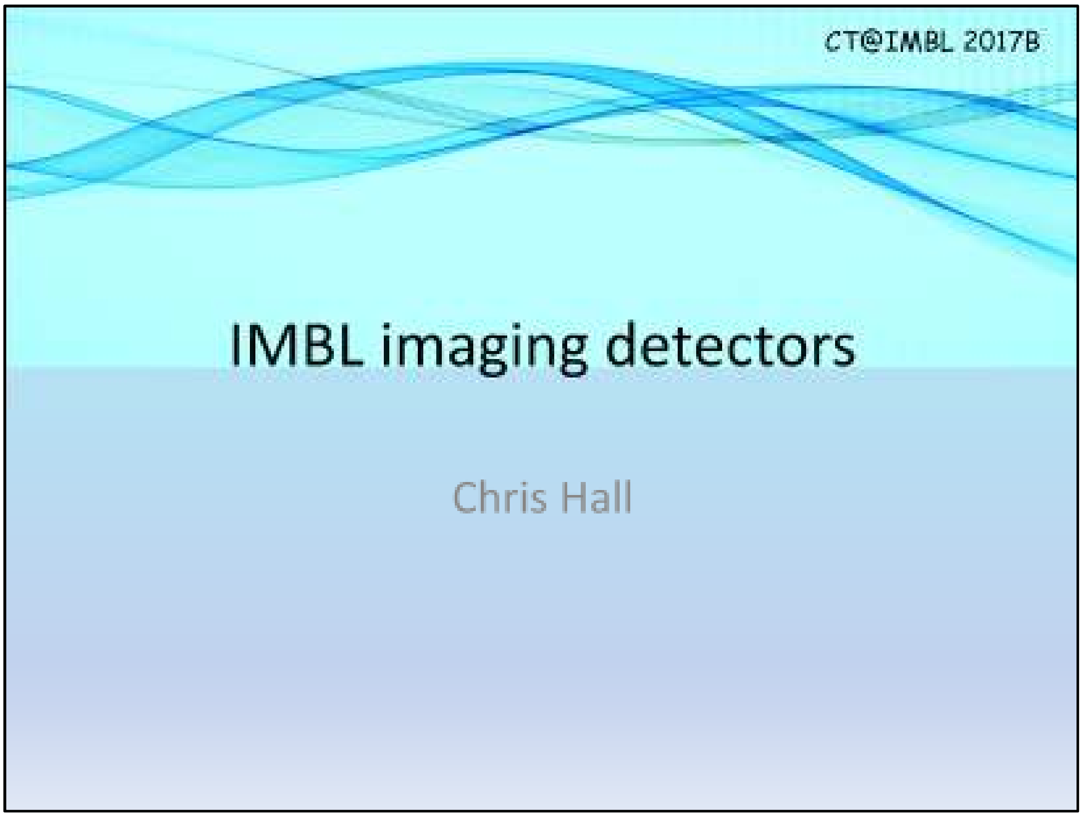
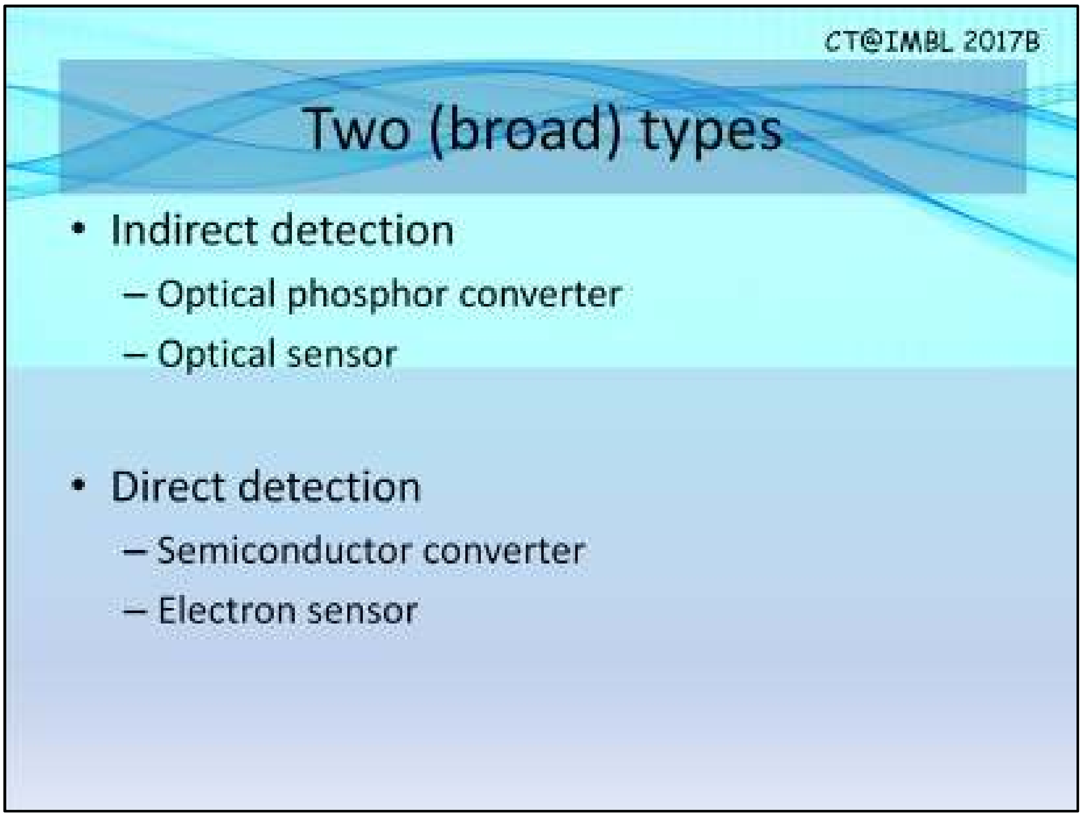
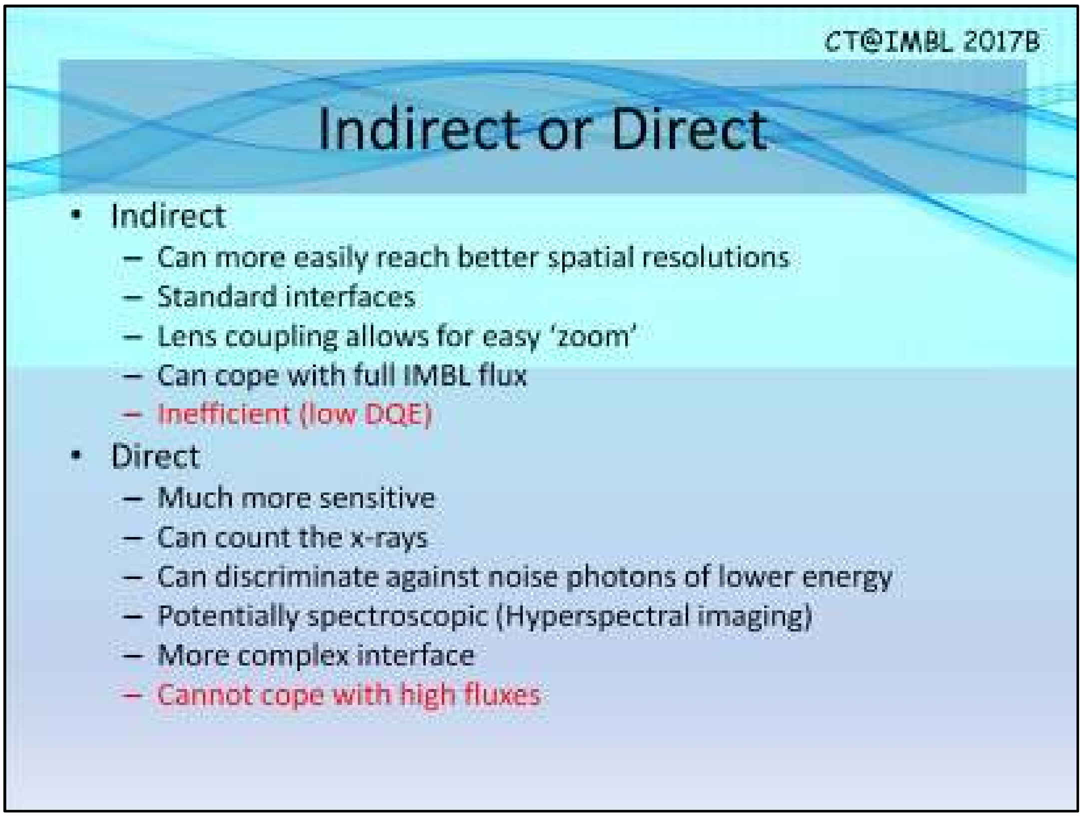


IMBL has designed and purchased a number of x-ray imaging detectors. To suit the experimental requirements.
Although the Users need not be concerned about the technical details. The overall characteristics of the detectors are important to know, when making the choice for your experiment.
We have other detectors to measure flux and dose. These are not covered in this talk though.



We categorise the detectors depending on the way they convert the x-ray intensity into a numerical array representing intensity.
In both cases the sensor eventually measures charge generated by the x-rays.
In the first type the x-ray energy is first converted into optical photons.
Optical imaging detectors are highly developed, and provide a large of choice.
Alternatively if the x-ray energy is directly converted to electrons in the converter material. There are fewer losses.
Direct detection is more efficient, but not so supported by consumer markets.



Conversion to optical photons allows sophisticated optics to be used to refine spatial resolution
Using lens coupling allows the potential for altering magnification, and field of view.
Losses in the coupling mean poor efficiency, but these are matched by the bright beams on IMBL

If minimal dose is important then by implication so is detector efficiency.
Direct detection systems are significantly better in this respect.
They can be designed to count individual x-ray photons if the flux density is low enough.
When counting photons there is a potential for measuring the photon energy.
A simple threshold on the pulse height (~=energy) can remove unwanted scattered photons.
Because these systems are produced in low volume they are often expensive.

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Ruby

- Sensor: PCO.edge scientific CMOS
- Coupling: Nikon macro lenses
- Converter: Gadox, CsI(Tl), CdWO4

- Zoomable field-of-view
- Interchangeable converter
- Moderate pixellation (5.5 Mpix)
- Inefficient

Field of view (mm)	Pixelation/size (µm)	Full frame rate (fps)
16.2 x 13.7	2560 x 2160 / 6.3	35
110 x 93	2560 x 2160 / 43	35

Ruby is our workhorse imaging detector.
It uses a high dynamic range, cooled 5.5 megapixel CMOS sensor.
The coupling is by the brightest camera macro lens.
The sensor/lens is mounted on a vertical positioner, which can be moved remotely to give a field-of-view change (zoom)
The focussing is achieved using a combination of a lens driver and the positioner.
The converter is mounted on interchangeable frames.
A variety of phosphors/scintillators are available to suit the imaging task.
Coupling via lenses is inevitably inefficient. So the DQE of Ruby is not high.
(Single photon counting is very hard to achieve in any optically coupled system and spectroscopic capability even harder.)

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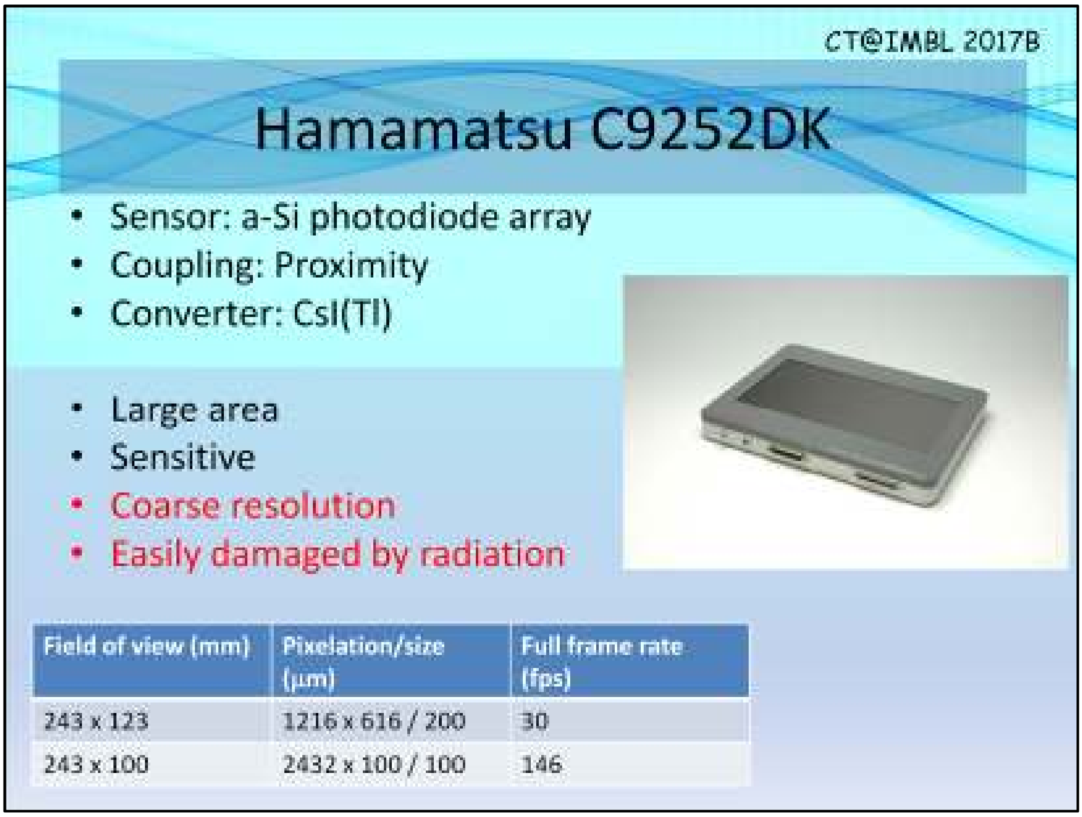
Diamond (Optique Peter)

- Sensor: PCO.edge scientific CMOS
- Coupling: Microscope objective lenses
- Converter: LSO, YAG

- Microscopic level resolution
- Single crystal scintillators
- Very inefficient

Field of view (mm)	Pixelation/size (µm)	Full frame rate (fps)
1.66 x 1.40	2560 x 2160 / 0.64	35
13.5 x 11.4	2560 x 2160 / 5.3	35

Our Diamond detector is similar to Ruby. It uses the same sensor.
The lenses are microscope objectives, allowing high magnifications with reasonable numerical apertures.
Powder phosphors don't have sufficient inherent resolution, so single crystal materials are used for Diamond.
The reduction in the thickness of converter to achieve high resolution makes this detector inefficient.



This detector was originally designed for human dental imaging, so it is highly efficient.
The 1mm thick CsI(Tl) converter gives plenty of optical light for each x-ray
The optical photon detector (photodiode) is mounted directly under the converter.
The converter material is grown in needles, so it acts like a tiny fibre optic array channelling the optical photons down to the diode.
The photodiode array, and readout electronics are in the path of the x-ray beam. This makes it susceptible to radiation damage.

Hamamatsu C10900D

- Sensor: a-Si photodiode array
- Coupling: Proximity
- Converter: CsI(Tl)
- Large area
- Sensitive
- Coarse resolution
- Easily damaged by radiation

Field of view (mm)	Pixelation/size (μm)	Frame rate (fps)
122 × 123	1216 x 1232 / 100	35
122 × 7	1216 × 72 / 100	70
122 × 123	608 x 618/ 200	17
122 × 62	608 × 310/200	280

ScintX was one of our first x-ray detectors. It uses a cooled low noise CCD as the sensor. (Although CMOS sensors are faster and easier to make they used to be far more noisy. Scientific grade CMOS are now as good as CCD)
A columnar grown CsI(Tl) plate is proximity coupled to the CCD. Making it quite sensitive.
It is a 10 megapixel camera viewing the 36 by 24 mm field, giving good spatial resolution.
The CCD is slow to readout though. So this detector's maximum frame rate is 3 fps.

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Argus Ceph

- Sensor: Photodiode array
- Coupling: Proxmity
- Converter: CsI(Tl)

- High efficiency
- High aspect ratio
- Time Domain Integration for large objects
- Slow readout

Field of view (mm)	Pixelation/size (µm)	Full frame rate (fps)
220 x 7	8160 x 256 / 27	< 1

Although square arrays of photodiodes are hard to make, and expensive. Arrays with high aspect ratios are more readily available.
This detector was designed for scanning applications, where the few detector rows are clocked out in synchrony with the object moving across its field-of-view. The technique is called Time Domain Integrations.
The image is built up row, by row inside the detector's memory. Then read out after it's completed the scan.
Although only 7 mm high this detector will image an object up to 800 mm high (and 220 mm wide).
Unfortunately the readout is designed for industrial process scanning, and is very slow.

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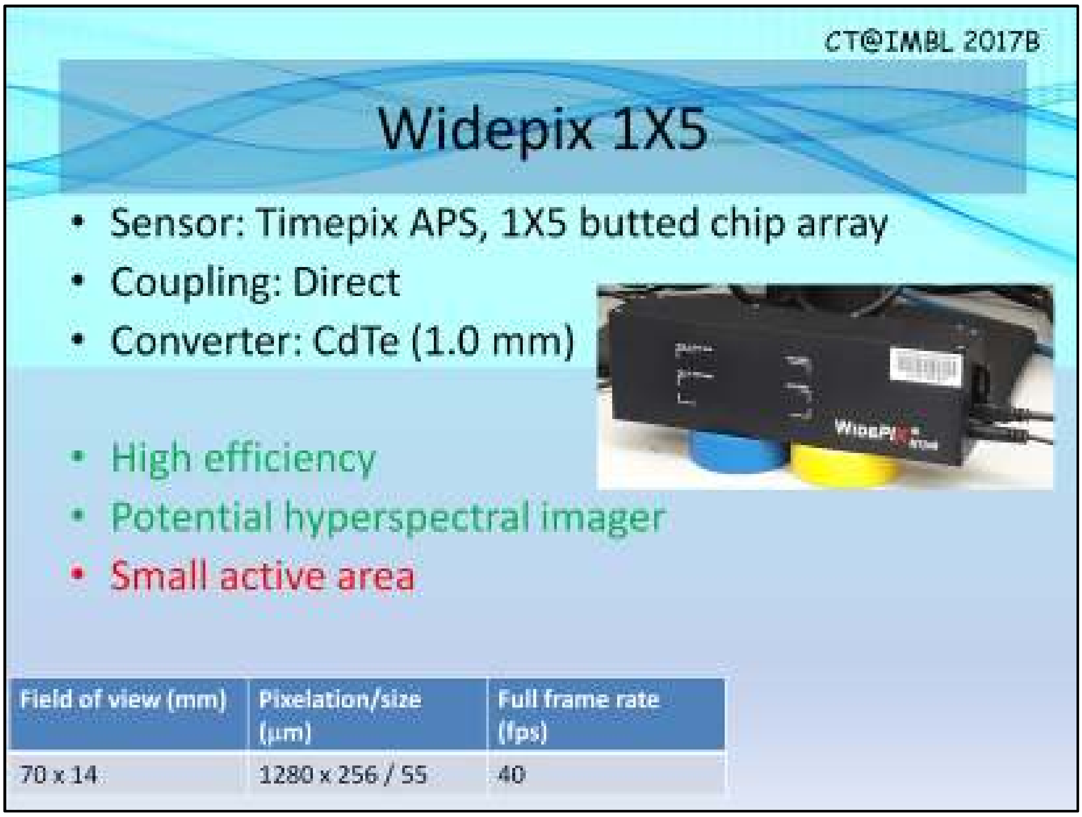
CPro

- Sensor: Large area CMOS
- Coupling: Schneider macro lens
- Converter: Gadox

- Very large area
- Good resolution
- Low efficiency

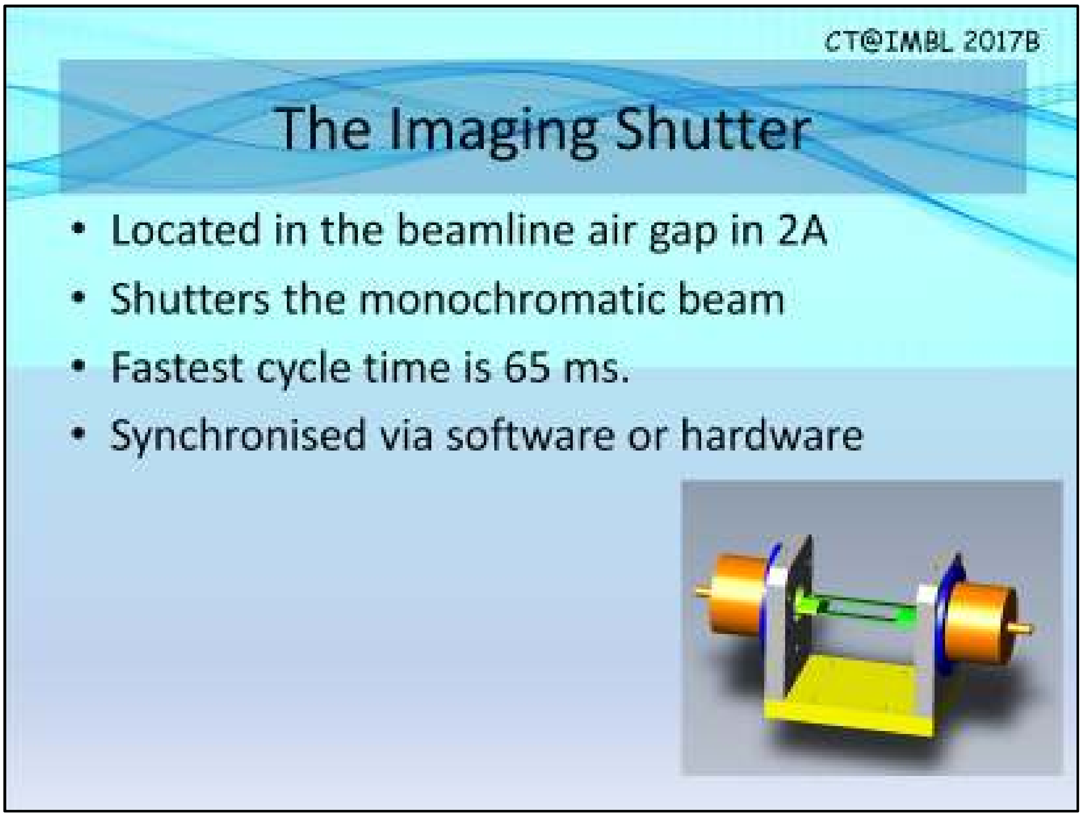
Field of view (mm)	Pixelation/size (µm)	Full frame rate (fps)
204 x 85	12000 x 5000 / 17	10
504 x 210	12000 x 5000 / 42	10

Our need to detect the full width of the beam in IMBL hutch 3B, led us to design a detector with simple lens coupling.
A very large CMOS array was purchased (60 Mpix). This uses a high quality macro lens to view the converter.
The resulting detector has two fixed fields-of-view (It’s not zoomable)
With the first magnification setting the field of view is over 0.5 metres horizontally, and 21 cm high, with 42 micron pixels.
Since our x-ray beam is not this high we have placed three converters of different types in the FOV.
Selecting the converter type is then a matter of changing where the x-ray beam illuminates the detector, and choosing a suitable region-of-interest (ROI) on the sensor.
The second magnification setting gives a FOV > 20 cm. The pixels in this mode are 17 microns.

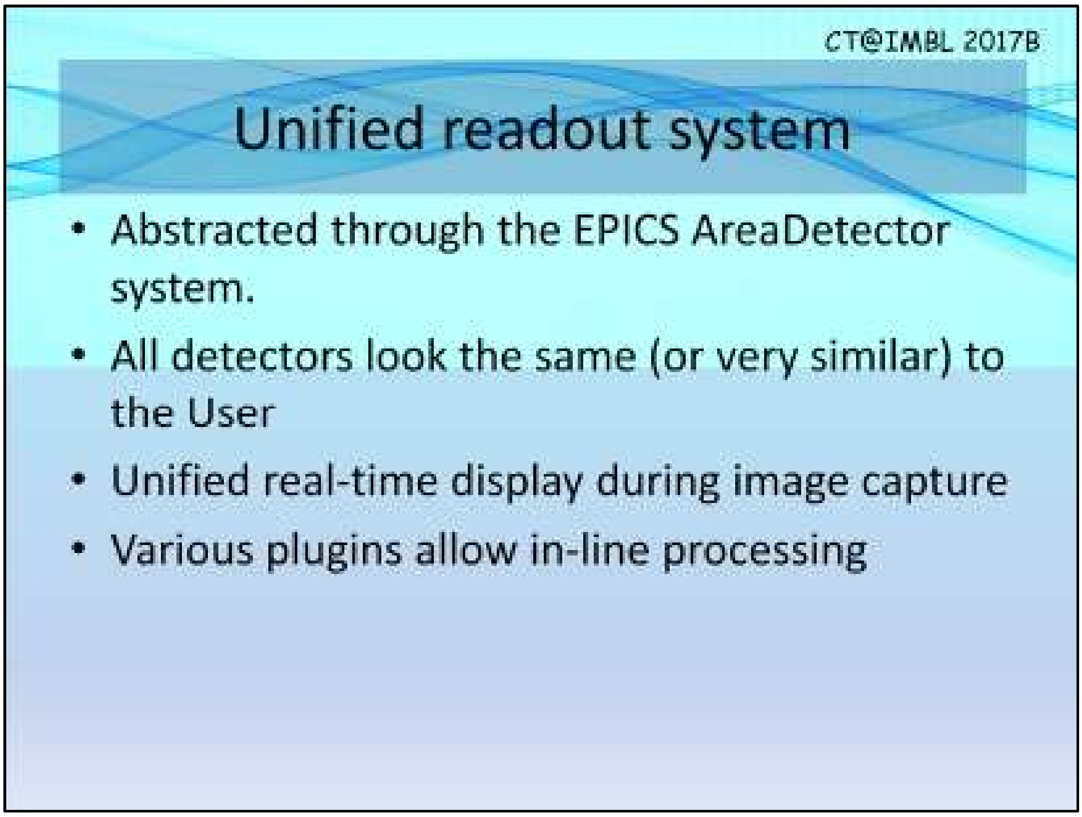


The first photon counting detector we have purchased is based on a well known CERN spinoff Medipix
The Medipix active pixel sensor (APS) has been developed over ten years. It has pixels of 55 microns.
Widepix is a direct detection system, with a converter of a room temperature semiconductor CdTe, 1 mm thick.
The quantum efficiency is close to 100% out to 60 keV, and ~60% at 100 keV.
There is one pulse height threshold for photon counting.
It will run in a mode where it counts how long the pulse stays above threshold.
This mode can be used for determining the energy of the photon.

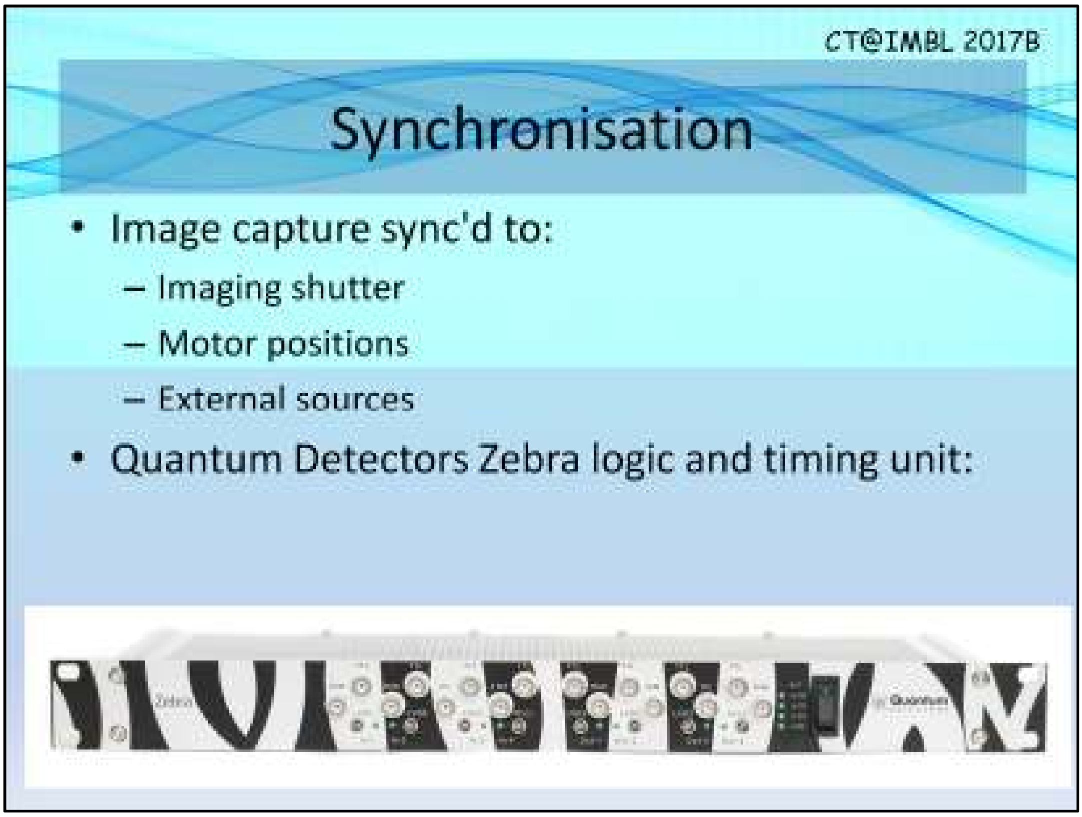
XCounter can tile their APS chips across a wide area (300 mm).
The idea is to use this for large area dose sensitive imaging.
The test device we have at the moment is limited to ~ 5 cm by 2.5 cm active area.



We have recently installed an x-ray shutter in the second optics hutch.
This is designed for rapid shuttering of the monochromatic beam.
The fastest exposure time is currently limited to 65 ms. This can be made lower with a non-linear timing function.
The fastest cycle time is about 150 ms. Again this could be made faster with some engineering tweaks.
At the moment the shutter opens when the detector is made active from the GUI. It will close the beam whenever the detector is not collecting images.
We have recently installed a hardware signal capability. This will keep the shutter open for as long as this TTL signal is held high.
This is interfaced to the experiments in hutch 3B via the Zebra timing unit described later.



Our beamline uses the Experimental Physics and Industrial Control System (EPICS)
Within EPICS, the detector readout section is called AreaDetector
Using this allows versatile and easily designed graphical interfaces.
areaDetector uses plug-in modules to allow image processing within the controller.
These are fast, since they work at a low level in the system.
There are several to choose from but most commonly used are:'file', 'statistics', and 'process'.
The File plugin allows buffered image file saving in a variety of formats (TIFF and HDF5 are relevant to us).
The Statistics plugin makes calculations on the image. For instance thick line-outs, mean and variance calculations.
A Process plugin allows flat and dark field processing.



In some circumstances taking the image needs to be synchronised with the imaging shutter, and/or other devices.
For slow CT acquisition we currently use software shutter synchronisation.
In this case the shutter opens at the start of the acquisition, and closes at the end
Ideally we would like to shut off the beam during the readout phase for each projection image.
This might be only a few milliseconds. The Zebra synchronisation unit will allow this if the shutter can react fast enough.
Zebra can also allows pulse trains from position information fed-back from a motor controller.
The Time Domain Integration detector modes requires this signal to work.
The Zebra can be fed with signals from physiological measurements, blood pressure, breath cycles etc.
Allows physiologically gated imaging.