Investigation of 3D SPECT Reconstruction with Multi-energy Photon Emitters

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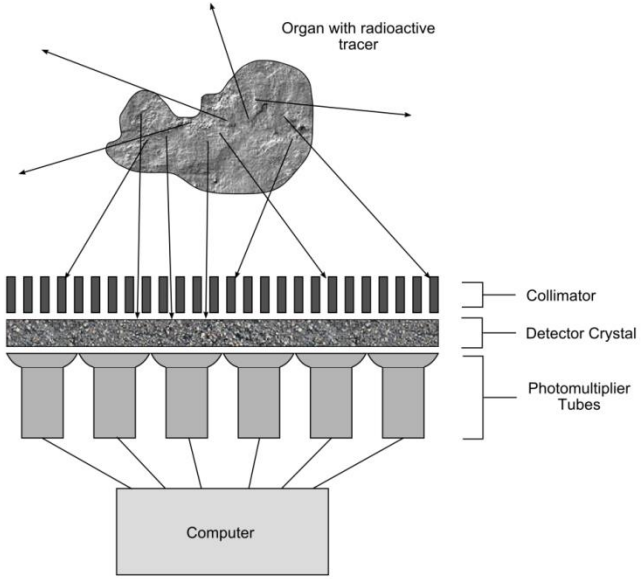
SPECT

- diagnostic medical imaging
- detects physiological function
- uses gamma photon emitting radionuclides
- that are injected into the patient and are designed in a way that they go to the organ in question
- gamma cameras gather 2D projection images of the nuclide distribution
- planar images are reconstructed into a 3D distribution map

Gamma camera

- (parallel) collimator
- scintillation crystal
- photomultiplier tubes
- electronics
  - compute the position and energy
  - several image corrections
  - create 2D histograms



The most significant imperfections in parallel based SPECT imaging

1. Non-homogenous attenuation medium

2. Depth dependent resolution of the parallel projection

- Non-linear image distortion
- Hole and septa size

3. Poisson noise

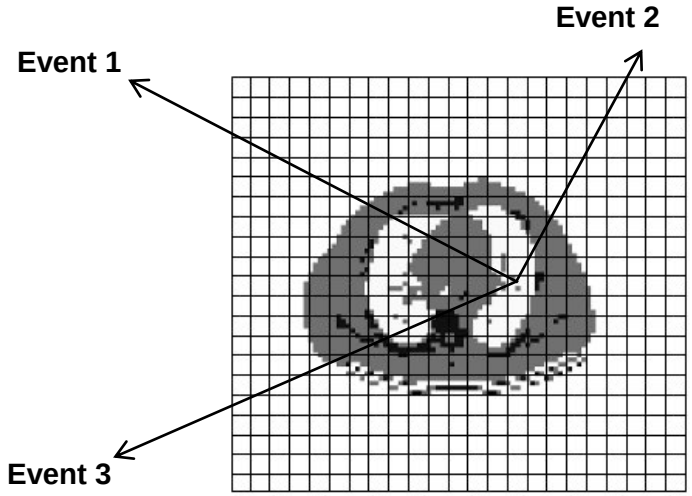
Both phenomena depends on the energy of the gamma photon.

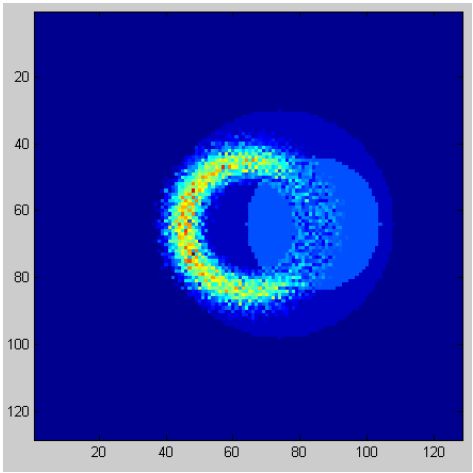
Effect of γ photon attenuation

- Non-homogenous attenuating medium
- Detecting less events in different directions.
- Result: distortion effects in the reconstructed image

Attenuation can be calculated according to the Beer–Lambert formula:

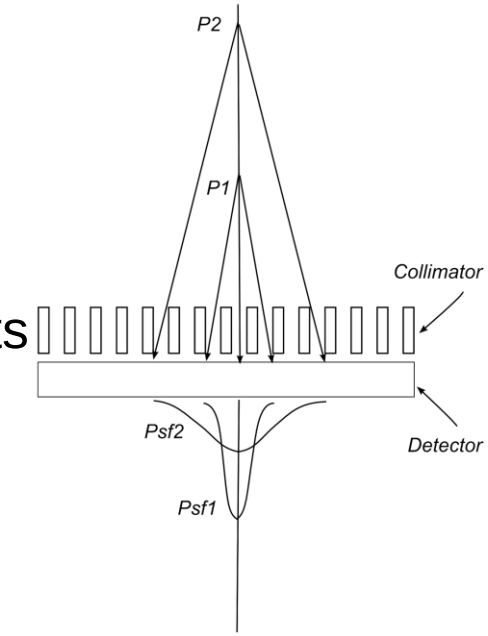
$$I = I_0 \cdot e^{-\mu \cdot x}$$

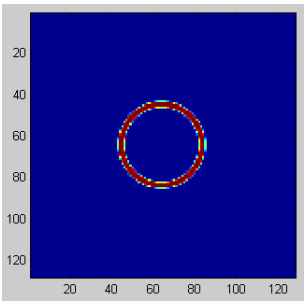


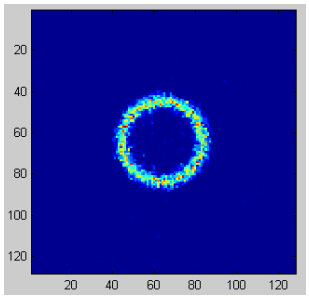


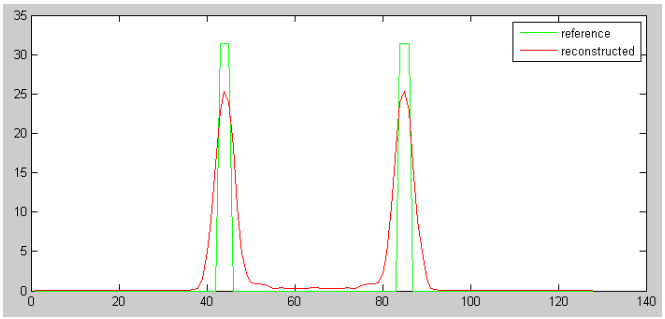
Influence of Distance Dependent Spatial Resolution (DDSR)

- Distance dependent spatial resolution:
  - Crystal intrinsic resolution
  - Geometrical properties of the collimator
    - finite hole and septa size as well as hole misalignments
  - γ photon penetration between the collimator holes
- Result: Gaussian blurring



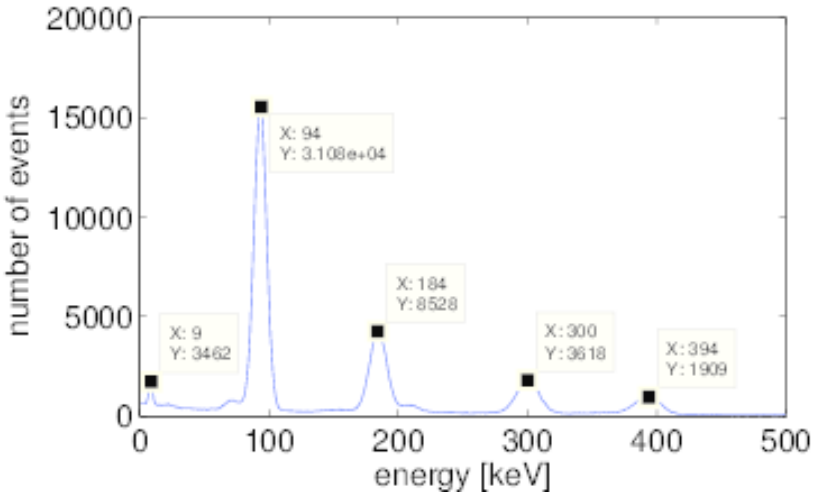






Isotopes

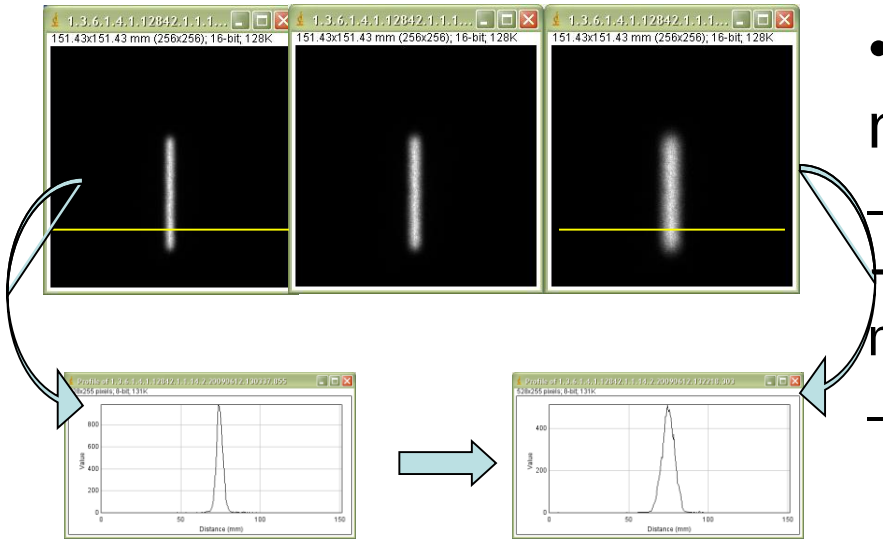
- Technetium-99m
  - 140 keV
- Indium-111
  - 171 (90%), 245 keV (94%)
- Gallium-67
  - 93 (38%), 184 (21%), 300 keV (17%)

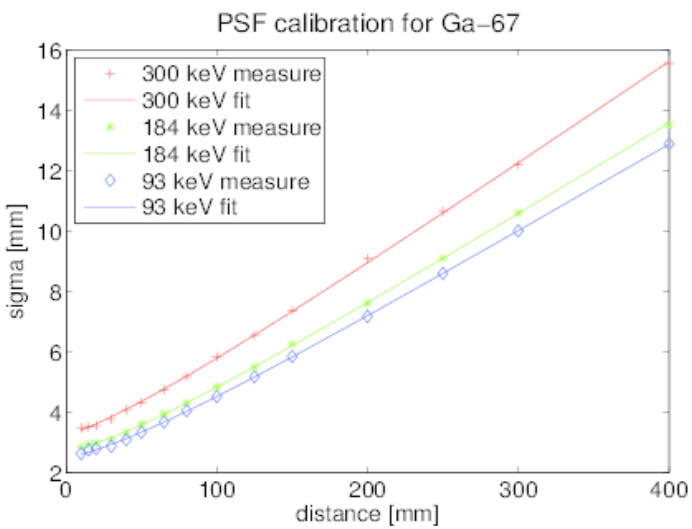


Goal of the study

- Current algorithms
  - Single energy window
  - Technetium-99m
- How to use the information from multiple energy windows?
  - combine them into a single projection image
  - or use them separately
- Simulation only
  - OpenGATE framework for DDSR calibration
  - Good agreement with real data
  - Phantom studies created with analytical forward projection
  - Poisson noise was added

Calibration procedure for DDSR compensation





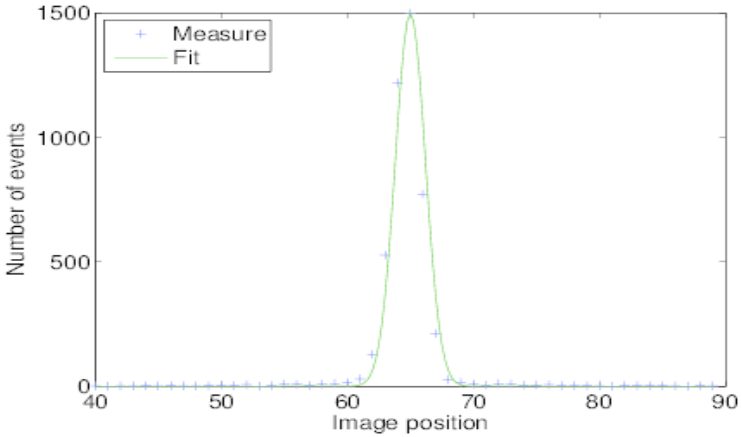
- Calibration procedure is necessary:
  - Line Spread Function (LSF) response → i.e. PSF is determined by capillaries measurements in different distances
  - Gaussian fitting on lines:

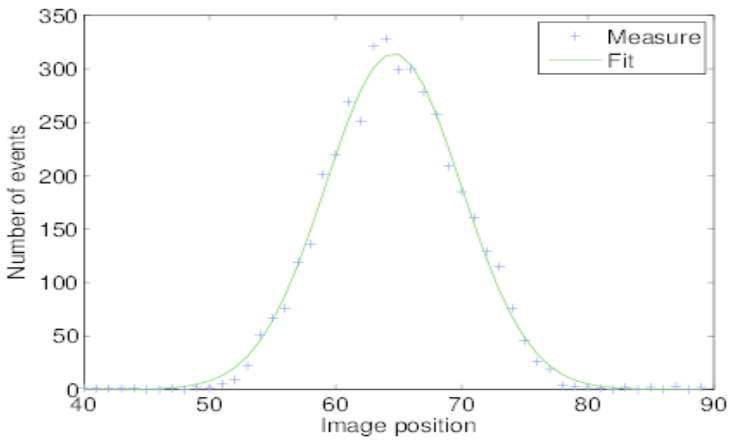
$$y = a \cdot e^{-\frac{x^2}{2 \cdot \sigma^2}}$$

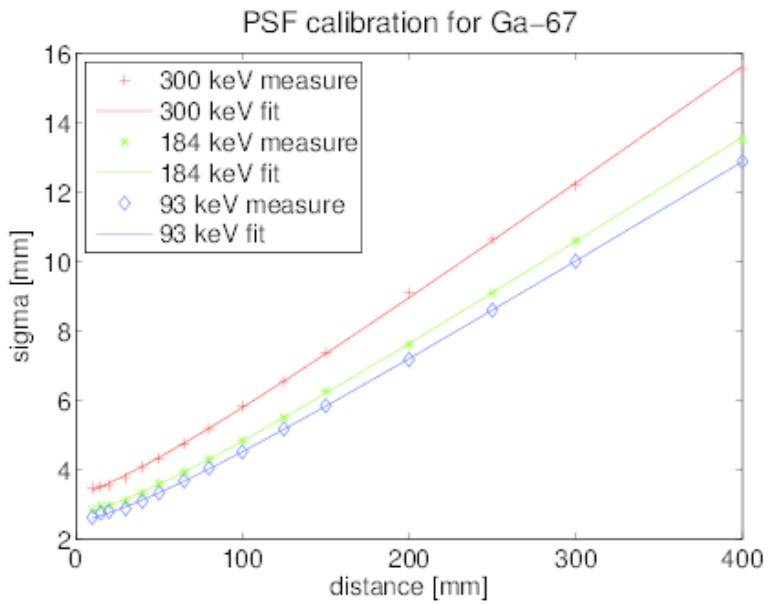
  - Model fitting on "σ":

$$\sigma^2(d) = \sigma_I^2 + (A + B \cdot d)^2$$

Ga-67 calibration data







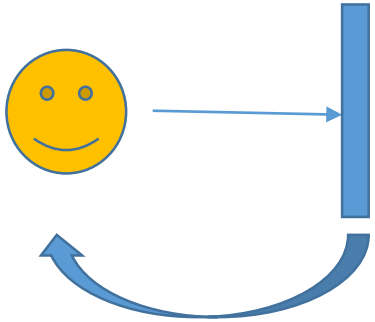
- OpenGATE simulation
- Mediso AnyScan geometry
- MEGP collimator

Iterative reconstruction

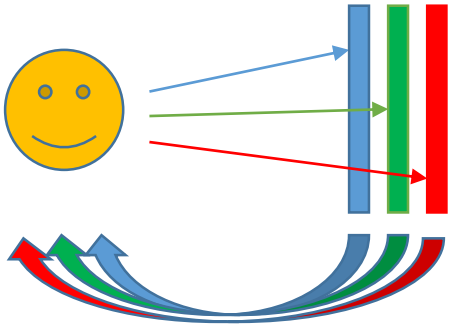
- MLEM scheme
- Ordered subsets
- Model based DDSR correction
- CT based attenuation correction
- Fast GPU implementation
- Verification (single energy): simulation and patient studies

Algorithm schemas

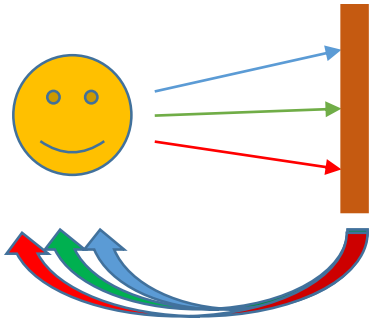
Using one energy peak



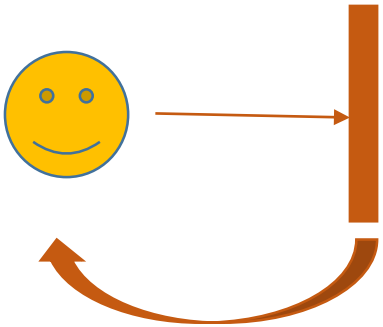
Multiple projections



Sum of energy windows

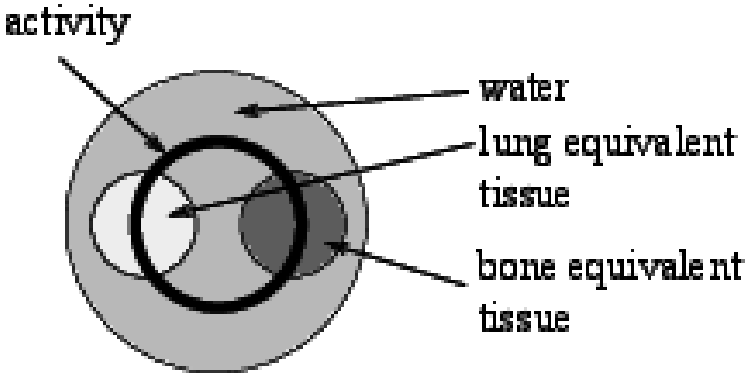


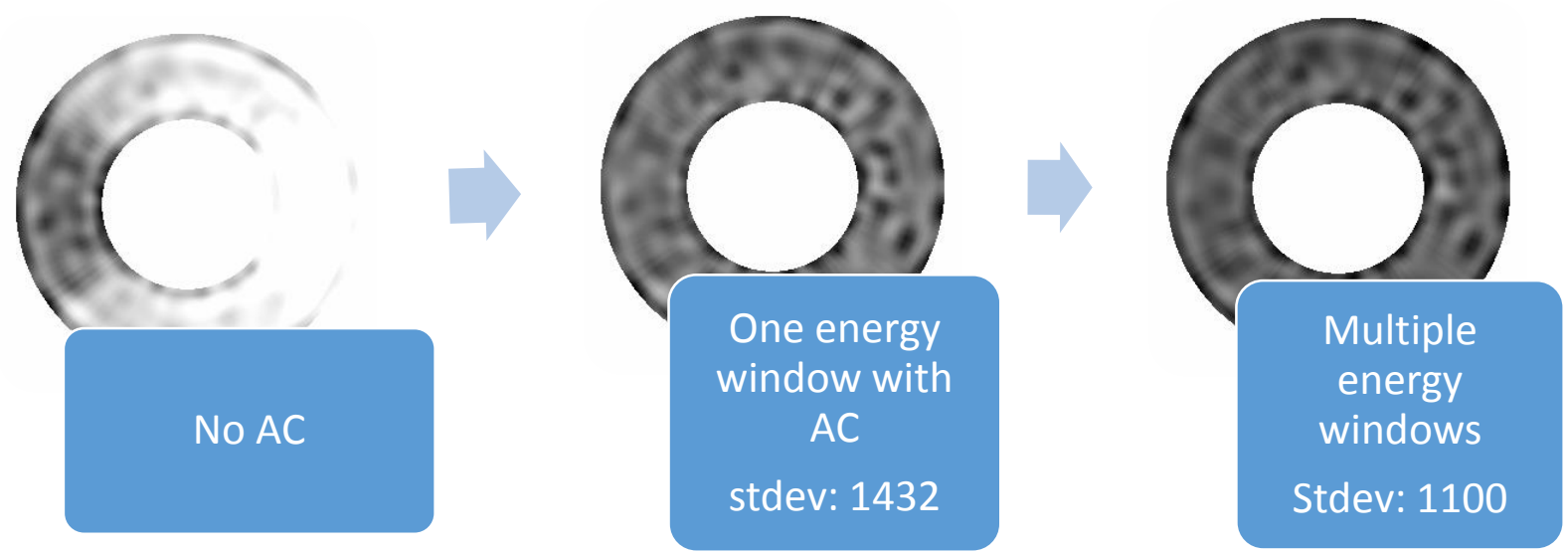
Using averaged values



Attenuation correction

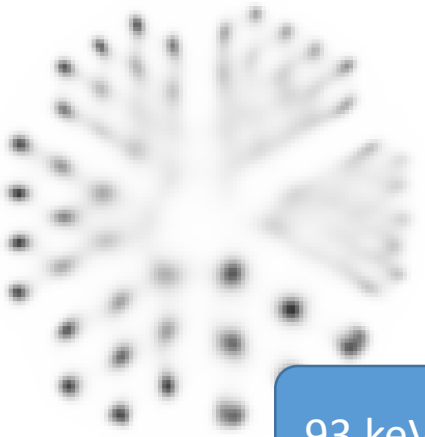
- Simple phantom
  - Large water cylinder
  - Lung and bone tissue equivalent inserts
- Ring-shaped activity
- 2.5 million events



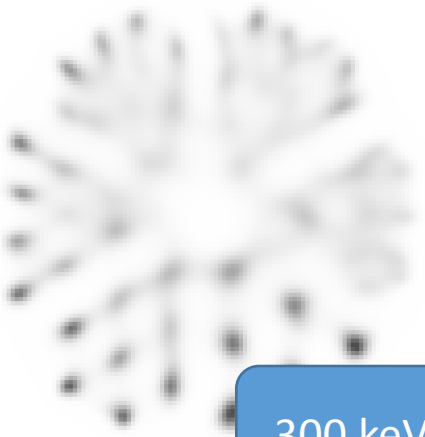


Resolution recovery

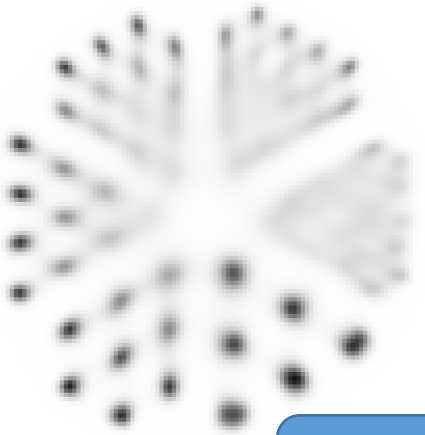
- Derenzo phantom
  - Homogenous water cylinder
  - Rod size from 10.2 to 25.4 mm
- 20 million events
- Analytical simulation with added Poisson noise



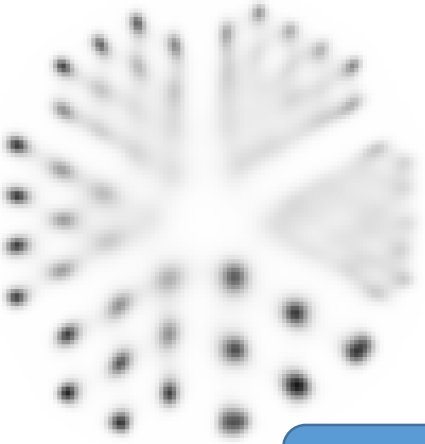
93 keV



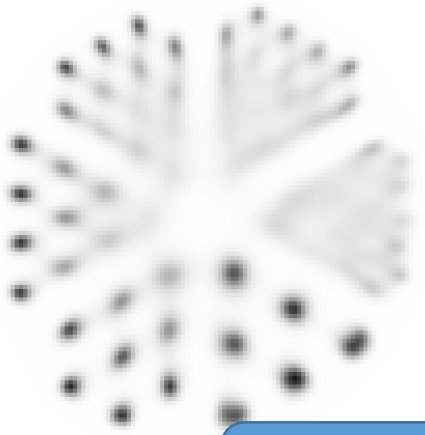
300 keV



Averaged



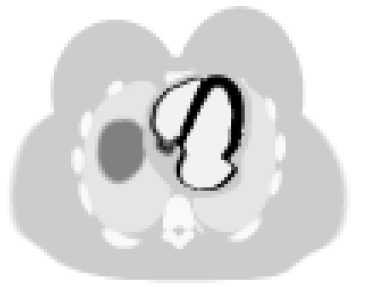
Summed



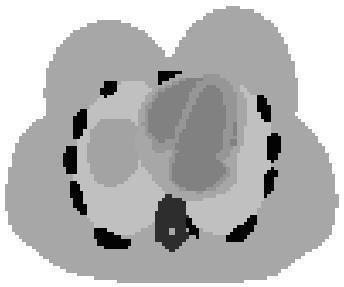
Multiple

Convergence rate

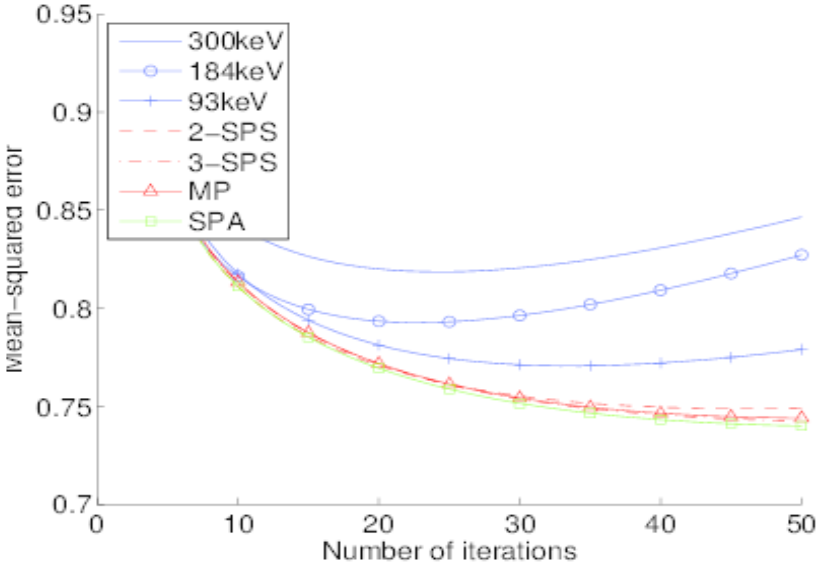
- NCAT phantom (thorax)
  - Inhomogenous attenuation media
  - Not realistic distribution
- 40 million events
- Analytical simulation with added Poisson noise



Activity



Attenuation



Conclusion

- Three reconstruction algorithms were compared
  - each using information from major photopeaks
- Better homogeneity and convergence
  - than using a single energy window
- Using averaged attenuation and collimator model values is faster
  - than the other two strategies
- Future:
  - scatter correction, improved collimator model

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Thank You for Your Attention!

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