Silicon Detectors: Radiation Issues

Nicola Bacchetta

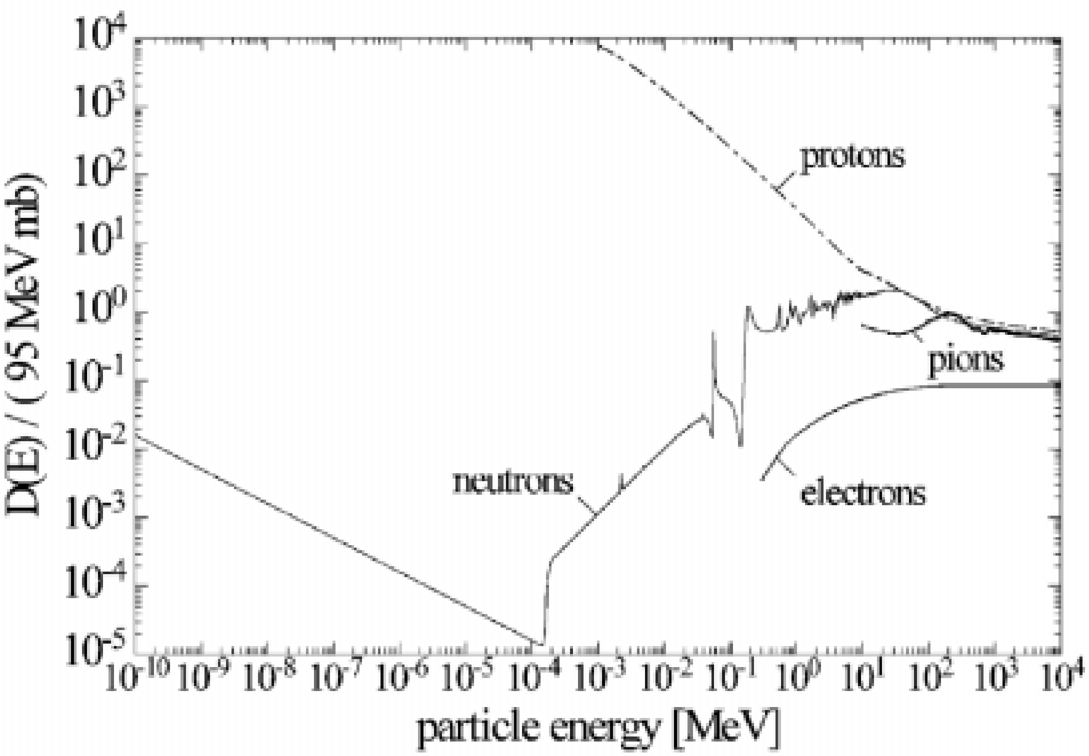
March 15 2000

- Main radiation effects are:
  - Surface damage due to ionising radiation
  - Bulk damage due to the non ionising part of the energy loss.
- For Si detectors most important is bulk damage

- Macroscopic effects are:
  - Change in doping concentration
  - Increase of leakage current
  - Deterioration of the charge collection efficiency

Silicon Detectors: bulk damage

Nicola Bacchetta
15/3/00



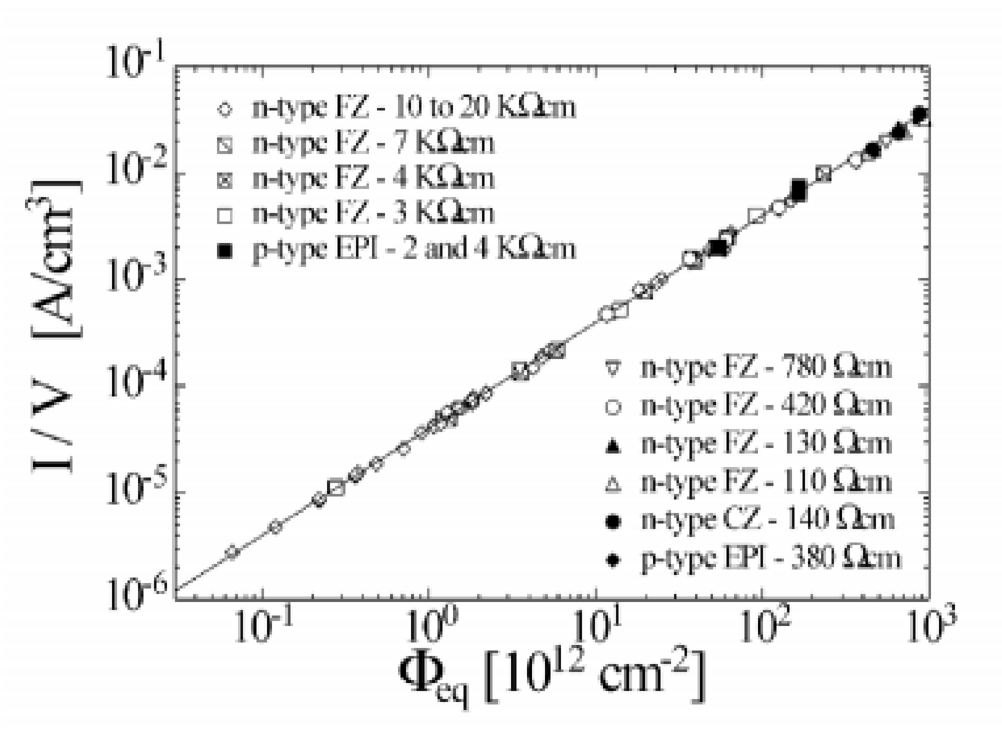
Non Ionising Energy Loss chart

Damage constants for various particles and energies are all calculated relative to 1Mev neutrons

- Caused primarily by displacing a PKA out of the Si lattice.
- It creates a pair V-I
- Binding energy is " 25eV
- If kinetic energy is sufficient the PKA will travel creating more point defects and finally will come to rest in a highly disordered area (cluster).
- Energy loss via ionisation does not play a role:

  bulk damage depends exclusively on NIEL

Silicon Detectors: leakage current



$\alpha = 4 \cdot 10^{17}$ A/cm

- The generation/recombination rate in bulk silicon increases linearly with radiation:

$$\Delta I = \alpha\,[A/cm] \cdot \Phi_{eq}\,[cm^{-2}] \cdot Vol[cm^{3}]$$

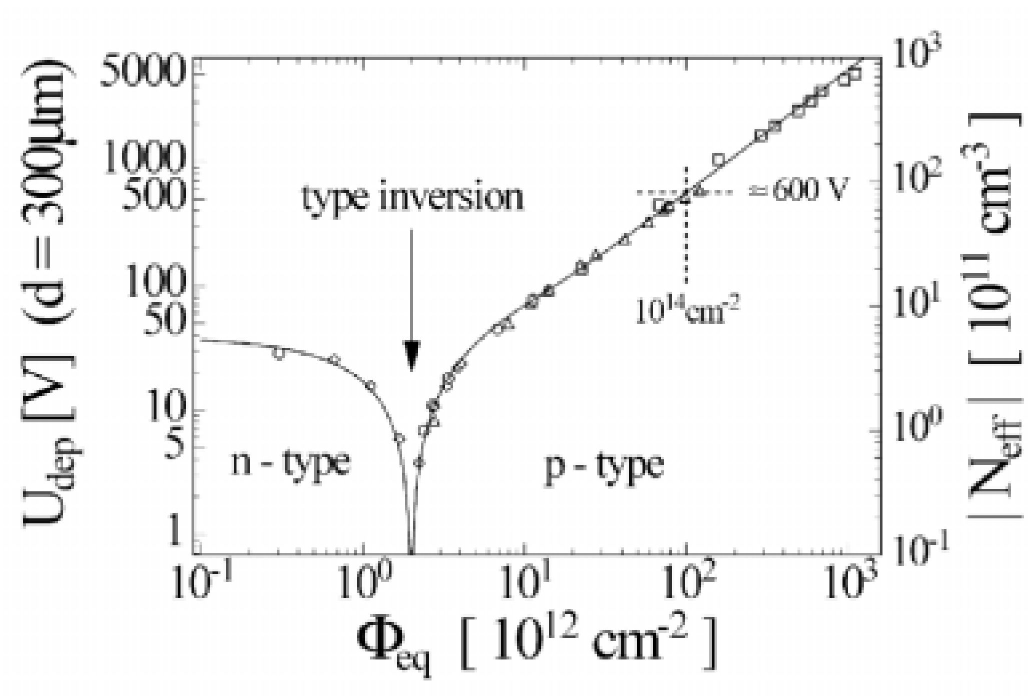
- α is called the damage constant and is indipendent of the specific silicon material. All α values are normalized at 20C and after “infinite” annealing.
- Leakage current scales with T:

$$I(T) = T^{2} \cdot \exp(-Eg/(2 \cdot k_{B} \cdot T))$$

The only way to limit the increase of leakage current with dose is running the detectors at lower temperature

Silicon Detectors: radiation issues

Nicola Bacchetta
15/3/00



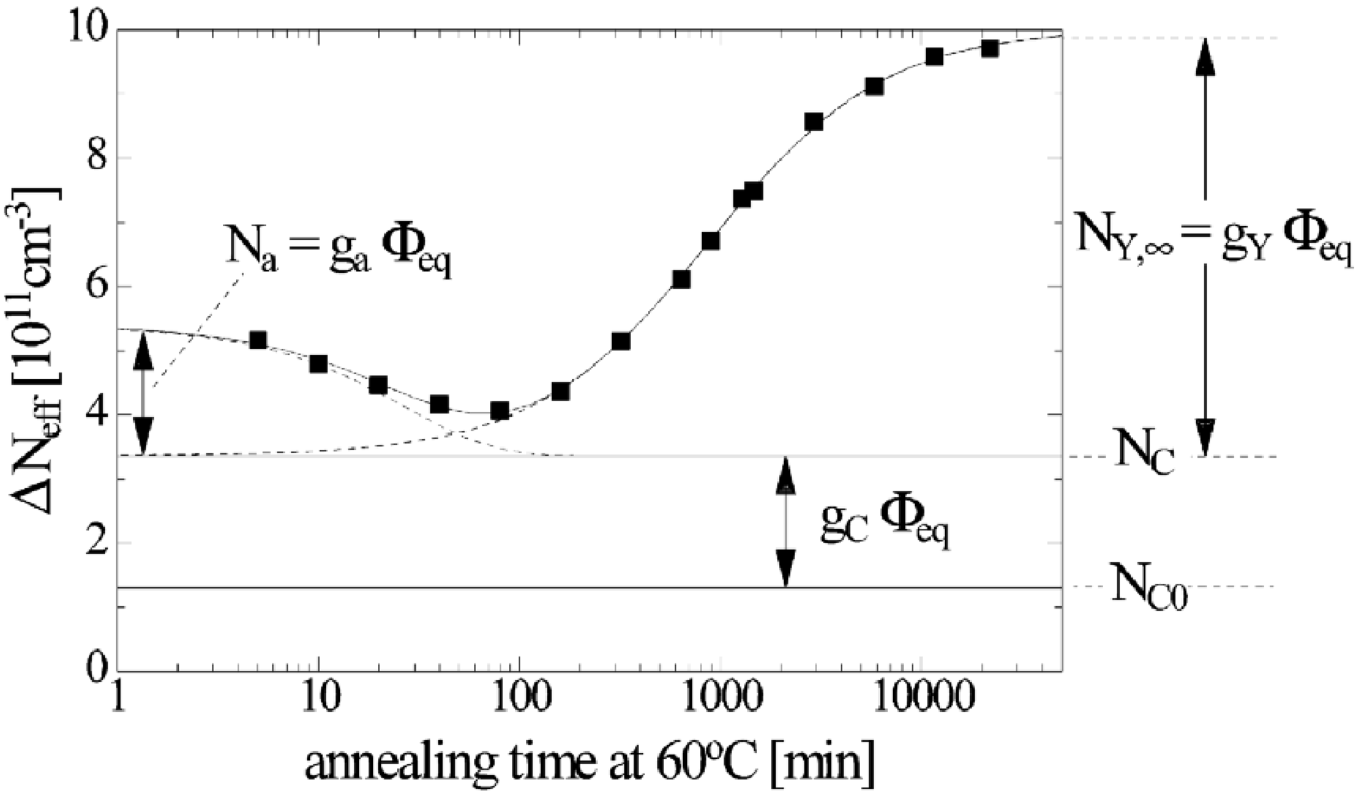
Variation in effective dopant concentration (depletion voltage) immediately after irradiation

- A more complex situation occurs for the change in effective doping concentration.
- This change has been parametrized using the follwing formula:

$$\Delta N_{eff}(\Phi_{eq}) = N_{eff0} \cdot \exp(-c \cdot \Phi_{eq}) + g_c \cdot \Phi_{eq}$$

Silicon Detectors: radiation issues

Nicola Bacchetta
15/3/00



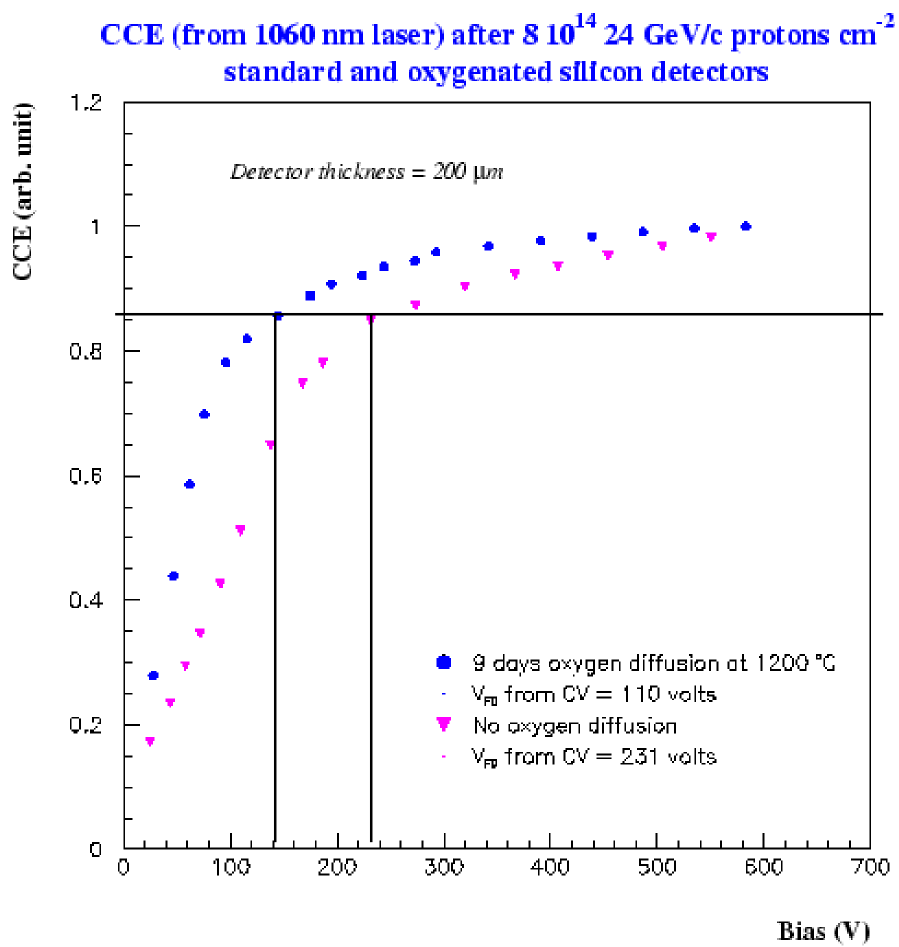
Silicon Detectors: radiation issues

Nicola Bacchetta

- It is important to note that the time constant associated with the reverse annealing strongly depends upon temperature.
- In practice, by keeping the detectors at temperature below 5-10C there is NO reverse-annealing.

Silicon Detectors: radiation issues

Nicola Bacchetta
15/3/00



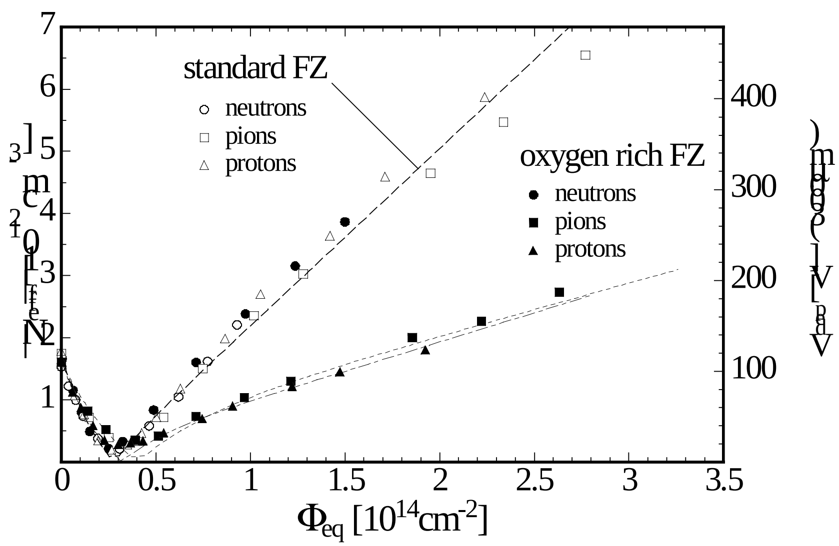
- Charge collection efficiency:

  due to trapping and other effects the voltage needed to collect the whole charge does not coincides with the depletion voltage as for the non irradiated detectors.

- It has been shown however that full charge collection is achievable as long as one can increase the operational voltage well above depletion.
- Already 85% of the full charge is collected at just the depletion voltage !

Silicon Detectors: new development

Nicola Bacchetta
15/3/00



- As predicted Oxygen enriched silicon detectors show a better tolerance to radiation.
- Oxygen enriched material are grown via a drive-in process (many hours at T>1000 ^{0}C) from the natural SiO_2 or ion implantation.
- Radiation tolerance:
  - no effects for neutron irradiation
  - improved for protons and pions
- Full size silicon detectors are already available in oxygen rich substrates (even L00 detectors).

Nicola Bacchetta
15/3/00

Silicon Detectors: conclusions

- Almost no degradation is expected in silicon detectors up to fluences of 10^{14} 1MeV n_{eq}/cm^2 as long as high voltage operation can be achieved (few hundreds of Volts)
- With the use of oxygenated detectors this limit can be expended to more than a few 10^{14} 1MeV n_{eq}/cm^2 , expecially if the dominant source of radiation is not coming from neutrons.