Feasibility of Pair-Production Positron Annihilation Coincidence Counting during Photon Radiotherapy

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INTRODUCTION

- PET imaging of positrons generated from radioactive species activated during charged particle radiation therapy has been studied and has progressed to clinical implementation for treatment verification and in-vivo dosimetry.
- This inspires motivation to bring this to megavoltage radiotherapy, where positrons are produced through pair-production interactions during treatment, requiring imaging while the beam is on.
- The main obstacle to implementation is the large photon flux, potentially saturating the scintillators.
- This work begins to address these challenges by investigating the conditions under which a coincidence counting experiment could be performed inside a linac vault.

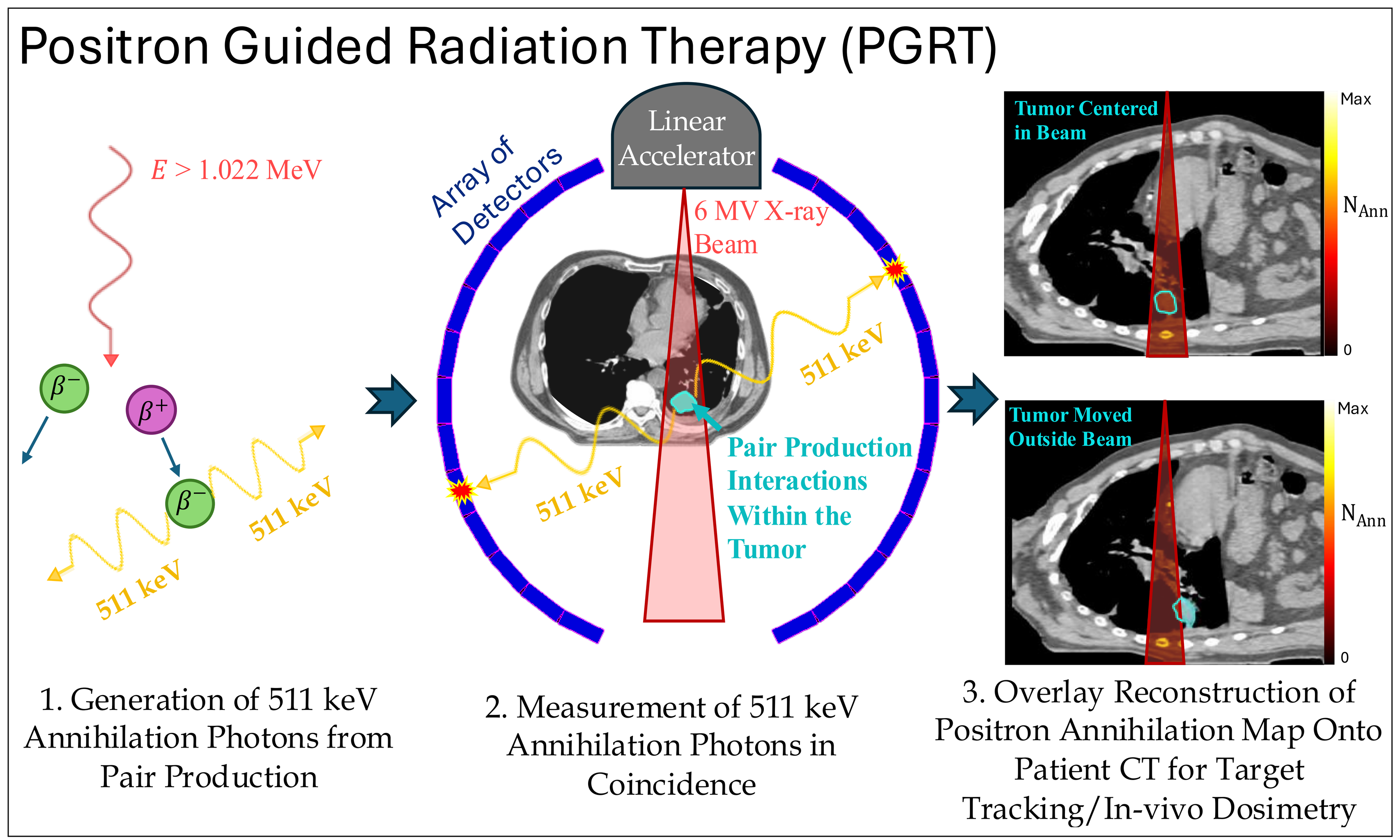

Figure 1. Overview of the imaging workflow.

METHODS

GATE Monte Carlo Simulation of a photon counting experiment inside a linac vault

Geometry:
- 6.5 MV linac photon point source (right, green), FS of 1 cm x 1 cm or 10 cm x 10 cm
- Cubical water phantom, 30cm per side, at 90 cm SSD (right, blue)
- Saint Gobain $LaBr_3$ scintillator 2.5m from beamline at 90-degree scattering angle (right, grey)
- Concrete linac vault shielding (left, grey)

Scoring:
- Absorbed dose in water cube, 2 mm x 2 mm x 2 mm voxels
- Energy spectrum of photons entering $LaBr_3$ crystal, bin width of 0.5 keV

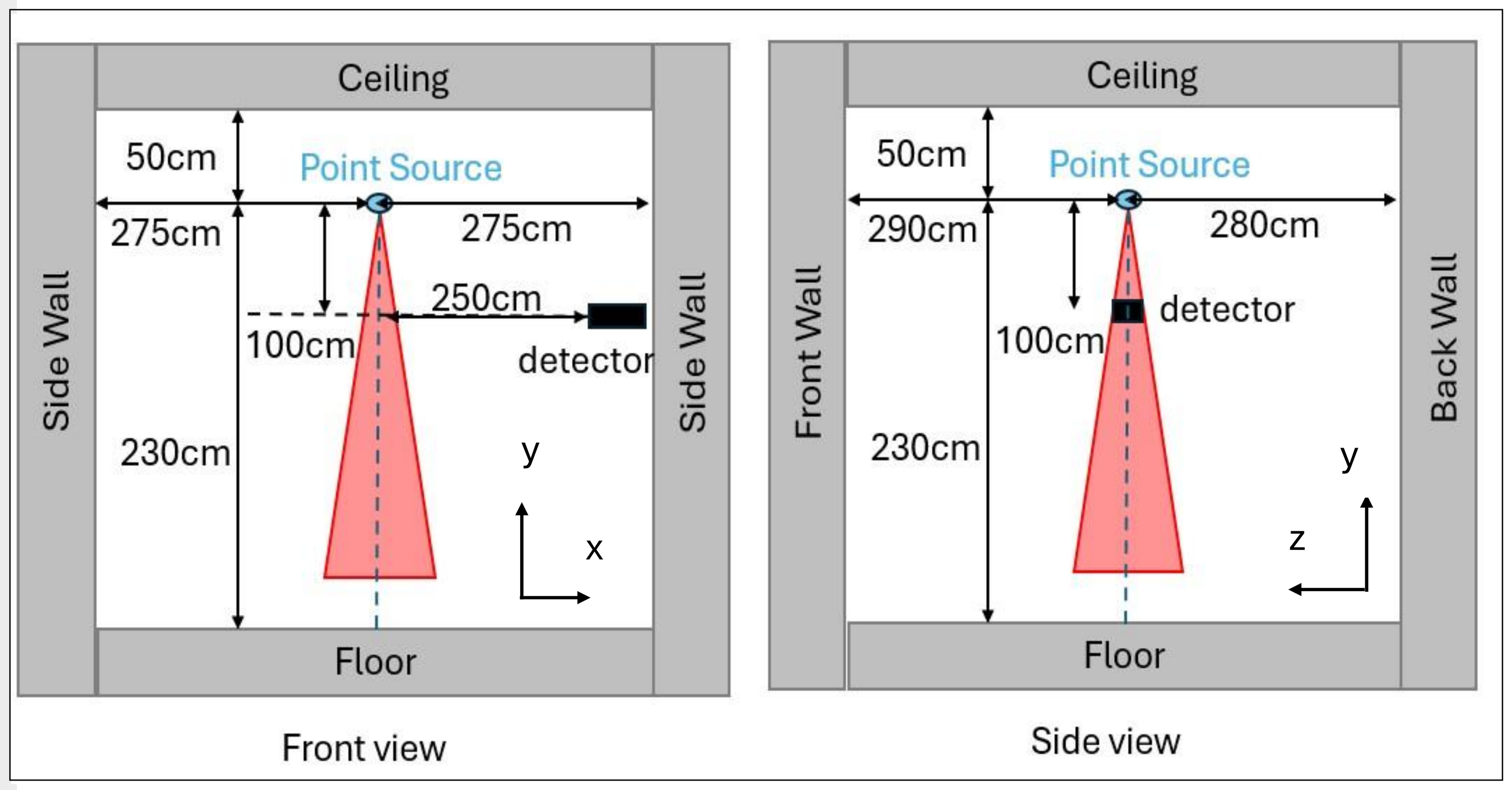

Figure 2. Schematic of concrete vault shielding included in simulation, each side is 3 feet thick

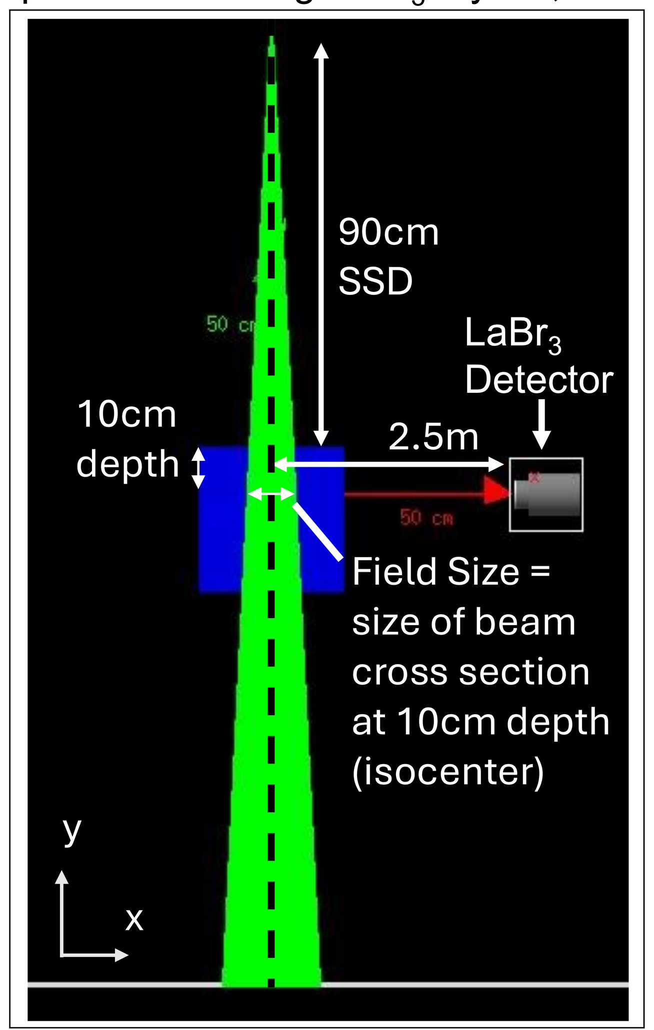

Figure 3. Simulation geometry built in GATE. (shielding not shown)

RESULTS

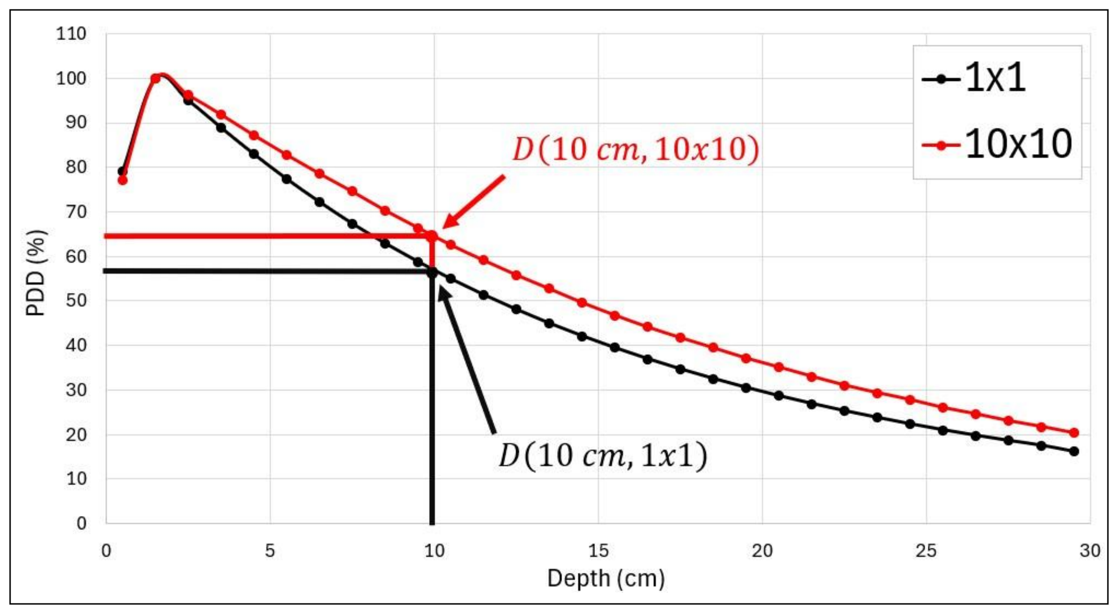

Figure 4. Monte Carlo scored depth dose curves in water cube, 10 cm x 10 cm and 1 cm x 1 cm field sizes.

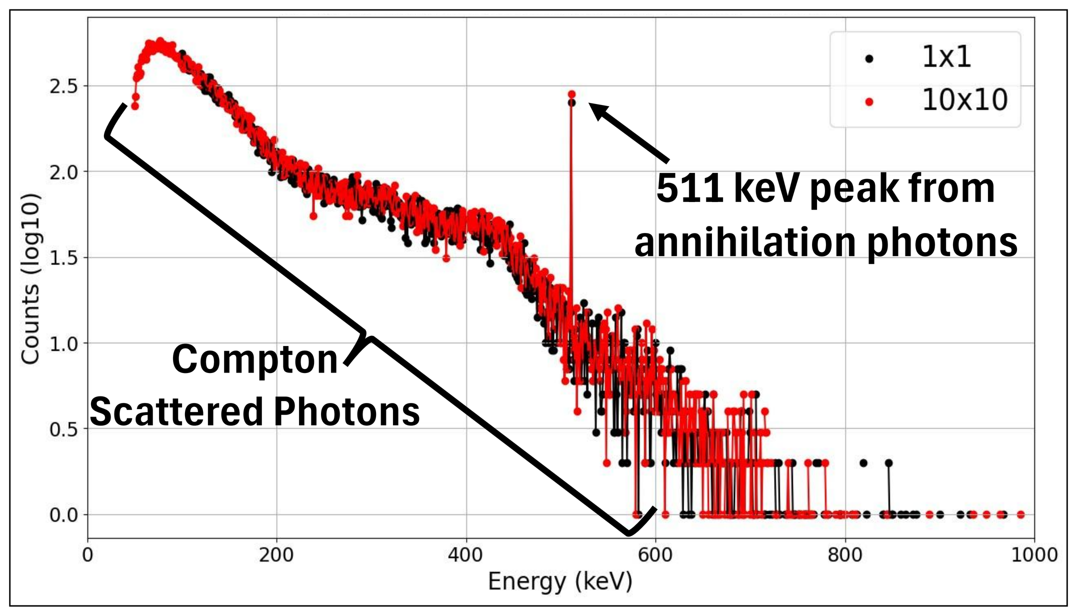

Figure 5. Monte Carlo scored photon energy spectra entering detector, 10 cm x 10 cm and 1 cm x 1 cm field sizes.

MU/Primary Photons

Micropulses/MU

Primary Photons/Micropulse

Photons Entering Detector/Primary Photons

Photons Entering Detector/Micropulse

Average Time between Photons Entering Detector

Duration of Micropulse & Delay Between Micropulses

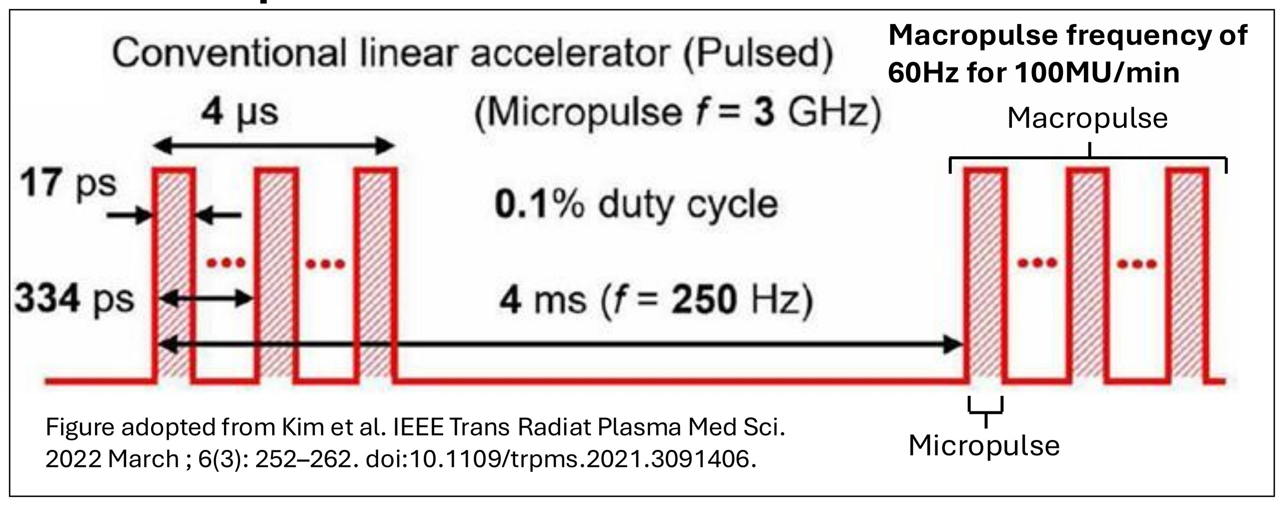

Figure 6. Example of linac pulse structure. Beam pulse structure assumed for calculations of photons entering the detector per micropulse. Figure adopted from Kim et al.[1]

Field Size (cm^2)	Dose at 10cm Depth	Primaries /MU	Primaries/ micropulse	Photons Entering Detector per 2e9 Primaries	Average Number of Photons Entering Detector per micropulse	Average Time Between Photons Entering Detector
10x10	0.0101 cGy	1.54×10^{11}	3.56×10^5	1.04×10^5	18.5	0.92 ps
1x1	0.78 cGy	1.5×10^9	3.47×10^3	6.81×10^4	0.118	3 ns

Table 1: Summary of results from calculations estimating the average time between photons entering a detector inside the linac vault.

CONCLUSIONS

- Under these conditions, the simulated count rates exceeded conventional scintillator limits.
- Ultrafast scintillators, such as BaF_2, with decay times below 1 ns, would make this experiment possible for a 1 cm x 1 cm field size.
- Additional measures, such as shielding or collimating the scintillator and a smaller phantom, would reduce the expected count rates and improve experimental viability.

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REFERENCES

1. Kim et. al. IEEE Trans Radiat Plasma Med Sci. 2022 March ; 6(3): 252–262. doi:10.1109/trpms.2021.3091406.

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