TCT Studies in FZ, DOFZ and MCz Silicon

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Florence, Italy

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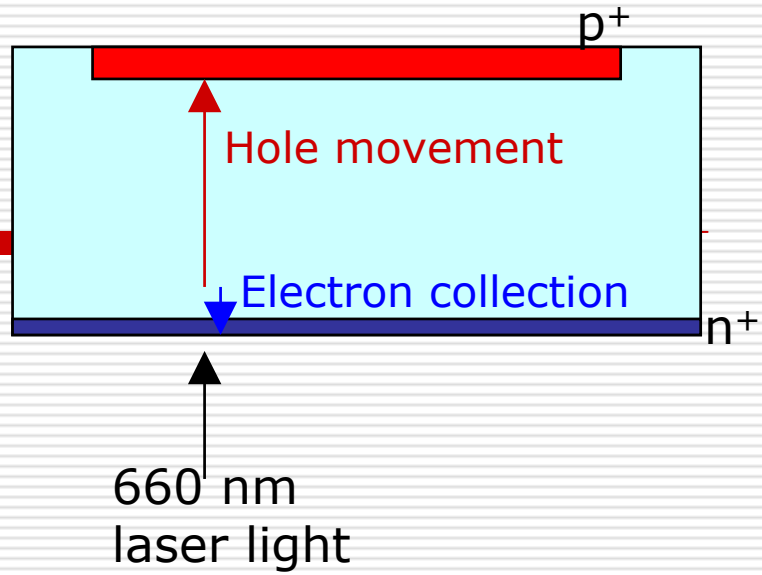
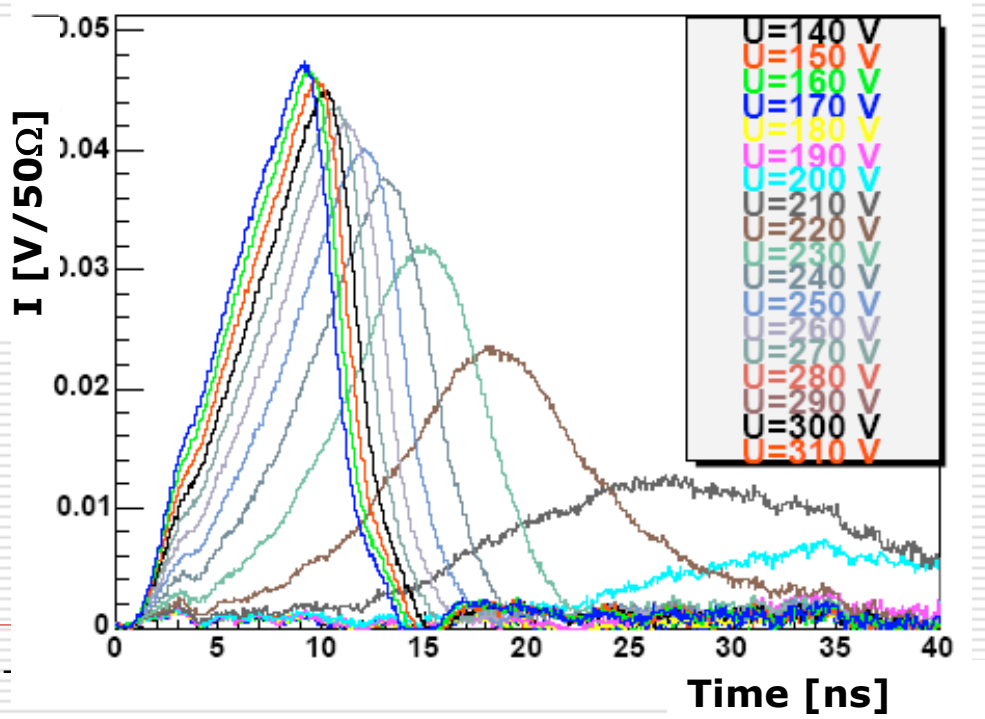
Overview

- Transient Current Technique review
- The new CERN TCT set-up
- Material characterisation
  - IV/CV
  - TCT
    - QV => V_{fd}
    - Trapping time determination
    - β value determination
    - Type inversion in DOFZ
    - SCSI in MCz?

TCT Review

- Illuminate front (p^+) or rear (n^+) side of detector with 660 nm photons
- Light penetrates only a few μm depth
- Ramo's theorem dictates signal will be dominated by one type of charge carrier
- $I(t)=q\ E(\upsilon(t))\ \upsilon(t)_{drift}$
- e.g. hole dominated curent (hole injection)
  - Illuminate rear (n^+) side of detector





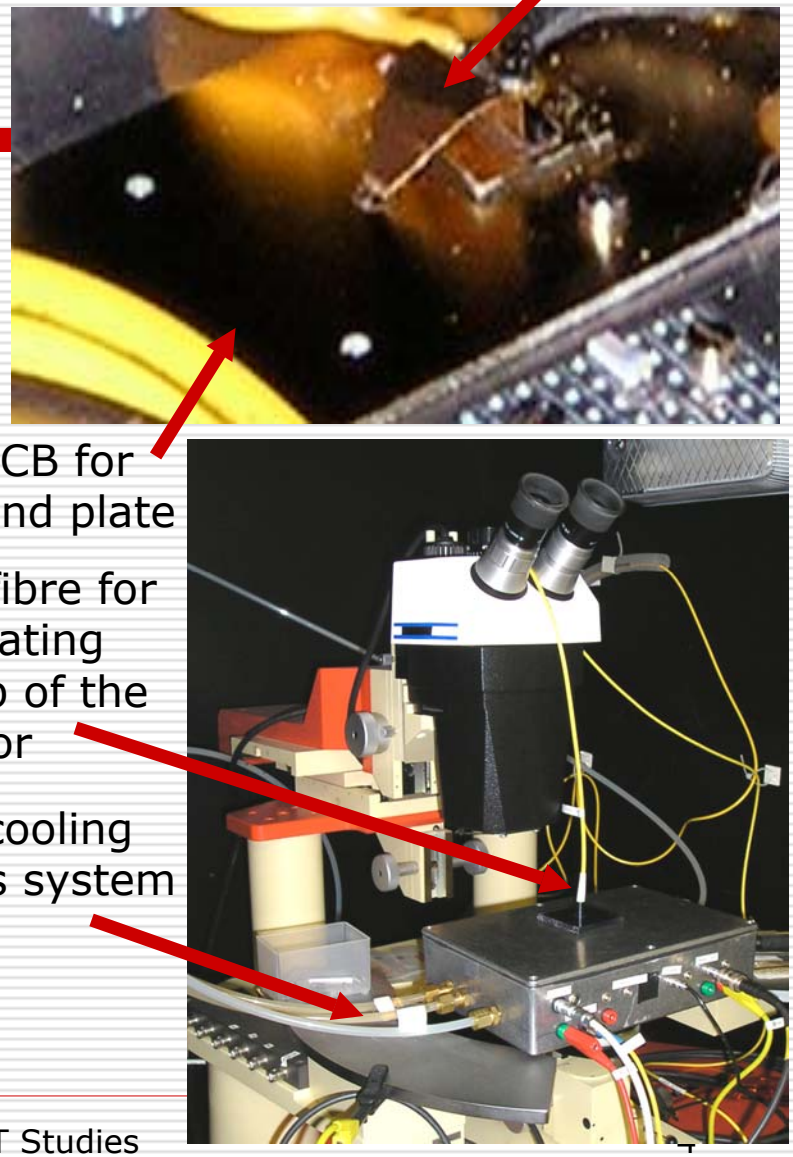
CERN TCT set-up(1)

- Easy detector mounting
- Floating guard ring

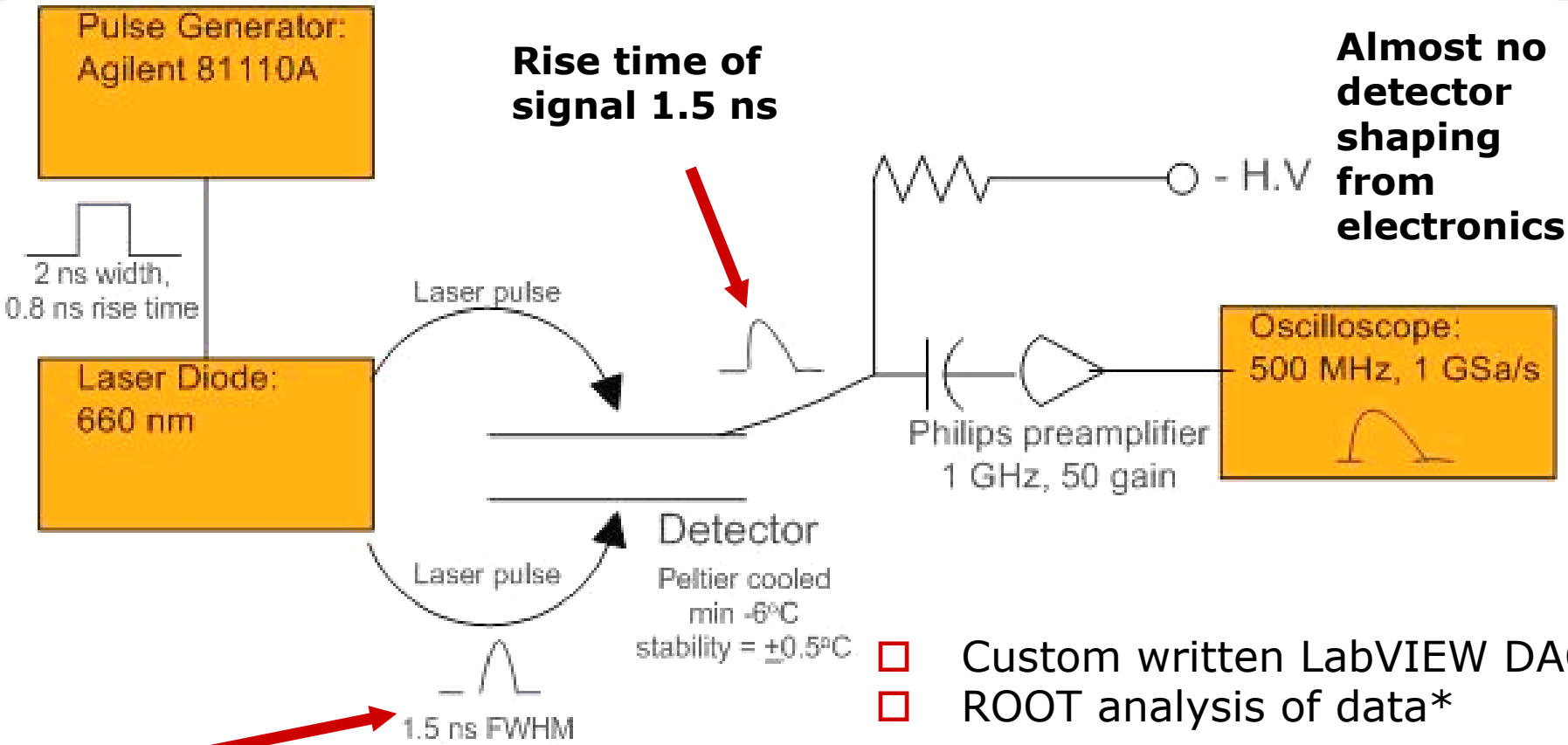
- Front and back illumination possible

- Peltier cooled to ~-10°C
- Temp. stability to ±0.1°C
- Flushed with N_2 gas

- Red 660 nm laser diode
- IR 1060 nm laser diode
- Amount of charge deposited can be tuned - laser diode output controlled by pulse generator signal



CERN TCT set-up(2)



- Custom written LabVIEW DAQ
- ROOT analysis of data*

*Data analysis software courtesy from the wonderful Gregor Kramberger

Materials studied

- Okmetric Oyj silicon processed at the Helsinki Institute of Physics*
  - FZ (f2)
  - DOFZ (d1)
  - MCz (n320)
- 15 kΩcm DOFZ (W317) silicon diodes

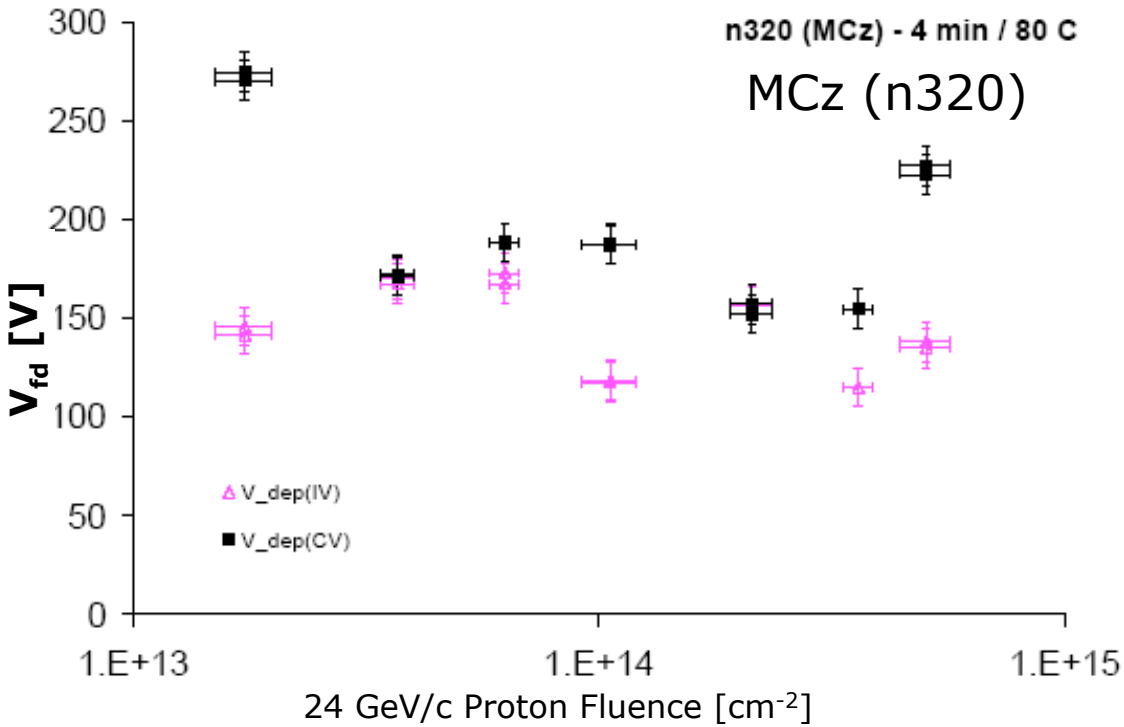
- All irradiations were performed at the CERN PS using 24 GeV/c protons**

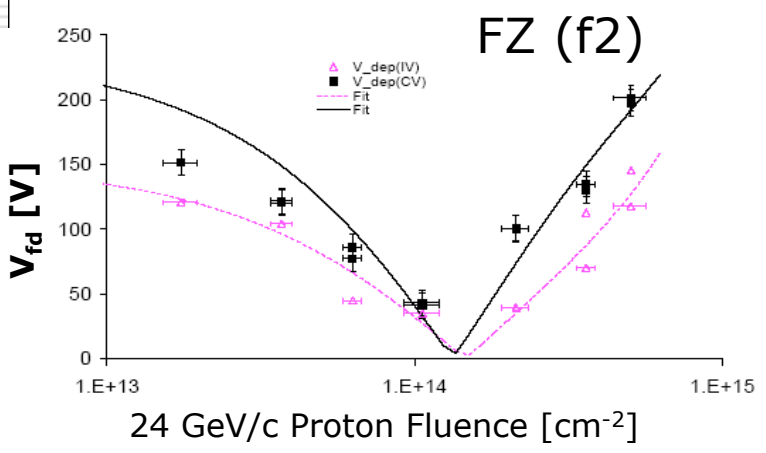
*Many thanks (yet again!) to Jaakko Haerkonen and the Helsinki Institute of Physics

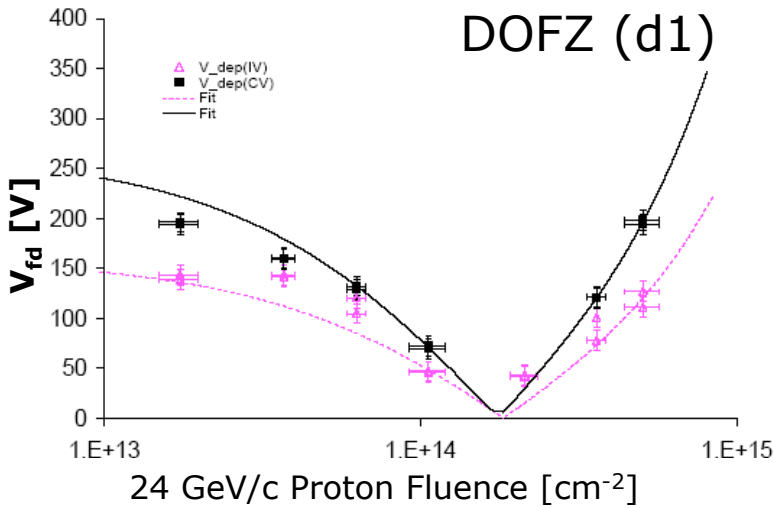
** Maurice, Michael and Federico have now irradiated hundreds of detectors for these studies alone. They provide a truly unique service and are usually taken for granted!

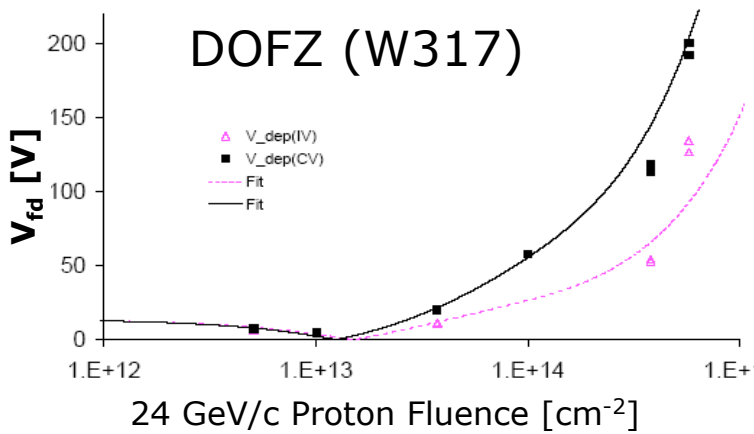
IV/CV analysis

- CV measurements - 10kHz
- Measurement at room temperature, then corrected to 20°C
- Guard rings grounded
- Annealed for 4 min / 80°C







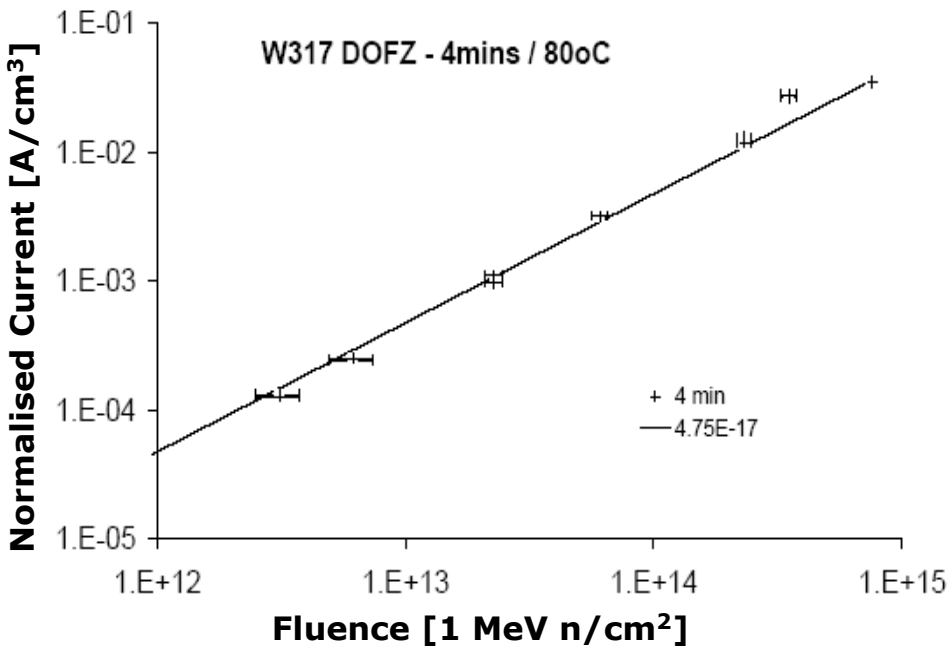


Normalised Leakage Current

- Annealed for 4 mins/80°C
- Normalise the leakage current to volume
- Using annealing parameterisation:

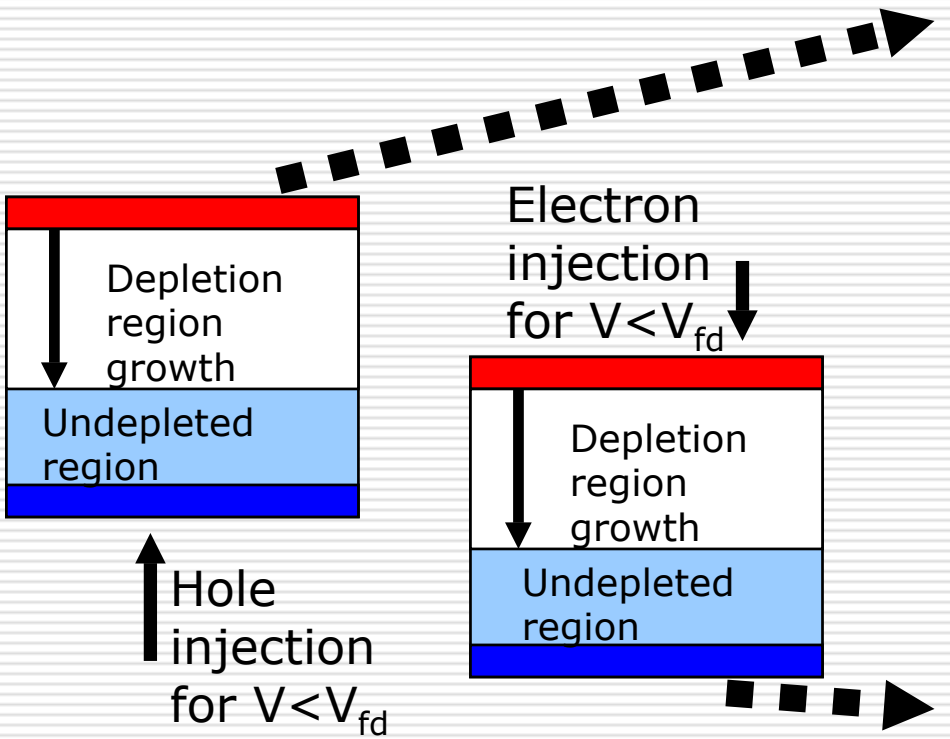
$\alpha(t)=\alpha_1 e^{(-t/\tau_1)}+\alpha_0-\beta\ln(t/t_o)$ =>α(4mins/80°C)=4.56x10^{-17} A/cm

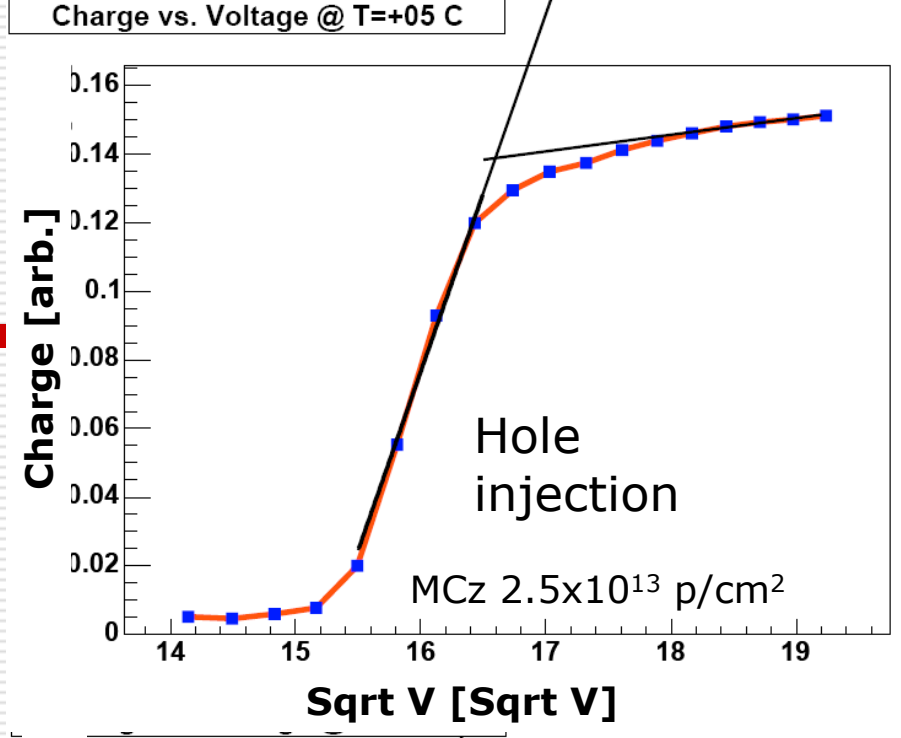
W317(DOFZ) α = 4.75 x 10^{-17} A/cm
f2 (FZ) α = 4.96 x 10^{-17} A/cm
d2 (DOFZ) α = 4.85 x 10^{-17} A/cm
n320 (MCz) α = 4.73 x 10^{-17} A/cm

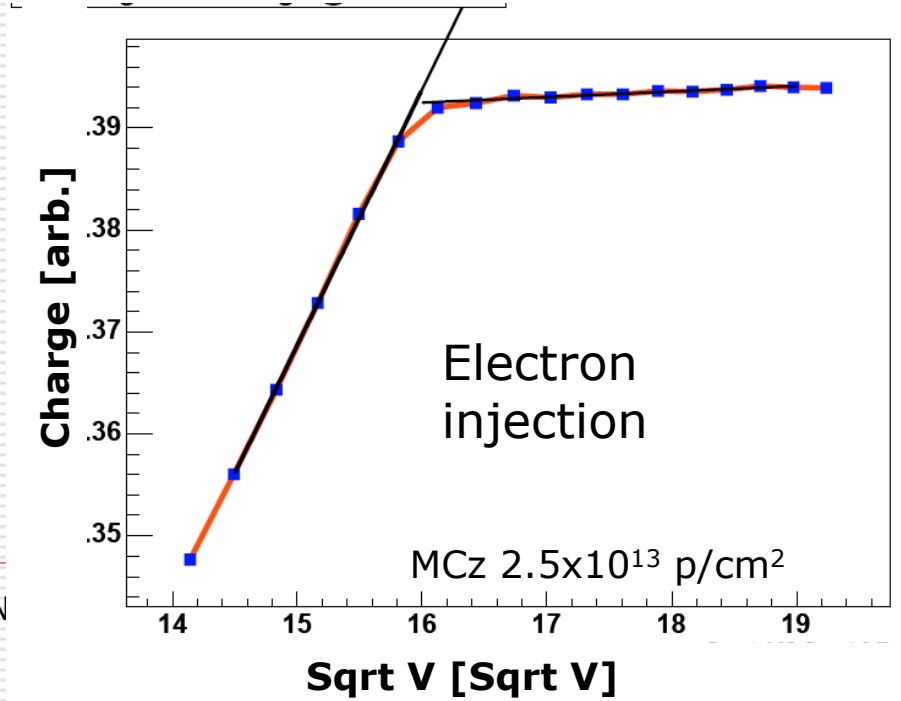


TCT Results – QV method

- Charge collected as a function of voltage







QV compared with IV/CV

Brown Circles

● = QV (h injection)

Blue Triangles

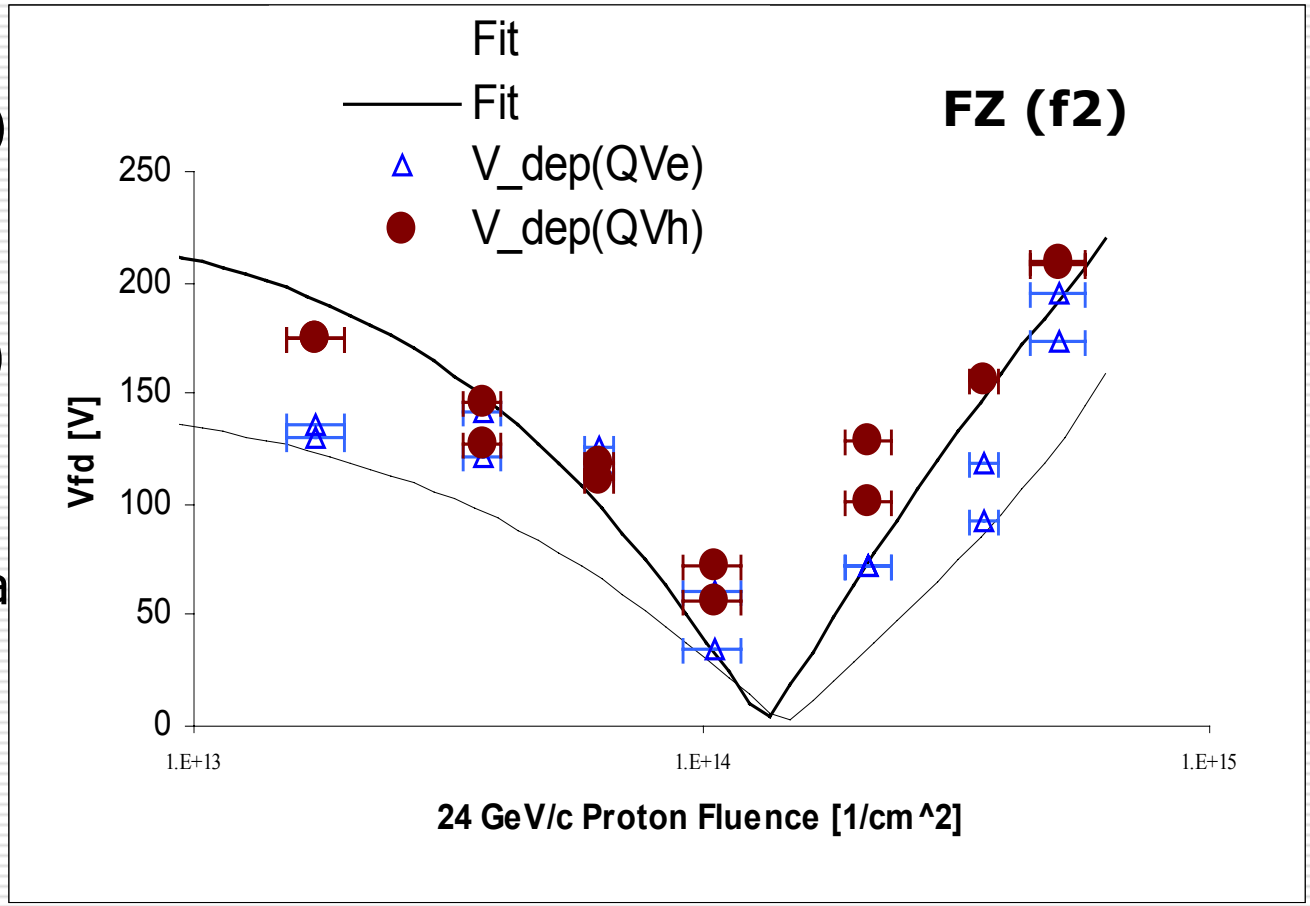
△ = QV (e injection)

Black solid line

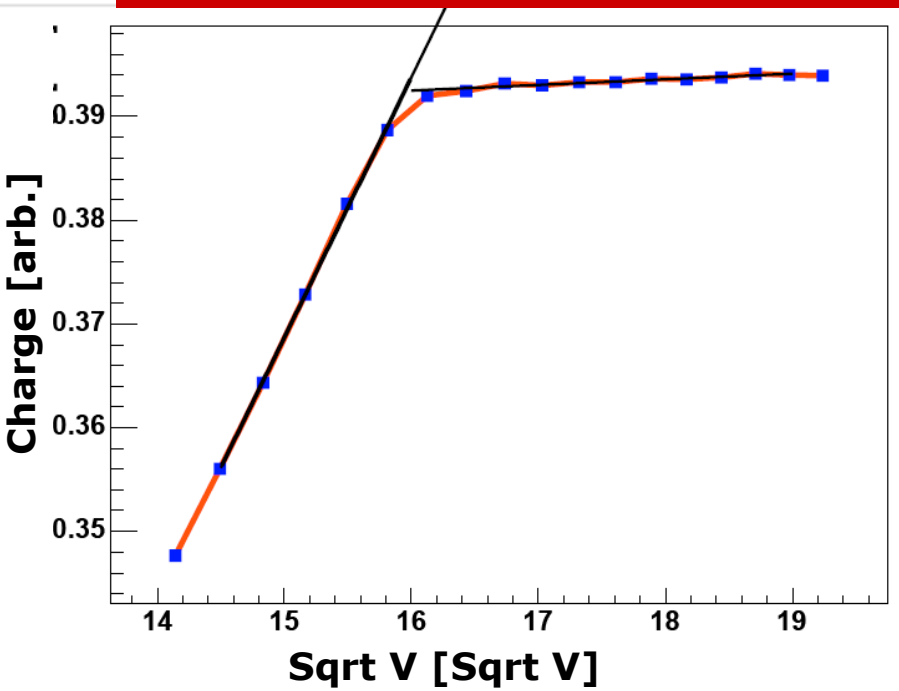
/ = fit from CV data

Purple dashed line

⁄ = fit from IV data



Effective trapping time – Charge Correction Method (CCM)

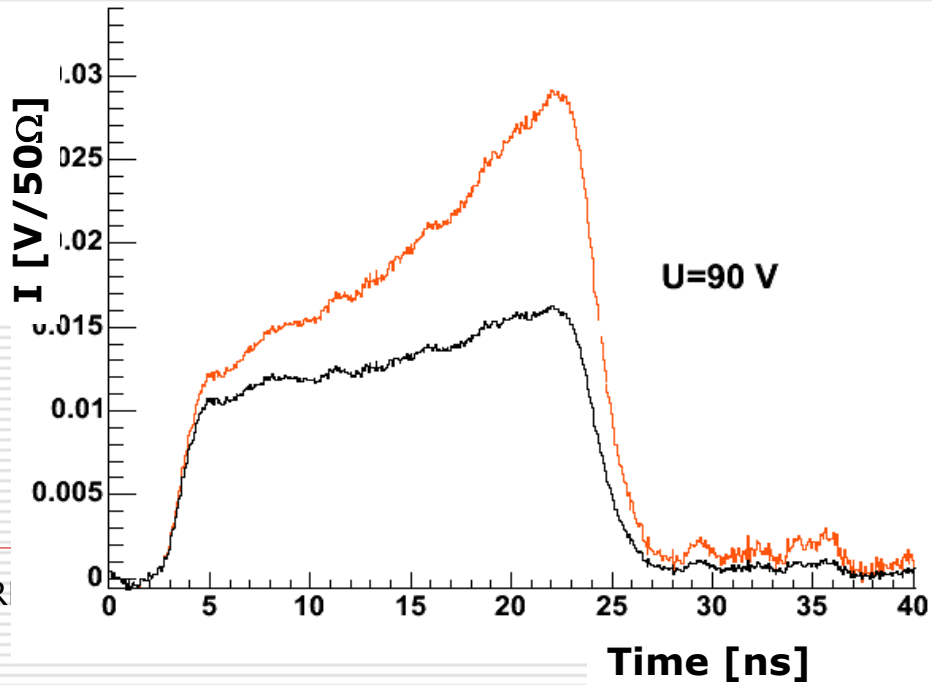


For $V>V_{fd}$, then:

$\Rightarrow$ constant Q collected if no trapping

$\Rightarrow$ try various τ_{eff} values

$\Rightarrow$ correct τ_{eff} value is when gradient of this line is zero



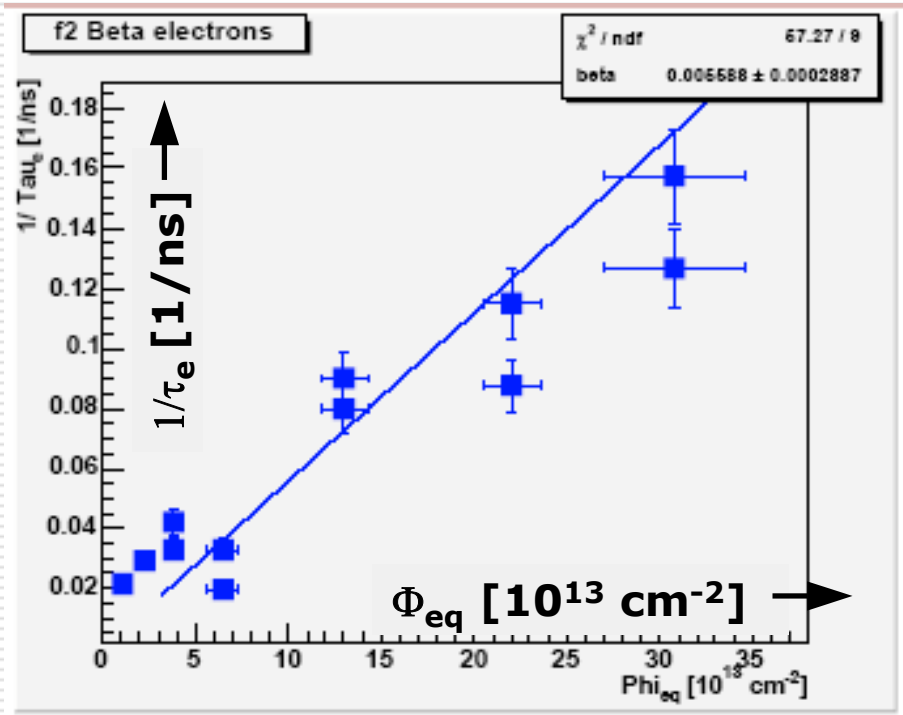
Black = signal from oscilloscope

Red = signal corrected for trapping

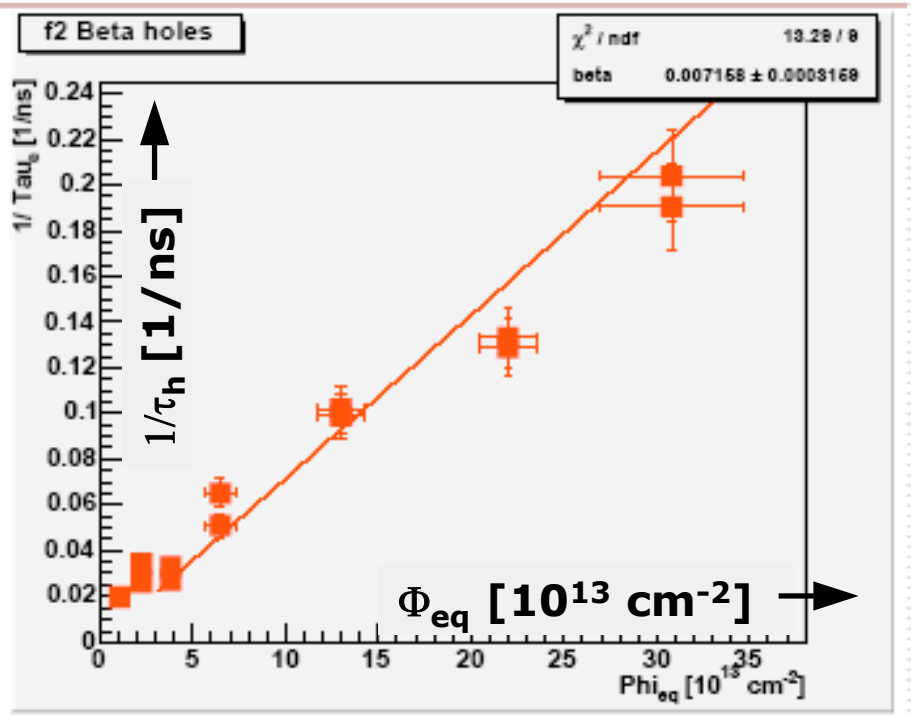
$\beta_{e,h}$ values

$1/\tau_{effe,h} = \beta_{e,h}\Phi_{eq}$

Example plots from FZ (f2);



Electron Injection



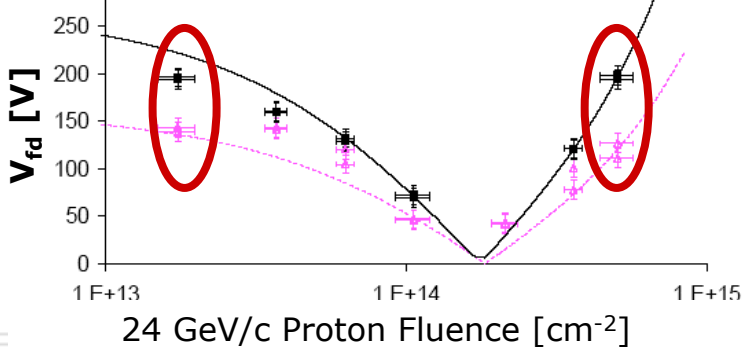
Hole Injection

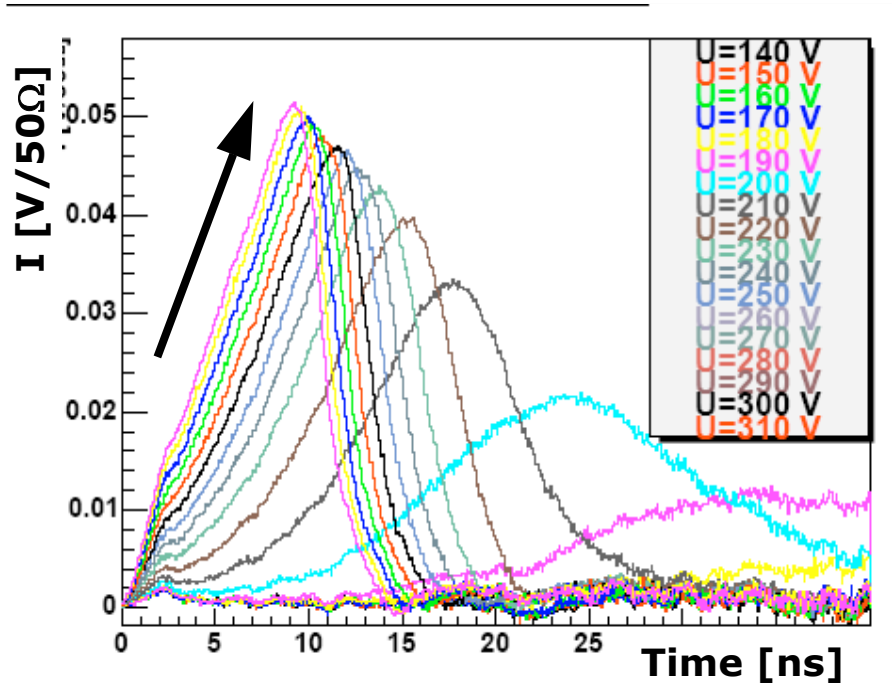
β parameter summary

	β_e [10^{-16} cm²/ns]	β_h [10^{-16} cm²/ns]	T [°C]
Dortmund	5.16 ± 0.16	5.04 ± 0.16	0
Ljubljana	5.6 ± 0.2	7.7 ± 0.2	-10
Hamburg	4.85 ± 0.15	5.72 ±0.5	+20
f2 (FZ)	5.59 ± 0.29	7.16 ± 0.32	+5
d1 (DOFZ)	5.73 ± 0.29	6.88 ± 0.34	+5
n320 (MCz)	5.81 ± 0.32	7.78 ± 0.39	+5
W317 (DOFZ)	5.48 ± 0.22	6.02 ± 0.29	+5

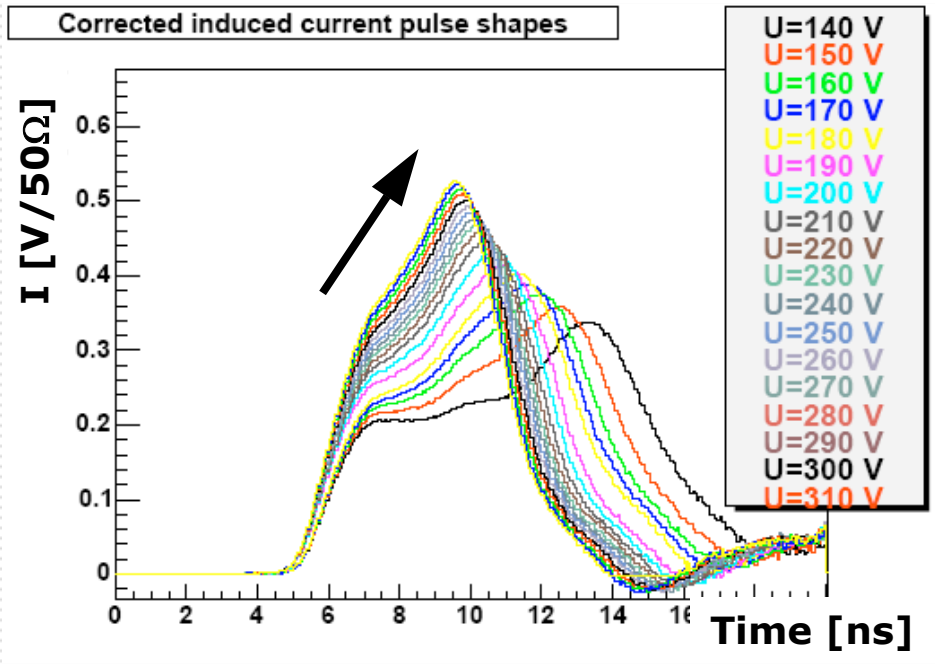
New results!

SCSI in DOFZ

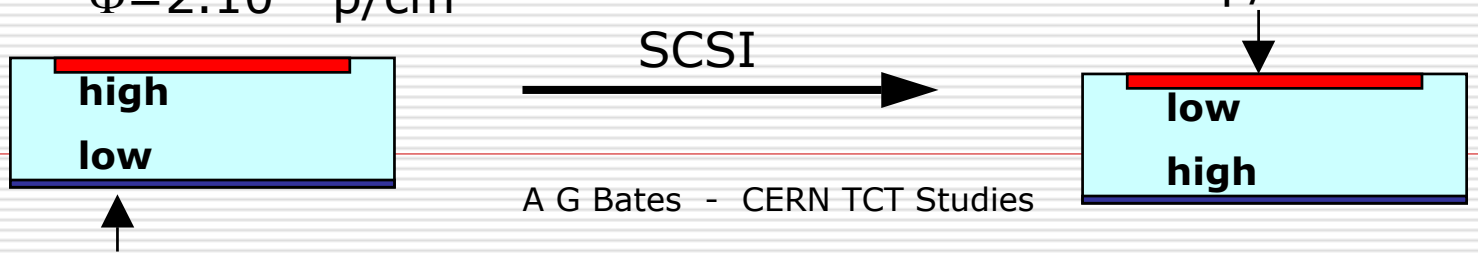




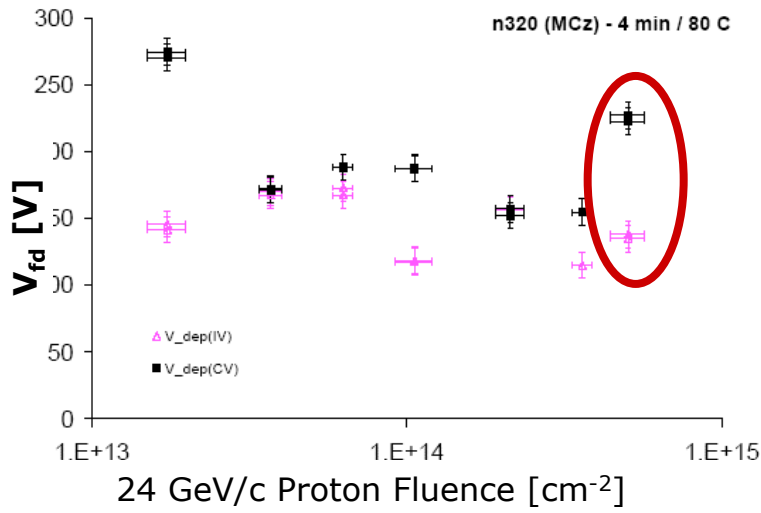
hole injection in DOFZ(d1) at $\Phi=2.10^{13}$ p/cm^2

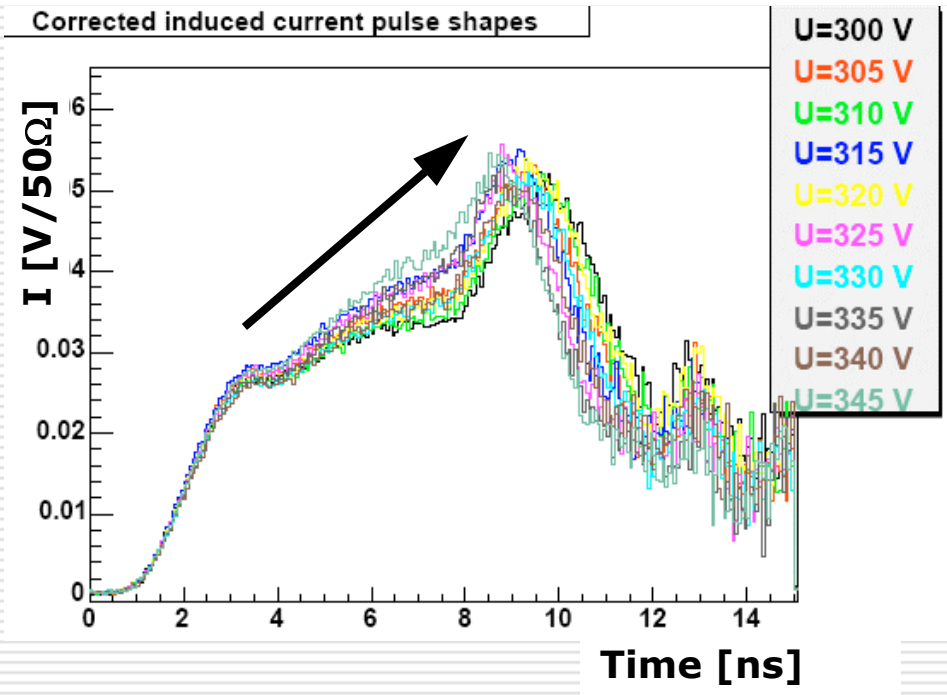


electron injection in DOFZ(d1) at $\Phi=5.10^{14}$ p/cm^2

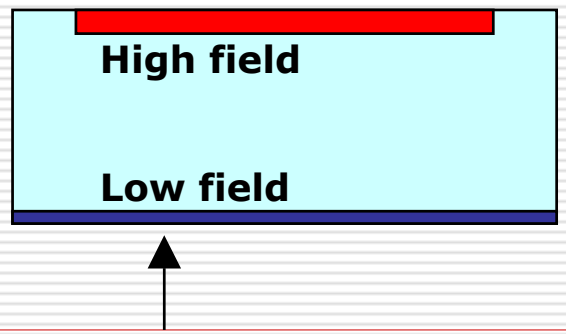


SCSI in MCz? –No!

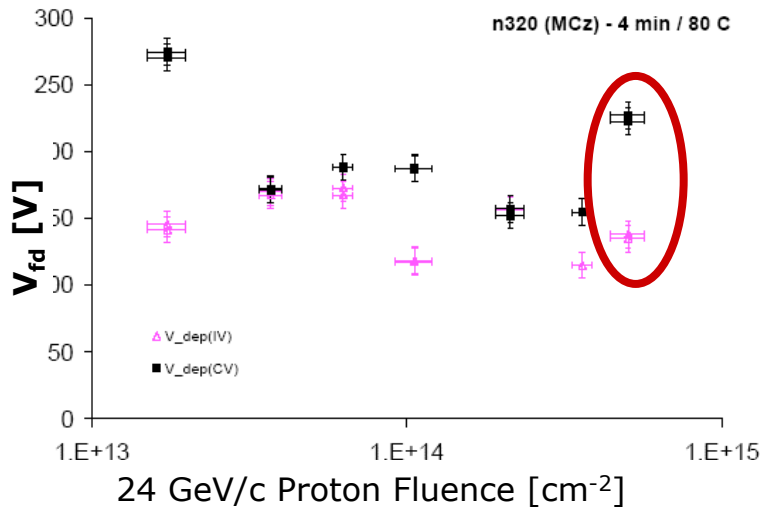


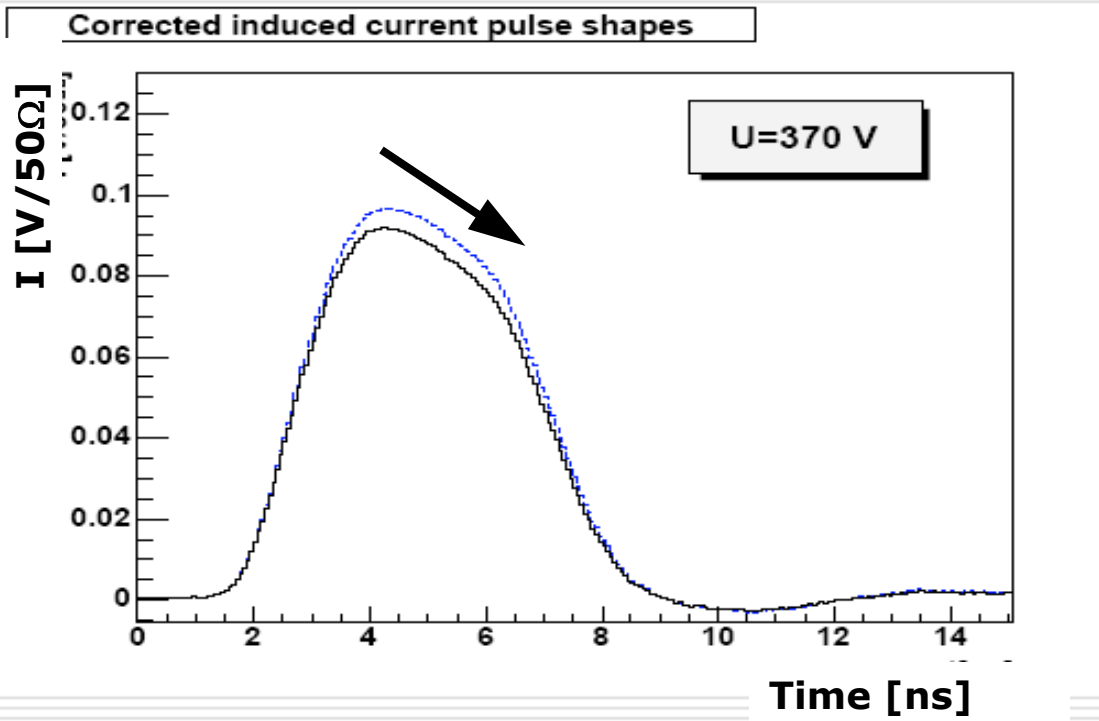


hole injection in MCz (n320) at $\Phi=5.10^{14}$ p/cm^2

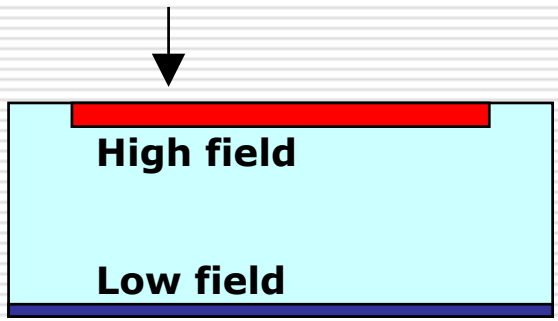


SCSI in MCz? –No!





electron injection in MCz (n320)
at Φ=5.10^{14} p/cm^2



Summary

- 4 materials studied in detail using IV/CV and TCT
  - Leakage current behaviour
  - IV/CV evolution of V_{fd} with Φ
  - V_{fd} from QV method
  - β value comparison with Dortmund, Hamburg and Ljubljana – agreement with Ljubljana
  - Examples of SCSI in DOFZ (also seen in FZ)
  - Showed no SCSI in MCz
- Other studies (not shown):
  - CCE of MCz, FZ and DOFZ silicon
  - Temperature effects on trapping times
  - Annealing study for DOFZ and MCz silicon

(All of the above will be summarised in an RD50 paper)

Signal treatment

- Deconvolution of the true signal from the measured signal

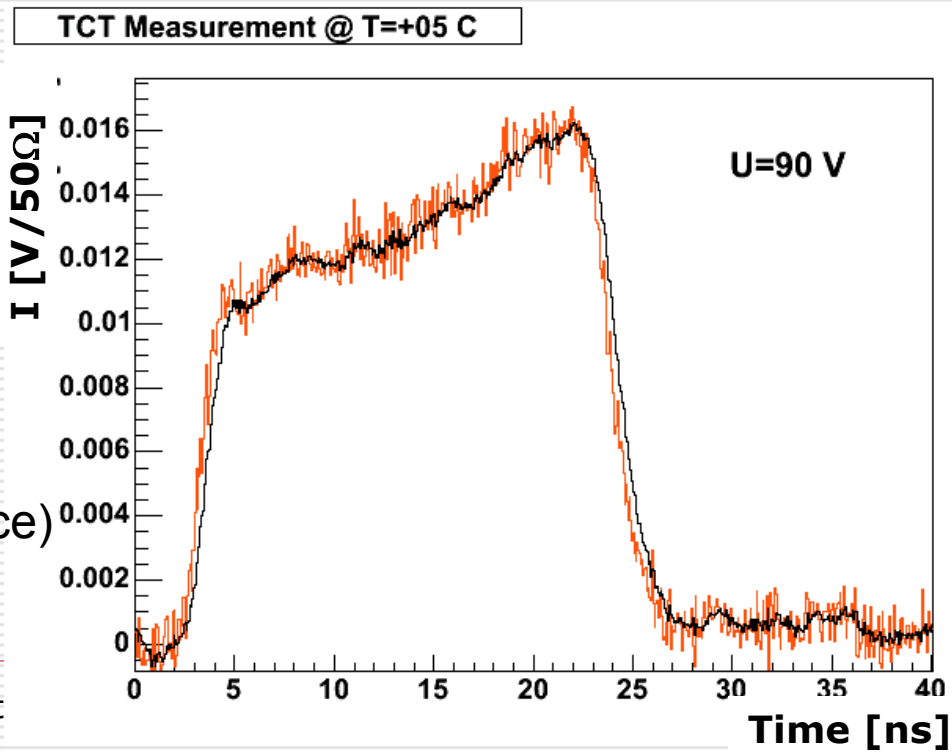
  Measured signal = detector signal ⊗ transfer function

Transfer function:

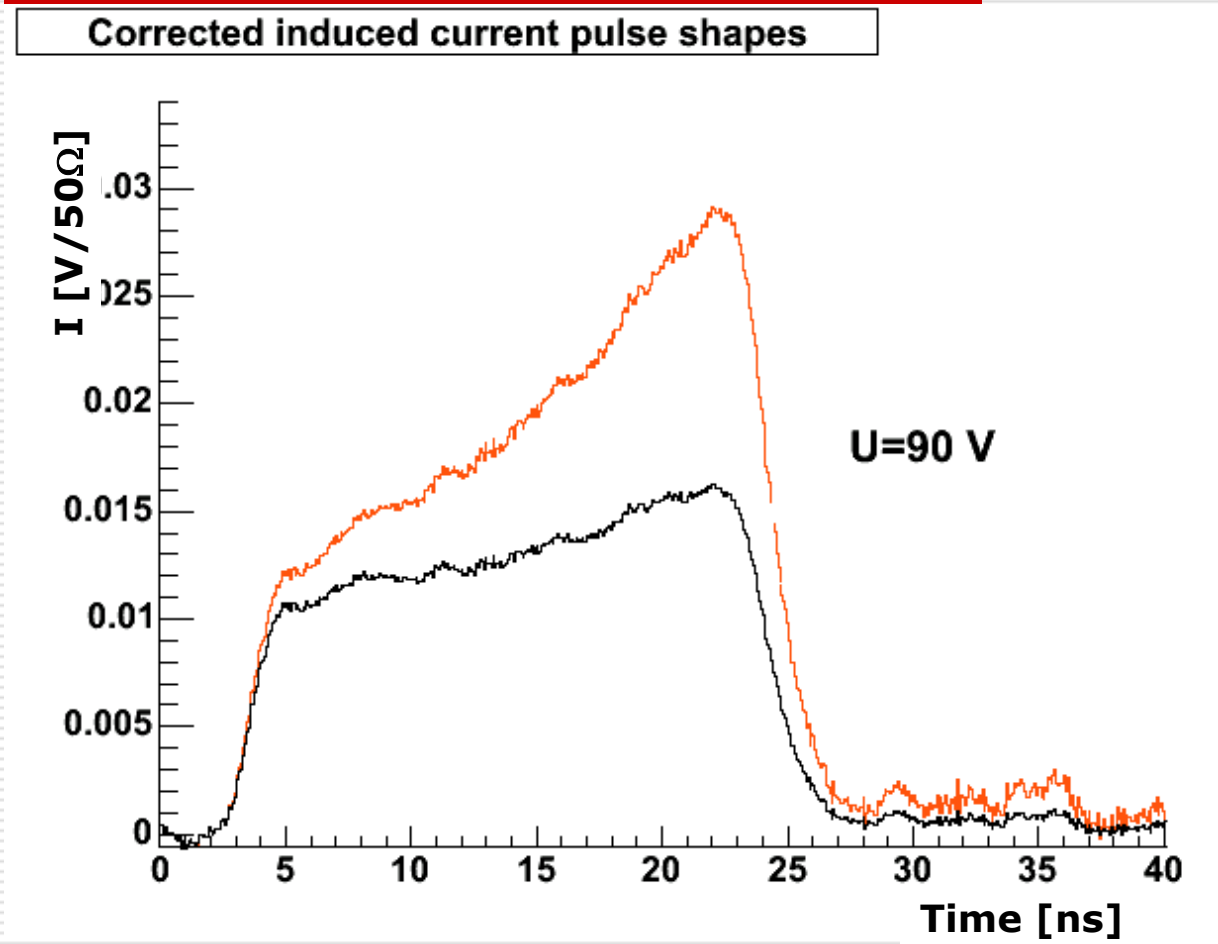
$I(t)=\tau_{TCT}/R \times dU_{osc}(t)/dt + U_{osc}(t)/R$

R = 50Ω from input of preamp

$\tau_{TCT}= RC_d$ (C_d = detector capacitance)



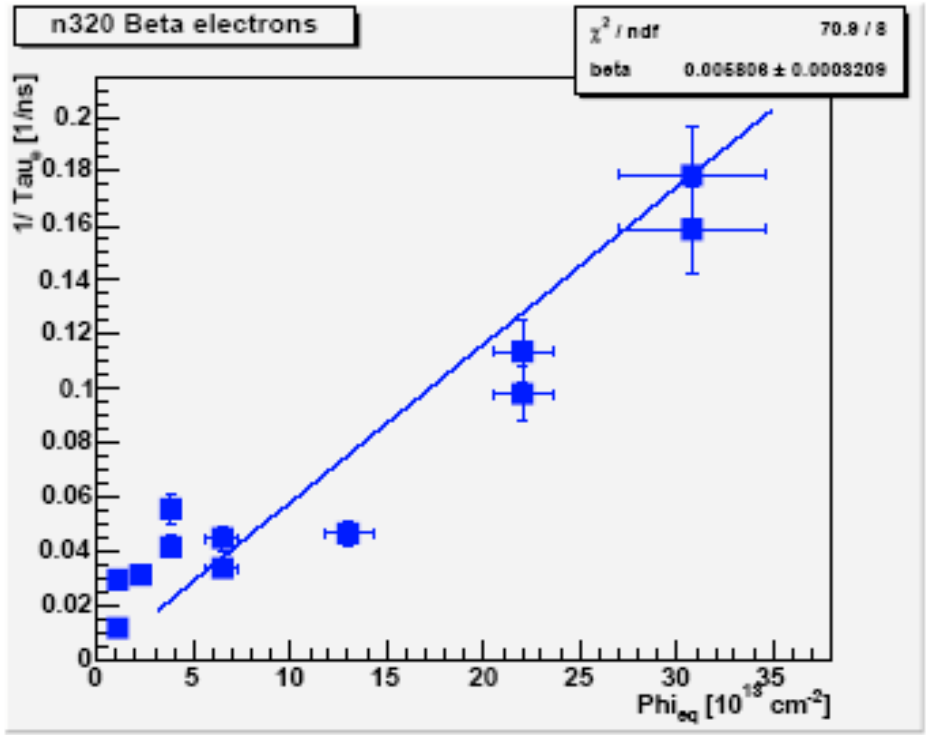
Back up slide 2 – signal examples

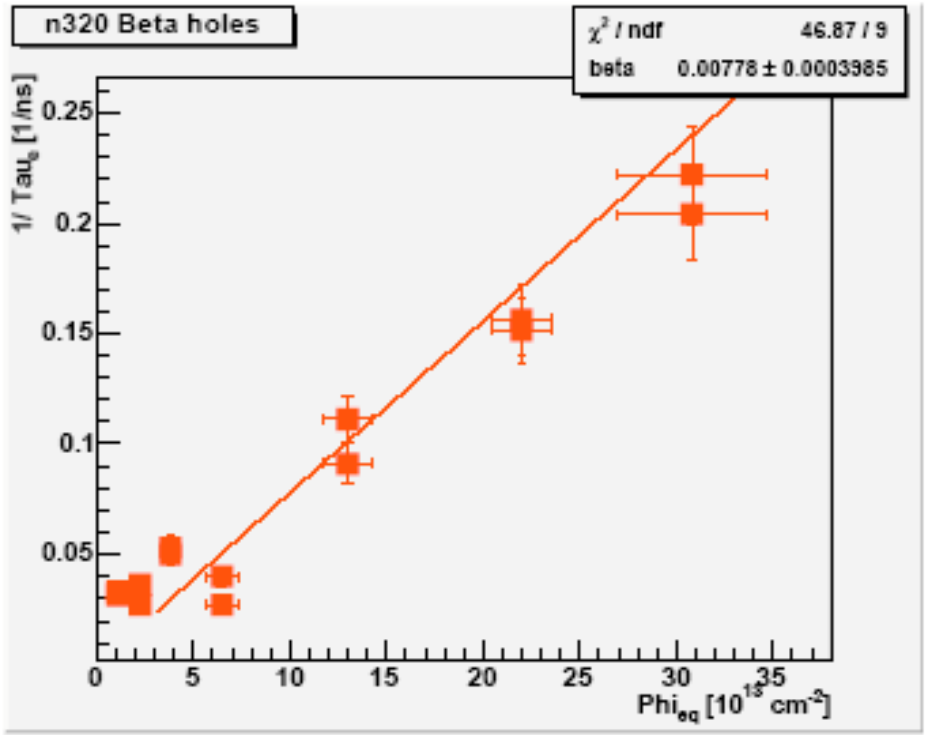


Black = signal as measured on the scope

Red = Trapping corrected signal

MCz $\beta_{e,h}$ fits





Electron injection in MCz at 1.7×10^{13} p/cm^2