Charge Collection and Trapping in Epitaxial Silicon Detectors after Neutron-Irradiation

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Outline

- Introduction
- Transient Current Technique (TCT)
- Determination of field dependent trapping time τ
  - Simulation of TCT signal
  - Electric field and space charge distribution
  - Field dependent τ
  - Fit of the Charge Collection Efficiency (CCE)
- Fluence Dependence of $1/\tau$
- Summary and Conclusion

Introduction

Trapping

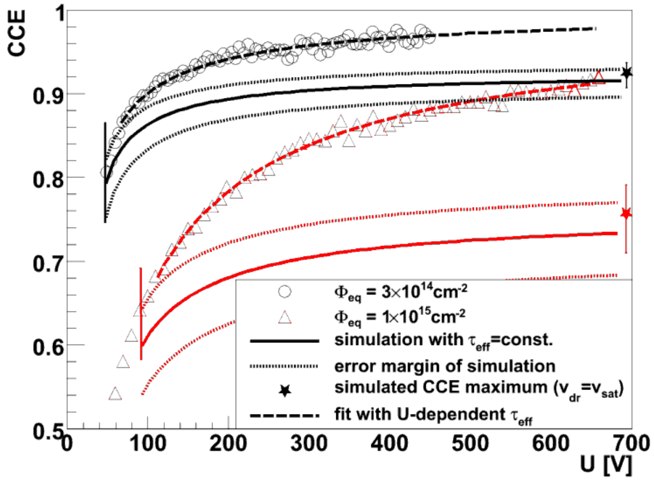
- Most limiting factor for S-LHC
- Charge Collection Efficiency (CCE) decreases

Aim of this work

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

Introduction

Why field dependent?



τ = constant

- often used for $\phi < 2{\cdot}10^{14}\ cm^{-2}$ (FZ, MCz)
- not suitable for $\phi > 10^{15}\ cm^{-2}$

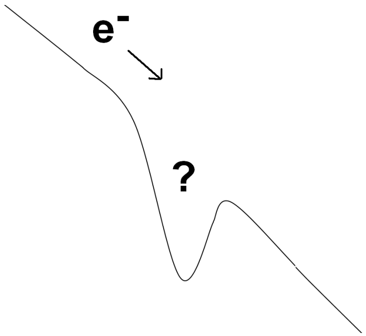
τ voltage dependent

empirical model, good description for $\phi > 10^{15}\ cm^{-2}$ possible

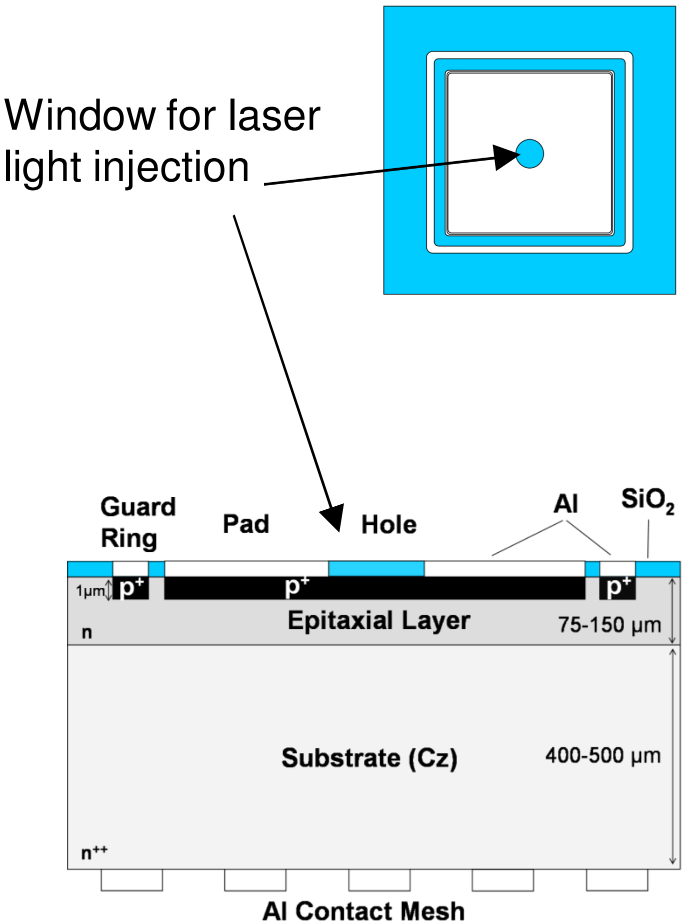
τ field dependent

motivated by:

- field dependent trapping cross section σ(E) ?
- field enhanced detrapping ?
- trap filling ?



Investigated Samples



Samples and irradiation

n-type epitaxial silicon pad detectors

- thickness d: 150 µm
- area: 2.5 x 2.5 mm^2
- neutron fluence ϕ: $1 \cdot 10^{15}$ to $4 \cdot 10^{15}$ cm^{-2}
  - $\Rightarrow$ type inversion
  - $\Rightarrow$ probably below charge multiplication range

Why epitaxial detectors?

- thin layer can be grown (device engineering)
- high oxygen concentration (good radiation hardness)

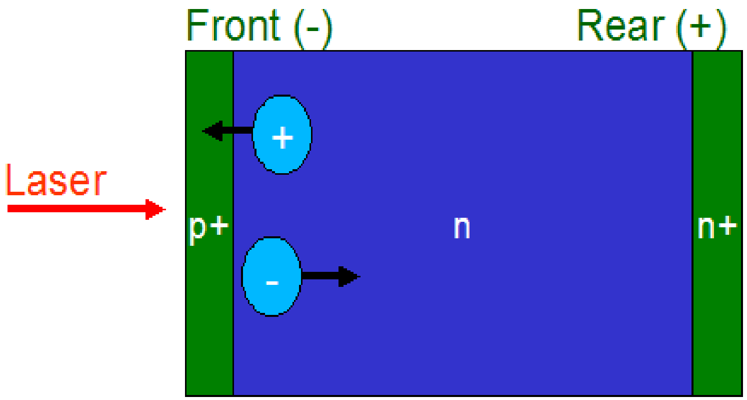
All properties can be tuned

$\Rightarrow$ Optimization of radiation hardness possible

Transient Current Technique (TCT)

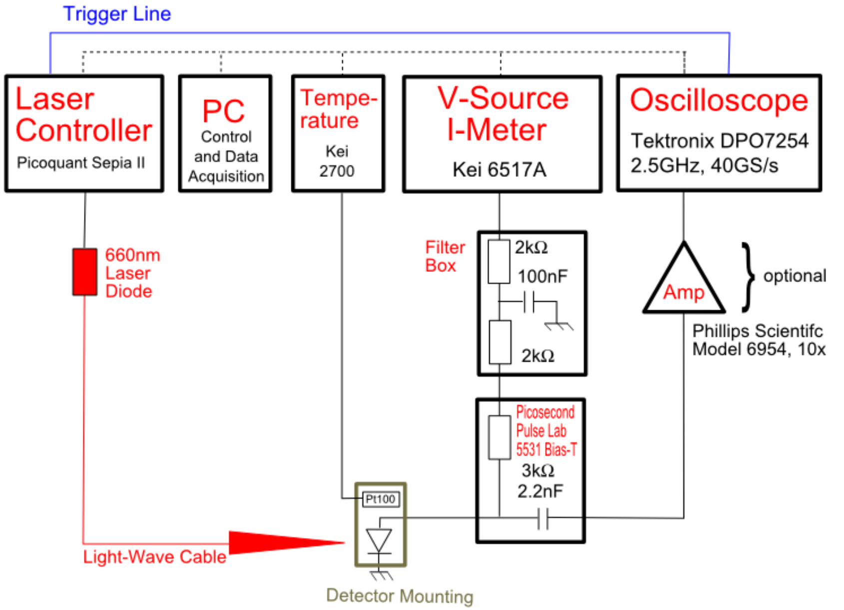
- Front side injection (p+ side)
- 660 nm / 670 nm laser light (penetration depth 3 μm)

⇒ electron signal



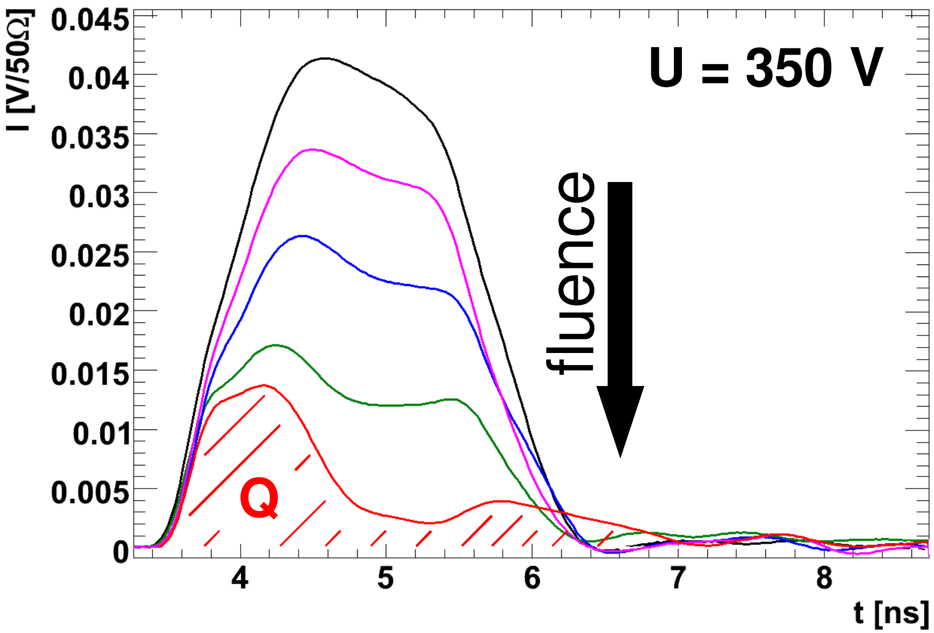
- Short laser pulse
  - FWHM 70 ps
- Small pad diodes
  - d = 150 μm, C = 4.3 pF
- 2.5 GHz Oscilloscope

measured rise time = 600 ps

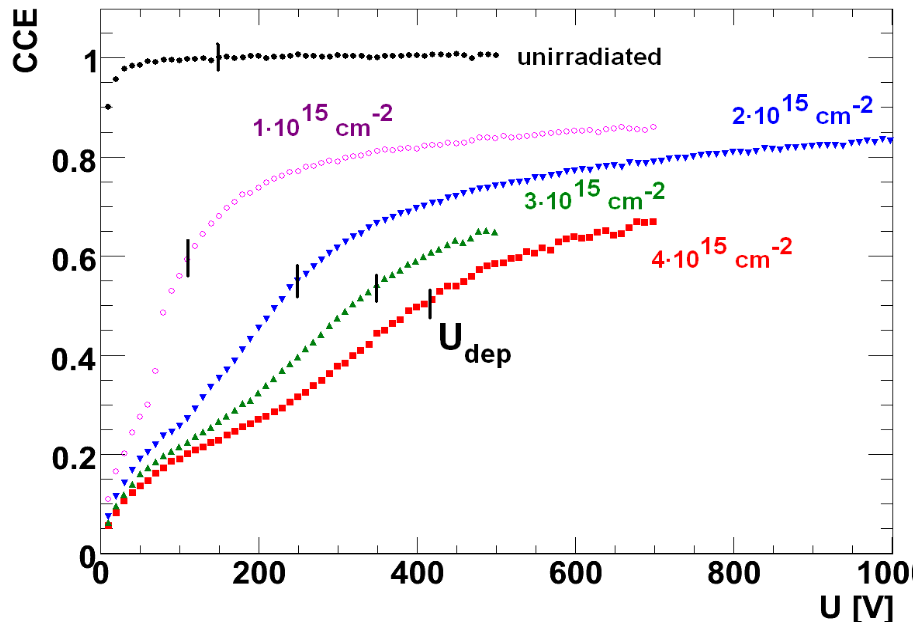


Determination of Charge Collection Efficiency from TCT Measurements

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

Determination of $\tau(E)$

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

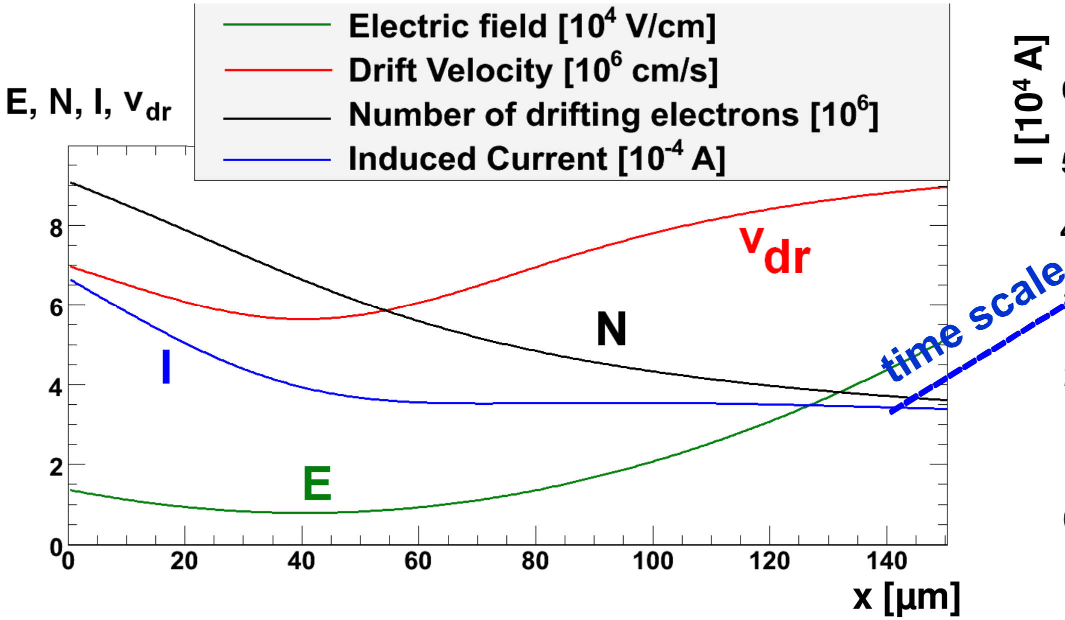
- Assumption of electric field parameters
- Fit of CCE curves by simulation with parameter τ
- Agreement of measured and simulated TCT signal? Yes / No

modification of E(x)

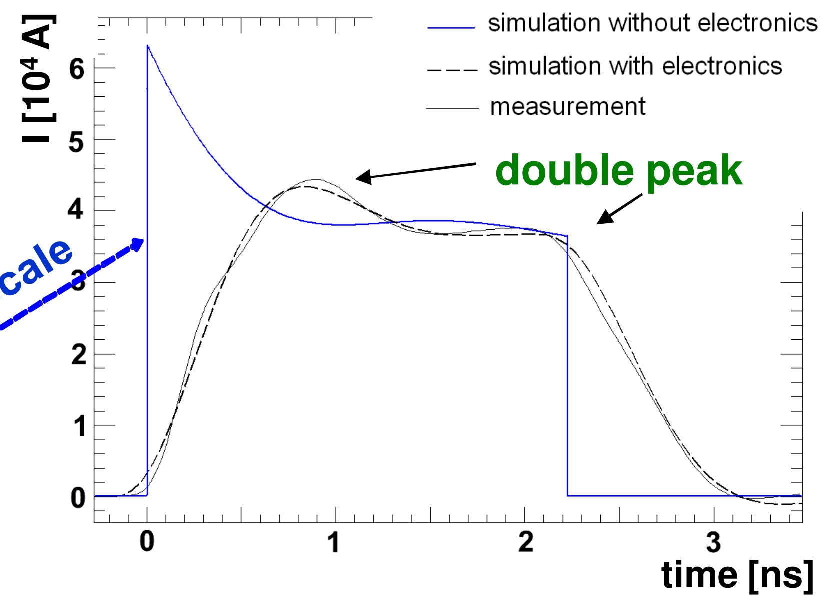
$\tau(E)$

Simulation of TCT Signal

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



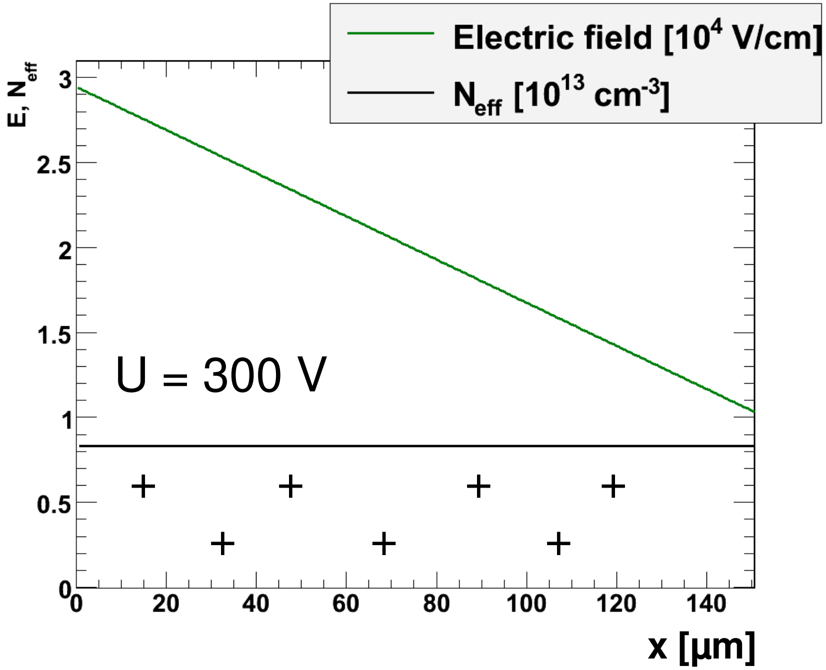
TCT signal smearing
U = 300 V, $\phi = 2 \cdot 10^{15}$ cm^{-2}



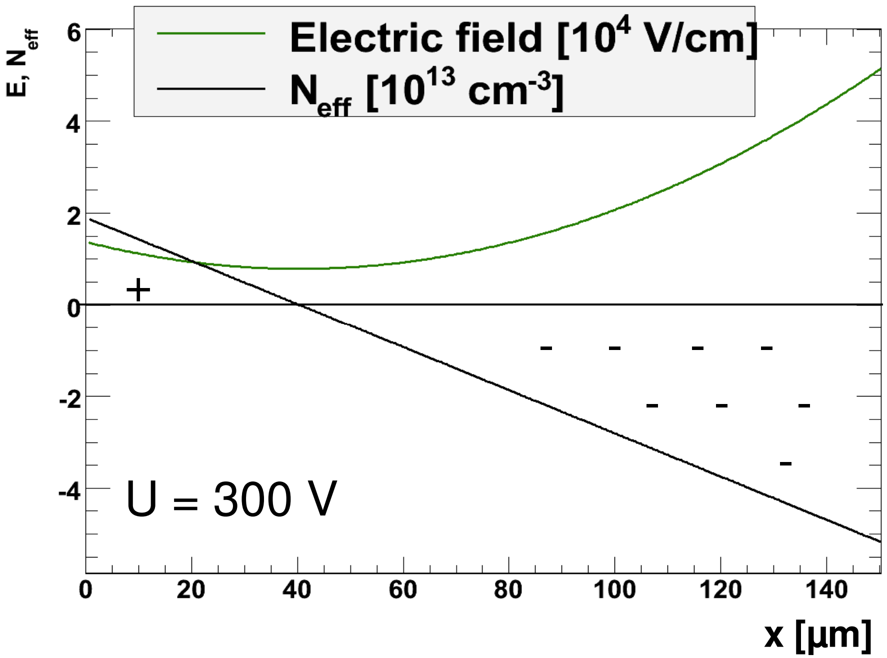
Simulation takes into account:
- Number of drifting electrons N reduces while drifting (trapping)
- Parabolic E-field needed to describe double peak (space charge distribution)
- Saturation of drift velocity $v_{dr}(E(x))$
- Induced current $I(t) = v_{dr} \cdot N \cdot e_0 / d$ (Ramo's Theorem)
- Electronic circuit effects (calculated with SPICE)

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

$\Rightarrow$ double peak not described

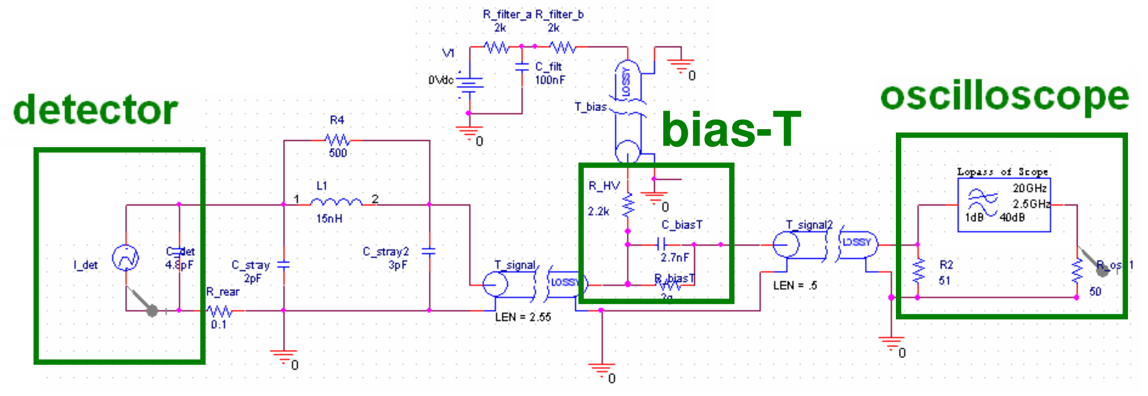
linear space charge distribution => parabolic electric field

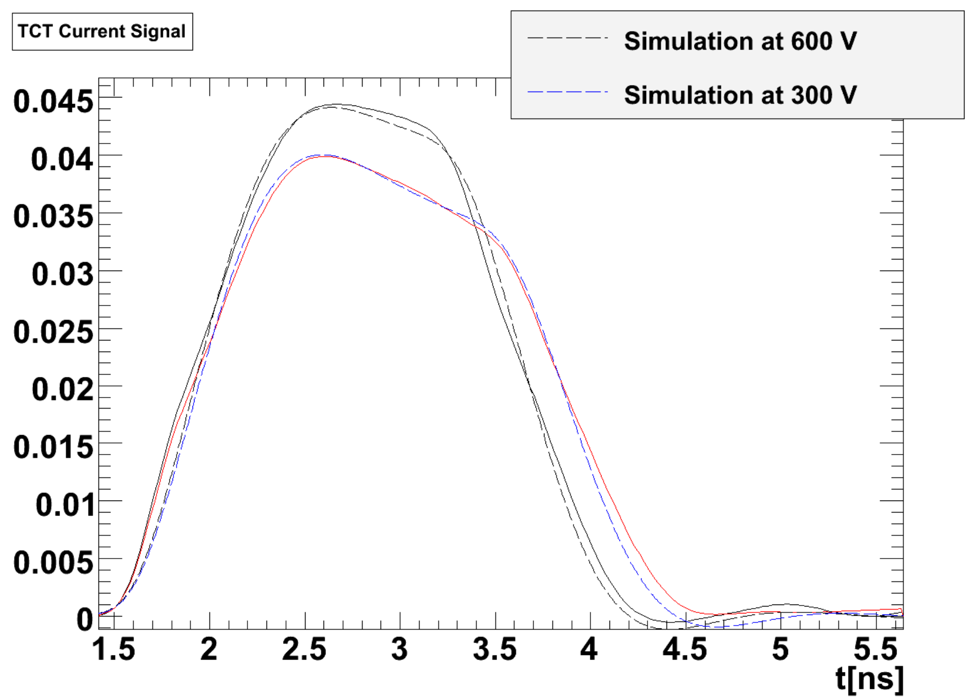
$\Rightarrow$ good agreement between simulated and measured TCT signal possible

Circuit Simulation

Circuit simulation

- Calculated with SPICE
- Unirradiated diodes used for calibration





Fit of the CCE curve

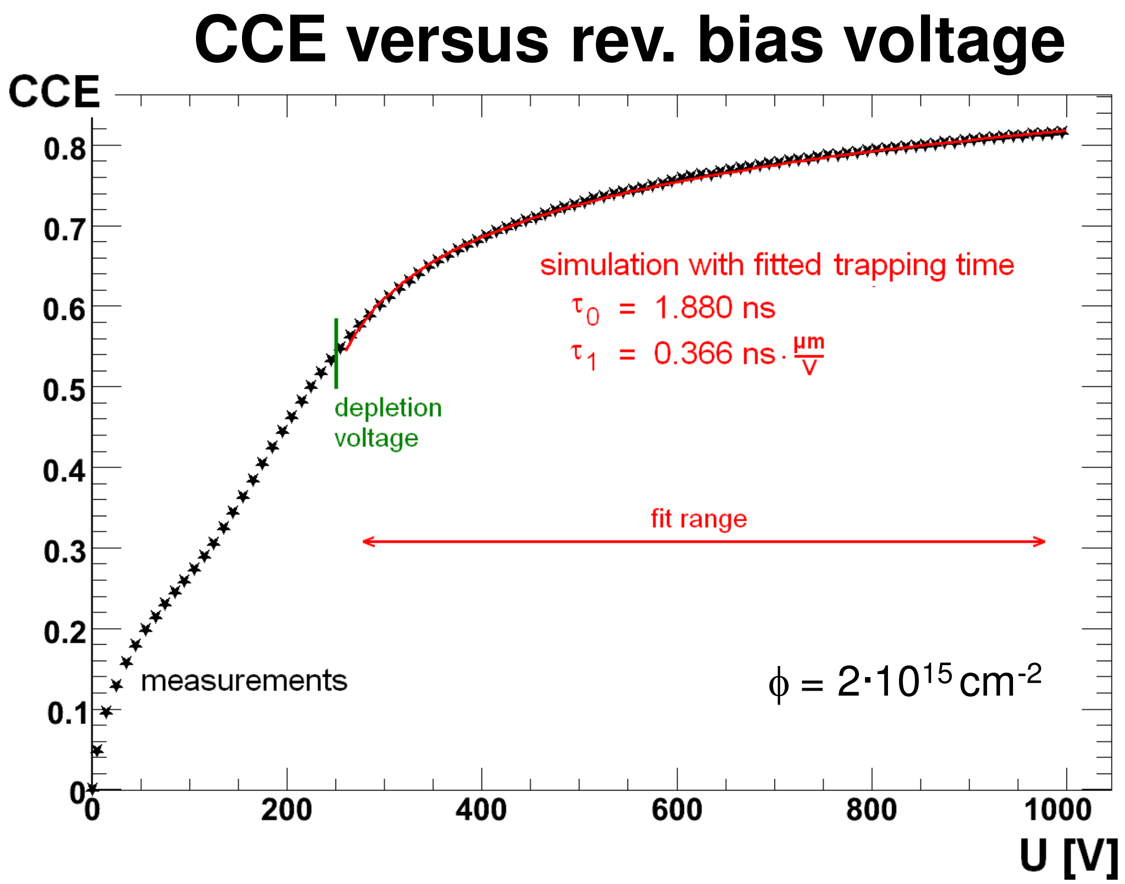
Trapping model:

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

Parameterisation of τ:

$\tau = \tau_0 + \tau_1 E$

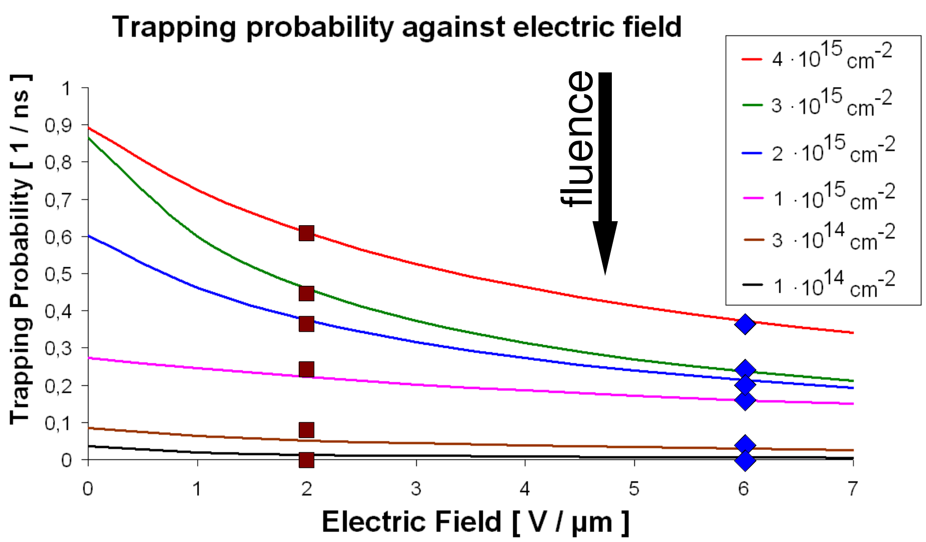
- fit simulated CCE curve to the measured CCE values
- free parameters: τ_0 , τ_1



Field Dependence and Fluence Dependence of 1/τ

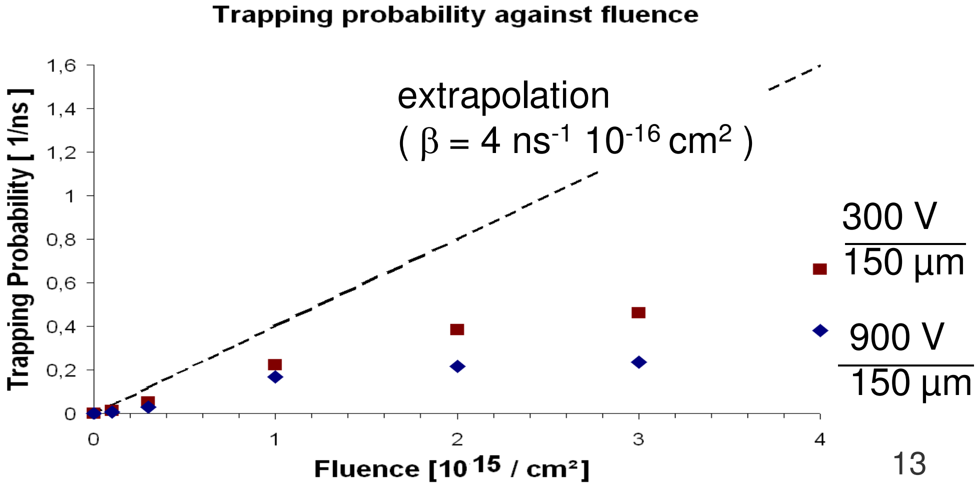
Trapping probability 1/τ decreases with increasing electric field E

$$\frac{1}{\tau} = \frac{1}{\tau_0 + \tau_1 \cdot E}$$



Previous investigations (by G. Kramberger):

- Method: Charge Correction (CCM)
- up to fluences of $2{\cdot}10^{14}$ cm^{-2}
- τ = const
- 1/ τ = β ϕ



Summary and Conclusion

Charge collection and trapping can be well described taking into account

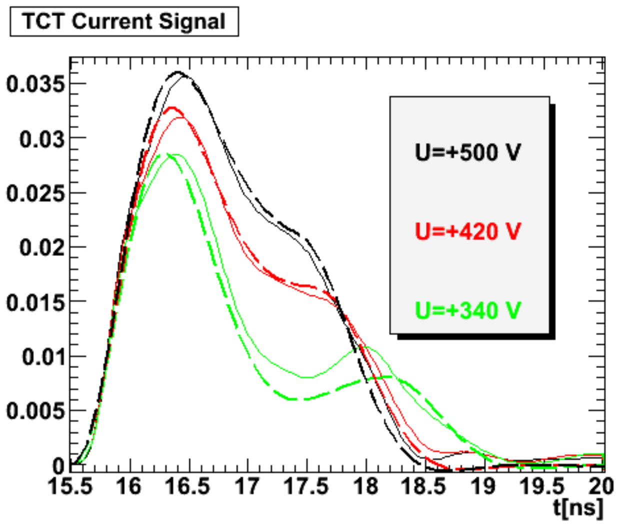
- distortions to the space charge distribution leading to parabolic electric fields (double peak)
- field-dependence of trapping time τ (to fit CCE curves)
- electronic circuit effects (to simulate TCT signals)

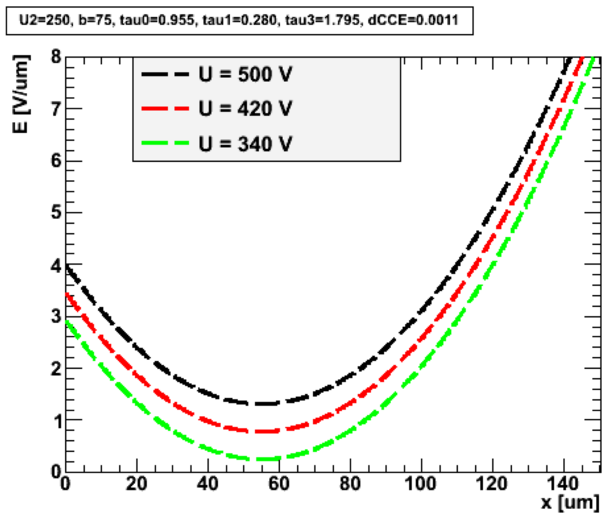
Trapping probability decreases with increasing E-field

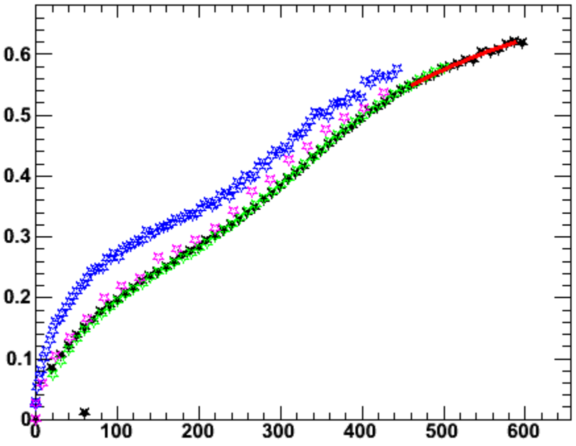
$\Rightarrow$ high E-fields desirable to reduce trapping probability

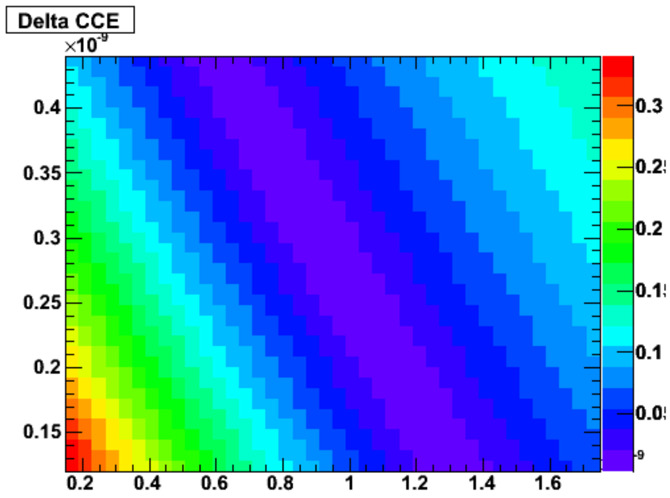
Backup Slides

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

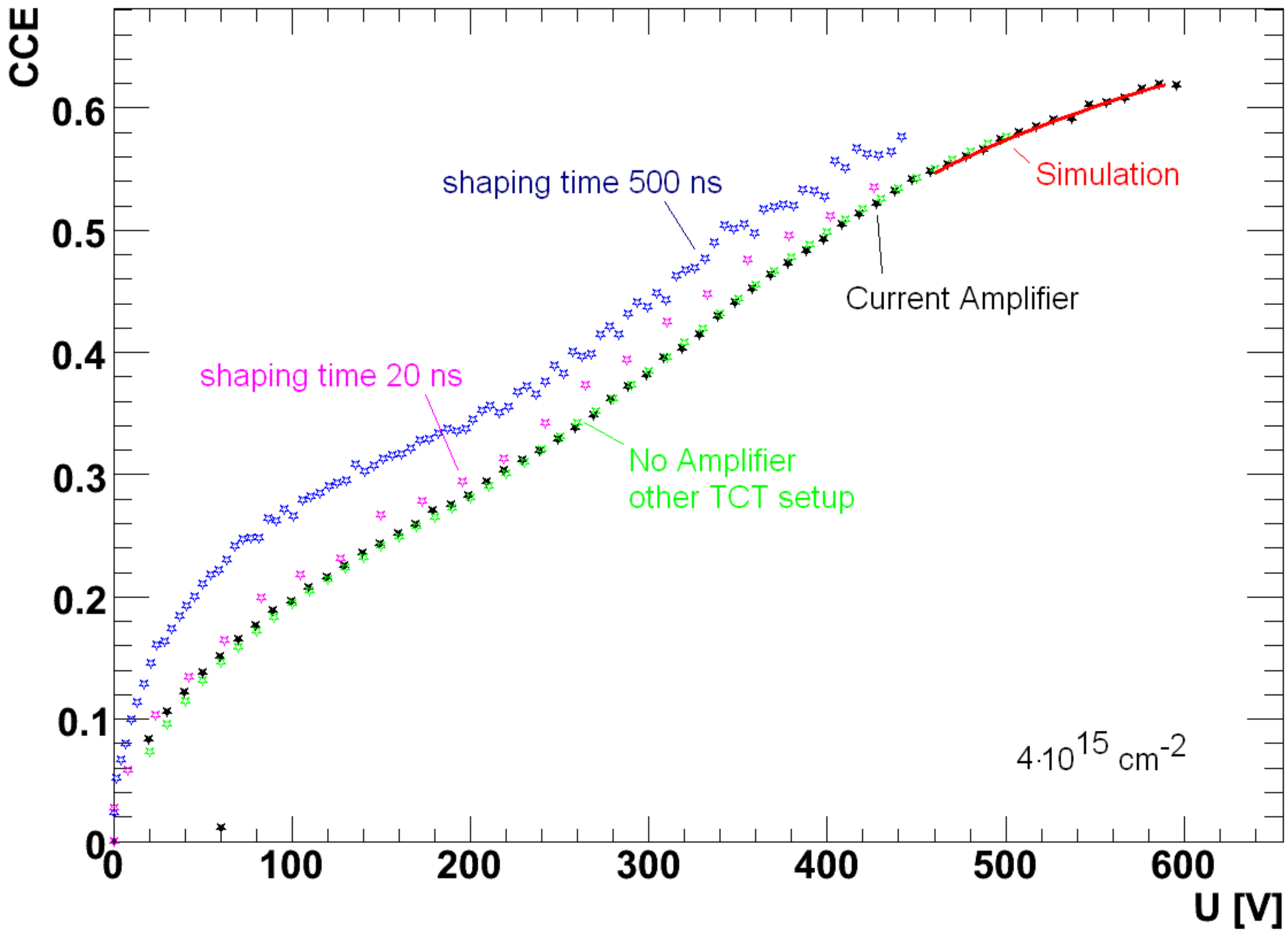




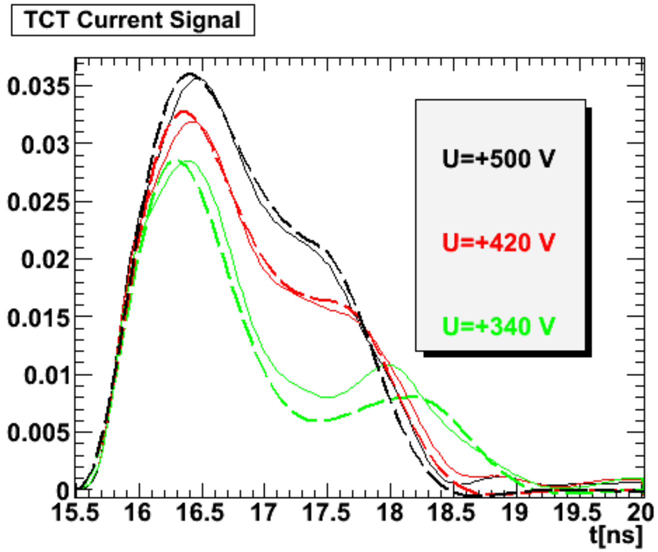


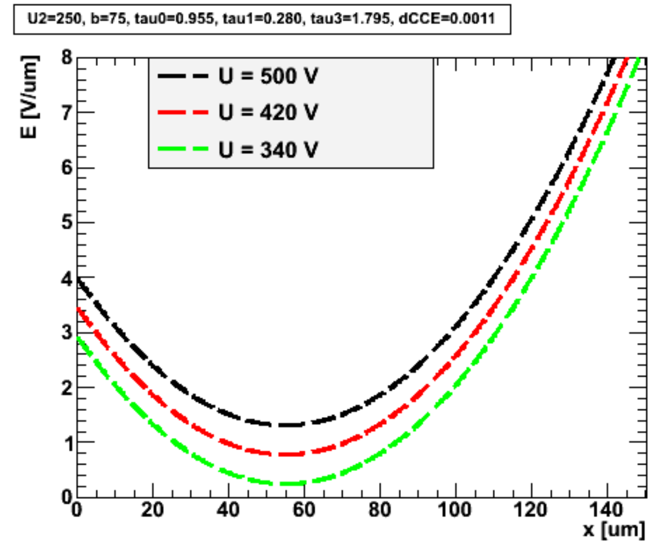


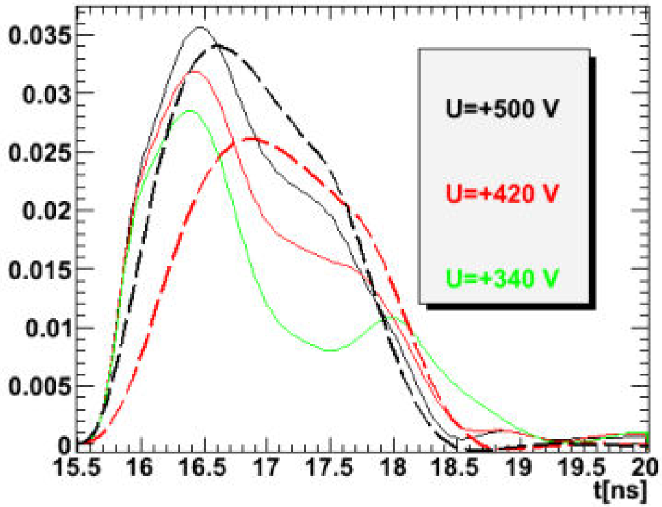
CCE-curves measured with different setups

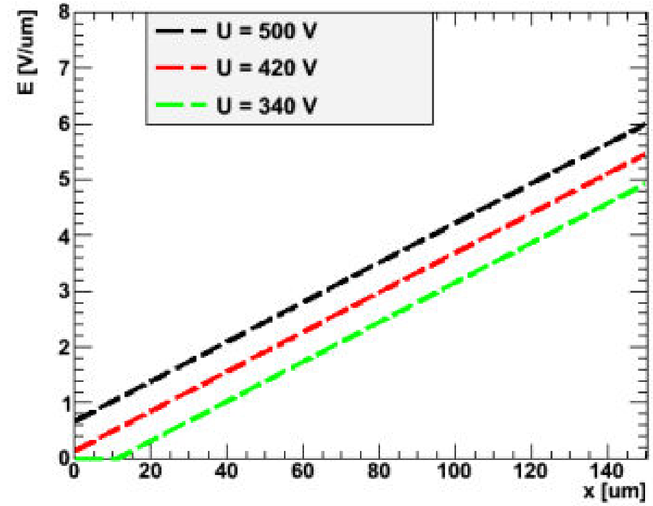


Parabolic and Linear Electric Field for $4 \cdot 10^{15}$ cm^{-2} DO

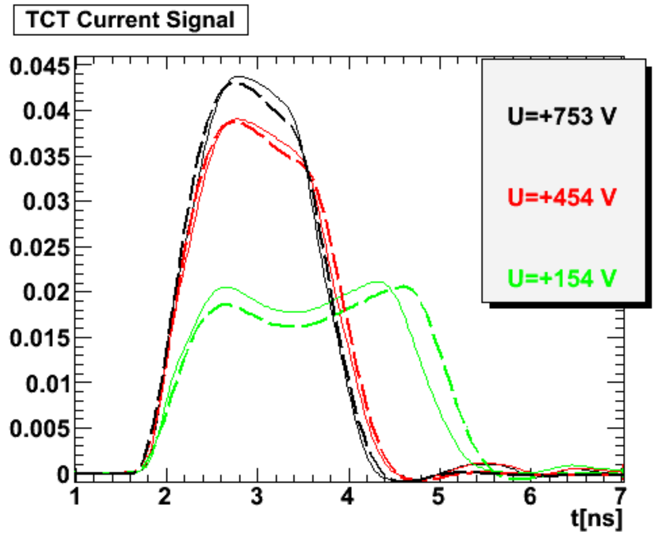


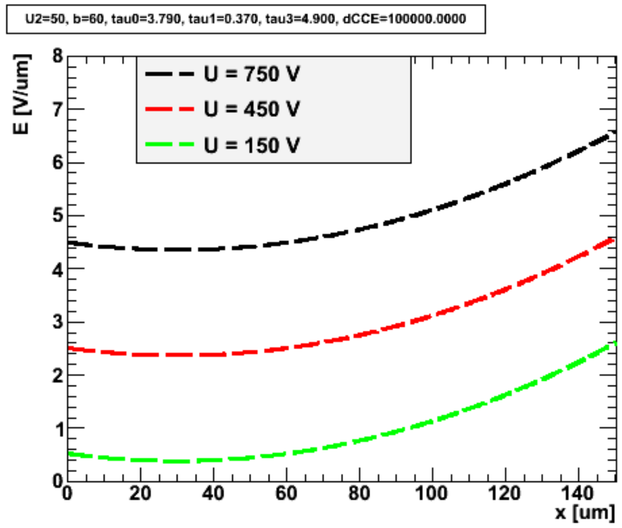


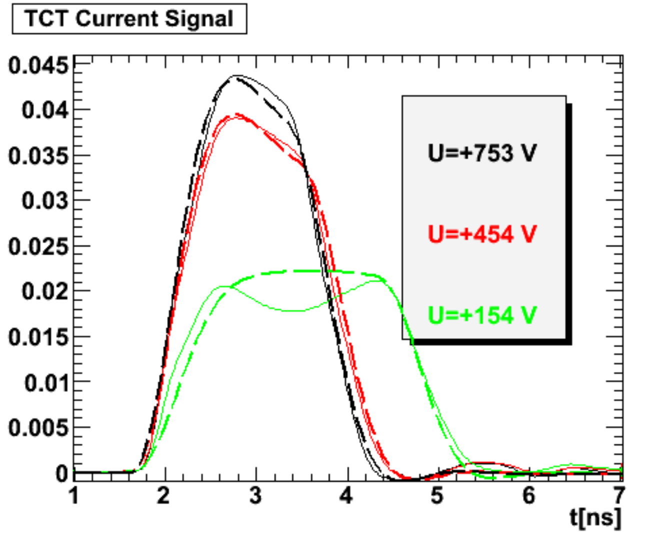


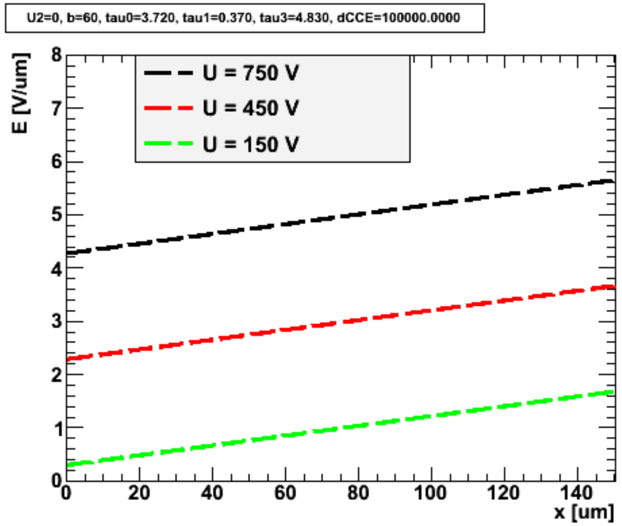


Parabolic and Linear Electric Field for $1 \cdot 10^{15}$ cm^{-2} DO









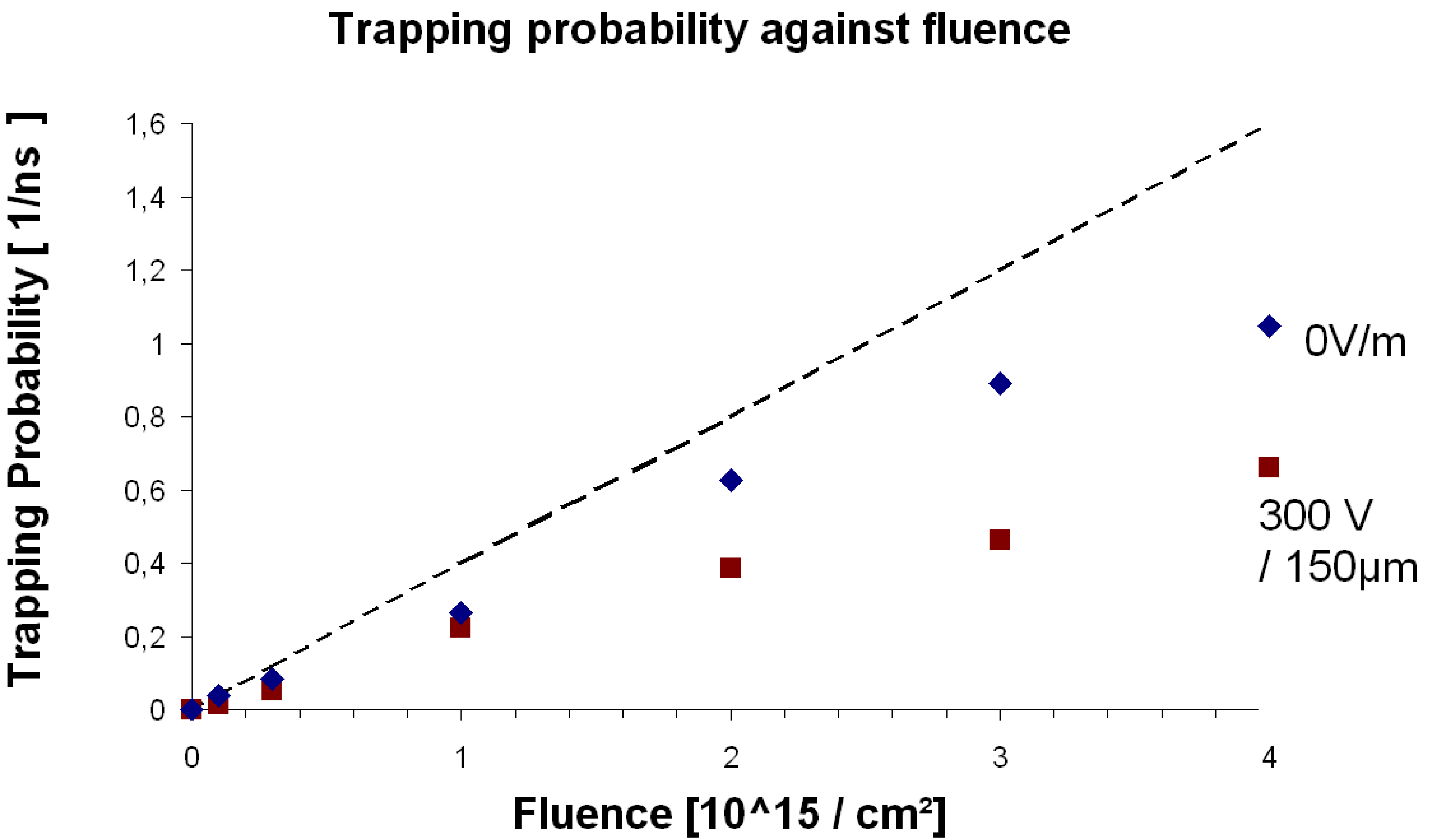
Drift Velocity

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

$v_{sat} = 9.814 \cdot 10^4$ m/s
$\mu_0 = 0.1447$ m^2/Vs
$\beta = 1.1073$

(modified Jacoboni at 294 K)

TCT Signal of Unirradiated Diode



Comparison of Different Models for E(x) and τ