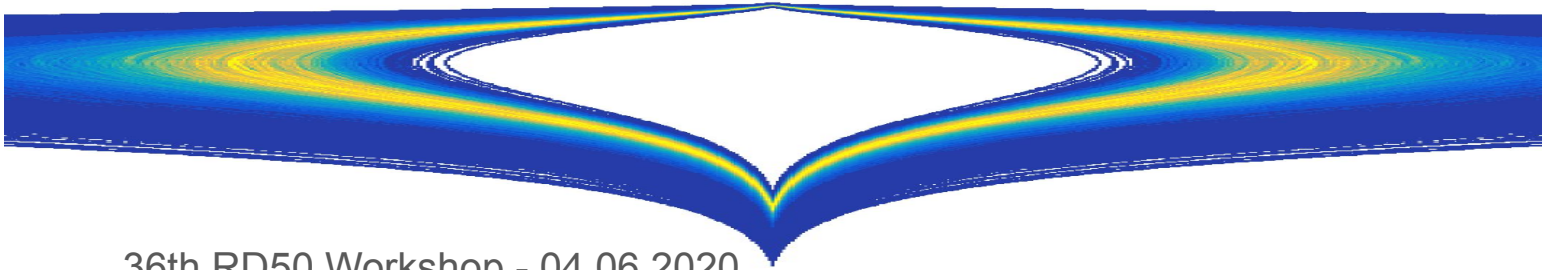
Simulation of thickness dependence of time resolution for simple planar devices



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Outline

- Framework and aim of study
- Brief introduction of Garfield++
- Method
- Simulations of pad detectors
- Simulations of pixel detectors
- Time correction methods
- Summary and outline

Framework of study

- Collaboration between LHCb VELO and CERN SSD lab.
- Work as a part of a master thesis at NTNU.

Aim of study

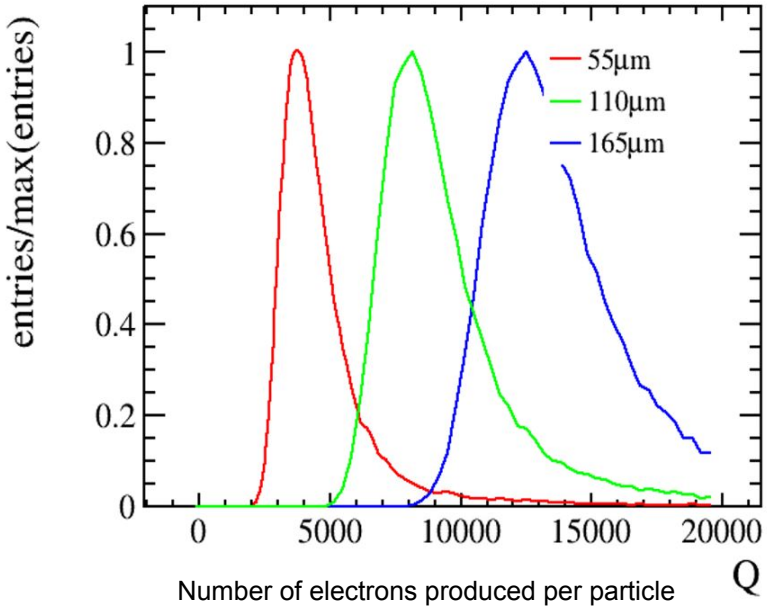
- Understand fundamental properties of detectors and how they affect time resolution.
  - Study how thickness, noise, weighting field and electric field impact the time resolution for different sensors
- Method:
  - Use Garfield++ to simulate simplified pad and pixel sensors
- Disclaimer: Theoretical study only. No validation against measurements yet.

Garfield++

- Simulation toolkit for detailed simulation of particle detectors that is based on ionization measurements in gases and semiconductors
- Program provides
  - Ionisation model
  - Interface with finite element programs to import electric and weighting fields
  - Monte Carlo charge transport
  - Shaper, noise model, ++
- More details: https://garfieldpp.web.cern.ch/garfieldpp/

Procedure

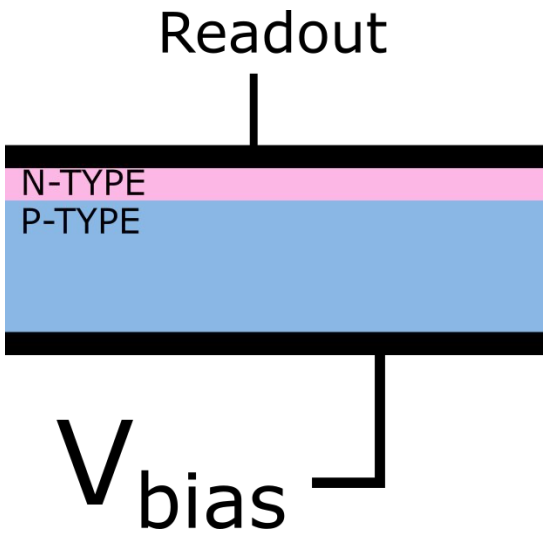
- Sensors of thicknesses 55μm, 110μm and 165μm are simulated
- Charge deposition is simulated by Garfield++ using the Photo-Absorption Ionization (PAI) model.
  - Simulation of energy loss, atomic relaxation and delta electron transport is included.
  - 180GeV/c pions are simulated
- The electric field is approximated to be uniform.
  - Field used is 10V/μm
- A moving charge generates a signal according to Ramo theorem $i=-qE_w v$
  - q is the charge,
  - E_w is the weighting field
  - v is the velocity vector for the moving charged particle



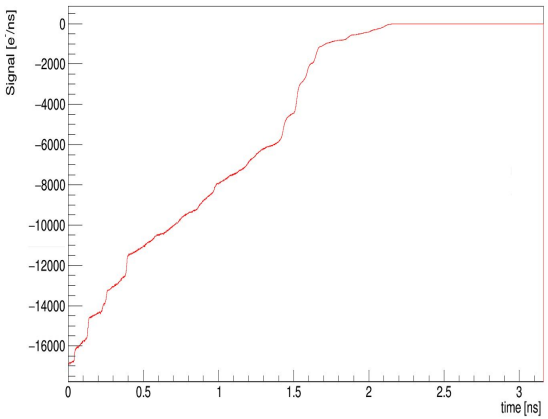
Number of electrons produced per particle crossing

Infinite pad with a uniform electric field

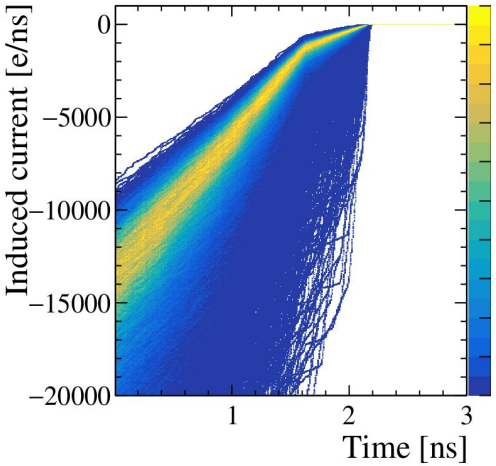
- **Uniform weighting field E_w=1/thickness**



Signal from one particle crossing

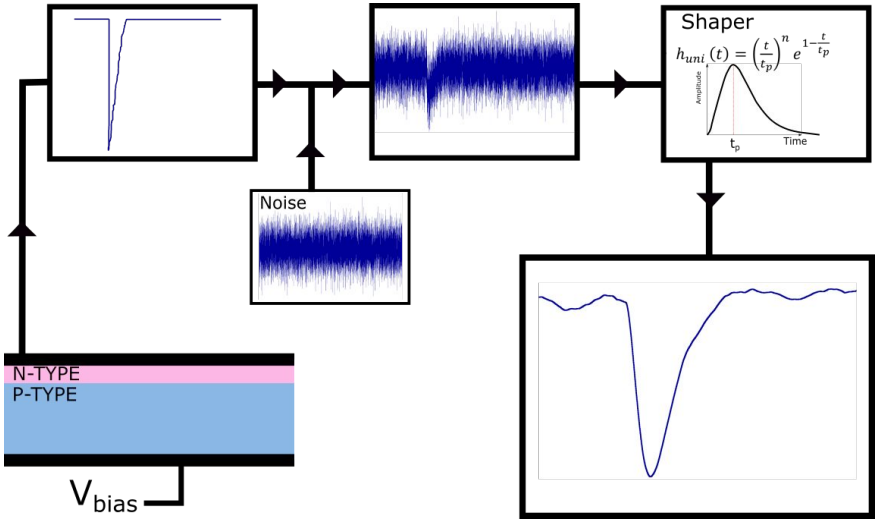


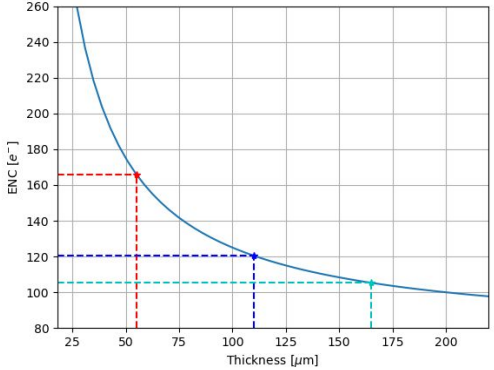
10000 superimposed plots of signals from one MIP



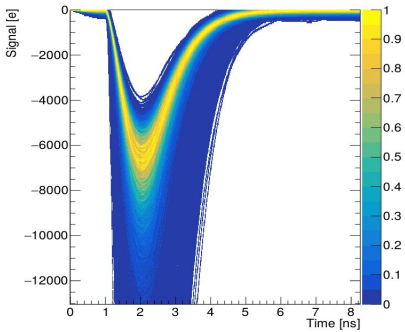
Signal from a charge sensitive amplifier

- White noise of a pixel detector is added to the induced current.
  - ENC is based on measurements from Timepix3
  - Noise: ENC(d)=75+5000/d [e^-]
- The output signal is a convolution of the shaper and the induced current with noise
  - Shaper: t_p = 0.5ns, n=1





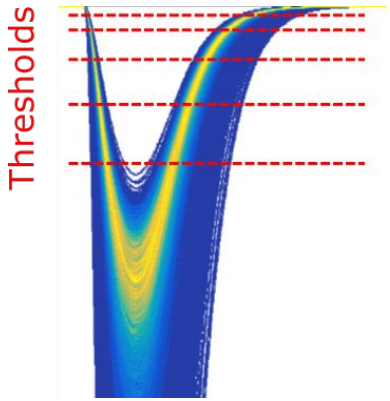
Noise model of Timepix3

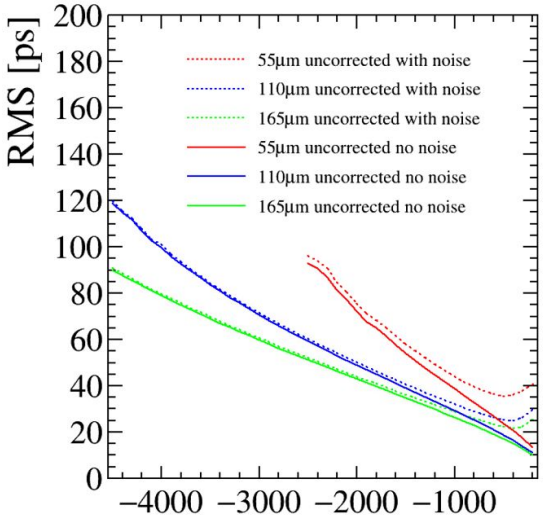


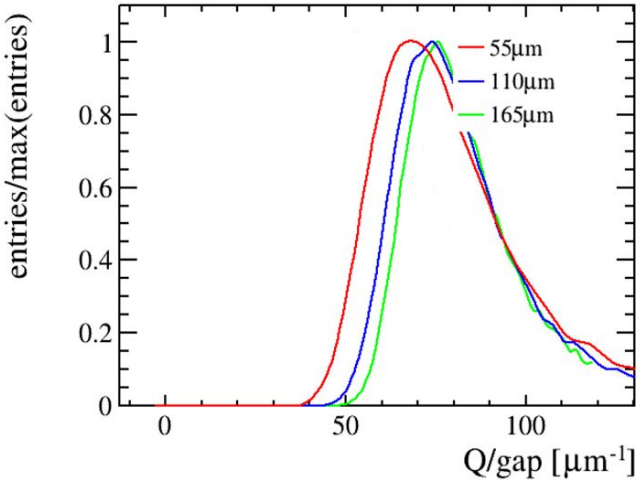
10000 superimposed shaped signals.

Time resolution of pad simulations

- Threshold scan: For a given threshold, the RMS of the threshold crossing times is evaluated.
- Threshold scan shows a larger RMS for the thinner sensors
  - Ramo theorem with uniform weighting field i=-vq/d
  - Relative charge deposition spread is larger for thinner sensors.

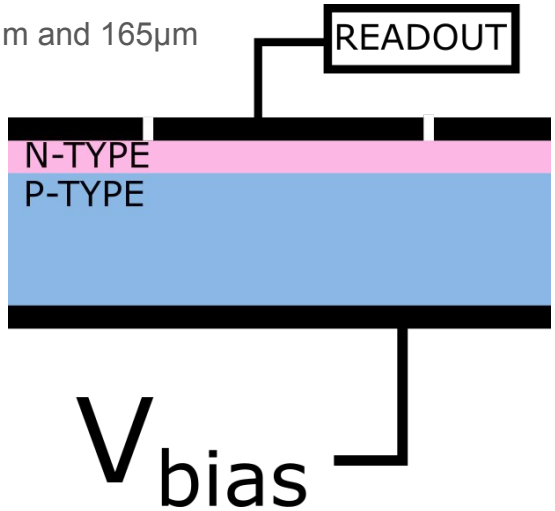




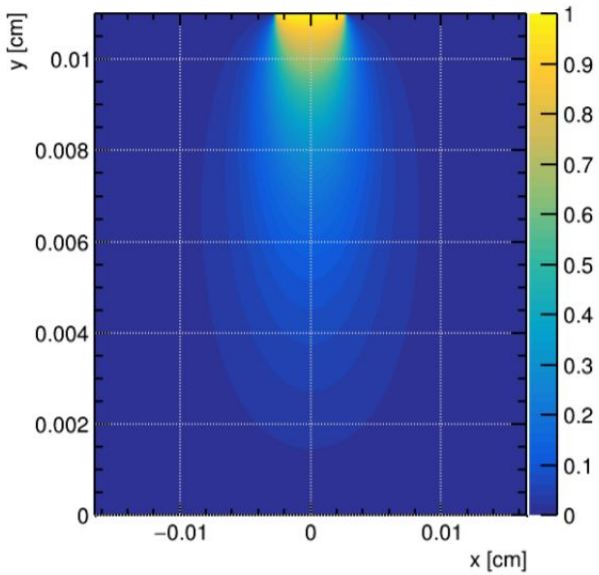


Simulation of a pixel detector

- Weighting field changes
- Pitch is 55μm
- Charged particle enter the sensor at a random position within the pixel.
- Thicknesses simulated
  - 55μm, 110μm and 165μm



Weighting potential
of a pixel sensor

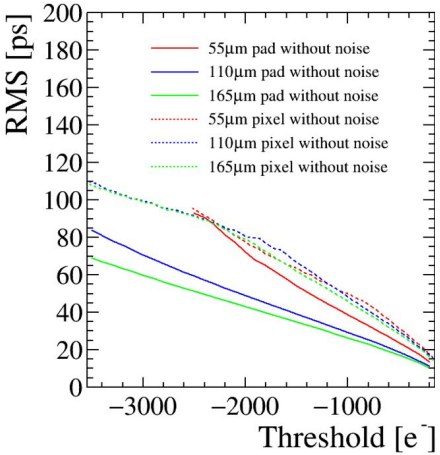


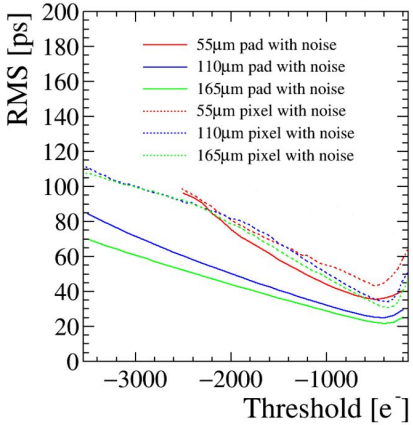
Time resolution of pixel simulations

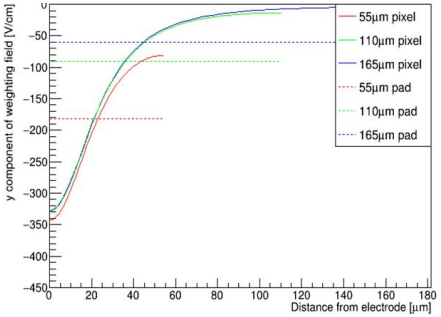
- Compared with the RMS of the simulated pad detector, the RMS of the simulated pixel sensors increases and coincides.

- The weighting fields behave similarly through the first pitch depth of the sensor, and is small after the pitch depth. It gives an “active region”

- Current explanation: The spread of the initial current reflects the spread of the charge deposition in the first pitch depth, which is about the same for thicknesses larger and equal than the pitch







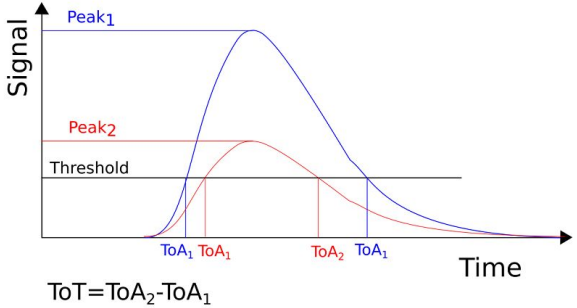
Weighting field, y-component of field through pixel center

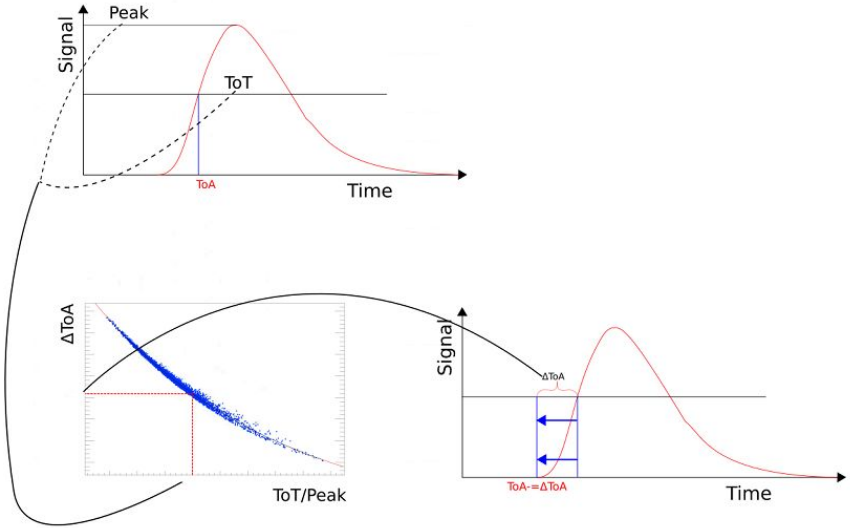
Time correction methods

- The threshold crossing times for shaped pulses are prone to time walk, which can be corrected.

- Time over threshold (ToT) correction and “peak magnitude correction” have been studied.

- 5000 pulses are used for calibration and 5000 pulses are used for testing

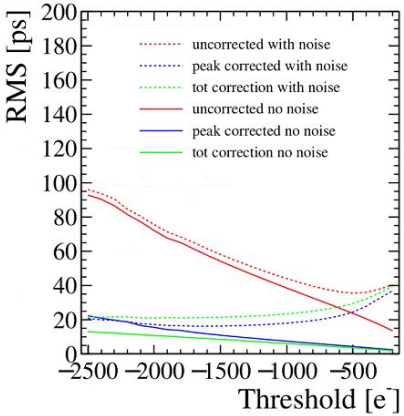




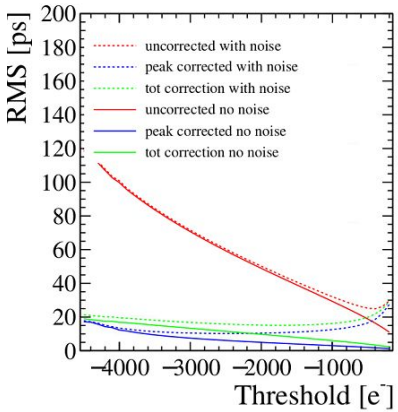
Preliminary results for time correction methods

- Time correction methods improve the time resolution in all simulated cases
- “Peak magnitude correction” gives a better RMS than the ToT correction when noise is present.

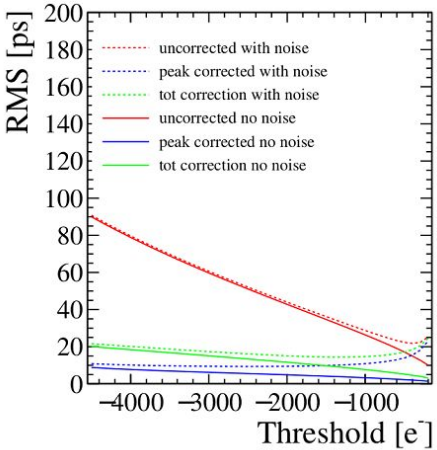
55µm pad



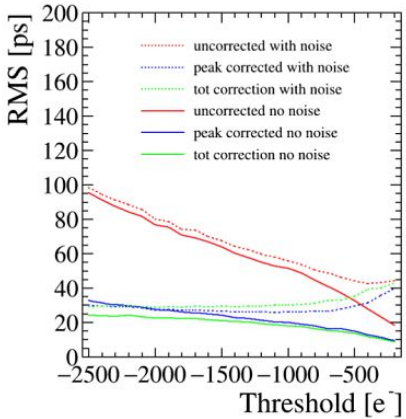
110µm pad



165µm pad



55µm pixel



NB! Different x-axis

Summary

- Simulations of simple planar silicon sensors with pad and pixel electrodes have been studied
- At the same electric field, the thicker pad detectors simulated gave a better time resolution than the thinner pad detectors.
  - The relative spread in charge deposition is larger for the thinner sensors
- The simulated pixel detectors with thicknesses equal to and larger than the pitch show comparable time resolution.
- Time resolution can be improved by time correction methods

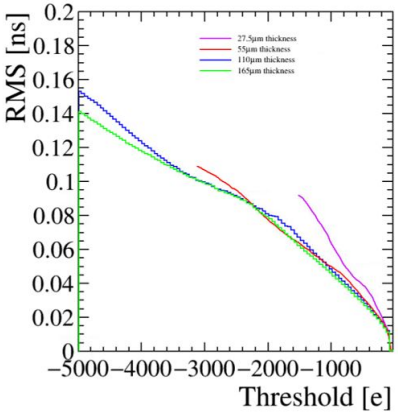
Future work (after submission of master thesis)

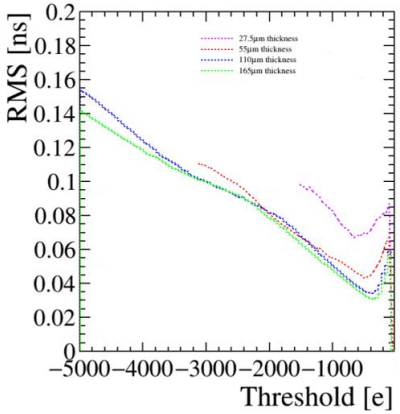
- Vary amplifier (shape, peaking time …)
- Import electric field and weighting field from TCAD
- Include radiation damage to simulations.

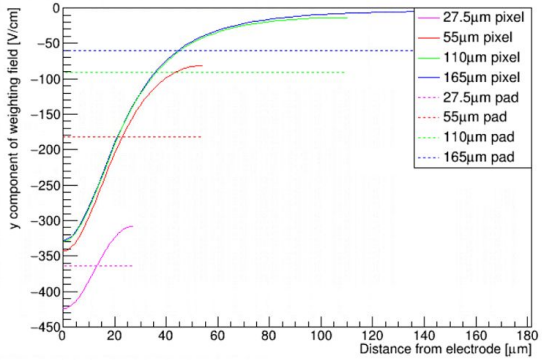
Thank you for you attention

Backup

Pixel detector resolutions simulations with thicknesses 27.5μm 55μm, 110μm and 165μm.







Induced current

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