LARGE-AREA SIPM PIXELS (LASIPS) IN SPECT

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ABSTRACT

The **weight and size of a gamma camera for full-body Single Photon Emission Computed Tomography (SPECT)** could be **significantly reduced** by using **silicon photomultipliers (SiPMs)** instead of photomultiplier tubes (PMTs). However, one would need a few thousands channels to fill a camera with SiPMs due to their limited area. As a solution we propose to use **Large-Area SiPM Pixels (LASiPs)**, which are built by **summing individual currents of several SiPMs** into a single output. To study the feasibility of using LASiPs in SPECT we: (i) built a **proof-of-concept SPECT micro-camera** for lab measurements; (ii) used those measurements to **validate Geant4 simulations of the system**; (iii) extended the **simulations to a full-body SPECT camera** and evaluated the **impact of LASiP size** (number of SiPMs summed) and **noise** in its performance.

INTRODUCTION

Single Photon Emission Computed Tomography (SPECT) is an nuclear imaging technique that employs a single-gamma-ray tracer. A typical SPECT camera uses a 500 x 400 mm^2 scintillation camera coupled to 50-100 Photomultiplier tubes (PMTs). It is surrounded by a thick layer of lead, making it heavy (can weigh a few hundred kilograms) and bulky.

- About 50 % of the volume is occupied by the PMTs. **Weight and volume of a SPECT camera could be significantly reduced if PMTs were replaced by Silicon photomultipliers (SiPMs)** (see Figure 1).
- Main limitation: SiPMs are available in sizes < 6 x 6 mm^2 → ~ 4000 channels would be needed to fill a camera.

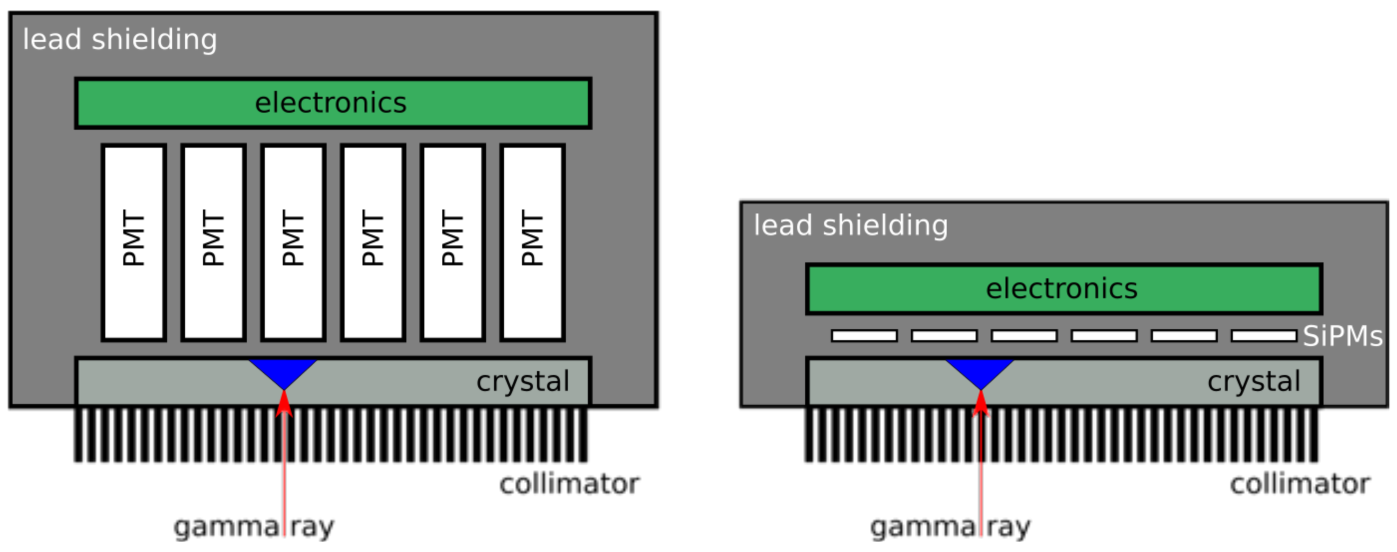

Figure 1: Left: Main components of a gamma camera are a lead collimator, a scintillator crystal and an array of PMTs; **Right:** Replacing PMTs by SiPMs would allow to reduce the volume of the camera (and thus the amount of lead needed for the shielding).

THE LASIP CONCEPT

As a solution we propose **to use Large-Area SiPM Pixels (LASiPs) in SPECT**. A **LASiP** is built by **summing the individual currents of several SiPMs into a single output** (see Figure 2).

- Less readout channels without a dramatic increase in capacitance.
- Flexibility to build pixels with different geometries.
- Sum can be performed using an ASIC (e.g. the MUSIC [1]).

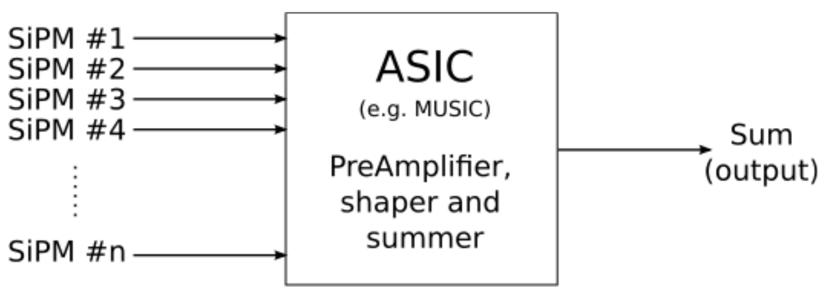

Figure 2: The ASIC sums the input of *n* SiPMs in a single output.

PROOF-OF-CONCEPT MICRO-CAMERA

- We developed a **LASiP prototype** that uses a MUSIC ASIC to sum **eight SiPMs of ~ 6 x 6 mm^2** (pixel area ~ 2.9 cm^2), see Figure 3.
- We built a **proof-of-concept micro-camera** consisting of **4 LASiPs coupled to a 40 x 40 x 8 mm^3 NaI(Tl) crystal** (see Figure 3).
- We evaluated its performance in the lab:
  - **Energy resolution**: ~ 11.6% at 140 keV
  - **Intrinsic spatial resolution**: (2.2 ± 0.2) mm
- **Good agreement with Geant4 simulations of the system** (see Figure 4). SiPM parameters like dark counts, optical crosstalk or PDE were included in the simulations (see [2] for details).

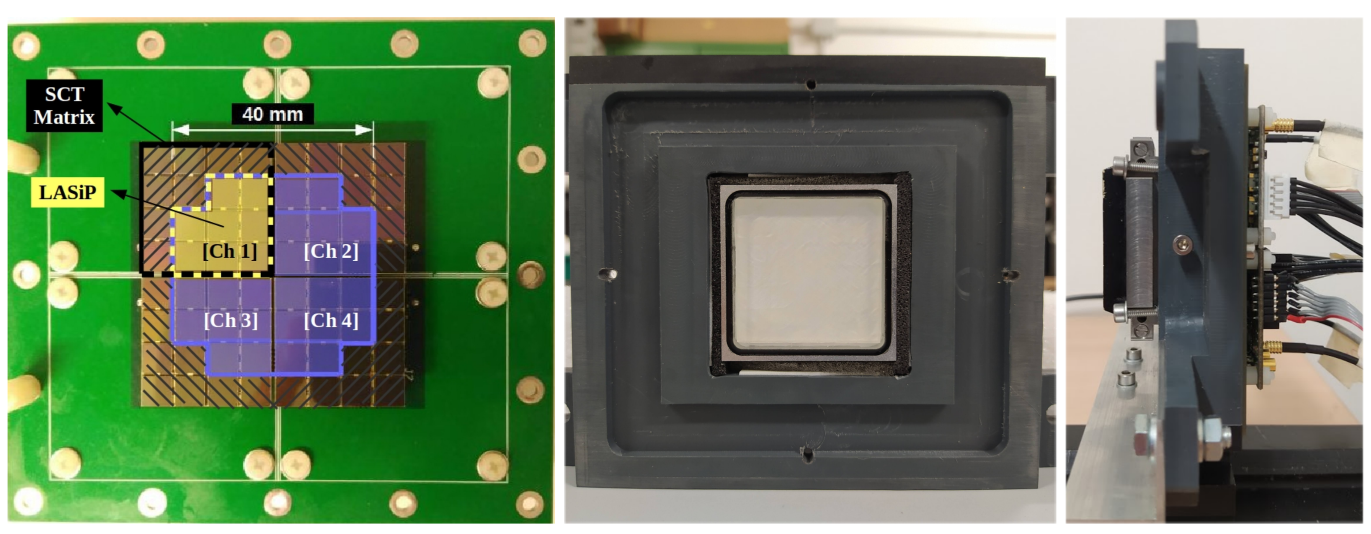

Figure 3: Left: Top-view of the 4 LASiPs mounted in the readout board. **Center**: The NaI(Tl) crystal placed in a custom designed holder. **Right**: Side-view of the fully-assembled micro-camera, including a lead collimator

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References:

[1] S. Gómez, D. Gascon, G. Fernández, A. Sanuy, R. Graciani Diaz, and D. Sanchez. "MUSIC: An 8 channel readout ASIC for SiPM arrays". In: Apr. 2016, 98990G. URL: https://doi.org/10.1117/12.2231095.

[2] D. Guberman, R. Paoletti, A. Rugliancich, C. Wunderlich, and A. Passeri. "Large-Area SiPM Pixels (LASiPs): A cost-effective solution towards compact large SPECT cameras". In: *Physica Medica* 82 (2021), 171–184. URL: http://dx.doi.org/10.1016/j.ejmp.2021.01.066.

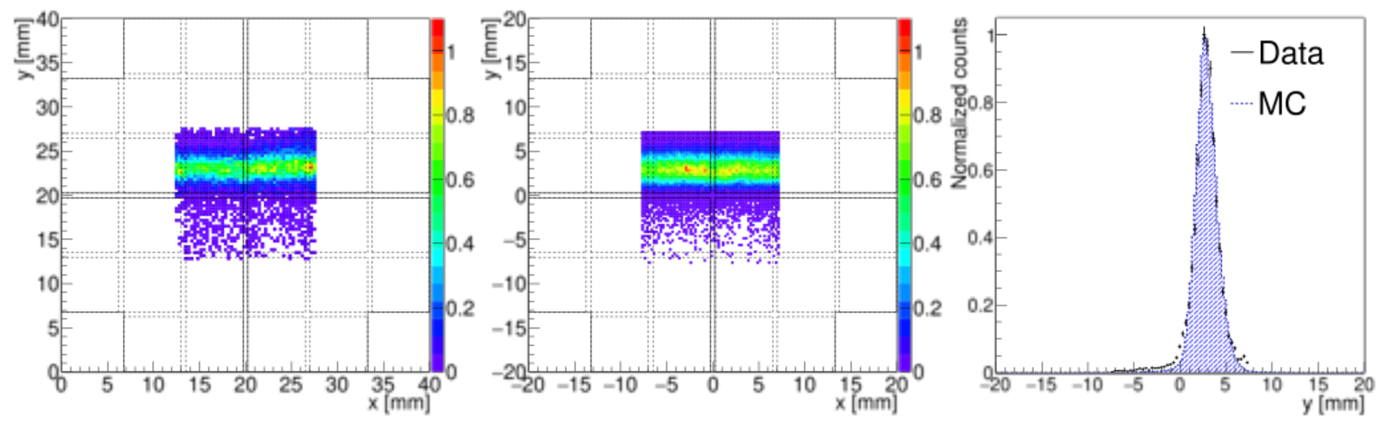

Figure 4: Left: Image of ^{99m}Tc capillary of 0.5 mm diameter taken with the micro-camera, at a distance of 2 cm using a LEUHR collimator (3 cm thickness, 1.2 mm hole diameter). **Center:** Monte Carlo (MC) image obtained when the same experimental conditions were simulated. The black solid lines show the borders of the LASiPs and the dashed lines show the borders of the SiPMs that are part of those LASiPs. **Right:** Projection of the left and center images in the y axis.

EXTENSION TO A LARGE SPECT CAMERA

- We **extended the simulations** of the micro-camera to a ~ **500 x 400 x 9 mm^3** camera equipped with 6 x 6 mm^2 SiPMs.
- The SiPMs could be grouped to **form square-shaped LASiPs** of 9, 16, 25 and 36 SiPMs or **flower-shaped LASiPs** summing 24 SiPMs (see Figures 5,6 and Table 1).
- **Three dark count rate (DCR) levels** were simulated (see Figure 7):
  - "cooled-SiPM" noise: DCR = 0.015 MHz/ mm^2
  - "room-SiPM" noise: DCR = 0.054 MHz/ mm^2
  - "hot-SiPM" noise: DCR = 0.150 MHz/ mm^2
- Image reconstruction using a **Maximum-Likelihood estimation**.

Nr of SiPMs per LASiP	pixel area [mm^2]	shape	intrinsic spatial resolution [mm]
9	324	square	1.8
16	576	square	2.3
25	900	square	3.5
36	1296	square	6.0
24	864	flower	2.7

Table 1: Intrinsic spatial resolution for a simulated capillary of negligible diameter at **room-SiPM noise** with LASiPs of different sizes.

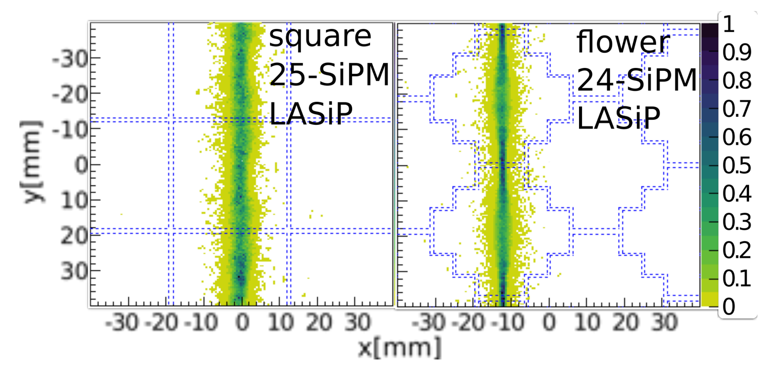

Figure 5: Reconstructed image of a simulated capillary of negligible diameter at **room-SiPM noise** with LASiPs of different shapes. The dashed lines mark the position of the LASiPs.

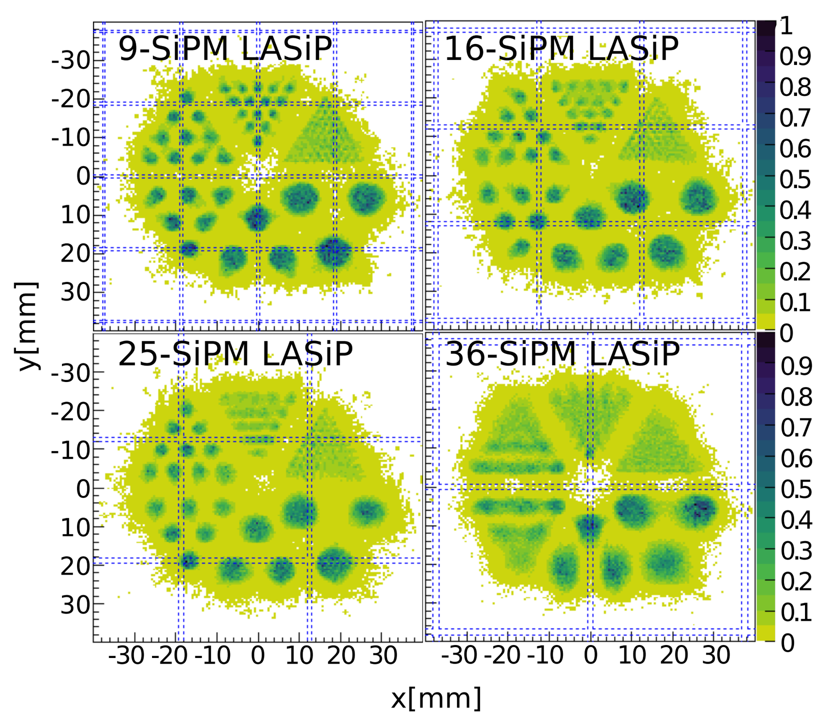

Figure 6: Reconstructed image of a simulated phantom source with point diameter of (1, 2, 3, 4, 6, 8) mm at **room-SiPM noise** with square shaped LASiPs of different sizes. The dashed lines mark the position of the LASiPs.

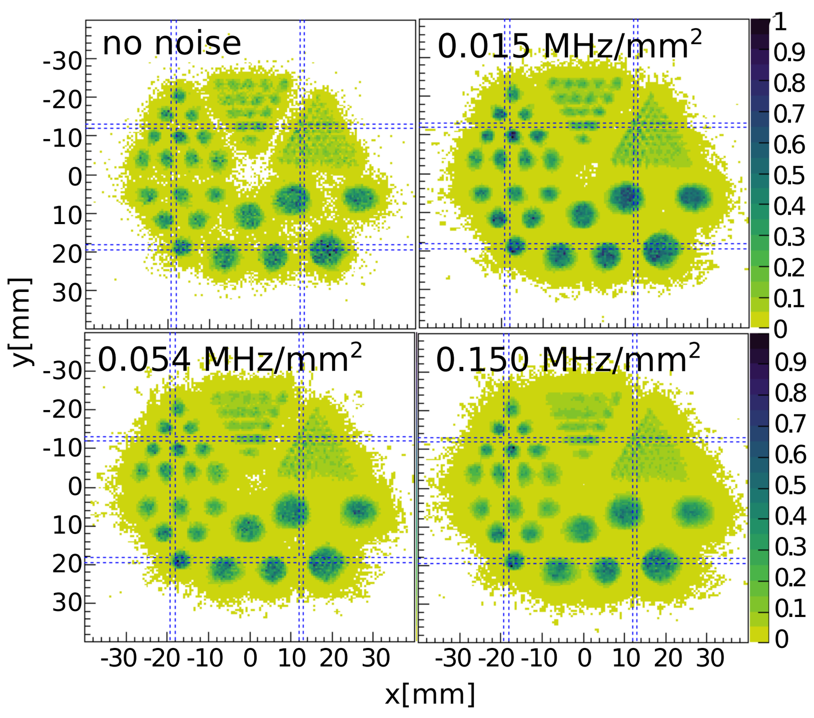

Figure 7: Reconstructed images of a simulated phantom with square 25-SiPM LASiPs for noise with different DCR levels. The dashed lines mark the position of the LASiPs.

CONCLUSIONS

- With the micro-camera we could reconstruct simple images with a **performance that is comparable to standard SPECT cameras**.
- Simulations of a large camera: we evaluated the **expected spatial resolution for different LASiP sizes**. A LASiP summing ~25 SiPMs of 6x6 mm^2 appears as a reasonable trade-off between performance and number of readout channels.
- **DCR can significantly degrade the performance**, especially for large LASiPs. In this cases cooling the SiPMs might be needed.
- These preliminary results support the **feasibility of using LASiPs in SPECT**.