Nested plastic scintillator PET detector geometries have distinct spatial resolution advantages

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Introduction

- Total Body Positron Emission Tomography (TB-PET) scanners are commercially available, but not widely installed due to high costs
- TB-PET offers, e.g., short scan times, low dose & dynamic imaging
- The currently developed TB-Jagiellonian-PET (TB-J-PET) is a more cost-effective approach built with plastic scintillators [1,2,3]
- Simultaneously, several dedicated brain PET scanners are developed to enable high-resolution imaging of brain metabolism [4]
- This study investigates the spatial resolution characteristics of the TB-J-PET combined with a Brain PET Insert (BI)

Geometry

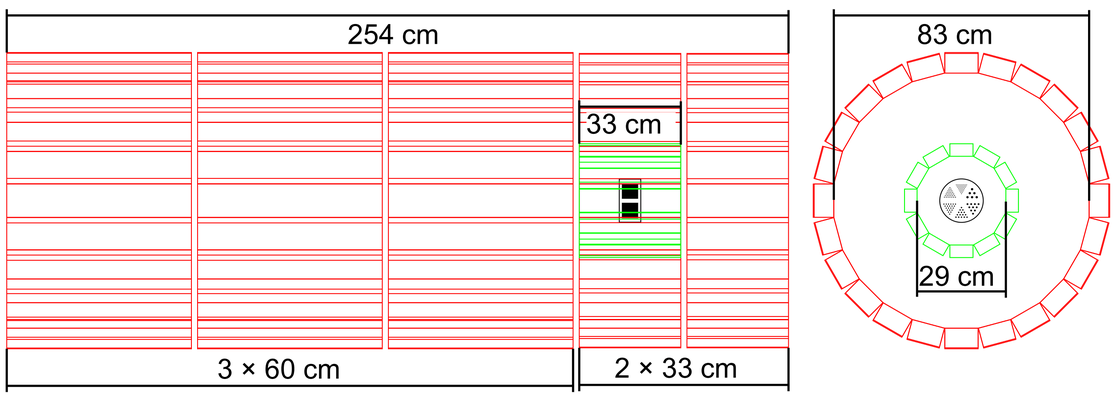


Fig. 1 TB-J-PET (red) with the BI (green) with the Derenzo phantom (black).

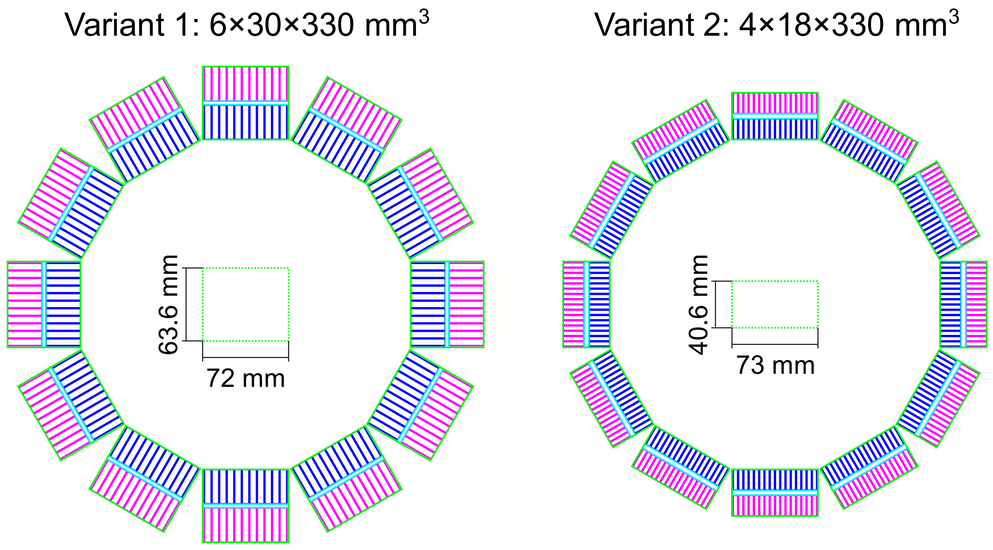


Fig. 2 Brain PET Insert (BI) detector variants considered in this work.

Methods

- Monte Carlo simulations via GATE v9.4.1 [5] with custom patches
- TB-J-PET: 5-ring design of Ref. [3] (see Fig. 1)
- Two detector variants (6×30 vs 4×18 mm^2) for the BI (see Fig. 2)
- Simulating the Derenzo phantom (1 MBq) to assess spatial resolution
- 200 keV minimum energy deposition threshold (Compton scatters)
- MLEM reconstruction with CASToR [6] (200 iterations)
- The spatial resolution is estimated by fitting a Modulation Transfer Function (MTF) model to the image contrast (see poster *MIC-15-258*)

$$\mathrm{MTF}(k) = (1 + \alpha k^2\sigma^2/2)e^{-k^2\sigma^2/2}$$

- We divide coincidences into four categories as tabulated below:

ALL	TB-TB	TB-BI	BI-BI
All coincidences	Both hits in the TB-J-PET	One hit each in TB-J-PET and BI	Both hits in the BI

Detector resolution minimum

- The blurring originating from the scintillator size $2D$ depends on the position p of the annihilation event along the Line-Of-Response (LOR) with length $2L$ (see Fig. 3 for the p-distribution):

$$\mathrm{FWHM}_{\mathrm{det}}(\tilde{p}, D) = D\sqrt{1+\tilde{p}^2}, \qquad \tilde{p} = p/L \in [-1,1]$$

- For a coincidence between two differently sized scintillators:

$$\mathrm{FWHM}_{\mathrm{det}}(\tilde{p}, D_{-1}, D_1) = D\sqrt{\frac{(1-\tilde{p})^2}{2}D_{-1}^2 + \frac{(1+\tilde{p})^2}{2}D_1^2}$$

- The TB-BI coincidences are located at the resolution minimum

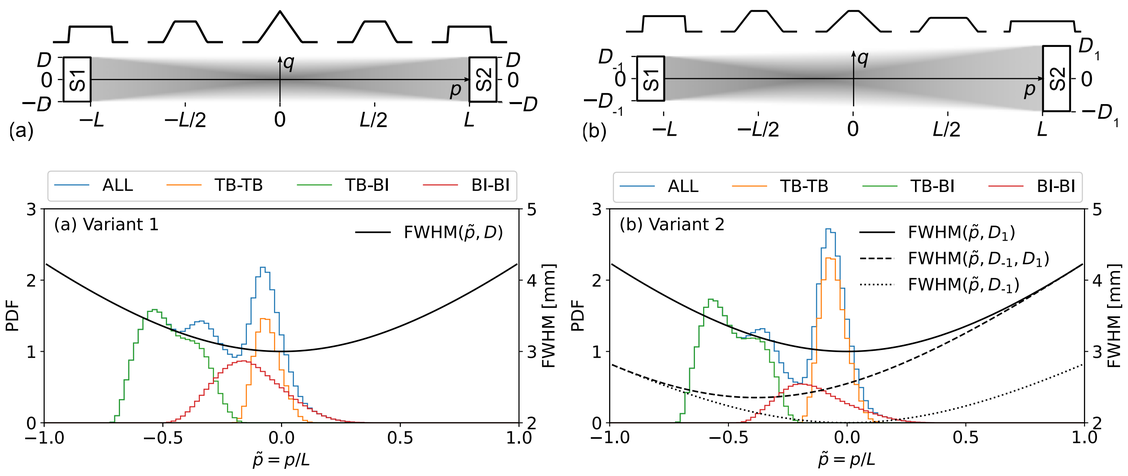


Fig. 3 Distribution of $\tilde{p}$ for the Derenzo phantom for both BI variants.

Reducing the non-collinearity error

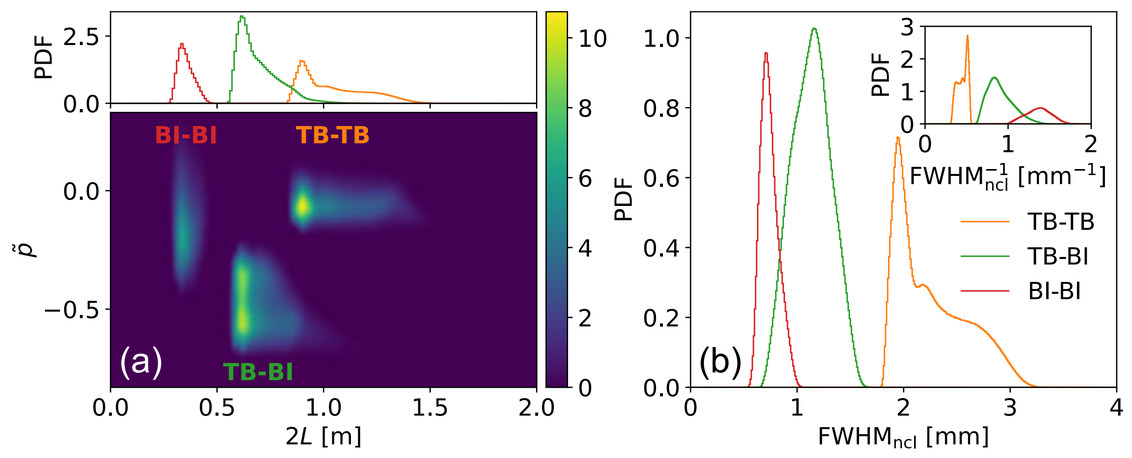


Fig. 4 (a) joint distribution of $\tilde{p}$ and $2L$ and (b) distribution of $\mathrm{FWHM}_{\mathrm{ncl}}(\tilde{p}, L)$.

- Non-collinearity error ($\mathrm{FWHM}_\alpha = 0.5°$):

$$\mathrm{FWHM}_{\mathrm{ncl}}(\tilde{p}, L) = L(1-\tilde{p}^2)\,\mathrm{FWHM}_\alpha/2$$

- Using a correction of the GATE implementation [7]
- The off-centered (see Fig. 4) TB-BI coincidences (~50% of ALL coincidences) suppress the non-collinearity error (see Fig. 5)

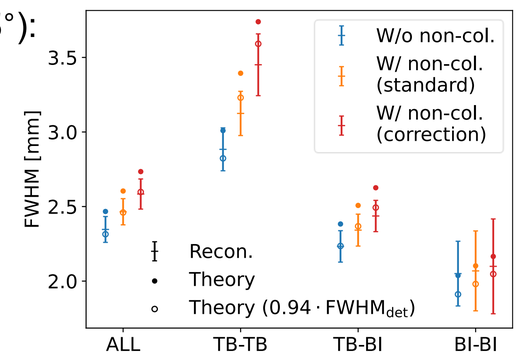


Fig. 5 FWHM comparison.

Conclusions

- For Variant 2, the coincidences between the TB-J-PET and the BI are situated at the minimum of the effective spatial resolution model
- The insert geometry suppresses the non-collinearity uncertainty due to the off-centered TB-BI coincidences
- The image's spatial resolution of the joint reconstruction using ALL coincidences does not add up quadratically but harmonically, giving higher weight to the high-resolution contributions
  → Further enhancement of the spatial resolution

References

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