Simulation Method for Position and Energy Corrections in Scintillation Detectors

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The first steps towards a Monte Carlo simulation method for energy and position corrections in a gas scintillator detector are presented. Recent developments on gas avalanche detectors based on microstructures operating at high pressure allow fair detection efficiency for hard X- and gamma-rays. A hybrid system combining an assisted scintillation in a high pressure xenon gas medium and two UV photosensors based on microstructures operating face to face, having the xenon medium sandwiched between them, is under investigation. One of the actual studies is the simulation of the position and amplitude response of the detector and their correction obtained by mapping the detector response. This method can also be applied to solid scintilators.

INTRODUCTION

Monte Carlo simulation of the detectors response allows us to evaluate their potential characteristics and at the same time to define strategies for future developments and pulse corrections in order to improve the detector response. The present simulation is focused in a new γ-ray gaseous scintillation detector that is being developed at the Physics Department of the University of Aveiro. The position and energy responses of this detector were simulated and amplitude and position corrections were evaluated.

The simulated detector uses two Micro-Hole & Strip Plate (MHSP) photosensors with and active area of 30x30mm^2 positioned face-to-face and 7 stainless-high transparent grids separated from each other by 1.4mm [1]. The grids are polarized with a high voltage difference. For the detection of the 140.5 keV, a 10 bar xenon medium is used.

For the simulation, the MHSP photosensor was considered to have an intrinsic position resolution of 0.25 mm, represented by a net of square segments.

MONTE CARLO SIMULATION

To simulate the detector response to 140.5 keV gamma photons from ^{99m}Tc, we have considered a cell volume of xenon (one quadrant) limited by the two photosensors. The interaction point (x,y,z) of the incoming gamma ray is generated taking into account the 10 bar xenon attenuation length. This interaction produces a given number of primary electrons.

The number of primary electrons produced by these ionizations follows a Poisson distribution with a Fano factor F = 0.17. The average number of the primary electrons, $\overline{N_e}$, is given by

$$\overline{N_e} = \frac{E_i}{W_{Xe}} \qquad (1)$$

Where E_i is the gamma photon energy and W_{Xe}=22eV is the mean energy to produce an ion pair. The number of primary electrons was randomly generated considering this non-uniform distribution.

In the simulation, for simplicity, a major approximation was done: the electron cloud spatial distribution is considered to be point like. This is a critical approximation for the position resolution,, since the contribution of the spreading of the electron cloud will be dominant. In fact, using multiple scattering through small angles formula for the photoelectron (140 keV gamma interactions in 10 bar of Xe), preliminary calculations return a value of about 1.5 mm for the FWHM of the electron distribution [2]. Simulations for the primary electrons spatial distributions are being done. These distributions will be included in future simulations of this model, which will return a more realistic value for the position resolution of the overall system.

We also have considered a number of produced Vacuum Ultra-Violet photons (VUV) photons in our real model, whose value is dependent upon the voltage applied between grids. The voltage difference used was about ΔV =3kV. For this voltage the electrons gain enough energy between collisions to excite but not to ionize the xenon atoms, producing VUV as a result of the gas de-excitation processes. The number of the produced VUVs photons N_{UV} by each primary electron was considered to be constant, and is given by

$$N_{UV} = \frac{1}{2}\frac{\Delta V}{\varepsilon_{UV}} Q_{SC}, \qquad (2)$$

where ε_{UV} = 7.2 eV is the average energy of the VUV photon energy and Q_{SC} the scintillation efficiency.

The generated VUV photons are random isotropically emitted from the gamma interaction point (considering to be point like the distribution of the primary electron cloud) and a large number can reach the MHSP photosensors, in the model, represented by the net of 0.25mm square boxes. Due to the presence of the holes in the MHSP only 85% of the area is effective (A_{ef} = 0.85). For each VUV photon that reached the square box (photosensor) there is a probability for photoelectron emission with a quantum efficiency of 30% (EQ = 0.3) and 20% of probability for that photoelectron be effectively extracted and collected (PE = 0.2) .

So, the probability of a VUV photon to produce a detected photoelectron is given by the product of the individual probabilities, i.e., the total photoelectron collection efficiency is

$$TP = A_{ef} \times EQ \times PE$$

For each gamma photon a large number of VUV photons are distributed over the photosensor's area, i.e., in the boxes of the considered net.

By adding all the number of the detected photoelectrons for each gamma photon, the amplitude distribution can be obtained and the energy resolution calculated. By calculating the centroid of the VUV photons distribution in the considered net, the position resolution of the system can be evaluated. This simulation also allows us to test and perform corrections in the detector pulse amplitude and in the position of the interaction point.

RESULTS AND DISCUSSION

In a first stage we have simulated 9 different orthogonal incident positions (x,y) of the 140.5 keV gamma rays. The z coordinate of the interaction point for each gamma photon was generated randomly with a non-uniform distribution that depends on the mass attenuation coefficient of the xenon for this energy and pressure.

The result of the simulated position response is depicted in Fig.1 for all the simulated positions.

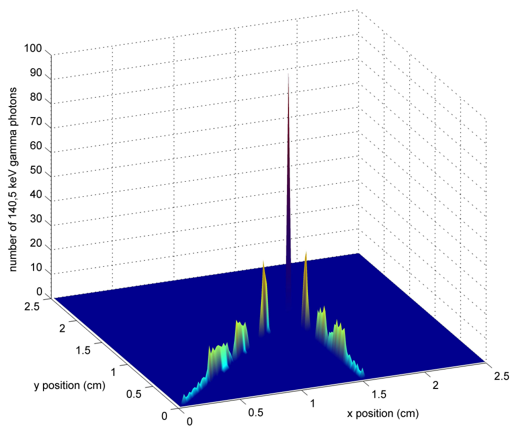

Fig. 1 - Position response for 9 different (x,y) positions of incidence: (0.025, 0.025), (0.025, 1.5), (0.375, 0.375), (0.375, 1.5), (0.75, 0.75), (0.75, 1.5), (1.125, 1.125), (1.125, 1.5), (1.5, 1.5) (cm)

From the figure we can conclude that when the interaction point approaches the border an increasing distortion of the position distribution is observed. This shows that a correction of the position output of the detector should be made, mainly for the peripheral points.

In terms of the amplitude distribution we have calculated the amplitude response for the bottom and top plates and for the sum of both plates at (1.5, 1.5) incident position. At this position the z position of the interaction was randomly generated for 2000 gamma photons. The results are shown in Fig.2. The amplitude distribution for the individual photosensors shows a flat spectrum difficult to resolve. When the amplitudes of both photosensors, for the same gamma photon, are summed, a nice peak distribution is shown. So, the use of the response of both photosensors will strongly improve the quality of the detector response and thus the energy resolution. The small tail presented in the sum spectrum is due to solid angle variation along the z axis.

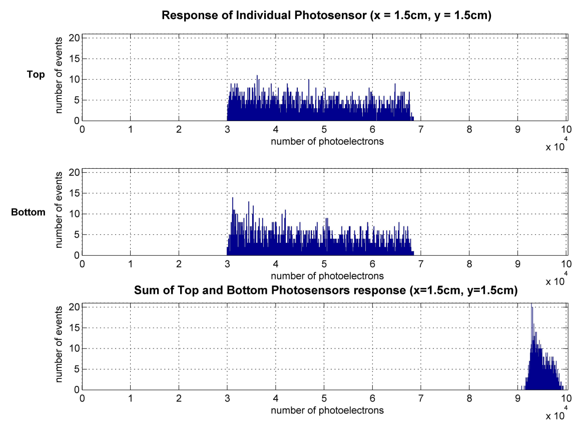

Fig. 2 - Distribution of the number of collected photoelectrons at each gamma photon at top MHSP, bottom MHSP and to the sum of two MHSPs

In order to minimize this tail, a correction method was developed. A mapping of the amplitude response was established for the mentioned 9 points in order to find an amplitude correction as a function of the *z* interaction position. The z position was calculated using the ratio between top MHSP amplitude, A_t, and the sum of both MHSPs amplitudes, A_S. A linear fitting function, *f*, was introduced for each *z*.

$$z = f\left(\frac{A_t}{A_S}\right)$$

Figure 3 shows the results of fittings for the (0.375, 0.375), (0.75, 0.75), (1.125, 1.125) and (1.5, 1.5) interaction position points.

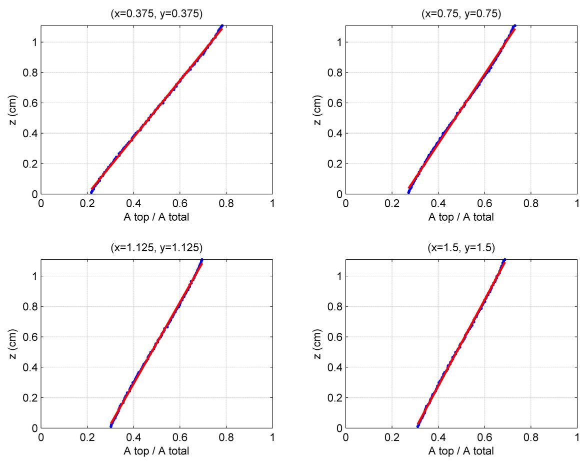

Fig. 3 - Obtained fits to z (cm) for the function of the ratio between top amplitude, A_t, and total amplitude, A_S, for (0.375, 0.375), (0.75, 0.75), (1.125, 1.125) and (1.5, 1.5) interaction position points.

Considering the maximum number of collected photoelectrons by the MHSP plates for one gamma photon as the reference amplitude, another polynomial fit was produced

$A_r - A_S = g(z) = g\left(f\left(\frac{A_t}{A_S}\right)\right)$ that allows us, by knowing the sum amplitude of each event, obtain the corrected amplitude,

$$A_c = A_S + g(z).$$

In Fig.4 a plot of the obtained g(z) functions calculated for the above interaction positions are shown.

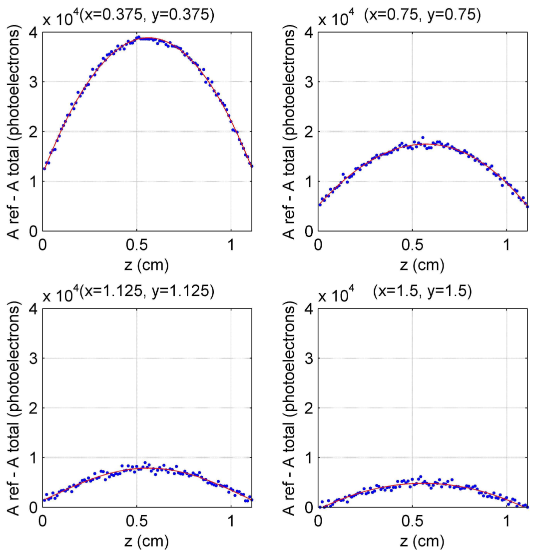

Fig. 4 - Obtained fits to $A_\gamma - A_S$ (photoelectrons) as a function of z (cm) for (0.375, 0.375), (0.75, 0.75), (1.125, 1.125) and (1.5, 1.5) interaction positions along the diagonal of the detector.

The output and corrected amplitudes produced by the gamma beam incident on (1.5, 1.5), at the center of the detector window, are presented in Fig.5.

As observed, an effective correction was produced. In fact, a significant improvement in the energy resolution from 4.7% of the non-corrected distribution to 1.4% after correction was achieved. For comparison the intrinsic distribution is also plotted in Fig. 5.

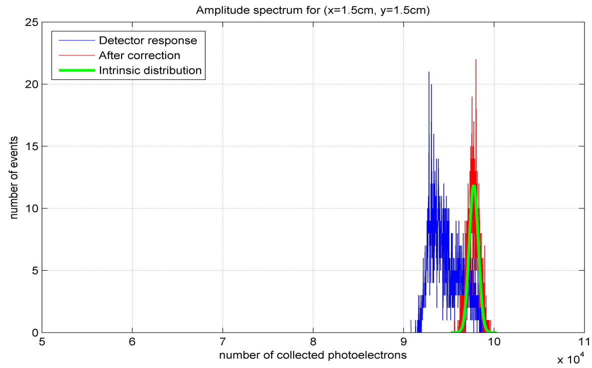

Fig. 5 - Distribution of the number of collected photoelectrons of each gamma photon interacting at the centre of the detector window.

To evaluate the efficiency of the correction over a large area of the detector window, random interaction positions (x,y,z) of the gamma photons were generated. A number of 1700 gamma photons interacting in a volume of $22.5\times22.5\times11 mm^3$ were considered. For each gamma photon the amplitude correction was made by using the calculated fits for the nearest point. Output and corrected amplitudes for this case are presented in Fig.6. Different methods for correction, by weighting the neighbouring fitting points, are in course.

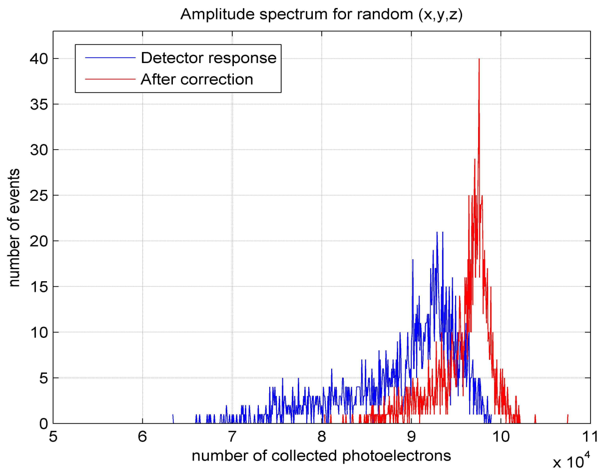

Fig. 6 - Distribution of the number of collected photoelectrons of each gamma photon interacting at (x,y,z) random position.

Again, a significant improvement of the energy resolution from 9.6% of the non-corrected distribution to 3.4% for the corrected distribution was achieved. Nevertheless, a small low amplitude tail is present. Since the calculated (x,y) position is a little bit shifted from the actual position (Fig.1), the fitting points used for the correction were not always the more adequate. So, also corrections for the (x,y) positions need to be done.

ACKNOWLEDGEMENTS

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