A Software Framework and Toolkit for Developing Simulations of 2D Pixel Detectors

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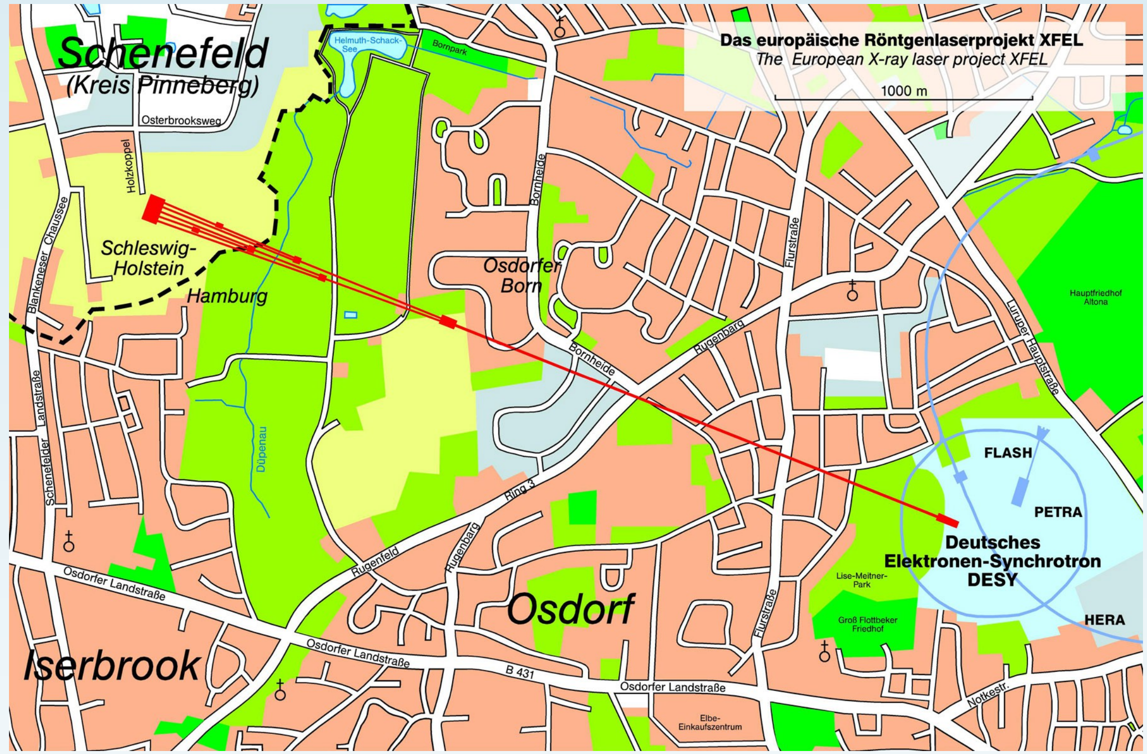
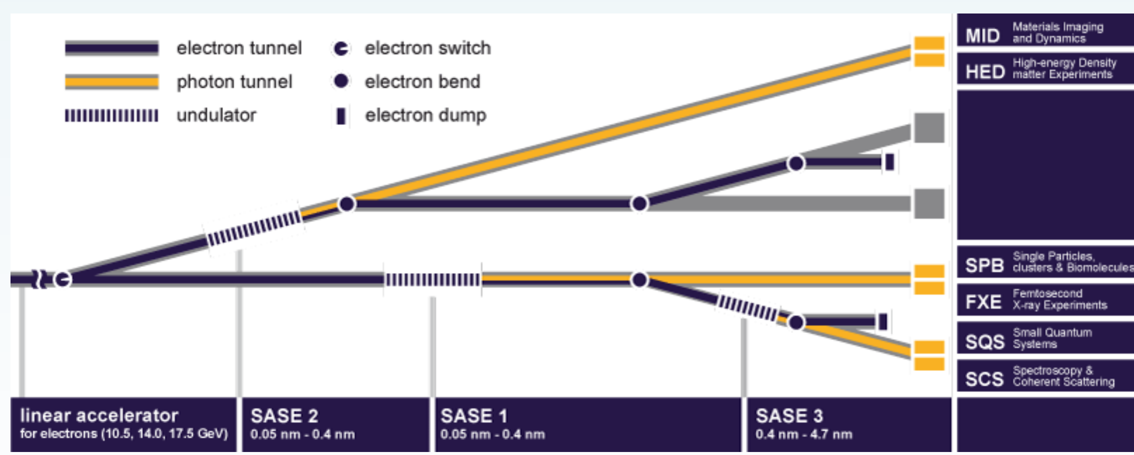
European XFEL

- Located at DESY in Hamburg.
- Self-Amplified Stimulated Emission (SASE) Free Electron Laser (FEL).
- Up to 27,000 light flashes per second.

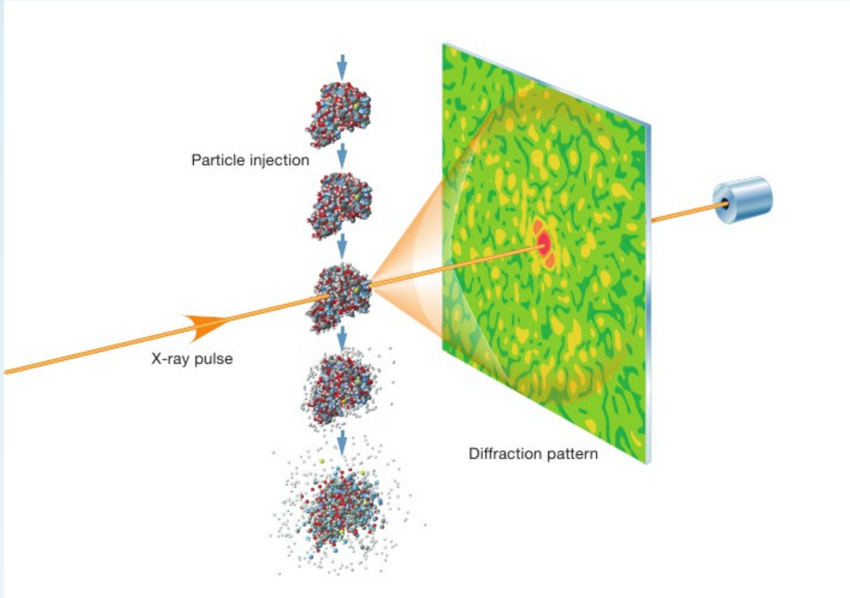


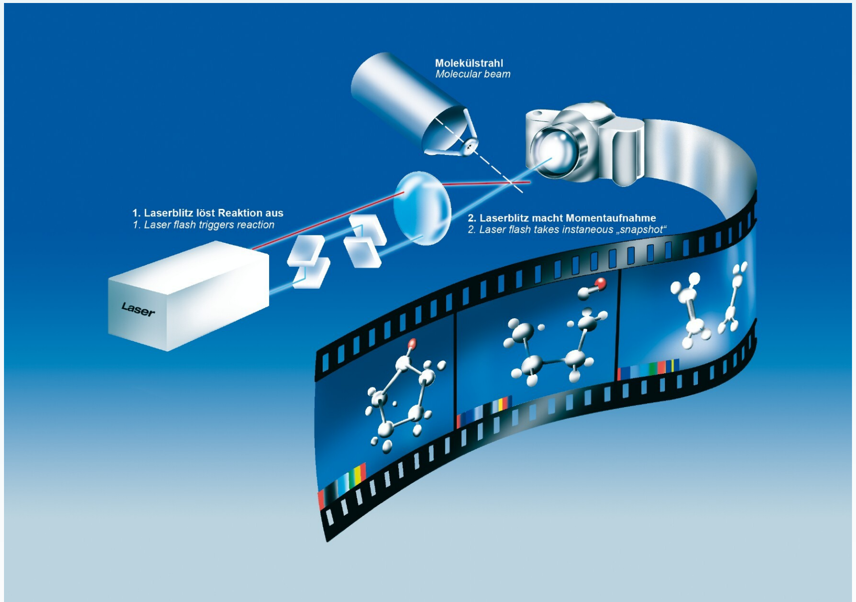
- 2 beamlines (SASE 1, 2) producing light at 3-25KeV (0.4–0.05nm).
- SASE 1 beam reused by SASE 3 to produce 0.26-3KeV light.



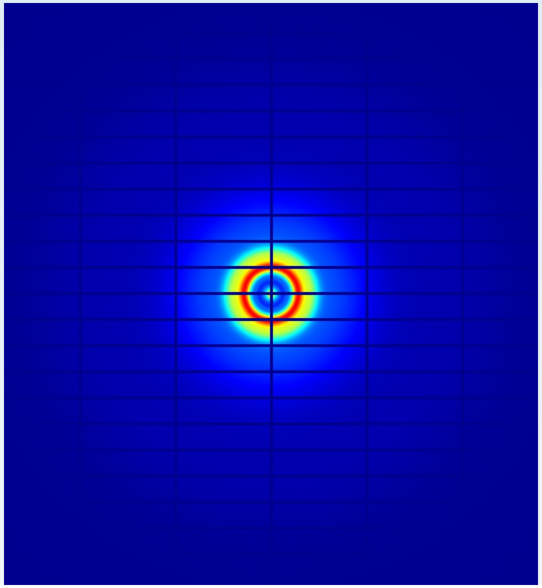
Science at XFEL

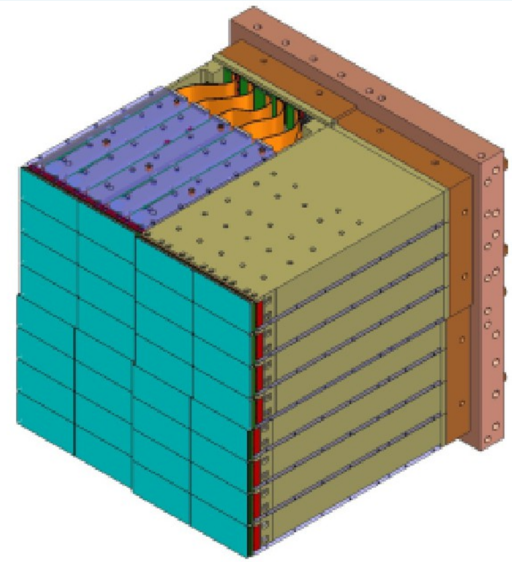
- The light from XFEL will be used for a variety of different experiments and scientific fields
- The light pulses will be intense enough to image single biomolecules and short enough to do so before the molecule is destroyed
- The short pulse length will allow filming of chemical reactions without motion blur
- The beam can be used to create and study extremely high temperature plasmas
- The beam can investigate the properties of materials at the nano scale



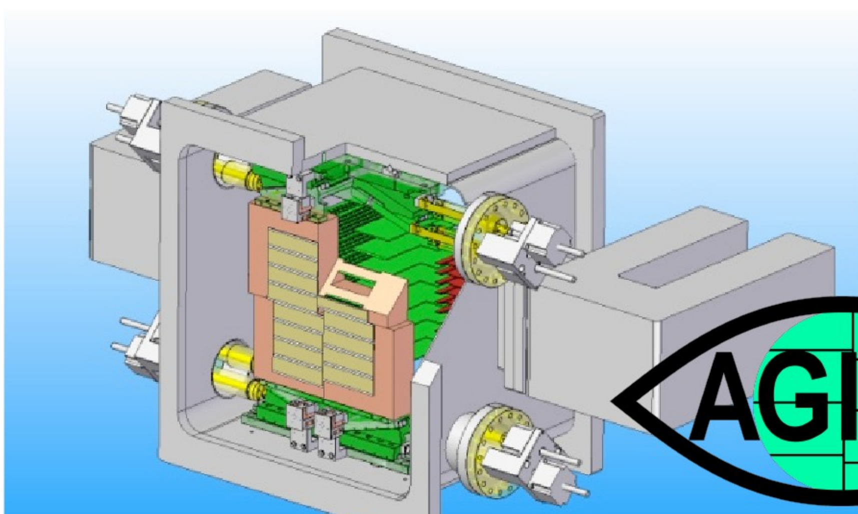


2D Pixel Detectors at XFEL





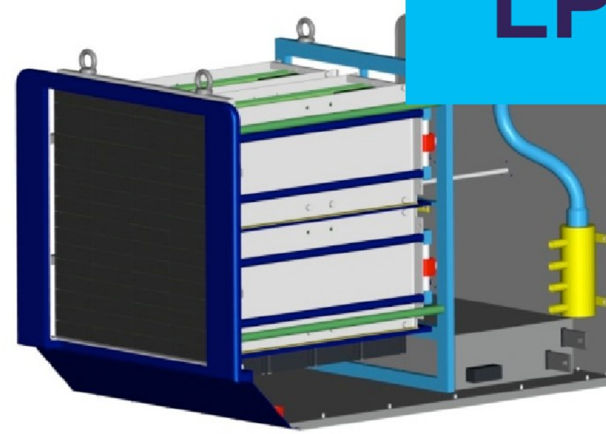
DSSC



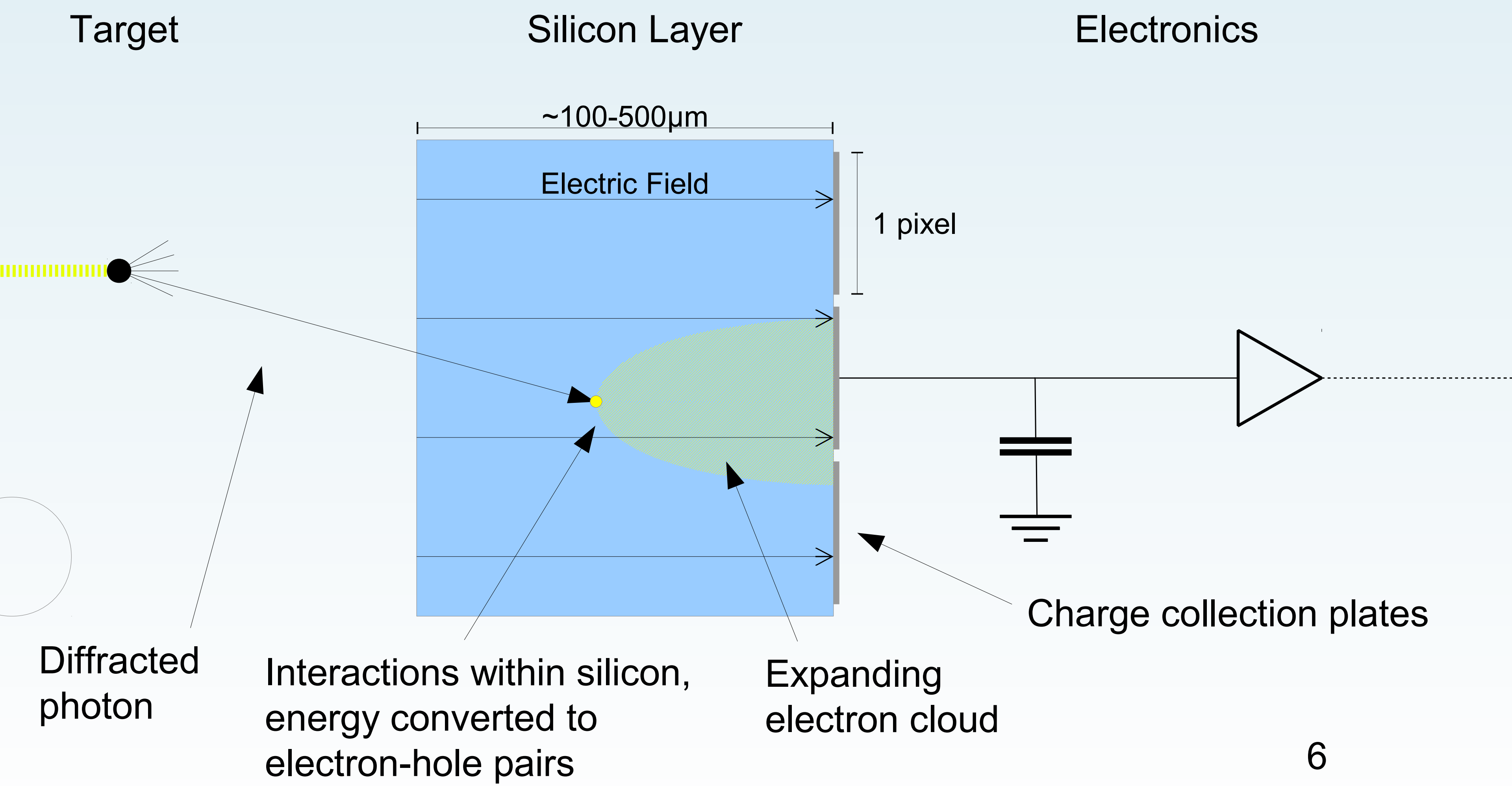
AGIPD

Courtesy H Graafsma DESY (AGIPD Consortium)

LPD

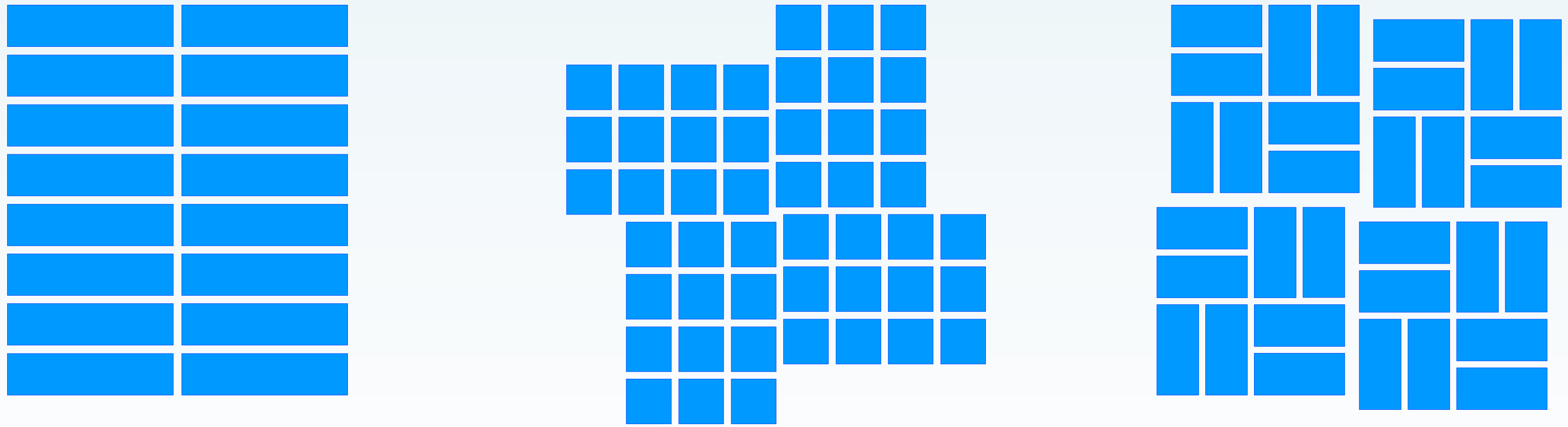


The Workings of a Pixel Detector



Variations in Pixel Detectors

- Large variations in the size, shape and layout of modules
- Detector segments of multiple modules can often be adjusted
- Pixel size can vary from 50-500μm
  - Can be square or hexagonal
- Detectors may not be perpendicular to the target, or may not be in a plane



Motivation

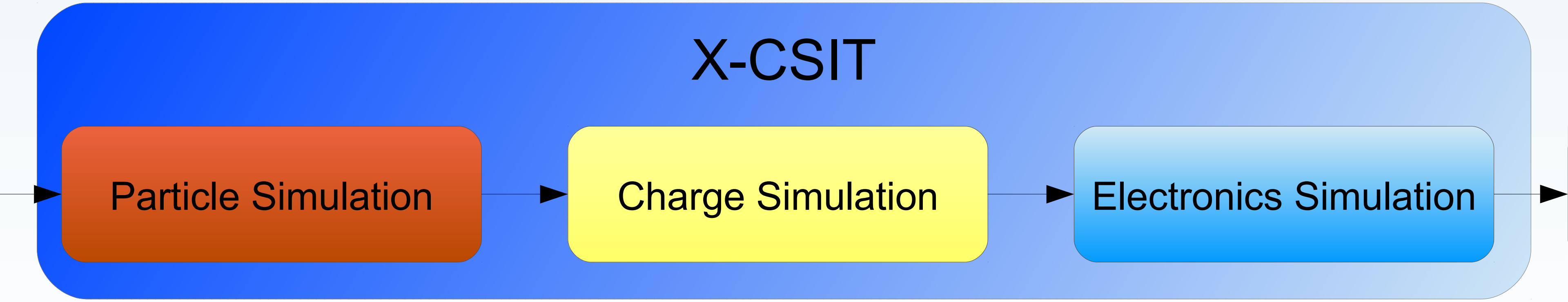
- Reasons for simulating detectors
  - Help build detectors
  - Understand physics
  - Understand radiation dosage
  - Help users plan their experiments
  - Assist users understand their data and the detectors

X-CSIT (X-ray Camera Simulation Toolkit)

- A toolkit for creating simulations of X-ray Pixel Detectors
- Written in C++ including use of the boost library
- Designed to be modular and adaptable to account for the wide variations in pixel detector design
- Users will add the characteristics of a detector, such as the geometry and electronics flow, to the toolkit, to create a simulation
- The toolkit will provide the framework to create the simulation and most or all of the functionality, depending on the detector
- If the toolkit does not provide the specific functionality required, then its modular design will allow the addition of the extra functionality required

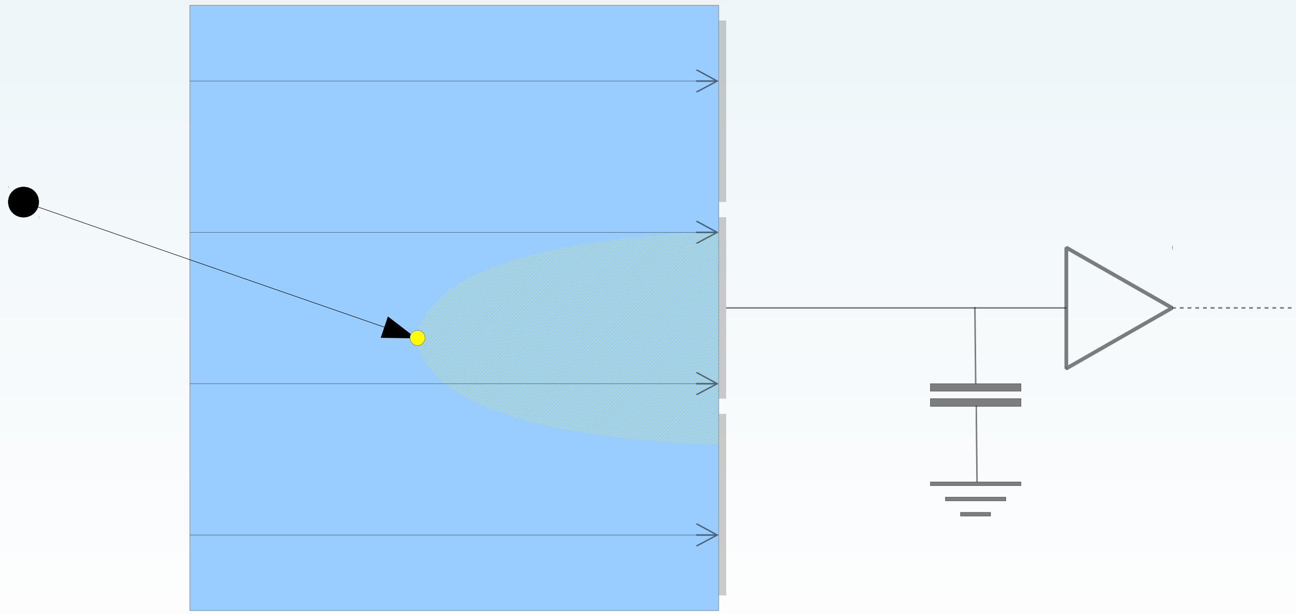
X-CSIT Layout

- X-CSIT separates the workings of X-ray pixel detectors into three distinct simulations
  - The Particle Simulation
  - The Charge Simulation
  - The Electronics Simulation



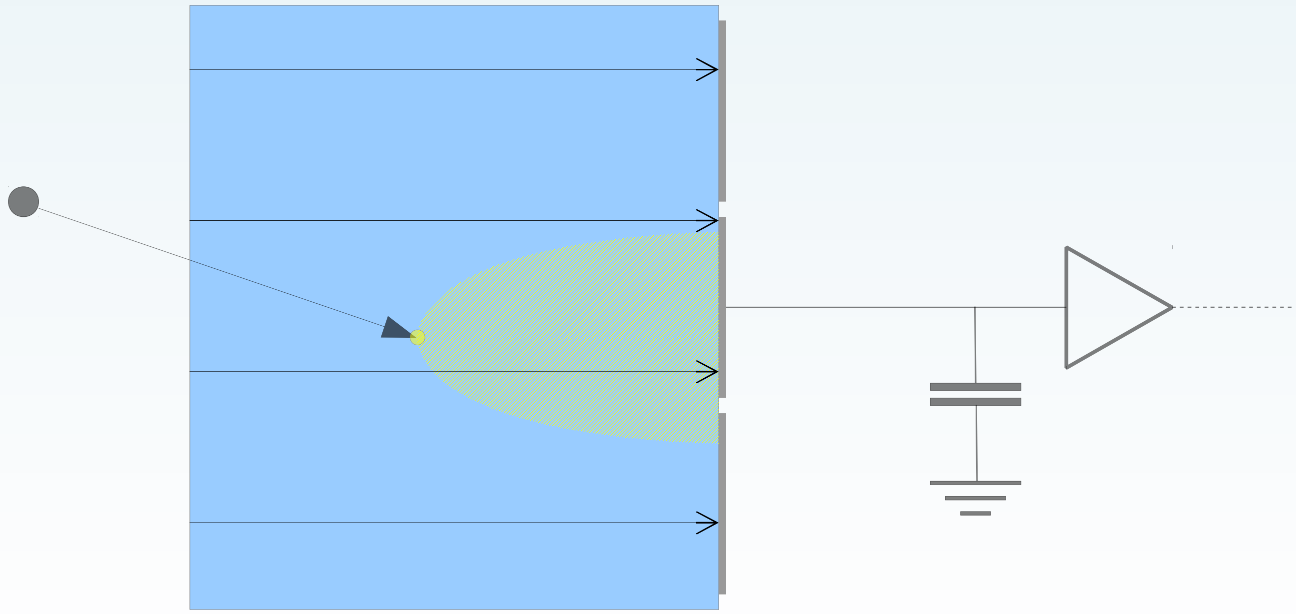
Particle Simulation

- Tracks particles in 3D within the geometry, primarily X-ray photons as they enter the sensitive detector materiel
- Calculates photon interaction and where energy is converted into electron-hole pairs. Photoelectric effect, fluorescence, auger emissions etc
- Will primarily use Geant4, integrated into the X-CSIT framework



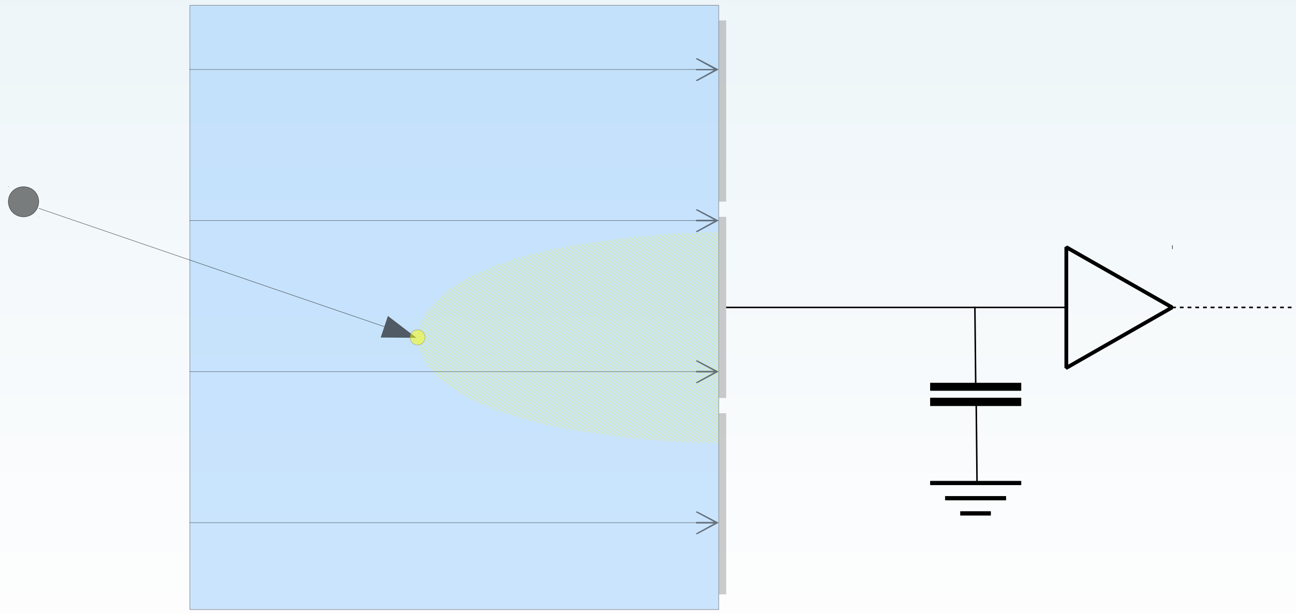
Charge Simulation

- Simulates the flow of electrons in the silicon from the point of interaction to the collection bonds/pixels
- Will primarily use a statistical Gaussian distribution with a bell curve diffusion function to calculate the spread of the charge cloud over depth
- Will also include a simulation of plasma like effects that can occur at high carrier densities



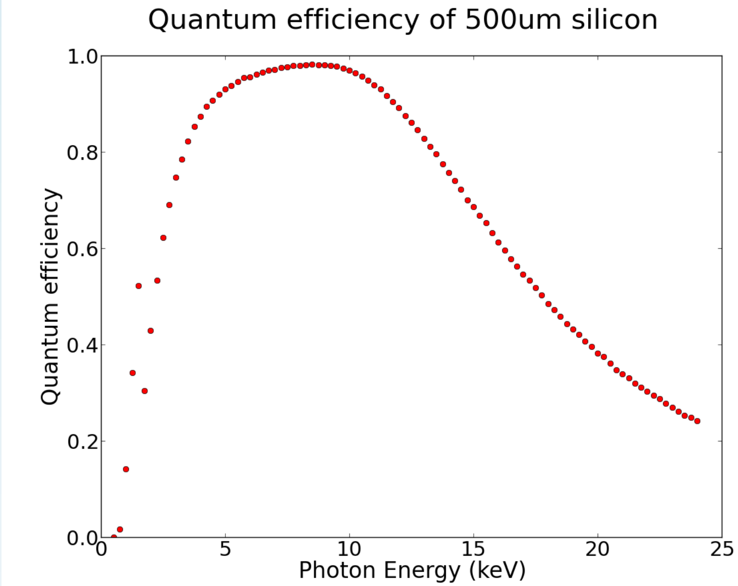
Electronics Simulation

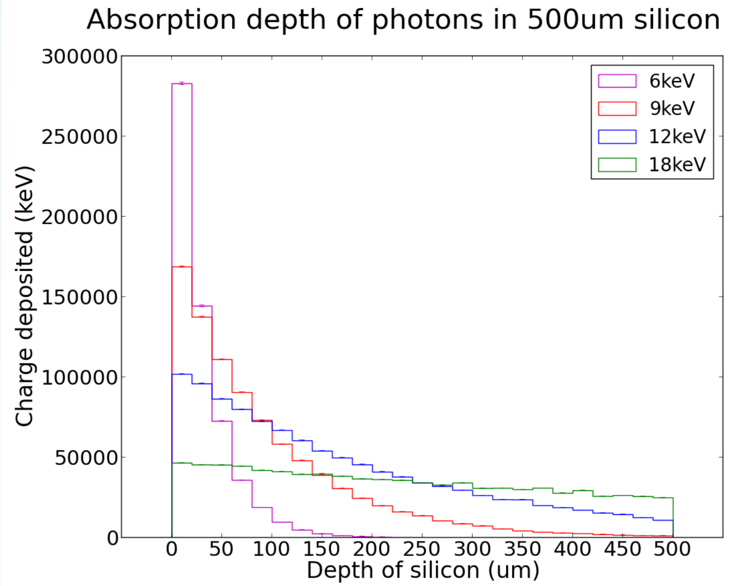
- Simulates the electronics of each pixel, from charge collection to readout
- Because the electronics of pixel detectors can vary so widely, the electronics simulation will consist of smaller electronic functions that can be combined together to form a simulation
- The user can then pick from a selection of customisable classes representing electronic components and string these together to form a simulation



Current Status

- Currently the framework for X-CSIT has been written and is undergoing unit testing
- Geant4 has been integrated into the particle simulation of the framework
- For testing, a Geant4 simulation of a single block of silicon 500um thick, with a 1um thick entrance window, has been implemented
- The framework has also been linked to the python interpreter. These plots were made with matplotlib (a python plotting library)





Quantum efficiency and absorption graphs with 100k photons per energy bracket.

Use at European XFEL

- X-CSIT will be used to create simulations of the three bespoke detectors being built for XFEL, AGIPD, DSSC and LPD
- X-CSIT and the simulations created with it will be integrated into Karabo, the data processing and control system at XFEL
- Through Karabo, these simulations will be made available to users and written so they can replace detectors in the data chain, allowing users to test their analysis before taking data
- There are also plans to validate X-CSIT with data taken by an early prototype of LPD, which took test data at the SLAC and PETRA III facilities early in 2013
- X-CSIT will also be released publicly for other users, collaborations and groups to create simulations of their own detectors

Thank you for your time

www.hep.ucl.ac.uk/xfel/
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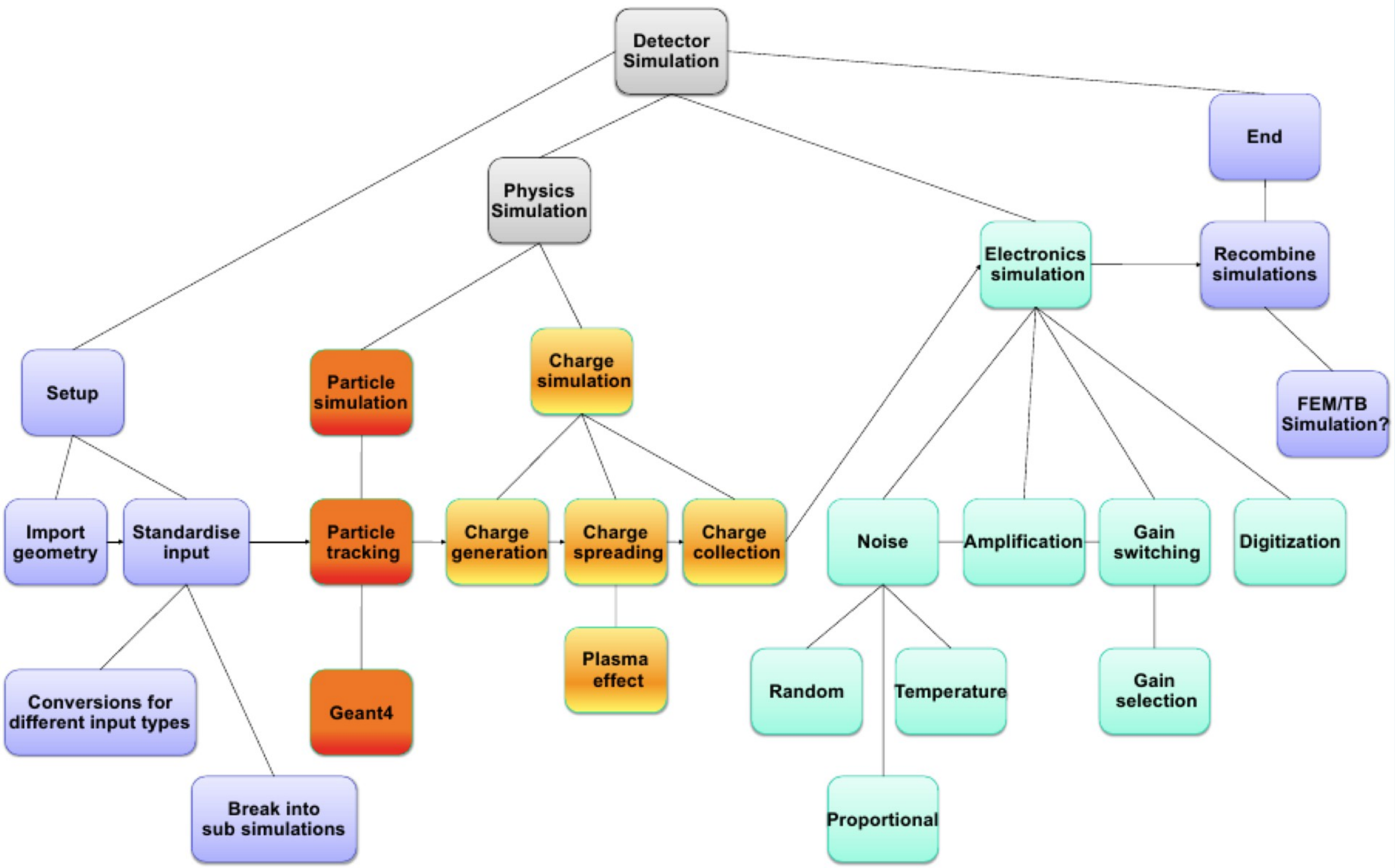
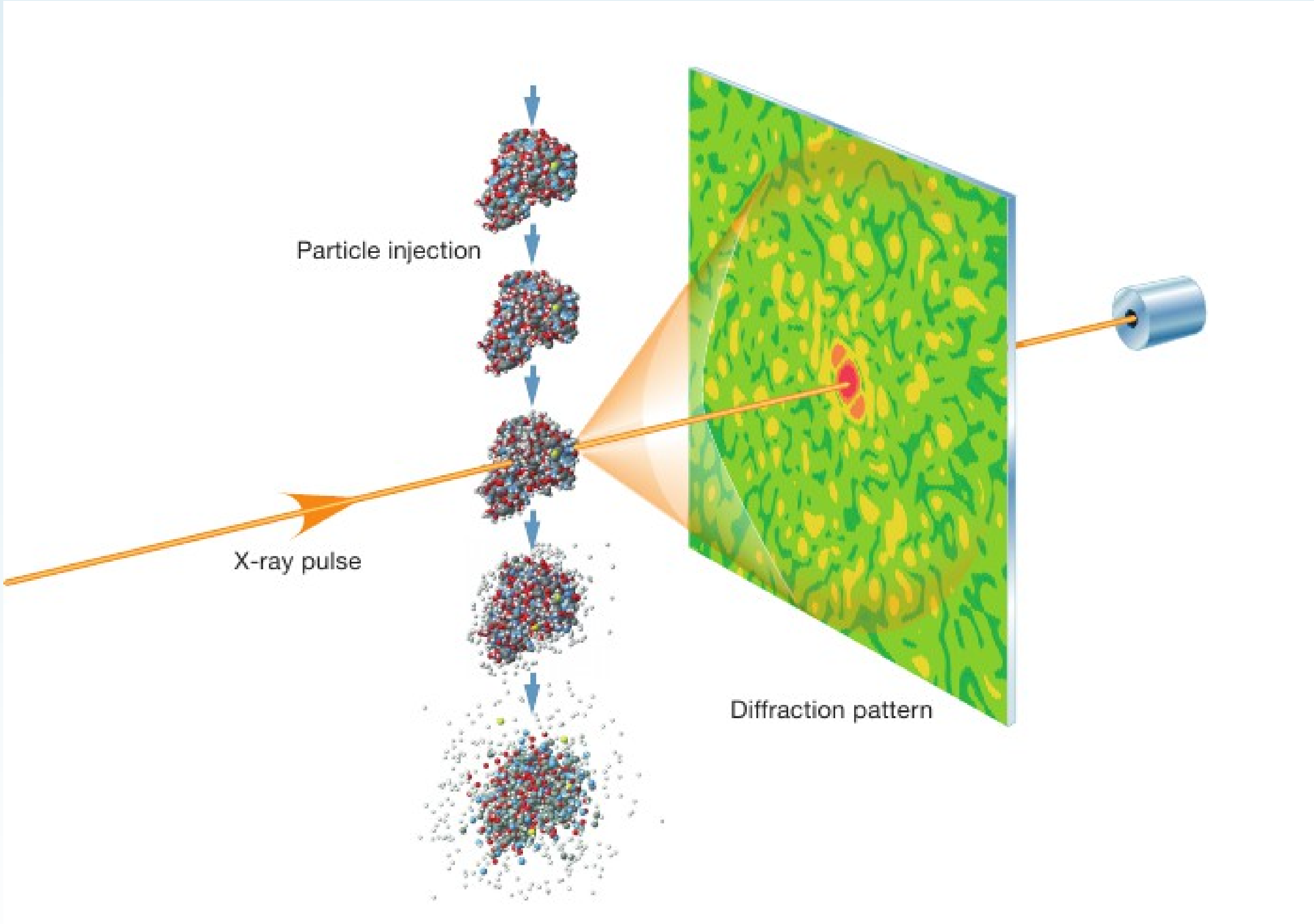
Extra Slides

X-CSIT Early Draft Plan



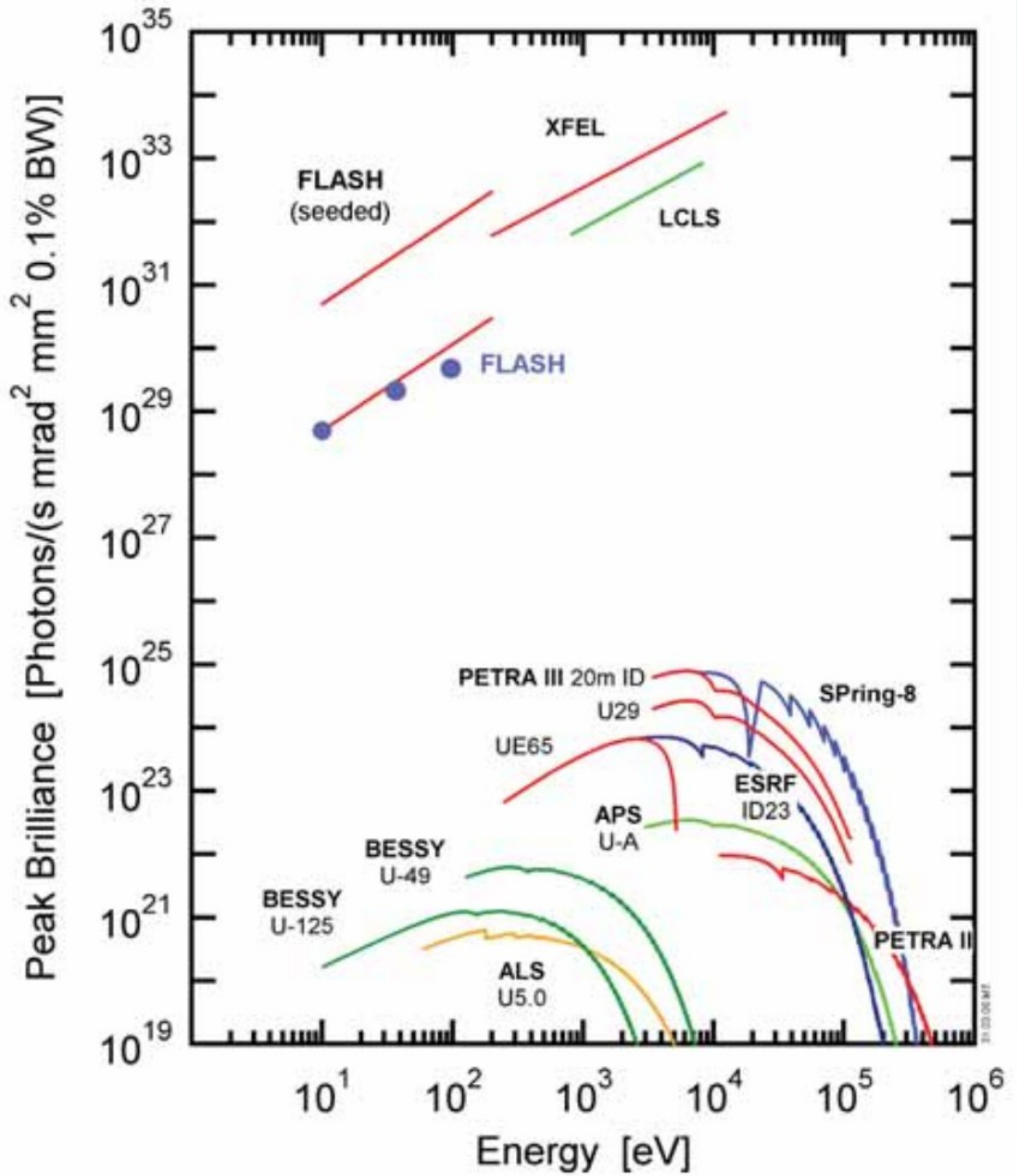
Experimental Layout



Comparison

	LCLS	SACLA	European XFEL
Abbreviation for	Linac Coherent Light Source	SPring-8 Angstrom Compact Free Electron Laser	European X-Ray Free-Electron Laser
Location	California, USA	Japan	Germany
Start of commissioning	2009	2011	2015
Accelerator technology	normal conducting	normal conducting	superconducting
Number of light flashes per second	120	60	27 000
Minimum wavelength of the laser light	0.15 nanometres	0.1 nanometres	0.05 nanometres
Maximum electron energy	14.3 billion electron volts (14.3 GeV)	6-8 billion electron volts (6-8 GeV)	17.5 billion electron volts (17.5 GeV)
Length of the facility	3 Kilometer	750 Meter	3.4 Kilometer
Number of undulators (magnet structures for light generation)	1	3	5
Number of experiment stations	3-5	4	6, upgradeable to 10
Peak brilliance [photons / s / mm^2 / mrad^2 / 0.1% bandwidth]	$8.5 \cdot 10^{32}$	$5 \cdot 10^{33}$	$5 \cdot 10^{33}$
Average brilliance [photons / s / mm^2 / mrad^2 / 0.1% bandwidth]	$2.4 \cdot 10^{22}$	$1.5 \cdot 10^{23}$	$1.6 \cdot 10^{25}$

Brilliance



Peak Brilliance [Photons/(s mrad^2 mm^2 0.1% BW)]
10^{35}
10^{33}
10^{31}
10^{29}
10^{27}
10^{25}
10^{23}
10^{21}
10^{19}
XFEL
FLASH
(seeded)
LCLS
FLASH
PETRA III 20m ID
U29
UE65
SPring-8
ESRF
ID23
APS
U-A
BESSY
U-49
BESSY
U-125
ALS
U5.0
PETRA II
10^1
10^2
10^3
10^4
10^5
10^6
Energy [eV]

Charge Spreading

- J.Becker et al., Impact of plasma effects on the performance of silicon sensors at an X-ray FEL, Nucl. Instr. and Meth. A, 615 (2010), p. 230
- R.F. Fowler et al., Computational modelling of semiconducting X-ray detectors, Nucl. Instr. Meth. A, 477 (2002), p. 226
- H. Spieler, Semiconductor detector systems, Oxford Science Publications, Oxford U.K. (2008)

Bunch Timing