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Spatial distributions of energy absorption and noise in a linear array of scintillators for megavoltage cargo-container inspection

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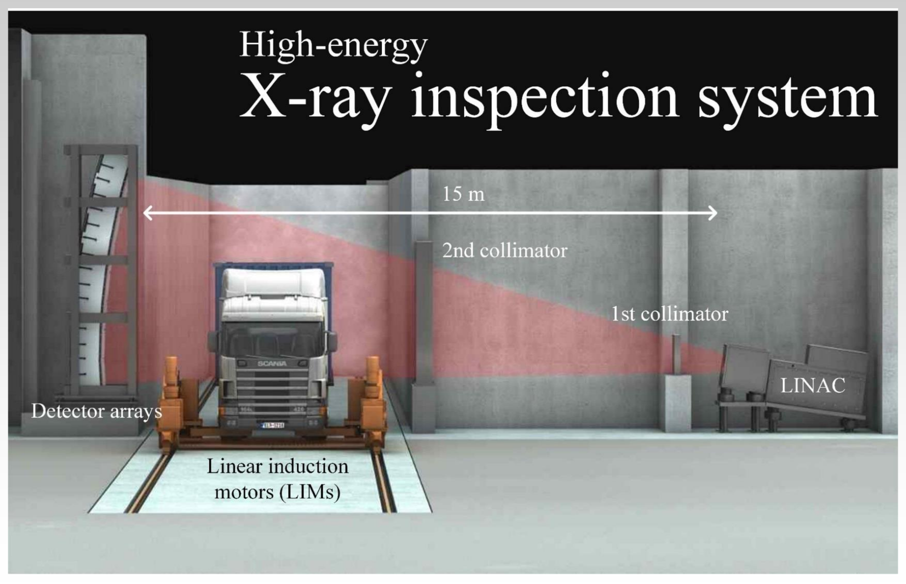
Background

- Related to homeland security and contraband control, the megavoltage (MV) x-ray scanning system with linear detector arrays is widely used
- Since at MV energies the Compton scatter dominates the photoelectric absorption, spatial spreading of energy absorption through pixels is inevitable in the detector array, and the pair production can further affect the energy-absorption distribution
- Stochastic variation in energy absorption appears in images as noise, and which is known as the Swank noise
- Therefore, it is important to understand the energy-absorption distributions and their noise to optimize the detector design

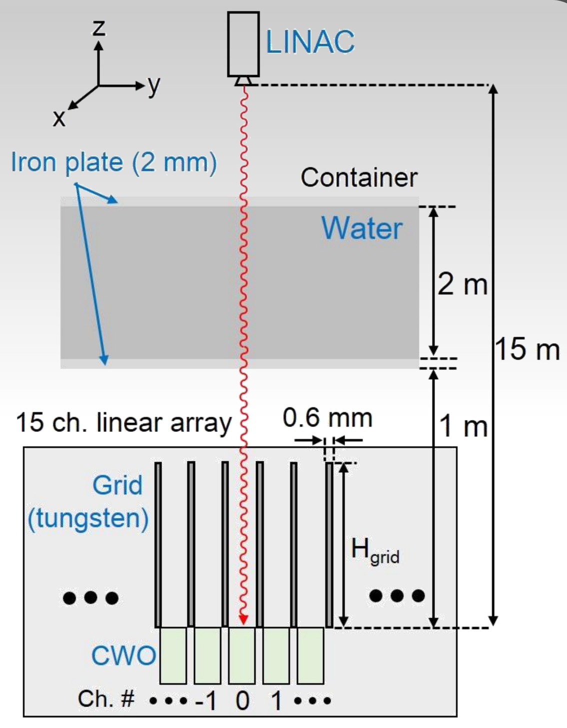


Research Objective

- To investigate the spatial energy-absorption distributions in the linear scintillation detector array for MV x-ray photon detection
- To suggest the spatial-frequency-dependent noise –transfer function (NTF) and to quantify the energy-absorption noise in the linear scintillation detector array in terms of NTF

Monte Carlo simulations

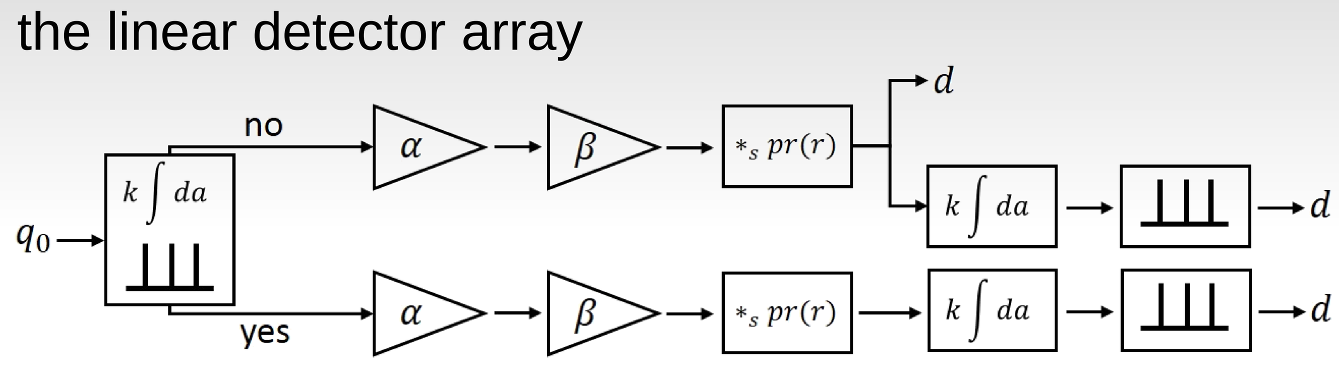
- Simulation code : the MCNP version 5 (RSICC, Oak Ridge, TN)
- Monte Carlo geometries
  - The MC geometry consists of a tungsten anti-scatter grid array and a 15-channel linear detector array arranged in a pitch of 4.6 mm
  - Each channel scintillator is a block of $CdWO_4$ with dimensions of $x \times y \times z = 4 \times 4 \times 30$ mm^3
- Spatial energy distribution
  - The spatial distribution of energy absorption is obtained by using the list-mode analysis, which calculates both the position and the deposited energy of each particle interaction



Beam (9 MV)	Pencil beam	Areal beam
H_{grid} (cm)	0 – 25	17.5
ρ_{water} (g/cm^3)	0.2-1.0	-

Cascaded-system analysis

- Cascaded linear-systems models describing several signal-transfer cases in the linear detector array



$$\mathrm{DQE}_{pre} = \alpha \times I = \alpha \times I \times \frac{T^2(v)}{\left(1-\frac{I}{\beta}\right)T^2(v)+\frac{I}{\beta}} = \alpha \times I_{pre}(v) = \alpha \times I \times \mathrm{NTF}_{pre}(v)$$

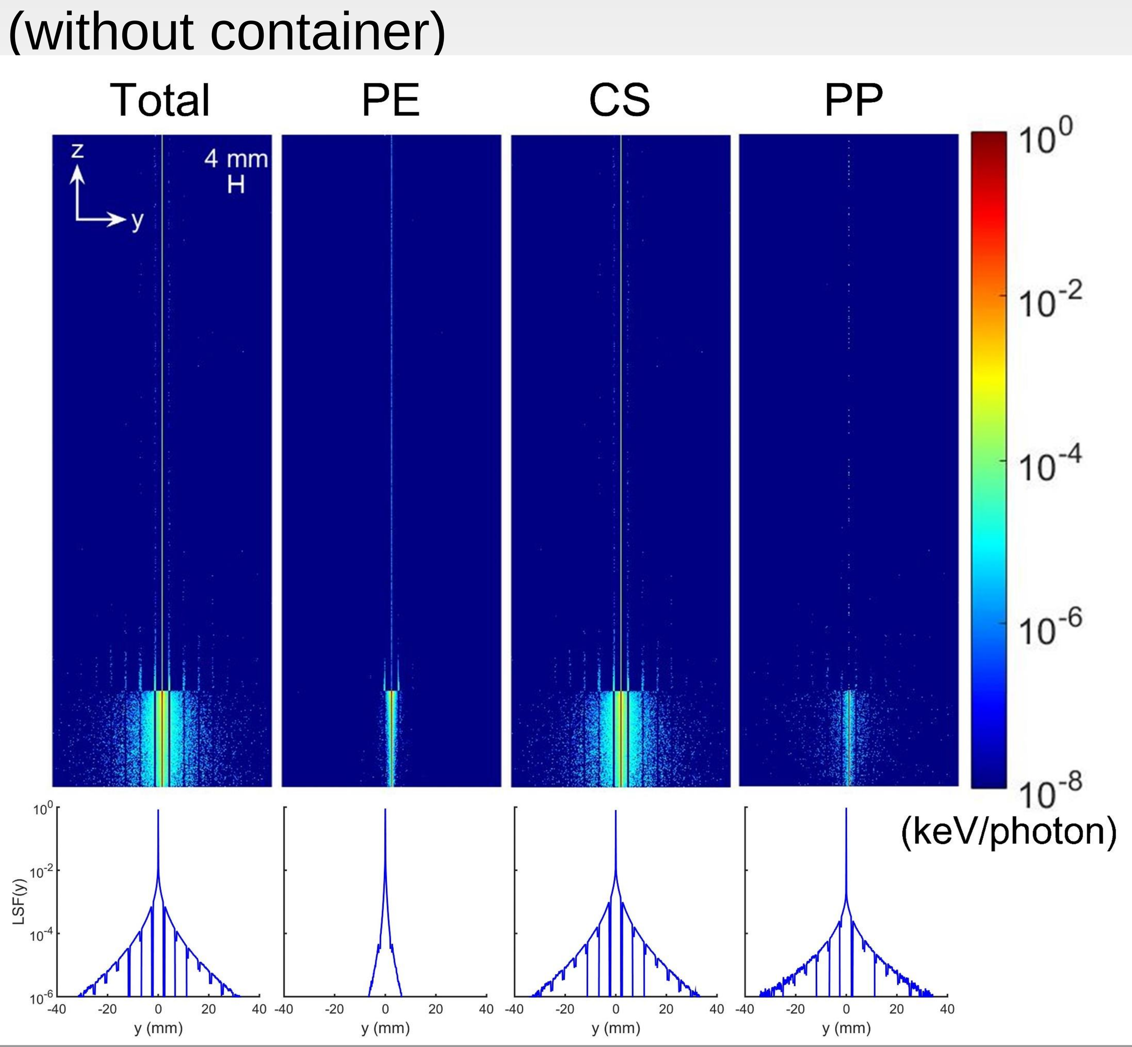
$$\mathrm{DQE}_{post} = \alpha \times I = \alpha \times I \times \frac{T^2(v)sinc^2(\pi a_y v)}{\left(1-\frac{I}{\beta}\right)T^2_{aliased}(v)+\frac{I}{\beta\gamma_y}} = \alpha \times I_{post}(v) = \alpha \times I \times \mathrm{NTF}_{post}(v)$$

$$\mathrm{DQE}_{post\ w/\ grid} = \alpha \times I = \alpha \times I \times \frac{T^2(v)sinc^2(\pi a_y v)}{\left(\frac{1}{\gamma_y}-\frac{I}{\beta\gamma_y}\right)T^2_{aliased}(v)+\frac{I}{\beta\gamma_y}} = \alpha \times I_{post\ w/g}(v) = \alpha \times I \times \mathrm{NTF}_{post\ w/g}(v)$$

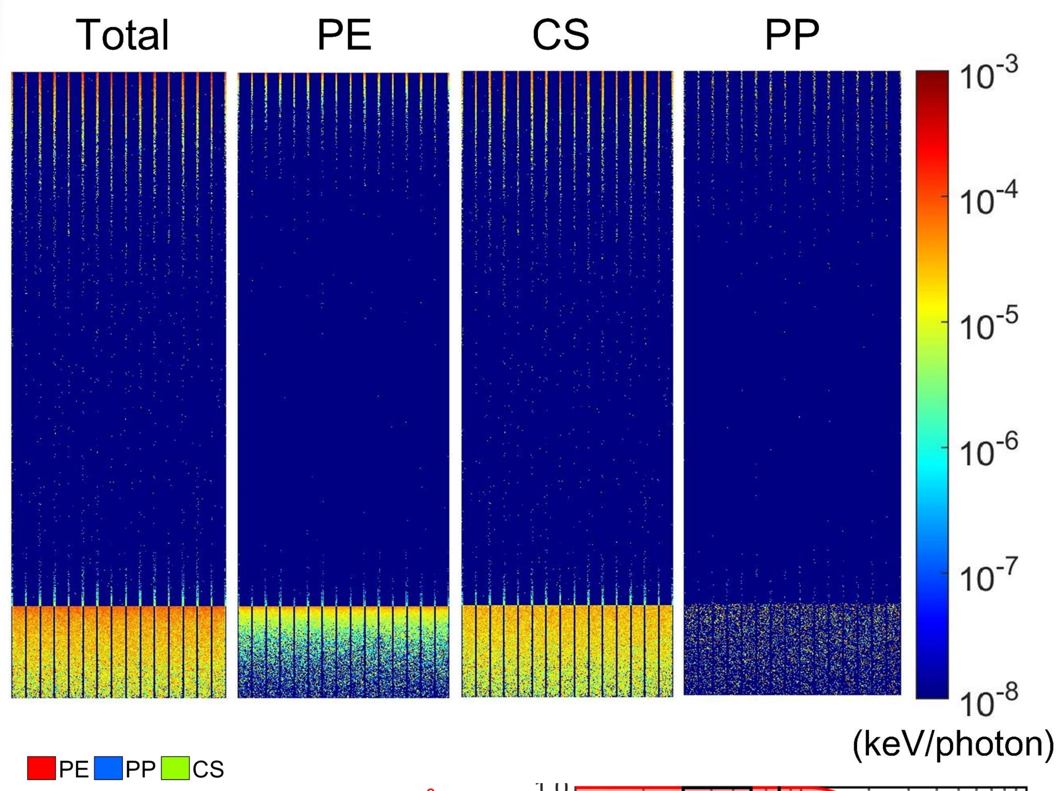
$$T_{aliased}(v) = \sum_{j=0}^{\infty} T_{x-ray}\left(v \pm \frac{j}{p_y^{scn}}\right) sinc\left(\pi a_y^{scn}\left(v \pm \frac{j}{p_y^{scn}}\right)\right)$$

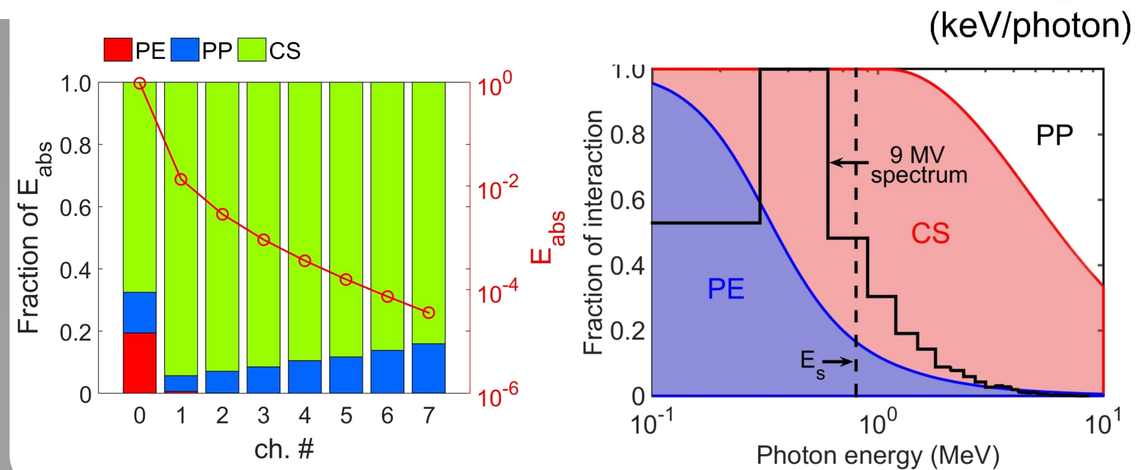
Results

- Spatial energy-absorption distributions (without container)

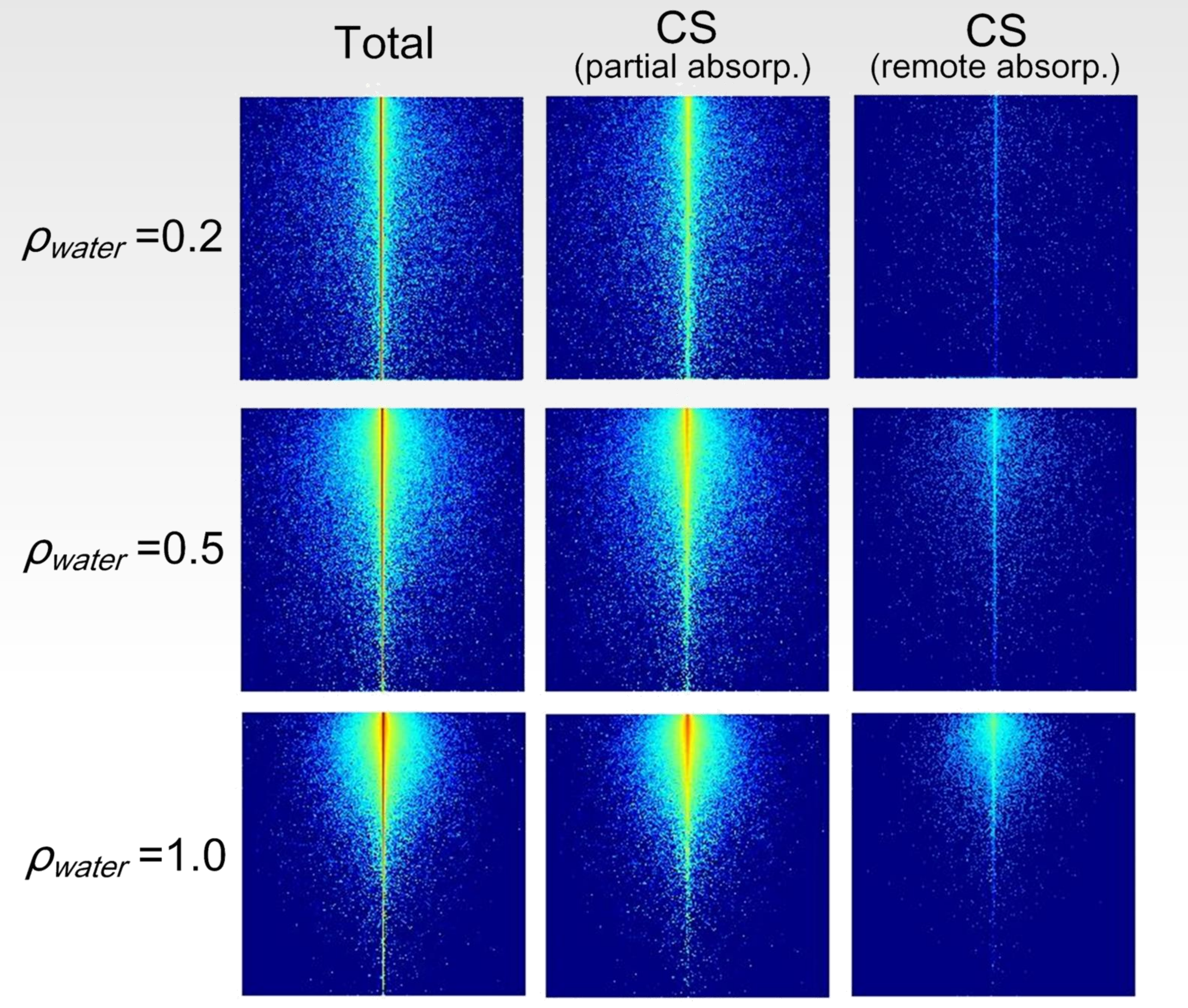


- Figures show the spatial energy-absorption distributions due to each interaction such as the photoelectric absorption (PE), the Compton scatter (CS), the pair production (PP), and their sum
- The plot shows the absorbed energy at each channel and the fractional contributions of interaction types

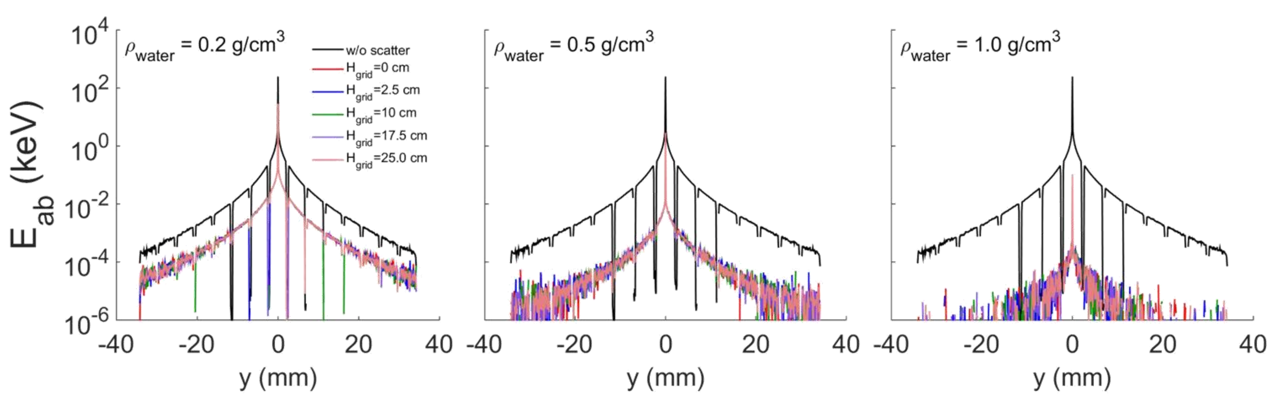




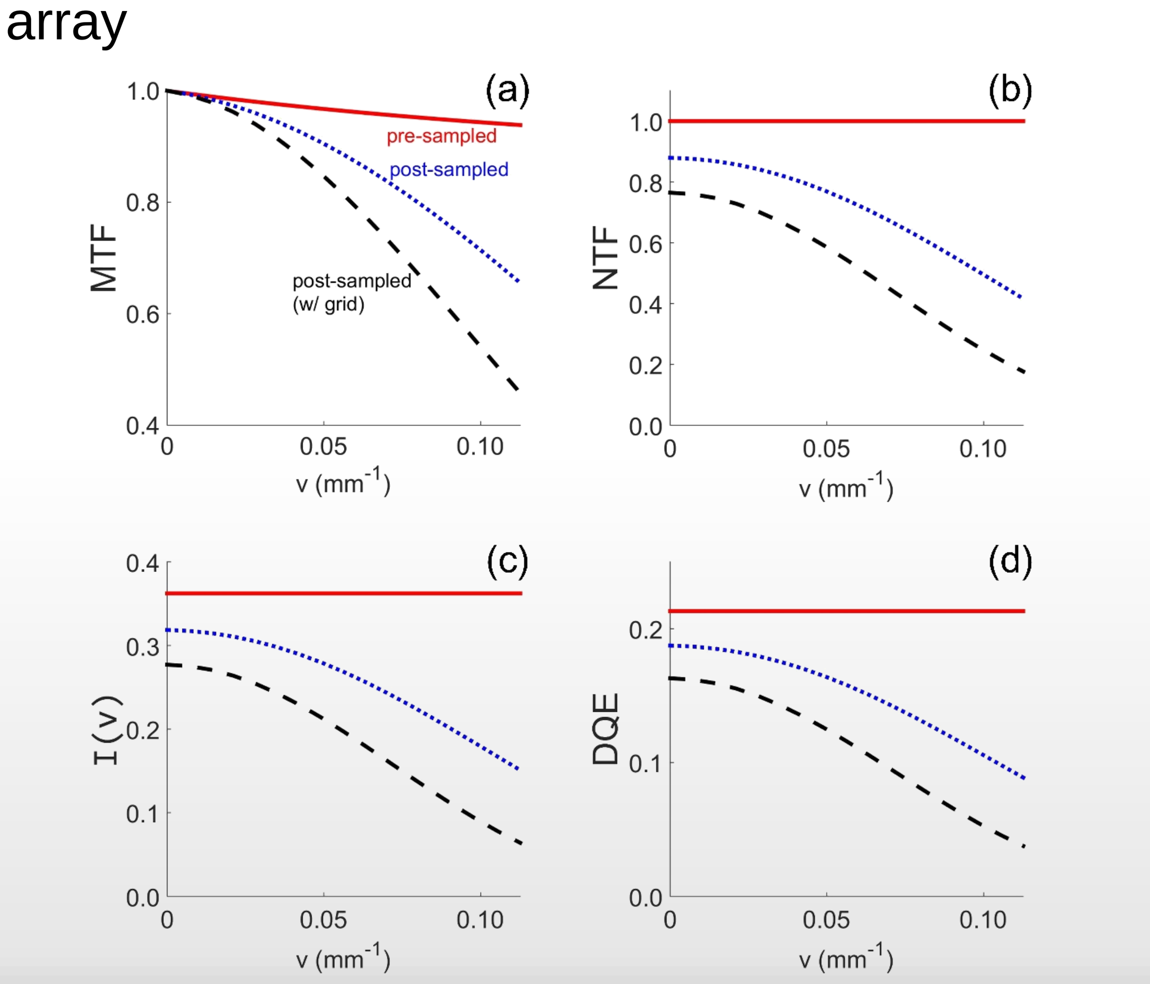
- Absorbed-energy distributions within a container



- Spatial energy-absorption distributions in linear detector arrays



- Spatial-frequency-dependent analysis of energy absorption and its noise in the linear detector array



Summary

- Although the Compton scattering is the main interaction mechanism in the linear detector array for MV x-ray detection, the spreading of energy absorption to neighboring pixels is negligibly small even without the anti-scatter grid array because of the large air gap
- To quantify the role of the anti-scatter grid array, a further study considering harsher scatter conditions is required
- The digital sampling process degrades significantly the noise-transfer characteristics over the entire spatial-frequency region, and the related aliasing effect decreases the noise performance at the zero frequency by more than 10%
- The use of anti-scatter grid array degrades further the noise-transfer characteristics by a factor of its geometric efficiency (i.e. the ratio of its aperture to the pitch)
- Consequently, the degradation in NTF reduces the DQE performance

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