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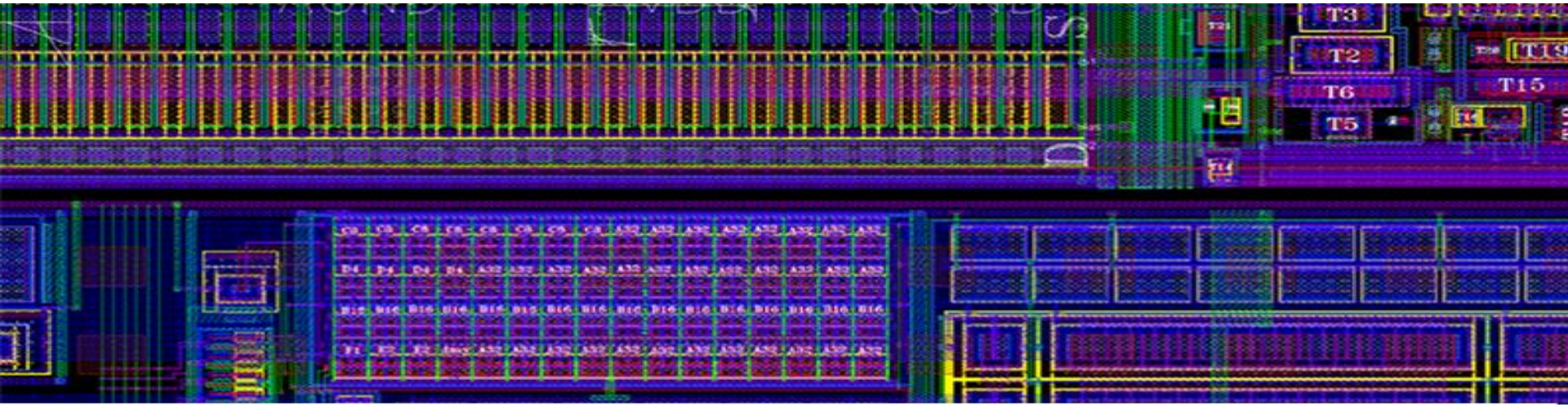
CRYSTAL CLEAR

FAST

Development of a highly integrated PET readout system scalable to several 10'000 channels.



MEDAMI, Corsica, May 2016

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Until about 15 years ago all detection of weak light signals relied on photomultiplier tubes

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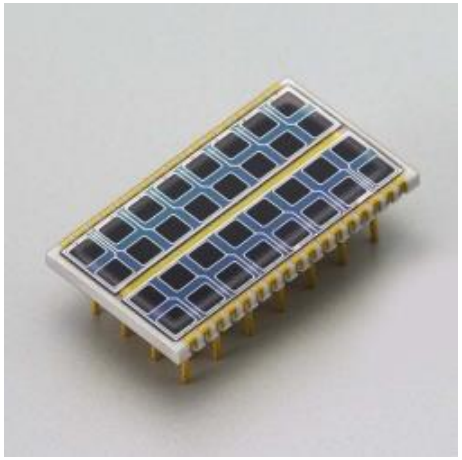

About 15 year ago the avalanche photodiode began to be replace Photomultiplier tubes in some applications

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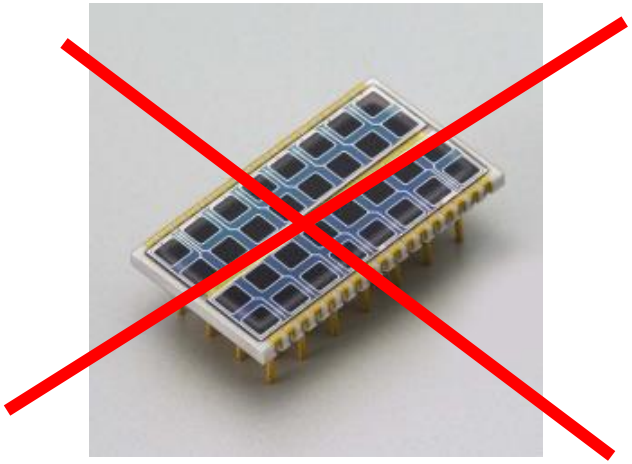
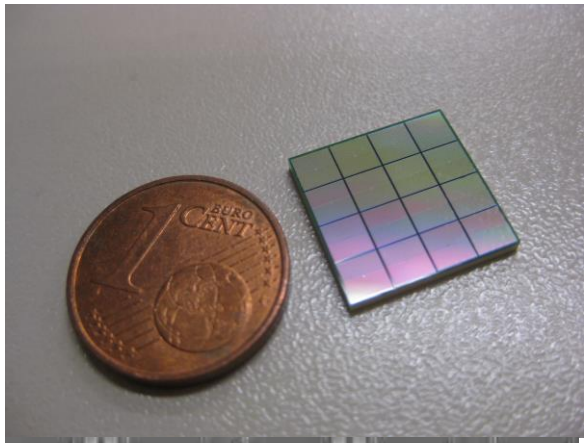
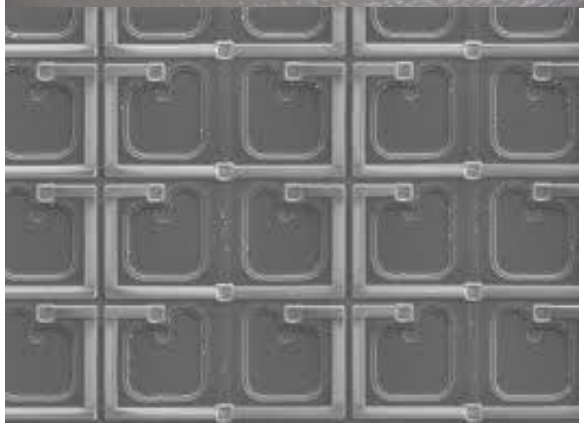
The Silicon photomultiplier is a disruptive innovation







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Advantages of SiPMs compared to PMTs

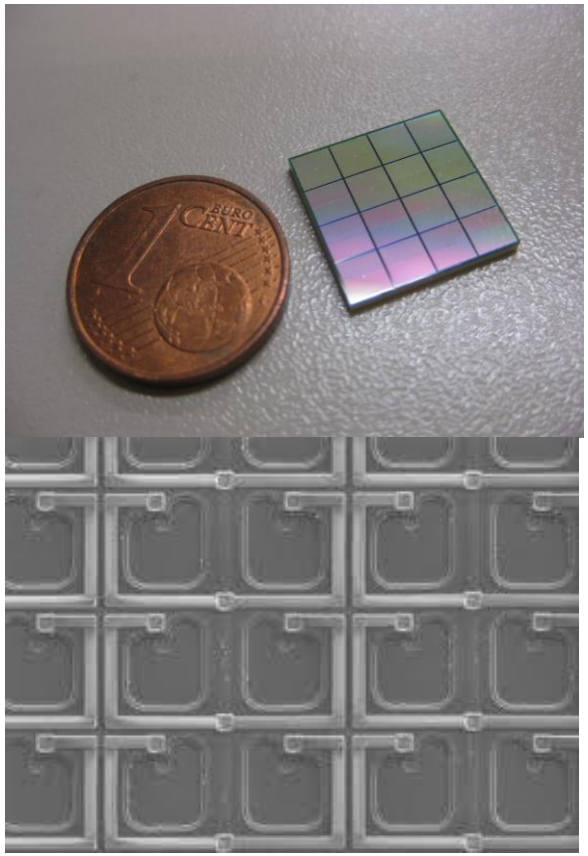
- SiPM allow much better timing measurement

- SiPM can be easily divided in a number of small pixels

- SiPM is small, compact and robust

- Operating voltage 30-70V, compare to >1'000 V for PMT

- Potentially low cost



Drawbacks

- large dark count ≈ 100'000 /mm^2

- sensitive to temperature variations

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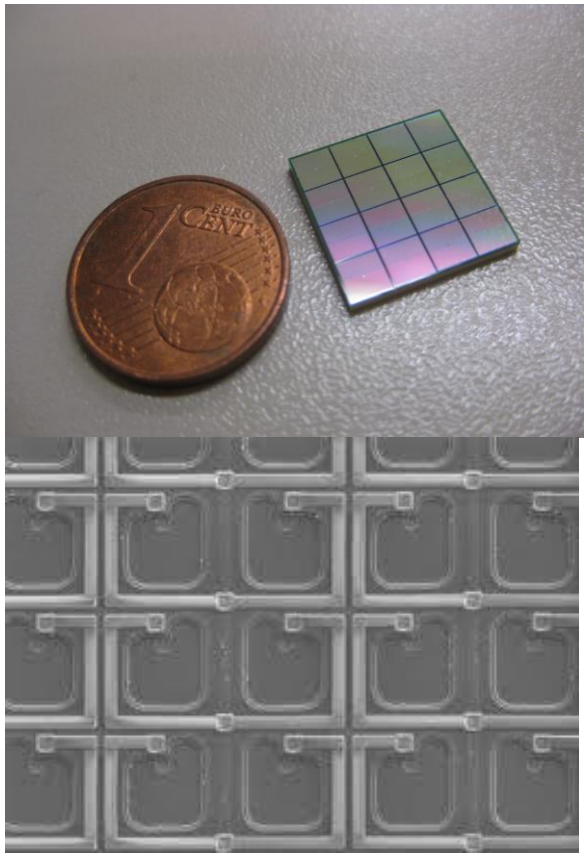
However, to take full advantage of of the SiPM one needs a highly integrated readout electronics, i.e. everything must be done in an ASIC.

After the ASIC everything should be digital
>> only firmware and software



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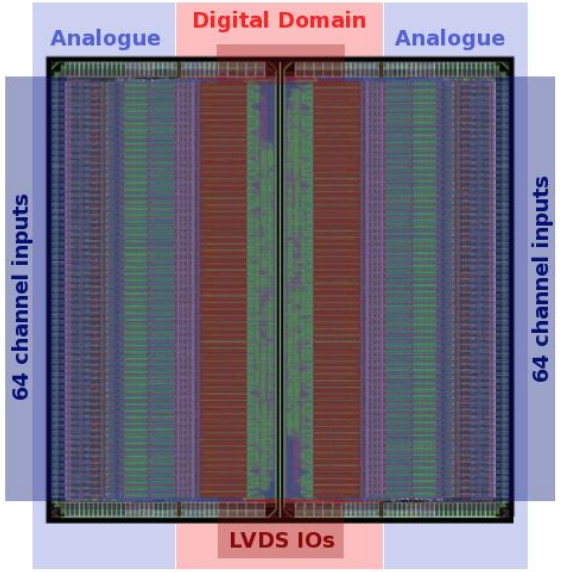
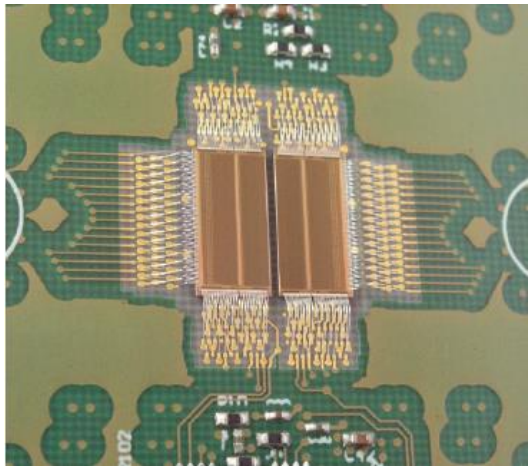
TOFPET ASICs

TOFPET1 ASIC

SiPM readout from analog frontend to digital system interface

- 2 x 64 channels in 7 x 7 mm^2
  - CMOS 130nm
- Positive or negative signal polarity
- SNR (one photon signal): 25 dB
- Time and ToT digitization
- TDC time binning 50 ps
- Optimized for low power
  - 10 mW per channel
- Event rate: up to 100 kHz per channel with negligible loss
- Dead time ≈ 100 ns
- On-chip calibration circuitry



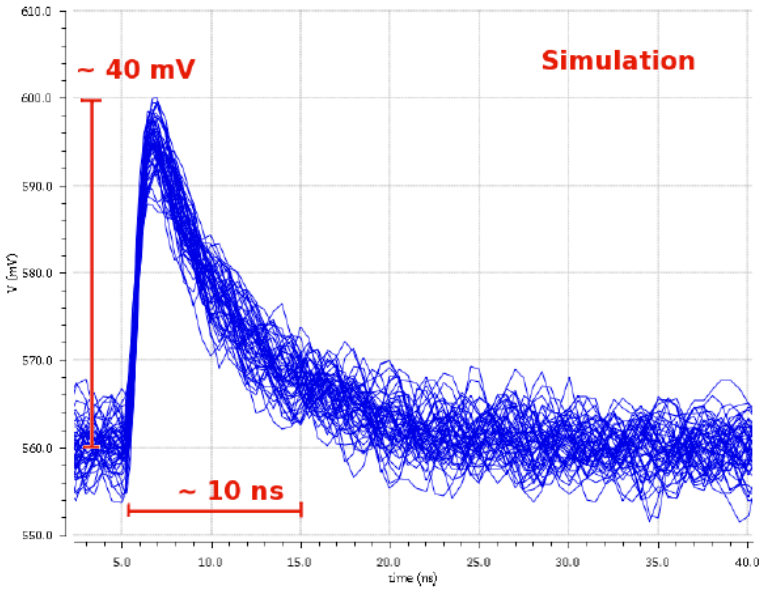


Two 64-channel chips assembled back-to-back

TOFPET1 SiPM low-noise frontend

Frontend amplifiers and discriminators are optimized for the measurement of scintillating light with SiPMs

- Low noise frontend
  - Single photo-electron pulse amplitude is 40 mV
  - Measured noise is 2.6 mV (SiPM 320 pF)
- Time Threshold in the range 0.5-15 p.e.
- Innovative triggering:
  - Dark counts are rejected without triggering the TDC
- For SiPM characterization, a dark count meter per channel is available



Single photo-electron pulses at amplifier output

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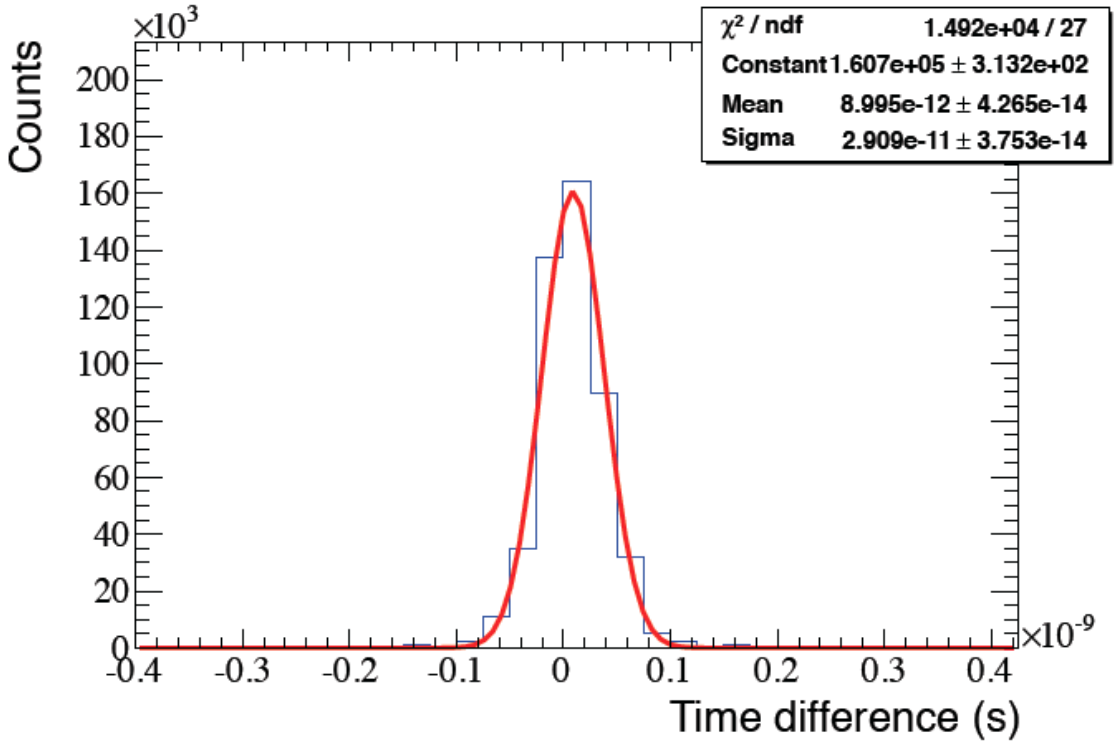
TOFPET1 TDC resolution

Distribution of the time difference between two channels triggered simultaneously by internal test pulse

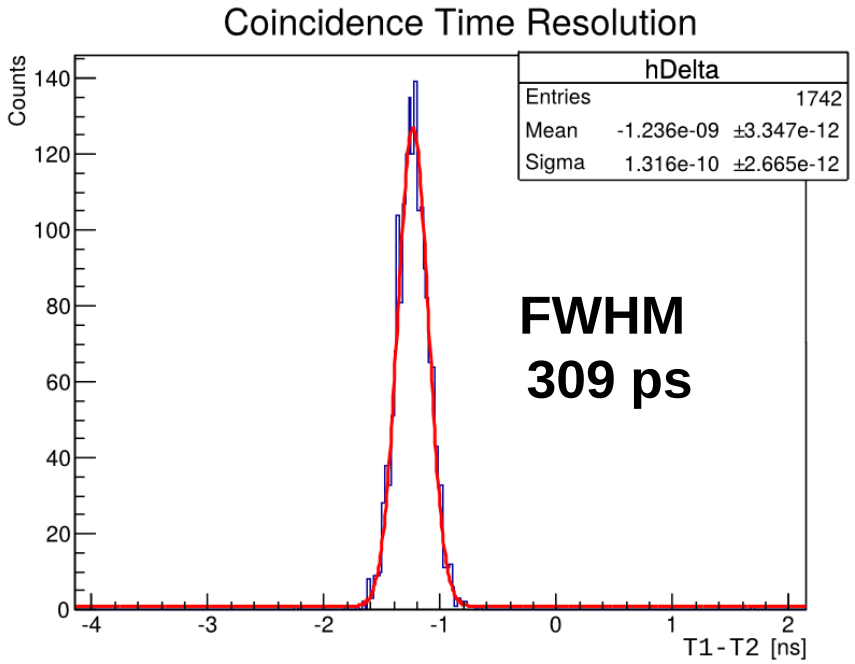


Channel resolution

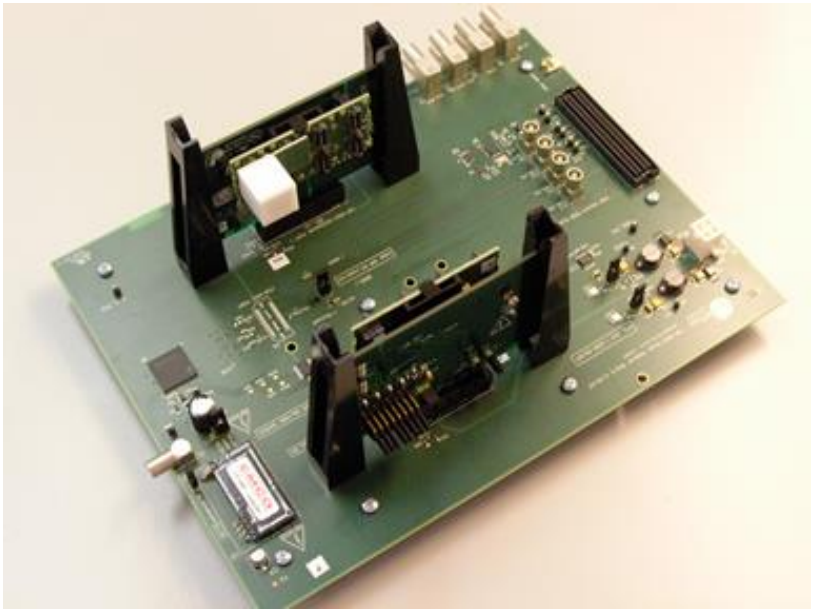
$\sigma = 21$ ps r.m.s.

TOFPET1 Coincidence time resolution

- Coincidence Time Resolution with Na22 point source
  - Two LYSO 4x4 crystal matrices
  - Crystal pixels: 3.5 x 3.5 x 15 mm^3; MPPC 3x3 mm^2



ASIC EVALUATION KIT



COMPATIBLE WITH TOFPET2

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TOFPET DAQ SYSTEM

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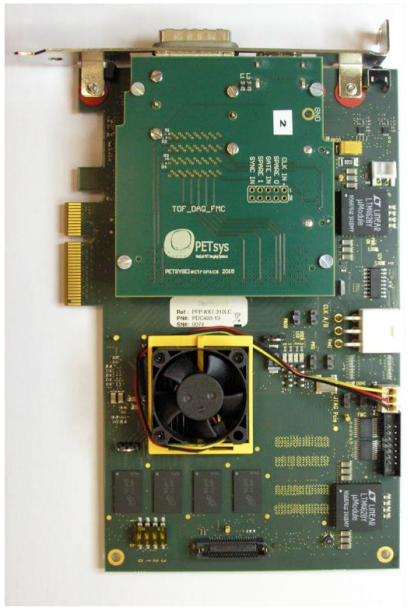
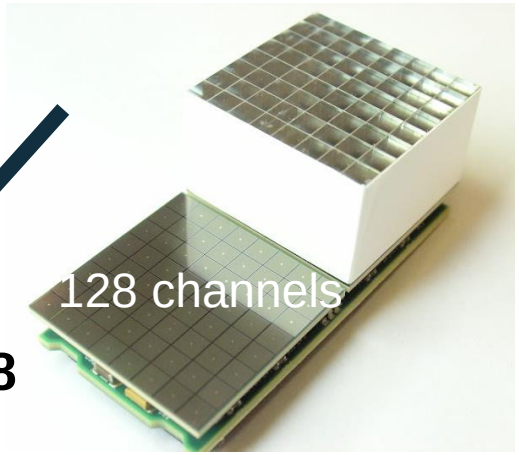
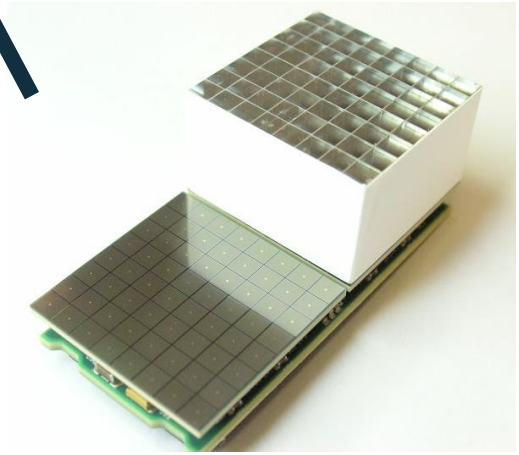
Allows building a PET scanner with several 10'000 channels



x 12

x 8





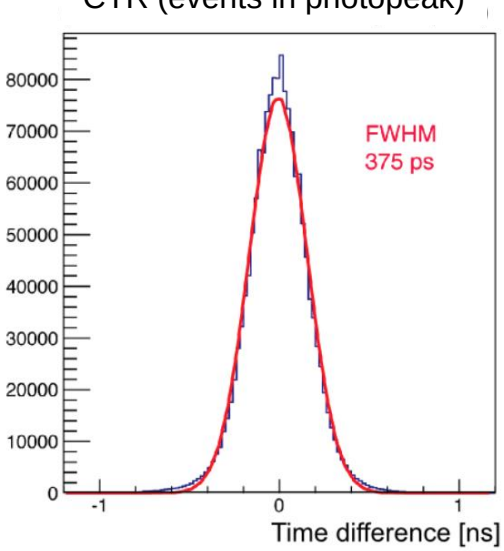
FEB/D daisy chaining allows to extend the total number of cannels

TOFPET demonstrator

- 16 Detector Modules, 2048 SiPM channels
- Inner diameter of 230mm

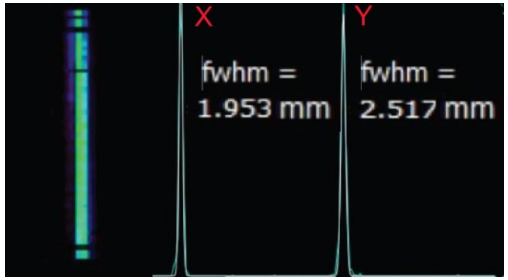
System demonstration with 2048 channels

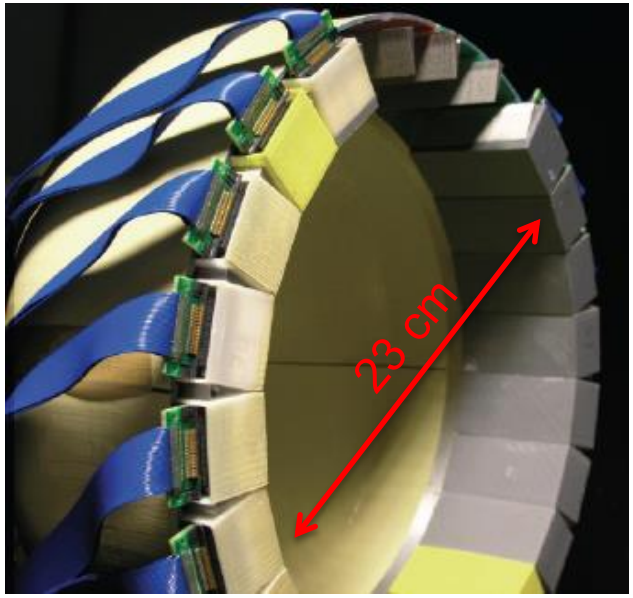
CTR (events in photopeak)

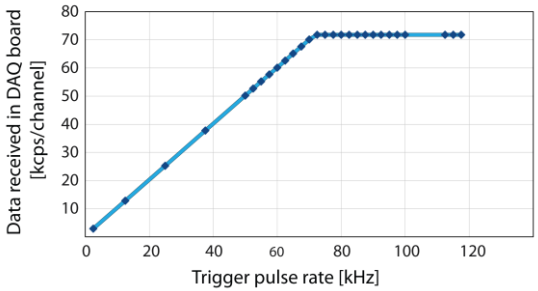


Point source

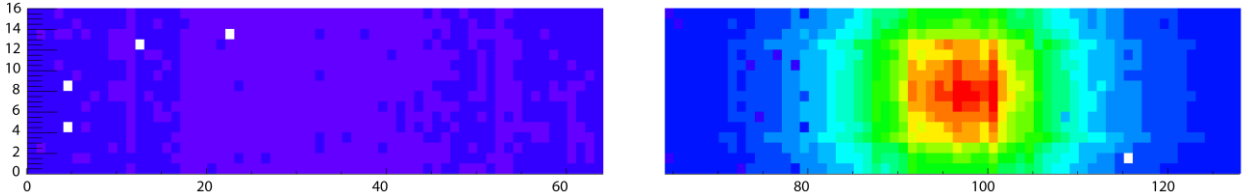
Line source







Flood map with the ^{22}Na point source off-center (# events in Photopeak)



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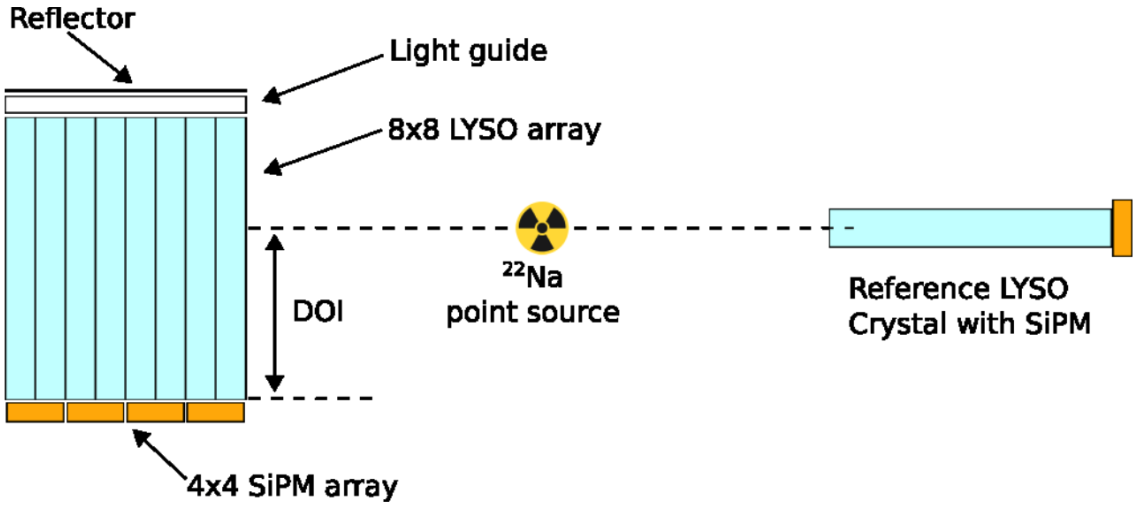
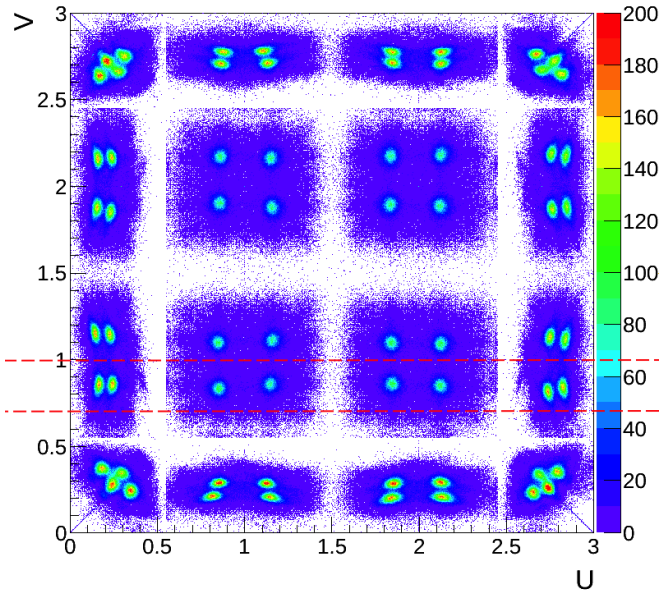
PET Detector Module with DoI

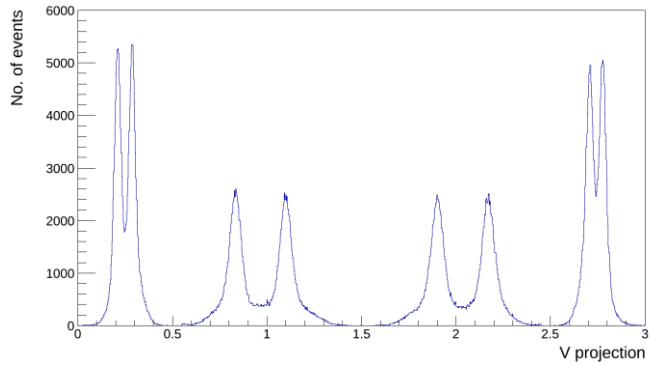
ASIC1 Detector module with DOI



- Module with 8x8 scintillator matrix
- Each pixel 1.53x1.53x15 mm^3
- MPPC array with 4x4 pixels with 3.2 mm pitch
- New light sharing method (patented)
- TOFPET1 readout

ASIC1 Detector module with DOI



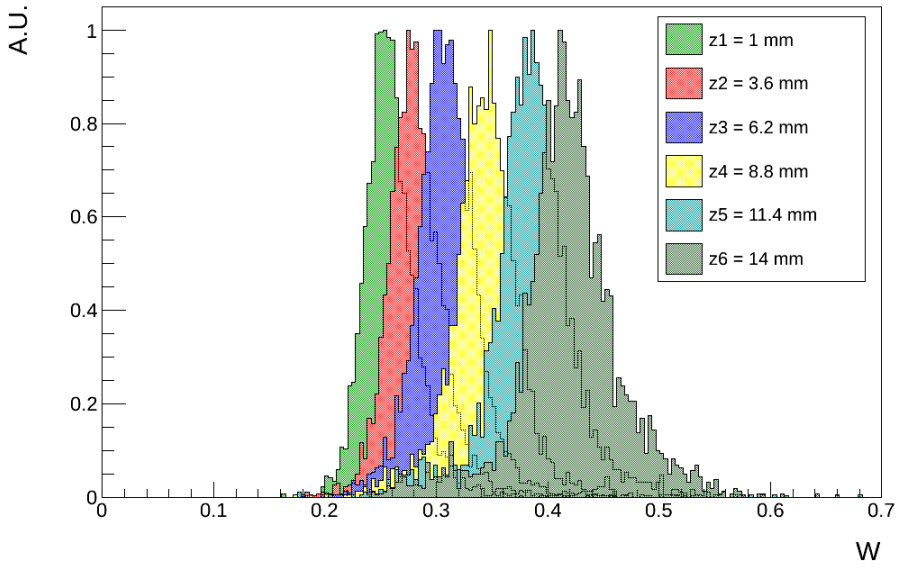


$$E = \sum E_i$$

$$U = \frac{1}{E}\sum x_i.E_i \qquad V = \frac{1}{E}\sum y_i.E_i$$

$$W = \frac{E_{\max}}{E}$$

DoI resolution: 5 mm FWHM



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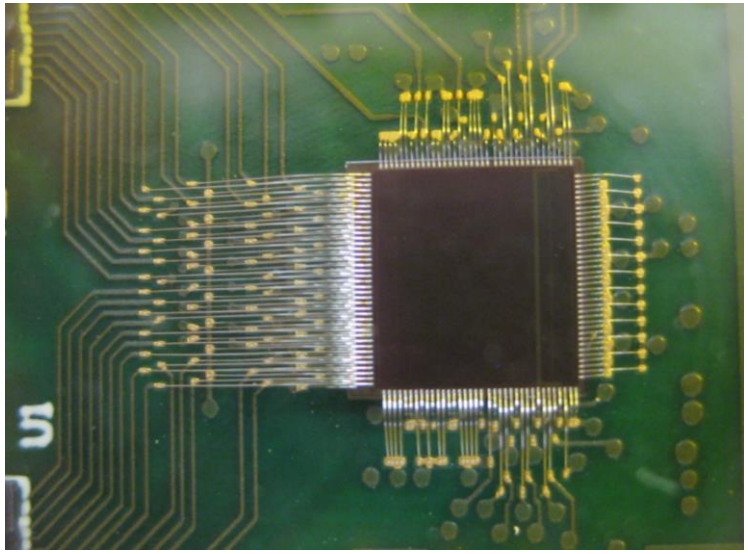
First results with TOFPET2 ASIC

TOFPET2 ASIC

- Improved timing measurement
  - Aiming at PET CTR of 200 ps
- Linear energy measurement in the range 0-1500 pC
  - Compatible with high gain SiPMs
  - Charge integration ADC
- Event rate up to 600 kHz per channel
  - Suitable for PET modules with light sharing
- Reduced power consumption
  - 5-6 mW/channel

TOFPET2 ASIC available since a few weeks



CMOS 110 nm
Die size 5x5 mm^2

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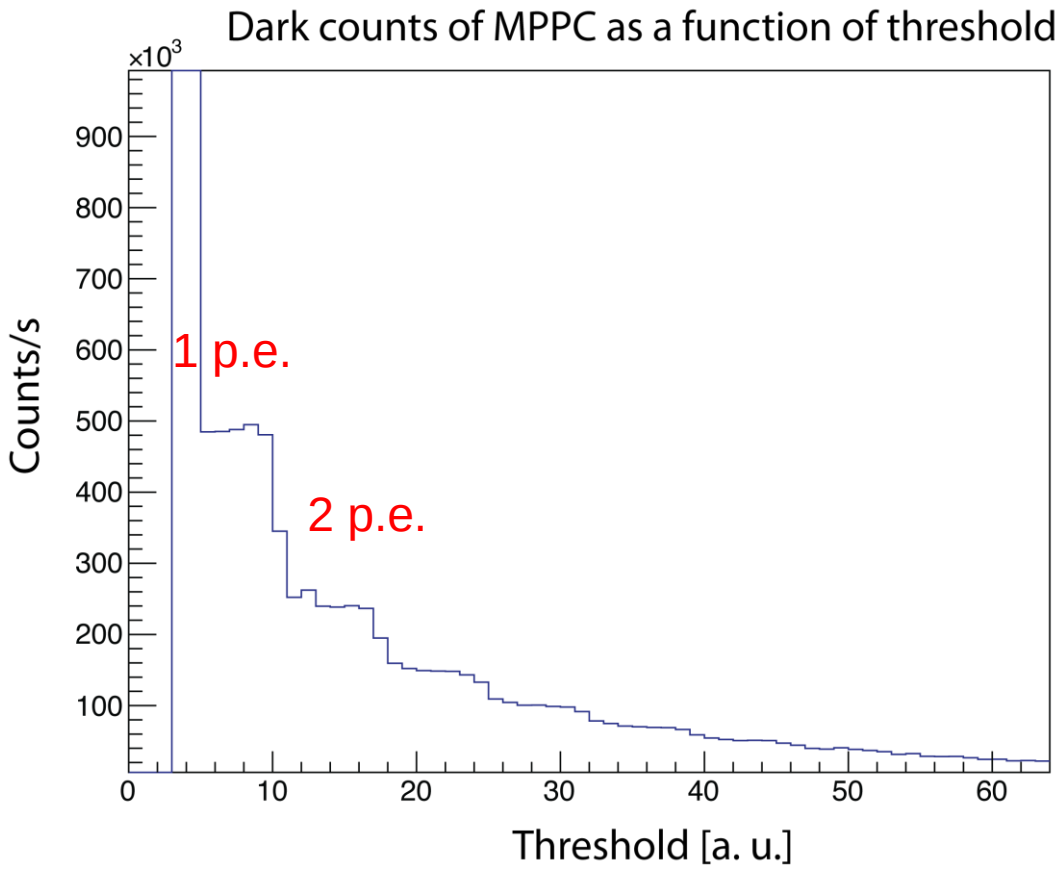
TOFPET2 ASIC



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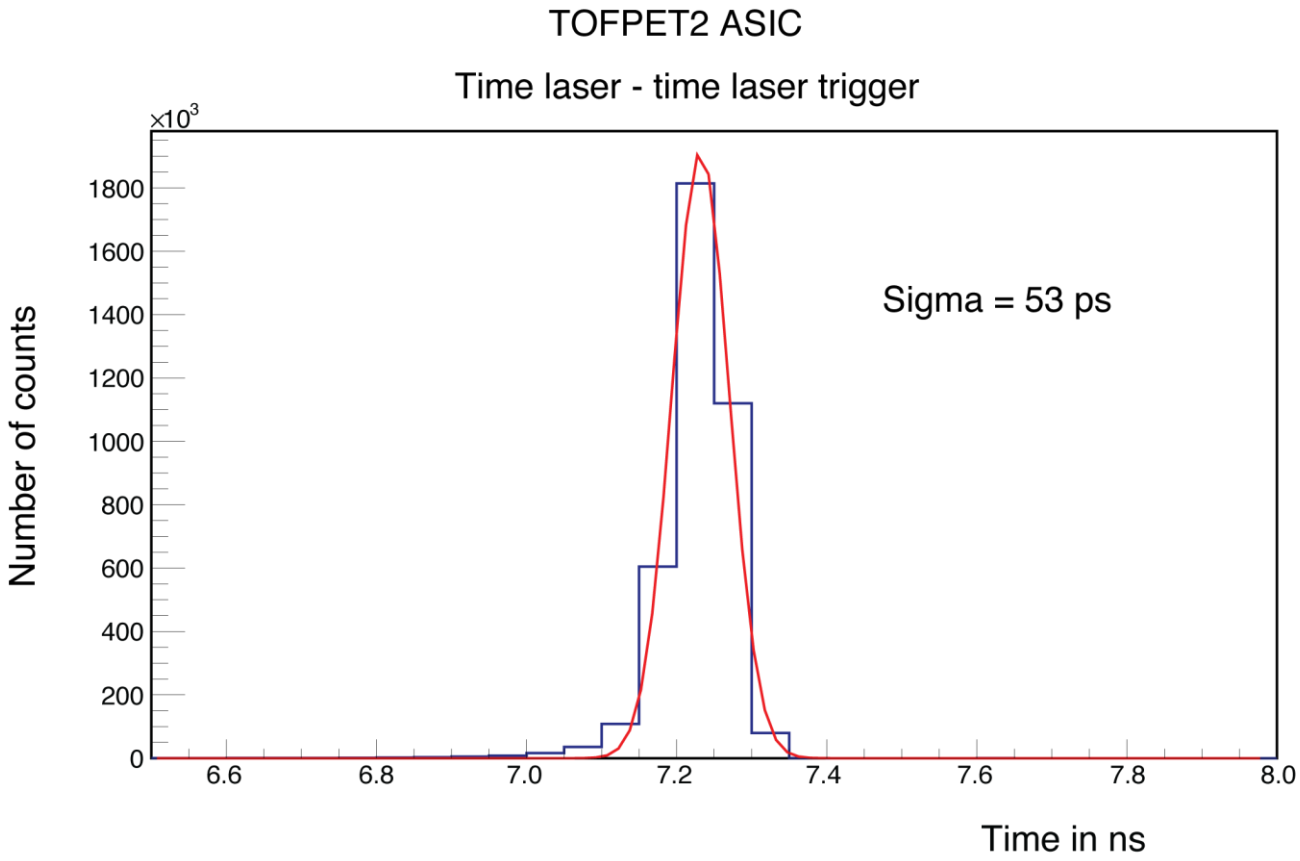
TOFPET2 ASIC



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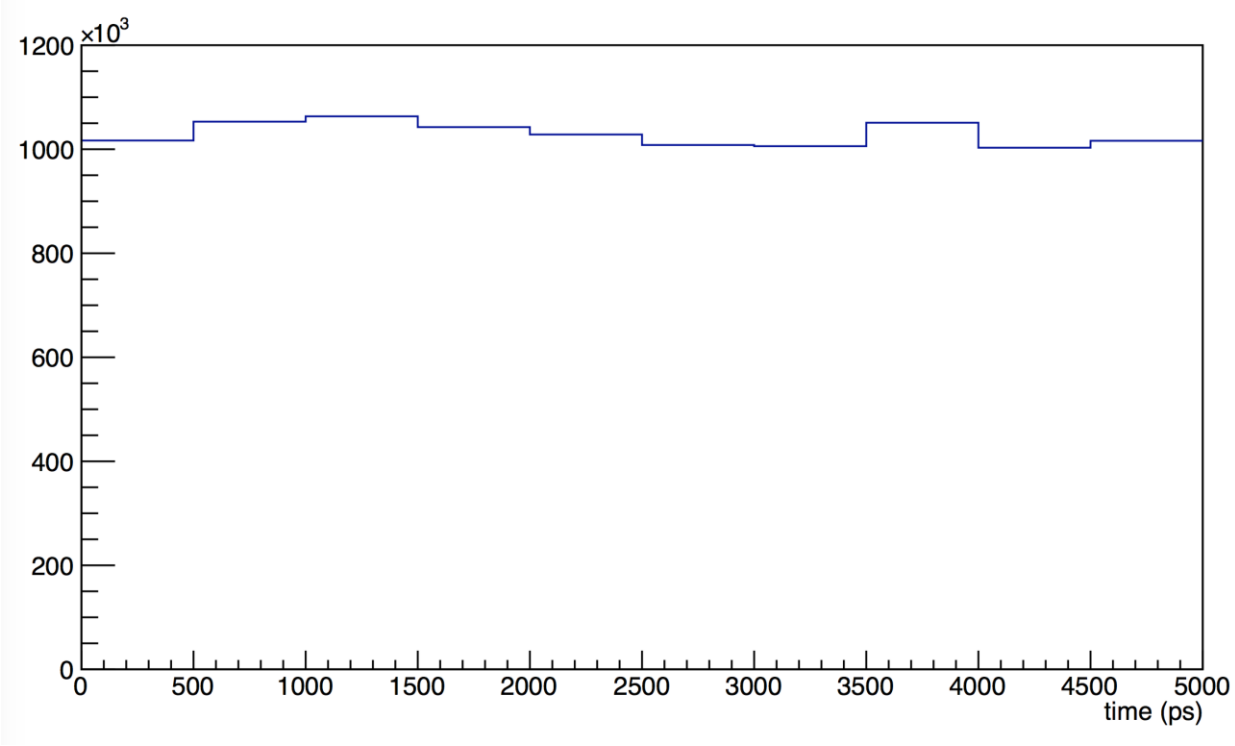
TOFPET2 ASIC

Fine time for dark count evens



time (ps)

Clock 200 MHz

Time least count 40 ps

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Summary and conclusion

- PETsys has developed a powerful and versatile readout for PET scanners scalable to several 10'000 channels.

- We have developed a novel DOI registration principle that is simple and inexpensive.

- First result with the new TOFPET2 ASIC are very promising.

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Thank you for your attention

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TOFPET1 architecture

Time and Energy measurement of 64 individual channels