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A comparison of different approaches to simulate semiconducting sensor layers for a hybrid pixel X-ray detector

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7th IWORID

Outline

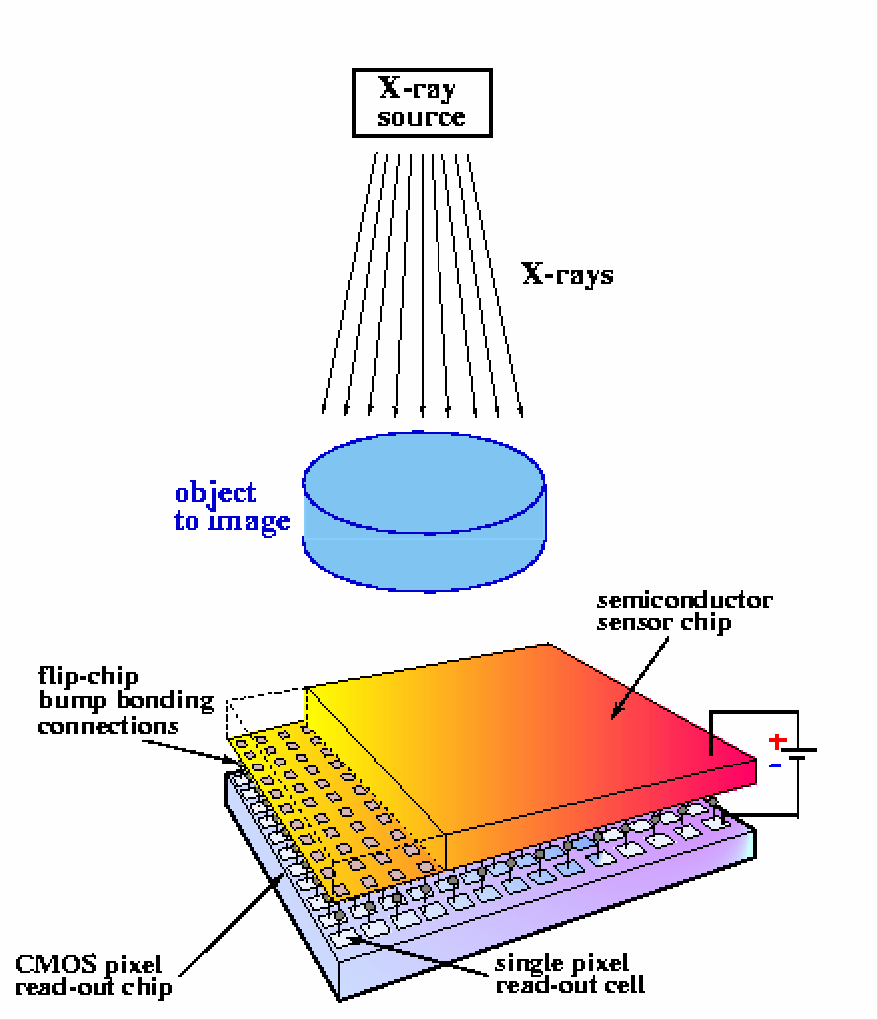
- Interactions between X-rays and Detector
- Diffusion of Charge Carriers
- Charge Sharing Measurements
- Comparison Simulation / Experiment

Medipix detectors

Hybrid design: readout asic bump bonded to sensor

Different sensor materials possible

- Pixel size 55 µm
- Low and high energy threshold
- Single photon counting technique



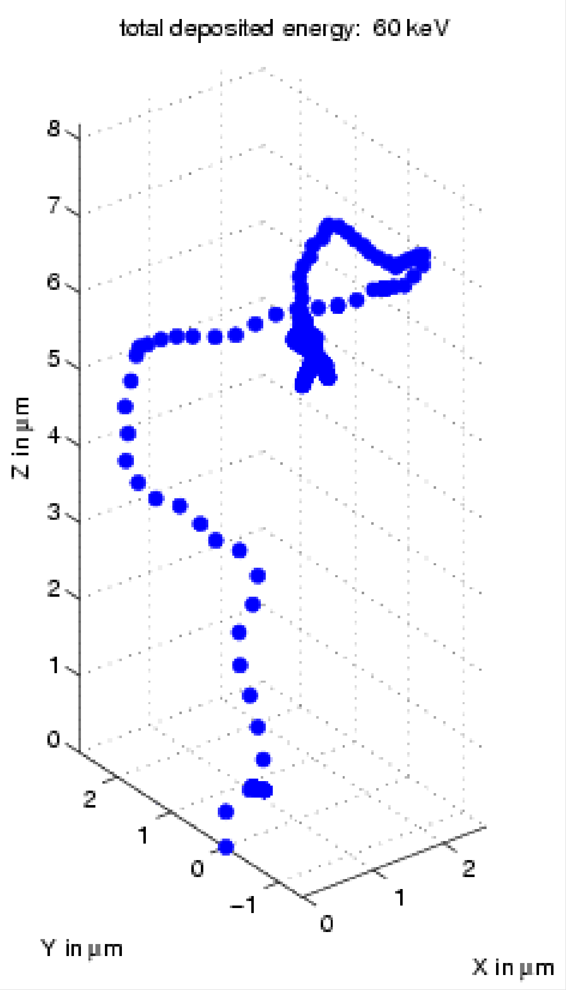
Intrinsic Resolution

➡ **Talk by Gisela Anton:**

- **Intrinsic Resolution** is a function of the detector material and photon energy
- Electron travel and multiple scattering are not neglectable concerning spatial and energy resolution of detectors
- Travel of electrons can be larger than diffusion width of the charge cloud
- Energy is transmitted at an equal rate along the path of the electron

- Multiple interactions (Compton scattering, Fluorescence) cause additional loss of spatial information
- Incomplete Absorption causes loss in energy resolution (Escape peaks)

- **A Monte Carlo Simulation is required**



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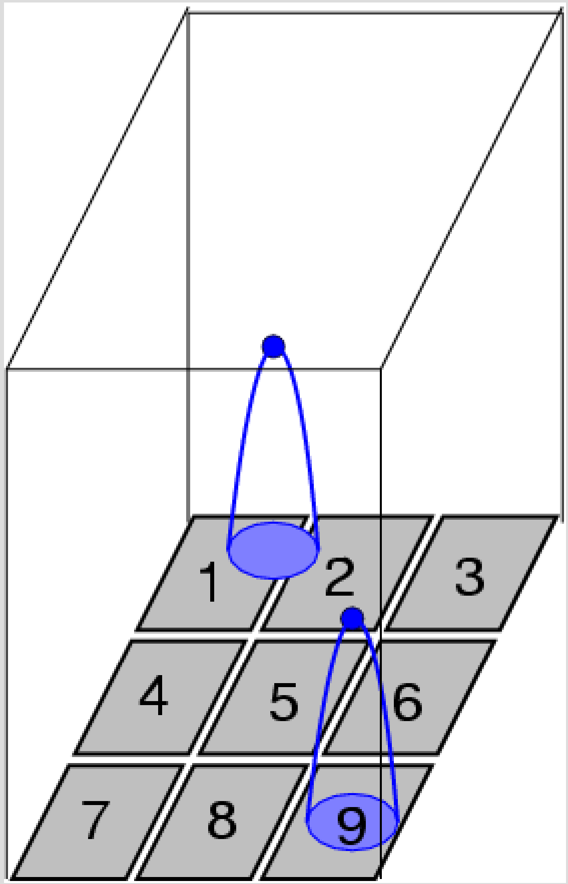
Diffusion & Charge Sharing

- Diffusion of charge carriers causes charge sharing
- Diffusion approximation with Einstein relation

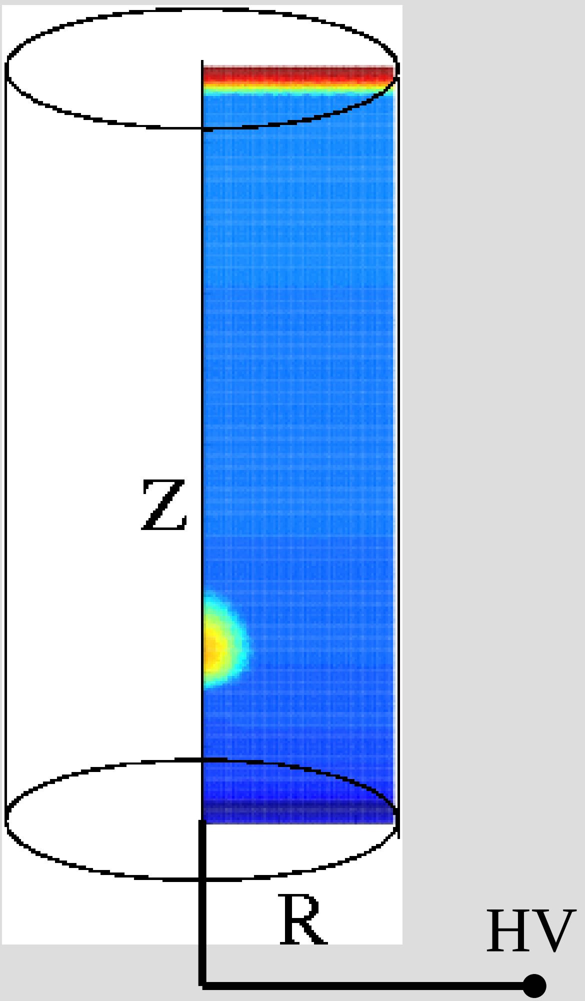
$$L = \sqrt{2Dt} = \sqrt{2\frac{kT}{e}\frac{d}{E}}$$

- Or a detailed carrier transport simulation with finite element methods or commercial device simulation programs, like medici



MEDICI simulation: Carrier Diffusion

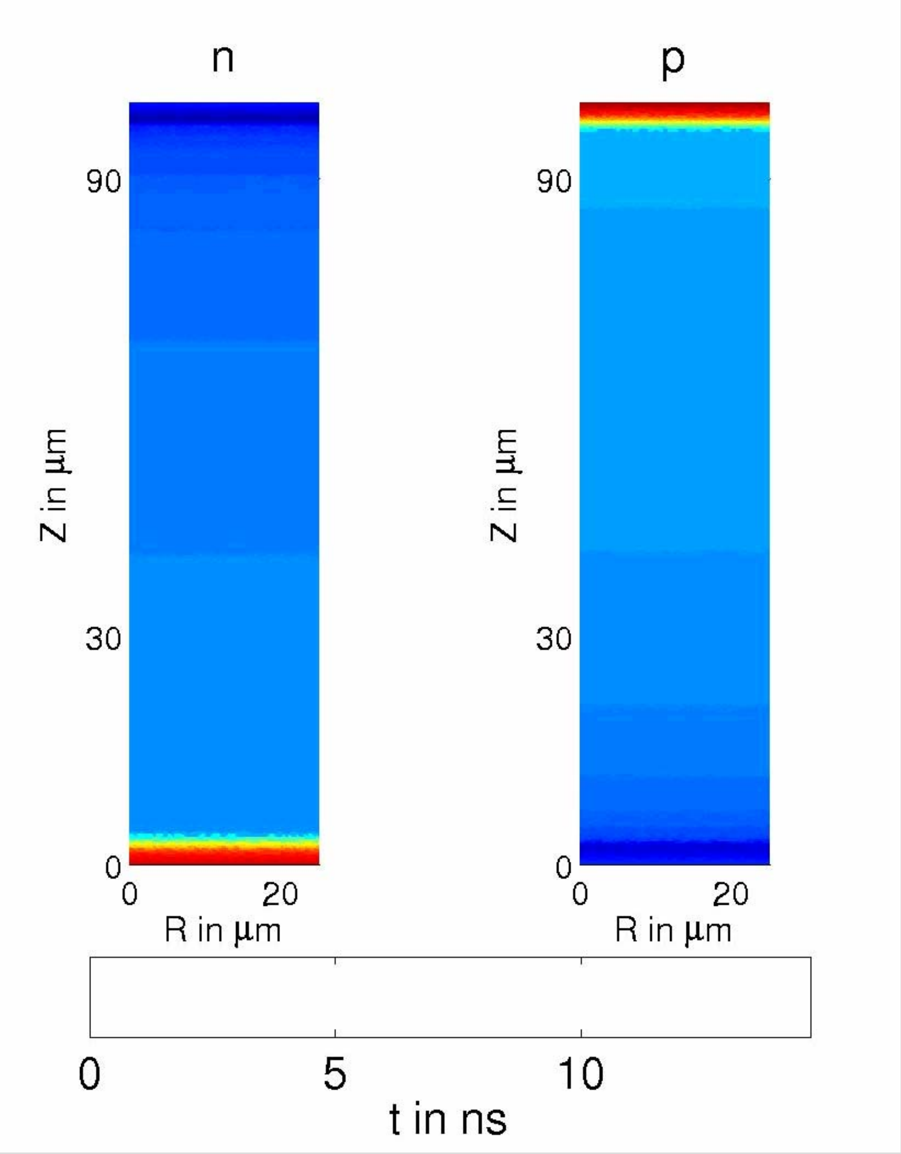
- Cylindrical diode (2D)
- Limited number of mesh points
  - -> choose very small device
  - 100 µm x 25 µm with 0.25µm mesh
  - Original size of charge cloud: 1µm x 2µm ($2\pi(\mu m)^3$)
- Charge is created close (15 µm) to the electron collecting contact, to investigate diffusion of holes
- Different voltages



Hole cloud (p)

Carrier Transport in MEDICI

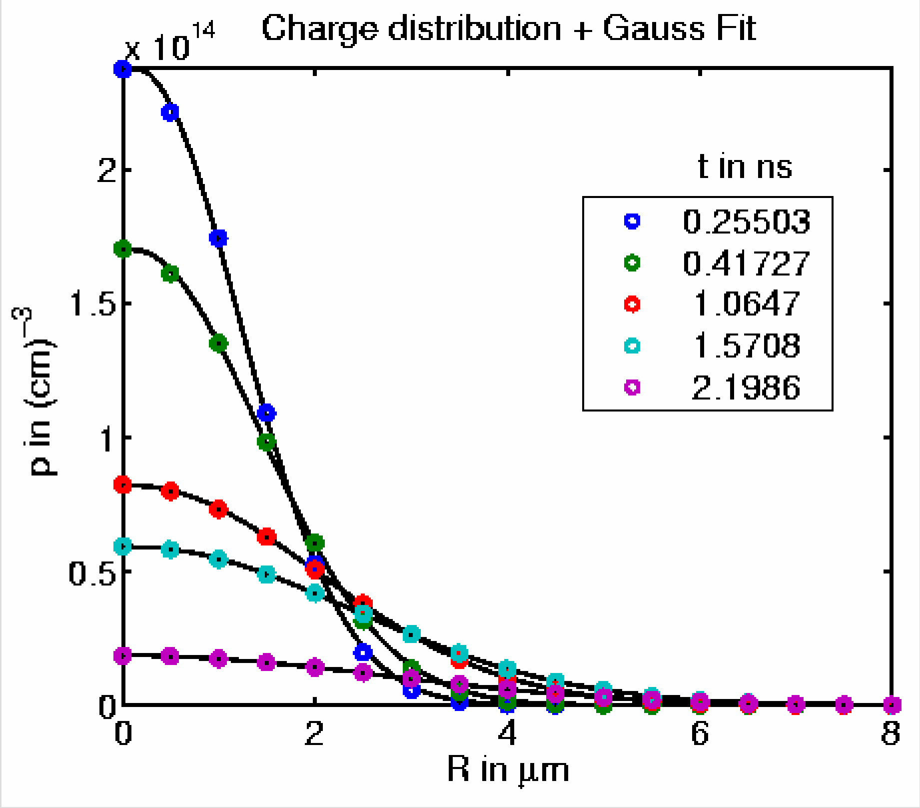
- 30 V
- EHP created at Z = 15 µm
- Exponential increase of time steps in transient simulation

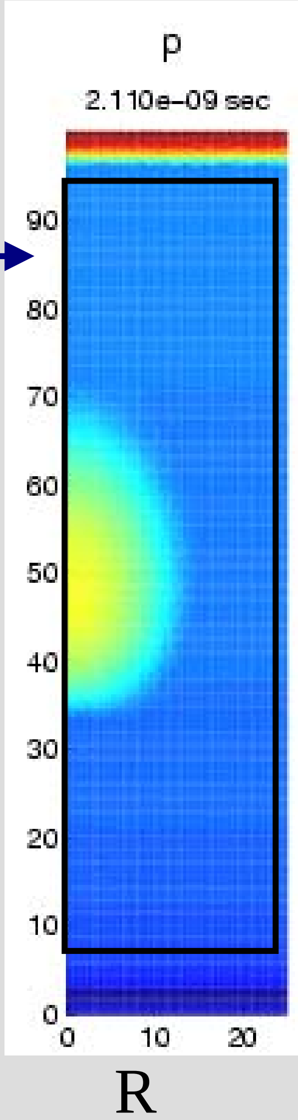


Lateral charge diffusion 1

For every step of the transient simulation:

Sum the carrier concentration (n,p) in the rectangle (away from doped contacts) in Z direction, yielding the lateral charge distribution





Sigma of Charge Cloud

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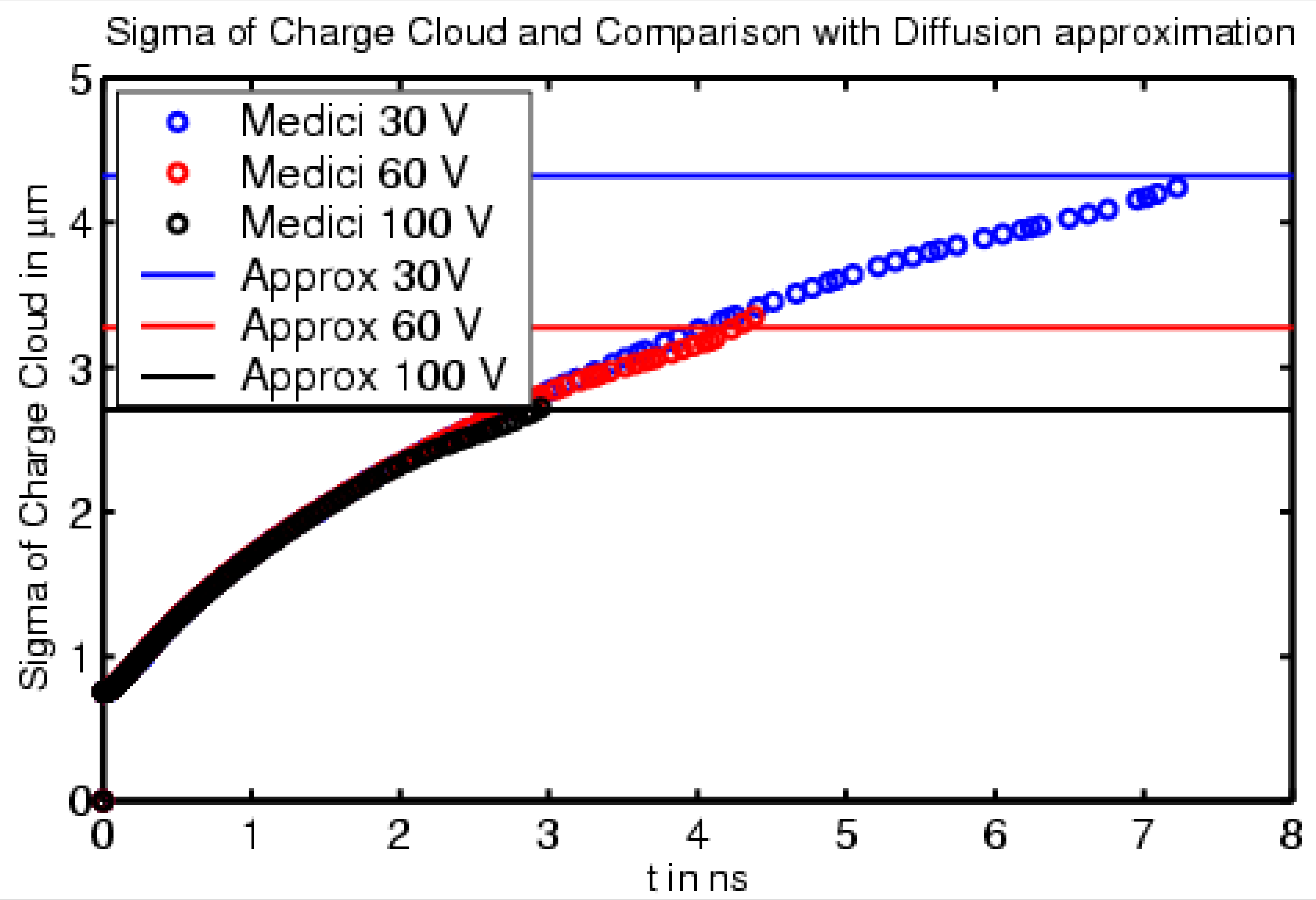
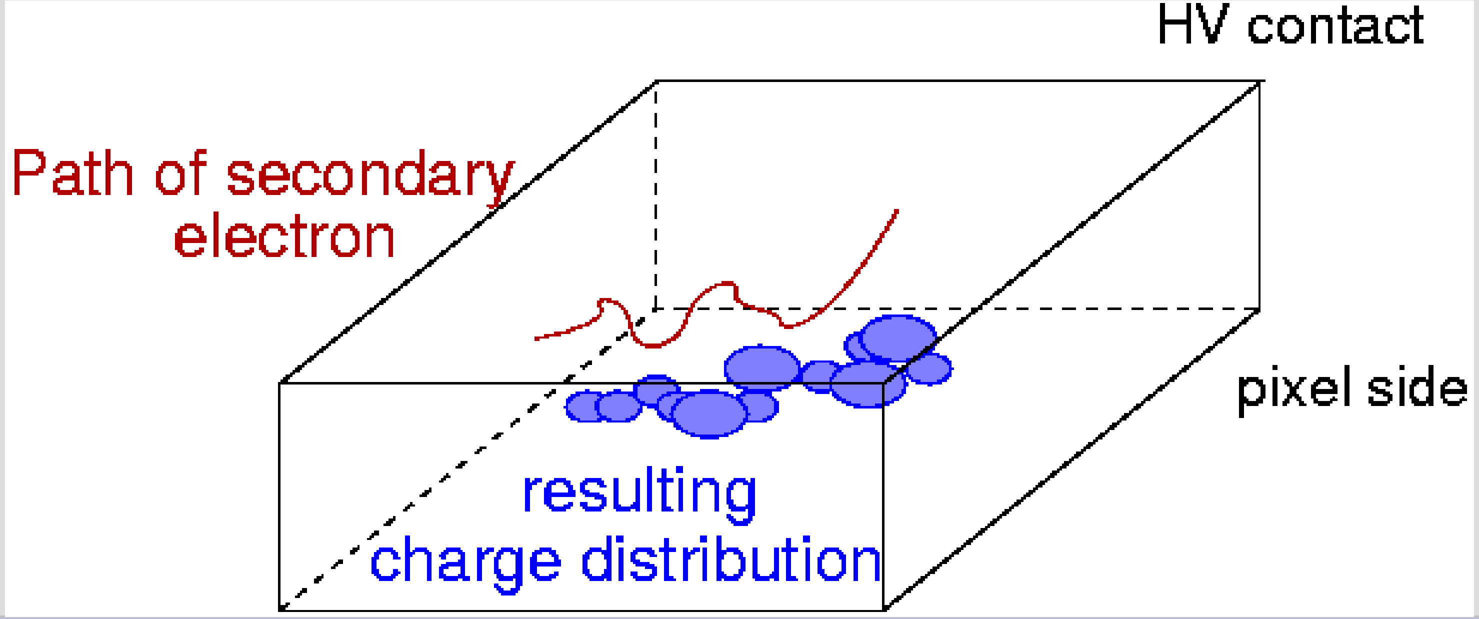
- Final sigma (at complete collection) corresponds with Einstein relation approximation

$$L = \sqrt{2Dt} = \sqrt{2\frac{kT}{e}\frac{d}{E}}$$



Monte Carlo + Diffusion

- Einstein approximation seems to be a sufficient approximation to estimate charge carrier diffusion.
- Incorporate diffusion approximation in Monte Carlo Code like ROSI.
- Analytical approximation is huge gain in computation time!
- Both, carrier diffusion and interactions in the sensor material can be considered for every photon.



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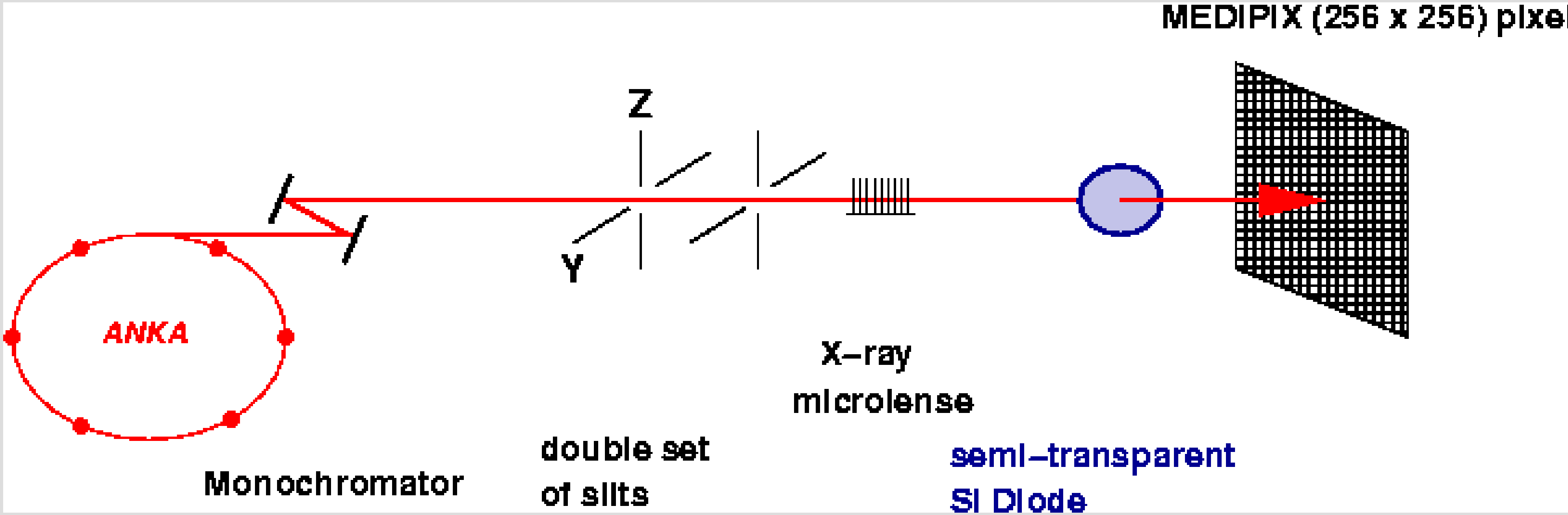
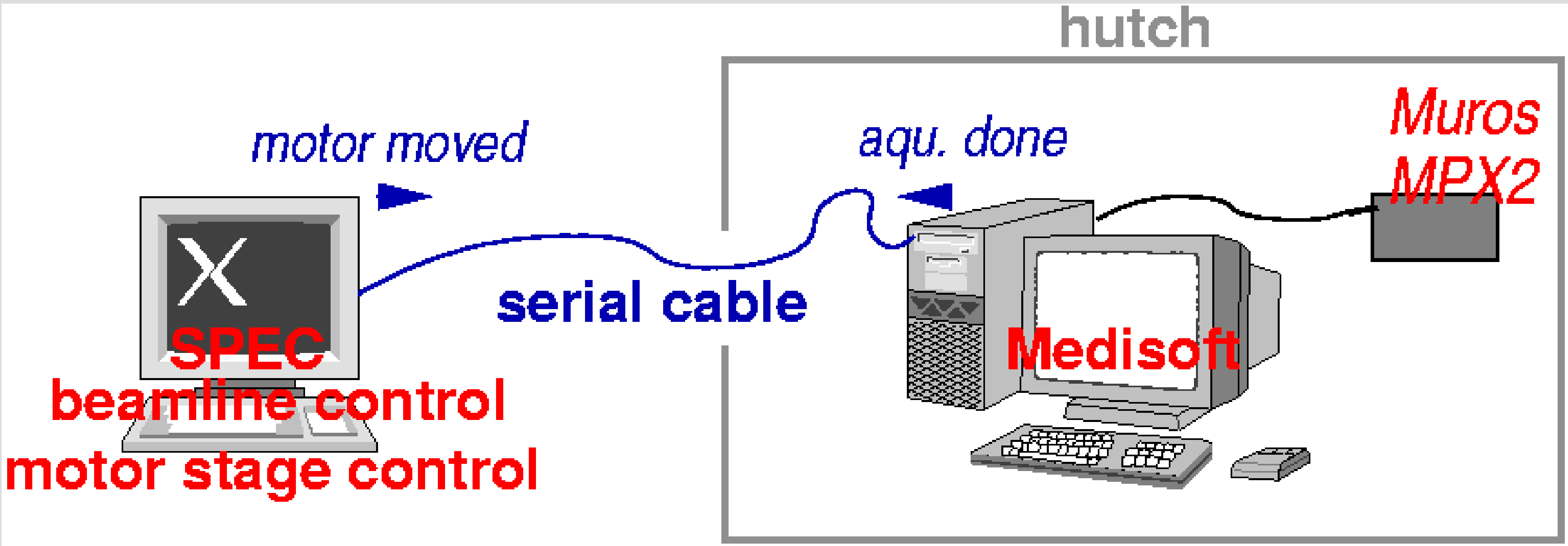
ANKA Setup



- ANKA Synchrotron light source in Karlsruhe, Germany
- 12.4 keV monochromatic beam
- Collimated to (1µm)² with X-ray microlense

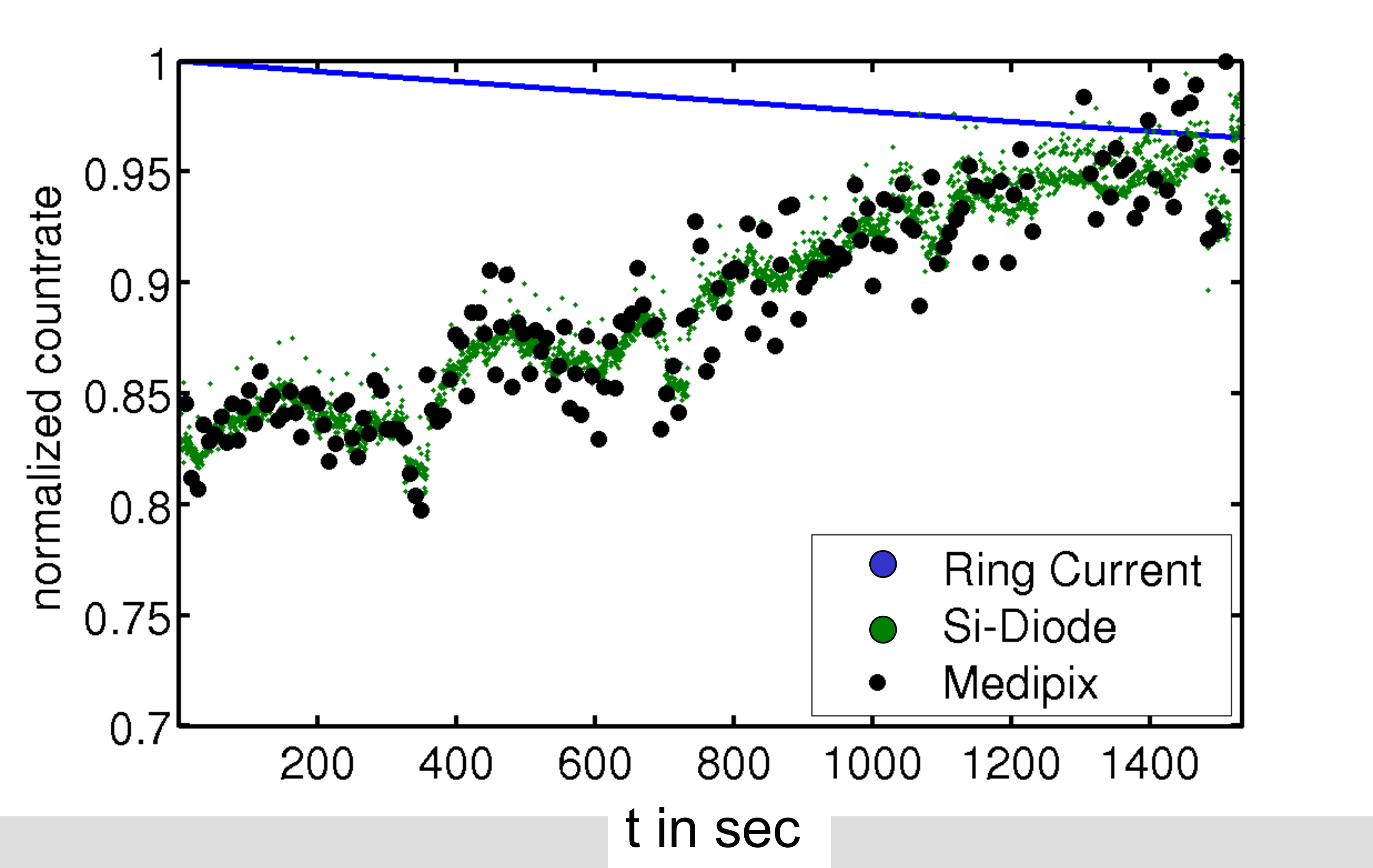
- Response of pixels was mapped for beam position

Medipix2 Setup



- Automated acquistions by communication between Medisoft and SPEC
- At each position of the beam, change HV and THL.

Intensity variations (1 µm Beam)



- The intensity of the collimated beam is very susceptible to small variations in the orbit positions of the electrons in the ring. The ring current is not sufficient to normalize the countrate

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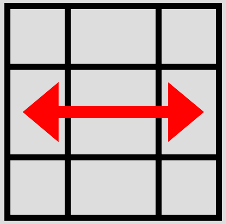
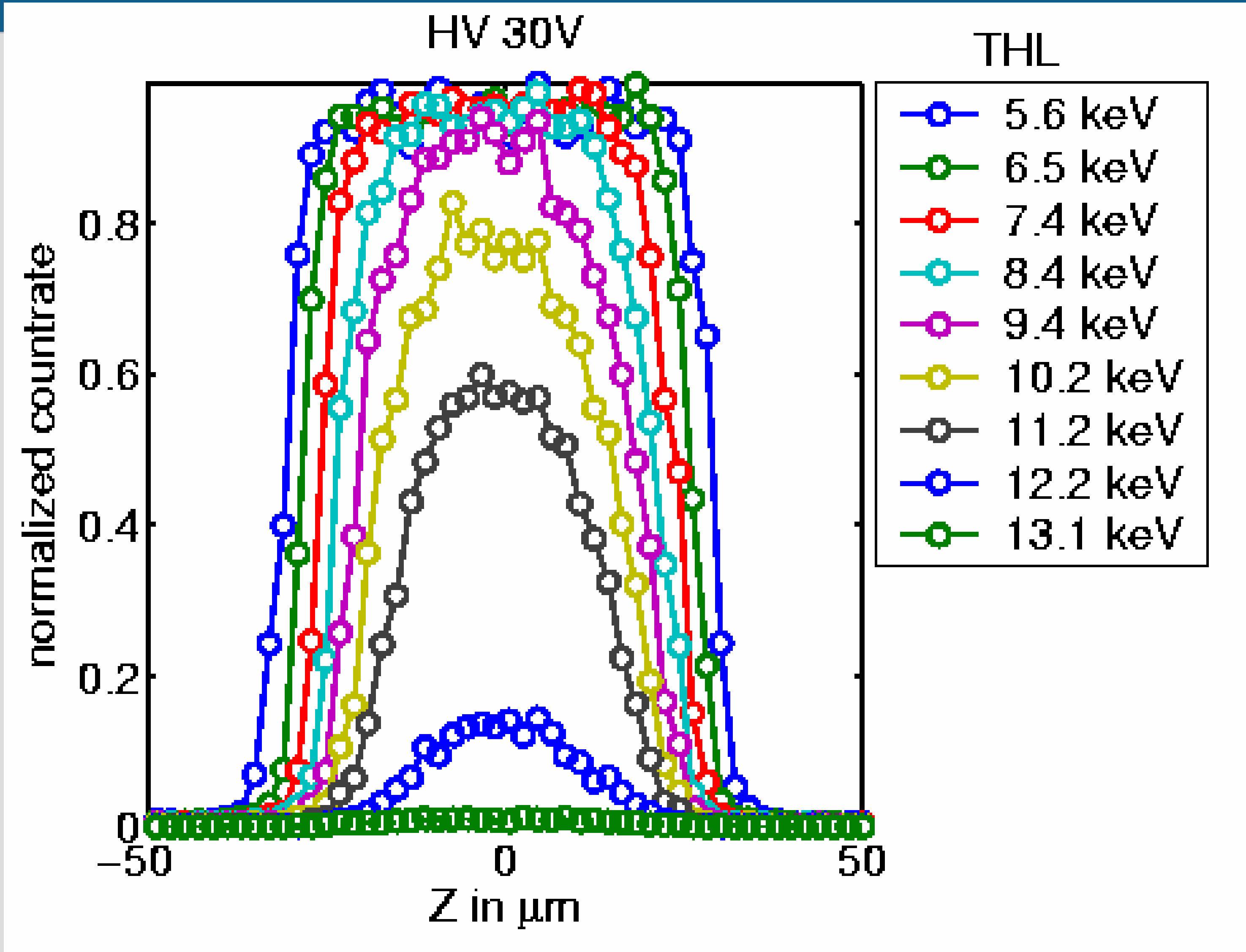
Threshold Variation



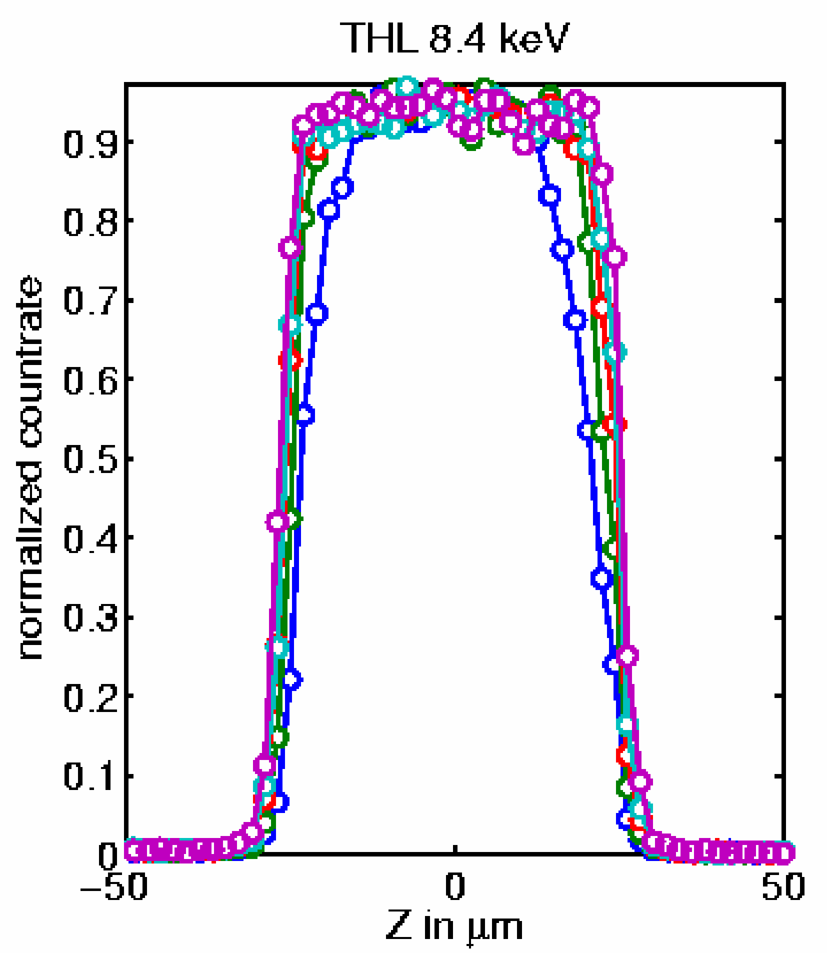
beam pos.

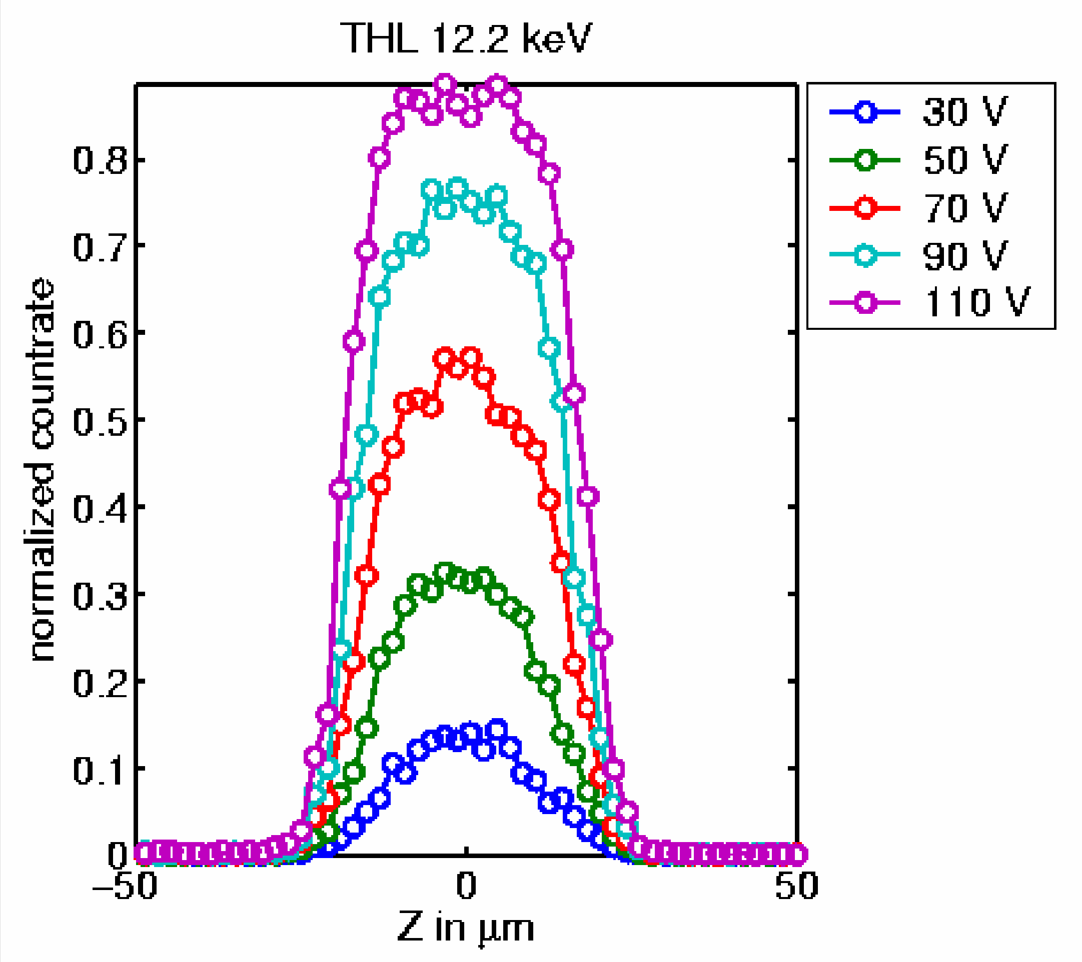
moves on pixel



Changing the threshold changes the apparent pixel size
The higher the threshold, the more charge needs to be collected

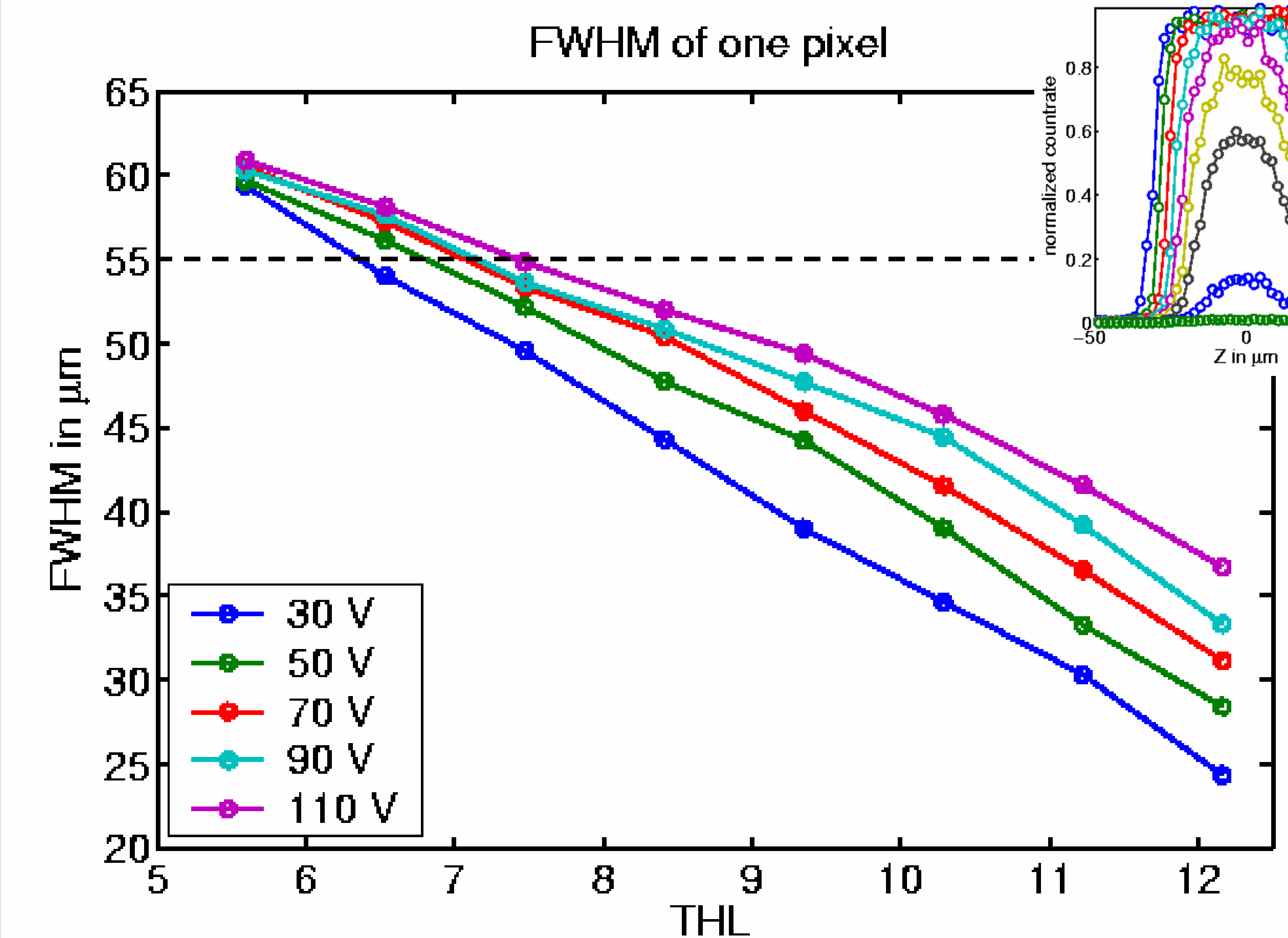
Bias Variation

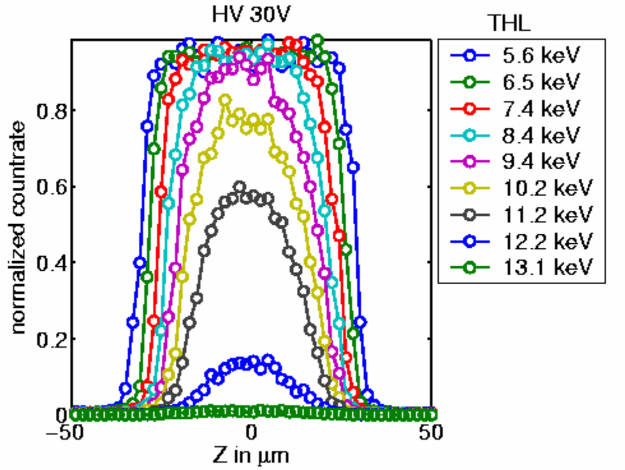




Influence of bias voltage varies with threshold

FWHM Pixel response





The FWHM of the pixel response depends on threshold and bias voltage

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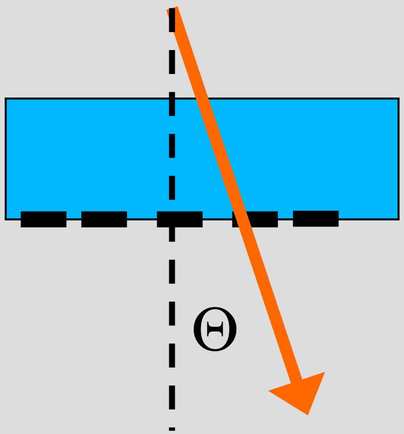
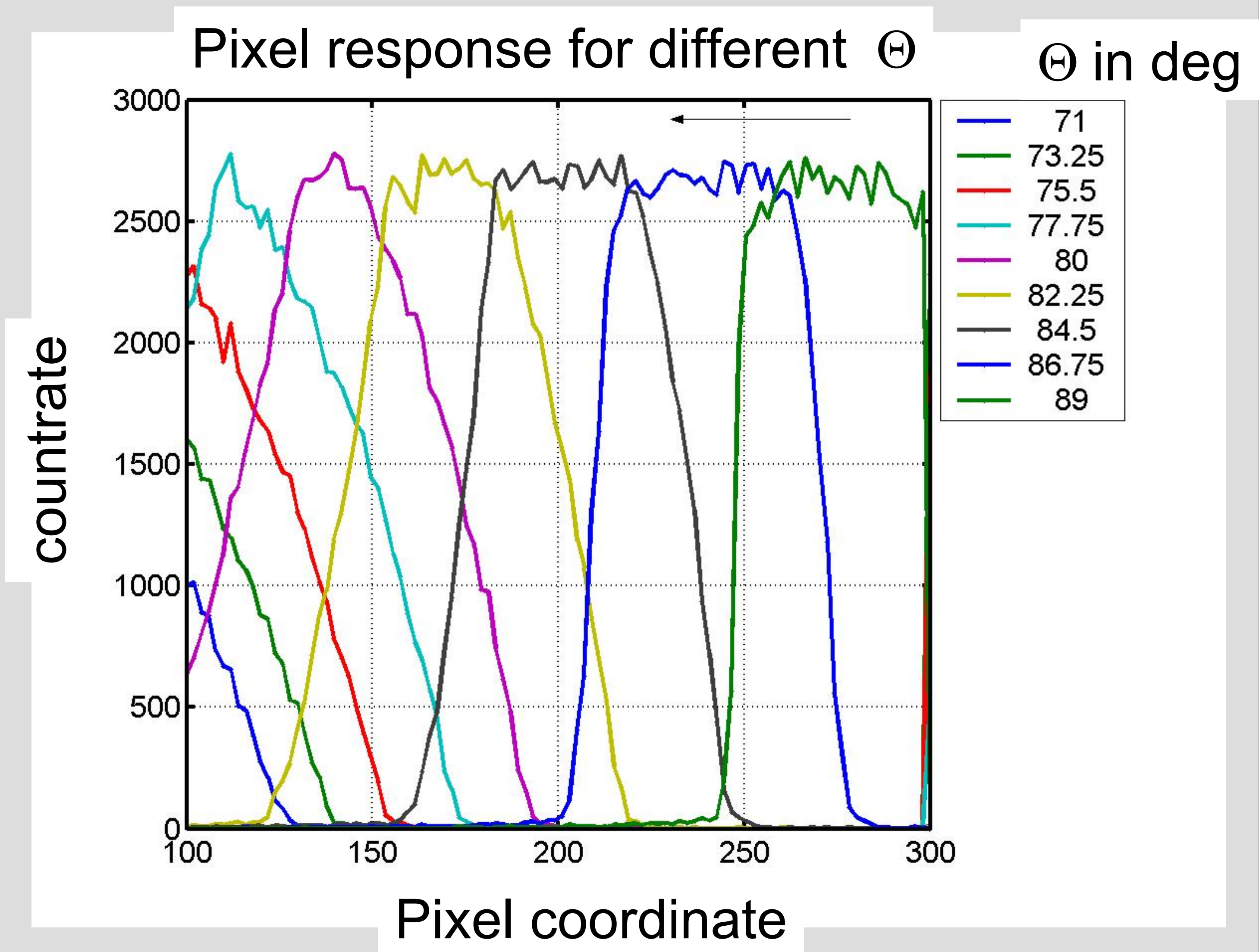
Aligning the Detector / Tilt

Already a small tilt influences the respose curve of a pixel





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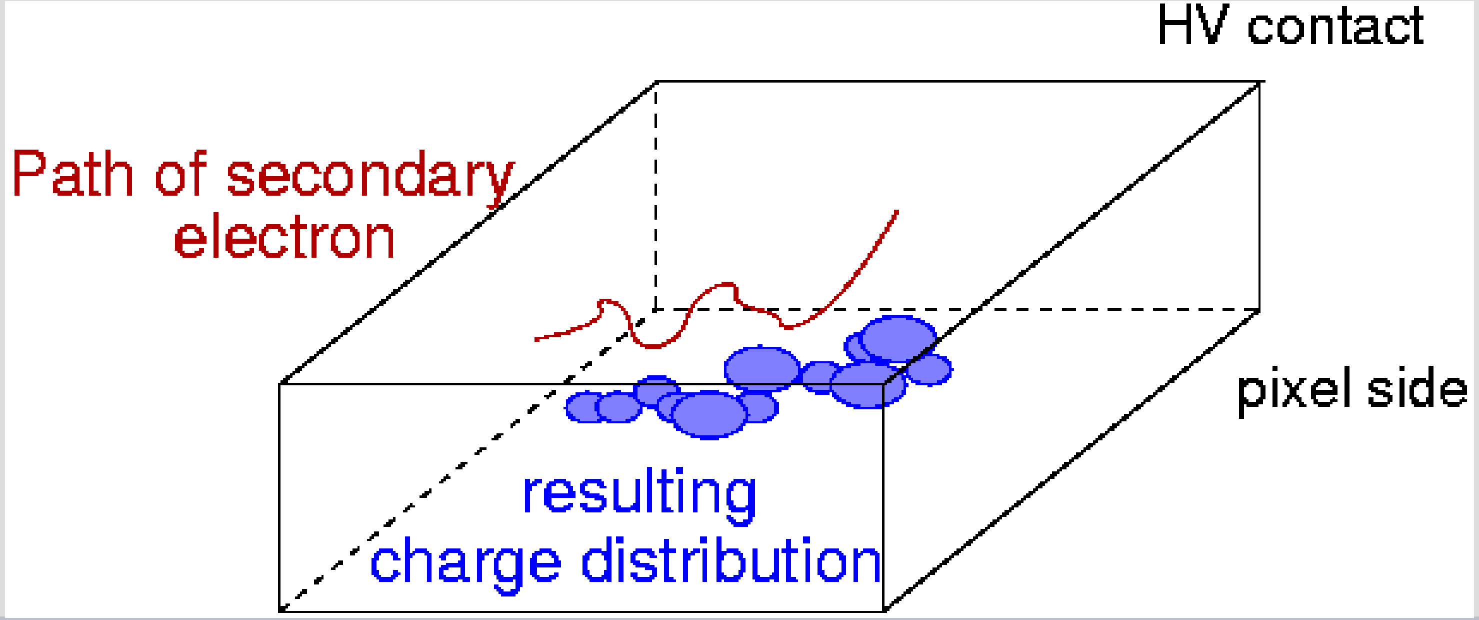
Simulation Model

- Monte Carlo Simulation with ROSI, together with diffusion approximation
- Full charge collection assumed (Silicon detector)
- Assumed readout noise of Medipix2: between 0.4 keV - 1 keV



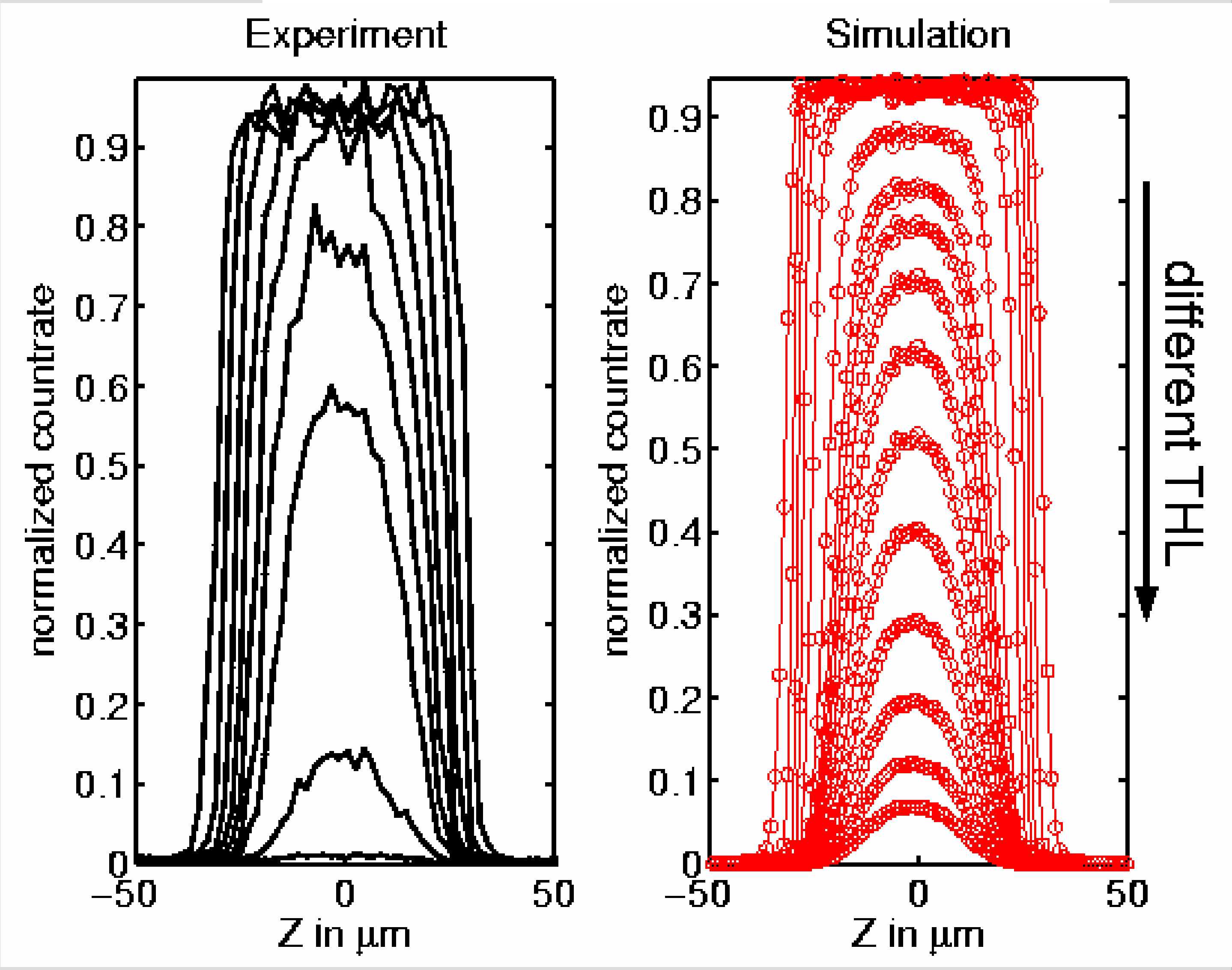
Comparison Simulation - Experiment

Similar response curves for different threshold but:

- Possible small tilt (steeper pixels)
- Problems with energy-THL calibration
- Unknown readout noise (ASIC)

-> needs more simulation!

HV = 30 V, readout noise 0.6 keV



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Summary

- ROSI + Einstein diffusion yields good results but lacks:
  - repulsion of charge carriers
  - Consideration of mobility, lifetime & pixel size
- The next step: create look-up table for ROSI that includes small pixel effect, mobility and lifetime.
- Travel of electrons can be larger than diffusion width of the charge cloud

Acknowledgements:

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