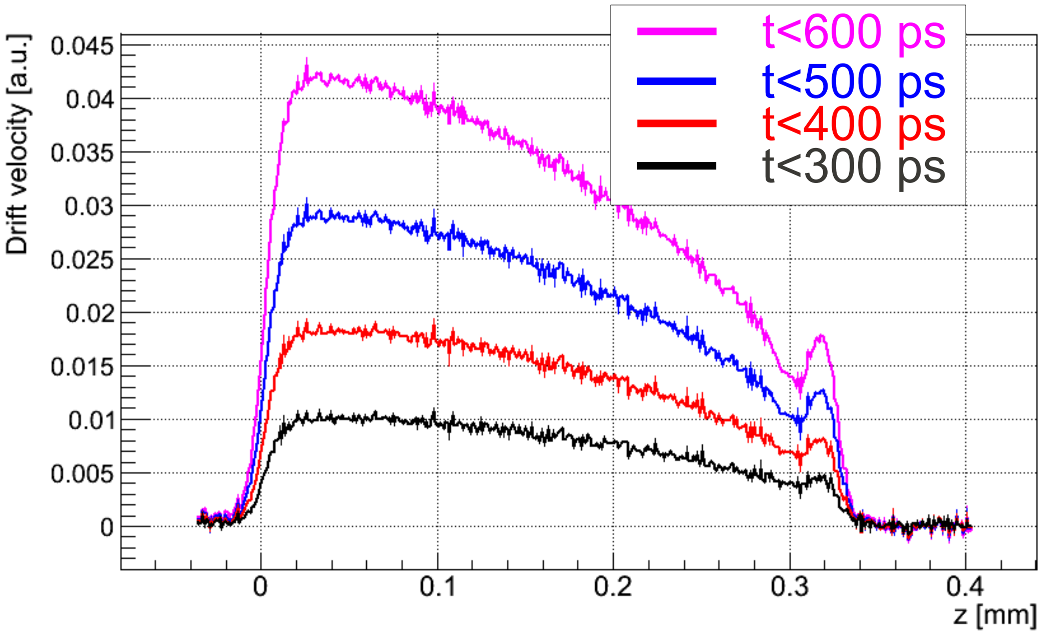
Two unknowns:

1) Number of e-h pairs $N_{e,h}(z)$ → for non-irrad detectors we can calculate it from the charge collected (see backup).

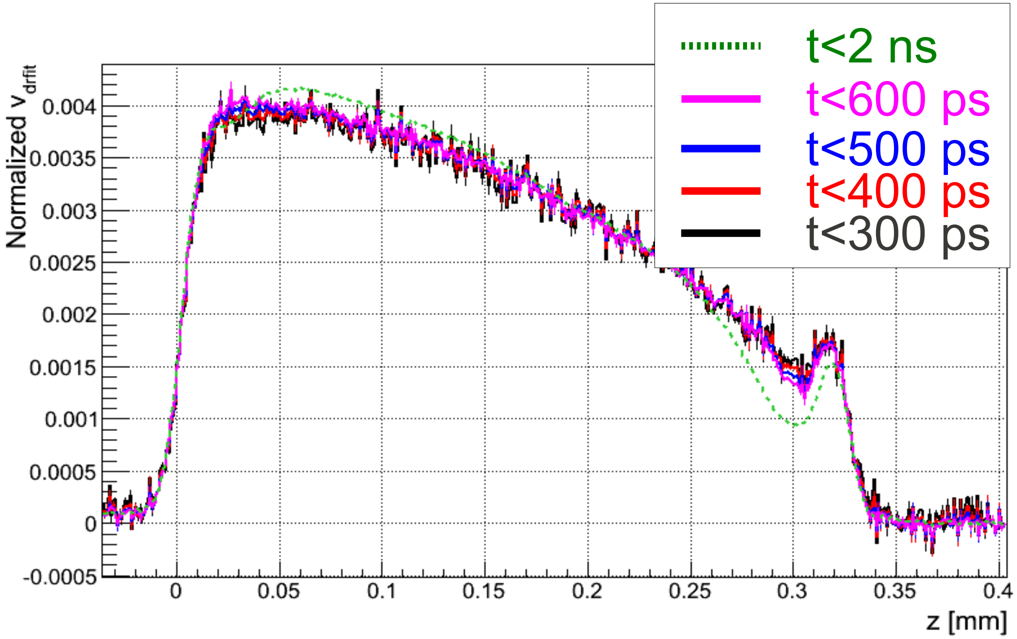
2) BUT how is I(t~0;z) defined?? I use an average of I(t) over 400 ps:

$$v_{drift}(z_i)=\frac{d}{Ae_0 N_{e,h}}\cdot\frac{1}{N_{400}}\sum_{j=0}^{400\,ps} I(t_j,z_i)$$

Drift velocity for different t~0 definitions



Absolute vdrift ([a.u.]) for different averaging times



Normalized vdrift ([a.u.]) for different averaging times

Even if the relative information in the range [300-600] ps is the same, the **absolute** value of vdrift is different.

Different averaging times, will lead to **different absolute values of vdrift** and therefore of E-field.

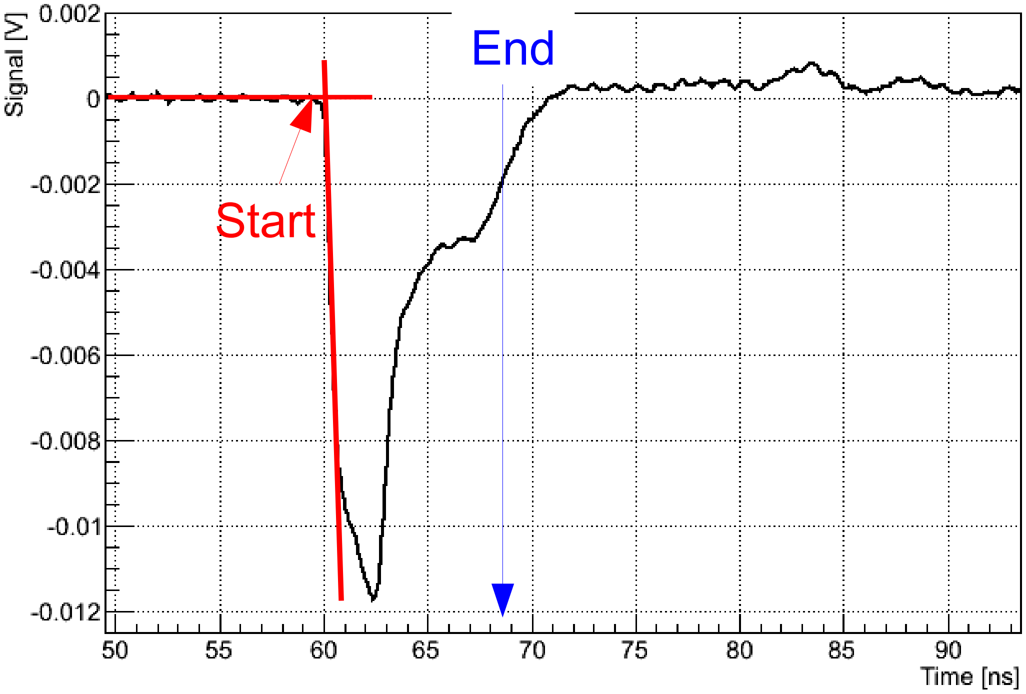
⇓

So to extract the E-field we need a method not based in v_{drift}

Measuring collection time

- In eTCT we can **measure** the collection time as a function of depth ($t_{coll}(z)$). Different collection times at different injection depths.

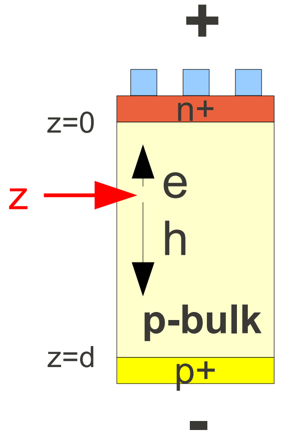
- The collection time is **measured** as the time lapse between rise edge and falling edge of current pulse.



- Pulse start: calculated as intersection of baseline with straight line fit of the pulse raising edge.

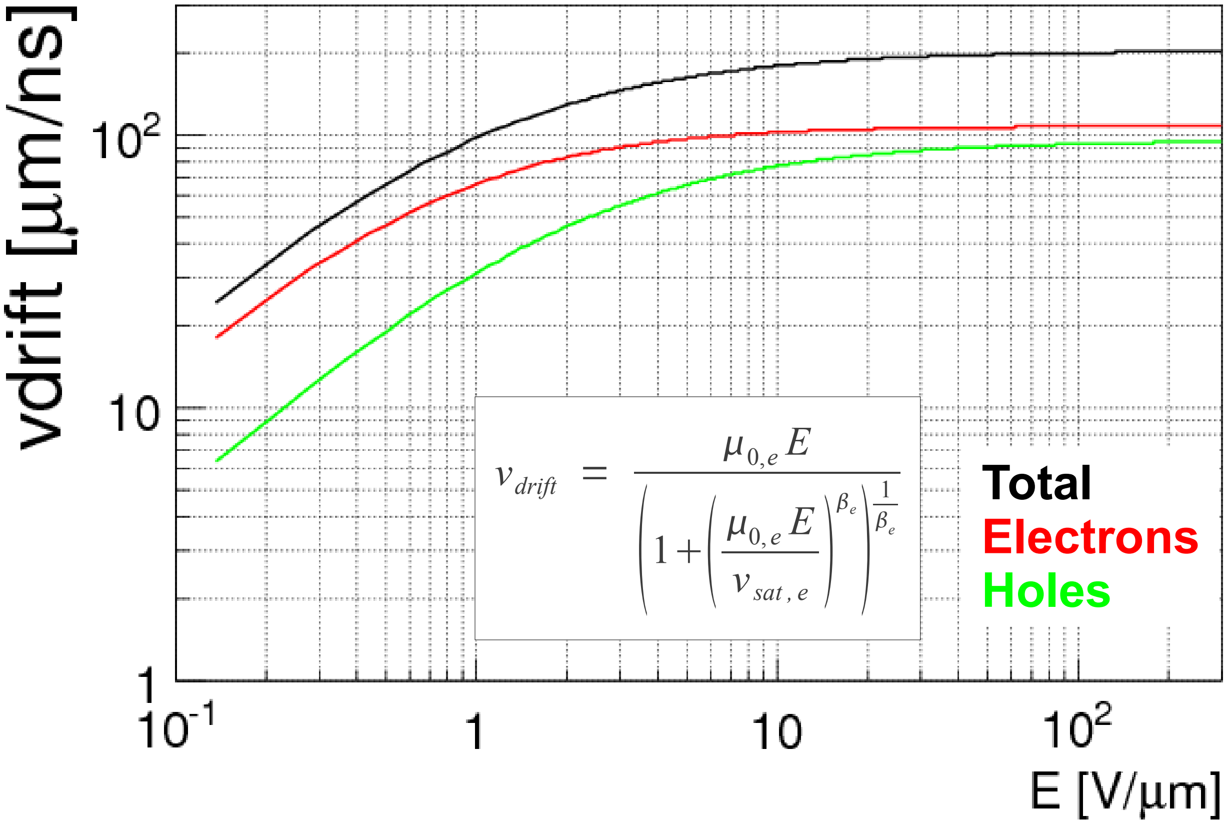
- Pulse end: calculated as time needed to collect 98% of the total charge

Calculating collection time



The collection time can be calculated as the longest of the drifting times of the 2 types of carriers:

$$t_{collection}(z)=\mathrm{Max}\left(t_e(z)\,,\,t_h(z)\right)\;;\quad \text{where}\quad \begin{cases} t_e(z)=\displaystyle\int_z^0 \frac{1}{v_e(z')}\,dz' \\ t_h(z)=\displaystyle\int_z^d \frac{1}{v_h(z')}\,dz' \end{cases}$$



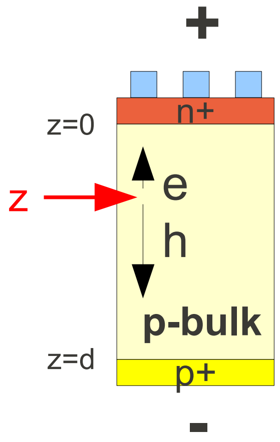
$$v_{drift}=\frac{\mu_{0,e}E}{\left(1+\left(\frac{\mu_{0,e}E}{v_{sat,e}}\right)^{\beta_e}\right)^{\frac{1}{\beta_e}}}$$

$v_{e,h}$ **Jacoboni's parametrization**

Depends on E-field:

- E(z) is a linear (non irrad.)
- E(z) quadratic (irradiated)

Calculating **Electric field** from collection time



The collection time can be calculated as the longest of the drifting times of the carriers:

$$t_{collection}(z)=\mathrm{Max}\left(t_e(z)\ ,\ t_h(z)\right)\ ;\quad \text{where}\ \begin{cases} t_e(z)=\displaystyle\int_z^0 \frac{1}{v_e(z')}dz' \\ t_h(z)=\displaystyle\int_z^d \frac{1}{v_h(z')}dz' \\ v_{e,h}\ \text{Jacoboni's parametrization} \end{cases}$$

- We then extract E(z) from t_{coll}:

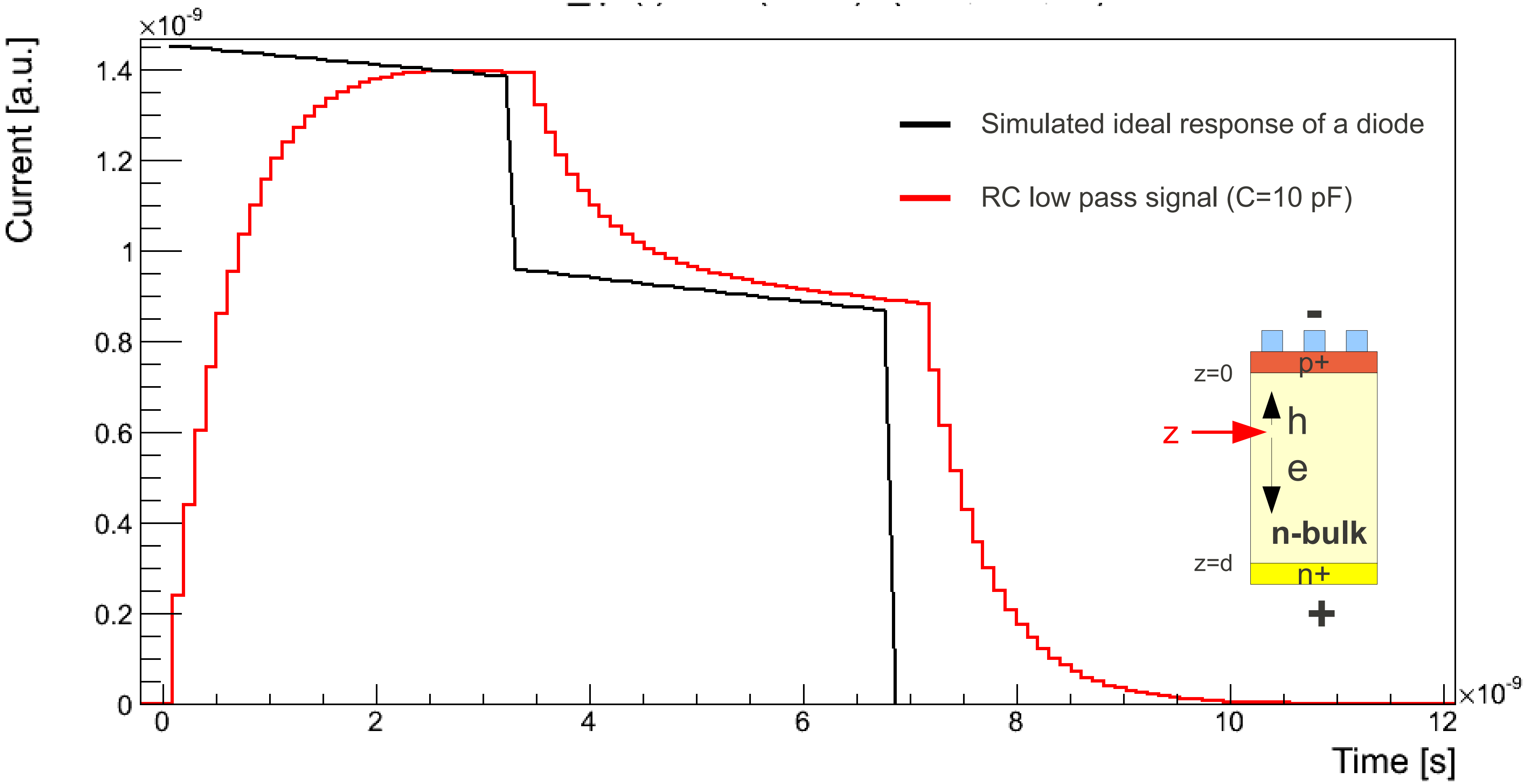
$$\chi^2 = \sum_{z=0}^{d}\left[t_{coll,meas}(z)-t_{collection}\right]^2$$

- Note that this method does **not need** the **measured v_{drift}** at all.

- Once we extract the E-field → we can calculate the “real” vdrift, fixing the normalization issue.

Question: how much RC degrades the timing information?

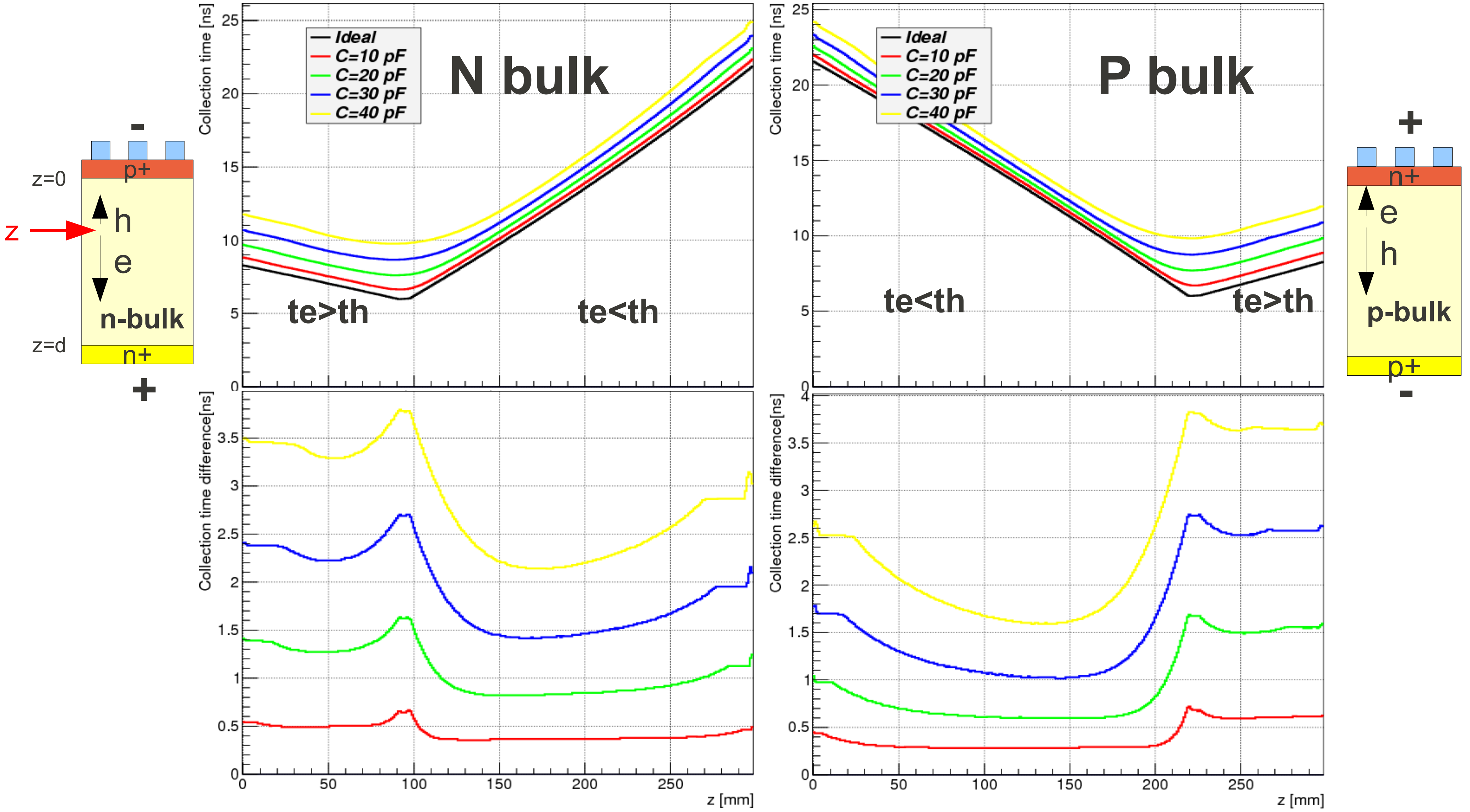
- ETCT equivalent circuit behaves like an amplifying low pass filter



- Simulated response for an over-depleted diode with C=10 pF, d=296 μm, light injection 50 μm below the strips.

Question: how much RC degrades the timing information?

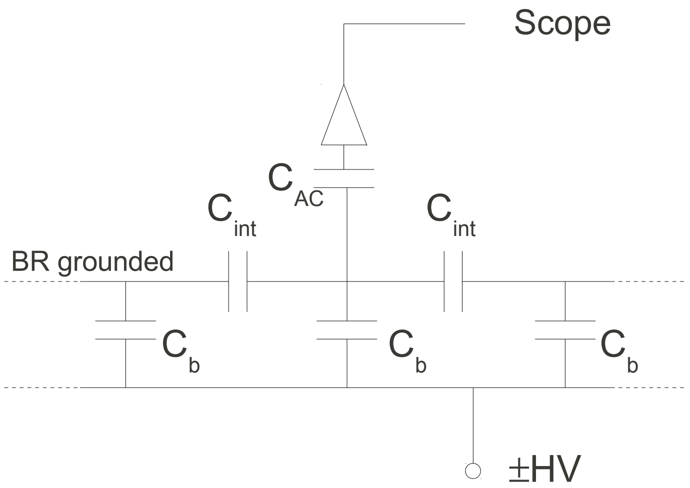
Simulated effect of RC low pass filter

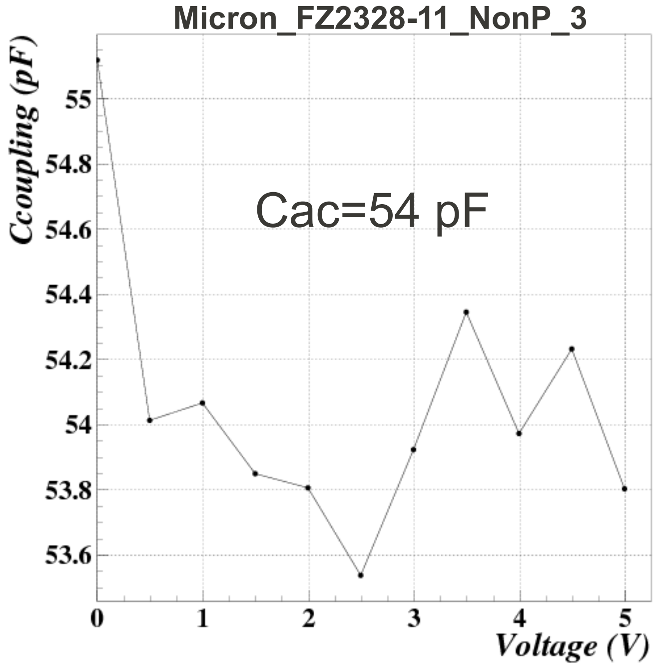


- Simulation using overdepleted diode, no diffusion considered
- **Below C=10 pF**, the contribution of RC to the collection time is <u>below the experimental error</u>.
- Higher spread with electrons.

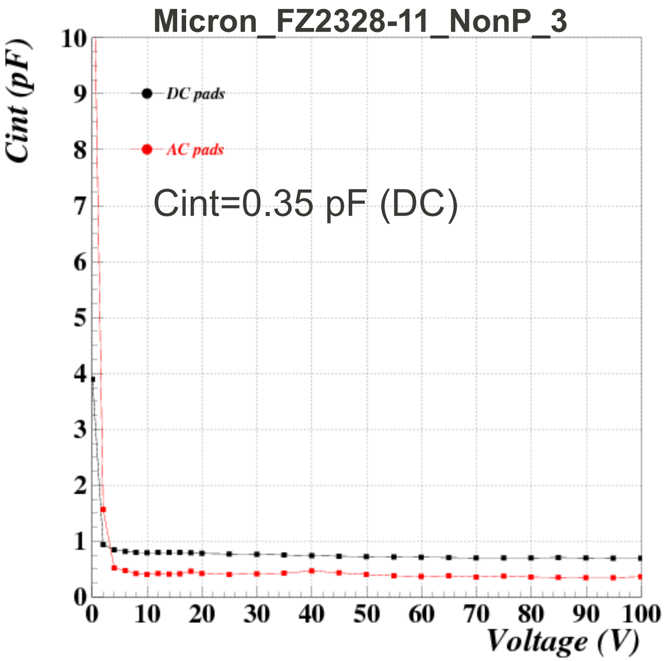
Question: How much capacitance is seen by the amplifier in eTCT?

eTCT: 5th strip connected to amplifier, Bias Ring is grounded, backplane biased





Cac=54 pF



Cint=0.35 pF (DC)

$$C_{strip} = C_b + \frac{2 \cdot C_b C_{\text{int}}}{C_b + C_{\text{int}}}$$

$$C_{tot} = \frac{C_{AC} C_{strip}}{C_{AC} + C_{strip}}$$

Micron: **Ctot=0.62 pF** Cb=0.3 ; Cint=0.35 ; Cac=54 pF
VTT: **Ctot=0.48 pF** Cb=0.18 ; Cint=1.04 ; Cac=32 pF
Badd: **Ctot=2.254 pF**

Conclusion: RC smearing should not be important for depleted sensors

Fitting method for non-irradiated detectors

1) Fit collection time using linear E-field → $E_{coll}(z)$

2) Calculate theoretical drift veloctity:

$$v_{drift} = \frac{\mu_{0,e} E_{coll}}{\left(1 + \left(\frac{\mu_{0,e} E_{coll}}{v_{sat,e}}\right)^{\beta_e}\right)^{\frac{1}{\beta_e}}}$$

Scale **measured** drift velocity to theoretical

3) Fit v_{drift} and extract $E_{vdrift}(z)$

Note: for the moment, method applied only to unirradiated det. at V ≥Vdep

Starting parameters for non-irradiated detector

- Far from electrodes, E-field must resemble that of a diode

$$E(z)=a+bz$$

- Conditions for the field ($V \geq V_{dep}$):

$$\left.\begin{array}{l} V_{bias}=\int_0^d E(z)\,dz=\int_0^d (a+bz)\,dz \;\Rightarrow\; a \\ E(z=d)=0 \text{ at } V=V_{dep} \Rightarrow b \text{ parameter} \end{array}\right\} \quad E(z)=\frac{V_{bias}}{d}-2\frac{V_{dep}}{d^2}\cdot\left(z-\frac{d}{2}\right)=a'+b'\cdot\left(z-\frac{d}{2}\right)$$

- If we fix parameter a' in the fit, the V_{bias} condition is fulfilled by construction

Fit of v_{drift} with border effects

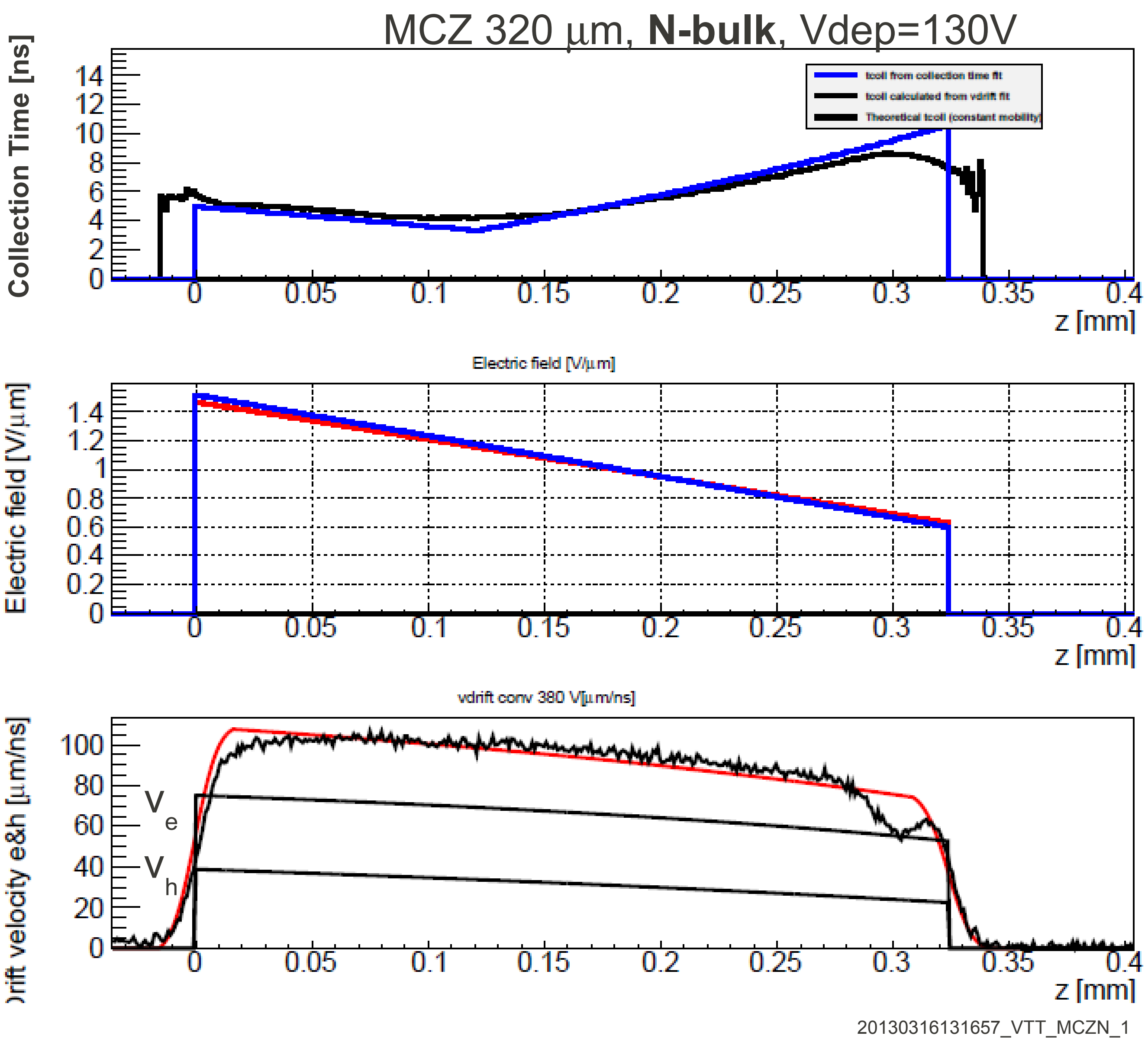
- We minimize a χ^2 function that depends on polynomial coefficients of the E-field

$$\chi^2 = \sum_0^d \left[v_{drift,meas} - \left(\frac{\mu_{0,e} E}{\left(1+\left(\frac{\mu_{0,e} E}{v_{sat,e}}\right)^{\beta_e}\right)^{\frac{1}{\beta_e}}} + \frac{\mu_{0,h} E}{\left(1+\left(\frac{\mu_{0,h} E}{v_{sat,h}}\right)^{\beta_h}\right)^{\frac{1}{\beta_h}}} \right) \right]^2$$

- Laser beam has a width of ~ 8 µm. At the sensor boundaries, the beam is not fully inside the detector and the measured drift velocity falls to zero softly (no sharp edges)

$$v_{drift}(c) = \int_{c-\sigma}^{c+\sigma} v_{drift}(z) G(z-c) dz$$

Measured and fitted collection time (VTTN, Micron, HPK FZ320Y)



20130316131657_VTT_MCZN_1

Measured collection time

Collection time fit

Fit not good at sensor boundaries

Blue: E_{coll} (E-field from t_{coll} fit)

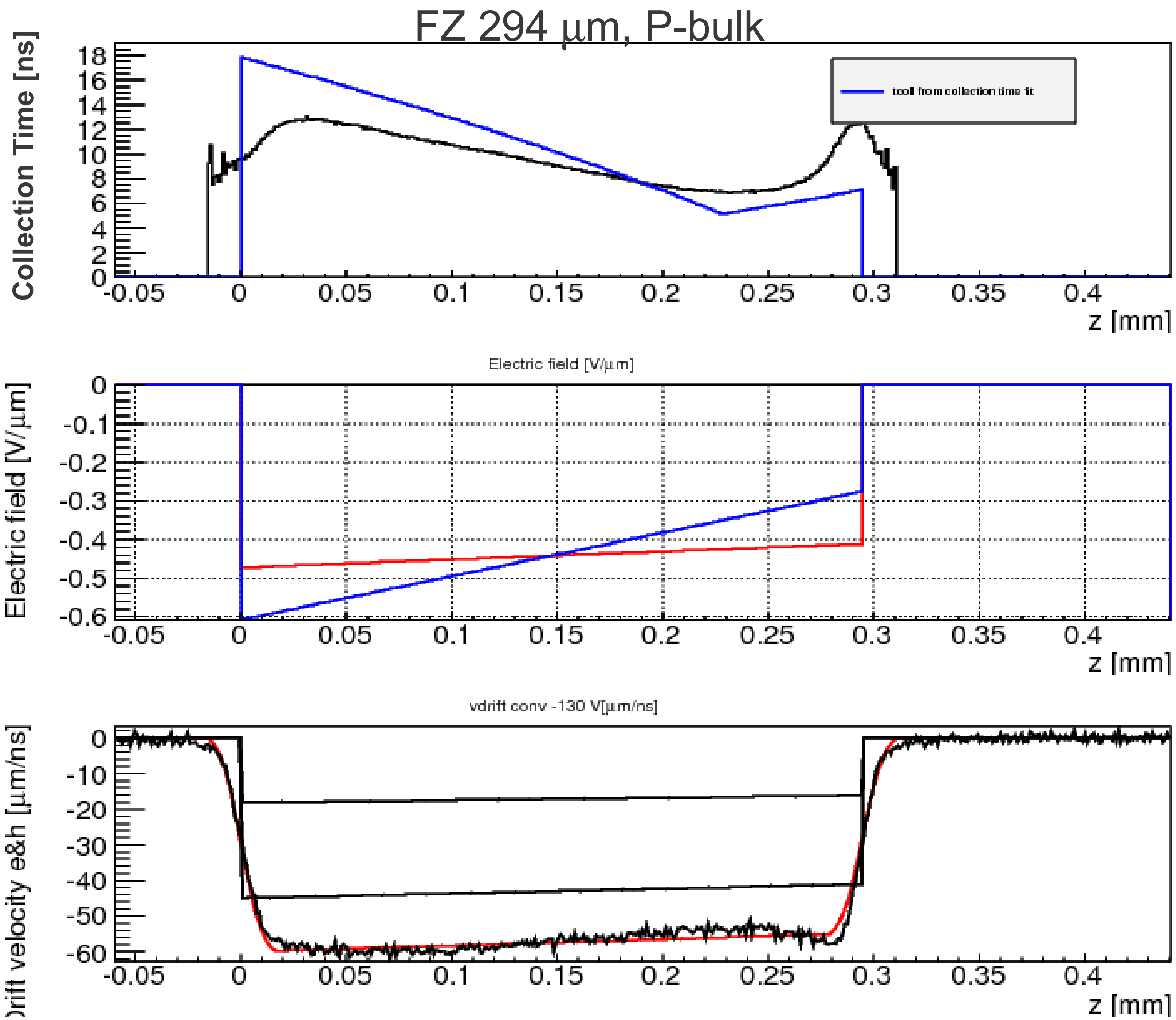
Red: E_{vdrift} (E-field from v_{drfitl} fit)

Scaled v_{drift}

Vdrift fit, using E_{coll} as starting parameter

Good fit at boundaries

Measured and fitted collection time (VTTN, Micron-P, HPK FZ320Y)



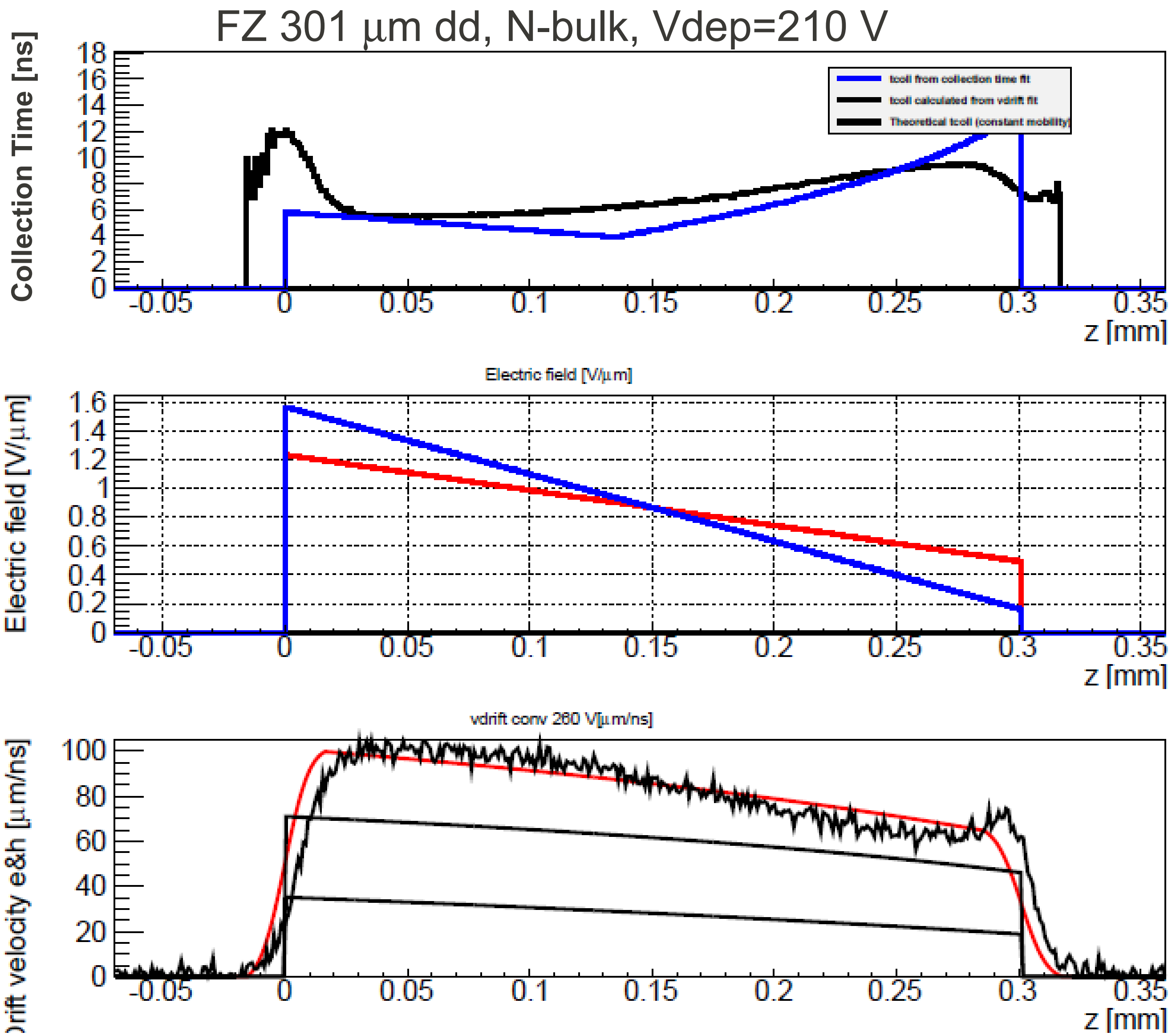
20120802001225_Micron_FZ2328-11_NonP_3

Magnitude of the collection time reproduced, but worse agreement than with VTT-N

~20% difference in the electric filed estimated from collection time and from vdrift

Good vdrift fit!!

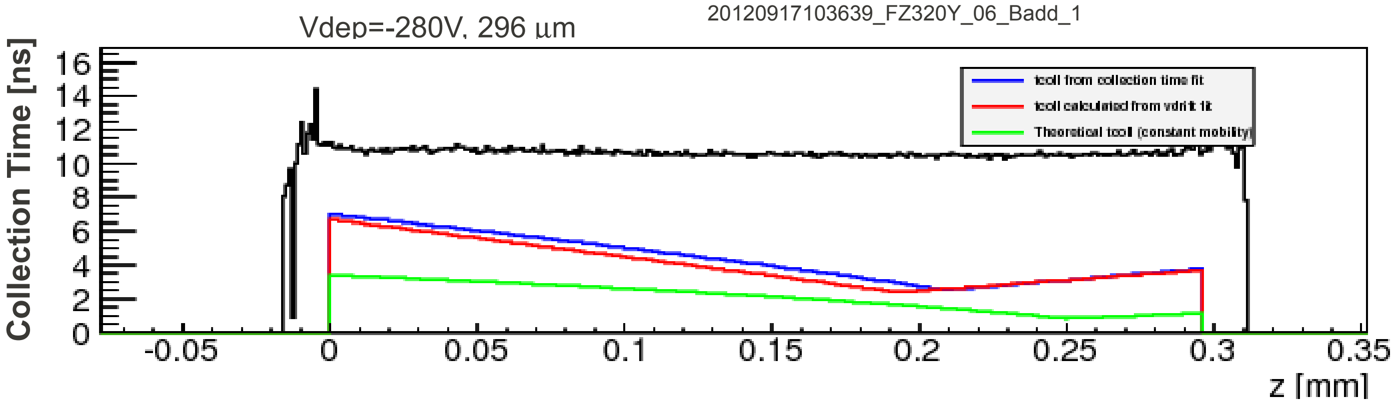
Measured and fitted collection time (VTT, Micron, HPK FZ320N)



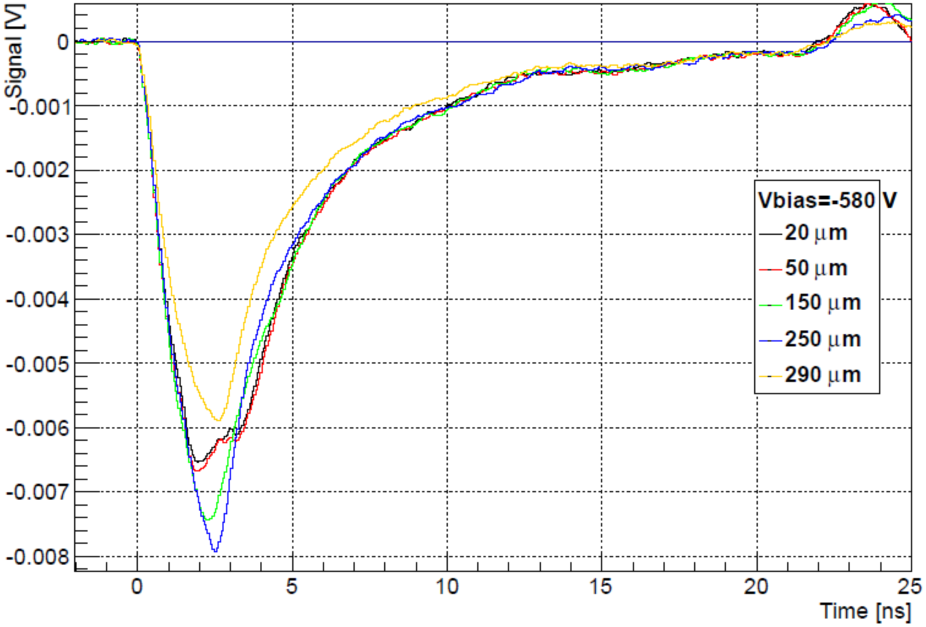
20121101165527_FZ320N_03_Badd_1

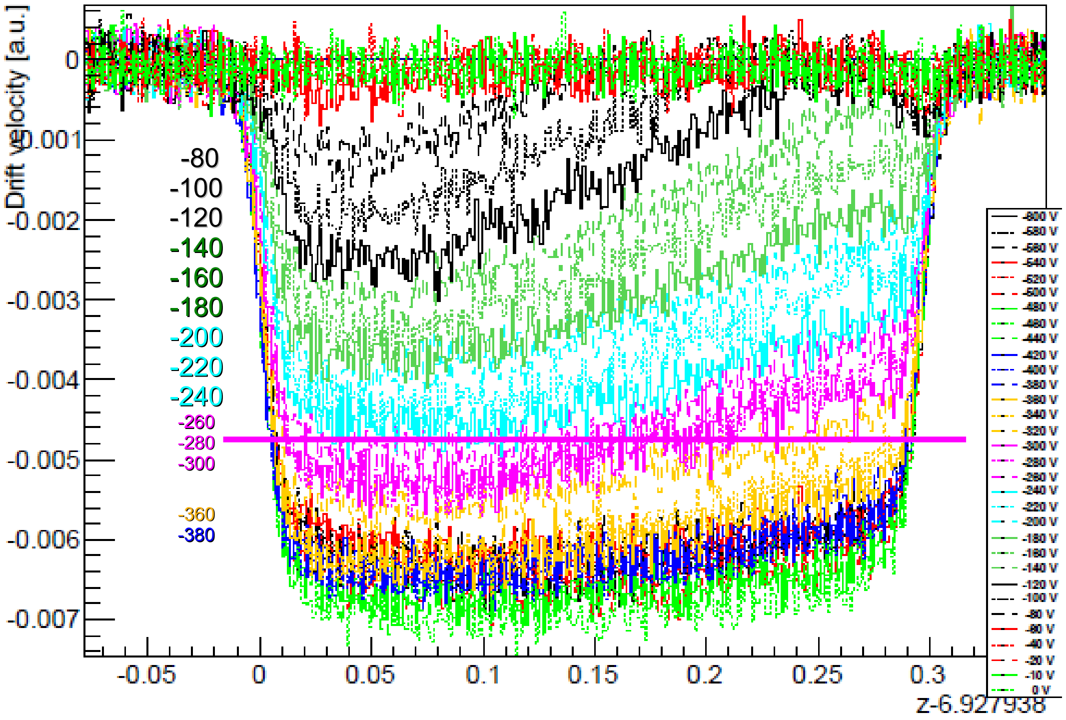
Fails:

Some collection times in HPK are **flat, as well as the vdrift estimated from raising edge:**
Possible explanation:
E-field is too high, electrons and holes have almost same speed …
BUT tcoll is too long (10 ns!!)



Deconvolution changes offset, but not the shape





Conclusions

- Calculated E-field from vdrift in eTCT depends on the absolute value of rise time chosen.
- A method was proposed to fix this normalization, using the measured collection time.
- The collection time is used to get a first estimate of the E-field. This E-field is used to scale the measured drift profile. The final E-field is obtained from a fit to vdrift.

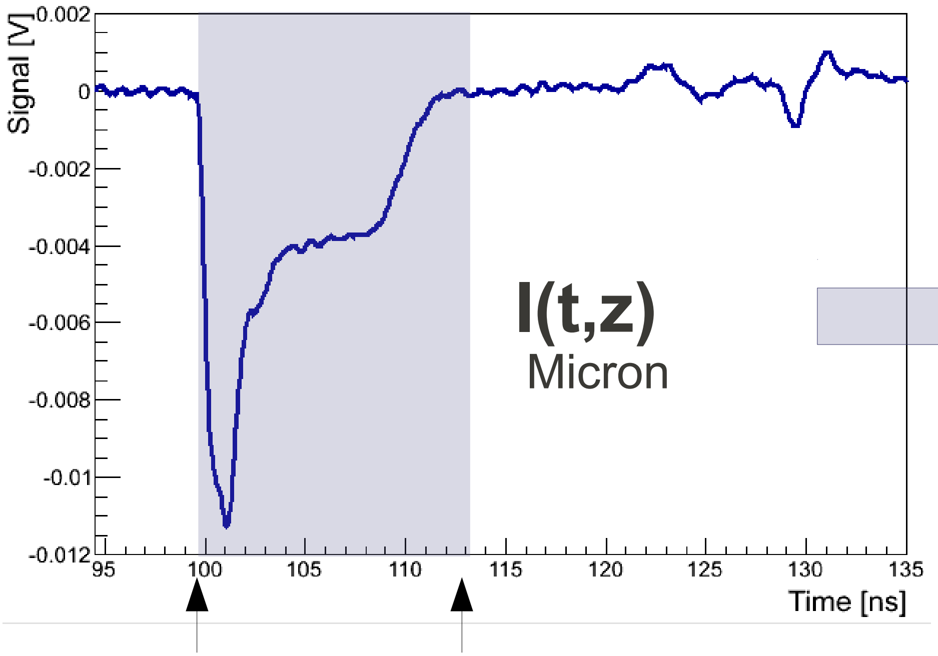
➔ We use a 2 fit approach because border effects are better reproduced in drift velocity than in the collection time profiles

Next steps:

- Apply method to unirradiate detectors below Vdep … almost finished
- Aply method to irradiated detectors … next RD50 meeting?

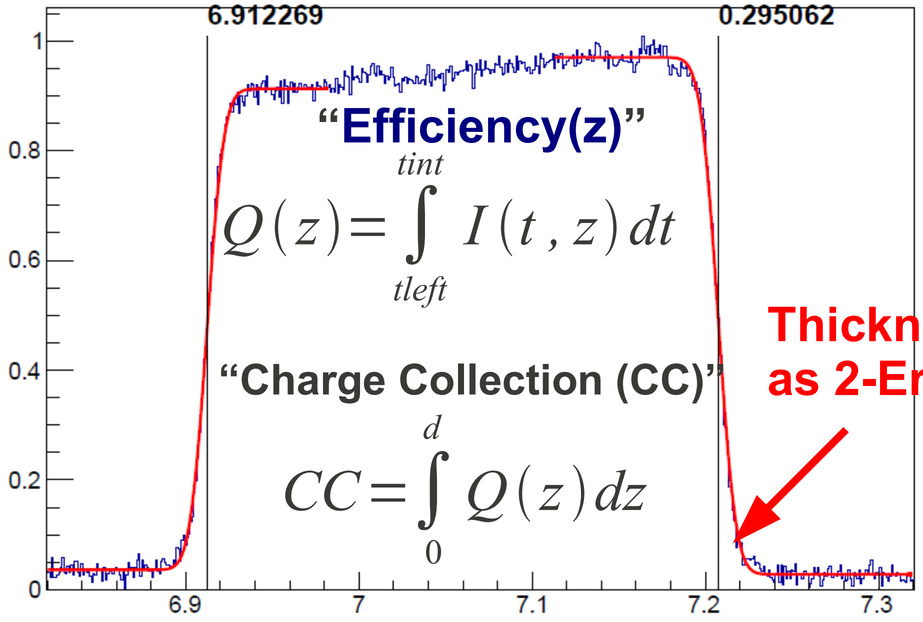
BACKUP

Analysis of eTCT pulses



I(t,z)
Micron

tleft **tint**



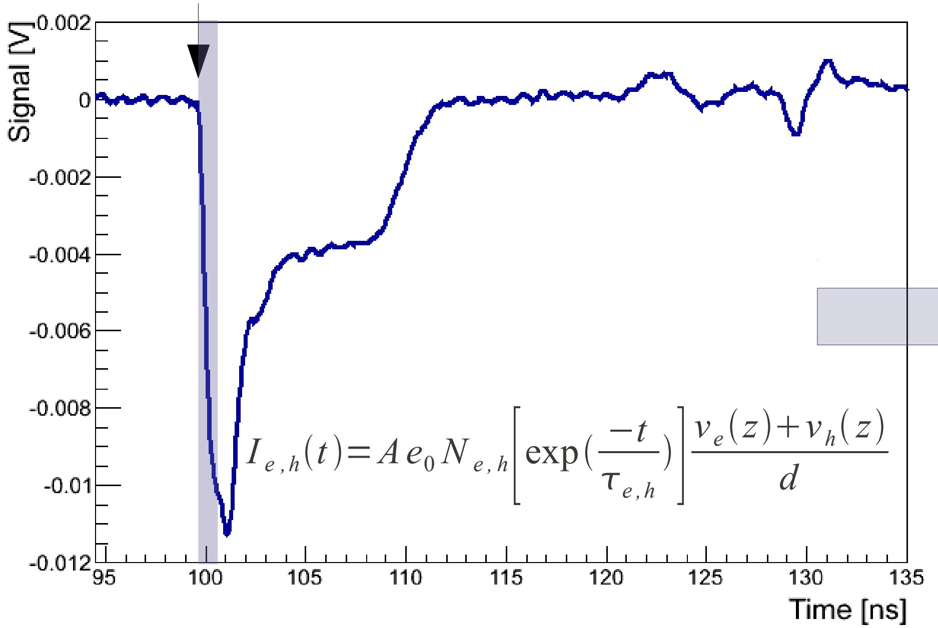
"Efficiency(z)"

$$Q(z)=\int_{tleft}^{tint} I(t,z)\,dt$$

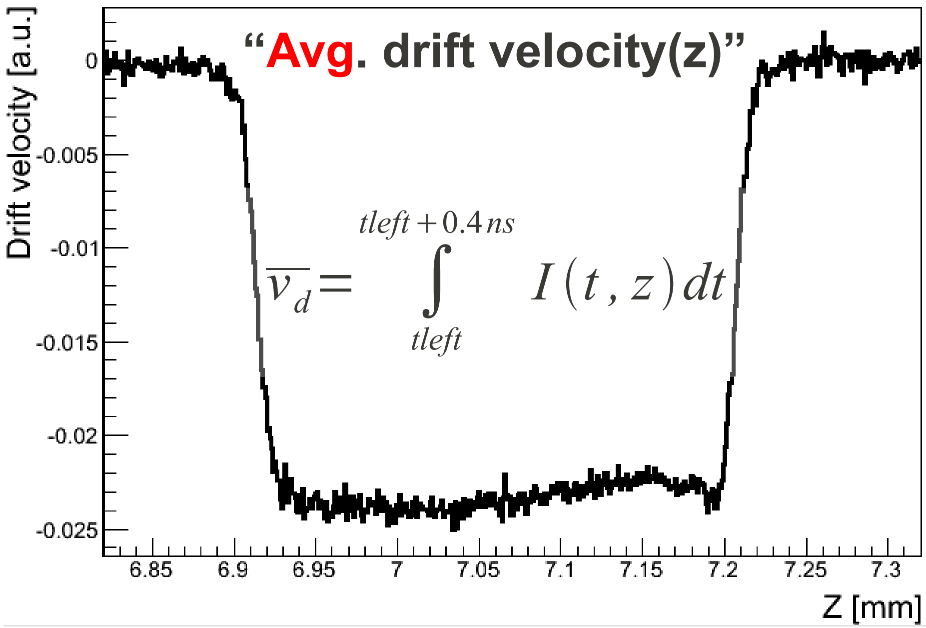
"Charge Collection (CC)"

$$CC=\int_{0}^{d} Q(z)\,dz$$

Thickness as 2-Erf



$$I_{e,h}(t)=A e_0 N_{e,h}\left[\exp\left(\frac{-t}{\tau_{e,h}}\right)\right]\frac{v_e(z)+v_h(z)}{d}$$



"Avg. drift velocity(z)"

$$\overline{v_d}=\int_{tleft}^{tleft+0.4ns} I(t,z)\,dt$$

Calculating vdrift normalization

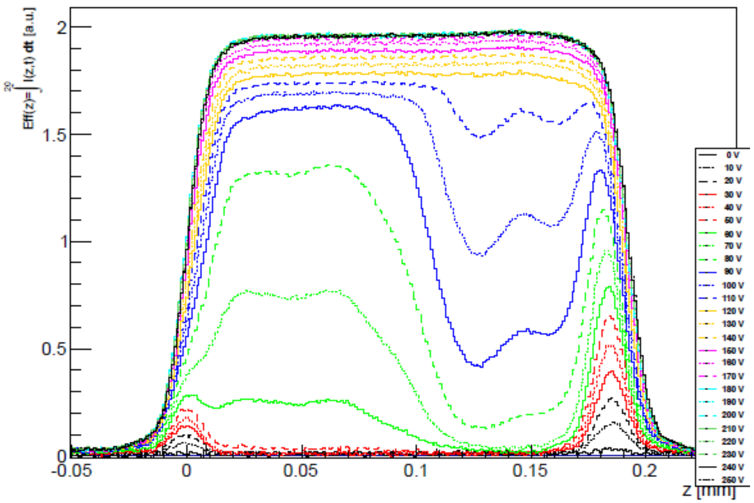
Method #1: Ne,h from Q(z)

vdrift known from eTCT up to a normalization constant.

- Ne,h pairs can be extracted from Q(z), at V>depletion: Q(z)~Ae$_0$N

$$Q(z)=Ae_0N(z)\underbrace{\int_0^{tint}\frac{(v_e(t)+v_h(t))}{d}dt}\;\Rightarrow\;Q(z)=Ae_0N(z)$$

=1 depleted
<1 non-depleted, and function of (z,V)



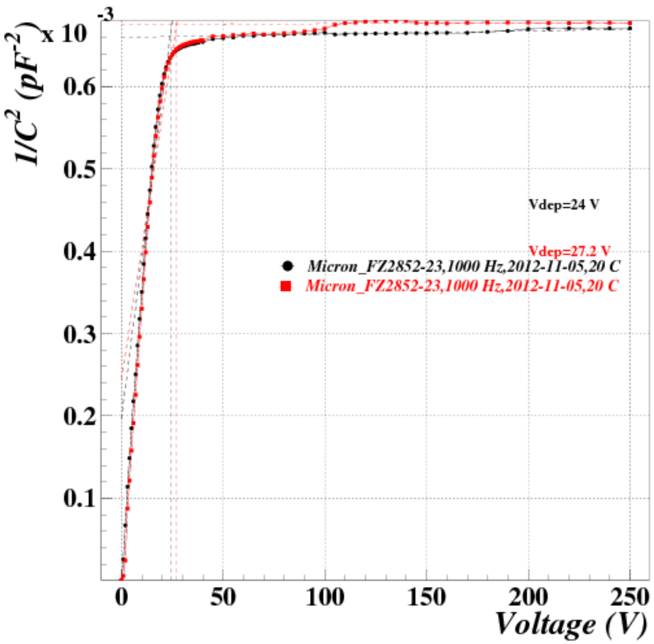
- Take average of N(z): $\overline{N}=\frac{1}{N_d}\sum_0^d N(z_i)$

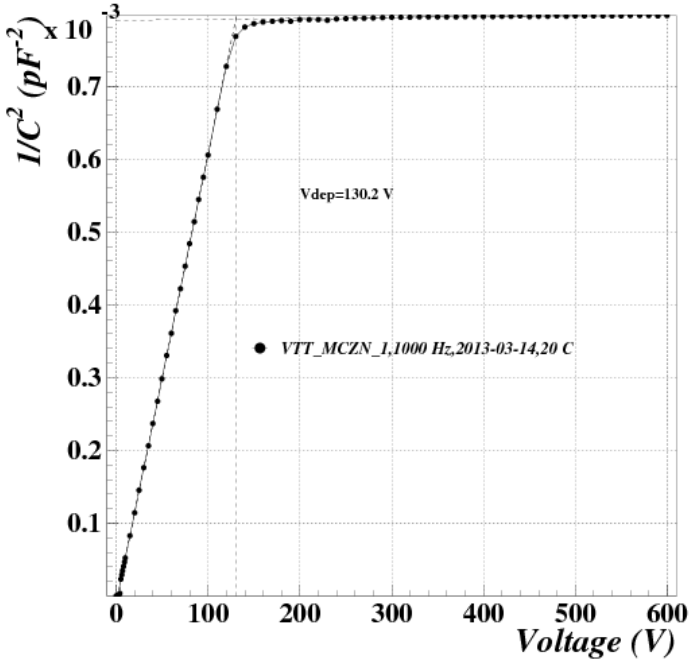
- Calculate "normalized averaged" drift velocity:
  - … normalized to $\overline{\text{N}}$
  - … averaged for 400 ps

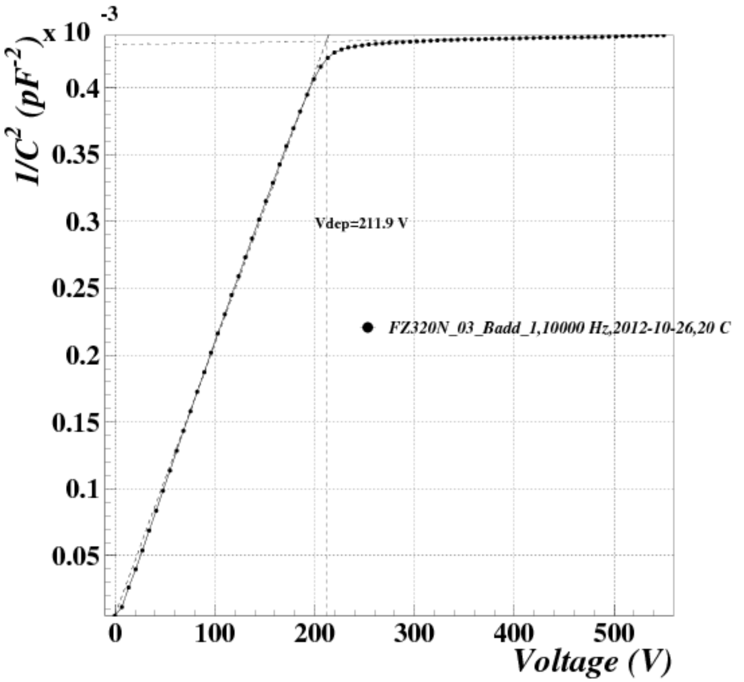
$$v_{drift}(z_i)=\frac{d}{Ae_0\underset{\uparrow}{\overline{N}}}\underbrace{\frac{1}{N_{400}}\sum_{j=0}^{400\,ps}I(t_j,z_i)}$$

Normalized Averaged

Equivalent to drift velocity due to 1 pair e-h







	Micron	**VTT**	**FZ320N/Y**
Neff [cm^{-3}]~	2.3e11	1.5 e12	2e12 / 3e12
Vdep [V]~	25	130	212 / 280
ρ[kΩ.cm]~	20	2	1.5 /
Cend[pF]~	38	35	48 / 52
1.2*Vdep~	30	160	260 / 336

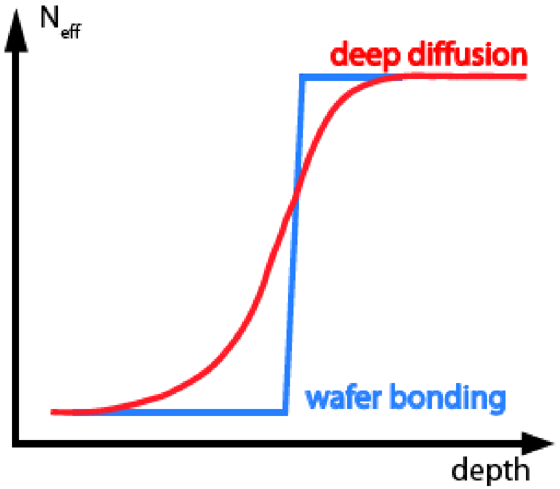
Neff for HPK is the biggest → highest E-field.

Doping profiles of deep diffused FZ

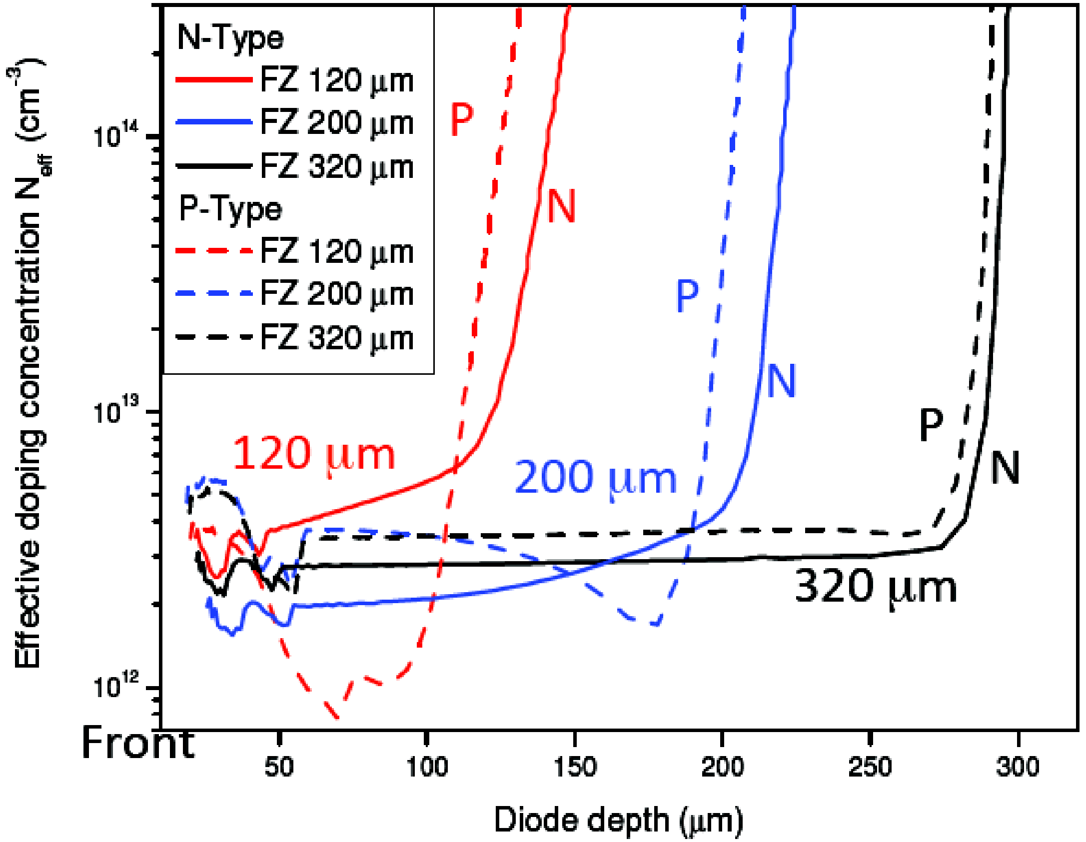
Calculation of depth profile via:

$$\frac{d(1/C^2)}{dV} = -\frac{2}{A^2 \varepsilon \varepsilon_0 q_0 |N_{eff}|}$$

Reason: *Deep diffusion* process



N_{eff} – depth profile from C-V characteristics



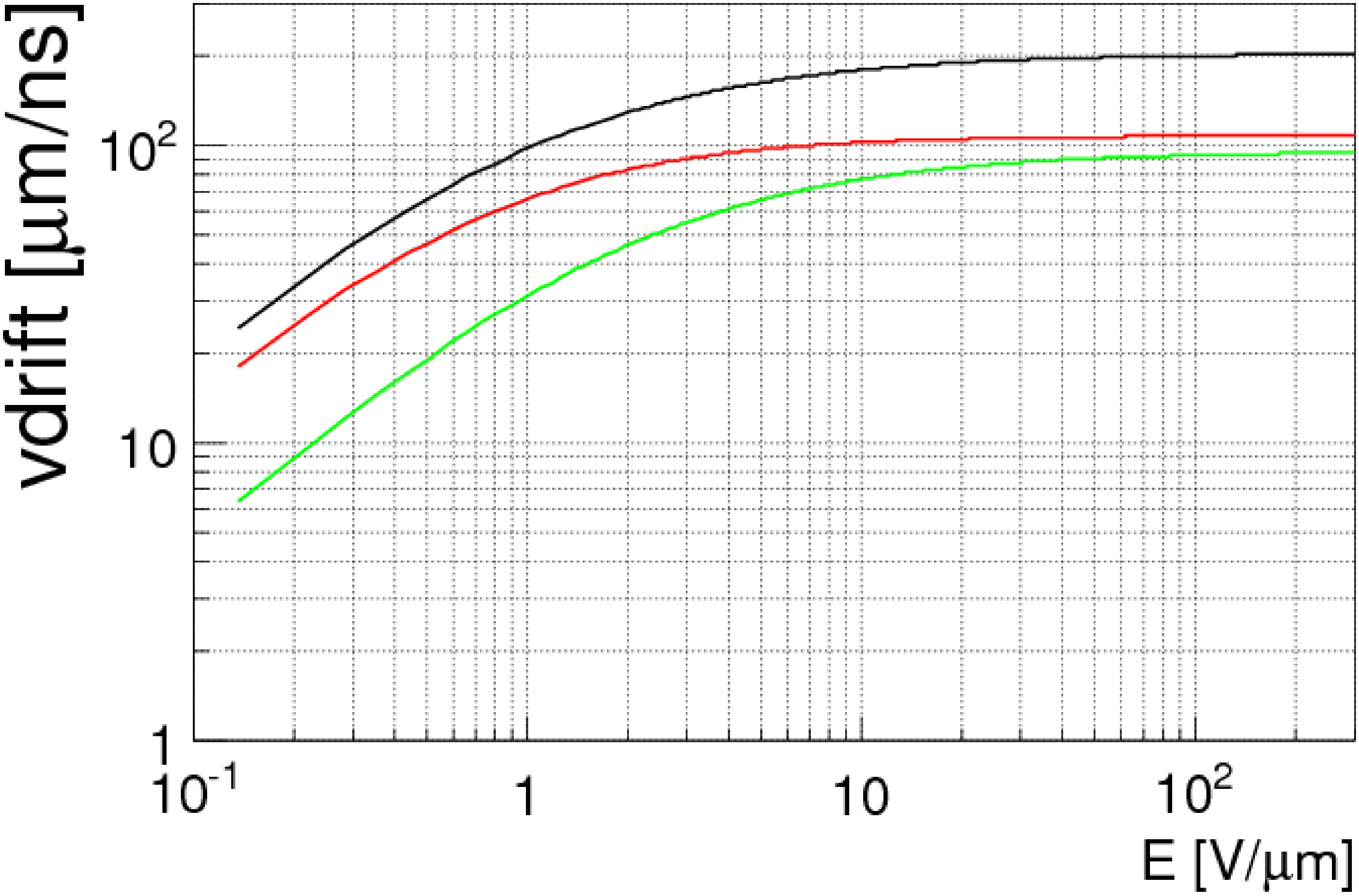
Inhomogeneous doping profiles in thin diodes

Correlations in vdrift fits

If we use a polynomial for the electric field, then we cannot extract the vdrift normalization using only the Vbias equation, since the parameters would be all correlated

$$\left(V_{bias} - \int_0^d E(z)\,dz\right)^2 = \left(Vbias - k\int_0^d (p_0 + p_1 z + p_2 z^2)\,dz\right)^2$$

k is 100 % correlated to p0,p1,p2,...



$$v_{drift} = \frac{\mu_{0,e} E}{\left(1 + \left(\frac{\mu_{0,e} E}{v_{sat,e}}\right)^{\beta_e}\right)^{\frac{1}{\beta_e}}}$$

Total
Electrons
Holes