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Investigating Microchannel Plate PMTs with TOFPET2 multichannel picosecond timing electronics

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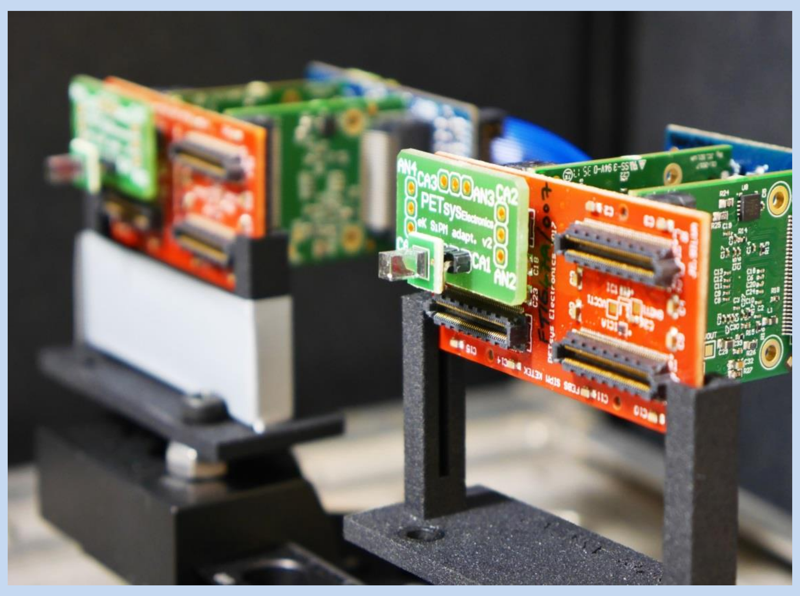
Introduction

TOFPET2 is the second-generation design of a high-performance multichannel picosecond timing readout electronics ASIC produced by PETsys Electronics SA, Portugal [1]. Originally developed for time-of-flight positron emission tomography (TOFPET) using silicon photomultipliers, in this work we describe an experimental programme to evaluate the performance of TOFPET2 with pixelated microchannel plate (MCP) photomultiplier tube (PMT) detectors.

Previous work investigating the first generation TOFPET ASIC demonstrated MCP PMTs operation and multi-anode MCP imaging in single photon counting mode with time resolution of 43 ps [2]. This current work now focusses on the TOFPET2 generation ASIC incorporating significant design advances.

TOFPET2 Summary

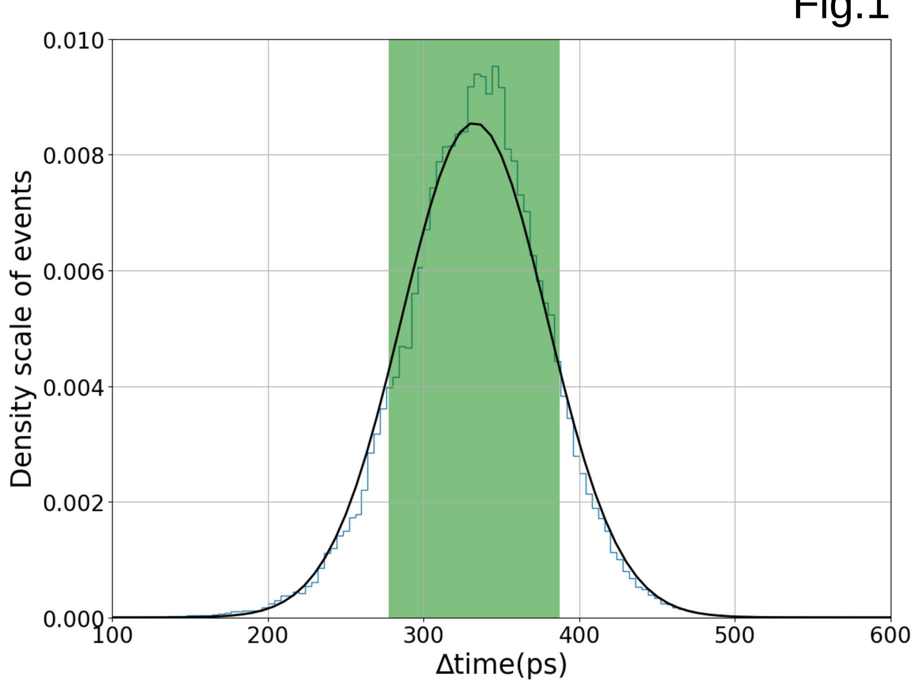
- 64 independent channels - 5x5 mm^2
- Low-noise and low-power
- Optimised for TOFPET
- Standard CMOS 110 nm
- Positive signal polarity
- Dynamic range 100 fC - 1500 pC
- Noise 1.5 mV (1 p.e. ~ 30 mV)
- Charge integration ADC - 10 bit
- TDC time binning 30 ps
- Low power: <12.5 mW/Channel
- Very high event rate capability up to 30 Mcps per ASIC
- On-chip calibration circuitry
- Maximum event rate is 480kHz per channel
- Up to 2 MHz dark counts rejection



The TOFPET2 SiPM front-end

TOFPET2 ASIC Performance with SiPM

Fig.1



The two SiPMs front-ends from the e-kit hardware were arranged inside a dark-box along with a pulsed laser, partial mirror, ND filter and Peltier cooler to stabilise the SiPM temperature. The SiPM was illuminated using a 40 ps 650 nm laser pulse, synchronised to the TOFPET2 ASIC clock, the individual channel timing resolution was measured at 110 ps FWHM.

References

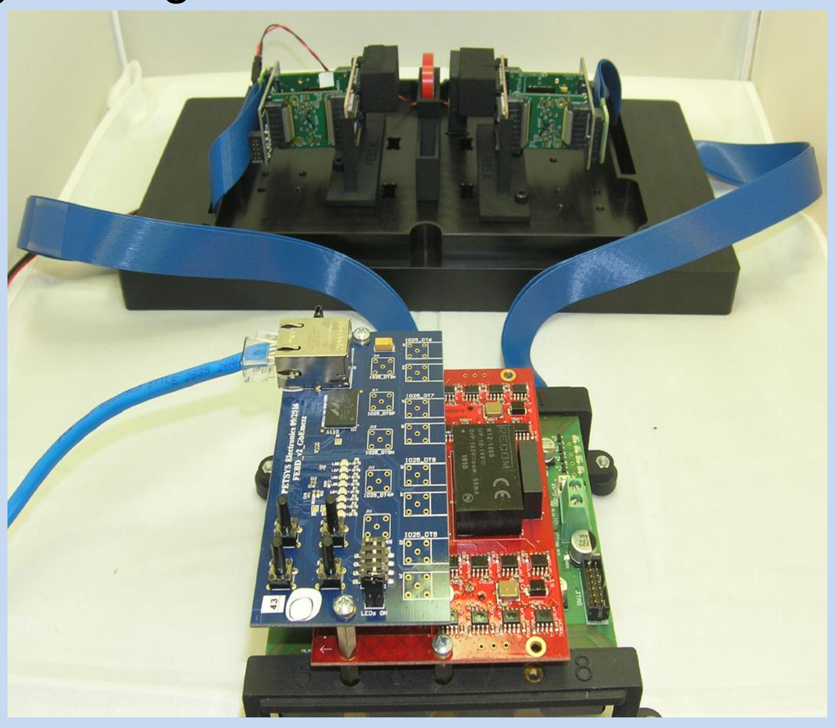
[1] Di Francesco, A., et al. "TOFPET2: a high-performance ASIC for time and amplitude measurements of SiPM signals in time-of-flight applications." Journal of Instrumentation 11.03 (2016): C03042.

[2] LEACH, S.A., LAPINGTON, J.S., MILNES, J.S., CONNEELY, T., BUGALHO, R. and TAVERNIER, S., 2018. Operation of microchannel plate PMTs with TOFPET multichannel timing electronics. NIMA

[3] PETsys. High performance TOFPET2 ASIC Flyer E-kit2_V23.pdf

PETsys TOF ASIC evaluation kit

The latest e-kit consists of FEB/D board with Ethernet link, mechanical assembly, two FEM128 modules, two SiPM pixels with attached LYSO crystal together with and enclosure incorporating a Peltier cooler [3].

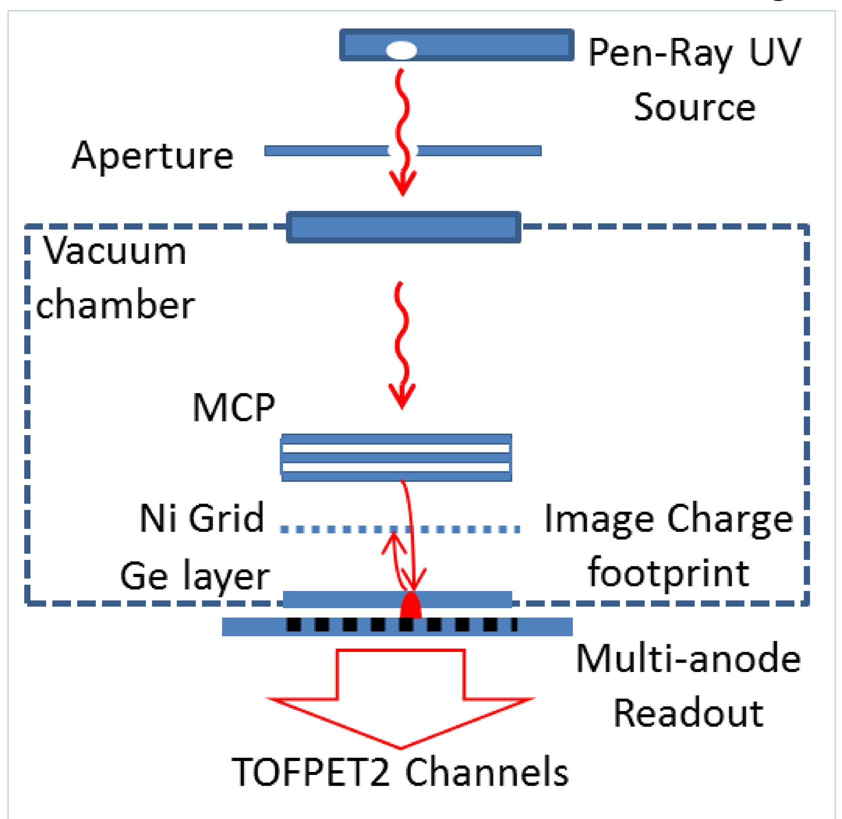


TOFPET2 is optimised for SiPM array applications but this study investigated operation with microchannel plate photomultipliers.

The e-kit hosts 4x 64 channel TOFPET2 ASICs → 256 independent channels.

Imaging with a MCP Detector

Fig.2



The e-kit hardware is primarily designed for positive input signals so to interface with a MCP detector (producing an electron signal) a novel "active anode" approach was employed to generate positive signals. The experimental setup consisted of an open-faced Z-stack MCP detector housed in a vacuum chamber (fig.2) and illuminated with a Pen-ray Hg discharge lamp.

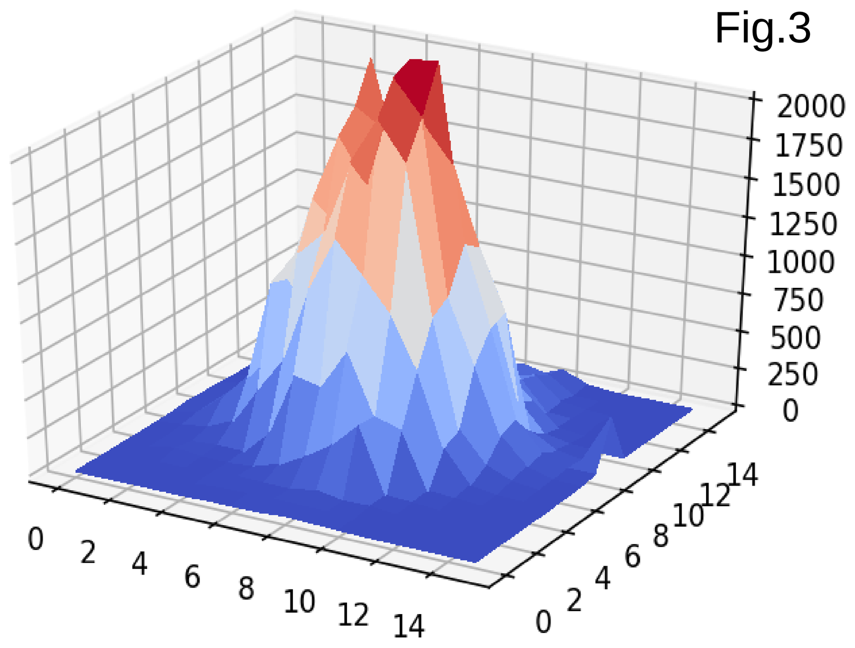
The detector signal was read out by a 16 x 16 discrete pixel readout array, each pixel coupled to a TOFPET2 channel, allowing images to be generated by illuminating the MCP using an UV light source (fig.3).

Active Anode Technique

This utilises a conductive grid directly behind, and positively biased wrt the MCP stack. The primary electron signal transits the grid and impacts the dynode whose potential lies between the MCP output and grid. The dynode (a Ge layer here) is resistive (MΩs/□) and has high secondary electron emission (SEE), deposited on an insulating substrate. Secondary electrons emitted from the dynode are collected by the more positive grid (the anode) leaving a net positive charge on the dynode. When a high SEE dynode material is utilised the dynode acts as a gain element. It also performs an Image Charge role, inducing a transient positive signal through the substrate onto the capacitively coupled 16 x 16 discrete pixel readout array, the DC component of the signal slowly leaking away through the resistive dynode. The charge footprint induced on the readout spreads across several pixels due to the substrate thickness allowing centroiding to be used to generate sub-pixel spatial resolution combined with picosecond timing.

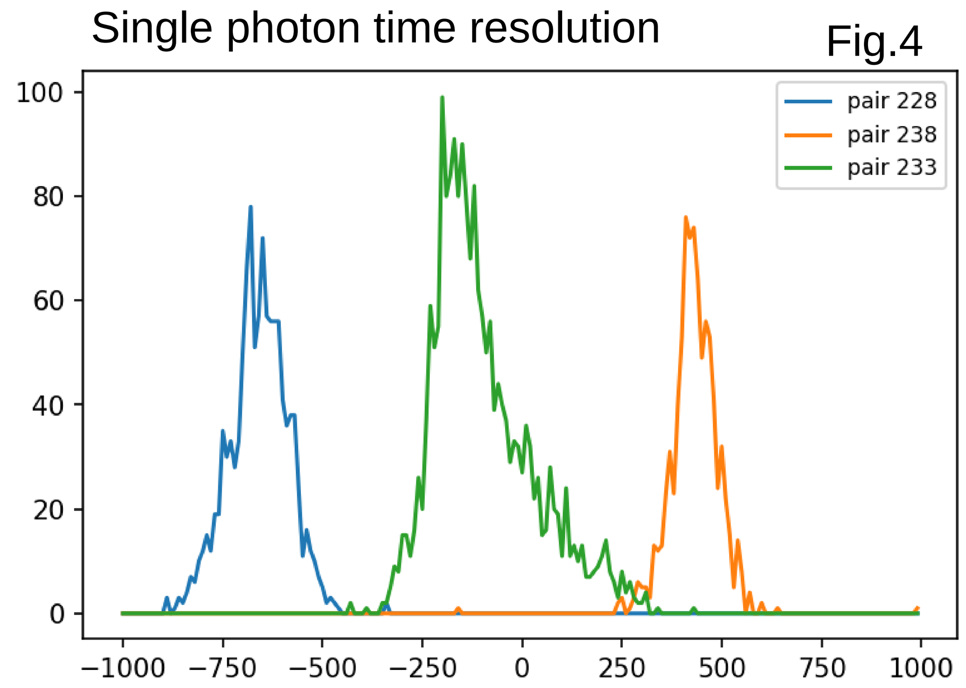
Timing Resolution

Fig.3



Single photon time resolution

Fig.4



Because single events are spread across several pixels, the corresponding TOFPET2 channel hits are simultaneous and can be used to investigate the timing resolution. Fig.4 shows histograms of the time difference between pairs of adjacent pixels (3 different pairs shown) resulting from single events. The TOFPET2 timing resolution for coincident events ($\sqrt{2}$ x the single channel resolution) is represented by the width, the time offsets being caused by fixed skews between channels.

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