Neural Network Approach for Photon-counting Detection – The First Step: PPE Correction

Ruibin Feng, Ph.D.
Biomedical Imaging Center,
CBIS/BME, RPI
fengr@rpi.edu

David Rundle
JairiNovus Technologies Ltd.
david.rundle@jairinovus.com

Ge Wang, Ph.D.
Biomedical Imaging Center,
CBIS/BME, RPI
wangg@rpi.edu

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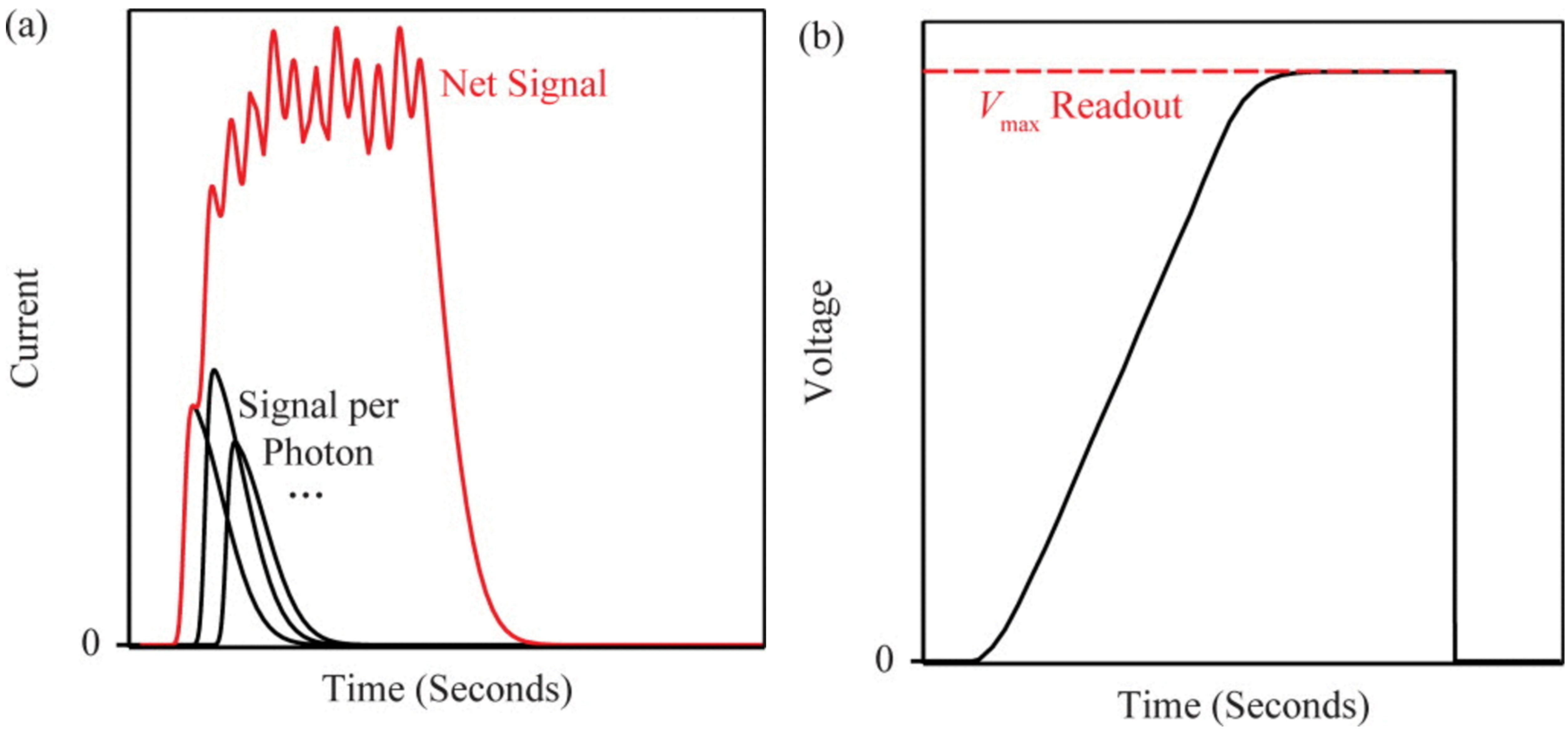
Outline

- X-ray Detectors: EIDs vs. PCDs
- PCD Data Degradation
- Trigger Threshold Correction
- Monte-Carlo Simulation
- Discussions & Conclusion

Energy-integrating Detectors (EIDs)

- Mature technology in all current x-ray scanners
- Energy integration over the entire x-ray spectrum

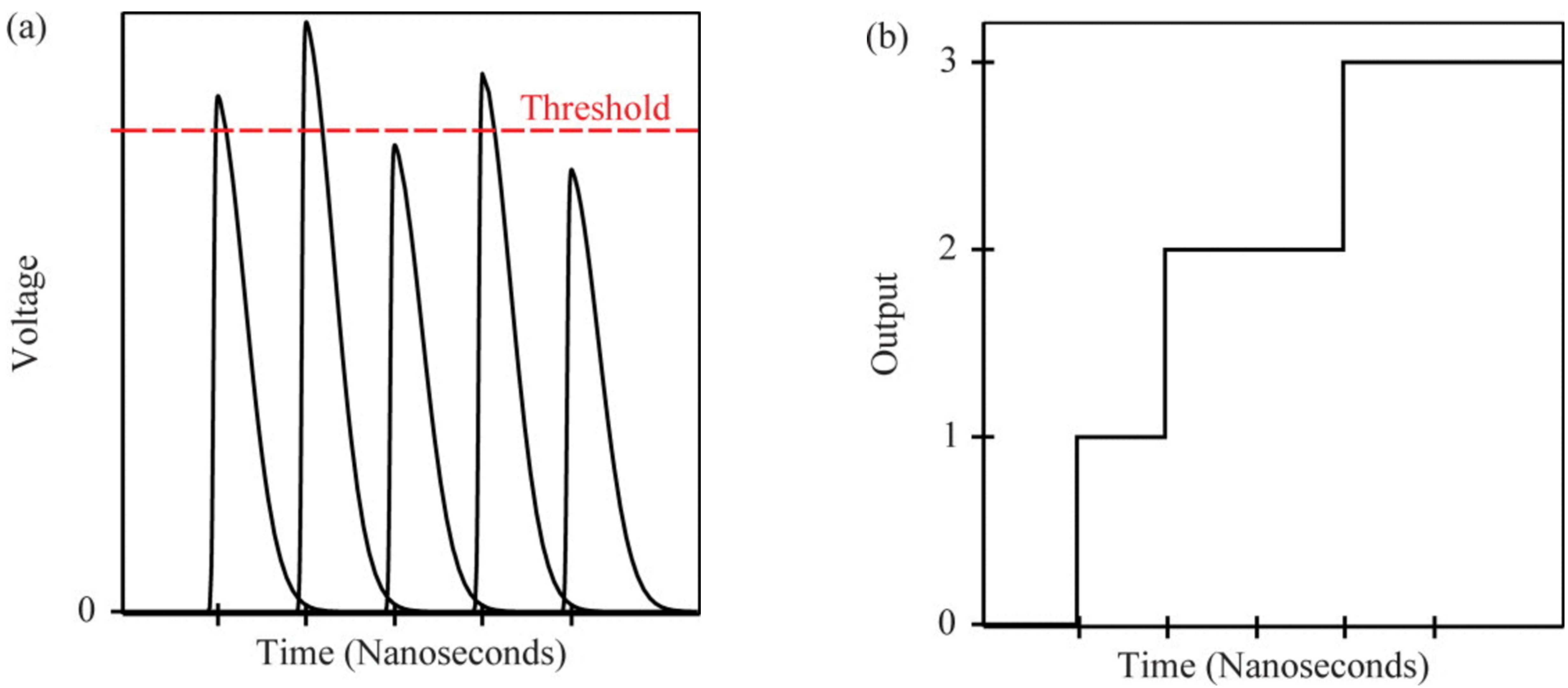


Drawbacks of EIDs

- Energy-dependent information lost
  - Linear attenuation not tissue-type sensitive
- Data quality degenerated due to the dark current (electric/Swank noise)
  - Low SNR
- Low-energy photons under weighted
  - Poor contrast, beam-hardening

Photon-counting Detectors (PCDs)

- **Voltage cross the threshold counted, individually and energy-sensitively**
- **Multiple energy windows spanning the spectral dimension for CT imaging**



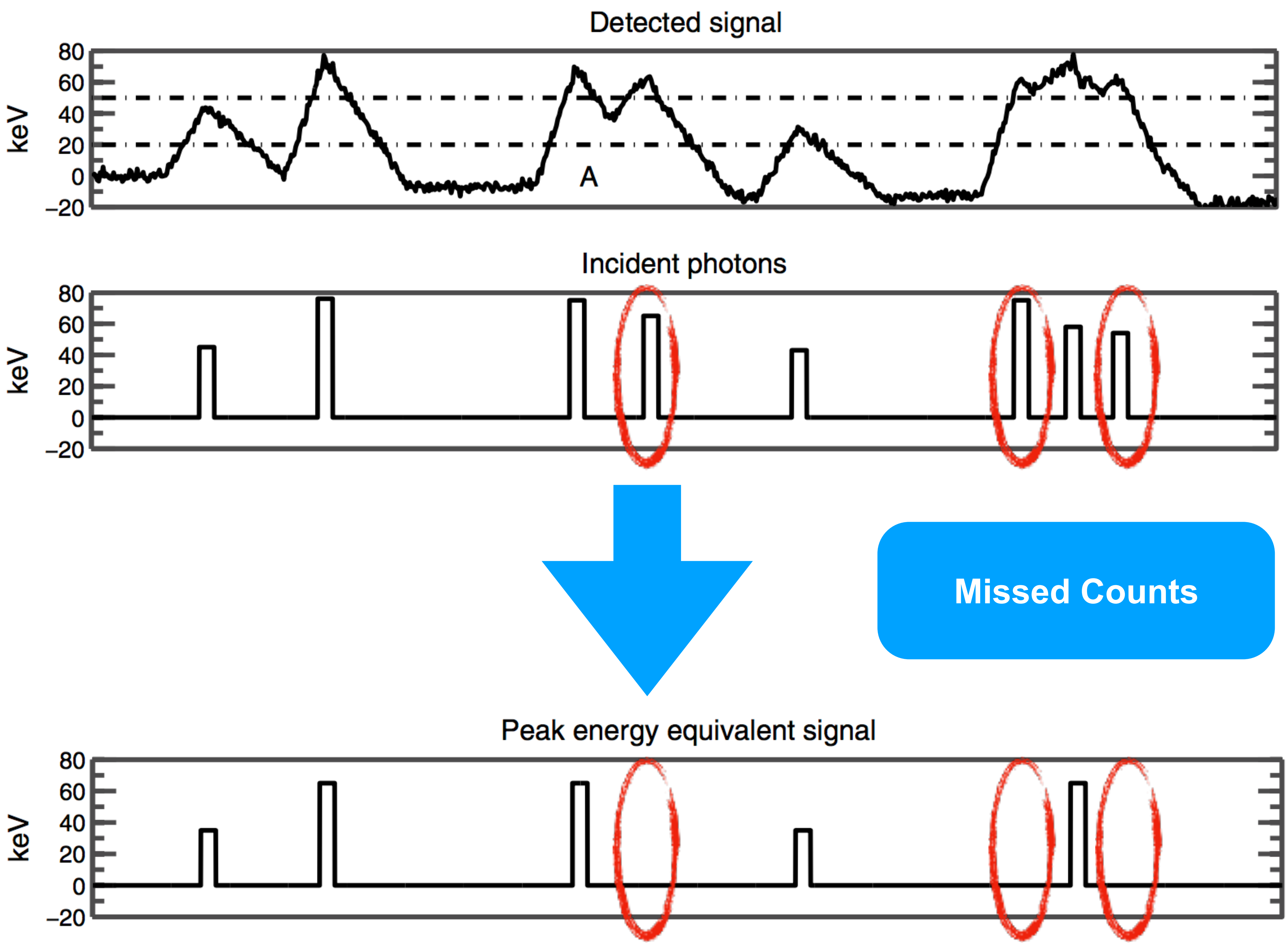
Advantages of PCDs

- Spectrally unique contrast
  - K-edge and fluorescence imaging,
    beam-hardening avoidance
- Low radiation dose
  - No electronic noise,
    balanced photon weights, improved SNR
- High spatial resolution
  - Desirable for radiomics

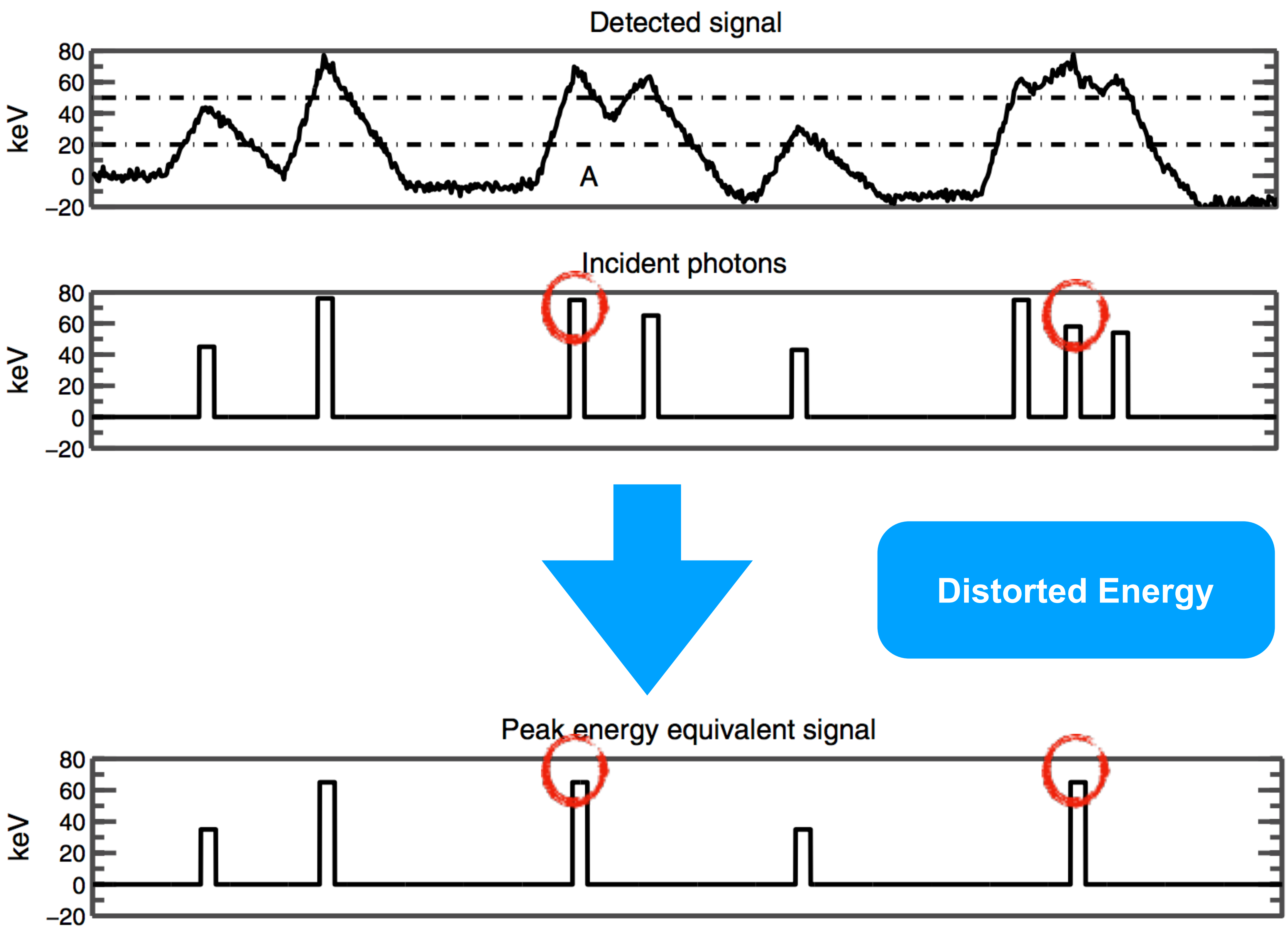
PCD Data Degradation

- Pulse Pileup Effect (PPE)
- Charge sharing
- K-escape x-rays
- Compton scattering

Pulse Pileup Effect (PPE)



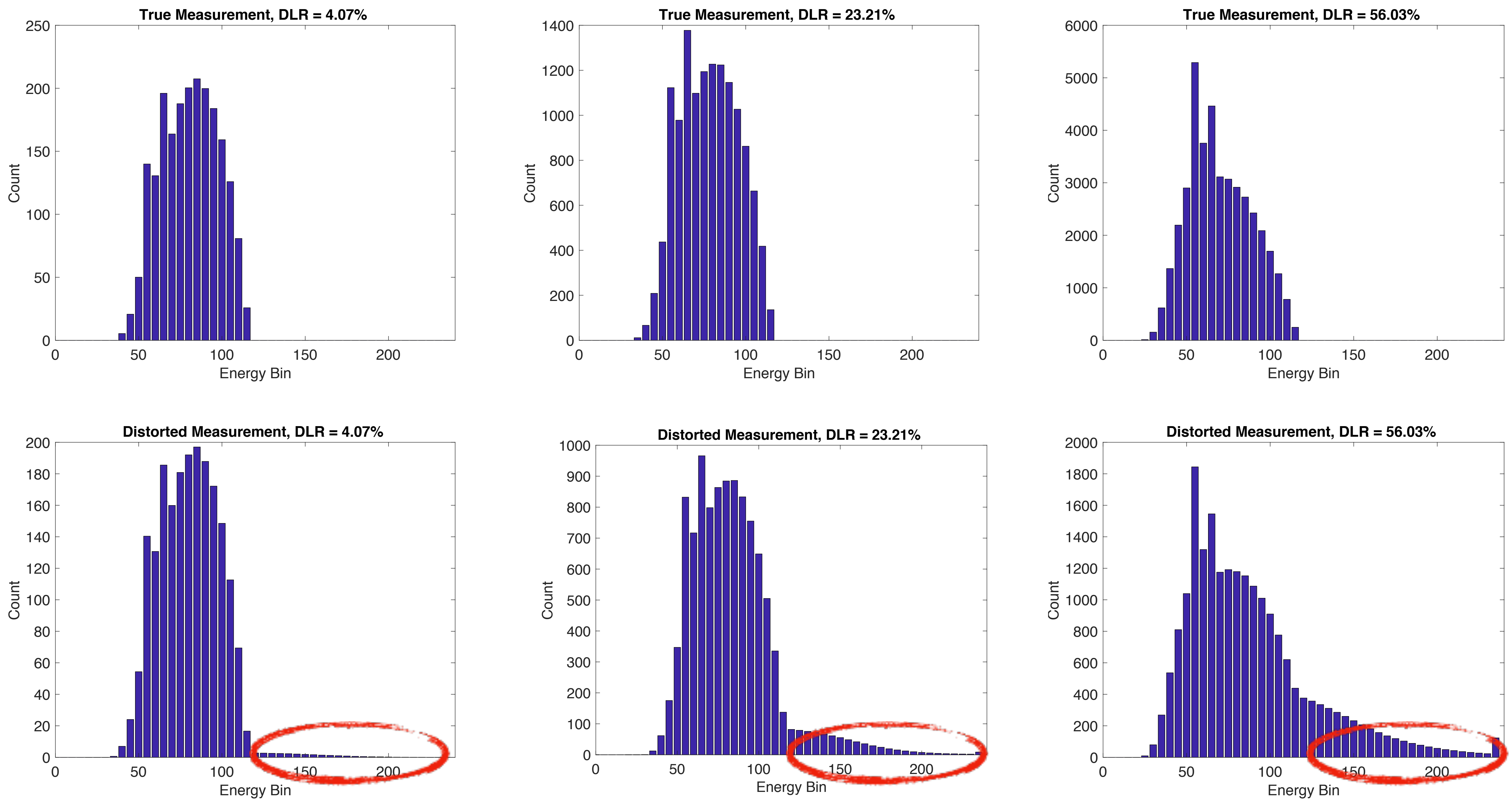
Pulse Pileup Effect (PPE)



Pulse Pileup Effect (PPE)

- PCDs degrade in the performance of detection tasks when the count rate exceeds 20% of the maximum rate
- Current compensation/calibration methods are not optimal and difficult to extend for different applications
  - Model must be accurate to describe the detection process
  - Optimization must be specific to address intended tasks such as material decomposition or contrast estimation

NN-based Trigger Threshold Correction

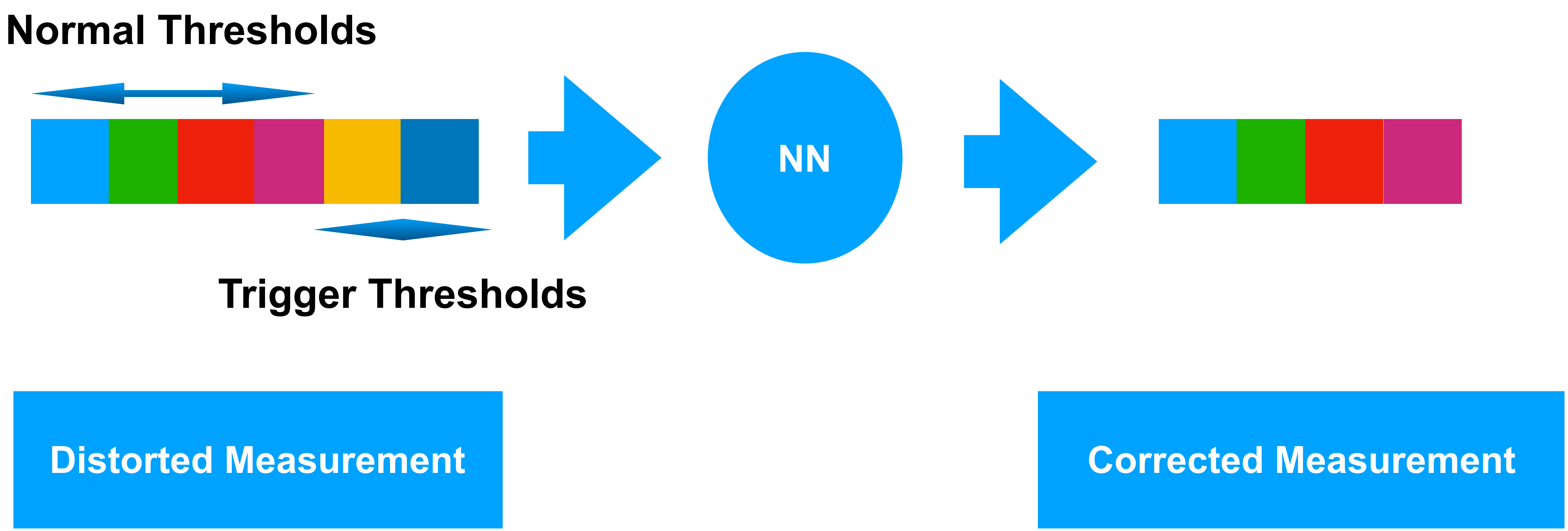


Trigger Threshold

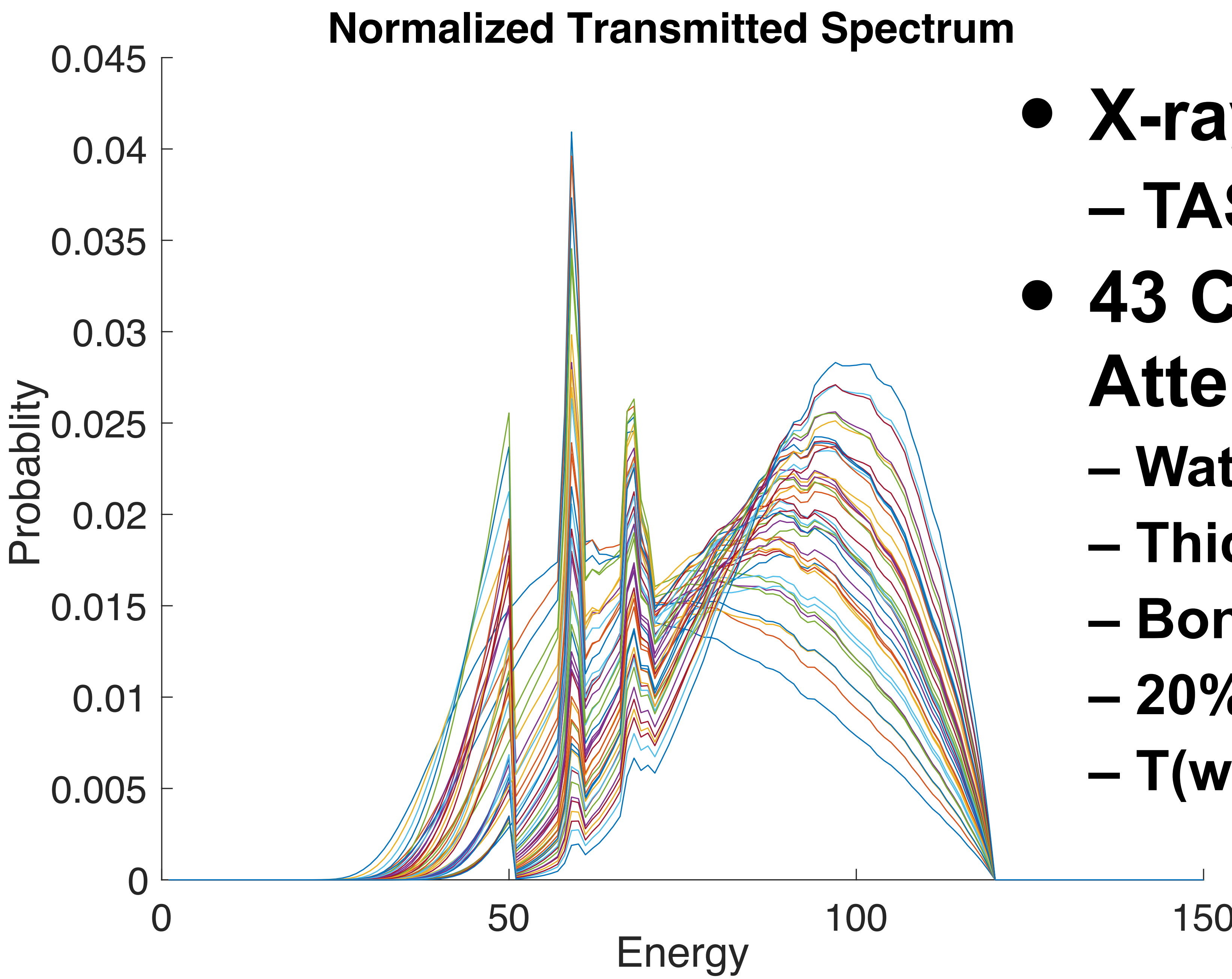
- X-ray tube energy: 120 KeV
- Normal threshold: < 120 KeV
- Tigger threshold: > 120 KeV

Signal strength over the trigger threshold indicates whether PPE occurs and how severe it is

NN-based Correction for PPE



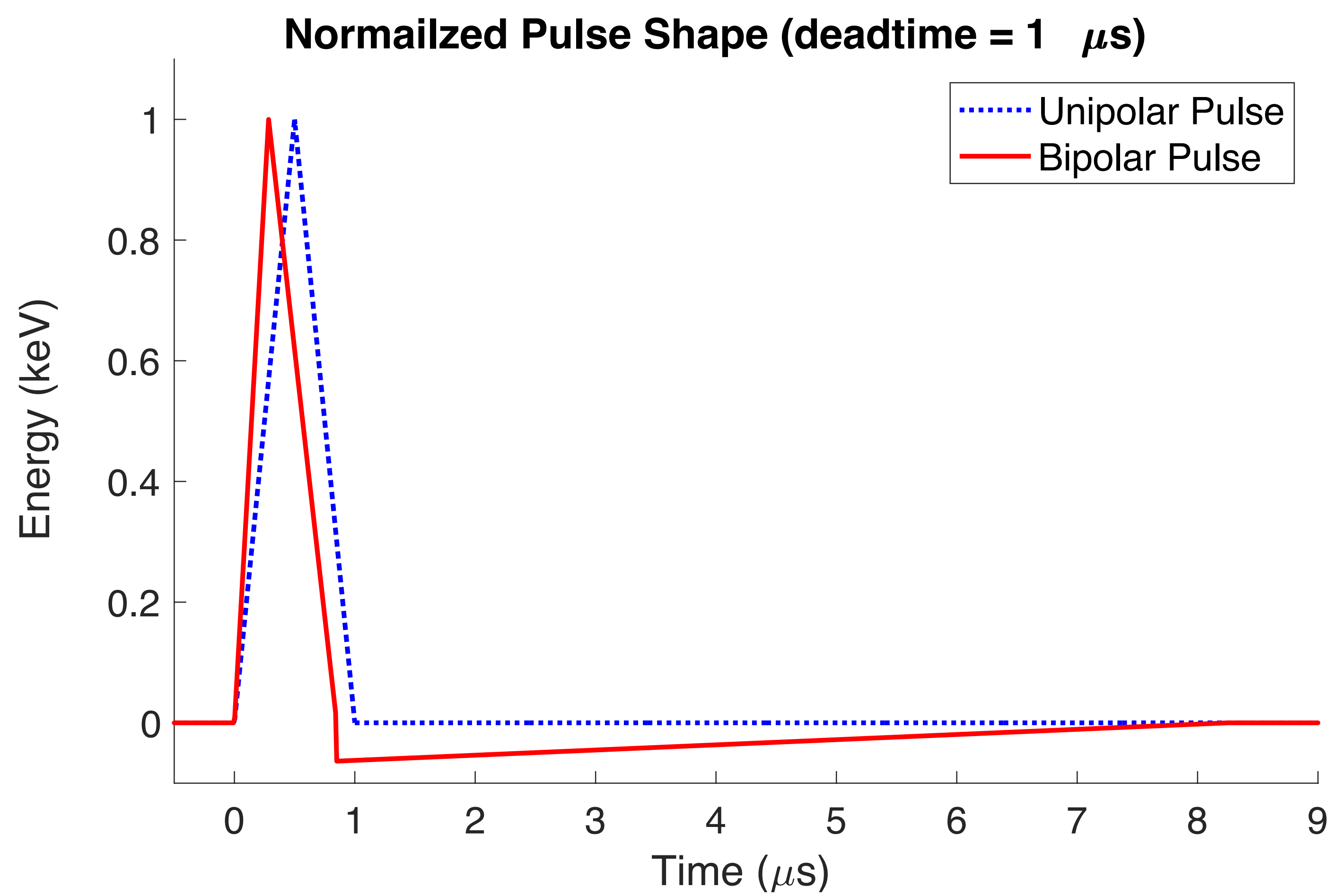
Monte-Carlo Simulation



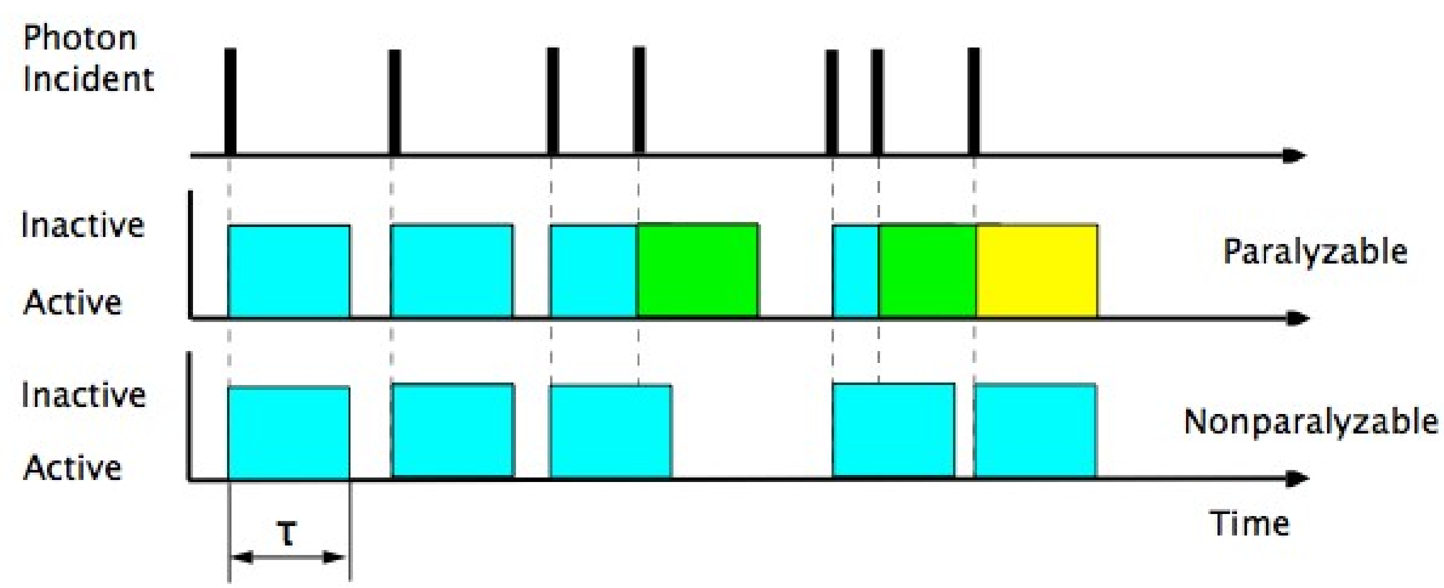
- X-ray spectrum
  - TASMICS
- 43 Combinations of Attenuators
  - Water, Bone, Blood w. 20% Gd
  - Thickness T = {20, 30} cm
  - Bone: T(bone) = {0, 1, 3, 5} cm
  - 20% Gd: T(Gd) = [0:4:20] cm
  - T(water) = T - T(bone) - T(Gd)

Monte-Carlo Simulation

- Pulse Shaper
  - Unipolar Pulse
  - Bipolar Pulse



- Detector Type
  - Paralyzable
  - Nonparalyzable



Monte-Carlo Simulation

Training and Testing Datasets

- 1,000 measurements for each attenuator
- Dataset 1:
  - 36 attenuators
  - Training, validation, testing = 60%, 20%, 20%
- Dataset 2:
  - 7 attenuators

Monte-Carlo Simulation

- **Deadtime Loss Ratio (DLR)**
  - **Paralyzable detector:** $DLR = 1 - \exp(-rate * deadtime)$
  - **Nonparalyzable detector:** $DLR = 1 - 1/(1 + rate * deadtime)$
- **Coefficient of Variation (COV)**

$$COV = RMSD/mean(\sum_{bin=1}^{N_b} n_{true,bin})$$

$$RMSD = \sqrt{mean(\sum_{bin=1}^{N_b} (n_{true,bin} - n_{predict,bin})^2)}$$

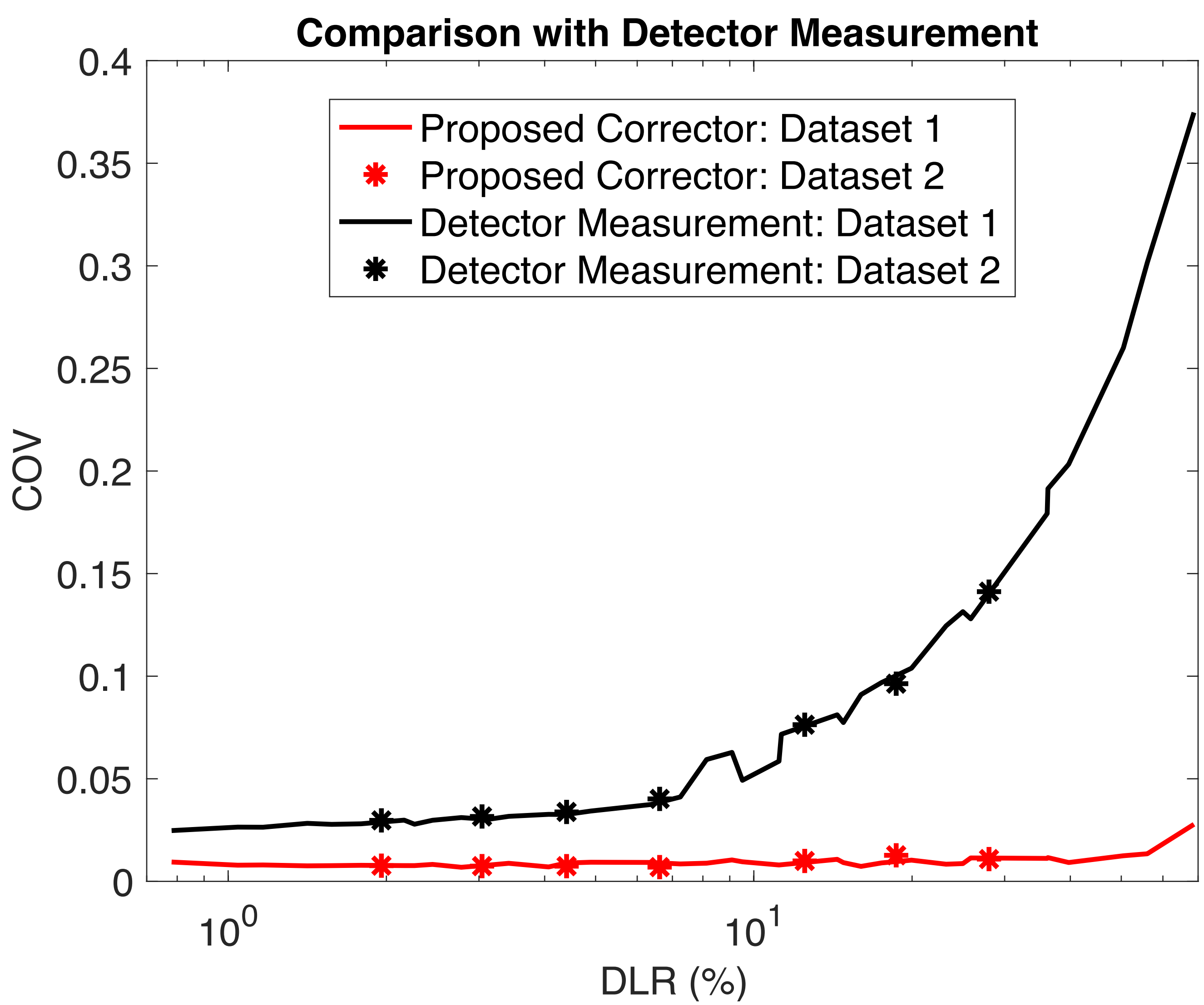
Monte-Carlo Simulation

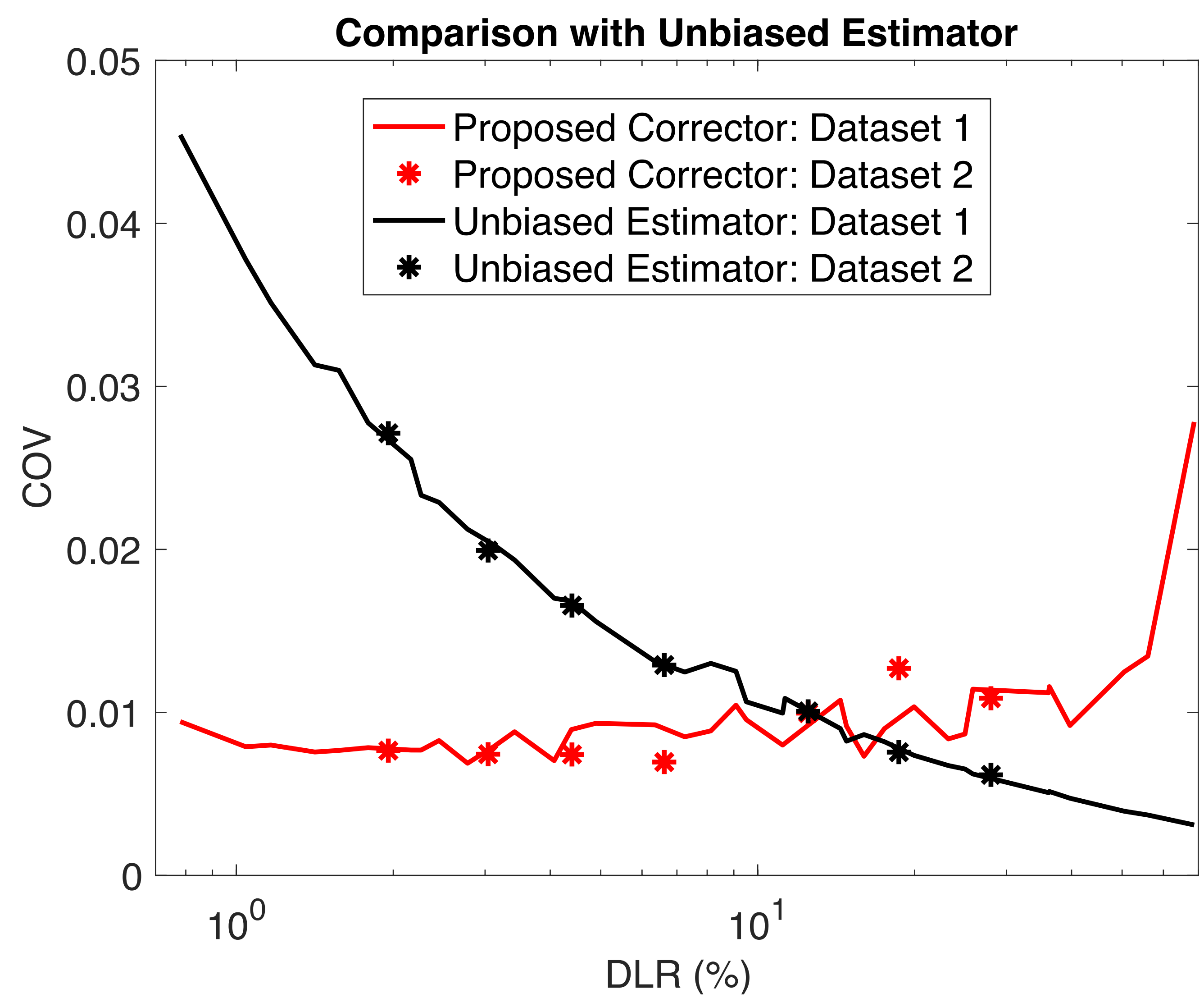
- Neural Network Model
  - ✦ Fully-connected NN with 1 hidden layer
  - ✦ 512 hidden units
  - ✦ Dropout and L2 regularizer
- Unbiased Estimator

$$n_{unbiased,bin} = \frac{1}{N}\sum_{i=1}^{N} n^{i}_{true,bin}$$

Numerical Results

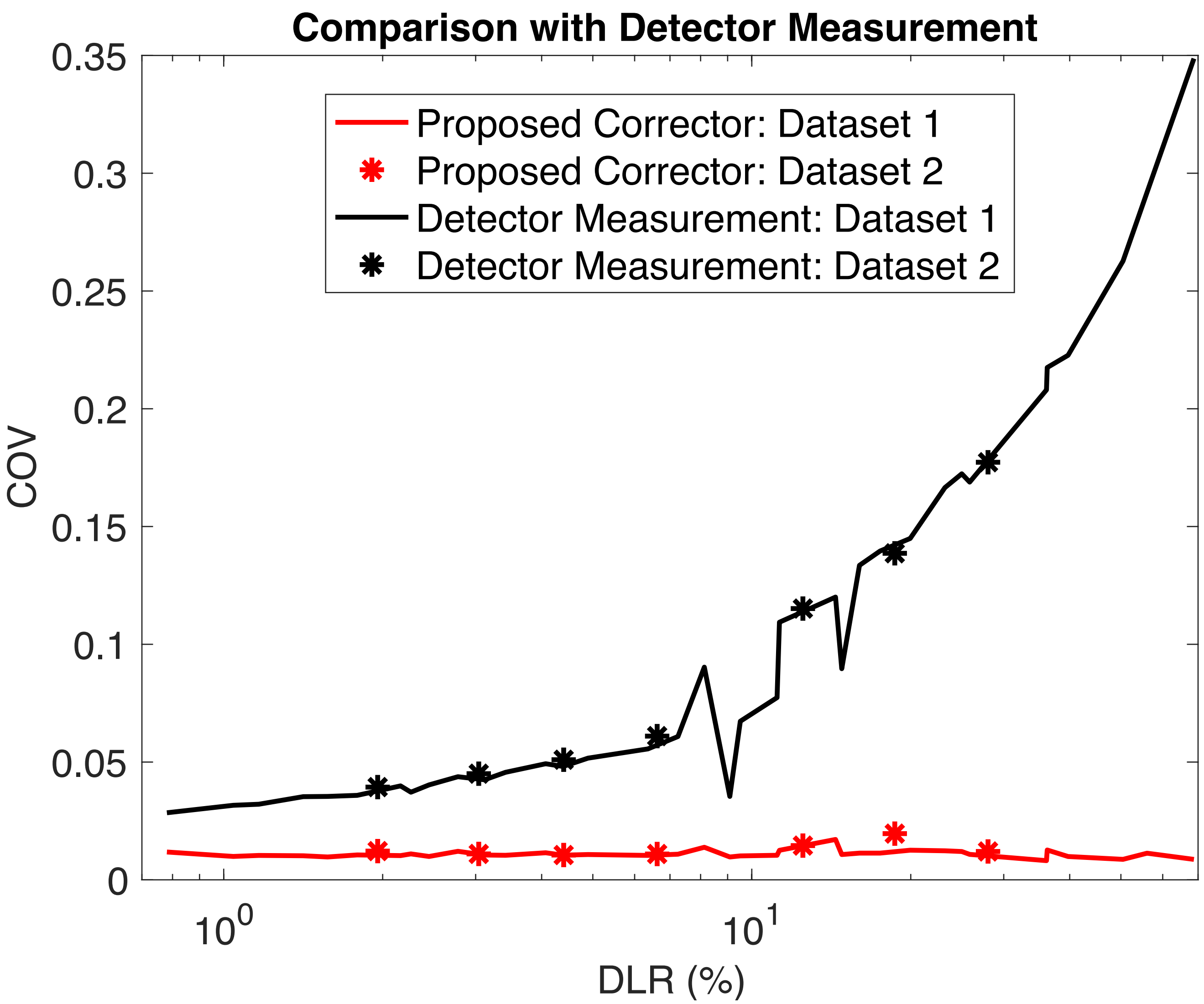
- **Unipolar Pulse & Paralyzable Detector**

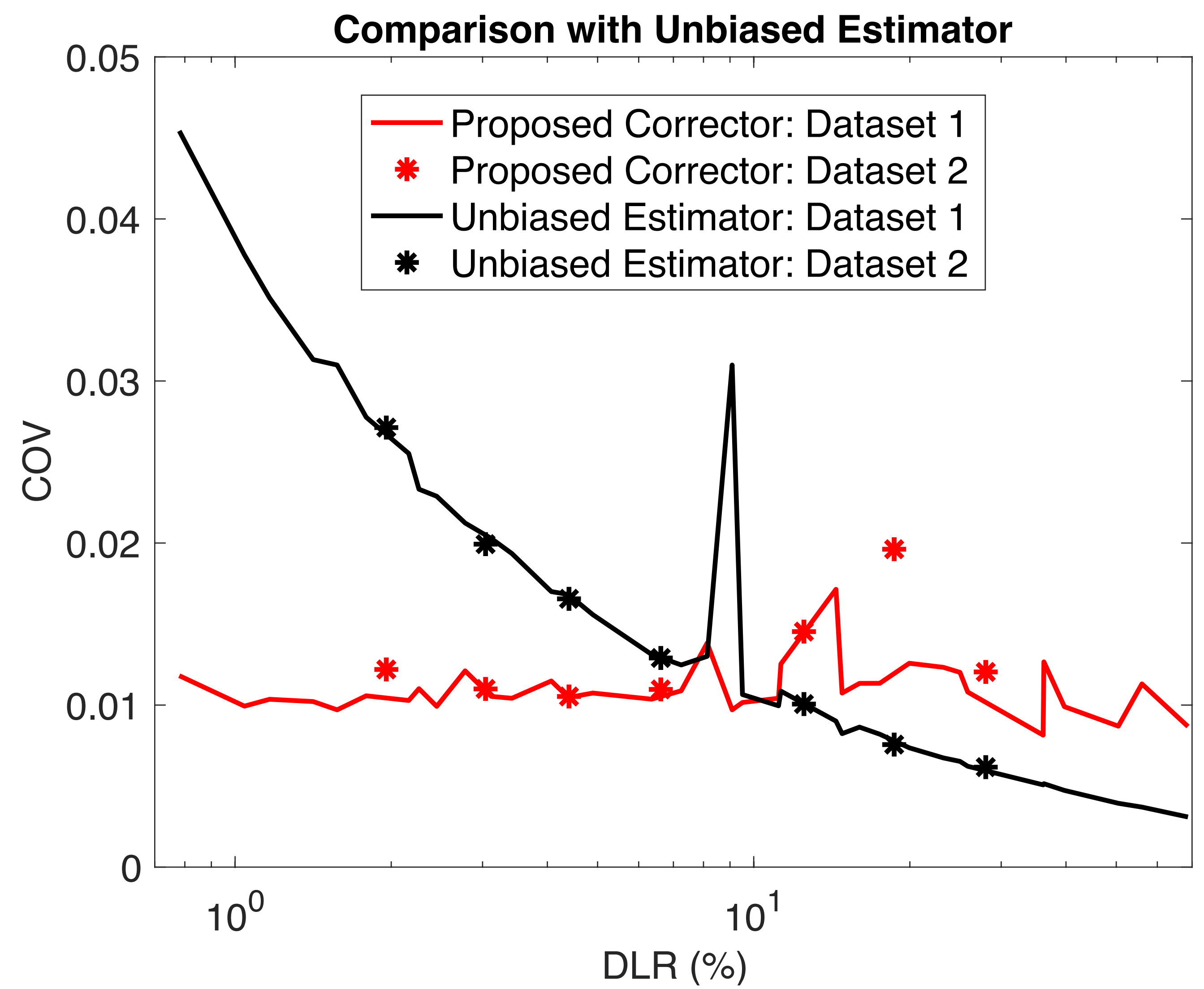




Numerical Results

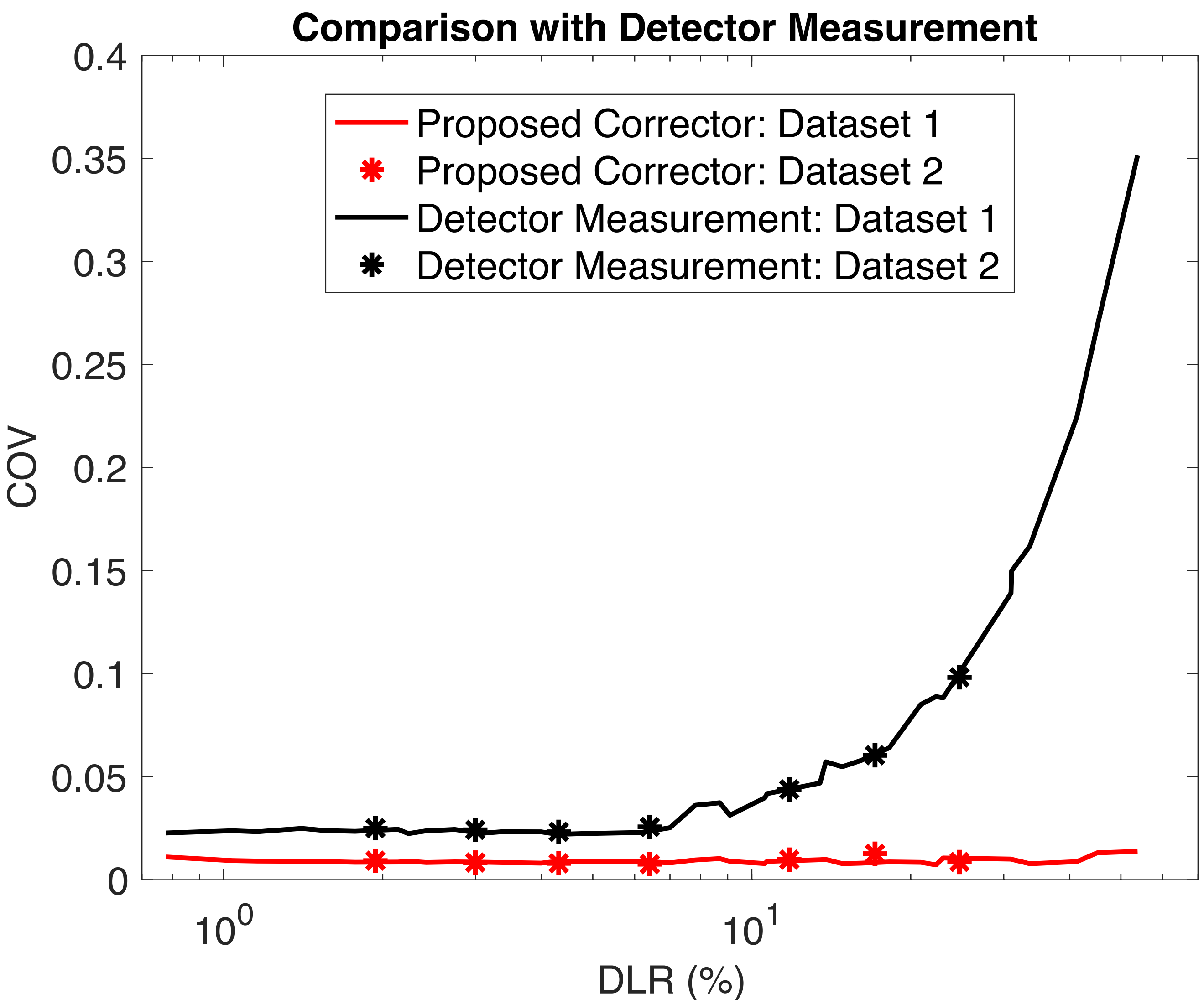
- **Bipolar Pulse & Paralyzable Detector**

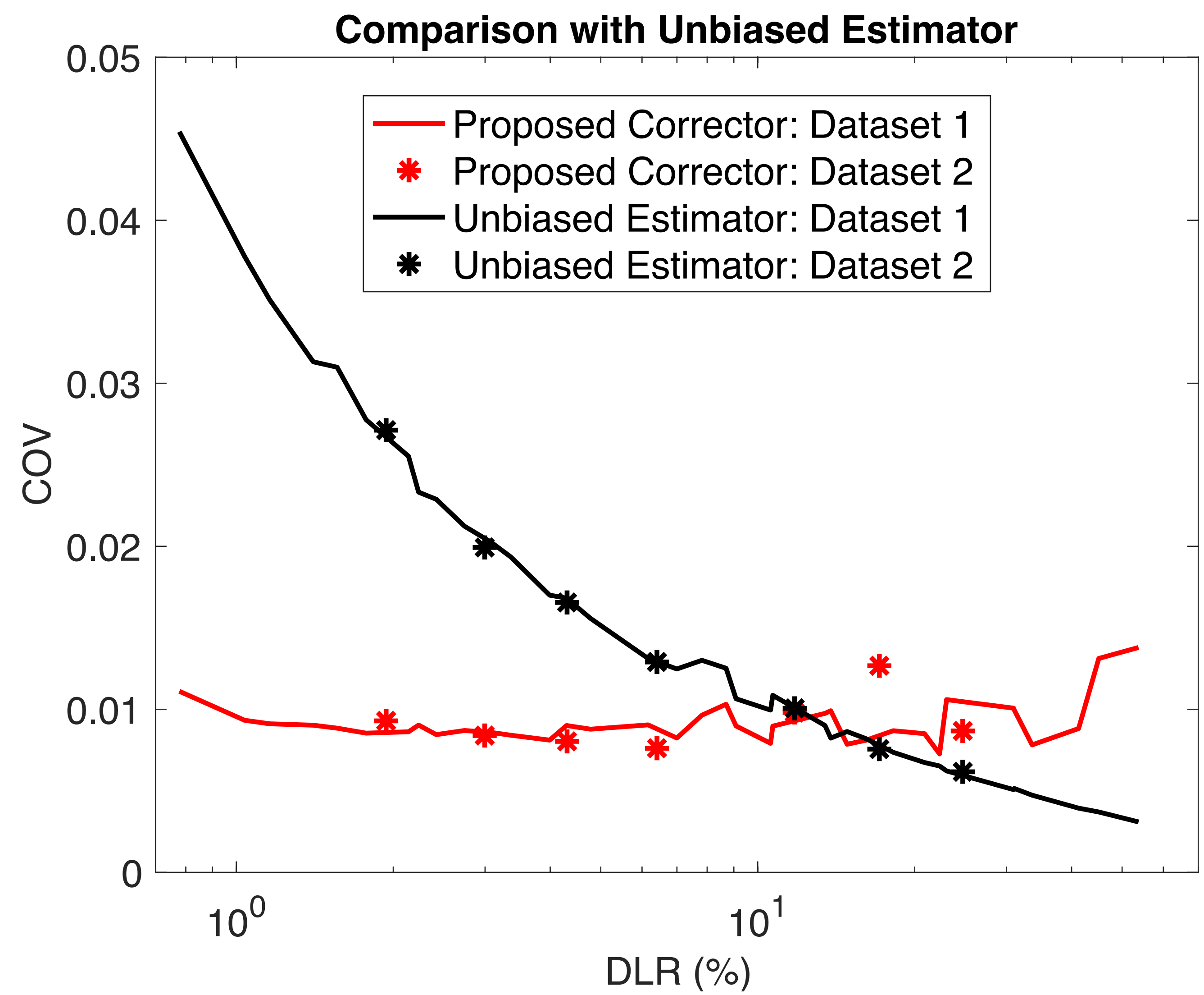




Numerical Results

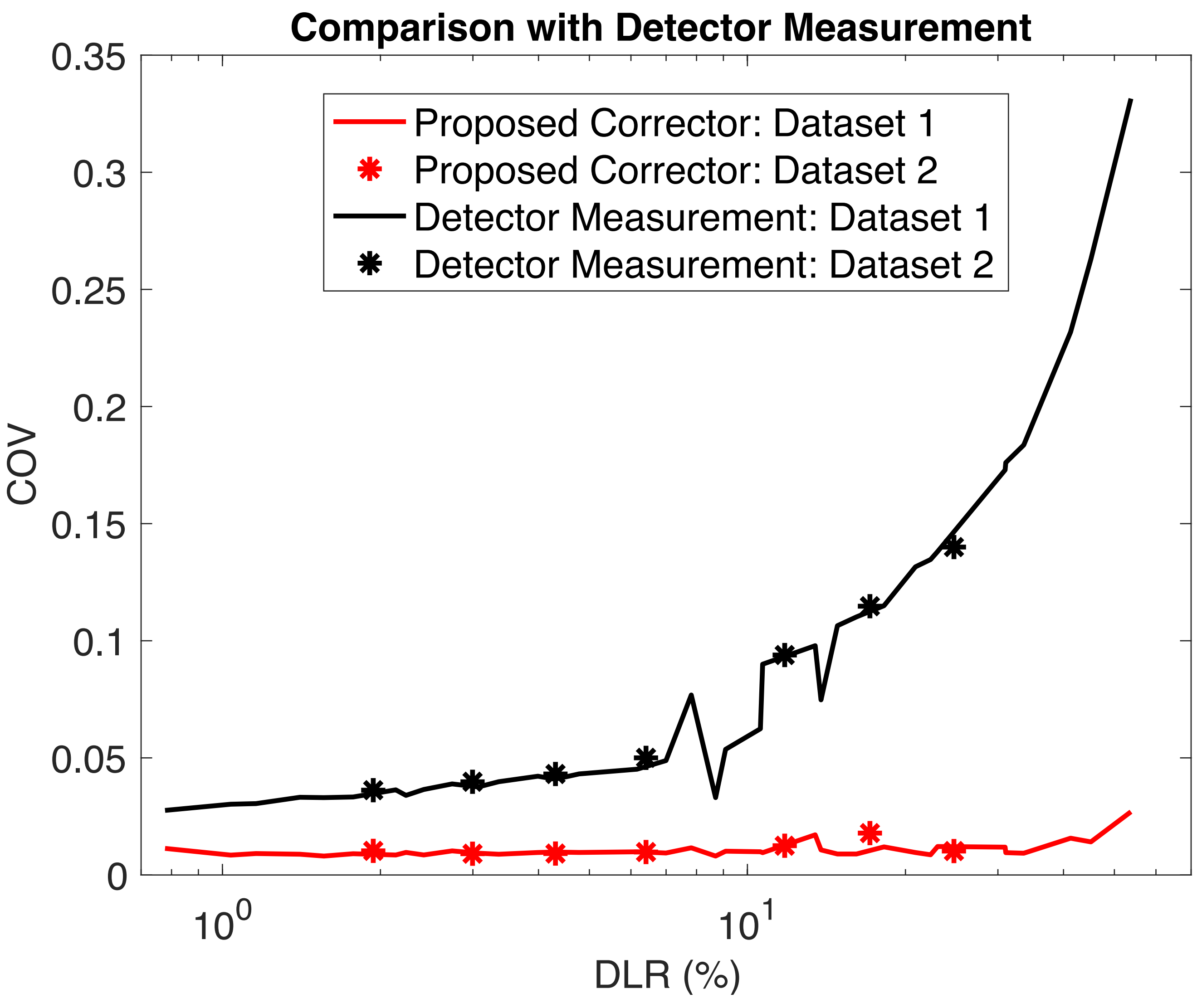
- **Unipolar Pulse & Nonparalyzable Detector**

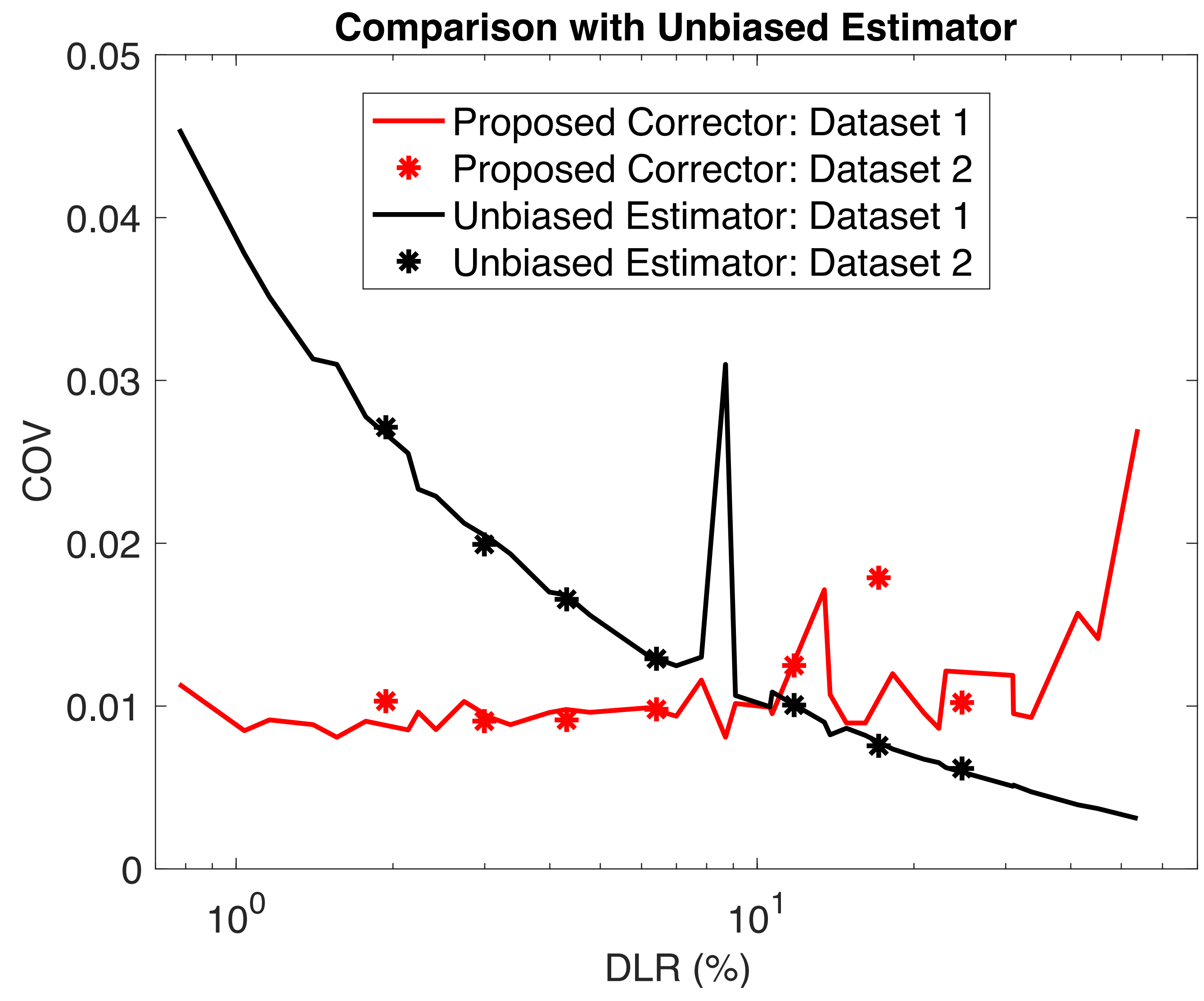




Numerical Results

- **Bipolar Pulse & Nonparalyzable Detector**





Future Plan for PPE Correction

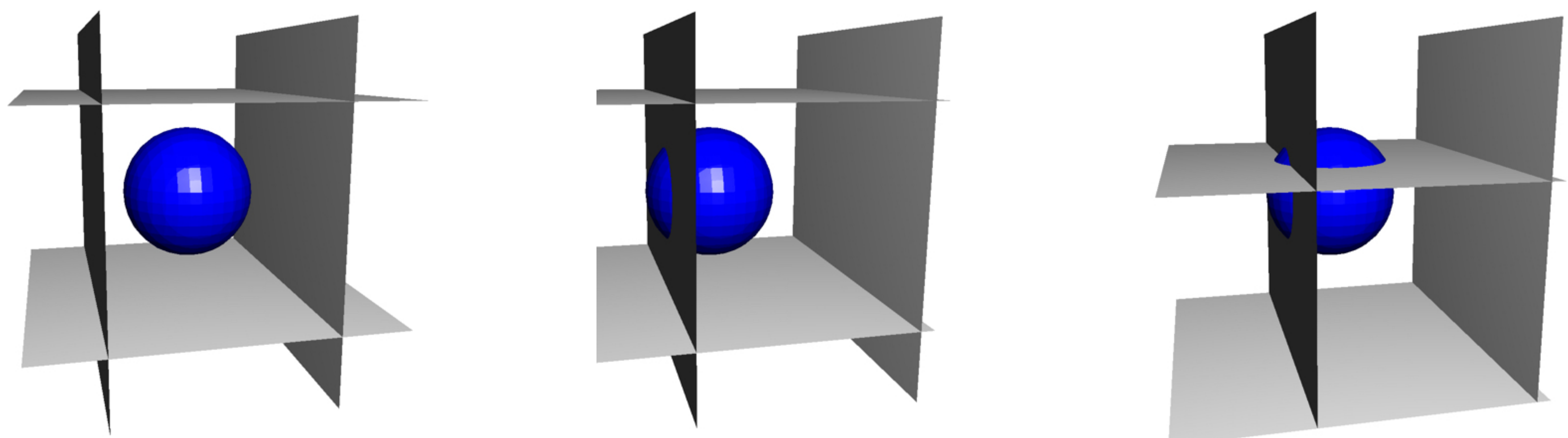
- Systematic Simulation Study
- Phantom Experiments
- Preclinical Testing

How to Collect Unbiased Data?

- – Perform realistic simulation with professional software tools
- – Reduce the incident flux for PPE-free data via time integration

Future Plan for CS Correction

Charge Sharing: one photon is detected by multiple pixels with lower energies



Conclusion

We have proposed an NN/ML approach to handle PPE and other artifacts in PCD data

- **Extract an optimal relationship between PCD data before and after degradation of any kind**
- **Potentially, the NN/ML approach can outperform the existing patented methods for PCD data correction, and improve photon-counting CT image reconstruction**

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