PETsys Electronics

ASICs and readout systems for photosensors

- PET scanners and other SiPM based applications

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AMICSA 2025

PETsys Electronics

Created in 2013 with 1M€ investment, as a CERN related Spin-off

Location: Oeiras, Portugal

Personnel: 10

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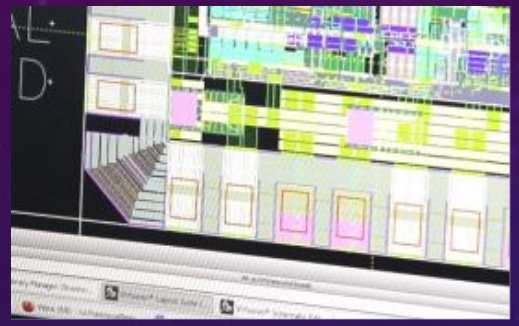
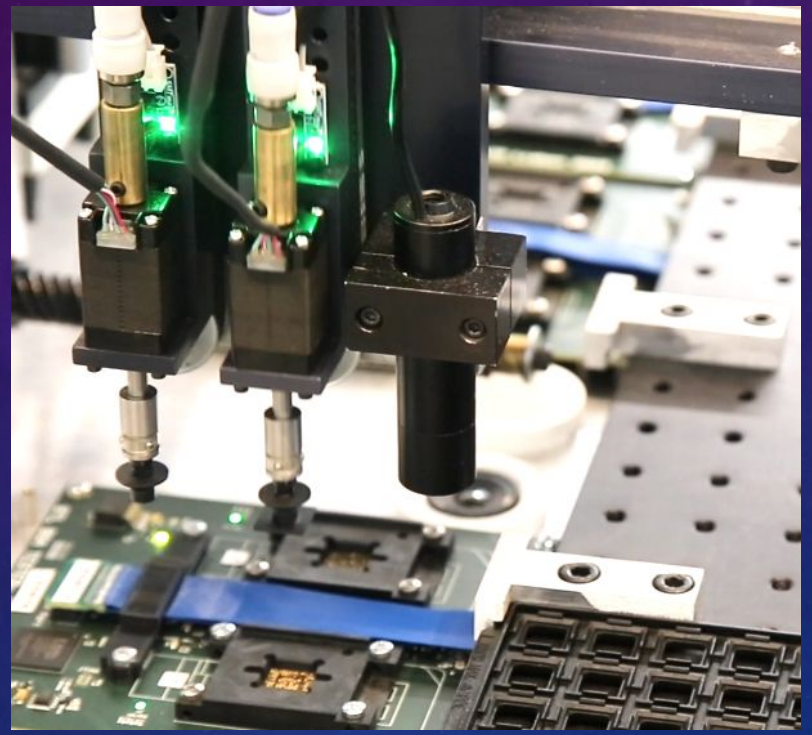
ASIC and PCB design



ASIC testing



Burn in equipped

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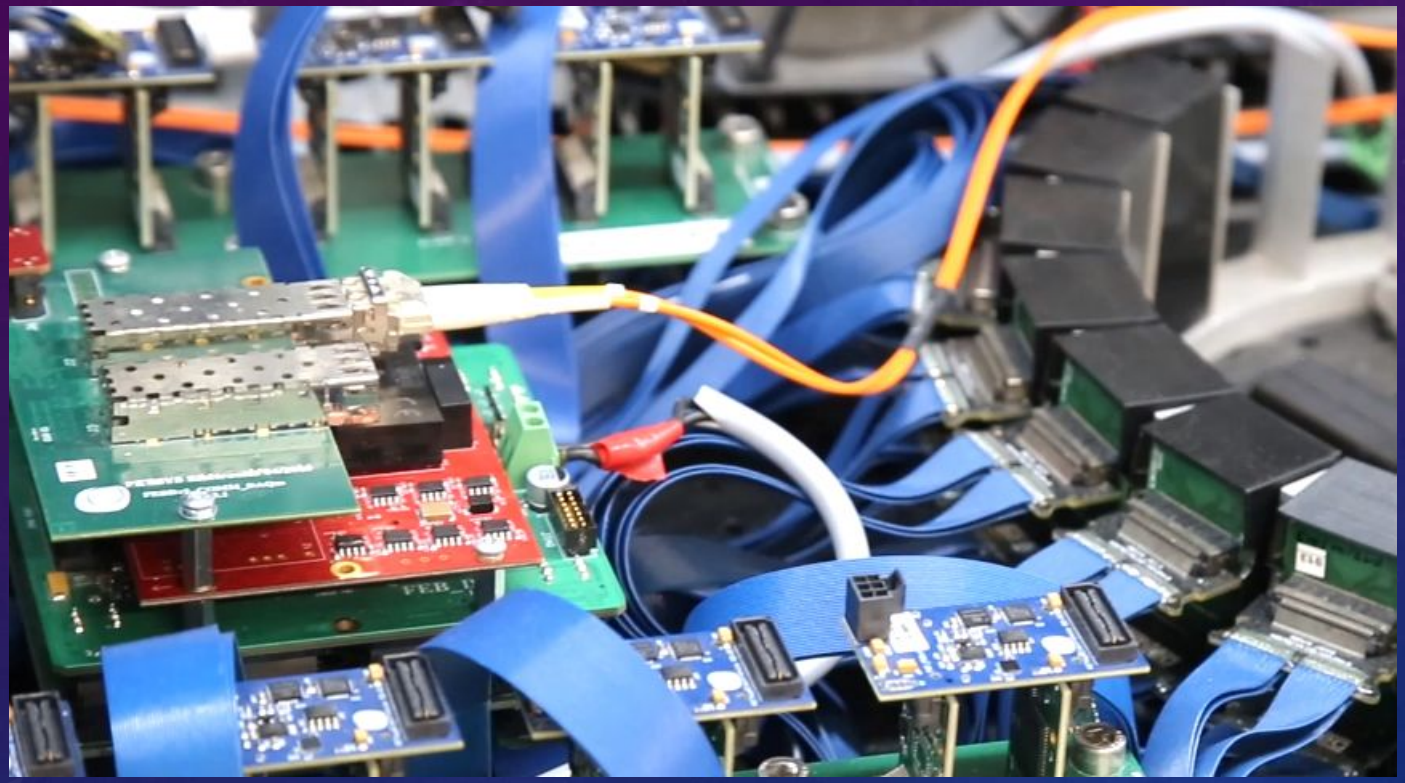

Various Applications:

PET scanners
SPECT
GEO Tomography
LIDAR
Cargo scanning
Astronomy
Fundamental particle physics
…

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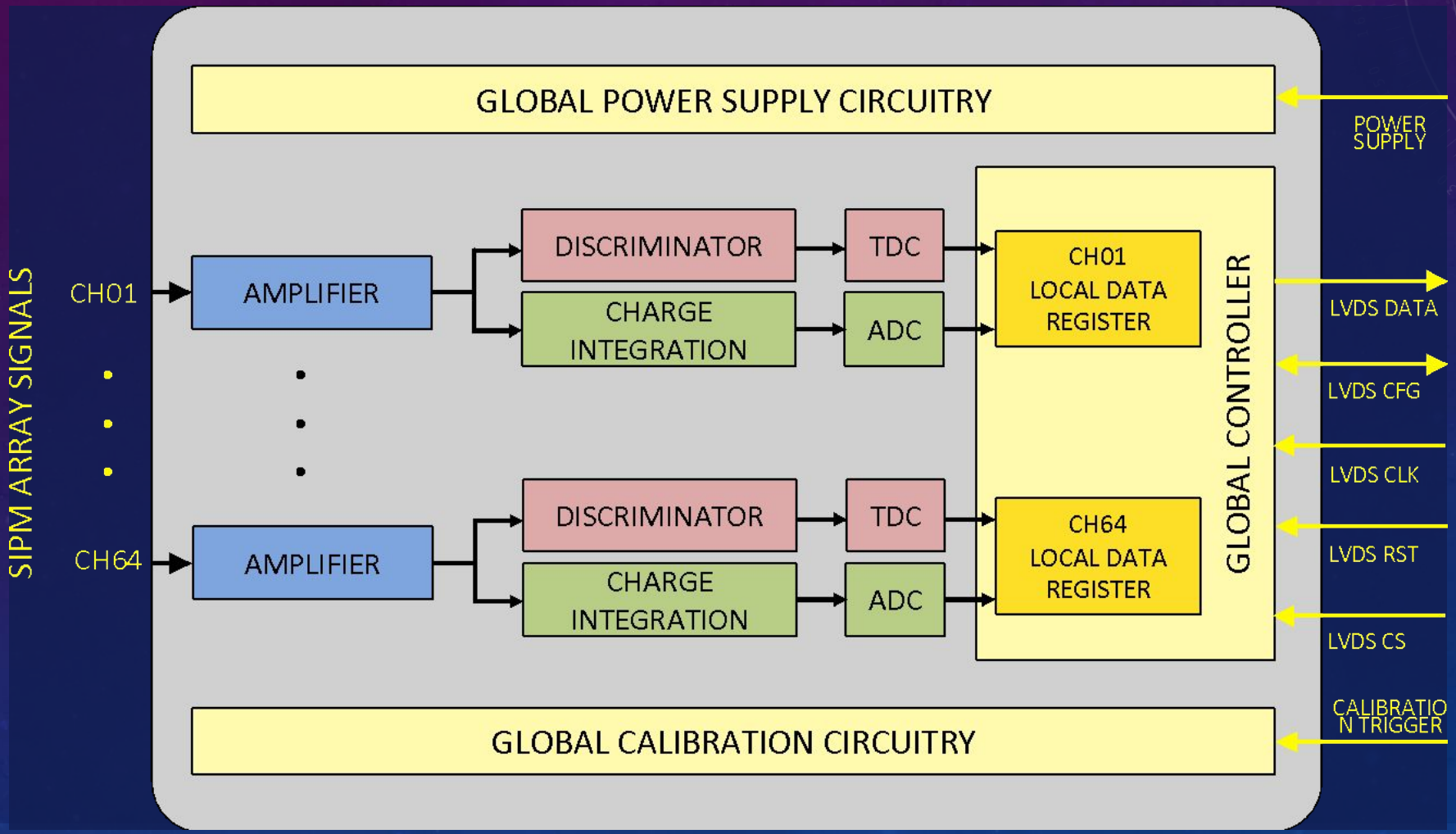
PETsys TOFPET2 ASIC

PETsys TOFPET2 ASIC

Simplified block diagram



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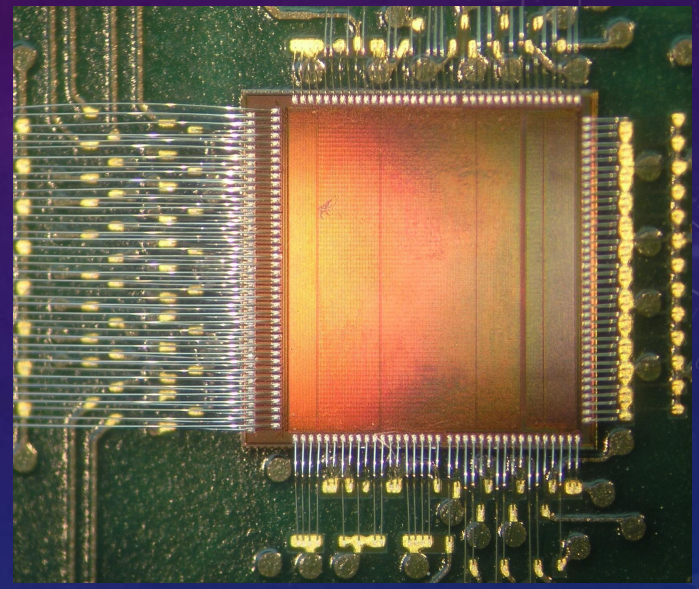
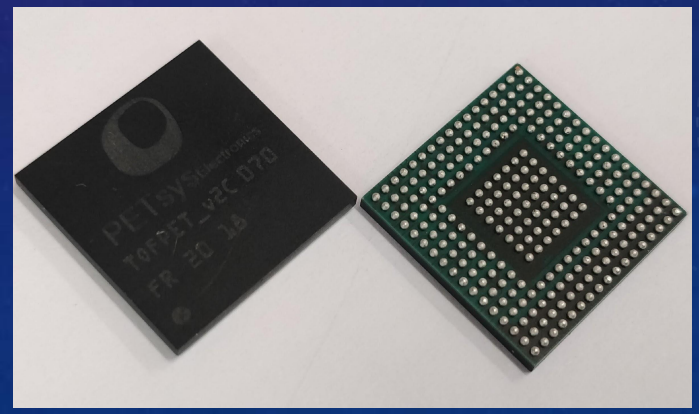
PETsys TOFPET2 ASIC

Main Features:

- 64 independent channels in 5x5 mm^2
- Standard CMOS 110 nm
- 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 600 kHz per channel
- On-chip calibration circuitry
- Generates digital event record every time the trigger conditions are fulfilled



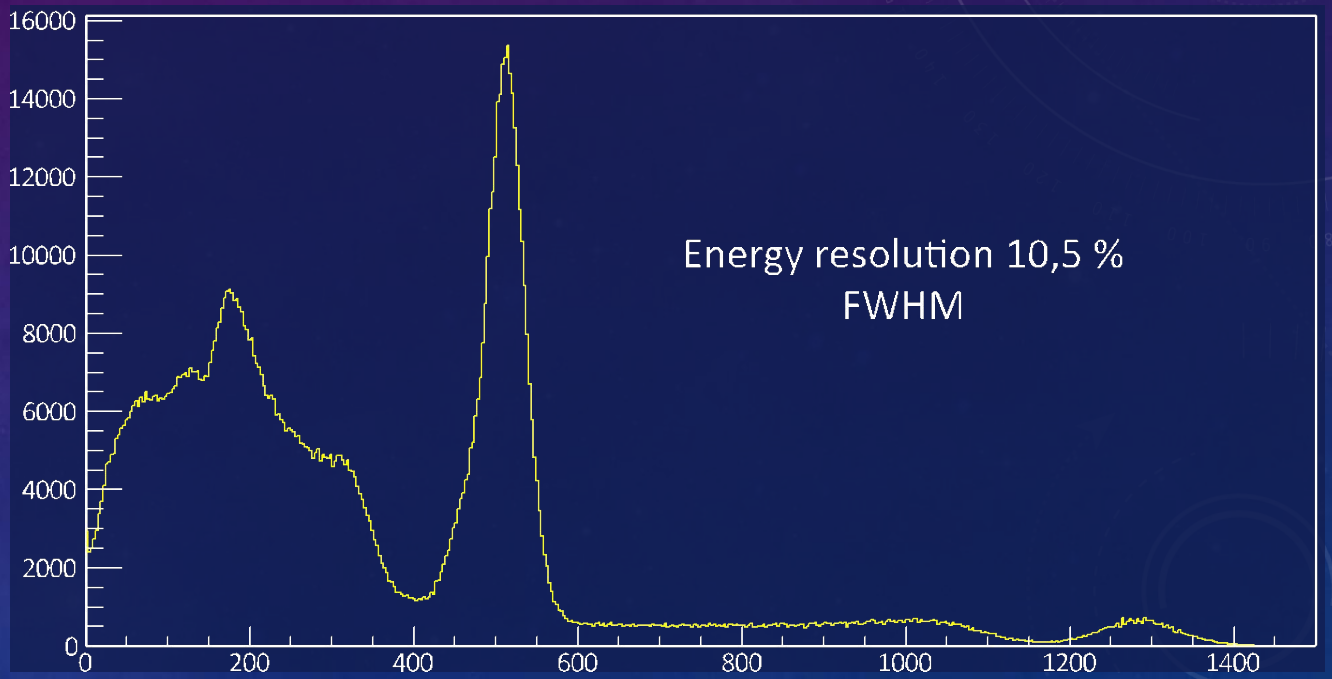


PETsys TOFPET2 ASIC

Energy resolution with LYSO : 10,5%

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

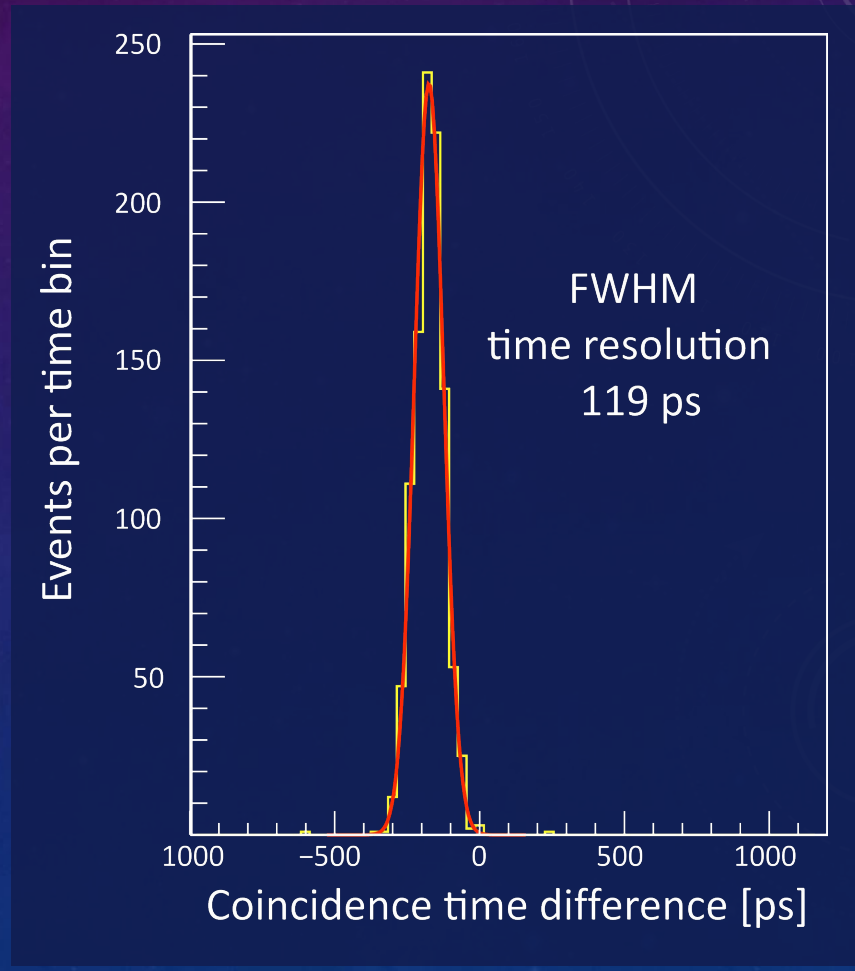
Corrected for SiPM non-linearity



PETsys TOFPET2 ASIC

TOFPET2 time resolution (CTR)
LYSO 2x2x3 mm^3 : 119 picoseconds

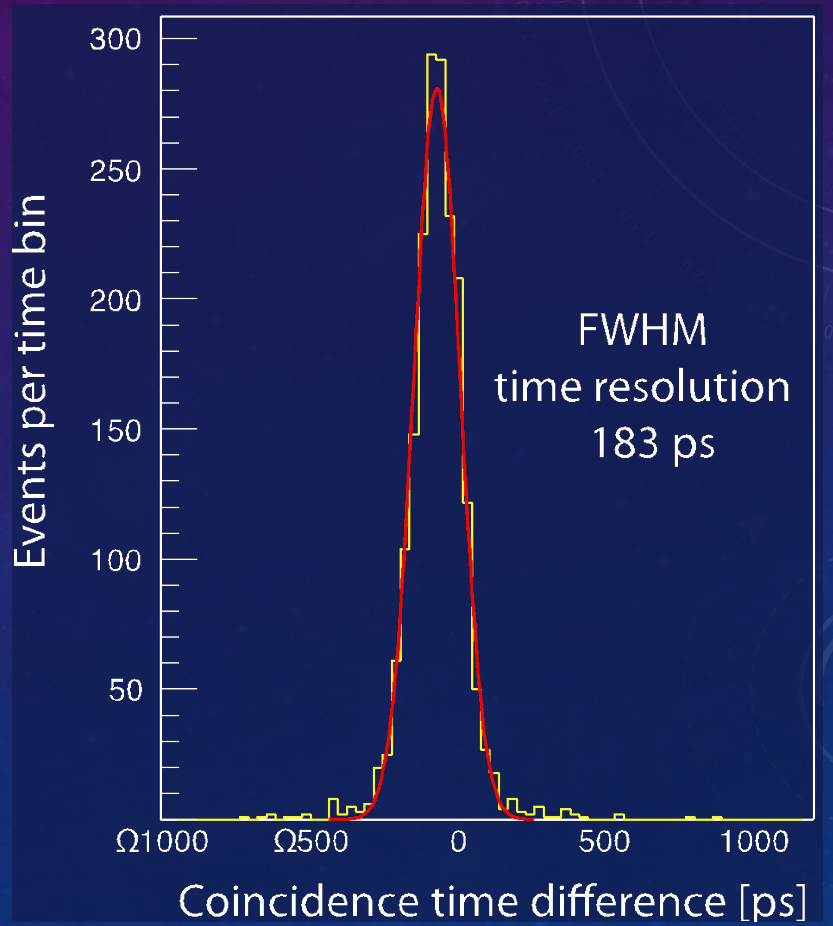
- Hamamatsu MPPC S13361-3050AE-04
- LYSO:Ce,Ca 2x2x3 mm^3
- 3 V over-voltage
- 4 p. e. threshold
- 15 °C
- Na22 Gamma source



PETsys TOFPET2 ASIC

TOFPET2 time resolution (CTR)
LYSO 3x3x20 mm^3 : 183 picoseconds

- Hamamatsu MPPC S13361-3050AE-04
- LYSO:Ce,Ca 3x3x20 mm^3
- 3 V over-voltage
- 4 p. e. threshold
- 15 °C
- Na22 Gamma source



Readout electronics

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- Almost all PET systems are based on using scintillating crystals and photo-detectors, usually SiPMs.
- The readout electronics typically has several 10’000 channels and must handle of the order of 100 kcps per channel.
- In a Total Body PET the coincidence even rate is of the order of 4 M events per second, the single rate is of the order of 60 M gamma interaction events/second.
- It must have a high-performance ASIC, readout electronics, and firmware allowing coincidence selection and DAQ software.
- PETsys Electronics provides all the above.

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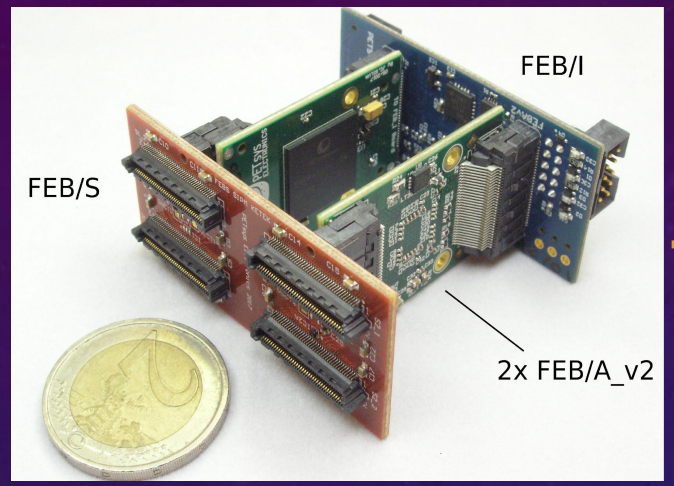
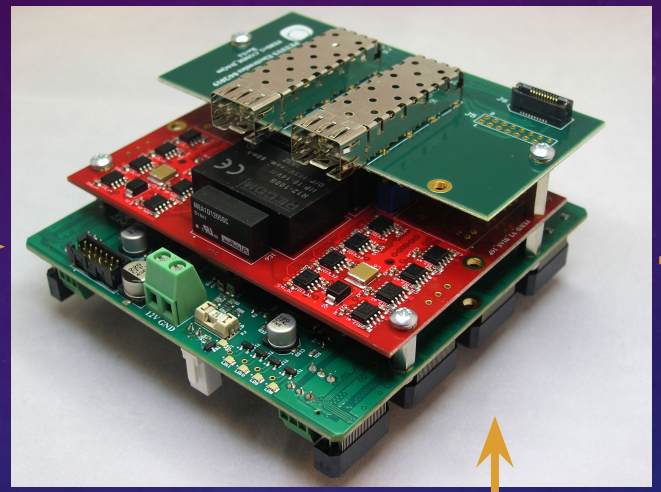
PETsys Readout Chain

Front-end module FEM-128



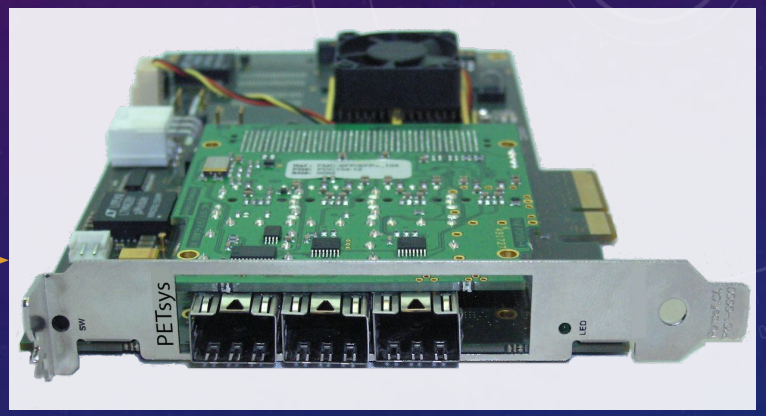
Up to 8x

FEB/D-1k unit



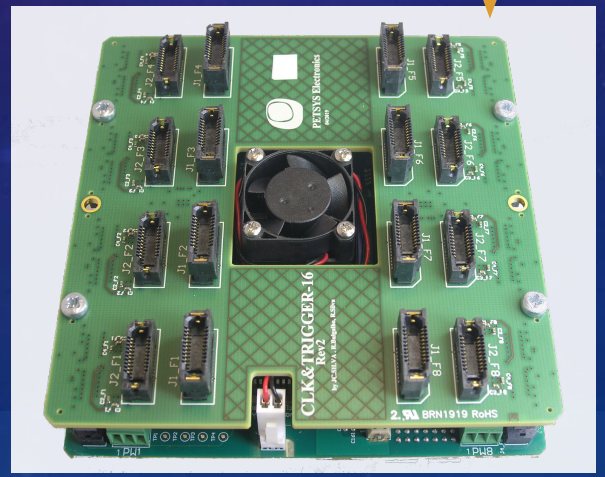
Up to 16x

PCIe DAQ unit



Up to 16x FEB/Ds

CLK & TRG module



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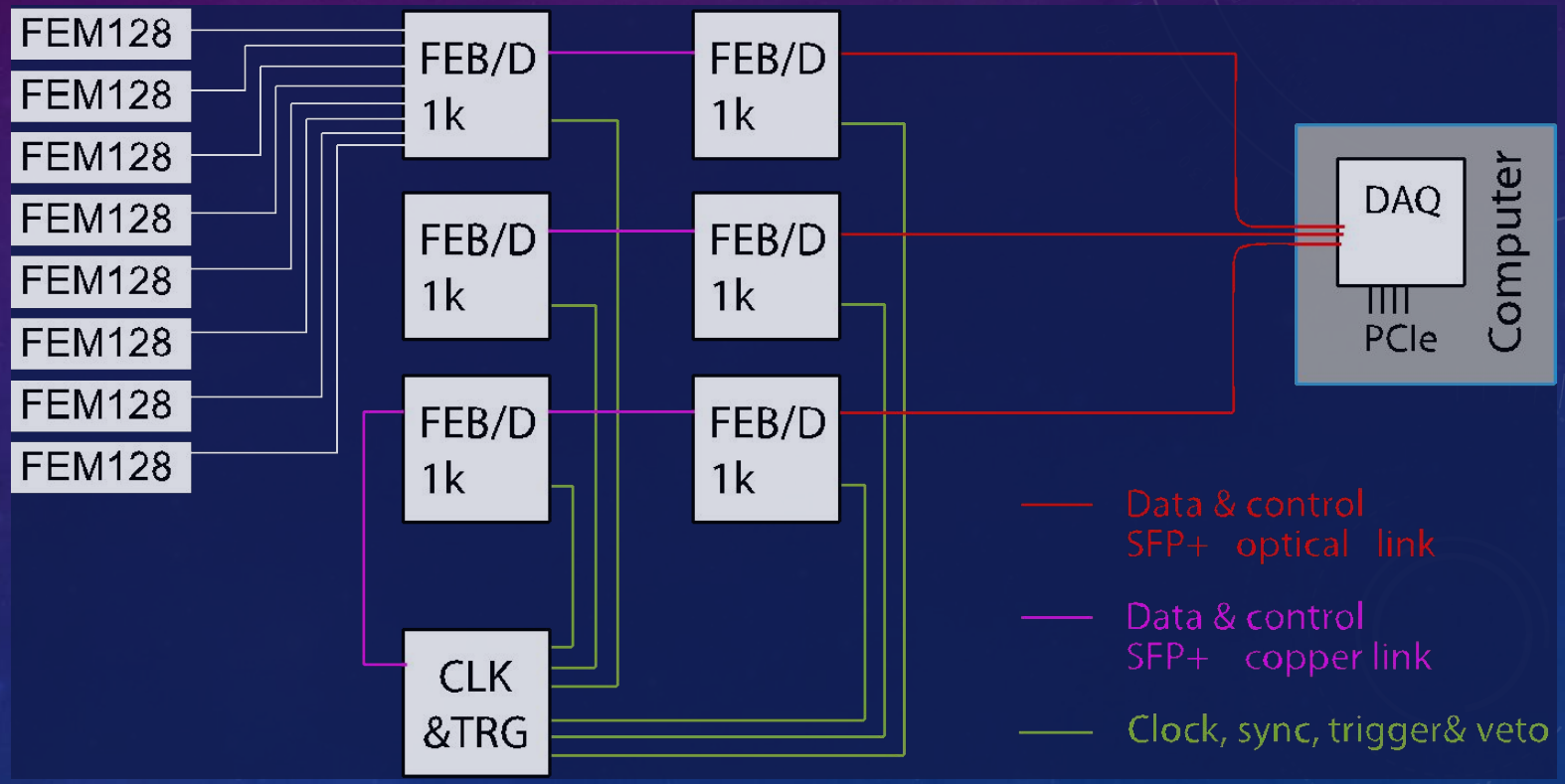
PETsys Readout Chain

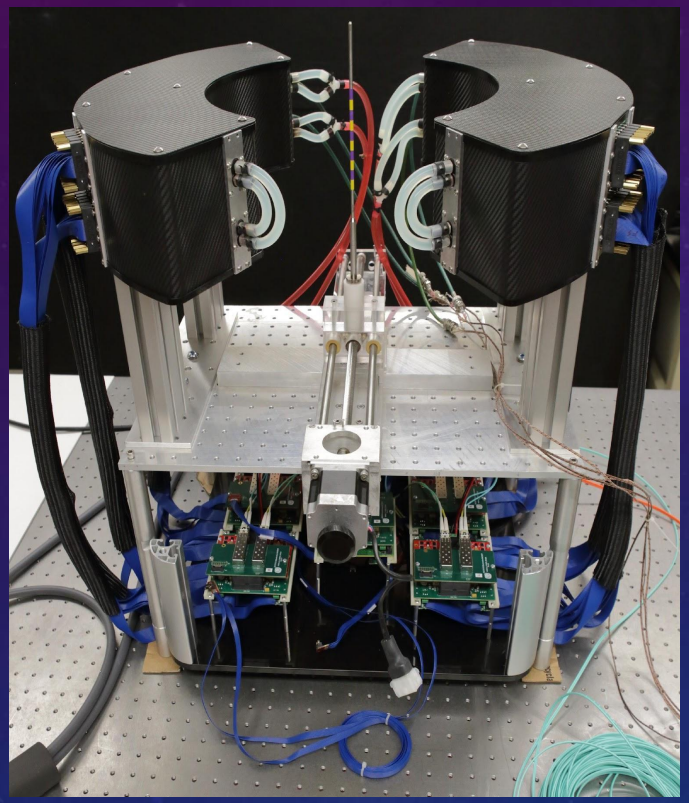
Example of a Readout system for a PET scanner with up to 16'384 channels

- Each FEB/D-1k module controls 16 ASICs in 8 FEM128
- The CLK&TRG module allows coincidence selection in the firmware
- The DAQ card



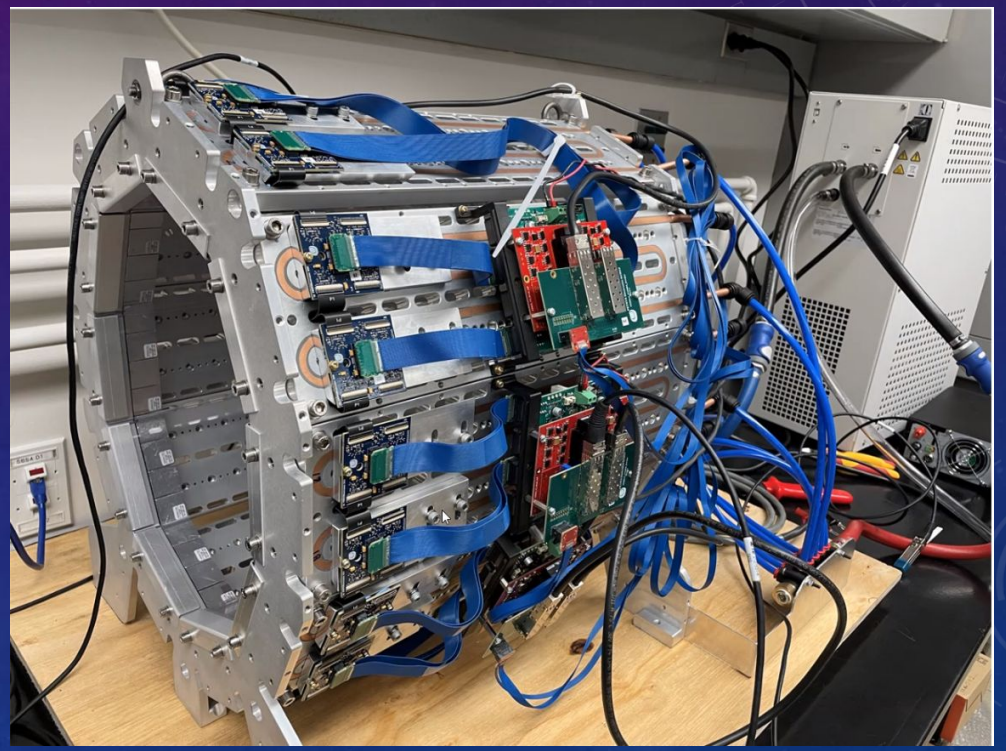
PETsys Readout Chain

PET for proton therapy UT Texas



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

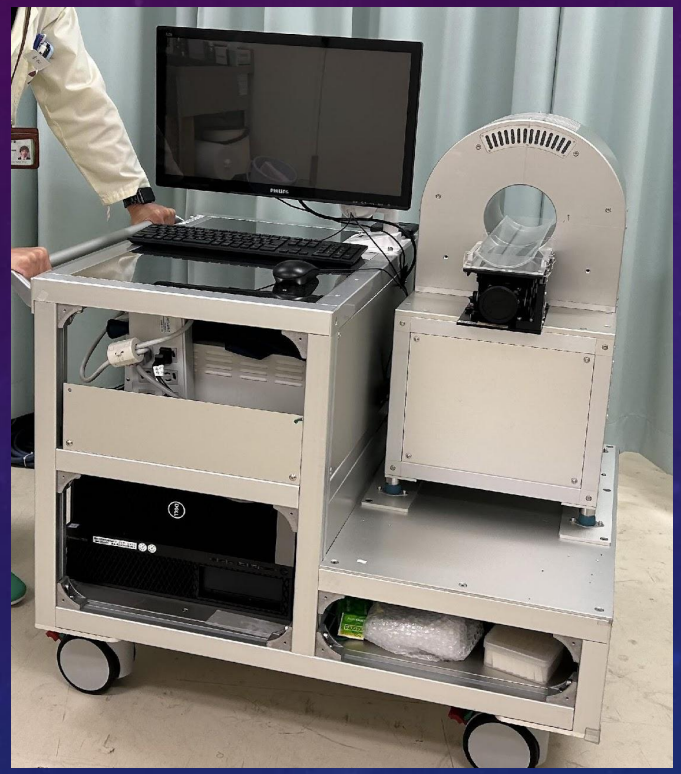
Brain PET at Cornell University



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

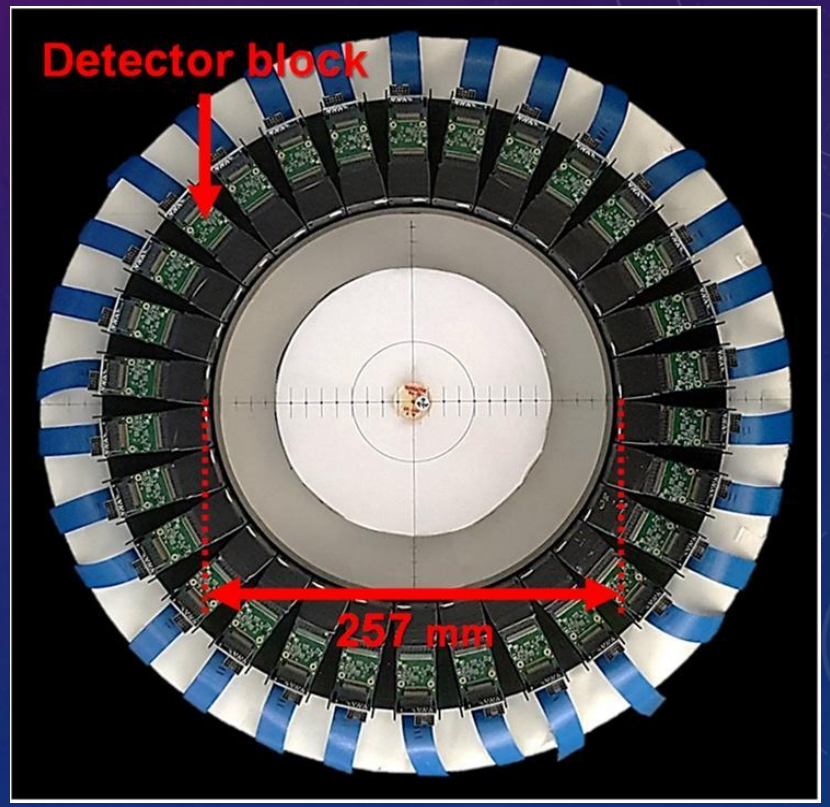
PETsys Readout Chain

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

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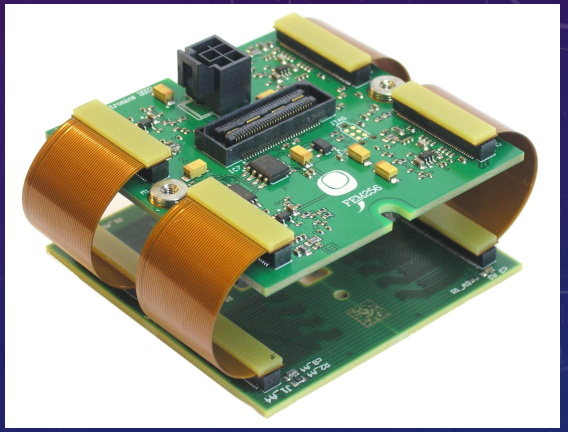
Solutions for larger number of channels

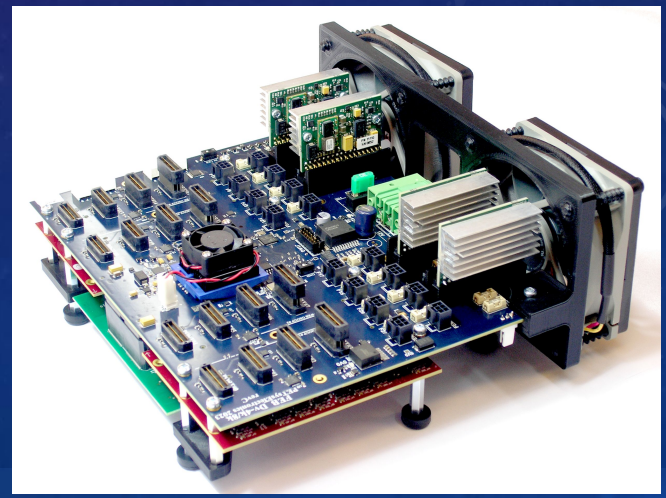
	FEB/D-1K		FEB/D-8K		
	FEM-128	FEM-256	FEM-128	FEM-256	FEM-512*
Max # of FEMs per FEB/D	8	4	16	16	16
Max # of channels per FEB/D	1024	1024	2048	4096	8192
Max # of FEB/Ds	16	16	16	16	16
Max # of channels	16384	16384	32768	65536	131072
Max data rate per 1 FEM (Mcps)	40	40	40	40	40
Max data rate per FEB/D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

FEM-256 module



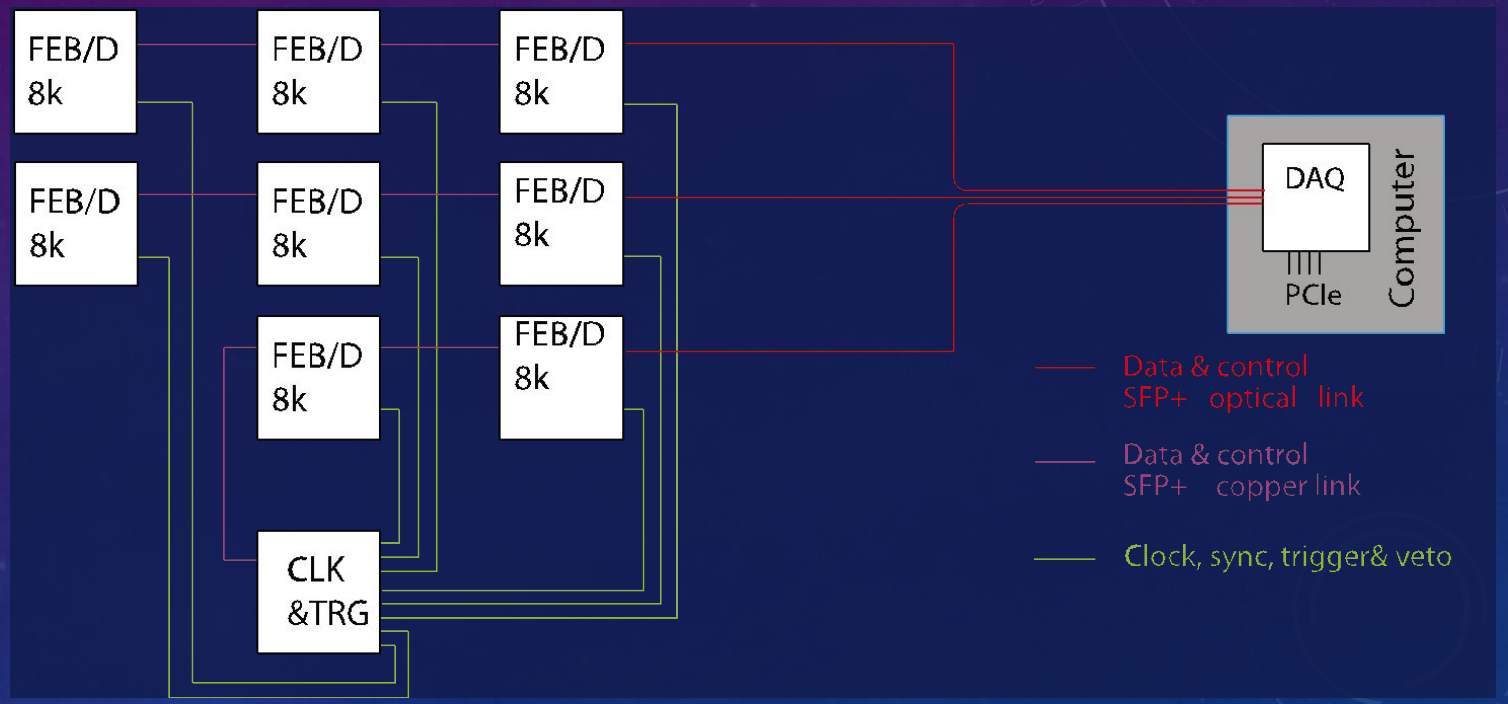
FEB/D-8k unit



Solutions for larger number of channels

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 (to be developed).
- It is possible to use several DAQ boards to handle larger total data rates.



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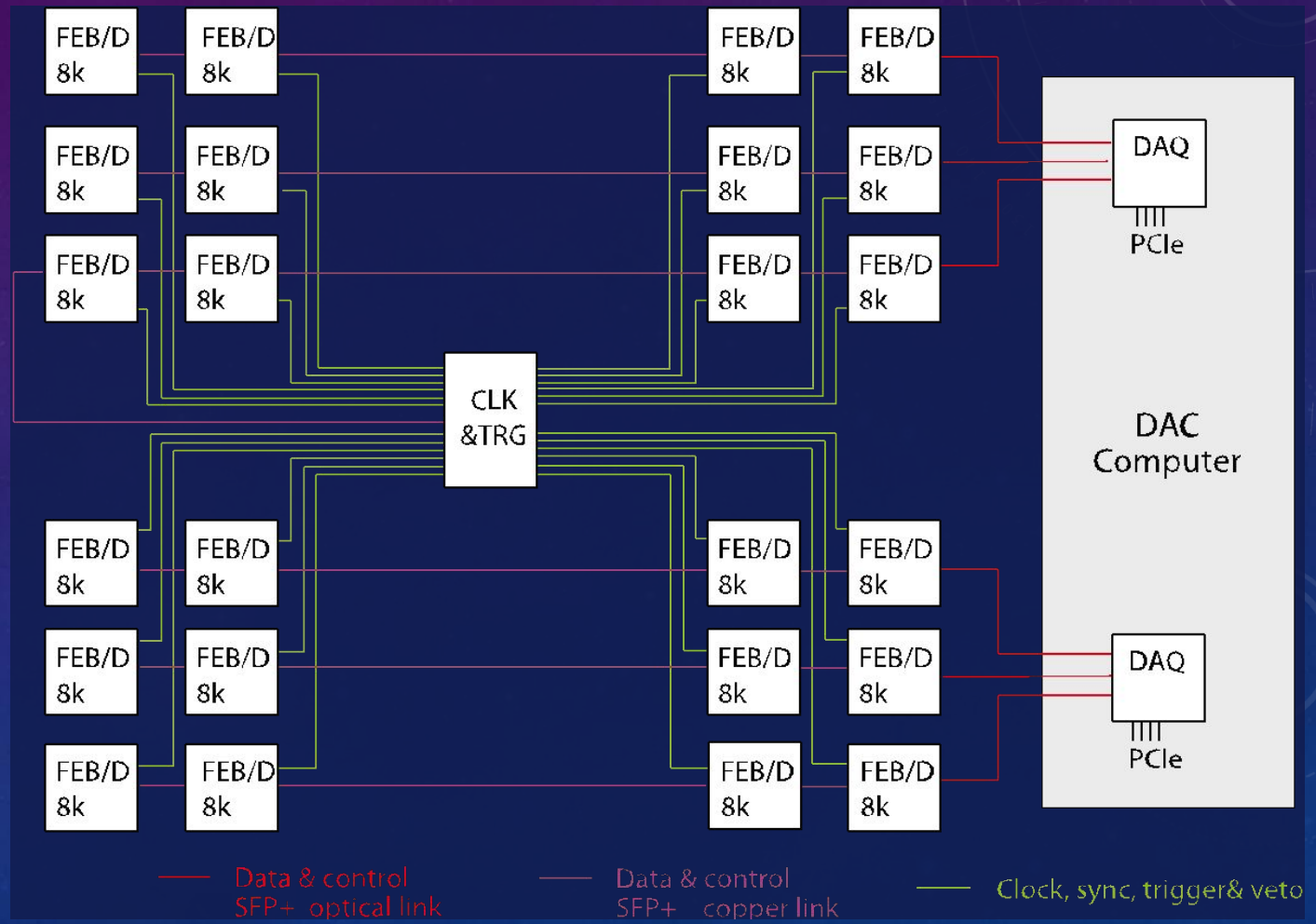
Solutions for larger number of channels

Readout for a PET scanner with more than 131’072 channels

A readout that can handle more than 131’072 channels will need a different CLK&TRG module (to be developed).

The example to the right would read 196’608 channels.



Solutions for larger number of channels

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

30’720 electronic channels

- Presented at IEEE NSS MIC RTSD 2023: See M-04-01, M-17-11, M-17-102, M-17-081.

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DAQ firmware and software

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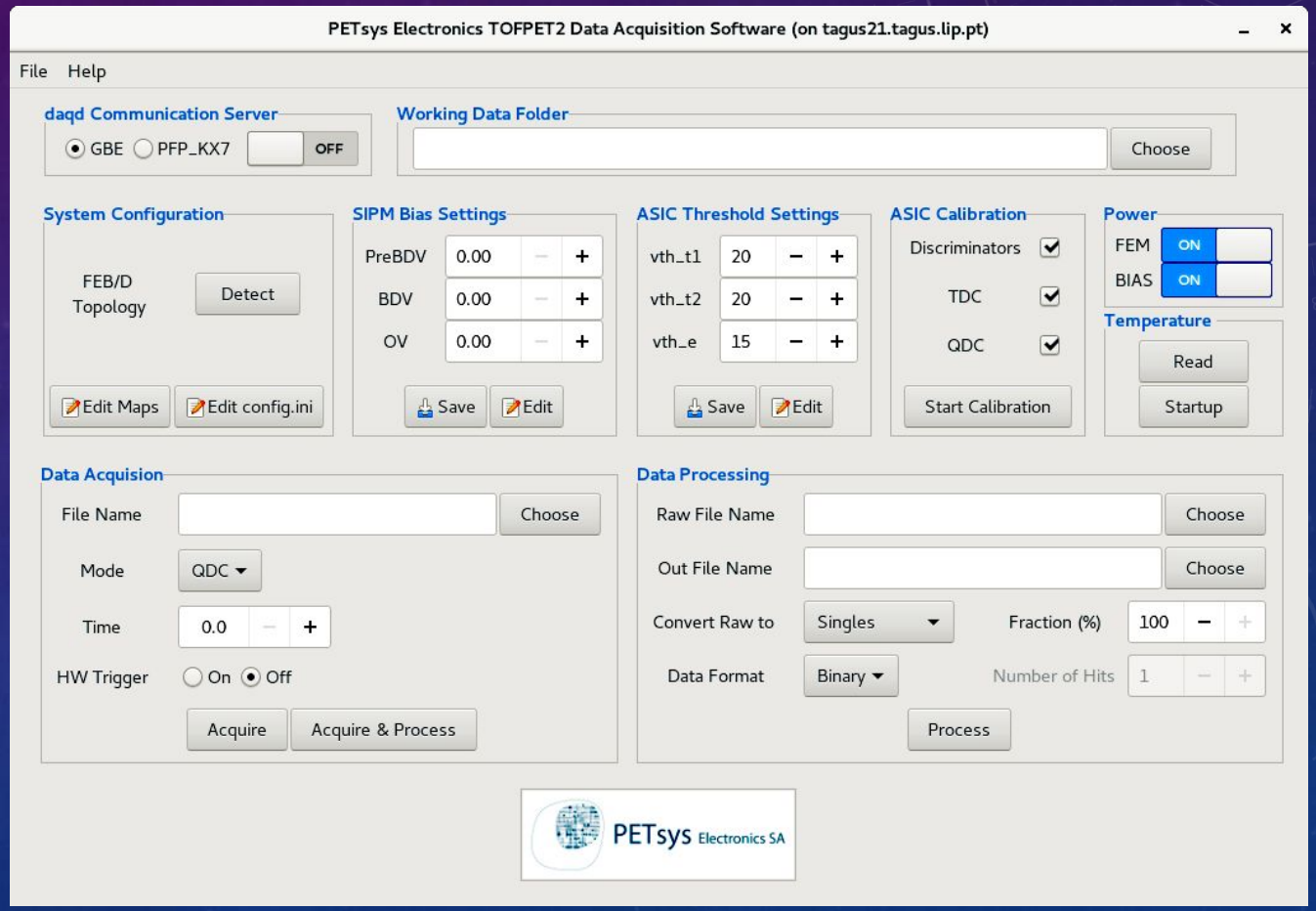
DAQ Firmware and Software

- PETsys provides coincidence selection in the 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 graphics user interface, controlling the same commands and system temperature monitoring.



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Upcoming solutions

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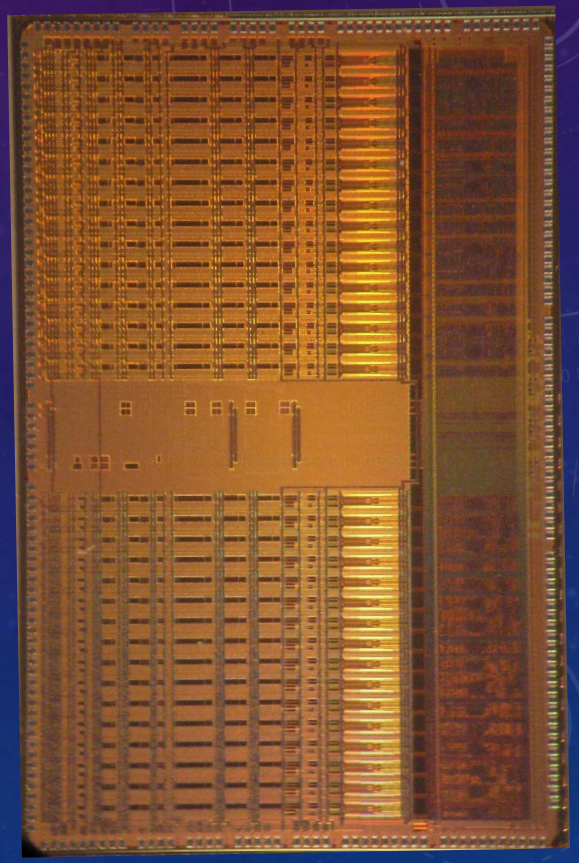
New PETsys TOFPET3 ASIC

- 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)
  - Max event rate per channel 500 MHz, Output rate 3.8 Gb/s
  - New timing and energy circuits with outstanding performance
    - PETsys TOFPET3 contribution to CTR: 26 ps FWHM
      CTR = 80(120) ps due to crystal and SiPM, increases to 84(123) with TOFPET3
    - Contribution to 511 keV photopeak resolution is 0.8%
    - Average deviation to linearity is $^{+4}_{-2}$% in the range 300-3000 p.e.
  - Four additional channels with sums of 16, 32 or 64 channels (configurable)
  - Advanced triggering features: selective readout of group of channels seeded by energy of one channel
  - Low power consumption



PETsys TOFPET3

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PETsys TOFPET3 Specifications

From the analog front-end to the digital system interface

Performance specifications	TOFPET2	TOFPET3C
Number of channels	64	64
Baseline stabilization, pulse tail cancelation, dark noise rejection, gain configuration	no	yes
10-bit TDC/QDC per channel	1	2/1
Number of digitization per event	2	3
SPTR of analog front-end for SiPM $G=3.5.10^6$ (FWHM)	98 ps	35 ps
Contribution of analog front-end to CTR for 3000 p.e. and $G=3.5.10^6$ (FWHM)	-	<10 ps
TDC resolution (rms)	30 ps	7 ps
Number of configurable discriminators	3	3
QDC contribution to energy resolution of 511 keV photopeak with LYSO (FWHM)	-	0.8%
Max energy non-linearity (INL) for LYSO and SiPM $G=1.75.10^6$ @ 300-3000 p.e.	-	±6 LSB
Pulse filtering and charge integration configurable for different crystals (LYSO, BGO, NaI, CsI)	-	yes
Sum channels	no	yes
Advanced triggering (regional readout)	no	yes
Maximum input rate per channel (kcps)	500	3000
Max clock frequency (MHz)	200	480
Max output bandwidth (Gb/s)	0.8	3.8
Power consumption per channel (mW)	9	8

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Summary and conclusions

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Summary and Conclusions

- PETsys Electronics S.A. provides versatile solutions for reading out SiPM arrays in PET and other applications. The solution is delivered as a comprehensive package, inclusive of both software and firmware providing a list mode output.
- A total of 13 PET scanners based on our redout solution are currently deployed or are under construction.
- Several applications of our electronics outside the area of PET:
    - SPECT, mining, cargo scanning, astronomy, elementary particle physics, etc ...
- In addition to commercial companies, we have many top universities and research institutions worldwide among our customers:
    - CERN, GSI, NASA, Lawrence Livermore, Sandia labs, Oak ridge national lab, Harvard, EPFL, Beida & Qinghua (China), ...
- New PETSys TOFPET3 ASIC is in last stage of development. This new ASIC will provide improved performance for applications requiring the best timing and triggering options possible.

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Thank you for your attention

Visit us outside

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PETsys TOFPET3 Availability

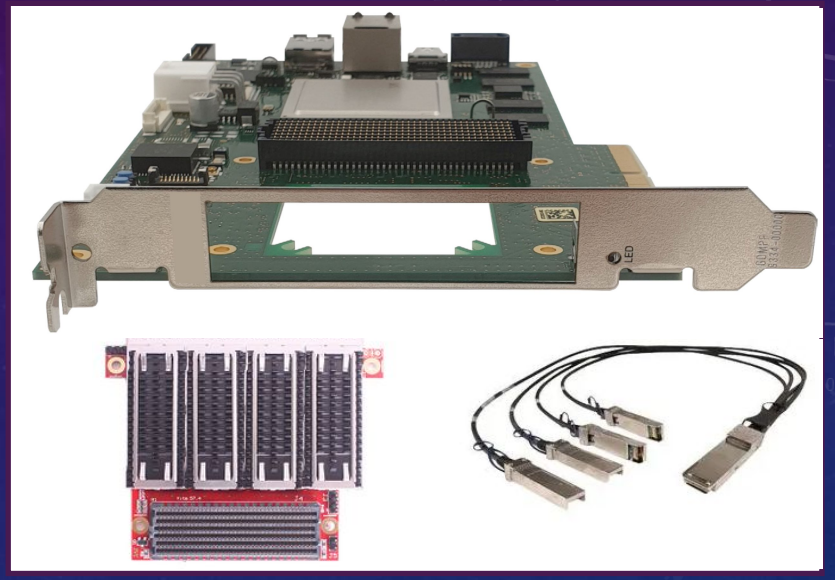
- Prototype PETsys TOFPET3A:
  - 32 channels
  - Sum channels and advanced triggering features not included
  - Evaluation-kit available in Q1 2024
- Full chip PETsys TOFPET3B:
  - 64 channels
  - Includes sum channels and advanced triggering features
  - Improved TDC resolution (7ps rms)
  - Evaluation-kit available in Q3 2024
  - Production version available in Q1 2025
- PETsys TOFPET3 is fully compatible with PETsys Readout System
  - Costumers may upgrade their systems to PETsys TOFPET3
- PETsys TOFPET2 is suitable for many applications and continues to be available

ASIC Availability		2023	2024				2025
			Q1	Q2	Q3	Q4	Q1
PETsys TOFPET 2	Production						
PETsys TOFPET 3A - prototype	Evaluation-kit						
PETsys TOFPET 3B - prototype	Evaluation-kit						
PETsys TOFPET 3B	Production						

Handling very large data rates

- New DAQ card with PCIe gen3 x16 up :
  - Up to 1.8 Gcps (14.4GB/s).
  - 20 individual links to FEBD.

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



- 4x SFP to maximize FEBD throughput allowing up to 400 Mcps from a single FEBD.

- QSFP connector also under development.