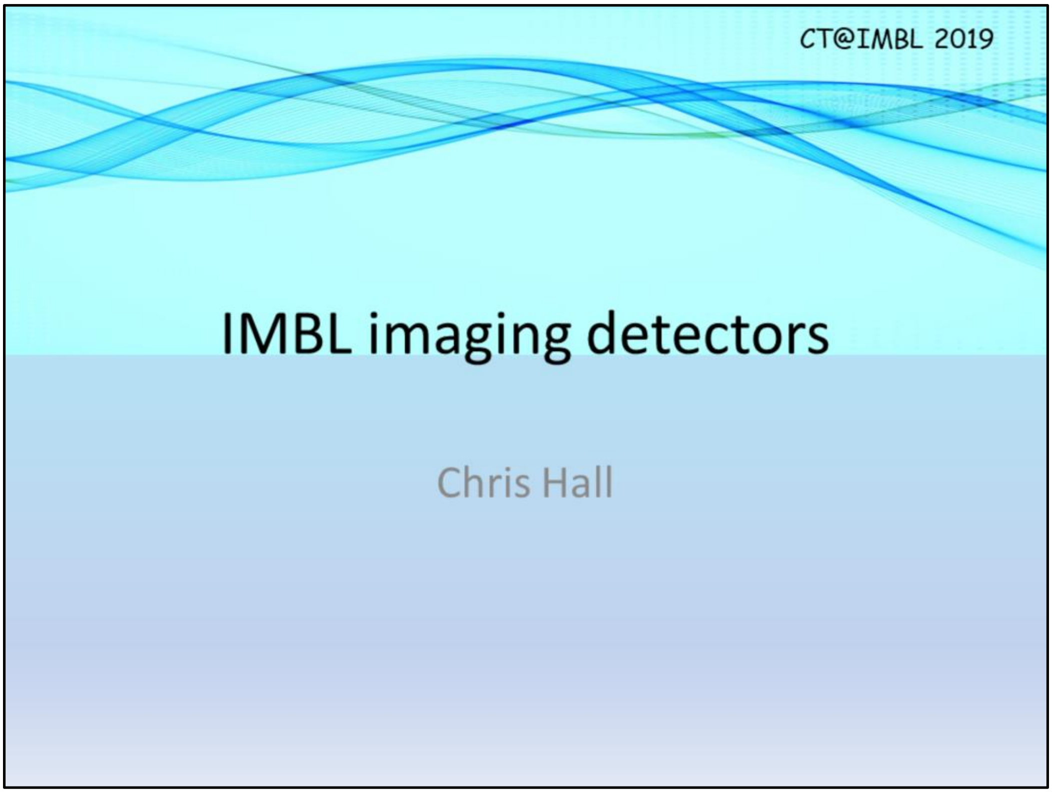
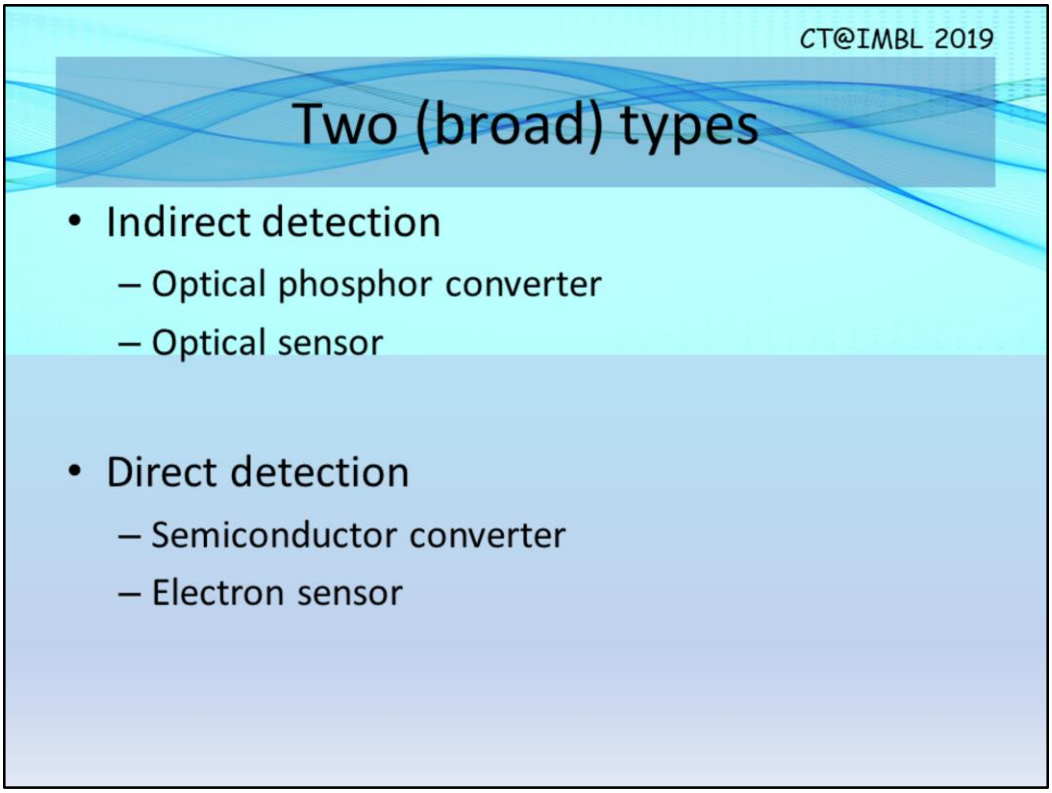
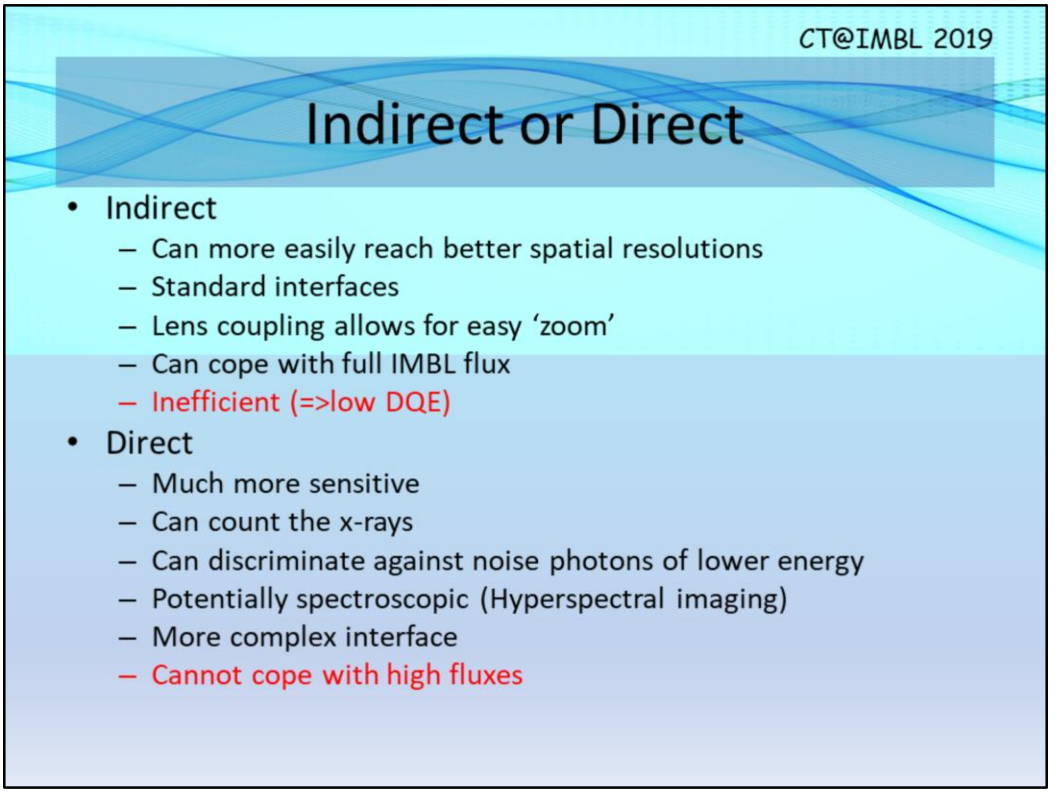


- IMBL has designed and purchased a number of x-ray imaging detectors. To suit the experimental requirements.
- Although the Users need not be concerned about the technical details. The overall characteristics of the detectors are important to know, when making the choice for your experiment.
- We have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

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.

Hamapapa (Hamamatsu C9252DK)

- Sensor: a-Si photodiode array
- Coupling: Proximity
- Converter: CsI(Tl)

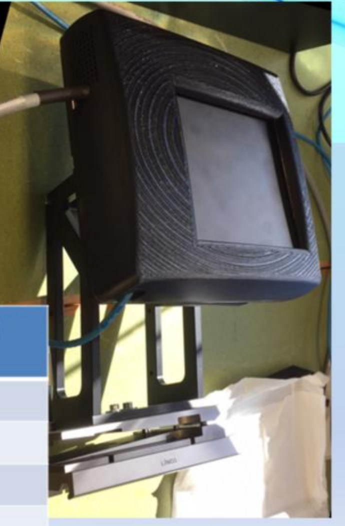
- Large area
- Sensitive
- Coarse resolution
- Easily damaged by radiation

Field of view (mm)	Pixelation/size (μm)	Full frame rate (fps)
243 x 123	1216 x 616 / 200	30
243 x 100	2432 x 100 / 100	146

- 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.

Hamamamma (Hamamatsu C10900D)

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

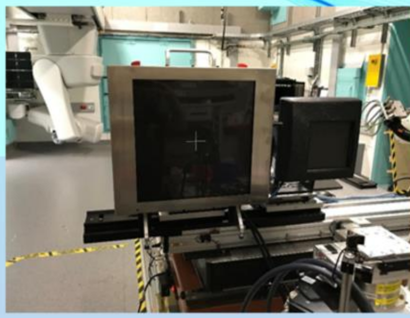


Field of view (mm)	Pixelation/size (μm)	Frame rate (fps)
122 × 123	1216 x 1232 / 100	35
122 × 7	1216 × 72 / 100	70
122 × 123	608 x 618/ 200	17
122 × 62	608 × 310/200	280

- A modern version of the Hamapapa detector.
- Smaller active area, but with 100 micron pixels.

Xenia (Teledyne Xineos 3030HR)

- 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)
296 × 296	2994 x 2997 / 99	31
148 x 148	1497 x 1498 / 99	57
148 x 148	748 x 748 / 198	108

- Our first clinical imaging detector.
- Uses the same technology as the Hamamatsu flat panels.
- A substantially larger active area, with 99 micron pixels.

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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.

Others

- These detectors are not generally available, but can be used for technical developments

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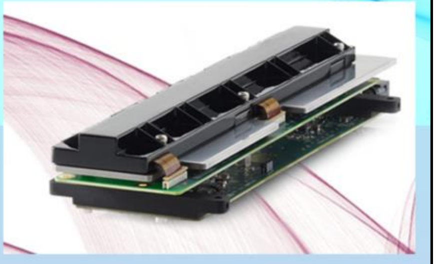
Argus Ceph

- 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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Widepix 1X5

- Sensor: Timepix APS, 1X5 butted chip array
- Coupling: Direct
- Converter: CdTe (1.0 mm)

- High efficiency
- Potential hyperspectral imager
- Small active area

Field of view (mm)	Pixelation/size (μm)	Full frame rate (fps)
70 x 14	1280 x 256 / 55	40

- 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.

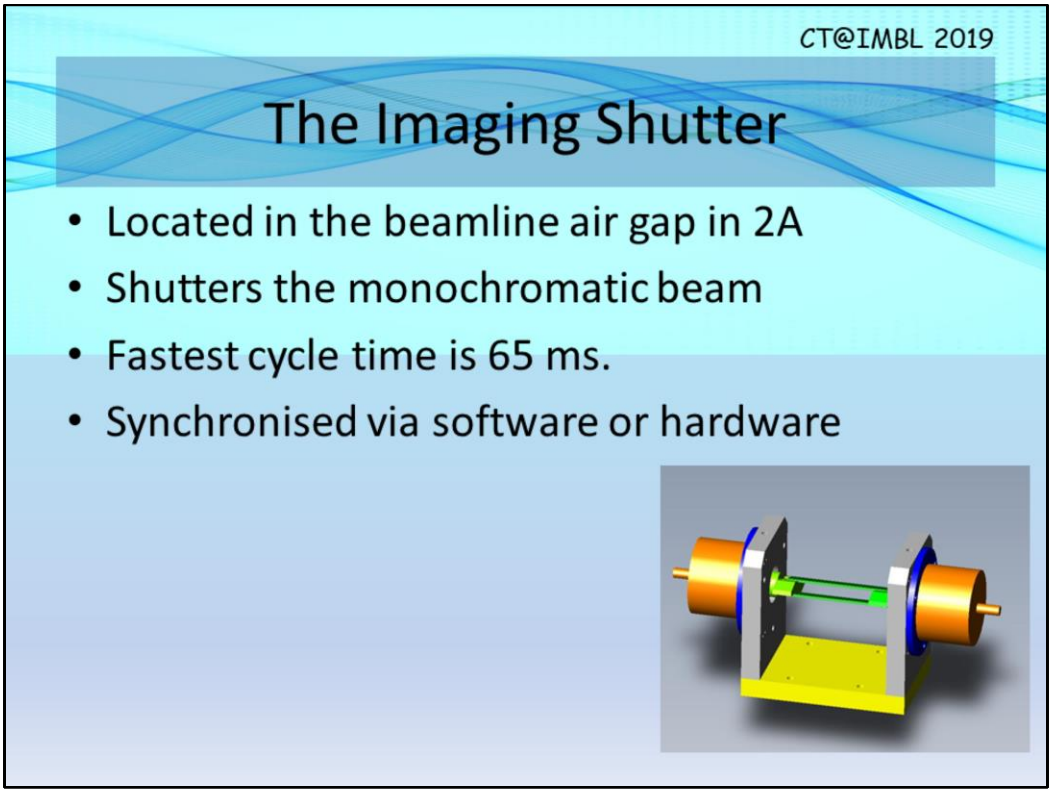
XCounter Actaeon

- Sensor: Proprietary APS
- Coupling: Direct
- Converter: CdTe (0.75 mm)

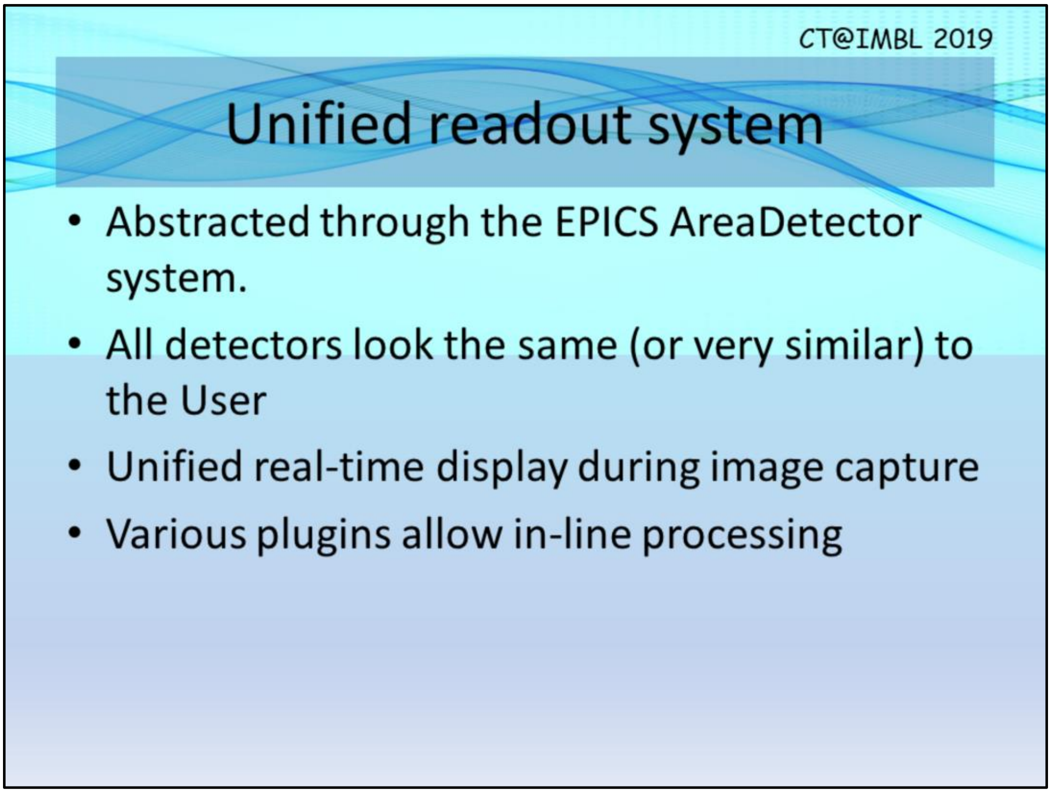
- High efficiency
- Potential for large width
- Good frame rate
- Lower resolution

Field of view (mm)	Pixelation/size (μm)	Full frame rate (fps)
51 x 25	512 x 256 / 100	200

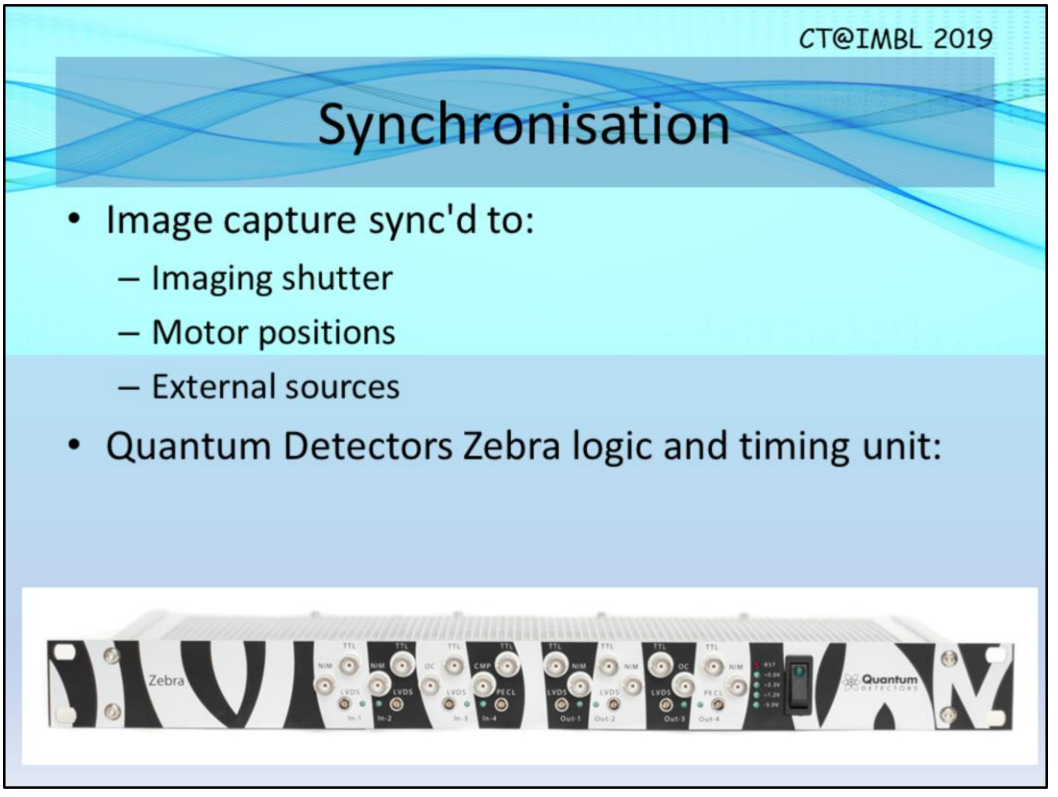
- XCounter can tile their APS chips across a wide area (300 mm).
- The idea is to use this for large area dose sensitive imaging.
- The test device we have at the moment is limited to ~ 5 cm by 2.5 cm active area.



- 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.