Radiation Damage in Silicon

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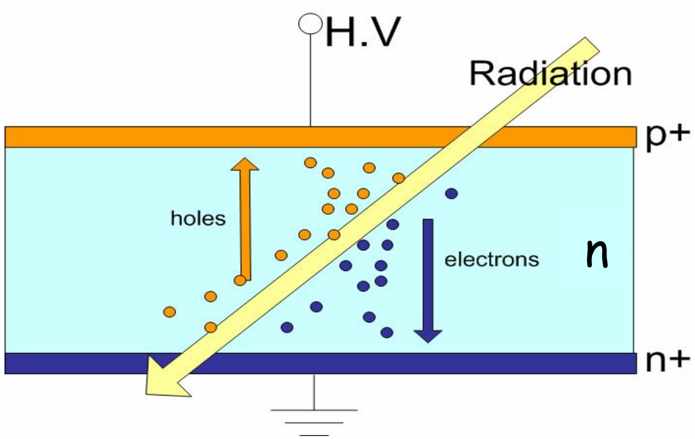
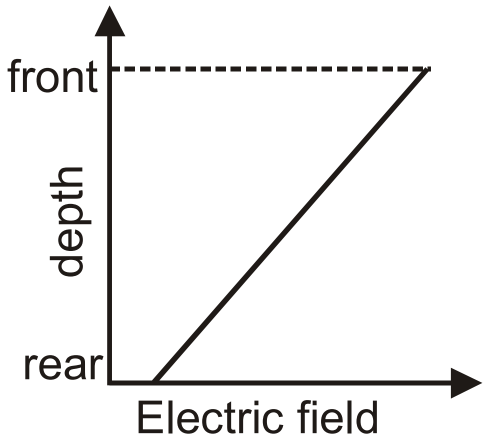
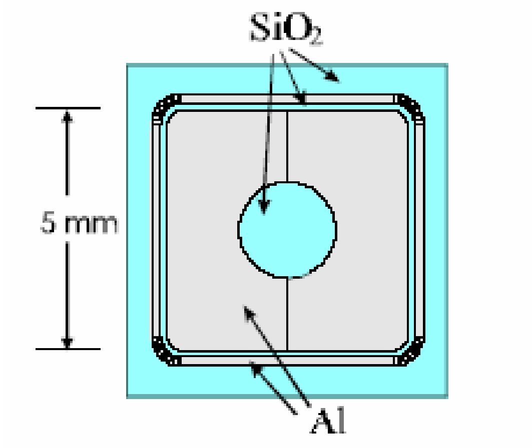
Operation of a detector





Electric field across a new detector

Our test structures



Radiation creates electron and hole pairs

-holes are attracted to the p+ electrode

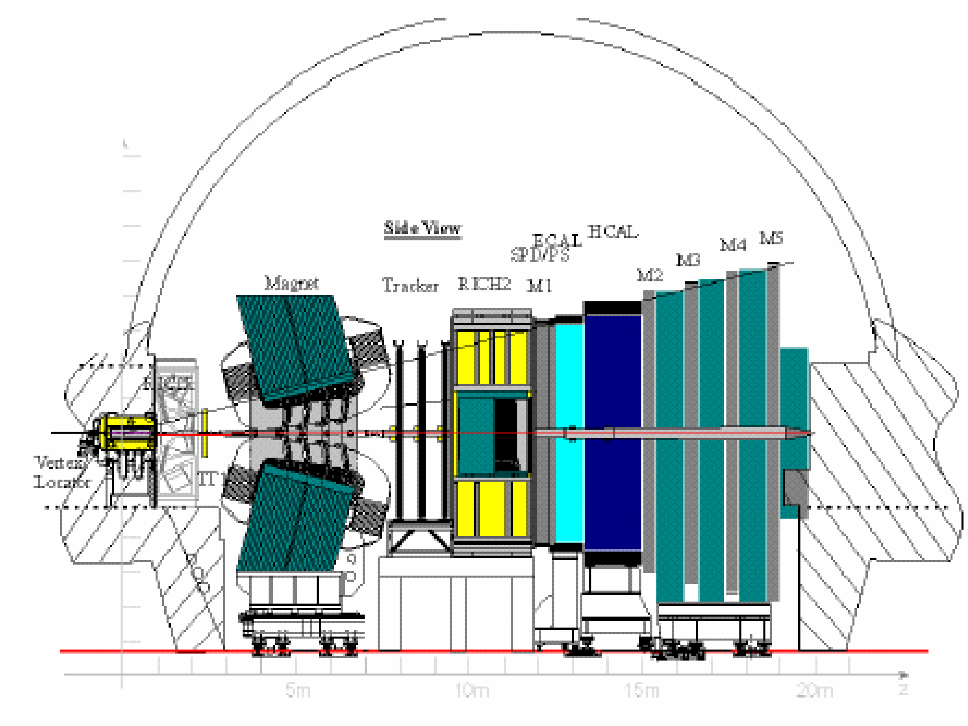
-electrons are attracted to the n+ electrode

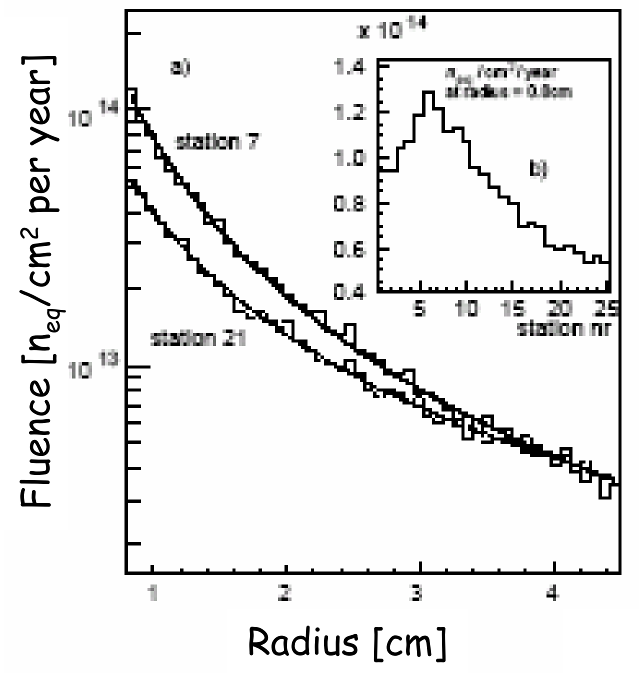
Movement of charge carriers induces a signal.

Why radiation hard silicon?

LHCb VELO (VErtex LOcator) detector:

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





Defects in Silicon

Main (macroscopic) effects of radiation damage in silicon:

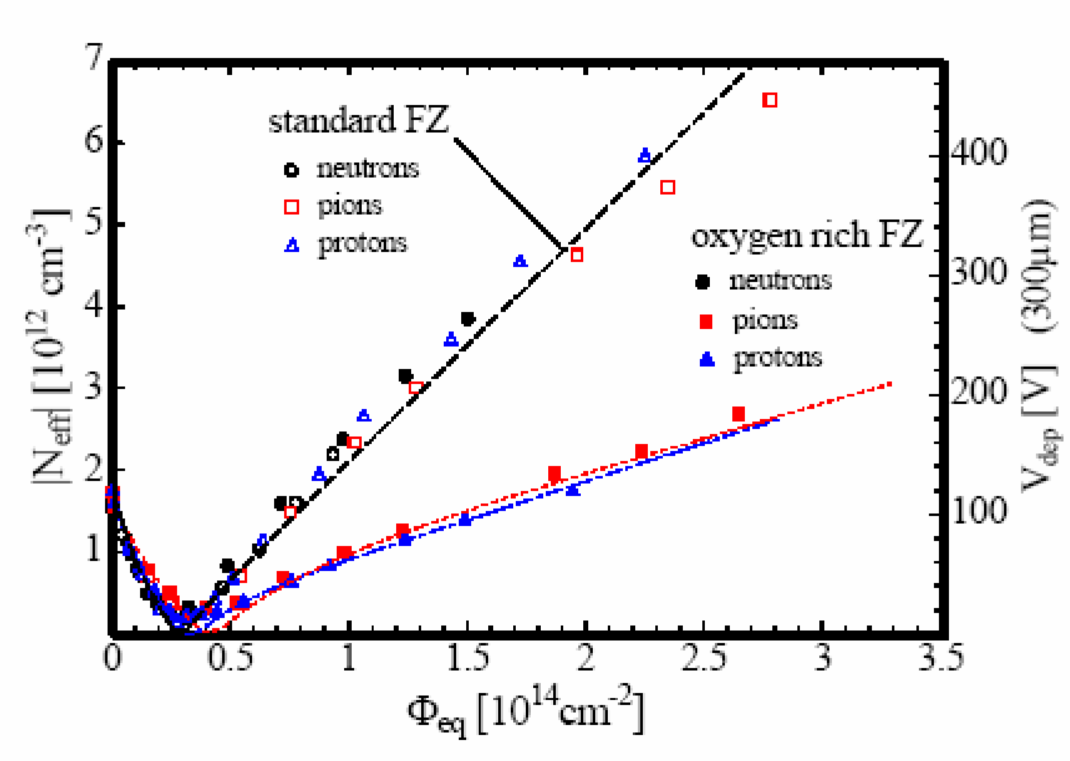
- Increased leakage current
- Increased depletion voltage
- Increased trapping

Types of Silicon

Float Zone (FZ) silicon: $1x10^{-15}$ cm^{-3} O_2

Oxygenated silicon: $1x10^{-17}$ cm^{-3} O_2

Czochralski (CZ) silicon: $1x10^{-18}$ cm^{-3} O_2



Oxygenated silicon seems to be better than Float Zone silicon.

CV and IV measurements

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

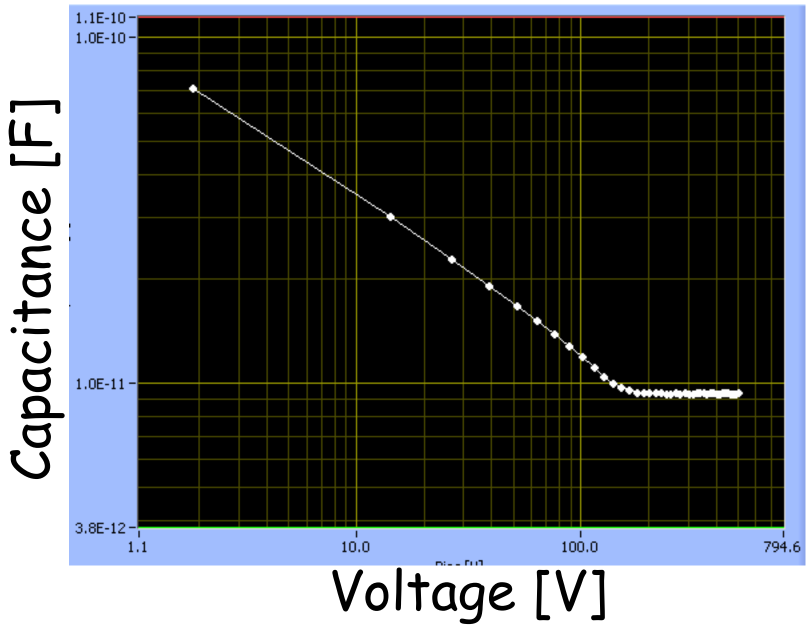
can be used to determine:

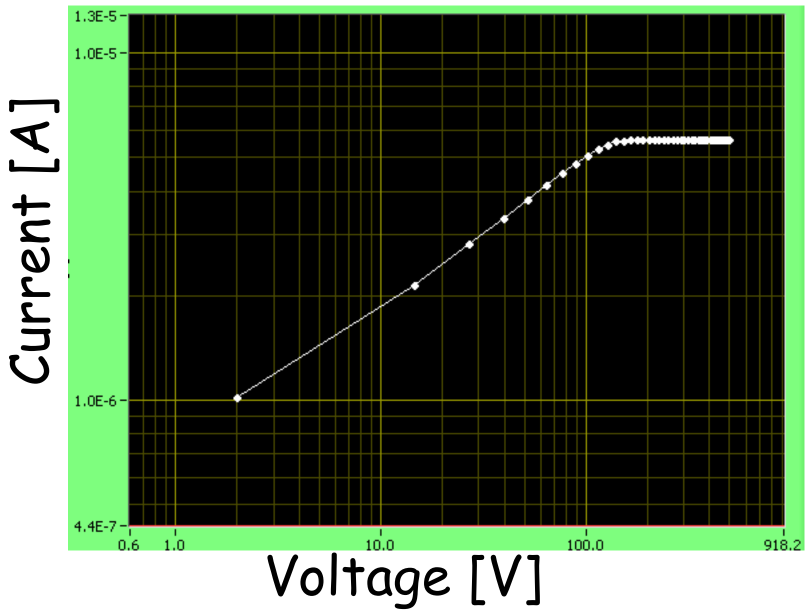
CV

- Full depletion voltage
- End capacitance

IV

- Full depletion voltage
- Leakage current

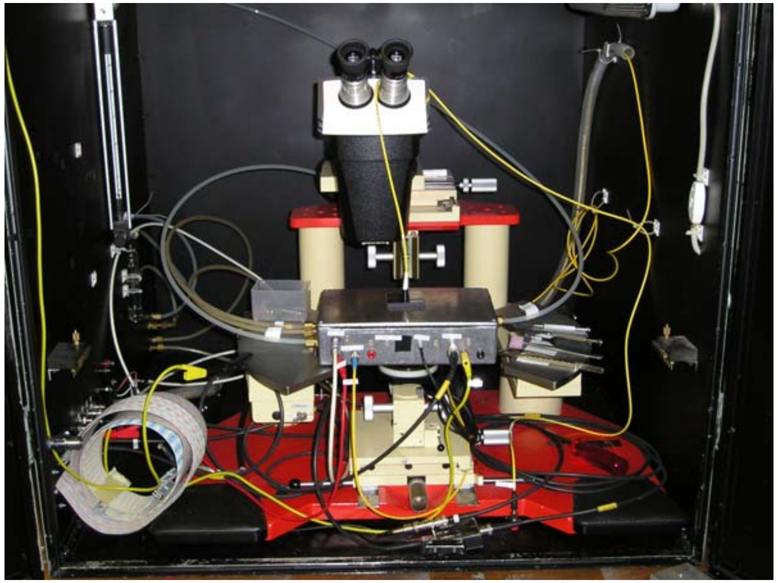




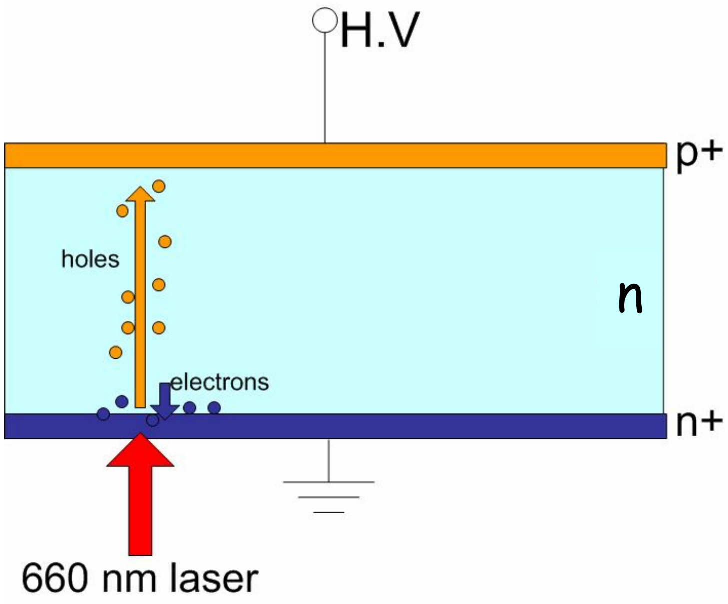
Transient Current Technique

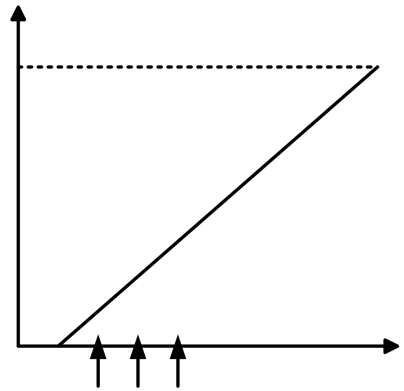
A technique to study radiation damage in silicon by measuring:

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

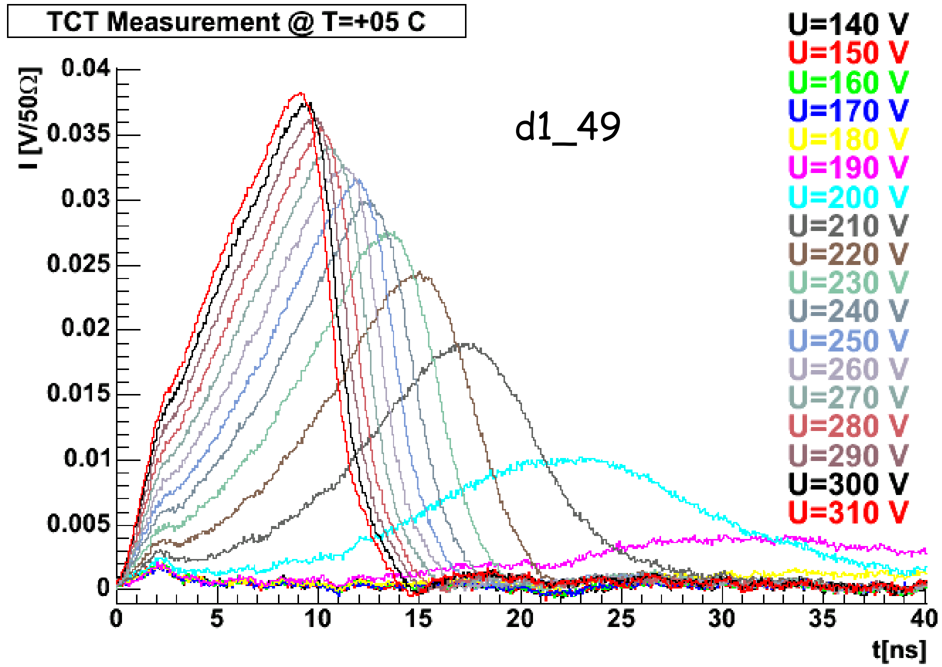


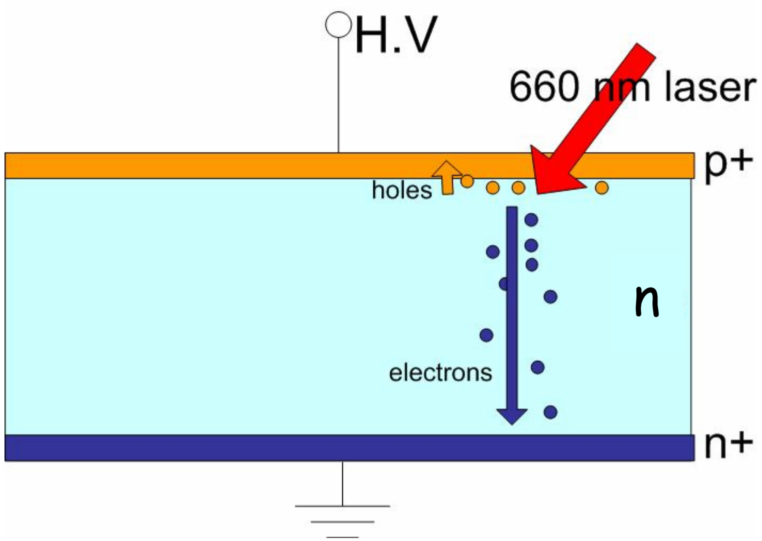
How does TCT work?

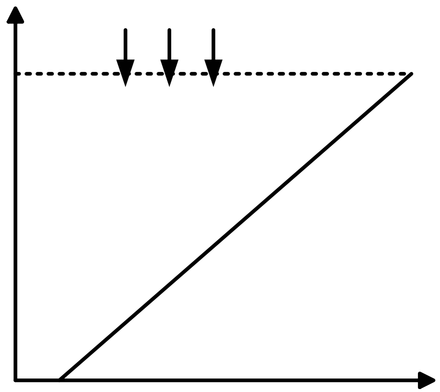




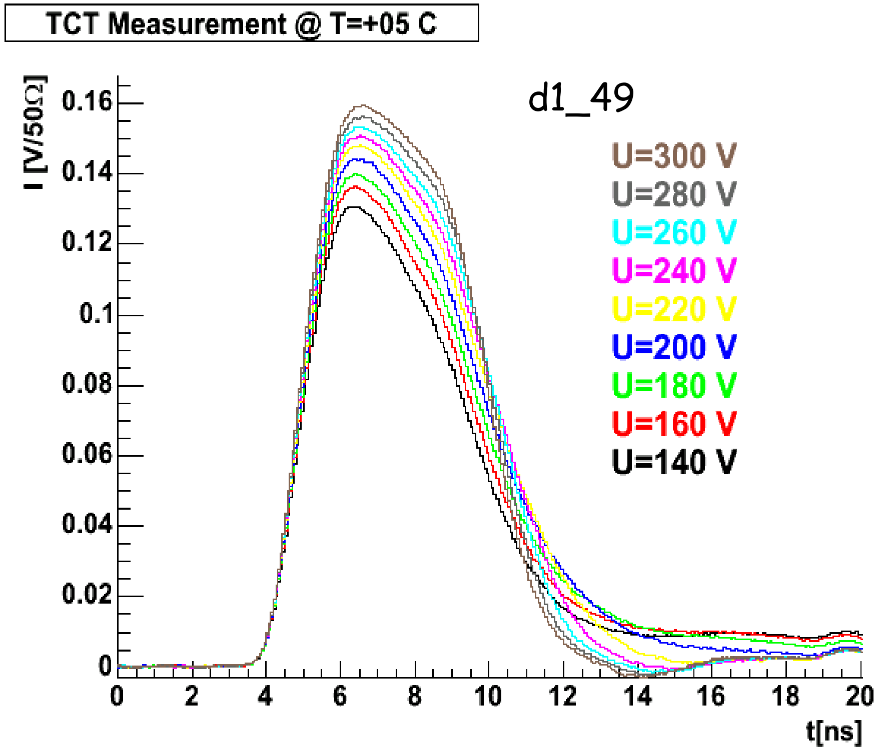
hole dominated signal





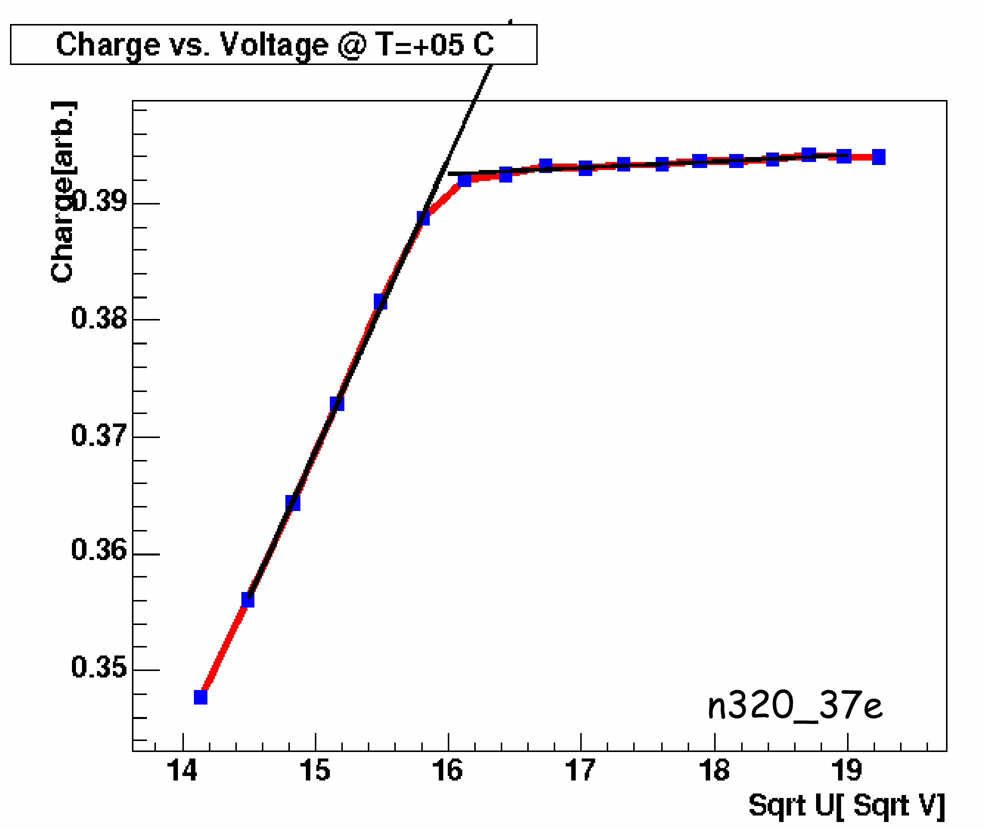


electron dominated signal



QV method

Charge vs. Voltage



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

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

We have found that the QV method is compatible with the IV and CV method.

Effective trapping time

Charge gets trapped in the detector due to radiation damage.

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

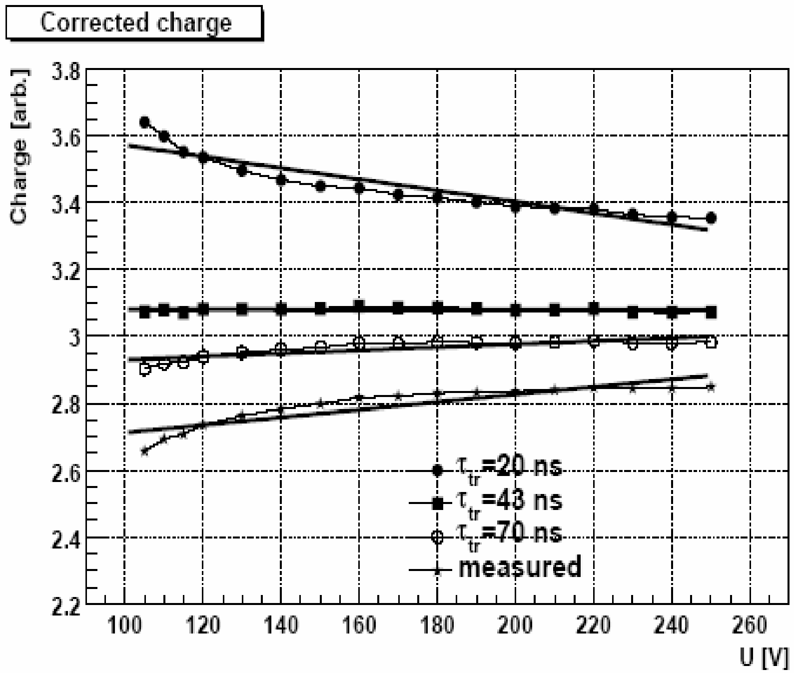
-> higher drift velocity

-> fewer charge carriers trapped

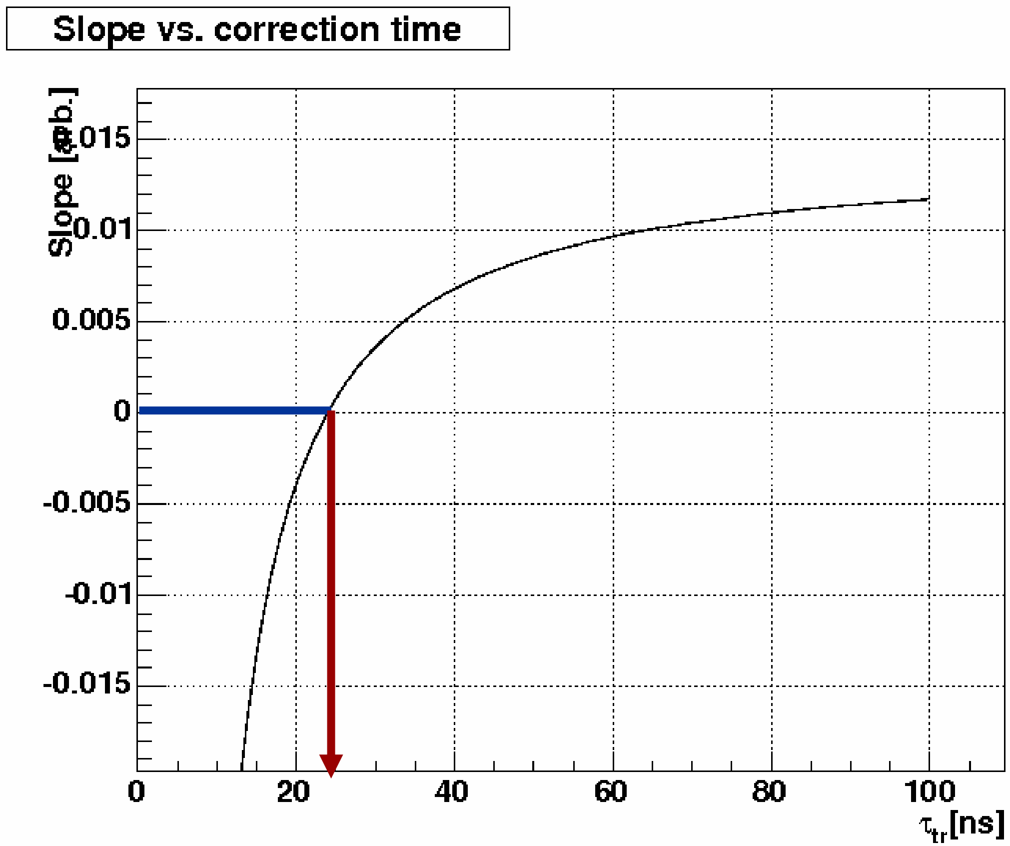
-> more charge measured

How to get the trapping time?

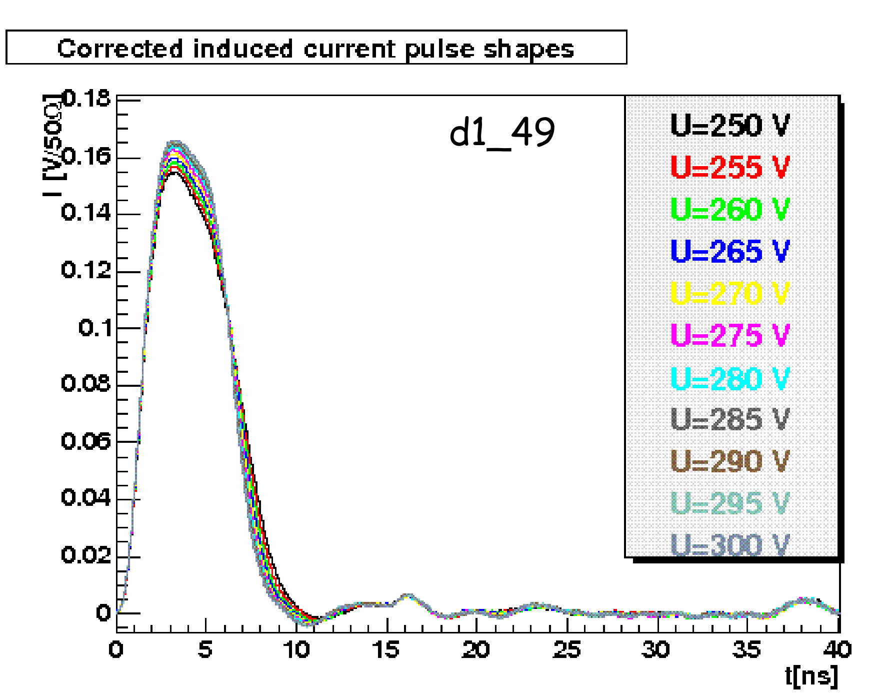
The corrected charge is constant with voltage ($V>V_{FD}$)

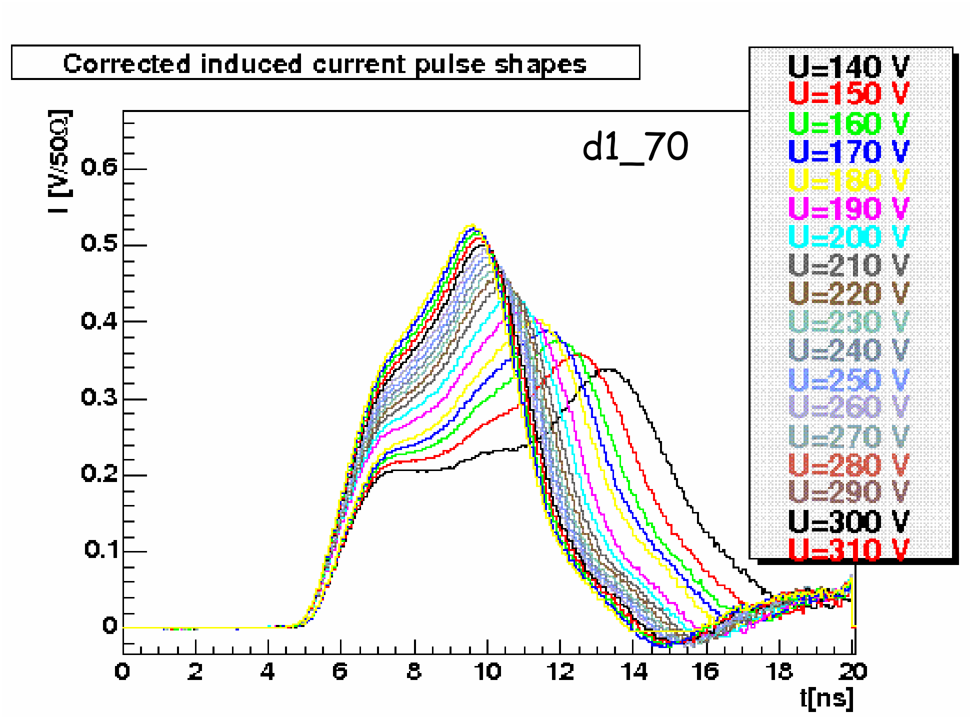


$$Q(t) = \int I_0(t)dt = \int I(t)e^{-\frac{t}{\tau}}dt$$



Type inversion



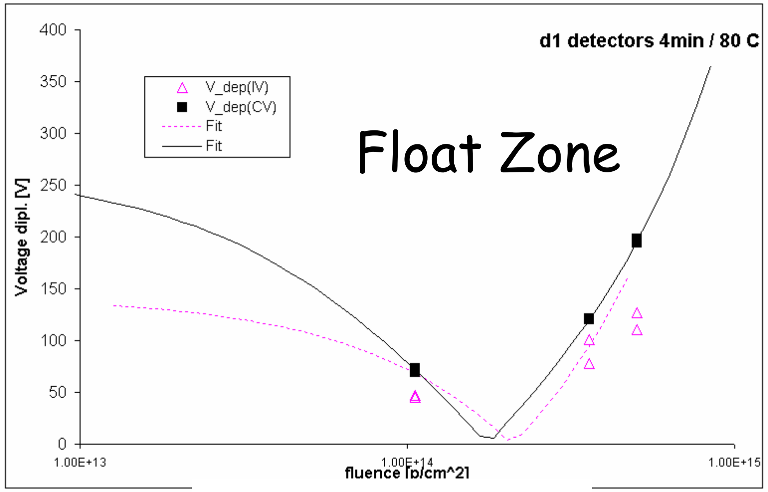


electron signal before type inversion

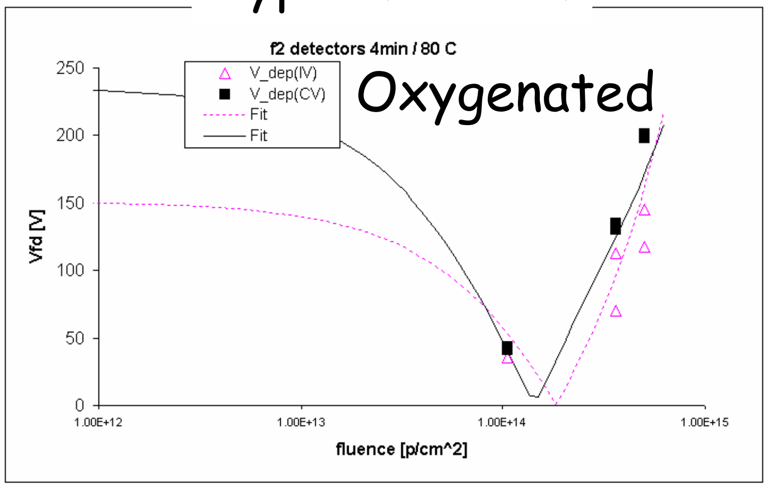
electron signal after type inversion

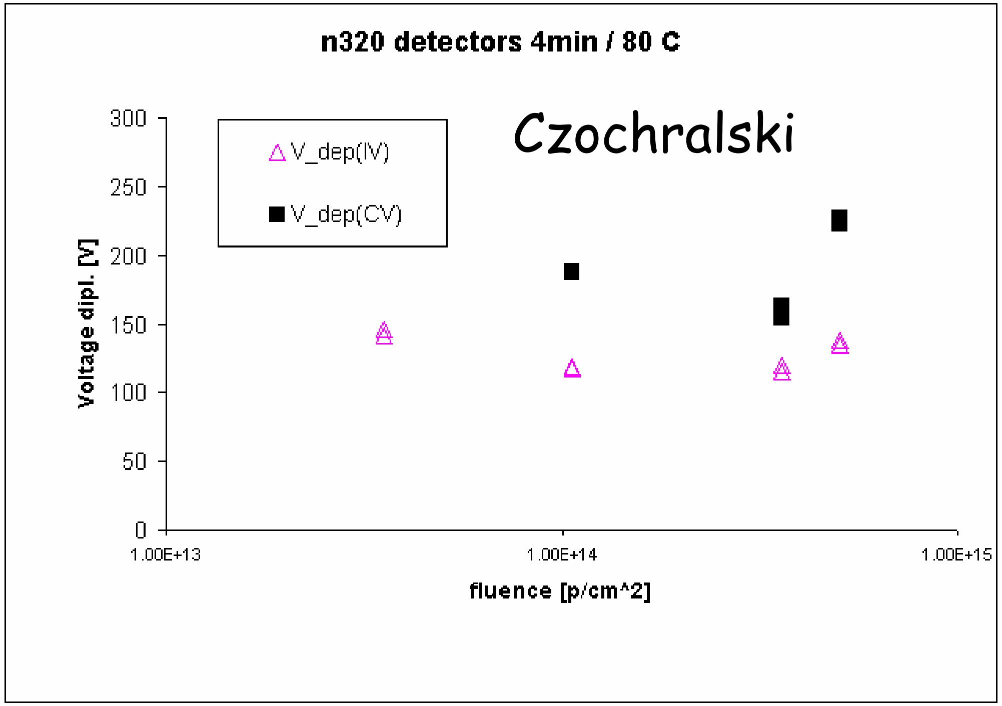
Results for Cz Silicon

From IV-CV measurements:



Type inversion

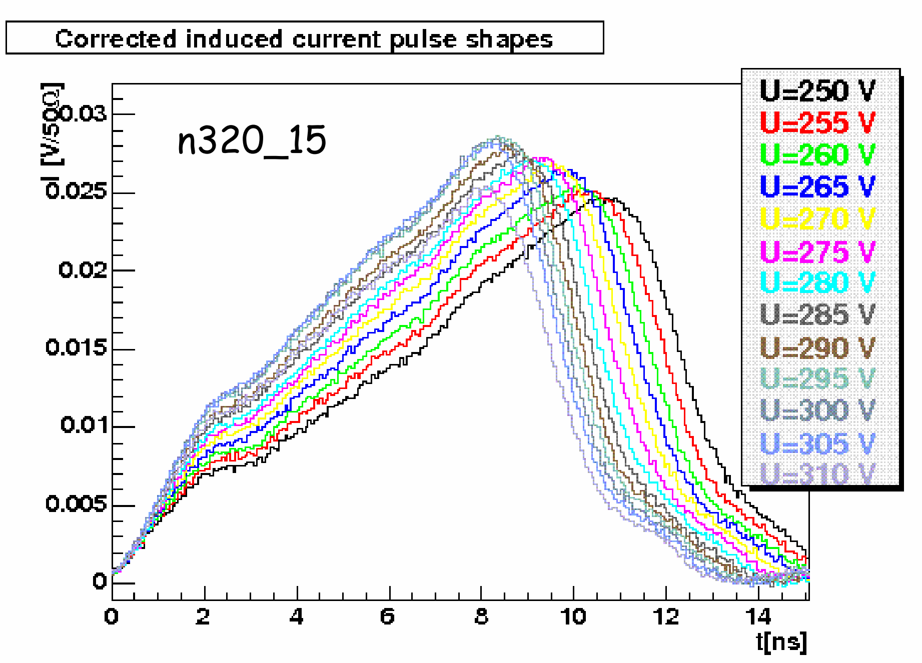


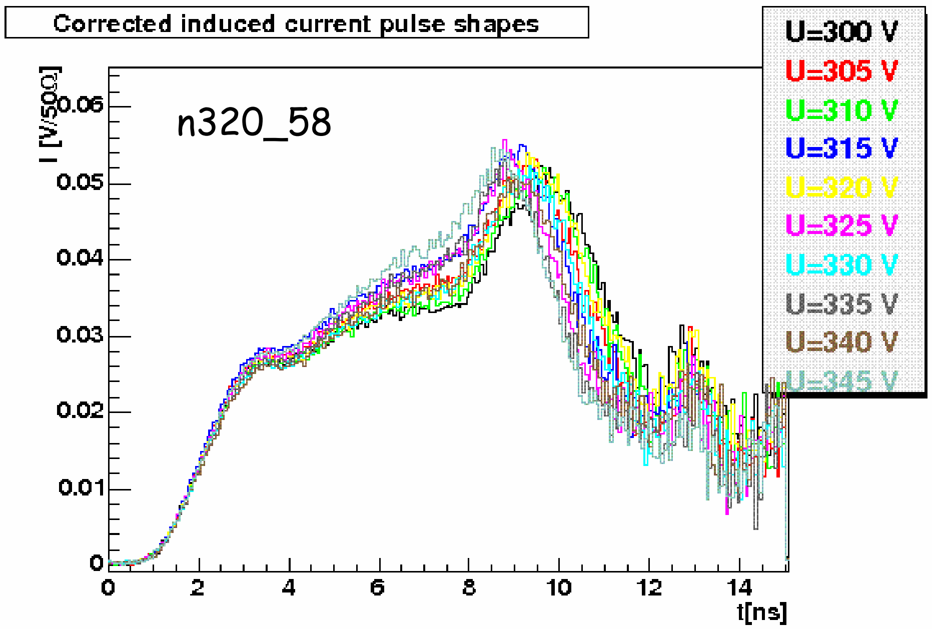


Type inversion....?

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 5×10^{14} p/cm^2 in CZ silicon

Conclusions

- Float Zone and Oxygenated silicon type invert
- The QV method is compatible to CV and IV
- Czochralski silicon doesn't type invert

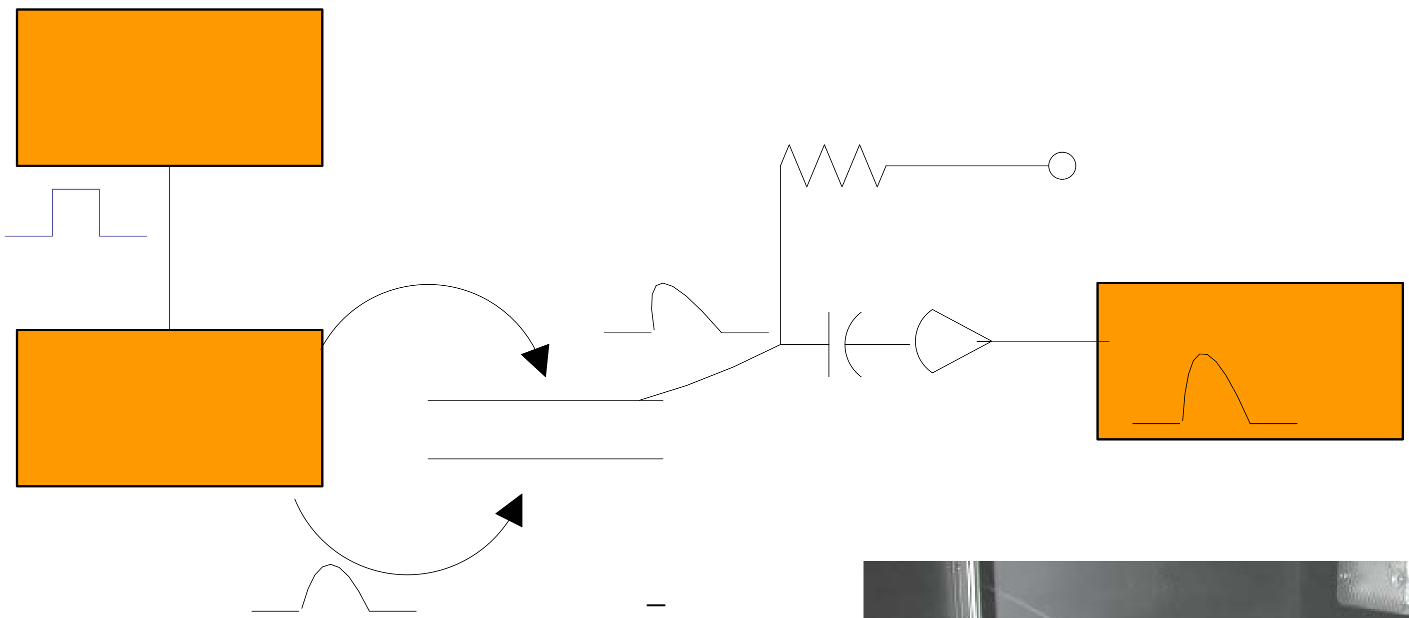
QUESTIONS?????

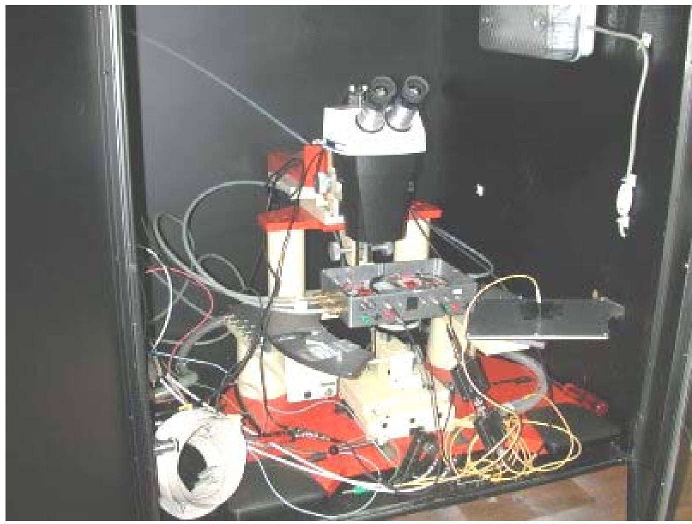
Irradiation and annealing

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





ator:

0A

How to get the trapping time?

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

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

From this relation follows for the charge

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