

Modeling of Depth of Interaction with Inter-crystal Scattering for PET Reconstruction

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PET scanners with *depth of interaction (DOI)* capability measure how deep the photons are absorbed within the detector crystals so that the emission point can be located more precisely. However, most DOI-based reconstruction algorithms do not take into account that photons may scatter within the detector¹, which reduces the accuracy of the resulting image. In this poster, we propose a model that incorporates inter-crystal scattering into DOI-based PET reconstructions.

We decompose the particle transport process into two phases:

- object phase: photon transport from the annihilation point to the detector surface
- detector response phase: all phenomena happening in the detectors, e.g. inter-crystal scattering

Geometric LOR: the two crystal surfaces where the photons enter the detector ($G = (\mathbf{i}_1, \mathbf{i}_2)$)

Observable LOR: the two crystal subvolumes where the photons are absorbed ($L = (\mathbf{D}_1, \mathbf{D}_2)$)

Transport probability: probability that a photon is absorbed in crystal subvolume $\mathbf{D} = (\mathbf{d}, Z)$ provided that it arrived at crystal surface $\mathbf{i}$ from the direction given by angles θ and Φ .

$$p_{\mathbf{i} \rightarrow \mathbf{D}}(\theta, \Phi) = \Pr\{\mathbf{d} - \mathbf{i}, Z | \theta, \Phi\}$$

↑
assuming crystals are identical

Subvolume sensitivity: $\varepsilon_{\mathbf{D}} = E[\# \text{ of single events} \mid \text{photon absorbed in } \mathbf{D}]$

Transport probability from geometric LOR $G = (\mathbf{i}_1, \mathbf{i}_2)$ to observable LOR $L = (\mathbf{D}_1, \mathbf{D}_2)$:

$$p_{G \rightarrow L} = p_{\mathbf{i}_1 \rightarrow \mathbf{D}_1}(\theta_1, \Phi_1) p_{\mathbf{i}_2 \rightarrow \mathbf{D}_2}(\theta_2, \Phi_2)$$

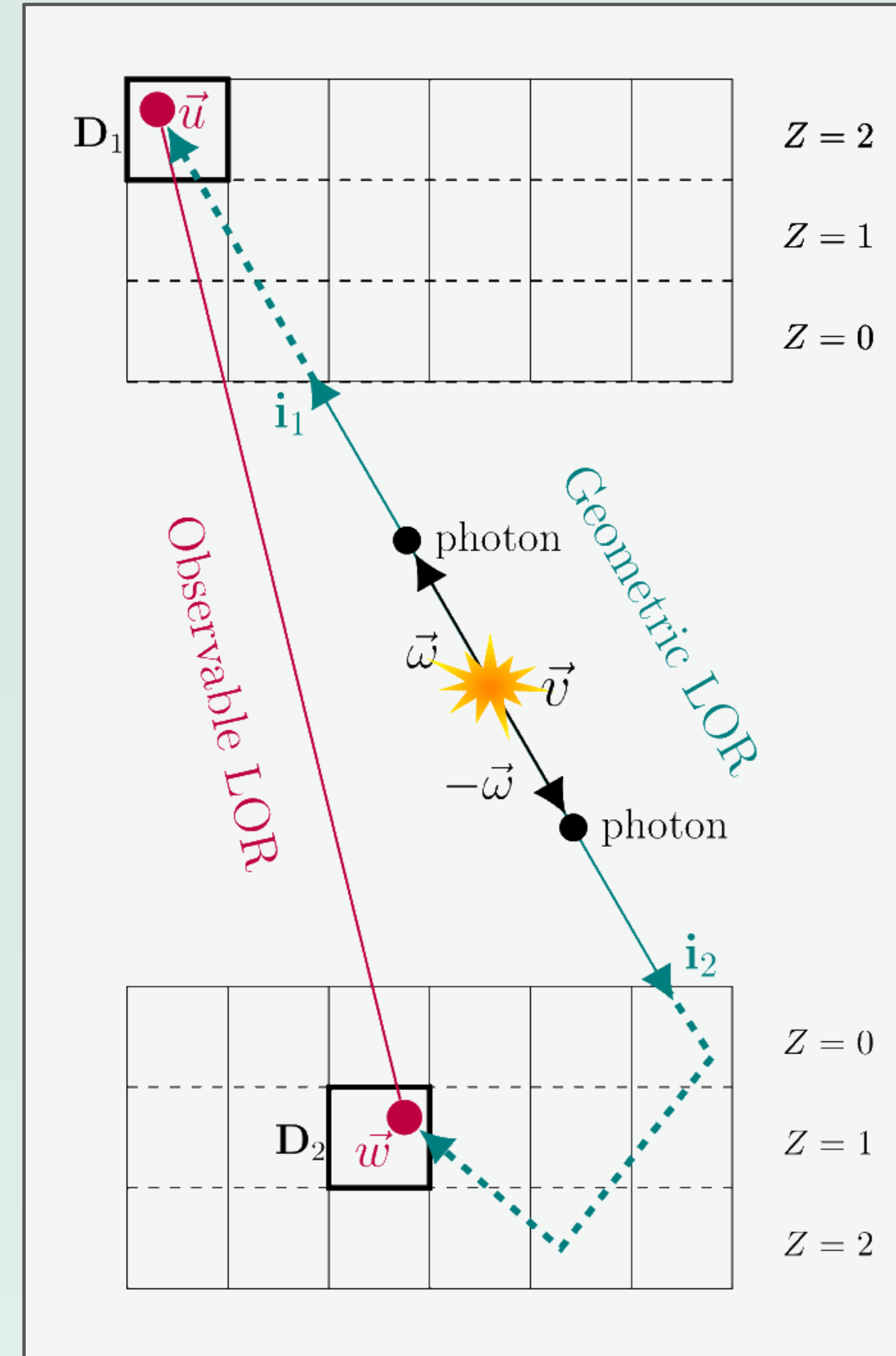
The expected number of hits in observable LOR L :

$$\tilde{y}_L = \varepsilon_{\mathbf{D}_1} \varepsilon_{\mathbf{D}_2} \sum_{\mathbf{i}_1} \sum_{\mathbf{i}_2} \tilde{y}_G^{\text{geom}} p_{G \rightarrow L}$$

Monte Carlo estimation, M random crystal-surface-to-DOI-subvolume offsets $(t_1(i), t_2(i))$:

$$\tilde{y}_L \approx \frac{\varepsilon_{\mathbf{D}_1} \varepsilon_{\mathbf{D}_2}}{M} \cdot \sum_{s=1}^M \frac{\tilde{y}_{G(s)}^{\text{geom}} p_{G(s) \rightarrow L}}{p(G(s))},$$

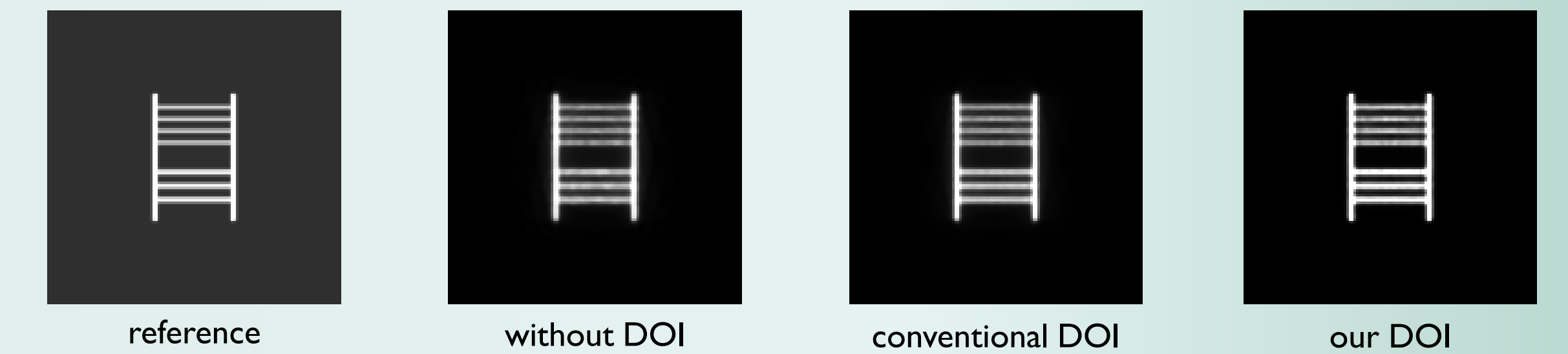
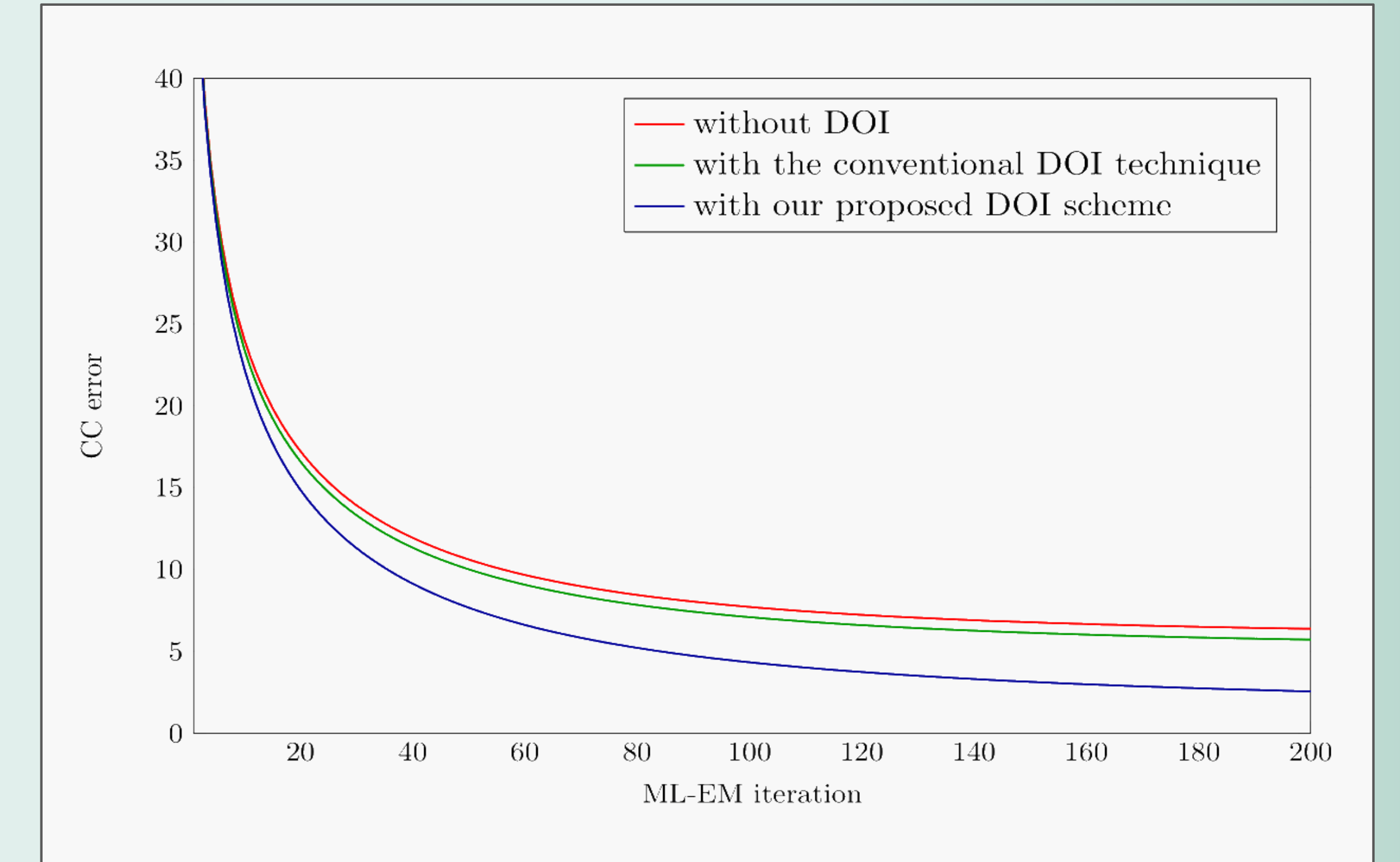
where $G(s) = (d_1 - t_1(s), d_2 - t_2(s))$ and $p(G(s))$ is the probability of sample s , which is made proportional to the transport probability (*importance sampling*).



Pre-computed sample offsets: layer detection probability maps are calculated by simulation, then Monte Carlo offset vector sets are pre-generated that contain just a few samples, but their cumulative distribution is as close to the simulated distribution as possible. A different set is used in every iteration.

Evaluation

Derenzo phantom, $120 \times 120 \times 172$ voxels
NanoPET/CT scanner²



Conclusion

Incorporating inter-crystal scattering significantly improves the quality of the reconstructed image. Moreover, due to the efficient Monte Carlo evaluation scheme, the additional computation time of the proposed improvement is also negligible.

References

- [1] H. T. van Dam et al., "A practical method for depth of interaction determination in monolithic scintillator PET detectors," *Physics in Medicine and Biology*, vol. 56, no. 13, pp. 4135–4145, jun 2011. [Online]. Available: <https://doi.org/10.1088%2F0031-9155%2F56%2F13%2F025>
- [2] M. Magdics et al., "TeraTomo project: a fully 3D GPU based reconstruction code for exploiting the imaging capability of the NanoPET/CT system," in *World Molecular Imaging Congress*, 2010.