Photon-counting CT*: Potential Advantages over Conventional CT

Taly Gilat Schmidt, PhD

Department of Biomedical Engineering

Marquette University

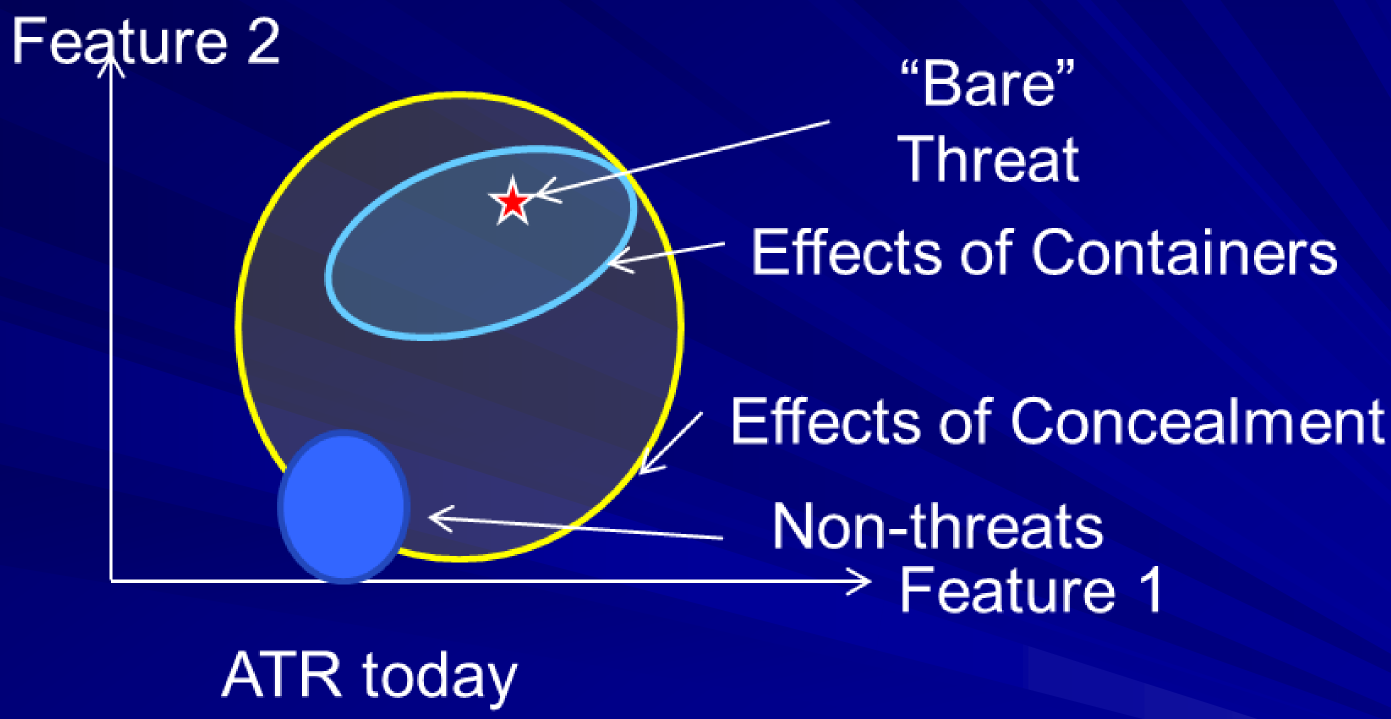
*Spectral Photon-Counting CT: Using a photon-counting detector to detected x-rays into 2 or more energy bins

Conclusions

Spectral photon-counting CT:

- Improves SNR and reduces beam hardening through optimal energy weighting
  - Limited additional benefit for N > 5 bins
  - May help explosive detection by reducing clouds
- Reduces noise in material decomposition
  - Limited additional benefit for N > 2 bins
  - May help explosive detection if task is SNR limited
  - Not fully realized due to detector issues
- Identifies K-edge materials
  - K-edge of explosives too low to be detected
  - K-edge may be useful to identify non-threats

Goal: Reduce Cluster Size



PD / PFA improved by reducing clouds and overlap between threats/non-threats

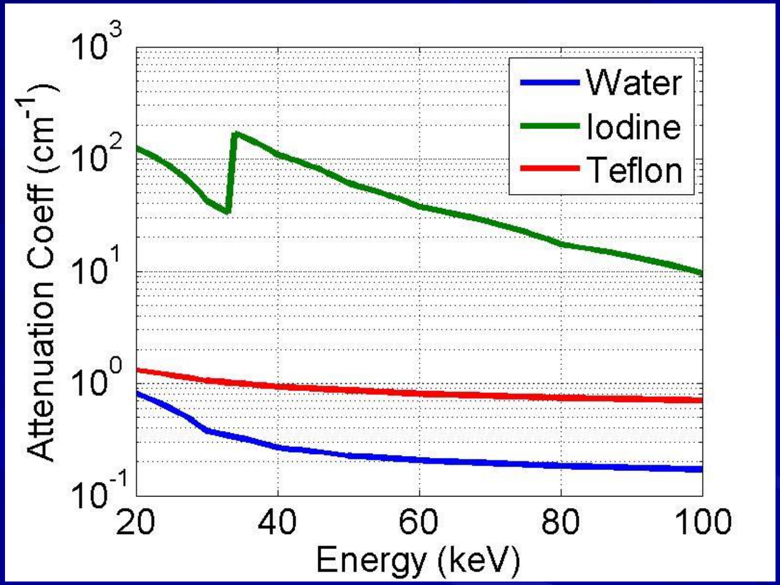
*Courtesy of Carl Crawford

Conventional CT

- Doesn't take advantage of higher contrast at lower energies

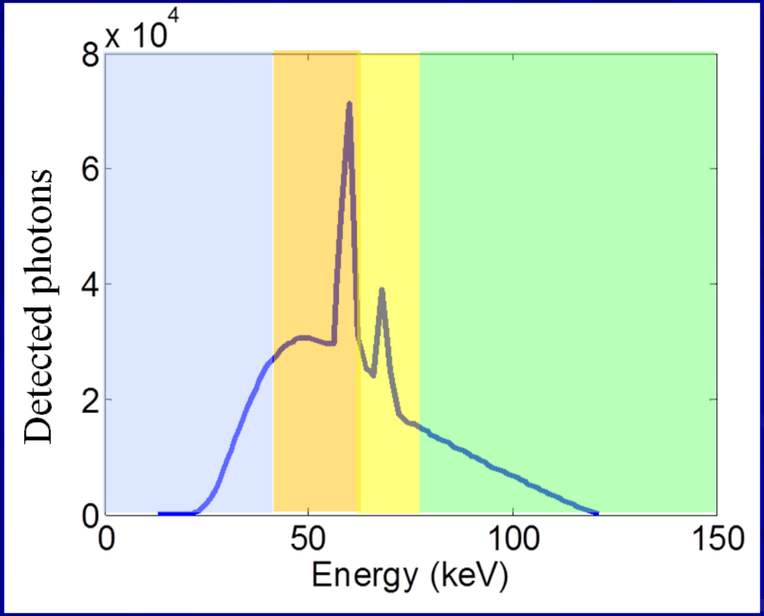
- Different materials may have same gray level (μ value) in the reconstructed image

- The reconstructed μ value depends on the thickness of the material



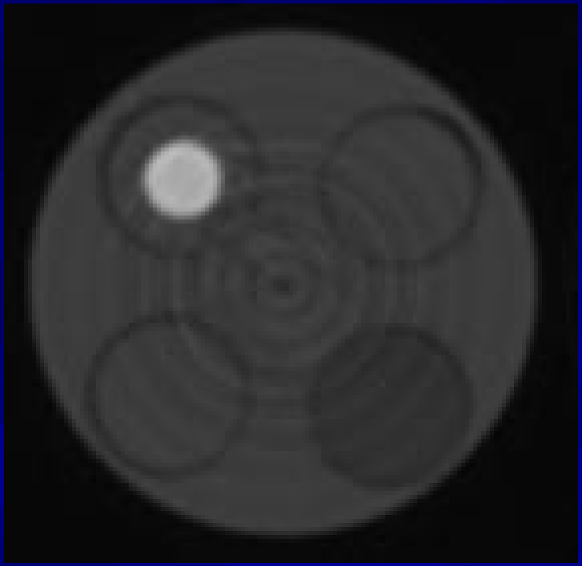
Spectral Photon-Counting CT

- Photon-counting detectors sort photons into energy bins
- What can you do with energy information?
  - Energy Weighting: Optimally weight and combine energy-bins to form improved HU image
  - Material Decomposition

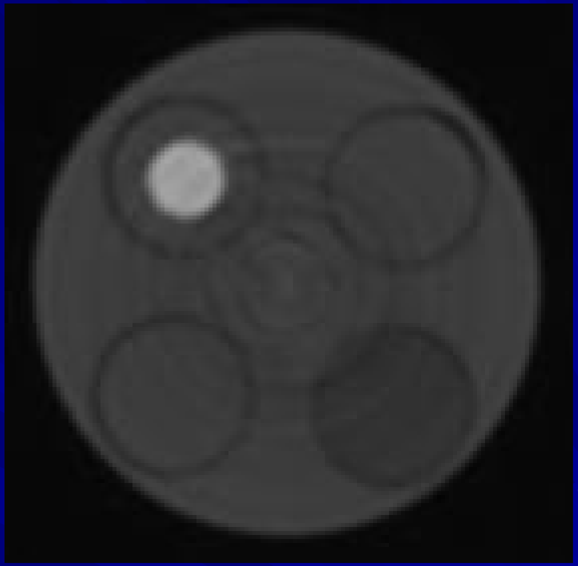


Energy-weighted Images

- Energy weighting increased CNR by 40% over photon-counting
- CNR improvement depends on energy-bin configuration
- Opportunity to optimize bins for explosive imaging



Photon-counting

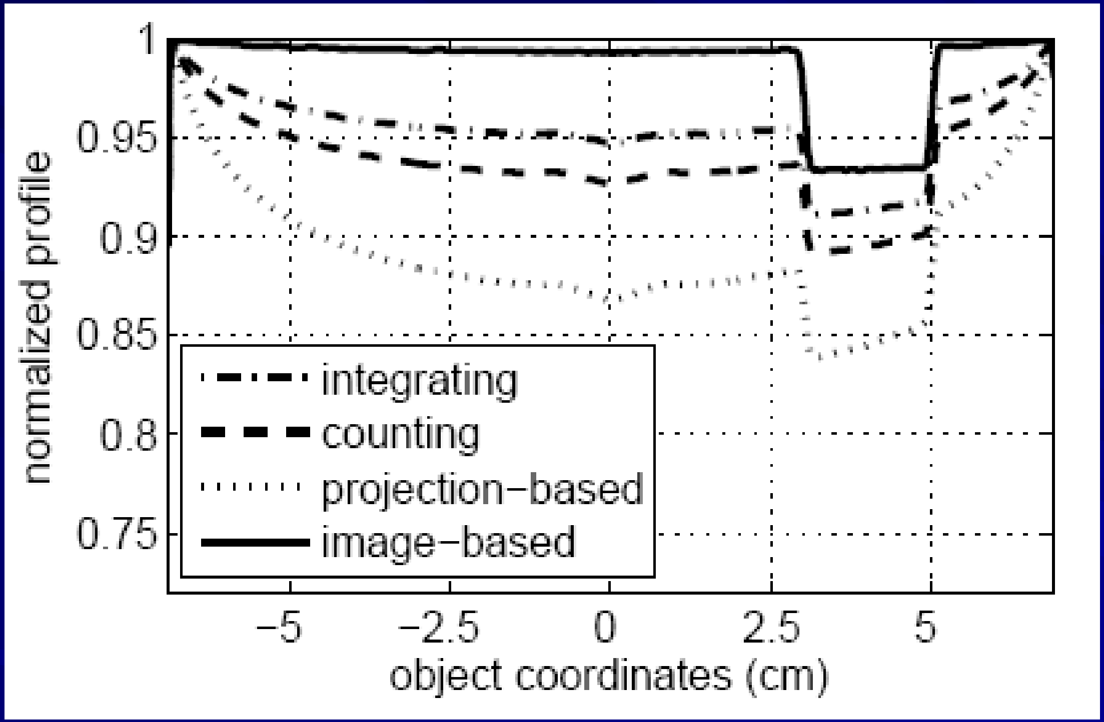


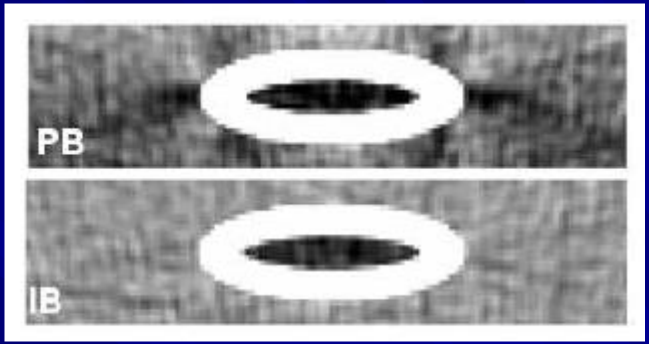
Optimal Energy Weighting

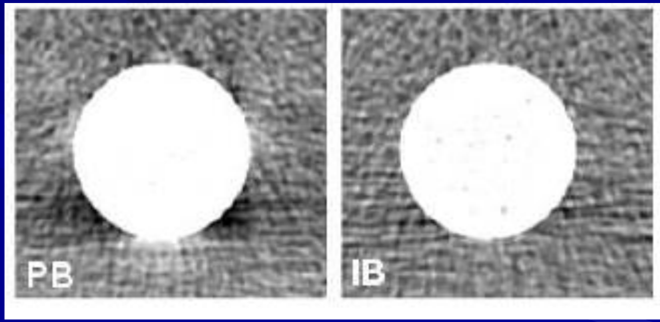
Reduced Clouds

Rupcich & Schmidt (2013)
Shikhaliev & Fritz (2011)
Le et. al (2010)

Beam Hardening Effects







PB: Projection-based optimal weighting

IB: Image-based optimal weighting

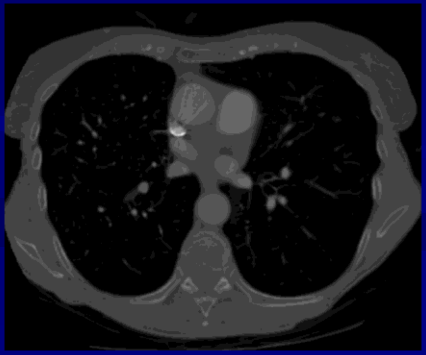
Reduced Clouds

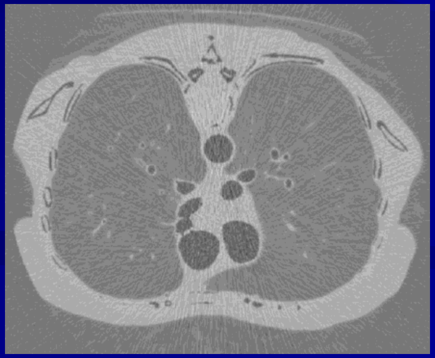
T. G. Schmidt , 2009

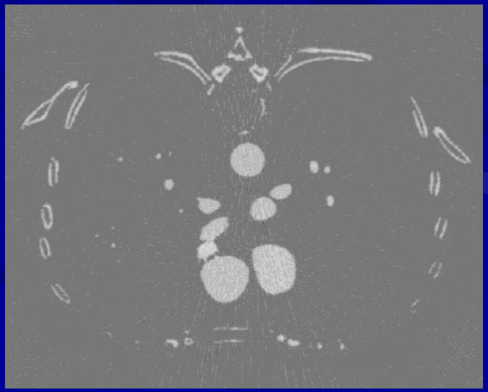
Material Decomposition

The attenuation coefficient can be decomposed into basis functions

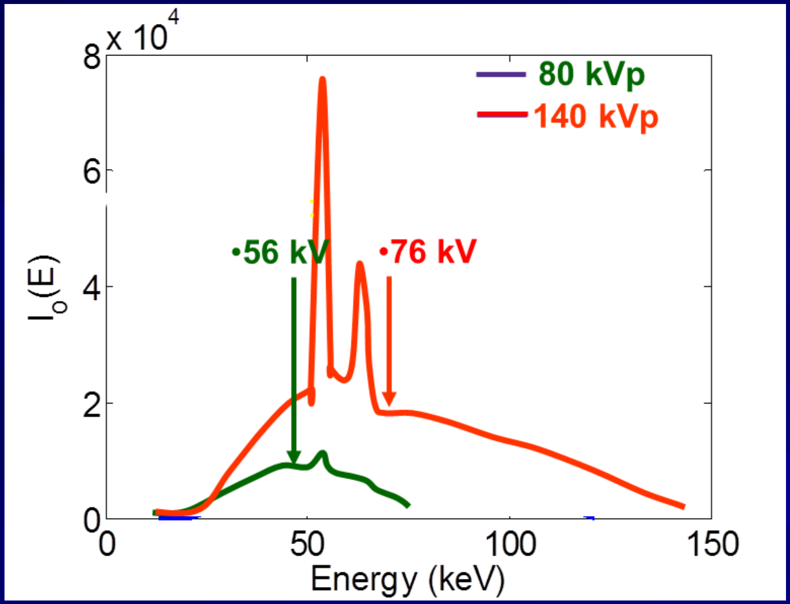
$$\mu(x,y,z) = a(x,y,z)\,\mu_A + b(x,y,z)\,\mu_B$$



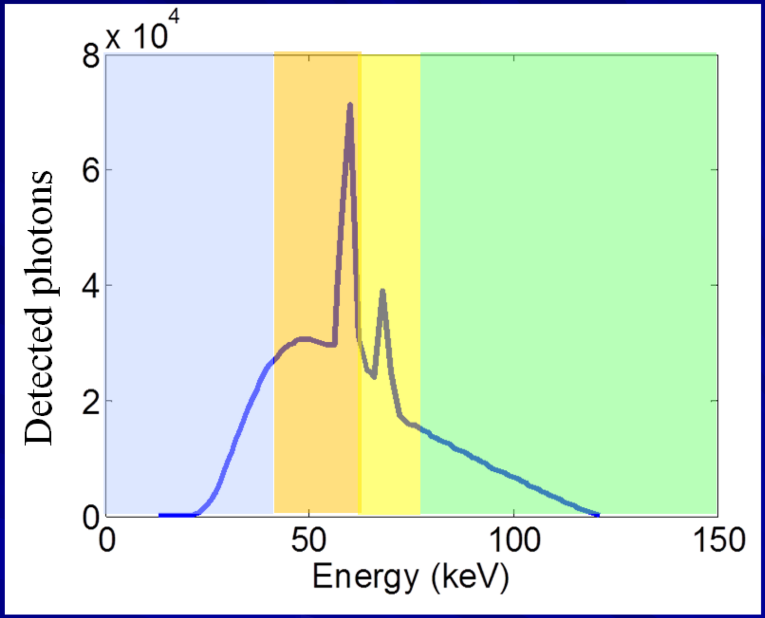




Material Decomposition



Dual kV



Spectral Photon-Counting

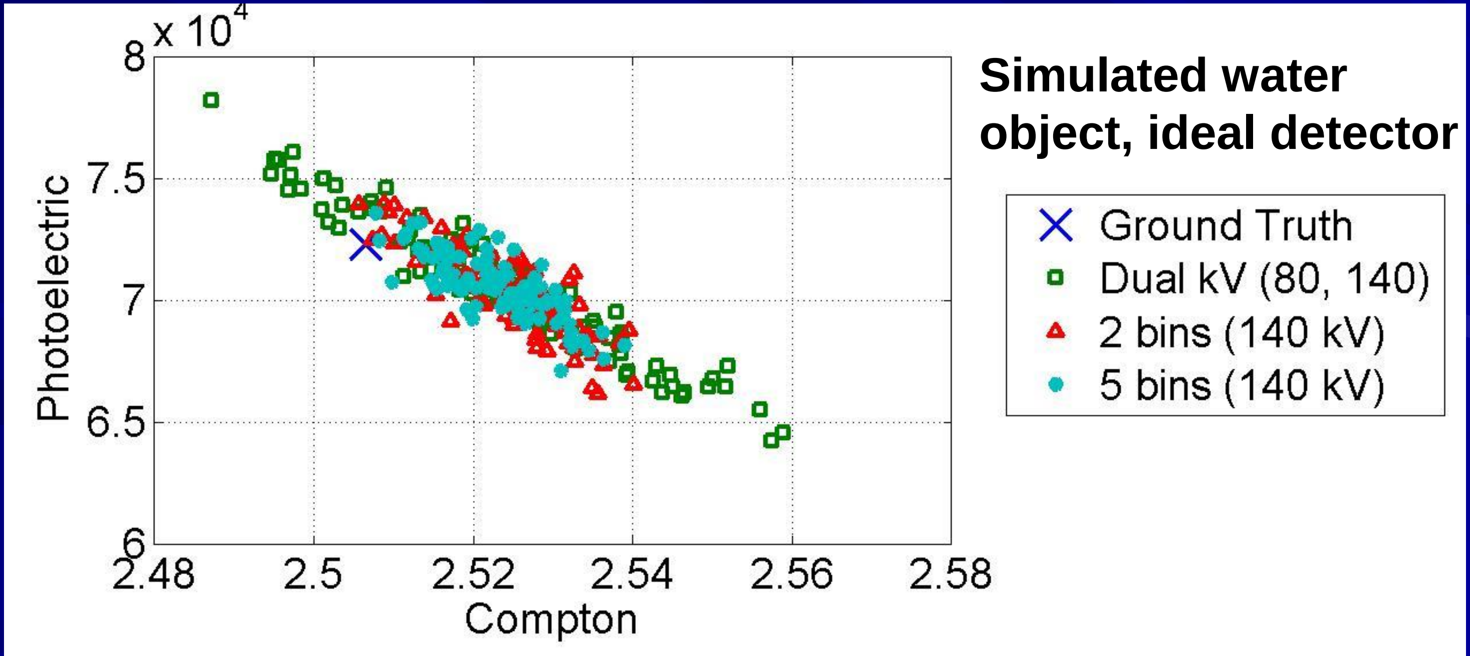
Spectral photon-counting CT has more unique energy information → reduced noise

Material Decomposition

- How does photon-counting compare to dual kV? Same mean, lower noise
- How many bins do you need?

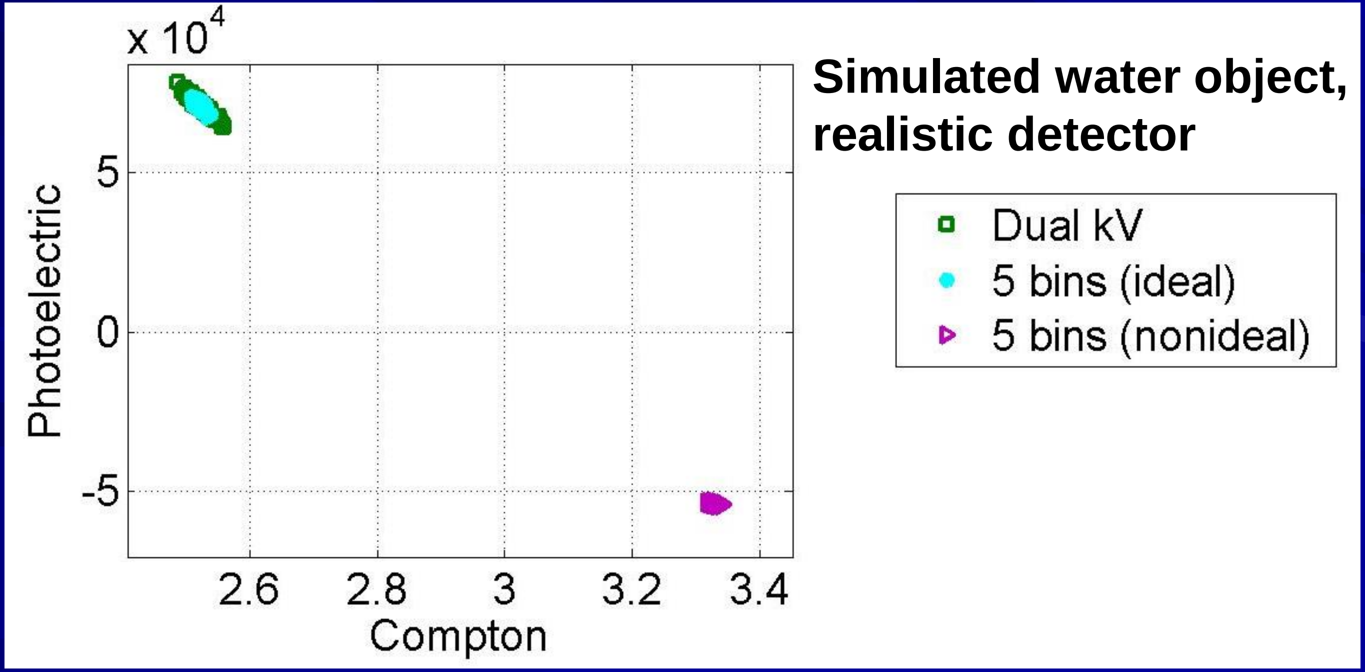
Limited additional benefit for N>2

Reduced Clouds



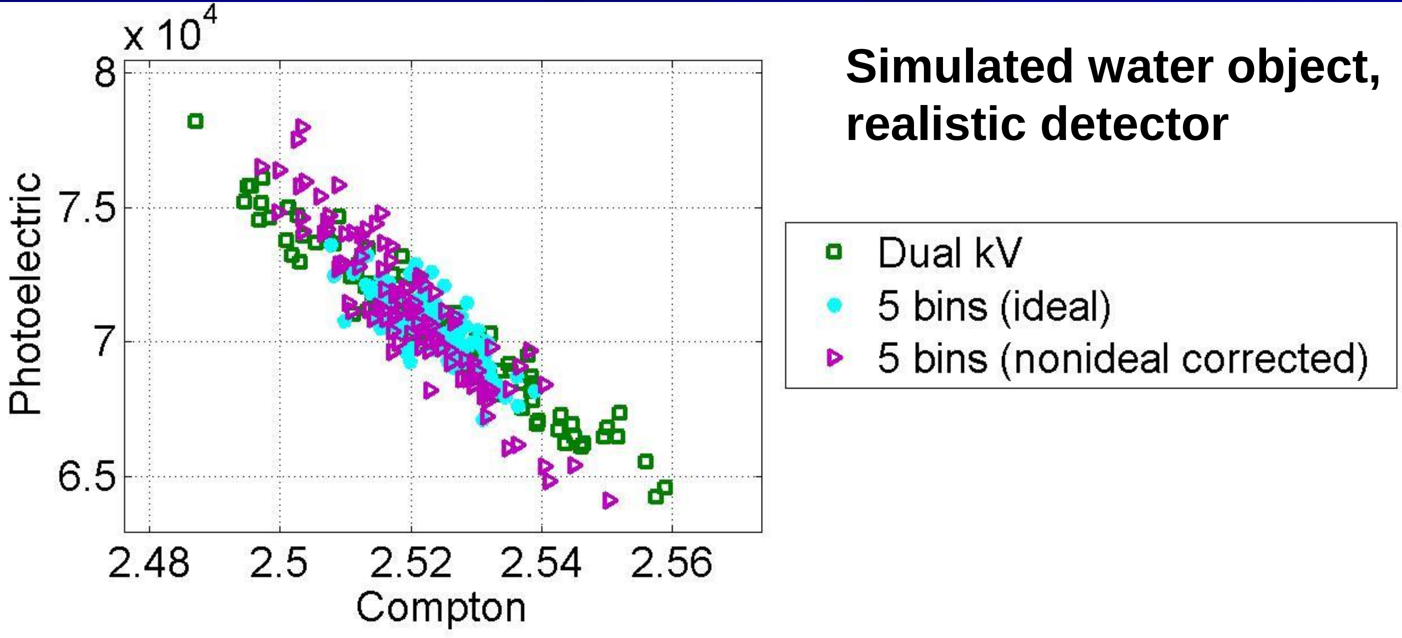
Material Decomposition

- How does photon counting compare to dual-kV when a realistic photon-counting detector is simulated (photons detected in incorrect bins)? Large bias for photon counting



Material Decomposition

- How does photon-counting perform when detector nonidealities included in decomposition algorithm? Bias corrected, but same noise as dual kV. No benefit for PC



Simulated water object, realistic detector

K-edge Imaging

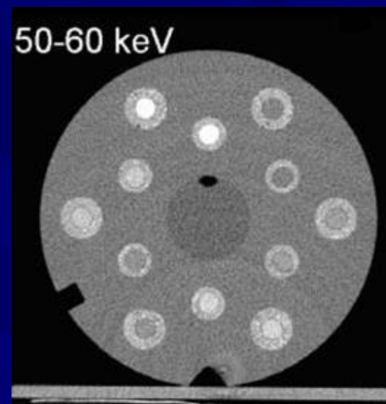
By having N>2 bins, can isolate and directly quantify the concentration of K-edge materials

10x error,
3x noise

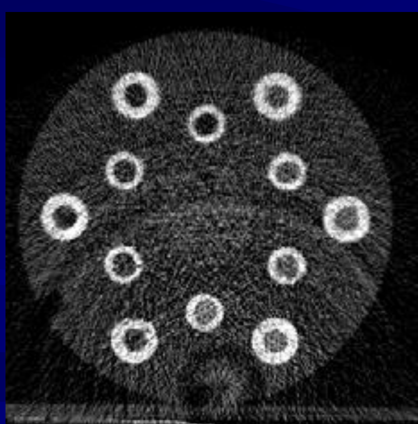
Conventional CT | Photon-counting | Dual kVp

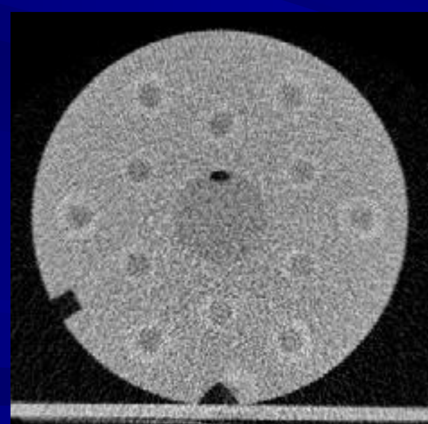
K-edge Imaging

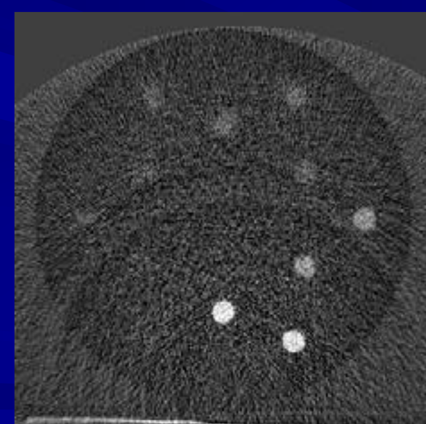
Reduce
Overlap
Threat /
Non-threat

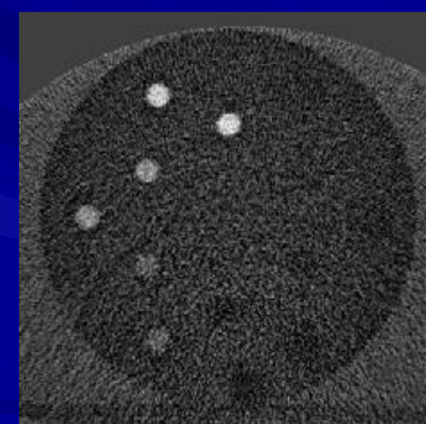


Schlomka, PMB 2008


Photoelectric


Compton


Iodine


Gadolinium

K-edges of Explosives

- K-edges of explosives too low to be detected
- Could be detected by removing object from bag

Material	K-edge (keV)
H	0.01
C	0.3
N	0.4
O	0.5

K-edges of Non-threats?

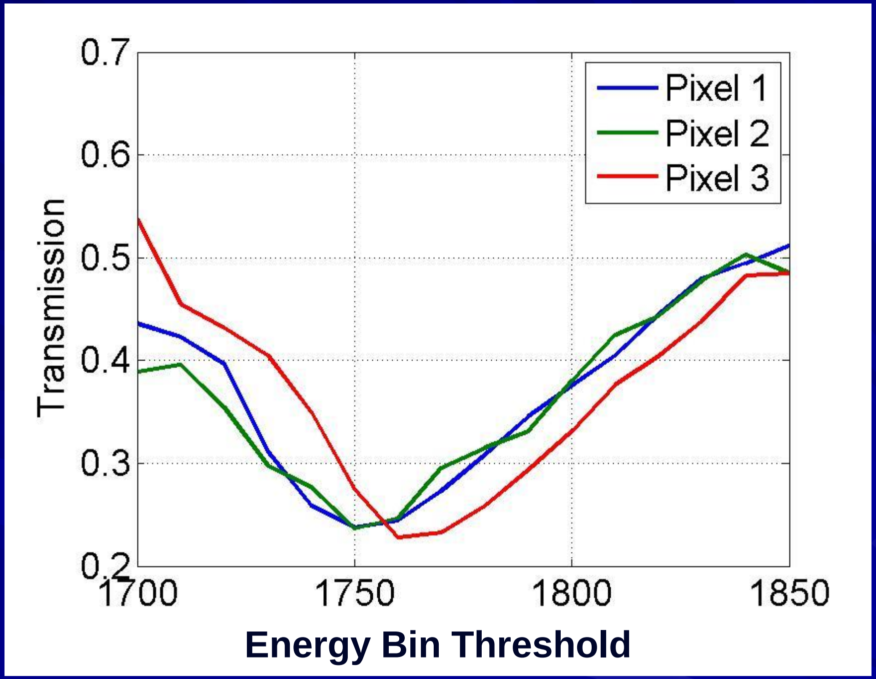
Material	K-edge (keV)
Sn	29
Sb	30
Te	32
I	33
Xe	35
Cs	36
Ba	37
La	39
Ce	40
Pr	42
Nd	44

Material	K-edge (keV)
Pm	45
Sm	47
Eu	49
Gd	50
Tb	52
Dy	54
Ho	56
Er	57
Tm	59
Tb	61
Lu	63

Material	K-edge (keV)
Hf	65
Ta	67
W	69
Re	72
Os	74
Ir	76
Pt	78
Au	80
Hg	82
Th	85
Pb	88

K-edge of Iodine

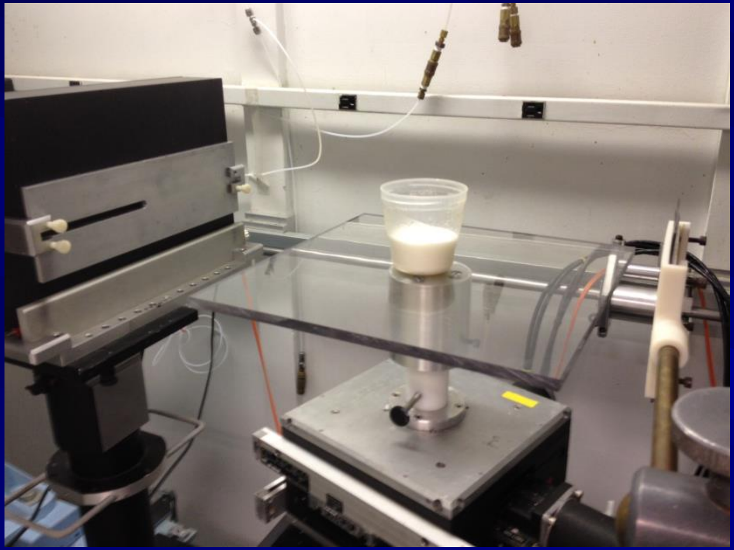
- X-ray transmission generally increases with energy
- Transmission decreases sharply at K-edge
- K-edge can be identified for iodinated contrast agent

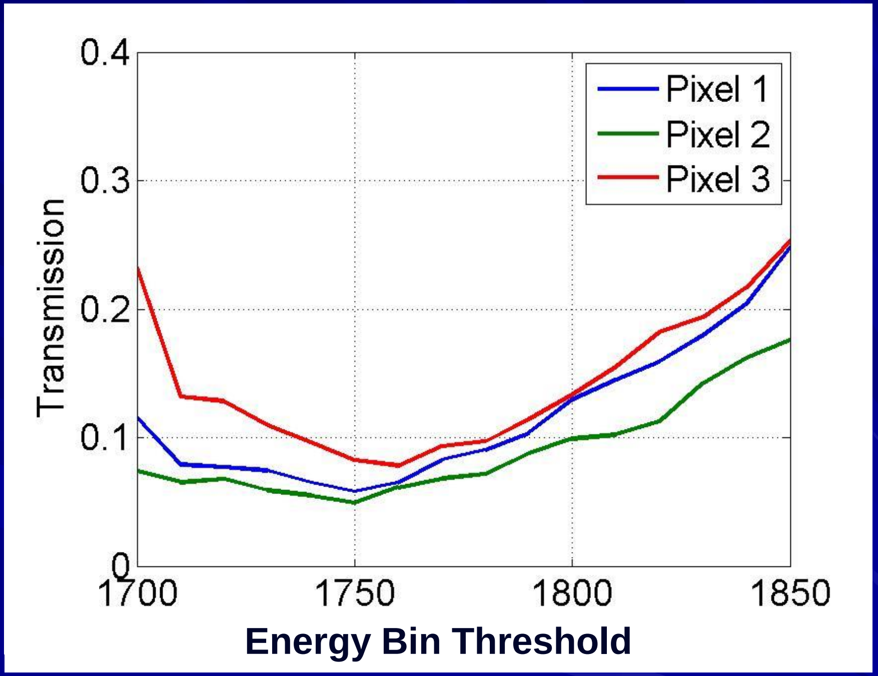


Iodinated X-ray Contrast Agent

370 mg/cm^3 Iodine

Detect the K-edge of Salt?



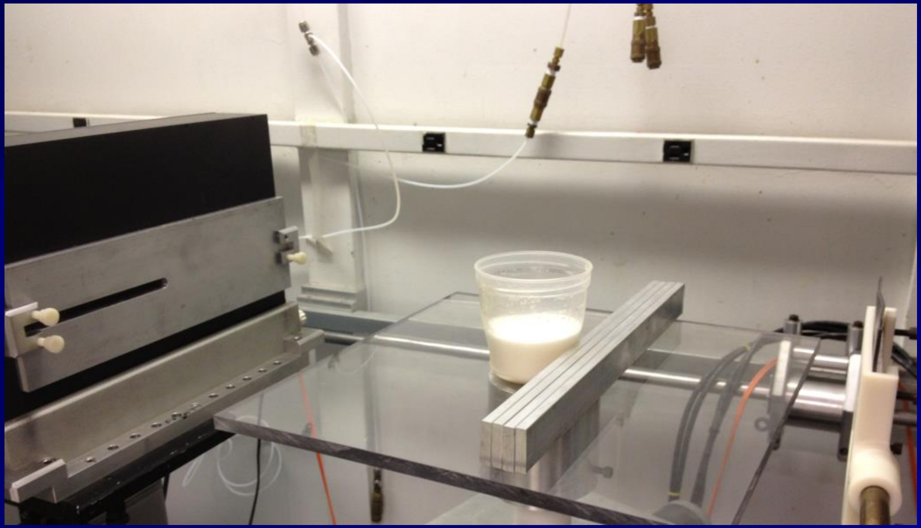


Identifying salt may be useful for discriminating non-threat

Table Salt

0.1 mg/cm^3 Iodine

Detect the K-edge of Salt?



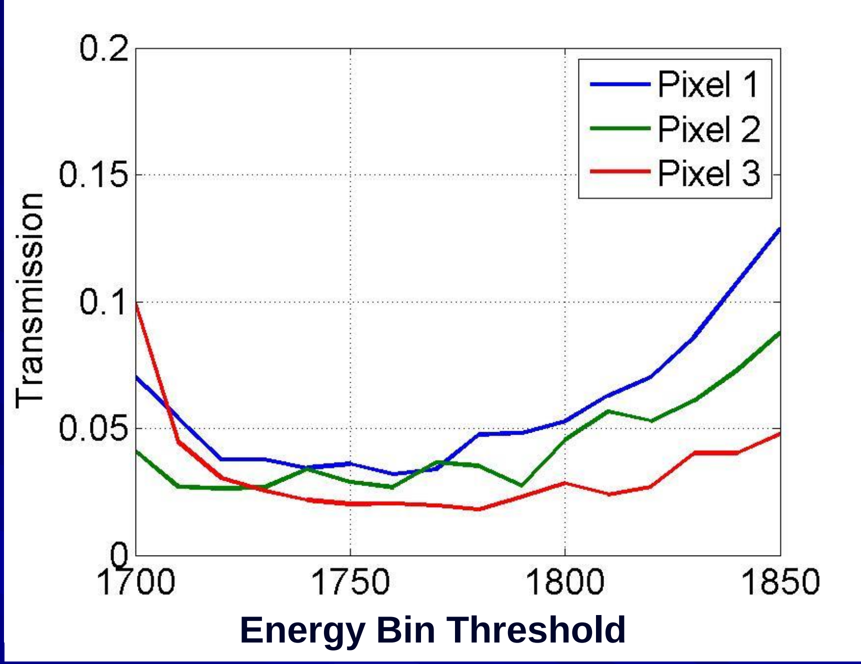


Table Salt

0.1 mg/cm^3 Iodine

Not many 30-40 keV photons penetrate, difficult to see K-edge

Conclusions

Spectral photon-counting CT:

- Improves SNR and removes beam hardening through optimal energy weighting
  - Limited additional benefit for N > 5 bins
  - May help explosive detection by reducing clouds
- Reduces noise in material decomposition
  - Limited additional benefit for N > 2 bins
  - May help explosive detection if task is SNR limited
  - Not fully realized due to detector issues
- Identifies K-edge materials
  - K-edge of explosives too low to be detected
  - K-edge may be useful to identify non-threats

Acknowledgments

Franco Rupcich, Fatih Pektas, Kevin Zimmerman (Marquette)

Steve Haworth (MCW)

NIH R21 EB015094-01A1

This study was supported in part by an appointment to the Research Participation Program at the FDA Center for Devices and Radiological Health