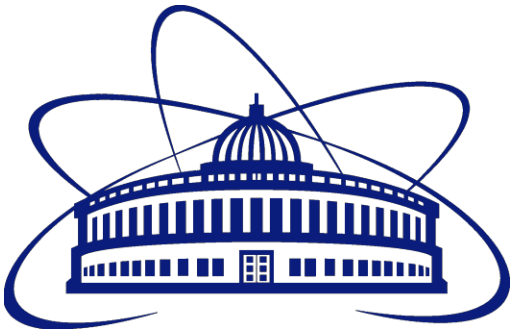

JOINT INSTITUTE FOR NUCLEAR RESEARCH

FINAL REPORT ON THE START PROGRAMME

Fabrication of micromegas chamber prototype and study of gas mixtures for micromegas-based central tracker for SPD experiment

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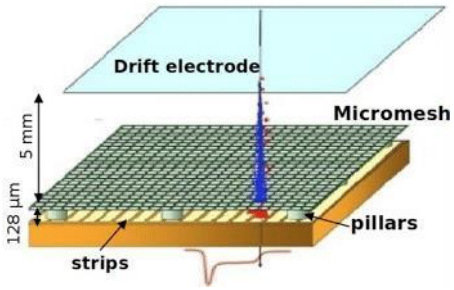
Abstract

Micromegas (MM) detector is a micropattern gaseous detector working on the principle of gas amplification which takes place in a thin gap ($\approx 100\ \mu m$) between readout anode and stretched metal mesh (or, micromesh) above it. When high electric field (10-70kV/cm) is applied across this gap, electrons from drift region focus in mesh holes and multiply in the amplification gap.

- Spatial resolution for MM detectors is better than $100\mu m$;
- Rates up to 100kHz/cm^2;
- Gas gain reaches 10^4 in Argon containing mixtures. Due to their good features, Bulk MM are already used at a various experiments such as CLAS 12, T2K, etc. It is planned to install Micromegas chambers to ATLAS NSW upgrade.



The purpose of our work was to compare the performance of the test micromegas chamber with 3 gas mixtures ArCO2 (93:7), ArCO2 (30:70), and ArCO2 - iC4H10 (91:7:2)

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Introduction

The working principle of most gaseous detectors is ionization: incoming radiation ionizes gas atoms (or molecules), creating electron-ion pairs. If a voltage difference is applied, electrons and ions do not recombine, rather they drift in opposite directions. During their drift electrons can acquire sufficient energy to further ionize the gas, giving birth to an "avalanche" charge multiplication. This net movement of charges induces, on proper readout electrodes, and electric signal that can be registered and recorded.

The purpose of our work was to compare the performance of the test micromegas chamber with 3 gas mixtures ArCO2 (93:7), ArCO2 (30:70), and ArCO2 - iC4H10 (91:7:2)

During the work, we took part in the gathering and installation of the detector components. Then we performed measurements with different ratios of ArCO2.

Gaseous Detector

The working principle of most gaseous detectors is ionization: incoming radiation ionizes gas atoms (or molecules), creating electron-ion pairs. If a voltage difference is applied, electrons and ions do not recombine, rather they drift in opposite directions. During their drift electrons can acquire sufficient energy to further ionize the gas, giving birth to an "avalanche" charge multiplication. This net movement of charges induces, on proper readout electrodes, and electric signal that can be registered and recorded.

The filling gas mixture in a ionization-based gaseous detector must meet some requirements, such as allowing high gains, low operating voltage, high rate capability. Operation at low voltages is addressed by choosing noble gases as main components of the mixture; among noble gases argon is often chosen. However in pure argon high gains can not be obtained: high energy excited states yield high energy γ which may induce discharges. In order to increase the gain, hence, it is necessary to add a quencher, a gas, such as CO2, for instance, which can absorb γ in non radiative processes. In order to further increase the gain it is possible to add a small amount of an electronegative gas, which can absorb γ and e –. Gaseous detectors have been intensively studied and produced because of the several advantages they provide. Nowadays, in order to meet different requirements in very different applications, a wide range of geometries has been studied and implemented.

MicroMegas

Micromegas (Fig. 1) is a gaseous parallel plate detector in which several innovative properties rely on a narrow amplification space, typically 50-100μm, between two parallel electrodes, the cathode and anode conducting plates. The cathode is made of a thin metallic micromesh, few microns thick, the anode microelements (strips or pads) of a conductor, printed on a insulator board. The technological challenge in such a detector is to keep the small gap constant over the active area.

The cathode-anode distance is kept by small insulating pillars, deposited by standard photographic methods on the anode or cathode, covering a small part (1%) of the surface. This technical solution permitted the construction, at low cost, of large chambers up to 40×40 cm^2 and can be extended to larger surfaces.

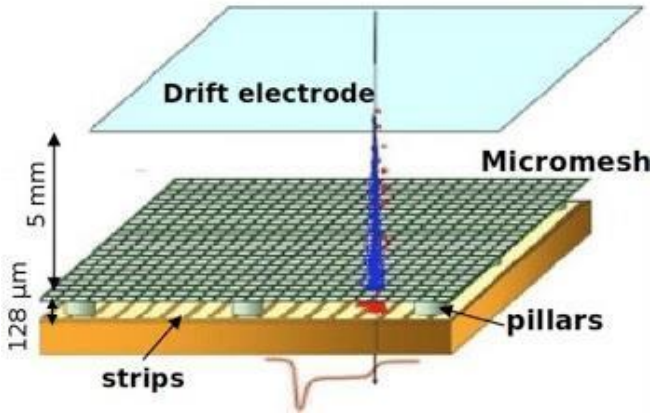

Figure 1. Schematic of a Micromegas detector

The signal on the anode strips or the cathode mesh is induced by the movement of the negative electrons towards the anode and the positive ions towards the cathode. The charge signal is mainly due to the positive ions drifting to the micromesh electrode, which takes place typically within 100 ns, depending on the width of the amplification gap and on the gas

mixture. Whereas, the fast current signal is mainly due to the electrons because of their higher mobility (about 100 times faster than the ions).

A consequence of the fast collection of the ions is that the whole induced signal can be catchet without loss due to ballistic electronic deficit and permits comfortable detection at quite moderate gains of the order of 10^3. The uniformity of the electric field allows the development of the avalanche is such a way that the fast signal induced by the electrons has a rise time of about 1 ns. So, the detection of signals induced by the electrons is within reach using fast current preamplifiers. One can observe a very fast rise in the signal due to the electrons drift, followed by a tail due to the ions drift. In most gaseous detectors, for instance the proportional counter, the detection of the signal due to the electron movement is much more difficult.

Due to the small pitch of the holes in the micromesh, the time dispersion in the path length of the different electron trajectories is very small. Therefore, the detector can provide an excellent time resolution. The transverse development of the induced signal is limited to a small area of the anode elements (extended to a width of the order of the amplification gap), it therefore can provide an excellent spatial resolution. Very high reachable gain allows the detection of signal electrons with a high efficiency, an exceptional property in the panel of the gaseous detectors.

Fabrication

One of the major advantages of Micro Pattern Gaseous Detectors is the industrial production of many components of the detector, which provides a cost-effective solution in many applications, especially when large sensitive surfaces are required. Readout anodes, for example, are often printed on fiberglass with standard industrial technique, reaching high precision at affordable prices. In our prototypes also high voltage distribution lines are printed on fiberglass, while pillars for suspending the mesh are carved out of a photoresitive film, using UV lithography technique. Fabrication of the prototypes is a multi stage process; at each step several parameters need to be chosen in order to optimize the final product. Parameters that need to be tuned are, for example, lamination temperature, UV exposure energy, definition of the cleaning procedure.

Figure 2. Fabrication chain at JINR DLNP. From left stretching machine, oven, laminator, UV insulator, etching machine

4.1 Lamination of the photoresistive film

Whichever building technology is chosen (bulk or floating mesh), the first step is the lamination of the photoresistive layer on the detector PCB. After chemical etching, in fact, it will form the pillars needed for suspending the mesh. The used phototresistive film is DuPont Pyralux 1025. It is a negative phototresist, which means that UV exposed parts will eventually become resistant to the chemical solution and will not be washed away. Photoresistive film is 64 μm thick; higher anode – mesh distances can be obtained by laminating more than one layer. In particular, most of the prototypes in this R&D programme have a 128 μm amplification gap, which means a double phototresistive layer. In JINR DLNP a C SUN CSL – M25E laminating machine is available. In order to get a optimal lamination, machine parameters have been finely tuned, resulting in a sort of standardized procedure. Before lamination, the PCB is preheated at 50◦ C. During lamination process, lamination roller temperature is set at 100◦ C, while hold down roller temperature at 50◦ C; the pressure between the two rollers is set at 3 kg/cm^2. Lamination speed is set at 1 m/min.

Figure 3. Lamination of a prototype at JINR DLNP

4.2 Mesh stretching

The micrometric metal mesh suspended above the readout plane is the heart of a Micromegas detector. Careful attention should be paid in mesh stretching operation, since small non uniformities might cause charge accumulation and, subsequently, discharges. The mesh chosen for prototype fabrication is made of woven stainless steel 18 μm diameter wires spaced by 45 μm. A stretching machine is available in JINR DLNP. As mentioned in the previous sections, different Micromegas technologies require different strategies for assembling the mesh electrode. For bulk Micromegas production, the mesh is stretched above a frame and glued with epoxy glue; measured tension must be around 10 ÷ 15 N/cm in both dimensions. The mesh is then laminated on the photoresist and a final, single, photoresistive film is laminated on top of it. The mesh is hence embedded in photoresistive layers. After pillar carving the mesh is cut and soldered on the amplification voltage pad. For floating mesh Micromegas production, instead, the mesh is glued on a metal frame with no needs for lamination; the mesh frame is eventually laid on top of the photolithographically carved pillars. However, some difficulties arise from the shape of the frame. In the floating mesh prototypes produced so far, the mesh frame has a flared cross section; mesh needs to be glued on the sloping side, in order to avoid possible non uniformities on the flat part due to a non uniform glue spreading. Hence mesh stretching requires a two-step process: mesh is first stretched and glued on a provisional frame, called transfer frame, with the help of the stretching machine. Later the mesh is glued on its proper frame using weights in order to let it perfectly adhere to the frame slope. Mesh is then cut and edges are polished with sandpaper, in order to prevent charge accumulation on spikes.

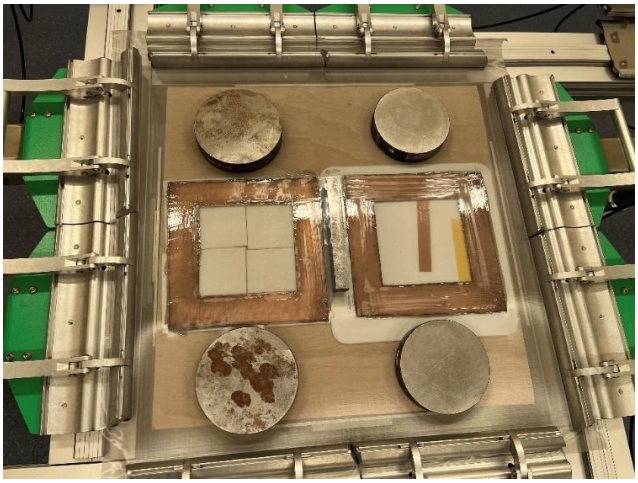

Figure 4. Mesh glued on its frame for a "floating mesh" prototype

4.3 UV exposure

As previously explained, photolitographic method for carving the pillars require a UV light exposure of the parts that will be resistant to the washing, i.e. the pillars themselves; a special mask is then needed. In JINR DLNP a C SUN UVE – M500 UV is available; it is equipped with a mercury vapour lamp. Power fine tuning has been a crucial step in technology development, since many problems may come from non uniform pillar shape. In fact, overexposure or underexposure of the photoresist film may lead to a non cylindrical shape of the pillars, enhancing dust accumulation. Chosen operating power is 0.2 mJ/cm^2 per layer, since it gives the best uniformity in pillar carving, according to microscope observation.

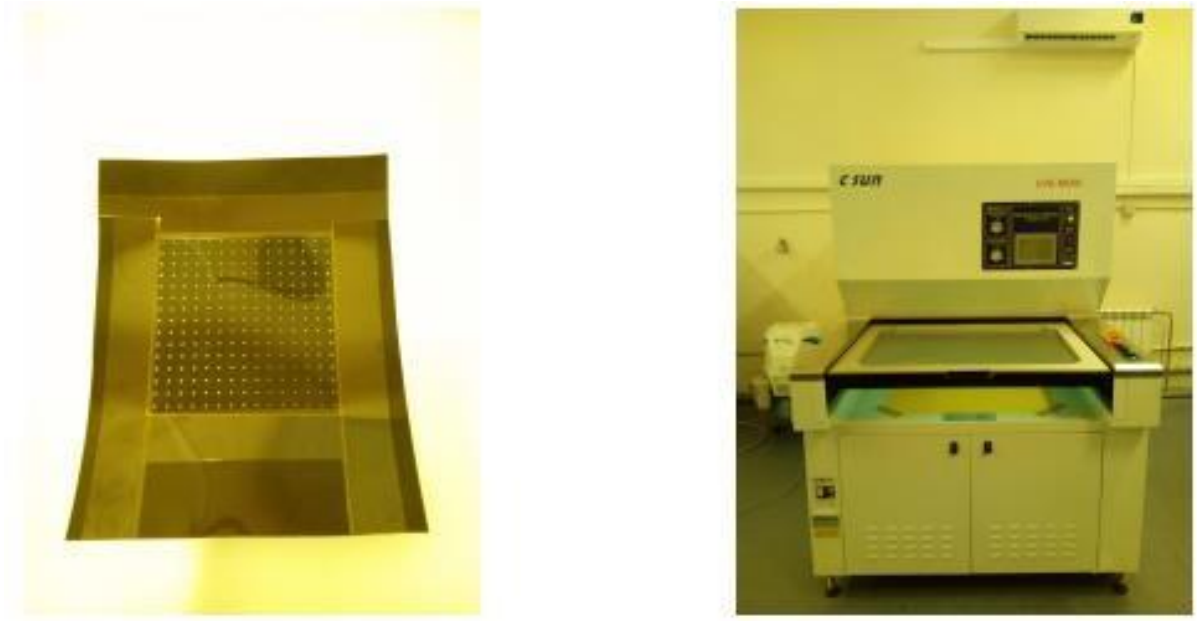

Figure 5. Left: mask used for pillar photolithography. Right: UV insulator.

4.4 Chemical etching

A Bungard Sprint 3000 is used for etching of the non exposed photoresistive material with a 1 % N a2CO3 solution. Chemical etching parameters have been carefully chosen; in order to obtain the best etching, according to observations, washing temperature must be around 23◦ ÷ 24◦ C and the speed around 0.2 ÷ 0.4 m/min. Higher speeds or lower concentrations may cause the presence of non etched areas, while lower speeds or higher concentrations may leave overetched areas. In both cases uniformity in the shape and dimension of the pillars is not ensured, causing a possible dust accumulation, which might lead to electrical discharges in an operating detector. As the non exposed film is etched, the detector is washed with deionized water and dried at the temperature of 140◦ C for four hours to cure photoresistive material.

4.5 Cleaning

Even though cleaning should be a major issue at every step of the fabrication chain, it is almost impossible to avoid dust or dirt accumulation during the whole process. Hence, a final deep cleaning is necessary in order to avoid discharge or excessive current flowing once the

detector is operating; obviously in case of floating mesh Micromegas both the PCB and the mesh must be cleaned. Cleaning procedure is the result of several years experience in detector fabrication. For the first cleaning a commercial detergent and warm tap water (30◦ ÷ 40◦ C) are used; in order to remove dust that may remain close to the pillars a brush is needed. Detergent is removed with tap water and then components are washed with high pressure (30 ÷ 40 atm) deionized water[2]. After drying at ∼ 40◦ C, a final dry cleaning is carried out with a dust cleaning roller.

4.6 Drift electrode mounting

The raw detector structure is completed by adding the so-called drift electrode, the electrode used for establishing the correct electric field in the conversion gap. It is made of a metal mesh stretched and glued on a frame connected to the power supply.

4.7 Assembling

Final step towards a working prototype is the assembling. Assembling of a bulk prototype requires to suspend drift electrode on glued screws by spacers and fixing it with nuts. A floating mesh prototype, on the other hand, is slightly more complicated, requiring to fix mesh frame first and drift electrode later. Fixing the mesh frame does not require extreme precision since mesh adherence to pillars is ensured by the electrostatic attraction exerted by the anode once a voltage difference is applied. On the PCB detector core holes are dug for placing the screws; those holes link the outer part of the detector with its inner part, where gas need to be contained. They can, thus, pose a problem in gas-tightness of the detector itself. Hence, careful attention has been paid in gluing the screws, ensuring that an epoxy glue ring leaves no room for gas leakage.

Gas Mixtures study

5.1 Research objective

For the Micromegas Cental Tracker SPD experiment to operate successfully, the gas mixture must provide

1) stable operation of the detector with gain $G=10^4$

2) the electron drift speed in the drift gap is at least 3 cm/μs

3) The Lorentz angle is no more than 15 o in a magnetic field B=1T.

Standard mixtures, such as Ar-CO2-iC4H10 with a fraction of CO2 and isobutane of 5-7% and 2%, respectively, have a Lorentz angle of over 40 ° with an optimal drift field of about 600 V/cm. The Lorentz angle can be reduced by raising the drift field to 2.5-3 kV/cm, but this will lead to a significant decrease in the charge collection efficiency. An interesting possibility is to use mixtures with a high CO2 content, for example Ar-CO2 (30%-70%), which has a very small Lorentz angle. The dependence of the drift velocity and the Lorentz angle for this mixture is shown in the figure.

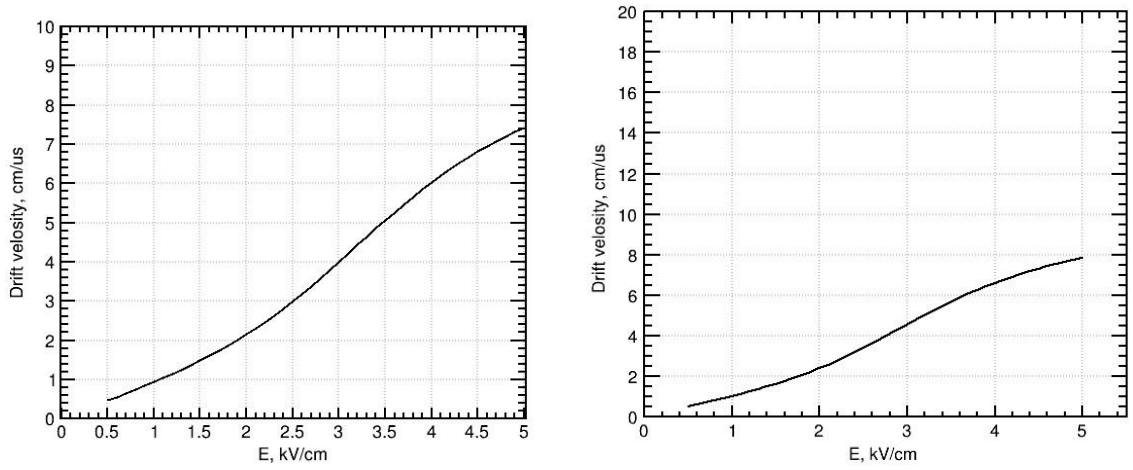

Figure 6. Dependence of energy on drift velocity

Unfortunately, this mixture was not used to operate microstructure detectors in experiments. The purpose of our work was to compare the performance of the test micromegas chamber with 3 gas mixtures $ArCO_2$ (93:7), $ArCO_2$ (30:70), and $ArCO_2$ - iC_4H_{10} (91:7:2)

5.2 Measurement procedure

For each gas mixture, the dependence of the charge collection efficiency on the drift field strength and the dependence of the gas gain on the operating voltage were measured and the maximum stable gas gain was determined.

For this purpose, the signal amplitude was measured when irradiated with a Fe55 gamma source. The gas gain was measured using an Fe^{55} source placed on top of the detector directly above the middle sense wire. The signal was output to an oscilloscope.
The 55Fe source produces monoenergetic x-rays at 5.9keV.
The average ionization energy for argon is 26eV. Then, for a 5.9keV photon which gives up all its energy to the detector 225 electrons are produced on average.
Using the measured charge Q and the primary charge produced by the photon, 225 × e with e =$1{,}6 \cdot 10^{-19}$C the charge of an electron, the gas gain is

$$G = \frac{q}{225 \cdot e}$$

Knowing the initial ionization and sensitivity of the amplifier, we can determine the value, where G is the gas gain and is the charge collection efficiency. For each gas mixture

- First, the dependence of the amplitude on the drift voltage was determined. Assuming that for the optimal voltage the charge collection efficiency is close to 1, we can assume that.
- Then, at the optimal value of the drift field, the dependence of the amplitude and, consequently, the gas gain on the operating voltage was measured

5.3 Calibration

To determine gas gain, we need to know the sensitivity of the amplifier. To calibrate the setup, a signal of a known charge was applied to the input of the amplifier.

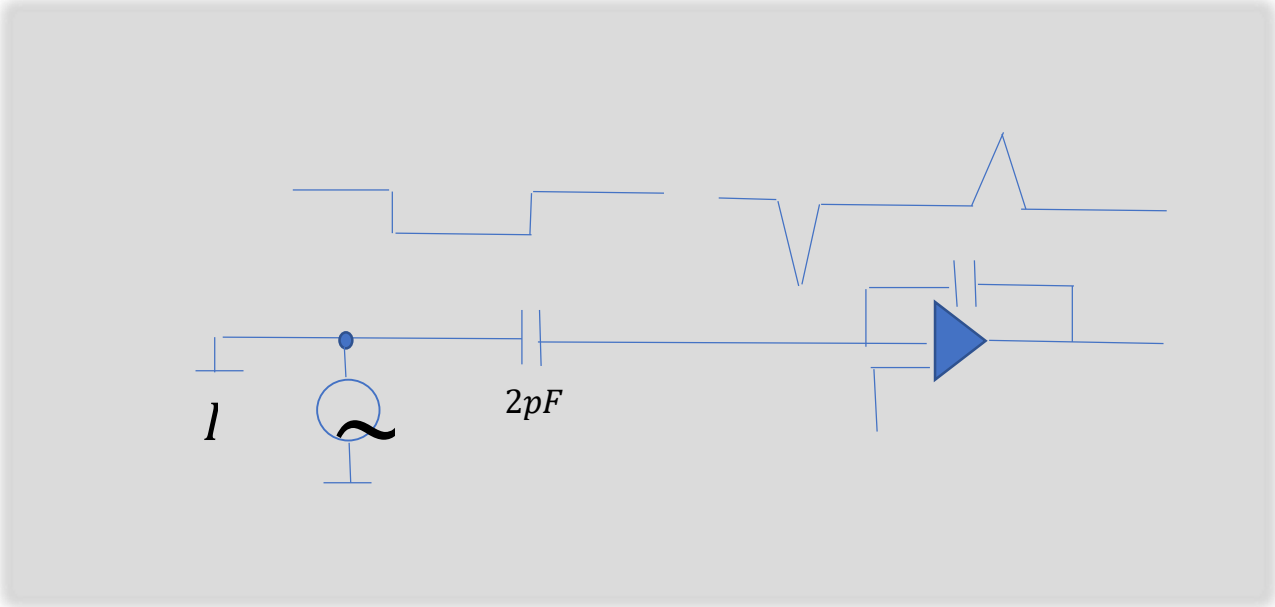

Figure 7. Calibration scheme

Knowing that the testing would be done using a Fe55 source that provides primary ionization of 225 e^- the result was immediately converted to "Gas enhancement as a function of apparent amplitude".

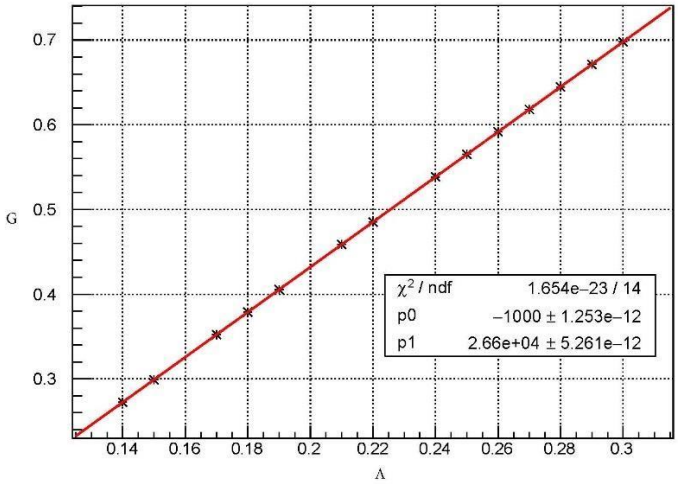

Figure 8. Dependence of gas gain on amplitude

Results

The restoring results are shown in the figures.

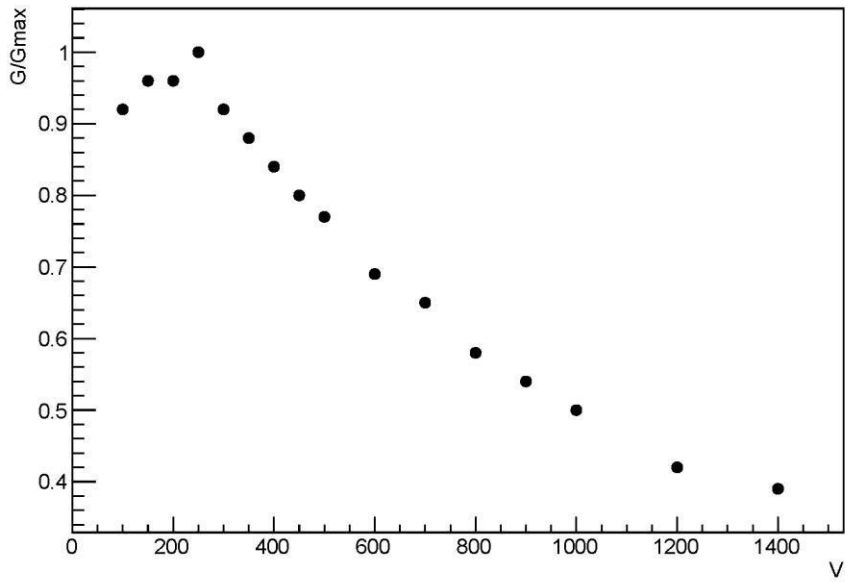

Figure 9. ArCO2 (93:7) dependence of gas gain on Vdrift

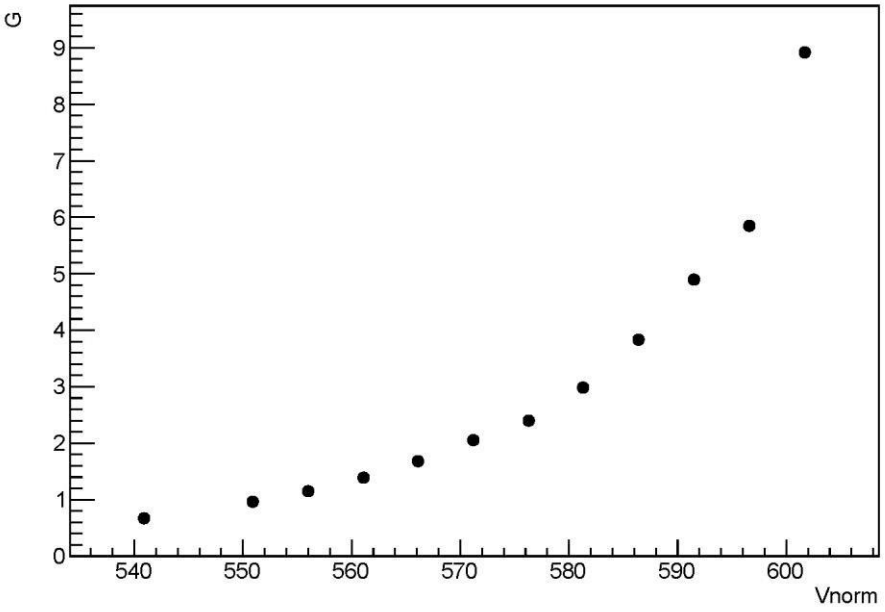

Figure 10. ArCO2 (93:7) dependence of gas gain on Vnorm

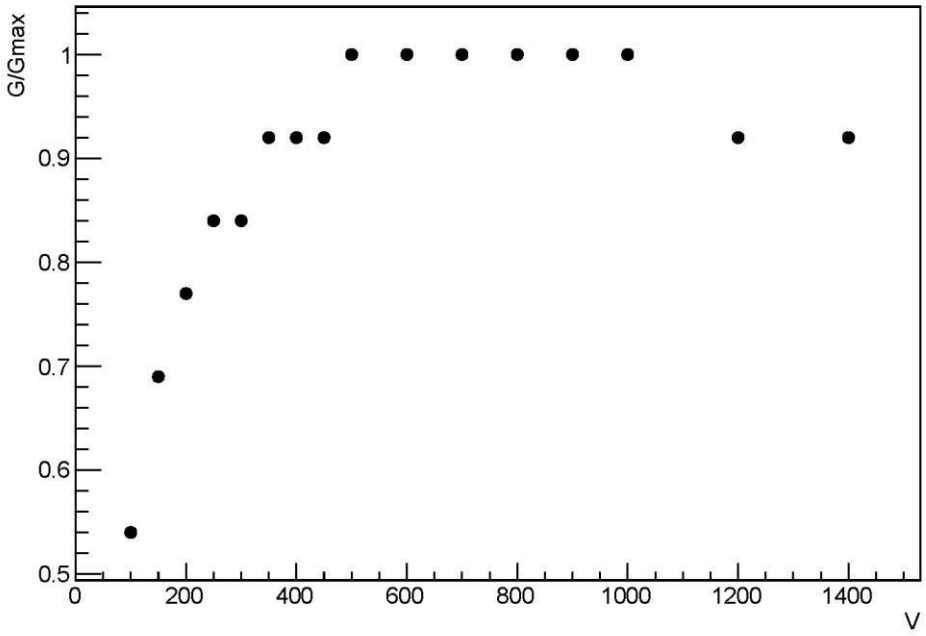

Figure 11. ArCO2 (30:70) dependence of gas gain on Vdrift

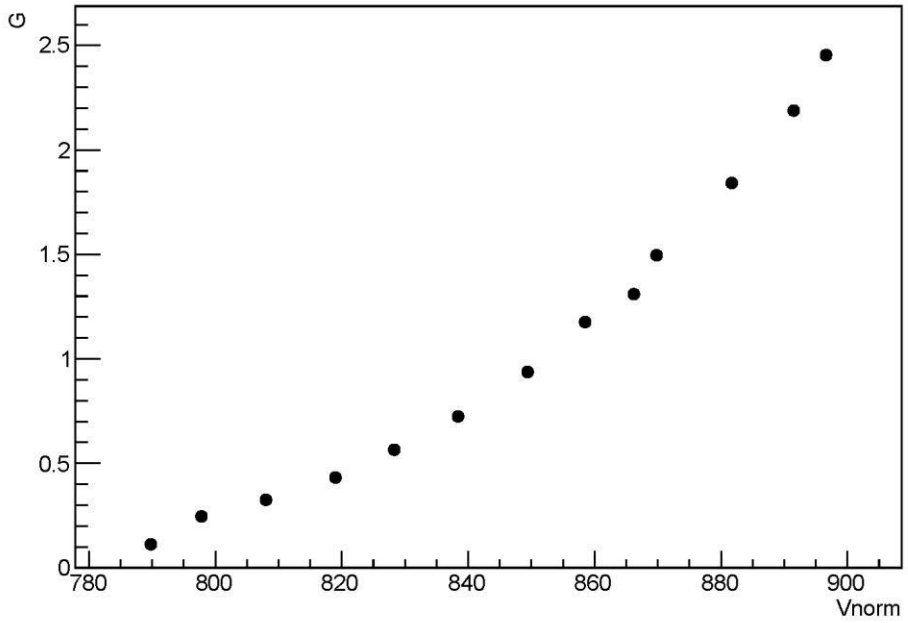

Figure 12. ArCO2 (30:70) dependence of gas gain on Vnorm

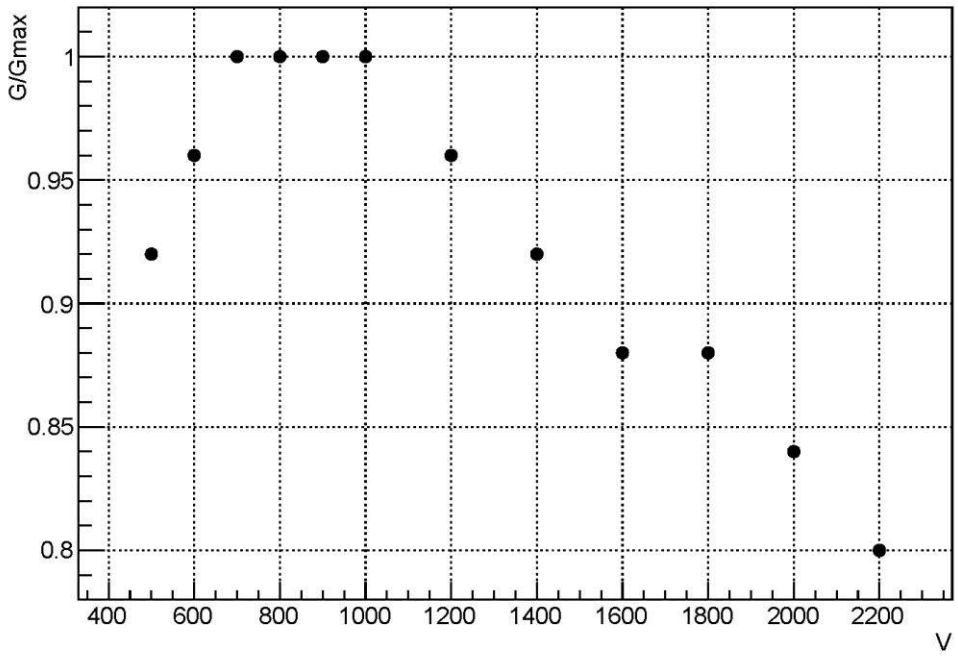

Figure 13. ArCO2-iC4H10 (91:7:2) dependence of gas gain on Vdrift

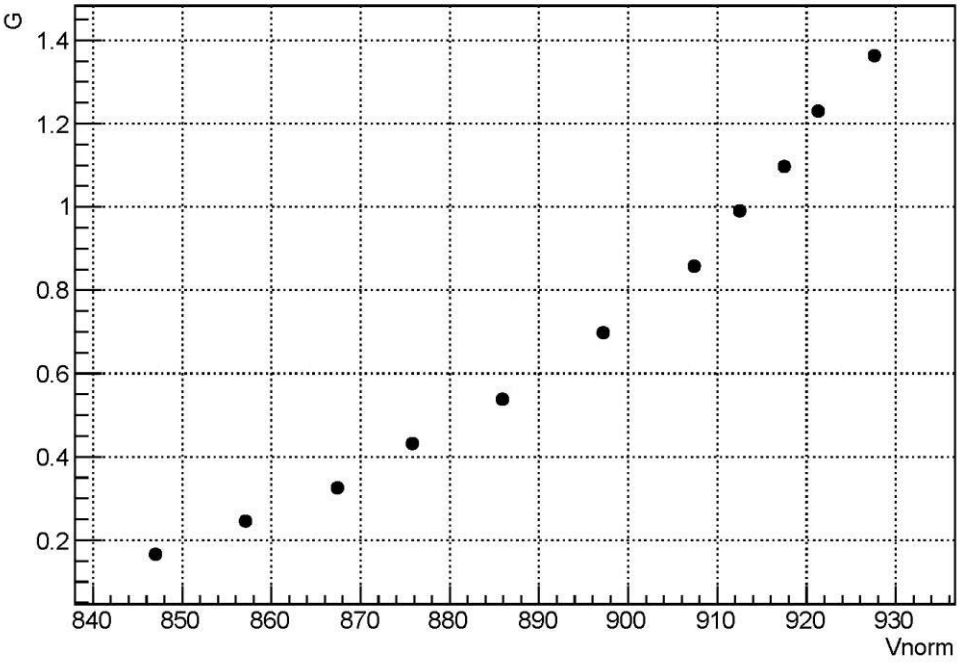

Figure 14. ArCO2-iC4H10 (91:7:2) dependence of gas gain on Vnorm

As can be seen from the results, the Ar-CO2 mixture is a promising candidate for using micromegas detectors in a magnetic field. It ensures stable operation of the detector with a

gain of 10 4, has a small Lorentz angle, and with an increase in the drift field to 2-2.5 kV/cm provides acceptable electron drift speed without noticeable degradation of charge collection efficiency.

Acknowledgements

Heartfelt thanks to my supervisor Dmitry Dedovich: he always found time to answer my questions, even the most trivial ones. I learnt much from his expertise. I want to thank also Igor and Natalia and all the members of the of the Micromegas group: it has been a pleasure for me to be warmly welcomed in such a "family". Warm thanks go to JINR for this great research opportunity and for the financial support. I am obliged to mention here the kindness and constant support of the members of the local organizing committee: to them goes my gratitude. Finally I want to thank all the participants of the START programe science is fun, with friends is more fun.