CT-less Attenuation Correction

DS using *Detector-Scattered Photons* AC

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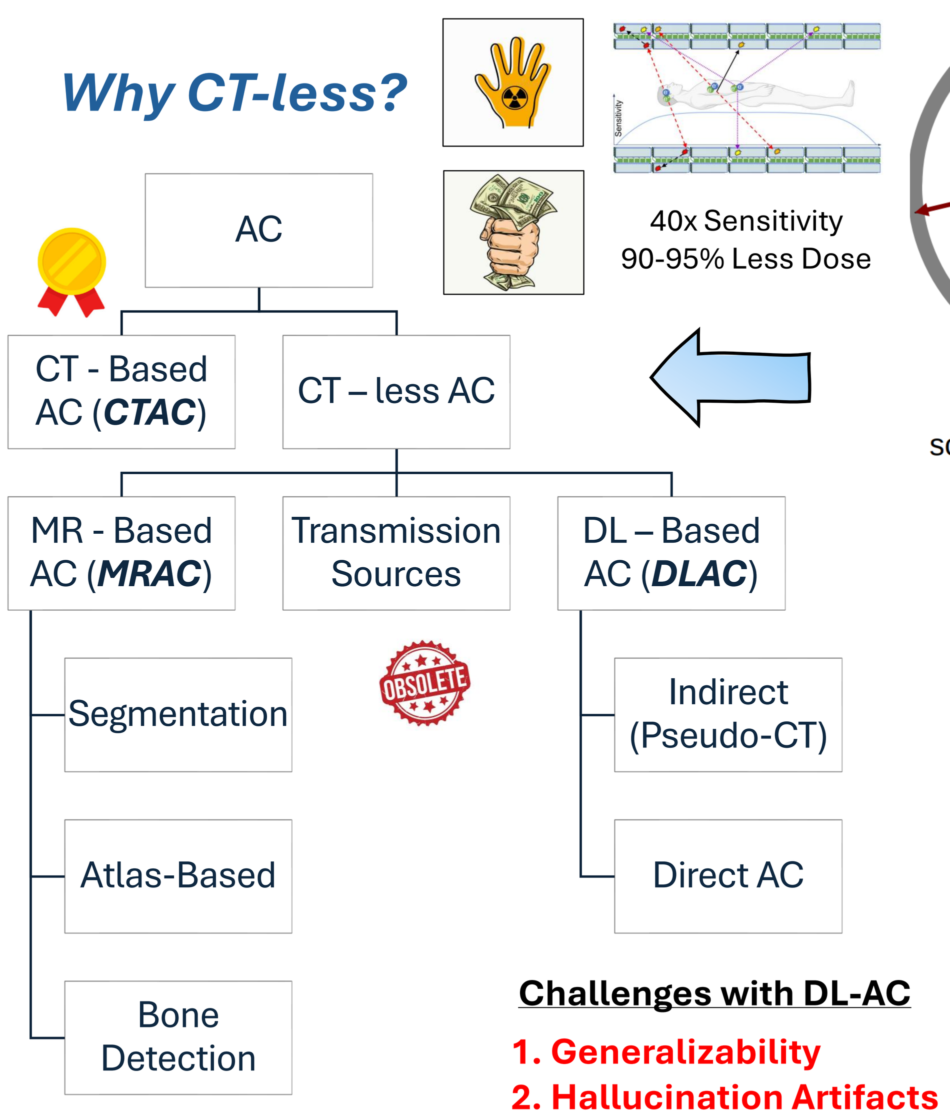
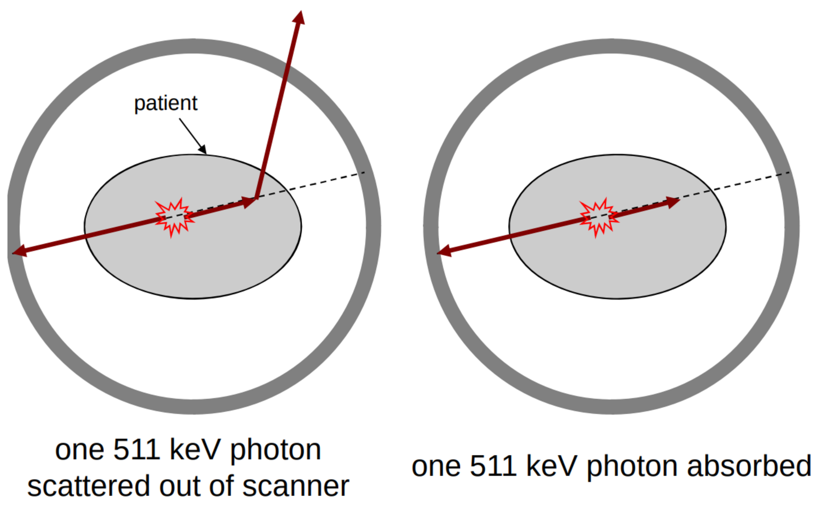
BACKGROUND

Why CT-less?



Challenges with DL-AC
1. Generalizability
2. Hallucination Artifacts

Challenge with MRI
MRI signals lack a direct physical relationship with photon attenuation.



Normal PET	5-9 mSv
Normal CT for AC (***Low Dose***)	**2-8 mSv**
Diagnostic CT	**15-30 mSv**
Total Body PET	0.5 - 2.5 mSv
Total Body CT for AC (***Ultra-Low***)	**0.05 - 2.0 mSv**

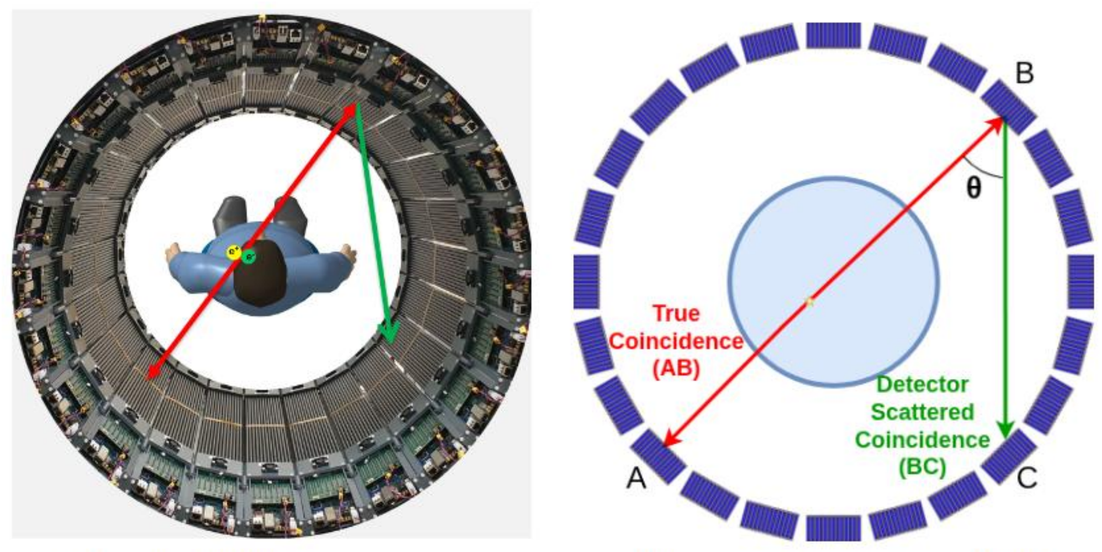
DSAC

(*Detector Scattered Attenuation Correction*)

Tiwari et al. (2025)
https://doi.org/10.5604/01.3001.0055.4655

Approx **50% of all events recorded**, involve photons that scattered between detector modules.

JPET => Plastic Scintillator => Lot of Detector Scatterings



(a) Modular J-PET scanner prototype. (b) True and detector-scattered LORs.

DS-LORs => BCs => where one or both 511 keV photons interacts with one detector module and is subsequently registered in another, creating a Detector Scattered - LOR.

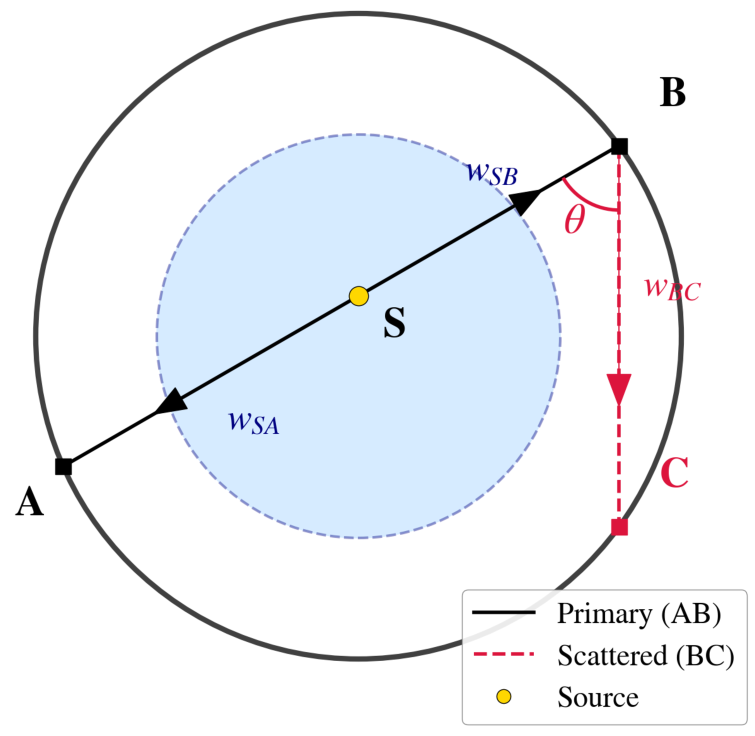
Core Idea: While typically discarded as noise, these scattered photons traverse the patient volume and encode attenuation information.

Aim: To utilize these scattered photons for "blank-scan-free" attenuation correction to create a self-calibrating scanner without external hardware.

DS-MLAA : A *NOVEL* Joint Reconstruction Algorithm

Geometry & *Objective*

"***A valid event requires one direct photon and one scattered photon.***"



Objective

$$(\lambda^*, \mu^*) = \arg\max_{\lambda,\mu} \left\{ \sum_{i=1}^{I} [y_i \ln \bar{y}_i(\lambda,\mu) - \bar{y}_i(\lambda,\mu)] - \beta R(\mu) \right\}$$

Forward Model

$$\bar{y}_i = \underbrace{\mathcal{N}_i}_{\text{system normalization}} \underbrace{\left(\sum_{j=1}^{J} h_{ij}\lambda_j\right)}_{\text{emission from voxel } j}$$
$$\times \exp\underbrace{\left(-\sum_{j=1}^{J} l_{ij}^{SA}\mu_j\right)}_{\text{attenuation along } S\to A}$$
$$\times \exp\underbrace{\left(-\sum_{j=1}^{J} l_{ij}^{SB}\mu_j\right)}_{\text{attenuation along } S\to B}$$
$$\times \exp\underbrace{\left(-\kappa_i\sum_{j=1}^{J} l_{ij}^{BC}\mu_j\right)}_{\text{attenuation along } B\to C}$$

Energy Dependent Scaling Factor (κ_i)

Effective Attenuation Length

$$\mathcal{W}_{ij} = l_{ij}^{SA} + l_{ij}^{SB} + \kappa_i l_{ij}^{BC}$$

Geometric Sensitivity

$$\bar{y}_i(\boldsymbol{\lambda},\boldsymbol{\mu}) = \mathcal{N}_i\left(\sum_j h_{ij}\lambda_j\right)\exp\left(-\sum_j \mathcal{W}_{ij}\mu_j\right)$$

Flowchart & Update Equations

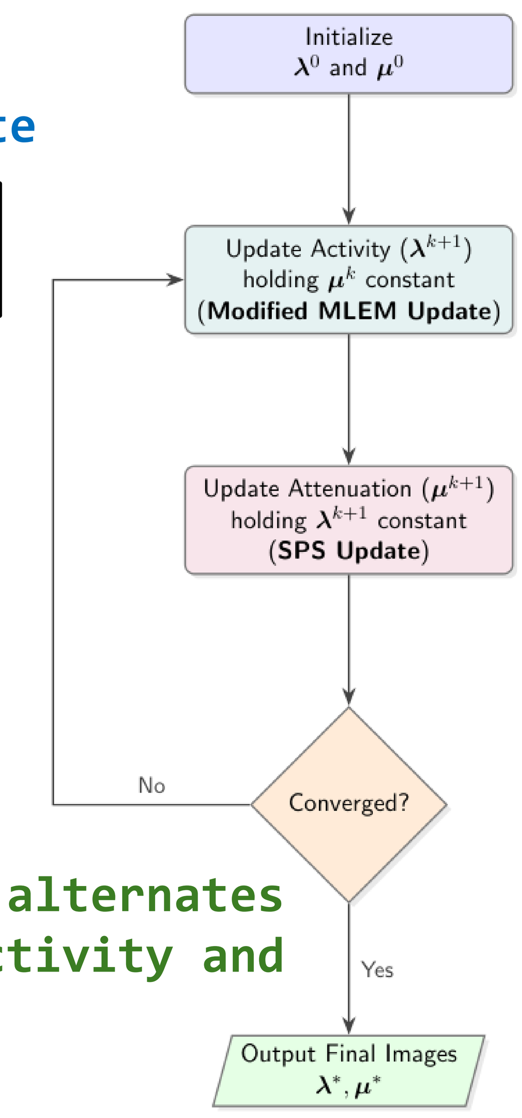
Modified MLEM Update

$$\lambda_k^{(n+1)} = \frac{\lambda_k^{(n)}}{S_k}\sum_i h_{ik}A_i(\boldsymbol{\mu}^{(n)})\frac{y_i}{\bar{y}_i^{(n)}}$$

SPS Update

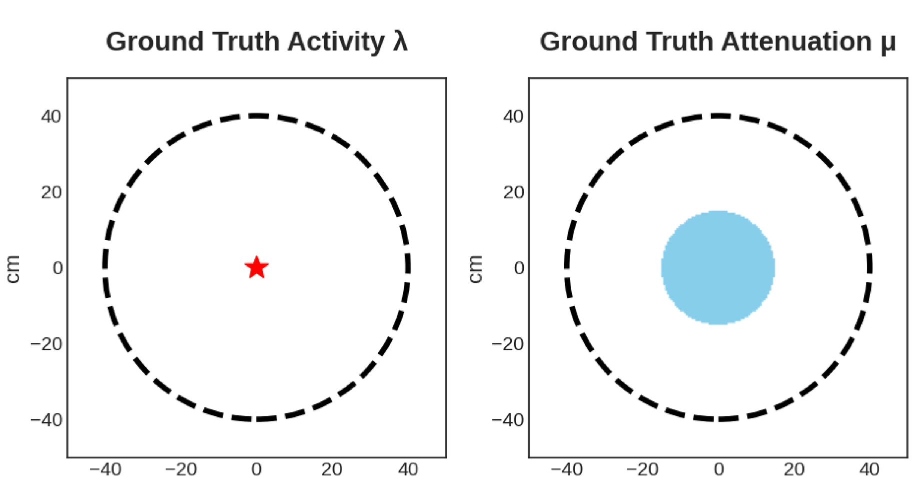
$$\mu_k^{temp} = \mu_k^{(n)} + \alpha\frac{g_k + \beta\nabla R_k}{c_k}$$

$$\mu_k^{(n+1)} = \max\left(0, \min(\mu_{max}, \mu_k^{temp})\right)$$



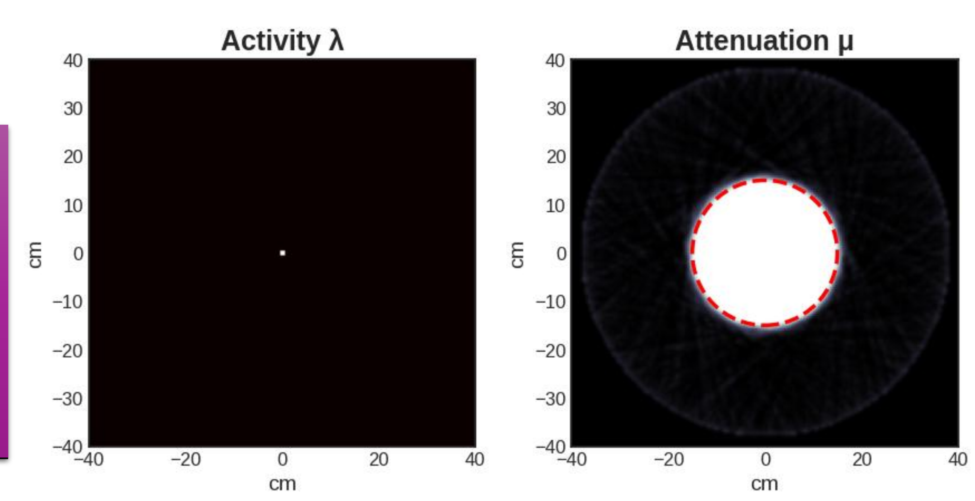
The MLAA algorithm alternates between updating activity and attenuation.

Preliminary Results

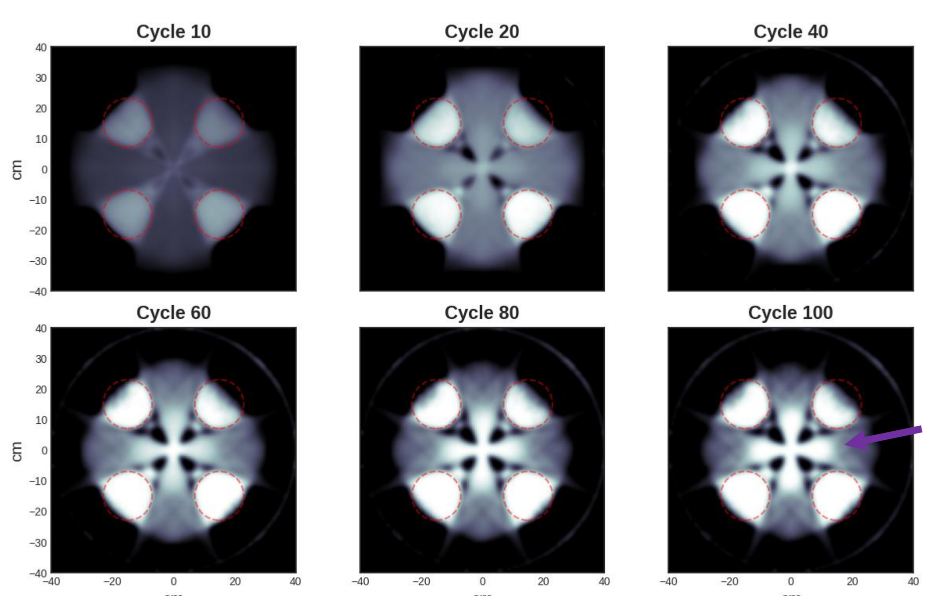


Joint Reconstruction

Number of alternating cycles	100
MLEM iterations per cycle	1
Attenuation update iterations per cycle	5
Total Variation regularization (β)	100
SPS step size (α)	0.5
Post-reconstruction Gaussian smoothing (σ)	0.8



Phantom shifted +10 cm along the horizontal axis.

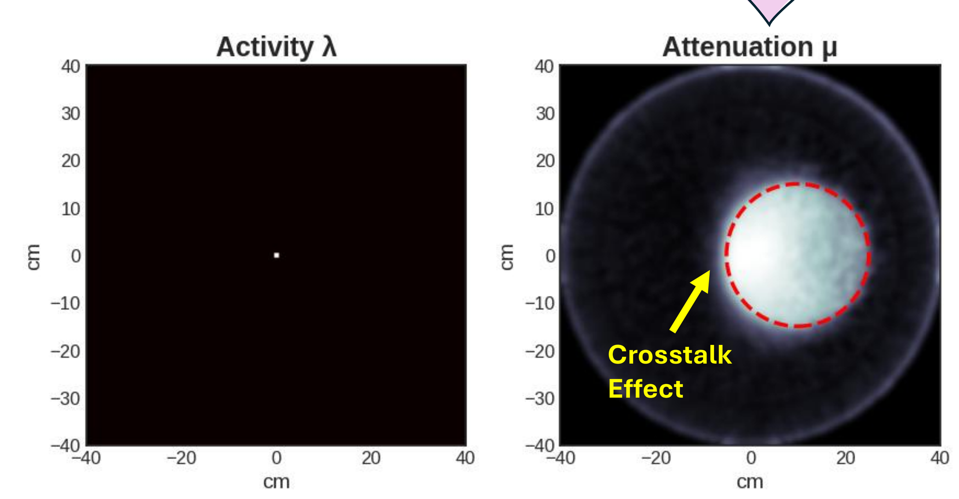


Position (x,y) @ r	μ	Label
(15, 15) @ 8	0.08	Soft Tissue
(-15, 15) @ 8	0.10	Water
(-15, -15) @ 8	0.12	Trabecular Bone
(15, -15) @ 8	0.14	Cortical Bone

Star Artifact due to Crosstalk Effect

TOF = True

Multi-region phantom with a central point source.



Conclusion & Limitations

- ✓ **DSAC** (**Detector Scattered AC**) **recovers attenuation.**
- ✓ **DS-MLAA** (**Detector Scattered MLAA**) **works.**
- ✓ **Low Statistics & severe cross-talk issue persists.**

Future Work

- ✓ **Try DSAC with other possible approaches.**
- ✓ **Resolve the crosstalk issues with deep learning.**
- ✓ **Expand the approach to *3D* LAFOV Total-body JPET.**

Key References

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Acknowledgements

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