Performance Study of Silicon Photomultipliers as Photon Detectors for PET

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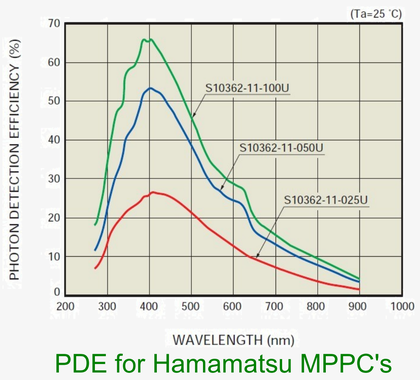
Motivation

Positron Emission Tomography (PET) is a non-invasive method for in-depth and in-vivo imaging of tissue. The annihilation gamma-rays of 511 keV,originating from a positron-electron annihilation, are usually detected indirectly, through scintillation in inorganic crystals. Photon detectors, like Photomultiplier Tubes (PMTs), detect the scintillation light. The majority of PET devices use PMTs, but due to their size, relatively poor ratio of active to total surface and high price, which is a significant fraction of the total cost of the device, it is worthwhile to search for alternate detectors of visible and infrared photons. The sensitivity of PMTs to magnetic fields and the increasing requirement to unify different image modalities in one measurement, provides an additional reason to search for new detectors. One would like to incorporate a PET apparatus inside a MRI magnet for simultaneous imaging of tissue function and density. A new type of semiconductor detector, the Silicon Photomultiplier (SiPM) looks very promising. Surface sensitivity, energy resolution and timing resolution have been measured for several different samples and types.

Typical SiPM Characteristics:

- Low operating voltage ~ 10 – 100 V
- High gain ~ 10^5 – 10^6
- Peak PDE up to 65% (@400nm)
  PDE = QE x ε_{geig} x ε_{geo}
  ε_{geo} ~ microcell fill factor
- Good time resolution ~ 100-200 ps
- Insensitive to magnetic fields
- High dark counts ~several 100kHz/mm^2



PDE for Hamamatsu MPPC's

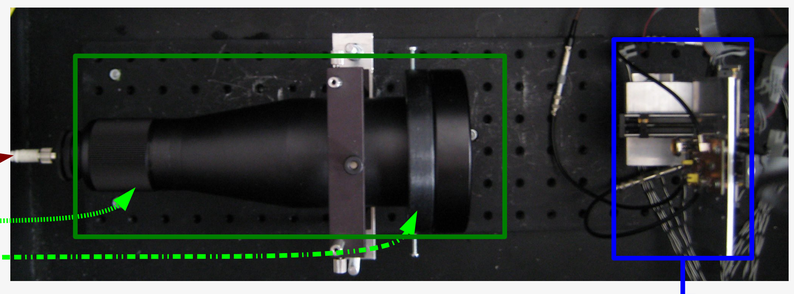
Surface Sensitivity

Surface sensitivity is assessed by exposing each SiPM to a pulsed laser beam. The SiPM is placed in the focal plane of the laser beam ($\sigma \approx$ 5µm). To produce 2D scans the SiPM is moved relative to the light source to measure of the count rate of single photons hits over the surface of the silicon photomultiplier. Selection was done on single pixel pulse height in a ~ 10 ns TDC time window.

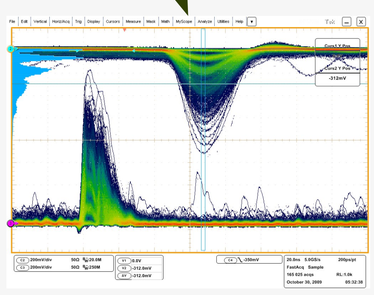
Surface Scan Setup

•Laser optics:

- Laser (635nm)
- Beam expander
- Focusing lens

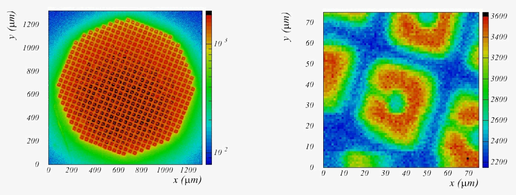


Typical SiPM signal for low light intensities



	Hamamatsu S10931-100P	Photonique 0607	STM
Package type	Surface Mountable	Printed Circuit Board w/ pins	Metal package
Size (mm^2)	3 x 3	2.1 x 2.1	3.5 x 3.5
Op.Voltage (V)	70	25	30
Gain	~ 2 x 10^6	~ 8 x 10^5	~ 10^6
Pixel Size(µm)	100	40	25
# of pixels	900	1700	4900

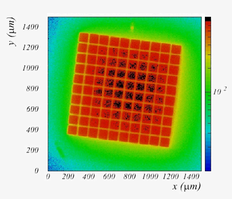
S137 (CPTA/Photonique)



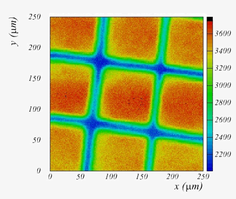
5 µm step size

1 µm step size

Hamamatsu MPPCs H100C

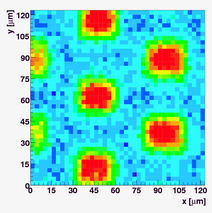


5 µm step size

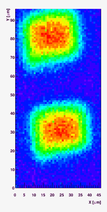


1 µm step size

STMicroelectronics



3 µm step size

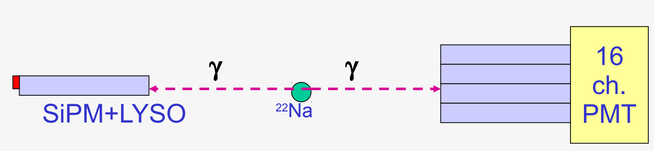

1 µm step size

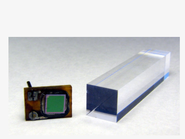
The SiPM of STMicroelectronics (STM) has special trenches between the pixels filled with a metal oxide which aims to reduce electro-optical crosstalk between neighbouring pixels. This results in a smaller fill factor (~36%) compared to the others.

Energy Resolution

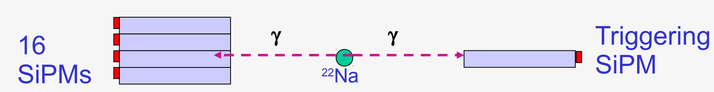
Performance of several SiPMs have been measured by coupling a LYSO crystal to the SiPMs and measuring the coincidence annihilation γ's from ^{22}Na source.

PET Setup: Single SiPM

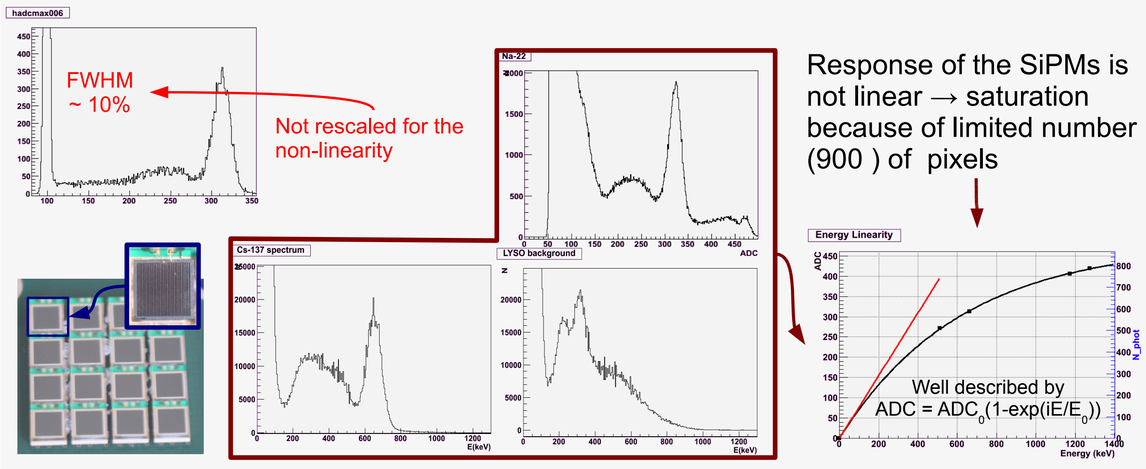




PET Setup: SiPM Module (4x4 SiPMs)

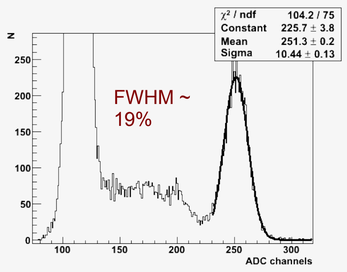


Hamamatsu

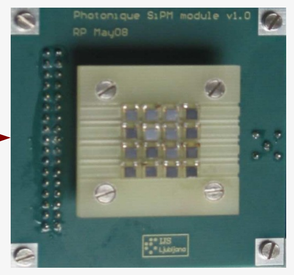


Photonique

- 4x4 array of LYSO crystals (4.5 x 4.5 x 20(30) mm^3)
- 16 SiPMs (Photonique 2.1x2.1 mm^2)



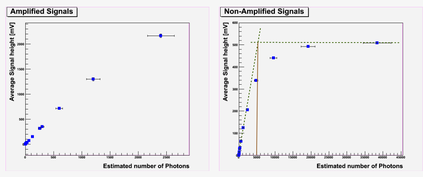
- Big variation in the position of the photopeak:
  - 16% RMS for different channels
- Small light yield!
- Problematic coupling of the module to the LYSO scintillator array

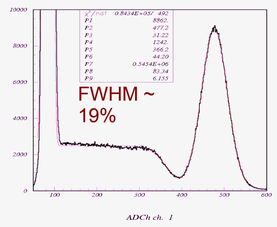


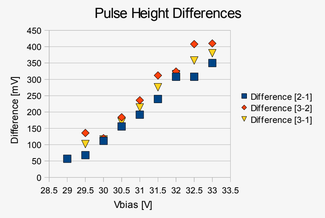

2.1x2.1 mm^2
1700 pixels

STMicroelectronics

Linearity study with laser





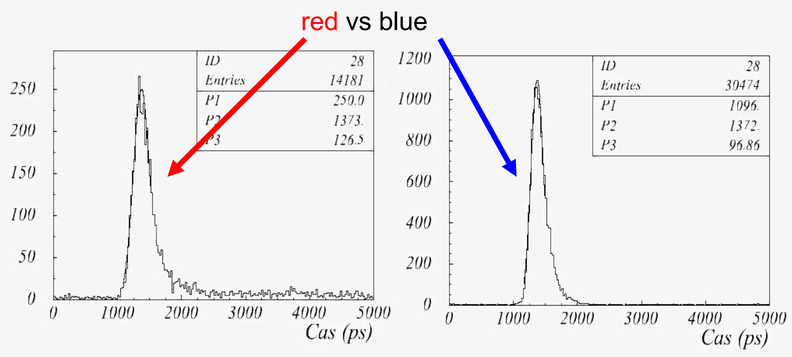


- Uniform light distribution over SiPM
- Neutral density filters → control the intensity of illumination

Time Resolution at Single Photon Level

Response of the Silicon Photomultiplier to low light intensity pulses (single photon level) from a PILAS laser. Without a scintillator attached – pure SiPM. SiPM's with larger pixels have better timing properties.

Hamamatsu (H050C, H100C) vs. **Photonique** (S137) vs. **Pulsar/MEPH** (E407)



Timing resolution for small devices (1mm^2)

larger devices

larger capacitance

longer signal / worse timing

1mm^2 SiPMs	E407	S137	H100C	H050C
σ_{red} (ps)	127	182	145	212
σ_{blue} (ps)	97	151	136	358

$\sigma \approx$ 100-200 ps