

# Photon Counting Detector CT: An Emerging Technology for CT Imaging

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# Disclosure

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▶ None

# Outline

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## ▶ Introduction

- PCD vs. EID
- Whole body PCD-CT system
- PCD Configuration

## ▶ Benefits

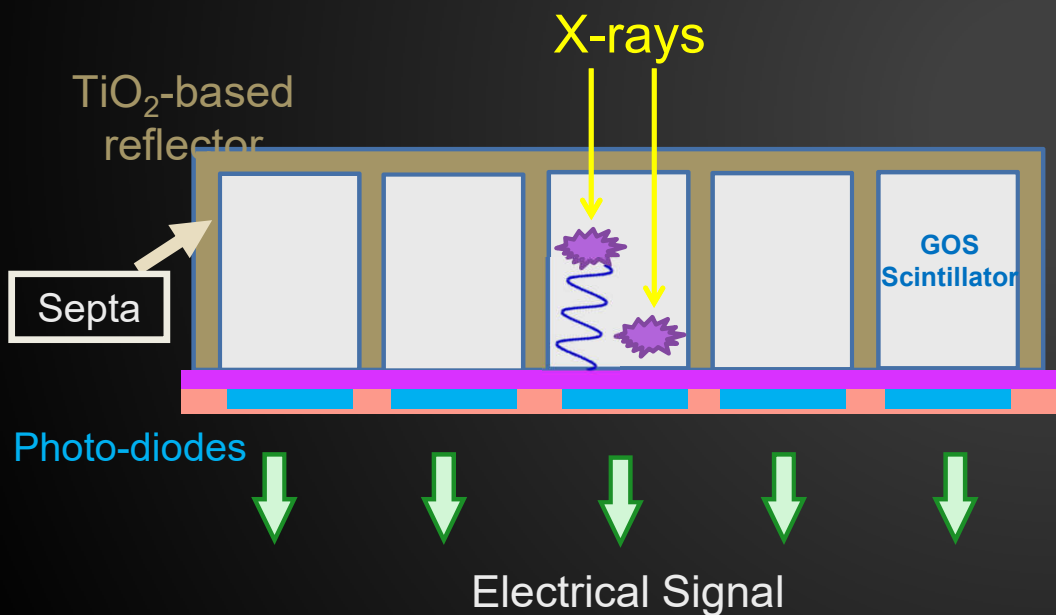
- Reduced Electronic Noise
- Increased CNR/Dose Efficiency
- Increased Spatial Resolution
- Simultaneous, single kV, multi-energy CT
- Ability to differentiate multiple k-edge contrast agents

## ▶ Future development

# Photon Counting Detector CT

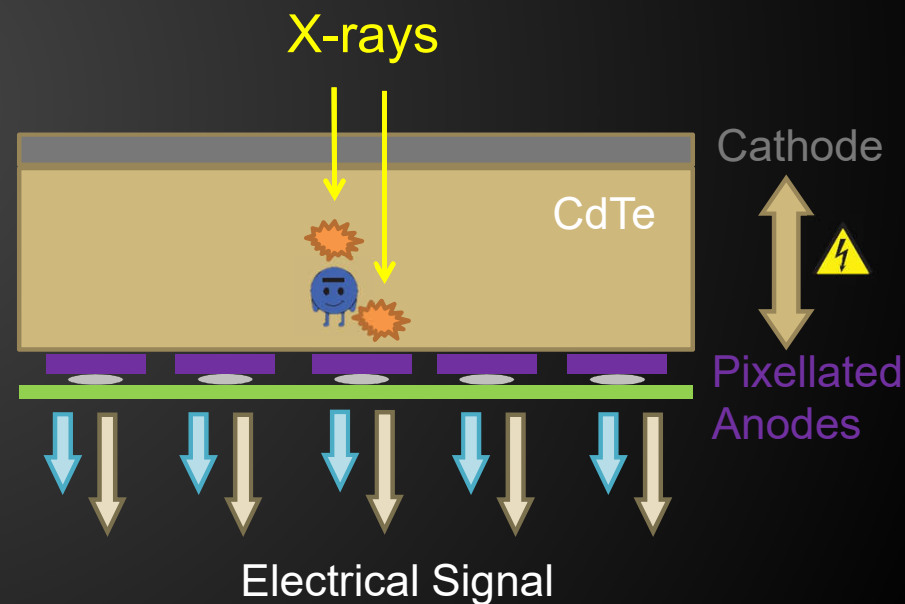
## Energy integrating detector (EID)

- ▶ X-ray to electrical signal: **Indirect** conversion (Accumulative Signal) -- **State of Art**



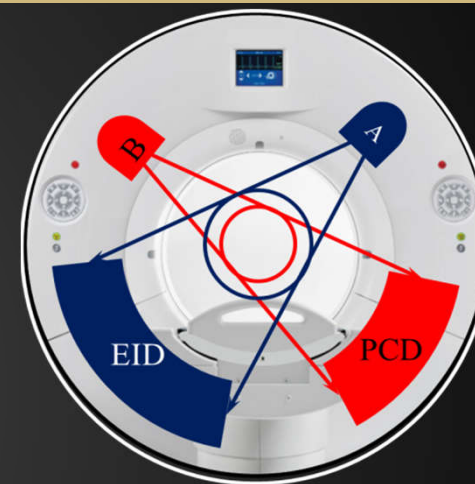
## Photon Counting Detector (PCD)

- ▶ X-ray to electrical signal: **Direct** conversion
- ▶ Pulse height proportional to x-ray energy



# Whole-Body PCD-CT Systems

- ▶ Siemens: based on Flash platform
  - Siemens Healthcare (Erlangen, Germany); Mayo Clinic, NIH; German Cancer Research Center
  - First patient in 2015
  
- ▶ Philips: based on iCT system
  - Université Claude Bernard Lyon 1, France



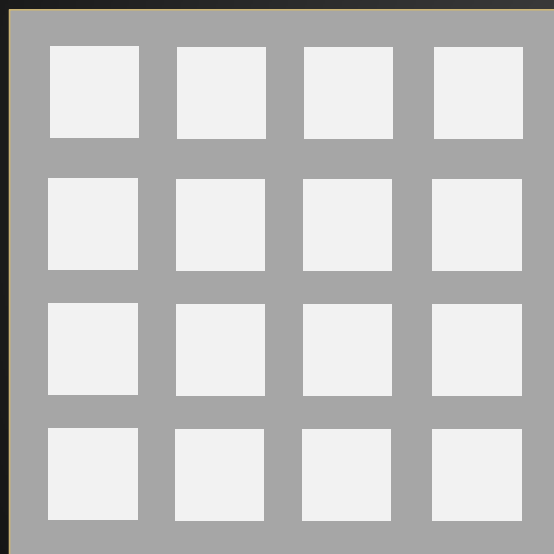
	EID-CT	PCD-CT
Detector Size	0.6 mm	0.25 mm
Collimation	128 x 0.6 mm	32 x 0.25 mm / 64 x 0.5 mm
FOV	500 mm	275 mm
Max Current	800 mA	550 mA



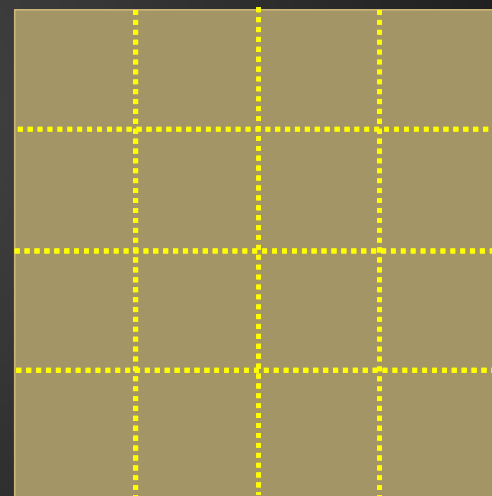
# PCD-CT Detector Configuration

- ▶ Several clinical applications require high resolution (smaller acquisition pixel)

EID-CT

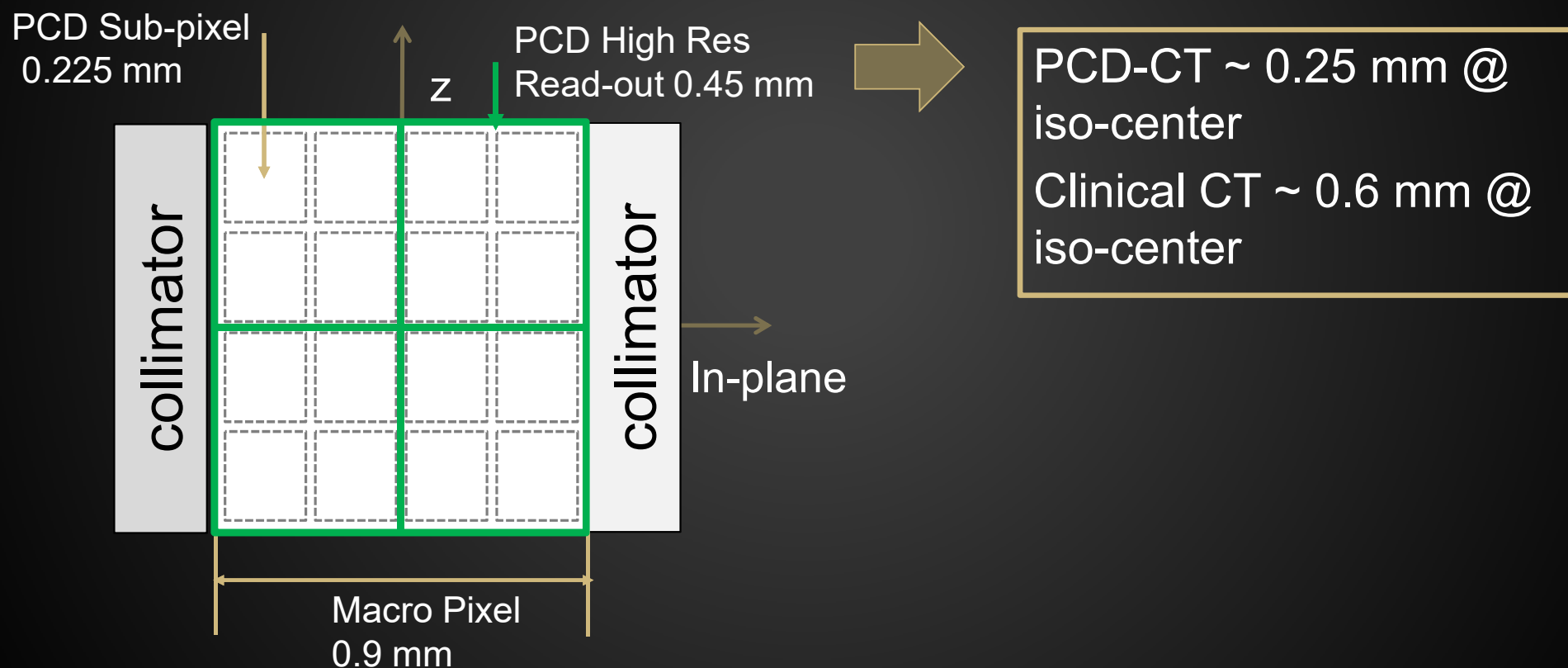


PCD-CT



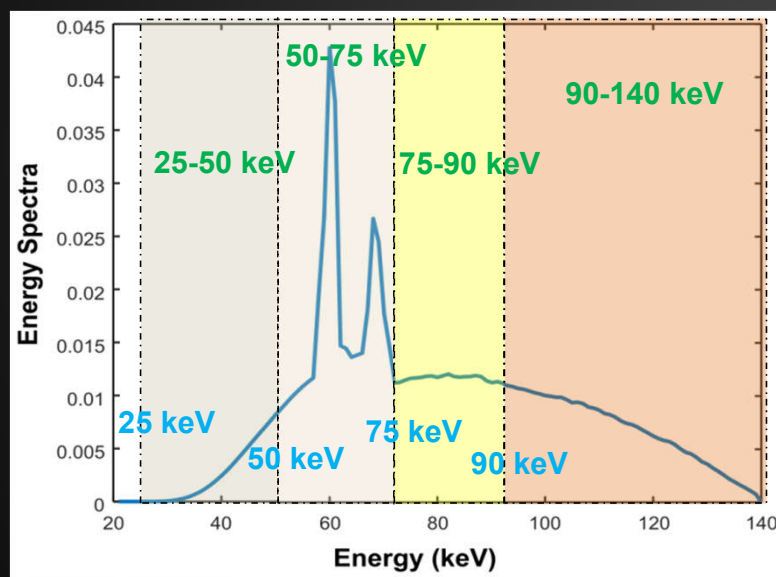
Yu *et al.*, PMB 2016

# PCD-CT Detector Configuration



# PCD-CT Spectral Acquisition

- ▶ Counting individual photons
- ▶ Energy Discrimination with pre-defined threshold



Threshold L1: 25 – 140 keV  
Threshold L2: 50 – 140 keV  
Threshold H1: 75 – 140 keV  
Threshold H2: 90 – 140 keV

Bin 1: 25 – 50 keV  
Bin 2: 50 – 75 keV  
Bin 3: 75 – 90 keV  
Bin 4: 90 – 140 keV

Yu *et al.*, PMB 2016  
Willemink, *et al.*, Radiology 2018

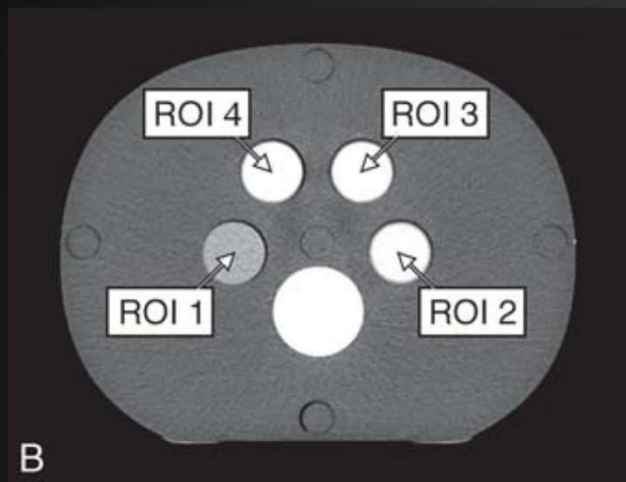


# Benefits of PCD-CT

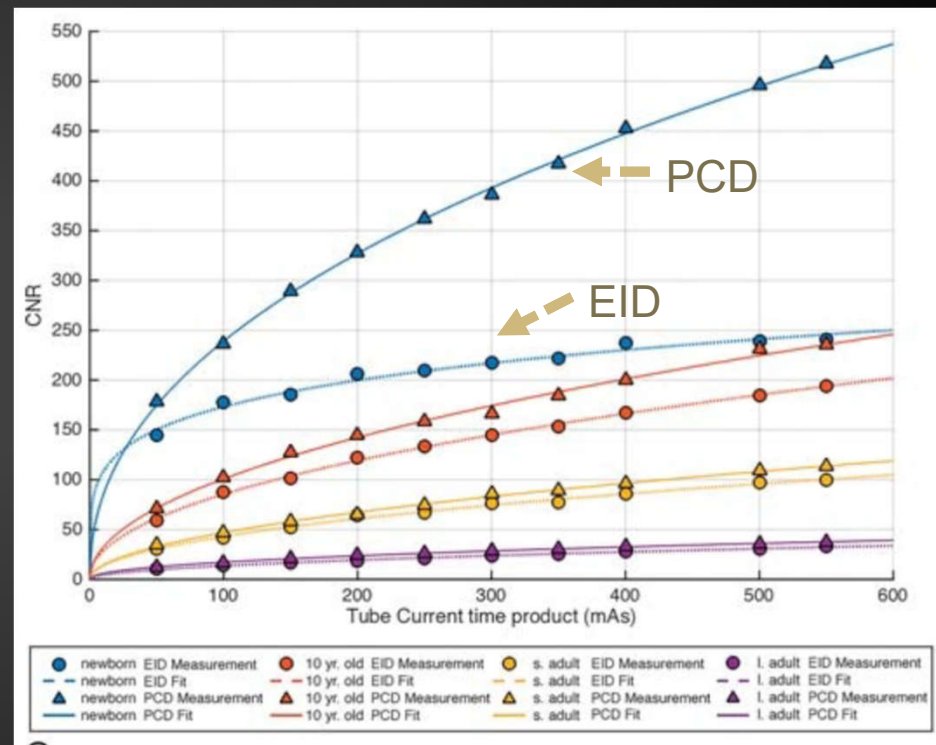
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- Reduced Electronic Noise
- Increased CNR/Dose Efficiency
- Increased Spatial Resolution
- Simultaneous, single kV, multi-energy CT
- Ability to differentiate multiple k-edge contrast agents

# Reduced Noise/Increased Contrast



	Clinical CT	PCD-CT
Iodine Contrast (HU)	603.76	721.79
Noise (HU)	11.36	10.82
CNR	53.15	66.68

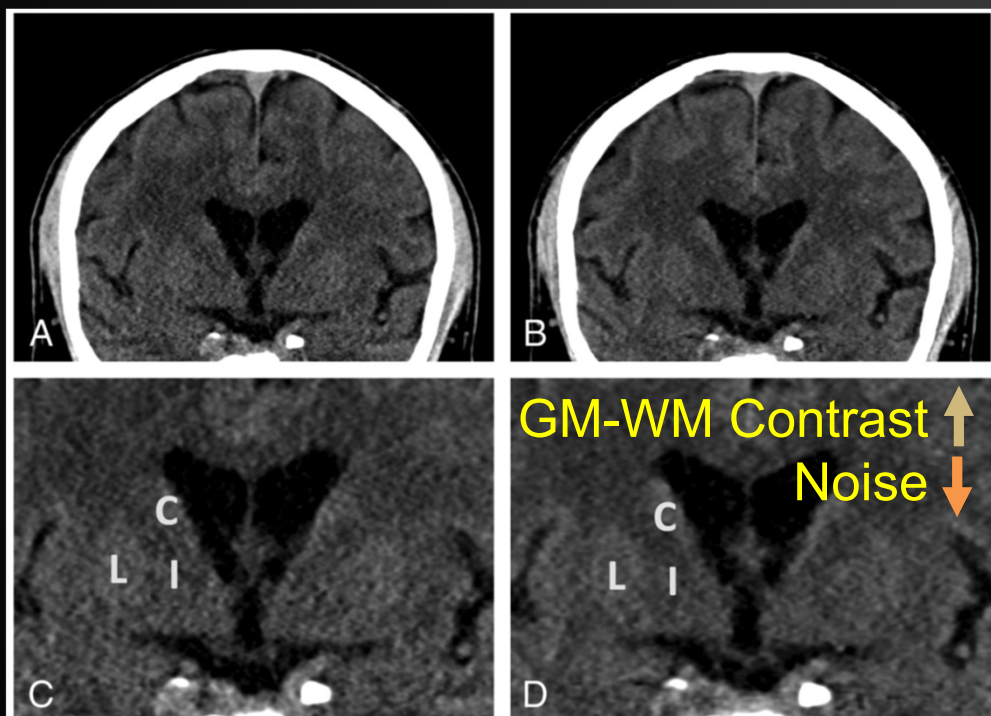


Yu *et al.*, PMB 2016  
 Gutjahr *et al.*, Invest Radiol 2016

# Reduced Noise/Increased Contrast

Clinical CT

PCD-CT



**Table 3: Image-quality comparison between energy-integrating detector and photon-counting detector CT for gray matter, white matter, and CSF**

Image-Quality Index	EID <sup>a</sup>	PCD <sup>a</sup>	P Value	Improvement Ratio <sup>b</sup> (%)
GM noise (HU)	3.9 ± 1.0	3.2 ± 0.5	<.001	17.9
WM noise (HU)	3.4 ± 0.8	2.7 ± 0.7	.002	20.6
CSF noise (HU)	3.9 ± 0.8	3.4 ± 0.7	<.001	12.8
GM SNR	10.5 ± 2.5	12.6 ± 2.2	<.001	19.0
WM SNR	9.5 ± 2.3	11.4 ± 2.7	.01	20.0
GM-WM contrast (HU)	8.9 ± 1.8	10.3 ± 1.9	.02	15.7
GM-WM CNR	1.8 ± 0.5	2.4 ± 0.8	<.001	33.3

Pourmorteza *et al.*, AJNR 2018

# Benefits of PCD-CT

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- Reduced Electronic Noise
- Increased CNR/Dose Efficiency
- Increased Spatial Resolution**
- Simultaneous, single kV, multi-energy CT
- Ability to differentiate multiple k-edge contrast agents

# Increased Spatial Resolution - Phantom

- Improved assessment of nodule morphology using ultra-high-resolution (UHR) in PCD-CT system.

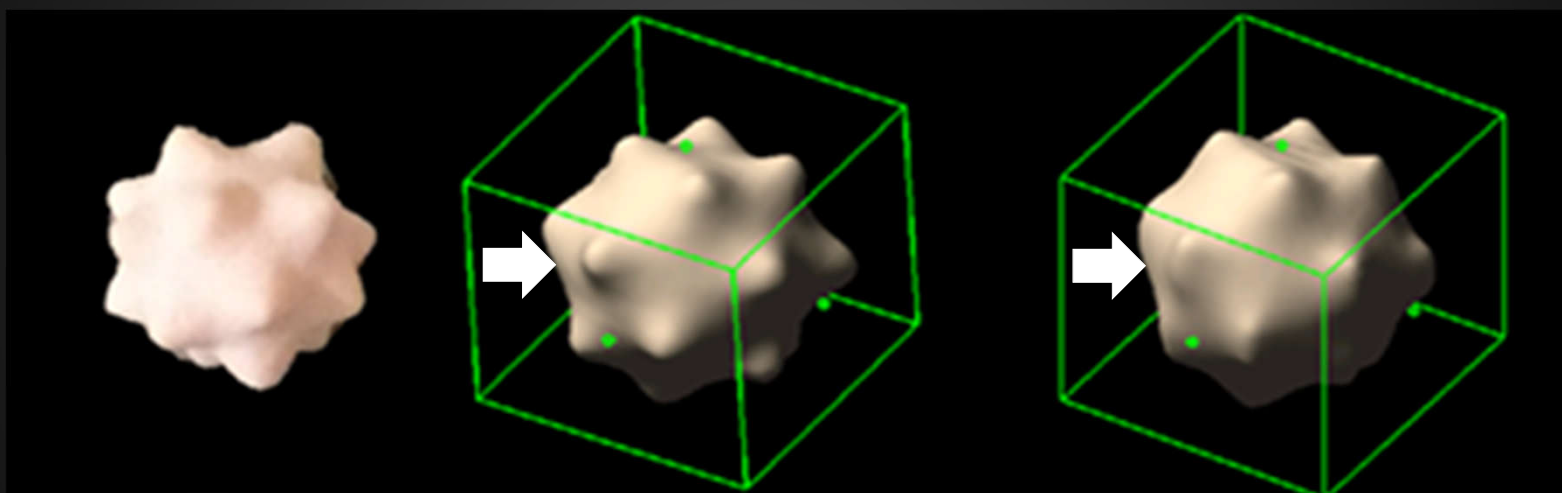


Photo of a 10-mm nodule

PCD UHR Mode

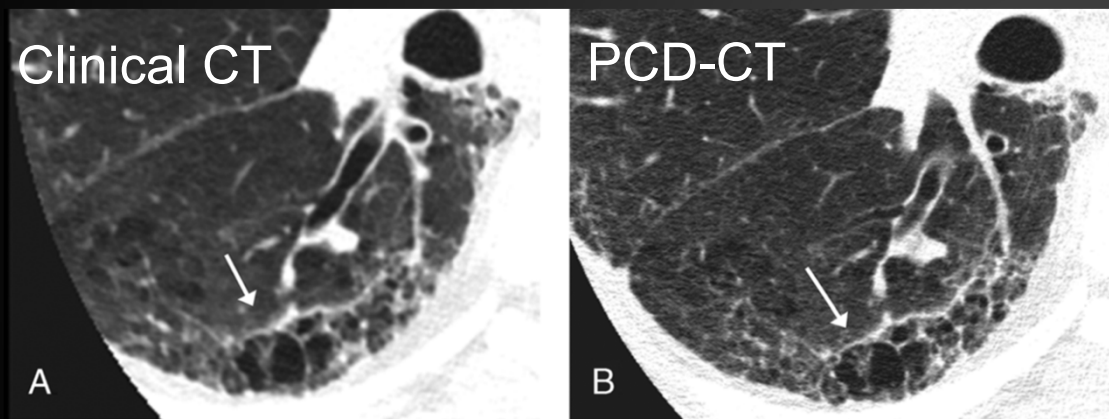
PCD Macro Mode (Similar to Clinical CT)

Zhou *et al.*, JMI 2018

# Increased Spatial Resolution – Patient

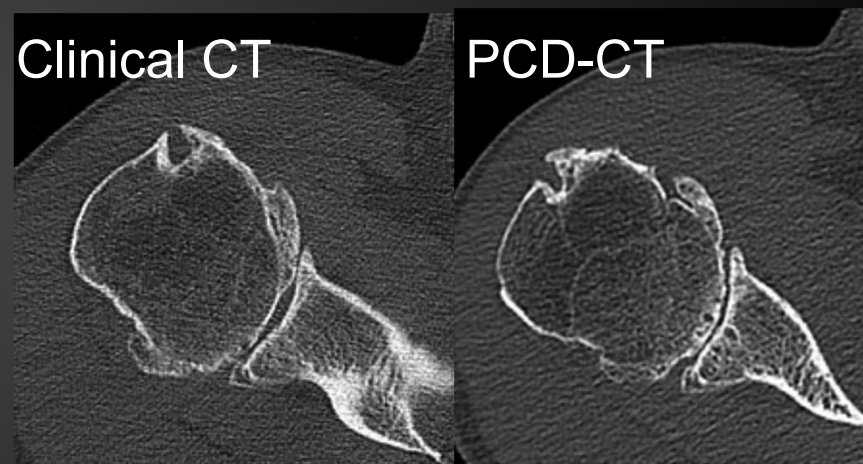
## Lung CT

- ▶ Improved definition of fibrosis



## Shoulder CT

- ▶ Sharper cortex and trabecular bone



Leng *et al.*, Invest Radiol 2018  
Bartlett *et al.*, Invest Radiol 2019

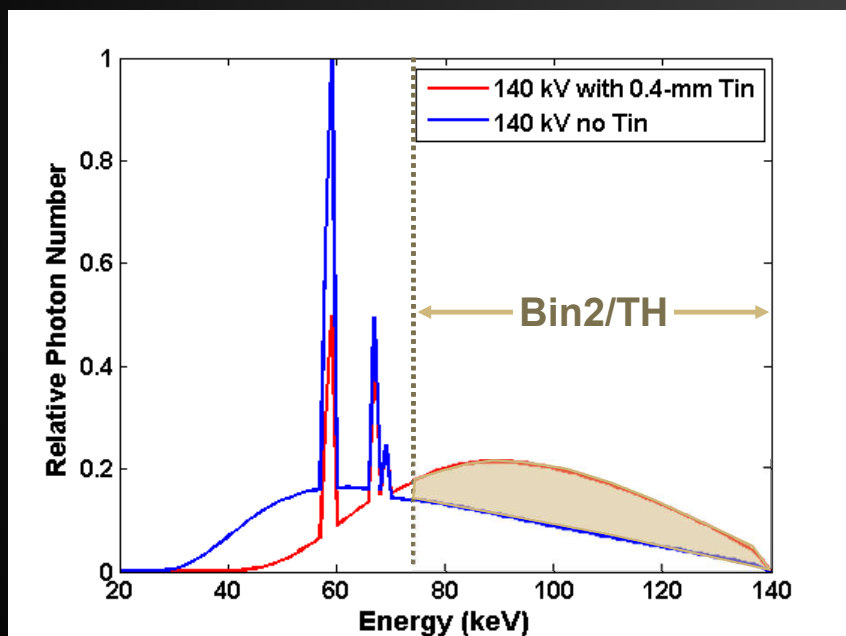
# Benefits of PCD-CT

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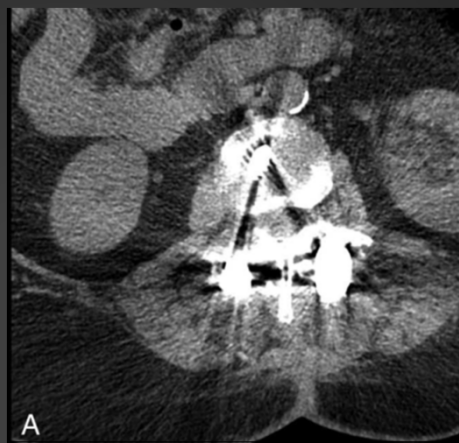
- Reduced Electronic Noise
- Increased CNR/Dose Efficiency
- Increased Spatial Resolution
- Simultaneous, single kV, multi-energy CT**
- Ability to differentiate multiple k-edge contrast agents

# Simultaneous Multi-Energy - MAR

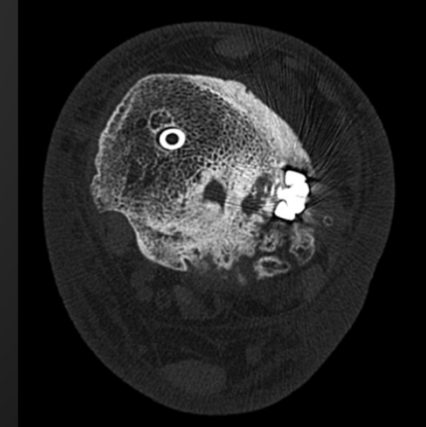
- Use spectral shaping and high energy bin images (Bin2/TH) to reduce metal artifacts (MAR)



Clinical CT



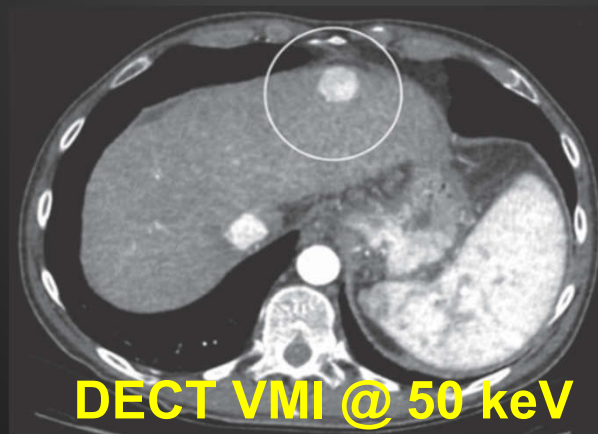
PCD-CT Bin2





# Simultaneous Multi-Energy – Universal Protocol

- ▶ kV needs to be manually selected or automatically determined in current workflow, based on patient size, clinical tasks, etc.
  - A substantially increased risk for unacceptable image quality
- ▶ Virtual mono-energetic images (VMIs) at low keV can be synthesized from dual energy (DE) CT or PCD-CT



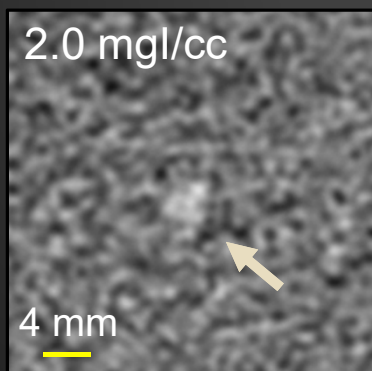
Matsumoto *et al.*, Radiology, 2010  
Leng *et al.*, Radiology, 2011  
Shuman *et al.*, AJR, 2014  
McCollough, *et al.*, Radiology 2015

# Simultaneous Multi-Energy – Universal Protocol

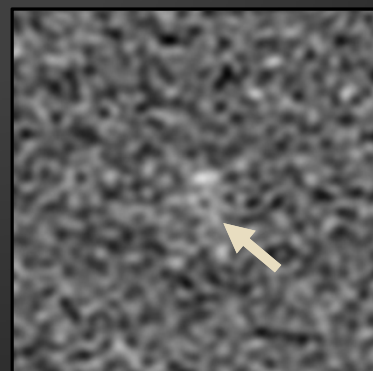
- ▶ Can we use a single-kV universal protocol (140 kV, 25/75 keV) to generate VMIs on PCD-CT for enhanced CT exams (abdominal iodine detection) across different adult patient sizes?



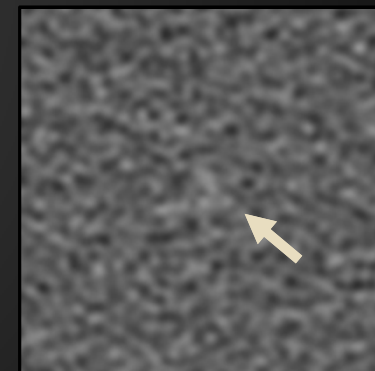
**PCD-CT  
VMI@50keV**



**EID DE  
VMI@50keV**



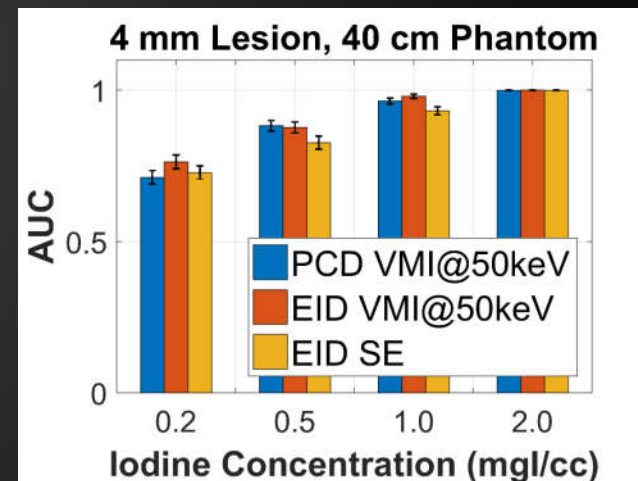
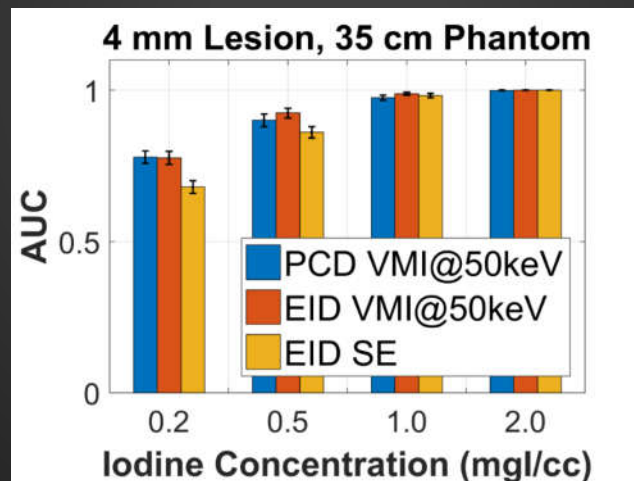
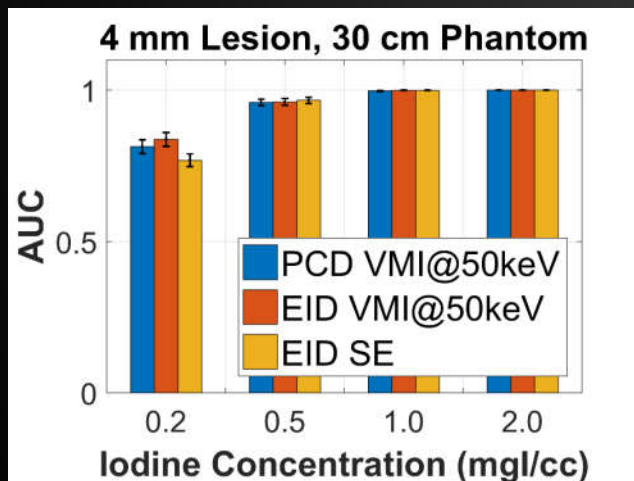
**EID SE  
100 kV**



Zhou *et al.*, Invest Radiol (In Press)

# Simultaneous Multi-Energy – Universal Protocol

- ▶ VMI@50 keV generated from a universal PCD protocol provides comparable detectability relative to optimal EID-SE CT at size-specific kV settings.
- ▶ Streamline the clinical workflow for enhanced CT exams and reduce inadvertent selection of inferior settings.



Zhou *et al.*, Invest Radiol (In Press)

# Simultaneous Multi-Energy – SPR

- ▶ Stopping power ratio (SPR) calculation determines the accuracy of dose delivery in charged-particle therapy (e.g. proton).
- ▶ PCD-CT method produced similar or better SPR results than the SECT- and DECT-based methods.

Taasti *et al.*, Med Phys 2018

Noise level	RMSE (%)	Mean error (%)	[5%,95%] (%)
<b>PCD-CT 4 Bins</b>			
No noise	0.5 ←	0.0	[-0.9,0.9]
Low	1.6	0.1	[-2.4,2.7]
Medium	2.1 ←	0.1	[-3.0,3.4]
High	3.1	-0.1	[-4.3,4.2]
<b>PCD-CT 2 Bins</b>			
No noise	0.5 ←	-0.0	[-0.9,0.9]
Low	1.6	0.1	[-2.4,2.7]
Medium	2.1 ←	0.1	[-3.0,3.3]
High	3.0	-0.0	[-4.2,4.2]
<b>DECT</b>			
No noise	0.4	-0.1	[-0.8,0.6]
Low	3.0	0.0	[-4.5,5.0]
Medium	5.8 ←	0.2	[-8.3,9.9]
High	10.6	0.2	[-15.9,16.4]
<b>SECT</b>			
No noise	1.5 ←	0.0	[-2.4,2.6]
Low	1.6	0.0	[-2.6,2.8]
Medium	2.0	0.1	[-3.0,3.2]
High	3.2	0.1	[-4.3,4.7]

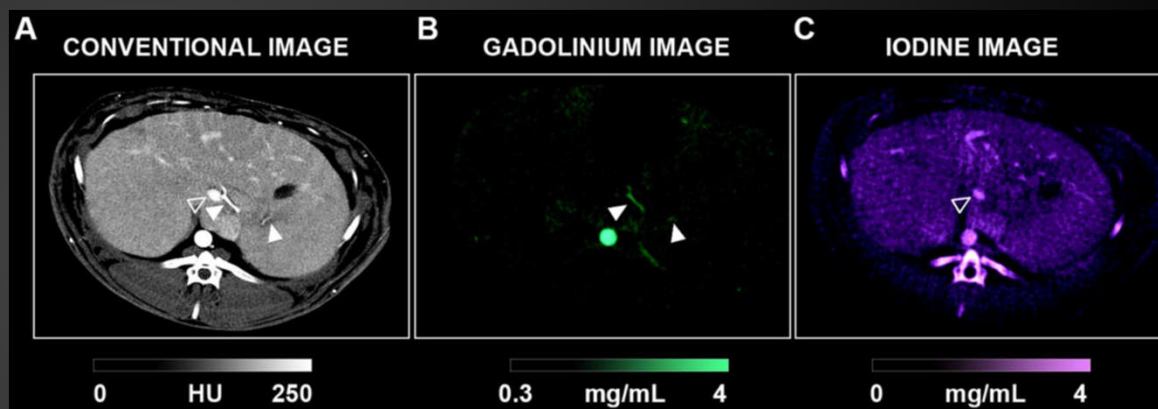
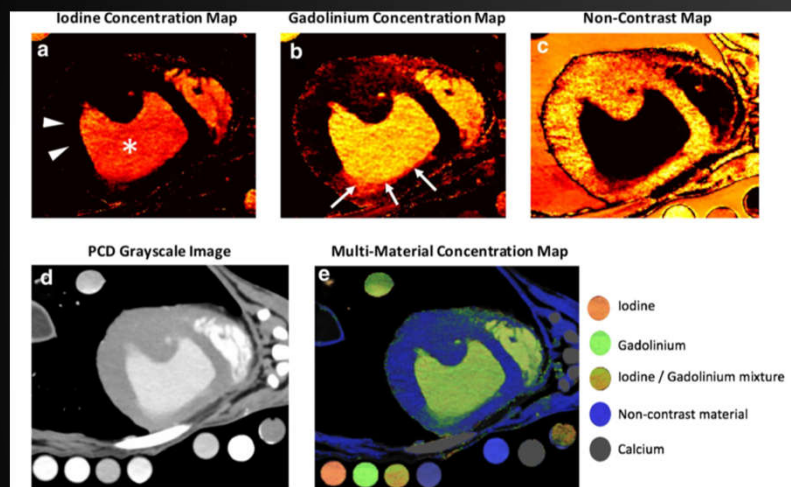
# Benefits of PCD-CT

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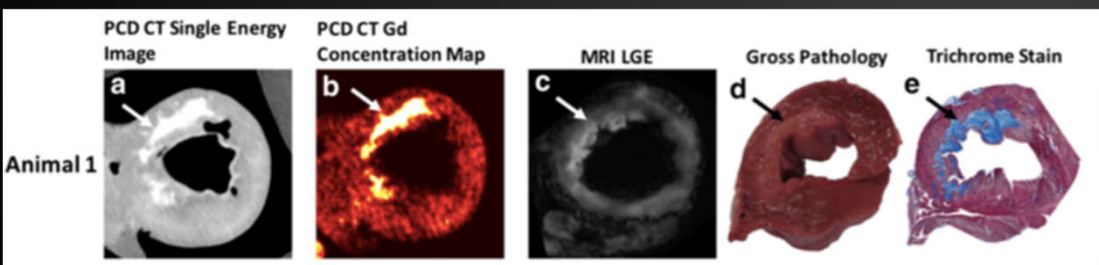
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# Multi K-edge Contrasts Imaging

► Differentiate multiple contrast agents simultaneously in a single acquisition



Rabbits N = 4	Attenuation (HU)	Concentration of Gadolinium (mg/mL)	Concentration of Iodine (mg/mL)
Aorta	1103.1 ± 108.0	20.5 ± 2.07	6.9 ± 0.5
Hepatic Artery	605.6 ± 171.9	8.5 ± 3.9	0.7 ± 0.1
Portal Vein	253.5 ± 49.0	0 ± 1.3	4.2 ± 0.3
Liver	149.2 ± 18.25	0.5 ± 0.3	2.1 ± 0.1



Symons *et al.*, Int J Cardiovasc Imaging 2017  
Si-Mohamed *et al.*, Scientific Reports 2019

# Challenges/Opportunities

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## Techniques

- ▶ Pulse pile-up
- ▶ Charge sharing
- ▶ Elevated noise in narrow bin/ultra high resolution images
- ▶ Spectral image post-processing

## Clinical Applications

- ▶ Chest
- ▶ Breast (Experimental PCD breast CT systems)
- ▶ Cardiovascular

# Q & A