Micromegas planes for the neutrinoless double beta decay search with NEXT

T. Dafni, on behalf of the NEXT Collaboration
Laboratorio de Física Nuclear y Astropartículas, Universidad de Zaragoza, 50009 Zaragoza, Spain
E-mail: Theopisti.Dafni@unizar.es

Abstract. NEXT is a project to look for the neutrinoless double beta decay of $^{136}$Xe in the Canfranc Underground Laboratory (LSC) in the Spanish Pyrenees. The goal of the project is to construct NEXT-100, which will hold 100 kg of pressurized Xe gas, planned to run in late 2013. The project is currently progressing through its R&D phase: the first big (1 kg) prototypes will be taking data during 2011, exploring different options for the readout. One of them is reading the charge with the help of microbulk Micromegas planes. This option is discussed here.

1. Introduction

Although they have been known to exist since the 1950s, there is still important information on the neutrinos that eludes us, such as their mass and whether they are of Majorana or Dirac type. The field of neutrino physics is very active in the late years and several experiments that are trying to address this kind of questions are looking for the answers through the double beta decay process. The current generation of these experiments aims at detector target masses at the 100 kg scale. The next step would require their scaling up to few-tonnes in order to completely explore the inverse hierarchy models of neutrino mass. The main requirements are a very good energy resolution and ultra-low background levels.

NEXT (Neutrino Experiment with a Xenon TPC) is one of these experiments [1]. It is a project approved by the Canfranc Underground Laboratory (Laboratorio Subterráneo de Canfranc, LSC) in the Spanish Pyrenees. It has been funded by the Consolider Program of the Spanish Ministry of Science to carry out the construction of a 100 kg enriched high-pressure xenon gas (HPGXe) TPC.

The merit of the proposal lies on the excellent prospects that it has regarding the requirements of such a project: the excellent energy resolution which can be achieved, the background rejection power provided by the topological information of the electron tracks, the ability to define a t0 (thus a fiducial region away from any surface), and the scaling-up to large masses. The final detector, NEXT-100, will hold 100 kg of Xe gas enriched in $^{136}$Xe, its $\beta\beta$-decaying isotope.

The project baseline is focused on the EL technique using a PMT plane for the energy measurement and SiPMs for the topological information[2]. Another option studied is using APDs[3], while here we will discuss the option of the charge collection with Micromegas.
2. NEXT with Micromegas

Since their conception 15 years ago, the Micromegas detectors [4] have been used in several experiments in which they have presented outstanding performance in spatial, temporal and energy resolutions, as well as robustness and stability of operation. They are known to provide a very stable amplification factor due to the particular geometry of the avalanche, which makes it rather insensitive to the amplification gap imperfections and other external parameters like temperature and pressure [5].

The latest generation of the Micromegas planes, called microbulk Micromegas, is fabricated in such a way that provides superior mechanical homogeneity of the gap and mesh geometry [6]. Energy resolutions of 11% FWHM at 5.9 keV are routinely achieved with the new planes in mixtures of Argon-Isobutane. Because the structure is mainly made out of copper and kapton, the radioactivity levels are not expected to be high, something confirmed by the radioactivity measurements performed with microbulk planes, as commented later on. These characteristics, open the way for the application of the Micromegas in rare event searches, such as NEXT.

In the present paper we report on the results achieved with microbulk Micromegas in a small prototype called NEXT-0-MM using different gas mixtures. The commissioning of a 1 kg prototype, NEXT-1-MM is also described.

2.1. Tests in NEXT-0-MM

NEXT-0-MM is the first small prototype built in order to test microbulk planes in high pressure (Figure 1). It is a 2 litre chamber made of Stainless Steel, with a diameter of approx. 14 cm and a drift region of 6 cm. The vessel has been tested to hold pressures of up to 12 bar. With the help of resistors fitted at its exterior, the vessel can be heated up to 110°C. A field cage consisting in 6 copper rings held together with three columns made of PEEK and interconnected by resistors. The structure is topped by a copper disk as a cathode. A hole is made in the cathode to accommodate the sources used in the tests (Figure 2).

Two types of microbulk Micromegas have been used for the tests in NEXT-0-MM: circular readouts with an amplification gap of 50 µm and 35 mm diameter whose anode was not segmented and a bigger one, with an active area of 10×10 cm² (Figures 3 and 4). The latter has a pixelized anode with a total of 144 pixels and at the time was the largest Micromegas built with the microbulk technique. During the tests both signals of the anode and of the mesh are recorded.
At the first phase of the measurements, the response of the detectors in different mixtures of Ar-Isobutane was studied, with the concentration of Isobutane in the mixture varying from 0.1% to 5%. The pressure inside the vessel was raised up to 10 bar and the tests were done with the alphas coming from an $^{241}$Am source. The best energy resolution achieved in that configuration was 0.7% (FWHM) for the 5.5 MeV of the alphas coming from an source, at 4.75 bar in Ar-2% Isobutane gas mixture [7].

At a later stage, measurements were performed introducing pure Xenon in the chamber increasing the pressure up to 5 bar. In the range between 2 and 5 bar energy resolutions around 3% (FWHM) for the 5.5 MeV alphas of the $^{241}$Am source were obtained [9], the best one being 2.5% for the 4 bar case (Figure 5). Using a selection of events based on risetime the aforementioned values improve to $\sim$2% (FWHM) (the best value at 1.8% FWHM for the 4 bar case). The system was working mainly in a closed mode, meaning that the gas was introduced and then the vessel sealed. However at times it was working in a recirculating mode, in which case the gas was passing through a purifying filter. In all the cases, the limitation in the increase of pressure was the gas quality; the energy resolution measurements started to be clearly affected by attachment.

The second campaign of measurements was focused on pure Ar and pure Xe gases. The quality of the gas was improved after long pumping periods but as well after prolonged bake-out periods in vacuum and circulating warm Nitrogen gas through the system. Figures 6 and 7 show the best results achieved in each case, for the 5.5 MeV $\alpha$ of the $^{241}$Am, namely 2.03%
(FWHM) at 8 bar of Ar and 1.94% (FWHM) at 4 bar of Xe. Under these conditions the effect of attachment in the gas started to be evident only in higher pressures, allowing thus data-taking up to 8 bar in pure Ar and pure Xenon. At 8 bar of Xe, the attachment effect was already apparent and therefore the resolution achieved of 4.8% (FWHM) at 5.5 MeV was not as good.

By this time, when the pixelized microbulk detector was used, part of the pixels were read with a reduced version of the T2K electronics, allowing the 3D reconstruction of the tracks gathered. Figure 8 shows an $^{241}$Am alpha track in pure Ar at 1.23 bar, as recorded in the two-dimensional plane, and its reconstruction.

**Measurements with $\gamma$ in pure Xe** Flipping the $^{241}$Am source upside down, the $\alpha$ emitted from the deposition remain blocked. However, the source emits a $\gamma$ line at 59.54 keV, which served to probe the lower energy region. Measurements were done at 1, 2 and 3.5 bars. These first measurements at high pressure, yield an energy resolution of 7.8% at 2 bar and 9.3% (FWHM) for the 60 keV $\gamma$ of the $^{241}$Am at 3.5 bar (Figure 9). If extrapolated to the $Q_{\beta\beta}$ value of Xe (2458 keV), they would correspond to 1.2% and 1.45% (FWHM) respectively. Interesting results in high pressures were obtained by other colleagues in a smaller setup [10]. We plan to extend the measurements with $\gamma$ in the upcoming tests.

2.2. NEXT-1-MM

During the tests performed in NEXT-0-MM a bigger prototype was prepared, NEXT-1-MM, made of Stainless Steel. The vessel has an inner volume of approximately 75 litres, measuring 600 mm of height and almost 400 mm in diameter (Figure 10). The vessel was tested up to
Figure 9. Spectrum of 59.54 keV $\gamma$ in pure Xenon at 3.5 bar with an energy resolution of 9.6% (FWHM). The spectrum is acquired with an $^{241}$Am source from which the alphas were blocked. The peak on the left is composed mainly of escape peaks from the 60 keV $\alpha$, due to the fluorescence of Xe at 30 and 33 keV and partly of the 26 keV $\gamma$ line of $^{241}$Am.

12 bar and should hold 1 kg of Xenon at a pressure of 10 bar. Following the example of NEXT-0-MM, NEXT-1-MM is equipped with a field cage which defines a drift length of 35 cm. The structure, shown in Figure 11, is composed of 34 copper rings, interconnected with 10 M$\Omega$ resistors. The cathode is a copper disk, machined to accommodate the possible sources to be used in the tests. In order to reach the needed drift fields voltages of the order of 50 kV are needed. There are no commercial connectors for such high voltages which comply with the radiopurity requirements for the experiment. As a consequence, a dedicated study for the development of suitable feedthroughs was started.

Figure 10. A photo of the NEXT-1-MM prototype and its supporting structure.

Figure 11. The field cage of NEXT-1-MM: 34 copper rings, connected through resistors and held by PEEK bars.

The first readout plane fabricated for NEXT-1-MM was a bulk detector. It has a diameter of 30 cm and the anode is segmented into 1252 pixels. The pixels are individually read with the use of a full chain of the electronics used in the T2K experiment. Preliminary tests were performed introducing a $^{222}$Rn diffuse source in Ar-2% Isobutane at atmospheric pressure. In these tests
only the signal from the mesh was read, not the anode. After several hours a clear spectrum of the Rn alpha decays was gathered (Figure 14), proving that all of the detector’s volume was active.

**Figure 12.** A photo of the bulk Micromegas detector installed in the NEXT-1-MM. It has a diameter of $\sim 30\,\text{cm}$ and its anode is segmented to $\sim 1200$ pixels.

**Figure 13.** A photo of the new microbulk Micromegas recently constructed. It is one of the four sectors that will be installed in order to cover the sensitive surface of NEXT-1-MM.

The first tracks were seen when the T2K electronics were implemented in the chain. At the level of the readout plane, the signal of the pixels is grouped in 4 parts of 288 pads each. Flat cables are used to carry each group outside the vessel with the help of home-made feedthroughs. Outside the chamber, the 288 pads are divided into four groups of 72 with the help of an interface

![Graph](image)

**Figure 14.** Spectrum of a gas diffused Rn source in Ar-2% Isobutane at 1 bar obtained with the bulk detector inside NEXT-1-MM. The main peak comes from $\alpha$ emission of the $^{222}\text{Rn}$ chain at 5.5 MeV. Two more alphas are expected from later on the chain at 6 MeV ($^{218}\text{Po}$) and 7.7 MeV ($^{214}\text{Po}$), which are collected in the tail of the spectrum.
card. This division fits the expected input of the T2K electronics, which is then easily connected to the chain. An example of an alpha track from the $^{222}$Rn source can be seen in Figure 15.

![Figure 15. An alpha track of approximately 4 cm obtained with the $^{222}$Rn source in NEXT-1-MM. The shaded area corresponds to the active surface of the bulk detector.](image)

In late December the first microbulk detectors to be tested in NEXT-1-MM were received. The detectors have the form of a quarter of a circle (Figure 13), therefore four of them will be used to cover the sensitive area of the detector.

**Next steps** More measurements are ongoing with the NEXT-1-MM setup. The behaviour of the bulk detector at higher pressures is one of the first things to study. Currently, the system is prepared for measurements with pure Xe. The system is designed in a way that allows the incorporation of a plane where a small number of Photomultiplier tubes would be put. This will allow the $t_0$ measurement of the event. In the meantime, the newly arrived microbulk quarters will be characterized in a test bench prior to their installation in NEXT-1. Then the capabilities of large microbulk planes with respect to tracking and regarding energy resolution in Xe will be studied.

### 2.3. Radiopurity of Micromegas planes

As mentioned at the introduction, in experiments like NEXT, looking for the lowest background possible, a limiting factor could be the readout plane introduced. The first measurement of the radiopurity of Micromegas planes were performed in the low background facilities of the Canfranc Underground Laboratory (LSC) with a high purity germanium detector [9]. The obtained results prove that Micromegas readouts of the microbulk type are currently manufactured with radiopurity levels below $30 \mu$Bq/cm$^2$ for Th and U chains and $\sim 60 \mu$Bq/cm$^2$ for $^{40}$K, already comparable to the cleanest detector components of the most stringent low background experiments at present. Considering that the readouts measured were manufactured without any special care from the radiopurity point of view, after dedicated development these results will most probably be improved.

### 3. Conclusions

We have here presented the status of the Micromegas readout planes as an option for the equipment of a high pressure gas TPC for double beta decay searches such as NEXT. Current results show excellent energy resolutions achieved with the microbulk Micromegas like 1.94% (FWHM) at 4 bars of pure Xenon for the 5.5 MeV alphas of $^{241}$Am, while measurements with the 60 keV photons of the same source have yield an energy resolution of 9.3% (FWHM) at 3.5 bar which would correspond to 1.45% (FWHM) if extrapolated to the $Q_{\beta\beta}$ value of Xe (2458 keV). At the same time, they have the advantage of rather low radioactivity levels, an important requirement in this field of searches. An intensive R&D program is underway for a complete study of the behaviour of these planes in even higher pressures. A big prototype able to hold
approximately 1 kg of Xe, NEXT-1-MM, is already commissioned with a bulk Micromegas. Four new Micromegas of the microbulk type are being characterized in order to install them in NEXT-1-MM. The micromegas readouts offer a simple and compact way to equip an experiment like NEXT, since both the energy measurement and the tracking could be done in the same plane.

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