

Dark matter sensitivities of the MAJORANA DEMONSTRATOR

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Abstract. The MAJORANA DEMONSTRATOR is an array of natural and enriched high purity germanium detectors that will search for the neutrinoless double-beta decay of Germanium-76 and perform a search for weakly interacting massive particles with masses below 10 GeV. To reach the background rate goal in the neutrinoless double-beta decay region of interest of 4 counts/keV/t/y, the DEMONSTRATOR will utilize a number of background reduction strategies, including a time-correlated event cut for ^{68}Ge that requires a sub-keV energy threshold. This low energy threshold allows the DEMONSTRATOR to extend its physics reach to include a search for light WIMPs. We will discuss the detector systems and data analysis techniques required to achieve sub-keV thresholds as well as present the projected dark matter sensitivities of the MAJORANA DEMONSTRATOR.

1. The MAJORANA DEMONSTRATOR

The MAJORANA collaboration is currently building the MAJORANA DEMONSTRATOR, an ultra-low background array of 40 kg of high purity germanium (HPGe) detectors. Between 20 kg and 30 kg of these detectors will be constructed from material enriched to 86% in ^{76}Ge , allowing the DEMONSTRATOR to establish the feasibility of constructing a future tonne-scale neutrinoless double-beta decay germanium experiment [1, 2] while also testing the Klapdor-Kleingrothaus claim of neutrinoless double-beta decay in ^{76}Ge [3, 4]. The HPGe detectors will be mounted in holders constructed of ultra-low background electroformed copper [5] and arranged in closely packed arrays inside two vacuum cryostats. Both cryostats will be surrounded by a compact shield of electroformed copper, commercial copper, lead, plastic neutron moderator, and an active muon veto. The array will be located at the 4850' level of the Sanford Underground Research Facility (SURF) in Lead, SD. The background goal for the DEMONSTRATOR is 4 background counts/tonne/year in the 4 keV region of interest (ROI) around the 2039 keV ^{76}Ge endpoint energy. This scales to a rate of 1 count/tonne/year for a DEMONSTRATOR style tonne-scale ^{76}Ge experiment, the desired background level for sensitivity to the inverted hierarchy mass spectrum region. The first underground cryostat, containing a mixed array of natural and enriched germanium, is expected to begin taking data in mid-2013.

To achieve the background goal of 4 counts/tonne/year/ROI, the DEMONSTRATOR must be able to identify background multisite events, resulting from the interaction of gamma rays within an HPGe detector, from the neutrinoless double-beta decay signal, which is a localized, effectively single-site event. Initially, segmented N-type coaxial detectors were considered for their ability to tag events occurring across multiple segments. However, these detectors are more difficult to manufacture than P-type detectors and, because each segment requires its own readout channel, require an increase in the amount of material with potential radio-impurities inside the cryostat. An alternative to segmented detectors are P-type point contact (PPC) detectors, a relatively new HPGe detector technology with a cylindrical geometry and a small, ~ 6 mm diameter signal contact. These detectors have an even weighting potential throughout the bulk of the crystal that rapidly increases around the point contact, resulting in characteristically different signal shapes for multi-site and single-site events. This feature allows for multi-site event discrimination comparable to or better than a segmented detector [6]. PPC detectors are simpler to fabricate than segmented detectors and require one set of readout electronics per detector, reducing the amount of material within the detector cryostat. For these reasons, the MAJORANA collaboration elected to use PPC detectors in the DEMONSTRATOR.

PPC detectors have other desirable properties that increase the background rejection capabilities and the physics reach of the DEMONSTRATOR. Because of their small point contact size, PPC detectors have a capacitance on the order of 1 pF, resulting in low intrinsic noise and the possibility of sub-keV energy thresholds [7]. This low threshold allows for the reduction

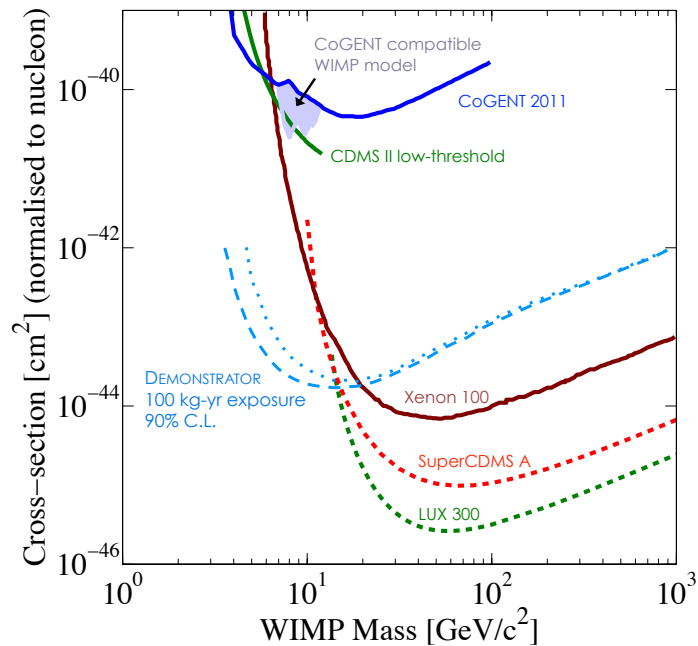


Figure 1. The projected sensitivity of the MAJORANA DEMONSTRATOR for 100 kg-yr of exposure with a 0.3 keV energy threshold (dashed blue line) and a 0.5 keV threshold (dotted blue line). A selection of current and proposed dark matter experiments are shown for reference. Plot generated with dmttools.brown.edu.

of backgrounds from cosmogenically produced ^{68}Ge using a time correlated analysis cut. Long lived ^{68}Ge ($Q_{ec} = 106$ keV, $T^{1/2} = 270.8$ days) decays via electron capture to ^{68}Ga ($Q_{ec} = 2921.1$ keV, $T^{1/2} = 67.7$ min), which can contribute background events to the $0\nu\beta\beta$ ROI. By tagging the 1.3 keV and 10.3 keV K and L-shell X-rays emitted during the ^{68}Ge decay and vetoing for several ^{68}Ga half-lives, this source of background can be reduced by 98%.

The low energy threshold of PPC detectors also makes them sensitive to low energy nuclear recoils from weakly interacting massive particles (WIMPs) [7]. The MAJORANA collaboration is currently investigating the requirements for maximizing the sensitivity of the DEMONSTRATOR to WIMPs. As part of this effort, we have deployed a modified, low-background broad energy germanium (BEGe) detector at the Kimballton Underground Research Facility (KURF) in Ripplemeade, VA (MALBEK) [8]. The cryostat and internal components of the MALBEK detector were constructed of radio-pure materials and assembled in a clean environment to achieve low intrinsic radioactive backgrounds. This detector is investigating point-contact, modified BEGe detector performance and serving as a test-bed for electronics, software, and data analysis techniques for the MAJORANA DEMONSTRATOR.

At its underground, shielded location the dominant backgrounds in the low-energy region of the MALBEK detector are gamma events that occur in the transition region between the bulk germanium and the lithium drifted n+ contact. Events occurring in this region are energy degraded and have significantly slower rise times than events that occur within the fully active region of the crystal. In order to detect a signal from nuclear recoils due to WIMPs, these transition region events must be removed. We are currently investigating the contribution of these slow rise time pulses to the low energy continuum, examining various pulse shape analysis techniques to cut the events, and characterizing our efficiencies in this part of the PPC spectrum.

2. Projected dark matter sensitivity

The DEMONSTRATOR will have at least 20 kg of Ge detectors constructed of material enriched in ^{76}Ge . A simulation of the low energy spectrum of these 20 kg of detectors was done to determine their sensitivity to low energy nuclear recoils from WIMPs [9]. Several assumptions were made about the contributions of various backgrounds to the low energy spectrum for this simulation.

Due to the expected high radio-purity of the DEMONSTRATOR, the major background at low energies should arise from the decay of cosmogenically produced tritium. A conservative estimate of 200 ^3H atoms/kg/day was used as the tritium activation rate [10], and it was assumed that detectors would spend a total of 15 days at the surface for fabrication after the initial crystal pulling. The second contribution to the background at low energy is a continuum from higher energy processes. The IGEX experiment was a low-background ^{76}Ge based experiment operated at the Canfranc Underground Laboratory. They measured a continuum of 0.1 counts/keV/kg/day in the region from 4-10 keV [11]. The goal is that the DEMONSTRATOR will be 100 times cleaner than the IGEX experiment, resulting in 0.001 counts/keV/kg/day in the region from 0-10 keV. The expected neutron background can also be estimated from IGEX, who estimated a contribution from cosmic-ray induced neutrons and neutrons from spontaneous fission events in the rock surrounding the detector as 0.01 counts/keV/kg/day [12]. Due to the increased external shielding of the DEMONSTRATOR and its deeper location, it is assumed that the contribution of neutrons will be negligible relative to the tritium beta-decay spectrum.

The projected sensitivity of the DEMONSTRATOR for a 0.3 eV and a 0.5 eV threshold after 100 kg-yr of exposure is shown in Figure 1 alongside the sensitivities of several existing and proposed dark matter experiments. The DEMONSTRATOR is particularly sensitive to masses smaller than 10 GeV and will be complementary to the next generation of dark matter experiments.

Acknowledgments

We acknowledge support from the Office of Nuclear Physics in the DOE Office of Science under grant numbers DE-AC02-05CH11231, DE-FG02-97ER41041, DE-FG02-97ER41033, DE-FG02-97ER4104, DE-FG02-97ER41042, DE-SC0005054, DE-FG02-10ER41715, and DE-FG02-97ER41020. We acknowledge support from the Particle and Nuclear Astrophysics Program of the National Science Foundation through grant numbers PHY-0919270, PHY-1003940, 0855314, and 1003399. We gratefully acknowledge support from the Russian Federal Agency for Atomic Energy. We gratefully acknowledge the support of the U.S. Department of Energy through the LANL/LDRD Program. N. Fields is supported by the DOE/NNSA SSGF program. G. K. Giovanetti is supported by the Department of Energy Office of Science Graduate Fellowship Program (DOE SCGF), made possible in part by the American Recovery and Reinvestment Act of 2009, administered by ORISE-ORAU under contract no. DE-AC05-06OR23100.

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