Energy resolution of alpha particles in a Micromegas detector at high pressure

F. J. Iguaz¹, T. Dafni¹, E. Ferrer-Ribas², G. Giomataris², P. Gordetzyky³, I. Irastorza¹, P. Salin³ and A. Tomás¹

¹ Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza, Zaragoza, Spain
² Centre d’Études Nucleaires de Saclay, IRFU/CEA-Saclay, Gif-sur-Yvette, France
³ APC-Astroparticule et Cosmologie, CNRS-CEA-IN2P3-Observatoire de Paris, Université Paris Diderot-Paris7, France

E-mail: iguaz@unizar.es

Abstract. The latest Micromesh Gas amplification Structures (Micromegas) are achieving outstanding energy resolution for low energy photons, with values as low as 11% FWHM for the 5.9 keV line of $^{55}$Fe in Argon/Isobutane mixtures at atmospheric pressure. At higher energies (MeV scale), these measurements are more complicated due to the difficulty in confining the events in the chamber, although there is no fundamental reason why resolutions of 1% FWHM or below could not be reached. There is much motivation to demonstrate experimentally this fact in Xe mixtures due to the possible application of Micromegas readouts to the Double Beta Decay (DBD) search of $^{136}$Xe, or in other experiments needing calorimetry and topology in the same detector. We report on systematic measurements of energy resolution with state-of-the-art Micromegas using a 5.5 MeV alpha source in high pressure Ar/Isobutane mixtures. Values as low as 1.6% FWHM have been obtained. Same measurements in Xe, of which a preliminary result is also shown here, are under progress.

1. Introduction
The neutrino flavour oscillation observed in atmospheric and solar neutrinos experiments has increased the interest on Neutrinoless DBD [1, 2]. This rare process has never been observed and its detection would give information about the mass and the Dirac or Majorana nature of the neutrino. The requirements for this kind of experiments are challenging: a large amount of DBD emitter, a selection of low-background materials, the use of signal-background discrimination techniques and good energy resolution. Time Projection Chambers (TPCs) have been generally used as tracking detectors but their energy resolution wasn’t good enough to compete with Germanium or bolometers in DBD. The appearance of new charge readout planes based on micropattern techniques (like Micromegas) with better energy resolution capabilities is a further motivation for the application of these detectors in Neutrinoless DBD.

The MICROMesh GAseous Structure (MICROMEGAS)[3, 4] readout for TPCs consists of a metallic micromesh suspended over a (usually pixellised) anode plane by means of isolator pillars, defining an amplification gap of the order of 50 to 150 µm. Electrons drifting towards the readout go through the micromesh and their amplification induces signals both in the anode pixels and in the mesh. The latest generation of these detectors has obtained an energy resolution of 11% FWHM for the 5.9 keV $^{55}$Fe line for a mixture of Ar - 2% $iC_4H_{10}$ at 1 bar. Supposing
Figure 1. Upper and lower parts of the high pressure vessel. The drift cathode and the source keeper are shown at the upper part and the microbulk detector and the metallic support at the lower one.

A square root energy dependency of the energy resolution, this would lead to a value less than 1% FWHM for electrons at 2.480 MeV (the Q value of the DBD for $^{136}$Xe) and would fulfill the requirements of DBD experiments [5]. The experimental confirmation of this hypothesis is the aim of this work.

In section 2 we describe the experimental setup used for the measurements. In section 3 we present the energy resolution results in Argon/Isobutane mixtures and pure Xenon. In section 4 results on the alpha quenching factor are given. We finish with our conclusions and future plans in section 5. A more detailed description of the setup and results is made in [8].

2. Setup description
The experimental setup was adapted from the former HELLAZ one at CEA-Saclay[6], which was already designed for research with gas mixtures of high purity and at high pressures. It consists of a high pressure vessel, a turbomolecular pump and a gas distribution system with a gas mixer, an oxysorb filter, a pressure controller and an exhaust line with a bubbler. The main element is a high pressure vessel of 1 liter of volume, which provides high voltage (SHV) and signal (BNC) feed-throughs for the internal readout setup, as well as a CF40 outlet for pumping, equipped with an all-metal UHV high-pressure valve. As it is shown in figure 1, the upper part of the vessel consists of a drift copper cathode, which supports an unsealed Americium source in a sourcekeeper. At the lower part, a Micromegas readout was placed on a metallic support, used to shape the drift electrical field. Both pieces were electrically isolated. The drift distance of the vessel was 31 mm and as alpha tracks in Argon and Xenon are longer, no data was taken at atmospheric pressure.

The Micromegas readout is a 2.3 cm diameter circular one of 50 microns gap. It was made with the microbulk manufacturing technique developed at CERN, known to yield the highest precision in the gap homogeneity and the best energy resolutions among Micropattern detectors. The one used in this measurements was tested before and after the measurements campaign with a $^{55}$Fe source in Ar - 2% $iC_4H_{10}$ at atatmospheric pressure, presenting the spectrum shown in 2. The energy resolution is 11.2 % FWHM at the 5.9 keV line. No appreciable deterioration was seen after the year-long duration of the measurements campaign.

The signal was read out from the Micromegas mesh using a CANBERRA 2004 preamplifier, whose output was fed into an ORTEC VT120 amplifier/shaper and subsequently into a multichannel analyzer AMPTEK MCA-8000A for spectra building. Alternatively, the output of the preamplifier was digitized directly by a LeCroy WR6050 oscilloscope and saved into disk for an offline pulse shape analysis.
Figure 2. Energy resolution of the Micromegas readout used in the measurements. The spectrum was obtained with a $^{55}$Fe source in Argon - 2\%$iC_4H_{10}$ at 1 bar.

Figure 3. Americium spectrum in Argon - 2\%$iC_4H_{10}$ at 4.75 bars. Energy resolution was better than 2\% FWHM. Landau deconvolution analysis points an intrinsic 0.7\% FWHM.

3. Energy resolution in Argon and Xenon

Before each measurement, the system was cleaned either by pumping it with the turbo-molecular pump down to pressures below $10^{-6}$ mbar or by purging it with Argon or Xenon several times. The desired gas mixture was then introduced into the vessel using the gas mixer with the appropriate relative flows. Gases used were a mixture of Argon-Isobutane (between 2\% and 5\%) and pure Xenon. The gas used was provided by MESSER and its purity was always 4.6 or superior. The final gas purity, determined in addition by the leak-tightness of the system, the outgassing of materials and the effect of the oxysorb, was proven to be adequate for Argon mixtures but not for pure Xenon, as evidence of some degree of attachment was found.

An energy resolution of 1.5 – 2\% FWHM for mixtures of Argon-Isobutane (2 and 5\%) at pressures between 2 and 5 bars was obtained, as it is shown in figure 3. This result was independent of amplification fields and electronics but a dependence on drift field was clearly observed. The peak showed an asymmetric shape which can be attributed to external effects like an uncomplete charge collection. These effects are well parameterized by an inverse Landau function convoluted by a gaussian, which contains the intrinsic energy resolution of the Micromegas. The analysis indicates an energy resolution of 0.7\% FWHM.

In pure Xenon, measurements were made in pressures between 2 and 4 bars were used. The
energy resolution was not very good due to a clear presence of attachment which was not so evident in Argon-Isobutane mixtures. As it is shown at figure 4, the signal amplitude increases with the drift field until this effect is compensated with the lost of the mesh transparency. Apart from that, there is a clear dependence of the amplitude on risetime. An almost horizontal alpha track, whose electrons drift on average longer distances than those of a vertical one, has a small amplitude because its electrons suffer more the effect of the attachment. This track has also a shorter risetime due to its shorter vertical projection.

For estimating the energy resolution in absence of attachment, a cut on risetime (100-200 ns) was applied. In this way, events with similar risetime were taken in order to minimize the spread due to different attachments. Preliminary values with this analysis were 2.8% FWHM for pure Xenon at 2 bar and 4.5% FWHM at 4 bar. It should also be stressed that these numbers are conservative, because the subset of events kept by the cuts still suffers from attachment. Nevertheless, the values obtained are positive and already approach the requirements of a DBD experiment.

Another fact that should be taken into account is that absolute gains up to 200 were reached (as shown in figure 5), before getting a spark at the mesh. This value may be limited by the source rate (about 200 Hz) because higher gains were obtained with a more collimated source when trying to measure quenching factor in pure Xenon. Further measurements should be done to confirm this hypothesis.

4. Quenching factor in Argon

Alpha particles of a given energy do not ionize in theory as much as electrons of the same energy due to the electron-ion pairs recombination, which is stronger in denser alpha tracks. The fraction of energy going to ionization with respect to the one of an electron of equal energy, or quenching factor, is needed in order to know the electron-equivalent energy of our 5.5 MeV alpha peak. This value is difficult to find in literature for gases and it may depend on pressure, electric field and the presence of quenchers.

The x-rays and gammas can be easily observed when blocking alphas with an aluminium foil (figure 6, left). However as it is needed to keep the same gas conditions, the source was collimated to reduce alpha-induced background and sparks generated at higher gains. The same lines were observed (figure 6, right) but without increasing too much the alpha background level at the low energy region.
5. Outlook and conclusions

We have presented first results from measurements of energy resolution at high energy and high pressures for a Micromegas readout. A value of less than 2% (FWHM) in Argon-Isobutane mixtures (2 – 5%) at pressures between 2 and 5 bars was obtained. An indication of an intrinsic resolution of 0.7% based on the asymmetry of the peak was observed. Measurements in pure Xenon were made. By performing a pulse analysis on the digitized waveforms of the preamplifier output and cuts on the risetime, a conservative estimation of the energy resolution of 2.8% for 2 bar and 4.5% for 4 bar was found. An alpha quenching factor of almost unity was obtained for Ar - 2% $iC_4H_{10}$ at 2, 3 and 4 bars. A more detailed description of the setup and results is made in [8].

This is the first time that energy resolution measurements of alpha particles at high pressure with microbulk type of Micromegas are published. Similar measurements were done in [7] although with considerable worse results. At present we are working on the upgrade of the system to improve its leak-tightness and outgassing in order to resume the measurements in pure...
Xenon in appropriate conditions of gas purity. We also plan to use an enlarged high pressure vessel big enough to contain high energy electron events, and perform similar measurements with photon/electron sources and not only with alphas. Finally, we plan to explore the effect of quenchers in Xenon in the energy resolution as well as going up to higher pressures than the ones in the present paper (from 5 to 10 bars).

Acknowledgments

This work was supported by the Spanish Science and Innovation Ministry (FPA2004-00973 and FPA2007-62833) and a grant of the same institution (AP2005-0360).

We would also like to thank all the technical support of the SEDI departement at the IRFU/CEA-Saclay center.

References

[1] Angel Morales, *Nucl. Phys. (Proc. Suppl.)* **77** (1999), 335-345.
[2] S.R. Elliot and J. Engel, *J. Phys G* **30** (2004), R183.
[3] Y. Giomataris, P. Rebourgeard, J. P. Robert and G. Charpak, *Nucl. Instrum. Meth. A* **376** (1996) 29.
[4] I. Giomataris *et al.*, *Nucl. Instrum. Meth. A* **560** (2006) 405, Preprint arXiv:physics/0501003.
[5] F. T. Avignone, G. S. King and Yu. G. Zdesenko, *New J. Phys.* **7** (2005) 6.
[6] J. Dolbeau, I. Giomataris, P. Gorodetzky, T. Patzak, P. Salin and A. Sarat, *Nucl. Phys. Proc. Suppl.* **138** (2005) 94.
[7] L. Ounalli, J. L. Vuilleumier, D. Schenker and J. M. Vuilleumier, *JINST* **4** (2009) P01001, Preprint arXiv:hep-ex/0810.0445.
[8] Th. Dafni *et al.*, Preprint arXiv:0906.0534.