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Status of the TREX-DM experiment at the Canfranc Underground Laboratory

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Abstract. The TREX-DM experiment is conceived to look for low mass WIMPs by means of a gas time projection chamber equipped with novel micromegas readout planes at the Canfranc Underground Laboratory. The detector can hold 20 l of pressurized gas up to 10 bar, which corresponds to 0.30 kg of Ar, or alternatively, 0.16 kg of Ne. The micromegas will be read with a self-triggered acquisition, allowing for effective thresholds below 0.4 keV (electron equivalent). The preliminary background model, following a complete material screening program, points to levels of the order of 1-10 counts keV^{-1} kg^{-1} d^{-1} in the region of interest, making TREX-DM competitive. The status of the commissioning, description of the background model and the corresponding WIMP sensitivity will be presented here.

1. Introduction

Looking for low mass WIMPs which could be pervading the galactic dark halo requires the use of light elements as target and detectors with very low energy threshold and very low radioactive background. Gas Time Projection Chambers (TPCs) with micromegas planes have excellent features to fulfill these requirements. TREX-DM (TPC for Rare Event eXperiments-Dark Matter) [1, 2] is a micromegas-read High Pressure TPC for low mass WIMP searches using Ar or Ne mixtures, not focused on directionality. The detector was built and operated at surface in the University of Zaragoza as proof of concept. The experiment has been approved by the Canfranc Underground Laboratory (LSC) in Spain and is expected to be installed underground by the end of 2017. The detector set-up and performance are described in section 2, while the background model developed and the corresponding sensitivity for WIMP direct detection are discussed in sections 3 and 4.

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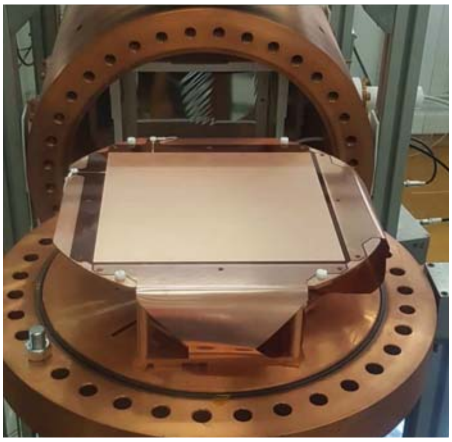

Figure 1. Microbulk micromegas of TREX-DM (the largest ever fabricated) being tested at the University of Zaragoza.

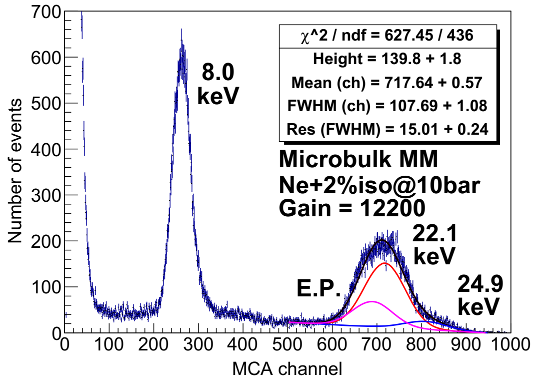

Figure 2. Energy spectrum obtained in the characterization of microbulk micromegas with Ne using a ^{109}Cd source. The results of a multi-Gaussian fit for estimating the FWHM at 22.1 keV are shown.

2. Detector set-up and performance

Micromegas are consolidated readout structures; a micro-mesh is suspended over a pixelated anode plane, forming a thin gap where charge amplification takes place. Detectable signals in the anode and the mesh are generated. Different technologies have been built: bulk micromegas have the readout plane and the mesh all in one and microbulk micromegas are in addition more homogeneous and radiopure [3]. They offer important advantages for rare event detection: possibility of scaling-up, topological information to discriminate backgrounds from the expected signal (just a few microns track for dark matter, giving a point-like event) and low intrinsic radioactivity as they are made out of kapton and copper, potentially very clean. Indeed, after a first screening of micromegas readouts using a germanium detector in Canfranc [4], more sensitive measurements using the BiPo-3 detector [5] and a germanium detector with larger samples are available now. The activity of the lower part of the ^{238}U and ^{232}Th chains is below 0.1 μBq/cm^2 [6]. An activity of (3.45±0.40) μBq/cm^2 of ^{40}K has been quantified, which seems to be related to the production of holes by kapton etching using a potassium compound.

The TREX-DM detector, as built and operated at University of Zaragoza, is described in detail in [1]. Two active volumes (19×25×25 cm^3 each) are separated by a central cathode made of mylar inside a copper pressure vessel. The field cage, made of kapton and copper, is covered by teflon. Two bulk micromegas readouts were installed at the anode planes. Signals were extracted by flat cables to the AFTER-based electronics. For the set-up at hall A of LSC, the detector will be upgraded using new more radiopure connectors, microbulk micromegas and an AGET-based DAQ system; a complete shielding consisting of 5 cm of copper, 20 cm of low activity lead, 40 cm of neutron moderator is being installed and there will be a Rn-free atmosphere inside shielding. Signals from 256×256 strips (∼1 mm pitch) will be digitized for tracking and additional energy spectra are taken from the mesh. The microbulk micromegas of TREX-DM are the largest area single microbulk readout ever produced so far, with an active area of 25×25 cm^2. After fabrication at CERN, they are being tested inside the TREX-DM detector for the first time (see figure 1).

First results from the commissioning phase of TREX-DM on surface were shown in [1]. More recently, microbulk micromegas have been characterized in Ar+1%iC_4H_{10} and Ne+2%iC_4H_{10} mixtures at 1-10 bar using a ^{109}Cd source. Energy resolution has shown some degradation with

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pressure, being the FWHM at 10 bar 16(15)% for Ar(Ne) at 22.1 keV (see figure 2). An excellent behavior has been registered for gain, with maximum values above $10^3(10^4)$ in Ar(Ne) for all pressures, which is very important for achieving low energy thresholds. In principle, a very low threshold is possible thanks to the intrinsic amplification in gas. In practice, the readout area, the sensor capacitance and the electronic noise set the threshold. A value of 0.45 keV$_{ee}$[5] has been currently achieved in a CAST-like detector using AFTER electronics [7]. In the Zaragoza set-up, the trigger was limited by the mesh channel noise level; therefore, trigger is going to be obtained from low capacitance strips, using the AGET electronics. In this way, the TREX-DM nominal (conservative) aim for effective threshold is 100 eV$_{ee}$ (400 eV$_{ee}$).

3. Background model

Ultra-low background conditions are a must in the direct detection of WIMPs. An exhaustive material screening campaign underway for several years has allowed to design and construct the detector and shielding according to the radiopurity specifications [1, 6, 8]; it is based on germanium gamma spectrometry in Canfranc complemented by other techniques (GDMS, ICPMS and BiPo-3 measurements). A preliminary background model of TREX-DM for operation at LSC was presented in [1] and is being completed, including as inputs the material activity from the screening program together with the measured fluxes of environmental backgrounds at LSC (gamma-rays, neutrons and muons). Simulations of the detector response are based on Geant4 (for physical processes) and the custom-made REST code (for electron generation in gas, diffusion effects, charge amplification at micromegas, signal generation and analysis to select point-like events). A detailed geometry of the set-up including shielding has been implemented (see figure 3) considering Ar and Ne mixtures at 10 bar.

Table 1 presents the background rates from 2 to 7 keV$_{ee}$[6] due to primordial or cosmogenic activity in components inside or close to the vessel. The largest contribution comes from the copper vessel, cosmogenically activated after being a few years at sea level; an activity of (0.24±0.05) mBq/kg of ^{60}Co was quantified in a dedicated germanium measurement and included in the model. This important contribution could be suppressed by constructing a new vessel. The measured ^{40}K activity in the micromegas readout (see section 2) gives also a significant rate; new chemical treatments are being analyzed to reduce this activity. The use of underground argon has been assumed, considering the ^{39}Ar activity measured by DarkSide [9]. The total expected background level is around 5(6) counts keV^{-1} kg^{-1} d^{-1} for Ar(Ne). Table 2 shows the same background rates but from activity in components outside the vessel and backgrounds at the laboratory. The effect of radon-induced activity on copper surfaces has been assessed, considering the deduced limit (<0.32 mBq/cm^2 of ^{210}Pb) from a direct germanium measurement on exposed copper. The contribution from muons and environmental neutrons is under control in the simulated conditions. All in all, the TREX-DM expected background is between 1 and 10 counts keV^{-1} kg^{-1} d^{-1}.

4. Sensitivity prospects

Figure 4 presents the attainable exclusion plots (90% C.L.) in the direct detection of WIMPs, for both Ar and Ne-based gas mixtures at 10 bar, obtained assuming spin independent (SI) interaction and standard values of the WIMP halo model and astrophysical parameters. Three different scenarios for flat-shaped background, energy threshold and exposure have been considered (see table 3). A data-taking campaign of approximately three years is foreseen, starting with Ne with the option to change to depleted Ar. TREX-DM has a good potential to be sensitive to low mass WIMPs beyond current bounds even at the scale of current detector.

[5] Electron equivalent energy.

[6] This energy range corresponds to 5.2-16.3 keV for Ar and 5.5-17.1 keV for Ne for nuclear recoils, following

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Table 1. Background rates (in counts keV^{-1} kg^{-1} d^{-1}) expected in 2-7 keV$_{ee}$ from activity in components inside or close to the vessel using Ar or Ne mixtures in TREX-DM. Isotopes giving the dominant contribution are indicated in the last column.

Component	Argon	Neon	Main contribution
Vessel (primordial)	<0.088	<0.104	^{238}U
Vessel (cosmogenic)	1.25	1.50	^{60}Co
Copper Boxes (primordial)	<0.026	<0.034	^{238}U
Copper Boxes (cosmogenic)	0.034	0.046	^{60}Co
Field Cage (PTFE)	<0.033	<0.051	^{238}U
Field Cage (resistors)	<0.35	<0.63	^{238}U
Field Cage (kapton-Cu PCB)	<1.06	<1.81	^{238}U
Field Cage (cable)	<0.028	<0.052	^{238}U
Cathode (copper)	<0.0081	<0.012	^{238}U, ^{40}K
Cathode (PTFE)	<0.064	<0.085	^{238}U
Readout Planes	<1.24	<1.14	^{40}K
Flat Cables	<0.0097	<0.013	^{238}U
Connectors	<0.19	<0.24	^{238}U
Epoxy	<0.0044	<0.0056	^{232}Th
Mesh Cable	$<6.1\times10^{-4}$	$<7.7\times10^{-4}$	^{238}U
Other PTFE Components	<0.017	<0.026	^{238}U
Target	0.15		^{39}Ar
Total	<4.6	<5.8	

Table 2. Background rates (in counts keV^{-1} kg^{-1} d^{-1}) expected in 2-7 keV$_{ee}$ from activity in components outside the vessel and backgrounds at LSC using Ar or Ne mixtures in TREX-DM. Contributions marked with (*) are 90% C.L. limits when no event was registered in preliminary simulations.

Component	Argon	Neon
Neutrons at LSC	$(2.52\pm0.22)\times10^{-2}$	$(7.06\pm0.61)\times10^{-2}$
Neutrons from ^{238}U fission in Pb	$(5.82\pm0.39)\times10^{-5}$	$(1.094\pm0.074)\times10^{-4}$
Neutrons from ^{238}U fission in Cu	$<2.1\times10^{-6}$	$<4.1\times10^{-6}$
Muons (+ muon-induced neutrons)	0.205 ± 0.021	0.336 ± 0.034
^{210}Pb in Pb shielding (*)	<0.12	
Surface ^{210}Pb on Cu vessel	$<3.5\times10^{-3}$	$<6.2\times10^{-3}$
Surface ^{210}Pb on Cu shielding (*)	<0.025	<0.034
Cosmogenic ^{60}Co in Cu shielding	0.0250 ± 0.0018	0.0288 ± 0.0020
^{222}Rn in air	0.1495 ± 0.0024	0.0841 ± 0.0013
External gammas from ^{232}Th (*)	<9.9	
External gammas from ^{238}U (*)	<18	
External gammas from ^{40}K (*)	<27	

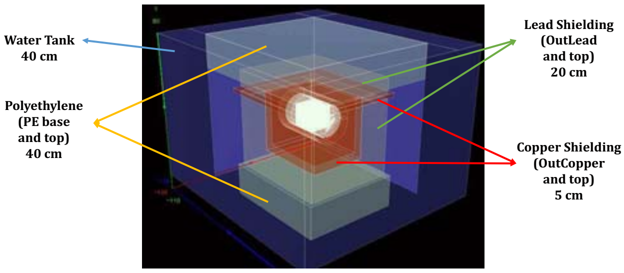

Figure 3. TREX-DM geometry implemented in Geant4 simulations.

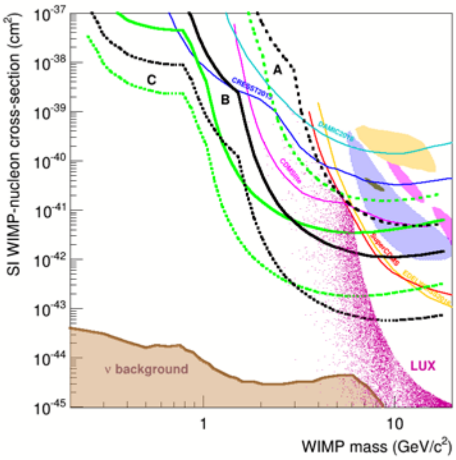

Figure 4. 90% C.L. sensitivity of TREX-DM under different conditions (see table 3) for Ar+1%iC_4H_{10} (black lines) and Ne+2%iC_4H_{10} (green lines).

Table 3. Conditions assumed in the calculations of the TREX-DM sensitivity shown in figure 4.

	A	B	C
Background level (counts keV^{-1} kg^{-1} d^{-1})	10	1	0.1
Energy threshold (keV_{ee})	0.4	0.1	0.1
Exposure (kg y)	0.3	0.3	10

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