

**Supplemental Figure 1**. Electronics schematic for timing signals in the prototype scanner. Det: detector, Tf: timing signal from the front PSAPD, Tb: timing signal from the back PSAPD, Fan in: Linear fan in/out, TFA: timing filter amplifier, CFD: constant fraction discriminator, OR: logic OR, COIN: logic coincidence.



**Supplemental Figure 2**. Electronics schematic showing shaping amplifier for the energy signals, multiplexer and data acquisition. Each data acquisition (DAQ) board can digitize 8 signals.



**Supplemental Figure 3**. (A) Monte Carlo simulation curve of the interaction probability of 511 gamma rays versus depth in the scintillator array for a point source at the center of the FOV of the scanner. (B) Measured DOI response of an array for a point source at the center of the FOV of the scanner. (C) Comparison of the DOI calibration curve obtained with the method proposed in this work and the DOI ratio measured at different depths (solid dots) with the gold standard coincidence side-irradiation method.



**Supplemental Figure 4.** (A) Geometry used to measure the counting rate performance of the scanner. (B) Singles, (C) randoms, and (D) NEC measured with and without a 3 mm thick lead tube. The inner diameter of the lead tube is 26 mm and the length is 60 mm. The mouse sized phantom is 25 mm in diameter and 70 mm long. A line source is inserted to a hole located 10 mm off the center of the phantom. The 3 mm lead tube reduces the singles by 30%, the randoms by 60%, and the scattered events by 40% and increases NEC rate by 60%.



**Supplemental Figure 5**. (A) Flood histogram, (B) energy spectrum of a central crystal (top) and a crystal in the second row from the edge (bottom), (C) DOI response averaged over all crystals measured at five specific depths for one detector. The crystals for which the energy spectra are shown are indicated by the red boxes in (A).



**Supplemental Figure 6**. Representative intrinsic spatial resolution profiles from two middle rows of crystals (summed over all crystals in the row) for one pair of detectors.



**Supplemental Figure 7**. (Top) Sensitivity of the scanner for lower energy thresholds of 150 keV and 250 keV. The coincidence timing window was 60 ns. (Bottom) The relative sensitivity of the scanner for different timing windows (150 keV energy threshold).