Status of the Laboratory

Universität Hamburg
Institut für Experimentalphysik
Detektorlabor

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1st Detector Workshop of the Helmholtz Alliance *Physics at the Terascale*
Karlsruhe, 3rd and 4th of April 2008

Outline:

- Projects
- Aims
- Expertise and Infrastructure
- Examples

Detector R&D Projects

funding within the Alliance:

WP1: The Virtual Laboratory for Detector Technologies

- **WP1.2: Sensors: Materials, Design and Characterisation**
- **WP1.3: Detector Systems: Development, Infrastructure and Testing**

WP2: Detector R&D Projects

- **WP2.4: Radiation hard silicon sensors for the sLHC**

time/annealing for different materials

other:

- **CMS (funded by BMBF)**
- **HPAD-XFEL (with Bonn, PSI, DESY)**
- **Marie Curie International Training Network MC-PAD (with CERN, DESY, …)**
- **FP7 Proposal**

Aims

- quantitative understanding of Si sensor performance in harsh radiation environment

- improve sensor performance by defect engineering

- optimize sensor design (for given material, dose/fluence)

Expertise and Infrastructure

I. Irradiation campaigns
(CERN, Ljubljana, Stockholm, Darmstadt, Karlsruhe, DORIS,…)

II. Macroscopic damage vs. time/annealing for different materials
- Dark current ➔ I/V
- N_{eff} → V_{dep} ➔ C/V
- CCE → τ_{eff} ➔ TCT
- N_{ox}, N_{eff} → sensor stability ➔ C/V
- evolution with time ➔ annealing
- overall performance ➔ multi-channel TCT (*new*)
  testbeam

III. Microscopic damage vs. time/annealing for different materials: TSC, DLTS
- characterisation of damage levels
- kinetics vs. time/annealing
- relate to macroscopic damage

IV. Incorporate results I. and II. into simulation of
- sensor "static"
- charge collection

➔ reliable prediction of long-term performance in the experiments environment

Strategies

Study of macroscopic properties:

IV, CV, TCT (transient current technique)

Study of microscopic properties: Defects
DLTS: deep level transient spectroscopy,
TSC: thermally stimulated current method)

N_{eff}, I, $t_{e,h}$:f(Doping, t, radiation dose, …)

→

Sensor simulation/ optimization:

E, I, C as a function of irradiation, material

•simulation

•experiment:
-multi-TCT
-testbeam

Simulation of charge collection in detector

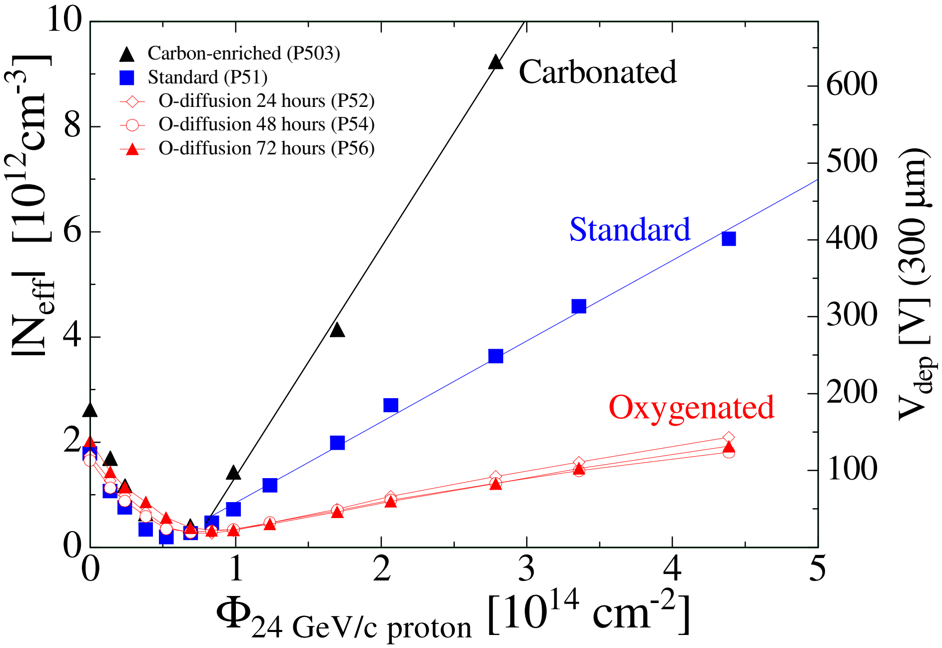
e, spatial resolution, reconstruction

Monte Carlo

detector

= dE/dx x sensor x FE electronics

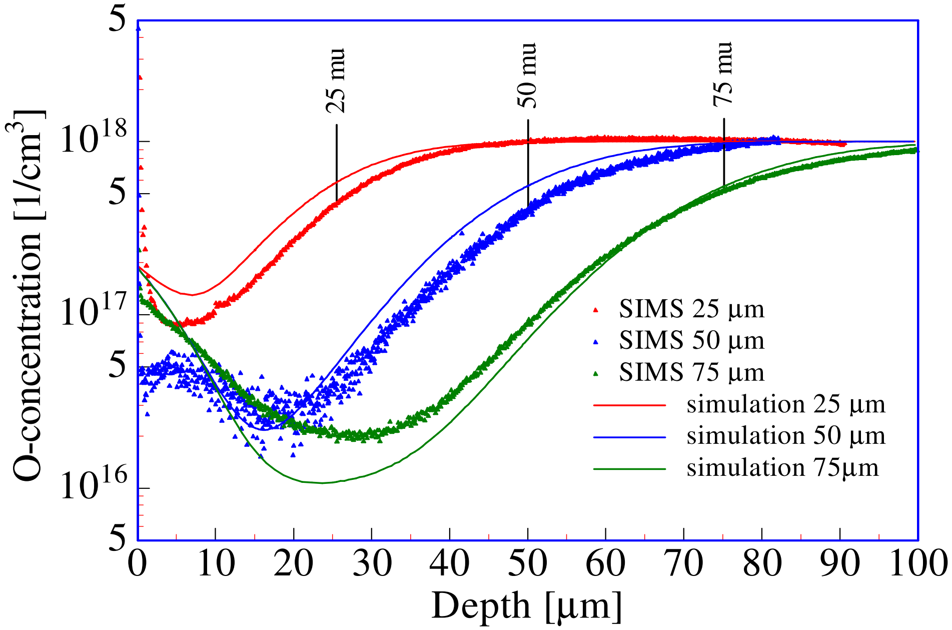
Example: Epitaxial Silicon Detectors



- for LHC oxygenated Si chosen
- based on findings of RD48

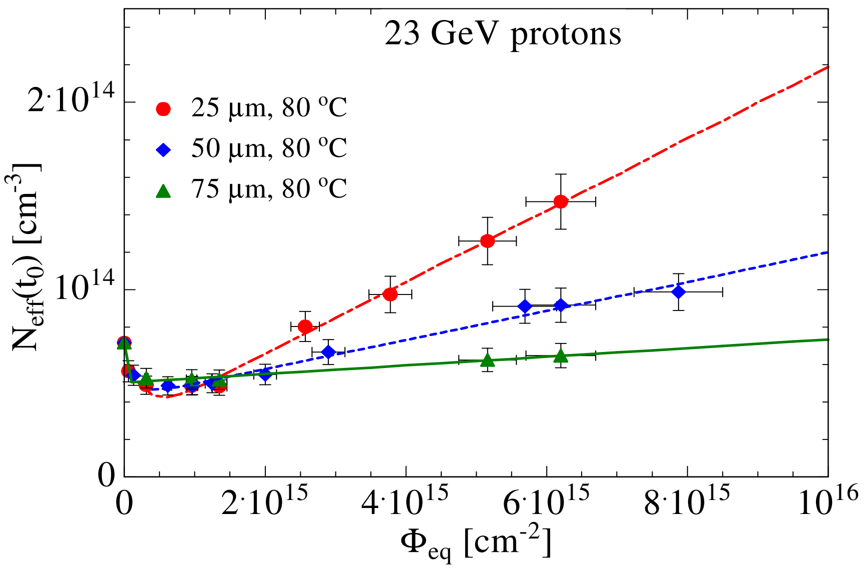
Now for SLHC: try naturally oxygen rich material
➔ epitaxial and MCz materials
try thin material (trapping!)

- **Epitaxial silicon**
  - Chemical-Vapor Deposition (CVD) of Silicon
  - CZ silicon substrate used ⇨ diffusion of oxygen
  - Growth rate about 1µm/min
  - Excellent homogeneity of resistivity



[O](25µm) > [O](50µm) > [O](75µm)

Epitaxial Silicon contd…



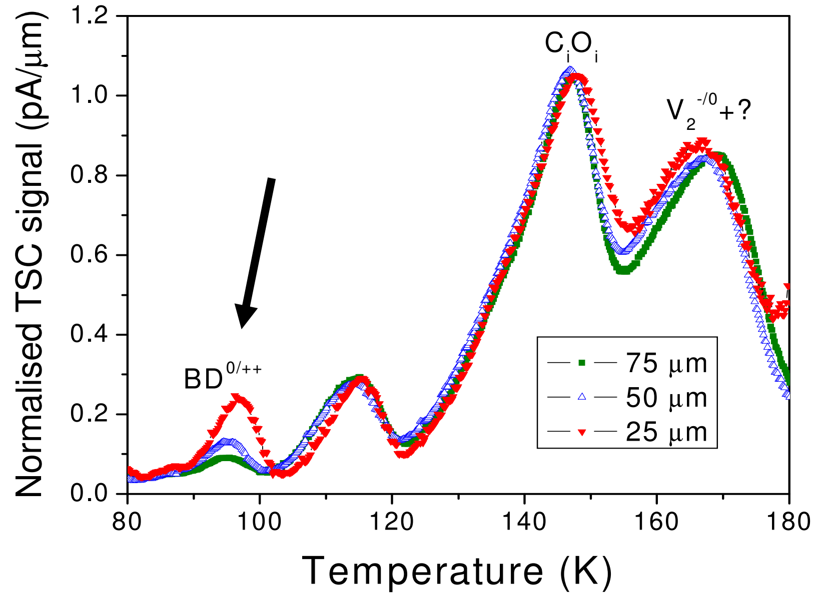
$N_{eff}(t_0)$: Value taken at annealing time t_0 at end of short term annealing (10 min @ 80°C)

No SCSI after proton (and neutron) irradiation

Introduction of shallow donors overcompensates creation of acceptors

Neff(25µm) > Neff(50µm) > Neff(75µm)

Defect spectroscopy after p-irradiation (TSC)



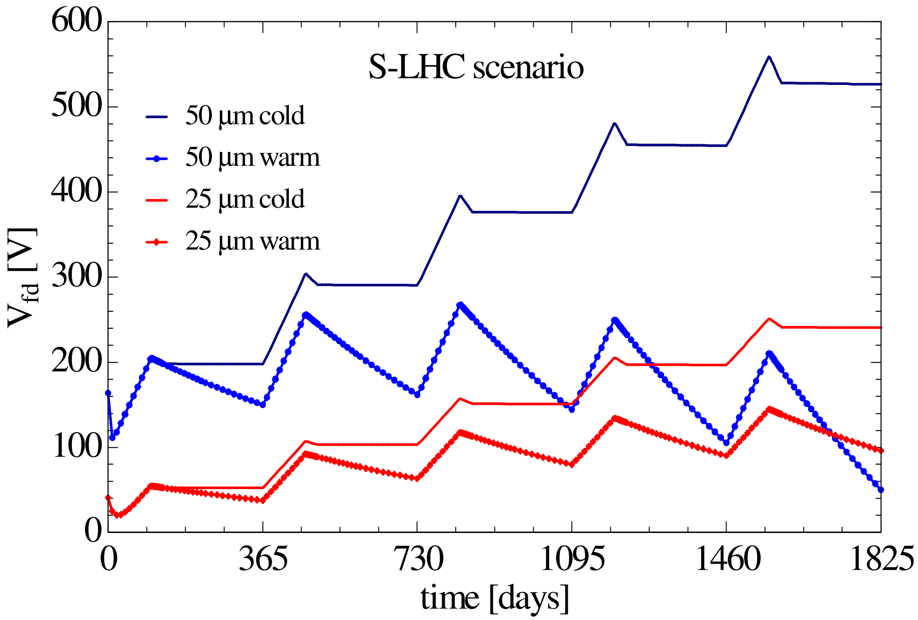
Generation of shallow donors BD (Ec-0.23 eV) strongly related to [O]

[BD](25µm) > [BD](50µm) > [BD](75µm)

Strong correlation between [O]-[BD]-N_{eff}
generation of O (dimer?)-related BD reason for superior radiation tolerance of EPI Si detectors

G.Lindstroem et al., NIM A568 (2006) 66-71

Example: SLHC operating scenario – simulation and experiment



- Radiation @ 4cm: $\Phi eq(year) = 3.5 \times 10^{15}$ cm^{-2}
- SLHC-scenario:
  – 1 year = 100 days beam (-7°C)
  – 30 days maintenance (20°C)
  – 235 days no beam (-7°C or 20°C)

- **Operation without cooling is beneficial!!!**

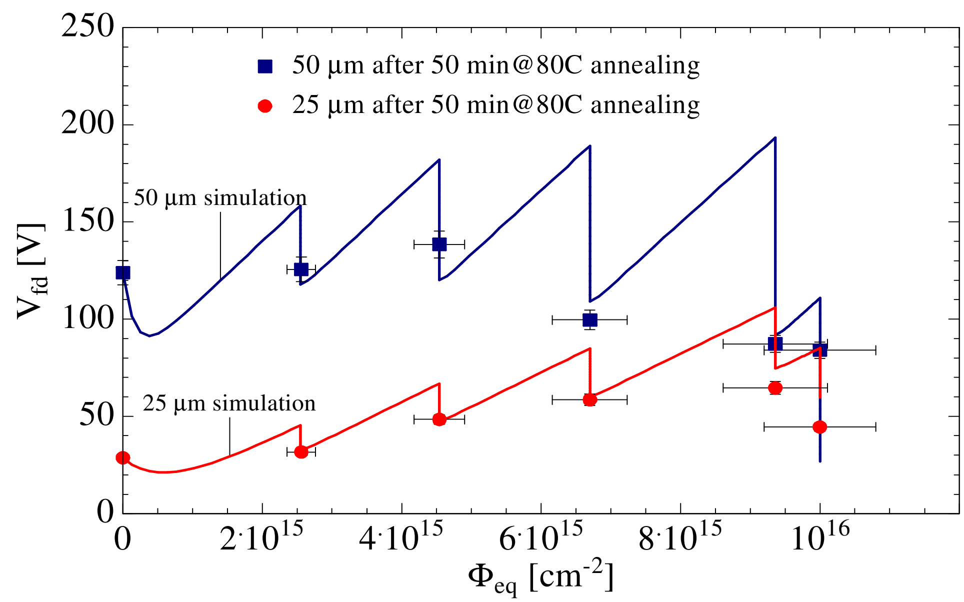
▪ Experimental parameter:

➢ Irradiation: fluence steps ≈ 2.2×10^{15} cm^{-2}
irradiation temperature ≈ 25 ℃

➢ After each irradiation step annealing at 80 ℃ for 50 min, corresponding 265 days at 20 ℃

Excellent agreement between experimental data and simulated results

➢ **Simulation + parameters reliable!**



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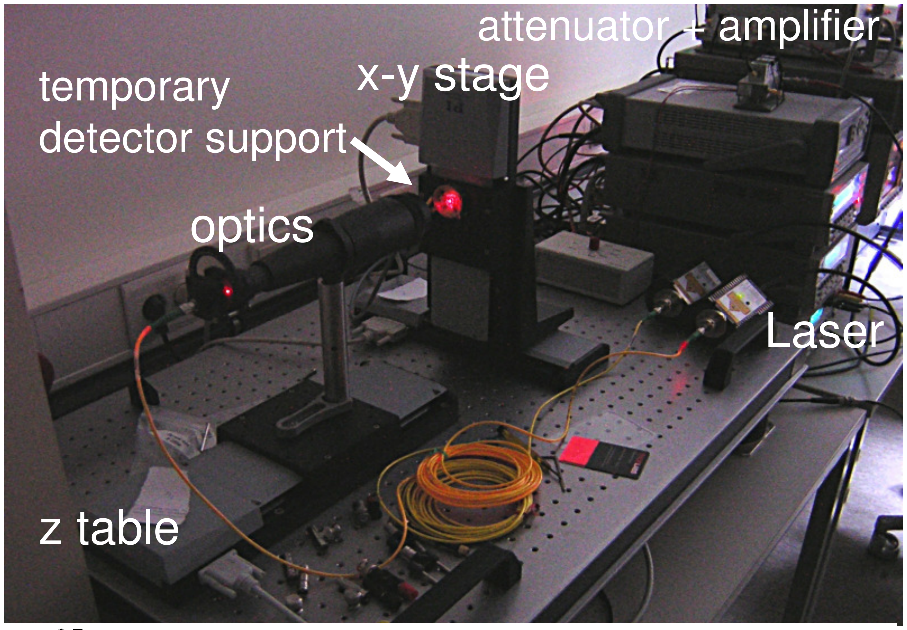
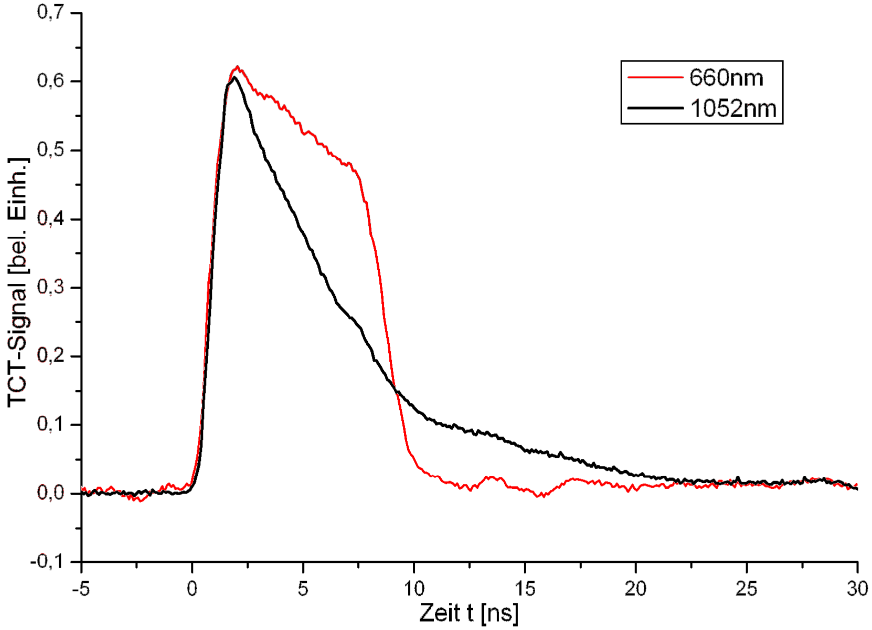
New: multi-channel TCT

Goal: Time-resolved measurement of charge collection in Si-pixel and strip detectors in multiple channels up to very high charge densities. fine-grain position and angle scans.

Multi-TCT under construction in Hamburg:

- ps laser (1052 nm and 660 nm), <90ps, W_{max}~200pJ, spot size <10 µm (red)
- penetration depth 3 µm (red), 1000µm (IR)
- fast amplifiers (miteq)
- data acquisition with fast oscilloscope (500 MHz, 1GS/channel), possible upgrade to digitizer cards with up to 20 ch, synchronized
- cooled detector support (Peltier)





Summary

Aims:

- quantitative understanding of Si sensor performance in harsh radiation environment
- improve sensor performance by defect engineering
- optimize sensor design (for given material, dose/fluence)

Techniques:

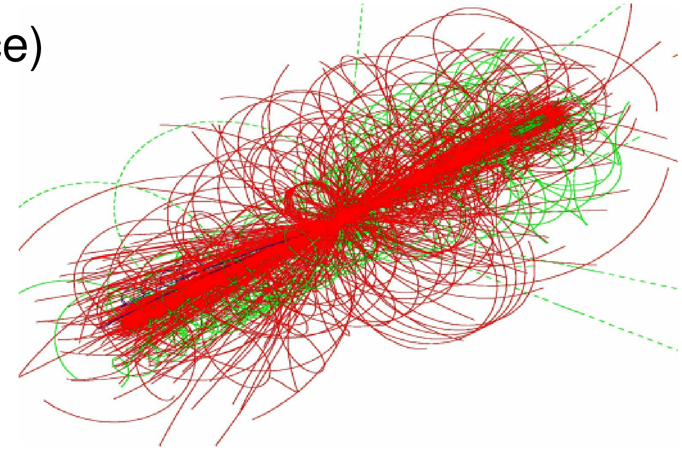
- I/V, C/V, TCT, multi-TCT, DLTS, TSC

BACKUP

Silicon Detectors for Vertexing and Tracking

Silicon detectors:

- ✓ are used for vertexing, lifetimes, triggering, tracking, even dE/dx
- ✓ are used in all current HEP experiments
- ✓ detect MIPs
- ✓ are fast (~10ns) and precise (~10µm)
- ✓ (crazy geometries, run in vacuum, cover large surface)
- ✓ are radiation tolerant



LHC starting 2008:

- ➢ Luminosity L = $10^{34}\ cm^{-2}s^{-1}$
- ➢ in 10 years (500 fb^{-1}) Φ (r=4cm) ~ $3 \cdot 10^{15}\ cm^{-2}$
- ➢ Oxygenated Silicon (ROSE-Collaboration RD48)
- ➢ replacement might be necessary

sLHC starting 201x:

- ➢ Luminosity L = $10^{35}\ cm^{-2}s^{-1}$
- ➢ in 5 years (2500 fb^{-1}) Φ (r=4cm) ~ $1.6 \cdot 10^{16}\ cm^{-2}$
- ➢ new materials/technologies under investigation (RD50 Collaboration)

Radiation Damage in Silicon Sensors

Two general types of radiation damage:

• **Bulk damage due to Non Ionizing Energy Loss**
- displacement damage, built up of crystal defects –

• Change of ***Effective Doping Concentration N_{eff}***
→ type inversion
→ higher depletion voltage ➔ possibly under-depletion ➔ loss of signal, increased noise
→ junction moves from p+ to n+ side
← influenced by impurities in Si (oxygen, carbon,…) ← **defect engineering, material dependence!**

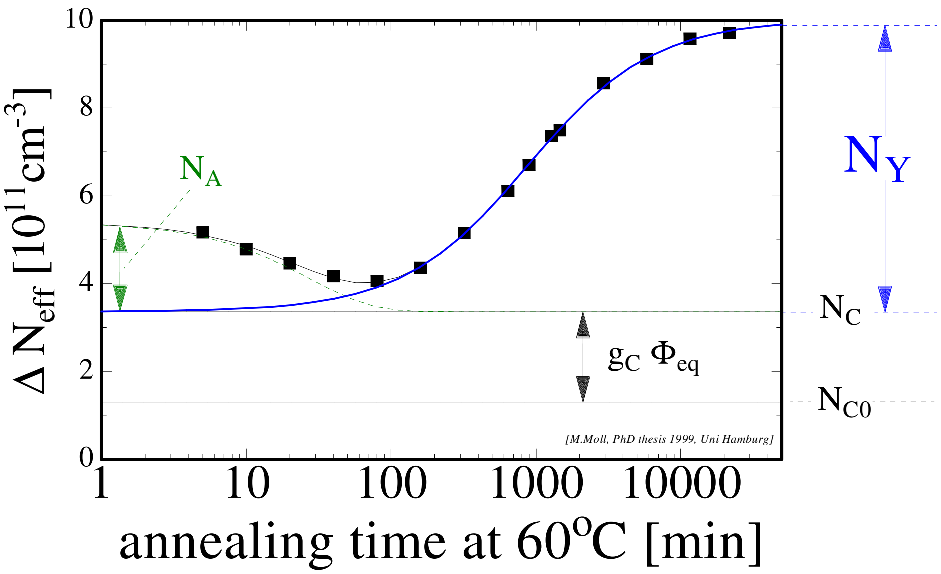
• Increase of ***Leakage Current***
→ shot noise ➔ thermal runaway, power consumption ➔ hard to bias
← temperature dependent ← need cooling

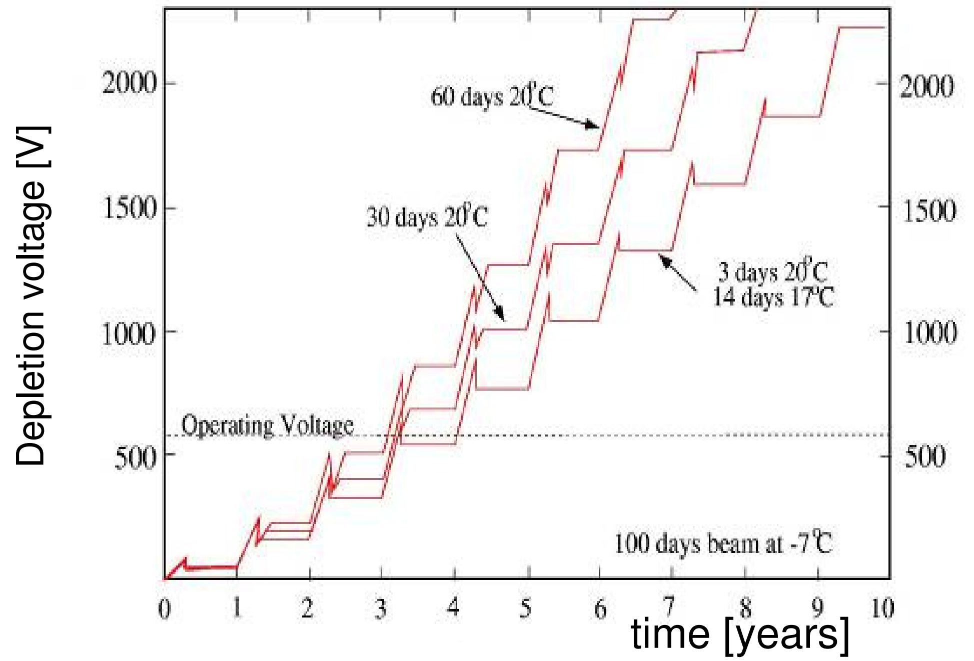
• Increased carrier ***Trapping***
➔Charge loss ➔ at $10^{16}cm^{-2}$ $\lambda \leq 20\mu m$ charge collection distance!

• **Surface damage due to Ionizing Energy Loss**
→accumulation of charge in the oxide (SiO_2) and Si/SiO_2 interface
➔ interstrip capacitance (noise factor), breakdown behavior, …

Radiation Damage - Annealing

Change of N_{eff} with time





Short term: "Beneficial annealing"

Long term: "Reverse annealing"

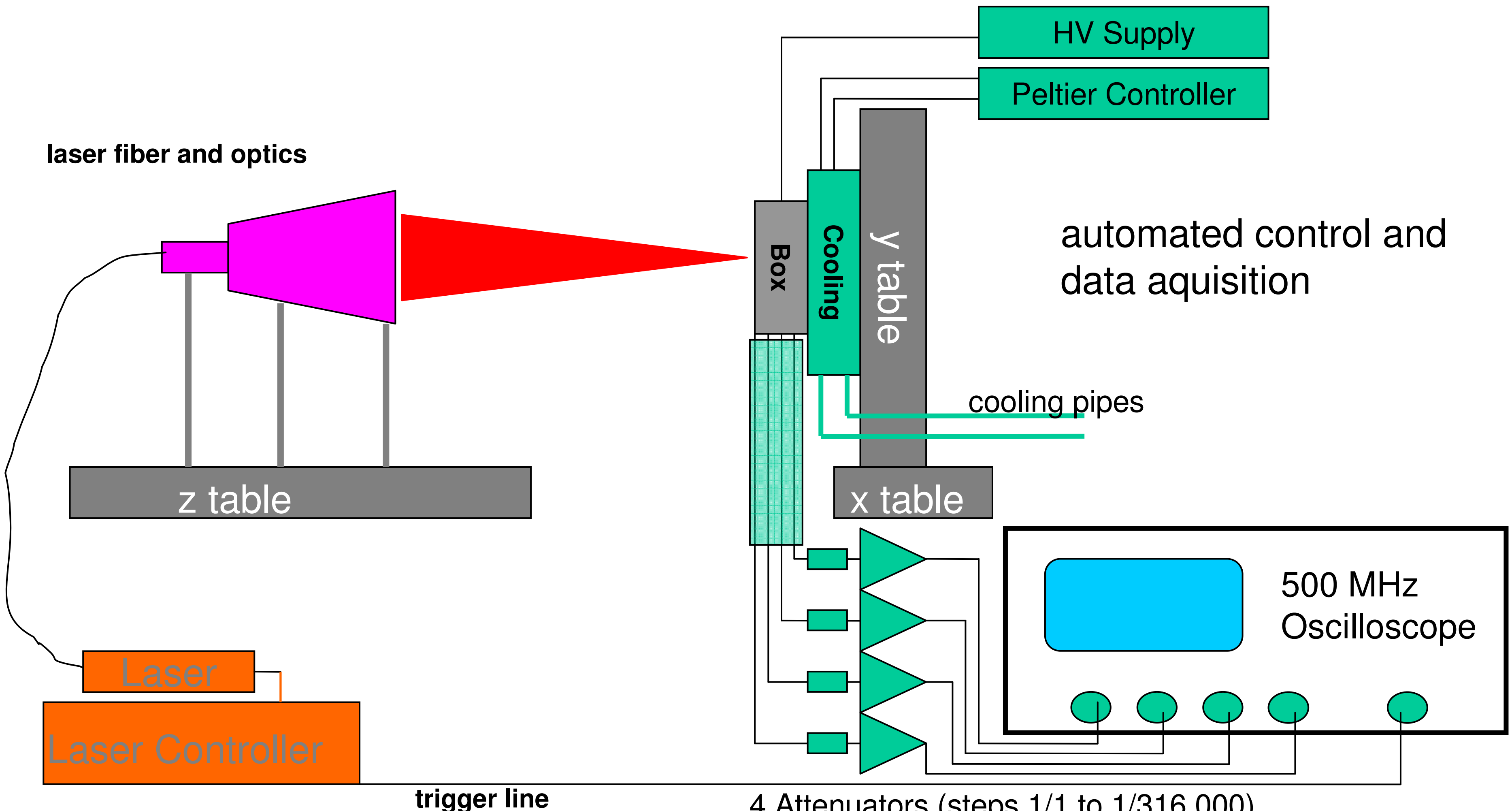
- time constant depends on temperature:

~ 500 years	(-10°C)
~ 500 days	(20°C)
~ 21 hours	(60°C)

Consequence:

Cool Detectors even during beam off
alternative: acceptor/donor compensation by defect engineering

Schematic Set-up



4 Attenuators (steps 1/1 to 1/316.000)
4 Amplifiers (x500)