

PicoPET--An advanced data acquisition architecture for PET imaging

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Outline

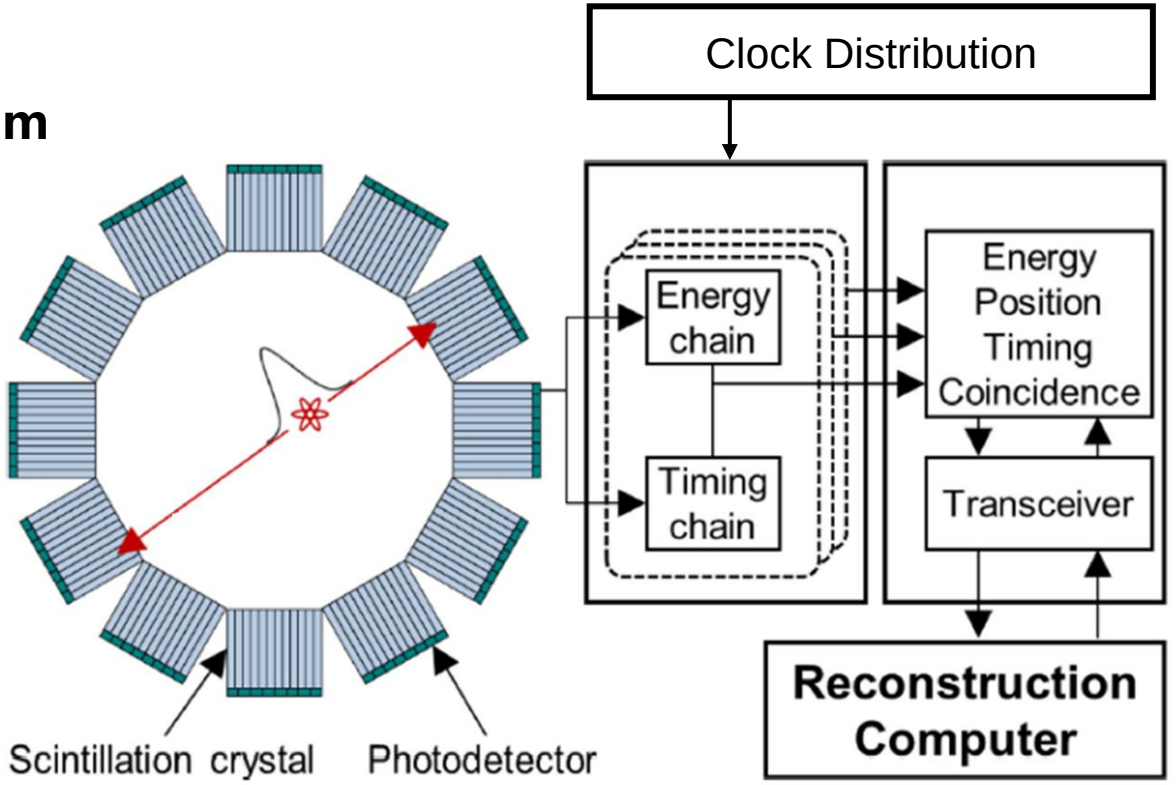
1. Introduction
2. PicoPET architecture and implementation
3. PETs constructed with PicoPET
4. Conclusions and on-going works

Introduction

➢ **Positron Emission Tomography (PET) system**

- Detectors
- Readout electronics

  (energy, timing, crystal decoding)
- Clock distribution and synchronization
- Coincidence processor
- Image reconstruction



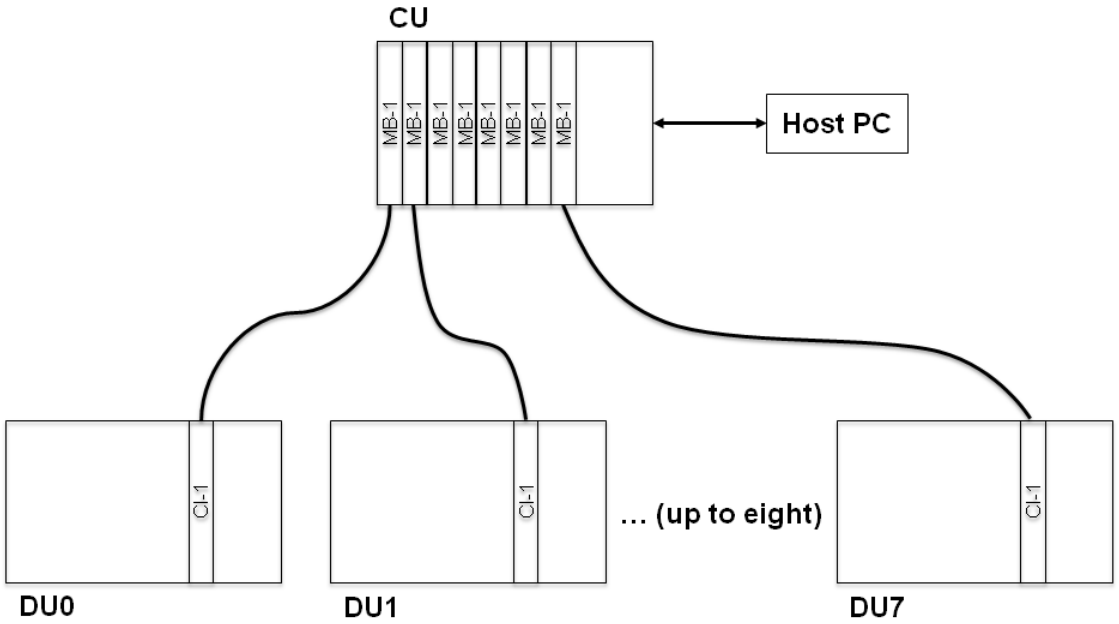
Positron Emission Tomography (PET) system

Won, J. Y. , & Lee, J. S. . (2018). Highly integrated fpga-only signal digitization method using single-ended memory interface input receivers for time-of-flight pet detectors. IEEE Transactions on Biomedical Circuits and Systems, 1-1.

Introduction

➢ **Conventional OpenPET architecture**

- Open source architecture developed by LBNL
- Tree topology
- Detector unit (8 detector boards, 128 channels)
- Coincidence unit (supports up to 8 detector units)
- Host PC (system configuration and image reconstruction)

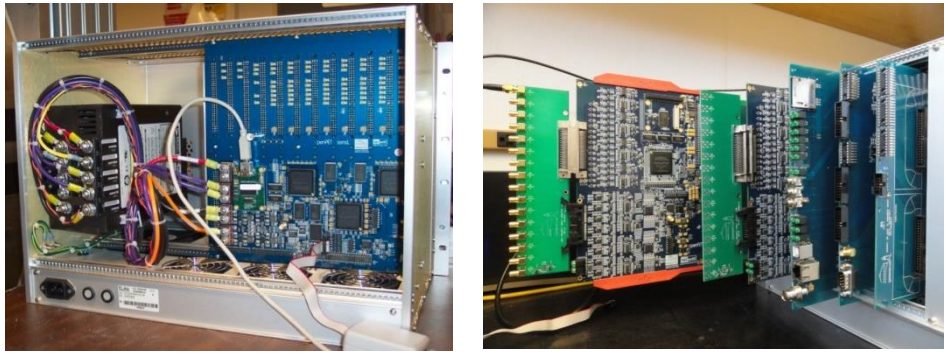


Conventional OpenPET architecture

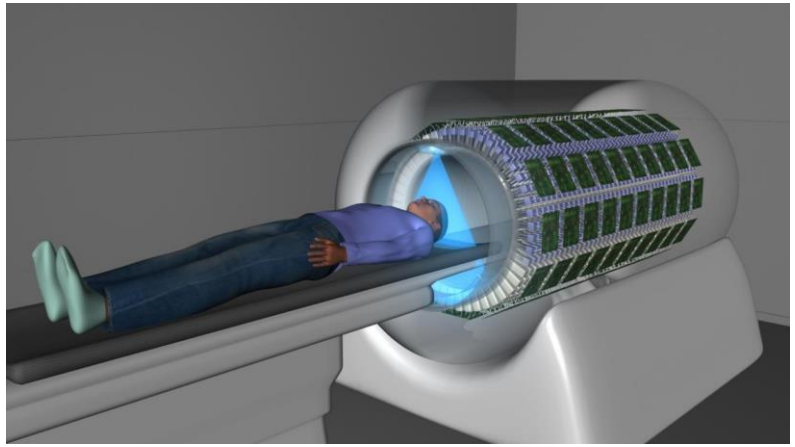
Introduction

➢ **Limitation of the OpenPET architecture**

- Expensive (~$ 30k for 128-ch detector unit)
- Bulky (detector unit: 30 cm x 30 cm x 44 cm in size)
- Power hungry (> 100 W per 128 chs)
- Mainly for PMTs (Not support SiPMs)
- Limited performance (~125ps TDC)
- Not suitable for very large PET systems (e.g. 2-metter explorer PET system)



OpenPET Hardware



2-meter PET system

W.-S. Choong, F. Abu-Nimeh, W. W. Moses, Q. Peng, C. Q. Vu and J.-Y. Wu, “A front-end readout Detector Board for the OpenPET electronics system,” J. Inst., vol. 10, pp. T08002, 2015.

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3. PETs constructed with PicoPET
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Our strategies to overcome the challenges

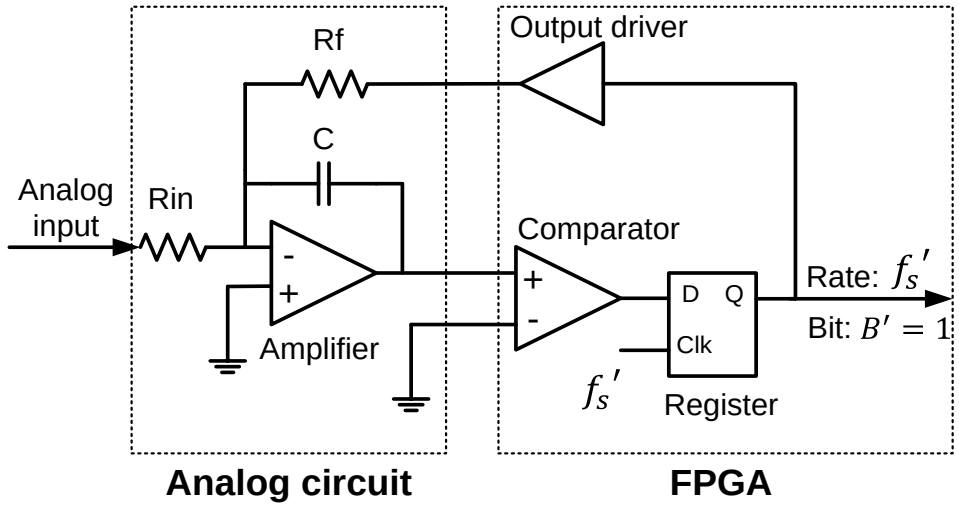
➢ **Challenges**

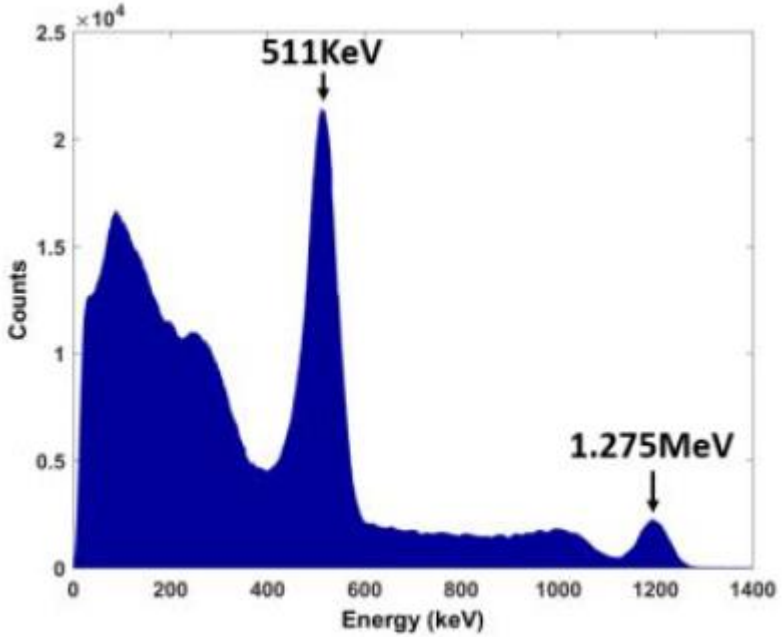
- Low-cost, compact, low power consumption
- Support different detectors (PMTs and SiPMs from different vendors)
- High performance (10ps timing resolution)
- Scalable for very large PET systems (e.g. 2-metter explorer PET system)

➢ **Our Strategies :**

- Implement almost all functions of the front-end readout (ADC, TDC etc.) in a FPGA (PicoPET module)
- A combination of tree topology and daisy-chain topology is adapted to link multiple PicoPET modules to construct PET systems.

ADCs and TDCs implemented in FPGAs



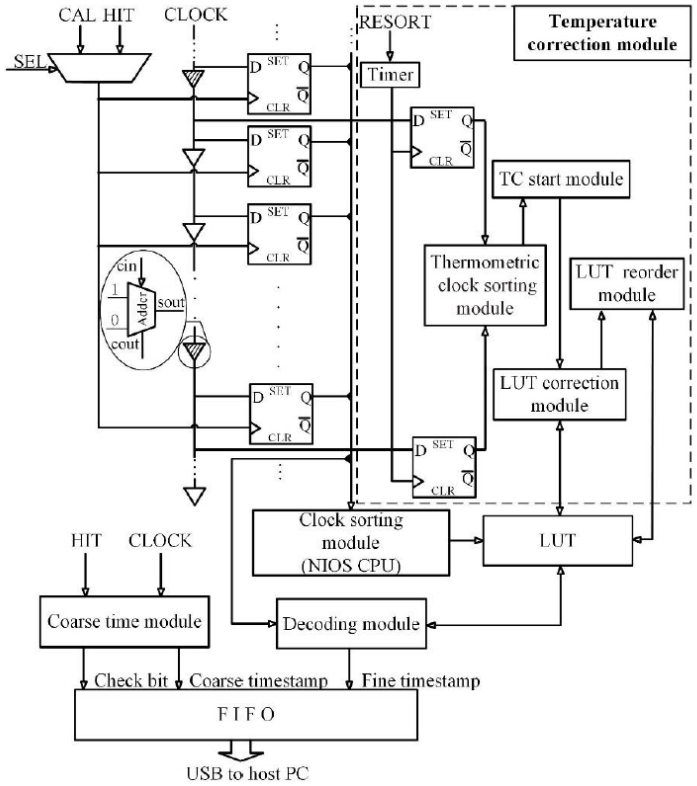


Energy: high-performance 1-order, 1-bit over-sampled delta-sigma ADC

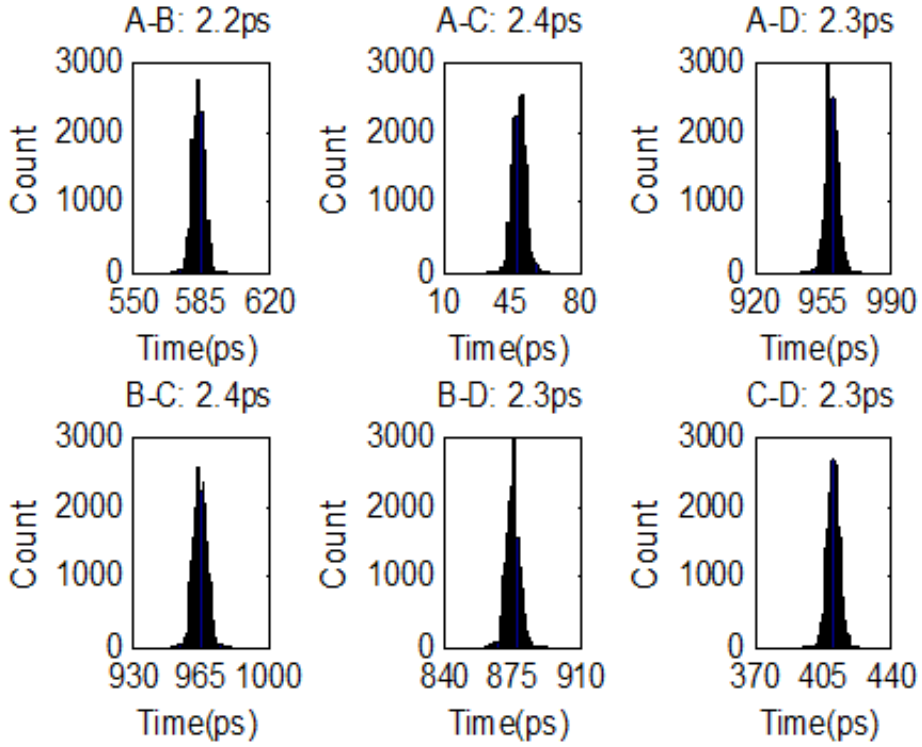
Typical energy spectrum (^{22}Na shone on a detector constructed with LYSO and SiPM)

Z. Zhao, Q. Huang, Z. Gong, Z. Su, W.W. Moses, J. Xu, Q. Peng . A novel read-out electronics design based on 1-bit sigma-delta modulation. IEEE Transactions on Nuclear Science. Volume: 64, Issue: 2, Feb. 2017. Page: 820 – 828

ADCs and TDCs implemented in FPGAs



Nonuniform multiphase (NUMP)TDC implemented in a FPGA

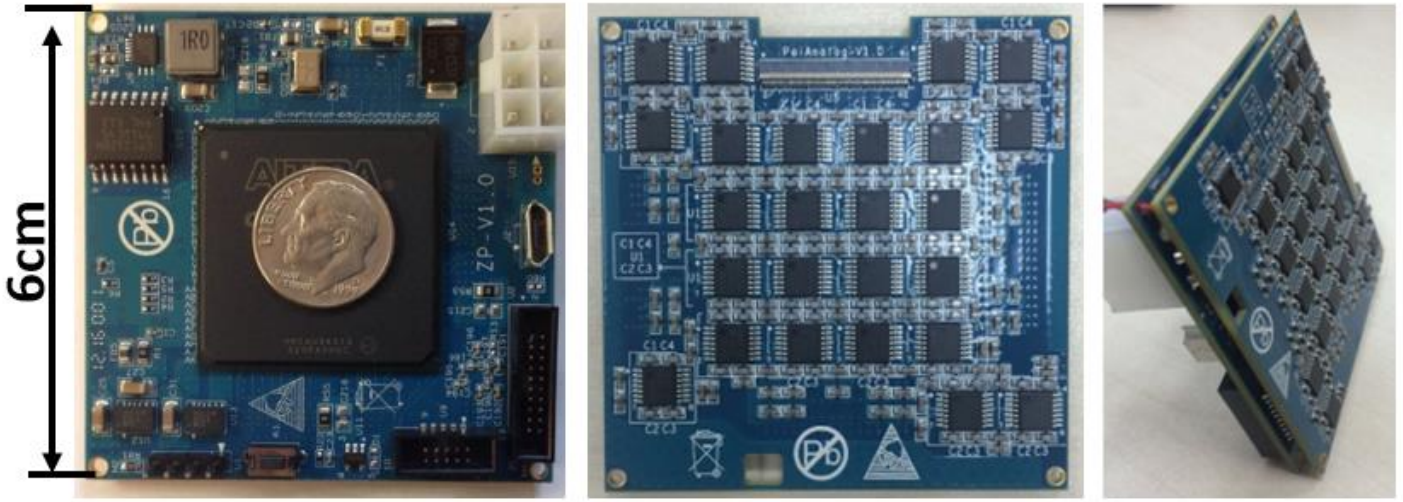


Typical results: 2.3-ps RMS timing resolution

Tengjie Sui, Zhixiang Zhao, Siwei Xie, Yangze Xie, Yanyan Zhao, Qiu Huang, JianFeng Xu, and Qiyu Peng. A 2.3 ps RMS Resolution Time-to-Digital Converter Implemented in a Low-Cost Cyclone V FPGA. IEEE Transactions on Instrumentation & Measurement. Date of Publication: 13 December 2018

PicoPET FPGA modules

- **Features of version 1.0**
- Read 100 individual SiPMs in parallel
- Compact: 6 cm x 6 cm x 0.88 cm
- Low-power consumption: 3~5 W

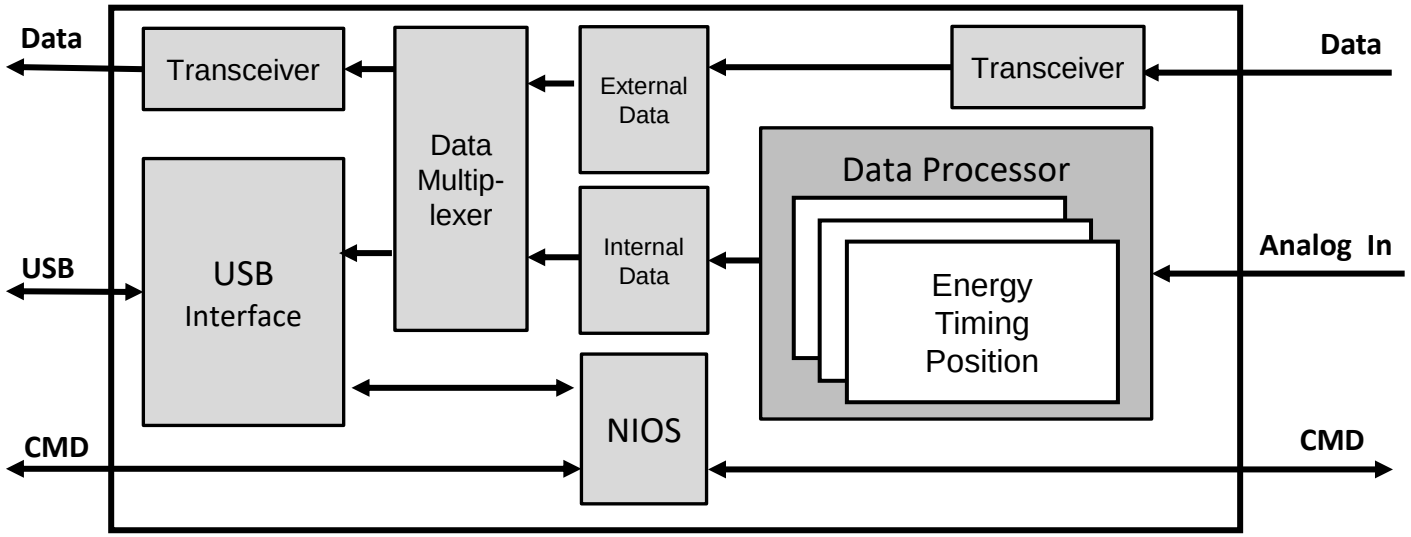


Zhixiang Zhao, Siwei Xie, Xi Zhang, Jingwu Yang, Qiu Huang, JianFeng Xu, and Qiyu Peng. An Advanced 100-Channel Readout System for Nuclear Imaging. IEEE Transactions on Instrumentation & Measurement. Date of Publication: 15 November 2018.

PicoPET FPGA modules

➢ **Firmware framework**

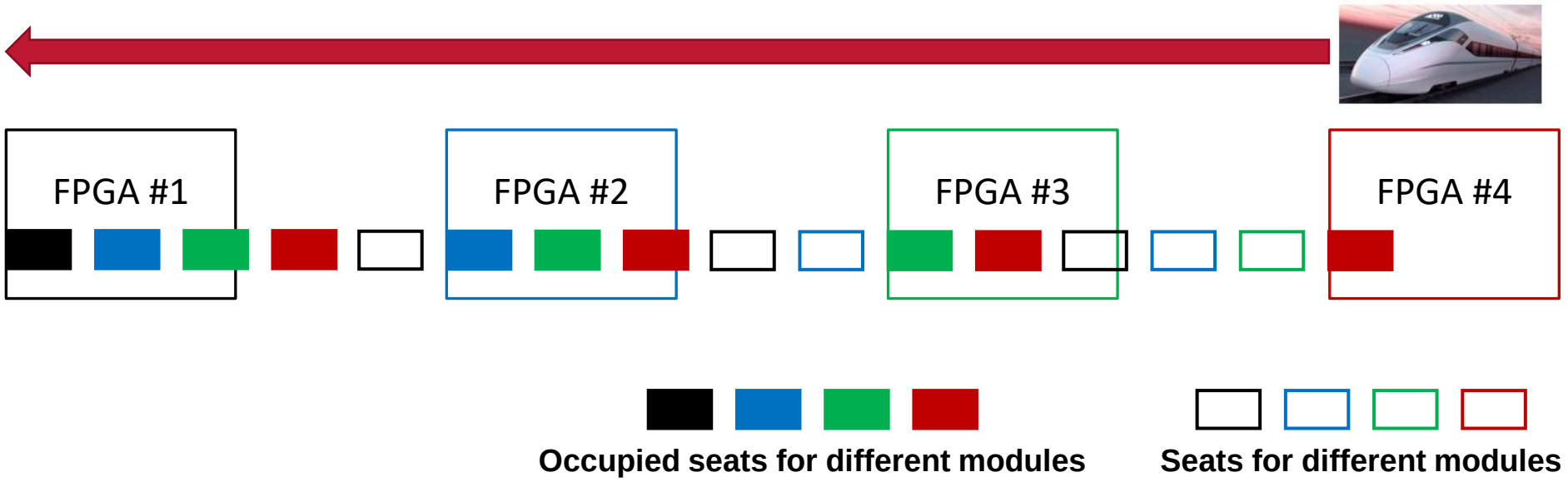
- Standalone smart module with excellent energy and timing performances
- High-speed (up to 12.5Gbs) bi-directional data streams



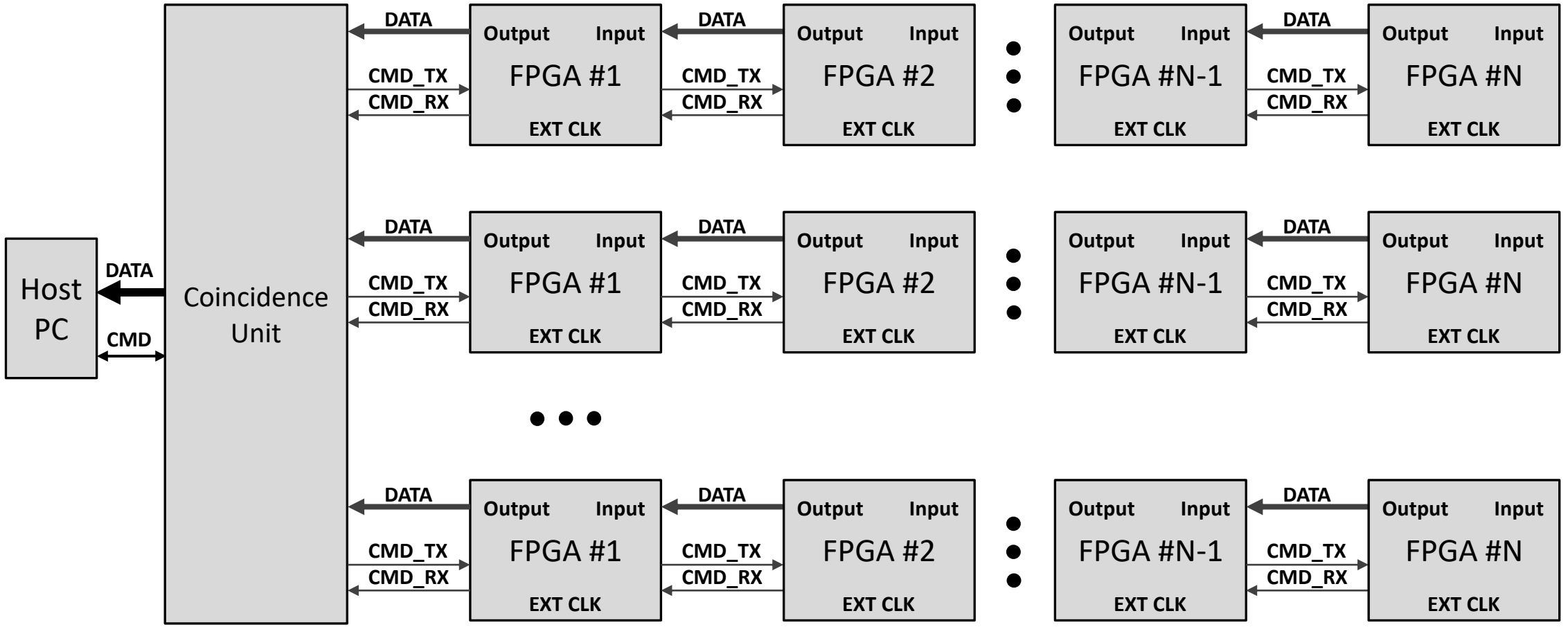
PicoPET FPGA modules linked using daisy-chain topology

- **It works like a high-speed train system**
- Train stations: FPGA modules
- Passengers: event data
- Features: high-speed, efficiency, reliable and scalable

Schematic diagram of a 4-module daisy-chain



Combination of tree topology and daisy-chain topology



Multiple daisy-chain structure for large system

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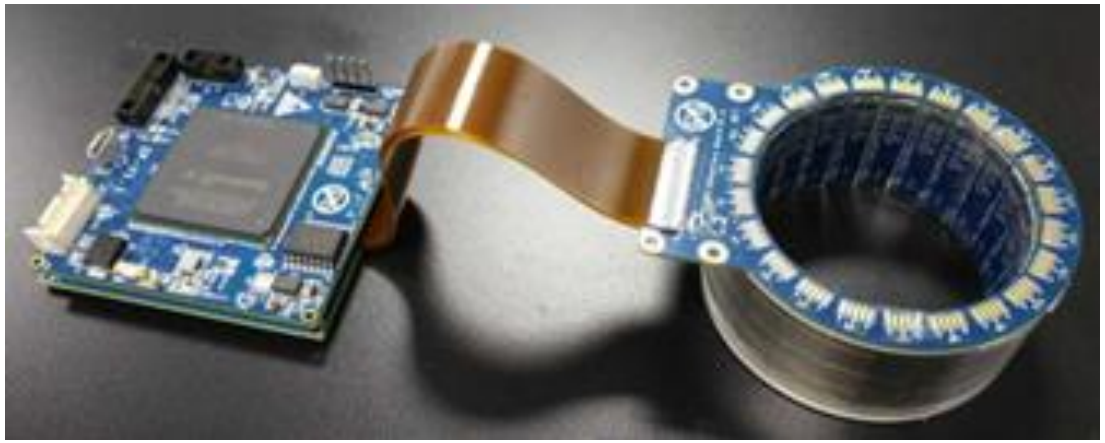
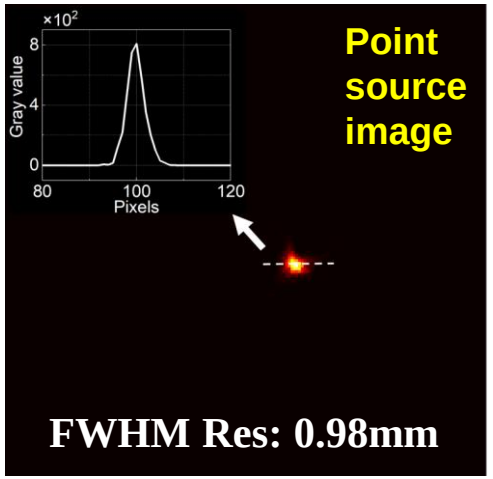
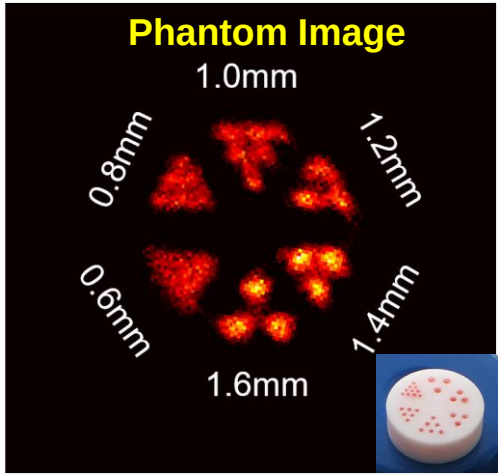
A system with a single PicoPET FPGA module

- **A portable small animal PET imager**
- A LYSO monolithic scintillator ring and 92 SiPMs
- Diameter: 48.5 mm; axial length: 25.1mm
- Weight：~200g
- Power consumption: 5W



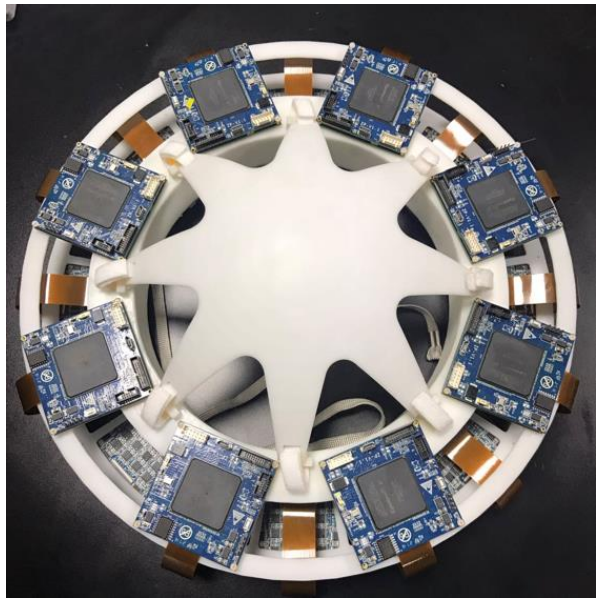


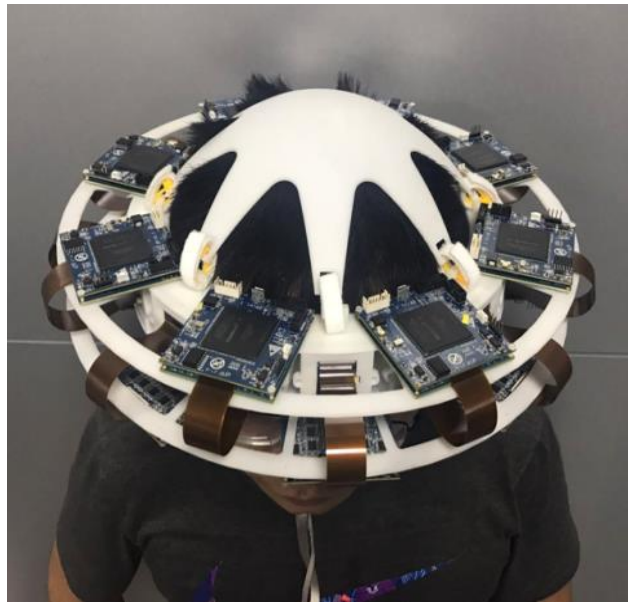


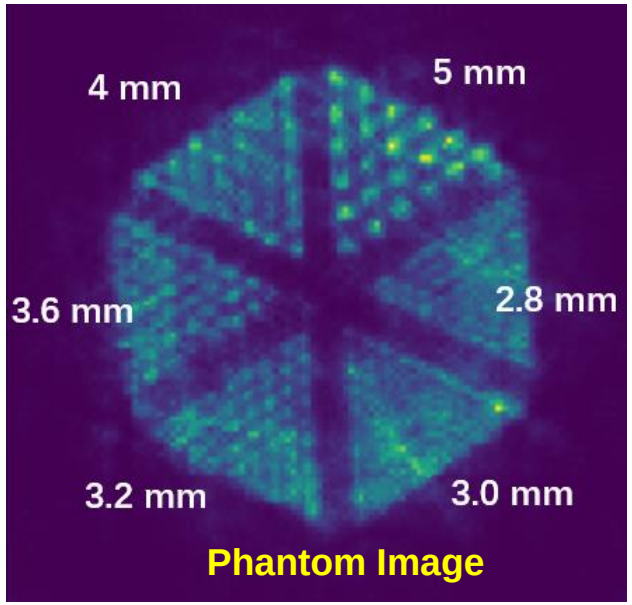
Xu J, Xie S, Zhang X, Tao W, Yang J, Zhao Z, Weng F, Huang Q, Yi F, Peng Q. A preclinical PET detector constructed with a monolithic scintillator ring. Physics in Medicine and Biology. 64(15): 155009 (12 pages), August 6, 2019.

A system with a chain of 16 modules

- **A wearable brain PET system**
- Diameter: 20 cm; Axial length: 33.6 mm
- 1600 SiPMs read by 16 PicoPET modules
- Weight：3.3 kg



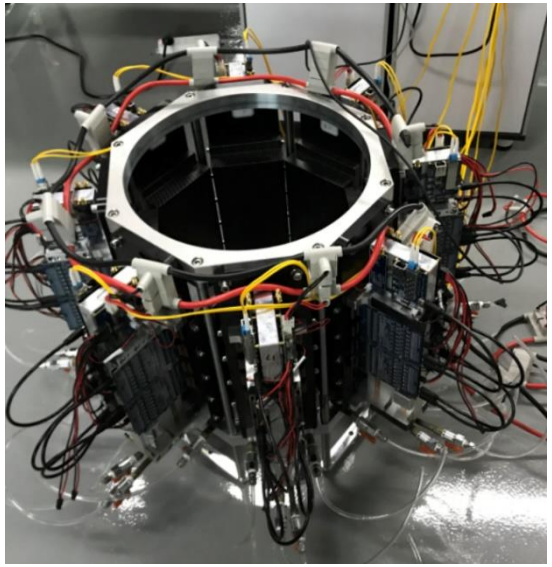


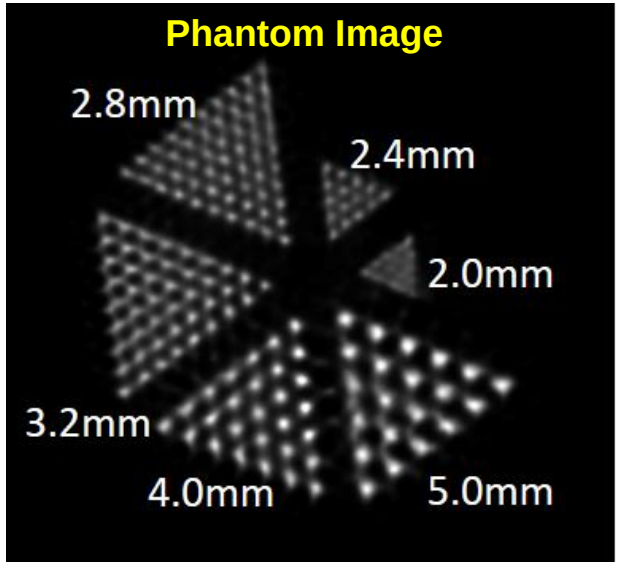


Mind-Tracker PET: A wearable PET camera for brain imaging. J. Xu, Z. Zhao, S. Xie, D. Shi, Q. Huang, and Q. Peng (NSS/MIC 2017)

A system with 8 chains of 4 modules

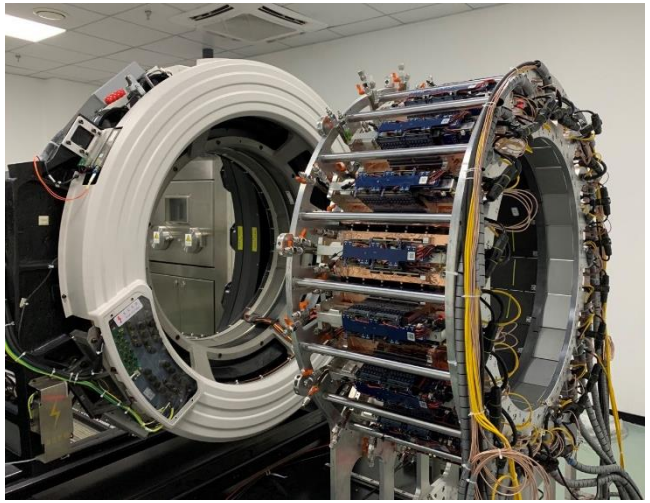
- **A high-performance brain PET system**
- Diameter: 30 cm; Axial length: 16 cm
- 3456 SiPMs read by 32 PicoPET modules (8 chains, 4 modules per chain)
- 247ps timing resolution

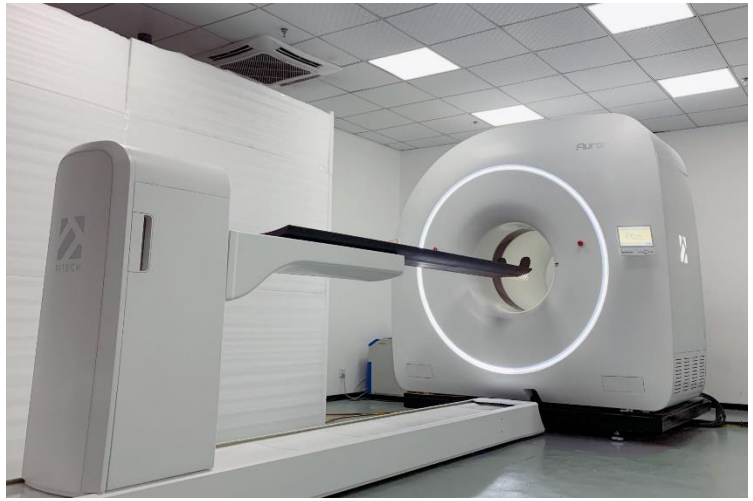


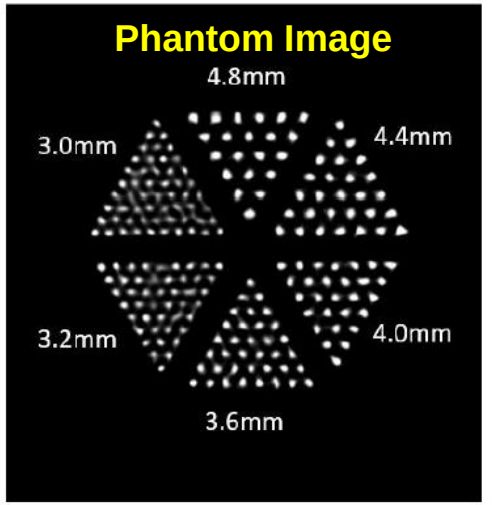


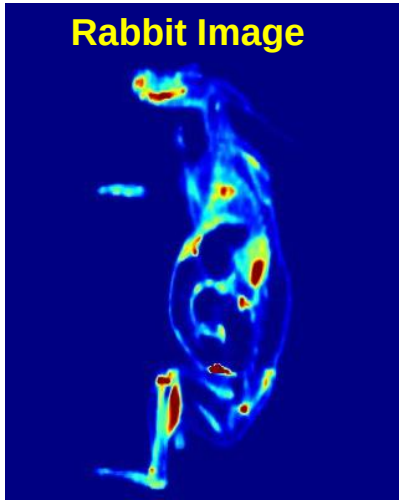
A system with 20 chains of 6 modules

- **A high-performance whole-body TOF-PET system**
- Diameter: 80 cm; Axial length: 24 cm
- 12960 SiPMs read by 120 PicoPET modules (20 chains, 6 modules per chain)
- ~250ps timing resolution









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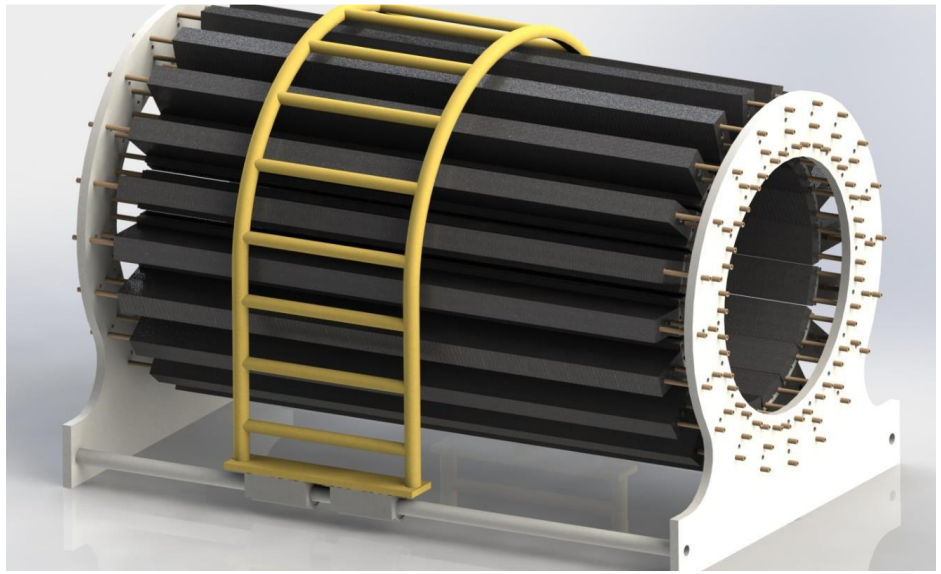
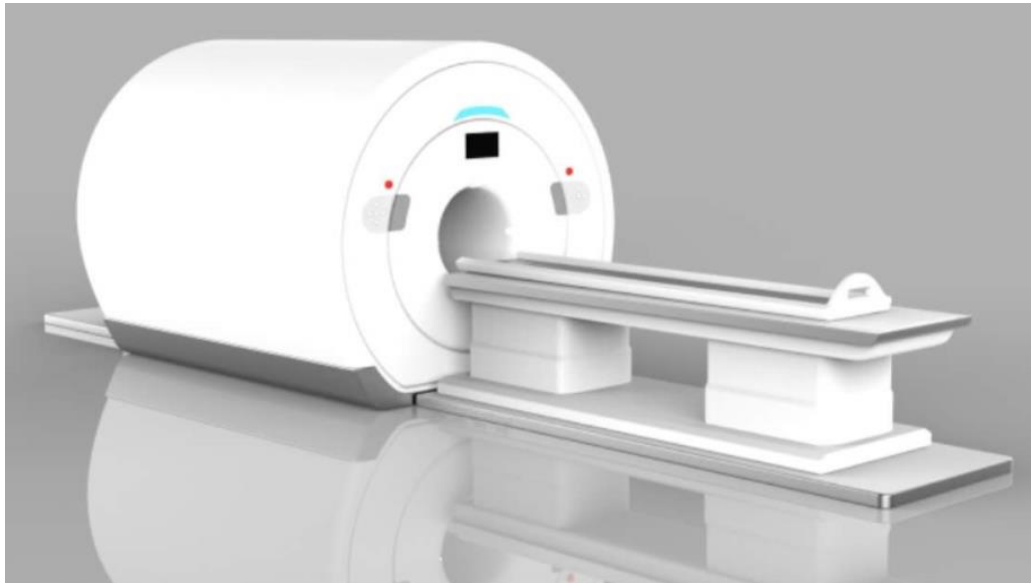
A system with 80 chains of 12 modules (under construction)

- **A 2-meter total-body TOF-PET system (under construction)**
- Diameter: 80 cm; Axial length: 2 m
- 103,680 SiPMs read by 960 PicoPET modules (80 chains, 12 modules per chain)
- Targeted timing resolution: 250ps





Summary and conclusions

➢The two major features of the PicoPET electronics system are

- Almost all functions of the front-end readout (ADC, TDC etc.) are implemented in a FPGA (called PicoPET module);
- A combination of tree topology and daisy-chain topology is adapted to link multiple PicoPET modules to construct PET systems with different scales.

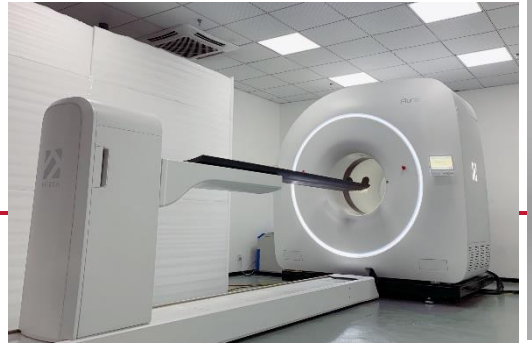
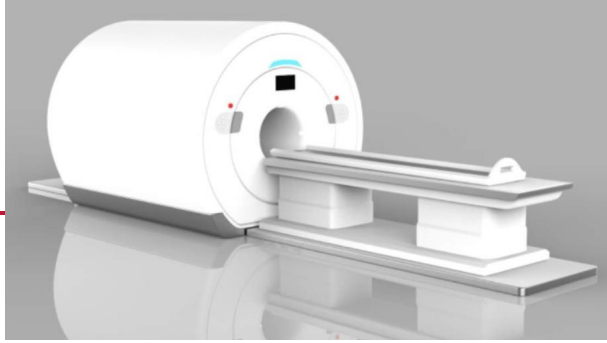
➢The PicoPET have been successfully deployed in 4 PET systems.

- The smallest system only used one PicoPET module.
- The largest system were constructed with 20 chains of 6 PicoPET modules.
- We are currently constructing a 2-meter PET system using 960 PicoPET modules (80 chains, 12 modules per chain) to read out 103,680 SiPMs.

➢ Conclusions

- The PicoPET is a new generation of low-cost, high-performance, compact, scalable and reliable electronics system for the development of advanced PET cameras.



Thank you!