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Comparison of efficiency and activity recovery coefficients of Compton and Anger cameras in Nuclear Medicine



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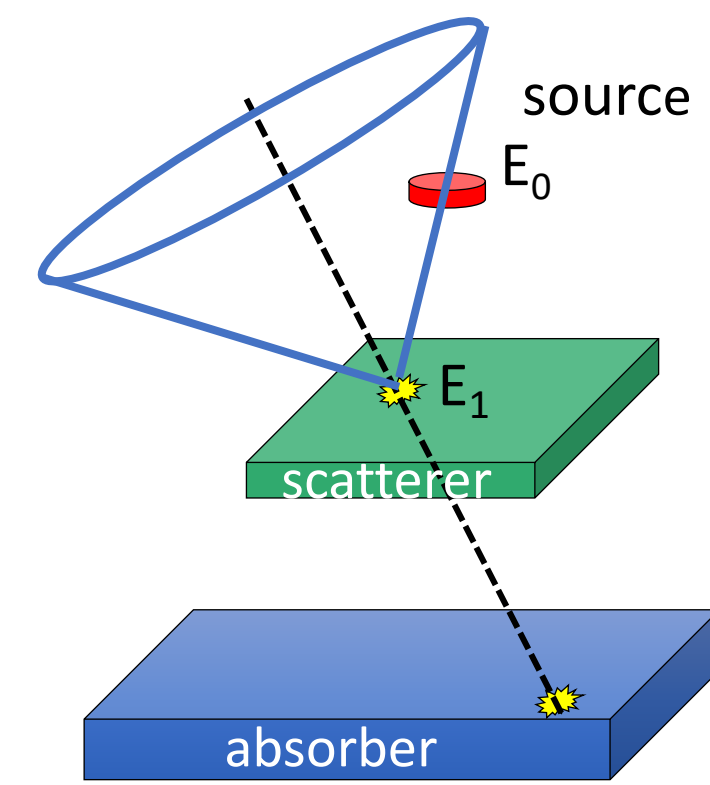
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Introduction

The application of **Compton cameras (CCs)** in Nuclear Medicine, in particular in therapy monitoring, has received significant attention in the recent years. Due to the **electronic collimation** these systems can outperform **Anger cameras (ACs)** in some aspects (e.g. efficiency)

Illustration of a conventional **CC** based on a scatterer and an absorber working in time coincidence



CCs with respect to ACs

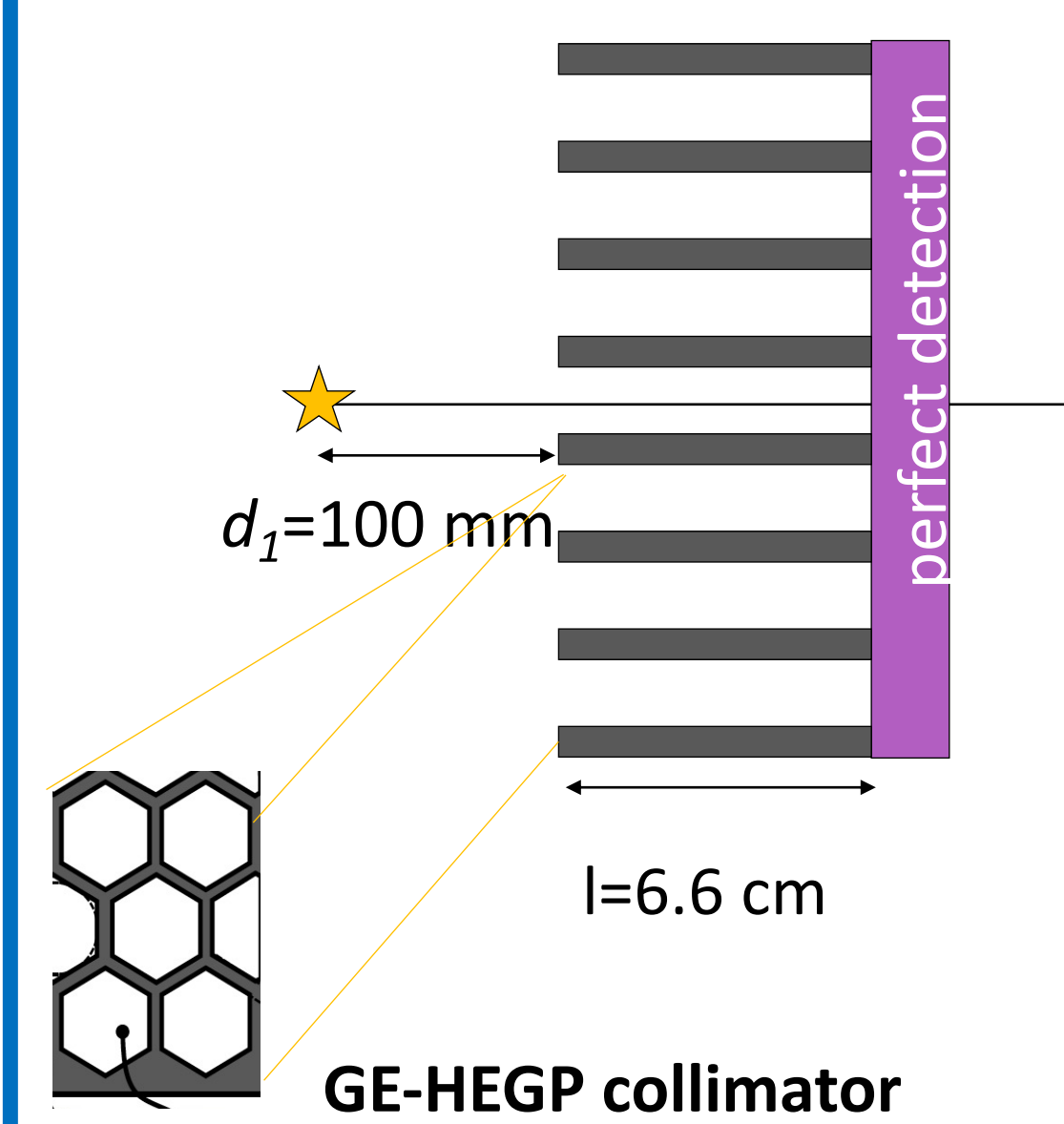
- + High efficiency (**electronic collimation**)
- + May provide higher spatial resolution
- + Wider energy acceptance
- + 3D capability
- Based on time coincidences
- Complex image reconstruction algorithms

Main goal

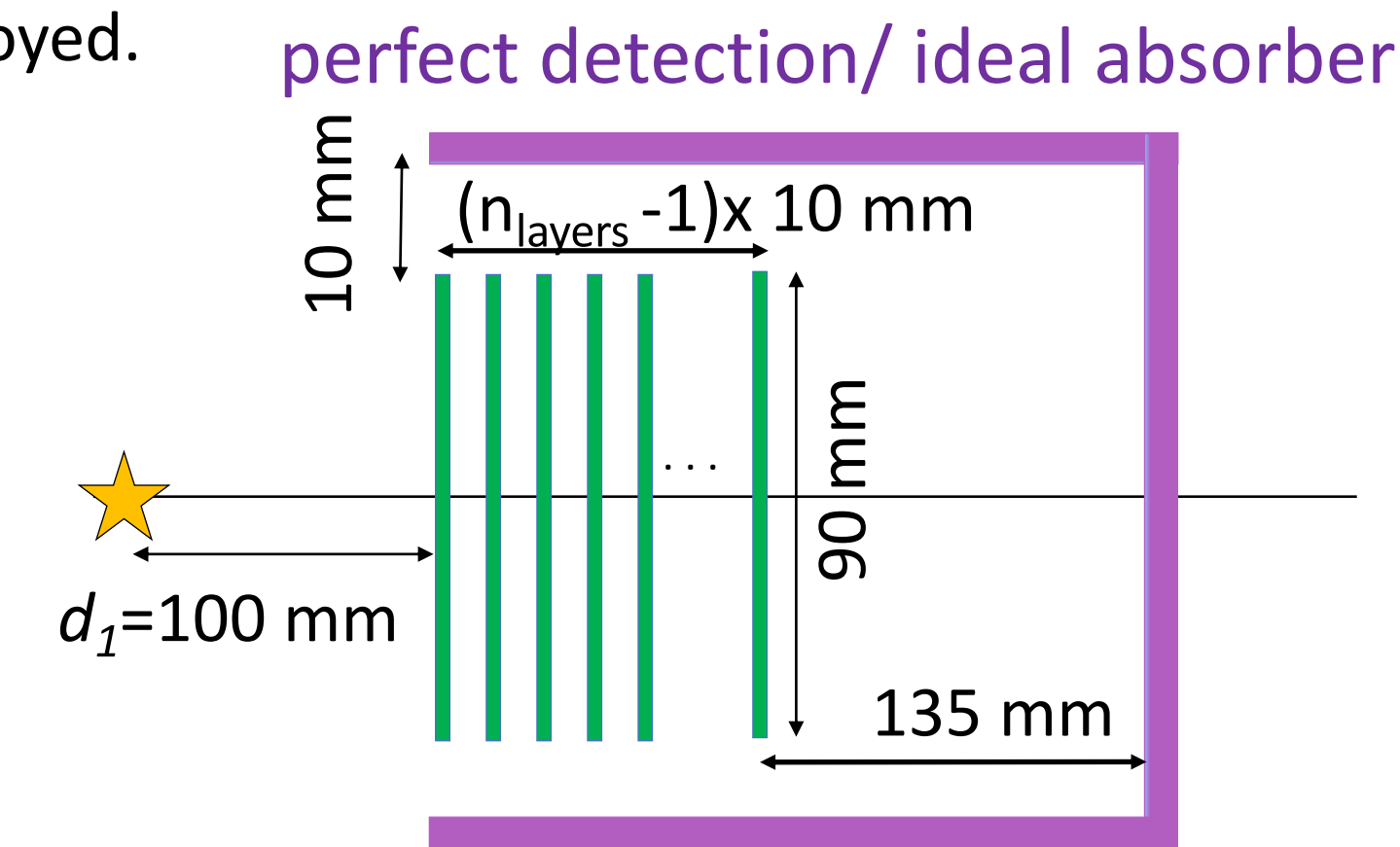
Previous studies [1,2] have shown electronic collimation allows a gain in detection efficiency of a factor 20 with respect to standard ACs. In this work, we present ongoing MC simulation studies for further enhancing detection efficiency through a CC design with high angular coverage over the scattered photons. The performance of the CC is compared with a standard AC in terms of detection efficiency and activity recovery coefficients.

Simulation characteristics

Monte Carlo simulations were performed with GATE/Geant4 [4] version 9.0. **Perfect detection** (100% detection efficiency and perfect energy and spatial resolution) was considered in the **AC** as well as in the **absorber of the CC** by using a phase-space actor. Physics list (em-opt4) with Doppler broadening was selected. Mono-energetic gamma sources emitting in [140,511] keV range were employed.



Lead ($\rho=11.34 \text{ g/cm}^3$)
hexagonal holes (d=4 mm)
septal thickness (t=1.8 mm)



Scatter detector (composed of 9 parallel layers using GATE CCMOD [3]).

- layers based on CLaRyS CC prototype [2]
- 9x9x0.2 cm³ silicon strip detectors (double sided 2x64 strips, 1.4 mm pitch)
- grid discretization module + first neighbour policy
- depth of interaction set to the centre of the layer
- energy resolution of 2.5% at 200 keV, inverse square root energy law
- 5 keV energy threshold

Coincidences sorted by event identification (no randoms)

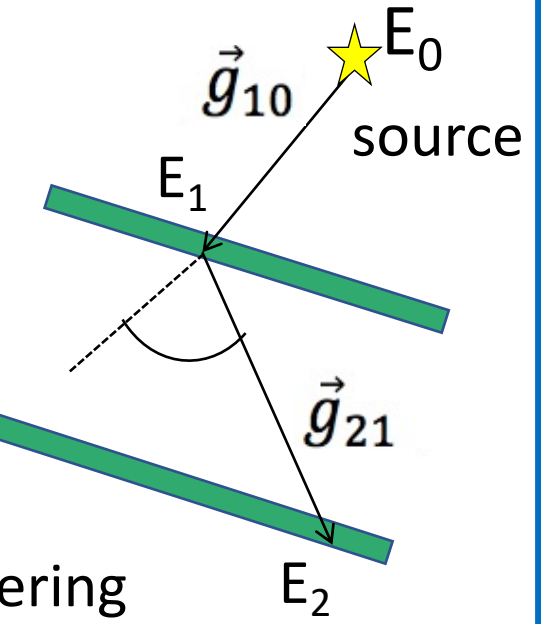
70-80% of coincidences: one single in scatterer and one in absorber

Perfect coincidence sequence reconstruction:

Singles within a coincidence are ordered by increasing time-stamp value

Detector head characterization

Detection Efficiency (DE)	Angular resolution (RMS)
Anger camera	
fraction of events (after energy selection around the incident photon energy) exiting the collimator surface towards ideal detector	rms of the angular distribution (source position known) of energy selected events
Compton camera	
fraction of events that produce a detected coincidence (at least a single in the scatterer with the scattered photon traversing the absorber)	$(\theta^{geom}-\theta^{energy})$ distribution
	$\cos(\theta^{energy}) = 1 - \frac{m_e c^2 E_1}{E_0(E_0 - E_1)}$
	$\cos(\theta^{geom}) = \frac{\vec{g}_{10} \cdot \vec{g}_{21}}{ \vec{g}_{10} \vec{g}_{21} }$
	E_1 energy deposited in the Compton scattering m_e mass of the electron



Results: point-like sources at 100 mm from first scatterer layer (CC) / collimator surface (AC)

	140 keV		245 keV		364 keV		511 keV*	
	DE(%)	RMS(°)	DE	RMS	DE	RMS	DE	RMS
CC	0.89	7.1	0.93	5.2	0.88	4.3	0.82	4.0
AC	0.012	2.5	0.014	3.8	0.018	9.8	0.067	21.1

*High collimator transparency at 511 keV.

Tomographic data: Activity Recovery Coefficients (ARCs)

Tomographic acquisitions for CC (t-CC) and AC (t-AC):

180 views, step of 2 degrees
0.5 s/view at 100 mm from rotation center

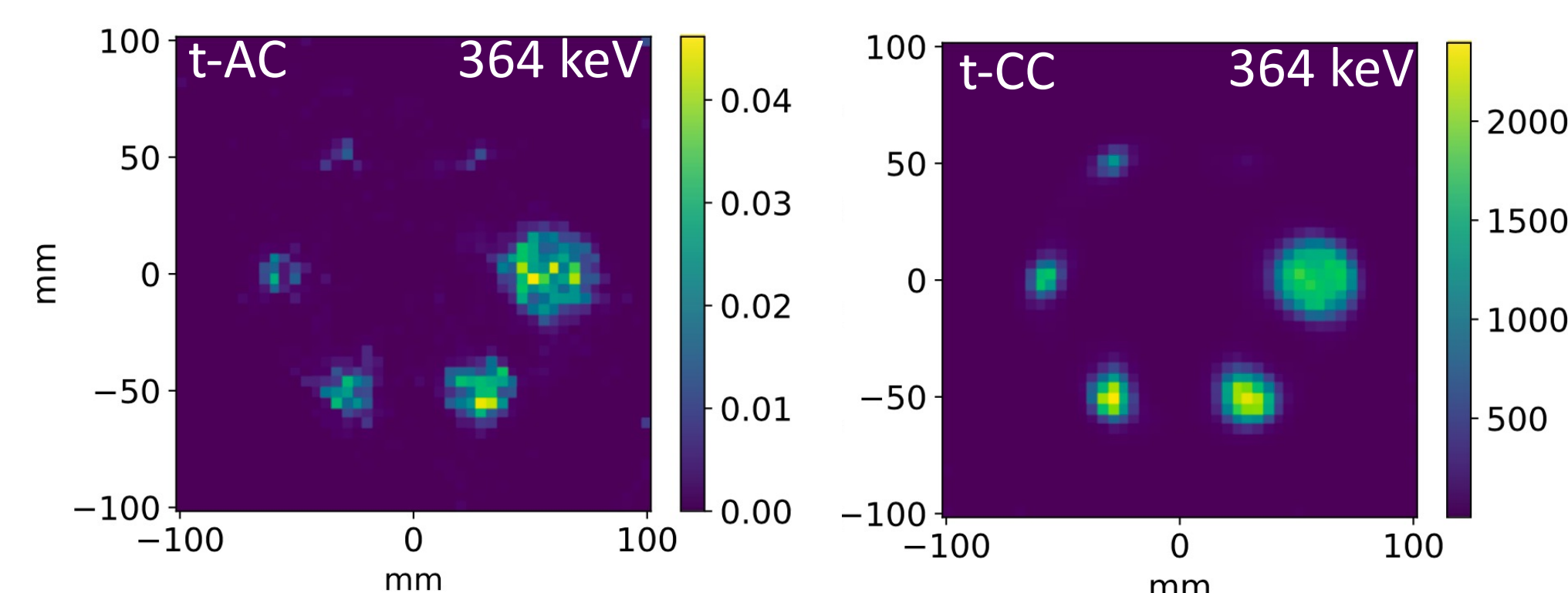
Source distribution (NEMA IEC body phantom config):

6 spheres of 10/13/17/22/28/37 mm diameters distributed along a circumference of D=114.4 mm
Constant activity concentration: 20.5 kBq/mL
mono-energetic gamma sources [140, 245, 364, 511] keV

Reconstruction, ML-EM algorithm :

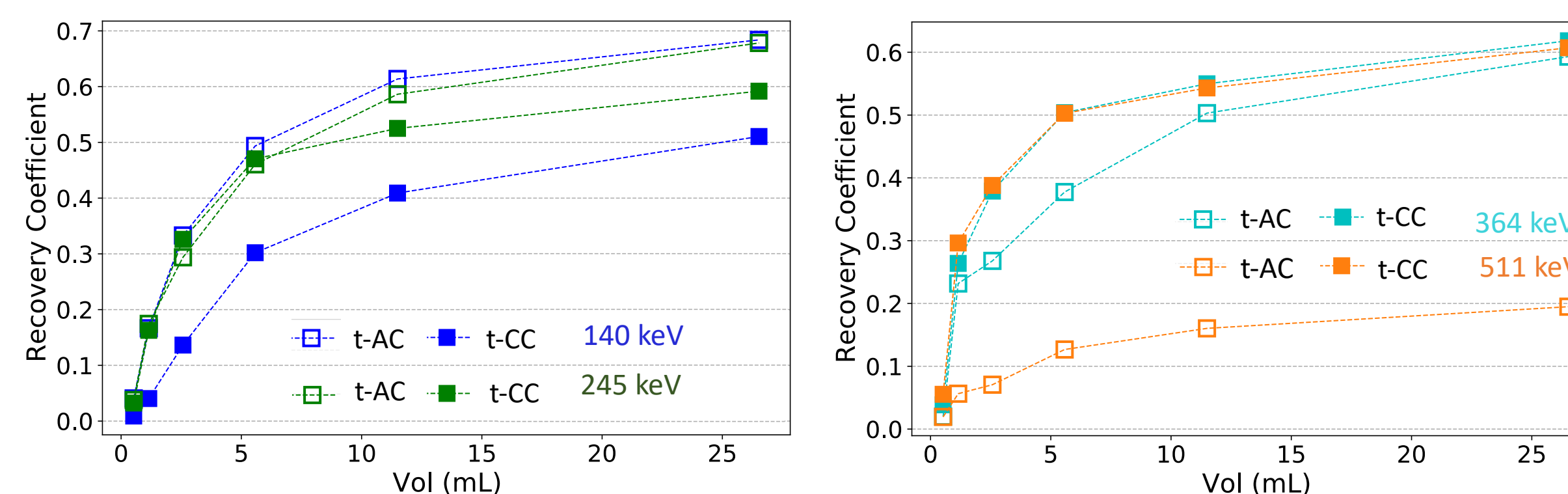
RTK toolkit [5] for t-AC
in-house code [6] for t-CC
FoV 46x46x46 voxels of 4.4 mm³

Reconstructed transversal central slice for t-AC and t-CC



Quality of images has been quantified through **ARC** defined as the ratio between the fraction of activity reconstructed in each simulated source volume and the ground truth

ARCs (t-CC and t-AC) as a function of the sphere volume for different energies.



Better ARC values were obtained for t-AC for energies below 245 keV
for higher energies, better ARC values were obtained for t-CC

Conclusions

Results showed an increase of the detection efficiency of CC up to a factor 74 in the studied energy range as compared to standard AC. For energies above 245 keV, a better angular resolution and ARC were obtained for t-CC, whereas for energies below 245 keV the quality of the reconstructed image in terms of ARC, under the studied conditions, was better for t-AC.

Future work

In the future, we plan to include realistic conditions in absorber detectors and compare the performance of this CC design with commercial SPECT AC system designs. In addition, we plan to evaluate in more detail the quality of the different types of coincidences detected in the CC system.

References

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