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Status of low mass WIMP detector TREX-DM

J. Castel[1,2], S. Cebrián[1,2], T. Dafni[1,2], J. Galán[1,2], I.G. Irastorza[1,2], G. Luzón[1,2], H. Mirallas[a,1,2], A. Ortiz de Solórzano[1,2], A. Peiró[1], E. Ruiz-Chóliz[1,2]

[1]Laboratorio de Fsica Nuclear y Astropartculas, Universidad de Zaragoza. C/ Pedro Cerbuna 12, 50009 Zaragoza, Spain.
[2]Laboratorio Subterrneo de Canfranc (LSC). Paseo de los Ayerbe s/n, 22880 Canfranc Estacin, Huesca, Spain.

E-mail: [a]`mirallas@unizar.es`

Abstract. TREX-DM (TPC Rare Event eXperiment for Dark Matter) is a high-pressure Micromegas-based TPC designed to host a few hundreds of grams of light nuclei (argon or neon) with energy thresholds potentially at the level of 0.4 keVee or below. Preliminary background studies suggest that the levels expected are of the order of $1-10$ counts keV^{-1} kg^{-1} d^{-1}, making TREX-DM competitive in the search for low mass WIMPs (<10 GeV). The experiment has been approved by the LSC (Laboratorio Subterrneo de Canfranc) and the last months have been devoted to its installation underground. Here we will report on the first commissioning phase.

1. Introduction

Dark Matter experiments are focusing their detection techniques in low-mass WIMPs (<10 GeV), which requires the use of light elements and low energy threshold. In this context, we present the TREX-DM experiment [1], a low background Micromegas-based TPC for low-mass WIMP detection. Its main goal is the operation of an active detection mass of ~ 0.300 kg of Ar or ~ 0.160 kg of Ne at 10 bar, with an energy threshold below 0.4 keVee and fully built with previously selected radiopure materials. This proceeding describes the actual setup, the first results of the commissioning in Ar+1% iC_4H_{10} at 1.5 bar and the future updates for a possible physics run at the Canfranc Underground Laboratory in 2019. A background model is also presented, suggesting that the expected levels are of the order of 1-10 counts keV^{-1} kg^{-1} d^{-1}, based on Geant4 simulations and discrimination methods. A road-map to further decrease it down to 0.1 counts keV^{-1} kg^{-1} d^{-1} is underway.

2. Motivation and goals

The detection of Dark Matter (DM) [2] is one of the open challenges of Astroparticle and Particle Physics for the next years. Its solution may involve new particles with masses and cross-sections characteristic of the electroweak scale. The most compelling ones are the weakly interactive massive particles (WIMPs) [3] or axions and axion-like particles (ALPs) [4]. From the first type, some positive hints of signals have been reported. The most important one is due to DAMA/LIBRA experiment [5], which has observed an annual modulation (20 cycles) compatible with that expected for galactic halo WIMPs.

A long-standing strategy of DM experiments is based on accumulating large target masses of heavy nuclei (like Xenon), keeping low background levels by a systematic radiopurity control of all components and an enhancement of the electron/neutron discrimination methods. However, this strategy is not suitable for low WIMPs masses as for heavy nuclei this translates into very low nuclear recoil energies, and discrimination methods normally fix a relatively high energy threshold (1-10 keV). Given that low WIMP masses are invoked to explain the reported hints, there is now strong interest in exploring new strategies better focused on the low mass range. For instance, CDMSlite experiment [6] has recently reached an energy threshold as low as 90 eVnr in Germanium detectors.

Gaseous detectors may also play an important role in future experiments, as they can reach sub-keV energy threshold ($\sim$ 100 eV) and have access to richer topological information. Most of these experiments (like DRIFT [7] and MIMAC [8]) are focused on directional detection of DM [9], aiming to exploit the relative inhomogeneity of the WIMP incoming momenta, with a maximum expected in the direction of the Cygnus constellation. This stream could be observed by a low-pressure gaseous detector, as it will effectively select nuclear recoils from electrons [10] and it could determine their direction and sense of the nuclear recoil tracks [11]. However, these last features very fast degrade for long drift distances, which may limit the scalability of this type of experiments.

In this context, the TREX-DM experiment proposes another strategy based on high gas pressures, even if neutron/electron discrimination could be less effective, but keeping a low energy threshold. The TREX-DM experiment, conceived for low-mass WIMP detection, is formed by a low background TPC working at high gas pressures and uses the Micromegas technology for the readout planes [12] [13] [14]. The low background strategy is based in the measurement and selection of radiopure materials [15] [16], specially those carried out in CAST [17] and NEXT-MM [18] projects. TREX-DM can hold, in its active volume, 20 l of pressurized gas up to 10 bar corresponding to $\sim$ 0.300 kg of Ar or $\sim$ 0.160 kg of Ne, with an energy threshold below 0.4 keVee (as already observed in [17]) or lower. Another experiment with a similar approach is NEWS-G [19], a Spherical Proportional Counter filled with a neon-helium mixture at high pressure that has reached an energy threshold as low as 0.1 keVee.

This article describes the actual setup of TREX-DM and the first results after its commissioning at the LSC (Laboratorio Subterrneo de Canfranc) during 2018. In a second part, the background model of the experiment is presented.

3. Setup description

The actual setup (see figure 1) is composed of a high purity copper vessel of 6 cm thickness, with an inner diameter of 0.5 m and a length of 0.5 m. The vessel contains two active volumes (a), separated by a central copper cathode (b). At each side there is a field cage (d) that makes uniform the drift field along the 19 cm between the cathode and the Micromegas. Each Micromegas detector (e) is screwed to a copper base, which is then attached to the vessel inner walls by means of four columns. The gas enters the vessel by a feedthrough at the bottom part (h) and comes out by another one at the top part (i). The calibration system consists of a plastic tube entering in the bottom part (h), which allows to calibrate in each active volume with a ^{109}Cd source, emitting X-rays of 22.1 keV (K_α) and 24.9 keV (K_β). Finally, the vessel can be pumped from the feedthrough (i) at the top to reduce outgassing from the inner walls.

The shielding of the experiment is built: the detector copper vessel is sitting inside a 5 cm thick oxygen-free copper box, as seen in the figure 2 right, surrounded by 20 cm of lead (an inner, 10 cm thick, layer of LSC bricks produced from lead from the OPERA experiment and another 10 cm thick layer of TREX-DM bricks). The whole lead castle is enclosed by a plastic cover into which evaporated N_2 is flushed with a nominal flow of 15 l/h, in order to ensure the suppression of Rn in the vicinity of the detector. A neutron shielding surrounding the lead castle

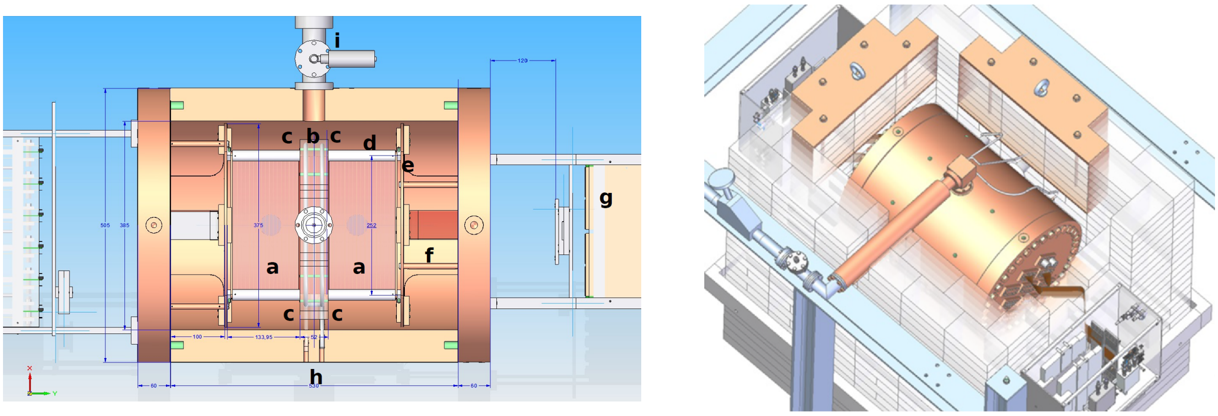

Figure 1. Left: Drawing of the TREX-DM detector. Its different parts are described in detail in the text: active volumes (a), central cathode (b), calibration points (c), field cage (d), Micromegas detector and support base (e), flat cables (f), AGET-based electronics (g), gas system (h) and pumping system (i). **Right**: 3D drawing of the TPC including part of the shielding and other components.

is also foreseen: it consists of 40 cm of polyethylene (PE) at the top and bottom of the castle, while the lateral walls will be covered with water tanks.

The design of the two microbulk micromegas detectors is a modified version of one used in CAST [17], with 50 μm amplification gap. The active surface of 25 x 25 cm^2 is divided in squared pads of about 1 x 1 mm^2 (see figure 2 left). Pads are alternatively interconnected in X and Y directions (256 strips per direction) through metallized holes, which are rooted into two connector footprints at two sides of the active area. A flat cable is linked to each connector footprint by means of a Fujipoly connector (see figure 2 center). Each flat cable goes out from the vessel by means of a copper feed-through.

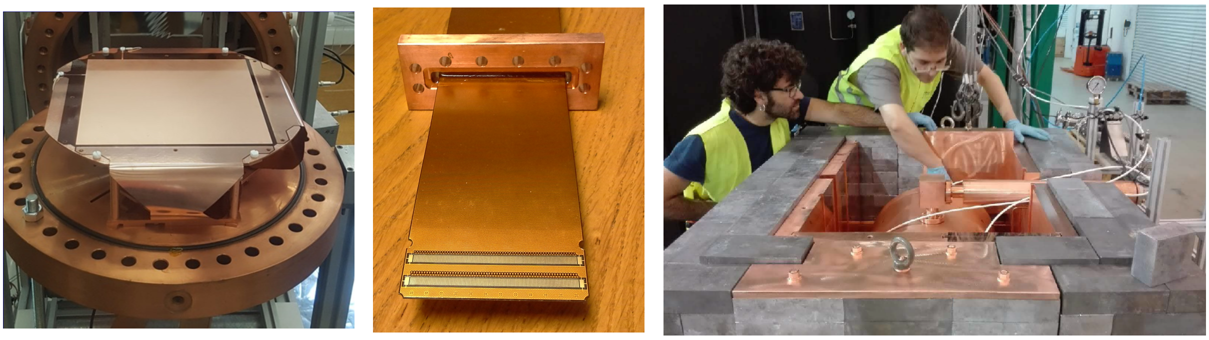

Figure 2. Left: Picture of one microbulk Micromegas placed at one flat end-cap of the vessel, the second micromegas is placed similarly at the opposite end-cap. It can be seen how the flexible circuit, in which the micromegas is fabricated, is bent in the bottom and right sides in order to connect the flat cable. **Center**: Picture of one flat cable that is connected to the micromegas inside the vessel and take the signals out of the vessel. One square flange is fixed by means of epoxy to the flat cable in order to get a tight feed-through. The Fujipoly connector footprint can be seen at the end of the flat cable, which is used to connect the flat cable with the micromegas. **Right**: Shielding assembling process, the different walls of lead and copper can be seen with the vessel in the center.

The operation principle is the same as in any Micromegas-based TPC. An event interacts in the active volume and releases some electrons, which drift toward the Micromegas plane. Electrons are then amplified in a gap of 50 μm and the charge movement induces signals both at the mesh and the strips. In previous phases of the detector the mesh signal was used to trigger the electronics readout (Front End Card based on the chip AFTER), but at this last stage of the setup the Front End Card has been switched to a new one based on the chip AGET, with significant new features. Among all the new features it is worth noting the self-trigger, which allows to trigger the electronics with the very signal from the strips and without the need of using the mesh signal as external trigger. Two Front End Cards (FEC), with 4 AGET chips on each card, read out the 2 x 256 channels of each micromegas detector. Employing more than one FEC makes necessary the use of a trigger manager (Trigger Clock Module, TCM). The TCM distributes a common 100 MHz reference clock and trigger signals to all the FECs. Each FEC collects and samples the strip signals continuously in 512 samples per channel, recording a window of about 20 μs, which is longer than the maximum drift time of charges created in the active volume. When trigger happens the analog data from each channel is digitized by an A/D converter included in the FEC, then a pure digital electronics card gathers the ADC data, performs the pedestal subtraction and sends it to the DAQ system by means of a standard network. One event from a calibration round and directly extracted from the DAQ system, without applying any analysis, can be seen in the figure 3.

4. Detector performance

Once the detector was placed in the final position inside the underground laboratory, and the slow control and DAQ systems were operative, the chamber was filled with Argon + 1% iC_4H_{10} at 1.5 bar. The first calibration rounds with ^{109}Cd source were done in both active volumes of both micromegas. An example of the acquired spectrum can be seen in the figure 4 (up left), where the 2 peaks corresponding to the 8 keV fluorescence of Cu (see one of these events in the figure 3) and the sum of the main emission X-rays of ^{109}Cd (22.1 keV from K_α and 24.9 keV from K_β) can be identified.

The spectrum reflects a qualitative agreement with the spectrum from simulations (figure 4 up right). The 88 keV is not expected to be prominent at this pressure, and neither is the 2.9 keV edge of Ar (the escape photon should be absorbed within the large volume of the detector). However, another peak, at around 45 keV, due to event pileup is visible.

The projection to the readout plane of the distribution of the events in the volume is in agreement with the one expected from simulations, as also shown in the figure 4 down left and right.

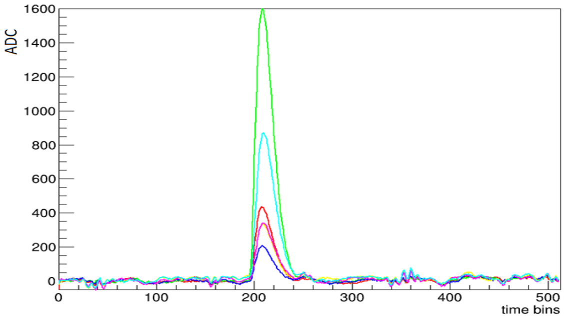

Figure 3. Event of 8 keV, from fluorescence of Cu, recorded by the electronics after a trigger during a calibration round with a ^{109}Cd source. Although the electronics is able to record all the channels (strips) at one time for one trigger, here we can see only the five channels that crossed the imposed threshold.

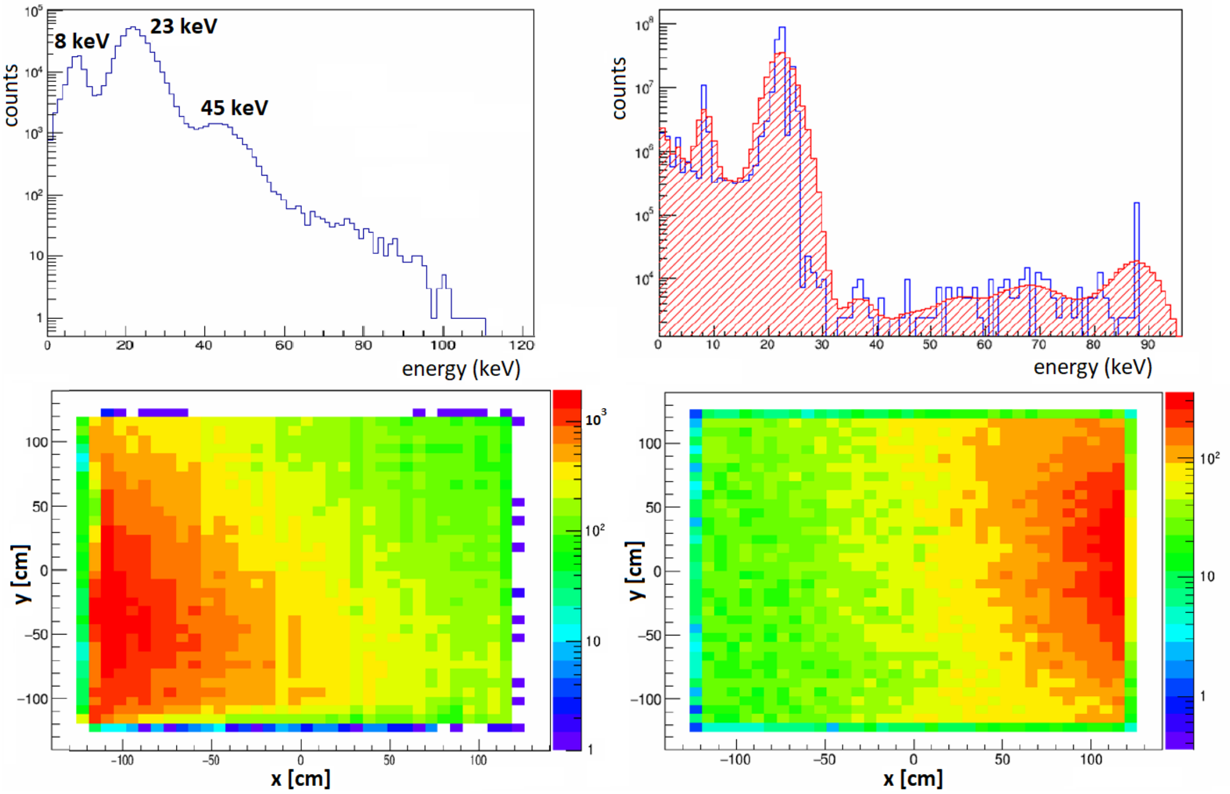

Figure 4. **Up**: Raw energy spectrum of a ^{109}Cd calibration with one of the micromegas (left), compared to the spectrum obtained by simulations (right), where a smearing reflecting the energy resolution has been applied. **Down**: Distribution of the events in the active surface with the same micromegas used to build the spectrum (left) compared to those from simulations (right). Note that the surfaces are symmetric because the simulations were carried out for the micromegas placed in the opposite side of the chamber.

5. Background model

The preliminary background model of TREX-DM for operation at LSC, presented in [1], has been completed: it includes the activities of most of the components used in the detector and ancillary systems obtained from a complete screening program together with the measured fluxes of environmental backgrounds at LSC (gamma-rays, neutrons and muons) [20]. The model points to levels of the order of 1 to 10 counts keV^{-1} kg^{-1} d^{-1} in the region of interest in the conditions of the current setup, making TREX-DM competitive in the search for low-mass WIMPs. A few points to improve have been identified and could be undertaken in an attempt to further decrease the background by a factor 10 at least.

The complete simulation of the detector response to background sources to build the TREX-DM background model is based on Geant4 and a custom-made code called REST [21], properly interfaced. The main background sources have been simulated in order to evaluate their contribution to the counting rate in the region of interest for dark matter searches: radioactive isotopes in the elements of the setup (either primordial or cosmologically produced), radon-induced activity and backgrounds at the LSC (including gamma-rays, muons and neutrons).

The total expected background level from the internal activity (inside or close to the vessel) should be below 6.1(6.6) counts keV^{-1} kg^{-1} d^{-1} for Ar(Ne). From that, 70(64)% come from activities actually quantified. One of the largest contributions is due to the copper vessel, cosmologically activated after being a few years at sea level, as shown in a dedicated germanium measurement but potentially suppressible by constructing a new vessel. Also it has been measured a ^{40}K activity in the micromegas readout that gives a significant rate, but new chemical treatments are being analyzed in an attempt to reduce this activity. The use of underground argon has been assumed, considering the ^{39}Ar activity measured by DarkSide [22]. It has been verified that a saturation activity of tritium in the gas media could be very relevant, but the gas purification and procurement from underground sources will hopefully avoid this contribution.

Concerning background sources out of the vessel, the ^{210}Pb from the lead bricks of the shielding could be important, therefore lead with lower activity or an additional copper shielding would be necessary to reduce this contribution. The other external components give much lower rates, as the effect of radon and radon-induced activity on copper surfaces which are non-dominant at the present phase, or the contribution from muons and environmental neutrons which are under control in the simulated conditions (thanks to the offline background rejection capabilities and the shielding).

For more details about the background assessment and the corresponding sensitivity see [20].

6. Conclusions

The first results from the first calibration rounds during the commissioning in Ar+1% iC_4H_{10} at 1.5 bar have been presented here, with a qualitative agreement with the simulations. The first data-taking campaign with Neon in the chamber can be foreseen for the next months, after the pertinent commissioning time, until reaching the operation pressure of 10 bar.

From the background assessment it can be concluded that the conservative background assumption of 10 counts keV^{-1} kg^{-1} d^{-1} is at reach in the present conditions of the simulations. To get a level of 1 counts keV^{-1} kg^{-1} d^{-1}, a significant reduction of the two main contributions from the quantified activities should be enough: a new copper vessel produced using fresh copper and a reduction of the own micromegas activity by new chemical treatments.

These expected conditions for TREX-DM provide a competitive sensitivity in the direct detection of low mass WIMPs.

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