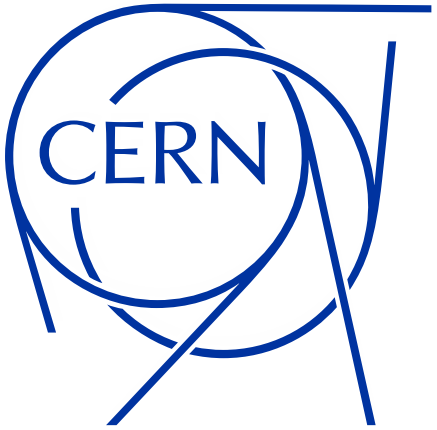


Getting to know a hybrid pixel detector

Functional tests, equalization and energy calibration of Timepix1 pixel detector assembly

Chiara Marina Jerkovic

Supervised by Justus Braach & Peter Svihra

3rd November 2023

Hybrid Silicon Pixel Detector

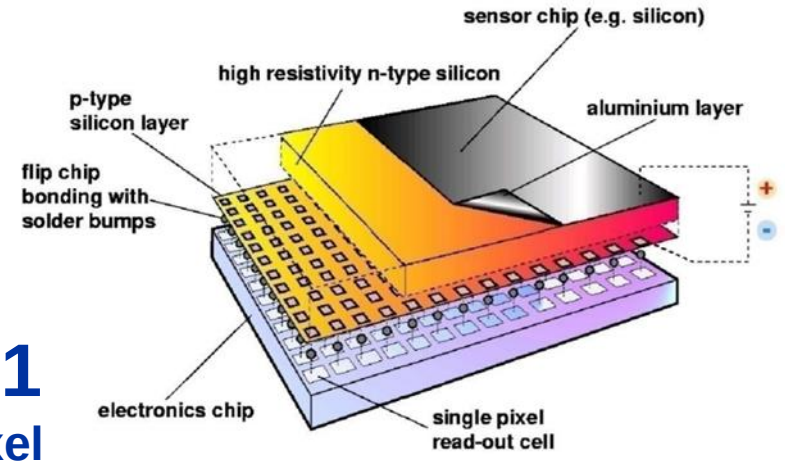
Structure

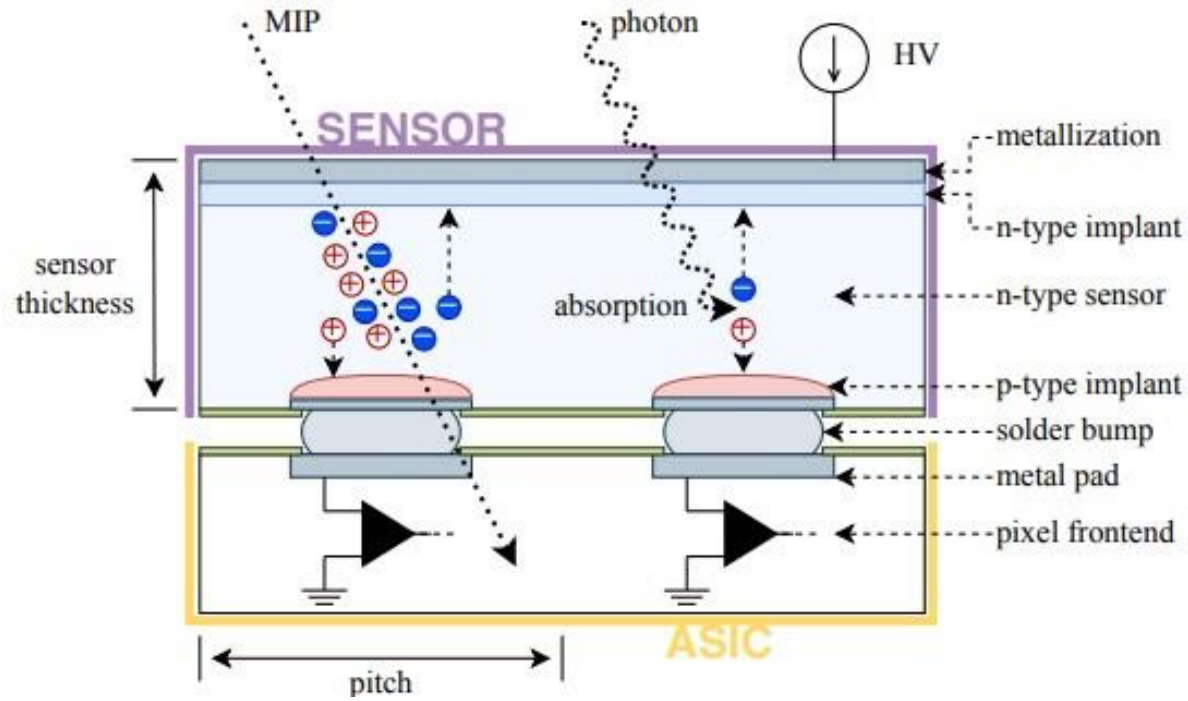
- Sensor (pixel array, matrix of silicon diodes) + read out chip
- Sensor and ASIC connected with solder bumps
- Charge is collected by sensor and is read out by an individual ASIC channel
- Further signal processing in read-out ASIC

Reversed bias operation

- Interaction of Si atoms and charged particle produce electron-hole-pairs
- Holes collected by anode, electrons move to cathode
- Moving charge induces measurable signal

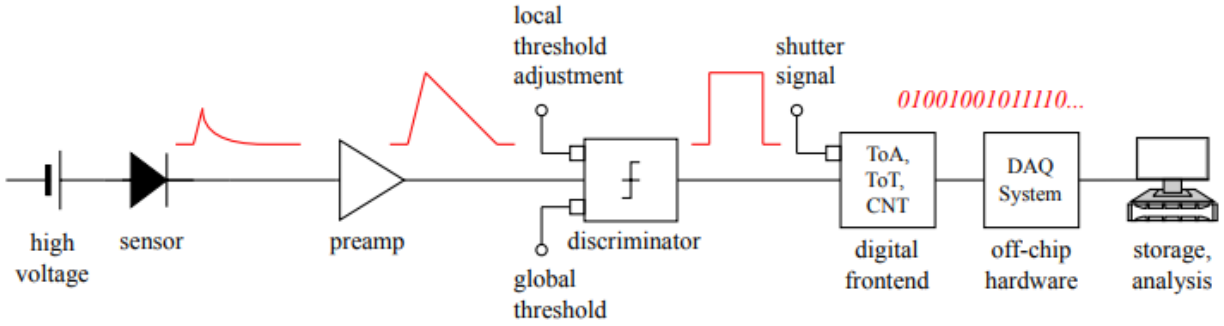
Timepix1
256 • 256 pixel

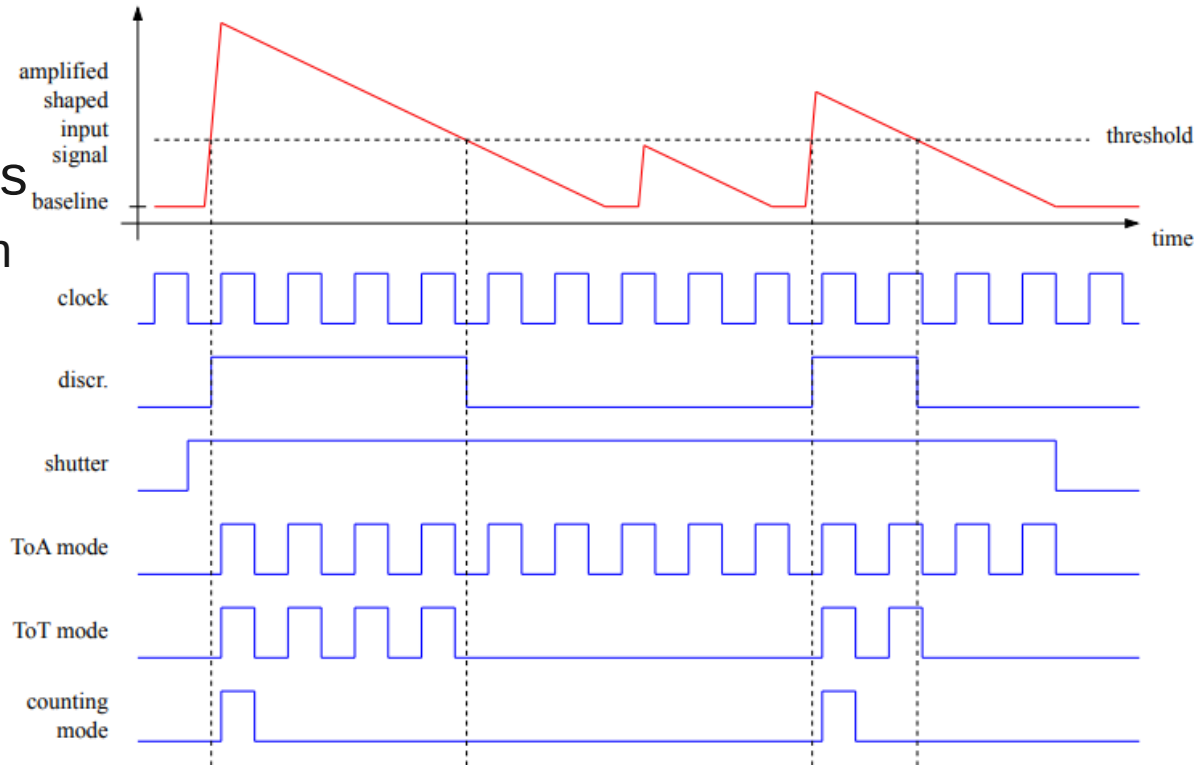




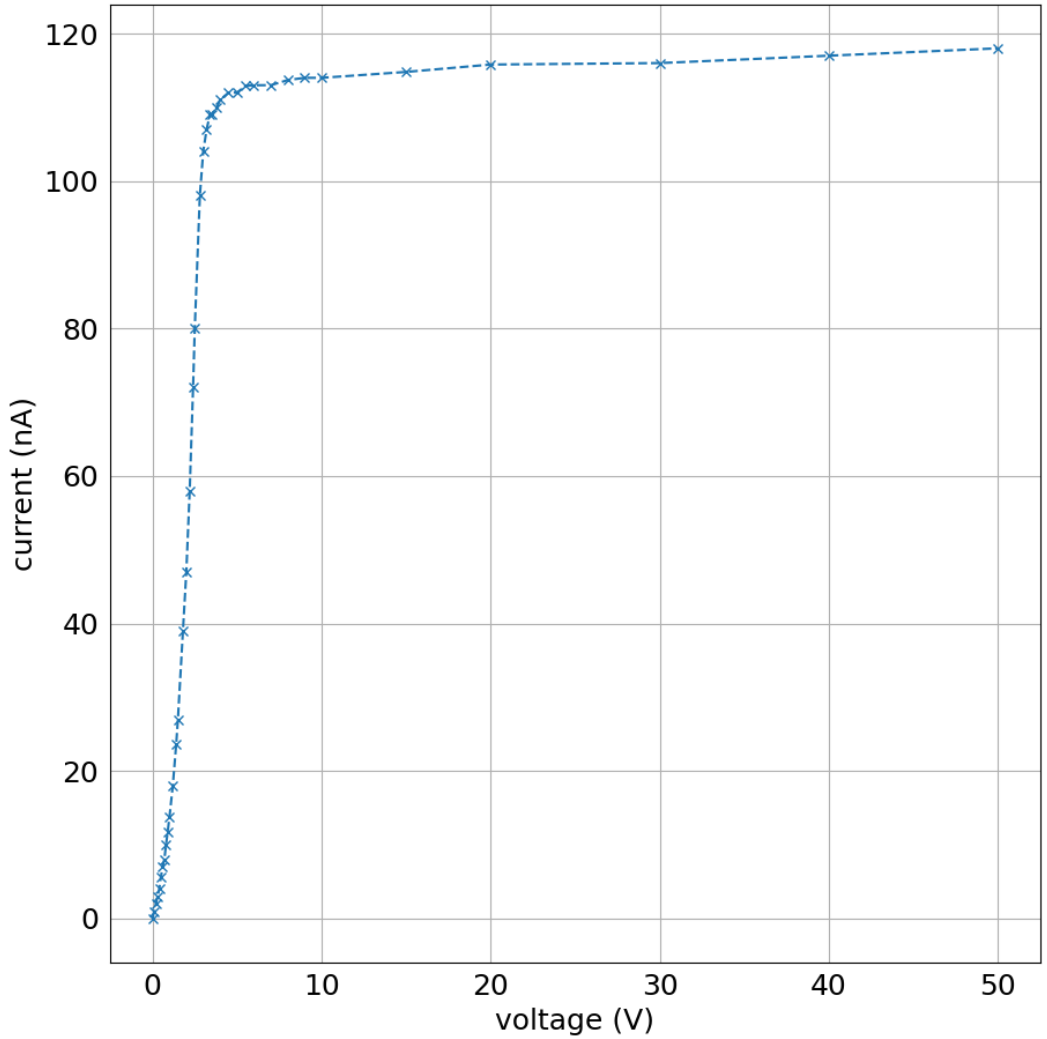
Signal Processing

- Sensor output small & complex in shape
  → Amplification & signal shaping (triangular)
- Discriminator compares signal to threshold
  → Filter unwanted information (e.g. noise)
  → Reduces complexity of signal information
- Information represented by counting clock cycles
  → Triangular signal shape retains amplitude information by measuring time over threshold
- Observables:
  - Time of arrival (ToA)
  - Time over threshold (ToT)
  - Ooccurrence (count)





Current-Over-Voltage Measurement



- First test of basic principles of sensor
- Verification of voltage range for reverse biased operation at stable current
- Positive voltage is applied
  → Small, largely constant current
  → Reversed direction, depletion region grows with increasing voltage until it spans the thickness of sensor

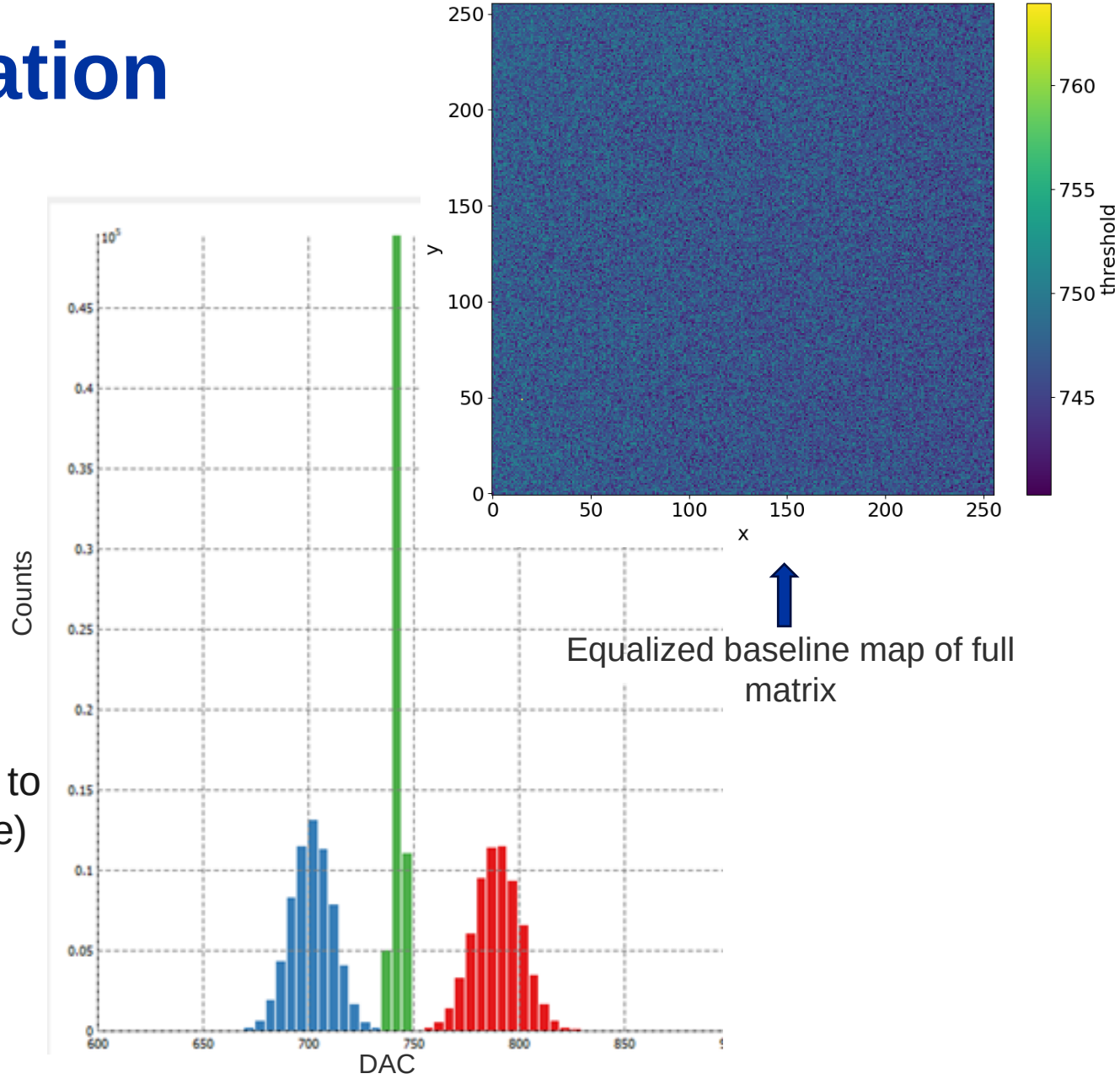
► **Reverse bias operation by applying positive voltages**

► **Signal by hole collection**

Pixel Response Equalization

- Read-out channels show differences in response to a given signal
  → Different baselines, caused by little differences in production
- Local per-pixel adjustment enables to equalize differences in response
  → Adjust every pixel to maximum of local adjustment (blue distribution)
  → Adjust every pixel to minimum of local adjustment (red distribution)
  → Calculate the per pixel adjustment necessary to shift all pixels to center (between red and blue)

► **Equalization result (green): most probable baseline at 749DAC**



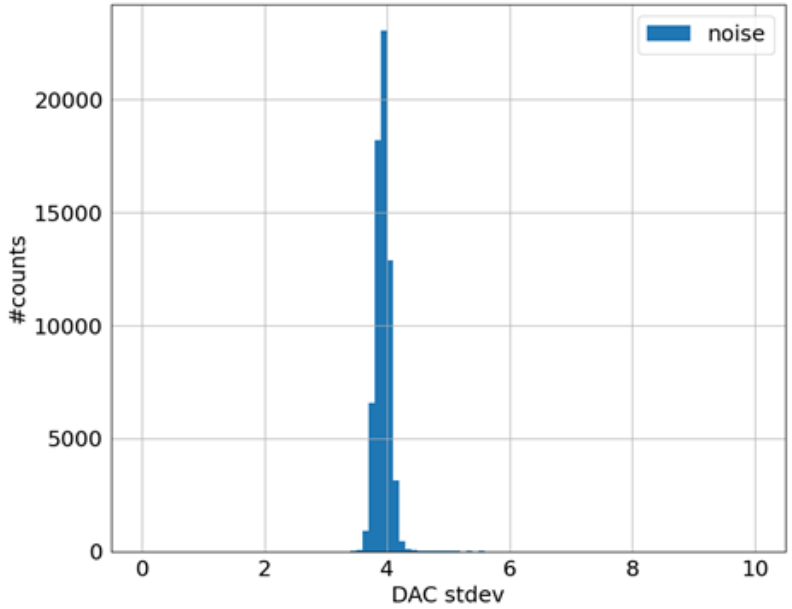
Pixel Noise

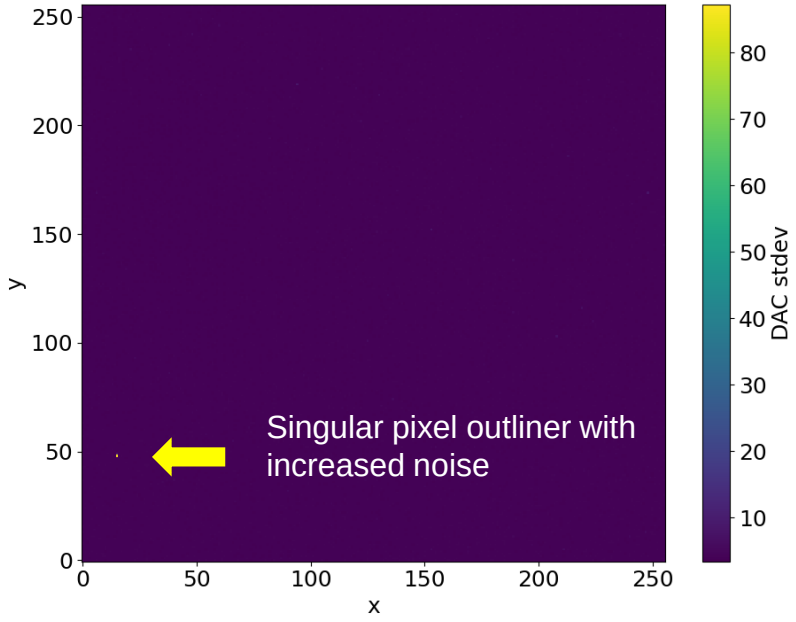
- Every pixel has noise→ adjust threshold to only see physics signals
- Scanning global threshold across most probable baseline

  → Turn-on s-shaped curve as threshold is lowered into noise
- Standard deviation of turn-on curve is a measure for the noise
- **σ = 3.9** most probable noise for all pixels
- 5 sigma from threshold away

  → Close to 100% chance of not seeing noise
- **Calculated operational threshold**: 749DAC – 5 • 3.9DAC = **729DAC**

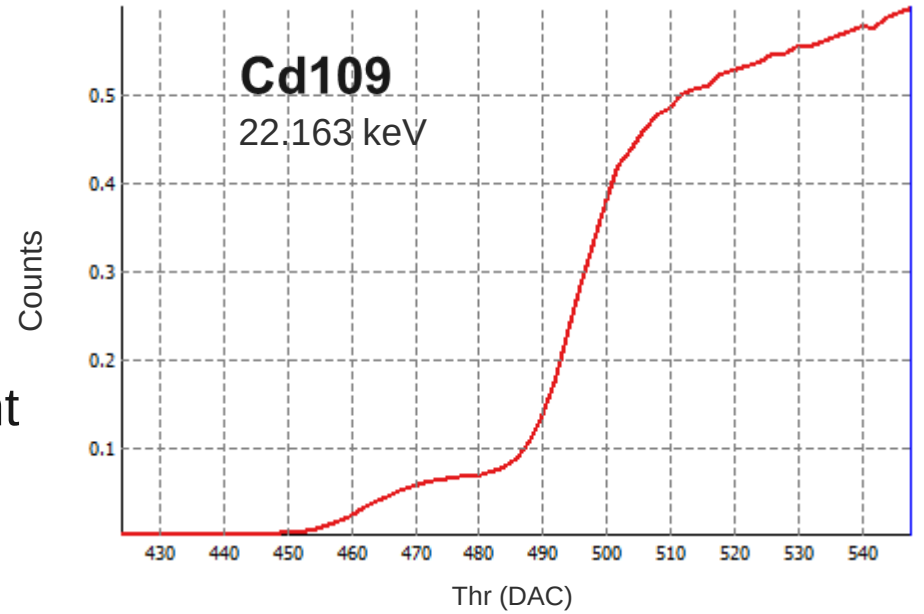
► **Manual threshold adjustment to 720DAC** because of non-gaussian behavior in tails of distribution

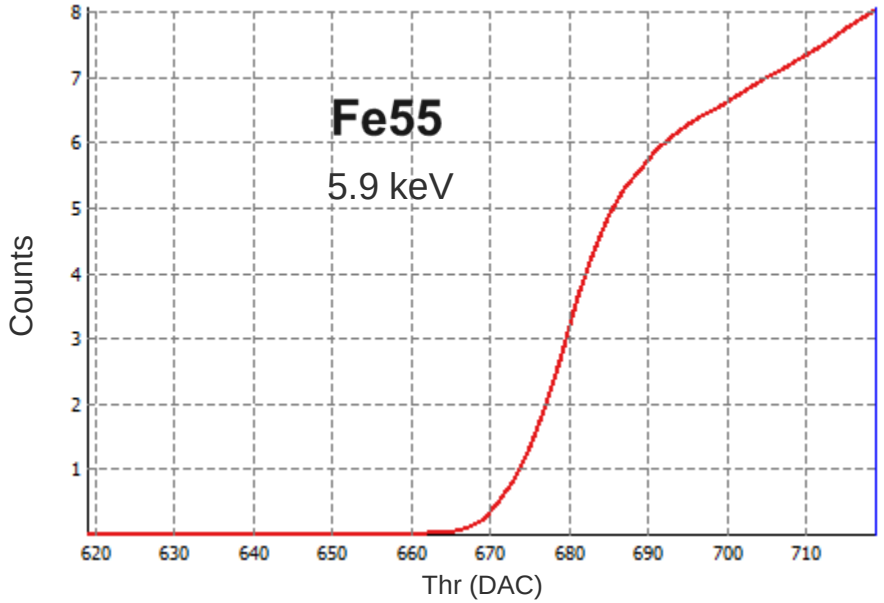




Threshold Calibration

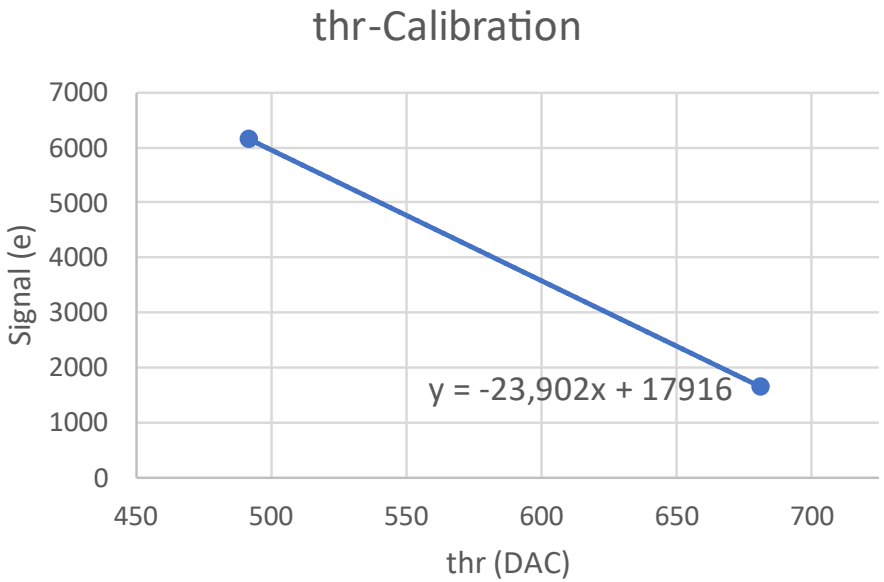
- Photons from gamma sources of known energy
  - → Nuclei decay to a lower energy state by emitting a gamma ray photon of characteristic energy
- Assuming constant rate from source during measurement
  - → Constant count per frame with shutter length 1ms
- Threshold scan with source
  - → Record number of hits in frame per threshold
  - → Steepest slope when thr_DAC crosses photon energy of the source
  - → S-like curve
- Deformation of s-shape at turn-on and linear slope for threshold below signal amplitude
  - → Fluctuations of baseline
  - → Charge sharing between pixels reduces single-pixel signal → detection occurs at lower threshold



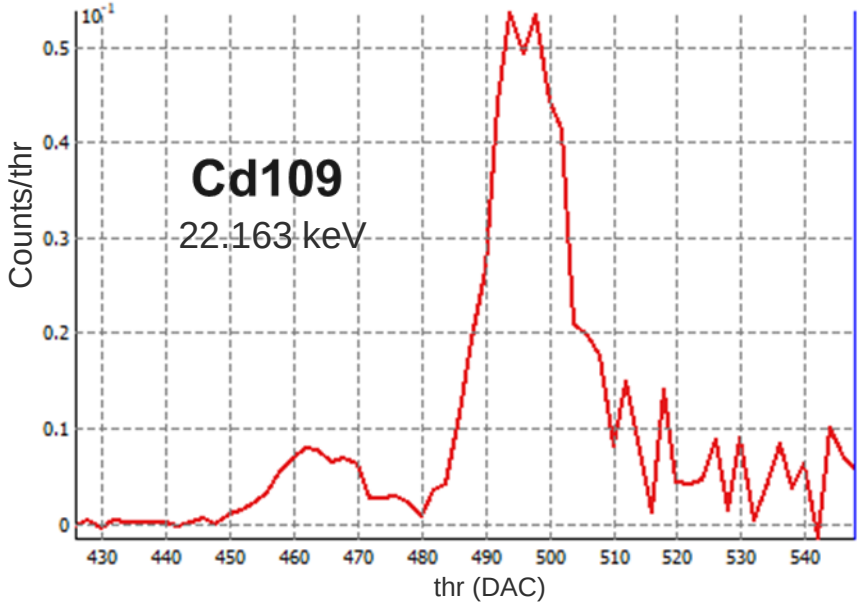


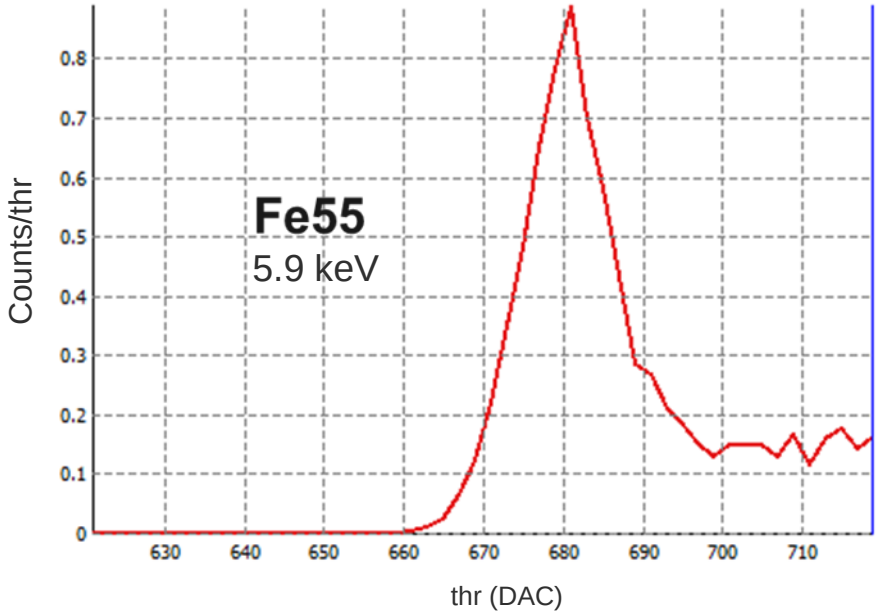
Threshold Calibration

- Analysis of s-curve
  - → Find maximum of derivative
  - → Extract corresponding thr_DAC value
- Plotting signal in electrons (3.6eV per e-h-pair) over thr_DAC



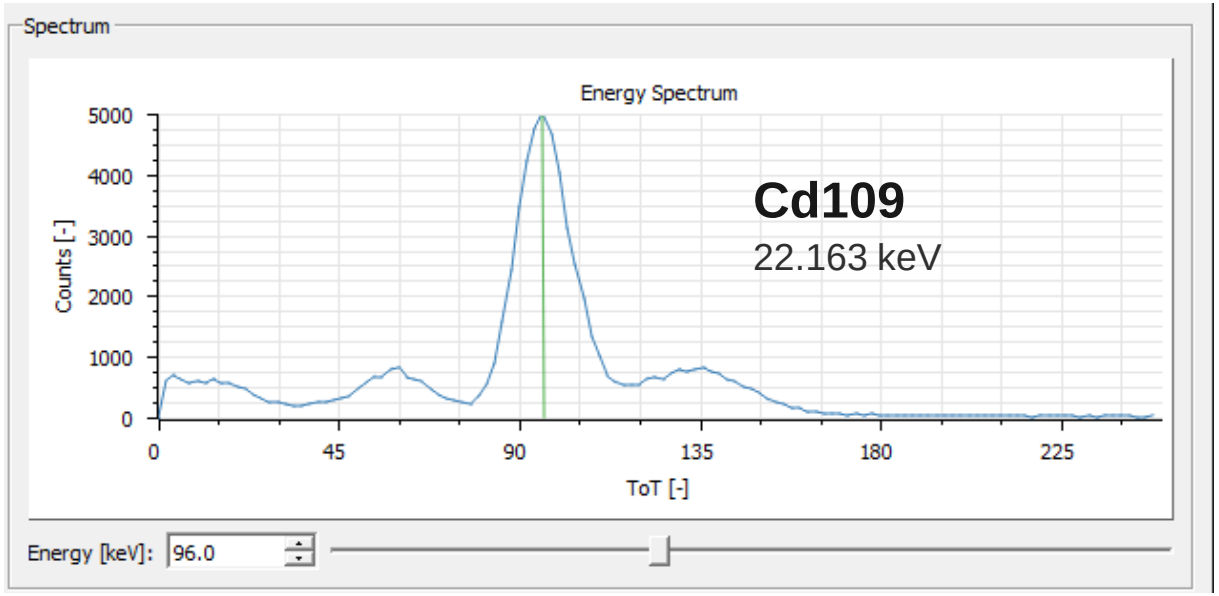
► Operational threshold = 720 DAC → **706 electrons**

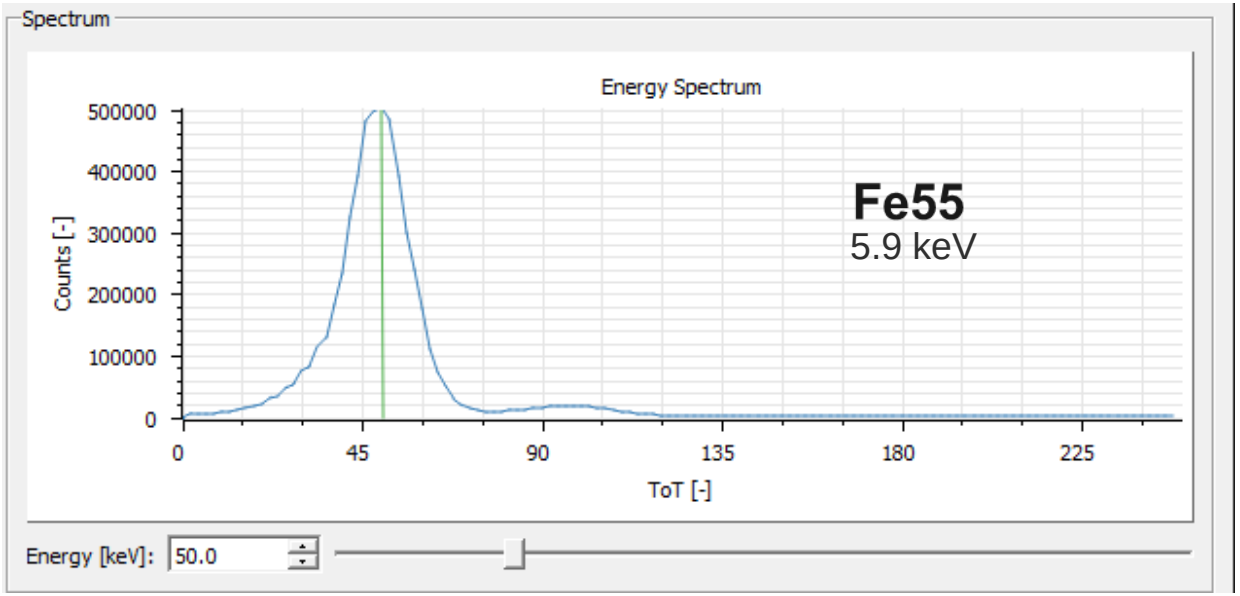




ToT Energy Calibration

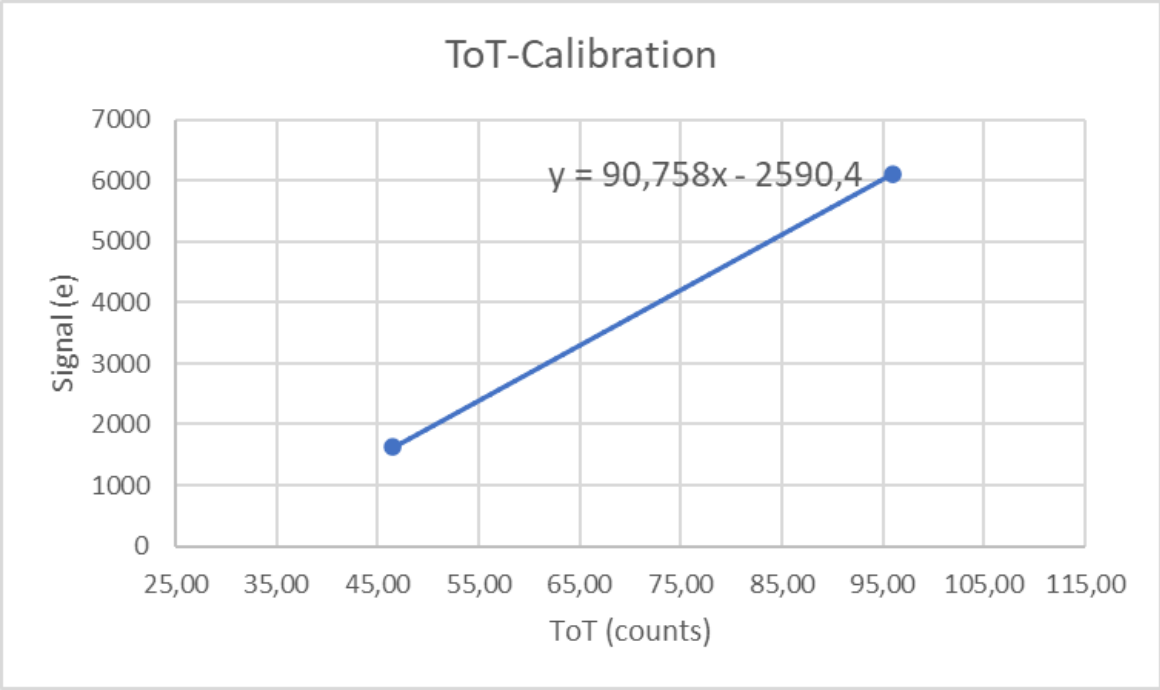
- Photons from gamma sources of known energy
- Dominant peaks form in ToT spectrum for both sources
  → Peak relates to energy of source emission line
  → Convert energy to equivalent signal (3.6eV per e-h-pair)



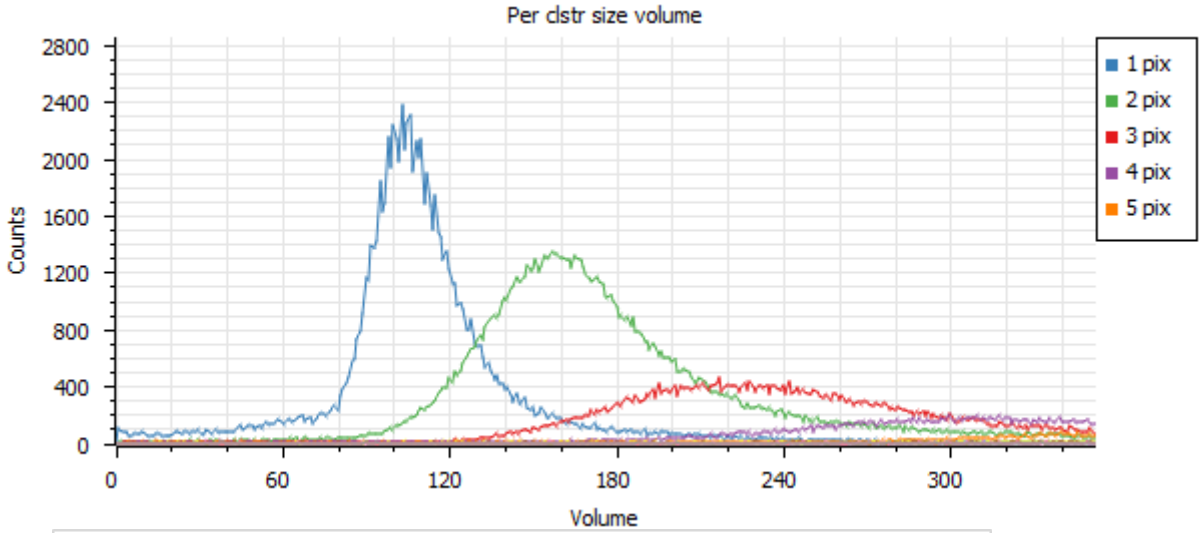


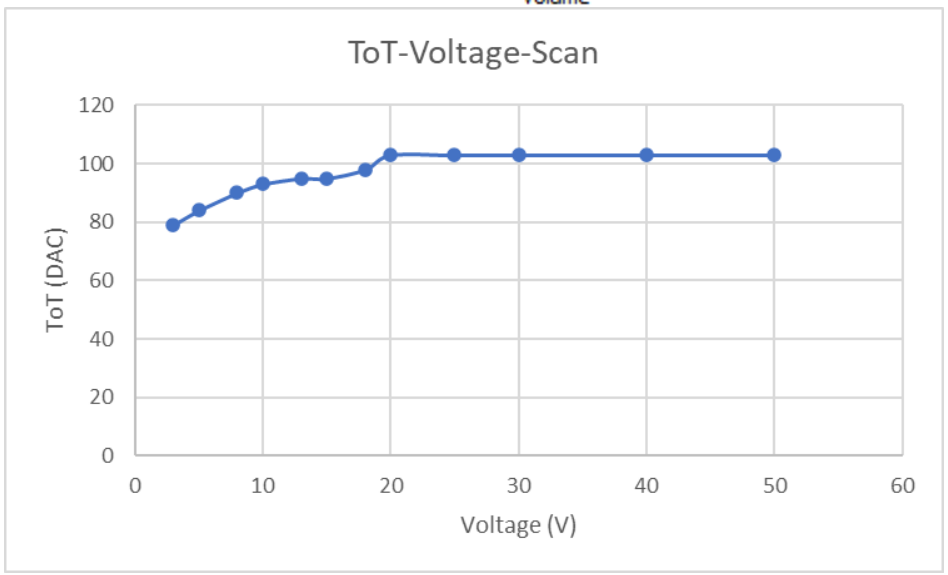
ToT Energy Calibration

- Plotting signal against MVP ToT (peak position) yields linear relation
- Fit parameters slope & offset allow a conversion of measured ToT (DAC) to Signal (e)



Depletion Voltage and Thickness of Sensor





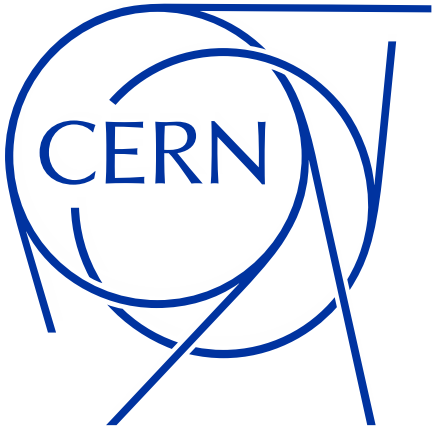
- Measure with Sr90 (minimum ionizing particles)
  → Signal through ionization along path through sensor
  → 76 e-h-pairs per µm in silicon
- Apply clustering to select particle tracks that cause single pixel deposition
  → Selecting straight tracks, mostly perpendicular to sensor surface
- Plotting most probable ToT against voltage
  → Drop signal below 20V; depletion depth smaller than physical thickness
  → Full depletion above 20V; constant ToT value; depletion reached physical thickness of sensor
- Calculate sensor thickness
  → From ToT calibration: 103 DAC = 6750e
  → 6750e/76e per µm = 88.8µm

Conclusion

- Objective: Functional tests, equalization and energy calibration of a Timepix1 pixel detector assembly
- Verification of voltage range for reverse biased operation at stable current
- Equalization of pixel baselines to most probable value of 749DAC
- Average pixel noise of 4DAC steps → noise free operational threshold below 729DAC
- Operational threshold was manually adjusted to 720DAC steps
- Threshold energy calibration using radioactive photon sources yields an operational threshold of 706 electrons
- Time over threshold calibration: signal = -24 • ToT + 17900
- From single-pixel ToT-over-voltage scan → full depletion found for bias voltages above 20V
- Calibration confirmed by extracting width of depleted volume at full depletion → 88.8µm

Sources

- **ADVACAM s.r.o. Pixet Pro.** 2020.
  www.advacam.com
- Justus Braach, Eric Buschmann, Dominik Dannheim, Peter Svihra. **Laboratory course: Characterisation of silicon pixel detectors.** EP-DT-TP, CERN, Geneva, Switzerland
- Hermann Kolanoski, Norbert Wermes. **Teilchendetektoren - Grundlagen und Anwendungen.** Springer Spektrum Berlin, Heidelberg, 2016.
  https://doi.org/10.1007/978-3-662-45350-6
- M. Campbell , J. Alozy, R. Ballabriga, N. Egidos, J. Fernandez, E.H.M. Heijne, I. Kremastiotis, X. Llopart, V. Sriskaran, and L.Tlustos. **The timepix family of pixel detector readout chips**. VERTEX 2020 29th International Workshop on Vertex Detectors. 2020.
  https://indico.cern.ch/event/895924/contributions/4020698/attachments/2119022/3565847/Vertex2020MC.pdf
- Thomas Kluyver, Benjamin Ragan-Kelley, Fernando Pérez, Brian Granger, Matthias Bussonnier, Jonathan Frederic, Kyle Kelley, Jessica Hamrick, Jason Grout, Sylvain Corlay, Paul Ivanov, Damián Avila, Safia Abdalla, and Carol Willing. **Jupyter notebooks – a publishing format for reproducible computational workflows.** In Positioning and Power in Academic Publishing: Players, Agents and Agendas, pages 87 – 90. IOS Press, 2016.
  http://dx.doi.org/10.3233/978-1-61499-649-1-87.



Thank you for your attention

Getting to know a hybrid pixel detector

Chiara Marina Jerkovic

3rd November 2023

Basic principles
Silicon-Diode

Silicon is an element of 5th group

P-type

- Doping with element of 3rd group
- Dopants are prone to accept an electron

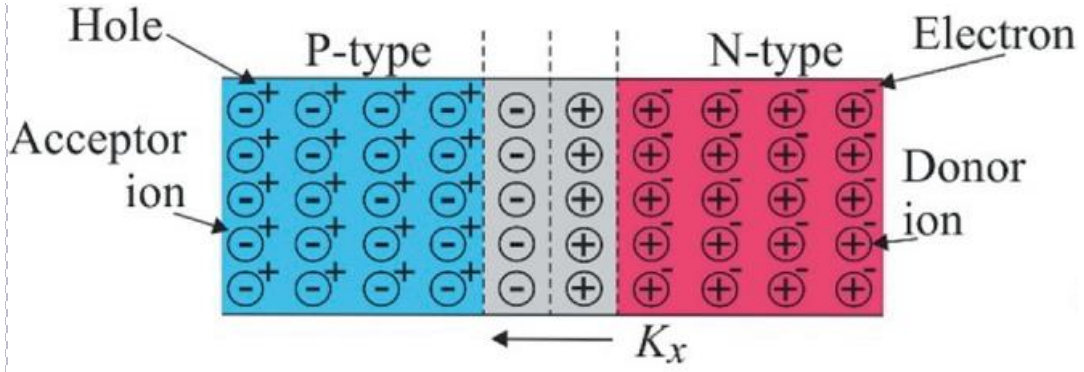
N-type

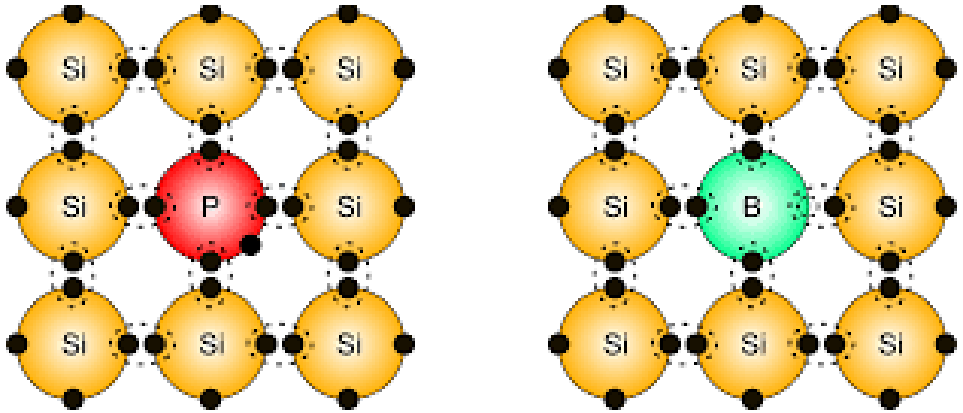
- doping with element of 5th group
- Dopants are prone to donate an electron

Depleted region

- Holes and electrons recombine at the interface
- Applying external potential changes amount of available fee charge carriers in diode
  → modifies the depleted region
- Depletion can be decreased -> current is able to flow
  → forward biased
- Depletion can be increased -> current is hindered to flow
  → reversed operation

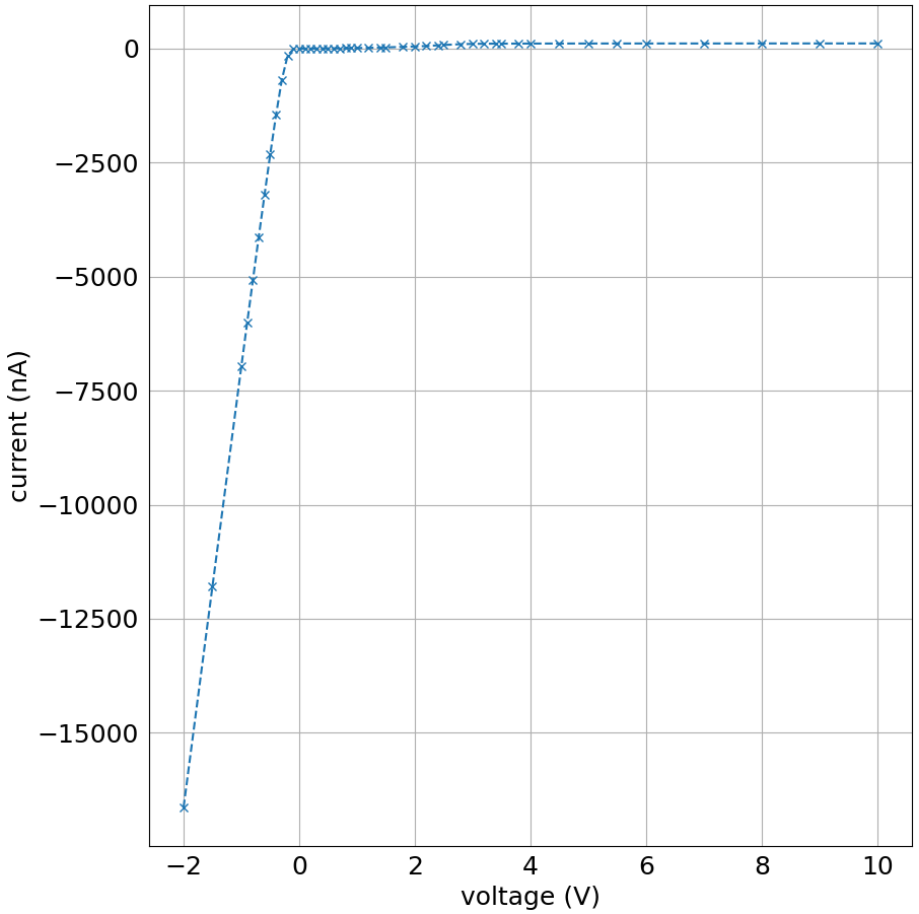
► **Forward/reversed operation**





n-Dotierung p-Dotierung

Current-Over-Voltage Measurement



- First test of basic principles of sensor
- Verification of voltage range for reverse biased operation at stable current
- Negative voltage is applied
  → Current increasing with increasing negative voltage
  → forward direction, no depleted region
- Positive voltage is applied
  → small, largely constant current
  → reversed direction, depletion region grows with increasing voltage until it spans the thickness of sensor

► **Sensor contains p-in-n pixel diodes**

► **Reverse bias operation by applying positive voltages**

► **Signal by hole collection**