Performances of silicon detectors for the SiliPET project: A Small Animal PET Scanner based on Stacks of Silicon Detectors

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Abstract– In this paper we propose a new scanner for small-animal positron emission tomography based on stacks of double sided silicon detectors. Each stack is composed of 40 planar detectors with dimension 60× 60×1 mm^3 and 128 orthogonal strips on both sides to read the two coordinates of interaction, the third being the detector number in the stack. Multiple interactions in a stack are discarded by an exclusive OR applied between each plane detector of a stack.

In this way we achieve a precise determination of the interaction point of the two 511 keV photons. The reduced dimensions of the scanner also improve the solid angle coverage resulting in a high sensitivity. Preliminary results were obtained with MEGA prototype tracker (11 double sided Si detector layers), divided into two stacks 2 cm apart made of respectively 5 and 6 prototype layers, placing a small spherical ^{22}Na source in different positions.

We report on the results, spatial resolution, imaging, spectral and timing performances obtained with double sided silicon detectors, manufactured by ITC-FBK, having an active area of 3 x 3 cm^2 and a strip pitch of 500 µm. Two different strip widths of 300 µm and 200 µm, and two thicknesses of 1 mm and 1.5 mm, equipped with 64 orthogonal p and n strips on opposite sides were read out with the VATAGP2.5 ASIC, a 128-channel "general purpose" charge sensitive amplifier.

We will present the improvements made on the new more compact version of the board containing the control signals conditioning, the ASIC control voltages, interface isolator and ADC. We will use a recent version of the VATAGP with the peaking time of the fast chain at 50 ns nominal to reduce the time walk variations.

We will report on the timing performances obtained with stacks made of a detector couple.

Summary

In this paper we present a new scanner for small-animal positron emission tomography (PET) taking into consideration that the energy information of the signal generated by a γ photon is not necessary, to discard scattered coincidences, because the spatial resolution degradation due to scattering of 511 keV in small animals is negligible [1,2]. We have to determine only which strips have been hit. The proposed scanner is based on stacks of double sided silicon detectors. Each stack is composed of 40 planar detectors with dimension 60 × 60 × 1 mm^3 and 128 orthogonal strips on both sides (see figure 1). This configuration permits the measurement of the X and Y coordinates of the position of interaction in the plane of the detector, selecting which strips have detected a photon, while the Z coordinate (depth of interaction) is determined by the element of the stack that contains these strips, with a precision determined by its thickness. All planes in a stack are in exclusive OR imposing therefore a single interaction. The capability of measuring the depth of interaction makes it possible to design a very compact scanner with large solid angle coverage. Furthermore due to the compactness, non collinearity effects become negligible.

Preliminary results were obtained with MEGA prototype tracker (11 double sided Si detector layers, each with a thickness of 0.5 mm and a strip pitch of 470 microns), divided into two stacks 2 cm apart made of respectively 5 and 6 prototype layers, placing a small spherical ^{22}Na source in different positions [3]. A spatial resolution at FWHM of 640 μm was obtained.

We have tested some double sided silicon strip prototype detectors, manufactured by ITC-FBK, characterized by an active area of 3 x 3 cm^2, a strip pitch of 500 ❍m, strip widths of 300 μm and 200 μm, thicknesses of 1 or 1.5 mm and equipped with 64 orthogonal p and n strips on opposite sides.

In this work we present the experimental characterization of some 1 mm and 1.5 mm thick detectors, coupled with a VATAGP2.5 ASIC and their imaging and spatial performances. The figure 2 shows a photo of a module containing the sensor (n-side) bonded to a VaTaGP2.5 ASIC on a PCB support. The ASIC is built in 0.35 μm N-well CMOS technology by Ideas.

A ^{22}Na spherical source with a diameter of 1 mm was located between two opposed detectors in seven different positions (see figure 3a) to evaluate the spatial resolution of the microstrip detector, reported in figure 4b as a function of the position on the silicon sensors [4].

The estimated energy threshold is ~25 keV. In Fig. 4 we report the distribution of the energy threshold values measured for a sensor evaluating the minimum energy relievable in the spectra of a ^{133}Ba source. The calculated distribution shows two energy threshold values at (22.28 ± 0.02) keV and (23.94 ± 0.04) keV.

The resolution uniformity across the FOV was evaluated using a Pb mask 2 mm thick and equipped with the following hole pattern (see Fig. 5).

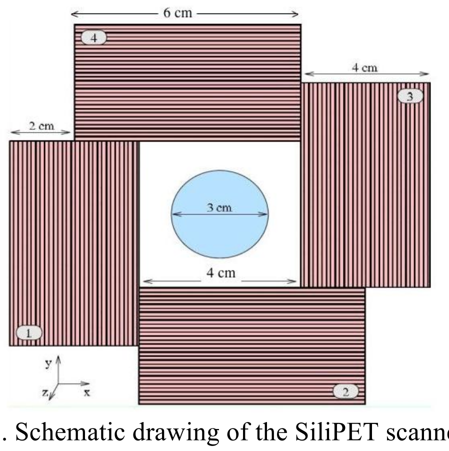

Figure 1. Schematic drawing of the SiliPET scanner.

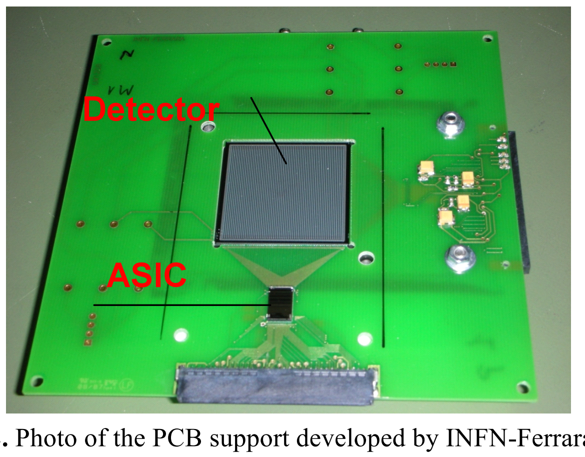

Figure 2. Photo of the PCB support developed by INFN-Ferrara.

The first set of holes is composed of 3 holes having 1 mm diameters and placed at a distance of 2 mm center-to-center. The second set has 3 holes having 0.7 mm diameters and placed at a distance of 1.4 mm center-to-center, the third by 3 holes having 0.5 mm diameter and placed at a distance of 1 mm center-to-center and finally the fourth set by 3 holes having 0.4 mm diameter and spaced of 0.8 mm center-to-center. The detector was irradiated with ^{57}Co and ^{241}Am sources. We can note in the images reported in Fig. 6 that the holes are well resolved when the horizontal separation is greater than the strip pitch, while they are not distinguished when the spacing is less than the strip pitch. The relative horizontal profiles are shown in Fig. 7, while in table 1 the mean center-to-center distance and the FWHM of a Gaussian fit are reported. The background present in the image acquired with ^{57}Co is due to the photons at 692 keV (79% of photons at this energy passes through the Pb mask). We can conclude that the spatial resolution of the detector is dominated by the strip pitch.

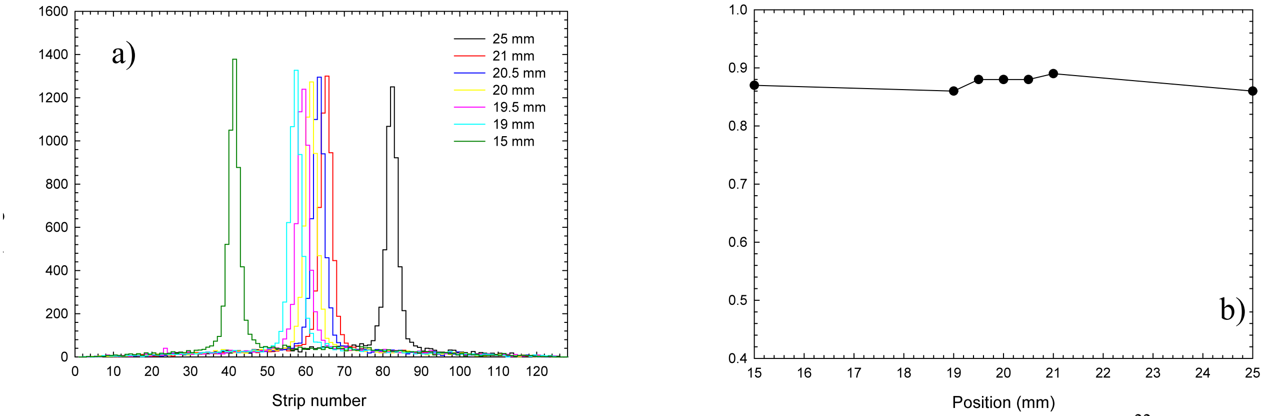

Figure 3. a) Profiles acquired at different positions, b) Spatial resolution measured with a 1 mm diameter ^{22}Na source.

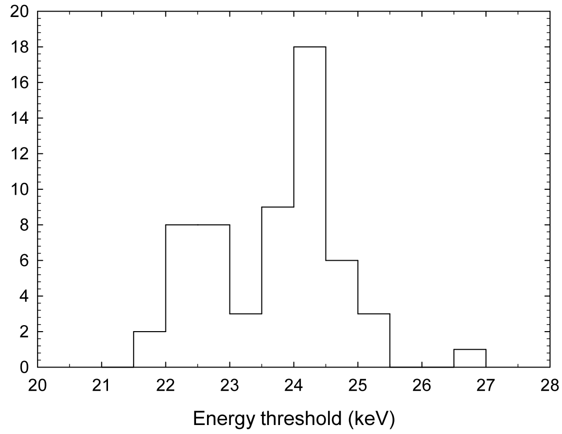

Figure 4. Energy threshold distribution of a silicon detector

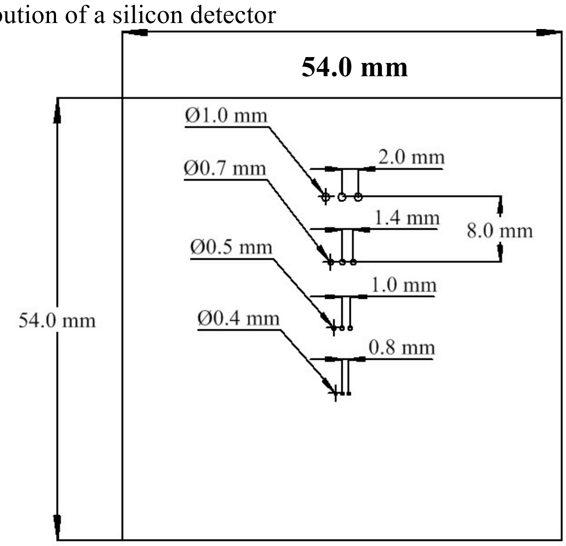

Figure 5. Schematic drawing of the Pb mask used to evaluate the spatial resolution.

We will report on the results obtained with stacks composed of two detectors, read by a VATAGP7.1 having the peaking time of the fast chain at 50 ns nominal to reduce the time walk variations. We will use a new more compact version of the board containing the control signals conditioning, the ASIC control voltages, interface isolator and ADC.

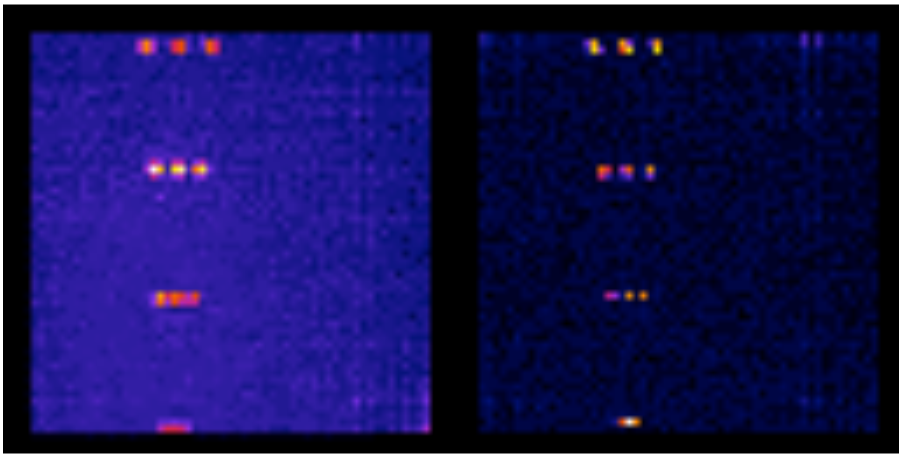

Figure. 6. 2-D images acquired illuminating a sensor through the Pb mask above described with ^{57}Co (left) and ^{241}Am (right).

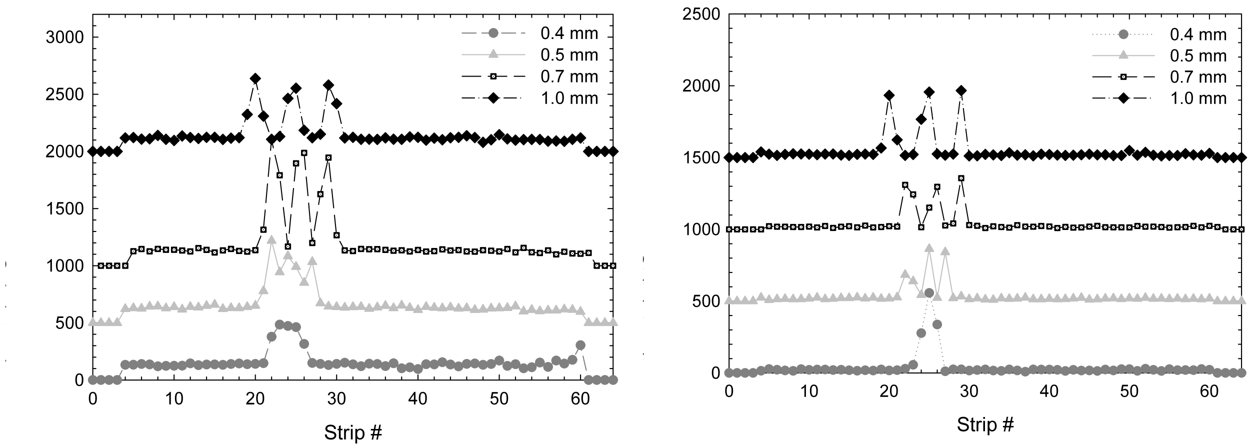

Figure. 7. Horizontal profiles of the 2-D images illustrated in Fig. 24: ^{57}Co (left) and ^{241}Am (right). The distributions are intentionally shifted along the vertical axis to obtain a more readable graph.

TABLE I
GAUSSIAN FIT PARAMETER OF THE 1-D PROFILES

Diameter (mm)	^{241}Am		^{57}Co	
	Spacing (pixel*)	FWHM (pixel)	Spacing (pixel)	FWHM (pixel)
0.5	2.37	1.02	2.32	1.53
0.7	3.25	1.29	3.19	1.49
1.0	4.44	1.22	4.67	1.60

*1 pixel = 0.25 mm

[1] G. Zavattini et al., “SiliPET: An ultra high resolution design of a small animal PET scanner based on double sided silicon strip detector stacks”, NIMPA 568 (2006) 393–397.
[2] N. Auricchio et al., “First Measurements for the SiliPET project: A Small Animal PET Scanner based on Stacks of Silicon Detectors”, Nuclear Science Symposium Conference Record, 2007. NSS '07. IEEE Volume 4, Oct. 26 2007-Nov. 3 2007 Page(s):2926 – 2929.
[3] di Domenico G., et al., “SiliPET: An ultra-high resolution design of a small animal PET scanner based on stacks of double-sided silicon strip detector”, NIMPA 571 (2007), pp. 22-25.
[4] N. Auricchio et al., “Experimental Measurements for the SiliPET project: A Small Animal PET Scanner based on Stacks of Silicon Detectors”, 2008 IEEE Nuclear Science Symposium Conference Record, R12-77.