Commissioning of TREX-DM, a Low Background Micromegas-based Time Projection Chamber for Low Mass WIMP Detection

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Dark Matter experiments are recently focusing their detection techniques in low-mass WIMPs, something which requires the use of light elements and low energy threshold. In this context, we describe the TREX-DM experiment, a low background Micromegas-based Time Projection Chamber for low-mass WIMP detection. Its main goal is the operation of an active detection mass ∼0.3 kg, with an energy threshold below 0.4 keVee and fully built with previously selected radiopure materials. This work focuses on the commissioning of the actual setup situated in a laboratory on surface. A preliminary background model of the experiment is also presented, based on Geant4 simulations and two discrimination methods: a conservative muon/electron and one based on a ^{252}Cf source. Based on this model, TREX-DM could be competitive in the search for low mass WIMPs and, in particular, it could be sensitive to the WIMP interpretation of the DAMA/LIBRA hint.

1 Motivation

The main strategy of Dark Matter experiments [1] 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, some recent positive hints, which may be interpreted in terms of low mass WIMPs, have changed the detection strategy to sub-keV energies and light gases. This research line could be led in future experiments by Time Projection Chambers (TPCs), as they can reach energy thresholds ∼ 100 eV and have access to richer topological information. In contrast to current gaseous-based experiments, focused on directional Dark Matter detection [2], the TREX-DM experiment proposes a strategy based on high gas pressures, even if neutron/electron discrimination could be less effective, but keeping a low energy threshold. TREX-DM is a low background Micromegas-based TPC for low-mass WIMP detection and will profit from all developments made in Micromegas technology [3, 4], as well as in the selection of radiopure materials [5, 6], specially in CAST [7] and NEXT-MM [8] projects. Its main goal is the operation of an active detection mass ∼0.3 kg with an energy threshold below 0.4 keVee (as already observed in [7]).

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2 Description and commissioning

The actual setup (Fig. 1) is composed of a copper vessel, with an inner diameter of 0.5 m, a length of 0.5 m and a wall thickness of 6 cm. The vessel contains two active volumes (a in the design), 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 detector. Each bulk Micromegas detector (e) [9] is screwed to a copper base, which is then attached to the vessel's 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 each side at four different points (c) with a ^{109}Cd source, emitting X-rays of 22.1 (K_α) and 24.9 keV (K_β).

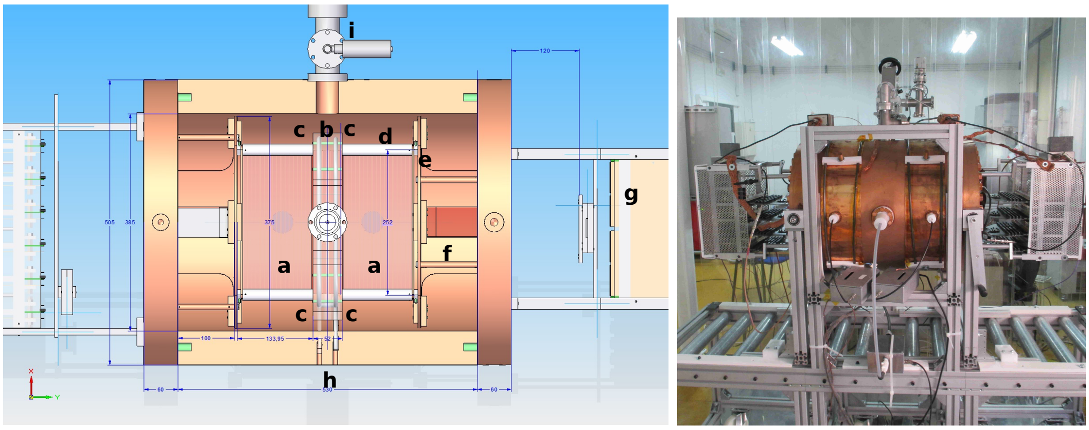

Figure 1: Left: Design of the TREX-DM detector. Its different parts are described in detail in the text: active volumes (a), central cathode (b), calibration points (c), field cage (d), Micromegas detector and support base (e), flat cables (f), AFTER-based electronics (g), gas system (h) and pumping system (i). Right: A view of the experiment during the comissioning.

The TREX-DM prototype is part of the wider scope ERC-funded project called TREX (TPCs for Rare Events eXperiments), that since 2009 is devoted to R&D on low background TPCs and their potential applications in axion, double beta decay and dark matter experiments. Work on the TREX-DM prototype started in 2012 with the first designs and it is now being commissioned at the TREX lab at Zaragoza. Most of the components have been validated: the leak-tightness of all feedthroughs has been verified for pressures up to 10 bar, the drift cage has been tested at high voltage, and all experimental parameters like the pressure, the temperature and voltages are continuously monitored by a slow control. Moreover, during the first semester of 2015, some issues have been successfully solved: the noise level has been effectively reduced by a new High Voltage filter for the central cathode and a Faraday cage for the interface cards, a new field cage has been installed to reduce border effects, and a new DAQ to read both detectors at a rate of 45 Hz each side has been installed. During the next months, the detector will be characterized in Ar+2%iC_4H_{10} and Ar+5%iC_4H_{10}, with the aim to detect sub-keV energies at high gas pressures. In parallel, the first designs of a fully radiopure setup are being made, which include a lead shielding and the replacement of some dirty components in terms of radiopurity.

3 Background model of TREX-DM

The sensitivity of the experiment has been studied creating a first background model which reproduces the conditions at the Canfranc Underground Laboratory (LSC). We have considered two light gas mixtures at 10 bar: Ar+2%iC_4H_{10} and Ne+2%iC_4H_{10}, with an active mass of 0.3 and 0.16 kg respectively and which are good candidates to detect low mass WIMPs. However, the sensitivity of an argon-based mixture may be limited by one of its isotopes (^{39}Ar), which is β-emitter and has a long life-time. In our model, we have considered the lowest content of this isotope, measured in argon extracted from undeground sources [10]. We have also simulated the main radioactive isotopes of all the inner components using their measured activities [5, 6] and the cosmic muon flux in Canfranc. In some cases like the Micromegas detectors or their connectors, we have considered the activities of their radiopure alternative. The external gamma flux has not been included as its contribution may be supressed by an external shielding.

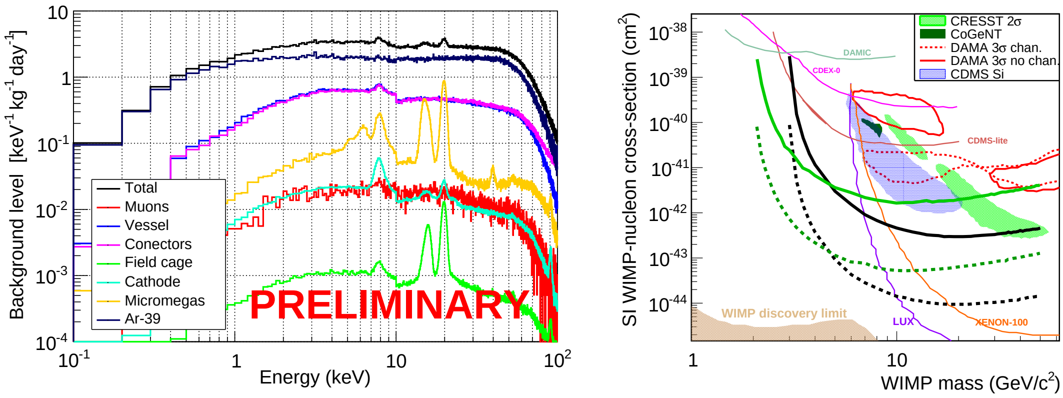

Figure 2: Left: Background spectrum expected in TREX-DM experiment (black line) during a physics run in an underground laboratoy if operated in Ar+2%iC_4H_{10} at 10 bar. The contribution of the different simulated components is also plotted: external muon flux (red line), vessel contamination (blue line), connectors (magenta line), field cage (green line), central cathode (brown line), Micromegas detector (purple line) and ^{39}Ar (dark blue line). Right: WIMP parameter space focused on the low-mass range. Filled regions represent the values that may explain the hints of positive signals observed in CoGeNT, CDMS-Si, CRESST and DAMA/LIBRA experiments. The thick lines are the preliminary sensitivity of TREX-DM supossing a 0.4 keVee energy threshold and two different hypothesis on background and exposure: 100 (solid) and 1(dashed) keV^{-1} kg^{-1} day^{-1}, and 1 and 10 kg-year respectively, and for both argon- (black) and neon-based (green) mixtures.

Two analysis have been used in this background model. The first one is a modified version of the CAST one [7], optimized to discriminate low energy X-rays from complex topologies like gammas and cosmic muons. It uses two likelihood functions generated by the X-rays' cluster features of a calibration source. Fixing a total of 80% signal efficiency, the expected background level for an argon- (neon-) based mixture gas at 10 bar is ∼3.1 (∼1.4) keV^{-1} kg^{-1} day^{-1}, dominated by the ^{39}Ar isotope in the case of argon and by the connectors and the vessel in the case of neon. The contribution of each component is shown in Fig. 2 (left) for the argon case. The second analysis is based on the simulation of a ^{252}Cf neutron source, which reproduces better WIMPs signals. The level obtained in argon is a ∼44% lower, as nuclear recoils show narrower cluster widths. Suposing a 0.4 keVee energy threshold and former background levels, the TREX-DM experiment could be sensitive to a relevant fraction of the low-mass WIMP parameter space (see Fig. 2, right) including the regions invoked in some interpretations of the DAMA/LIBRA results and other hints of positive WIMPs signals, with an exposure of 1 kg-year.

4 Conclusions and prospects

TREX-DM is a low background Micromegas-based TPC for low-mass WIMP detection. Its main goal is the operation of a light gas at high pressure (active mass ∼0.3 kg) with an energy threshold of 0.4 keVee or below and fully built with previously selected radiopure materials. The detector is being comissioned at TREX laboratory and may be installed at the LSC during 2016 for a possible physics run.

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