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Characterization of THGEM coupled to submillimetric induction gaps in Ne/CH_4 and Ar/CH_4 mixtures

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Abstract: The coupling of a THGEM to an induction region having a thickness below 1 mm allows the application of intense induction electric fields, resulting in a more efficient extraction of the avalanche electrons into the anode electrode and the extension of the charge avalanche amplification into the induction region. In the present work, we investigate the performance of such configuration, operating in Ne-5% CH_4 and Ar-20% CH_4 mixtures, in terms of gain characteristics and energy resolution for 5.9 keV X-rays. Gains above 10^5 can be achieved in both mixtures without jeopardizing the energy resolution for induction gaps of 0.8 and 0.5 mm, while applying lower biasing voltages to the THGEM. We have demonstrated that it is possible to implement gas electron multiplier configurations having an effective reduction of its thickness and that high gains can be achieved in Ar-based mixtures having CH_4 concentrations as high as 20%. Ar based mixtures present higher ionization yields and lower electron diffusion coefficients, when compared to Ne-based ones.

Keywords: Charge transport and multiplication in gas; Electron multipliers (gas); Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc)

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Contents

1 Introduction

The electron multiplier configuration of a THGEM [1] coupled to a submillimetric induction gap was recently proposed [2]. The characteristics of such configuration have been investigated in Ne/CF$_4$ (95:5) atmosphere and it was possible to reach gains similar to those achieved with a double-THGEM configuration operating in the same gas mixture, but using lower biasing voltages. Compared to a double-THGEM cascade with a transfer and an induction regions of a few millimeters, the THGEM coupling to a submillimetric induction region allows a much more efficient extraction of the charge from the THGEM into a high-field induction region, where a second charge multiplication may occur, minimizing the loss of electrons to the THGEM's bottom electrode as well as to the top electrode of the second THGEM in the cascade (without transfer field optimization).

The results obtained for the THGEM coupled to a submillimetric induction gap operating in Ne-CF$_4$ mixtures have revealed the presence of photon-induced feedback effects. These effects are attributed to VUV photons production during electron multiplication when using CF$_4$. This imposes a limitation for the maximum gains that could be achieved in the THGEM and/or in the induction gap in those mixtures due to the onset of secondary effects induced by the unquenched VUV photons emitted from the electron avalanches. As CH$_4$ does not scintillate in the VUV or UV range, the above limitation is not present in Ne-CH$_4$ mixtures and, therefore, higher gains might be possible in these mixtures. In addition, Ar-based mixtures are preferable over Ne-based ones, e.g. for the detection of Minimum Ionizing Particles (MIPs), since they present higher ionization yields and lower electron diffusion, leading to improved signal to noise ratios. On the other hand, the higher voltages required for THGEM operation in Ar to achieve comparable gains when using Ne-based mixtures [3] are a drawback. However, it is possible to circumvent this problem by coupling the THGEM to a submillimetric induction gap and using the charge multiplication in the THGEM holes as well as in the induction gap to obtain high gains.

The THGEM coupled to a submillimetric induction gap may be an interesting solution for producing thin sampling elements in Digital Hadronic Calorimeters (DHCAL), as envisaged by the CALICE collaboration for future linear collider, either the International Linear Collider (ILC) or the Compact Linear Collider (CLIC) [4, 5]. Comparing to the recently proposed RPWELL [6], a single-sided copper-clad THGEM electrode, coupled to a readout anode through a high bulk resistivity plate, the THGEM-submillimetric induction gap solution may present a simpler and more cost effective alternative for applications requiring economic solutions at moderate spatial and energy resolutions, having higher gains and faster signal readout avoiding the use of the resistive plate.

Therefore, it is important to investigate the performance of THGEMs coupled to submillimetric induction gaps. In this work, we investigated the THGEM coupled to a submillimetric induction region operating in Ne/CH_4 mixtures and Ar/CH_4 mixtures.

2 Experimental setup

The experimental setup, shown in figure 1, consists in a single THGEM assembled within nylon pillars, coupled to an induction gap which was varied from 0.5 mm to 0.8 mm. The detector was irradiated through a 75 μm thick Kapton window with 5.9 keV X-rays from a ^{55}Fe source, collimated to 1.5 mm — with drift field below $\sim$ 0.5 kV/cm the average counting rate on the detector was $\sim$ 400 Hz. The radiation conversion region above the THGEM was fixed at 15 mm. The THGEMs used had an active area of 20 × 20 mm^2 and the following geometrical parameters: 0.4 mm thick G-10 with 0.02 mm thick copper clad on both sides, cylindrical holes of 0.3 mm diameter arranged in a hexagonal pattern with 1 mm pitch and an etched rim around holes of 0.1 mm. The anode was composed of a square shaped, full copper layer on a G10 substrate. The measurements were performed in pulse mode with an electronic chain which consisted of a Canberra charge sensitive preamplifier model 2004 (measured sensitivity of 19.2 mV/pC) followed by an Ortec 570 linear amplifier and an Ortec Maestro multi-channel analyzer.

The chamber was vacuum pumped down to $\sim 10^{-5}$ mbar prior to filling with the desired gas mixture at 1.1 bar. The gases used were research grade Ne 4.0 (Ne 99.990%), Ar 5.0 (Ar 99.999%) and CH_4 4.5 (CH_4 99.995%).

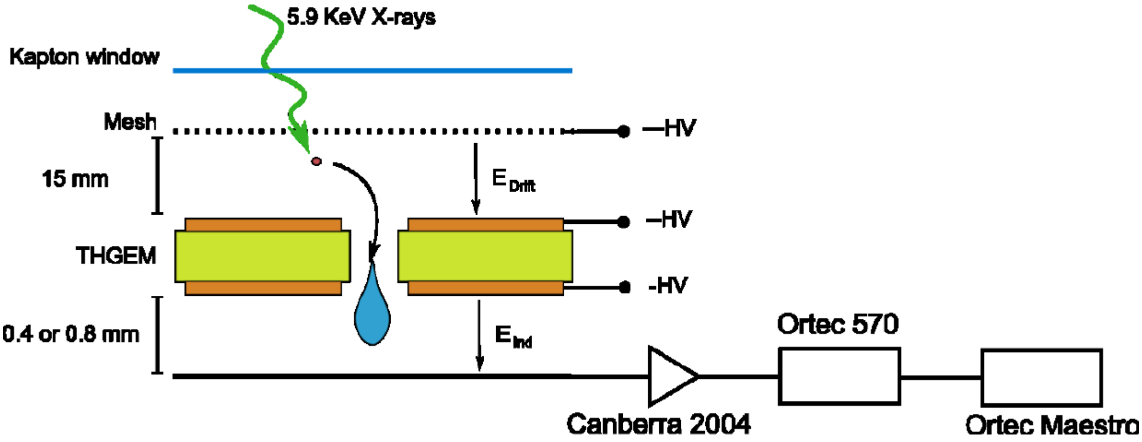

Figure 1. Schematic of the experimental setup used for gain determination, highlighting applied bias, the THGEM used with induction region and the electronic chain.

3 Results and discussion

3.1 0.8 mm induction gap

Figure 2 shows the avalanche charge gains achieved in this work with a THGEM coupled to a 0.8 mm induction gap, as a function of the THGEM voltage for different electric fields applied to the induction gap. As can be seen, the presence of high electric fields in the induction gap permits higher gains with lower applied voltages to the THGEM. By utilizing the additional gain contribution from the induction gap, the resultant gains were almost a factor of ten higher when compared to the gains achieved from the THGEM holes alone. We have demonstrated that gains in excess of 10^5 were possible by exploiting the submillimetric gap. Ar-20% CH_4 reaches gains that are only a factor of two lower than those obtained in Ne-5% CH_4. These latter gains are almost a factor of five higher than the maximal achievable gain for the RPWELL (with 0.6 mm Semitron) in [6], with comparable detector area and geometry. While for Ne-5% CH_4 mixture the effect of photon feedback seems to be present at the higher voltages, it is not present in the case of Ar-20% CH_4 — except for the highest applied induction field. This effect can be seen by the deviation from the purely exponential gain increase on the highest applied voltages.

As shown in figure 2, the total voltage applied in Ar-20% CH_4 is about 1000 V, while for Ne-5% CH_4 it is still below 400 V. These voltages are lower than those applied to the RPWELL, ~ 1700 and ~ 950 V for Ar-5%CH_4 and Ne-5%CH_4, respectively [6, 7]. Nevertheless, high gains are achieved in the present work as the charge avalanche in a standard THGEM extends somewhat out of the holes into the induction region [1], in opposition to that in WELL-type geometry where the avalanche is forced to stop at the very bottom of the holes. Even though in WELL-type detectors the avalanche electrons are subject to a higher field than in the induction-gap structure [8], the region available for avalanche development is confined by the bottom of the holes while in the present geometry, the presence of an extended multiplication region in the form of a high field applied in the sub-millimetric induction gap [2], circumvents this limitation.

While in the Ar-based RPWELL studies CH_4 concentrations of 5% have been used [3, 5], the present work shows that for the THGEM coupled to a submillimetric induction gap it is possible to attain charge gains above 10^5 even for CH_4 concentrations as high as 20%.

Figure 3 depicts the energy resolution for 5.9 keV X-rays obtained with the THGEM coupled to the 0.8 mm induction gap as a function of the THGEM voltage and for different electric fields applied to the induction gap. For Ne-5% CH_4 mixture a degradation of the energy resolution occurs with the presence of charge multiplication in the induction region. We note that while for Ne-5%-CH_4 the threshold for charge multiplication is around 0.5 kV/cm [9], for pure Ar this value is about 3 kV/cm/bar [10, 11] and, therefore, for Ar-20% CH_4 mixture a significant charge multiplication is not achieved in the induction gap, even for the higher fields applied to this region. This results in a small dependence of the observed energy resolution on the induction electric field and justifies the absence of photon feedback effects. While the degradation of the energy resolution for the higher THGEM biasing voltages in Ne-CH_4 is due to the onset of the photon-feedback processes and to the much larger intensity of the electric field inside the holes, which results in the loss of some of the avalanche electrons to the THGEM bottom electrode, for the Ar-CH_4 mixture only the latter effect is present.

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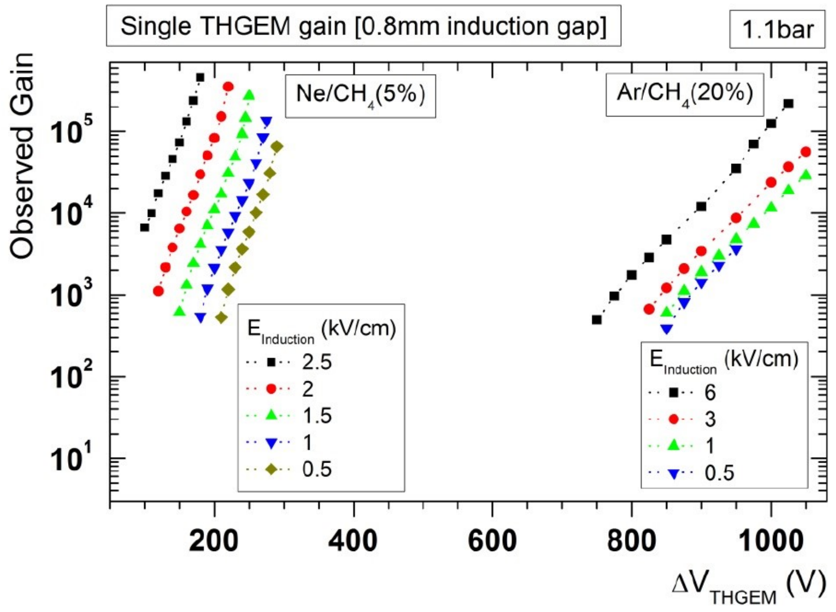

Figure 2. Observed gain as a function voltage difference across a THGEM electrode in Ne/CH$_4$(5%) and in Ar/CH$_4$(20%) with a single-stage THGEM coupled to a 0.8 mm induction gap, as a function of the voltage difference applied to the THGEM electrode for several values of induction field. The dotted lines serve as eye guides.

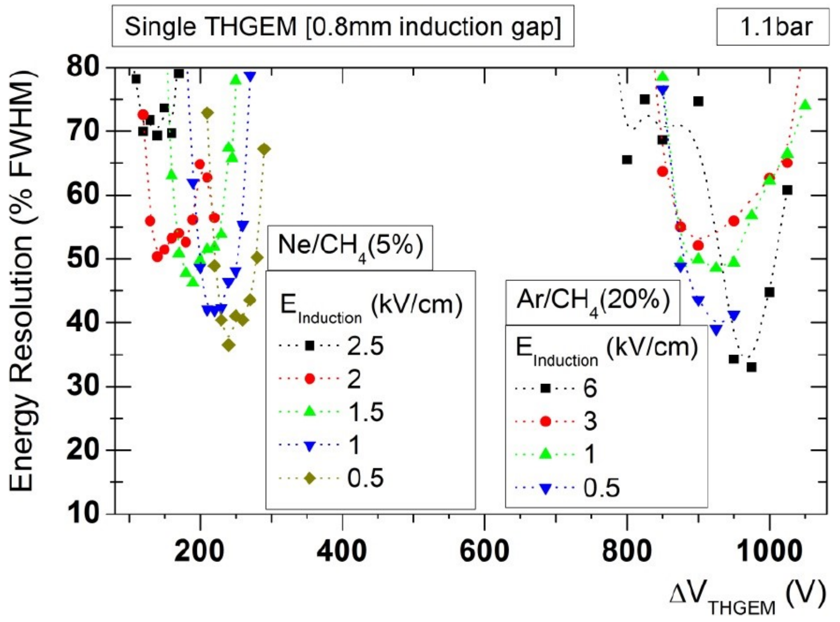

Figure 3. Energy resolution (as % of FWHM) as a function of voltage difference across a THGEM electrode for 5.9 keV X-rays obtained with a single-stage THGEM coupled to a 0.8 mm induction gap, in Ne/CH$_4$(5%) and in Ar/CH$_4$(20%), for several values of induction field. The dotted lines serve as eye guides.

Figure 4 depicts the avalanche gains as a function of the electric field intensity in the induction gap, for several values of voltage differences applied to the THGEM electrodes and for the Ne-CH$_4$

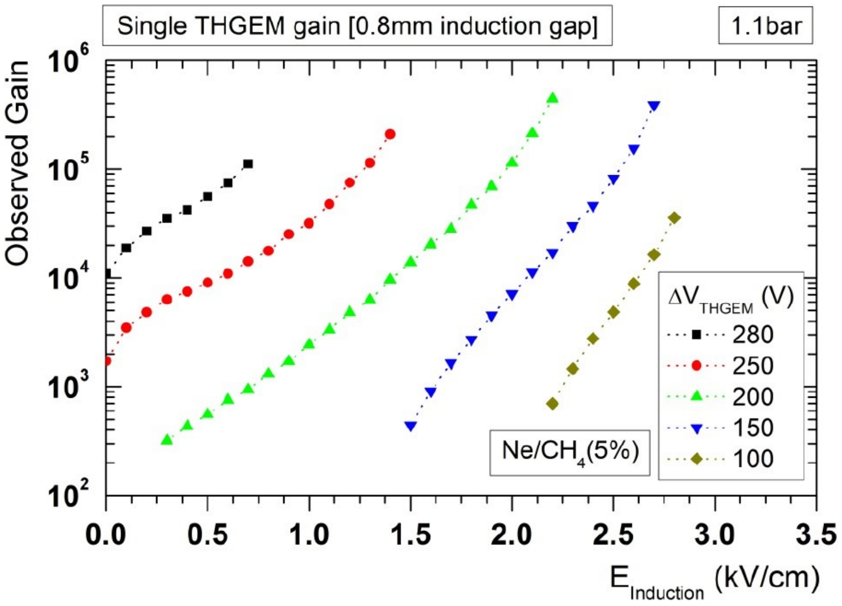

Figure 4. Observed gain in Ne/CH_4(5%) with a single-stage THGEM coupled to a 0.8 mm induction gap, as a function of the induction field for several values voltage applied to the THGEM electrode. The dotted lines serve as eye guides.

mixture. Figure 5 presents the energy resolution obtained with the THGEM coupled to a 0.8 mm induction gap as a function of the gain, as obtained with the data taken for figure 4. The improvement of the energy resolution from 100 V to 150 V applied on the THGEM electrode can be explained by the increase of the electron collection efficiency as the field inside the THGEM holes increases relative to the drift field, while the degradation followed by improvement from 200 V to 280 V can be explained by the de-confinement of the avalanche at high induction fields out of the THGEMs holes into the induction region, followed by re-confinement as the induction field is reduced for higher THGEM voltages, at the same gain. Gains of 10^5 are possible without a significant degradation of the energy resolution. Figure 4 also shows that the maximum induced electric field that can be set to the induction region is about 2.8 kV/cm, for values above this threshold discharges occur in the induction field due to the positive photon feedback.

3.2 0.5 mm induction gap

In figure 6 and in figure 7, we present the same data as it was presented in figure 2 and in figure 3 but for an induction gap of 0.5 mm thick, instead of 0.8 mm. It can be seen that almost the same gains are achievable with the smaller induction gap thickness. This may present an advantage for the R&D that is being carried out to develop a thin element for the DHCAL calorimeter, since the induction gap can be reduced from 1 to 0.5 mm without sacrificing the gain that is possible to achieve, while also using lower applied voltages. The dependence of the energy resolution on the induction field for a 0.8 mm gap as opposed to a 0.5 mm gap in Ne/CH4(5%) can be explained by a significant avalanche extension into the larger induction region at high induction fields associated to a combination of: 1) a larger electron diffusion (transverse and longitudinal) and 2) a stronger photon-feedback effect, contributing to a more significant degradation of the energy resolution.

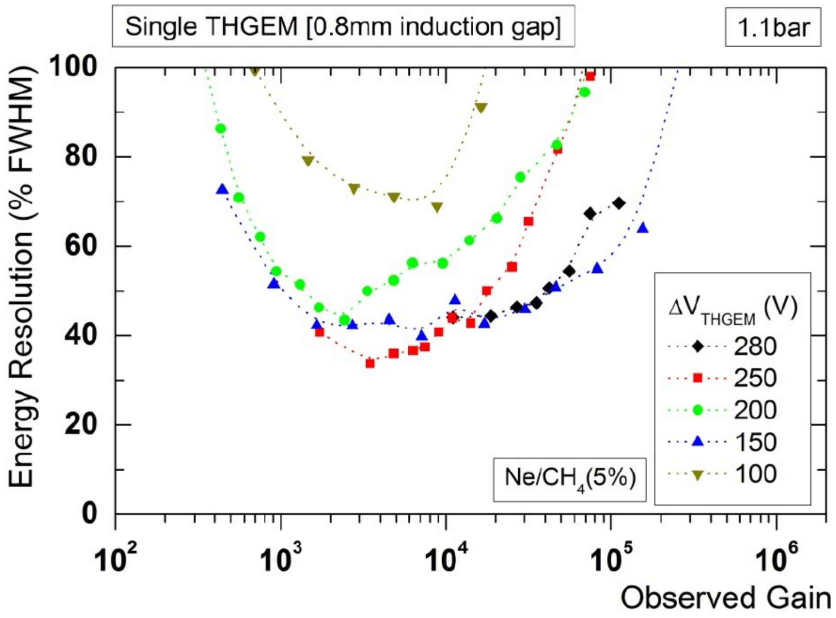

Figure 5. Energy resolution (as % of FWHM) for 5.9 keV X-rays as a function of observed gain for a single-stage THGEM coupled to a 0.8 mm gap in Ne/CH$_4$ (95:5). The dotted lines serve as eye guides. Each set corresponds to a constant voltage across the THGEM. The induction field was gradually increased.

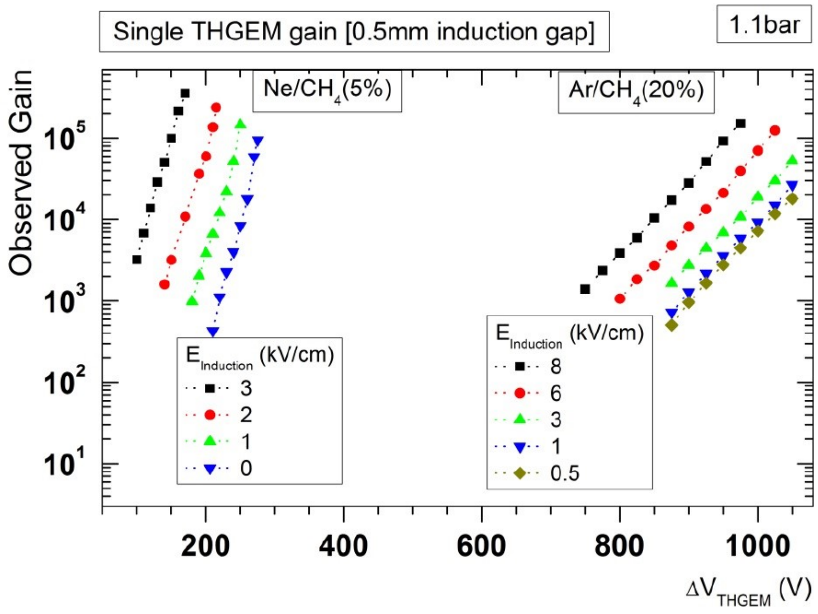

Figure 6. Observed gain in Ne/CH$_4$(5%) and in Ar/CH$_4$(20%) with a single-stage THGEM coupled to a 0.5 mm induction gap, as a function of the voltage difference applied to the THGEM electrodes for several values of induction field. The dotted lines serve as eye guides.

Figure 8 shows the charge avalanche gain as a function of the electric field applied to the 0.5 mm thick induction gap for several values of voltage differences applied to the THGEM electrodes and for several values voltage applied to the THGEM electrodes, operating in the Ne/CH$_4$ (95:5) and

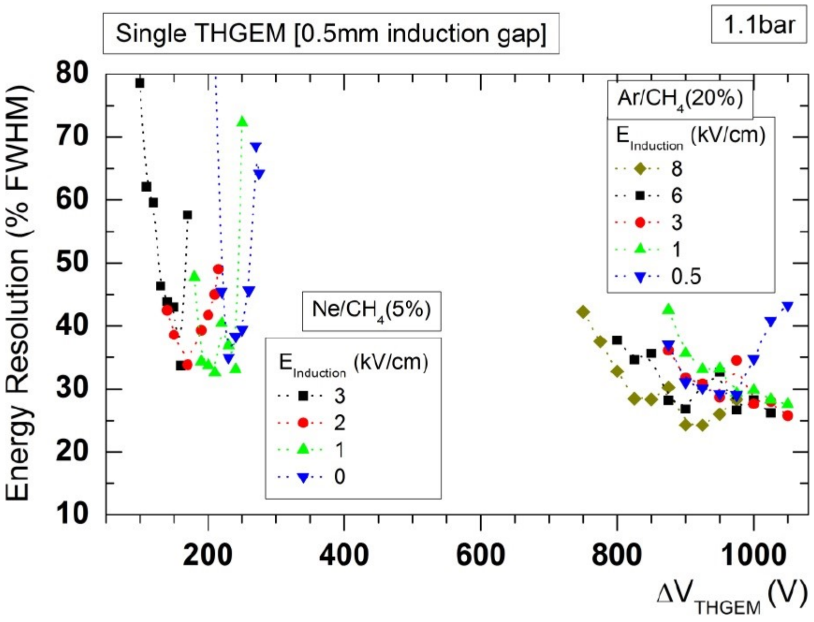

Figure 7. Energy resolution (as % of FWHM) as a function of voltage difference across a THGEM electrode for 5.9 keV X-rays obtained with a single-stage THGEM coupled to a 0.5 mm induction gap, in Ne/CH$_4$(5%) and in Ar/CH$_4$(20%), for several values of induction field. The dotted lines serve as eye guides.

Ar/CH$_4$ (80:20) gas mixtures. The respective energy resolutions obtained for 5.9 keV X-rays are depicted in figure 9 as a function of the gain, for the different electric field applied to the 0.5 mm thick induction gap.

Figure 8 shows that it is possible to use low voltages applied to the THGEM compensating with a corresponding increase in the voltage difference applied to the induction gap. For the Ar-20%CH$_4$ mixture it is possible to set induction fields as high as 16 kV/cm without having photon-feedback effects, due to the strong quenching effect of the 20% CH$_4$ content. There is no significant difference in the energy resolutions observed for both mixtures. With both mixtures it is possible to achieve gains in excess of 10^5 without having a significant degradation on the energy resolution.

4 Summary and conclusions

An investigation of THGEM coupled to a submillimetric induction region operating in Ne/CH$_4$ mixtures and Ar/CH$_4$ mixtures, was performed. The results obtained in these studies have shown important issues:

1) In contrast to the Ne-CF$_4$ mixtures studied previously [2], the Ne-CH$_4$ mixture with an effective UV quenching capability studied in this work, enabled higher charge gains in stable operating conditions.

2) In contrast to results using Ne-CF$_4$ mixtures, with a 0.5 mm thick induction gap it was possible to achieve similar charge gains to those achieved in the 0.8 mm thick induction gaps using Ar-CH$_4$ or Ne-CH$_4$ mixtures. Therefore, it is possible to implement an effective reduction

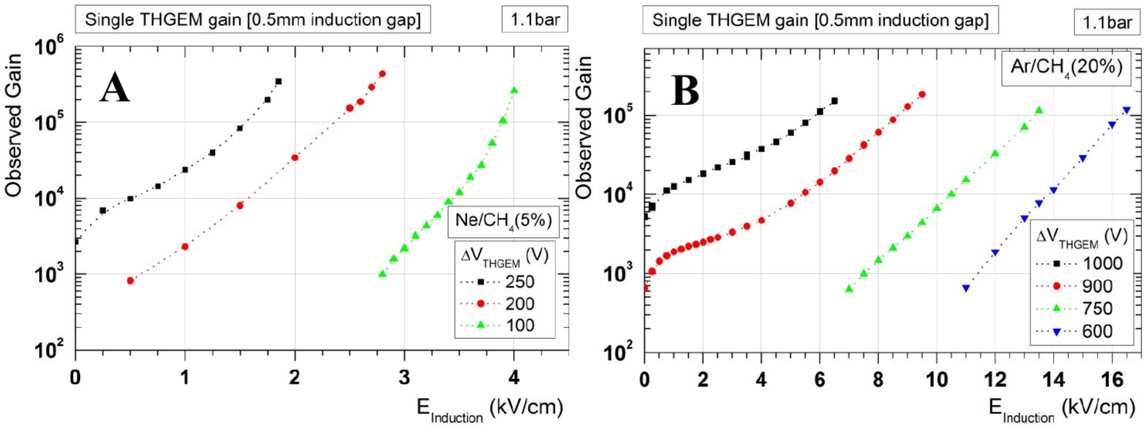

Figure 8. Observed gain in Ne/CH4(95:5), A, and in Ar/CH4(80:20), B, with a single-stage THGEM coupled to a 0.5 mm induction gap, as a function of the induction field for several values voltage applied to the THGEM electrode. The dotted lines serve as eye guides.

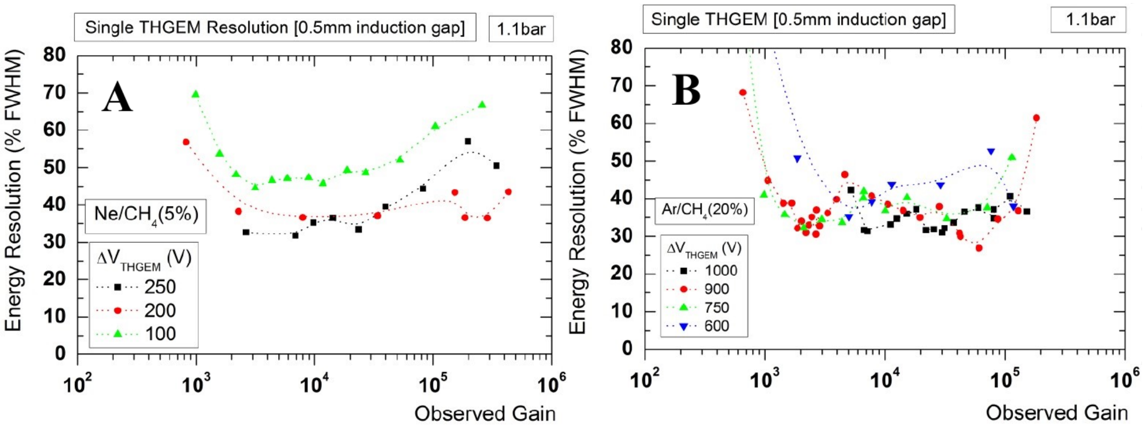

Figure 9. Energy resolution (as % of FWHM) for 5.9 keV X-rays as a function of observed gain for a single-stage THGEM coupled to a 0.5 mm gap in Ne/CH4 (95:5), A, and in Ar/CH4 (80:20), B. Each set corresponds to a constant voltage across the THGEM. The induction field was gradually increased. The dotted lines serve as eye guides.

of the thickness of the thin elements to be developed for the calorimeter for the ILC, using a single THGEM coupled to an induction gap as low as 0.5 mm.

3) We have shown that it is possible to use Ar-CH$_4$ mixtures having CH$_4$ content as high as 20% achieving charge gains above 10^5.

4) Using a submillimetre induction gap coupled to a THGEM operating in Ar-20%CH$_4$ mixtures, it is possible to achieve gains that are only a factor < 5 lower than those achieved with Ne-5%CH$_4$ mixtures. This is very important for improving the SNR in the detection of MIPs as Ar-based mixtures present higher ionization yields and lower electron diffusion coefficients, when compared to Ne-based mixtures, thus making them attractive for thin element applications for the future ILC.

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