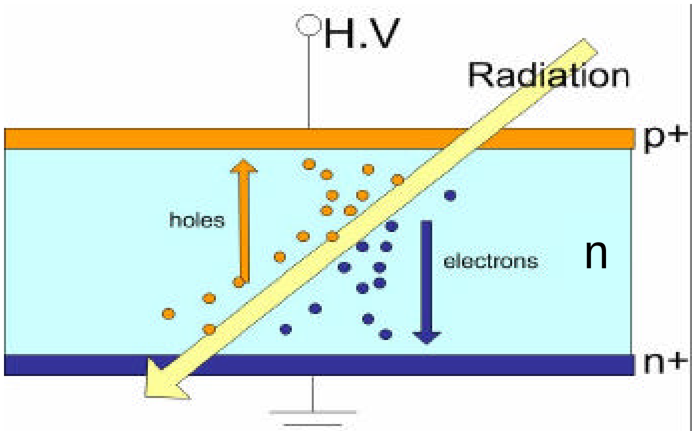
Radiation Damage in Silicon

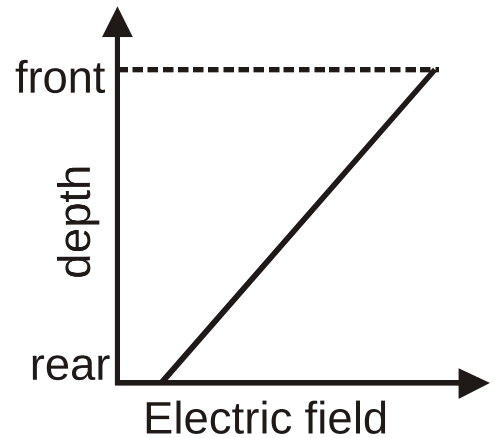
Katharina Kaska

TA1-SD

Alison Bates, Christian Joram, Michael Moll

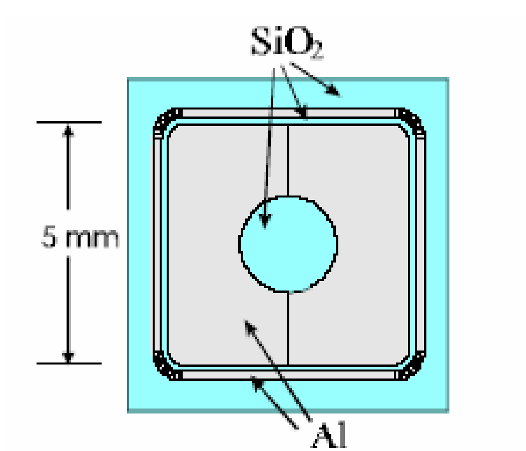
Operation of a detector





Electric field across a new detector

Our test structures



Radiation creates electron and hole pairs

-holes are attracted to the p+ electrode

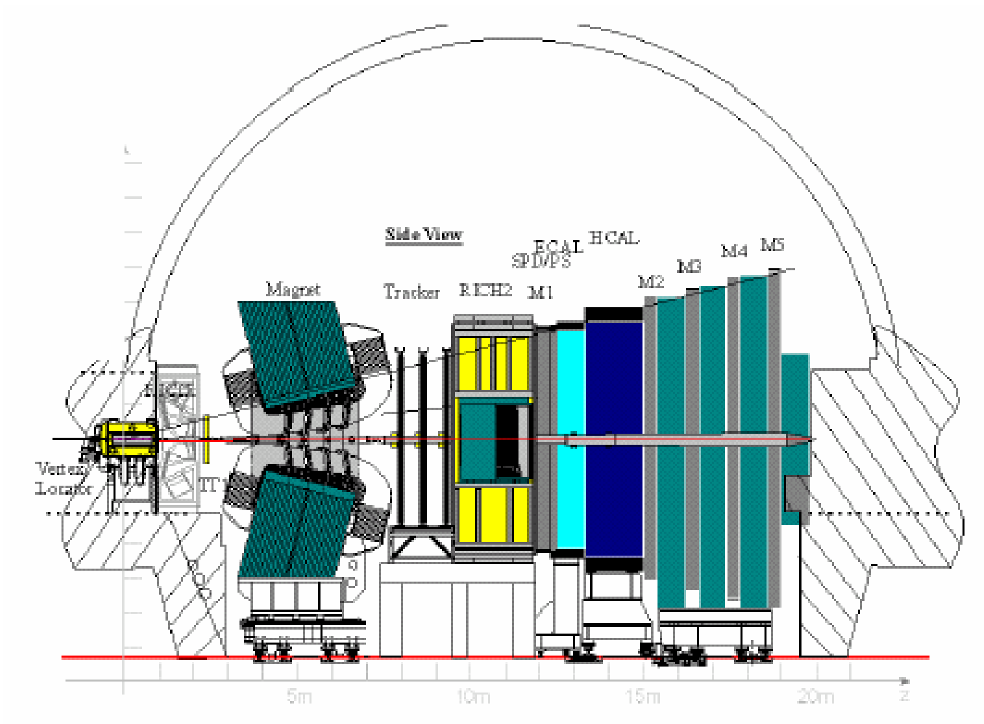
-electrons are attracted to the n+ electrode

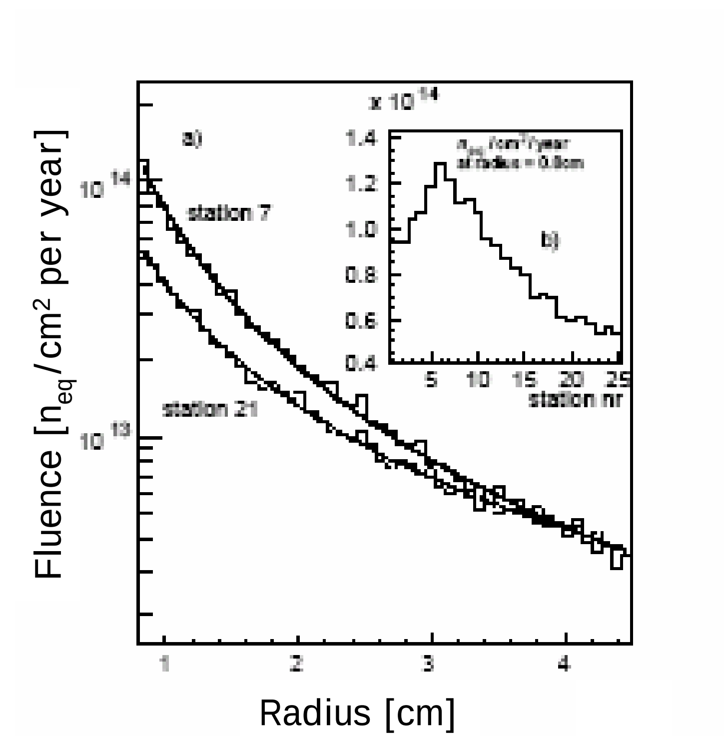
Movement of charge carriers induces a signal.

Why radiation hard silicon?

Example: LHCb VELO (VErtex LOcator) detector:

- 8 mm away from the beam (10^{14} 1 MeV n_{eq})
- new detectors needed within ~3 years





Defects in Silicon

Main (macroscopic) effects of radiation damage in silicon:

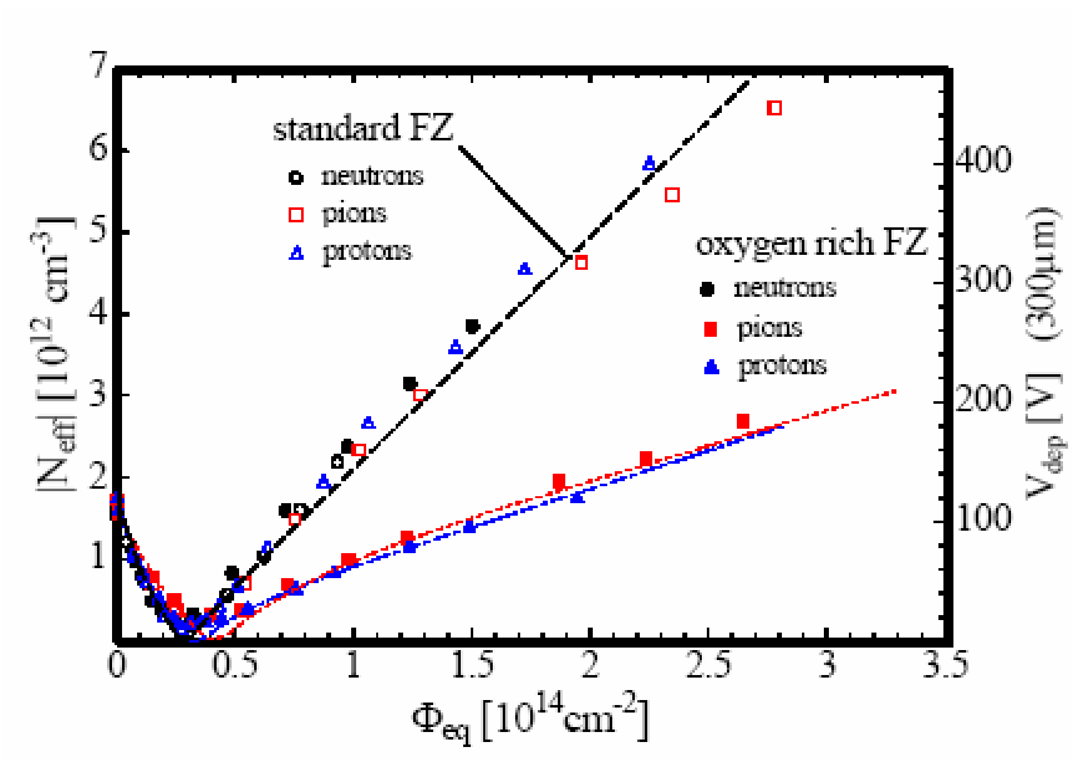
- Increased leakage current
- Increased depletion voltage
- Increased trapping

Types of Silicon

Float Zone (FZ) silicon: $1x10^{15}$ O cm^{-3}

Oxygenated silicon: $1x10^{17}$ O cm^{-3}

Czochralski (CZ) silicon: $1x10^{18}$ O cm^{-3}



Oxygenated silicon seems to be better than Float Zone silicon.

CV and IV measurements

Capacitance [C] and Current [I] vs. Voltage

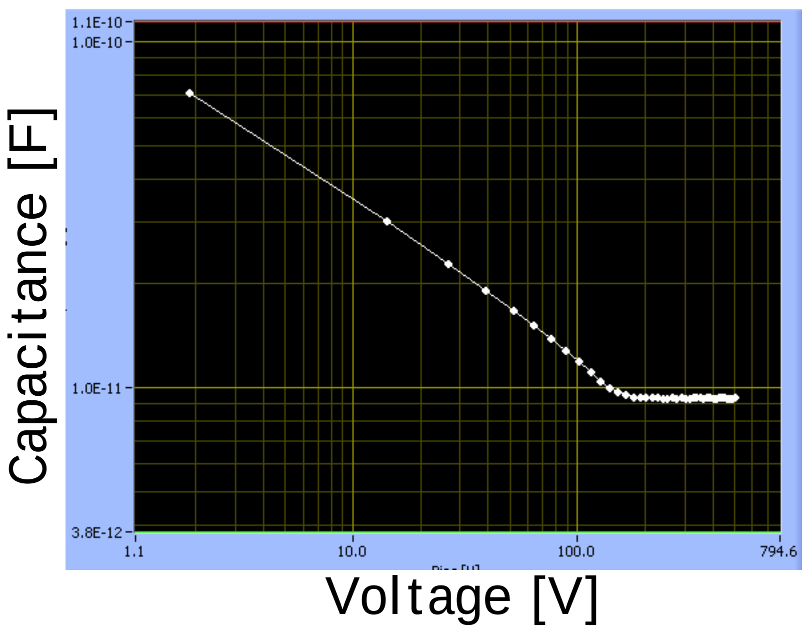
can be used to determine:

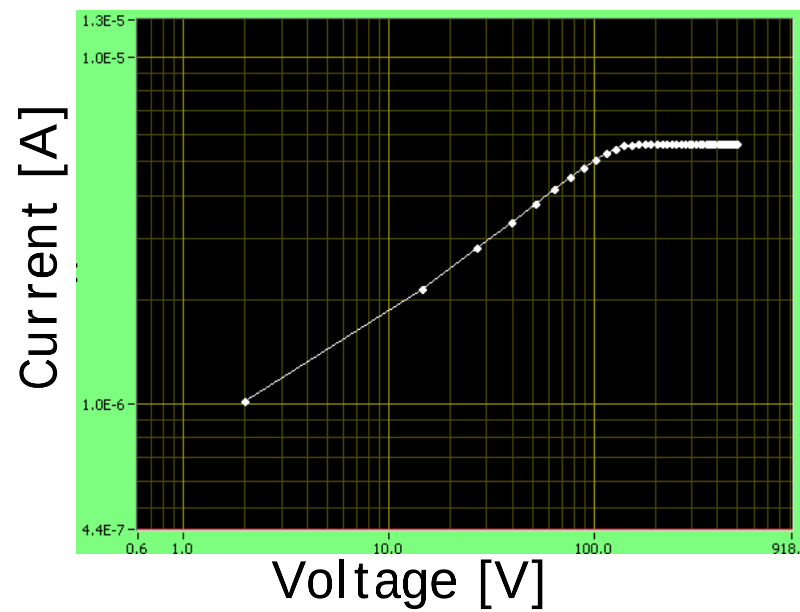
CV

- Full depletion voltage
- End capacitance

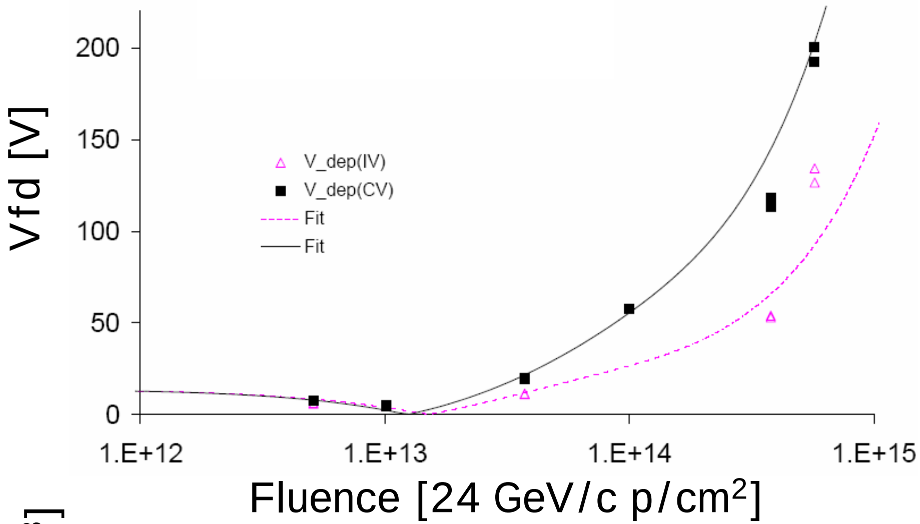
IV

- Full depletion voltage
- Leakage current



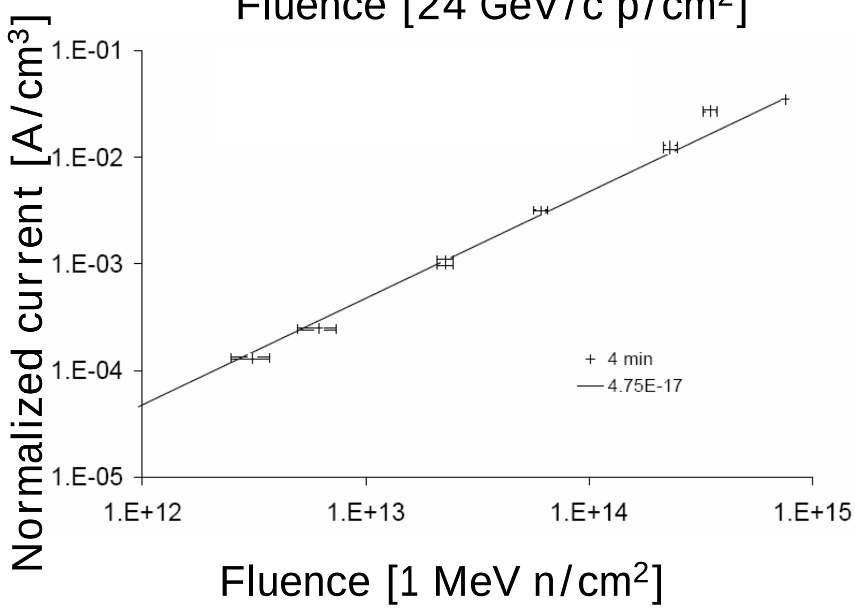


Results for irradiated detectors



W317 (DOFZ)
oxygenated

Annealed for 4 min/80°C



Leakage current normalized to volume

$\alpha = 4.75 \times 10^{-17}$ A/cm

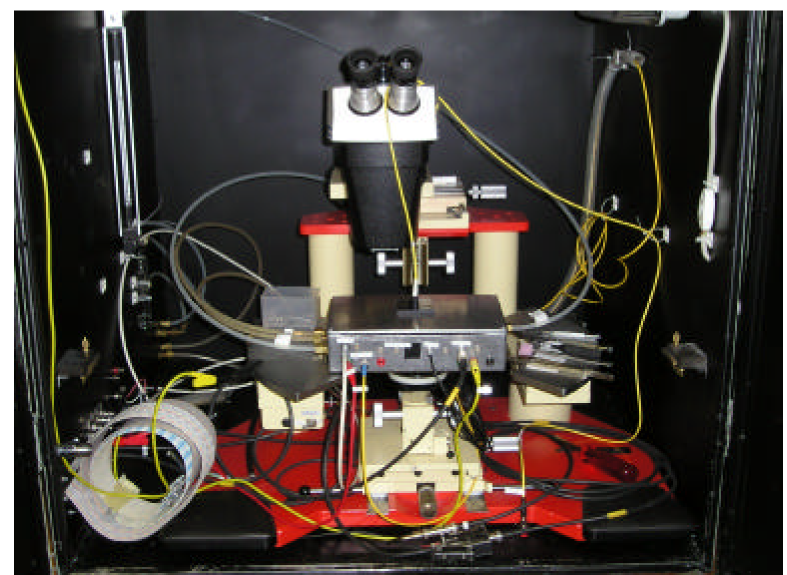
Previous works (M. Moll):

$\alpha = 4.56 \times 10^{-17}$ A/cm

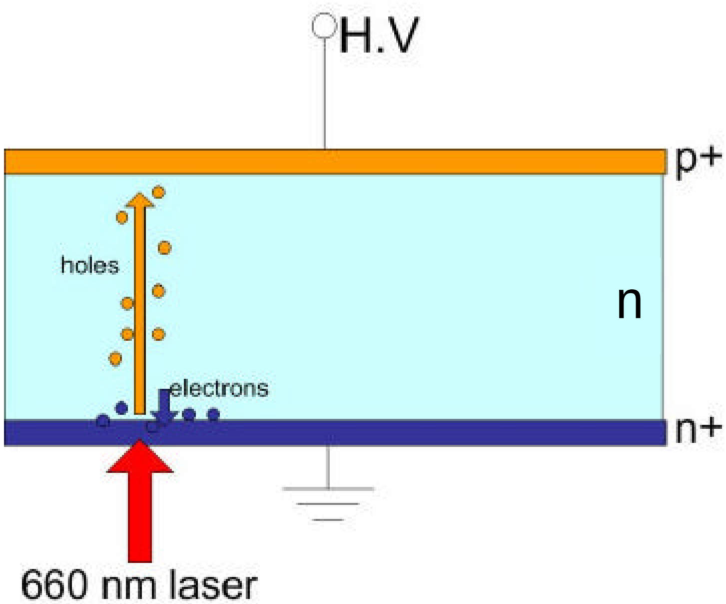
Transient Current Technique

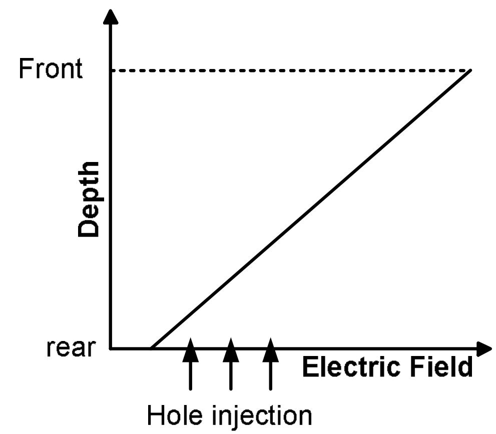
A technique to study radiation damage in silicon by measuring:

- Full depletion voltage
- Effective trapping time
- Sign of space charge

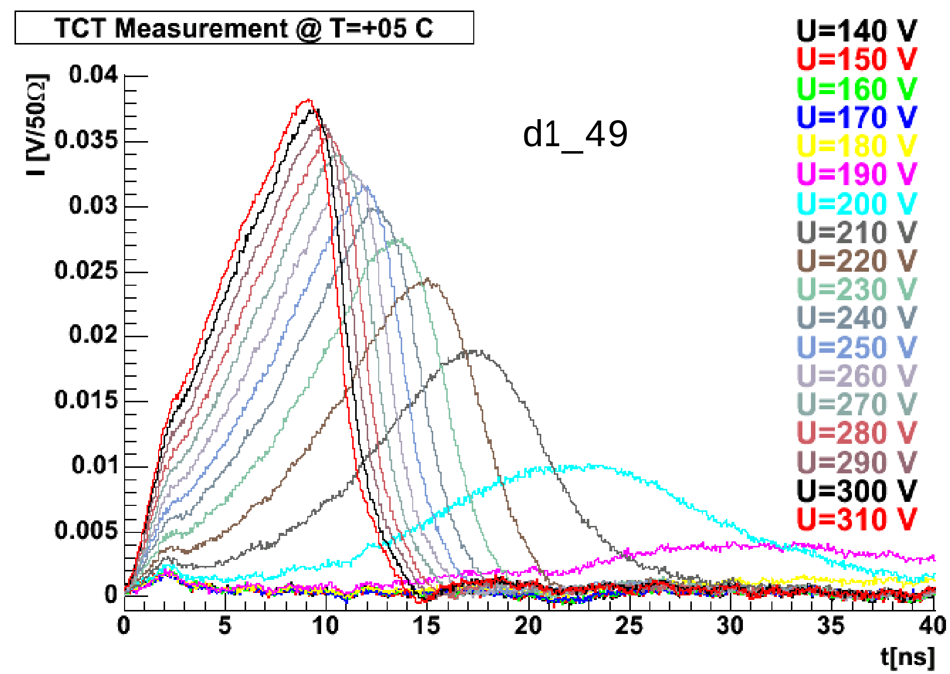


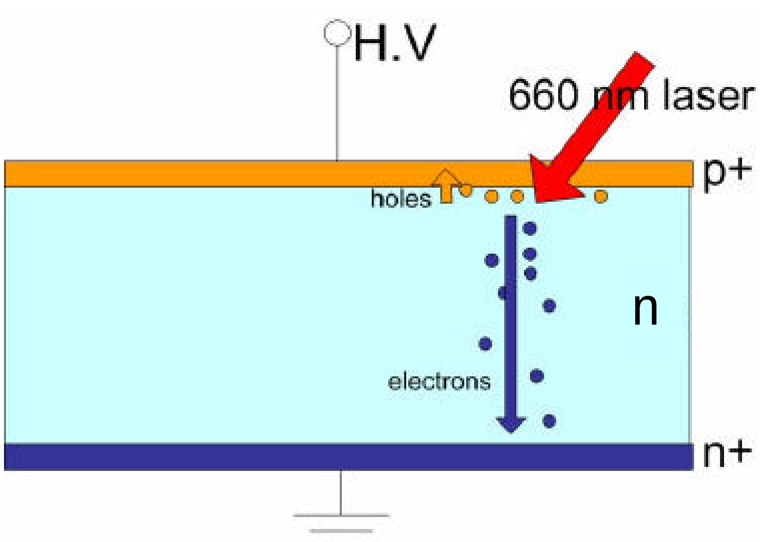
How does TCT work?

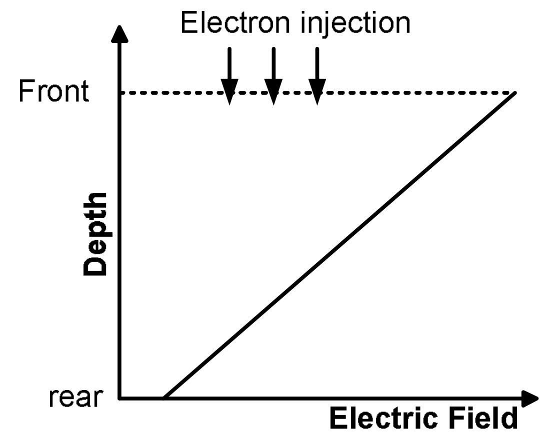




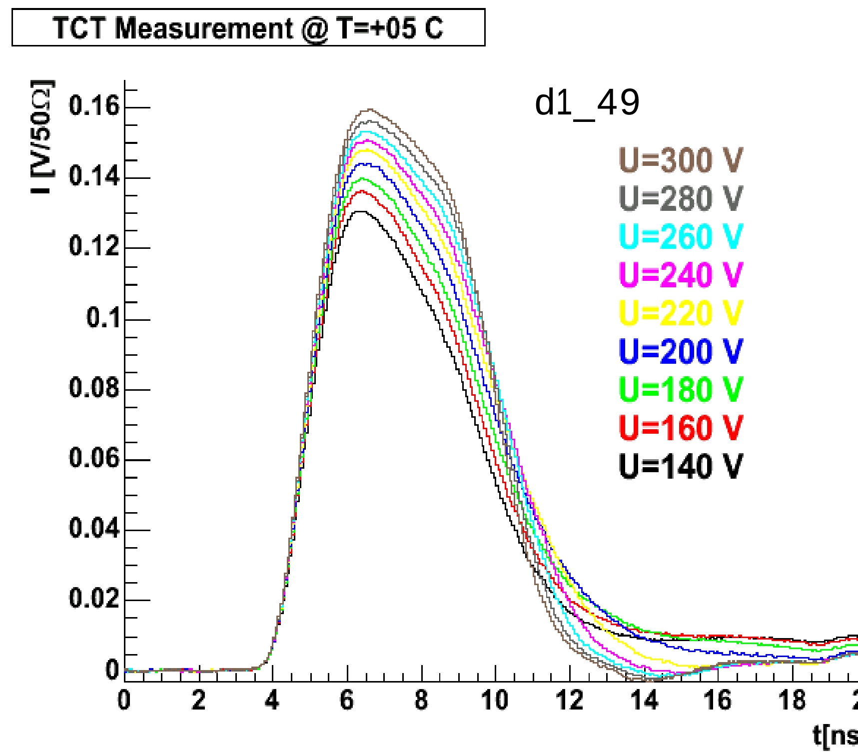
hole dominated signal





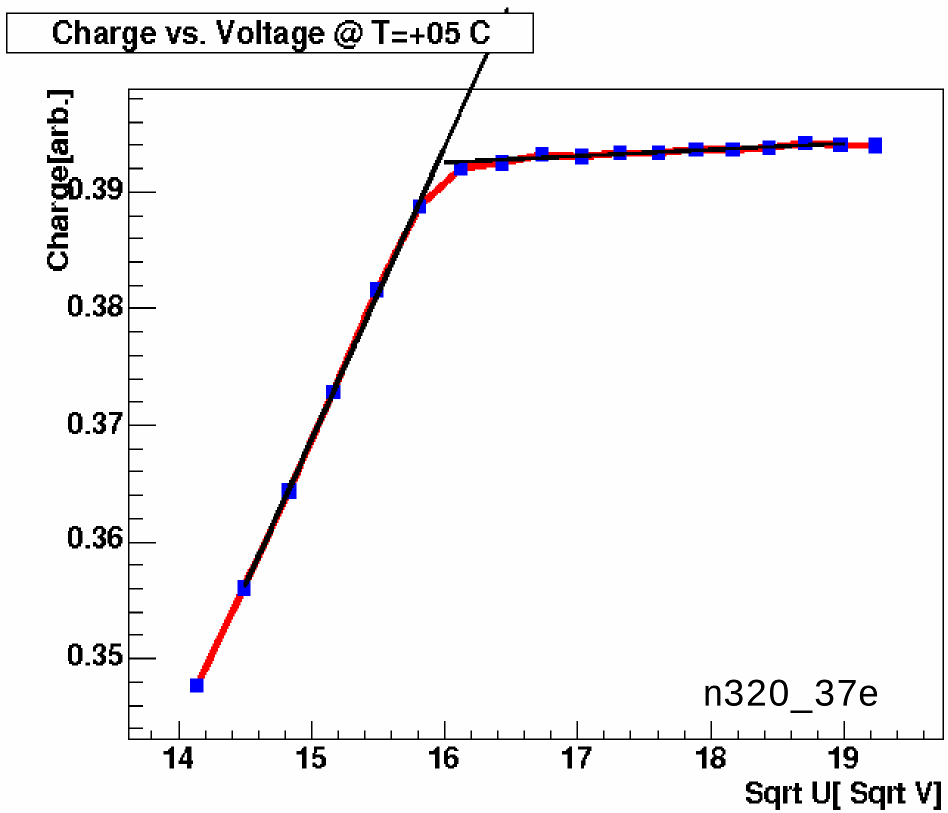


electron dominated signal



QV method

Charge vs. Voltage



The QV-method can be used to get the full depletion voltage

$$Q = \int_{t_0}^{t_1} I(t)dt$$

Effective trapping time

Charge gets trapped in the detector due to radiation induced defects.

The amount of charge trapped depends on the number of defects (hence on the fluence) and also on the applied voltage (over full depletion):

Higher voltage

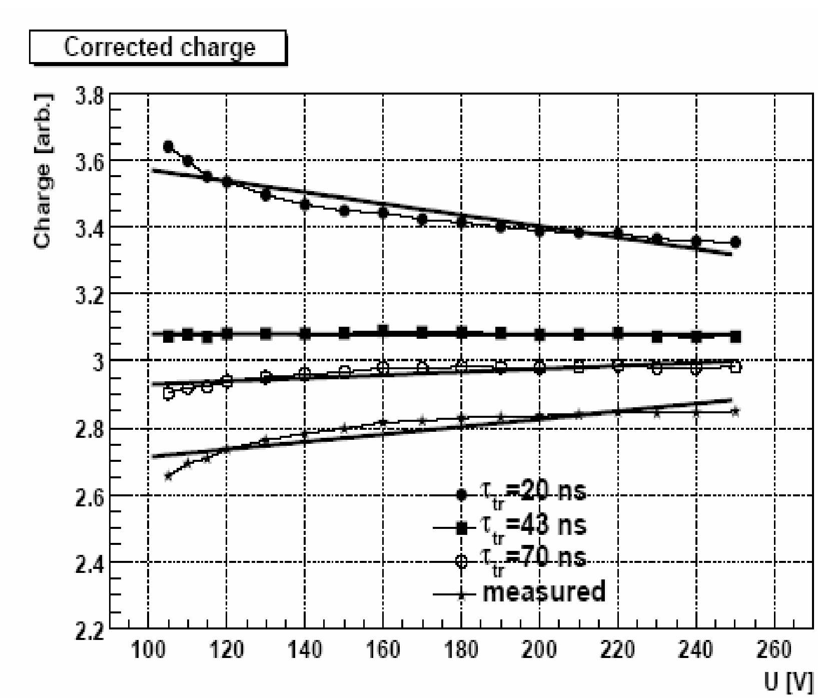
-> higher drift velocity

-> fewer charge carriers trapped

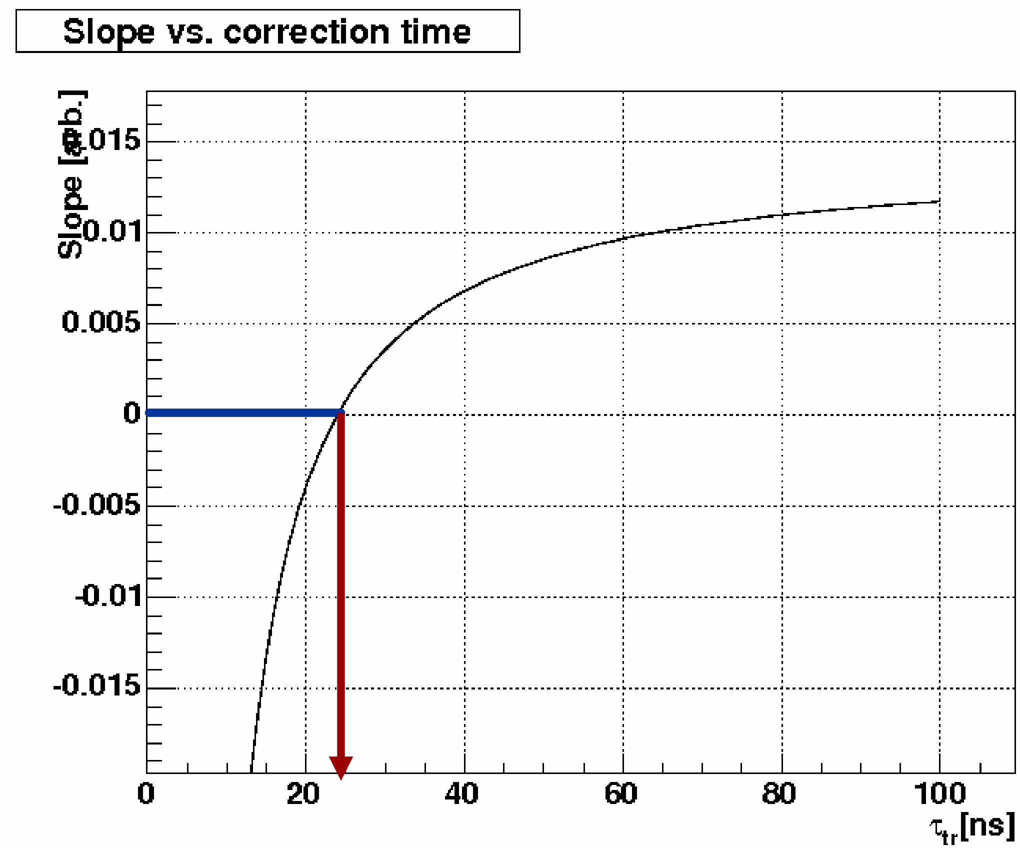
-> more charge measured

How to get the trapping time?

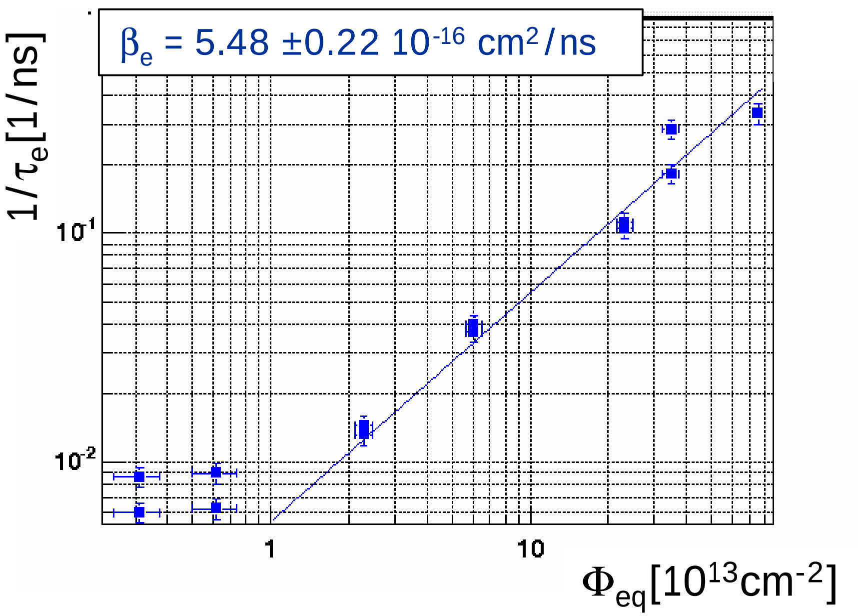
The corrected charge is constant with voltage ($V>V_{FD}$)

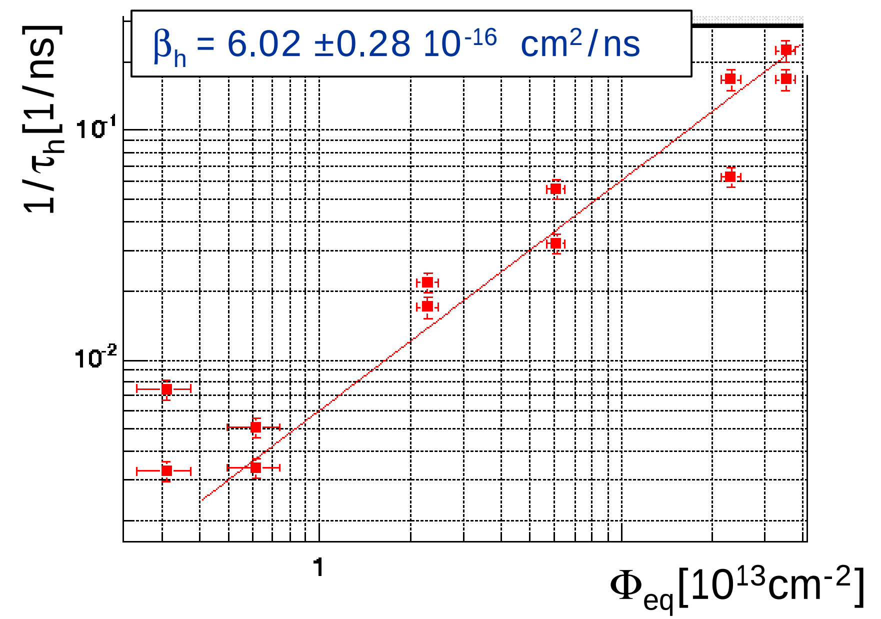


$$Q(t)=\int I_0(t)dt=\int I(t)e^{-\frac{t}{t}}dt$$



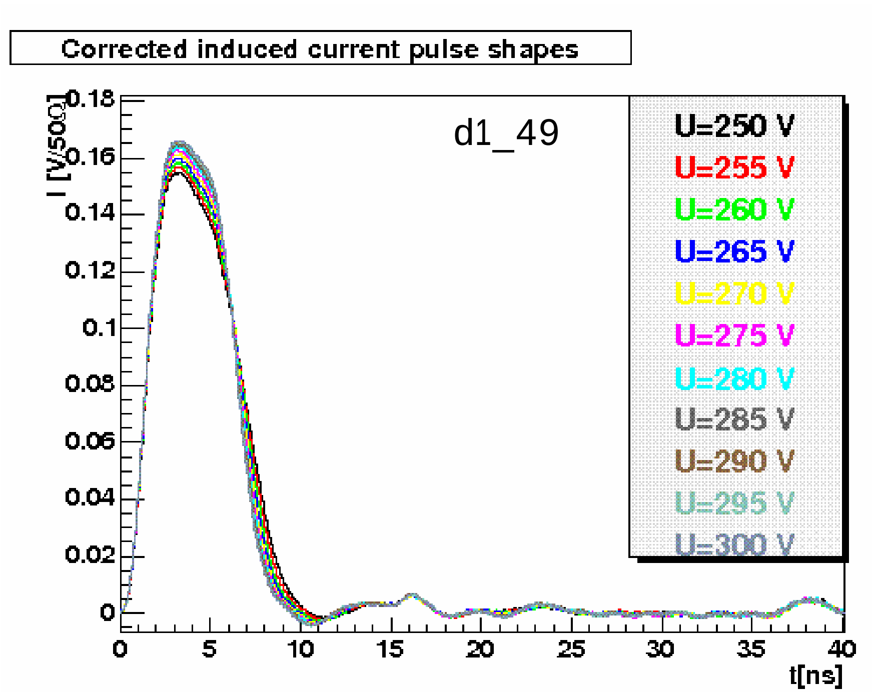
b - values



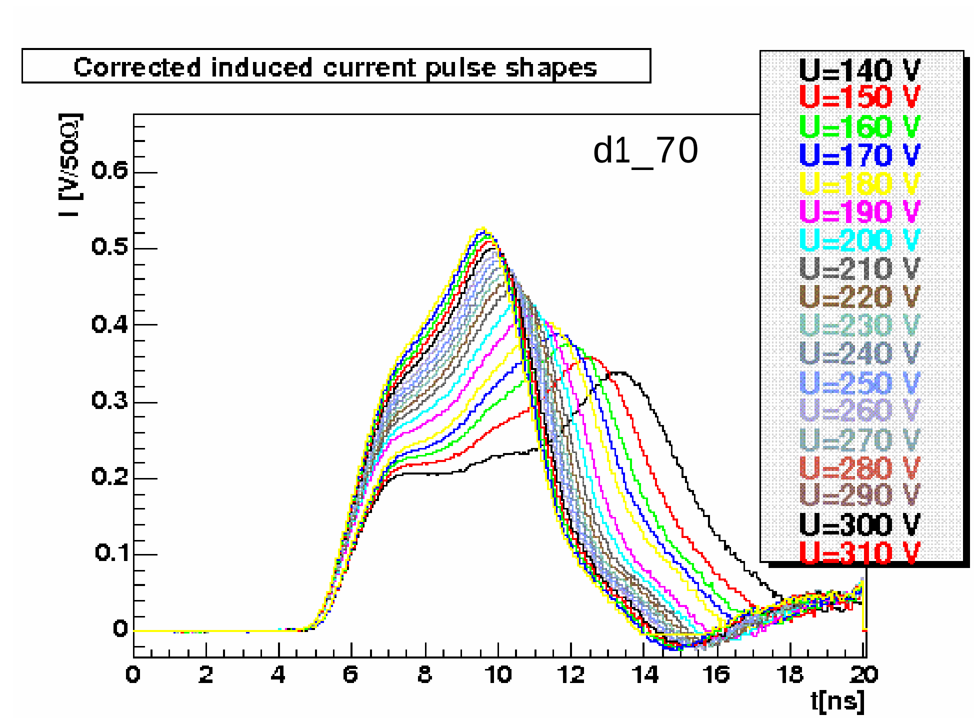


University	b$_e$ **10^{-16} cm^2/ns**	b$_h$ **10^{-16} cm^2/ns**	**Reference**
Dortmund	5.16 ± 0.16	5.04 ± 0.16	O. Krasel et al., 2nd RD50 workshop
Ljubljana	5.6 ± 0.2	7.7 ± 0.2	G. Kramberger et al, NIAM A481 (2002) 297-305
Hamburg	4.85 ± 0.15	5.72 ± 0.5	E. Fretwurst et al., 3rd RD50 workshop

Type inversion



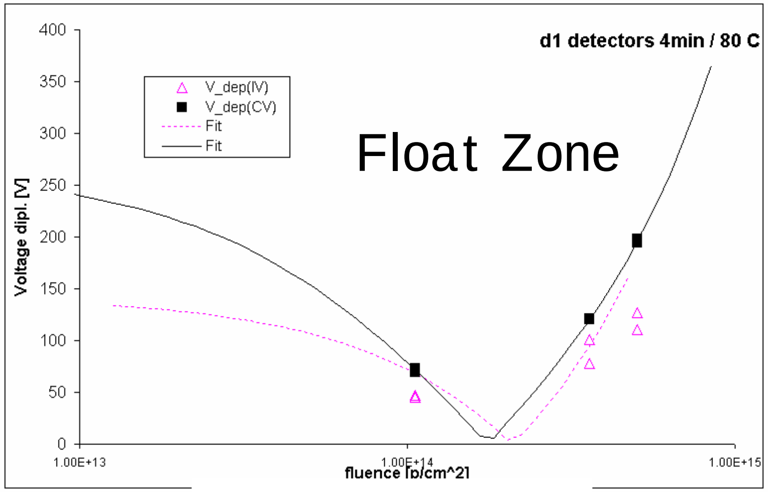
electron signal before type inversion



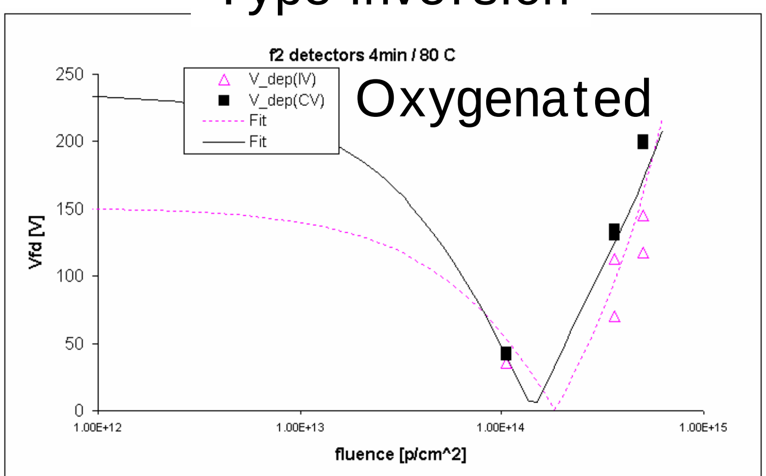
electron signal after type inversion

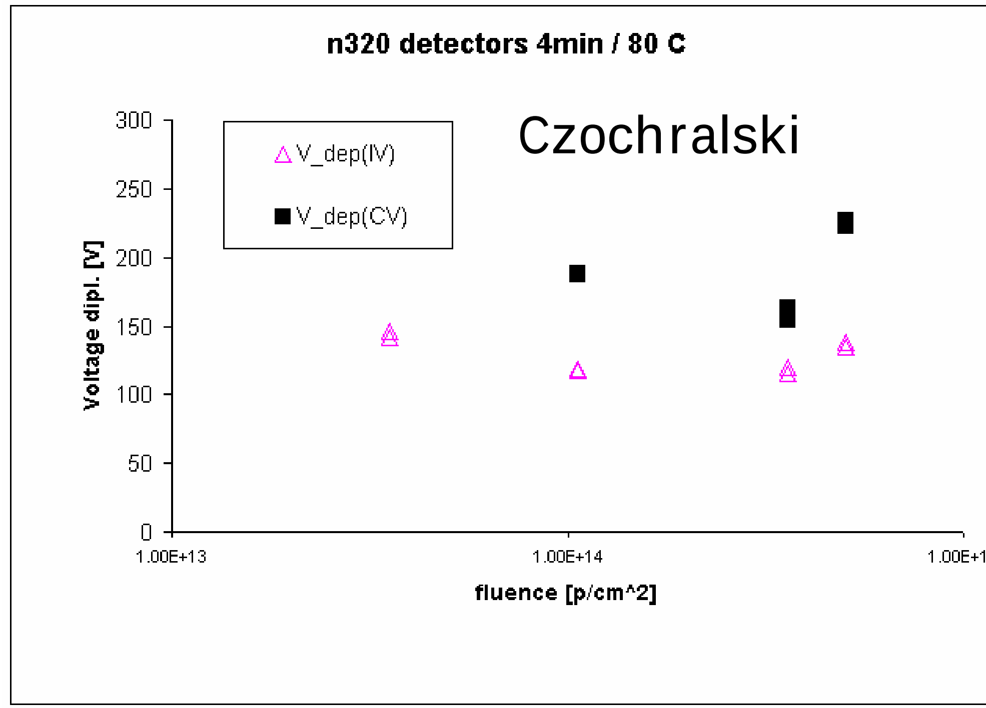
Results for Cz Silicon

From IV-CV measurements:



Type inversion

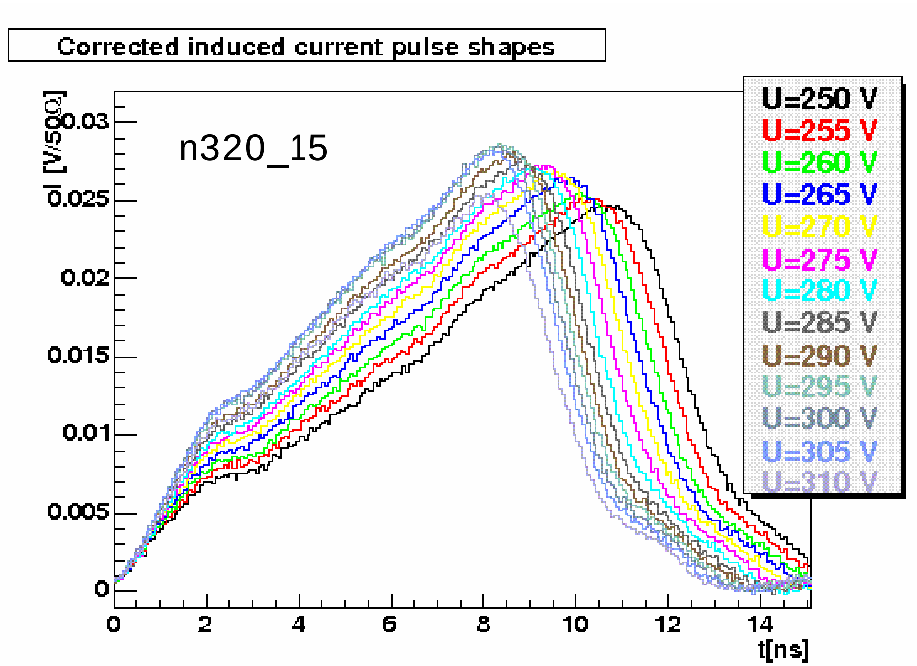


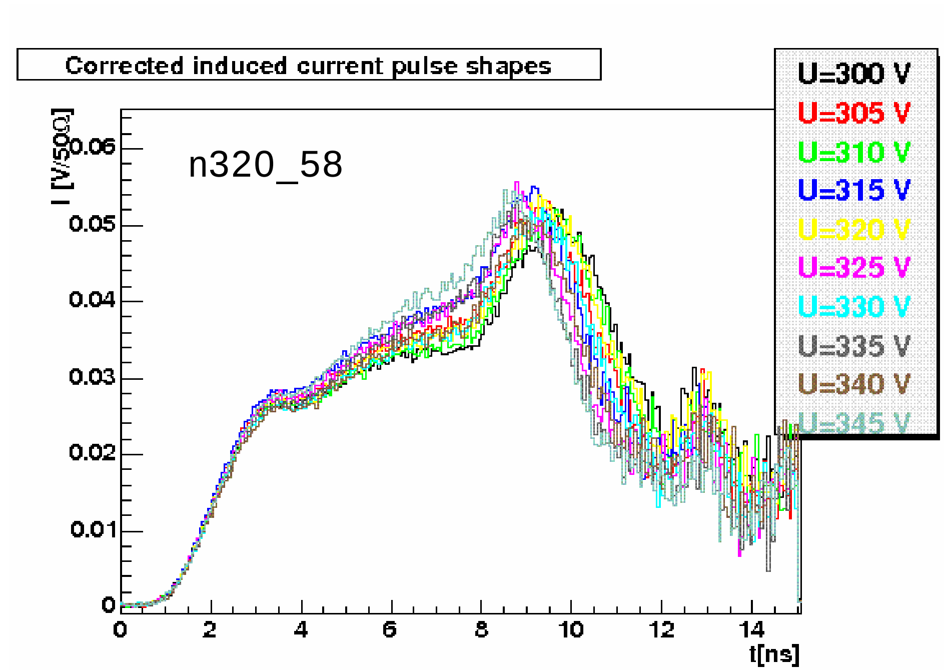


Type inversion....?

TCT can determine the space charge:

(i.e. whether the bulk is still n-type or has changed to p-type)





No type inversion up to $5x10^{14}$ p/cm^2 in CZ silicon

Conclusions

- Float Zone and Oxygenated silicon type invert
- The QV method is complementary to CV and IV to determine the depletion voltage
- Preliminary β-values for electrons agree with previous results, holes agree with Hamburg group (for W317)
- Czochralski silicon doesn't type invert up to $5x10^{14}$ p/cm2

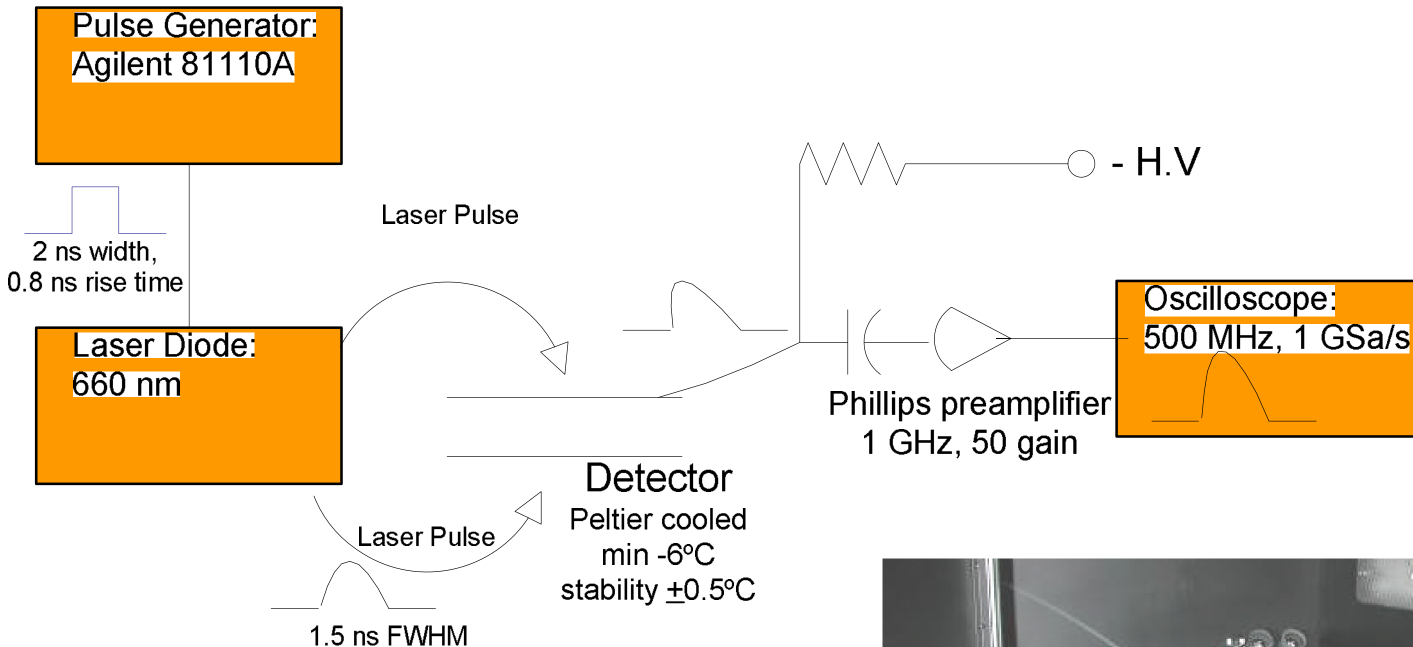
QUESTIONS?????

Irradiation and annealing

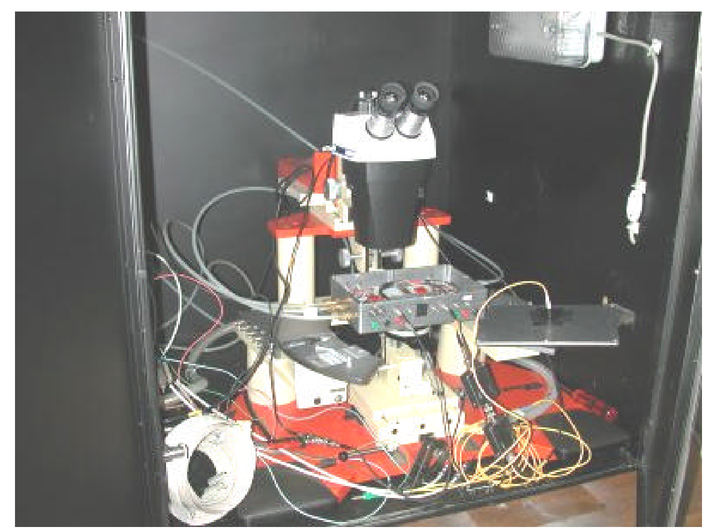
The samples are irradiated with a fluence between $10^{12} - 10^{15}$ p/cm^{-2} (24 GeV protons) at IRRAD1 (PS).

Before measurements the detectors are annealed to remove movable carriers and get them all on the same damage level.

TCT Setup



Pulse Generator:
Agilent 81110A
2 ns width,
0.8 ns rise time
Laser Diode:
660 nm
Laser Pulse
Laser Pulse
1.5 ns FWHM
Detector
Peltier cooled
min -6ºC
stability ±0.5ºC
- H.V
Phillips preamplifier
1 GHz, 50 gain
Oscilloscope:
500 MHz, 1 GSa/s



How to get the trapping time?

Due to trapping the current measured
is lower than the actual current I_0:

$$I(t) = I_0(t)e^{-\frac{t}{t}}$$

From this relation follows for the charge

$$Q(t) = \int I_0(t)dt = \int I(t)e^{-\frac{t}{t}}dt$$