Charge Collection and Space Charge Distribution in Epitaxial Silicon Detectors after Neutron-Irradiation

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Outline

- Introduction
- Transient Current Technique (TCT)

- Simulation of TCT current signal for unirradiated diodes
- Simulation of TCT current signal for irradiated diodes
  - Electric field and space charge distribution
  - Fit of the Charge Collection Efficiency (CCE) / Parameterisation of $\tau(E)$

- Results
  - Trapping time τ
  - Space charge distribution

Summary

Introduction

Trapping

- Most limiting factor for S-LHC
- Charge Collection Efficiency (CCE) decreases

Aim of this work

- Determination of trapping time τ
- Taking into account the structure double peak to the electric field
- Investigation of field dependence of τ

Introduction

Why field dependent?

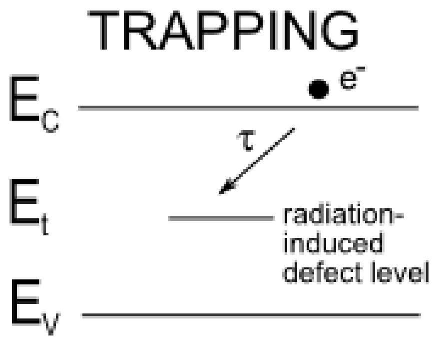
τ constant

- common description for $\phi < 2\cdot10^{14}$ cm^{-2} (FZ, MCz)
- not suitable for $\phi > 10^{15}$ cm^{-2} (higher CCE observed, especially at high U)

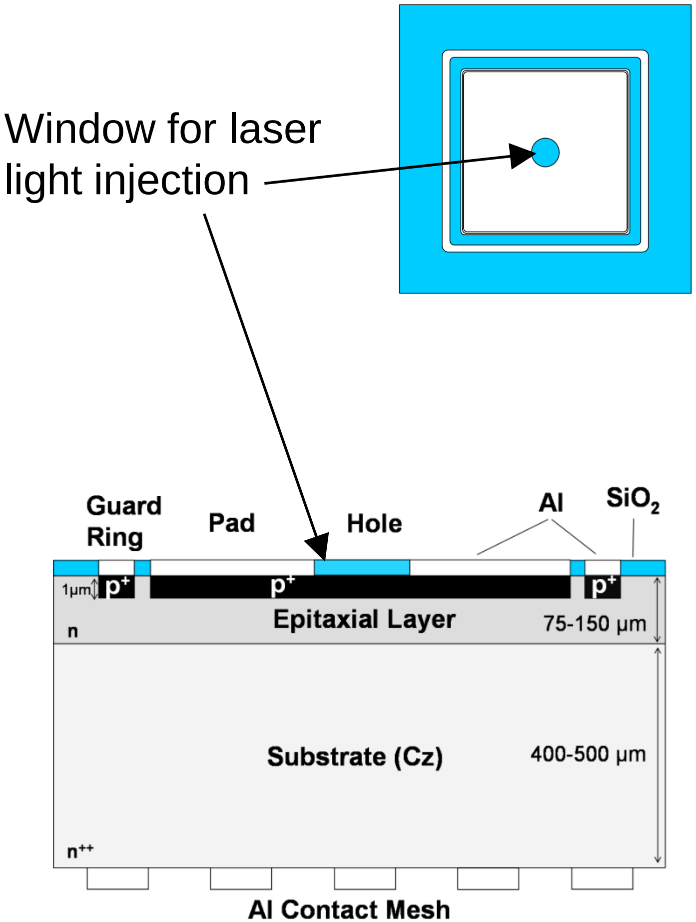
τ field or voltage dependent

motivated by:

- field dependent trapping cross section $\sigma(E)$?
- field enhanced detrapping ?
- trap filling ?



Investigated samples



Samples and irradiation

n-type epitaxial silicon pad detectors

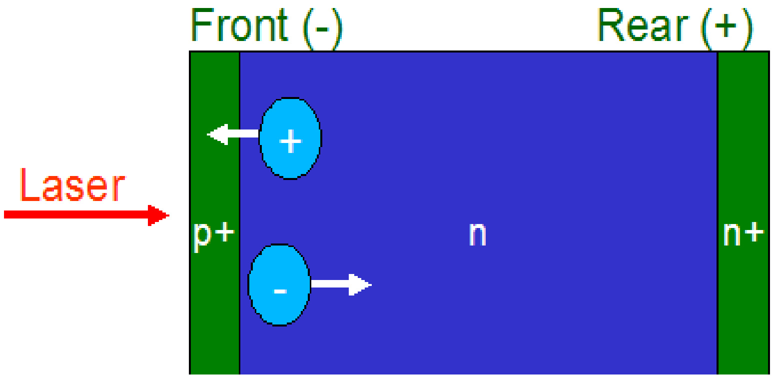
- thickness d: 100 µm and 150 µm
- area: 2.5 x 2.5 mm^2 (small)
  or 5 x 5 mm^2 (big)
- neutron fluence ϕ: $1 \cdot 10^{14}$ to $4 \cdot 10^{15}$ cm^{-2}

  $\Rightarrow$ type inversion for $\phi > 2 \cdot 10^{14}$

Transient Current Technique (TCT)

- Front side injection (p+ side)
- 660 nm / 670 nm laser light (penetration depth 3 µm)

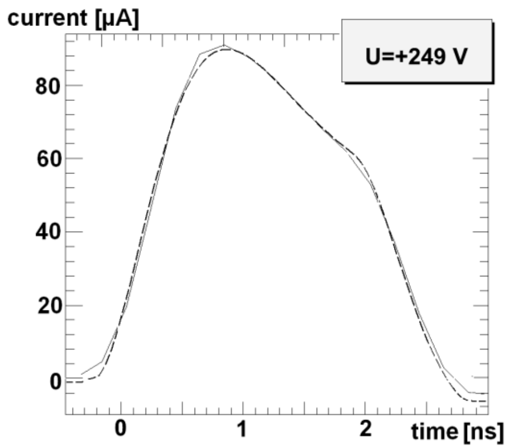
⇒ electron signal



- Short laser pulse: FWHM ~ 40 ps
- Small pad diodes: C = 4.3 pF for d = 150 µm
- 1 GHz Oscilloscope

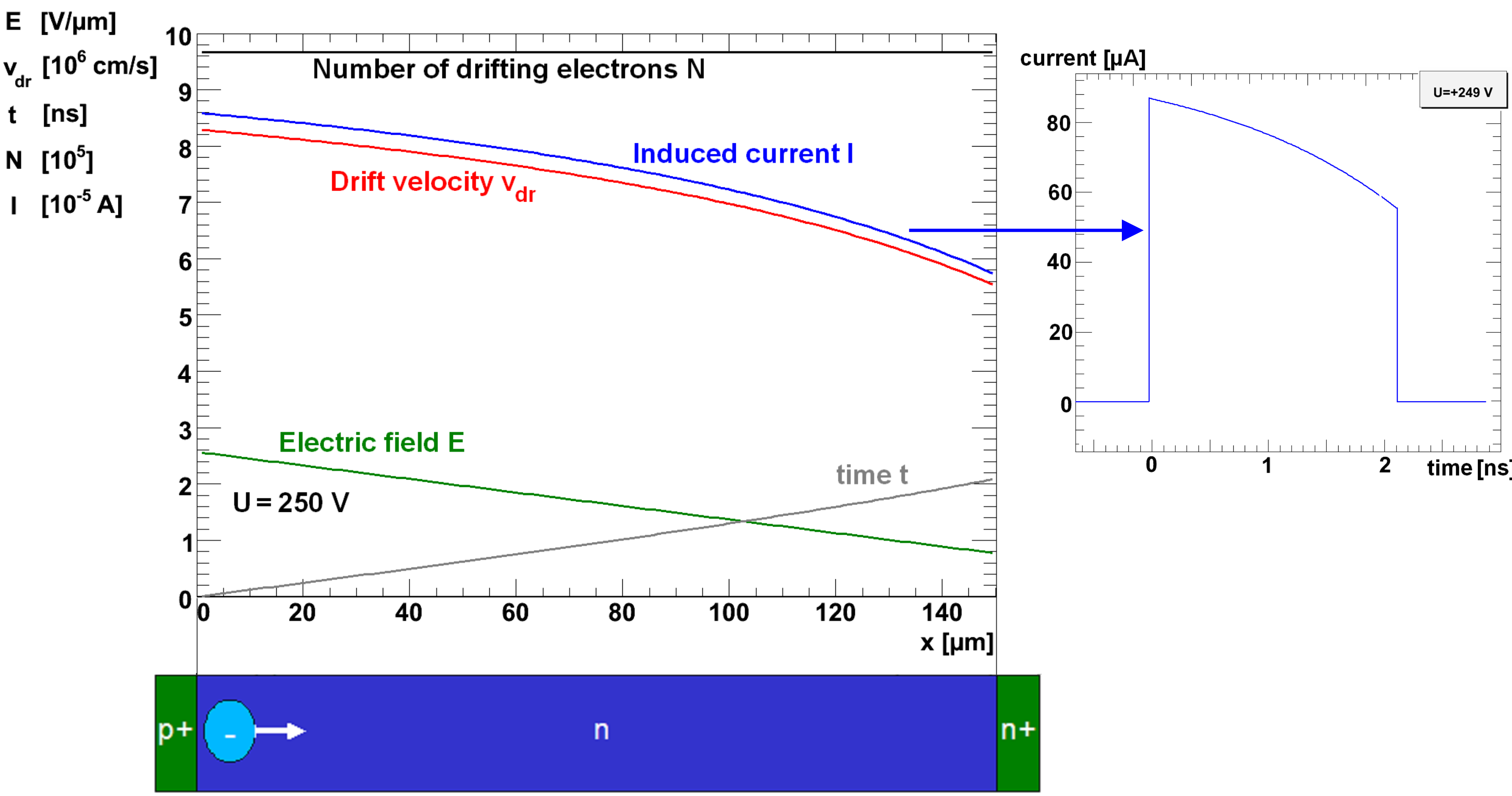
⇒ measured rise time = 650 ps

(for the small 150 µm thick diodes)



Simulation of TCT current signal for unirradiated diodes

Induced current $\mathbf{I} = v_{dr}(\mathbf{E}) \cdot \mathbf{N} \cdot q_0 / d$

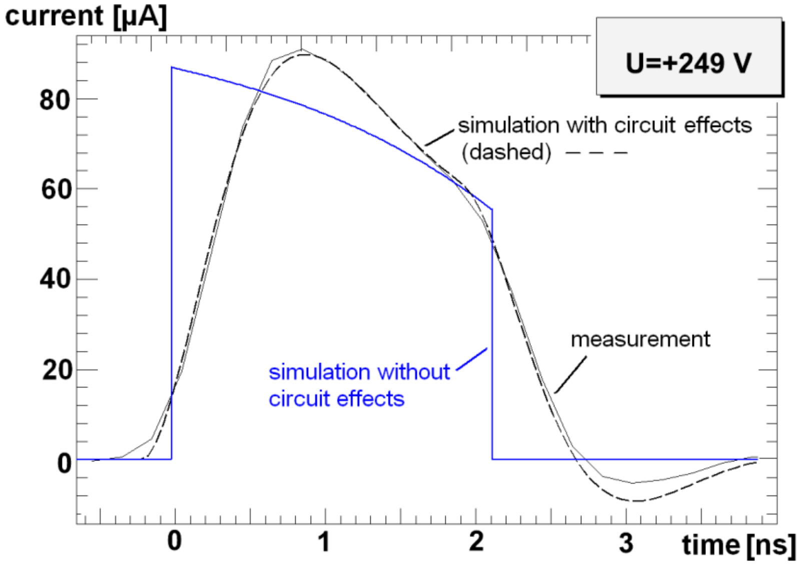


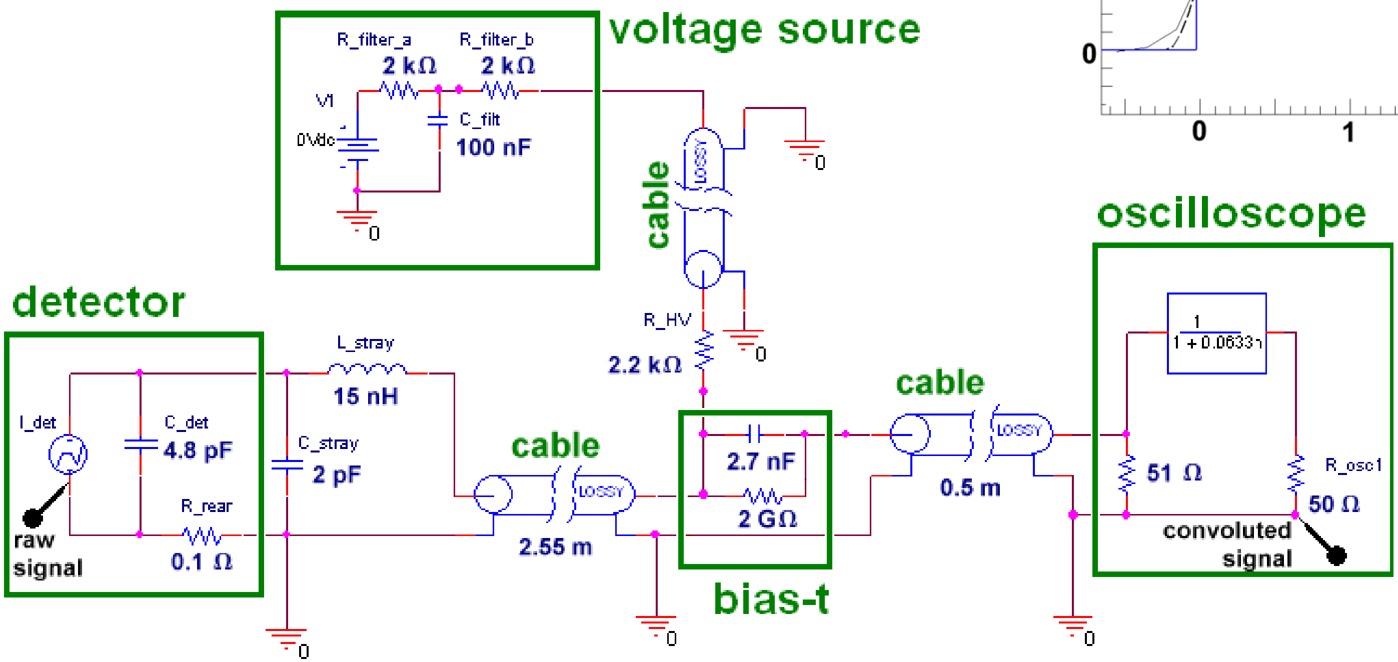
Circuit simulation

Circuit simulation

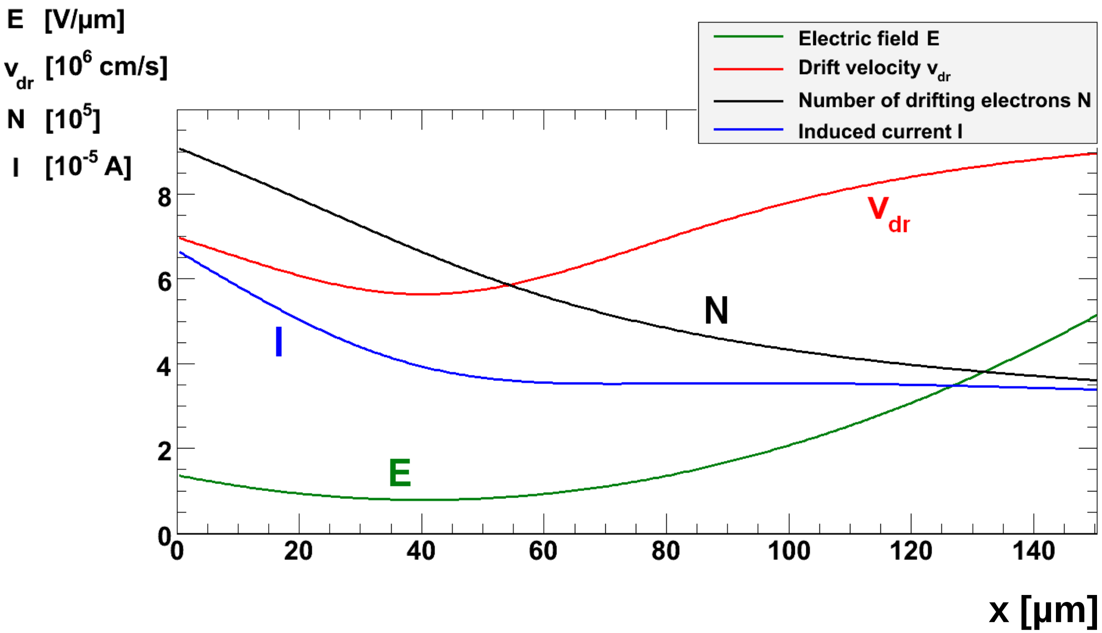
- calculated with SPICE
- unirradiated diodes used for calibration

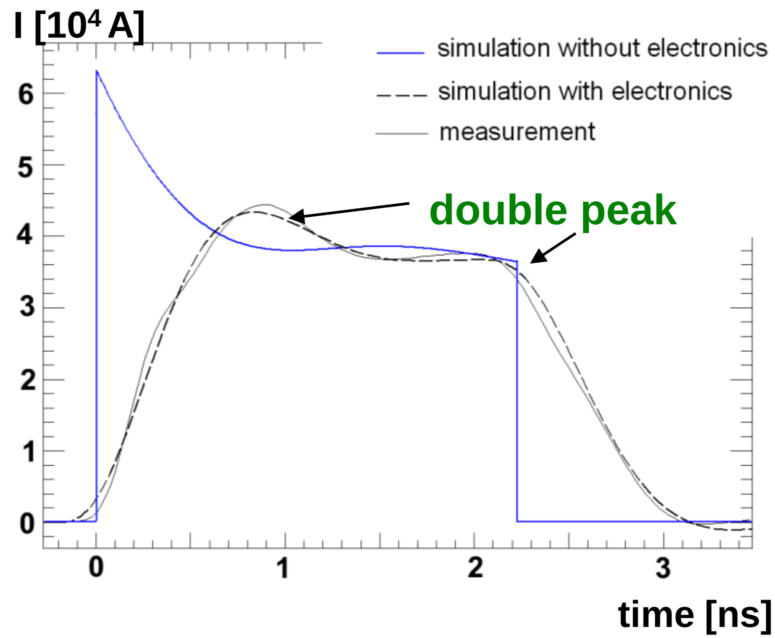
⇒ data well described





Simulation of TCT current signal for irradiated diodes





$U = 300$ V, $\phi = 2 \cdot 10^{15}$ cm^{-2}

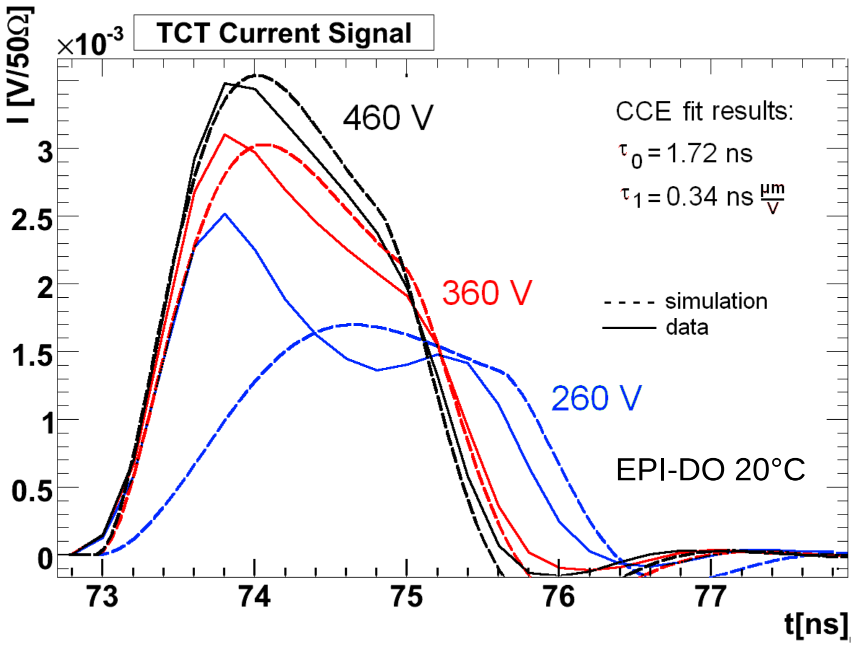
- Number of drifting electrons N reduces while drifting (trapping time τ)

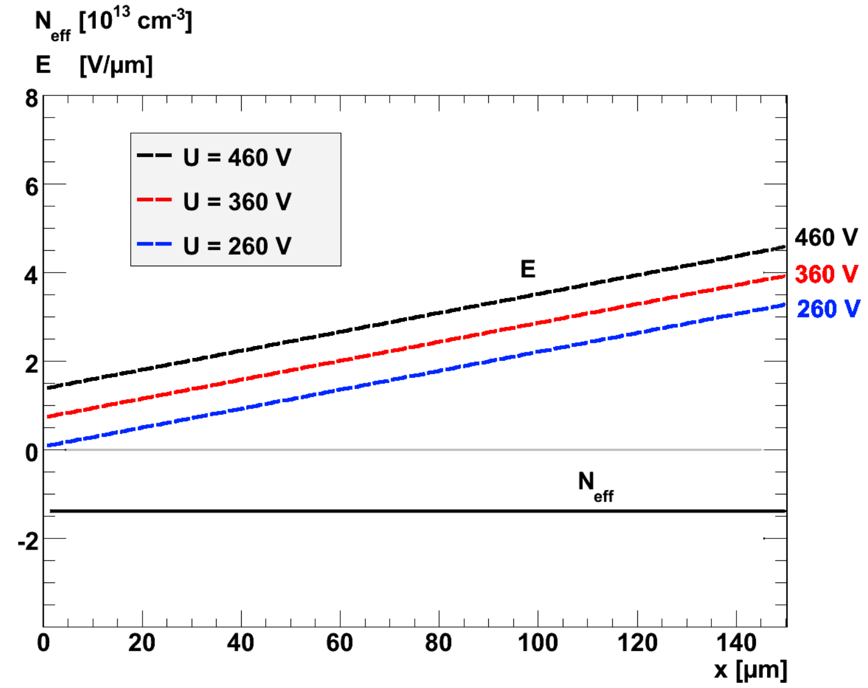
- Trapping time, space charge distribution and E-field not known

$\Rightarrow$ Fit space charge distribution N_{eff} and trapping time $\tau(E)$

Simulation for irradiated diodes

N_{eff} = const from U_{dep} = 250 V (CV measurements)

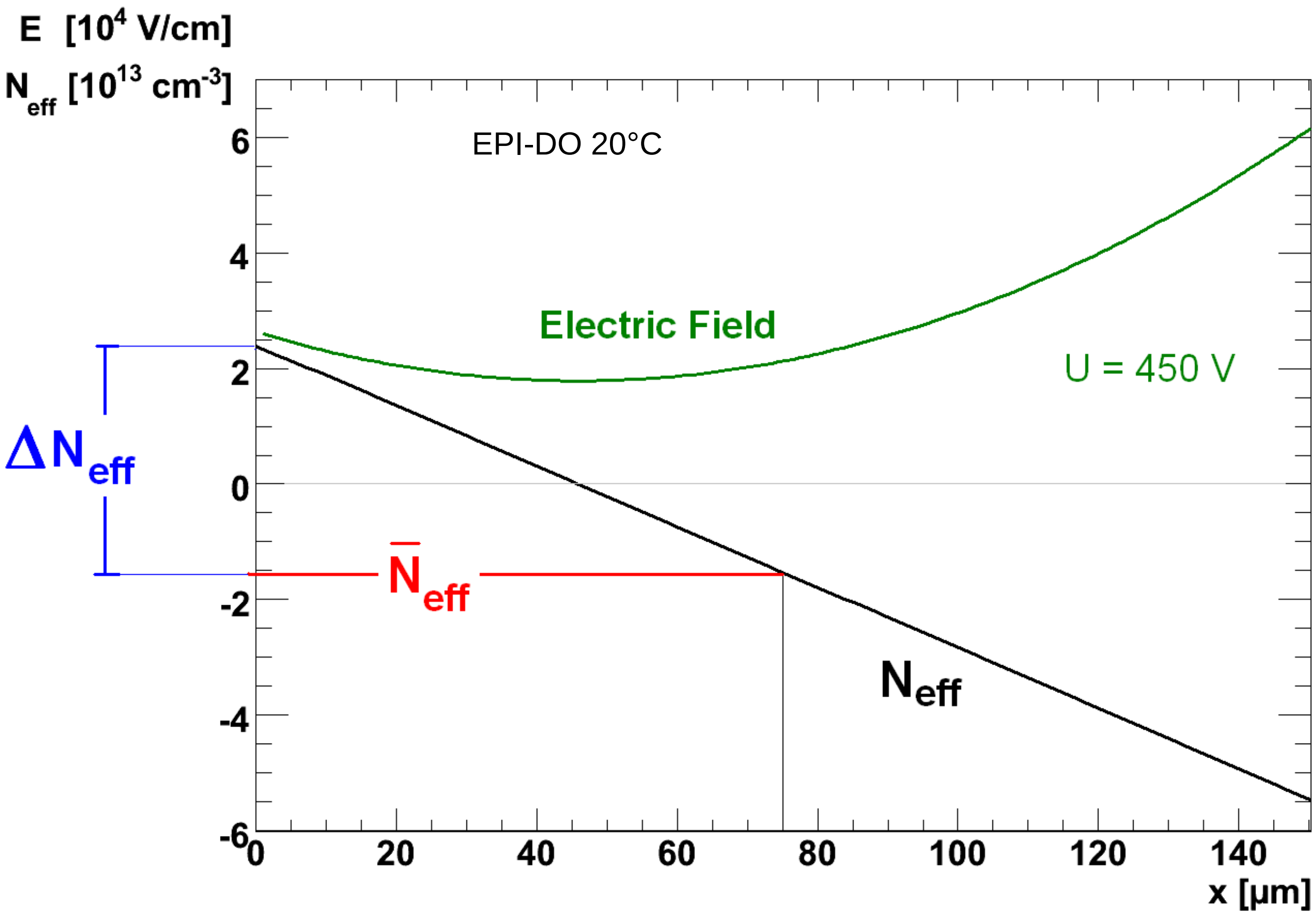




$\Rightarrow$ data not well described with N_{eff} = const

Parameterisation of space charge distribution

$$N_{eff}(x) = \bar{N}_{eff} + \left(1 - \frac{x}{d/2}\right) \Delta N_{eff}$$

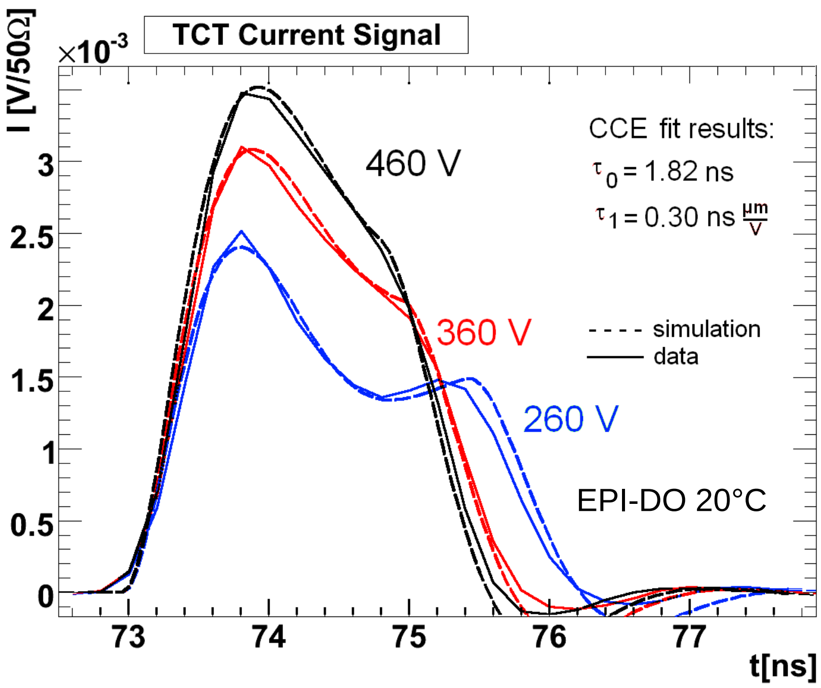


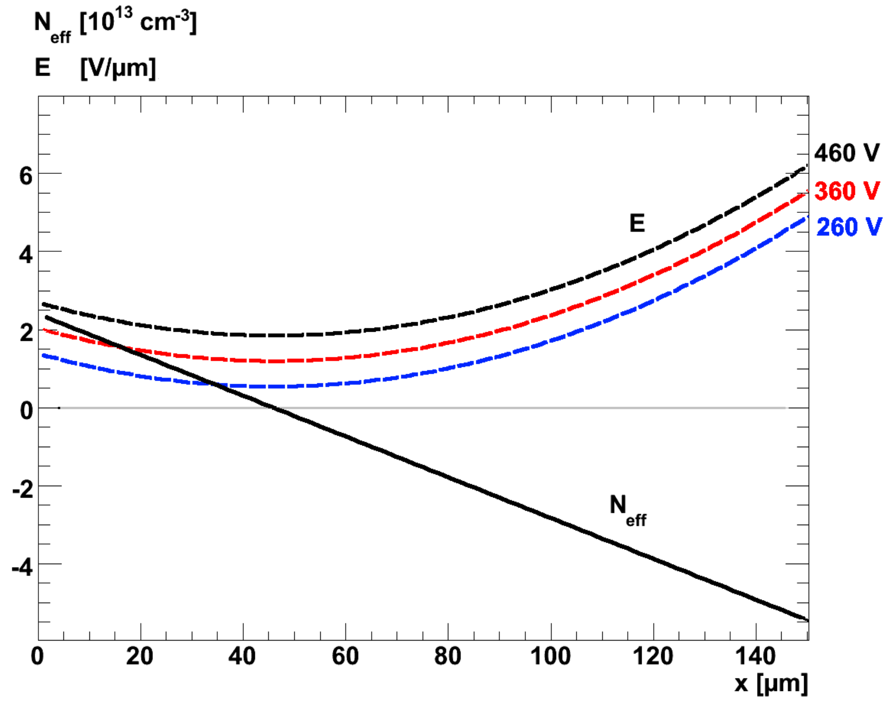
ΔN_{eff} = 4 10^{13} cm^{-3}

$\overline{N}_{eff}$ = -1.6 10^{13} cm^{-3}

Simulation for irradiated diodes

best values for $\bar{N}_{eff}$, ΔN_{eff} were taken, U_{dep} = 250 V





⇒ data described with N_{eff} linear in x

Fit of the CCE curve

Trapping model:

$$- dN = \frac{1}{\tau\,(E(x(t)))}\, N\, dt$$

Different possible parameterisations of τ:

$\tau = \tau_0$

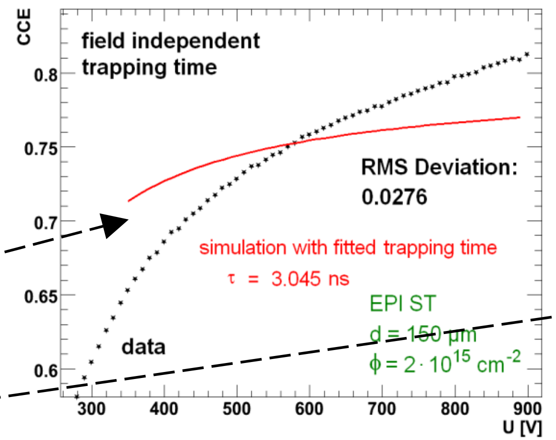
$\tau = \tau_0 + \tau_1 E$

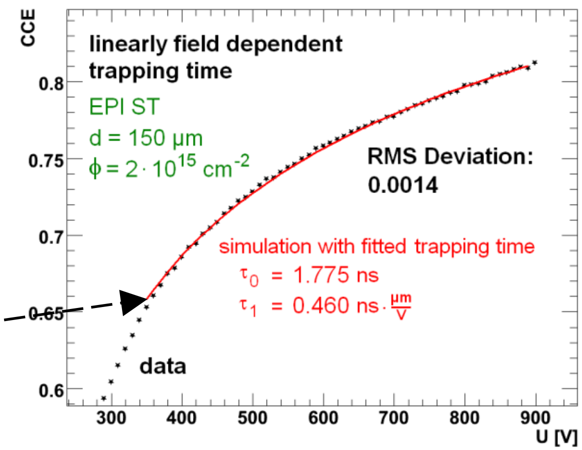
$1/\tau = 1/\tau_0 + 1/\tau_1 E$

$1/\tau = 1/\tau_0 + 1/\tau_1 v_{dr}(E)$

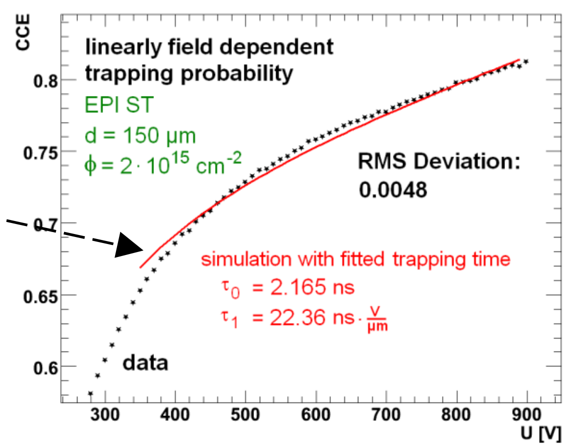
- fit simulated CCE curve to the measured CCE values
- free parameters: τ_0 , τ_1

CCE versus rev. bias voltage





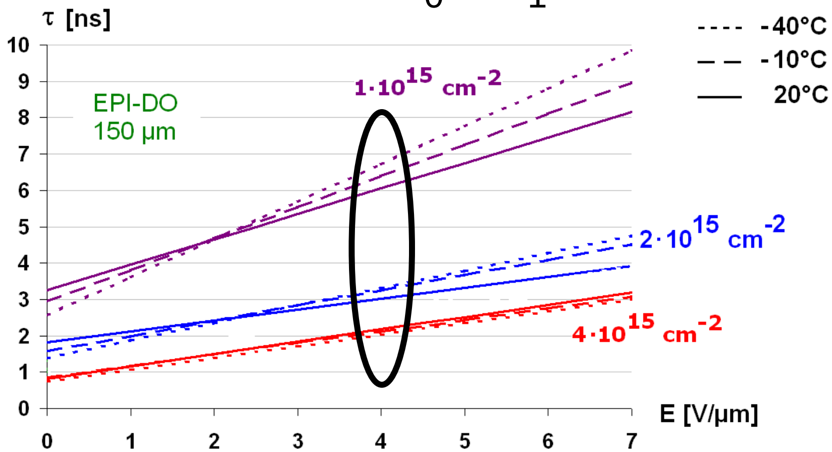
EPI-ST 20°C

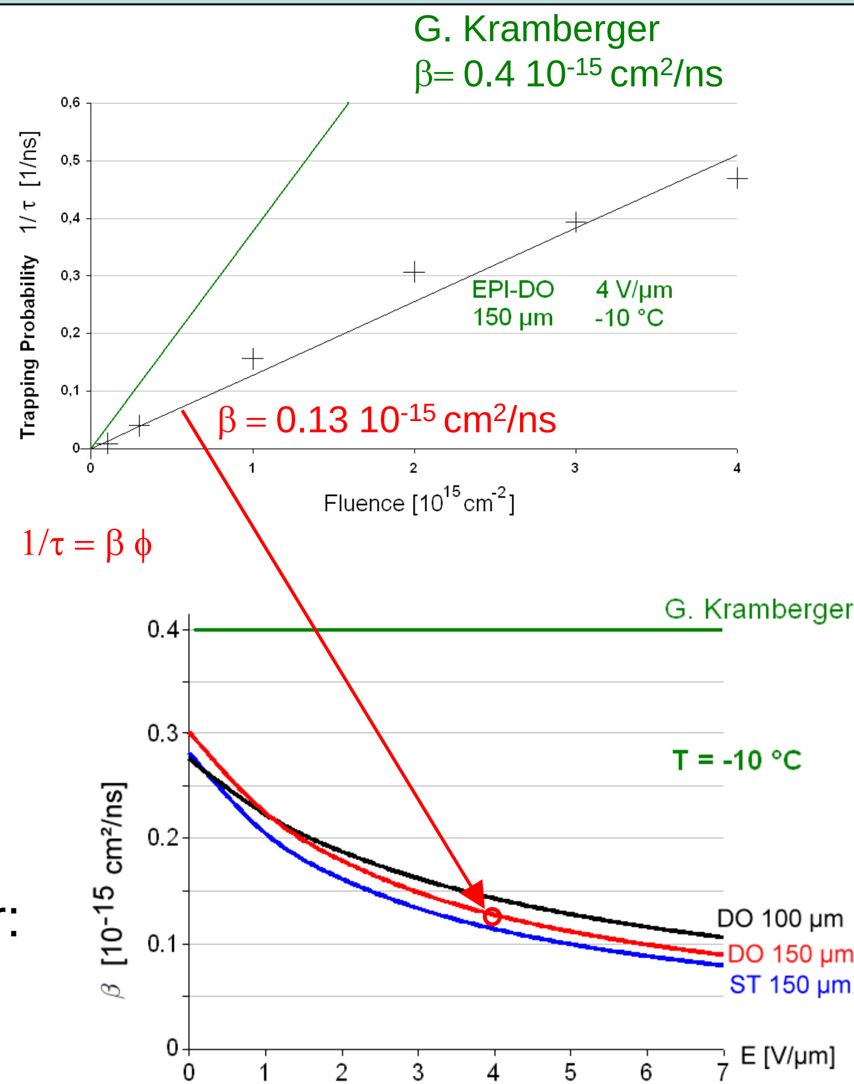


$\Rightarrow$ best parameterisation: $\tau = \tau_0 + \tau_1 E$

Results: trapping

$\tau = \tau_0 + \tau_1 E$





Strong field dependence seen!

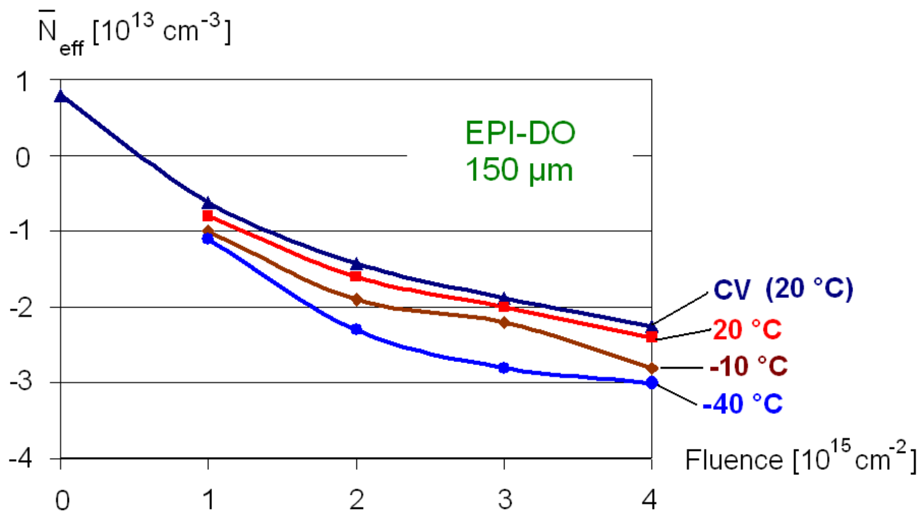
Less trapping for high fields.

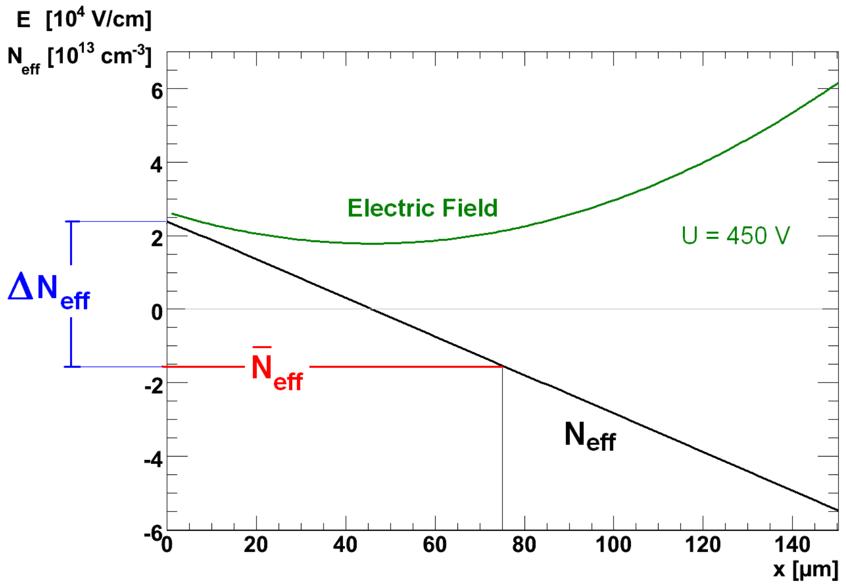
Previous investigations by G.Kramberger:

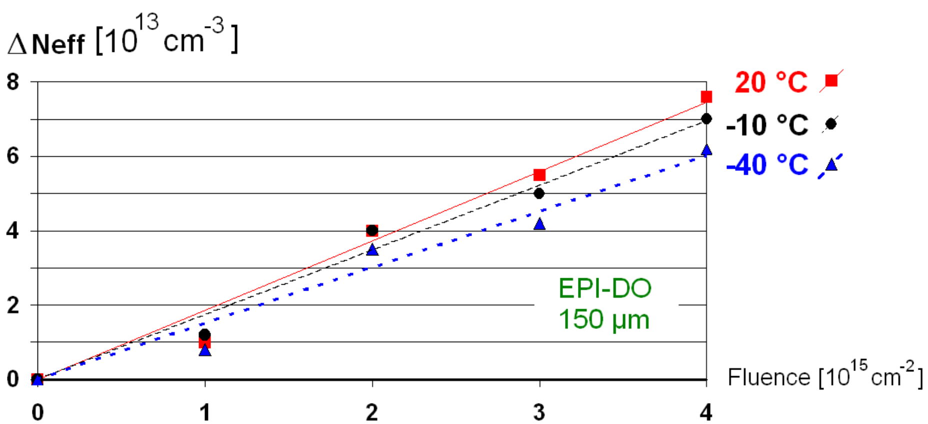
τ = const, charge correction method,

fluences up to $\phi = 2\cdot10^{14}$ cm^{-2}

Results: space charge



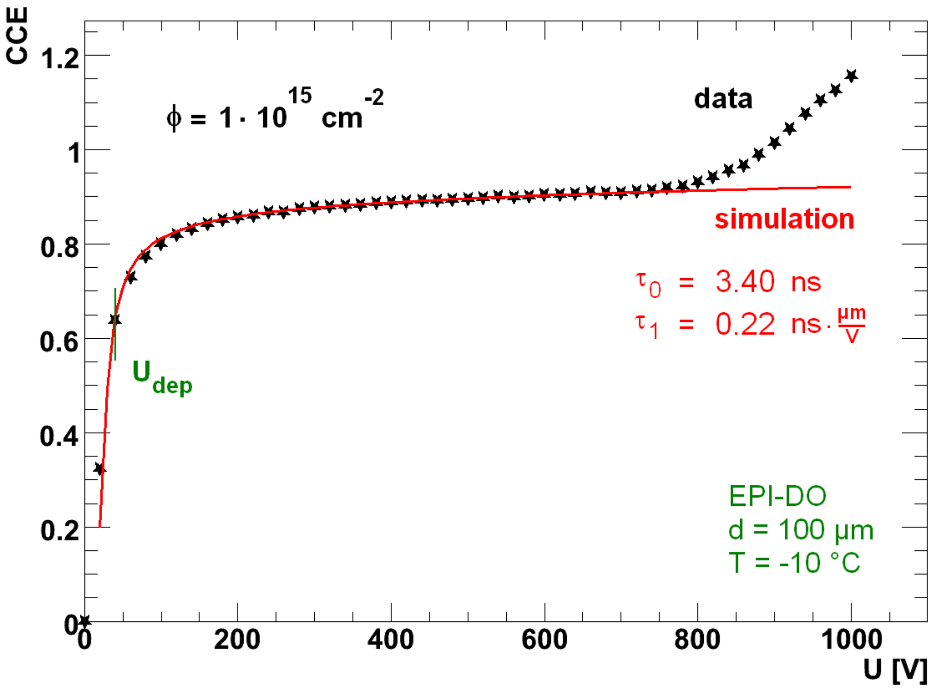


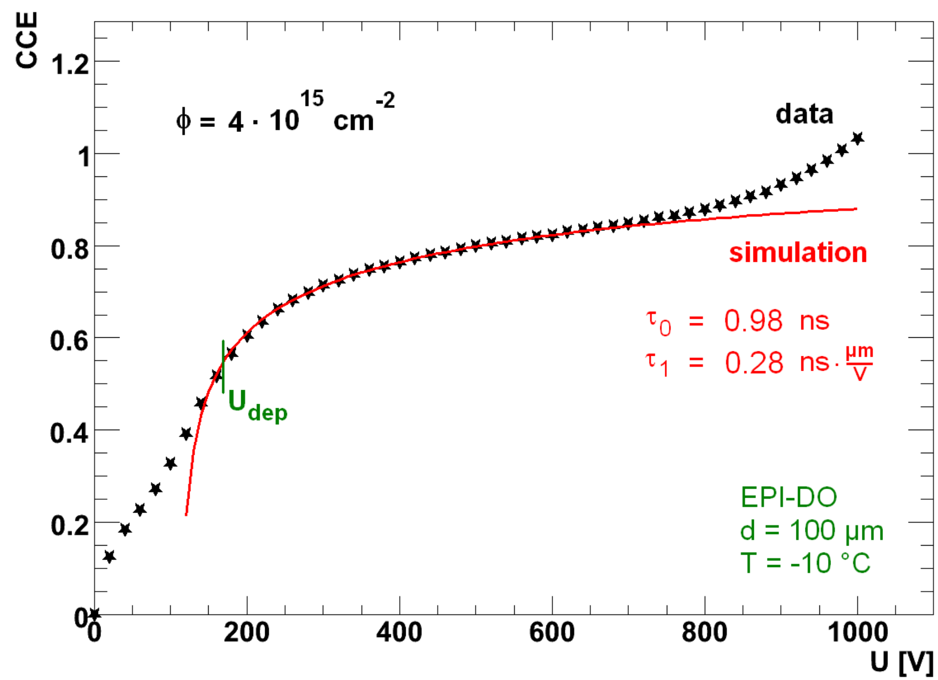


N_{eff} (T, ϕ, x)

N_{eff} linear in x
higher $|N_{eff}|$ for low T
higher ΔN_{eff} for large ϕ

Charge multiplication





Charge multiplication seen for 100 µm thick diodes and U > 800 V

Summary

Charge collection and trapping can be well described taking into account

- distortions to the space charge distribution leading to parabolic electric fields (double peak)
- field-dependence of trapping time τ * (to fit CCE curves)
- circuit effects (to simulate TCT signals)

Trapping probability decreases with increasing E-field

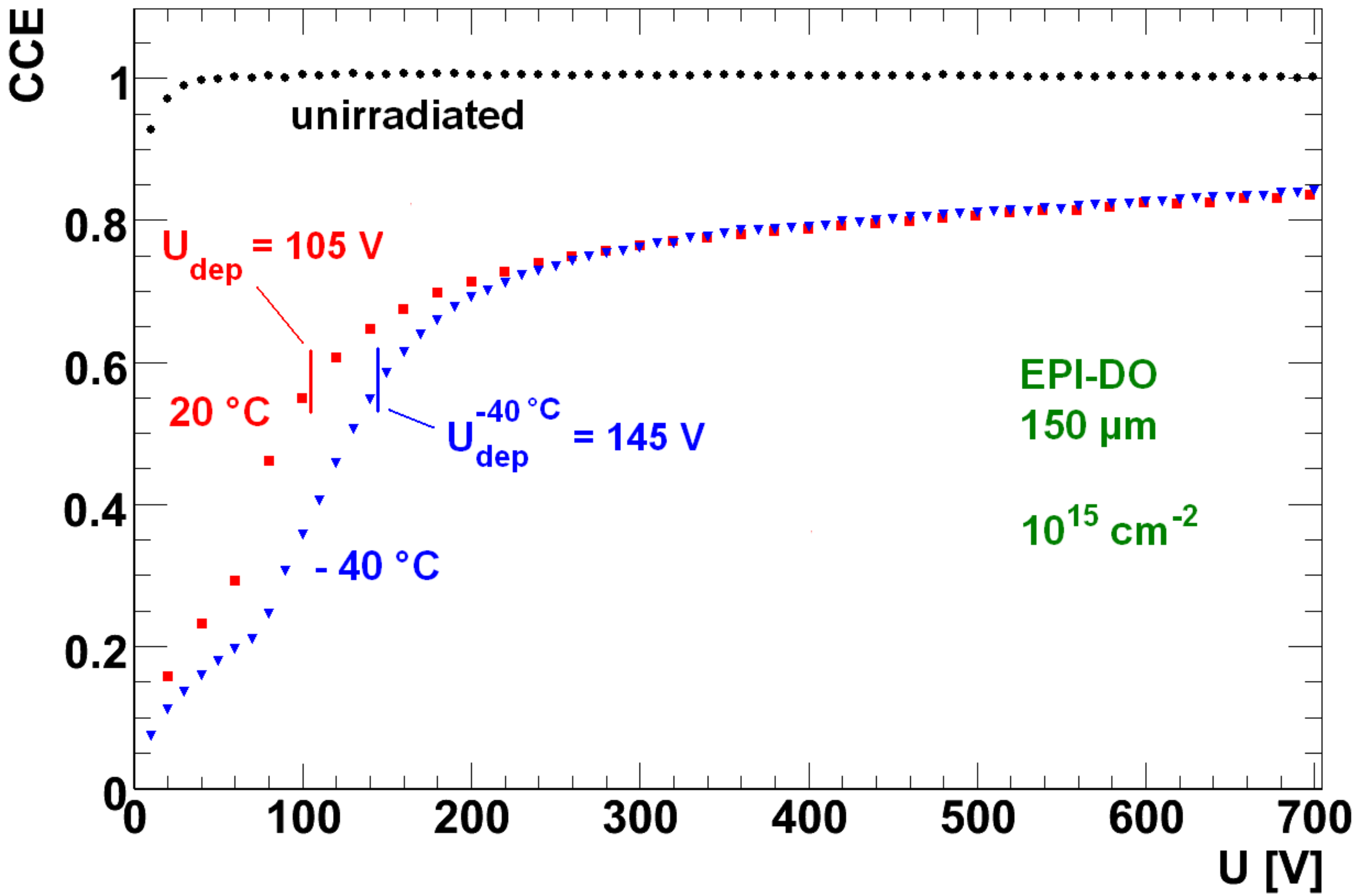
$\Rightarrow$ high E-fields desirable to reduce trapping probability $1/\tau$ *

|Neff| larger (more negative) for lower temperatures

* here τ is an effective trapping time including trapping and detrapping

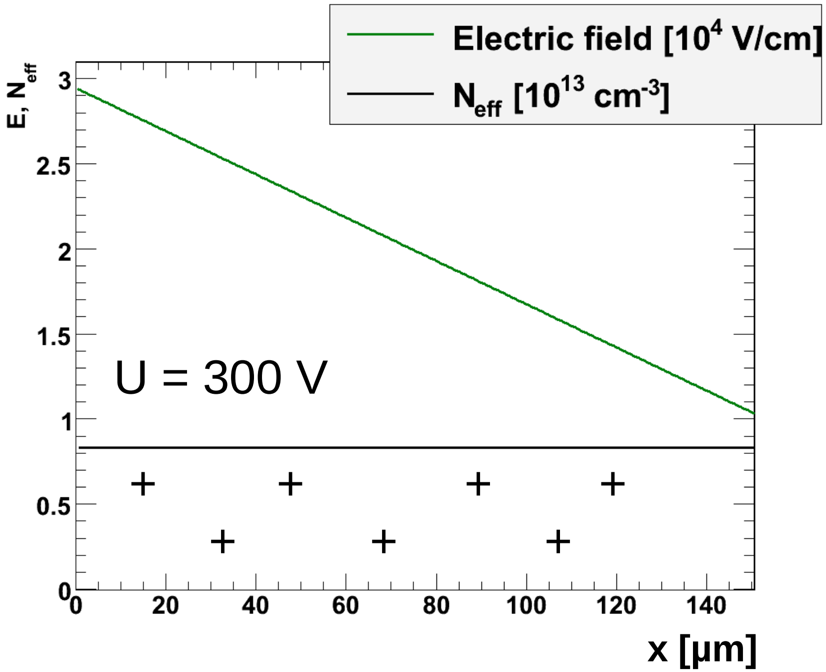
Backup Slides

U_{dep} dependence on temperature

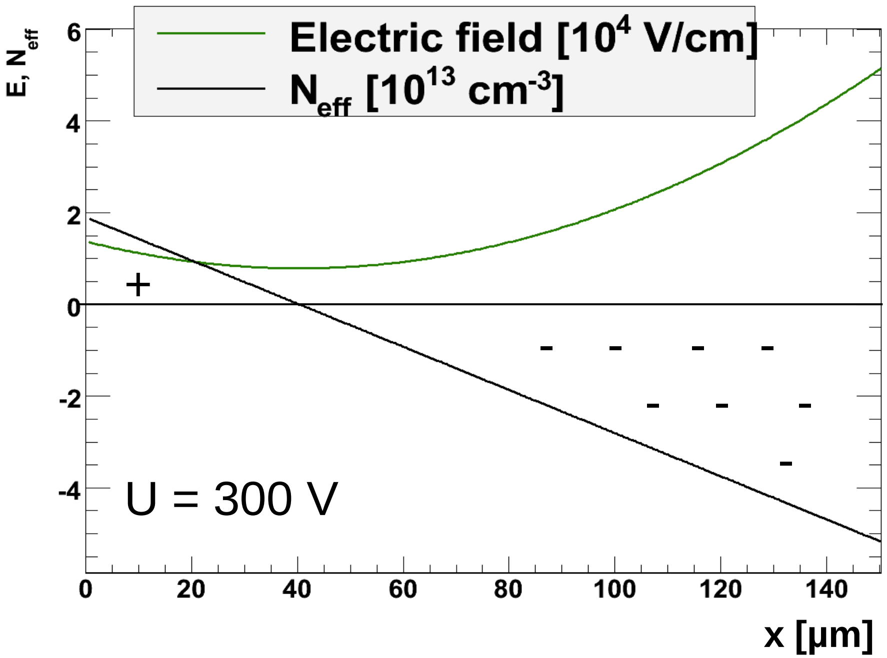


Electric Field and Space Charge Distribution N_{eff}

Unirradiated diode p^+ n



Irradiated diode: $\phi = 2 \cdot 10^{15}$ cm^{-2}



homogenous space charge distribution ⇨ linear electric field

linear space charge distribution ⇨ parabolic electric field

Determination of $\tau(E)$

Initial guess of field distribution (i.g. linear, parabolic)

- Assumption of electric field parameters
- Fit of CCE curves by simulation with parameter τ
- Agreement of measured and simulated TCT signal?

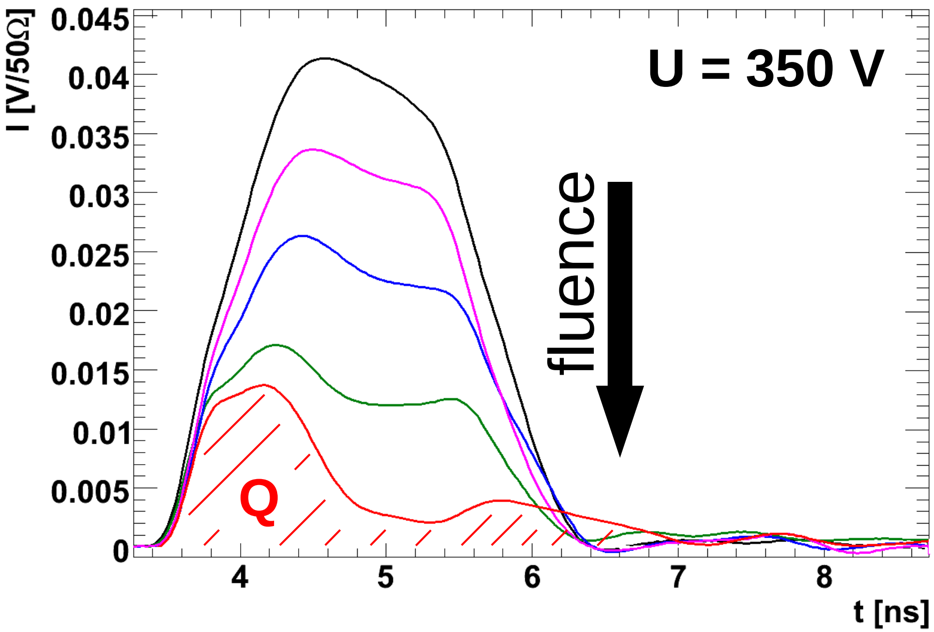
Yes / No

modification of E(x)

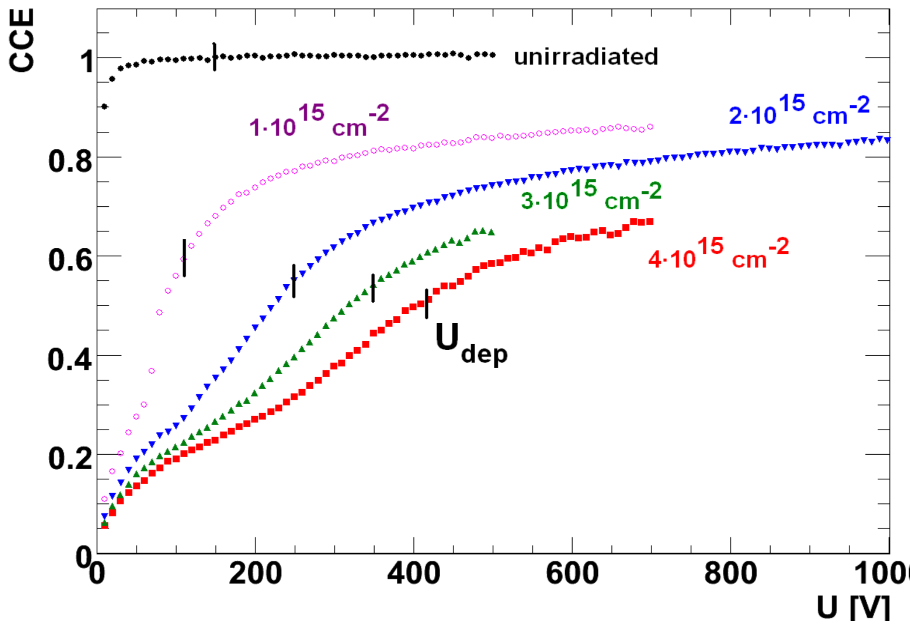
$\tau(E)$

Determination of Charge Collection Efficiency from TCT Measurements

TCT signal

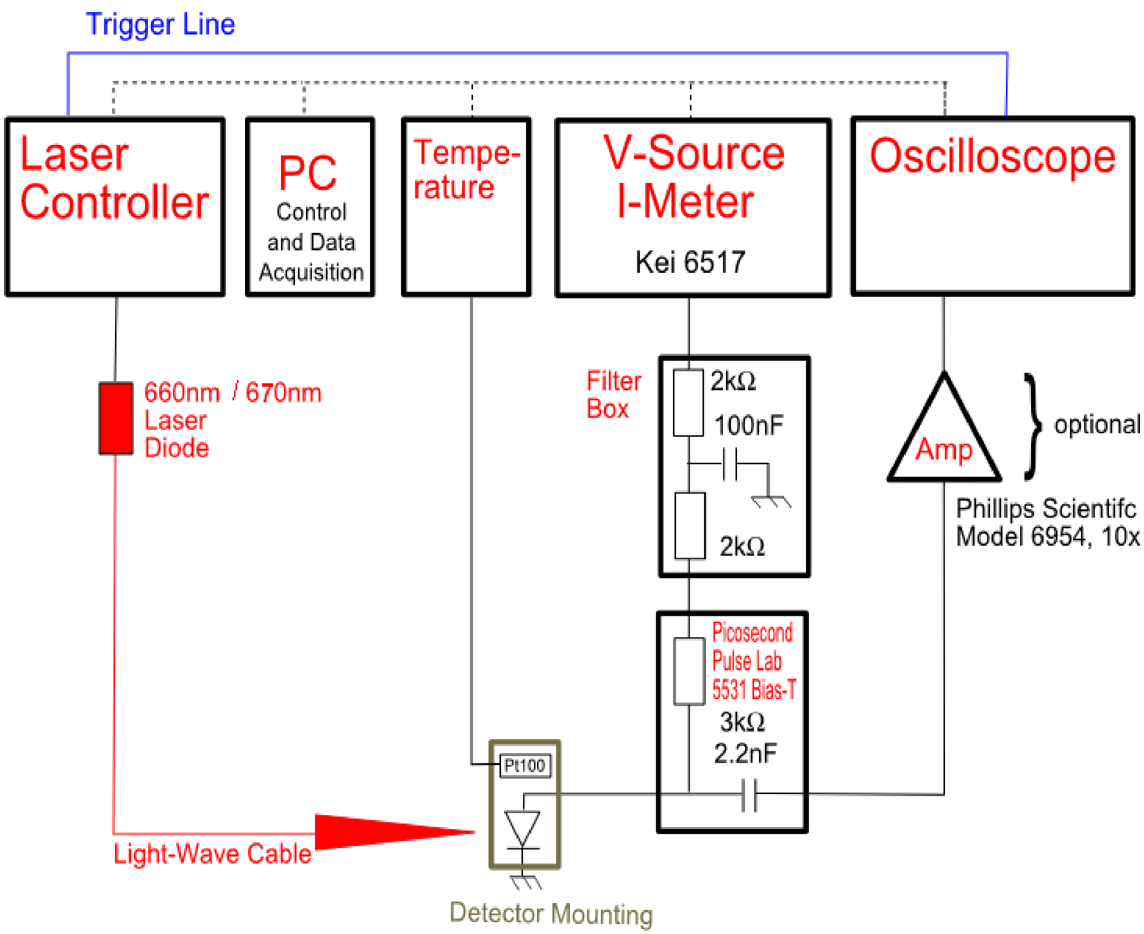


Charge Collection Efficiency (CCE)

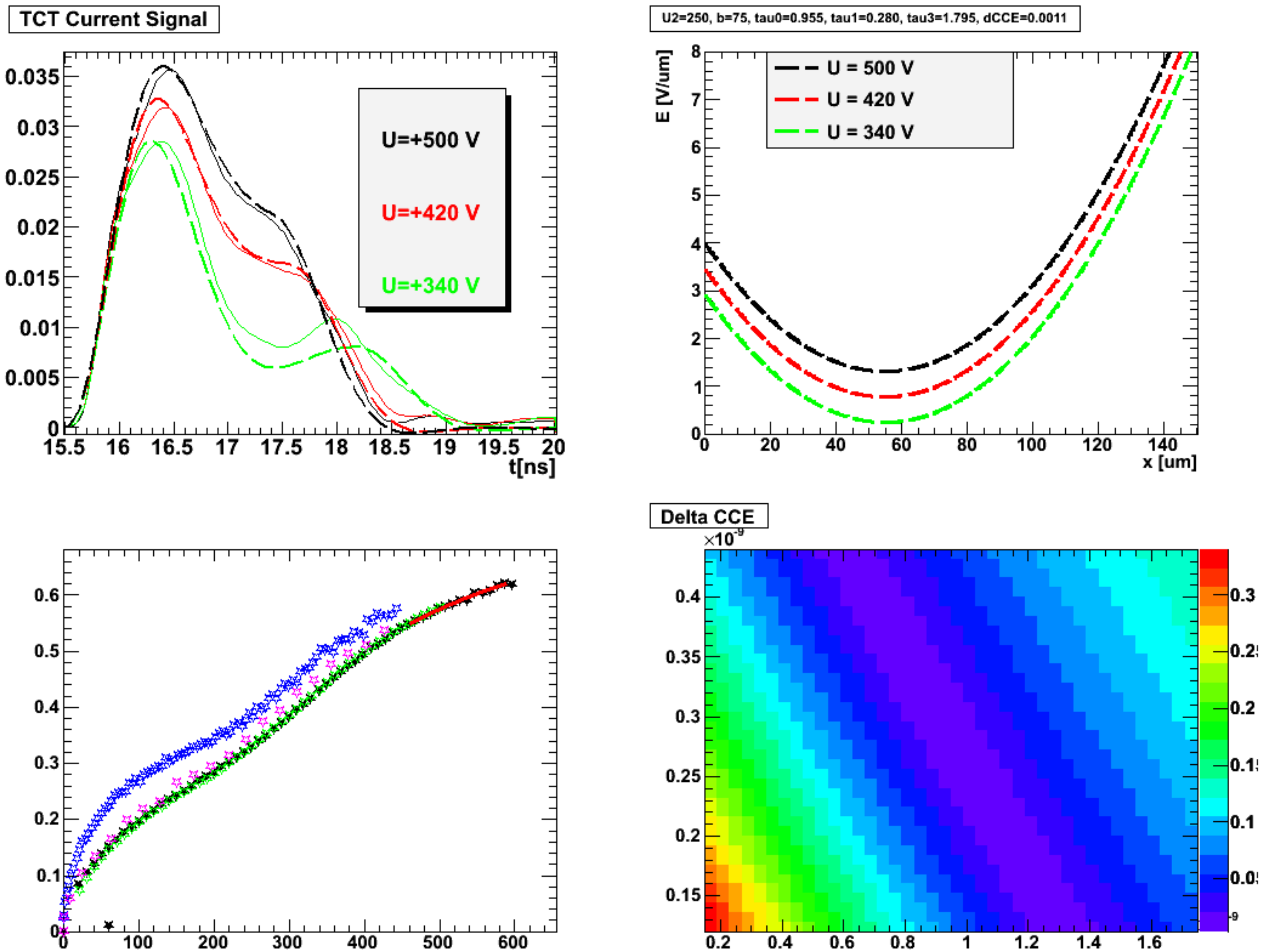


- Collected Charge Q = $\int I \, dt$
- Deposited Charge Q_0 = $\int I_{non-irradiated} \, dt$
- Trapping reduces collected charge Q.

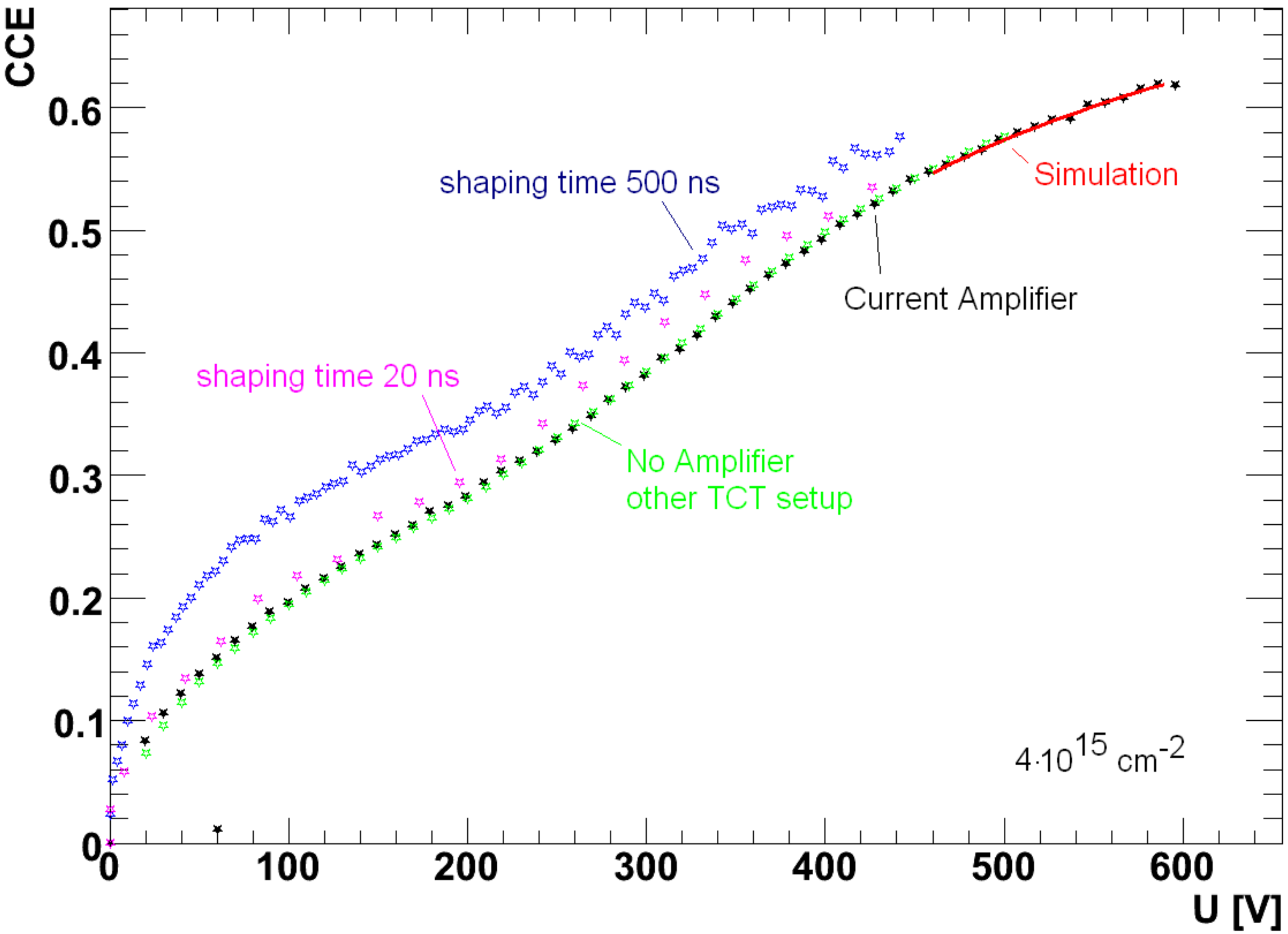
- CCE = Q / Q_0
- Unirradiated diodes: CCE = 1


Trigger Line
Laser Controller
PC
Control and Data Acquisition
Tempe-rature
V-Source I-Meter
Kei 6517
Oscilloscope
660nm / 670nm Laser Diode
Filter Box
2kΩ
100nF
2kΩ
Amp
optional
Phillips Scientifc Model 6954, 10x
Picosecond Pulse Lab 5531 Bias-T
3kΩ
2.2nF
Pt100
Light-Wave Cable
Detector Mounting

Overview of E(x), I(t) and CCE(U) for a $4 \cdot 10^{15}$ DO



CCE-curves measured with different setups



Drift Velocity

$$v_{dr} = \frac{\mu_0 E}{\left(1 + (\frac{\mu_0 E}{v_{sat}})^{\beta}\right)^{1/\beta}}$$

$v_{sat} = 9.814 \cdot 10^4$ m/s
$\mu_0 = 0.1447$ m²/Vs
$\beta = 1.1073$

(modified Jacoboni at 294 K)