Detection module based on position-sensitive large-area Silicon photomultipliers

F. Acerbi[1], S. Merzi[1], A. Nagai[2], A.V. Barroso[2], D. Della Volpe[2], A. Gola[1]

[1)] Fondazione Bruno Kessler (FBK), via Sommarive 18, Trento, Italy
[2)] University of Geneva, 24, quai Ernest-Ansermet, Genève, Switzerland
email: acerbi@fbk.eu

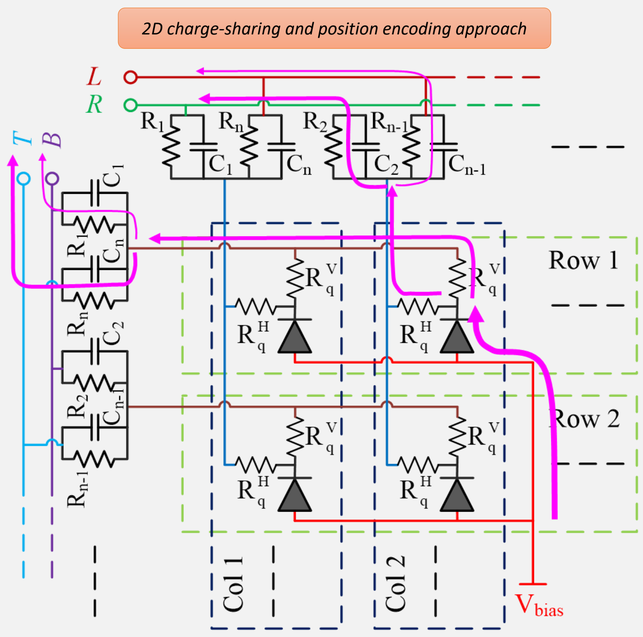
Introduction

- Silicon Photomultipliers are compact single-photon-sensitive detectors, widely used in many applications. In FBK we develop large area SiPMs based on different technologies
- We have been developing position-sensitive SiPM (PS-SiPM) technology based on charge-sharing approach.
- Such large area detector with position sensitivity is very interesting in applications like ultra-high spatial resolution, MR-compatible PET and in the creation of a compact (but large active-area) gamma and beta cameras with a reduced number of channels, for radio-guided surgery or other clinical decision support tools for diagnostic imaging.
- In this contribution, we propose a detection module based on a 2×2 tile of large-area PS-SiPMs, including front-end amplifiers and shaped like a very-compact "handleable" probe.
- Total area is 1.6x1.6 cm^2. PS-SiPMs are connected in a smart configuration. Measured position resolution (with pulsed LED, scanned over active area) is better than 0.5 mm.

Position-Sensitive Silicon photomultipliers

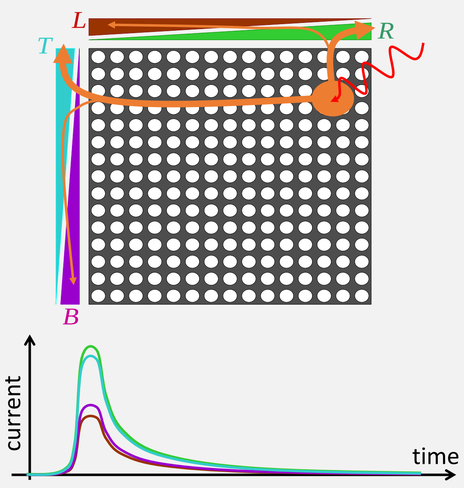
- FBK Position-sensitive SiPMs (PS-SiPMs), made in RGB-HD tech., are 8×8 mm^2 SiPMs, with 4 output pads (instead of 1): "top", "bottom", "left" and "right" signals.
- Device presented here are based on the so-called "linearly graded" (LG) technology.
- 2D charge sharing approach:
  - the output charge from each single micro-cell (SPAD) is split in two branch, one for vertical axis and one for horizontal axis information.
  - Each of these branches is then going to a weighed resistive divider, thus outputting the four signals.

2D charge-sharing and position encoding approach



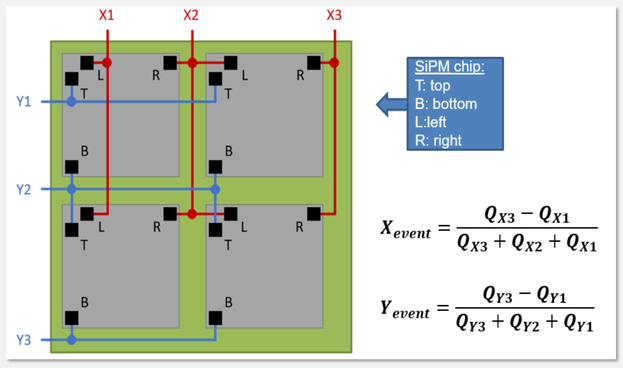
Characteristics of the LG-SiPM (RGB-HD tech.)

Chip dimension	8x8	mm^2
Cell pitch	20	µm
PDE (545nm)	35	%
Dark count rate	~300	Kcps/mm^2



Compact large-area handleable probe

- We developed a complete module based on a 2×2 tile of LG-SiPMs.
- The SiPMs are connected in a smart configuration, with a very low number of channels:
  - while for a single 8×8mm2 LG-SiPM there are 4 output,
  - for a 2×2 tile, thus 16×16 mm2 we have just 6 outputs, instead of 16 channels.

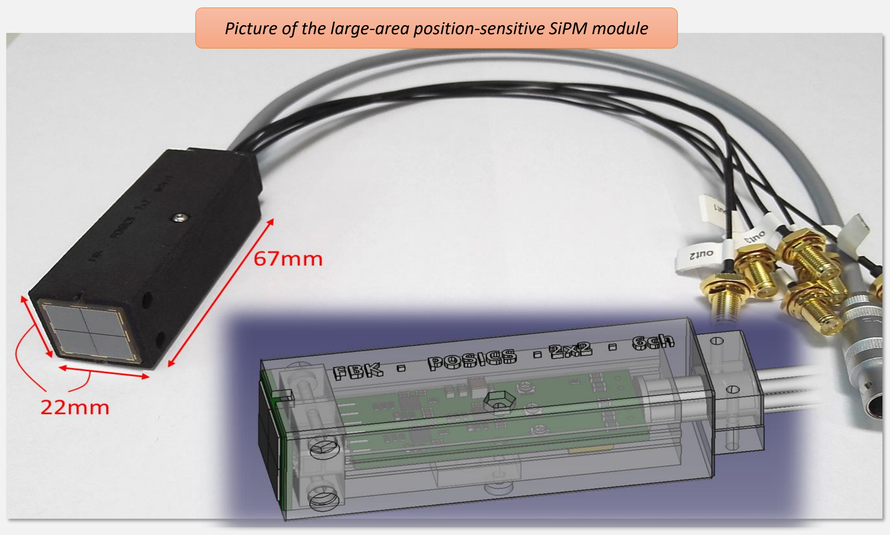


$$X_{event} = \frac{Q_{X3} - Q_{X1}}{Q_{X3} + Q_{X2} + Q_{X1}}$$

$$Y_{event} = \frac{Q_{Y3} - Q_{Y1}}{Q_{Y3} + Q_{Y2} + Q_{Y1}}$$

- *Note: without position-sensitive device, to reach 1 mm spatial resolution, we would need up to 16×16 devices, and many more output channels to be processed.*
- *Note: this approach is highly scalable, thus, the same or similar number of outputs can be preserved even with bigger area SiPMs*

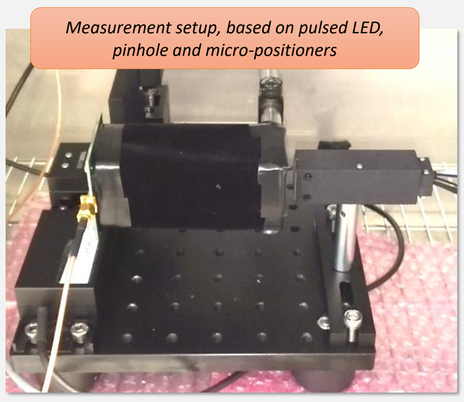
Picture of the large-area position-sensitive SiPM module



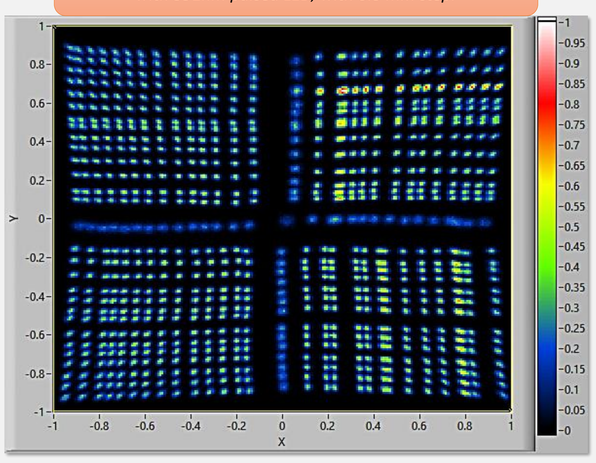
Measurements of position resolution

- We measured the energy and the position resolution of the proposed SiPM detection module (with 591 nm pulsed laser, spot of 200 µm, area 1.6×1.6 cm^2, step of 0.5 mm).
- Position are well distinguishable. Resolution is better than 0.5mm. Minor issues of compressions of adjacent column/rows.
- It can be seen a small pincushions effect of the map (reasons under investigation).

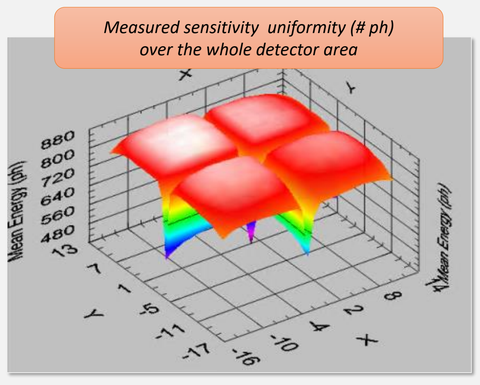
Measurement setup, based on pulsed LED, pinhole and micro-positioners



Reconstructed-position map of the 2x2 SiPM time, at 20°C, with 591nm pulsed LED, with 0.5 mm step.



Measured sensitivity uniformity (# ph) over the whole detector area



Gamma camera in tumor detection

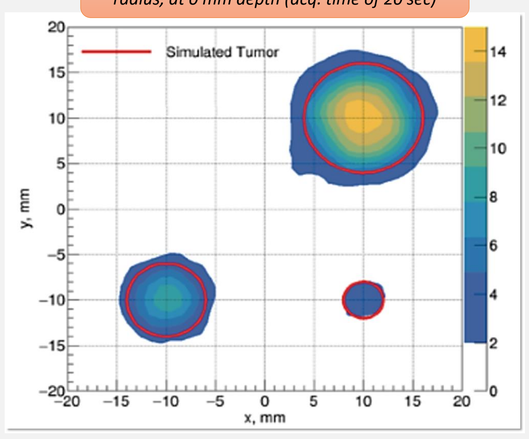
- Performance of proposed SiPM module when used to build a compact and portable gamma camera has been evaluated with OpenGATE software.
- Simulations were performed for different tumor sizes and depth, with 240 kBq/ml activity for tumor and 30 kBq/ml for the uptake.
- To calculate the tumor position, the signal difference to noise ratio (SdNR) was used:

$$SdNR = \frac{|\langle x_a \rangle - \langle x_b \rangle|}{\sigma_{x_b}}$$

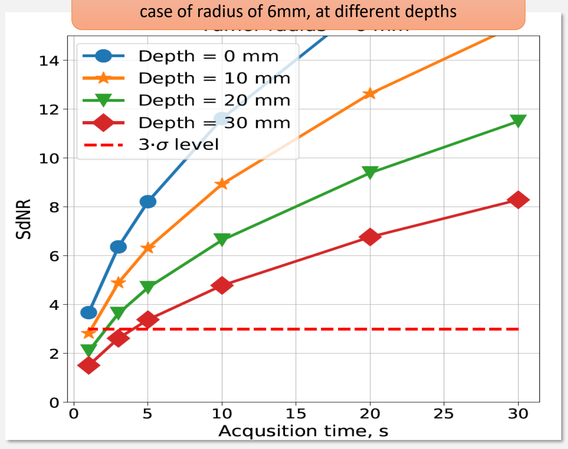
xa and xb: signal and background regions,
σ_(x_b)is the standard deviation of the background

- Acquisition of 5s → detection of tumor with 6 mm radius 3 cm deep inside patient.

Reconstructed image of 3 tumors with different radius, at 0 mm depth (acq. time of 20 sec)



OpenGate simulation of tumor shape reconstruction, in case of radius of 6mm, at different depths



Results and conclusions

- ✓ The proposed 2×2 tile of PS-SiPM (active area 1.6x1.6 cm^2) can reconstruct the light position with σ=0.338 mm.
- ✓ Despite a small degradation of spatial resolution, the gain in the reduction of read-out channels is significant.
- ✓ With OpenGate simulation, we proved that for a radio-tracer emitting gamma of lower energy, as Tc99m, the gamma camera could achieve an excellent performance.
- ✓ Superficial tumors of about 2 mm, could be well reconstructed in less than 20 seconds. Tumors bigger than 6 mm in radius at 30 mm deep within about 10 seconds.
- ✓ SiPM technology development is ongoing in FBK. We developed blue-light-sensitive LG-SiPMs: chips of 10x10 mm^2 area. Better performance and larger area are expected.

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