MONASH University
Centre for Synchrotron Science

GO Boldly.

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Assessment of signal sharing in a hybrid pixel detector

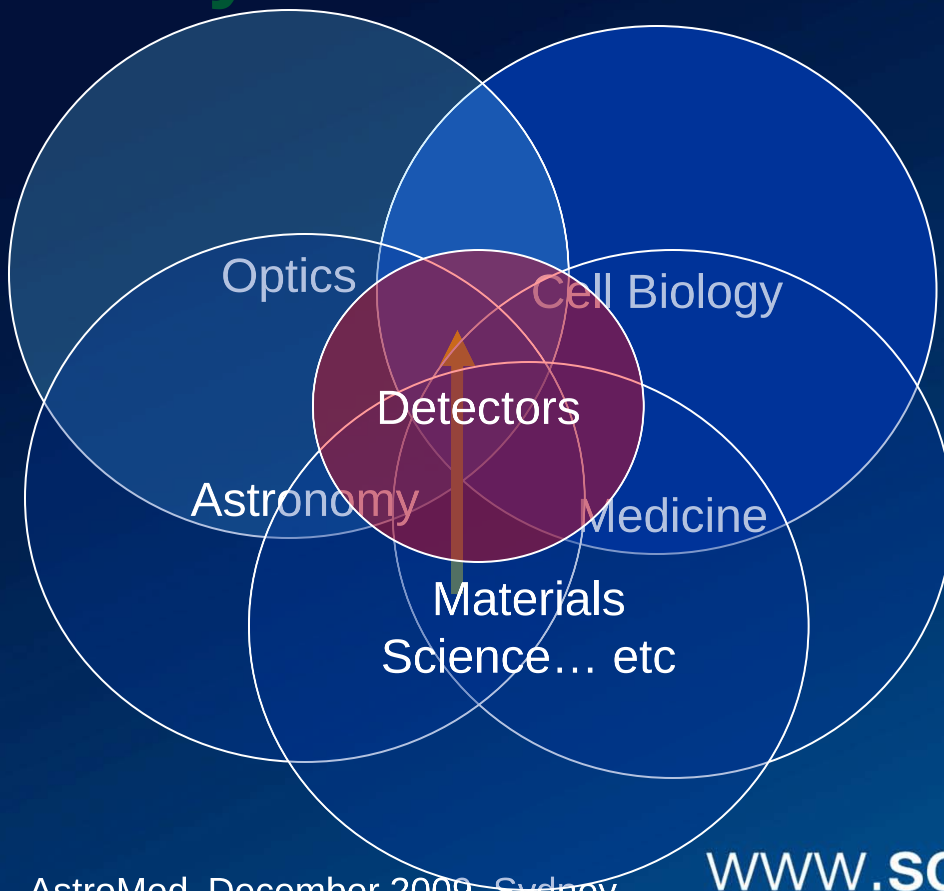
… and the relevance of synchrotron sources

ARC Centre of Excellence for COHERENT X-RAY SCIENCE

AstroMed, December 2009, Sydney

www.sci.monash.edu

Coherent X-ray Science CoE



Trends in biomedical x-ray imaging

- **There is a general demand for improved spatial resolution, over larger fields of view**
- **This is especially true in the life sciences because:**
  - Imaging reveals function and dysfunction
  - Cells are fundamental units, and are small (~ 10 microns)
  - Tissues are complex and need to be viewed on macroscopic scales (in 3-D).

Coherent X-ray Diffractive Imaging (CXDI)

- Exploits the coherence of the illuminating source
- Has the potential to rival electron microscopy in resolution
- Requires far less sample preparation. Could be done in air
- May enable single molecule diffraction patterns using the new FEL sources.

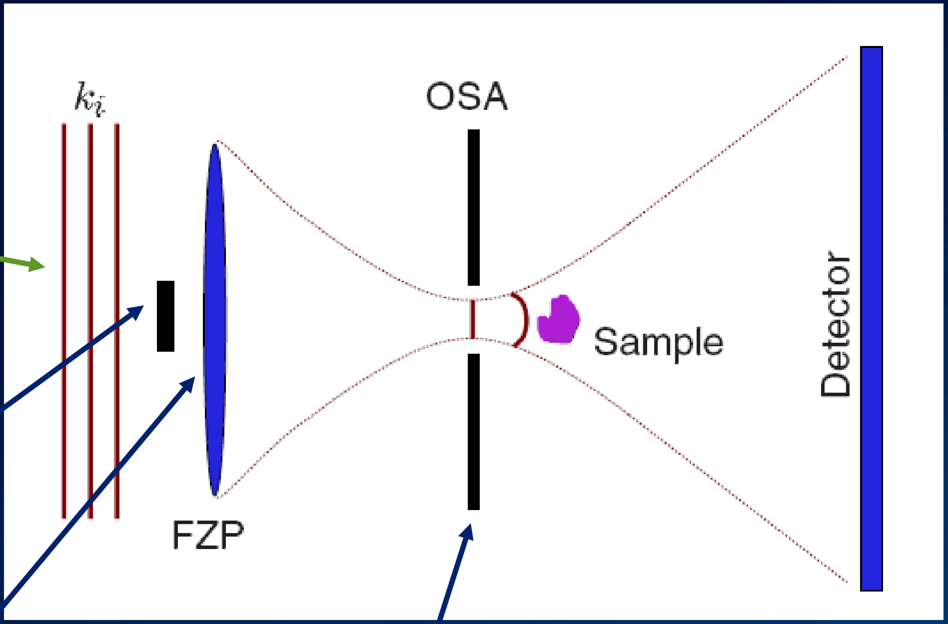
Fresnel CXDI

Incoming coherent x-ray flux

Central stop

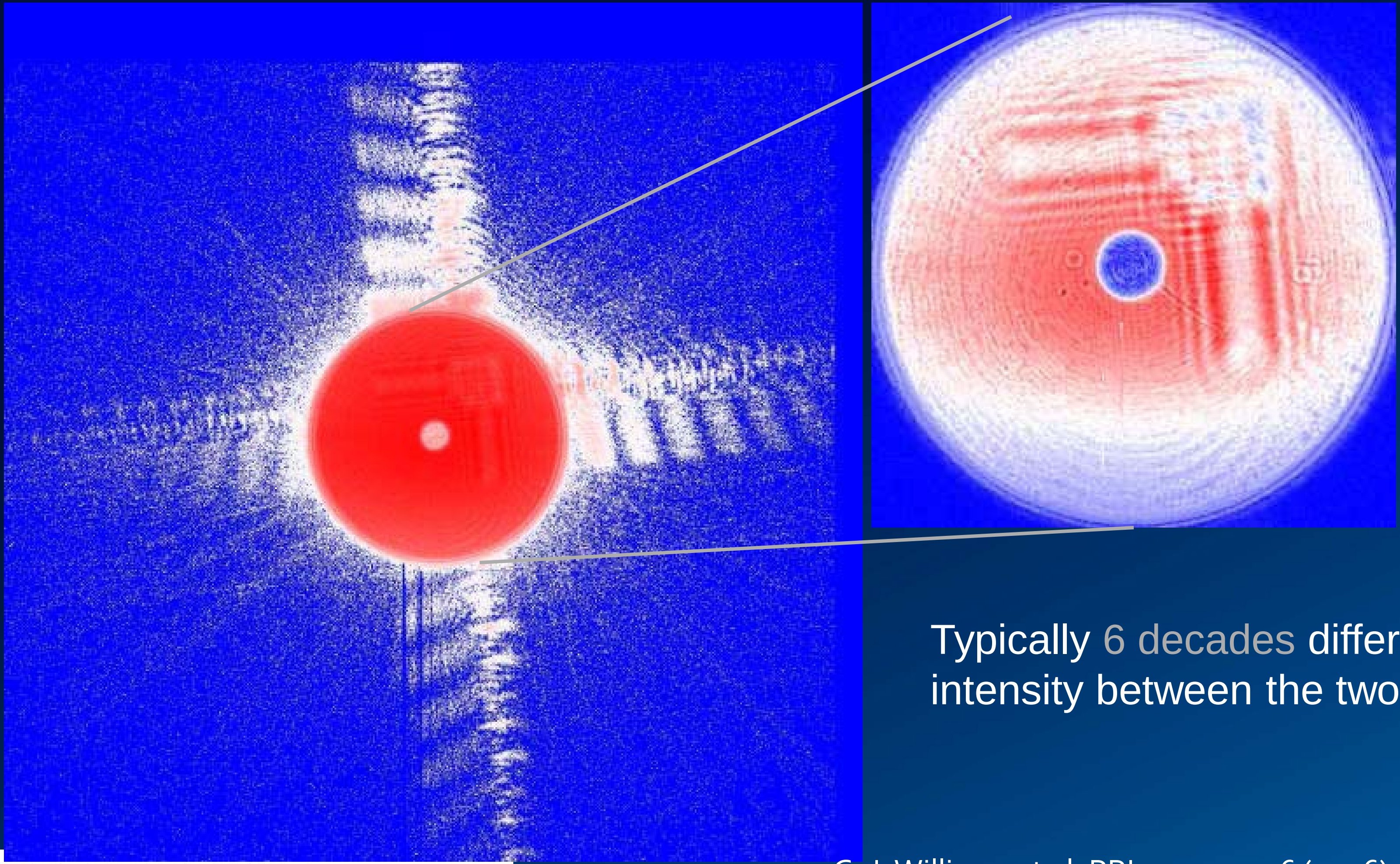
Zone plate ‘lens’

Aperture to remove all but the first order



Propagation distance < 1.5 metres

FCDI image at the detector



Typically 6 decades difference in intensity between the two areas.

G. J. Williams et al; PRL **97**, 025506 (2006)

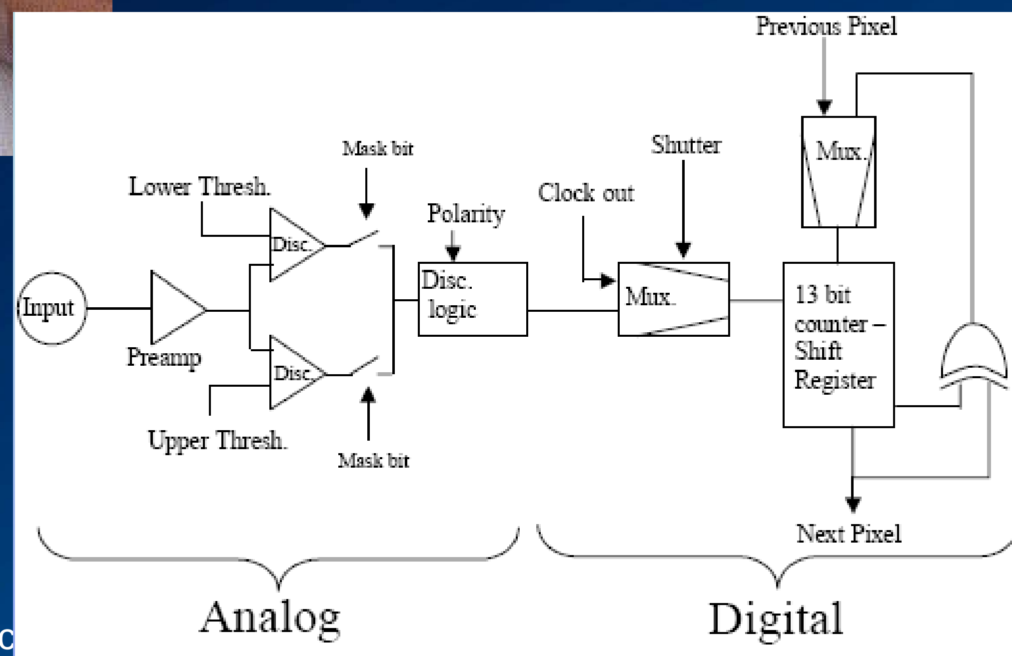
(F)CXDI demands on the detector

Detector characteristic	*Essential for a CXDI detector*	*Desirable for a CXDI detector*
Dynamic range	10^4	10^7
Pixelation	2048 x 2048	>4096 x >4096
Pixel Size	<100 µm	< 50 µm
Energy range	0.5 keV to 3 keV	0.5 keV to 3 keV
Detective Quantum Efficiency	10%	50%
Rate Capability	> 10^4 / pixel/ second	> 10^6 / pixel/ second
Frame rate	1 Hz	1 kHz
Vacuum compatibility	10^{-4} bar	10^{-6} bar
Dead time fraction	10%	1%
Parallax error	< 1 pixel at 20 degrees	None
Gaps in FOV	Acceptable	None

- Square pixels of 55 µm
- 256 x 256 pixels per chip
- Sensitive to positive or negative charge
- Leakage current compensation per pixel
- Maximum count rate: ~1 MHz

- Energy windowing
- 13 bit counter per pixel
- 90 msec serial, 0.3 msec parallel readout
- Three side buttable

For more information see:
http://medipix.web.cern.ch/MEDIPIX/



X-ray detector interactions 101

- Cascade of energy exchange produces mobile charge. (Usually modelled as a sphere.)
- Initial radius of this sphere approximated by the range of the highest energy electron (Continuous Slowing Down Approximation range)
- This is usually much smaller than the electrodes used to detect it.
- The size of the initial charge cloud increases with diffusion over time
- The effect of the size of the cloud needs consideration at the edges of the electrode
- Can we use signal sharing to improve the detector resolution?

Sampling the charge cloud

- **Can we sample the charge cloud? There may be information from the size and shape that can be used to gain more information (see the poster by Jeremy Brown).**
  - Depth of interaction knowledge
    Diffusion changes the cloud size – is this important?
  - More accurate positioning
    Use a parameter other than a weighted centroid to estimate first interaction position
  - Photo electron 'tracking'

Detector system modelling

Geometry / material parameters

Photon interactions and electron transport (GEANT4)

Static electric field model

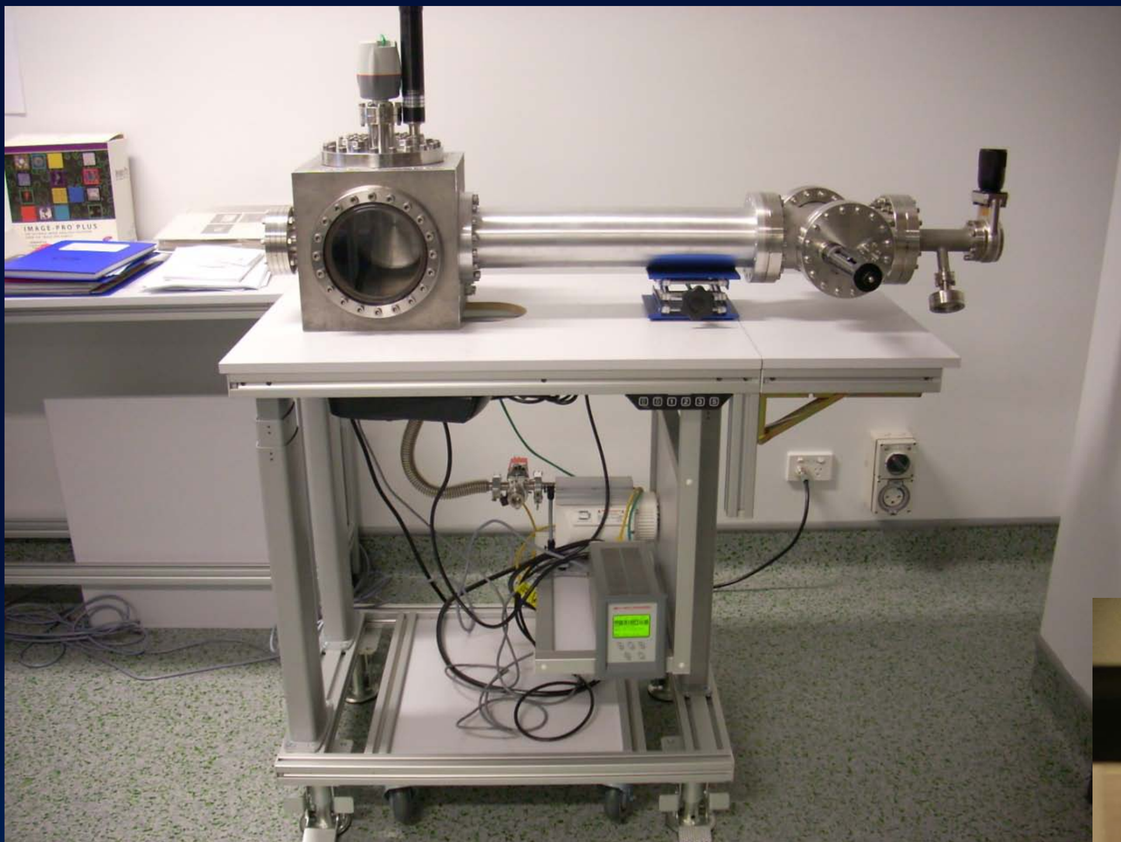
Weighting potentials / fields (MGS)

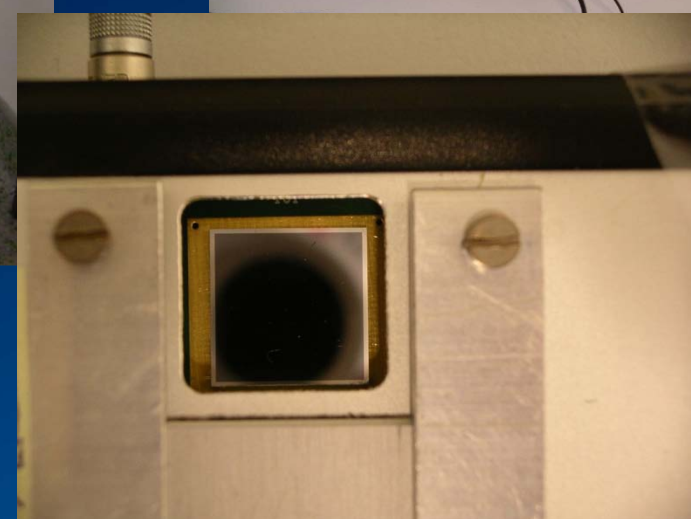
Signal generation and data processing

Results

Verification using hardware

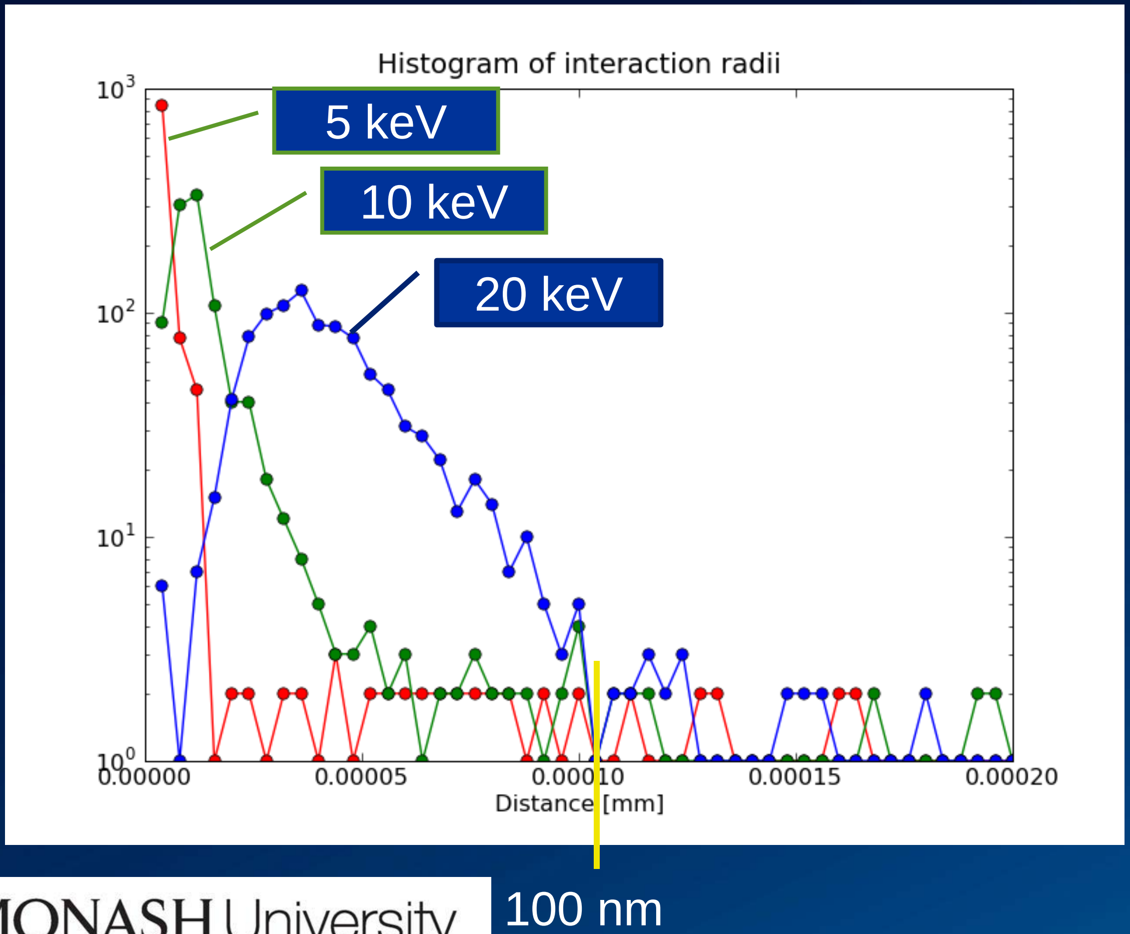
Avoid the cost of prototyping, before design.
Risks are minimised





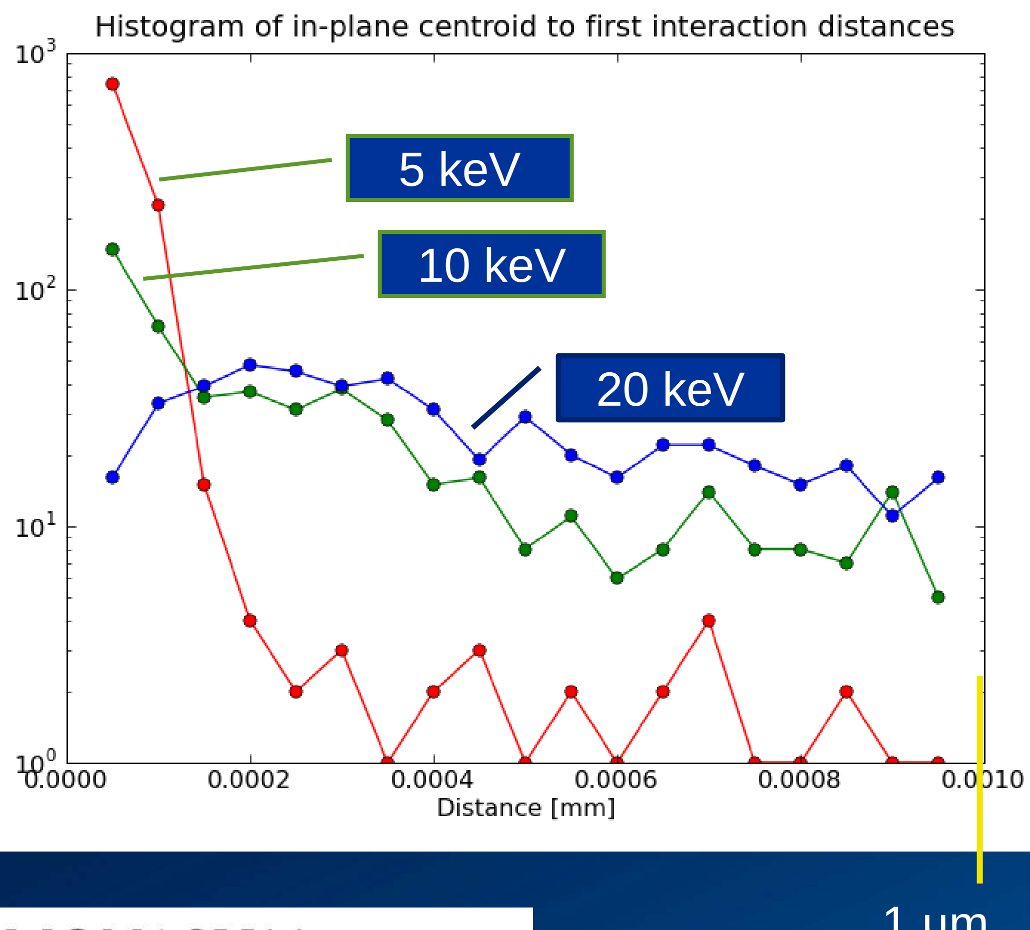
Vacuum system for low energy x-ray testing

Radius of initial charge creation region in silicon



- GEANT4 simulation using low energy physics…
- Radius defined as the distance from the weighted centroid of the cloud to the farthest energy deposit in the history.

- Confirms that for low energies initial charge cloud size is << than the final size due to diffusion



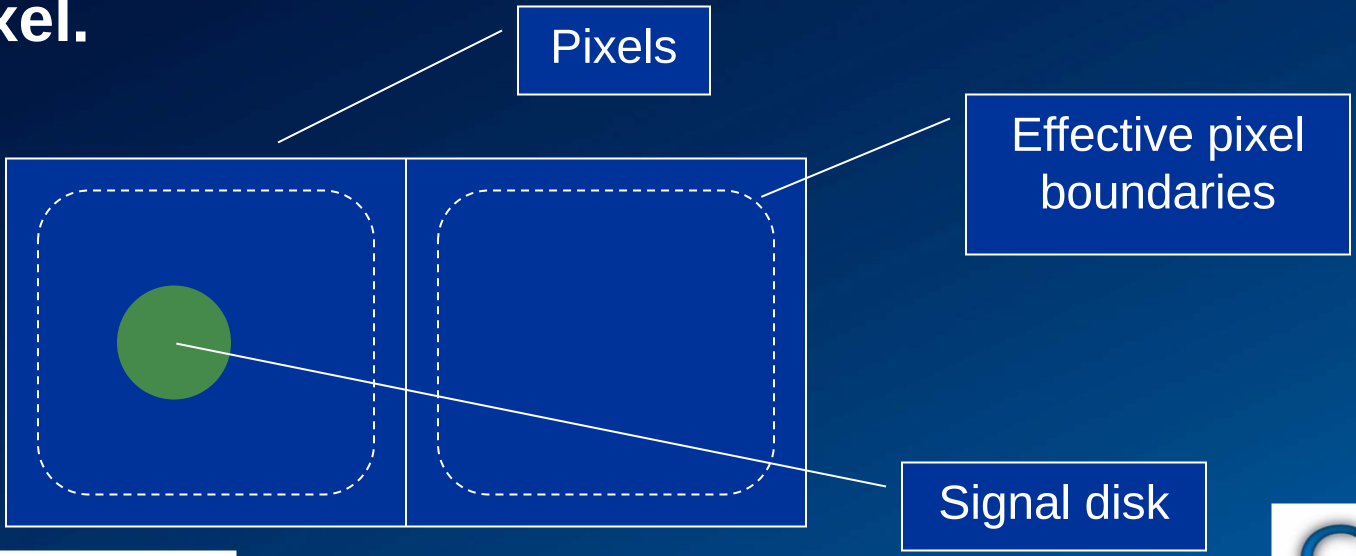
- The first interaction position is what we really want to measure.
- A charge weighted average of the diffuse cloud is what we would actually measure.
- For low energies the weighted centroid is a good approximation of the initial interaction position

Counting photons

- We want to end up with a measurement that accurately reflects the numbers of detected photons per output pixel (voxel)
- Easiest if pixel size is = to the physical electrode size.
- Modern lithography means electrode sizes might be made commensurate with charge cloud size (for high energies).
- Coupled with new high z detector materials (CZT etc) to detect higher energy photons => cloud sizes increase.

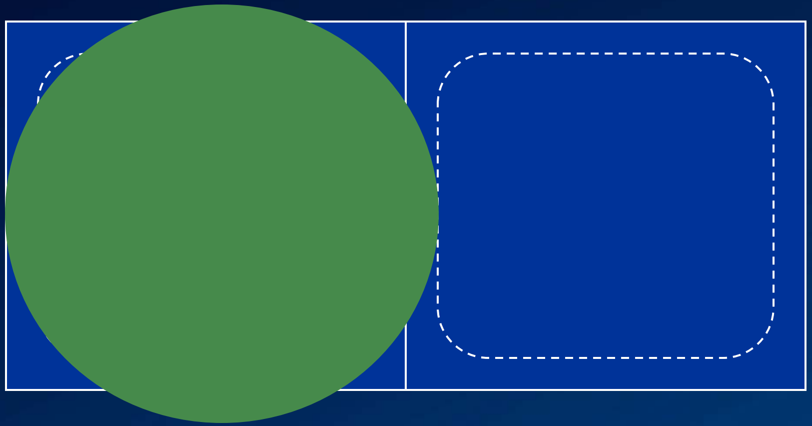
Simple geometric model

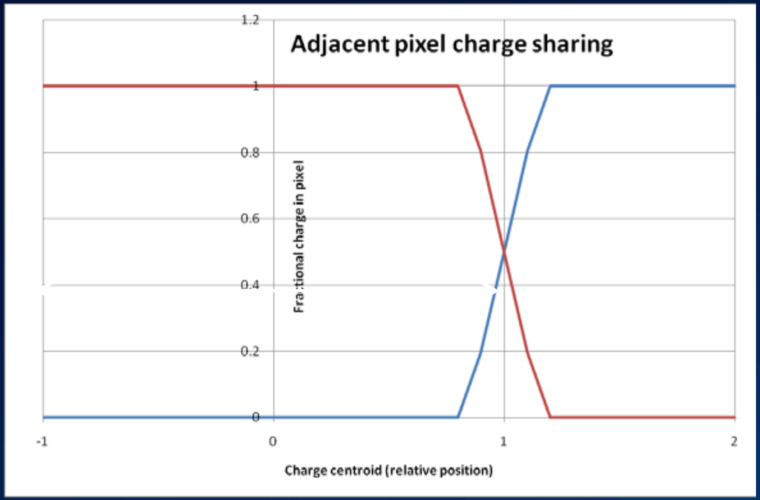
- **Signal distribution across electrodes is modelled as a disk**
- **Superimpose this on electrode structure and calculate signal sharing based on area in each pixel.**



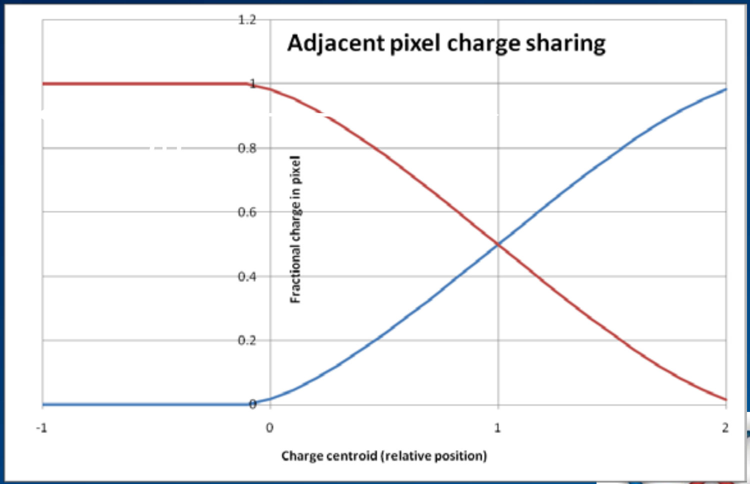
Charge division in strip detectors

At the cost of reduced rate (and SNR) the spatial resolution can be increased by using the signal sharing





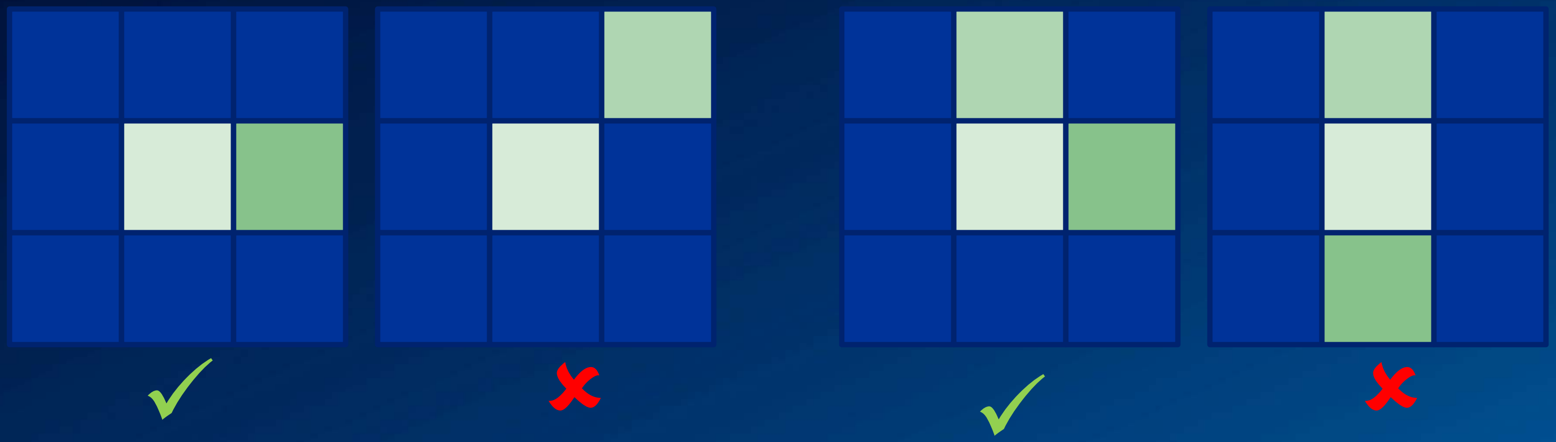
Charge cloud = 0.3 P



Charge cloud = 1.2 P

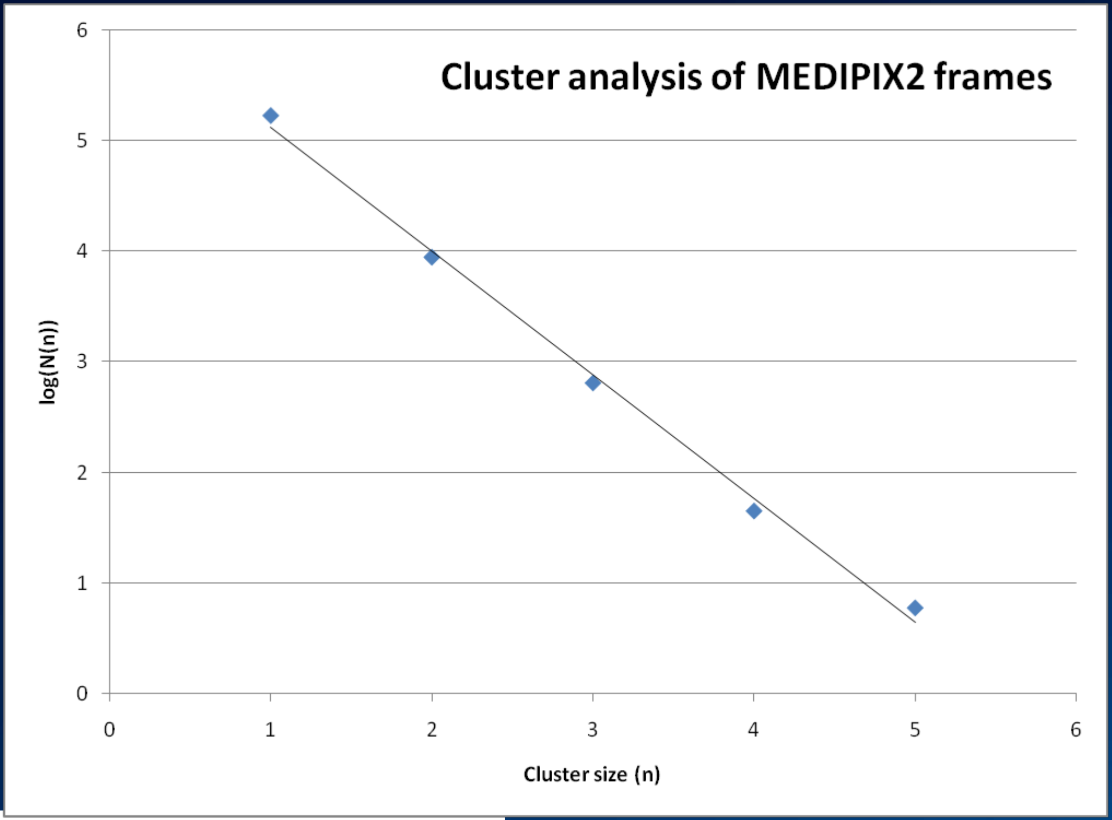
Cluster analysis

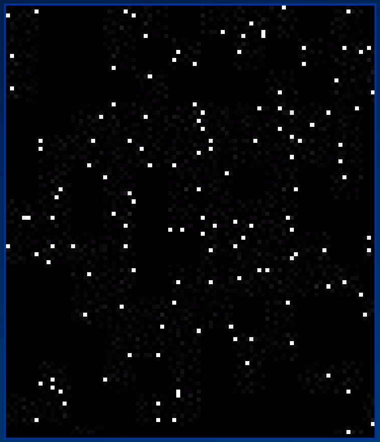
- **Signal sharing expected only over adjacent pixels**
- **Use cluster analysis on single events to evaluate the charge sharing.**



Data from Medipix

- **Statistical treatment of a uniform illumination to determine signal sharing.**

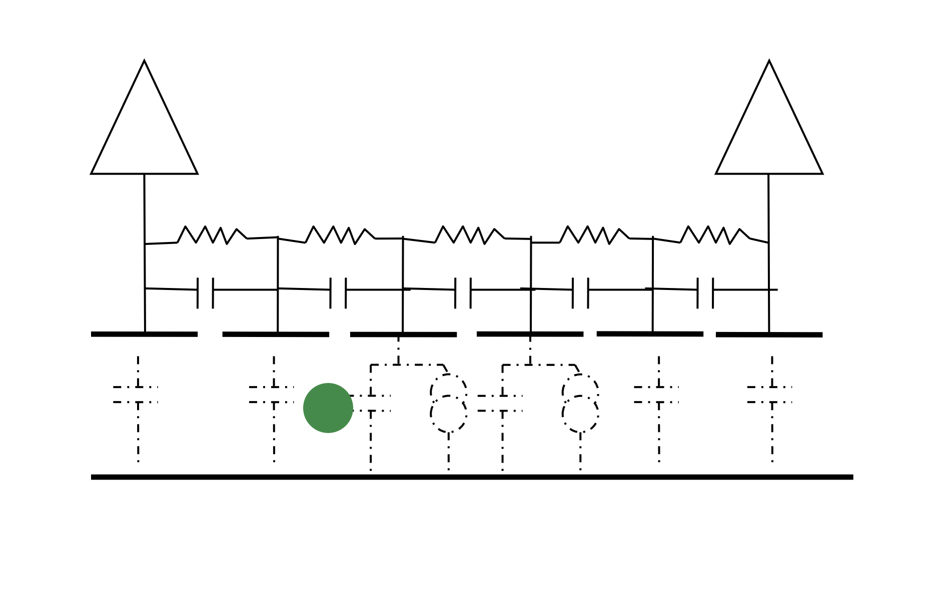




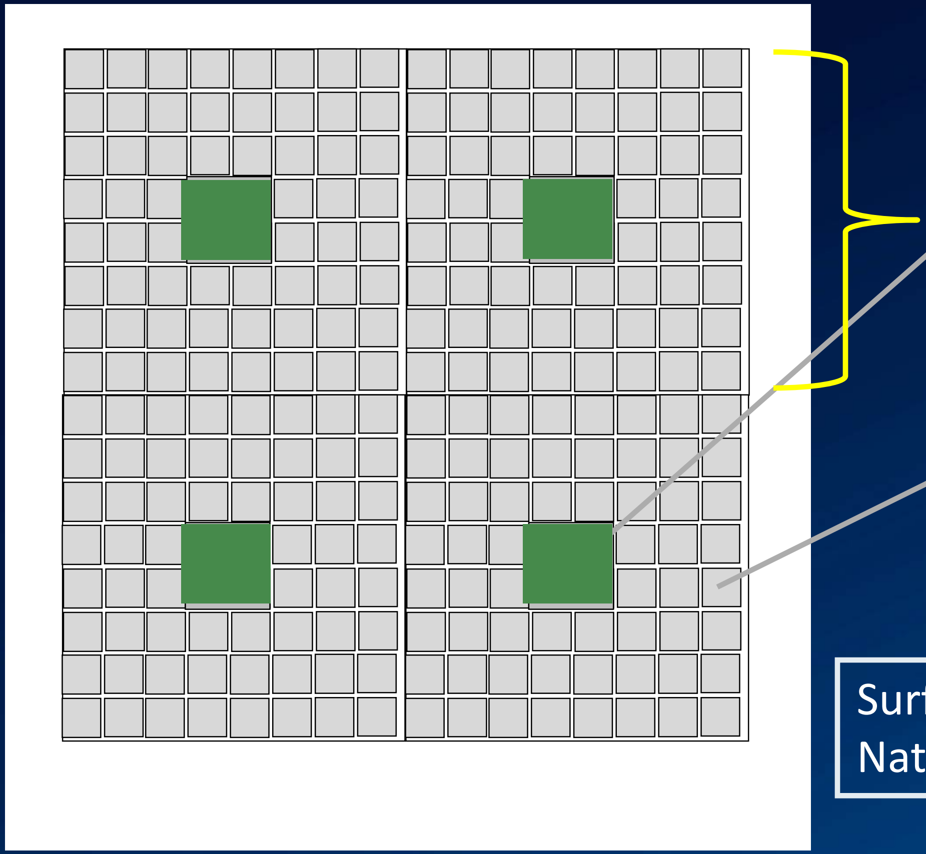
Compare the statistical expectation of the size of clusters with that measured.

Signal sharing in a strip detector

- **Non readout electrodes coupled with RC network**



Signal division in 2-D



Pixel size 200 μm

Minimum bond pad size = 50 μm

Sub-pixel pad size = 25 μm

Surface treatment provides bias resistance.
Natural capacitance provides A/C coupling.

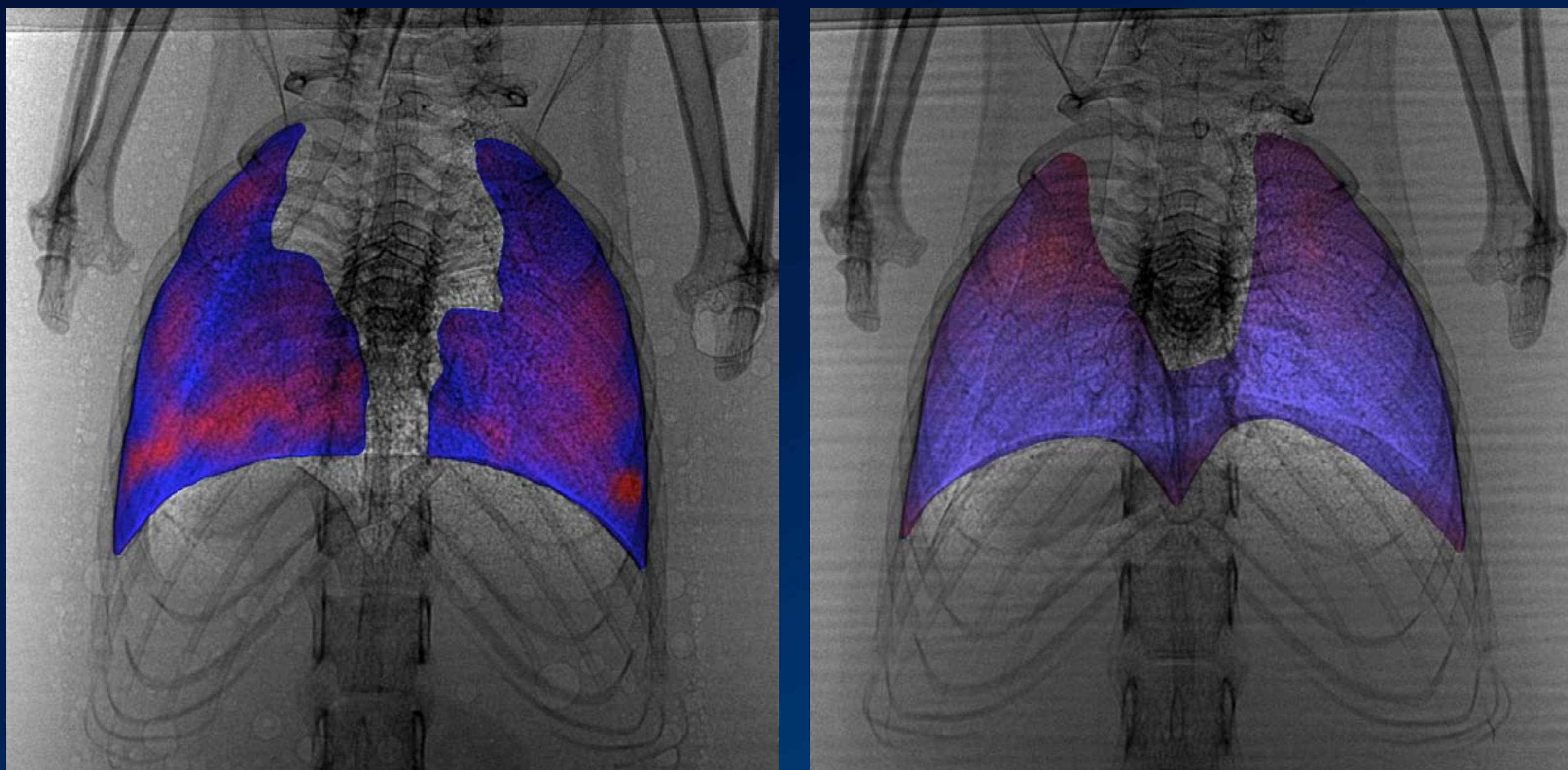
Parting shot – synchrotron radiation in medicine

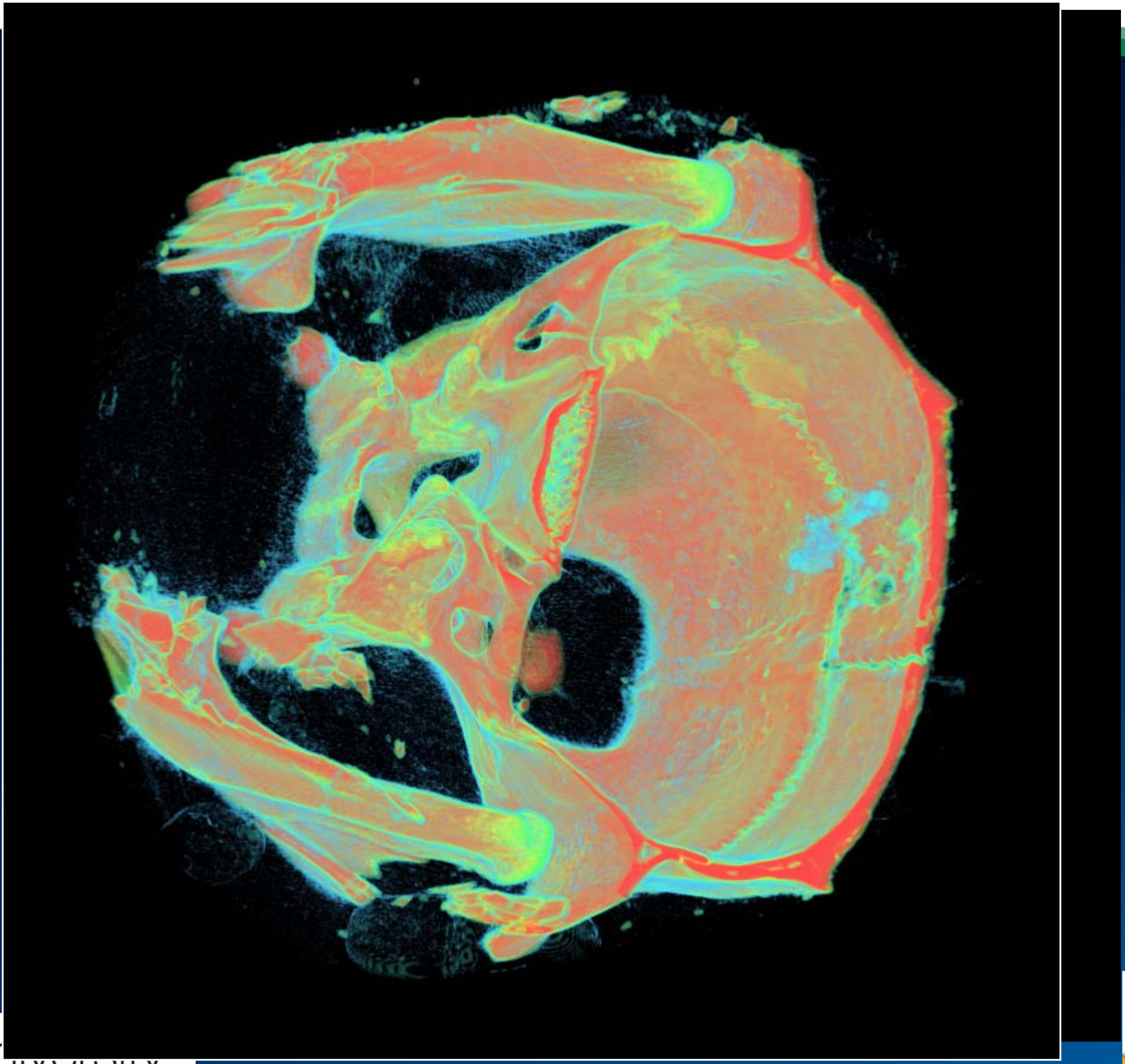
Imaging and Medical Beam Line (IMBL)

IMBL

- Radiotherapy (1A/1B) – small intense polychromatic beams
- Moderate size imaging (2A/2B) – 10 cm wide, 1 cm high mono/poly-chromatic beams
- Large object imaging (3A/3B) – 60 cm wide 5 cm high mono/poly-chromatic beams

Lung aeration studies





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Thank you for your attention

The meetings of Biology and Synchrotron Radiation (BSR) and Medical Applications of Synchrotron Radiation (MASR)

15th-18th February 2010 **Melbourne Convention and Exhibition Centre, Australia**

For further information:

http://www.masr2010.org/

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