Revisited algorithms for gamma cameras with $LaBr_3(Ce)$ continuous crystals

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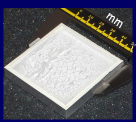
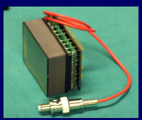
Recent developments of small Field of View (FoV) gamma cameras based on $LaBr_3(Ce)$ crystals make their application as a gamma imager for SPECT very attractive. The excellent light yield and the fast decay of $LaBr_3(Ce)$ provides the potential to replace NaI(Tl). We use a GEANT4 Monte Carlo simulation to model the point spread function (PSF) of a gamma imager consisting of a large $LaBr_3(Ce)$ slab read out by a Hamamatsu H8500 64 ch Flat Panel Multi Anode Photomultiplier (MA-PMT). We assume the "Polished" model in GEANT4 which agrees well with available experimental data for our crystals. The aim of the present work is to study different algorithms for reconstructing the impact position of a ^{99m}Tc 140 keV photon hitting the crystal. Detailed simulation of the optical photons and of all the boundary layers of the imager is carried out to produce the light pulse seen by the MA-PMT. As it is well known, a linear algorithm suffers from bad linearity because of reflections and absorptions from the sides of the crystal. This turns into a distortion of the image and a poor position resolution. A quadratic algorithm allows the linearity to be recovered close to the lateral edges of the crystal, and a cubic algorithm can improve further the linearity and extend it. The position resolution, which improves substantially using a quadratic with respect to the linear algorithm, seems however not to improve with higher powers. A Gaussian algorithm for fitting the light pulse shape has also been tried with satisfactory results for the position linearity. The Gaussian model can include reflections and absorptions from the sides of the crystal and permits the deposited energy to be recovered even close to the side boundaries. Some of the results of the simulation are compared with experimental data.

Experimental Setup



$LaBr_3(Ce)$ crystal

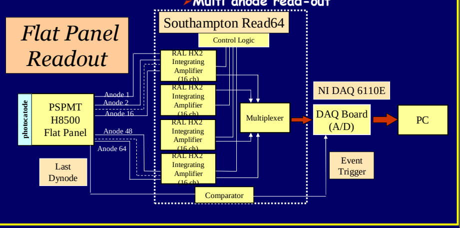
- LaBr3(Ce) scintillating planar polished crystal 51 x 51 x 4 mm³ with 3 mm glass window. Lateral surfaces are black for light absorption at the edges of the crystal.



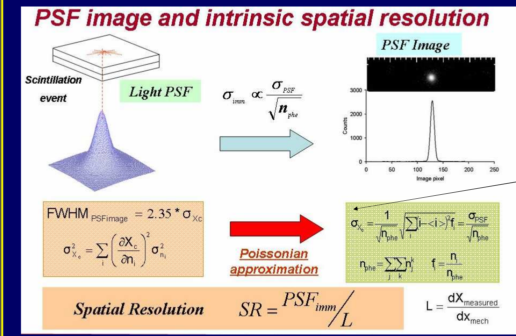
Photodetector: Hamamatsu Flat Panel PMT H8500

- 51.7 × 51.7 × 14.4 mm³ (ext. dim.)
- 49.7 x 49.7 mm² active area
- bialcali photocatode, 27% Q.E.
- metal channel dynodes
- 8 × 8 matrix, 6 × 6 mm² anodes
- **Multi anode read-out**

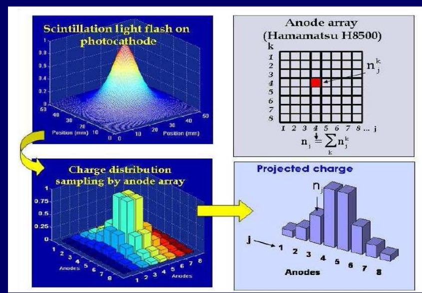
Flat Panel Readout



Linearity and Position Resolution



Sigma definition



Schematic illustration of Sampling Procedure

$$X_C = \frac{\sum_j n_j x_j}{\sum_j n_j}$$

Linear Position Algorithm

Linear Algorithm, proposed by Anger in 1958, where X_C is the centroid coordinate along the x direction, $n_j = \Sigma_k n_k$ is the linear sum of the charges collected in the j-th column, x_j is the x of the anodes in that whole column. The same applies for the y direction

$$X_C = \frac{\sum_j n'_j x_j}{\sum_j n'_j}$$

$$n'_j = \Sigma_k (n_k - t)^p$$

where "t" indicates a flat background level (here we use t = 0) and p = 2,3

Quadratic or Cubic Position Algorithms

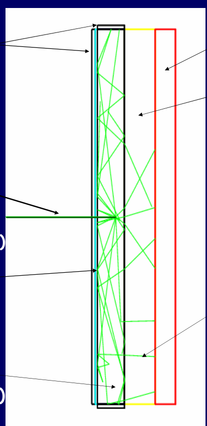
Simulation Setup

Al (0.5 mm)

140 keV γ Central Interaction

Teflon (0.3 mm) Lambertian reflector R = 0.95

$LaBr_3(Ce)$ (48x48x4 mm³) n = 1.9



MA-PMT Q.E. = 27%

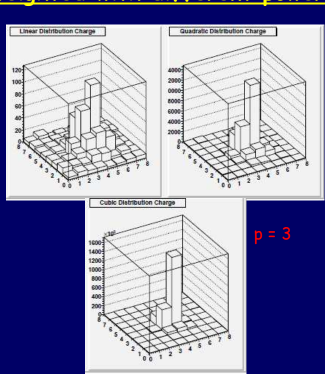
Glass (3 + 1.5 mm) n = 1.49

GEANT4 simulated Optical Photons' distribution inside the LaBr3(Ce) Crystal, and as seen by the MA-PMT

Optical Photons

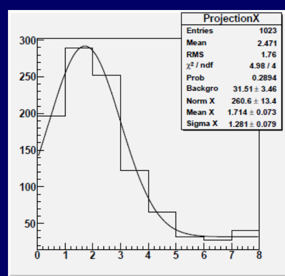
"Polished" Model of $LaBr_3(Ce)$ lateral surfaces with R = 0.6 reproduces experimental distributions

Simulated charge distributions weighted with different powers



The units are H8500 pixels [horiz.] and (charge in photoelectrons)ᵖ, with p = 1,2,3 [vert.]

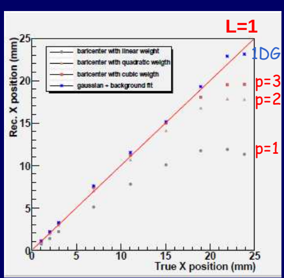
1D Gaussian fit of projected charge distributions



Projected charge (in units of photoelectrons) released by a 140 keV simulated γ fitted with a Gaussian distribution superimposed on a flat background

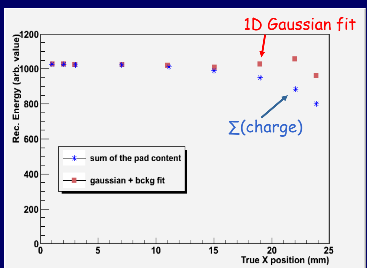
RESULTS

Position Linearity



With "nonlinear algorithms" the linearity is greatly improved, since the trends converge at that expected and the edge effect is corrected.

Energy Response



	MC "Polished" model	Exp. Data
<Nphe>	1047 ± 1	-
ER_{stat} (%)	7.2 ± 0.1	-
ER_{tot} (%)	8.5 ± 0.1	9.0 ± 0.1
SR_{lin} (mm)	1.2 ± 0.1	1.6 ± 0.1
SR_{qua}(mm)	0.77 ± 0.04	1.1 ± 0.1
L_{lin}(mm/mm)	0.67 ± 0.05	0.65 ± 0.05

L_{lin} = Position Linearity (Linear Algorithm)
SR_{lin} = SR (Linear Algorithm), SR_{qua} = SR (Quad. Algorithm)
ER_{Intr} = 4.5%

$$ER_{tot} = \sqrt{(ER_{Stat})^2 + (ER_{Intr})^2}$$

Conclusions

✓The use of powers of the charge higher than linear to find the impact position of 140 keV photons improves the position linearity and the position resolution. The improved position resolution is expected to be better than 0.8 mm FWHM over most of the FoV. Gamma imagers consisting of a single LaBr3(Ce) crystal can therefore compete with pixellated crystals.

✓1D Gaussian fits also perform well in reconstructing the impact point and allow the energy of the incoming photon to be recovered close to the crystal lateral surfaces.

✓Experimental data collected with a pencil 140 keV photon beam from a ^{99m}Tc source impinging on a $LaBr_3(Ce)$ crystal show a positon resolution ~ 30% worse than the MC, and a central energy resolution comparable to MC and equal to (9.0 ± 0.1)% FWHM.

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