Characterisation Of Substrate Resistivity For A Backside Biased HV-CMOS Pixel Test Structure By eTCT

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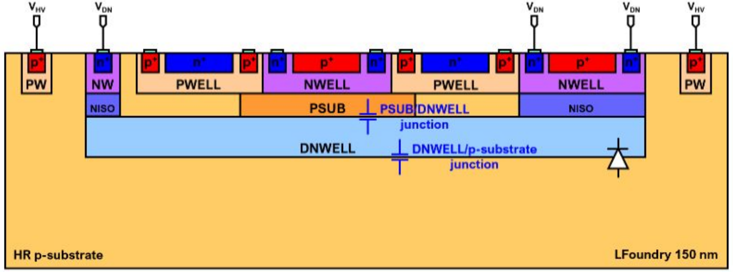
14/06/2022

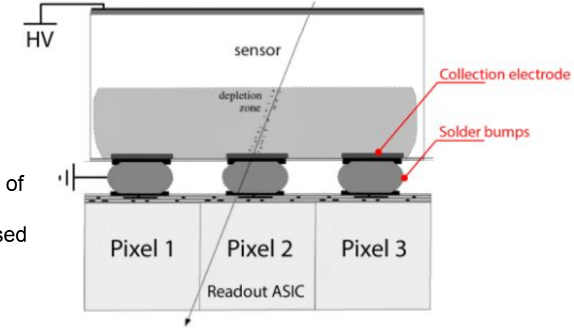
HV-CMOS

- Industrial standard manufacturing process
- Extension of conventional CMOS technology
  - Used in Cameras, Particle trackers
  - Integrated Circuitry (IC), Monolithic
- Produce pixels with high substrate bias voltages
  - Fast time resolutions
  - Radiation tolerance
- Combines CMOS Thinness and Hybrid high voltages

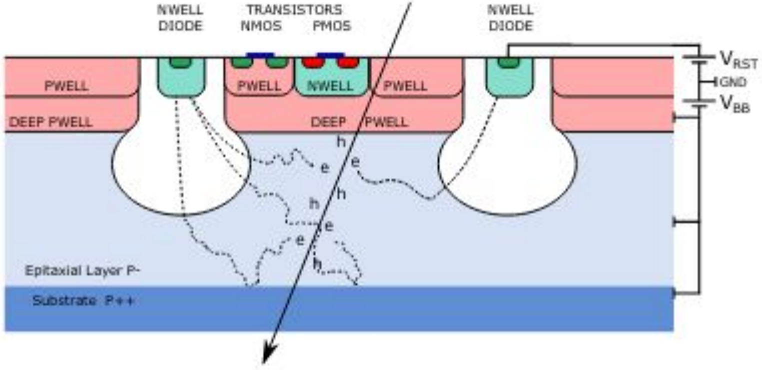
Cross-section of a typical HV-CMOS pixel



Cross-section of a hybrid pixel design proposed for CLiC



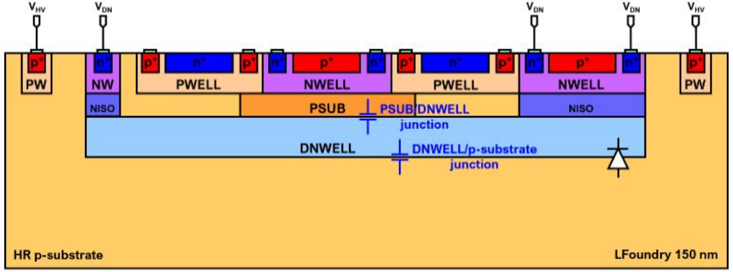
Cross-section of standard CMOS pixel ALPIDE used in ALICE



HV-CMOS

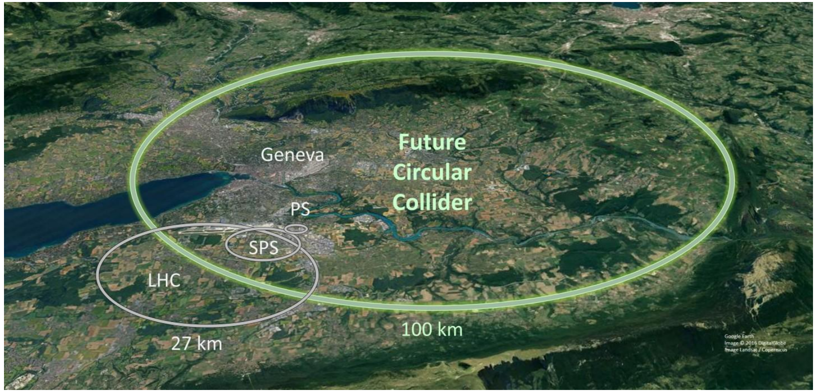
- Industial Standard Manufacturing Process → No specialised (expensive) processes
- High Voltage → Radiation tolerant, Fast time resolution
- Monolithic → Thin

Cross-section of a typical HV-CMOS pixel



	Pixel Size (μm)	Time Resolution (ps)	Radiation Tolerance (NIEL) (1 MeV $n_{eq}cm^{-2}$)
HL-LHC	50 x 50	30	10^{16}
FCC-hh	25 x 50	100	10^{16} to 10^{17}
Current HV-CMOS	50 x 50	3160	10^{15}

Future tracking detector specifications, and current HV-CMOS capabilities



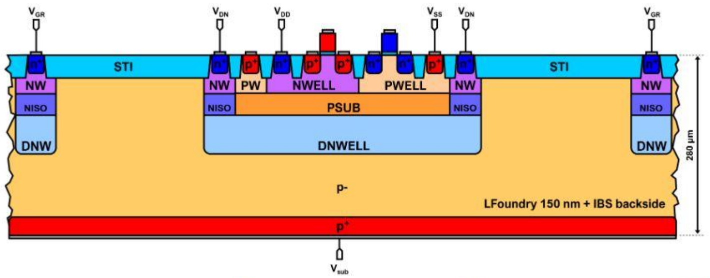
https://cds.cern.ch/record/2653532/files/FCC%20v2.jpg?subformat=icon-1440

UKRI-MPW0

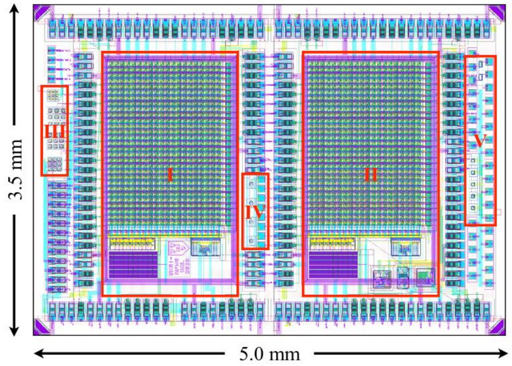
- LFoundry 150 nm, HV-CMOS
- 1.9 kΩ cm Substrate Resistivity
- 280 µm Thickness
- Fully backside biased only

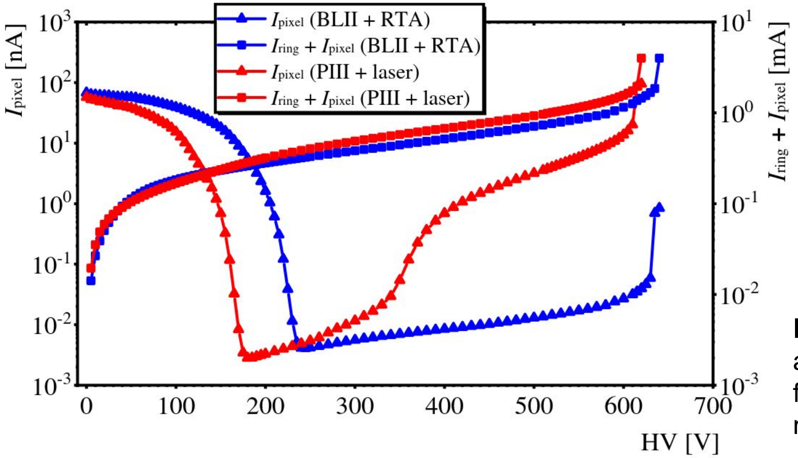
- 2 Backside Processing Methods (IBS)
- 2 Matrices of 20 x 29 Pixels
- 60 x 60 µm Pixel Size
- 3 Sets of Test Matrices
  (3 x 3 Passive pixels for eTCT)

Cross-section of UKRI-MPW0 pixel



Layout of the UKRI-MPW0 Pixel chip





I-V behaviour through the pixe and the CTR of test structures for each backside processed methods

	Breakdown Voltage (V)
UKRI-MPW0	**~ 600**
LF-monoPix2	~ 460
Astropix	~ 250

eTCT

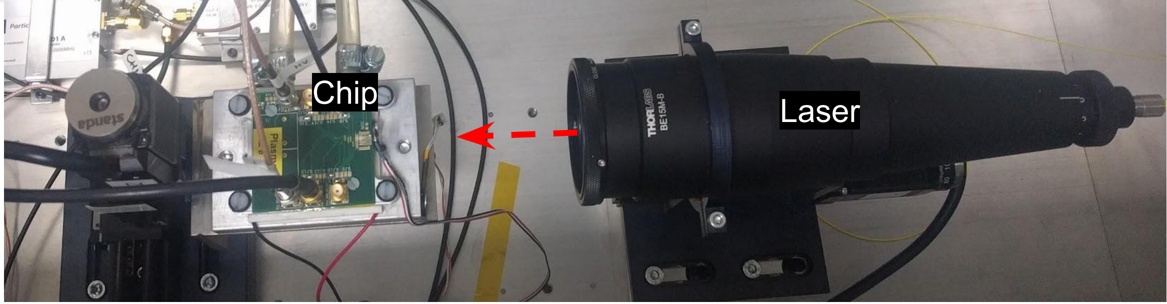
- Chip mounted on movement stage and Peltier

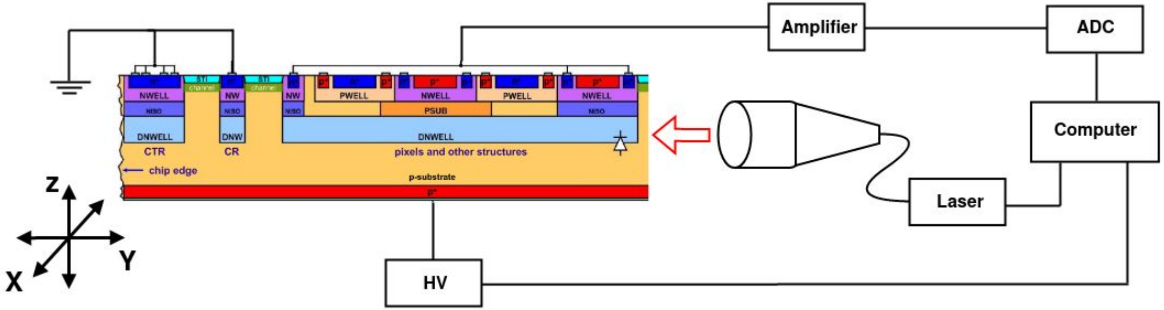
- Laser induces electron-hole pairs in depletion region of the passive diode

- Central diode replicates behaviour of diode in a wider matrix

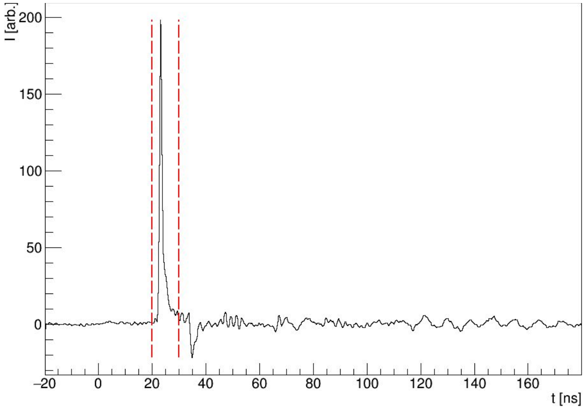
- Diode current recorded and integrated for charge (10 ns around the signal peak)

- Integrated current plotted with spatial coordinates to map depletion region



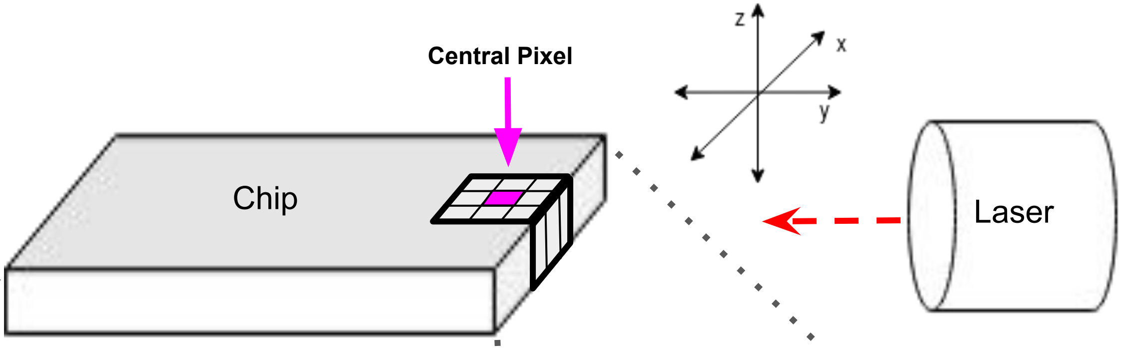


eTCT setup with signal chain and coordinate system

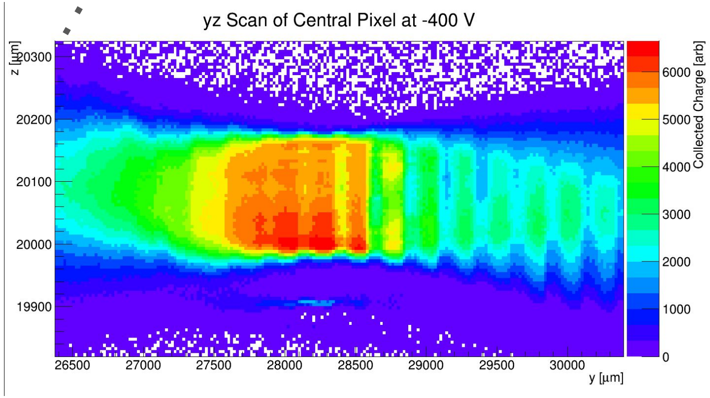


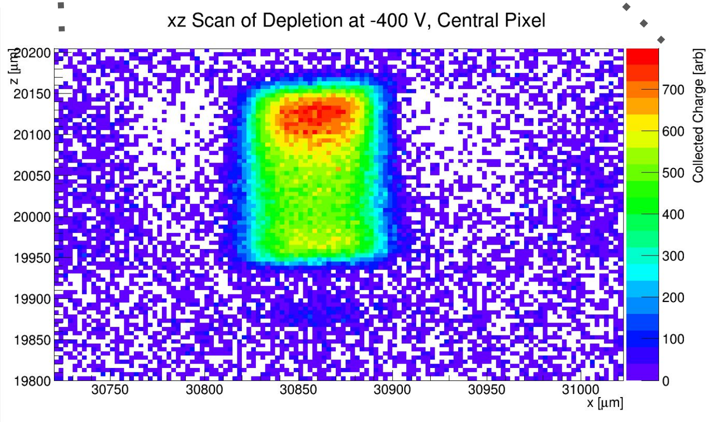
Example waveform with integration window (dashed red line)

Spacial Scan Types



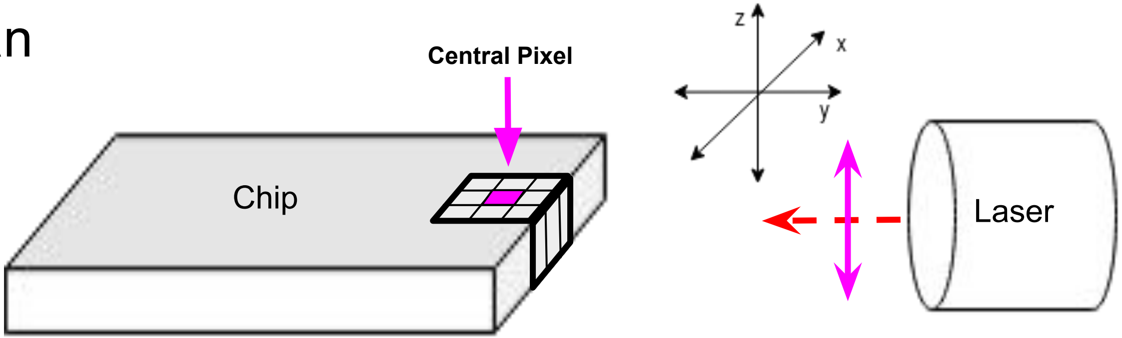
- Chip moved in 3 dimensions
- Focus the laser on central diode in 3 x 3 test structure
- Find ideal x & y coordinates to measure depletion depth of central pixel

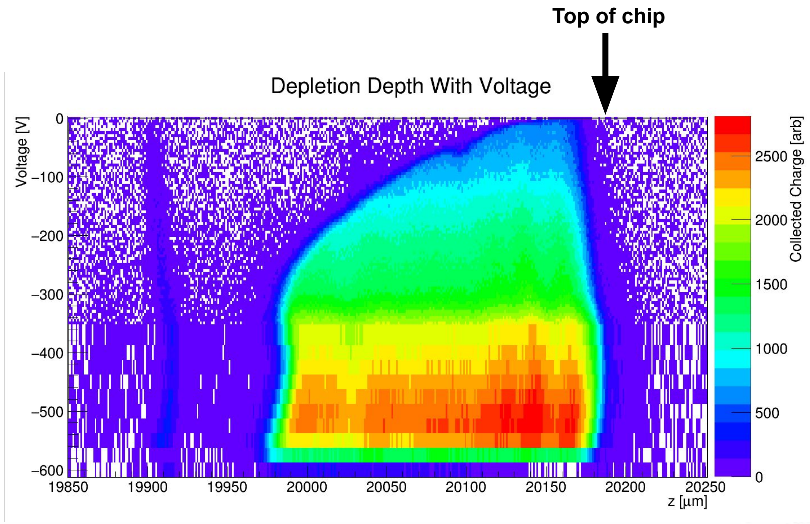


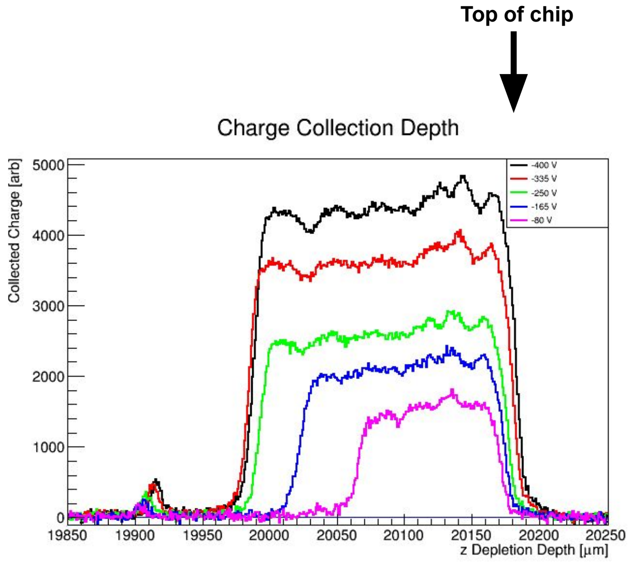


Depletion Depth Voltage Scan

- x and y values fixed
- z scanned (up/down) to measure depletion region growth
- Sensor biased between 0 to -600 V





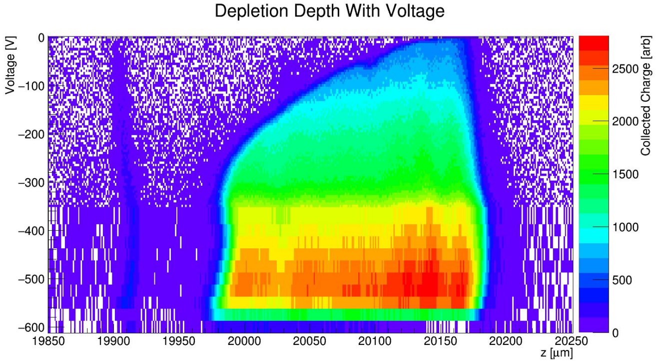


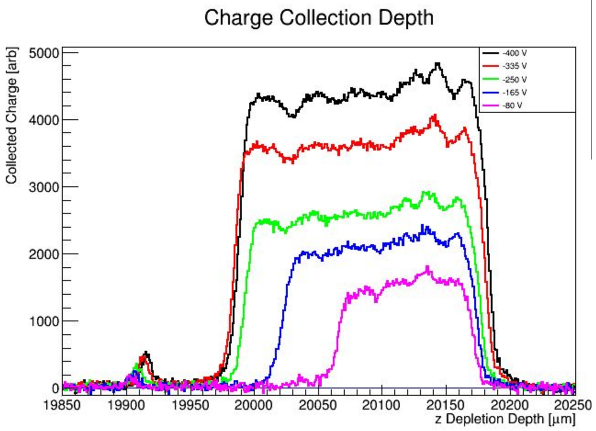
Depletion Depth

- FWHM of collected charge found for the region at each Voltage
- Substrate resistivity and doping concentration calculated from fit

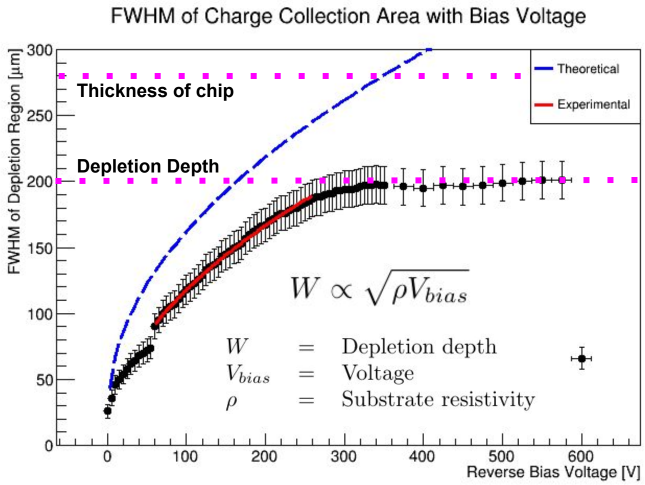
- Unexpected depletion region stop
  - Bulk Damage?
  - Scratch on chip edge?
- Resistivity found

	Resistivity (kΩ cm)
UKRI-MPW0 Nominal	1.9
UKRI-MPW0 Experimental	1.4 ± 0.2
RD50-MPW1 Experimental (Same Wafer)	1.3





FWHM from all V values

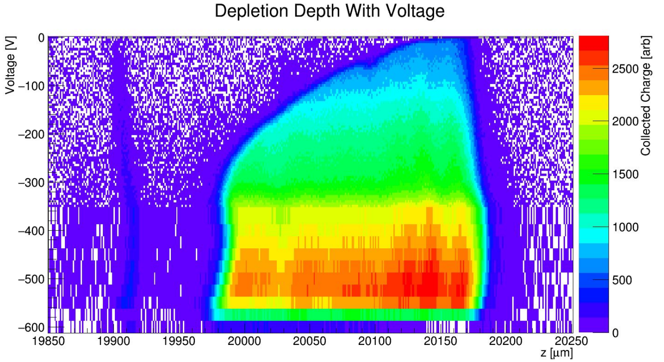


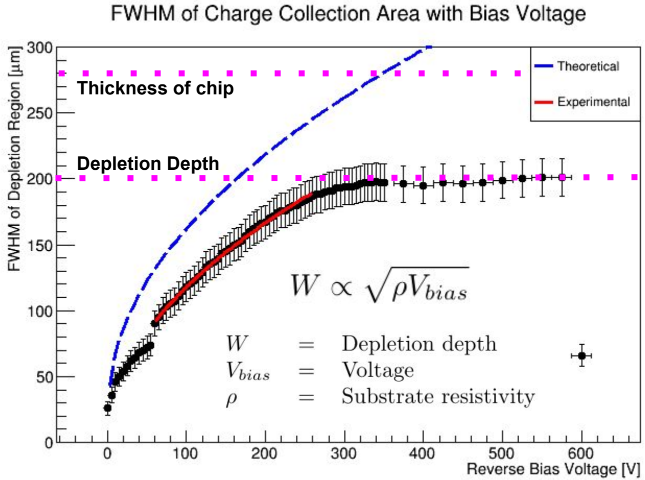
Conclusion & Outlook

- 600 V unprecedented breakdown for HV-CMOS pixel
- Depletion region measured, resistivity found
- Unexpected stop in region growth (bulk damage?)

- Polish chip edges
- Measure samples of other backside processing method
- Explain backside peak and depletion stop
- Measure irradiated samples (up to 10^{16} 1 MeV n_{eq} cm^{-2})

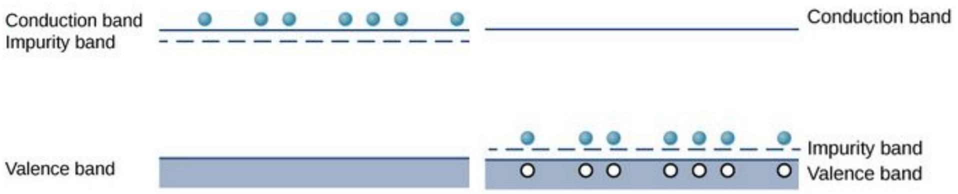
- Start TCAD simulations of UKRI-MPW1
  - Improve leakage current
  - Increase bias voltages





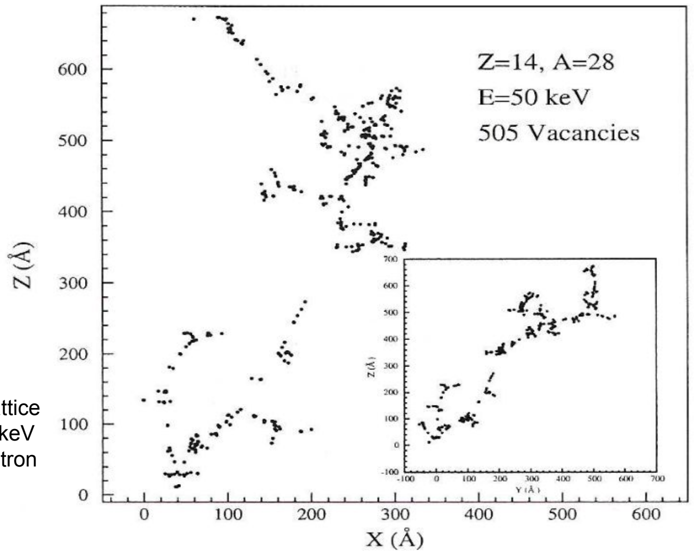
Backup: Radiation Damage in Silicon (NIEL Bulk effects)

- Incident radiation causes a Primary Knock-on Atom (PKA)
- Travels through the lattice disturbing other atoms
- Causes atom-hole pairs (Frenkel Pair)
- Interstitial atoms introduce new energy levels in the band structure
- Changes doping profile and resistivity



Band structure of n and p-type semiconductors (left to right)

S. J. Ling, J. Sanny, and B. Moebs, University Physics Volume 3, 1st ed. Houston, TX: Rice University 2016



Vacancies in a silicon lattice caused by a PKA of 50 keV caused by a 1 MeV neutron

F. H¨onniger, "Radiation damage in silicon. defect analysis and detector properties", 2008.

Backup: Focussing