Iterative reconstruction of SiPM light response functions in a square-shaped compact gamma camera

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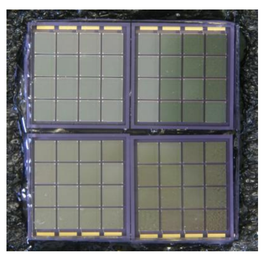
- Statistical reconstruction of event position/energy for compact gamma camera (30x30x2 mm^3 LYSO scintillator, 64 SiPMs)
- Axially-symmetric LRFs can be used, results in low level of image distortions
- Light response functions (LRFs) of all SiPMs can be obtained using an iterative method
- Only flood field calibration is required to compute the LRFs

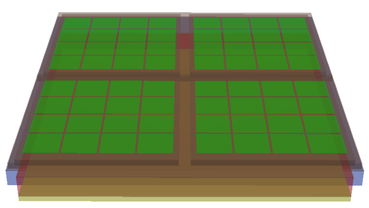
Prototype and simulation models

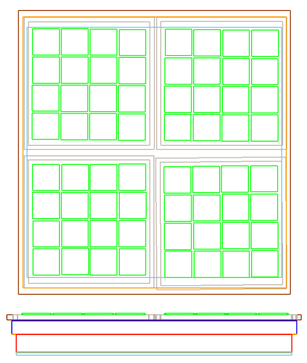
- Ce:LYSO crystal 30x30x2 mm^3 (~4500 photons per 140 keV γ)
- 64 SiPMs: 2 x 2 ArraySB-4 arrays from SensL, each contains 4 x 4 MicroSB-30035 sensors
- Acrylic glass lightguide (2mm thick)
- PTFE reflector
- BC-630 silicone optical grease
- Side surfaces of the scintillator and the lightguide are painted with black paint



SiPM array of the camera prototype

Simulation model configured according to the prototype



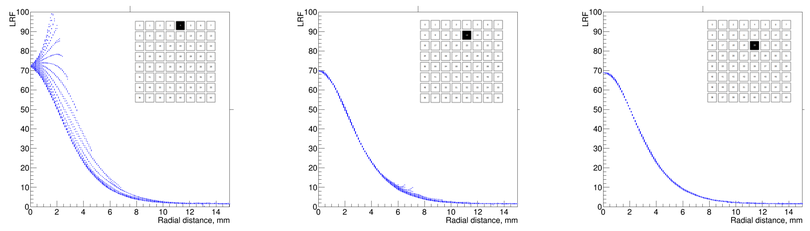


Strong internal reflection on the side surfaces of the crystal due to the large difference between the refractive indexes (1.82 for LYSO and 1.5 for the paint). Critical angle is 54 degrees.

Second camera model simulated in the study had a regular array of SiPMs.

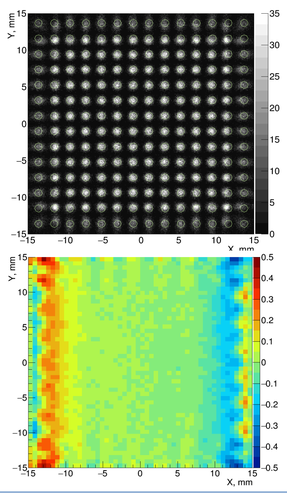
All simulations and reconstructions were performed using the **ANTS2** toolkit.

Can we use axially-symmetric LRFs?



Profiles of the spatial response of the SiPMs as a function of radial distance from the SiPM center. Each plot contains 50 profiles for azimuthal directions regularly distributed over 2π.

Maximum likelihood reconstruction with axially-symmetric LRF parameterization. LRFs were directly computed (not iterative!) using known true positions of the events:

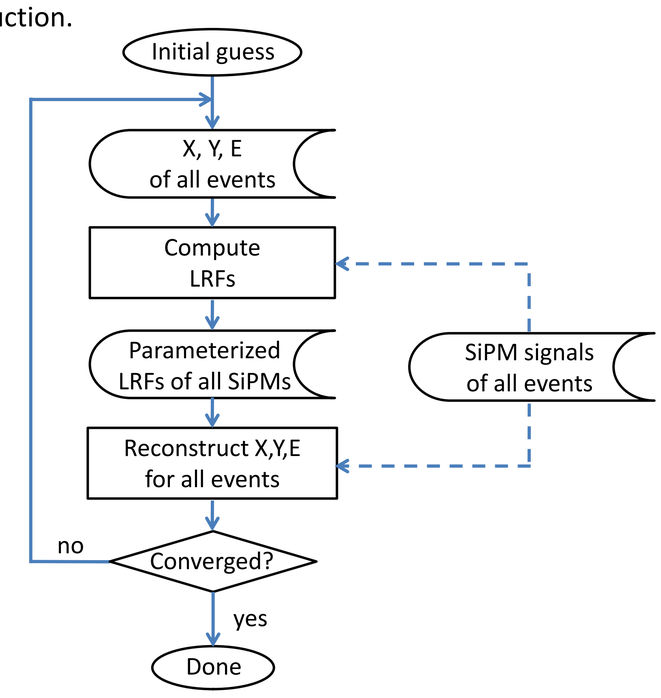


The density map of the reconstructed positions of a scan dataset, superimposed with the circles indicating the true positions of the pencil beam source.

The difference between the true and the reconstructed X coordinates (color-coded, scale is in mm) for another flood dataset.

Iterative LRF reconstruction

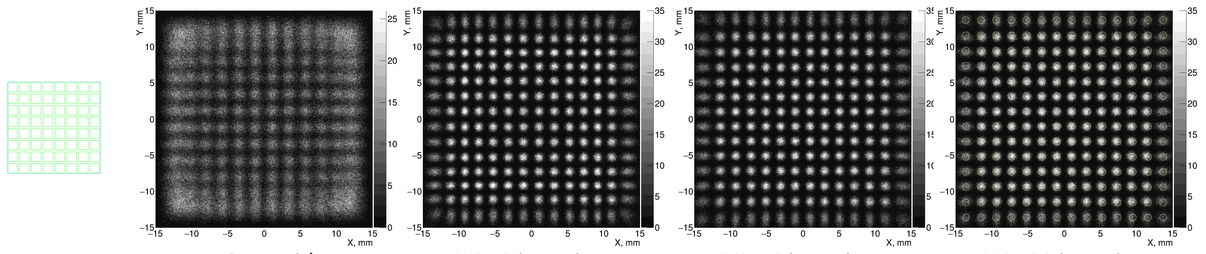
Method requires a calibration dataset with SiPM signals for events recorded with flood field irradiation. The initial guess on the event positions can be made using, for example, centroid reconstruction.



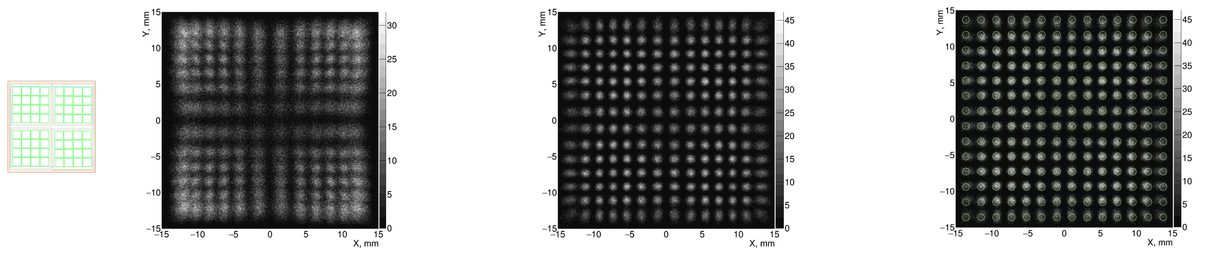
Convergence: one can directly monitor the variation of the LRF profiles from iteration to iteration, or observe a parameter describing how well the reconstructed LRFs represent the provided sensor signals.

Iterative reconstruction of LRFs: simulations

LRFs (axially symmetric parameterization) were reconstructed from a flood field dataset with 5x10^5 events. Scan dataset (2.1mm pitch, ø1mm pencil beam) is used to demonstrate improvement of the image quality.

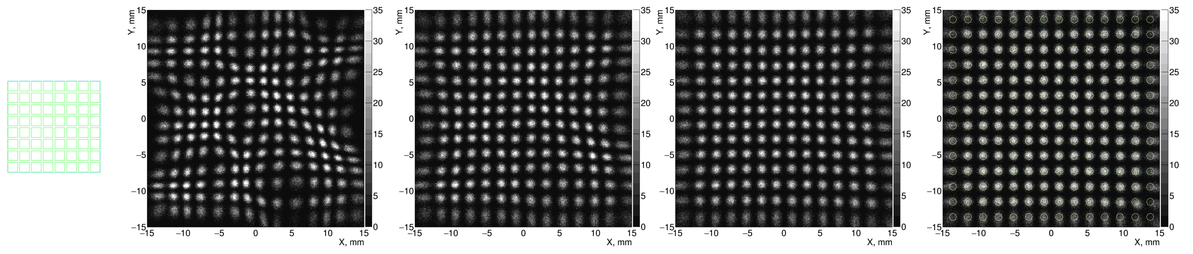


Centroid | ML, 1 iteration | ML, 4 iterations | ML, 11 iterations



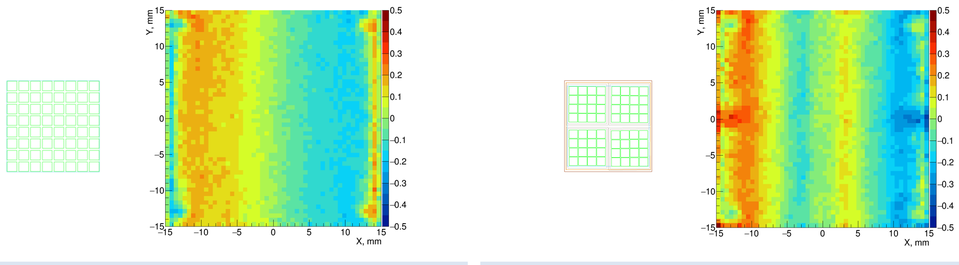
Centroid | ML, 1 iteration | ML, 14 iterations

Simulation with scaled sensor gains (sampled from uniform distribution, factor 0.5 ... 1.5). First guess is provided by the ML reconstruction with LRFs reconstructed from a simulation with unitary gains:



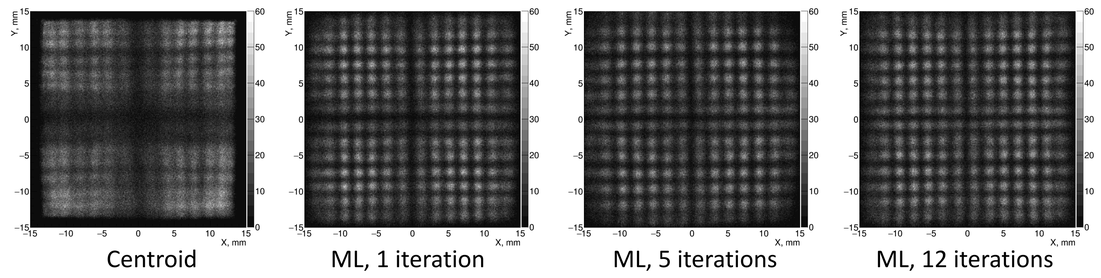
ML, guess | ML, 1 iteration | ML, 4 iterations | ML, 20 iterations

Difference between the true and the reconstructed X coordinates (color-coded, scale is in mm):

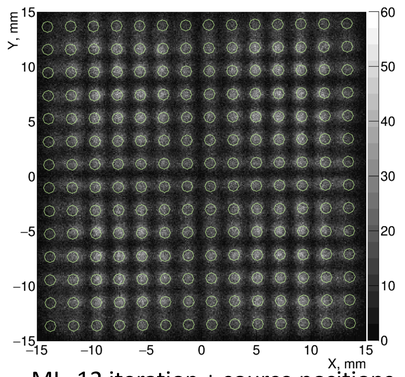


Iterative reconstruction of LRFs: experiment

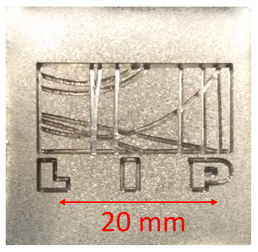
LRFs (axially symmetric parameterization) were reconstructed from a flood field dataset with 5x10^5 events. Convergence was reached after 12 iterations. Scan dataset (2.1mm pitch, ø1.1mm pencil beam) is used to demonstrate improvement of the image quality.

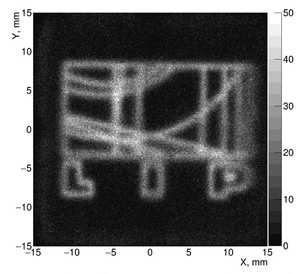


Centroid | ML, 1 iteration | ML, 5 iterations | ML, 12 iterations

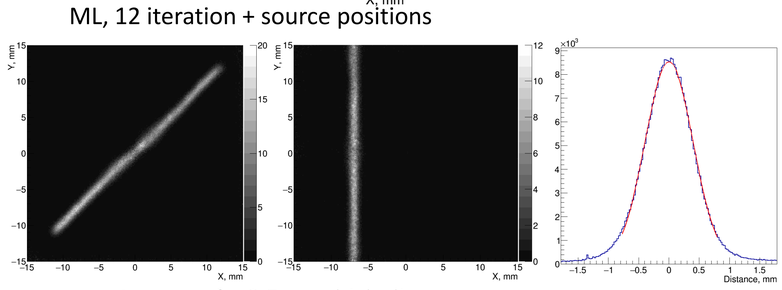


ML, 12 iteration + source positions



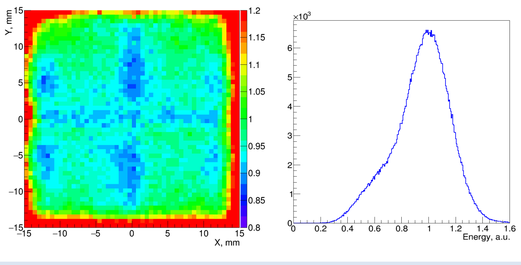


LIP logo mask (0.5mm thick grooves) and the reconstructed image.



Images of a 0.5mm thick slit

Gaussian fit of the projection of the vertical slit image gives FWHM of 0.93mm.
Camera optimization to maximize spatial resolution will be conducted in a separate study.



Map of the reconstructed energy (left) and the reconstructed energy spectrum (right) for flood irradiation data. The spectrum is shown for the central area of 24 x 24 mm^2.

- **No scan-based calibration is required**

The LRFs of all SiPMs can be computed iteratively from flood field calibration data, assuming axial symmetry of the response of all sensors. Centroid reconstruction can provide the initial guess on event positions.

- **Low level of image distortions is demonstrated**

Simulations: the difference between the reconstructed and the true positions (X or Y) is ≤0.2 mm in the central area of 22x22 mm^2 and ≤0.4 mm for the rest of the camera.

Experiment: The maximum difference in X (and Y) coordinate between the center of the pencil beam and the corresponding mean reconstructed coordinate is <0.3 mm for the central area of 24x24 mm^2.

- **Quick LRF reconstruction**

On a PC with 3.4 GHz Intel Core i7 and Nvidia GTX970 board the time to reconstruct 64 LRFs from a dataset of 5x10^5 events is below 2 minutes.

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Preprint: arXiv:1610.02656

ANTS2 toolkit (open source): http://coimbra.lip.pt/ants/ants2.html

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