Improving the Design of CZT Ring-Drift Detectors with Sentaurus TCAD

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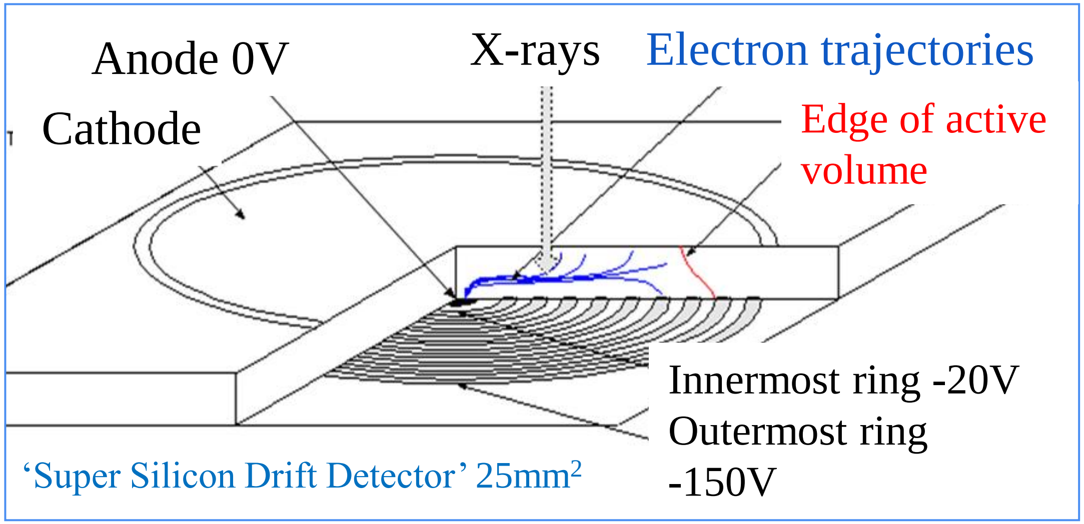
- [If time remains] Modelling CZT material

What is a Ring-Drift Detector?



[1]Amptek Inc. (2013)

- Planar cathode covers one face (-ve)
- ‘Point’ anode at centre of other face (ground).
- lateral electric field is applied by biasing concentric rings around anode

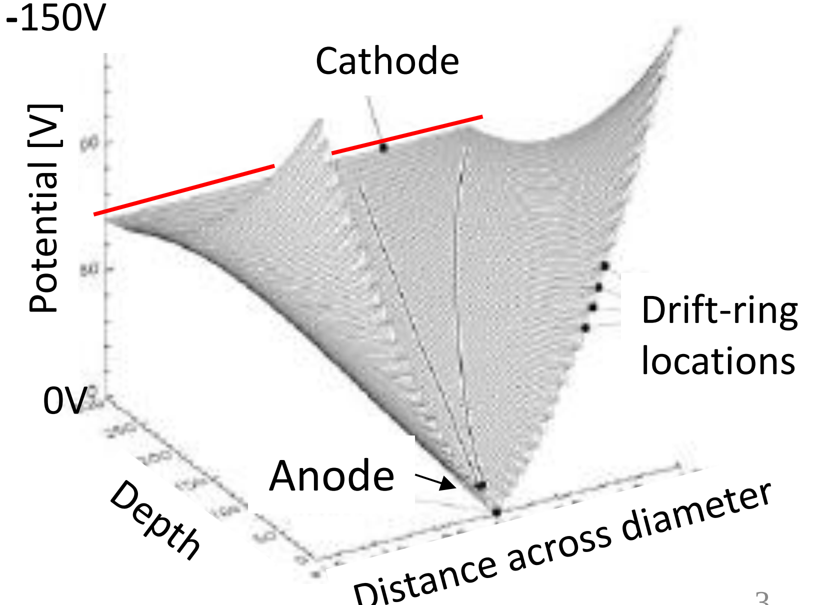
  to form a potential ‘funnel’.

- State-of-the-art for silicon **soft** x-ray detectors: lower capacitance and leakage than pn diodes.

Why use CZT?

- High-Z material for **hard** x-rays (25-150keV).
- Room-temperature operation.
- CZT has poor hole mobility →Ring-drift is most effective for single-carrier sensing.

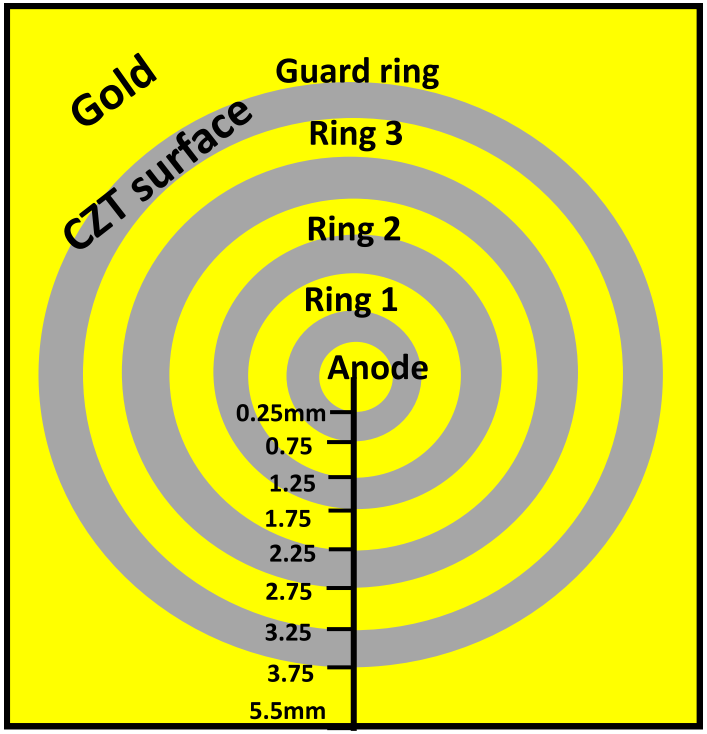
Our CZT is produced by Redlen Technologies [3]



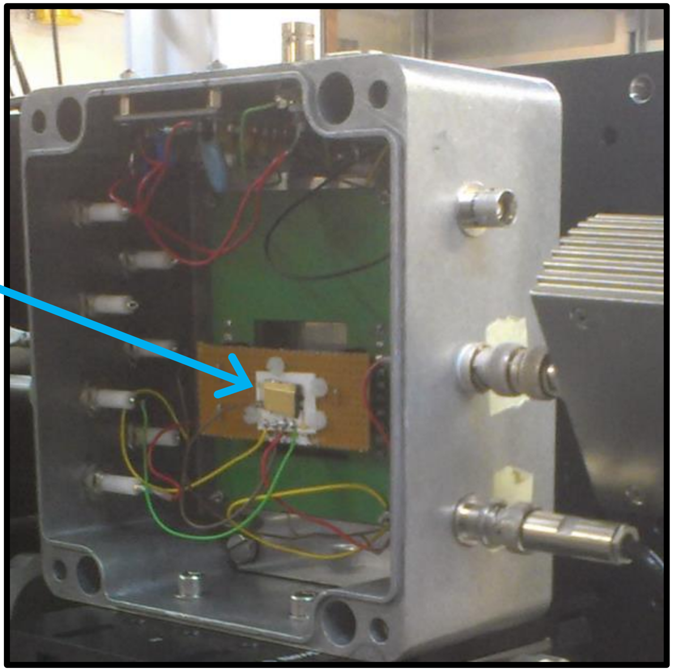
[2]Lechner, P., et al (1996)

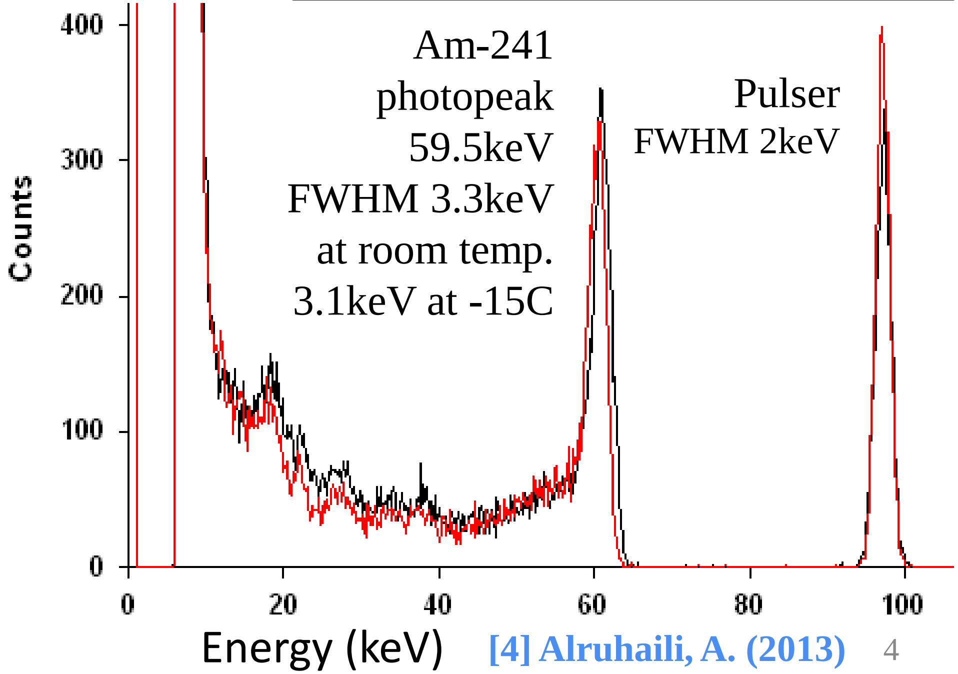
Prototype 3-Ring CZT device

- Bonded rings-down to gold contacts on special tile.
- Each ring and the cathode independently biased.
- Anode grounded through CoolFET preamp
- Irradiation through planar cathode.



CZT Wafer 10 x 11 x 2.3mm.
0.5mm ring and gap widths.



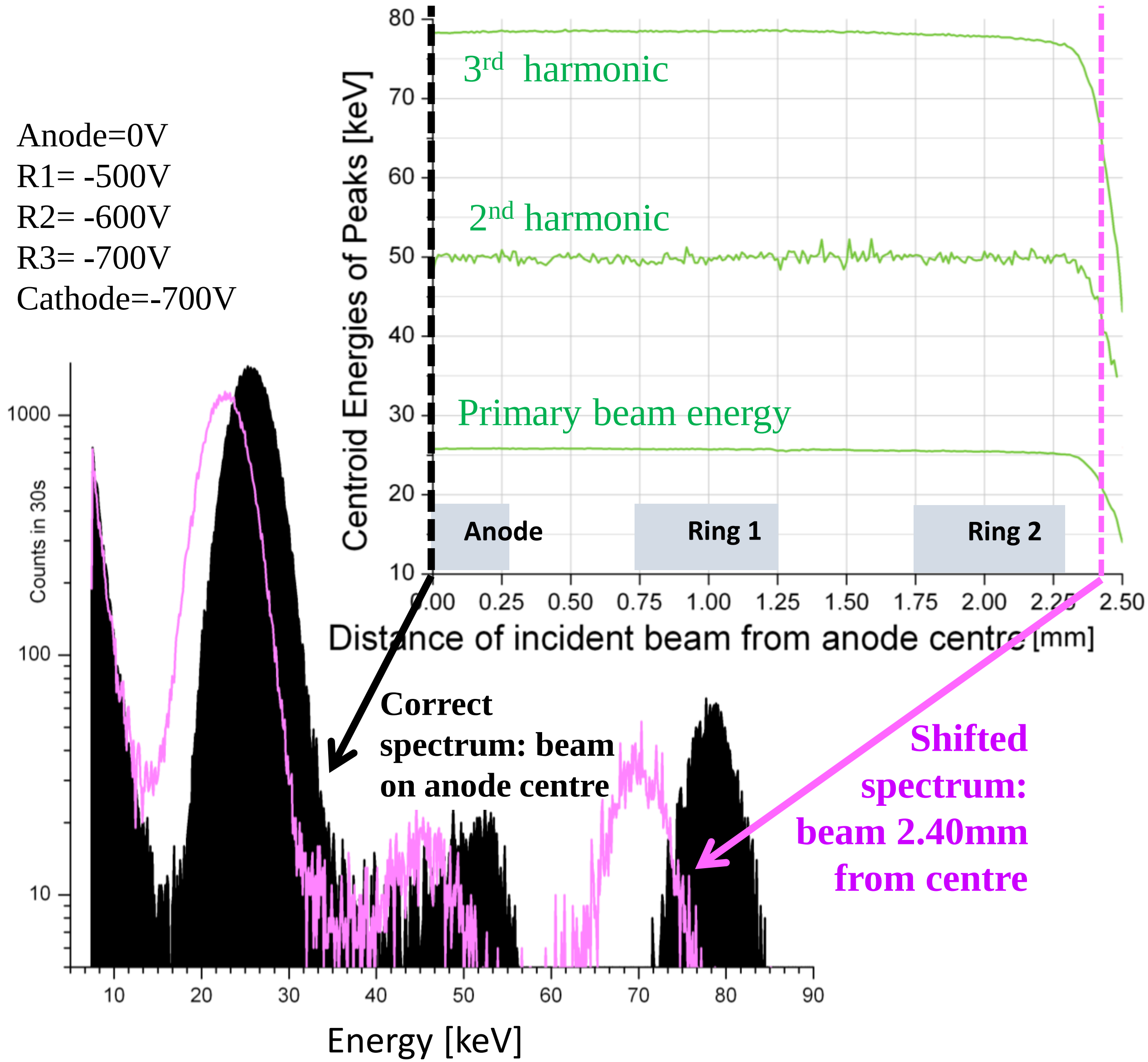


[4] Alruhaili, A. (2013)

Microbeam Linescans of 3-Ring Prototype

10μm 25keV x-ray microbeam was scanned across the device radius. **[5] Diamond Light Source Ltd.**

Anode=0V
R1= -500V
R2= -600V
R3= -700V
Cathode=-700V



- Spectra recorded at 10-100μm intervals.
- Resolution dominated by electronic noise.
- Bias conditions were varied.

Increasing lateral field as a fraction of bulk (up to R3=Cathode voltage) increased **active area** and **sensitivity.**

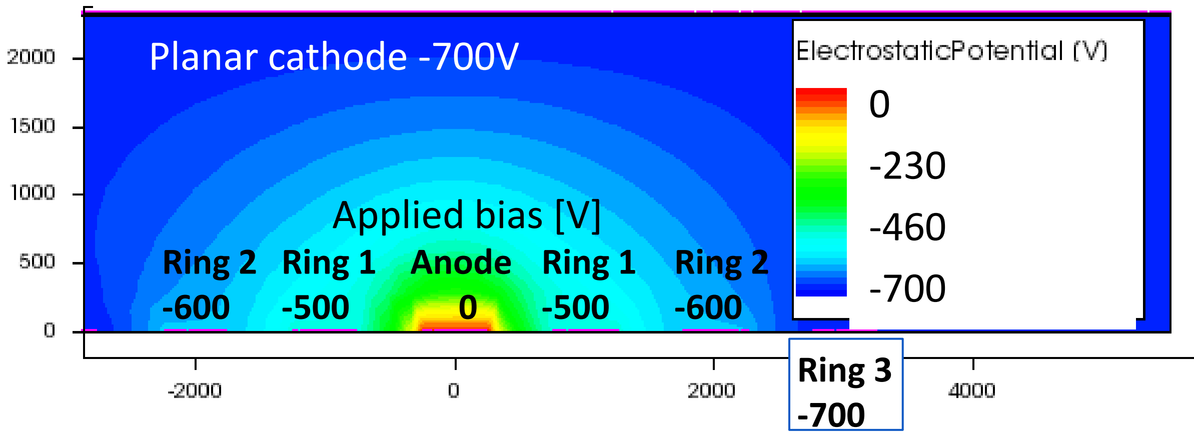
Increasing both fields while maintaining their ratio caused further improvement.

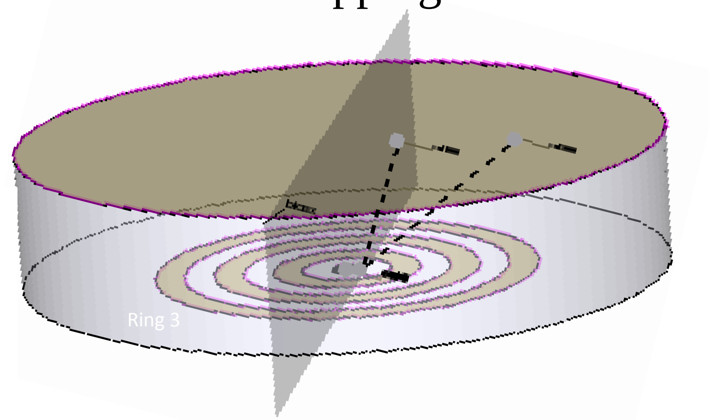
Raising the bulk field alone did not improve performance.

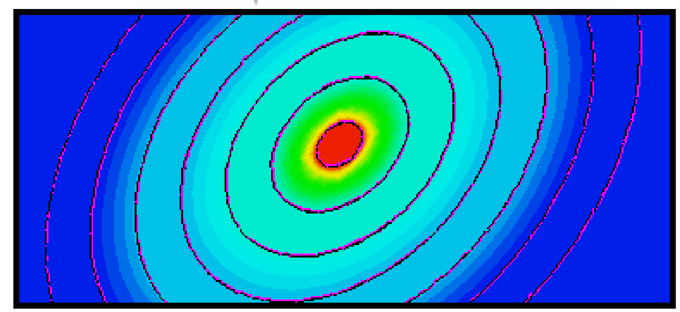
Modelling Ring-Drift Devices

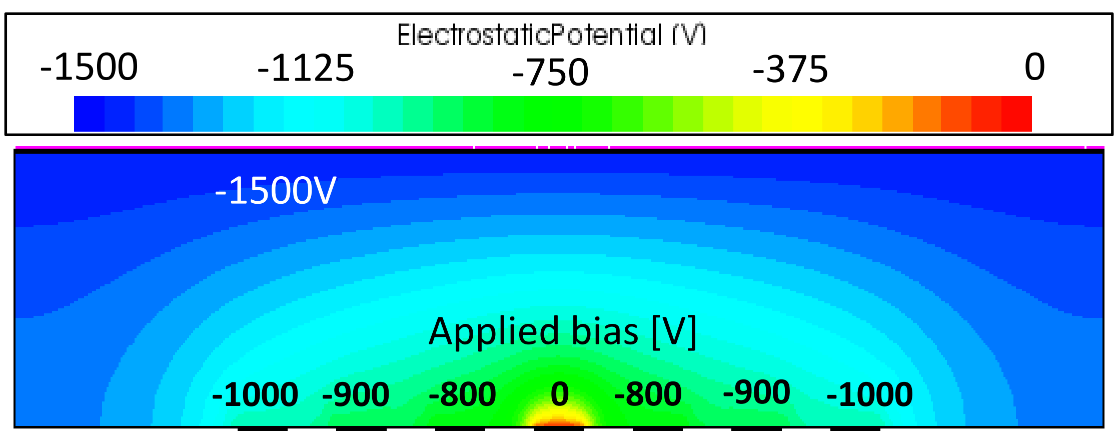
TCAD enables material customisation, fully 3D simulation and visualisation of all electrode signals, fields, potentials, charge densities and velocities and trapping.

A model was constructed of user-defined CZT with variable ring size, number and spacing.





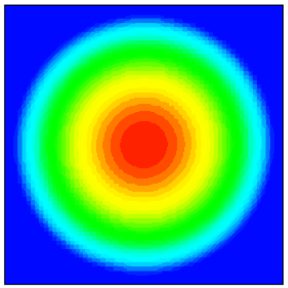




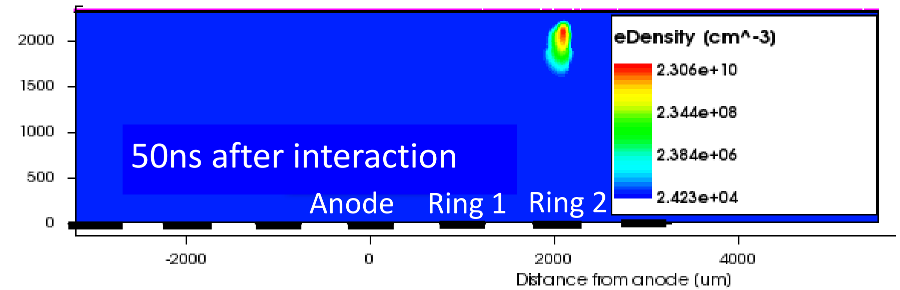
Sections through 3D datasets illustrating Potential field under two different bias schemes.

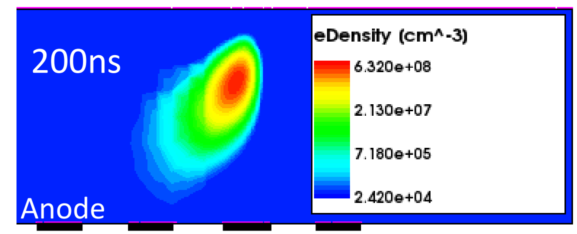
Simulation of Linescans: Methods

1) A charge density deposition profile was defined for a 25keV photon.

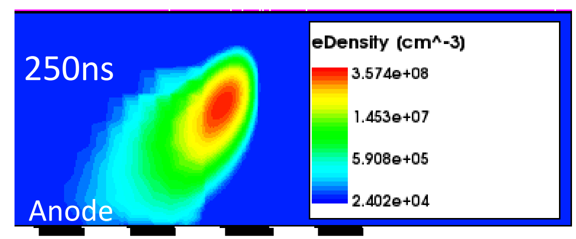


Spherical Gaussian charge density represents average photoelectron path.



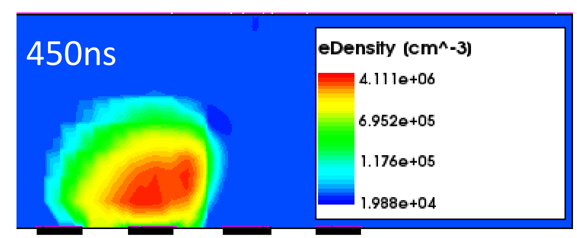


2) Photon was deposited at a chosen radius and depth. 80μm was selected as the most probable depth at 25keV.



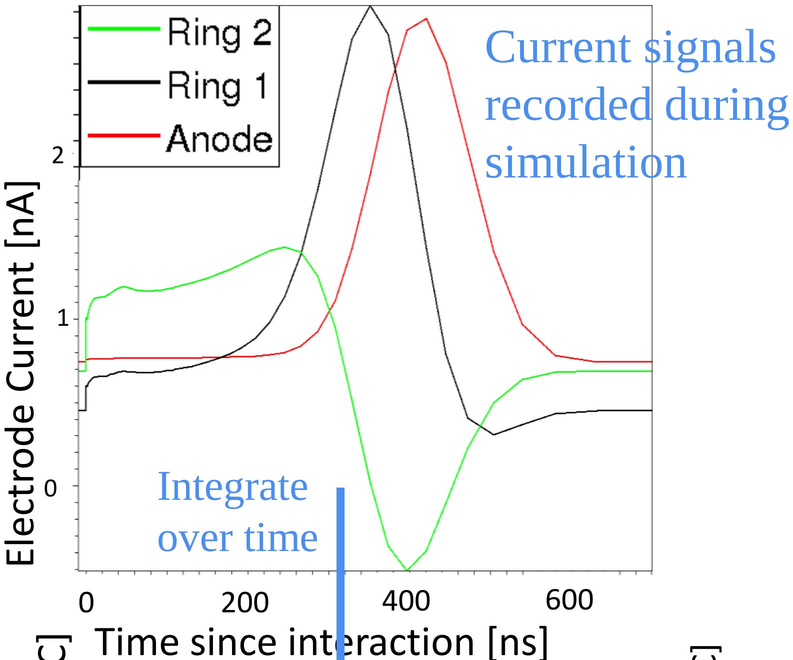
3) Electrode current signals and 3D datasets of fields and charge densities were recorded during deposition and drift.

Electron charge cloud after 25 keV interaction at 2200μm radius.



In this example, charge is shared between the Anode and Ring 1

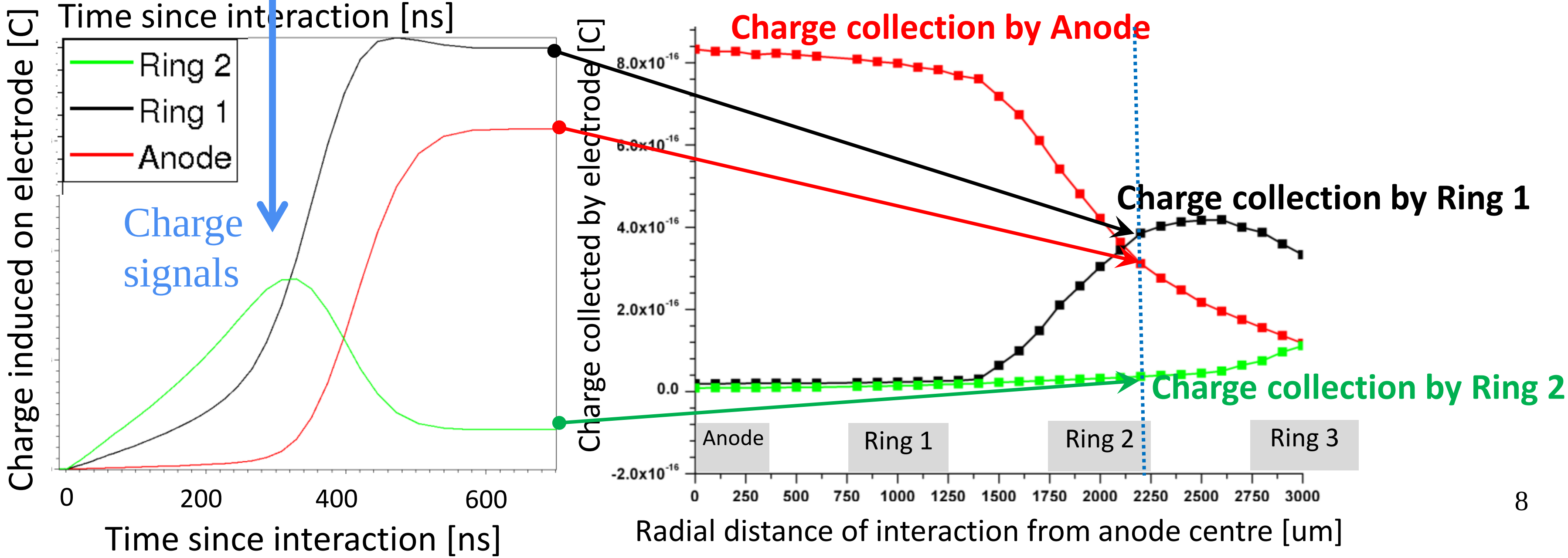
Simulation of Linescans: Analysis



Below: Charge collection as a function of interaction radius

Detector performance is represented by ANODE charge collection.

- Magnitude → sensitivity
- Profile of decline with interaction radius → active area and resolution

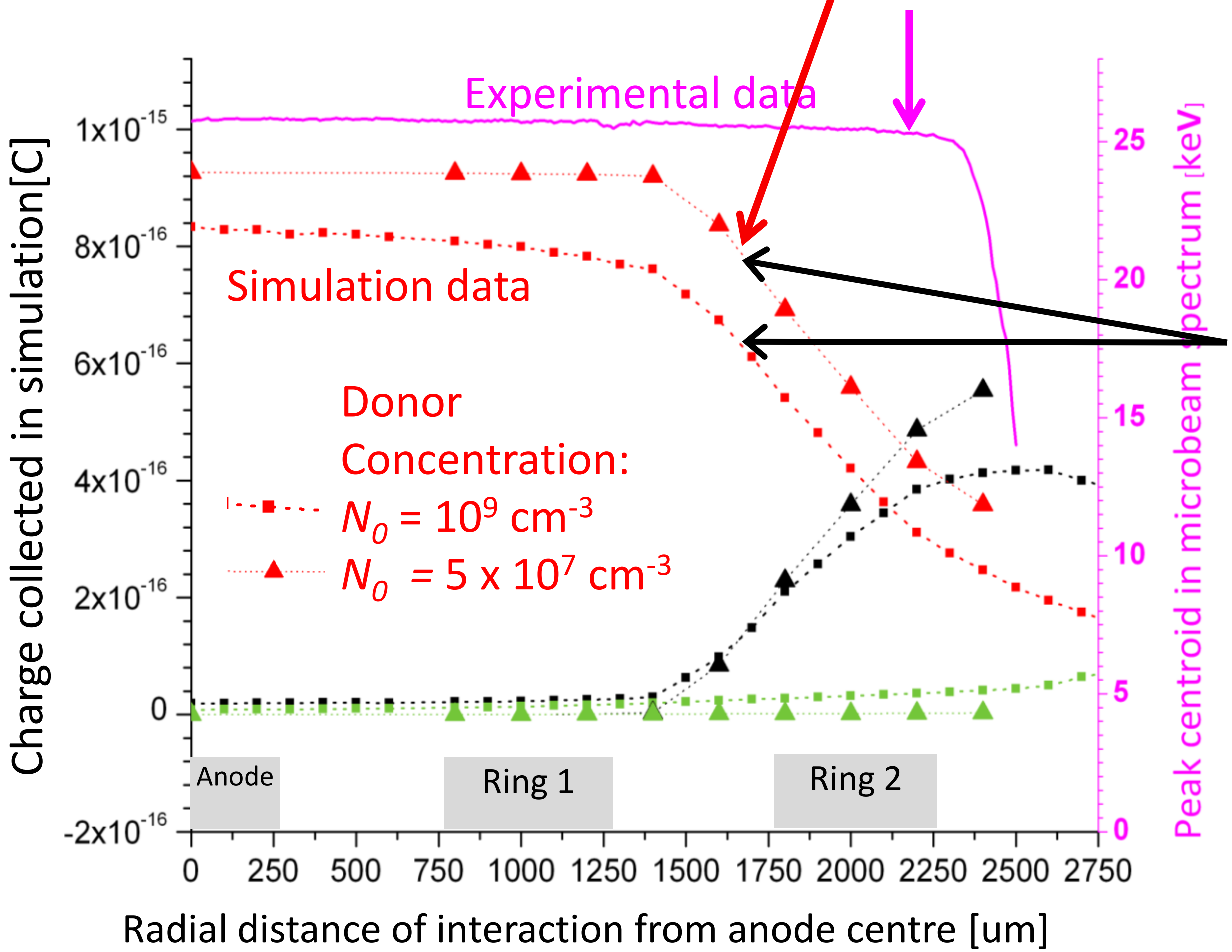


Experimental vs. Simulated results

Current model has a smaller active radius than the real device.

Model anode charge collection declines gradually at moderate radius.

The real device maintains a flat response until beyond Ring 2, then declines steeply.



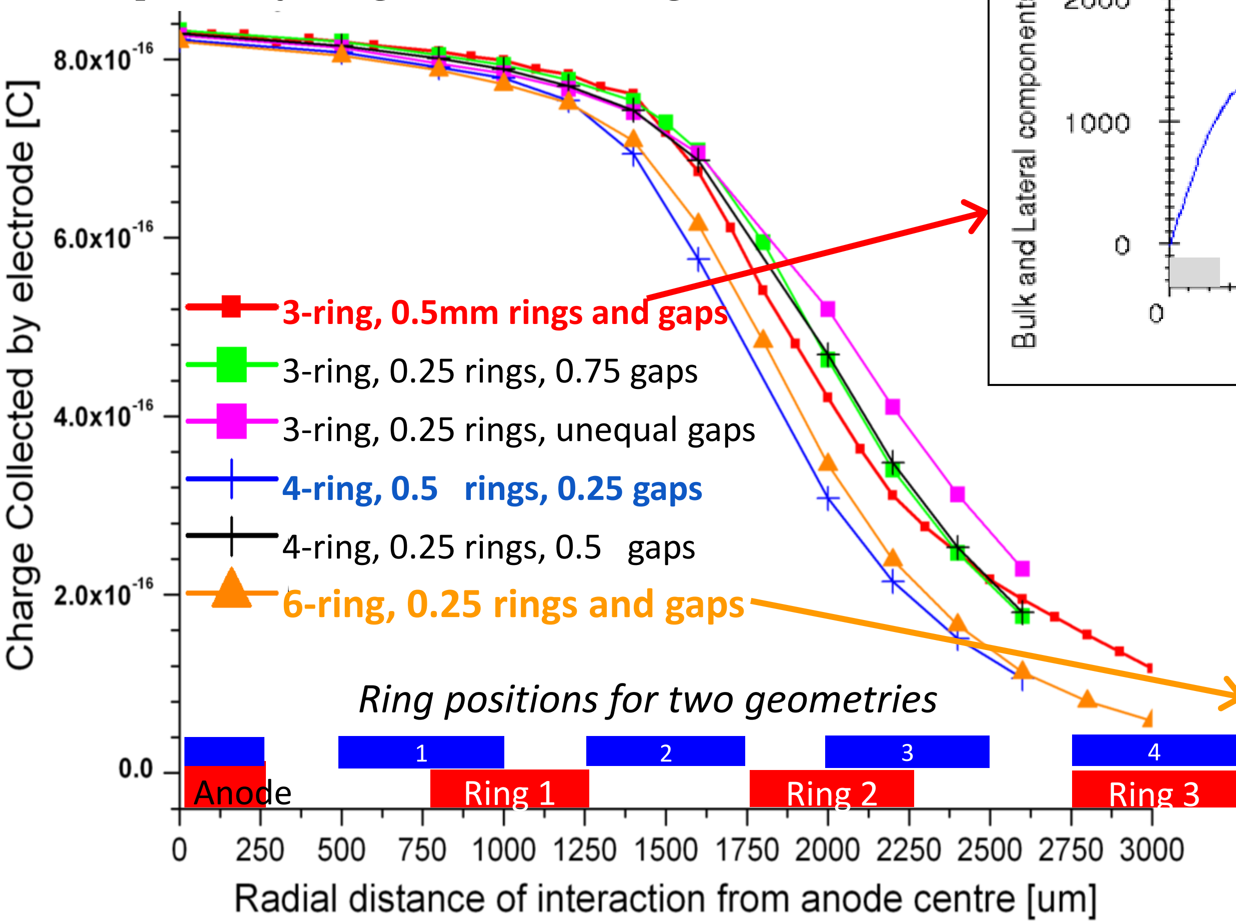
Reducing trap concentration improves charge collection but does not alter the response profile.

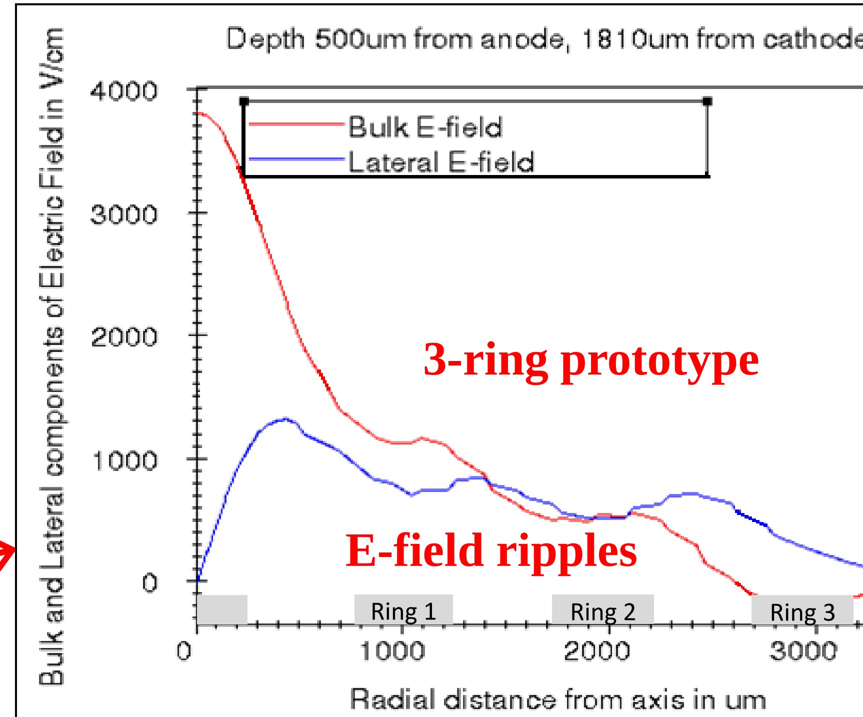
Anode=0V
Ring 1= -500V
Ring 2= -600V
Ring 3= -700V
Cathode=-700V

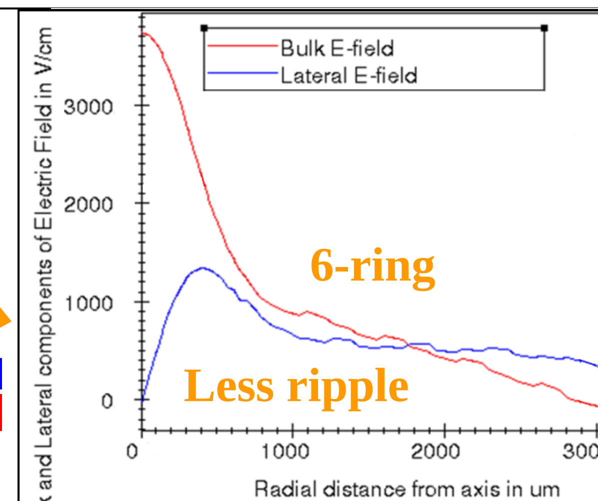
Simulation of varying Ring Geometry

Silicon drift detectors have 10+ rings over ~5mm diameter.
Coarse rings create ripples in E- field.

Do the minima of lateral field cause charge to be captured by Ring 1? Are finer rings better?

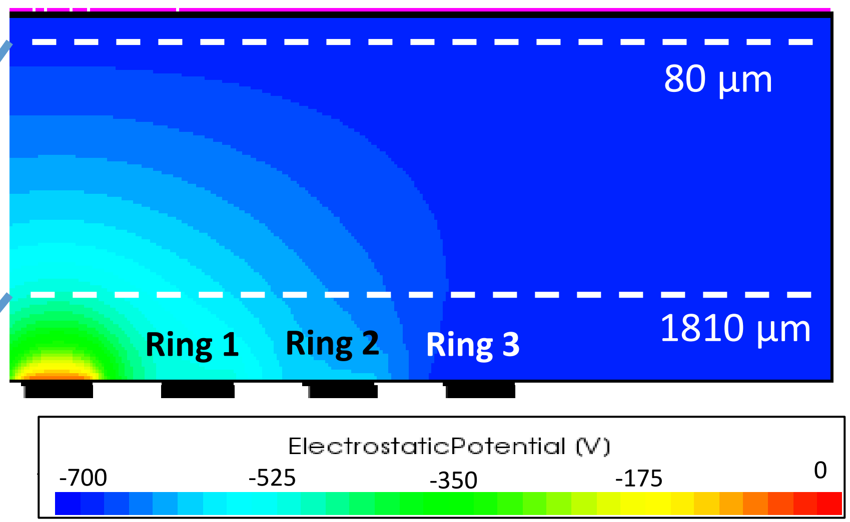


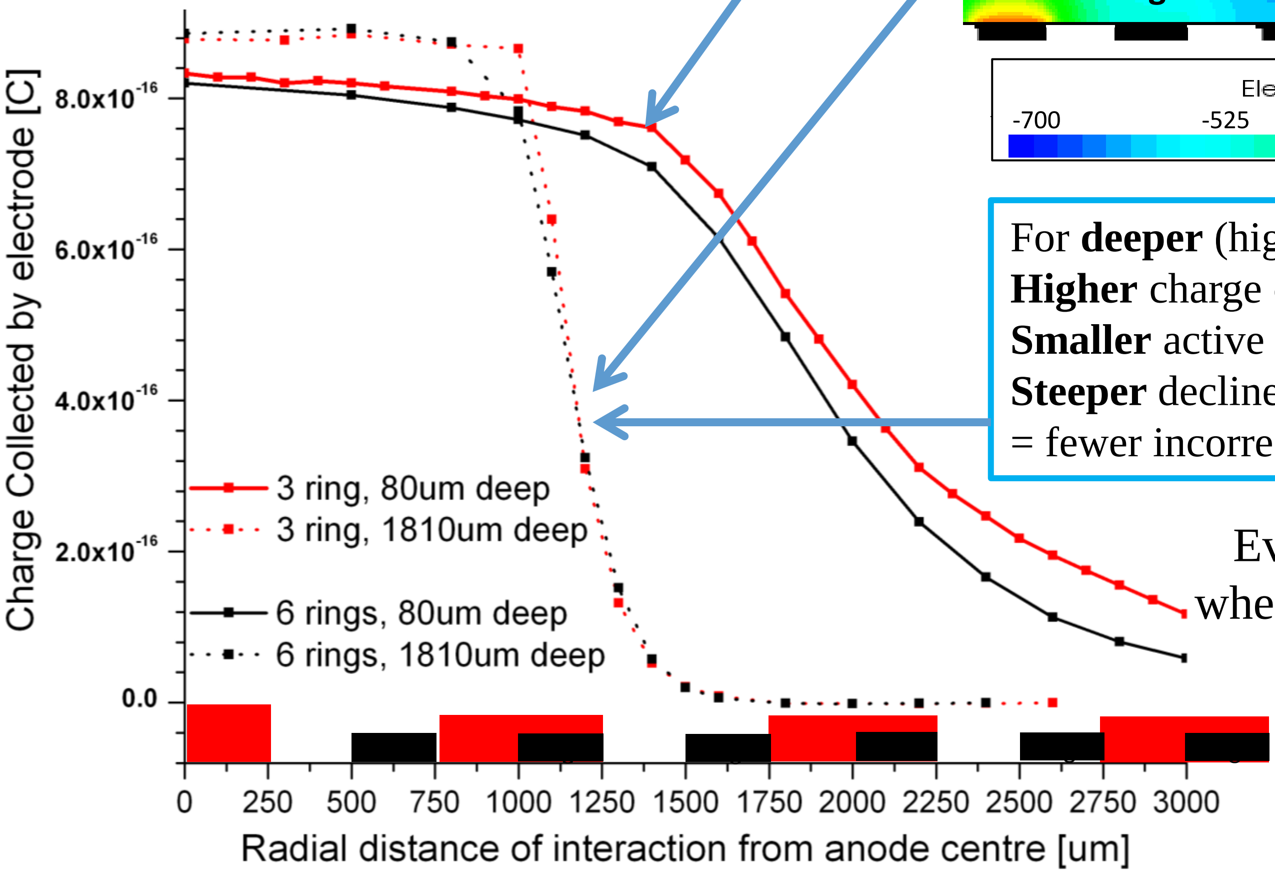




Simulation of varying interaction depth

Simulations were repeated at interaction depths of 80, 810, 1310 and 1810µm from the cathode
to represent different x-ray energies.



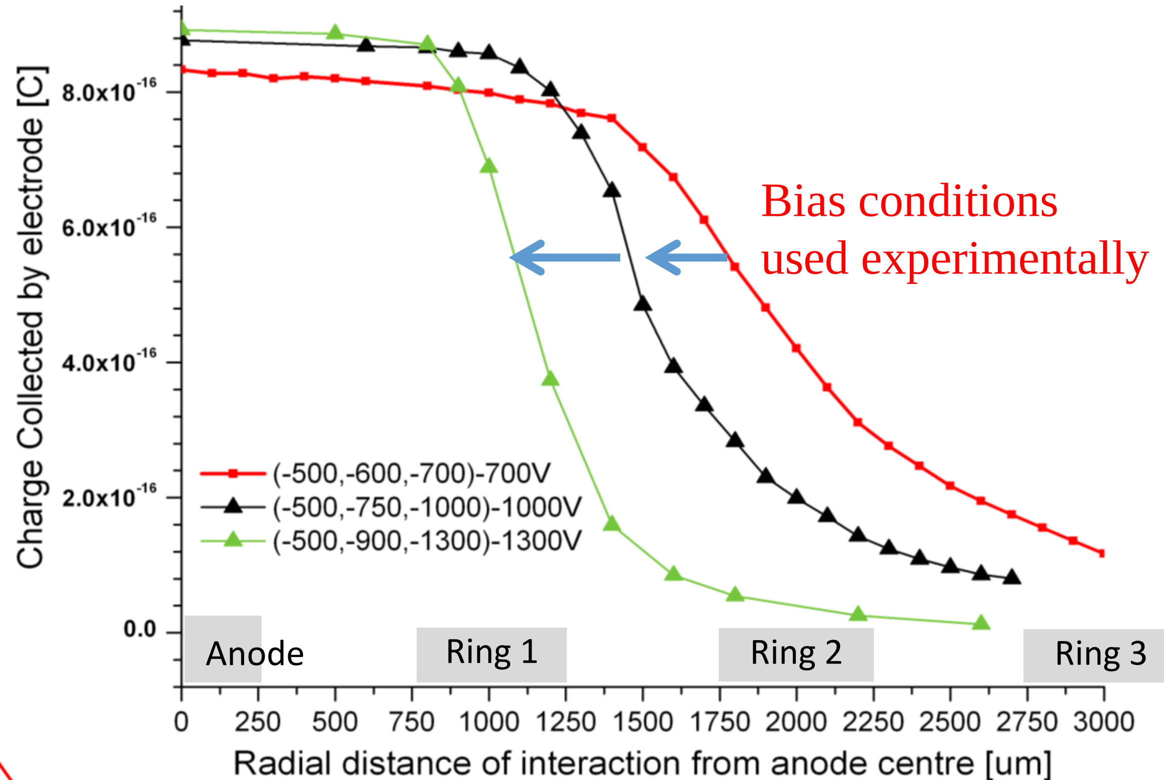


For **deeper** (higher-energy) interactions:
Higher charge collection at centre
Smaller active area,
Steeper decline at edge of active area
= fewer incorrect counts, finer resolution.

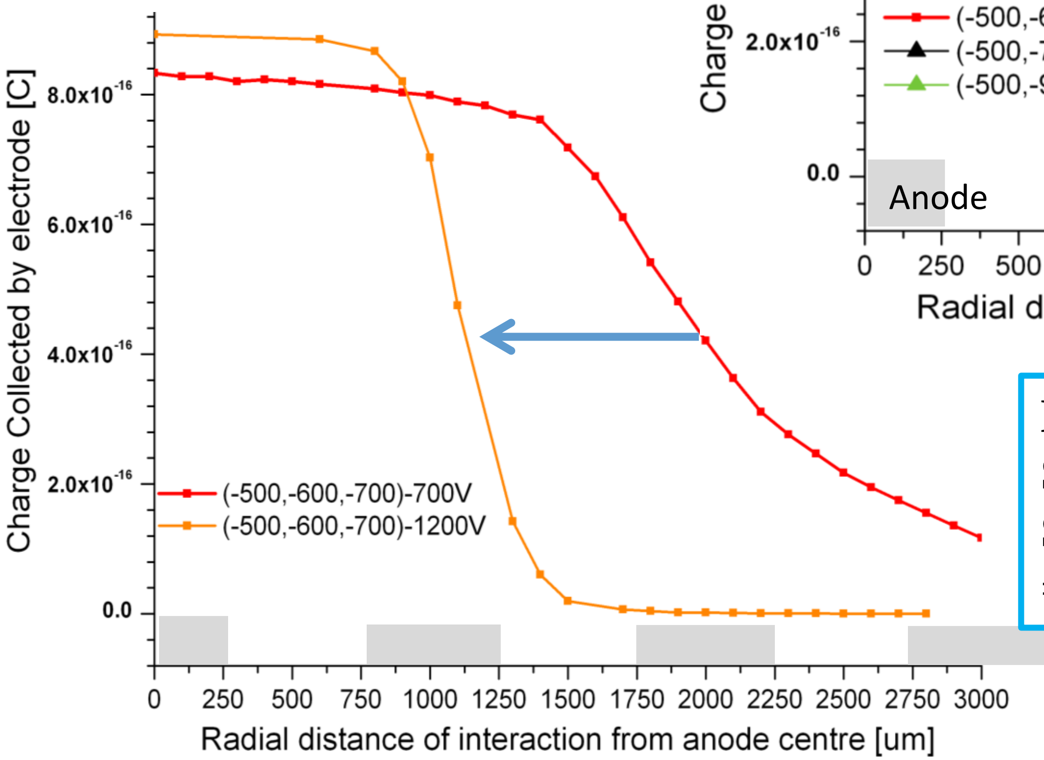
Even for the deepest interaction, where E-field ripples are greatest, fineness of ring structure has **no effect**.

Simulation of varying Electric Field conditions I.

Right: **increasing lateral and bulk field** with R3=Cathode voltage.



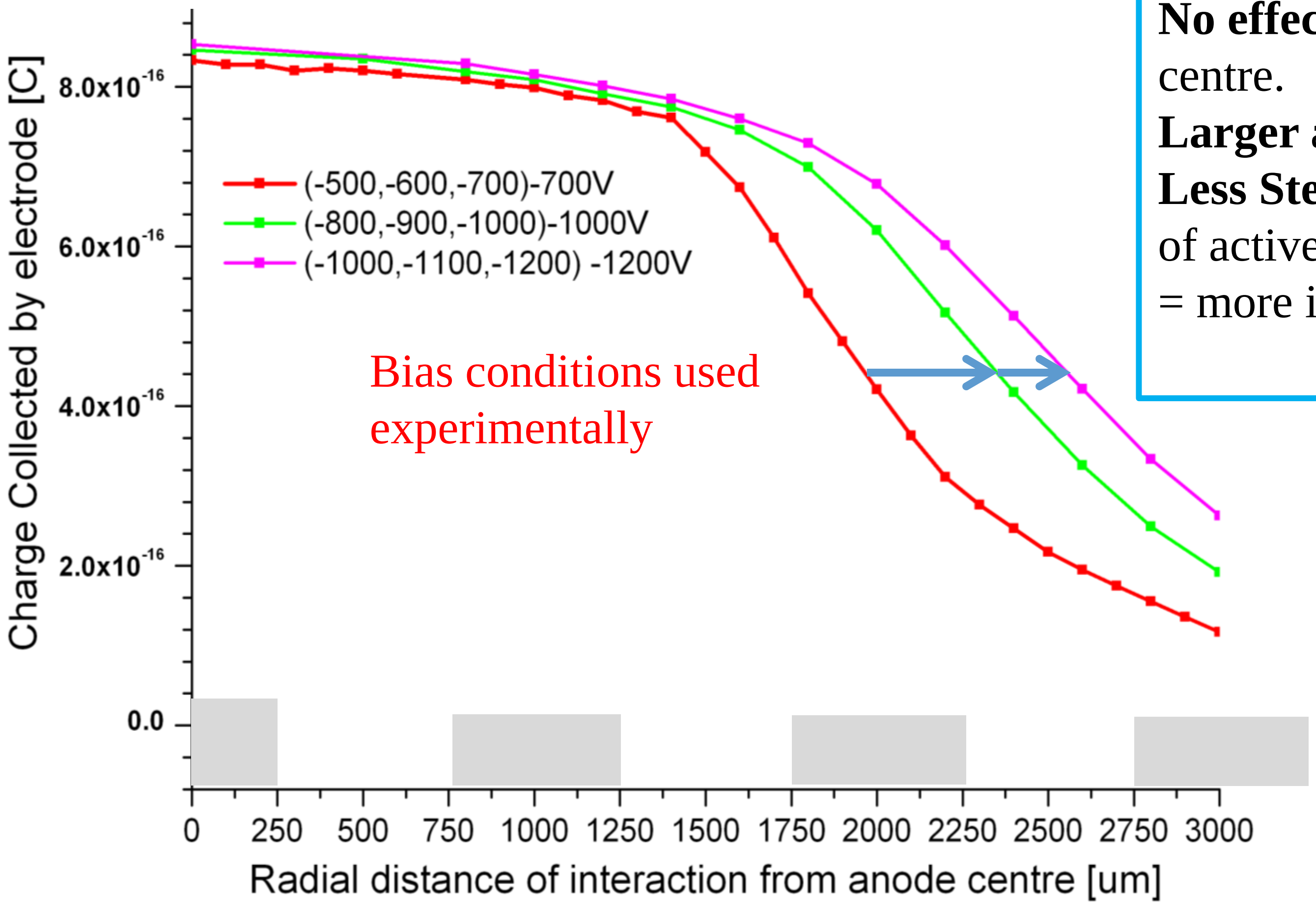
Below: **increasing bulk field** with constant lateral field



Higher charge collection at centre
Smaller active area,
Steeper decline at edge of active area
= fewer incorrect counts, finer resolution.

Simulation of varying Electric Field conditions II.

Effect of increased potential difference between anode and Ring 1.
with constant inter-ring differences.



No effect on charge collection at centre.
Larger active area,
Less Steep decline at edge of active area
= more incorrect counts,
worse resolution.

Conclusions

Experimental Results

- The protoype device has high sensitivity and resolution limited by electronic noise to 3.3keV at room temperature. Its active radius extends beyond Ring 2 under the best bias combination available so far.
- Increasing lateral field as a fraction of bulk (until R3=cathode voltage) increases active area and sensitivity.
- Increasing both fields while maintaining their ratio causes further improvement.
- Raising the bulk field alone does not improve performance.

Simulation results

- Trends in charge collection and active area with bias were qualitatively reproduced under the same conditions used in experiment.
- Changing the ring geometry does not affect performance (within the constraint that contacts cannot be bonded to rings narrower than 0.25mm)
- Active area falls with increasing interaction depth.
- Increasing the lateral and bulk field further (with R3=cathode voltage) OR bulk field alone decreases active area, raises sensitivity and improves resolution under conditions simulated so far.
- Further increasing the anode−Ring 1potential difference degrades resolution.

Further work

- More variations in bias conditions will be studied to optimise active area, sensitivity and resolution.
- The CZT material model requires improvement to reproduce experimental results.

Thank you for your attention.

Acknowledgements

Dr M. Veale and Dr N. Tartoni for their assistnce with microbeam experiments.

References

[1] Amptek Inc.(2011) 'FAST SDD® High Performance Silicon Drift Detector (SDD)', http://www.amptek.com/products/fast-sdd-silicon-drift-detector/

[2] Lechner, P., *et al* (1996) 'Silicon drift detectors for high resolution room temperature X-ray spectroscopy', *Nuclear Instruments & Methods in Physics Research Section A-Accelerators Spectrometers Detectors and Associated Equipment*, 377 (2-3), pp. 346-351.

[3] Redlen Technologies, 123 – 1763 Sean Heights, Saanichton, Canada. http://redlen.ca/

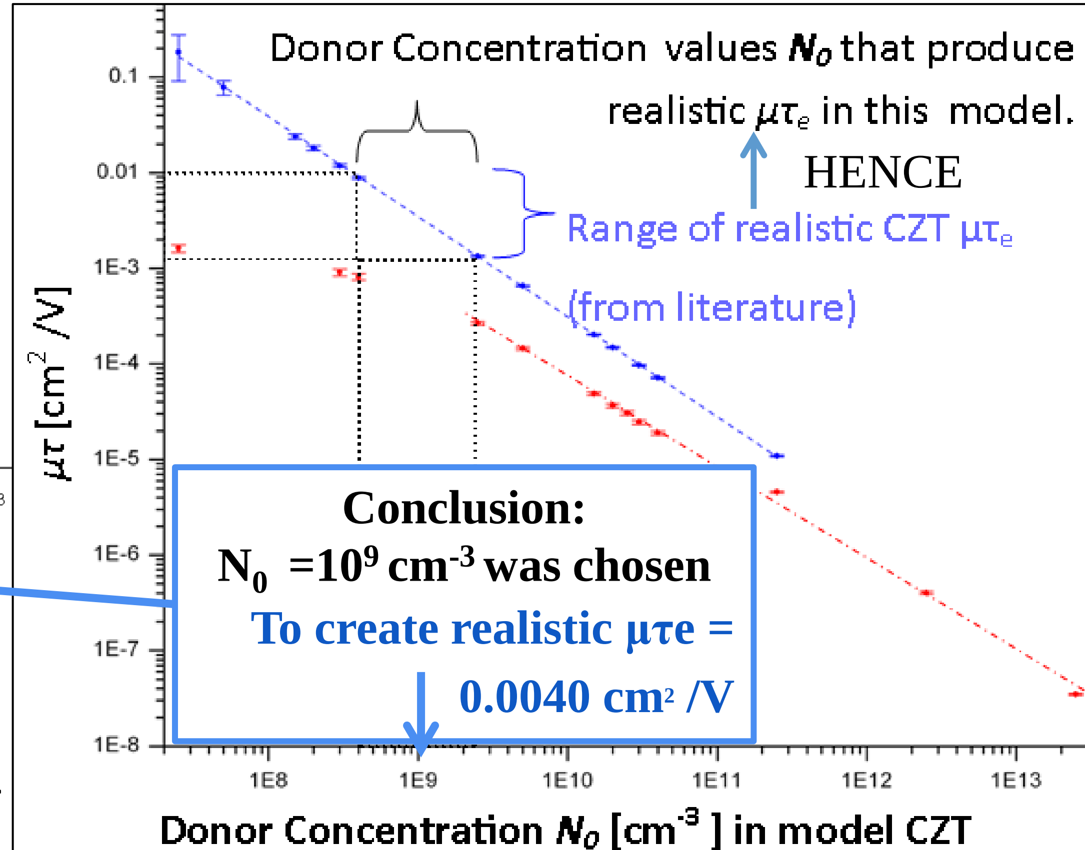
[4] Alruhaili, A. (2013) Am-241 spectrum from CZT ring-drift detector. Unpublished data, University of Surrey.

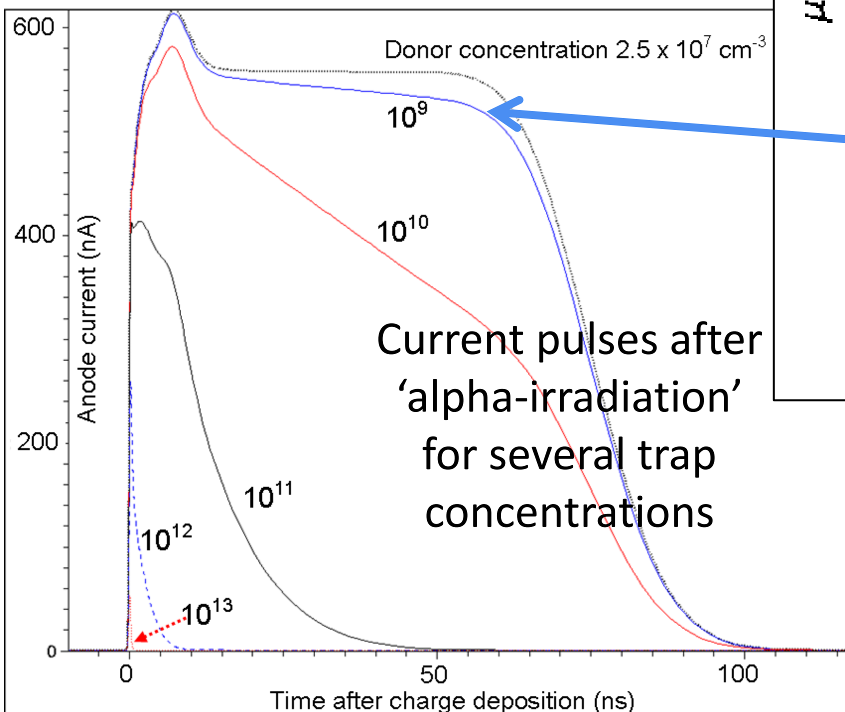
[5] Diamond Light Source Ltd. Diamond House, Harwell Science & Innovation Campus, Didcot, Oxfordshire. http://www.diamond.ac.uk.

[6] Bell, S.(2011) 'The development of a TCAD model of cadmium zinc telluride'. Report in partial fulllment of EngD, University of Surrey and STFC Rutherford Appleton Laboratory.

Modelling CZT Material with Sentaurus TCAD

- TCAD model of CdTe was adapted by adding traps at 4 energies, based on literature.
  [7] Bell, S.(2011)
- **Relative** concentrations were chosen to give realistic high resistivity, determined by I-V simulation.



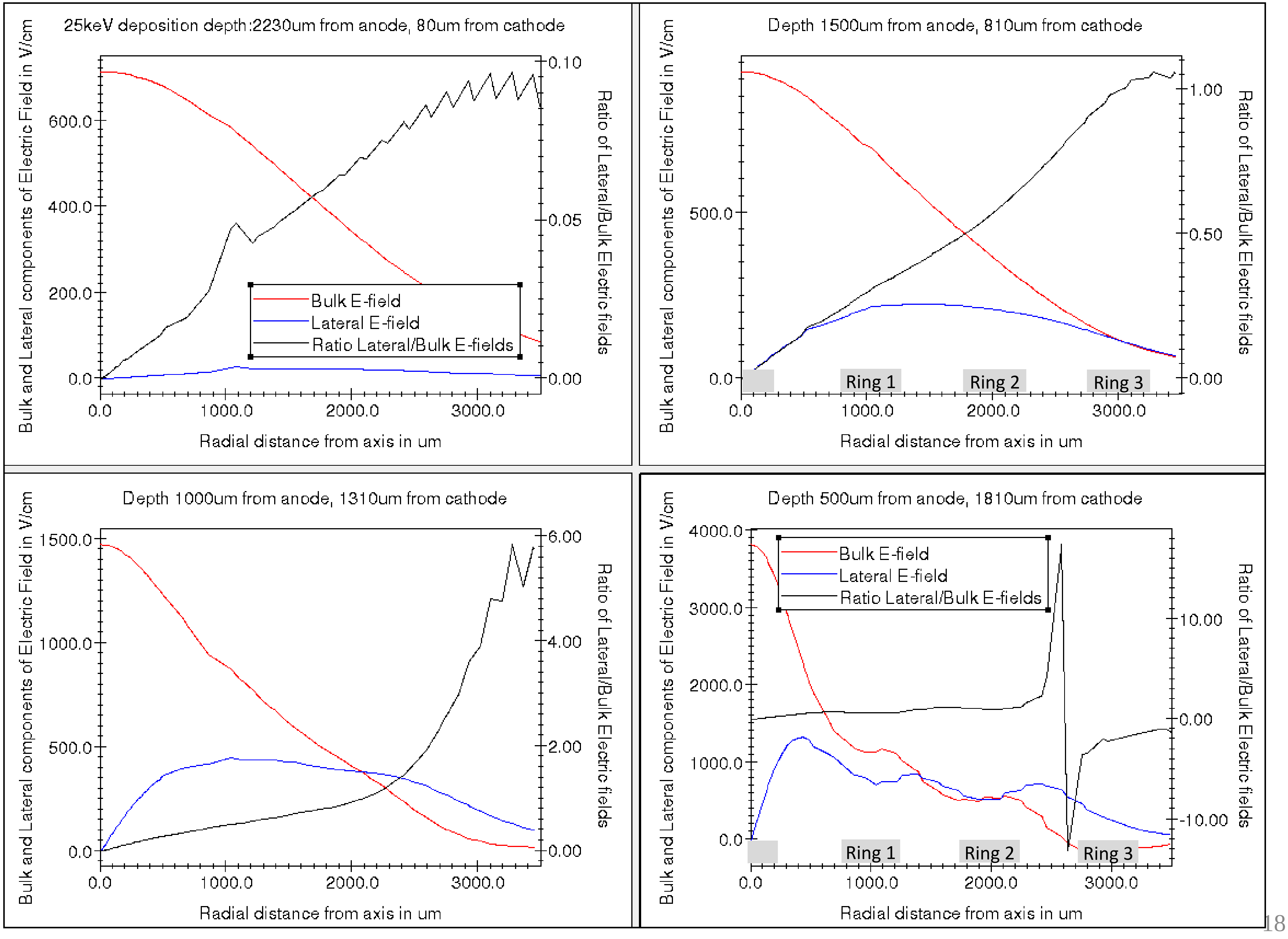


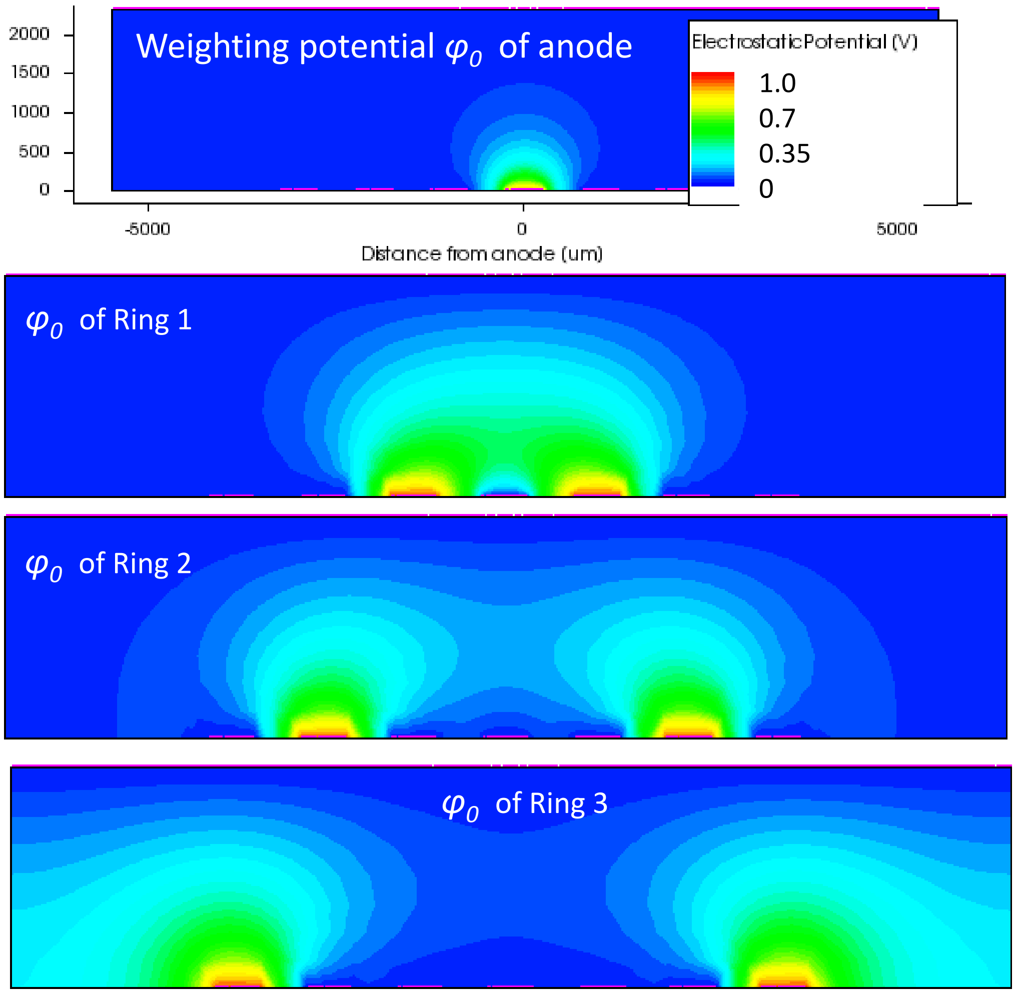
Absolute concentrations were chosen to give realistic charge transport .

μτ was obtained by simulating alpha-irradiation.

μ was calculated by time-of-flight analysis.

Original 3-ring geometry. (R1= -500,R2= -600, R3= -700) Cathode= -700V





The weighting potential of the anode rises from 0 to 1 between the innermost ring and the anode.