Rare event searches based on Micromegas detectors: the T-REX project

T Dafni[1], S Aune[2], S Cebrián[1], G Fanourakis[3], E Ferrer-Ribas[2], J Galán[2], J A García[1], A Gardikiotis[4], J G Garza[1], T Geralis[3], I Giomataris[2], H Gómez[1], D C Herrera[1], F J Iguaz[2], I G Irastorza[1], G Luzón[1], T Papaevangelou[2], A Rodríguez[1], J Ruz[5], L Segui[1], A Tomás[1], T Vafeiadis[6,5,4] and S C Yildiz[7,8]

[1] Grupo de Física Nuclear y Astropartículas, University of Zaragoza, Zaragoza, Spain
[2] IRFU, Centre d' Études de Saclay, CEA, Gif-sur-Yvette, France
[3] Institute of Nuclear Physics, NCSR Demokritos, Athens, Greece
[4] University of Patras, Patras, Greece
[5] CERN, European Organization for Particle Physics and Nuclear Research, Switzerland
[6] Aristotle University of Thessaloniki, Thessaloniki, Greece
[7] Boğaziçi University, Istanbul, Turkey
[8] Doğuş University, Istanbul, Turkey

E-mail: tdafni@unizar.es

Abstract. Micromegas readouts are an attractive option for many of the rare event searches, due to their performance regarding energy resolution, gain stability, homogeneity and material budget. The T-REX project aims at developing further these novel readout techniques for Time Projection Chambers and their potential use in experiments searching for rare events. Here we will refer to the latest results regarding the use and prospects of Micromegas read-outs in axion physics (CAST and the future helioscope), as well as the R&D carried out within NEXT, to search for the neutrinoless double-beta decay.

1. Introduction: the T-REX project

The rare event searches, like the axion, the dark matter or the neutrinoless double-beta decay ($0\nu\beta\beta$), are a field involving processes with very low expected rates and dictate challenging requirements on the allowed experimental backgrounds. These are achieved through techniques that include the use of active and passive shielding, operation in underground sites, event discrimination and a careful selection of the detector materials from the radiopurity point of view. One of the powerful tools in event discrimination is the topological information and the directionality of the event. This is a feature that Gaseous Time Projection Chambers (TPC) can offer, in contrast to other detectors, especially after the recent advances in readouts based on micropattern gas detectors (MPGD). The simplicity, robustness and mechanical precision in these are much higher than those of conventional planes of wires and have allowed the competitive proposal of gas TPCs in different rare event applications. Among them, one of the most attractive for their application in rare events, is the Micromegas readout plane [1]. In the last years the efforts to improve the detectors' construction technique have resulted in two new types of detectors, built with the bulk [2] and microbulk [3] technologies. These types provide better robustness, uniformity and therefore stability of operation but also have been measured to have very low radioactivity levels [4].

The T-REX project proposes to merge the latest gas TPC readout concepts in general and the Micromegas one in particular, and the ultra-low background techniques know-how in order to develop practical ideas that could be used in the field. The main component of these studies is the use of the latest generation Micromegas microbulk readout planes and their further development to meet the rather strict requirements of these searches. We present here two applications in which much activity is going on lately, the Micromegas detectors for low background x-ray detection in the CAST experiment [5, 6, 7, 8] for axion searches, and the studies of Micromegas readouts for double beta decay within the NEXT project [9, 10].

2. Micromegas for solar axion searches

The CAST (CERN Axion Solar Telescope) experiment is the most powerful helioscope ever built to search for hypothetical axions coming from the Sun. The energy range of the expected signal is between 1 and 10 keV and therefore low background detectors are necessary to achieve a high sensitivity. While CAST finished its primary data-taking in the summer of 2011, a new proposal for a next-generation axion helioscope has come forward, the IAXO (International Axion Observatory) project [11]. The main features of the latter is the exploitation to the maximum of the powerful characteristics of CAST with the aim to improve substantially the sensitivity, namely the use of a powerful magnet, x-ray focusing optics but also x-ray detectors with very low background levels.

The first Micromegas detectors of the CAST experiment, installed in 2003, have been the first ones with a 2D readout pattern [12]. Parameters like the use of shielding, the screening of the detector components and the advanced discrimination techniques applied, have lead to an enhanced performance of these detectors, manifested by the very low background levels recorded. Since 2007, when the number of Micromegas at the experiment was increased from one to three, a great improvement has been noted on the detector performance. As it can be seen in Figure 1, the background levels recorded by the detectors have dropped by at least a factor of 20 through the years, with the current ones showing levels of 6–9$\times10^{-6}$c s^{-1}cm^{-2}keV^{-1}.

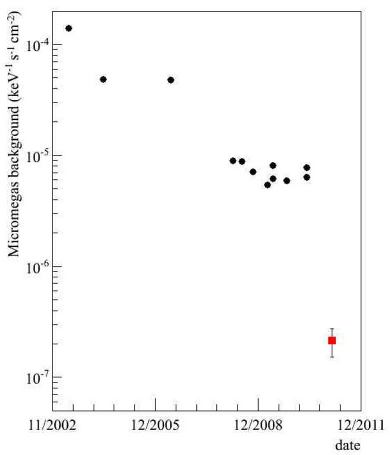

Figure 1. History of the background levels of the Micromegas detectors in different periods in the CAST experiment. The background levels have improved by at least a factor of 20 with respect to the first detectors. The last point on the right represents the background level recorded in the LSC when the detector was covered with 20 cm of lead. This level is approx. 20 times lower than the levels registered in the CAST experiment.

These results have initiated more dedicated studies in order to understand the origin of the background in these detectors, with the aim to further reduce it. A copy of one of the systems in CAST was prepared and installed to take data in the lab in Zaragoza and later moved underground in the Canfranc Underground Laboratory (LSC). In an initial stage of the studies, levels as low as 2×10^{-7}c s^{-1}cm^{-2}keV^{-1}, much lower than those measured in CAST, are reached by adding more lead all around the detector (Figure 1). The results obtained indicate that this level would correspond to the intrinsic level of the radiopurity of the detector components while the background at CAST is most probably driven by the external gamma radiation. In parallel, a simulation of the detector setup has been performed, with a detailed description of the geometry of the detector and its shielding but also implementing the detector response from signal generation to the electronic chain as is currently used in CAST. The experimental data and the simulated signals are in good agreement, even after the off-line analysis is performed. The combination of the studies mentioned here provide the needed information in order to design improvements on the shielding of some of the detectors in CAST. The aim is to identify and reduce effective sources of background in order to reach levels of the order of $10^{-8}\mathrm{c\,s^{-1}cm^{-2}keV^{-1}}$, in view of the requirements for the IAXO project. More details on the tests performed can be found in [13, 14].

3. Micromegas for double beta decay in the frame of the NEXT project

The NEXT (Neutrino Xenon TPC) experiment will build a 100 kg gas Xe TPC to look for the neutrinoless double-beta decay and will be operated at the LSC. Although the decided baseline for the NEXT100 detector is an electroluminescent photosensor readout, the development of Micromegas is still motivated as a backup option or for an eventual future extension to larger masses, due to the promising prospects for large areas offered by MPGDs. Another collaboration, EXO-gas, also develops a gas TPC to search for the double beta decay of ^{136}Xe, and considers Micromegas as an option for its readout [15]. Here we describe the latest results performed in the framework of the NEXT project to develop Micromegas readouts for $\beta\beta$ searches [16].

The two main aspects of the work performed so far were relative to establishing the operation of Micromegas planes in high pressure Xe and to exploring their energy resolution under these conditions. Two stainless steel prototypes have been built, one with a volume of 2 litres and a drift length of 6 cm and a bigger one (NEXT-MM), with a readout area of 30 cm and a drift region of 35 cm, long enough to contain a high energy electron track. The first one is dedicated to mainly study small-size microbulks in different gas mixtures. NEXT-MM will study the electron tracks, essential for event discrimination as that is the expected signal in such an experiment.

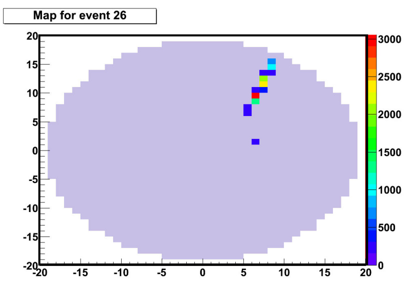

Figure 2. An alpha track obtained with a ^{222}Rn source with the bulk detector inside NEXT-MM.

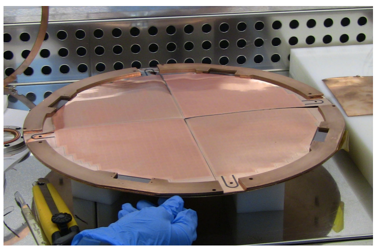

Figure 3. The microbulk readout, divided in 4 segments, recently installed in NEXT-MM.

Here we will only mention some conclusions with the smaller chamber, while a more detailed description of the prototypes and the results can be found in [17, 18]. A long series of tests have been performed, showing that the microbulk readouts perform well in high pressure pure Xe, with gains higher than 100. Representative of the measurements with the 5.5 MeV alpha peak of the ^{241}Am, energy resolutions down to $\sim$2% (FWHM) in pure Xe, roughly independent of pressure, have been measured. When blocking the alphas, the energy resolution achieved for the

59.5 keV photon peak of the same source is of 9.3% (FWHM) at 3.5 bar, which are consistent with other measurements performed [19]. Tests adding a quencher to the Xe are being performed as well, as they are of potential interest because of the higher gains achieved with these mixtures. NEXT-MM was equipped at first with a bulk readout which had 1252 pixels, independently read, with electronics based on the AFTER chip. First alpha tracks were recorded using this readout (Figure 2). Recently, the bulk was replaced by four microbulk Micromegas with the shape of circular segments (Figure 3). The prototype equipped with this readout, the largest surface built up to now with microbulks, is in its commissioning phase.

4. Conclusions

The T-REX project is promoting the development of microbulk Micromegas in combination with ultra-low background techniques, for their use in rare event searches. We have presented the performance of these readouts in two areas of interest, solar axions and double beta decay, gathering characteristics such as the stability of operation, very low background levels (6–9$\times10^{-6}$c s^{-1}cm^{-2}keV^{-1}), excellent spatial resolution, good operation at high pressures and with very encouraging results regarding the energy resolution.

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