Advantages of using the Compton radiation for radiography

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Instrumentation developments for High energy physics
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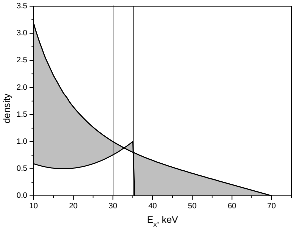
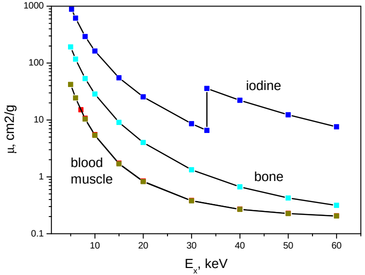
Imaging: Compton Radiation vs Bremsstrahlung



Compton spectrum vs. bremsstrahlung

- Bremsstrahlung radiation
  - Spectral density decreases with energy
  - Maximal energy $\approx$ kinetic energy of electrons
  - Wide cone of radiation
  - Relatively low energy of electrons (compact source)
- Compton x–radiation
  - Spectral density increases with energy
  - Pencil–like cone of radiation, $\Delta\psi \sim 10\,\mathrm{mrad}$
  - Energy of electrons necessary $50 \ldots 100\,\mathrm{MeV}$
  - Steep high–energy cutoff: slope width $\sim \Delta E_e / E_e$
  - Maximal energy $\propto \gamma^2$ – tunable

Angiography



Attenuation coefficients from [NIST]

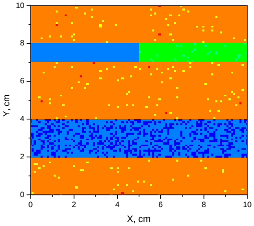
- Blood attenuation = muscle one
- Radio–contrast agent (e.g. iodine) added
- Peripheral angiography: subtraction technique – digital subtraction angiography (DSA). 2–3 frames per second
- Pulsing object (heart) demands multiple – 15–30 frames/sec (x–movie)

Compton K-Edge Angiography

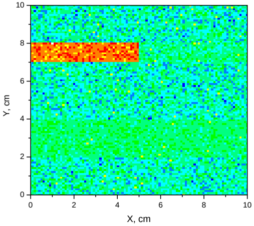
[E.Bulyak, J.Urakawa, RREPS 2013, arXiv:1312.6785 (2013)]

- Procedure
  - Obtain the image at $E_x^{\max} < E_k$
  - Obtain the image at $E_x^{\max} > E_k$
  - Produce sum of the images
    (to enhance statistics)
  - Produce difference of the images to reveal localization
- Expected
  - Contrast agent may be injected before
  - Subtraction possible for pulsing object (heart)
  - Shorter time of picturing
  - Small number of frames sufficient

Compton K-Edge Angiography
[E.Bulyak, J.Urakawa, RREPS 2013, arXiv:1312.6785 (2013)]



sum



dif

Simulation parameters

- Tissue density (g cm^{-2})
  - muscle – 5,
  - bone – 0.5,
  - blood – 0.5,
  - iodine – 0.0125
- Compton radiation
  - Ideal spectrum,
  - Range (21–30) keV and (23–35) keV
- Statistics
  - # photons 2×10^7 per spectrum
  - Mesh 100×100 pixels
  - Random position, uniform distribution

Phase–Contrast Imaging

Advantages stem from small phase volume x–ray beams

- Objects (specimen):
  - thin
  - composition varies slightly
- Compton beams – small phase volume:
  - small opening angle (almost parallel)
  - narrow spectral width
  - small emitting area (tens of micrometers)

Phase contrast principle

Permittivity of electron gas is proportional to its density

turn of the wave front

$n = 1 - \delta + i\beta$

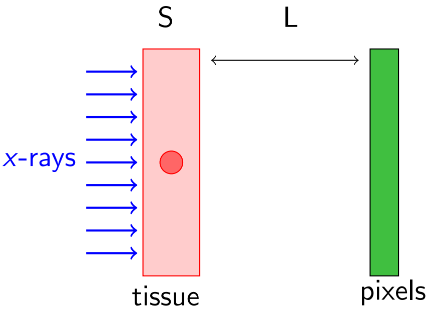
$\beta \ll \delta \ll 1$

$$\Delta\theta = -415.19 \frac{\Delta s \nabla_{\perp} \rho_r}{\epsilon^2} \left\langle \frac{Z}{A} \right\rangle$$

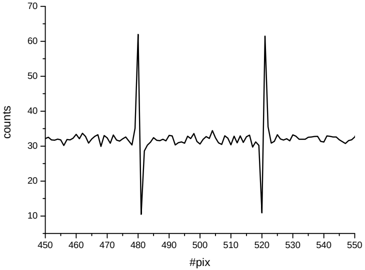
enhance in spatial resolution/contrast

- contrast in tiny inhomogeneity
- weak inhomogeneity disclosure

Phase Contrast: Edge Enhancement

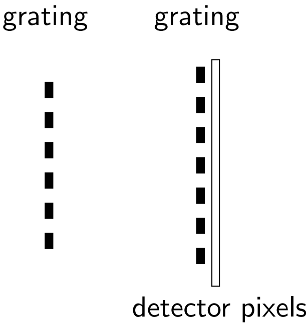


Edge–enhancement setup



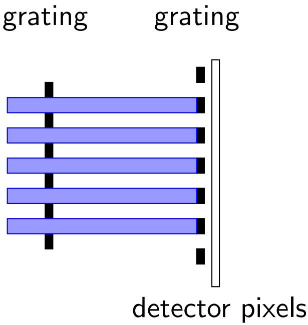
- \# photons 10^6.
- Tissue thickness 10 cm, density $1.02\,\mathrm{g/cm^2}$.
- Fiber radius 10 μm density $2.04\,\mathrm{g/cm^2}$.
- X-energy range 22.5–30 keV,
- Distance tissue–pixel array 2 m.

Dark-Field Imaging Principle



- Gratings adjusted to block the ‘light’
- Diffracted rays passed through second grating produce image
- Second grating not necessary if the screen is a pixel sensor (interleave of diffracted – absorbed images)

Dark-Field Imaging Principle



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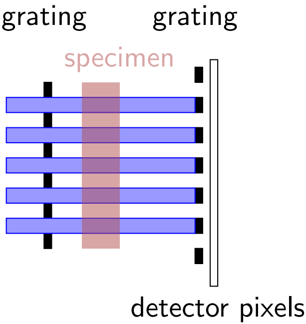

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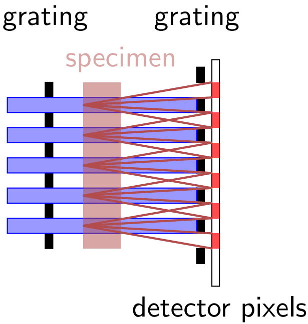

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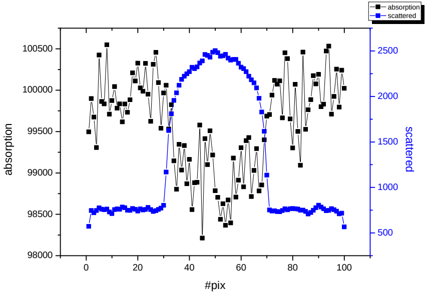
Phase Contrast: Dark–Field Imaging

model

- # photons 10^7;
- energy range (15–30) keV;
- length of pixels array 5 mm (tissue width);
- # pixels 100 (50 μm pixel width);
- tissue thickness 20 μm;
- 'hill' width 2 mm;
- tissue to pixels $L = 0.5$ m



Contrast ratio of DFI is about 3.5 as compared with AI of 0.015

Summary and outlook

- Compton radiation possesses advantages as compared to regular x-rays
- Compton angiography capable to reduce duration of the procedure and radiation load
- Edge enhancement techniques is rather simple
- Preliminary results of simulation show that the phase contrast x-ray imaging procedure based on Compton collimated spectra works. No monochromator is necessary. Definition of the image strongly dependent on the pixel's dimension and proper distance between the object and the register device. (Higher energies require longer distances.)