Fast Calibration of SPECT Detector Response Using Adaptive Iterative Technique

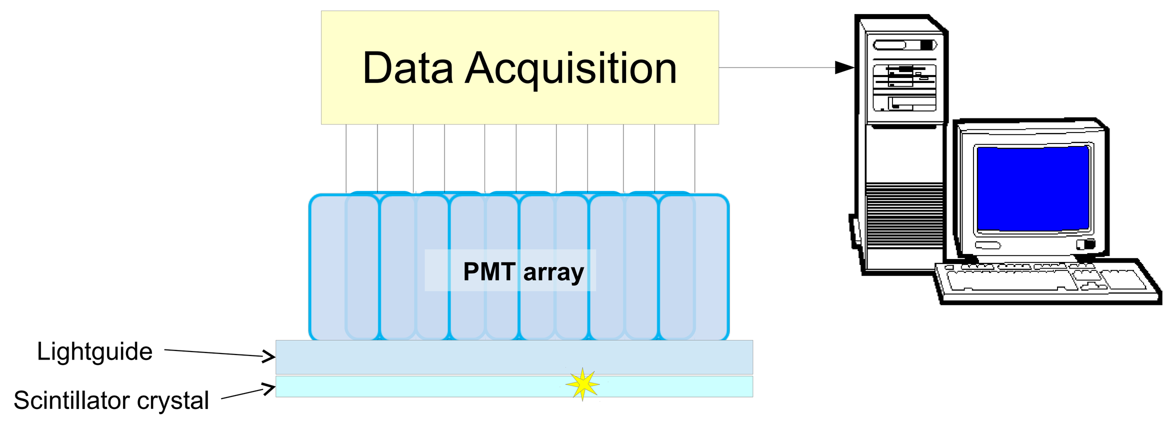
V. Solovov[1], A. Morozov[1], V.Chepel[1], V. Domingos[1], R. Martins[1], F. Alves[2]

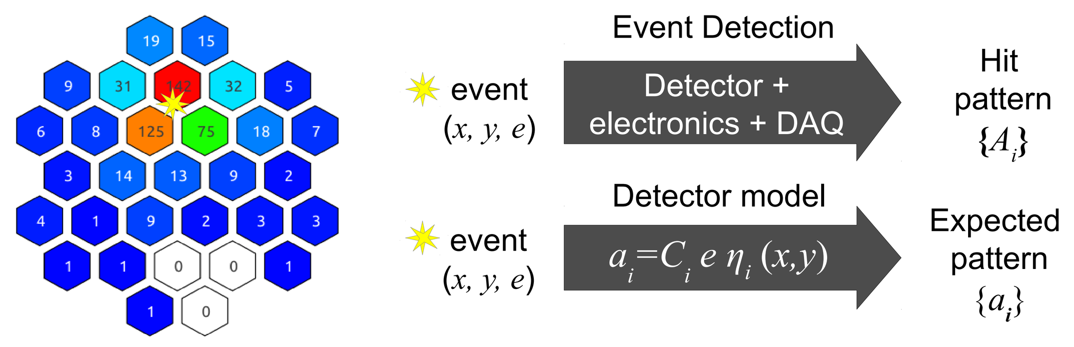
[1] LIP-Coimbra and Department of Physics of the University of Coimbra, 3004-516 Coimbra, Portugal

[2] Faculty of Medicine, Coimbra University, Portugal

ABSTRACT: statistical event reconstruction in a monolithic scintillation camera is an advanced technique which can give better results than traditionally used centroid method. However, to successfully employ this technique, detailed knowledge of PMT light response functions (LRFs) is required. Here we present an iterative technique which allows to obtain such LRFs from flood irradiation data. We show a successful implementation of the technique for medical gamma cameras using both simulated and experimental data. We also demonstrate that the same technique can be used for monitoring of the PMT gain variations in a gamma camera or SPECT detector.

Gamma camera and Statistical event reconstruction





To reconstruct an event from a hit pattern, find x, y and e for which the expected pattern $\{a_i\}$ is in the best agreement with hit pattern $\{A_i\}$.

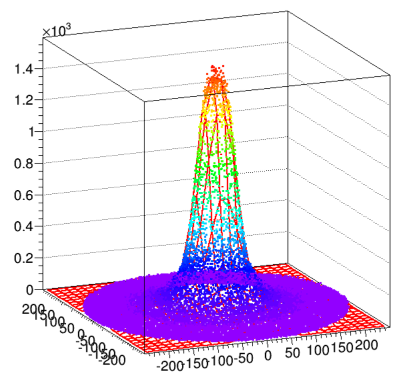
How to find this best match?

- Maximum likelihood (Gray & Macovsky, 1976)
- Least squares

Light Response Function $\eta_i(x,y)$ needed

Light Response Function (LRF) $\eta_i(x,y)$ characterizes response of a PMT as a function of light source position (x,y). LRFs can be obtained from:

- Direct measurements (time consuming and expensive)
- Simulations (requires detailed knowledge of detector geometry, material optical properties and PMT properties)
- **Iterative Reconstruction** from flood irradiation data

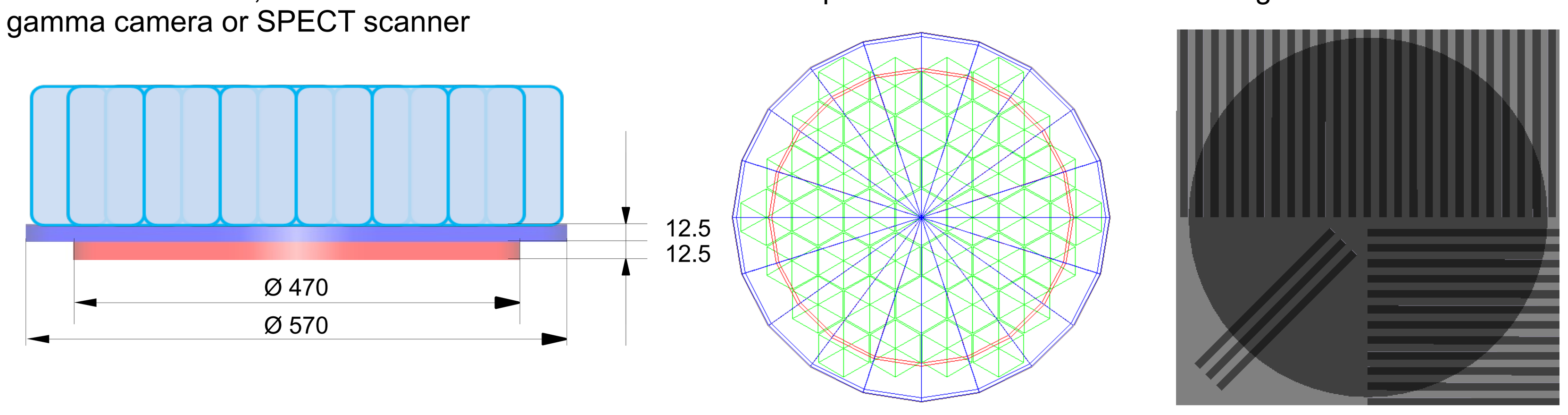


Iterative LRF reconstruction

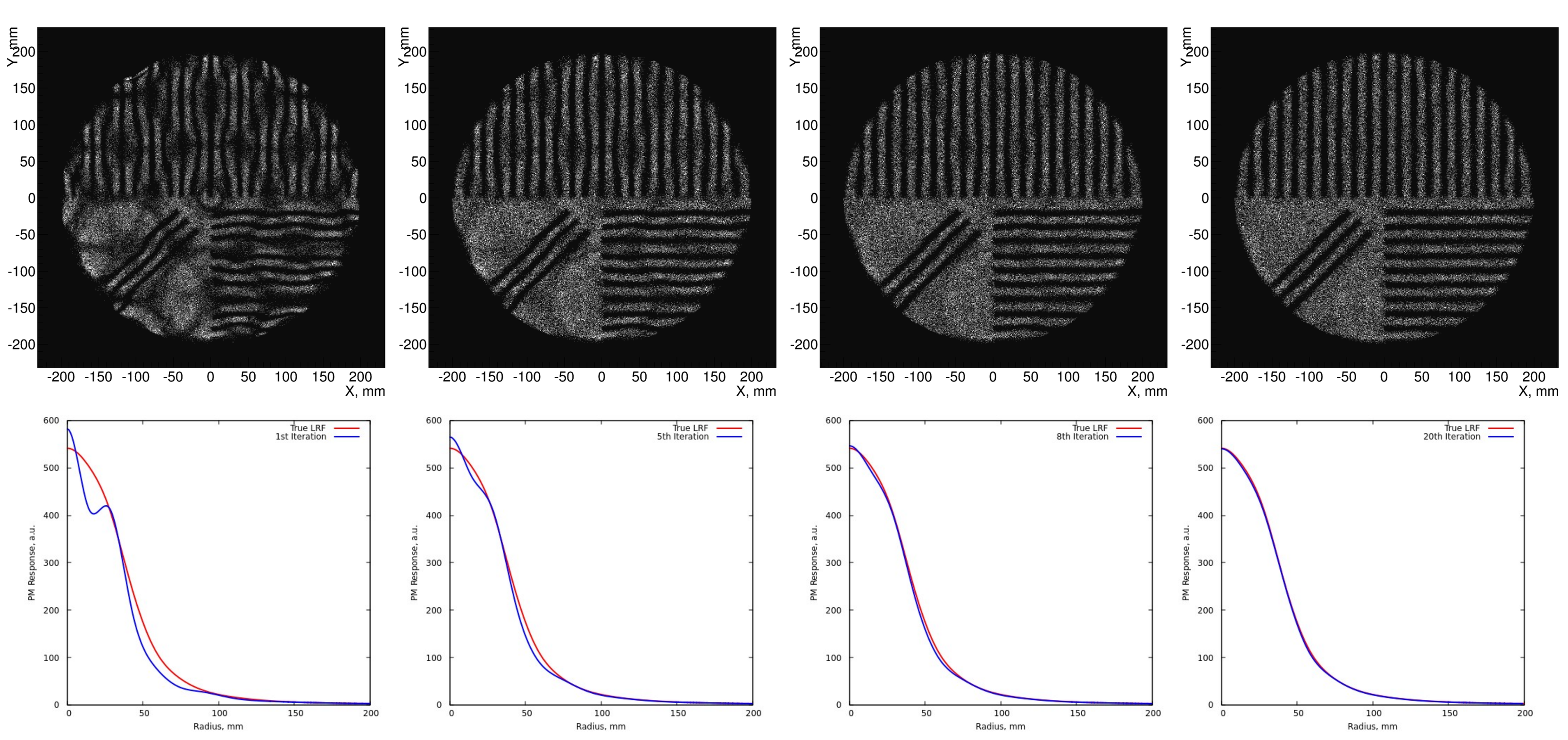
For a detector with N photo-sensors a scintillation event is fully described by only three parameters (x, y and energy) while N signals amplitudes are recorded. As, typically, N >> 3, this set of N amplitudes contains information not only on the event itself but on the detector response as well. An iterative technique for extracting this information and reconstructing the LRFs from flood irradiation data was first developed for ZEPLIN-III dark matter detector. It was found that under favorable conditions (very high scintillation output and low fraction of indirect light) LRFs can be reconstructed by the following procedure:

1) Chose a 1st approximation for LRFs (e.g. from simulation)
2) Reconstruct the event positions using the LRFs
3) Use the reconstructed event positions to update the LRFs
4) GOTO 2

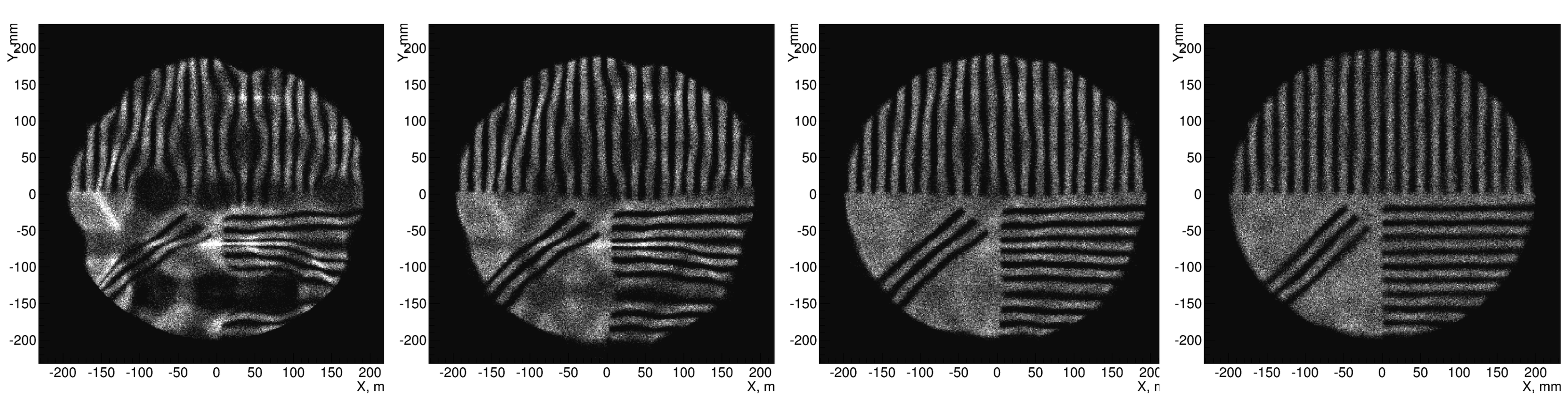
In the current work, it was demonstrated that the same technique can be used for reconstructing LRFs in a medical gamma camera or SPECT scanner



Simulations were performed for a model of a commercial gamma camera. The NaI(Tl) crystal is read out with an array of 37 hexagonal PMTs with QE of 30%. The crystal is irradiated with a parallel beam of 122 keV gamma rays (~4000 photons in NaI(Tl)) through a lead mask shown on the right. A common axially symmetric LRF is used for all PMTs. An LRF quite different from the true one was used as a starting point. However, after 20 iterations, the reconstructed LRF is almost identical to the true one. Also, the reconstructed image of the mask shows no significant distortion.

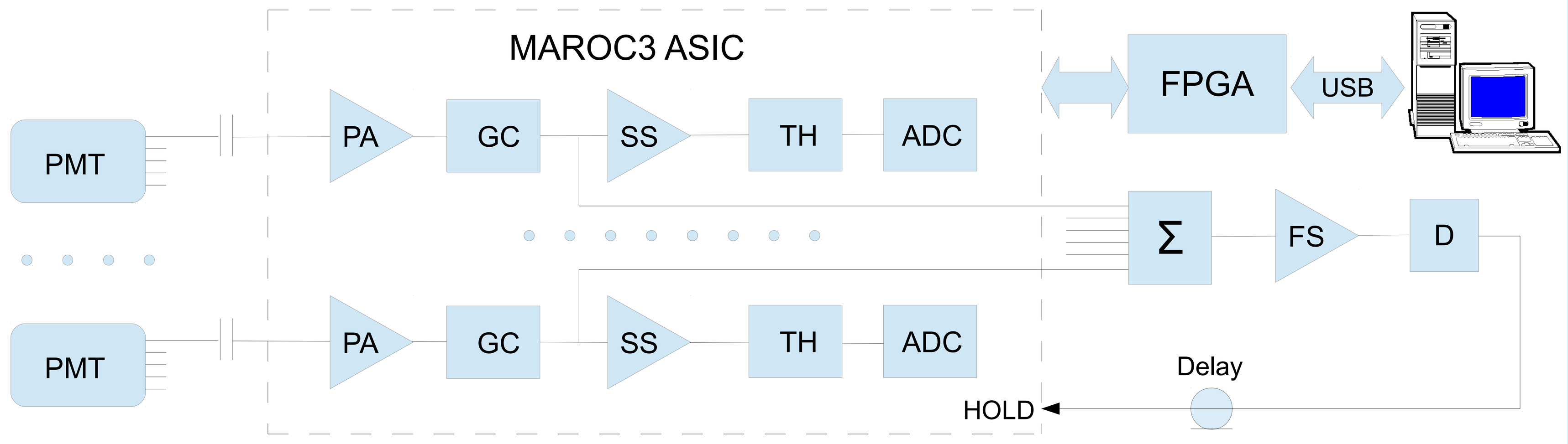


The method still works even under harsher conditions. In the example below, the photon statistics is less by a factor of two (~2000 photons per event) and the PMT gains are not equalized. Yet, after 40 iterations, the correct mask shape is recovered.



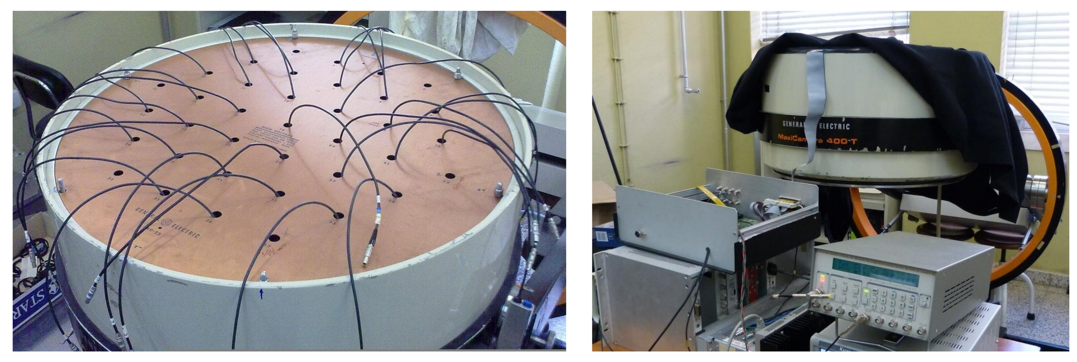
Experimental Set-Up

A decommissioned commercial gamma camera (GE Maxicamera 400T) was retrofitted with a custom multichannel data acquisition system based on MAROC3 front-end ASIC. This allowed readout of individual PMTs required for statistical event reconstruction.



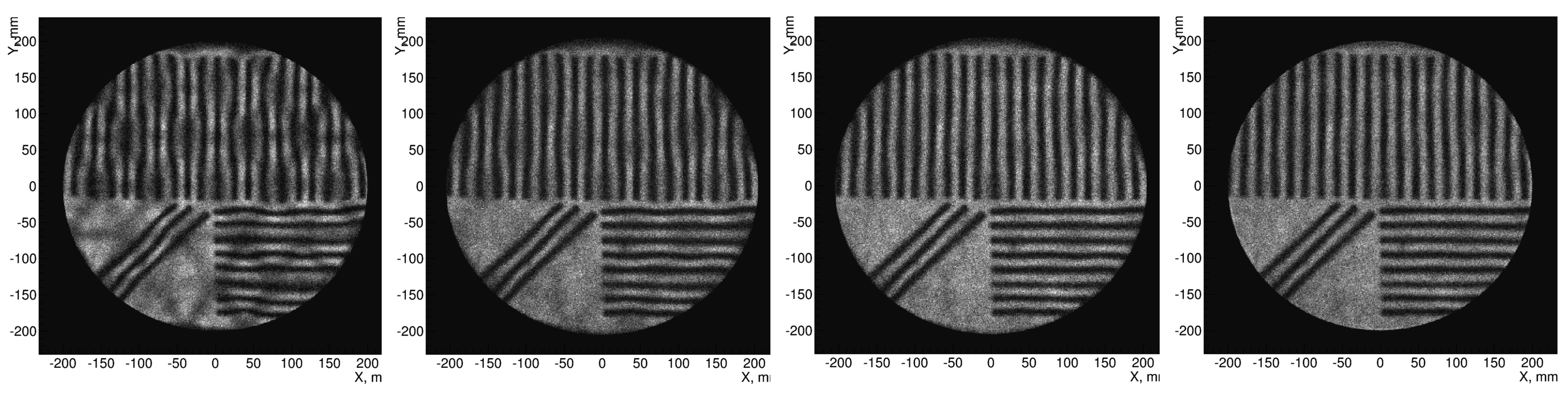
PA – preamplifier, GC – programmable gain control, SS – slow shaper, TH – track and hold, FS – fast shaper, D – discriminator.

The integration time of slow shaper was set to 150 ns – maximum allowed by MAROC3 chip. Unfortunately, this resulted in sub-optimal light collection, as the decay time of NaI(Tl) scintillator is ~250ns.

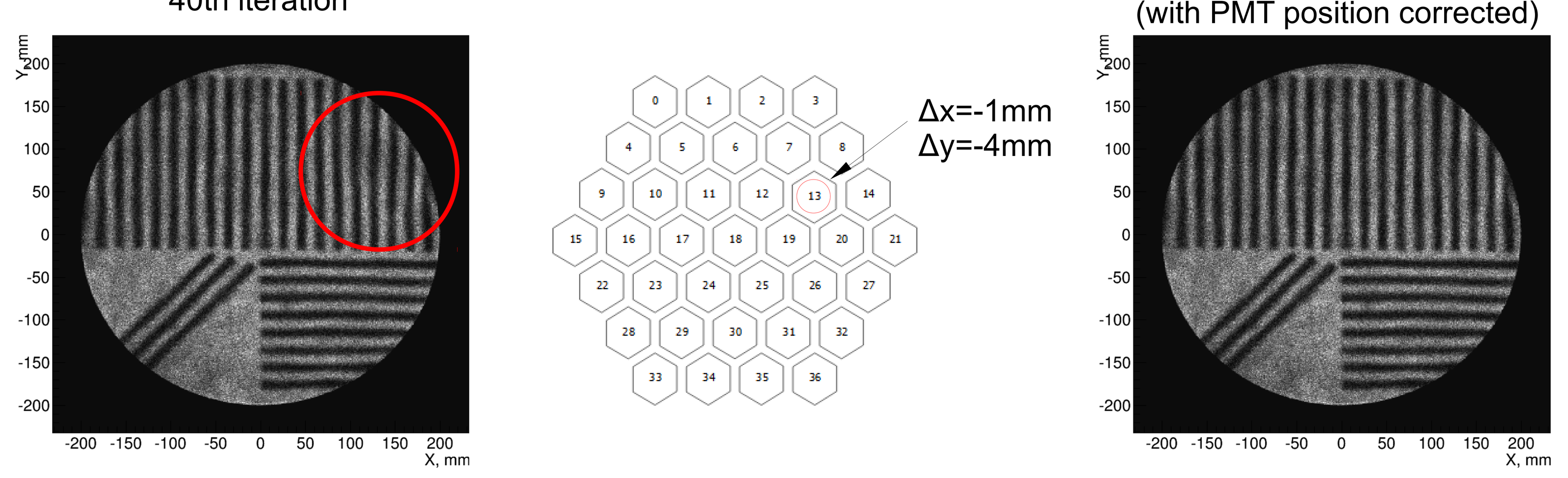


Experimental Results

The camera was irradiated by a ^{57}Co flood source through a lead mask (with geometry similar to the one used in simulation) and the factory-supplied high resolution lead collimator. The data samples of 3×10^5 events were used for iterative reconstruction process. On a modern computer system (Intel i7 + NVIDIA GTX 770) one iteration takes about 5 seconds for this sample size if a GPU is used for event reconstruction. As a first approximation, simulated LRFs were used. Up to 9th iteration one LRF was used for all PMTs with individual gain scaling. Beginning with 10th iteration, LRFs for each PMT were adjusted separately.

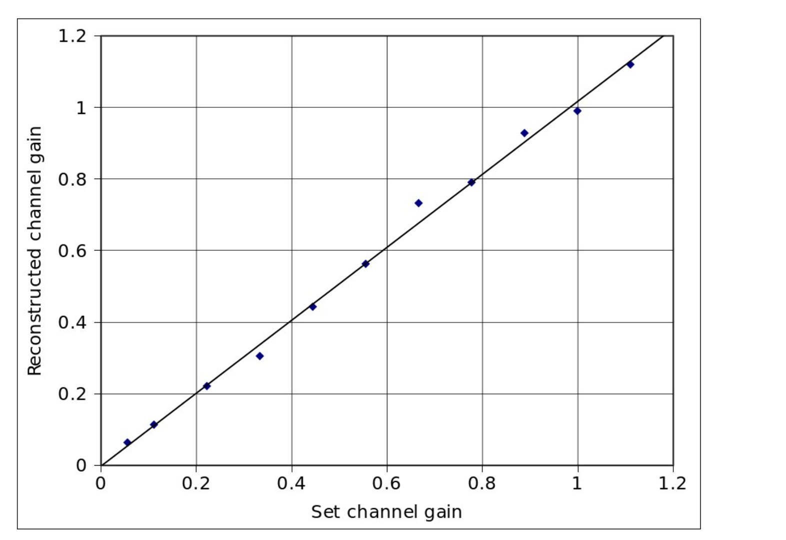


After 40 iterations almost the whole field of view becomes distortion-free except for the top-right corner. Upon individual examination of matching between reconstructed LRFs and the data, it was discovered that for one of the PMTs the axis of symmetry of the LRF does not coincide with its physical axis. After moving the axis of the LRF to the correct position the distortion almost completely disappeared.

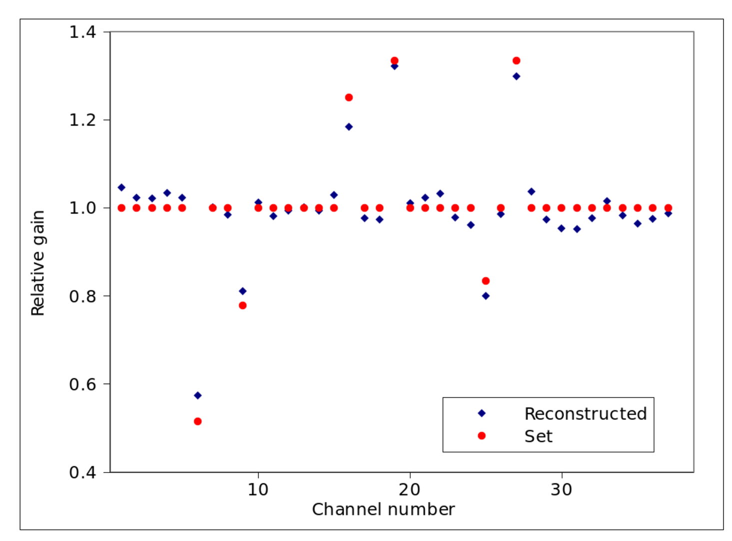


Once the LRFs are reconstructed, similar iterative technique can be used to monitor the individual PMTs for gain variations. In this case the shapes of the LRFs are fixed and only the multiplication factors are adjusted. To verify feasibility of this method the PMT gain drift was simulated by varying corresponding channel gain of the MAROC3 chip.

In one study the gain of one of the channels was adjusted in the range 0.1-1.2 compared to the reference gain and then estimated using the iterative procedure on ^{57}Co flood data. The estimated gain was found to be typically within a few percent of the set one.



In another study, the gains of several channels were changed simultaneously to see how the iterative algorithm handles this situation. Again, the estimated gains were close to the set ones.



Conclusions

This study demonstrated the feasibility of iterative reconstruction of LRFs in a medical gamma camera or SPECT detector from flood irradiation data. This opens possibility for performing fast linearity calibration using flood ^{57}Co source instead of linear one. It also allows for fast assessment of gain stability of the PMT array.

Simulations and data processing were performed using a dedicated software package for position sensitive scintillation detectors ANTS2 developed at LIP-Coimbra. The package is open source and can be downloaded form http://coimbra.lip.pt/ants/

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