# Effective trapping probability of electrons in neutron irradiated Si detectors using Transient Current Technique simulations

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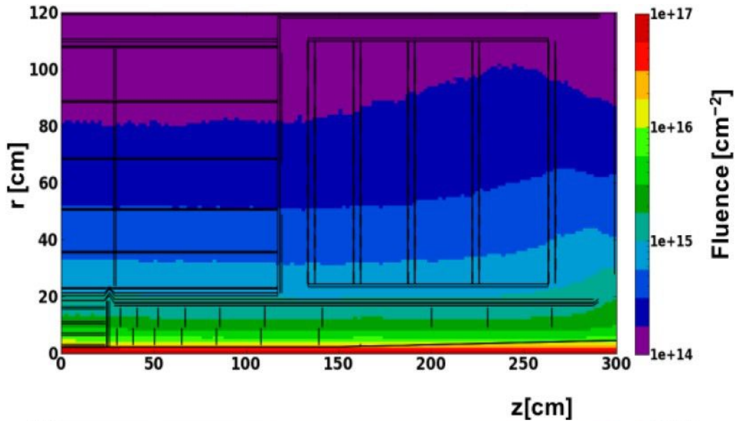
# ***Outline***

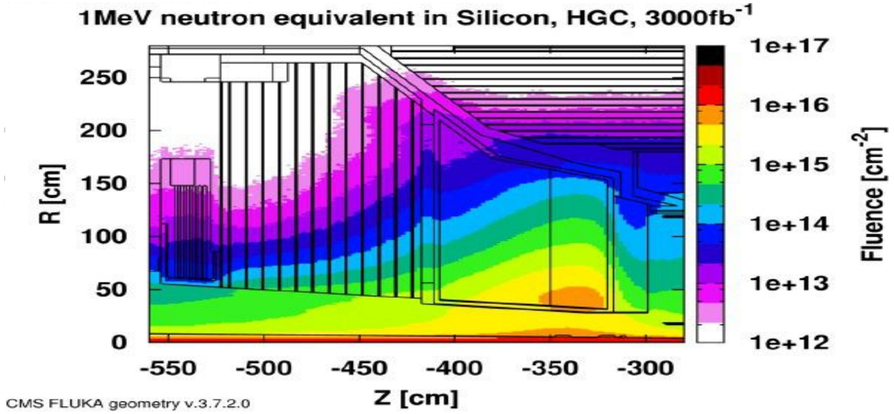
- *Introduction and Motivation*
- *Radiation damage Models*
- *Simulation Structure and parameters*
- *Transient Current Technique Simulations*
  - ✓ *Trapping probability of electrons*
- *Summary and future outlook*

# Introduction and Motivation

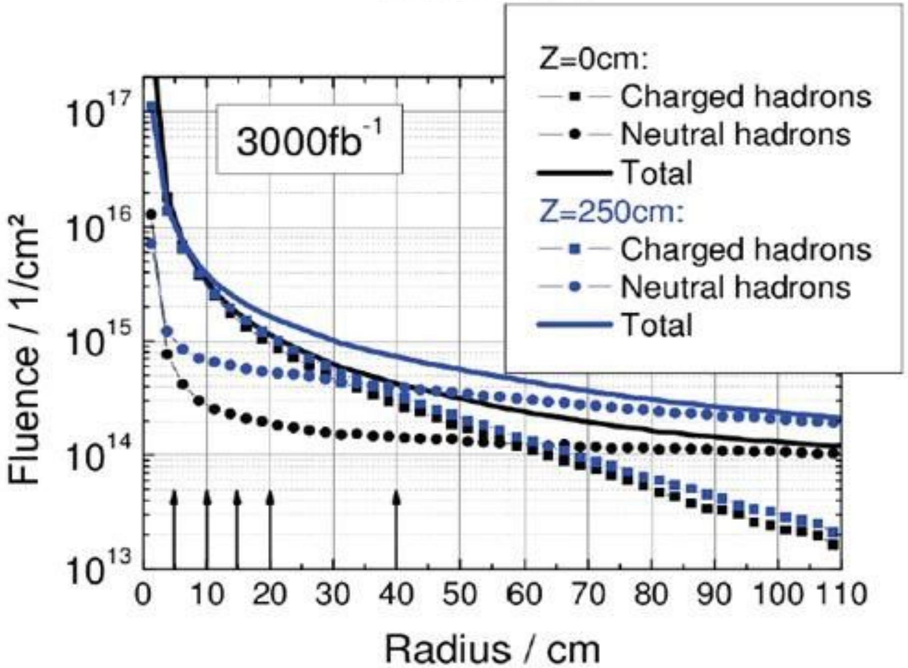
**Predictions** of the maximum 1MeV $n_{eq}$ fluences normalized to 3000$fb^{-1}$ of **HL-LHC**




Expected particle fluence in the ***Tracker volume***




Expected particle fluence in ***End cap calorimeter***




**HL-LHC Phase**

- Peak L ~ 5-7 x $10^{34}$ $cm^{-2}s^{-1}$
- Integrated L = 3000 $fb^{-1}$ (10 yrs of operation)
- Pileup ~ 140-200
- Particle density: 5-10 times higher

| Region | $\phi_{max}$ (1 MeV $n_{eq}$ $cm^{-2}$) |
|---|---|
| Outer tracker | 1.1 x $10^{15}$ |
| Calorimeter | 1.5 x $10^{16}$ |

# Simulations in TCAD Silvaco

# Radiation Damage Models

## Proton Damage Model

- Bulk Damage = 2 Trap Proton Damage Model* (Delhi Model)
- Surface Damage = Oxide charge density ($Q_F$) + 2 Interface traps

| Trap Type | Energy Level (eV) | $g_{int}(cm^{-1})$ | $\sigma_e\ (cm^2)$ | $\sigma_h\ (cm^2)$ |
|---|---|---|---|---|
| Acceptor | $E_c - 0.51$ | 4 | $2 \times 10^{-14}$ | $3.8 \times 10^{-15}$ |
| Donor | $E_v + 0.48$ | 3 | $2 \times 10^{-15}$ | $2 \times 10^{-15}$ |

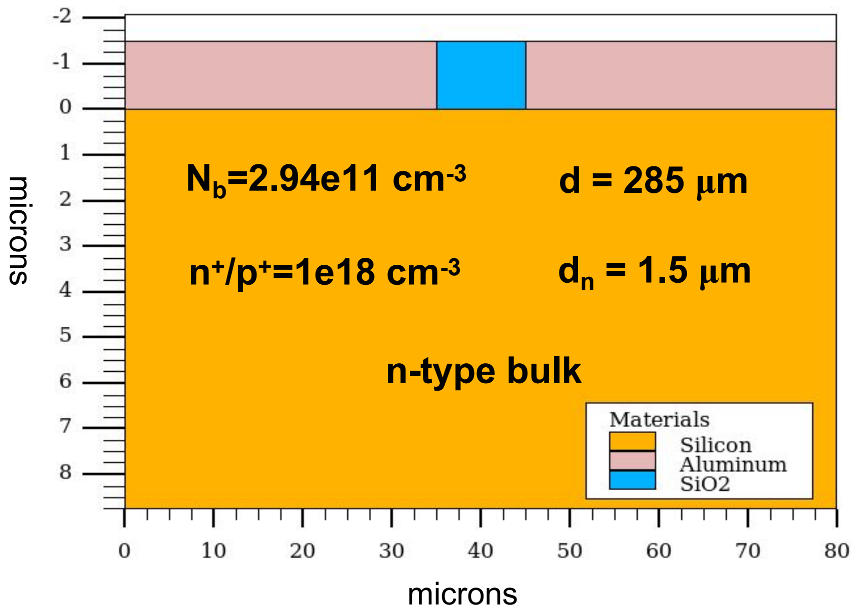
## Neutron Damage Model

| Trap Type | Energy Level (eV) | $g_{int}(cm^{-1})$ | $\sigma_e\ (cm^2)$ | $\sigma_h\ (cm^2)$ |
|---|---|---|---|---|
| Acceptor | $E_c - 0.51$ | 4 | **$9 \times 10^{-15}$** | $3.8 \times 10^{-14}$ |
| Donor | $E_v + 0.48$ | **1** | **$1 \times 10^{-14}$** | **$1 \times 10^{-14}$** |

Surface Damage is not required to be incorporated

R. Dalal. *Simulation of Irradiated Si Detectors.* PoS, Vertex-2014 030.

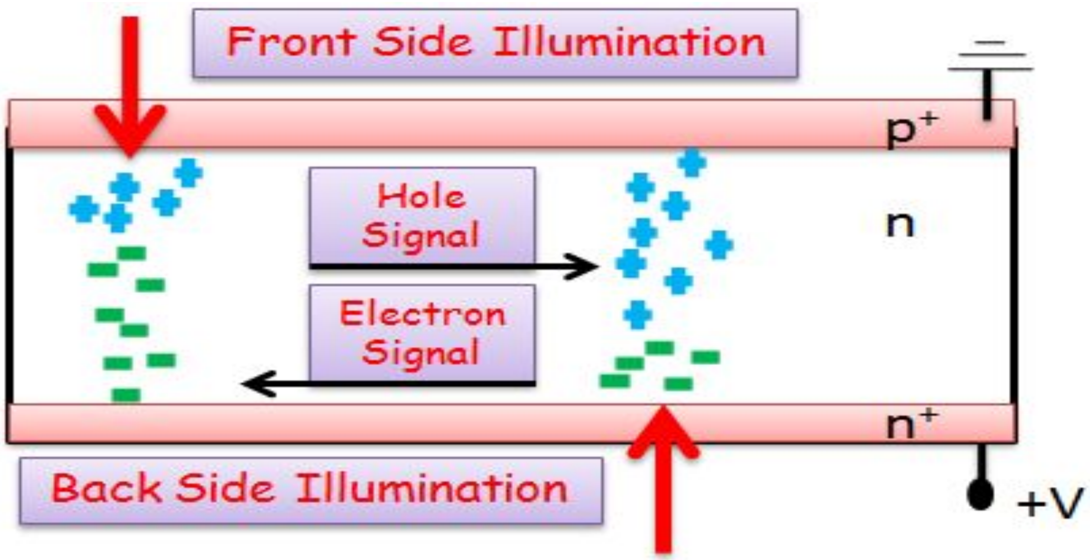
# Simulation structure and parameters




| Optical Source | |
|---|---|
| Laser | Red |
| Wavelength | 660 nm |
| Mixed mode circuit | |

| Simulation Parameters | |
|---|---|
| X Dimension | 80 µm |
| Y Dimension | 285 µm |
| Z Dimension | 1 µm |
| n-bulk doping density | 2.94e11 $cm^{-3}$ |
| $n^+/p^+$ peak doping density | $1x10^{18}$ $cm^{-3}$ |
| Junction depth | 1.5 µm |
| Temperature | 253 K |

# Transient Current Technique Simulations




- ❑ **Red laser ( λ = 660 nm) has been used in TCT simulations for determination of effective trapping time**
- ❑ **Penetration depth for red laser is only about 3.3 μm**
- ❑ **Laser is fired at mid position of pads**
- ❑ **When laser is shone from p-side then the signal is called the electron signal**
- ❑ **When laser is shone from n-side the signal is called hole signal**

# Induced current and 'correction term'

The induced current in the device because of generation of electrons and holes is given by,

$$I_s(t)_{e,h} = e.N(t)_{e,h}.\frac{1}{D}.v(t)_{e,h}$$

***(Ramo's Theorem)***

*Where,* $N(t)_{e,h}$ *= number of drifting electrons and holes*

$D$ *= detector thickness*

$v(t)_{e,h}$ *= drift velocity of carriers*

Because of trapping the number of drifting charge carriers decrease with time as :

$$N(t)_{e,h} = N(0)_{e,h}.\exp\left(\frac{-t}{\tau_{eff_{e,h}}}\right)$$

$N(0)_{e,h}$ *= generated carriers*

$\tau_{eff_{e,h}}$ *= effective trapping time*

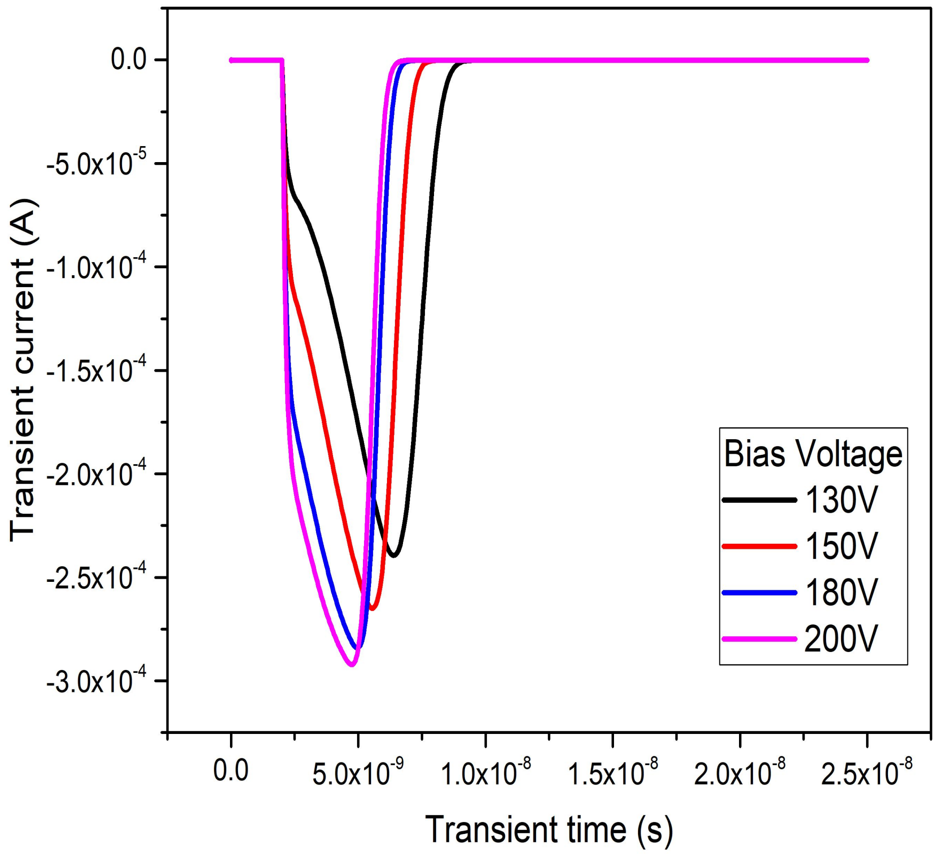
The corrected current signal incorporating a compensation term for trapping is as follows :

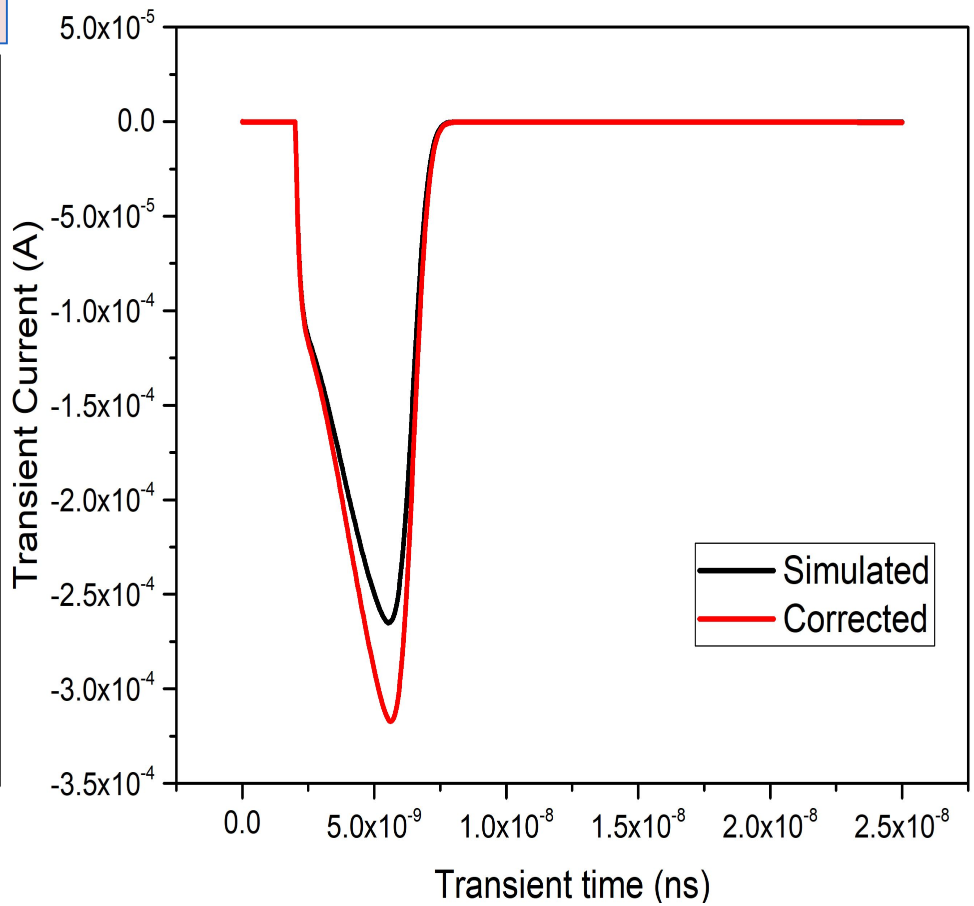
$$I_c(t) = I_s(t).\exp\left(\frac{t}{\tau_{tr}}\right)$$

*G. Kramberger. Determination of effective trapping times for electrons and holes in irradiated silicon. Nuclear Instruments and Methods in Physics Research A 476 (2002) 645–651

# Simulated and Corrected TCT signals

**Simulated signal**




- **With increase in the bias voltage charge collection time decreases.**
- **Peak of the signal increases and shifts towards left.**

- **Simulated and corrected TCT signals at 130 V.**
- **Corrected TCT signal is calculated with trapping time $\tau_{tr}$ of 20 ns.**

# Collected charge vs Bias voltage

$$I_s(t)_{e,h} \propto N(t)$$

$$N(t)_{e,h} = N(0)_{e,h} . \exp\left(\frac{-t}{\tau_{eff\, e,h}}\right)$$

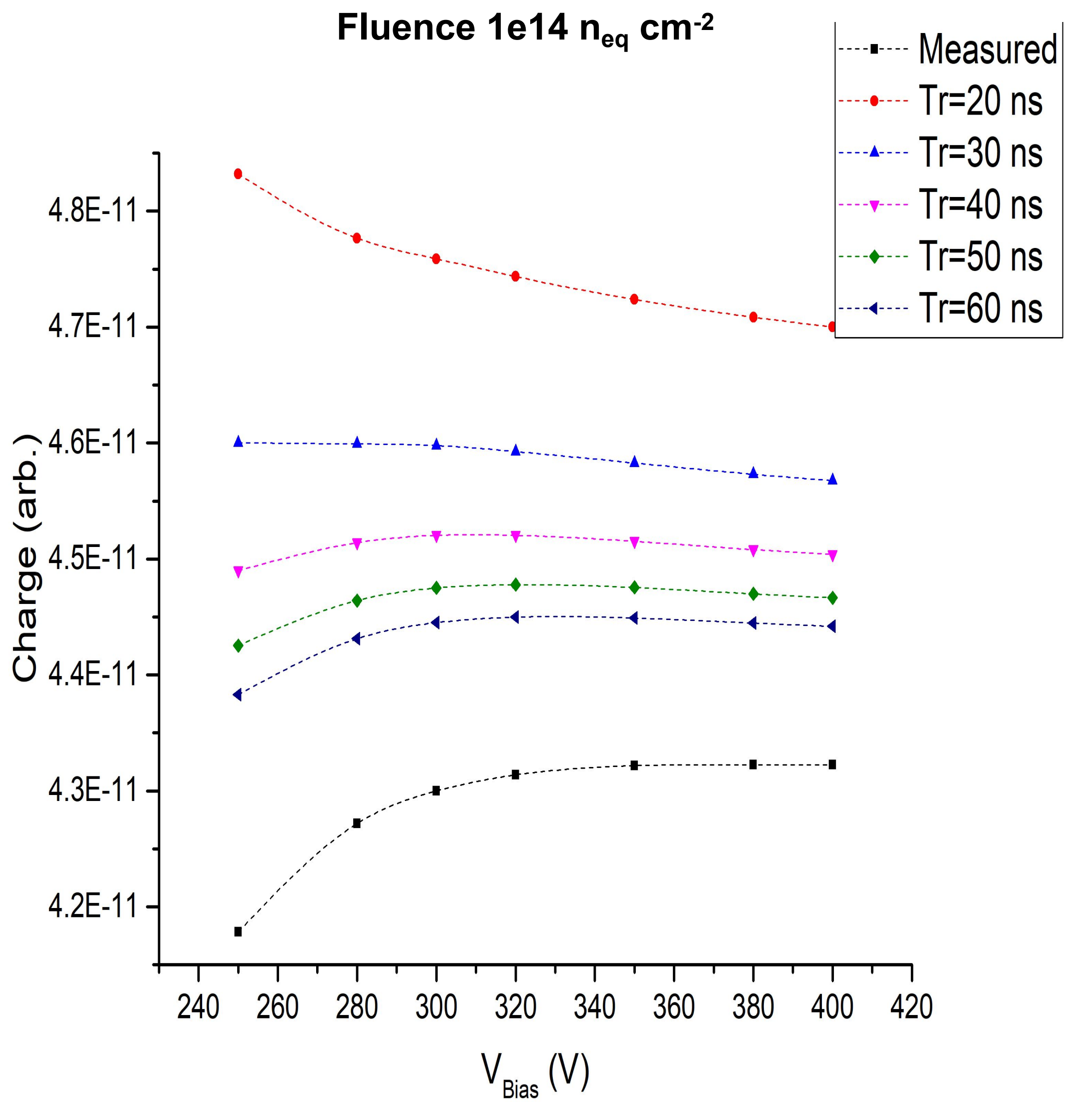
$$I_c(t) = I_s(t). \exp\left(\frac{t}{\tau_{tr}}\right)$$

➢ **Three cases are possible :**

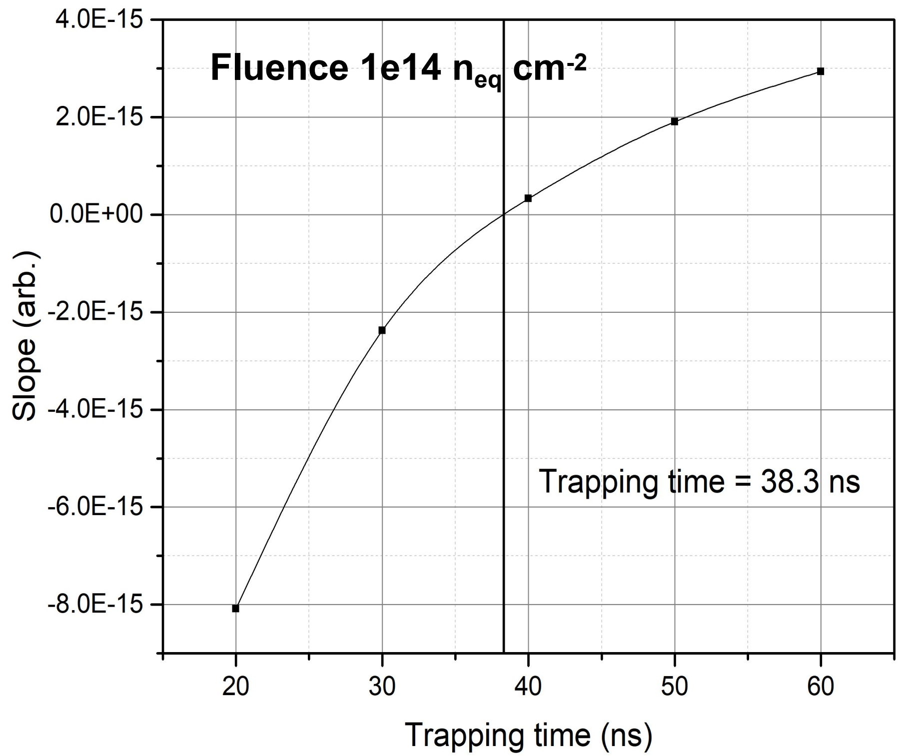
**Case 1). 1/ $\tau_{tr}$ > 1/ $\tau_{eff}$**
**Returns more electrons as were originally trapped.**

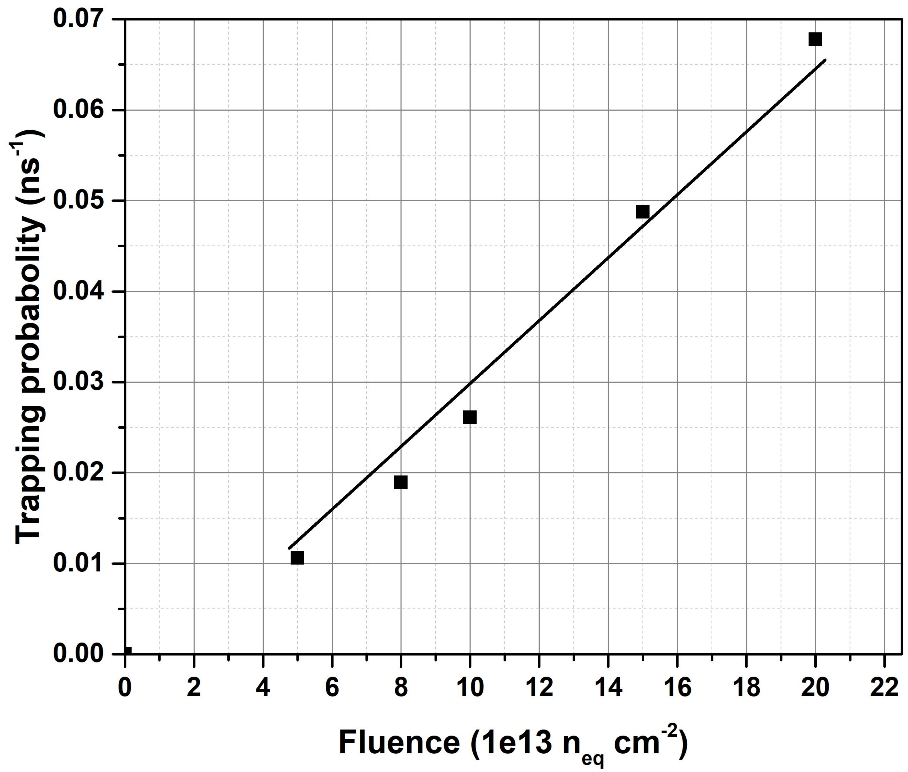
**Case 2). 1/ $\tau_{tr}$ < 1/ $\tau_{eff}$**
**Returns less electrons as were originally trapped.**

**Case 3). 1/ $\tau_{tr}$ = 1/ $\tau_{eff}$**
**Returns exactly the same number of electrons as were originally trapped.**



# Trapping probability of electrons vs Fluence




- The slope of the linear fit to the corrected charge vs $V_{Bias}$ plot as a function of $\tau_{tr}$ for a fluence of 1e14 $n_{eq}$ cm$^{-2}$.
- The value of $\tau_{tr}$ for which the slope is zero gives the value of effective trapping time.

- Trapping probability is found to increase with increase in fluence.
- The value of slope is found to be $3.9 \times 10^{-16}$ cm$^2$ · ns$^{-1}$ which is in reasonable agreement with the experimental value* of $4.2 \times 10^{-16}$ cm$^2$ · ns$^{-1}$

*G. Kramberger et al., Effective trapping time of electrons and holes in different silicon materials irradiated with neutrons, protons and pions. NIM A 481 (2002) 297–305.

# Summary and Future Outlook

- The effective trapping times of electrons in neutron irradiated p-on-n Si detectors is computed by performing TCT simulations.
- The trapping probability of electrons is found to increase linearly with the neutron fluence.
- The simulation result is found to be in reasonable agreement with measured result.

- Further simulations would be performed for higher fluences.
- Simulations would be done for effective trapping times of holes.
- More TCT Simulations would be done to find out effective trapping probability of charge carriers in p-type substrate.

Thanks for your attention !