Validation of a Monte Carlo Model of a Dual-Layer Flat-Panel Detector

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

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INTRODUCTION

- Incorporating multi-energy capabilities into diagnostic imaging systems may improve soft tissue contrast:
  - ➢ Overlapping anatomies can be discriminated due to differences in tissue sensitivity to different X-ray energies.
- **Dual-layer flat-panel detectors** utilize two scintillating layers, each sensitive to different parts of the spectrum, where the detector signal in each layer, I_i, can be written as,

$$I_L = -\ln \int S_L(E) e^{-\rho_1\mu_1(E) + \ \rho_2\mu_2(E)}\, dE,$$

$$I_H = -\ln \int S_H(E) e^{-\rho_1\mu_1(E) + \ \rho_2\mu_2(E)}\, dE.$$

- However, integrating dual-layer flat-panel detectors into radiotherapy applications faces challenges:
  - ➢ Use of a second scintillation layer, farther from the source, reduces the resolution and the signal magnitude.

Purpose: To develop and validate a Monte Carlo model of a dual-layer flat-panel detector; to optimize the composition of the bottom scintillation layer to improve spectral separation, while maintaining adequate resolution and detection efficiency.

METHODS AND MATERIALS

- A dual-layer flat-panel detector is modelled in TOPAS, an extension wrapping GEANT4.
- Optical transport is modelled using the UNIFIED model.
- The model is validated against simulation and experimental results from the literature.
- Multiple detector configurations are simulated by varying the thickness of the bottom scintillator.
- Detector performance is evaluated using the MTF_{50} and the DQE(0), a multi-parameter space for detector optimization.
- The MTF is derived from a slanted edge technique and a precomputed incident spectrum consistent with RQA 9.
- The DQE(0) is computed using the Swank formalism, where the Swank factor is computed from the moments, M_i, of the pulse height spectra,

$$A_s = \frac{M_1^2}{M_0 M_2}.$$

- The energy separation is computed using the detected energy spectra of the two layers.

Parameter	Value
Scintillation yield	54000 optical MeV^{-1}
Emission wavelength	550 nm
Column diameter	10 µm
Packing fraction	0.79
Surface roughness	0.2
Reflection type	Lambertian

Table 1. Scintillation and geometry parameters used in the simulations.

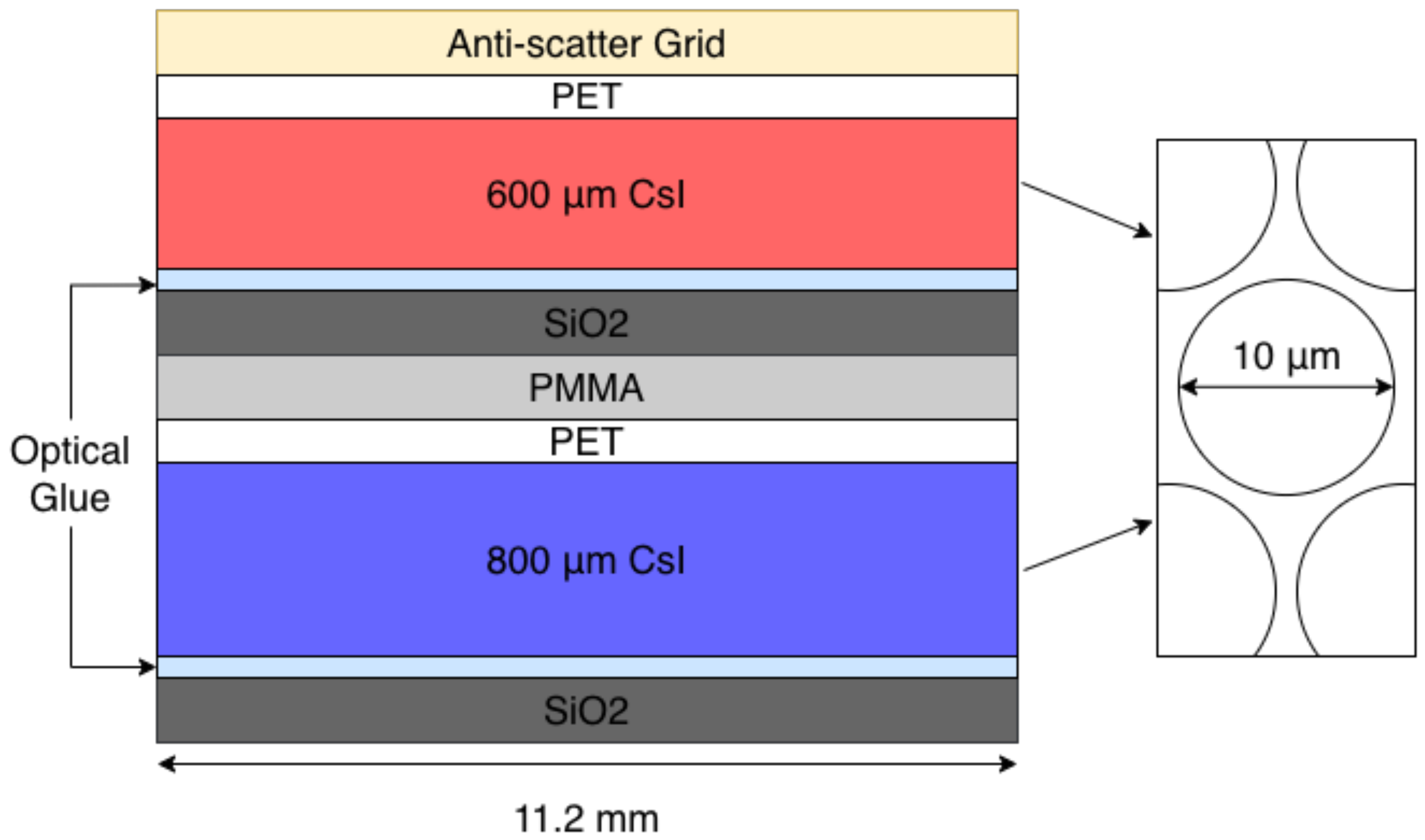

Figure 1. Schematic of the detector construction and scintillator geometry.

RESULTS

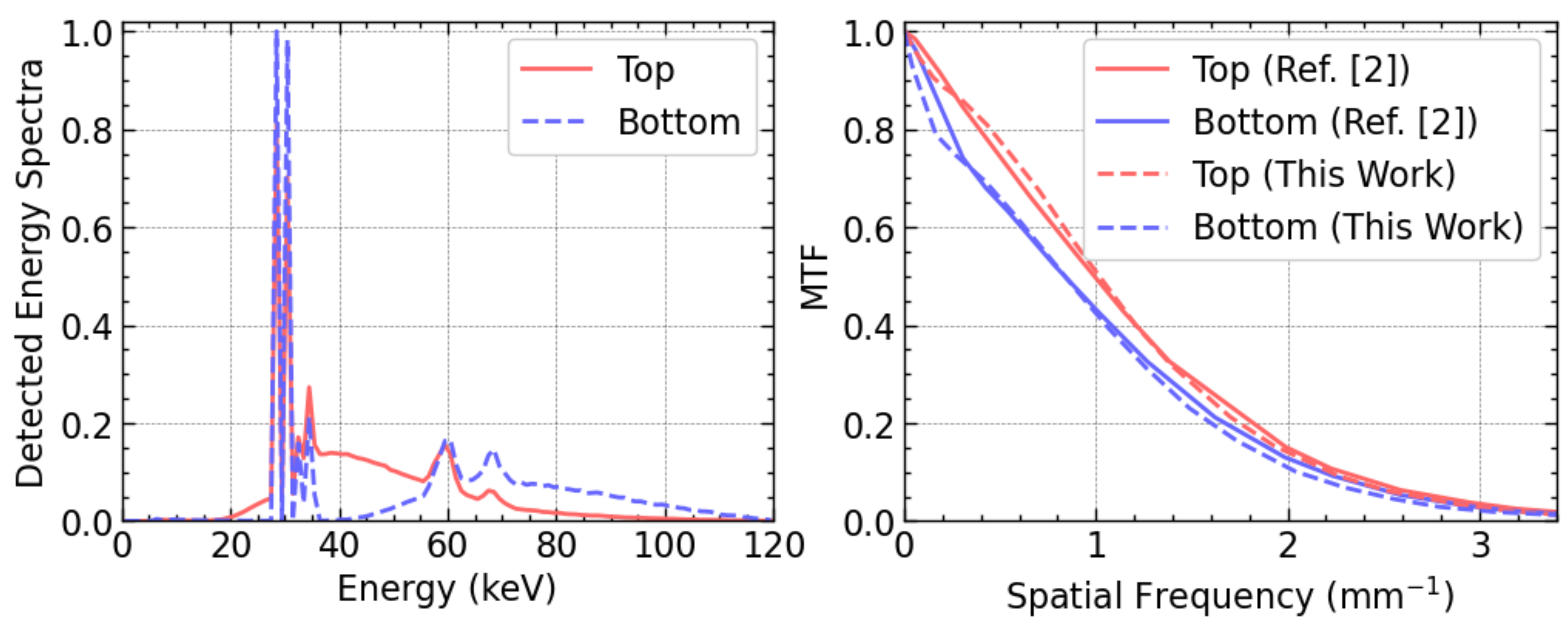

Figure 2. (Left) Detected energy spectra of the two layers under a RQA 9 beam and (Right) a comparison of the MTF against experimental results from Ref. [2].

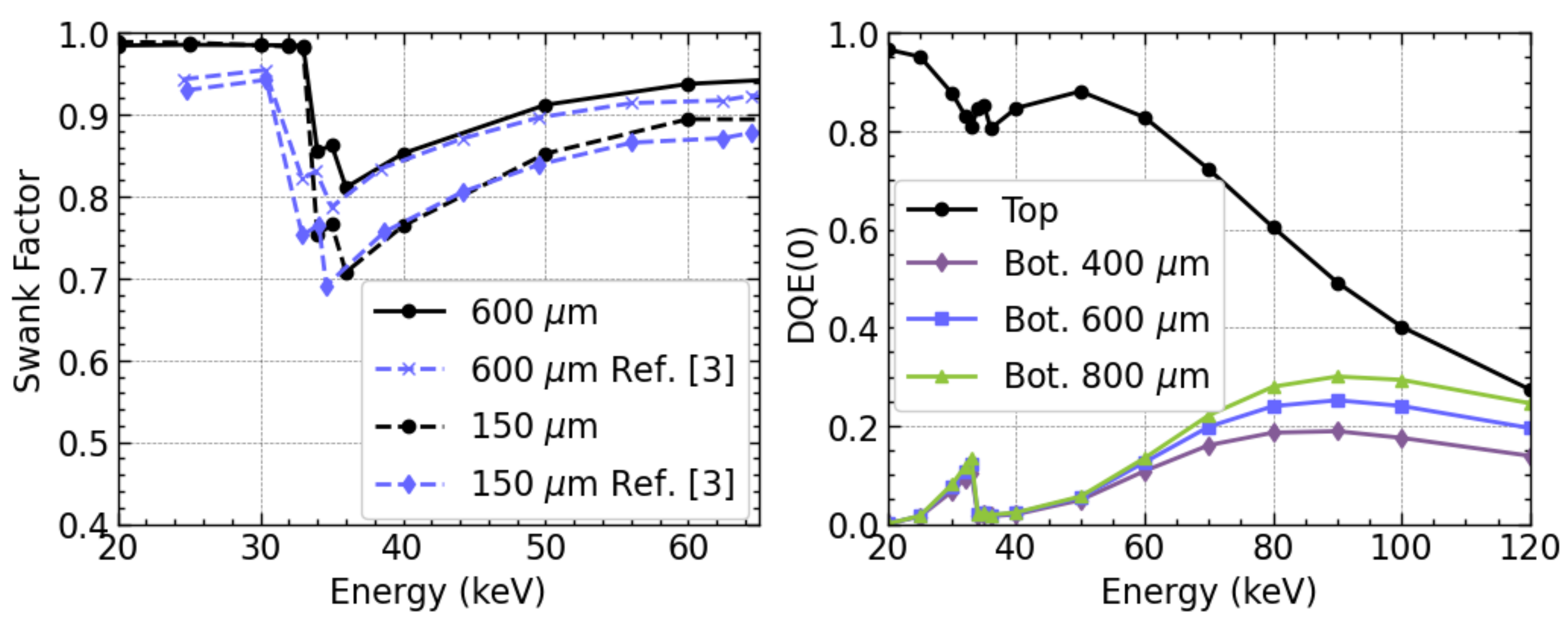

Figure 3. (Left) Single layer Swank factor and (Right) DQE(0) for a mono-energetic pencil beam incident on the detector with varying bottom layer thicknesses.

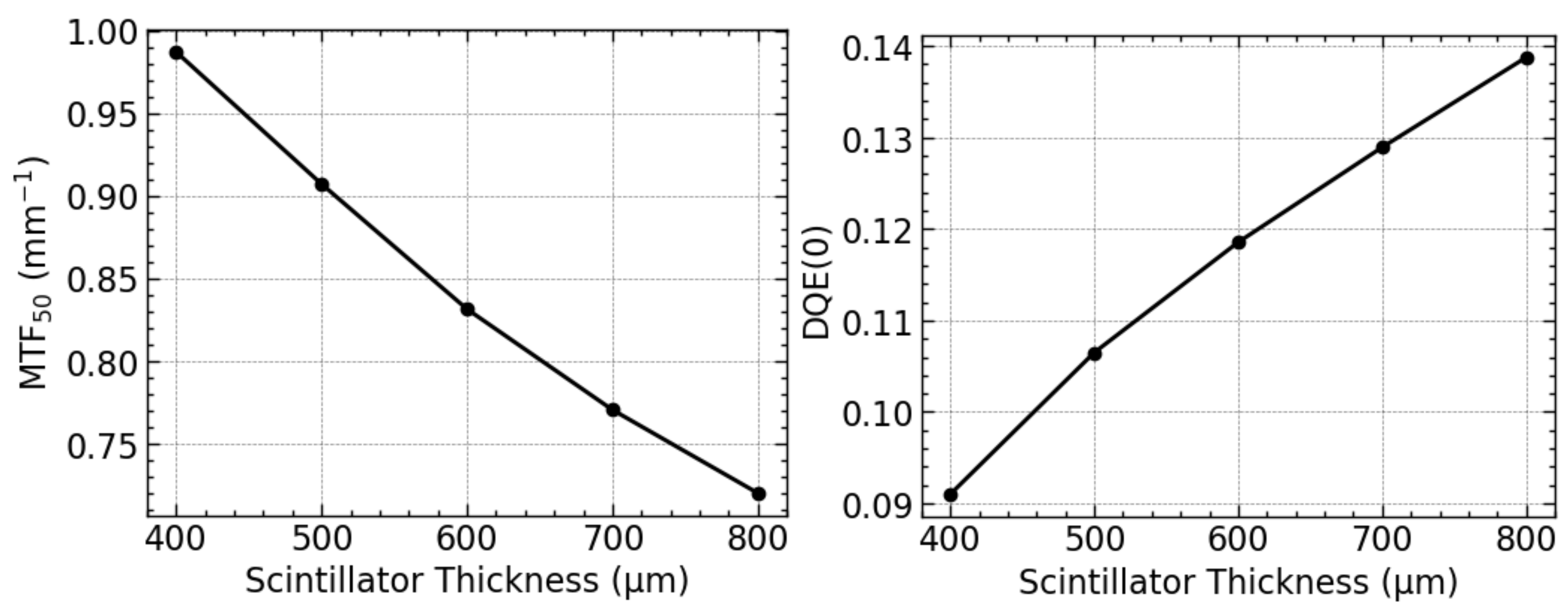

Figure 4. (Left) The MTF_{50} and (Right) DQE(0) for varying bottom layer thicknesses.

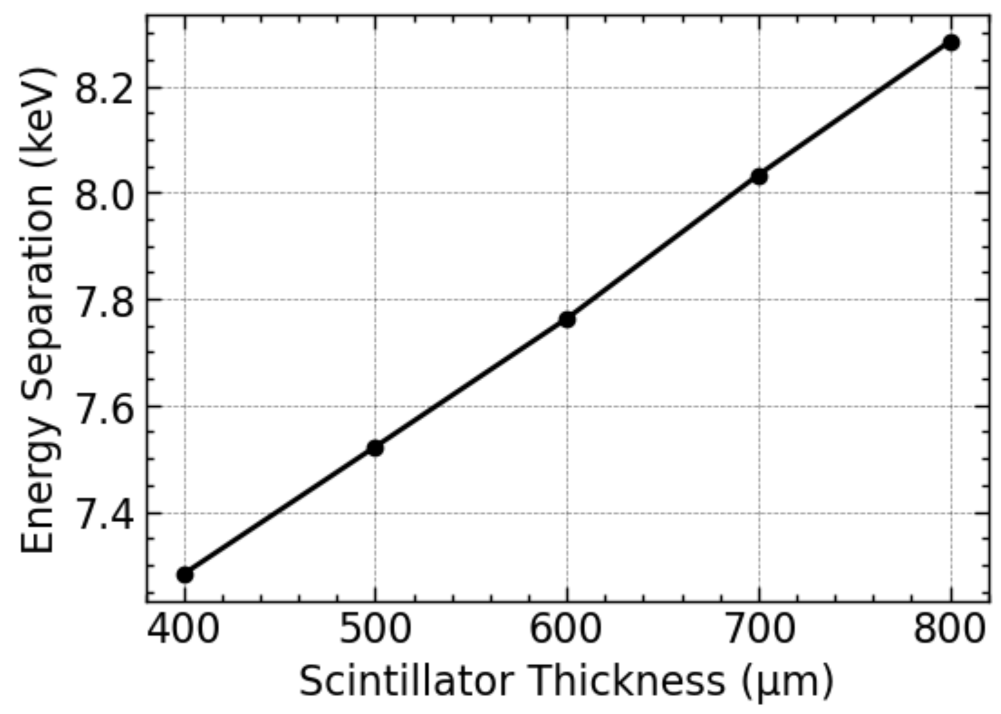

Figure 5. Energy separation between the two layers for varying bottom layer thicknesses.

- Validation against results from Ref. [2] yielded NRMSEs over frequencies from 0 to 3.5 mm^{-1} of 0.007 and 0.016 for the MTF curves of the top and bottom layers, respectively.
- The DQE(0) for both the top and bottom layer agreed with results from Ref. [4] to within 2%.
- Varying the bottom scintillator thickness from 400 to 800 µm:
  - ➢ increased the DQE(0) from 0.09 to 0.13;
  - ➢ decreased the MTF_{50} from 1.01 to 0.74 mm^{-1};
  - ➢ increased the energy separation between the two layers from 7.3 to 8.3 keV.

CONCLUSIONS

- This work developed and preliminarily validated a Monte Carlo model of a dual-layer flat-panel detector.
- Optical transport parameters were identified by tuning the model to match resolution and detection efficiency from literature.
- Simulated DQE and MTF spaces and calculated spectral separation of the bottom detector layer illustrated image metric tradeoffs.
- Using these parameters, this work identified opportunities for further optimizing the configuration of the two scintillation layers.

REFERENCES

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