# Feasibility Study of a Time-of-Flight Brain Positron Emission Tomography Employing Individual Channel Readout Electronics


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## Introduction

- ❑ There is growing demand for a dedicated brain positron emission tomography (PET) because a conventional whole-body PET is not optimized for brain imaging, resulting in increased **radiation dose** or **scanning time** and compromised **image quality**.
- ❑ The purpose of this study was to investigate the feasibility of a **time-of-flight (TOF) brain PET** providing high-quality images.

## Materials and Methods

### *A. Geometry of the TOF Brain PET*

- ❑ The developed TOF brain PET consisted of 30 detector blocks arranged in a ring with a **diameter of 257 mm** and an axial field of view (FOV) of 52.2 mm.
- ❑ Each detector block was composed of two detector modules and two application-specific integrated circuit (ASIC) chips.

### *B. TOF PET Detector*

- ❑ The detector module was composed of an 8 × 8 array of 3 × 3 mm$^2$ multi-pixel photon counters (MPPCs) and an 8 × 8 array of 3.11 × 3.11 × 15 mm$^3$ lutetium yttrium oxyorthosilicate (LYSO) scintillators.
- ❑ The **thickness of the LYSO** was chosen as **15 mm** by considering the trade-off among sensitivity, TOF capabilities, and parallax error.
- ❑ To achieve excellent coincidence timing resolution (CTR), each LYSO was mechanically **polished except for a roughening entrance surface**.
- ❑ **All lateral surfaces and the entrance surface** of the LYSO were optically isolated by **enhanced specular reflector (ESR) film and Teflon tape**, respectively.

### *C. Individual Channel Readout Electronics*

- ❑ The individual channel readout electronics were based on a 64-channel commercial ASIC providing **readout and digitization of signals from individual channels** to acquire the position, energy, and time information of an interacted gamma ray in each scintillator.

### *D. Performance Evaluation*

- ❑ The performance of the TOF brain PET was measured using a 1.8 MBq of $^{22}$Na point source and a custom hot-rod phantom filled with 10.4 MBq of $^{18}$F placed at the center of the FOV.
- ❑ To optimize the performance of the detector module, the energy resolution and CTR were measured with a pair of channels (repeated three times) while changing the overvoltage ($V_{OVER}$) of the MPPC and the timing threshold value, called *T1*, of the ASIC.
- ❑ The tomographic images of the point source and hot-rod phantom were reconstructed by a 2D filtered backprojection algorithm and 3D maximum-likelihood expectation-maximization algorithm, respectively.
- ❑ All tomographic images were nonTOF images reconstructed without attenuation, normalization, scatter, and random corrections.
- ❑ Spatial resolution was measured by acquiring reconstructed images of point sources located at the following transaxial distances from the center: 0, 20, 40, 60, and 80 mm.
- ❑ All experiments were carried out at room temperature and detector blocks were cooled using air circulation.

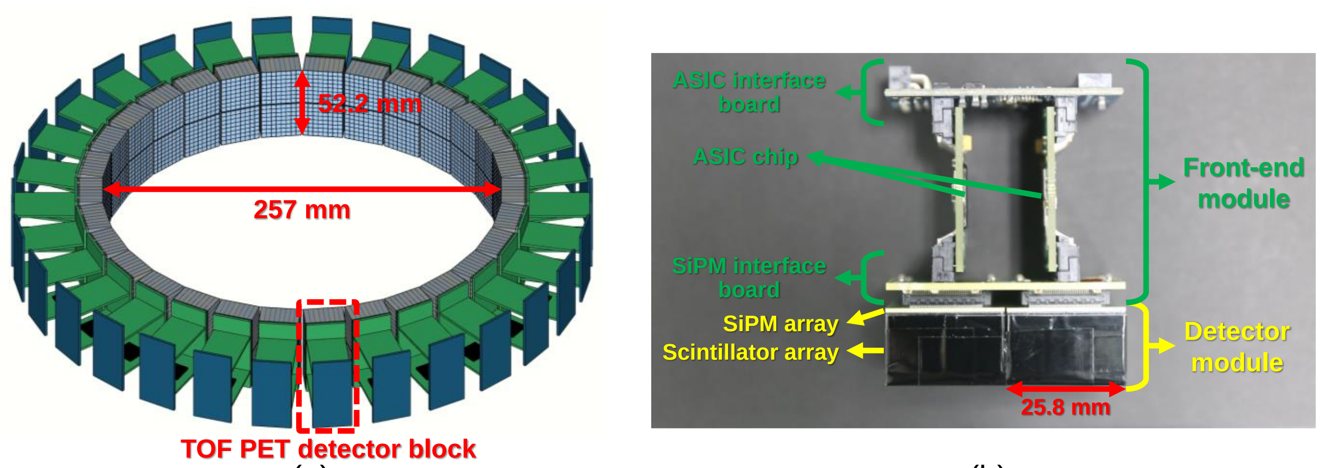


Fig. 1. (a) Geometry of the proposed TOF brain PET. (b) Configuration of the TOF PET detector block.

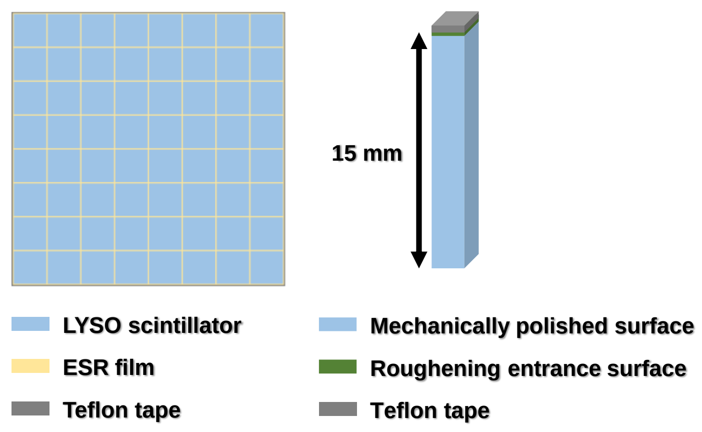


Fig. 2. Design of the LYSO array considering optimal optical properties (surface treatment and reflective materials).

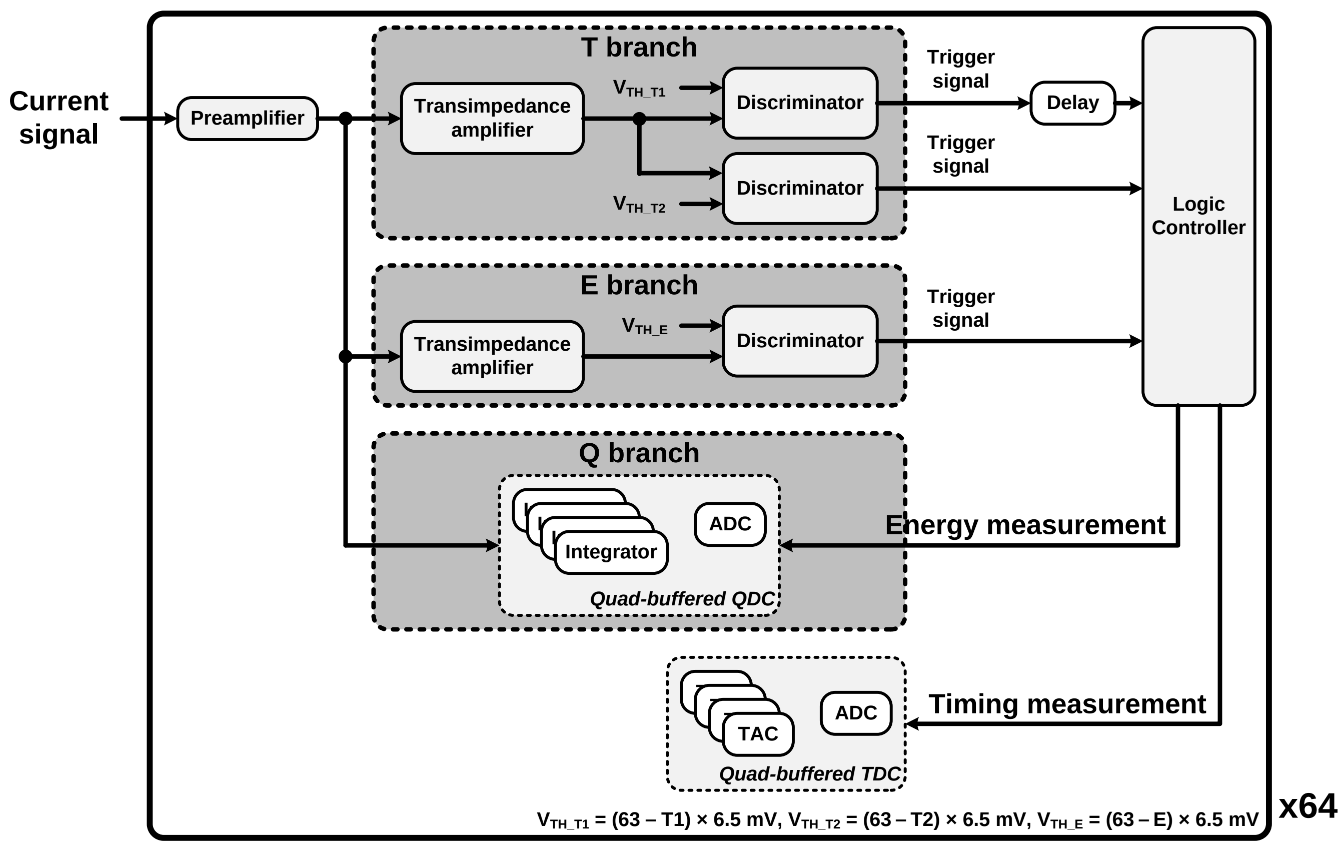


Fig. 3. Block diagram of the ASIC.

## Results

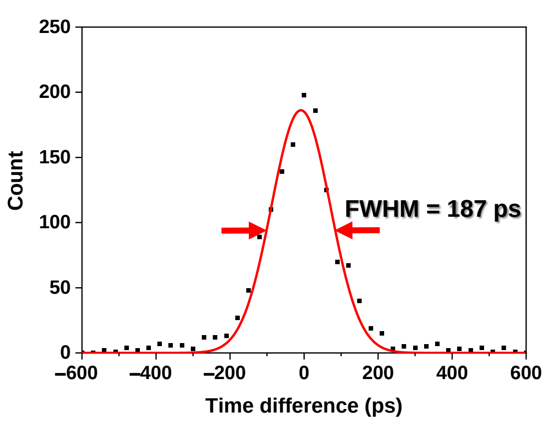


Fig. 4. Time spectrum acquired with a pair of channels. The best average CTR of 187 ps full width at half maximum (FWHM) was measured at the $V_{OVER}$ of 5 V and T1 of 30.

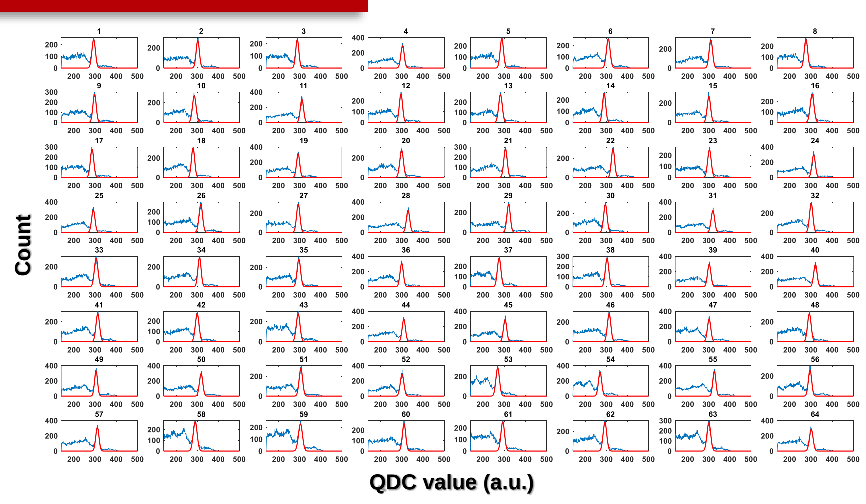


Fig. 5. Representative energy spectra of one of 60 detector modules (64 channels). The average energy resolution of the prototype TOF brain PET was 6.6 ± 0.6% FWHM.

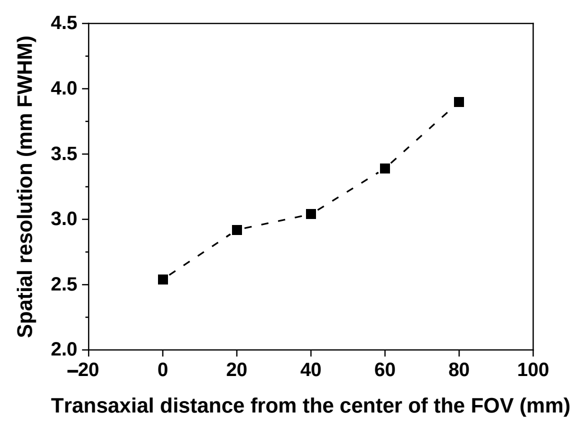


Fig. 6. Spatial resolution of the TOF brain PET as a function of the transaxial distance from the center of the FOV. The transaxial spatial resolution of 2.5 mm FWHM was achieved at the center of the FOV.

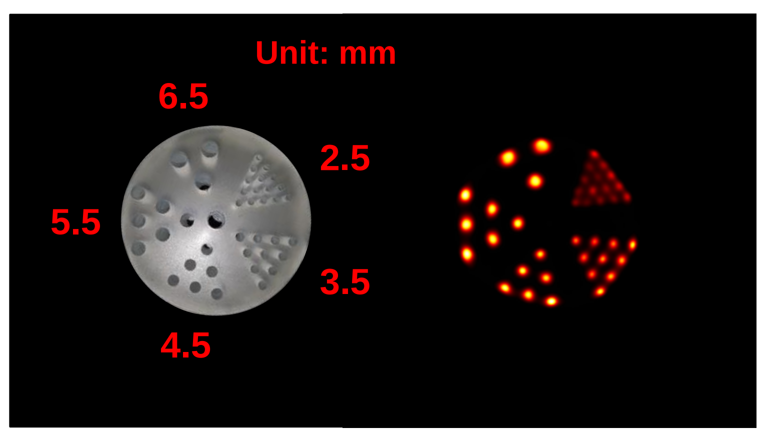


Fig. 7. Transverse slice of the hot-rod phantom image acquired using the TOF brain PET. The rods were clearly resolved down to a diameter of 2.5 mm in the hot-rod phantom image.

## Conclusions

- ❑ We have developed and evaluated the performance of a proof-of-principle TOF brain PET with the geometry optimized for brain imaging by employing a PET detector with optimized optical properties and individual channel readout electronics.
- ❑ The results of this study demonstrate that the developed TOF brain PET could provide excellent performance, allowing for the reduction in radiation dose or scanning time for brain imaging due to improved sensitivity and signal-to-noise ratio.