Charge Transfer Inefficiency Simulation for CCD Vertex Detector Studies

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Outline

- Introduction
- Charge Transfer Inefficiency (CTI)
- CTI of initially empty traps
- From initially empty to partially filled traps
- Frequency variation
- Toy CTI model and comparison
- Summary

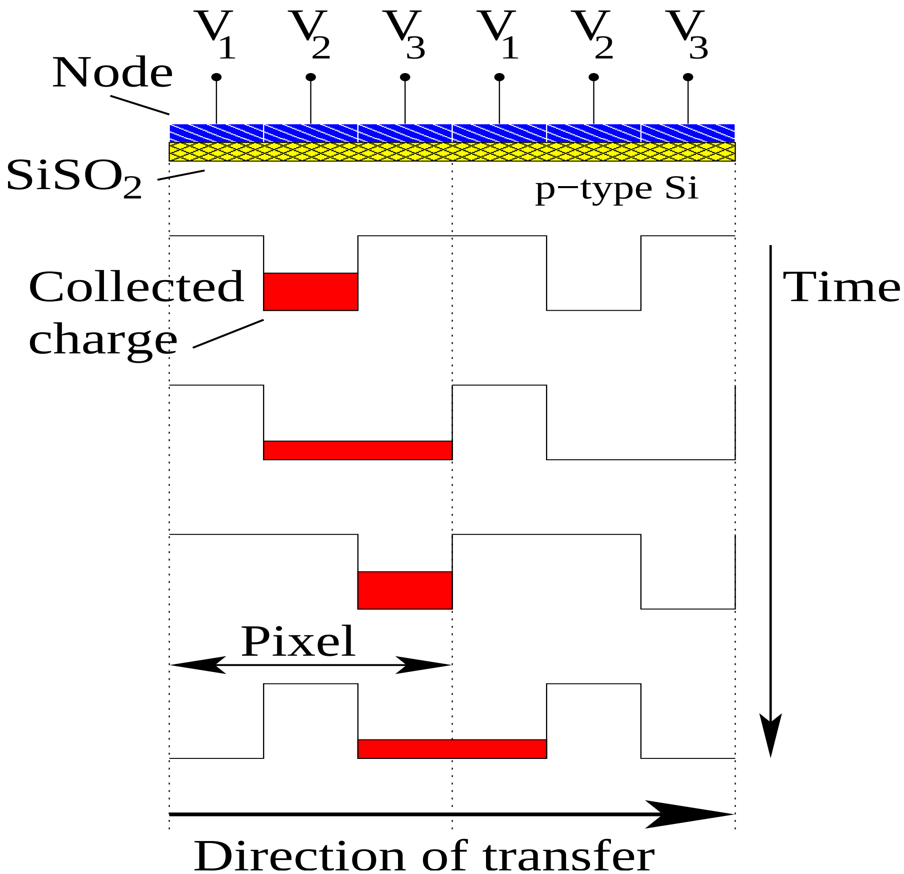
Introduction

Linear Collider Flavour Identification (LCFI) collaboration:

- Motivation:
  Construction of a CCD based vertex detector for a future Linear Collider, operating at up-to 50MHz.
- Requires:
  Study of radiation hardness due to high particle flux near interaction point.
- Experiment:
  Test system at Liverpool: will study irradiated CCD prototype at temperatures down to 90K.
  Irradiation corresponds to a ^{90}Sr dose of 30krad.
- Simulation:
  Study effects of radiation damage.
  Verify with forthcoming experimental data.
  Propose improvements for future CCD design.

3-Phase CCD

Charge transfer for a 3-phase CCD

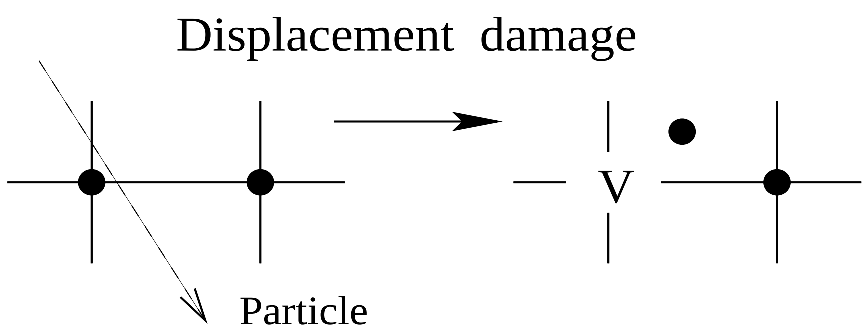


Electrons are collected from ionization of incident particle.

Charge is transfered to output by applying voltage changes to nodes.

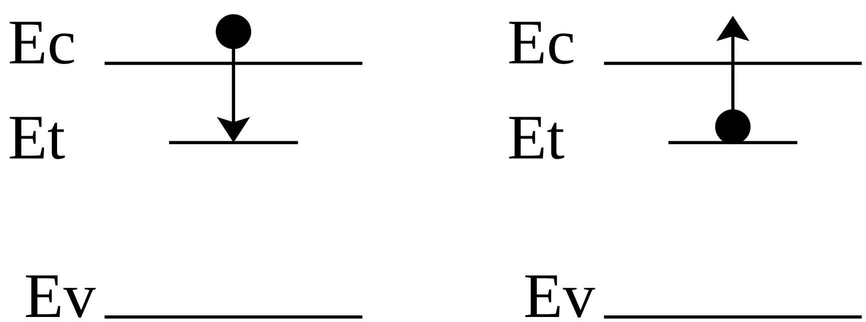
Radiation Damage

Reduction of transfer efficiency due to electron traps (defects in CCD).



Radiation damage produces energy levels within the band gap.

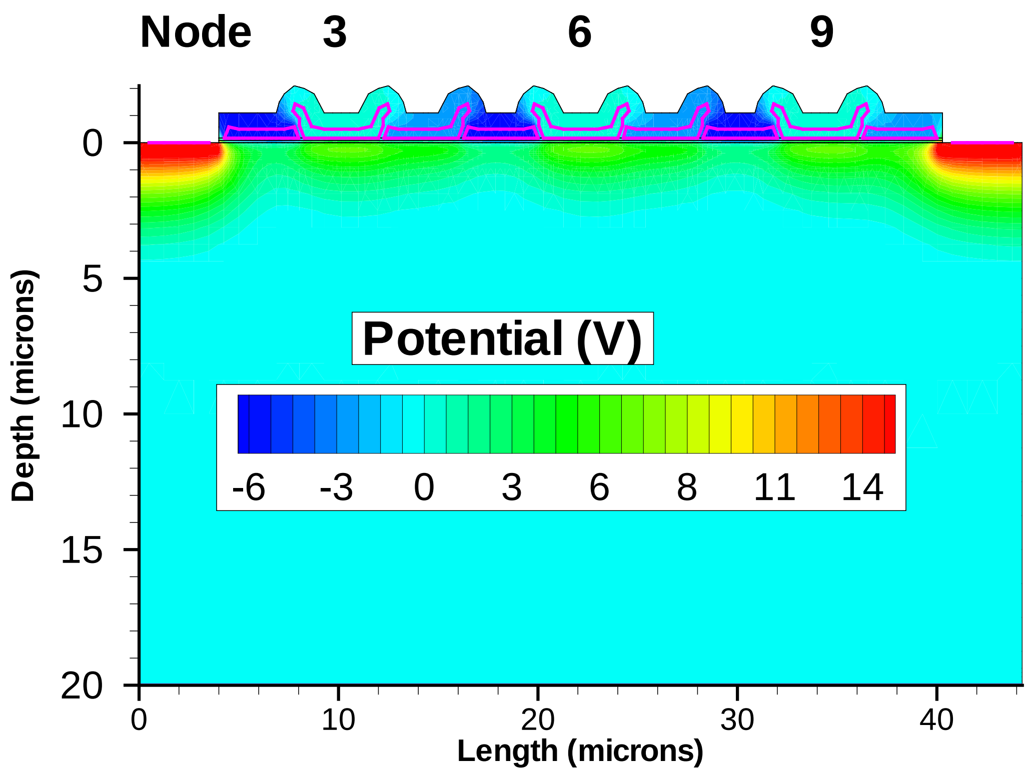
Traps capture electrons from the conduction band which are later released.



Simulated traps at $E_C - 0.17$eV and $E_C - 0.44$eV (observed levels).

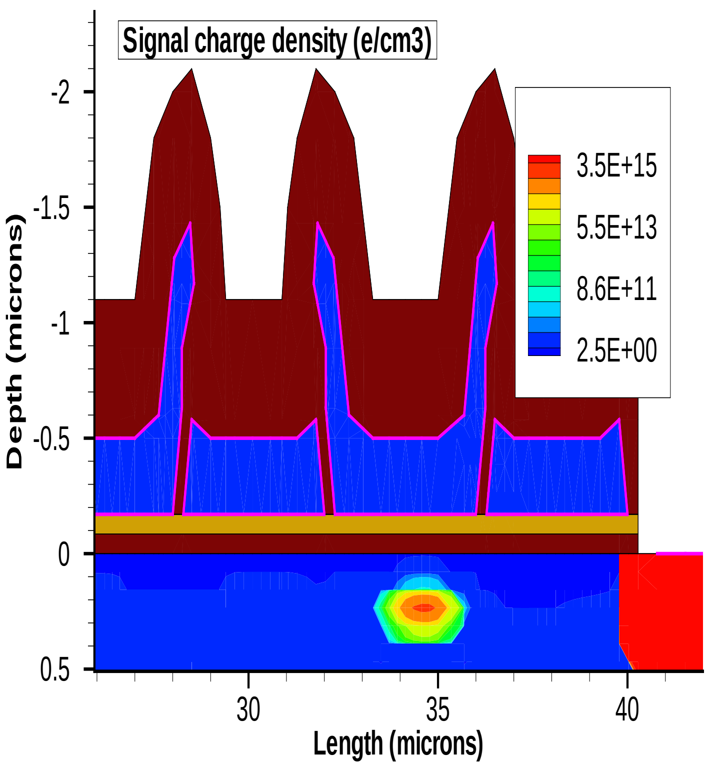
Simulation CCD

Detector structure and potential at nodes after initialization. The signal charge is injected under node 3 and transfered to the output node 10.

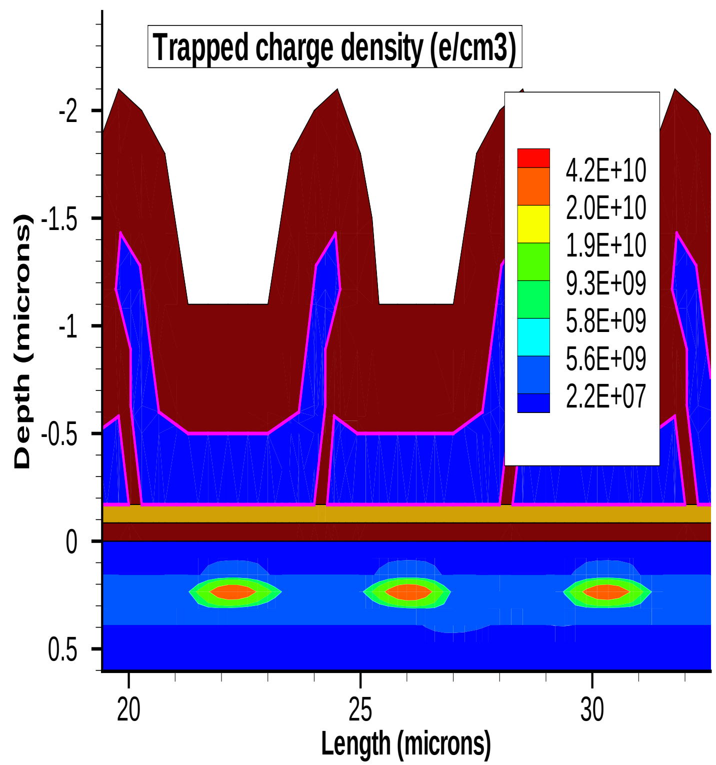


Charge Transfer

Signal charge density almost at output node.



Trapped charge density from transfer of signal charge.



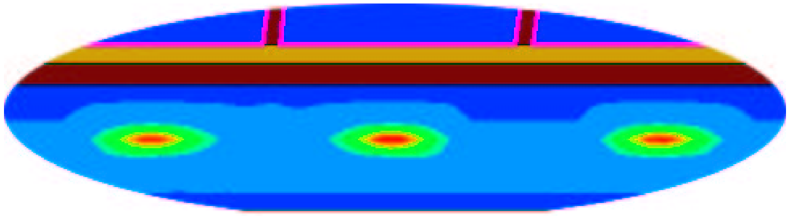
CTI Definition

Traps capture electrons from the passing signal charge ($\mathrm{e_S}$).
For transfer over m pixels,

$$\mathrm{e_S}(m) = \mathrm{e_S}(0)\{1 - CTI\}^m \ .$$

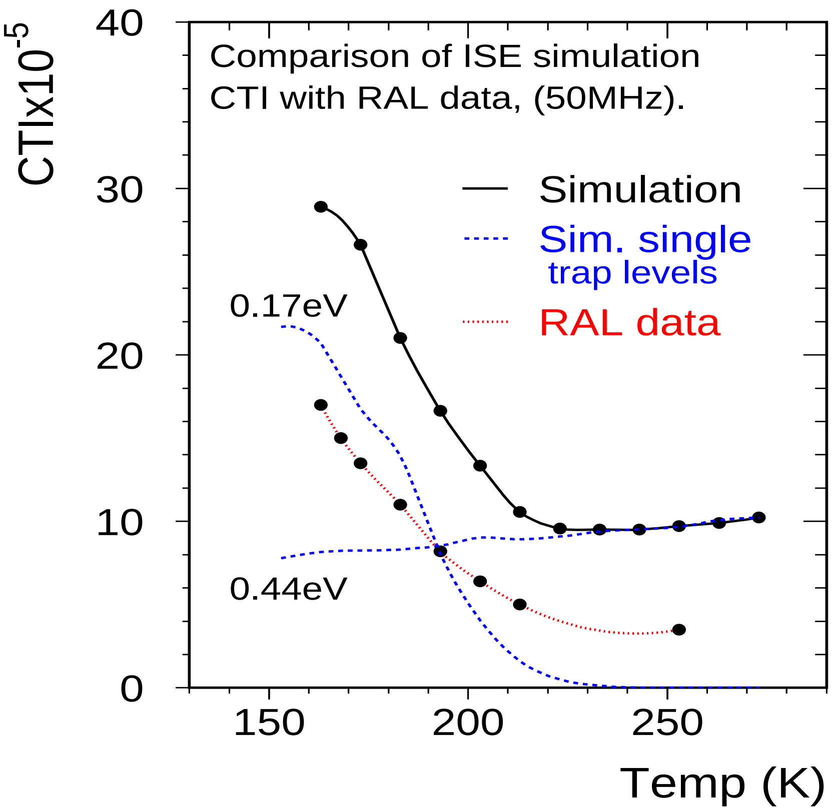
Trapped charge (e_T) determined by surface integral: loss of signal charge.
CTI for one pixel: sum over three nodes (n) of trapped charge.

$$CTI = \sum_{n=6}^{8} \frac{e_\mathrm{T}(n) - e_\mathrm{B}}{e_\mathrm{S}(0)} \ ,$$



where e_B is the background trapped charge.

Empty Traps: CTI Simulation



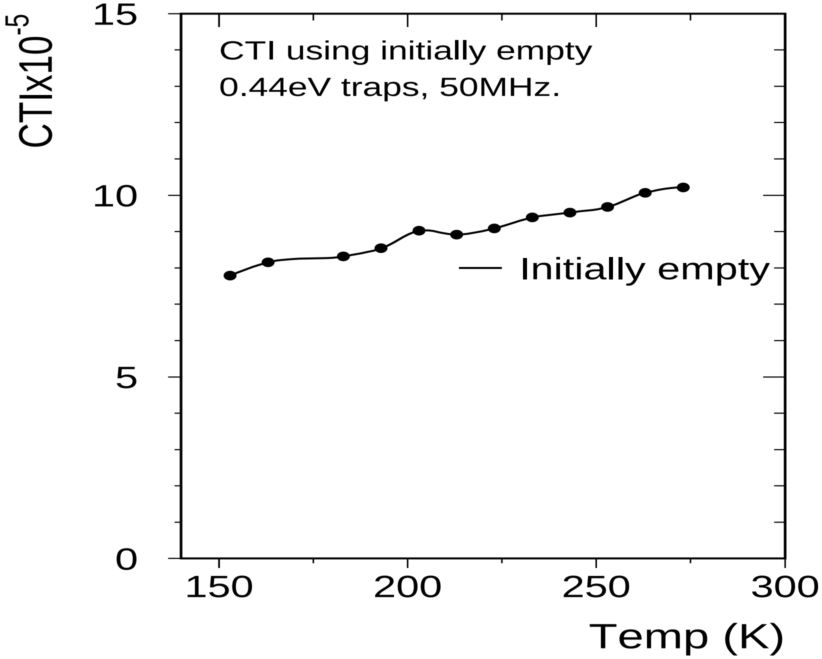
Traps initially empty.

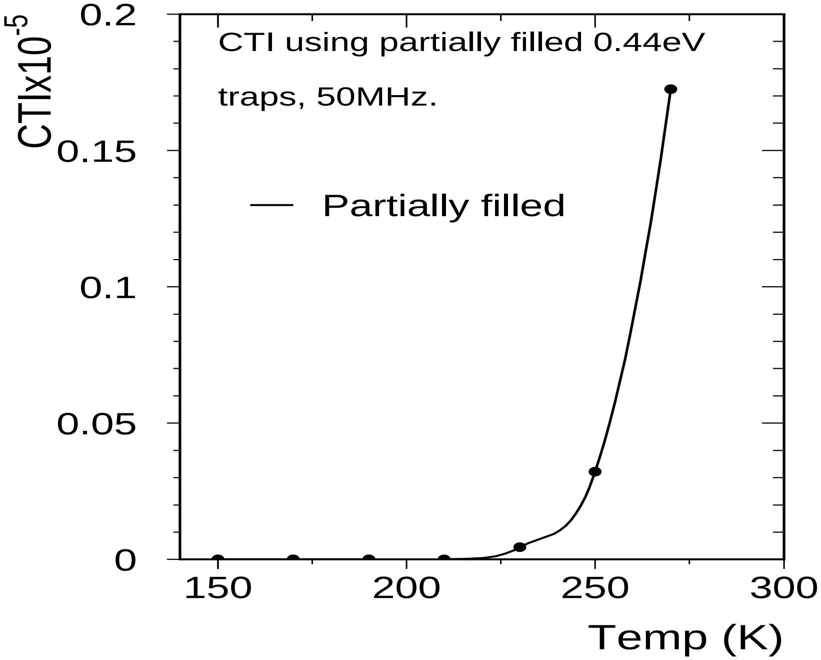
- Differences between ISE simulation and RAL data.
- Possibility: empty trap simulation is not a good approximation.

Consider partially filled traps: improves simulation by representing a continuous readout process.

0.44eV Trap CTI Contribution

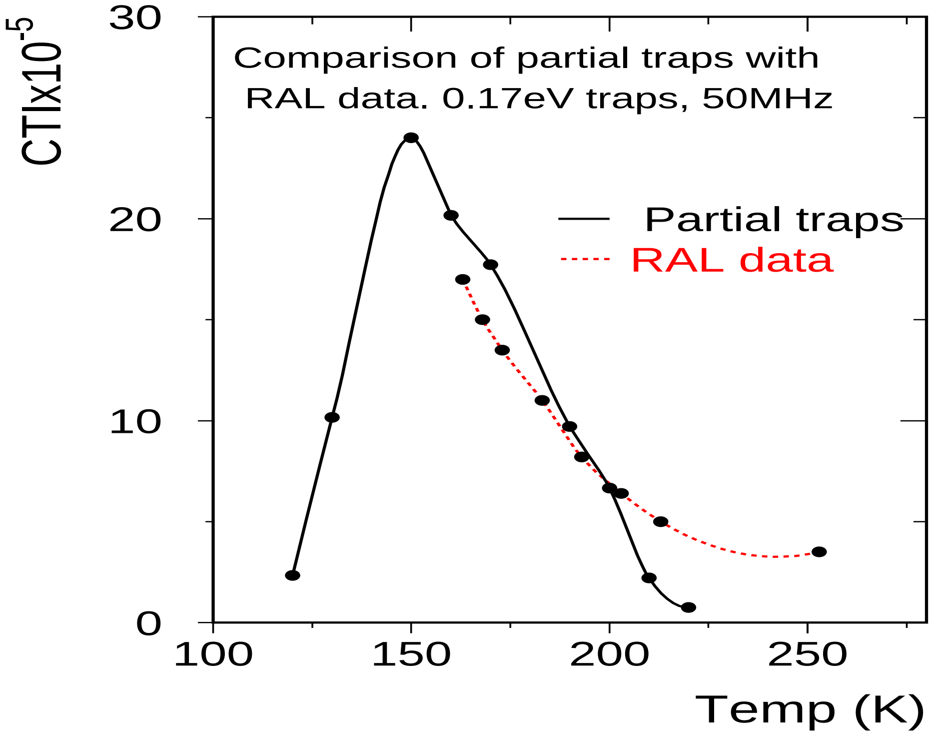
Comparison between initially empty and partially filled traps.





- Negligible contribution to CTI from 0.44eV trapping for partially filled traps (due to long emission time).
- Thus, neglect 0.44eV traps in further study.

0.17eV Trap CTI Contribution

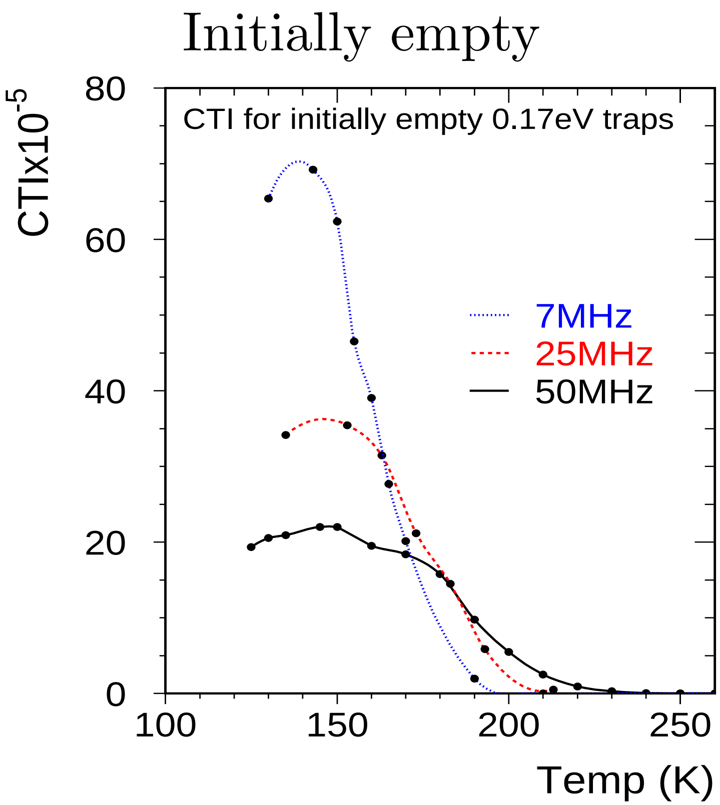


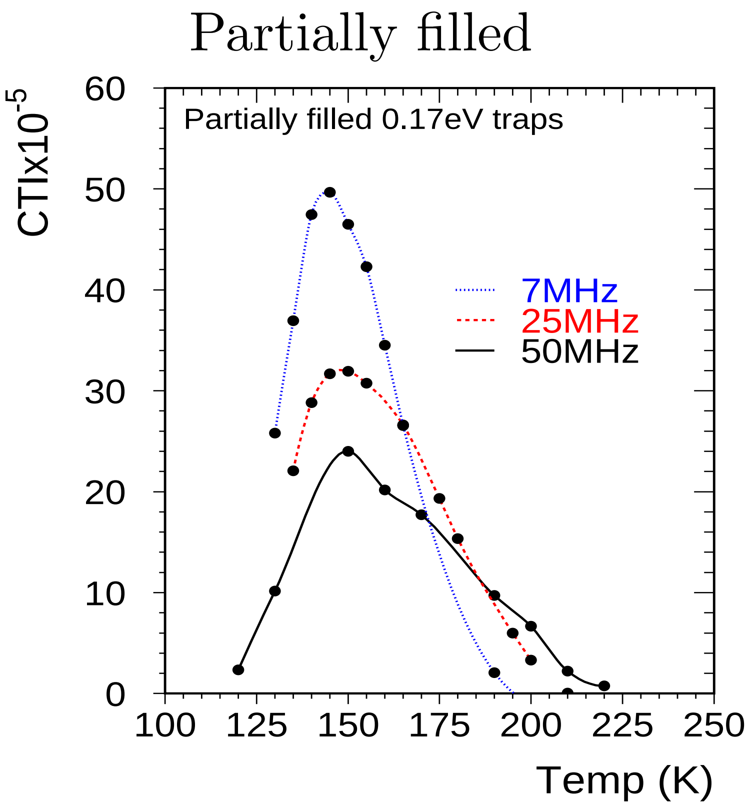
Traps partially filled:

- Clear peak structure.
- CTI slope differs between simulation and data (could be related to trap concentration. Simulation: $1 \times 10^{11}\mathrm{cm}^{-3}$).
- Above 200K disagreement, possibly due to dark currents.

New data will extend temperature range: possibility to measure peak structure.

Frequency Dependence





At high temperature: emission time so fast that trapped charge rejoins passing signal.

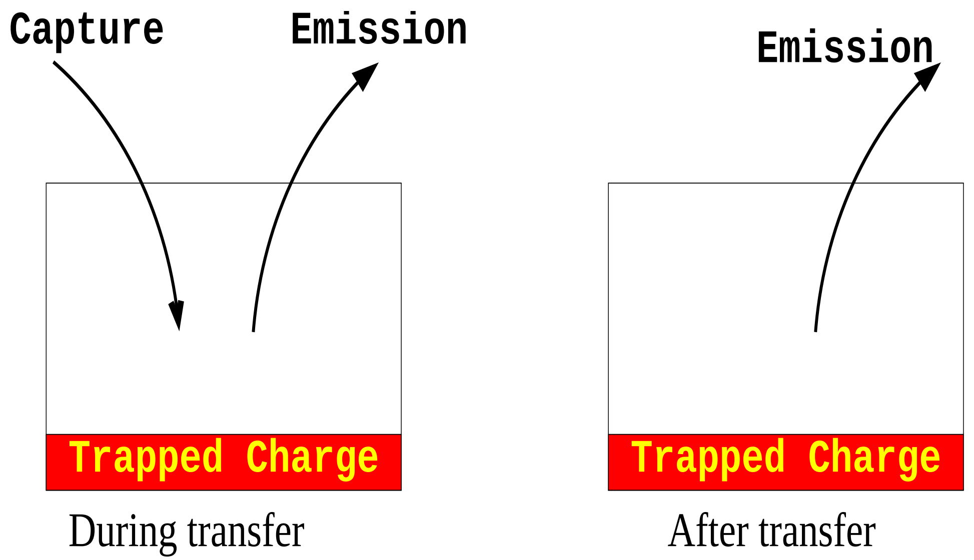
Near peak: for higher readout frequency there is less time to trap charge.

CTI Toy Model

Better understanding of underlying processes:

1. Traps capture electrons from the signal charge.
2. Electrons are emitted from filled traps.

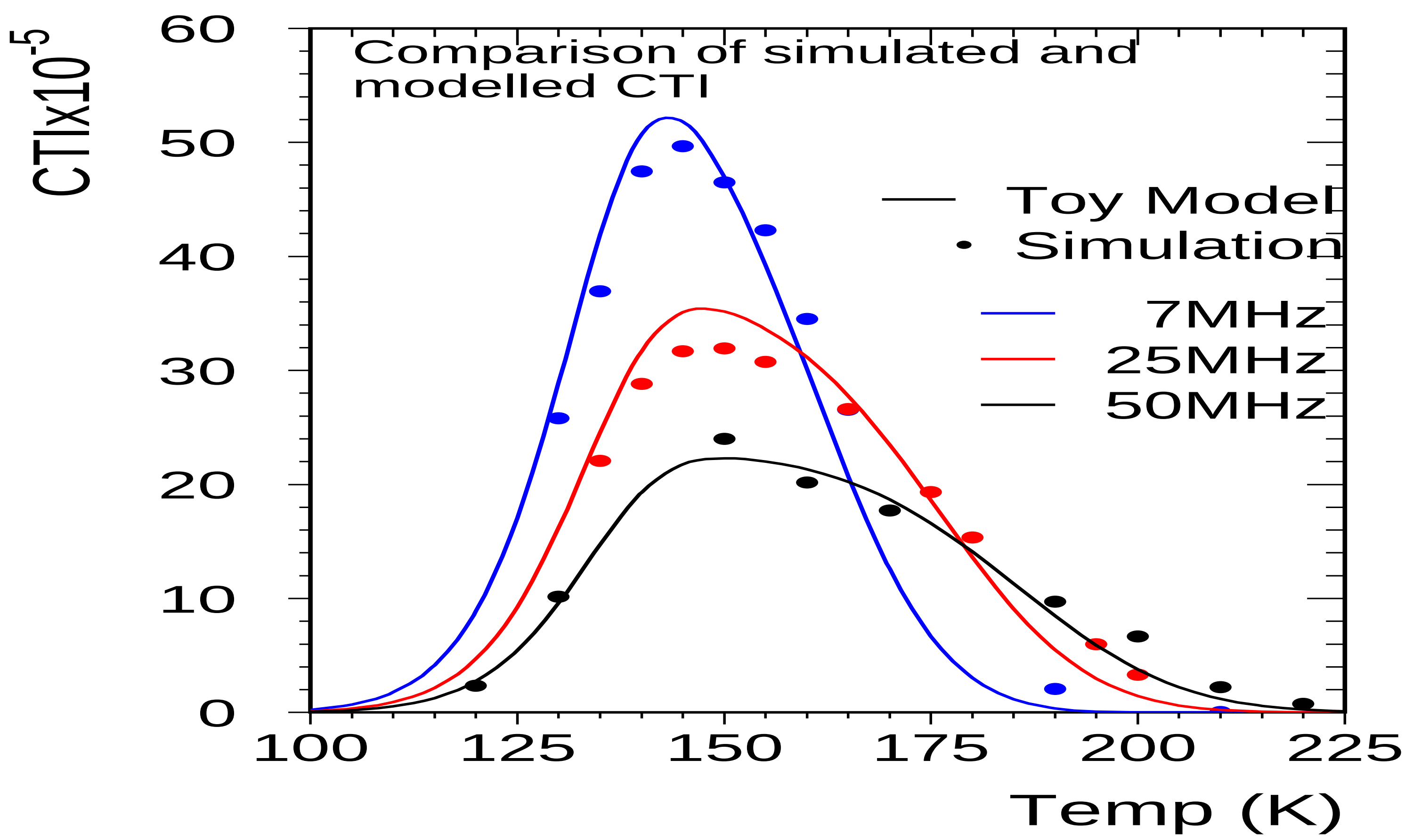
These processes occur at different rates, which are governed by the capture τ_c and emission τ_e time constants.



CTI is found by modeling the net increase in trapped charge.

Comparison ISE Simulation and Toy Model

0.17eV partially filled traps at 7, 25, 50 MHz.



Summary

- Detailed radiation hardness simulation of a CCD prototype.
- Temperature range 100K to 250K: CTI peak structure for 0.17eV traps.
- Partially-filled traps (continuous readout): 0.44eV energy level negligible due to large trap emission time.
- Toy model shows good agreement with commercial software.
- Comparison with forthcoming CTI measurements.
- Adjustment of radiation dose to new Linear Collider expectations.
- Investigation of factors to reduce CTI.