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Keynote - Imaging at the Speed of Light: Reconstruction-free Imaging of Positron-emitting Radionuclides

Positron emission tomography (PET) is a widely used medical imaging technique and, like many other tomographic imaging modalities, relies on an image reconstruction step to produce cross-sectional images from projection data. Detection and localization of the back-to-back annihilation photons produced by positron-electron annihilation define the trajectories of these photons, which, when combined with tomographic reconstruction algorithms, permit recovery of the distribution of positron-emitting radionuclides. Time-of-flight information, typically at the level of 200-400 ps in modern PET systems, is used to constrain the reconstruction locations, improving the signal-to-noise ratio.
Once the time-of-flight resolution can be improved by an order of magnitude to around 30 ps, a new regime is encountered where radioactive decay events can be directly localized without the need for tomographic reconstruction. We call this direct positron emission imaging. In this presentation, we show how prompt Cherenkov luminescence, photodetectors with very fast single photon response times and deep-learning based timing pickoff algorithms are combined in an ultra-fast radiation detector to achieve a timing resolution of 32 ps, localizing positron-electron annihilation sites to 4.8 mm. We also show this is sufficient to directly generate a cross-sectional image of positron-emitting radiotracers without reconstruction and without the geometric and sampling constraints that normally present for tomographic imaging systems. Future prospects for scaling up the approach, and technological innovations for addressing detection sensitivity limitations, will also be addressed.

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