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A gas scintillation counter with imaging optics and large area UV-detector

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Abstract

We report on the improvements in the position sensitive readout of a xenon-filled gas scintillation proportional counter. Using an imaging optic for UV-light in the region of 170 nm, the position resolution could be improved by more than 30%. In addition, we have obtained first encouraging results for the use of the recently developed gas electron multiplier together with a CsI-photocathode as a large area UV-detector system. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Many modern experiments using X-ray spectroscopy require position sensitive detectors for X-rays in the energy range of a few keV to several hundred keV. Applications range from the basic research of ion–atom collisions with heavy, highly charged ions to material analysis and medical imaging. While the standard semiconductor detectors have a very good energy resolution and high efficiency, they are restricted in active area and in the methods available for position readout. Gaseous detectors on the other hand can be built with almost arbitrarily large active areas. This allows to cover a large solid angle of the X-ray emission pattern without performing a time consuming angular scan. Thus, experiments with low intensities become feasible. For example, at the SIS/ESR facility at GSI the beam intensity for decelerated 46 MeV/u Pb^{81+} ions extracted from the storage ring into an endstation is in the order of 10^5 ions/s [1]. In addition, a large variety of methods for position readout have been developed for gaseous detectors (see for example Ref. [2]).

It has been shown [3–6] that xenon-filled gas scintillation proportional counters (GSPC) are ideal detectors for many such experiments. Besides

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having a much better energy resolution as compared to multi-wire proportional counters (MWPC), they allow for parallax-free detection of the X-rays as well as the identification of the absorption process in the detector via K-fluorescence gating. The latter allows to discriminate against a gamma-induced Compton background present in many heavy-ion experiments. In addition, GSPCs have a good time resolution, which makes them suitable for modern many-parameter coincidence experiments. Their only disadvantage is the high-gas pressure required to obtain a reasonable efficiency at high-X-ray energies.

In this article, we focus on improvements in the position sensitive readout of the scintillation light and the use of UV-detectors in a high-pressure environment using recent developments by Sauli et al. on gas electron multipliers (GEM) [7].

2. Detector principle

Fig. 1 shows the operation principle of a GSPC as described in Ref. [6]. It consists of two parts: the xenon gas scintillator and the 2D imaging UV-detector. Incoming photons interact with xenon, producing primary scintillation light and primary electrons. The primary scintillation light serves as a fast timing signal. The primary electrons drift in the homogeneous electric field towards the secondary scintillation gap (SSG), where they gain enough energy to produce further scintillation light by excitation without ionization. This secondary scintillation light is used to determine the energy of the X-ray and its position in the plane perpendicular to the detector axis. The statistics of the secondary scintillation process is such that a better energy resolution can be obtained as compared to an electron avalanche. In the ideal case, one can reach the Fano limit of the primary interaction. Fig. 2 shows the spectrum of a ^{241}Am source acquired with a GSPC [8]. The energy resolution is 7.8% at 18.6 keV. The time delay between primary and secondary scintillation is given by the electron drift time and its measurement thus allows the determination of the absorption depth.

The energy resolution is dependent on the number of detected scintillation photons. The position resolution is, in addition, dependent on the spread of the scintillation light over the UV-detector. In our earlier designs [6,9] a low-pressure MWPC with a solid CsI-photocathode was used as a UV-detector. The scintillation light was spread out over the whole UV-detector and the position was determined by the centroid of the photon distribution on the photocathode. The broad distribution leads to a position resolution in the order of a few mm. In addition, technical requirements for a detector with 25 bar xenon and 200 mm active diameter as described in Refs. [8,9] negatively influence energy and position resolution.

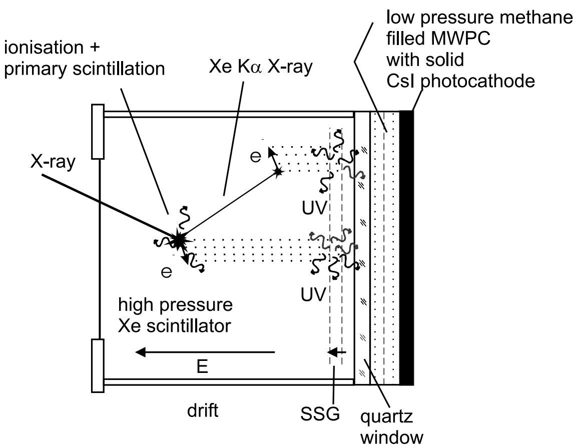

Fig. 1. The operation principle of the gas scintillation counter. The photon and electron tracks inside the scintillator part are shown for the case of an X-ray interaction by photoabsorption.

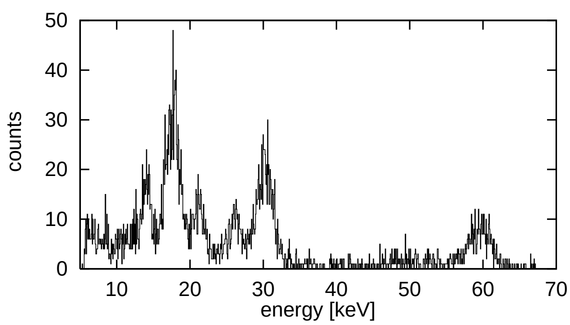

Fig. 2. Energy spectrum of a ^{241}Am source acquired with the system shown in Fig. 1.

3. UV-readout with imaging optics

To improve the position resolution, the size of the image spot of the secondary scintillation light on the photocathode must be reduced. This can be reasonably achieved by the use of an optical imaging system. However, the wavelength of xenon scintillation light at 170 nm severely limits the choice of the optical elements. Commercially, off-the-shelf lenses are available that are made only of quartz glass. Since the absorption edge of quartz glass overlaps with the wavelength distribution of the scintillation light, losses in the optical elements are not negligible. This prohibits the usage of several lenses or thick lenses.

For our first prototype, we have chosen a single lens with 40 mm diameter and 80 mm nominal focal length at 585 nm. The set-up with an image scale of 1 : 1 is shown in Fig. 3 together with a calculation of the optical system using the program WinLens [10]. The lens also serves as the window between the high- and the low-pressure parts of the detector, where its small diameter improves the stability against the high-pressure difference. As a disadvantage, the small solid angle of the lens leads to a severe reduction in the intensity of scintillation light on the UV-detector. The MWPC used as a UV-detector suffered strongly from the resulting small signal height.

Good results, however, were obtained using the prototype of a position sensitive sealed micro-channel-plate (MCP) detector with a photocathode for UV-light [11]. The active diameter of this detector was only 25 mm so that only a fraction of the scintillator area could be imaged. With this prototype set-up, a position resolution of 1.7 mm could be achieved (see Fig. 4) as compared to 2.5 mm without the imaging optics. In addition, the 1.7 mm value includes a parallax error of 0.5 mm as the primary scintillation light could not be detected. Simulations show that a position resolution of 0.9 mm should be achievable with the set-up in Fig. 3. In addition, a sealed MCP detector significantly improves the ease of handling the complete GSPC.

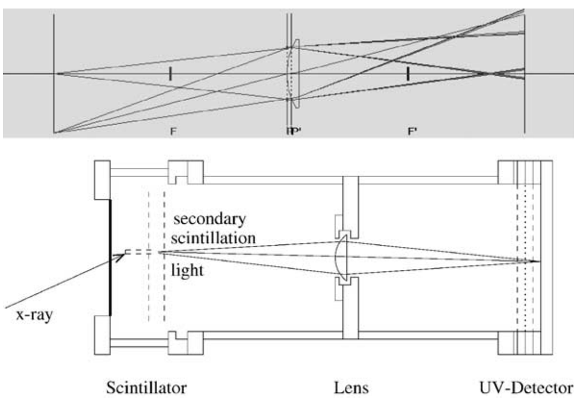

Fig. 3. Ray path (top) and schematic set-up (bottom) of a GSPC with imaging optics for the scintillation light. The magnification of the optics is unity.

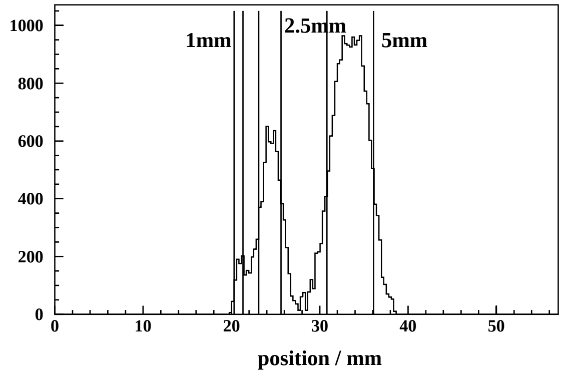

Fig. 4. Projection of a Pb mask with three slits of 5, 2.5 and 1 mm clear width imaged with a GSPC as shown in Fig. 3, but using a UV-sensitive MCP detector instead of a low-pressure MWPC. The Pb mask was irradiated with a ^{241}Am source, placed at a distance of 30 cm.

Thus, the use of an imaging lens system can improve the position resolution of a GSPC and make the construction of high-pressure detectors easier. However, the big loss in the intensity of scintillation light completely destroys the energy resolution and makes it impossible to detect the primary scintillation light. To retain these important properties of the GSPC, a second UV-detector is needed to detect with high efficiency and large solid angle the primary and secondary scintillation light.

4. GEM-based UV-detectors

One main challenge in the engineering work of realizing a large area UV-sensitive readout for the

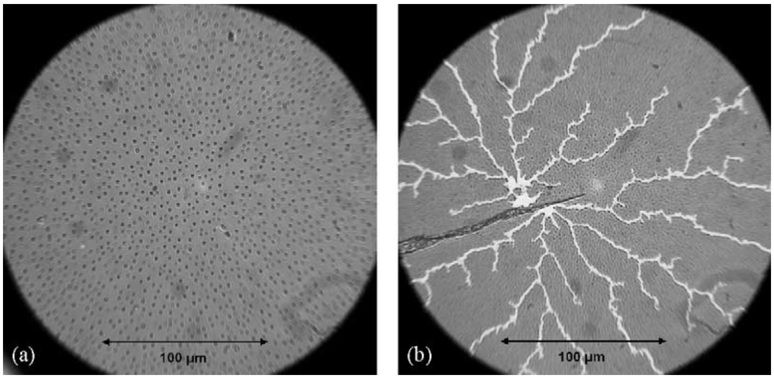

Fig. 5. Microscope images of two semi-transparent photocathodes. The left figure shows a fresh photocathode. The photocathode in the right picture shows the destruction caused by a spark in the detector. To make the usually clear CsI layer visible, the photocathodes have been exposed to humid air before taking the picture.

xenon scintillation light is the pressure difference between the scintillator and the UV-detector volumes and the necessity to use adequately thin quartz windows. Recently developed micro-structure devices like the GEM [7] are able to work under high pressure and even in pure noble gases. It has been shown by Bressan et al. [12] that GEMs can be successfully operated in pure argon at high gain. That might render the use of a quartz window obsolete.

The GEM consists of a 50 μm thick Kapton polymer foil, metal coated on both sides with 5 μm copper and perforated by a regular matrix of 70 μm holes with 140 μm pitch for gas amplification. As a photon convertor for UV-photons CsI-photocathodes are widely used. It has already been shown by Aprile et al. that it is possible to extract electrons from a CsI-photocathode into high pressure or even liquid noble gases [13]. We consider two methods to couple a GEM to a CsI-photocathode: direct deposition of CsI on the GEM surface and deposition of a semi-transparent photocathode on a thin quartz window in front of the GEM.

In the first case, we have evaporated a 200 nm thick CsI layer directly on a GEM. The GEM was then mounted behind the quartz window instead of the MWPC as shown in Fig. 1. The electrons were collected on a wire plane located 4.5 mm behind the GEM. For a very first test, the UV-detector was operated in 25 mbar methane like the MWPC. Reasonable pulse heights for scintillation pulses could be achieved with this set-up. However, long term stability could not be reached, as the CsI reacts chemically with the copper coating of the GEM.

To test the second set-up, a semi-transparent CsI-photocathode consisting of a 5 nm thick chromium layer and a 9.5 nm thick CsI layer evaporated on the quartz window has been realized. In combination with a GEM and a wire plane, reasonable pulse heights for the scintillator readout could be achieved. However in a longer run up, charging effects have been observed and the photo-cathode proved to be very sensitive to sparks in the detector (see Fig. 5), which is not so significant for opaque photocathodes.

5. Conclusions

We have shown that the position resolution of GSPCs can be significantly improved by using imaging optics for the UV-readout of the scintillator. Position resolutions comparable to MWPCs seem to be achievable. In addition, we have started to investigate the possibility of using GEMs as a large area UV-detector in a high-pressure environment with encouraging results so far. As the effective mass of a GEM based UV-detector is rather low, it is possible to install it directly behind the detector's entrance window in transmission for

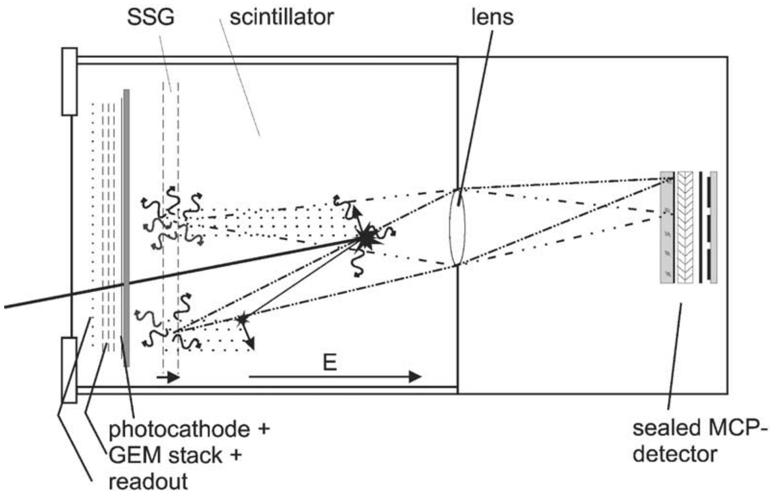

Fig. 6. Schematic diagram of a possible GSPC with imaging optics readout and large area GEM UV-detector directly behind the entrance window.

the incoming X-rays. Thus, a complete GSPC with imaging optics based on an MCP UV-detector and a GEM could be envisioned as in Fig. 6.

Acknowledgements

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