



On the possibilities for the readout of gas scintillation detectors for neutron scattering applications

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Abstract

A gaseous scintillation detector consisting of an $^3\text{He}+\text{CF}_4$ filled micropattern detector coupled with an optical readout has been investigated for an application for high resolution and high counting rate position sensitive neutron detector. Measurements of the photons' emission as a function of the gas mixture have been carried out indicating that filling the detector with $^3\text{He}+\text{CF}_4$ is a very good choice also from the point of view of optical readout and not only for charge readout. The light yield has been systematically measured as a function of the CF_4 concentration and operating voltages. We also studied the emission of primary light, rather strong in CF_4 mixtures, which allows the observation of the light signal even in the absence of high voltage on the electrodes. Finally some measurements of the position resolution have been performed.

1 Introduction

It has been demonstrated [1], [2] that a micropattern structure, installed in a gas volume suitable for neutron detection, can generate a number of photons during the avalanche process sufficient for detection via a CCD camera. This is a consequence of the fact that every avalanche multiplication or charge migration in a gas volume is accompanied by the emission of photons. Those photons are the result of inelastic collisions between charged particles and gas molecules. The use of this light producing phenomenon, never used before in neutron detection, is at the origin of the study of a GSPC detector currently carried out at the Institut Laue Langevin in Grenoble.

2 System description

At the ILL we developed a GSPC system for neutron detection. The detector consists of a stainless steel box equipped with a 5 mm thick *input* Aluminum window for the neutrons to enter the gas volume and a 5 mm thick *output* Quartz (Suprasil) window for reading out the photons produced in the gas. The Al window is installed in a flange that allows it to recess into the gas vessel in such a way that its distance from the detecting element can be minimized. The Quartz window diameter is 6 cm and it is certified to sustain a gas pressure of 12 bars. The text box can hold a 10×10 cm² μ pattern device to ensure avalanche multiplication and charge collection. In order to check the possibility

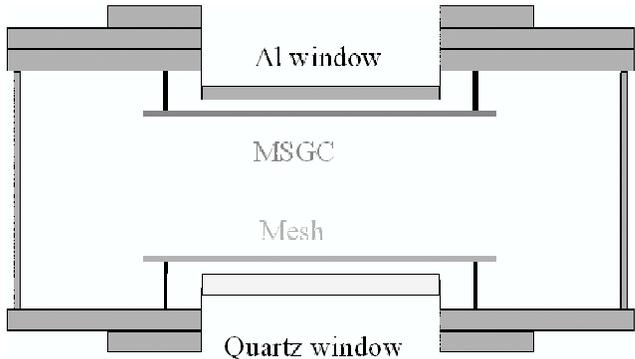


Fig. 1. Schematic drawing of the test vessel

of a real use if this type of detector for neutrons, we investigated the use of bidimensional 8×8 cm² MSGC plates and 10×10 cm² GEMs. A special light tight flange allows the positioning of a 1 inch photomultiplier in front of the Quartz window. In front of the quartz window is also possible to install a CCD camera for imaging purposes. Several feed-throughs allow the application of the voltages to the electrodes and the read out of the charge signals. The bidimensional MSGC used for the tests is of the Bidim-bis type developed at the ILL and described in [3]. The MSGC has been installed on a support which was then placed into the chamber at a distance of 1 mm from the Al window and at 3 cm from the glass one. Just in front of the glass window a mesh has been positioned in order to act a drift electrode. In this application the MSGC has been mounted in a reverse way (with the cathodes facing the entrance window) compared to what would be done in a normal neutron detector, the reason being the need to have the anodes, where the light is produced, facing the glass window. For this reason, the gap between the Al entrance window and the plate has to be the smallest possible, in order to guarantee that most of the neutron beam interacts in the conversion region between the grid and the anodes. Similarly, the GEM has been assembled on its support and then inserted in the gas vessel at a distance of 2.5 cm from the Al entrance window and of 5 mm from the glass one. In the case of the GEM those distances do not have very tight restrictions as in the MSGC case

because the GEM is essentially transparent to the photons that are going to be created in its holes. As mentioned, in order to allow a simultaneous study of the charges and photons creation in the gas volume, it is possible to perform two independent readouts:

- a charge readout system allows to verify the behavior of the electronic gain, of measuring its value as a function of the applied high voltage and to realize a 2D image of the irradiated detector (for the MSGC only). We used a in-house made preamplifier, specifically designed for the MSGC detector. The characteristics of the amplifiers (2 for the anodes signals and 2 for the cathodes ones in the MSGC, 1 for each electrode plane in the GEM) are a gain $G = 30 \text{ V/pC}$ and a shaping time $\tau = 4 \mu\text{sec}$. Every detected event generates, by the way of the electronic amplification, a current that is then converted in a proportional voltage by the preamplifier. The pulses are injected in an ADC then connected to the readout system which allows the recording of pulse height spectra.
- a light readout allows to collect the photons on a visible or UV sensitive photomultiplier or to visualize the images produced by the beam through a mask on the detector in order to measure the position resolution of the system. The quartz window allows to see and record the light produced during the avalanche multiplication, via a photomultiplier or a CCD camera. The photomultiplier was directly connected to the high voltage power supply and the read out was done through a preamplifier having a gain $G = 0.09 \text{ V/pC}$ and a shaping time $\tau = 5 \mu\text{sec}$. The link between the PM entrance window and the quartz window is simply made with optical grease.

3 GEM Measurements

Some of the measurements have been performed mounting a GEM foil [4] in the test vessel instead of the MSGC plate. As already mentioned, being transparent to the light it produces, the GEM can be installed in the middle of the gas gap. To power the GEM mesh a simple resistive network has been used; the ratio between multiplying and lower drift voltages can be modified changing the external resistors. The upper drift electrode (entrance window) is kept at ground potential. Despite preliminary measurements showed a better light emission with a GEM foil, soon other uncertainties appeared. As reported from other groups (Delft), GEM operation appears to be difficult for CF_4 pressures ≥ 1 bar. The attainable gain before sparks appearance is lower and lower as the pressure increases to the point that it is not sufficient anymore and makes the operation of the GEM foil not safe anymore. On the other hand a few groups working on high energy physics and other applications reported safe operation of GEMs (triple GEMs systems) in CF_4 pressures higher than 1 bar and more. Since the only obvious difference in the operation seems to

be the type of radiation detected, this might suggest that the problem is a consequence of the large amount of primary charge produced by the neutron interaction with the ^3He . Most of the measurements have been performed in a single GEM configuration, the reason being trying to keep the system as simple as possible (for example voltage distribution on a multi-GEM detector is somehow tricky). On the other hand some quick measurements realized with a double GEM setting led to the same results.

3.1 Single GEM

During the tests, the GEM has been powered through a resistive chain giving this ratio:

$$V_{GEMup} = V_{GEMdown} \times \frac{8}{21} R \quad (1)$$

where R is a resistance of 120 k Ω . The signals of the 2 GEM electrodes and the one from the photomultiplier (Hamamatsu UV sensitive R292) have been read out through charge preamplifiers, and they looked like the ones shown in Figure 2. The influence of the high voltage applied to grid on the charge

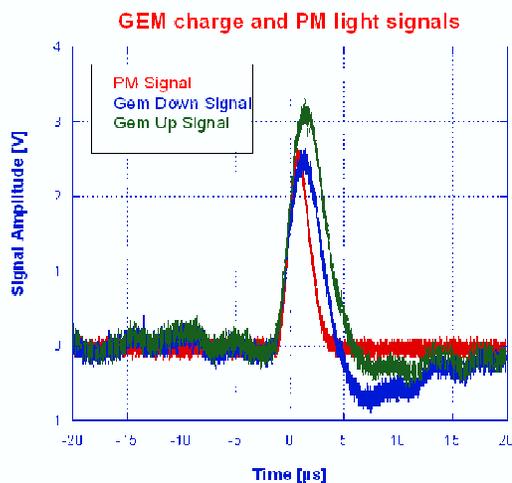


Fig. 2. Oscillogram of the coincident signals from the two GEM electrodes and the photomultiplier

distribution on the electrodes has been investigated: for a fixed detector set up the high voltage on the grid has been steadily increased from 0 to 2200 Volts, giving the result shown in Figure 3. As expected, the increased electric field on the extracting region (the gas volume between the lower GEM electrode and the grid) helps to extract charges from the GEM holes, so that the signal on

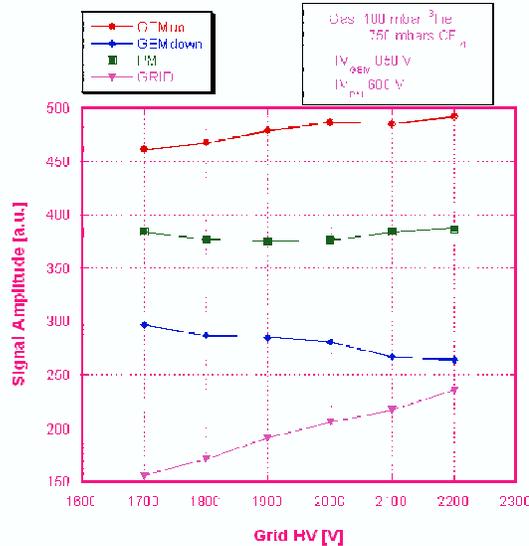


Fig. 3. Change of the charge distribution on the GEM electrodes and on the grid due to the increased electric field on the grid itself

the grid increases (with a corresponding decrease on the lower GEM signal). It is interesting to remark that the light signal remains unchanged.

3.2 Measurements with $^3\text{He}-\text{CF}_4$

The aim of those measurements was to learn more about the GEM behavior in increasing concentrations of CF_4 . Gain measurements have been performed increasing step by step the amount of CF_4 in the gas mixture. As it is shown in Figure 4, increasing the amount of CF_4 in the gas mixture has the expected consequence of increasing the needed applied high voltage (for same gain) but we can also observe that it provokes a rather dramatic limitation in the attainable maximum gain. Each set of measurements has been carried on until small sparks appeared in the oscilloscope signals. With 1 bar of CF_4 the sparks suddenly originated very large signals and in a matter of seconds the GEM stopped working. This behavior has been repeatedly observed with several GEMs, so the conclusion is that the value of high voltage required for the GEM to operate in high CF_4 concentration is too high for it to sustain it. Trying to use a double GEM system, in order to reduce the maximum gain needed from each foil did not help, because in that case at exactly 1 bar of CF_4 the lower GEM stopped working. Even if from the point of view of the light emission the GEM seems to generate more photons than the MSGC, and then possibly less CF_4 would be needed to produce the same amount of light, the proton and triton track lengths would be too long to allow a good position resolution.

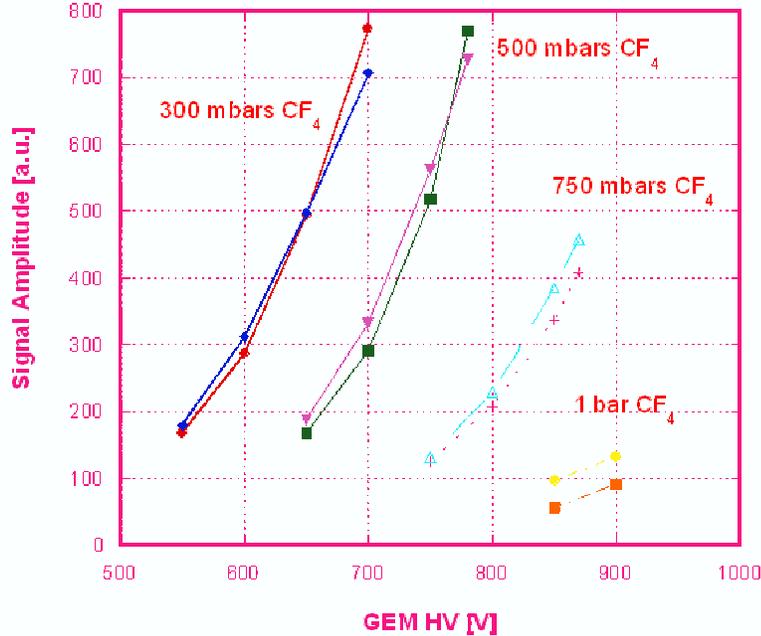


Fig. 4. Gain measurements of the charge and light signals in gas mixtures with increased percentage of CF_4

4 MSGC measurements

Most of the work here reported has been done using a MSGC plate as an amplifying element, since this device is now considered reliable and well know; few examples of it are in use on some of the ILL instruments. The MSGC used is a Bidim80 plate, made of Schott S8900 black glass, 0.5 mm thick. The Chromium anodes are engraved on one side of the $10 \times 10 \text{ cm}^2$ glass plate and have a thickness of $10 \mu\text{m}$ and a pitch of 1 mm. The strips are connected together by a resistive line, made out of Chromium too, having a total resistivity of about $2.5 \text{ M}\Omega$. Gold plated Chromium pad allows the application of the voltage and signal readout. The cathodes, made out of Chromium too, are engraved on the opposite glass side and are $980 \mu\text{m}$ wide at a pitch of 1 mm. In order to allow bidimensional readout of the signals, the cathodes are perpendicular to the anodes. They are also connected all together by a resistive line of about $7 \text{ M}\Omega$. For this application the MSGC plate needs to be assembled in the gas vessel in a reverse way compared to a normal neutron detector (i.e. with the cathodes facing the Aluminium entrance window) because we need the anodes, where the light is produced, to be facing the Quartz window. I have been using a Bidim-bis MSGC plate essentially for two reasons: we had it available at the ILL and it allows a direct comparison of light and charge readouts. Of course once a sufficient knowledge of the scintillating properties of such a device will be acquired there will be no need for a bidimensional structure.

4.1 Measurements with $^3\text{He}\text{-CF}_4$ mixtures

The measurement with the $^3\text{He}\text{-CF}_4$ gas mixture had the aim to better understand the light emission process, its dependence from the concentration of the two gases, the amount of visible/UV light emitted in the process. As already mentioned the choice of the gas mixture used in the test had the aim to optimize the light emission keeping a rather short track length (high CF_4 pressure) and at the same time using a small amount of ^3He . The first measurement with this gas mixture has been to see the variation of the emitted light as a function of the quantity of CF_4 present in the gas mixture (see Figure 5). The amount of ^3He was of 100 mbars. The light spectra have been recorded with the R292 UV photomultiplier having an high voltage of 750 V. The MSGC gain has been kept constant through the entire measurement by increasing the applied high voltage with the increase of the gas pressure. The

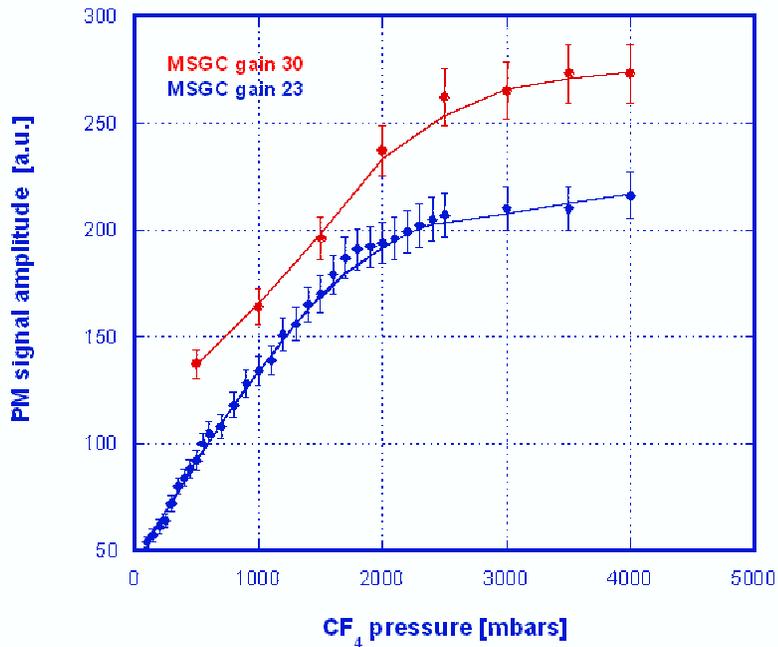


Fig. 5. Signal amplitude of the light signal from the MSGC plate as a function of the CF_4 pressure, for 100 mbars of ^3He and two different MSGC gains

quantity of emitted light reaches a plateau for a CF_4 pressure higher than 2.5 bars; in order to maximize the light emission then a similar amount of CF_4 would be sufficient but in order to decrease the proton and triton track length it is better to use a higher pressure.

The next measurement has been to check the light emission as a function of the CF_4 pressure for different ^3He concentrations in the gas mixture, in order to see if the ^3He has any influence on the number of emitted photons. The measurement conditions were the same as in the previous case. Figure 6 show

the amplitude of the light signal (recorded with the UV photomultiplier) for the different gas mixtures. It is clear that at least at low ^3He concentration the amount of this gas present in the mixture does not affect the light emission. During all the measurements the MSGC gain was kept constant.

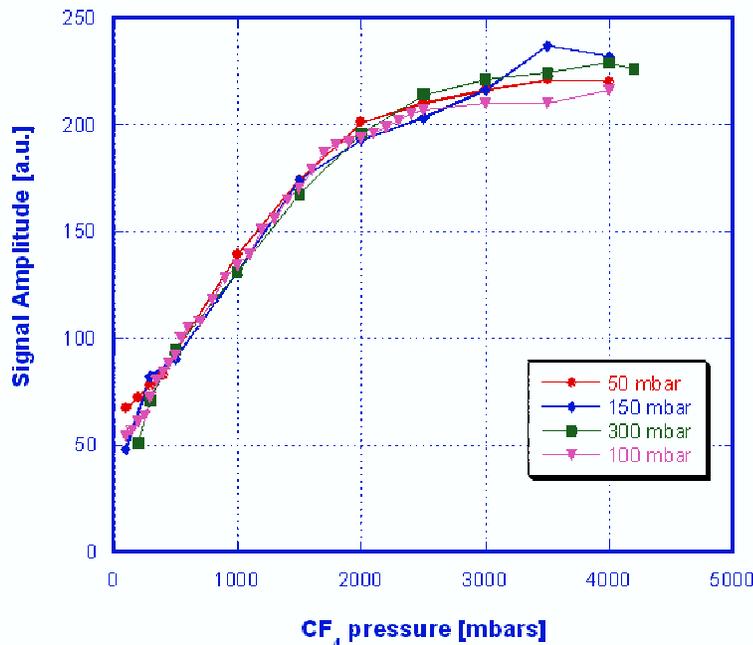


Fig. 6. Signal amplitude of the light signal from the MSGC plate as a function of the CF_4 pressure, for 50, 100, 150 and 300 mbars of ^3He

4.2 Others gas mixtures

In the literature it has been often reported [5] that the best scintillating gas mixtures contain big concentrations or pure noble gases, especially Xenon and Neon. Having already demonstrated that for different reasons our scintillating gas mixture must contain ^3He and CF_4 I wanted to verify if the addition of small amounts of a noble gas would improve the light emission. The measurement has been performed starting with the standard gas mixture to which small amounts of noble gases have been added in order to see if this would increase the amount of emitted light. All the gases used in those tests are high grade purity (99.999 %) gases from different producers. Figure 7 shows the amount of light emitted if an increasing amount of Ne is added to the standard gas mixture and Figure 8 shows the corresponding spectra. From those plots it is clear that even a very small amount of Neon in the gas mixture has a rather dramatic effect on the amount of light emitted, which decreases of more than 40 % when the amount of Neon present in the gas mixture increases

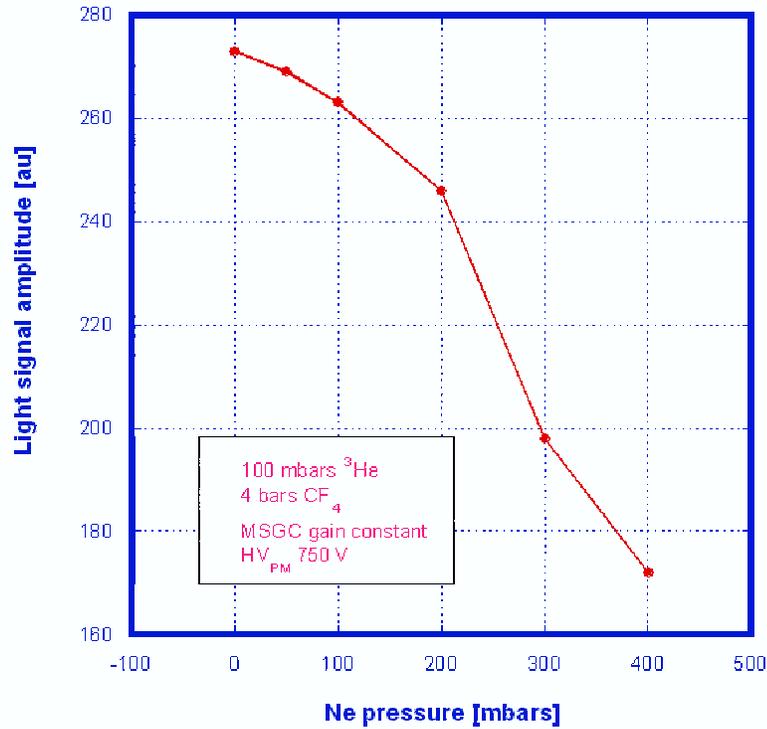


Fig. 7. Signal amplitude of the light signal from the MSGC plate as a function of the Ne pressure

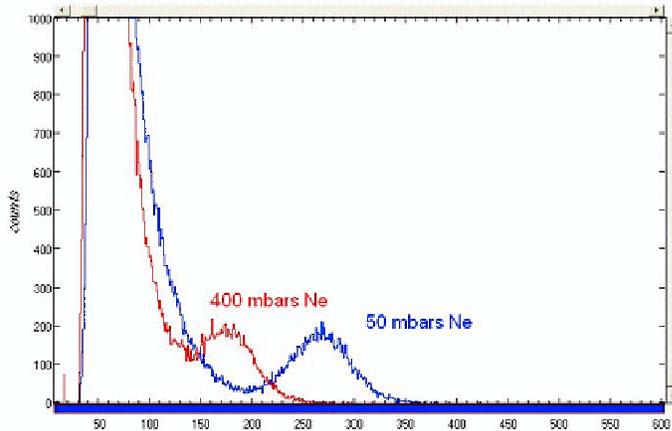


Fig. 8. Signal amplitude of the light signal from the MSGC plate as a function of the Ne pressure

from 0 to 400 mbars.

A similar effect can be observed if small quantities of Xenon are introduced in the standard gas (see Figure 9) while the addition of small amount of Argon does not seem to affect very much the total light emission (Figure 10), a part for a higher gamma sensitivity.

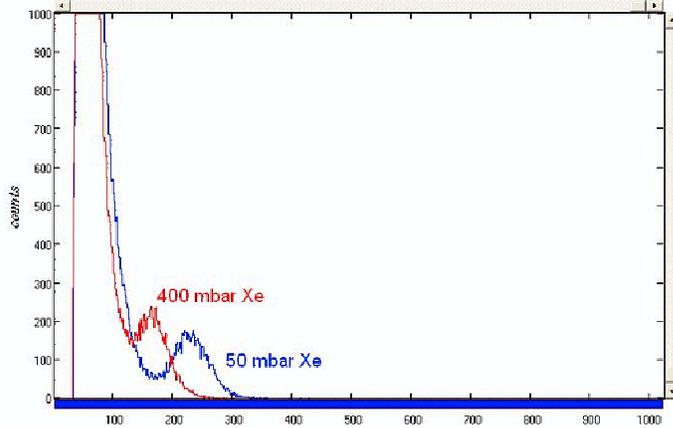


Fig. 9. Signal amplitude of the light signal from the MSGC plate as a function of the Xe pressure and example of 2 spectra

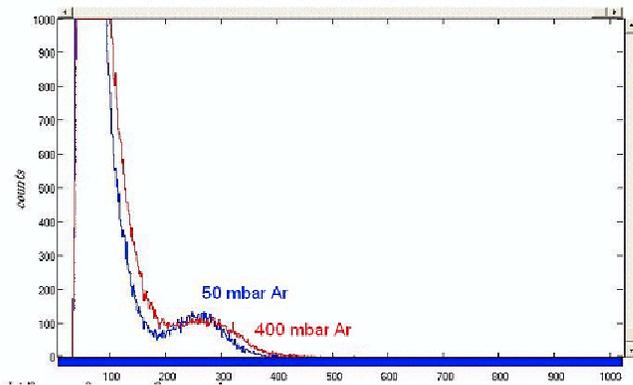


Fig. 10. Signal amplitude of the light signal from the MSGC plate as a function of the Ar pressure and example of 2 spectra

4.3 Comparison with the GS20 scintillator

A comparison with the GS20 Lithium glass scintillator [6] has been carried on, in order to establish which one of the two detectors offers the best performances. The same photomultiplier, an UV sensitive Hamamatsu R292 has been used for both measurements, once been connected to the MSGC test box via the light tight flange, and then to the GS20 scintillator simply using optical grease. Both detectors have been irradiated with a n beam by using a Cadmium slit of $1 \times 10 \text{ mm}^2$ and the gain on the photomultiplier has been kept constant; the MSGC high voltage was of 1900 V. Figure 11 shows the comparison of the pulse height spectra measured when irradiating the GS20 and the MSGC with the n beam, with a PM high voltage of 650 V in both cases. The difference in count rate is due to the difference of efficiency of the detectors; for the GS20 it is of 78 % while with only 100 mbars of ^3He it was of 6.8 % for the MSGC. Correcting Figure 11 for the difference in detection efficiency we obtain Figure 12 where we can observe that the performances of the GPSC

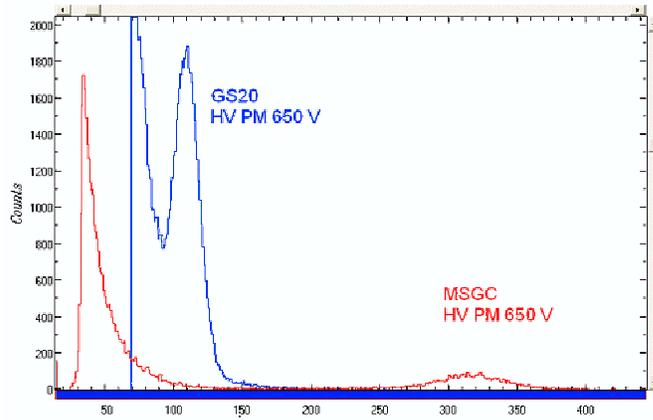


Fig. 11. Comparison between the GS20 and MSGC light spectra obtained irradiating the detector with a thermal neutron beam
 are better than the GS20 scintillator ones. Better gamma discrimination, very good energy resolution and counting rate.

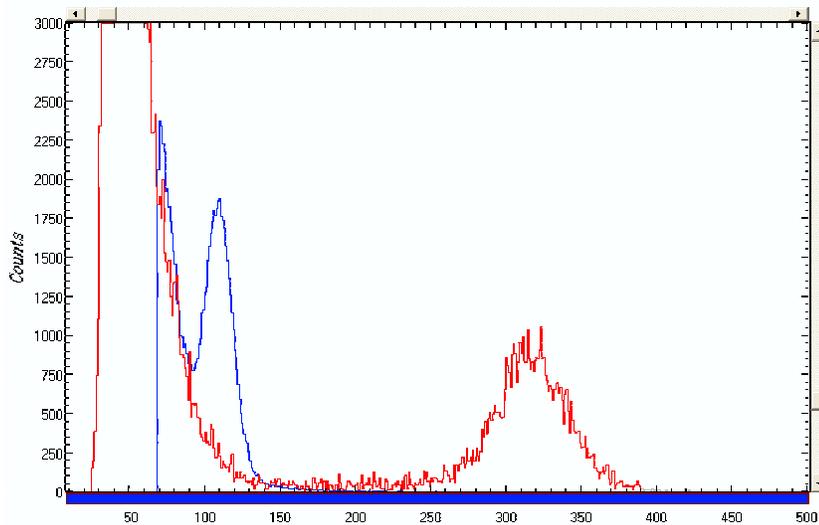


Fig. 12. Comparison between the GS20 and MSGC light spectra obtained irradiating the detector with a thermal neutron beam; the MSGC spectrum has been corrected in order to simulate a 78 % efficiency

5 CCD measurements

The detector has then been coupled to a high sensitivity CCD camera via a 50 mm lens, f 1.8, positioned at 33 cm from the MSGC plate, in order to focus on the anodes where the maximum of light should be emitted. All the measurements have been realized on a test beam line with a Cadmium slit of 1 x 2 cm². With a gas mixture of 100 mbars of ³He and 1 bar CF₄

we have been able to measure the intensity of the light emitted in the gas volume as a function of the MSGC high voltage and, thanks to the possibility of a simultaneous readout of the charge and light signals, compare it to the MSGC gain. From figure 13 we can note that it is possible to observe photons

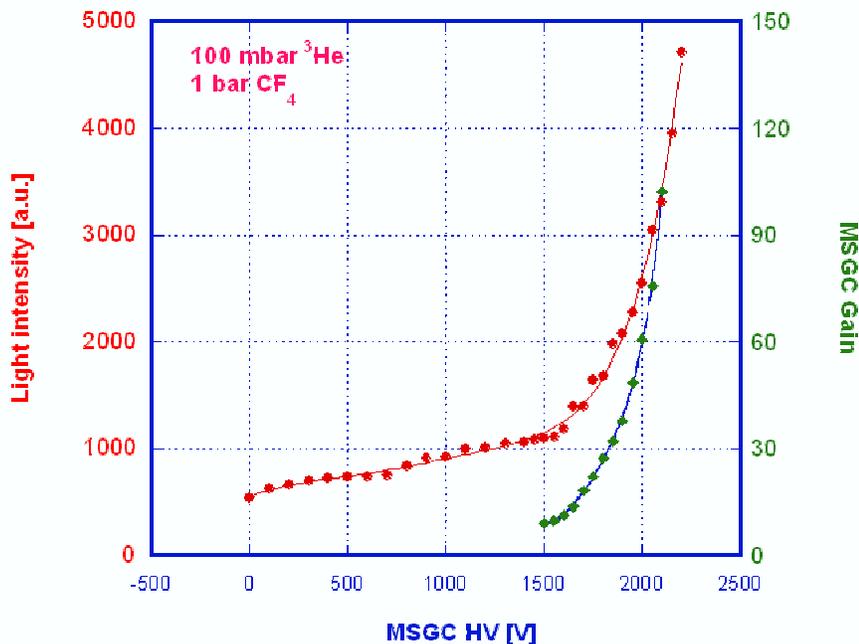


Fig. 13. Light intensity and MSGC charge gain as a function of the MSGC high voltage.

emitted in the gas volume well before avalanche multiplication takes place in the detector, in fact even when no high voltage is applied to the MSGC. This means that the interaction of the charged particles generated by the neutron absorption in the gas volume is enough to produce photons and their number is sufficient for the signal to be seen by the CCD camera in a relatively short acquisition time of 20 seconds. The same effect can be observed in the recorded CCD images; Figure 14 shows the slit image obtained with no high voltage applied to the MSGC and the horizontal projection of the 2D image. The edges of the image are rather well defined and the light emission uniform across the slit. Applying a high voltage of 2700 V to the MSGC, we can observe from Figure 15 that of course the number of collected photons is much higher for the same acquisition time and also that the anodes structure is now easily visible. This is explained with the fact that the avalanche electron multiplication takes place in the immediate vicinity of the anodes strips so this is also the location of the maximum light emission. The image with the high voltage on on the MSGC plate clearly shows that the system is easily able to resolve light sources

inside the detector as close as 1 mm. This suggests that by using a structure with a finer pitch it would be possible to obtain a better position resolution.

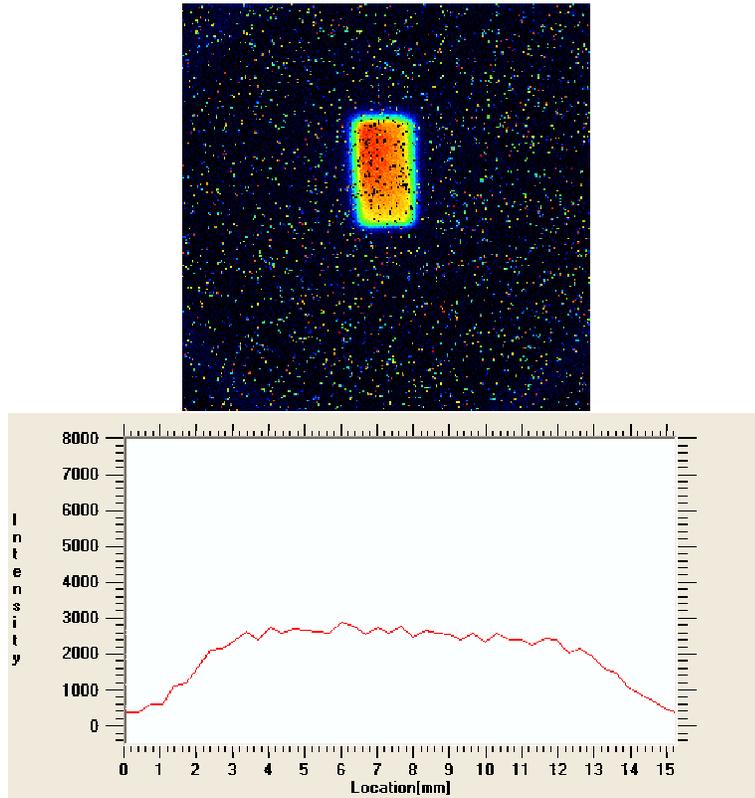


Fig. 14. Image of the light emitted by the GSPC irradiated through a $1 \times 2 \text{ cm}^2$ Cadmium slit when no high voltage is applied to the MSGC electrodes and the horizontal projection of the image.

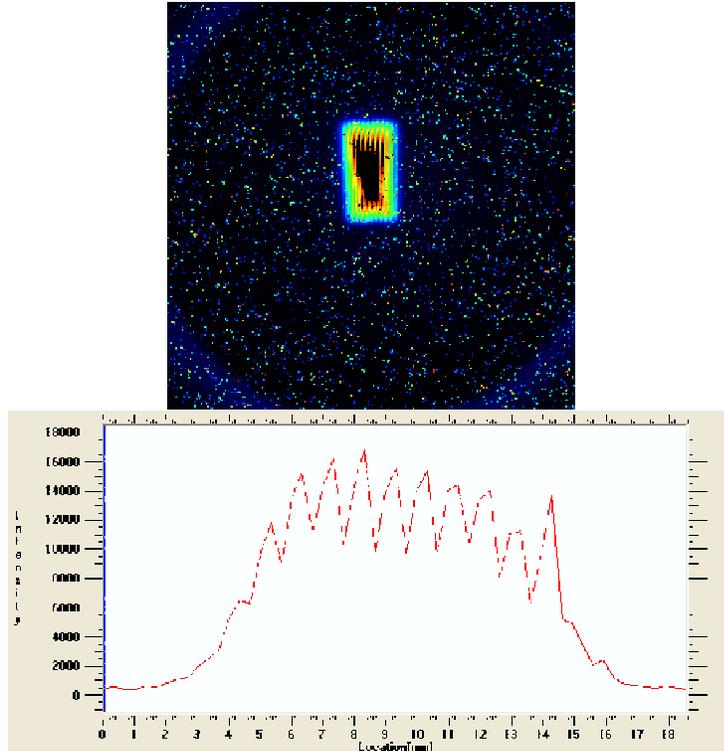


Fig. 15. Image of the light emitted by the GSPC irradiated through a $1 \times 2 \text{ cm}^2$ Cadmium slit with a high voltage of 2700 V applied to the MSGC electrodes and the horizontal projection of the image. The granularity of the plate is now visible.

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