State-of-the art electronics for PET scanners and other applications

PSMR2024 – Elba Italy, May 2024

- **Microelectronics:**

  - ASICs reading and digitizing fast signals from SiPMs, MCPs, etc.

  - Radiation tolerant ASICs

  - IP blocks: amplifiers, discriminators, charge integrators, DACs, ADCs and TDCs

- **Readout systems**

  - Front-end electronics boards interfacing to sensors

  - Data acquisition and system control (including firmware and software)

  - Complete readout solutions, scalable up to hundred thousands electronics channels

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Electronics

Main Features:

- Digitizes time and amplitude of SiPM signals
- 64 independent channels in 5x5 mm^2
- Accepts positive and negative signal polarity
- Noise 1.2 -1.5 mV -> 1 p.e. 30 mV
- Charge integration: 10 bit
- TDC time binning: 30 ps
- Low power : 4 - 8.2 mW / Channel
- Event rate: up to 500 kHz per channel
- On-chip calibration circuitry
- Generates digital event record every time the trigger conditions are fulfilled
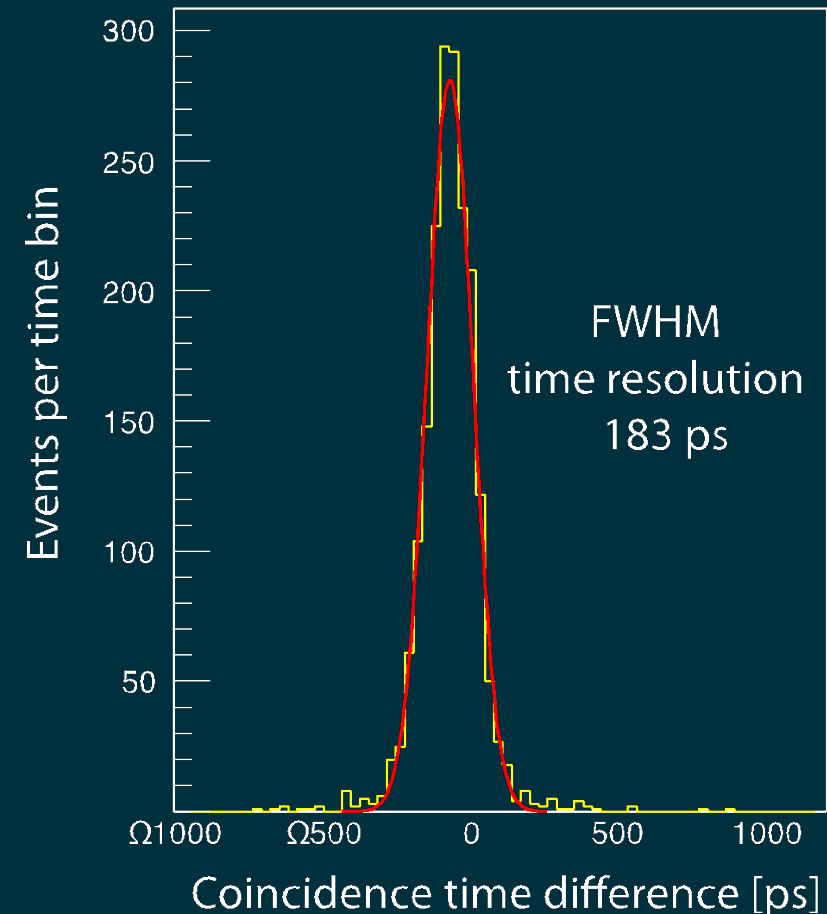
PETsys
Electronics
10 years
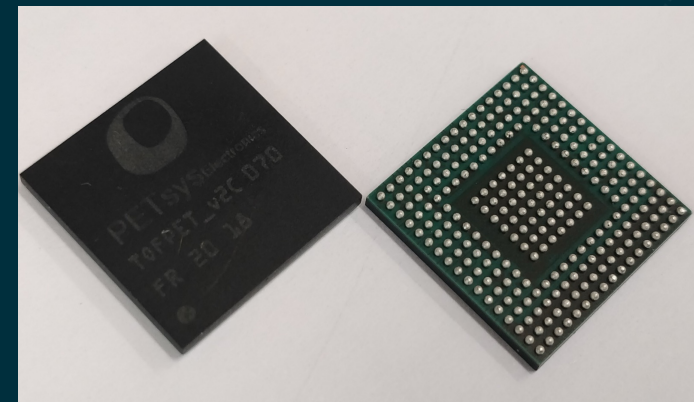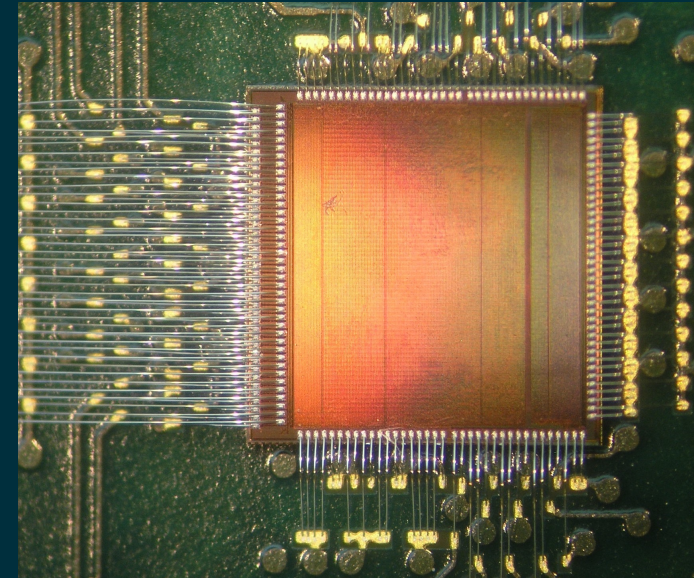
TOFPET2 time resolution (CTR)
LYSO 2x2x3 mm^3 : 119 picoseconds

- Hamamatsu MPPC S13361-3050AE-04
- LYSO:Ce,Ca 2x2x3 mm^3
- 3 V over-voltage
- 4 p. e. threshold
- 15 °C
- Na22 Gamma source

FWHM
time resolution
119 ps

PETsys Electronics — 10 years
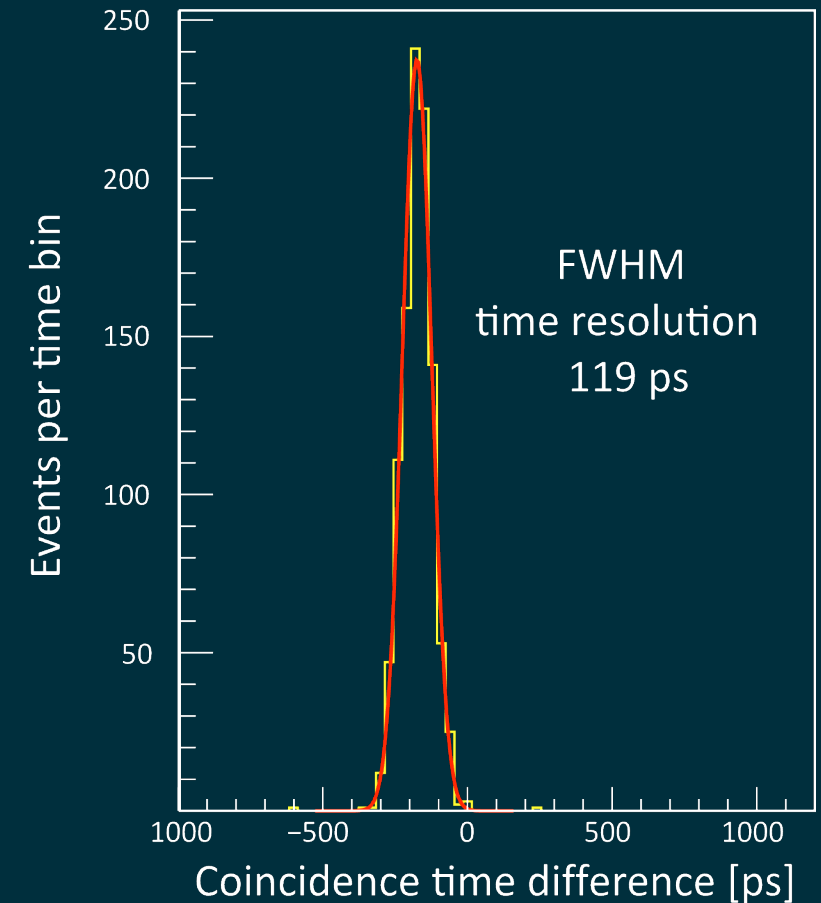
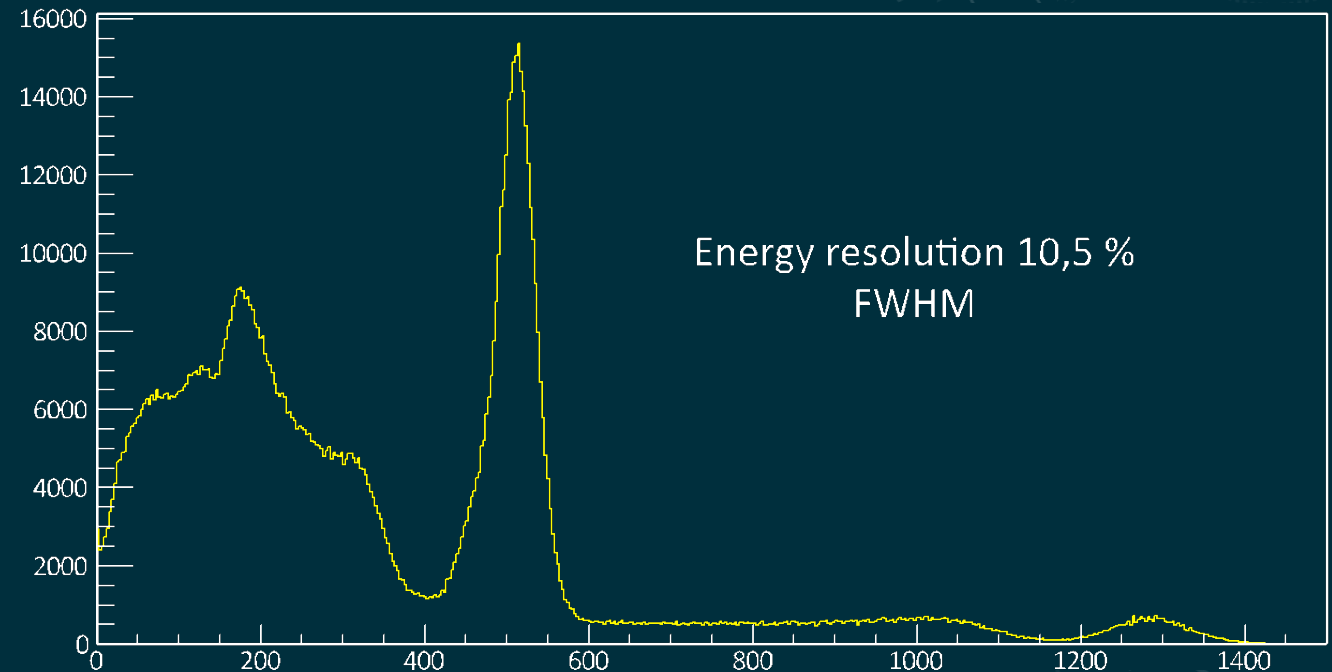## TOFPET2 time resolution (CTR)
LYSO 3x3x20 mm³ : 183 picoseconds

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- LYSO:Ce,Ca 3x3x20 mm³
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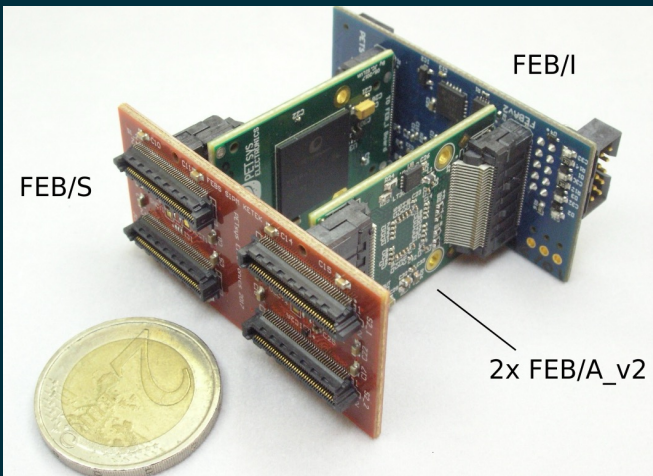- 15 °C
- Na22 Gamma source

FWHM
time resolution
183 ps

Events per time bin

Coincidence time difference [ps]

PETsys Electronics
10 years

Energy resolution: 10,5%

Na22 point source
LYSO: 3 x 3 x 5 mm^3
KETEK-PM3325_WB SiPM

Corrected for SiPM non-linearity

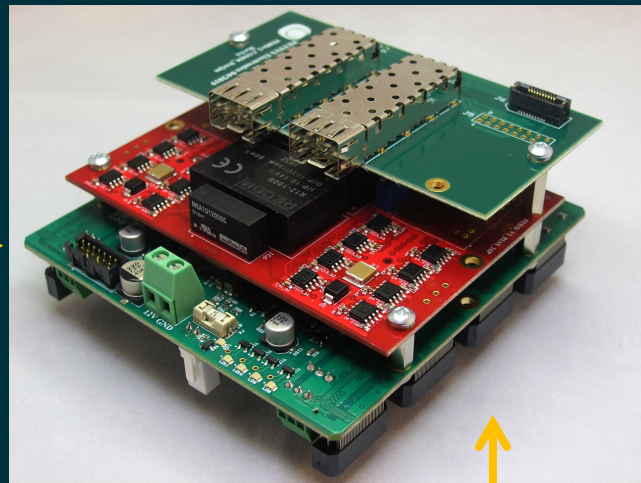Energy resolution 10,5 %
FWHM

PETsys Readout System

Readout solutions for PET Imaging scanners and other SIPM-based applications

Front-end module FEM-128

FEB/I

FEB/S

2x FEB/A_v2

Up to 8x

FEB/D-1k module

Up to 16x

PCIe DAQ module

Up to 16x FEB/Ds
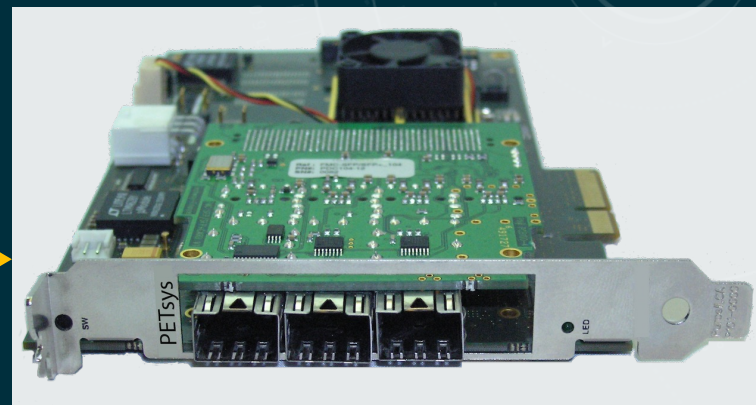
CLK & TRG module
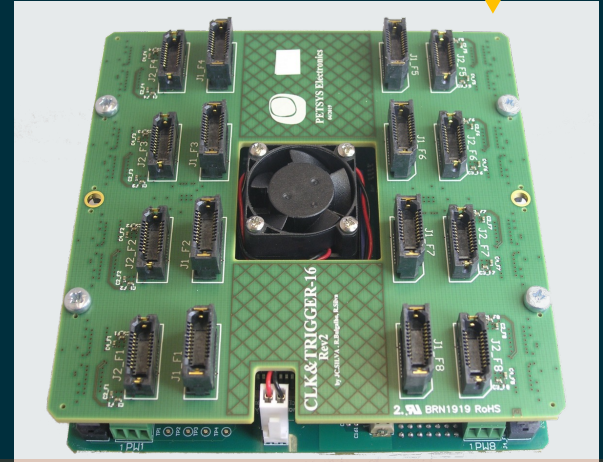
PETsys
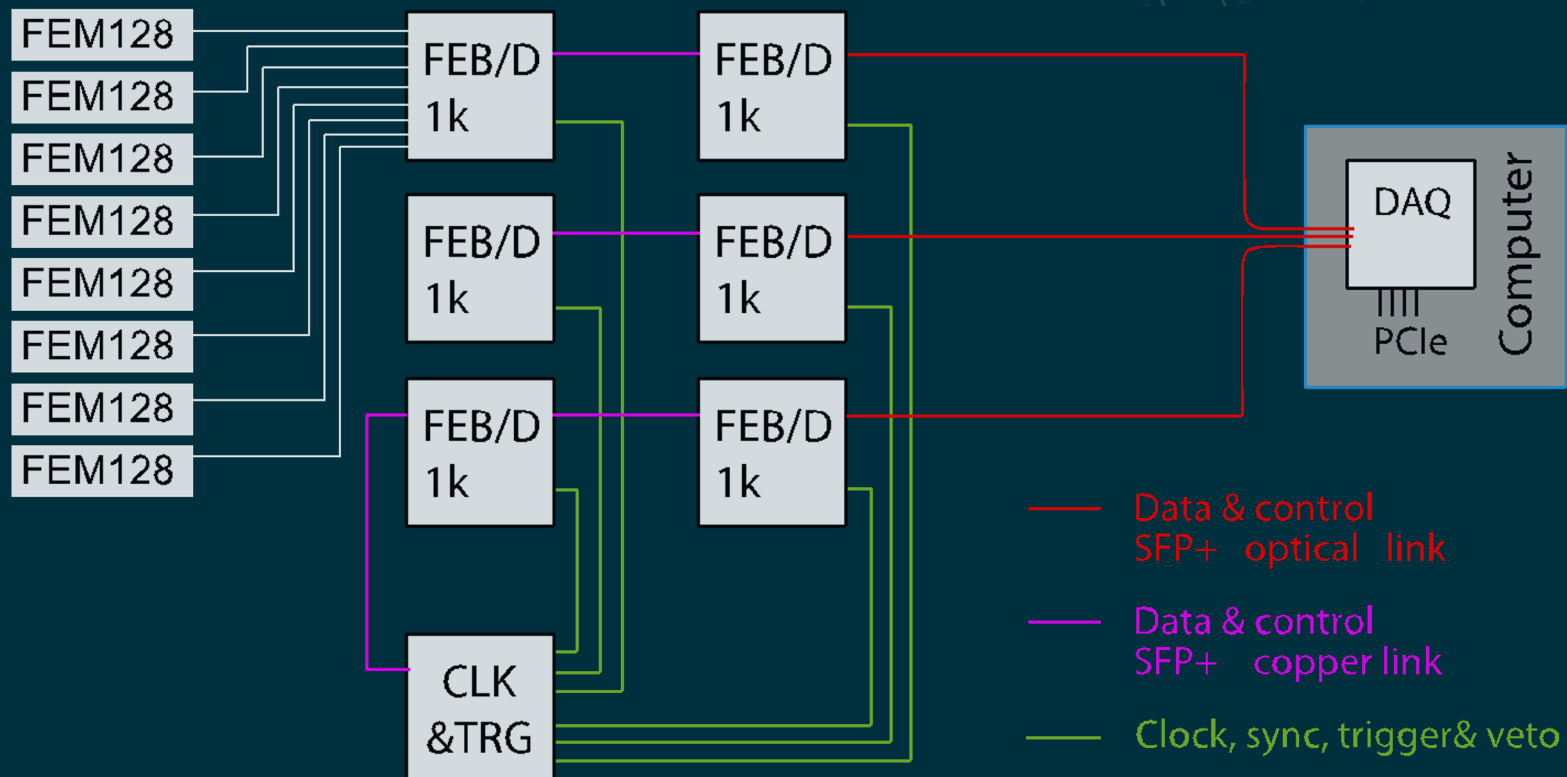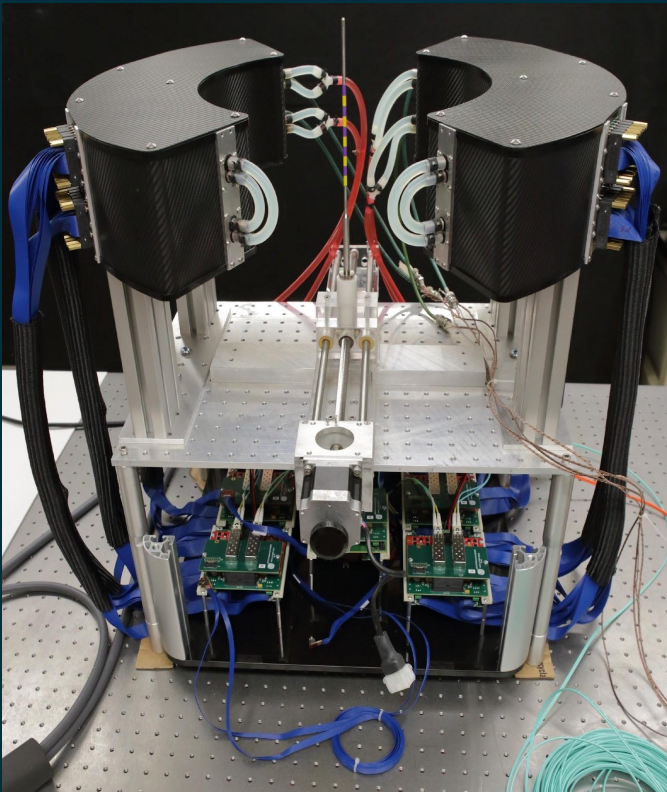Electronics
10 years

Example of a readout system for a PET scanner with up to 16'384 channels

- Each FEB/D-1k module controls 16 ASICs in 8 FEM128

- The CLK&TRG module allows coincidence selection in the firmware

- The DAQ card receives and transfers the digital data to the computer

— Data & control SFP+ optical link

— Data & control SFP+ copper link

— Clock, sync, trigger& veto

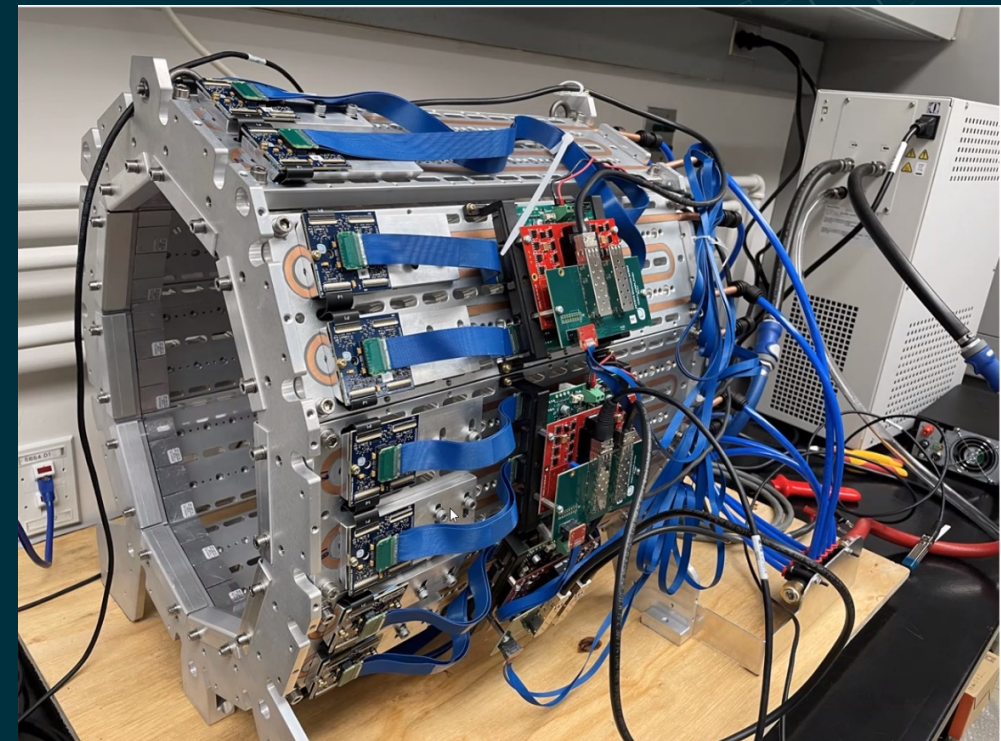**PETsys Electronics** — 10 years

PET for proton therapy UT Texas

TPPT Consortium, IEEE NSS MIC RTSD, 2022, MIC-04-385

Brain PET at Cornell University

Zeng, X, Wang, Z, Tan, W, et al., Med Phys. 2023; 50: 3401–3417

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Preclinical PET in Japan

National Institute for Quantum and Radiological Science and Technology

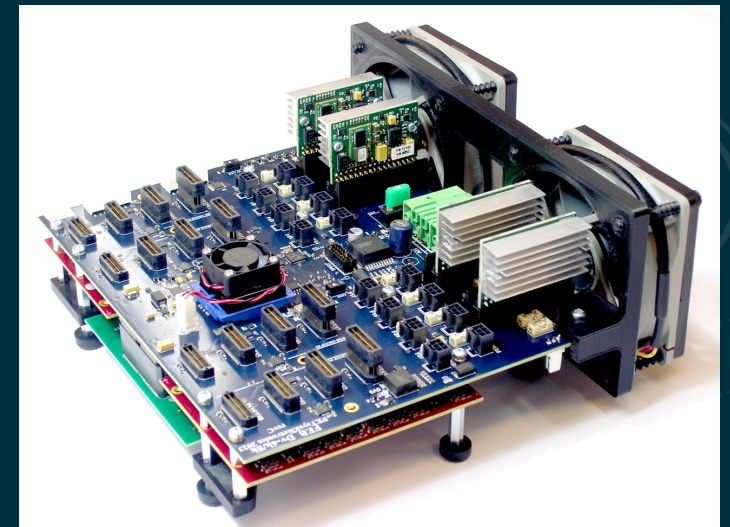## Brain PET in South Korea
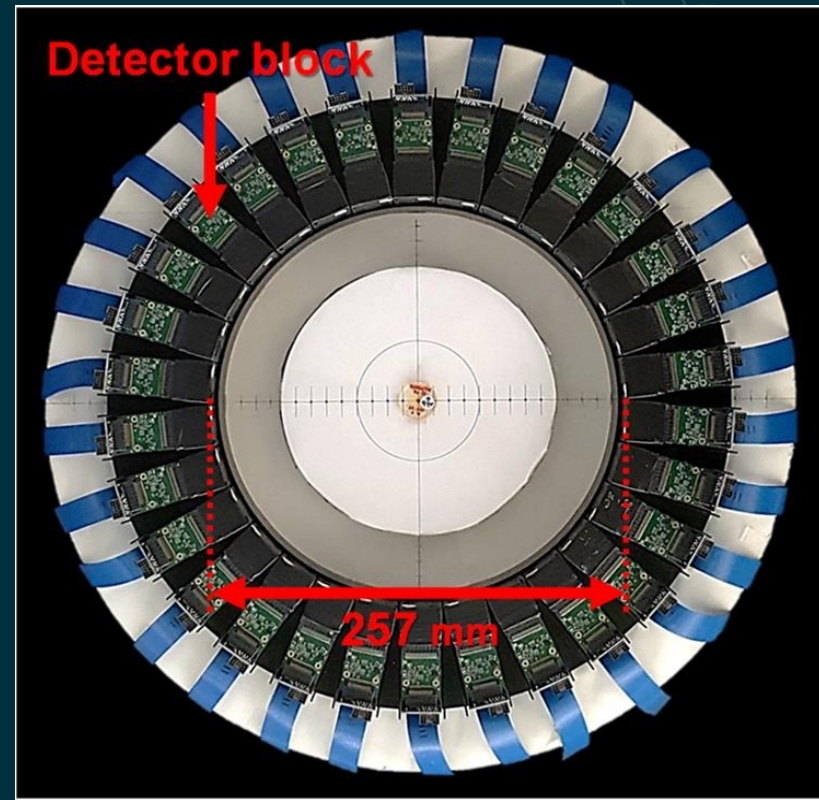
Park, K.; Jung, J.; Choi, Y.; Leem, H.; Kim, Y.. Sensors 2021, 21, 5566
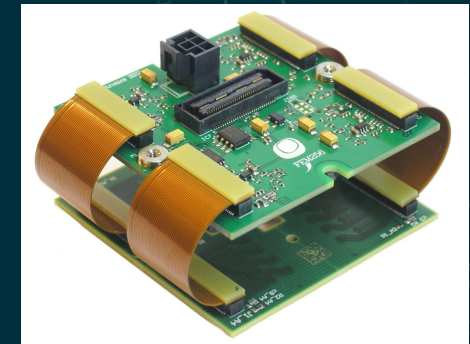
FEM-256 module

	FEB/D-1K		FEB/D-8K		
	FEM-128	FEM-256	FEM-128	FEM-256	FEM-512*
Max # of FEMs per FEB/D	8	4	16	16	16
Max # of channels per FEB/D	1024	1024	2048	4096	8192
Max # of FEB/Ds	16	16	16	16	16
Max # of channels	16384	16384	32768	65536	131072
Max data rate per 1 FEM (Mcps)	40	40	40	40	40
Max data rate per FEB/D (Mcps)	100	100	100	100	100
Max data rate per DAQ card **	230	230	230	230	230

* To be developed under request.
** Max rate can be extended using more DAQ cards. Tested with 2 DAQ cards up to 400 Mcps.

FEB/D-8k module

Readout for a PET scanner with up to 131'072 channels

- Each FEB/D-8k module controls and reads up to 128 ASICs.

- Needs FEB/D-8K and FEM256 (available) or FEM512 (development under request).

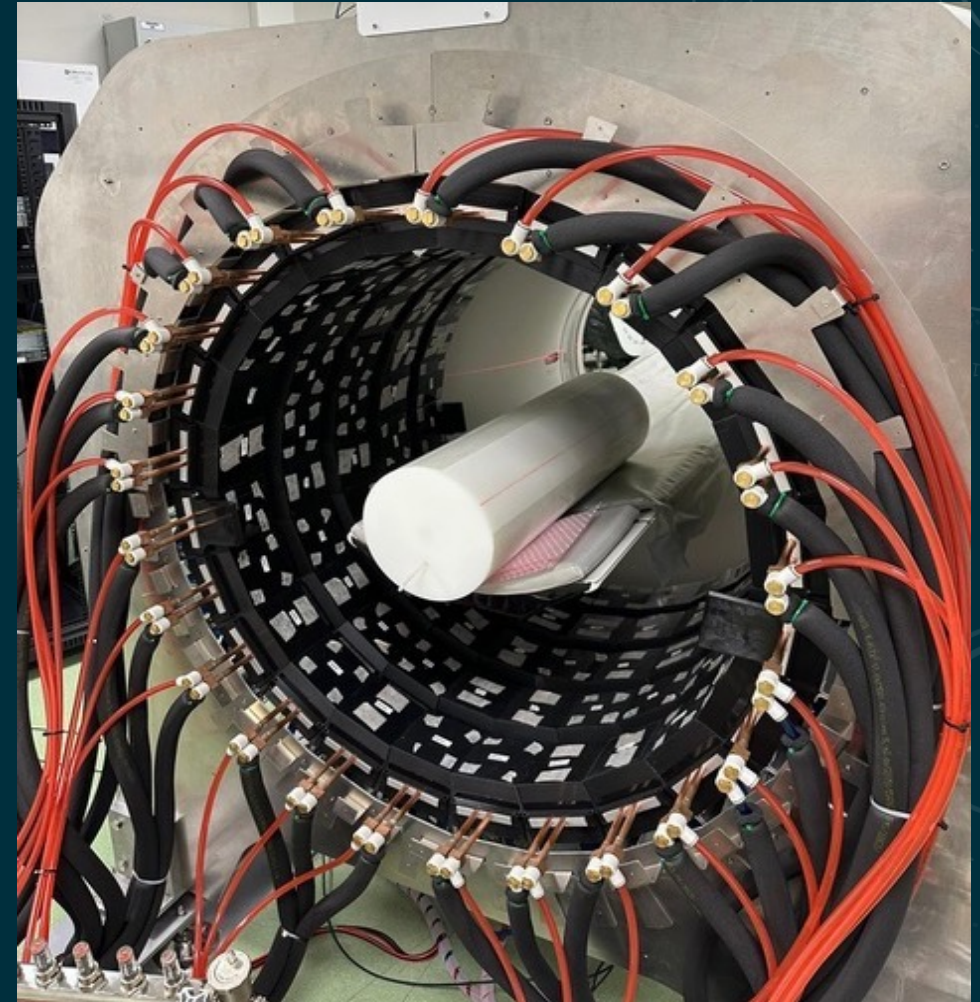- It is possible to use several DAQ boards to handle larger total data rates.
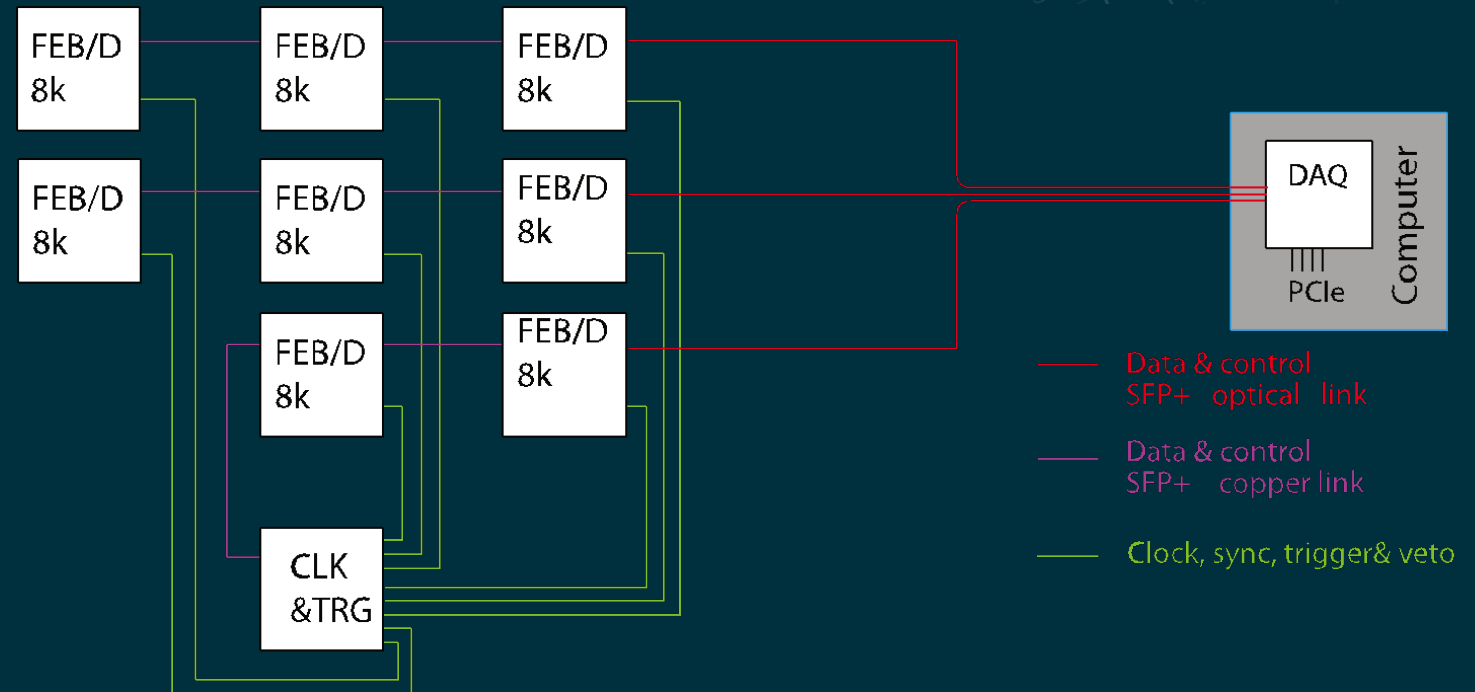
With 64 channel CLK-TRG board, the system could be expanded up to 524'288 channels

**IMAS Total-Body PET Scanner (I3M Valencia, Oncovision):**

30'720 electronic channels

- Presented at IEEE NSS/MIC 2023

See presentation by Antonio Gonzalez at this conference

- PETsys provides **coincidence filtering** in firmware, reducing the data rate to the DAQ computer by at least an order of magnitude.

- PETsys also provides DAQ Software allowing to **control, monitor and calibrate the system.** The DAQ software produces the data (channel, timestamp and charge) for list mode.

- ASIC calibration, configuration and data acquisition are controlled with a **Python/C++ API** and execution programs are provided for automation and scripting.

- There is also an easy-to-use **graphical user interface**, controlling the same commands and system temperature monitoring.

New developments

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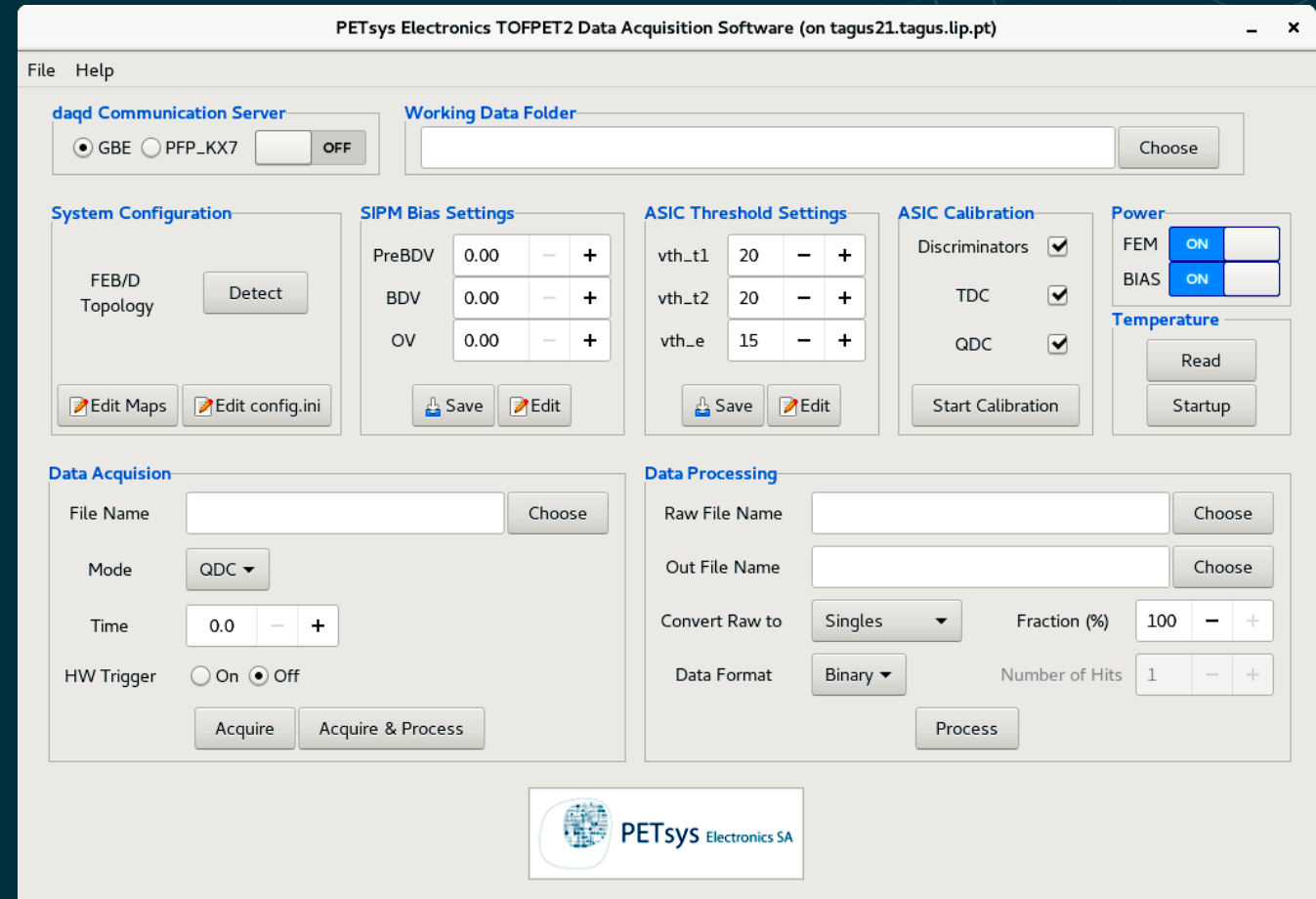
10 years

- **New ASIC in the TOFPET series suited for high performance applications:**

  - 64-channel analog front-end with baseline stabilization, pulse tail cancelation, dark noise rejection and gain configuration
  - Three 10-bit digitization per event (2 TDC, 1 QDC)
  - New timing and energy circuits with outstanding performance
    - TOFPET3 contribution to CTR: 24 ps FWHM
    - Energy measurement (3000 pe, G=3.5e6) with non-linearity of 1% and resolution of 1.1% (photopeak 511keV)
  - Four additional channels with sums of 16, 32 or 64 cannels (configurable)
  - Advanced triggering features: selective readout of group of channels seeded by energy of one channel
  - Max event rate per channel 500 MHz, Output rate 3.8 Gb/s
  - Low power consumption

Evaluation-kit available in the fall 2024.

*See presentation at this conference*

- **New DAQ card with PCIe gen3 x16:**
  - Up to 1.8 Gcps -14.4GB/s (8x more than the currently available DAQ card).
  - 20 individual links to FEB/D.

- Mezzanine with QSFP to SFP or QSFP to fiber optics: maintains full compatibility with existing systems.

- 4x SFP to maximize FEB/D throughput allowing up to 400 Mcps from a single FEB/D.

- QSFP connector also under development.
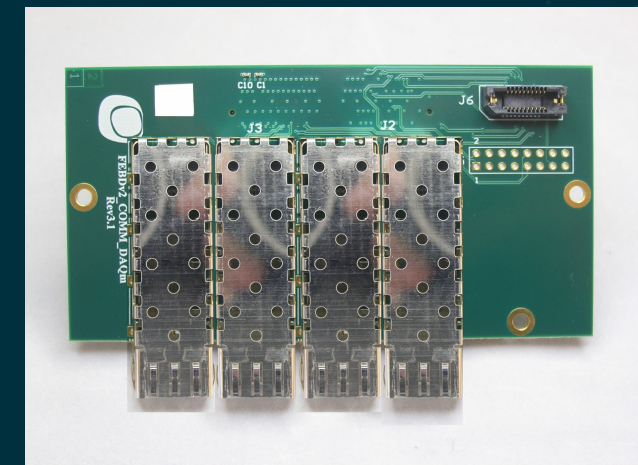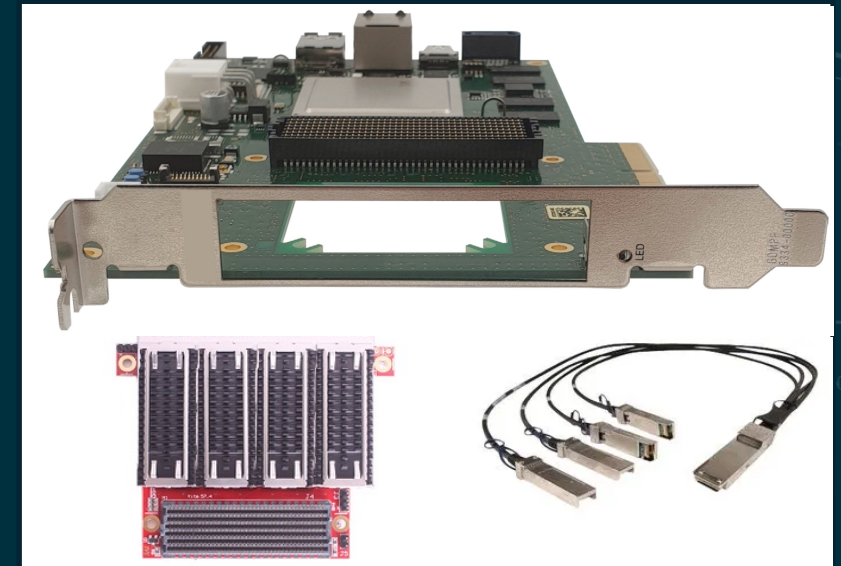
- CERN/CMS TOFHIR ASIC, 2019-2023

- CMS (CERN) Industrial Award, 2023

- TPPT project (TOF PET for Proton Therapy), 2020-2023

- R&D Project with GE (USA) for PET, 2021-22

- R&D demonstrator project with EU/PT2020 support

- 3 Seals of Excellence from the European Commission, 2016-2017

- Selected to the Web Summit 2016 (Lisbon)

- Award winner at the European Venture Contest 2015 (European Commission)

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10 years

Evolution of Sales 2013-2023
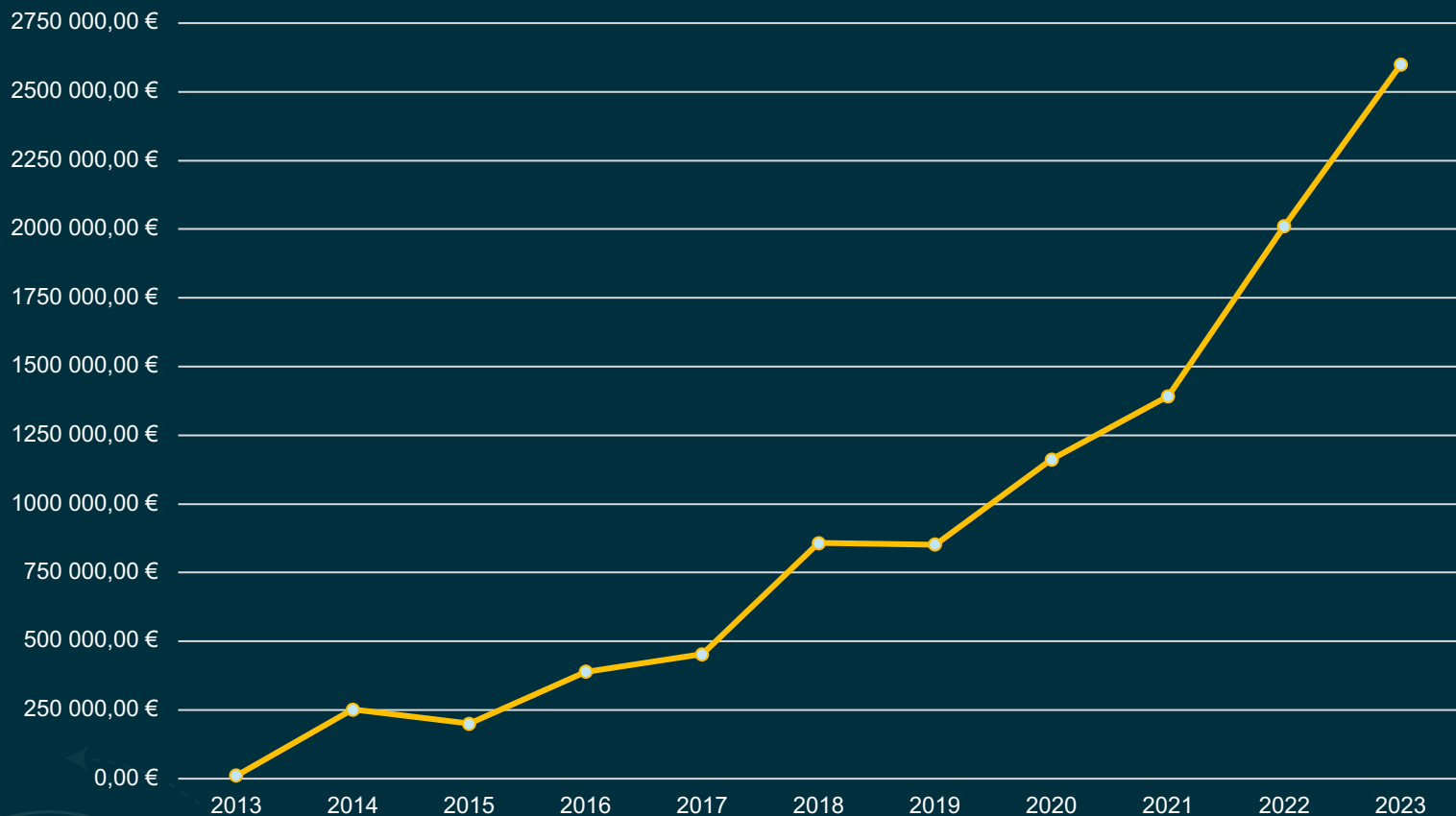
A total of 13 PET scanners based on our readout solutions are currently deployed or are under construction.

Several applications outside the area of PET: SPECT, LIDAR, mining, cargo scanning, astronomy, elementary particle physics, …

In addition to commercial companies, we have many top universities and research institutions among our customers: CERN, GSI, NASA, Lawrence Livermore, Sandia labs, Oak Ridge national lab, Harvard, EPFL, QST (Japan), Beida & Qinghua (China), ...

Thank you for your attention