Compton X–ray Imaging Advantages

E.Bulyak, J.Urakawa

NSC KIPT, KEK

Mini-Workshop on Advanced Accelerator and Laser Technologies for New Generation Light Sources
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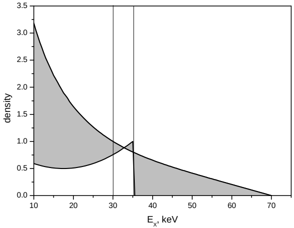
Outline

- Compton radiation vs bremsstrahlung
- Differential imaging
- Phase–contrast imaging
- Scan of extended objects
- Outlook

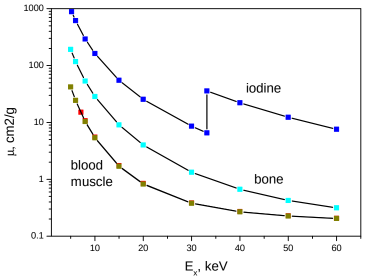
Compton Radiation vs Bremsstrahlung



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 $50\ldots100\,\mathrm{MeV}$
  - Steep high–energy cutoff: slope width $\sim \Delta E_e/E_e$
  - Maximal energy $\propto \gamma^2$ – tunable

Angiography

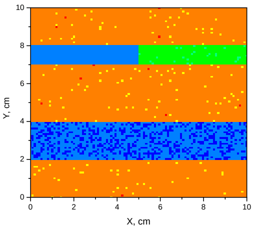


Attenuation coefficients from [NIST]

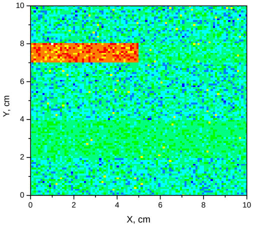
- Blood attenuation = muscle one
- Radio–contrast agent (e.g. iodine) added
- Peripheral angiography: subtraction technique – digital subtraction angiography (DSA). 2–3 frames per second
- Pulsing object (heart) demands multiple – 15–30 frames/sec (x–movie)

- 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



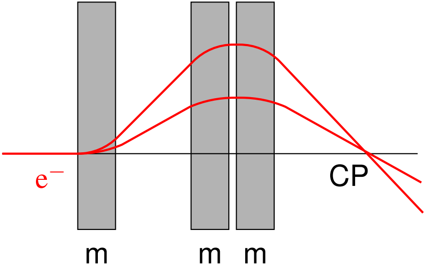
dif

Simulation parameters

- Tissue density ($\mathrm{g\,cm^{-2}}$)
  - 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

Dose Estimation per (double)Frame

- $2 \times 2 \times 10^{7} \times 30\,\mathrm{keV} = 2 \times 10^{-7}\,\mathrm{J}$
- From 80% to 90% x–ray quanta absorbed
- Suggest the irradiated area $10 \times 10 = 100\,\mathrm{cm}^2$, mass $\approx 0.5\,\mathrm{kg}$
- Absorbed dose $\approx 0.4\,\mu\mathrm{Gy}$
- Dose area product (DAP)$40\,\mu\mathrm{Gy}\,\mathrm{cm}^2$
(c.f. 20 to $100\,\mathrm{Gy}\,\mathrm{cm}^2$ for adult Coronary angiography)



flat dipole rectangular magnets

3-Magnet sweeper

- CP position remains const, independent on electron energy
- weak dependence of $E_{\max}$ on collision angle, $\Delta E_x/E_x = \Delta\phi \sin\phi/2 \approx \phi\Delta\phi/2$

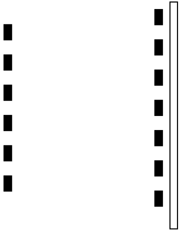
Example

Sweep of crossing angle by $2^\circ = 0.035\,\mathrm{rad}$ may be sufficient: $LB = 6 \times 10^{-5}\gamma$ Tesla m

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)

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)
- First grating not necessary if source emits comb–like profile rays

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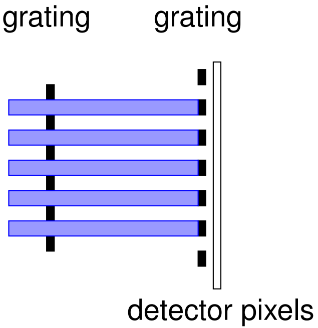

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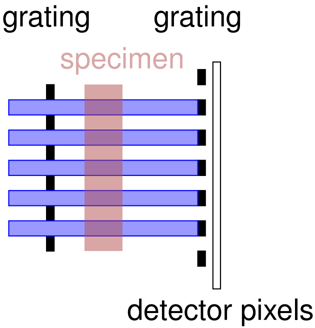

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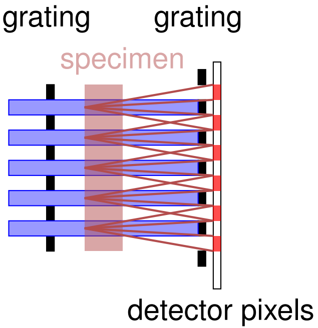

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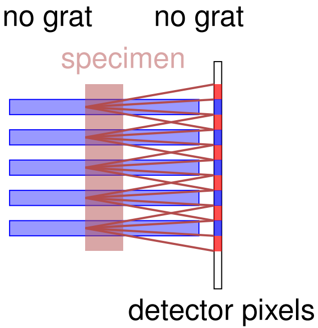

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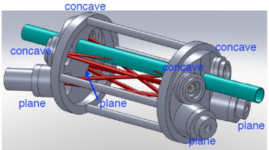
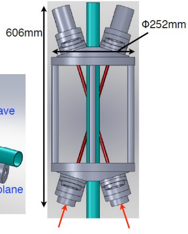
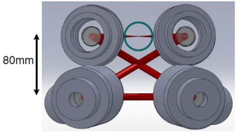
・162.5MHzの平面4枚鏡共振器2台を1つの真空チェンバーに収める。
・曲率半径420mmのconcave mirrorを使う。直径は1インチ。
・レーザーの光軸の半径を5σサイズで描いている。
・ビームダクトは内径35mm、厚さ2mmを改定している。
・この図で衝突角17度。
・plane mirrorにはpiezoを取り付ける。

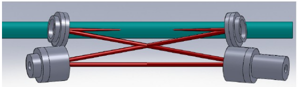


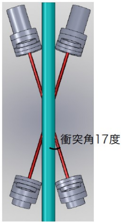


This is not aggressive. I think when we use small electron beam pipe we makes smaller crossing angle, say 10 degrees. Also, we can reduce 80mm to about 60mm with special design.

ミラーホルダーはATFの共振器と同じ
外径Φ80mmで描いている。

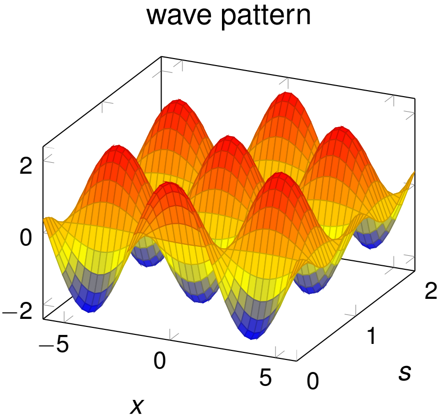


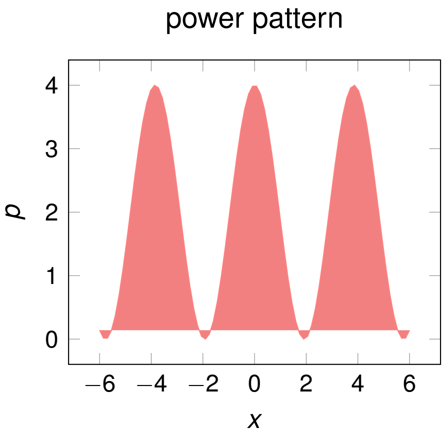




Crossed Resonator [J.Urakawa] – a way to comb–like profile

- Double power
- Interference possible, spacing $\lambda/(2\sin\phi)$
- Enables comb–like shape


wave pattern
2
0
−2
−5
0
5
x
0
1
2
s



power pattern
p
4
3
2
1
0
−6
−4
−2
0
2
4
6
x

Advantages of Employing Compton Source

- Conventional transmission imaging
  - Much less radiation load
  - Much faster
  - Enable subtracted images of heart
- Phase–contrast imaging
  - Point–like emitter:
    edge enhanced contrast imaging [Sakaue *et al* AIP Conf. Proc. 1466, 272 (2012)]
  - ‘Striped’ emitter: the dark-field (or scattering) imaging
  - Other phase–sensitive techniques . . .