Poster Number
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X-CSIT: A toolkit for simulating 2D pixel detectors

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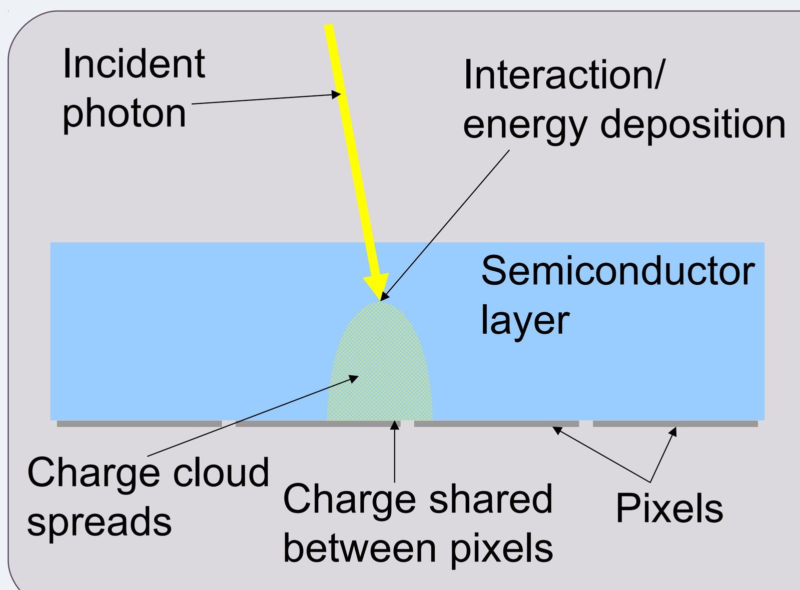
Abstract

X-CSIT (X-ray Camera SImulation Toolkit) is a new, modular toolkit for creating simulations of 2D X-ray pixel detectors currently in development. The toolkit uses three sequential simulations of detector processes including photon interactions, electron charge cloud spreading with a high charge density plasma model and many electronic components used in detector readout. In addition, because of the wide variety in pixel detector design, X-CSIT has been designed as a modular platform so that existing functions can be modified or additional functionality added easily if the specific design of a detector demands it. X-CSIT is under development at UCL for European XFEL, and will be used to create simulations of the three bespoke 2D detectors at European XFEL, AGIPD, LPD and DSSC. These simulations and X-CSIT will be integrated into the European XFEL software framework, Karabo, and through that be available to users to aid with planning of experiments and analysis of data. In addition X-CSIT will be released standalone publicly for other users, collaborations and groups to create simulations of their own detectors.

2D Pixel Detectors



Pixel detectors use a semiconductor sensor layer to absorb scattered X-ray light.

This photon energy is absorbed as freed electron-hole pairs, which move towards the pixels under the reverse bias of the sensor.

The electrons are collected and moved as charge to an electronic circuit.

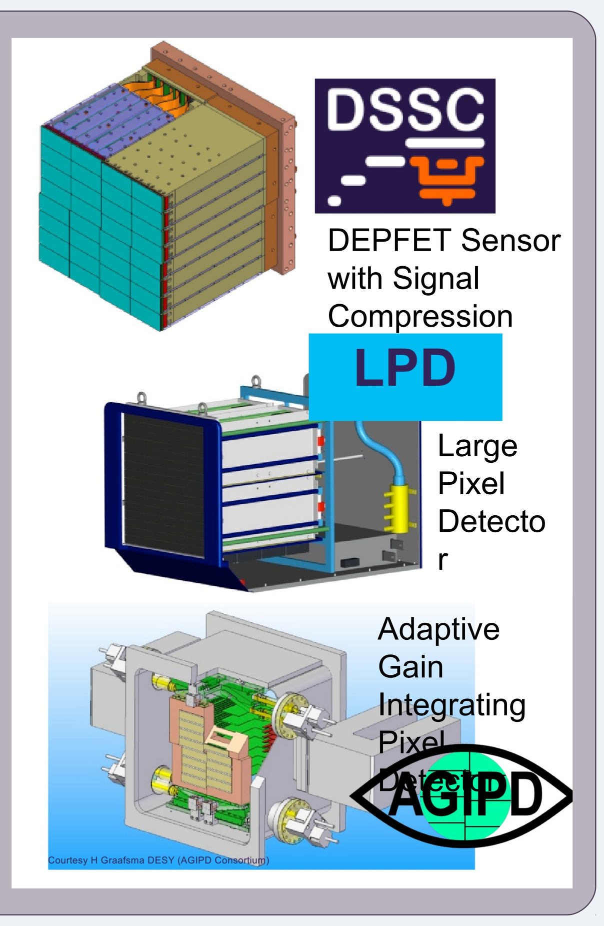
Detectors at European XFEL

XFEL will use a range of 2D pixel detectors for imaging, including three built specially for the project: DSSC, LPD and AGIPD.
These three detectors will all feature

- 1024x1024 pixels
- 4.5 MHz capture
- Dynamic energy range and single photon sensitivity

However despite similar design goals they still differ substantially

- Pixel size and shape (200μm to 500μm, square and hexagonal)
- Total dynamic range (6000 1 keV photons to $10*10^5$ 12 keV photons)
- ASIC chip size (32*16 pixels to 256*128 pixels)
- Dynamic energy range profile and method



Objectives of X-CSIT

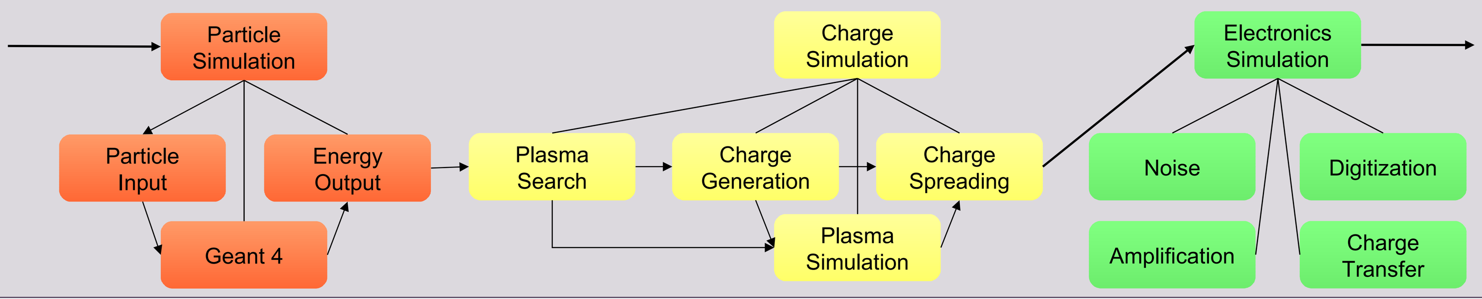
X-CSIT is designed to provide a single common simulation framework for the pixel detectors to be used at XFEL. These simulations will be important for understanding detector characteristics and helping XFEL users plan and analyse experiments.

X-CSIT must reconcile a desire for a common simulation with detectors that can differ substantially, it solves this by creating a modular tool kit for creating simulations that provides validated physics simulations dependent on user provided detector definitions. If X-CSIT does not simulate a specific detector design or layout, it is modular enough for code to be added or replaced.

X-CSIT and simulations of the XFEL detectors are being integrated into Karabo, the control, DAQ and processing framework at XFEL, where they will be available to users on XFEL's computer network. Integration into Karabo will include dependency on calibration data taken from the real detectors and output in the same format, allowing X-CSIT simulations to be slot into an analysis chain in place of a real detector. This will enable users at XFEL to test analysis pipelines with respect to detector performance before arriving to perform their experiments and after conducting experiments, X-CSIT simulations will help understanding measurements and detector uncertainties.

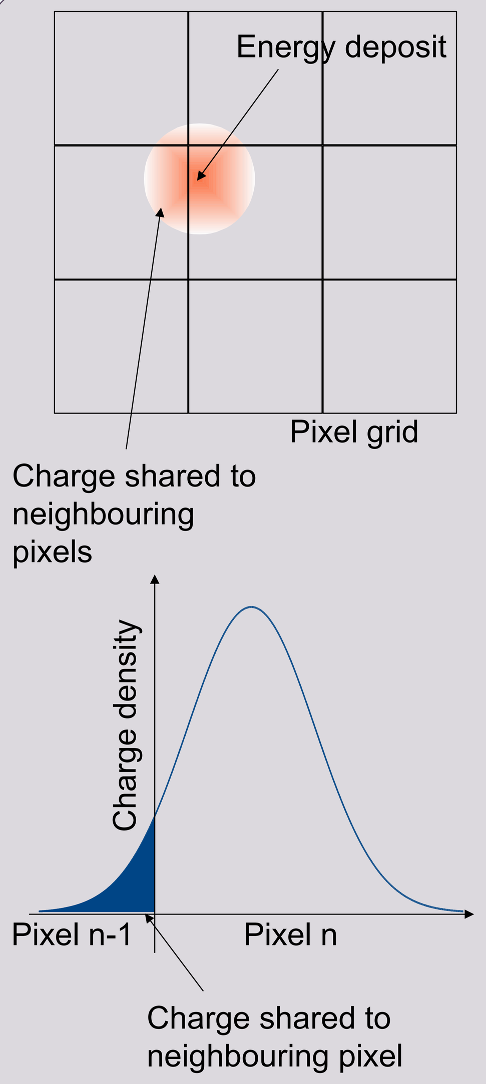
X-CSIT splits the simulation of semiconductor detectors into three stages

- A particle simulation of incoming photons and any scattered particles
- A charge simulation of the electron-hole clouds in the semiconductor
- An electronics simulation of the ASIC circuit and front end electronics



Particle Simulation

The particle simulation uses Geant4 [1], [2] to simulate incident photons on the detector and calculates where they deposit energy in the semiconductor. X-CSIT provides an incident photon list and extracts the energy deposition data from Geant4, which is fully packaged inside the particle simulation module.
Geant4 can simulate photo electric effects, Compton and Rayleigh scattering as well as fluorescence and auger emissions down to 250 eV using the livermore physics list [3]. Geant4 has previously been validated for low energy EM processes and additional validation will be carried out in-house.



Charge Simulation

The charge simulation has been built to simulate how energy deposited in the semiconductor layer is moved onto the readout pixels, including charge sharing between neighbouring pixels. Because of the large number of electron-holes present, the charge simulation uses a statistical simulation.

In most cases, electron-holes act independently of each other and only diffusion contributes to charge sharing.

This diffusion is a normal distribution, with a standard deviation proportional to the root of the distance to the collection plates. The two dimensional normal is approximated as a normal distribution in both X and Y [4].

The proportion of charge crossing a pixel boundary in either X or Y can then be calculated inexpensively with the cumulative distribution function.

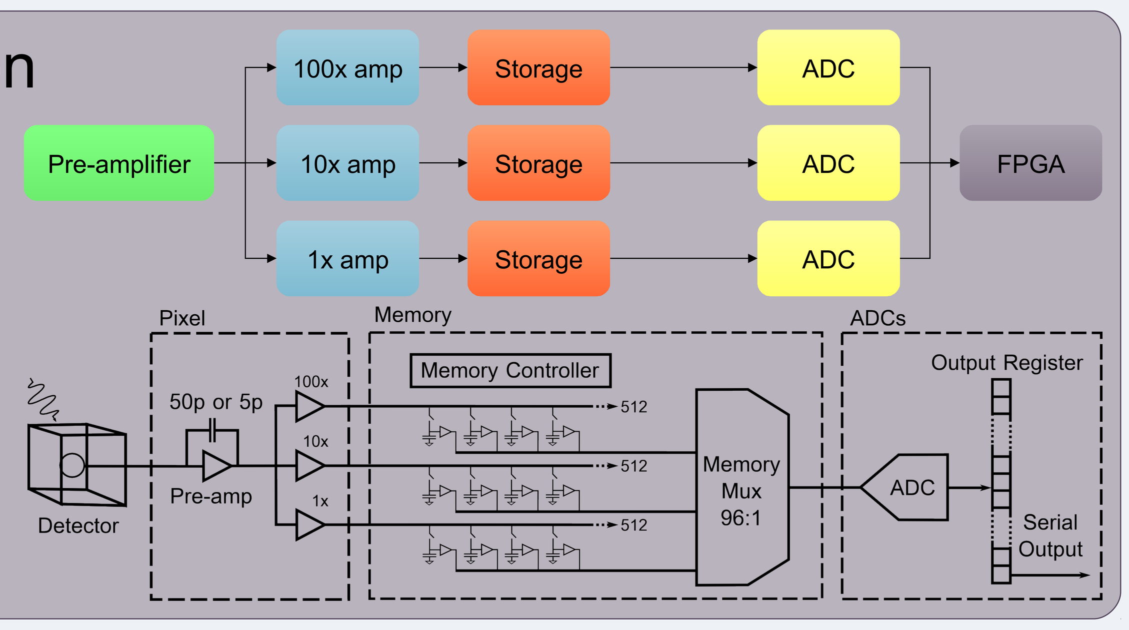
At very high electron-hole densities charge begins to screen itself from the electric field of the sensor, creating a pocket of electron-hole plasma.

This effect is expected to occur at XFEL but is poorly studied in the field of X-ray detectors [5]. This will be investigated later this year when sources become available at XFEL.

Electronics Simulation

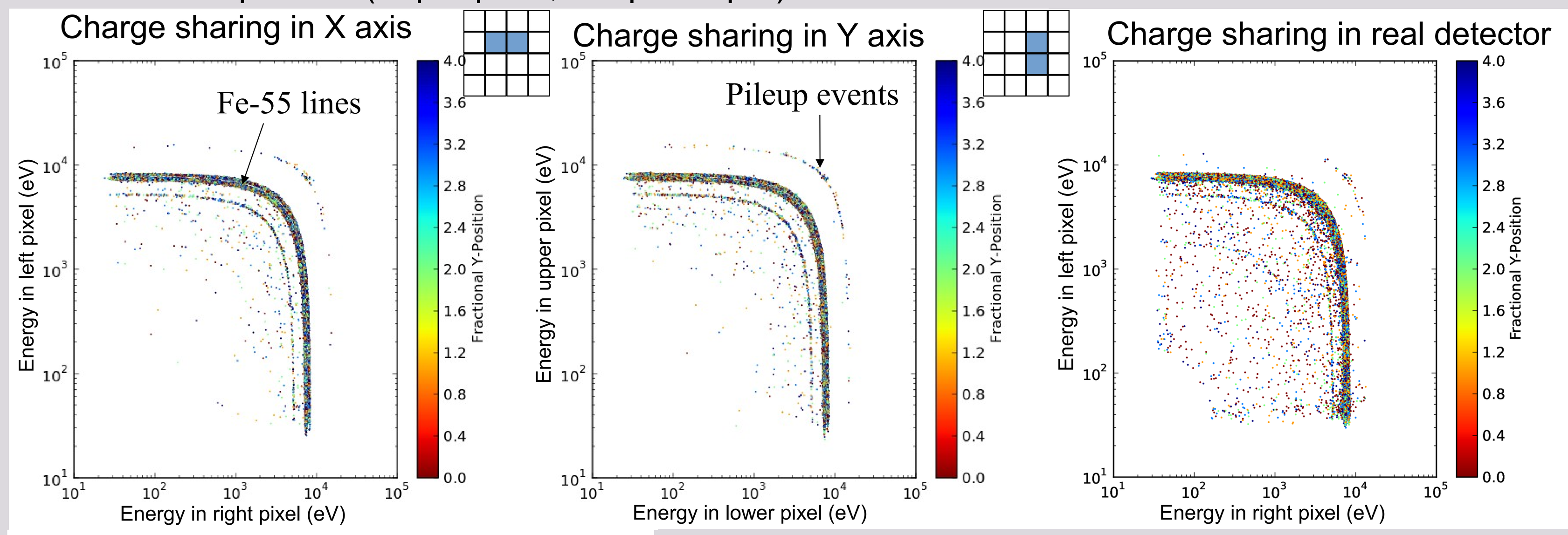
The electronics simulation consists of a set of modular devices to simulate common electronic components.

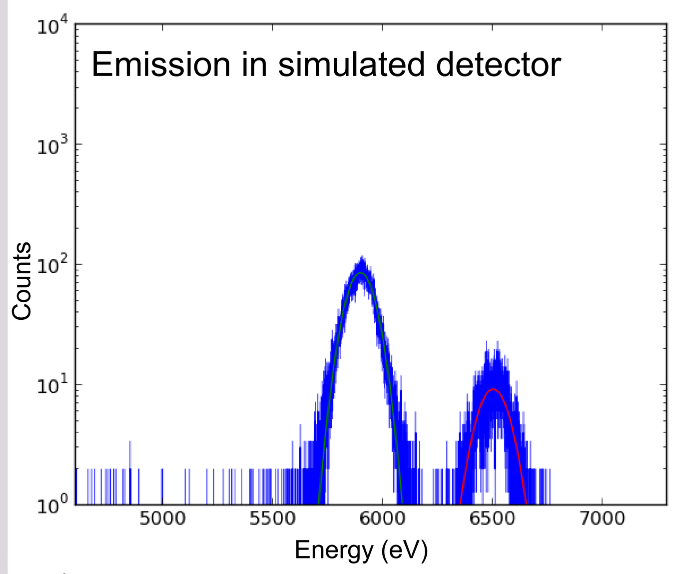
A simulation of the electronics of a detector is then created by chaining together these functions to create a functional representation of a real circuit.

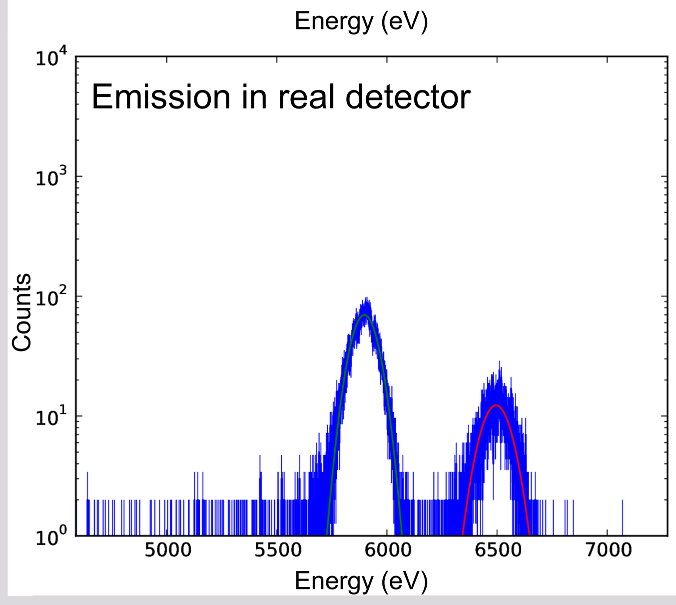


Testing

Before release, X-CSIT will require testing and validation. Some initial testing has been done with a simulation of a pnCCD (75μm pitch, 450μm depth) and data taken with an iron-55 source



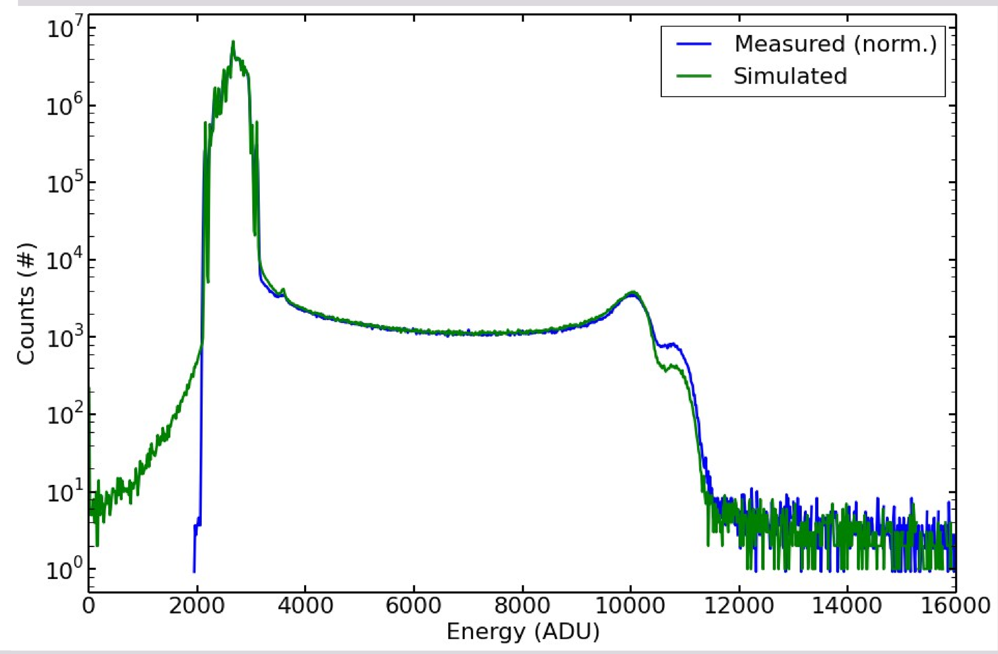




Above: Scatter plots of energy absorbed from the same event by two pixels, two plots are from simulated data showing isotropy, the third is real data showing similarity to simulated data, plus background noise.

Left: Fitted emission spectra of iron-55 as calculated from simulated and real data.

Below: Total spectra observed by the simulated and real detectors.



Conclusion and Outlook

X-CSIT is a toolkit for creating simulations of 2D semiconductor pixel detectors. While still in development, an early version of X-CSIT has been used to simulate a prototype of LPD and a pnCCD, which has been used for early testing.
All of the simulations and components of X-CSIT will be validated using detectors and sources available at XFEL, after which X-CSIT will be made available to European XFEL users through integration into Karabo and for free as open source for other users or groups.

References

[1] S. Agostinelli, et al., "Geant4 a simulation toolkit", Nucl. Instr. Meth A, 506, 250–303, 2003
[2] J. Allison, et al., "Geant4 developments and applications", IEEE Trans. Nucl. Sci., 53, 270–278, 2006
[3] CERN, "Geant4 Phyics Reference Manual 10.0", http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/PhysicsReferenceManual/fo/PhysicsReferenceManual.pdf, Dec, 2013
[4] R.F. Fowler et al. Nucl. Instr. And meth. A 477 (2002) 226
[5] J. Becker et al. Nucl. Instr. And meth. A 615 (2010) 230

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