Project GAMMA: Adaptive Methods for Medical Applications

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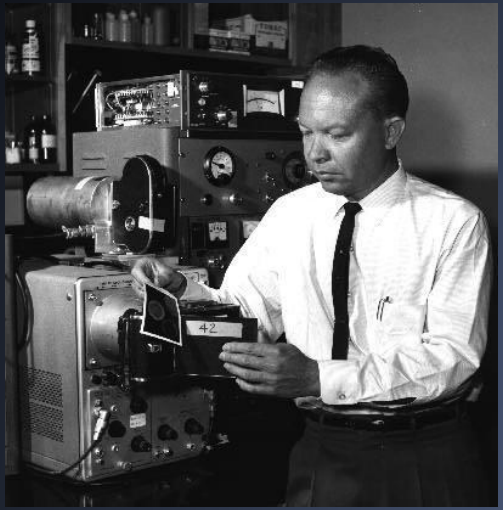
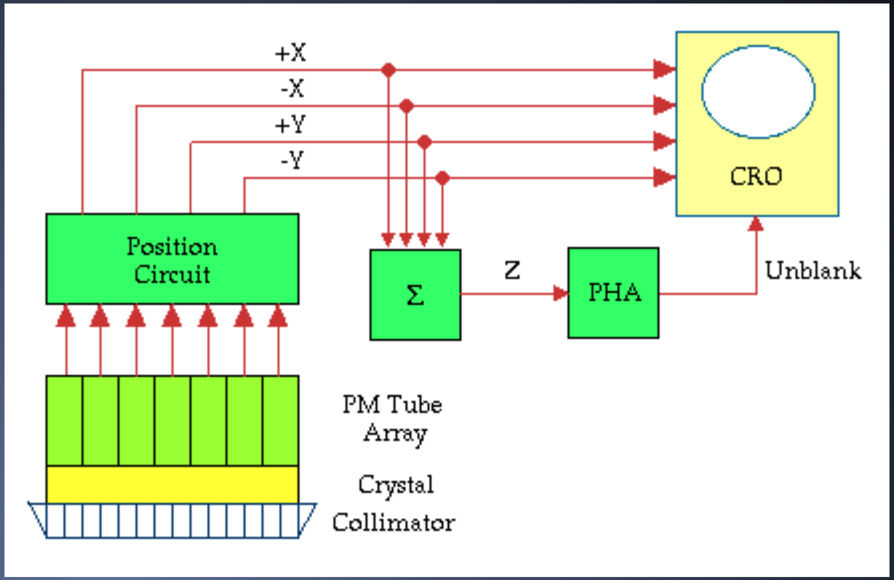
Scintillation Camera



Hal Anger, 1957



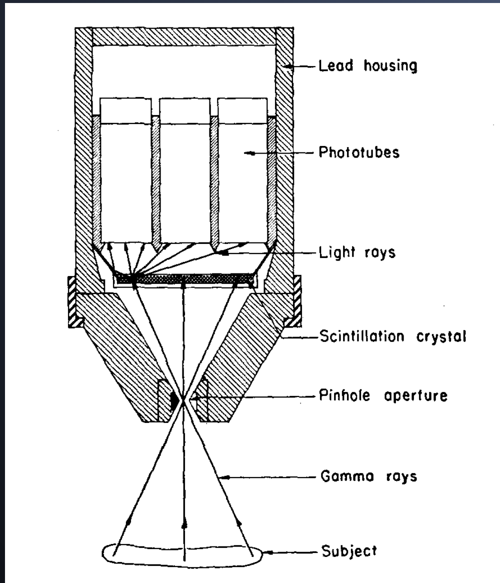
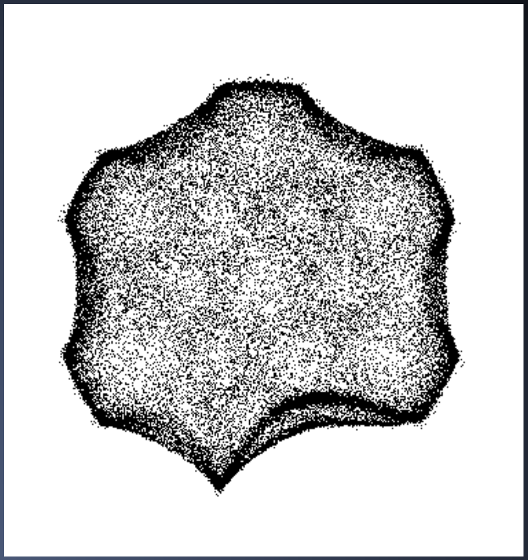


FIG. 1. Sectional drawing of scintillation camera.

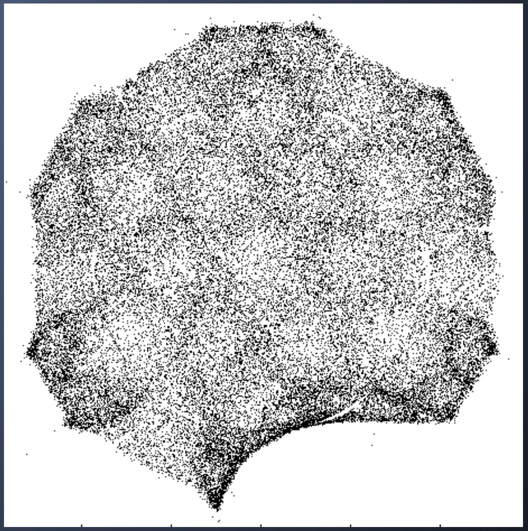
- Applications:
  - Nuclear medicine
  - Astrophysics
  - Neutron detection

Centre of Gravity

- Advantages:
  - Robust and easy to implement
  - Very fast
  - Works “out of the box” for virtually any configuration
- Problems:
  - Image distortion
  - No way to filter out bad events
- Workarounds:
  - Stretched centroid (periphery)
  - Correction table (local nonlinearity)
  - + Many patented techniques from gamma camera manufacturers
- The net result can be good image quality for the price of frequent re-calibrations
  - OK for a commercial device but might be unacceptable for a research instrument

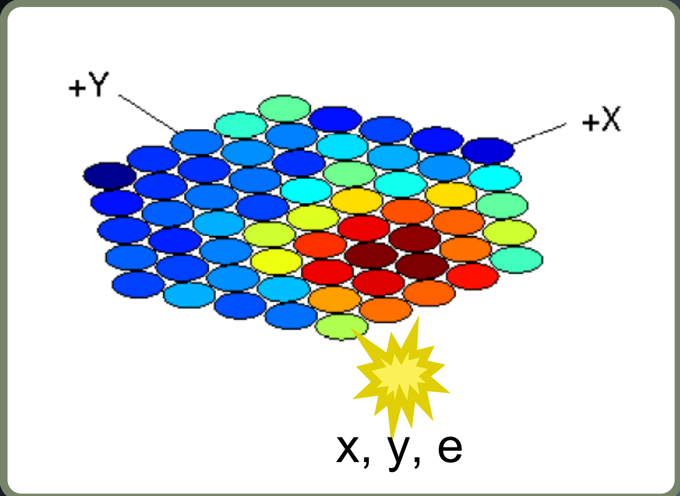


Centroid



Stretched Centroid

Event reconstruction (2D)



Event Detection

event (x, y, e) → Detector + electronics + DAQ → Hit pattern $\{A_i\}$

Detector model

event (x, y, e) → $a_i = C_i \, e \, \eta_i(x,y)$ → Expected pattern $\{a_i\}$

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
  - Neural network

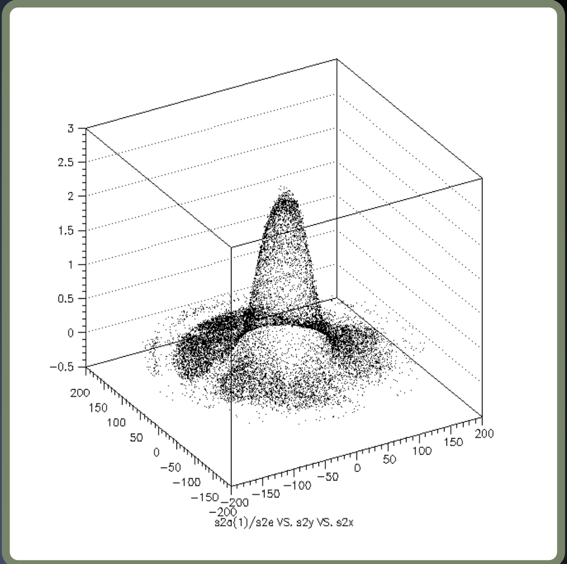
All these methods require

$$\eta_i(x,y)$$

Light Response Function

- What if no agreement was found?
  - Either the event is bad
  - Or the model is wrong

Light Response Functions



Light Response Function (LRF) $\eta_i(x,y)$ characterizes response of a PMT as a function of a light source position (x,y). In many cases it has axial symmetry and can be reduced to $\eta_i(r)$ where r is the distance from the PMT axis

How to find $\eta_i(r)$?

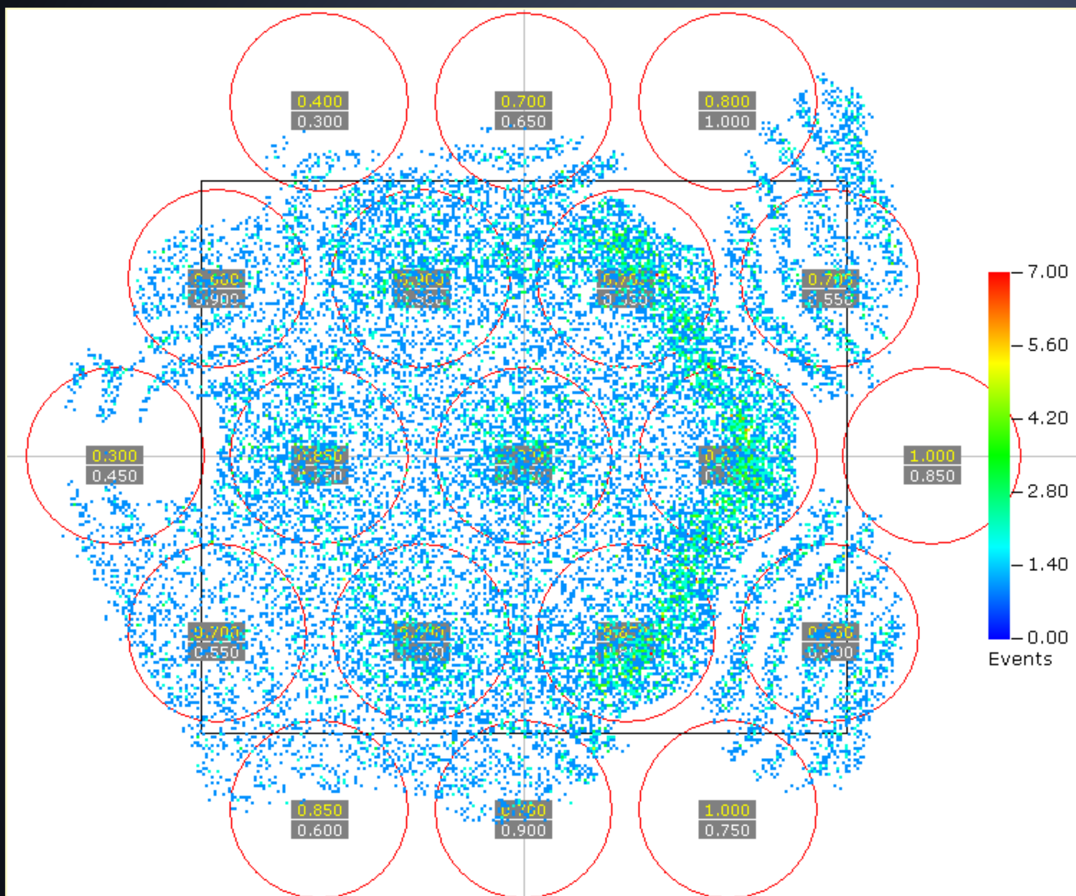
- Measure (time consuming in 2D, extremely difficult in 3D)
- Simulate (requires detailed knowledge of detector geometry, material optical properties and PMT properties)
- Use Iterative Reconstruction with experimental data (a technique first developed in LIP for ZEPLIN-III experiment)
  1. Chose a 1st 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

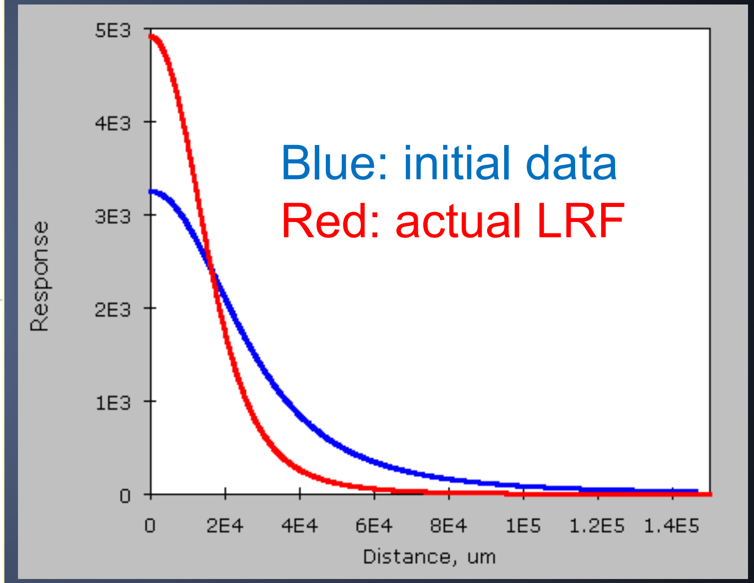
Under “right” conditions, the LRFs converge to the true PMT response.

Iterative reconstruction: (simulated data)

Initial data

Flood field: events uniformly cover the outlined area (black rectangle)
Energy spread: 20% FWHM



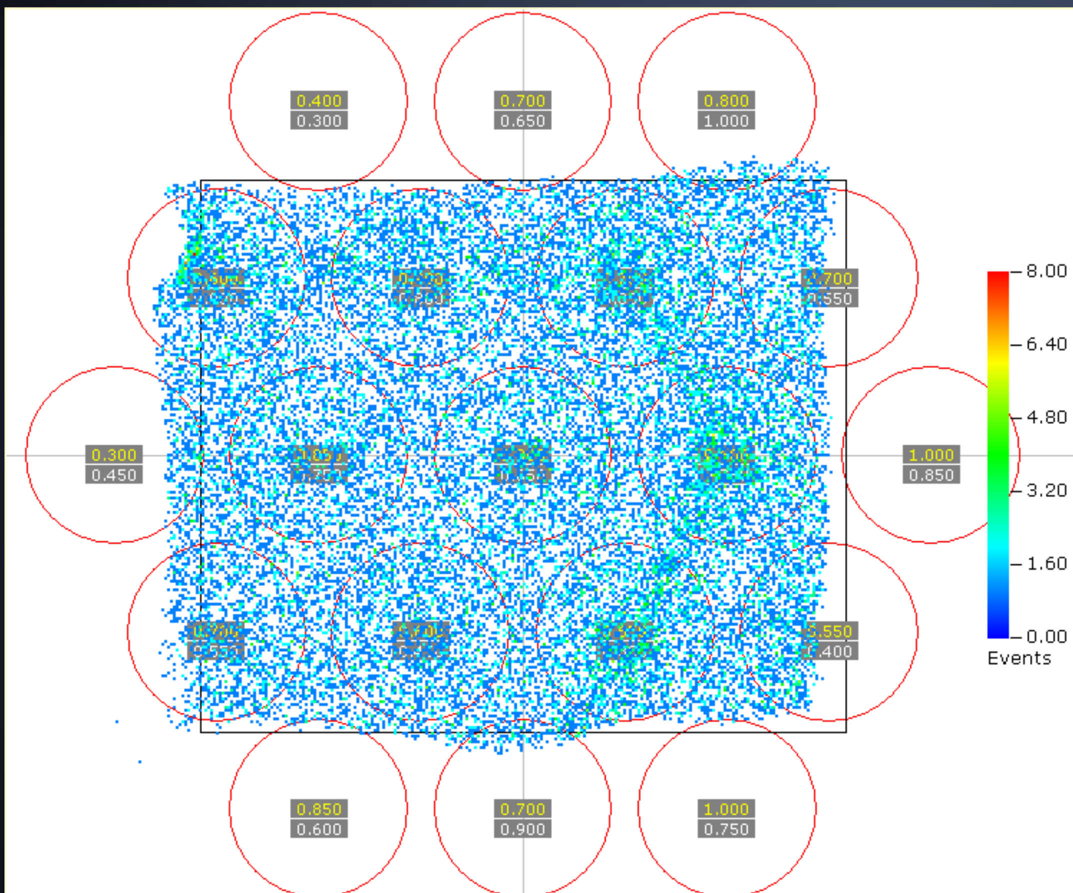


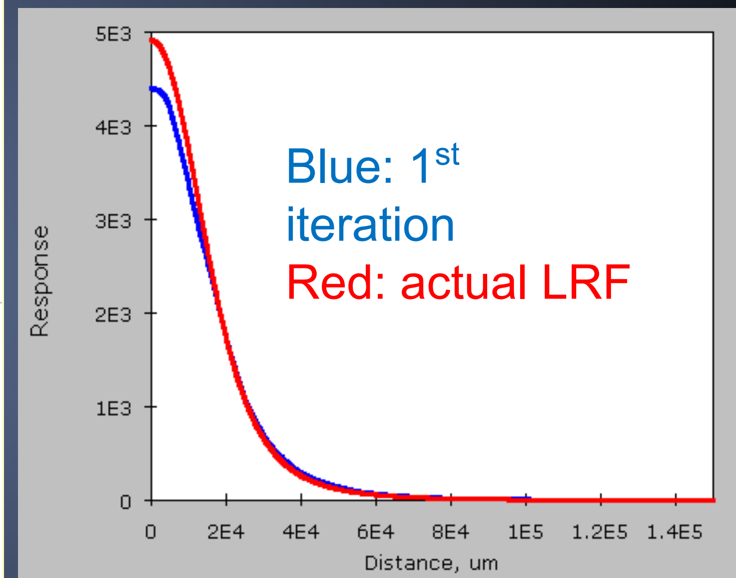
Initial gains: random, up to 30% off the actual values

LS reconstruction of the flood field data

Iterative reconstruction: (simulated data)

After one iteration

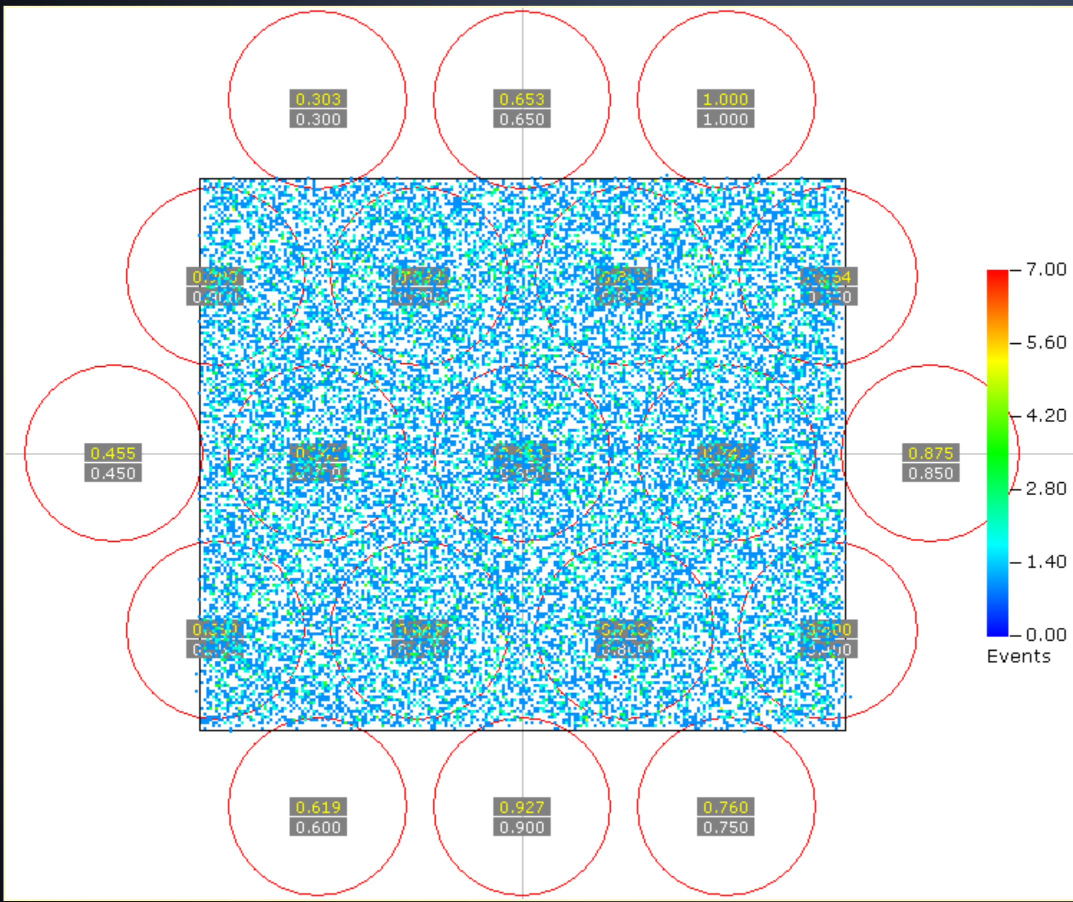


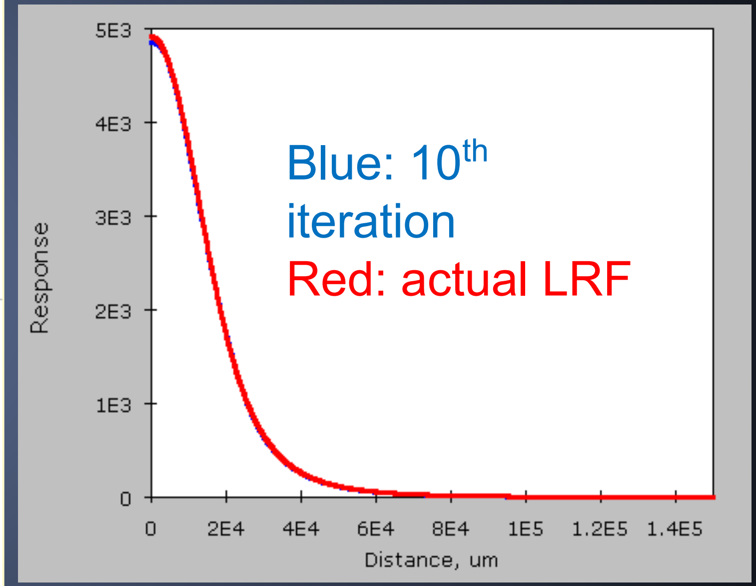


LS reconstruction of the flood field data

Iterative reconstruction: (simulated data)

After 10 iterations

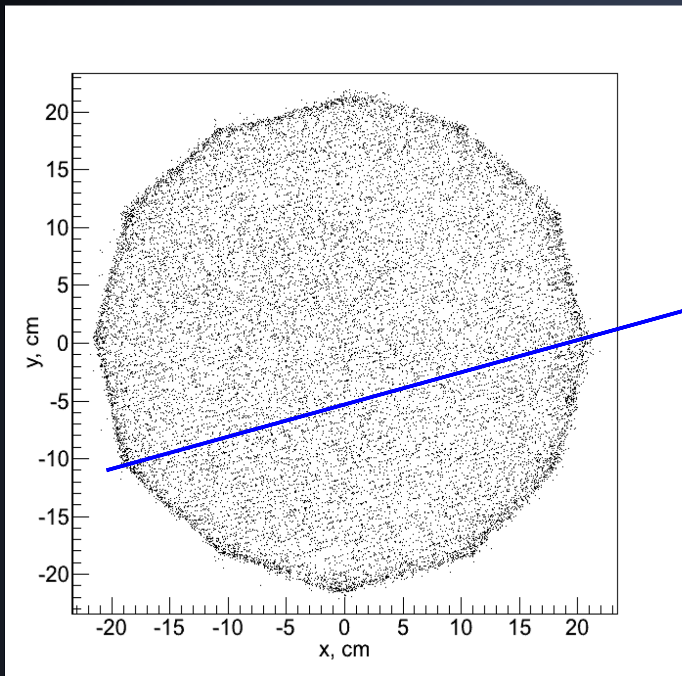


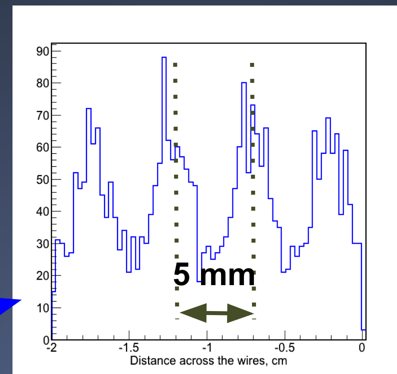


Reconstructed gains are within 5% from the actual values!

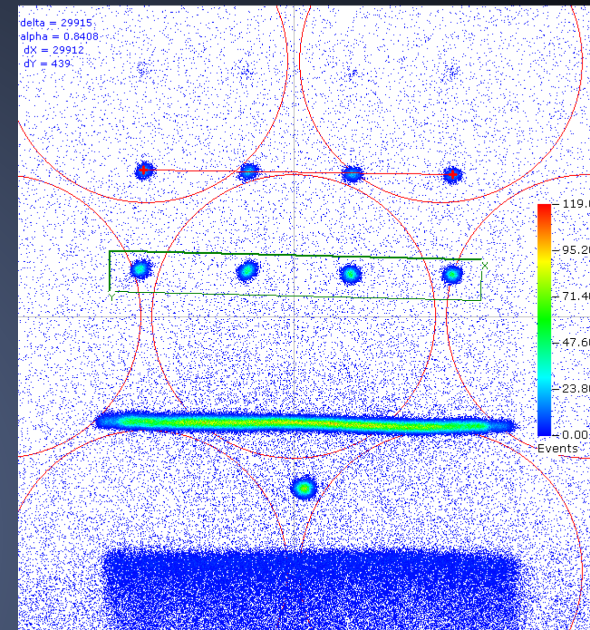
LS reconstruction of the flood field data

Real life examples

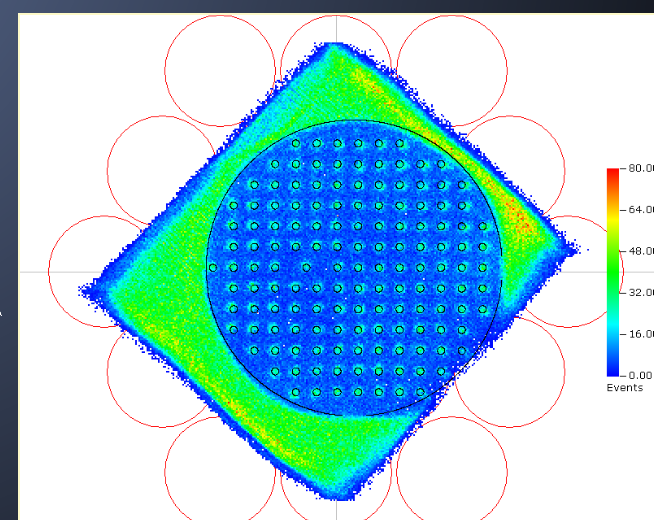


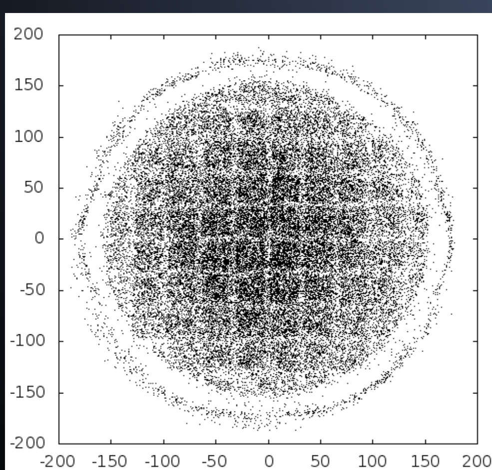


LUX



GSPC neutron detector





ZEPLIN-III

Adaptive methods

It was shown that PMT response in Anger camera can be correctly reconstructed from flood irradiation data under favorable conditions:

- High light output (secondary scintillation)
- Low fraction of indirect light

Reconstructed PMT response includes relative PMT gains, thus making possible auto-calibration for Anger camera

LRFs can change over time (PMT gain drift, photocathode and crystal degradation, etc.) Iterative reconstruction can follow these changes, hence: Adaptive Methods

Medical application

Can we apply LRF based event reconstruction techniques + adaptive LRF reconstruction methods to medical imaging?

- Advantages:
  - Better image on periphery
    - Improved useful field of view
    - Important for small devices, e.g. prostate imaging cameras
  - Automatic tracking of PMT gain fluctuations
    - Less frequent and simpler calibration (reduced downtime)
    - Save money on maintenance
    - Improve image quality
- Challenges:
  - Lower signal to noise ratio
  - Multiple scattering
  - 3D reconstruction (in some cases)

Work in progress

A project (FCT + QREN, part of Rad4Life) in a partnership with ICNAS is ongoing since May 2013:

- ANTS-II: new integrated simulation & analysis package (A. Morozov's talk)
- Anger camera emulation system (L. Pereira's talk)
- Multichannel data acquisition system (J.P. Rodrigues' master project @ UC/LIP - finished)
- Building a SiPM-based prototype of a miniature high-resolution medical gamma camera
- Modification of a commercial medical gamma camera to use adaptive algorithms
- System for calibration of SiPM arrays (R. Martins' master project @UC/LIP - ongoing)

Data Acquisition

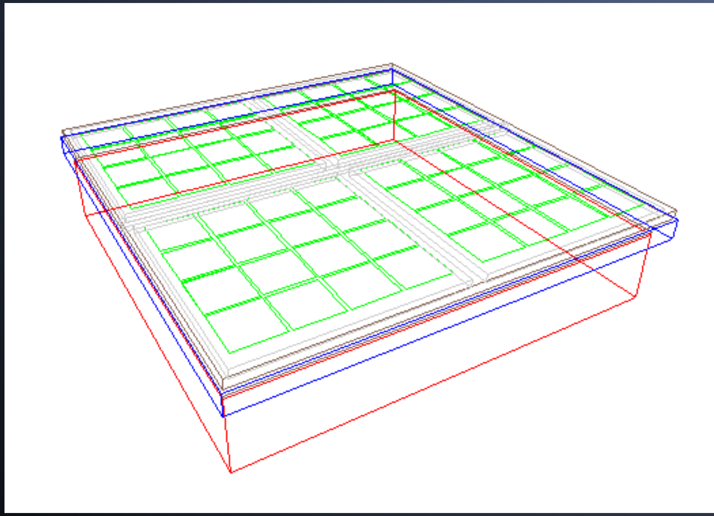
Crucial for both SiPM prototype and modified commercial camera

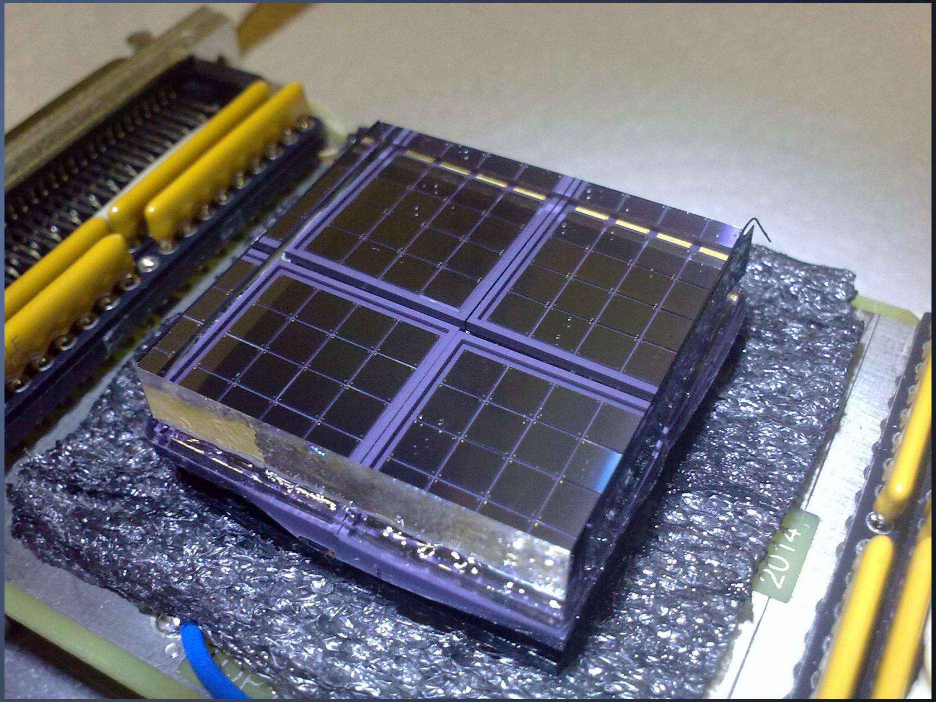
- Hardware: MAROC3 test board by LAL/Omega
  - 64 channels
  - Low noise input optimized for PMT/SiPM
  - Adjustable shaping time
  - Self-triggered
  - Individual gain settings per channel
  - USB interface with host PC
- Software: LULAS (LIP Ultra-Light Acquisition Software)
  - Full control over MAROC3 configuration
  - Automatic channel gain adjustment
  - Acquisition rate up to 3 kHz @ 64 channels x 12 bits
  - Multiplatform: Windows/Linux

GAMMA-64

Miniature gamma camera prototype with SiPM readout

- LYSO crystal 30x30x5 mm
- 8x8 array of SensL SiPM
- Directly coupled to MAROC input
- Adjustable mechanical design

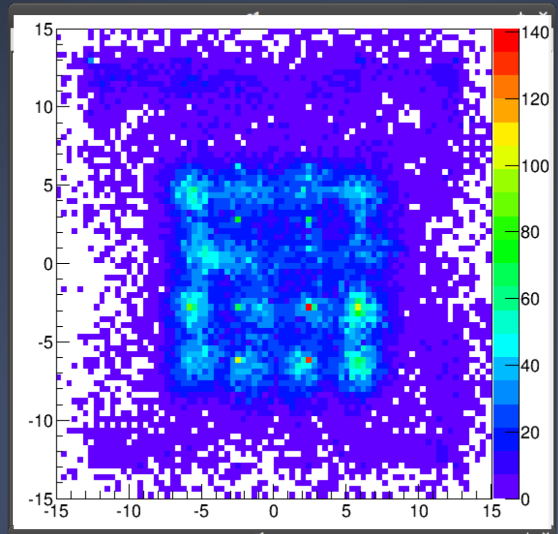


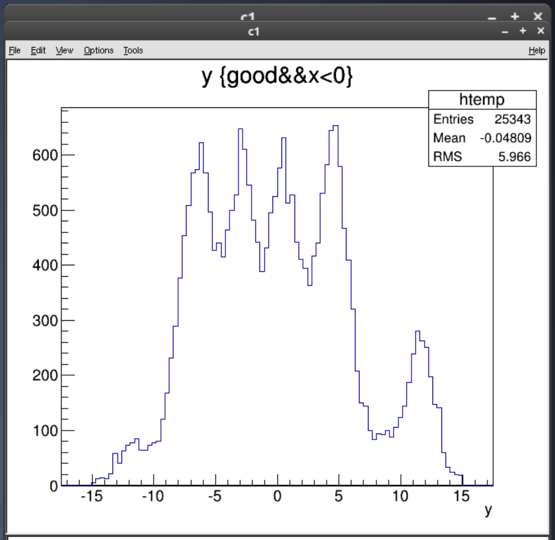


GAMMA-64

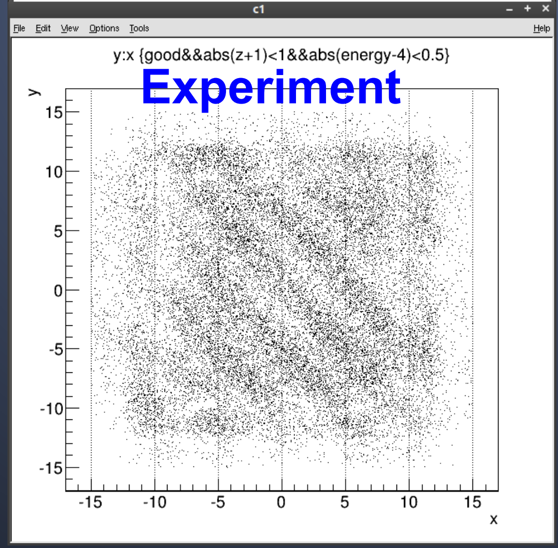
First data were obtained in the beginning of March 2014

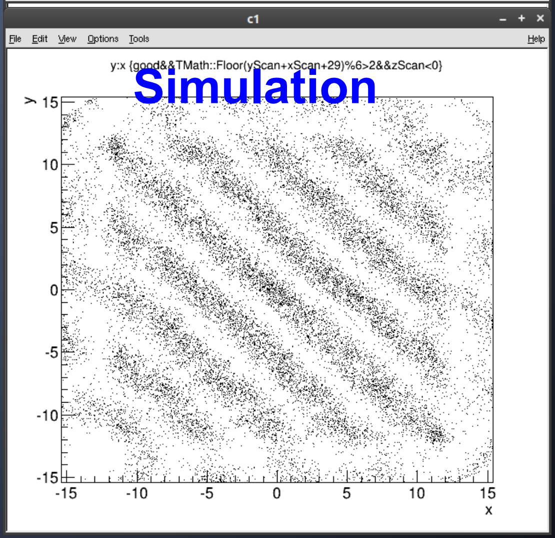
- ^{57}Co source (122 keV)
- Lead mask
- 2mm holes
- 4mm grid





- ^{57}Co source
- Bar phantom (2.5 mm bars, 2.5 mm space)
- 45 degrees





Statistical event reconstruction done with ANTS-II package

Commercial gamma camera upgrade

A decommissioned commercial gamma camera is being modified for list mode acquisition

- Done already:
  - HV distribution fixed
  - Data acquisition hardware and software is ready
- To Do:
  - Break-out board and cabling
  - Possibly (depending on the results of the first test) front-end and shapers

Thanks to

João Pedro Rodrigues for development of data acquisition system (his master project)

Pedro Assis for help with DAQ platform choice and understanding MAROC test board firmware