Micromegas-TPC development for rare event detection

L Ounalli, J-M Vuilleumier, D Schenker, J-L Vuilleumier
Department of Corpuscular Physics, University of Neuchâtel, A.-L Breguet 1, CH.
E-mail: leila.ounalli@unine.ch

Abstract. We present some important results related to Micromegas-TPC development for rare event detection:
First, we show the influence of the detection plane structure on the energy resolution, where, replacing the wires planes (MWPC) by the Micromegas micropattern, gave a high collection efficiency with good uniformity and good energy resolution.
Second, we prove that the increase of the height of the amplification zone permits a good charge collection at higher gas pressure.
Third, we present a new gas mixture "Xe(98)CF₄(2)", which is convenient for the search of neutrinoless double beta decay in $^{136}$Xe.
Forth, large size Micromegas, with 50 cm of diameter is operated in the Gotthard-TPC (200 l) and showed high efficiency and good energy resolution with low energy sources.

1. Introduction
Solar neutrinos, double beta decay and dark matter, are experiments with very low events rate and low energy threshold. Thus, there are some restrictive conditions for these rare event detections: we need large detector masses to insure better containment of interactions and reasonable event rate. In the case of gaseous detectors high pressure is required. Moreover, the energy resolution must be good. In the case of the double beta decay it allows a distinction of the "0νββ" mode from the "2νββ". This is why we study this important parameter. In addition, the search for tiny signals (dark matter), requires higher gains. This is why we are also interested to this crucial factor.
For these reasons, we investigated the performance of a Micromegas-TPC detector filled with Xe-CF₄ gas mixtures.

2. Detector description
We used a Time Projection Chamber (TPC) with a Micromegas [1] detection plane, called "Micromegas-TPC". A miniTPC (20 l), with a 18 cm drift length and 9 cm detection area, is installed in the basement of the Neuchâtel laboratory, to study electron transport properties in Xe-CF₄ gas mixtures and to develop Micromegas techniques in order to achieve higher gains with good uniformity and energy resolution. This prototype was used initially to study the transport properties in CF₄ gas in a "long drift volume", using a MWPC as a detection plane, in view of the MUNU experiment [5]. It was also used to study the performance of a Micromegas using a woven wire mesh as a grid in pure CF₄ gas, compared with a nickel grid [2].
Figure 1. Photographic view of the detection plane (left) and a microscopic zoom on one spacer (right). The diameter of the spacer is 250 µm.

A second TPC, with about 70 cm of drift length, which is the old detector of the $^{136}\text{Xe}$ double beta decay search in the underground Gotthard laboratory [3], is also used to test the efficiency of the largest Micromegas with 50 cm of diameter.

The detection plane is a Micromegas. The anode and the grid, separated by spacers, are compacted "two in one" as it is shown in figure 1. It is also called a "compact" Micromegas [4]. The full anode with spacers was developed by the CERN surface treatment service and the grid was tensed delicately. The anode is a continuous copper plane with cylindrical pin spacers. These spacers are formed with kapton, placed every 1 mm and their height defines the amplification gap dimension. The grid is made of stainless steel wires with 20 µm of diameter, woven with a 53 µm spacing. This grid is cheap, easy to handle, robust, with low radioactivity (no chemical etching), and it can be obtained in large sizes ($2.5 \times 30.5$ m$^2$).

3. Why we replace the MWPC by a Micromegas micropattern?

The advantage of a Micromegas micropattern compared to the wires in the MWPC is robustness and simpler geometry. This insures gain uniformity and good energy resolution.

Figure 2. $^{55}\text{Fe}$ pulse height spectrum with MWPC wires (left), extracted from reference [5], and with Micromegas detection plane (right) tested in the mini-TPC at 1 bar of CF$_4$ pressure.
A comparison between these two detection planes is given in figure 2, with the same chamber (miniTPC) and tested at the same conditions (pressure, settings ...). Replacing the MWPC detection plane by the Micromegas one improves the energy resolution by a factor 1.3 at 6 KeV. Energy resolutions are 50 and 37 %, respectively.

A second advantage is that we have less mass using the compact detection plane than the MWPC (no bulky frame), which leads to low radioactivity and thus, low contribution to the background. In addition, the electric field near the anode in the case of the Micromegas structure is very homogenous. On the other hand, the equipotentials are almost circular in the case of the MWPC wires. The field lines near the anode wires bend toward the wires and the charges are drawn towards the anode wire. This phenomena worsens the energy resolution and degrades the efficiency of the detector.

4. How to operate the Micromegas-TPC at higher pressures?

Since the drift distance is chosen long enough to go up to higher detector volumes, gap dimensions are also studied to select the best suited one. Good energy resolution and highest pressure are the most important parameters. This is why we have studied the dependence of the gas gain and the pulse height resolution of the Micromegas detector as a function of various gaps. Two different gaps were investigated: 75 and 225 µm at various gas pressures extending from 1 bar to the highest achieved pressure. Figure 3 shows measurements of the gas gain versus the grid potential obtained for the P10 (Ar(90)CH₄(10)) gas at different pressures: (1, 2, 3) bar for 75 µm and (1, 2, 3, 4) bar for 225 µm gaps.

![Figure 3](image)

**Figure 3.** Gas gains measured in P10 gas, with 75 µm (▲) and 225 µm (⋆) gap heights in different pressures as a function of the grid voltage, using a $^{55}$Fe source.

With a reasonable gap value (225 µm), gas gains greater than $10^4$ are comfortably achievable.
The maxim
um gain in each curve corresponds roughly to the maximum stable operating points, which is the limit for discharges. A remarkable fact is that, the maximum achieved gas gain drops with pressure. The same effect was observed with a triple-GEM detector [6, 7], operated at different pressures of argon, krypton and xenon.

The collection efficiency is higher with 75 μm gap, but the working region is smaller and we can reach the same gain as with a higher gap with a lower applied voltage. With a 225 μm gap, much higher voltages are needed to reach the same gain obtained by 75 μm, but the working region is larger. If we go up to higher gaps, we decrease the relative gap variations over the entire height. We insure gain uniformity in the avalanche region and we can achieve larger detection plane surfaces. This was our argument to choose this gap dimension for the Gotthard-TPC detector.

5. Xe(98)CF$_4$(2) is the best for double beta decay search in $^{136}$Xe

The gas medium is one of the most important components, determining good electron drift. The choice of the gas is therefore crucial to obtain a high amplification and a good energy resolution. In the framework of the EXO [8] collaboration, we studied the charge collection in Xe gas and electron transport properties, seeking a suitable gas mixture for neutrinoless double beta decay in $^{136}$Xe, if the gas version is chosen.

![Figure 4](image_url)

**Figure 4.** Pulse height spectra in the grid, measured in Xe(98)CF$_4$(2) admixture at approximately the same gas gains at 1 bar (left) and 3 bar (right) with 225 μm gap.

The miniTPC was filled with Xe(98)CF$_4$(2) and the $^{55}$Fe source was replaced with an $^{241}$Am one faced to the cathode, with 37 kBq of activity.

Spectra presented in figure 4, show the performance of the Micromegas structure operated in Xe(98)CF$_4$(2) mixture at 1 (left) and 3 bar (right) pressures. The Cu-activation (8.05 keV) and the Xe-K$_\alpha$ transition (29.779 keV) are clearly separated with the energy resolutions 63.5% and 19.65% at 1 bar. The Np-L$_\alpha$ (13.944 keV) and Np-L$_\beta$ (17.75 keV) fluorescence from the source are merged, because their energies are close and energy resolution is not good enough to distinguish them.

The dependence of the gas amplification and the energy resolution of the Micromegas-miniTPC filled with Xe(98)CF$_4$(2) on the grid voltage at pressures from 1 to 4 bar are shown in Figure 5. Gas amplification versus the grid voltage showed the stability of the detector. The grid voltage
increases with the pressure and charge collection is less favored at 4 bar with a moderate energy resolution (about 50% at 30 keV) and a very small working region. Obviously, measurements are done at the same conditions including the time of purification: 1 day for each pressure, which is not optimized for a dense medium. Circulating longer time at higher pressure and increasing the opening of the grid, lead to better charge collection with wide working region and make it possible to work at even higher pressure. Moreover, the tracking capability of the MUNU detector and the good results obtained with the CF$_4$ gas (the best limit of the electron neutrino magnetic moment [9]), encouraged us to optimize the TPC detector by reducing the CF$_4$ attachment. This gas could be used for solar neutrinos and dark matter search. Results related to this field are subject of a future paper.

6. Energy calibration of the Gotthard-TPC in CF$_4$ gas

Results presented above, are encouraging to elaborate a large scale Micromegas detection plane with 50 cm of diameter or more. The largest operating Micromegas until now is mounted in the COMPASS [10] experiment (40 $\times$ 40 cm$^2$).

The Gotthard-TPC was filled with CF$_4$ at atmospheric pressure because of its fastness. Two external gamma ray sources, $^{241}$Am and $^{133}$Ba with equal activities (370 KBq), are used to calibrate the TPC. They are placed outside, in a conic window. The $^{241}$Am source has a single $\gamma$-line at 59.5 keV and the $^{133}$Ba emits several $\gamma$-lines between 81 and 383.85 KeV. Spectra shown in figure 6, respectively for external $^{241}$Am and $^{133}$Ba sources added to an internal $^{241}$Am one (37 kBq), showed the good efficiency of the big Micromegas detection plane. The energy resolution at 59.5 keV is about 53.5% at 1 bar of CF$_4$. In addition, the Compton structure of the Ba source is seen in the right plot of the figure 6, with the 81 keV retrodiffusion gamma-line peak. The black spectrum in both plots represented the response of the detector with only the internal source. Better containment with the larger Micromegas is thus obvious.

Figure 5. Gas gain (left) and energy resolution (right) measurements in Xe(98)CF$_4$(2) at different pressure with 225 $\mu$m gap, using an $^{241}$Am source.
Figure 6. The effect of external $^{241}$Am (left) and $^{133}$Ba (right) sources, with 50 cm of Micromegas diameter at 1 bar of CF$_4$.

7. Conclusions
We described the performance of the Micromegas-TPC tested in view of the neutrinoless double beta decay search in $^{136}$Xe. On the other hand, we showed the good collection efficiency of the the Micromegas micropattern in a large scale in the CF$_4$ gas. Large TPC with small drift volume and filled with high pressure of the Xe(98)CF$_4$(2) admixture and with Micromegas readout plane is convenient for low rate medical imaging.

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