Determination of Trapping Time Constants in Neutron-Irradiated Thin Silicon Pad Detectors

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Charge Collection in Silicon Sensors

- charge dQ induced on electrons by drifting charge q

$$dQ = \frac{q(t)}{d}\, dx = \frac{q(t)}{d}\, v(t)\, dt$$

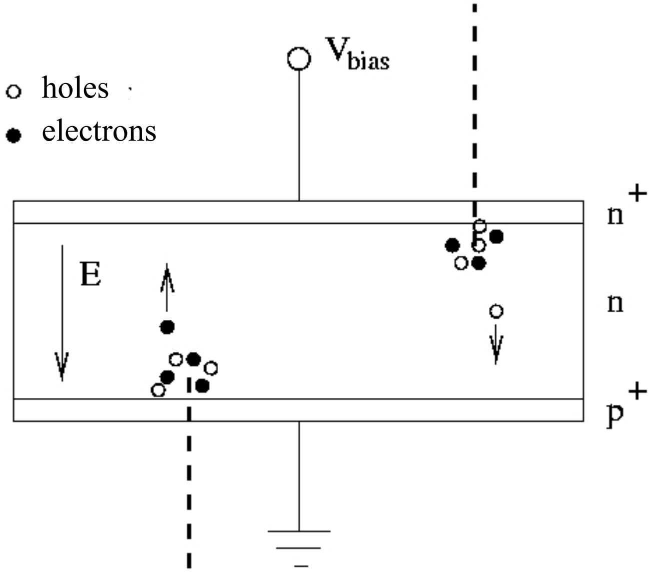
- trapping leads to charge carrier loss

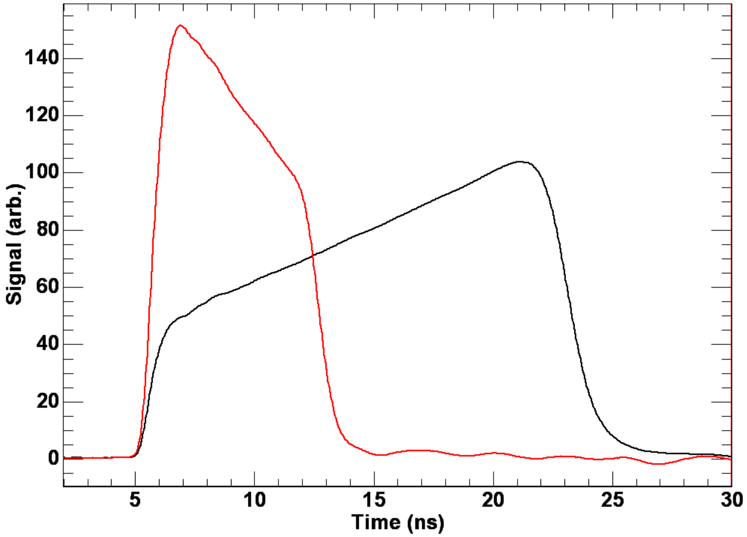
$$dq(t) = -\frac{1}{\tau_{eff}}\, q(t)\, dt, \quad \text{with} \quad \tau_{eff} = \tau_{eff}(\Phi_{eq})$$

- resulting (measured) signal current

$$i_m(t) = \frac{q_0}{d}\, v(t) \exp(-t/\tau_{eff})$$

- injection with short range laser from one side allows to distinguish between electron and hole signal



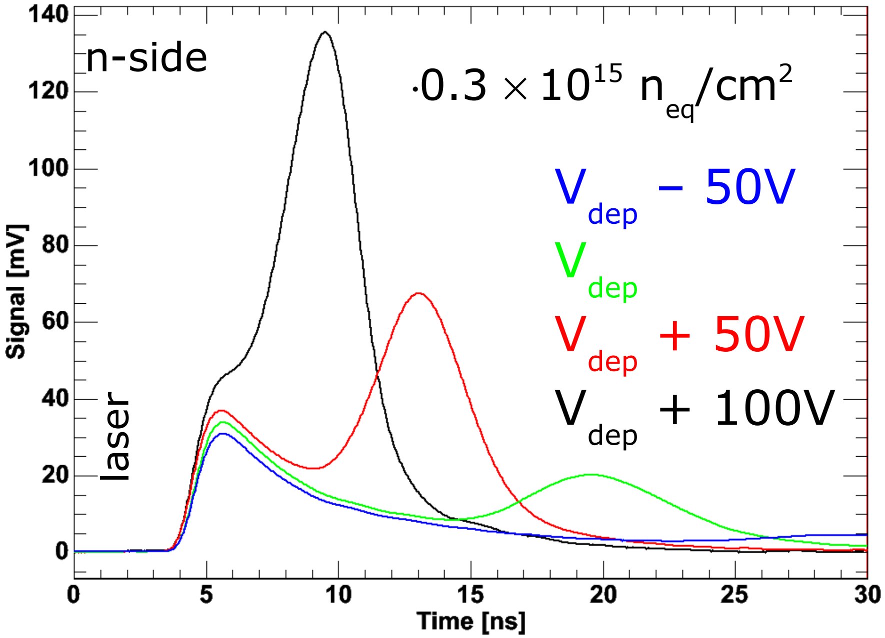


Signal Examples (thick diodes)

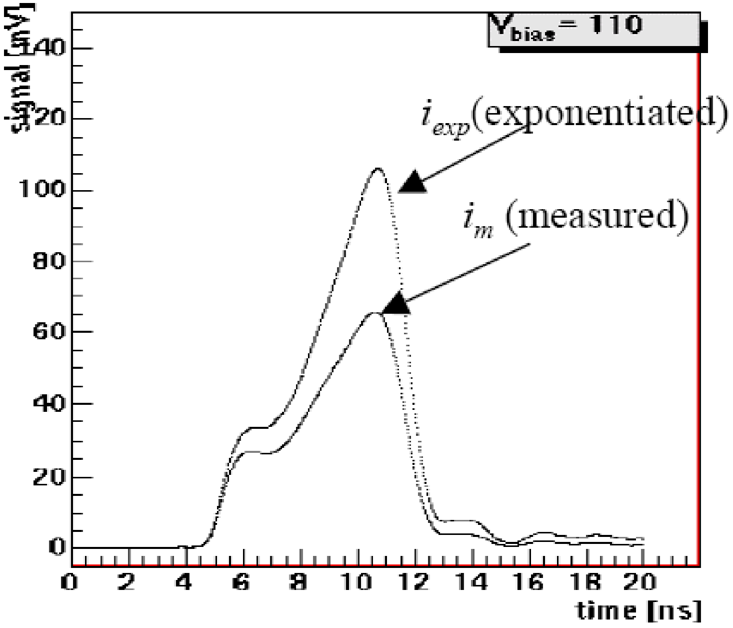
need time resolved signal to extract trapping time

→ two methods:

1. Charge Correction Method (CCM)
2. Exponentiated Charge Crossing (ECC)

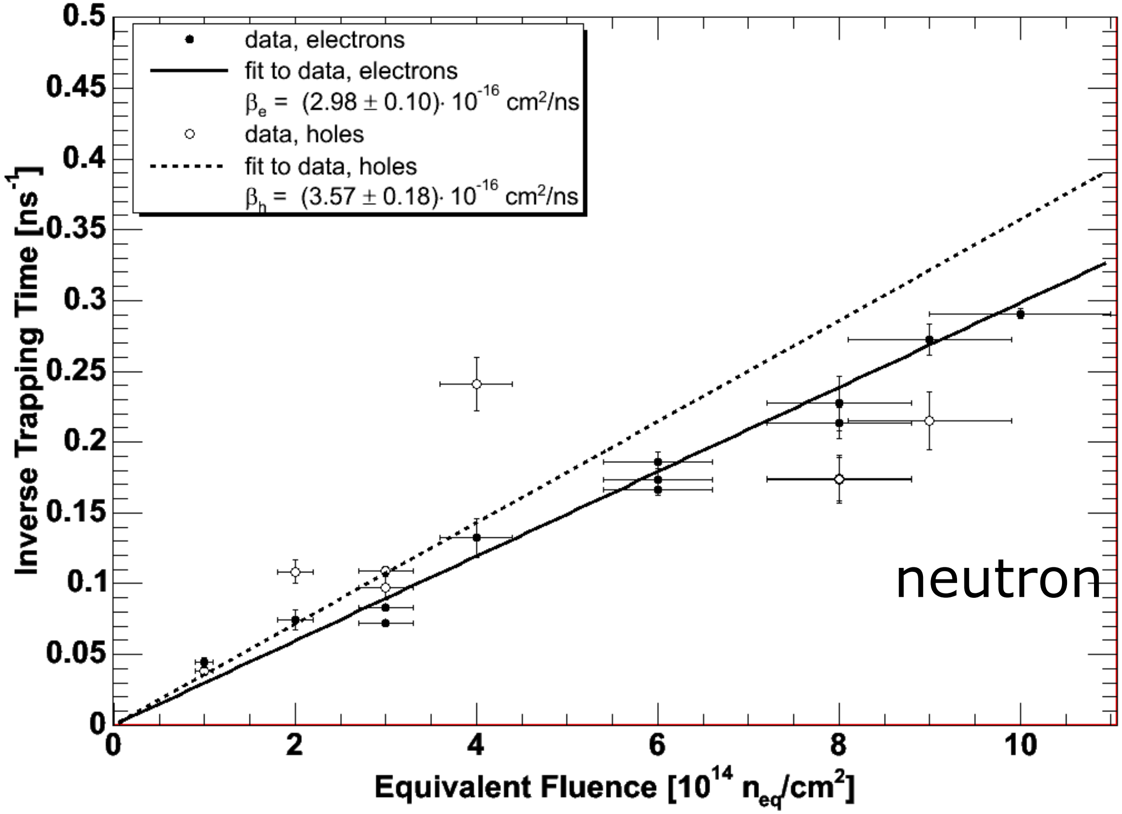


Assumption: $i_{\exp}(t) = i_m(t)\exp(-t/\tau_{eff})$



Results with Thick Diodes

neutron irradiated
DOFZ samples
with thickness between
250µm and 300µm



→ with: $\frac{1}{\tau_{eff}} = \beta(t,T)\Phi_{eq}$

$$\beta_{n,e} = (2.98 \pm 0.10)\cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns},$$

$$\beta_{n,h} = (3.57 \pm 0.18)\cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

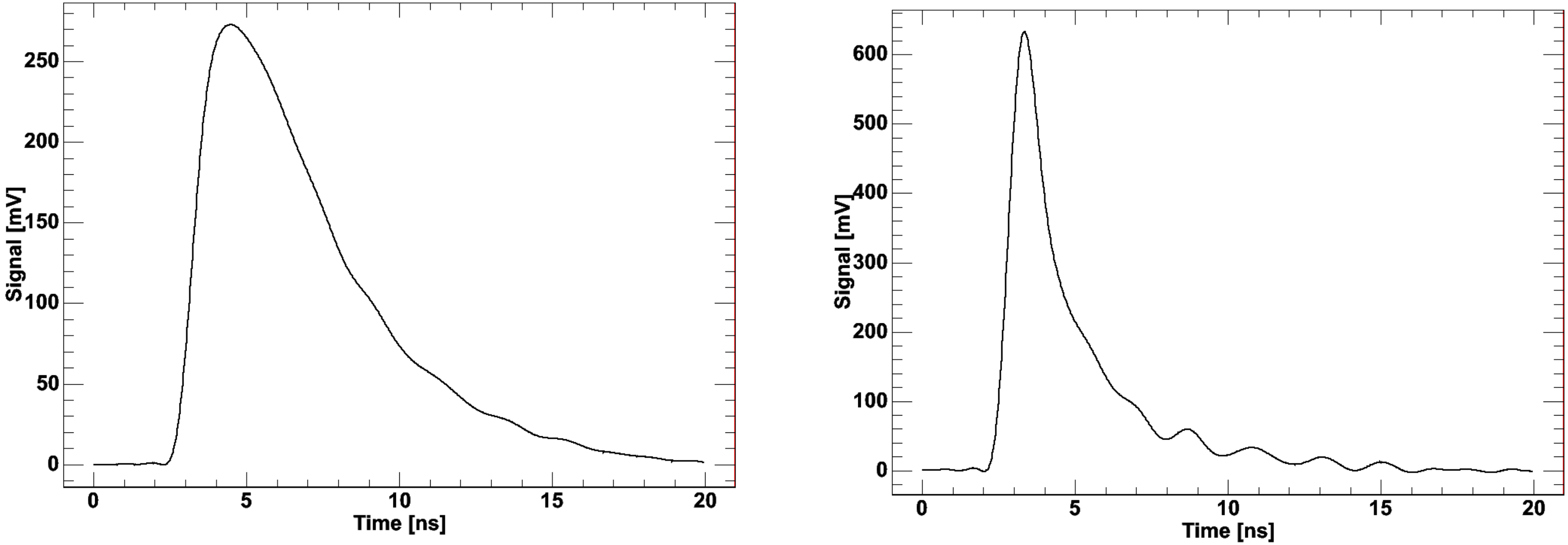
J.Weber, R. Klingenberg

„Free Charge Carriers Trapping Properties in Neutron-Irradiated DOFZ Silicon Pad Detectors“

accepted for publication in Trans. Nucl. Sci. (2007)

Signals of Thin Diodes

Signal of sample en1 (epi-Si; 75µm thick, $5.0 \times 10^{14}\ n_{eq}/cm^2$)



no bandwidth correction

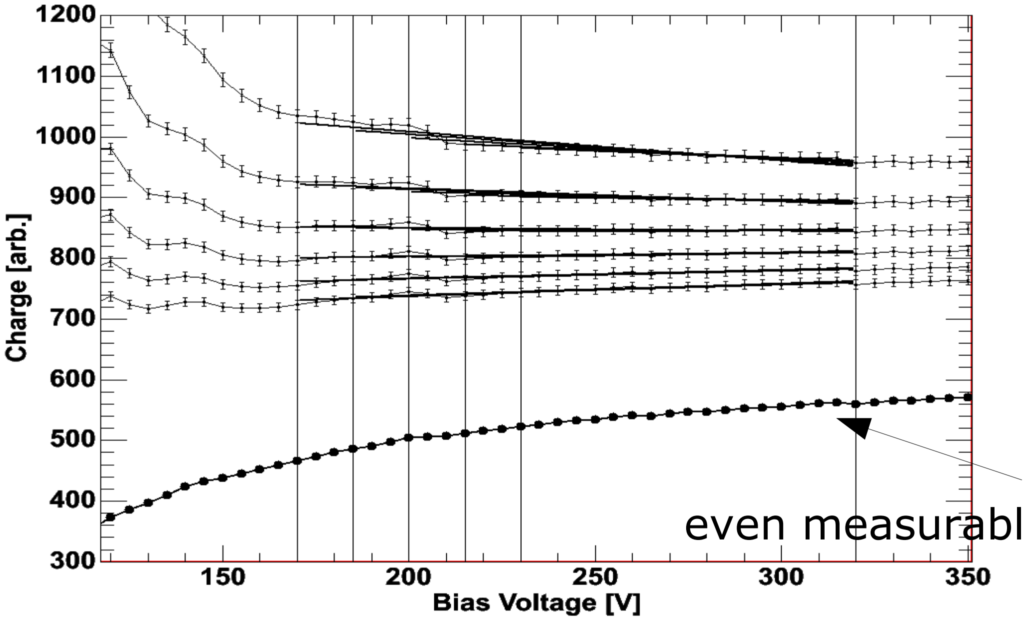
with bandwidth correction; C = 40pF

→ time resolution too bad to use one of the two methods

Solution?

but remember Charge Correction Method:

→ collected charge for different V_{bias} depends on trapping time



even measurable with thin diodes

calculate: $i_m(t) = i_0(t)\exp(-t/\tau_{eff})$

with different τ

→ if slope = 0, trapping time determined

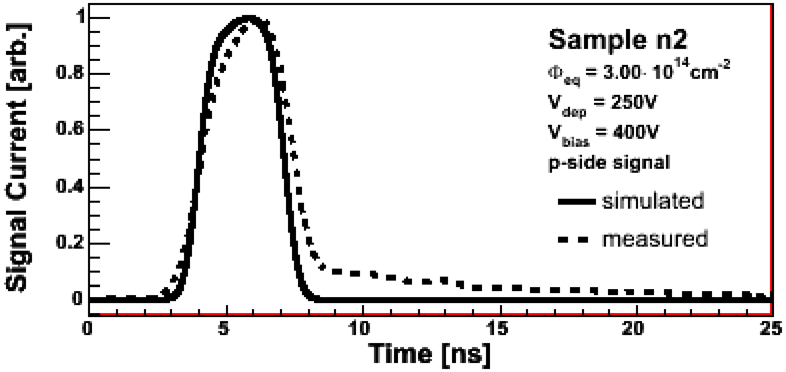
How to do?

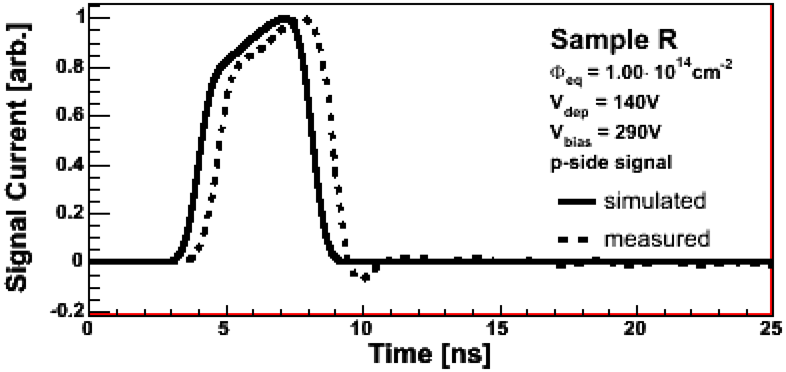
possible solution:

- simulate collected charge with different trapping time constants
- calculate slope of collected charge of simulated samples and measured curves
- extract trapping time constant by comparison

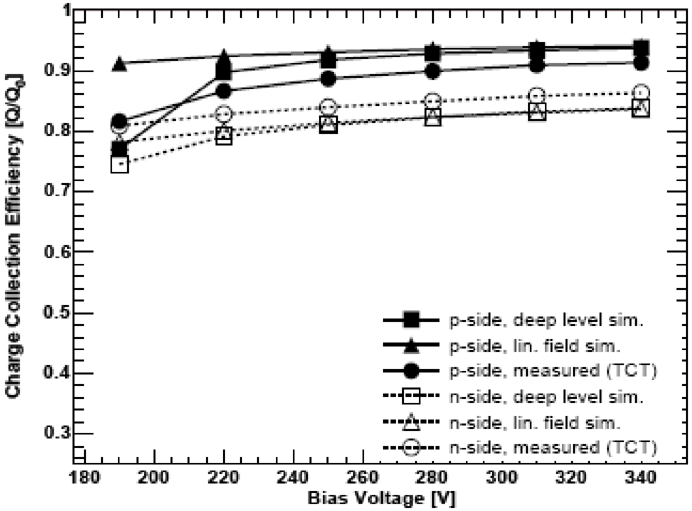
Simulated versus Measured Signal

Check simulated pulse shapes

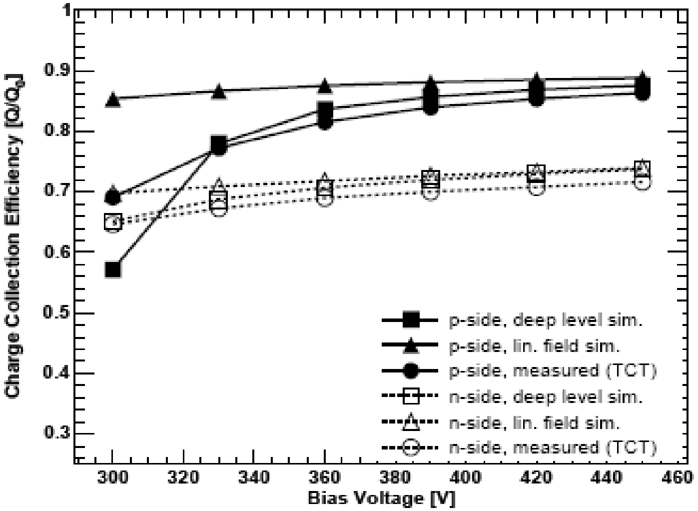




and simulated charge collection

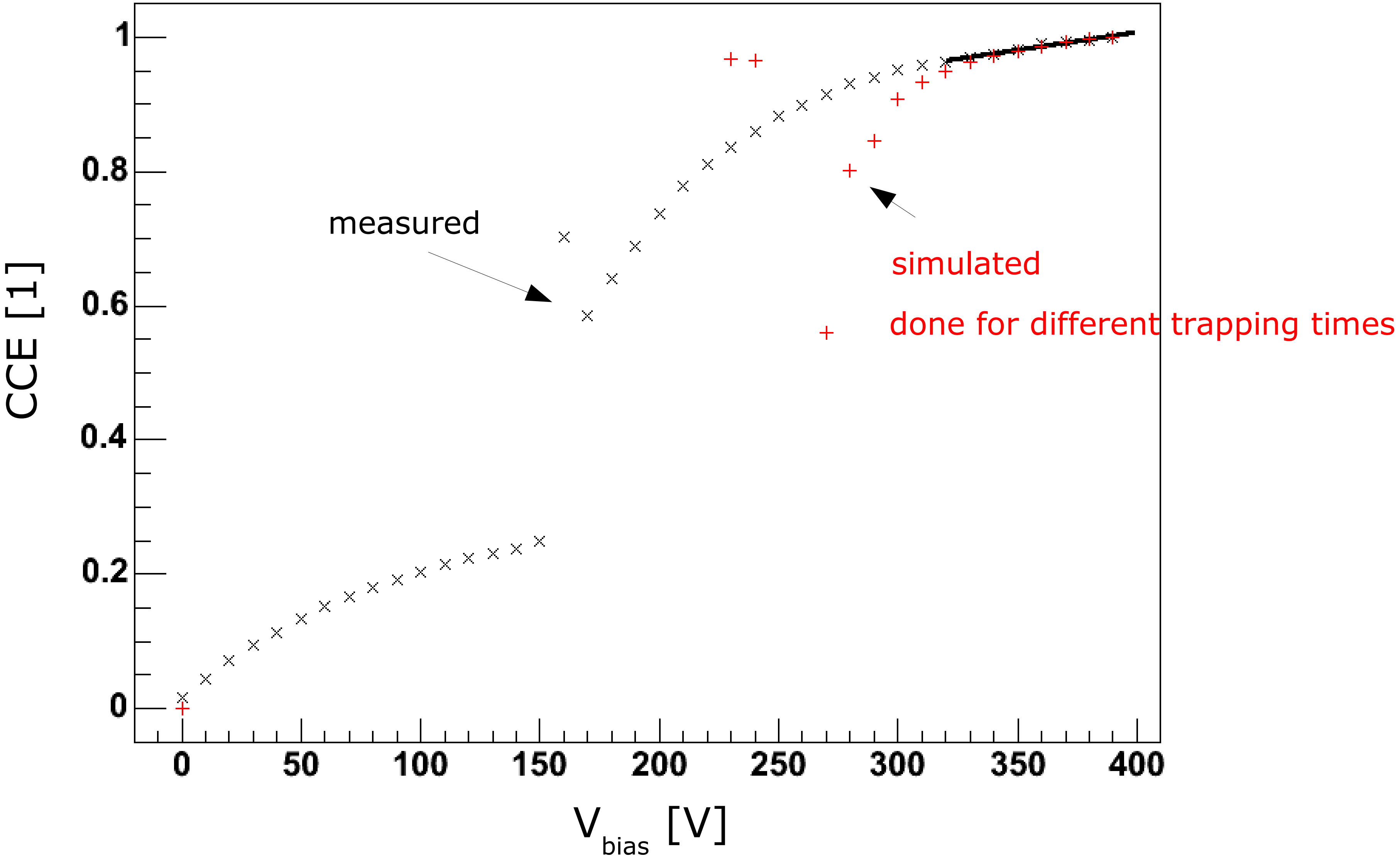


(a) Sample R, V_{dep}=140 V



(b) Sample V, V_{dep}=250 V

Calculation of Slope



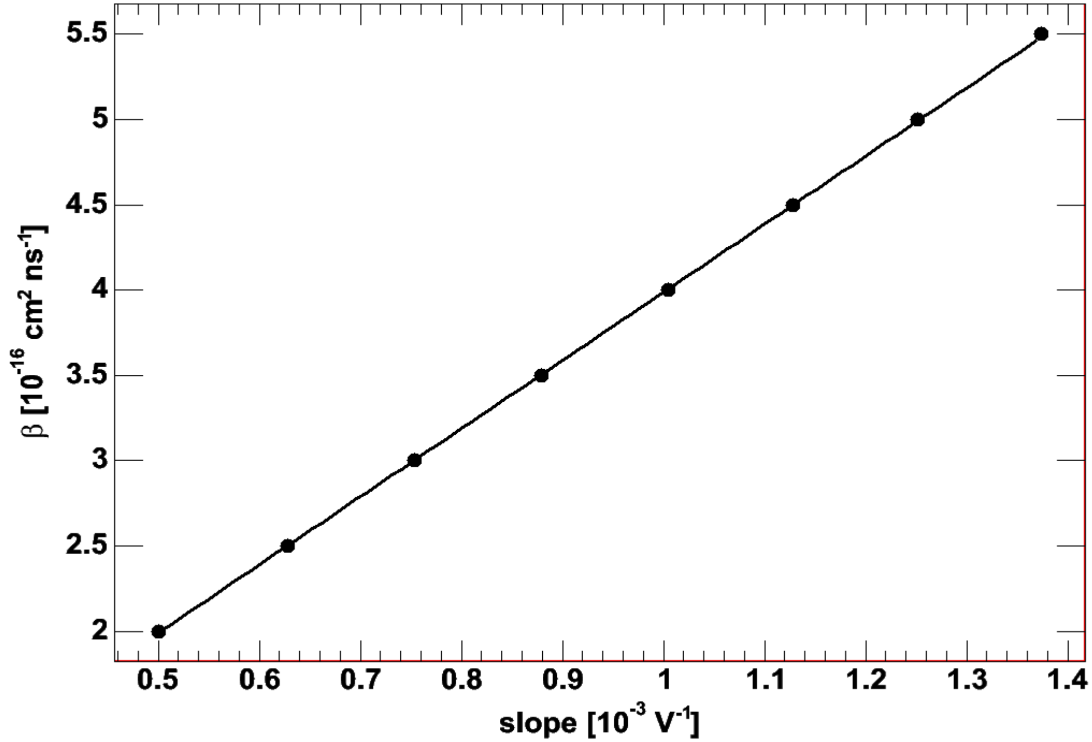
Extracting of Trapping Time Constant

- ► plot slope vs β

here as an example:

sample R with known τ

- ► DOFZ Silicon
  300µm thick
  $2.0 \times 10^{14}\ n_{eq}/cm^2$



- ► with linear fit:

$$\beta = 3.99 \cdot 10^{-16} x \text{ cm}^2\text{V/ns} - 0.05 \cdot 10^{-16} \text{ cm}^2\text{/ns}$$

and with slope of measured charge collection: $1{,}252\ 10^{-3}\ V^{-1}$:

► $\beta = 4.95 \times 10^{-16}\ cm^2/ns$

Check of Method with Thick Samples

Method checked with already measured thick samples

Sample	Φ [*]	d [μm]	β [10^{-16} cm^2/ns]	τ_{sim} [ns]	τ_{ECC} [ns]
Set R	0.1	300	4.95	20.2	22.59 ± 1.88
Set V	0.2	300	3.87	12.9	13.41 ± 1.29
Set n16	0.3	250	2.39	13.9	13.95 ± 0.18

=> τ determinable

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* = 10^{15} n_{eq}/cm^2; error Φ: 10%

Results of Measurement and Simulation

simulation (deep level) with epi-parameters** and measuremet (all samples 75µm thick) leads to:

Sample	Φ [*]	β_{sim} [10^{-16} cm^2/ns]	τ_{sim} [ns]
Set EN1	0.5	3.80 ± 1.19	5.26 ± 1.65
Set EN2	0.5	3.43 ± 0.62	5.83 ± 1.05
Set EN3	1.0	3.39 ± 0.48	2.95 ± 0.42
Set EN4	1.0	3.27 ± 0.19	3.06 ± 0.18
Set EN6	2.0	3.00 ± 0.19	1.67 ± 0.11
Set EN7	3.0	2.66 ± 0.29	1.25 ± 0.14
Set EN8	3.0	2.92 ± 0.29	1.14 ± 0.11

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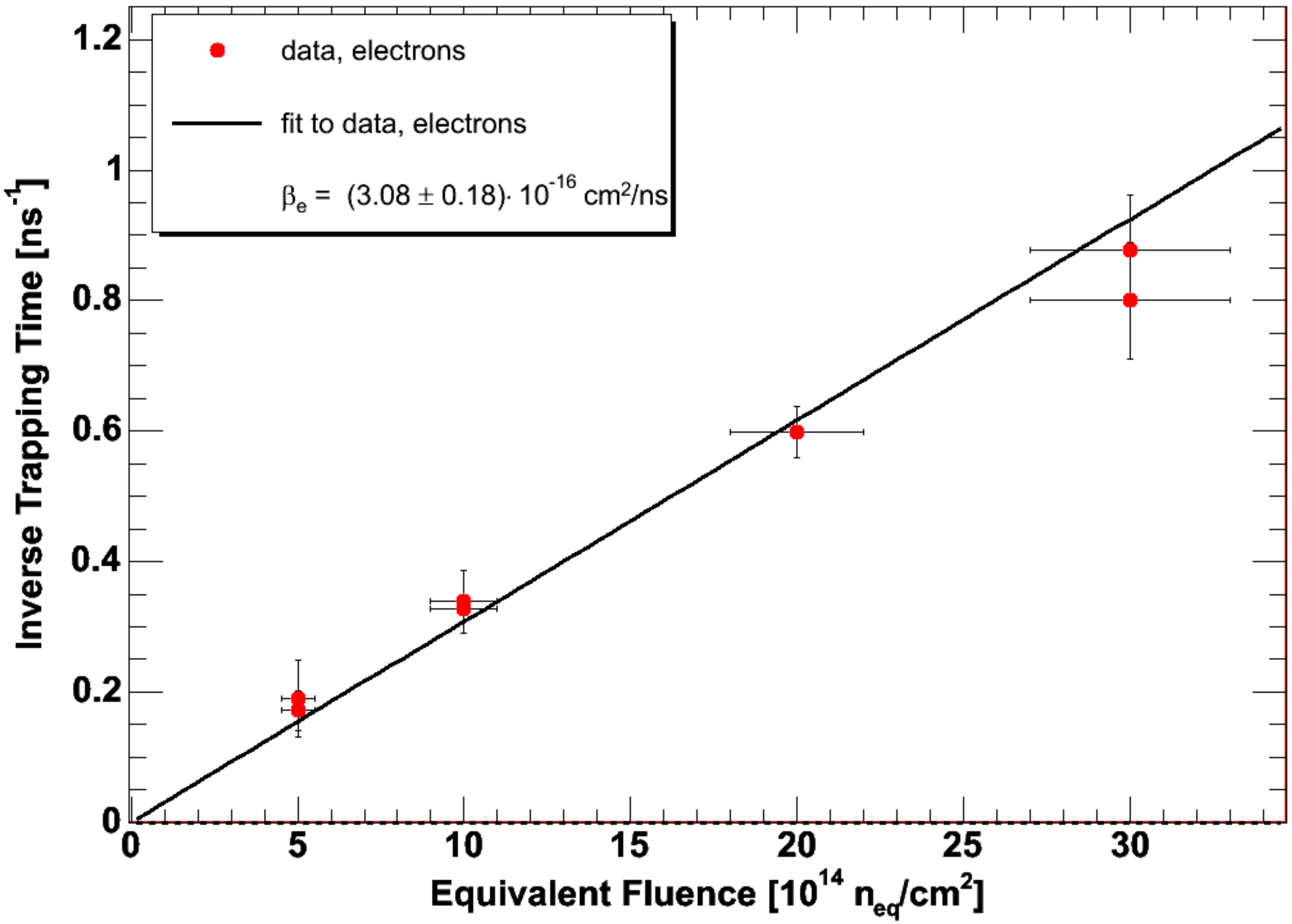
* = 10^{15} n_{eq}/cm^2; error Φ: 10%

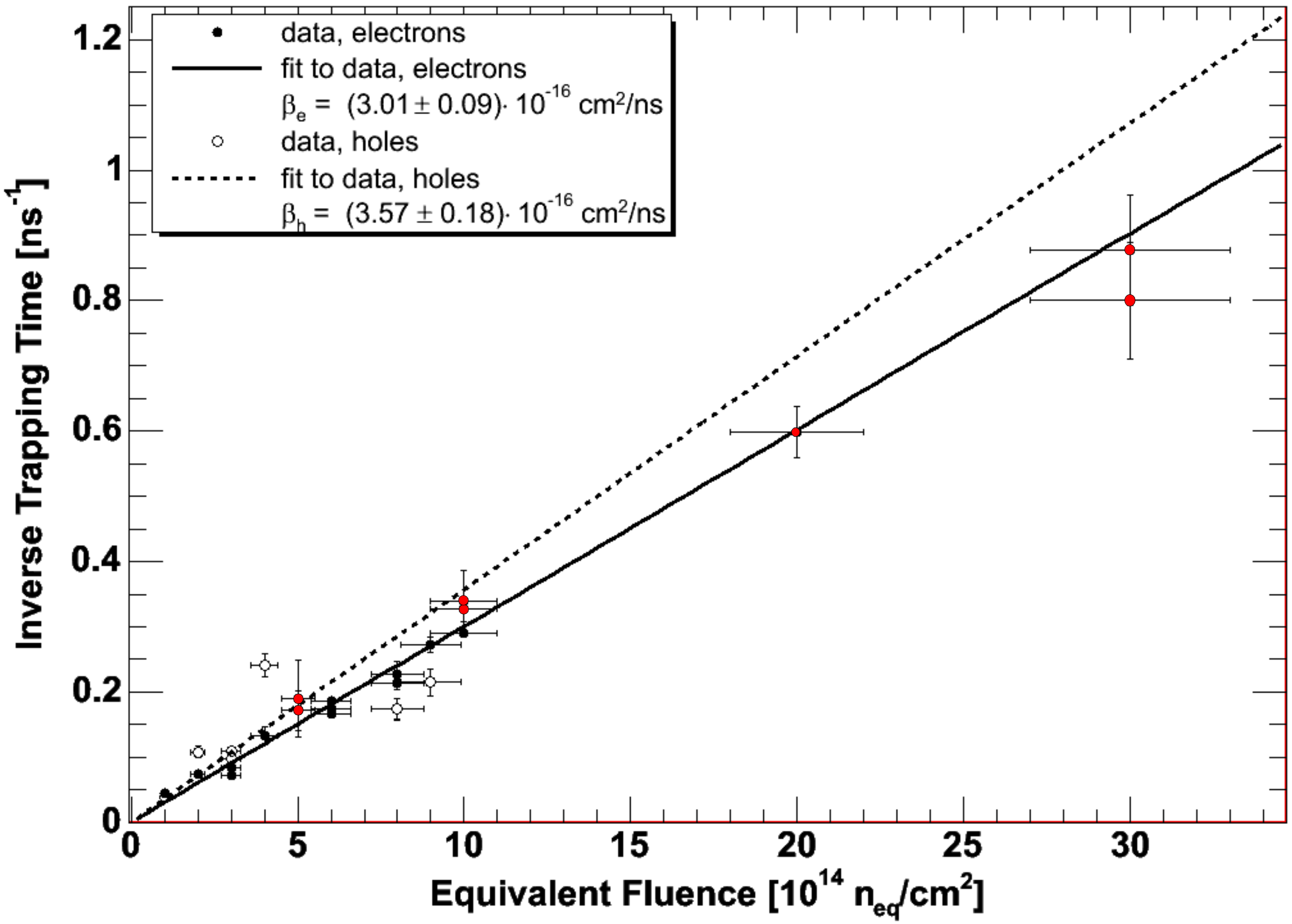
** see E.Fretwurst „Comparison of neutron damage in thin FZ, MCz and epitaxial silicon detectors“ 10th RD50 Workshop

Inverse Trapping Time vs. Fluence (epi)



$$\beta_{n,e} = (3.08 \pm 0.18) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns},$$

Inverse Trapping Time vs. Fluence (DOFZ + epi)



$$\beta_{n,e} = (3.01 \pm 0.09) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns},$$

Summary

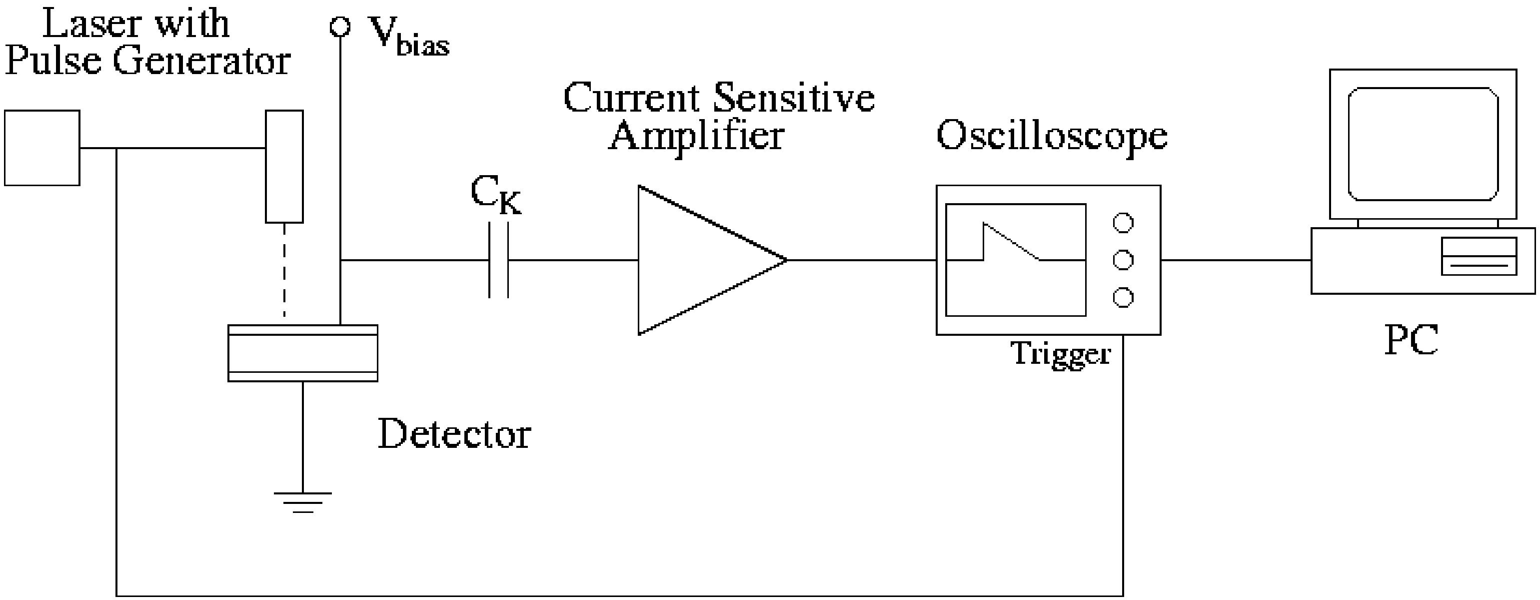
- classic analysis for trapping times failed due to time resolution

  ↳ developing method based on
  simulation and measurement of collected charge

=> determination of the trapping times possible
without time resolved signal
only with charge collection

Ende

Measurement Setup



- 672nm red laser (3.6µm absorption length, FWHM = 44ps),
- applicable bias voltage range 0-1500V
- fast pulse amplifier (10x, 100 kHz - 1.8 GHz), (*current sensitive!*)
- oscilloscope (Tektronix TDS 784D, **band width 1 GHz**)
- **rise time of system (incl. detector) about 1 ns**
- PC readout system (LabVIEW)
- cooling system (-20°C - +20°C, rms 0.2°C)

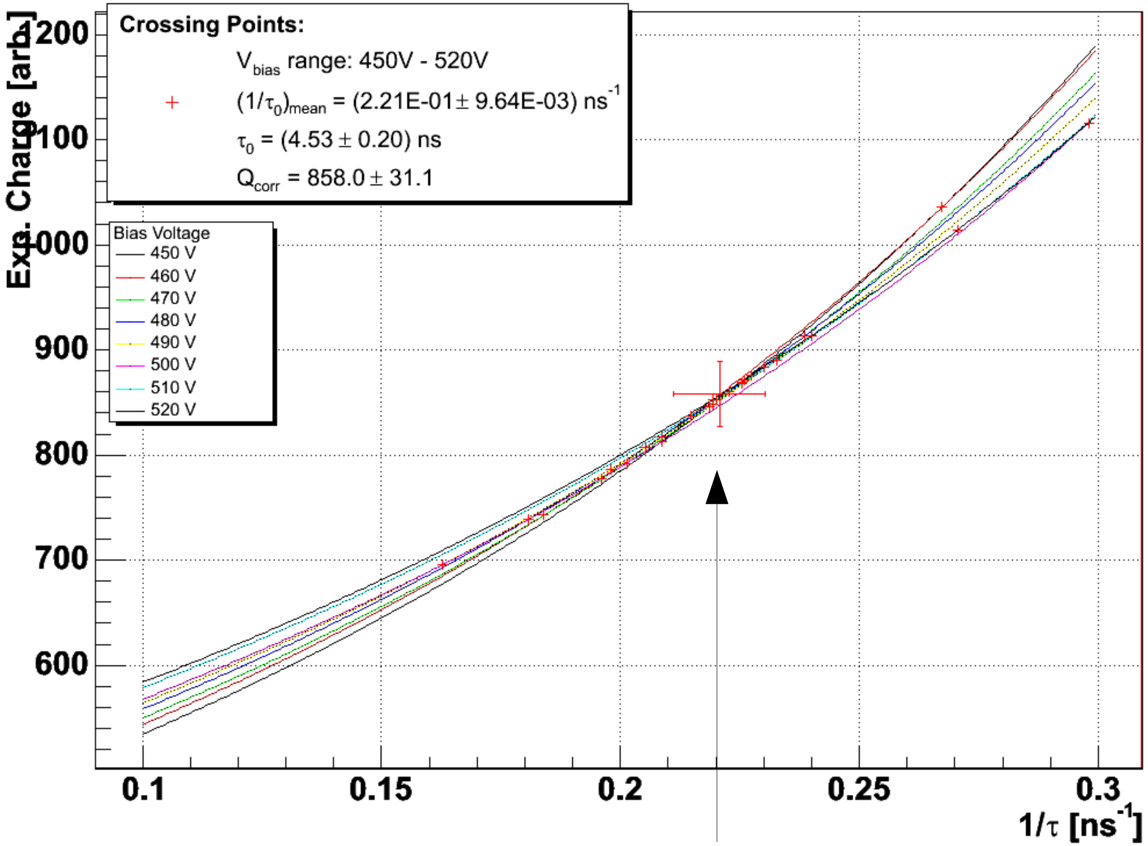
Exponentiated Charge Crossing (ECC)

- calculate exponentiated charge and vary $1/\tau$ for diffent V_{bias}

$$Q_{exp} = \int i_m(t)\exp(+t/\tau)\,dt$$

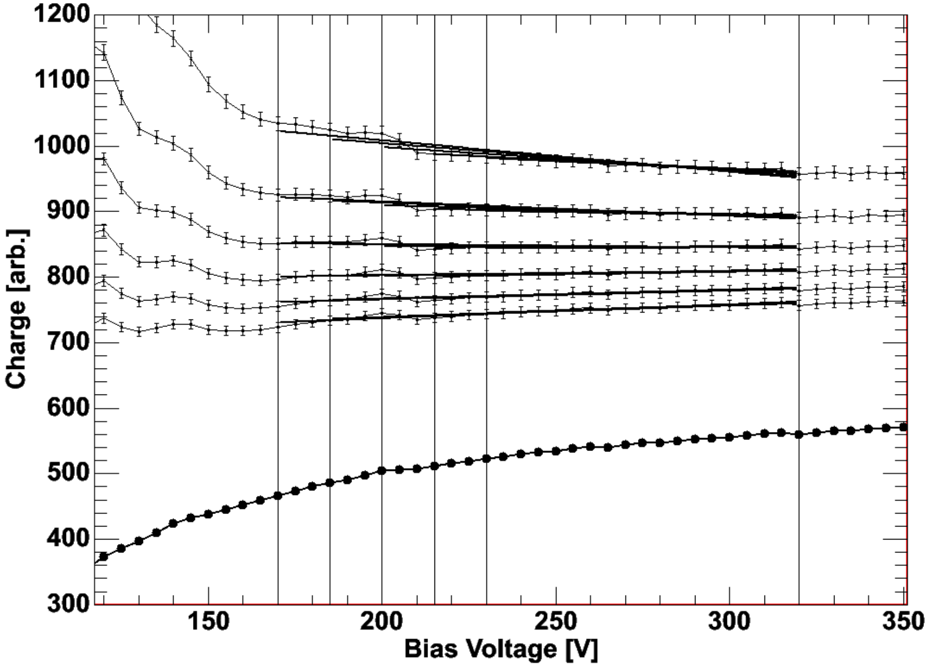
- V_{bias} is plotted vs. $1/\tau$

- $1/\tau_0$ is obtainted from mean of intersection points of line pairs



$1/\tau_0$

Charge Correction Method



calculate: $i_m(t) = i_0(t)\exp(-t/\tau_{eff})$

with diffrent τ

plot charge versus bias voltage and calculate slope

plot slope versus assumed τ

└► if slope zero correct τ found