Trapping of electrons and holes in p-type silicon irradiated with neutrons

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Vladimir Cindro, RD50 Workshop,
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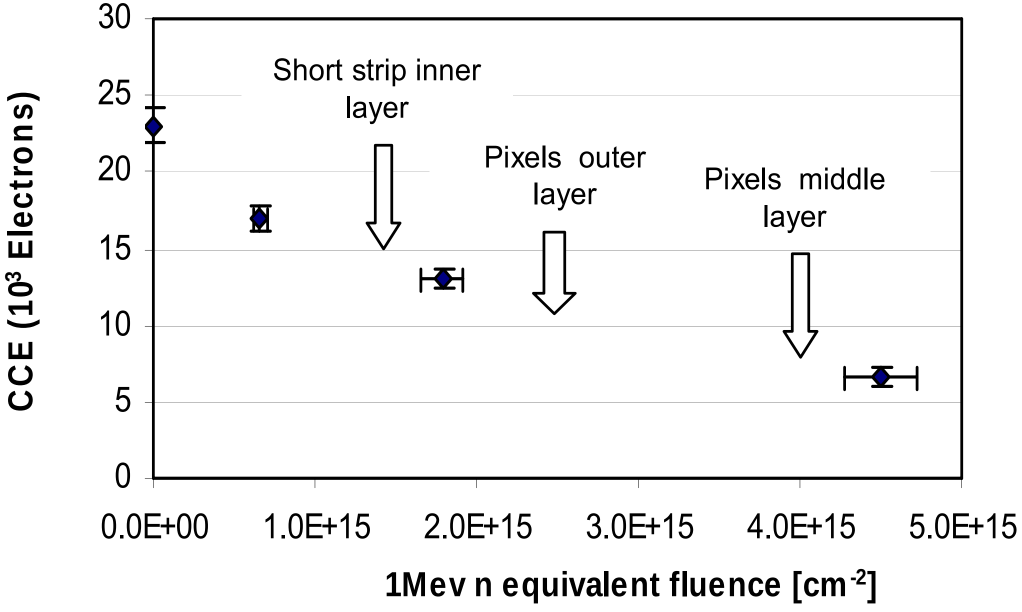
Outline

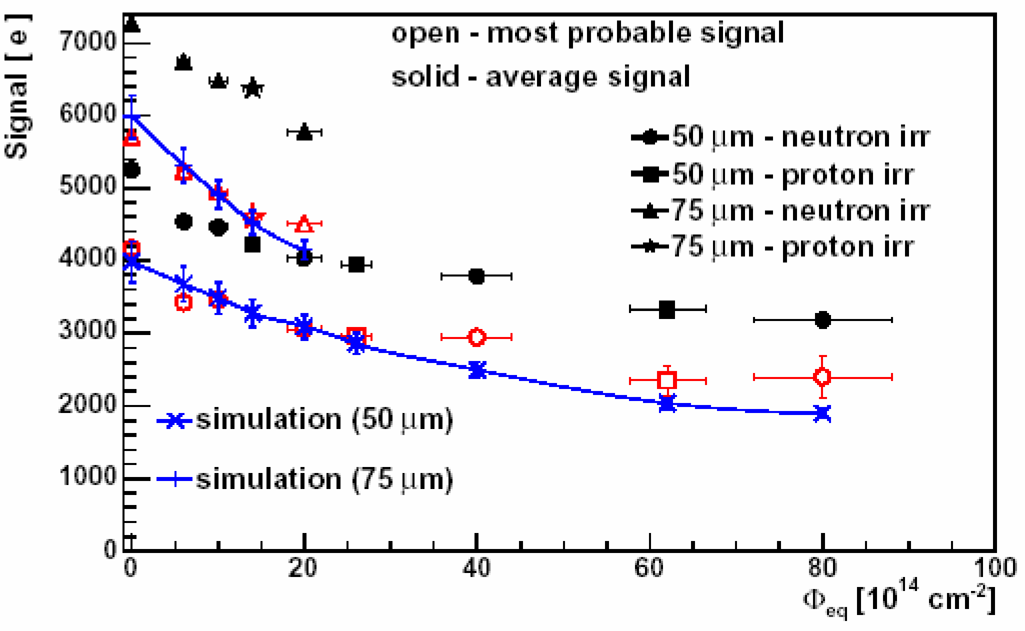
- Trapping of mobile carriers reduces signal after irradiation
- Systematic measurements of trapping times for n-type material (G. Kramberger et al. : **NIM** *Volume 481, p. 297-305* , 2002), annealing at different temperatures (M. Batič et al., this workshop). Measurements also in CERN, Dortmund, Hamburg, Lancaster.
- CCE depends on trapping. High E field, short drift length, proper readout side (electron signal dominates on n-strips) can reduce the effect of trapping on CCE
- p-type microstrip detectors with n-side readout have shown good performance after irradiation to high fluences

Measurement of CCE after irradiation of microstrip detectors with protons:



G. Casse, 2nd Trento workshop

Also measurements on n-type detectors give larger CCE than simulations – at large fluences.



G. Kramberger, 2nd Trento workshop

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Description of silicon detectors

- Diodes n+-p-p+. Characteristics:
- active area: 5×5 mm2
- substrates:
- Silicon <100>; 300 ± 15 μm; 20kΩ·cm
- DOFZ <100>; 300 ± 15 μm; 20kΩ·cm, [O]~2*10^{17}
- MCZ <100>; 300 ± 15 μm; 5 kΩ·cm , [O]~5*10^{17}
- guard ring: 200 μm wide at 100 μm distance from the central diode
- n+-p junction depth: 2 μm
- P concentration on surface: $2 \cdot 10^{19}$ cm^{-3}
- p+-n junction depth: 1.5 μm
- B concentration on backside surface: 10^{20} cm^{-3}
- Total dimensions of the device: 7.11×7.11 mm^2
- Isolation: p-spray blanket, depth~2um, peak=$10^{15}$$cm^{-2}$

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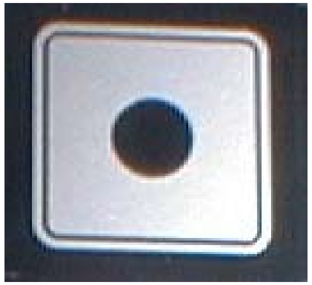
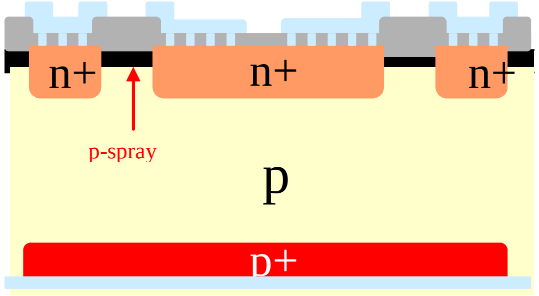




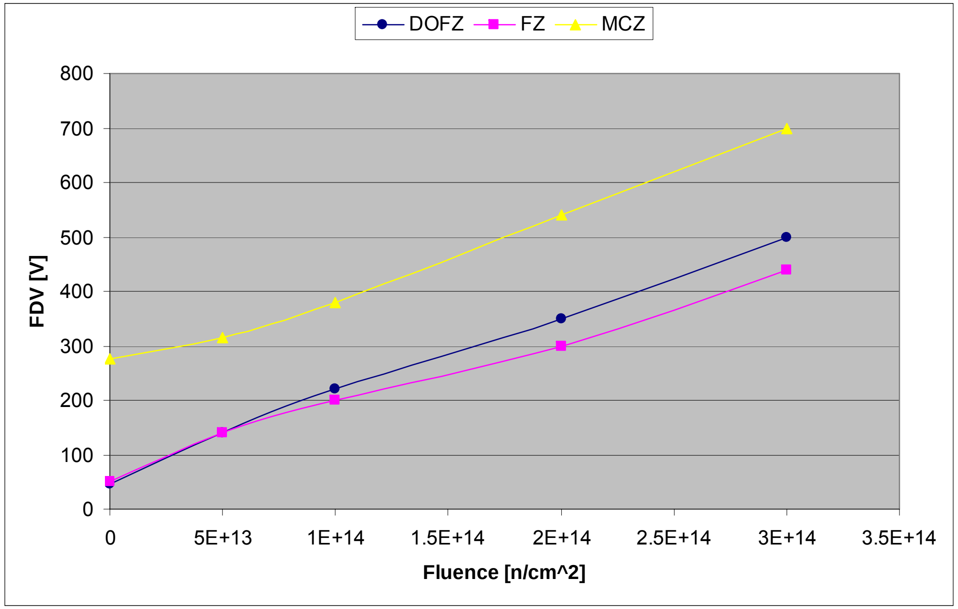
Fabrication procedure (CNM Barcelona)

- Summary of fabrication steps:
- Thick oxide growth (1 µm)
- Oxide patterning
- N+ implant
- Backside P+ implant
- Implant annealing (950ºC, 30 min)
- Contact opening
- Metal deposition and patterning
- Metal annealing (350ºC, 30 min)

Irradiations:

- Irradiations with neutrons at TRIGA reactor, Ljubljana
- Samples kept cool to prevent annealing
- Few hours at RT before first measurements were taken

CV measurements



Measurements taken after 3 weeks at 20°C (approxim. “stable” damage)

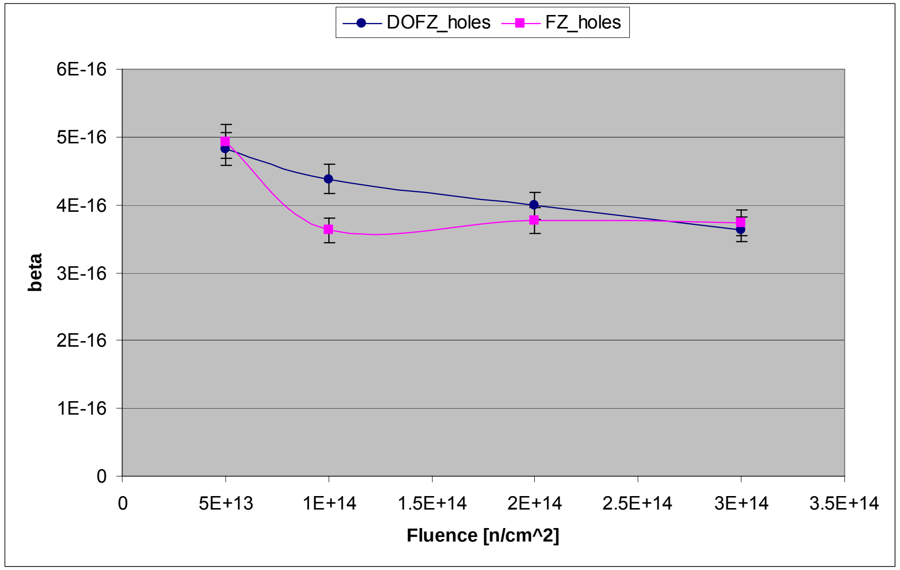
If $\Delta N_{eff} = g\ \Phi_{eq} \rightarrow\ g \sim 2\ 10^{-2}\ \mathrm{cm}^{-1}$

Trapping

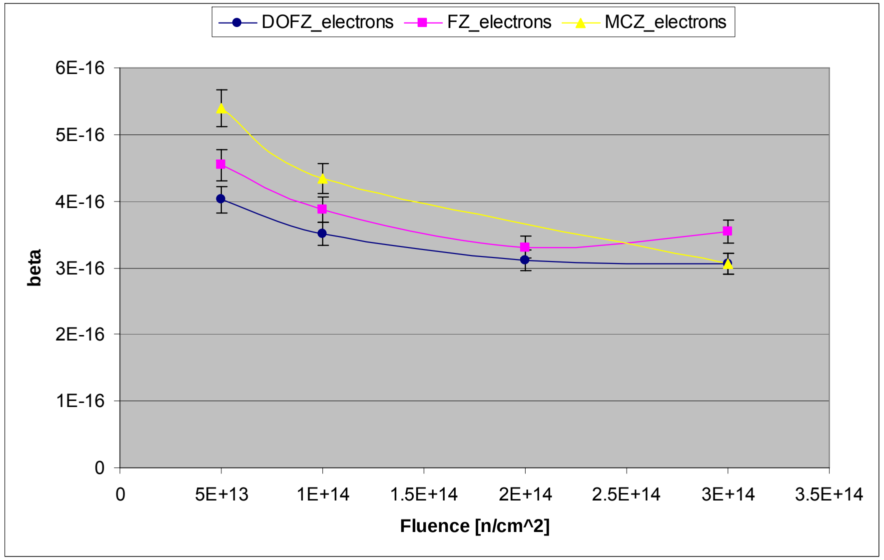
$$\frac{1}{\tau_{eff,e,h}} = \beta_{e,h}(t,T)\ \Phi_{eq}$$

β measured at 20°C !!

Holes



Electrons



$\beta_{hav} = 4.1\ 10^{-16} cm^2\ ns^{-1}$

$\beta_{eav} = 4.0\ 10^{-16}\ cm^2\ ns^{-1}$

It seems that β drops with increasing fluence...

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Trapping is measured above FDV.

Higher fluence →higher E needed to measure trapping (true for p-type, also in inverted n-type)

We expect that trapping time good parameter if v_{dr} much smaller than v_{th}

Electron thermal velocity 23 10^6m/s

Hole thermal velocity 16.5 10^6cm/s

electrons

E = 1V/μm 7 10^6 cm s^{-1}

2V/μm 9 10^6 cm s^{-1}

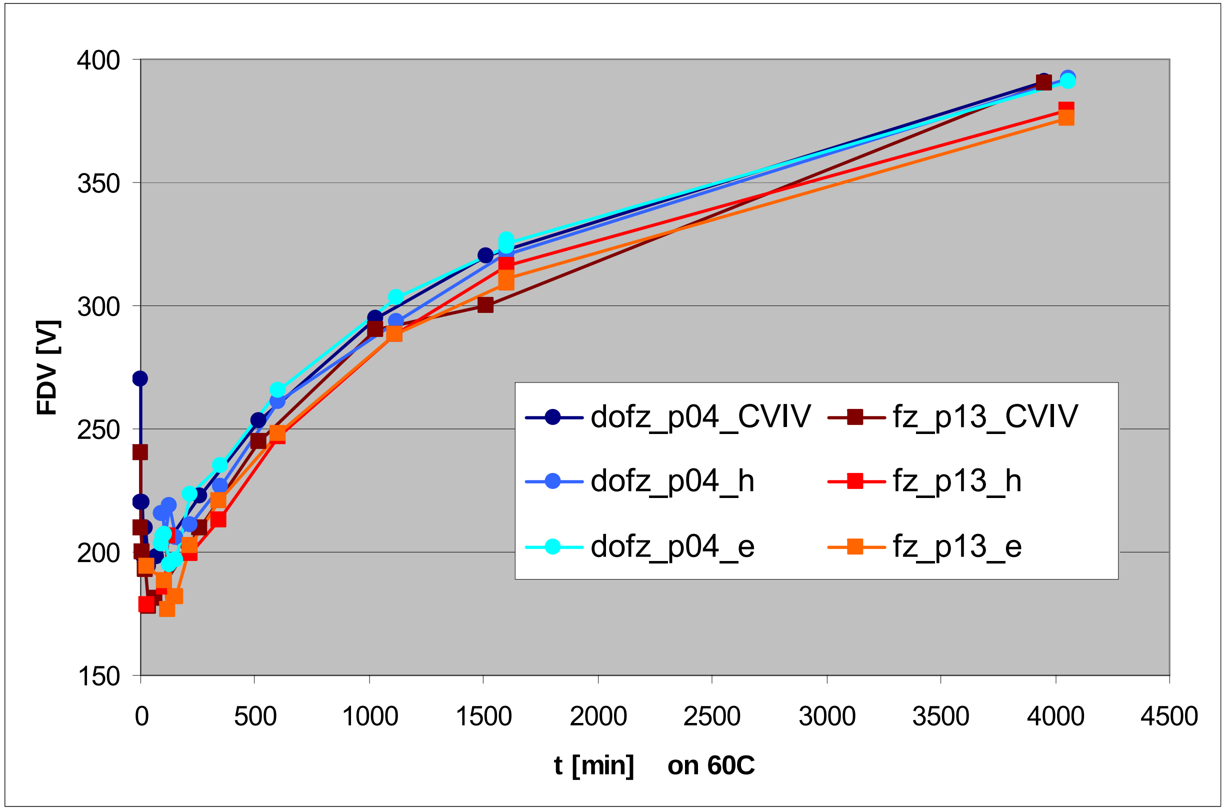
Holes

E = 1V/μm 3.3 10^6 cm s^{-1}

2V/μm 5 10^6 cm s^{-1}

FDV during annealing

Pad detectors irradiated to 10^{14}cm^{-2}



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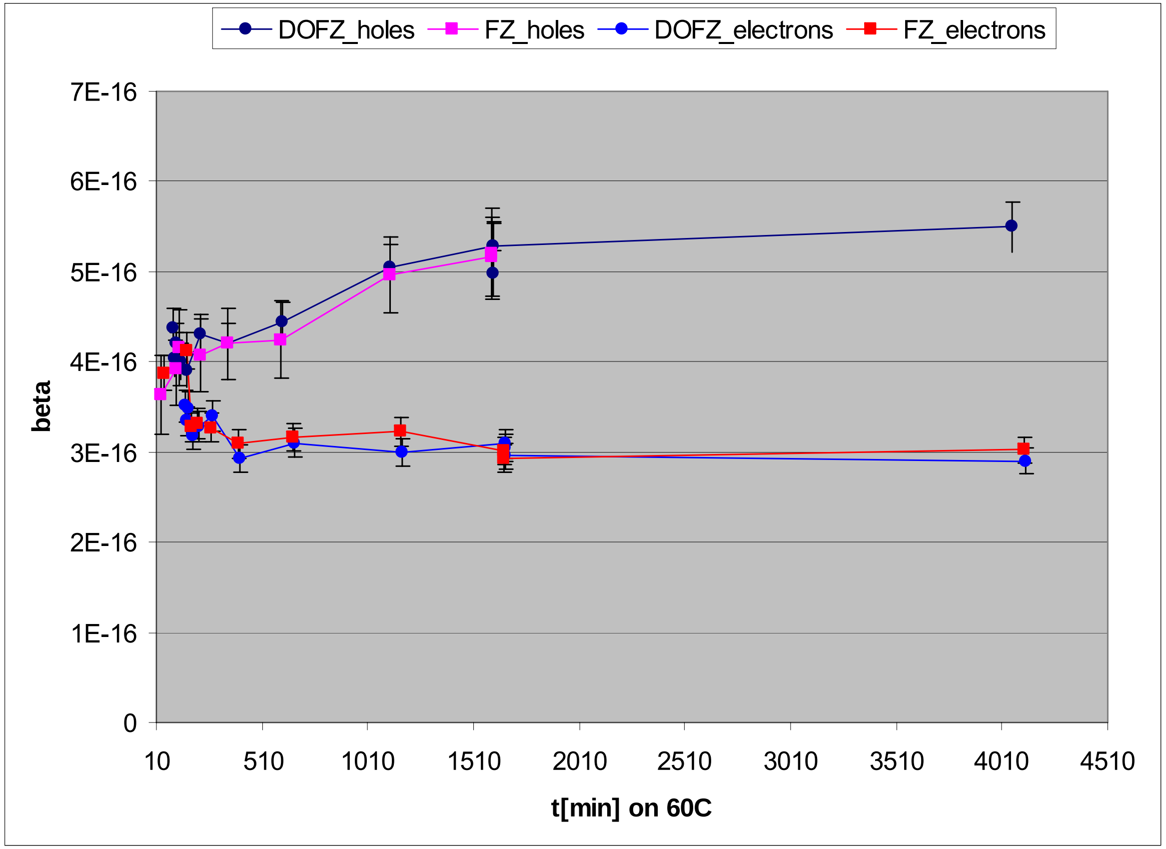
Trapping after annealing at 60^{o}C, measured at 20^{o}C



1000 min at 60^{o}C → 80 days at 20^{o}C if E_a= 1.0 eV

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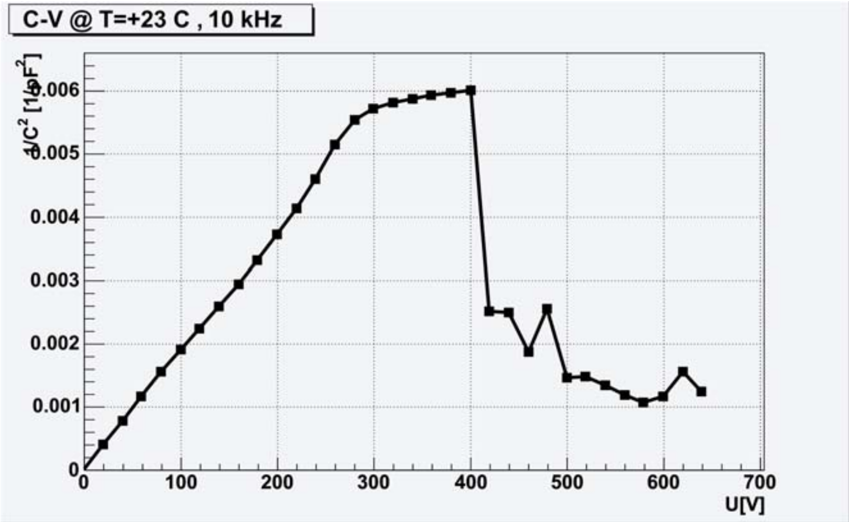
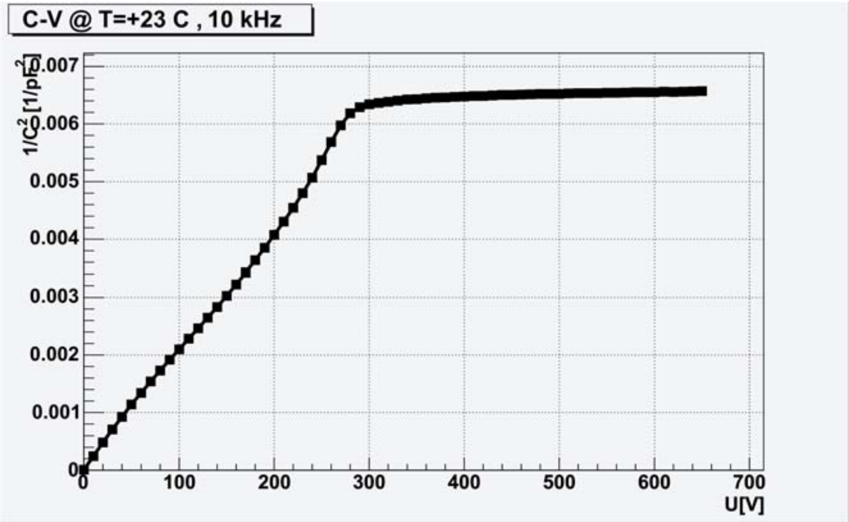
Summary

- Trapping in in p-type silicon similar to trapping in n-type
- Hole trapping increases for about 40% after annealing
- Electron trapping decreases for about 25 % after annealing
- There is evidence for fluence (E field?) dependence of trapping
- Continue with Cz annealing, proton irradiations


C-V @ T=+23 C , 10 kHz
1/C² [1/pF²]
0
0.001
0.002
0.003
0.004
0.005
0.006
0
100
200
300
400
500
600
700
U[V]


C-V @ T=+23 C , 10 kHz
1/C² [1/pF²]
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0
100
200
300
400
500
600
700
U[V]

Effective trapping times

Measurement performed using Charge Correction Method on TCT signals!

$$\frac{1}{\tau_{eff,e,h}} = \Phi_{eq}\left[\sum_t g_t\,(1-P_t^{e,h})\,\sigma_{t,e,h}(T)\,v_{th,e,h}(T)\right] = \beta_{e,h}(t,T)\,\Phi_{eq}$$

T=0°C **proton irradiation**	β_e [10^{-16} cm^2/ns]	β_h [10^{-16} cm^2/ns]
CERN (DOFZ, FZ, MCz)	5.48 ± 0.22	6.02 ± 0.29
Dortmund (DOFZ)	5.08 ± 0.16	4.90 ± 0.16
Ljubljana (DOFZ, FZ, MCz)	5.34 ± 0.19	7.08 ± 0.18
Lancaster/Hamburg (FZ)	5.32 ± 0.30	6.81 ± 0.29
Hamburg (FZ, DOFZ, MCz)	5.07 ± 0.16	6.20 ± 0.54

☺reactor neutrons seem to be less damaging than protons

$$\beta_e = 4\cdot 10^{-16}\,\frac{\mathrm{cm}^2}{\mathrm{ns}},\ \beta_h = 5.7\cdot 10^{-16}\,\frac{\mathrm{cm}^2}{\mathrm{ns}}$$

☺ $\beta_e \leq \beta_h$

☺ No dependence on material (DOFZ,STFZ, MCz, C-enriched, different ρ, p-type silicon ?)

☹The highest fluence used in the measurements was <10^{15} cm^{-2} !

☹No microscopic “explanation” for measured trapping times