The direct read-out of organic and inorganic scintillators with the Multi Pixel Photon Counter

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Abstract

The Micro Pixel Photon Counter (MPPC) is a new silicon-based photo-detector developed by Hamamatsu. Its key-features are the small active area, the easy biasing and read-out circuit, the high gain and the optimisation of the sensitivity in the blue spectral region. Hence the MPPC seems to be the ideal candidate for the read-out of radiation detection devices which are based on a large number of fast scintillator arrays.

In this paper we study the direct read-out of organic and inorganic (LSO and LSF crystals) scintillators via MPPC, with the aim to investigate their technological potential for the design of highly granular positron emission tomographs and calorimeters.

Key words: Photo-detectors, Silicon PhotoMultiplier, MPPC, calorimetry, PET
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Introduction

Silicon pixel photo-detectors operated in Geiger mode [1–3] are a new sort of silicon-based photo-detectors. Their active area ranges between 1×1 mm^2 and 5×5 mm^2 and they are very easy to operate. They reach, in fact, a gain

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up to 10^6 with a relative low voltage supply typically ranging between 30 V and 70 V. The resulting current signal is sizable even for a single detected photon and has a rise time of less than 100 ps. It can be extracted with a simple electronic circuit, usually just with a large bandwidth voltage amplifier. In addition, this photo-detector is insensitive to strong magnetic fields. The first devices of this family, so called Silicon PhotoMultipliers (SiPM), have a sensitivity mainly peaked in the green spectral region. The Micro Pixel Photon Counter (MPPC) tested in this paper have been developed by Hamamatsu [4] and inherits all the properties of the SiPM. Moreover, for the first time, they provide very good sensitivity in the blue spectral region.

There is a big interplay between the improvements in the Silicon Photomultiplier technology and the research and development of many scintillator based detectors, ranging from particle physics to space and medical applications. The aim of this paper is to investigate if some of the benchmarks properties of the photodetectors for highly granular calorimetry and positron emission tomography are satisfied by the MPPC.

Calorimeters are devices dedicated to the measurement of the energy of particles. This measurement is a experimental challenge at high energy colliders, due to the dense multi-jet environment. A lateral granularity and a longitudinal segmentation of few centimeters would allow the reconstruction of the topology of the showers induced by each single particle within a jet. The different treatment of electromagnetic, hadronic and neutral components would improve the energy resolution. The instrumentation of such detector is a difficult technological task. Millions of channels have to be read out in a strong magnetic field (up to 5 T). Compactness and hermeticity of the calorimeters are essential requirements. Plastic scintillator tiles directly read out by silicon pixel photo-detectors operated in Geiger mode are well-suited for this application; as this kind of photo-detector is small and insensitive to the magnetic field, it can be directly installed onto the scintillator tiles. The coupling between the scintillator and the photo-detector is still under test. A first proposal is to collect the scintillation light via a green wavelength shifting fibre installed in a semicircular groove on the tile itself. Such a set-up is needed when using the green sensitive SiPM. It ensures a light collection which is independent on the incidence position of the detected particle on the scintillator. A second proposal is to couple the photo-detector directly to the scintillator which would simplify the manufacturing of the calorimeter cells. In this case, the blue sensitivity of MPPC would allow a sufficiently good light collection efficiency. However, the uniformity of the response remains to be proven. Calorimeter prototypes using both methods have been developed and are currently tested in the framework of the International Linear Collider project [5].

Positron emission tomography (PET) is a functional imaging technique. A $\beta+$ tracer is injected into a living organism and the two 511 keV annihilation pho-

tons are detected in coincidence by an array of detectors around the observed biological system. A detector for PET has to provide a good energy resolution of something like 10% at an energy of 511 keV in order to discriminate the signal from the lower energy Compton scattered photons, which constitute the main source of degradation of the image [6]. This is achieved using inorganic scintillators like BGO and LSO. They are better suited for PET application than organic scintillators as they have a higher density and are thus more efficient in detecting 511 keV photons. The traditional detector block for PET tomographs is made of a pixelated array of crystals read out by four photomultipliers — the signal being reconstructed with a resistive chain weighting technique [7]. Many studies aim at improving the spatial resolution of the system with highly segmented arrays of crystals individually read out by an appropriate photo-detector. Besides, the signal to noise ratio of the image can be enhanced with a more precise localization of the sources, using the time of flight information of the two detected photons (ToF-PET) [8,9]. The SiPM is a natural candidate for this application, due to its small size, high gain and easy read-out circuit. The blue sensitivity introduced with the MPPC is a key feature for PET as it allows a much better energy resolution at 511 keV, compared to the green sensitive SiPMs. An application of MPPCs in ToF-PET systems is also under investigation, as the excellent timing response of these new devices makes them competitive to the traditional photomultiplier tubes. In addition, their insensitivity to magnetic field makes them a good candidate for use in combined PET-NMR system.

The aim of this study is to investigate whether the light collection efficiency of MPPCs directly coupled to organic and inorganic scintillators (LSO, LSF-7 [1]) and their timing properties match the benchmark requirements for highly granular calorimetry and positron emission tomography.

1 Description of the test set-up

This study is based on a set of MPPC with different size (1×1 mm^2 up to 3×3 mm^2) and with different number of pixels (400 up to 1600). Five pieces of each detector type have been available for testing. The suggested operation voltage ranges between 70 V and 78 V. The main properties of the MPPCs tested in this report are shown in Table 1.

In the following sections the results of two different studies are described. One is dedicated to the read-out of plastic scintillators using MPPCs (plastic scintillator response study; section 2), the other investigates the properties of directly coupled crystal-MPPC systems (inorganic scintillator response study;

[1] Lutetium Fine Silicate, developed by General Physics Institute, Moscow [10]

size [mm^2]	**Number of pixels/mm^2**	**Bias** [V]	**Gain** [10^6]	**Dark Rate >0.5 pixels** [kHz]	**Dark Rate >1.5 pixels** [kHz]
1×1	400	76	7.4-7.5	220-250	9-10
1×1	1600	78	2.6-2.7	50-60	0.05-0.1
3×3	400	70	7.4-7.5	3200-3300	320-330

Table 1
Characterization of the MPPC used in this study.

section 3). The different test set-ups used for the two studies are described below.

For the plastic scintillator response study ^{106}Ru is used as an electron source delivering minimum ionizing particles (m.i.p.) to be detected via the light they produce in scintillator tiles. Two different $3 \times 3 \times 0.5$ cm^3 plastic scintillators tiles are used, both manufactured by *Uniplast* enterprise (Vladimir, Russia), which also delivered the tiles of the CALICE hadronic calorimeter prototype [5]. One of the tiles contains a green wavelength shifting fibre (Kuraray multicladding WLS fibre Y11(200)) of a 0.5 mm radius and t is used to test the traditional fibre-mediated read-out. The second tile has no wavelength shifter installed and is used to investigate the direct read-out of the blue scintillation light produced. Both tiles are wrapped in a Super-radiant VN2000 foil (3M).

A second test set-up is operated to study the response of directly coupled crystal-MPPC systems. A ^{22}Na source is used to provide two coincident 511 keV annihilation photons; the analysis is based on the simultaneous detection of both photons by a pair of crystals directly coupled to two MPPCs using optical grease. Three different crystal pairs are used for this study. Two pairs of $1 \times 1 \times 15$ mm^3 and $3 \times 3 \times 15$ mm^3 LSO crystals (Hilger crystals) and one pair of $3 \times 3 \times 15$ mm^3 LFS-7 crystals are used in this study. All six crystals are wrapped in a Teflon layer of 2-mm thickness .

The relative position and the optical coupling between the scintillators and the MPPC are the most important source of systematic error for both studies. In order to reduce its size different structures are used for coupling the MPPCs to tiles and crystals. For the plastic scintillator response study, the MPPCs are kept fixed to a rigid holder such that for the tile with the wavelength shifter (WLS) the device can be easily positioned in front of the WLS fibre; for the plane tile without a WLS fibre installed the holder is moved to two different well defined points along the edges of the plastic scintillator tile. When studying the inorganic scintillator response the crystal-MPPC

systems are fixed and can only move towards or away from the ^{22}Na source. The remaining uncertainty on the energy resolution is estimated by repetitive measurements of the spectra and is found to be 3%, 10% and 15% respectively for the plastic scintillators, the 3×3 mm^2 and the 1×1 mm^2 crystals.

The signal of the 1600 pixels MPPC is amplified by a wide-band voltage amplifier (Phillips Scientific 6954). The 400 pixels devices do not need amplification. Signal integration is done by a QDC Lecroy 1182, using a gate of 80 ns. For the plastic scintillator response study the QDC is triggered by an additional scintillator which is installed behind the scintillator/MPPC system and read out by a traditional photomultiplier tube. In case of the crystal-MPPC set-up the trigger is provided by a coincidence signal from the two MPPCs formed via standard NIM logic.

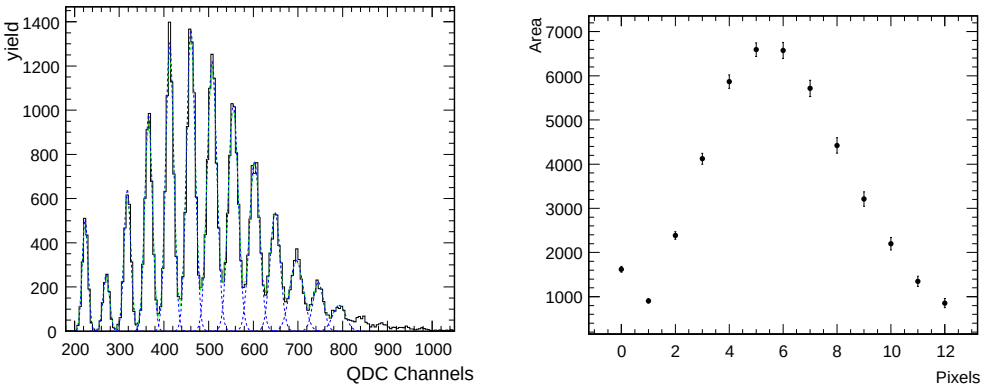
For timing studies the signals of crystal-MPPC systems are also digitized without any amplification, using a 4-GHz True-Analog Bandwidth oscilloscope (TDS7404B by Tektronix) triggered internally; in acquisition mode it provides a sampling rate of 20 GS/s resulting in a time resolution of 100 ps as two channels are used simultaneously; the digitized signals are stored with an acquisition rate of about $\sim$1 Hz for offline analysis.

2 The Read-out of Plastic Organic Scintillators Using MPPCs

2.1 Comparison Between Direct and Wavelength-shifter Mediated Read-out

Plastic organic scintillators are mainly used to detect charged particles. Hence the most probable value (MPV) for the number of photo-electrons produced in a MPPC when a minimum ionizing particle (m.i.p.) traverses the scintillator is chosen as characteristic measure. The typical signal distribution of a scintillator/MPPC system is shown in Fig.1.a. Each peak corresponds to a certain number of pixels firing in the MPPC. The good separation of the peaks indicates the good uniformity of the device. The signal is fitted with a multi-Gaussian function. From this fit the area under each peak is extracted and plotted as a function of the number of pixels fired (Fig. 1.b). The resulting data points follow a Landau distribution smeared by a Poissonian photo-statistics. The maximum of this distribution is the sought-after MPV and estimated with a Gaussian fit to the peak region. Fig. 2 shows the resulting MPV as a function of the over-voltage [2] for (a) the read-out via WLS fibres and (b) the

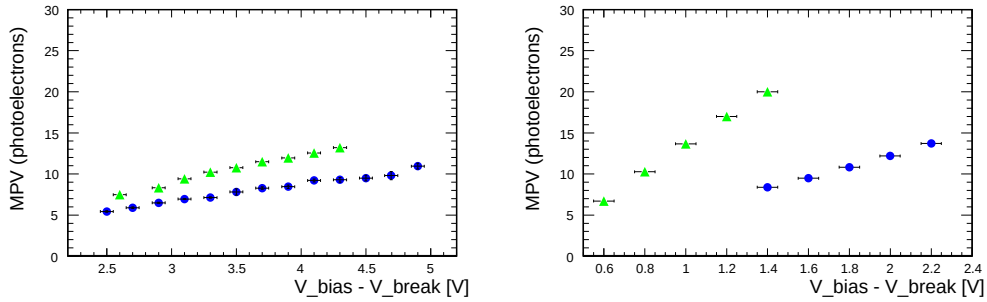
[2] The over-voltage is defined as the difference between the operation bias voltage and the breakdown voltage.



(a) (b)

Fig. 1. M.i.p. signal distribution of a scintillator/MPPC system; in this particular example the plastic scintillator tile is directly read out by a 1600 pixels MPPC, operated at 2 V over-voltage. The diagram shows the measured distribution (histogram) together with Gaussian fits (dashed lines) used to determine the area under each individual peak (a) and the area under each peak as a function of the number of pixels fired (b); the maximum of this distribution determines the MPV (see text).

direct coupling as detected by the 400 and 1600 pixel MPPC devices [3]



(a) (b)

Fig. 2. MPV distribution as a function of the over-voltage; (a) 1600 pixel MPPC and (b) 400 pixel MPPC. The blue dots are the result for a direct scintillator/MPPC coupling, the green triangles those for the wavelength shifter mediated read-out.

As a result, the signal size in number of photo-electrons (pixels) is found to be half as big for the 1600 pixel MPPC compared to the signal size observed with the 400 pixel device; this is in agreement with expectation when comparing

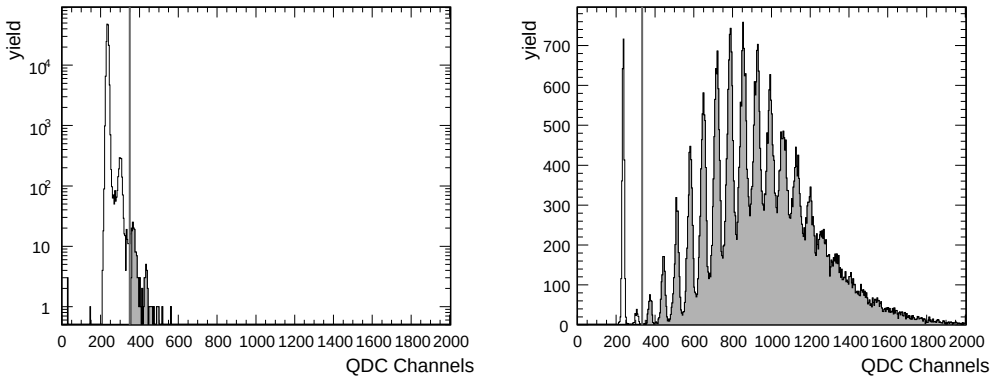
[3] The noise and the allowed precision of the experimental system constrain the minimum number of mean detected photo-electrons to 5. The balance between the amplifier and the input of the QDC limits the maximum number of mean detected photo-electrons approximately to 20. The response of the 400 pixel MPPC could be studied, hence, only for $V_{bias} - V_{break} > 1.4$ V in the direct coupling configuration and for $V_{bias} - V_{break} < 1.4$ V in the wavelength shifter mediated read-out configuration.

the photo-detection efficiencies of these devices as quoted in the Hamamatsu data sheet [4] . Repeating the measurements for the direct coupling case with the MPPCs positioned at different locations w.r.t. the tile center (edges,corners) yields similar results, all compatible within the quoted systematic uncertainty of 3%.

2.2 Implications for Hadronic Calorimetry

The most important parameters determining the performance of a calorimeter are the response and the noise of a single channel. To quantify the response m.i.p. signals are used as a reference the MPV of the signal produced by a m.i.p. sets the energy scale for each channel; the signal-to-noise ratio determines the detection efficiency.

The discrimination between noise and physics signals is typically done using an amplitude threshold [5] . The normalized integral of the m.i.p. signal dis-



(a) (b)

Fig. 3. (a) Noise spectrum of the 400 pixel MPPC; an amplitude threshold (line) is defined requiring that the maximum rate of the remaining noise (shaded area) is 3 kHz; (b) m.i.p. spectrum. The detection efficiency is defined by the shaded area, i.e. the integral of the spectrum above threshold (line).

tribution above this threshold determines the m.i.p. detection efficiency. All signals above threshold constitute a hit in the calorimeter. The procedure is

[4] The direct comparison between the efficiency quoted in the data sheet and the light yield measured in this experiment is qualitative. While Hamamatsu quotes the response of the MPPC to a monocromatic photon source, the *green* and *blue* light used in this experiment consist of a wide spectrum resulting from the mechanism of scintillation.

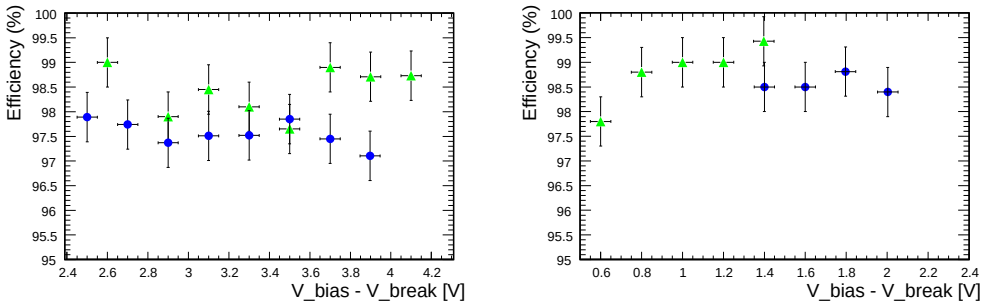
[5] The total charge of the signal is considered as amplitude in this application.

depicted in Fig. 3. As the amplitude threshold is determined by the pedestal noise spectrum (Fig. 3a) lower noise allows for higher detection efficiencies.

In practice the amplitude threshold is fixed considering the allowed channel occupancy. For the ILC calorimeter a relative channel occupancy of 10^{-4} is required. For a beam crossing interval of 300 ns this translates into a maximum noise rate of 300 Hz. For the existing 8000 channel hadronic calorimeter 1 m^3-prototype [5] integration time is only 200 ns; the maximum noise rate presently allowed for test beam studies is 3 kHz resulting in a relative occupancy of 6×10^{-4}.

After fixing the amplitude threshold the m.i.p. detection efficiency is calculated by integrating the m.i.p. spectrum (Fig 3b) above threshold. For the scintillator/SiPM system used in the ILC calorimeter prototype this procedure yields a 95% detection efficiency; the MPV of a m.i.p. signal observed for this system is 15 ± 2 photo-electrons.

The measured m.i.p. detection efficiencies for the 1600 pixel and the 400 pixel MPPCs are shown in Fig. 4 as a function of the over-voltage[6]. Results are



(a) (b)

Fig. 4. Signal detection efficiency for a 1600 pixels (a) and a 400 pixels (b) MPPCs. The blue dots are the result for a direct scintillator/MPPC coupling, the green triangles those for the wavelength shifter mediated read-out.

shown for both the direct scintillator-MPPC coupling as well as for the wavelength shifter mediated read-out. Due to a very low dark rate and low cross talk the MPPCs show very low noise such that with the requirement of 3 kHz noise rate the amplitude threshold can be set to a value of only 1.5 to 2 pixels. Correspondingly a detection efficiency of more than 97% is observed; the value measured for the wavelength shifter mediated read-out is slightly higher ($\sim$ 98%). In order to reach these efficiencies the 1600 pixel MPPC must be operated at an over-voltage of 2.5 V to 3.5 V; in this case the corresponding MPV of a m.i.p. signal lies between 6 and 7 photo-electrons. In contrast the 400 pixel device must be operated at over-voltages of 0.6 V to 2 V.

[6] The over-voltage is the biasing voltage relative to the breakdown voltage.

For both direct coupling as well as wavelength shifter mediated read-out the 1600 pixel MPPC provides a better solution compared to SiPMs as it yields a similar detection efficiency but has a larger dynamic range. For the 400 pixel MPPC the detection efficiency is higher than for SiPMs but the reduced number of pixels imposes strict bounds on the dynamic range.

It has to be noted that for both MPPC types the dark rate drops rapidly if the amplitude threshold is raised. Thus by using a threshold of 2 to 4 pixels the tighter ILC requirements on the noise can be easily met. In this case it is still possible to operate the MPPCs at an over-voltage such that a m.i.p. detection efficiency of above 95% is obtained. If in the final ILC calorimeter thinner scintillators (e.g. 3 mm instead of 5 mm thickness) are used, the lower light yield may be compensated by a better coupling or a larger sensitive area of the photo-detector (e.g. 3×3 mm^2). Further studies are needed in order to prove the applicability of MPPCs under such conditions.

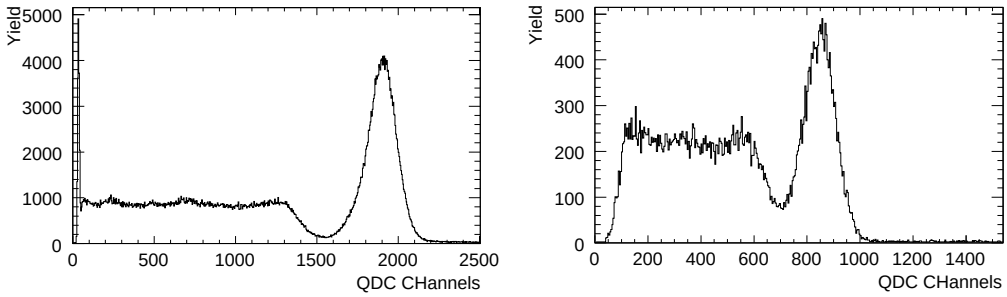
3 Direct Read-out of LSO and LFS Crystals Using MPPCs

3.1 Energy resolution of a crystal-MPPC system

The energy spectrum of 511 keV photons measured with one detector is presented in Fig. 5. The photo-electric peak is clearly separated from the energy continuum of Compton-scattered photons. The energy resolution of the detector is extracted using a Gaussian fit to the peak region. The ratio of the FWHM over the mean of the fit is quoted as an estimate for the energy resolution. An energy resolution of $10.0\% \pm 0.3\%(stat) \pm 1\%(sys)$ is obtained for the $3 \times 3 \times 15$ mm^3 system (Fig. 5a), while $14\% \pm 0.4\%(stat) \pm 2\%(sys)$ is measured with the $1 \times 1 \times 15$ mm^3 system (Fig. 5b). The lower statistics of Fig. 5b with respect to Fig. 5a is due to the reduced acceptance of the $1 \times 1 \times 15$ mm^3 system. The rather large systematic uncertainties on the result for the $1 \times 1 \times 15$ mm^3 system measurements are due to a still imperfect setup of the test system. Improvements are possible especially concerning the technical reproducibility and the crystal-MPPC coupling. The finite number of pixels of the MPPC causes its response to be non-linear at high photon fluxes.

The effect of the non-linearity of the MPPC on the energy scale is investigated measuring the response of the system to photon radiation from ^{137}Cs (662 keV), ^{122}Ba (80 keV, 320 keV) as well as ^{22}Na(511 keV). Fig. 6 shows a linear response in the region of interest, up to 622 keV.

The signal corresponding to the photo-electric interaction of a 511 keV photon



(a) (b)

Fig. 5. Energy response to 511 keV photons of (left figure) a $3 \times 3 \times 15$ mm^3 LSO crystal coupled to a 3×3 mm^2 MPPC (3600 pixels), and (right figure) of $1 \times 1 \times 15$ mm^3 LSO crystal coupled to a 1×1 mm^2 MPPC (400 pixels). The 511 keV photons are provided by a ^{22}Na source

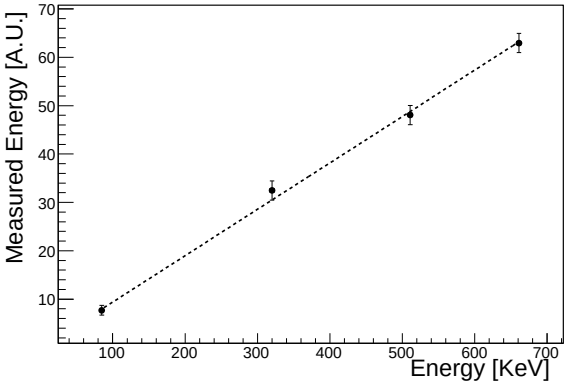


Fig. 6. Linearity of the energy response of a $3 \times 3 \times 15$ mm^3 LSO crystal coupled to a 3×3 mm^2 MPPC (3600 pixels).

in the LSO crystal is shown in Fig. 7. Note that although the overall number of photons is large the photon flux from the crystal is quite small. The photons are emitted over a wide time window of more than 40 ns. As the recovery time of the MPPC is only about 4 ns the pixels recover fast compared to the duration of light emission, and the saturation mechanism is strongly suppressed. The amplitude of the signal, rescaled to the single photoelectron size, gives an indicative order of magnitude of the time distribution of the detected photons [7]. The instantaneous amplitude never exceeds 500 photo-electrons. The probability that two or more photons are detected in the same pixel is hence minimal in this setup, as a maximum flux of 500 photo-electrons is distributed on 3600 pixels and on a total active area of 3×3 mm^2.

The measurements were repeated for the $3 \times 3 \times 15$ mm^3 LFS crystal. They result in an energy resolution of 11% (Fig. 8), which is comparable to the measurement using the same sized LSO crystal, within the systematic uncertainty.

[7] The integral is directly proportional to the total number of photo-electrons.

3.2 Time Resolution

The time resolution of the system is determined by measuring the time difference between the two signals of two back to back scattered photons. As an estimate of the time resolution, the FWHM of the time difference distribution is taken. For the measurement of the signal timing, a fixed amplitude threshold is used in this study instead of the constant fraction discriminator method traditionally used in Tof-PET system. This is justified due to the fast response of the LSO crystals together with the fast rise time of the large photo-electron signal of the MPPCs, and significantly simplifies the read-out electronics. It requires the calibration of each detector cell to the same light yield which is easily achieved tuning the bias voltage of the MPPCs.

The two signals from the detector elements are directly sent to the inputs of the oscilloscope, where they are discriminated if above a tuneable threshold. This threshold is kept at approximately 4 mV (or ∼13-15 pixels). The minimum allowed threshold is constrained by the electronic noise level (2.0 ± 0.5 mV corresponding to 10 ± 1 photo-electrons). A coincidence is formed after the discrimination and used as trigger to store the full signal waveform starting considerably before the trigger time. The offline analysis is, hence, independent from the coincidence threshold.

The timing measurement is mainly influenced by the selection of the signals and the timing threshold as it was previously shown in [11]. Fig. 9 illustrates the improvement in time resolution obtained when applying an energy cut of $\pm 1\sigma$ around the photo-electric peak value. When selecting only events with energies near the photo-electric peak a sharp time difference distribution is

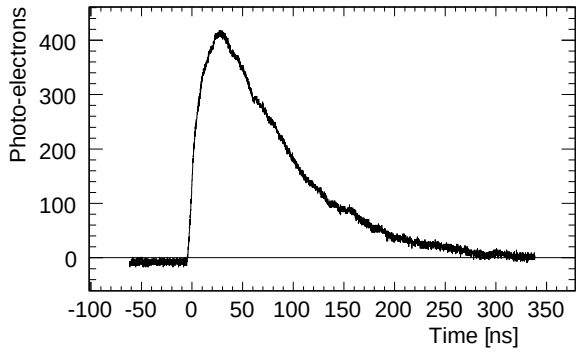


Fig. 7. Photo-electric signal of a 511 keV photon detected by a $3 \times 3 \times 15$ mm^3 LSO crystal coupled with a 3×3 mm^2 MPPC with 3600 pixels. The signal amplitude is shown in unit of a single photo-electron signal.

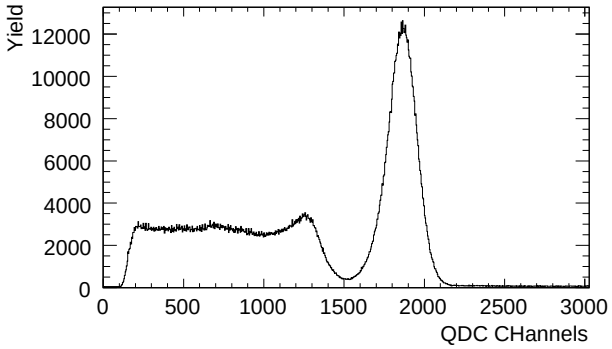


Fig. 8. Energy response to 511 keV photons of a $3 \times 3 \times 15$ mm^3 LFS crystal coupled to a 3×3 mm^2 MPPC (3600 pixels). The 511 keV photons are provided by a ^{22}Na source

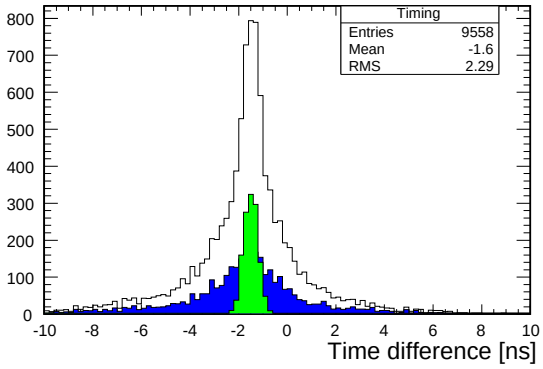


Fig. 9. Time resolution of a system of two $3 \times 3 \times 15$ mm^3 LSO crystals directly read out by two MPPCs of the same size. The total sample, without cuts, is shown as a black line. The sharp signal peak (green) corresponds to the events with energies near the 511 KeV photoelectric peak in both crystals. The blue background corresponds to the events in which one of the two photons looses energy through the Compton effect.

observed (green). Its FWHM is measured to be 647 ± 3 ps, estimated with a gaussian fit in the interval $\pm 2\sigma$ around the mean value. The events in which one or both photons undergo Compton scattering are the main background of the measurement. The timing spread of these events is widely distributed and ruins the time resolution of the system (blue). This effect can be directly extrapolated from the signal shapes observed on the oscilloscope. Photons which undergo Compton scattering are observed as signals of smaller amplitude and slope if compared to signals from photons depositing their full energy inside the crystals.

The influence of the chosen threshold on the time resolution is shown in Fig. 10. The time resolution degrades fast with increasing coincidence threshold, as the measurement becomes more sensitive to the variation of the rise time of

the signals. The improvement of the observed time resolution when selecting events from the photo-electric peak is almost a factor of 2.
In order to fully benefit from the fast intrinsic time resolution of the MPPC the coincidence threshold should in principle be lowered to below the amplitude corresponding to a single photoelectron. However, this region is outside the dynamic range of the current instrumentation and can be analysed only after improving the present set-up.

3.3 Implications for the design of a PET system

As the traditional photo-detector commonly used in PET is the photomultiplier a comparison between the obtained results and the typical performances of a PET detector block explicates the good perspectives of the use of MPPCs in this field. The measured energy resolution allows an efficient separation between the photoelectric peak and the Compton scattered events. In similar experiments [12,13], it has been shown that the traditional SiPM (from CPTA and MEPHI) coupled to a $3\times3\times15$ mm^3 crystal provides a resolution of about 25-35% due to the poor photo-detection efficiency in the blue spectral region. LSO crystals show a $\sim$10% energy resolution for 511 keV photons when read out by a traditional photomultiplier tube [8] (mainly originating from the LSO intrinsic energy resolution of about 9% [14]). The results obtained indicate that the MPPC provides an energy resolution for PET application which is competitive with that of PMT with the advantage of an easy direct coupling to a small crystal. Using MPPC for a PET detector would thus allow to reduce the single crystal pixel size down to 1 mm^2 improving the spatial resolution of the scanner. Improvements in the reconstruction of the depth of interaction using multi-layer imaging modules are also currently under investigation [15].

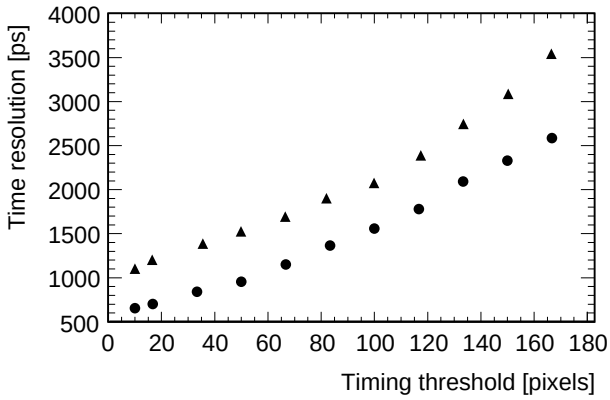


Fig. 10. Time resolution as a function using fixed amplitude threshold for a system of two $3\times3\times15$ mm^3 LSO crystals coupled to 3×3 mm^2 MPPC 3600 pixels using fixed amplitude threshold. Results obtained with (points) and without (triangles) energy cut are shown (see text).

The obtained time resolution is compatible with the typical value quoted in similar studies — 475 ps in [9] — suggesting a possible application of MPPCs also to ToF-PET.

4 Conclusions

This study shows that the Multi Pixel Photon Counter represents an effective technological improvement of the silicon pixel photo-detectors operated in Geiger mode. The new key-feature of this photo-detector is the blue sensitivity, which allows the direct read-out of scintillators, both organic and inorganic, with high efficiency.

The measured light yield corresponding to a m.i.p. particle detected by a plastic scintillator tile with size $3 \times 3 \times 0.5$ cm^2, directly read out by a MPPC on the edge, is 10-15 photoelectrons. The low dark rate of this device allows discriminating the m.i.p. signal from the noise with a threshold at 1.5-3 photoelectrons, yielding high m.i.p. signal collection efficiency. The 1600 pixels MPPC matches most of the requested parameters for a possible application in hadronic calorimetry, although uniformity and stability of a large sample need to be proved. The issue of the uniformity of the response over a scintillator tile with direct read-out still has to be investigated.

The energy resolution of a $3 \times 3 \times 15$ mm^3 LSO crystal, directly read out by a MPPC with an active area of the same size, reaches 10% FWHM and a timing resolution of 650 ps. Slightly worse results - $\sim 14\%$ energy resolution - are obtained with the 1×1 mm^2 crystals and photo-detectors, mainly due to systematic effects in the alignment of the setup. More systematic studies of the 1×1 mm^2 MPPC as well as of the energy and timing behaviour of the LFS crystals will follow. This MPPC/crystal detector system fulfils the strongest requirement for a positron emission tomography scanner. In addition, the MPPC would allow a significant simplification of the technological design and of the read-out electronics.

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