Mesaurements of Trapping Time Constants in Neutron Irradiated Pad Detectors

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Praha

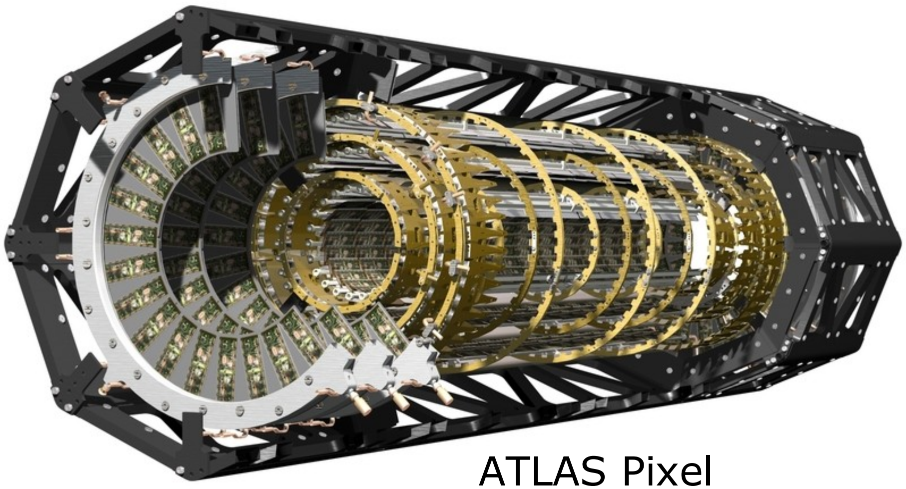
Motivation

all LHC Experiments and probably all SLHC experiments use silicon for their tracker detectors

→ trapping of charge carriers is one of the main issues for the design of new sensors for SLHC since reducing charge collection efficiency

data on collection behavior are needed for:

- detector simulation
- optimization of operation condtitions



ATLAS Pixel

Charge Collection in Silicon Sensors

- charge dQ induced on electrons by drifting charge q

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

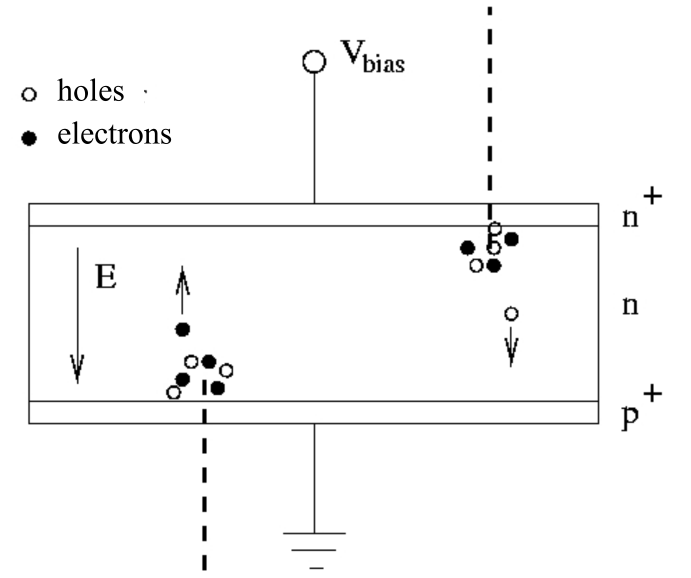
- trapping leads to charge carrier loss

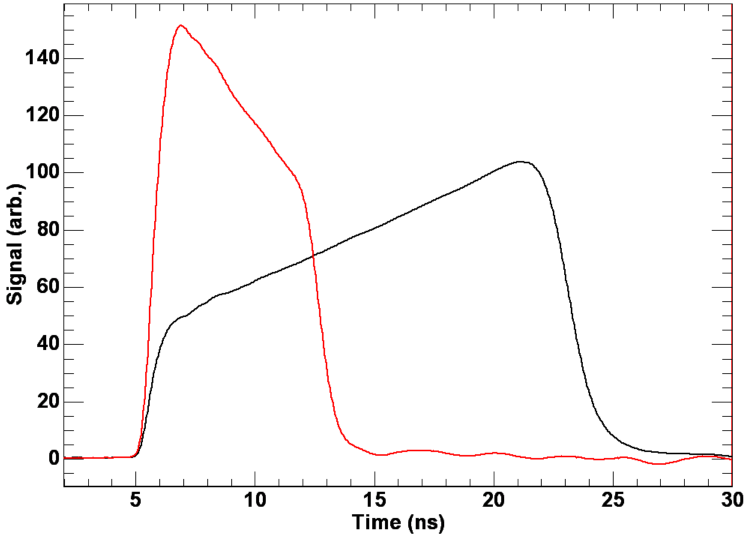
$$dq(t) = -\frac{1}{\tau_{eff}}\,q(t)\,dt\,, \quad \text{with} \quad \tau_{eff} = \tau_{eff}(\Phi_{eq})$$

- resulting (measured) signal current

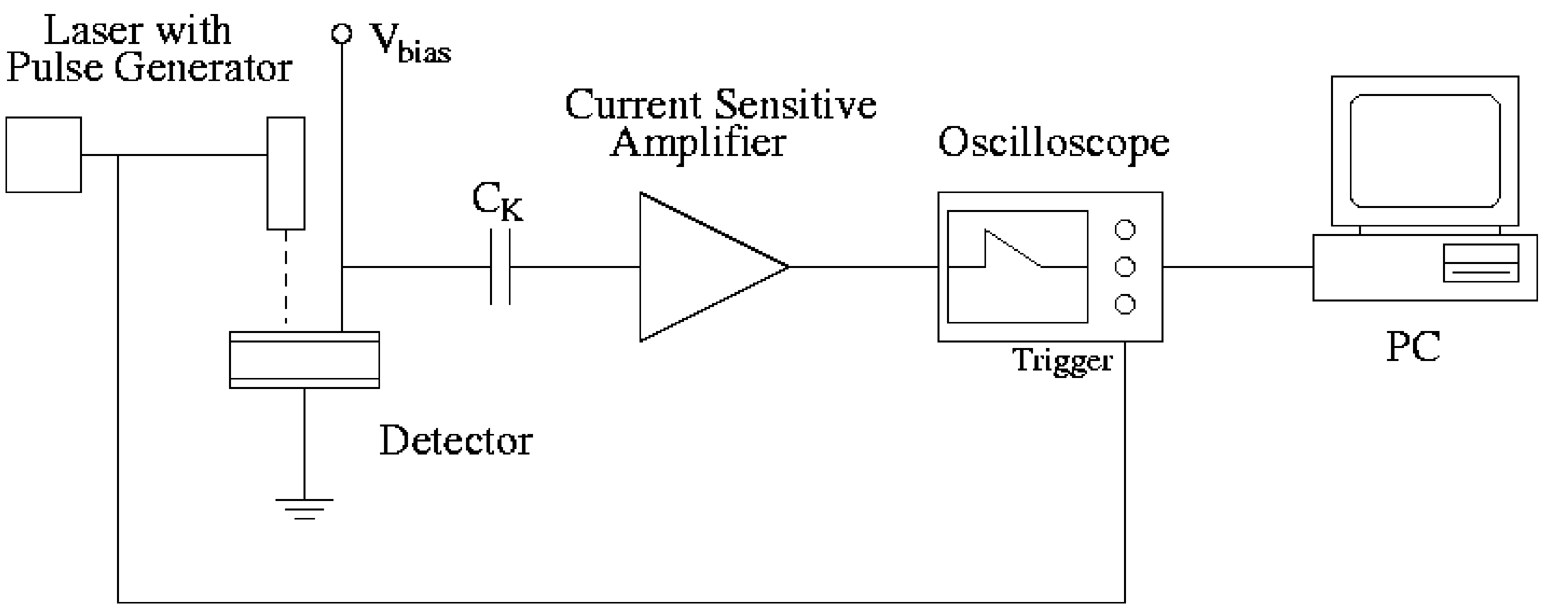
$$i_m(t) = \frac{q_0}{d}\,v(t)\,\exp(-t/\tau_{eff})$$

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



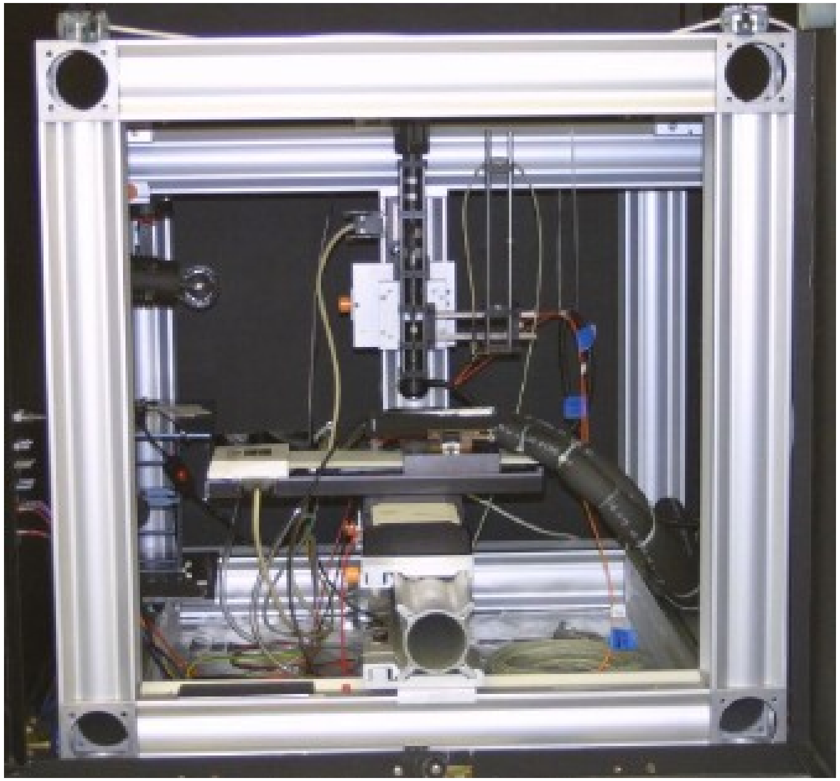


Measurement Setup

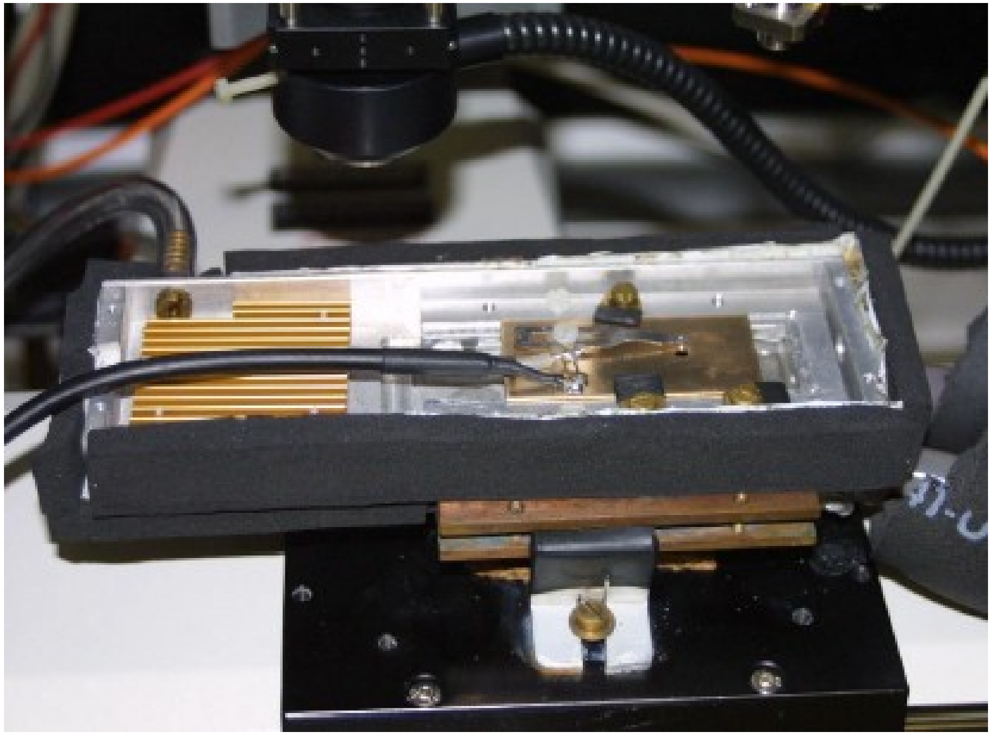


- 672nm red laser (3.6μm absorption length, FWHM = 44ps),
- applicable bias voltage range 0-2000V
- fast pulse amplifier (10x, 100 kHz - 1.8 GHz), (*current sensitive!*)
- oscilloscope (Tektronix TDS 784D, band width 1 GHz)
- rise time of system (incl. detector) about 1 ns
- PC readout system (LabVIEW)
- cooling system (-20°C - +20°C, rms 0.2°C)

Measurement Setup



- setup inside metal box
- peltier cooling
- (gaseous) N2 to keep DUT dry



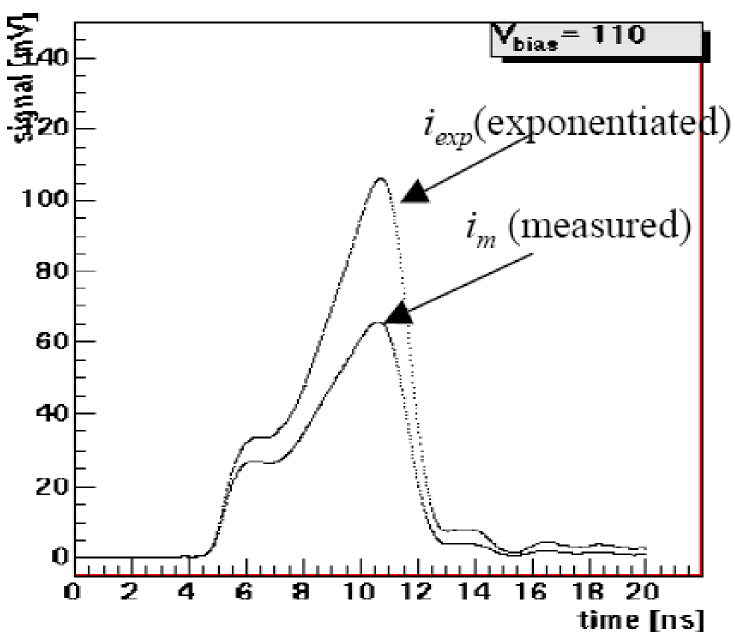
diode lies with n-side
on gold-plated metal,
tongue presses on p-side

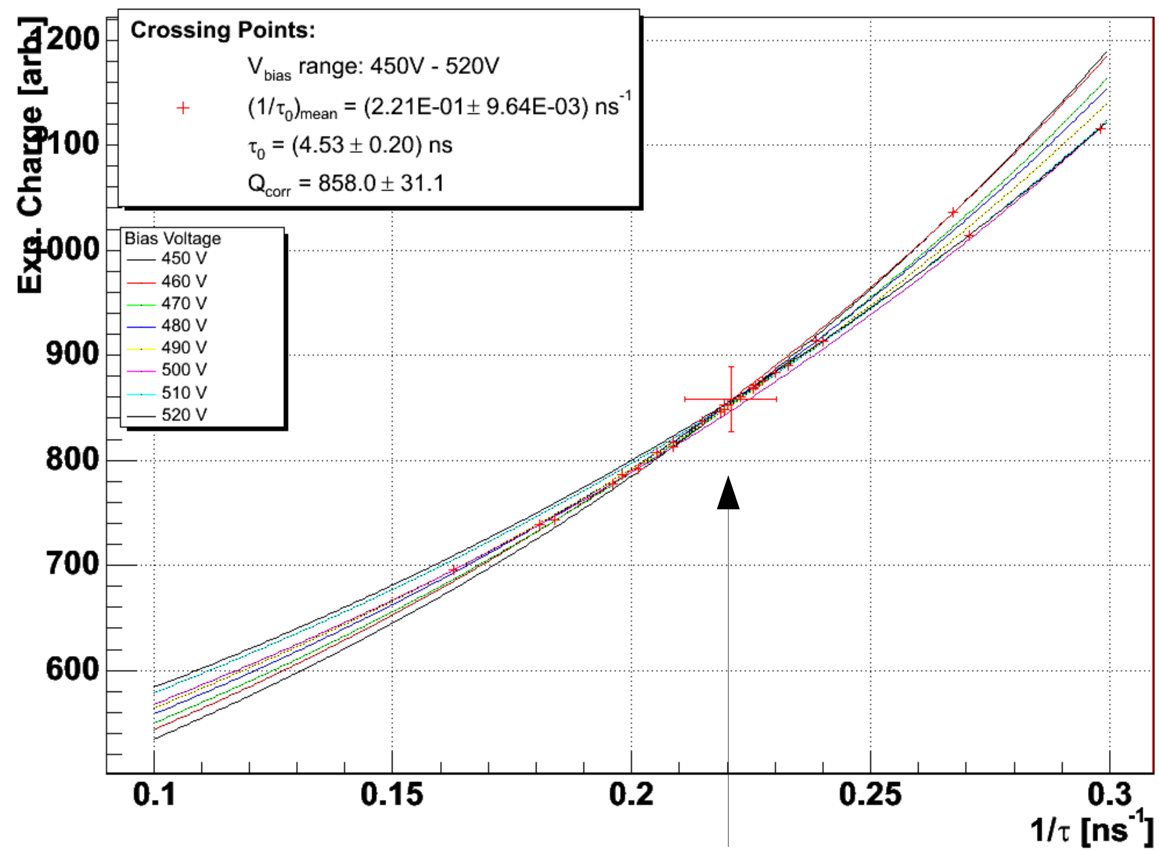
Exponentiated Charge Crossing (ECC)

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

from diffent V_{bias} are plotted vs. $1/\tau$

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





$1/\tau_0$

Samples

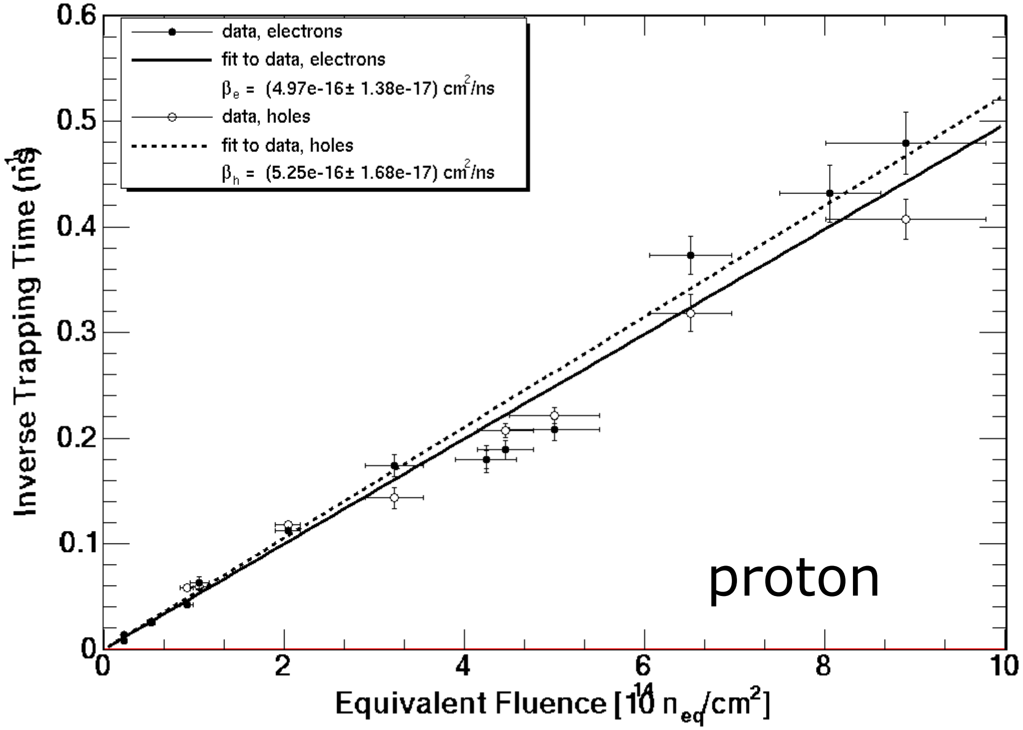
- $5\text{mm} \times 5\text{mm}$ n-bulk pad detector
- thickness 250-300*µm
- DOFZ silicon (ATLAS type)
- $\langle 111 \rangle$ crystal orientation
- neutron irradiation at TRIGA reactor, Ljubljana
- fluence range from $0.1 \times 10^{15}\ n_{eq}/cm^2$ to $4 \times 10^{15}\ n_{eq}/cm$

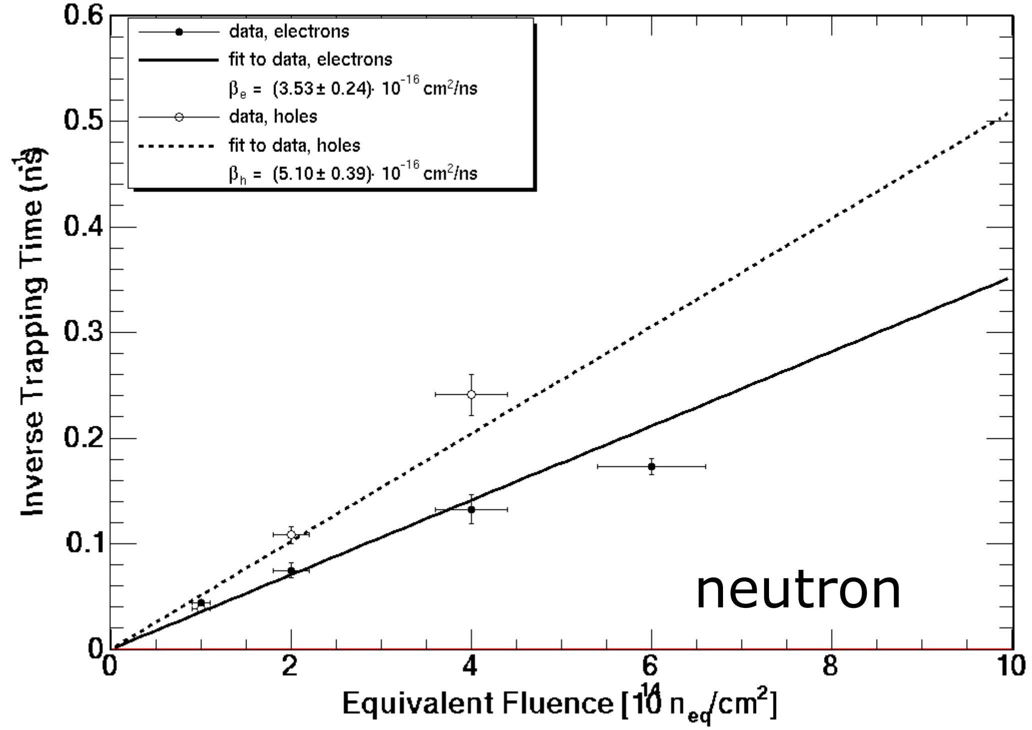
  ↳ up to $0.6 \times 10^{15}\ n_{eq}/cm^2$
  some data by Olaf Krasel*

We kindly acknowledge the help by Gregor Kramberger for irradiation

* O Krasel et. al. „Measurement of Trapping Time Constants in Proton Irradiated Silicon Pad Detectors", IEEE Trans. Nucl. Sci. 51 (2004) 3055-3062

Results so far...





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

$$\beta_{p,e} = (4.97 \pm 0.14) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

$$\beta_{n,e} = (3.53 \pm 0.24) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

$$\beta_{p,h} = (5.25 \pm 0.17) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

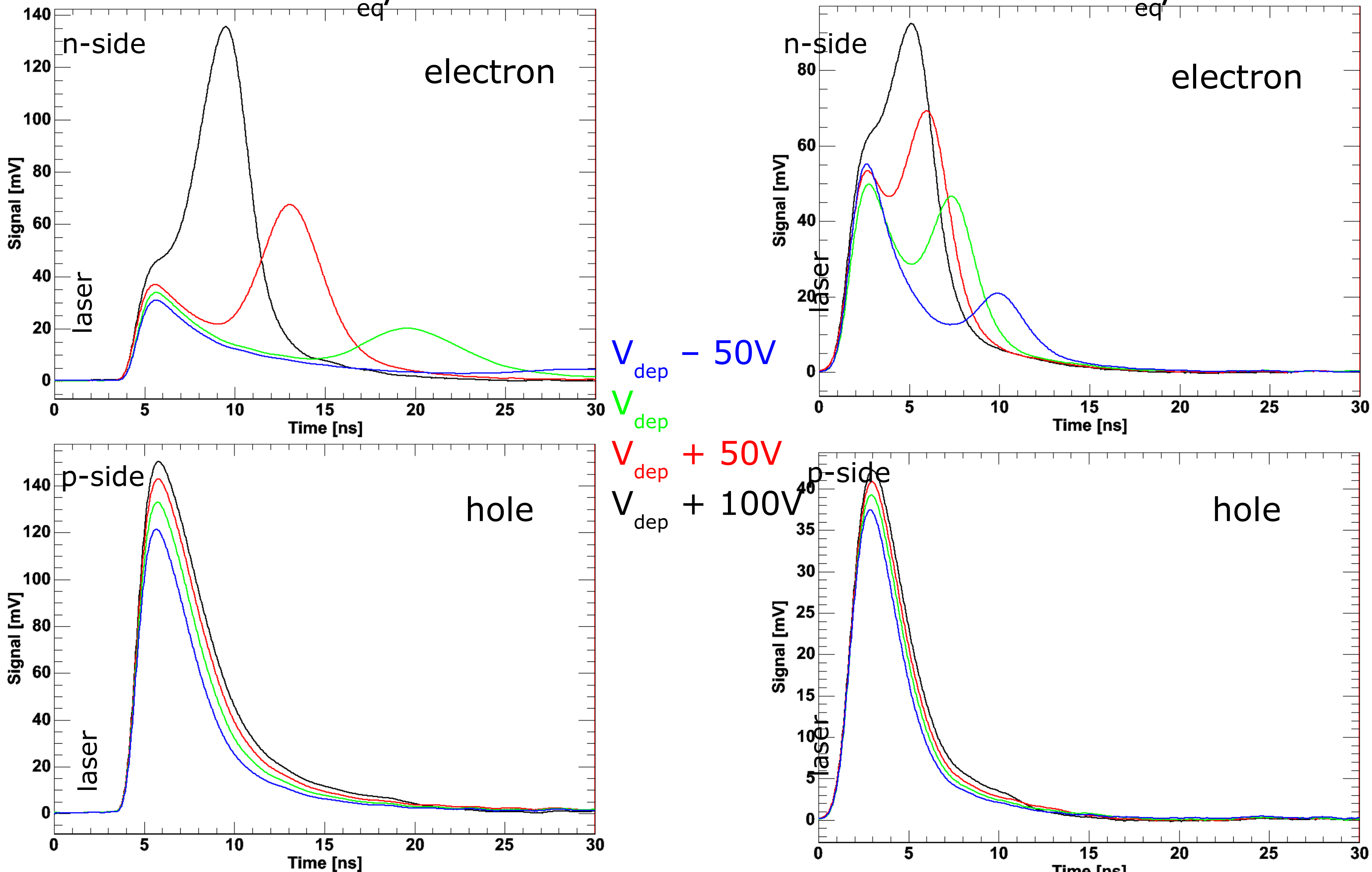
$$\beta_{n,h} = (5.10 \pm 0.39) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

$$\beta_{p,e} = \beta_{p,h}$$

$$\beta_{p,e} \neq \beta_{p,h}$$

Signal Examples

$0.3 \times 10^{15}\ n_{eq}/cm^2$ | $0.9 \times 10^{15}\ n_{eq}/cm^2$



Comparability of Results

comparision between trapping times

- Krasel – this work:

	O Krasel	this work
$\tau_{0,e}\,(0.6 \times 10^{15}\ n_{eq}/cm^2)$:	5.77 ± 0.25	5.33 ± 0.29

- this work (examples):

	sample 1	sample 2
$\tau_{0,e}\,(0.3 \times 10^{15}\ n_{eq}/cm^2)$:	12.04 ± 0.15	11.63 ± 0.86
$\tau_{0,h}\,(0.8 \times 10^{15}\ n_{eq}/cm^2)$:	5.75 ± 0.55	5.76 ± 0.51

Results (O Krasel)

Sample	Φ [*]	d [µm]	U_{dep} [V]	τ,e [ns]	τ,h [ns]
Set R	0.1	300	139.8 ± 5.9	22.59 ± 1.88	25.99 ± 2.19
Set V	0.2	300	249.0 ± 2.1	13.41 ± 1.29	9.23 ± 0.69
Set n2	0.3	250			
Set n16	0.3	250			
Set T	0.4	300	479.7 ± 2.2	7.56 ± 0.78	4.15 ± 0.33
Set S	0.6	300	620 ± 12	5.77 ± 0.25	—
Set n8	0.6	250			
Set n3	0.6	250			
Set n12	0.8	250			
Set n13	0.8	250			
Set n0	0.9	250			

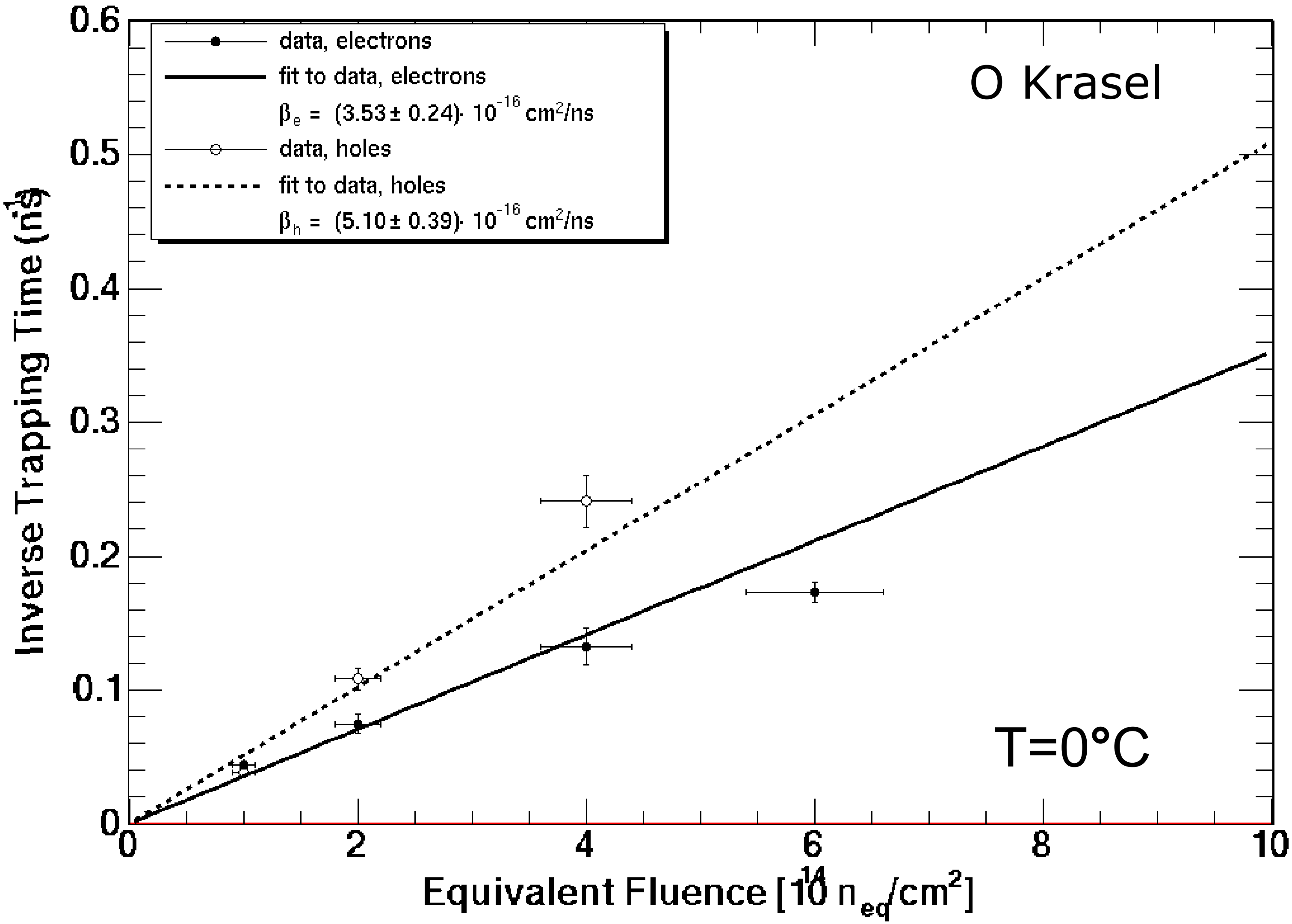
* => 10^{15} n_{eq}/cm^2 error Φ: 10%

Results (Overview)

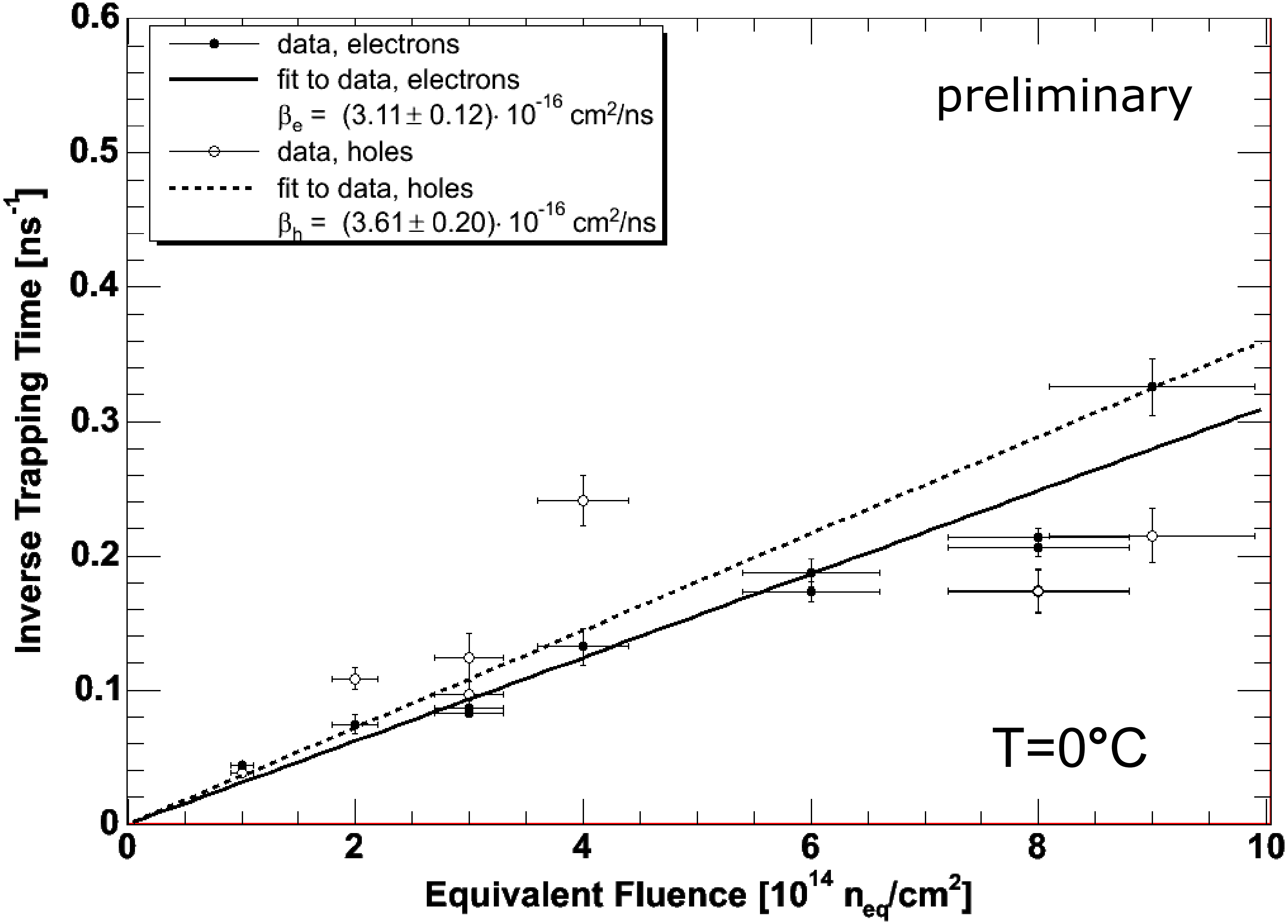
Sample	Φ [*]	d [µm]	U_{dep} [V]	τ,e [ns]	τ,h [ns]
Set R	0.1	300	139.8 ± 5.9	22.59 ± 1.88	25.99 ± 2.19
Set V	0.2	300	249.0 ± 2.1	13.41 ± 1.29	9.23 ± 0.69
Set n2	0.3	250	196.4 ± 6.5	12.04 ± 0.15	10.28 ± 0.92
Set n16	0.3	250	176.3 ± 2.7	11.63 ± 0.86	8.05 ± 1.16
Set T	0.4	300	479.7 ± 2.2	7.56 ± 0.78	4.15 ± 0.33
Set S	0.6	300	620 ± 12	5.77 ± 0.25	—
Set n8	0.6	250	371.8 ± 3.6	(7.70 ± 0.71)	
Set n3	0.6	250	361.4 ± 5.4	5.33 ± 0.29	
Set n12	0.8	250	546 ± 13	4.85 ± 0.16	5.75 ± 0.55
Set n13	0.8	250	369.7 ± 8.5	4.68 ± 0.20	5.76 ± 0.51
Set n0	0.9	250	440.3 ± 6.3	3.07 ± 0.20	4.65 ± 0.44

* => 10^{15} n_{eq}/cm^2 error Φ: 10%

Trapping Time – Fluence Dependence



Trapping Time – Fluence Dependence



=> $\beta_{n,e} = (3.11 \pm 0.12) \cdot 10^{-16}$ cm^2/ns, $\beta_{n,h} = (3.61 \pm 0.20) \cdot 10^{-16}$ cm^2/ns

Trapping Times $> 1 \times 10^{15}\ n_{eq}/cm^2$

Tried to measured diodes with fluences above $1 \times 10^{15}\ n_{eq}/cm^2$

but breakdown voltage too low

$\Phi\ [n_{eq}/cm^2]$	U_{bd} [V]
2×10^{15}	480
2×10^{15}	470
3×10^{15}	350
3×10^{15}	350
4×10^{15}	340
4×10^{15}	340

→ $U_{dep} > 500V$

=> τ not determinable

possible solution:

- determine trapping time with underdepleted diodes?
- new irradiation with thinner diodes (material)?

Summary & Outlook

Summary

- τ for electrons and holes up to 1×10^{15} n_{eq}/cm^2 determined

$$\beta_{n,e} = (3.11 \pm 0.12) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}, \qquad \beta_{n,h} = (3.61 \pm 0.20) \cdot 10^{-16}\ \mathrm{cm}^2/\mathrm{ns}$$

- no τ´s above 1×10^{15} n_{eq}/cm^2 due to breakdown voltage

  ↳► underdepleted analysis? thinner samples?

Outlook

- some annealing studies with neutron sample
- measurement of samples with high proton irradiation
- signal studies (TCT) on irradiated pixel structures