Evaluation of electron and hole detrapping in irradiated silicon sensors

Markus Gabrysch[1], Mara Bruzzi[2], Michael Moll[1],
Nicola Pacifico[3], Irena Dolenc Kittelmann[4],
Marcos Fernandez Garcia[5]

[1] PH-DT-TP, CERN (CH)
[2] INFN and University of Florence (IT)
[3] Université Montpellier II (FR)
[4] Ohio State University (US)
[5] Universidad de Cantabria (ES)

20th RD50 Workshop, Bari, 30th May - 1st June 2012

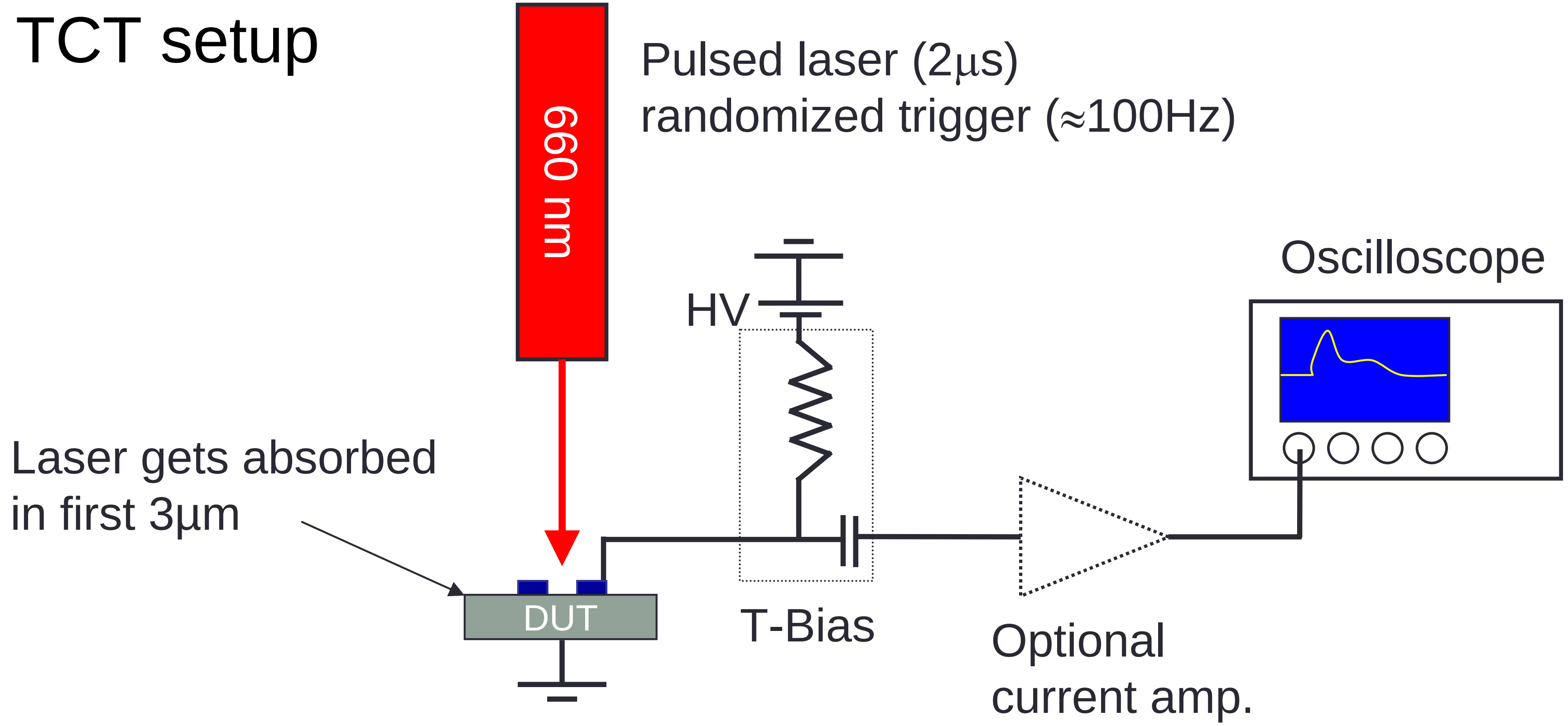
Outline

1. Motivation/Aim
2. TCT-DLTS setup
3. Investigated diodes
4. Measurement principle
5. First measurements
6. Conclusions

Motivation/Aim

- Knowledge of energy levels and cross-sections of de-trapping centres is crucial for defect characterization
- These parameters can be determined by investigating the temperature dependence of the time-constant τ for de-trapping
- For defects deep in the bandgap the de-trapping happens on a µs-timescale (around RT)

CERN TCT setup



- Red laser illumination with two different pulse width (80ps or 2µs)
- T-Bias (20kHz-10GHz, constant HV < 200V) used
- Amplifier was not needed for 2µs illumination
- Temperature controlled (flushed with dry air for T < 10°C)

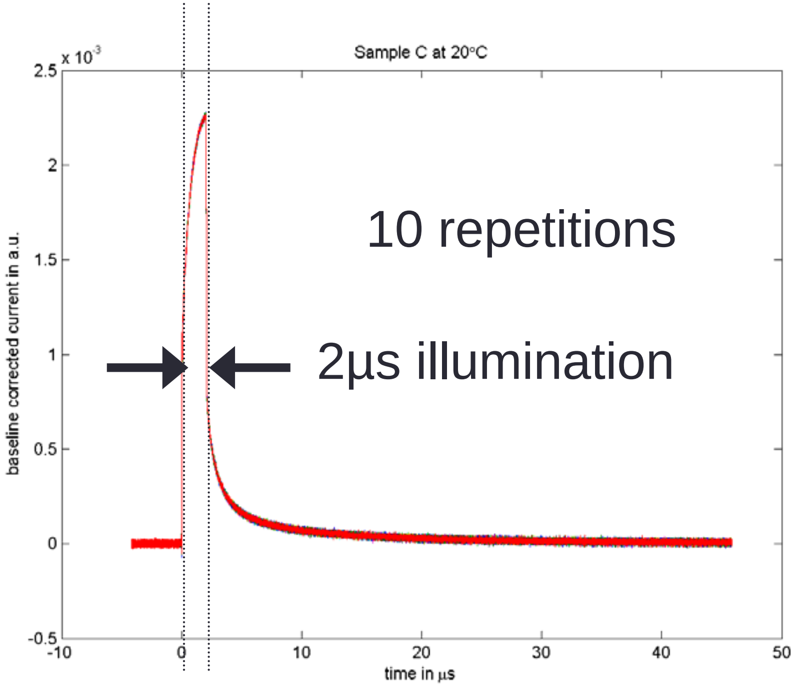
Investigated diodes

Name	Sample A (HIP_05_C16)	Sample B (HIP-MCz-01-n-23)	Sample C (FZ_2328-11_A)	Sample D (FZ_2852-23)
Material	HIP FZ n-type 300μm	HIP MCz n-type 300μm	Micron FZ p-type 300μm	Micron FZ n-type 300μm
Irradiation	--	24GeV protons $\Phi = 9\times10^{14}$ cm^{-2}	24GeV protons $\Phi = 5\times10^{14}$ cm^{-2}	24GeV protons $\Phi = 5\times10^{14}$ cm^{-2}
Annealing	--	4min at 80°C	80min at 60°C	80min at 60°C
Illumination	660nm (2μs) front	660nm (80ps) front/back	660nm (2μs) front	660nm (2μs) front

Measurement method

Measurement method

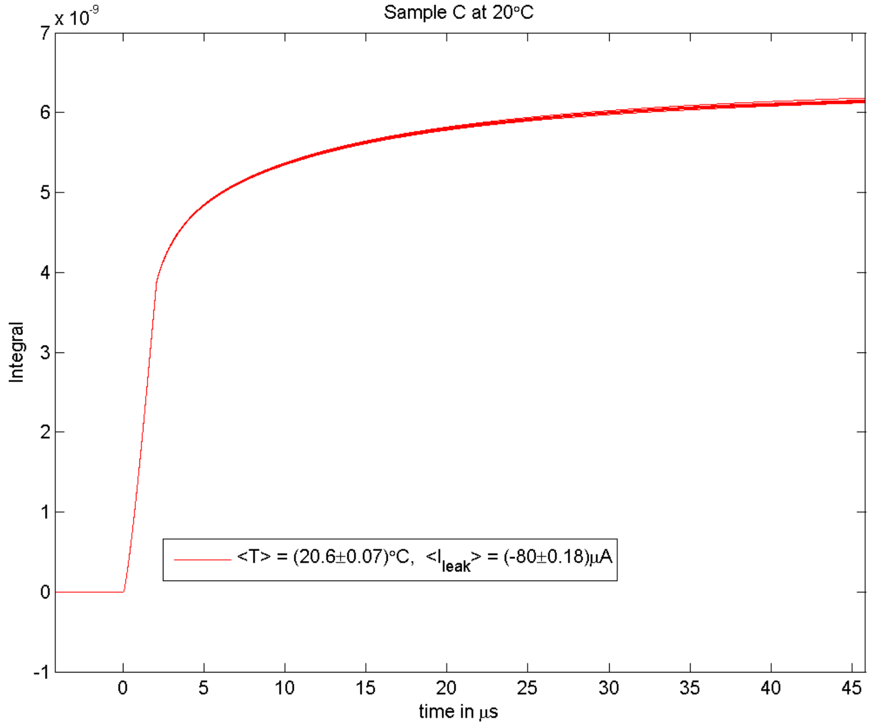
- TCT signals have been measured with long integration times (up to 50µs)
- Temperature range investigated: ca. 10 - 50°C
- Stability of signal confirmed by recording 10 times the (same) waveform which itself is an average of 1024 shots



10 repetitions

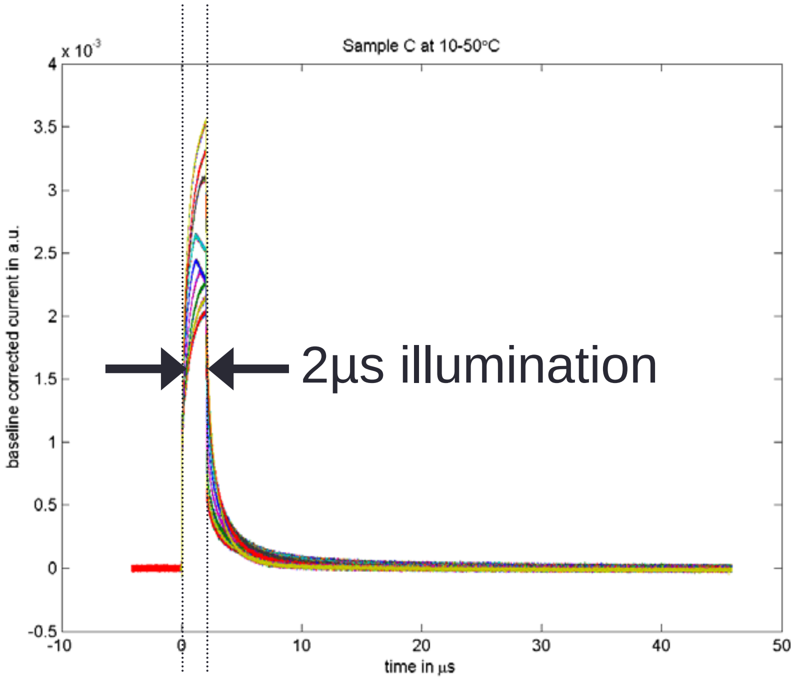
2µs illumination

$$S(t)=\int_0^t I(t')\,dt'$$

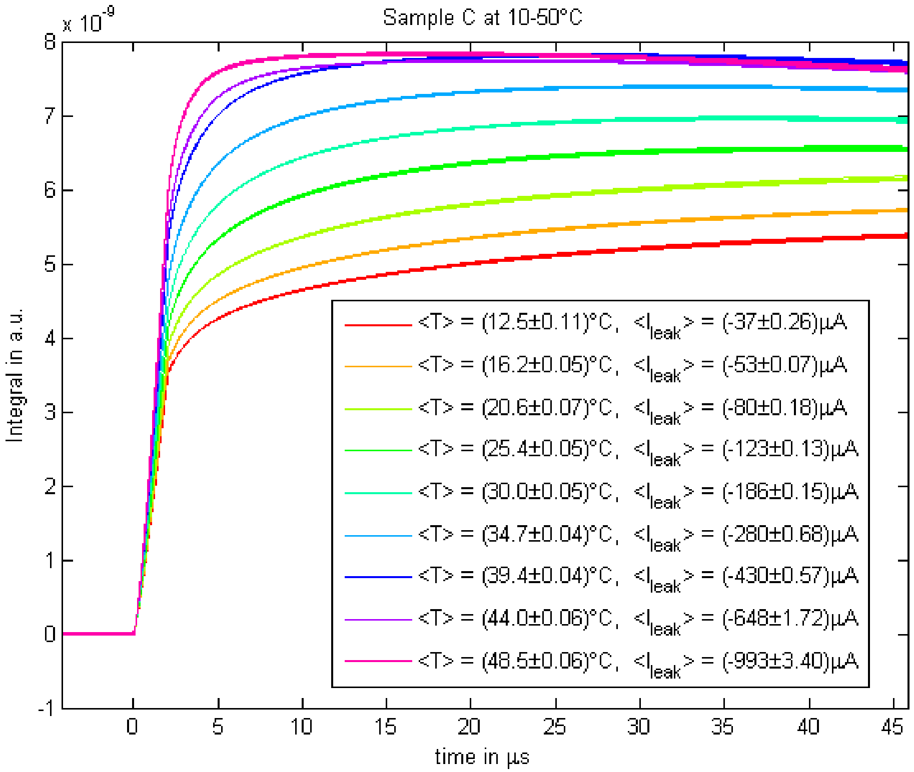


Measurement method

- TCT signals have been measured with long integration times (up to 50µs)
- Temperature range investigated: ca. 10 - 50°C
- Stability of signal confirmed by recording 10 times the (same) waveform which itself is an average of 1024 shots

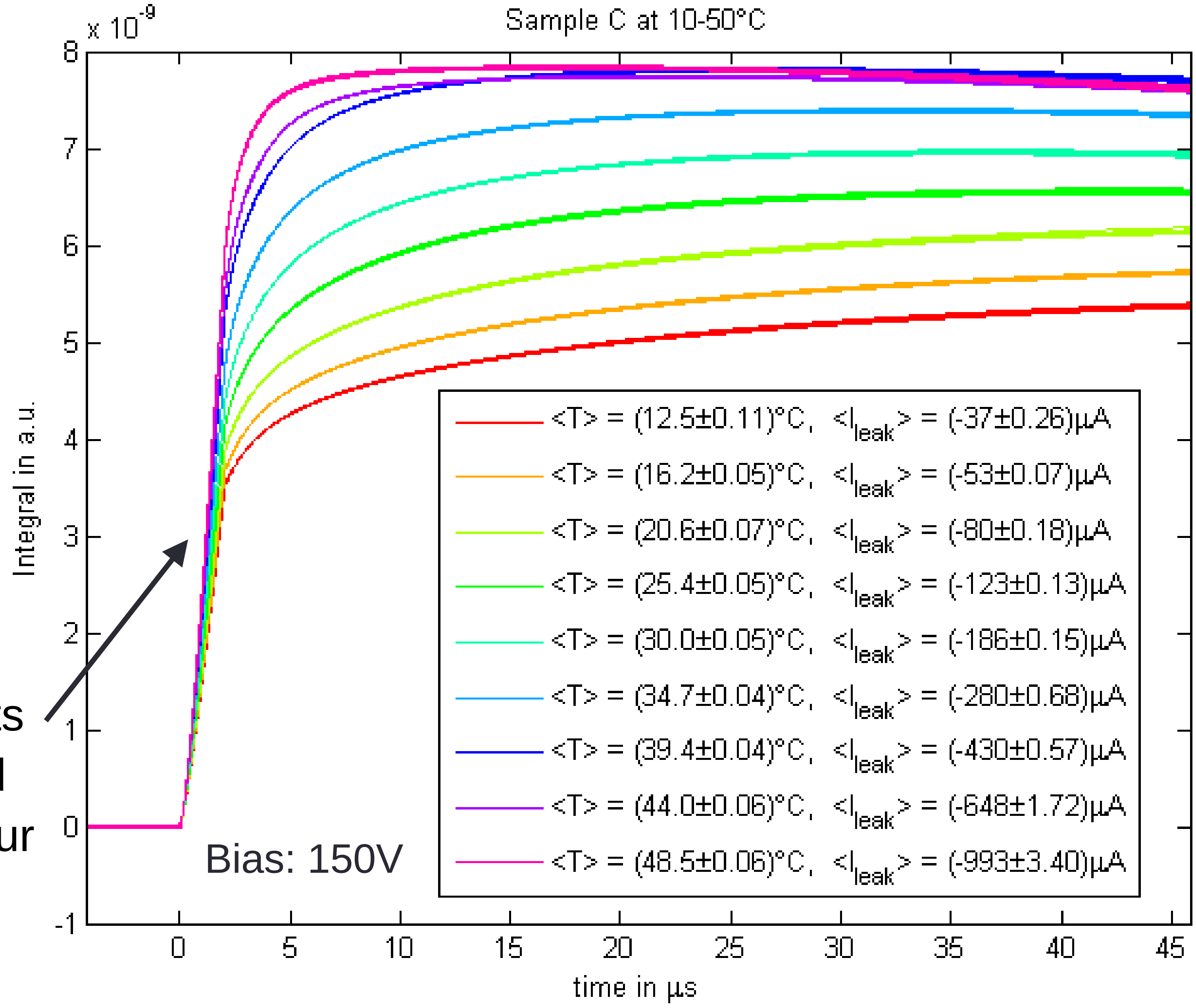


$$S(t) = \int_0^t I(t')dt'$$



Measurement method

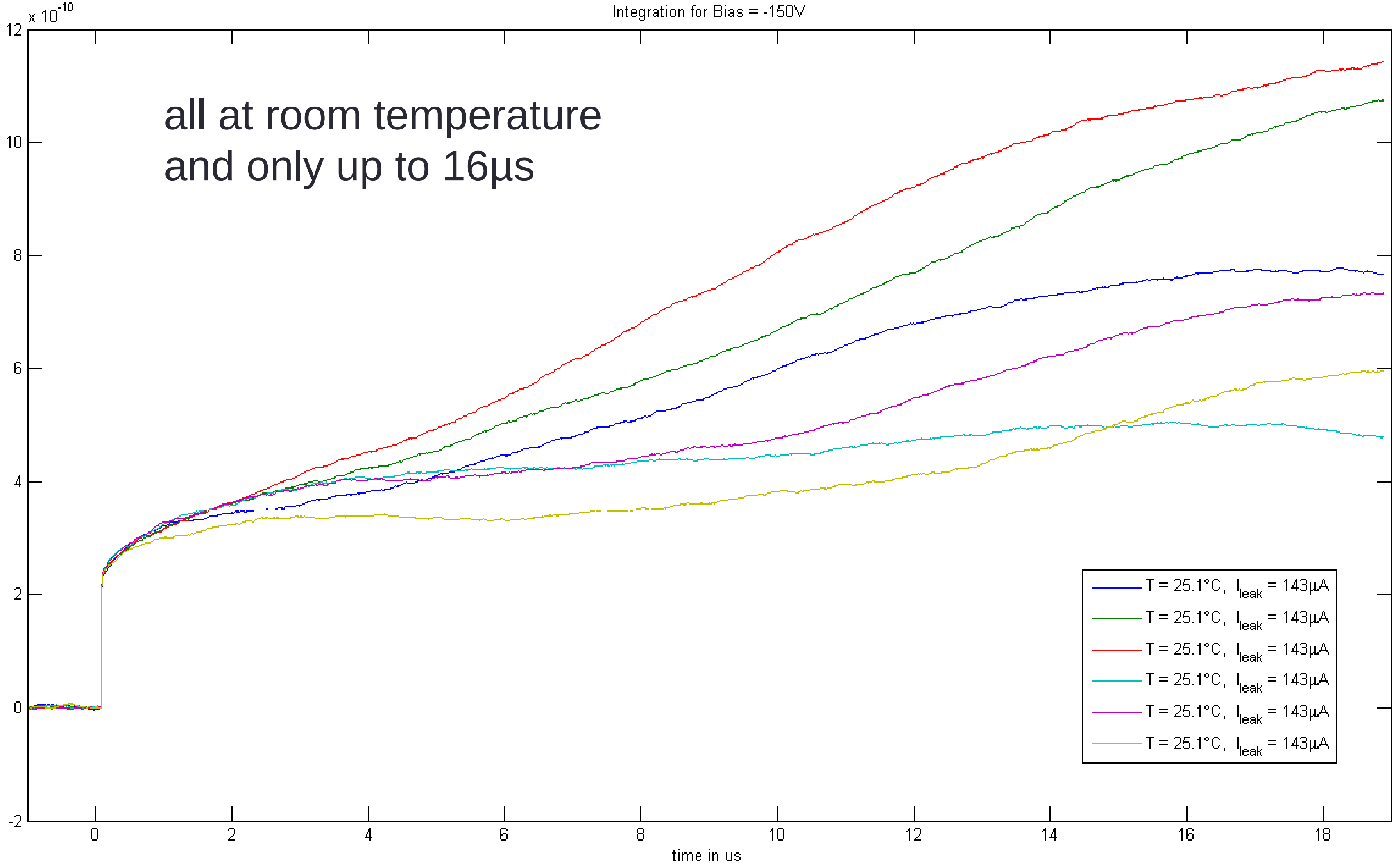
Zoomed:



Each set consists of 10 curves and has its own colour

Measurement method

before: without randomized trigger and 80ps pulse width



all at room temperature
and only up to 16µs

Signal Components

- For irradiated detectors we expect the integrated current to have the form:

$$S(t) = A + \sum_i N_i (1 - \exp(-t/\tau_i))$$

Due to charge collected during carrier drift

- In the case of two time-constants:

$$S(t) = A + N_1\left(1 - \exp(-t/\tau_1)\right) + N_2\left(1 - \exp(-t/\tau_2)\right)$$

with free parameters A, N_1, N_2, τ_1 and τ_2. The first ones should be temperature independent.

Parameter extraction – Alternative 1: τ-fitting

- The detrapping time constant is linked to defect parameters by:

$$\tau_h = \frac{1}{\sigma_h v_h N_V} \exp\left(\frac{E_t}{k_B T}\right)$$

absolute value of the energy level calculated from valence band maximum

σ_h … hole detrapping cross-section
v_h … thermal hole velocity
N_V … effective density of states in valence band maximum

- Looking explicitly on T-dependence:

$$v_h \, N_V = \sqrt{\frac{3k_B T}{m_h}} \; \frac{1}{4}\left(\frac{2m_h k_B T}{\pi\hbar^2}\right)^{3/2} \equiv \gamma_h T^2$$

- And we can analyse data in an Arrhenius plot:

$$\ln(\tau_h T^2) = \frac{E_t}{k_B T} - \ln(\sigma_h \gamma_h) \qquad \Rightarrow \text{ read off } E_t \text{ and } \sigma_h \text{ from slope and intersect}$$

Parameter extraction – Alternative 2: DLTS Scan

- In DLTS (Deep-Level Transient Spectroscopy) we look at the difference of signals measured at two different times t_1 and t_2: $\Delta S = S(t_1) - S(t_2)$ during a temperature scan.
- Temperature independent contributions cancel out:

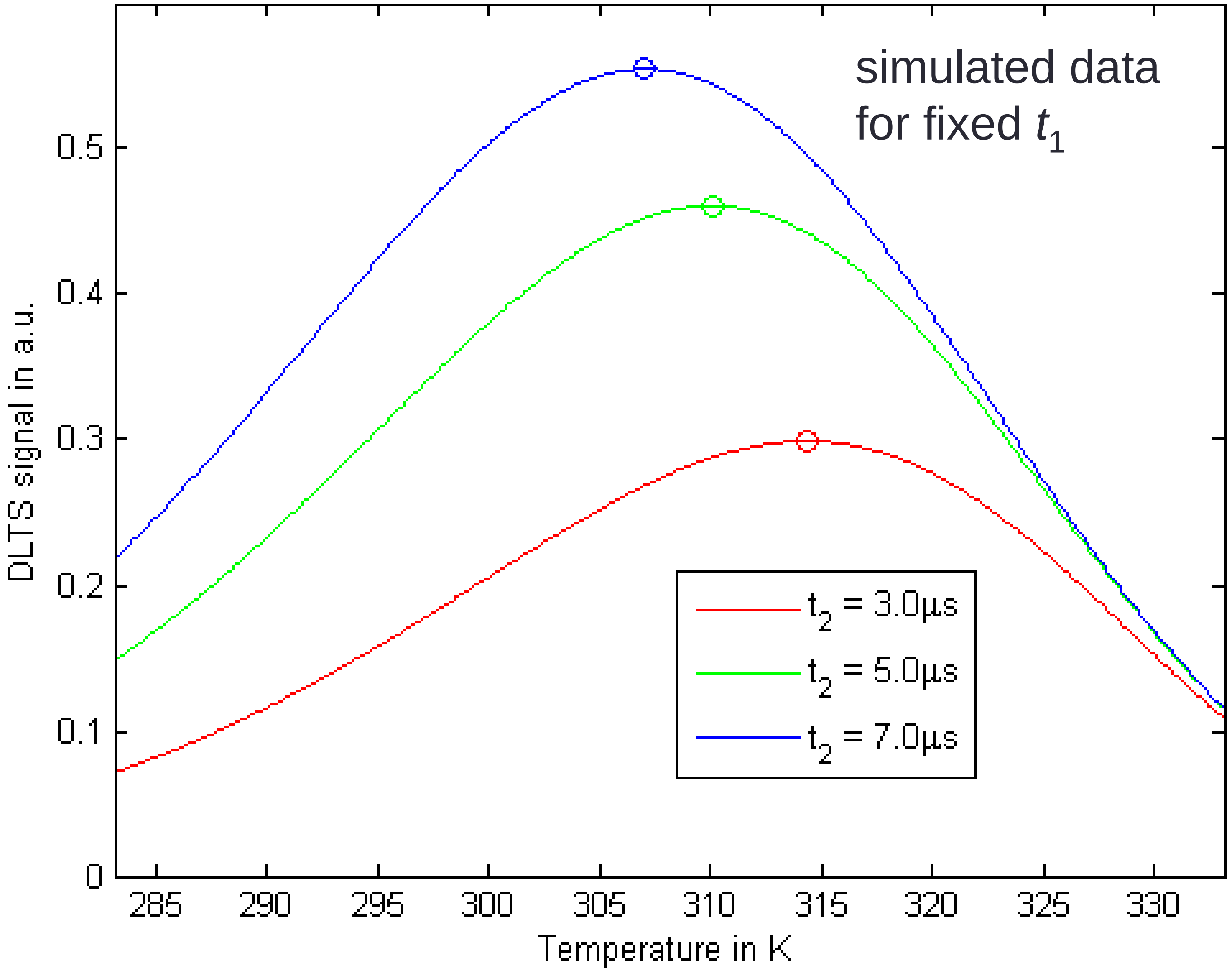
$$\Delta S(T) \propto \left[\exp(-t_1/\tau_d(T)) - \exp(-t_2/\tau_d(T))\right]$$

- The function ΔS(T) goes to zero for high and low temperatures but peaks at intermediate temperatures. The time constant at peak temperature can be determined as a function of t_1 and t_2 as:

$$\tau(T_{S\max}) = \frac{t_1 - t_2}{\ln(t_2/t_1)}$$

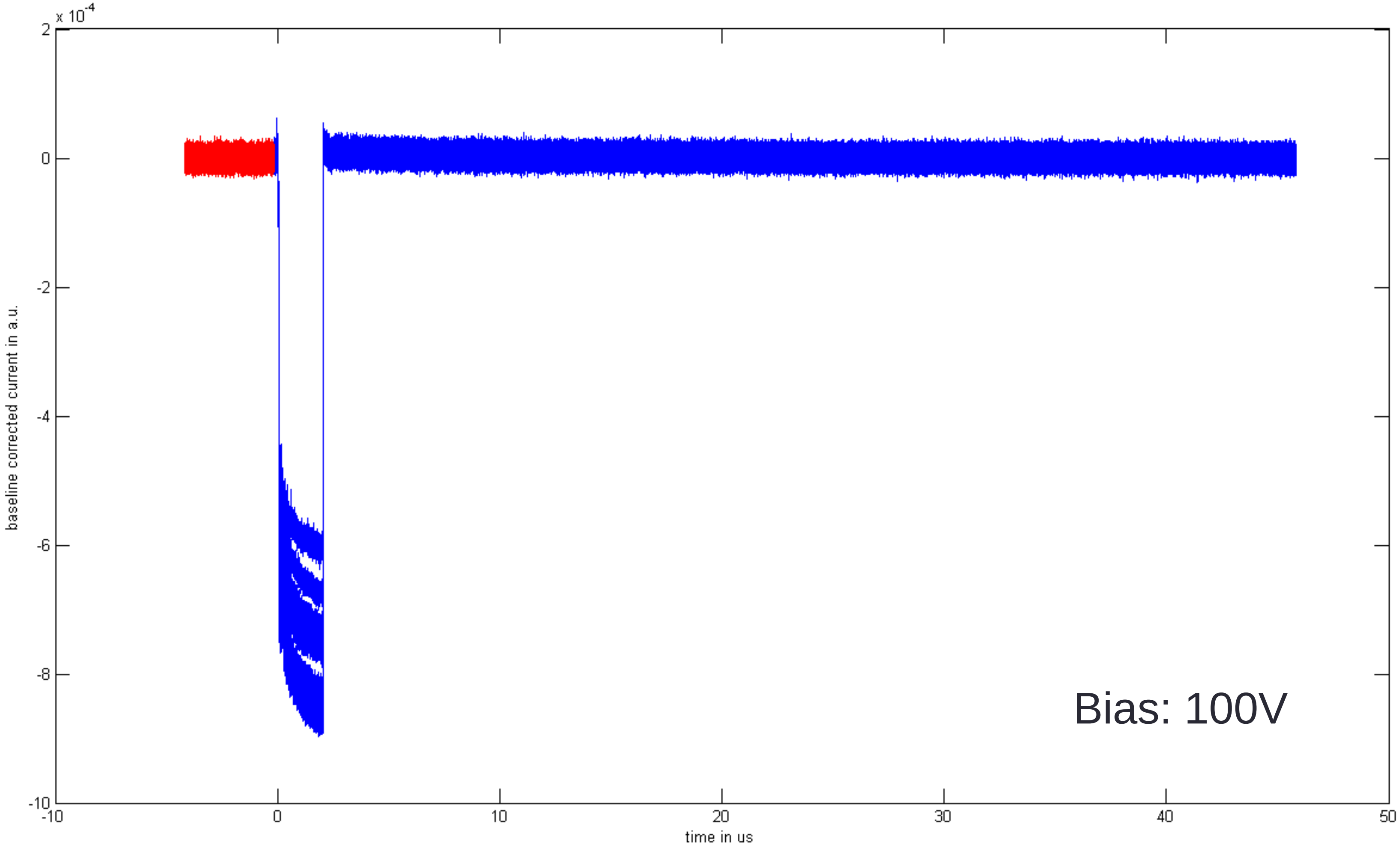
- These data pairs can be analysed in an Arrhenius plot

Parameter extraction – Alternative 2: DLTS Scan



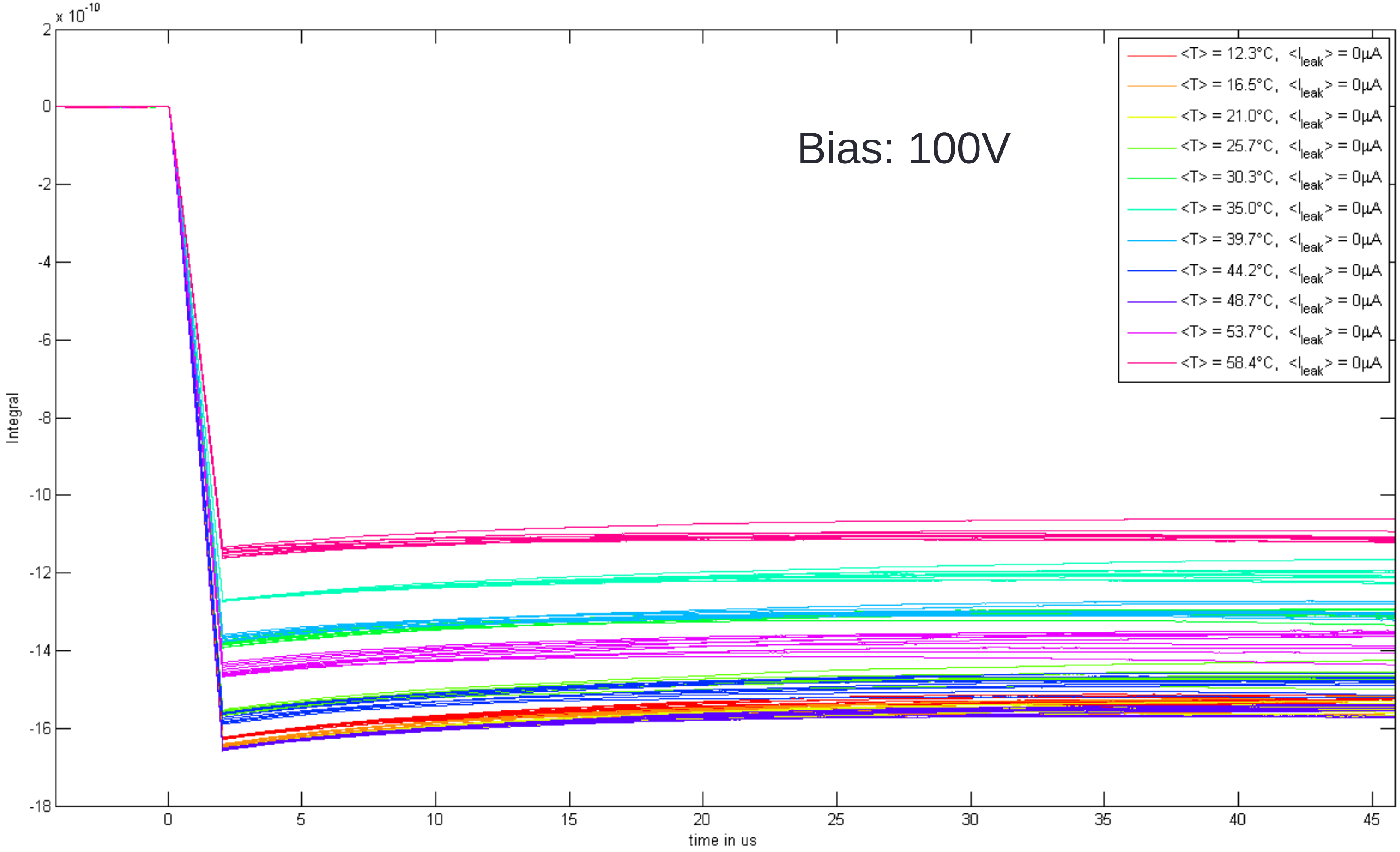
First measurements

Integrated current for unirradiated diode (Sample A)



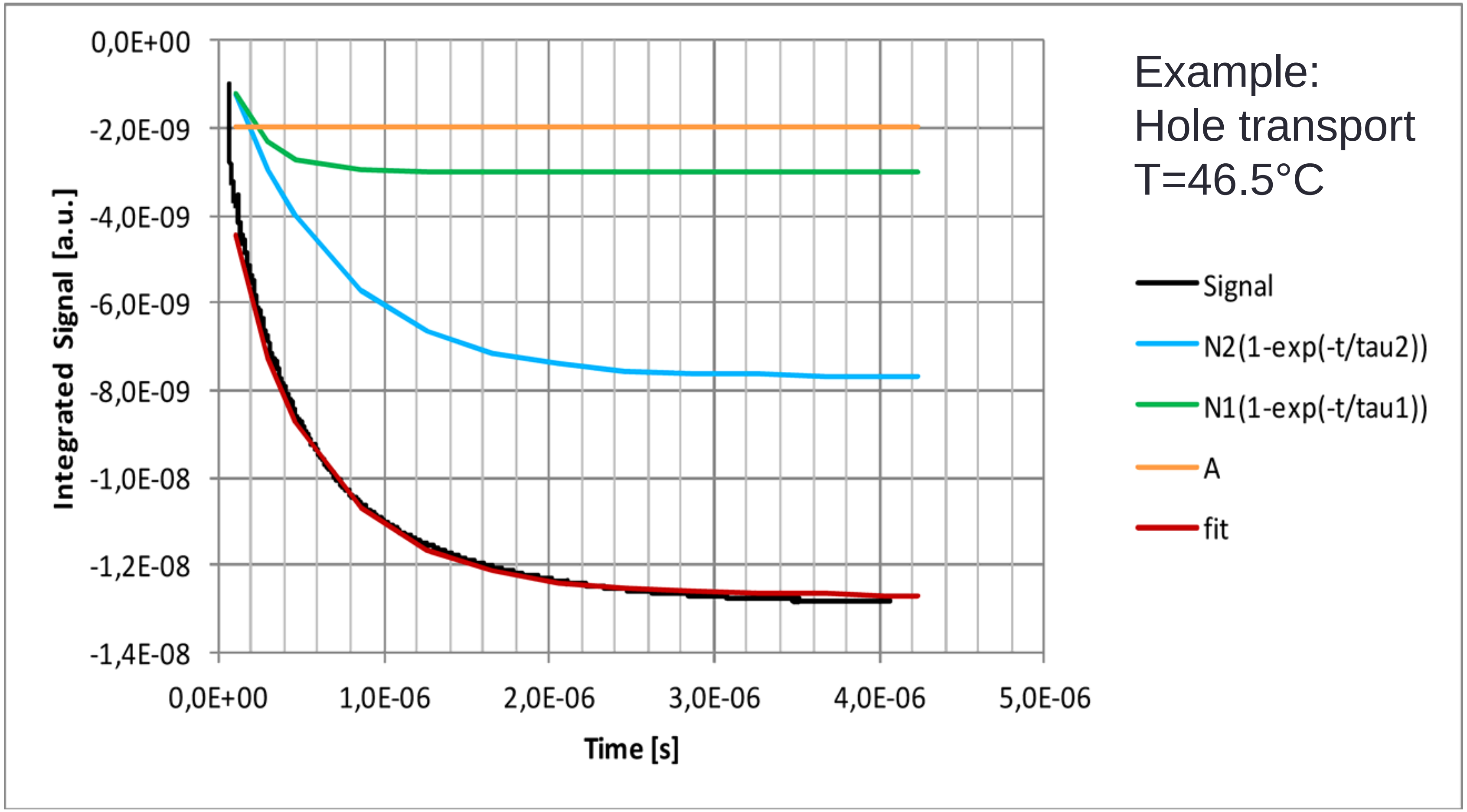
Current drops to zero “instantly” after illumination

Integrated current for unirradiated diode (Sample A)



No clear time-constant and no temperature trend observable
→ small rise most likely due to imperfect offset correction

Integrated hole current for irradiated MCz diode (Sample B)

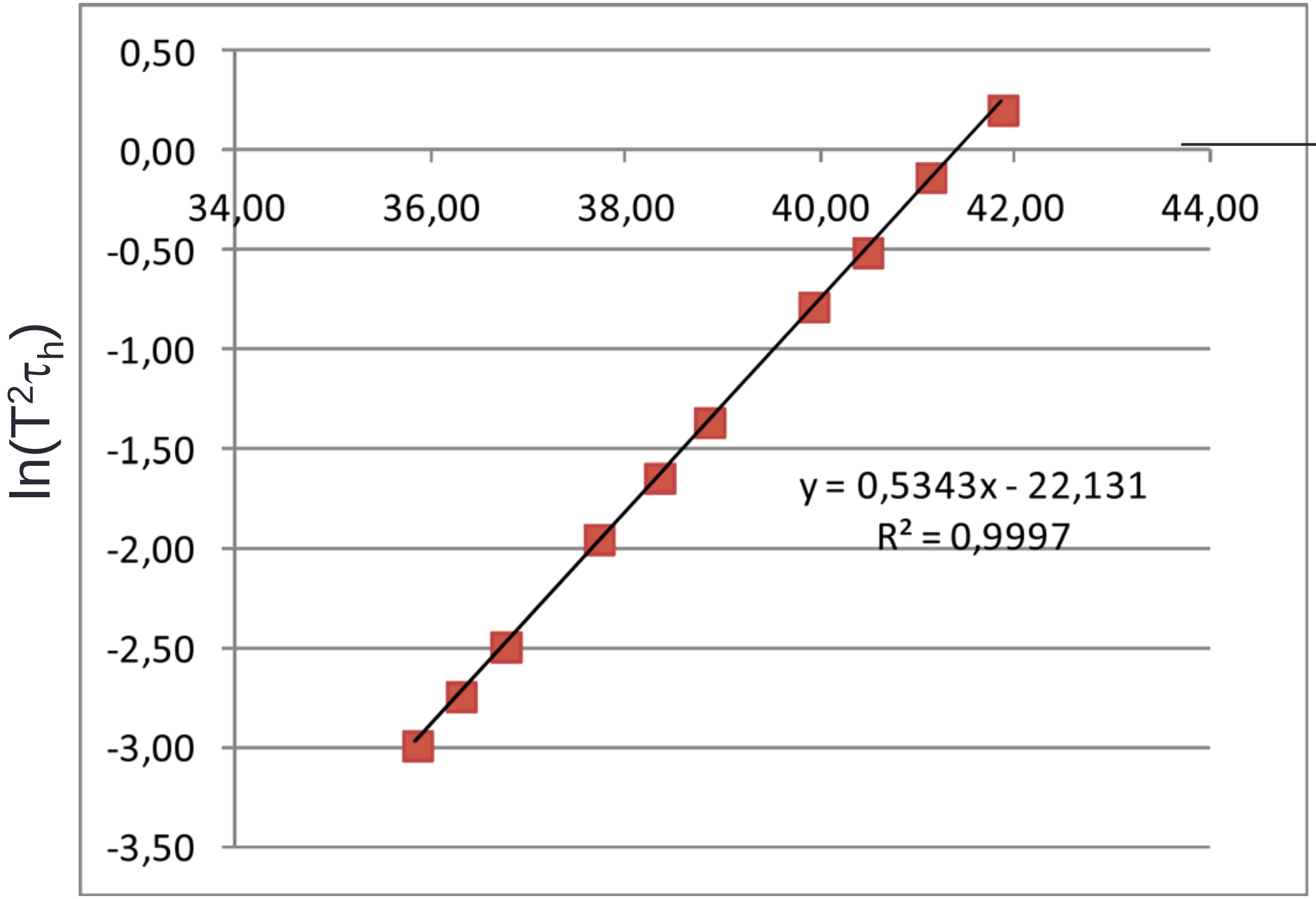


Example:
Hole transport
T=46.5°C

Sum of two exponentials used to fit the data:
one faster τ_1 (T-independent) and one slower $\tau_2=\tau_d$ (trapping)

Arrhenius plot for hole transport MCz diode (Sample B)

PRELIMINARY



$1/(k_B T)$

from slope:

$E_{th} = 0.53\text{eV}$

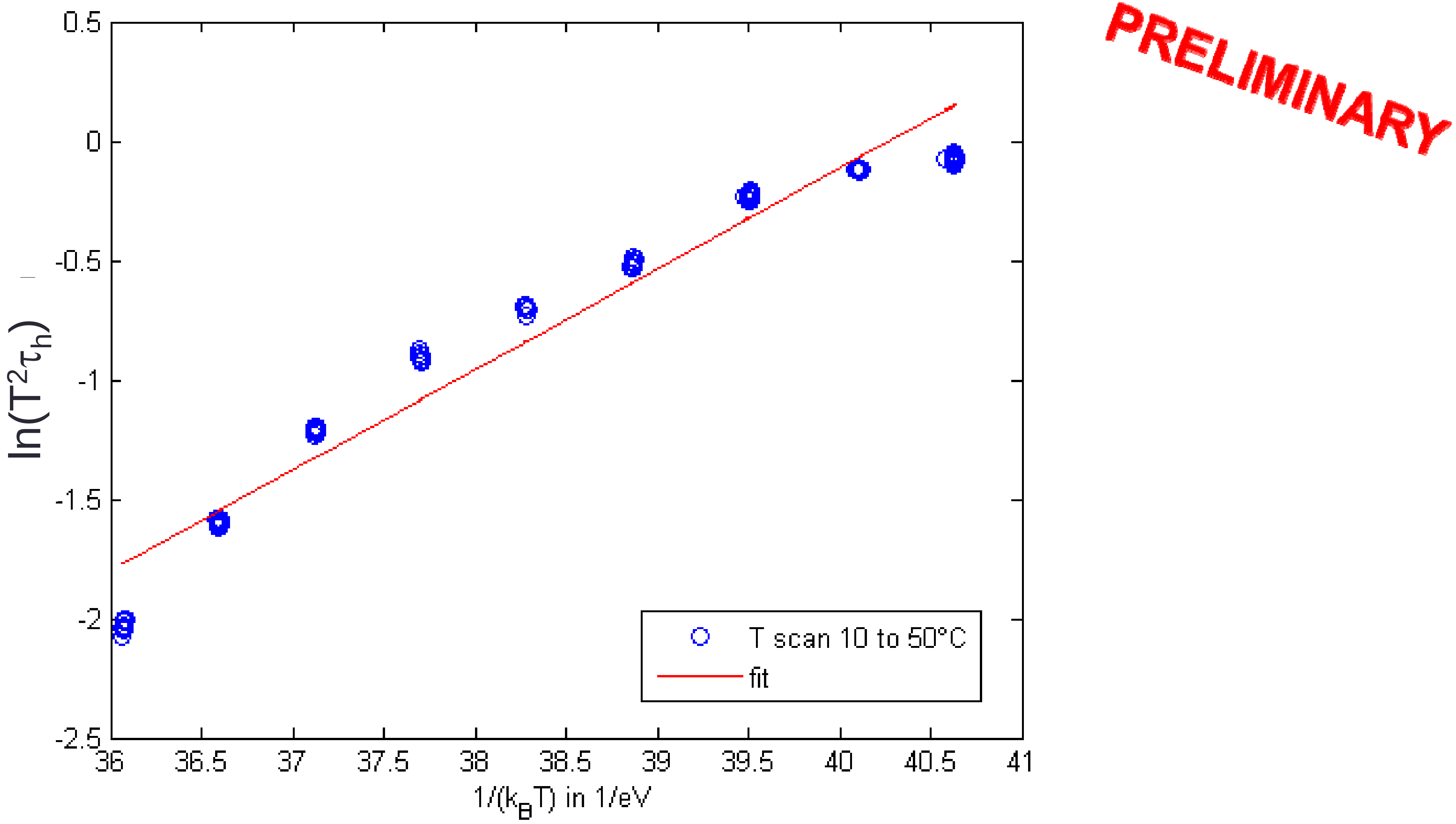
from Intercept &

$\gamma_h = 1.81\text{x}10^{25}\ \text{s}^{-1}(\text{mK})^{-2}$

$\sigma_h = 1.57\text{x}10^{-12}\ \text{cm}^2$

Data points correspond to time-constants extracted from fits to integrals S(t)

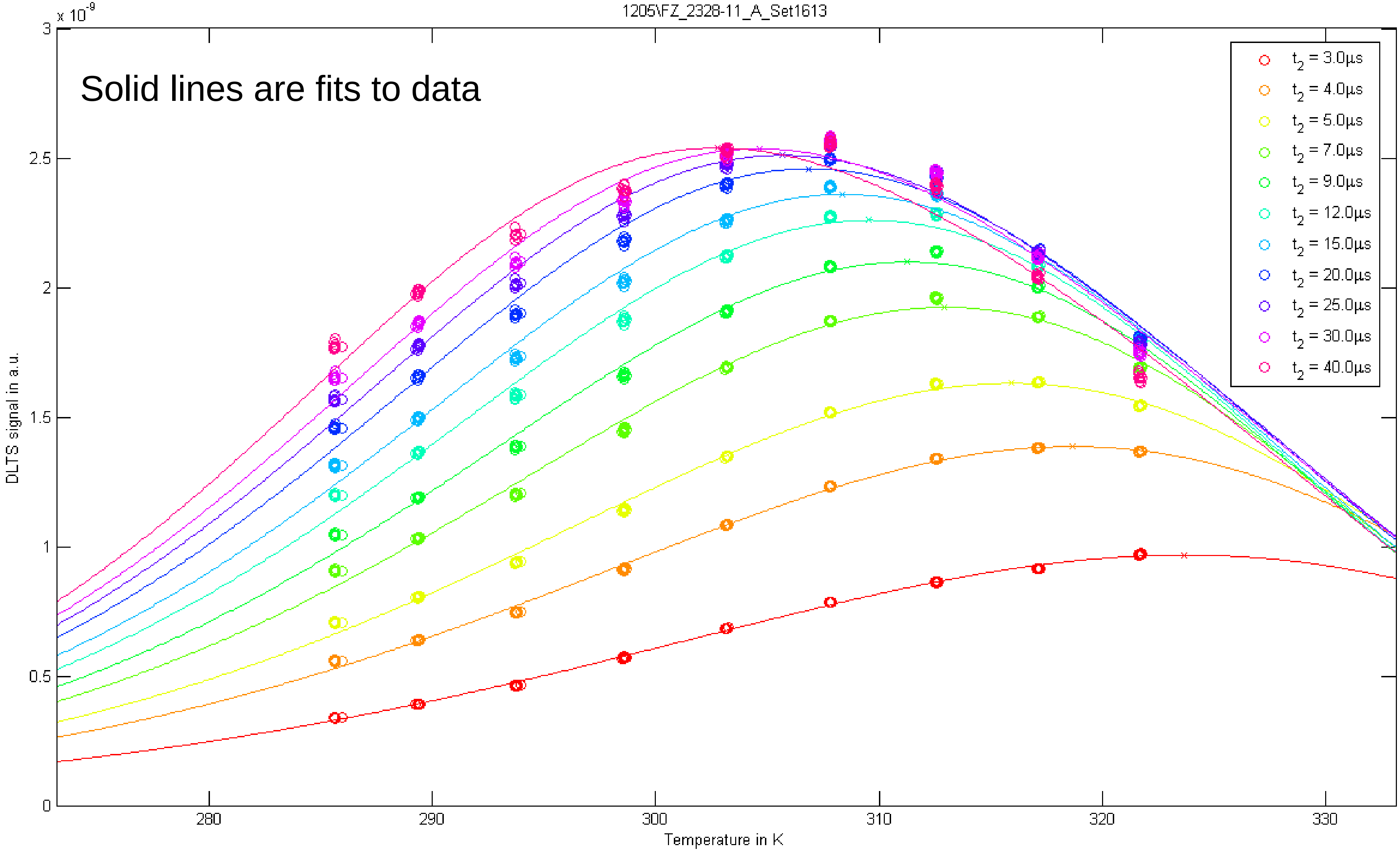
Arrhenius plot for hole transport FZ diode (Sample C)



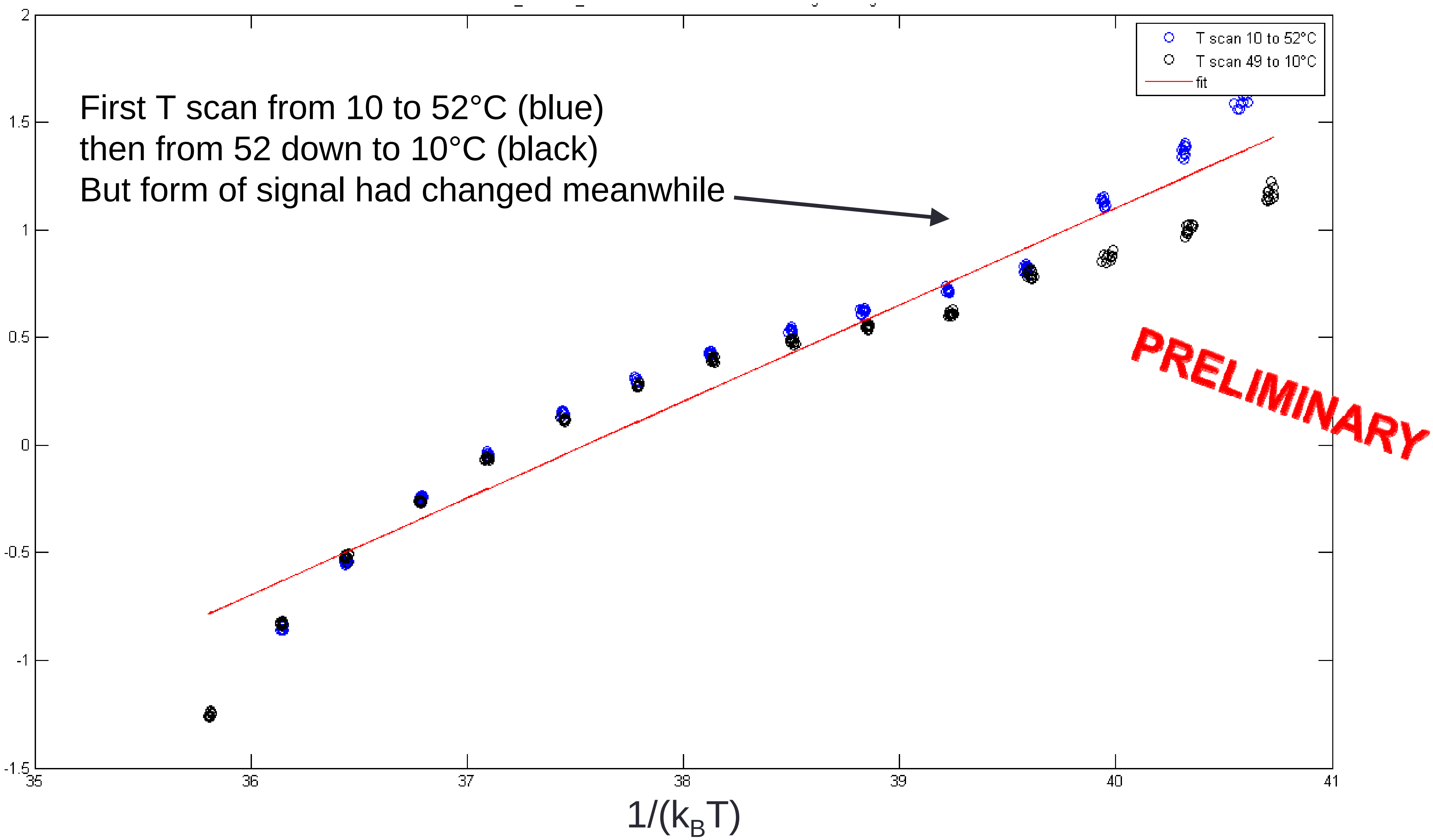
Time-constants were not extracted well, since fitting [exp(.)+exp(.)] is tricky …

PRELIMINARY

DLTS Scan for hole transport FZ diode (Sample C)

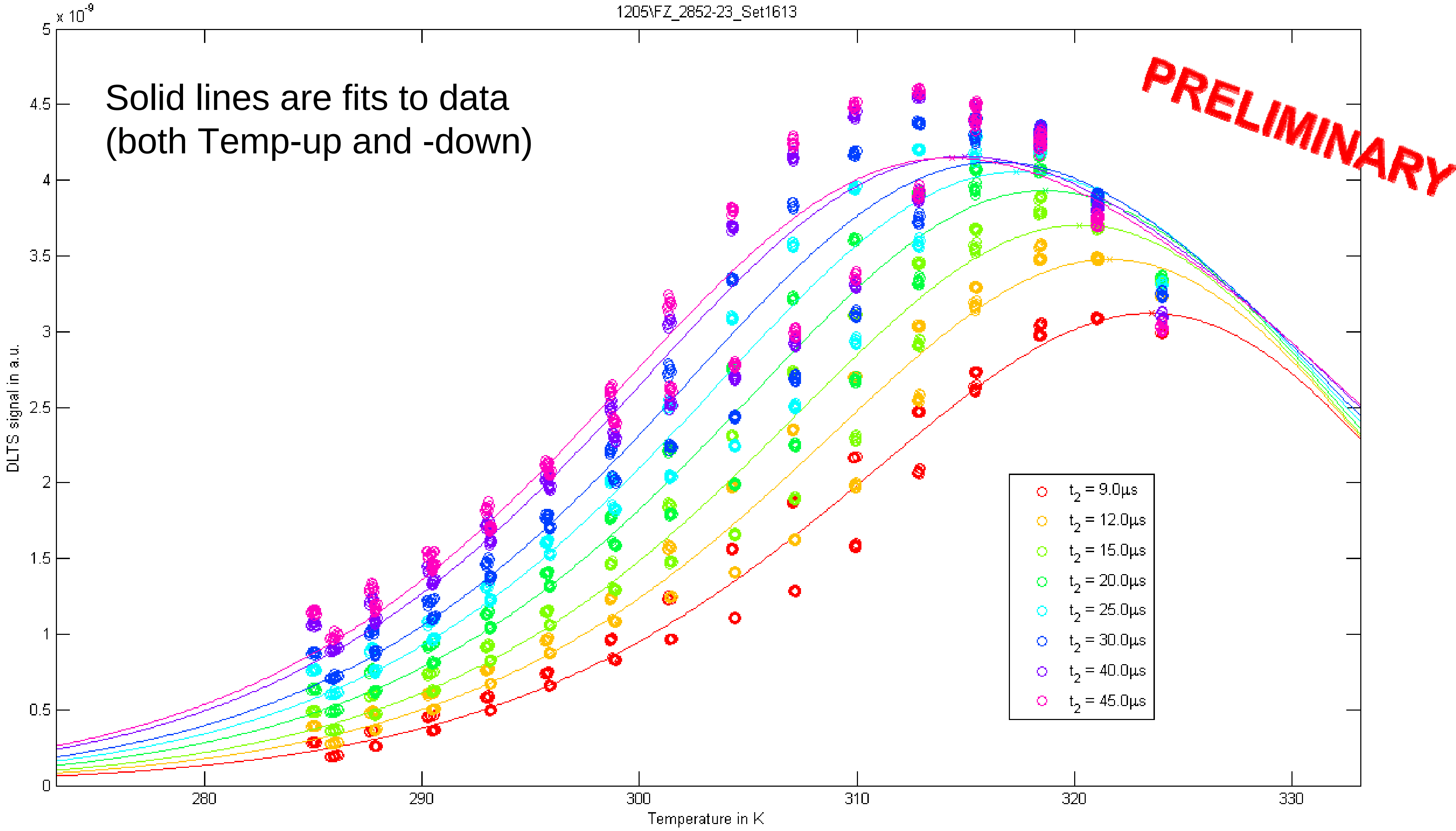


Arrhenius plot for electron transport FZ diode (Sample D)



First T scan from 10 to 52°C (blue)
then from 52 down to 10°C (black)
But form of signal had changed meanwhile

DLTS Scan for electron transport FZ diode (Sample D)



Solid lines are fits to data
(both Temp-up and -down)

Conclusion

- Setup improved to guarantee reproducibility even for 50µs integration time
- Important changes:
  - Randomized triggering
  - 2µs instead of 80ps illumination to obtain large enough signal even without current amplifier
- Observed τ_e = 2-40µs (for 10-50°C) and τ_h = 1-10µs (for 10-50°C)
- Still more improvements are necessary …
  - to extract time constants from S(t) or I(t).
  - to minimize leakage current but still to deplete the same volume for each temperature
  - …

Thanks for your attention!