Design and Optimisation of Ultra-Compact, High-Resolution X-Ray Imaging Systems

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3rd OMA Topical Workshop – Medical Accelerator Design and Diagnostics

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A MONTE CARLO APPROACH TO IMAGING AND DOSE SIMULATIONS IN REALISTIC PHANTOMS USING COMPACT X-RAY SOURCE

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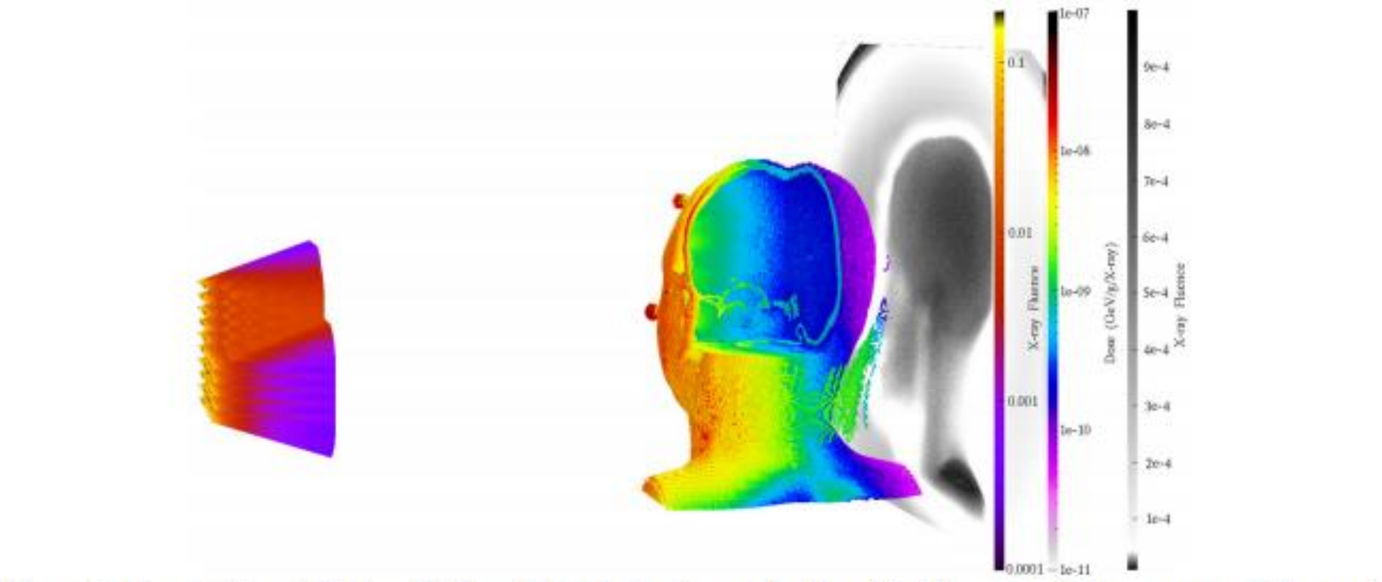
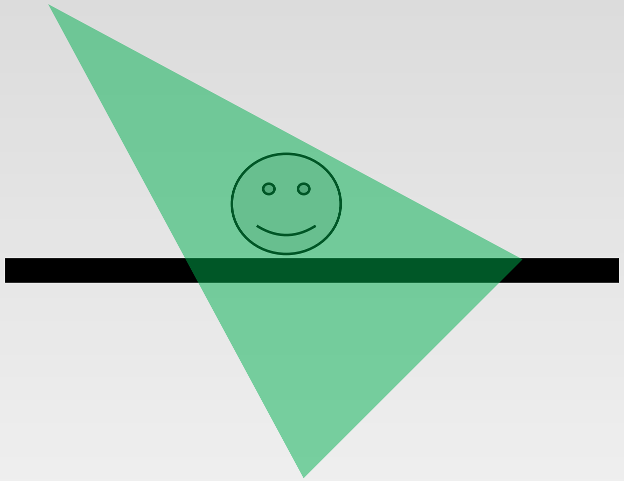
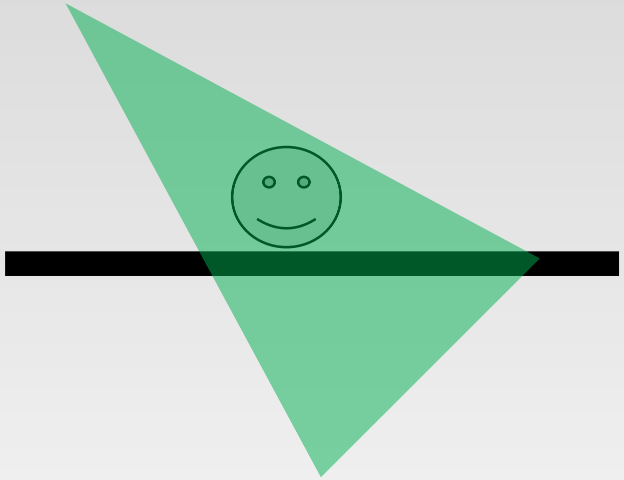


Figure 3: From left to right: Visualisation of the photon fluence by the 10 x 10 array of X-ray sources, 3d map of absorbed dose in the head phantom, image reconstruction (figure 4). The fluence is given in photons/cm^2/primary X-ray and the dose in GeV/g/primary X-ray.

Figure 4: X-ray radiography image reconstruction by visualisation of the X-ray fluence behind the phantom.

Digital Tomosynthesis vs Computerised Tomography





Around double dose than X-ray but offers depth information.

Much higher dose than X-ray but offers great 3D detail.

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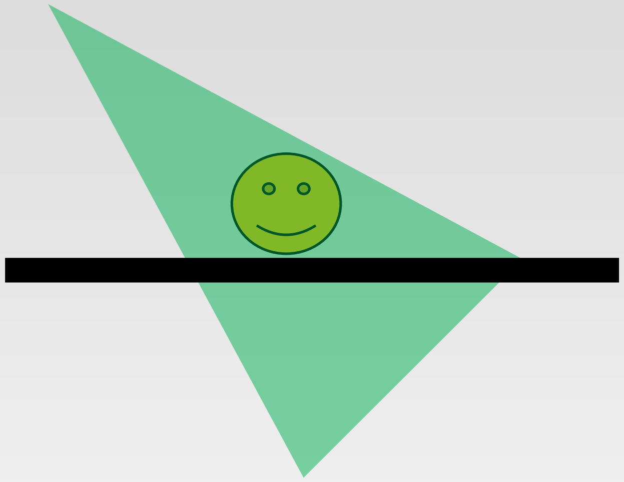
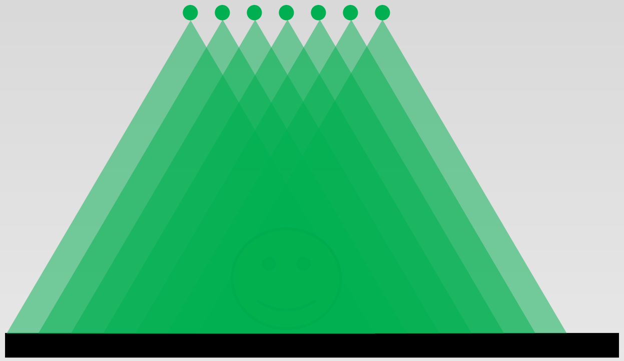
The benefit of the emitter array





Contents

1. Electron generation and acceleration
2. X-ray production from deceleration of electrons in a high Z target.
3. Filtration of the X-ray beam.
4. Transport of X-rays in the phantom-patient.
5. Radiation collection in a pixelated detector and generation of an image.
6. 3D image reconstruction using generated images.
7. Discussion on the methods, approximations and next steps.

X-ray generation

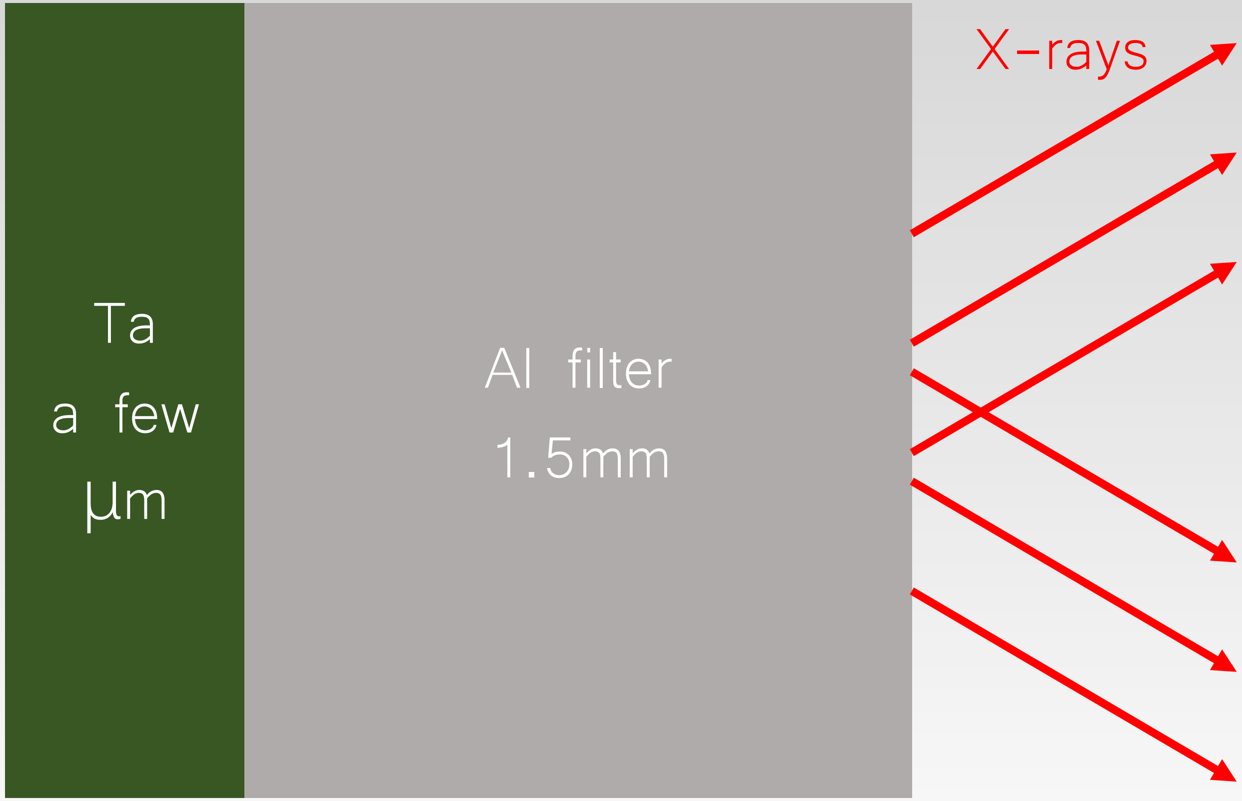
60 keV e- pencil beam

0 emittance

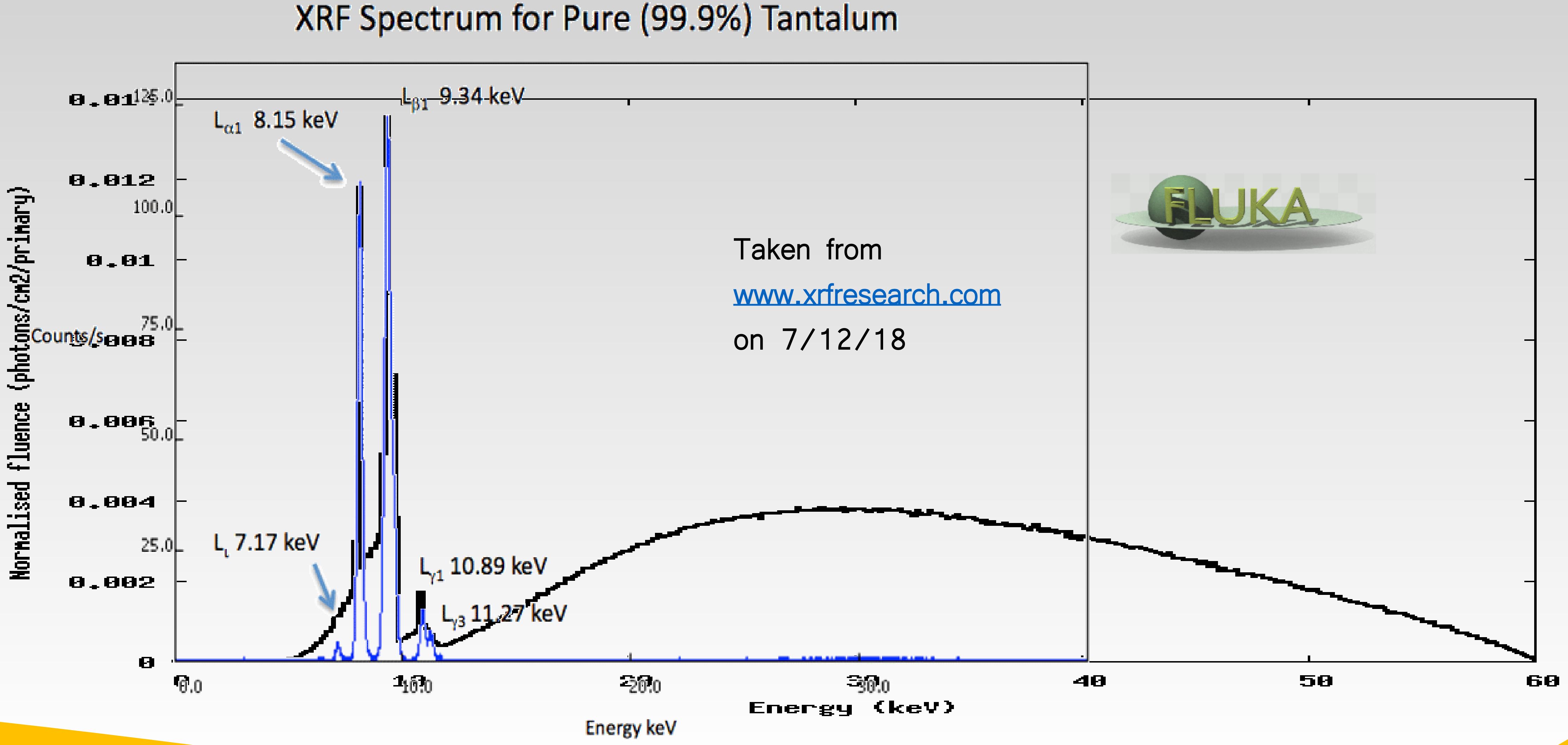
90 degrees incident angle

No magnetic field

No electric field

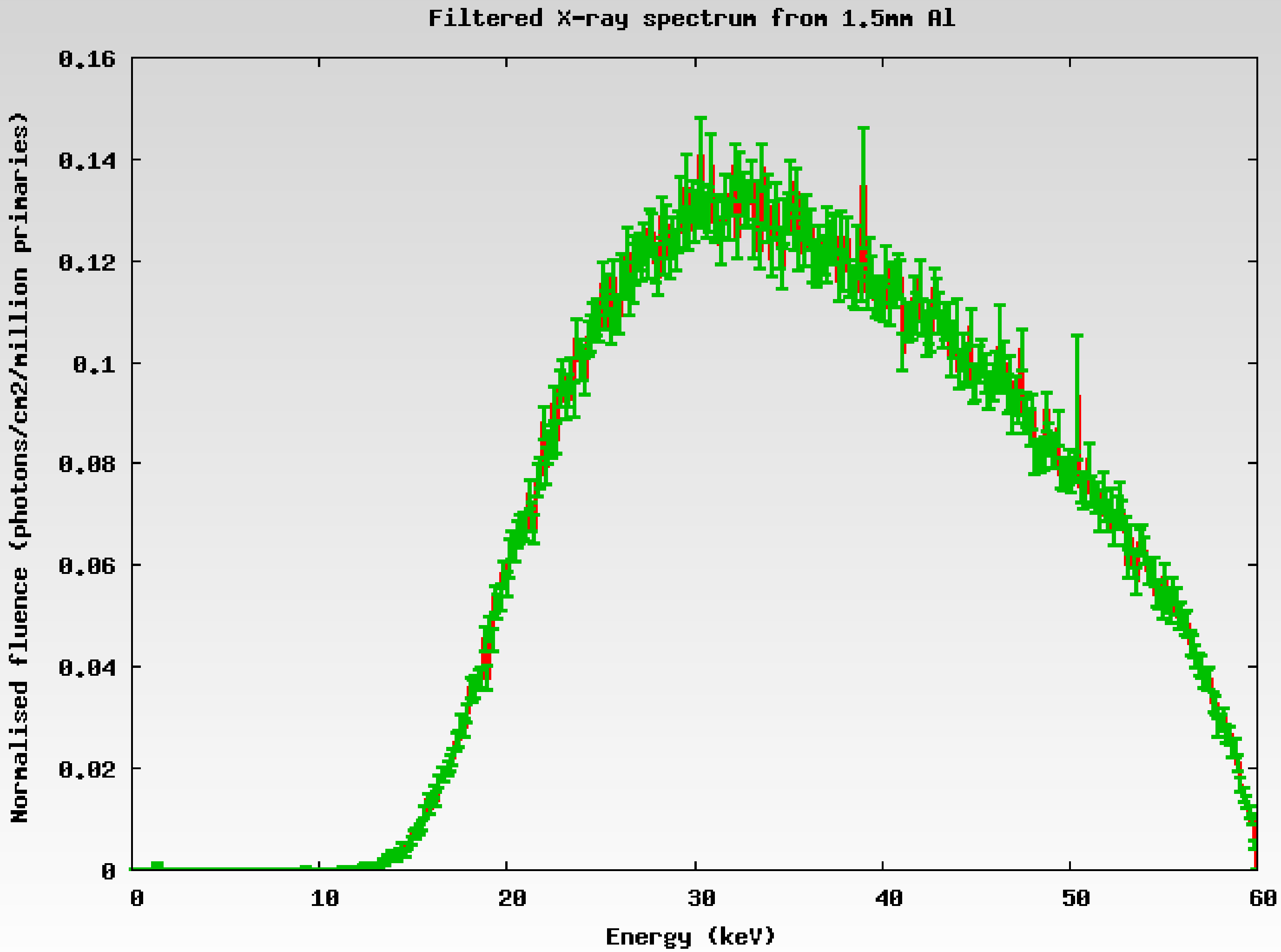


Compare the unfiltered spectrum with literature



Taken from www.xrfresearch.com on 7/12/18

The spectrum after the Al filter.



Approximate this with a Gaussian:

μ=30keV

3σ=20keV

The emitter array

45 point X-ray sources

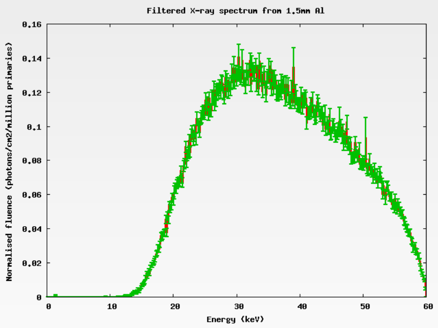
7x7 configuration

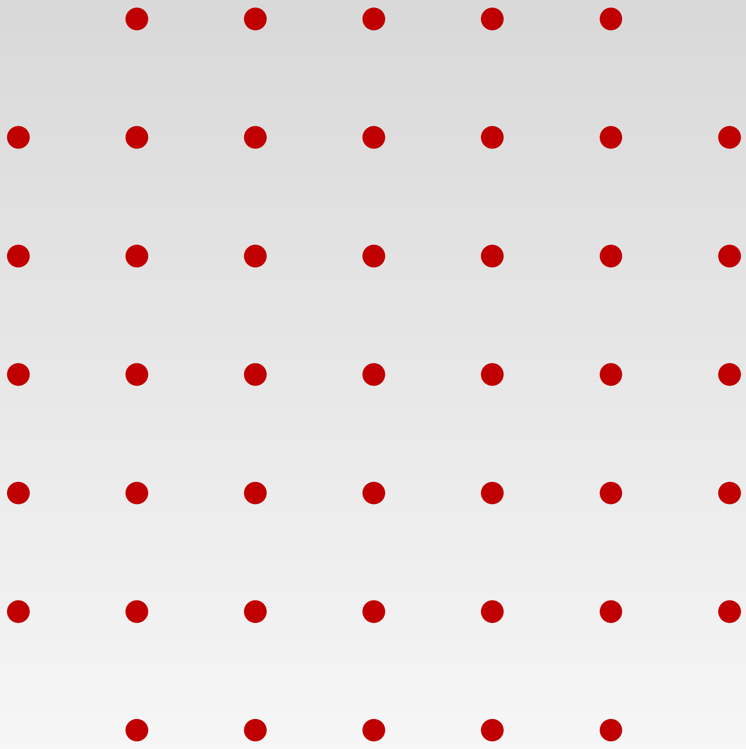
1cm pitch

Uniform cone beam each of

40 degrees full cone angle

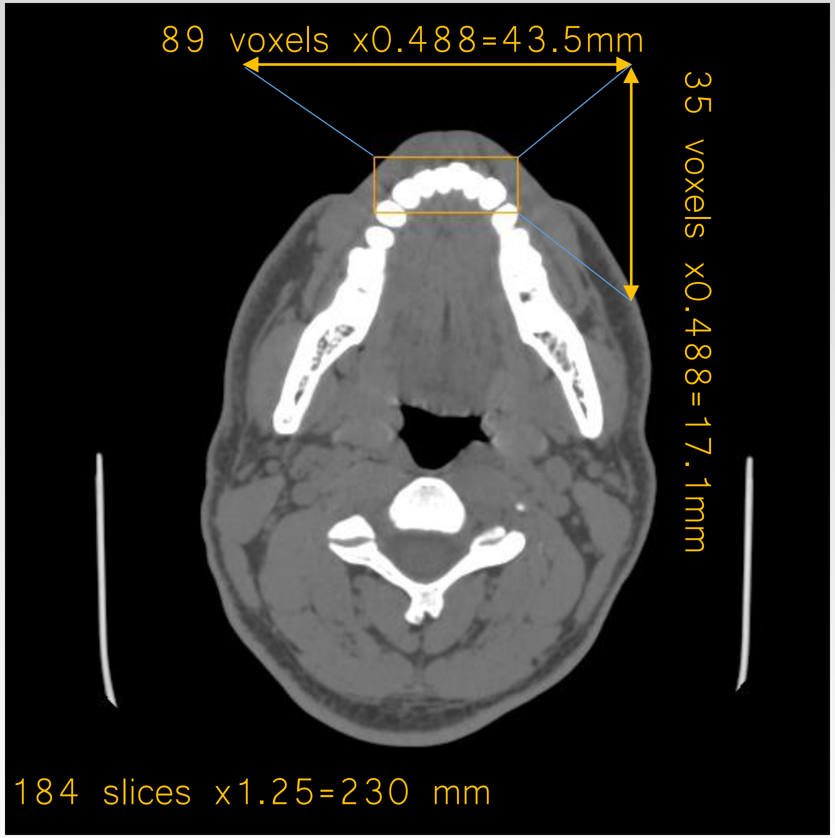
Spectrum is Gaussian approximation of the previous simulation.





The phantom human head

Voxel size: 0.488mmx0.488mmx1.25mm



Anonymous phantom in DICOM format taken from: Patient Contributed Image Repository www.pcir.org

Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions

Wilfried Schneider, Thomas Bortfeld and Wolfgang Schlegel

Physics in Medicine & Biology, Volume 45, Number 2

The ideal X-ray detector

260 pixels, 26mm total height

360 pixels, 36 mm total width

100% X-ray detection efficiency

100µm x 100µm pixel size

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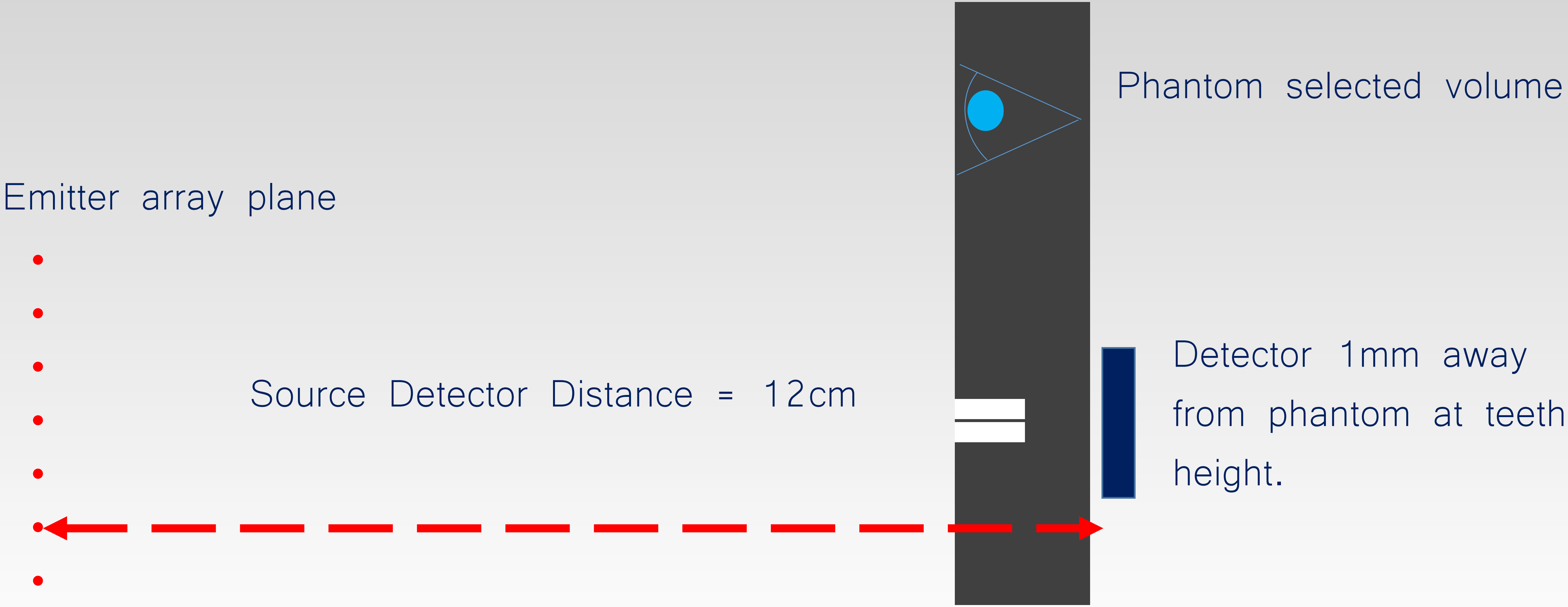
The simulation geometry



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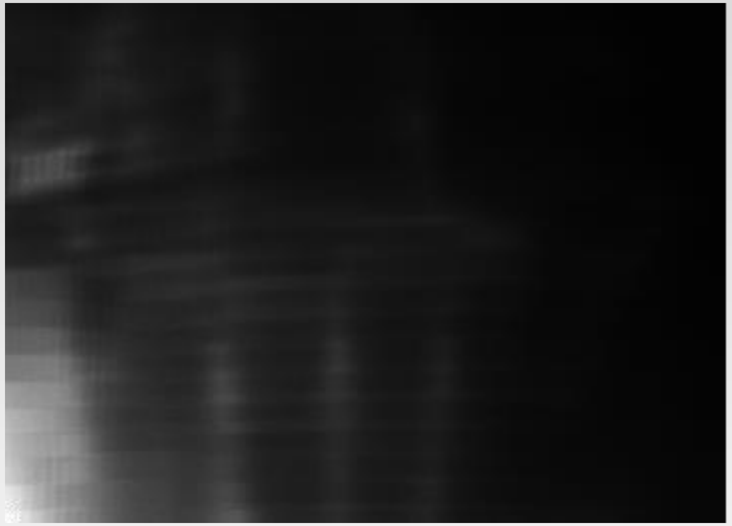
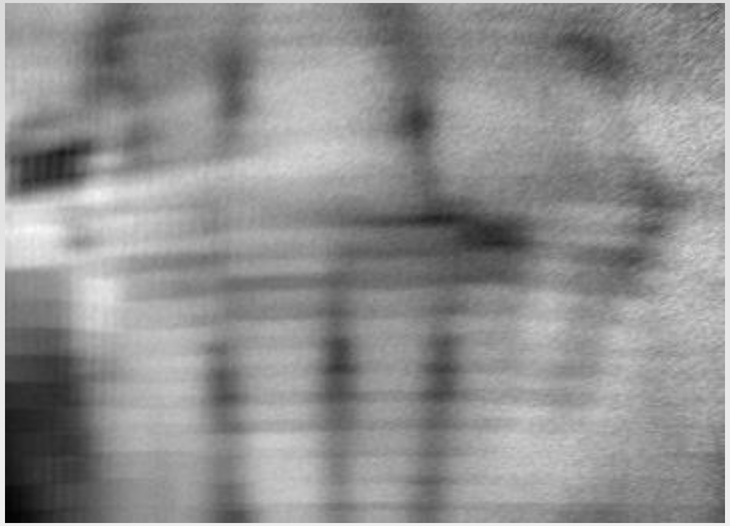
X-Ray images

I_0



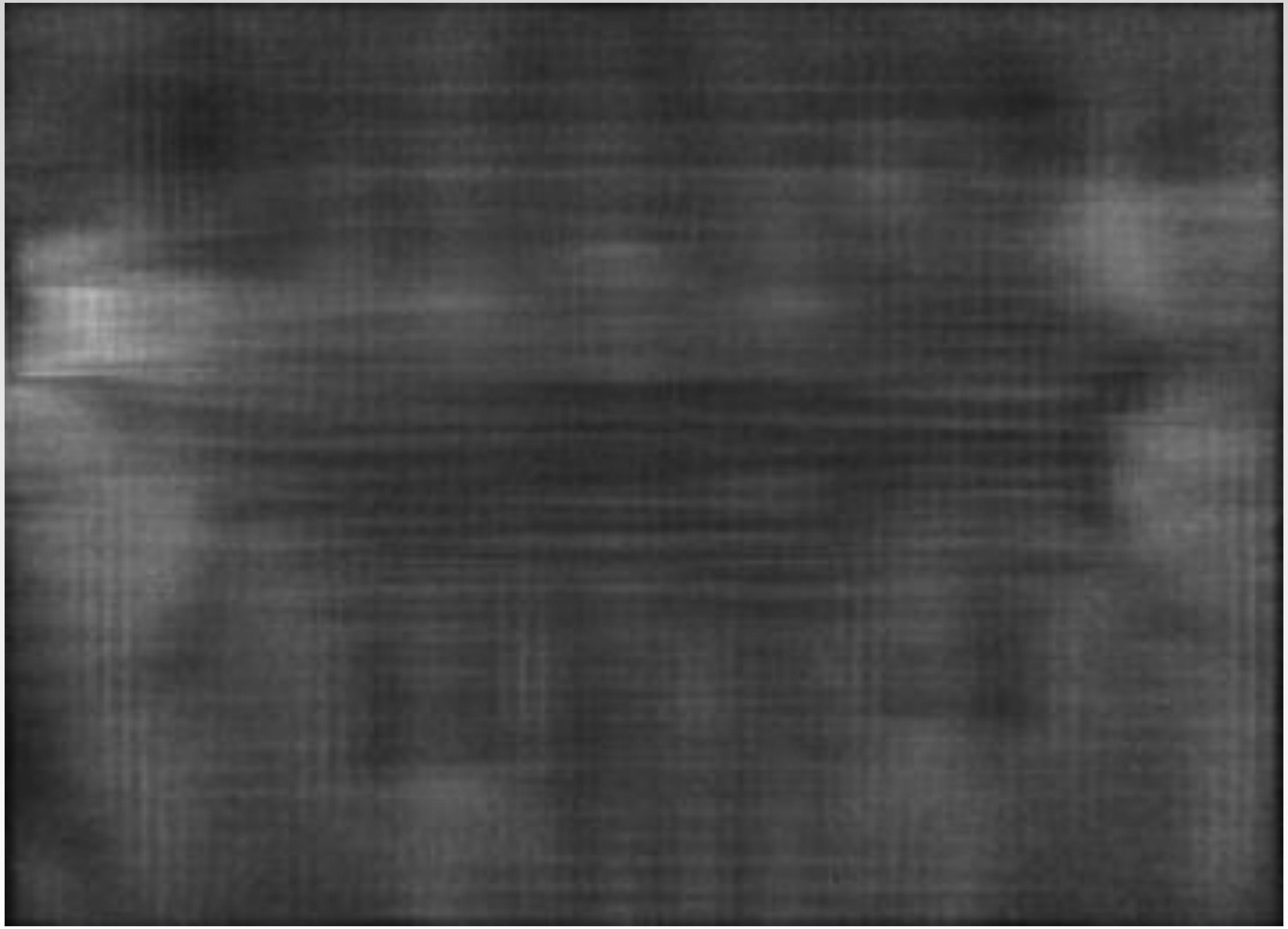
$I = I_0 e^{-\mu}$



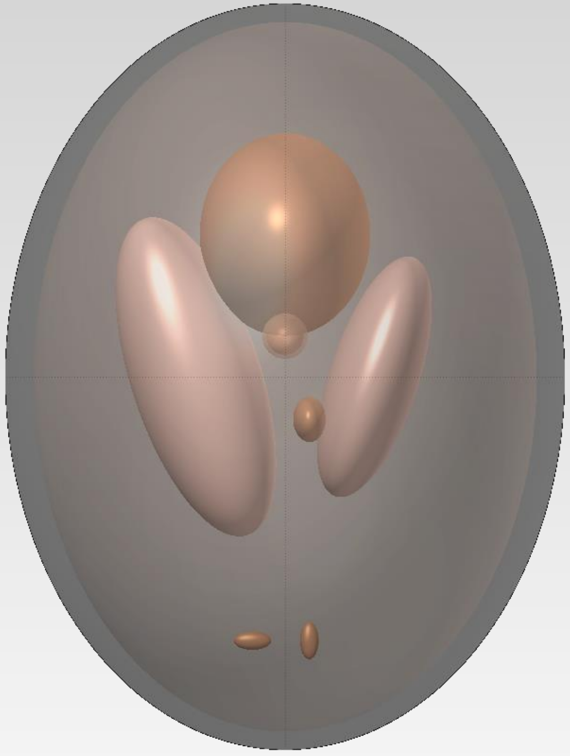
$\mu = ln\left(\frac{I_0}{I}\right)$

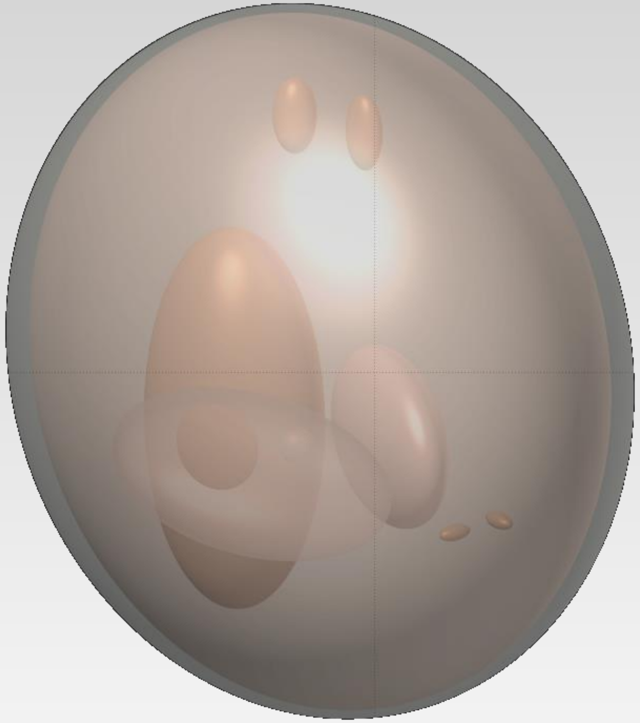
Beer-Lambert Law

Image reconstruction



3D Shepp-Logan phantom





Ellipsoid parameters taken from:

LI, Y.L., SUN, F.R., Liu, Z., QU, H.J. and LI, Q.N., 2005. The computation of three-dimension Shepp-Logan head phantom simulation projection data. *Journal of Shandong University (Engineering Science)*, *1*, p.013.

HU to material conversion by

Correlation between CT numbers and tissue parameters needed for Monte Carlo simulations of clinical dose distributions

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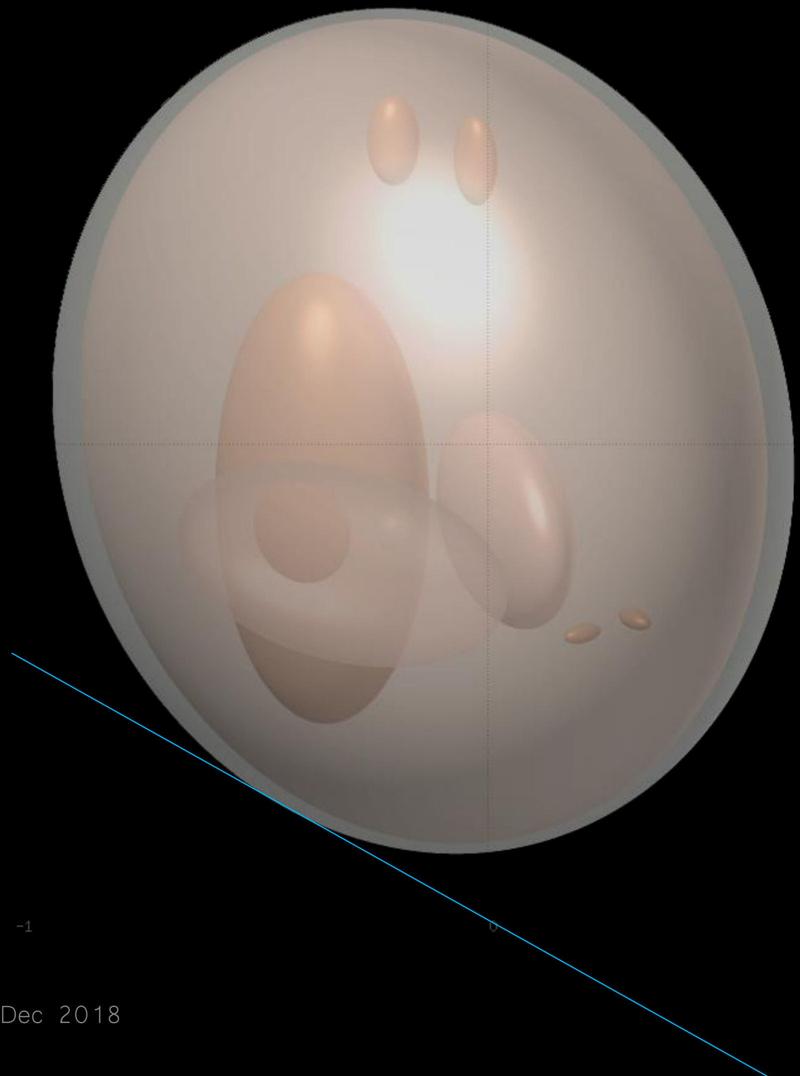
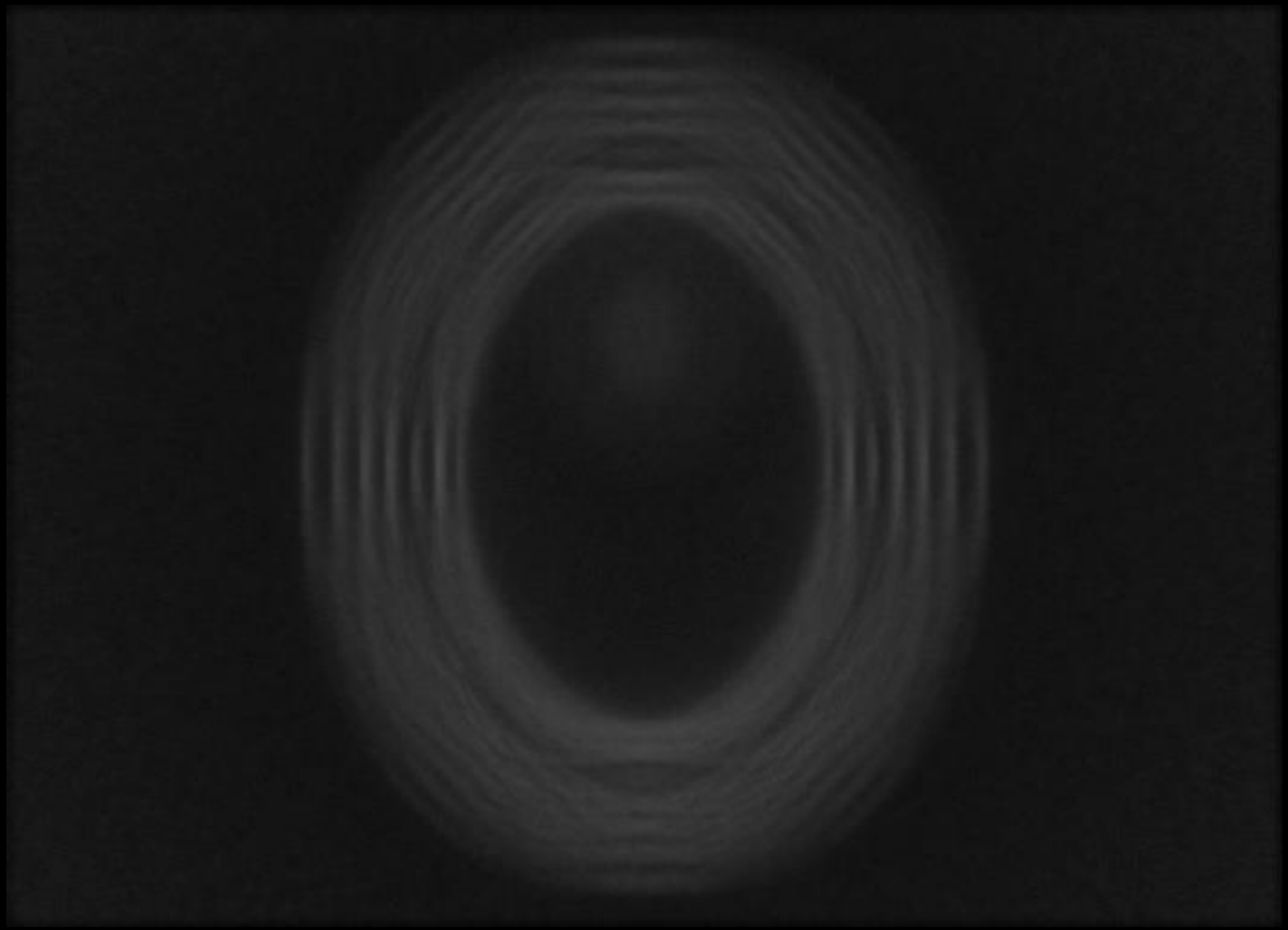
Shepp-Logan phantom digital tomosynthesis



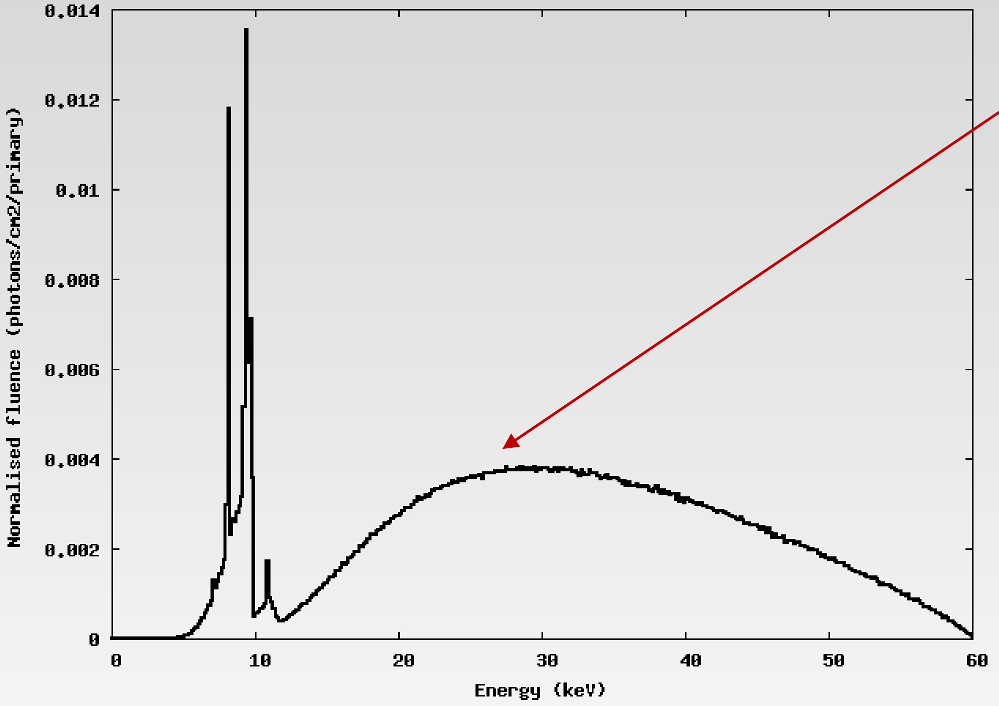


Next steps: Use realistic description of the following

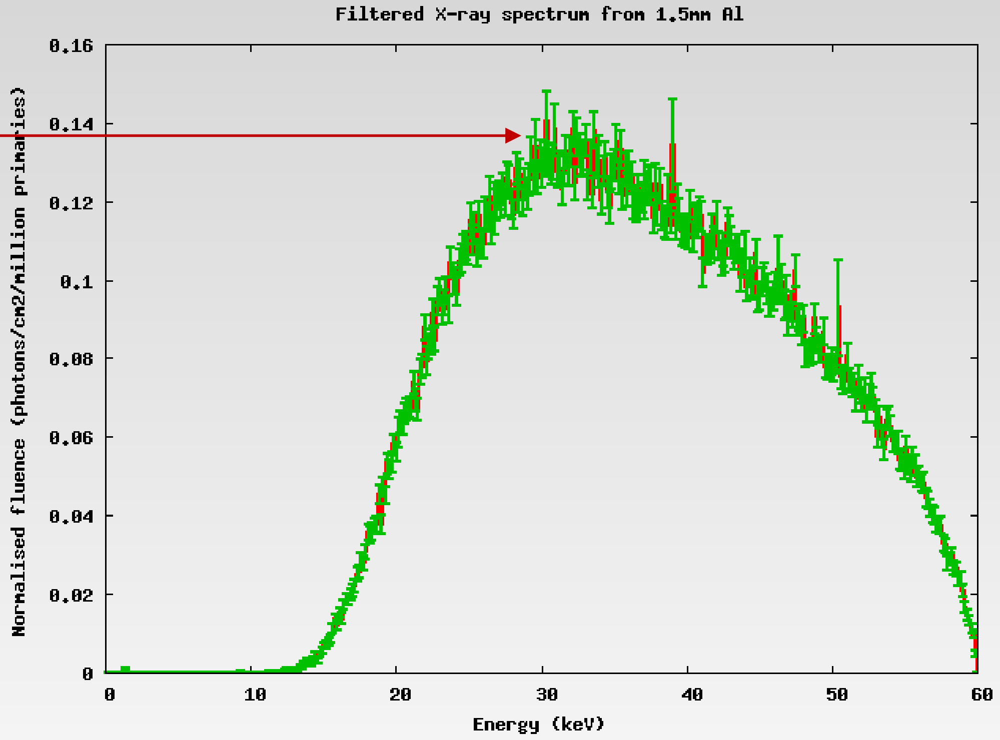
- Assumed monoenergetic e- pencil beam with zero emittance.
- Neglected electric and magnetic fields in the source geometry.
- Fitted a Gaussian instead of sampling energies from the actual spectrum.
- Assumed point sources.
- Assumed uniform cone beam of X-rays.
- Used an ideal detector.
- Did not include all the components of the system like collimators etc.

This is only a proof of principle that the image quality of DT can be assessed with Monte Carlo techniques and offer system optimisation potential.

Most important challenge: Phase space sampling



5 orders of magnitude difference



- Source simulations only generate a few 100.000 X-rays per day on cluster.
- Imaging with high resolution detector requires trillions of X-rays to reduce stat. uncert.

Most important challenge: Phase space sampling

- Source simulations only generate a few 100.000 X-rays per day on cluster.
- Imaging with high resolution detector requires trillions of X-rays in MC.

A fast way to generate million times more particles must be found.

- Discrete multivariate distributions E(x,y,x`,y`)
- Multivariate Kernel Density Estimation
- Generative Adversarial Neural Networks
- Biasing techniques like particle splitting or even rare event.
- Apply some reasonable approximations.

Thank you

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