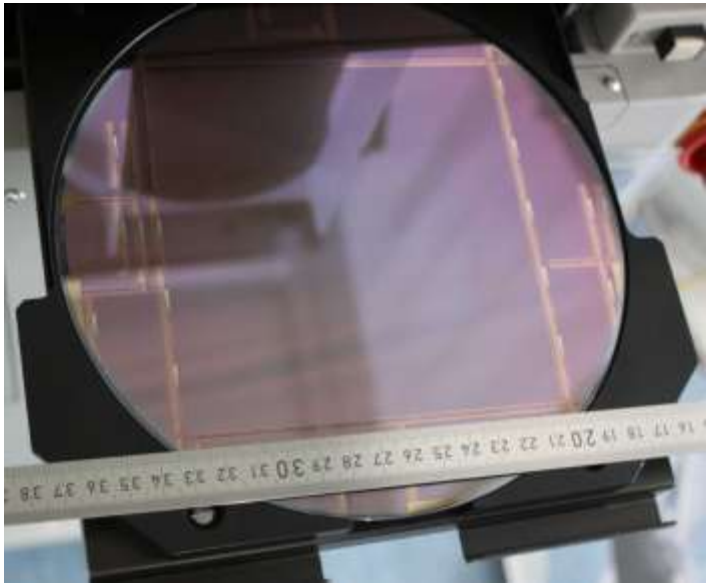
A novel wafer-scale CMOS APS x-ray detector for breast cancer diagnosis using x-ray diffraction studies

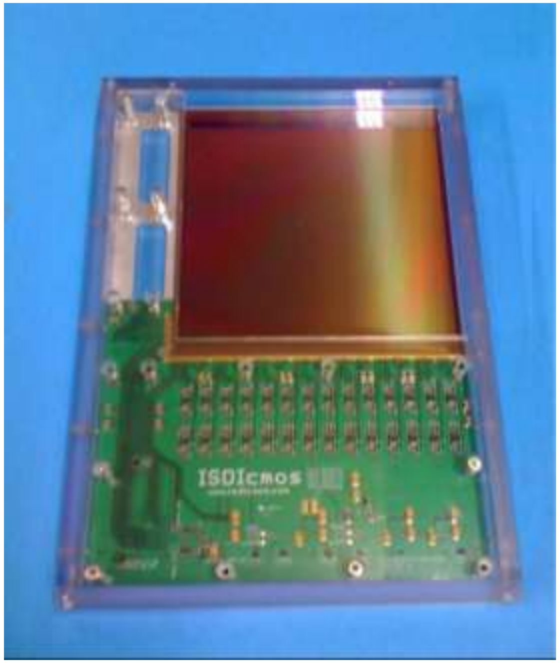
Anastasios Konstantinidis[1], Yi Zheng[1], Dany Philip[2], Thalis Anaxagoras[3,4], Michela Esposito[5], Nigel Allinson[3,4] and Robert Speller[1]

[1]Department of Medical Physics and Bioengineering, University College London, U.K.
[2]School of Engineering and Materials Science, Queen Mary University of London, U.K.
[3]Image Engineering Laboratory, University of Lincoln, U.K.
[4]ISDI Ltd, Oxford, U.K.
[5]Centre for Vision, Speech and Signal Processing, University of Surrey, U.K.

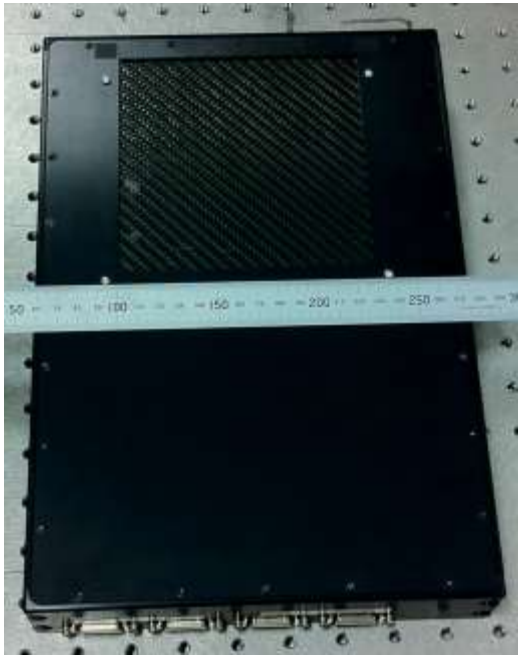
Outline of the presentation



[Esposito *et al.*, Proc IEEE NSS, 2011]



[Esposito *et al.*, JINST, 2011]

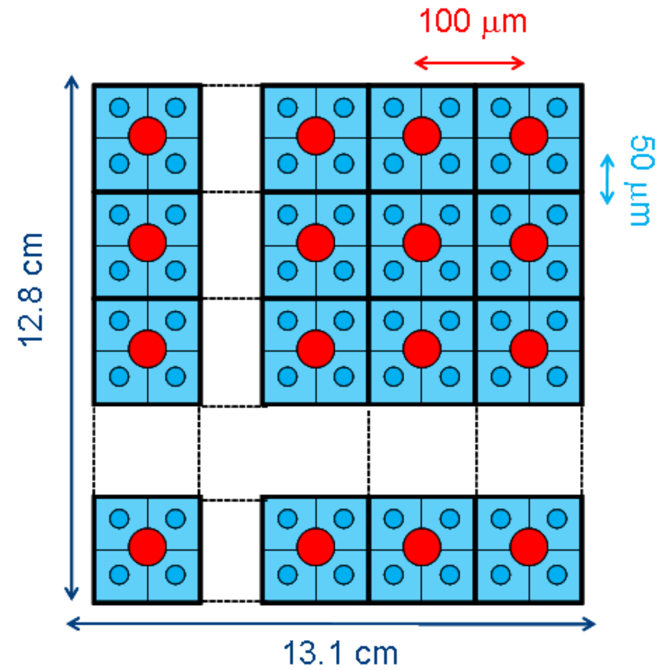


[Konstantinidis *et al.*, Proc SPIE, 2012]

1. Overview of DynAMITe
2. X-ray performance of DynAMITe (MTF, NPS, DQE)
3. ADXRD measurements and breast tissue analysis
4. Conclusions / Future work

1. Overview of DynAMITe

- DynAMITe: Dynamic range Adjustable for Medical Imaging Technology
- The Multidimensional Integrated Intelligent Imaging Plus (MI^3 +) consortium (Lincoln, UCL, Surrey and ICR)
- Special properties of the detector: P and SP camera, destructive and non-destructive readout.
- Applications
  - Tissue imaging & diffraction
  - Radiotherapy verification
  - Proton imaging
  - Life science imaging



[Esposito *et al.*, JINST, 2011]

Pixels (P) camera:

1280 x 1312 pixels (100 µm)

Sub-Pixels (P) camera:

2560 x 2624 pixels (50 µm)

2. X-ray performance in terms of DQE

- Detective Quantum Efficiency (DQE): The ability of an x-ray detector to transfer the Signal-to-Noise Ratio (SNR) from input to output (i.e. to translate the input x-rays to useful signal).

$$DQE(f) = \frac{SNR^2 out}{SNR^2 in} = \frac{pMTF^2(f)}{\Phi \cdot NNPS(f)} = \frac{pMTF^2(f)}{\frac{\Phi}{K_a} \cdot K_a \cdot \frac{NPS(f)}{(\overline{Signal})^2}}$$

pMTF: Presampling Modulation Transfer Function (spatial resolution)

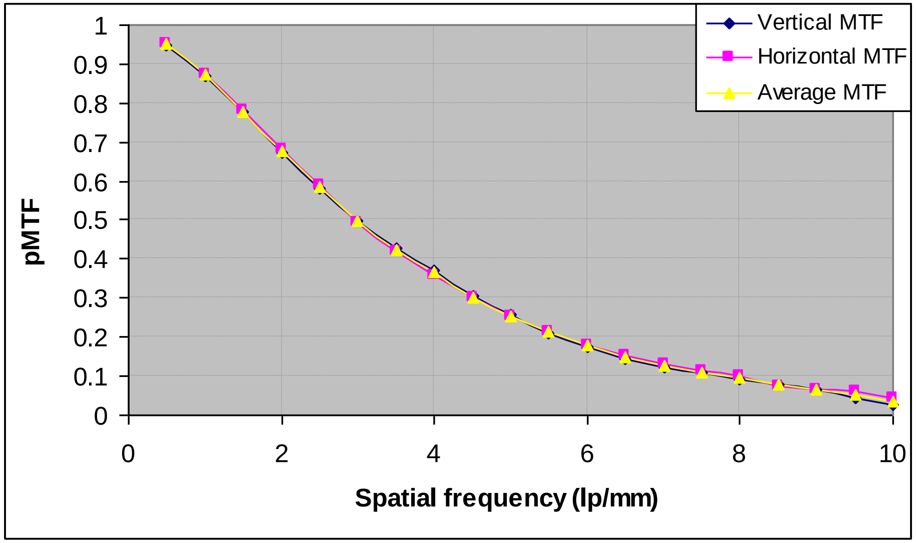
NPS: Noise Power Spectrum (Variance as a function of frequency)

Φ: Photon Fluence (x-rays per mm^2)

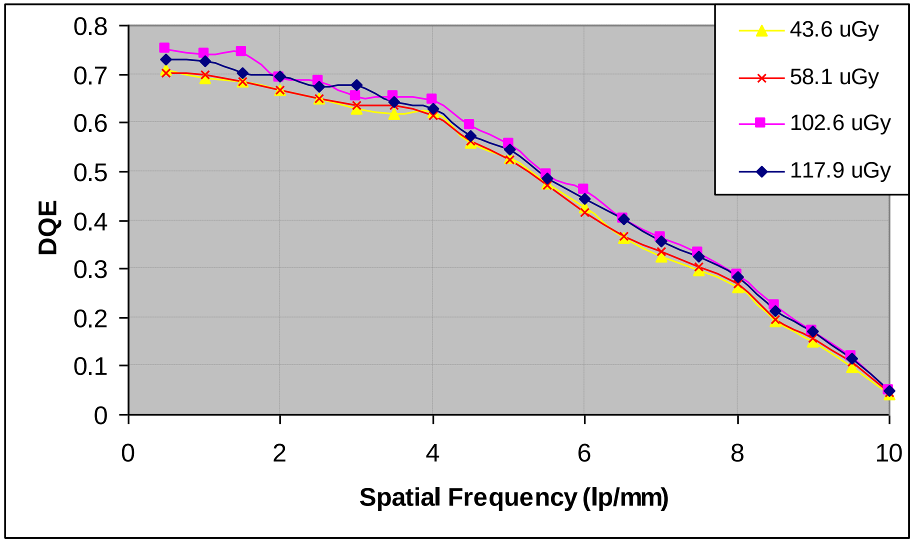
K_a: Air Kerma at detector surface

Signal: Average Digital Number (DN)

2. X-ray performance of DynAMITe



Presampling MTF



DQE

1) SP camera only

2) 200 µm CsI:Tl scintillator

2) The measurements were made according to the IEC 62220-1-2 standard:

- W anode x-ray source at 28 kV
- Al filtration to achieve 0.83 mm Al HVL
- Source to Detector Distance (SDD): 65 cm
- Tilted edge to get the pMTF

2. DynAMITe vs other digital x-ray detectors

Detector	Detector technology	X-ray absorber material	Radiation quality	pMTF 50% (x;y – lp/mm)	DQE peak (x;y) at specific Ka level
[1] **FUJIFILM *AMULET***	a-Se TFT	200 µm a-Se	W/Rh (28 kV)	4.4	0.75 at 103 µGy
[2] **Sectra *MicroDose***	Direct photon counting	Crystalline Si wafer	W/Al (28 kV)	6.2; 3.3	0.63; 0.61 at 113 µGy
[3] **Fischer *Senoscan***	CCD	180 µm CsI:Tl	W/Al (28 kV)	5.5	0.24 at 131 µGy
[3] **GE *Senographe 2000D***	a-Si:H TFT	100 µm CsI:Tl	Mo/Mo (28 kV) (RQA-M 2)	4	0.53 at 131 µGy
[4] **Hologic *Lorad Selenia***	a-Se TFT	200 µm a-Se	Mo/Mo (28 kV) (RQA-M 2)	5.8	0.59 at 92.5 µGy
[5] **LAS**	CMOS APS	150 µm CsI:Tl	W/Al (28 kV)	1.5	0.73 at 60.3 µGy
[5] **Hamamatsu *C9732DK***	CMOS PPS	160 µm CsI:Tl	W/Al (28 kV)	3.3	0.48 at 120.5 µGy
[5] **Anrad *SMAM***	a-Se TFT	200 µm a-Se	W/Al (28 kV)	6.1; 5.3	0.67; 0.66 at 108.6 µGy
[5] ***Remote* RadEye *HR***	CMOS APS	85 µm Gd_2O_2S:Tb	W/Al (28 kV)	4.3	0.33 at 120.5 µGy
DynAMITe SP camera	CMOS APS	200 µm CsI:Tl	W/Al (28 kV)	3	0.75 at 102.6 µGy

[1] [Rivetti *et al.*, Med. Phys., 2009] [2] [Honey *et al.*, CEP, 2006] [3] [Lazarri *et al.*,Med. Phys., 2007]

[4] [Blake *et al.*, CEP, 2006] [5] [Konstantinidis, PhD thesis, UCL, 2011]

3. Tissue imaging and the X-ray Biopsy Project

Basic concept:

1) Take mammogram

2) Identify suspicious regions and follow suspected disease infiltration

3) Determine complete region affected by disease and plan surgery

All carried out at the same examination

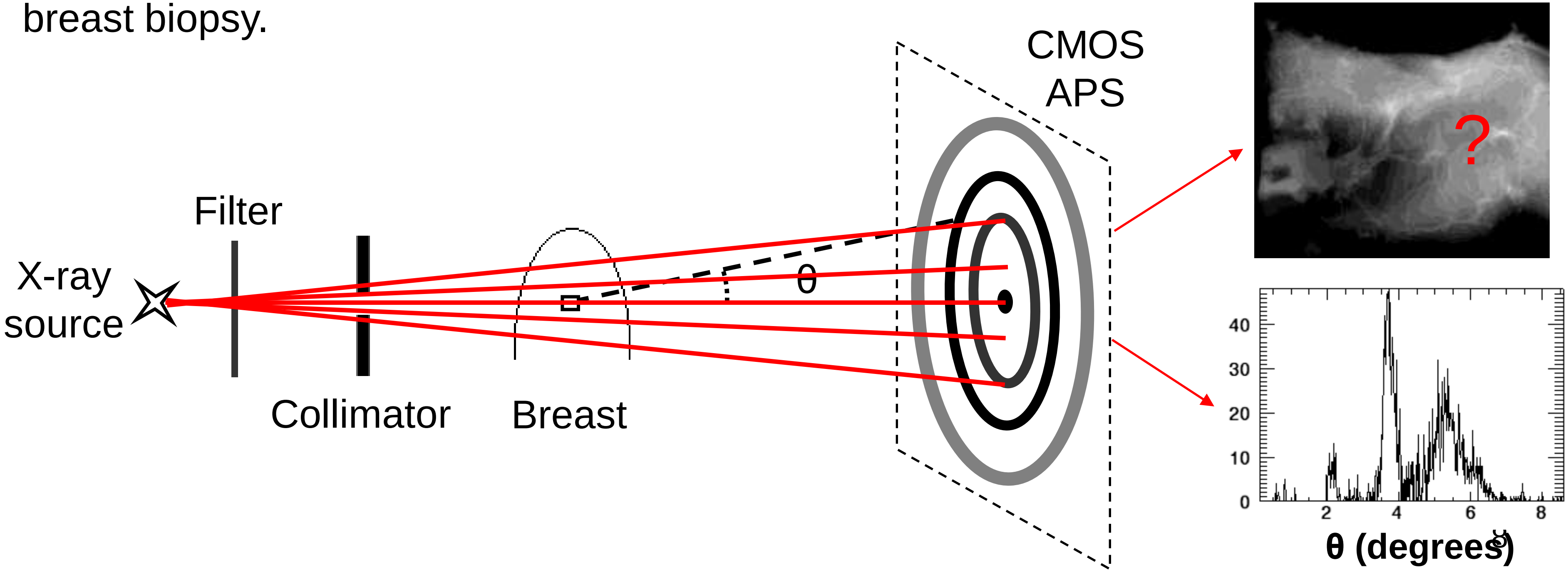
3. X-ray Biopsy Project – setup

1) Use DynAMITe for mammographic imaging

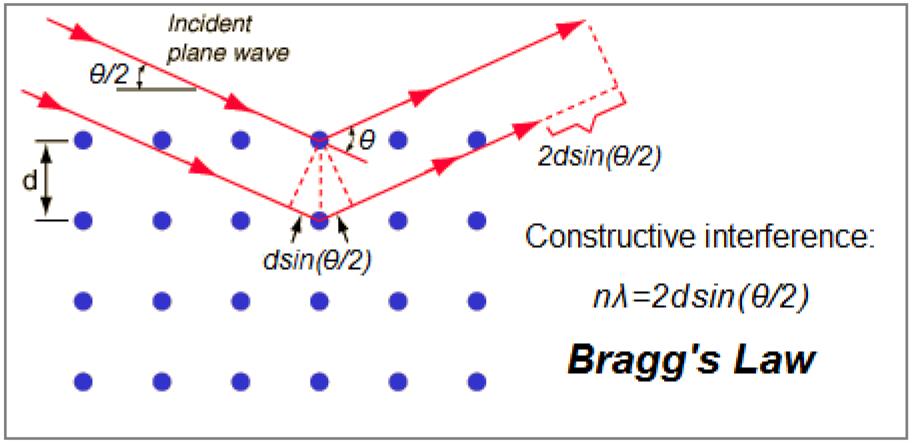
- Capture a mammogram
- Identify suspicious areas on the mammogram

2) Combine the absorption imaging with XRD measurements

- Move filters and pinhole collimators using LabVIEW through the selection of an ROI on the mammogram to perform Angle Dispersive X-ray Diffraction (ADXRD) breast biopsy.



3. Interpretation of tissue XRD measurements



Momentum transfer x (nm^{-1}):

$$x = \frac{1}{2d} = \frac{E}{hc}\sin\left(\frac{\theta}{2}\right)$$

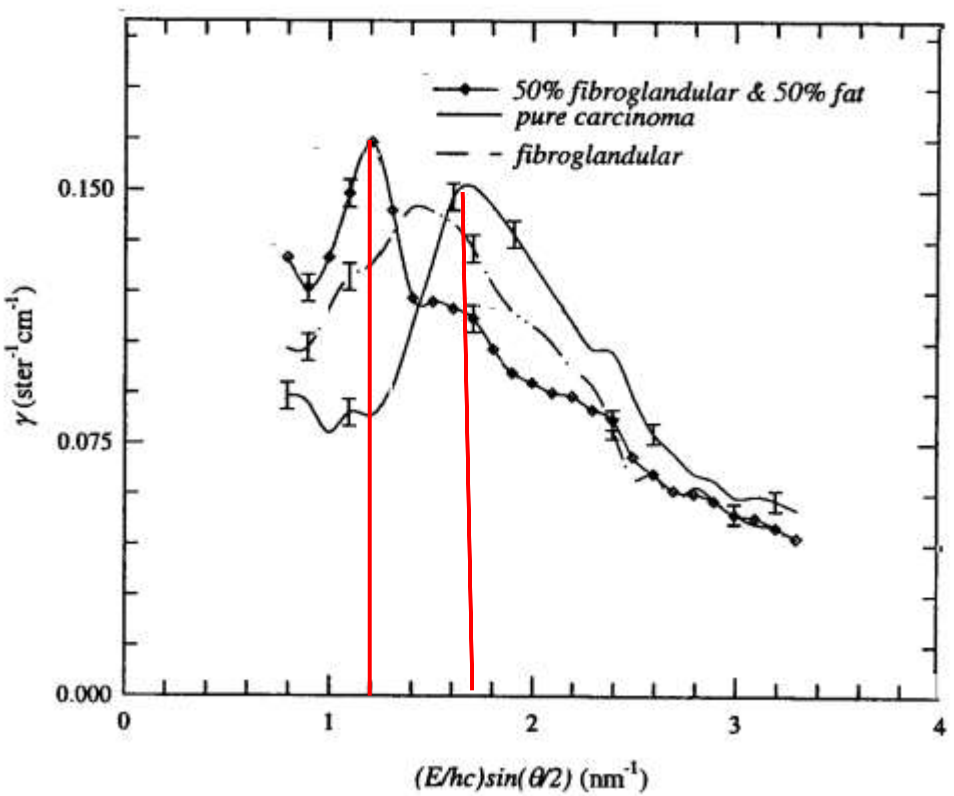
d: distance between the atoms (in nm)

E: Energy of X-ray photons (in J)

h: Planck's constant (i.e. $6.63 \cdot 10^{-34}$ $m^2 kg/s$)

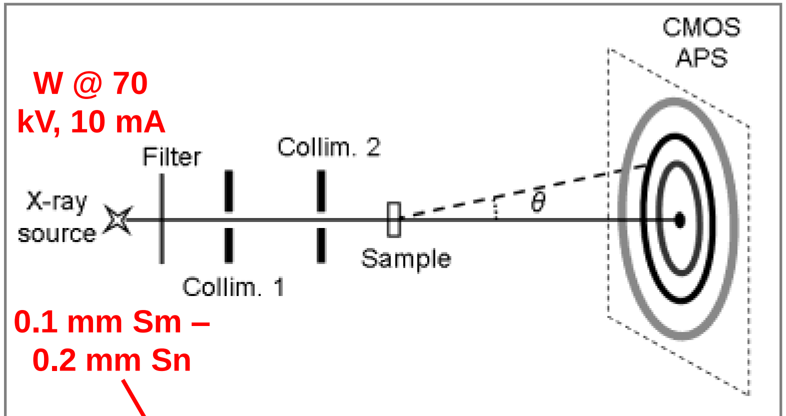
c: speed of light (i.e. $3 \cdot 10^8$ m/s)

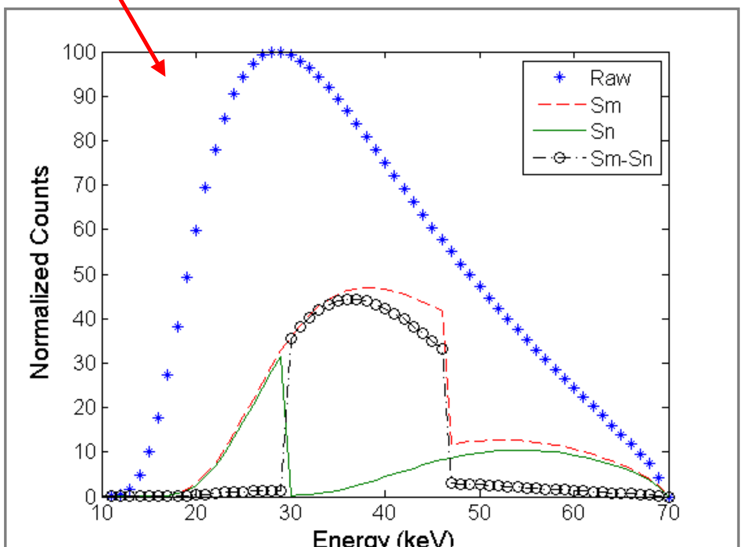
Momentum transfer for breast

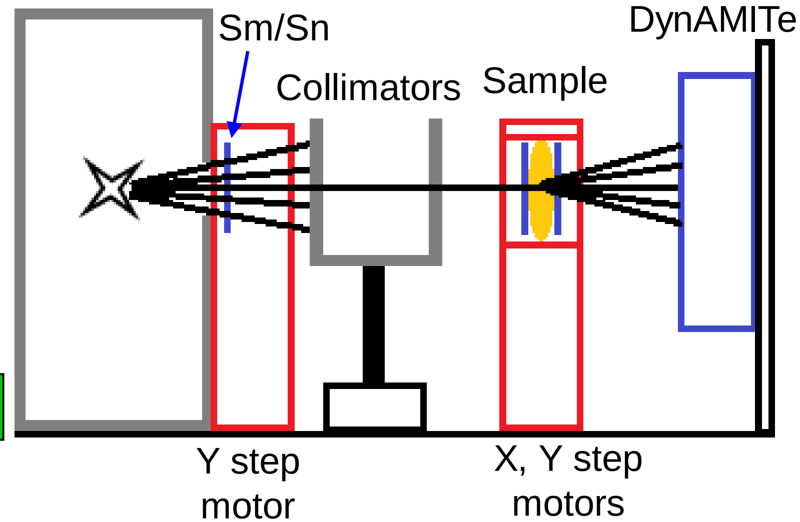


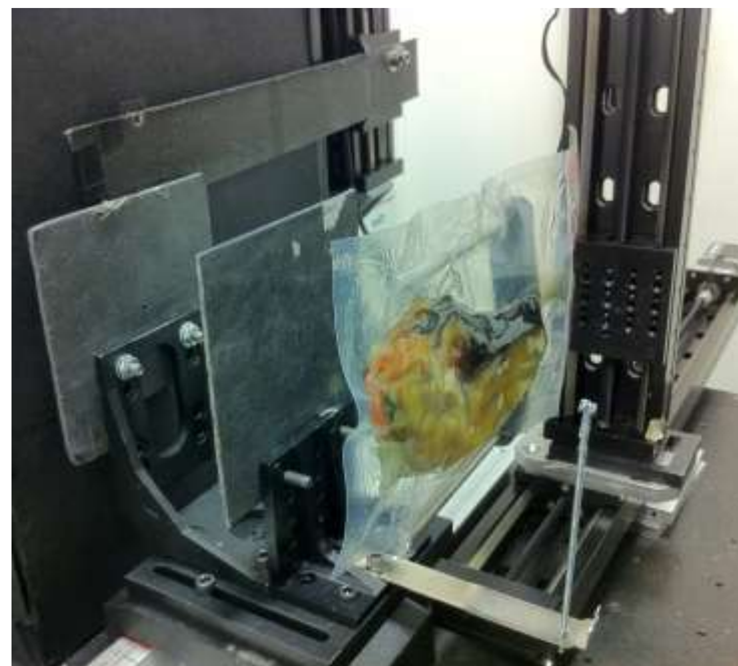
[Kidane *et al.*, Phys. Med. Biol., 1999]

3. Angle Dispersive X-ray Diffraction setup





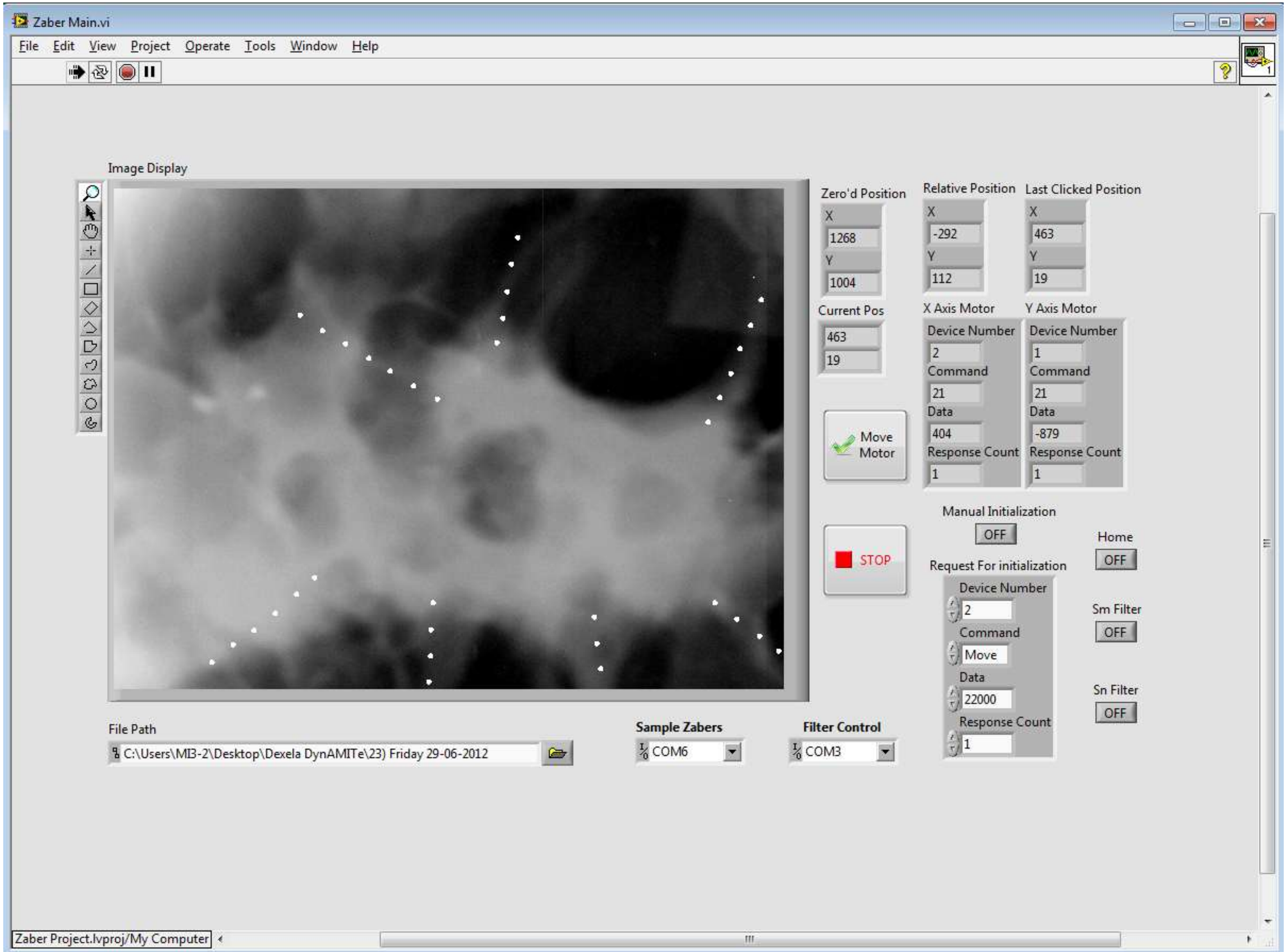




	Raw spectrum	Balanced filters (Sm-Sn)
Mean En. (keV)	36.5	38.5
Spectral width (%)	33.3	16.1

[Bohndiek *et al.*, Phys. Med. Biol., 2008]

3. Custom-made software used for automation



3. Mammograms and ADXRD measurements (1)

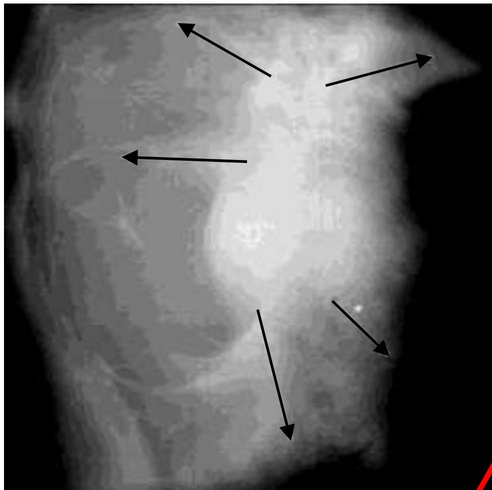
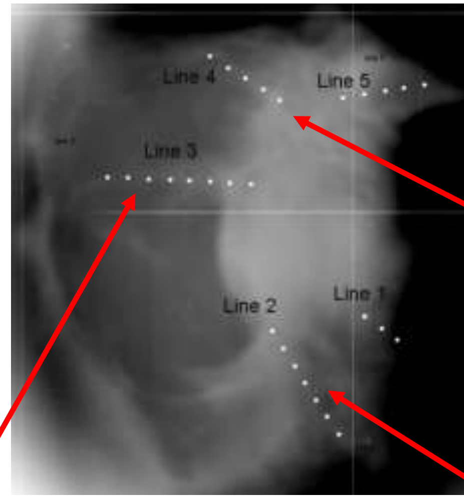
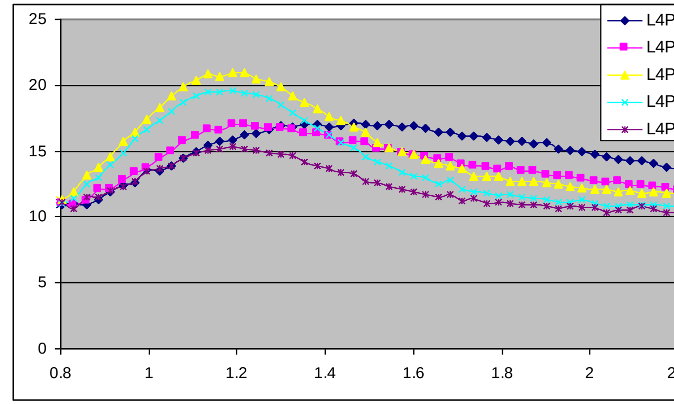


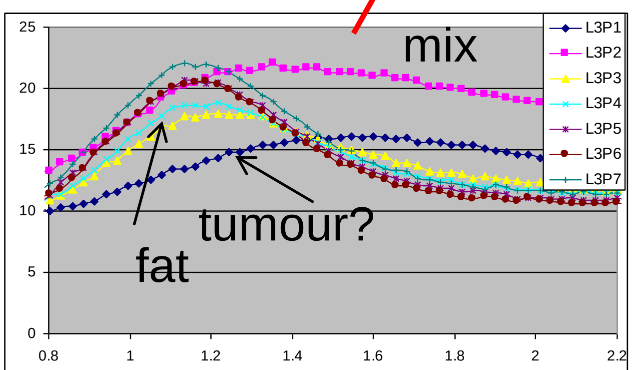
Image marked up by radiologist



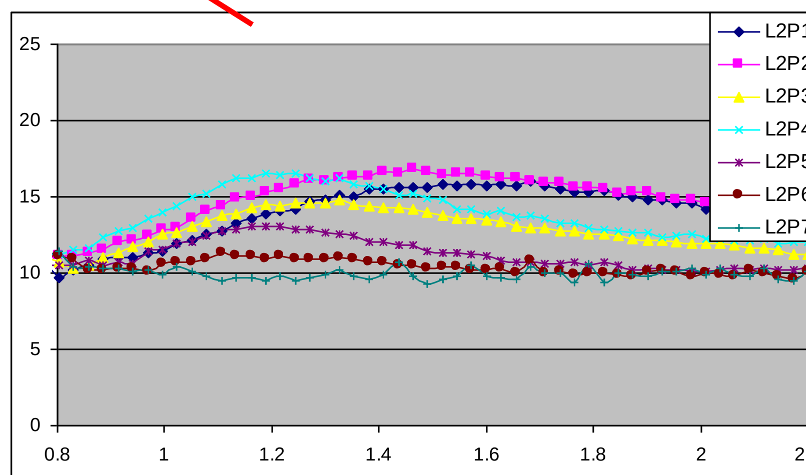
DynAMITe image



Momentum transfer (nm^{-1})



Momentum transfer (nm^{-1})



Momentum transfer (nm^{-1})

Conclusion: edge of tumour well defined as seen in image

3. Mammograms and ADXRD measurements (2)

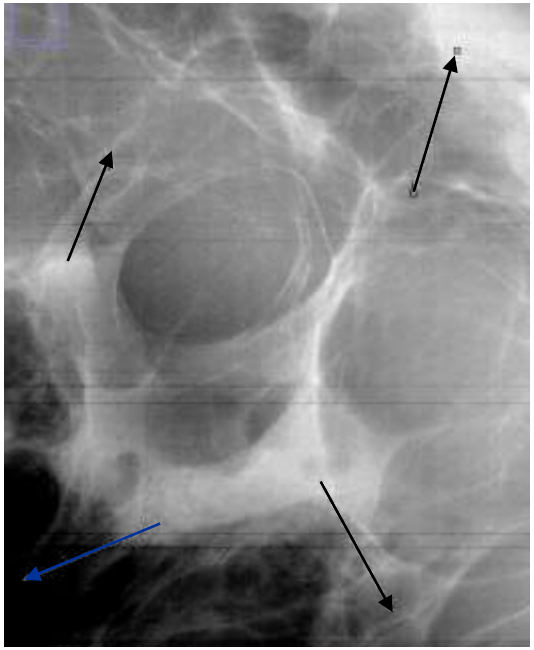
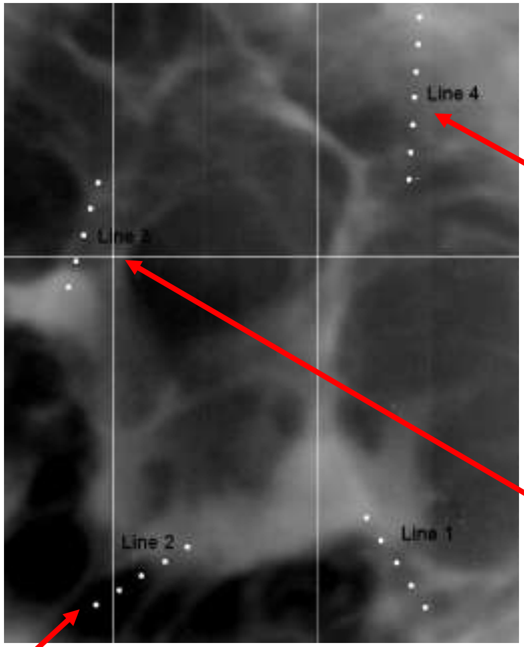
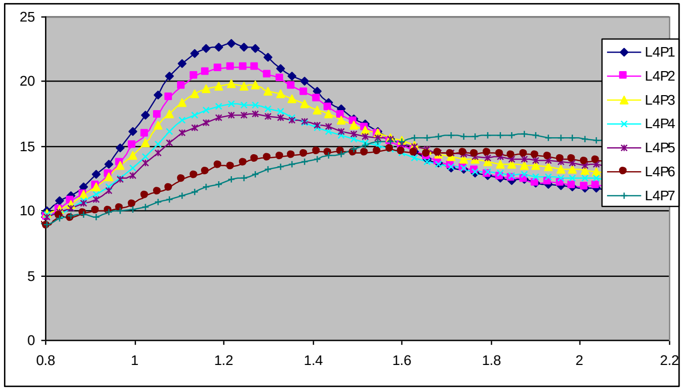


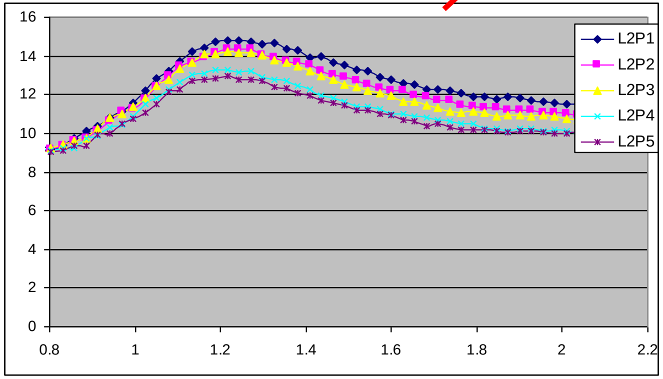
Image marked up by radiologist



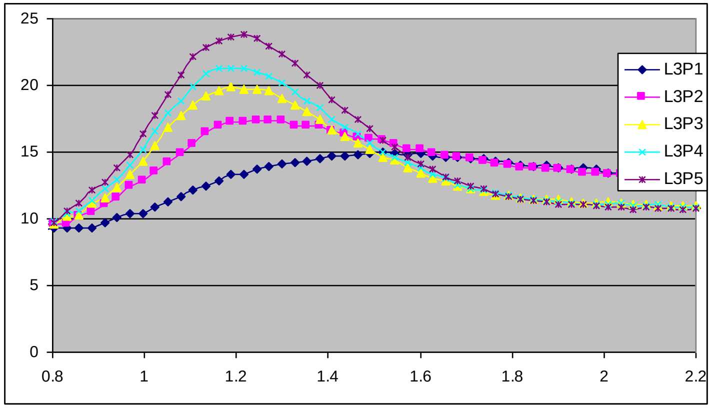
DynAMITe image



Momentum transfer (nm^{-1})



Momentum transfer (nm^{-1})



Momentum transfer (nm^{-1})

4. Conclusions / Future work

- We built a system that captures mammograms and applies x-ray breast biopsy in one examination.
- The maximum DQE of DynAMITe detector is quite high (~ 0.75 maximum).
- Evidence of tumour invasion seen in diffraction data that is not seen in mammograms.
- We will build a digital library with XRD patterns and use multivariate analysis (MVA) to identify the percentage of tumour in unknown areas.
- We will use micro-focus Mo/Mo (anode/filtration): a) no need for balanced filtration and b) better quality mammograms.
- Future versions of DynAMITe will allow us to normalize the scatter signature based on the primary beam.