THE POSITION LINEARITY OF PHOTO-IONIZATION DETECTORS

M. ALEGRIA FEIO and A. J. P. L. POLICARPO

Departamento de Física, Universidade de Coimbra
3000 Coimbra, Portugal

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ABSTRACT

Data are presented for the linearity of photoionization detectors coupled to scintillators, mainly for gas proportional scintillation counters and also for other detecting media. The influence of electronic noise for low charge gain is considered.

1 — INTRODUCTION

The coupling of multiwire proportional chambers as photoionization detectors (PID) to gas scintillation proportional counters (GSPC) [1, 2, 3, 4], giving rise to the so called PIPS chambers, takes profit essentially of the vacuum ultraviolet nature of the emitted photons [4, 5].

Many gaseous scintillators and condensed noble element media feature the same characteristic [4, 6] and its coupling to PIDs is being considered, in particular in the fields of fission fragments and heavy ions work, gamma ray detection, etc. [7]. Active research is going on trying to find crystals that would scintillate in regions suitable to its coupling to PIDs [8, 9]. PIDs are then of interest in the detection of events that correspond to energy deposits of several tens of eV to several GeV, mainly when simultaneous information in energy, position and time is required, over large areas of detection, together with multiple hit capabilities.

There is a revival of the research in the field of photoionization and the tetraminoethylenes and the organo-metallic compounds known as the ocenes may prove useful for detection of the ultraviolet light; recent results significantly lowered the longest wavelength detectable with photoionization vapours, up to 2313 Å, featuring very large photoionization efficiencies [3, 9].

Profit is being taken of the scanty knowledge of the mechanisms of light emission to shift the spectra to favourable regions of the photoionization vapours [4, 5, 10], looking for cheaper or more convenient detection media and, reversely, the very narrow band-widths of some photoionization vapours may lead to selected detection of special components, of eventual interest, for example, for time resolution.

Some of the predicted features for energy and position resolution have been confirmed, although only preliminary experimental information is available concerning this last parameter [2]. Previous calculations [11] showed that either the position resolution would be dominated by straggling in windows, range effects associated with photoelectrons or Auger electrons, etc., or the position resolution, although not limited by the physics of the interaction, was better than that of competing instruments. The linearity response of the system for position determination is then of importance, no information either computed or experimental is available, and it is the aim of this work to provide data in this subject, assuming realistic values of the relevant parameters, both intrinsic and instrumental. Charge division techniques [12], based on centroid determinations, make the use of this very usual method even faster, simpler and cheaper and it is then considered in this work.

Also, in particular because for low energies the use of lower noise amplifiers can be considered and some suitable photoionization vapours seem to be not very stable from the point of view of avalanche build-up, the influence of the electronic noise, for relatively low gains in the PID, is considered.

2 — MAIN FEATURES

Fig. 1 shows the geometry of the chamber. When looking for the secondary scintillation, it is assumed that the interaction region is in the absorption gap and it is either punctual or a segment of a line of force.

Calculations were made assuming that krypton, around atmospheric pressure, is the detecting medium [13] and that the photoionization vapour is triethylamine. As before [11] using a Monte-Carlo technique the mean number $\overline{T}_i$ of photoelectrons, per photon produced in the scintillation gap, detected at the anode i of the PID, of coordinate x_i, in the direction orthogonal to the anode wires, was determined. Electron diffusion both in the absorption and scintillation gaps [14], spectral distribution of the emitted light [15] and the variation of the window transparency (LiF window) and the photoionization efficiency within the molecular emission band, and transparencies of the grids were taken into account [16]. Isotropy of photon emission was assumed.

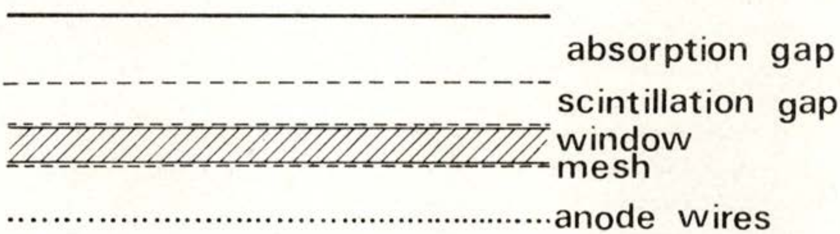

Fig. 1 — Schematic diagram of a photoionization proportional scintillation chamber. Dashed lines represent crossed wire meshes. Coordinates along the anode wire direction can be extracted from the centroid of the induced charge distribution on the strips of the cathode plane.

The number of ions pairs produced by an incident particle corresponding to a full energy deposition is well known, and some information is also available concerning its fluctuations [17]. The realistic assumption is made that to all anode wires corresponds the same charge gain k (relative variances are assumed as in [18]) the same r.m.s. noise charge in number of electrons, σ_e, and the same electronic bias b. The mean charge collected in wire i, $\overline{P}_i$, can then be calculated provided that the mean number of photons produced by one drifting electron in the scintillation gap, $\overline{H}$, is known. For krypton, for 3600 volts across 10 mm, at one atmosphere

$\overline{H} = 340$ [13]. Fluctuations in P_i, arising from a cascade of events [19], were generated taking into account fluctuations in the number of ion pairs associated with the interaction of the particle, fluctuations of the charge gain in the PID, and assuming that HT_i obeys a Poisson distribution. The electronic noise was also considered. For each simulated event $\Sigma_i (P_i - b)$ and $x_M = \Sigma_i x_i (P_i - b) / \Sigma_i (P_i - b)$ were calculated, with the restriction that if $P_i < b$, $P_i - b$ is taken as zero. Mean values and standard deviations of these quantities allow the determination of the energy and position resolution, as well as the position linearity of the system.

3 — RESULTS AND DISCUSSION

Fig. 2 shows $\overline{T}_i$ distributions assuming that the distance between anode wires in the PID is 11 mm, for three different positions x_F of the beam of incident particles. The thickness of the scintillation gap is 20 mm, the distance of the bottom grid of the GSPC to the LiF window is 1 mm, and the thickness of this window is 5 mm. The thickness of the scintillation gap and VUV window contributes to the relatively large width of the distributions ~ 20 mm. This can be compared for example with widths of ~ 8 mm for the spread of the induced charges in multiwire proportional chambers using cathode strips read out [20]. By itself this is a strong indication that indeed the system should possess very good position resolution capabilities, as using pulses induced in cathode strips, position resolutions $\sigma \sim 6\,\mu m$ have been obtained. Of course the use of thinner scintillation gaps and VUV windows would reduce the width of the $\overline{T}_i$ distribution, but lower voltages would have to be used, with a small loss in energy resolution.

Data concerning the linearity of the device are presented in Figs. 3 and 4. The geometrical structure of the GSPC, the voltage applied to the scintillation gap and the nature of the detection medium are the same in both cases and have been described relatively to Fig. 2; a charge gain $\overline{k} = 10^4$ is assumed in the multiwire proportional chamber.

Fig. 3 shows the variation of the difference between computed and real positions (in mm) as a function of the real position of the incident beam, in units of anode wires distance, in the direction orthogonal to the anode wires, for an electronic bias $b = 2\,\%$ of the total collected charge and for $\sigma_e = 1000$, for each amplifier. Clearly the linearity of the detector depends strongly on the distance between anode wires of the PID as could be expected in general terms. The larger contribution of the total electronic noise associated with the decrease

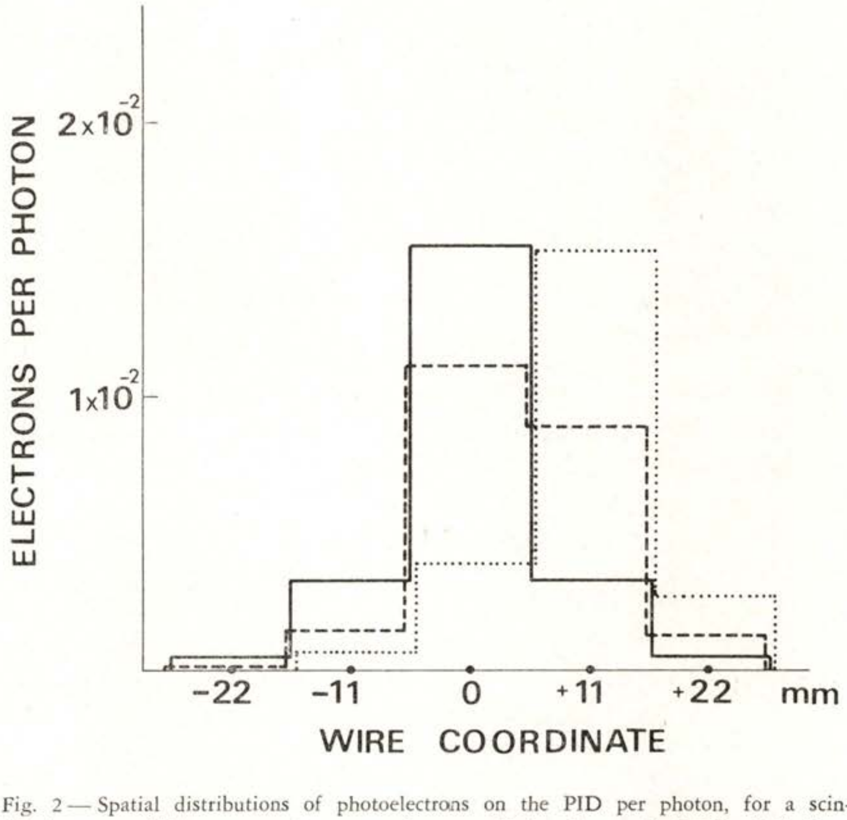

Fig. 2 — Spatial distributions of photoelectrons on the PID per photon, for a scintillation gap thickness $\Delta = 20$ mm and an applied voltage of 7200V. Full lines correspond to $x_F = 0$, dashed lines to $x_F = 5$ and dotted lines to $x_F = 10$ mm.

in the spacing between the anode wires does not affect significantly $\sigma_{\bar{x}_M}$ from 20 keV to 2 keV. And this even for an electronic noise σ_e, that although relatively low for large size systems, is in no way an unrealistic value. For the higher energy even for a 5mm distance between anode wires the non linearity is significant. But it should be noticed that for the lower energy region the non linearity is negligible and the very simple analog technique referred in ref. [12] is then of special importance.

Fig. 4 displays the variation of the difference between computed and real position as a function of the real position for two values of the electronic bias b (full curve corresponds to 2% and dashed curve

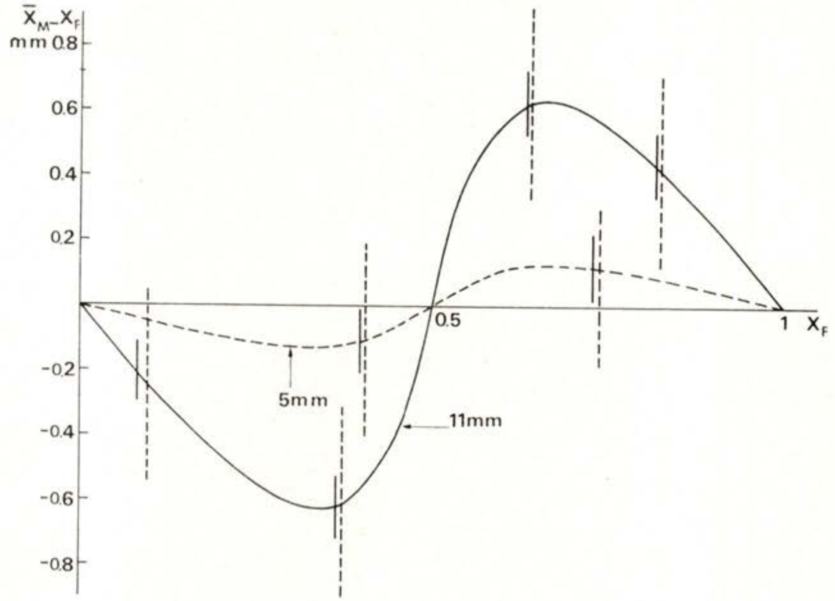

Fig. 3 — Linearity of the detector: $\bar{x}_M$ computed position, x_F real position (the coordinate x_F is expressed in unites of the distance between anode wires). Full curves correspond to a distance between anode wires of 11 mm and dashed curves to 5 mm. Full bars correspond to $\pm \sigma_{\bar{x}_M}$ for 20 keV and dashed bars $\pm \sigma_{\bar{x}_M}$ for 2 keV.

to 10% of the total charge collected in the multiwire proportiona chamber). Calculations were made for an energy deposit of 20 keV and the differences between both curves are within the computed values of $\sigma_{\bar{x}_M} \simeq 0.1$ mm, even for this large light output of the system. For energies lower than about 20 keV, then within the position accuracy of the system, a wide band of b can be used without appreciable change of its linearity, the effect of the 'far away' anode wires being negligible.

All data referred till now assume proper proportional counter operation of the PID. Specially difficult conditions are now considered, that could very well be related to vapours featuring instability for avalanche build-up, and the low charge gain $\overline{k} = 10^2$ is assumed

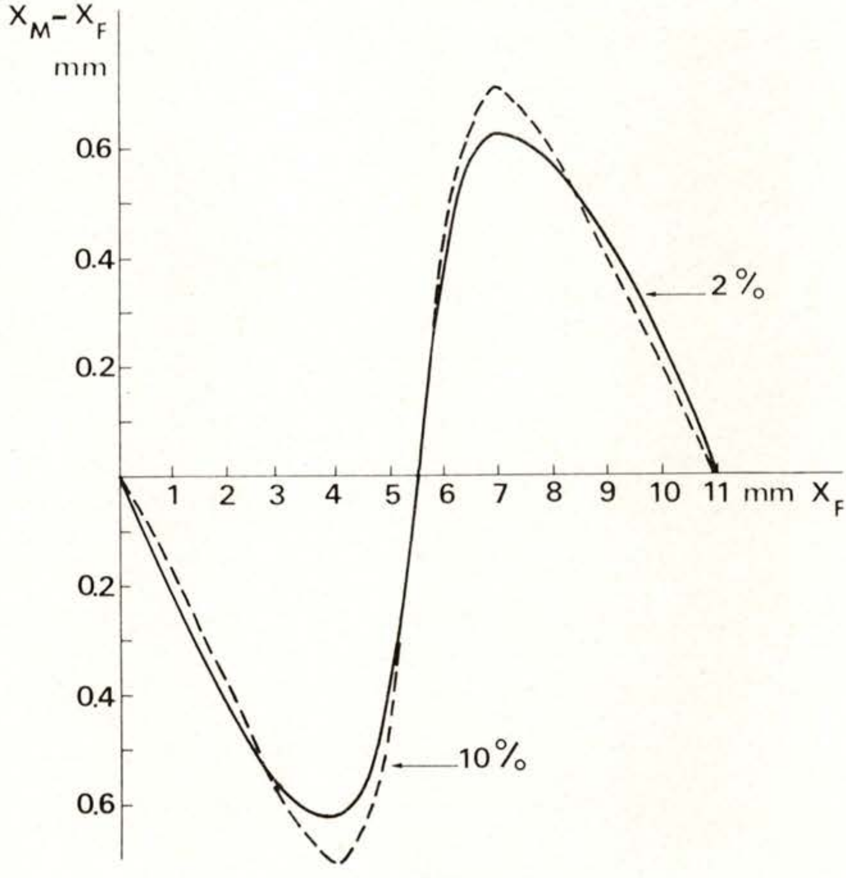

Fig. 4 — Linearity of the detector. Full curve corresponds to a bias b of 2 % of the total charge collected in the PID ; the dashed curve is for a bias of 10 %.

in the data shown in Fig. 5 Again as referred under 2., $\overline{H} = 340$ and $b = 2\%$. The low values of $\overline{k}$ and $\overline{H}$, together with a Fano factor $F = 0.17$ as well as the relatively low value of 31 % for the mean photoionization efficiency of TEA imply energy resolutions (dashed lines) and position resolutions (full lines) that, for the lower energies, depend strongly on the electronic noise σ_e. Values of $\sigma_e = 3000$, 1000 and 140 are considered, this last value implying the use of low noise, but room temperature, preamplifiers.

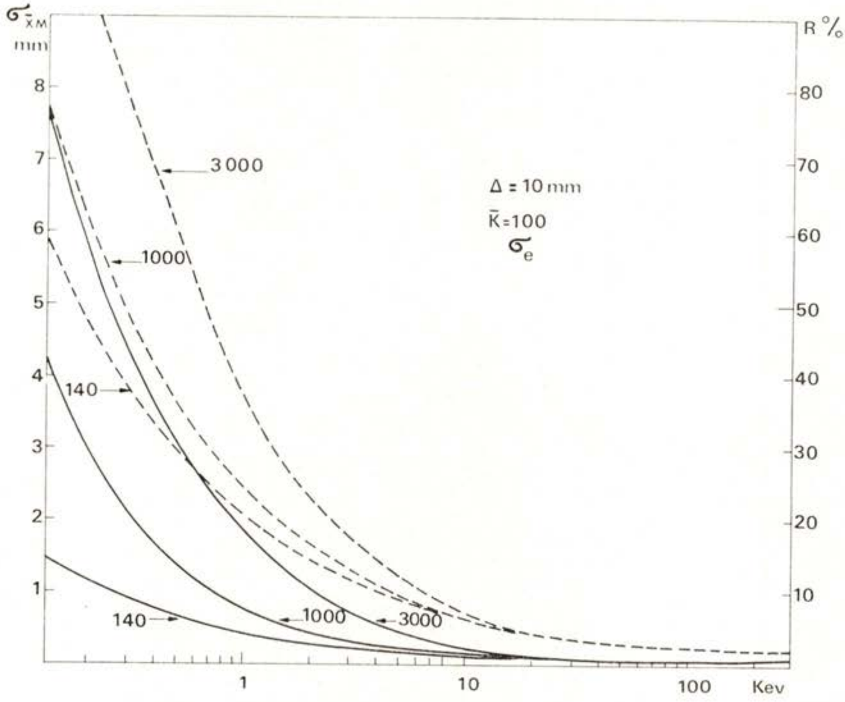

Fig. 5 — Intrinsic position (full lines) and energy (dashed lines) resolutions versus energy of the incident particles, for three values of σ, the r.m.s. noise (in number of electrons) of each amplifier.

4 — CONCLUSION

The data presented concerns directly operation of the device based on secondary light emission. For the low energy region, $\lesssim 2$ keV, of interest to astrophysics [21] and to the study of muonic X-rays [22] for example, the system is linear within its position resolution, provided that the spacing between anode wires is $\lesssim 5$ mm. This is of interest not only because lower spacing between anode wires is a common feature of multiwire proportional chambers, but also because larger distances between the anode and cathode planes can be used, leading to the possibility of working with vapours of lower photoabsortion cross sections.

For higher energies the system is non linear and adequate corrections have to be introduced. This is more important for the 11 mm spacing, that on the other hand would have the advantage of being a minimum reasonable distance compatible with a multiproportional counter configuration rather than a multiwire chamber. The importance of the non linearity effect can be made very clear, noticing, for exemple, that even for $\overline{H} = 50$, $\sigma_{\bar{x}_M} = 12\,\mu m$ at 10 MeV and 1 μm at 1 GeV [11].

For very difficult conditions of operation, the use of low noise preamplifiers for energies $\lesssim 5$ keV, restores the good energy and position resolution of the system and demonstrates the versatility of the device.

Within a good approximation the data shown concerning the linearity of the system can also be used for primary scintillations of higher energy particles, provided that the track of the particle coincides with a line of force of the scintillation gap, both for gaseous and condensed media. If this condition is roughly satisfied, and even neglecting range effects associated with δ rays, photoelectrons ranges, attenuation lengths of X rays associated with the physics of the interaction, etc., the system should be approximately linear up to energy deposits of a few MeV if one considerer scintillators of photon yields similar to liquid xenon, for example [23]. This covers fields like positron annihilation, nuclear medicine, industrial radiography, lower energy heavy ions physics, etc. For higher energies, its non-linearity would, of course, be again significant.

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