Evaluation of a high-resolution PET probe

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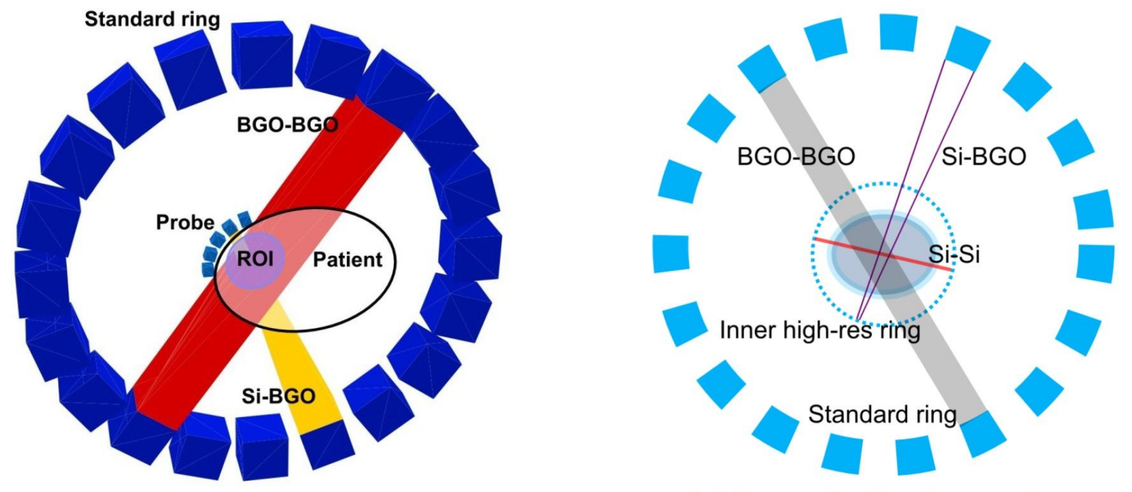
Introduction

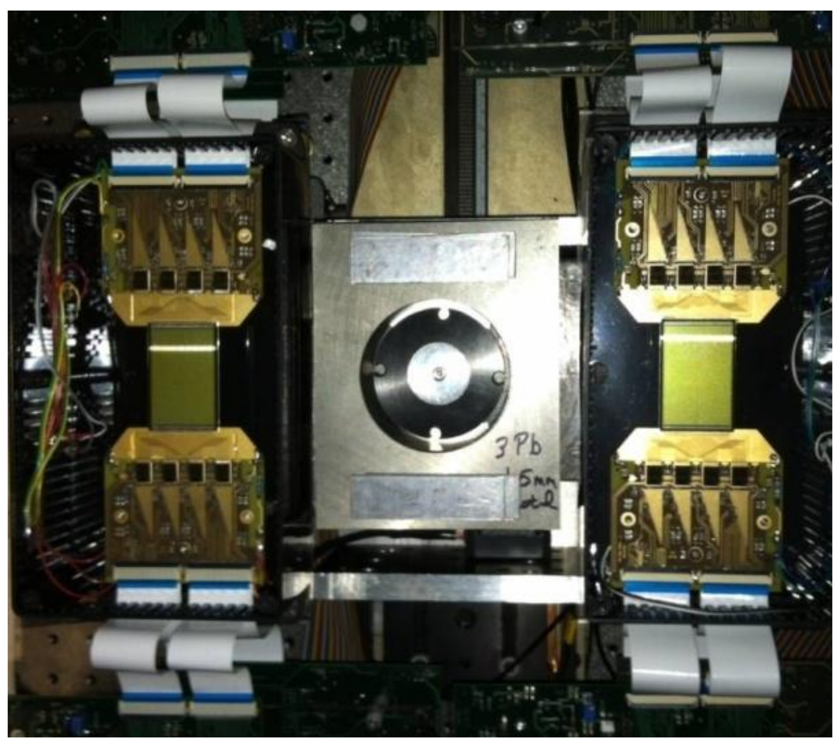
By adding a higher resolution data from an additional PET detector placed within the original PET system, the performance of the system should be improved. A number of such multi-resolution PET systems have been proposed by various groups [1-4]. In the approach investigated by our group, silicon detectors positioned in close proximity to the region of interest are used as a probe to record impact position of annihilation photons with high spatial resolution as determined by detector segmentation. Due to the small angular coverage and low efficiency of the probe, a combination with the standard PET ring is necessary.



PET probe — high-resolution inner ring

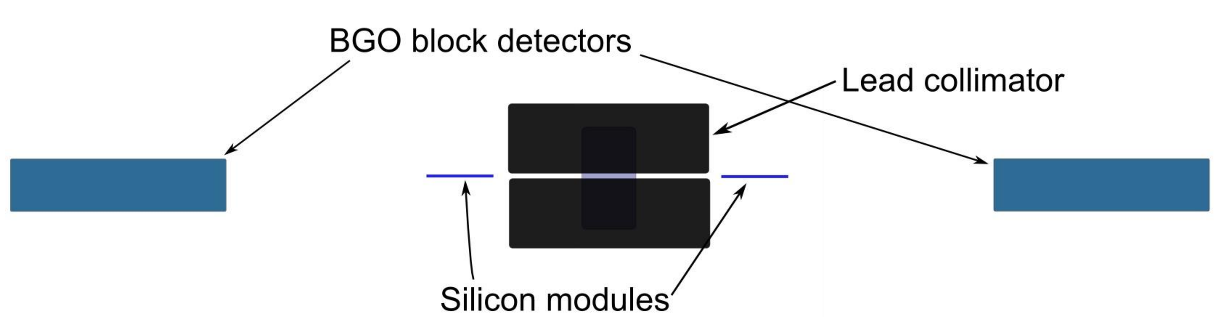
The high resolution PET probe consists of a pair of 1 mm thick silicon detectors, each segmented to 1040 independent pads with an area of 1 mm^2 [5]. The detectors are placed in a back-to-back configuration and are read out by 16 VATAGP7.1 ASICs, made by IDEAS [6]. The addition of the probe introduces new types of coincidence events. Together with regular low resolution ring-ring or BGO-BGO events, high-resolution probe-ring or Si-BGO events and (in the case of two probes) very high-resolution probe-probe or Si-Si events are available. The two envisaged applications can thus be evaluated: a) by adding high-resolution Si-BGO coincidences with a limited angle coverage to a low-resolution BGO-BGO events, impact of the PET probe as an add-on detector is evaluated and b) by combining all three types of events with full angular coverage, dedicated small animal PET scanner is simulated.

Evaluation setup



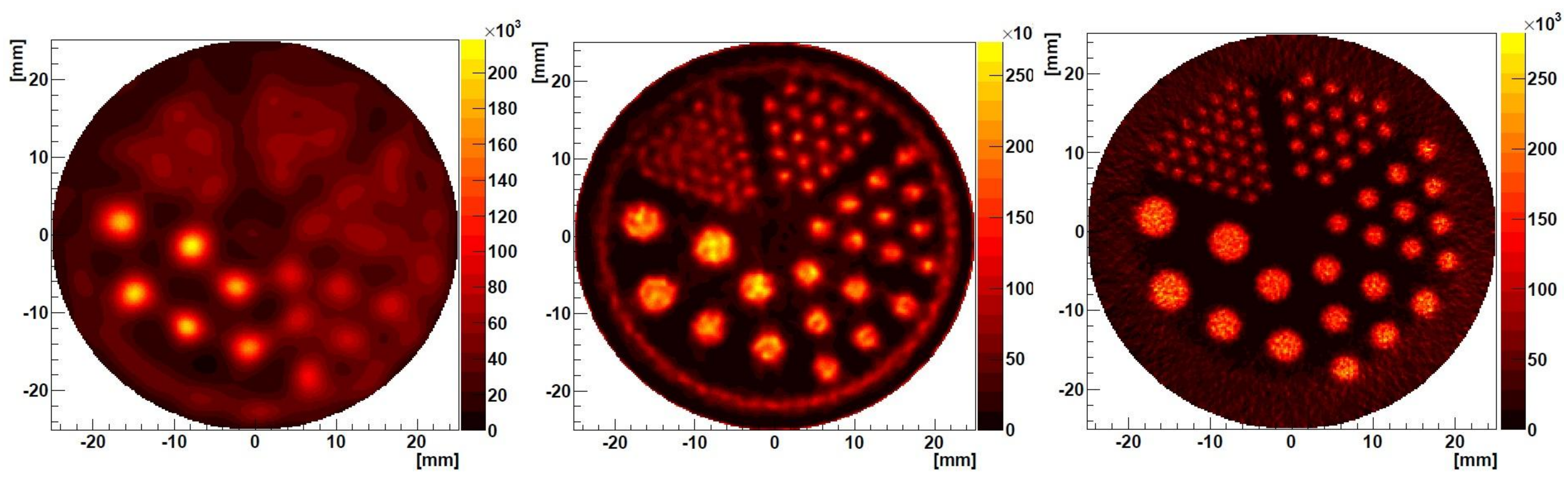
The probe was evaluated at the experimental partial PET ring assembled at the University of Michigan, consisting of 24 BGO block detectors arranged in two symmetric arcs and two silicon probes. Spatial resolution of the BGO detectors is around 6.5 mm FWHM circumferentially. The phantoms were positioned on a rotating table with a diameter of 5 cm and could be rotated in incremental steps. The inner diameter of the partial ring is 50 cm and the distance between the center of the silicon detector and the center of rotation is 10.8 cm.

The detectors were positioned in such a way that only a single 'slice' was imaged, increasing the effective thickness of the silicon detectors to 26 mm. Lead shields and tungsten leafs were used to collimate the source and compress the imaging field to a ~1.5 mm thick slice through the imaging object. Tungsten leafs that support the lead collimator were positioned outside of the FOV to minimize attenuation. Only one of the two detectors on the probe was used. Before each session of data acquisition, the phantom was filled with a solution of FDG with an initial activity of ~18Mbq/cc.



Performance of the system

A significant improvement in system resolution can be appreciated from the figures below, where reconstructions of a Jaszczak phantom (rod diameters 1.2, 1.6, 2.4, 3.2, 4.0 and 4.8 mm) with ML-EM [7] were performed for all three types of events.



Left figure: 9.1 M BGO-BGO events and 1000 iterations of ML-EM. Middle: 9.1 M Si-BGO events, 400 iterations. Right: 8.4 M Si-Si events, 150 iterations. No additional smoothing was applied after the iterative procedure.

Evaluation of the probe performance

Statistical method was developed [8] to quantitatively compare reconstructed images to each other, based on a mean squared estimator (MSE),

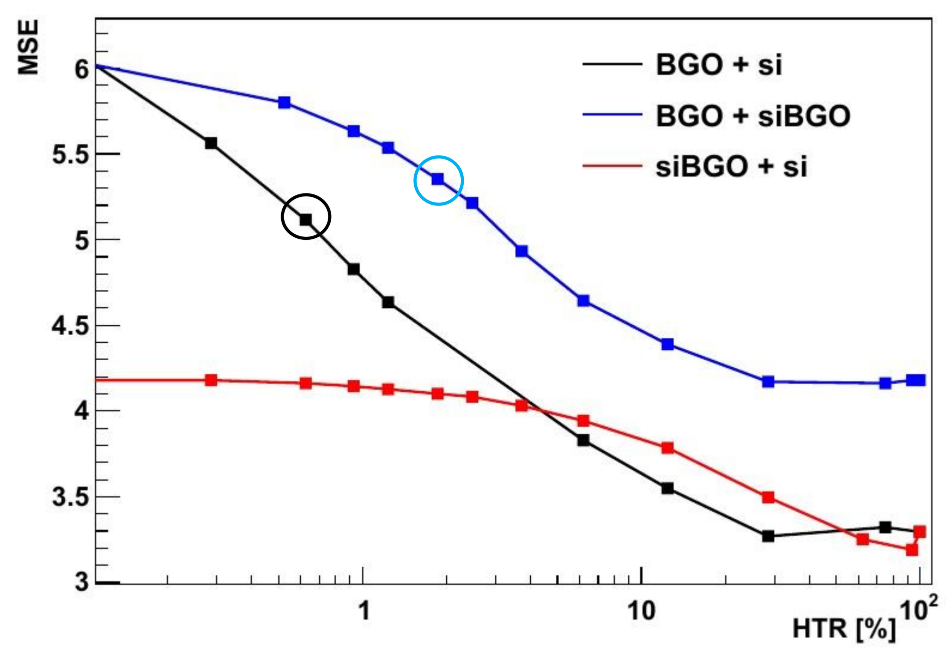
$$MSE = \sum_i \left(\frac{1}{q}\varrho_i - f_i\right)^2$$

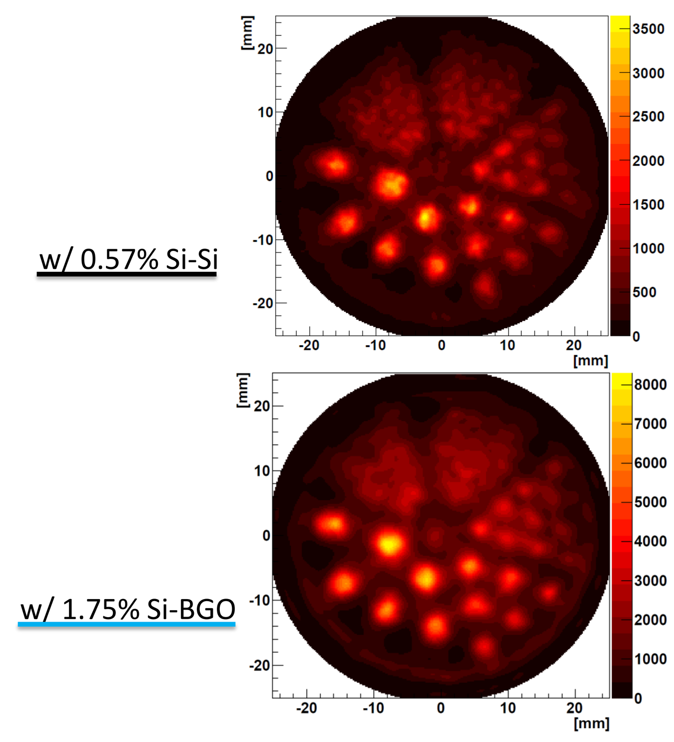
where ϱ_i is the reconstructed source density in pixel *i* and f_i is the Jaszczak phantom model, assuming a source density of 1 within the rods and 0 elsewhere. *q* is used to scale the number of recorded events to the model as

$$q = \frac{\sum_i \varrho_i}{\sum_i f_i}$$

Pixel values within the rods were averaged and a summation was performed over all pixels within the region of interest. MSE values were calculated for various combinations of the percentage of high-resolution information added to lower resolution data (HTR).

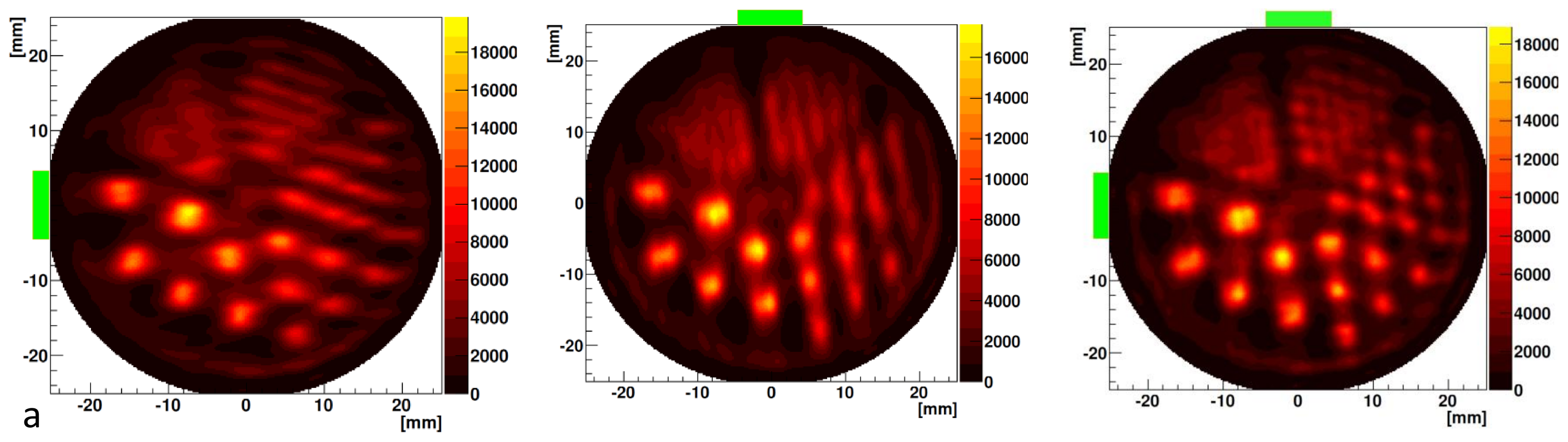
Image quality as a function of high-resolution Si-Si or Si-BGO events added on clean BGO-BGO events is shown on the bottom left figure. MSE value is plotted as a function of HTR (high-resolution to total ratio). A total of 8M events were used in each combination of events and 1000 iterations of ML-EM were performed for each reconstruction. Additional smoothing with a Gaussian kernel (0.4 mm FWHM) was performed after the reconstruction. Two examples of reconstructions with small amount of added higher resolution data are shown on the bottom right.





Limited angular coverage

Artifacts related to limited angular coverage can be reduced effectively when acquiring data from several angles. A feasible geometrical arrangement would be to use two probes positioned perpendicularly to each other. The reconstructions from such an arrangement are shown in the figure below. High-resolution Si-BGO events were acquired at seven angular positions (±18° in 6° steps) and the perpendicular arrangement was simulated by combining the previous two datasets. Same number of events is used for each reconstruction (i.e. right figure contains half the amount of Si-BGO events from left and middle figures). Positions of the two probes are highlighted in green for illustrative purposes.



Summary

The PET probe performance is stable and well understood. Reconstructed image such as the one shown on the upper right figure can be achieved with two probes positioned perpendicularly to each other and represents a significant improvement when compared to using BGO-BGO data only, demonstrating the feasibility of the investigated approach.

References

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