AllPix2 simulation of ALPIDE: Chip response simulation status

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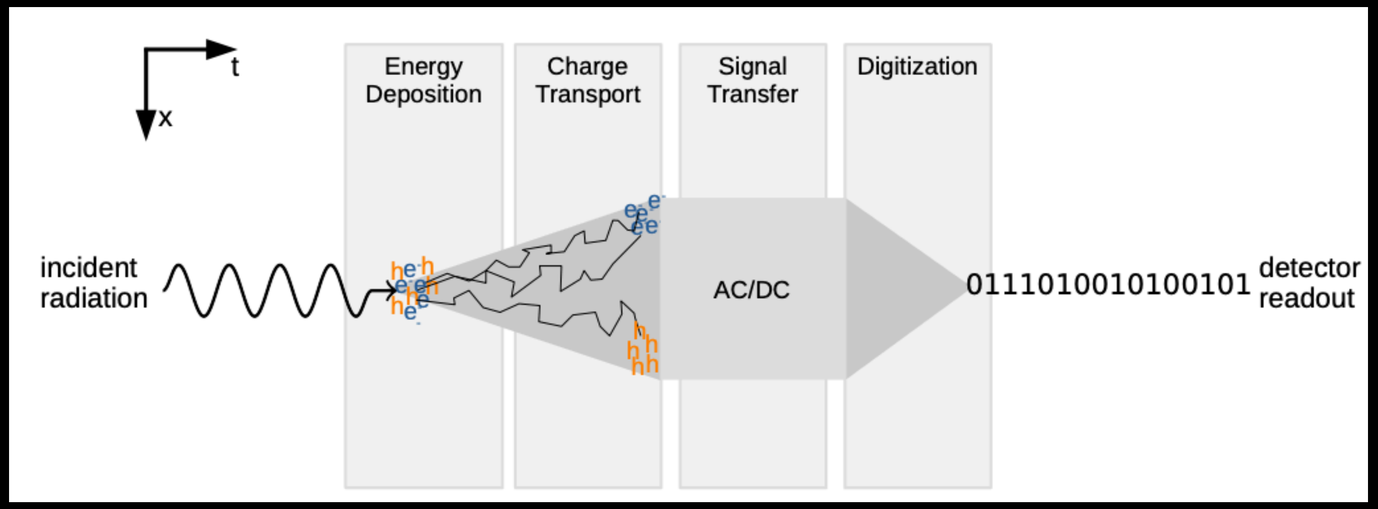
What is AllPix2?

- Generic simulation framework for silicon tracker and vertex detectors.
  - Very precise simulations of electric fields and microscopic properties of the silicon.
  - Package for simulating the performance of Silicon detectors.
    - Starting from ionizing radiation through the sensor and finishing with the digitization of hits in the readout chip.
  - Uses other packages
    - GEANT4: Simulating the deposition of charge carriers in the sensor.
    - ROOT: for producing histograms and storing the produced data.



★For our case:
- ★We will take the hits generated by GEANT4 simulation
- ★ Feed the hits (position, energy, particle type) to AllPix2 framework
- ★AllPix2 will give us the more realistic response of the silicon chips of ALPIDE given the electric field.

Check the response of ALPIDE

- A paper (2002:12602) written by the AllPix2 developers working on CMOS monolithic pixel chip - they compared the simulation with data.
  - We want to reproduce some of the results from the paper in order to see the response of our ALPIDE chips.
- Why are we interested in this?
  - This paper has the precise electric field (TCAD simulation) inside the monolithic chip - the field depends on the doping profile of the chip.
  - We are yet to have the precise doping profiles of the ALPIDE chips because of the TowerJazz proprietary restrictions (Noam is negotiating).
  - We don’t have the precise electric field yet
    - AllPix2 advised us to start with simple linear electric field up to a certain depletion depth and then use diffusion of charges.

Settings comparison in AllPix2

- The 2002:12602 Allpix paper used:
  - CMOS monolithic chip with thickness 100 um (25 um sensor, 75 um silicon substrate)
  - Pion beam with 120 GeV energy
  - Used more rigorous Generic propagation for charge transfer
    - Used TCAD electric field model, they have more accurate charge transport
  - Digitizer charge collection threshold 120e unless otherwise stated.

- I used:
  - ALPIDE with sensor thickness 25 um, chip thickness 75 um
  - Pion beam with 120 GeV energy
  - Played with depletion depth in the range 0.1 um to 25 um, bias voltage -0.1V to -12V, charge collection threshold 10e to 700e and integration time 10 ns to 500 ns
  - Optimum setup with comparison with the paper
    - Bias voltage -0.2 (*not very realistic for practical purpose*).
    - 20 um depletion depth.
    - Digitizer charge collection threshold 120e unless otherwise stated.
    - Charge collection integration time 15 ns
    - Less rigorous projection propagation.

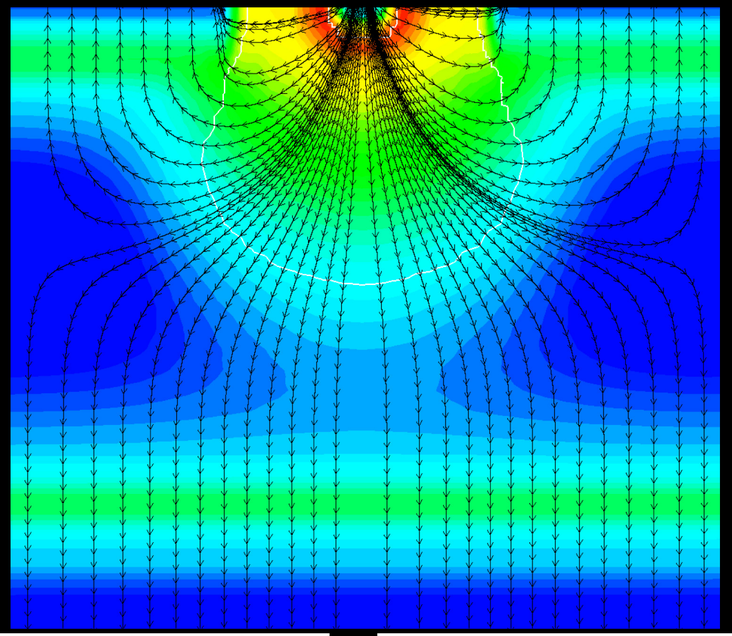
Disclaimer

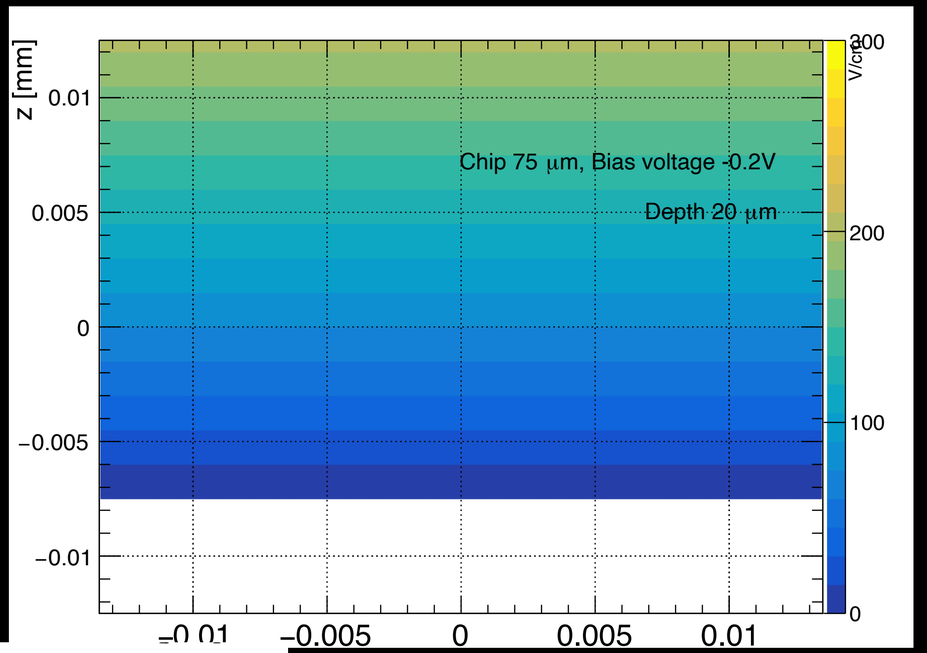
- The -0.2V bias voltage is unrealistic.
  - Just to see if the ALPIDE behavior from the AllPix2+ALPIDE paper can be reproduced with the existing degrees of freedom with AllPix2.
- In the latest release, AllPix2 has added option for custom electric field (a ROOT::TF3 read as a string).
  - This will help us setting more realistic electric field.
  - We tested this and this option has a bug.
    - Bug report submitted to AllPix2.
- Once the bug is fixed, the simulation will have a large impact on the performance of the sensor and hence also on everything which follows.

Electric field

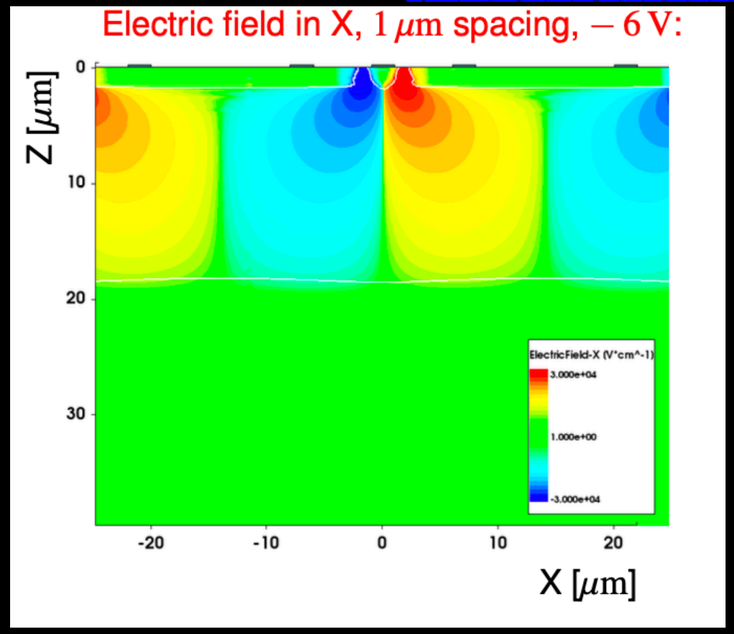
TCAD electric field

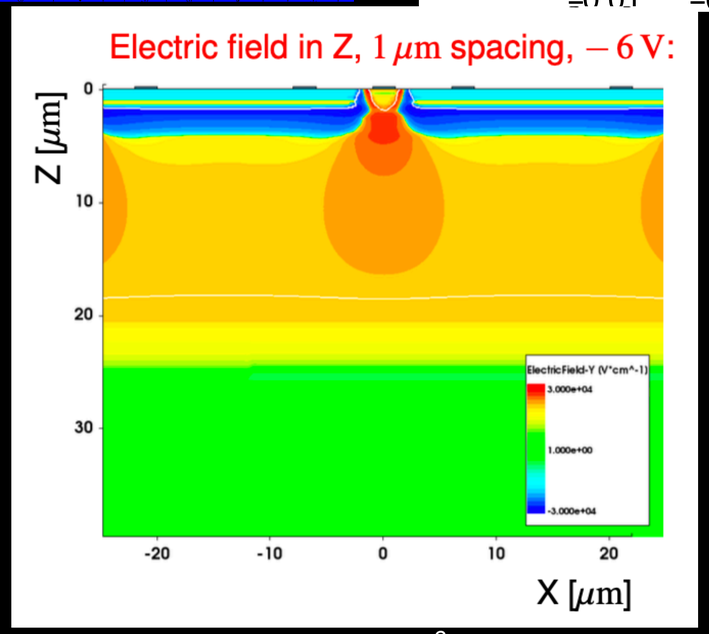
The paper does not give the meaning of the color.





My simulation, Bias voltage = -0.2V, depletion depth = 20 um

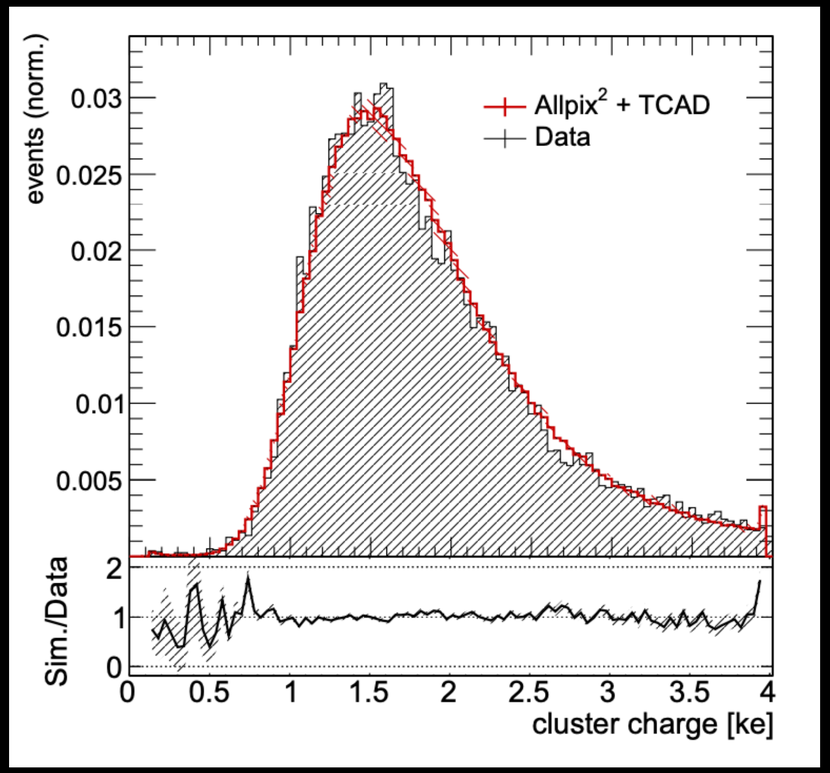




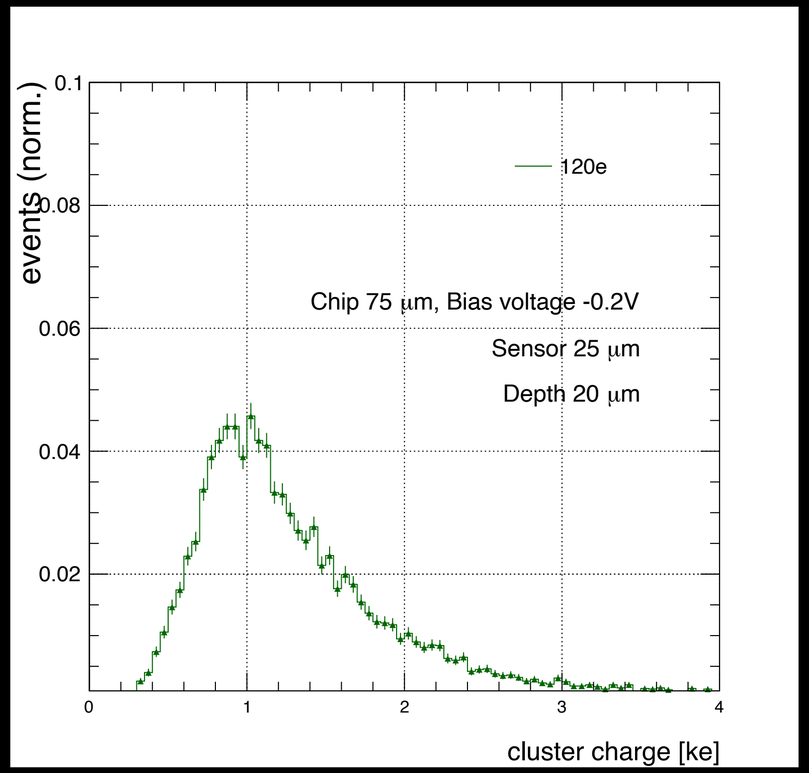
We found similar looking field (from TCAD) with axes labels from CERN-THESIS-2018-202

Comparison of cluster charge

Result from the paper



My simulation, linear scale

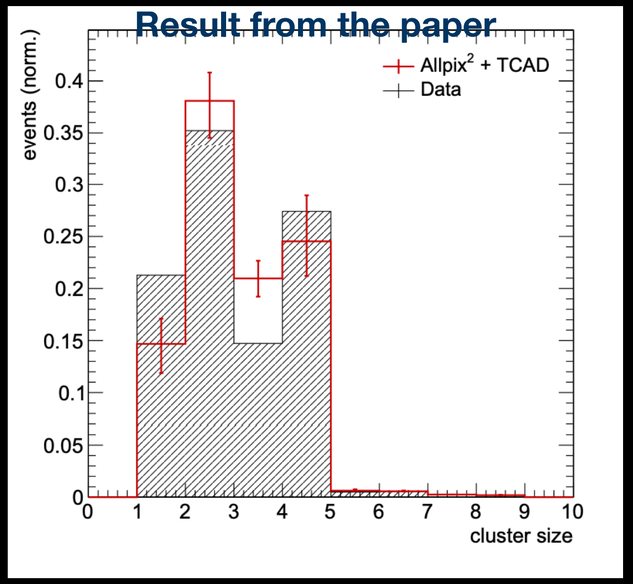


Note the Y axis range

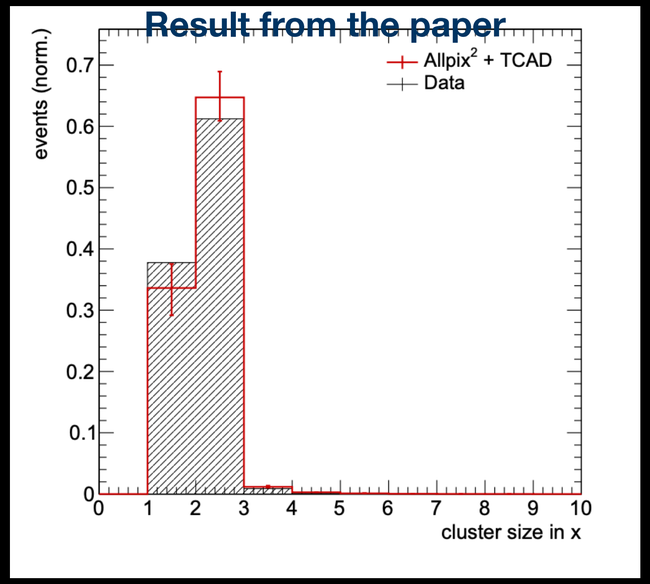
Cluster charge is consistently lower in my simulation. The peak is around 1 ke for my case, where as for the paper, the peak is at 1.5 ke.

Comparison of cluster size

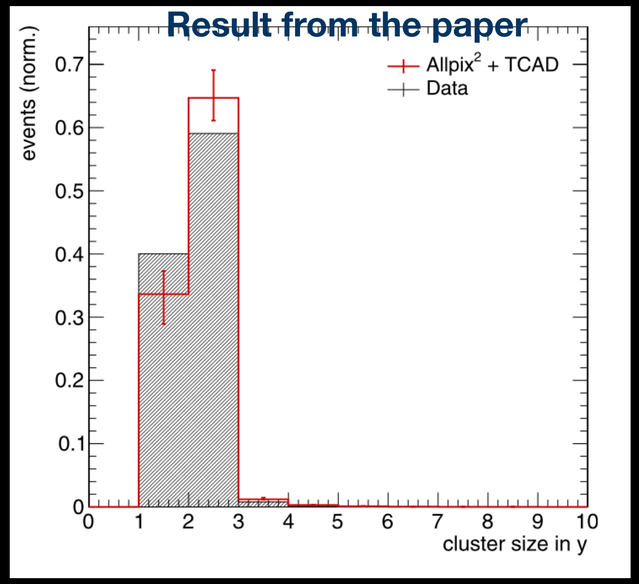
Result from the paper



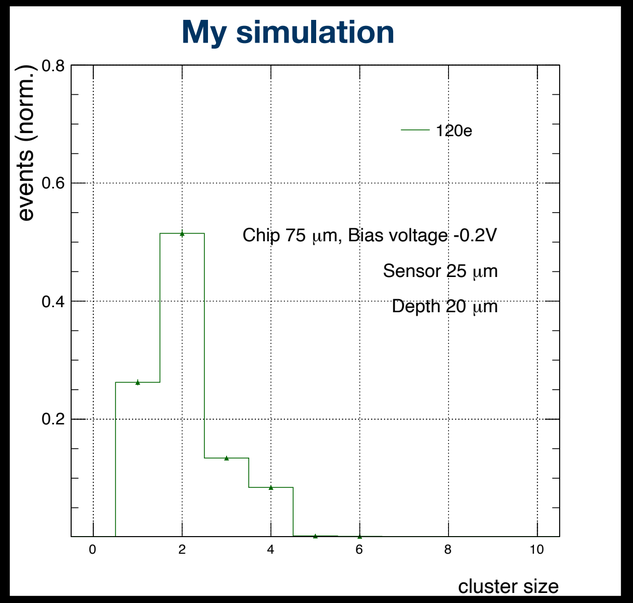
Result from the paper



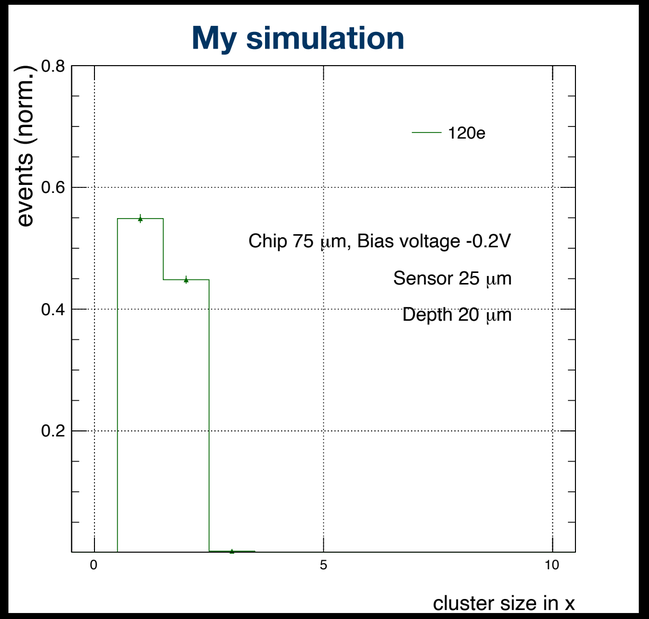
Result from the paper



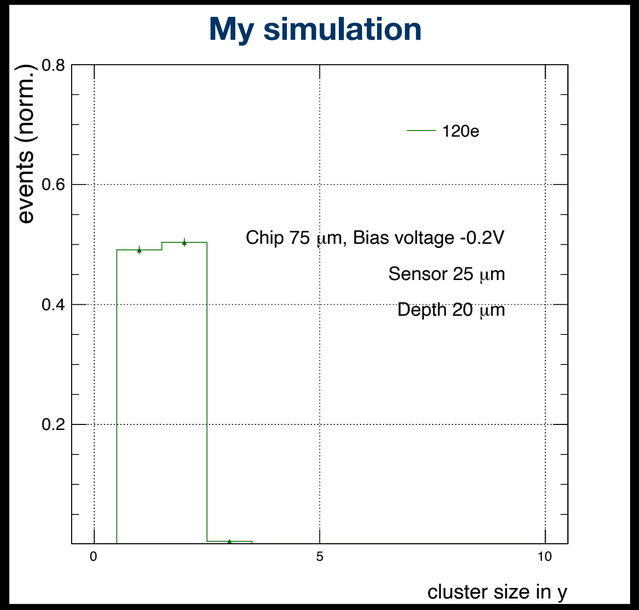
My simulation



My simulation



My simulation

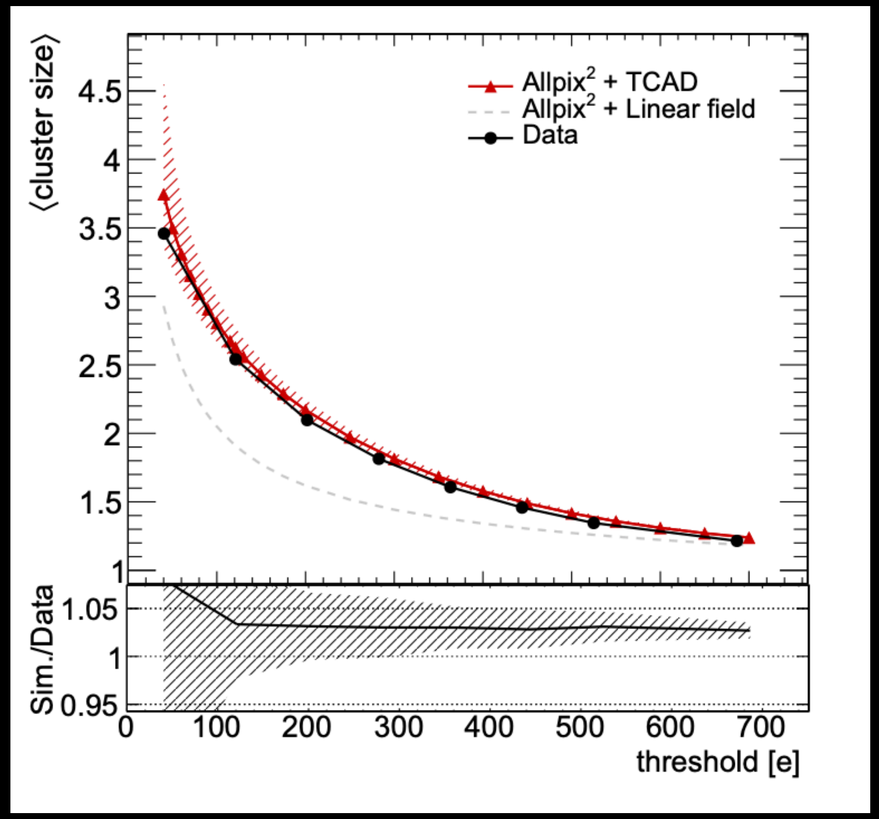


- My simulation has low cluster size, not much more than 4
- Less number of clusters with size >= 2

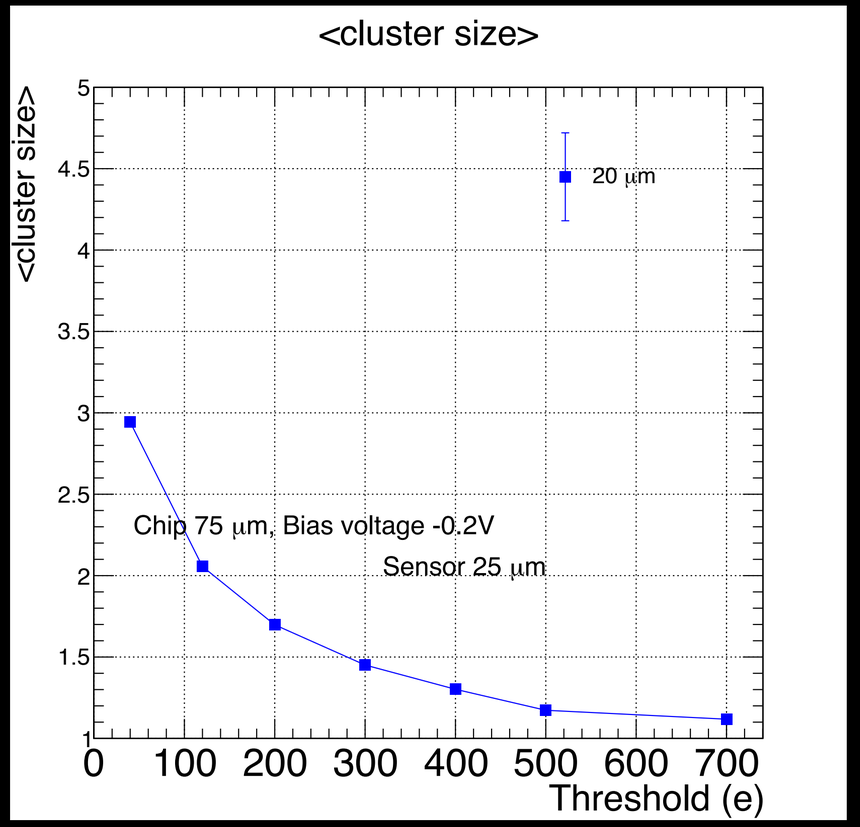
Note the Y axis range

Comparison of mean cluster size with threshold

Result from the paper



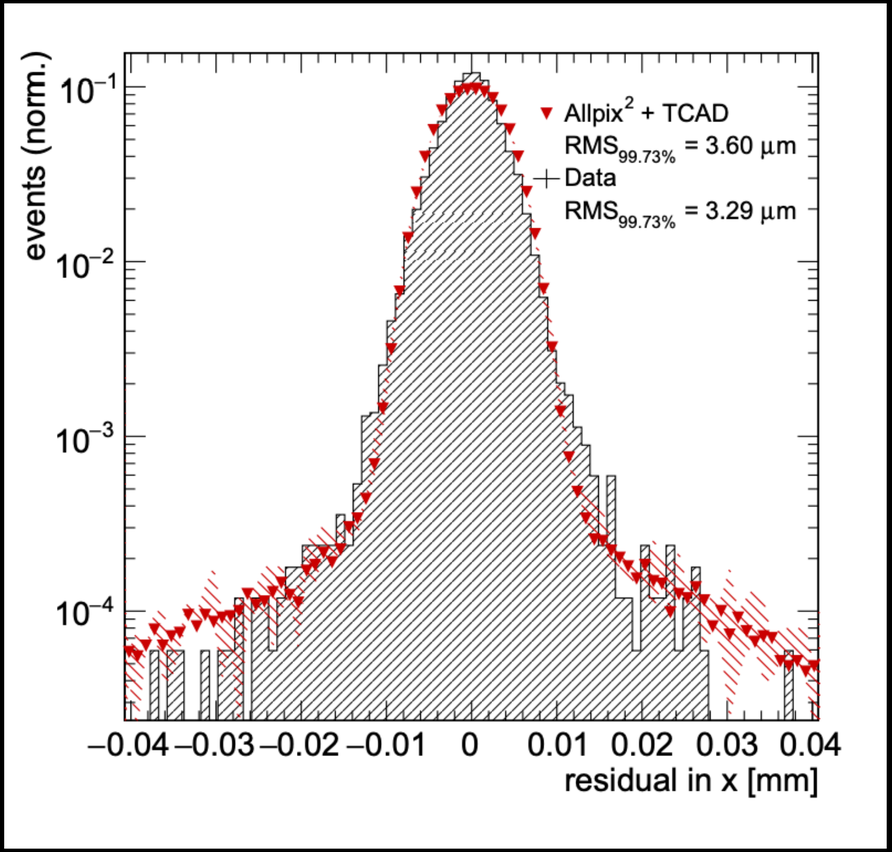
My simulation



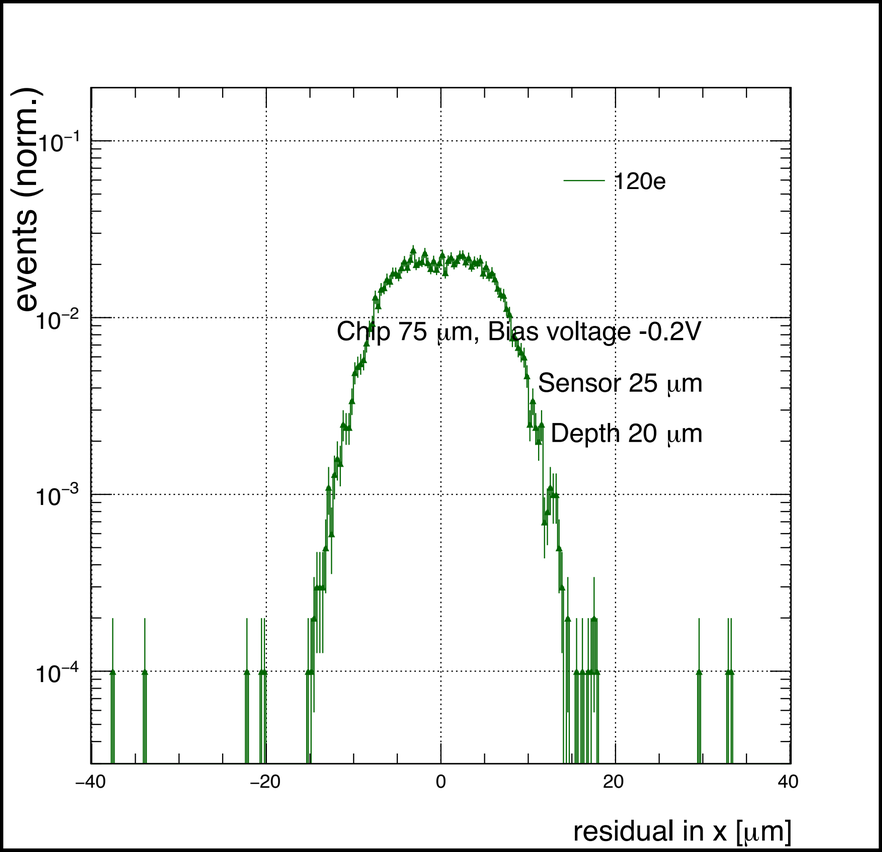
Cluster size is consistently lower in my simulation

Comparison of residual in x [mm]

Result from the paper

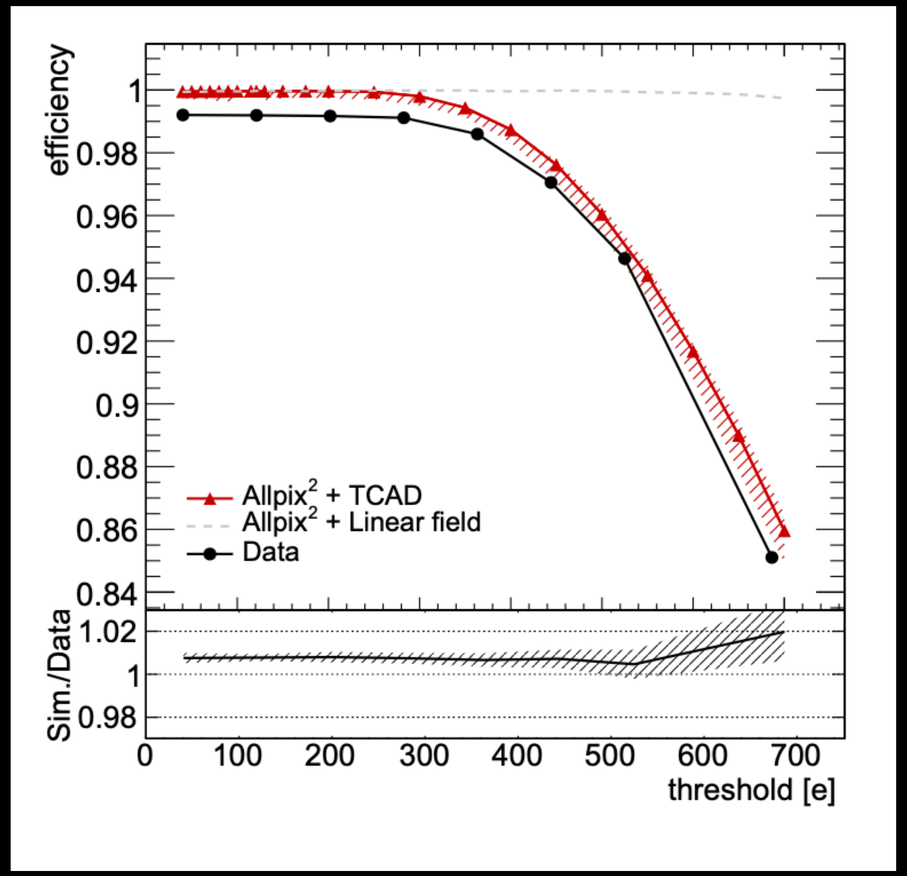


My simulation

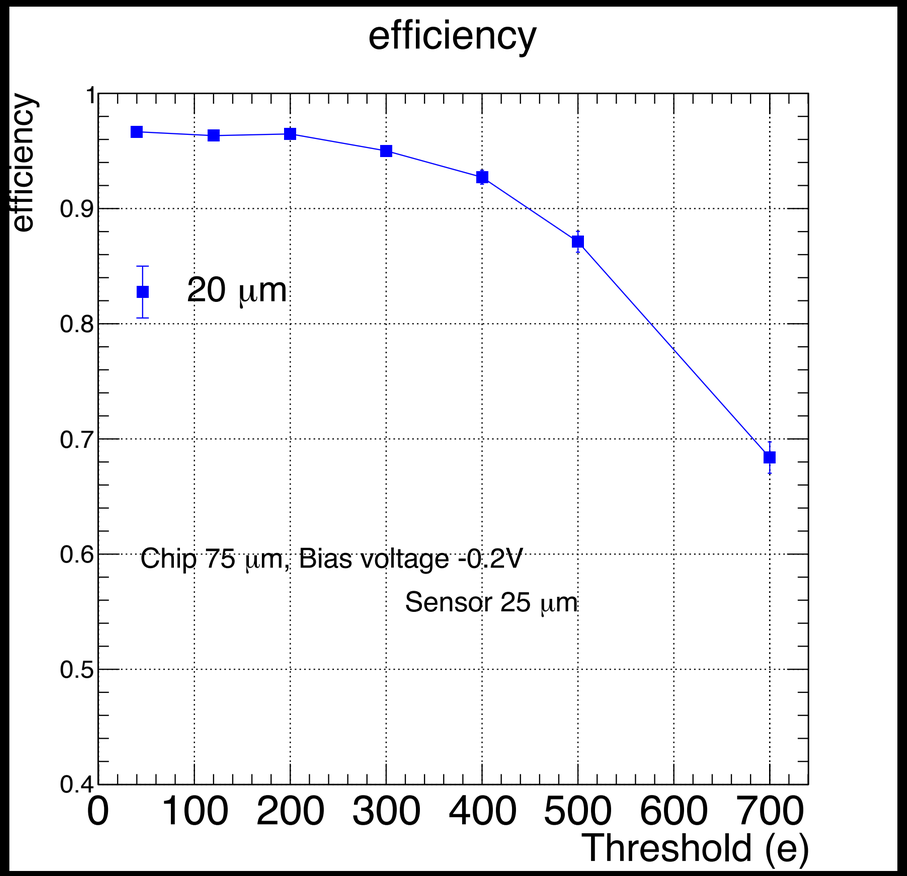


Comparison of efficiency with threshold [mm]

Result from the paper



My simulation

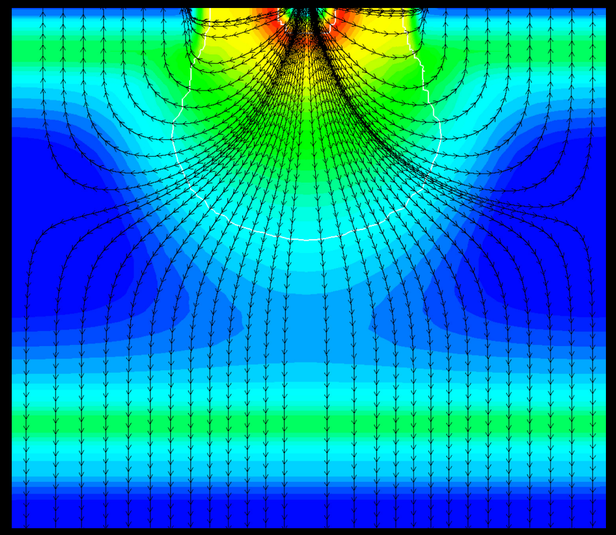


Note the Y axis range

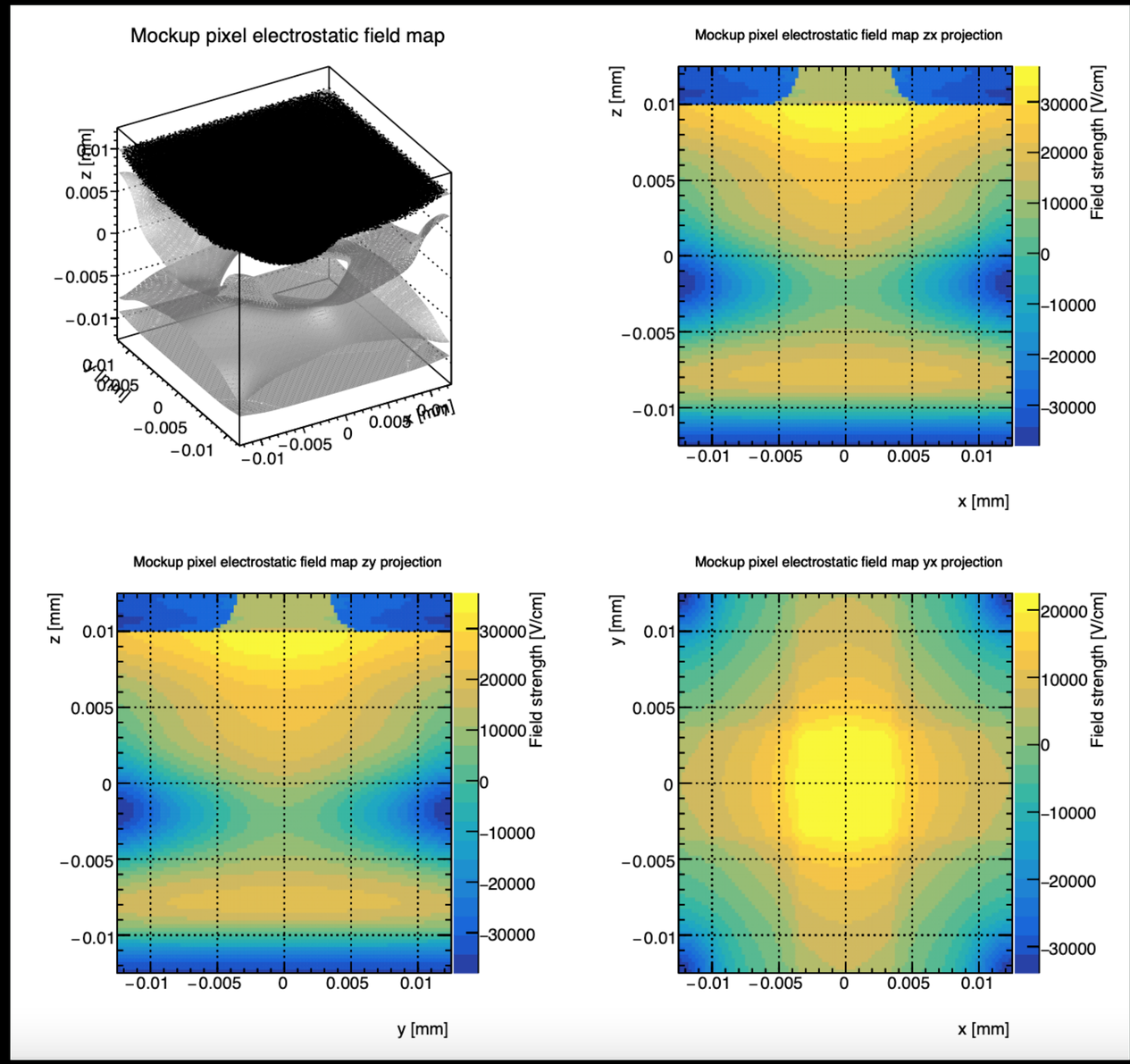
Efficiency is very low for higher charge collection threshold

Summary and To Do

- The result from my simulation is not matching with the AllPix2 paper result.
  - Main difference can be the electric field model.
- Noam came up with a function that mimics the TCAD electric field.
  - Working with this field, hope now we have better match.



TCAD electric field

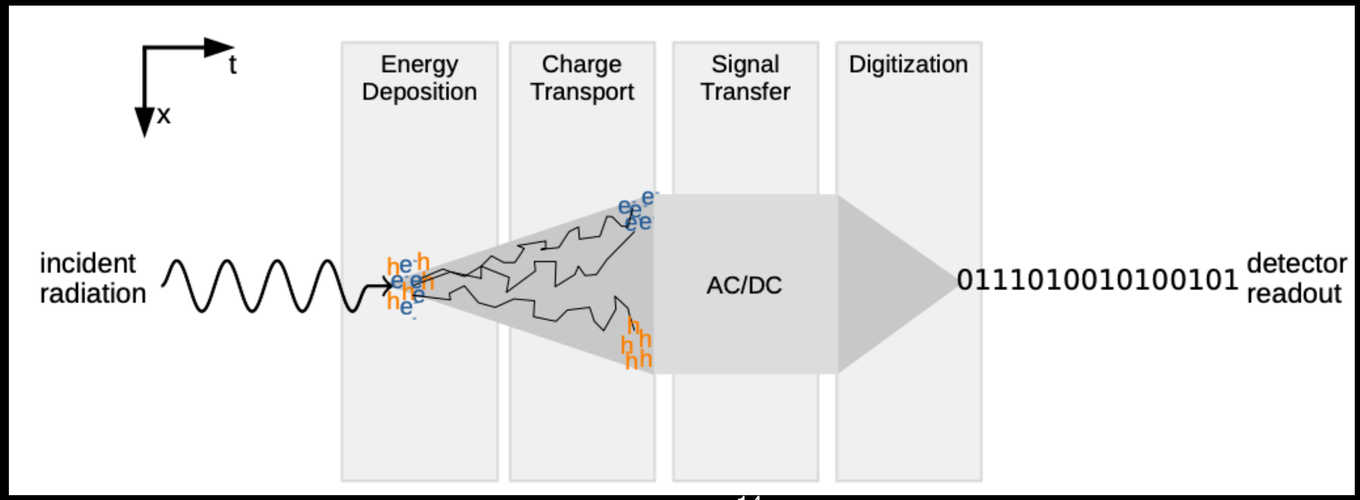


Prepared by Noam

Back up

The skeleton: Simulation configuration

- To use AllPix2, we need to first write the configuration file: tutorial-simulation.conf.
- This conf file has sequential module: each module has separate work to do.
  - GeometryBuilderGeant4/DepositionGeant4: When we want AllPix2 to simulate the event generation: we won't need them
  - DepositionReader: module to read from another input: we will use this to read from Sasha's file.
  - ElectricFieldReader: The electric field applied on the silicon sensors. They can be constant, linear or even more complex.
  - GenericPropagation: Propagation of electron and hole (drift) in the sensors after generated by the radiating particle.
  - SimpleTransfer: combines individual propagated charges to form a set of charges on the sensor
  - DefaultDigitizer: translates collected charges into digitized signal proportional to the input charge
  - DetectorHistogrammer: provides large collection of output data.



AllPix2 config file

```
[Allpix]
number_of_events = 1000
log_level = "WARNING"
detectors_file = "tutorial-geometry.conf"
model_paths = "/storage/agrp/arkas/
AllPixGrid/Threshold"
random_seed_core = 1234
root_file =
“modules_TrackerLayer1_Threshold120e_
Depth20um_Iteration1.root"

[GeometryBuilderGeant4]

[DepositionGeant4]
physics_list = "FTFP_BERT_EMY"
enable_pai = true
particle_type = "Pi+"
source_type = "beam"
source_energy = 120GeV
source_position = 0um 0um -200um
beam_size = 0.5mm
beam_direction = 0 0 1
number_of_particles = 1
max_step_length = 1.0um
```

```
[ElectricFieldReader]
model = "linear"
bias_voltage = -0.20V
depletion_depth = 20um
output_plots = 1

[ProjectionPropagation]
temperature = 293K
charge_per_step = 10
integration_time = 15ns
diffuse_deposit = true
output_plots = 1

[SimpleTransfer]
output_plots = 1

[DefaultDigitizer]
electronics_noise  = 10e
threshold          = 120e
threshold_smearing = 5e
output_plots = 1


[DetectorHistogrammer]
output_plots = 1

[ROOTObjectWriter]
file_name = “data.root”
```