

High Pressure Gas Scintillation Drift Chamber with Photomultipliers Inside of Working Medium

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Abstract

The first results of testing a high pressure gas scintillation drift chamber as with single photomultiplier and with matrix of 7 photomultipliers placed inside of pressurized xenon are presented. Two types of ordinary glass tube photo-multipliers that are found mechanically stable up to 8 and 45 bar of external pressure have been used. The quantum efficiency of vacuum deposited on glass PMT window p-terphenyl is about 90% at 170 nm. For 60 keV ^{241}Am γ -source energy resolution of 4% FWHM, intrinsic spatial resolution of 0.2 mm FWHM along the drift direction and 1.2mm FWHM in the perpendicular plane are achieved at 20 bar xenon filling.

I. INTRODUCTION

High pressure xenon scintillation drift chambers (SDC) attract attention about 20 years as imaging gamma-detectors for x-ray astronomy, particle physics and medical applications [1-4]. These detectors have demonstrated both good energy and spatial resolution for point-like events in the plane transversal to the drift field. Precision spatial resolution in the direction of drift field may be provided if a primary scintillation of a working medium is detectable [6,7]. Photomultipliers have a good time resolution and are quite attractive for triggering scintillation drift chambers. But the efficiency of light collection when photomultipliers are placed out of working medium [4-6] is quite poor to detect primary scintillation from 10-100 keV γ -rays absorbed in working medium. As a rule, this energy range is more interesting to be investigated using gas scintillation drift chambers.

In this paper we describe a high pressure xenon scintillation drift chamber with photomultiplier readout systems placed inside of working medium.

II. GLASS PHOTO-TUBES FOR HIGH PRESSURE

Photomultipliers with glass tubes were supposed to be too fragile to be placed inside high pressure (10-40 bar) drift chamber.

Our previous investigations for LKr/LXe scintillating calorimeters have demonstrated that some ordinary glass PMTs may be working in noble gases of several bar pressure and even inside of noble liquids [8, 9].

Table 1
Parameters of Glass Tube Photomultipliers with SbCs Semi-transparent Photocathodes (MELZ, Moscow) Tested in Pressurized Argon

	FEU-85	FEU-60
Diam. of photocathode, mm	25	10
Spectral sensitivity, nm	300-600	300-600
Maximum sensitivity, nm	340-440	380-490
Luminous sensitivity, $\mu\text{A}/\text{lm}$	78	50
Number of stages	11	10
Tube diameter, mm	30	15
Tube length, mm	110	70
Mass, g	50	12
Maximum outside pressure, bar	8	45

For application in high pressure scintillation drift chambers we have tested some types of photomultipliers produced in Russia for mechanical stability versus pressure of surrounding medium (argon) in the range of 0-45 bar. We have found at least two types of glass tube photomultipliers with non-polished entrance window which can be placed inside high pressure scintillation chamber to provide effective triggering and high sensitivity to low intensity luminescence signals (Table 1). For both types of PMT the p-terphenyl ($\text{C}_{14}\text{H}_{10}$) wave-length shifter of 1.0 mg/cm^2 thickness has been vacuum deposited on a glass entrance window.

III. EXPERIMENTAL

A. Chamber

In order to investigate two types of PMTs working in pressurized noble gases we have built a chamber workable up to 40 bar internal pressure. Schematic drawing of this chamber is shown in Fig.1. The electrode system of the chamber consists of two grid electrodes (50 μ m diameter stainless steel wires point-welded to a ring-frame with pitch of 0.5 mm) with the gap between them of 4 mm and placed in 17 mm distances between top and bottom flanges. Electrodes are separately installed on the top flange through teflon isolators. There is a hole of 50 mm in diameter in the center of the top flange with a cylindrical photodetector housing over the hole sealed to the flange. PMTs are placed inside this housing to view a sensitive volume of the chamber through the hole. The stainless steel wire grid of 70 μ m wires with 2 mm pitch have been welded on the internal surface of the top flange to assure the electric field in the chamber does not influence on the PMT photocathode.

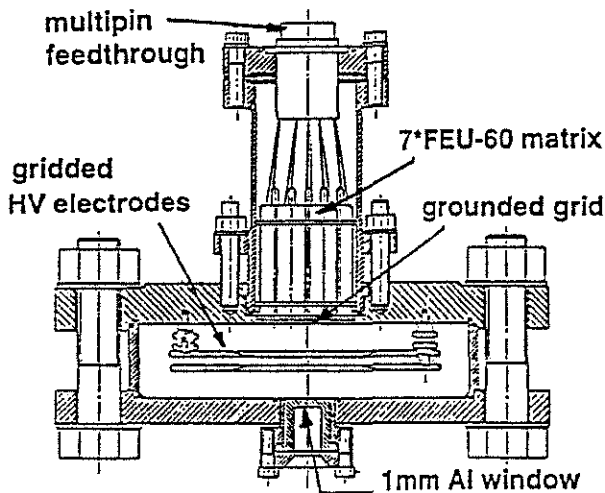


Fig.1. Schematic drawing of high pressure drift chamber with photodetectors placed inside of working medium.

There were two options of readout system investigated in this chamber: with single FEU-85 and hexagonal matrix of seven FEU-60 placed inside of the chamber.

Alumina 30 kV feedthroughs and 2 gas inputs are placed on the top flange (are not shown in the Fig.1). PMT dividers are placed outside of the chamber and connected to PMT pins via multipin feedthrough¹.

²⁴¹Am and ⁵⁷Co γ -rays were measured in the detector using collimated point sources placed outside the chamber at aluminium window (minimal thickness of 1 mm). Another series of measurements was made using a thin

²⁴¹Am α -source placed inside the chamber on the internal surface of the entrance window.

B. Wave Length Shifting

To detect luminescence of noble gases by glass photomultipliers we have used wave length shifter vacuum deposited on the entrance window of PMT. It was found that well-known scintillating dye, p-terphenyl, is effective wave length shifter in the range of 120-170 nm [1] and, what is very important, it doesn't contaminate xenon in gas and liquid phase [5,6,8,9].

Unfortunately, there are no published data about efficiency of p-terphenyl in free state (non included in PMMA matrix) in xenon. To estimate quantum efficiency of p-terphenyl in high pressure Xe we used the option of the chamber with α -source and single FEU-85 inside the chamber. The spectrum of α -scintillation was measured in 4.8 bar Xe (Fig.2).

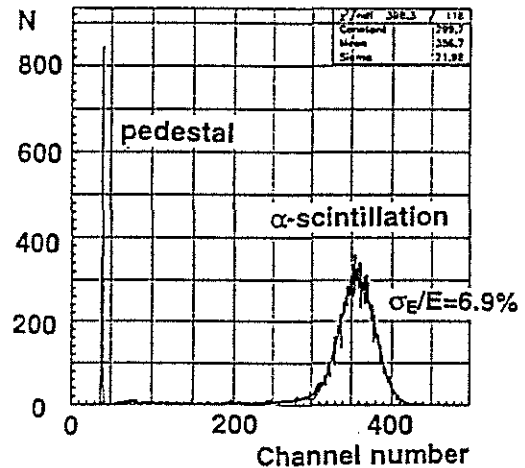


Fig.2. Spectrum of α -scintillations for ²⁴¹Am source in 4.8 bar Xenon viewed by FEU-85 PMT with p-terphenyl evaporated window

It has shown energy resolution $\sigma_E/E = 6.9\%$. A number of photoelectrons in PMT can be calculated as

$$N_{ph-e} = 0.5 Q_{E_{p-t}} Q_{E_{PMT}} (E_{\alpha}/\omega_{ph}) (1+k) \Omega, \quad (1)$$

where $Q_{E_{p-t}}$ is the quantum efficiency of p-terphenyl at 170 nm, the quantum efficiency of PMT for p-terphenyl emission light (360-400 nm) $Q_{E_{PMT}}$ is suggested to be about 20%, energy of α -particles $E_{\alpha} = 5.48$ MeV, the energy of scintillation photon production $\omega_{ph} = 76$ eV [6], a reflective index for α -source substrate is previously estimated as $k \sim 0.3$, Ω is a solid angle under which PMT views α -source (~ 0.024).

In suggestion that energy resolution depends only on fluctuation of photoelectrons ($\sigma_E/E = 1/\sqrt{N_{ph-e}}$) and using (1) equation, we may estimate quantum efficiency of p-terphenyl $Q_{E_{p-t}} \sim 90\%$ at 170 nm. It should be noted this estimation looks reasonable in comparison, for example, with 76% quantum efficiency of another scintillating dye of 9,10-diphenylanthracene at 220 nm [10].

¹ CERAMASEAL, Catalog No.989C10769

C. Electroluminescence

Drifting in high electric field (>1 kV/cm.bar in Xe) electrons generate electroluminescence or proportional scintillation. It was shown that intensity of electroluminescence is proportional to pressure of noble gas, integral light-output is proportional to a drift path of electrons and may achieve some thousand of photons per drifting electron per 1 cm of drift path [4,6]. We have repeated these measurements for 4.8 bar Xe (Fig.3) and have found dependence of intensity of electroluminescence per drifting electron (in photons per 1 cm of drift path) on applied electric field (in kV/cm.bar) in suggestion that electric field in light-production gap between two grids (Fig.1) is uniform as following:

$$dI/dx \sim 70 (E/p - 1.0) p. \quad (2)$$

This dependence is very close to one measured by Berkeley group for Xe/He (90/10) mixture up to 20 bar in similar experimental conditions [6].

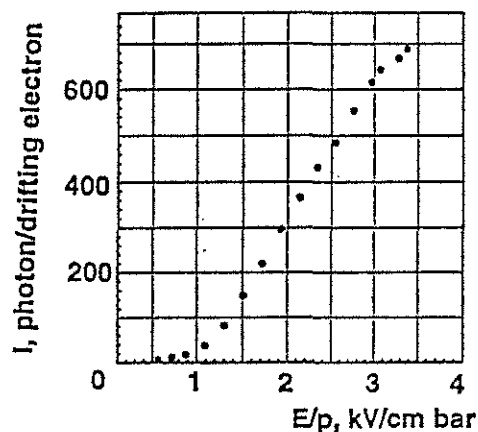


Fig.3. Intensity of electroluminescence of 4.8 bar Xe.

Detail observation of nonintegrated (at 50 Ω input impedance of a digital scope) electroluminescence signals has demonstrated complicated time structure of these signals depended on applied electric fields and real trajectory of electrons in vicinity of the electrode wires (Fig.4). This effect is specially occurred in the ranges of nonlinearity of experimental dependence of dI/dx on calculated E/p (Fig.3). But we did not observe any dramatical difference in amplitude of integrated signals and that provides spectrometric ability of the scintillation drift chamber. Any way wave-form selection of electroluminescence signals from gridded scintillation drift chamber should improve energy resolution.

IV. HIGH PRESSURE SCINTILLATION DRIFT CHAMBERS

As we mentioned above two options of high pressure scintillation drift chambers have been tested: with single FEU-85 PMT and with matrix of seven FEU-60 PMTs.

The goal of the first option was to build self-triggered SDC, sensitive to primary scintillation for measuring z-coordinate resolution. In the second option we were going to reach as high working pressure as possible to have a good energy resolution and to measure x,y-position resolution of the SDC.

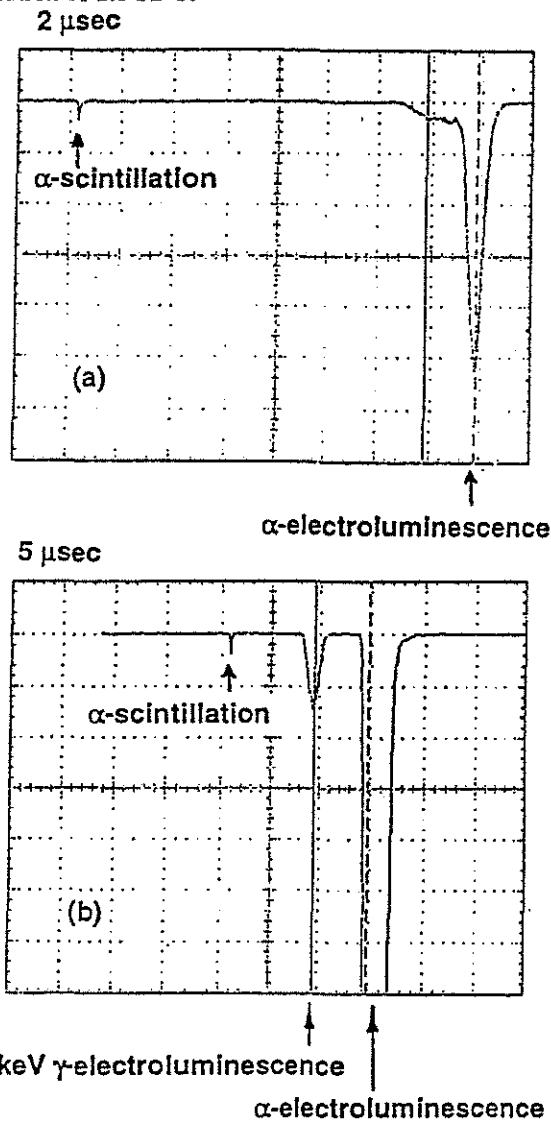


Fig.4. α -scintillation and α -electroluminescence signals at $E/p=1.2$ kV/cm.bar (a) and α -scintillation and 60 keV γ - and 5.48 MeV α -electroluminescence signals at $E/p=2.2$ kV/cm.bar (b) detected by FEU-85 placed at the distance of 1.7 cm from 4mm light-production gap at 1.7 cm thickness of the drift gap and 8.1 bar Xe.

A. SDC with FEU-85 readout

Thin α -source (^{241}Am on Al-Mylar substrate) of 1 mm diameter was placed in the center of aluminium window inside of the chamber (Fig.1). Readout system, being triggered by fast scintillation signal (<100 nsec), generated a gate (10 μsec) for ADC delayed for drift time

of electrons through the drift gap. Typical oscillograms of signals are shown in Fig.4.

It is shown the detection of both scintillation and electro-luminescence signals is possible through the same PMT channel. Fig.4b demonstrates the capability of this detector to measure both scintillation signals from 5.48 MeV α -particles and electroluminescent signals from 60 keV γ -rays. And at this conditions energy resolution of $\sigma_E/E=2.4\%$ for $\alpha(^{241}\text{Am})$ -particles in 8 bar Xe at 30mm distance between PMT and 4 mm light-production gap with 3 kV/cm.bar high-generating field is measured.

Due to different orientations of tracks of α -particles there is a significant spread in duration of electroluminescence signals which have practically the same integral charge. Time distribution of electroluminescent signals from α -particles is shown in Fig.5. The right wing of the distribution is related to α -tracks going perpendicular to drift field and to grid electrodes. Gaussian approximation of the right wing of this distribution gives us estimation of achievable spatial resolution of $\sigma_z \sim 0.1$ mm in the drift direction (at drift velocity in the drift gap 0.1 cm/ μsec). The measured spatial resolution in drift direction depends mainly on diffusion process. There are data showing that adding of helium suppresses diffusion process [11]. At the same time we have observed good correlation of our data with light-yield of electroluminescence in xenon with one measured in Xe/He mixture (see section III.C). Thus helium should be considered as a perspective dopant.

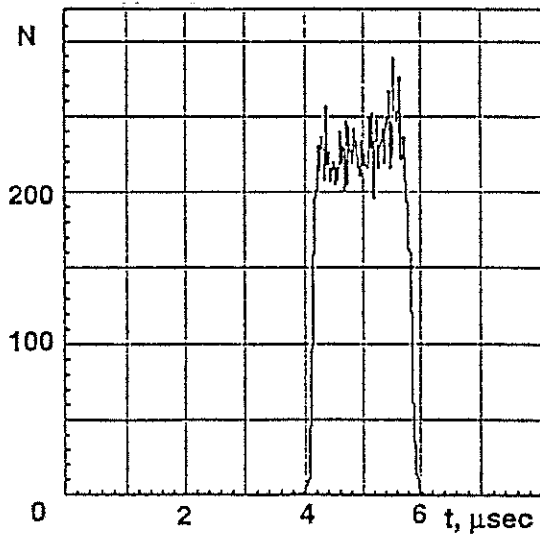


Fig.5. Time distribution of duration of $\alpha(^{241}\text{Am})$ -electroluminescence signals measured in the scintillation-triggered SDC viewed by FEU-85.

Spectrum of electroluminescence signals from 60 keV collimated ^{241}Am γ -source placed outside of the chamber is presented in Fig.6a and has demonstrated 4.0 % FWHM energy resolution. This spectrum includes a peak related to α -scintillation from the internal ^{241}Am source.

B. SDC with 7xFEU-60 matrix readout

In this option seven FEU-60 are placed inside the chamber in hexagonal manner at 2 mm distance from one to another and are fed from the same voltage divider placed outside the chamber. Anodes of PMTs are connected separately to individual Fera ADC inputs. Readout system is triggered by electro-luminescence signals. PMT matrix has been placed at 20 mm distance from 4 mm light-production gap; drift gap is 17 mm (Fig.1). N

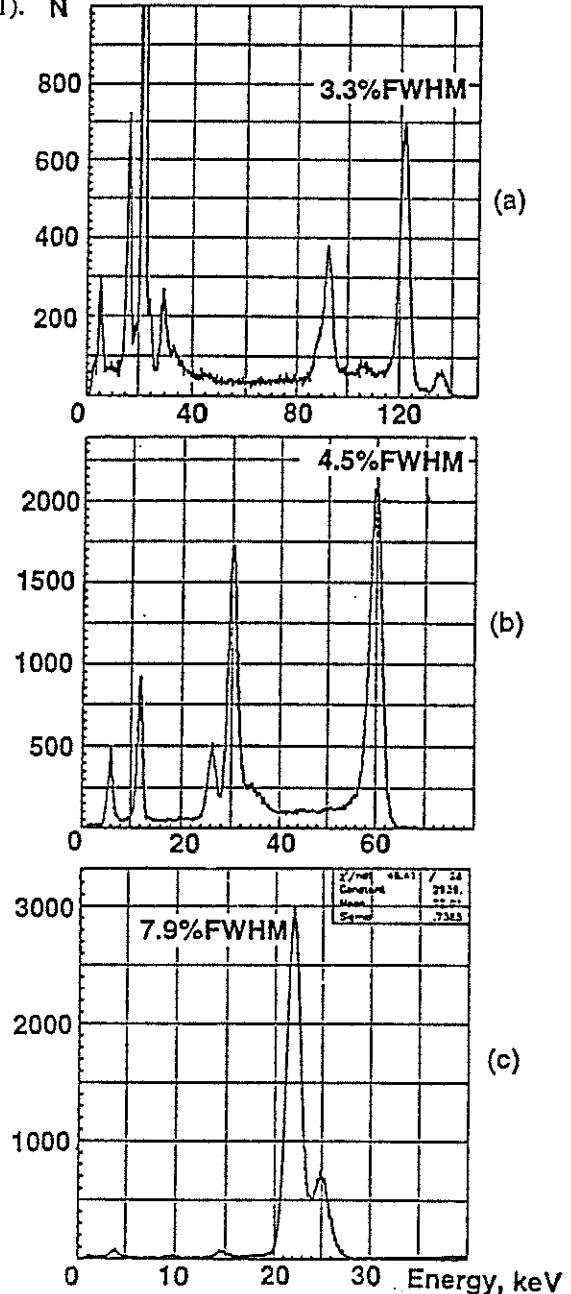


Fig.6. Energy spectra for a ^{57}Co 122 keV source (a), for ^{241}Am 59.6 keV(b), and for ^{109}Cd X-ray source (c) measured with 7 PMTs inside of 20 bar xenon at 2 kV/cm.bar in light production gap.

Energy spectra of different X- and γ -sources measured in SDC are shown in Fig.6. Energy resolution demonstrated with 7xFEU-60 matrix is a little worse in comparison with a single FEU-85. We suggest that it is the result of a some difference in quantum efficiency of these photomultipliers for the emission light of p-terphenyl in the range of 300-400 nm (Table 1).

Weighing electro-luminescence signals of PMTs in the matrix, we may build two-dimensional distribution of intensity of photoabsorbed 59.6 keV γ -rays (Fig.7). FWHM of this distribution is 1.7 mm. Taking into account diameter of collimator (1 mm) and geometry factor, we may estimate intrinsic spatial resolution of 7xFEU-60 SDC as 1.2 mm FWHM.

The main limitation of energy and spatial resolution achieved with SDC is connected with technical problems of supplying needed (~ 3 kV/cm.bar) high voltage to light-production gap to utilize all advantages of xenon SDC at pressure > 10 bar.

IV. CONCLUSION

It is found that some type of glass photomultipliers may be workable inside of scintillation drift chambers filled by xenon at pressure up to 45 bar.

Quantum efficiency of p-terphenyl wave-length shifter of 1 mg/cm² thickness, vacuum deposited on entrance window of glass PMT, is found about 90% in high pressure xenon at 170 nm.

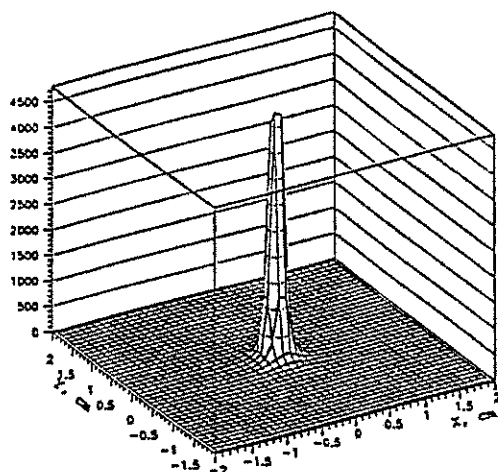


Fig.7. Distribution of photo-absorbed 60 keV γ -rays from collimated ^{241}Am -source over the 50 mm field of view of scintillation drift chamber with 7 PMTs readout matrix and 17 mm drift gap at xenon pressure of 20 bar.

It is shown the detection of both scintillation and electroluminescence signals is possible at the same PMT channel. We have shown with a single PMT and with a matrix of PMTs inside of gas xenon SDC:

- energy resolution of 4% FWHM at 60 keV ^{241}Am γ -sources;
- spatial resolution of 0.2 mm FWHM along of the drift direction;
- intrinsic spatial resolution of 1.2 mm FWHM in the plane perpendicular to the drift direction. We suggest the above technology of scintillation drift chambers based on PMT readout system placed inside of pressurized noble gases may be applied to development of miniature gamma-camera for precise measurements in the range of 30-140 keV radiotracers, of Compton camera for determination of direction of incoming γ -radiation, and of three-dimensional position sensitive spectrometers for low energy physics.

V. REFERENCES

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