SiPM-MAROC gamma-camera prototype with monolithic NaI(Tl) scintillator

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Goal of the project: *Development of a full-body gamma-camera based on SiPM readout as a part of MEPHI R&D activity supported in the framework of Russian Megagrants program.*

Our test-prototype

In order to study the proposed detection system in detail and obtain detector module parameters, a 64-channel small proof-of-concept prototype with usage 6x6 mm^2 SiPMs has been constructed and tested. SiPMs in SMD packages [1] have been assembled as a matrix of 8x8 elements and readout by MAROC-based [2] board (fig.1). Sum of 8 center channels energy spectrum was obtained on NaI(Tl) ø30 mm^2 x 20 mm (fig. 2). «Fitting» algorithm for extraction of gamma-event's energy and position are under development. They are based on fitting a matrix of individual SiPMs response clusters by an analytical function f(x,y). Fig.3 shows experimental SiPMs signals distribution (blue bars) fitted by analytical function (red curve) for single ^{137}Cs (662 keV) gamma-event. Their event has been taken from described above SiPM-MAROC prototype with flat NaI(Tl) scintillator (diameter 45 mm and thickness of about 5 mm) and 3 mm lead collimator. They will be tested with GEANT-simulated [3] events and experimental data.

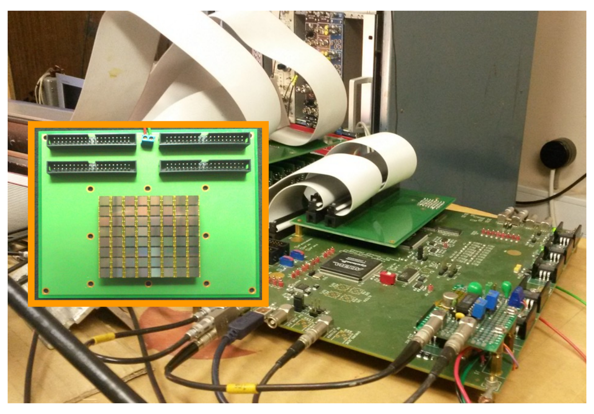

Fig.1. SiPM 8x8 elements matrix and MAROC readout board

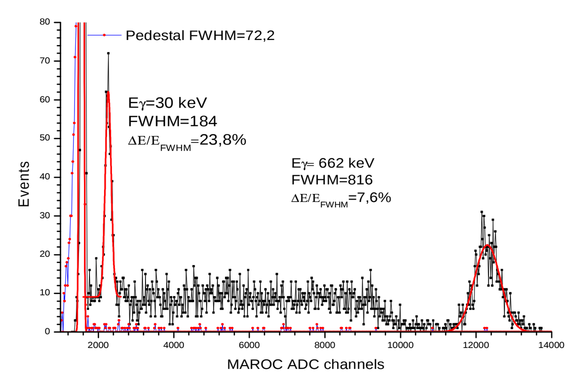

Fig.2. SiPM spectrum for ^{137}Cs from MAROC

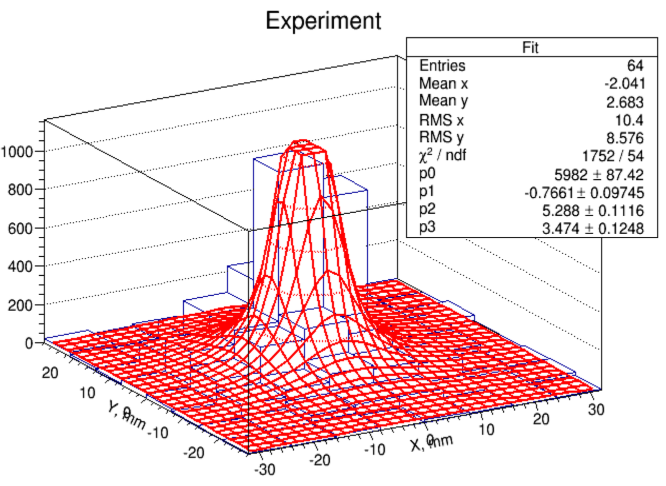

Fig.3. Experimental SiPMs signals distribution for single gamma-event fitted by analytical function (red line)

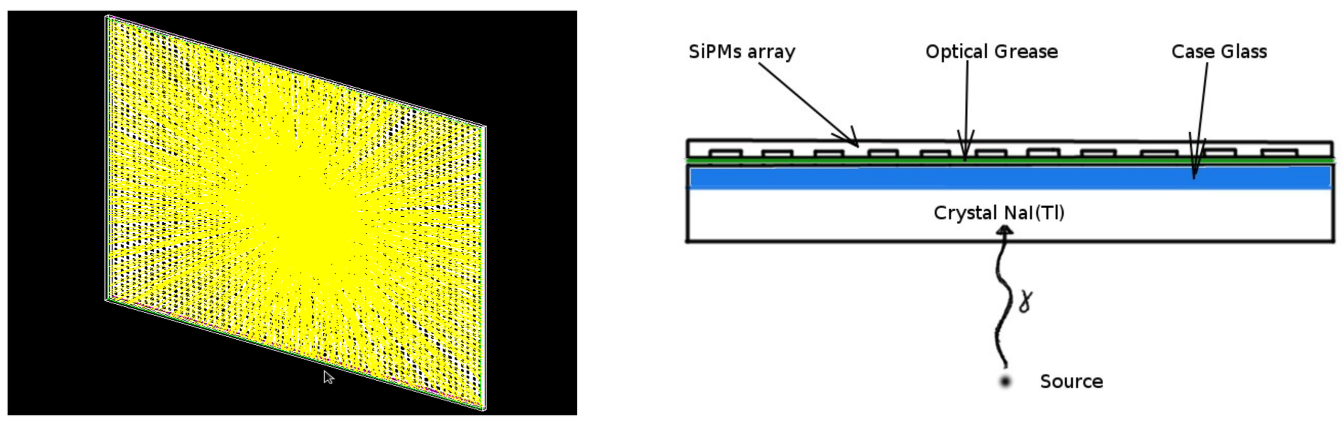

Fig.4. Left - Visualisation of light spread in scintillator. Right — scheme of Geant4 simulation.

Model in Geant4

A monolithic NaI(Tl) scintillator commonly used for conventional PMT-based gamma-cameras has been chosen for this study. The size of the crystal is 500x400x10 mm^3. Beam point source with mono-energy 140 keV was placed in coordinates (0;0;50) mm. The crystal was placed in aluminium case (only lateral sides). All surfaces between crystal and case were diffuse reflectors with 95 % efficiency. 62x56 SiPMs (model of 6x6 mm^2 KETEK, contain epoxy region 7.8x6.8 mm^2, silicon 6x6 mm^2 and glass fiber regions, refractive indexes are 1.53, 5.2, 1.53 respectively) with pitch 8 mm x 7 mm (X&Y respectively) were coupled with the scintillator via an optical guide (case glass, refractive index = 1.47, width = 2 mm) and optical grease (refractive index = 1.5, width = 50 um), figure 4.

Light simulation in scintillator

Light output of scintillator was 5 320 photons for 140 keV (38 000 ph/MeV). But after Geant4 simulation we observed only 3770 photons mean with 79 photons sigma (Geant4 «RESOLUTIONSCALE» was 1.0) due detector geometry, 95 % diffuse reflectivity from sides and light absorption in SiPM's array, figure 5.

Another simulation was how 2D function (its 1D projection) fits spread of light in crystal, figure 6.

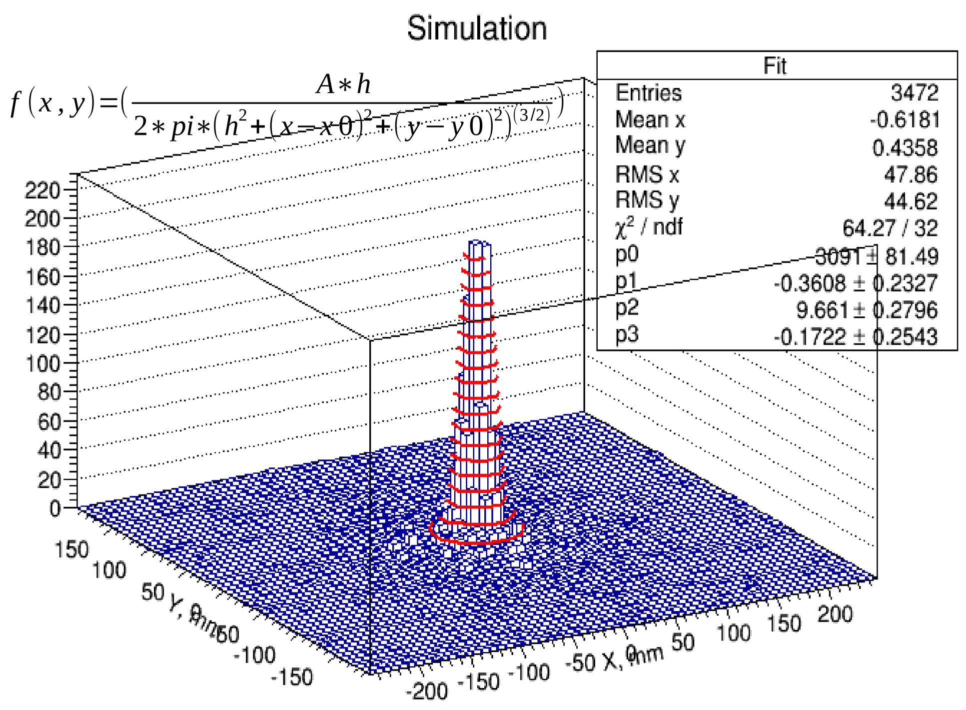

Fig.5. Light spread distribution for one gamma. Fit with 2D «function of direct light». (1 bin = 1 SiPM).

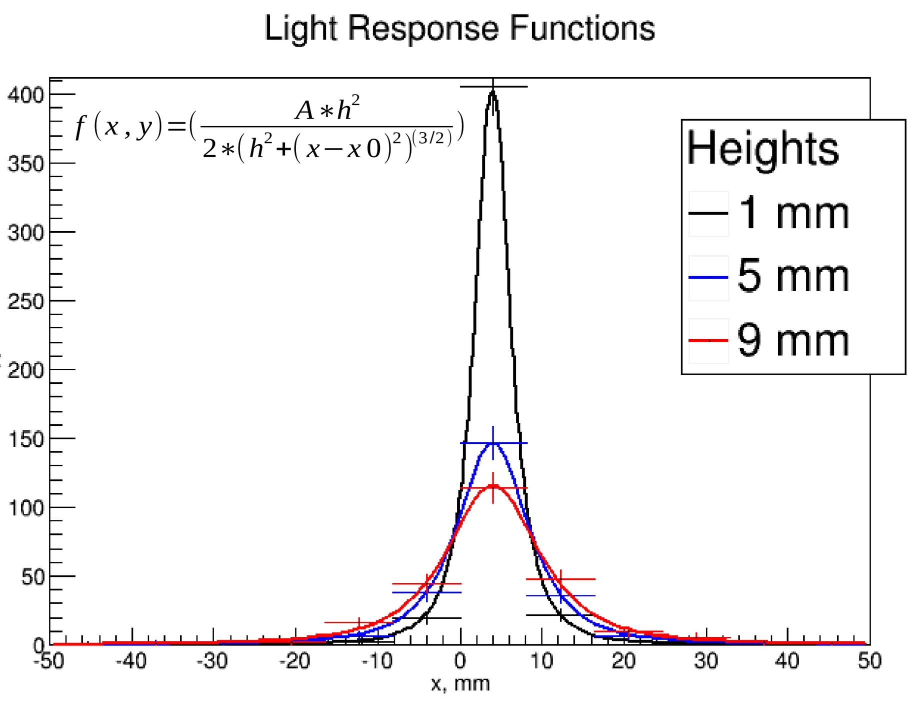

Fig.6. Light spread distribution in scintillator for different heights. Fit with 1D «function of direct light». Number of emitted optical photons is 1000.

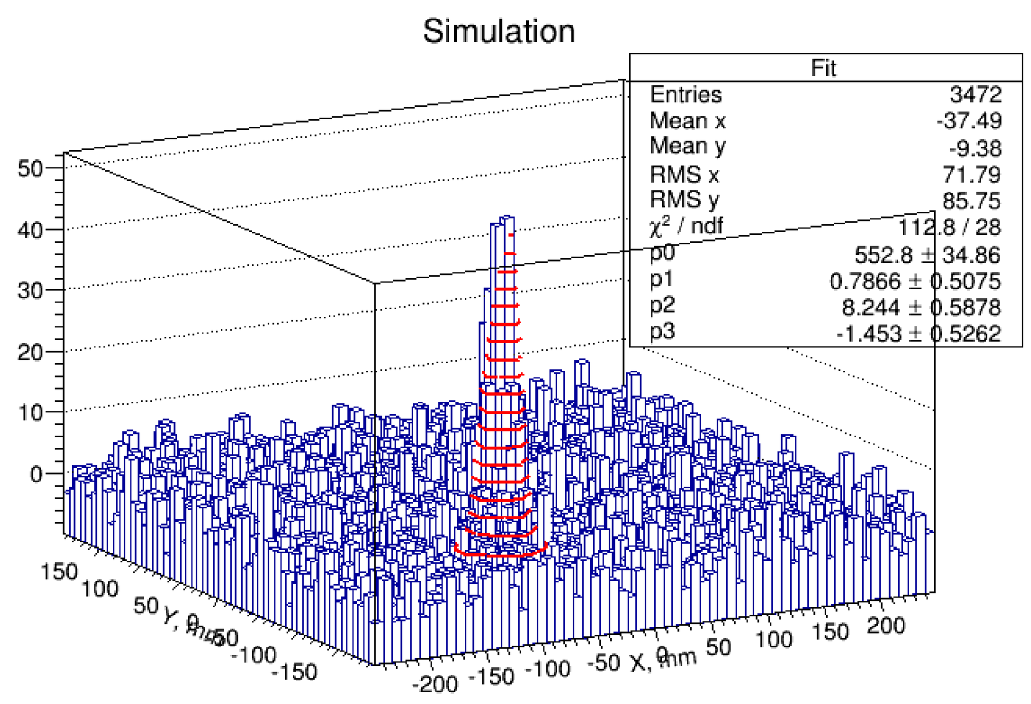

Fig.7. Light spread and dark events distribution after SiPM's simulation for one gamma.

Coordinates and Energy

14 MHz dark count rate was adopted for SiPM's simulation (typical for 6x6 mm^2 KETEK SiPMs at room temperature). Time of integration was 500 ns, so average dark counts per one gamma per one SiPM was 7 counts. Estimated average convertion efficiency (CE) from gamma photons to digital signal is 20 % (SiPM PDE ~ 40 %, geometry efficiency of array ~ 64 % and not full integration of scintillation signal in 500 ns window ~ 86 %). Dark counts and CE have been simulated by Monte-Carlo (Poisson distribution and Binominal distribution, respectively). Light spread distribution after SiPM's simulation is presented in figure 7.

Next, using «fitting» algorithm in cluster (size 8x8 SiPM's, optimal for energy resolution, figure 8) we obtained energy spectrum (photoelectrons) and spatial resolution as FWHM of point spread function. For comparison we did that for Center-of-Gravity method (or Anger method [4]) in same clusters. The results are shown in figures 9 and 10. For "fitting" algorithm energy resolution is 27.3 % and spatial resolution (FWHM, center region) is 1.7 mm. For COG algorithm energy resolution is 17 % and spatial resolution (FWHM, center region) is 2.5 mm.

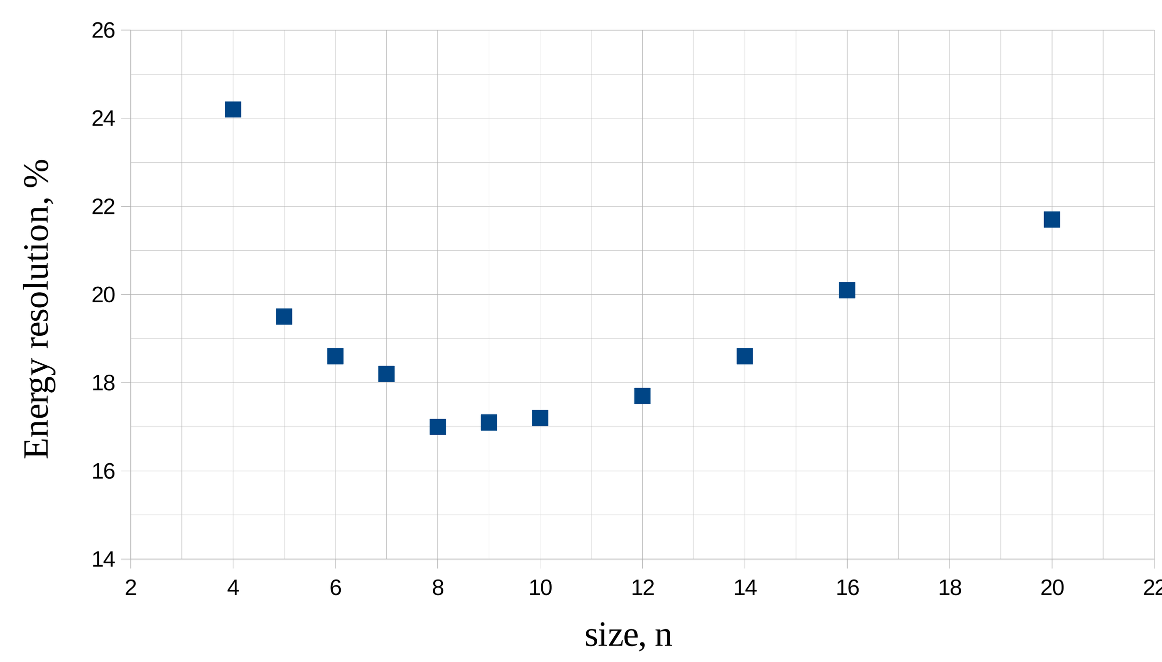

Fig.8. Energy resolution as function of cluster size.

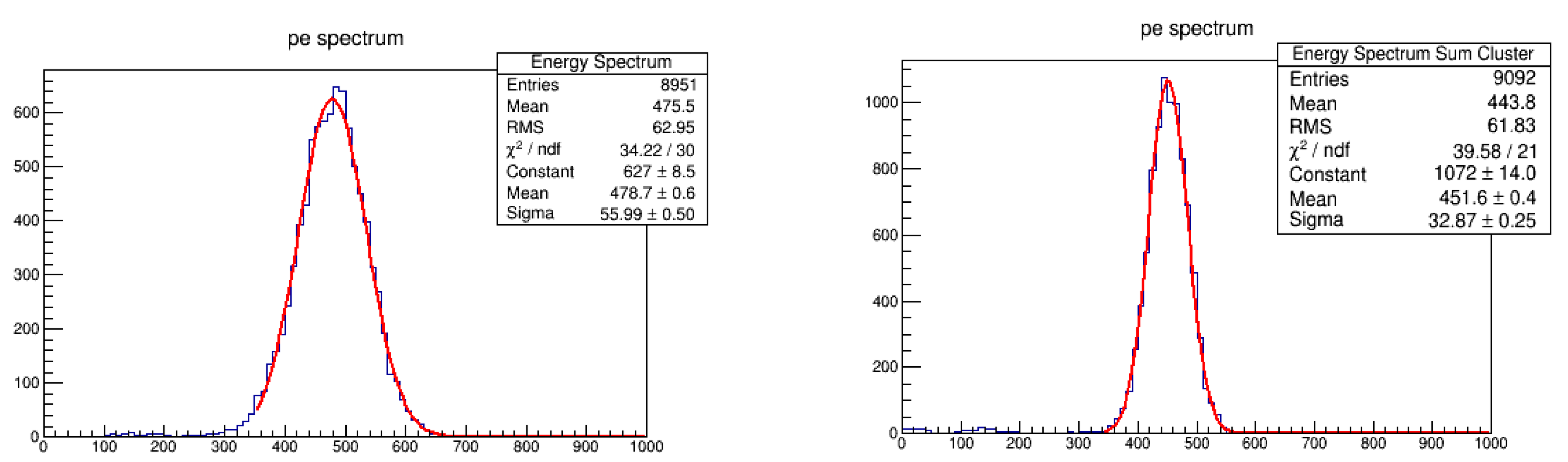

Fig.9. Energy distribution for dedicated cluster. Left — fitting. Right — COG.

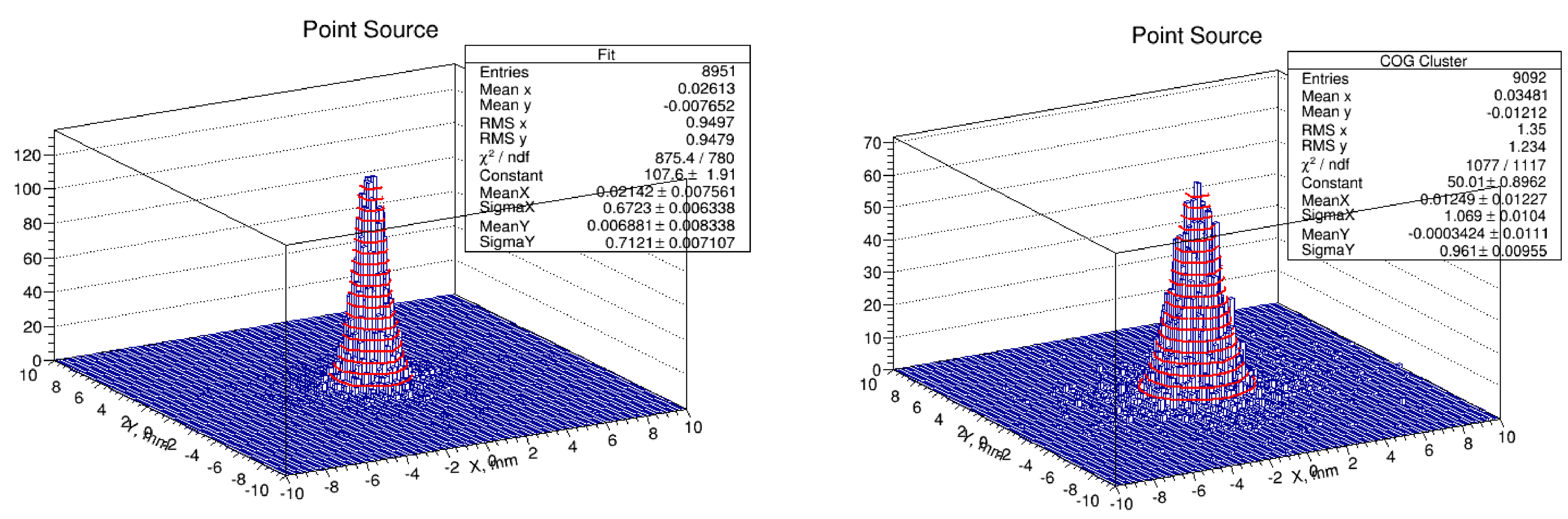

Fig.10. Point spread function for both algorithms. Left — fitting. Right — COG.

Summary

We tested first prototype of SiPM-MAROC gamma camera and develop algorithm to reconstruct (x;y) position of scintillation in crystal. However, while positioning reconstruction looks promisingly, the energy resolution obtained from «fitting» is very poor, so we suppose to get energy information from sum signal from 8x8 SiPM's cluster. But futher research in getting energy information from fitting function is ongoing.

Development of the next (engineering) prototype of SiPM's module for gamma-camera to utilize with real NaI(Tl) SPECT crystal will be started soon.

Acknowledgments

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Reference

[1] www.ketek.net, «SiPM PM6660 Datasheet».
[2] www.weeroc.com, «MAROC datasheet».
[3] http://geant4.web.cern.ch/geant4/, «Geant4 developments and applications», IEEE Transactions on Nuclear Science 53 No. 1 (2006) 270-278.
[4] Miles N. Wernick, Ph.D., and John N. Aarsvold, Ph.D., «Emission Tomography - The Fundamentals of PET and SPECT».
[5] Zhi Li, «Study of 3D position determination of the interaction point in monolithic scintillator blocks for PET», PhD thesis, 2011.