Extraction of physical quantities from edge-TCT measurements

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Outline

- Motivation
- Method
- Method explained on example of one of the measurements from N. Pacifico's talk:
  - MCz-p strip detector, $\Phi = 10^{16}$protons/cm^2
  - Not annealed
  - U_{bias}=700V
  - T=–25^{o}C

Motivation

- Classical TCT measurement with red laser:
  - Offers trapping time determination with the assumption: $\tau_{e,h}(E) = \text{const.}$
  - Difficulties with trapping time extraction for highly irradiated detectors $\rightarrow \tau_{e,h}(E) \neq \text{const?}$
- Edge-TCT measurement:
  - Offers $v_{dr}(z)$ extraction $\rightarrow \tau_{e,h}(E)$
  - Our aim: extract $\tau_{e,h}(E)$

How?

- Inputs (eTCT measurement):
  - signals(z, U_b)
  - $v_{dr,m}(z)$ profile across detector (for given bias U_b and temperature) extracted from the initial rise of signals $g^m(z)$
- Method to extract $\tau_{e,h}(E)$:
  - Disentangle "true" point charge $v_{dr,t}(z)$ profile from measured $v_{dr,m}(z)$ assuming $v_{dr,t}(z)$ is smeared with Gauss function to take into account laser width and imperfect polishing of detector: $v_{dr,m}(z) = G(0,\sigma) * v_{dr,t}(z)$
  - $v_{dr,t}(z)$ profile $\rightarrow$ $v^e{}_{dr,t}(z)$, $v^h{}_{dr,t}(z)$, $E(z)$
  - From $E(z)$:
    - Calculate induced current signal for either front or back injection, where only one type of charge carriers drifting
    - Add trapping
    - Convolve with transfer function of the measurement system to take into account the electronics
    - Vary the trapping model function parameters to fit the calculated waveforms $g^c(z)$ to the measured ones $g^m(z)$
- Method is still under development, but some preliminary results will be shown for an example of one measurement on MCz-p strip detector irradiated to 10^{16}protons/cm^2, not annealed, U_{bias}=700V

Drift velocity deconvolution (1/5)

- Problem: deconvolution most often ill posed problem
  $g(z)=h(z)*f(z)$
  - in Fourier space $G(\omega)=H(\omega)F(\omega) \rightarrow F(\omega)=G(\omega)/H(\omega)$
  - $H(\omega)$ is typically a low pass filter, the inverse $1/H(\omega)$ is a high pass filter → amplifies noise and numerical errors!

- How they usually deal with this problem
  - Regularization (filtering):
    - In real space:
      $g(x)=H(x)f(x)$, H=convolution matrix in real space
    - Instead of minimizing functional $min\|Hf\text{-}g\|^2$ to obtain the solution in the least squares sense add smoothing term(s) to regularize the problem
      $\min\{\|Hf\text{-}g\|^2 + \|\Omega\|^2\}$
    - Ω typically contains terms like $(d^n/dx^n)f$, each term has a regularization constants which defines the level of smoothness: puts a limit on the noise amplification but it smoothens both noise and f (bad for edges in f...)
    - In general, more terms in Ω give better estimation of f, but...
    - Regularization constants are chosen by the user, one should find optimal regularization constants which give "optimal" result, not an easy task...

  - "Fitting": take model function for f and vary parameters to fit the measured data
    - Gives best results, if the model function is known... :)

Drift velocity deconvolution (2/5)

Deconvolution problem $v_{dr,m}(z)=G(0,\sigma)*v_{dr,t}(z)$

- Several regularization methods tried
- For example: method which is meant to be "edge preserving" and gives an option to determine the σ, but...
  - Contains at least 4 regularization constants, no automatized method proposed to determine the regularization parameters proposed...
  - Tried to find a method to determine a quantity that could be monitored to tell which regularization constants give "best" result
  - Decided not to use this method, since it is time consuming and no reliable algorithm for automatization was found...

[1] L. Bar et al.,*"Semi-Blind Image Restoration Via Mumford-Shah Regularization"*, IEEE Trans. on Image Proc., Vol. 15, No. 2, pp. 483-493, 2006.
[2] L. Bar et al., "Image deblurring in the presence of impulsive noise",Int. J. Comput. Vision, Vol. 70, No. 3, pp. 279-298, 2006

Drift velocity deconvolution (3/5)

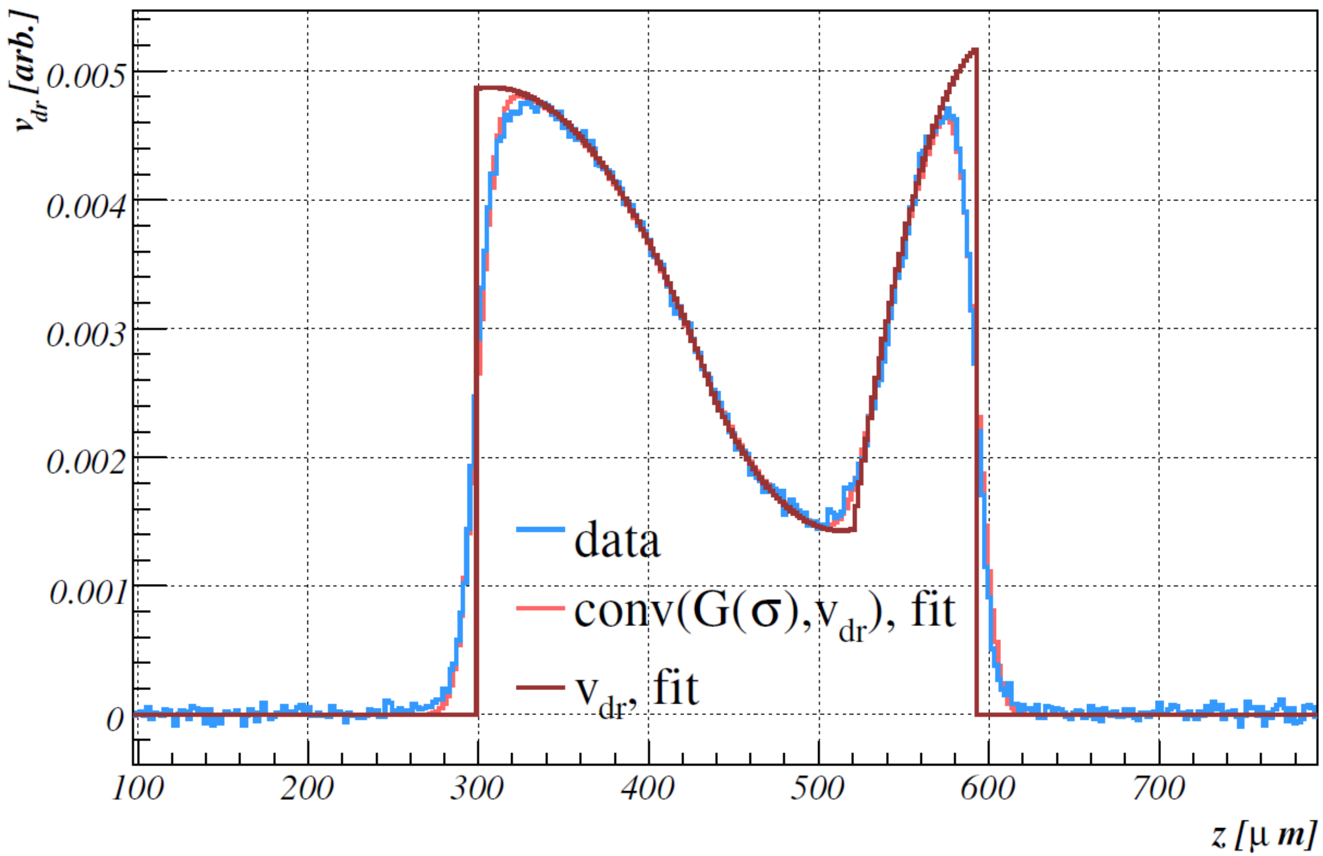
Deconvolution problem $v_{dr,m}(z) = G(0,\sigma) * v_{dr,t}(z)$

- Decided to use "fitting" strategy
- $v_{dr,t}(z)$ function is modeled with 2-3 parabolas/lines applied to different regions of detector
- Least squares minimization with TMinuit is performed: typically Simplex method is used to bring initial guess closer to solution, followed by Migrad minimization to improve the result
- Parameters
  - σ of Gaussian blur function
  - Points (z, v_{dr}) determining the 2 or 3 regions with different parabolas/lines
  - Constant a or b ($v_{dr}(z) = az^2 + bz + c$) for each parabola
  - depending on the problem, some can be fixed before Migrad and/or Simplex minimization

Drift velocity deconvolution (4/5)

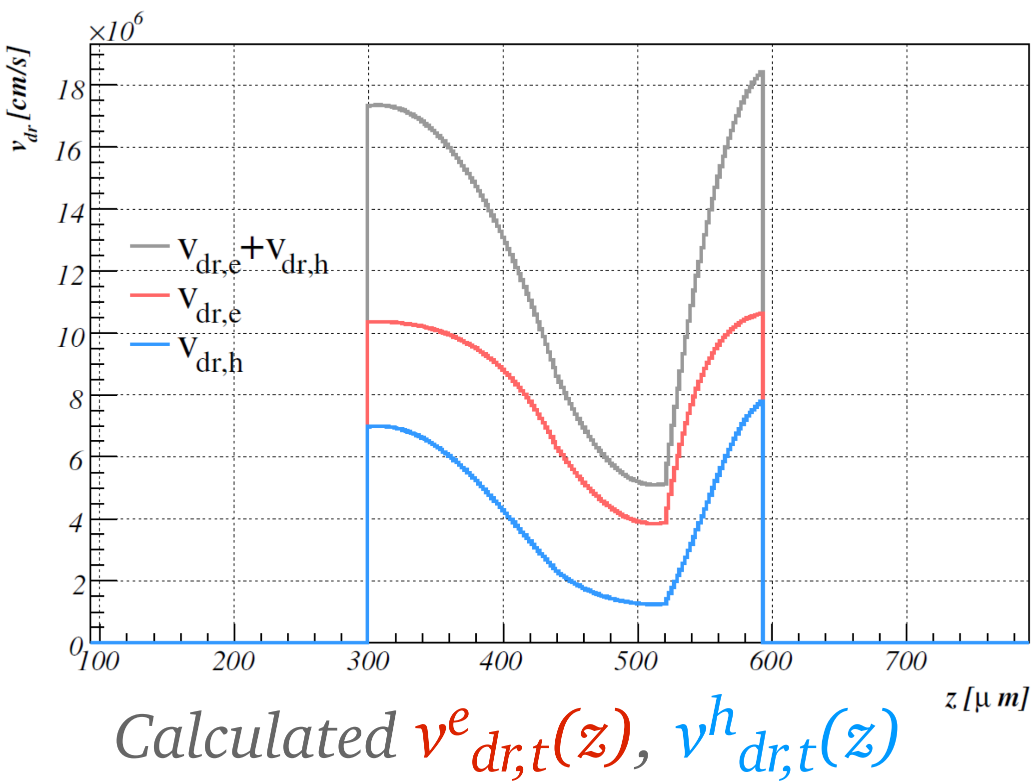
Example:

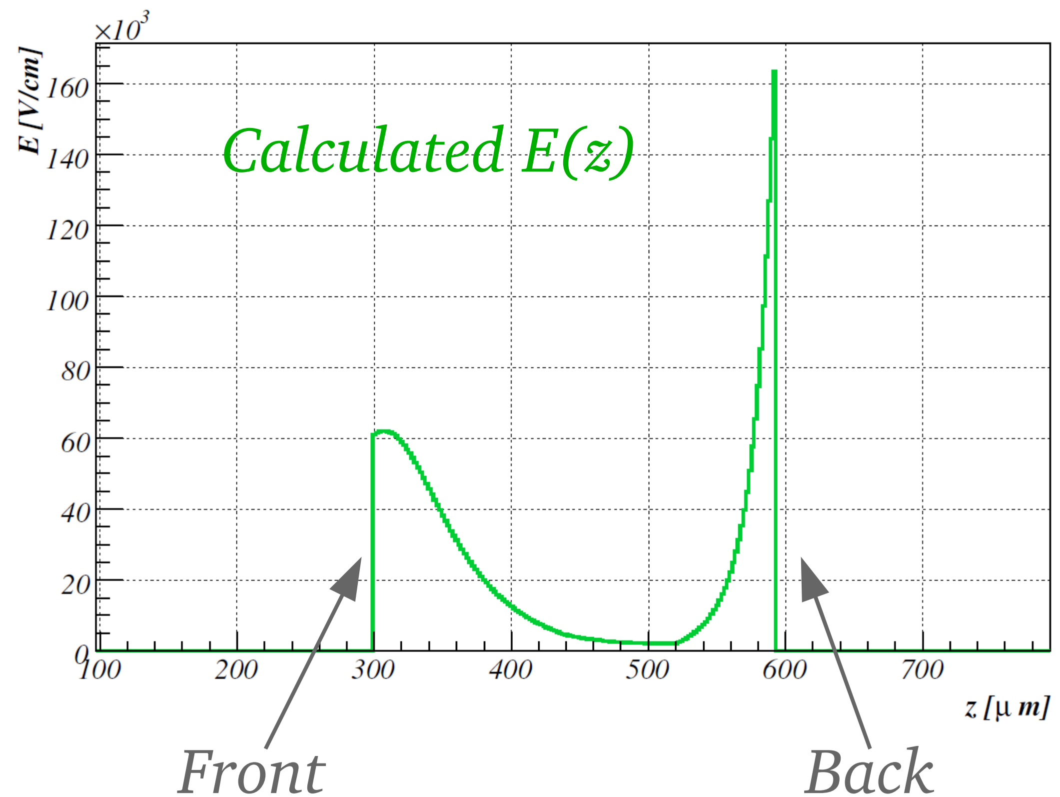
- MCz-p strip detector, $\Phi=10^{16}$protons/cm^2, no annealing, U_{bias}=700V, T=–25°C
- Model function: 3 parabolas in 3 different regions
- 5 fixed parameters: positions of 3 regions and σ of Gaussian blur function
- Compared results given by minimization with different values of the 5 fixed parameters to check which set gives best result:
  - σ_{best}=9μm (expected laser σ=7.5-8μm)
  - Detector thickness d_{best}=292μm



Drift velocity deconvolution (5/5)

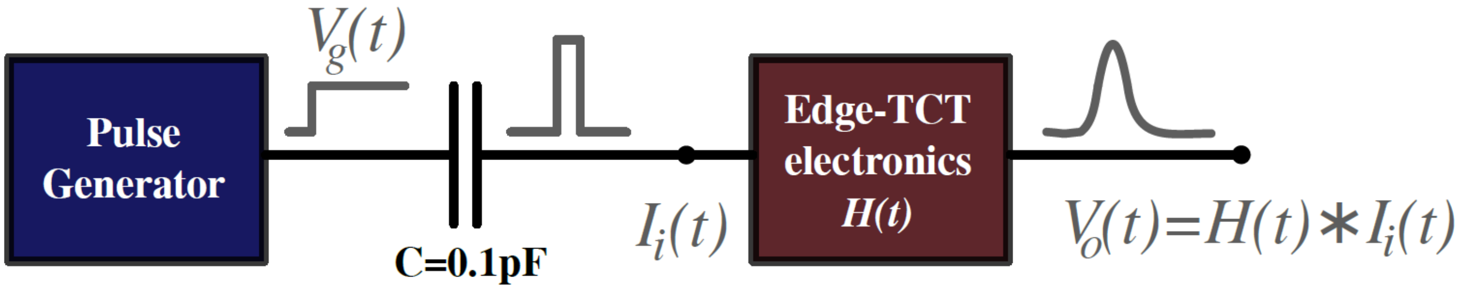
- $v_{dr,t}(z) \rightarrow$ Calculate of $v^e_{dr,t}(z)$, $v^h_{dr,t}(z)$, $E(z)$
  - Constraint $\int E(z)dz = U_{bias}$ to determine the absolute scale
  - Mobility model: MINIMOS4





Transfer function of the meas. system (1/4)

- Measured I_i and V_o(2.5GHz scope,Agilent DSO9254A):



I_i δ-like current spike
V_g: step-like voltage pulse

- H calculated in Fourier space (Riad-Parruck method [3]):

$$H(\omega) = \frac{V_o(\omega)}{I_i(\omega)} S(\omega)$$

- Filter (regularization):

$$S(\omega) = \frac{|I_i(\omega)|^2}{|I_i(\omega)|^2 + \lambda}$$

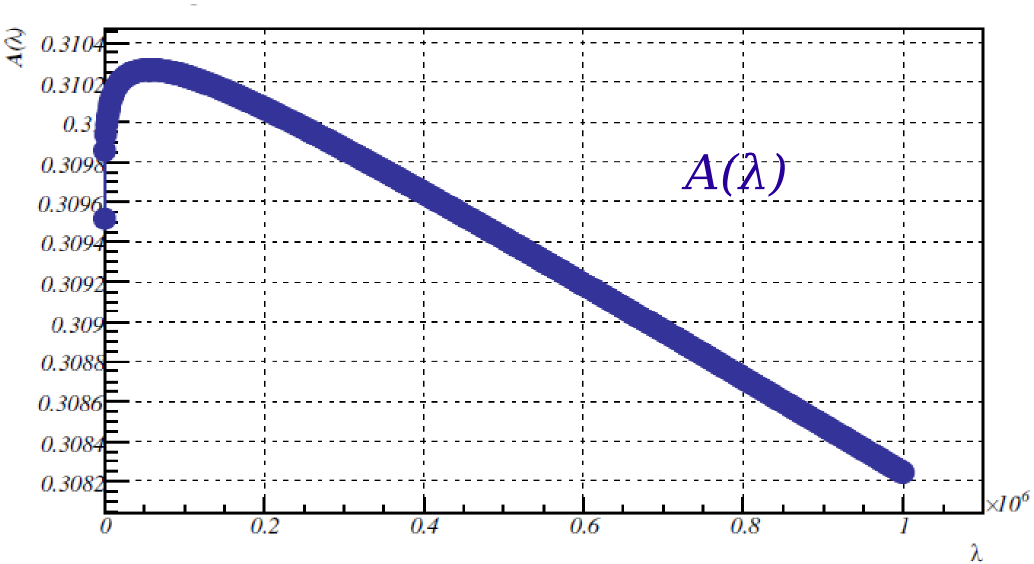
[3] B. Parruck, S. M. Riad, 1EEE Trans. Instr. & Meas, vol. IM-32, no. 1, pp. 137-140,. Mar. 1983

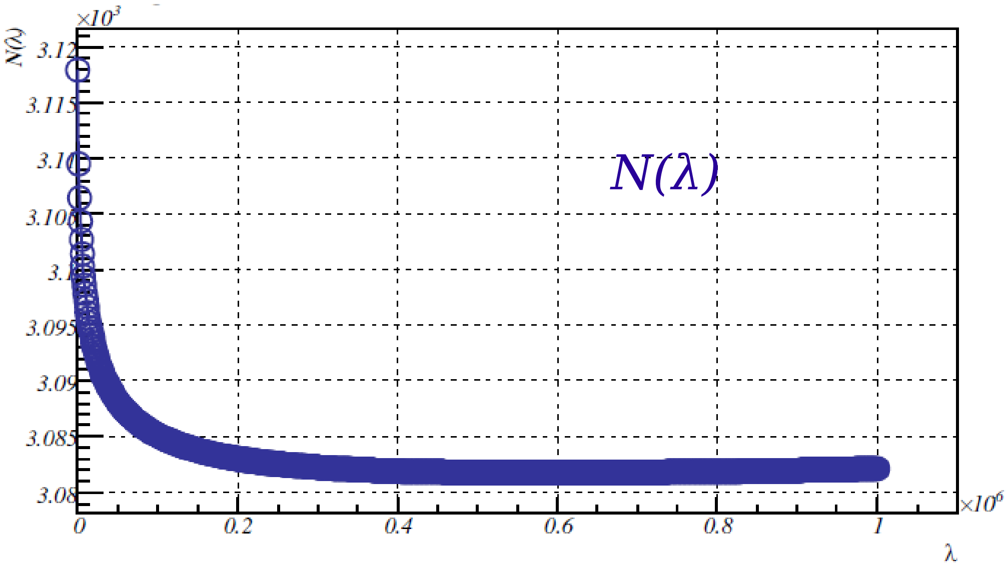
Transfer function of the meas. system (2/4)

- Optimal regularization constant λ determination:
  - For <u>each</u> λ:
    - Check the integral of calculated $H(t)$ to get a smooth step-like waveform (less sensitive to noise), $\int H(t)dt$
    - check mean, $A(\lambda)$, and RMS, $N(\lambda)$, in the tail part of the step-like response $\int H(t)dt$
  - <u>Optimum</u> λ_{opt}:

$$\frac{A(0) - A(\lambda_{opt})}{A(0)} \ll 1$$

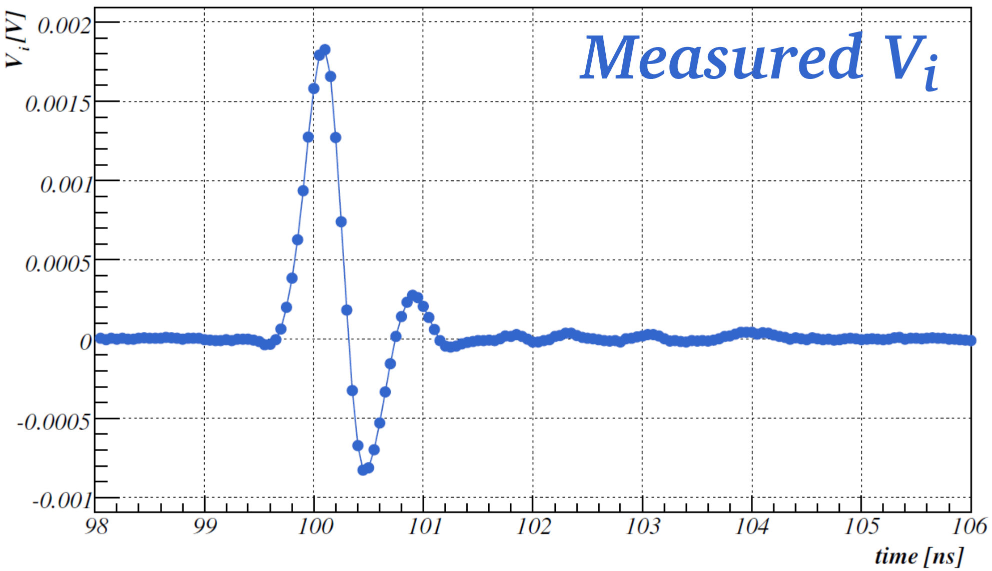
$$N(\lambda_{opt}) \ll N(0)$$

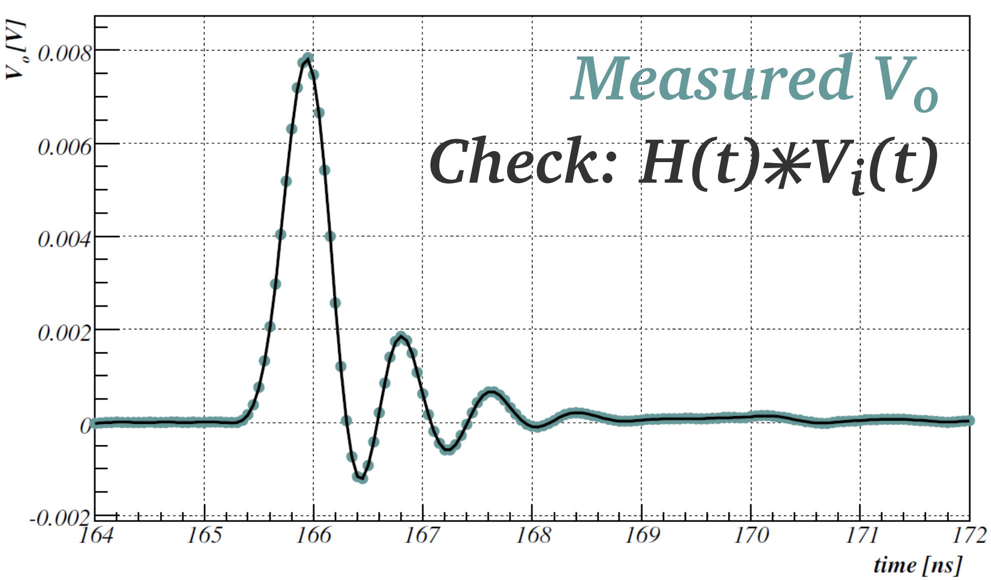


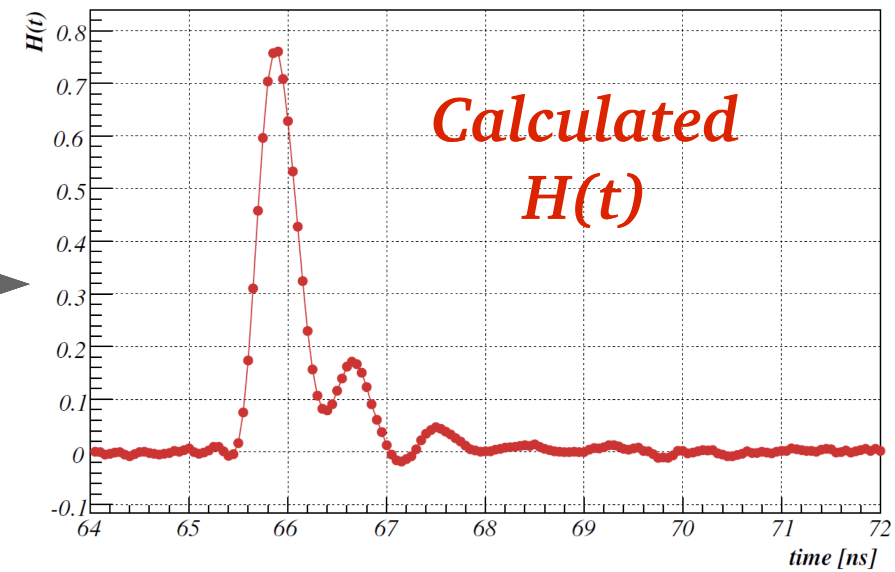


Transfer function of the meas. system (3/4)

Result

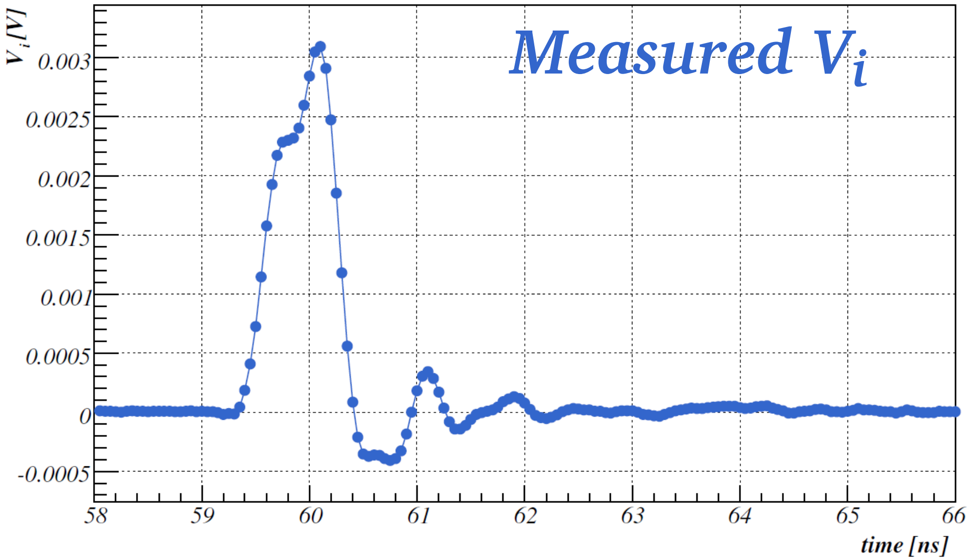


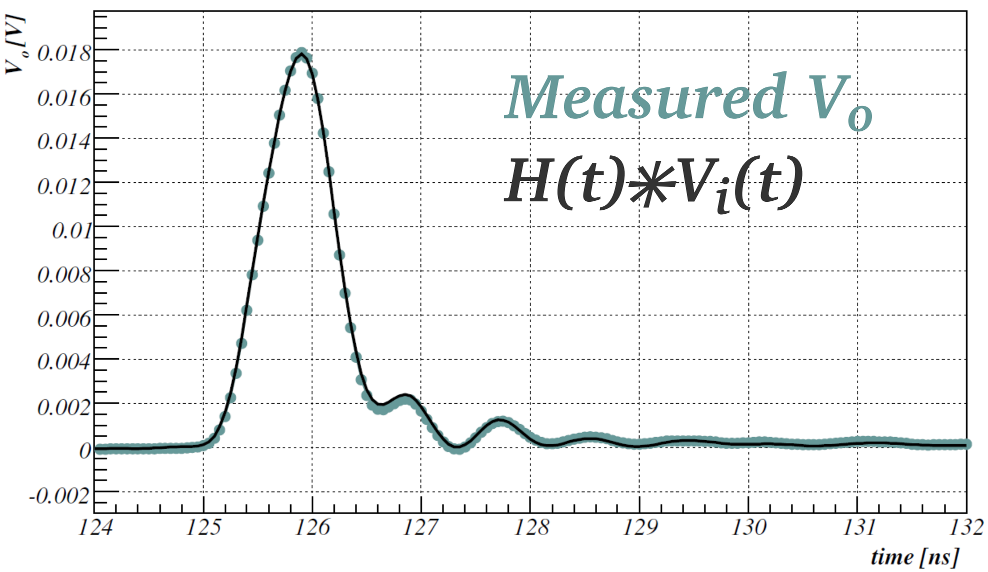




Transfer function of the meas. system (4/4)

Check: how calculated $H(t)$ transforms a different V_i?





Looks good, but...

Trapping time

- Procedure:
  - Consider front/back injection (only one type of charge drifting)
  - *E(z)* → calculate induced current
  - Add trapping, convolve with transfer function and vary trapping model parameters to fit the result to measured waveform in the least squares sense (Minuit minimization)

- Fit parameters:
  - Normalization constant
  - parameters for $\tau_{e,h}$ modeling

- $\tau_{e,h}$ modeling:

  1) Drift divided in n equidistant time regions with different trapping time for each region

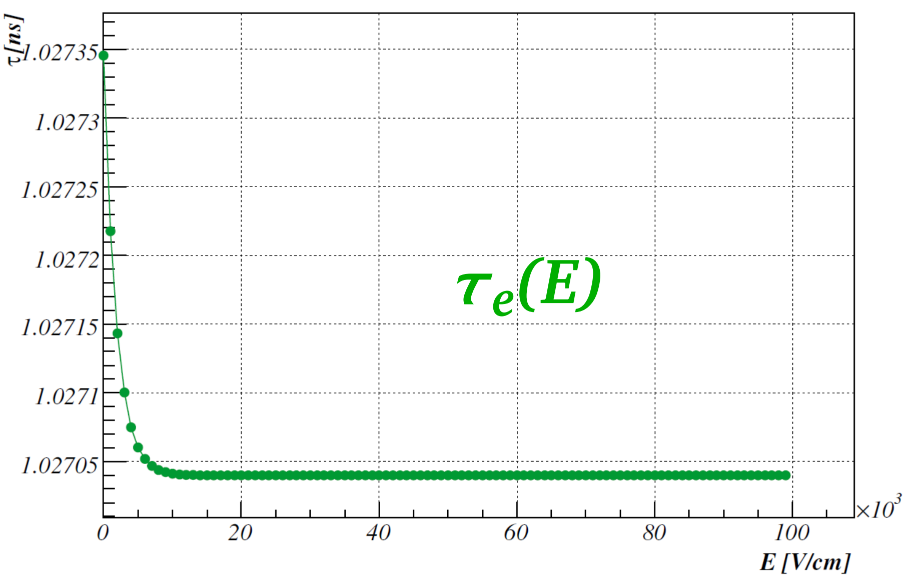
  2) Assume

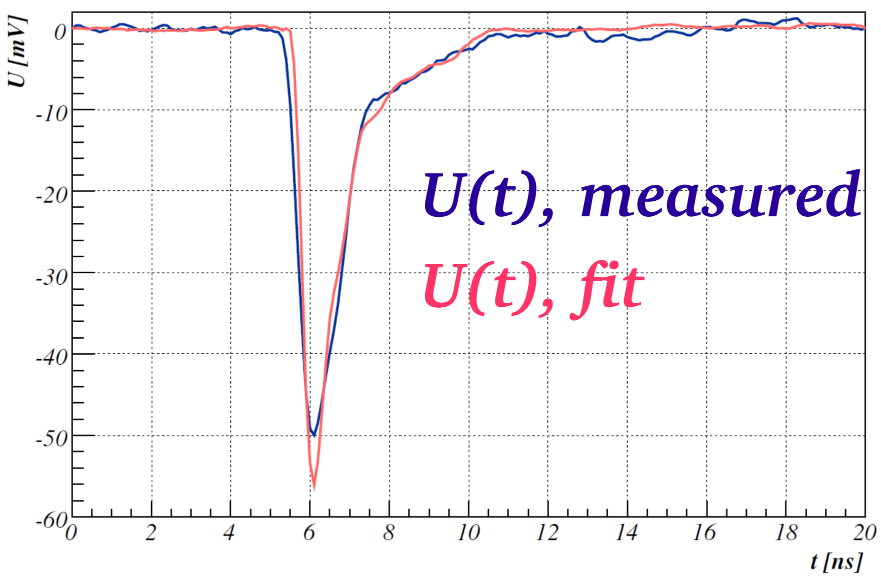
$$\tau_{e,h}(E) = \tau^0_{e,h} + \tau^1_{e,h}\mathrm{Exp}\left(-\frac{E}{E0}\right)$$

Trapping time: electrons (back injection)

Back injection for our example

- $\tau_e \sim$ 0.4ns expected from classic TCT measurements [4]
- Modeling with exponential dependence on E
- Observations:
  - Differences in rise time between measured and calculated signal, and ringing... → problems with transfer function?
  - $\tau_e \sim$ constant, higher than as expected from [4]

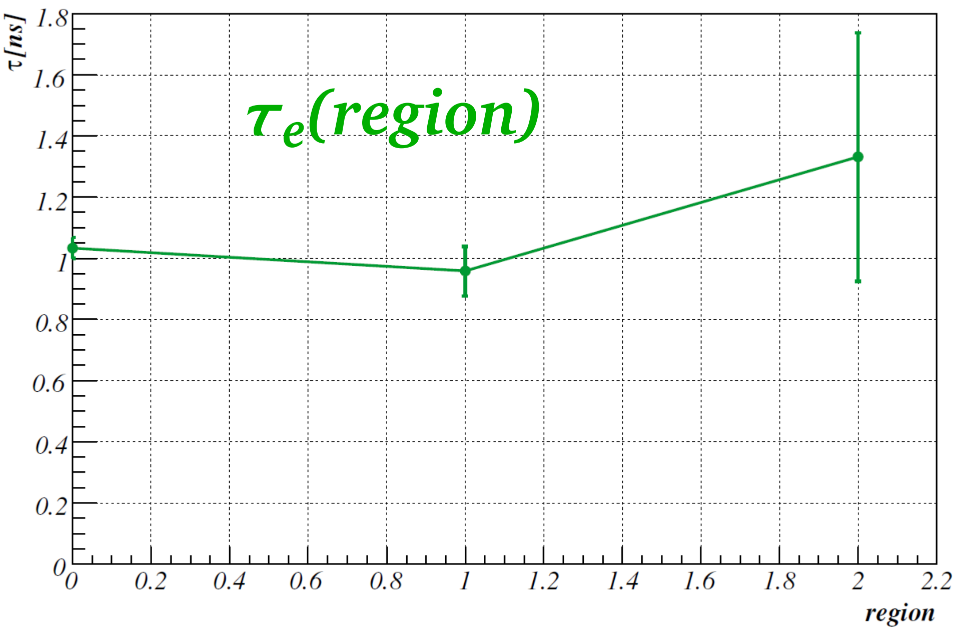


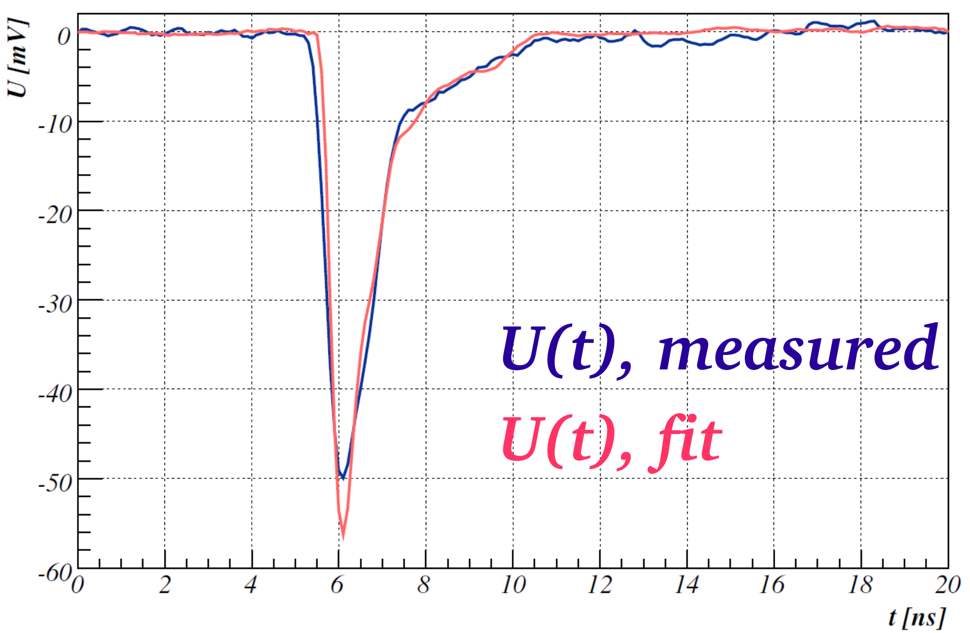


[4] G.Kramberger et al, NIM A,Vol.481, Issues 1-3, 1. April 2002, p. 297-305

Trapping time: electrons (back injection)

- Modeling with 3 equidistant time regions
  - Result consistent with result on previous page

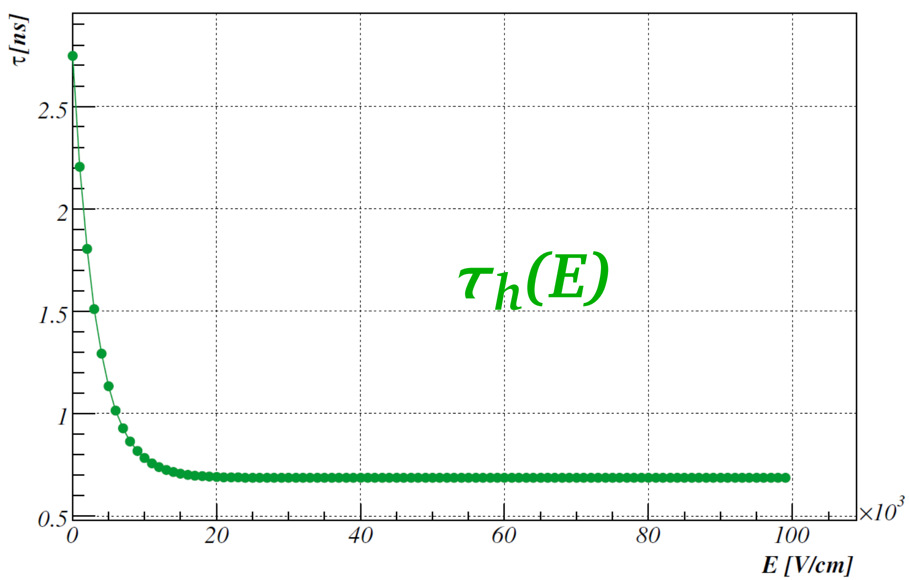


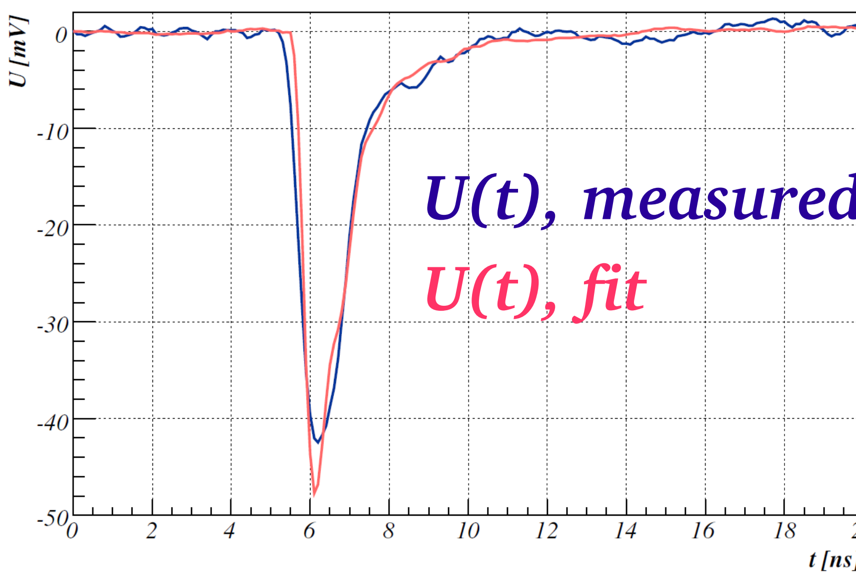


Trapping time: holes (front injection)

Front injection in our example

- $\tau_h \sim$ 0.2ns expected from classic TCT measurements [4]
- Modeling with exponential dependence on E
  - Again: differences in rise time between measured and calculated signal, ringing...
  - τ_h decreases with E, higher then expected from [4]





- Modeling with n time regions
  - Fit converged
  - But τ_h(region) not smooth: in some of the middle regions τ_h very high will in the rest τ_h between 0.7-1.5ns → ringing + signal in the tail too low to give meaningful result

Summary

- Presented a method to extract trapping times from edge-TCT measurements based on:
  - Point charge $v_{dr}(z)$ profile calculation
  - Fitting calculated signal waveform to the measured one by varying the trapping time model parameters
- Method still under development, but was explained on example of one measurement
- Future plans:
  - Test the method on <u>unirradiated</u> detector
    - Comparison of calculated and measured signal might reveal if our transfer function was not properly determined
    - Possible extraction of the transfer function itself with the Riad-Parruck deconvolution method by taking the calculated signal as input and measured signal as output
  - Test the method on detector irradiated with <u>lower fluencies</u>
    - Less trapping → longer pulses, expect less problems in the tail part of the signal
  - As a check: take calculated signal in the middle of detector and compare it to the measured one