Highlights of Radiation Damage Studies at HH

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Physics at the Terascale
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Detector Laboratory at Hamburg University

Measurement techniques

- Deep Level Transient Spectroscopy (DLTS)
- Thermally Stimulated Current (TSC)
- IV/ CV measurements
- Transient Current Technique (TCT) (Standard+ multi channel TCT*)

Silicon materials:

- Bulk and surface damage
- Characterisation of microscopic defects and correlation with macroscopic parameters.

Irradiation

with n,p,e, γ

Quality Control

Simulation of segmented silicon devices:

- static sensor simulation (Synopsis TCAD)
  - E, Φ, I, breakdown
- pulse shape (custom program)
  - S/N, efficiency, spatial resolution

Central European Consortium (CEC)

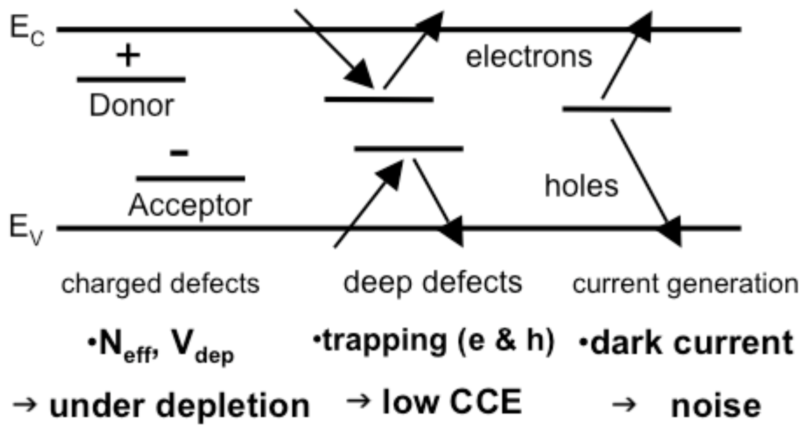
Strip and strixel sensors for the CMS Upgrade for SLHC

AGIPD Project

Silicon Pixel detector for XFEL

*Partially funded by HGF Alliance

Radiation Induced Damage



Bulk damage results in changes of detector properties such as

- Field distribution
  ⇒ Depletion voltage
- Dark current
- Trapping

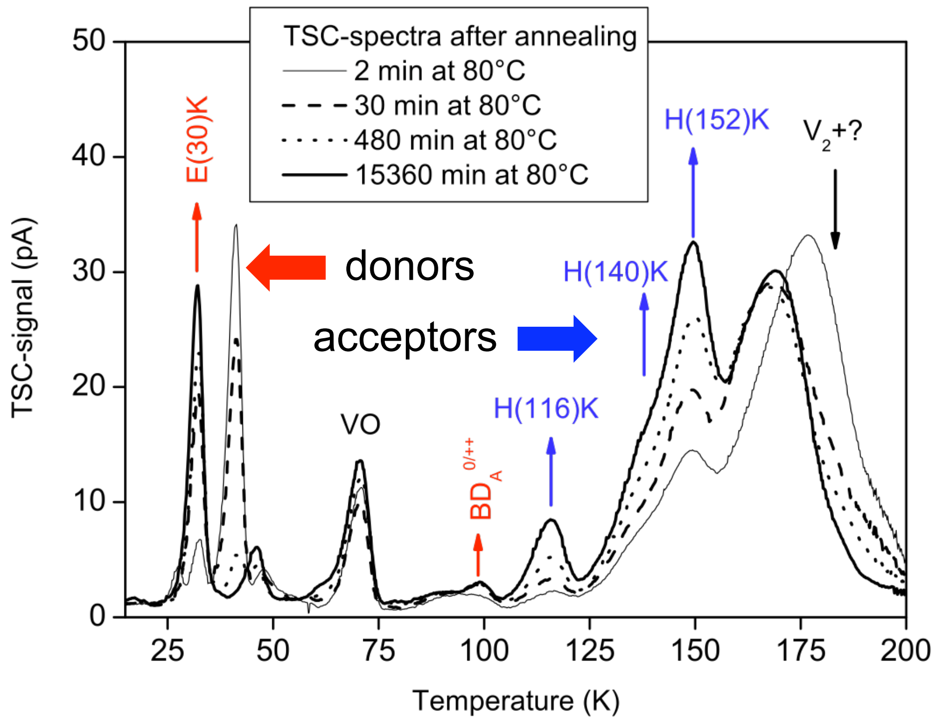
Approaches

- Understand radiation damage by combining microscopic (defect characteristics) and macroscopic (detector properties) measurements ⇒ „defect engineering“
- Find best material and geometry
- Optimise environmental and operational conditions
⇒ cooling, high bias

Effective Doping Concentration

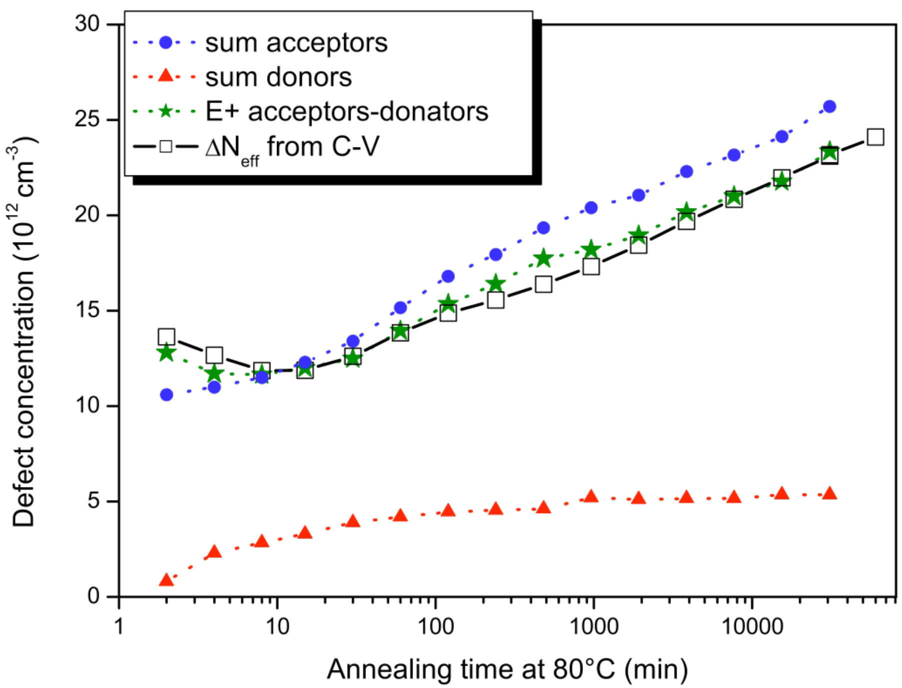
- Thermally Stimulated Current (TSC) - for Φ= $2x10^{14}$ cm^{-2} n
- Current due to emission from filled traps ⇒ defect concentrations

Defect concentrations by TSC



Microscopic vs. macroscopic

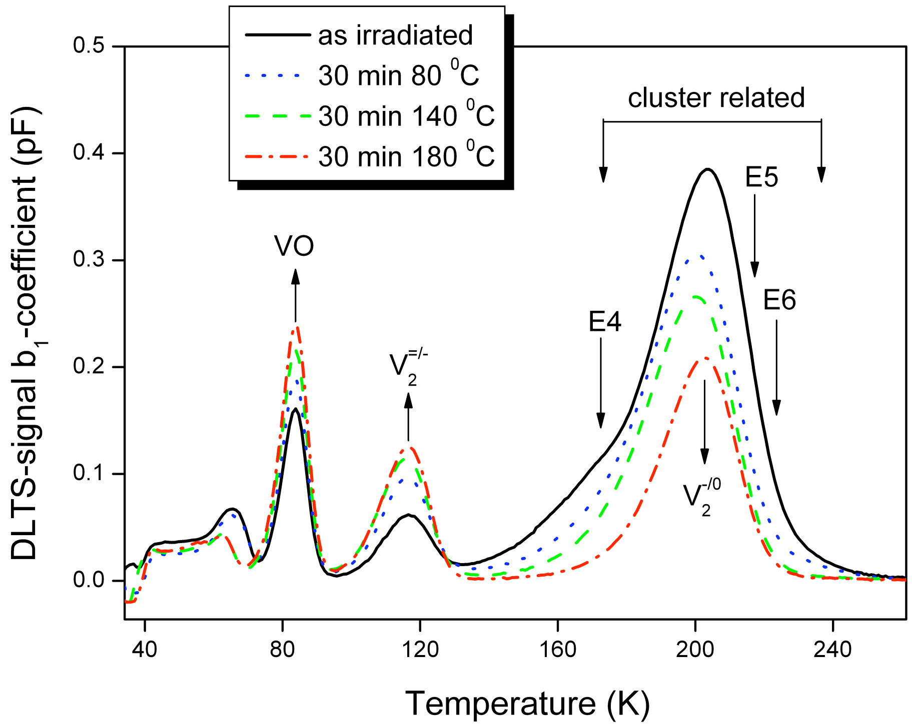
$V_{dep} \propto N_{eff} \cdot d^2$

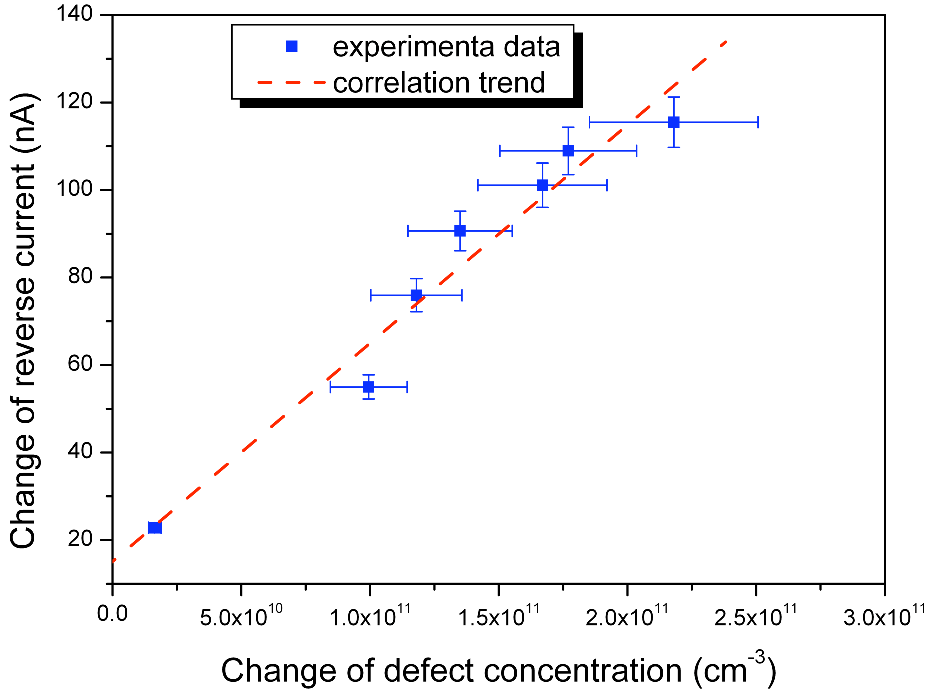


Reverse annealing can be explained by deep acceptor traps

Towards the Origin of Dark Current

- Deep Level Transient Spectroscopy (DLTS) – for $\Phi = 3x10^{11}$ cm^{-2} n
- Capacitance transients during the emission from filled traps
- $I_{dep} \propto \Phi_{eq}$





Close correlation to cluster related deep electron traps

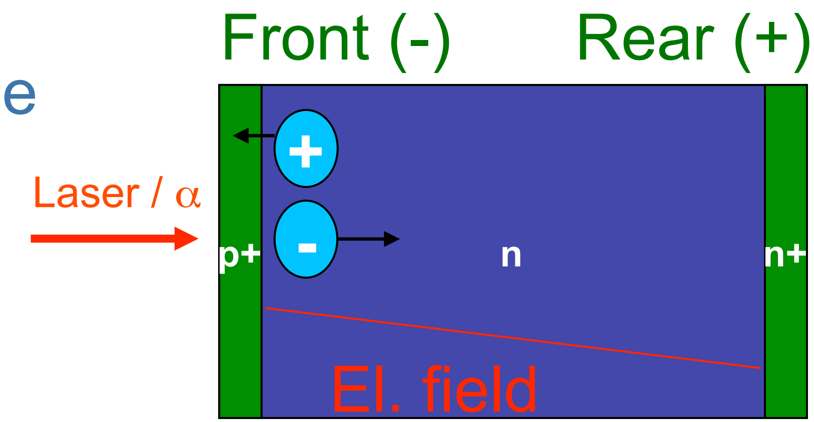
Charge Collection Studies

Topics

CCE/trapping in damaged sensors ⇒ S-LHC

Plasma effect ⇒ European XFEL

Method: Transient Current Technique (TCT)



TCT setups with different properties at UHH

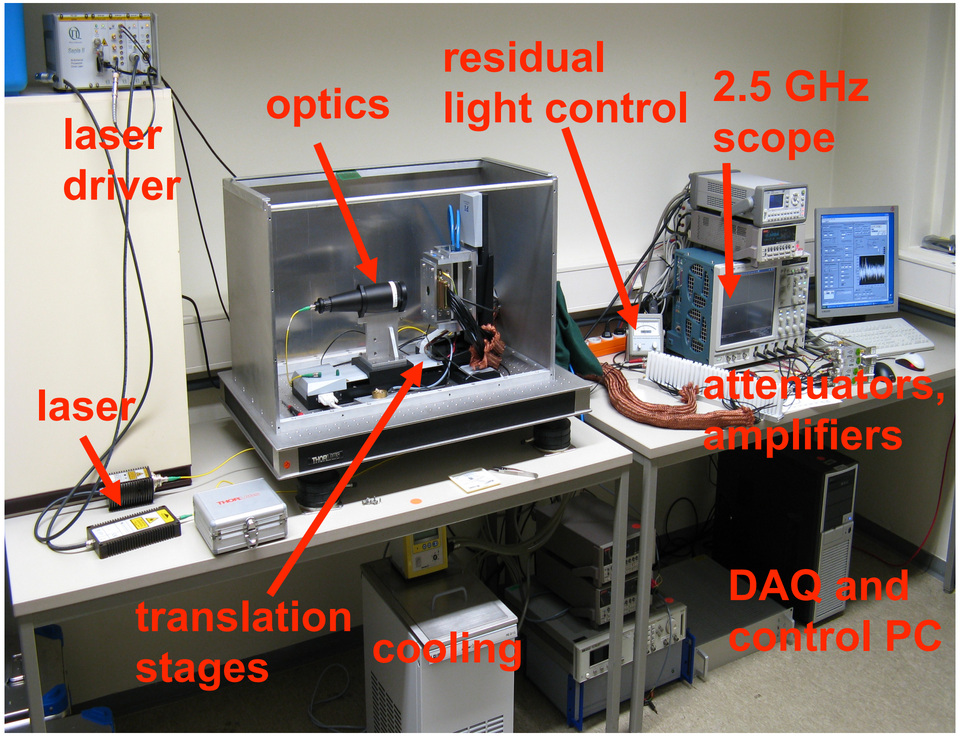
- 5.8 MeV α-particles with absorbers
- 670, 830, 1060 nm laser light (with improved stability/CCE precision)
- Multi-Channel TCT

Multi-Channel TCT Setup

Research aims

TCT on segmented sensors
- pulse shapes
- Trapping effects
- electric field profiles

Effects of high charge carrier densities (plasma effects PE)
- charge collection times
- spatial distribution of charge clouds



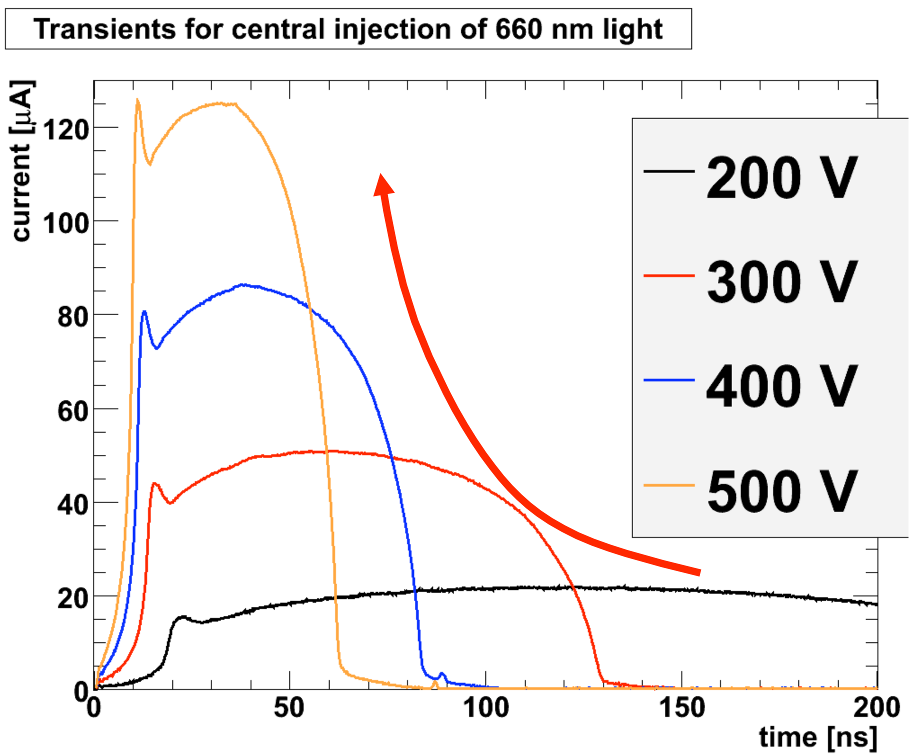
Key features

- fast (≤ 100 ps FWHM) laser pulses
  - ≤ 3 µm spot size
  - 660 nm, 1015 nm, 1052 nm wavelength*
- x-y-z position control
- multi GHz bandwidth electronics (<100 ps risetime)
- 32 channels (4 simultaneously)
- temperature control (-30 °C to 50 °C)
- front and back side injection possible

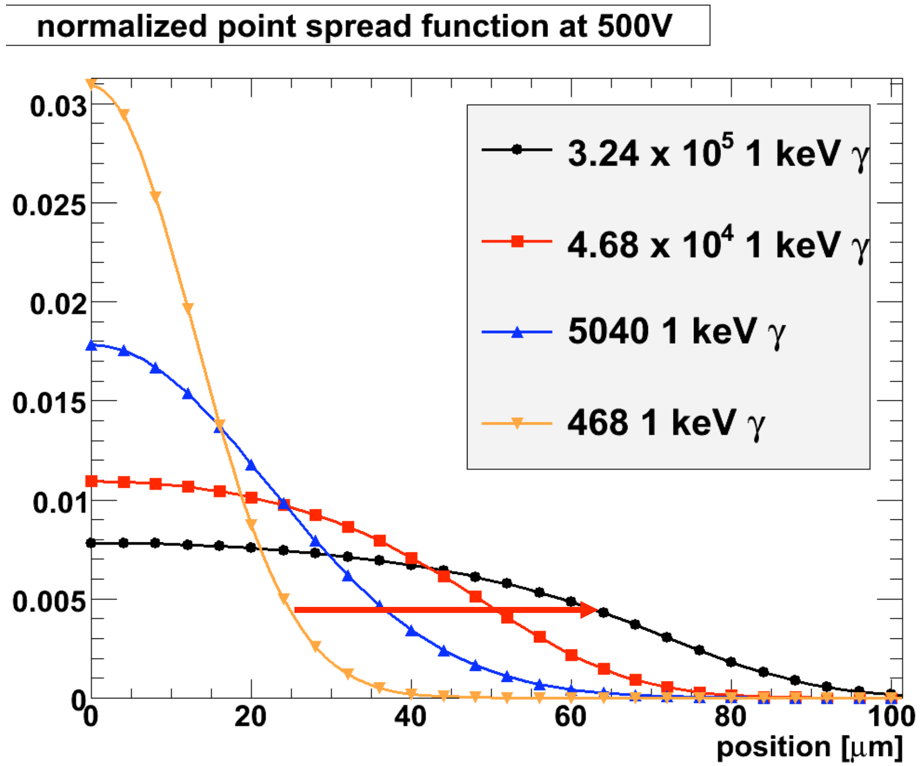
*absorption length:
660 nm -> 3 µm ~ 1 keV γ
1015 nm -> 250 µm ~ 12 keV γ
1052 nm -> 900 µm ~ mips

Results Linked to PE in Strip Detectors

Rise of Charge Collection Time



Spatial Broadening

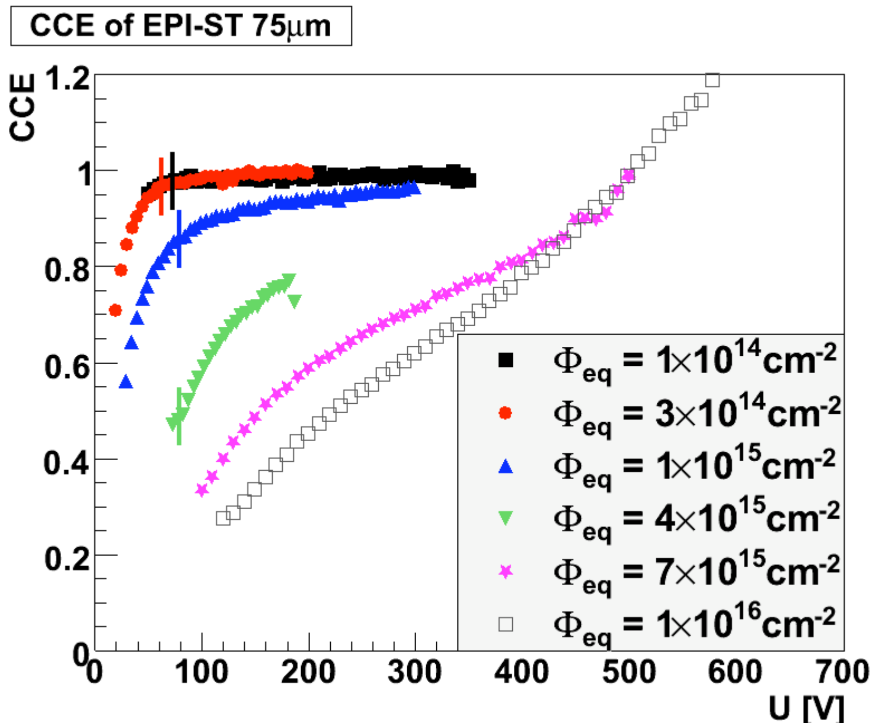


- $9x10^7$ e-h pairs = $3.24x10^5$ 1 keV γ, $\sigma \approx 3\mu m$
- rear side illumination with 660 nm laser

Strong impact on detector design for European XFEL

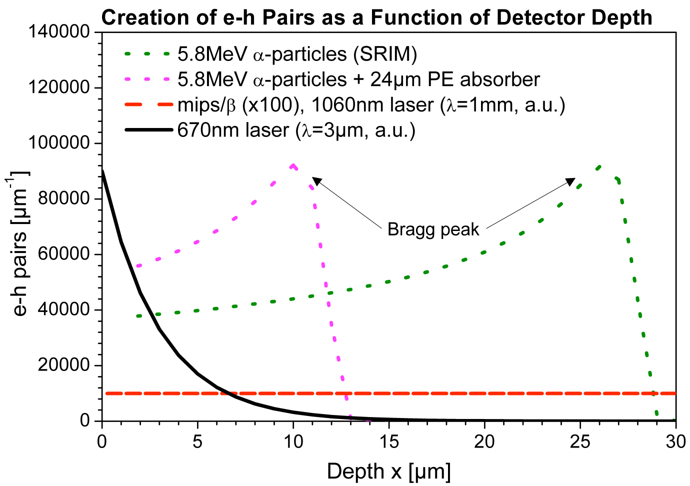
Trapping and Charge Multiplication

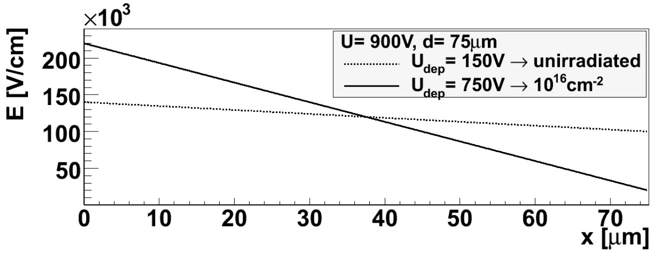
- Trapping: most limiting factor at S-LHC fluences
  ⇒ Degradation of Charge Collection Efficiency (CCE)
- But at high fluences and voltages: CCE>1
  ⇒ Trapping overcompensated by Charge Multiplication (CM)
- Can CM be used for highly damaged S-LHC detectors?
  ⇒ Detailed understanding of the formation and properties of CM in irradiated sensors needed

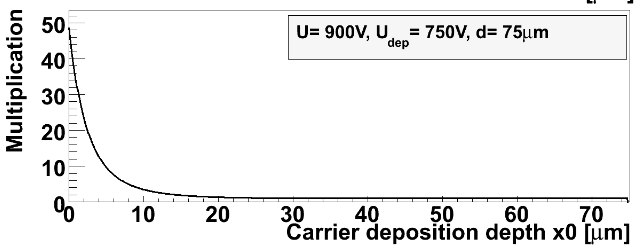


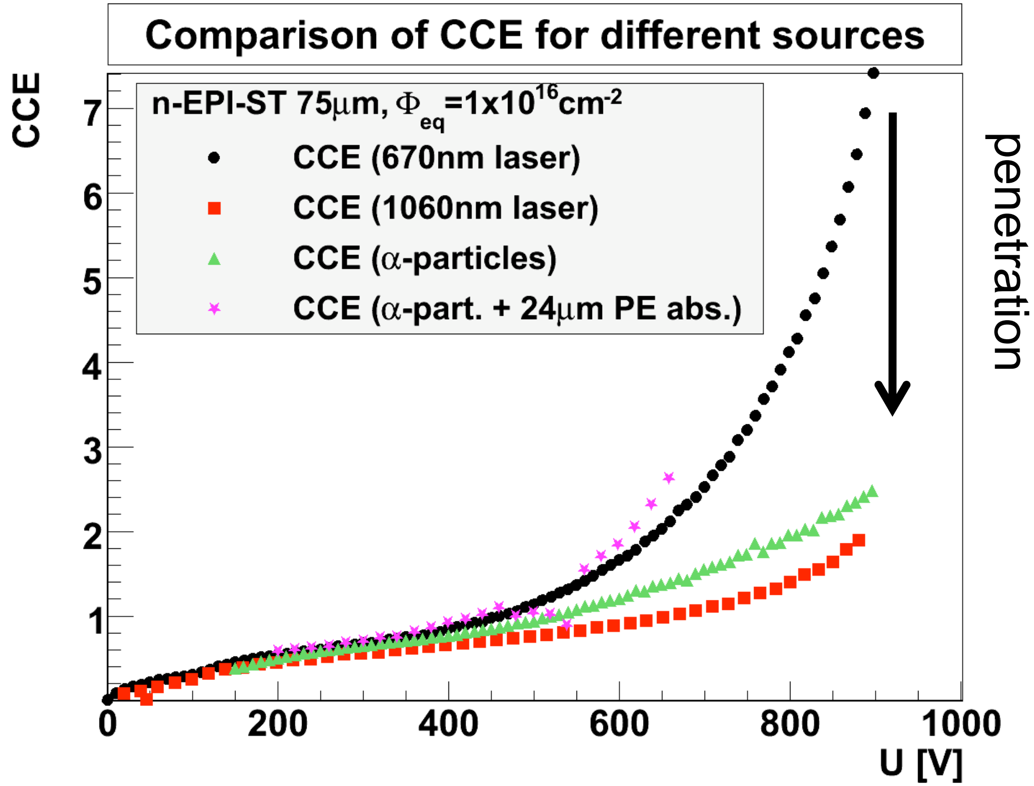
Localisation of CM Region

- Most extreme CM example: n-EPI-ST 75 µm, $\Phi_{eq}=10^{16}\,cm^{-2}$ (24 GeV/c p)



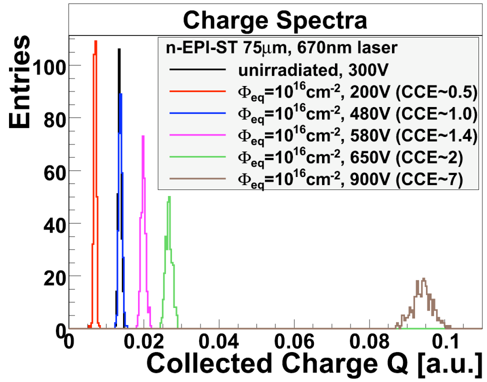


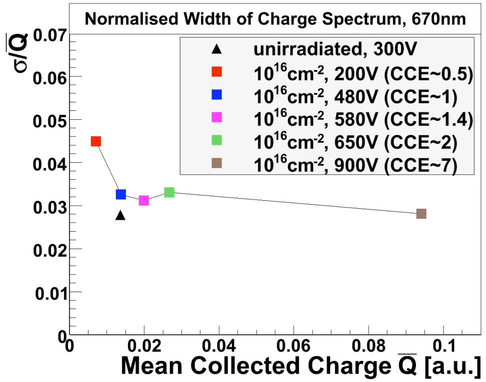


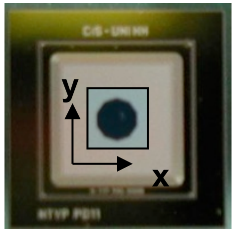


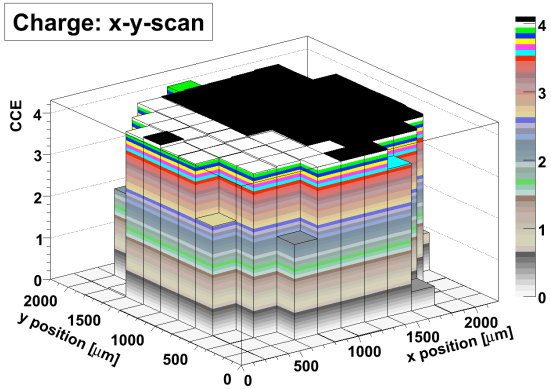
Smaller penetration depth
→ stronger charge multiplication
⇒ multiplication region (high field) located at the front side

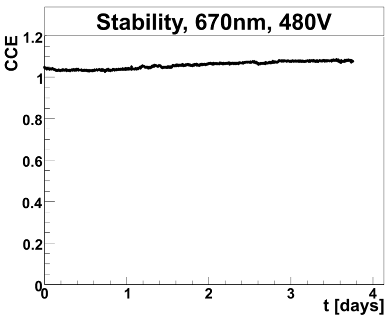
Charge Spectrum, Homogeneity, Stability

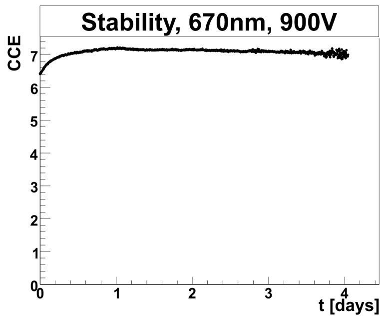












- Normalised width of charge spectrum constant also in CM regime

⇒ Stat. fluctuations not relevant

- CM is very homogeneous over detector area

- CM is stable for days
(at high voltages limited by micro discharges)

Summary

- Breakthrough in understanding radiation damage
  ⇒ Understanding reverseannealing
  ⇒ Close correlation for deep defects to dark current

- Multi Channel TCT part of virtual laboratory
  ⇒ External users welcome
  ⇒ Plasma investigations for European XFEL

- Charge multiplication a promising solution to overcome trapping in S-LHC