Charge Transfer Inefficiency Studies for a Future CCD Vertex Detector

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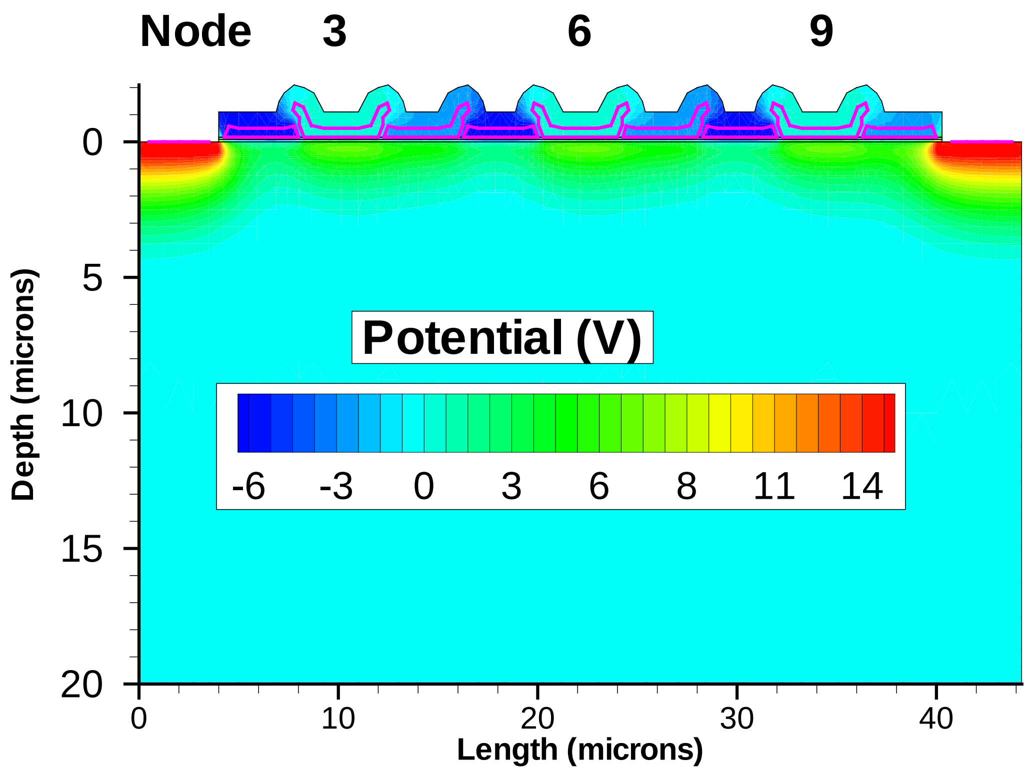
Outline

- Charge transfer inefficiency (CTI)
- ISE-TCAD (FEA 2D) simulation of 3-phase CCD:
  Radiation dose $\sim$ 30 krad bulk damage
- Effect of initial conditions
- Frequency variation
- Simple model of simulation
- Experimental set-up for column parallel CCD
- Dark current measurements
- Initial CTI test measurements
- Summary

Simulation CCD

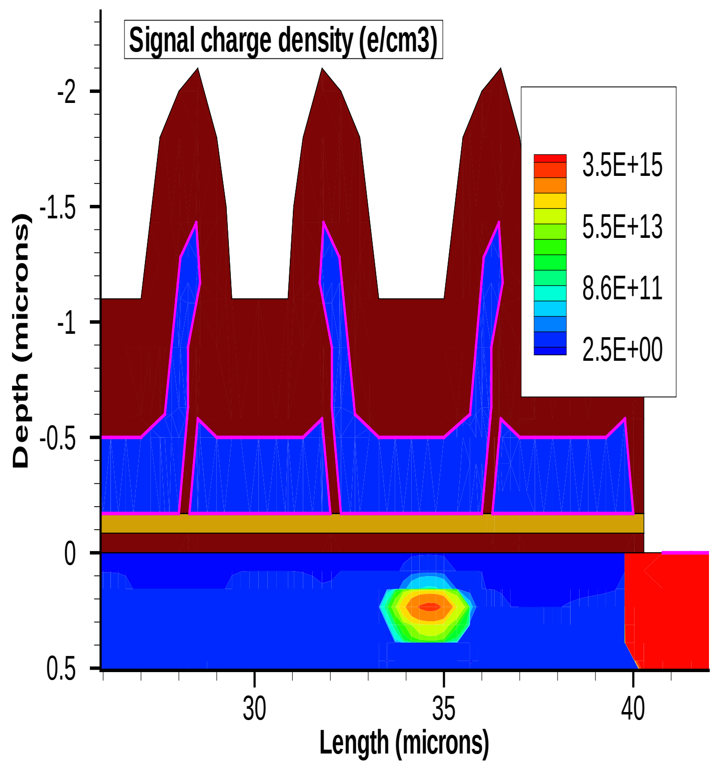
Detector structure and potential at gates after initialization. The signal charge is injected under gate 3.

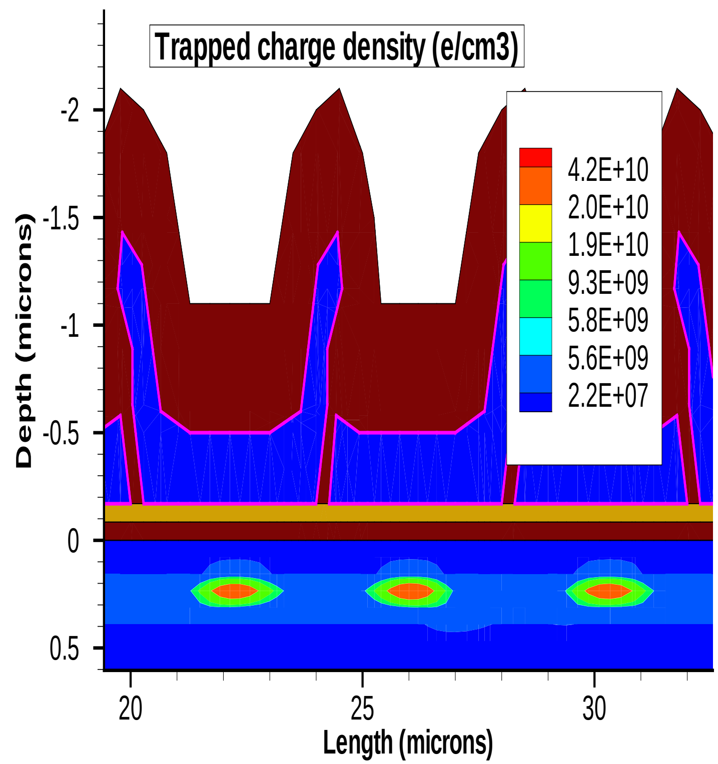


Charge Transfer

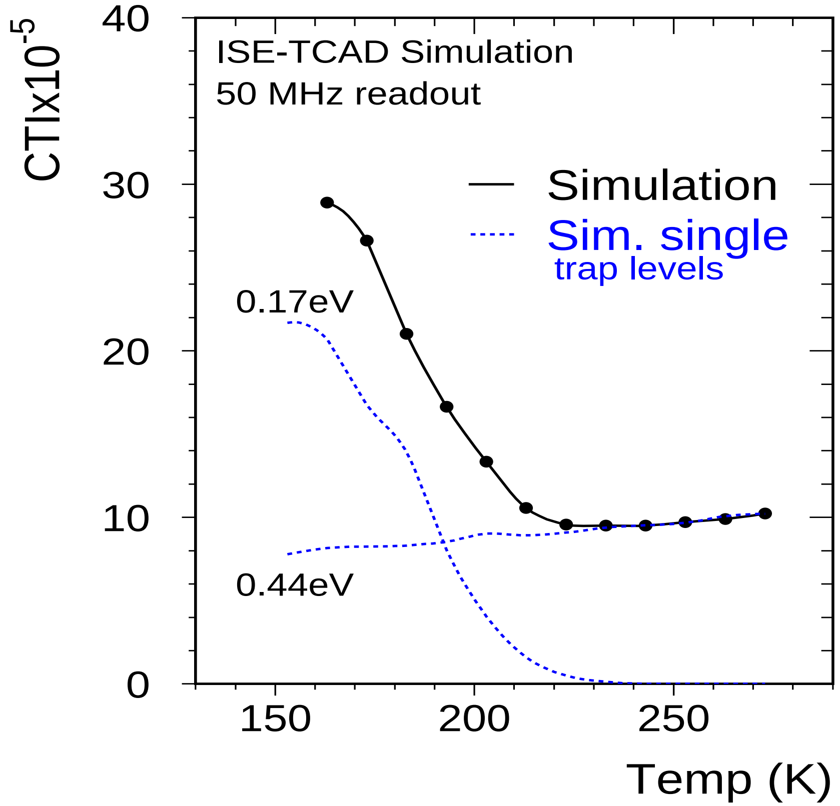
Signal charge density, almost at output gate.

Trapped charge density, from transfer of signal charge.





Empty Traps: CTI Simulation



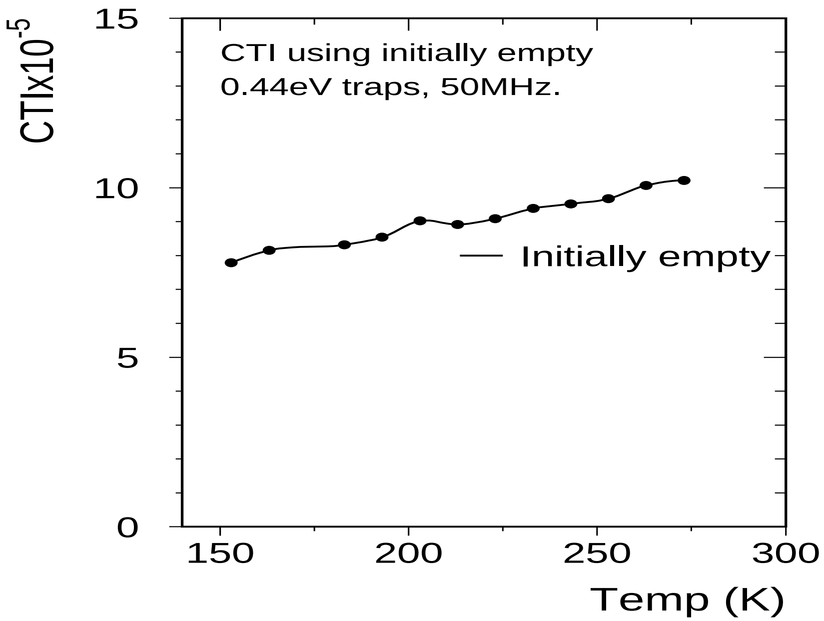
Traps initially empty.

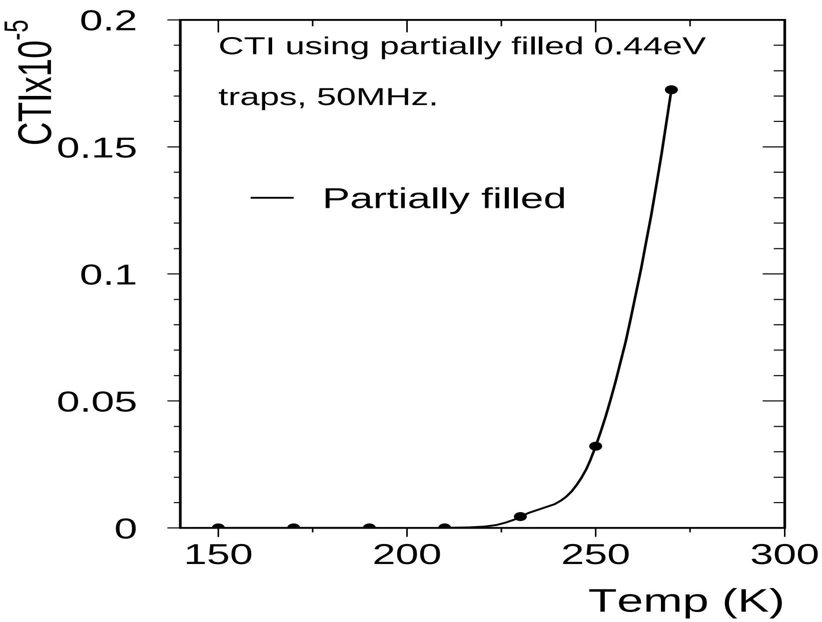
- Empty trap
  simulation may not be a good approximation.

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

0.44eV Trap CTI Contribution

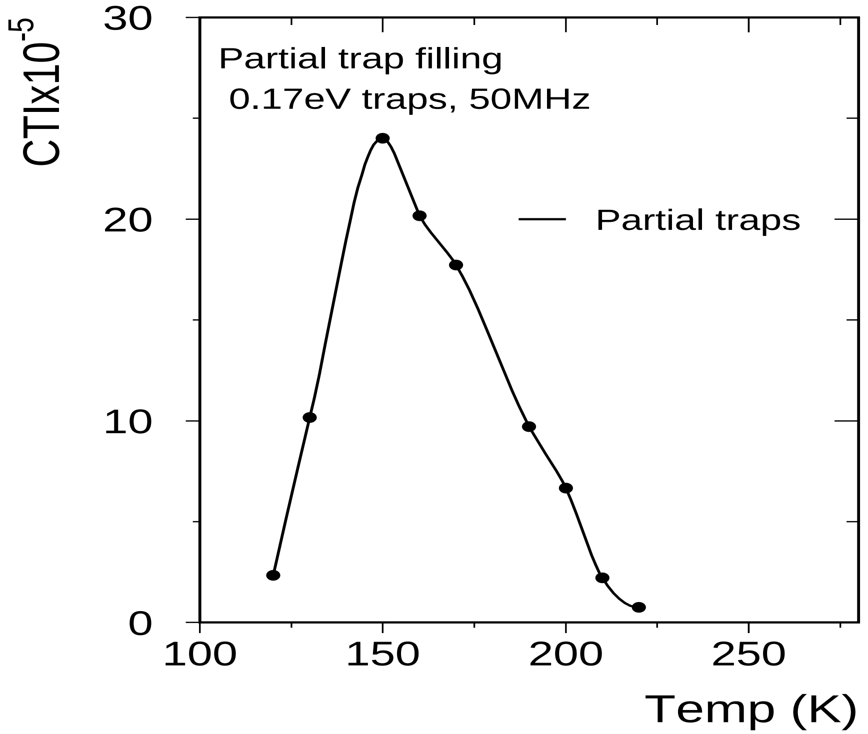
Attempt to improve simulation. Comparison of initially empty and partially filled traps.





- 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.
- Needs to be confirmed by experiment.

0.17eV Trap CTI Contribution

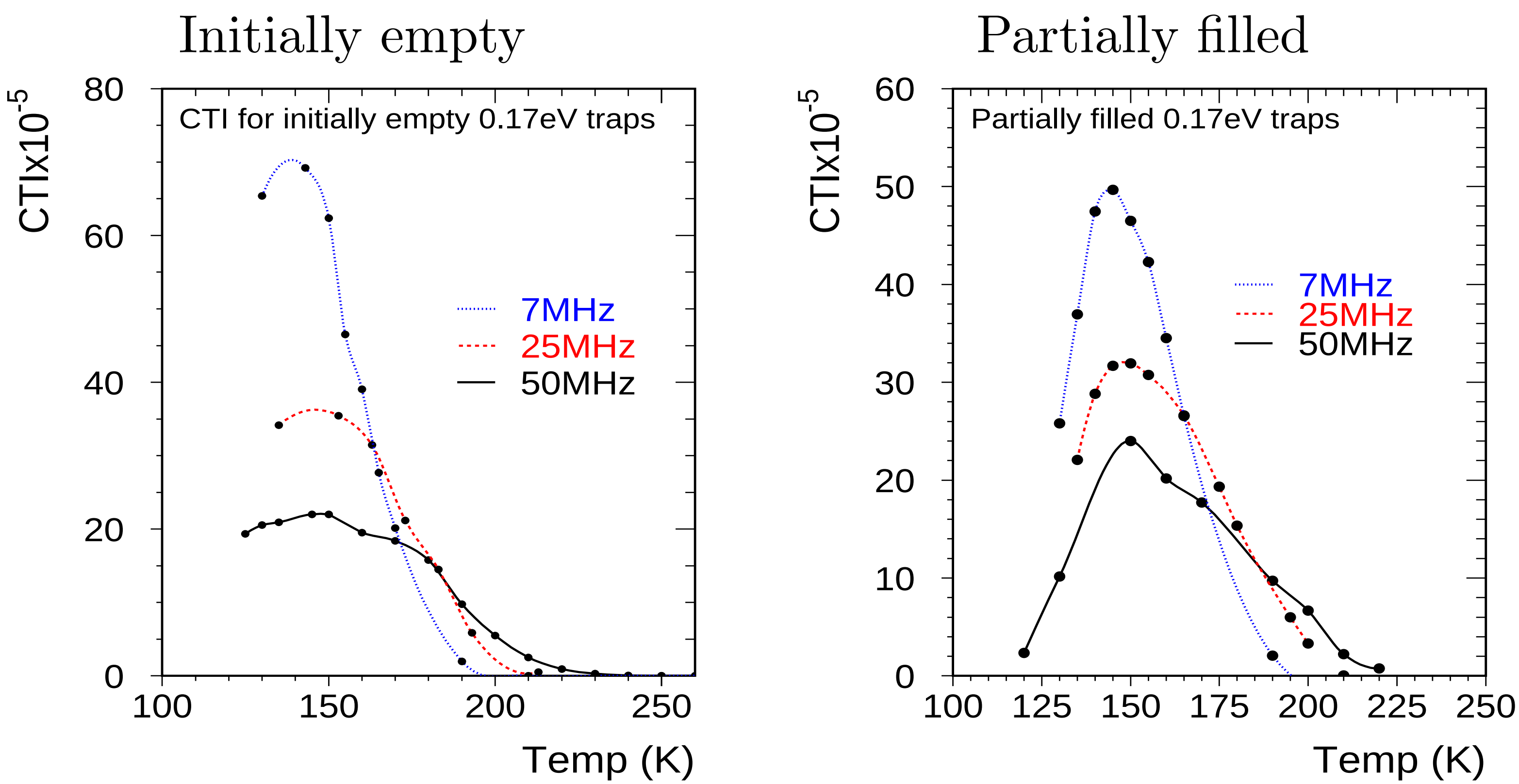


Traps partially filled:

- Clear peak structure.
- Above 250K, previous data indicates Dark Current effects.

New data to cover simulation 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.

Simple CTI Model for 3-Phase CCD

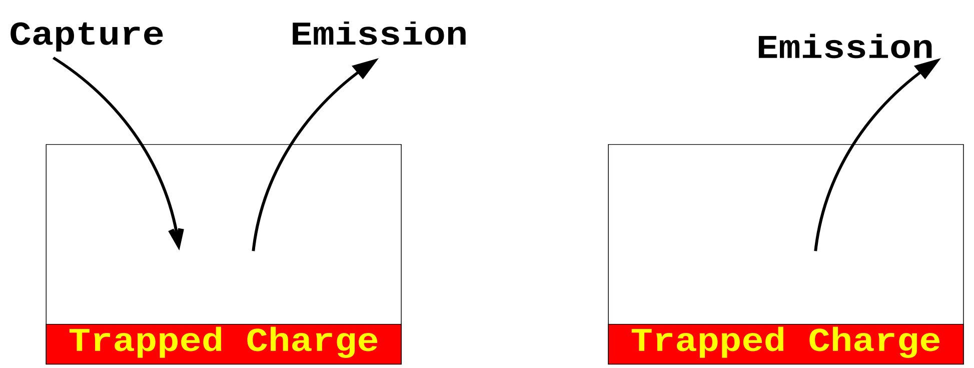
Why model a simulation?

Faster than full ISE simulation, provides insight into factors affecting CTI.

Traps undergo two basic processes:

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

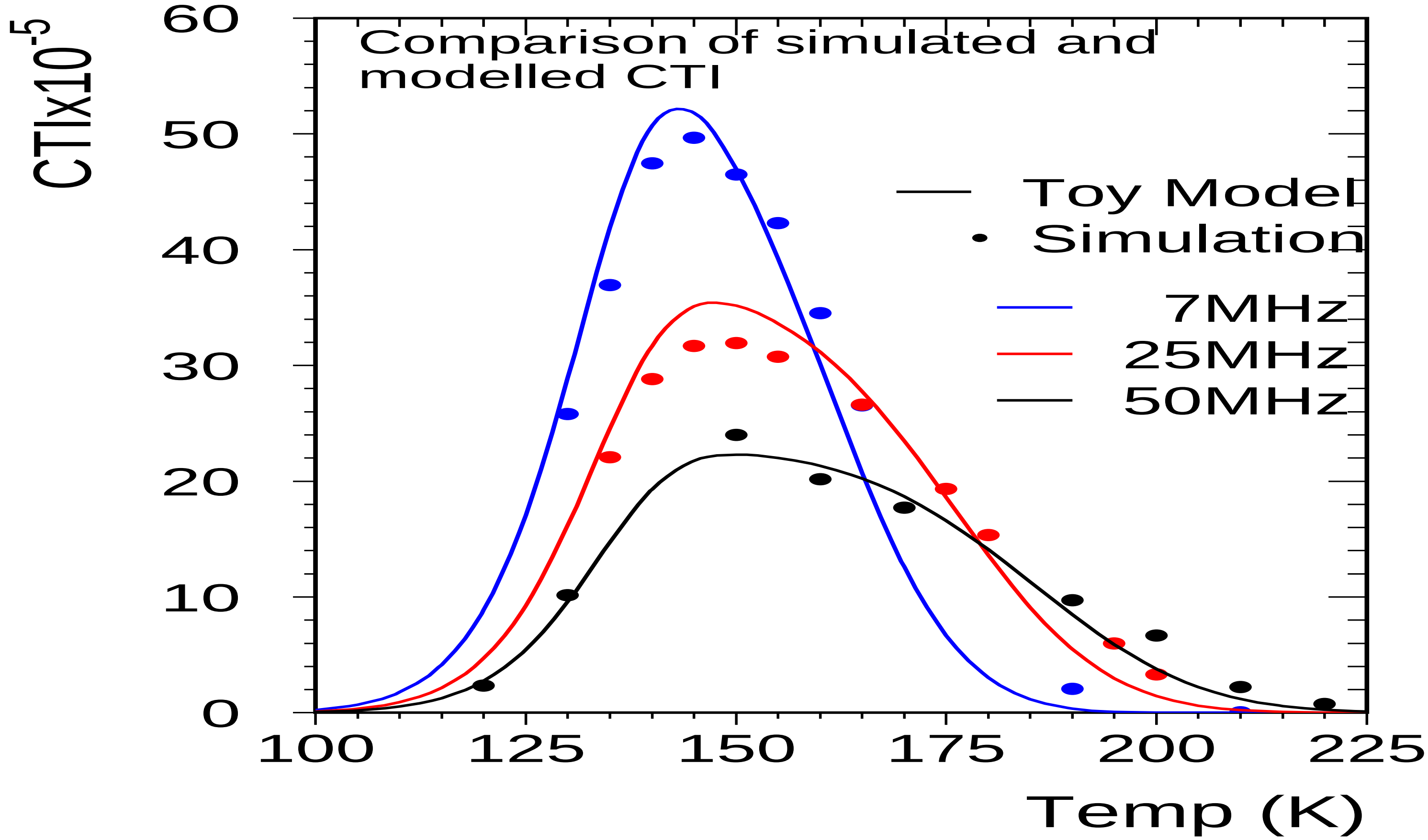
Processes occur at different rates. Governed by capture τ_c and emission τ_e time constants.



During transfer After transfer

ISE Simulation cf. Simple Model

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

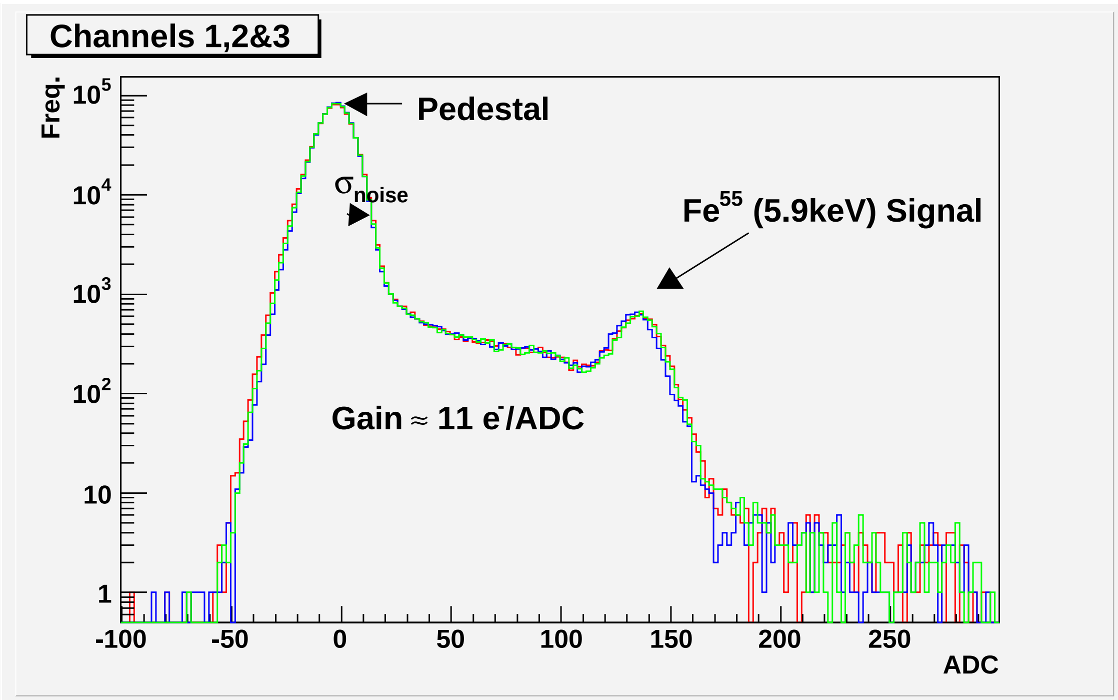


Column Parallel CCD Studies

- High readout speed requires column parallel technology.
- LCFI prototype device CPC-1 capable of 20 MHz readout per channel.
- Unirradiated tests performed at CCLRC - RAL
- Fe^{55} source used to mimic MIP.
- Standalone set-up uses four external ADC amplifiers.

CPC-1 Spectrum

Typical output from three columns of CPC-1 with Fe^{55} source.



Noise $\approx 60\,e^-$,

Freq. $= 1\,$MHz,

Integration time $= 500\,$ms,

$T \approx -30\,°$C,

2000 frames.

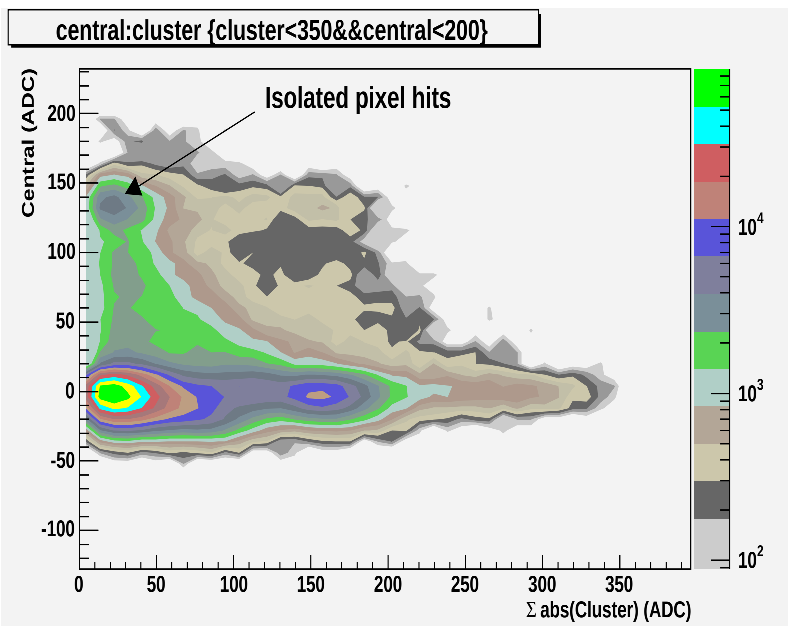
CTI - Event Selection

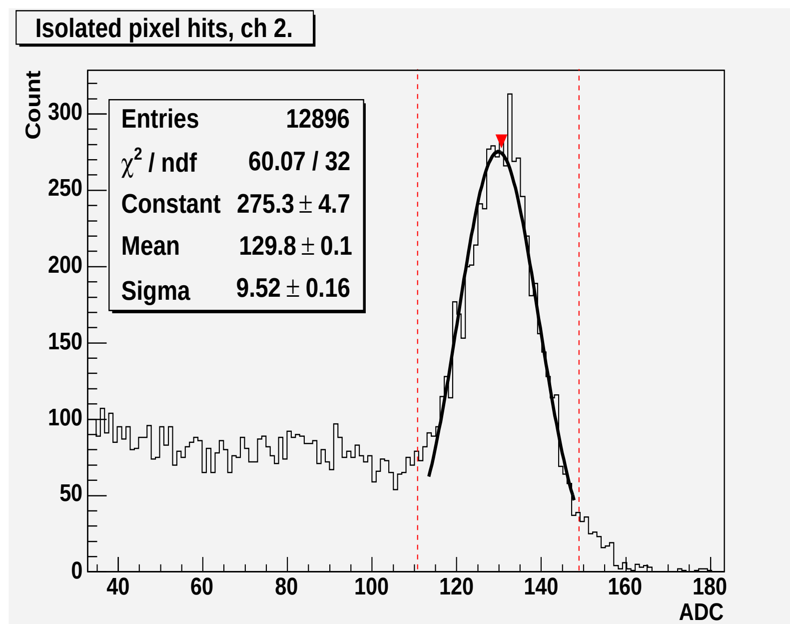
Fe^{55} isolated hits ($\approx 1620\,e^-$) used to determine CTI.

Hits located using 3x3 cluster method.
Loose selection criteria:

- Pixel amplitude $> 5\sigma_{\rm noise}$,
- $\Sigma_{i=1}^{8}|{\rm cluster}_i| < 8\sigma_{\rm noise}$.

Select events which are within $\pm 2\sigma$ of signal peak.





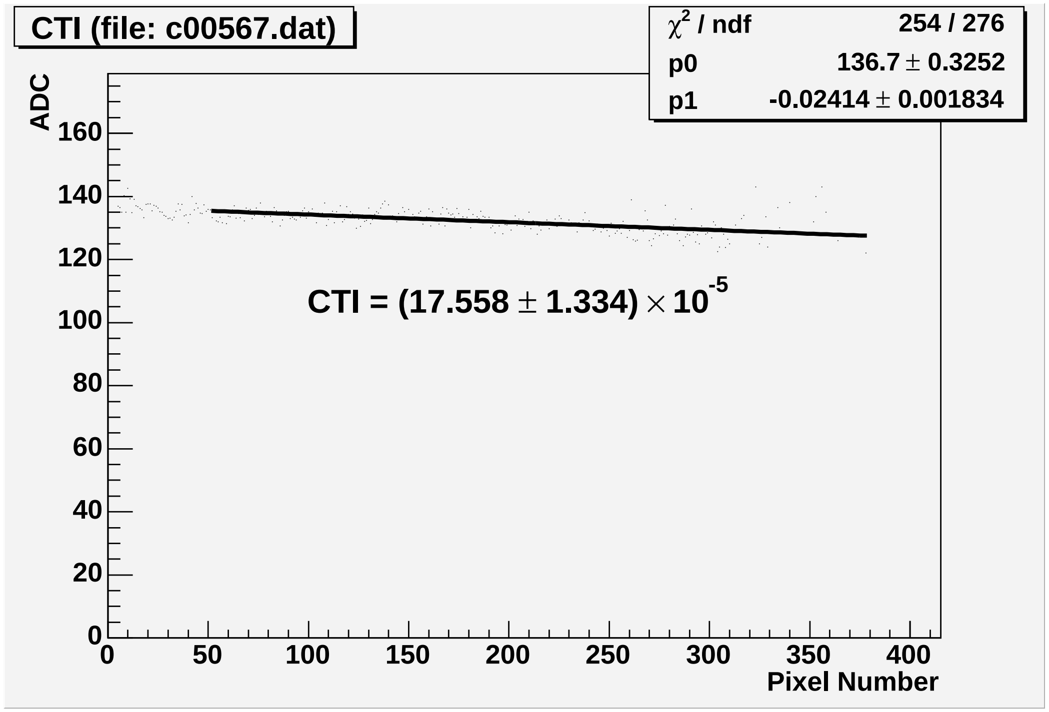
CTI - Determination

Scatter plot of isolated pixel hits; ADC amplitude Q against pixel number gives

$$\mathrm{CTI} = -\frac{1}{Q_0}\frac{\mathrm{d}\,Q}{\mathrm{d}\,(\mathrm{Pixel})},$$

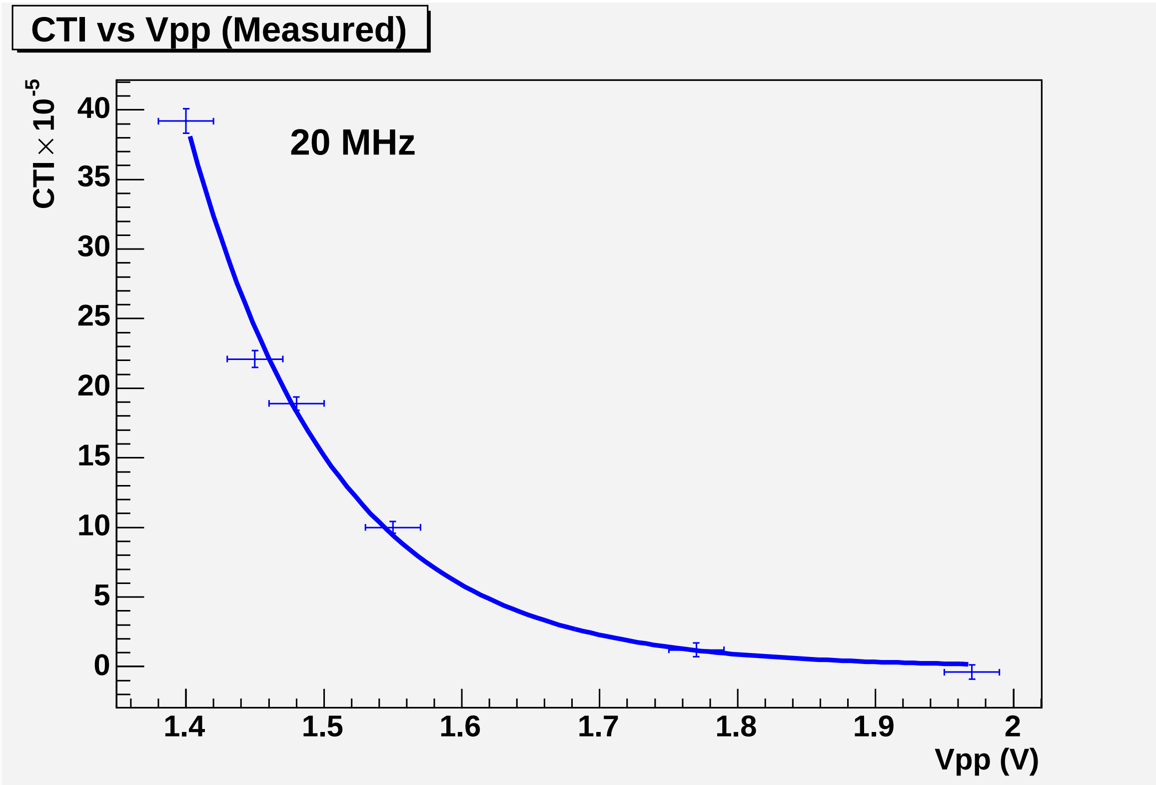
where Q_0 is intercept from straight-line fit.

Example for low clock voltage.



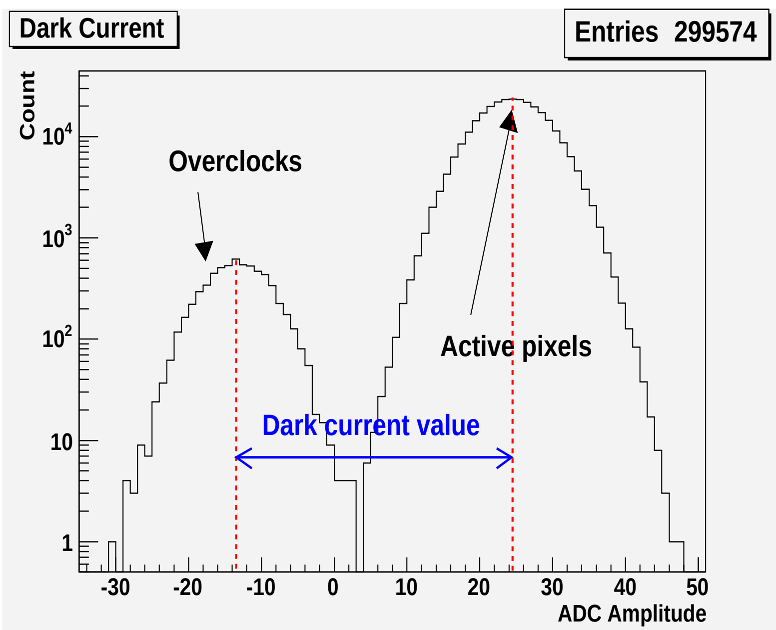
CTI - Voltage Induced

- Unirradiated device; small CTI ($< 10^{-5}$).
- However, decrease of clock voltage reduces transfer efficiency.
- Provides possibility to measure CTI as function of clock voltage.

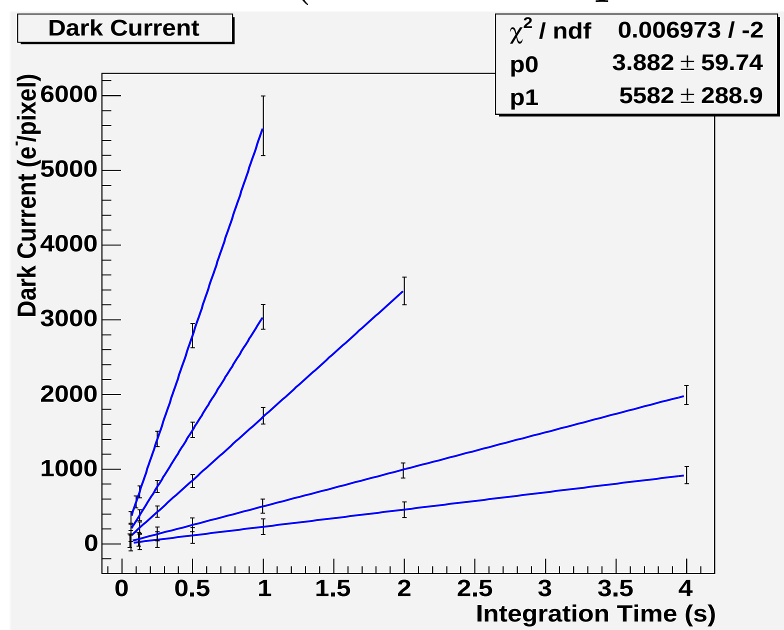


Dark Current - Measurement

- Thermally generated electrons captured in potential wells.
- Charge collected proportional to integration time.
- 10 overclocks sampled per frame - used as reference level.
- Gain (e^-/ADC) calibrated from Fe^{55} source (at each temperature).



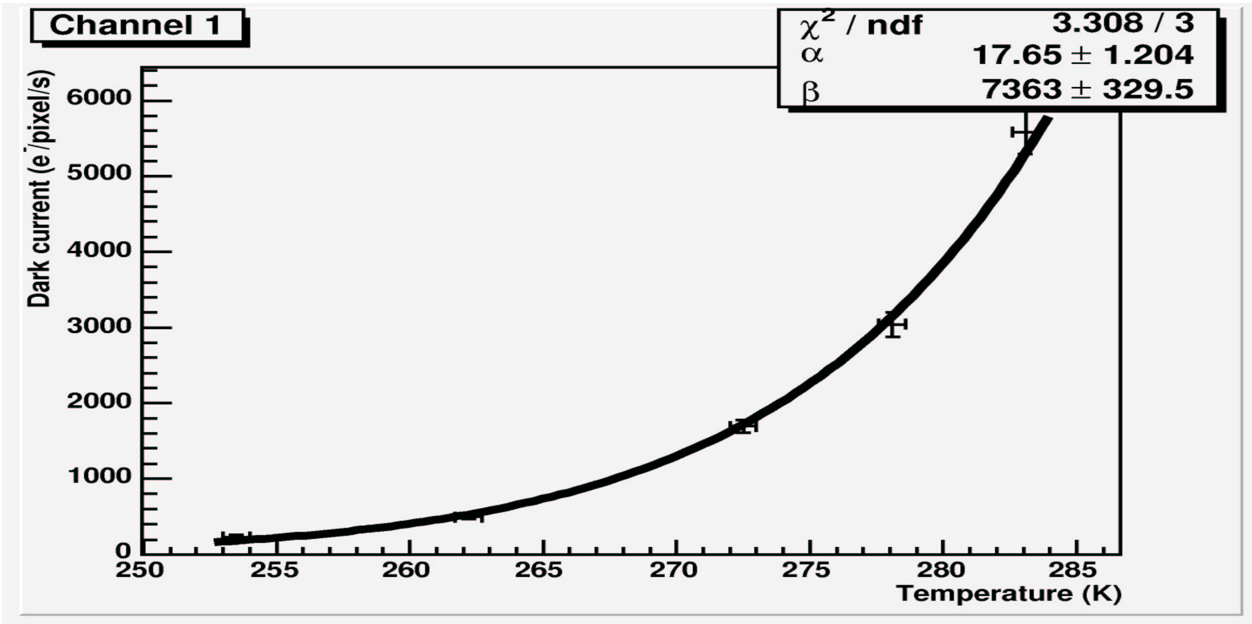
Dark current measurement



DC at different temperatures

Dark Current - Result

Fit to $J_{\mathrm{dc}} = T^3 \exp(\alpha - \beta/T)$.



Uniform dark current characteristics observed across the four channels

Summary and Outlook

Simulation

- Radiation hardness simulation of a CCD prototype studied.
- Clear CTI peak structure observed.
- Simple model (emission and capture time) agrees well.

Experiment

- Investigated with low statistics:
  - CTI (Voltage induced),
  - Dark Current.

Future

- Simulation of column parallel CCD ongoing for comparison with data.
- Data from Liverpool will allow confrontation with simulation.