Micromegas for charge readout of double phase Liquid Argon TPCs

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Abstract. The 128 μm bulk-micromegas detector is a mature semi-industrial technology well suited for high quality and large scale production of large active area MPGDs as illustrated by its use in the Time Projection Chambers (TPCs) of the ND280 near detector of the T2K experiment. The cooling of a 128 μm bulk-micromegas detector down to 77 K proves its robustness at low temperatures and that is therefore a natural candidate for charge readout in Giant Liquid Argon TPCs.

We propose the use of bulk-micromegas technology as charge readout in the vapour phase of a double phase Liquid Argon TPC. We have made a series of gain measurements with bulk and micro-bulk micromegas at room temperature up to 4.5 bars to predict the behaviour and performances of micromegas in the double-phase Liquid Argon TPC conditions at 87 K. Gas gains of up to 500 were measured in pure Argon at room temperature and 3.5 bars with a 50 μm standard micro-bulk. But the large diffusion of electrons in pure argon demands the operation of the detector with sufficiently low drift over amplification field ratios in order to fully transfer primary electrons in the amplification gap. Gain simulations are in good agreement with these measurements and a gain of 100 in a 128 μm bulk-micromegas is expected in pure Argon at 87 K. Such a large effective gain should be sufficient for charge readout of double-phase liquid Argon TPCs.

1. Introduction

Giant Liquid Argon TPCs are good candidates for next generation rare events experiments, such as neutrino physics or direct search of Dark Matter. A recent proof of operation in double phase conditions was reported by A. Badertscher et al.[1] : the ionization electrons released in the liquid phase argon are drifted towards a set of extracting grids to be transferred into the gas phase for amplification in a double stage Large Electron Multiplier (LEM). For such a use, the requirements for the amplification device are :

- sufficient electron multiplication and stable operation in pure argon vapour phase at 87 K: a goal of 100 may suit a large range of physics applications;
- high quality and high yield industrial production for low cost and large scale production;
- ability to cover hundreds of square meters of active area with low dead zones and good uniformity of performances;

We propose the use of the bulk-micromegas technology as charge readout in the vapour phase of a Liquid Argon TPC. After a quick review of the current micromegas technologies, we present a robustness test at 77 K and a series of gain measurements in pure argon and room temperature to prove the capabilities of this detector for such an application. The electron multiplication performances are measured at 3.5 bars since the density of argon at this pressure is roughly equivalent to the expected density of the vapour above liquid argon surface at 87 K.

2. The current Micromegas technologies

Micro-Pattern Gaseous Detectors (MPGDs) are well established and high performance devices widely used in Physics experiments. The international collaboration RD51 gathers 71 institutes on Development of Micro-Pattern Gas Detectors Technologies [2] and a dedicated Working Group is in charge of the development of cost-effective technologies and large scale industrialization through technology transfer.

The MICRO-MEsh GAseous Structure or MICROMEGAS is a MPGD invented in 1996 which amplifies electrons in a typical 100 μm gap defined by a metallic micromesh placed on top of an anode Printed Circuit Board (PCB)[3]. In 2004, a new way to define this amplification gap was introduced and called the bulk-micromegas[4]. A woven micromesh is embedded on top of the segmented anode plane of the micromegas by use of standard photolithographic techniques (fig. 1). This technology was chosen to equip the 3 TPCs of the ND280 near detector of the T2K experiment for its performances in terms of gas gain uniformity, energy resolution and space point resolution, and for its capability to efficiently pave large readout surfaces with minimized dead zones (fig. 2). Eighty six 128 μm gap 34x36 cm^2 bulk-micromegas modules were produced in 18 months. Eighty of them, for an equivalent total surface of 9 m^2 passed the quality and performance tests. The dispersion of gas gain and energy resolution at 5.9 keV within the whole surface of each module is respectively 2.8% and 6% r.m.s. The dispersion of mean gain and mean 5.9 keV energy resolution over the eighty modules is respectively 8% and 3% r.m.s[5]. The cost of the device is about 10 k€/m^2 with 80% of the cost in the 4 layers PCB. These facts illustrate the maturity of the bulk-micromegas technology for a uniform, cheap and high quality mass production.

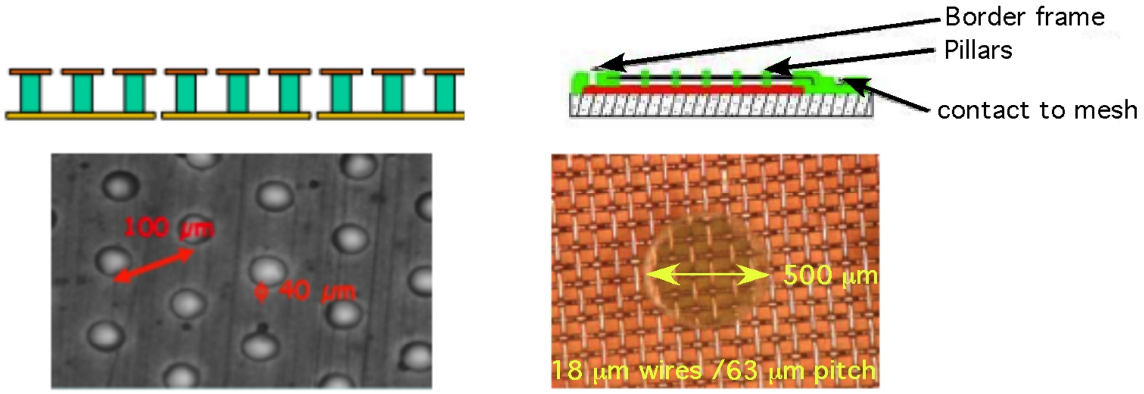

Figure 1. Side view sketch and mesh top view picture of a standard 50 μm micro-bulk (left) and a 128 μm bulk-micromegas (right)

In 2006, a new micromegas structure called micro-bulk was introduced and consists of building the amplification gap within a double side copper-cladded kapton foil [6] (fig. 1) by the same kind of chemical etching techniques as the ones used to make Gas Electron Multipliers

Table 1. Comparison of some bulk and micro-bulk specifications and performances. Gaps of 64 μm for bulk and 12.5 μm for micro-bulk need to be tested.

	bulk	micro-bulk
Standard amplification gap	128 μm	50 μm
Other possible amplification gaps	(64)-100-150-194 μm	(12.5)-25 μm
Standard Mesh pitch	63 μm	100 μm
Standard Mesh openings	45 μm	40 μm
Standard maximum size	40x40 cm^2	10x10 cm^2
R&D maximum size	500x1500 cm^2	30x30 cm^2
Best FWHM 5.9 keV resolution	19%	14%
Currently in use in experiments	T2K/TPC	Axion CAST experiment, nTOF
Current R&D programs	ILC/TPC, ILC/DHCAL, SLHC/Muon chambers upgrade, CLAS12 spectrometer, ...	NEXT, MIMAC, ...

(GEM). This more recent technology gives excellent performances especially in terms of energy resolution[6, 7]. A picture of the one used for some measurements done in this paper is shown on fig. 3.

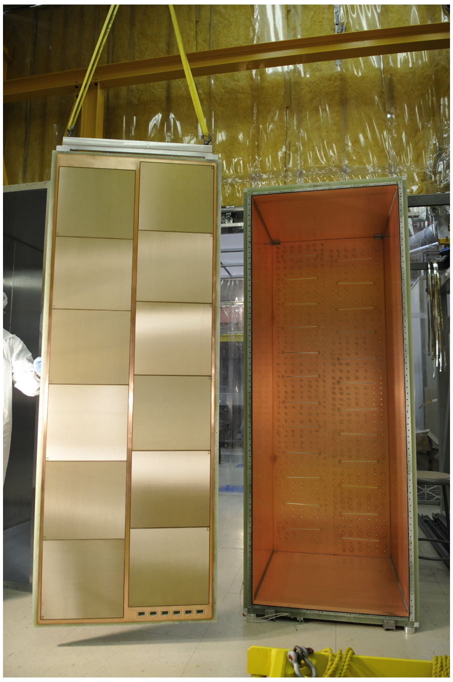

Figure 2. A T2K/TPC readout plane made of twelve 128 μm bulk-micromegas module for a total 1.5 m^2 active surface.

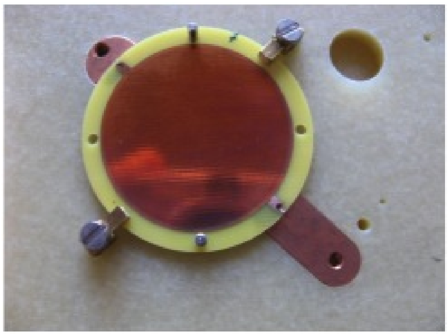

Figure 3. A standard 50 μm microbulk micromegas with a single 35 mm diameter anode.

Table 1 compares these two micromegas technologies for the specifications and performances of interest in double phase Liquid Argon application. The bulk-micromegas is today the more mature micromegas technology for next generation giant liquid Argon TPCs.

3. Cooling of a Bulk-micromegas detector down to 77 Kelvin

The Thermal Expansion Coefficients of the materials used to define the amplification gap of a bulk-micromegas are listed in table 2. They are similar for the Printed Circuit Board (FR4 epoxy and copper anode strips) and the stainless steel woven micromesh. But the pyralux PC1025 which makes the spacers and links the two to define the gap has a 10 times larger coefficient.

We cooled a 10x10 cm^2 128 μm gap bulk-micromegas down to 77 K by gradually plunging it in a Liquid Nitrogen filled dewar (fig. 4). A calibrated Pt100 temperature sensor was stuck on the top side of the detector and the micromesh was supplied with high voltage. At each step of the cooling, high voltage was raised until the first spark occurs to define the maximum amplification electric field. The current drawn through the CAEN 471A high Voltage supply was measured below the 2 nA current sensitivity of the power supply. The results are listed in Table 3.

After these measurements, the detector was dried in an oven at 80 ^{o}C during one night, and tested in Ar + 5%iC_4H_{10} at few mbars above atmospheric pressure and room temperature with a ^{55}Fe X-ray source (fig. 4). The mesh signal is read out through a 142B ORTEC preamplifier and a 472A ORTEC amplifier. After cooling and plunging into the liquid nitrogen, the detector was not damaged and its gain is comparable to our reference 128 μm gap bulk-micromegas.

These results also show the possible operation of a bulk-micromegas for charge readout in the 87 K Liquid Argon phase.

Table 2. Range of Thermal Expansion Coefficients of the materials used in a bulk-micromegas at 20-200 ^{o}C .

Material	ppm/^{o}C
FR4	[14 – 16]
Copper	[16 – 17]
Stainless steel	[14 – 17]
pyralux PC1025	[100 – 130]

4. Gain and electron transmission measurements in pure argon at room temperature

4.1. Bulk-micromegas at few mbars above atmospheric pressure

A T2K/TPC bulk-micromegas module was used to measure its gain in pure argon at few mbars above atmospheric pressure with a ^{55}Fe X-ray source. Anode pads were read out with T2K/TPC AFTER based electronics [8]. The 0.2 liter gas chamber is in aluminum with an entrance window in mylar and the drift electrode is a nickel 200 LPI mesh defining a 12 mm drift gap. An argon 6.0 grade bottle fills the chamber with a flow rate of 10 l/h through stainless steel tubes. Gas purity inside the chamber is therefore expected to be high but it was not measured.

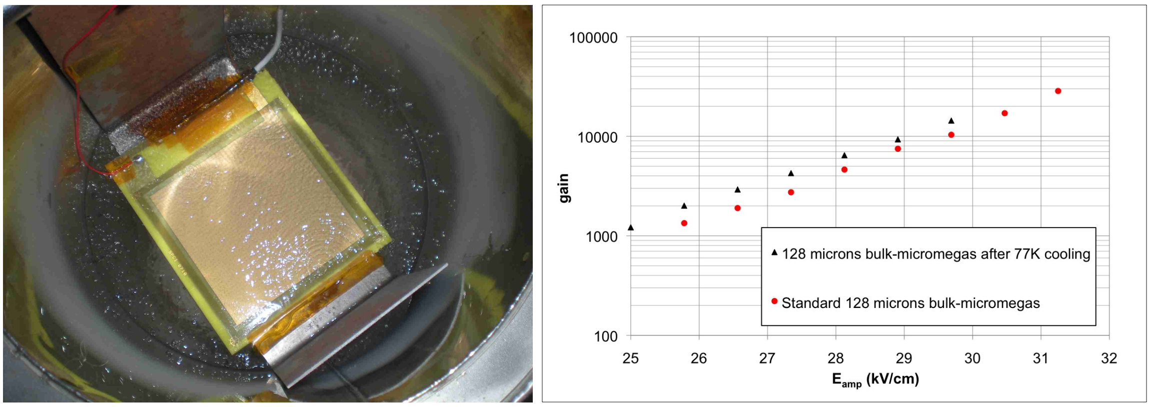

Figure 4. A 10x10 cm^2 128 μm gap bulk-micromegas cooled down to 77 K and plunged into the Liquid nitrogen (left) and its gas gain (right) in Ar + 5%iC$_4$H$_{10}$ at few mbars above atmospheric pressure and room temperature measured after one night of drying at 80 ^{o}C (black triangles). Gas gain of a standard 128 μm gap bulk-micromegas is also shown for comparison (red circles).

Table 3. Maximum amplification electric field of a 128 μm bulk-micromegas as a function of height above Liquid Nitrogen surface. At -10 mm, the bulk-micromegas is plunged in the liquid.

Height (mm)	Temperature (^{o}C)	Max V_{mesh}(V)	Max E_{amp}(kV/cm)
40	-47	670	52.3
25	-78	750	58.6
8	-119	850	66.4
0	-163	975	76.2
-10	-196	1300	101.6

Electron transmission was measured as a function of the E_{drift}/E_{amp} electric field ratio (fig. 5) and shows a drop for ratios higher than 2.2 10^{-3}. This loss of transmitted electrons from the drift volume into the amplification gap degrades the 5.9 keV r.m.s resolution as shown on fig. 6. A typical ^{55}Fe X-ray source spectrum measured with full electron transmission shows a 10.3% 5.9 keV r.m.s resolution (fig. 6) in contrast with the 9% measured in the T2K/TPC gas[5].

4.2. Micro-bulk micromegas at 3.5 and 4.5 bars

We measured the gas gain in pure argon at 3.5 and 4.5 bars of a 35 mm diameter 50 μm gap standard micro-bulk micromegas (fig. 3) with a ≈1 kBq ^{241}Am alpha source in the former HELLAZ setup[9] filled with 6.0 grade pure argon. This setup was recently used at Saclay/IRFU for development of high pressure micromegas detectors within the framework of our collaboration with the Instituto de Fisica Nuclear y Altas Energias at Zaragoza in Spain. Reference [7] describes the setup, reports on measurements performed in argon and xenon mixtures up to 4 bars and shows that the gas purity inside the vessel was high enough for short-term runs in argon mixtures for the 3.1 cm drift distance of alphas. The gas vessel is shown on fig. 7.

The signal was read on the plain anode of the micro-bulk detector through a 142C ORTEC preamplifier fed into an AMPTEK MCA-8000A multichannel analyzer for a counting rate of about 200 Hz.

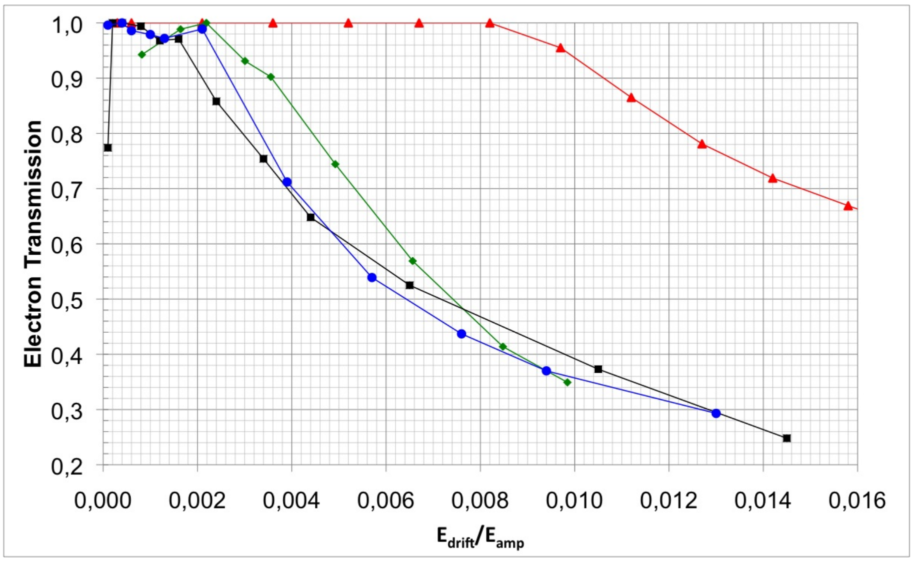

Figure 5. Electron transmission Vs $E_{\rm drift}/E_{\rm amp}$ Electric field ratio for a 50 μm micro-bulk in $Ar + 5\% iC_4H_{10}$ at few mbars above atmospheric pressure (red triangles), in pure argon at 3.5 bars (black squares) and in pure argon at 4.5 bars (blue circles). Electron transmission for a 128 μm T2K/TPC bulk-micromegas module at few mbars above atmospheric pressure is in green rhombs.

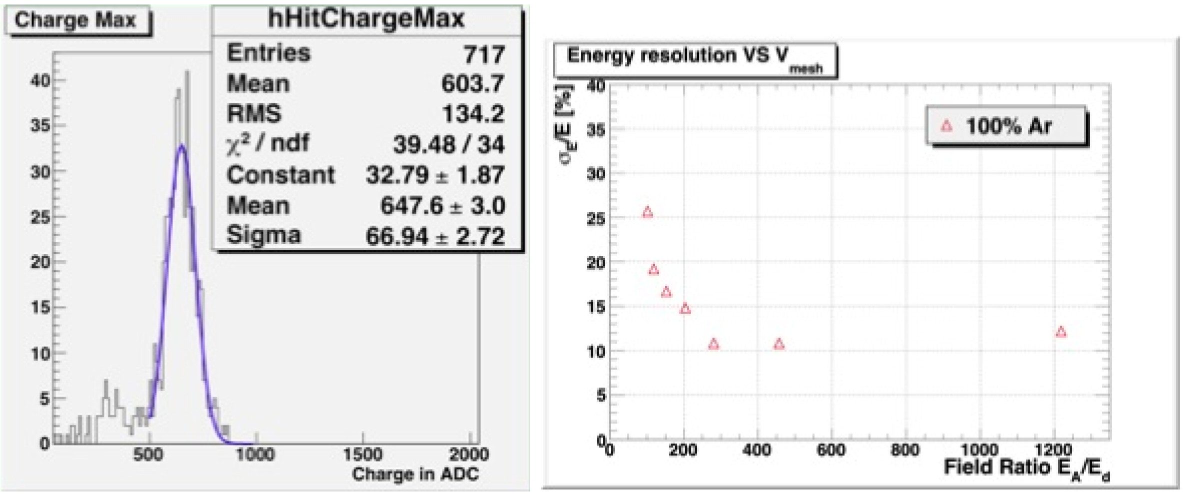

Figure 6. ^{55}Fe X-ray source spectrum operated with $E_a = 32$kV/cm and $E_d = 200$V/cm (left) and FWHM 5.9 keV energy resolution (right) of a 128 μm T2K/TPC bulk-micromegas module at few mbars above atmospheric pressure and room temperature. Drift electric field E_d is varied with a fixed 30.5 kV/cm amplification field E_a ($V_{\rm mesh} = -390$V).

The electron transmission at both pressures are comparable (fig. 5) and show the same drop as the one observed at atmospheric pressure. On this figure, electron transmissions in pure argon are compared to the one measured with the same kind of standard micro-bulk micromegas in $Ar + 5\% iC_4H_{10}$ for which the drop occurs at much higher electric field ratios. The ≈50% lower

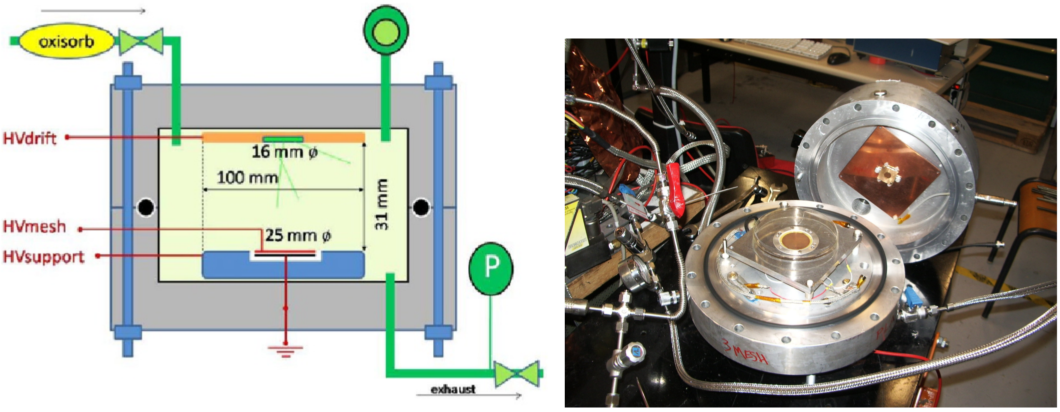

Figure 7. Sketch (left) and picture (right) of the gas vessel used for gain measurements at 3.5 and 4.5 bars.

electron transmission in pure argon compared to Ar + 5%iC_4H_{10} at the same E_{drift} and for the same mesh optical transparency (same micro-bulk micromegas), can be explained by the much larger diffusion of electrons in pure argon (fig. 8)

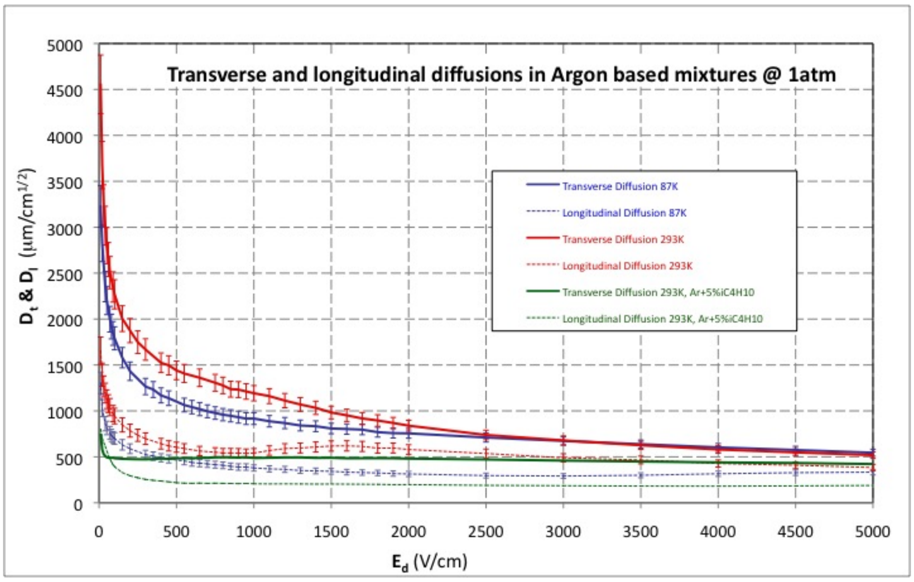

Figure 8. Magboltz simulated longitudinal and transverse diffusions as a function of the drift electric field E_d for different argon based mixtures at 1 atm. Magboltz simulated longitudinal and transverse diffusions of pure argon at 300 K and 3.5 bars are the same as the one for pure argon at 87 K and 1 atm (blue curves).

Gas gains in pure argon at 3.5 bars can reach 500 at 100 kV/cm amplification electric field (fig. 9). For a more stable operation of the detector without sparks, operation at 94 kV/cm (200 gain) should be favoured.

4.3. Gain simulations

A simple modelization of the gas amplification gain G in a micromegas detector of amplification gap x is $G = \exp\left(\alpha \cdot x\right)$, with $\alpha\left(E, P\right) = P \cdot \xi\left(\frac{E}{P}\right)$
with E the amplification electric field and P the gas pressure.
For a noble gas, $\xi\left(\frac{E}{P}\right) = A.\exp\left[-B\left(\frac{P}{E}\right)^{\frac{1}{2}} - C\frac{E}{P}\right]$
Tkachev et al.[10] recently simulated and compared to measurements the Townsend coefficients of pure argon: $\mathrm{A} = 43\,[\mathrm{cm.Torr}]^{-1}$, $\mathrm{B} = 27.5\,[\mathrm{V}/\left(\mathrm{cm.Torr}\right)]^{\frac{1}{2}}$, and $\mathrm{C} = 2.5 \times 10^{-4}\,[\mathrm{cm.Torr/V}]$. Using these coefficients, the calculated gain is in good agreement with the 3 measurements done (solid curves in fig. 9).

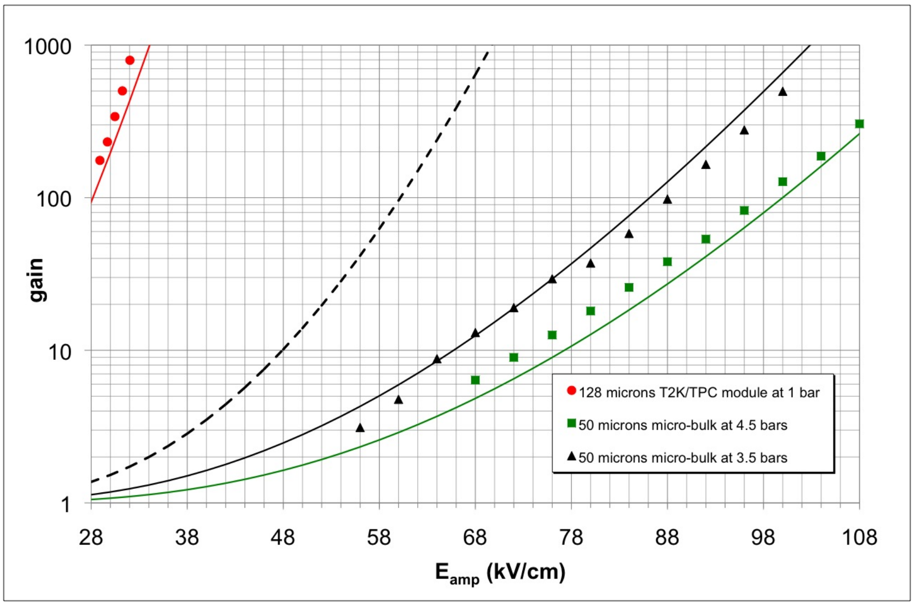

Figure 9. Gas gain in pure argon for a 128 μm T2K/TPC bulk-micromegas module at few mbars above atmospheric pressure (red circles), and for a 50 μm micro-bulk at 3.5 bars (measurements in black triangles, gain simulation in black line) and 4.5 bars (measurements in green squares and gain simulation in green line). Measurements were done with full electron transparency. The black dashed curve is the gain simulation for a 128 μm gap micromegas detector at 3.5 bars.

For a 128 μm gap bulk-micromegas, the black dashed curve of fig. 9 shows an expected 100 gain for an amplification electric field of 58 kV/cm ($\mathrm{V_{mesh}} = -740$V). For full electron transmission, this will require a drift electric field lower than 100 V/cm. For a 500 V/cm drift electric field, only 40% of the primary electrons will be transfered in the amplification gap, and an effective gain of 40 is still reachable and probably large enough for charge readout of double-phase Liquid Argon TPCs.

5. Conclusion and perspectives

Bulk-micromegas was shown to be robust enough to be operated at Liquid Argon temperature. Gas gains of up to 500 were measured in pure argon at room temperature and 3.5 bars with a 50 μm standard micro-bulk. These measurements, those done at 4.5 bars, and those done with a 128 μm bulk-micromegas T2K/TPC detector at atmospheric pressure are in good agreement with gain simulations. A gain of 100 for a 58 kV/cm amplification electric field in a 128 μm bulk-micromegas can thus be expected in pure argon at 87 K, as soon as the drift electric field is lower than 100 V/cm for a full transfer of the primary electrons into the amplification gap. Even if part of the primary electrons are lost in case of the use of a higher drift electric field, such a large effective gain should be sufficient for charge readout of double-phase liquid Argon TPCs.

We are collaborating with the Institute for Particle Physics, ETH Zurich (ETHZ, Switzerland) for the design of a 1D 3mm pitch 64 channels readout bulk-micromegas to be tested in the 3 Liters ETHZ Lar TPC[1] at CERN. 128 μm gap is the baseline design and manufacturing of a 64 μm gap will also be tried. The measurements done in this paper will be the fruitfull guides to tune the operation of the detector in terms of charge collection. The next step will be the design and optimization of a 2D readout bulk-micromegas prototype.

Acknowledgments

We would like to thank our colleagues from the Instituto de Fisica Nuclear y Altas Energias at Zaragoza (Spain) for sharing their experience in the operation of micro-bulk readouts at high pressure. We would like to also thank our colleagues from the Institute for Particle Physics, ETH Zurich (Switzerland) for inviting us to test a Micromegas detector in their 3 liters double phase Liquid Argon prototype at CERN.

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