Probability distribution maps of deposited energy with sub-pixel resolution for Timepix3 detectors

Pinelopi Christodoulou[1,2,3*], Jerome Alozy[1], Rafael Ballabriga[1], Michael Campbell[1], Erik Heijne[1,2], Xavier Llopart[1], Adithya Pulli[1], Viros Sriskaran[1], Lukas Tlustos[1,2], Jan Zemlicka[2]

[1.] EP Department CERN, [2.] Institute for Experimental and Applied Physics, Czech Technical University of Prague, [3.] Faculty of Biomedical Engineering, Czech Technical University in Prague

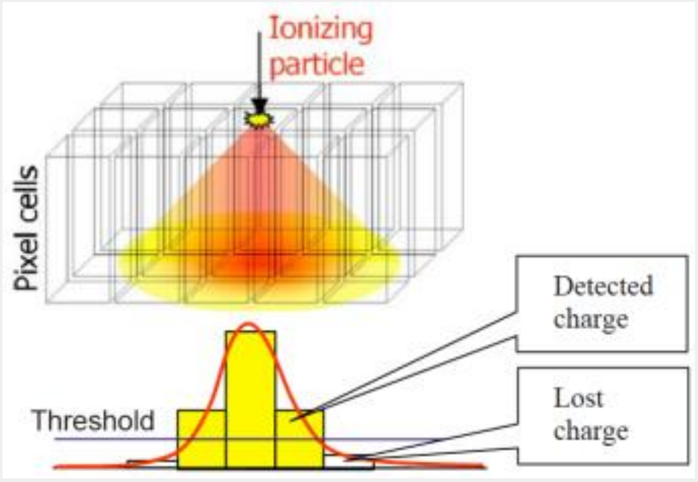
*pinelopi.christodoulou@cern.ch

INTRODUCTION

1. Timepix3 detectors

Timepix3 is a hybrid pixelated semiconductor detector with 256x256 pixels of 55μm pitch. (T. Poikela et al. 2014)

2. Charge Sharing



Primary ionization created by the incoming particle spreads out during the charge collection process resulting in clusters. This effect results in lost charge that affects both the spatial and the energy resolution of the detector.

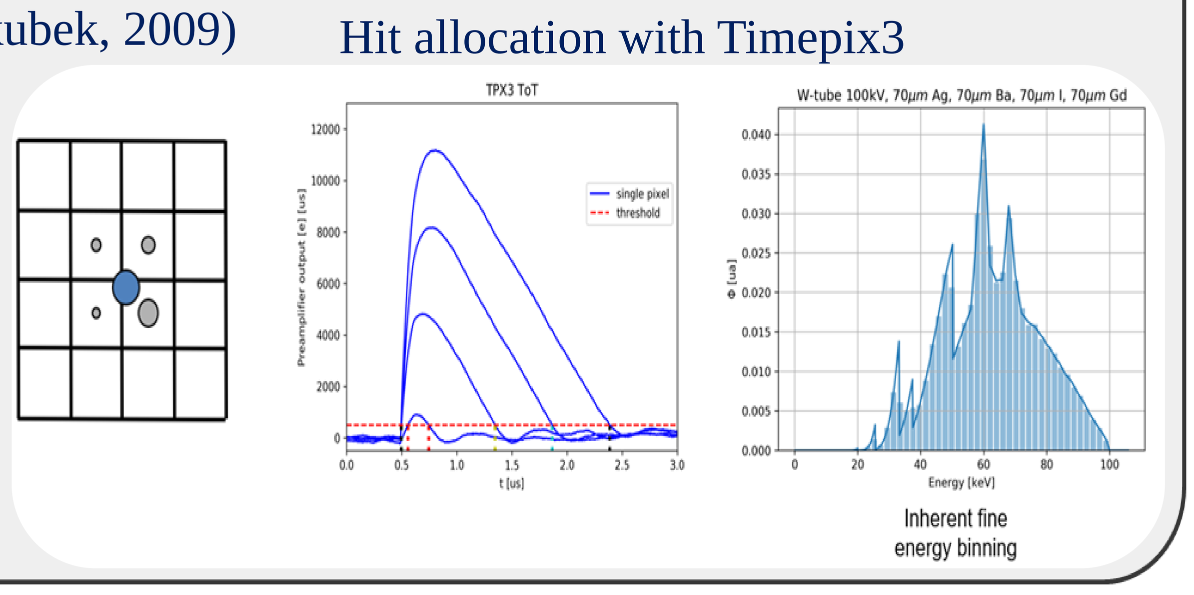
(Jakubek, 2009)

3. Spectroscopic X-ray Imaging with Timepix3:

Standard CT Scans → utilize energy integrating detectors

Spectral CT Scans → utilize photon counting detectors

Hit allocation with Timepix3

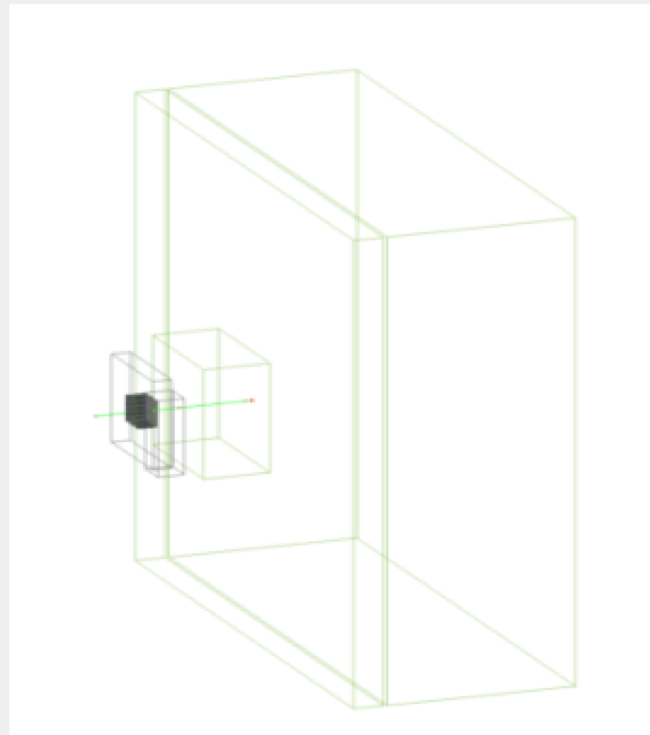


METHODOLOGY

Simulation Tool:
Allpix squared: simulation framework for tracker and vertex detectors written in modern C++. (S. Spannagel et al. 2018)

- Simulation of deposition maps for single Silicon pixel for wide range of monochromatic X-ray beams.
- Center of mass calculation of the position of hit utilizing the energy of the interaction as weight.
- Inversion of the deposition maps to generate probability maps.

Geant4 depiction of Timepix3



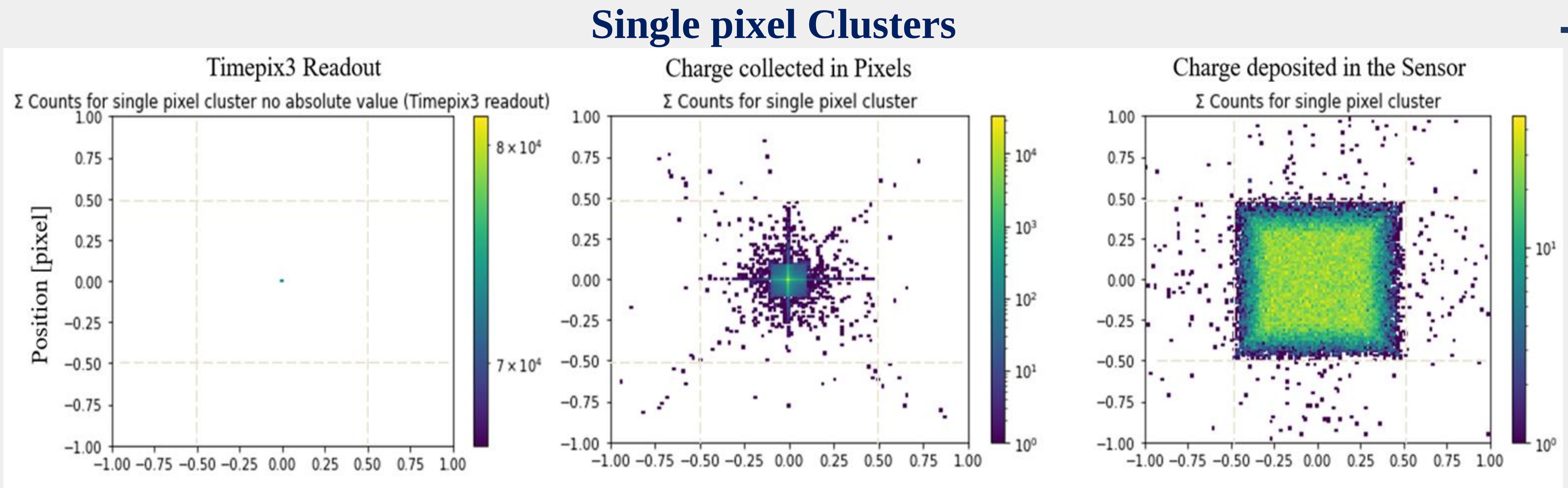
OBJECTIVES

1. Study the limits of Timepix3 in spectroscopic X-ray imaging with data driven architecture.
2. Generation of Probability maps: for the initial interaction position and initial energy. The goal is improved energy and spatial resolution.

RESULTS

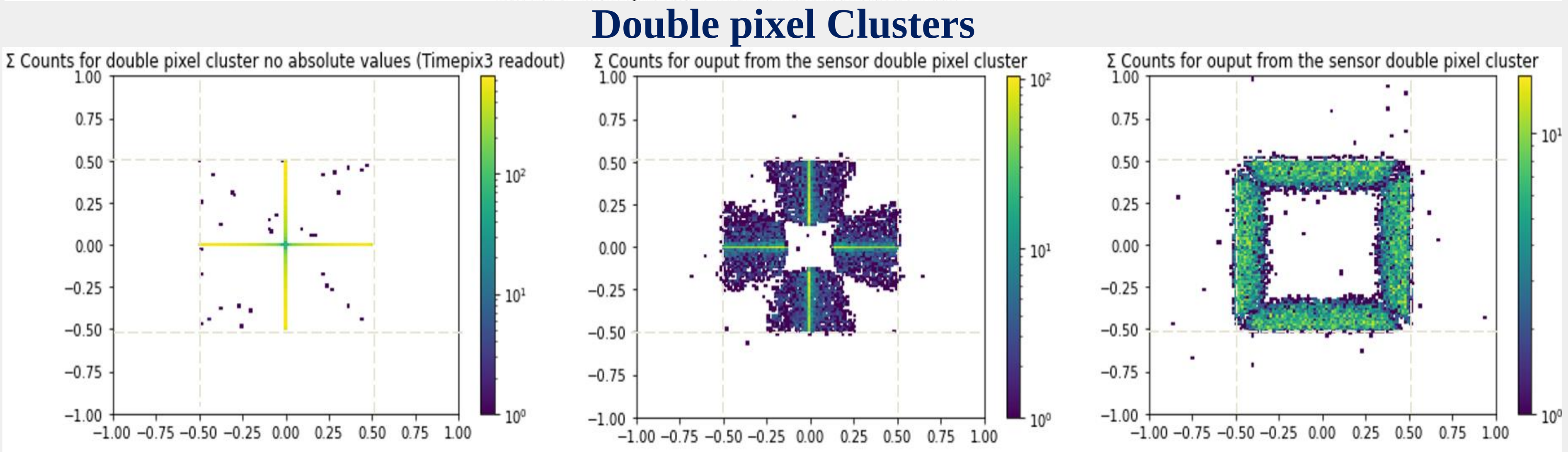
Deposition maps for different cluster types

Single pixel Clusters

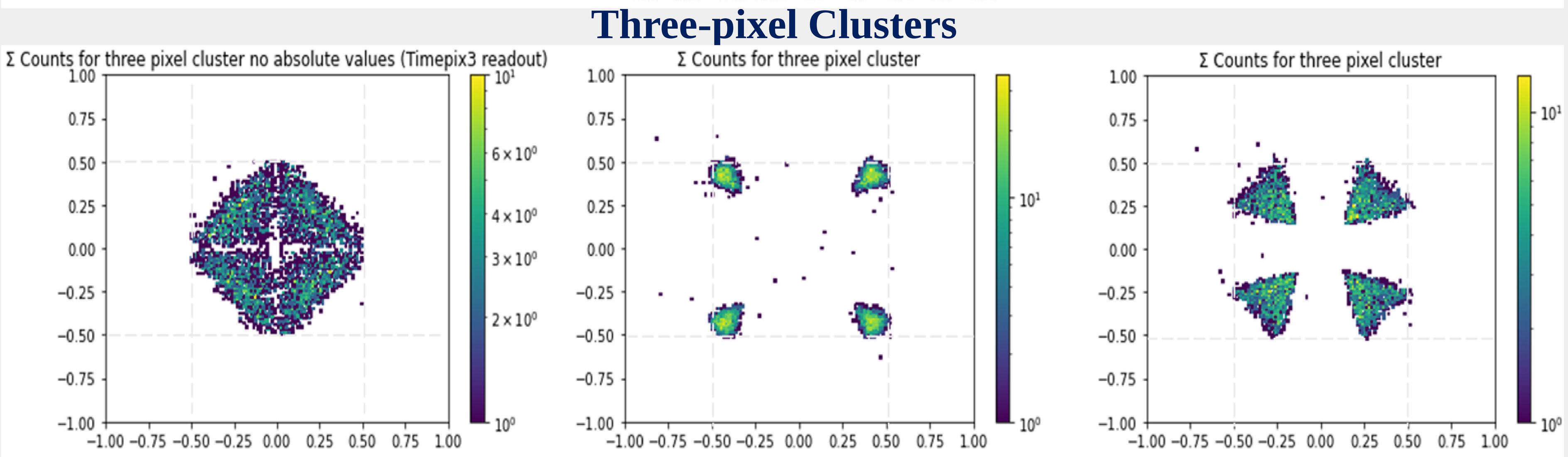


Borders of the pixel are shown with the dashed lines

Double pixel Clusters



Three-pixel Clusters



Four-pixel Clusters

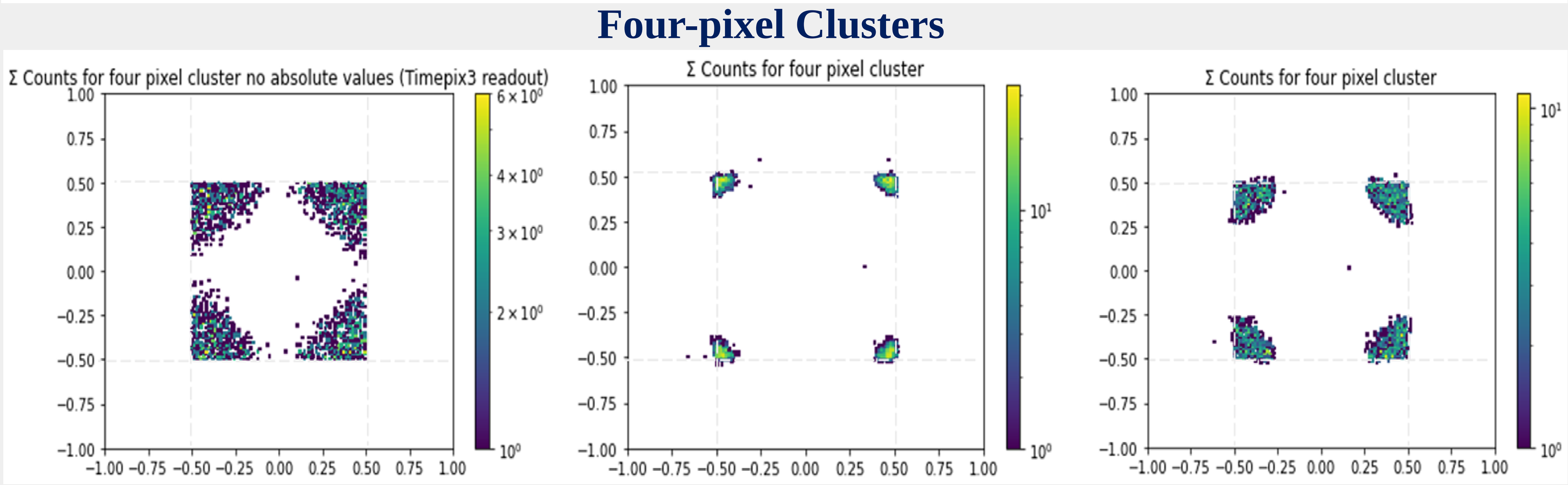


Figure 1: the borders of the pixel are marked with dashed lines.

In Figure 1, the deposition maps for the position of centre of mass (cms) of the simulated hits can be seen for different cluster sizes for the different simulation output files.

In Figure 1, from left to right the different output files from the simulation are compared. First, is the output of the readout of Timepix3 after the process of the simulated hit from the electronic chain. The per pixel ToT is used to calculate the cms of the detected cluster. The middle column shows the cms calculated from the charge collected in the sensor pixels. On the right side the position of the first interaction of the photon with the sensor is plotted. From inversion of these deposition maps one can derive the probability map for the initial position for a given detected pixel cluster cms. In Figure 2 the subpixel analysis of the double pixel cluster is presented.
In Figure 2, the subpixel events for the output of the Timepix3 readout were matched for the output of the simulated charge that was deposited in the sensor. Then the probability of these events being located in the particular subpixel region was calculated.

Probability maps: Initial Position
Double pixel cluster subpixel analysis

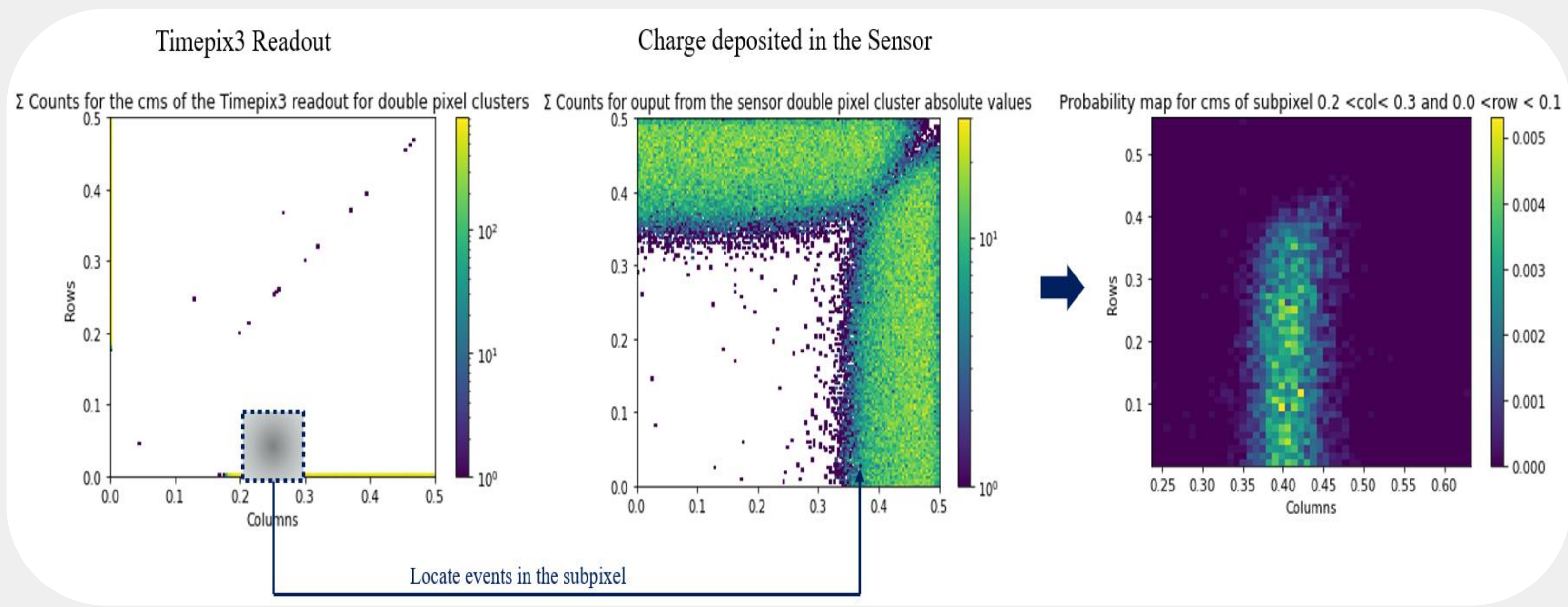


Figure 2

The energy spectra are distorted due to the effect of charge sharing, leading to sub-threshold losses in the cluster, which causes asymmetric distortion of the detected energy spectra. For example, for detected energy of 50keV there are contributions from the tails of other energies. In Figure 4 the measured probabilities that the 50 keV is generated by other energies is presented. Both Figures 3 and 4 are created for single pixel hits. The similar procedure is repeated for a wide range of monochromatic energies.

Probability maps: Initial Energy

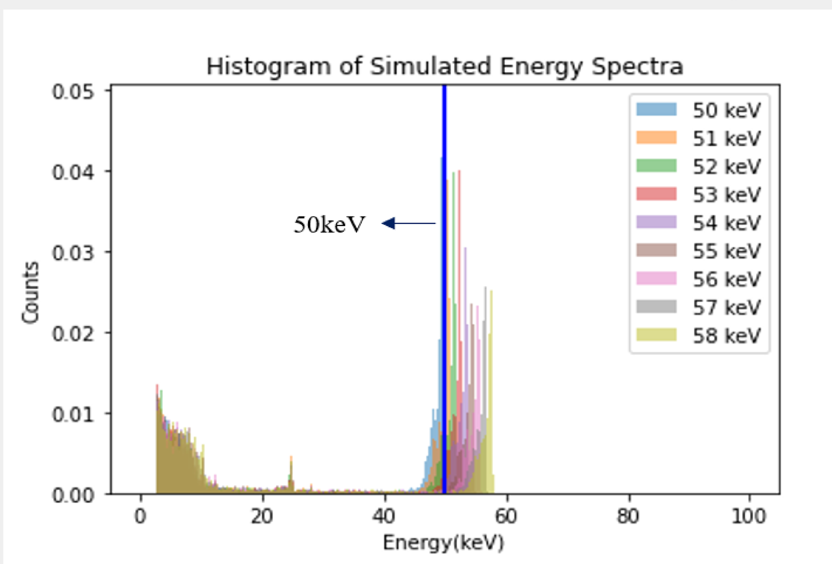


Figure 3

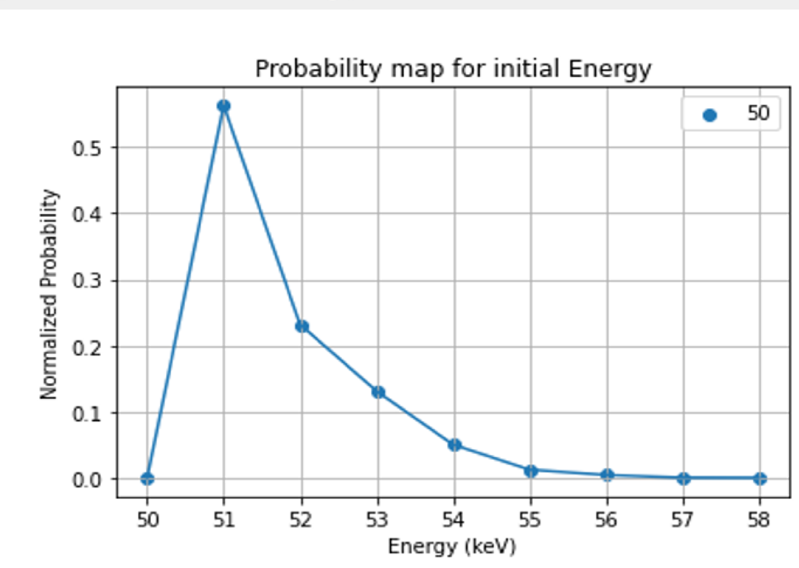


Figure 4

CONCLUSIONS

1. The offset between the simulated signal from the Timepix3 readout and the simulated output from the sensor for single- and double-pixel clusters is significant.
2. The inversion of the deposition maps lead to the generation of probability maps for the actual initial position of the interaction of the hit and its initial energy.

Next steps:

- Experimental verification of the probability maps
- Calculation of the probability maps for different detector materials.

REFERENCES

1. T. Poikela et al., Timepix3: a 65k channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout, Journal of Instrumentation 9 (2014), pp. C05013-C05013.
2. Jan Jakubek, Energy-sensitive X-ray radiography and charge sharing effect in pixelated detector, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 607, Issue 1, 2009, Pages 192-195, ISSN 0168-9002.
3. S. Spannagel et al., Allpix2: A modular simulation framework for silicon detectors, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 901 (2018), pp. 164-172.

ACKNOWLEDGMENTS

The authors acknowledge funding from the CERN Knowledge Transfer and the Medpix3 collaboration.