6th International Conference on
New Developments In Photodetection
NDIP2011
Lyon - France, July 4-8, 2011

Highlights of Poster Session I: SiPMs

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Poster Session I

- 21 contributions on SiPM characterization and their applications
- Many thanks to all contributors (17) who sent me their highlight slides
- Order of presentation is numerical – no preferences

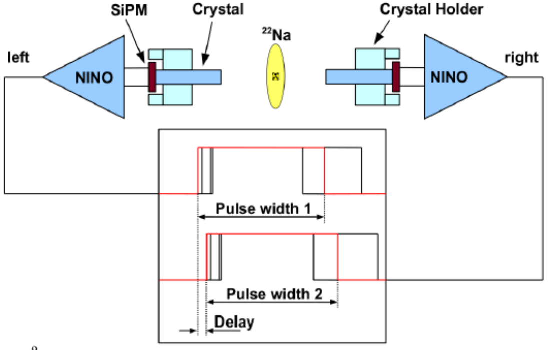
A Systematic Study to Optimize Crystal-SiPM Photodetectors for Highest Time Resolution (Stefan Gundacker et al. ID-22)

Tests comprised a series of systematic studies in terms of:

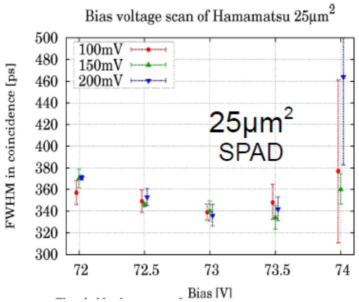
- SiPM fill factor or SPAD size, i.e. 25, 50, 100μm^2
- SiPM bias voltage
- Discriminator (NINO) threshold

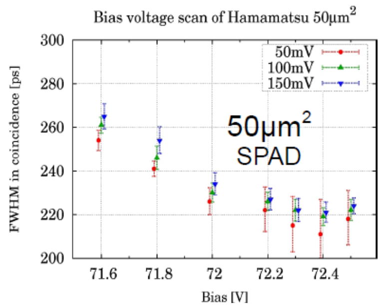
The main criterion for the optimization is the coincidence time resolution measurement:

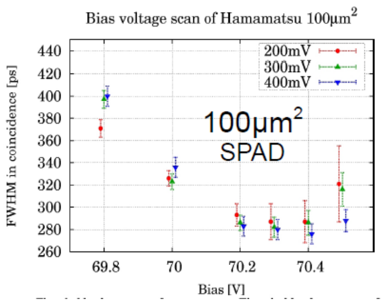
Type: S10931	SPAD size [μm^2]	Number of Cells	Fill Factor [%]	Dark Count [MHz]
-025P	25x25	14'400	30.8	4
-050P	50x50	3'600	61.5	6
-100P	100x100	900	78.5	8



Results







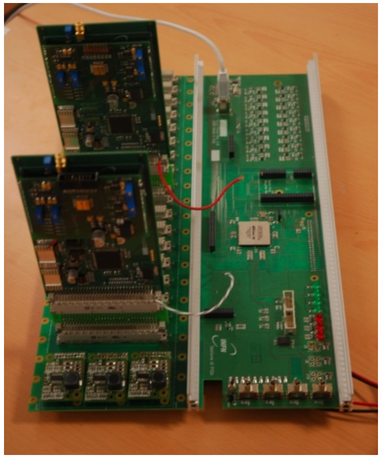
All three SiPM produced by Hamamatsu have the same active area of 3x3mm^2.

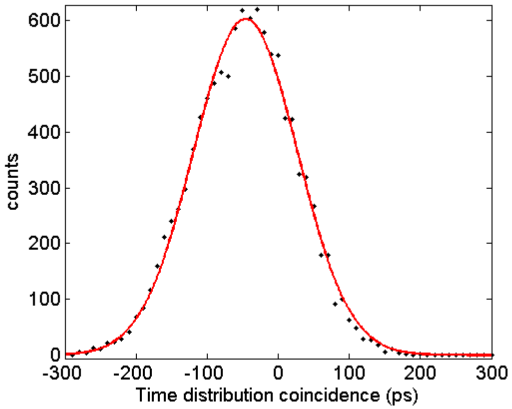
SPAD Size [μm^2]	SiPM Bias [V]	NINO Threshold [mV]	CTR FWHM [ps]
25	73	150	340±9
50	72.4	100	220±4
100	70.3	300	280±9

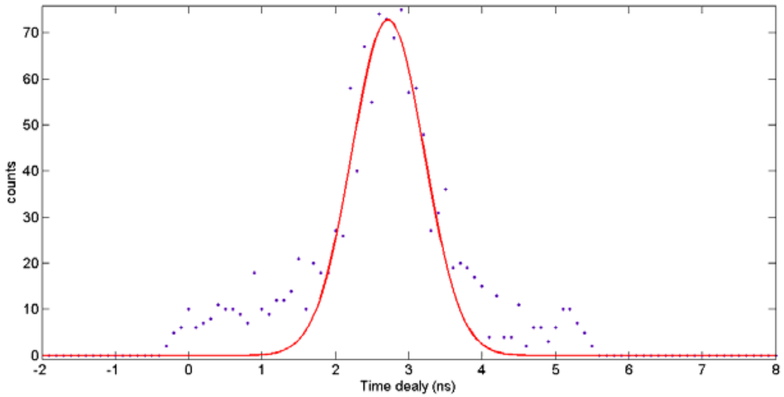
Within the limited reach of only three measurements in this test series, the SiPM with 50μm^2 SPAD size offers a "balanced optimum" between fill factor and dark noise rate, thus leads to best results. This is supported by the fact, that the highest photoelectron yield (PeY) is also achieved with the 50μm^2 SiPM type.

Test modeling of a data acquisition system for Time of Flight PET (Matteo Morrocchi et al. ID-43)

Performances of a data acquisition system for PET based on LSO crystal slabs and 64 channels Silicon Photomultipliers (SiPMs) matrices and with a custom front-end electronic (BASIC) was investigated



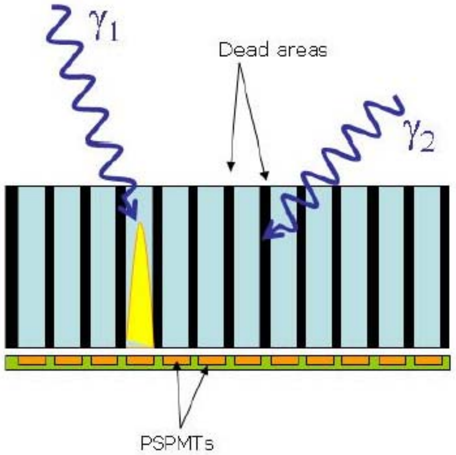




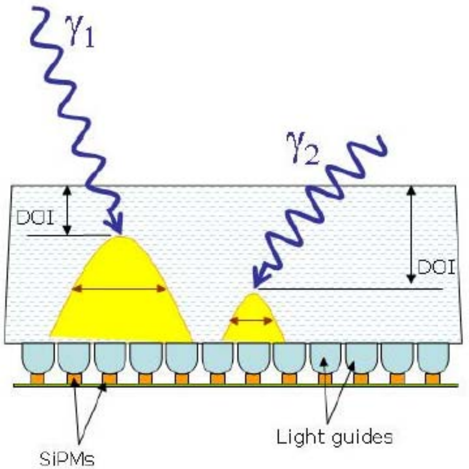
Coincidence time resolution of σ ≈ 70 ps was meaasured between two different ASICs using sincronous tests signals.

Coincidence time resolution of σ = 490 ps was obtained between two different matrices of SiPMs coupled with a continuous slabs of LYSO 12x12x5mm with a single low level trigger.

Innovative PET detector concept based on SiPMs and continuous crystals (Antonio J. Gonzalez Martinez et al. ID-49)



Current Technology



Proposed Technology

Monolithic crystals

increase sensitivity when compared with current technology
enable depth of interaction determination suppressing parallax error
no spatial resolution limitation due to pixel size

SiPM

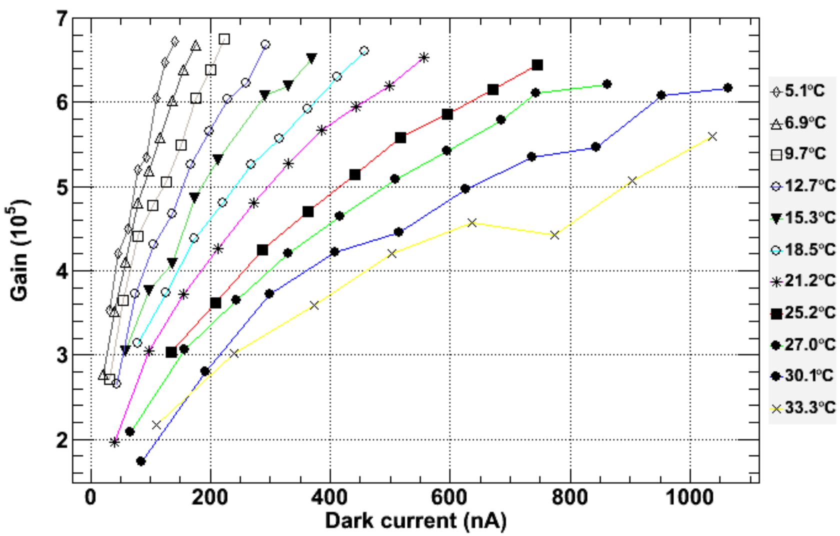
cheaper to manufacture when compared with PMTs
suitable to work in magnetic field environments
fast, enable Time of Flight measures in contrast to APD

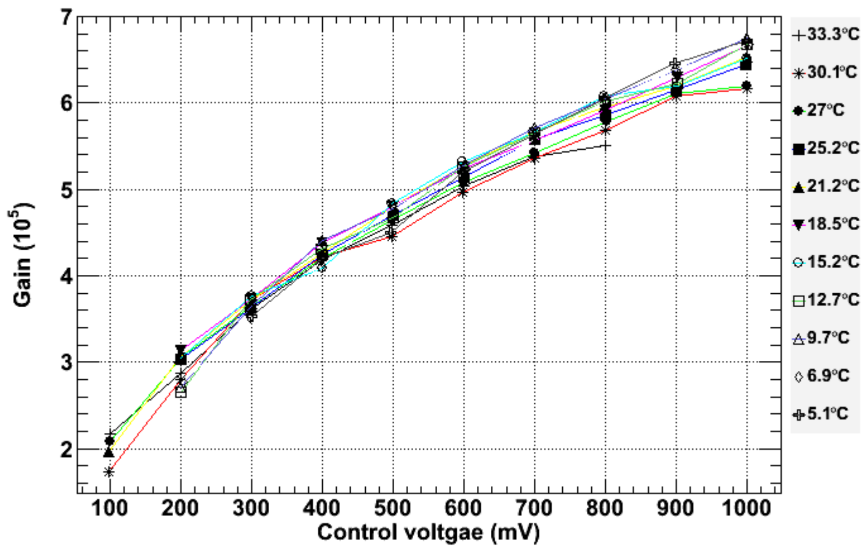
ASIC

the use of single crystals allows to easier return few signals describing the light distribution

A gain control and stabilization technique for silicon multipliers used in low light applications (Yupeng Xu et al. ID-69)

The relative high dark current of silicon multipliers (SiPM) can be approximated by a exponential function of temperature for a fixed gain which is similar to the behavior of the NTC thermistor. According these facts, a gain control and stabilization circuit for SiPM is developed by using a programmable current sink with temperature compensation. Detailed design and performance test of the circuit over a wide temperature will be discussed in this poster.





- The gain dependence on dark current was measured at different temperatures.
- The dark current follows the similar function of an NTC thermistor at fixed gains.
- Hence, a voltage-controlled current sink with temperature compensation was developed for gain stabilization.
- A relative variation less than±3% was achieved for gain about 5.5x10^5 in the temperature range of 5.1-33.3^{o}C.

New method for determination of non-quenching regime for silicon photomultipliers: A comparative study (Christian Jendrysik et al. ID-76)

A new method to estimate the initiation of the non-quenching condition in silicon photomultipliers (SiPM), limiting the maximum over-bias voltage will be presented. By determining the ratio of measured to calculated current, in which latter results from measuring the dark count rate, the start of the non-quenching regime can be identified by a disproportionately high increase of this ratio. First comparative studies of devices from Hamamatsu, SensL, MEPhI, and MPI semiconductor laboratory were performed.

Measurement procedure :

- *IV*-measurement of dark current
- measurements of dark counts *DC* vs. overbias
- measurement of optical crosstalk contribution N_X vs. overbias (integral of normalized count rate)
- measurement of internal gain *G* vs. overbias

Asymptotic steady-state value of diode current

$$I_f = \Delta V / R$$

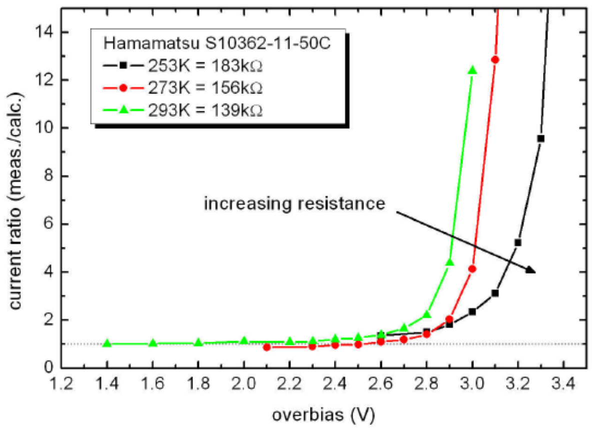
→ quenching condition: $I_f < 20\mu A$ (rule of thumb)

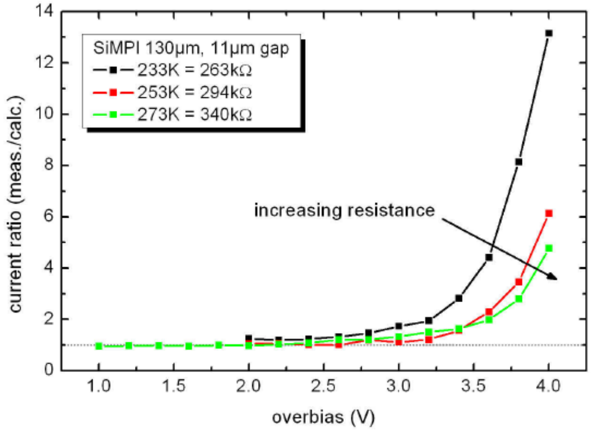
Our approach:

- compare measured with calculated dark current

$$I_{calc} = DC \cdot N_X \cdot G \cdot e \quad e\text{: elementary charge}$$

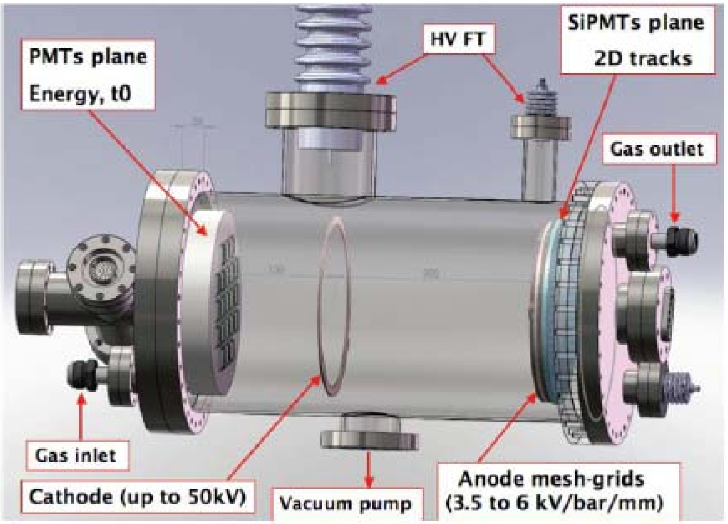
•Ratio $R = I_{meas}/I_{calc} >> 1$ indicates non-quenching



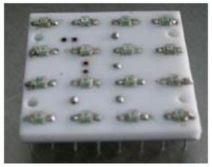


Readout electronics for the SiPM tracking plane in the NEXT-1 prototype (José Toledo-Alarcón et al. ID-79)

NEXT (Neutrino Experiment with a Xenon TPC) is a new experiment to search for neutrinoless double beta decay using a 100 kg radio-pure high-pressure gaseous xenon TPC with electroluminescence readout. NEXT-1 is a large-scale prototype equipped with two sensor planes in opposite sides of the detector vessel. One plane will measure event energy with PMTs and will also detect the primary scintillation light. The other plane will use a SiPM array to follow the primary electron paths and to help in the discrimination of interesting events from the background.



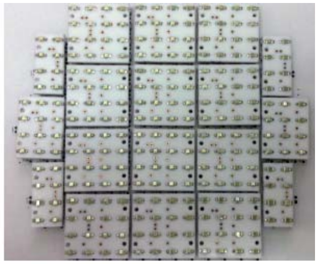
The NEXT-1 TPC. The anode is equipped with a SiPM plane used for the pattern recognition



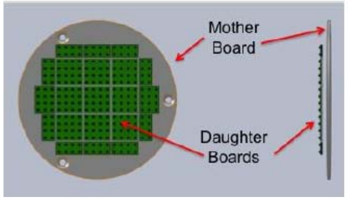
16-ch daughter board

The SiPM plane contains 248 sensor elements (Hamamatsu MPPC, 1mm^2 active area, SMD type) mounted on 18 daughter boards.

The daughter boards are in turn mounted on a 238-mm diameter mother board for mechanical support and electrical connections.



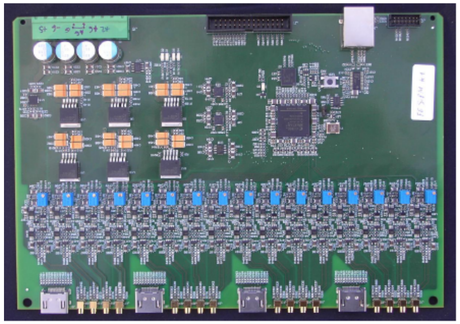
SiPM plane array



Sensors on the same daughter board share a common bias voltage. The gain dispersion in each daughter board is better than 4% while the average gain of each board is in (2,27–2,50)10^5. This ensures a uniform plane response.

The digital section is based on a small FPGA that reads the 10-bit ADCs (AD7277), controls the switches in the gated integrators, builds a frame with the digitized data and communicates with the upstream readout stage using a standard RJ-45 connector and CAT6 cable. Careful PCB layout techniques ensure that the digital part introduces very little noise in the analog section.

The upper stage in the readout chain is the Front-End Concentrator (FEC) card, designed as a joint collaboration between CERN and NEXT in the framework of the RD-51 Collaboration readout system [6-7]. Up to 16 front-end cards can be connected to a FEC, resulting in 256 channels, enough for NEXT-1. This readout system can be scaled up by simple addition of FEC cards. Data are sent to the DAQ PCs via gigabit Ethernet.

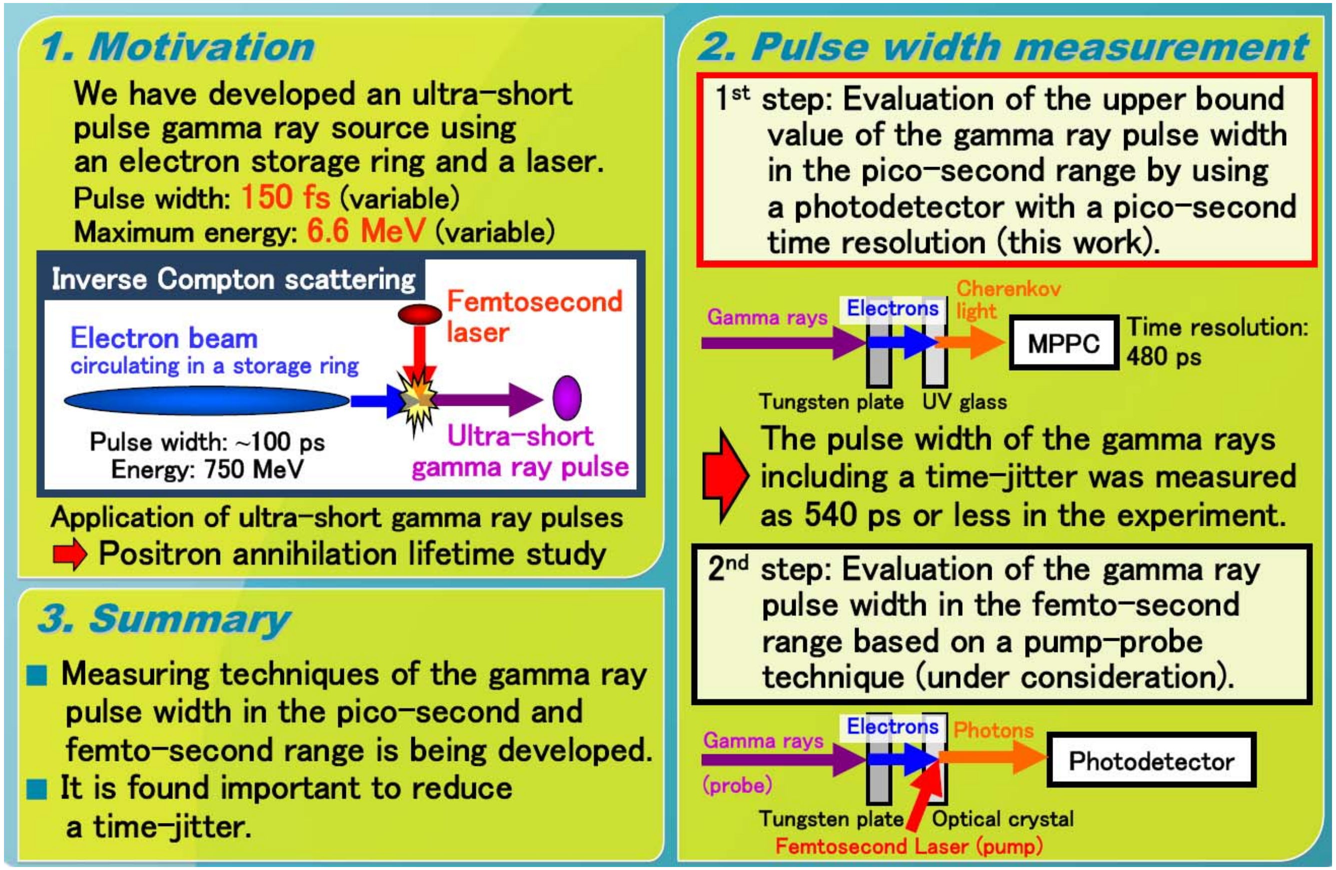


The FE-SiPM card. Digital section (top right), showing the FPGA and the RJ-45 socket to the DAQ (top right corner). BER<10^{-13} has been measured (380 Mb/s, 3 days without errors).

Analog section (bottom) with 16 analog stages (Section 3), one per channel. Input signal options are miniature coax (single ended) or HDMI (differential).

Development of pulse width measurement techniques of ultra-short gamma ray pulses (Yoshitaka Taira et al. ID-85)

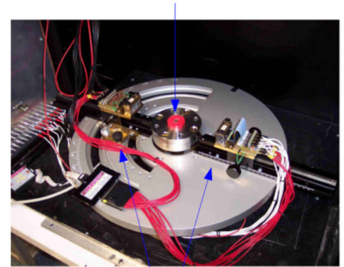
Contributors are developing pulse width measurement techniques of ultra-short gamma ray pulses. The ultra-short gamma ray pulses with the femtosecond pulse width can be generated via inverse Compton scattering at UVSOR-II, an electron storage ring. The fast response photodetectors (e.g. Geiger-mode APD and MCP-PMT) can be used for developing pulse width measurement techniques of the ultra-short gamma ray pulses by measuring the timing of the gamma rays.



Towards a multi-channel TOFPET system with SiPM readout (Alessandro Silenzi et al. ID-89)

This contribution describes a design solution for a multi-channel time-of-flight Positron Emission Tomography (TOFPET) test device with Silicon Photomultiplier readout featuring a spatial resolution of 2.5 mm for point-like sources. They discuss the possible readout system to achieve a coincidence time resolution of about 300 ps FWHM.

^{22}NA β^+source holder

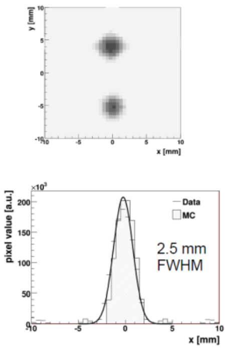


2 detector heads made of 16 3x3x15 mm^3 LFS (Zecotek) crystals 2x2 multi-anode Hamamatsu MPPC on a turning table.

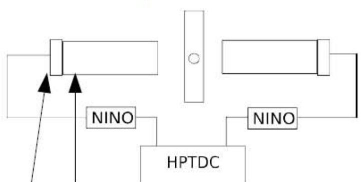
SiPM signal Digitization using ADCM:
PCI-e fADC (f_s=100 MHz)

High Voltage and Temperature compensation with HVSys USB modules

The prototype demonstrates a way of commissioning a PET, as well as providing a small scale testbed for PET electronics



^{22}Na β^+ Source



3x3x15 mm^3 LFS crystal

3x3 mm^2 50μm Hamamatsu MPPC

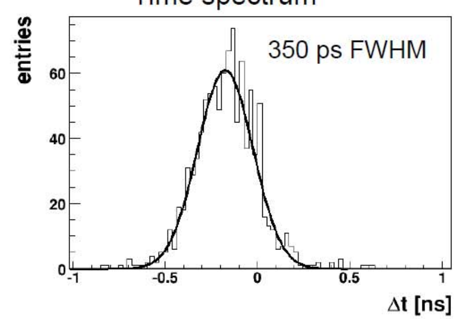
NINO ASIC translates collected energy into Time over Threshold.

HPTDC 25 ps bin width

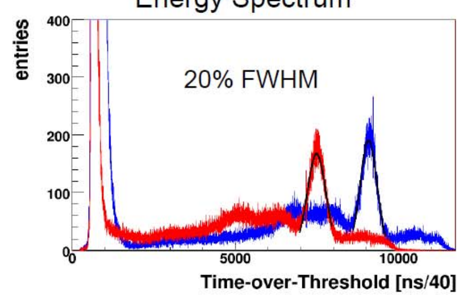
This measurement uses Front end electronics developed for HEP, in a medical oriented application.

NINO and HPTDC represent a scalable choice toward a TOF-PET.

Time spectrum



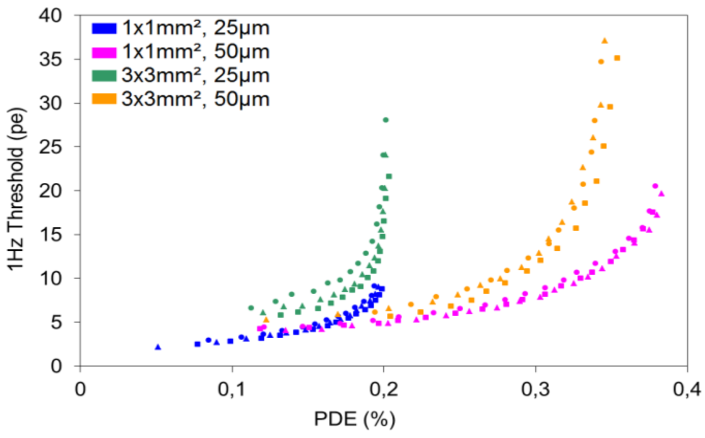
Energy Spectrum



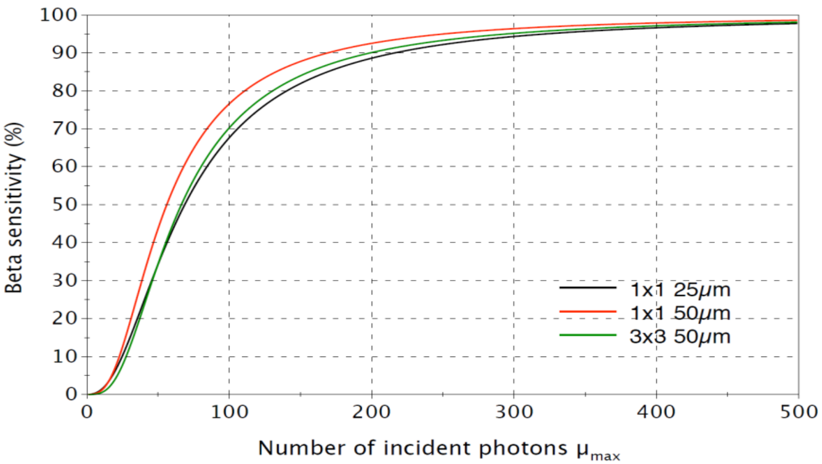
Characterization and Optimization of Silicon Photomultipliers for the Development of Intra-operative Beta Probes (Laurent Ménard et al. ID-107)

SiPMs are very promising detectors for developing intraoperative beta probes. This study aims to optimize their performances regarding bias voltage and temperature.

Intrinsic characterization of 4 SiPMs from Hamamatsu was performed:
- Thermal noise (Dark noise frequency and amplitude distribution)
- Absolute Photon detection efficiency
- Total Gain (Average number of cells fired by a primary trigger)



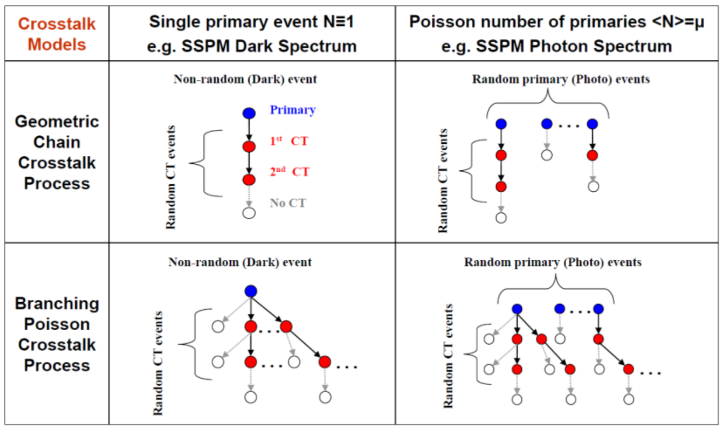
1Hz threshold is the energy threshold to achieve a 1Hz dark count rate



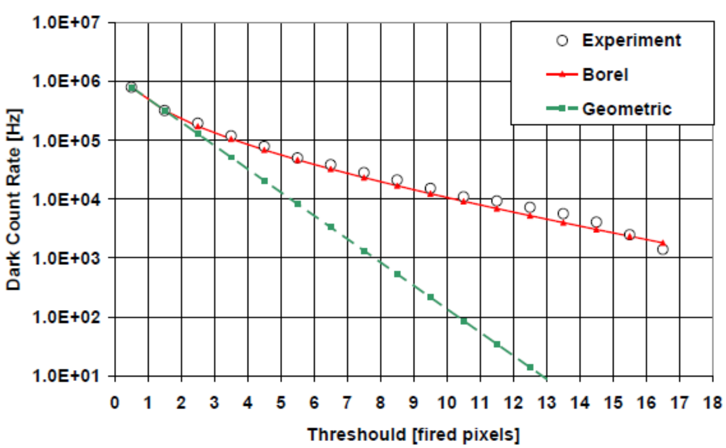
Beta sensitivity reaches up to 90% at a number of incident photons around 200.

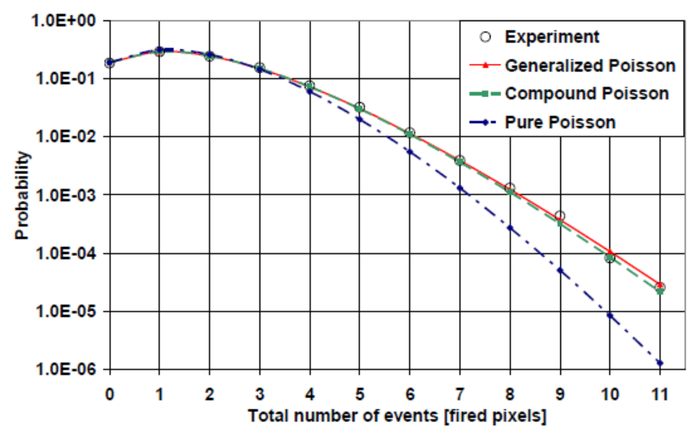
Analytical models of probability distribution and excess noise factor of Solid State Photomultiplier signals with crosstalk (Sergey Vinogradov et al. ID-110)

This study presents and discusses the analytical model of crosstalk processes based on the Borel distribution as an advance on the geometric distribution model. The model is found to be in a good agreement with the experimental probability distributions for dark count rates and photon spectra in a wide range of fired pixel numbers.



Results	Geometric chain process		Branching Poisson process	
Primary event distribution	Non-random single ($N\equiv1$)	Poisson (μ)	Non-random single ($N\equiv1$)	Poisson (μ)
Total event distribution	Geometric (p)	Compound Poisson (μ, p)	Borel (λ)	Generalized Poisson (μ, λ)
$P(X=k)$	$p^{k-1}\cdot(1-p)$	Ref. [1]	$\frac{(\lambda\cdot k)^{k-1}\cdot\exp(-k\cdot\lambda)}{k!}$	$\frac{\mu\cdot(\mu+\lambda\cdot k)^{k-1}\cdot\exp(-\mu-k\cdot\lambda)}{k!}$
$E[X]$	$\frac{1}{1-p}$	$\frac{\mu}{1-p}$	$\frac{1}{1-\lambda}$	$\frac{\mu}{1-\lambda}$
$Var[X]$	$\frac{p}{(1-p)^2}$	$\frac{\mu\cdot(1+p)}{(1-p)^2}$	$\frac{\lambda}{(1-\lambda)^3}$	$\frac{\mu}{(1-\lambda)^3}$
ENF	$1+p$		$\frac{1}{1-\lambda}\approx 1+p+\frac{3}{2}p^2+o(p^3)...$	

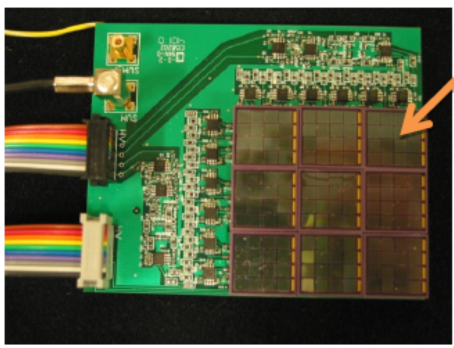


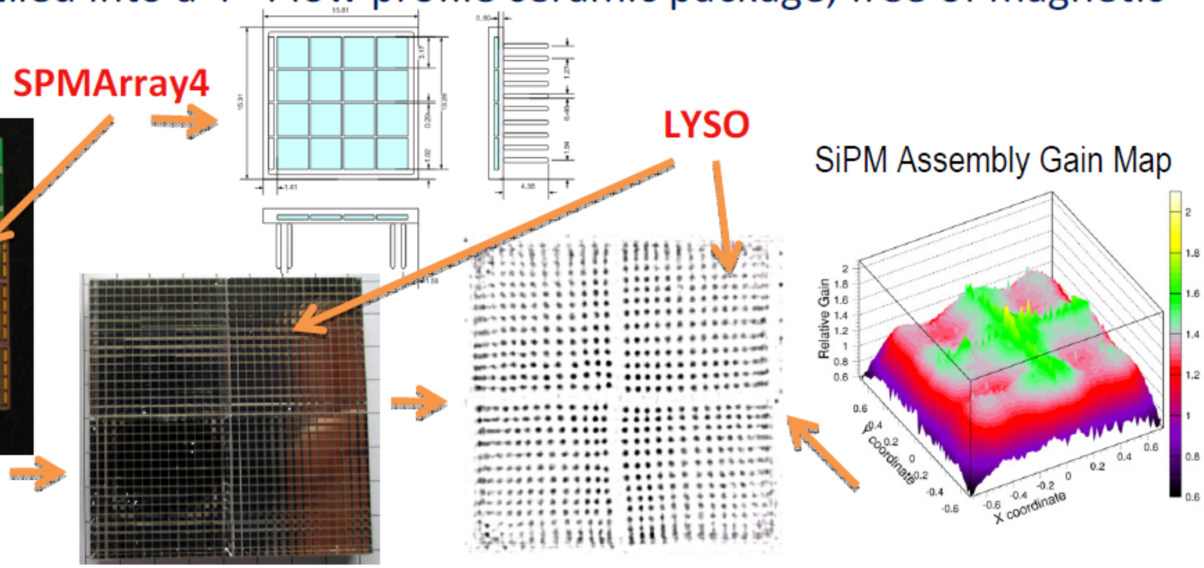


New modular readout for radiation imaging application (Vladimir Popov et al. ID-112)

Contributors have developed and tested a radiation imaging detector module for use in radiation imaging devices such as gamma cameras. The module combines nine SensL's SPMArray4 SiPM arrays in a 3×3 layout, producing a 48×46 mm^2 module with four coordinate signal outputs.

Each SPMArray4 device (15.81×15.31 mm^2) is comprised of 16 SiPM elements 3.17×3.17 mm^2 each, tiled into a 4×4 low profile ceramic package, free of magnetic material.



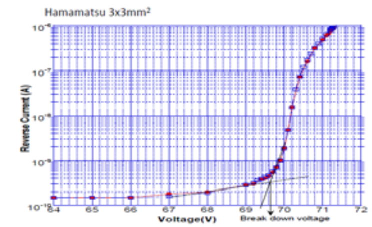


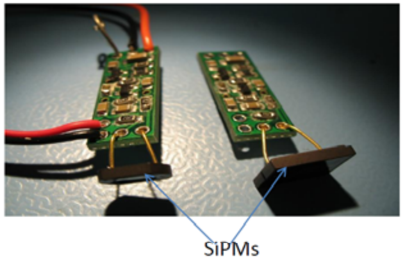
The new readout module was tested in a detector with pixelated LYSO crystal arrays using a ^{22}Na source with 511 keV and 1.27 MeV gamma lines. Position resolution in the range 1.3-2.0 mm was demonstrated both with a cooled setup and at the room temperature.

Characterization of Silicon Photomultipliers for Time-Of-Flight applications (Mahfuza Ahmed et al. ID-119)

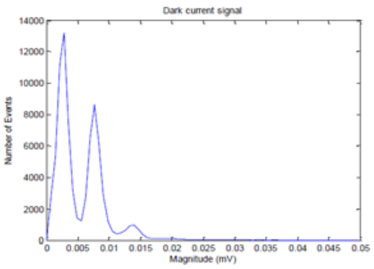
Silicon photomultipliers from 3 different manufacturers (Hamamatsu, Photonique and SensL) were characterized: the output signals in response to light sources were studied. The best timing resolution (~321 ps, RMS) was obtained for the 5 mm long LYSO crystals and 3x3 mm^2 Hamamatsu MPPCs.

I-V curve and Breakdown Voltage

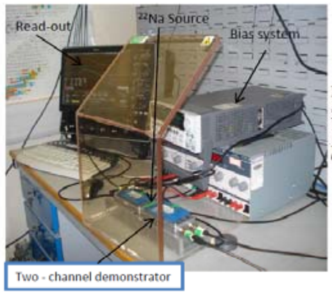




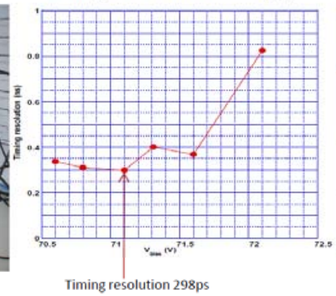
Dark noise spectra



- SiPMs of area 1x1mm^2 and 3x3mm^2 from three different vendors: Hamamatsu, Photonique and SensL
- Signal rise time:
  - with response to light are in the range 2.0–7.0ns
  - 1pe⁻, 2pe⁻ and 3pe⁻ from the dark noise are in the range 2.0–5.0ns.
- Dark count rates are in the range 0.4–6.0MHz.



Timing resolution - vs - V_{bias}



- Timing resolution as function of SiPM V_{bias}:
  - Carried out only for the $LaBr_3$ + Hamamatsu 3x3mm^2
  - Best timing resolution of 298ps measured at 0.2 below recommended V_{bias}
- Timing resolution studies at fixed V_{bias} recommended by manufacturer:
  - The best timing resolution is 321ps
  - Obtained for the 5mm length LYSO + Hamamatsu 3x3mm^2

Timing resolution at fixed V_{bias}

SiPM	Crystal	Crystal length mm	Timing Resolution σ (ns)
SensL 3x3mm²	LYSO Hilger Analytical	15	1.509
	LYSO Saint Gobain	10	1. 483
SensL 3x3mm² new 8" wafer	LYSO Hilger Analytical	15	1. 420
	LYSO Saint Gobain	10	1. 416
Hamamatsu 3x3mm²	LYSO Hilger Analytical	15	0.363
	LYSO Saint Gobain	10	0.358
	LYSO Saint Gobain	5	0.321
	$LaBr_3$ Saint Gobain	30	0.400

Crystal area 3x3mm^2

A study of Silicon Photomultipliers pulse structure (Paola Avella et al. ID-143)

In this work authors focus on the pulse structure of the SiPM signal both due to dark pulses and fast femtosecond laser pulses. The signal is readout through preamplifiers with different gain and bandwidth and is stored by a digital oscilloscope for off-line analysis. The parameters of the device that directly affect the pulse shape are calculated, i.e. quenching resistance and capacitance, diode capacitance and parasitic capacitance. The mean rise time obtained with the different preamplifiers and the intrinsic time resolution of the SiPM is measured.

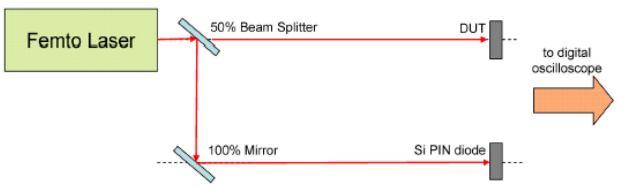


Figure 3: Measurement setup for the calculation of the rise time and of the time resolution of the SiPM using a laser and a Si PIN diode for calibration purposes.

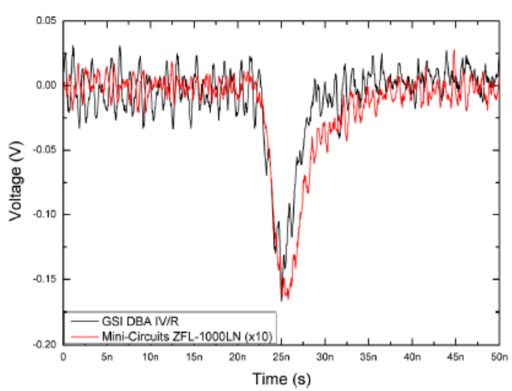
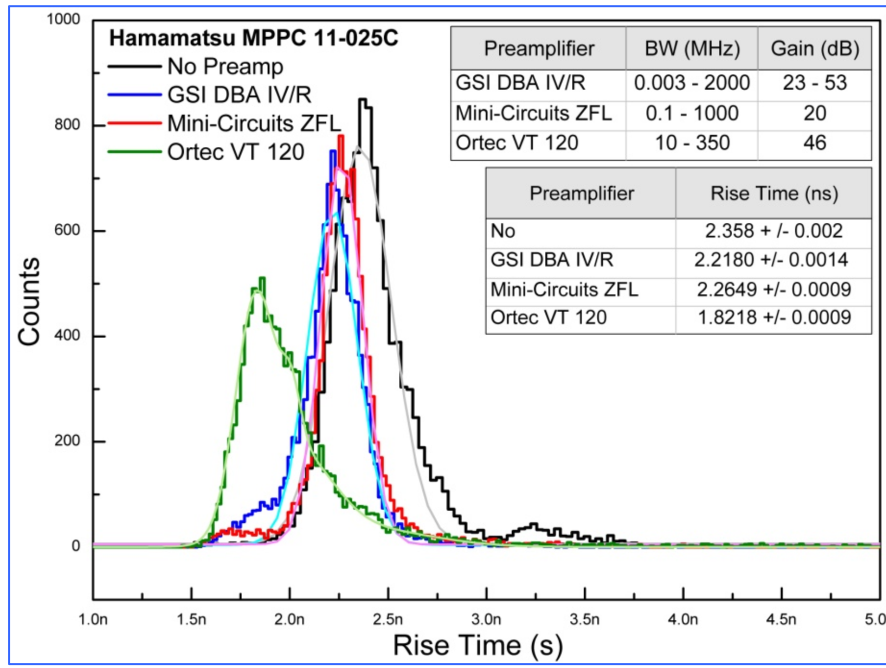
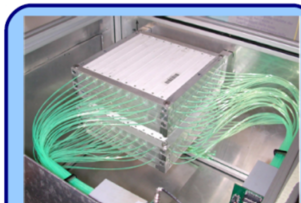


Figure 2: Dark pulses at V_{bias} = 70.4 V, acquired with the digital oscilloscope using two different amplifiers.

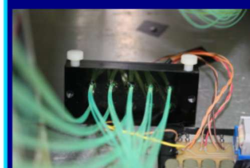


Silicon Photomultipliers for scintillating trackers (Simone Rabaioli et al. ID-155)

This contribution presents the use of an array of eight SiPMs (manufactured by FBK-irst) for the readout of a scintillating bar tracker (a small size prototype of the Electron Muon Ranger detector for the MICE experiment). The performances of the SiPMs in terms of signal to noise ratio, efficiency, time resolution and gain as a function of temperature are compared to the ones of a multi-anode photomultiplier tube (MAPMT) connected to the same bars. Both the SiPMs and the MAPMT are interfaced to a VME system through a 64 channel MAROC ASIC.

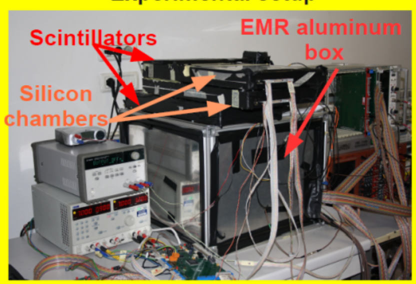


EMR Prototype
Prototype of a traker for the MICE experiment composed of 8 x-y planes of plastic scintillator bars with a 1.5x1.9 cm^2 cross section and 19 cm long, read out by 4 0.8 mm WLS fibers.
The readout of the scintillation light is performed with both SiPMs and a multianode PMT.



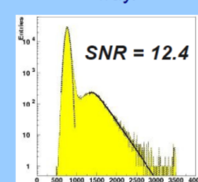
The first layer of the tracker has a dual WLS fibers readout system: the fibers are connected to both a multianode PMT and to a coupling mask holding an array of SiPMs with a ~1 mm diameter; 8 out of 10 SiPMs are connected.

Experimental setup

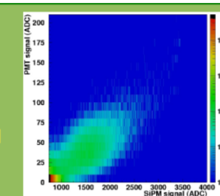


The Maroc3 Board

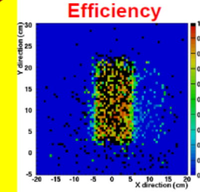
Both the SiPM and the PMT are interfaced with a 64-channel Maroc (Multi Anode ReadOut Chip) v3 board. Each channel features a preamplifier, a slow and a fast shaper, a discriminator and a sample & hold circuit. The Maroc3 board can be operated in an analog and a digital way.



Correlation PMT signal vs SiPM signal



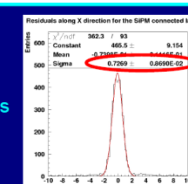
Efficiency



The efficiency plot has been obtained as the ratio of the beam profile reconstructed by the bars and the one measured by the silicon detectors.

Spatial Resolution

The spatial resolution calculated with the residuals method is 0.73 cm



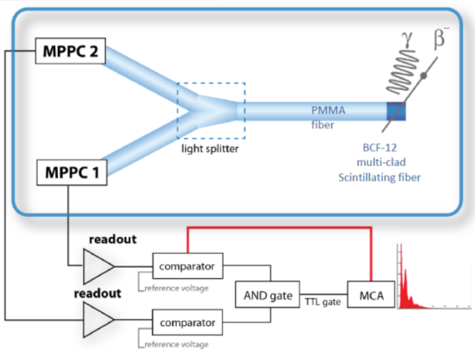
Scintillating optical fiber coupled to a SiPM for radiation dosimetry (Luis Moutinho et al. ID-180)

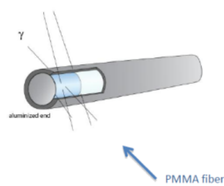
A radiation dosimeter for low dose rate, based on a scintillating optical fiber coupled to a SiPM, is proposed. This configuration satisfies most of the requirements for in-vivo and real-time dosimetry, due to the size, flexibility and water equivalent properties of the used optical fiber. To read the scintillation light from the optical fiber in low dose conditions, either in current or pulse mode, a suitable high gain and detection efficiency photosensor is required. SiPMs and PMTs can operate with high efficiency in current or pulse mode, being suitable for this application. Nevertheless, PMTs are bulky, expensive and not adequate when detection areas are of the order of $1mm^2$.

Objectives

- Development of a gamma-detector based on scintillating fibers using SiPM for light readout
- Reduce the effect of SiPM's high dark count rates due to thermal noise
- Evaluate the possibility of developing low-cost radiation dosimeters for medical applications

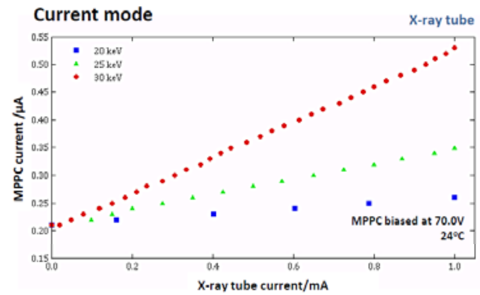
Principle of operation

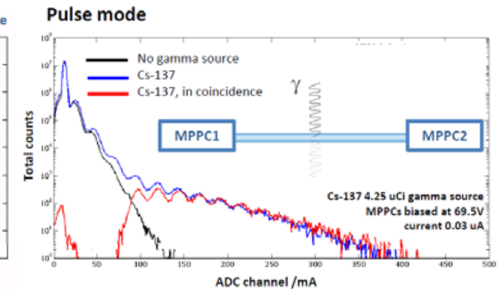




developed electronics for coincidence mode operation

1st results





Possible applications for different combinations of optical fibers

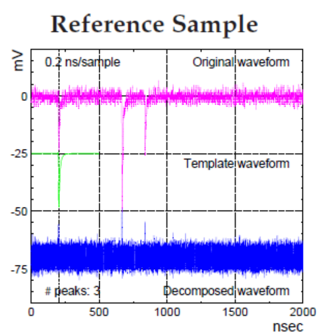
Main application
- Medical applications: dosimetry in brachytherapy and mammography

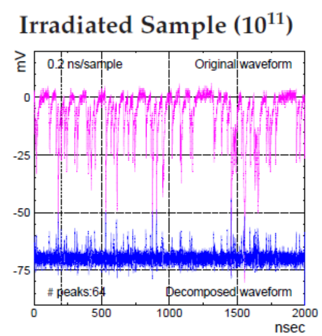
Other applications
- HEP for SiPM noise suppression
- Safety precautions
- Prevention of nuclear terrorism and nuclear smuggling
- Radiation detection in public spaces: Hospitals, transport systems, etc.

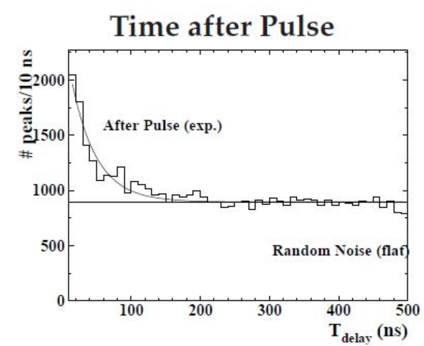
Radiation damage of Pixelated Photon Detector by Neutron Irradiation (Isamu Nakamura et al. ID-186)

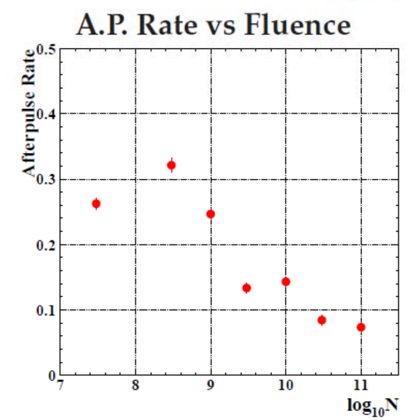
In the study Hamamatsu MPPCs are exposed to neutrons using reactor YAYOI up to 10^{12} /cm^2. After the irradiation it is known that the noise rate increases rapidly. But the effect of irradiation to the optical crosstalk and after-pulsing is not well studies. These properties are studies in this presentation using waveform analysis of the dark noise.

- MPPC irradiated to Neutron
  - Reactor 弥生 (YAYOI) of Univ. Tokyo @ Tokai
  - Hamamatsu MPPC 50μm pix
  - up to 10^{12} nuetrons/cm^2
- Measeurement of Afterpulse Rate with Waveform
  - Took 10000 Random noise event
  - Oscilloscope 5 GS/s $\times$ 10000 pts $\Rightarrow$ 2μs
  - Decomposition Filter with FFT (offline)
  - Timing and Pulseheight of noises
- Distribution fitted with exp (A.P.)+ flat (Random Noise)





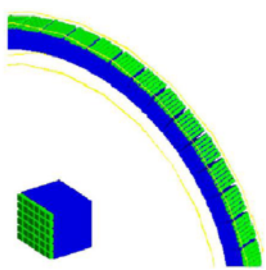




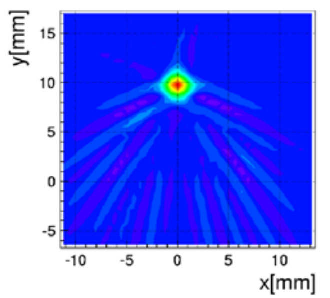
$$\text{Afterpulse rate} \equiv \frac{\#\ \text{After Pulse}}{\#\ \text{Trigger Pulse}}$$

Study of Silicon Photomultipliers for New Generation of PET (Nicola D'ascenzo et al. ID-187)

In the report the result of a study of the PET detection system prototype is presented. The prototype is based on the LSO crystals and silicon photomultipliers with individual read-out of the crystal by Silicon Photomultipliers (SPM). In the experimental study the authors use recently developed 1x1 mm^2 SiPMs from SensL. The measurement of the energy and coincidence time resolution was performed on the base of modern time stamping methods readout and fully digital analysis. A significant improvement of the parallax blurring in PET systems can be achieved with the reconstruction of the Depth Of Interaction (DOI). Experimental results and analysis methods are presented in this contribution.



Detailed geometry of the PET detection system on the basis of LSO scintillator crystal read-out individually by SiPM.



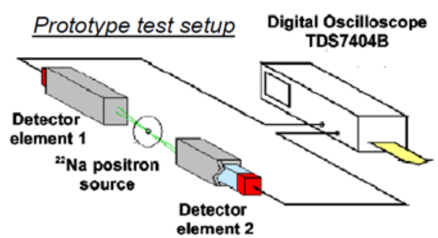
Response of the PET system to a point like source

Mathematical model of PET system based on LSO/SiPM detecting system with individual read-out, within the GEANT4/GATE simulation package.

The model includes optical photon propagation, radioluminescence spectrum of LSO and quantum efficiency of SiPM from published experimental data.

Image reconstruction algorithm implemented for highly granular SiPM/PET system

The transverse space resolution of PET system based on 3x3x25 mm^3 LSO/SiPM is found as (2.13±0.18) mm. Significant improvement respect to traditional PET systems.

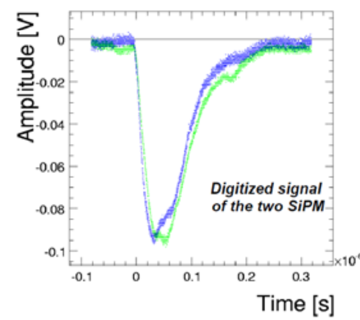


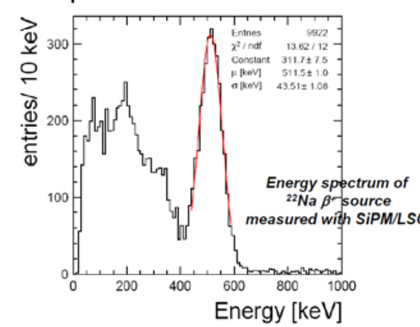
2.5x2.5x15 mm^3 LSO crystal individually read-out by 1x1 mm^2 SiPM (SensL, Cork).

Signal digitized with 4 GHz Oscilloscope. Offline data analysis with numeric methods.

Energy resolution: σ/E=(8.64±0.18)%
Time resolution : σ_t = (806 ± 26) ps

Mathematical model of test setup in agreement with experimental data





Welcome to the Poster Session !